SUSY in ATLAS

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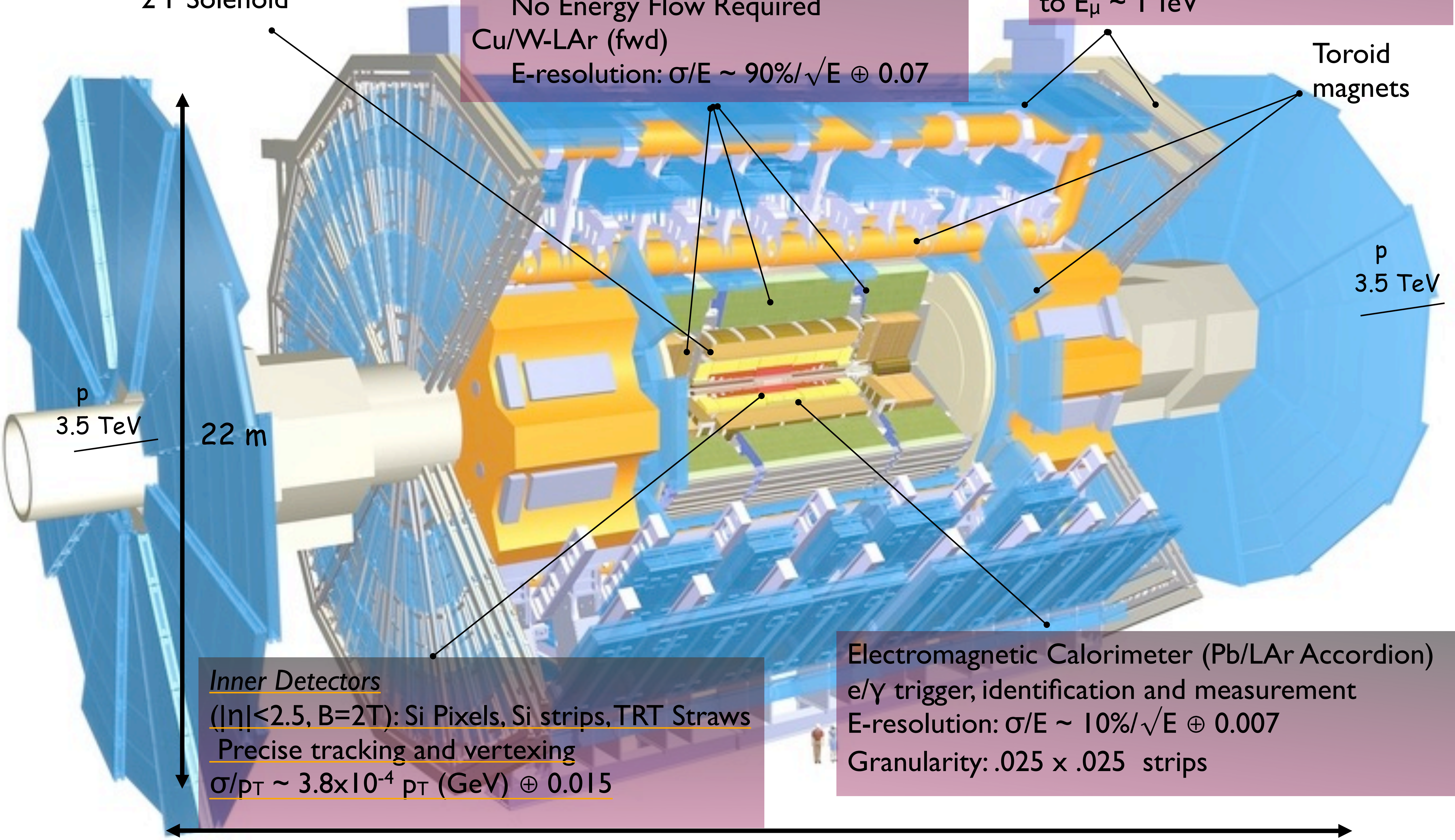
Thanks to all my ATLAS Colleagues who's slides I borrowed

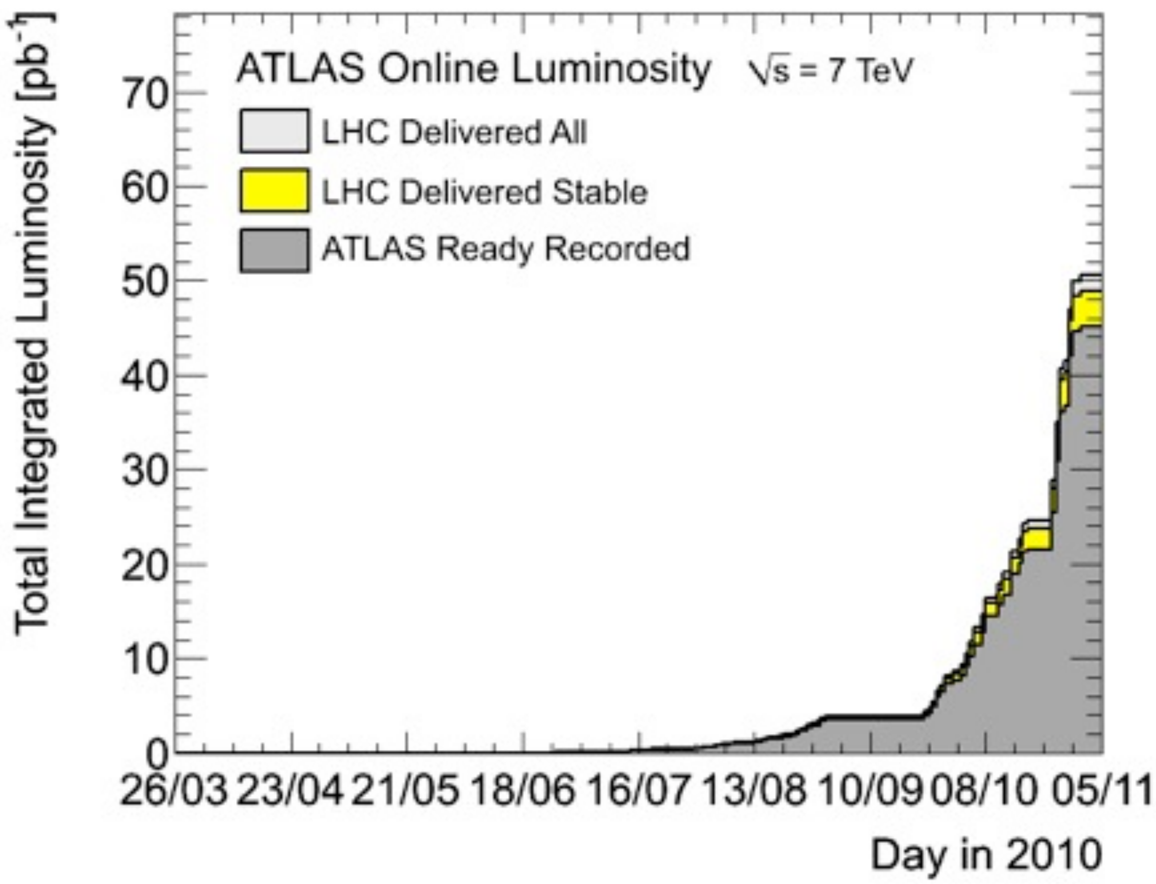
ATLAS



~10^8 electronic channels
3000 km of cables

Total mass ~ 7000 tonnes, installed 92 m underground.

2010 Operations



- ~ 35/pb used for most analyses
  - van der Meer Luminosity uncertainty of 11% will go down to 5%.
- Peak Lumi: 2.07 x 10^{32} cm^2 s^{-1}
- Lumi weighted data-taking efficiency ~ 92%

RECORDS

Peak Stable Luminosity Delivered	2.07×10^{32}	Fill 1440	10/10/24, 23:48
Maximum Luminosity Delivered in one fill	6304.61 nb^{-1}	Fill 1450	10/10/27, 18:39
Maximum Luminosity Delivered in one day	5983.78 nb^{-1}	Monday 25 October, 2010	
Maximum Luminosity Delivered in 7 days	24637.08 nb^{-1}	Sunday 24 October, 2010 - Saturday 30 October, 2010	
Maximum Colliding Bunches	348	Fill 1440	10/10/24, 23:48
Maximum Average Events per Bunch Crossing	3.78	Fill 1440	10/10/24, 23:48
Longest Time in Stable Beams for one fill	30.3 hours	Fill 1058	10/04/24, 01:13
Longest Time in Stable Beams for one day	22.8 hours (94.9%)	Saturday 24 April, 2010	
Longest Time in Stable Beams for 7 days	69.9 hours (41.6%)	Monday 02 August, 2010 - Sunday 08 August, 2010	
Fastest Turnaround to Stable Beams	3.66 hours	Fill 1284	10/08/14, 10:05
Fastest ATLAS Ready from Stable Beams	25.0 seconds	Fill 1285	10/08/14, 22:39
Best ATLAS Recording Efficiency for one fill	99.4 percent	Fill 1285	10/08/14, 18:26
Best ATLAS Recording Efficiency for one day (> 10 nb^{-1})	99.9 percent	Monday 16 August, 2010	
Best ATLAS Recording Efficiency for 7 days (> 100 nb^{-1})	99.7 percent	Thursday 12 August, 2010 - Wednesday 18 August, 2010	

Detector Status

- *Sources of data taking inefficiency:*
  - Si + Muons HV Ramp
  - LArg Noise Bursts
  - HV Trips (LArg/Tile)
- *Fraction of good data after further reprocessing is higher*

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
96.7	97.5	100	93.8	98.8	99.0	99.7	98.6	98.5	98.6	98.5

DATA TAKING EFFICENCY > 97%

March 30-Aug 30: Fraction of data (after stable beams declared)marked as good after 36-hours "calibration loop", before start of reconstruction at Tier0

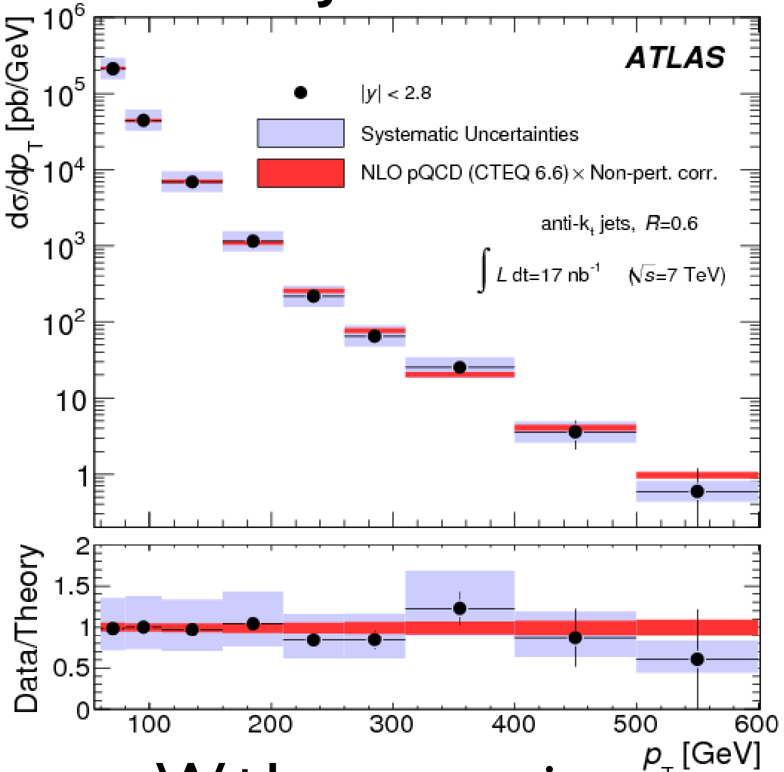
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.1%
LAr EM Calorimeter	170 k	98.1%
Tile calorimeter	9800	96.9%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

CHANNEL EFFICIENCY > 97%

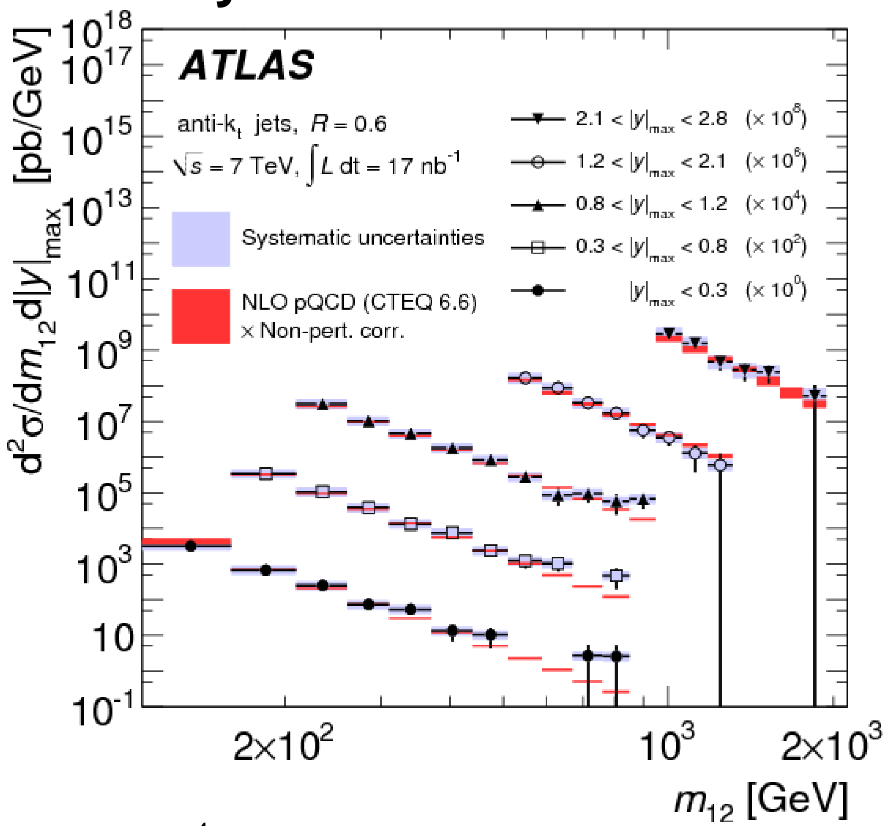
- *Sources of channel inefficiency:*
  - Failing LArg Front-end Optical Transmitters (~1/month). So far1.5%.
  - Failing SCT/Pixel Back-end Optical Transmitters (~a few/week). Replace as we go.
  - Failing Tile Low voltage power-supplies and Front-end interconnectivity.
- *No show stoppers...*
- *Repairs during Christmas recovered many inefficiencies*

Standard Model Measurements

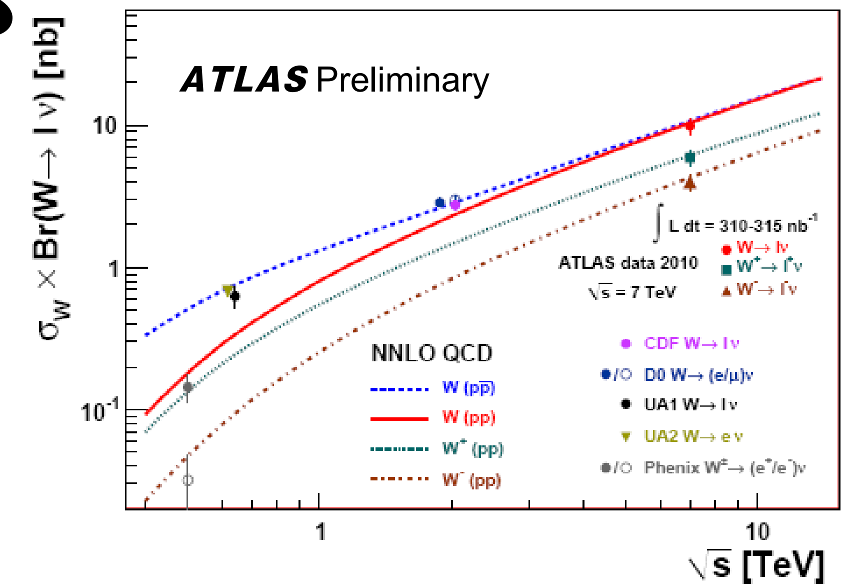
Inclusive Jet x-section



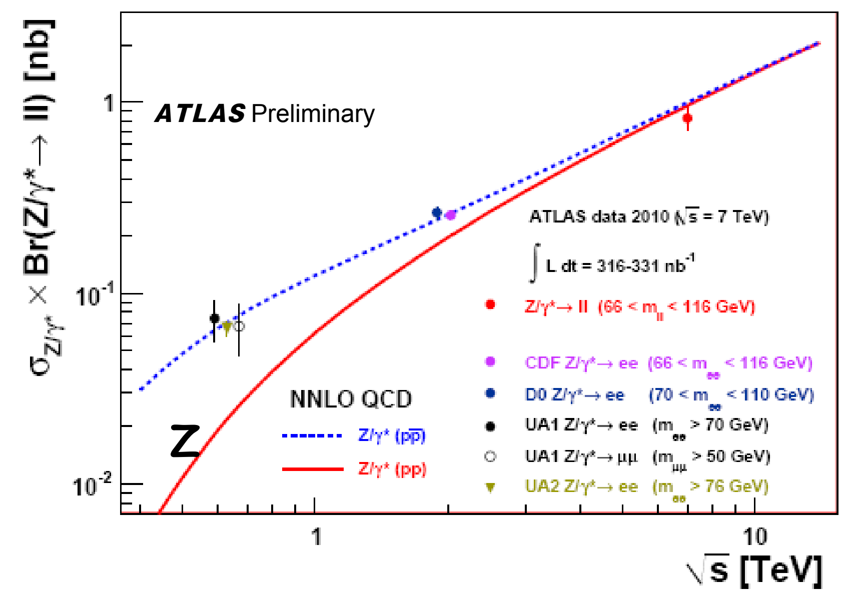
DiJet x-section



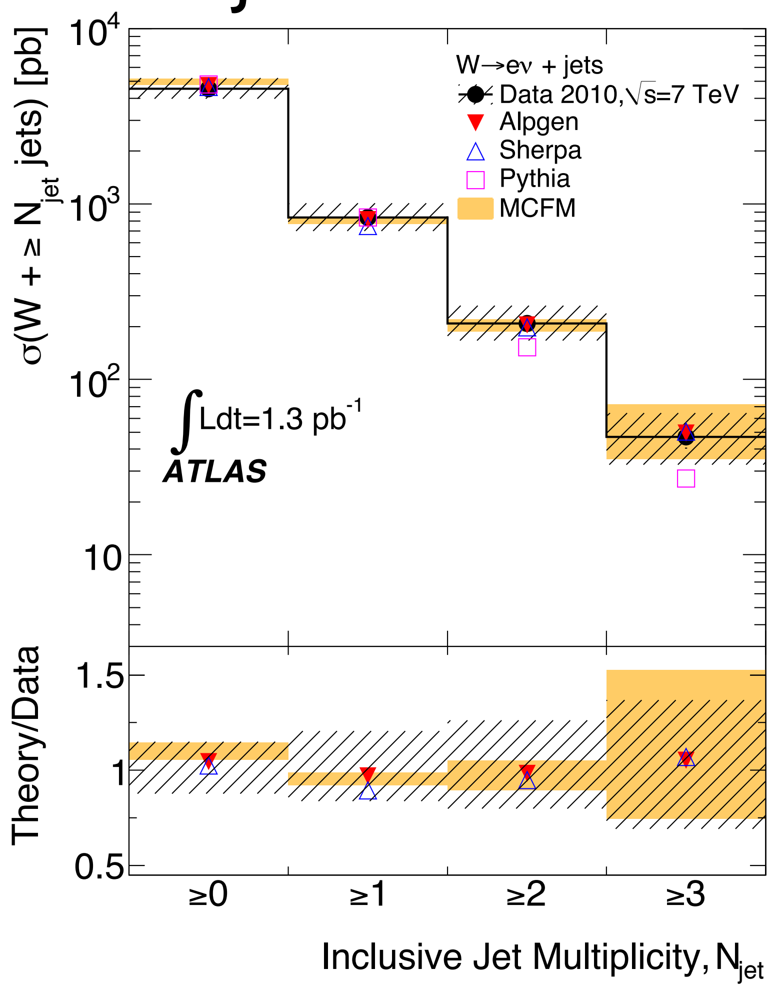
Inclusive W x-section

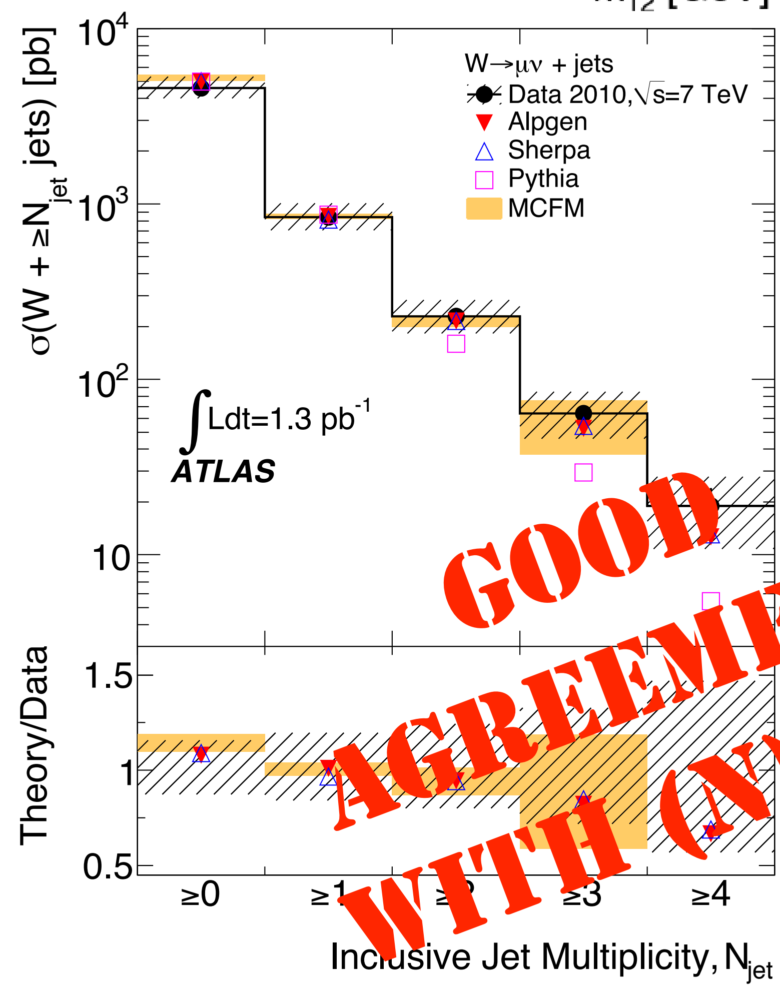


Inclusive Z x-section

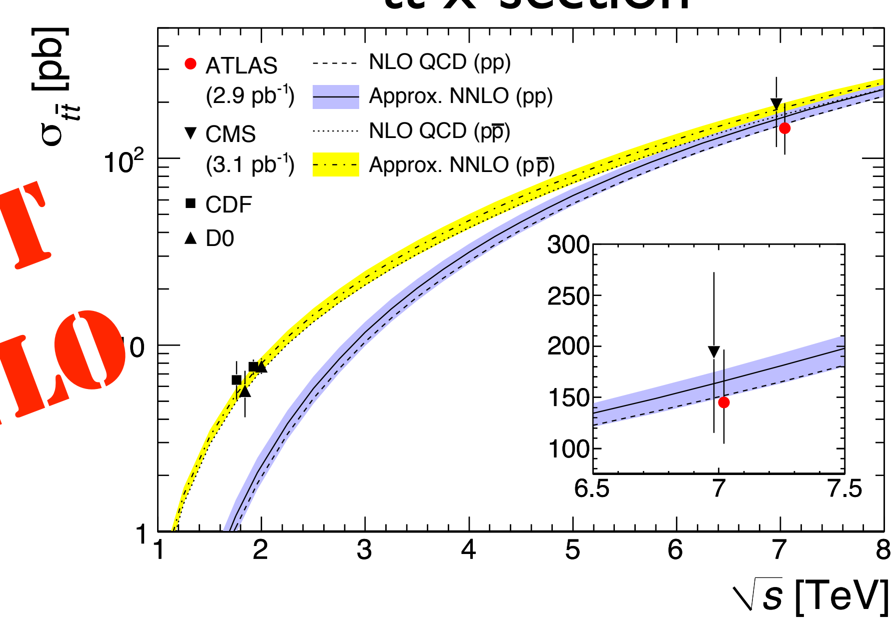


W+Jets x-section





tt x-section



GOOD AGREEMENT WITH (N)NLO

Questions

- Snapshot after Moriond (35/pb 2010 Data): Where are we in BSM searches?
  - Where can theory help?
    - Coverage, Interpretation, and Backgrounds...
- Coverage: Are we missing something?
- Interpretation: Where should we put the line between theory and experiment?
  - How do we communicate?
- Backgrounds: Are we limited by theory? What SM measurements help? Can we be theory independent?

New Physics Searches

- Resonances: jj, γγ, ll, γj, lν
  - q*, Graviton, W'/Z', ...
  - Edges: SUSY Like
  - DiJet Mass/Angular Correlations
    - Contact Interactions, Black-holes, Extra-Dim
- "Exotic"
  - Long-lived Highly Ionizing
  - Stable Hadronizing squark/gluino
- Large MET
  - +[b]-Jets
  - +leptons (1,2,3)
  - +photons (2γ)
- Some-Parity Conserving Theory: eg SUSY, UED, ...

Done, Needs Update, In progress

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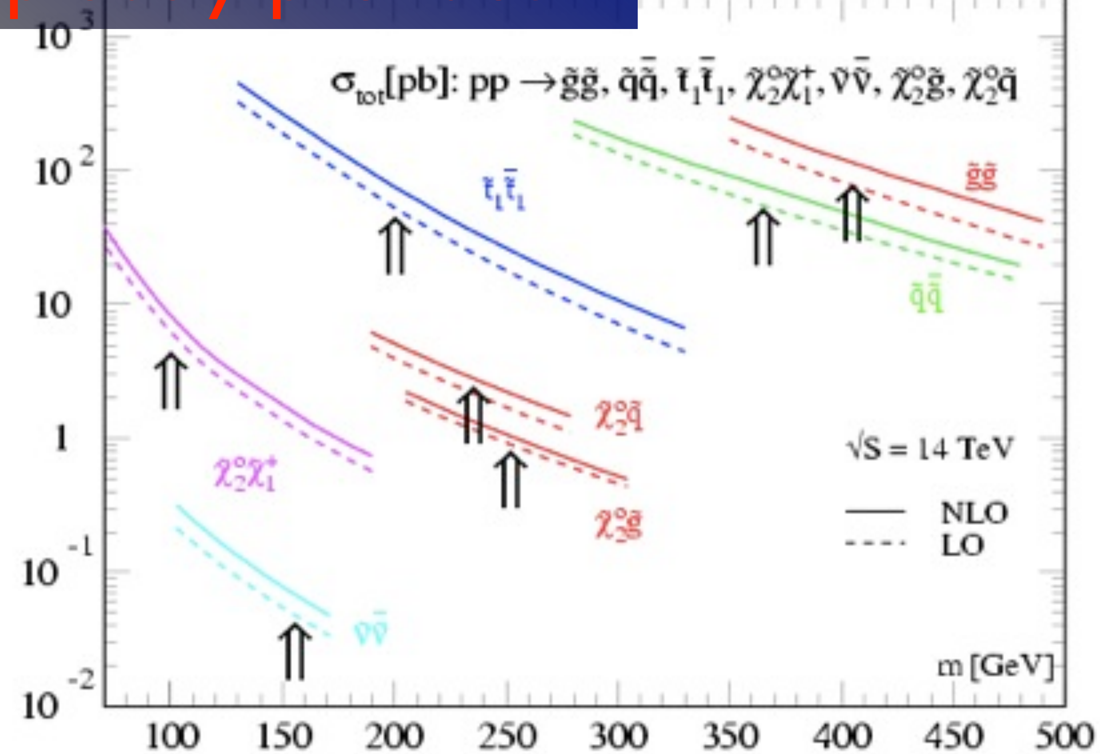
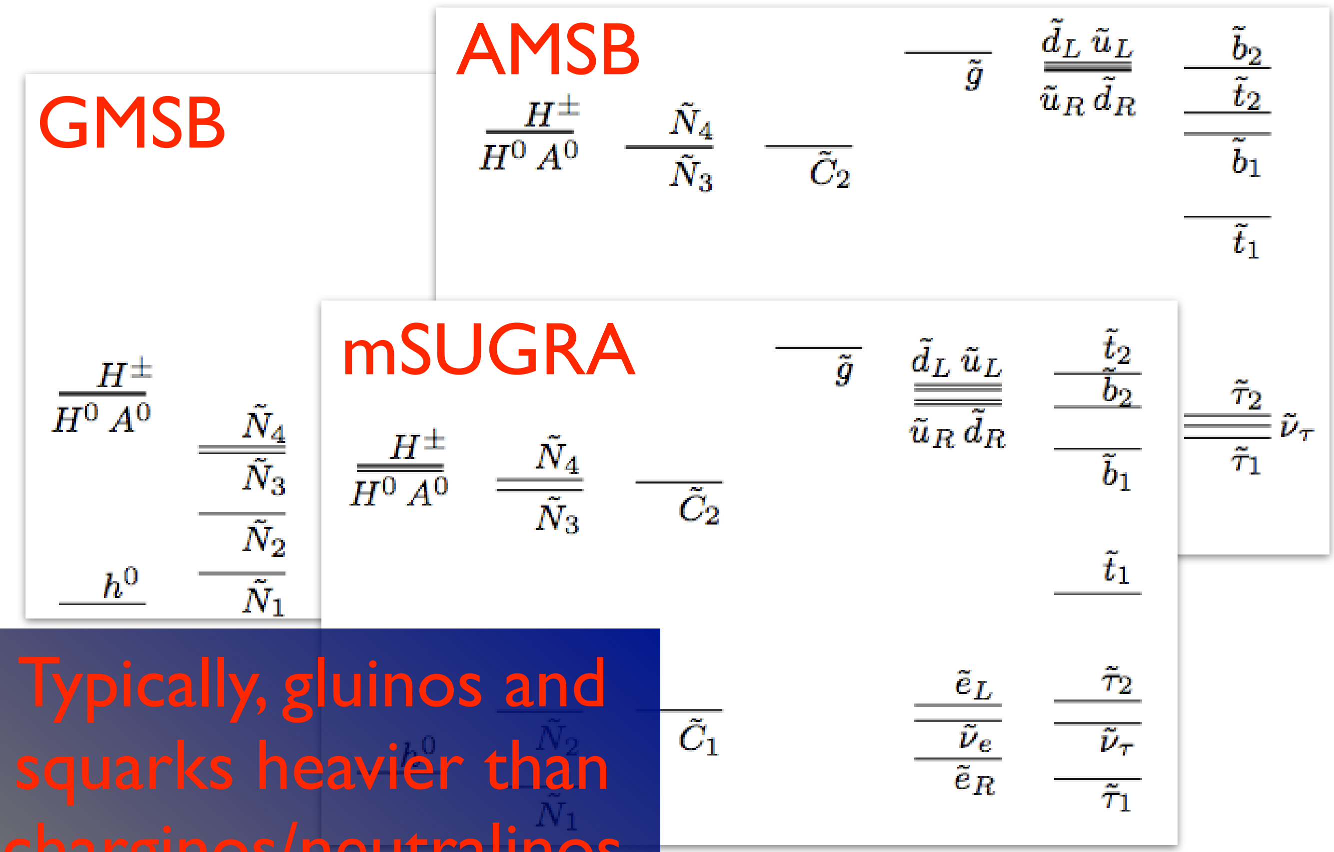
Searches covered in this talk: Interpreted with mSUGRA + Phenomenological MSSM

Done, Needs Update, In progress

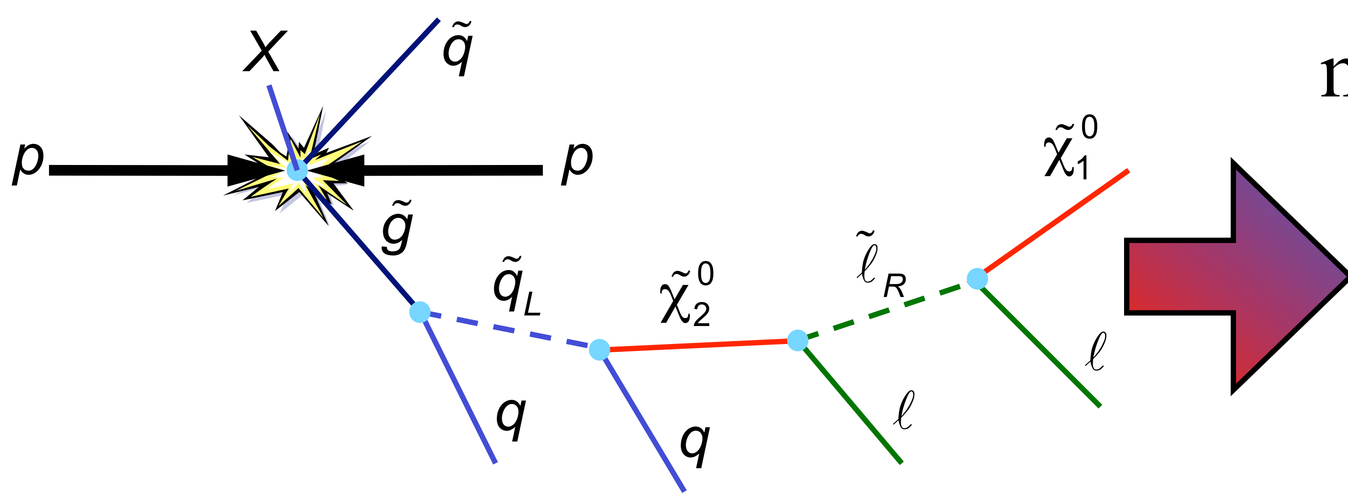
SUSY at LHC

Gluinos and squarks copiously produced

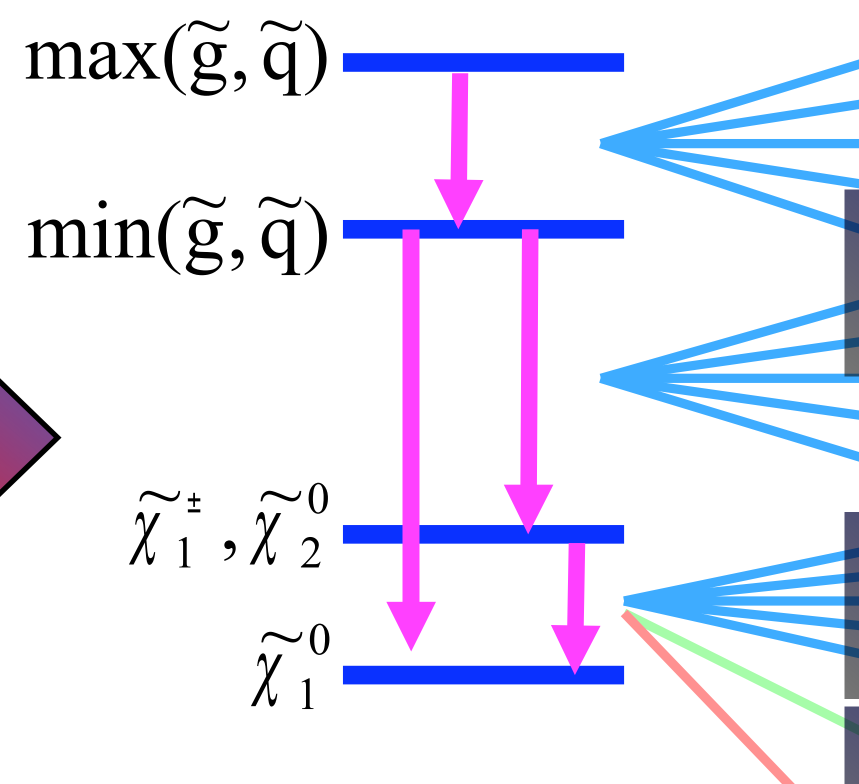




Typically, gluinos and squarks heavier than charginos/neutralinos



Long Cascades



Many Jets (100's of GeV)

Leptons (10's of GeV)

Missing Energy (100's of GeV)

Inclusive Signatures

Signature	Motivating Model(s)	Comments
1 Jet + 0 Lepton + MET 70/nb	• Large Extra Dim (ExoGraviton) • strong qG production, G propagate in extra Dim • Planck Scale is MD in 4+δ dim • Normal Gravity >> R • SUSY • qg→ISR + 2 Neutralino or squark + Neutralino	• Not primary discovery channel for SUGRA, GMSB, AMSB... but helps in characterization • Possible leading discovery for neutralino NLSP with nearly degenerate gluino
2X 2,3,4 [b]-Jet + 0 Lepton + MET 35/nb for b-jets 35/pb	• Squark/gluino production • squark→q+LSP, gluino→q+squark+LSP	• Possible leading squark/gluino discovery channel • Must manage QCD bkg
2X 2,3,4 [b]-Jet + 1 Lepton + MET 310/nb for b-jets 35/pb	• squark/gluino production with cascades which include electroweak (or partner) decays • high tan β leads to more b/t/τ's	• Lepton requirement suppresses QCD • τ's partially covered by e/μ
2X 2 lepton + MET 35/pb	• Same sign: gluino cascade can have either sign lepton... squark/gluino prod can produce same sign. • Opposite sign: squark/gluino decay mediated by Z (or partner) • Same flavor: 2 leptons from same sparticle cascade must be same flavor	• Reduced SM backgrounds for same sign • Opposite Sign-Flavor Subtraction
3 lepton + MET 35/pb	• SUSY events ending in Chargino/neutralino pair decays • Weak Chargino/Neutralino production • Exotic sources	• Low SM bkgs
2 photon + MET 3.1/pb	• GMSB models with gravitino LSP and neutralino or stau NLSP • UED- each KK partons cascade to LKP which decays to graviton + γ	• No SUSY limit (not sensitive at the time)

Pre-selections

Common across most analyses:

Vertex:

- At least 1 good vertex with > 4 tracks.

Trigger:

- Varying (with luminosity), offline cuts always in trigger efficiency plateau regions
- *0 lepton:* Single jets at L1 or L2, MET in EF. 97% efficient for 1 jet > 120 GeV, MET > 100 GeV
- *1 lepton:* Single lepton. In efficiency plateau for 20 GeV Leptons.

Jets: (|η|<2.5, p_T>20 GeV)

- Cleaning (for noise, cosmics) (1% rejection). Reject events with any bad Jets (for MET)
- Anti-K_t R=0.4 Topo Cluster Jets

Electrons: (|η|<2.47, p_T>20 GeV)

- *Medium*: Used for electron rejection. Inputs: shower shape, pixel hit, d0
- *Tight*: Used for selection. Inputs: medium + track match, transition radiation, E/p
- Reject events with medium electrons in problematic calorimeter and transition region (1.37<|η|<1.52)

Muons: (|η|<2.40, p_T>20 GeV)

- *Combined:* Good Combined fit to Inner Detector and Muon Spectrometer
- *Extrapolated*: Inner Detector track tagged by muon spectrometer segments)
- Require1 pixel, 5 strip, and TRT hits (η dependent number)
- Sum p_T of Tracks in ΔR<0.2 < 1.8 GeV
- Z_0<10 mm

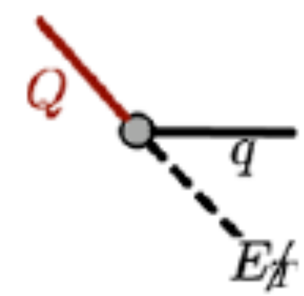
MET:

- calculated from objects + topo-clusters
- ΔΦ(Jets,MET) > 0.2 (1 lepton) or 0.4 (0 lepton) for the *N* required jets

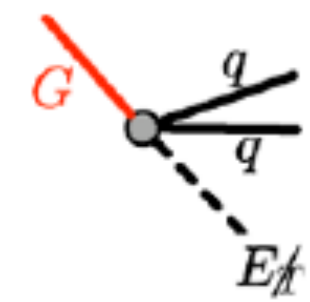
- Overlap Removal
  - R(jet,electron) < 0.2
    ➡ reject jet
  - 0.2 < R(jet,electron) < 0.4
    ➡ veto electron
  - R(jet,muon) < 0.4
    ➡ veto muon

Jets + MET

- Expect strong squark/gluino production
- Direct squark/gluino decays to LSP gives just Jets
- Also provides coverage of cascades producing leptons, where lepton is missed (eg very soft)
- 2 jets: qq production. 3 jets: qg. 4 jets: gg.
    - the most relevant parameters: m(gluino) vs m (squark) vs m(chi0)
- Should also consider cascades with hadronic W/Z



$$\tilde{q} \rightarrow q\tilde{\chi}_1^0$$



$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$$

0 Lepton Event Selections

- No leptons (medium electrons and muons) >10 GeV
- 4 signal regions defined to maximize m_{squark}-m_{gluino} coverage :
  - At least 2 Jets
    - Low mass squark anti-squark (A)
    - High mass squark anti-squark (B)
  - At least 3 Jets
    - Direct gluino pairs (C)
    - Associated gluino-squark (D)
      - Higher x-section → Tighter cuts!

		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

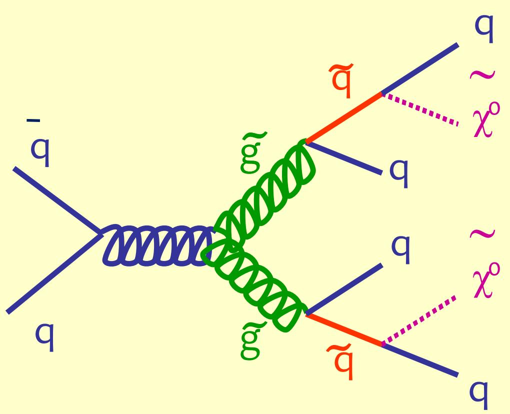
Signal QCD Trigger

$$m_{eff} \equiv \sum_{i=1}^{n} |\mathbf{p}_T^{(i)}| + E_T^{miss}$$

$$m_{T2}\left(\mathbf{p}_T^{(1)}, \mathbf{p}_T^{(2)}, \not{\mathbf{p}}_T\right) \equiv \min_{\not{\mathbf{q}}_T^{(1)} + \not{\mathbf{q}}_T^{(2)} = \tilde{\mathbf{E}}_T^{miss}} \left\{\max\left(m_T\left(\mathbf{p}_T^{(1)}, \not{\mathbf{q}}_T^{(1)}\right), m_T\left(\mathbf{p}_T^{(2)}, \not{\mathbf{q}}_T^{(2)}\right)\right)\right\}$$

$$m_T^2\left(\mathbf{p}_T^{(i)}, \not{\mathbf{q}}_T^{(i)}\right) \equiv 2|\mathbf{p}_T^{(i)}||\not{\mathbf{q}}_T^{(i)}| - 2\mathbf{p}_T^{(i)} \cdot \not{\mathbf{q}}_T^{(i)}$$

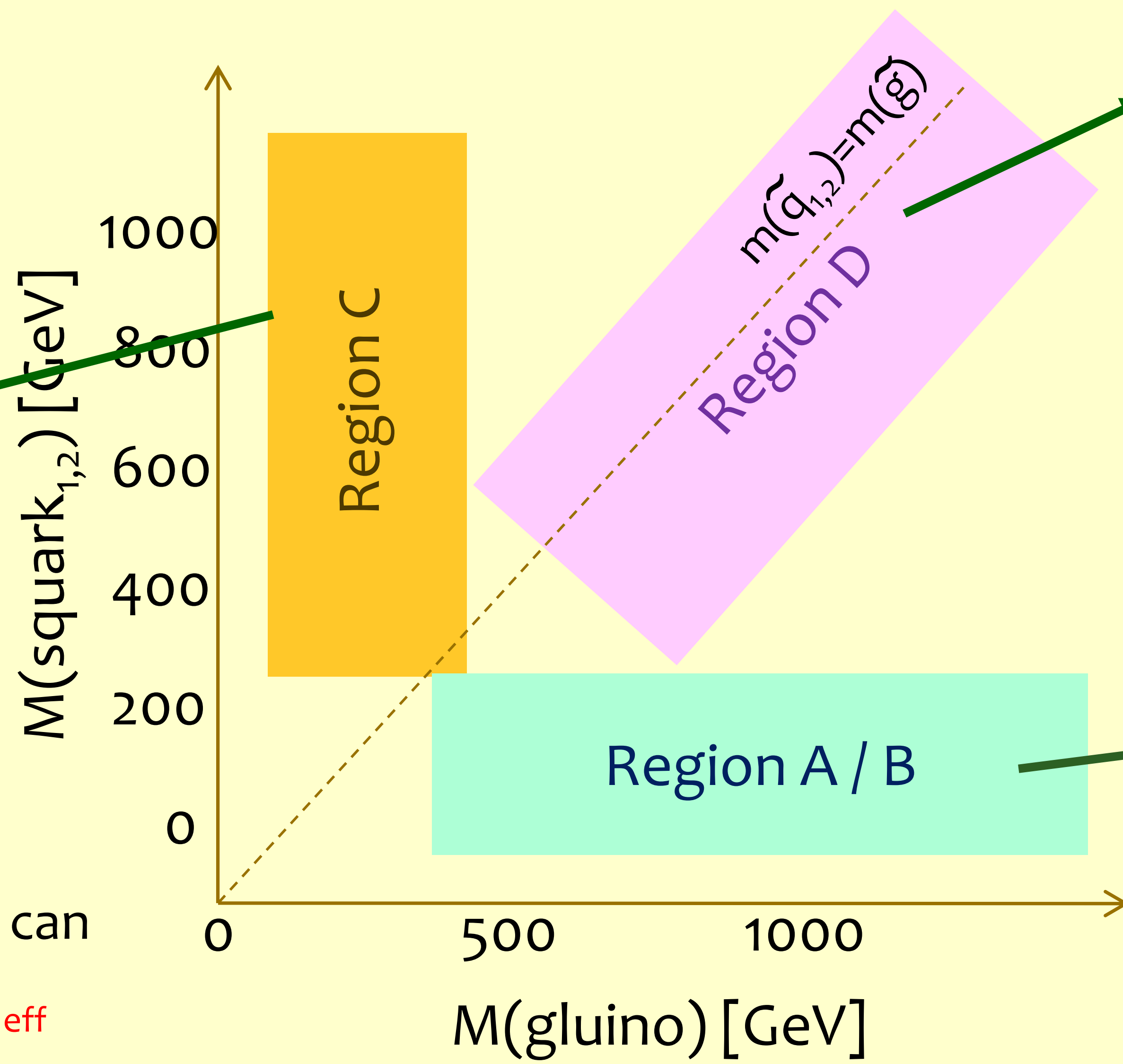
Signal regions sensitivity

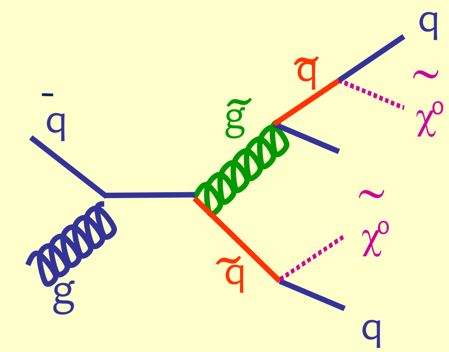


$M_{\tilde{q}} > M_{\tilde{g}}$

$\tilde{g}\tilde{g}$ final state dominates

≥ 4 jets expected , 1 can be soft, selection in m_{eff}

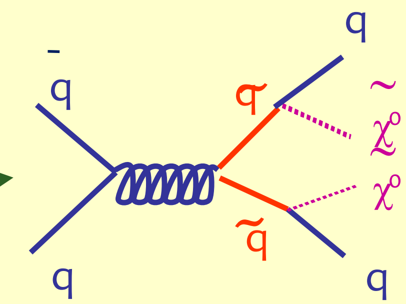




$M_{\tilde{q}} \sim M_{\tilde{g}}$

$\tilde{q}\tilde{g}$ final state dominates

≥ 3 jets expected, high m_{eff}



$M_{\tilde{q}} < M_{\tilde{g}}$

$\tilde{q}\tilde{q}$ final state dominates

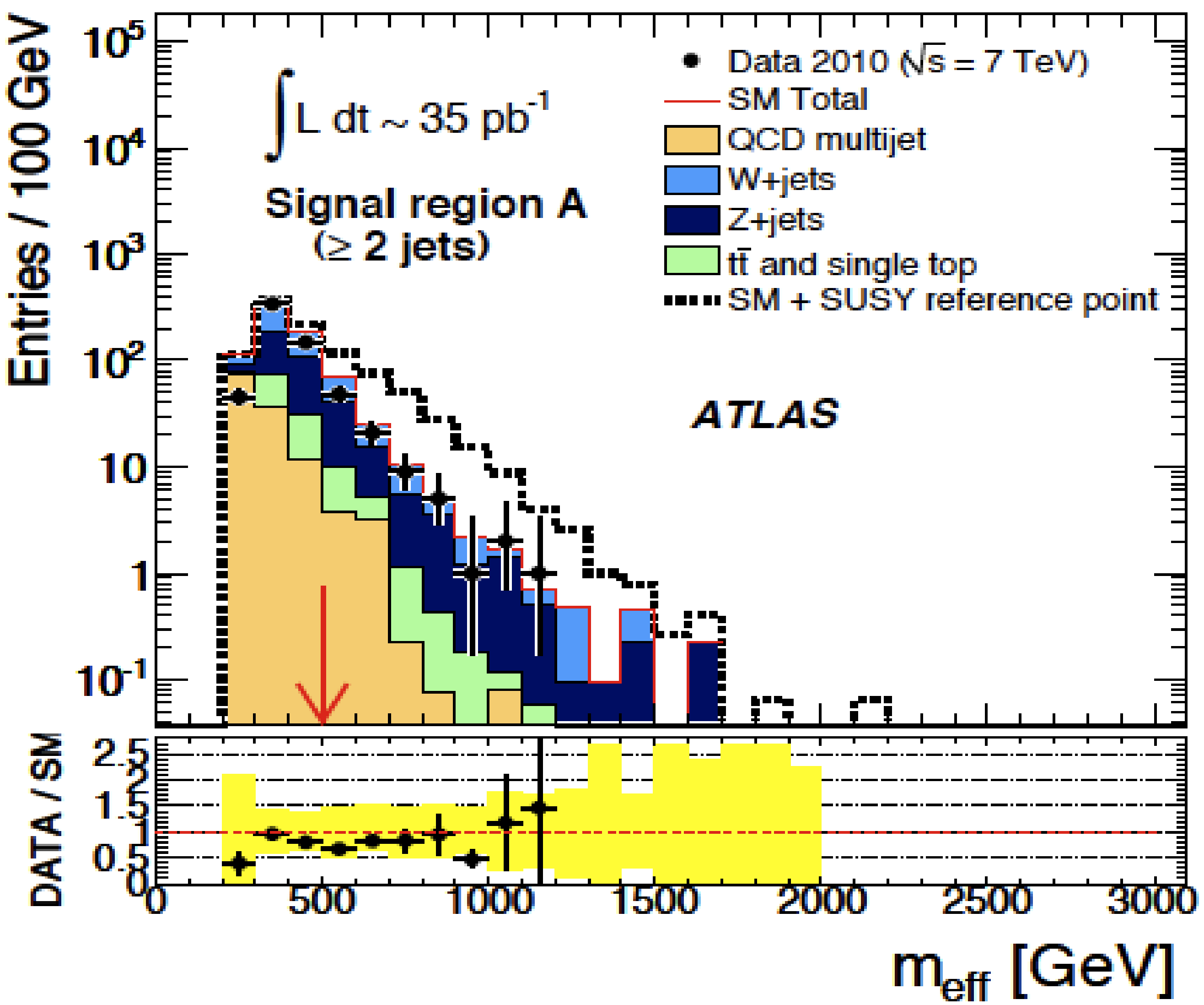
≥ 2 jets expected

m_{eff} or m_{T2} selection to exploit dependence in $\Delta M(\tilde{q}_{1,2}-\tilde{\chi}_0^1)$

Classification of signal regions almost independent on models

0 Lepton Results

	Signal region A	Signal region B	Signal region C	Signal region D
QCD	$7\ ^{+8}_{-7}[\mathrm{u}]$	$0.6\ ^{+0.7}_{-0.6}[\mathrm{u}]$	$9\ ^{+10}_{-9}[\mathrm{u}]$	$0.2\ ^{+0.4}_{-0.2}[\mathrm{u}]$
W+jets	$50 \pm 11[\mathrm{u}]\ ^{+14}_{-10}[\mathrm{j}] \pm 5[\mathcal{L}]$	$4.4 \pm 3.2[\mathrm{u}]\ ^{+1.5}_{-0.8}[\mathrm{j}] \pm 0.5[\mathcal{L}]$	$35 \pm 9[\mathrm{u}]\ ^{+10}_{-8}[\mathrm{j}] \pm 4[\mathcal{L}]$	$1.1 \pm 0.7[\mathrm{u}]\ ^{+0.2}_{-0.3}[\mathrm{j}] \pm 0.1[\mathcal{L}]$
Z+jets	$52 \pm 21[\mathrm{u}]\ ^{+15}_{-11}[\mathrm{j}] \pm 6[\mathcal{L}]$	$4.1 \pm 2.9[\mathrm{u}]\ ^{+2.1}_{-0.8}[\mathrm{j}] \pm 0.5[\mathcal{L}]$	$27 \pm 12[\mathrm{u}]\ ^{+10}_{-6}[\mathrm{j}] \pm 3[\mathcal{L}]$	$0.8 \pm 0.7[\mathrm{u}]\ ^{+0.6}_{-0.0}[\mathrm{j}] \pm 0.1[\mathcal{L}]$
$t\bar{t}$ and t	$10 \pm 0[\mathrm{u}]\ ^{+3}_{-2}[\mathrm{j}] \pm 1[\mathcal{L}]$	$0.9 \pm 0.1[\mathrm{u}]\ ^{+0.4}_{-0.3}[\mathrm{j}] \pm 0.1[\mathcal{L}]$	$17 \pm 1[\mathrm{u}]\ ^{+6}_{-4}[\mathrm{j}] \pm 2[\mathcal{L}]$	$0.3 \pm 0.1[\mathrm{u}]\ ^{+0.2}_{-0.1}[\mathrm{j}] \pm 0.0[\mathcal{L}]$
Total SM	$118 \pm 25[\mathrm{u}]\ ^{+32}_{-23}[\mathrm{j}] \pm 12[\mathcal{L}]$	$10.0 \pm 4.3[\mathrm{u}]\ ^{+4.0}_{-1.9}[\mathrm{j}] \pm 1.0[\mathcal{L}]$	$88 \pm 18[\mathrm{u}]\ ^{+26}_{-18}[\mathrm{j}] \pm 9[\mathcal{L}]$	$2.5 \pm 1.0[\mathrm{u}]\ ^{+1.0}_{-0.4}[\mathrm{j}] \pm 0.2[\mathcal{L}]$
Data	87	11	66	2

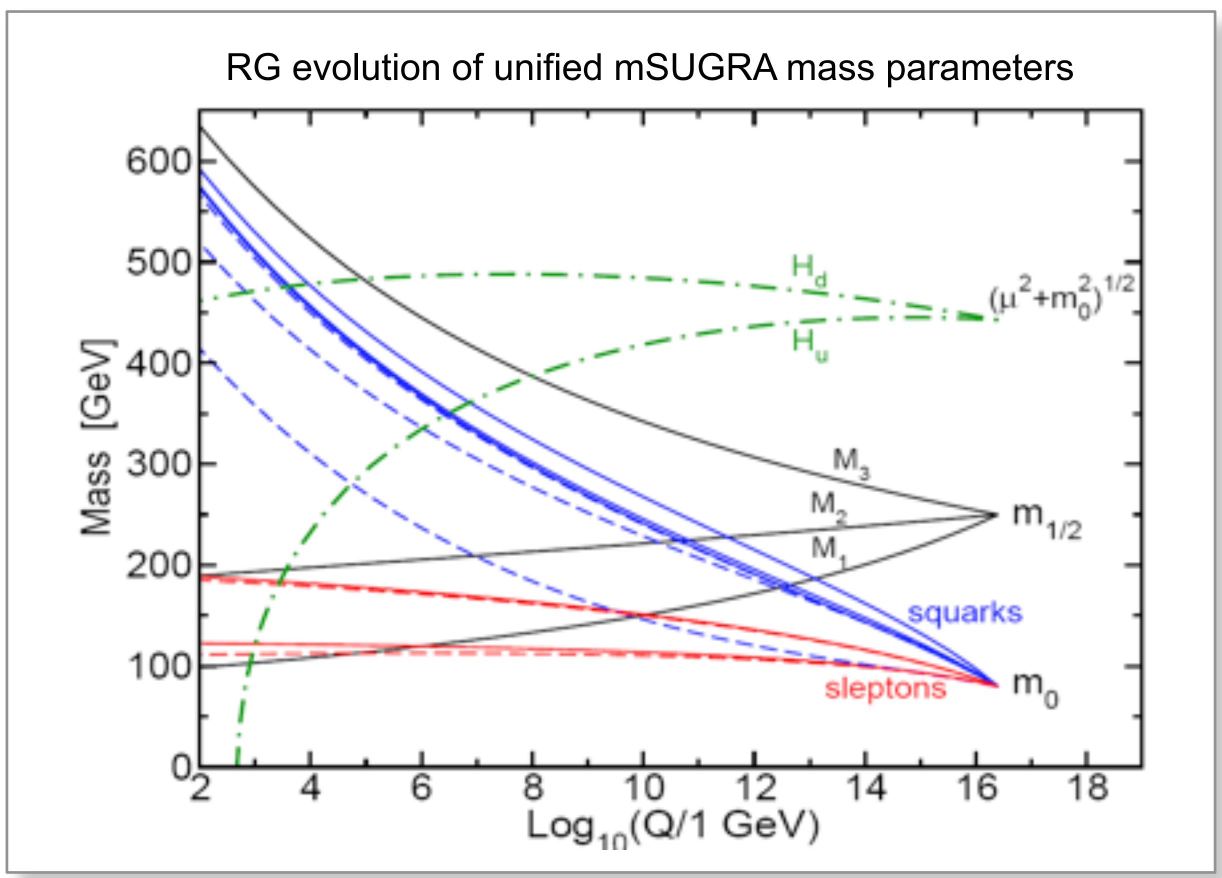


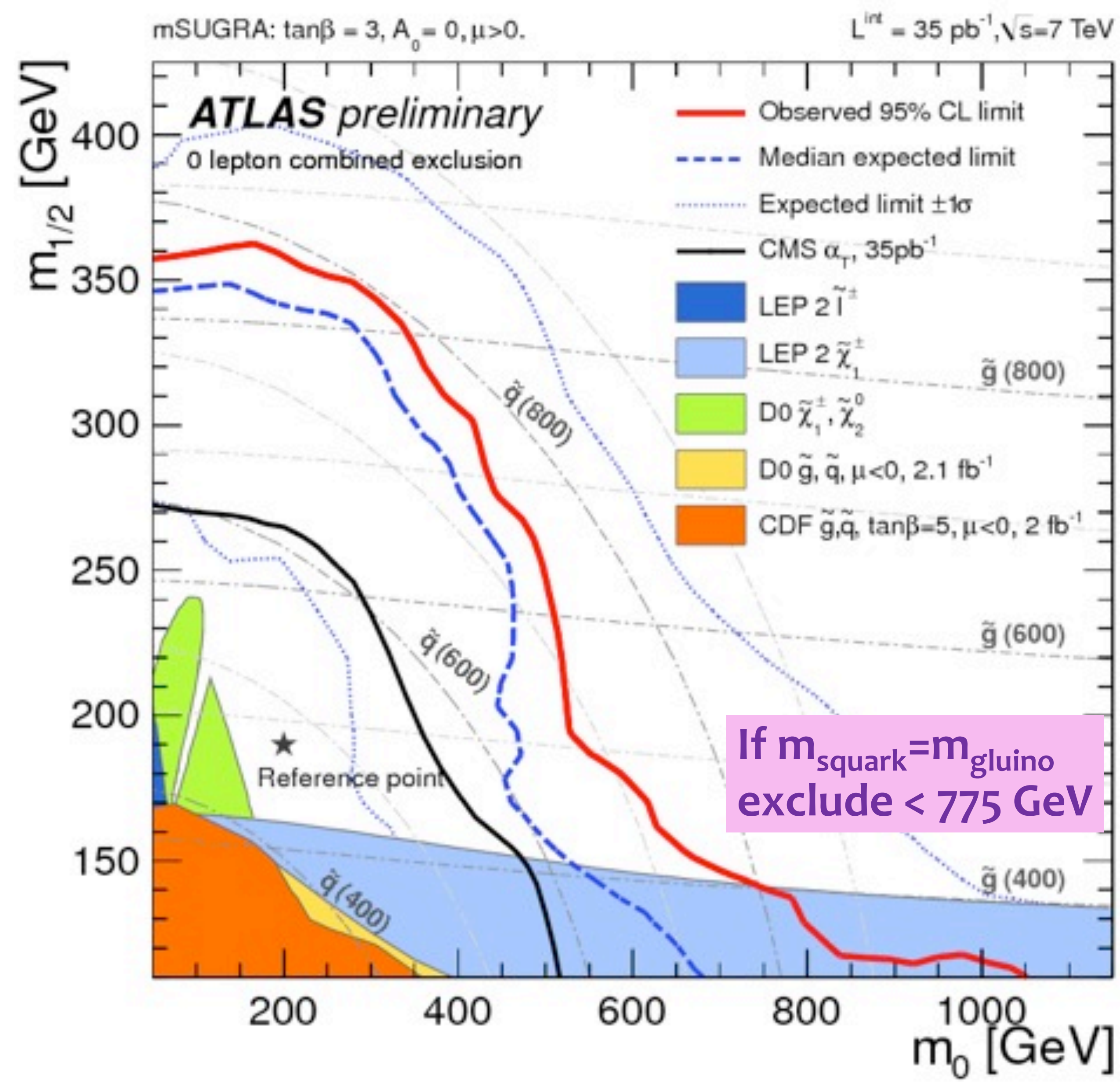
Systematics:
u= uncorrelated
j = JES
L = Lumi

- No Excess Observed
- Model-independent limits ($\sigma_{fid} = \sigma \times \varepsilon \times A$):
  - A: $\sigma_{fid} < 1.3$ pb
  - B: $\sigma_{fid} < 0.35$ pb
  - C: $\sigma_{fid} < 1.1$ pb
  - D: $\sigma_{fid} < 0.11$ pb

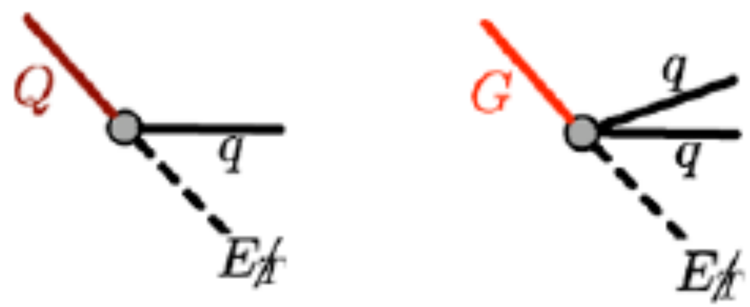
0 Lepton- mSUGRA

- Minimal Supergravity Mediated SUSY breaking
  - Considered too constrained to provide good coverage (fixed ratio of masses)
  - Long precedence of using mSUGRA
    - ➡ so it serves a means to compare to old results
- Run GUT scale model parameters to TeV scale masses:
  - scan m_0 and $m_{1/2}$ with fixed $\mu>0$, tan $\beta=3$, $A_0=0$ (don't strongly influence the exclusions)

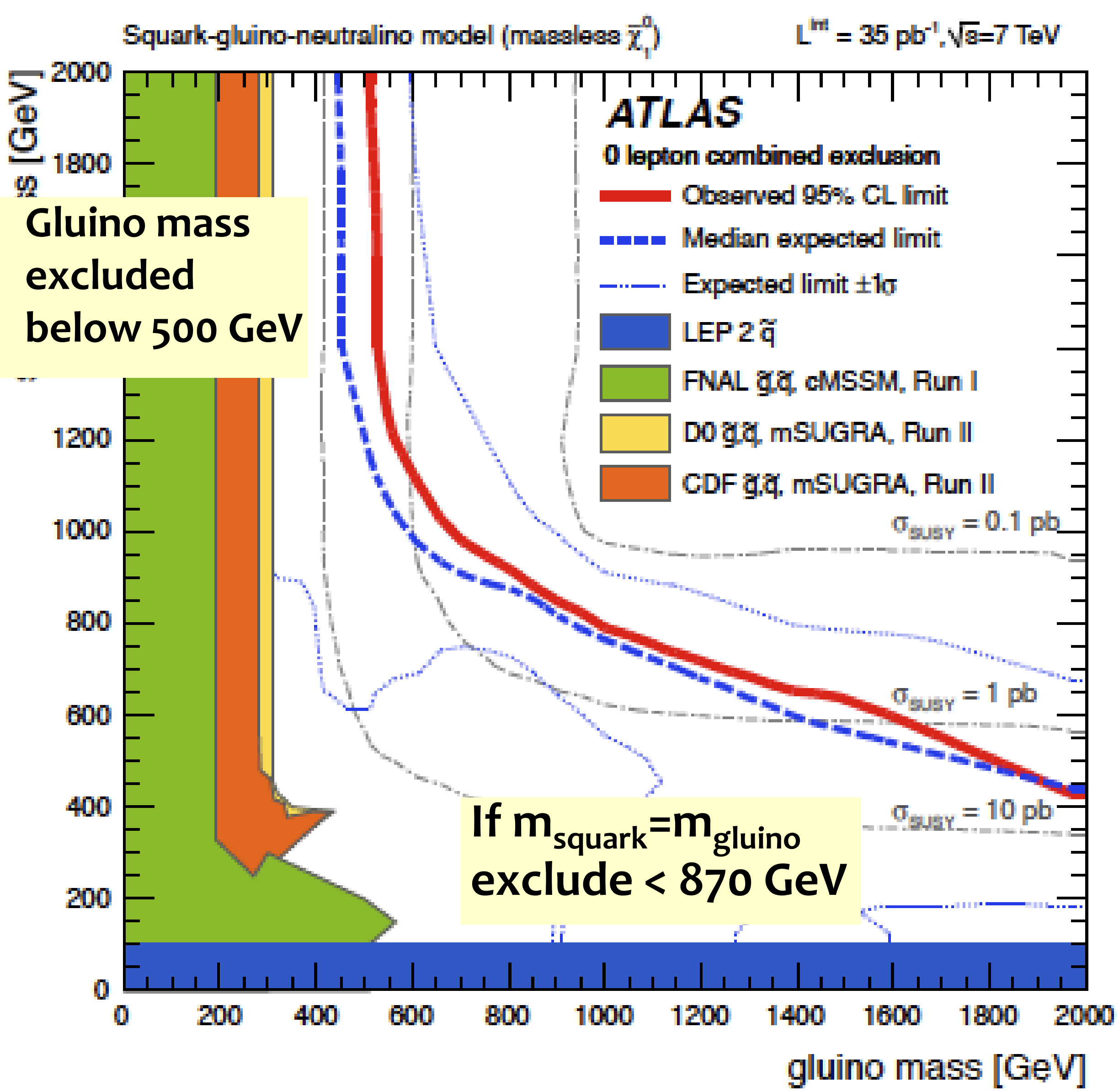




0 Lepton- Pheno



$\tilde{q} \to q\tilde{\chi}_1^0$ $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$



- Phenomenological Model: "Topology-motivated" slicing of MSSM...
  - For 0 lepton: m_{gluino} vs m_{squark}
  - m_{LSP} = 0, 50, 100 GeV.
    - Reach not very sensitive to LSP mass, so used 0 GeV.
  - other gauginos heavy
- Full SUSY x-sections/branching fractions, but probably equivalent to non-SUSY specific simplified models:
  - Same topologies
  - Strong squark/gluino production
  - large "other" masses = BR ~ 1
  - "shape invariance"
  - ➡ Really modeling any strongly interacting new particle that decays to Jets + undetectable particle
  - ➡ Unfortunately, these are not simple to build...

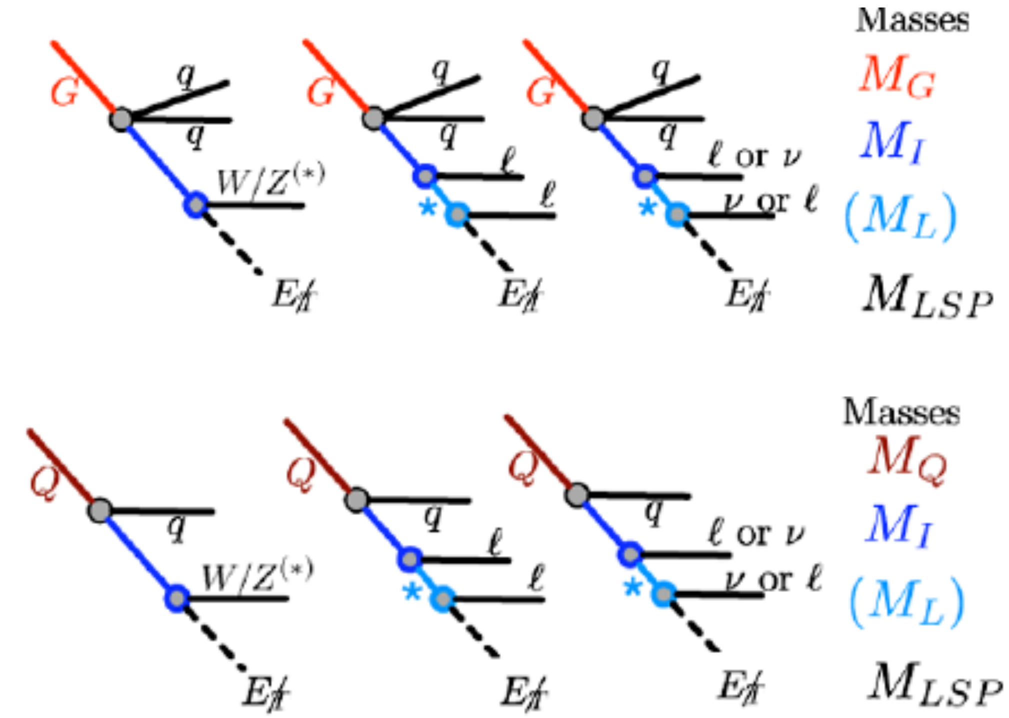
One lepton + Jets + MET

$$\tilde{g} \to q\bar{q}\tilde{\chi}_2^0$$

$$\tilde{g} \to q\bar{q}'\tilde{\chi}_1^\pm \qquad \tilde{\chi}_2^0 \to (Z^{(*)}/h)\tilde{\chi}_1^0 \qquad \tilde{\chi}_2^0 \to \tilde{l}\,l \to ll\tilde{\chi}_1^0$$

$$\tilde{q} \to q\tilde{\chi}_2^0 \qquad \tilde{\chi}_1^\pm \to W^{(*)}\tilde{\chi}_1^0 \qquad \tilde{\chi}_1^\pm \to \tilde{l}\,\nu \to l\nu\tilde{\chi}_1^0$$

$$\tilde{q} \to q'\tilde{\chi}_1^\pm$$



- Pheno Grids (not used... our first SUSY publication):
  - M(sq) – M(chi2/chi+-) – M(chi1) (heavy gluino)
  - M(sq) – M(chi2/chi+-) – M(sl) – M(chi1) (heavy gluino)
  - M(gl) – M(chi2/chi+-) – M(chi1) (heavy squark)
  - M(gl) – M(chi2/chi+-) – M(sl) – M(chi1) (heavy squark)
- And assuming chi1 is ~bino, chi2 is ~wino, M(chi2)=M(chi+-)
- Note Hadronic W/Z decays belong to 0 lepton signature

1 Lepton: Signal Region

➡ **Signal-enhanced region (SR)**

1. $m_T > 100$ GeV
2. $E_T^{miss} > 0.25 \times m_{eff}$
3. $m_{eff} > 500$ GeV

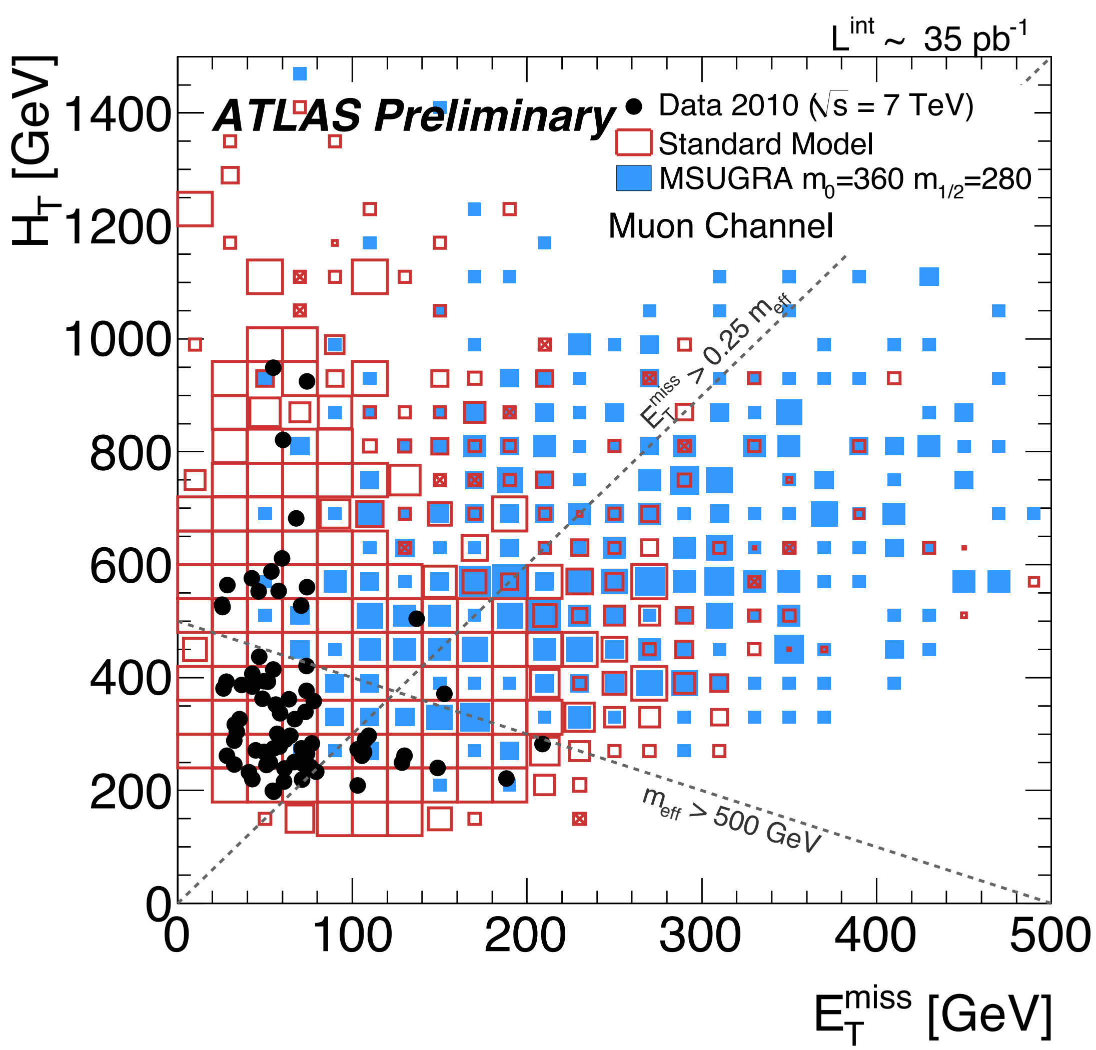
$$m_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{miss} \cdot (1 - cos(\Delta\phi(\ell, E_T^{miss}))}$$

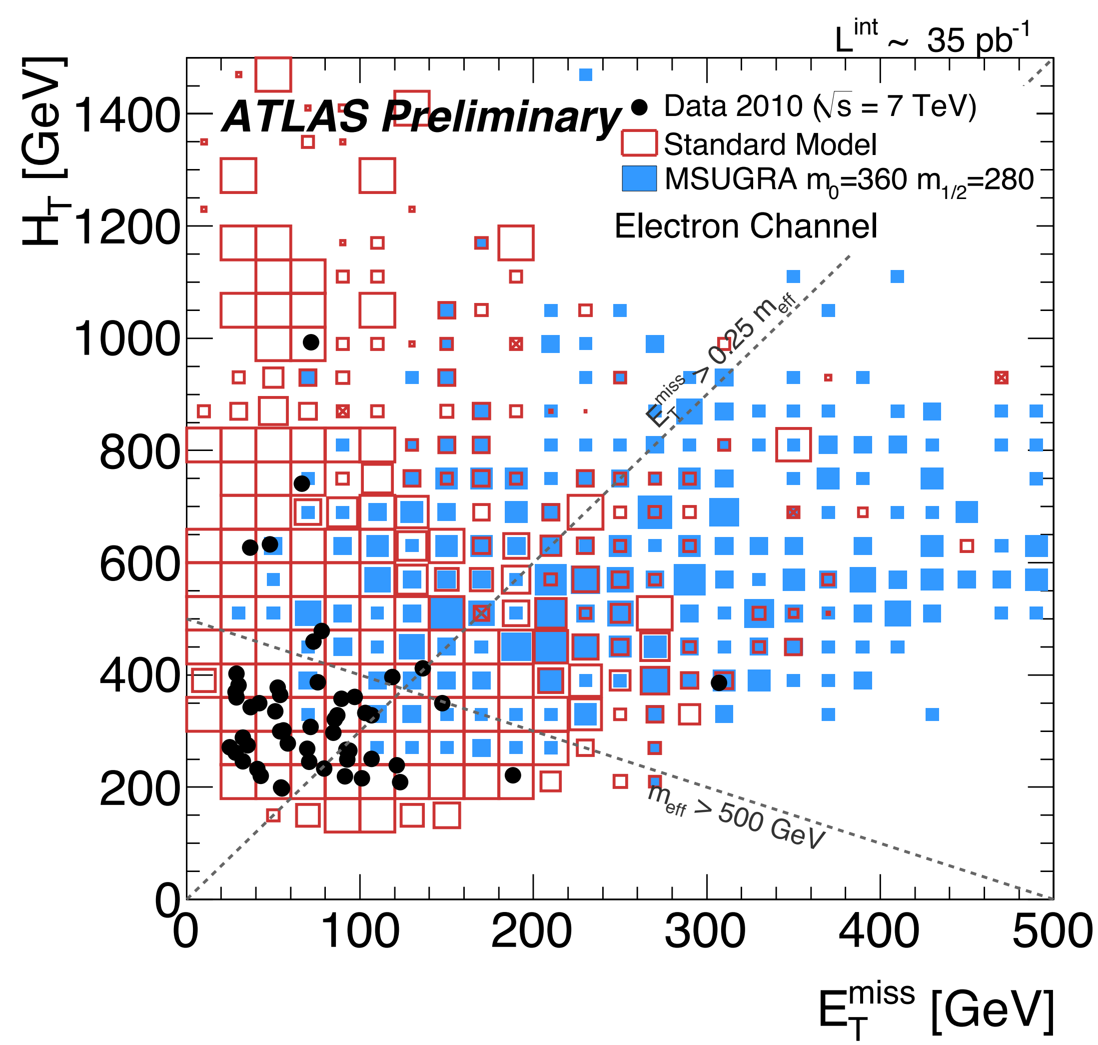
transverse scalar mass (HT):

$$H_T = p_T^{\ell} + \sum_{i=1}^{3} p_T^{jet_i}$$

"effective" mass (Meff):

$$m_{eff} = H_T + E_T^{miss}$$

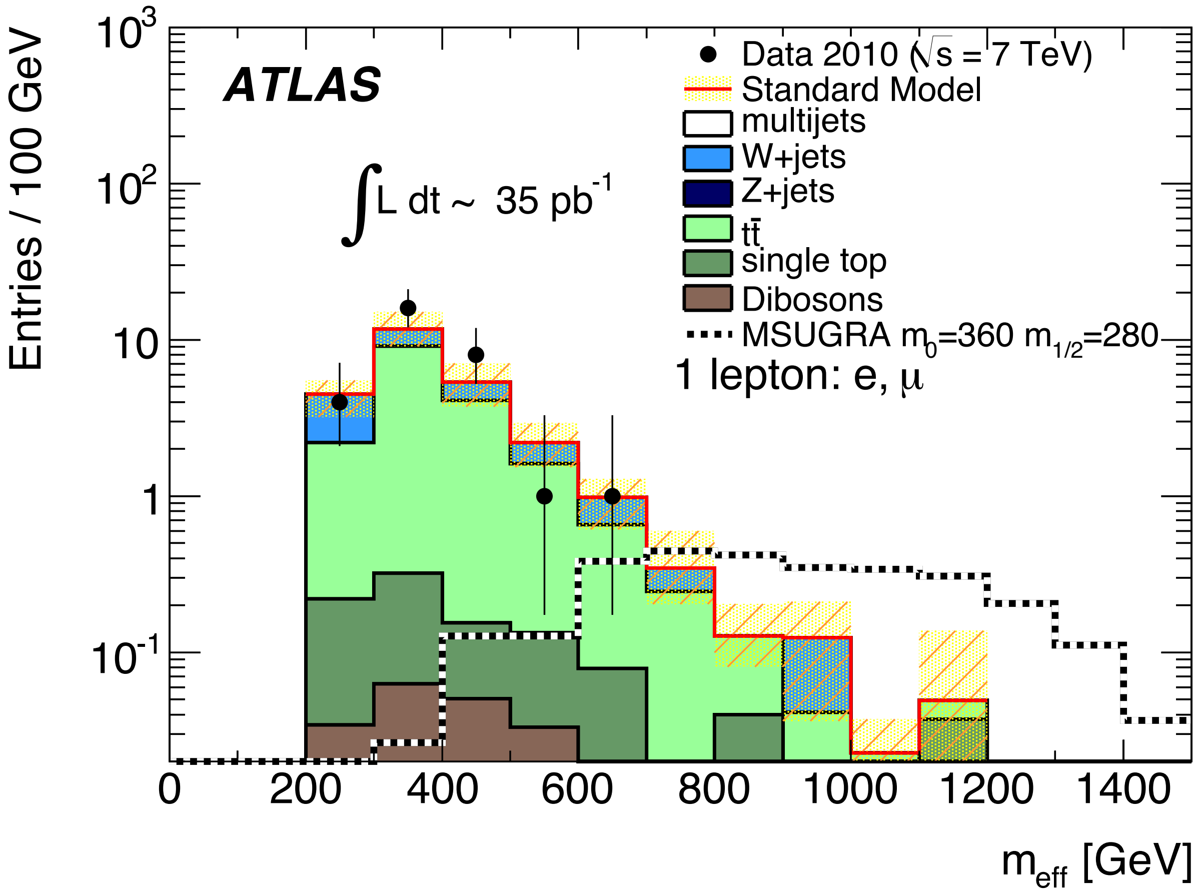




1 Lepton Results

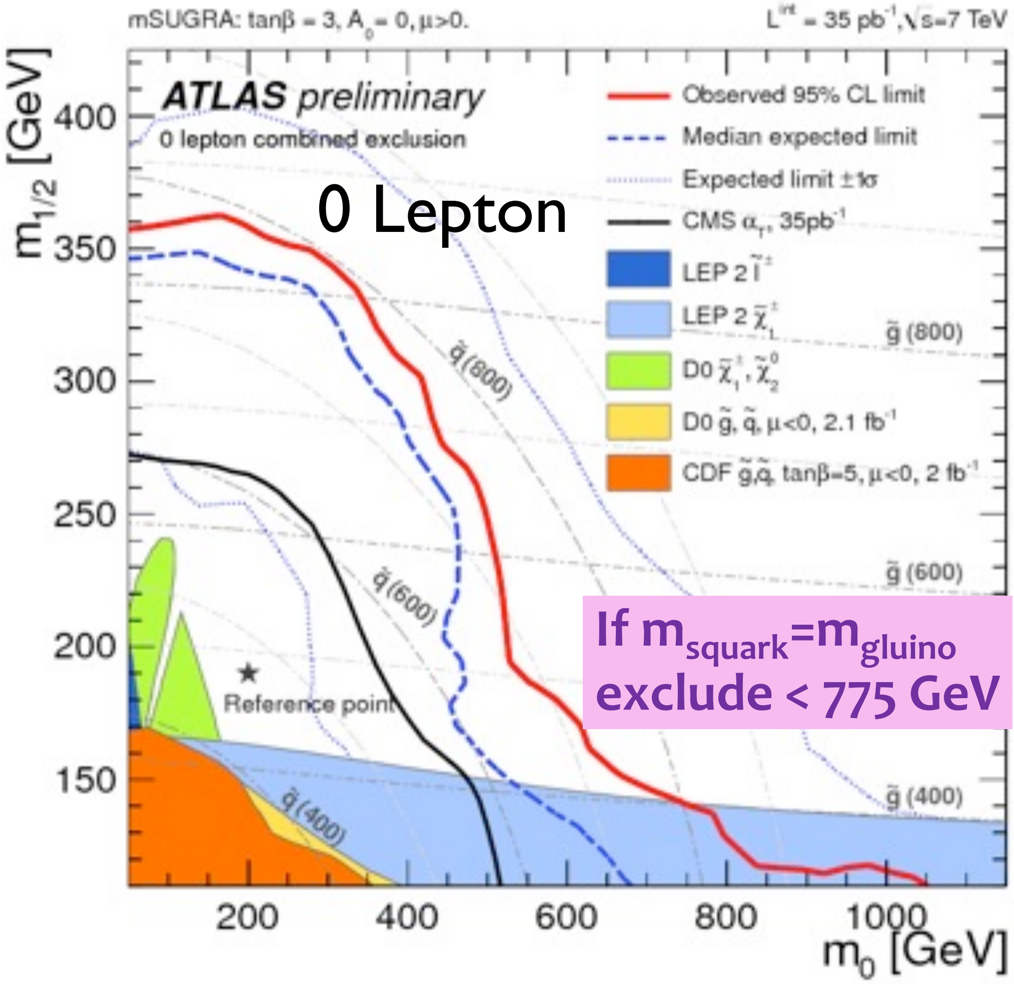
Electron channel	Signal region	Top region	W region	QCD region
Observed events	1	80	202	1464
Fitted top events	1.34 ± 0.52 (1.29)	65.0 ± 12.3 (62.9)	31.8 ± 15.8 (31.0)	40.1 ± 11.3
Fitted W/Z events	0.47 ± 0.40 (0.46)	11.2 ± 4.6 (10.2)	161 ± 27 (146)	170 ± 34
Fitted QCD events	$0.0^{+0.3}_{-0.0}$	3.7 ± 7.6	9.4 ± 19.6	1254 ± 51
Fitted sum of background events	1.81 ± 0.75	80 ± 9	202 ± 14	1464 ± 38

Muon channel	Signal region	Top region	W region	QCD region
Observed events	1	93	165	346
Fitted top events	1.76 ± 0.67 (1.39)	85.0 ± 10.5 (67.1)	41.8 ± 18.6 (33.0)	49.7 ± 10.2
Fitted W/Z events	0.49 ± 0.36 (0.71)	7.7 ± 3.3 (11.6)	120 ± 26 (166)	71.4 ± 16.4
Fitted QCD events	$0.0^{+0.5}_{-0.0}$	0.3 ± 1.2	3.4 ± 12.1	225 ± 22
Fitted sum of background events	2.25 ± 0.94	93 ± 10	165 ± 13	346 ± 19



- No excess observed
- 95% CL upper limit for new process in signal region
  - Electron: σ_{fid}<0.065 pb (2.2 events)
  - Muon: σ_{fid}<0.073 pb (2.5 events)

0 + 1 Lepton Combination



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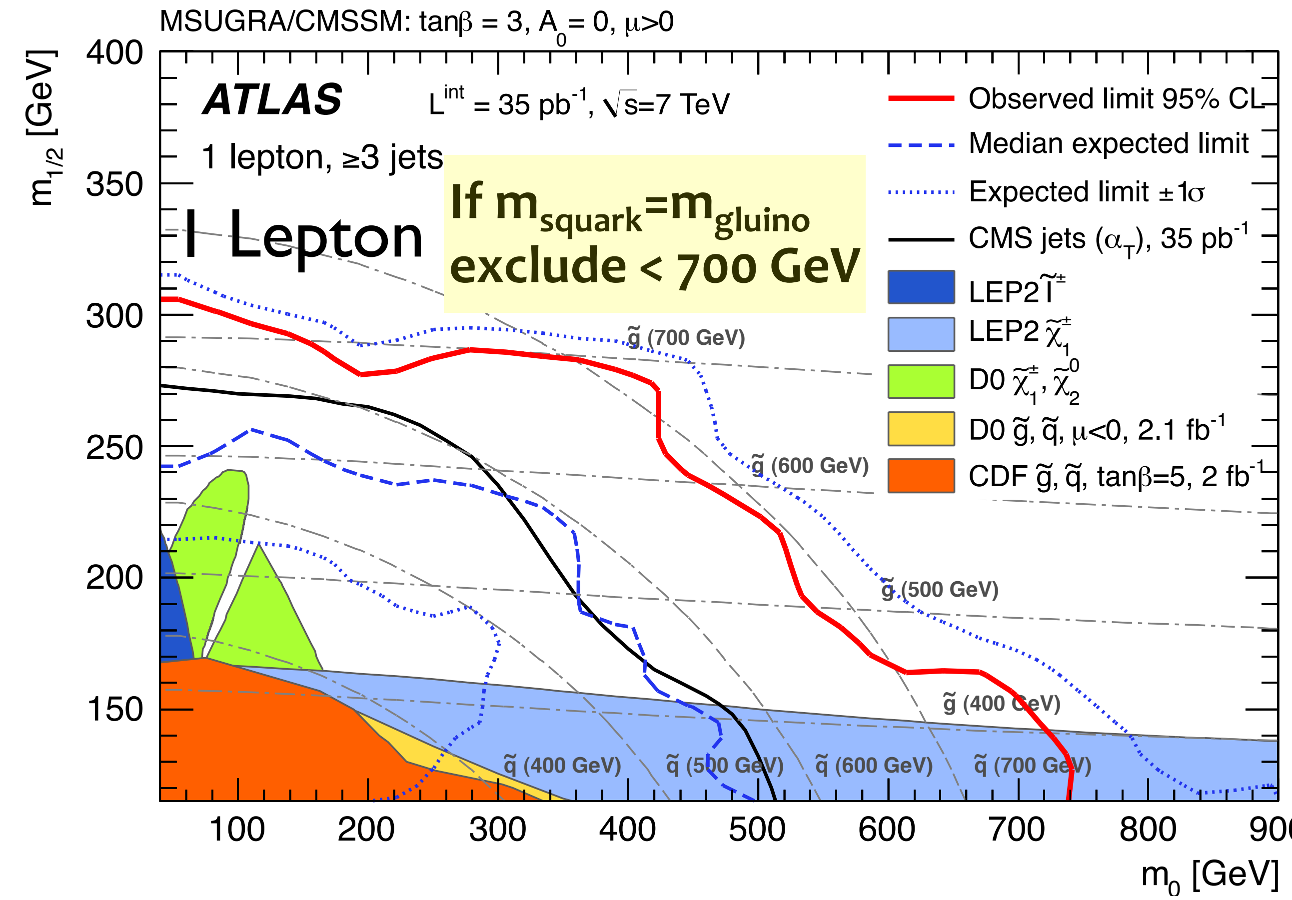

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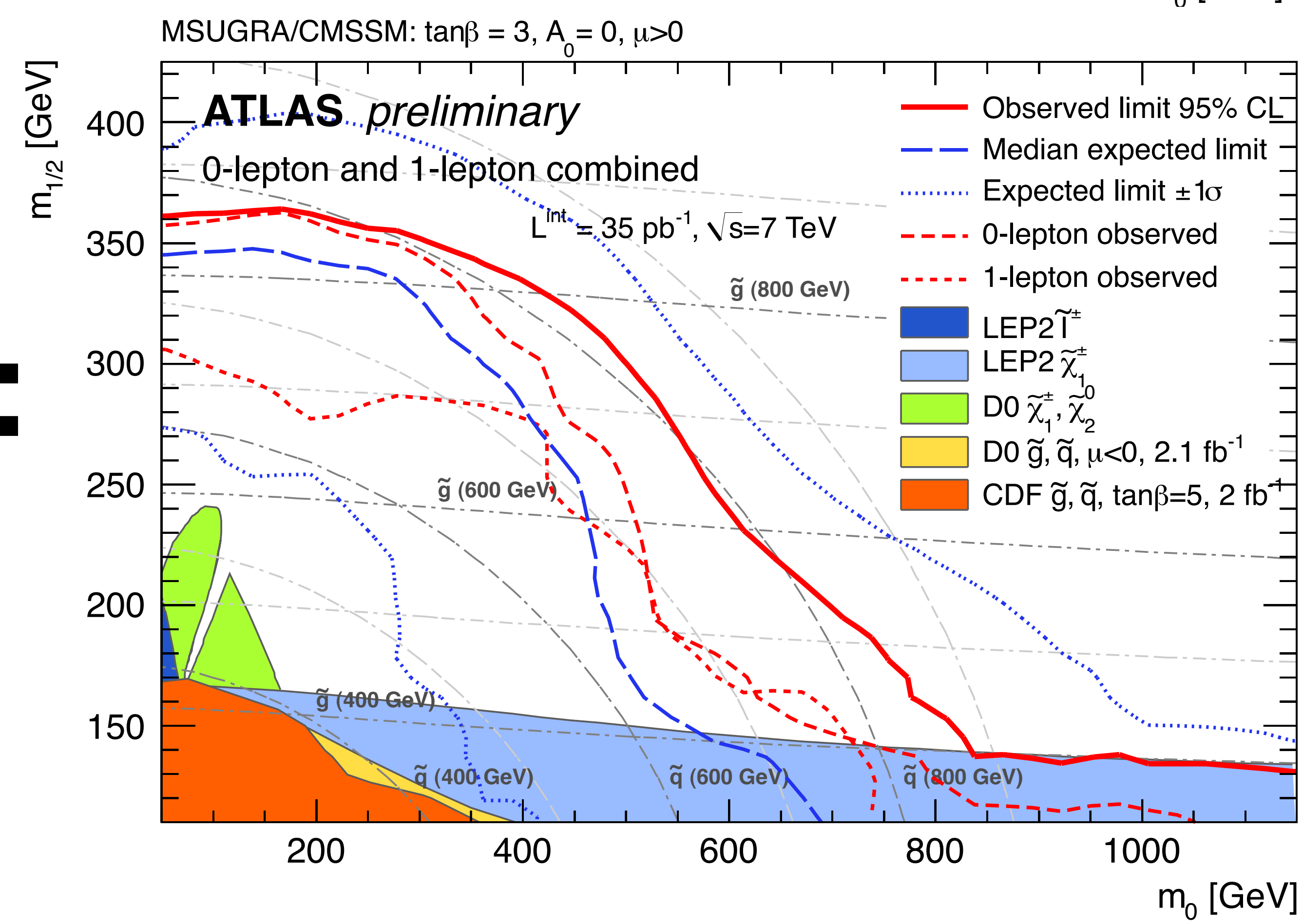
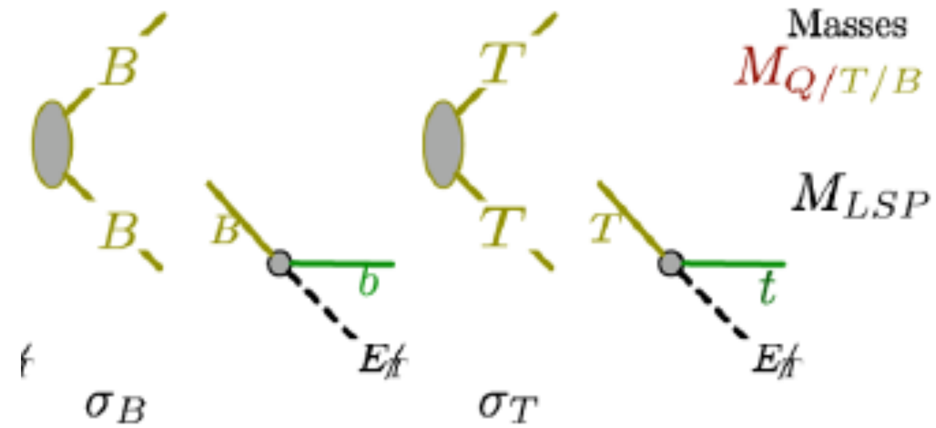


if $m_{squark} = m_{gluino}$

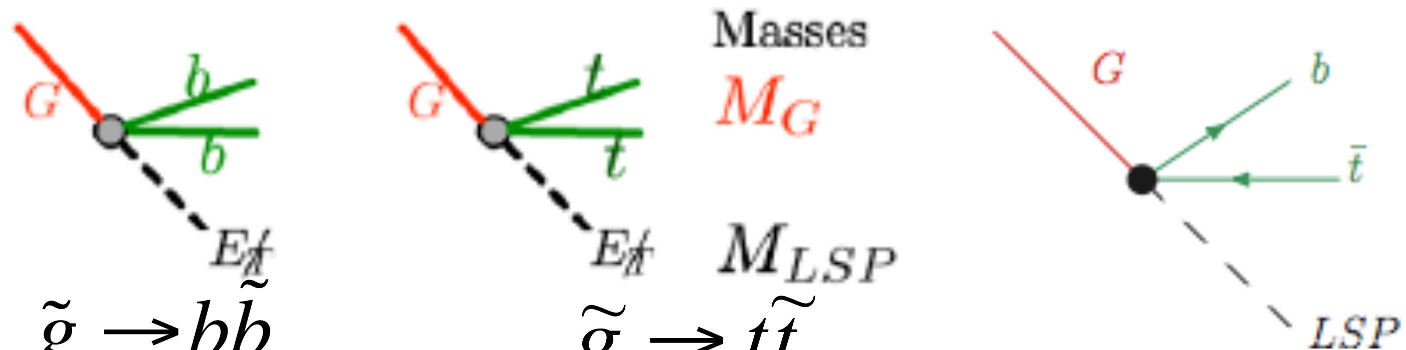
exclude < 815 GeV

Heavy Flavors

- Light 3rd Generation (high tan β)
- Heavy Flavor Production:
  - strong b,t partner production $\tilde{b}\tilde{b}, \tilde{t}\tilde{t}$



  - gluino production



$\tilde{g} \rightarrow b\tilde{b}$ $\tilde{g} \rightarrow t\tilde{t}$

- Decay: various possible depending on other sparticle masses

$\tilde{b} \rightarrow b\tilde{\chi}_1^0$ $\tilde{b} \rightarrow t\tilde{\chi}_1^\pm$ $\tilde{t} \rightarrow (t/c)\tilde{\chi}_1^0$ $\tilde{t} \rightarrow b\tilde{\chi}_1^\pm, bl\tilde{\nu}$

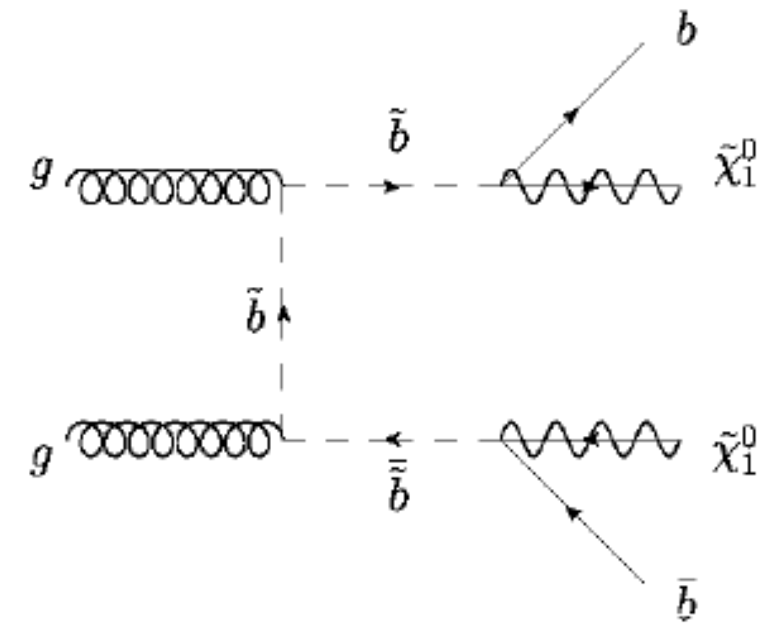
- Parameters: M(gluino) - M(stop)/M(sbottom) - M(chi0)

b-Jets + [1 Lepton] + MET

- 0-lepton + b-jets + MET: scenarios where sbottom is lightest squark

$\tilde{g} \rightarrow \tilde{b}_1 b$

$\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$

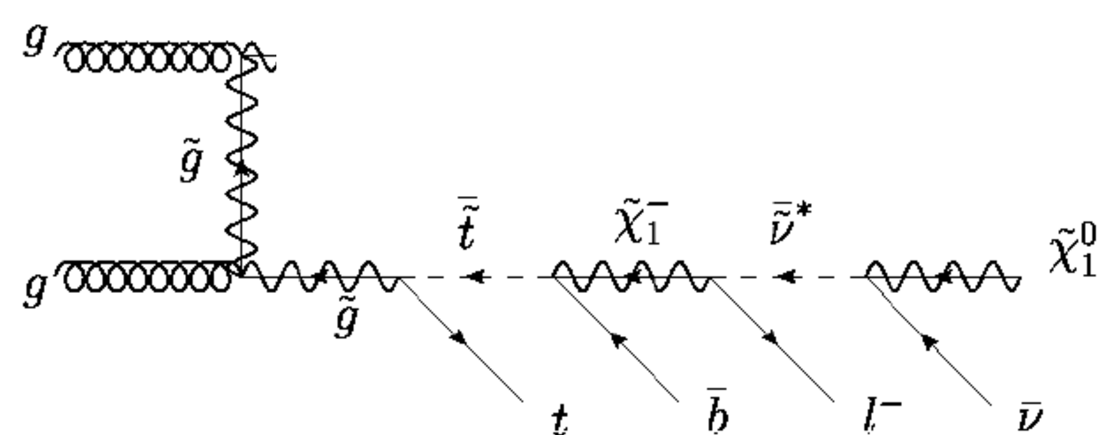


- 1-lepton + b-jets + MET:scenarios where stop is lightest squark

$\tilde{g} \rightarrow \tilde{t}_1 t \qquad \tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$

$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 l^{\pm}\nu$

0-lepton	1-lepton
no-lepton ($p_T > 20$ GeV)	≥ 1 lepton ($p_T > 20$ GeV)
jet $p_T > 120, 30, 30$ GeV, $\lvert\eta\rvert < 2.5$	jet $p_T > 60, 30$ GeV, $\lvert\eta\rvert < 2.5$
$E_T^{miss} > 100$ GeV	$E_T^{miss} > 80$ GeV
$E_T^{miss}/m_{eff} > 0.2$	–
At least 1 b-tagged jet (SV0, $L/\sigma(L) > 5.72$, $p_T > 30$GeV, $\lvert\eta\rvert < 2.5$)	
$\Delta\phi_{min} > 0.4$ rad	$m_T > 100$ GeV

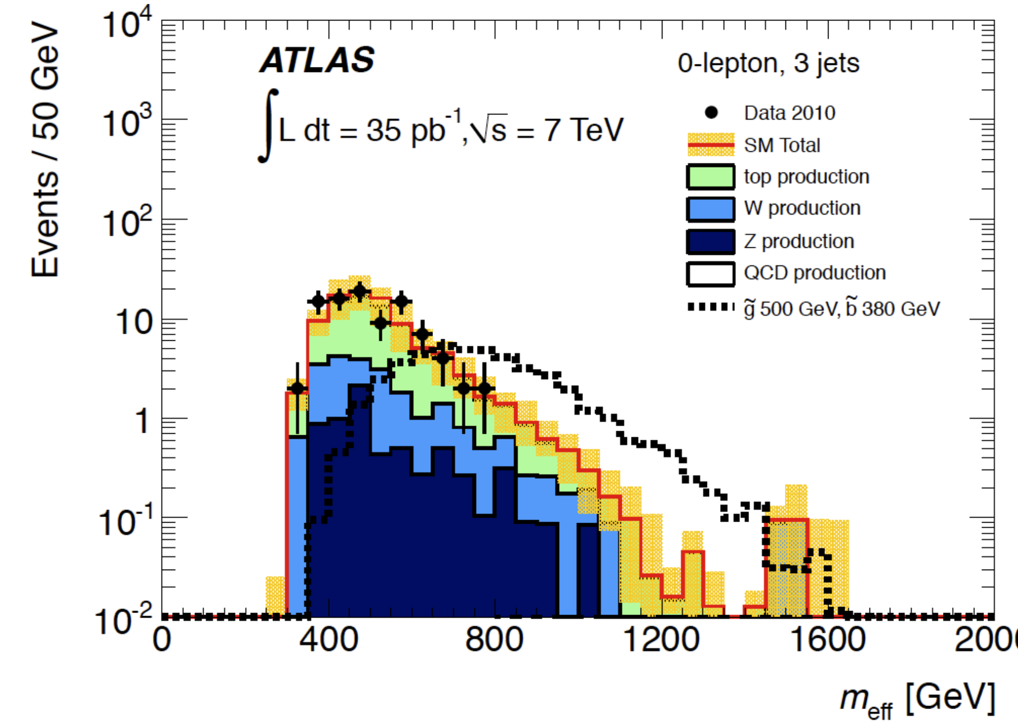


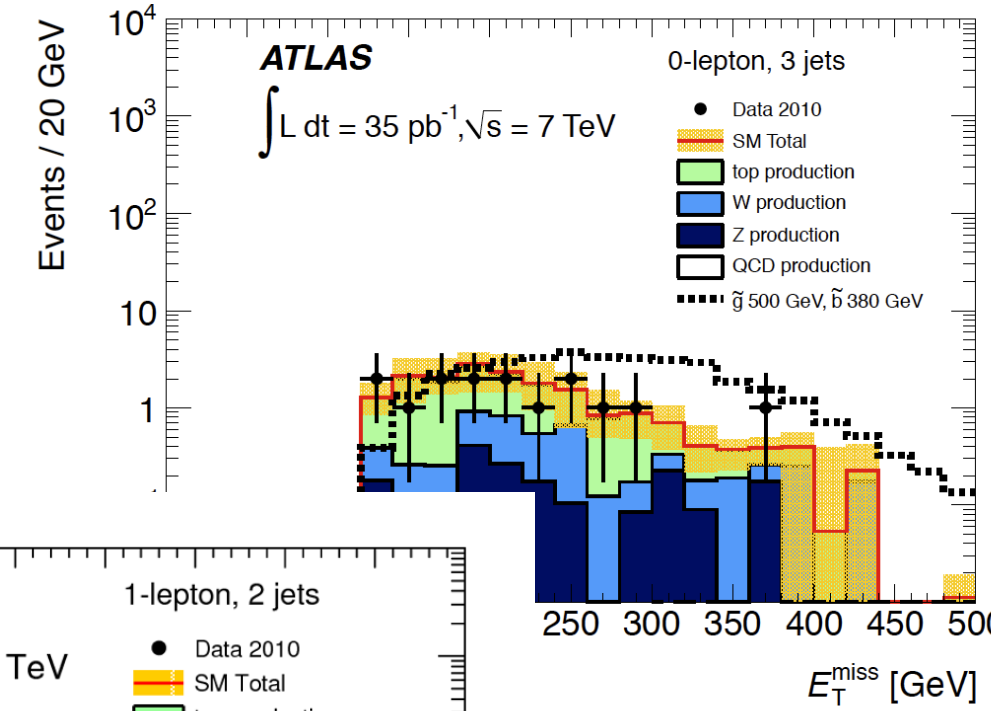
Signal-Regions:
0-lepton : $m_{eff} > 600$ GeV
1-lepton : $m_{eff} > 500$ GeV

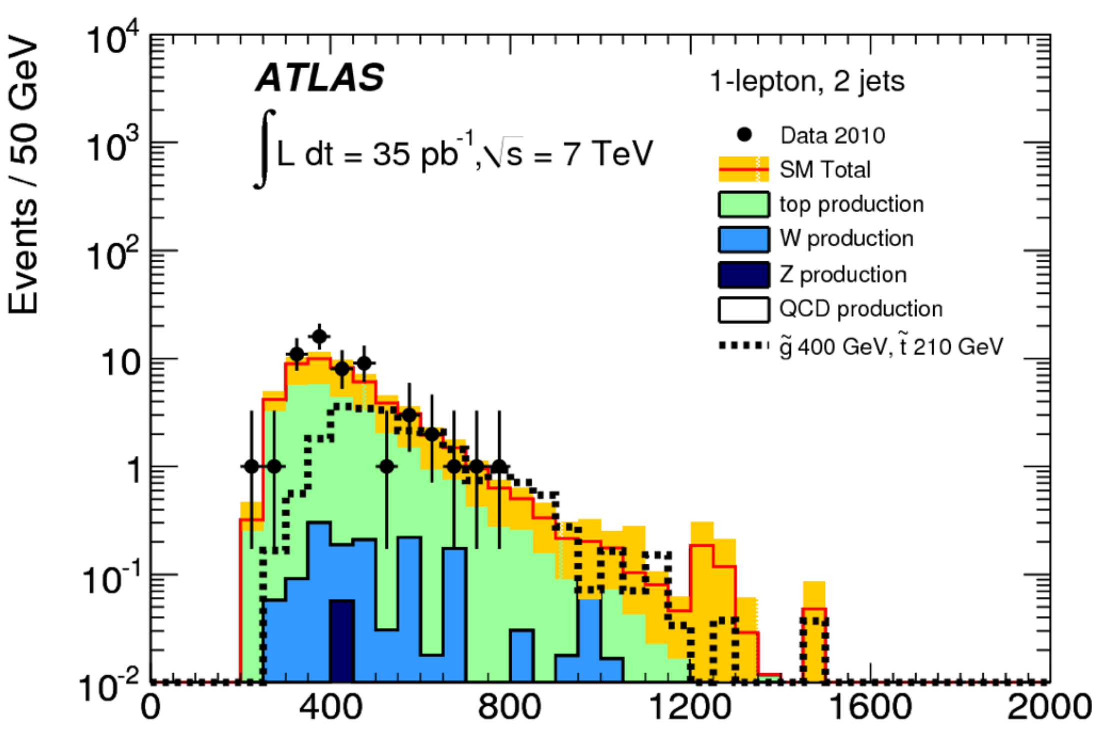
b-jets Results

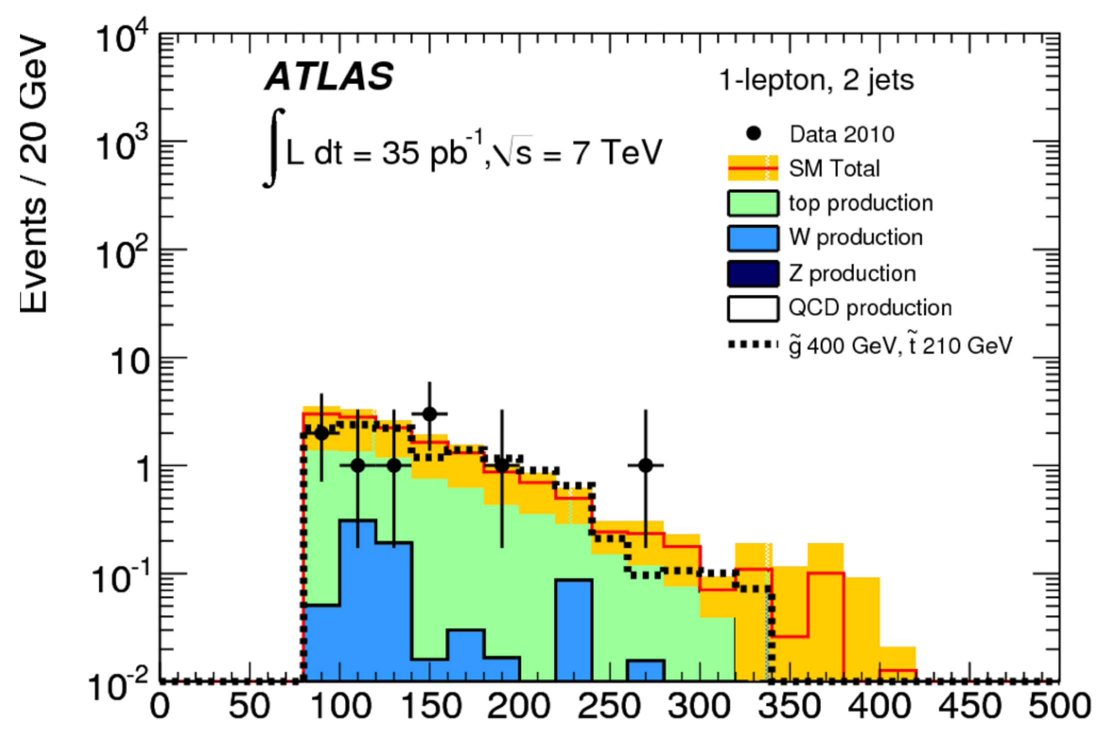
	0-lepton	1-lepton Monte Carlo	1-lepton data-driven
$t\bar{t}$ and single top	12.2 ± 5.0	12.3 ± 4.0	14.7 ± 3.7
W and Z	6.0 ± 2.0	0.8 ± 0.4	-
QCD	1.4 ± 1.0	0.4 ± 0.4	$0^{+0.4}_{-0.0}$
Total SM	19.6 ± 6.9	13.5 ± 4.1	14.7 ± 3.7
Data	15	9	9

- 0 lepton: $\sigma_{fid} < 0.32$ pb
- 1 lepton: $\sigma_{fid} < 0.13$ pb



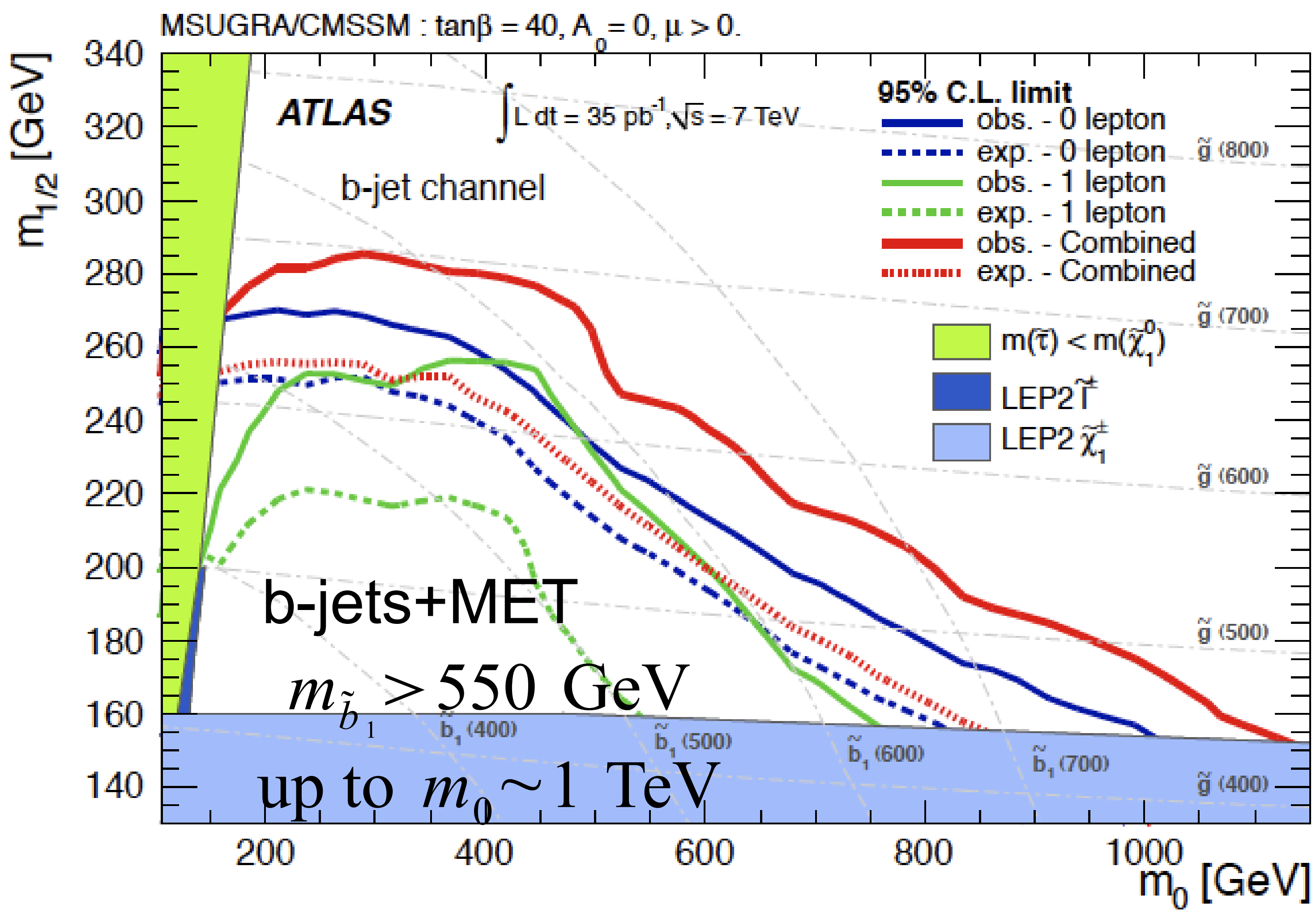






b-jets mSUGRA

- tan β = 40 (compared to 3 for Jet +MET) leads to light sbottom/stop
- Greatest sensitivity in 0 lepton



Exclusion of
gluinos below 500 GeV for the m_0 range 100 GeV - 1 TeV
stops, sbottoms below ~470, ~550 GeV respectively across the plane

If **A_0=0 => A_0=-500** :
sbottom and stop masses decrease by ~10% and ~30% respectively.
1-lepton sensitivity extends 0-lepton by ~20 GeV in $m_{1/2}$ for m_0 < 600 GeV

b-Jets Pheno

- gluino-mediated sbottom production where $m_{gluino} > m_{sbottom} > m_{neutralino} = 60$ GeV

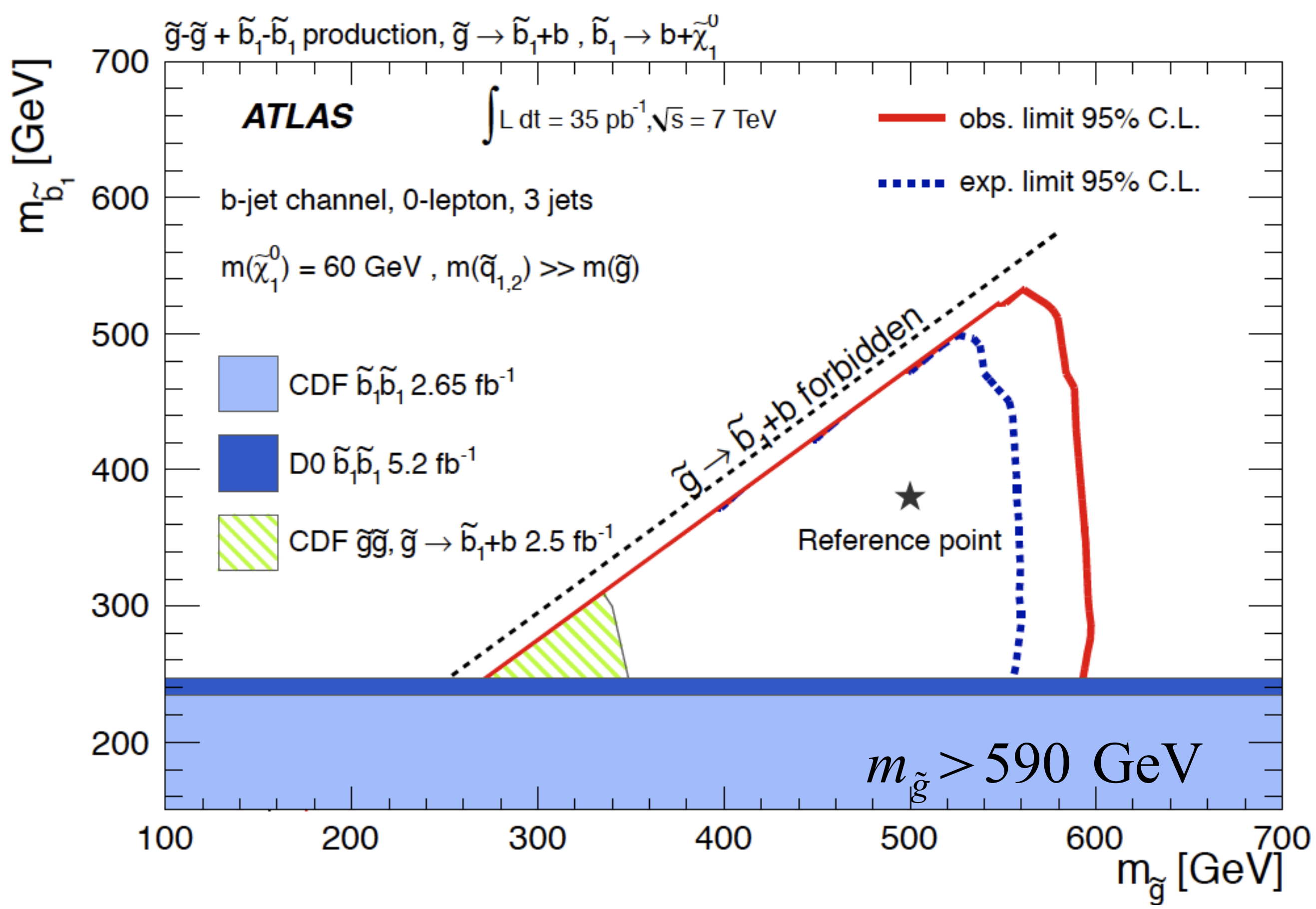
$$BR(\tilde{g} \rightarrow \tilde{b}_1 b) = 100\%$$
$$BR(\tilde{b}_1 \rightarrow b \tilde{\chi}_1^0) = 100\%$$

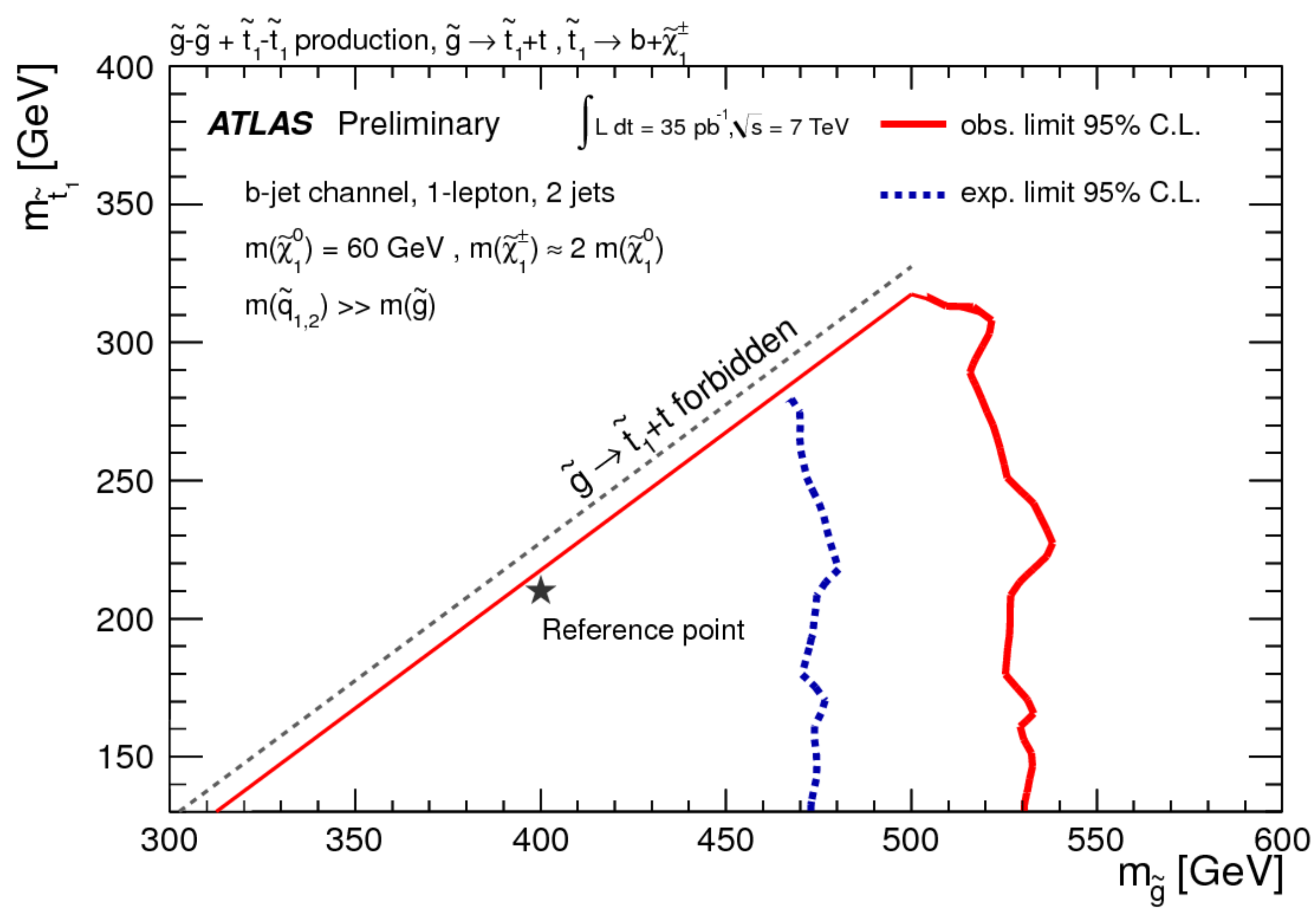
- gluino-mediated stop production where $m_{gluino} > m_{stop} > m_{chargino} > m_{neutralino} = 60$ GeV

$$\tilde{g} \rightarrow \tilde{t}_1 t$$
$$\tilde{t}_1 \rightarrow b \tilde{\chi}_1^{\pm}$$

BR($\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 l^{\pm} \nu$) = 11%

m($\chi^{\pm}$) = 120 GeV, m(χ^0)=60 GeV





2 Leptons + MET

MAIN SOURCE:
- decay of neutralinos&charginos

$$\tilde{\chi}_i^\pm(\to \ell^\pm\tilde{\nu}_\ell/\nu\tilde{\ell}^\pm/W^\pm\tilde{\chi}_j^0) \to \nu\ell^\pm\tilde{\chi}_j^0$$
$$\tilde{\chi}_i^0(\to \nu\tilde{\nu}_\ell/W^\mp\tilde{\chi}_j^\pm) \to \nu\ell^\mp\tilde{\chi}_j^\pm$$

$$\tilde{\chi}_i^\pm(\to \ell^\pm\tilde{\nu}_\ell/Z\tilde{\chi}_j^\pm) \to \ell^+\ell^-\tilde{\chi}_j^\pm$$
$$\tilde{\chi}_i^0(\to \ell^\pm\tilde{\ell}^\mp/Z\tilde{\chi}_j^0) \to \ell^+\ell^-\tilde{\chi}_j^0$$

single-lepton

di-lepton

Depends on:
- gaugino/higgsino composition of neutralinos&charginos
- slepton whereabouts (and type)
- squark whereabouts (and type)

SECONDARY SOURCE:
- *W* through third-generation squark

$$\tilde{g} \to t\tilde{t} \to Wb\tilde{t}$$
$$\tilde{g} \to tb\tilde{\chi}_i^\pm \to Wbb\tilde{\chi}_i^\pm$$
$$\tilde{b} \to W\tilde{t}$$
$$\tilde{b} \to t\tilde{\chi}_i^\pm \to Wb\tilde{\chi}_i^\pm$$
$$\tilde{t} \to t\tilde{\chi}_i^0 \to Wb\tilde{\chi}_i^0$$

Depends on:
- stop/sbottom mass / production

- Di-lepton transitions give leptons correlated in flavour and sign:

  (A) Opposite-Sign Same-Flavour (OSSF)

  $$e^+e^-,\ \mu^+\mu^-$$

- Di-leptons from two single-lepton transitions are uncorrelated in flavour, and often in sign.

  (B) OSSF and OSDF (same rate)

  $$e^+e^-,\ \mu^+\mu^-,\ e^\pm\mu^\mp$$

  (C) SSSF and SSDF (same rate)

  $$e^\pm e^\pm,\ \mu^\pm\mu^\pm,\ e^\pm\mu^\pm$$

SS vs OS

- Simple structure for neutralino/chargino single-lepton transition, e.g.:

$$\text{SS}: \quad \tilde{u}\tilde{u} \to dd\tilde{\chi}^+\tilde{\chi}^+ \to dd\nu\nu\ell^+\ell^+\tilde{\chi}^0\tilde{\chi}^0$$
$$\text{SS}: \quad \tilde{d}\tilde{d} \to uu\tilde{\chi}^-\tilde{\chi}^- \to uu\bar{\nu}\bar{\nu}\ell^-\ell^-\tilde{\chi}^0\tilde{\chi}^0$$
$$\text{OS}: \quad \tilde{u}\tilde{d} \to du\tilde{\chi}^+\tilde{\chi}^- \to du\nu\bar{\nu}\ell^+\ell^-\tilde{\chi}^0\tilde{\chi}^0$$

Standard Model background can also be classified in A-C:
- Type A: Z, Drell-Yan
- Type B: Top, (fully/partially) QCD-induced
- Type C: diboson, charge-mismeas., [few]

2 Lepton Signal Regions

2 Analyses:

OS/SS

Event selection
- exactly two leptons
- M(ll) > 5 GeV

Signal regions
- OS: $E_T^{Miss} > 150$ GeV
- SS: $E_T^{Miss} > 100$ GeV

Main SM Background
- OS: **top pair**, Z+jets
- SS: misidentified leptons (fakes) → data-driven as in 1-lepton analysis

OSSF

- Most SM di-lepton mechanisms, in particular ttbar, give uncorrelated (OS) di-leptons, with combinations that come in equal rates, SF = DF.
- Allows Flavor Subtraction

$$\mathcal{S} = \frac{N(e^{\pm}e^{\mp})}{\beta(1-(1-\tau_e)^2)} - \frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_\mu)} + \frac{\beta N(\mu^{\pm}\mu^{\mp})}{(1-(1-\tau_\mu)^2)}$$

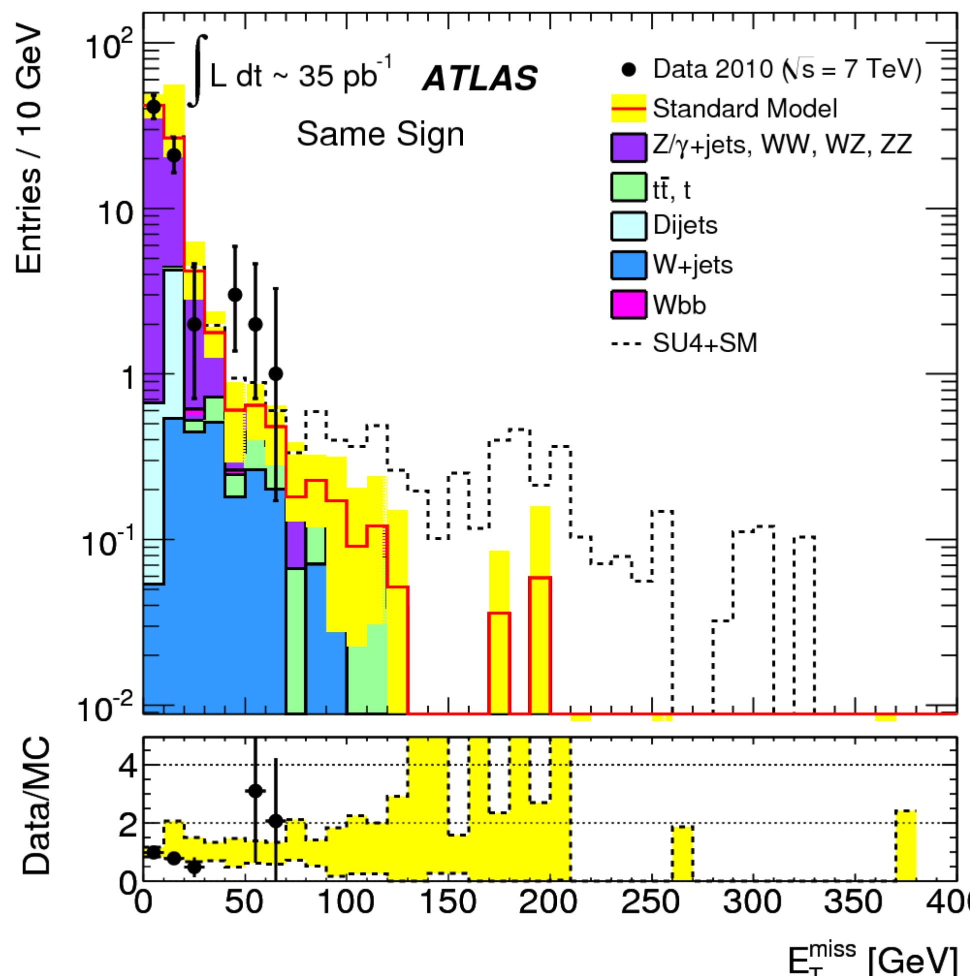
$$\tau_e = (98.5 \pm 1.1)\%,\ \tau_\mu = (83.7 \pm 1.9)\%,\ \beta = 0.69 \pm 0.03$$

ε_e, ε_μ = ID efficiency
$\beta = \varepsilon_e/\varepsilon_\mu$
τ_e,τ_μ = trigger efficiency

2 Lepton OS/SS Results

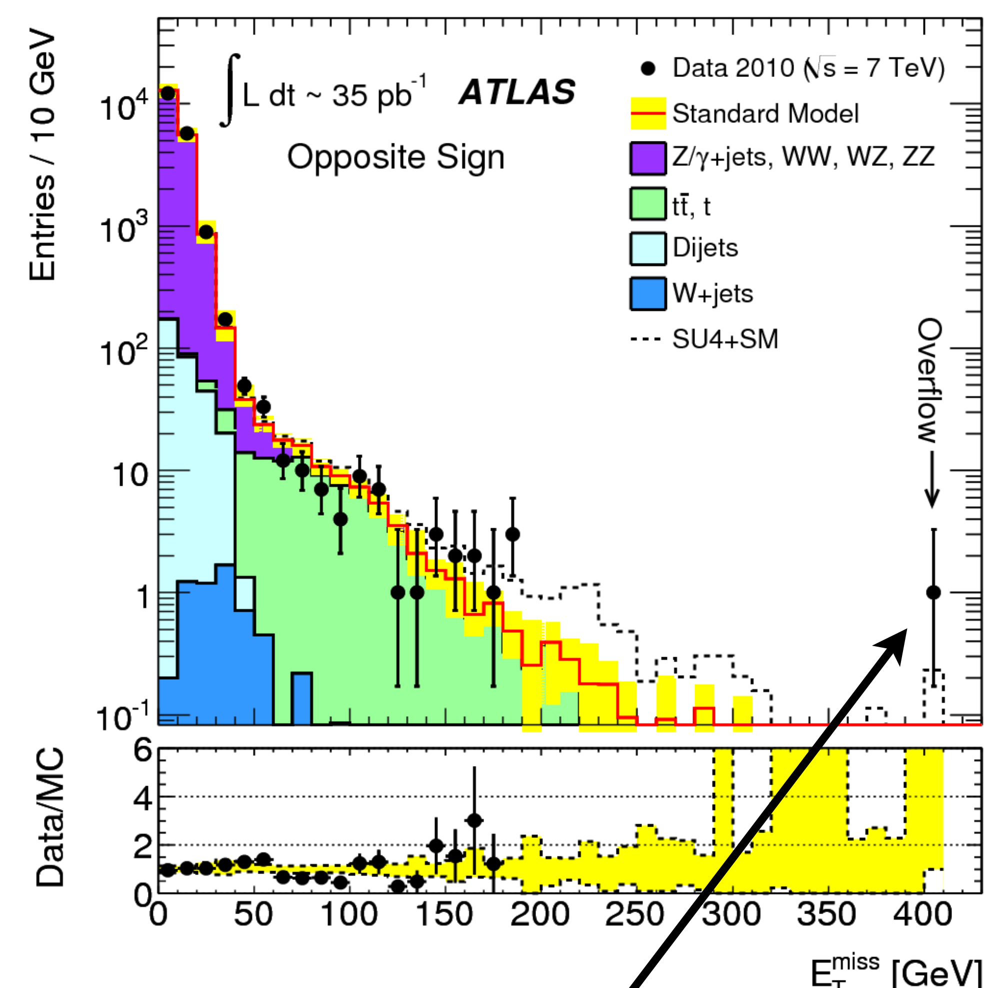
Same Sign, $E_T^{miss} > 100$ GeV	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Data	0	0	0
Fakes	0.12 ± 0.13	0.030 ± 0.026	0.014 ± 0.010
Di-bosons	0.015 ± 0.005	0.035 ± 0.012	0.021 ± 0.009
Charge-flip	0.019 ± 0.008	0.026 ± 0.011	-
Cosmics	-	$0^{+1.17}_{-0}$	-
Total	0.15 ± 0.13	$0.09^{+1.17}_{-0.03}$	0.04 ± 0.01

Opposite Sign, $E_T^{miss} > 150$ GeV	e^+e^-	$e^{\pm}\mu^{\mp}$	$\mu^+\mu^-$
Data	1	4	4
$t\bar{t}$	$0.62^{+0.31}_{-0.28}$	$1.24^{+0.62}_{-0.56}$	$1.00^{+0.50}_{-0.45}$
Z+jets	0.19 ± 0.15	0.08 ± 0.08	0.14 ± 0.17
Fakes	-0.02 ± 0.02	-0.05 ± 0.04	-
Single top	0.03 ± 0.05	0.06 ± 0.08	0.10 ± 0.07
Di-bosons	0.09 ± 0.03	0.06 ± 0.03	0.15 ± 0.03
Cosmics	-	-0.2 ± 1.18	-0.43 ± 1.27
Total	$0.92^{+0.42}_{-0.40}$	$1.43^{+1.45}_{-0.59}$	$1.39^{+1.41}_{-0.53}$



- SS: $\sigma_{fid} < 0.07$ pb
- OS ee: $\sigma_{fid} < 0.09$ pb
- OS eμ: $\sigma_{fid} < 0.21$ pb
- OS μμ: $\sigma_{fid} < 0.22$ pb

- Excess in eμ and μμ probability for bkg to exceed observed 14% & 13%



μμ event looks like Cosmic Ray

2 Lepton OSSF Results

$$\mathcal{S} = \frac{N(e^{\pm}e^{\mp})}{\beta(1-(1-\tau_e)^2)} - \frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_\mu)} + \frac{\beta N(\mu^{\pm}\mu^{\mp})}{(1-(1-\tau_\mu)^2)}$$

$$\tau_e = (98.5 \pm 1.1)\%, \ \tau_\mu = (83.7 \pm 1.9)\%, \ \beta = 0.69 \pm 0.03$$

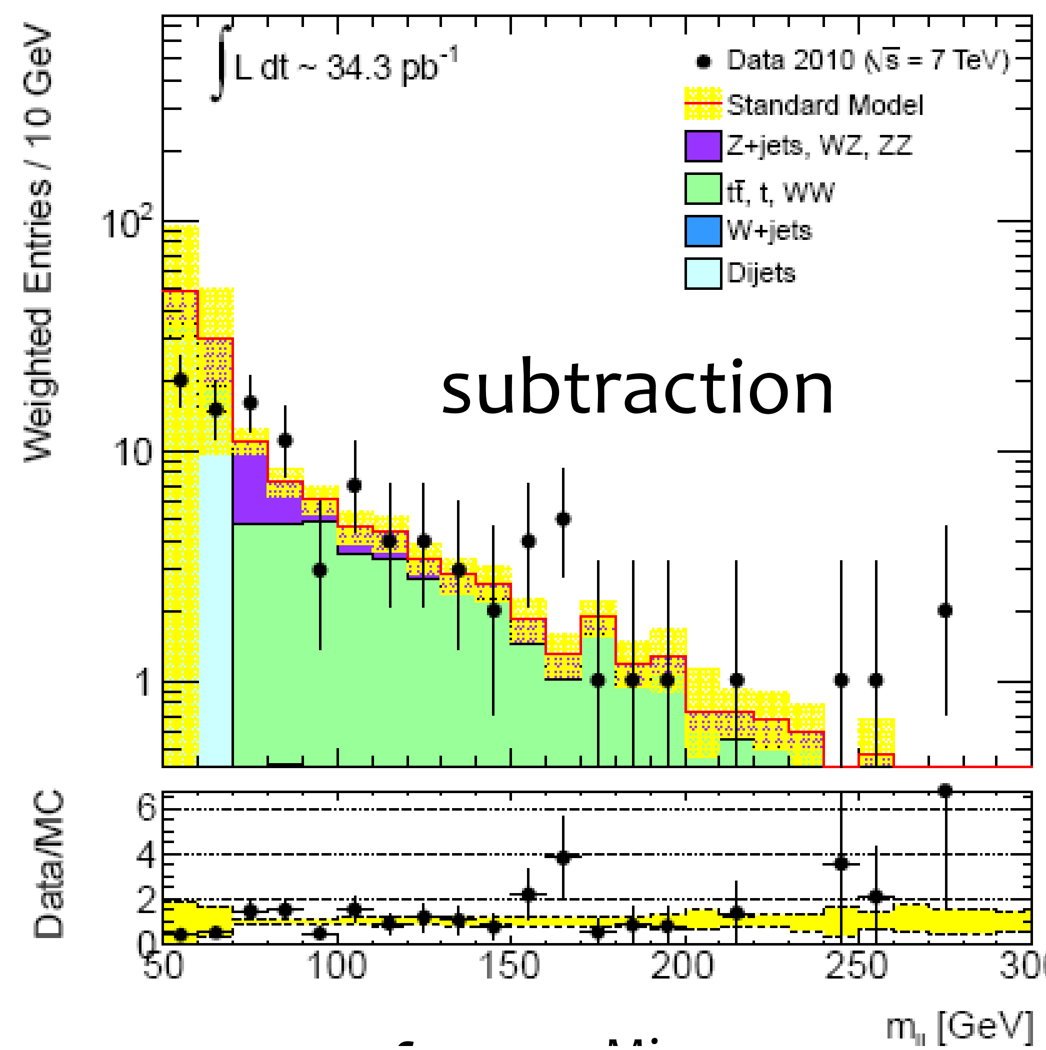
$\varepsilon_e, \varepsilon_\mu$ = ID efficiency
$\beta = \varepsilon_e/\varepsilon_\mu$
τ_e, τ_μ = trigger efficiency

$$\mathcal{S}_{obs.} = 1.98 \pm 0.15(\beta) \pm 0.02(\tau_e) \pm 0.06(\tau_\mu)$$

	$e^{\pm}e^{\mp}$	$e^{\pm}\mu^{\mp}$	$\mu^{\pm}\mu^{\mp}$
Data	4	13	13
Z/γ^*+jets	0.40±0.46	0.36±0.20	0.91±0.67
Dibosons	0.30±0.11	0.36±0.10	0.61±0.10
$t\bar{t}$	2.50±1.02	6.61±2.68	4.71±1.91
Single top	0.13±0.09	0.76±0.25	0.67±0.33
Fakes	0.31±0.21	-0.15±0.08	0.01±0.01
Total SM	3.64±1.24	8.08±2.78	6.91±2.20

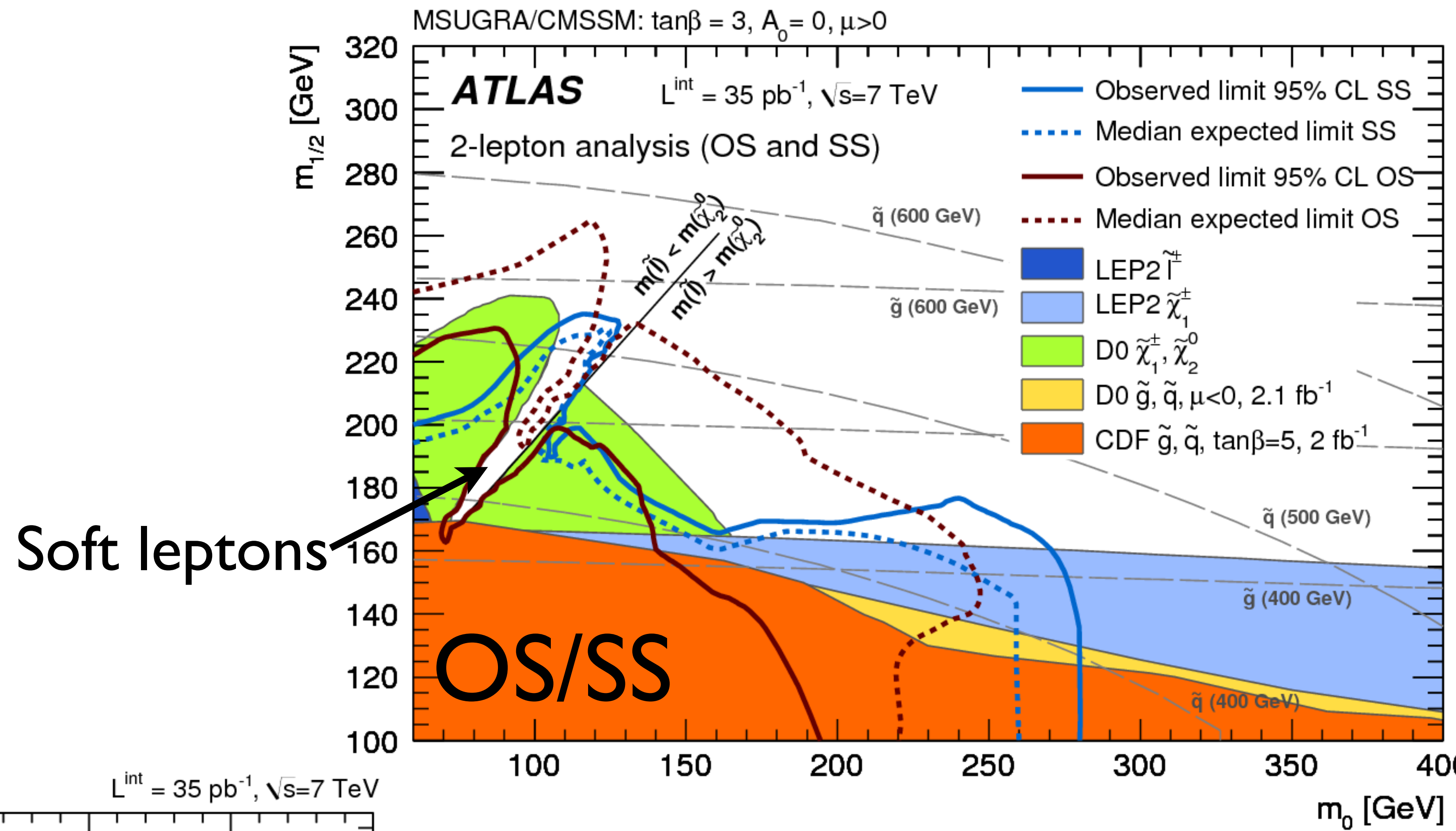
Flavour-subtracted

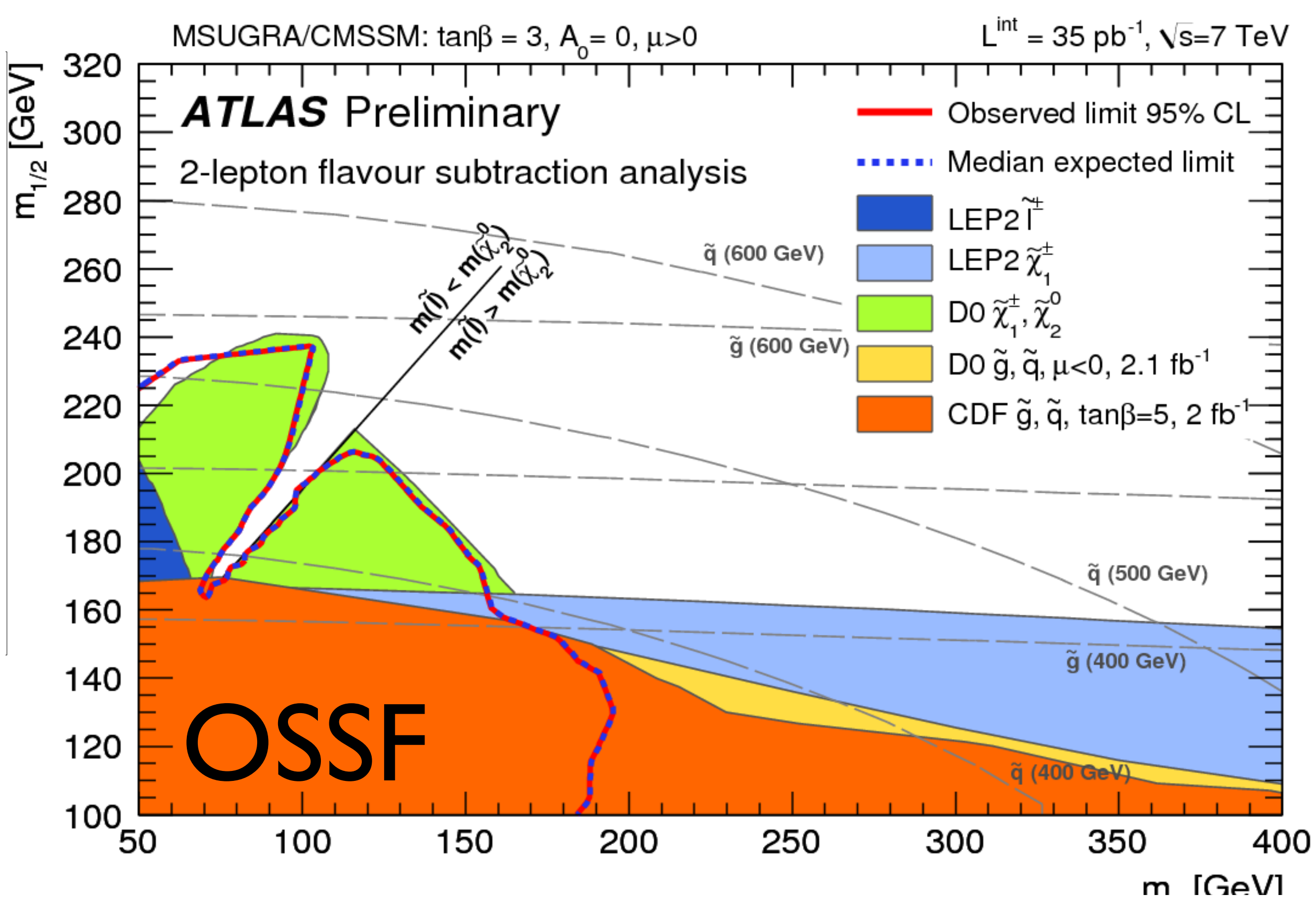
Process	$\mathcal{S}_b$
Z/γ^*+jets	0.86 ± 0.33 (stat.) ± 0.74 (sys.)
Dibosons	0.51 ± 0.04 (stat.) ± 0.12 (sys.)
$t\bar{t}$	0.34 ± 0.61 (stat.) ± 0.13 (sys.)
Single top	-0.10 ± 0.23 (stat.) ± 0.08 (sys.)
Fakes	0.46 ± 0.31 (stat.) ± 0.10 (sys.)
SM total	2.06 ± 0.79 (stat.) ± 0.78 (sys.)



2 Lepton- mSUGRA

- OS seen to have more potentiality ("expected") in mSUGRA plane than SS, though some complementarity
- SS better than expected
- OS worse than expected
- Limits partly extend previous 2L limits in mSUGRA
- (0 and 1-lepton searches exclude much larger parts of the mSUGRA plane)





- OSSF observed and expected limit are identical
- OSSF expected is less powerful than OS throughout the mSUGRA plane (for the given setup and lumi)
- Observed limit is better than SS and OS in part of the plane
- Follows very closely the D0 direct gaugino trilepton results

2 Lepton- Pheno

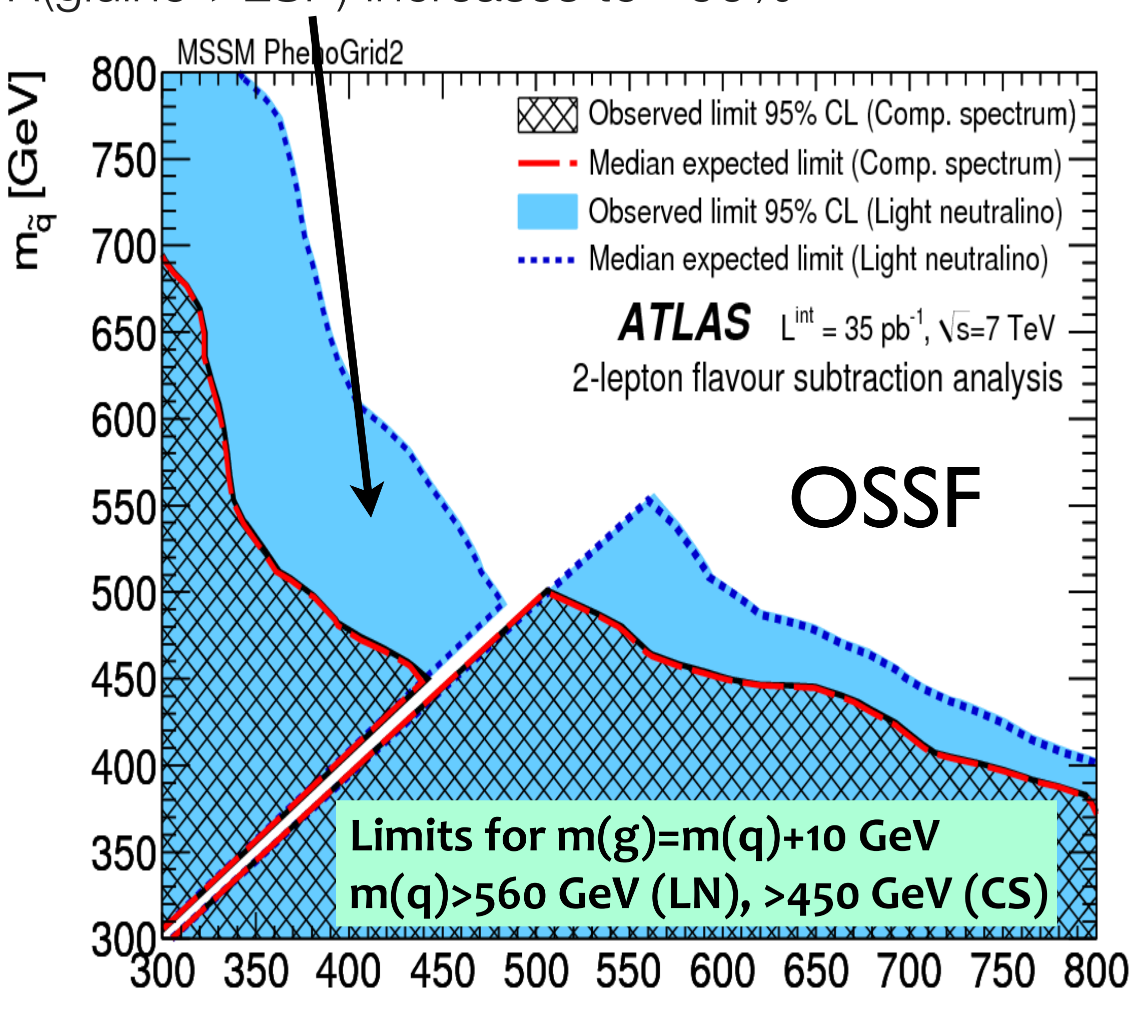
Phenomenological MSSM scenario:

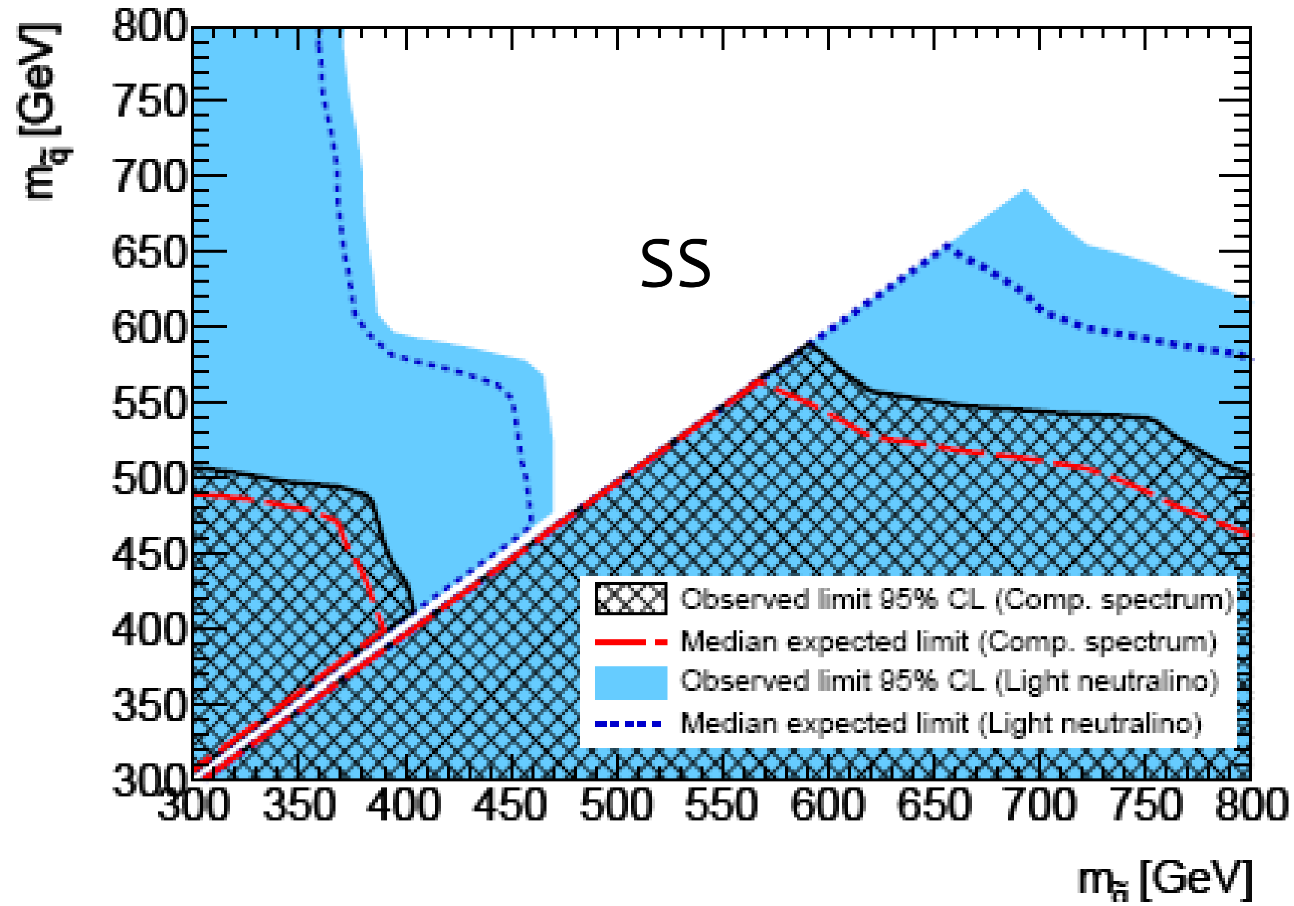
- bino-like LSP, wino-like chi $\chi^{\pm}_1$ and χ^0_2
- decays w/ sleptons enhance leptons
- 3rd generation scalars at very high mass

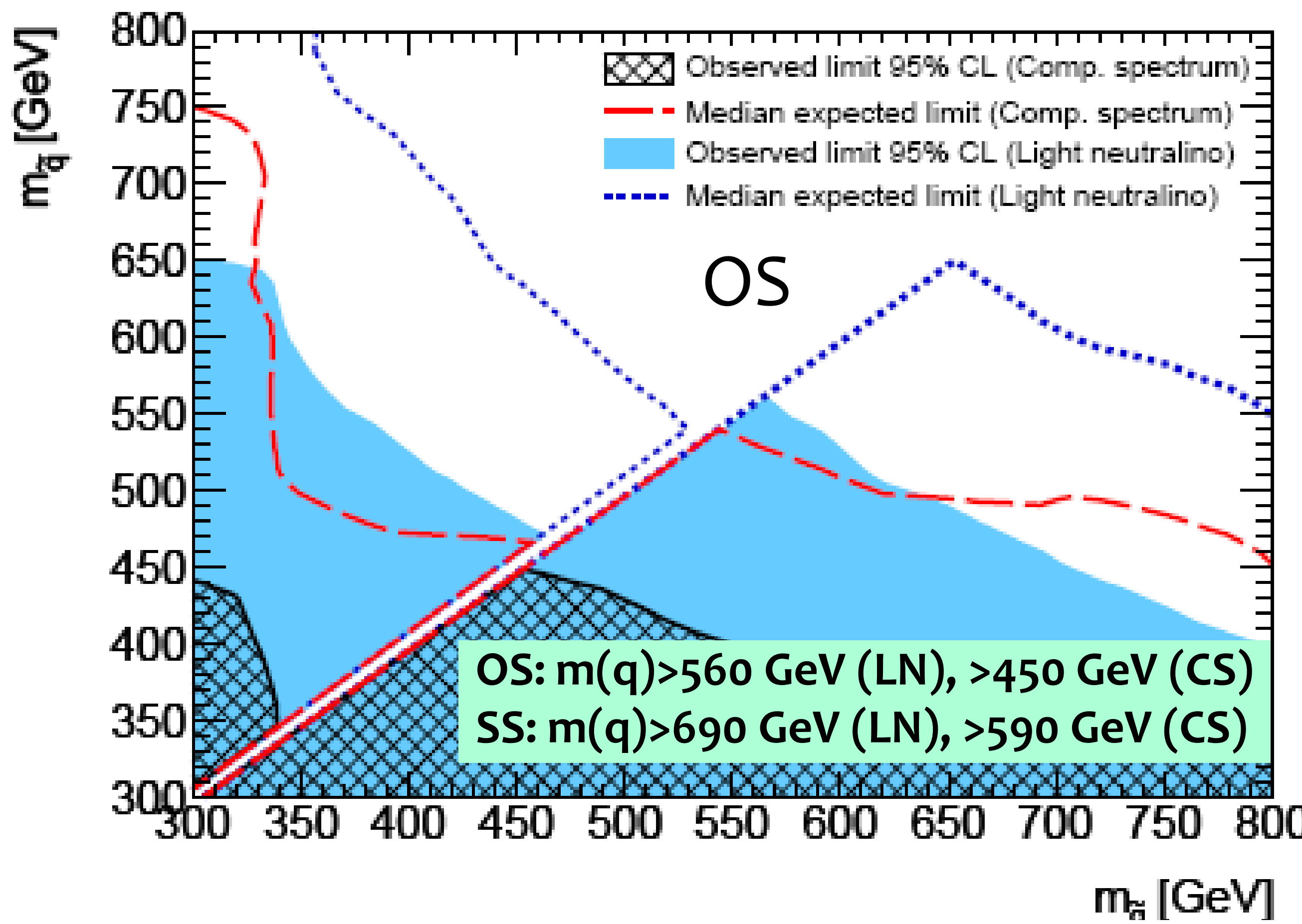
	"Compressed"	"Light neutralino"
$m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^\pm_1)$	h-50	h-100
$m(\tilde{\ell})$	h-100	h/2
$m(\tilde{\chi}^0_1)$	h-150	100

h = min(gl, sq mass)

For m(squark) > m(gluino) :
BR(gluino->LSP) increases to ~90%



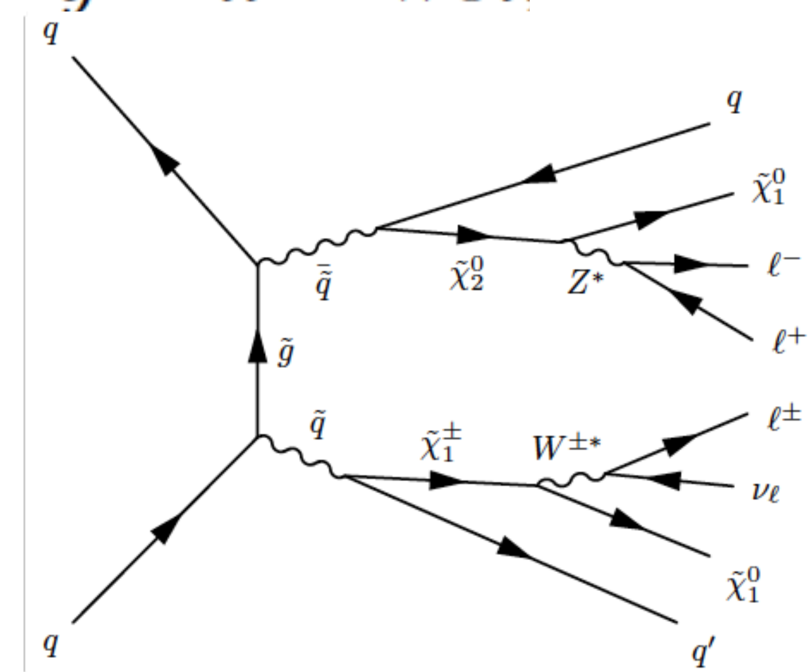




≥3 Leptons + ≥2 Jet + MET

- Multi-lepton final states from χ± and χ0 (produced directly or as intermediate states in long decay chains)
  - decay leptonically via emission of gauge boson, or intermediate sleptons
- Third generation squarks lead to W bosons, e.g.
- very little SM background

$\tilde{g} \to t\tilde{t} \to Wb\tilde{t}$



3 Lepton Results

- Event pre-selection: ≥3 leptons (el/mu)
- Signal-selection: ≥2 jets with pT > 50 GeV ETmiss > 50 GeV
- Z boson veto: invariant mass of same-flavour opposite-sign (SFOS) lepton pairs is required to be at least 5 GeV off from Z mass
- DY veto: invariant mass of SFOS lepton pairs > 20 GeV

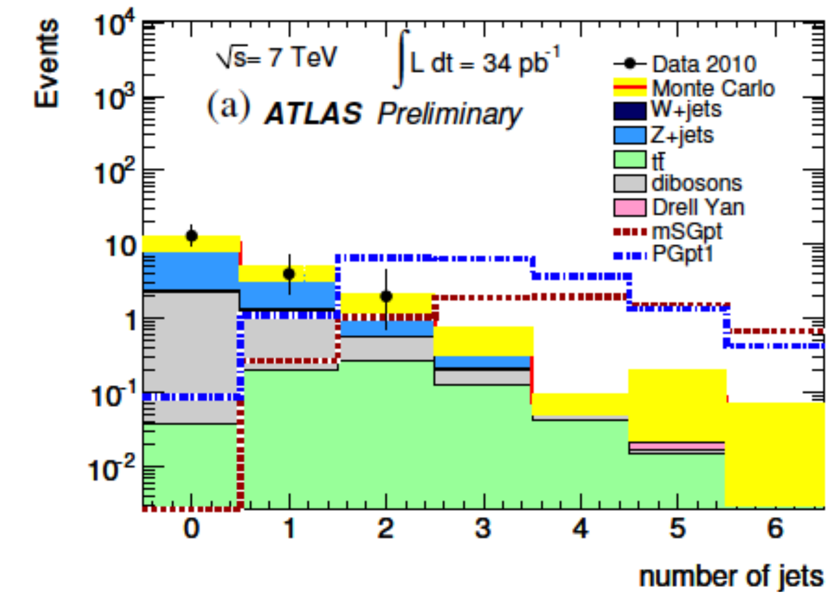
After Preselection

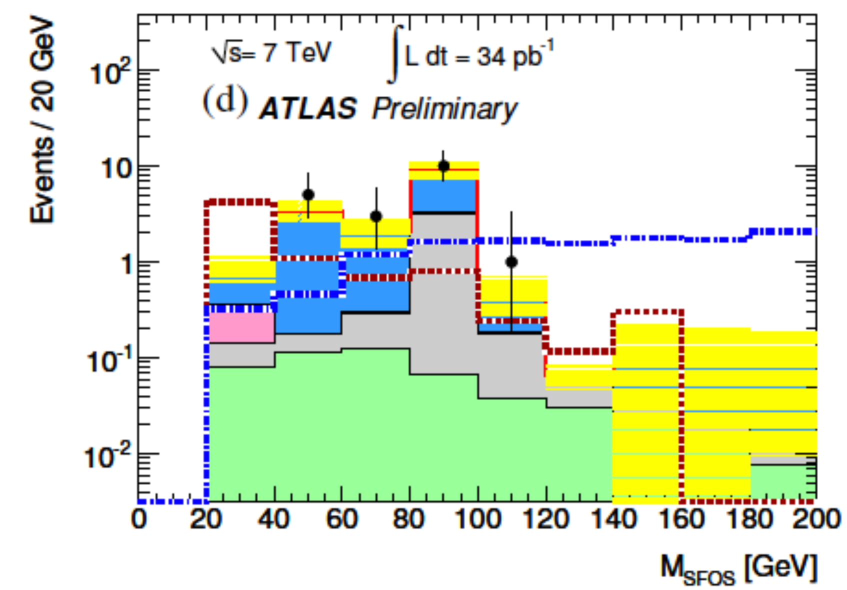
Multilep. events	All	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
$t\bar{t}$	0.68±0.16	0.032±0.016	0.24±0.07	0.31±0.08	0.096±0.030
Z backgrounds	15.6±1.3	3.8±0.8	1.60±0.34	7.9±1.0	2.4±0.4
Other backgrounds	0.28±0.13	0.02±0.14	0.03±0.06	0.21±0.09	0.01±0.11
Total SM	16.6±1.3	3.8±0.8	1.9±0.4	8.4±1.0	2.5±0.4
Data	19	2	1	10	6

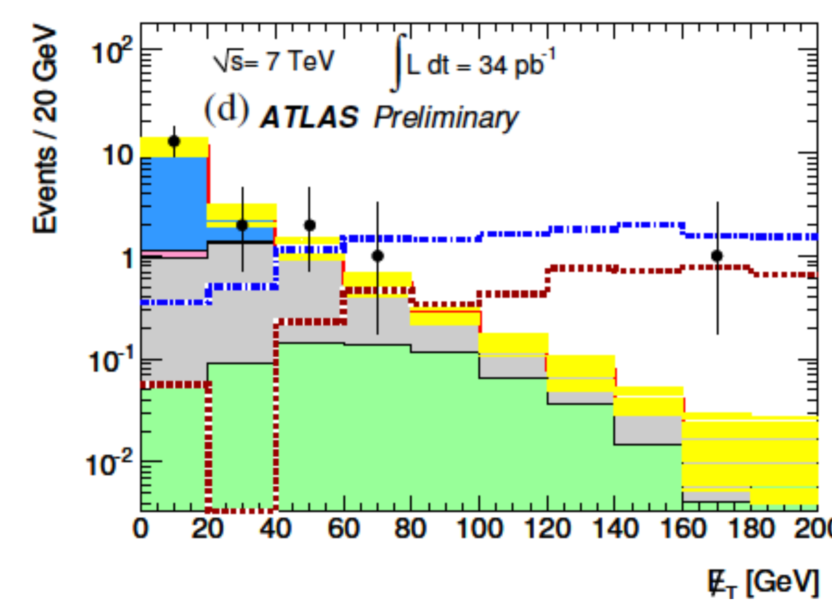
0 observed events in SR

SM prediction:

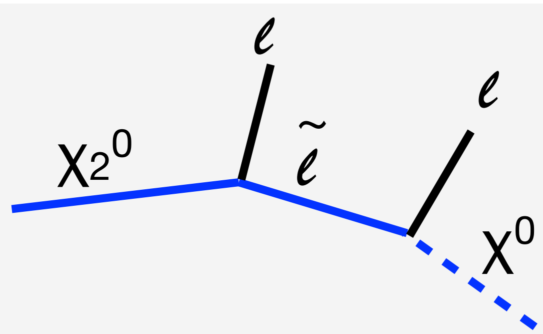
$$0.109 \pm 0.023^{+0.036}_{-0.025}$$



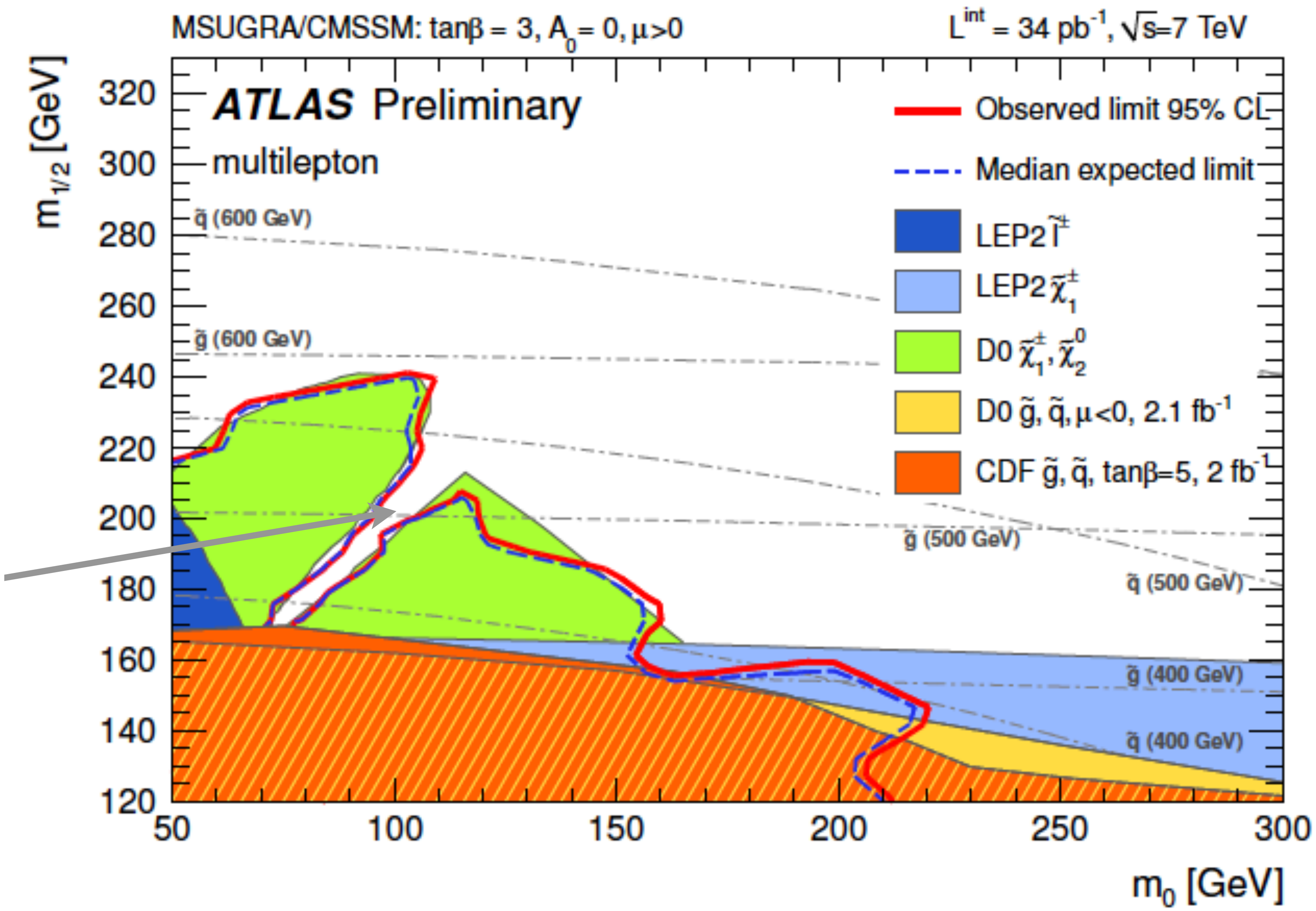




3 Lepton- mSUGRA



$m_{\ell} \lesssim m_{\chi}$: very soft lepton



Signal-model independent exclusion result :

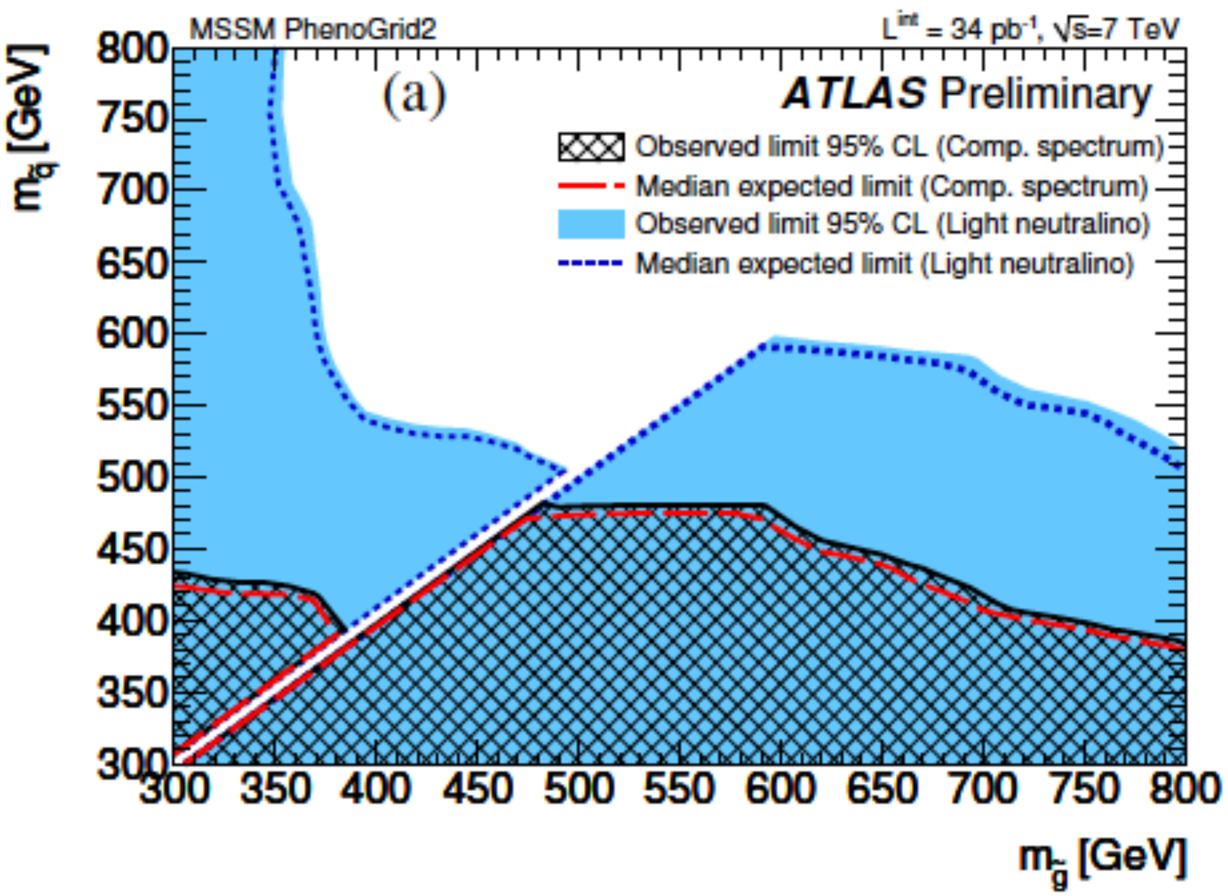
Upper limit on $\sigma_{eff} = \sigma$ x Acceptance x ε

62 fb

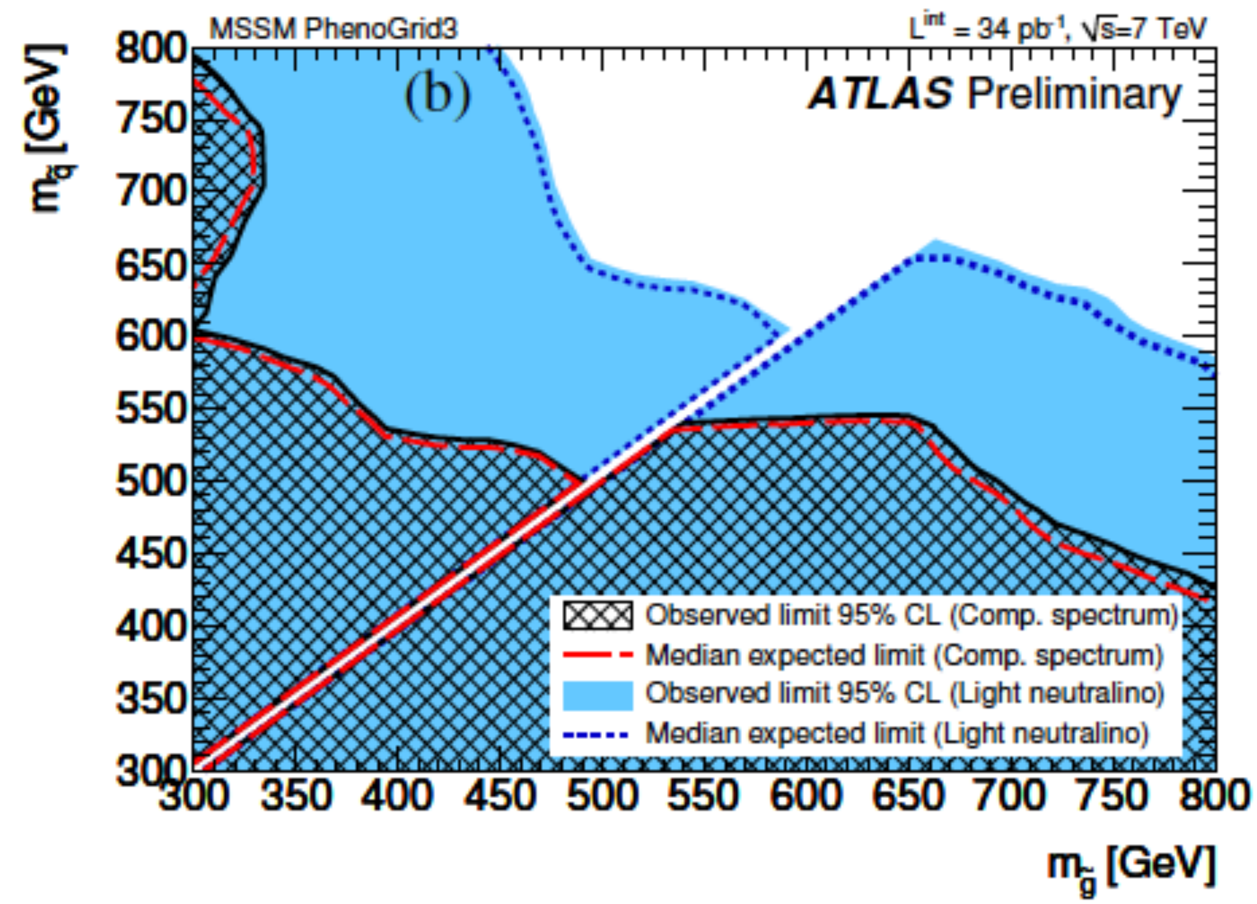
3-lepton Pheno

2 Pheno Scenarios:

- right-handed sfermions pushed to high mass
- cross-section slightly reduced
- lepton fraction increased (right-handed squarks decay to bino-like LSP)



For m(gluino) = m(squark) + 10 GeV
Exclusion of
squarks below 480 (600) GeV in the "compressed" ("light neutralino") scenario



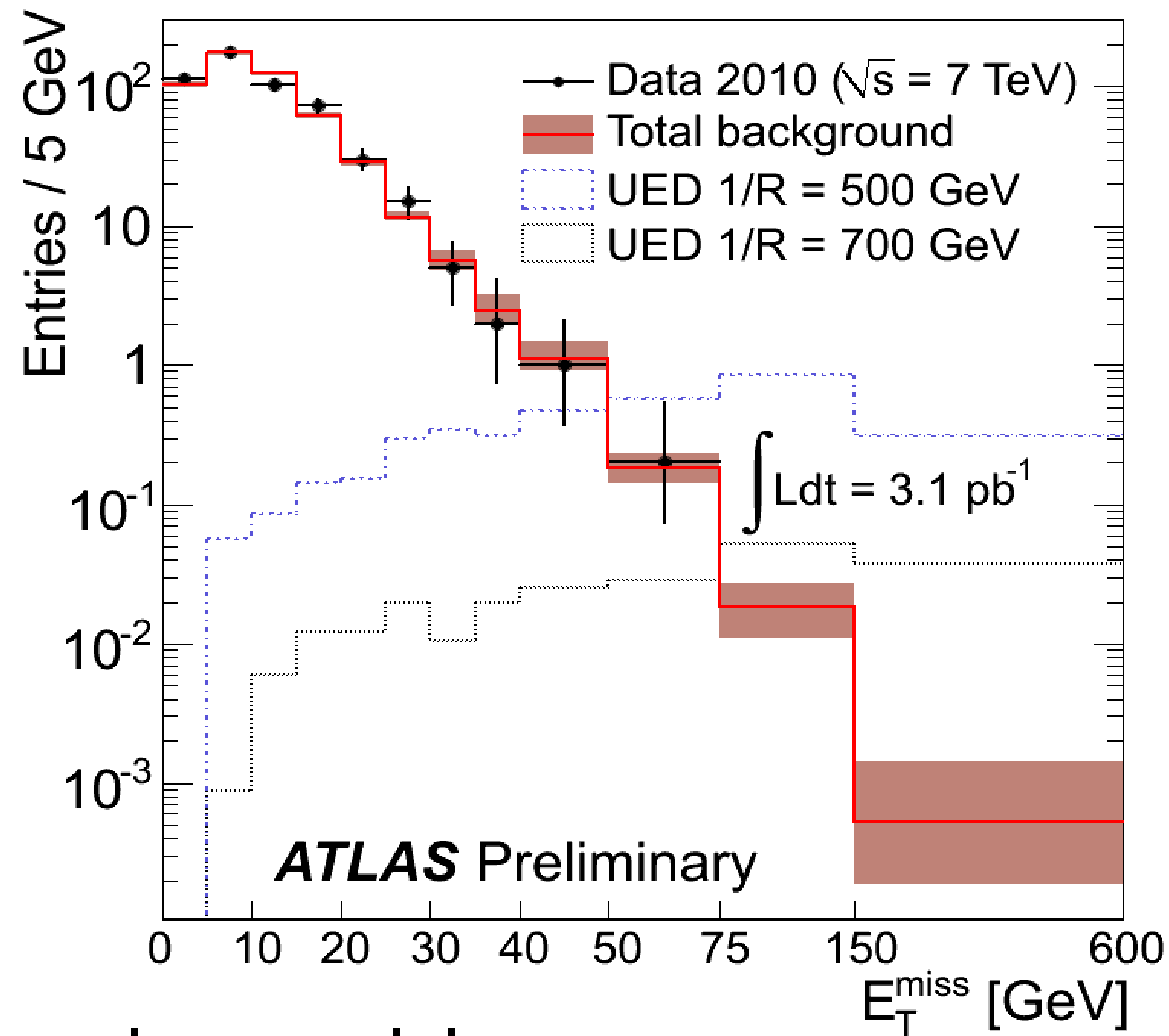
For m(gluino) = m(squark) + 10 GeV
Exclusion of
squarks below 540 (670) GeV in the "compressed" ("light neutralino") scenario

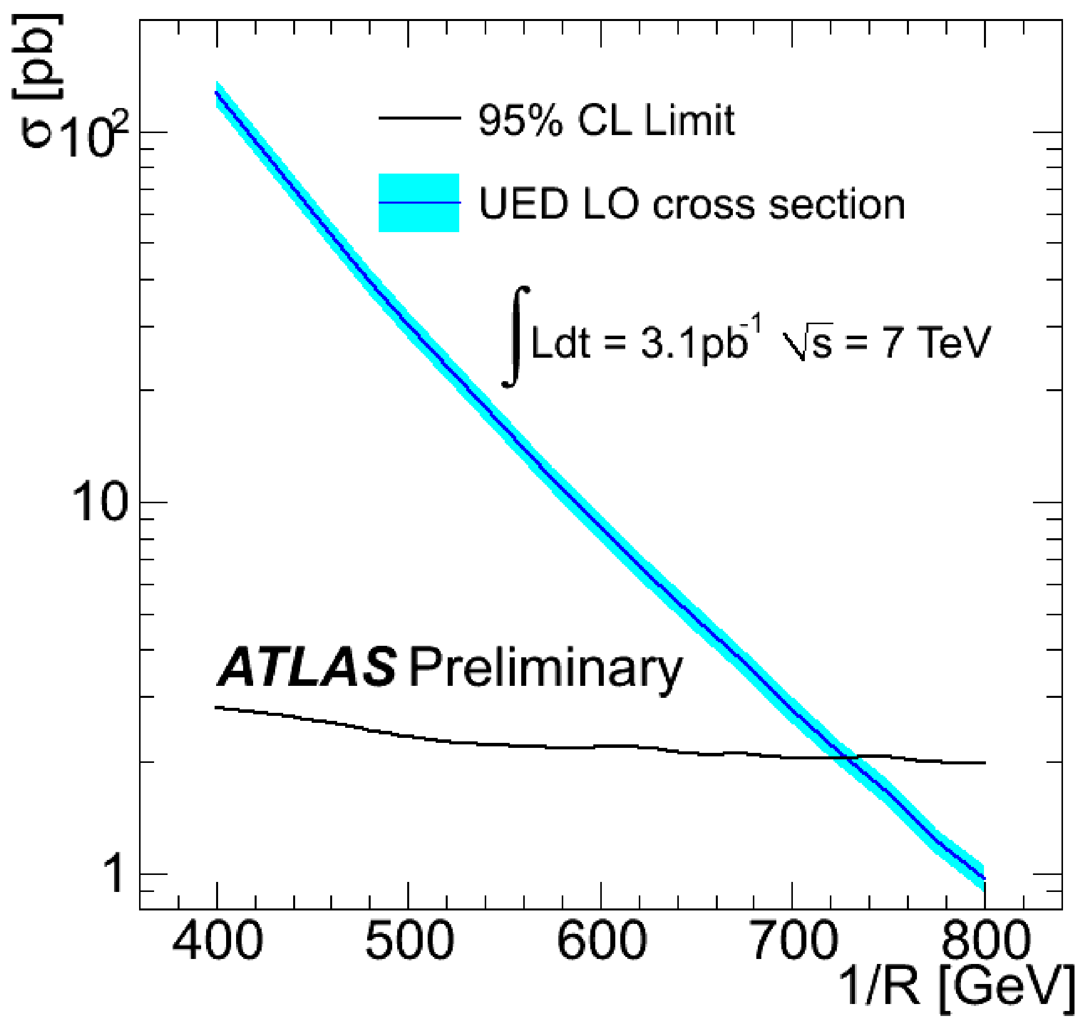
Diphoton+MET

3.1/pb

arXiv:1012.4272

- Look for 2 photons w/ E_T>25 GeV and $E^{Had}{}_T/E_T$<0.2
- UED signal expected at MET>75
  - keep expected bkg to 1



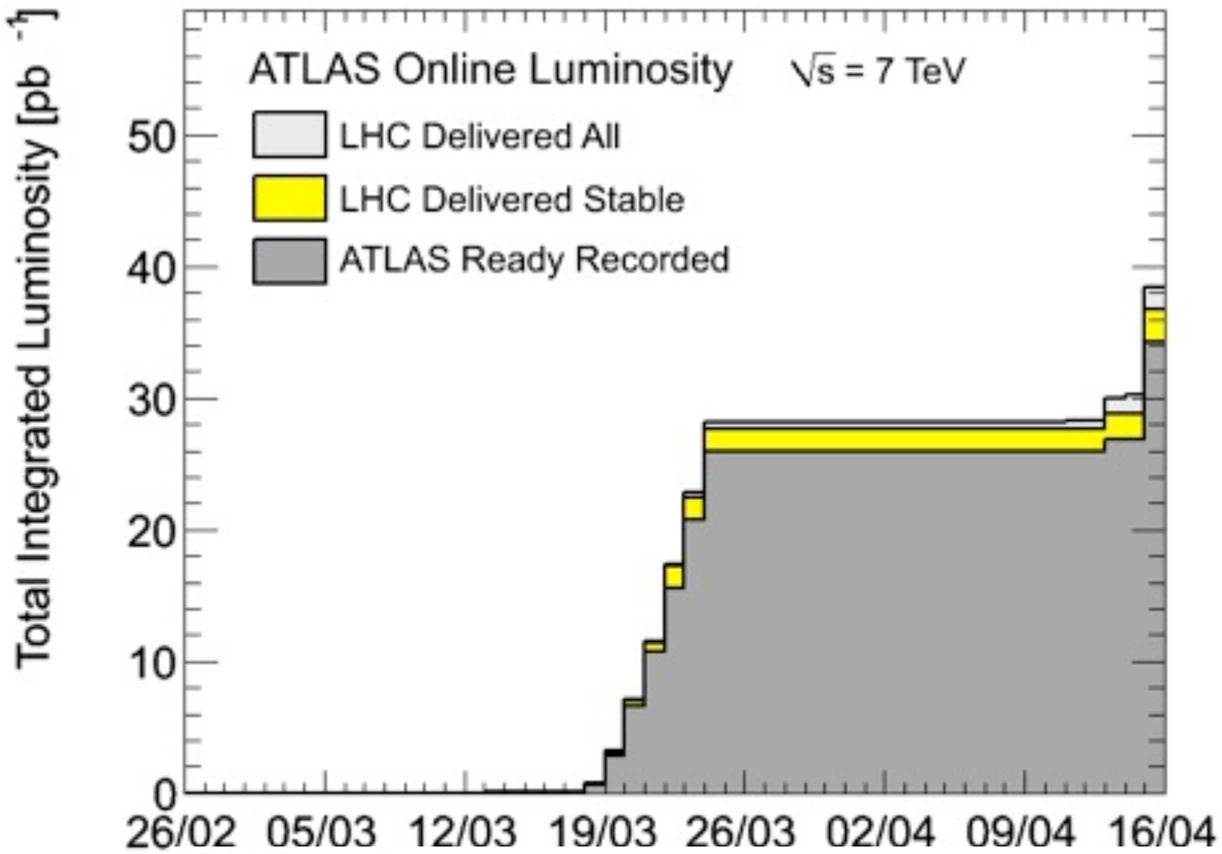


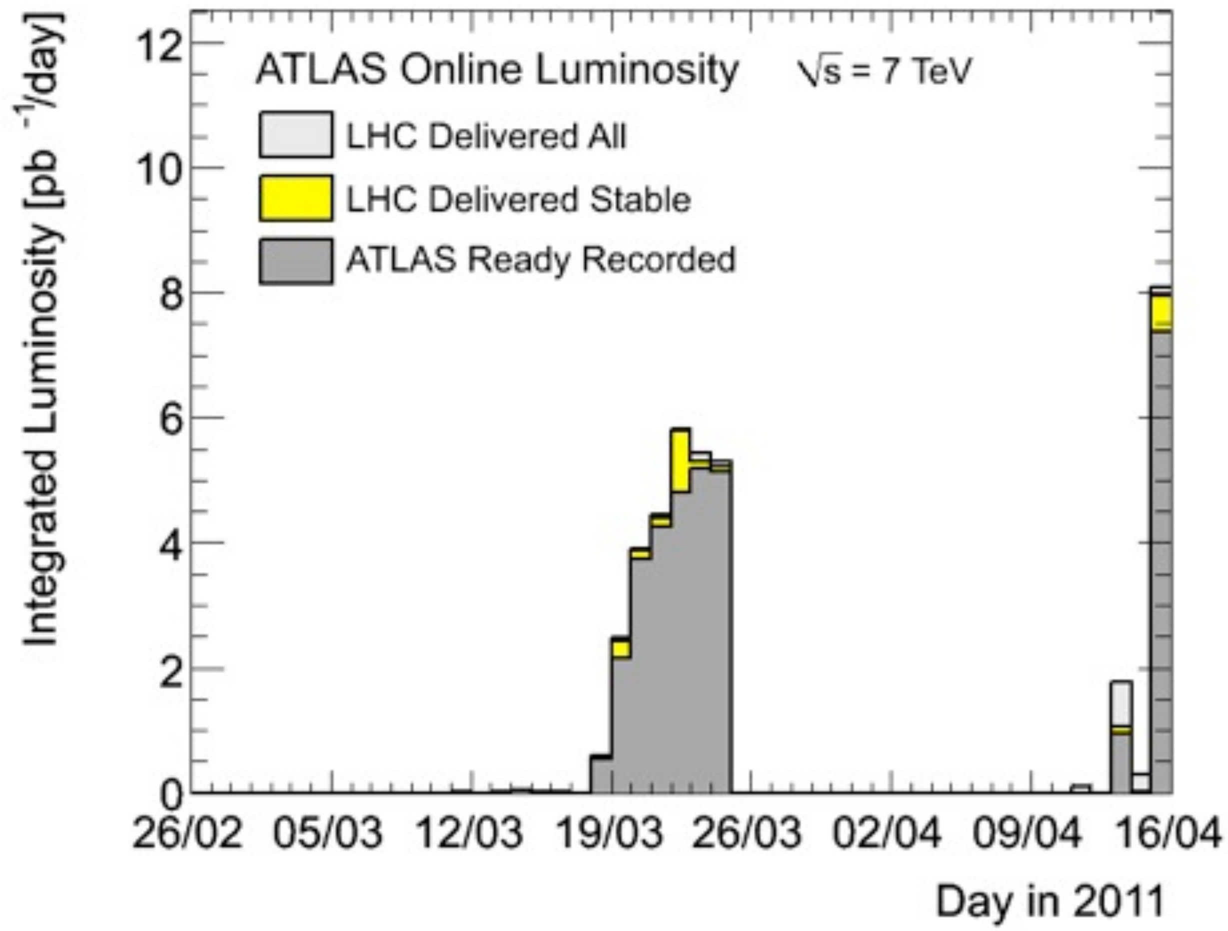
- Fix other model parameters (ΛR=20,N=6,M_D=5 TeV)... put limit on 1/R > 728 GeV
  - D0 limit is at 477 GeV
- No GMSB limit calculated (not competitive with 3.1/pb)

Summary of Searches

- Large MET signatures + [b]-Jets + leptons are well covered
  - Most stringent limits on squark/gluino-like masses come from 0 lepton... Limit at 500-870 GeV range.
  - b-jets give limits on 3rd generation partners ~ 500 GeV
- We are Missing τ's... but they are difficult.
- Nearly all results interpreted:
  - $\sigma_{fid} = \sigma \times \varepsilon \times A$
    - You'll need a model + simulation to interpret
  - mSUGRA: Historical
  - Phenomenological MSSM: Topology motivated... NLO SUSY x-sections

Status...





2011 Records

Items in red are records set in the past week

Peak Stable Luminosity Delivered	2.49×10^{32}	Fill 1645	11/03/22, 17:12
Maximum Luminosity Delivered in one fill	7362.97 nb^{-1}	Fill 1647	11/03/23, 08:34
Maximum Luminosity Delivered in one day	7993.48 nb^{-1}	Friday 15 April, 2011	
Maximum Luminosity Delivered in 7 days	27954.44 nb^{-1}	Friday 18 March, 2011 - Thursday 24 March, 2011	
Maximum Colliding Bunches	228	Fill 1704	11/04/13, 10:17
Maximum Peak Events per Bunch Crossing	13.66	Fill 1704	11/04/13, 10:17
Maximum Average Events per Bunch Crossing	8.93	Fill 1644	11/03/22, 02:20
Longest Time in Stable Beams for one fill	12.0 hours	Fill 1647	11/03/23, 21:20
Longest Time in Stable Beams for one day	19.7 hours (82.1%)	Sunday 27 March, 2011	
Longest Time in Stable Beams for 7 days	74.5 hours (44.3%)	Friday 18 March, 2011 - Thursday 24 March, 2011	
Fastest Turnaround to Stable Beams	2.42 hours	Fill 1635	11/03/18, 20:05
Fastest ATLAS Ready from Stable Beams	27.0 seconds	Fill 1634	11/03/18, 14:05
Best ATLAS Recording Efficiency for one fill	99.5 percent	Fill 1639	11/03/20, 04:52
Best ATLAS Recording Efficiency for one day (> 10 nb^{-1})	99.4 percent	Sunday 20 March, 2011	
Best ATLAS Recording Efficiency for 7 days (> 100 nb^{-1})	98.3 percent	Thursday 24 March, 2011 - Wednesday 30 March, 2011	

Next Steps...

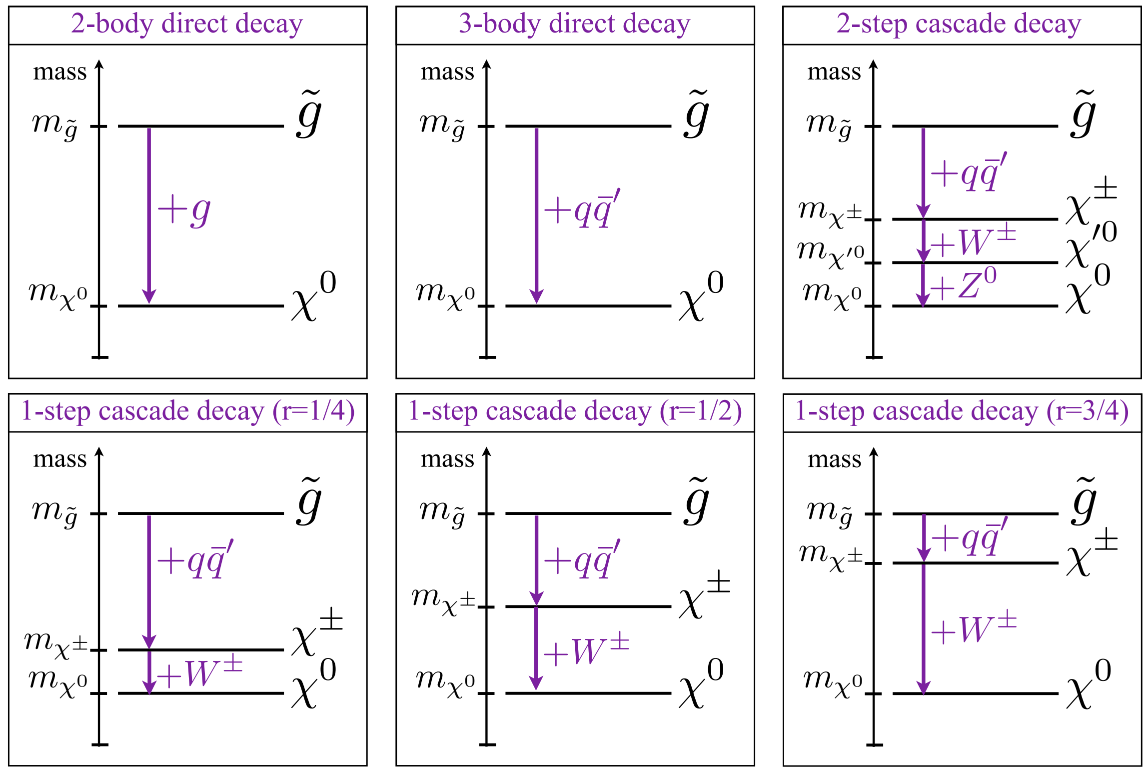
- What is happening for summer 2011?
  - Lots more data...
  - Understanding/handling Pileup (10x in time, 50 ns out of time)
    - We heard about 50 ns bunch spacing this week! Need MC!
  - Re-optimization of analyses
    - Many analyses will have a multiple signal regions to maximize coverage
  - Addressing problematic backgrounds
- Meanwhile... since we have data, we need to confront some big questions
  - Theory/Experiment Boundary

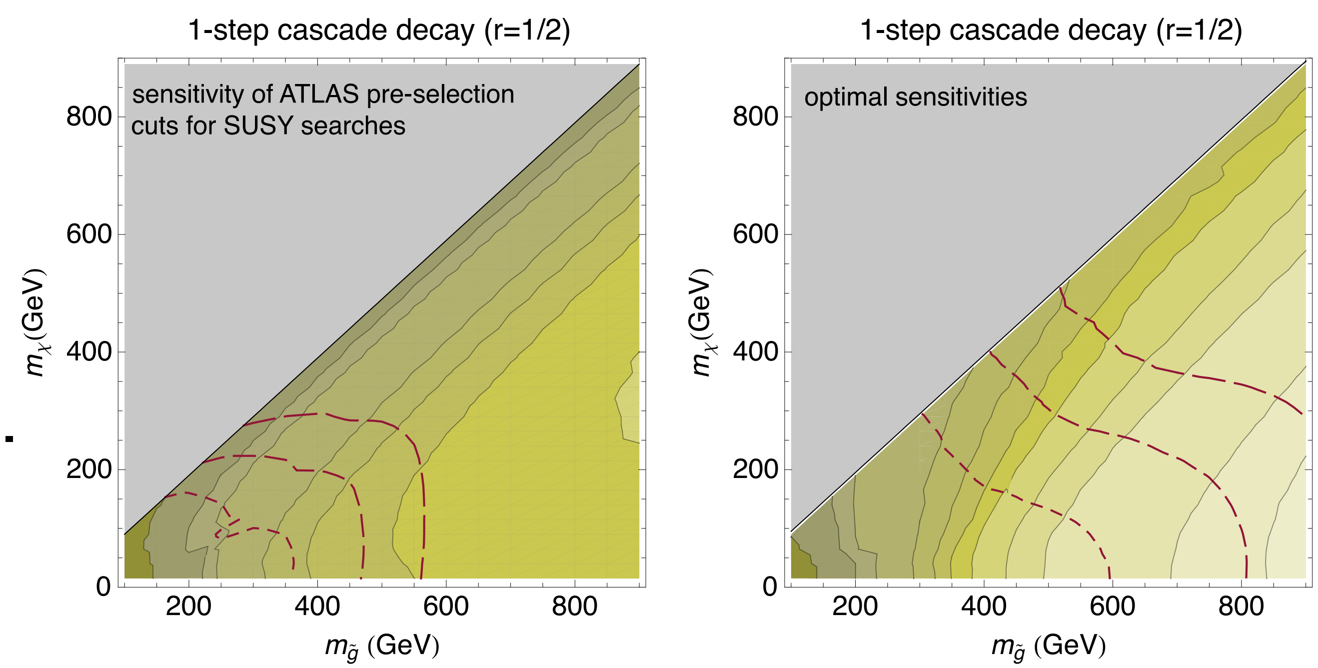
Theory/Experiment Boundary

- How should theorists and experimentalists communicate... and where should we draw the line?
  - Who runs the simulation?
    - Experimentalists: Full / Fast Geant4
      - Fast Simulation is being validated now... may help limit CPU/Disk constraints on signal grids and Background stats (sometimes dominant systematic)
    - Theorists: PGS/Delphes
      - ATLAS has be resistant to providing an official tune...
  - What is the appropriate level for communication?
    - Theories (GUT/Planck Scale) → SUSY Breaking Models (GUT/Planck to TeV Scale) → Phenomenological Models (TeV Scale) → Simplified Models (TeV Scale)
    - I'm hoping for a shift towards Simplified Models
- Approaches:
  - LHCNewPhysics.org: Database of Models for experimentalists to test
  - Recast: Building Mechanism of reinterpreting existing results.
- Maybe not an interesting topic to some... but critical to have a plan if you want a change and you consider the inertia of large collaboration

Simplified Models

- Idea: Identify New Physics topologies which contribute to an experimental signature
  - Simple Effective Theories with TeV scale parameters (masses of the particles)
- Effort by CERN + UTA + UCI + ... to replace Pheno MSSM GRIDs
  - Based on Alves, Izaguirre, Wacker [arxiv: 1102.5338] - 24 model points
  - Nearly 7K model points defined by our group
  - Some internal resistance, though CPU/Disk is not really an issue.
    - Direct Decays (mostly for 0 lepton) already approved
- Optimization: Best way to optimize in nearly model-independent manner since model parameters directly affect kinematics...





- The simplified models are starting to drive the definition of multiple signal regions.
- Interpretation: Hope to Produce Limits of BR x σ
  - Not everyone is convinced...

Backgrounds

- Category of Backgrounds: QCD vs top vs W/Z+Jet
- Categories of Approaches:
  - Fully MC dependent- Worry about Theory systematics and MC stats (we can't keep up)
  - Semi-data driven: Shapes from MC, normalization from Data (in control regions)
  - Fully Data-driven: MC only used for qualitative understanding/validation of method.
- Choice of observables matters: some observables provide natural side-bands/control regions (eg M_R arxiv: 1006.2727).
- Example:
  - 1 Lepton: backgrounds estimated with semi-data-driven methods.
  - 0 Lepton: backgrounds estimated using MC, cross-checked with data-driven methods.
    - The theory systematic is smaller than the statistical error of data-driven methods.
- Problems: In many cases, we increase sensitivity by requesting higher Jet Multiplicity - but then we are limited by theory systematics on W/Z+Jet bkg estimates or lack of stats for bkg estimation
  - γ+Jet is a solution here... expect cross-section and SUSY bkg estimations this summer
  - We can think of clever marriage of topological approaches (easier bkg estimation) and high jet multiplicity regions
- Good news: LHC's first SM measurements show that (N)NLO predictions (extrapolations from 2 TeV) are very reliable... this wasn't obvious 1 year ago.

Final Remarks

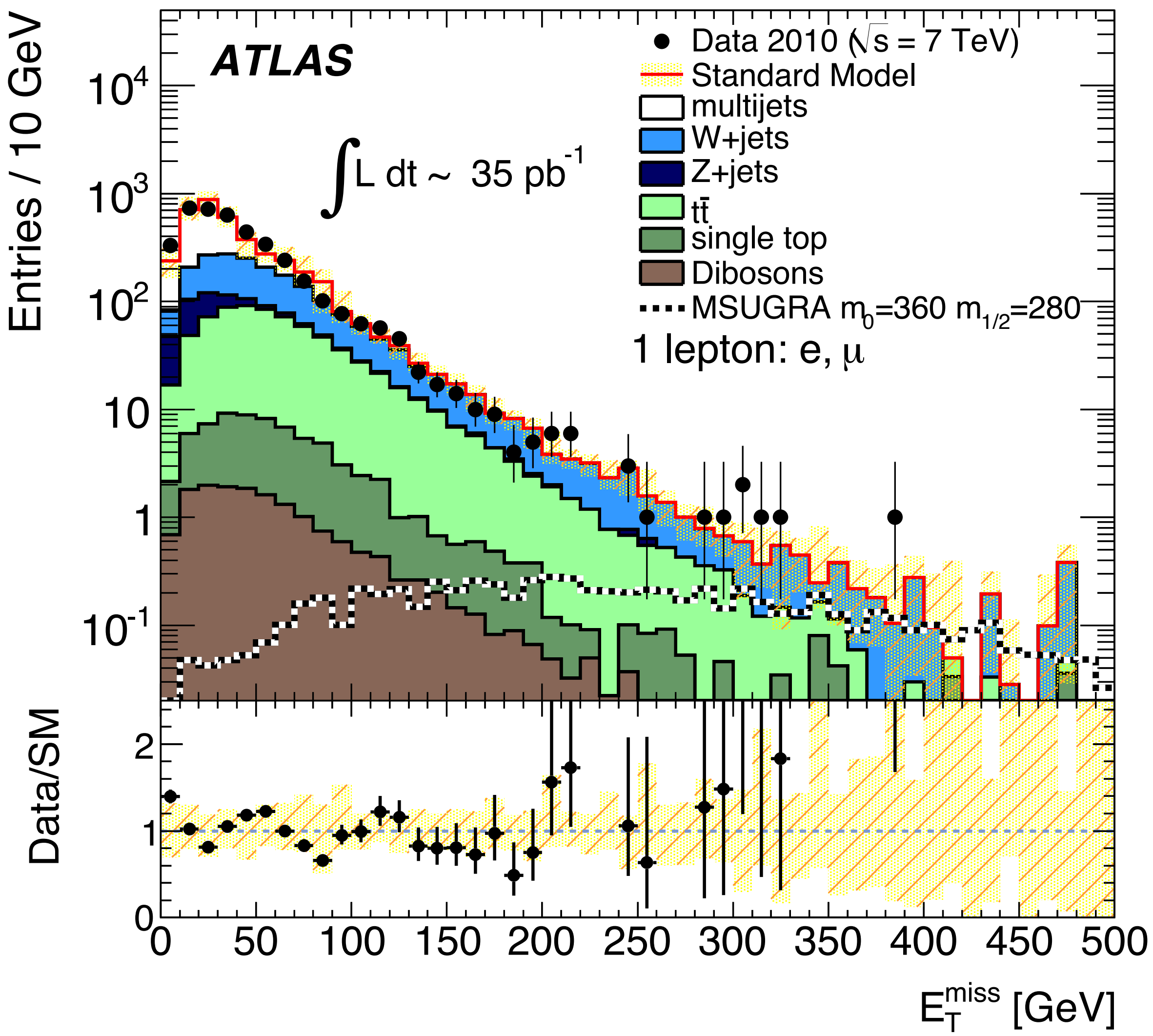
- LHC and ATLAS has performed remarkably.
- So have simulation and (N)NLO calculations.
- Lots of on-going effort to make sure we have good coverage...
- Worthwhile to discuss how theorists/experimentalist want to communicate
- Long history behind our approaches... but we are slowly evolving.

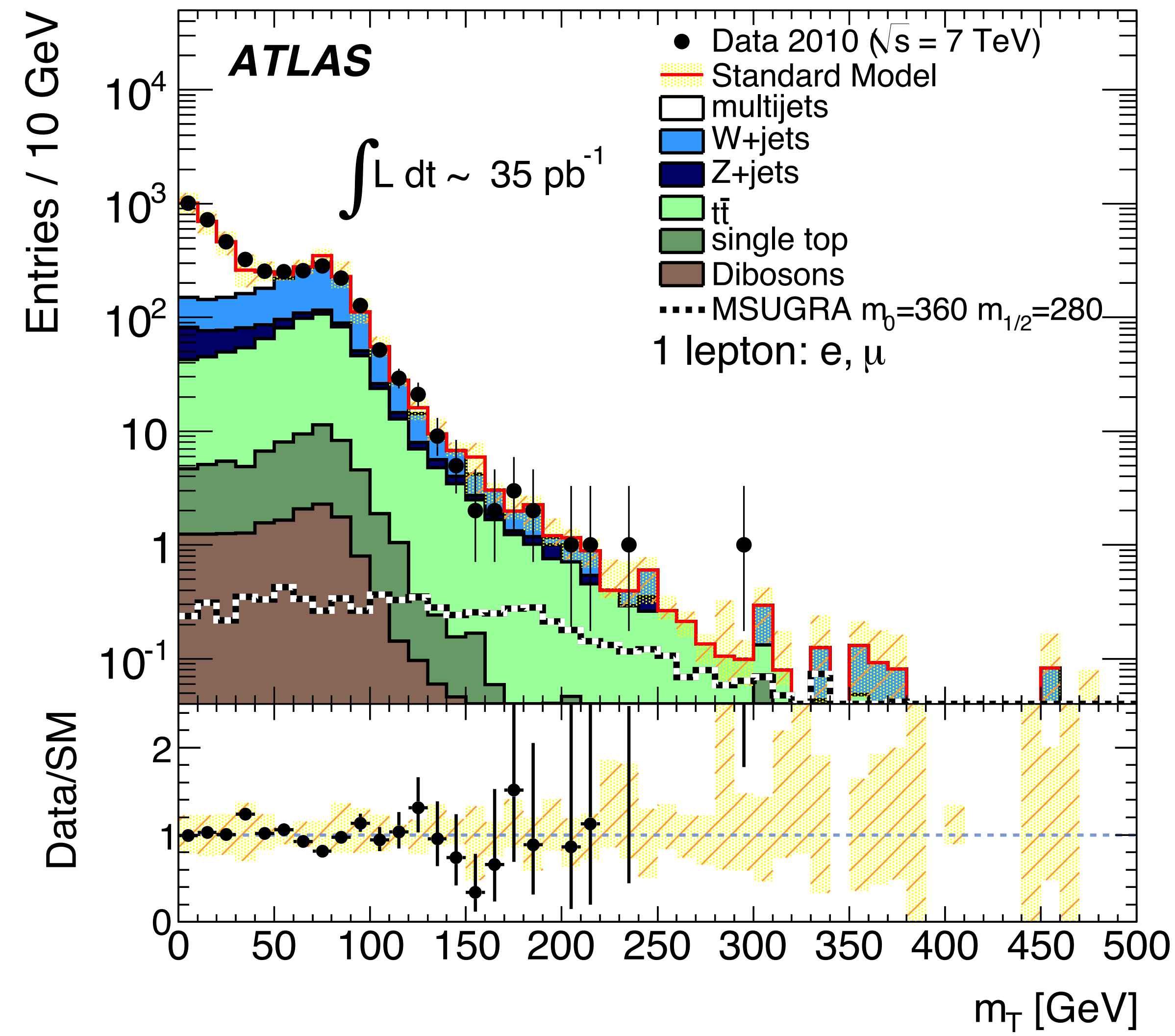
Backup

2 Lepton Pheno Grid

- Consider more general MSSM 24-parameter framework:
  - m_A=1000 GeV, $\mu=1.5\times\min(m_{gl},m_q)$, $\tan\beta=4$, $A_t=\mu/\tan\beta$, $A_b=A_l=\mu\tan\beta$
  - Common squark,slepton mass for 1st, 2nd generation, 3rd generation at high mass
- "compressed spectrum" (CS): $m(\chi^0_2)$ =M - 50 GeV, $m(\chi^0_1)$=M - 150 GeV, $m(l_L)$=M - 100 GeV, with $M=\min(m_{gl},m_q)$ → soft final state kinematics
- "light neutralino" (LN): $m(\chi^0_1)$=100 GeV , $m(\chi^0_2)$ =M-100 GeV, $m(l_L)$=M/2 GeV → hard kinematics

1 lepton- After Preselection





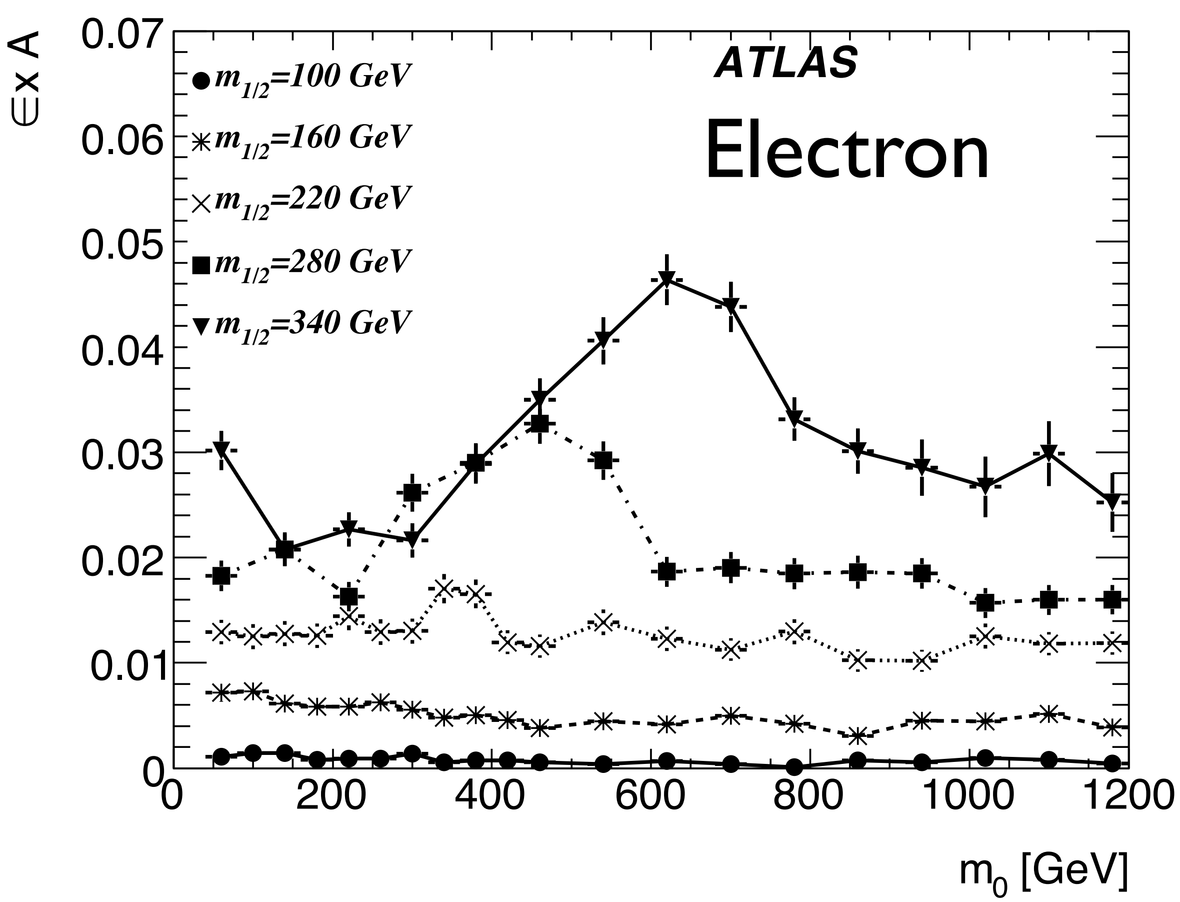
- Plots after lepton selection:
  - W/Z/top Backgrounds from MC
  - QCD Normalization from data-driven method (see later slides), shape from MC.
- Yellow bands: MC stats + JES systematics.

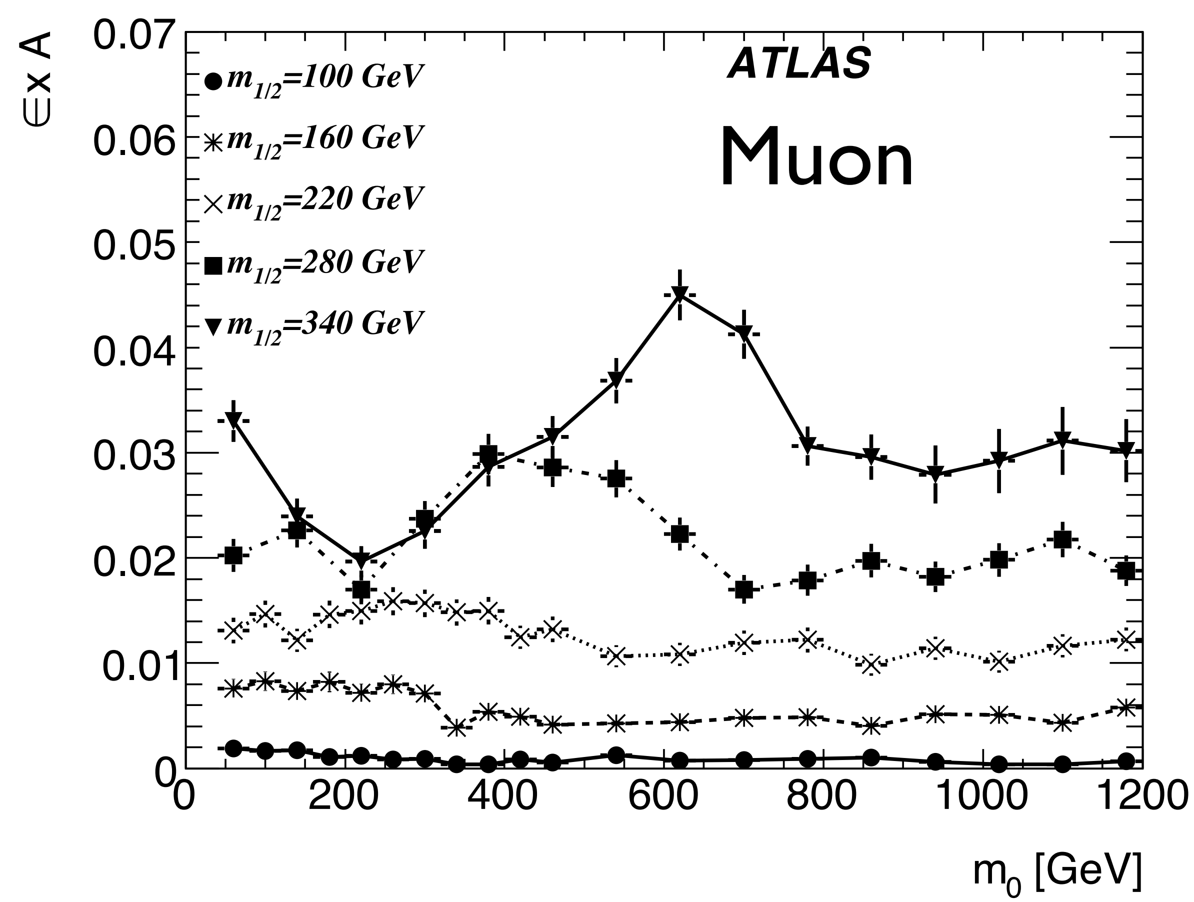
1 Lepton Event Selections

- Exactly Tight 1 lepton > 20 GeV (no overlap with 0 lepton sample)
    - 2 lepton covered by other analysis
- At least 3 Jets with p_T > 60, 30, 30 GeV
- m_T > 100 GeV (reject W+jet/top)
- MET > 125 GeV
- MET/m_{eff} > 0.25
- m_{eff} > 500 GeV

$$m_{\mathrm{T}} = \sqrt{2 \cdot p_T^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - cos(\Delta\phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}})))}$$

Eff ~ 0.01% - 4% (dominated by lepton branching fraction, $m_{1/2}$ dependent)





SO(10) GUT model

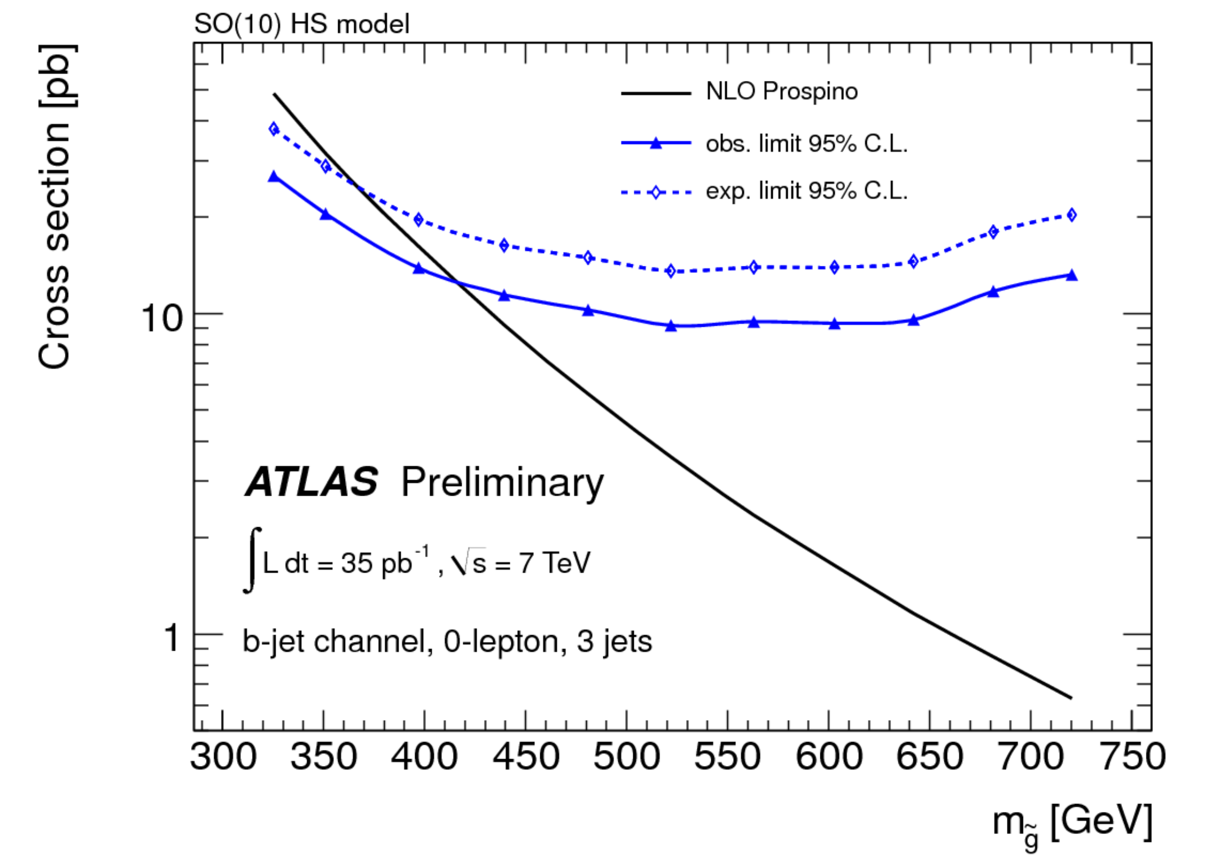
SO(10) models:
Baer et al, JHEP
1002 (2010) 055

-jets+MET

- Exclusion also calculated for SO(10) GUT model using b-jet+MET results

$$m_{\tilde{\chi}^0} \sim 50-90\ \text{GeV},\ m_{\tilde{\chi}^\pm} \sim 100-180\ \text{GeV},\ m_{\tilde{g}} \sim 300-600\ \text{GeV}$$

  - m(scalar) > TeV
  - Chargino-neutralino or gluino pair production with $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}^0_{1,2}$
  - Selection efficiency ~7-20%



Higgs Splitting (HS) model

$$m^2_{H_{u,d}} = m^2_{10} \mp 2M^2_D$$

$$m_{\tilde{g}} > 420\ \text{GeV}$$

D-term splitting (DR3) model

Mass splitting in Higgs and scalars

$+\nu_R$ Yukawa couplings

$+3^{rd}$ generation mass splitting

$$m_{\tilde{g}} > 500\ \text{GeV}$$

0 Lepton Background Estimation

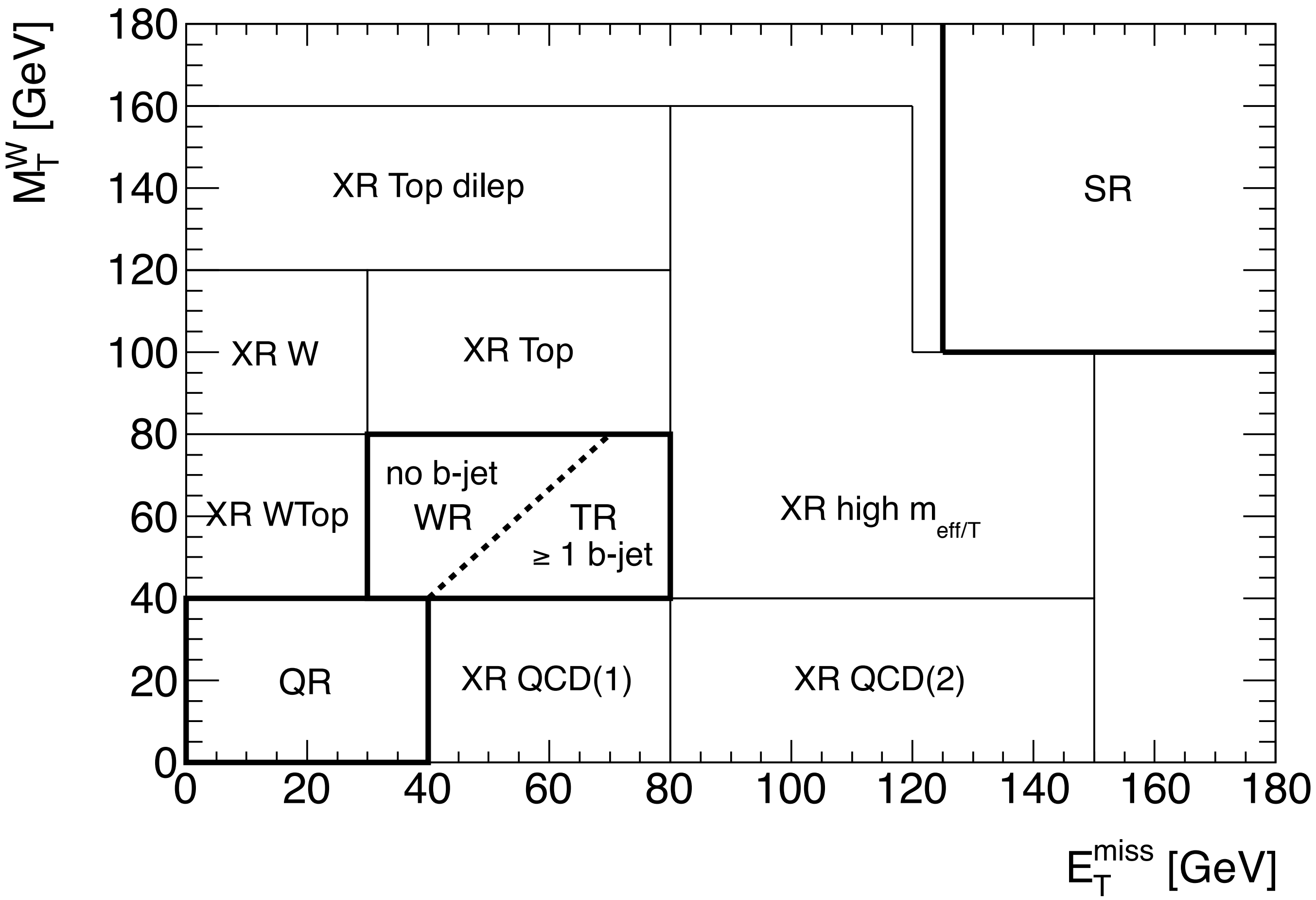
- ***W/Z+jets*** (dominant):
  - W→τν
  - W→lν, missed lepton
  - Z→ νν
- ➡ Estimated from MC
  - Theory Systematic smaller than statistical uncertainty of data-driven method
  - ALPGEN 2.15 2→5 parton (LO) normalized to FEWZ 2.0 (NLO)
  - Cross-checked with data
    - Leptons removed from W/Z in data
    - MC normalized to data control regions

- ***QCD***:
  - mostly mis-reconstruction + heavy flavors
  - ➡ Estimated from MC rescaled to control region
    - PYTHIA 6.4.21 with MRST2007 and ALPGEN
    - Reverse ΔΦ cut for control region
    - Good Data/MC agreement after rescaling
    - Cross-checked with Jet smeared MC (producing large MET)
    - Cross-checked with Scaling using control region based on MET/m_{eff} instead of ΔΦ

- ***Top pairs*** (mostly tt→bbτνqq) and ***Single Top***
  - ➡ Estimated from MC
    - MC@NLO 3.41 CTEQ 6.1
    - Cross-checked with data (muons replaced with taus)

1 Lepton Background Estimation

- ***W+Jets and Top***
  - ➡ Measured in a fit to W, Top, and QCD control regions (in MET/m_T plane)
    - extrapolated into signal region using MC.
    - Fits accounts for cross contamination (including QCD).
    - Cross-checked against MC and Extra control regions (XR below)
- ***QCD***
  - ➡ Estimated via Loose/Tight "Matrix" method
    - QCD dominated region created by loosing lepton selection
    - Expectation ~ 0 in signal region.



➡ **W control region (WR)**

1. 40 GeV < mT < 80 GeV
2. 30 GeV < ETmiss < 80 GeV
3. None of 3 selected jets is b-tagged

➡ **Top control region (TR)**

1. 40 GeV < mT < 80 GeV
2. 30 GeV < ETmiss < 80 GeV
3. ≥1 of 3 selected jets is b-tagged

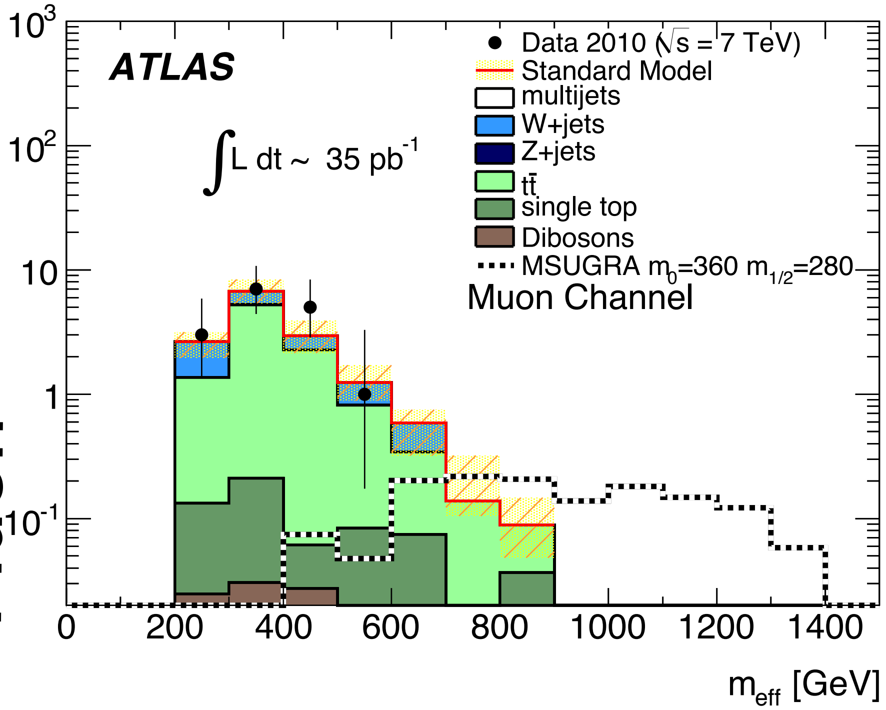
➡ **QCD control region (QR)**

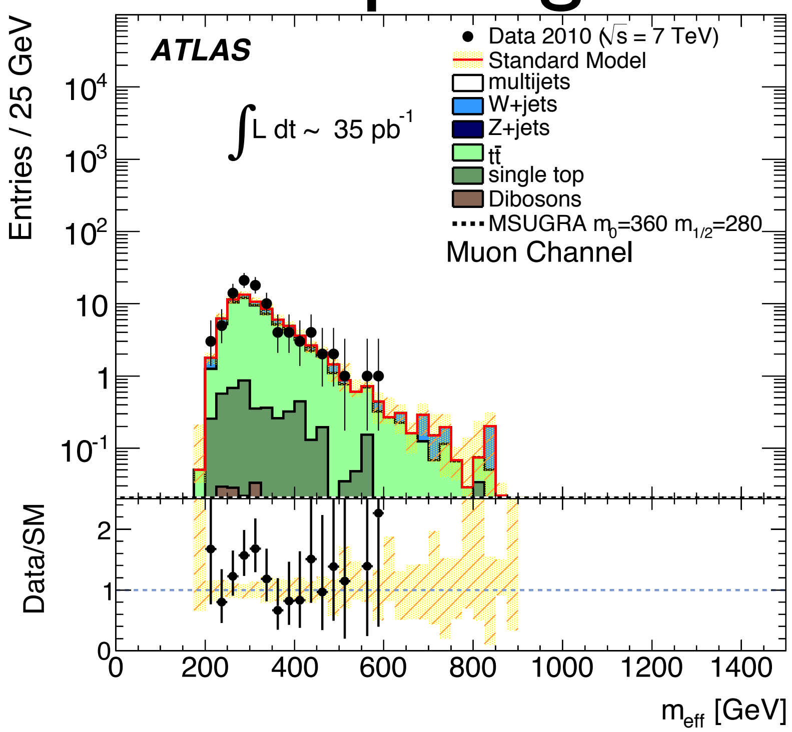
1. mT < 40 GeV
2. ETmiss < 40 GeV

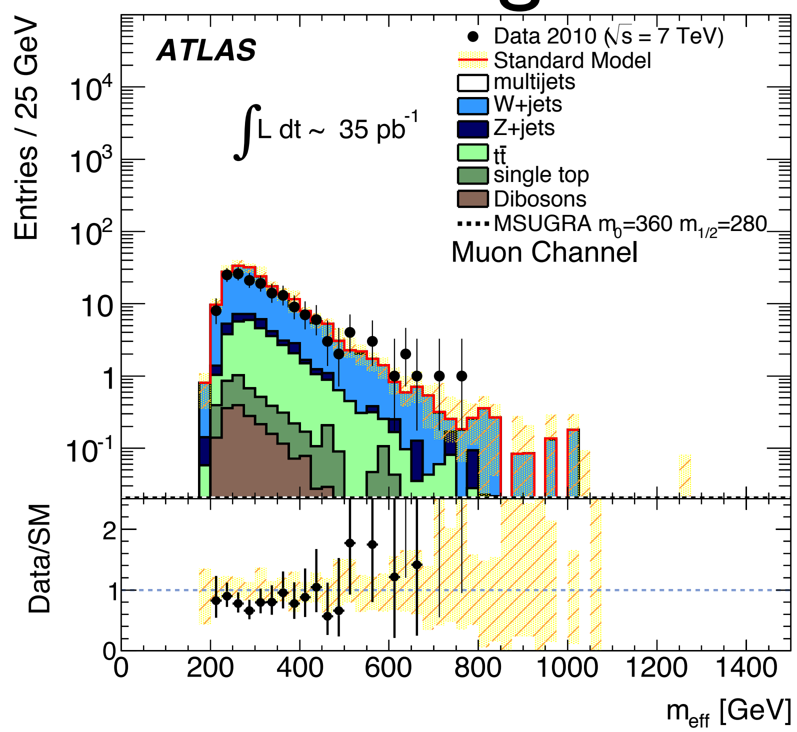
Control Regions

Signal Region | Top Region | W Region

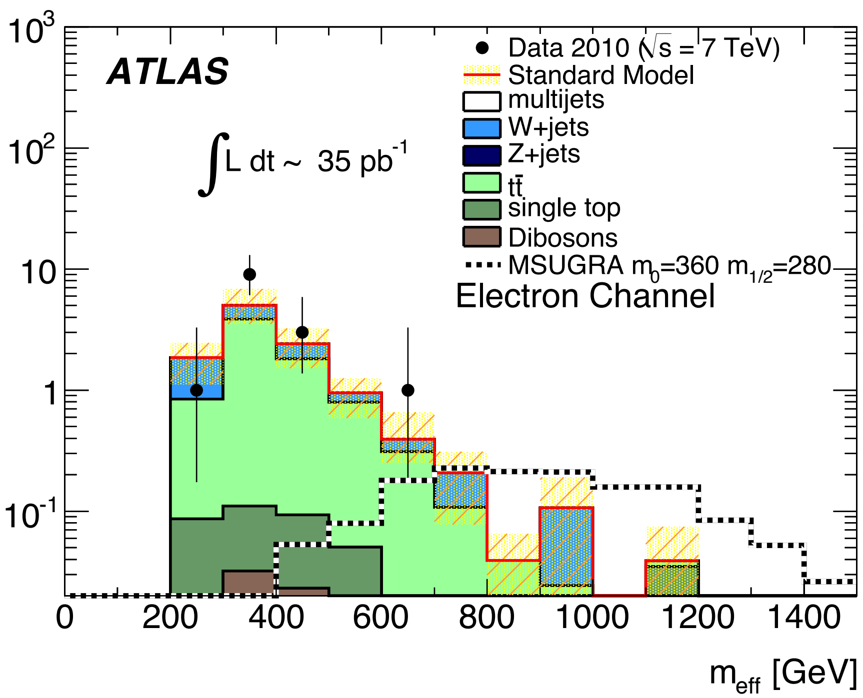
Muon

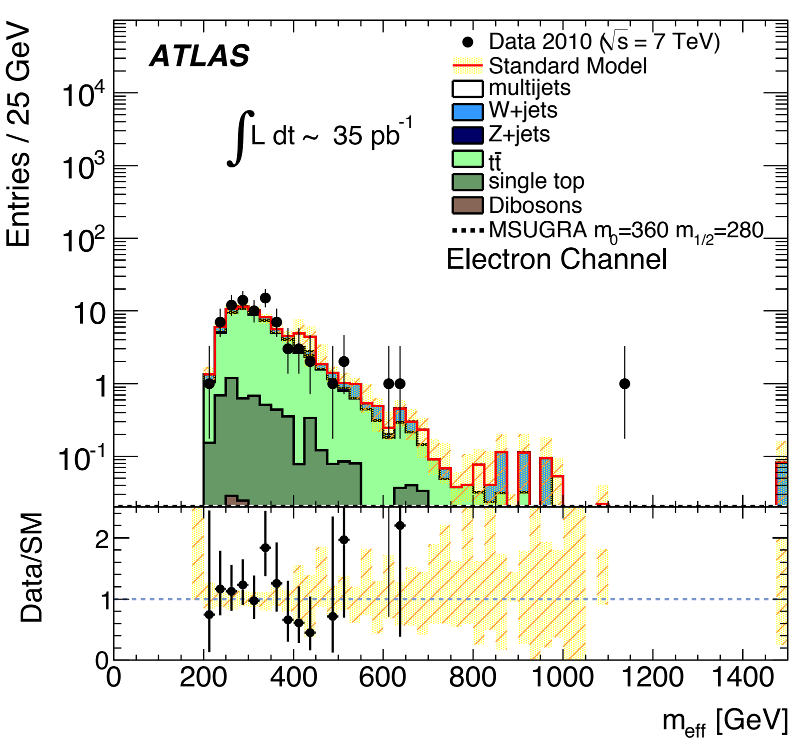


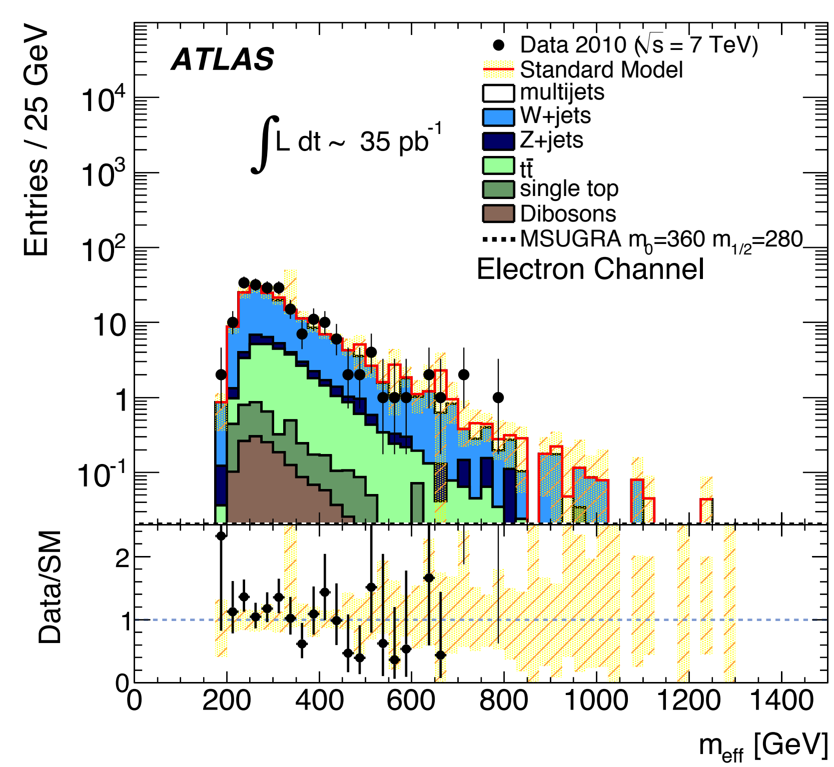




Electron





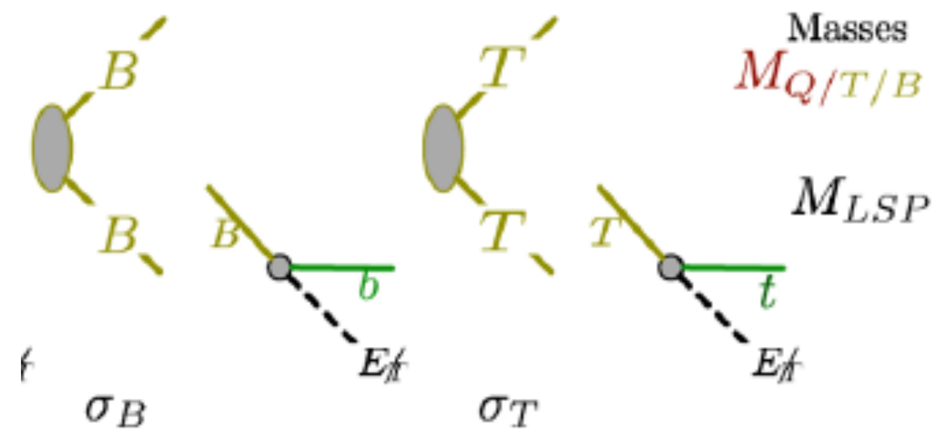


Heavy Flavors

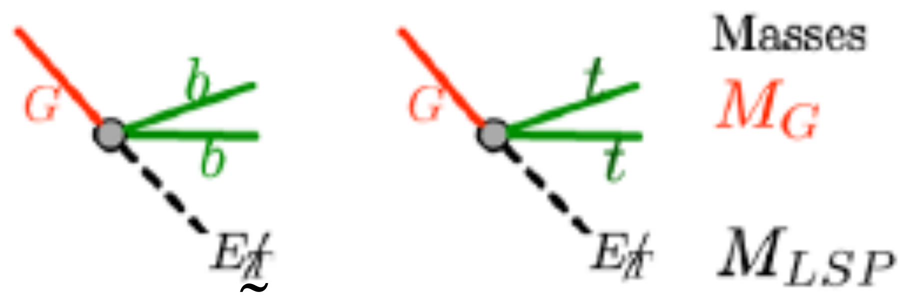
- Heavy flavors is a good example of possible complications, and how topology-based approaches can help develop a search.

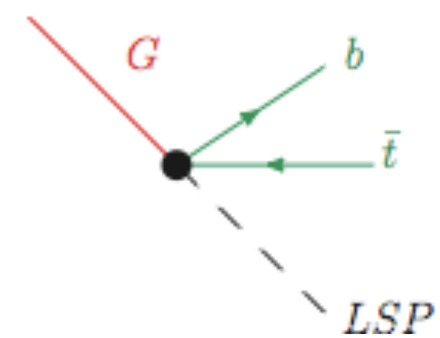
- Heavy Flavor Production:
  - strong b,t partner production

$$\tilde b \bar{\tilde b}, \tilde t \bar{\tilde t}$$



  - gluino production





$$\tilde g \to b\tilde b \qquad \tilde g \to t\tilde t$$

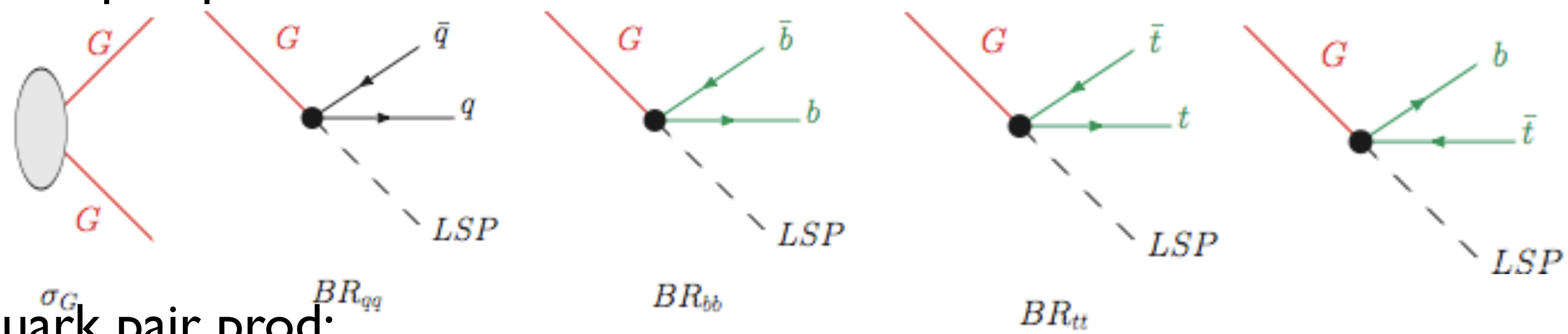
- Decay: various possible depending on other sparticle masses

$$\tilde b \to b\tilde\chi_1^0 \quad \tilde b \to t\tilde\chi_1^{\pm} \quad \tilde t \to (t/c)\tilde\chi_1^0 \quad \tilde t \to b\tilde\chi_1^{\pm}, bl\tilde\nu$$

- Parameters: M(gluino) - M(stop)/M(sbottom) - M(chi0)

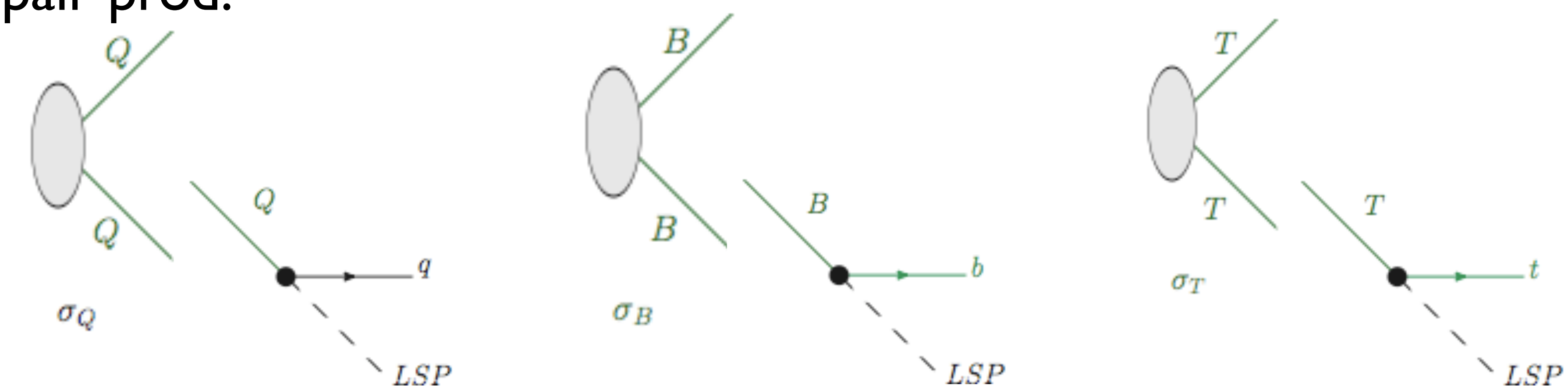
Heavy Flavor Parameters

- Must simultaneously consider all basic production and decay
  - eg gluino pair prod:



M_G
M_{LSP}

  - eg squark pair prod:



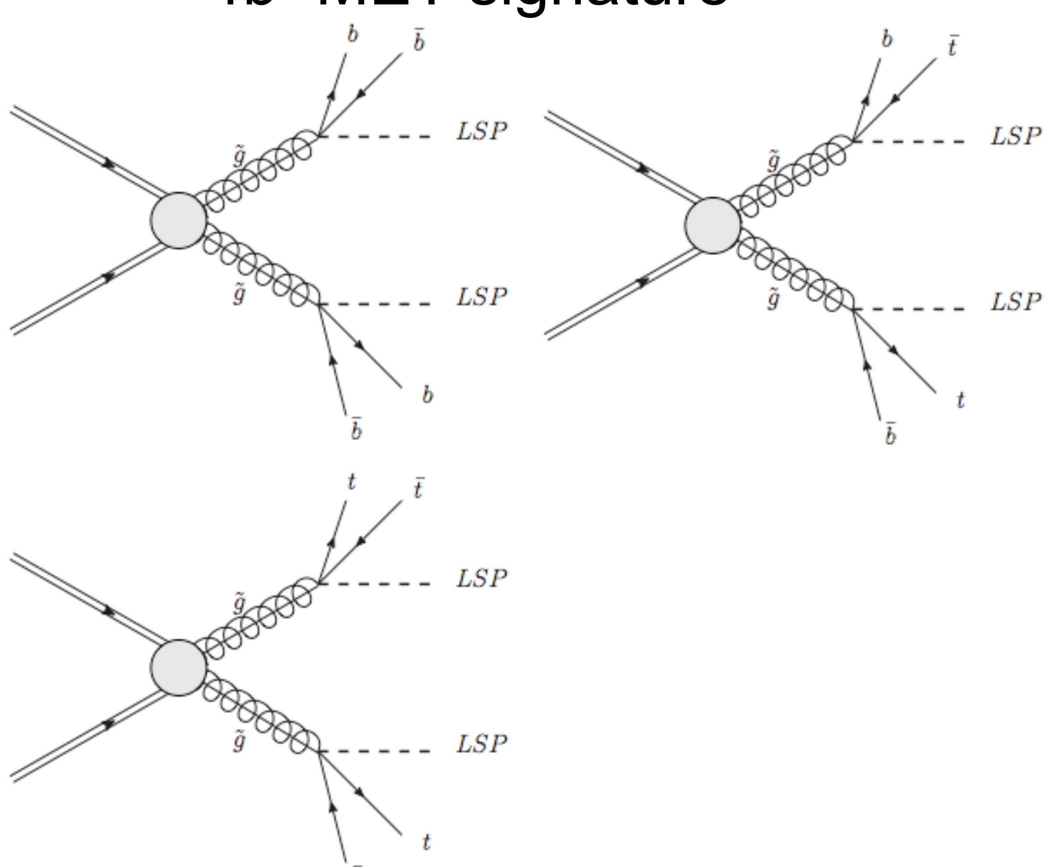
$M_{Q/B/T}$
M_{LSP}

  - Note that parameters are masses
  - Scan cross-sections and branching ratios by weighting events
  - Note that this is a subset of the simplified model case study in e.g. arXiv:0810.3921 which includes wider scope to constrain new physics (e.g. lepton count)

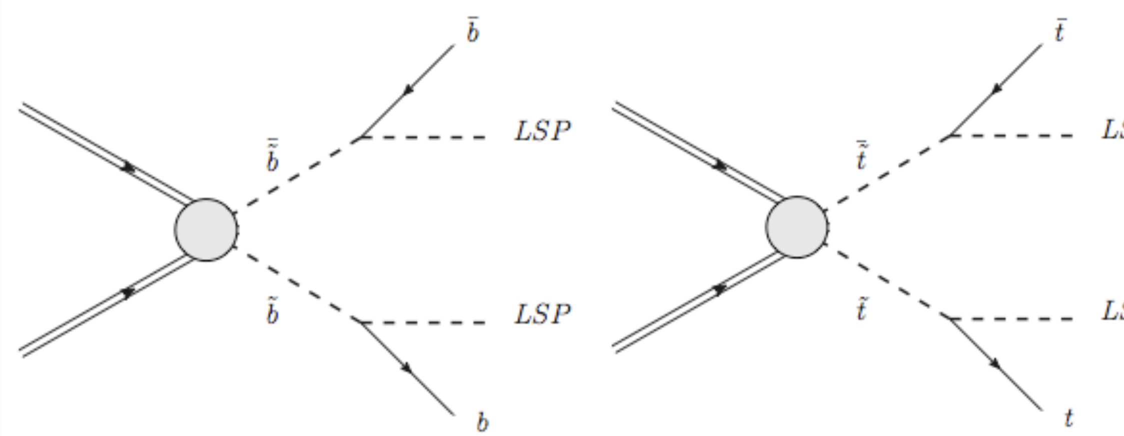
Mapping to Signatures

- Even with heavy flavor restriction, multiple topologies map to each signature
- Here assume 100% branching ratios to b/t (light branching ratio has wider scope)

“4b+MET signature”

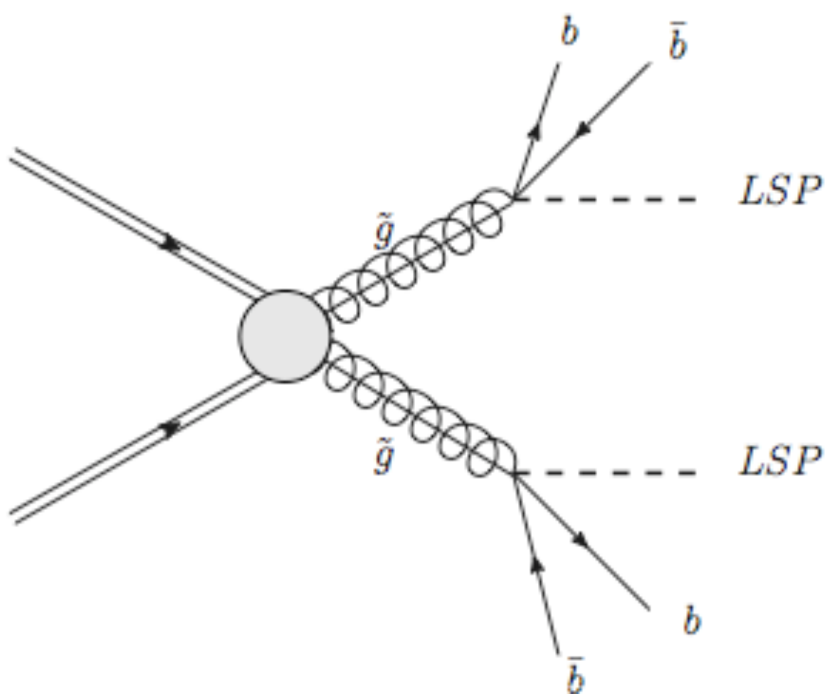


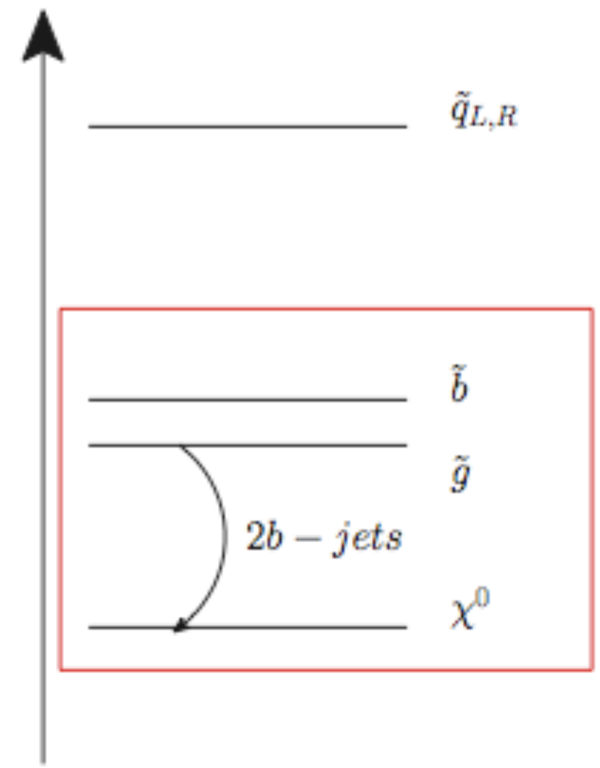
“2b+MET signature”



Let’s look at the topologies one by one...

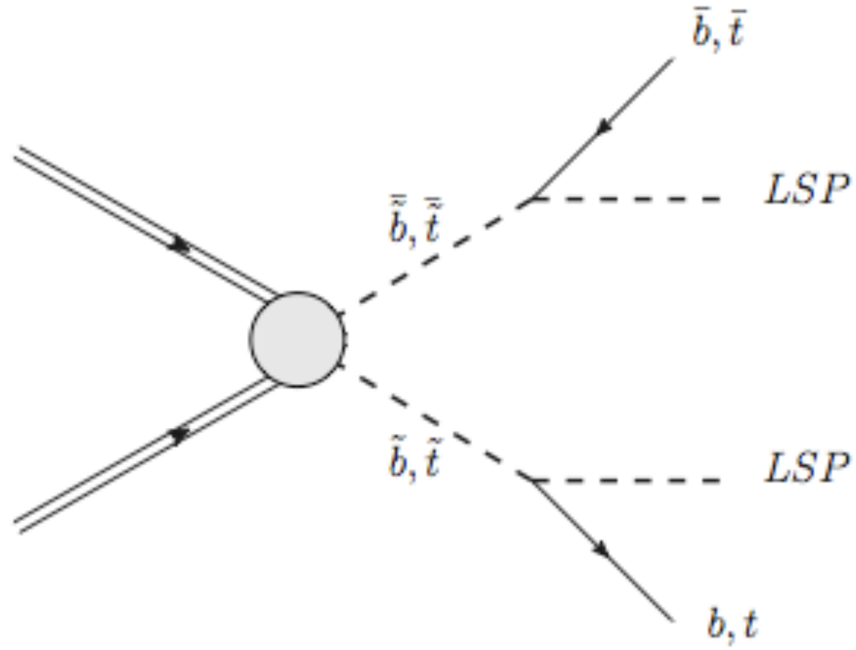
Gluino→ 4b-Jets + MET

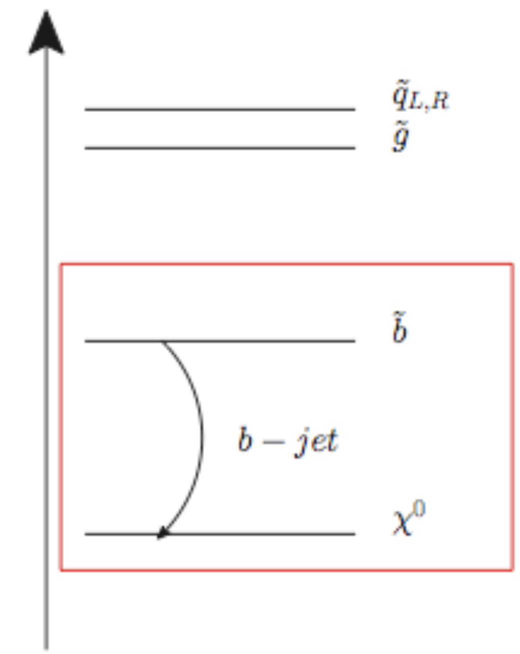




- 4b Jet signature
- We find that:
  - Observables such as Jet pT, M_{eff}, and MET are nearly only sensitive ΔM(~g,χ0)
  - Gluino mass affects mainly cross-section, not sensitivity
  - All 4 leading jets sensitive to mass difference
  - Expect b-jets with low pT

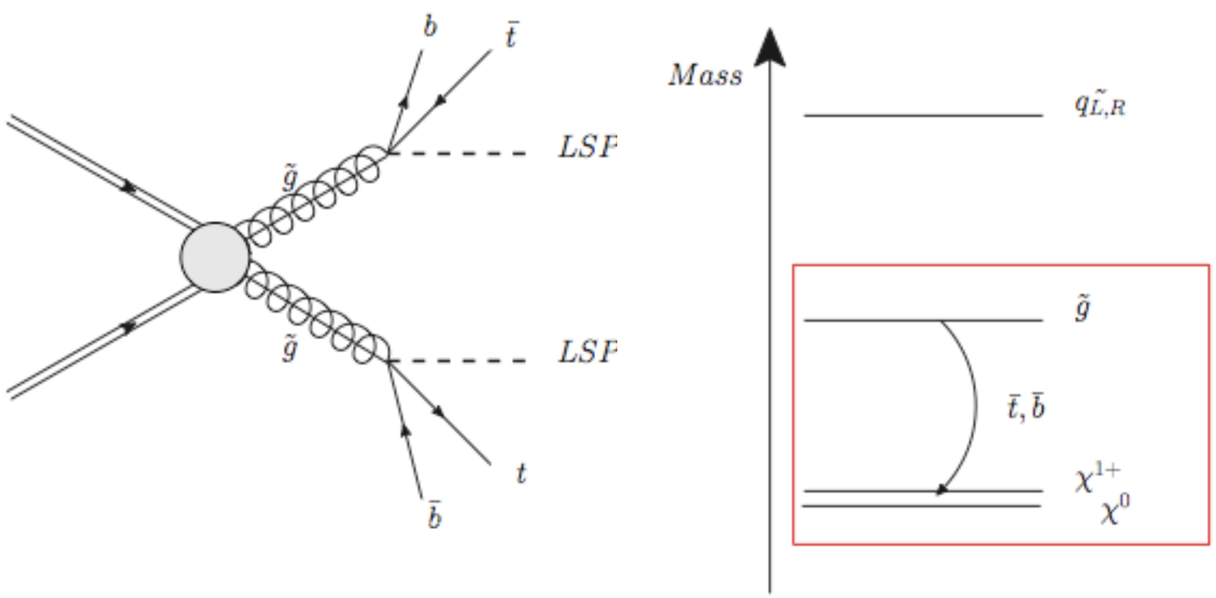
Squark→ 2 b-Jets + MET





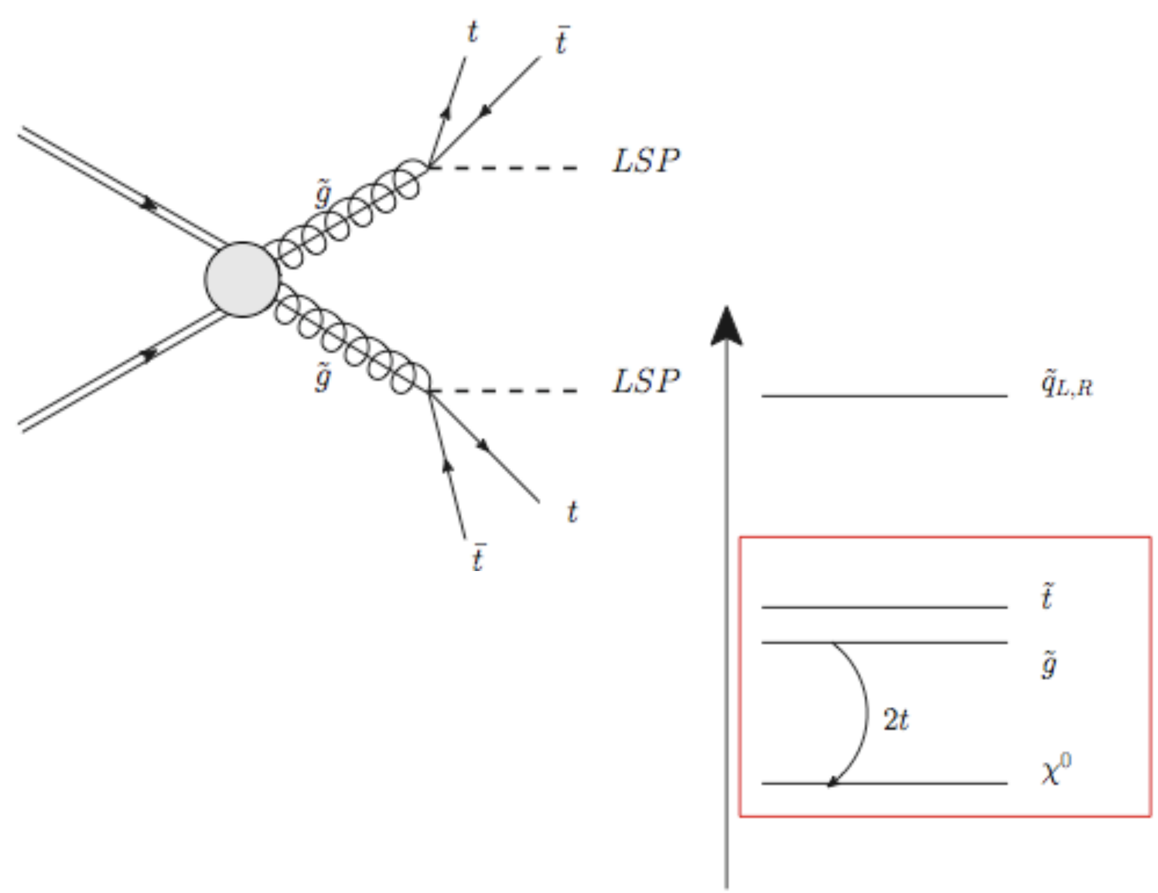
- Considered 2 b-jet signature only
  - 2 stop prod: more complicated final state is possible -> softer b-jets
- We find that:
  - Observables such as Jet pT, M_{eff}, and MET are nearly only sensitive to ΔM(~b,χ0)
  - Squark (partner) mass determines x-section, not sensitivity
  - Two (b-)jets sensitive to mass difference
  - Additional light jets not sensitive to mass difference (see 4th leading jet pT)
  - Low overall jet multiplicity: largely unaffected by mass difference

Gluino→ t/b-Jets + MET



- 2b2t + MET
  - 4 b-jet signature
  - Top production creates more complicated final state
    - Softer b-jets
    - Higher light jet multiplicity
  - ΔM(~g,χ0) still main parameter for jet and MET kinematics
  - Might expect two hard and two softer b-jets

- 4t + MET
  - 4 b-jet + MET signature
  - ΔM(~g,χ0) determines available jet and LSP kinematics
  - Moderated by top decay -> expect less sensitivity to mass difference
    - Softer b-jets
    - High (light) jet multiplicity (low pT)
  - Requires rather large gluino partner mass



Heavy Flavor Analysis Strategy

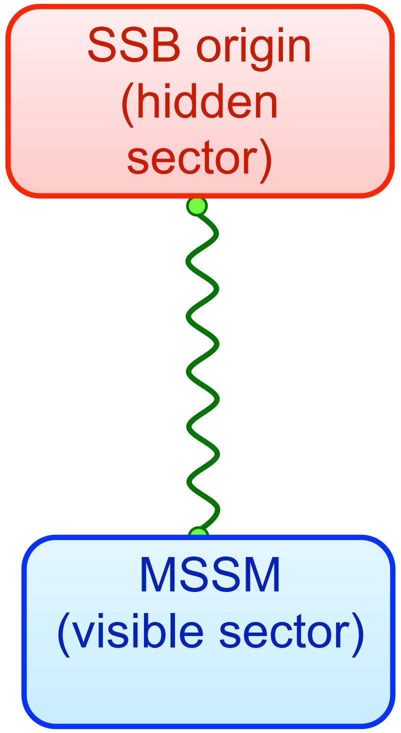
- Looking at topologies, we can develop an analysis strategy
- Helps trigger optimization
- Hard to create one analysis with good sensitivity in all signatures.
- Example strategy:
    - **Case 1: 2 high pT b-jets + large MET**
        - Can cover topologies
            - B->b+LSP or T->t+LSP w/ large ΔM
            - G->tb+LSP large ΔM
        - Possibly low jet multiplicity
        - Trigger: MET+jets, b-jets
    - **Case 2: 2 low pT b-jets + low MET**
        - Extends into cases with low pT 3rd, 4th b-jet
        - Can cover topologies (generally low ΔM)
            - B->b+LSP or T->t+LSP w/ small ΔM
            - G->2b/2t2b+LSP (small ΔM) and G->2t+LSP
        - Low pT b-tag optimization
        - Event variables
        - Trigger: b-jets,MET+jets
    - **Case 3: 4 high pT b-jets + large MET**
        - Generally 4b signatures with high ΔM
        - Can cover topologies: Gluino->4b and 2t2b
        - High b-tag multiplicity (>=3?, 4?)
        - Small backgrounds?
        - Trigger: b-jet, MET+jets, multijets
    - **Case 4: 4 low pT b-jets + small MET**
        - Generally 4b signatures with low ΔM
        - Can cover topologies: Gluino->4b, 2t2b, 4t
        - High b-tag multiplicity (>=3?, 4?)
        - Small backgrounds?
        - Trigger: b-jets, MET+jets

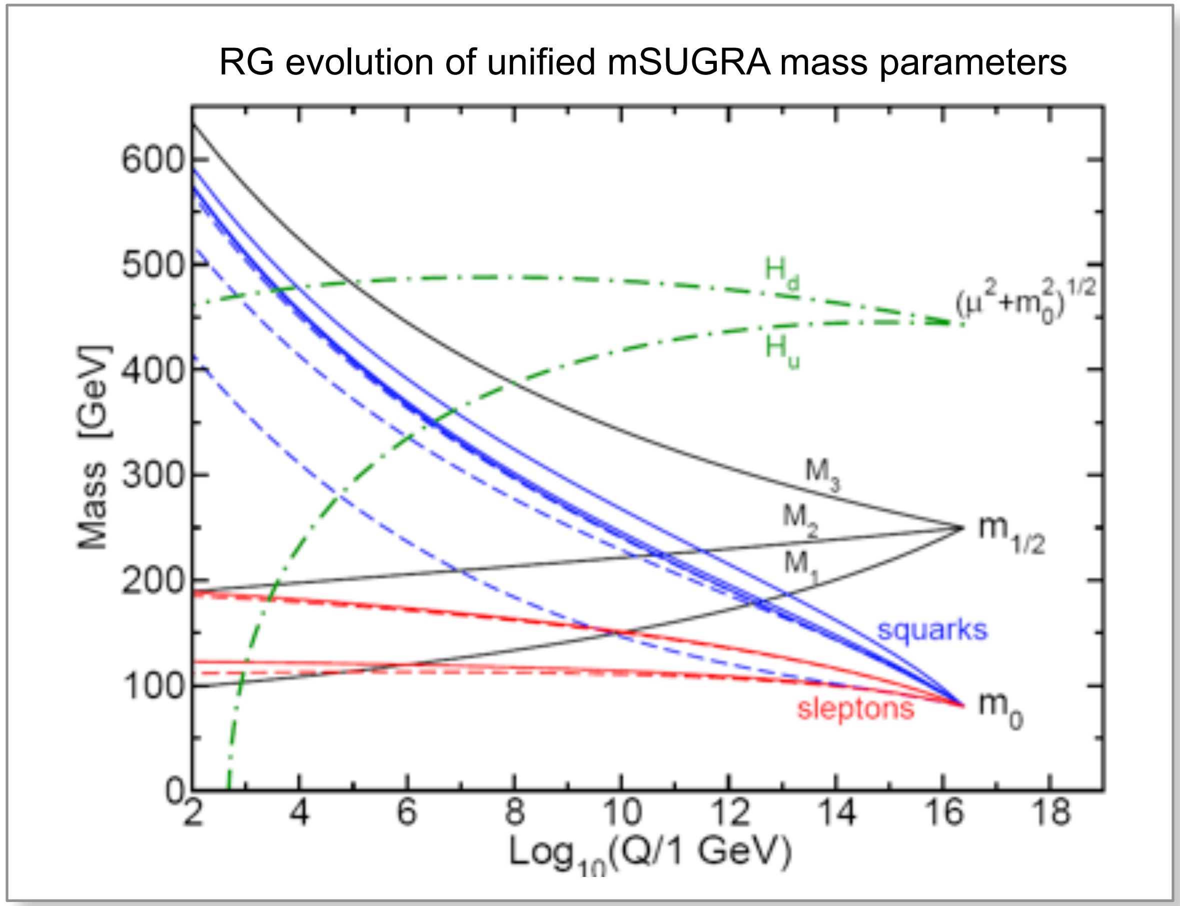
SUSY Phenomenology

- No scalar electron partner ⇒ SUSY broken
- If want SUSY to preserve EW naturalness ⇒ SUSY broken in hidden sector at scale $F < M_{pl}$
- SUSY has 105 parameters...
- Some SUSY Breaking Models take parameters to a practical handful, example:
  - Minimal Gravity Mediated (mSUGRA): m_0, $m_{1/2}$, sig(μ), tan β, A_0

➡ Just a useful framework for searches

- R-Parity = +1 (-1) for SM (SUSY) particles
  - RPC: no proton decay, dark matter (LSP), SUSY produced in pairs





SUSY Motivation

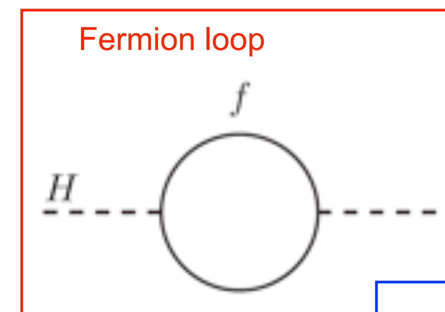
- Aesthetic: new space-time symmetry
  - Leads to new partners for every SM particle.
  - Removes quadratic divergences (Higgs mass).

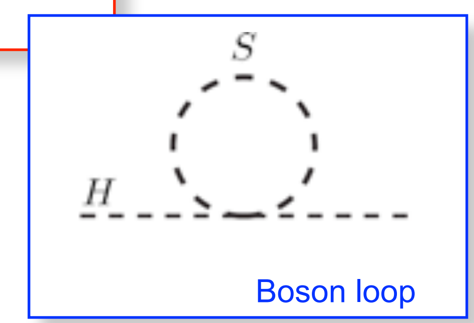
➡ Resolves Hierarchy problem

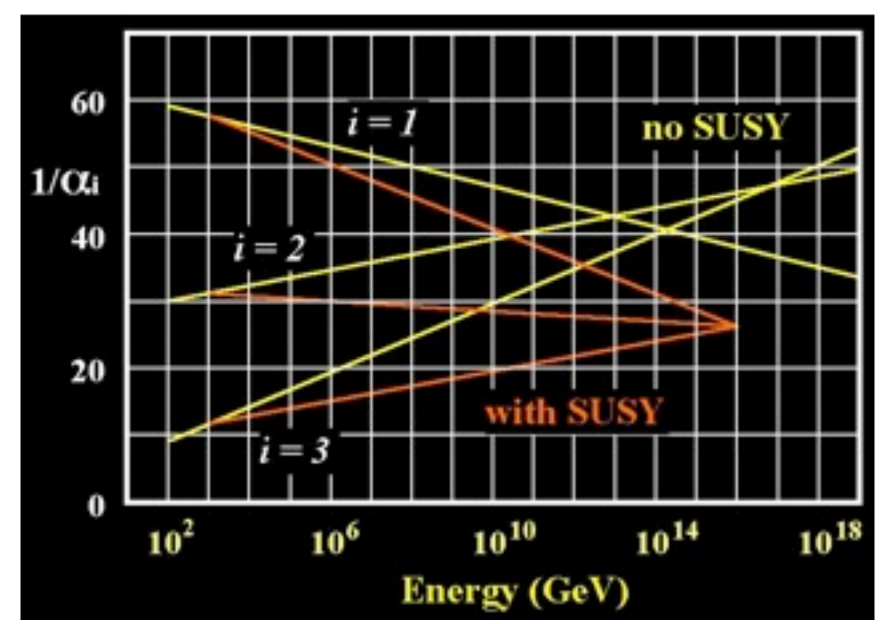
- Compelling because SUSY also:
  - Gauge unification
  - Has Graviton
  - Dark matter Candidate: The Lightest SUSY Particle can be a heavy stable neutral particle
  - "Predicted" by String theory
- Note: no explanation of the origin of SM parameters (masses, CP), or neutrino masses.

Spin 0	Spin 1/2	Spin 1	Spin 3/2	Spin 0
Higgs	Higgsino		Gravitino	Graviton
sLepton	Lepton			
sQuark	Quark			
	Gluino	Gluon		
	Photino	Photon		
	Zino	*Z*		
	Wino	*W*		

SM
SUSY

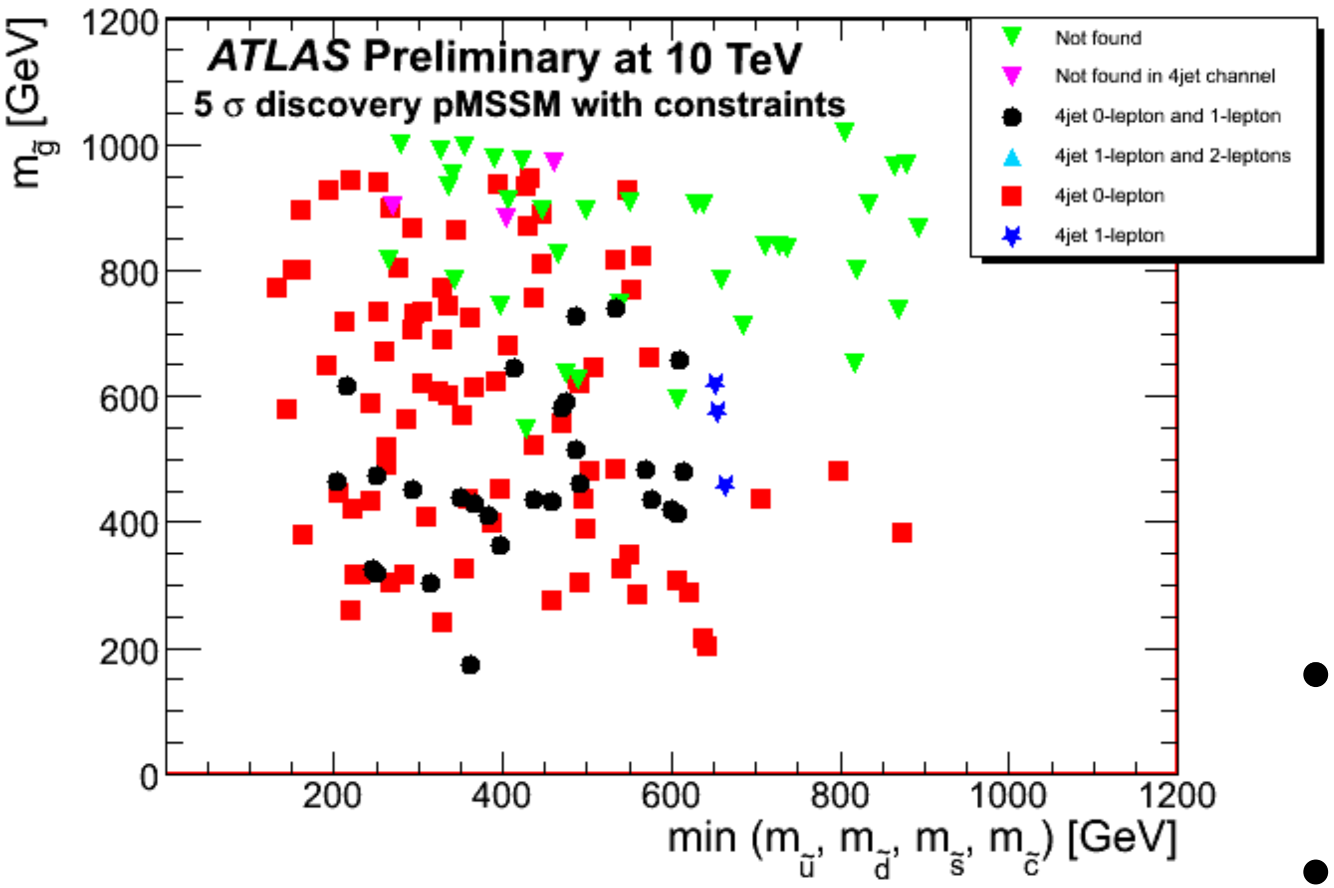






Coverage

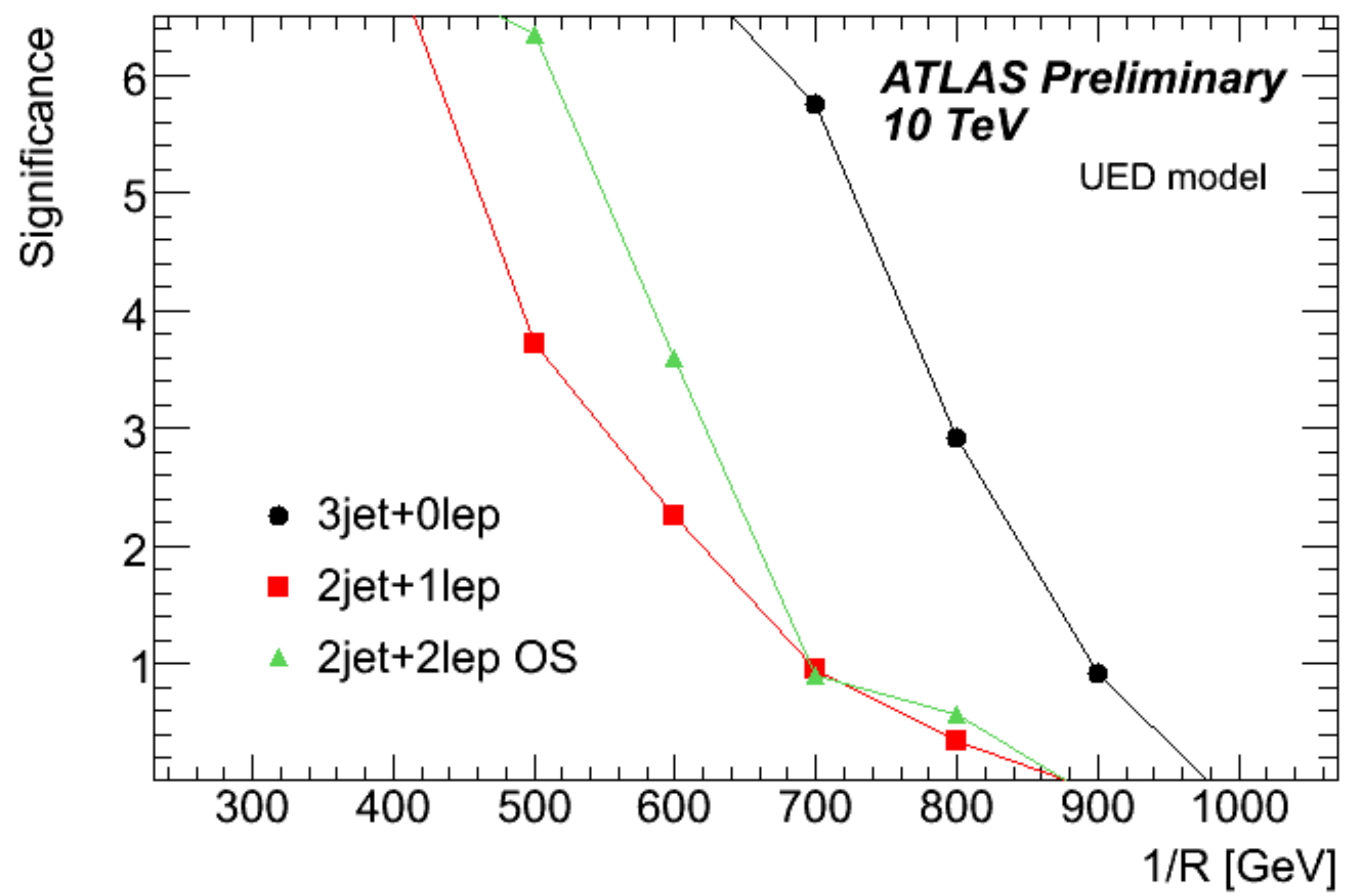
Number of analyses	Flat, 1 fb^{-1}	Flat, 10 fb^{-1}
0	0.56754	0.36796
1	1.3458	0.98841
2	3.396	2.5141
3	13.175	10.635
4	22.014	18.455
5	9.5512	10.3
6	15.227	16.929
7	20.081	17.697
8	7.6394	11.75
9	3.9205	6.3569
10	2.0825	2.7943
11	1.0013	1.2116



- pMSSM (Conley, Gainer, Hewett, Le, Rizzo arXiv: 1009.2539):
  - 19 dim reduction of MSSM, sampled with masses < 1 TeV
  - 98.8% discovered by at least one ATLAS search with 10/fb of 14 TeV data.
- ATLAS looked at pMSSM, assuming 200/pb of 10 TeV
  - Green is not found... rest is found
  - Closer look showed that not found because:
    - upper/right- low x-section
    - didn't consider b-jets channel
    - low p_T jets... difficult to see!
- So it appears that ATLAS coverage is very good... we don't miss much because of model bias.
- Exact same searches give similar sensitivity to UED

SUSY to UED

- Exact same searches give sensitivity to Minimal Universal Extra Dimensions
    - Provide similar reach in mass scale.
- Though our strategies are often inspired by a model (eg SUSY), our sensitivity is obviously not.



One Lepton

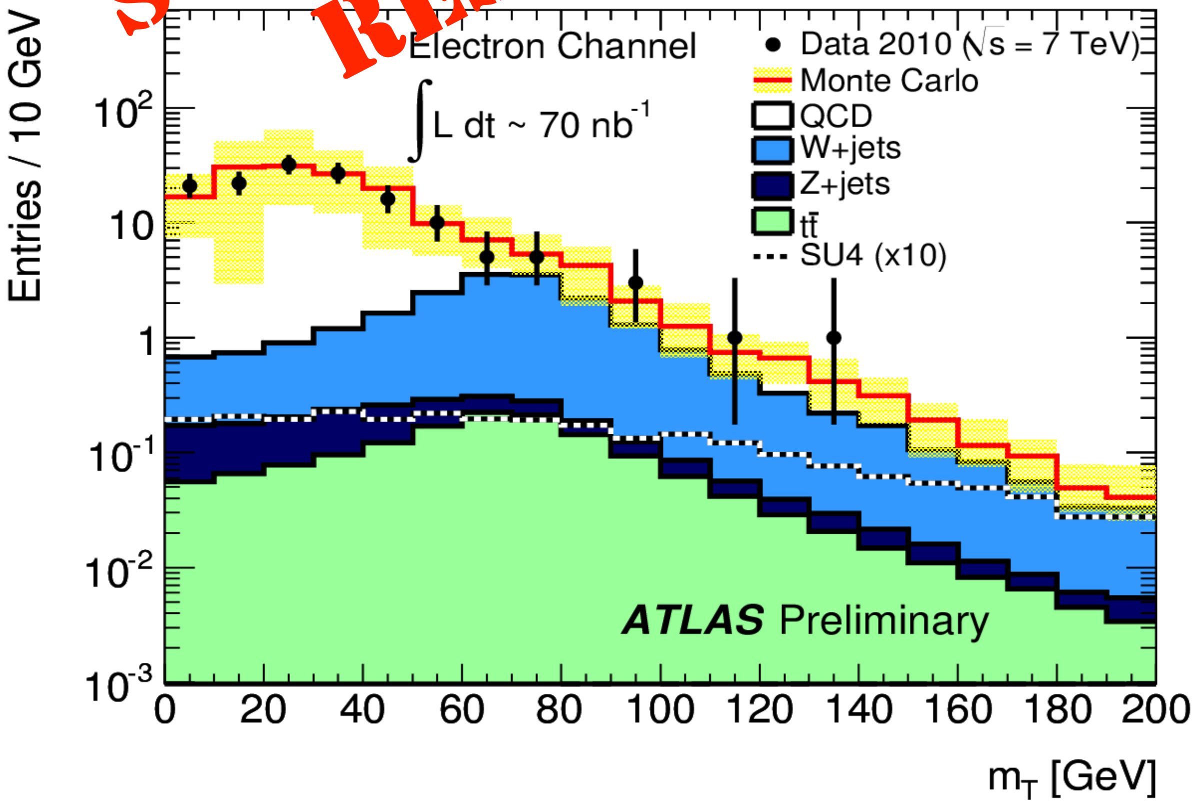
SUMMER 2010 RESULT

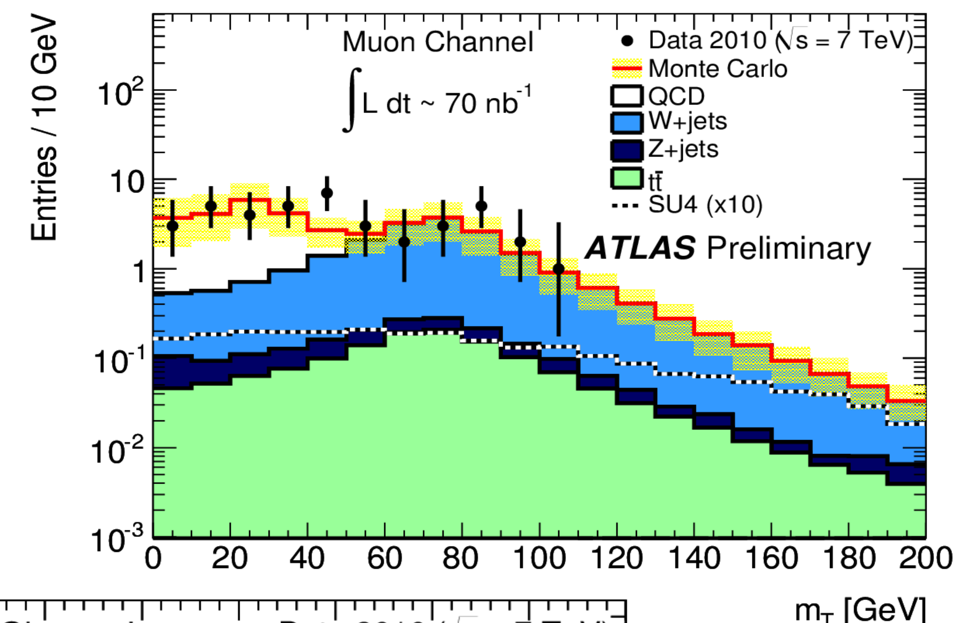
Results

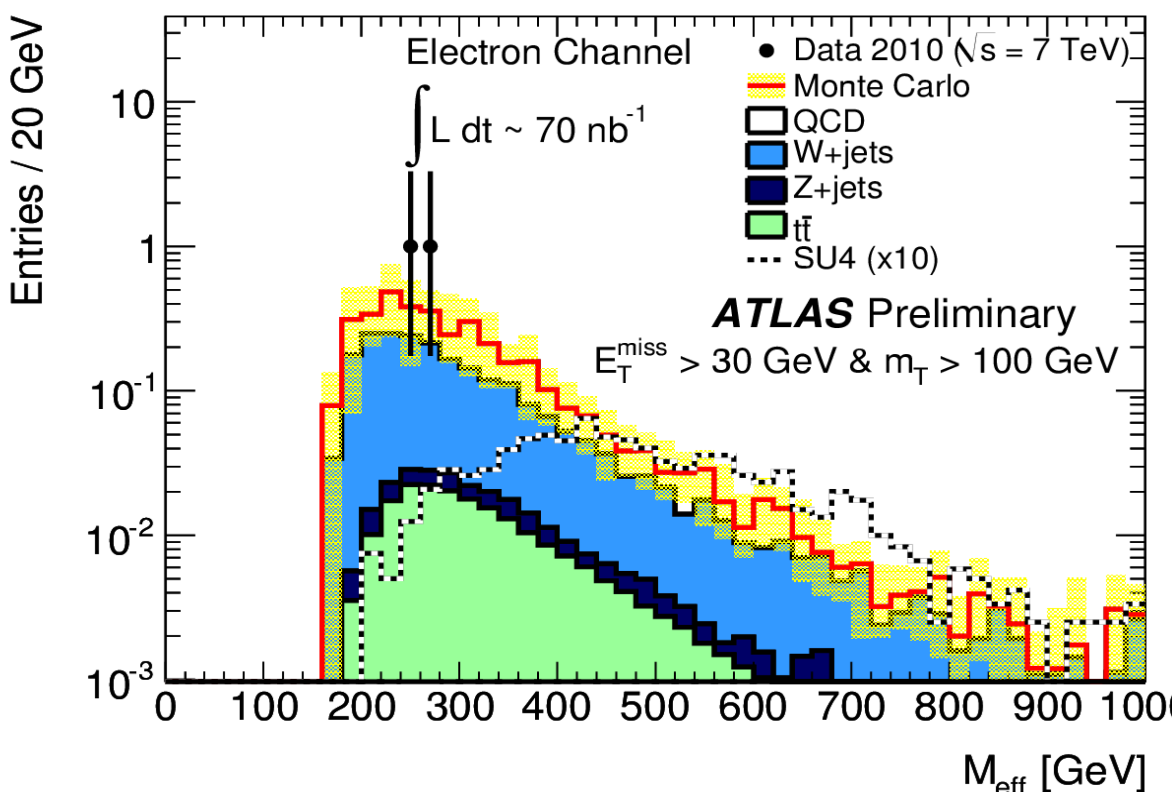
70/pb

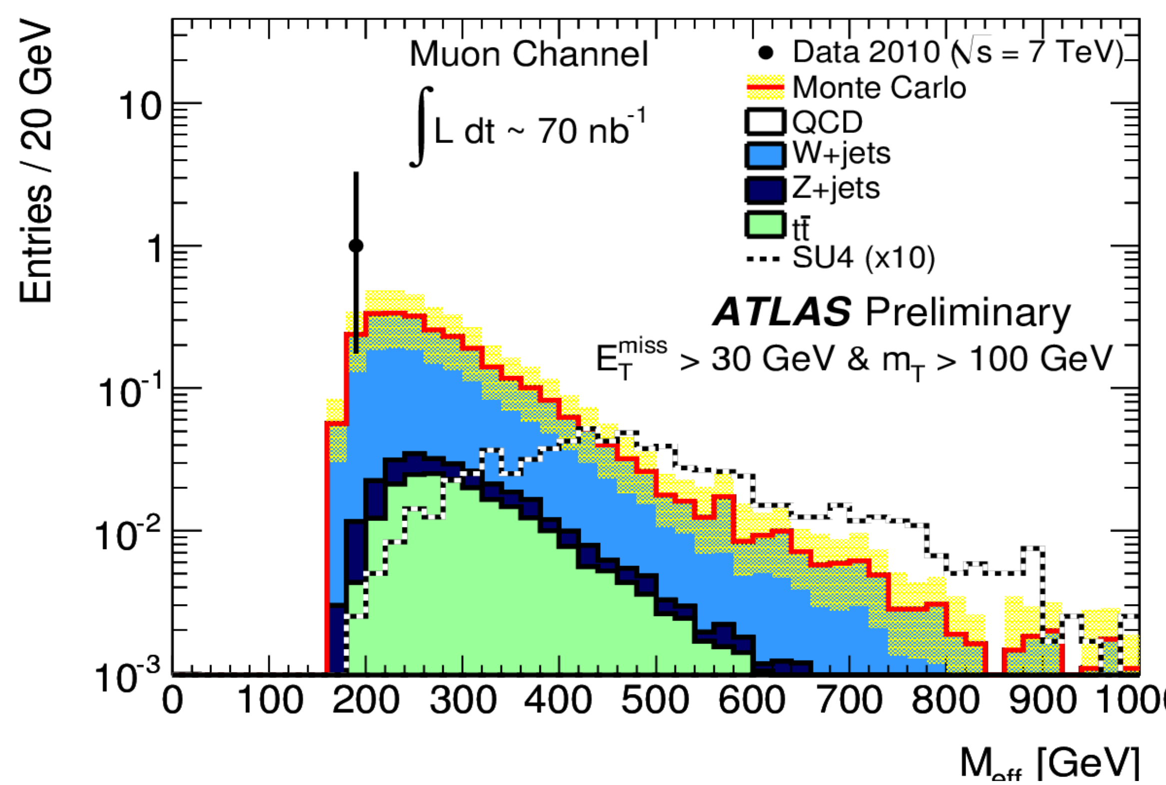
ATLAS-CONF-2010-066

Selection	Electron channel Data	Electron channel Monte Carlo	Muon channel Data	Muon channel Monte Carlo
$p_{\rm T}(\ell) > 20$ GeV $\cap$ ≥ 2 jets with $p_{\rm T} > 30$ GeV	143	157 ± 85	40	37 ± 14
$\cap\ E_{\rm T}^{\rm miss} > 30$ GeV	13	16 ± 7	17	15 ± 7
$\cap\ m_{\rm T} > 100$ GeV	2	3.6 ± 1.6	1	2.8 ± 1.2



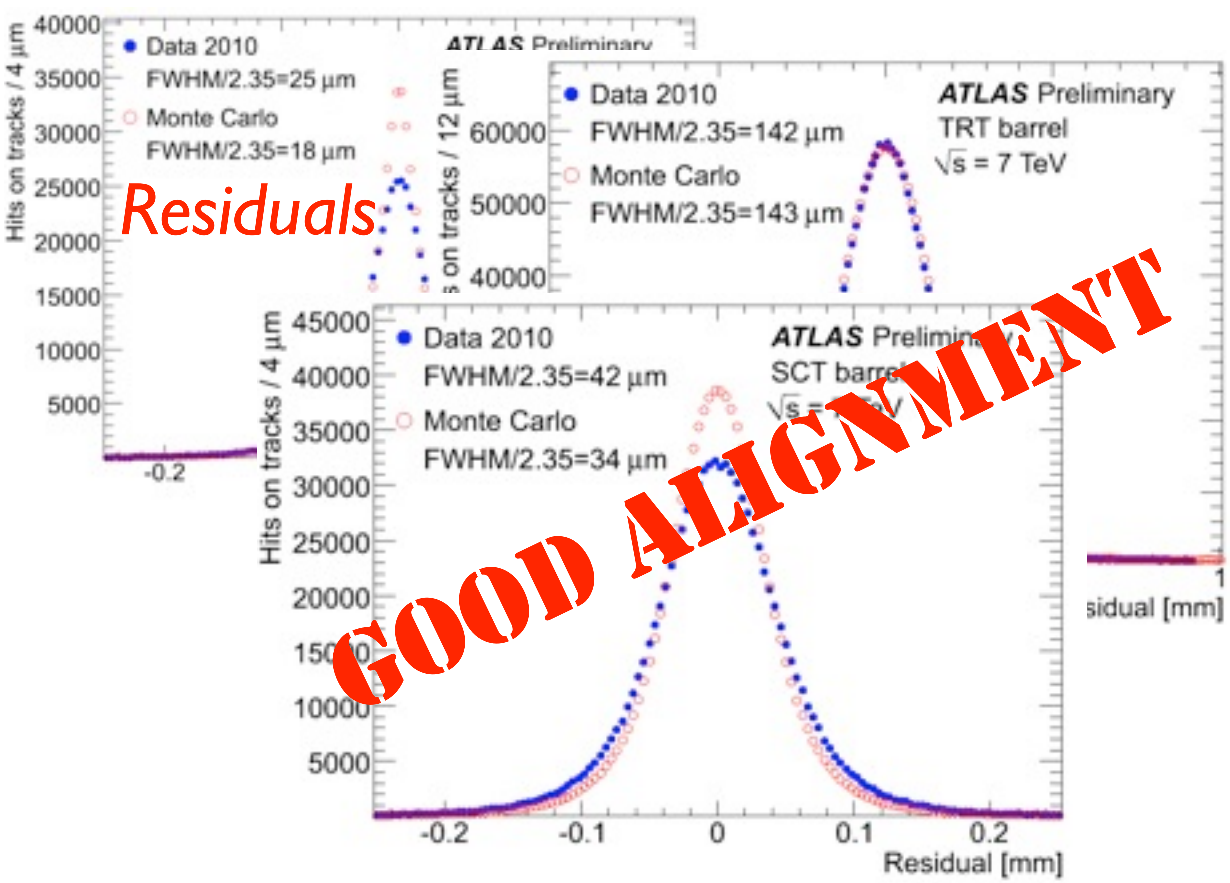






Inner-Detector

Inner-Detector



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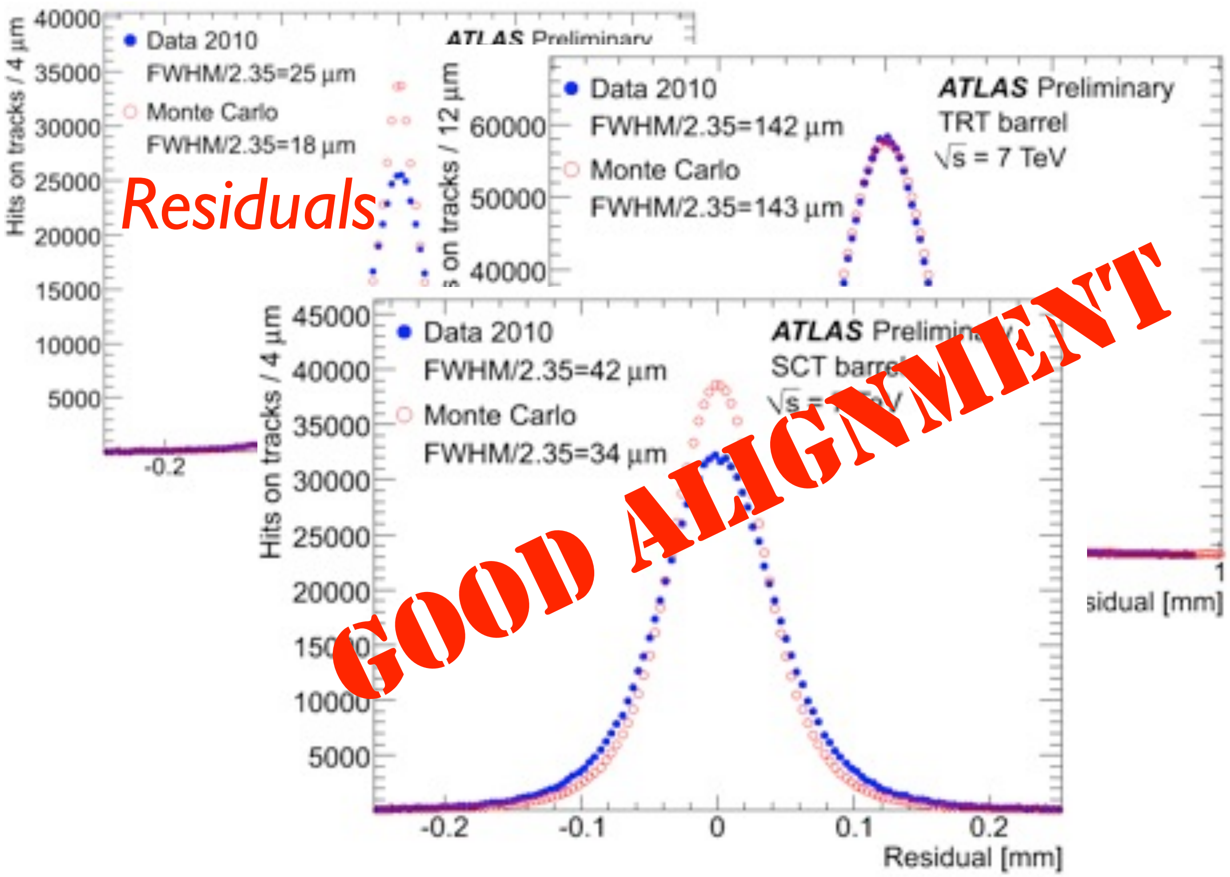
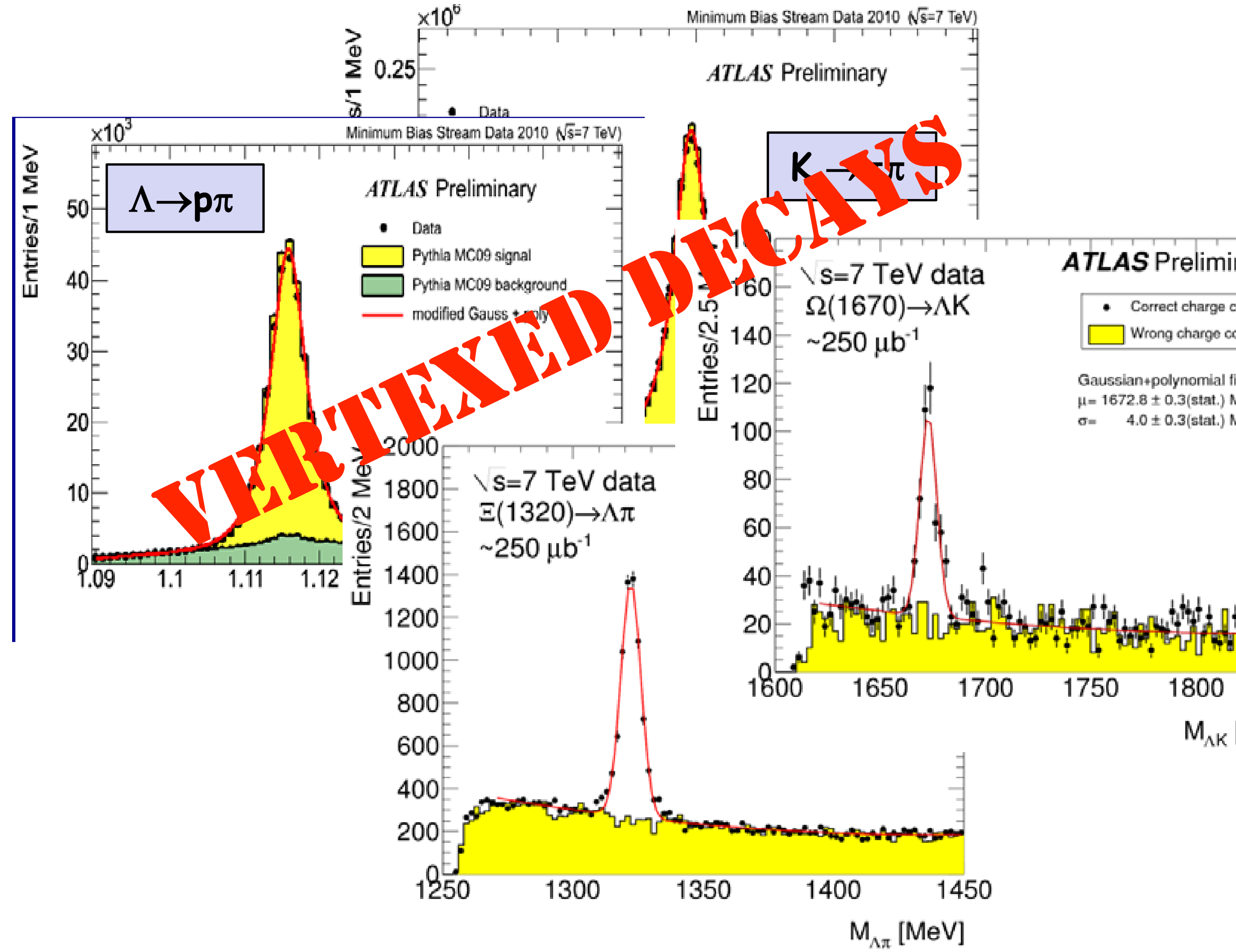
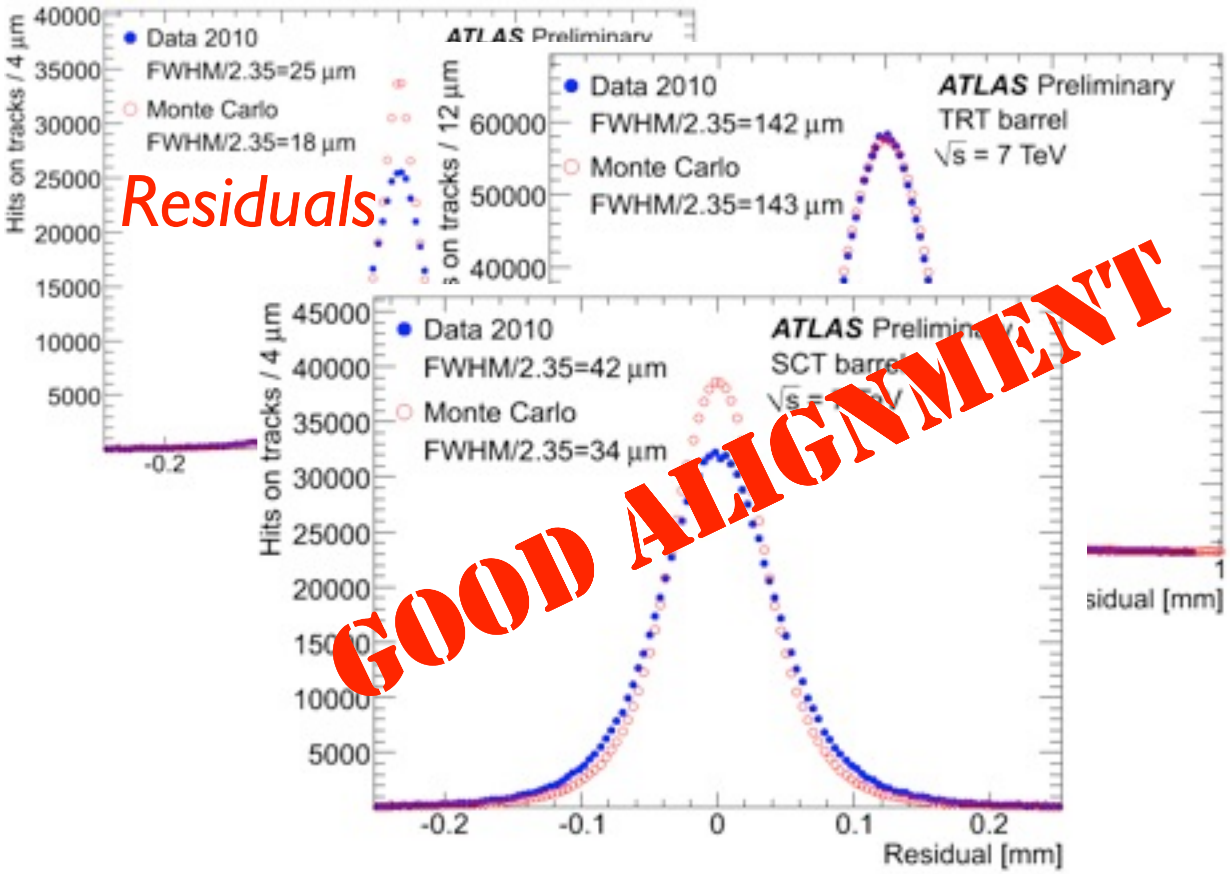
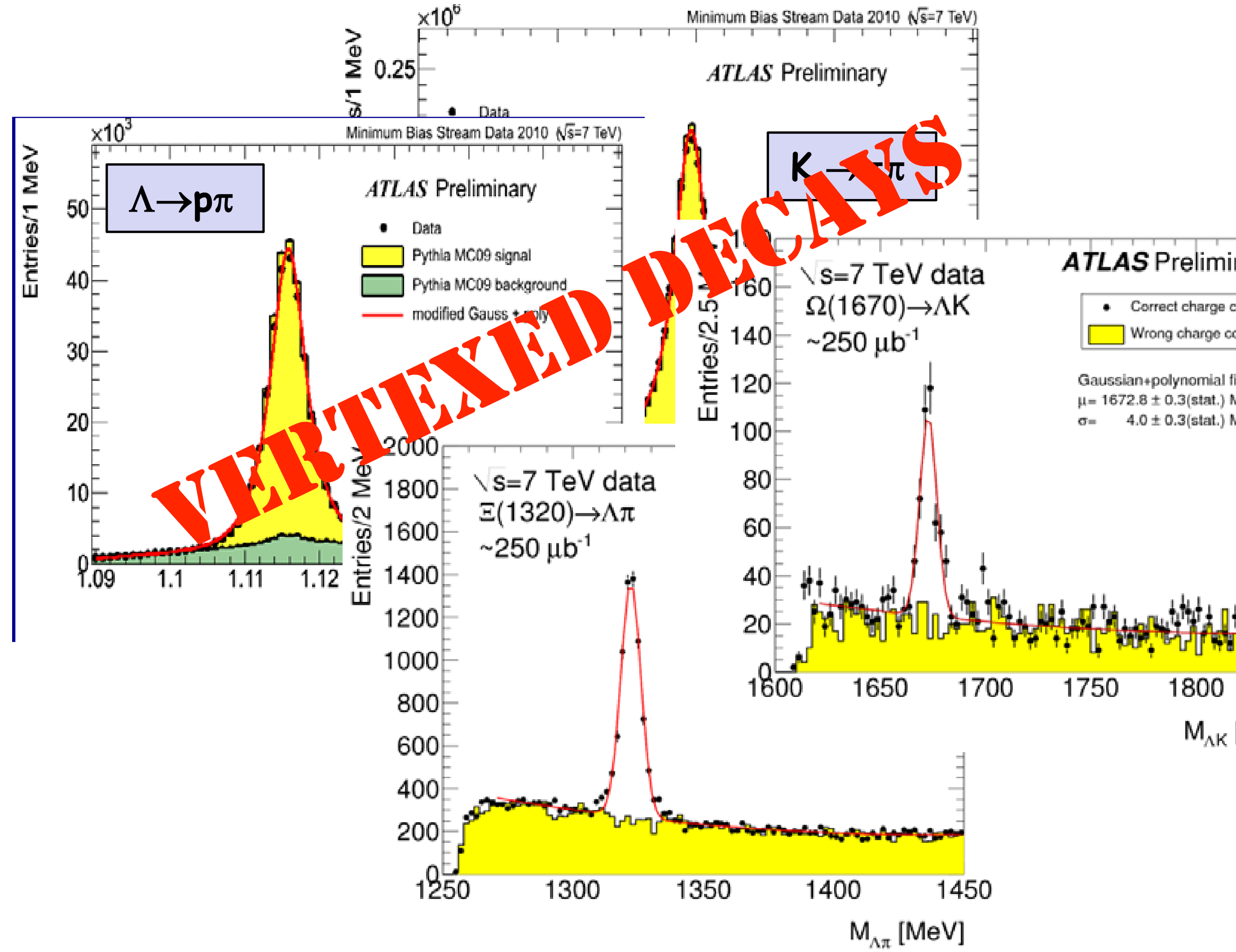
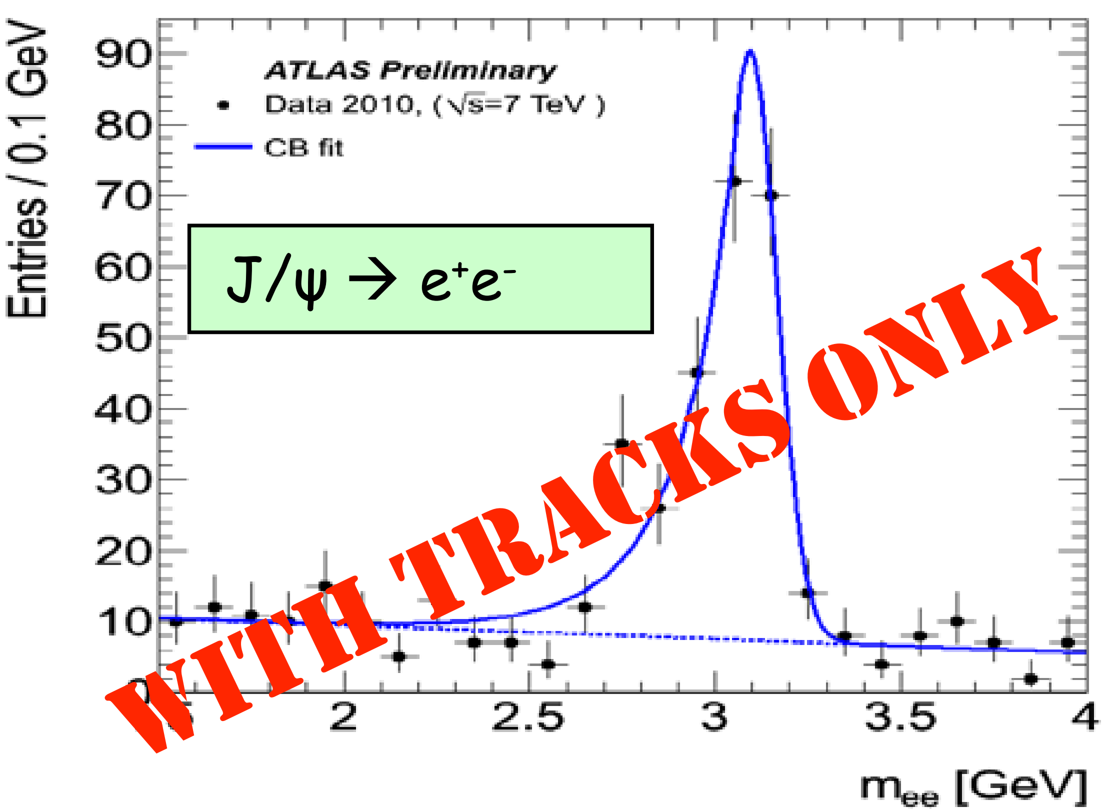




Inner-Detector







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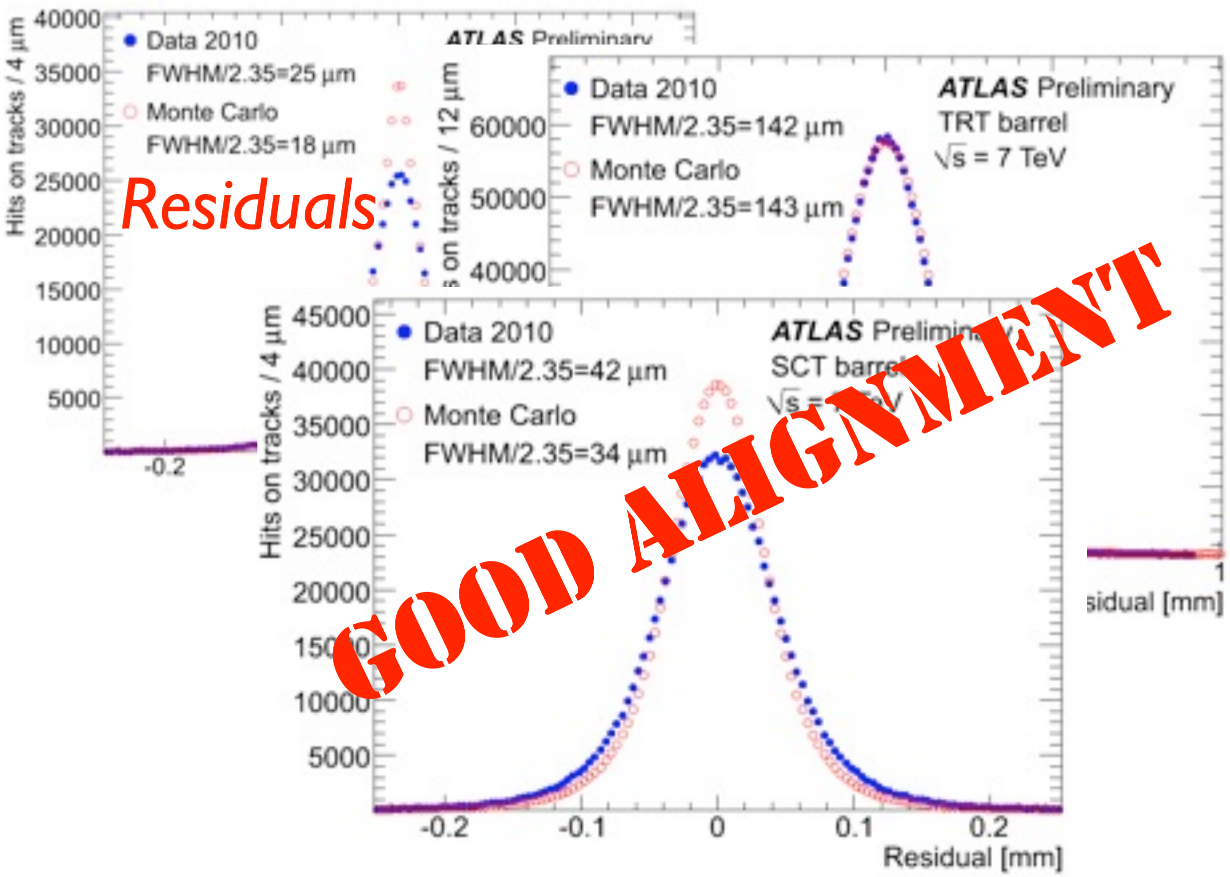
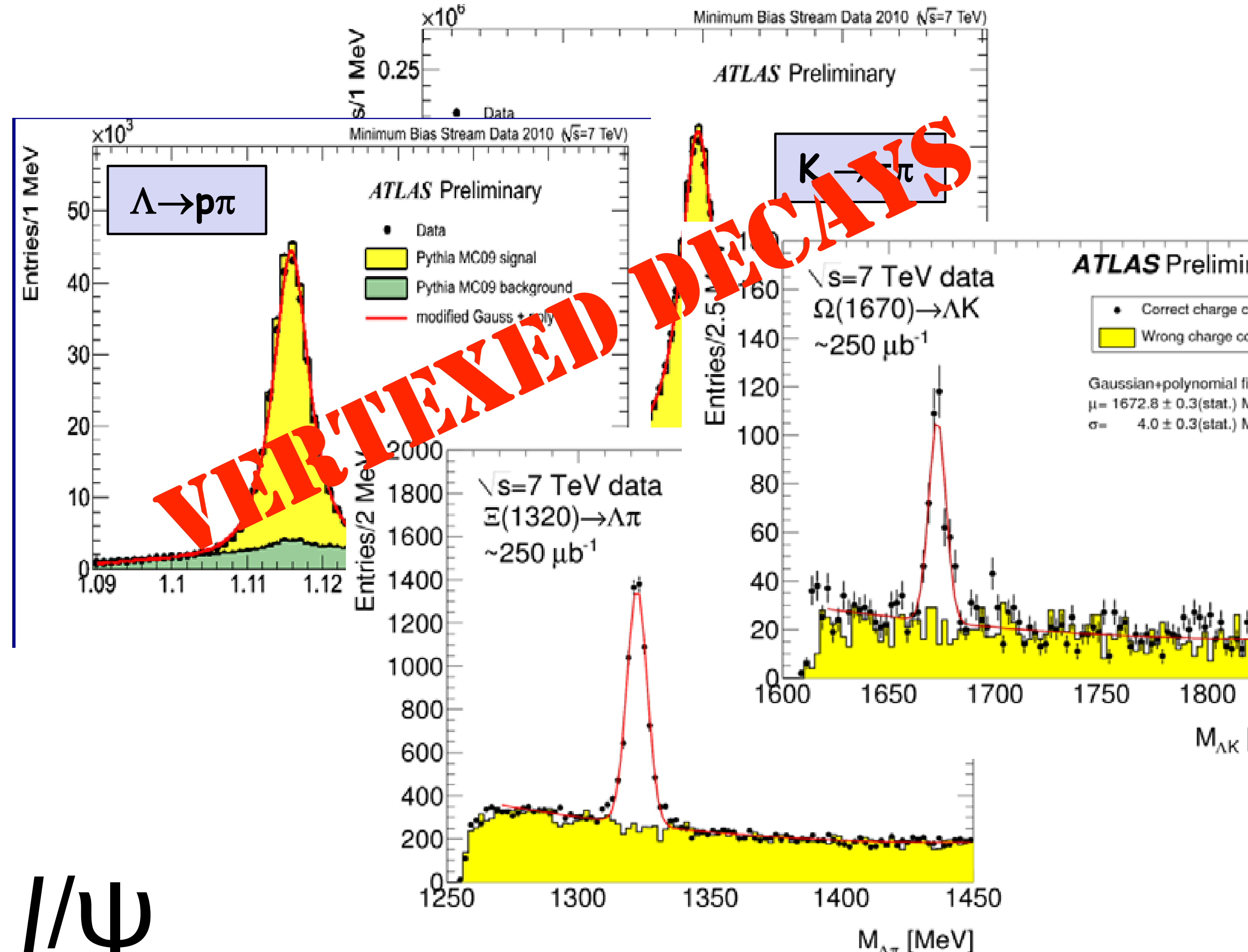
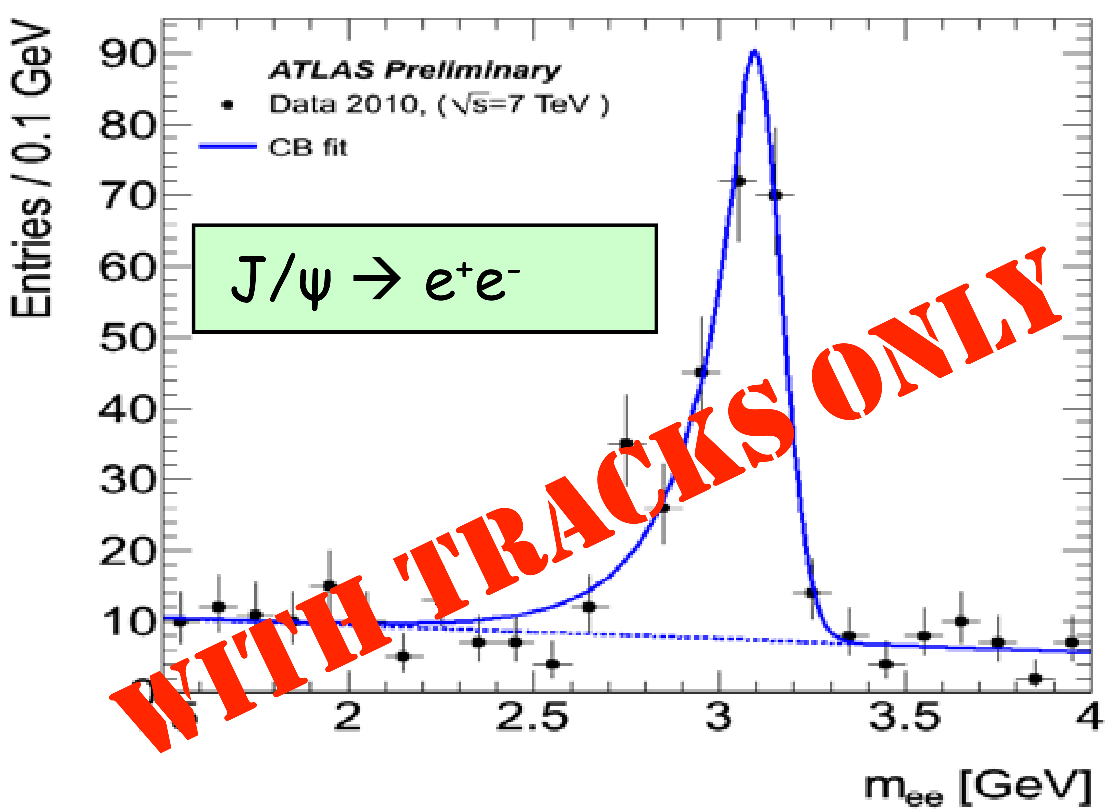


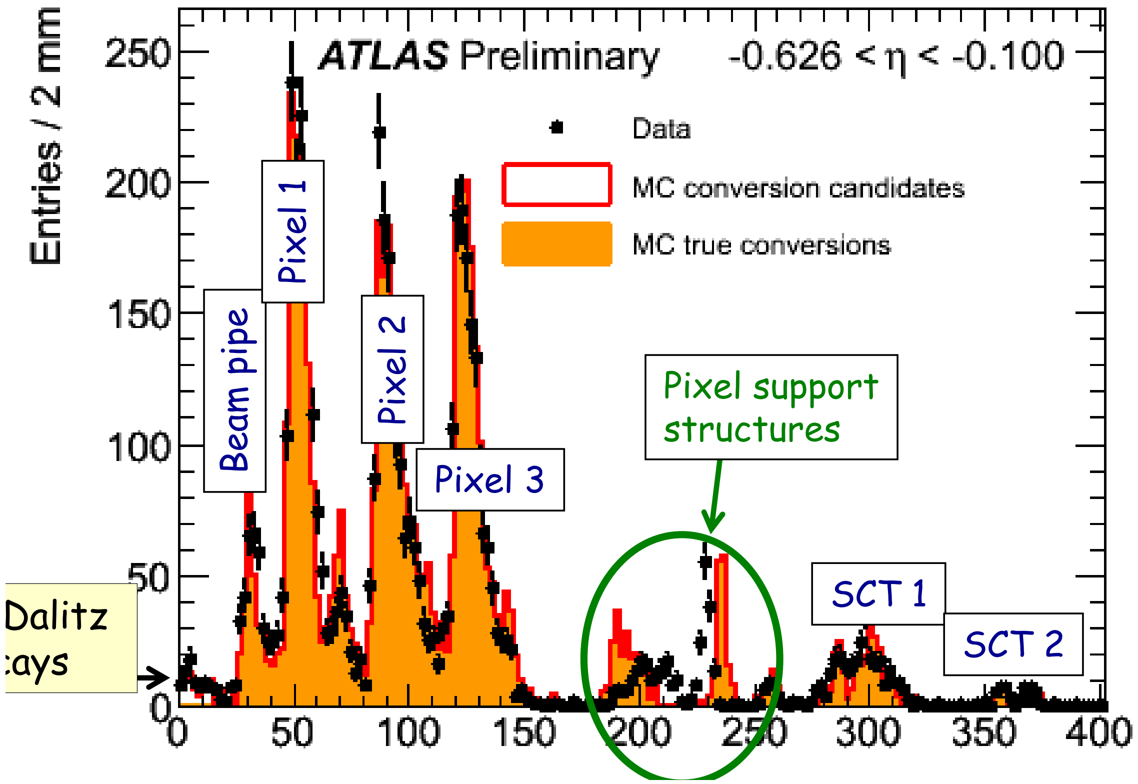




- J/ψ
  - Sig/Bkg= 222 ± 11 / 28 ± 2 events
  - Mass Mean/Res: 3.09± 0.01 / 0.07± 0.01 GeV

Material

- *Goal is to know Material better than 5%...*
    - *Currently 10%*



γ→ee Conversion Vertex Radius

Material

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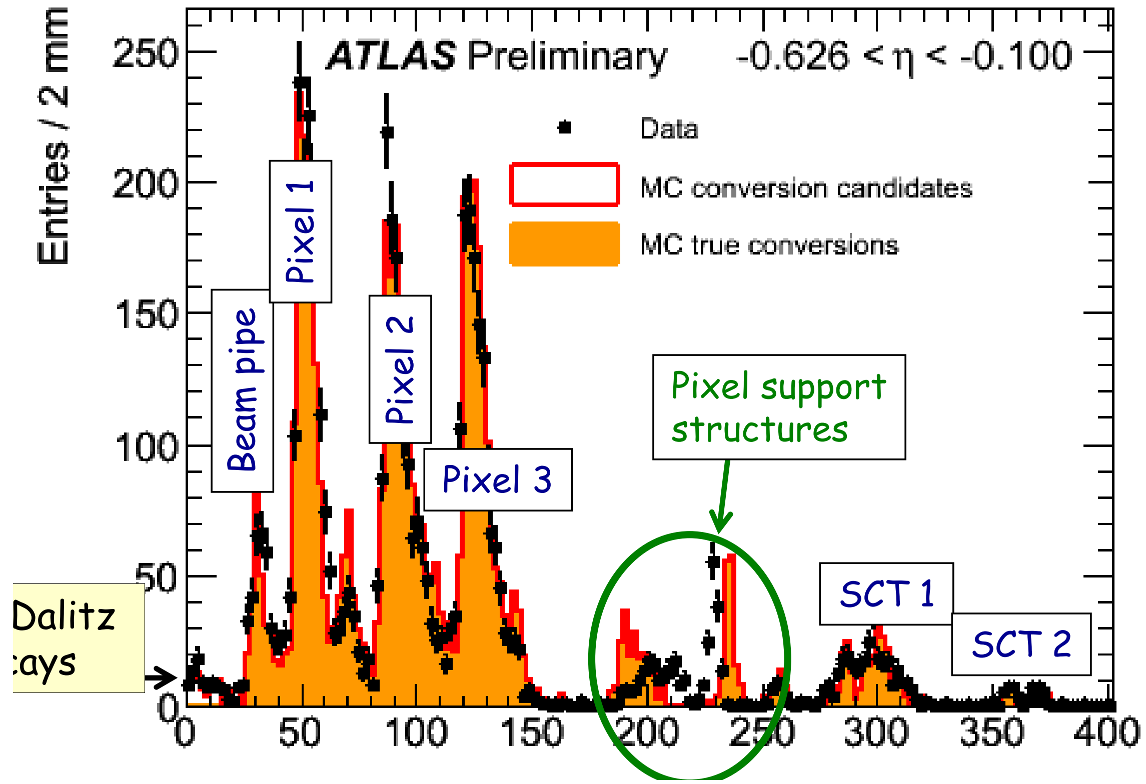
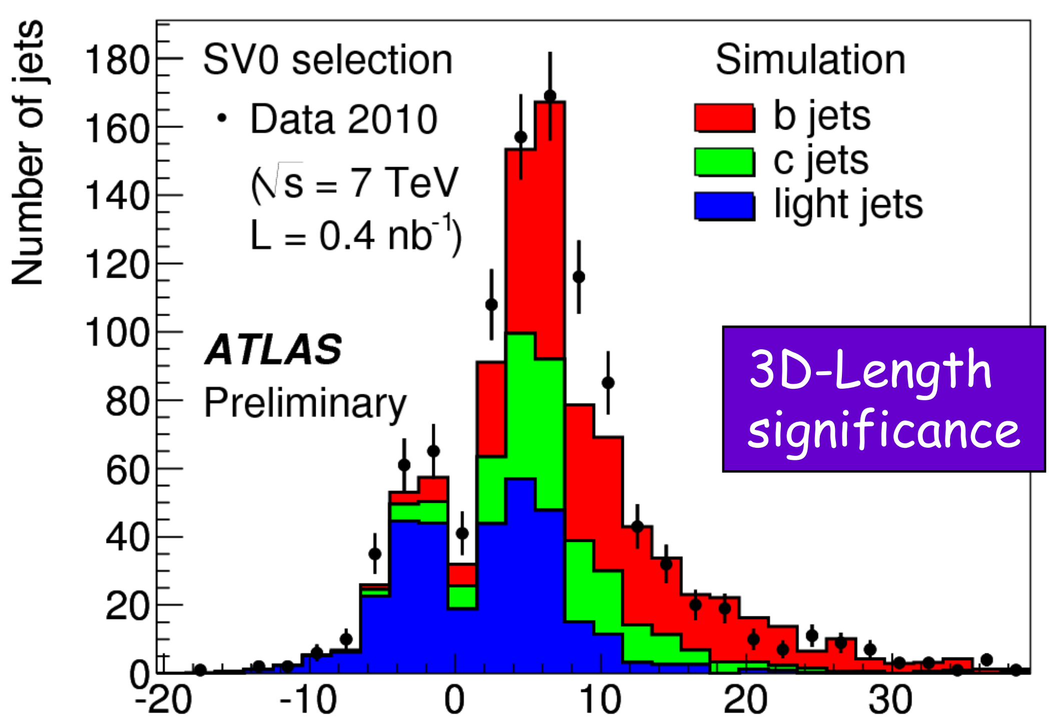


γ→ee Conversion Vertex Radius

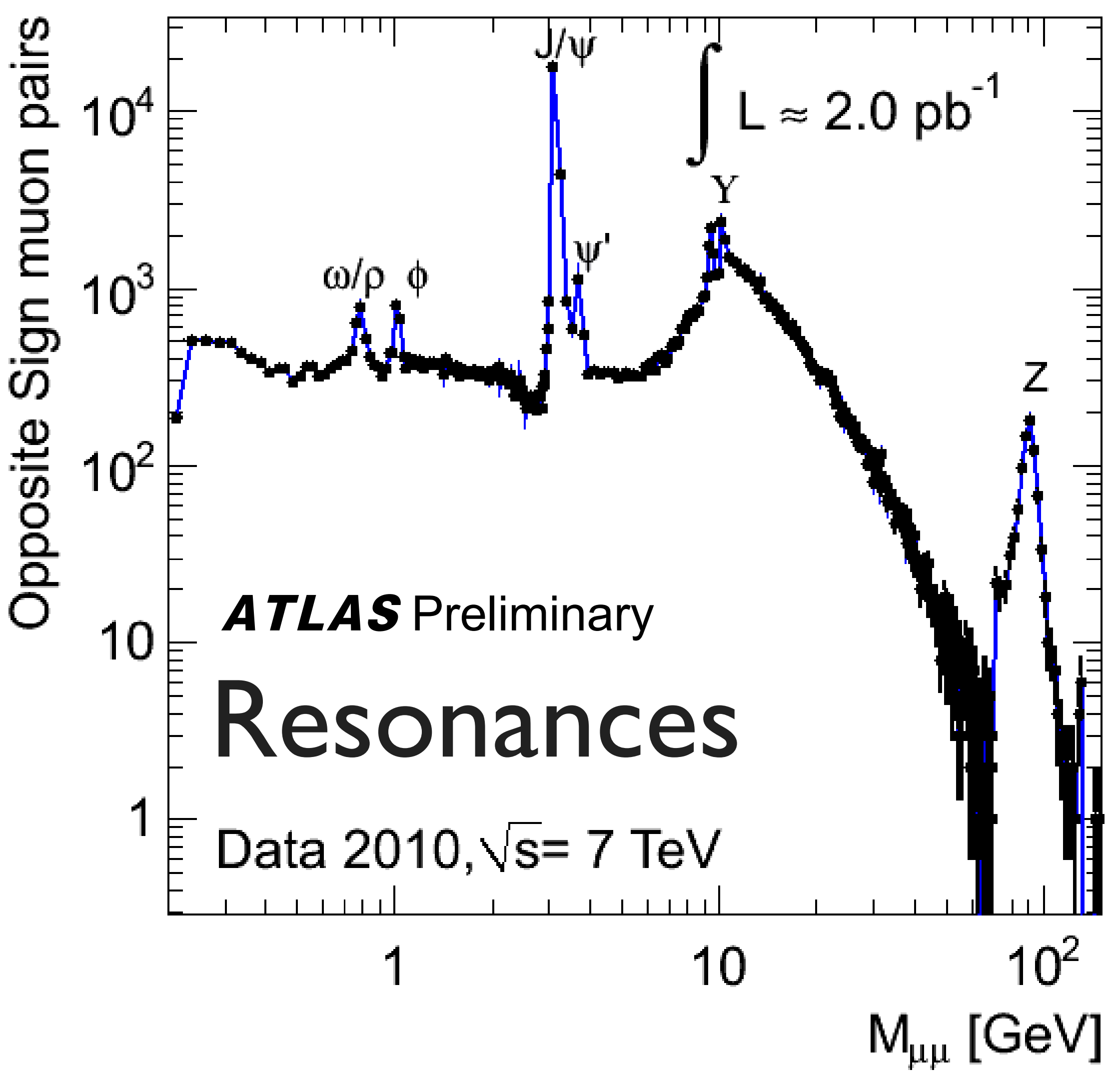


b-Tag

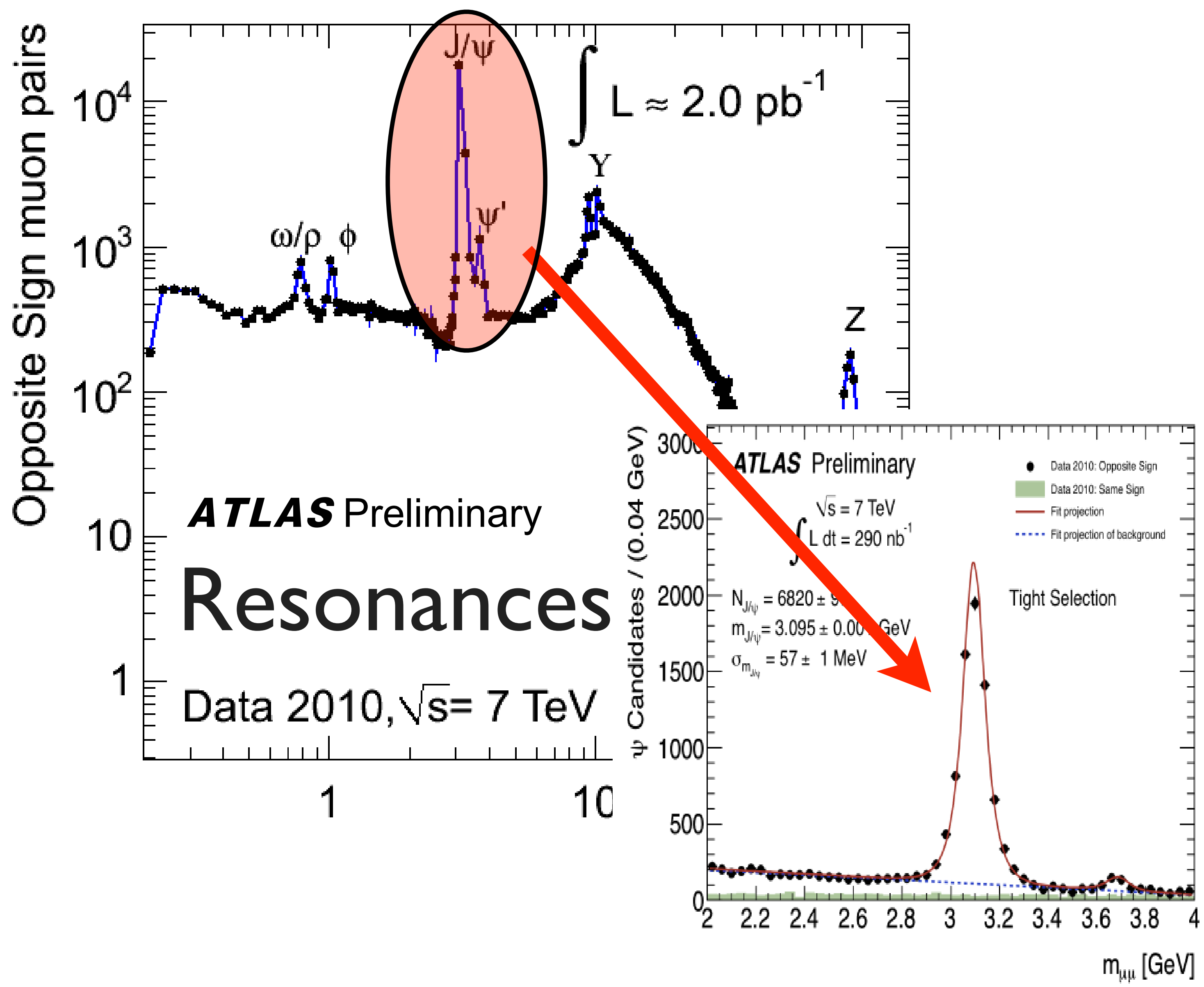
- Rejection at 50% Eff =
  - >98% (light), >80%(charm)
- Improvement after reprocessing due to new alignment

Muons

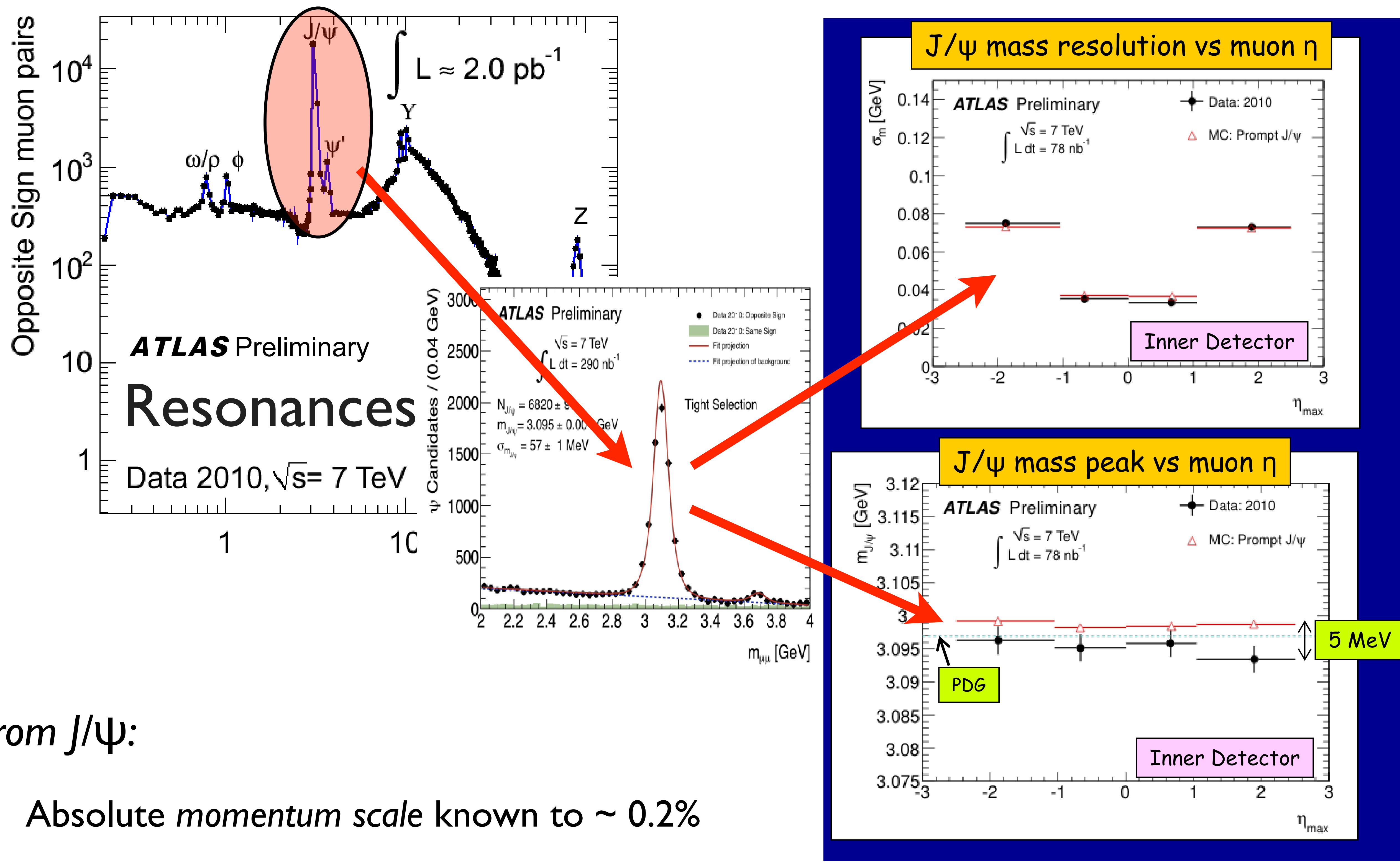
Muons


Opposite Sign muon pairs
10^4
10^3
10^2
10
1
ω/ρ
φ
J/ψ
ψ'
Υ
Z
$\int L \approx 2.0$ pb^{-1}
ATLAS Preliminary
Resonances
Data 2010, $\sqrt{s}$= 7 TeV
1
10
10^2
$M_{\mu\mu}$ [GeV]

Muons


Opposite Sign muon pairs
J/ψ
ψ'
ω/ρ
φ
Υ
Z
∫ L ≈ 2.0 pb⁻¹
ATLAS Preliminary
Resonances
Data 2010, √s= 7 TeV
ATLAS Preliminary
√s = 7 TeV
∫ L dt = 290 nb⁻¹
Data 2010: Opposite Sign
Data 2010: Same Sign
Fit projection
Fit projection of background
Tight Selection
m_μμ [GeV]

Muons



- *From J/ψ:*
  - Absolute *momentum scale* known to ~ 0.2%
  - *Momentum resolution* to ~2 % in the few GeV region

Electrons

Electrons

- *Many handles for identification*:
  - *loose*: rough shower shape and track
  - *medium*: ref shower shape, pixel hit, d0
  - *tight*: track match, transition radiation, E/p
- *Tight (>20 GeV) ~10^5 Jet rejection*
- *Initial E-scale transported from test-beam with help from MC*
- *Inter-calibration Checked (to ~2%) with π^0's and Z's*

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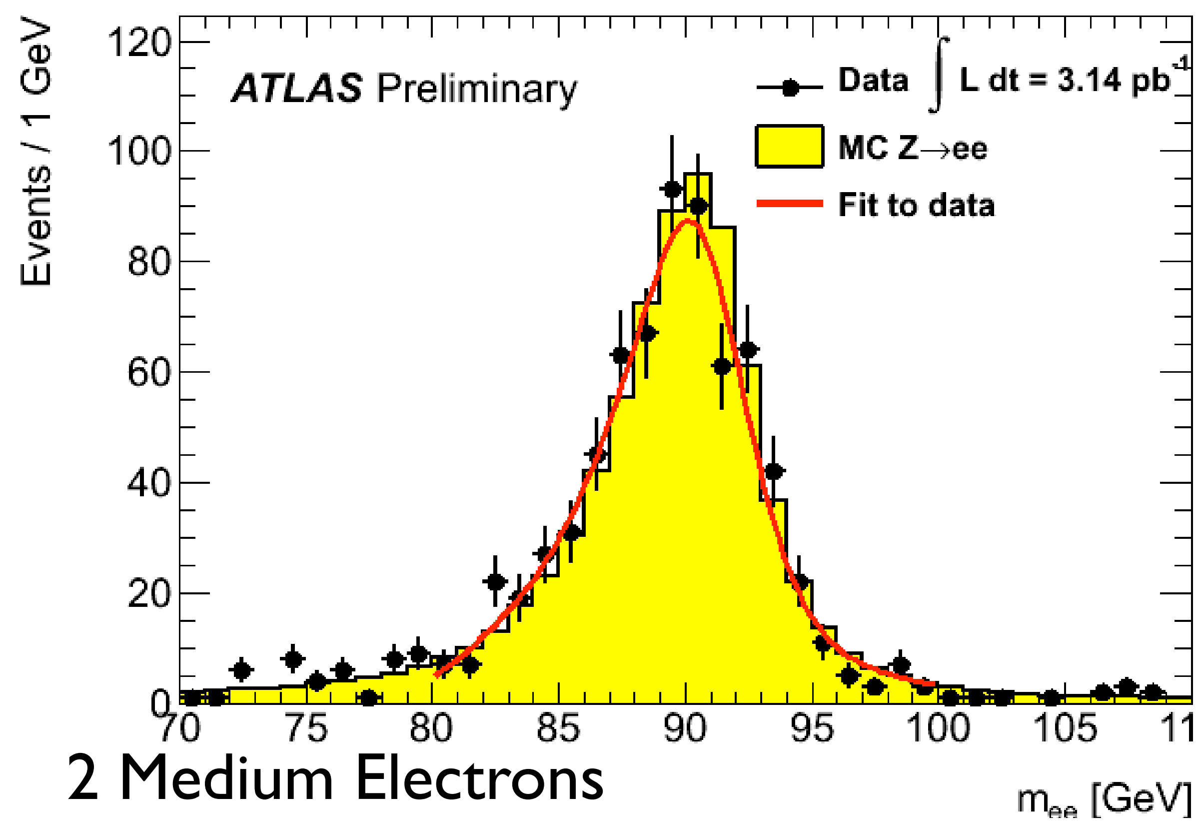

2 Medium Electrons

- *Z Resolution:*
  - σ(data) = 1.59±0.04 GeV
  - σ(MC) = 1.40±0.01 GeV

Photons

Photons

- *Tight Selection tuned to match MC:*
  - rely heavily on shower structure in strip section
  - completed by isolation
- *Jet rejection (leading π^0) less effective than for electrons*
  - *Retuning / better performance coming soon.*

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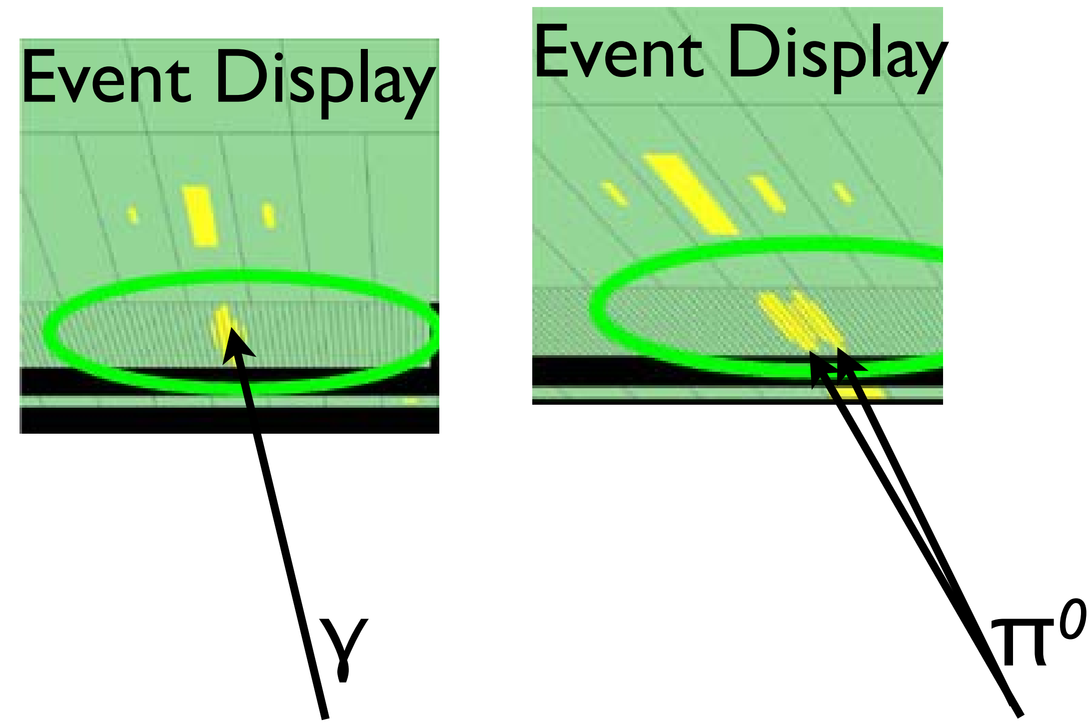

Photons

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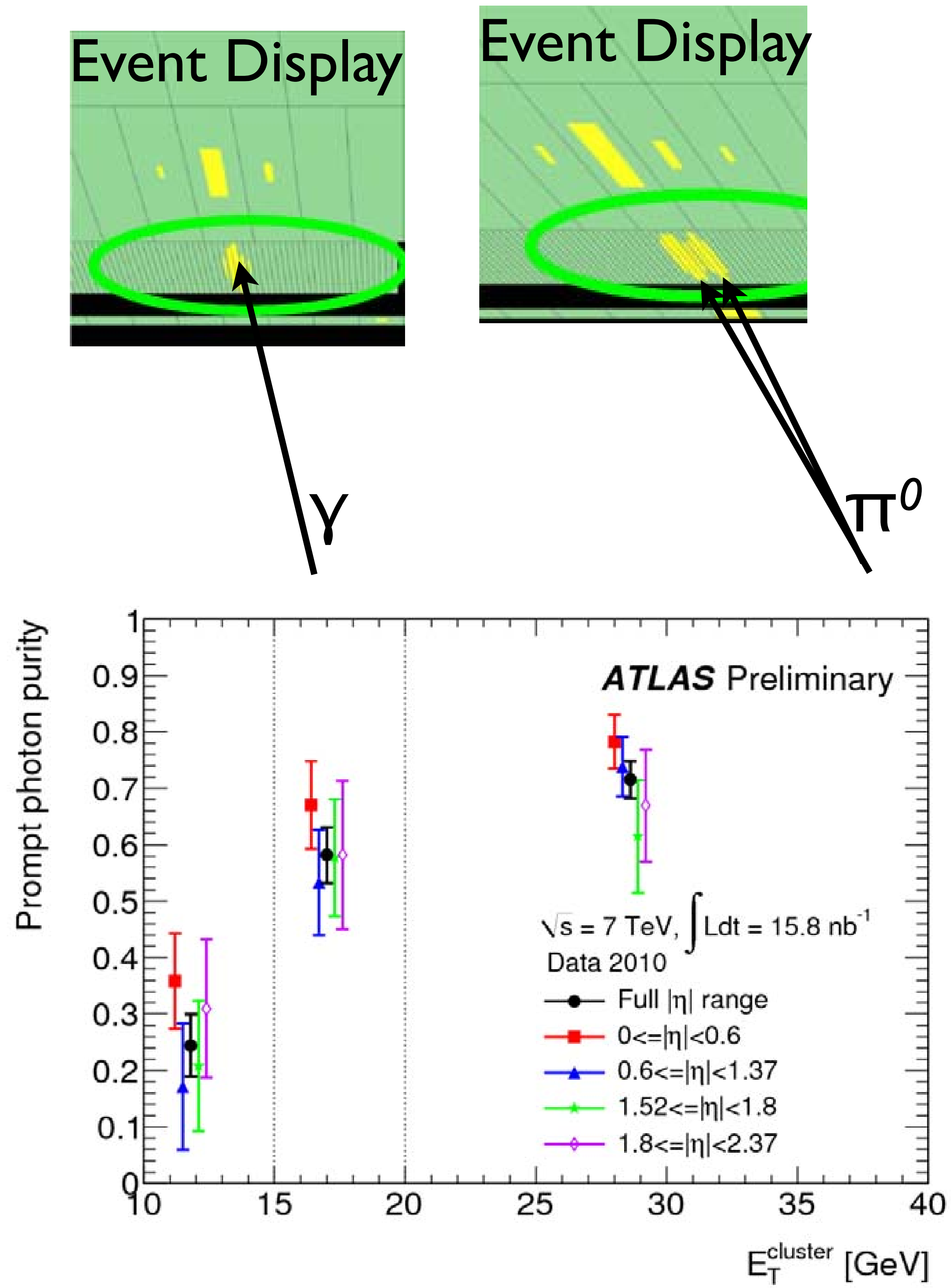
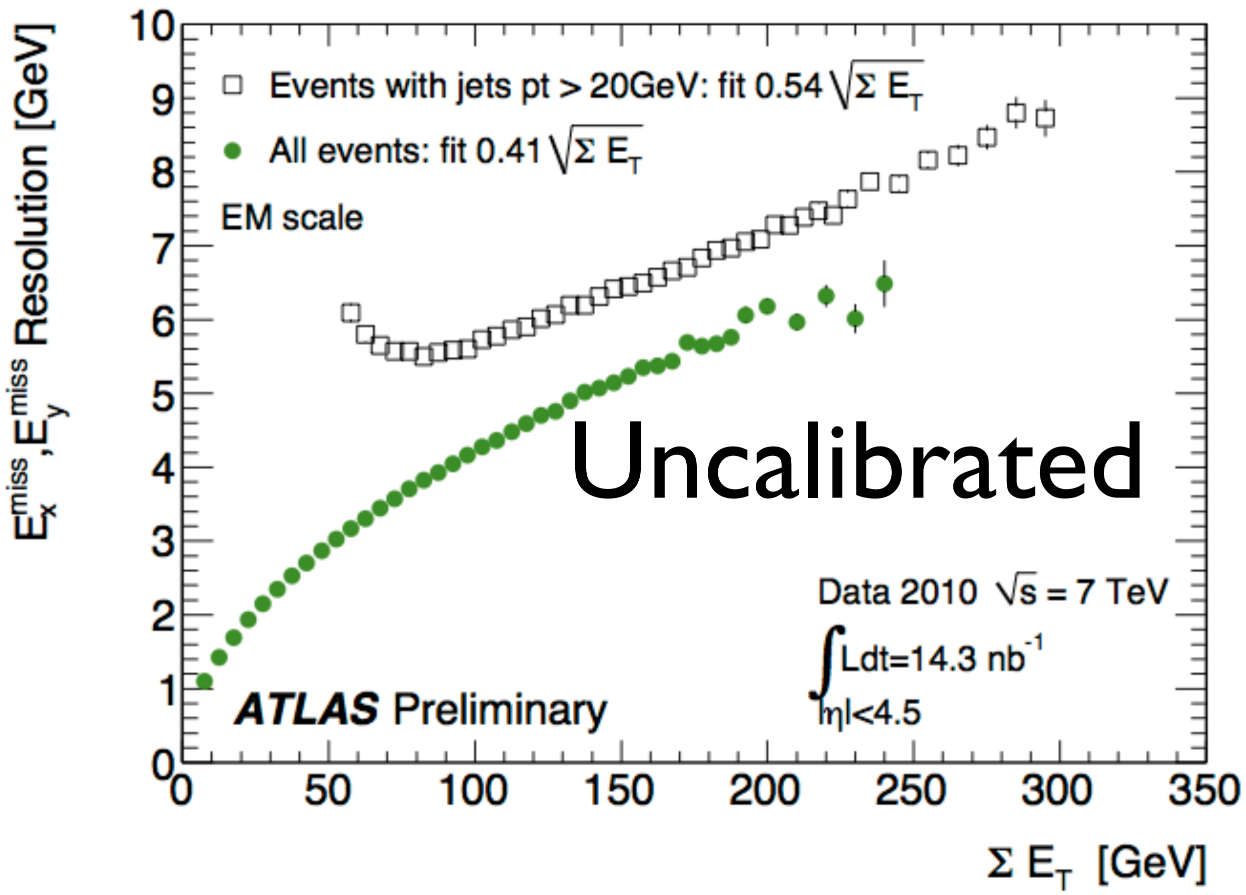
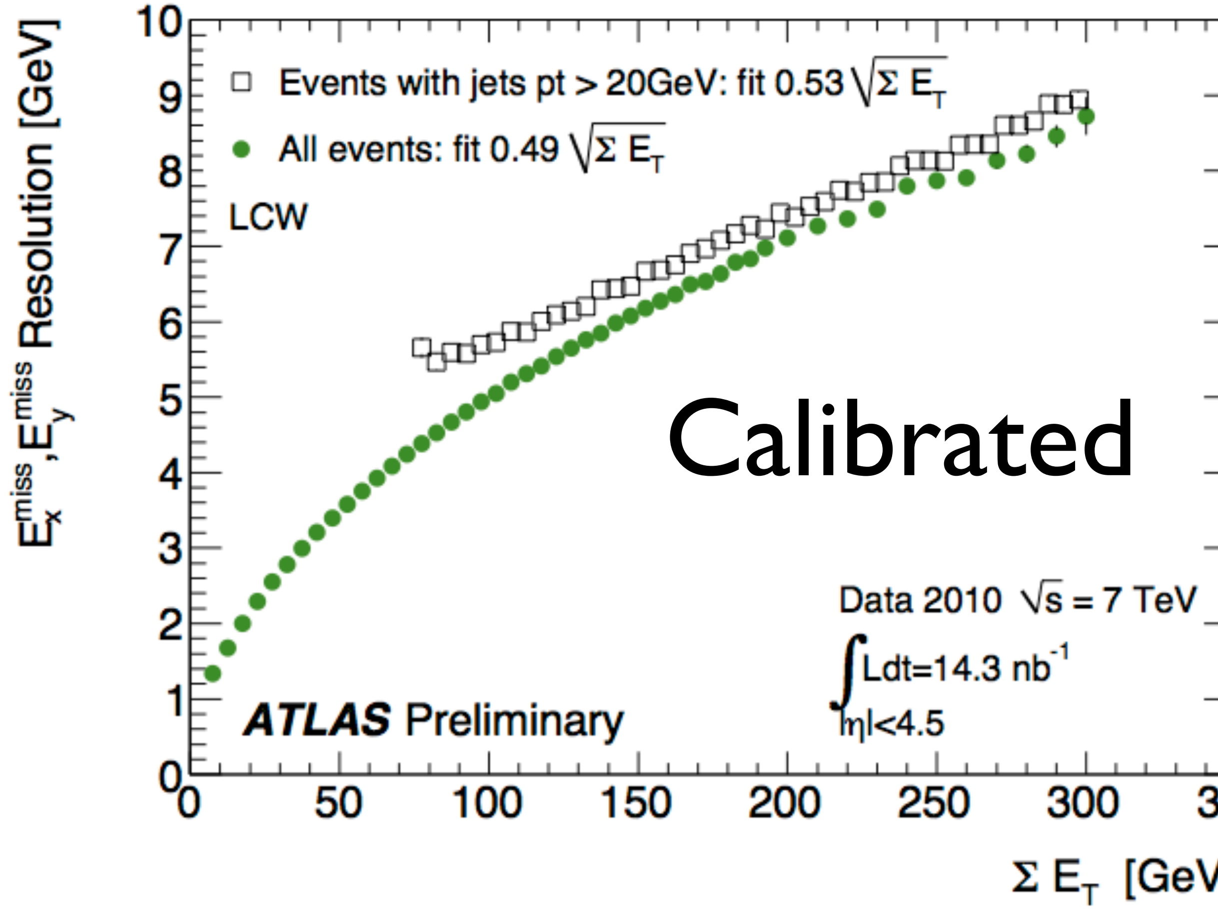


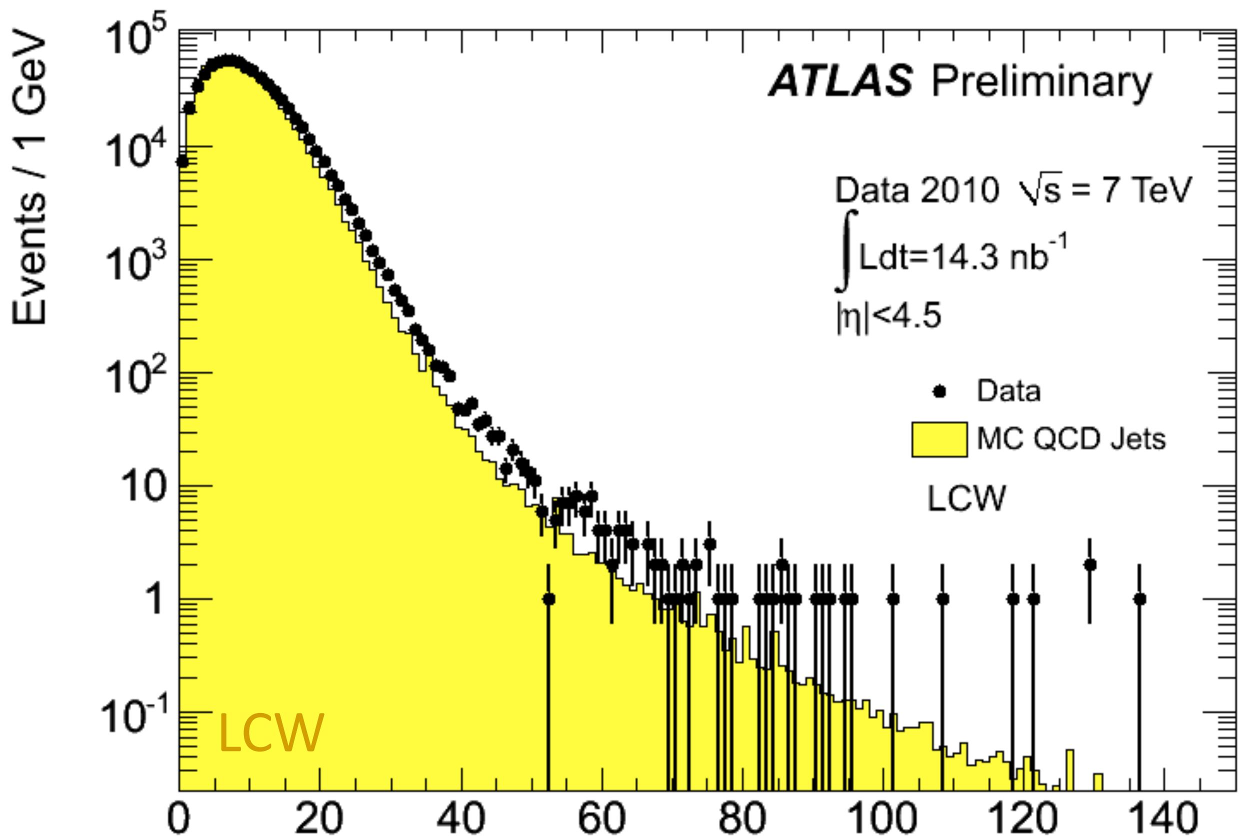
Purity Measured in Data

MET with high-pT Jets



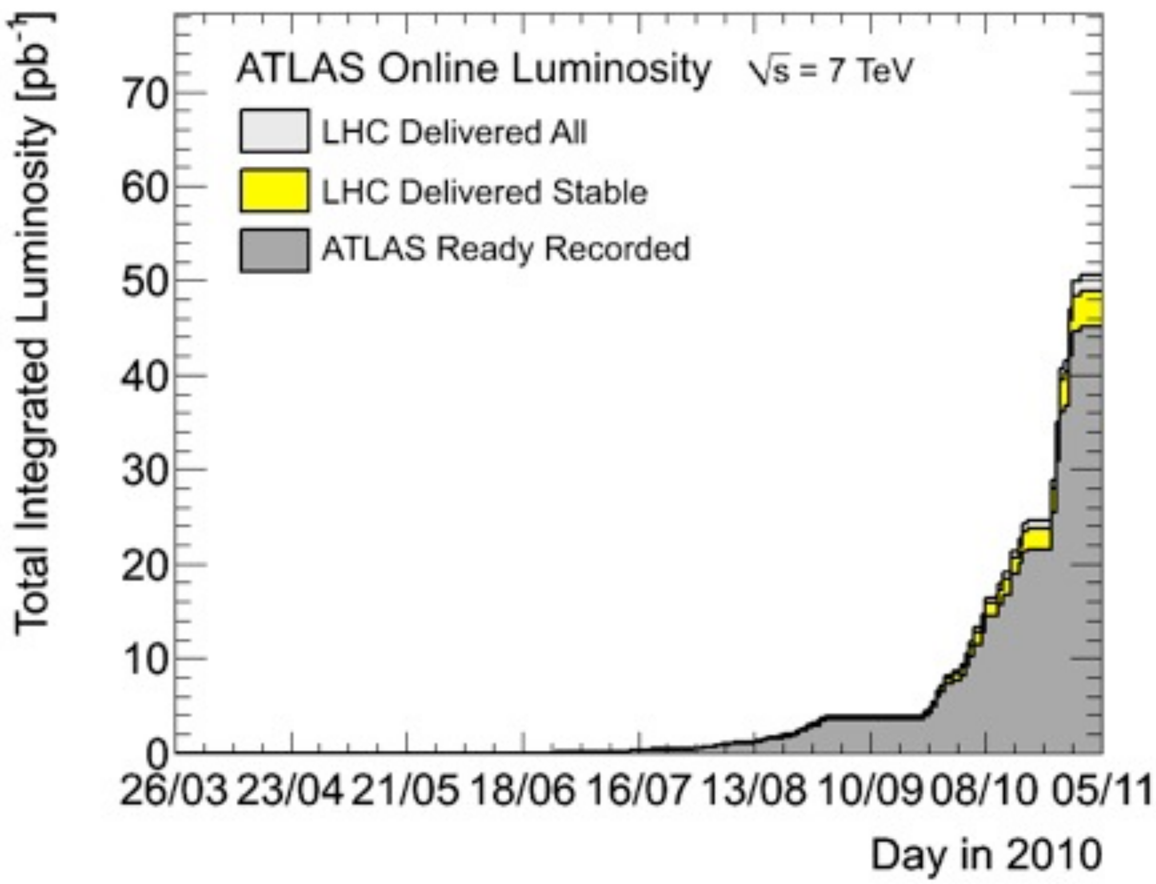


ATLAS-CONF-2010-057



- Some data/MC disagreement in MET for events with high pT jets
  - But tails are generally under control
  - Smearing Jets in MC to reproduce Data Jet performance produces good Data/MC agreement in MET

Operations



- 48.87/pb delivered by this morning since March 30th
  - van der Meer Luminosity uncertainty of 11% will go down to 5%.
- Peak Lumi: 2.07 x 10 ^{32} cm^{2} s^{-1}
- Lumi weighted data-taking efficiency ~ 92%

RECORDS

Peak Stable Luminosity Delivered	2.07×10^{32}	Fill 1440	10/10/24, 23:48
Maximum Luminosity Delivered in one fill	6304.61 nb^{-1}	Fill 1450	10/10/27, 18:39
Maximum Luminosity Delivered in one day	5983.78 nb^{-1}	Monday 25 October, 2010	
Maximum Luminosity Delivered in 7 days	24637.08 nb^{-1}	Sunday 24 October, 2010 - Saturday 30 October, 2010	
Maximum Colliding Bunches	348	Fill 1440	10/10/24, 23:48
Maximum Average Events per Bunch Crossing	3.78	Fill 1440	10/10/24, 23:48
Longest Time in Stable Beams for one fill	30.3 hours	Fill 1058	10/04/24, 01:13
Longest Time in Stable Beams for one day	22.8 hours (94.9%)	Saturday 24 April, 2010	
Longest Time in Stable Beams for 7 days	69.9 hours (41.6%)	Monday 02 August, 2010 - Sunday 08 August, 2010	
Fastest Turnaround to Stable Beams	3.66 hours	Fill 1284	10/08/14, 10:05
Fastest ATLAS Ready from Stable Beams	25.0 seconds	Fill 1285	10/08/14, 22:39
Best ATLAS Recording Efficiency for one fill	99.4 percent	Fill 1285	10/08/14, 18:26
Best ATLAS Recording Efficiency for one day (> 10 nb^{-1})	99.9 percent	Monday 16 August, 2010	
Best ATLAS Recording Efficiency for 7 days (> 100 nb^{-1})	99.7 percent	Thursday 12 August, 2010 - Wednesday 18 August, 2010	

Detector Status

- *Sources of data taking inefficiency:*
  - Si + Muons HV Ramp
  - LArg Noise Bursts
  - HV Trips (LArg/Tile)

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
96.7	97.5	100	93.8	98.8	99.0	99.7	98.6	98.5	98.6	98.5

DATA TAKING EFFICENCY > 97%

March 30-Aug 30: Fraction of data (after stable beams declared)marked as good after 36-hours "calibration loop", before start of reconstruction at Tier0

- *Fraction of good data after further reprocessing is higher*

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.1%
LAr EM Calorimeter	170 k	98.1%
Tile calorimeter	9800	96.9%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

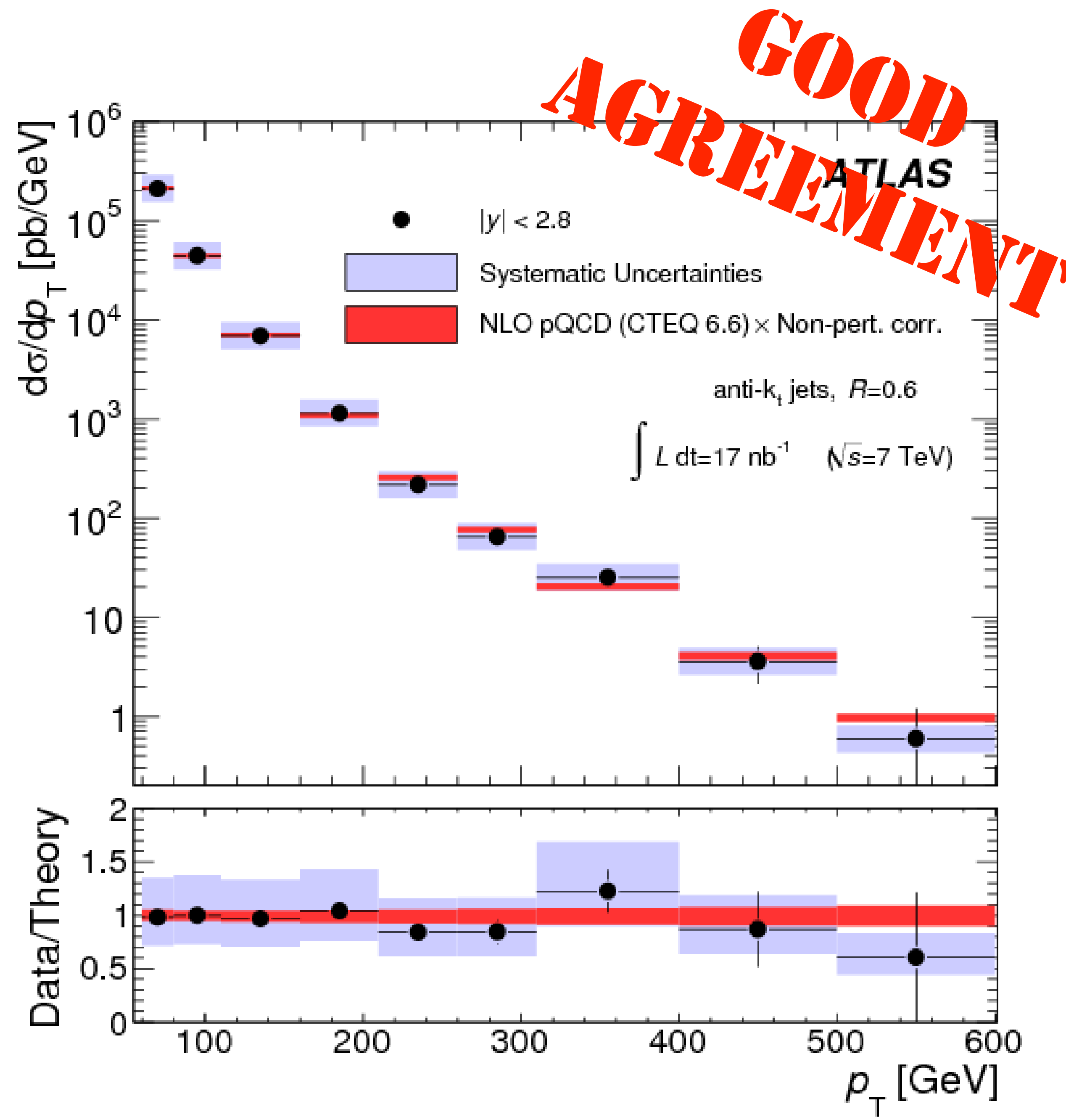
CHANNEL EFFICIENCY > 97%

- *Sources of channel inefficiency:*
  - Failing LArg Front-end Optical Transmitters (~1/month). So far1.5%.
  - Failing SCT/Pixel Back-end Optical Transmitters (~a few/week). Replace as we go.
  - Failing Tile Low voltage power-supplies and Front-end interconnectivity.
- *No show stoppers... spares in production.*
- *Repairs during Christmas 9-day/1-side access*

Inclusive Jet x-section

17/nb

- Measured jets corrected to particle-truth level (incl μ and ν) using parton-shower MC (Pythia, Herwig)
- Results compared to NLO QCD prediction after corrections for hadronization and underlying event
- Theoretical uncertainty: ~20% (up to 40% at large $|y_j|$) from variation of PDF, αs, scale (μ_R, μ_F)
- Experimental uncertainty: ~30-40% dominated by JES (known to ~7%,)
- Luminosity uncertainty(11%) not included

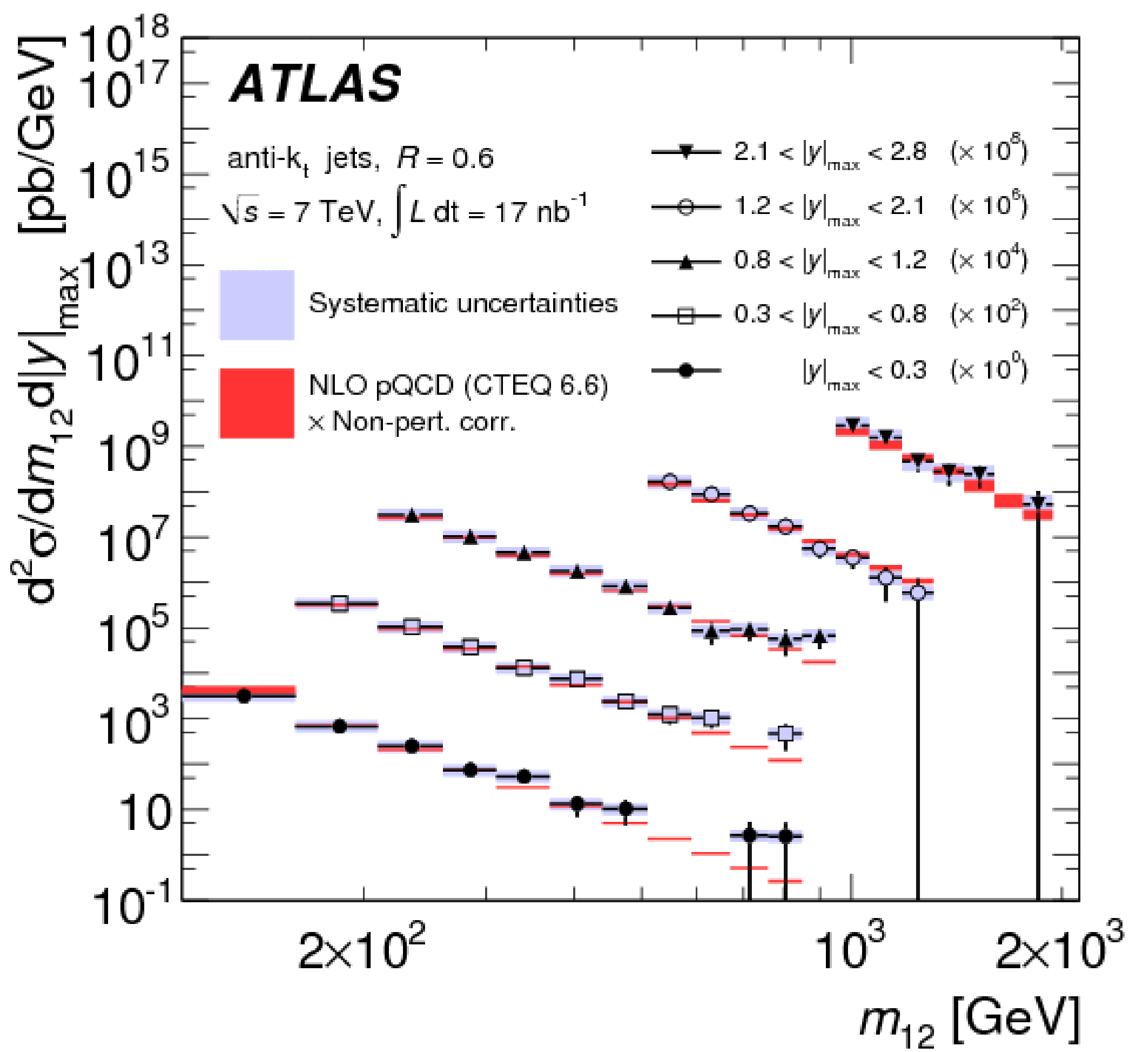


All Jets from events with at least one Jet pTj > 60 GeV, |yj|< 2.8

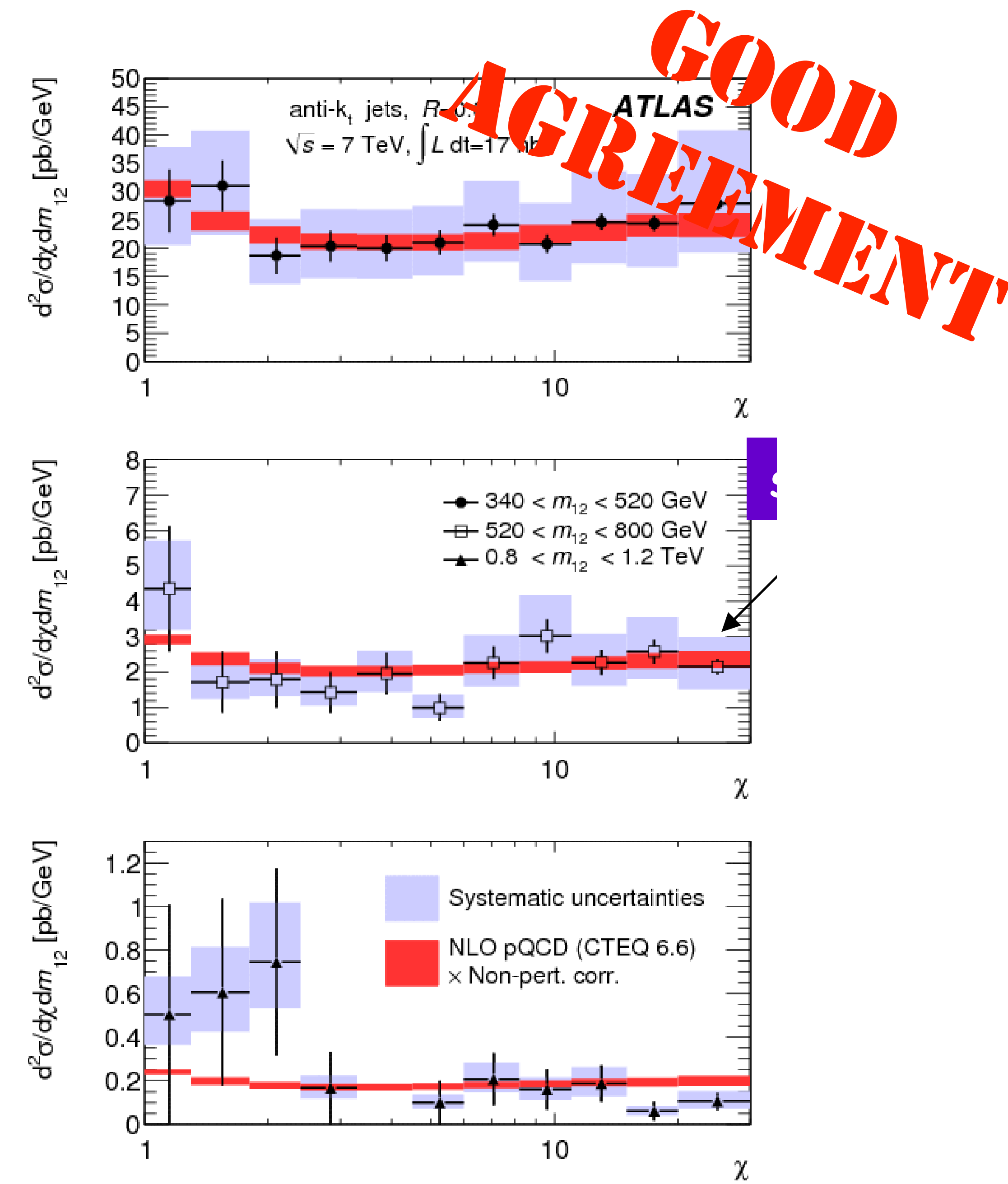
Dijet x-section

17/nb

arXiv:1009.5908



Di-jet cross-section vs mass



Di-jet cross-section vs angle

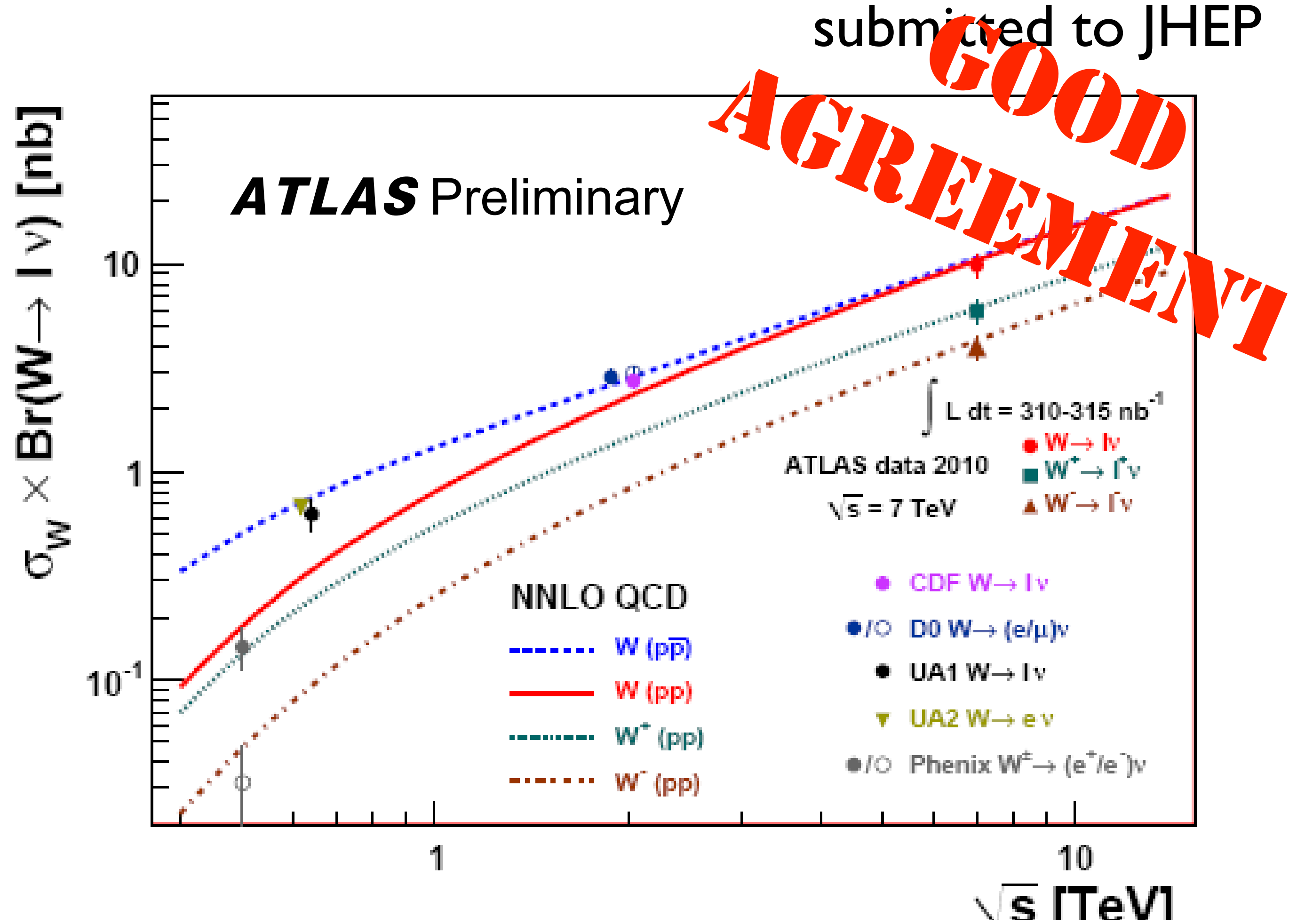
- Leading Jet p_T > 60 GeV, sub-leading > 30 GeV

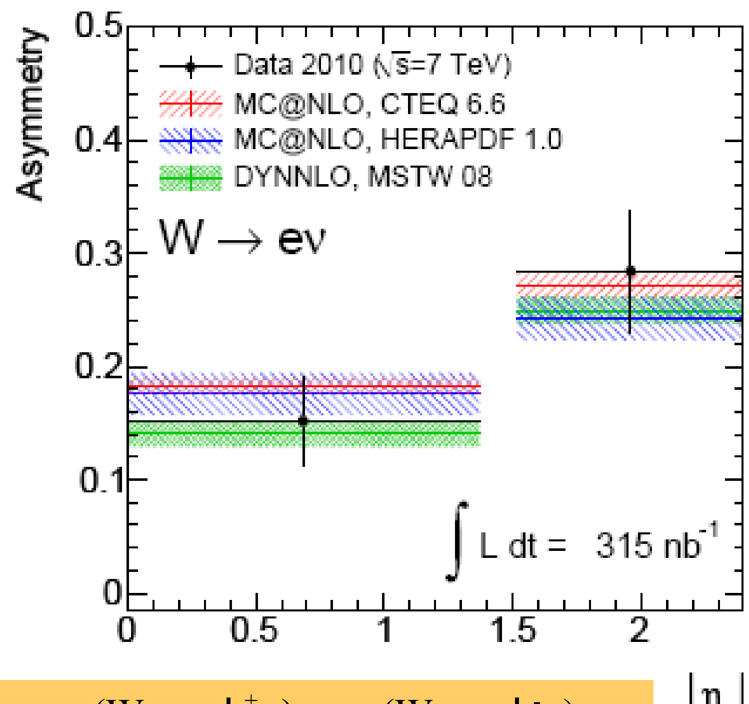
W x-section

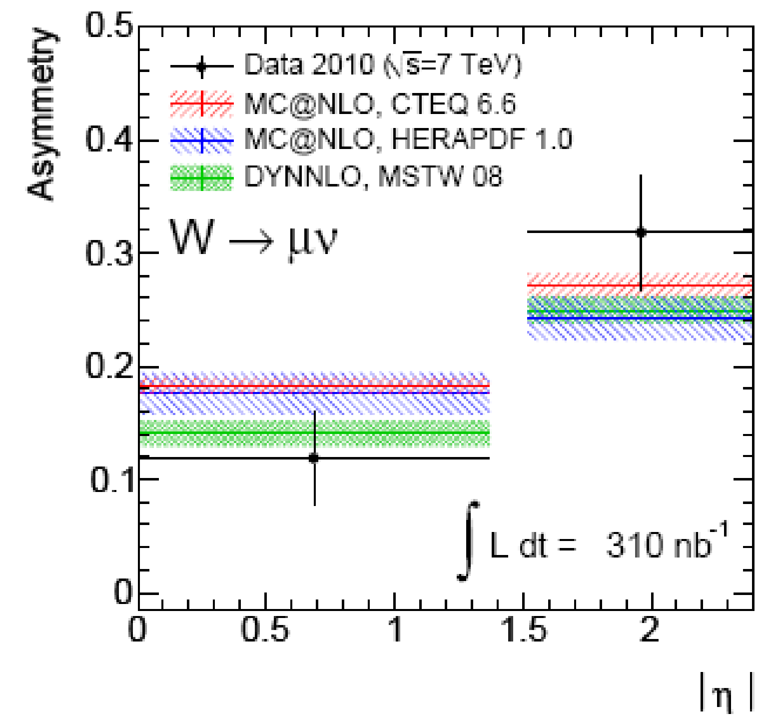
310/nb

arXiv: 1010.2130
submitted to JHEP

- *Measured at ~ 310/nb*
  - σ(W→lν)= 9.96±0.23(stat) ±0.50(syst) ±1.10(lumi) nb
  - σ(W→eν)= 10.51±0.34(stat) ±0.81(syst) ±1.16(lumi) nb
  - σ(W→μν)= 9.58±0.30(stat) ±0.50(syst) ±1.05(lumi) nb
  - A = 0.20 ± 0.02 (stat) ± 0.01 (syst)
- NNLO: σ(W→lν)= 10.46± 0.52 nb
- Soon to constrain PDFs
- Dominant experimental uncertainties:
  - e: identification efficiency
  - μ: trigger + reconstruction efficiency







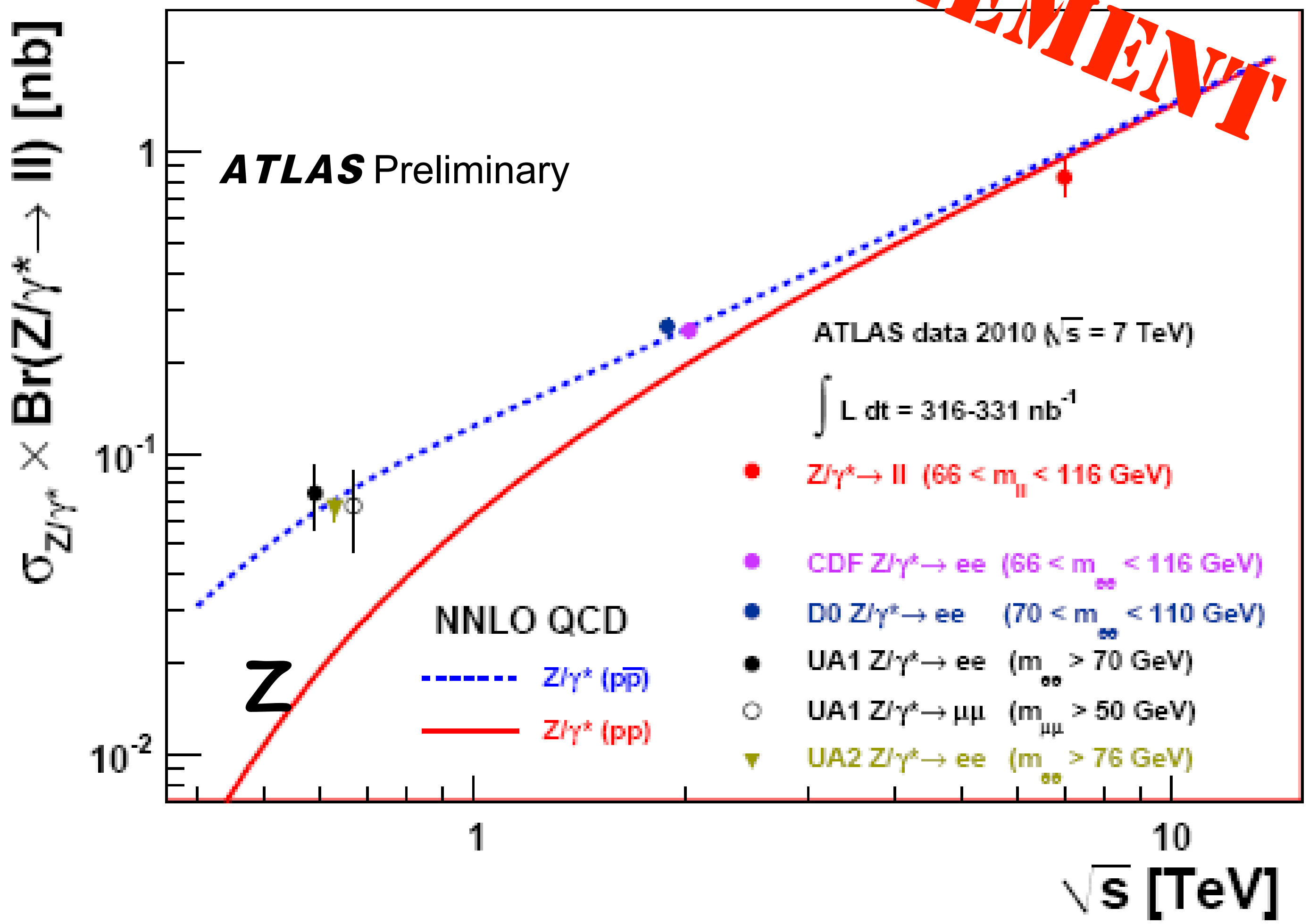
$$A = \frac{\sigma(W \to l^+\nu) - \sigma(W \to l^-\nu)}{\sigma(W \to l^+\nu) + \sigma(W \to l^-\nu)} \neq 0$$

Z x-section

315/nb
arXiv:1010.2130
submitted to JHEP

- Measured ~ 315/nb
  - $\sigma(Z \rightarrow ll)$ = 0.82 ± 0.06 (stat) ± 0.05 (syst) ± 0.09 (lumi) nb
  - $\sigma(Z \rightarrow ee)$ = 0.75 ±0.09(stat) ±0.08(syst) ±0.08(lumi) nb
  - $\sigma(Z \rightarrow \mu\mu)$ = 0.87 ±0.08 (stat) ±0.07(syst) ±0.10(lumi) nb
- NNLO: $(Z \rightarrow ll)$ = 0.96 ±0.05 nb per family for 66<M_{ll} <116GeV
- dominant experimental uncertainty: lepton reconstruction and identification
- Z+Jet x-section in progress.
  - $Z \rightarrow \mu\mu$ can be used to estimate $Z \rightarrow \nu\nu$ (though 6 times smaller)

GOOD AGREEMENT

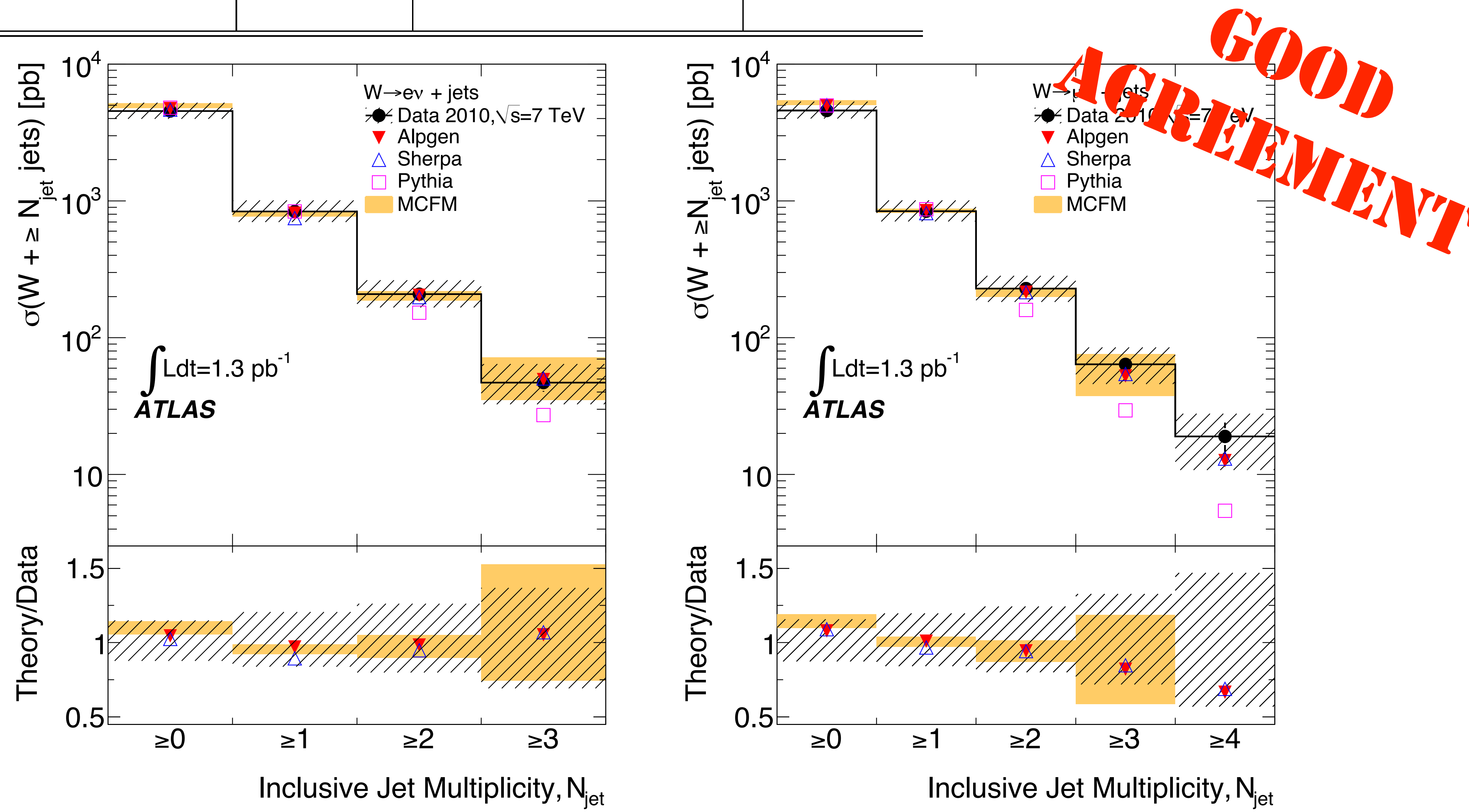


W+Jets x-section

1.3/pb
arXiv:1012.5382
submitted to Phys. Lett. B

Jet multiplicity	$W \to e\nu$ (nb)	MCFM $W \to e\nu$ (nb)	$W \to \mu\nu$ (nb)	MCFM $W \to \mu\nu$ (nb)
≥ 0	$4.53 \pm 0.07 \,^{+0.35}_{-0.30} \,^{+0.58}_{-0.47}$	$5.08^{+0.11}_{-0.30}$	$4.58 \pm 0.07 \,^{+0.38}_{-0.32} \,^{+0.61}_{-0.48}$	$5.27^{+0.11}_{-0.32}$
≥ 1	$0.84 \pm 0.03^{+0.13}_{-0.10} \,^{+0.11}_{-0.09}$	$0.81^{+0.02}_{-0.04}$	$0.84 \pm 0.03 \,^{+0.11}_{-0.09} \,^{+0.11}_{-0.09}$	$0.84^{+0.02}_{-0.04}$
≥ 2	$0.21 \pm 0.01 \,^{+0.04}_{-0.03} \,^{+0.03}_{-0.02}$	$0.21^{+0.01}_{-0.02}$	$0.23 \pm 0.02 \,^{+0.04}_{-0.03} \,^{+0.03}_{-0.02}$	$0.21^{+0.01}_{-0.02}$
≥ 3	$0.047 \pm 0.007^{+0.014}_{-0.011} \,^{+0.008}_{-0.006}$	0.05 ± 0.02	$0.064 \pm 0.008 \,^{+0.016}_{-0.014} \,^{+0.010}_{-0.008}$	0.05 ± 0.02
≥ 4	-	-	$0.019 \pm 0.005 \pm 0.006 \,^{+0.004}_{-0.003}$	-

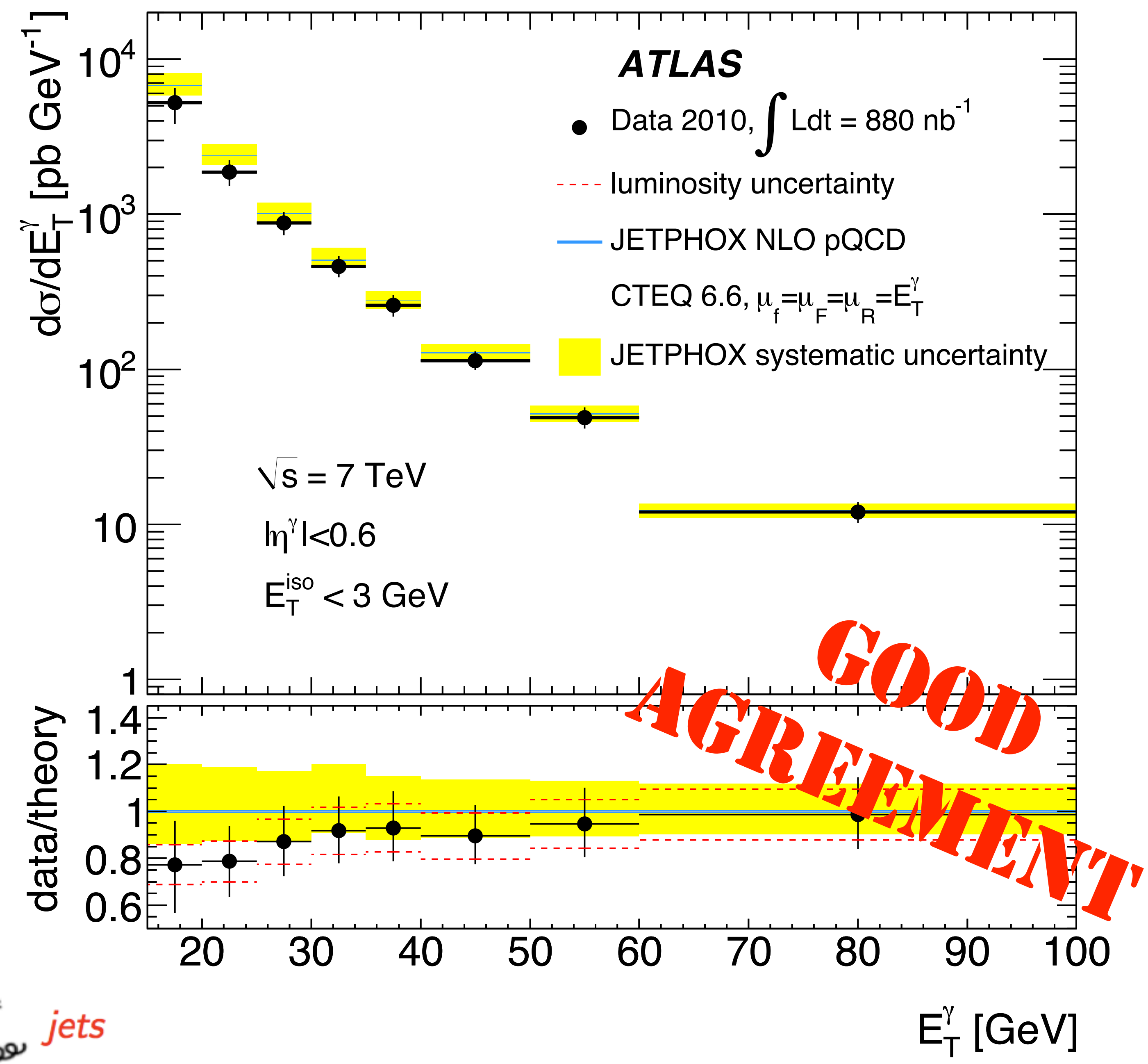
- Can also be used to estimate $Z \to \nu\nu$

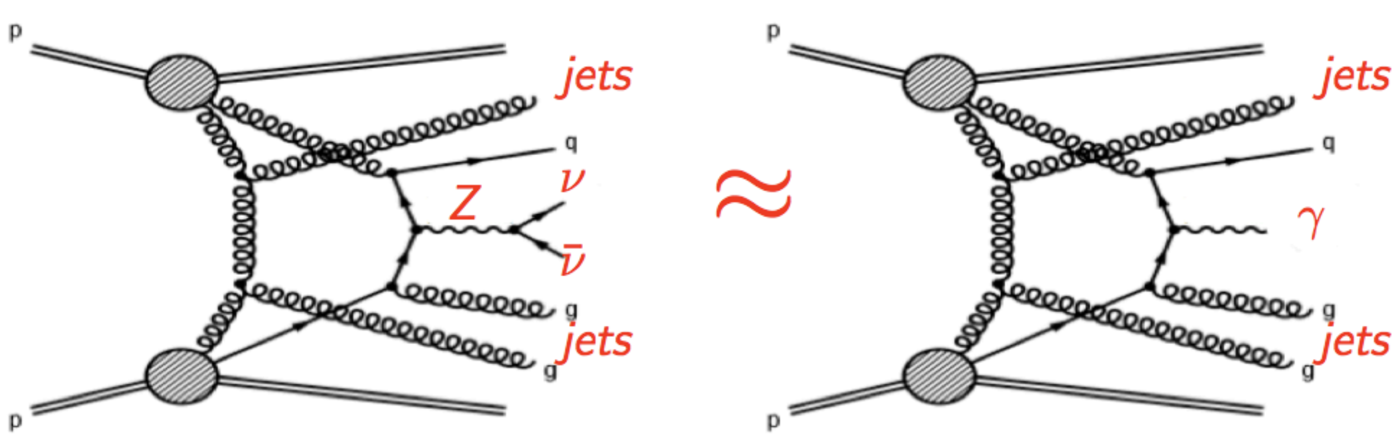


Inclusive Direct Photon

880/nb
arXiv:1012.4389
submitted to Phys. Rev. D

- Backgrounds to photon +MET
  - γ+Jet and diphoton x-sections are next
- But γ+Jet is also interesting because it allows estimating Z(→νν)+Jet.
  - Higher statistics than Z→ll or W.

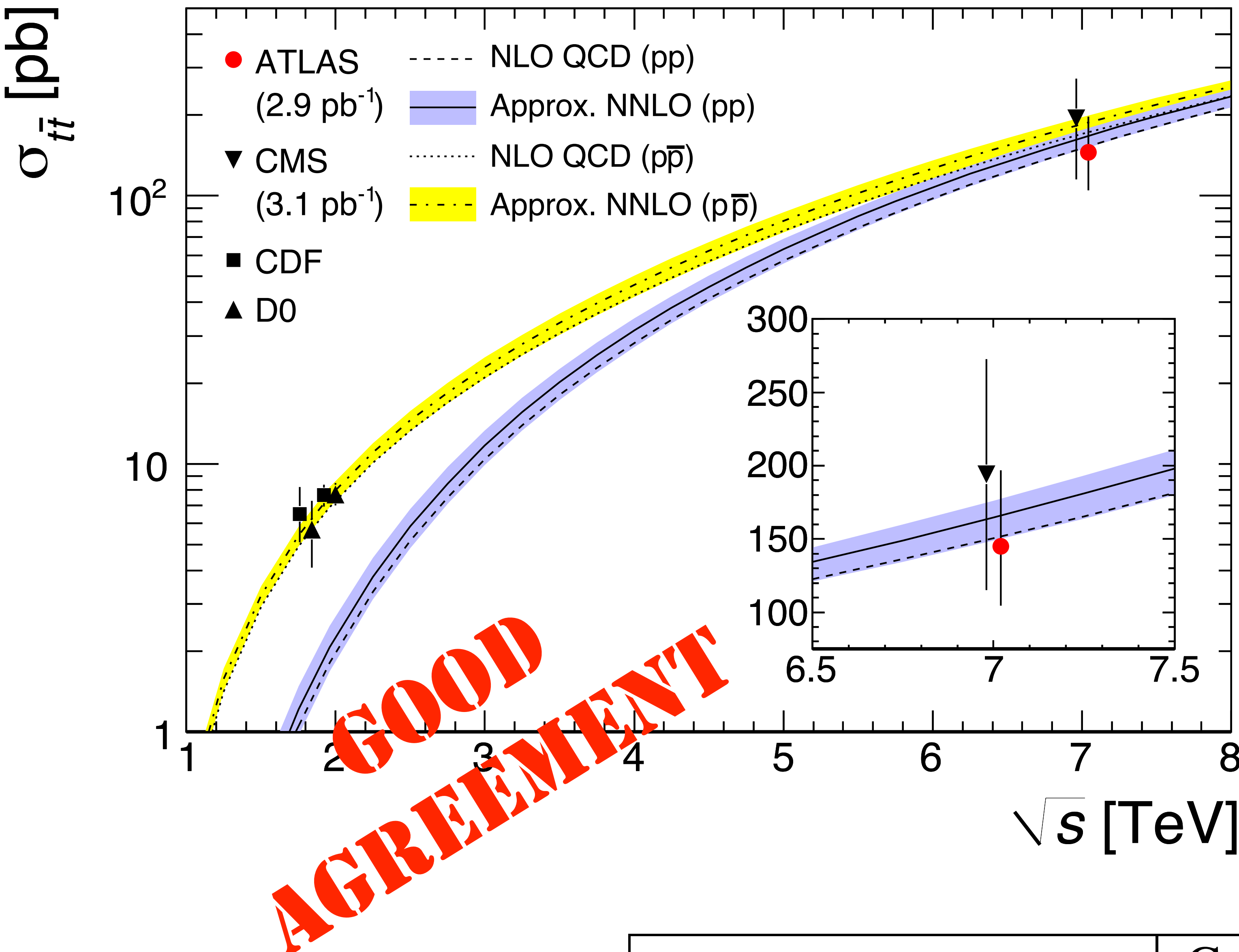




- The ratio $\frac{Z \to \nu\nu + jets}{\gamma + jets}$ stabilizes at high pT

Top

2.9/pb
arXiv:1012.1792
submitted to EPJC



- Measured in lepton +Jet and dilepton.

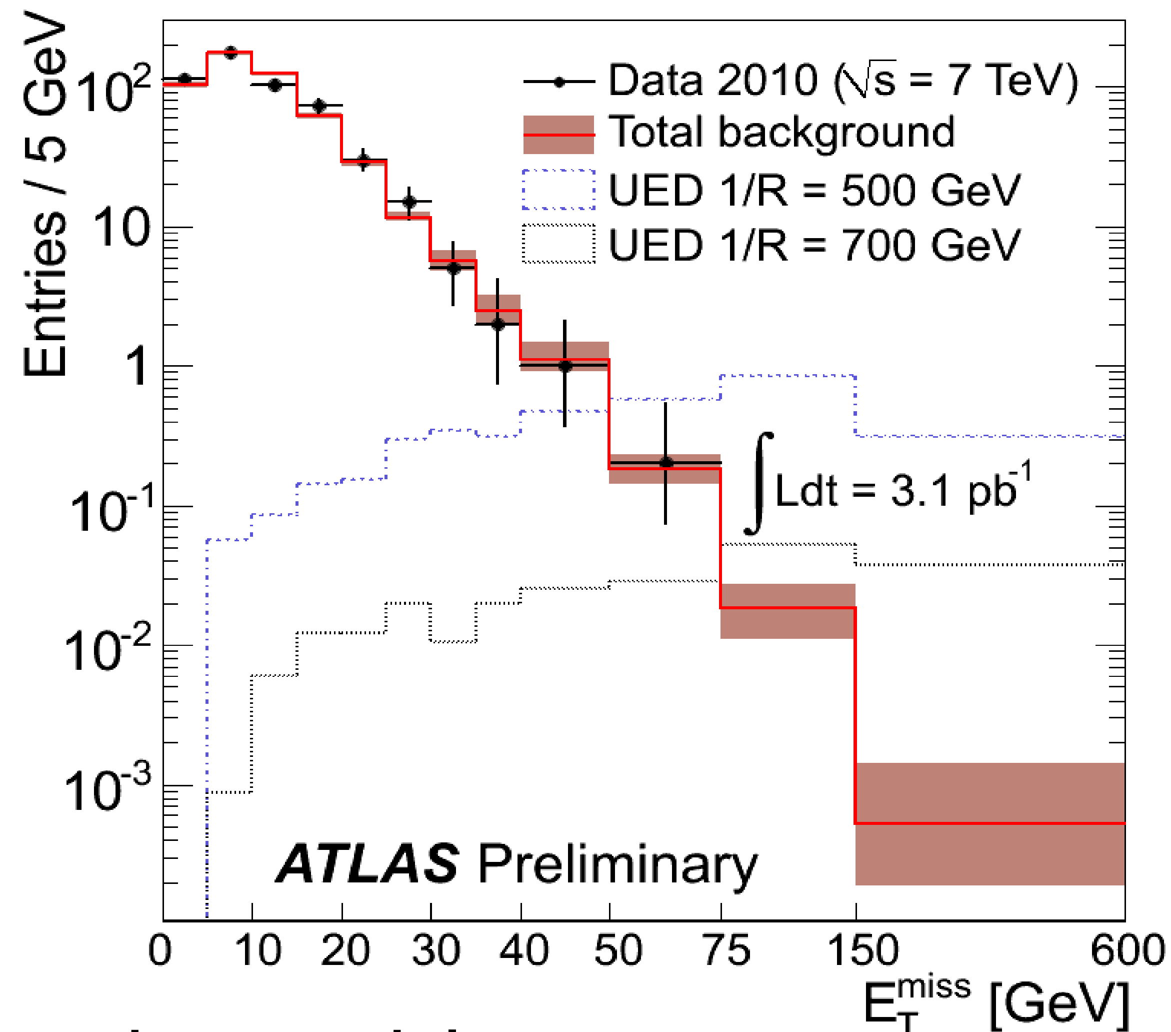
	Cross-section [pb]	Signal significance [σ]
Single lepton channels	$142 \pm 34\ ^{+50}_{-31}$	4.0
Dilepton channels	$151\ ^{+78}_{-62}\ ^{+37}_{-24}$	2.8
All channels	$145 \pm 31\ ^{+42}_{-27}$	4.8

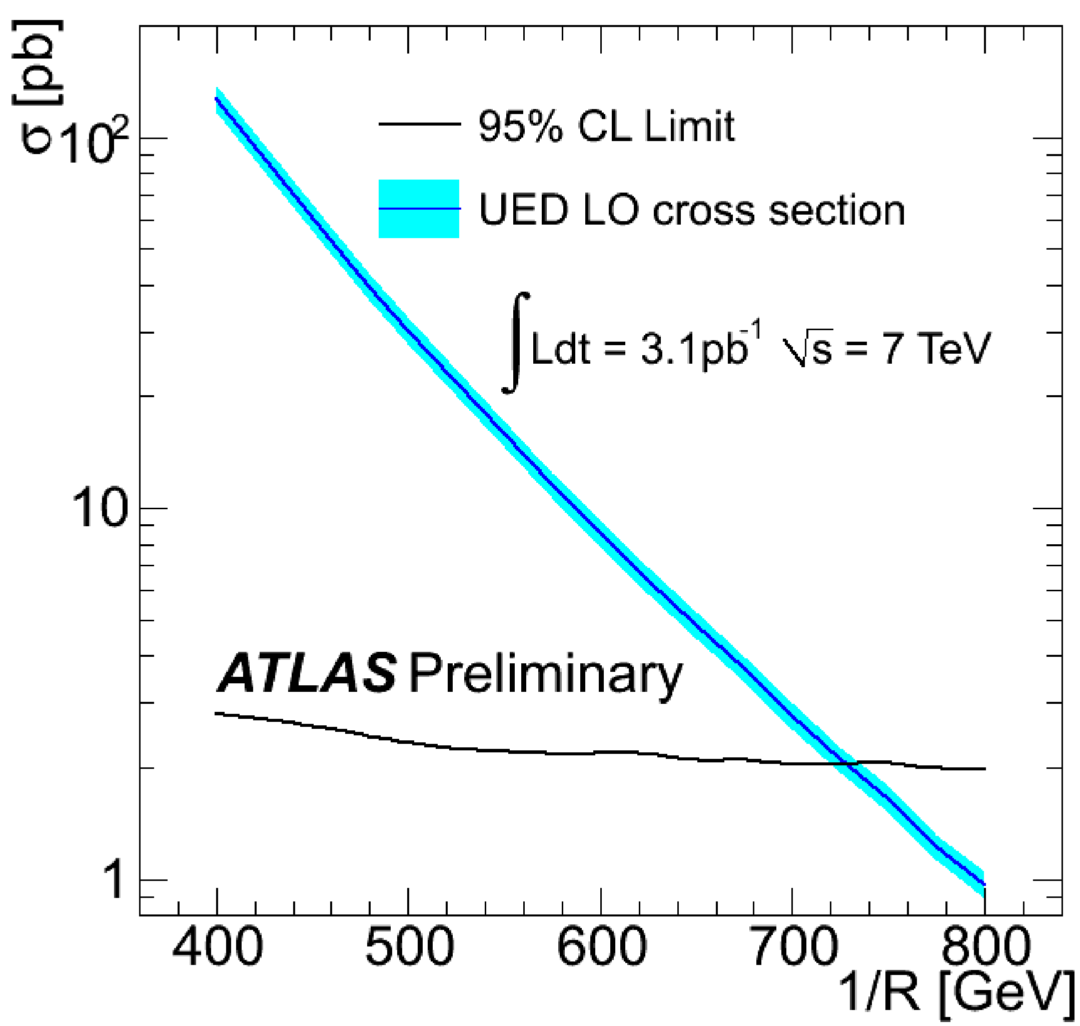
Diphoton+MET

3.1/pb

arXiv:1012.4272
Submitted to PRL

- Look for 2 photons w/ E_T>25 GeV and $E^{Had}{}_T/E_T$<0.2
- UED signal expected at MET>75
  - keep expected bkg to 1





- Fix other model parameters (ΛR=20,N=6,M_D=5 TeV)... put limit on 1/R > 728 GeV
  - D0 limit is at 477 GeV
- No GMSB limit calculated (not competitive with 3.1/pb)