Introduction to ATLAS

- part 1: ATLAS Detector (and LHC)
- part 2: Physics programme in ATLAS
- **part 3: Event Reconstruction and Physics Performance**
- part 4: Physicists' tools analyses in ATLAS

Wolfgang Liebig

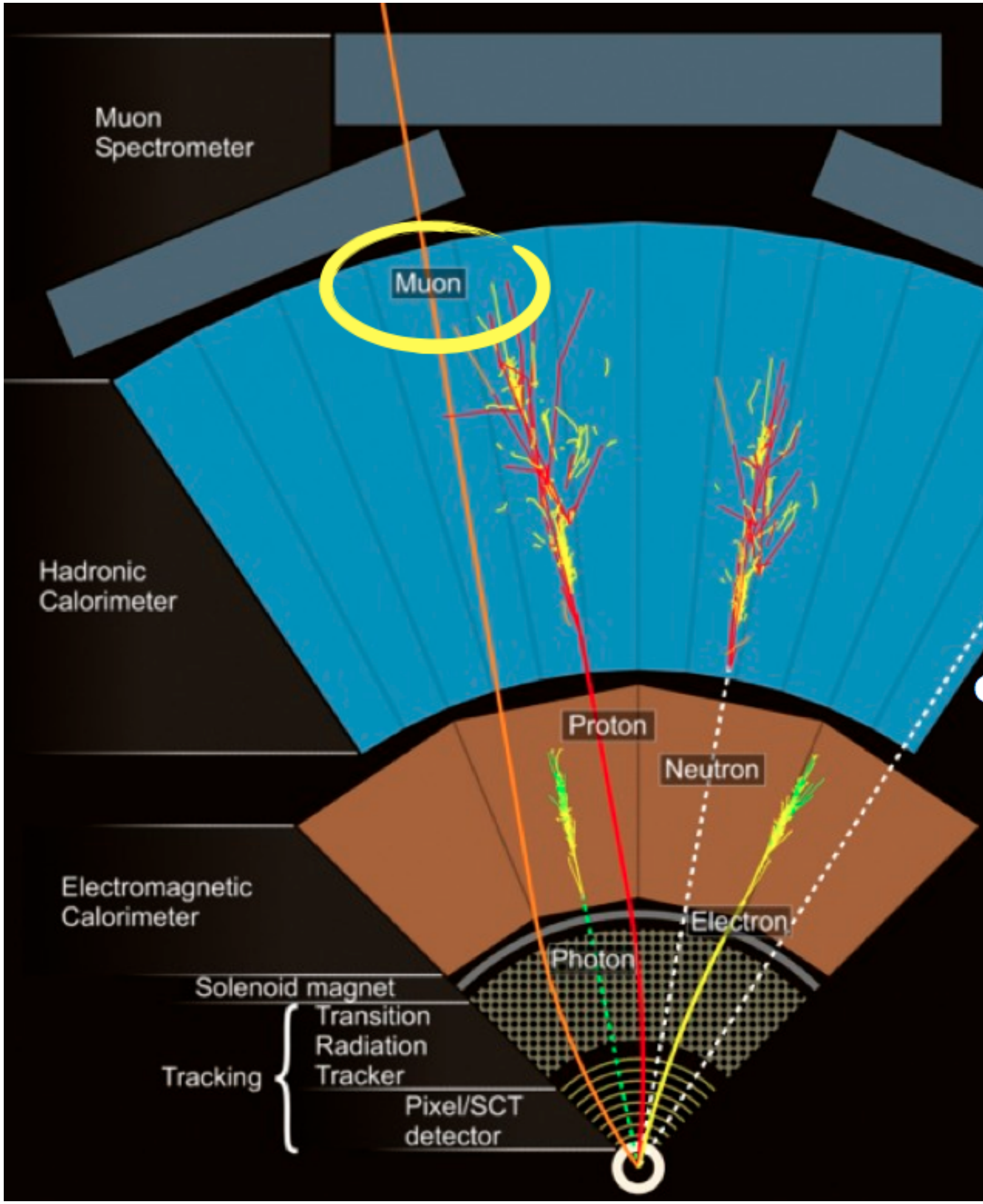
Part 3: Reconstruction & Performance

- Physics objects – overview
- Tracking
  – track representation, fit, performance
- muon performance
  – identification, performance, alignment
- vertex reconstruction
- b-tagging
- electron and photon reconstruction and performance
- jet reconstruction
- missing transverse energy
- tau lepton reconstruction

ATLAS EXPERIMENT

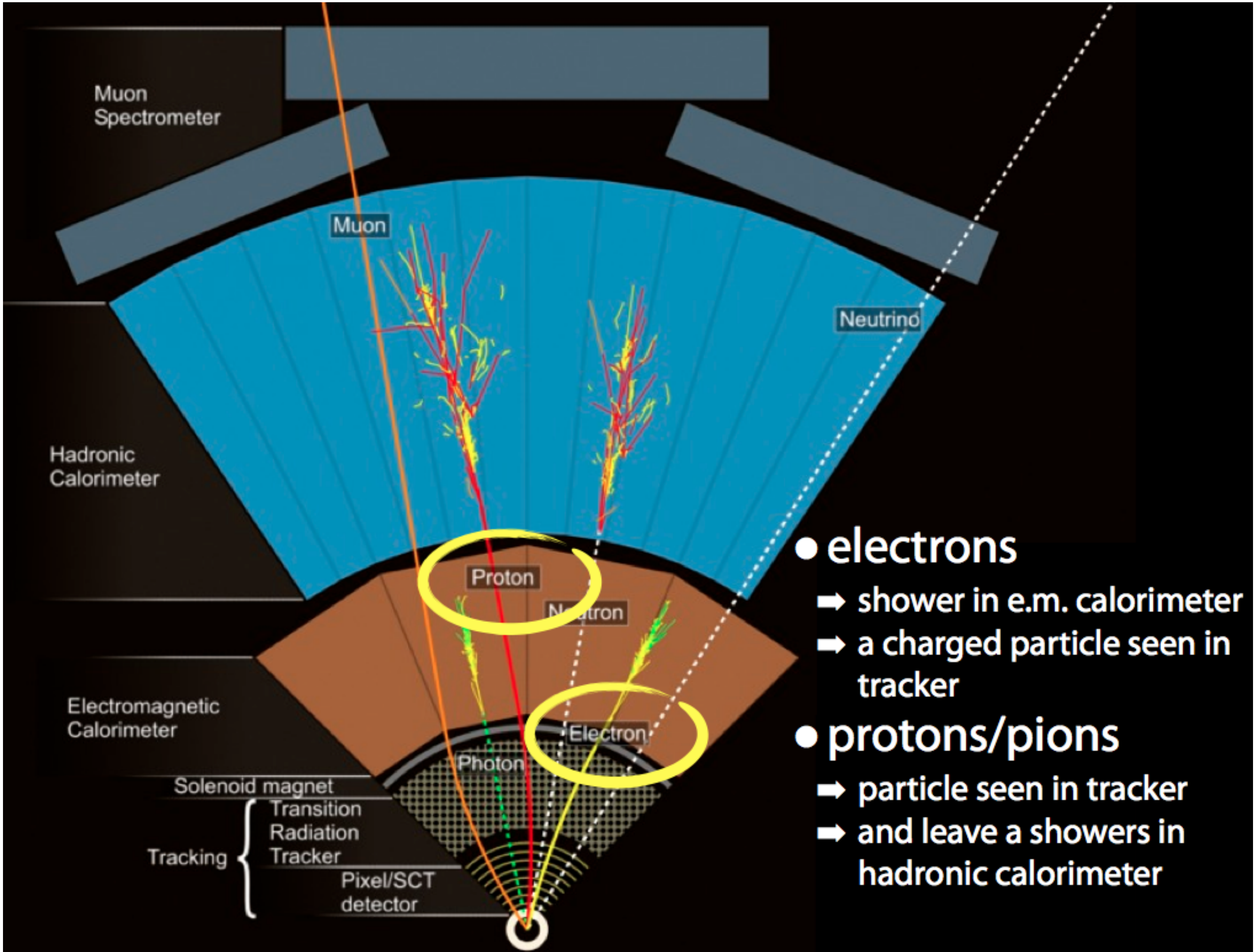
PD

Reconstruction in a Nutshell



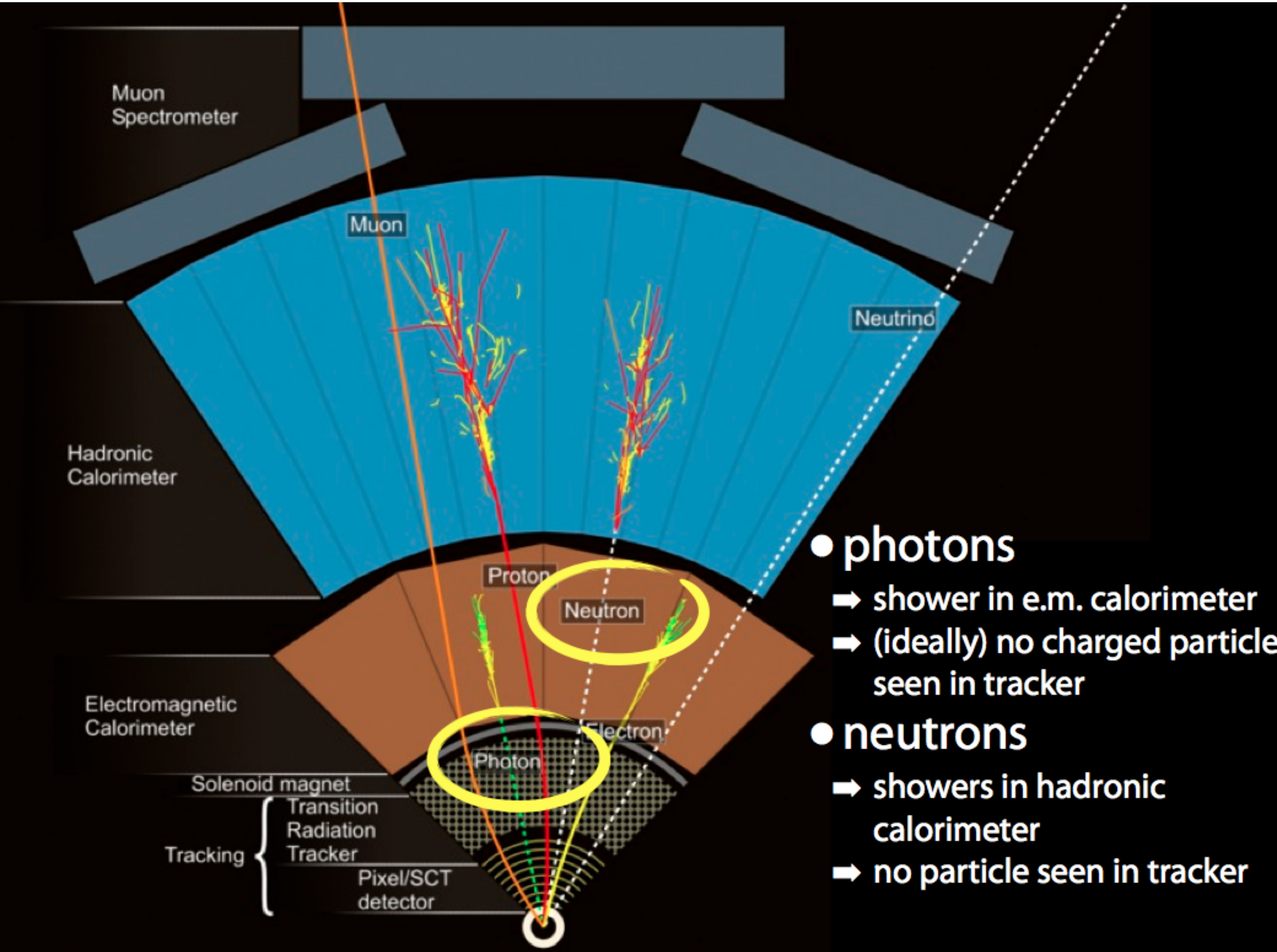
- muons
  - ➡ charged particle seen in tracker
  - ➡ little energy seen in calorimeters
  - ➡ particle seen in muon spectrometer

Electrons and Hadrons



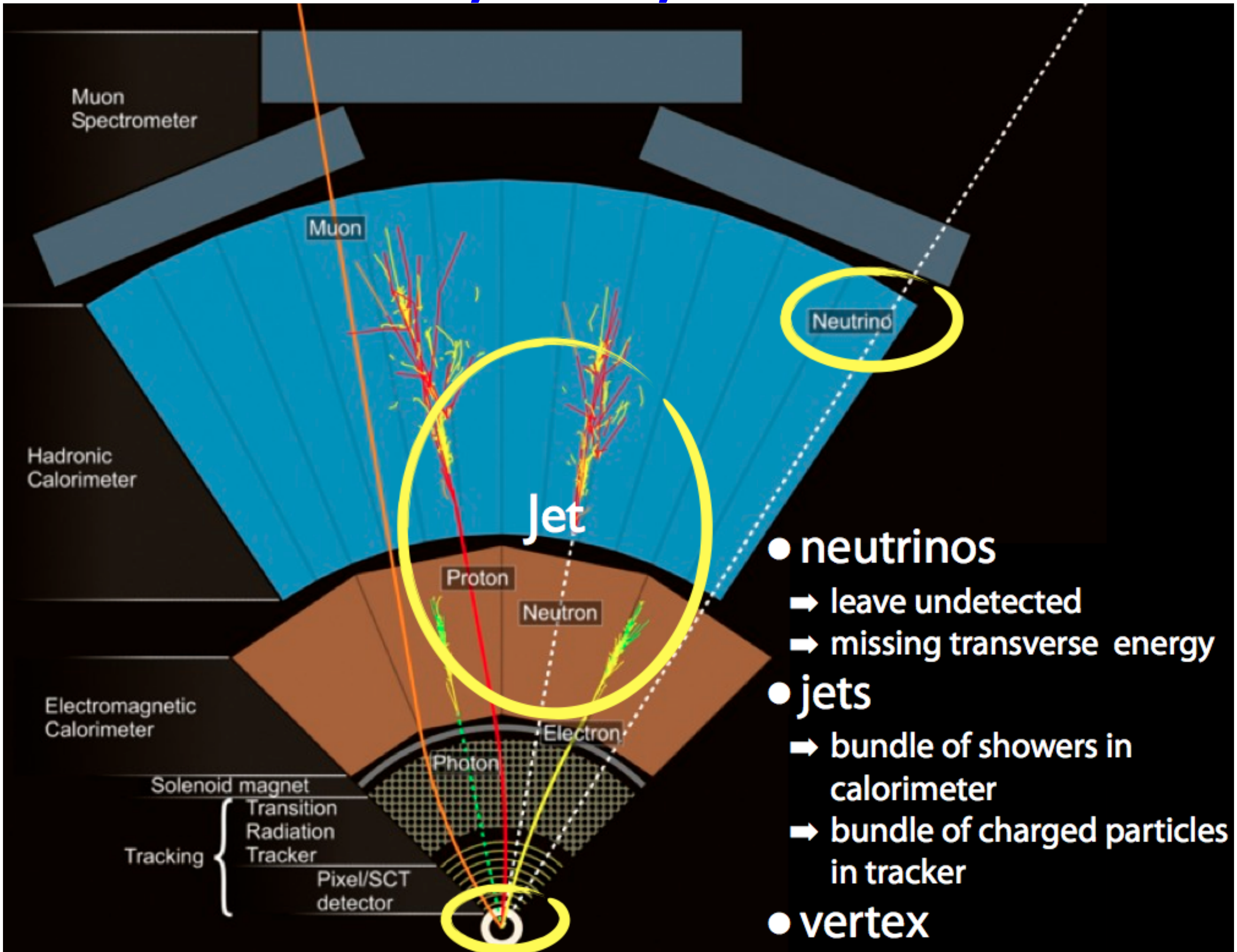
- **electrons**
  - ➡ shower in e.m. calorimeter
  - ➡ a charged particle seen in tracker
- **protons/pions**
  - ➡ particle seen in tracker
  - ➡ and leave a showers in hadronic calorimeter

Photons and Neutrons



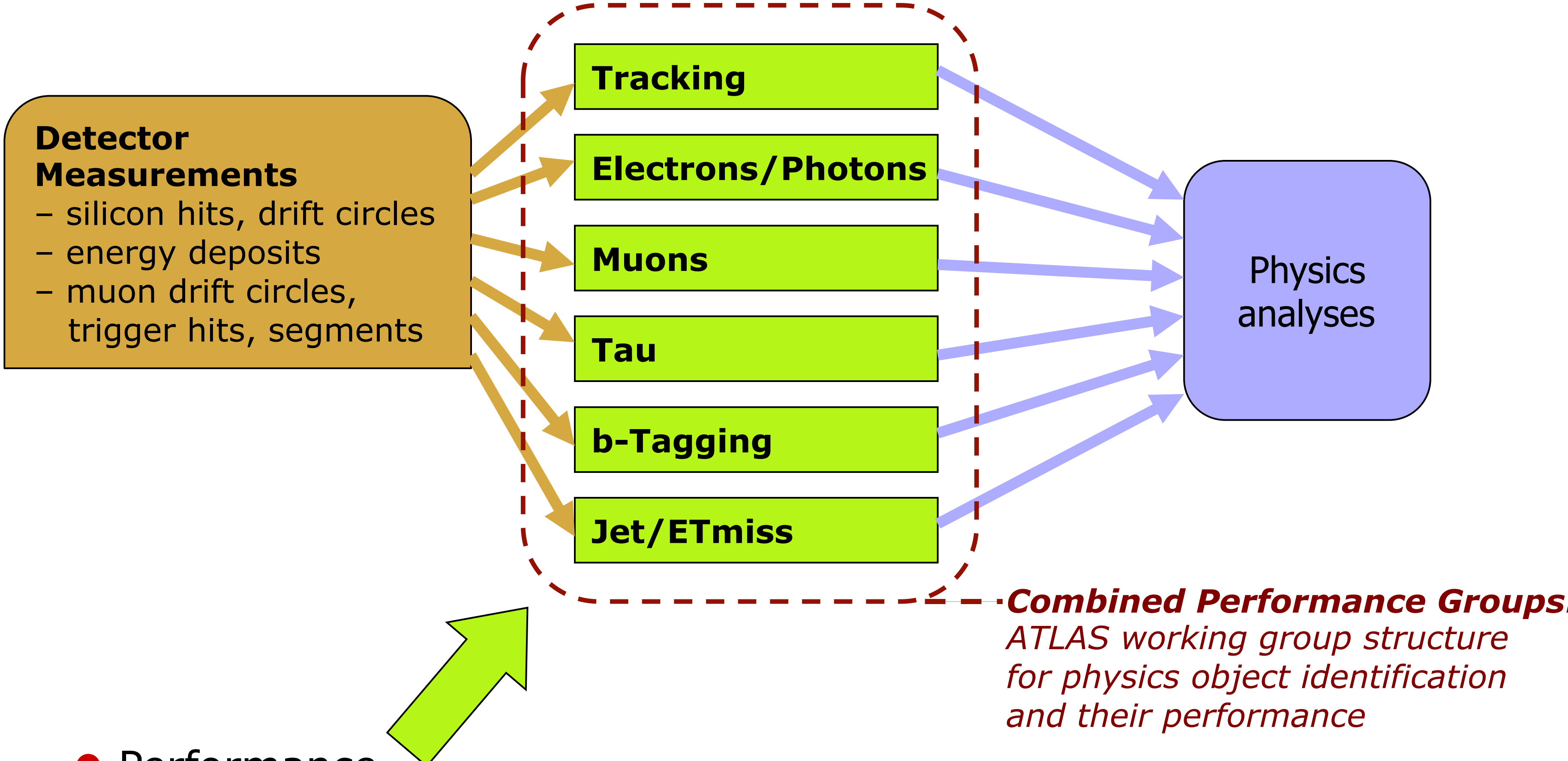
- photons
  - ➡ shower in e.m. calorimeter
  - ➡ (ideally) no charged particle seen in tracker
- neutrons
  - ➡ showers in hadronic calorimeter
  - ➡ no particle seen in tracker

Neutrinos, Jets, Vertex



- neutrinos
  - ➡ leave undetected
  - ➡ missing transverse energy
- jets
  - ➡ bundle of showers in calorimeter
  - ➡ bundle of charged particles in tracker
- vertex

Physics Objects in ATLAS



- Performance
  - Efficiency of object identification
  - Purity or fraction of false positive
  - Energy or momentum resolution
  - recommendations for physics analyses
  - combined data quality for physics object

- Tracking is input to all other
- Trigger
  - similar but separate group structure
  - trigger efficiency is main performance number

Performance: Basic Concepts

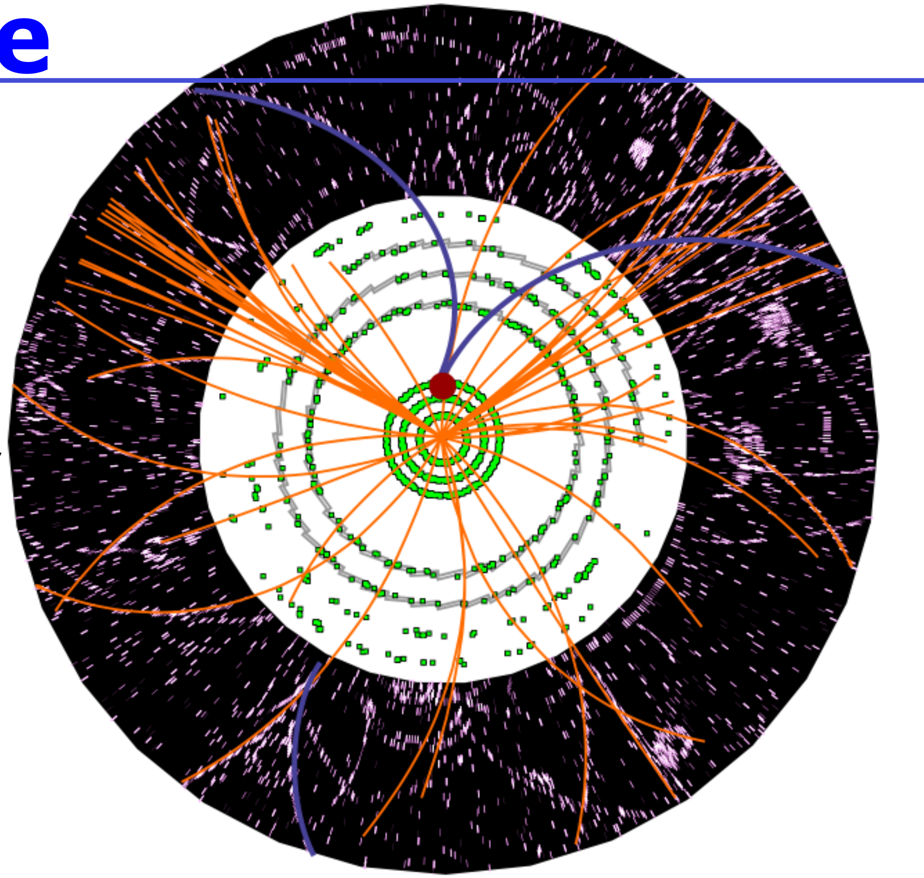
- **Efficiency** of identification
  - N_{true}(identified)/N_{true}(all)
  - multiplicative for events with several physics objects
- efficiency determination
  - simulation: MC truth tells N_{true}(all)
  - data: methods using known physics and/or detector redundancy
- **Trigger Efficiency**
  - of event passing trigger (–> stream)
  - of offline physics object (e.g. muon) being the one that fired trigger
- trigger eff. determination
  - simulation: combine L1–L2–EF
  - data: use offline object as 'truth'
- **Isolation efficiency**
  - object identified with additional isolation requirement

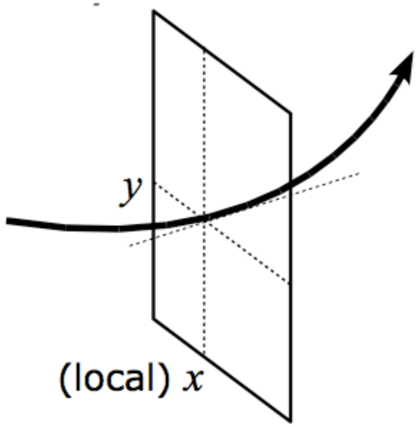
- **Fake Rate** of identification
  - N(misidentified)/N(identified)
  - simulation: MC truth tells misidentification
  - data: identification counts on sample known to be depleted of physics object
- **Resolution** of track parameters
  - average difference between true and reconstructed parameters
  - most common: momentum and impact parameter resolutions
  - simulation: MC truth for parameters
  - data: knowledge about physics process, detector redundancy etc.
- ideally resolution should be reflected by error on parameters

Tracking, Muons, B-tagging…

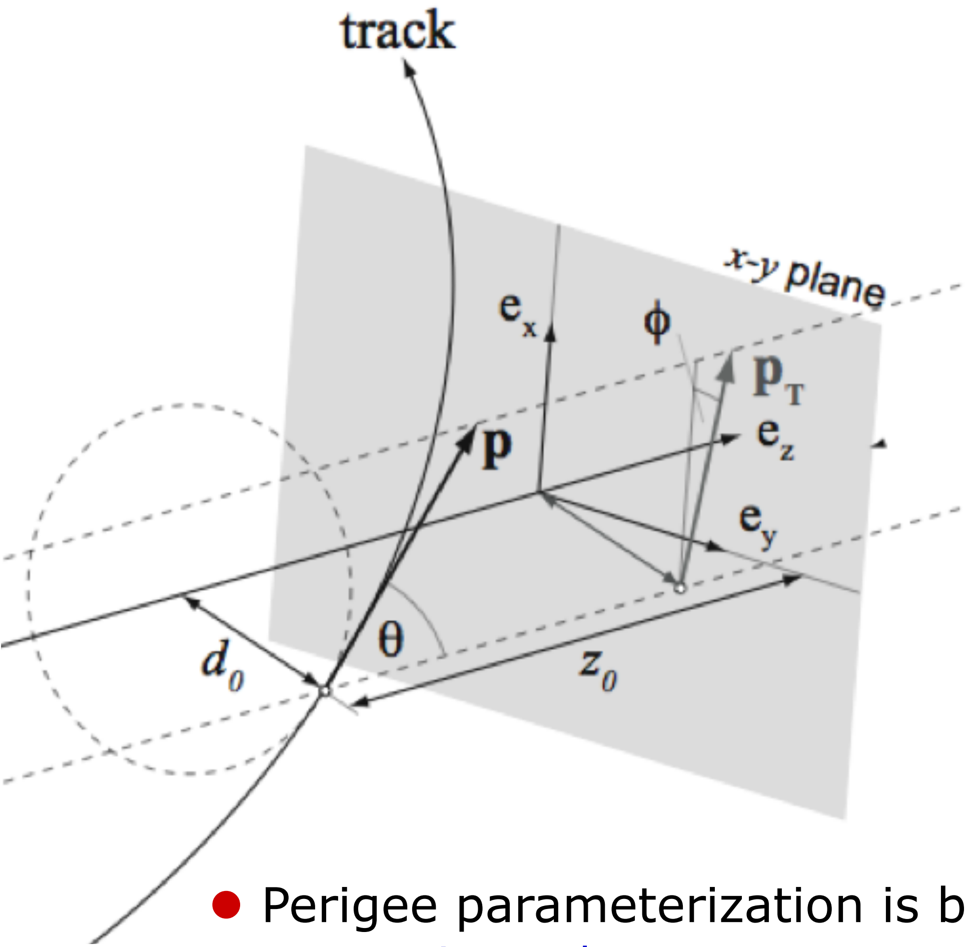
Tracking Software

- Charged particles leave a "cloud of hits" in the detector
  – further obscured by hits from noise, interactions with detector material, low energy curling tracks.
- Tracking software needs to identify particle trajectories, reconstruct their kinematic parameters
- Track model parameterizes trajectory with 5 parameters
  – stable particle moving in stationary B-field in vacuum described by 6 par
  – initial position along trajectory is free
- Local Parameters of track model
  – at an intersected reference surface:
    - 2 local coordinates
    - 2 angles
    - curvature q/p
  – and their 5x5 covariance matrix





Track Parameters at Collider Detectors



Perigee parameterization:

- d_0 signed distance of closest approach to z axis
- z_0 z of closest approach
- ϕ_0 azimuthal angle at cl. app.
- θ polar angle of track
- q/p charge-signed curvature

- Perigee parameterization is basis for
  - expressing track parameters at production vertex for instance Lorentz vectors in physics analysis
  - vertex finding algorithms
  - b-jet tagging

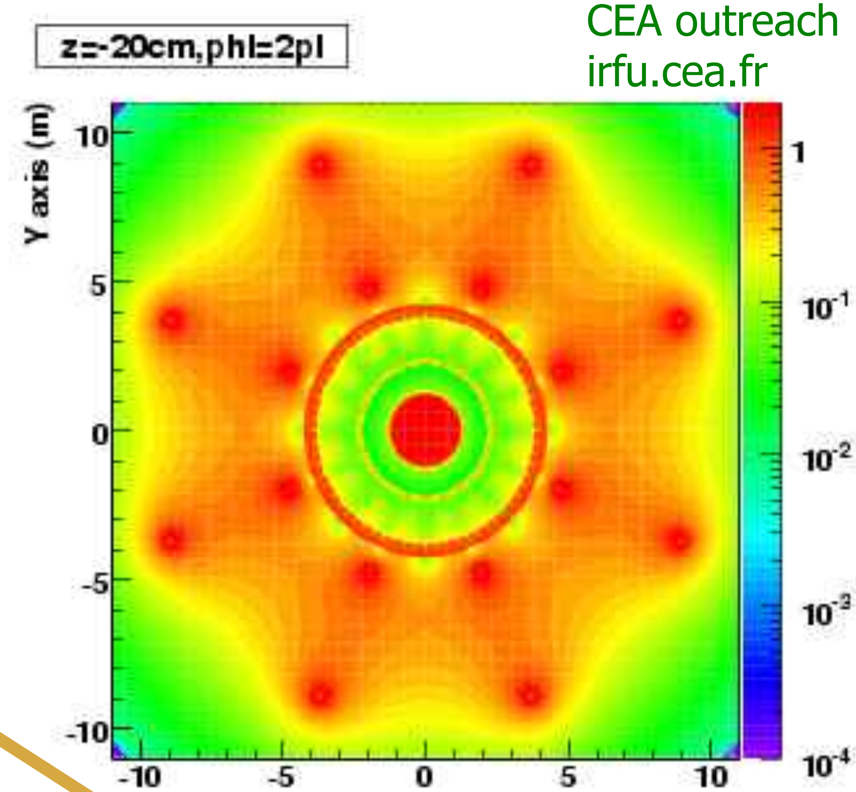
Track Propagation: Fields

- **Equation of Motion** of particle

$$\frac{d^2\boldsymbol{r}}{ds^2} = \frac{q}{p}\left(\frac{d\boldsymbol{r}}{ds} \times \boldsymbol{B}(\boldsymbol{r})\right)$$

- helix approximation not sufficient:
  - risk ~1% momentum bias (CMS?)
  - ATLAS InDet longer than solenoid
  - toroids produce inhomogeneous field
- *B(r)* inhomogeneous: diff. equation can only be solved numerically
- Runge-Kutta-Nystrom methods
  - divide integration interval in steps
  - each step becomes initial-value problem
  - solve equation for each step individually
- form the detailed track model
  - in ATLAS called **Propagator**
  - model of interactions in detector added separately

CEA outreach
irfu.cea.fr

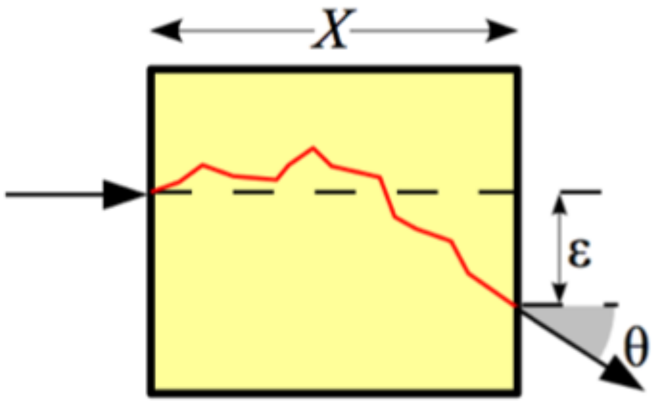


common tracking software designed to work in both Inner Detector and Muon Spectrometer

Multiple Scattering

Besides field effects, track propagation also affected by material:

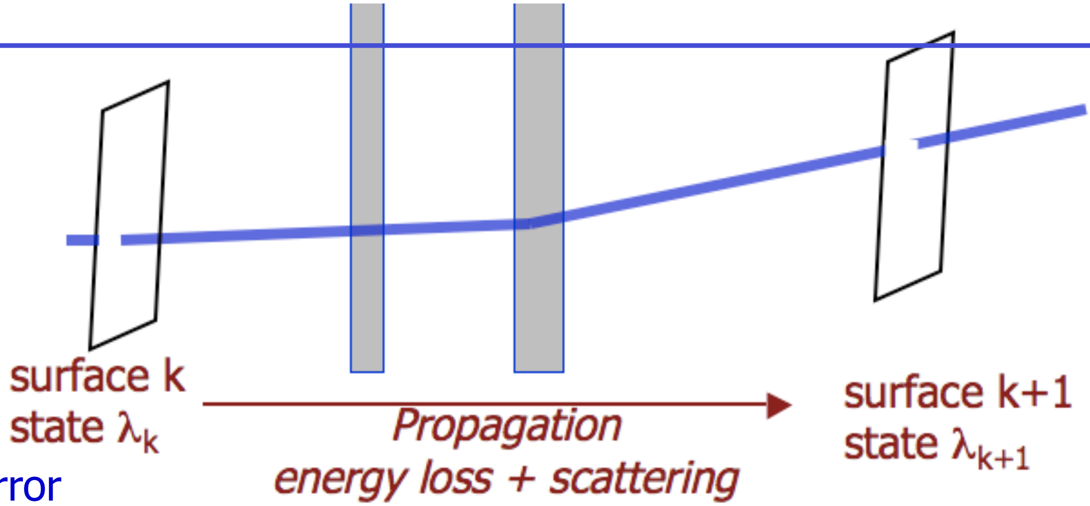
- energy loss (discussed in part 1 of lecture)
- **multiple scattering**
  - charged particle deflected when passing through matter
  - random deflection is result of many small-angle Coulomb scatterings on the nuclei
  - Gaussian distribution for central 98 % given by Highland formula



$$\sigma(\theta) = \frac{13.6\,\mathrm{MeV}}{\beta c p} z \sqrt{x/X_0}\left(1 + 0.038 \ln\left(x/X_0\right)\right)$$

- expect $E(\varepsilon) = 0$, $E(\theta) = 0$. $\sigma(\theta)$ is proportional to $1/p$
- x/X_0: thickness of material in fraction of radiation length

Track Fitting

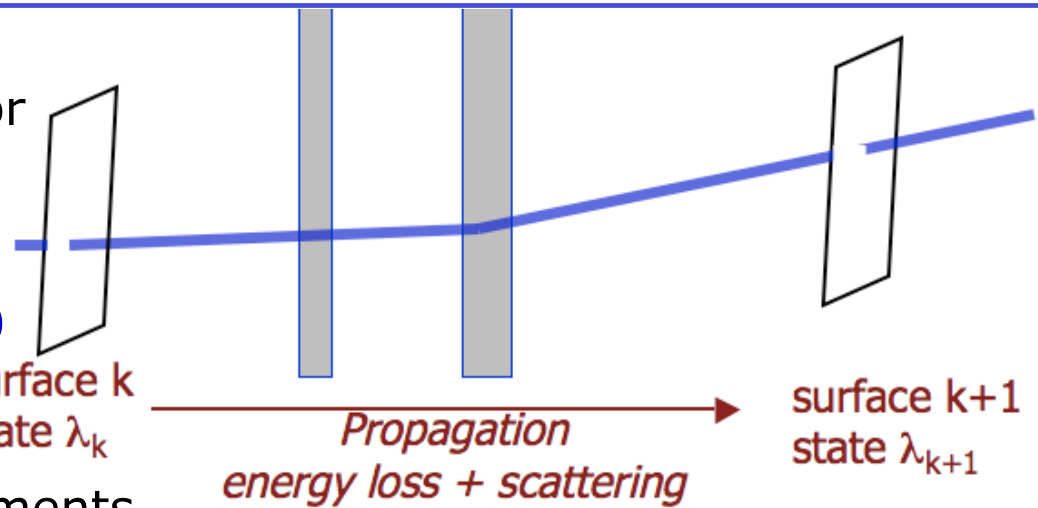


- Measurement constraints
  - $\boldsymbol{m}_k = \boldsymbol{h}_k(\boldsymbol{\lambda}) + \boldsymbol{\gamma}_k$
  - $\boldsymbol{\lambda}$: track parameter vector (propagation to be added)
  - $\mathbf{h}_k$: functional dependence of measurement on track parameters (meas't model)
  - γ_k: noise term, variation within error
- Now need an estimator for λ
  - could e.g. use MINUIT (max. likelihood) but that is not the case in tracking
- A linear model is applied
  - $\boldsymbol{h}_k(\boldsymbol{\lambda}) \simeq \boldsymbol{h}_k^0 + H_k \cdot \boldsymbol{\lambda}$
  - $H_k = \frac{d\boldsymbol{m}_k}{d\boldsymbol{\lambda}}$: Jacobian, typically a rotation or projection into measurement plane
- Measurements are Gaussian distributed
  - least squares estimator is best unbiased estimator

$$\chi^2 = \sum_i^{N_{\text{hits}}} \left(\frac{m_i - h_i(\boldsymbol{\lambda}, \theta^{\text{scat}})}{\sigma_i} \right)^2 + \sum_j^{N_{\text{planes}}} \left(\frac{E(\theta^{\text{scat}}) - \theta_j^{\text{scat}}}{\sigma^{\text{scat}}} \right)^2$$

Track Fitting in ATLAS

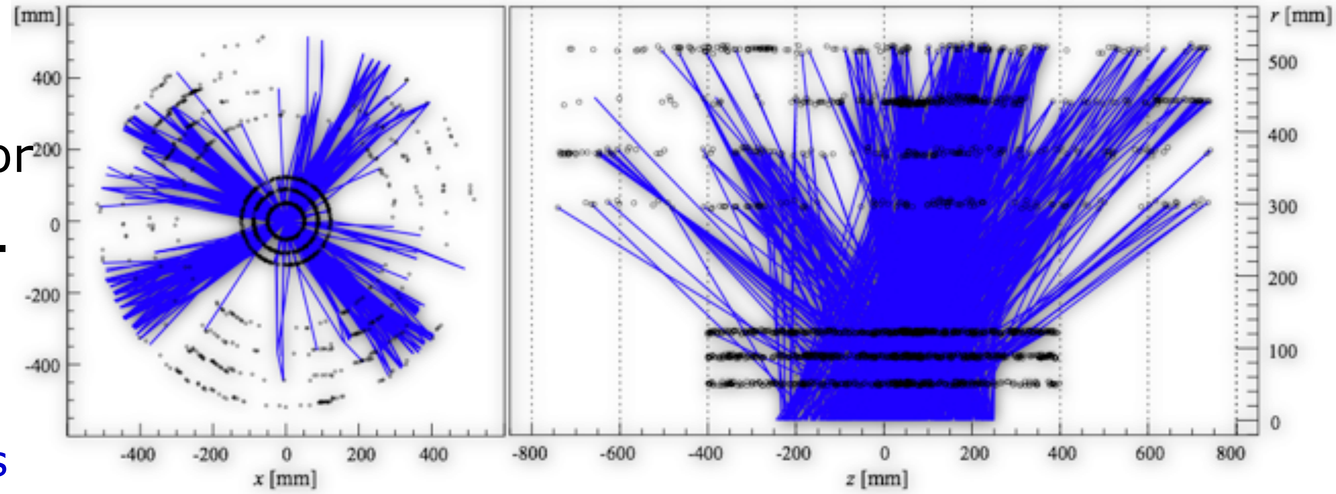
- Propagators transport λ vector
  - $\boldsymbol{\lambda}_k^{k-1} = f_k^{k-1}(\boldsymbol{\lambda}_{k-1})$
  - simplified geometry used (simpler+faster than full simulation)
  - algorithm "AtlasExtrapolator"



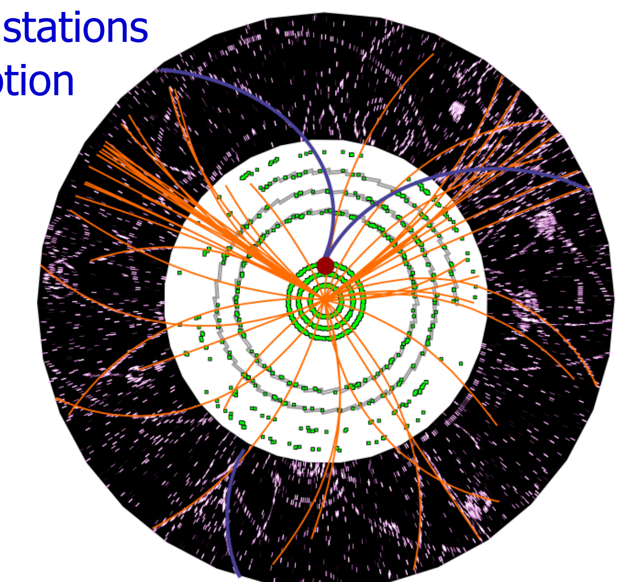
- "Global χ^2 fitters" solve lin. estimator for all measurements
  - needs inversion of large matrix dim=5+2N
  - fit follows trajectory closely, useful for large distances in ATLAS
  - mostly used in ATLAS
- Kalman filters in track fitting
  - steps through hits and updates parameters
  - progressive way of performing LSE, mathematically equivalent
  - fast: series of dim.5 matrix inversions
  - extended to estimate electron trajectories (bremsstrahlung, in use in ATLAS)

- Robust estimators
  - define 'pull' = $|m_k - h_k(\lambda)|/\sigma_k$
  - typically reject hit as an outlier if pull > 3.5
  - re-fit with outliers rejected if prob(χ^2) < 10^{-5}
  - avoids bias or degraded resolution

Track Finding

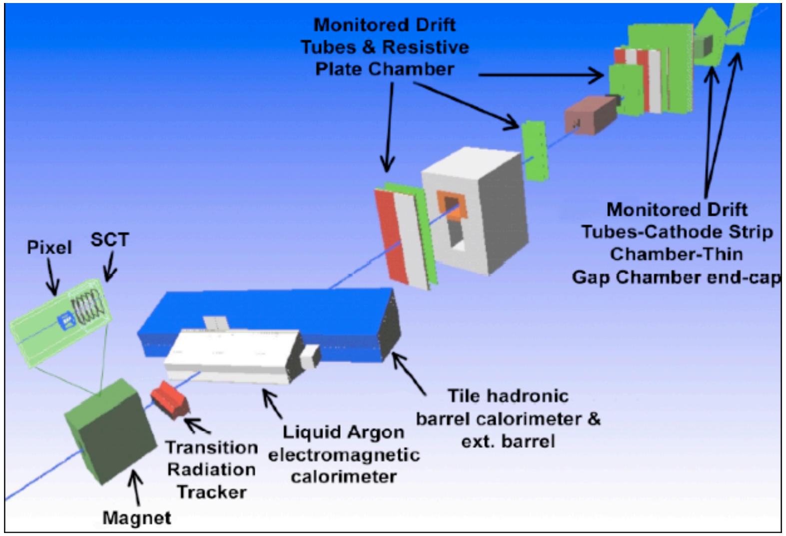


- Choice of track finding algorithm depends on detector
- Seed finding in e.g. silicon, TRT, muon chambers
  - robustness against combinatoric problems and detector ambiguities needed
  - algorithms use Hough-transforms or look-up tables
- seeds or segments extended by combinatorial track following
  - associates hits in adjacent layers or muon segments in other stations
  - upon ambiguities branch seed following and evaluate best option
  - often fast versions of track fit employed in track following
- combination of inside-out (for prompt tracks) and outside-in seeding (e.g. γ conversions)
- final track fit with precise material corrections and hit recalibration



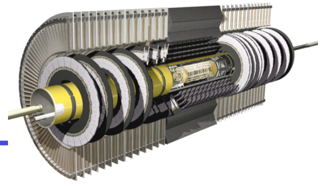
ATLAS Commissioning Programme

- 1995-2004 test beams
  2004 combined test beam
  - software integration
  - first performance measurements for single particle detection

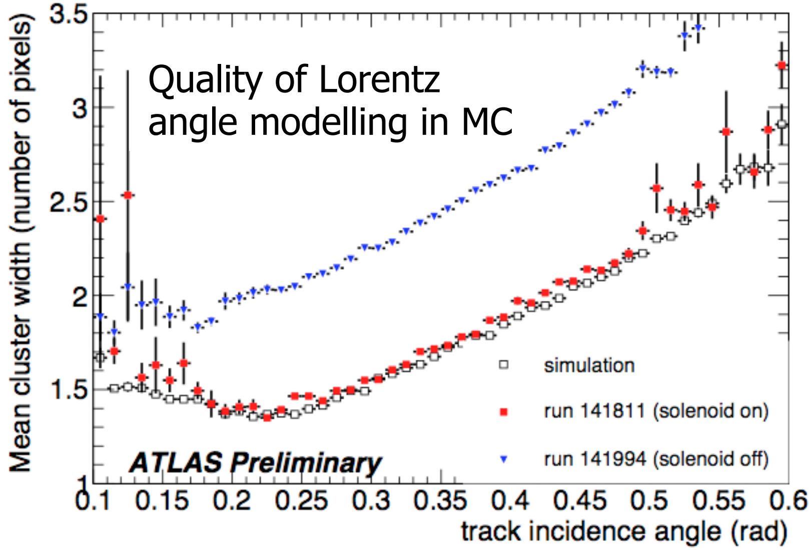


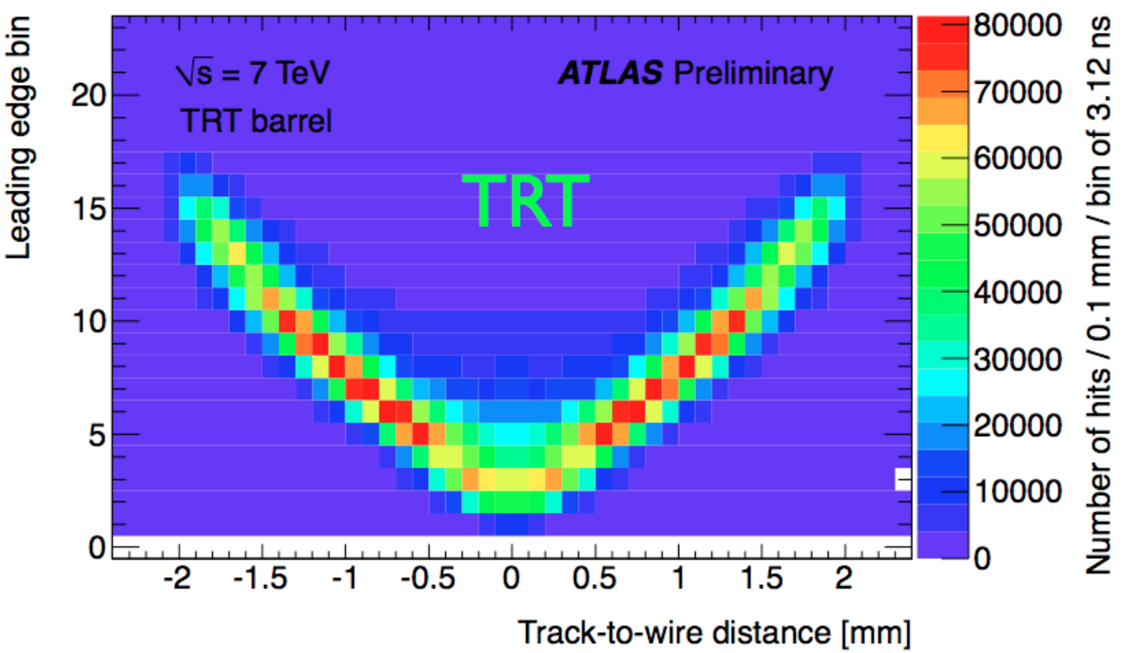
- 2006 cosmic rays (Inner Detector)
  2008/9 cosmic rays
  (whole ATLAS as installed in P1)
  - first performance measurements on real detector (tracks+muons)
- 2009 single beam events and 900 GeV collisions
  - correct some obvious performance mis-modelling (dead modules, missing large structures in detector geometry)
- 2010/11 p–p collisions
  - high statistics of tracks "illuminate" even remote MS chambers
  - high statistics of calibration objects, such as J/ψ and Z decays to e,μ,τ
  - methods often tricky and similarly involved as a physics analysis

Inner Detector Calibration

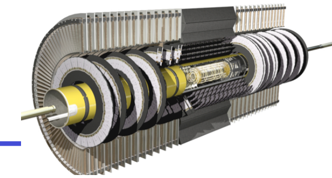


- Pixel detector
  - 50x400μm pixel size
  - 14x110μm initial resolution (50μm/√12)
  - instrinsic resolution down to 3μm by charge sharing & clustering algorithms
- SCT detector
  - 80μm strip pitch gives 22μm resolution
  - stereo angle produces ~500μm resolution in z direction (2nd coord.)
- TRT
  - ~150μm resolution
- Noisy channels masked, dead channels mapped
  - needs to be known for tracks not to be negatively scored
- Hit efficiency >99% in all 3 systems

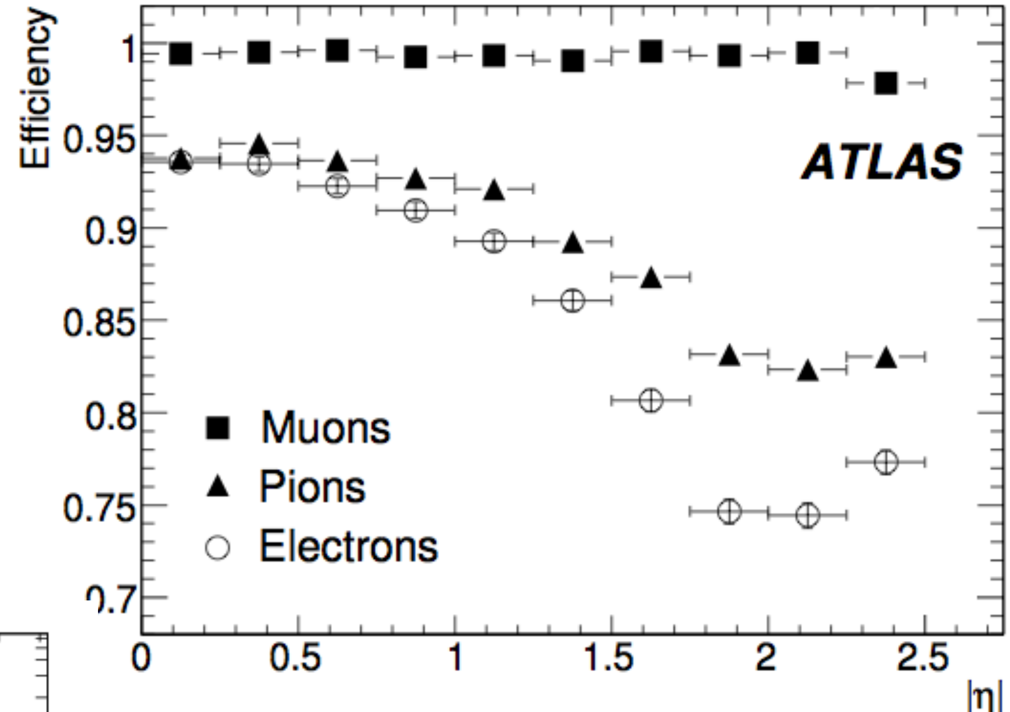


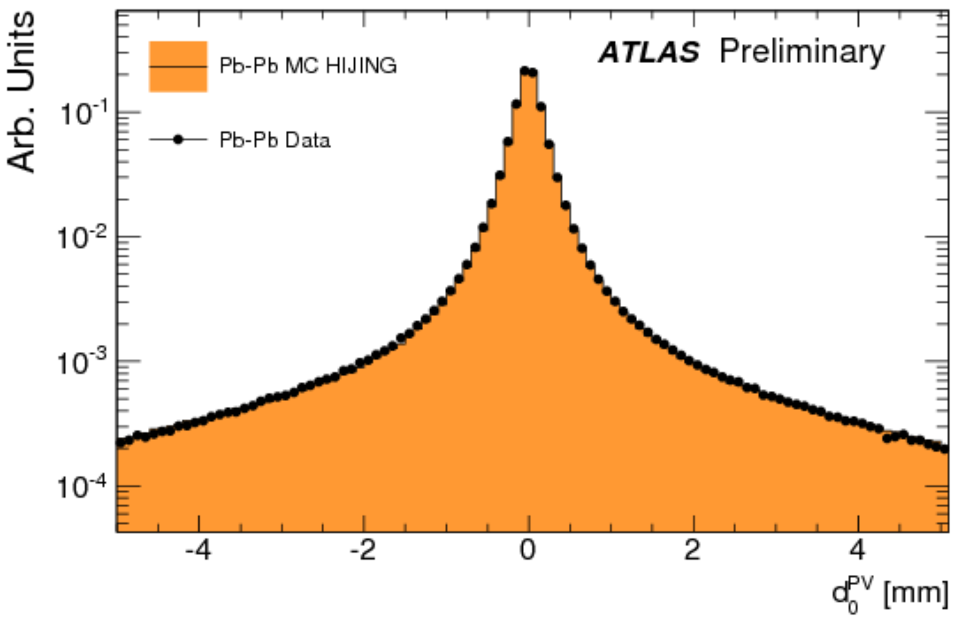


Inner Detector Performance



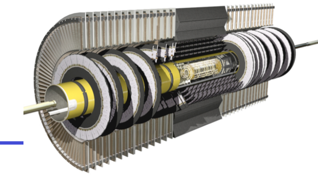
- Track Efficiency: 2 effects
  - detector: loss of track in an interaction large effect for electrons, pions
  - algorithms: track finding/fitting unsuccessful, small effect
- Measured on Data
  - back-extrapolated muons
  - total number of tracks (mainly pions)



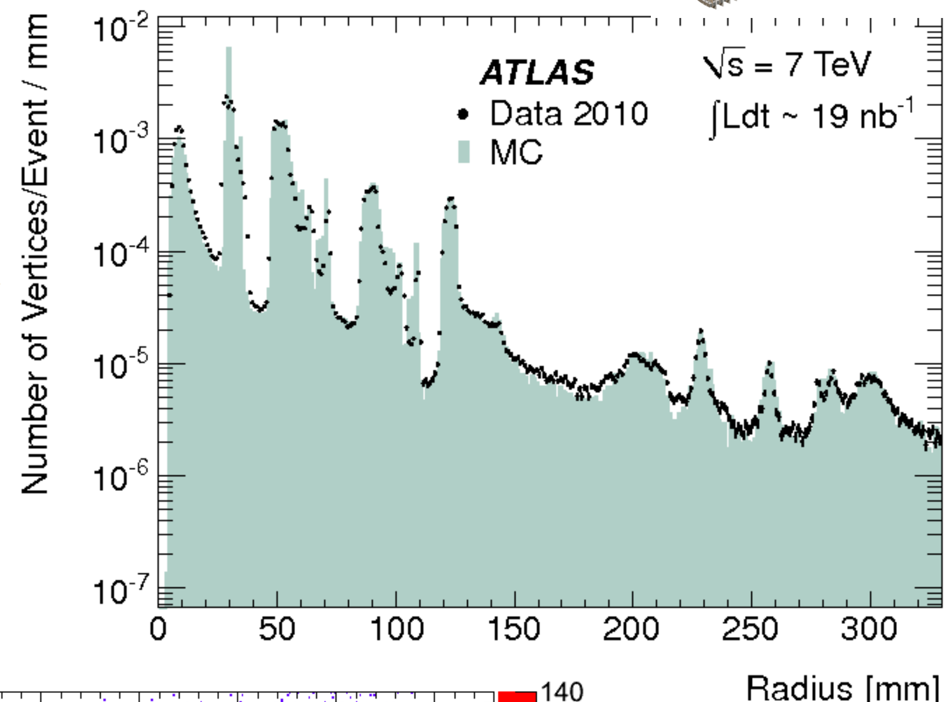


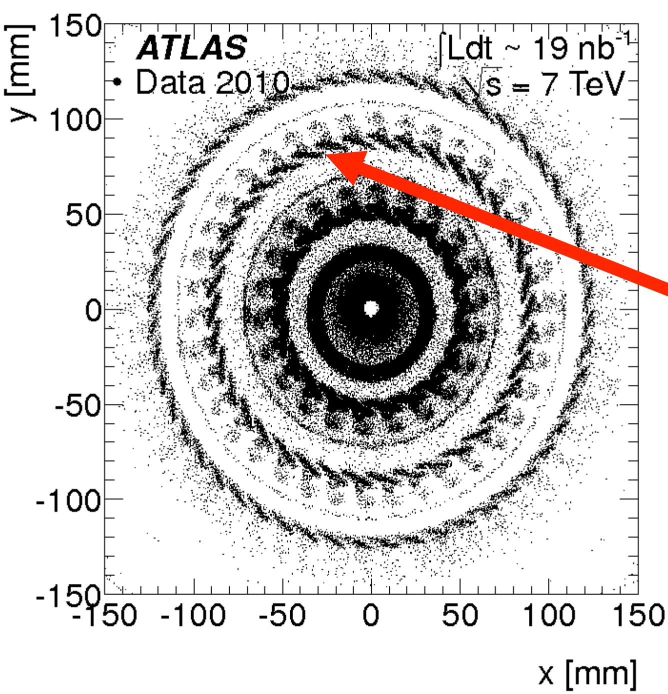
- Impact parameter d_0^{PV} = track extrapolated to vertex in transverse plane
  - good resolution and good MC model crucial for vertexing and b-tagging
  - studied in detail since cosmics, here: heavy ion performance

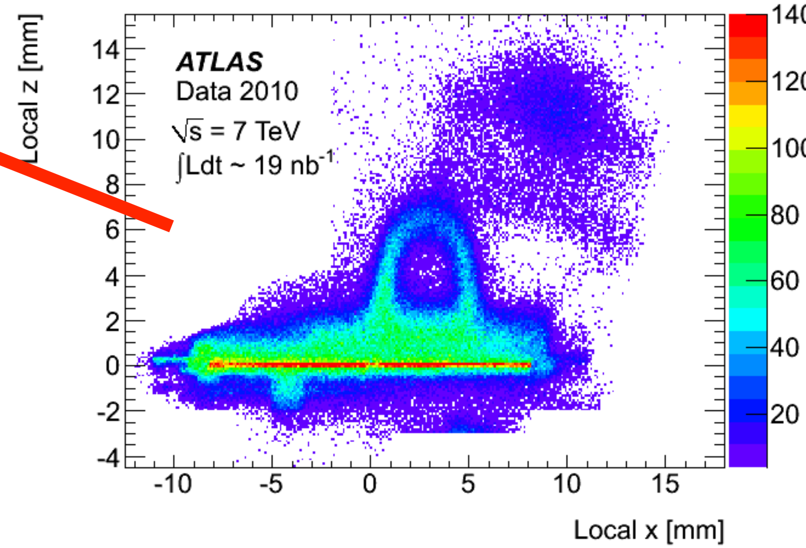
Material Studies



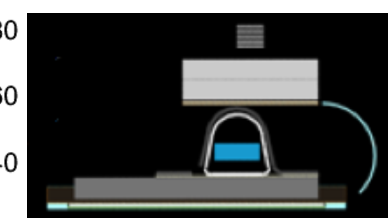
- Interactions in the detector and low mass resonances probe material with high precision
  - γ conversion vertex locations
  - hadronic interaction vertices
  - $K^0_s \to \pi\pi$ and $J/\psi \to \mu\mu$ inv. mass
- All were studied, showing that ID material uncertainties < 5%



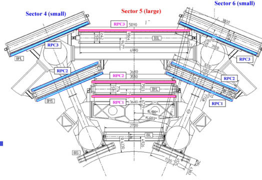




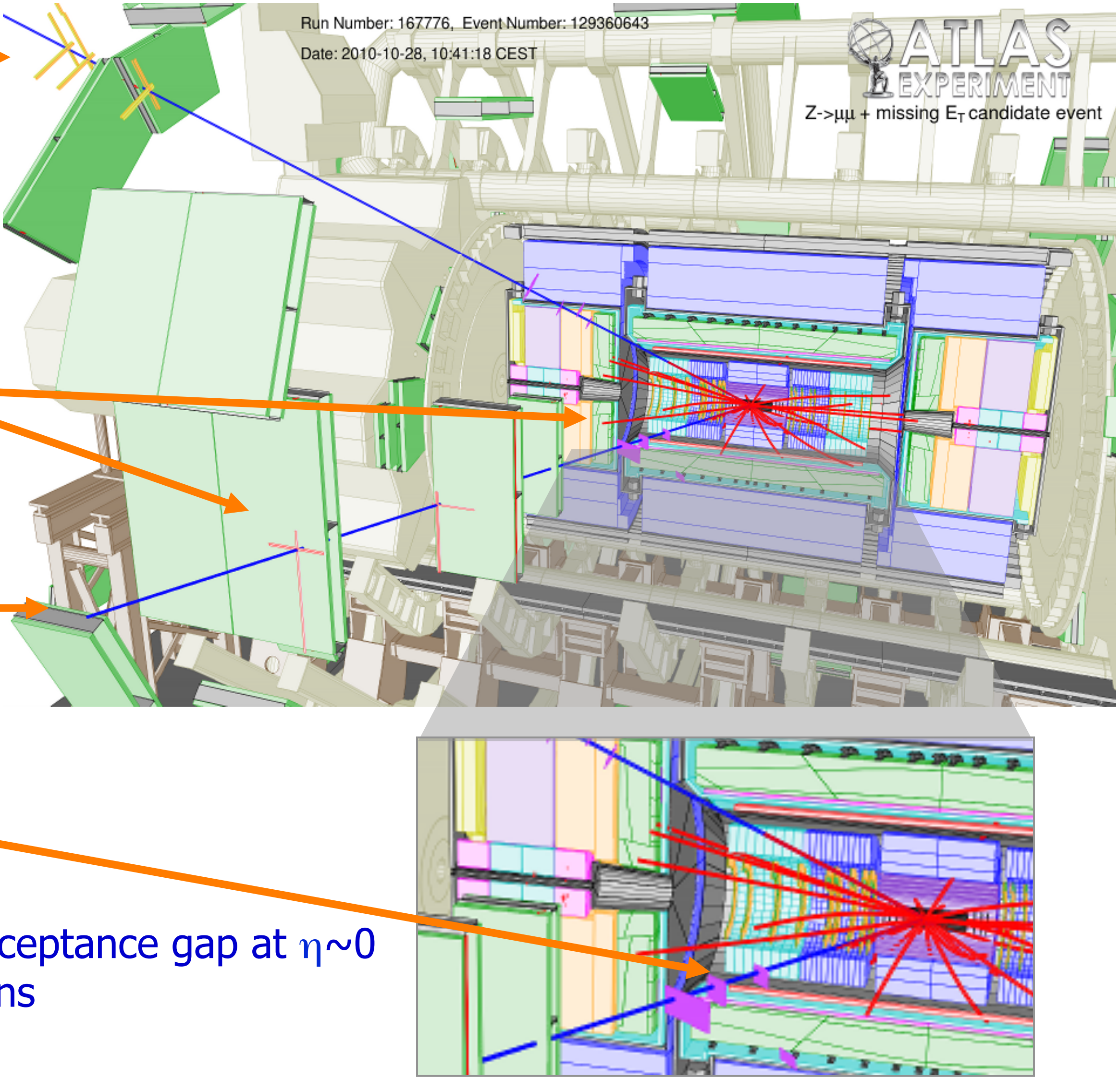
Pixel module in Geant4



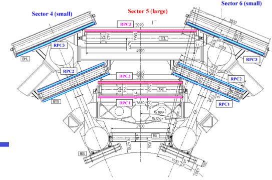
Muon Reconstruction



- Segment-tagged
  - available for $|\eta|<2.5$
  - most uniform coverage in η and pT
  - momentum from ID (ID and MS for MuGirl)
- Combined
  - available for $|\eta|<2.5$
  - ID and MS contribute to momentum accuracy
- Stand-alone
  - extend coverage to $|\eta|<2.7$
  - momentum from MS
  - poor position accuracy at IP
- calorimeter-tagged
  - available for $|\eta|<2.5$
  - uniform efficiency near MS acceptance gap at $\eta\sim0$
    - optimised for isolated muons



Muon Efficiencies



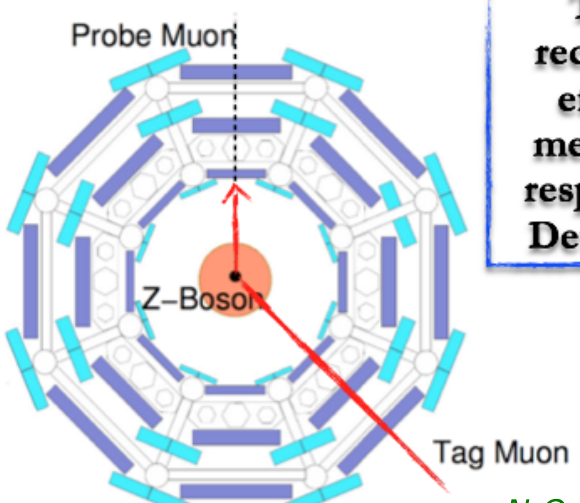
- Efficiency from Data: **Tag&Probe**

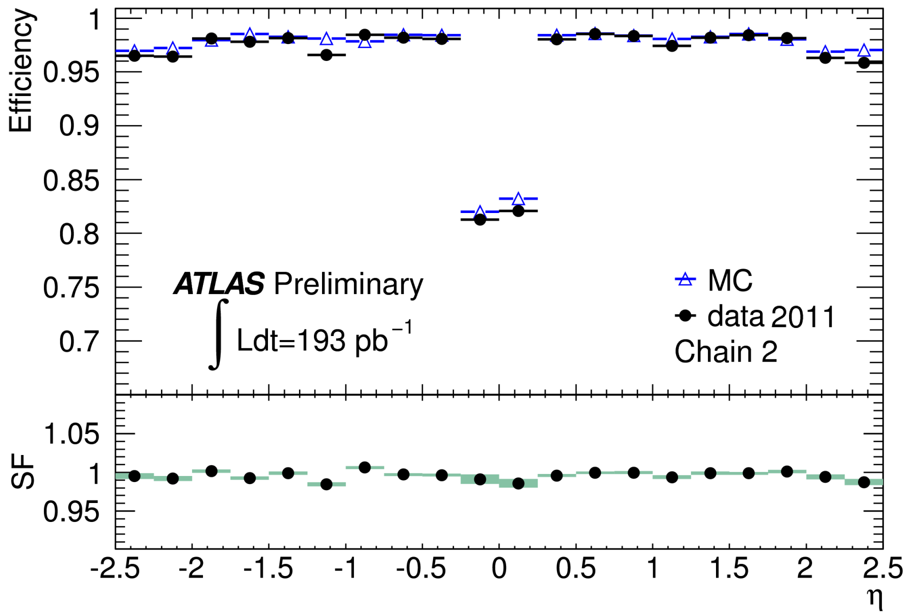
Total reconstruction efficiency

$$\varepsilon = \varepsilon(ID) \times \varepsilon(MS) \times \varepsilon(comb)$$

- $\varepsilon(ID)$: Inner tracker reconstruction efficiency
- $\varepsilon(MS)$: Muon Spectrometer reconstruction efficiency
- $\varepsilon(comb)$: Combination efficiency

The muon reconstruction efficiency is measured with respect to Inner Detector tracks

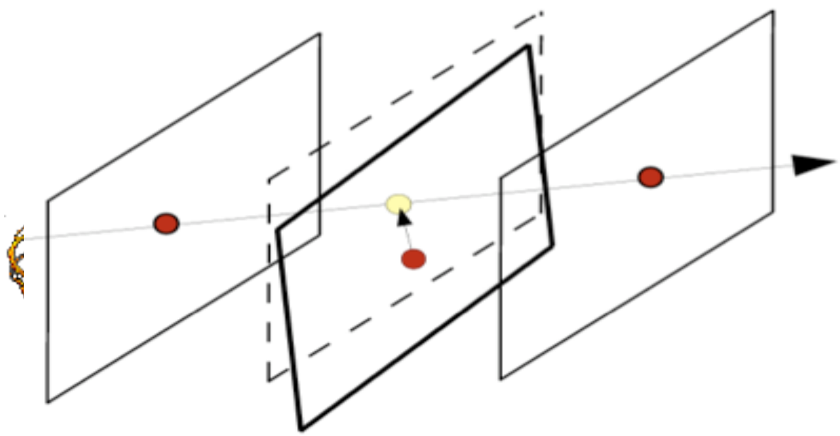




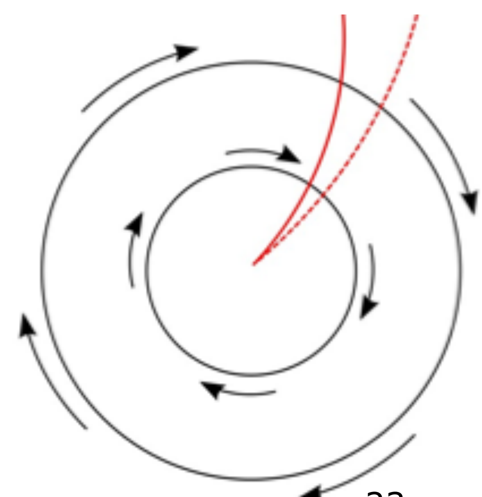
- Results: MC can be used to derive efficiency
  - low pT kinematic range accessible through J/ψ–>μμ decay
  - only few cases of scale factor SF > error

Alignment of Tracking Detectors

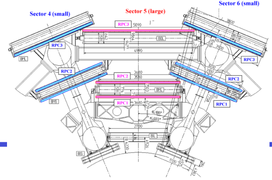
- Detector positioning accuracy
  - ~100µm sensors on supports
  - 1-5mm for larger structures
- But: intrinsic resolution 5-100µm
- Positions need to be aligned
  - from data: large track (µ) statistics
  - from detector: optical alignment able to follow “fast” movements
- software alignment is based on minimizing track-hit residuals
  - X2=sum_trk(rTV-1r), r=r(alpha, lambda_i)
  - minimization has two big challenges: large # alignment parameters, occurrence of weak modes



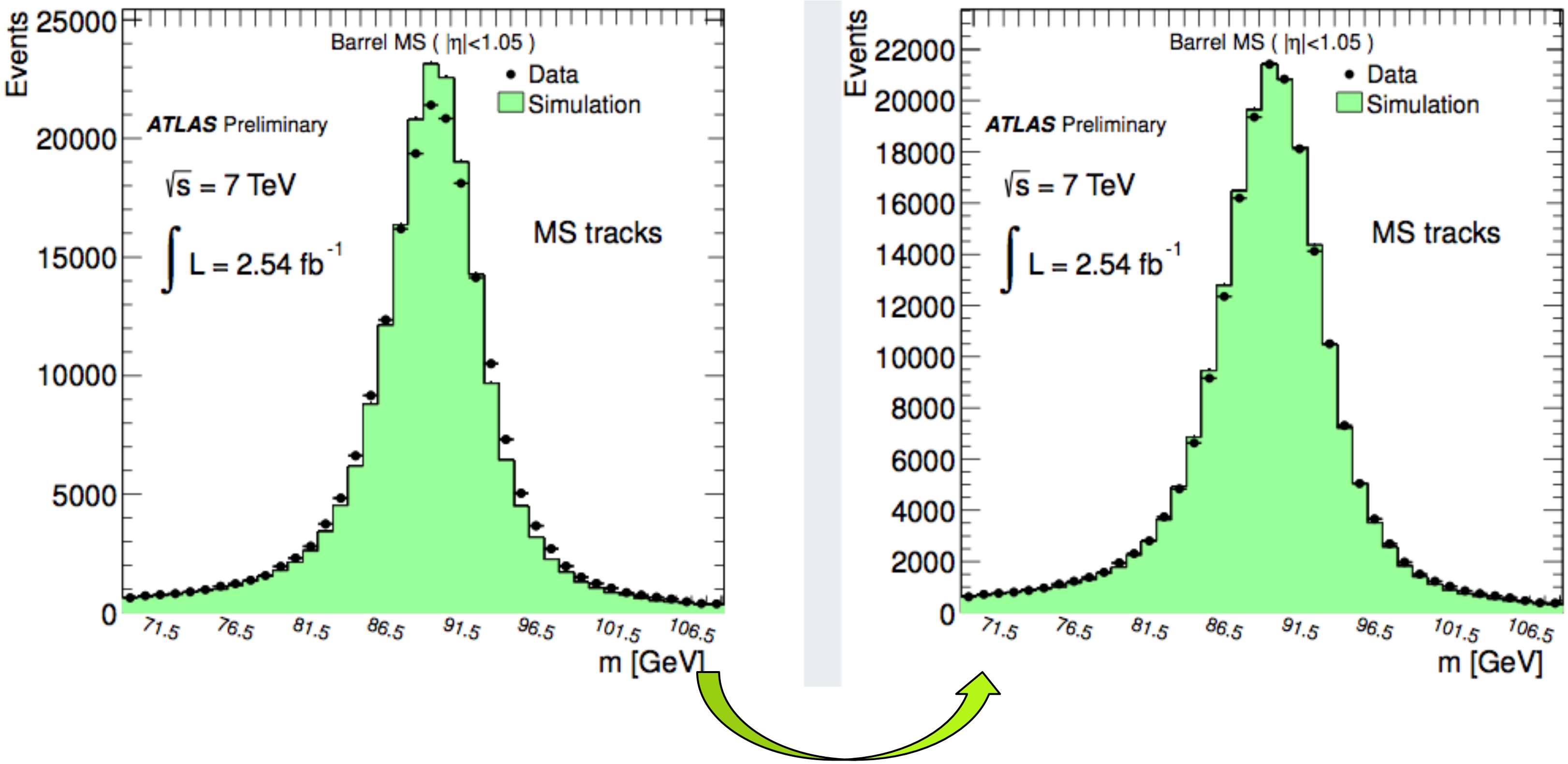
- **Large number of parameters**
  - 3 translations + 3 rotations per module
  - ATLAS Pixel+SCT: 5832 modules
- Two algorithmic approaches
  - global chi2: single large matrix including all correlations, fast solving techniques
  - local chi2: solving many small systems, correlations covered by iterations
- **Weak modes**
  - global deformations that do not add to alignment χ^2 but affect physics quantities
  - curls, twists
  - were studied beforehand but real detector is different



Muon Momentum Resolutions



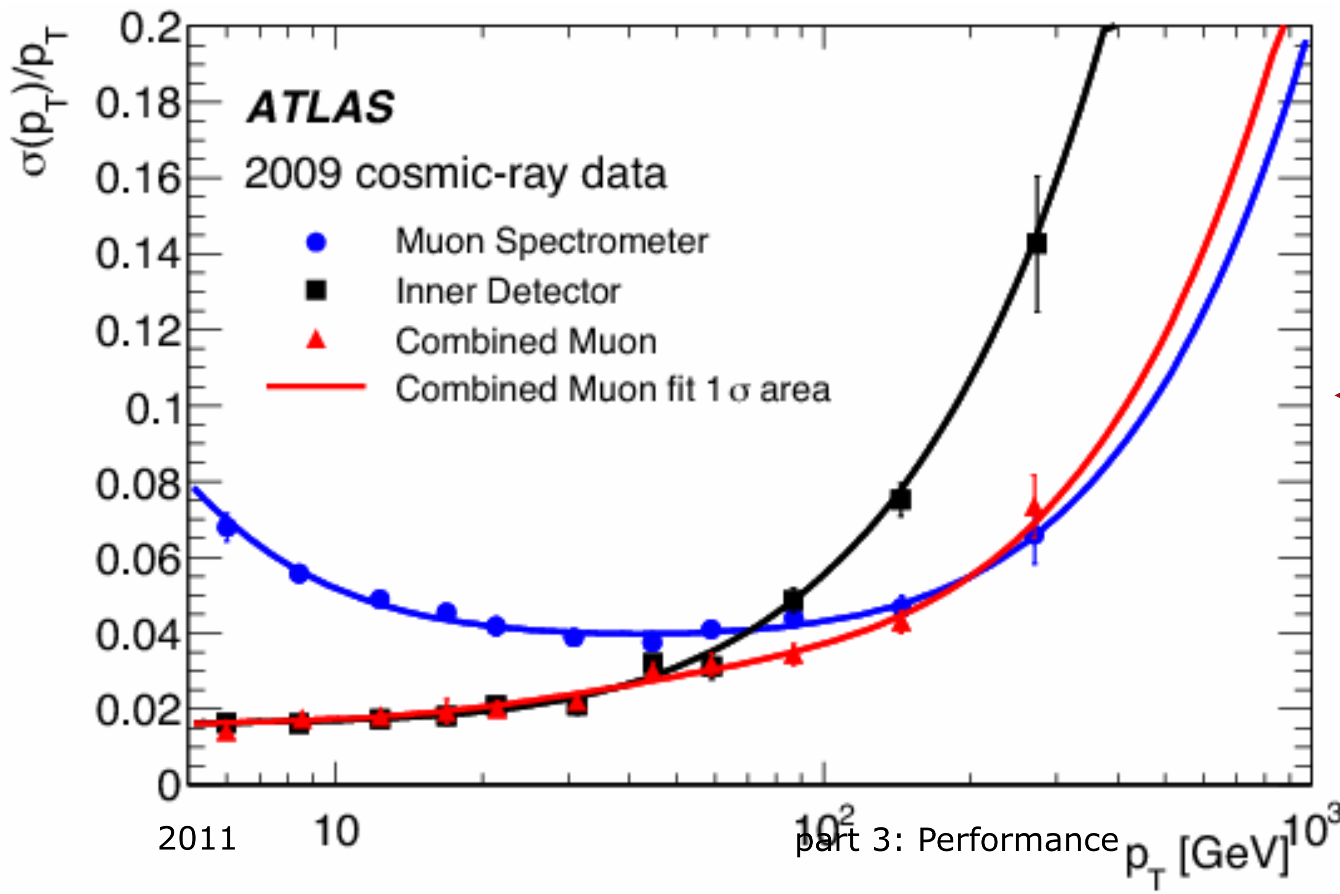
- Z–>μμ decay sensitive to detector effects
  – observed width is superposition of natural decay width and detector resolution
  – Z becomes excellent probe for momentum resolution and scale bias



- Momenta on MC smeared before entering physics analyses
  – reduces/quantifies systematic error contribution from cuts, kinematics etc

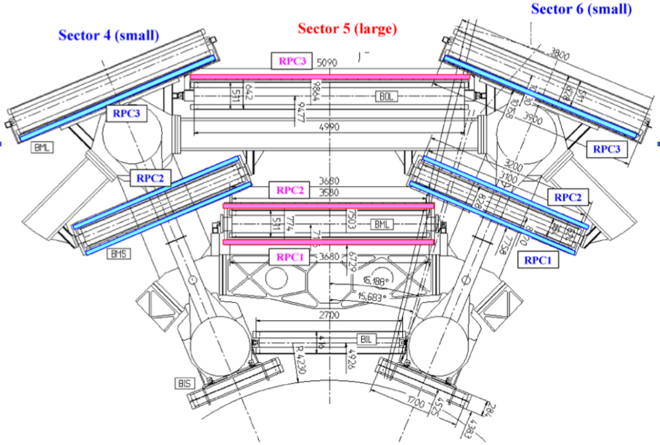
Highest p_T Muon Performance

- Muon momenta at p ~ 1 TeV estimated mainly by MS
  - high field integral, lever arm, hit precision in Muon Spectrometer (MS)
  - low momenta determined by ID (material effects in calo+MS strong)
  - TeV scale momentum precision depends on MS alignment
- Precisions alignment of huge MS is a challenge
  - track-based alignment needed to complement and probe quality of optical alignment

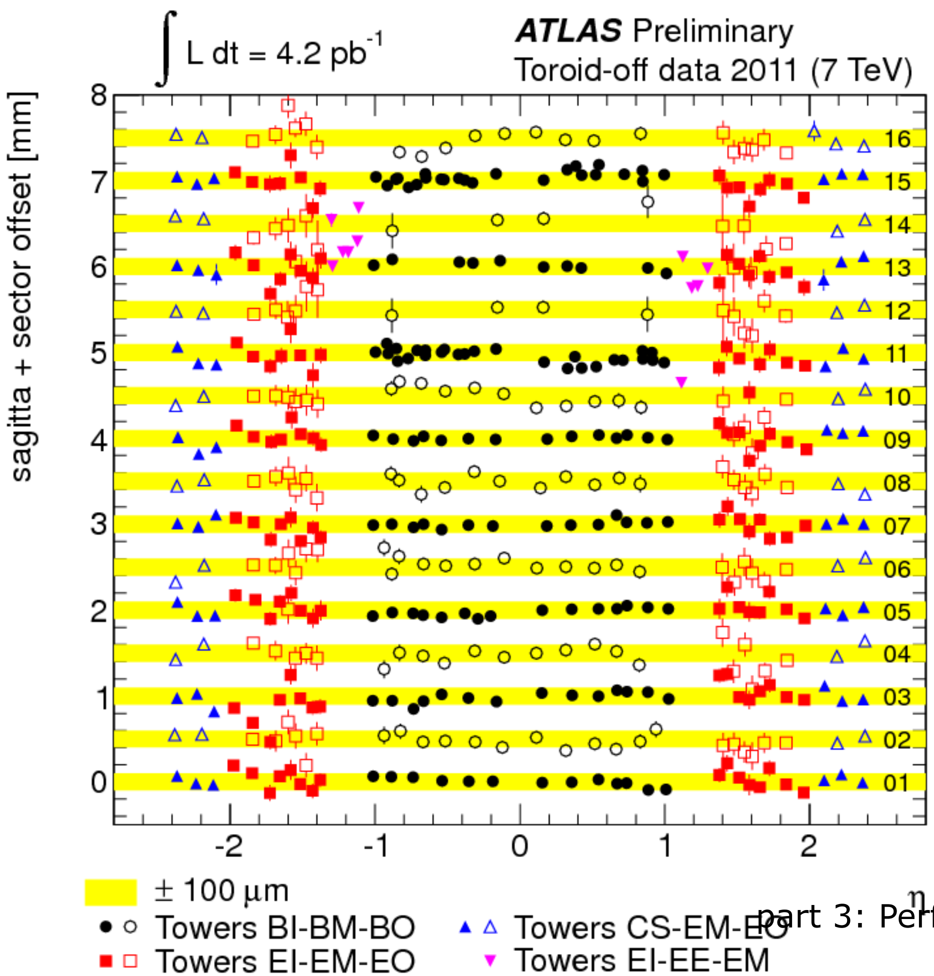


Design performance is 10% at 1 TeV

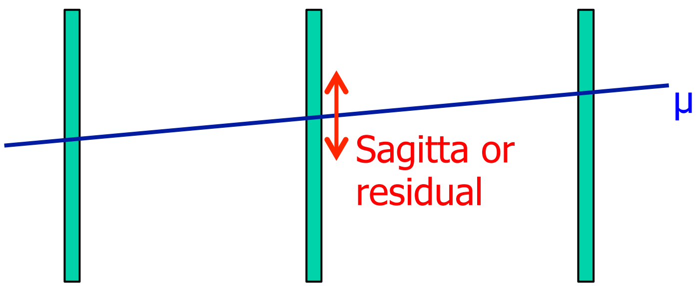
High p_T Performance



- Methods to achieve precision alignment
  - special runs: solenoid off, toroid on
  - overlaps between station sectors in Φ
  - cosmic rays (mainly 2009 preparation, see previous slide)



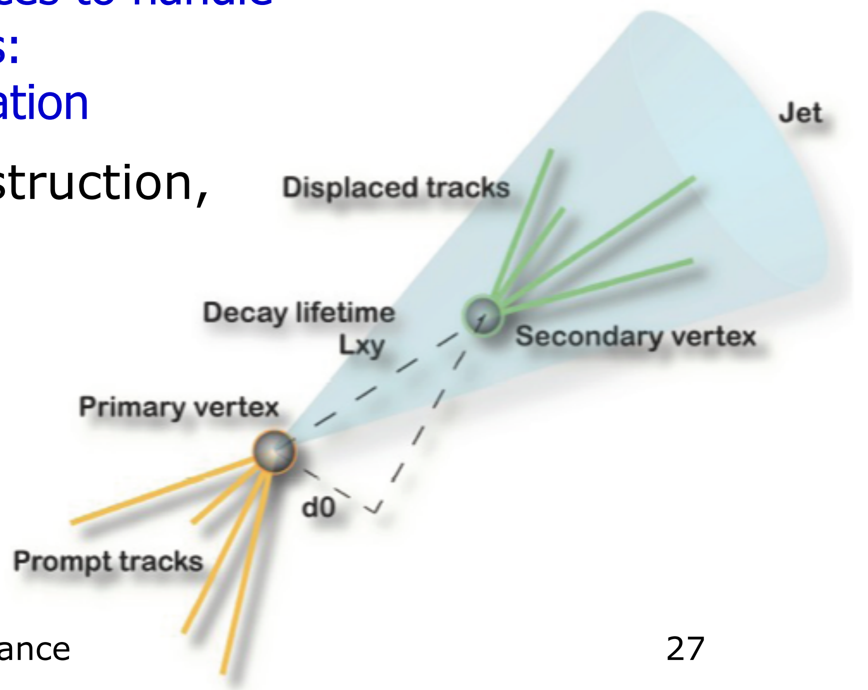
- Solenoid-off runs:
  - track muons using momentum from ID (mat. effects correctly parameterized)
  - study sagitta in 3-point system: should be 0 for straight tracks



  - difference from 0 allows alignment
  - optical alignment follows movements when toroids switched back on (!)
  - typical precision now < ~100μm

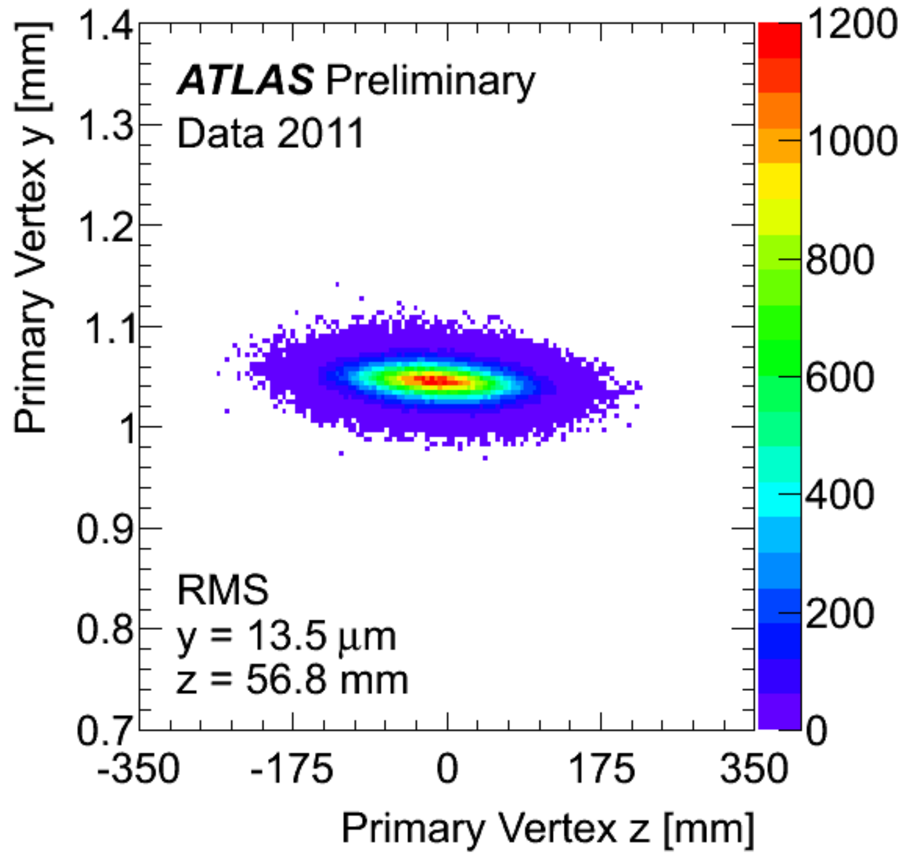
Vertex Reconstruction

- Task is to estimate vertex position ν
  - from N track parameter vectors (& cov)
  - and update track momentum vectors and full 3+3N covariance matrix
- Algorithms are similar to track fit
  - measurement model $\lambda_i = h(\nu, p_i)$ describes how track parameters depend on vertex and momenta at vertex
  - model is inherently not linear, large matrices to handle
  - use again linear estimators with iterations: progressive (Kalman) and global minimization
- Applications are primary vertex reconstruction, heavy flavour decay vertices, b-tagging, γ conversions, kinematic fits …



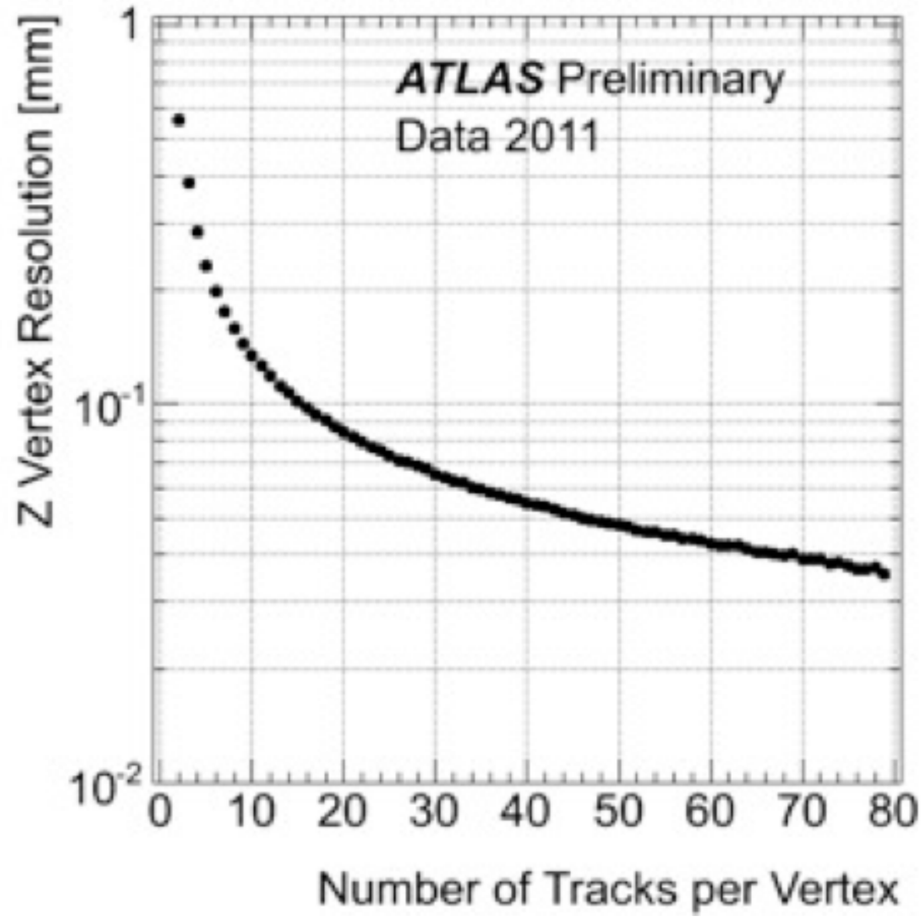
Vertex Finding

- Primary vertexing at LHC combined finding and fitting
  adaptive multi-vertex fitters
  – iterative, reweighted Kalman filter
    Kalman filter = adds tracks progressively to vertex candidate
  – robust fitter: outlying tracks are down-weighted automatically
  – new vertex candidate formed with outlying tracks
    (minimally 2 tracks form vertex)
  – list of vertex candidates is input to next iteration, vertices compete against each other for tracks
- **Beam spot**
  – cloud of primary vertices averaged over short period in time
  – routinely determined in data-taking
  – beam spot then used as constraint in primary vertex finding
- Measures **in-time pile-up**
  – μ = number of pile-up vertices



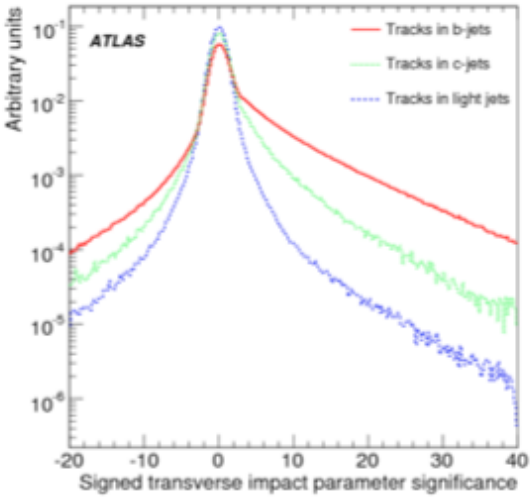
Vertex Reconstruction Perf

- Primary vertex in another physics object for which we need to know precisely its performance
- Vertex resolution on data measured with split-vertex method
  - randomly split PV into two
  - study difference between positions from two vertex fits
  - expect 0 with variance from resolution
- Resolution depends on number of tracks at vertex

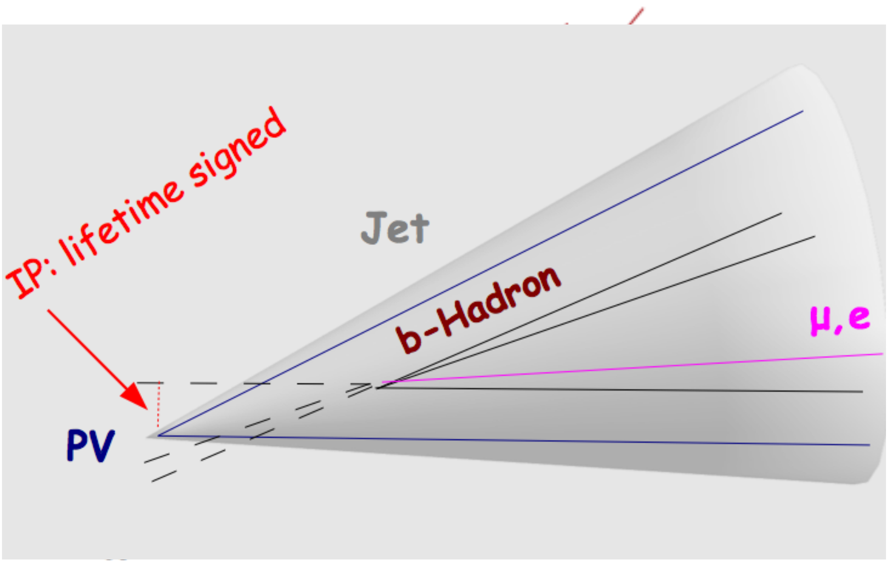


b-Jet Tagging

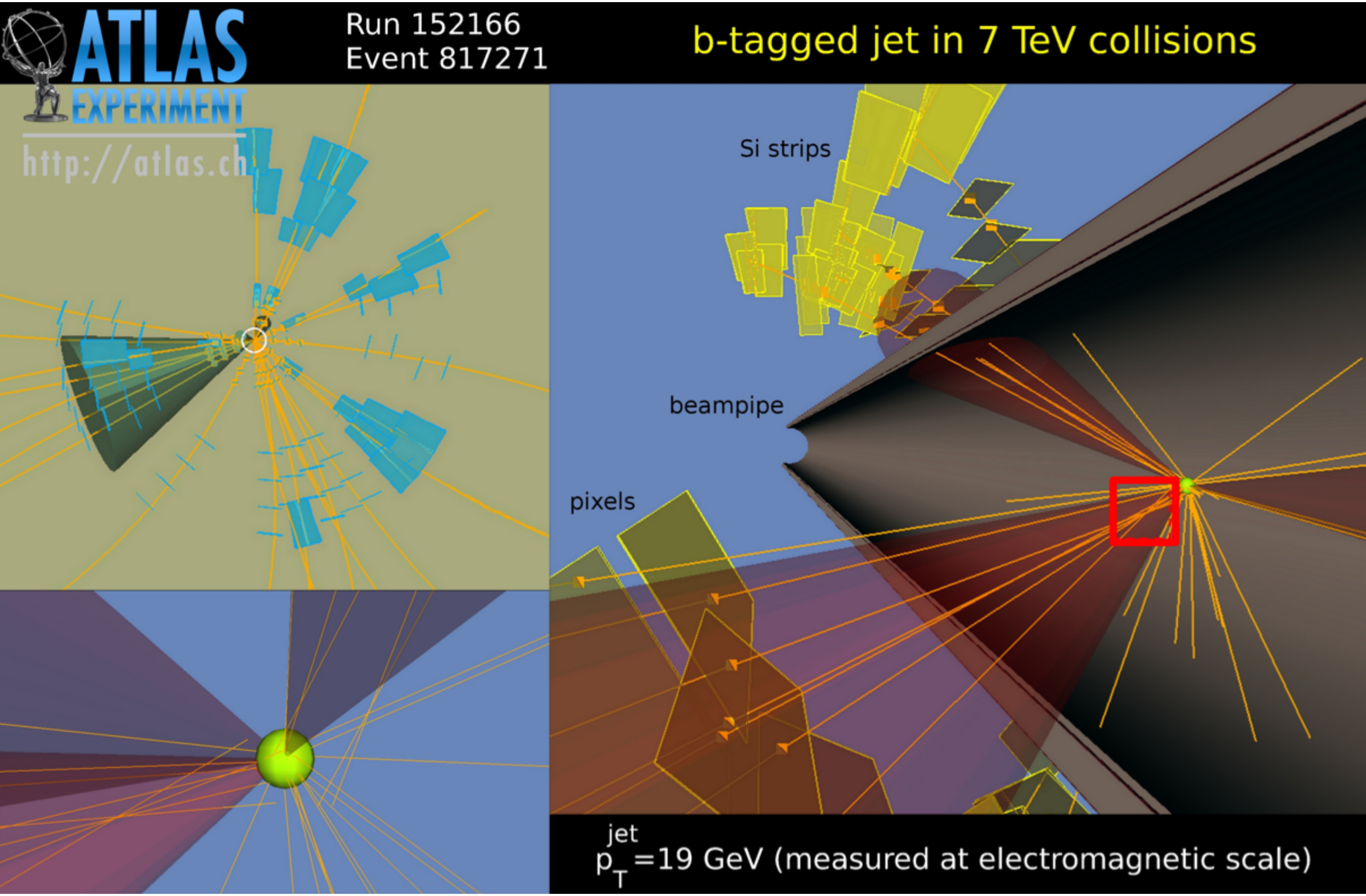
- Spatial tagging (or life-time tagging):
  - B hadrons have a significant flight path length:
    - E(B) ~ 50 GeV ⇒ L ~ 5 mm
  - Secondary vertex in jets.
  - Tracks with high positive impact parameter.



- Soft lepton tagging: Useful to commission other taggers
  - Low pT electron/muon from B/D decay.
  - Efficiency limited by (B/D l) branching ratio.



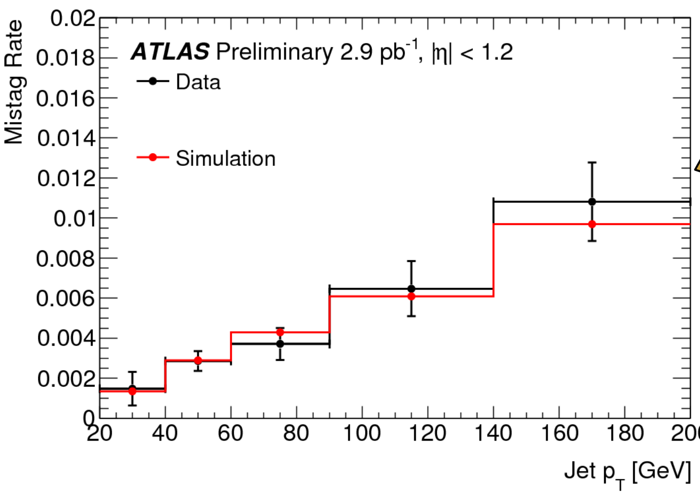
b-tagged jet



ATLAS EXPERIMENT
http://atlas.ch
Run 152166
Event 817271
b-tagged jet in 7 TeV collisions
Si strips
beampipe
pixels
p_T^{jet} =19 GeV (measured at electromagnetic scale)

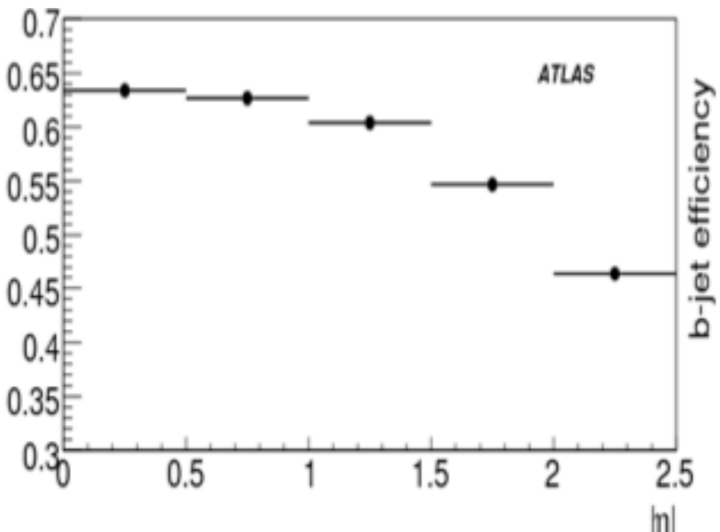
X B-Tagging Inventory

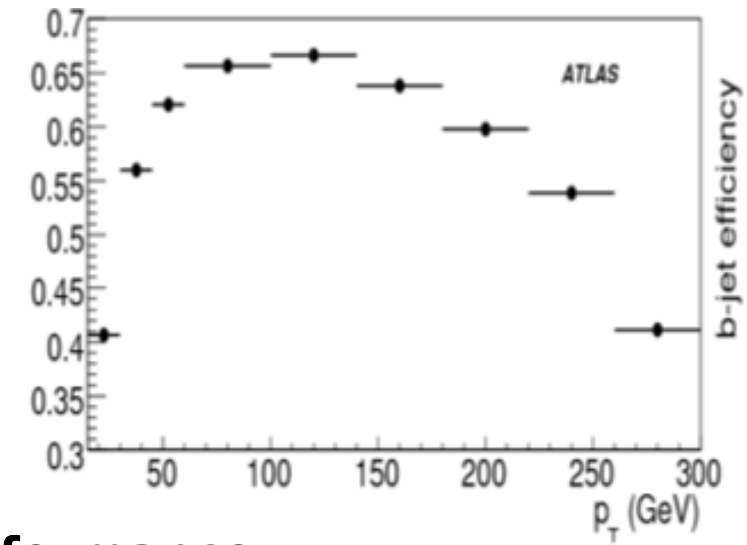
- **Simple taggers:** *robust, used on initial data (2010)*
  - **TrackCounting:** Counts tracks with high IP
  - **JetProb:** Track compatibility with the primary vertex
  - **SV0:** flight length significance of the SV
- **Advanced taggers :** *After commissioning, used for 2011 physics results*
  - **IP*n*D** (*n*=1,2,3) : IP based likelihood tagger
  - **SV*n*** (*n*=1,2): SV based likelihood tagger
  - **JetFitter*X*** (*X*=Tag,TagNN,COMB,COMBNN)
- **Soft lepton taggers :** *Limited efficiency, also tool for calibration*
  - SoftMuonTag
  - SoftElectronTag



B-Tagging Challenges

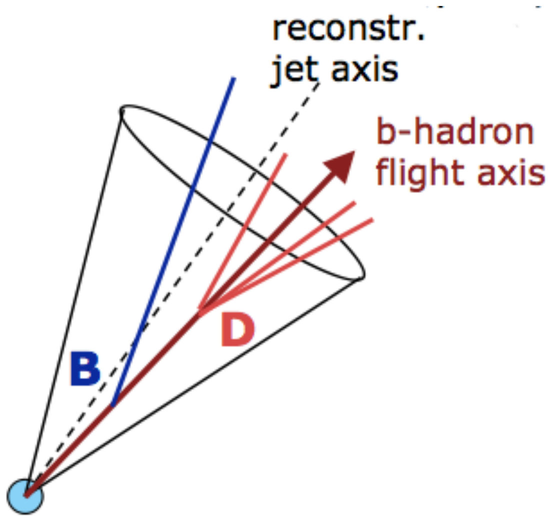
- strong dependence on **kinematics**
  - low p_T and high $|\eta|$: multiple scattering and material interactions
  - high p_T: two effects to cope with:
    1. collimated tracks –> limits of pattern recognition
    2. 'late' B decays in detector (p_T~200 GeV: 8% decay after b-layer)
  - shown for ttbar events: efficiency of IP3D+SV1 tagger at cut w>4





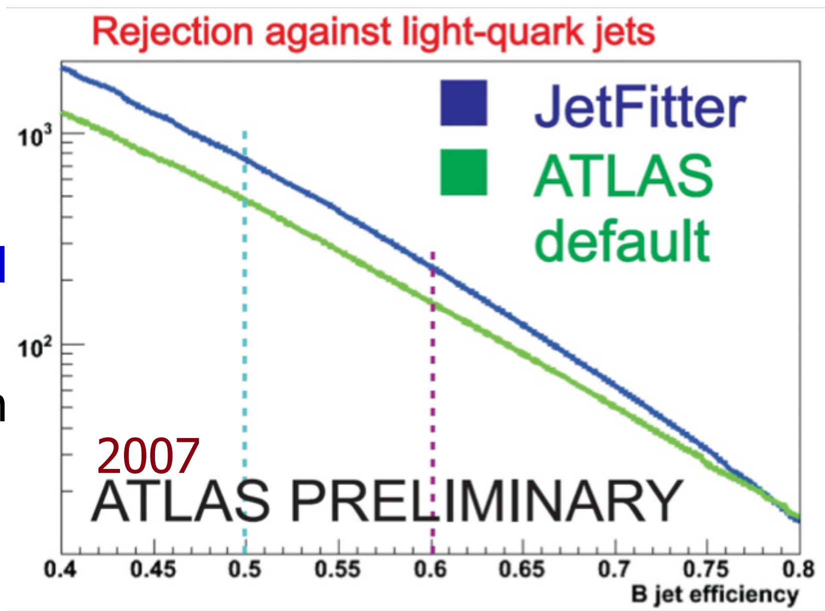
- excellent **control of tracking performance**
  - good local alignment, material description
  - study of impact parameter and vertex resolutions
- Use of sophisticated taggers in 2011 results is consequence of excellent tracking performance and collaboration tracking–btagging

JetFitter



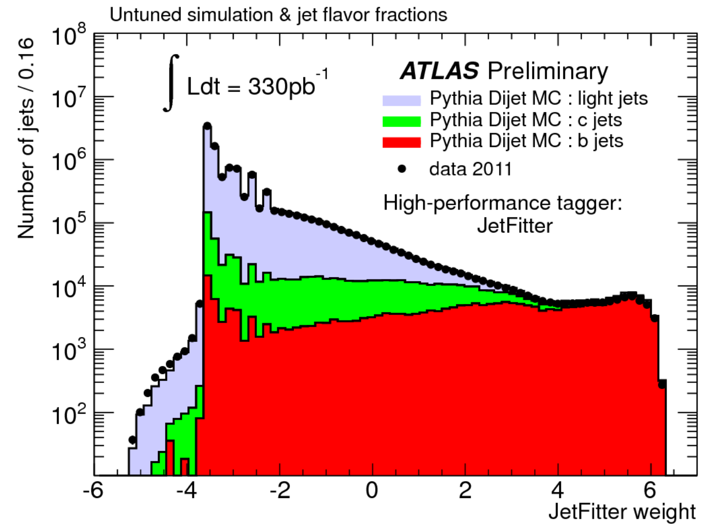
- B decay is actually a decay chain:
  - B –> D –> K/π with significant D decay length
- SV taggers improve b-tagging but do not use optimal/accurate information
  - B–>D cascade approximated by single vertex (# tracks and resolution not enough to fit 2nd + 3rd)
  - contaminated with light flavour jet (K_0, Λ decay)
  - statistical issues with 1-vertex assumption (χ^2, cov)

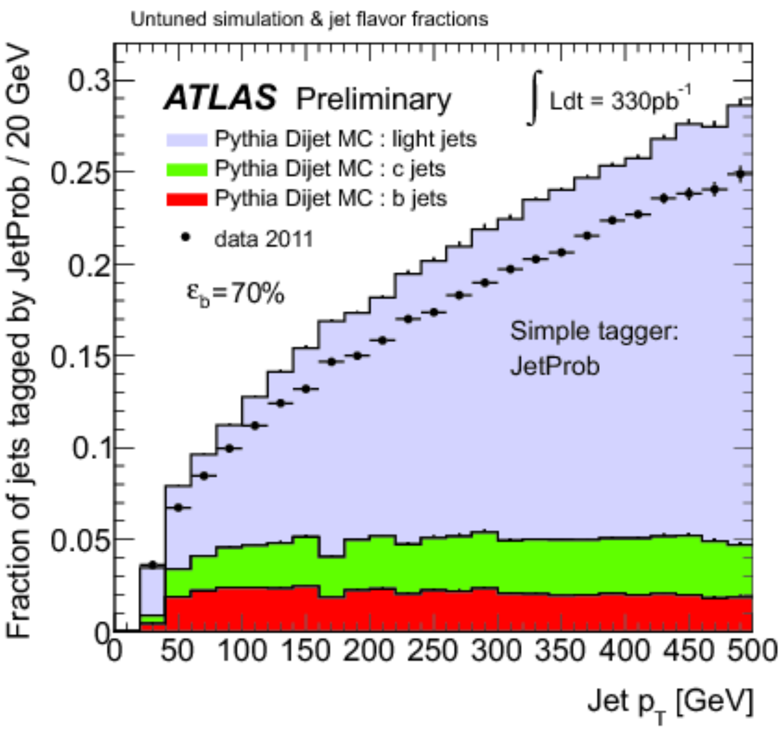
- JetFitter algorithm solves issues with a multivertex fit in 1 dimension along the jet axis: PV – B-vertex – D-vertex
  - robust against small number of tracks (1)
  - displacements from common jet axis small
  - Kalman filter based
- B hadron discriminators extracted from B-D system (m, E/E_{jet}, σ(d)/d)
- indeed rejection of light jets improved

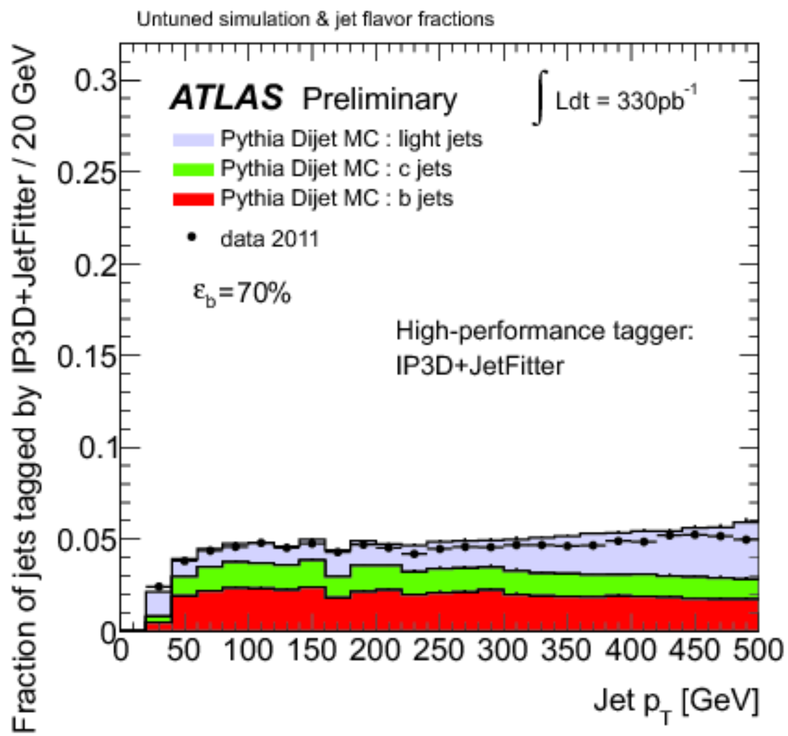


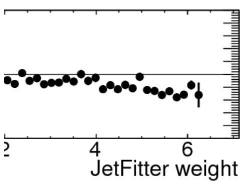
b-Tagging Performance

- Comprehensive studies of all b-taggers
  - input variables and output weights
  - relative comparisons in different kinematic regions
  - efficiencies
- Powerful combination IP3D+JetFitter









Electrons, Jets, Missing E_T, Tau

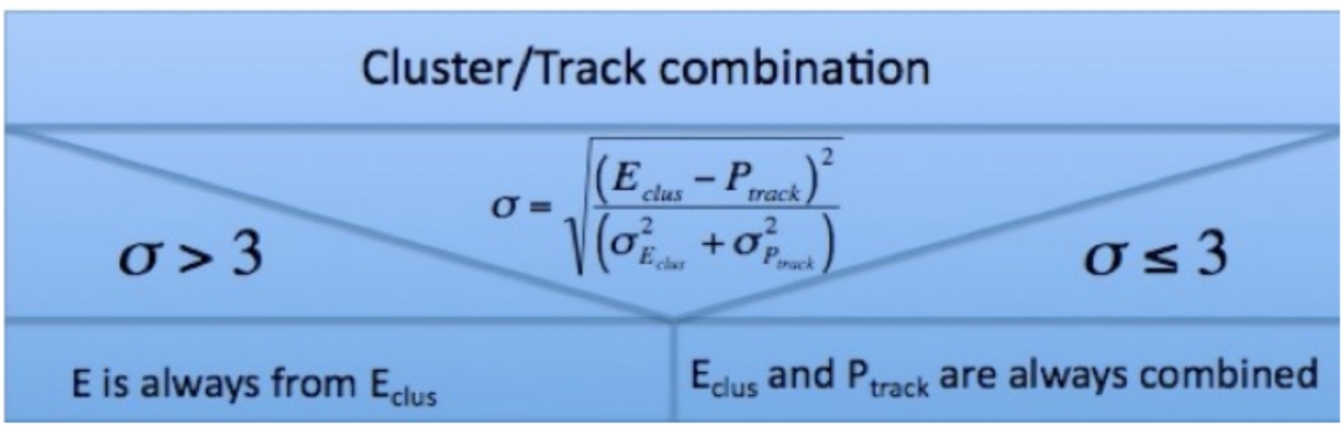
Electron Identification

- standard identification: LAr el-mag. **calorimeter seeded**
  - seeded by clusters reconstructed in LAr by a sliding window algorithm
  - attempt to match a track to the cluster
  - attempt to match a conversion vertex to the cluster
- Definition of objects
  - electrons: cluster + track
  - photons: two categories:
    1. unconverted photon
       = cluster + no track, no conversion vertex
    2. converted photon = cluster + conversion vertex
- additional identification: **track seeded**
  - tight pre-selection cuts to minimize false identification
  - keep standard track+cluster if track is the same
  - improves efficiency at low energies, ET<5GeV
- **forward electrons**
  - uses topological clusters, no InDet information $|\eta|>2.5$
  - dedicated identification algorithm

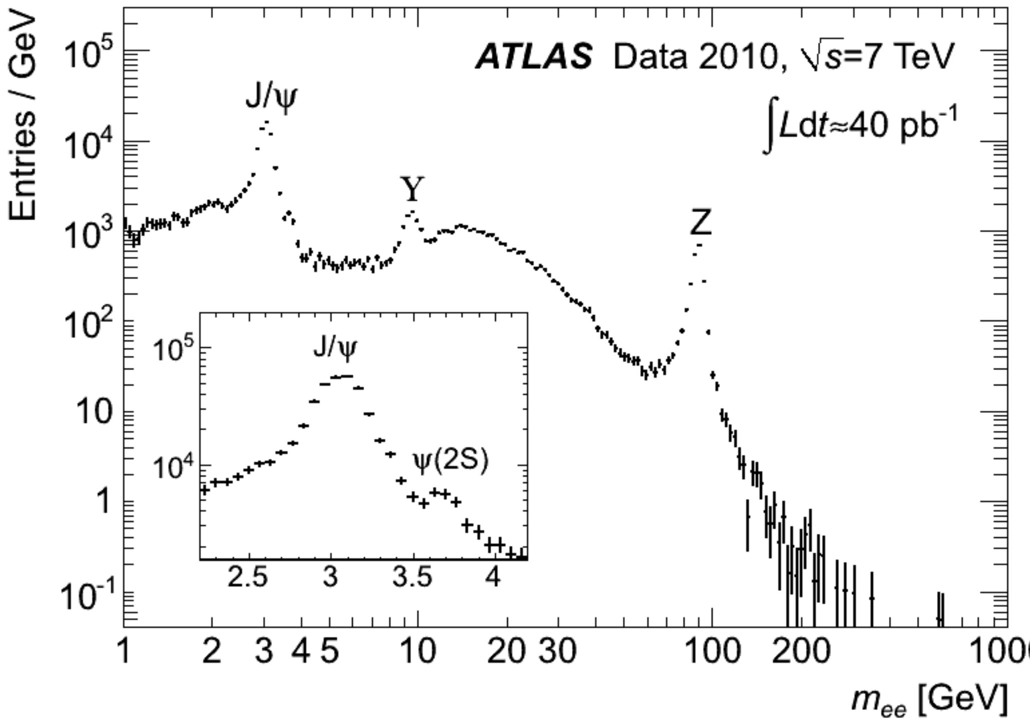
Electron Energy Reconstruction

egamma objects are massless, with four-momentum defined:

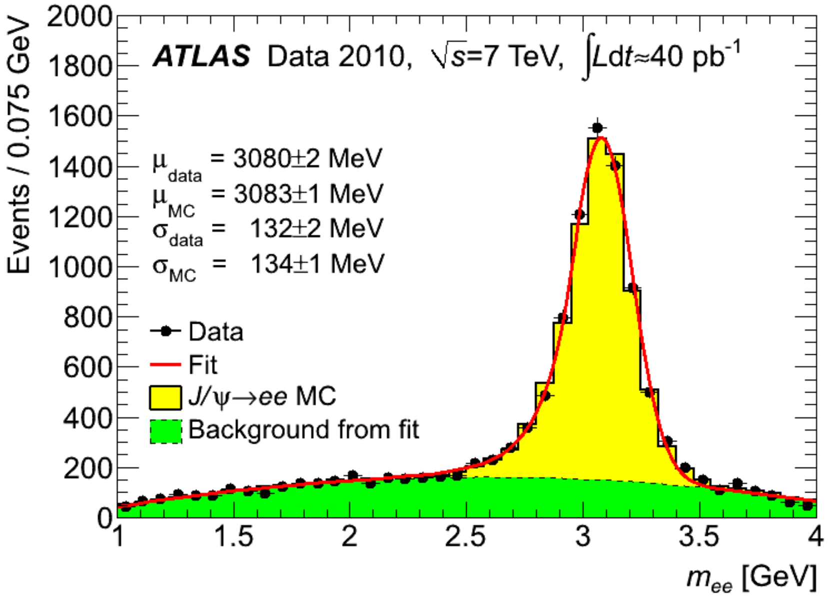
- For electrons: if σ < 3 and track is not low p_T TRT-only, the energy is from combining the cluster energy and the track momentum; else it comes from the cluster. φ is from the track, and η comes from the track, unless the track is TRT-only, in which case, the η is from the cluster pointing
- For unconverted photons, energy is from the cluster. η comes from cluster pointing, and φ is from the cluster position. From 15.8, φ is corrected for the primary vertex.
- For converted photons, energy is from the cluster, φ is from the track, and η comes from propagating from cluster to conversion vertex, unless the tracks are TRT-only, then cluster pointing



Electron Performance

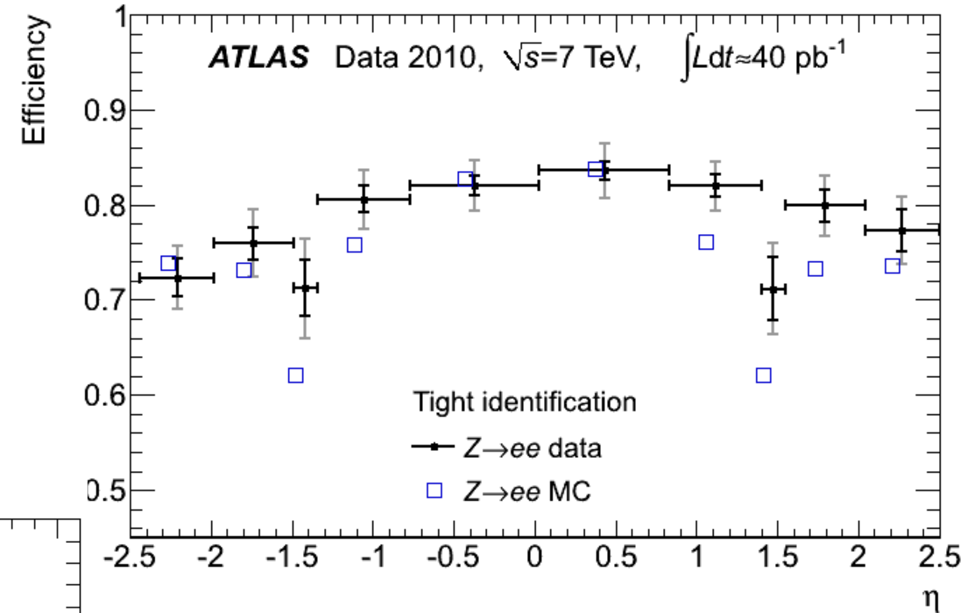


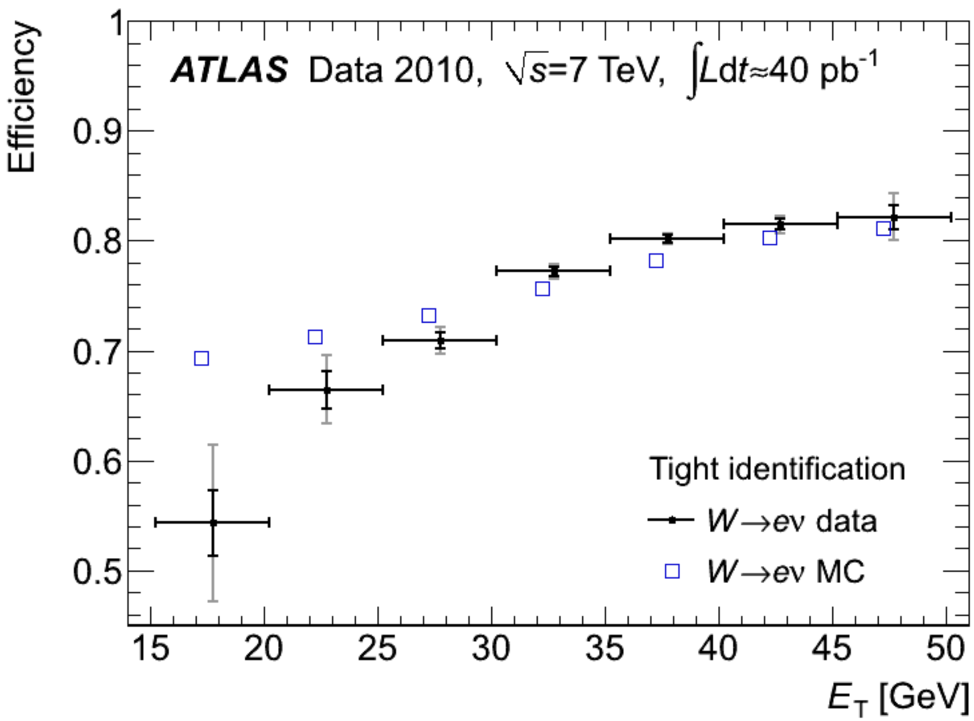
- same di-lepton spectrum as for muons
  - momentum resolution at low p_T: wider peaks or tighter selection
  - well described by MC



Electron Performance

- efficiency from Z−>ee
  - tag-and-probe like with μ
  - tight identification = few false ID
  - note the low efficiency ~80% compared to muons



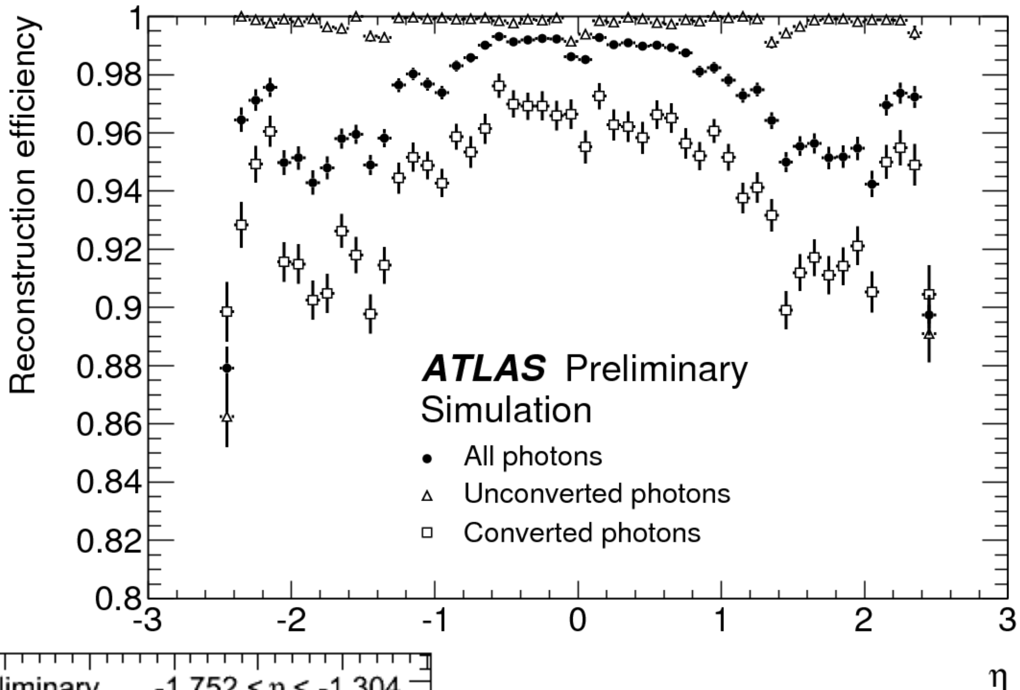


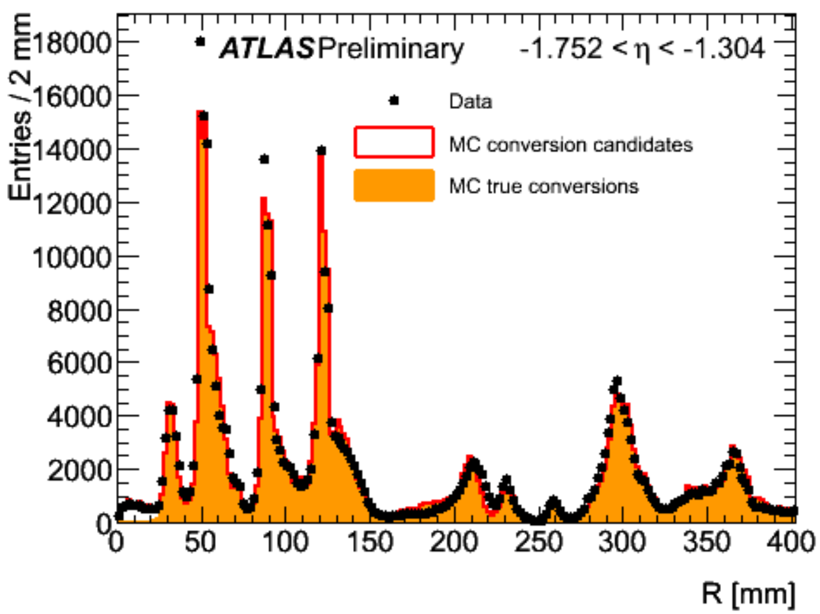
- efficiency from W−>eν
  - reaches lower in ET
  - some discrepancies (note: 1 year old reco software)

mance

Photon Performance

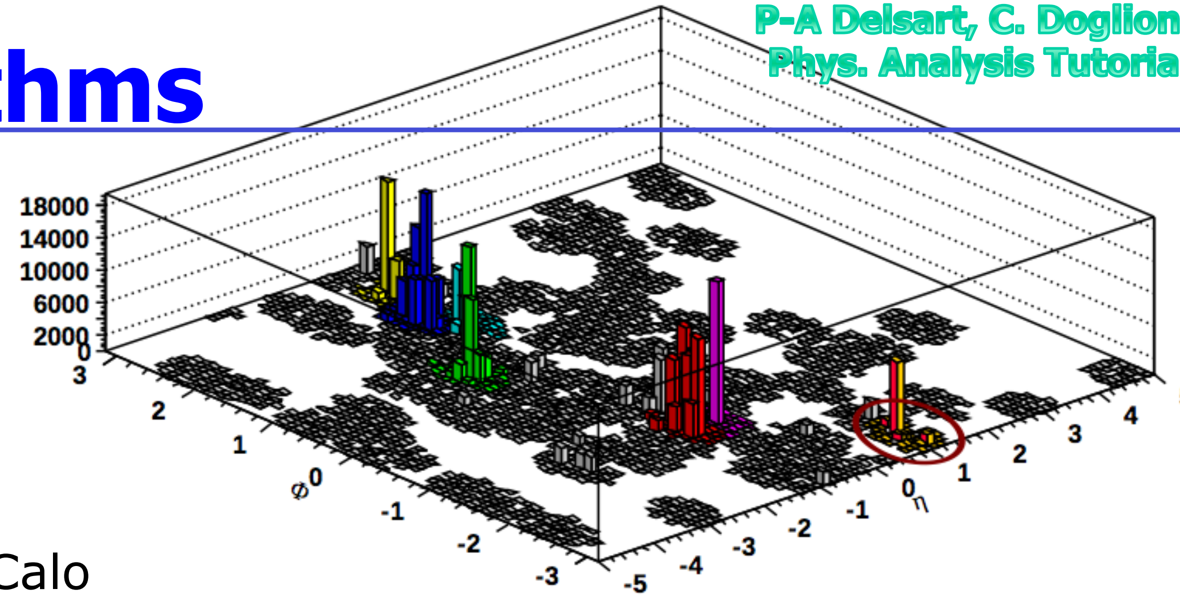
- more difficult to estimate
- conversions are main issue
  - main contributor to inefficiency, well known from simulation
  - studies therefore focus on understanding the material
  - conversions complement other material studies (slide 20)



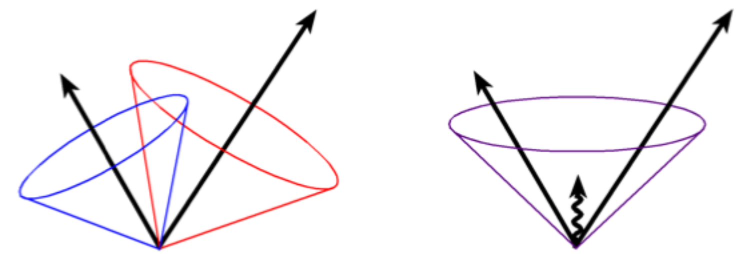


2011

Jets Algorithms



- Task: estimate
  direction and energy
  of prompt hadrons
  from energy map in Calo
- Geometrical cone algorithms
  simple but not infrared safe



- Kt/Cambridge clustering algorithms
  - define distance and limit

$$d_{ij} = min(p_{Ti}^2, p_{Tj}^2)\frac{\Delta R_{ij}^2}{R} \quad \text{and} \quad d_{iBeam} = p_{Ti}^2$$

  - keep merging two smallest distance objects i,j into new proto-jet until $d_{ij} > d_{iBeam}$

Jet Clustering Algorithms

Kt algorithm is collinear and Infrared safe. But has inconvenient :

- Irregular, complex shape
- "vacuum cleaner" effect

Some variants have been studied : replace distance definition by

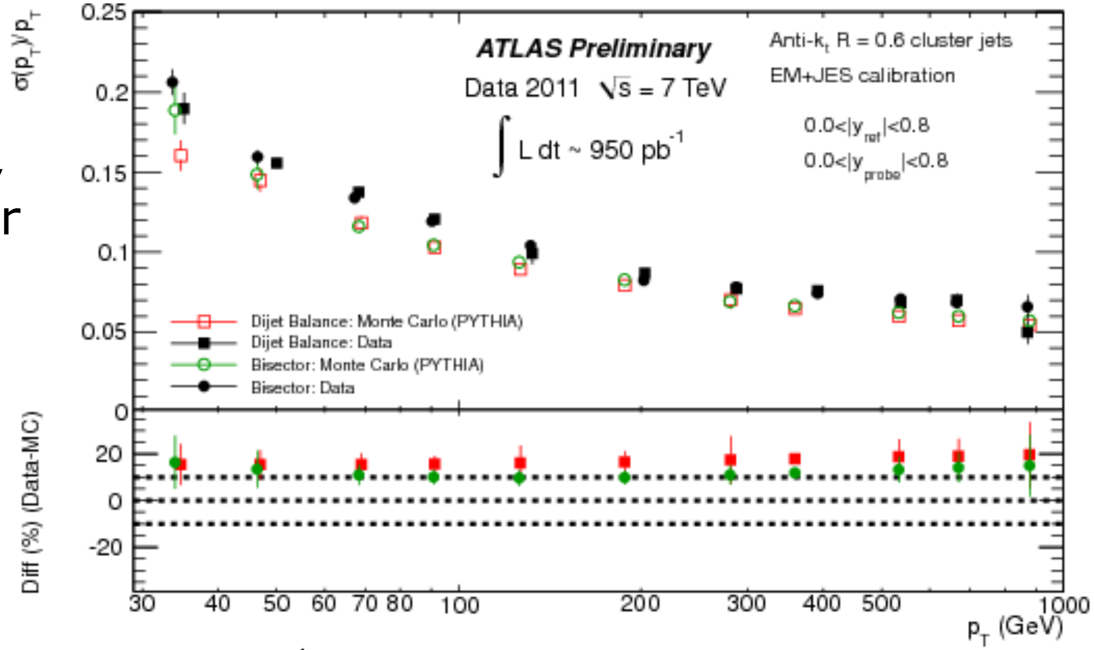
$$d_{ij} = min(p_{Ti}^{2p}, p_{Tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2} \quad \text{and} \quad d_{iBeam} = p_{Ti}^{2p}$$

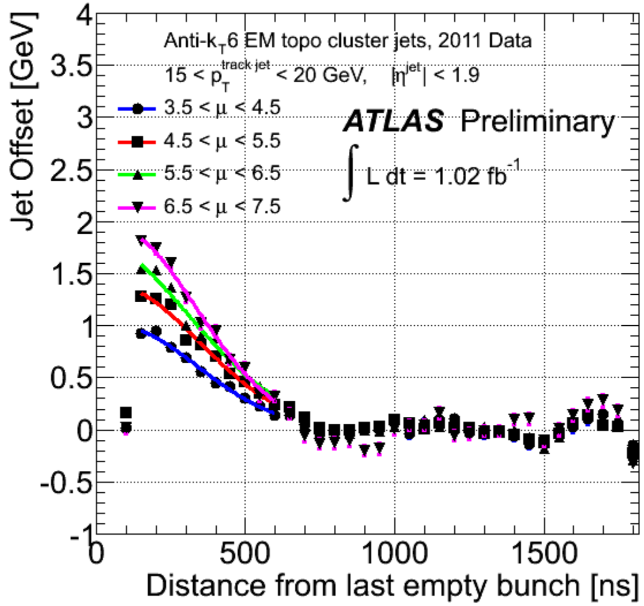
1. p=1 : Kt algorithm. Priority to low Pt constituents
2. p=0 : Cambridge variant. Purely geometrical
3. p=-1 : **Anti-kt** variant. Priority to high Pt constituents
4.

Anti-kt very recent (Salam, Cacciari, Soyez arXiv:0802.1189, independently of Atlas development [Atlas CVS ;)]), has several advantages.

Jet Reconstruction Performance

- Mainly energy resolution and reliability of jet energy, the **jet energy scale** factor (JES or JSF)
- various in-situ methods
  – in situ = measure on data
- look at known balanced events, like di-jet
- Another effect: **out-of-time pile-up**
  – Calo sensitive to energy from preceding collision
  – Energy may be overestimated
  – study by comparing to track-jets (hits on track have tighter timing)



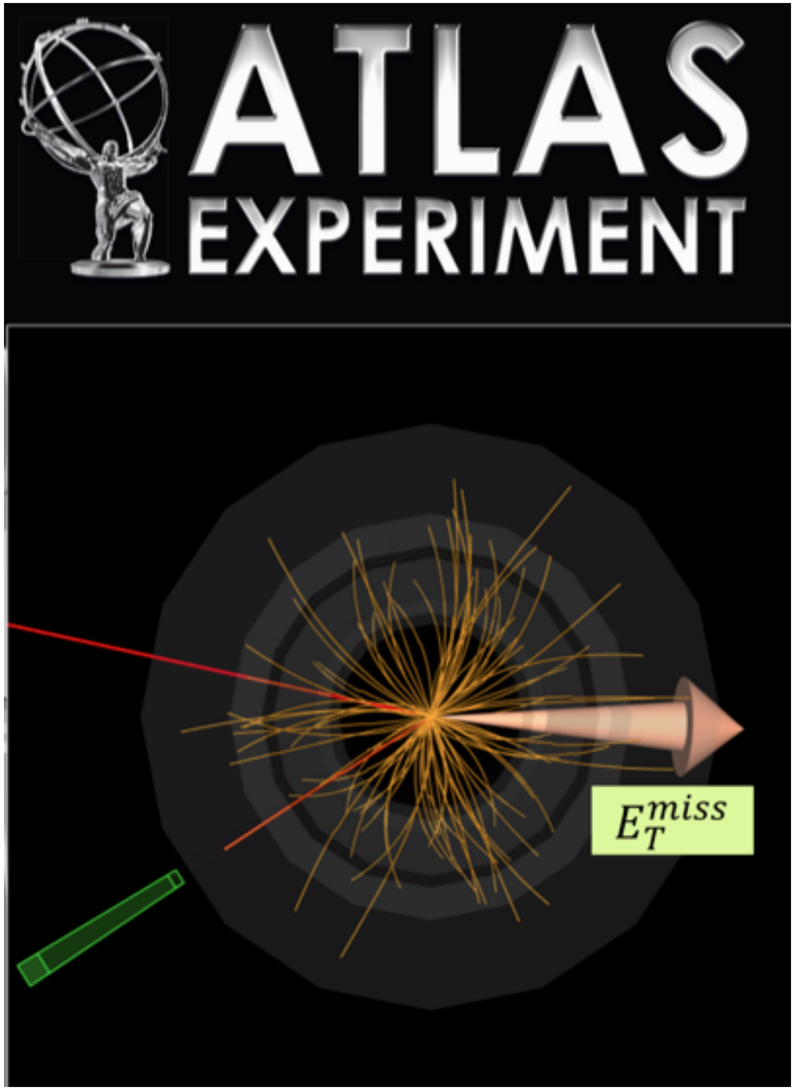


Missing Transverse Energy

- In hadron collisions a significant unmeasured amount of energy 'escapes' in z (=beam) direction
- total momentum in transverse direction is 0, conserved in collision
- missing total p_T or E_T points to weakly or non-interacting particles
  – neutrinos, new physics

$$E_T^{miss} = -\sum_{particles}(E_T)$$

- simple strategy: sum up calo clusters and energy of escaped muons in MS
- best strategy: take calibrated physics objects, overlap removal, add unassociated clusters
  – final, 'refined MET'



Part 2, slide 41 (WW event)

A. Yurkewicz

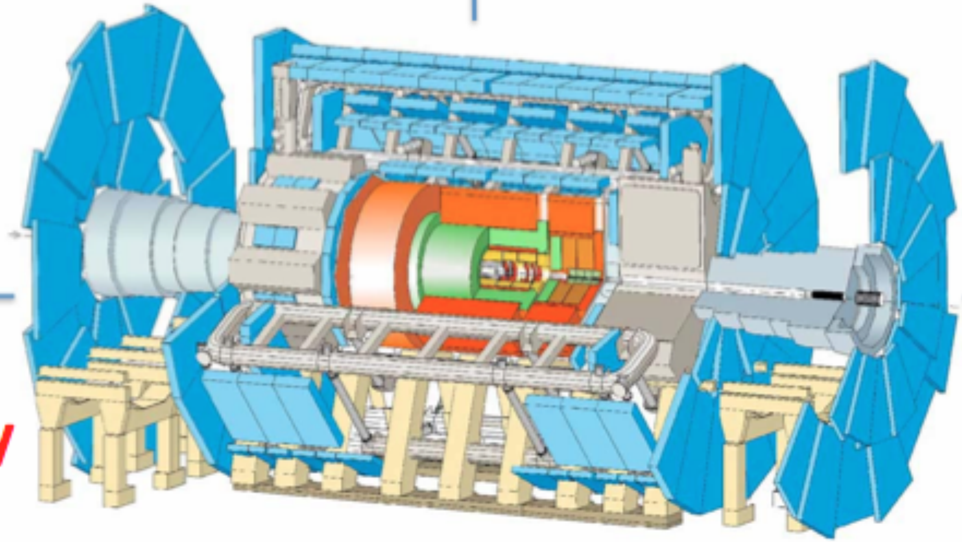
Inputs to Refined Missing ET

Electrons / Photons / Jets / Taus

- Overlap resolution needed for calorimeter-based signals
- Object quality cuts change MET
- Use best calibration for each

Muons

- Use good reconstructed muons
- Possible source of fake MET
- Avoid double-counting signal in calorimeters



Remaining Clustered Energy

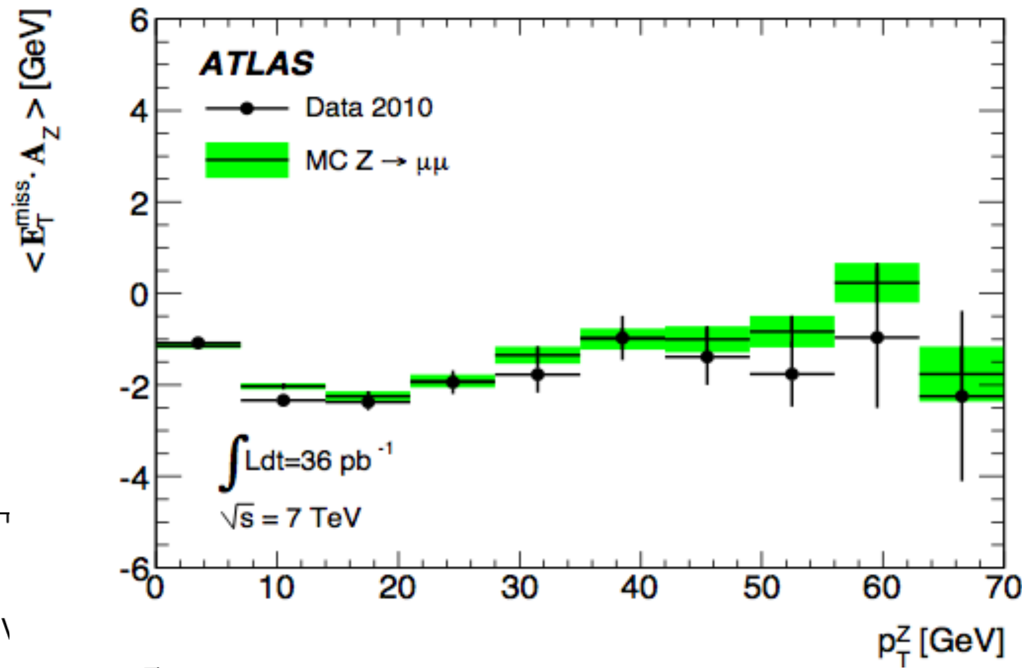
- Important to use all real signals in calorimeters, but ignore noise
- Need to derive calibration for soft signals
- Improve measurement with tracks

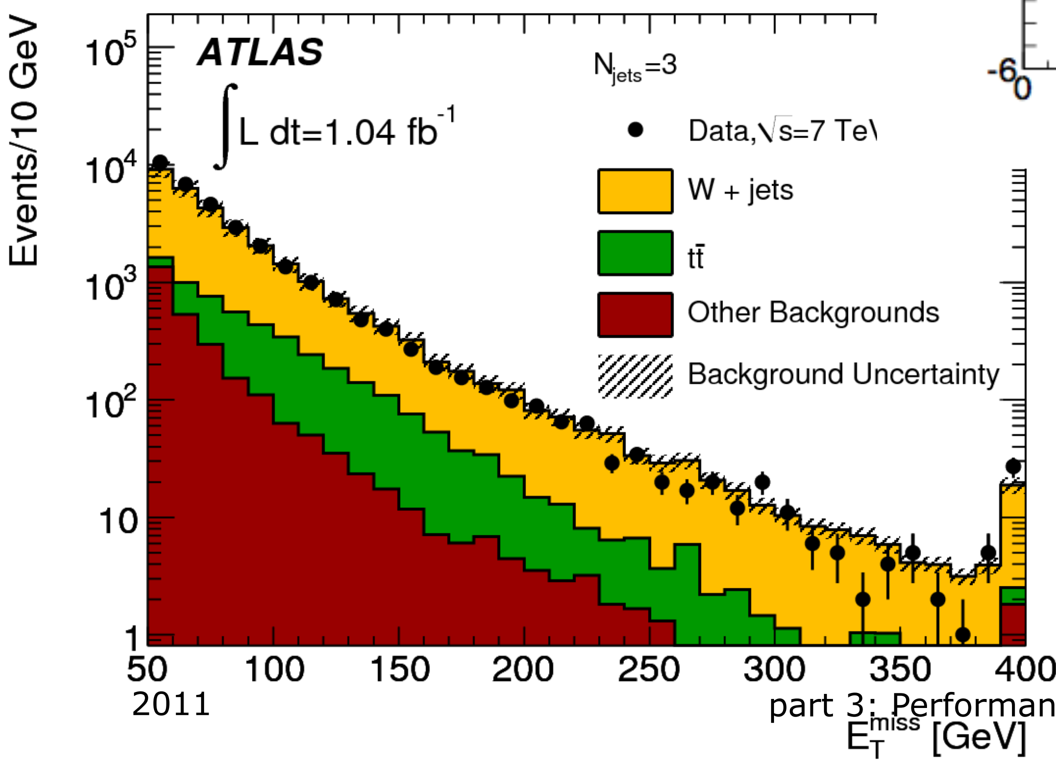
Data Quality/ Monitoring

- Physics analyses must exclude/ understand data with detector problems

Missing ET Performance

- Several methods for measuring MET performance, example
  - study Z–>μμ decays (MET known 0)
  - from residual bias calibrate hadronic recoil against more precisely known muon momenta

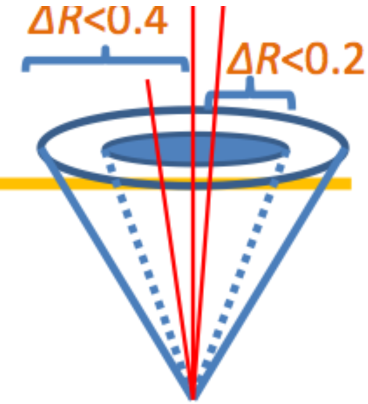




- No big surprises in inclusive MET distribution
  - detector effects vs. new physics

Tau Reconstruction

Only hadronically decaying taus considered
Decay to odd-numbered charged particles



- Track-seeded and calo-seeded candidates
  - Tracks(p_T>6GeV) used as seed.
  - Collected tracks(p_T>1GeV) around seed in cone ΔR<0.2, use them to define η, φ.
  - Look for jet (Anti-Kt algorithm with radius ΔR<0.4 on topological clusters) around track system(10GeV, ΔR<0.2)
  - Collected tracks(p_T>1GeV) around seed in cone ΔR<0.2.
  - Reconstruct π^0 subclusters
  - Calorimetric E_T with H1 calibration, E_T^{flow} from tracks and calo.

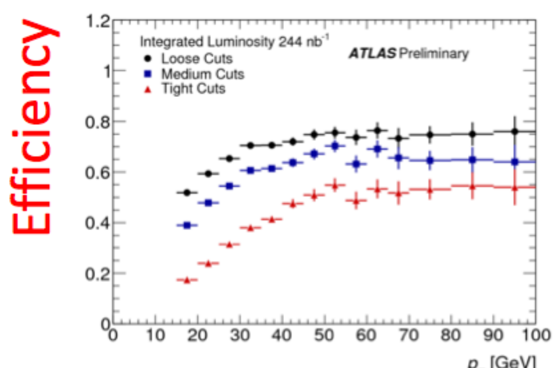
Tau Reconstruction

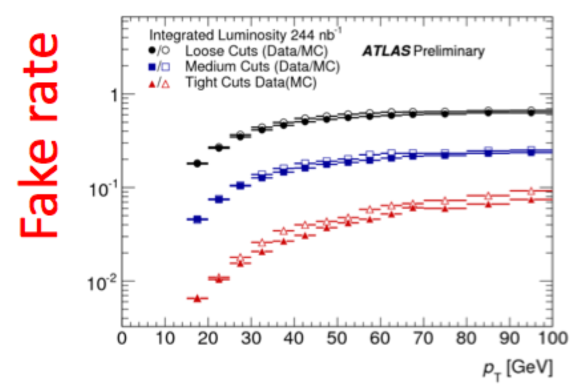
- Two more categories with only one of the two seeding strategies
- Calo-seeded only candidates
  - jet seed (not yet used in Calo+Track seeded)
  - collected tracks (pT>1GeV) around seed in cone R<0.2
  - calorimetric E_T with calibration
- Track-seeded only candidates
  - only a few % of all tau candidates
- Large number of identification variables form set of discriminators
  - including tau veto when overlap with electron/muons
- Commissioning:

Only three variables are used.
- Electro Magnetic Radius
- Track Radius
- p_T/E_T

Cut optimization (TMVA)

For 30%(tight), 50%(medium), 70%(loose) efficiency.

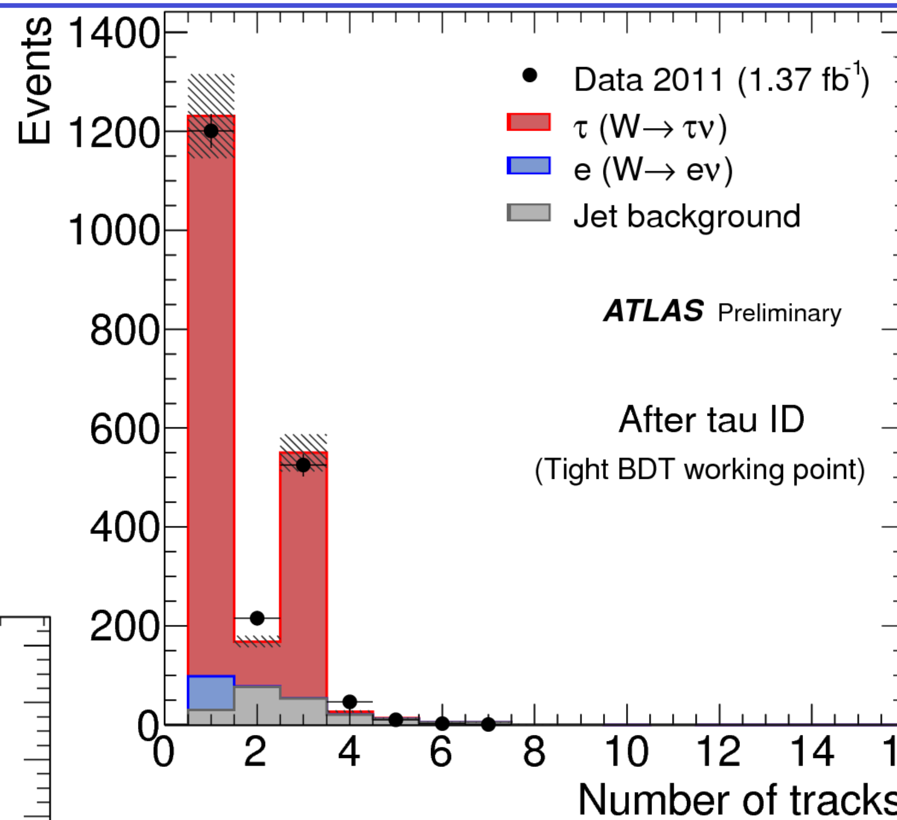


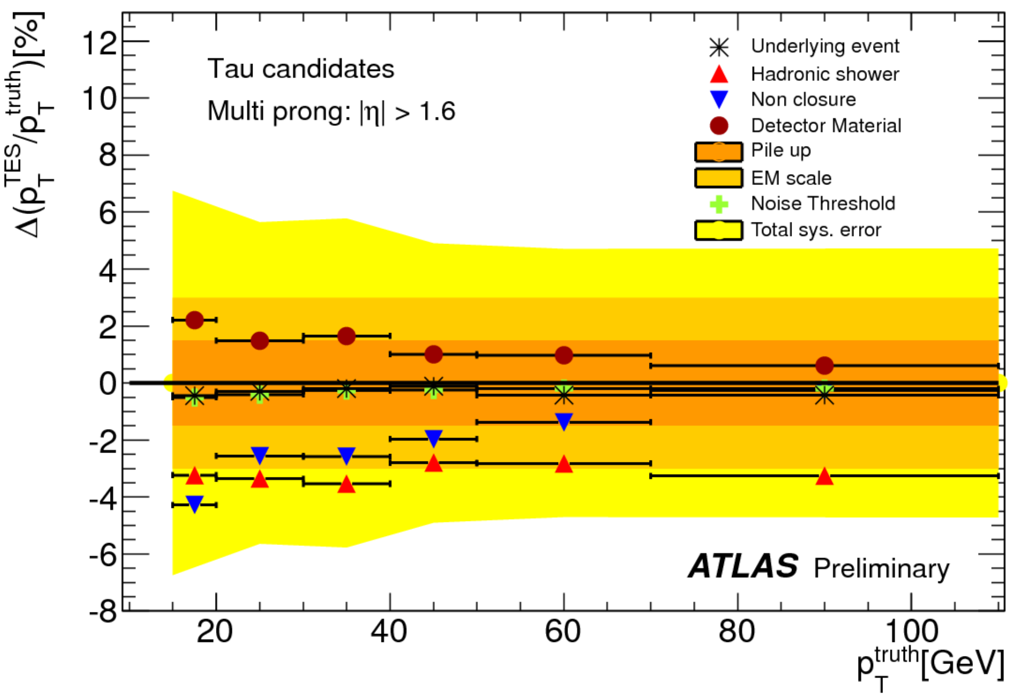


2011

Tau Identification Performance

- Now discriminator formed from full list of variables
  - multi-variate method: boosted decision tree (BDT)
  - high purity in W–>τν decays
- first studies of τ momentum resolution





Summary

- Discussed the different physics objects in ATLAS
  - outline of principal identification algorithms
  - methods to determine and improve performance on data
  - current performance, differences to simulation
- Found a remarkable performance close to design precision almost everywhere
  - only after 2 years of data-taking, previous experiments needed more time
  - a lot of effort has gone/is going into object identification and performance needs to be understood as part of physics analysis
- Last lecture will go into practical details

Further Reading

Track and Vertex reconstruction, R. Frühwirth and A. Strandlie, Rev.Mod.Phys 82 1419 (2010)
http://rmp.aps.org/abstract/RMP/v82/i2/p1419_1

Tracking Performance Results
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/InDetTrackingPerformanceApprovedPlots

ATLAS conference notes
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES

ATLAS papers
https://twiki.cern.ch/twiki/bin/view/AtlasPublic
– Electron Paper http://arxiv.org/abs/1110.3174
– Missing ET Paper http://arxiv.org/abs/1108.5602

Identification of b-jets and…, N.G. Piacquadio, CERN-Thesis-2010-024
https://cdsweb.cern.ch/record/1243771

The anti-kt jet clustering algorithm, M. Cacciari et al, arxiv: 0802.1189 [hep-ph]
http://arxiv.org/abs/0802.1189