# Top Event Search with the early data in ATLAS


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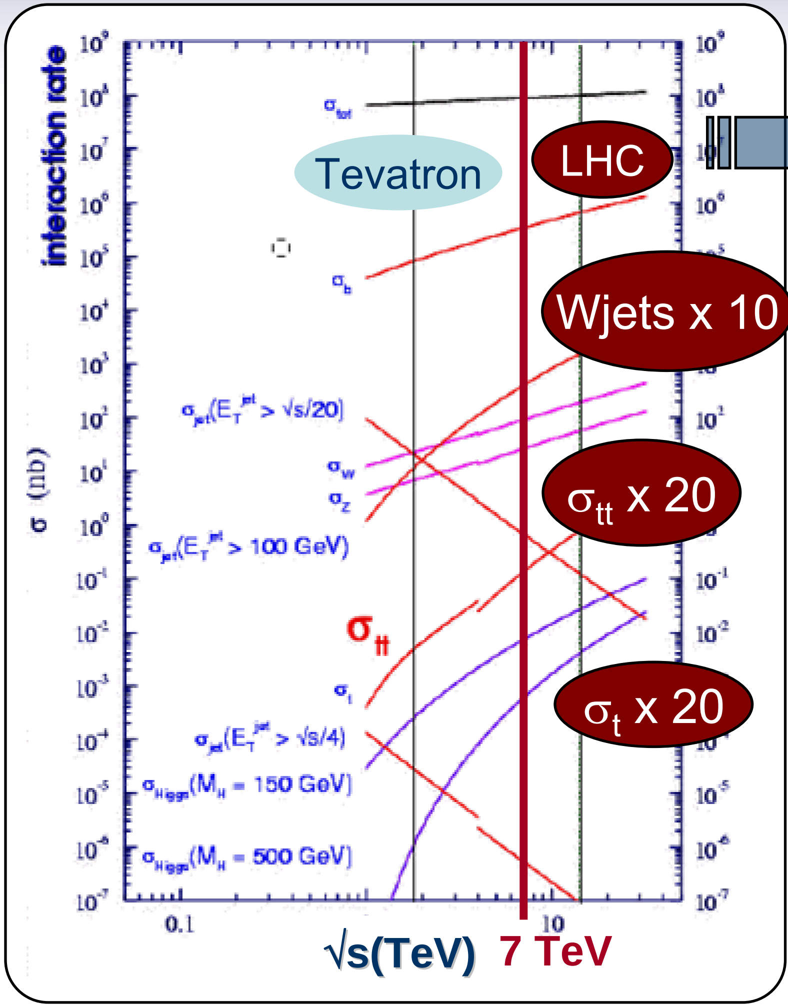
1. Context & Top quark search strategy with the early data
2. Towards the reconstruction of top quark decays
3. First Top event candidates

# Top Physics with the early LHC data …




**Expectations with 280 $nb^{-1}$**

Assuming 100% efficiency, we expect

Lepton+jets:

*~14 in l+jets with l=e,$\mu$*

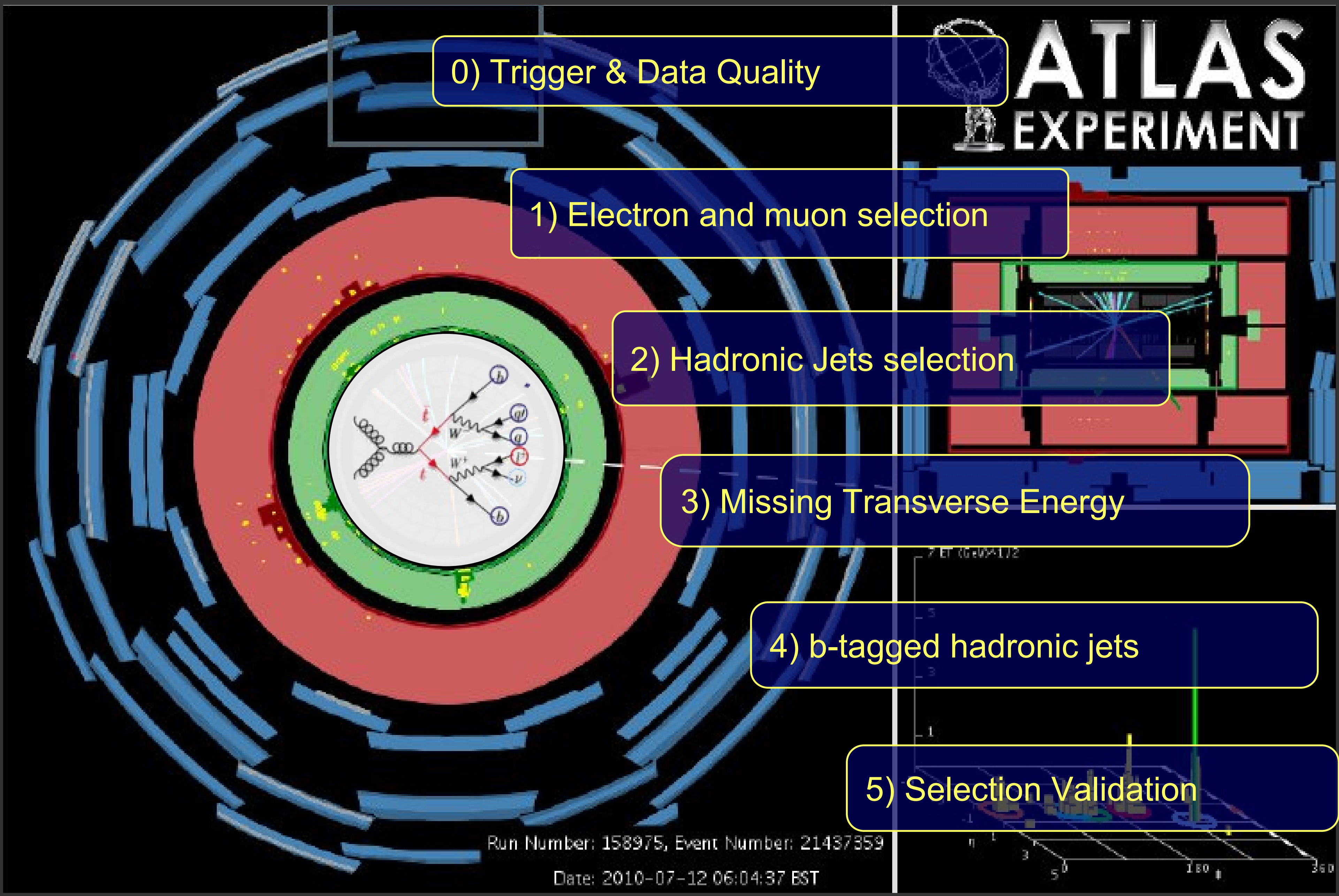
Di-lepton :

*~2 events in (ee,$\mu\mu$,e$\mu$)*

**Strategy with the early data…**

- Validate/Calibrate Object reconstruction
  - Quality, Trigger, Reconstruction, Calibration
  - Validate MonteCarlo descriptions
- Understand QCD & W/Z+jets background
  - Determine/Monitor multi-jet events
  - Measure W+(HF)jets background
  - Data Driven vs Simulation
- Select final state for top candidates
  - Define/ validate loose selections
  - Constitute control sample for bkgd and signal
  - Optimize selection for specific measurements

# Strategy for top quark search…




0) Trigger & Data Quality

1) Electron and muon selection

2) Hadronic Jets selection

3) Missing Transverse Energy

4) b-tagged hadronic jets

5) Selection Validation

# 1a) Electron

See S. Snyder's talk

## Electron Sources

W/Z boson electron : W(Z) → e(e)
Heavy flavour electron : b(→c)→e
Conversion electron : $\gamma$ →ee
Fake from charged hadron : h→ e

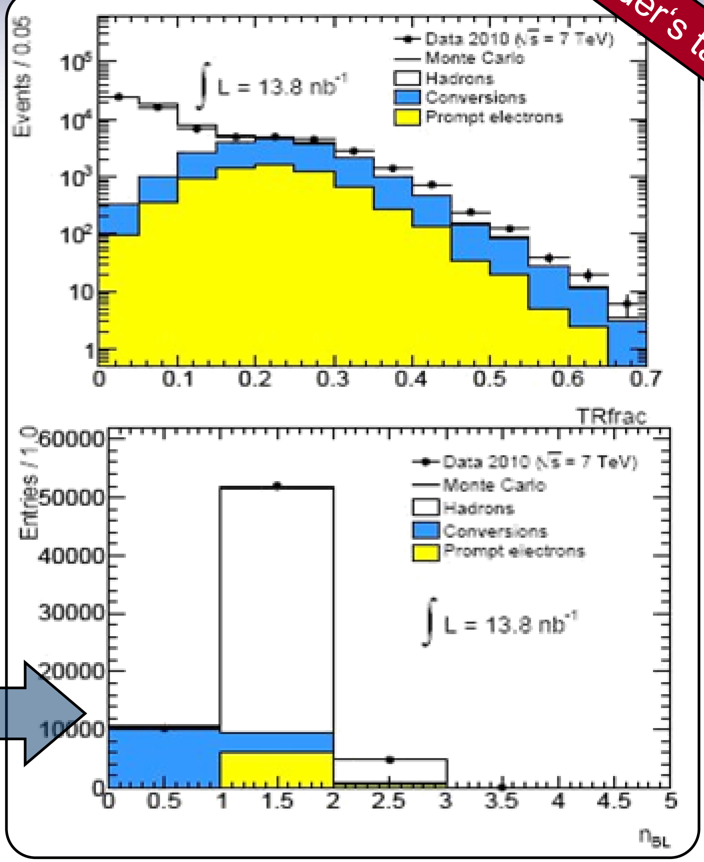
## Electron Identification Tools

**« Medium electron»**

– Strip layer information --against $\pi^0$'s
*fraction of energy, shower lateral size,*
– Cluster-Track Matching : $\Delta\eta<0.1$
– Track Quality
*hits in pixel, pixel+SCT,d0,fiducial B-layer*

**«Tight electron»**

– Hadronic Leakage
*ratio of $E_T^{HAD}/E_T^{EM}$ in 1st (all) Had sampling*
– Middle layer (Max. shower)
*ratio in $\eta$ of cell energies in 3x7 vs 7x7*
– Cluster-Track Matching : *Ratio E/p (vs hadron)*
– B-layer hit (vs conversion)
– Transition Radiation Tracker
*nb of hits, ratio of High/Low threshold (vs $\pi$'s)*




## Validation of ID tools

Using data driven techniques
→ Derive components using Matrix Method

# 1b) Electron

See L. Serin's talk

**Electron in W and Z selection**

Trigger efficiency of 99.8±0.2% in data

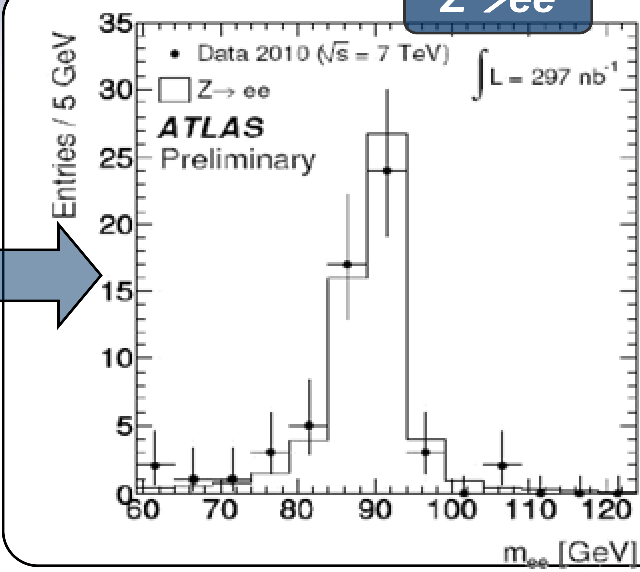
Select electron with $p_T$>20 GeV

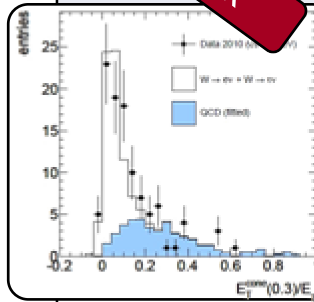
- *$|\eta|$ < 2.47 excluding Barrel-EC region*
- *Medium or Tight quality*
- *Isolated electron (calorimeter based)*

Measure relative efficiency in data/MC

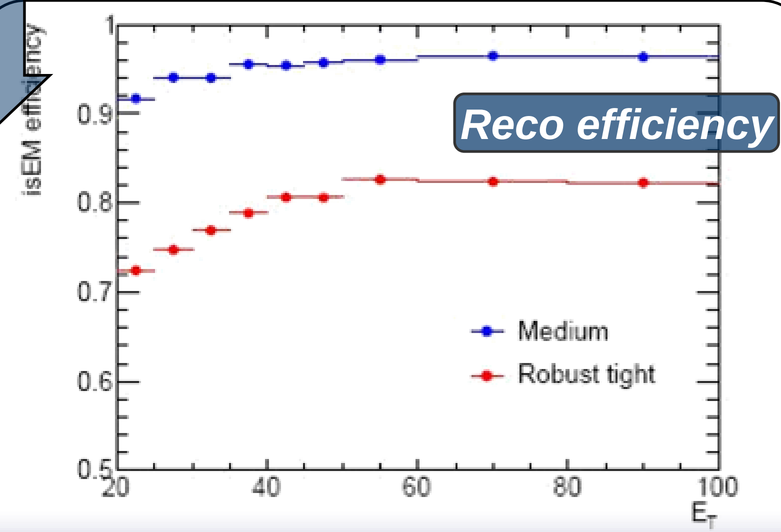
- Ratio Loose/Medium and Medium/Tight
- Validate variable description one by one
- → Agreement at the level of 3% (tight)

**Z→ee**



**Reco efficiency**




**Energy scale and resolution**

Energy scale & resolution dominated by EM

- Uncertainty (abs) is ±3% from TB,$\pi^0 \to \gamma\gamma$

Next: Trigger/Reco efficiency from data

- Via resonnances Z→ee, $J/\psi$,$\Upsilon$→ee
- *Tag e : tight isolated electron*
- *Probe : looser candidate*
  - $|M_{ee}-M_Z|$< 10 GeV

# 1c) Muon

See M. Woudstra's talk

**Muon Identification**

Two main sub-systems:

Muon Spectrometer

Inner Detectors: pixel/SCT **($|\eta|$<2.5)**,TRT **($|\eta|$<2)**

→*Form « Combined Muon » by $\chi^2$ matching*

*[chain1] Refit of the ID+MS track*

*[chain2] Stat. combination of MS & ID meas.*

Efficiency in MonteCarlo

99% of W→μ are « combined muons »

*MS adds 0.6% and calo-tag muon 0.4%*

Measurement of relative efficiency at the dca

Use *ID+calorimeter tagged* muon

→ Measure relative efficiencies in data / MC

→ *Validation of MC at the ~3% level*

| Muon Identification relative efficiency | | |
|---|---|---|
| $p_T(\mu)\geq$6 GeV | DATA $\varepsilon_{ID}$ | MC $\varepsilon_{ID}$ |
| *Chain 1* | (94.0±2.0)% | (96.8±0.3)% |
| *Chain 2* | (98.7±0.9)% | (97.4±0.2)% |

**Muon Fake Estimate**

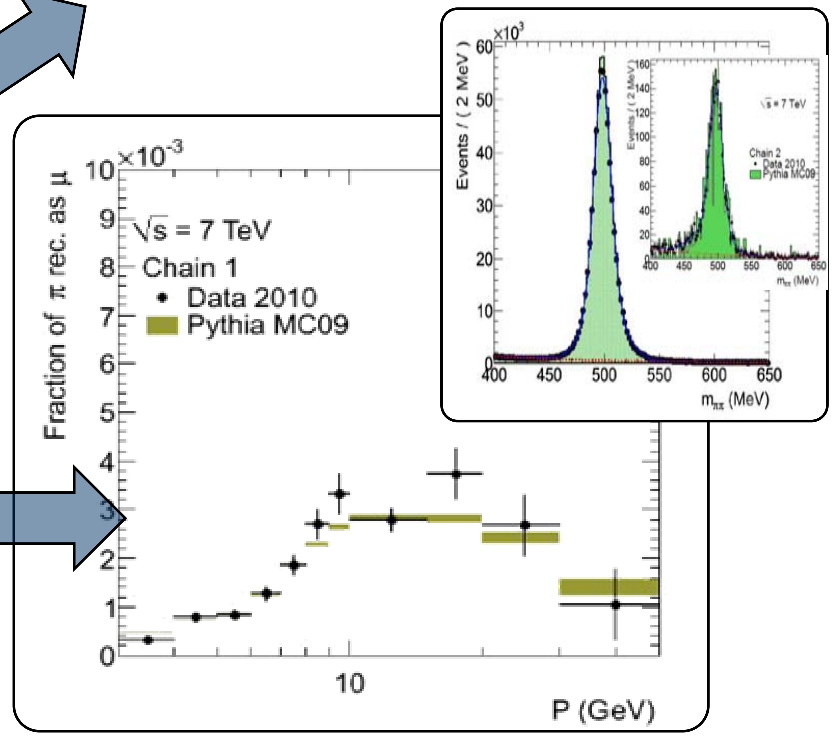
Main sources of non-prompt muon

*π/K decays & punch through*

Use extra cut on MS $p_T$ and $\Delta p_T$(ID-MS)<15 GeV

Constraint π/K rate from data using $K^0_S \rightarrow \pi^+\pi^-$

*Select vertex and count tracks seen as μ*



# 1d) Muon

**Muon in W and Z selection**

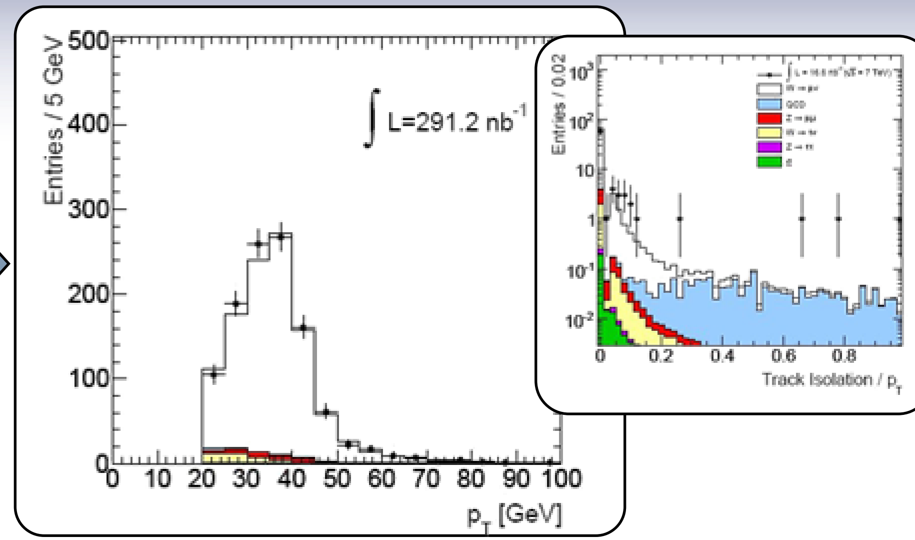
Trigger efficiency of ~99.7% in data

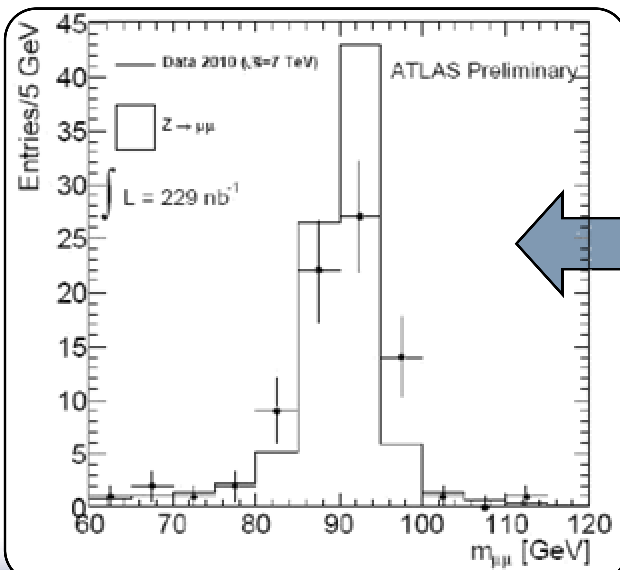
Select muon with $p_T$>20 GeV

- *Combined muon*
- *$|\eta|$ < 2.4*
- *Isolated muon ($\Sigma pT$ in R=0.3 cone)*
- $|p_T^{ID}-p_T^{MS}|$< 15 GeV

Measure relative efficiency in data/MC

- Validate variable description




**High $p_T$ Muon scale and resolution**

Select $p_T(\mu)$> 20 GeV/c

- Momentum scale known at a level <2%

Momentum resolution

- Known at 5% (Barrel) and 8.5%(EC)

Next: Trigger/Reco efficiency from data

- Tag & Probe using Z→$\mu\mu$, J/$\psi$,$\Upsilon$→$\mu\mu$
- *Tag : « tight » isolated muon*
- *Probe: « medium » muon*

# 2) Jet Reconstruction and calibration

See A. Schwartzman's talk

**Jet Reconstruction**

Anti-KT algorithm with radius of 0.4-0.6

Start from cells regrouped in 3D clusters

**Jet Calibration from MC**

Several calibration schemes tested vs data

– JES+EM scale (EM+JES)

*Corrections from MC truth as $f(p_T^{EM})$*

– Global Sequential (GS)

*Add jet-by-jet information (shower shape)*

– Global Cell energy-density Weighting (GCW)

*use cell weights based on energy density distribution wrt MC*

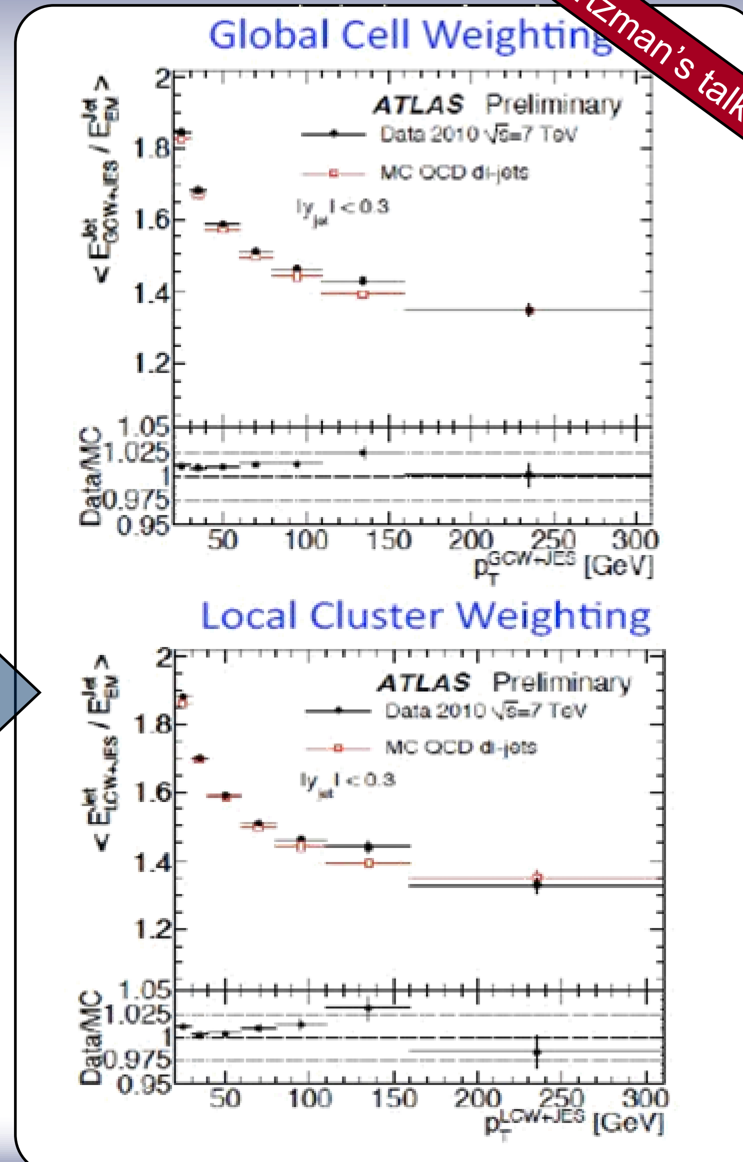
– Local Cluster Weighting (LCW)

*use topo-cluster properties for an individual calibration derived from MC of single $\pi$'s*

Performance

Same average corrections over uncalibrated jets

Agreement between data and MC at the ~2%



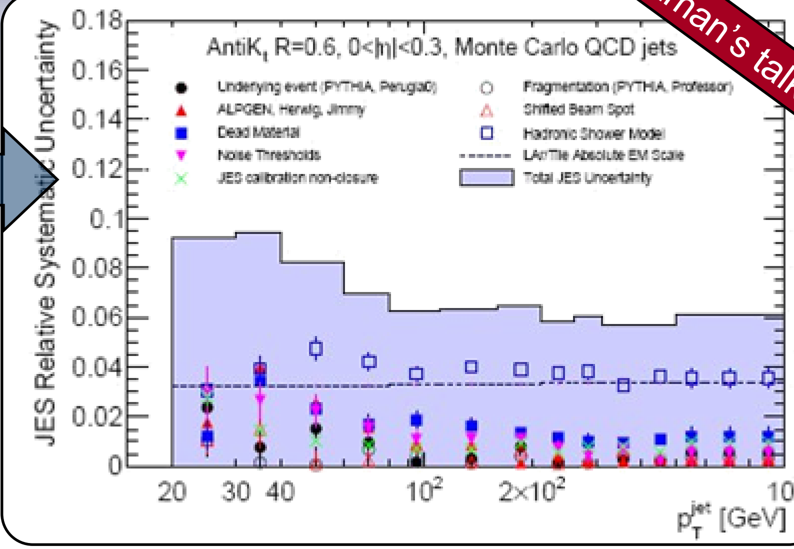
# 2) Jet Energy Scale and Resolution

See A. Schwartzman's talk

**Jet Energy Scale Uncertainty**

Dominant sources of systematic uncertainties

- Dead material (5%)
- Hadronic shower model (5%)
- Electronic Noise (3%)
- LAr/Tile absolute EM scale (3%)
  - 9.4% (10%) for $p_T^{jet}$<60 GeV Barrel (EC)
  - 7.0% (7.6%) for $p_T^{jet}$>60 GeV Barrel (EC)



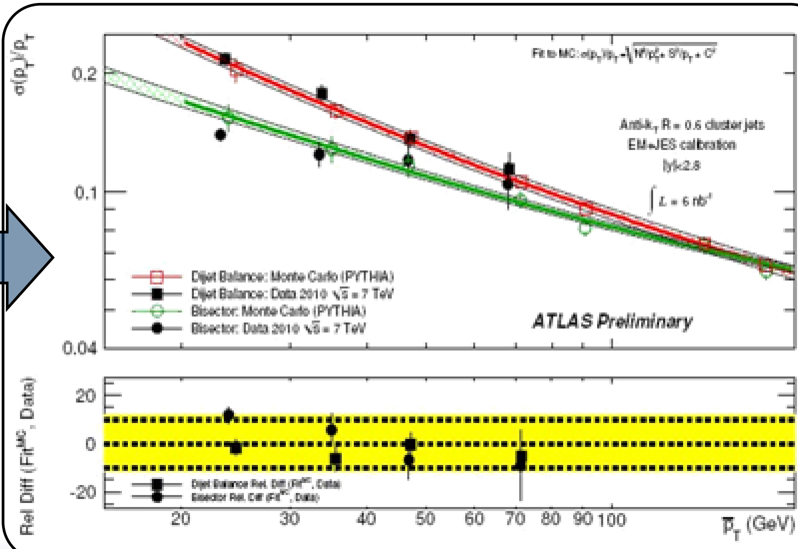

**Jet Resolution**

Use dijet balance method & Bisector method

- *Select back-to-back jet events*
- *Measure A = ($p_T^{probe}$-$p_T^{ref}$/$p_T^{avg}$)*
- Determination of $\sigma_{pT}$ / $p_T \cong \sqrt{2}\,\sigma_A$
- *MC and data agree within ~14%*
- *for jet of 20< pT <80 GeV*

Systematic Uncertainties

- *Difference of two methods*
- *MC Soft radiation correction (3rd jet)*



# 3) Missing Transverse Energy

**Missing ET Definition**

– Defined from cells belonging to topo-clusters and from muon contribution

**Missing ET Calibration**

– Global cell weighting calibration (cell level) or Local cluster calibration (cells w/in cluster level)

– Refined calibration correction from physics objects:

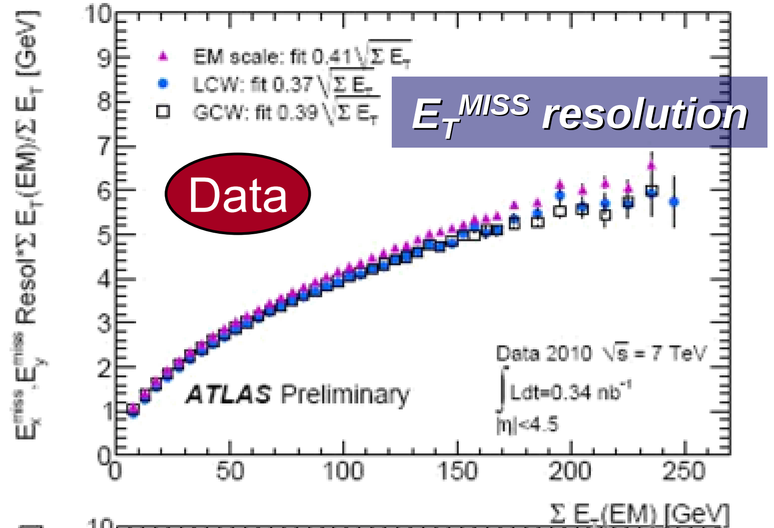
$$E_T^{mis,calo,calib}=E_T^{e}+E_T^{\gamma}+E_T^{\tau}+E_T^{jets}+E_T^{calo\mu}+E_T^{cellOut}$$

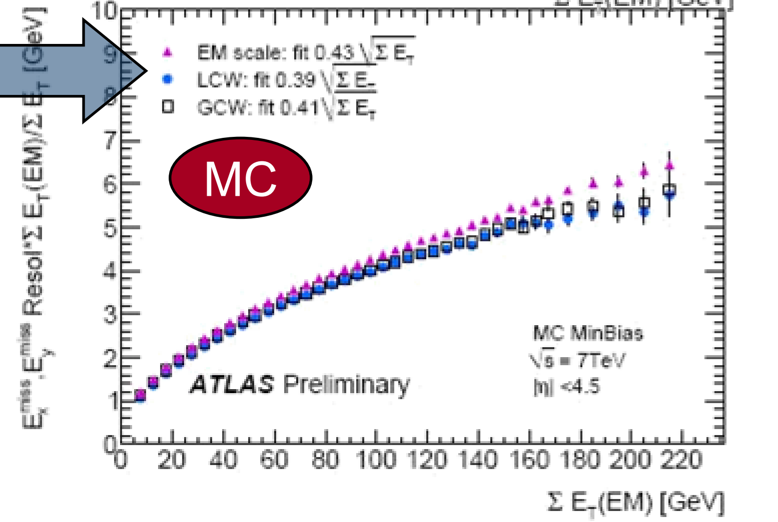
→Calibrated missing $E_T$ is well described by MC

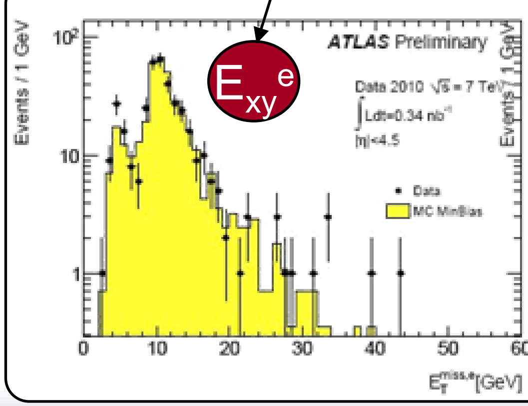
**Missing ET Resolution**

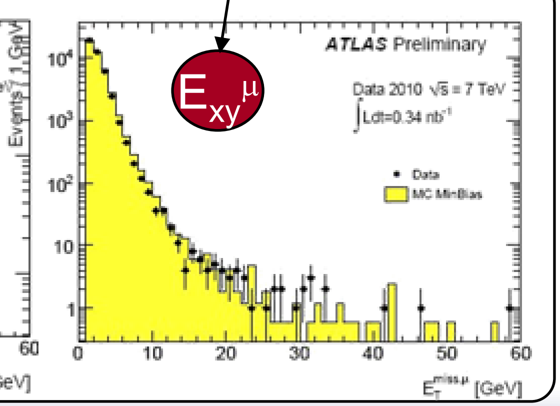
Overall good agreement / some tails in high jet $E_T^{MISS}$

Resolution in Data / MC in reasonable agreement



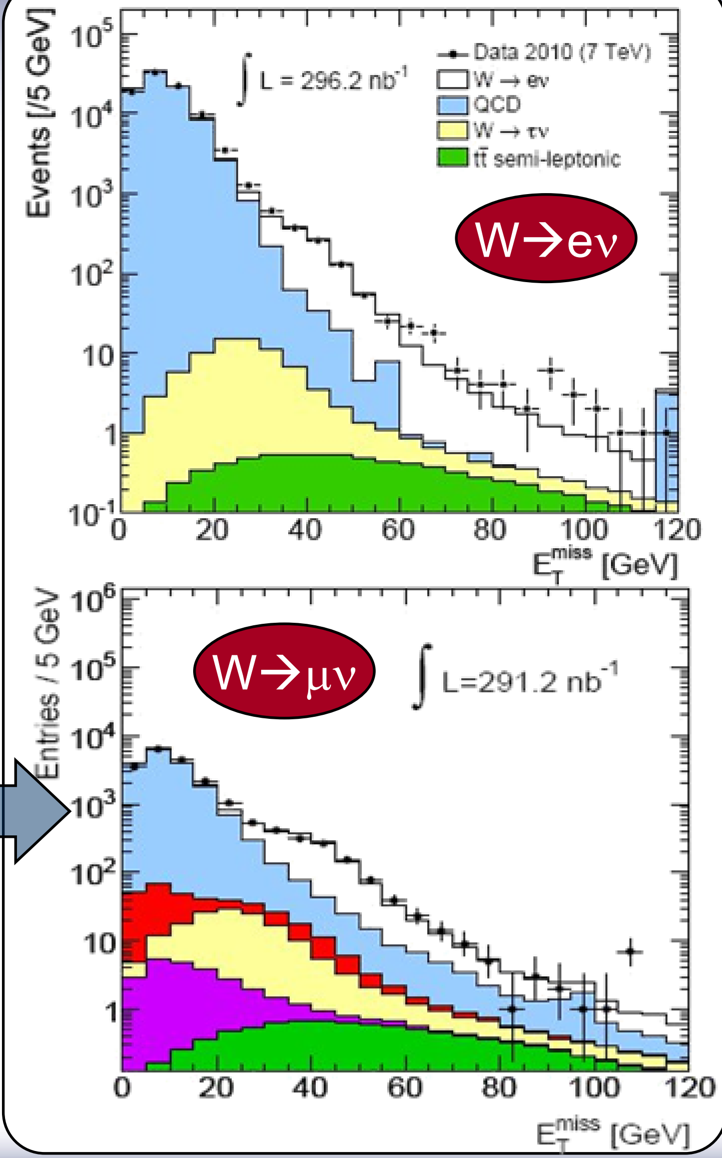
# 3) Missing Transverse Energy

**Missing ET Definition**
– Defined from cells belonging to topo-clusters (noise suppression) and from muon contribution

**Missing ET Calibration**
– Global cell weighting calibration (cell level) or Local cluster calibration (cells w/in cluster level)
– Refined calibration using physics objects:
$E_T^{mis,calo,calib} = E_T^{e} + E_T^{\gamma} + E_T^{\tau} + E_T^{jets} + E_T^{calo\mu} + E_T^{cellOut}$
→Calibrated missing $E_T$ is well described by MC

**Missing ET Resolution**
Overall good agreement / some tails in high jet $E_T^{MISS}$
Resolution in Data / MC in reasonable agreement

**Missing ET in W→lν events**
Select events with lepton with $p_T$>20 GeV
Isolated (remove fake, prompt …)
Extra Missing ET due to presence of neutrino
→$E_T^{MISS}$ Distributions in good agreement with MC



# 4) Jet Tagging : Impact Parameter Based

See J. Fleckner's talk

## Impact parameter based Taggers

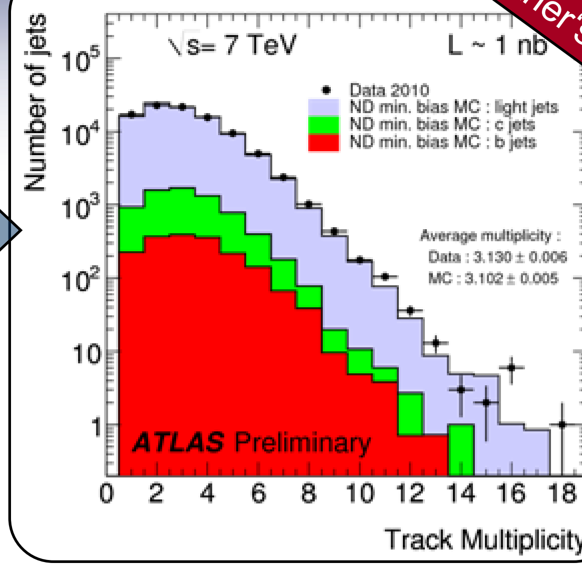
Select quality track in jets

Measure track dca to Primary Vertex

Define significance $S_{d0}=d_0/\sigma_{d0}$

Determine resolution functions

→ Validate MC description




## Jet Probability Tagger (Aleph)

– Compute proba. for a track to originate from PV

– Remove V0, conversions, hadron interactions

– Derive Jet Probability to originate from PV:

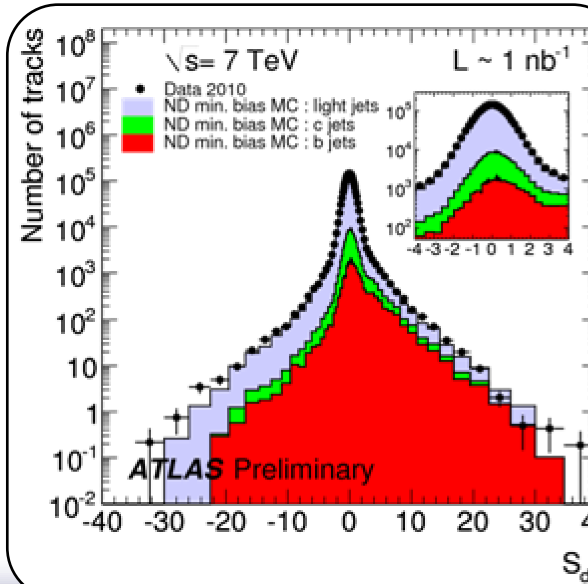
$$\mathcal{P}_{\text{jet}} = \mathcal{P}_0 \sum_{k=0}^{N-1} \frac{(-\ln\mathcal{P}_0)^k}{k!}, \quad \mathcal{P}_0 = \prod_{i=1}^{N} \mathcal{P}_{\text{trk}_i}$$

## TrackCounting Tagger

– Require ≥ 2 good tracks w/ $S_{d0}$ > threshold

– Use a 2nd highest $S_{d0}$ track cut to tag

– Good agreement Data/MC vs $p_T$ and $\eta$-ranges



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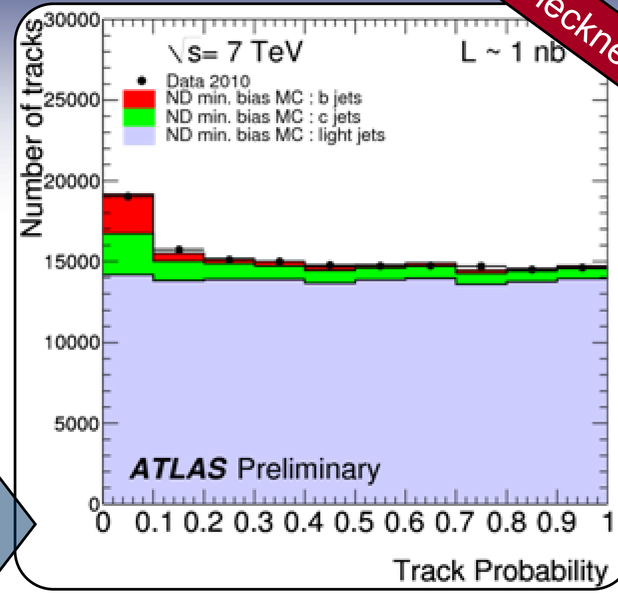


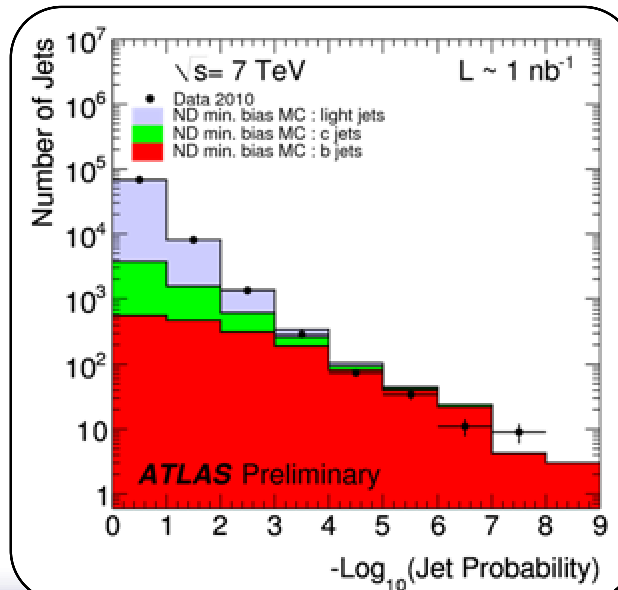


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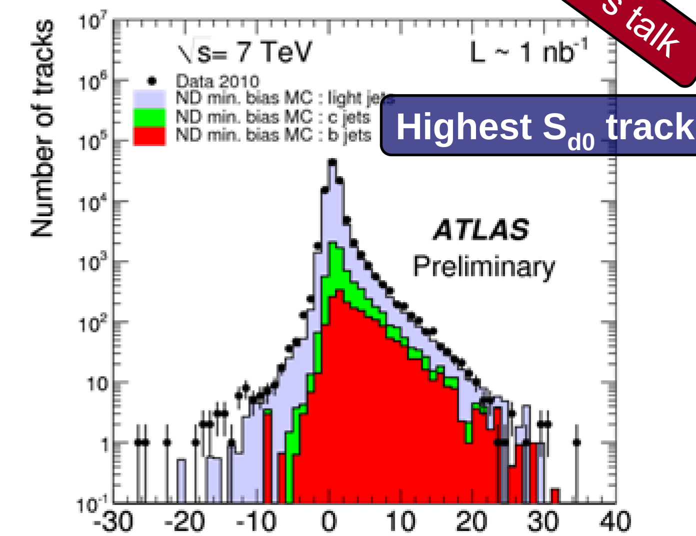
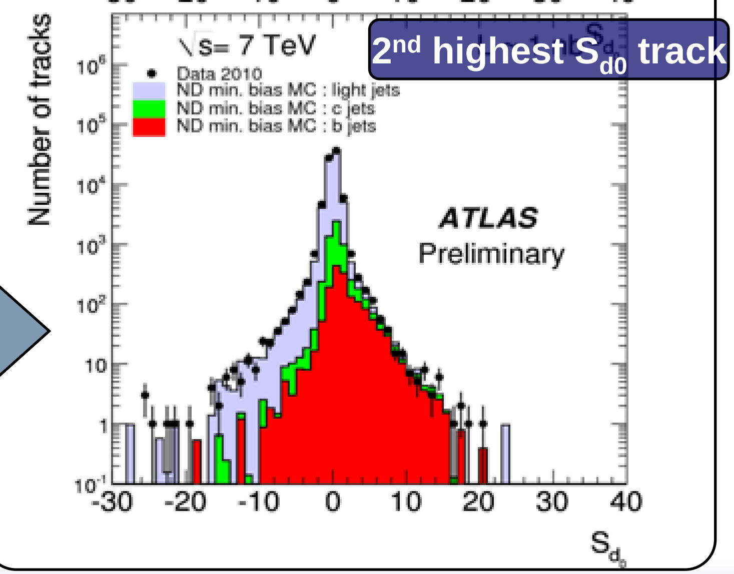


# 4) Jet Tagging : Soft muon & SV

See J. Fleckner's talk

**Soft Muon Tagger**

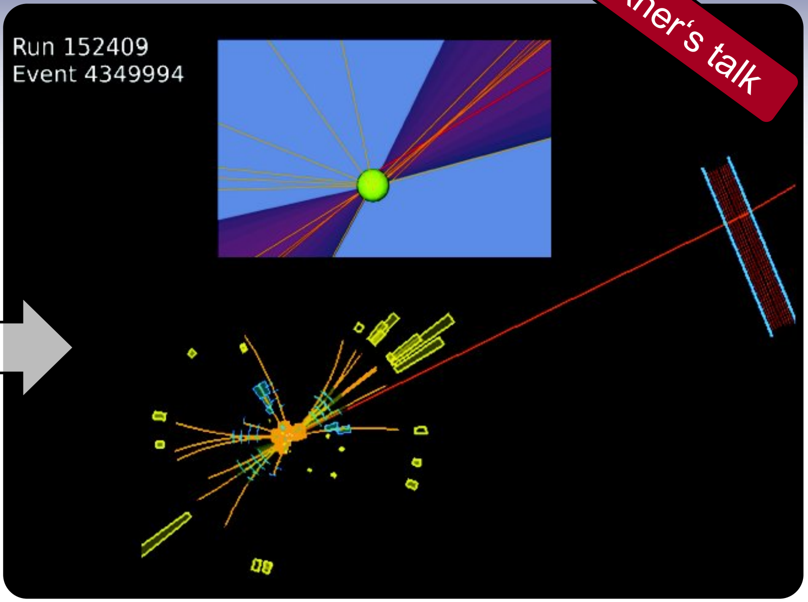
Tag soft muon from b(→c)→μ X  [BR~20%]

Select *combined muon* in jets

- Good MS and ID match
- Muon track w/ 7Si+2 pixels+1 BL hits
- $|d_0| < 1$ mm and $|Z_0 \sin\theta| < 1.5$ mm

Use $p_T^{rel}(\mu)$ as discriminant variable

→Fit templates of b, c and light jets



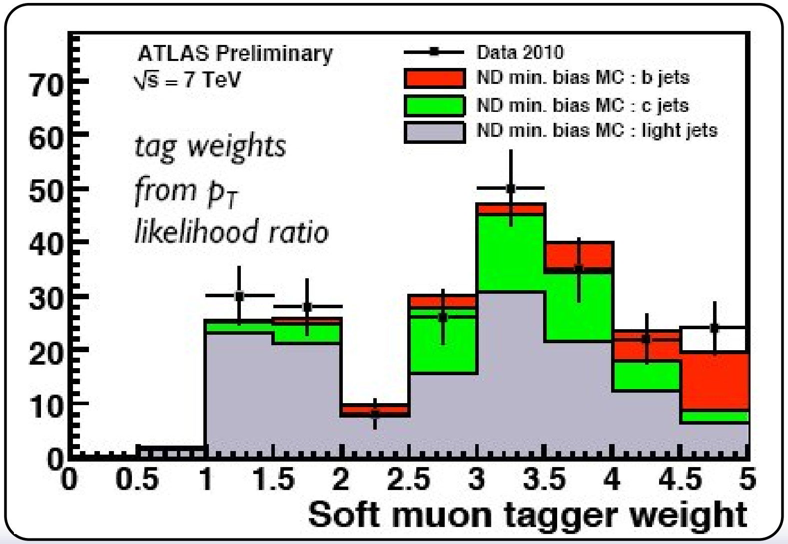

**Secondary Vertex Tagger**

– Reconstruct vertex from 2-track combinations with $dca/\sigma_{dca}$ above 2

– Compute 3D decay length significance
Impose tracks to have 2-track $\Sigma dca/\sigma_{dca} > 6$
Cut on $\chi^2$ to ensure bad compatibility w/ PV

– Removal of V0 and γ-conversion

– Removal of vertices in pixel layer (interactions)



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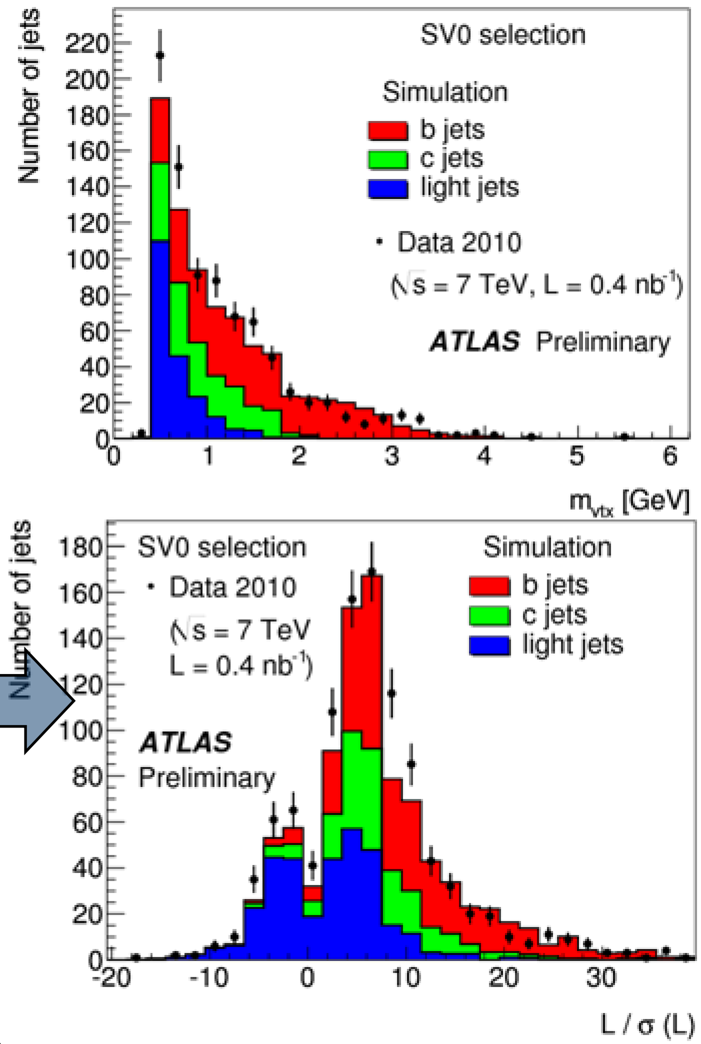


## Top quark Candidate Search with 280 $nb^{-1}$…

# Top quark search in « electron+jets »

**Electron+jets selection**

Primary Vertex with ≥5 tracks

One electron with $p_T$> 20 GeV

- *Trigger matched*
- *Medium quality*
- *Track with B-layer hit*
- *Isolated around e-direction*

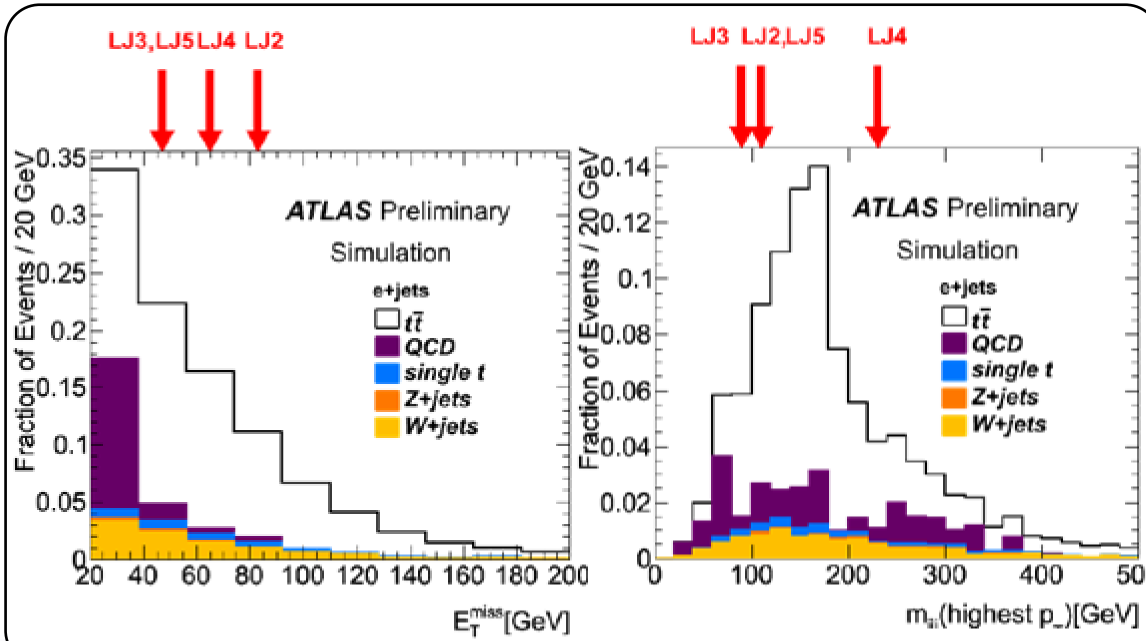
At least 4 jets with $p_T$>20 GeV

- *Pseudo rapidity $|\eta| \leq 2.5$*
- *EM scale + JES calibration*
- *≥1 b-tagged jet (SV0)*

Missing Transverse Energy

- $E_T^{MISS}$ > 20 GeV

| | $p_T^{lep}$ (GeV) | $N_{jet}$ ($N_{tag}$) | $E_T^{MISS}$ (GeV) | $m_T$ (GeV) | $M_{jjj}$ (GeV) |
|---|---|---|---|---|---|
| *LJ2* | 41.4 | 4 (1) | 89.3 | 68.7 | 106 |
| *LJ3* | 26.2 | 4 (1) | 46.1 | 62.6 | 94 |
| *LJ4* | 39.1 | 4 (1) | 66.7 | 102 | 231 |
| *LJ5* | 79.3 | 4 (1) | 43.4 | 86.7 | 122 |



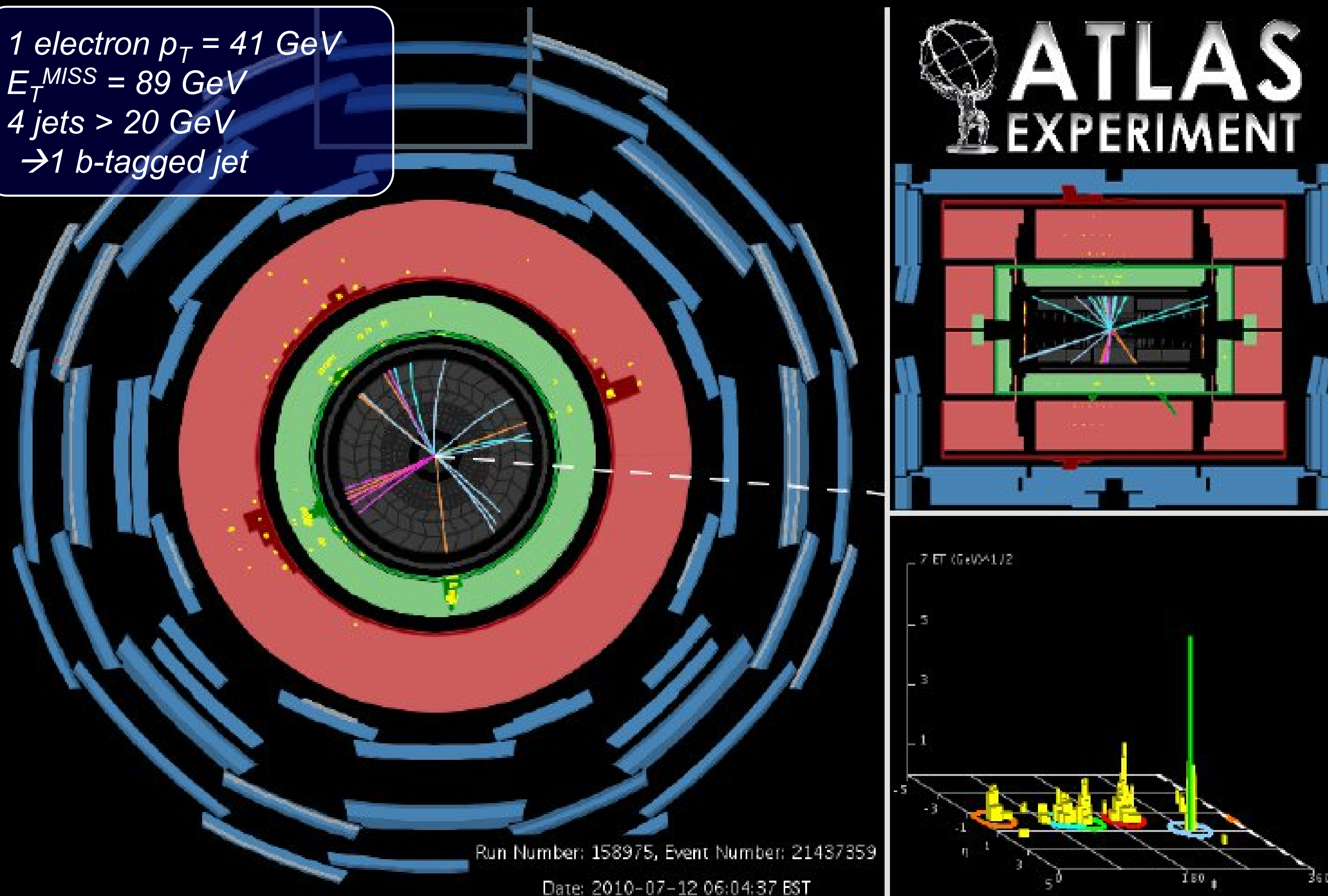

**Note on B-tagging**

SV0 is the default tagger

Jet by JetProb & TrackCount used as cross-checks

# Top pair candidates in « electron+jets »

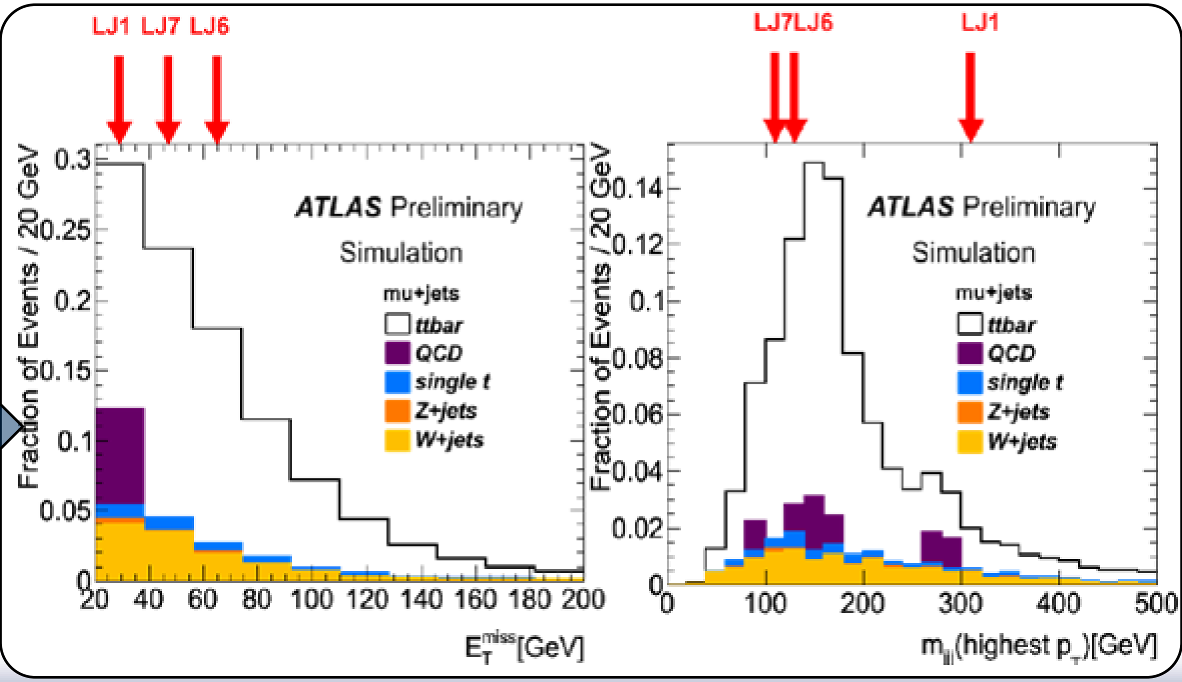
*1 electron $p_T$ = 41 GeV*
*$E_T^{MISS}$ = 89 GeV*
*4 jets > 20 GeV*
*→1 b-tagged jet*



# Top quark search in « muon+jets »

**Muon+jets selection**
Primary Vertex with ≥5 tracks
At least 4 jets with $p_T$>20 GeV
*Pseudo rapidity* $|\eta| \leq 2.5$
*EM scale + JES calibration*
*≥1 b-tagged jet (SV0)*
Missing Transverse Energy
$E_T^{MISS}$ >20 GeV
*one* muon with $p_T$> 20 GeV
*Trigger matched*
*Combined Tight*
*Isolated around* $\mu$ *direction*

| | $p_T^{lep}$ (GeV) | $N_{jet}$ ($N_{tag}$) | $E_T^{MISS}$ (GeV) | $m_T$ (GeV) | $M_{jjj}$ (GeV) |
|---|---|---|---|---|---|
| *LJ1* | 42.9 | 7 (1) | 25.1 | 59.3 | 314 |
| *LJ6* | 29.4 | 5 (1) | 65.4 | 64.1 | 126 |
| *LJ7* | 78.7 | 4 (1) | 40.0 | 83.7 | 108 |



# Top quark search in « dilepton channel »

**Di-lepton selection**

Primary Vertex with ≥5 tracks

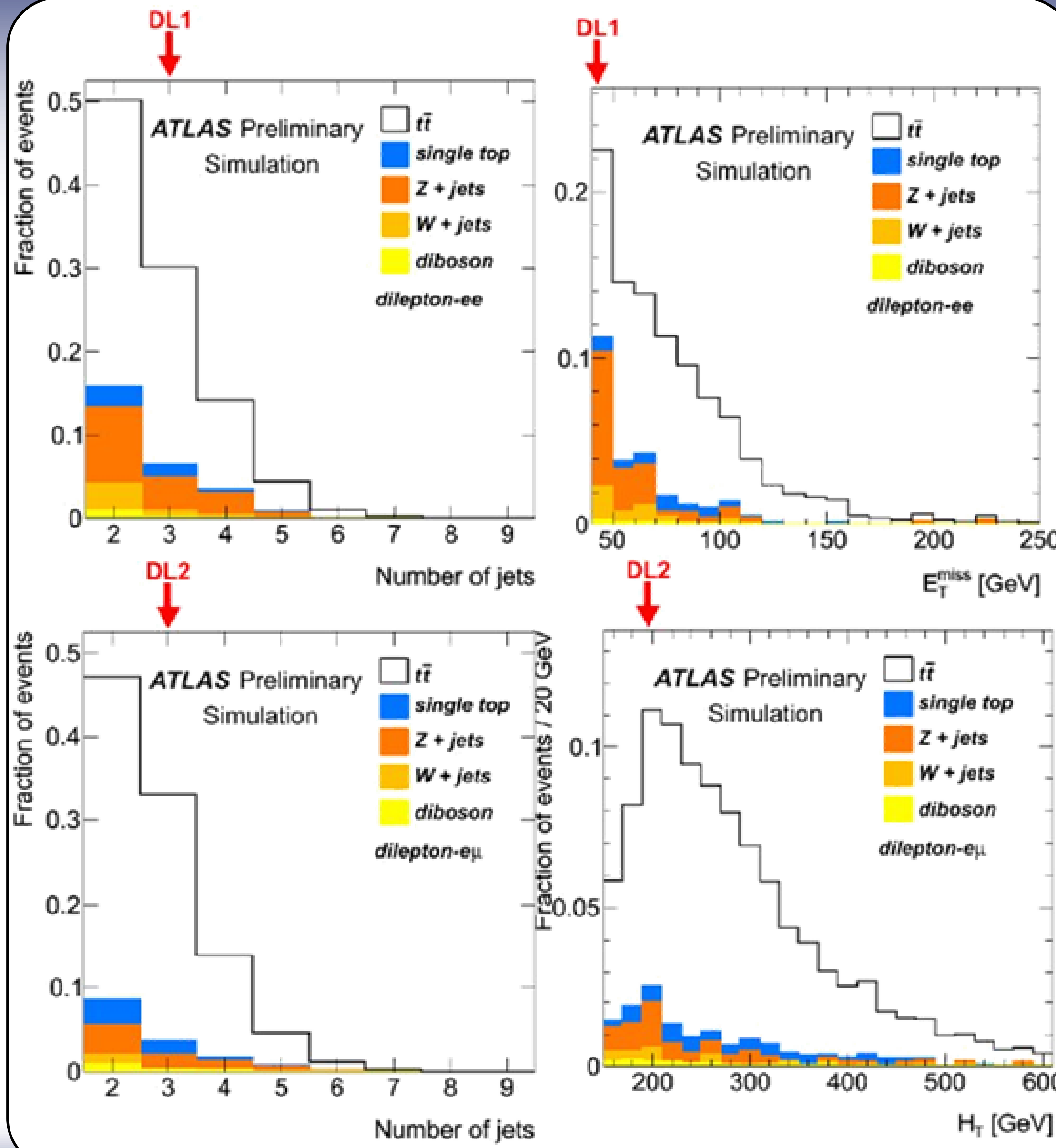
2 leptons with $p_T$ > 20 GeV

- Medium electron and/or
- Combined muon

At least 2 jets with $p_T$ > 20 GeV

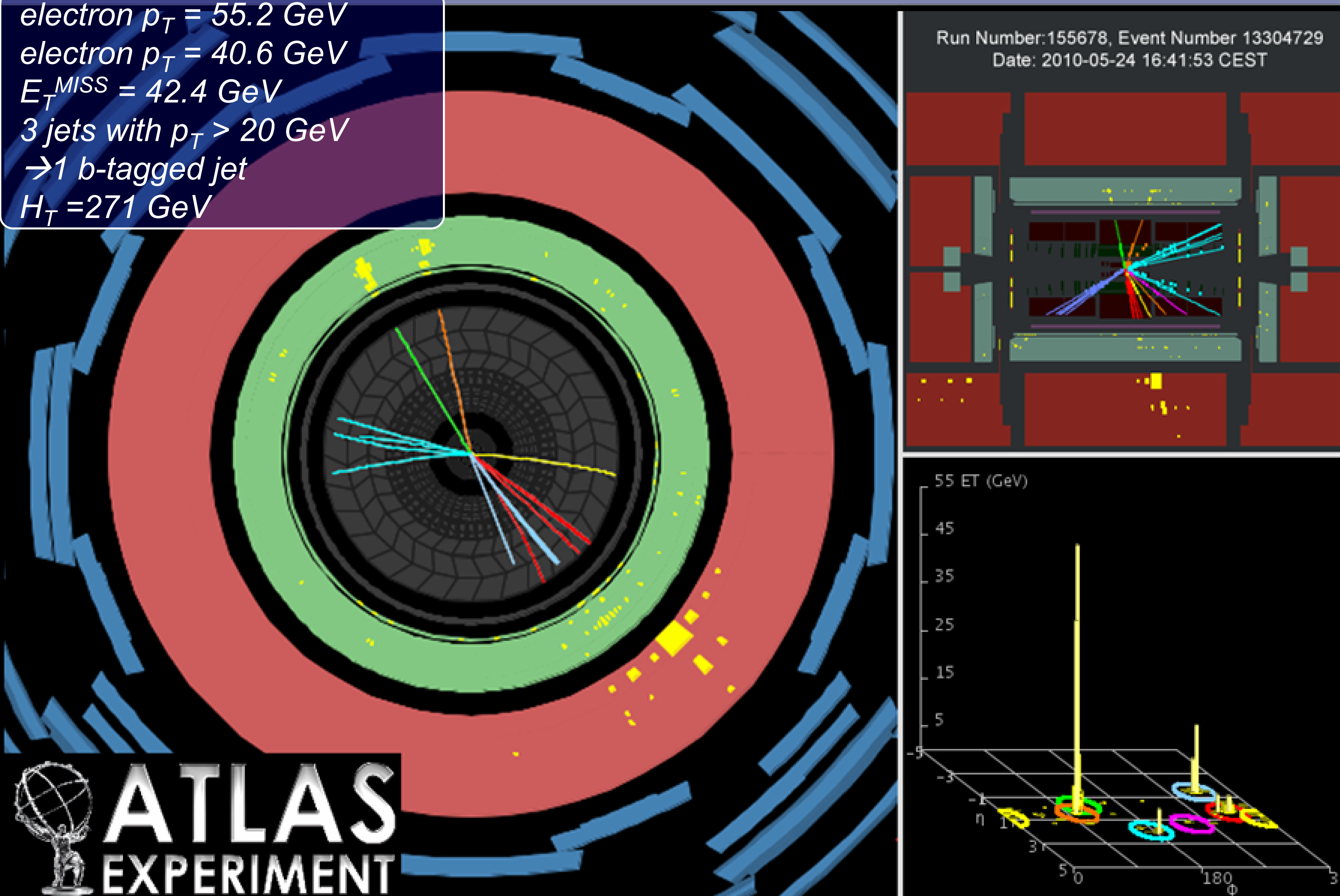
- No b-tagging required
- [ee] $E_T^{MISS}$ > 40 GeV
  - $|M_{ll}-M_Z|$>5 GeV
- [μμ] $E_T^{MISS}$ > 30 GeV
  - $|M_{ll}-M_Z|$>10 GeV
- [eμ] $H_T$(jets,leptons)> 150 GeV

| | $p_T^{lep}$ (GeV) | $N_{jet}$ ($N_{tag}$) | $E_T^{MISS}$ (GeV) | $H_T$ (GeV |
|---|---|---|---|---|
| ***DL1 ee*** | 55.2/40.6 | 3 (1) | 42.4 | 271 |
| ***DL2 eμ*** | 22.7/47.8 | 3 (1) | 76.9 | 196 |

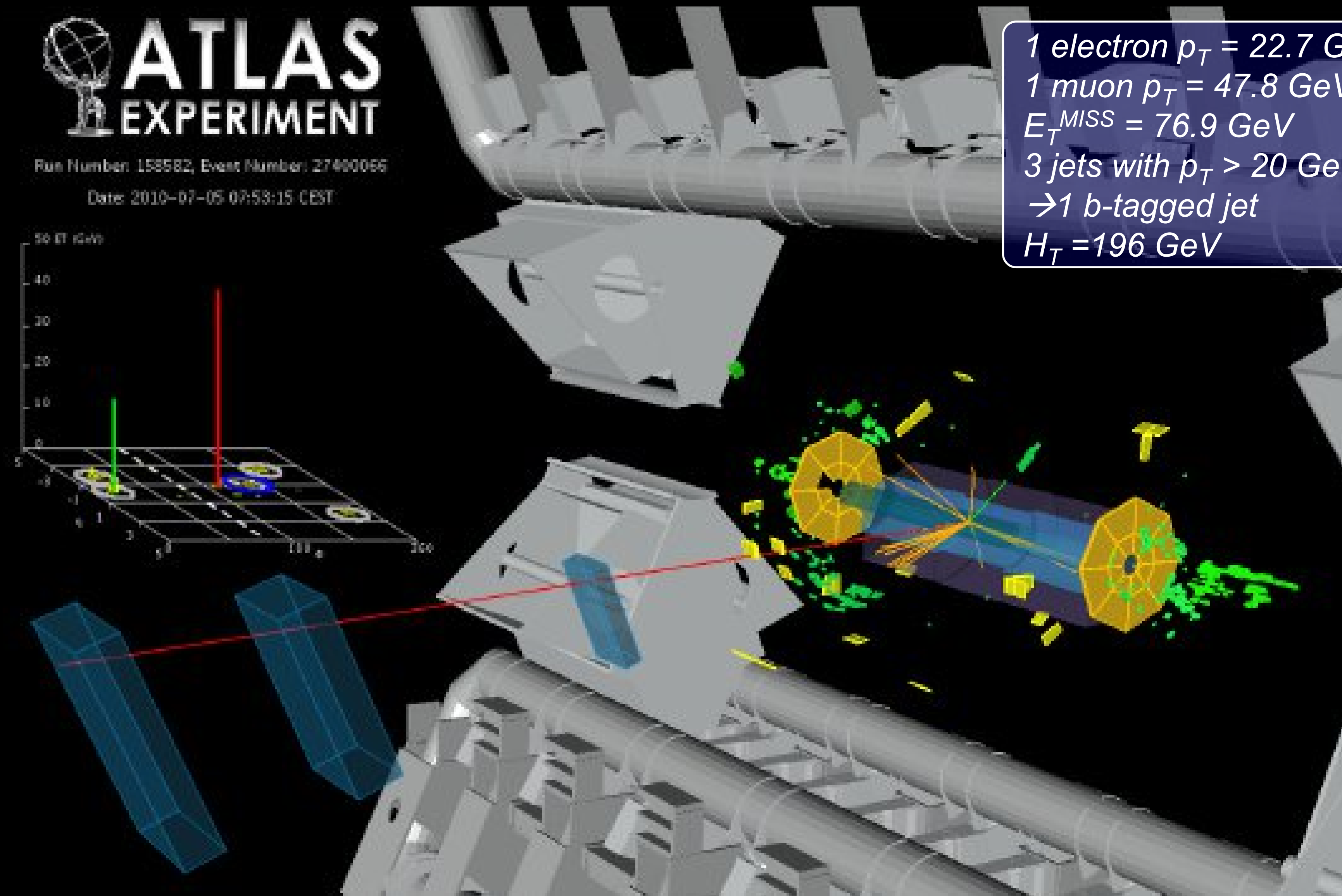


# Top pair candidate in **ee** channel

*electron* $p_T$ *= 55.2 GeV*
*electron* $p_T$ *= 40.6 GeV*
$E_T^{MISS}$ *= 42.4 GeV*
*3 jets with* $p_T$ *> 20 GeV*
*→1 b-tagged jet*
$H_T$ *=271 GeV*



# Top pair candidate in « eμ channel »




1 electron $p_T$ = 22.7 GeV
1 muon $p_T$ = 47.8 GeV
$E_T^{MISS}$ = 76.9 GeV
3 jets with $p_T$ > 20 GeV
→1 b-tagged jet
$H_T$ =196 GeV

# Summary & Perspectives

**Top quark physics requires an overall good understanding of the detectors**

A lot of progress in understanding most physics objects has already been achieved:

- Leptons reconstruction, ID and resolution performance
- Hadronic jets reconstruction, ID, calibration & resolution
- Missing transverse energy calibration, correction & resolution
- B-tagging tools (several taggers) tested against first data

Still a lot remains to be done:

- Lepton performance calibration with (Z) data
- In situ Jet energy scale calibration, higher statistics in situ resolution measurements
- Validate Background Estimate & Description in data control sample

**A search for top quark candidates has been conducted with 280 $nb^{-1}$**

Strategy has been defined to look for top (pair) candidates

- Specific selections developped for top pair in lepton+jets and dilepton channels

Some candidates have been identified

- Number of observed events is compatible with expectations
- Kinematic properties are consistent with top pair expectations

**Larger data sample is required to quantify background to a level where it can support a conclusive observation of top quark production in ATLAS**
**…but a new era for Top Physics is about to begin…**