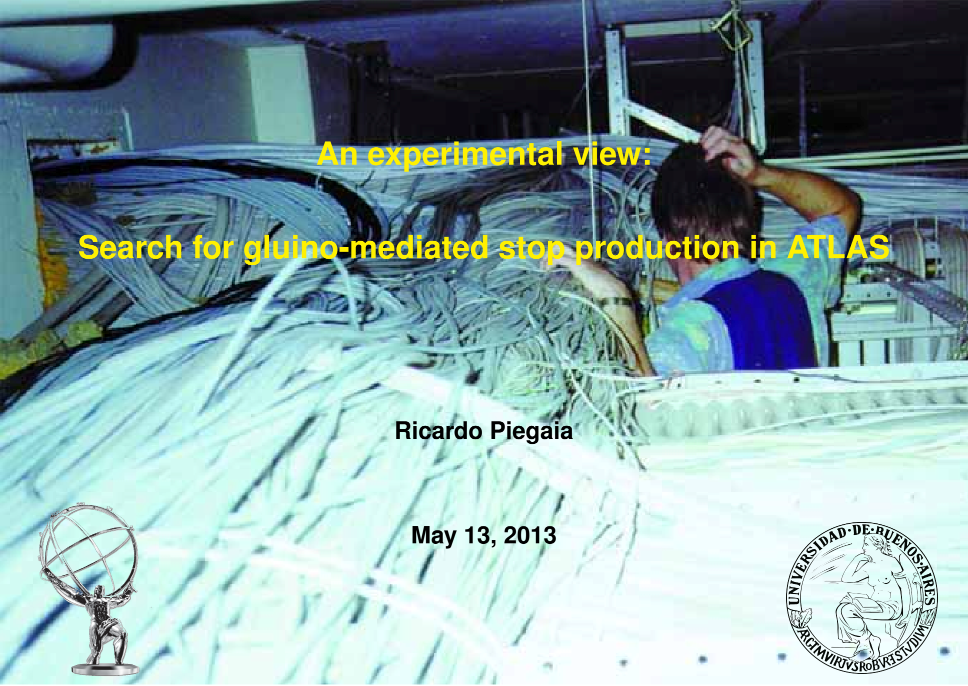


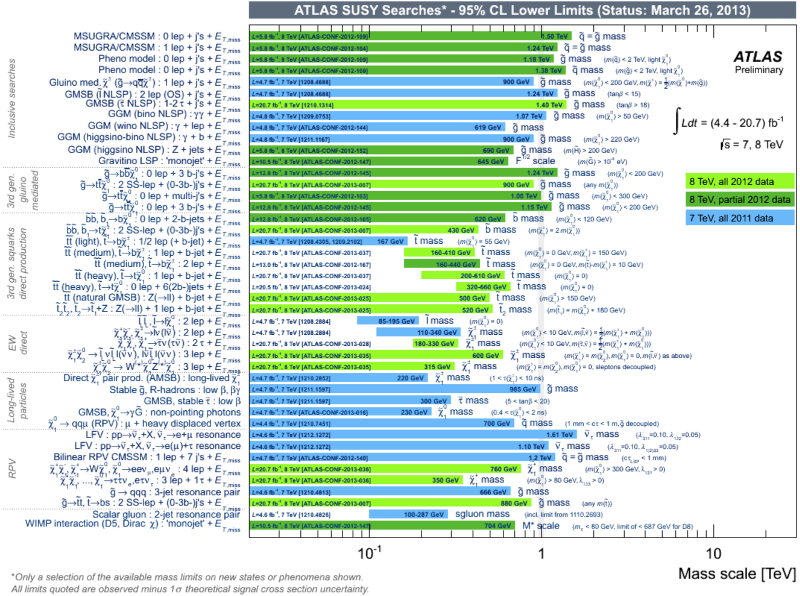
An experimental view:

Search for gluino-mediated stop production in ATLAS

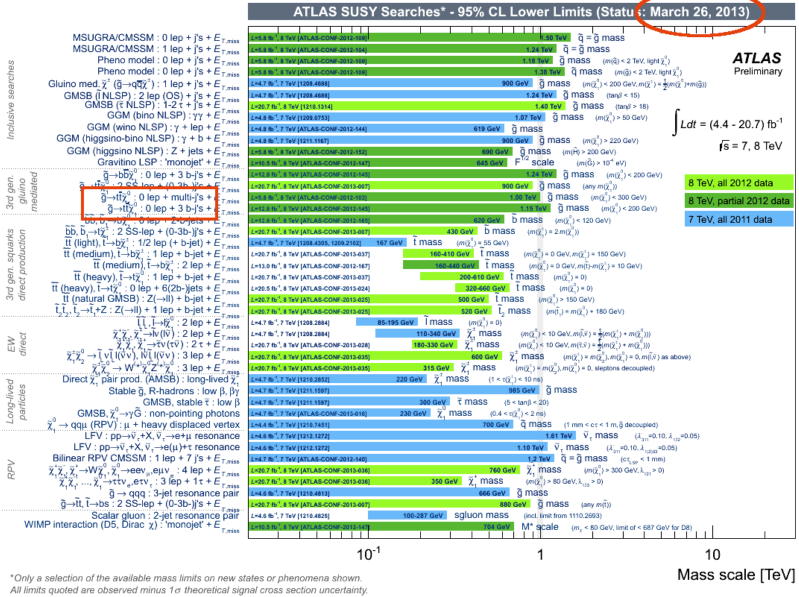
Ricardo Piegaia

May 13, 2013

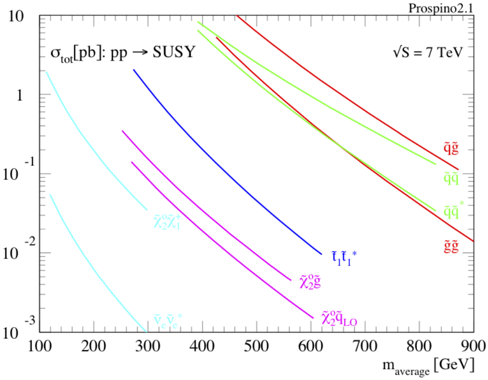
SUSY searches at ATLAS



SUSY searches at ATLAS



SUSY production at LHC



- Expect copious production of coloured SUSY particles
- If $m(\tilde{g}) \simeq 800$ GeV we should already have $\sim$1000 $\boldsymbol{p\,p \to \tilde{g}\,\tilde{g}}$ events
- "Natural" SUSY: 3rd generation squarks are lightest:

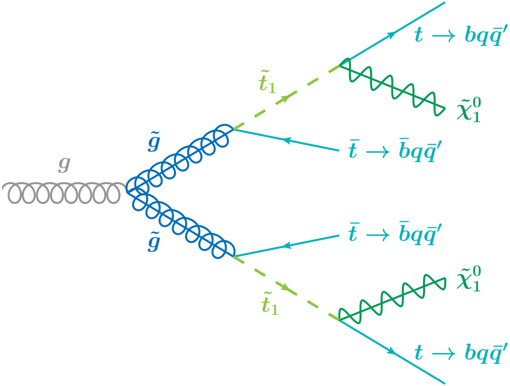
$$\text{masses of } \tilde{t}_1,\, \tilde{b}_1,\, \tilde{g} \lesssim 1 \text{ TeV}$$

Gluino-mediated stop production

- Search for $\boldsymbol{p\,p \rightarrow \tilde{g}\,\tilde{g}}$

  with $\boldsymbol{\tilde{g} \rightarrow \tilde{t}_1 \bar{t}}$ and $\boldsymbol{\tilde{t}_1 \rightarrow t\,\tilde{\chi}_1^0}$

  and hadronic tops: $\boldsymbol{t \rightarrow b\,q\,\bar{q}'}$.



- This means looking for a signature:

  $\boldsymbol{\tilde{\chi}_1^0}$: $E_{\mathrm{T}}^{\mathrm{miss}}$
  $\boldsymbol{q}$: 12 jets
  $\boldsymbol{b}$: 4 b-jets
  $\cancel{e}$: e veto
  $\cancel{\mu}$: μ veto

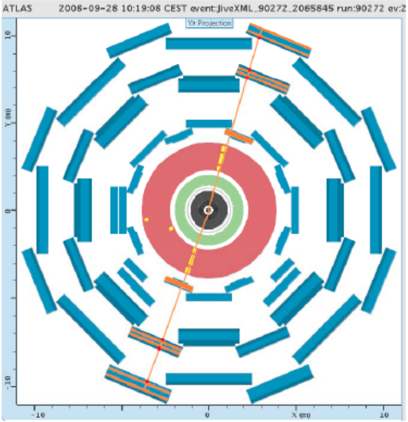
But there are no events with 12 jets, of which 4 are b-jets $\Rightarrow$ relax conditions:

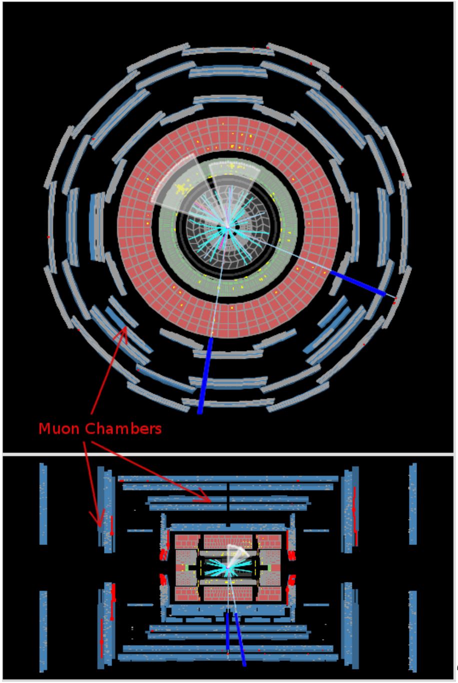
$\Rightarrow$ $E_{\mathrm{T}}^{\mathrm{miss}}$, at least 6 jets, 3 b-jets

$\Rightarrow$ $E_{\mathrm{T}}^{\mathrm{miss}}$, multijets (8, 9, 10+)

Identification of Muons

- They are the easiest.
  If at muon chambers: it's a muon
- Example 1: $H \to ZZ \to \mu\bar{\mu}\, b\bar{b}$ $\Rightarrow$
- Example 2: Cosmic muon $\Downarrow$



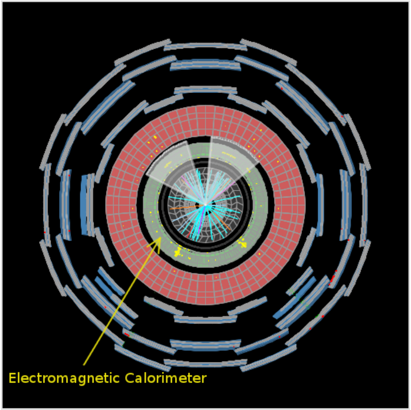


Identification of Electrons and Photons

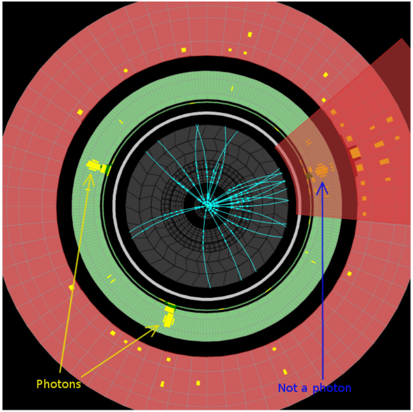
They leave a characteristic deposit at the Electromagnetic Calorimeter.

- If it has a track associated: an electron
- No track or 2 tracks associated: a photon

Example 1: $H \to ZZ \to e\bar{e}\,b\bar{b}$



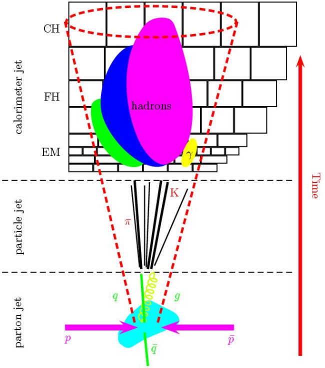
Example 2: $H \to \gamma\gamma + \text{jet}$

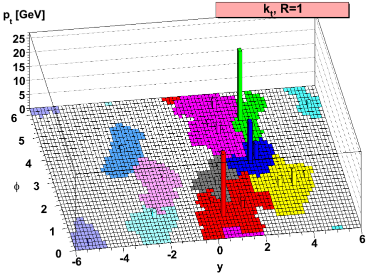


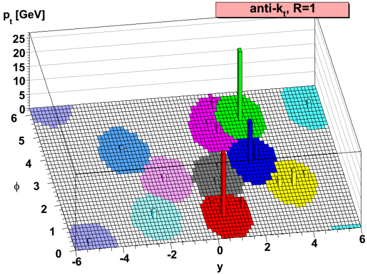
But jets also leave deposits at the Electromagnetic Calorimeter ...

Identification of Jets

- Collimated jets of hadrons are interpreted in terms of the fragmentation of quarks and gluons.
- Energy deposits in the electromagnetic and hadronic calorimeter are clustered using jet algorithms.
- The number and properties of the jets in an event depend on the algorithm used.

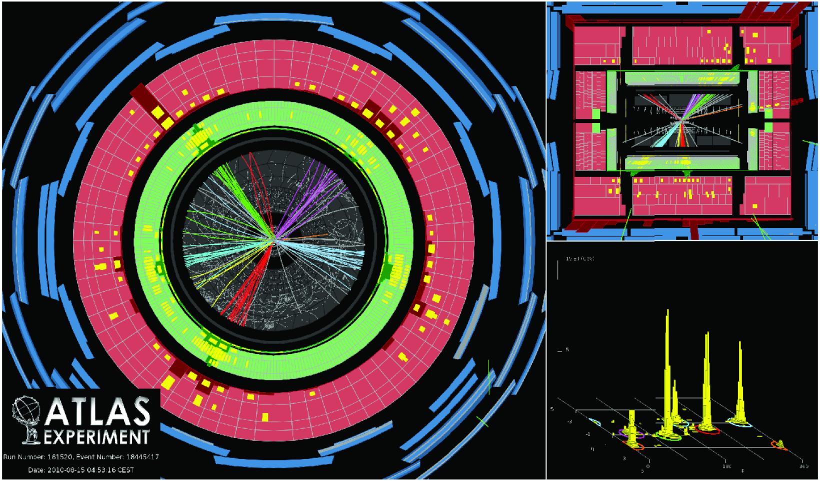






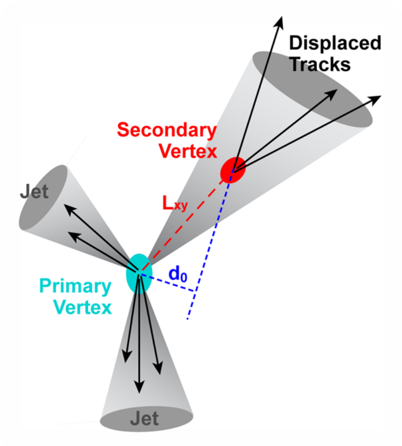
Identification of Jets

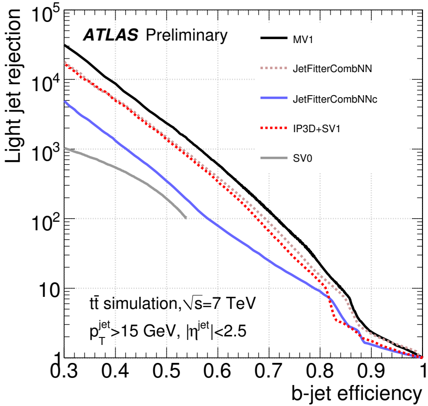
An example: a six-jet event



Identification of *b*-jets

- Exploits decay length of B hadrons: displaced tracks and secondary vertices.
- Combines information into a neural network.
- Three working points calibrated with data: 60%, 70% & 75% efficiency.





Non-interacting particles

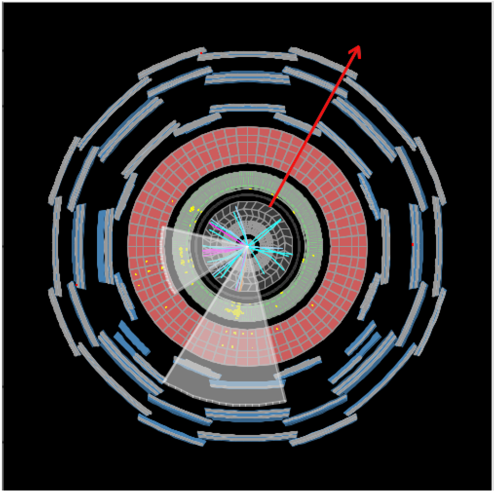
$Z\,H \rightarrow \nu\bar{\nu}\,b\bar{b}$ candidate

Presence of non-interacting particles

(neutrinos, neutralinos?) is inferred

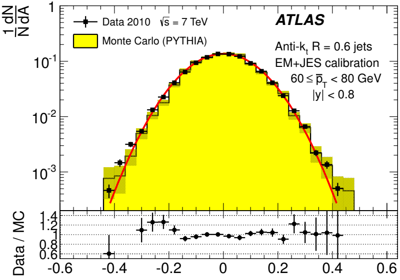
from momentum imbalance

in the transverse plane: $E_{\mathrm{T}}^{\mathrm{miss}}$

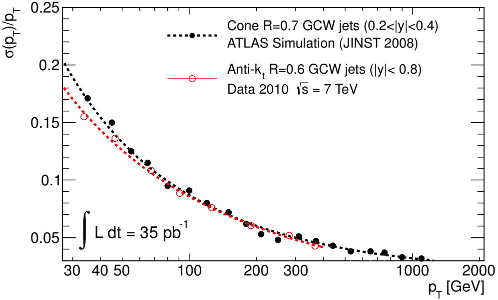


The jet energy resolution

- Jet energy resolution measured via p_T balance in dijet events
- Very good agreement with Monte Carlo predictions B.D.
- $\sigma(p_\mathrm{T}) \simeq \sqrt{p_\mathrm{T}} \quad \Longrightarrow \quad$ 3 $\times$ 300 GeV jets event can have $E_\mathrm{T}^\mathrm{miss} \simeq$ 100 GeV



$$A = \frac{p_{\mathbf{T},1} - p_{\mathbf{T},2}}{p_{\mathbf{T},1} + p_{\mathbf{T},2}}$$



Summary of the analysis

1 - *Identify signal-rich regions*

- Choose variables that discriminate SUSY signal from SM background
- Optimize cuts to maximize significance: $\mathcal{S} = \text{Signal}/\Delta B$

$$12 \text{ quarks } (4\ b) + 2\ \tilde{\chi}_1^0 \begin{cases} \Rightarrow & E_{\mathrm{T}}^{\mathrm{miss}}, \text{at least 6 jets, 3 } b\text{-jets} \\ \Rightarrow & E_{\mathrm{T}}^{\mathrm{miss}}, \text{multijets (8, 9, 10+)} \end{cases}$$

2 - *Background estimation*

- QCD, $t\bar{t}$, W+jets, $Z + b\bar{b}$, single top, Higgs... (data-driven and MC)

3 - *Systematic uncertainties (signal and background)*

- Detector: Energy calibration/resolution, *b*-tagging efficiency, pile-up
- Theoretical: MC generador, PDF, factorization/renormalization scales ...

4 - *"Open the box" (look at data in signal regions)*

- Significant excess of data wrt estimated background?

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4 - *"Open the box" (look at data in signal regions)*

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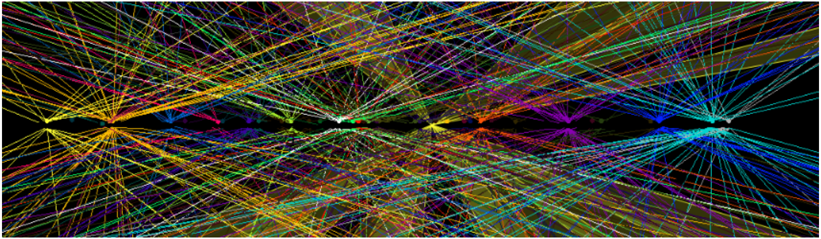
NOPE : set 95% CL limits

YEAP : buy ticket to Stockholm

Trigger selection

Every 50 nsec we get:



Rate needs to be reduced from 20 MHz to $\sim$600 Hz.

Triggers: sets of restricted conditions applied online to decide which are de $\sim$600 events to be stored per second to disk.

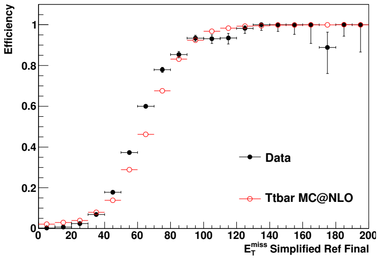
The trigger strongly restricts the optimization of the search

Trigger efficiency

j75_a4tc_xe75: 1 jet $p_{\mathrm{T}} > 75$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} > 75$ GeV

☹ Imposes a lower limit on $E_{\mathrm{T}}^{\mathrm{miss}}$ (150 GeV) and p_{T}^{1}

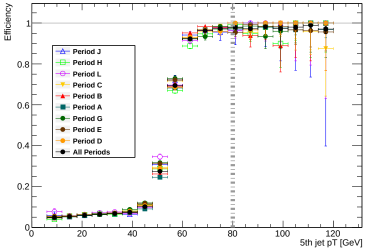
☺ Allows lowering the p_{T} of sub-leading jets



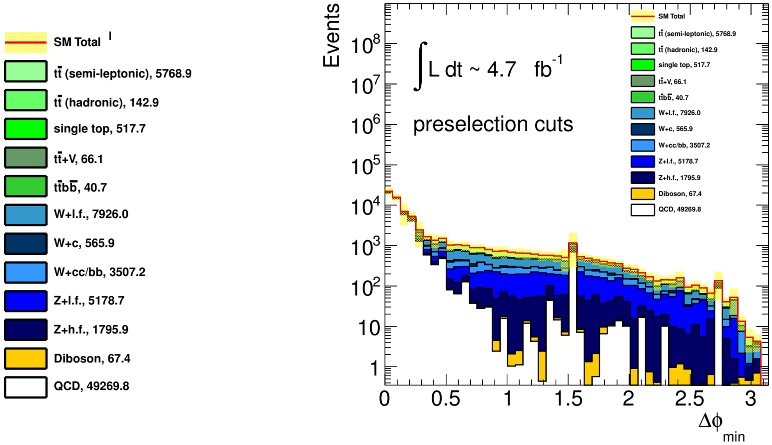
5j55_a4tc: 5 jets $p_{\mathrm{T}} > 55$ GeV

☹ Imposes lower limit on p_{T} of leading jets (70 GeV)

☺ Allows lowering the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the p_{T} of leading jet

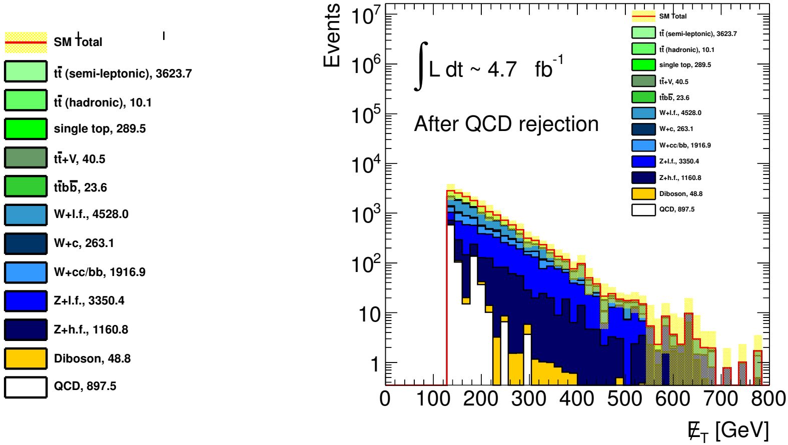


QCD background supression



- QCD: $E_{\mathrm{T}}^{\mathrm{miss}}$ comes from a mismeasured jet $\longrightarrow \phi(E_{\mathrm{T}}^{\mathrm{miss}}) \approx \phi(\mathrm{jet})$
- Define $\Delta\phi_{min}$: closest $\Delta\phi$ between $E_{\mathrm{T}}^{\mathrm{miss}}$ and a jet $\Rightarrow \Delta\phi_{min}^{QCD} \approx 0$
- SUSY, W/Z, $t\bar{t}$: genuine $E_{\mathrm{T}}^{\mathrm{miss}} \rightarrow$ uniform $\Delta\phi_{min}$
- $\Delta\phi_{min} > 0.4$ requirement selectively suppresses QCD

QCD background supression



- QCD: E_T^{miss} comes from a mismeasured jet $\longrightarrow \phi(E_T^{\text{miss}}) \approx \phi(\text{jet})$
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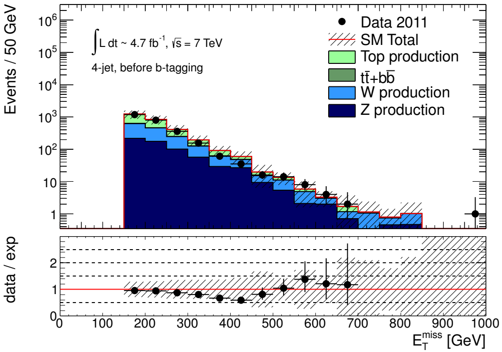
Other backgrounds

$t\bar{t}$+jets, W/Z+jets, $t\bar{t}+b\bar{b}$, $t\bar{t}+W/Z$, ...

- Require *b*-tagged jets to suppress SM bkgs with less *b*-quarks than signal (4 *b*s)
- Starting point: $\#$ *b*-jets $= 0$



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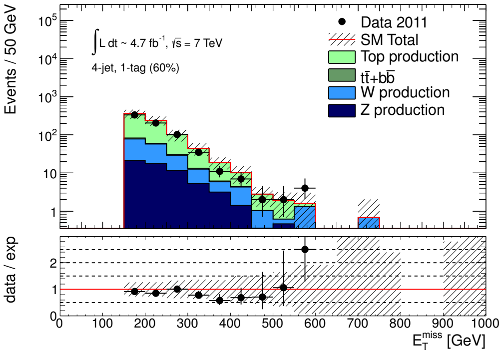

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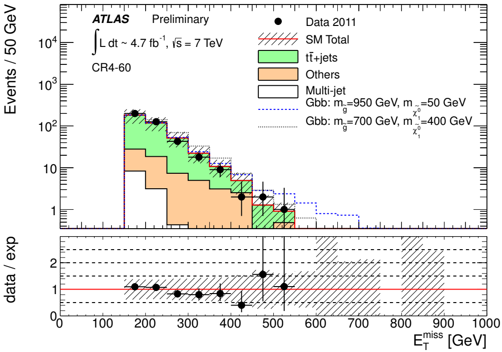
- $\#$ b-jets $= 1$: Reduces W/Z
- $\#$ b-jets $= 2$: Removes W/Z $\rightarrow$ Dominant bkg now $t\bar{t}$



Other backgrounds

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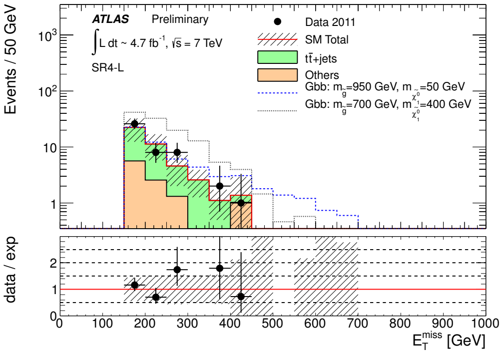
- $\#$ *b*-jets $= 1$: Reduces W/Z
- $\#$ *b*-jets $= 2$: Removes W/Z $\rightarrow$ Dominant bkg now $t\bar{t}$
- $\#$ *b*-jets ≥ 3: Suppresses $t\bar{t}$ $\rightarrow$ Signal now visible! ☺



Other backgrounds

$t\bar{t}$+jets, W/Z+jets, $t\bar{t}+b\bar{b}$, $t\bar{t}+W/Z$, ...

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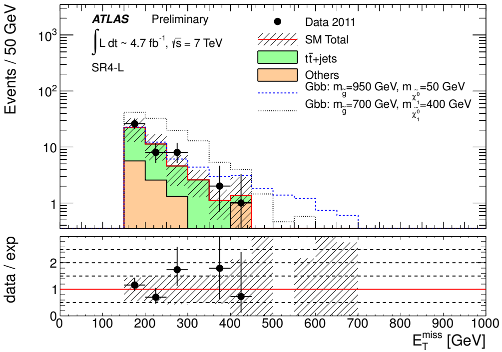
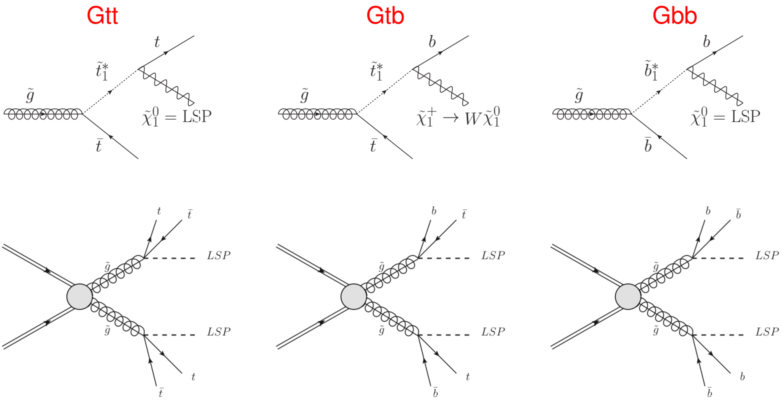


Data is consistent with $t\bar{t}$ prediction but not with these SUSY models ☹

Several $pp \to \tilde{g}\tilde{g}$ simplified models: Gtt, Gtb, Gbb (virtual or real $\tilde{t}, \tilde{b}$)



Topology	Process	Final state	# b-quarks	# other q
Gtt	$\tilde{g} \to t\bar{t} + \tilde{\chi}_1^0$	$t\bar{t}\, t\bar{t} + E_{\mathrm{T}}^{\mathrm{miss}}$	4	8
Gtb	$\tilde{g} \to \bar{t}b + \tilde{\chi}_1^+,\ \tilde{\chi}_1^+ \to W\,\tilde{\chi}_1^0$	$t\bar{t}\, b\bar{b} + E_{\mathrm{T}}^{\mathrm{miss}}$	4	4
Gbb	$\tilde{g} \to b\bar{b} + \tilde{\chi}_1^0$	$b\bar{b}b\bar{b} + E_{\mathrm{T}}^{\mathrm{miss}}$	4	-

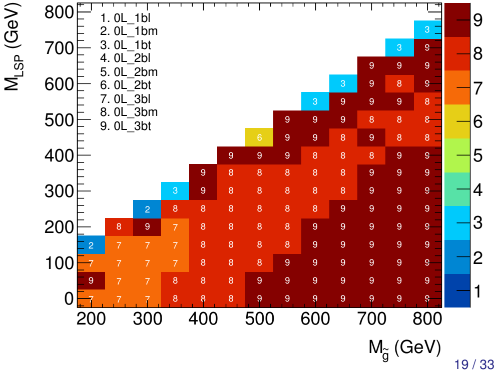
All three topologies give 4 b-jets, $E_{\mathrm{T}}^{\mathrm{miss}}$, and possible jets

An example: Optimization for Gbb topologies

Common selections to all Signal Regions

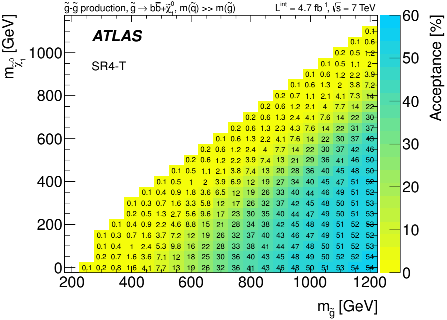
- p_{T} leading jet > 130 GeV (trigger)
- $E_{\mathrm{T}}^{\mathrm{miss}} > 160$ GeV (trigger)
- $\Delta\phi_{min} > 0.4$ (QCD)
- $E_{\mathrm{T}}^{\mathrm{miss}}/\mathrm{m}_{\mathrm{eff}} > 0.2$ (QCD)
- ≥ 3 b-jets with $p_{\mathrm{T}} > 30$ GeV
- At least 4 jets, $p_{\mathrm{T}} > 50$ GeV

SIGNAL REGIONS
1-6: Signal regions with at least 1 or 2 b-jets
7: ≥ 3 b-tag (60% WP), $\mathrm{m}_{\mathrm{eff}} > 500$ GeV
8: ≥ 3 b-tag (60% WP), $\mathrm{m}_{\mathrm{eff}} > 700$ GeV
9: ≥ 3 b-tag (70% WP), $\mathrm{m}_{\mathrm{eff}} > 900$ GeV



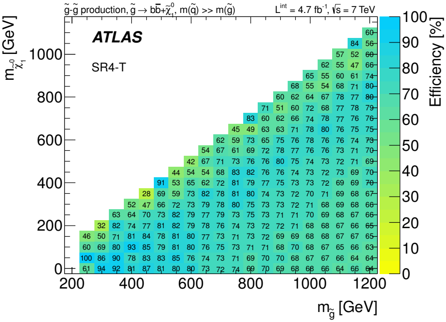
An example: Gbb acceptance and efficiency

Acceptance



Decreases as $m_{\tilde{\chi}_1^0} \rightarrow m_{\tilde{g}}$
(not enough phase space for jets)

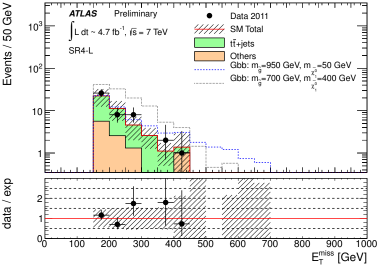
Efficiency

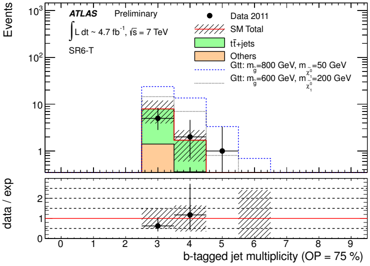


All in the 50-80% range

Experimental results: Model independent exclusion limits

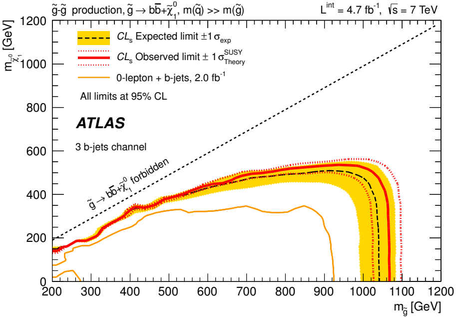
			Observed (expected) 95% CL upper limit	
SR	SM prediction	data	$N_{\mathrm{non-SM}}$	σ_{vis}(fb)
SR4-L	44.4 ± 10.0	45	23.8 (23.4)	5.1 (5.0)
SR4-M	23.0 ± 5.4	14	8.6 (12.8)	1.8 (2.7)
SR4-T	13.3 ± 2.6	10	7.1 (9.2)	1.5 (2.0)
SR6-L	12.7 ± 3.6	12	9.6 (10.1)	2.0 (2.1)
SR6-T	9.9 ± 2.6	8	7.1 (8.3)	1.5 (1.8)



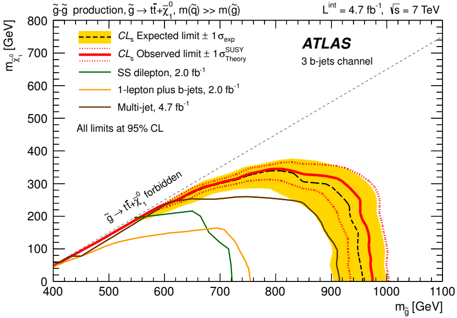


Model dependent exclusion limits: Gbb and Gtt (virtual squark)

Gbb



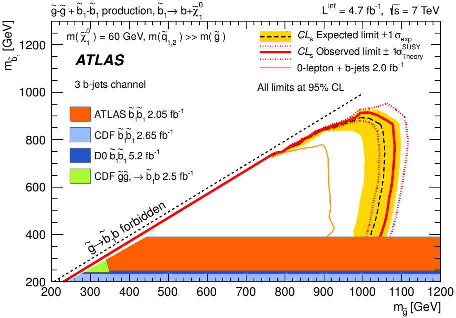
Gtt



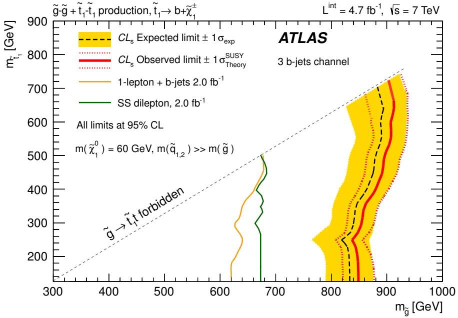
- Solid red line: observed 95% CL limit
- Dotted red line: $\pm 1\sigma_{\text{exp}}$ uncertainty
- Solid black line: exp. 95% CL limit
- Yellow band: $\pm 1\sigma^{\text{SUSY}}_{\text{Theory}}$ uncertainty

Model dependent exclusion limits: Gbb and Gtt (real squark)

Gbb $(m_{\tilde{b}_1} < m_{\tilde{g}})$



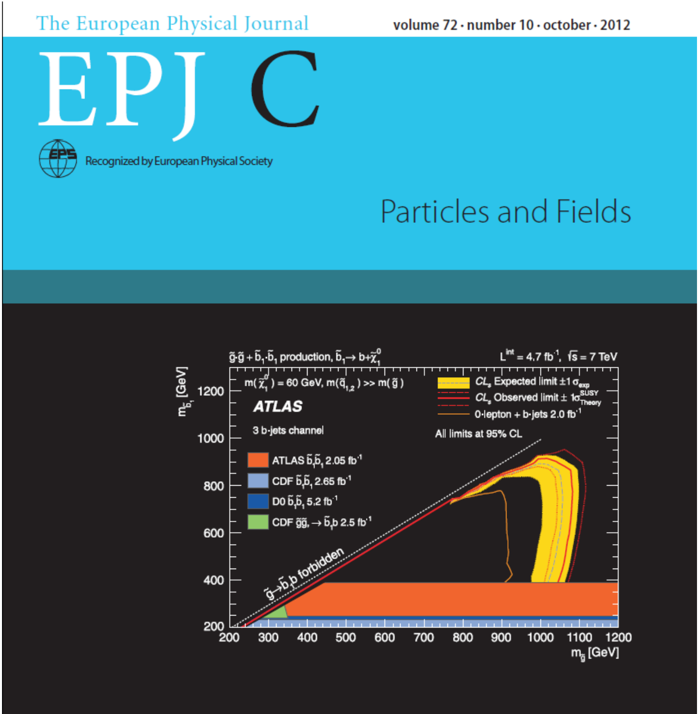
Gtt $(m_{\tilde{t}_1} < m_{\tilde{g}})$



- Sbottom produced via $\tilde{g} \to \tilde{b}_1 b$
- $\tilde{b}_1$ assumed the lightest squark
- Results presented in $m_{\tilde{g}}, m_{\tilde{b}_1}$ plane

- Stop produced via $\tilde{g} \to \tilde{t}_1 t$
- $\tilde{t}_1$ assumed the lightest squark
- Results presented in $m_{\tilde{g}}, m_{\tilde{t}_1}$ plane

($m_{\tilde{\chi}_1^0}$ fixed at 60 GeV)

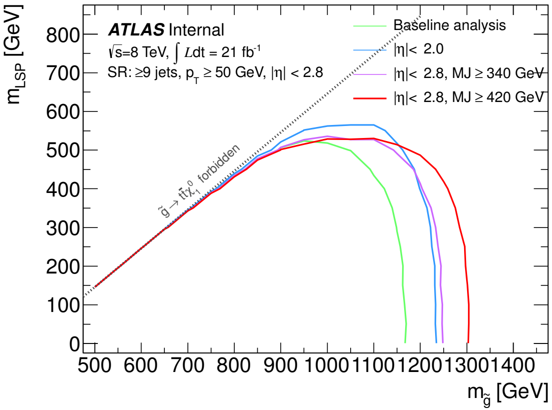

The European Physical Journal
volume 72 · number 10 · october · 2012
EPJ C
Recognized by European Physical Society
Particles and Fields
ATLAS
3 b-jets channel
All limits at 95% CL
ATLAS b̃₁b̃₁ 2.05 fb⁻¹
CDF b̃₁b̃₁ 2.65 fb⁻¹
D0 b̃₁b̃₁ 5.2 fb⁻¹
0-lepton + b-jets 2.0 fb⁻¹
L^int = 4.7 fb⁻¹, √s = 7 TeV
m(χ̃₁⁰) = 60 GeV, m(q̃₁,₂) >> m(g̃)
m_b̃₁ [GeV]
m_g̃ [GeV]

The Multijet Approach

Example of optimization procedure for a search with $\geq$9 jets with $p_{\mathrm{T}} > 50$ GeV.

Significance increases when requiring:

- more central jets: t-channel $t\bar{t}$ and QCD jets are more forward than s-channel $pp \to \tilde{g}\tilde{g}$.
- more massive jets ($M_{\mathrm{J}}^{\Sigma} = \sum m_{jet}^{R=1.0}$): $m_{jet}^{R=1.0} \simeq 170$ GeV if fat jet comes from top.



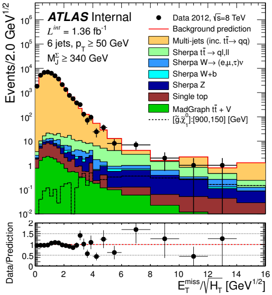
The Multijet Approach

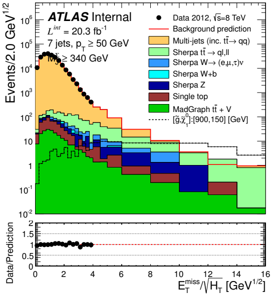
Significance increases

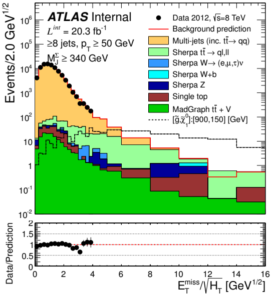
with number of jets.

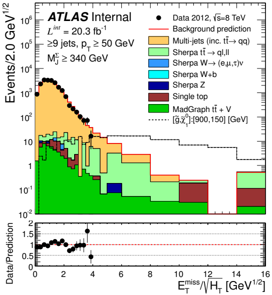
Region $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 4$

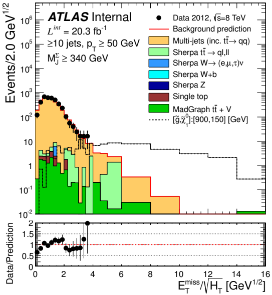
not unblinded yet.







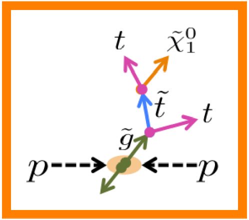


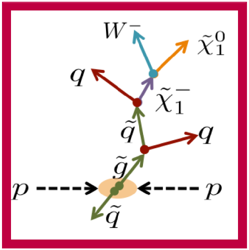


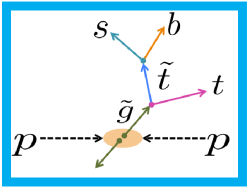
The Multijet Approach: Interpretations

To be applied to several models.

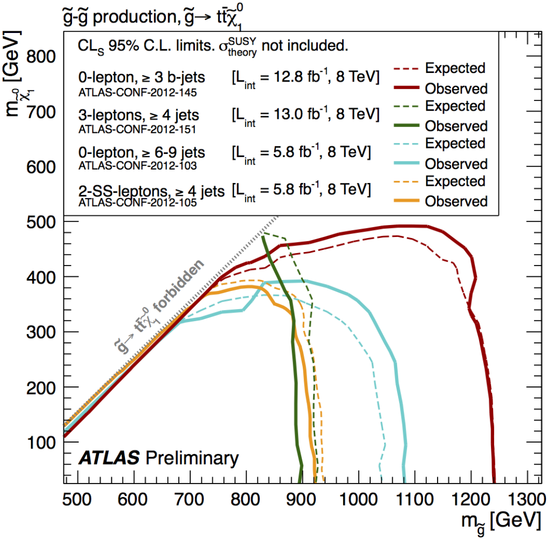
- **R-parity conserving**
  - **Gtt** (off-shell stop) & **Gtt-On-Shell** (on-shell stop)
  - **One-step** simplified model: $\tilde{g} \to q\,\bar{q}\,\tilde{\chi}^{\pm},\ \ \tilde{\chi}^{\pm} \to W^{\pm}\,\tilde{\chi}_1^0$
    - $m_{\tilde{\chi}^{\pm}} = (m_{\tilde{g}} + m_{\tilde{\chi}_1^0})/2$
    - $m_{\tilde{\chi}_1^0} = 60$ GeV
  - **mSUGRA**
- **R-parity violating models**
  - **RPV-UDD**: $\tilde{g} \to \tilde{t} + \bar{t},\ \ \tilde{t} \to s + b$





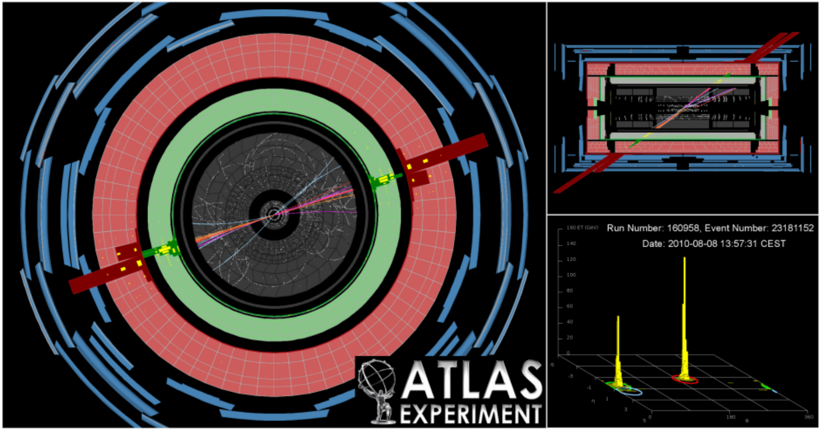


Summary of gluino-mediated stop production searches in ATLAS - 2012

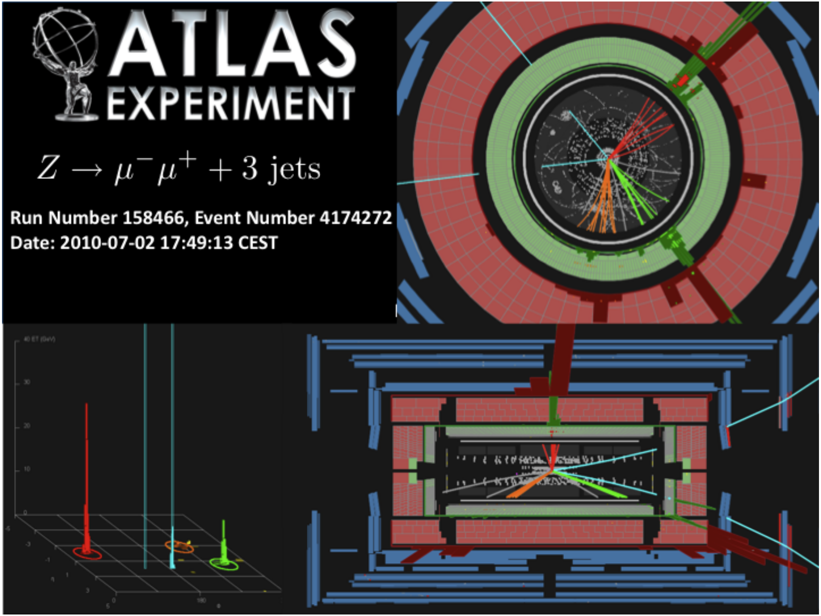


THANK YOU

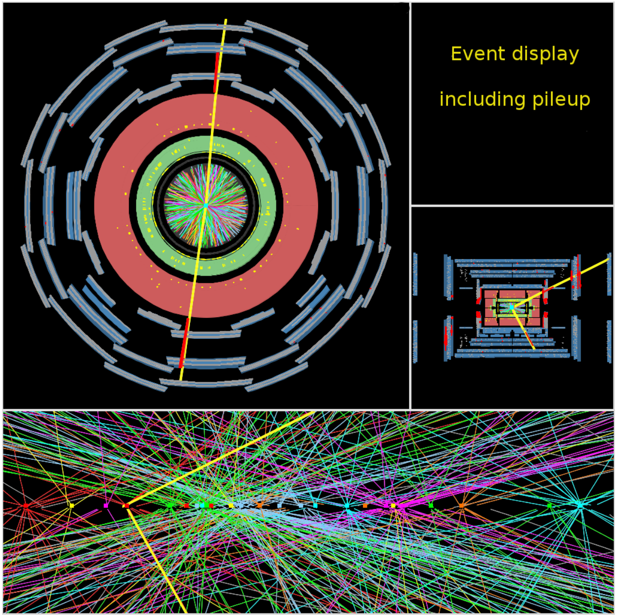
2-jet event


ATLAS
EXPERIMENT
Run Number: 160958, Event Number: 23181152
Date: 2010-08-08 13:57:31 CEST

$Z \to \mu\bar{\mu}$ + 3 jets



A $Z \to \mu\bar{\mu}$ event but without removing pileup tracks



Object Selection Details

Muones: ID+MS

Selección (Medium++):

- $p_{\mathrm{T}} > 20$ GeV y $|\eta| < 2.4$

Señal (Tight++): $p_{\mathrm{T}} > 25$ GeV

- $\sum_{track}^{\Delta R<0.2} p_{\mathrm{T}}(track) < 1.8$ GeV

Electrones: ID+EM

Selección (Medium++):

- $E_{\mathrm{T}} > 20$ GeV y $|\eta| < 2.47$

Señal (Tight++): $E_{\mathrm{T}} > 25$ GeV

- $\sum_{track}^{\Delta R<0.2} p_{\mathrm{T}}(track) < 0.1 \times p_{\mathrm{T}}^{e}$

Jets: EM + HAD

- Algoritmo: anti-k_t con R = 0.4
- Inputs: clusters topológicos
- Calibración: EM+JES
- $p_{\mathrm{T}} > 20$ GeV y $|\eta| < 2.8$

Eliminación de objetos coincidentes

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

1. $\Delta R(j, e) < 0.2 \rightarrow$ electron
2. $0.2 < \Delta R(j, e) < 0.4 \rightarrow$ jet
3. $\Delta R(j, \mu) < 0.4 \rightarrow$ jet

Energía transversa faltante ($E_{\mathrm{T}}^{\mathrm{miss}}$)

Suma vectorial de:

- Jets ($p_{\mathrm{T}} > 20$ GeV y $|\eta| < 4.5$)
- Leptones
- Clusters calorimétricos $\notin$ jets

b-jets: ID+EM+HAD

- Algoritmo MV1 (NN)
- 3 puntos de operación (OP): eficiencia 60%, 70% y 75% ($t\bar{t}$)
- $p_{\mathrm{T}} > 30$ GeV y $|\eta| < 2.5$