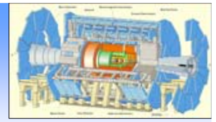
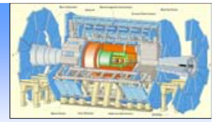


Commissioning with Physics Data at ATLAS

Dan Tovey
for the ATLAS Collaboration



Strategy

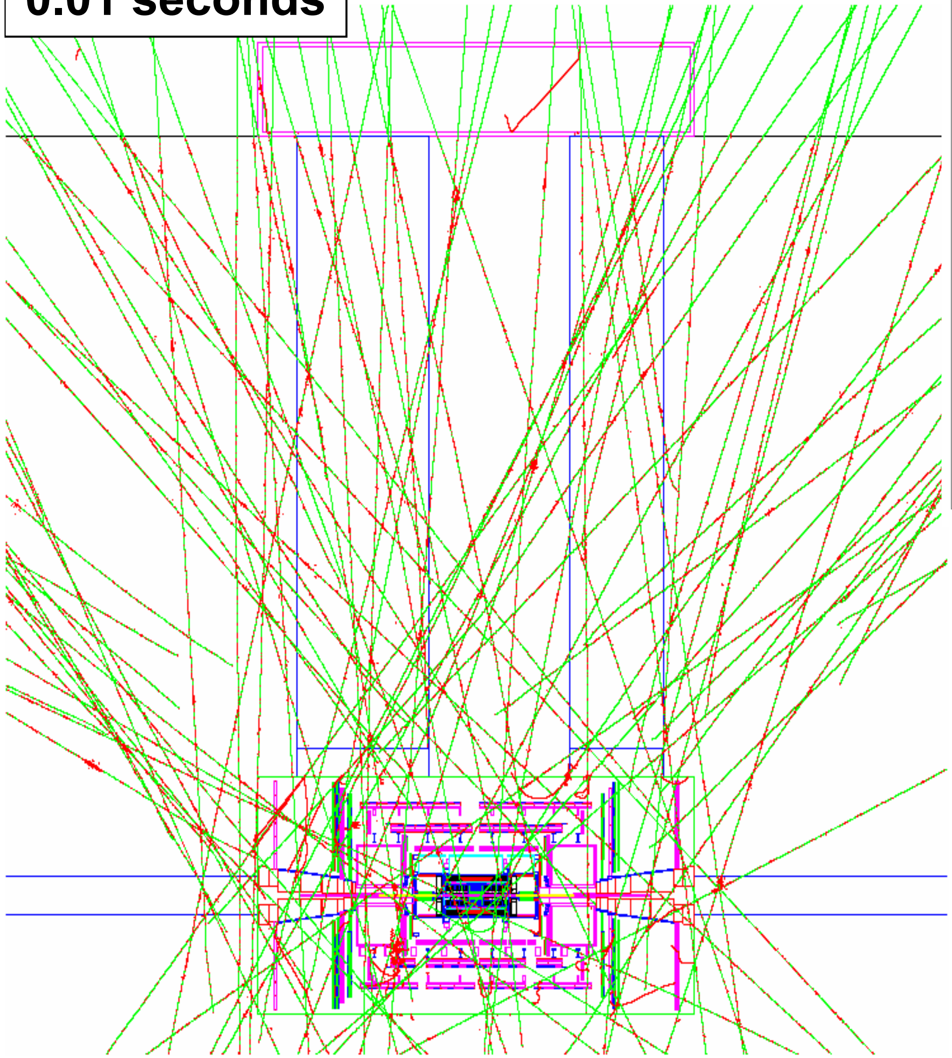
- Commissioning with physics data proceeds in four phases:
  - **Phase 3** : Cosmics running
    - ➔ initial physics alignment / calibration of the detector
    - ➔ debugging of sub-systems, mapping dead channels etc.
  - **Phase 4** : One beam in the machine
    - ➔ beam-halo muons and beam-gas events
    - ➔ more detailed alignment / calibration etc.

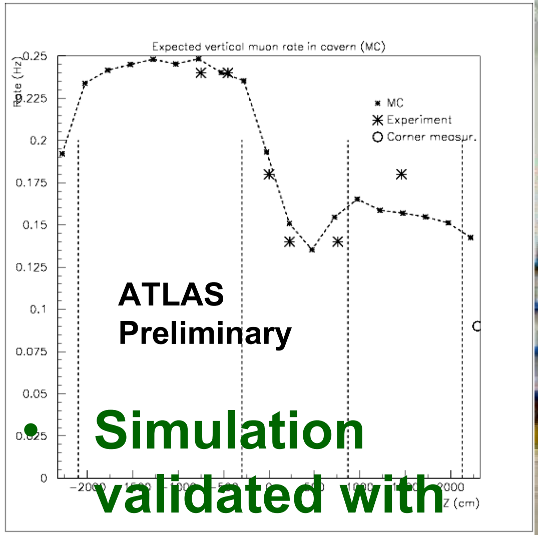
  (Phases 3 and 4: **Pre-collision Phases**)

  - **Phase 5** : First pp collisions : prepare the trigger and the detector
    - ➔ tune trigger menus / measure efficiencies
    - ➔ begin to measure reconstruction efficiencies, fake rates, energy scales, resolutions etc.
  - **Phase 6** : Commissioning of physics channels
    - ➔ Improve measurements
    - ➔ begin to understand backgrounds to discovery channels …
- Thinking now about what we can learn in each phase / how to use the data in practice
- Will give a few examples of recent work / work in progress …

Phase 3: Cosmics

0.01 seconds



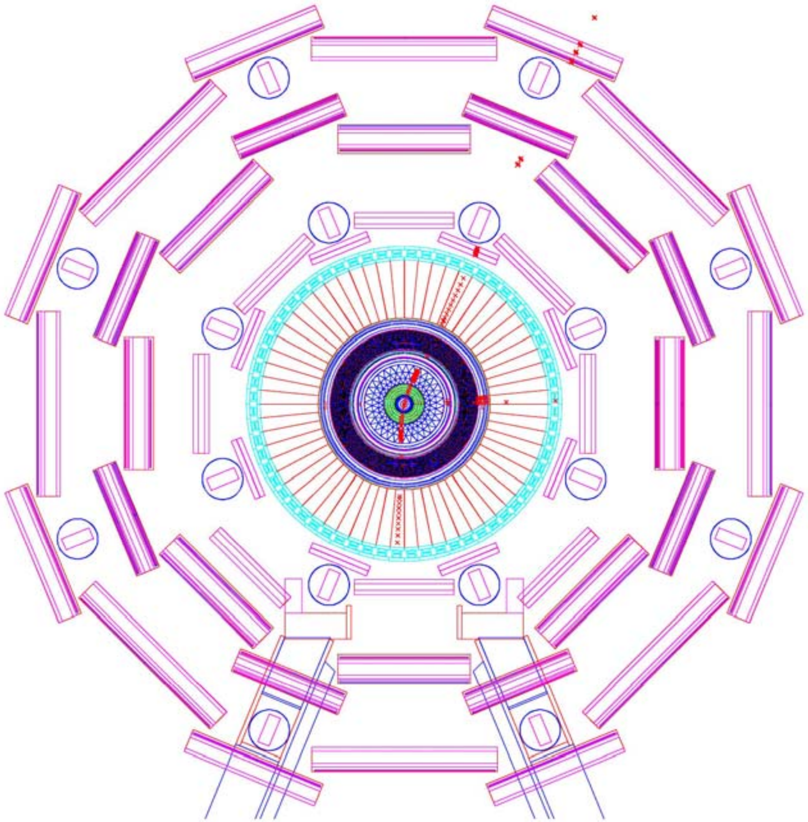


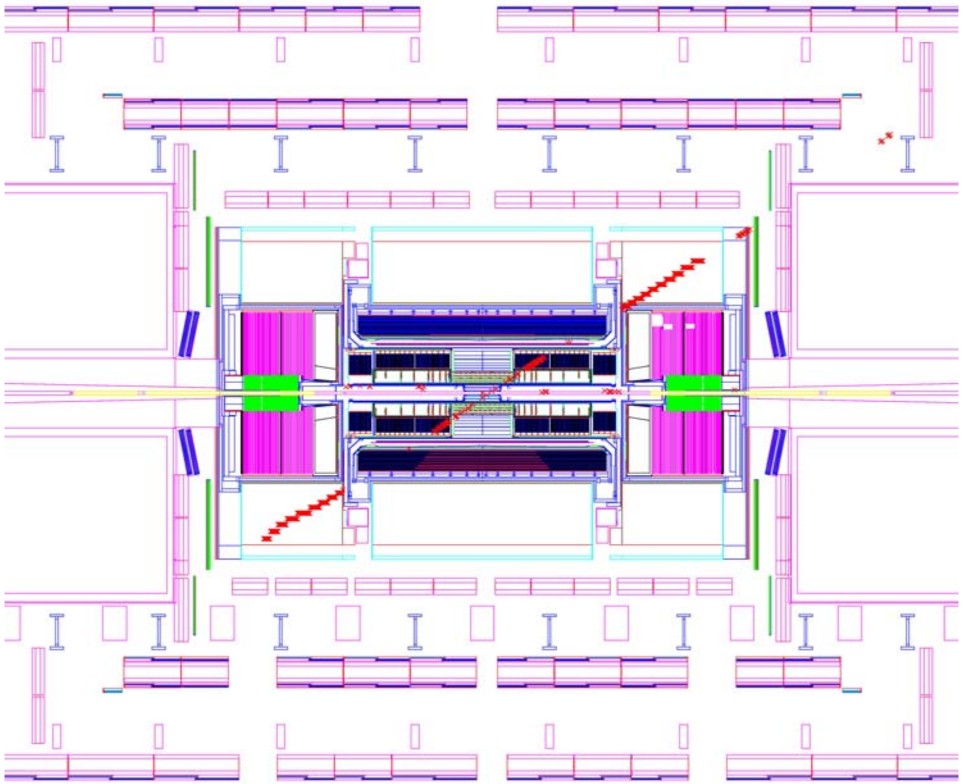
- Simulation validated with muon telescope of ~ 1000 cm^2

Location	ATLAS Preliminary	Rate (Hz) ($E_{surface}$>10 GeV)
ATLAS UX15	--	4900
ECAL	E_T^{TOTAL} > 5 GeV	0.4
Tile Cal	E_{TOTAL} > 20 GeV	1.2
HEC	E_{TOTAL} > 20 GeV	0.1
FCAL	E_{TOTAL} > 20 GeV	0.02

‘Typical’ Event

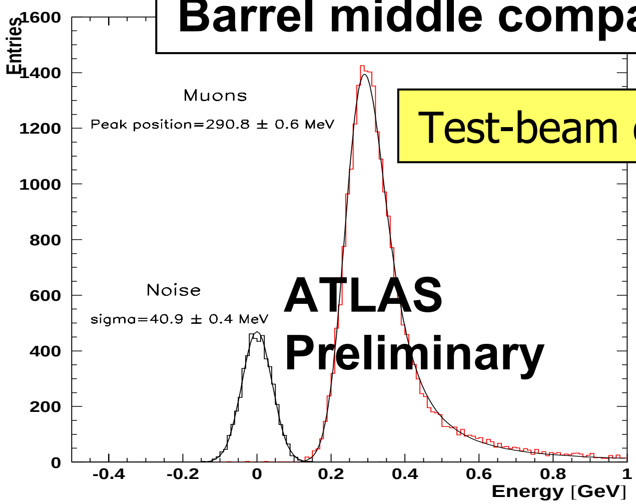
- One track reconstructed in Muon chambers
- Two tracks reconstructed in Inner Detector
- Will happen every ~ 10 s





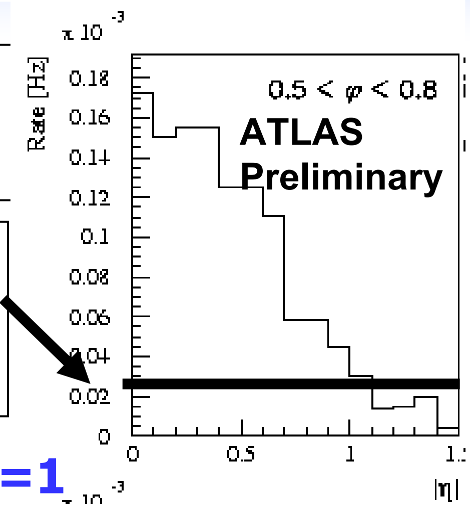
Cosmics in ECAL

Barrel middle compartment



Test-beam data

Cosmic muon rate/ECAL cell (with |z|<30 cm, E_{cell}>100 MeV)



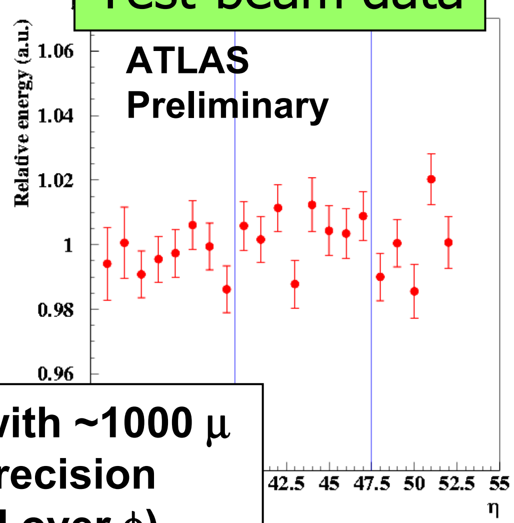
Rate needed to collect ~ 100 μ/cell over 3 months assuming 50% data taking efficiency

100 muons per cell over |η| <=1 and 70 % of φ coverage

With ~ 100 muons/cell in middle compartment:

- **check calorimeter timing to < 1 ns**
- **check calorimeter position in η / φ wrt other sub-detectors to < 1 mm**
- **check response uniformity vs η: ≈ 0.5% precision could be achieved**

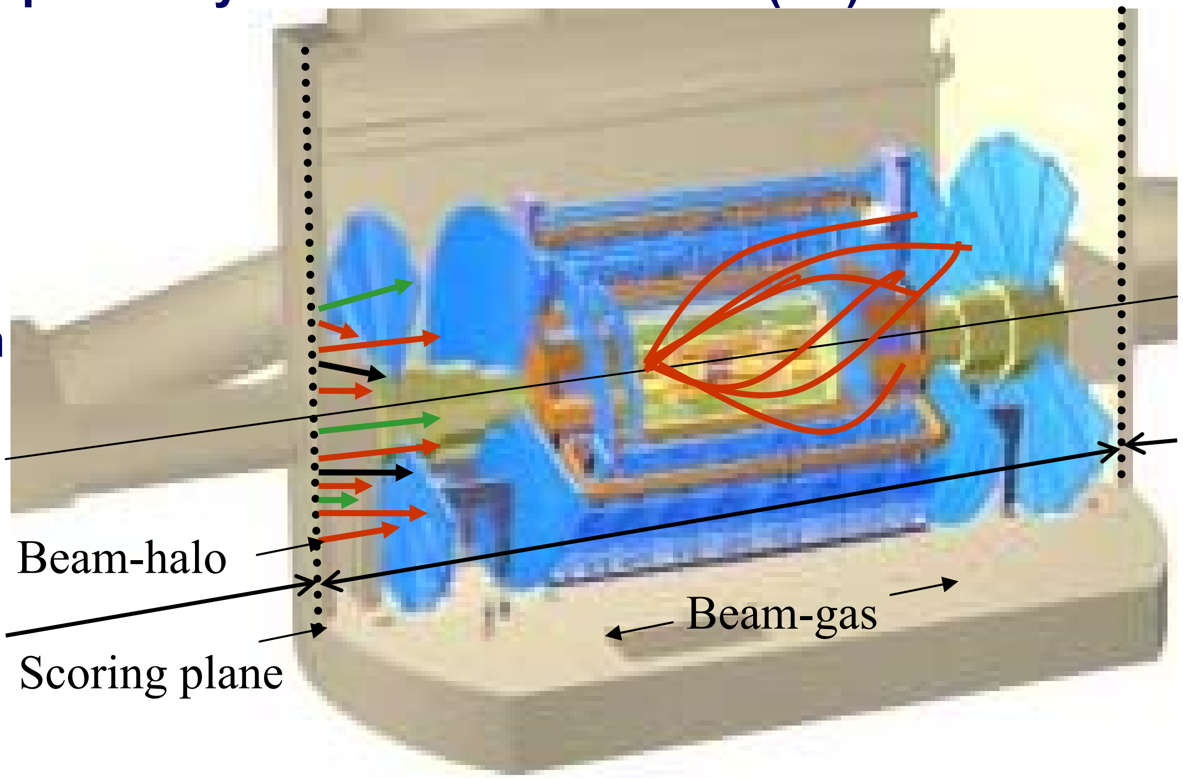
Test-beam data



1% precision measured with ~1000 μ
→ with ~ 5000 μ : 0.5 % precision (~ 100 μ /cell integrated over ϕ)

Phase 4: Single-beam period

- **Beam-halo**
  - Low p_T particles from machine.
  - Simulation of machine background by machine experts (V. Talanov):
    - based on MARS; machine optics V 6.4
    - scoring plane at the cavern entrance before ATLAS shielding (z = ± 23 m from IP)
  - Then particles are transported by ATLAS full simulation (G3)
- **Beam-gas**
  - Vacuum not perfect
  - p(7 TeV) on p(rest)
  - vertices uniformly distributed over ± 23 m
  - σ(pH, pC, pO, …) $\propto$ σ(pp)x$A^{0.7}$ (inelastic only)
  - vacuum estimate: ~3×10^{-8} Torr (~10^{15} mol/m^3)

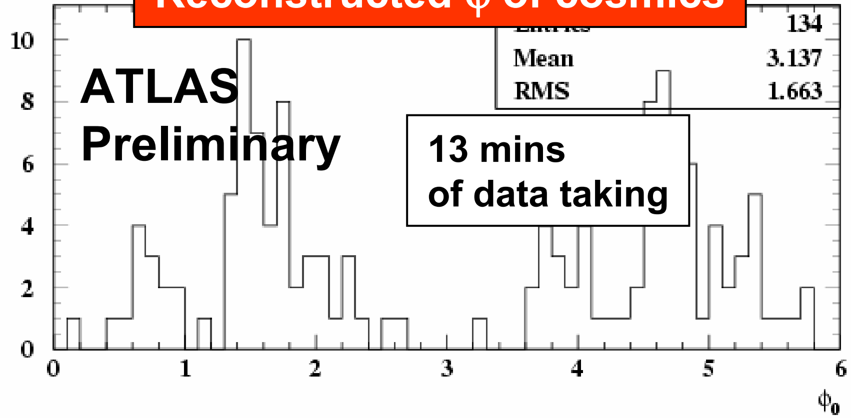


Cosmics & Beam Gas in ID

Cosmics : O (1Hz) tracks in Pixels+SCT+TRT

- **useful statistics for debugging readout, maps of dead modules, etc.**
- **check relative position Pixels/SCT/TRT and of ID wrt ECAL and Muon Spectrometer**
- **first alignment studies: may achieve statistical precision of ~ 10 μm in parts of Pixels/SCT**
- **first calibration of R-t relation in straws**

Reconstructed φ of cosmics



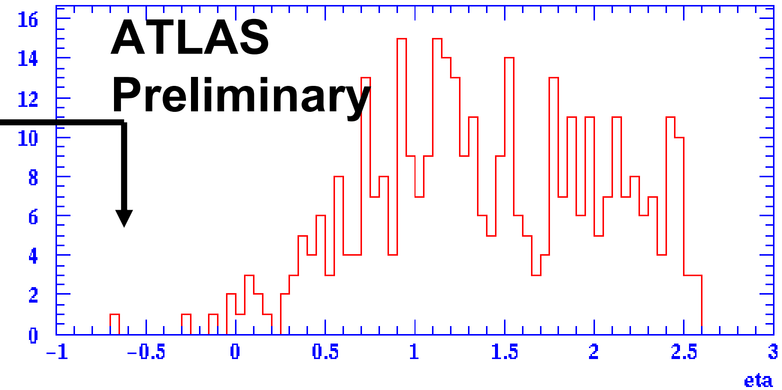
standard ATLAS pattern recognition (no optimisation for cosmics …)

Beam-gas :

- **~ 25 Hz of reconstructed tracks with p_T > 1 GeV and |z|<20 cm**

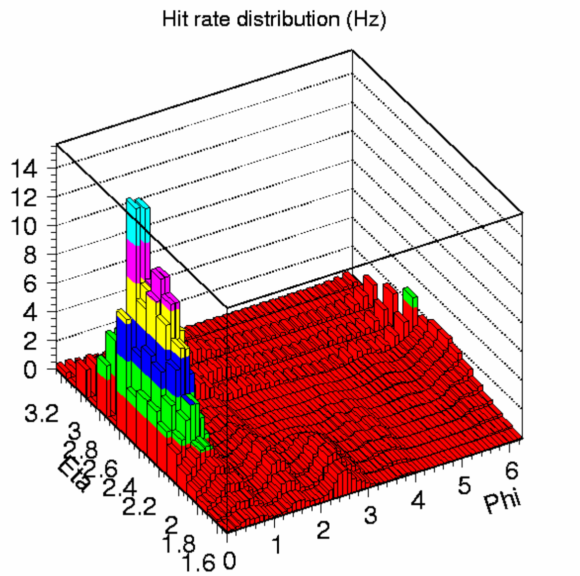
→ >10^7 tracks (similar to LHC events) in 2 months

- **enough statistics for alignment in "relaxed" environment → exceed initial survey precision of 10-100 μm**

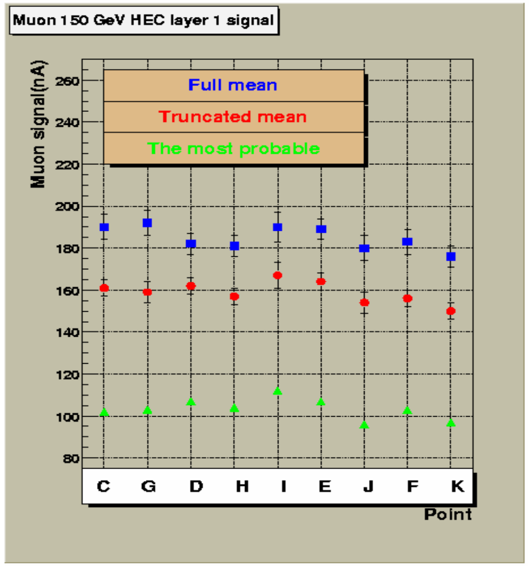


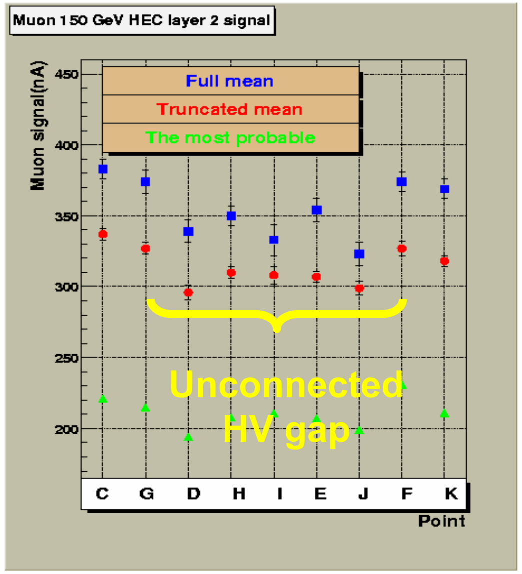
η of beam-gas tracks

Beam Halo in HEC



- **Halo muons:**
  - essentially parallel to z-axis
  - look much like test-beam μ (esp for endcap)
- **HEC-standalone efficiency for muon identification: ~ 25%, S/N ~ 4**
- **Max(Min) Rate ~ 3(0.02) Hz / cell**
  - 5×10^6 (3×10^4) μ in 2 months @ 30%

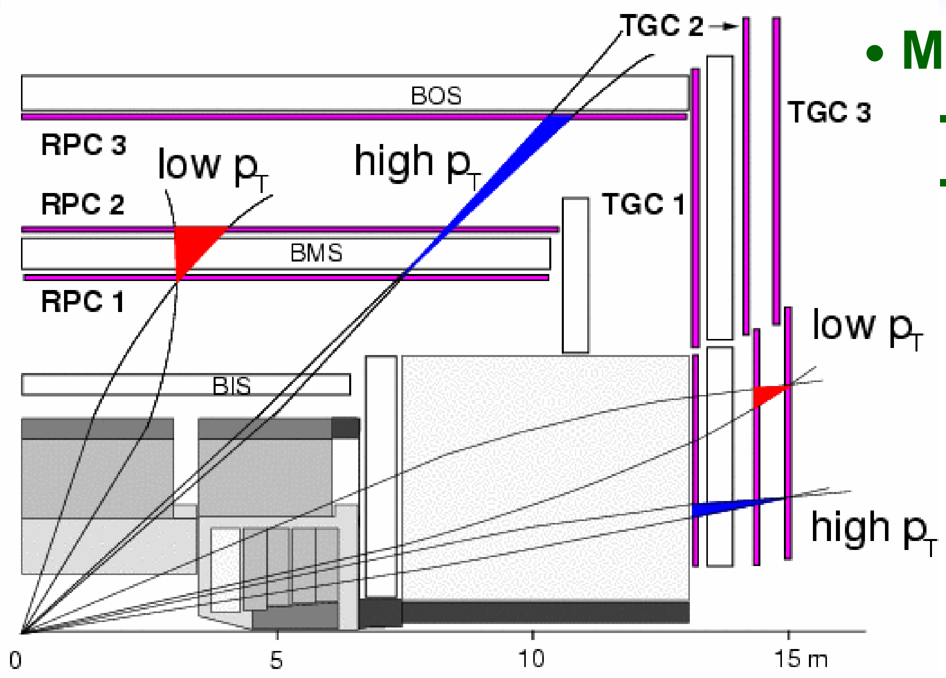




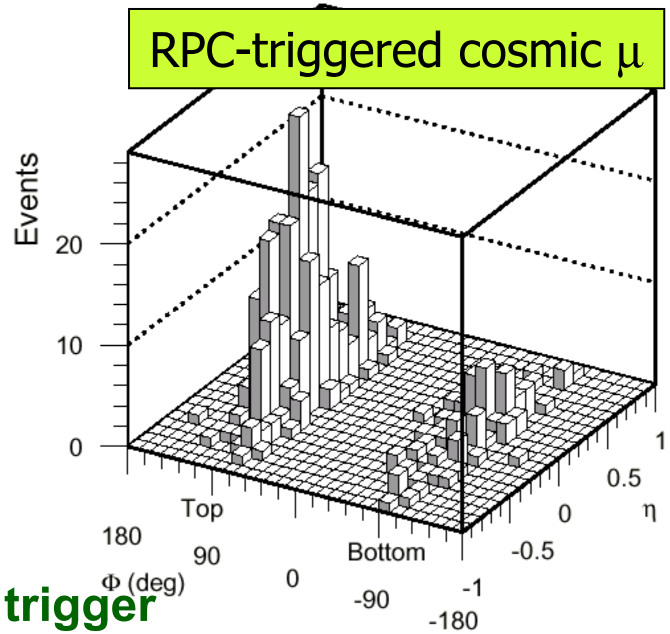
From test-beam studies:

- Cell timing: < 1 ns
- Cell Energy: < 1 %
- Cell, module and wheel alignment: few mm
- Detect unconnected HV gaps

Non-collision Triggers



- **Most obvious and unbiased way:**
  - **-- Cosmics : RPC**
  - **-- Beam-halo : TGC**



- **From preliminary full simulations of <u>LVL1 as it is</u>:**
  -- Cosmic muons : ~ 100 Hz pass low-p_T RPC LVL1 trigger
  -- Beam-halo muons : ~ 1 Hz pass low-p_T TGC LVL1 trigger
  - **small enough → not worrying for LHC data taking**
  - **high enough → useful samples (e.g. > 10^8 cosmics evts in 3 months if ε=50%) for commissioning (triggered muons cross the interaction region)**
- **Also studying ways of increasing trigger rates during commissioning (dedicated TileCal cosmic trigger, min bias scint. planes in forward regions)**

Phase 5: First Collisions

- **With first collisions will begin to understand / calibrate physics objects.**
- **Assume the detector is already ready for data taking**
  - **Calorimeters set to EM scale**
  - **Readout channels reasonably intercalibrated (electronics, cosmics, Cs etc)**
  - **Hadronic response set with weighting techniques in MC or from testbeam.**
  - **ID & muon system aligned roughly (initial survey, cosmics etc.)**
- **Aim to measure**
  - **energy scales,**
  - **Resolutions**
  - **Efficiencies**
  - **Fake rates etc.**
- **Requirements from physics e.g.:**
  - **0.1% for the electron/muon energy/momentum scale**
  - **1% for the jet energy scale**
  - **Also, uniformity …..**
- **Initially won't have this precision, e.g. 0.5% for muons from initial field maps and survey, 1-2% for EM from test-beam, 5-10% for JES from test-beam/MC.**

Strategy

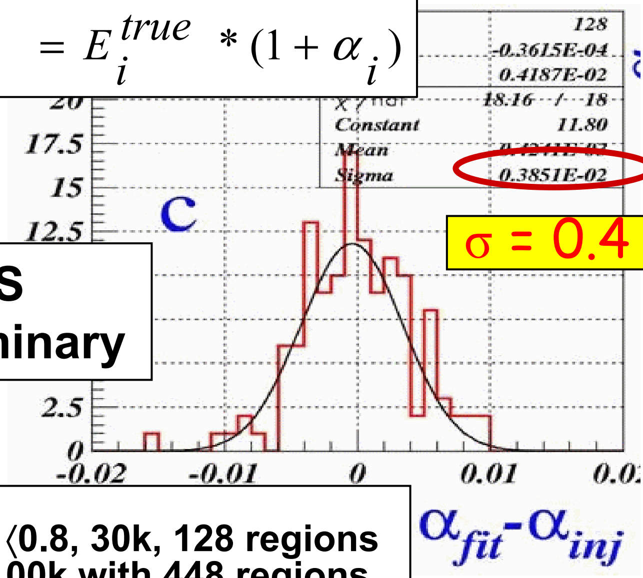
- Use isolated charged tracks (e.g. from τ decays) to
  - cross-check pre-collision alignment,
  - determine E/p matching precision,
  - determine hadronic energy scale,
  - Intercalibrate calorimeters
- Use J/ψ (low p_T) and Z^0 (high p_T) with mass constraint to
  - (Inter)calibrate LAr EM
  - Calibrate e/μ E/p scales
- Use W mass constraint in W→jj from ttbar production to set JES.
- Use Z^0/γ + jet events to calibrate across calorimeters (cracks, dead material) and monitor.
  - p_T balance between jet Z^0/γ
- Later use Z^0/γ + b-jet events to calibrate b-JES. Also measure b-tagging efficiency in situ with top events.

LArEM Intercalibration

Work in progress

- **From hardware and beam tests: calibration known to 0.5-0.6 % inside 448 windows of $\Delta\eta\times\Delta\Phi = 0.2 \times 0.4$ inside $|\eta| \langle 2.5$**
- **Need 0.3% intercalib to achieve 0.7 % global constant term**
- **Use real data to intercalibrate (Z^0, J/ψ, electron E/p, inclusive p_T distributions, photon conversions,…)**
- **Z ➔ ee decay**
  - **High rate (0.5-1 Hz), low background, easy trigger, uniform in η and φ, well known process, 2 correlated electromagnetic objects…**
  - **Define reference M_{ee} distributions and fit to invariant mass of e+e- in given pair of regions by tuning regional 'decalibration' coefficients α_i**

$$E_i^{new} = E_i^{true} * (1 + \alpha_i)$$



σ = 0.4 %

ATLAS Preliminary

$|\eta|\langle 0.8$, 30k, 128 regions
≡ 100k with 448 regions

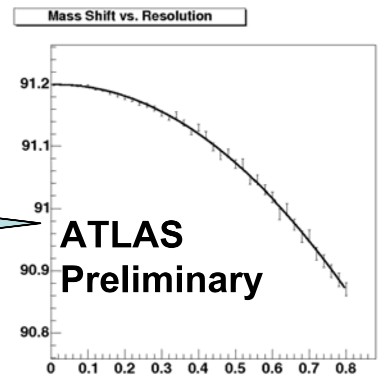
Extrapolation: 0.3 % with 448 regions with 170k (2-3 days)

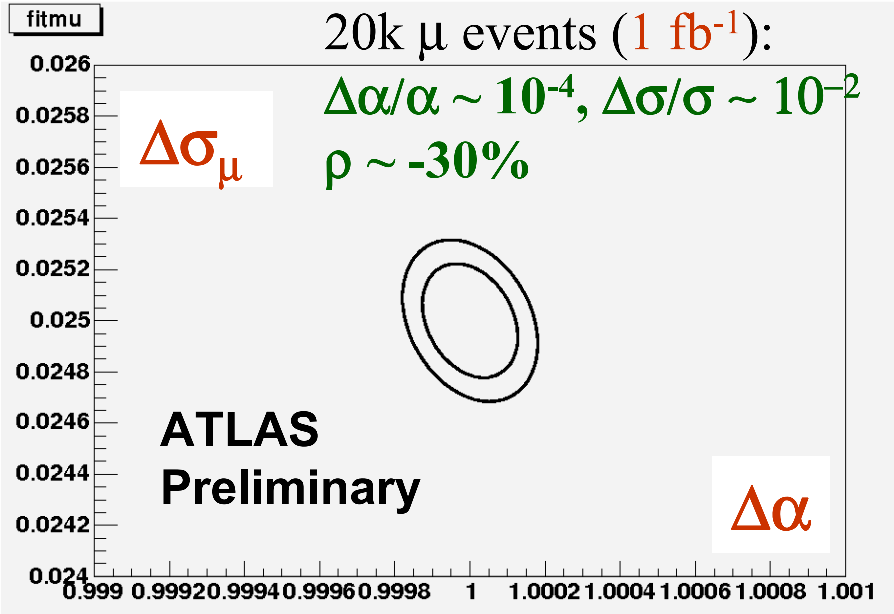
- **J/ψ ➔ ee decay**
  - **~ $5*10^5$ J/ψ in 1 year of low lumi (reconstruction eff=20%), trigger pt(μ) > 6 GeV**
  - **Gives check on linearity at low energy**
  - **Expected intercalibration precision of 0.6%**

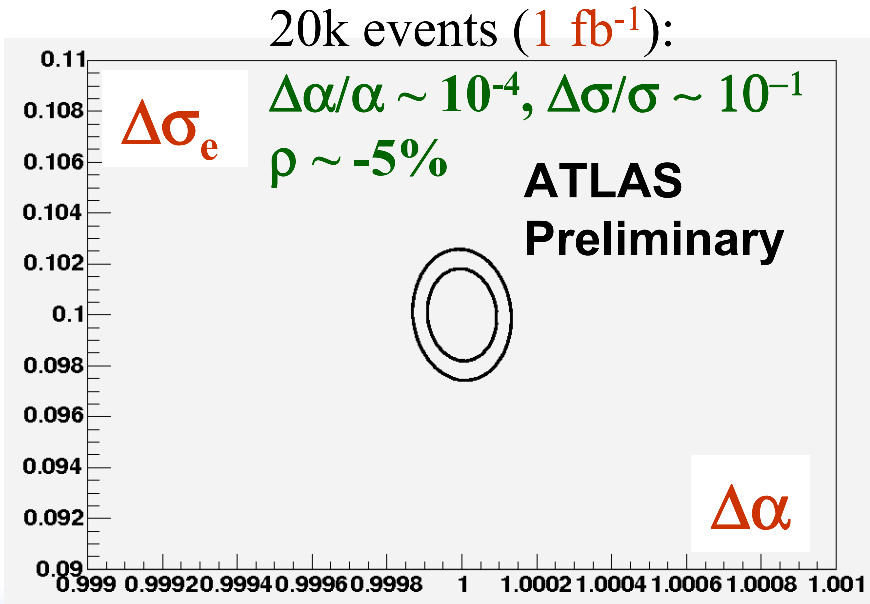
EM/μ Scales from Z^0

Work in progress

- Measure e/μ/γ energy scales using Z→ee(γ)/μμ(γ).
- Create reference distributions for each channel
- Then minimize χ^2 comparing reference distributions and data varying the e, μ, γ E/p scales α_e, α_μ, α_γ
- Also consider concurrently as accuracy improves:
  - resolution effects (can shift peak)
  - PDFs (" " ")
  - FSR (" " ")





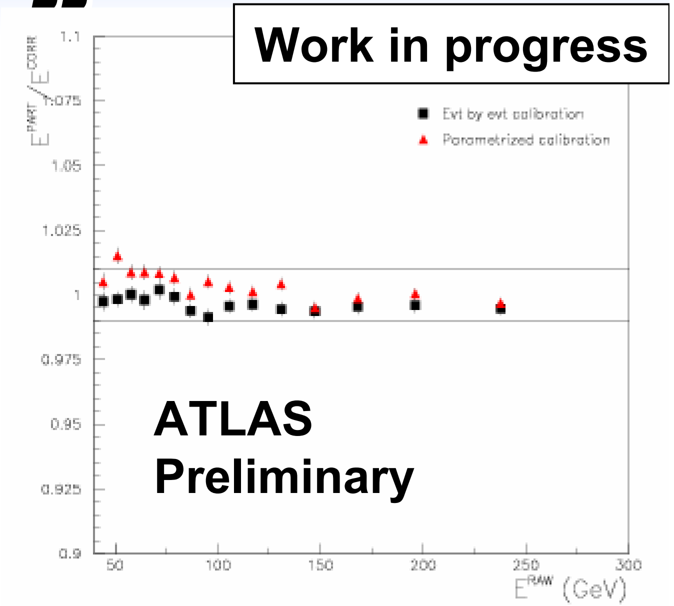


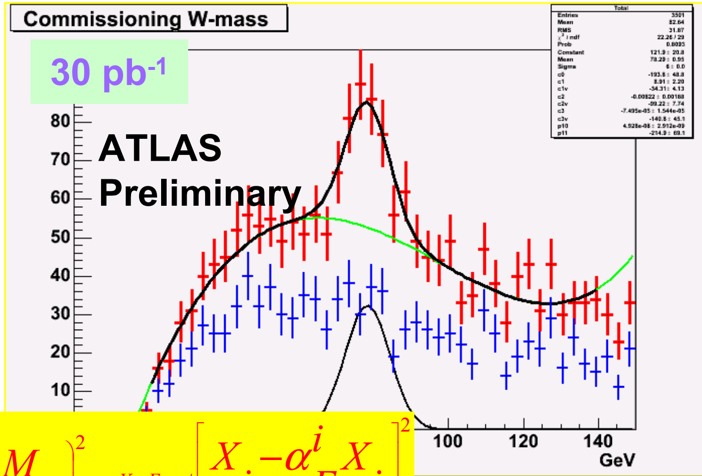
JES from W→jj

- Use the mass constraint of the W in ttbar events, to set the JES / rescale jet to parton energy $\alpha = E_{parton} / E_{jet}$

$$M_{jj} = \sqrt{2E_{j1}E_{j2}(1-\cos\theta_{j1j2})} = M_W$$

  - Take into account E, η and φ in the minimization procedure and corrected energies and angles.
  - E of parton and jet agree within ~ 1% over the range 50-250 GeV
  - Pros: Good statistics, easily triggerable, small physics backgrounds.
  - Cons: Only light q jets, limitations in E and η reach.
- More recently: investigating cases with 0, 1 or 2 b-tags.
  - Consider more sophisticated approach: fit to W mass dist rather than simple rescaling:
  - Takes into account variation of rescaling parameter with energy and correlation between energies and opening angle.

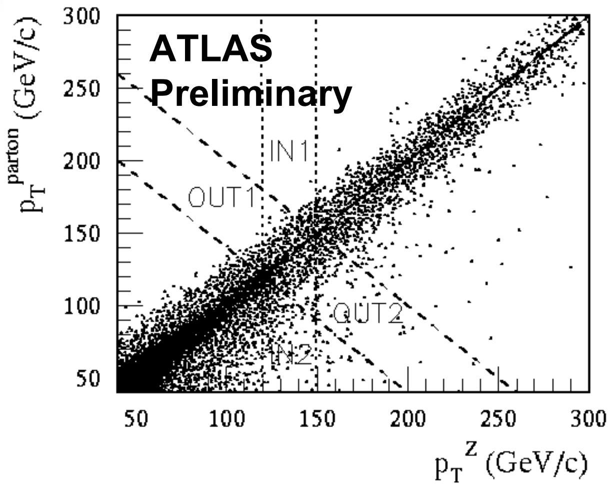




$$\chi^2 = \left(\frac{m_{jj} - M_W}{\sigma_W}\right)^2 + \sum_{1,2}^{X=E,\eta,\phi} \left[\frac{X_i - \alpha_E^i X_i}{\sigma_X}\right]^2$$

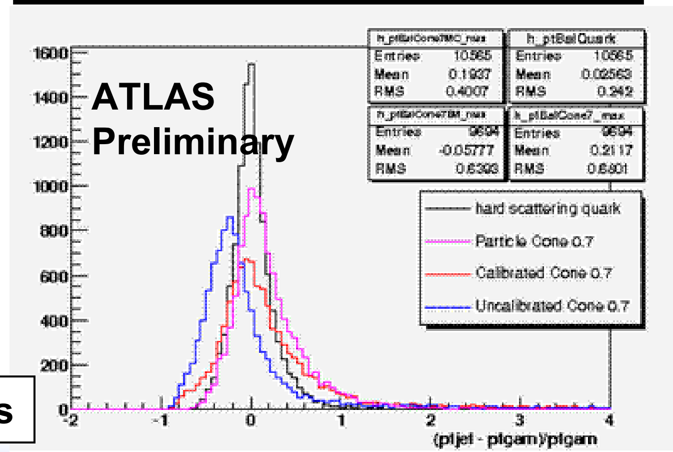
JES with γ/Z^0+jet

- **Use the p_T balance between Z or photon (precisely measured) and highest p_T jet**
  - **Reconstructed jet p_T rescaled to balance the Z p_T.**
- **Distribution systematically skewed, esp by ISR (and FSR)**
- **Pros:**
  - **Enlarged E and (especially) η reach wrt W→jj,**
  - **includes 6% of b-jets,**
  - **potentially large statistics available: γ+jet with p_T>20 GeV: ~10K events/min. (not incl. eff. & trigger)**
- **Cons:**
  - **Easy to introduce biases in the selection procedure,**
  - **sensitivity to ISR modeling, esp at low p_T,**
  - **background to the γ or Z^0 may bring additional bias**
  - **p_T range covered with good statistics limited.**
  - **The effect of the trigger has also to be considered (standard menu or downscaled)**
- **Also : dijet calibration, E_T^{miss} projection method**
- **Also use Z^0 + b-jet to calibrate b-JES**



20-60 GeV	60-120 GeV	>120 GeV
0.049	0.015	0.004

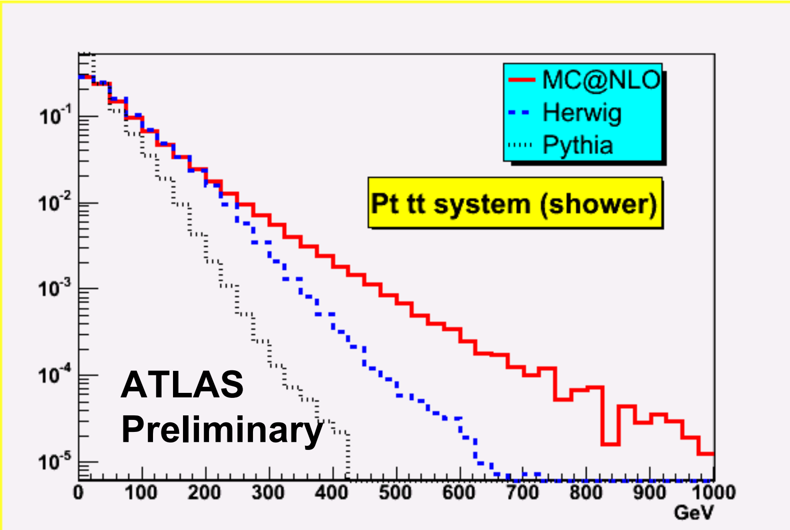
1% difficult below 60 GeV



Work in progress

Phase 6: First Physics

- Vast topic – in principle as many background estimation techniques as analyses
- In practice large degree of commonality, although different emphases.
- Need to
  - Minimise most poorly estimated backgrounds (at expense of statistics?);
  - Estimate remaining backgrounds from combination of data and MC;



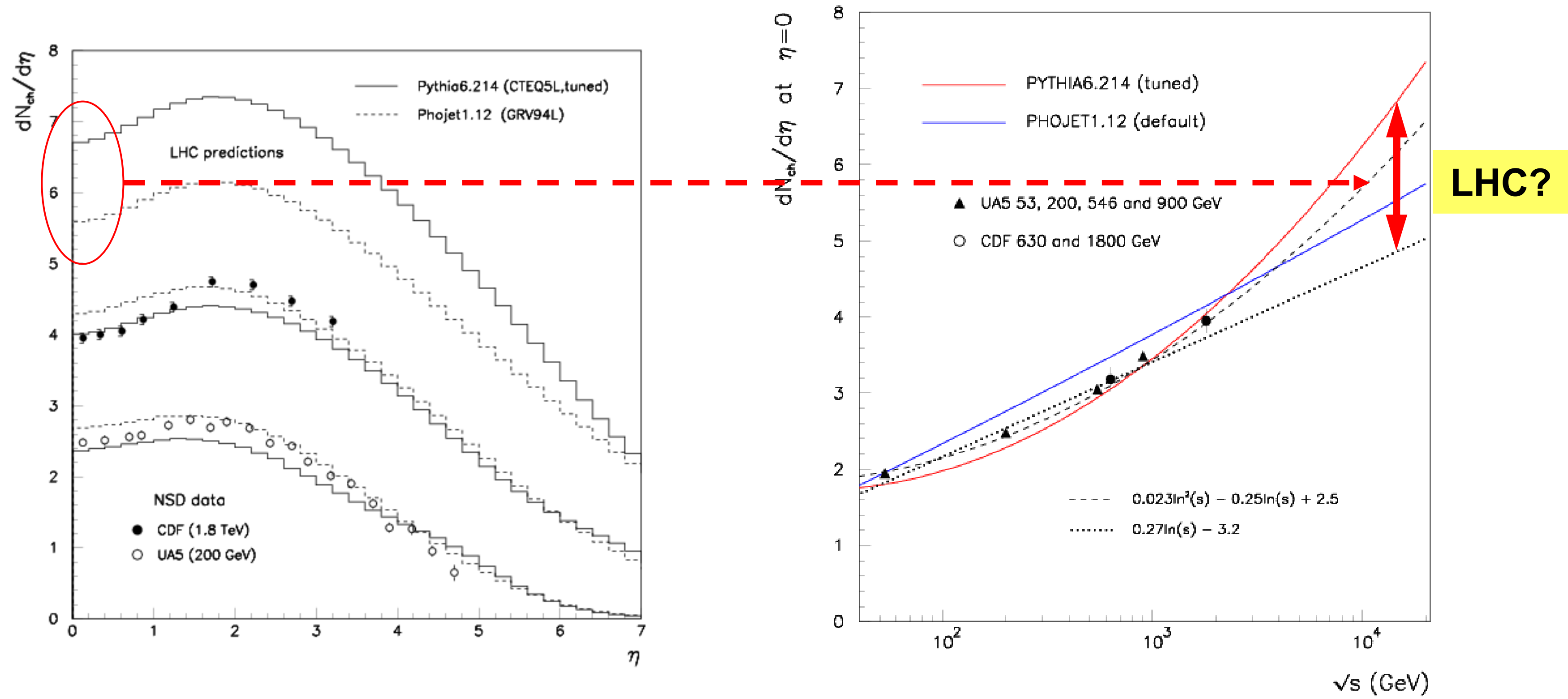
Large differences between NLO/LO MC codes ➔ Use even NLO codes with caution!

- We can learn a lot from RunII <u>but</u> one big difference:

  There will have been no previous measurements at similar √s!
- Will concentrate on three case studies: Min bias, Top and SUSY

Early Min-Bias Measurements

- **Charged particle density at η = 0**



- **Energy dependence of dN/dη ?**
- **Vital for tuning UE model (see later)**
- **Only requires a few thousand events.**

- **PYTHIA models favour $\ln^2(s)$;**
- **PHOJET suggests a ln(s) dependence.**

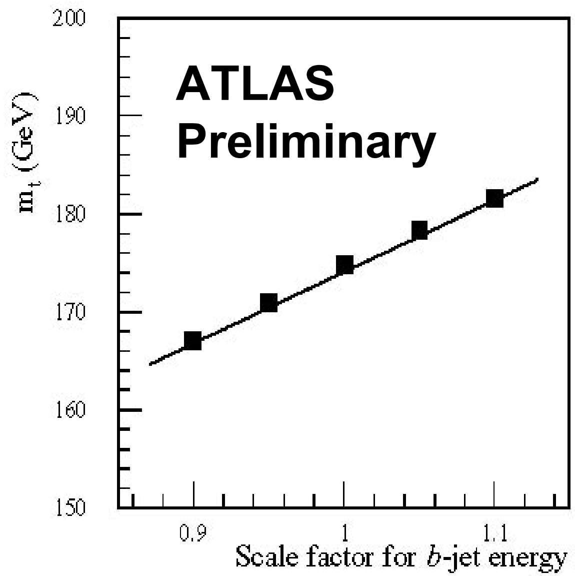
Top Mass

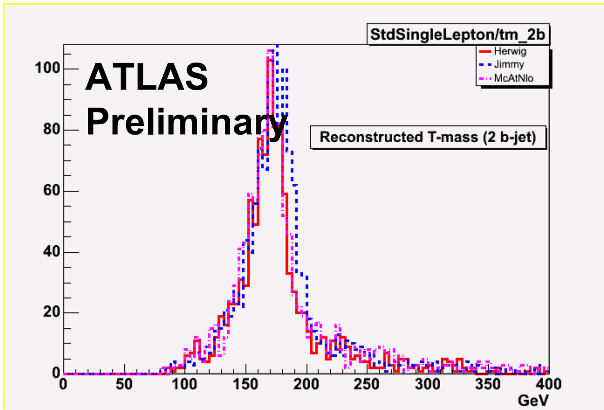
- **Assume low luminosity and/or detector pessimistic scenarios**
  - **Partly or non-working b-tagging at startup**
  - **Dead regions in the LArEM**
  - **Jet energy scale**
- **Initially uncertainty on b-jet energy scale expected to be dominant:**

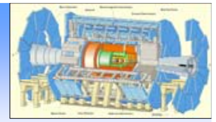
b-jet scale uncertainty	δM_{top}
1%	0.7 GeV
5%	3.5 GeV
10%	7 GeV

Cf: 10% on q-jet scale → 3 GeV on M_{top}

- **Important to understand UE (see earlier) ➔ can have a large effect (as large as 5 GeV on m_t)**







QCD Multijet Background

- **Not possible to realistically generate this background**
  - **Crucially depends on Atlas' capabilities to minimize mis-identification and increase e/π separation**
- **This background *has* to be obtained from data itself**
  - **E.g. method developed by CDF during run-1:**

Use missing ET vs lepton isolation to define 4 regions:

A. Low lepton quality and small missing E_T

Mostly non-W events (i.e. QCD background)

B. High lepton quality and small missing E_T

Observation of reduction in QCD background by isolation cut

C. Low lepton quality and high missing E_T

W enriched sample with a fraction of QCD background

D. High lepton quality and high missing E_T

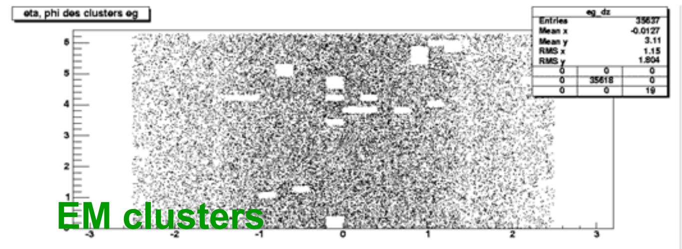
W enriched sample

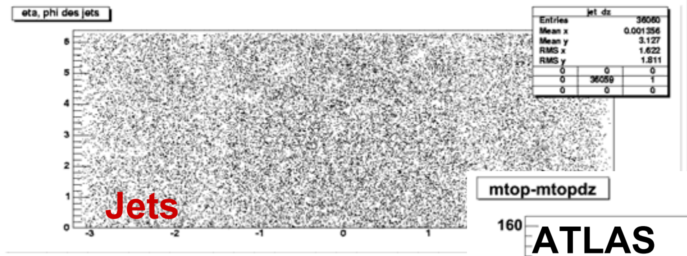
  - **The QCD reduction factor B/A can be applied to the "W enriched sample " (region C and D).**
  - **The non-W candidate in D will therefore be (B/A)xC. Therefore, the fraction of non-W events in the region D will be:**

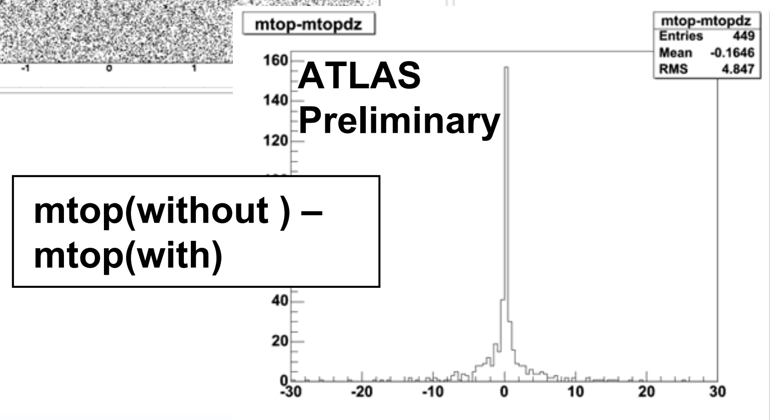
(B.C)/(A.D)

Effects of Dead Regions

- **Argon gap (width ~ 4 mm) is split in two half gaps by the electrode**
  - **~ 33 / 1024 sectors where we may be unable to set the HV on one half gap → multiply energy by 2 to recover**
- **Simulated 100 000 tt events (~ 1.5 days at LHC at low L)**
- **If 33 weak HV sectors die (very pessimistic), effects on the top mass measurement, after a crude recalibration, are:**
  - **Loss of signal: < 8 %**
  - **Displacement of the peak of the mass distribution: -0.2 GeV**
  - **(Increase in background not studied)**





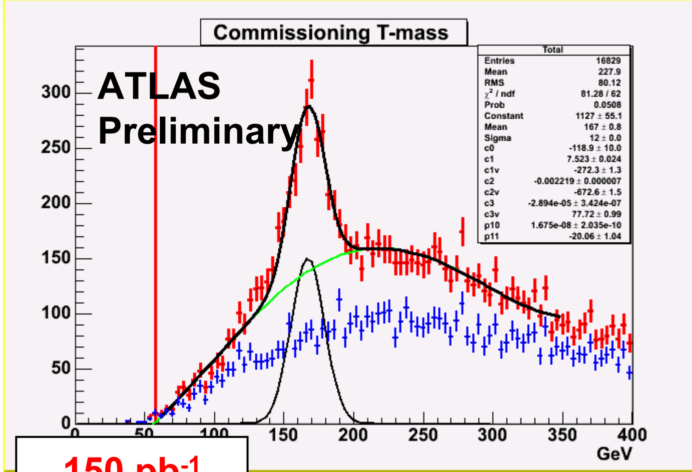


Top Mass without B-tag

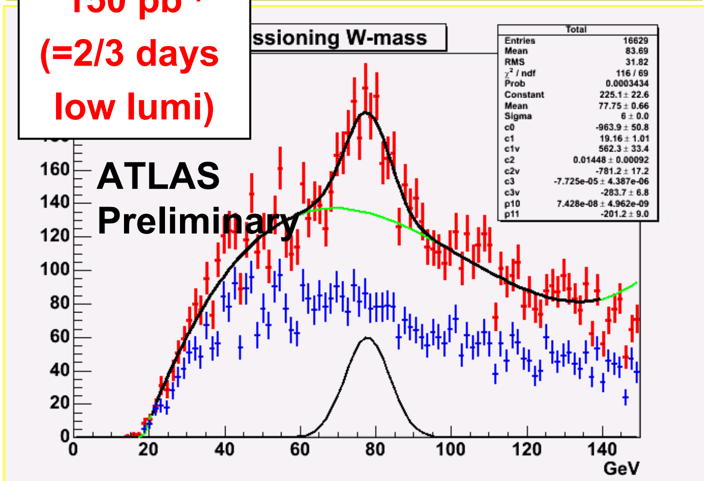
- Most important background for top: W+4 jets
  - Leptonic decay of W, with 4 extra 'light' jets
- Selection:
  - Isolated lepton with P_T>20 GeV
  - Exactly 4 jets (ΔR=0.4) with P_T>40 GeV
- Reconstruction:
  - Select 3 jets with maximal resulting P_T
- Try to identify W peak (also useful for JES calibration)
- Select highest p_T 2 jet combination
  - W peak visible in signal
  - No peak in background
  - Better ideas possible?

ATLAS Preliminary

150 pb^{-1}	mean	σ(stat)
Mtop	167.0	0.8
Mw	77.8	0.7



150 pb^{-1} (=2/3 days low lumi)



Health warning: Systematics not included / fast simulation used. Currently under detailed study

Lower luminosity?

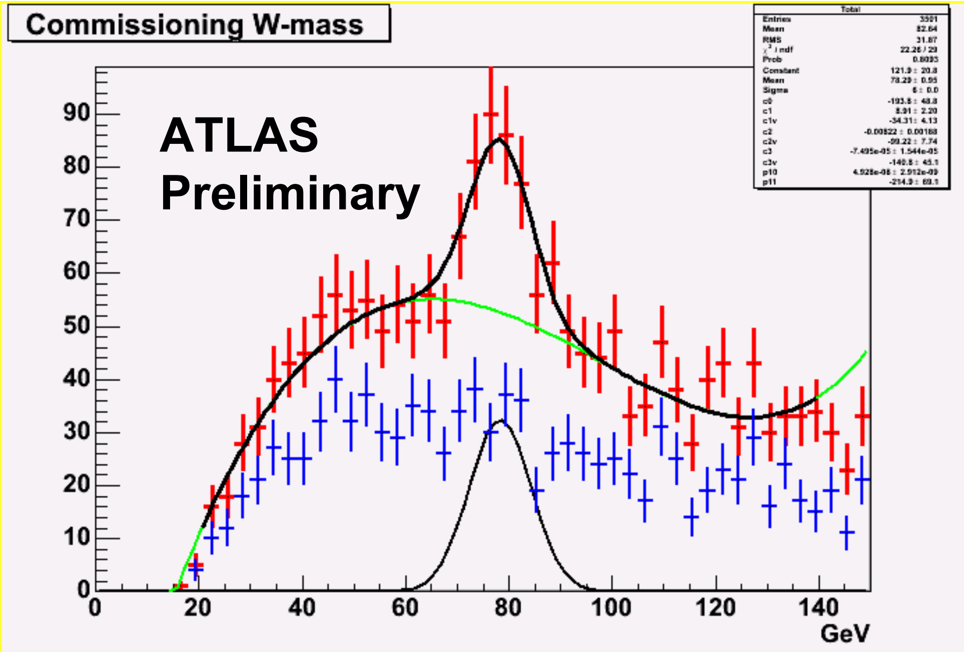
- Go down to 30 pb^{-1}
  - Both W and t peaks already observable
  - See something!

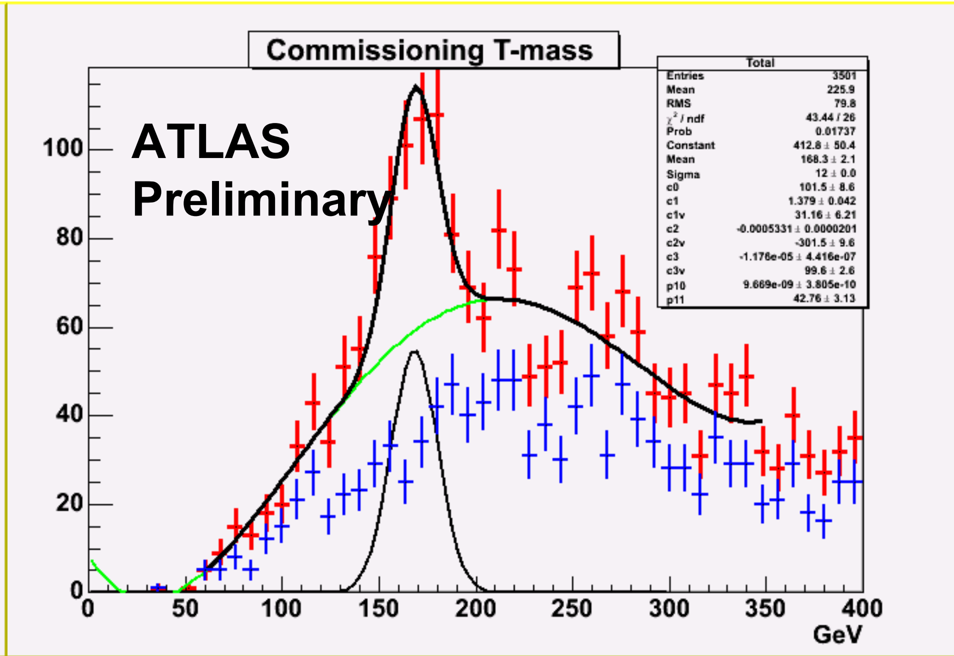
30 pb^{-1}

ATLAS Preliminary

30 pb^{-1}	mean	σ(stat)
Mtop	170.0	3.2
Mw	78.3	1.0

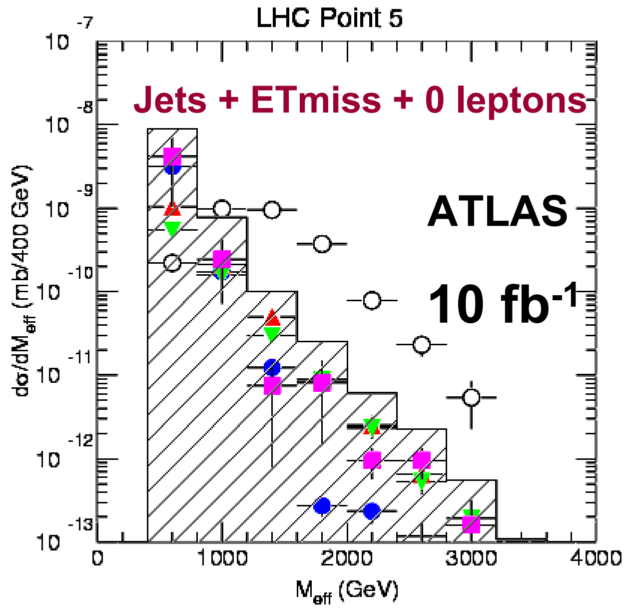
Health warning: Systematics not included / fast simulation used.
Currently under detailed study

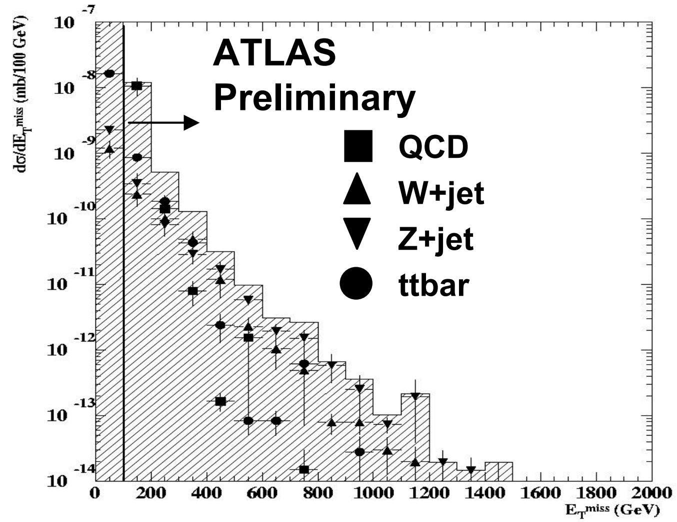




SUSY

- Inclusive signature: jets + n leptons + E_T^{miss}
- Main backgrounds:
  - Z + n jets
  - W + n jets
  - ttbar
  - QCD
- Greatest discrimination power from E_T^{miss} (R-Parity conserving models)
- Generic approach to background estimation:
  - Select low E_T^{miss} background calibration samples;
  - Extrapolate into high E_T^{miss} signal region.
- Extrapolation is non-trivial.
  - Must find variables uncorrelated with E_T^{miss}





Background Estimation

- Aim to use techniques developed at CDF/D0 + some new ones
- W/Z + n jets
  - $Z \rightarrow \nu\nu$ + n jets, $W \rightarrow l\nu$ + n jets, $W \rightarrow \tau\nu$ + (n-1) jets (τ fakes jet)
  - Estimate from $Z \rightarrow l^+l^-$ + n jets (e or μ)
  - Tag leptonic Z and use to validate MC / estimate E_T^{miss} from $p_T(Z)$ & $p_T(l)$
- QCD / fake E_T^{miss} (from gaps in acceptance, dead/hot cells, non-gaussian tails etc.)
  - Much harder : simulations require detailed understanding of detector performance (not easy with little data).
  - Strategy (learn from Tevatron):
    1) Initially choose channels which minimise contribution until well understood
    2) Reject events where fake E_T^{miss} likely: beam-gas and machine background, bad primary vertex, hot cells, CR muons, E_T^{miss} vector pointing in (opposite) direction of (to) jets (jet fluctuations), jets pointing at regions of poor response, large Missing E_T Significance
    3) Choose hard cuts which minimise contribution to background.
    4) Estimate background using data and/or calibrated fast MC: need to estimate jet resolution functions using e.g. E_T^{miss} projection

Top Background

- Estimation using simulation possible (normalised to data ttbar selection) - cross-check with data ?
- Standard (TDR) semileptonic top cuts look rather like SUSY cuts with looser E_T^{miss} requirement!

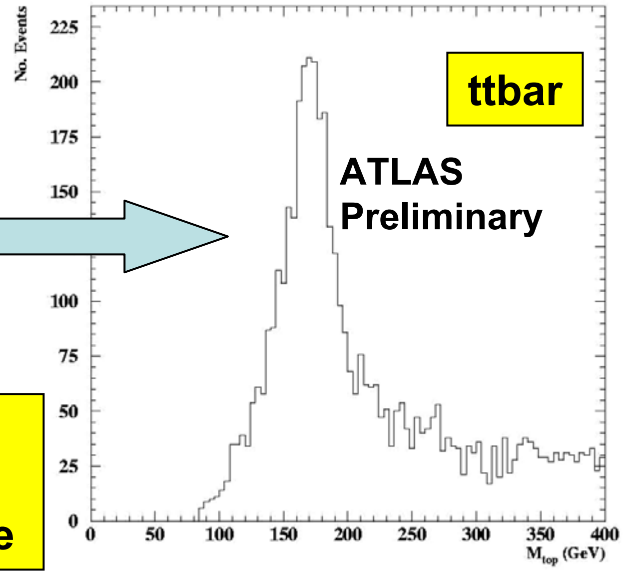
Process	$p_T^l > 20$GeV $E_T^{miss} > 20$GeV	As before, plus $N_{jet} \geq 4$	As before, plus $N_{b\text{-}jet} \geq 2$	Events per 10 fb^{-1}
$t\bar{t}$ signal	64.7	21.2	5.0	126 000
W+jets	47.9	0.1	0.002	1658
Z+jets	15.0	0.05	0.002	232
WW	53.6	0.5	0.006	10
WZ	53.8	0.5	0.02	8
ZZ	2.8	0.04	0.008	14
Total background				1922
S/B				65

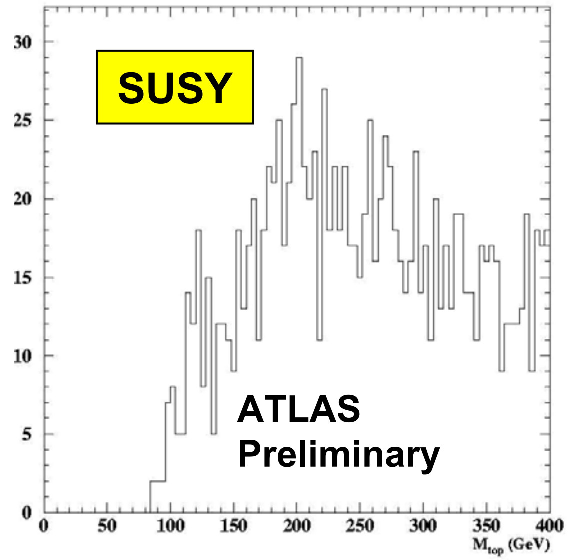
ATLAS Physics TDR

- If harden E_T^{miss} cuts top sample contaminated with SUSY signal (bias) …
- Possible approach?
  - Select semi-leptonic candidates (standard cuts – what btag available?);
  - Fully reconstruct top from E_T^{miss} & W mass constraint;
  - Reduce combinatorics with highest p_T W candidate
  - Reject (SUSY) background with mass cut & mtop sideband subtraction;
  - Use to validate top production in MC / estimate remaining E_T^{miss} background.

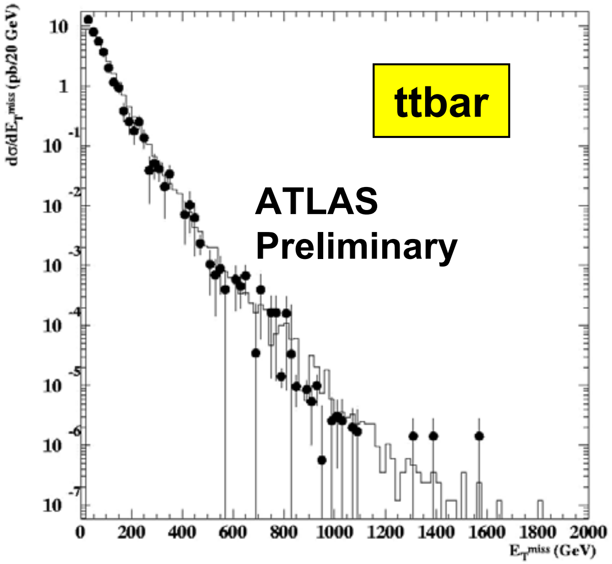
Top Reconstruction

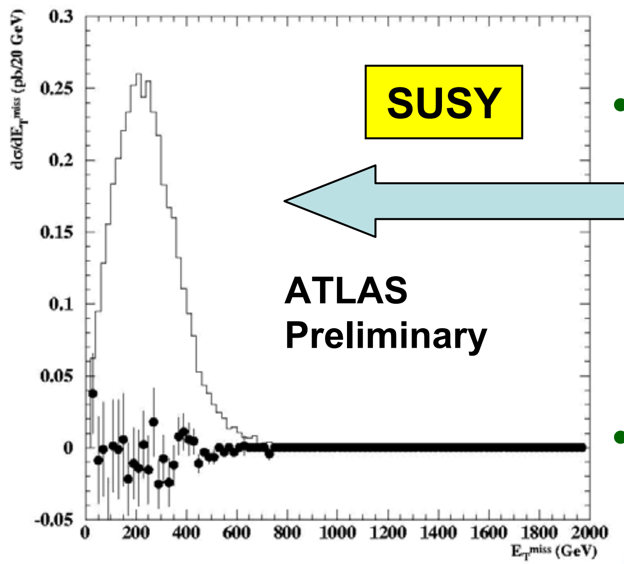
- Reconstructed leptonic top mass peak (c.f. SPS1a SUSY events)
- Significant combinatorial background





Histogram – 1 lepton SUSY selection (no b-tag)
Data points – background estimate





- Key question: does this approach select SUSY events (hence introduce bias)?
- No evidence for this

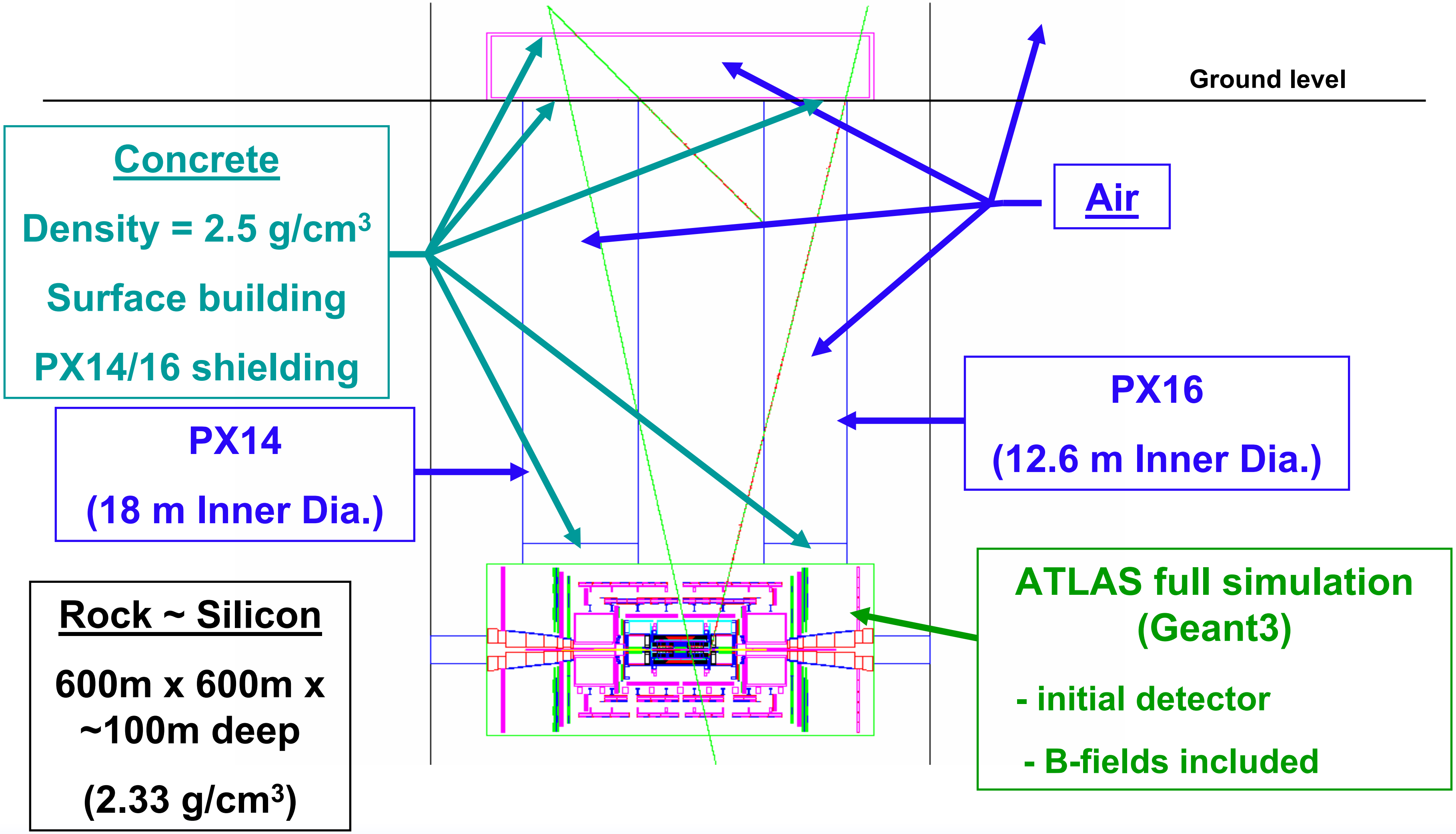
Conclusions

- **Lots of work currently being carried out preparing for first data.**
- **Detailed studies of calibration & alignment with cosmics and beam halo / beam-gas**
- **Preliminary studies of commissioning using collision data completed – more on-going.**
- **Physics Working Groups studying techniques needed to estimate/reduce backgrounds to specific channels → also requires development of new tools.**
- **ATLAS will be ready to make optimum use of first physics data when it arrives.**

Backup Slides

Phase 3: Cosmic μ

- Full simulation of cosmic ray muons in ATLAS developed (G3)



Expected Cosmics Rates

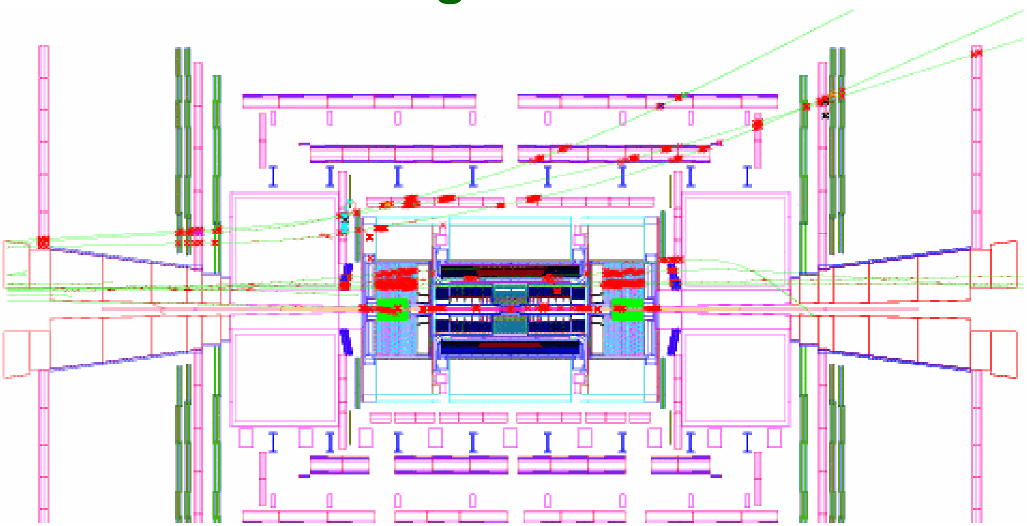
ATLAS Preliminary	Condition	Rate (Hz)	
		$E_{surface}$> 10 GeV ("PDG" approximation)	$E_{surface}$>10 GeV ("ALE" generator)
ATLAS UX15	--	5900	4900
Any G3 digit	--	2800	2300
Through going	$RPC_{Y>0}$ x $RPC_{Y<0}$ x ID_{DIGI}	28	24
	$RPC_{Y>0}$ x $RPC_{Y<0}$ x PIX_{DIGI}	0.6	0.4
Pass by ≈ origin	$\|Z_{DIGI}\| < 300$, $\|R_{DIGI}\| < 60$ cm	12.2	10.2
	$\|Z_{DIGI}\| < 100$, $\|R_{DIGI}\| < 30$ cm	2.3	1.9
	$\|Z_{DIGI}\| < 60$, $\|R_{DIGI}\| < 20$cm	0.6	0.5
EM Cal	E_T^{CELL} > 5 GeV	0.1	0.1
	$E_T^{CLUSTER}$ > 5 GeV	0.2	0.2
	E_T^{TOTAL} > 5 GeV	0.4	0.4
Tile Cal	E_{TOTAL} > 20 GeV	1.4	1.2
HEC	E_{TOTAL} > 20 GeV	0.1	0.1
FCAL	E_{TOTAL} > 20 GeV	0.02	0.02

Beam halo

- Rates for initial period scaled from high-luminosity rates by assuming
- 3 x 10^{10} p per bunch and 43 bunches → ~ 200 times lower current (but assuming same vacuum, etc.)
- Total rates assume two months single-beam w/ 30% data taking eff.

Detector	Rate (B-field off)	Total (B-field off)	Rate (B-field on)	Total (B-field on)
MDT barrel	15 Hz	2.5 10^{7}	72 Hz	1.5 10^{8}
MDT end-cap	145 Hz	2.5 10^{8}	135 Hz	2.5 10^{8}
Pixel/SCT	1.8/17 Hz	3 10^{6} / 3 10^{7}	2/19 Hz	3 10^{6} / 3 10^{7}
EM E > 5 GeV	2 Hz	3.5 10^{6}	1 Hz	1.7 10^{6}
Tile/HEC E > 20 GeV	1.7/1.2 Hz	2.9/2.1 10^{6}	1.6/0.9 Hz	2.8/1.6 10^{6}

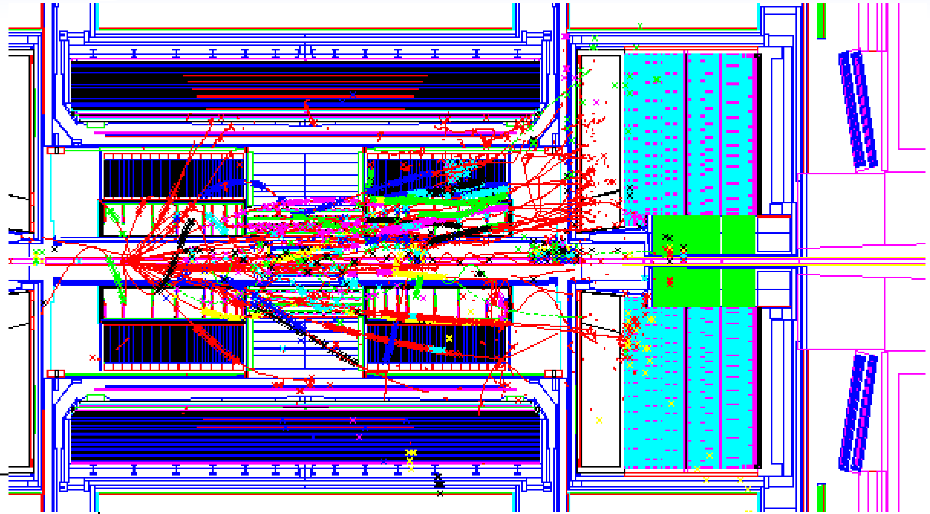
ATLAS Preliminary



- Simple definition of "useful tracks": 2-3 segments in MDT+ 3-4 disks in ID end-cap
- More recently: results from simulation of machine conditions in the commissioning period (including more realistic vacuum estimates, etc.) give rates ~ 7 lower

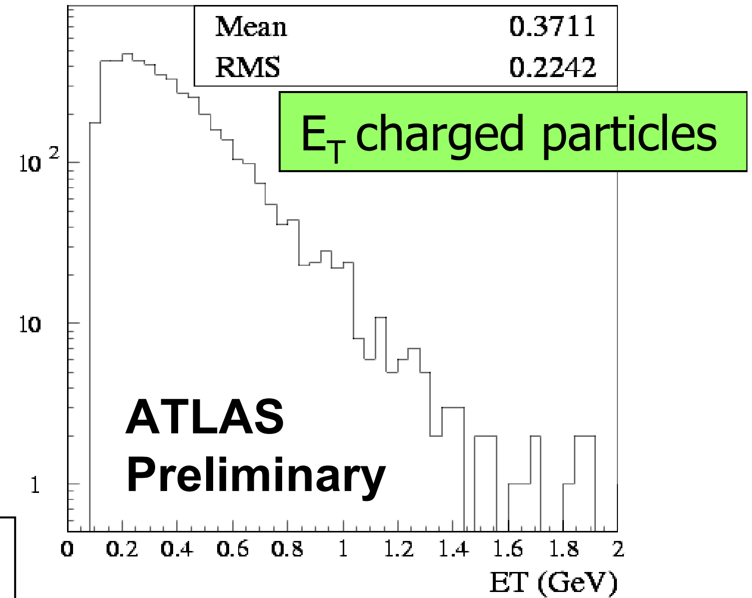
Beam-gas

- Essentially boosted minimum-bias events → low-p_T particles
- Rate : ~ 2500 interactions/m/s



Vertex z-position	Rate (Hz)	Total (2 months, ε=30%)
±23 m	1.2 10^5	2.1 10^{11}
± 3 m	1.6 10^4	2.4 10^{10}
± 20 cm	1.1 10^3	1.6 10^9
$\pi^\pm$ p_T > 1 GeV inside ± 3m	1.0 10^3	1.5 10^9
γ p_T > 1 GeV inside ± 3m	0.3 10^3	5.6 10^8

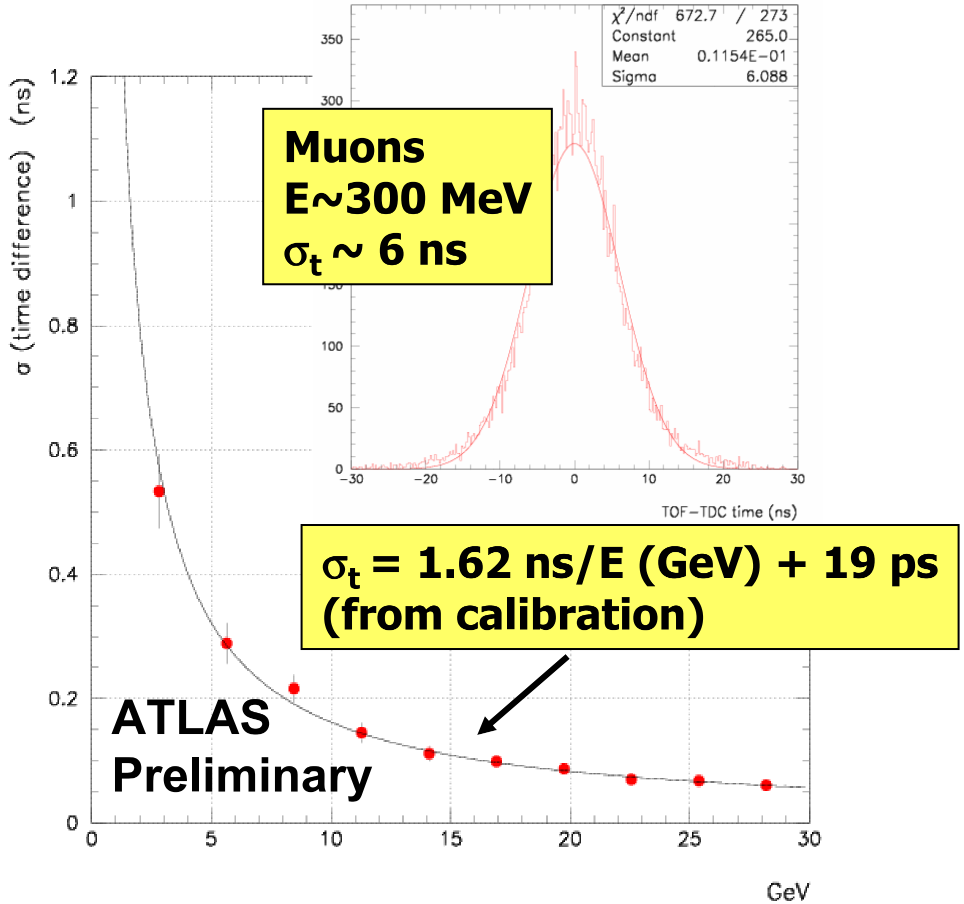
ATLAS Preliminary

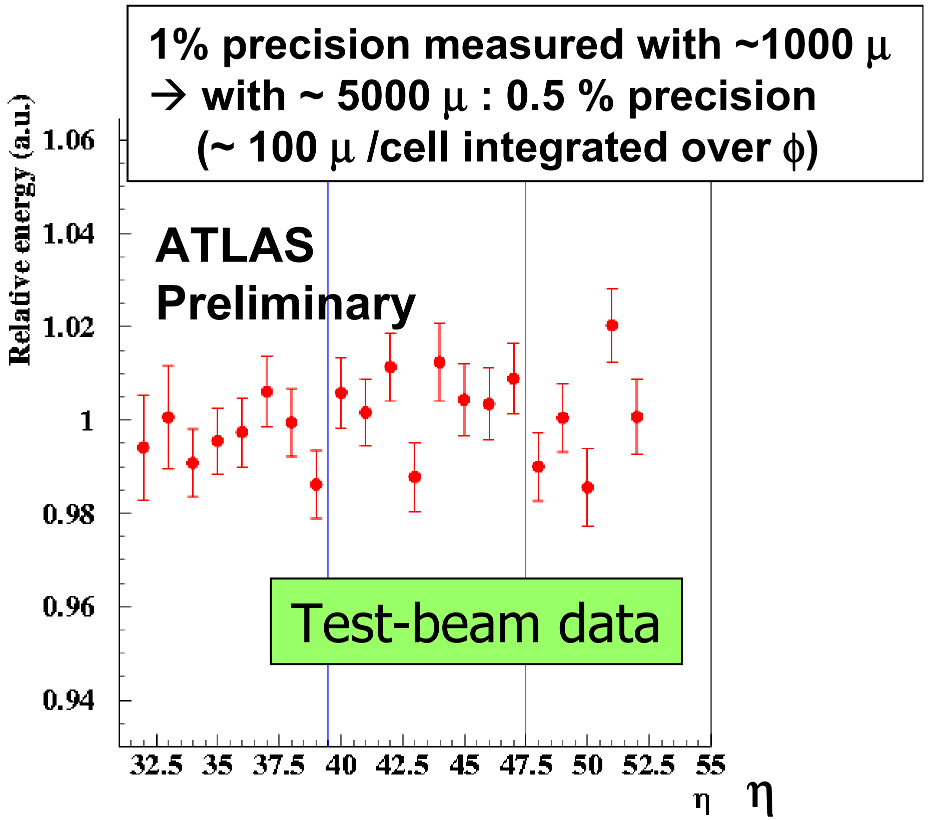


Cosmics in ECAL

With ~ 100 muons/cell in middle compartment:

- **check calorimeter timing to < 1 ns**
- **check calorimeter position in η / φ wrt other sub-detectors to < 1 mm**
- **check response uniformity vs η: ≈ 0.5% precision could be achieved**





Cosmics in μ System

- Cosmic rate high enough for polar angles up to $\theta=75^o$: ~1Hz/strad for muons going through the ID (almost projective) and $p_\mu>10$ GeV
  - Study of all barrel sectors (probably except sectors 1-9 with vertical chambers) and part of the forward chambers
- First test of the full reconstruction (field off/reduced/full field)
- Map dead channels, chase/replace faulty FE cards
- Tube efficiency, R-t relation (autocalibration):
  - 1000 (no field)-10000 (with field) μ/tube ⇒ ~10-100 days
- Check/calibration of the (barrel only?) alignment system with straight tracks (<30μm level): 2000μ/chamber ~10 hours
- Alignment μ barrel/ μ End cap, μ spectro/ID

B-Tagging Efficiency

- ε_{tag} = probability to tag at least one jet in a top event
  - $\varepsilon_{tag} = \varepsilon_{b\text{-}tag} + \varepsilon_{non\text{-}b} - (\varepsilon_{b\text{-}tag} \cdot \varepsilon_{non\text{-}b})$
  - $\varepsilon_{non\text{-}b} = \varepsilon_{c\text{-}tag} + \varepsilon_{nonhf}$
- $\varepsilon_{b\text{-}tag}$ is the sum of these possibilities:
  - Probability to tag 1 b-jet in the event, when 1 is found in the detector
  - Probability to tag 1 b-jet when 1 is found in the detector
  - Probability to tag 2 b-jets when 2 are found in the detector
- First simple evaluation (counting method):
  - Select a very pure ttbar sample with tight kinematical cuts
  - Count the number of events with at least 1 tagged b-jet
  - Divide this number by the number of pre-tag candidate events
- ε's are measured in MC. Account for difference in tagging between MC and data with Scale Factor:

$$\varepsilon_{b-tag}^{event} = F_{1b} \cdot \varepsilon_{btag} \cdot SF + F_{2b} \cdot \varepsilon^2{}_{btag} \cdot SF^2 + 2 \cdot F_{2b} \cdot \varepsilon_{btag} \cdot SF \cdot (1 - \varepsilon_{btag})$$

Probability to tag one B-jet when one is found	Probability to tag two B-jets when two are found	Probability to tag one B-jet when two are found

- F_{1b} = fraction of events with 1 taggable jets
- F_{2b} = fraction of events with 2 taggable jets