ATLAS detector performance and upgrade plans

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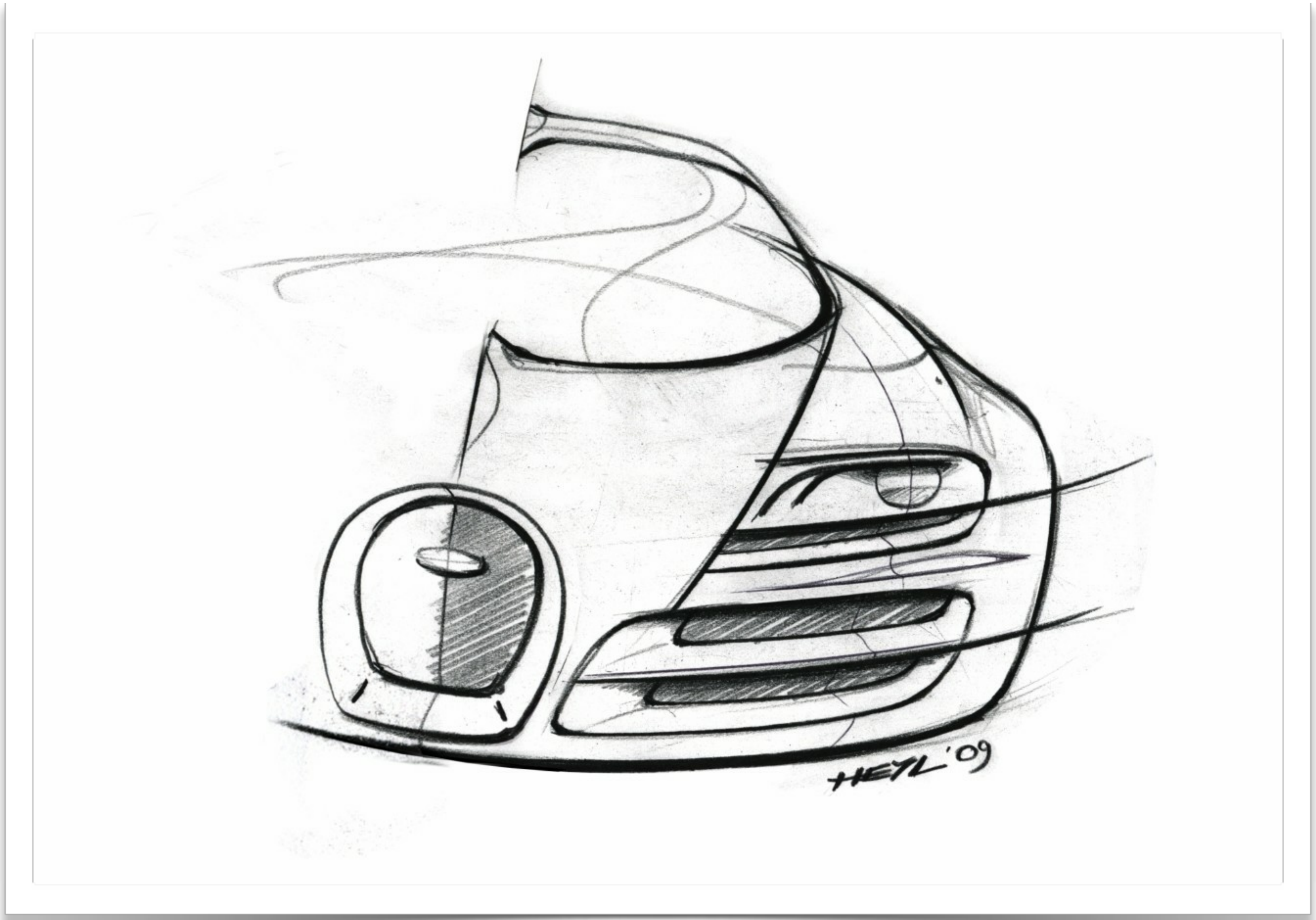
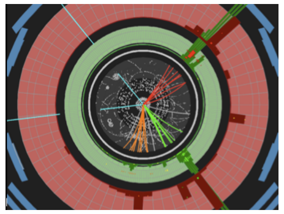
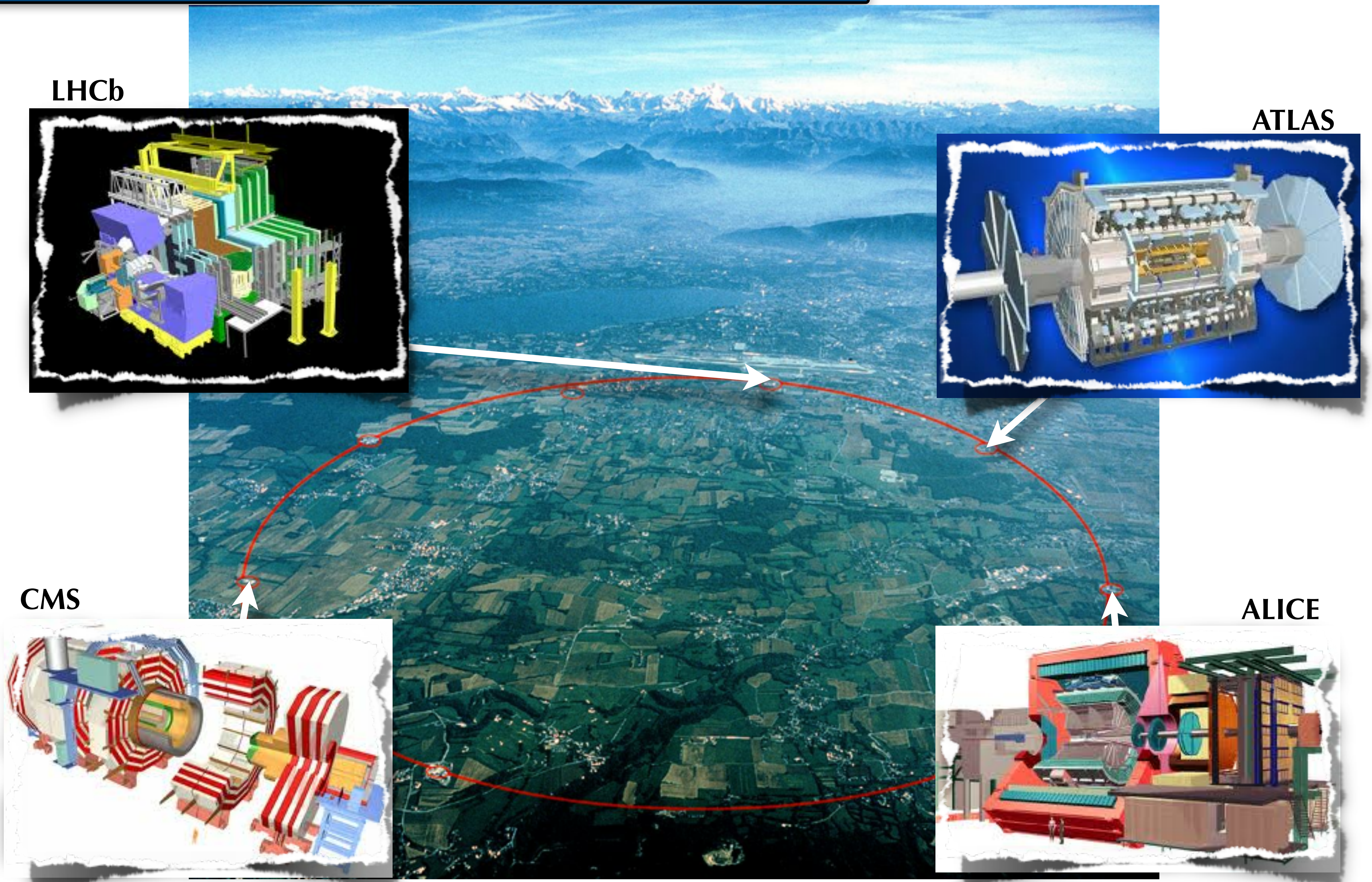
ATLAS

1.- Introduction

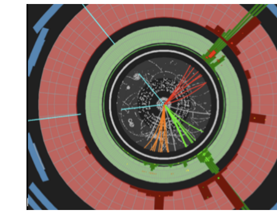


The Large Hadron Collider





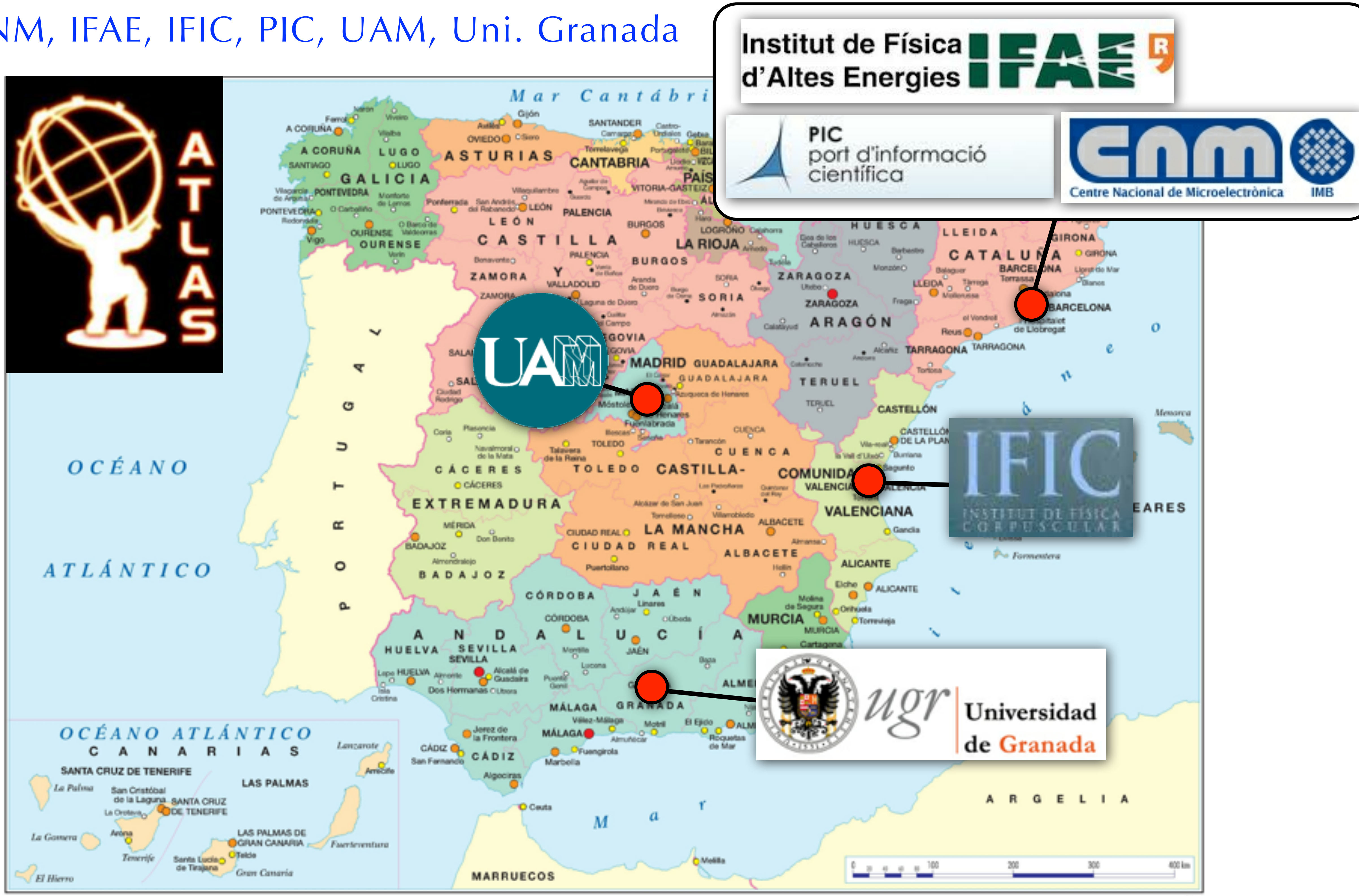
The ATLAS collaboration



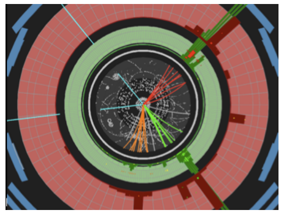
- 3000 scientists
- 38 countries
- 175 institutions

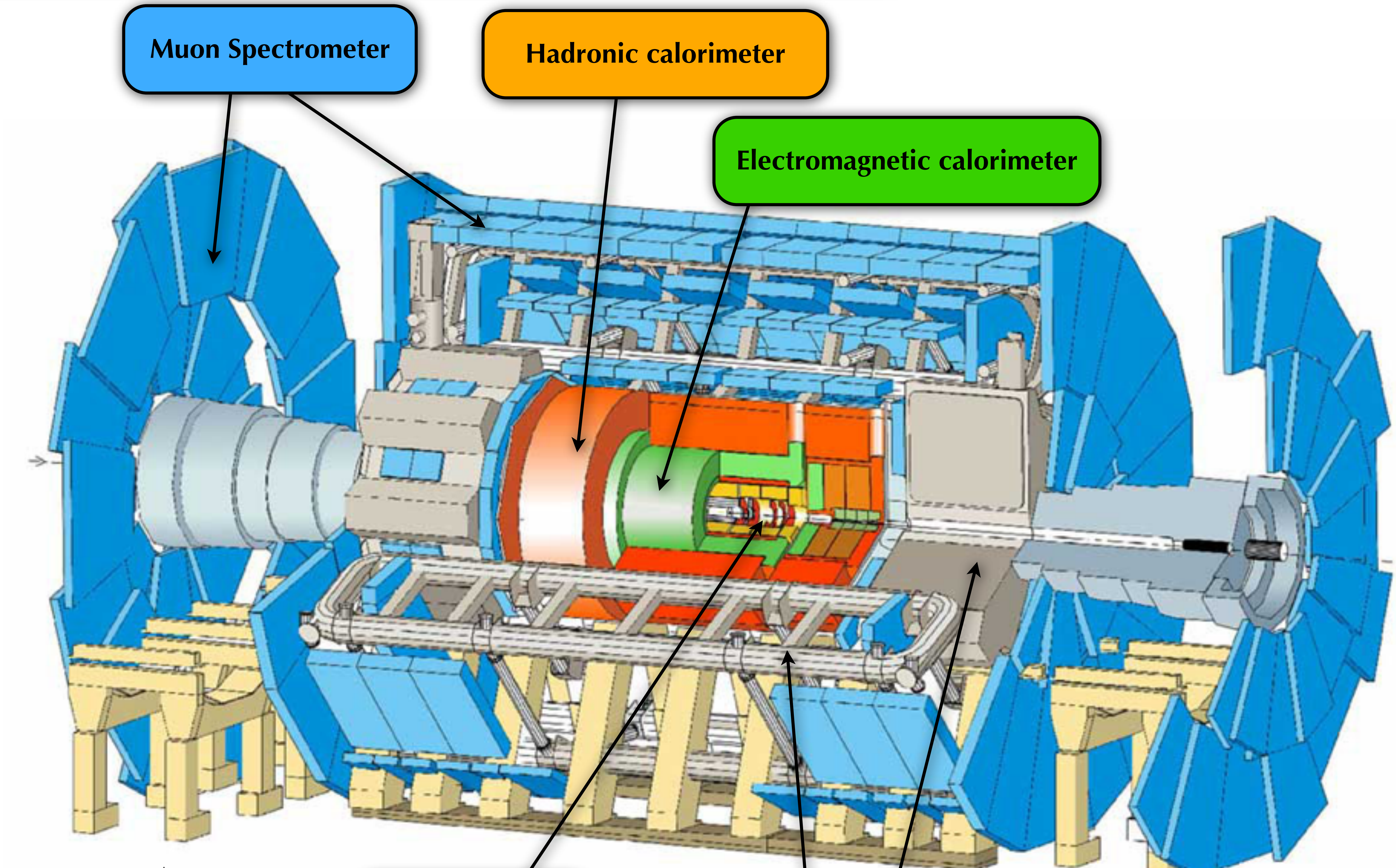
ATLAS spanish contribution

- Strong contribution of several spanish institutes to ATLAS
  - CNM, IFAE, IFIC, PIC, UAM, Uni. Granada

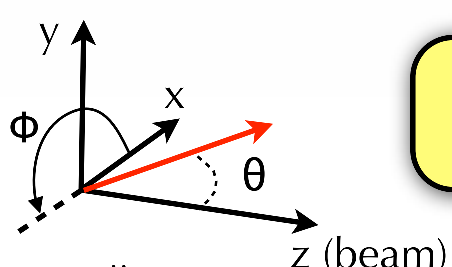


The ATLAS experiment

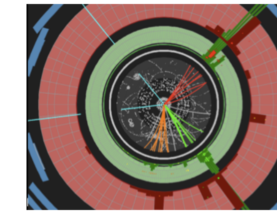


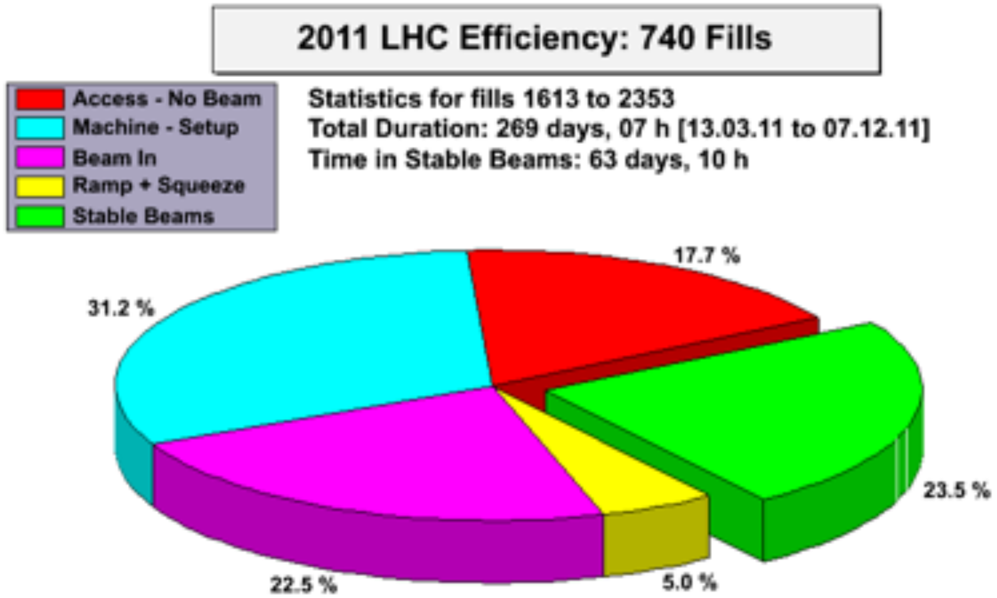


length = 44 m
heigth = 25 m
weight = 7000 tons



ATLAS data-taking

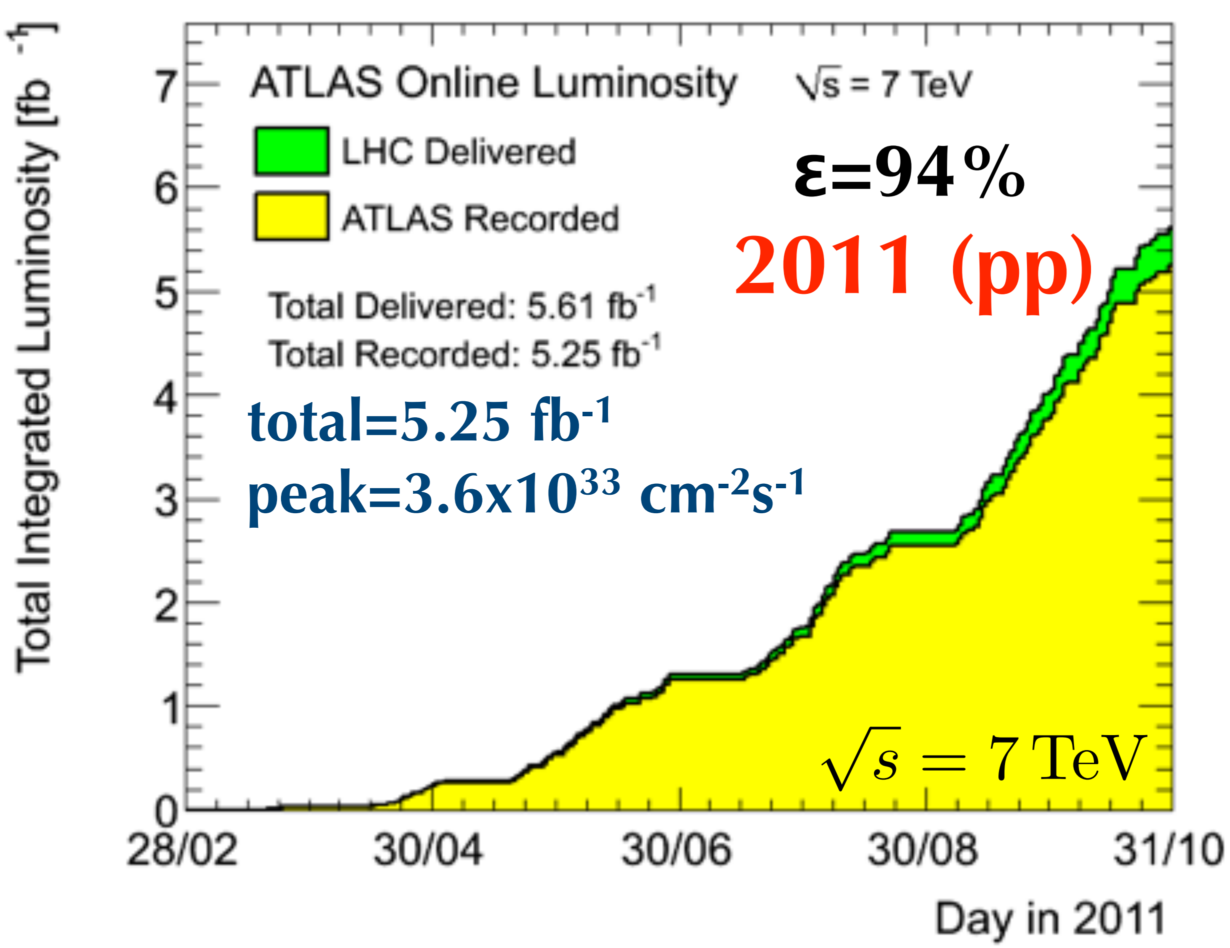


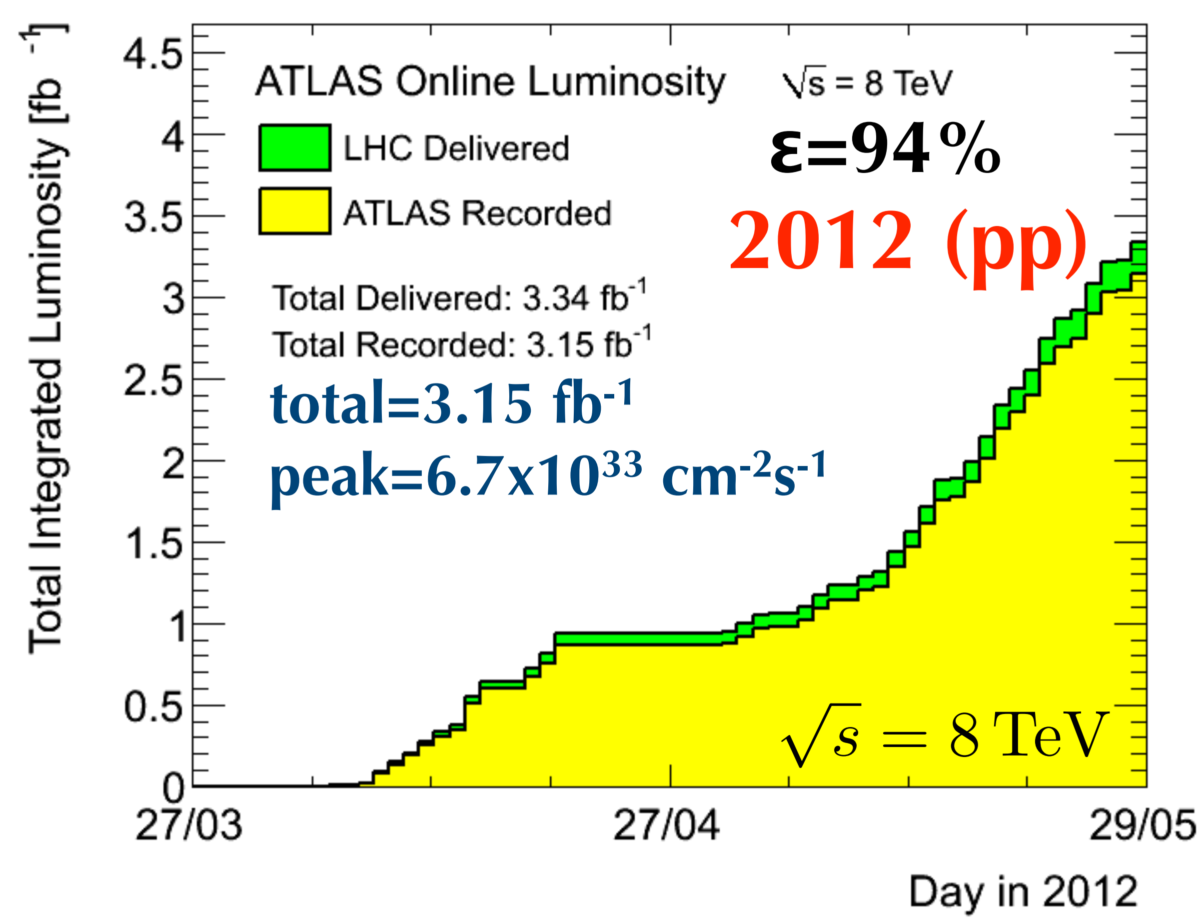


Fraction of good data quality per sub-system (2011, 5.23 fb^{-1})

ATLAS 2011 p–p run												
Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

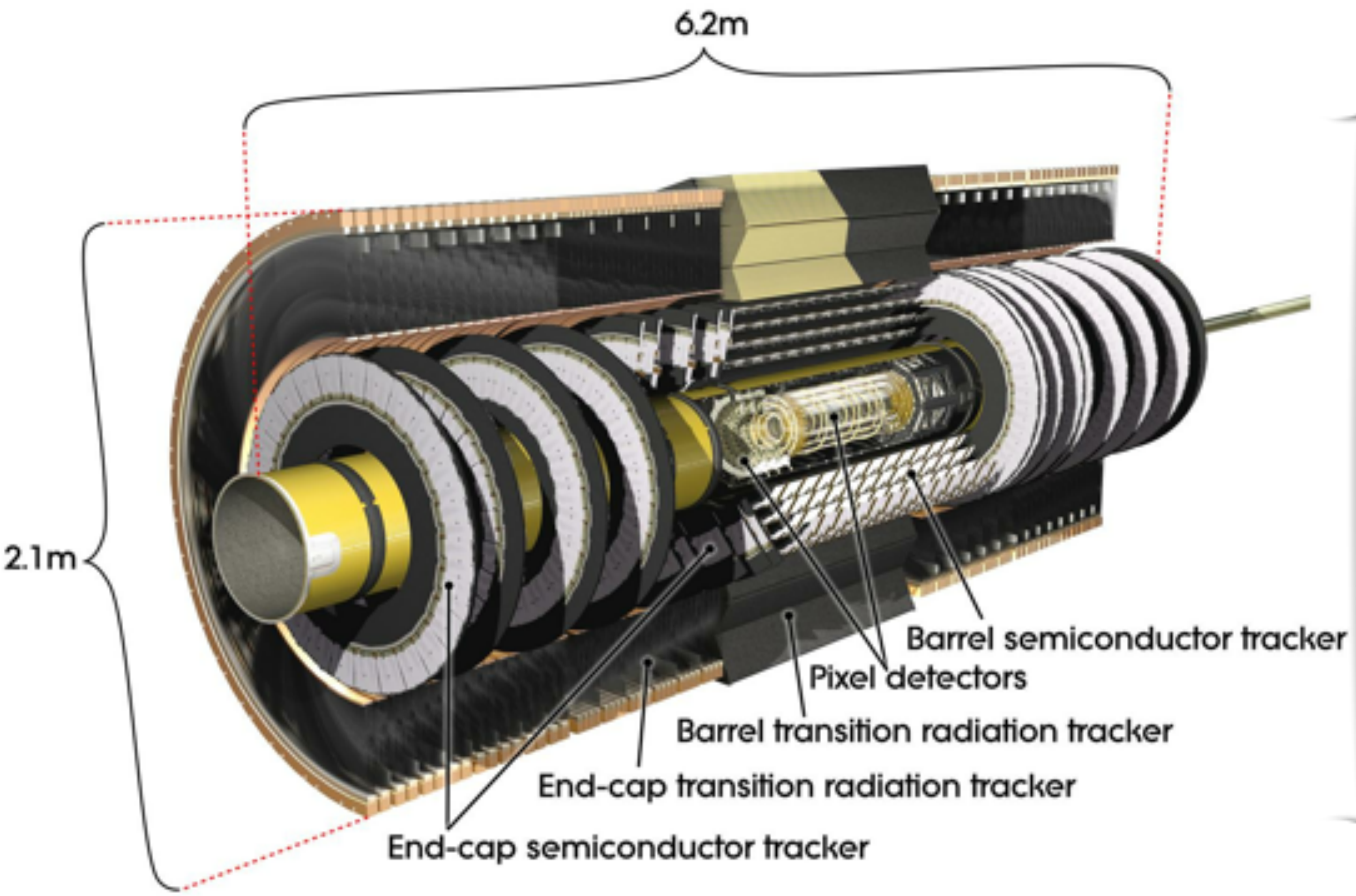


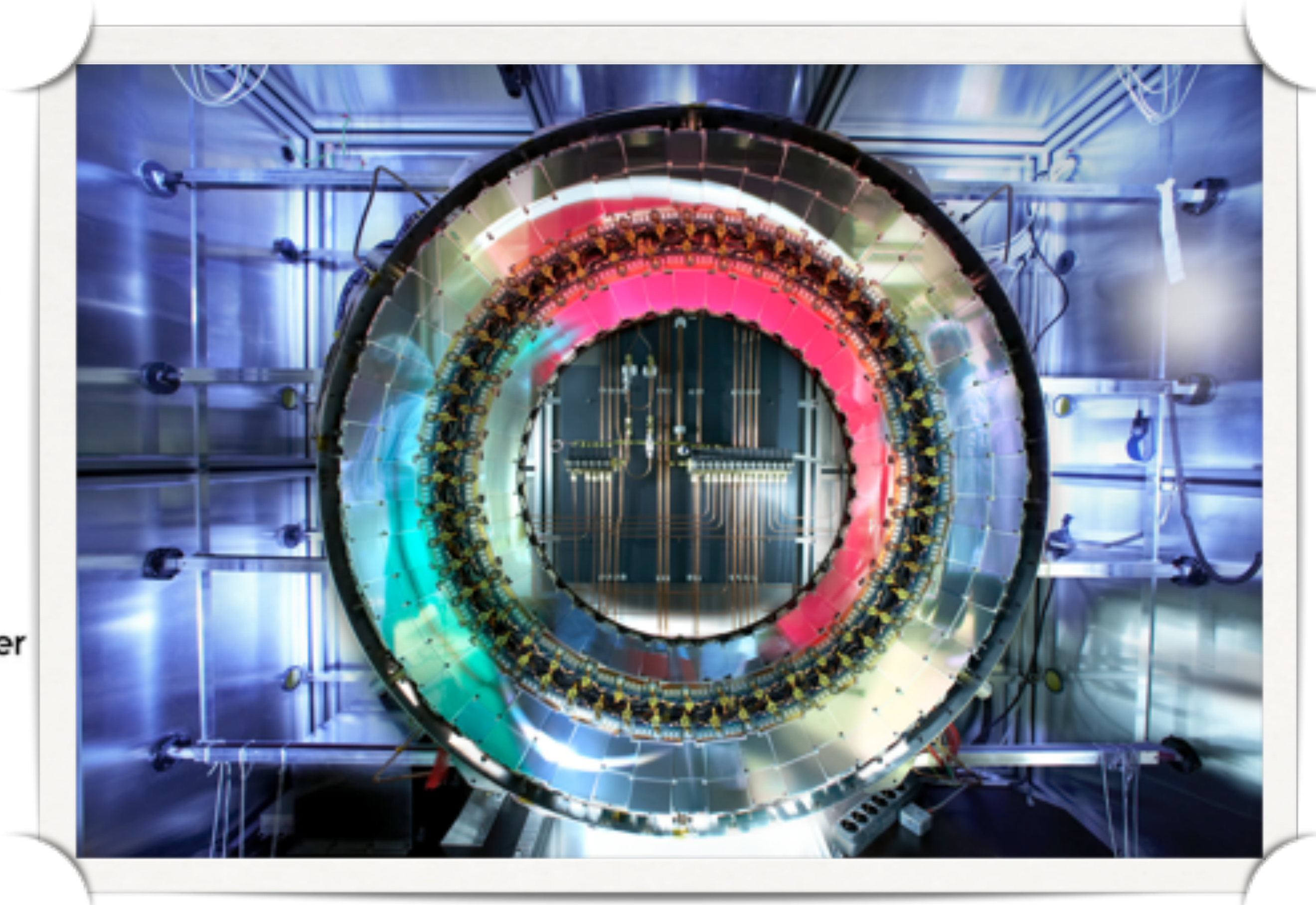


2.- Performance

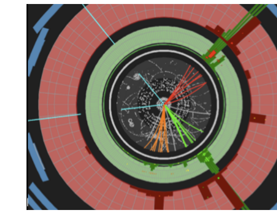
2.- Performance

2.1.- Inner Detector

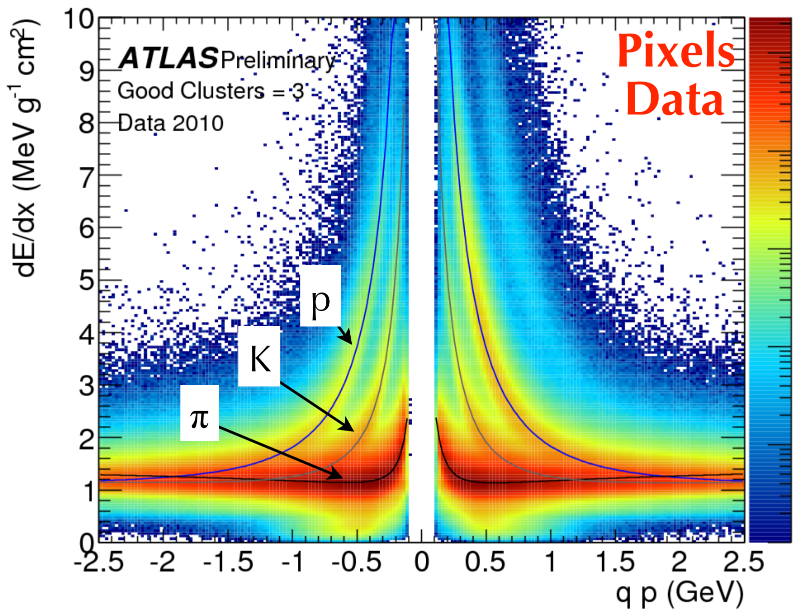


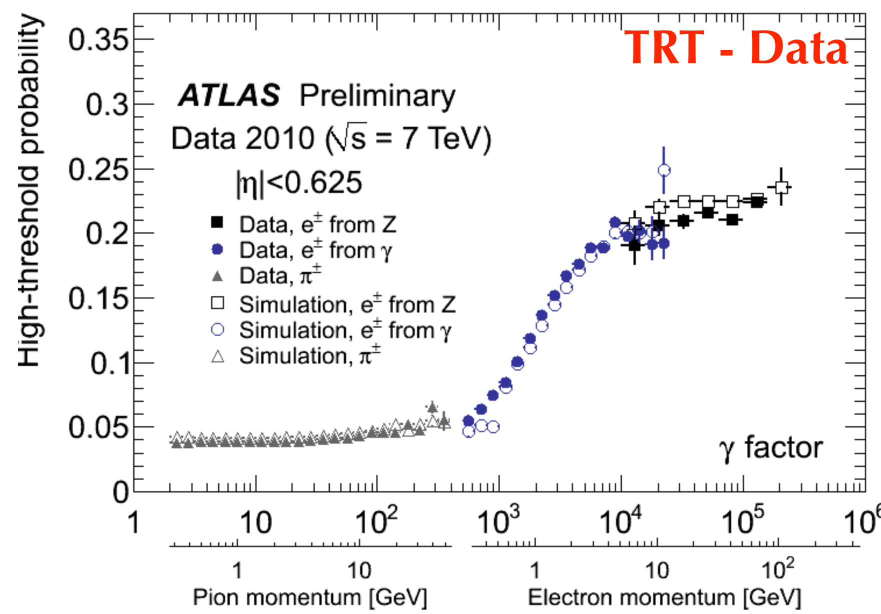


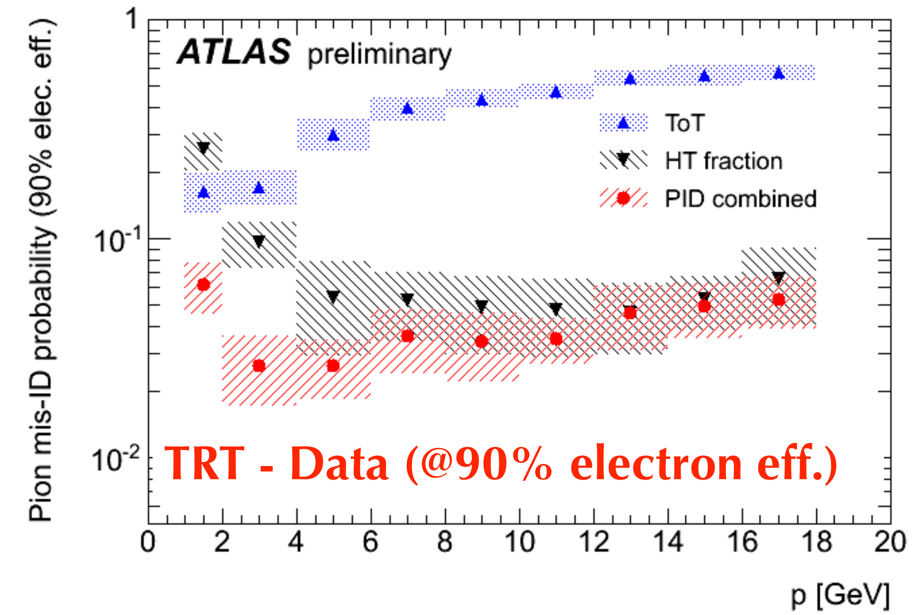
ID calibration and track reconstruction



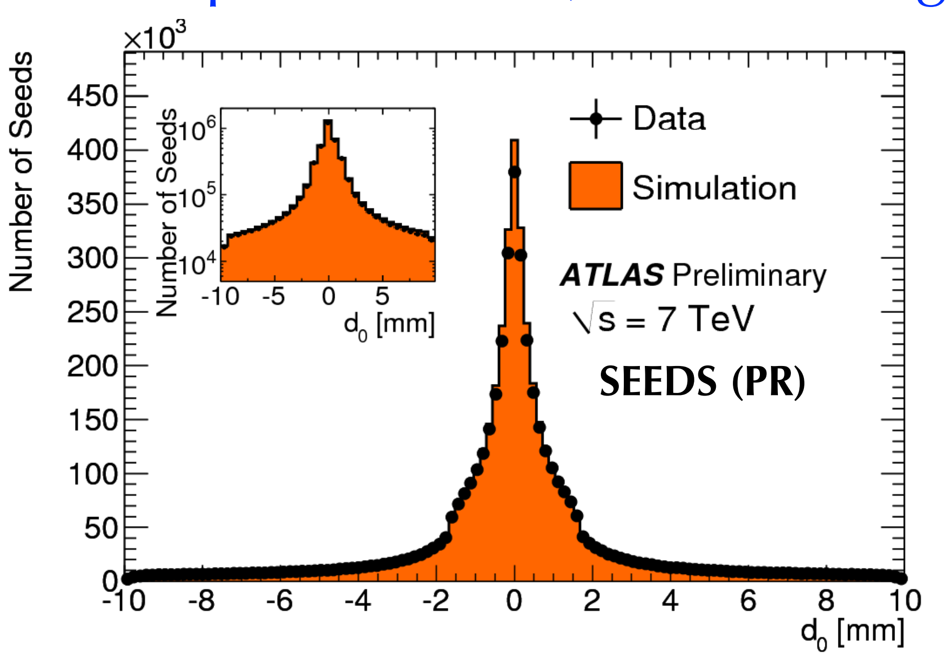
- ID calibration
  - **Pixels**: Time-over-Threshold calibration (charge sharing, dE/dx at low p_T)
  - **TRT**: R-t relations + high threshold probability for particle ID (e/π separation)

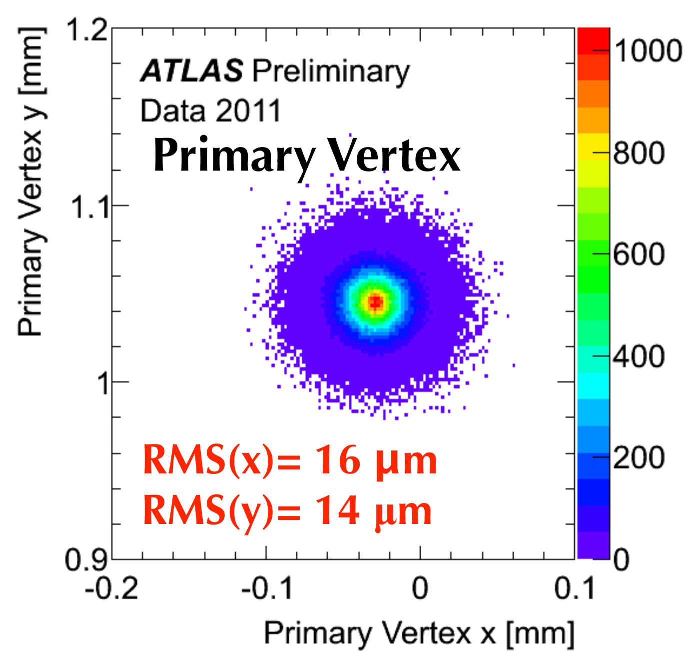


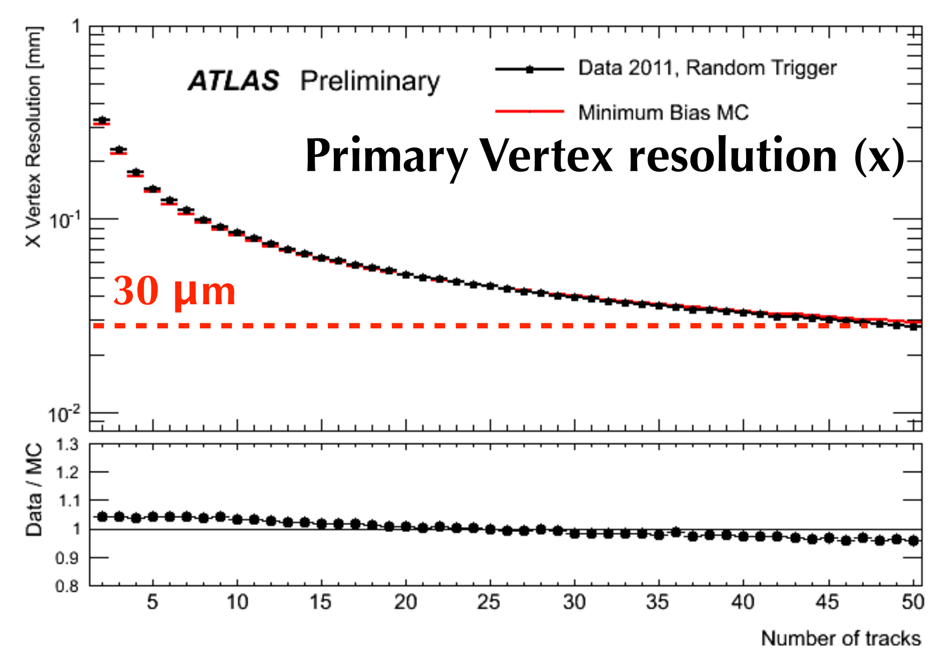




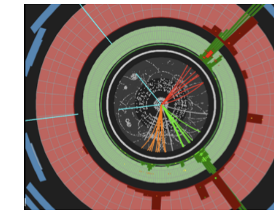
- Tracking: inside-out (seeds from silicon) or outside-in (from TRT)
  - pattern reco, track fitting, ambiguity resolution, vertex reconstruction







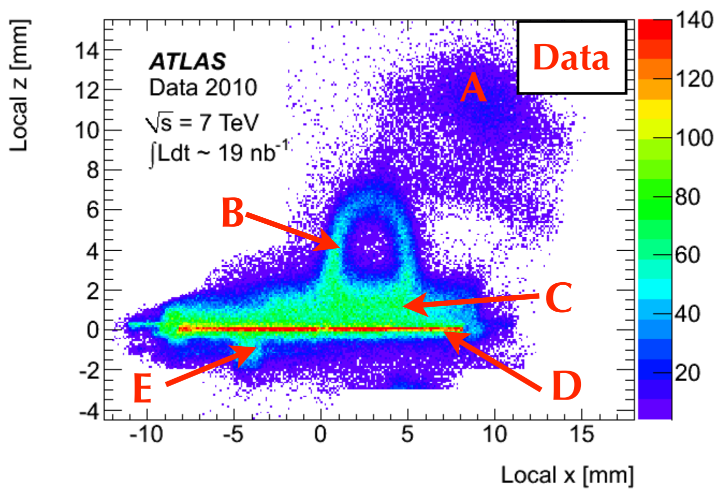
Material mapping

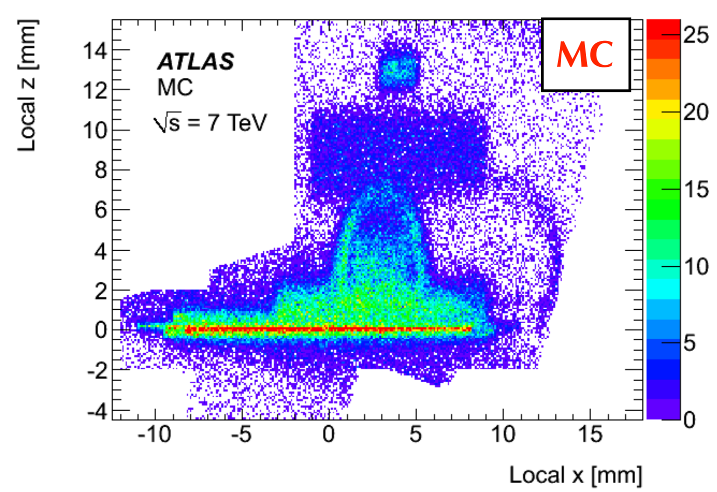


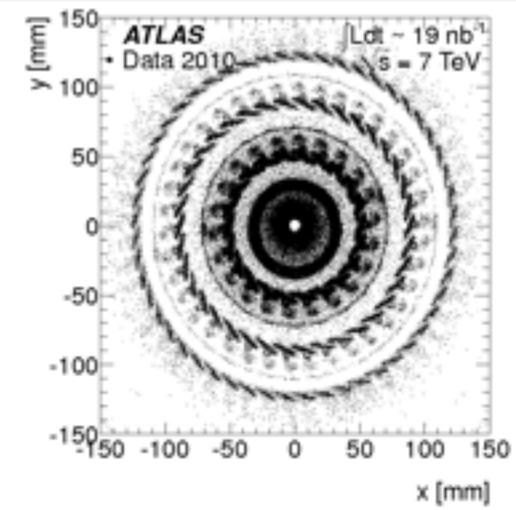
- Accurate description of detector material crucial for optimum track reco
  - effect on track resolution and efficiency
- Usage of techniques sensitive to interaction and radiation lengths
  - nuclear hadronic interactions (λ) and photon conversions (X_0): achieved 5%

Hadronic interactions

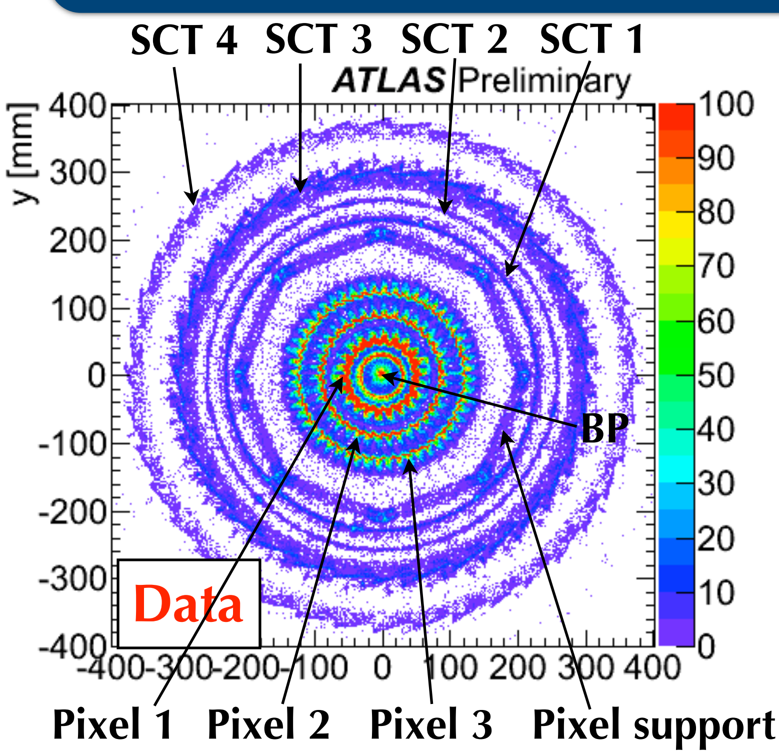
- A: cable bundles
- B: cooling pipe
- C: C-C support
- D: silicon sensor
- E: decoupling capa

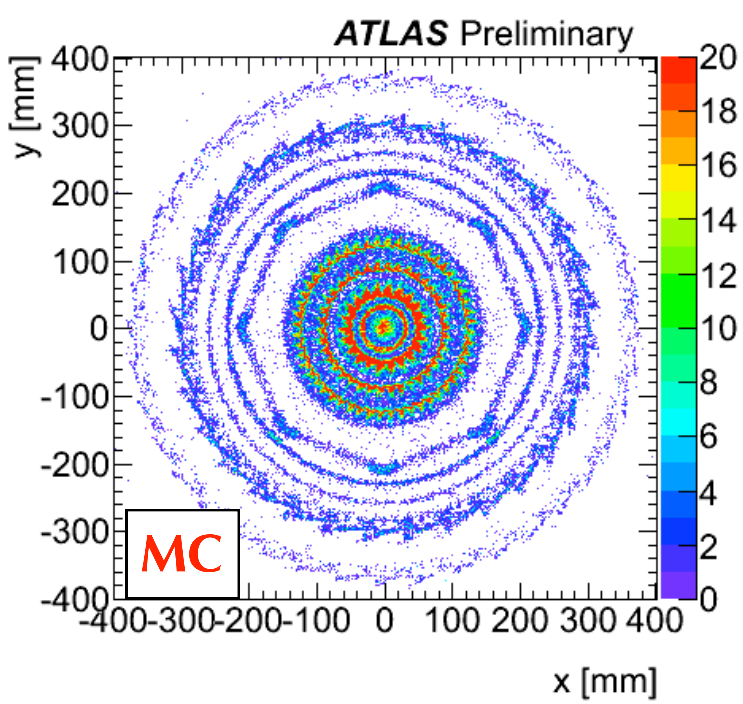


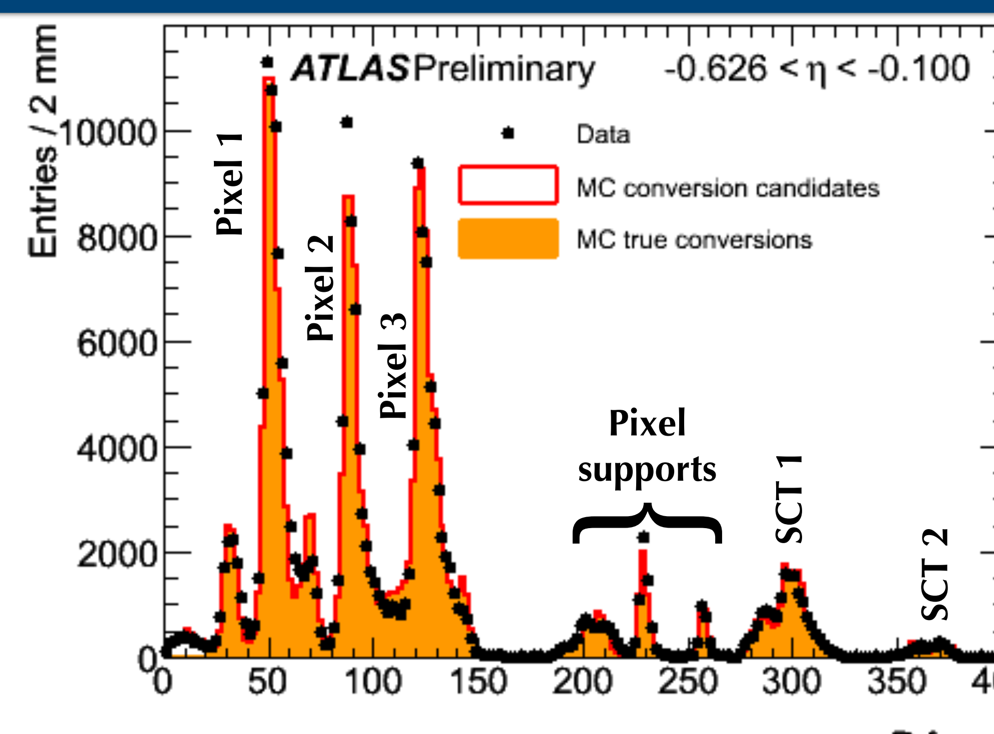




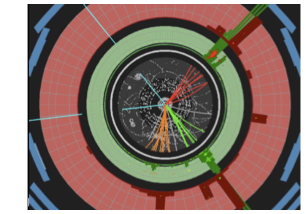
Photon conversions $\gamma \rightarrow e^+e^-$



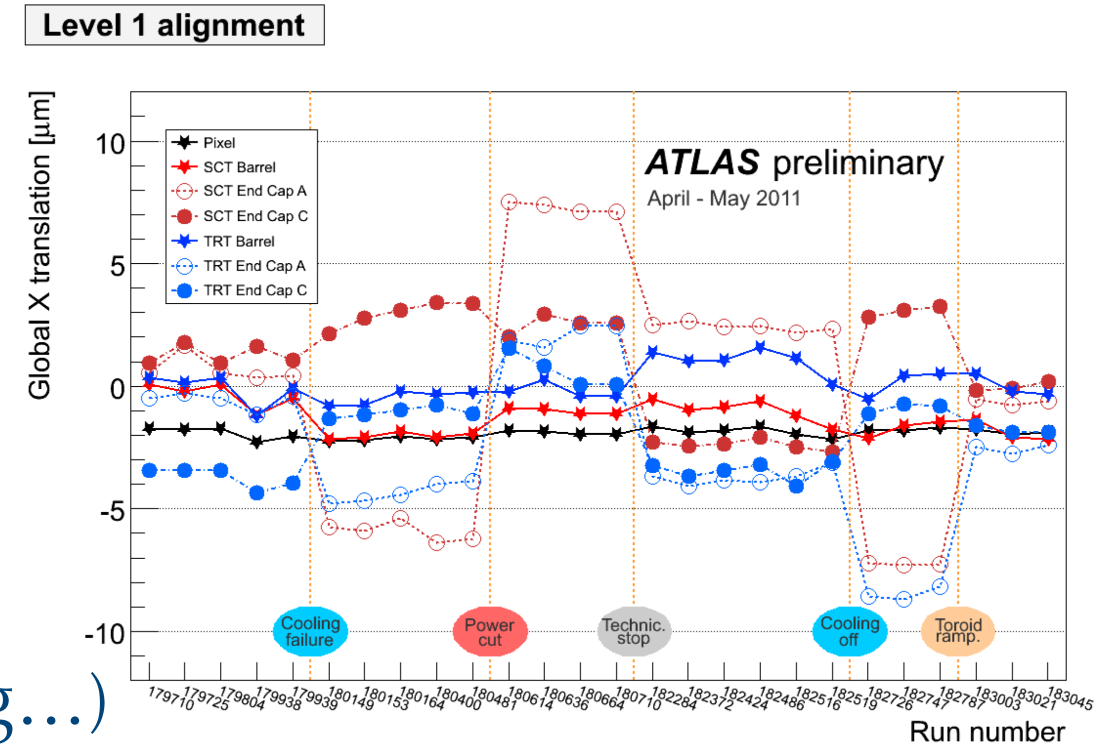


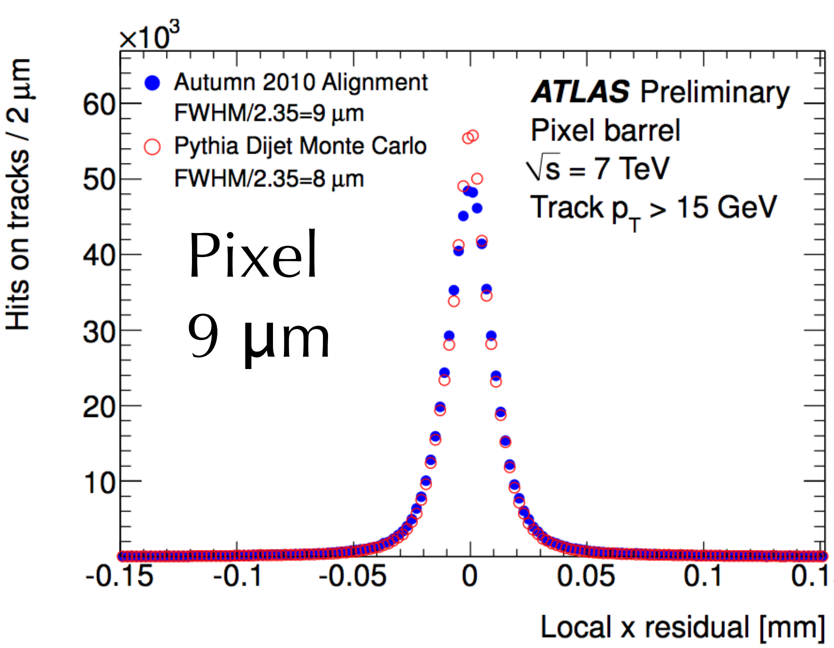


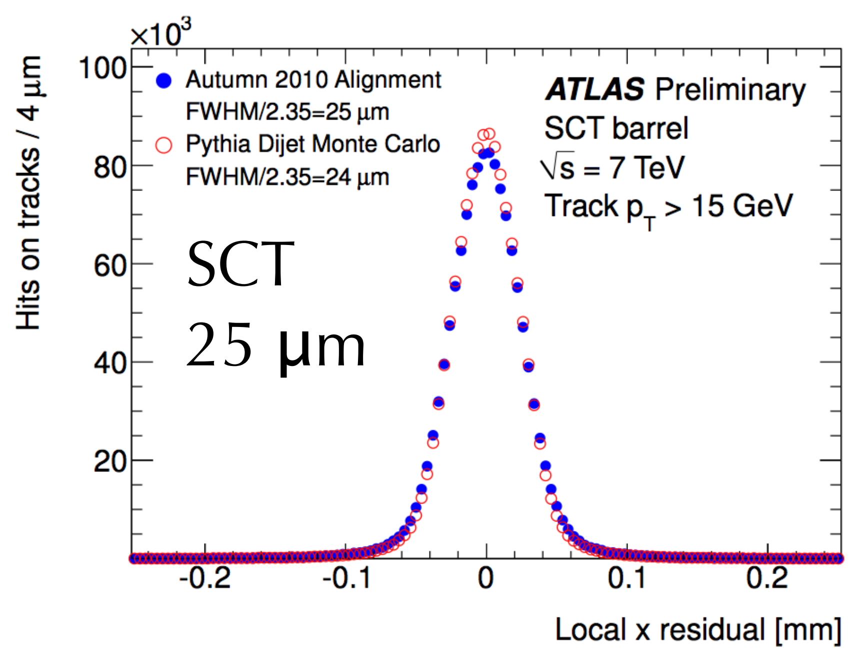
Inner detector alignment

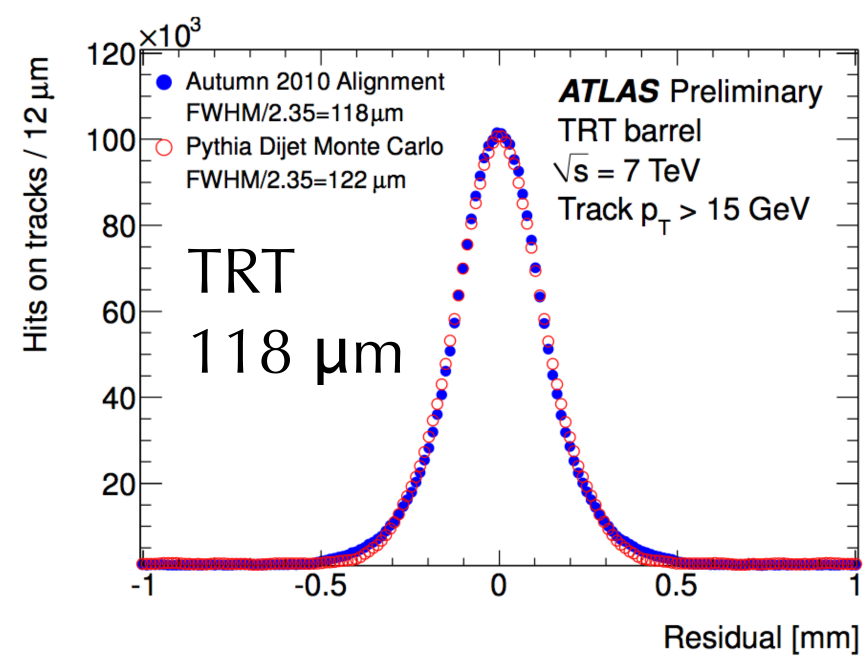


- High p_T tracks from cosmics and pp collisions
  - include assembly survey, beam-spot constraint
- χ^2 track-residual (unbiased) minimization
- Align at different levels of granularity
  - level 1 (sub-detector), 41 DoF
  - level 2 (substructure), 852 DoF
  - level 3 (module), ~700k DoF
- Changes over time (temp, solenoid ramping...)
  ➡ alignment performed on a run-by-run basis

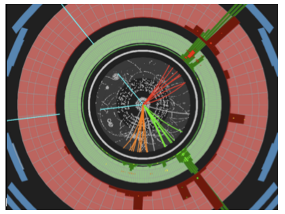




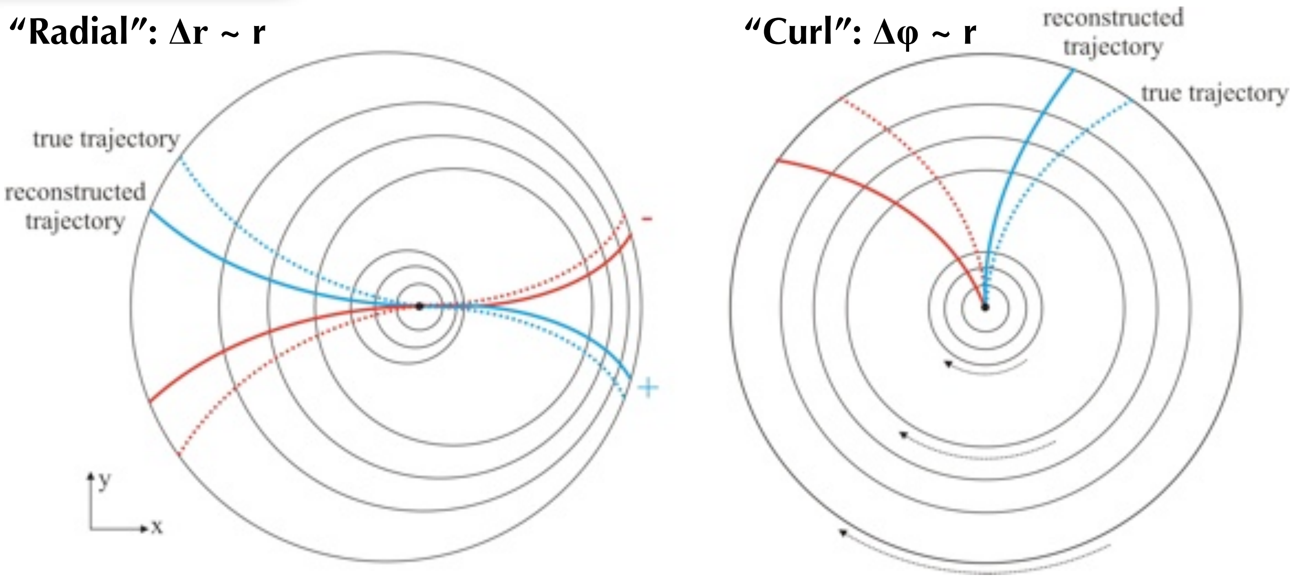




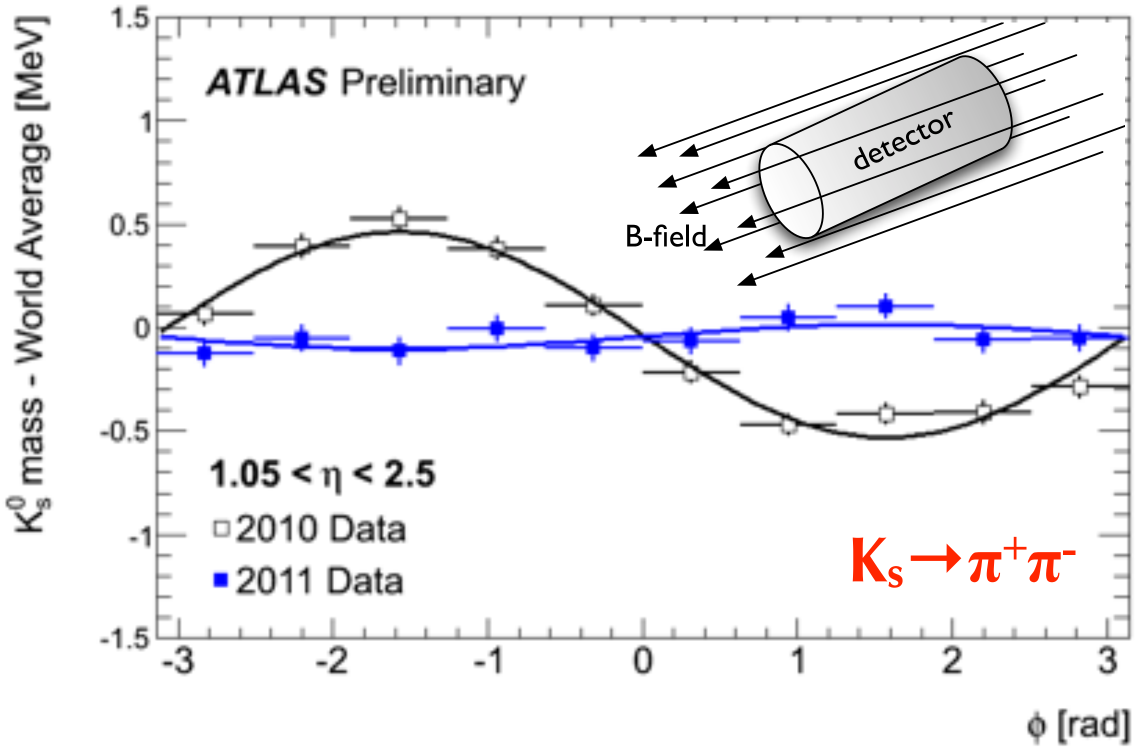
Inner detector alignment: weak modes

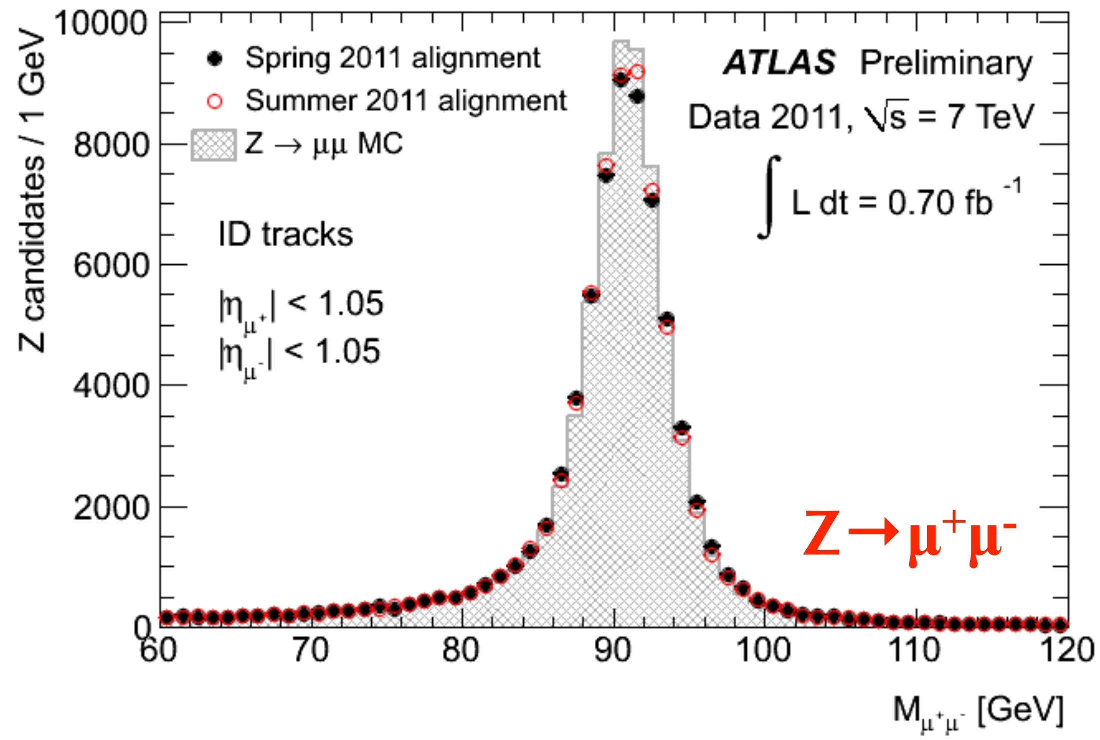


- **Weak modes:** *detector distortions that preserve the helical path (χ^2-invariance) but systematically bias the track parameters*
  - momentum bias, charge assymetries
  - residual minimization not enough ➡ use additional constraints (E/p, resonances...)

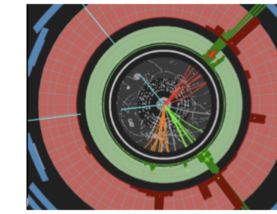


- *Example*: magnetic-field orientation
  - solenoid B-field uniform over the entire ID volume
    - its 3D position is of no concern for alignment
    - wrong orientation (~0.5 mrad rotation) wrt origin of coordinates ➡ p_T bias

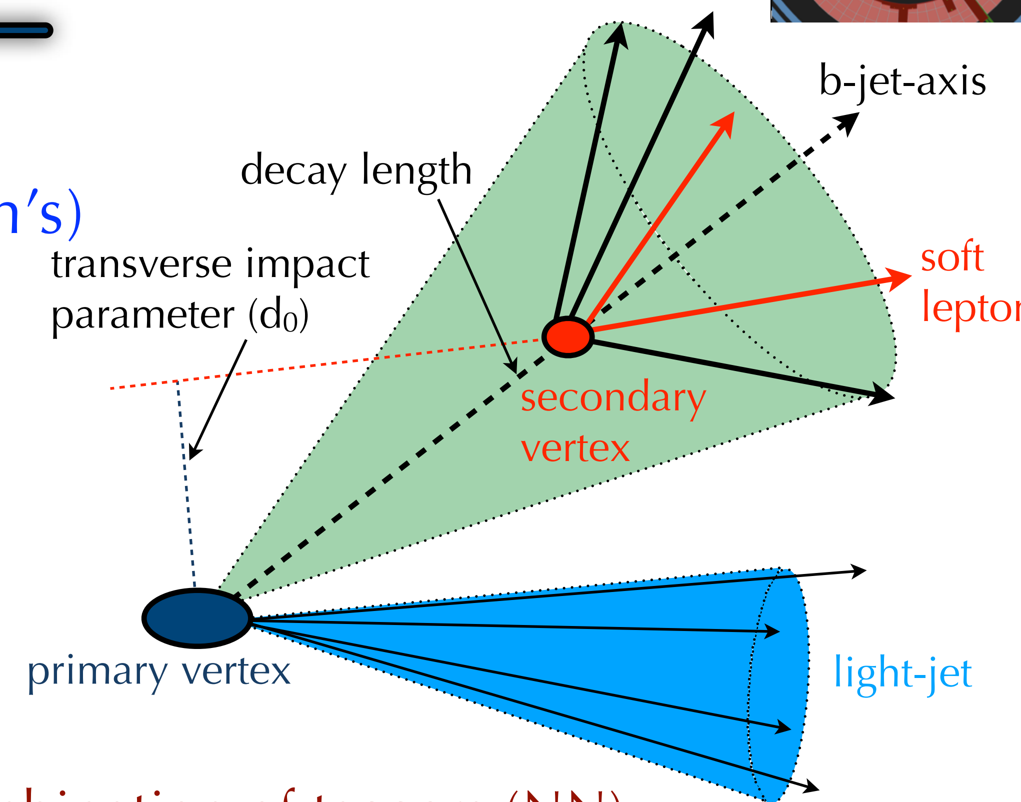




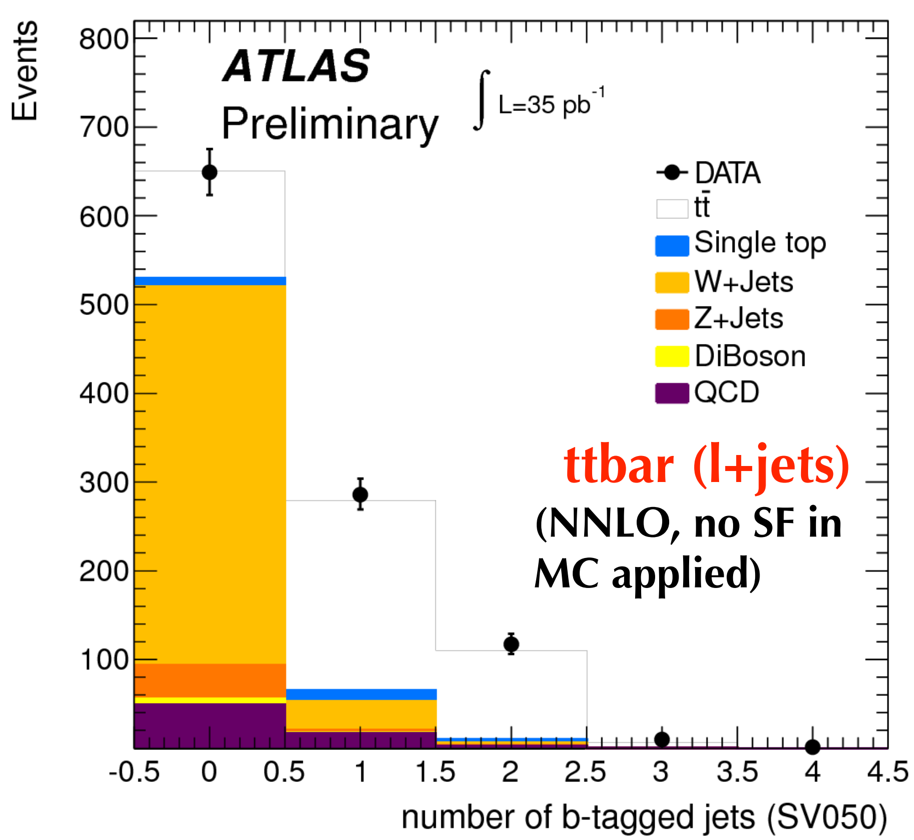
b-tagging

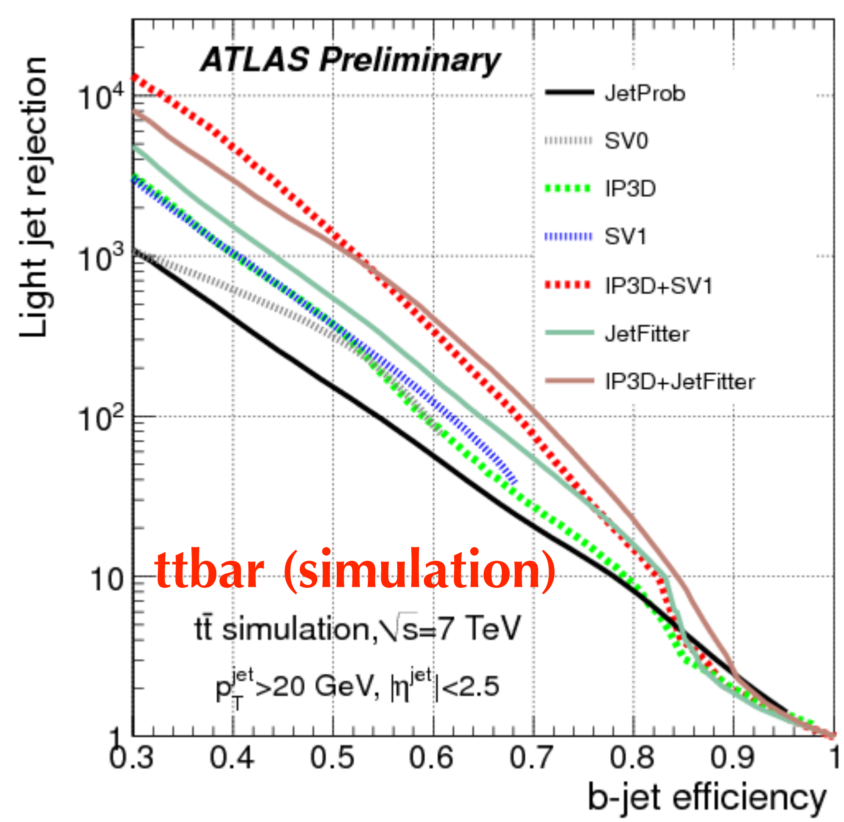


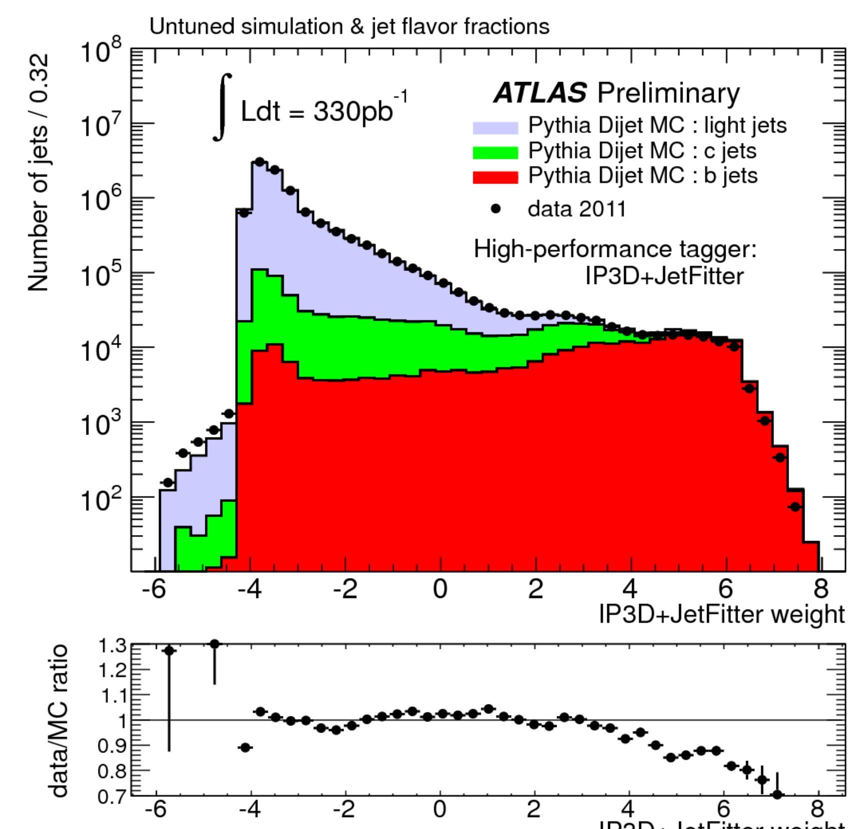
- Jets from hadronization of b-quarks (b-jets)
  - long life-time (~1.6 ps) ➡ secondary vertex (~mm's)
- Algorithms to identify b-jets:
  - impact parameter-based (JetProb, IP3D)
  - secondary vertex-based (SV1)
    - decay length significance
  - advanced b-tagging algorithms
    - multi-variate techniques, rec. vertex decay chain, combination of taggers (NN)



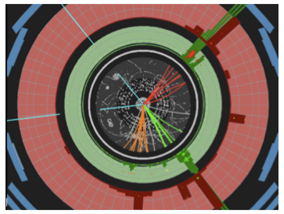
- Calibration of b-tagging efficiency and mistag rate: ttbar events (t→Wb)







Radiation damage

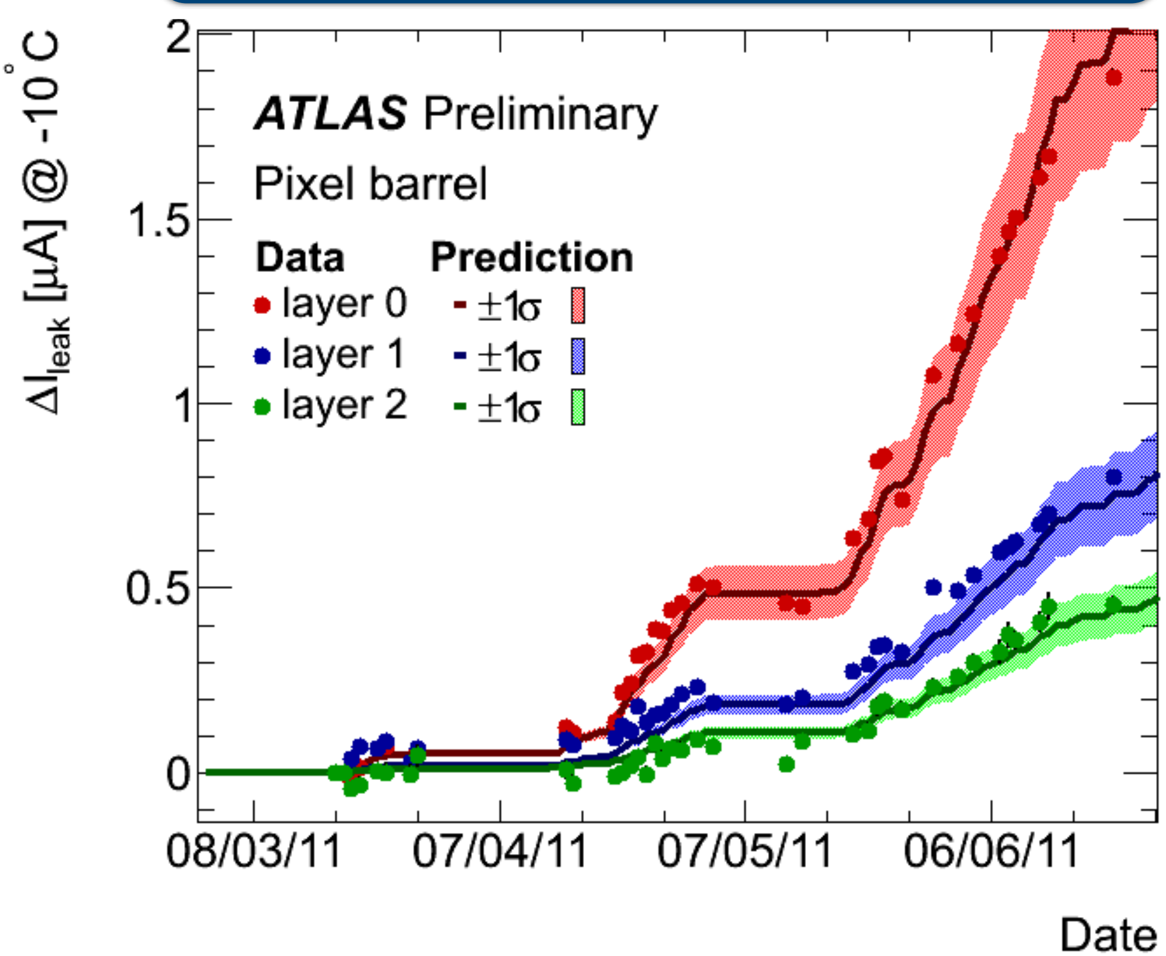


- Impact of radiation damage through measurement of leakage current

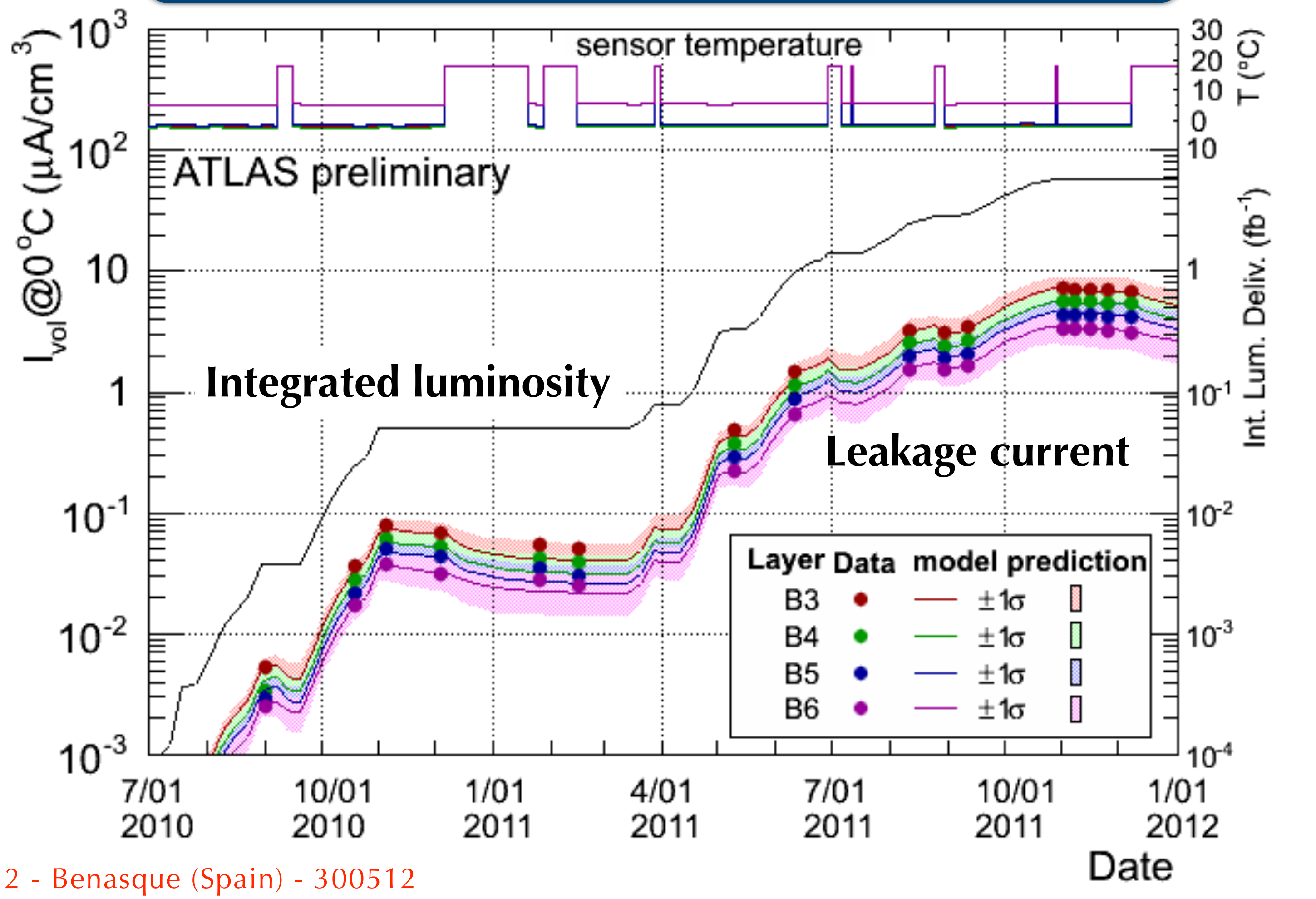
$$I_{\rm leak} = \alpha \cdot \Phi_{\rm eq} \cdot V$$

- Effects became visible in 2011, increasing with luminosity
- Pixel and SCT: very good agreement with predictions from the "Hamburg-Dortmund" model
  - predictions include time-dependent self-annealing effects, temperature profile, luminosity delivered and expected-fluences (Phojet+FLUKA)

Pixels

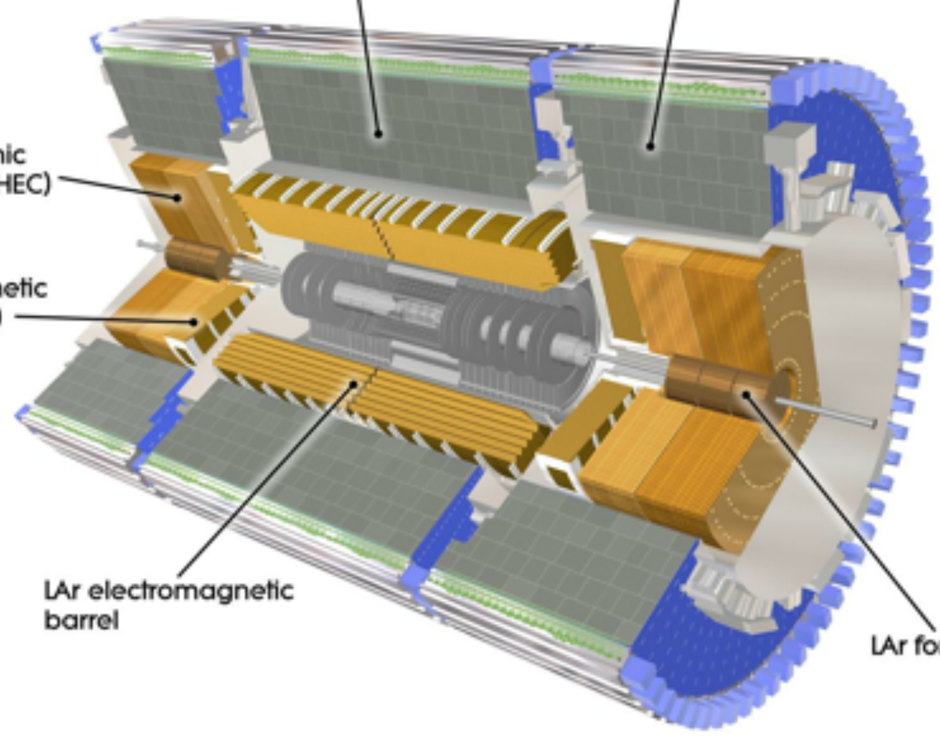


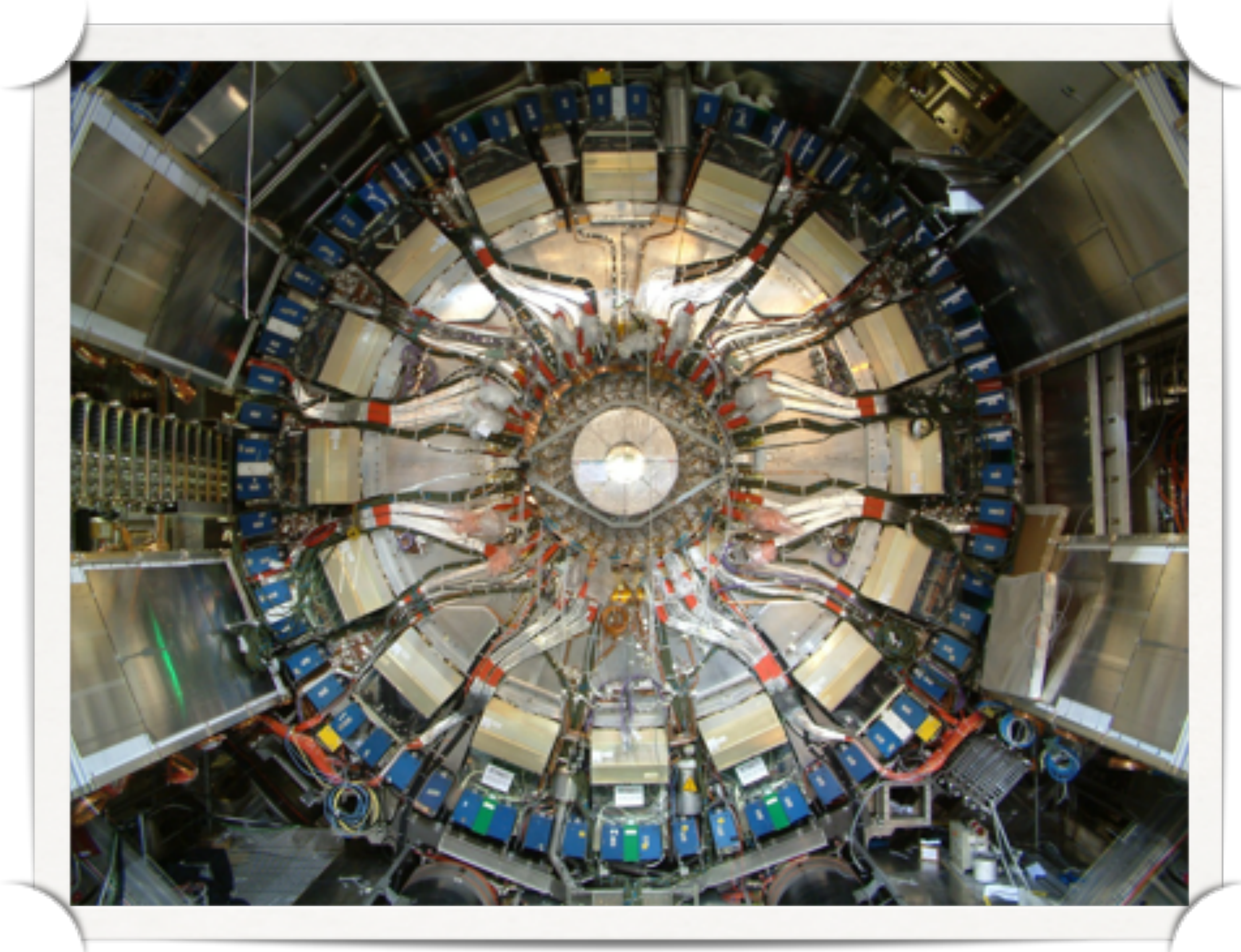
SCT



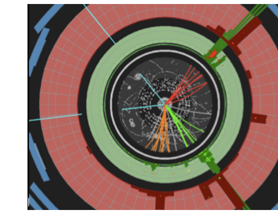
2.- Performance

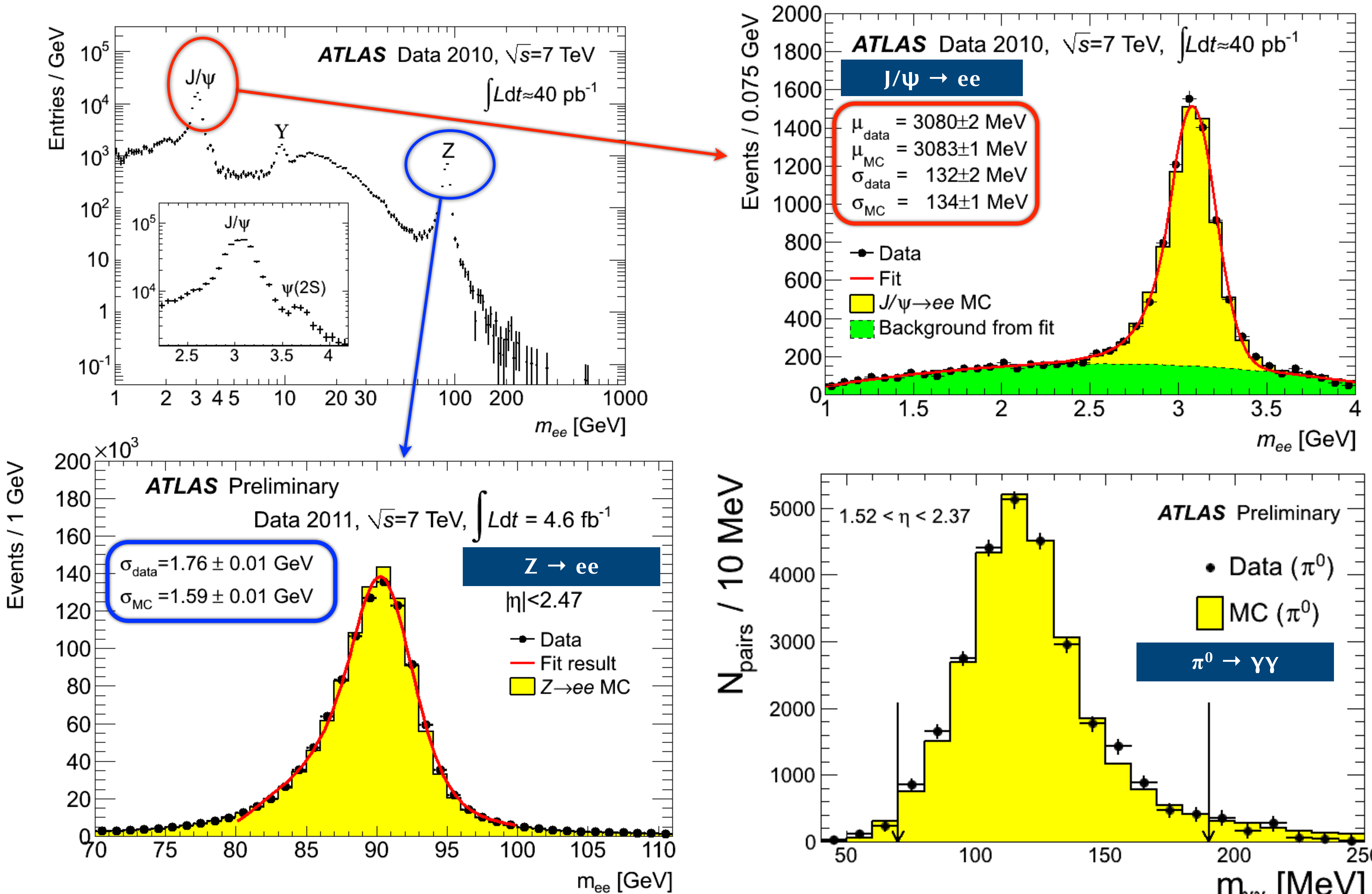
2.2.- Calorimetry



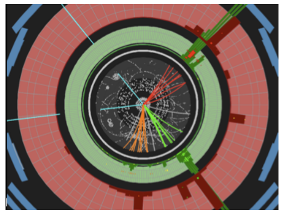


Electron and photon performance

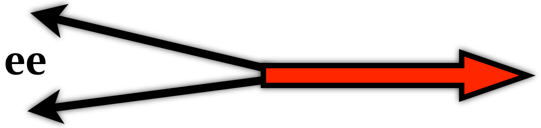


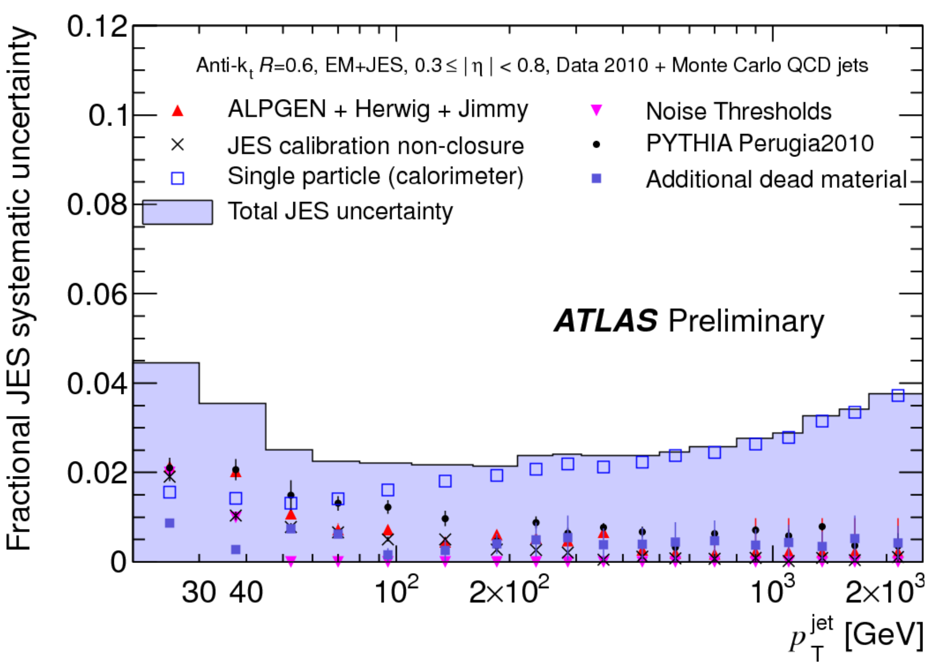


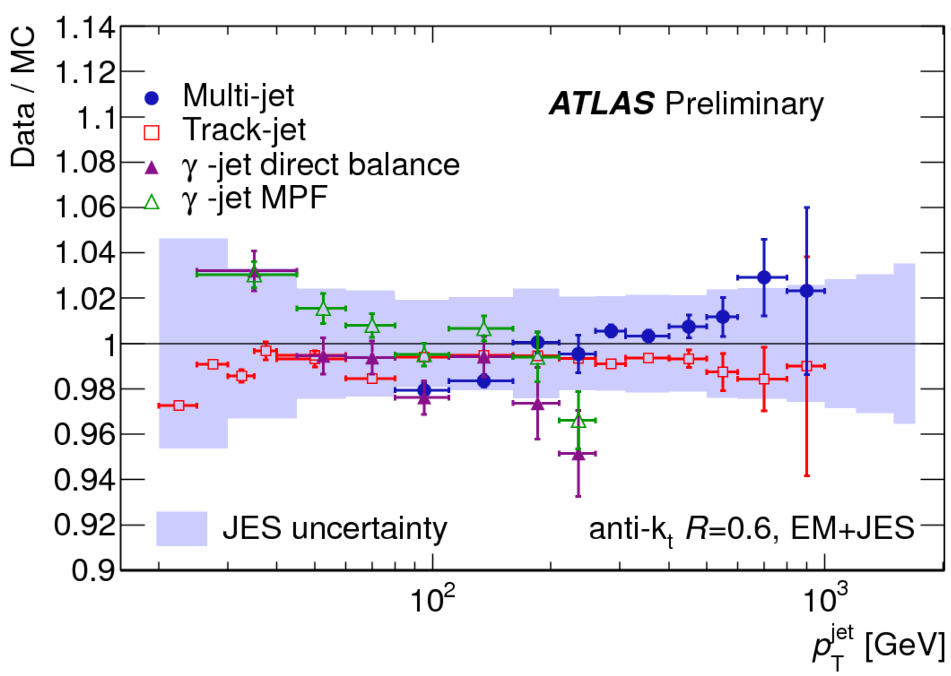
Jet energy scale

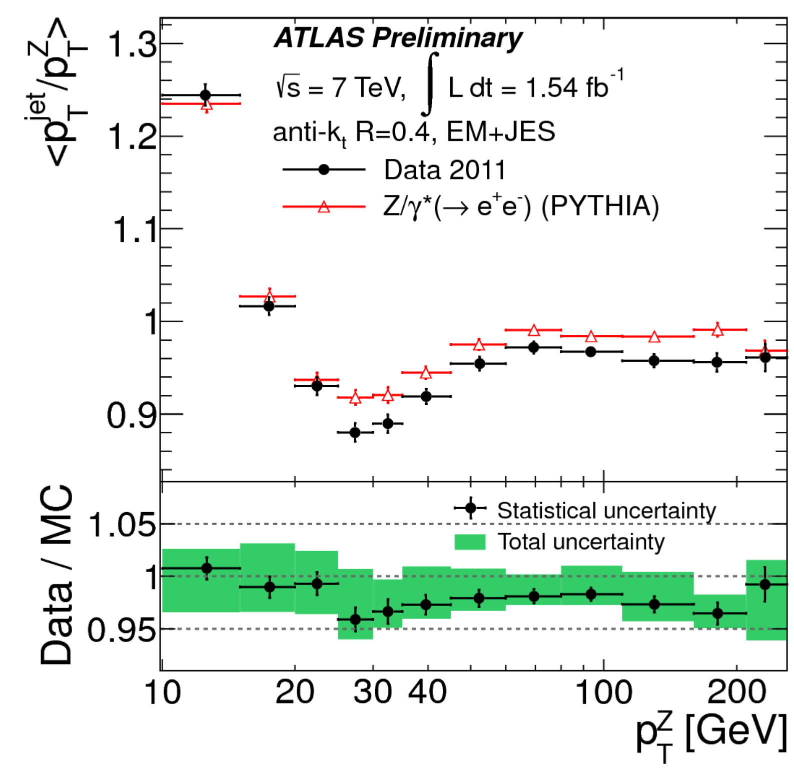


- Jet energy scale calibration: em scale → hadronic scale
  - pileup correction, origin correction, energy η and correction
- Uncertainty in the jet energy measurement is the dominant experimental uncertainty in many physics analyses
  - calo component dominant in central region
  - η-intercalibration component, due to MC modelling, dominant in forward region
- Jet energy calibration validated with in-situ techniques ➡ jet energy compared with well calibrated objects
  - γ+jet, multi-jet, track-jet
  - p_T balance in Z+jet events (Z→ee)

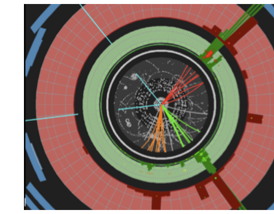




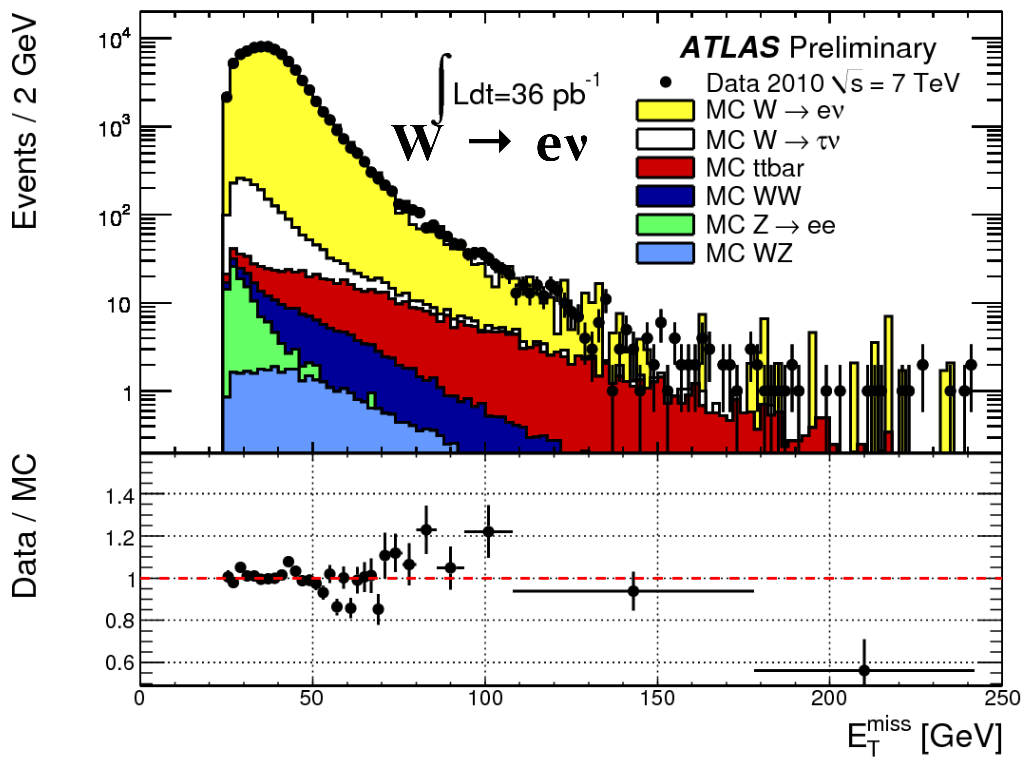




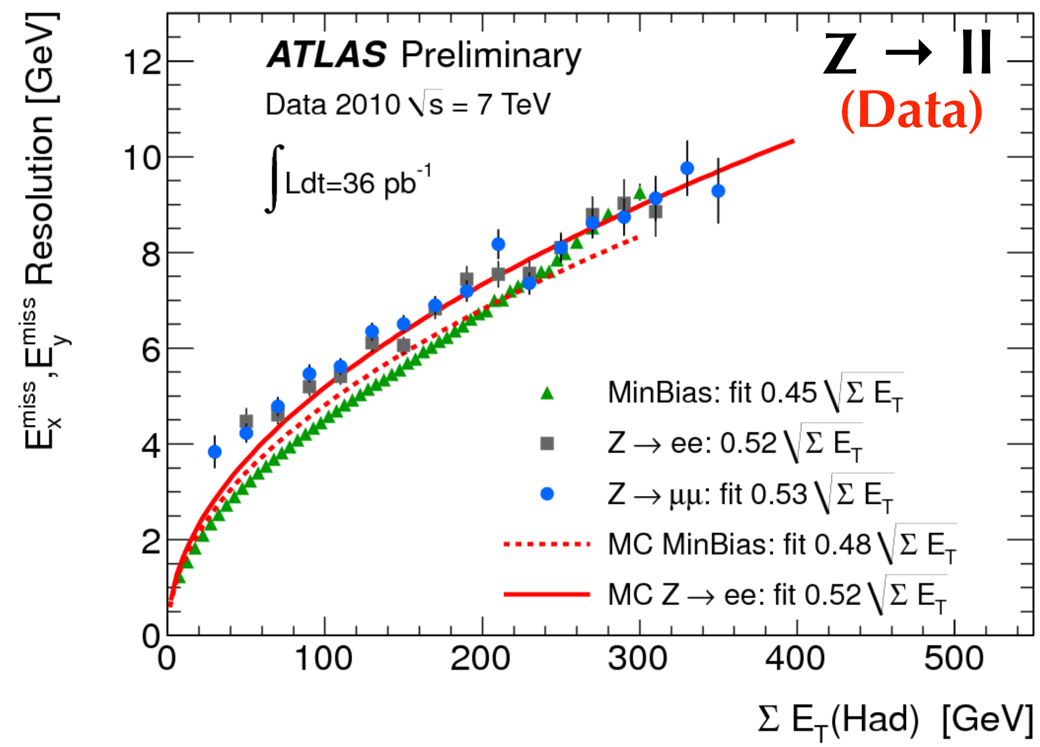
Missing transverse energy

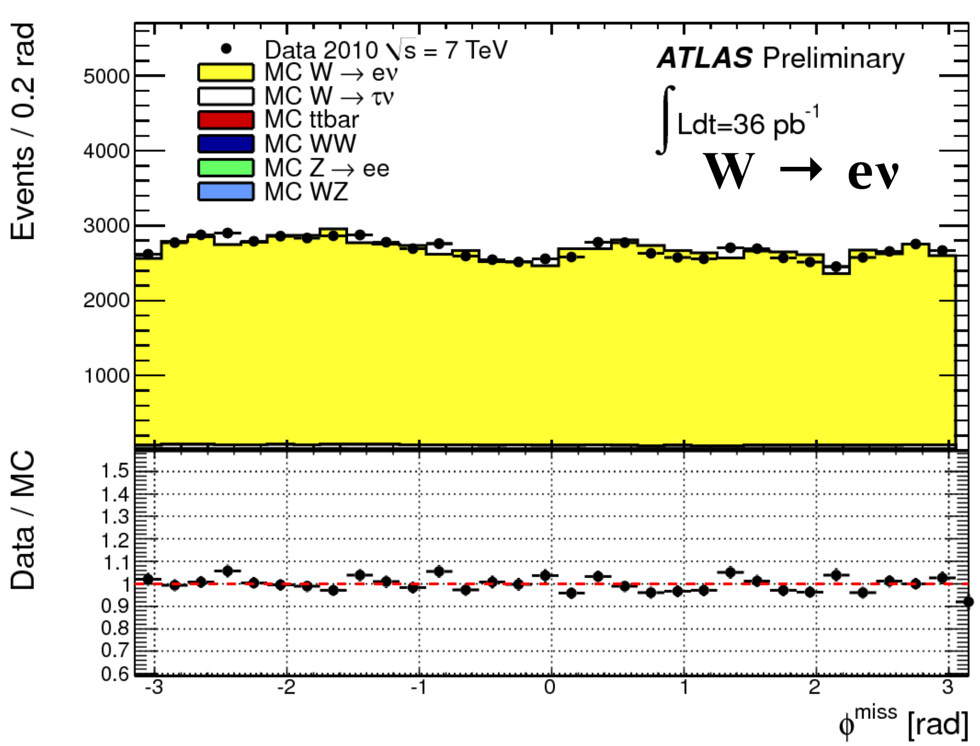


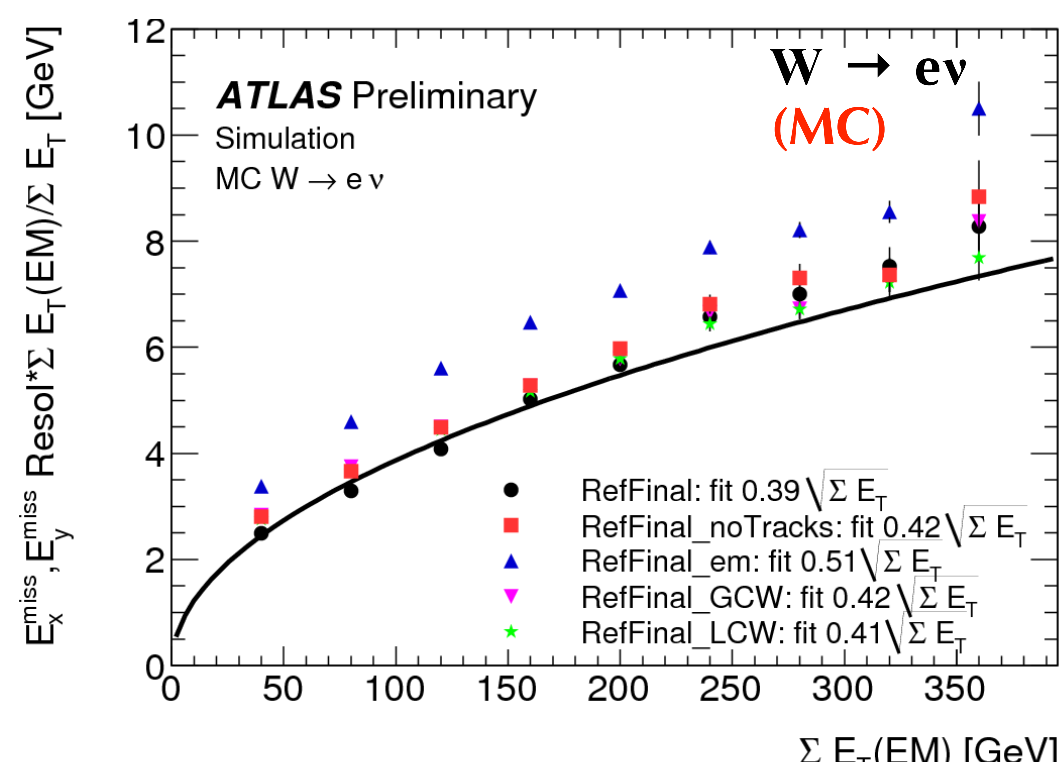
- Key for many precise measurements and searches
- good data-MC agreement, ~2% ($W\rightarrow l\nu$)



Etmiss resolution

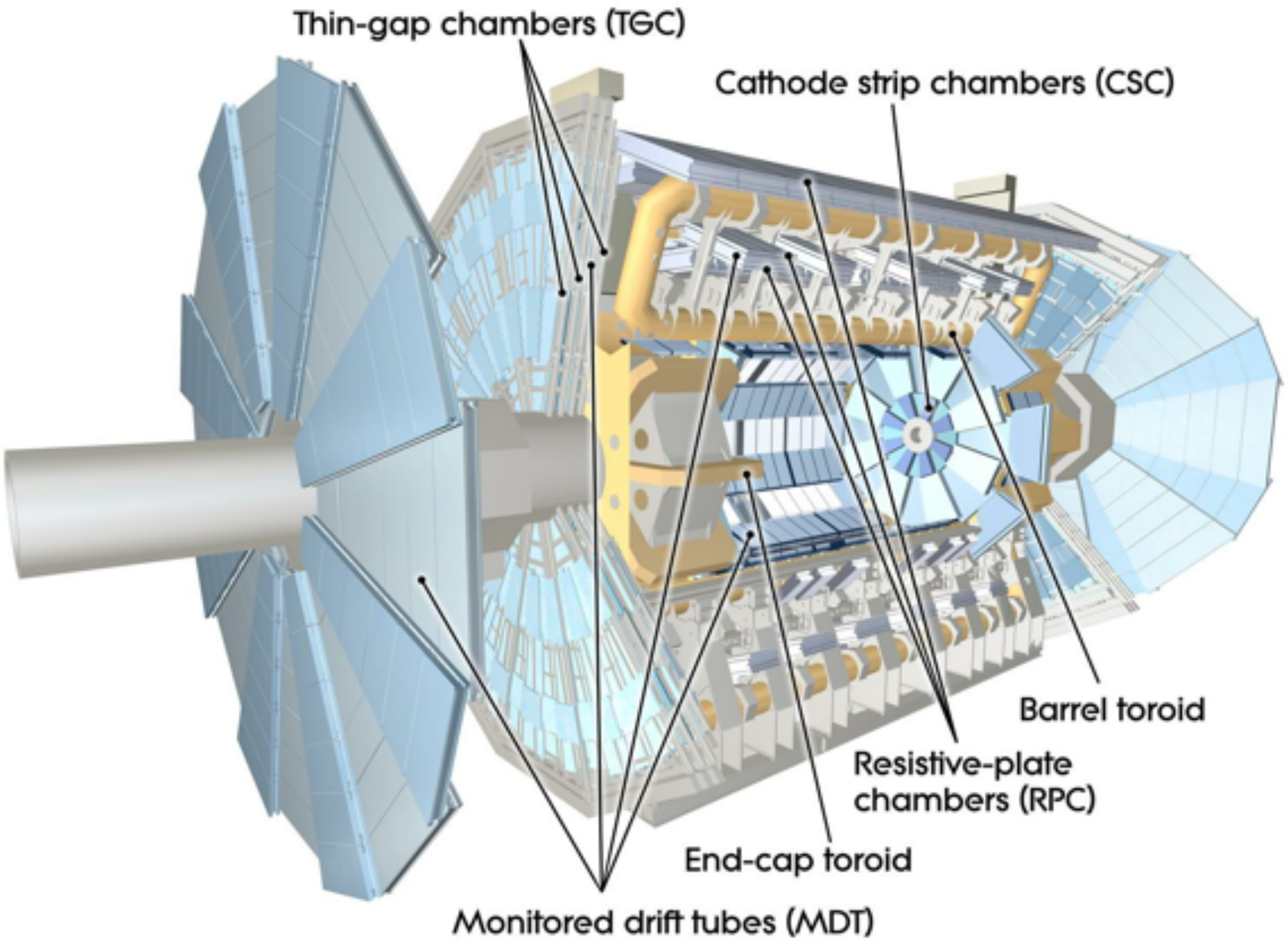


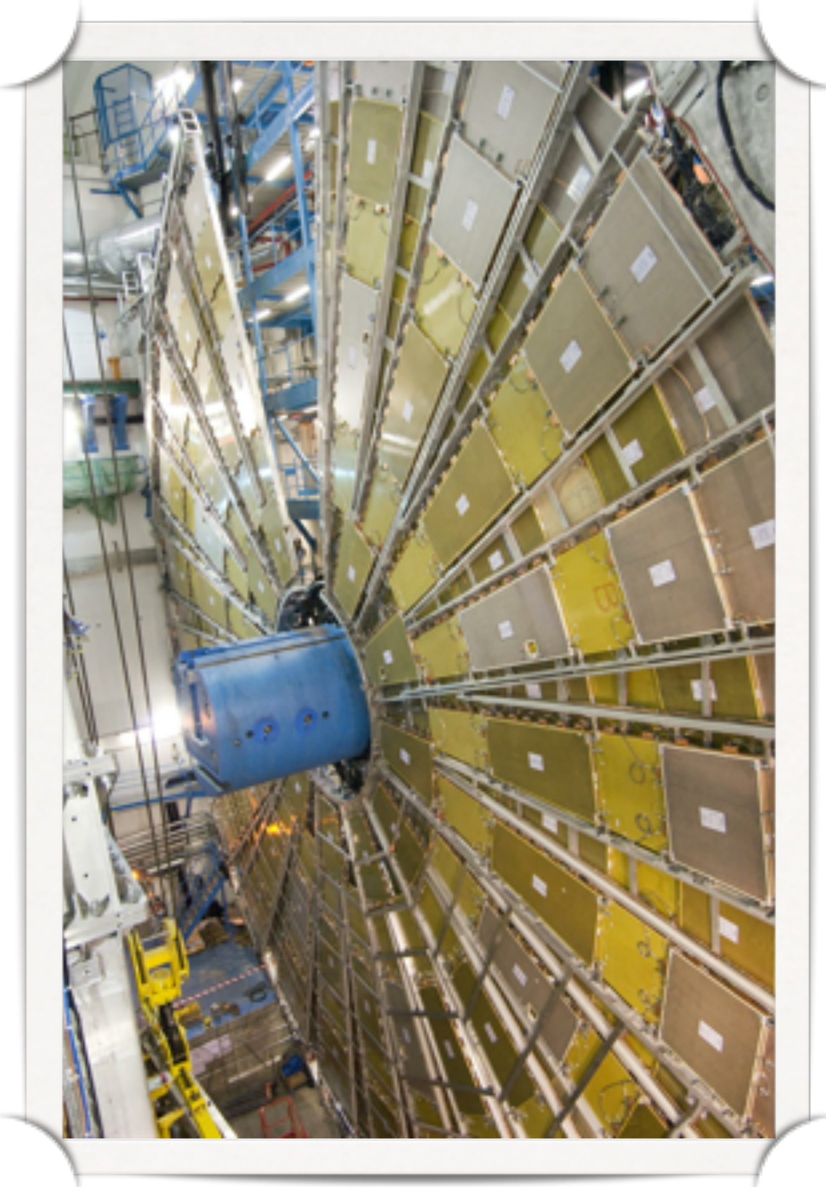




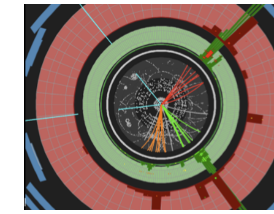
2.- Performance

2.3.- Muon Spectrometer

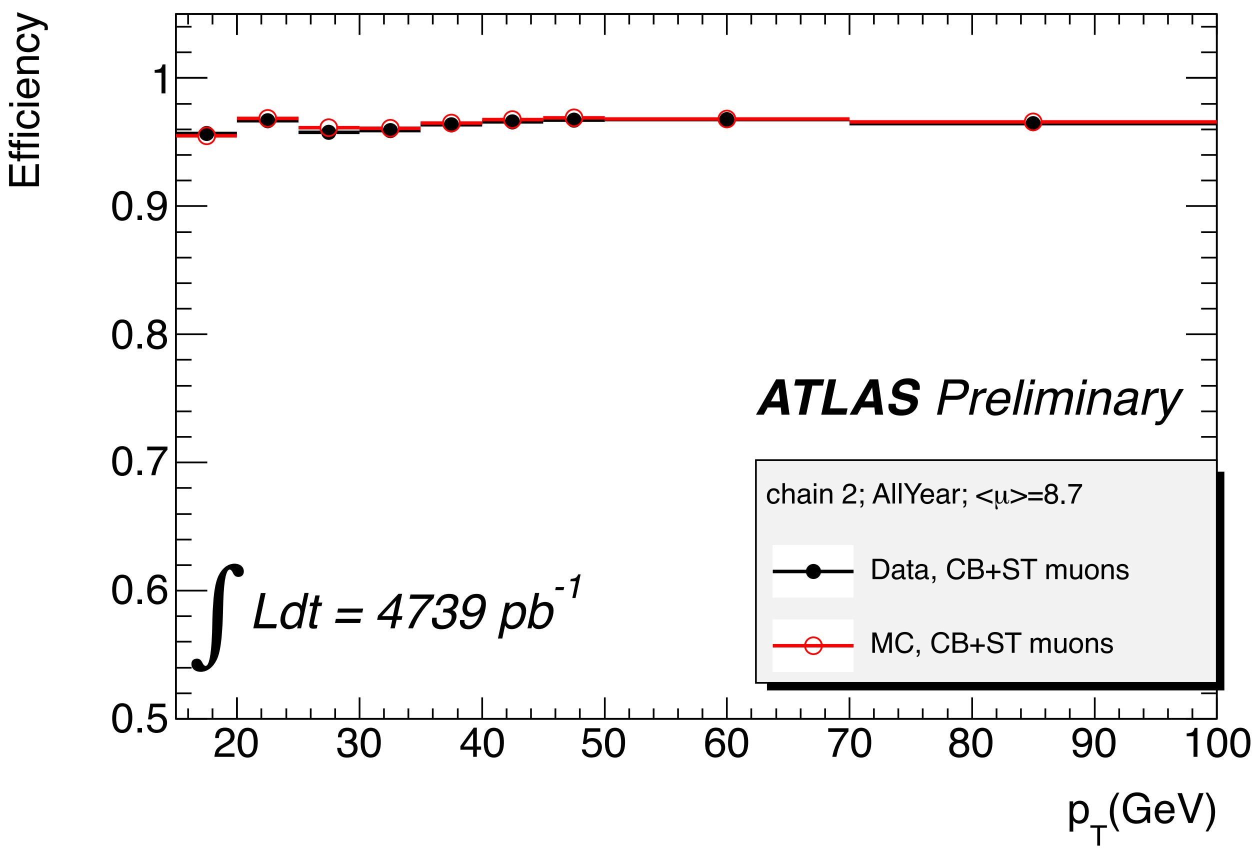


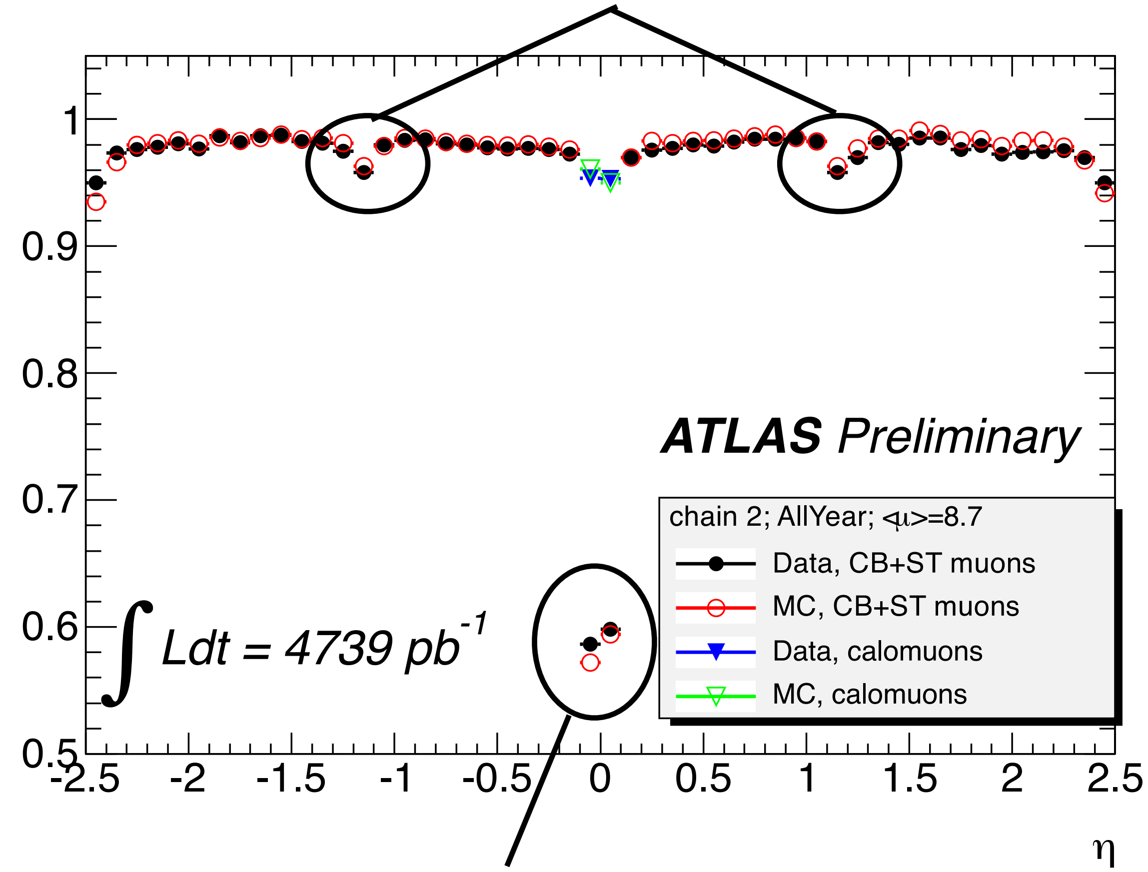


Reconstruction efficiency



transition region barrel-endcap (only one muon chamber)

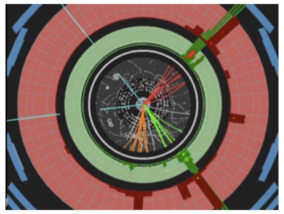


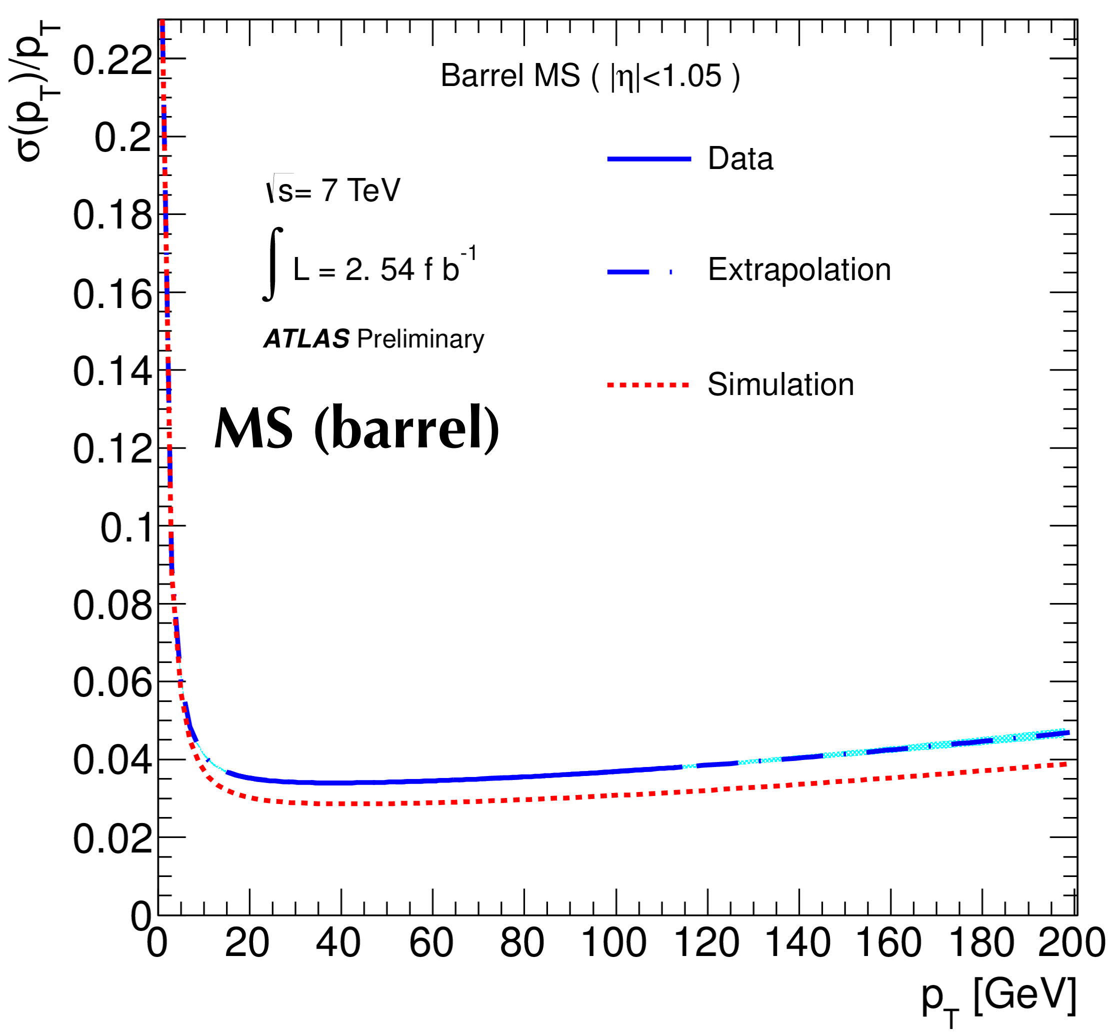


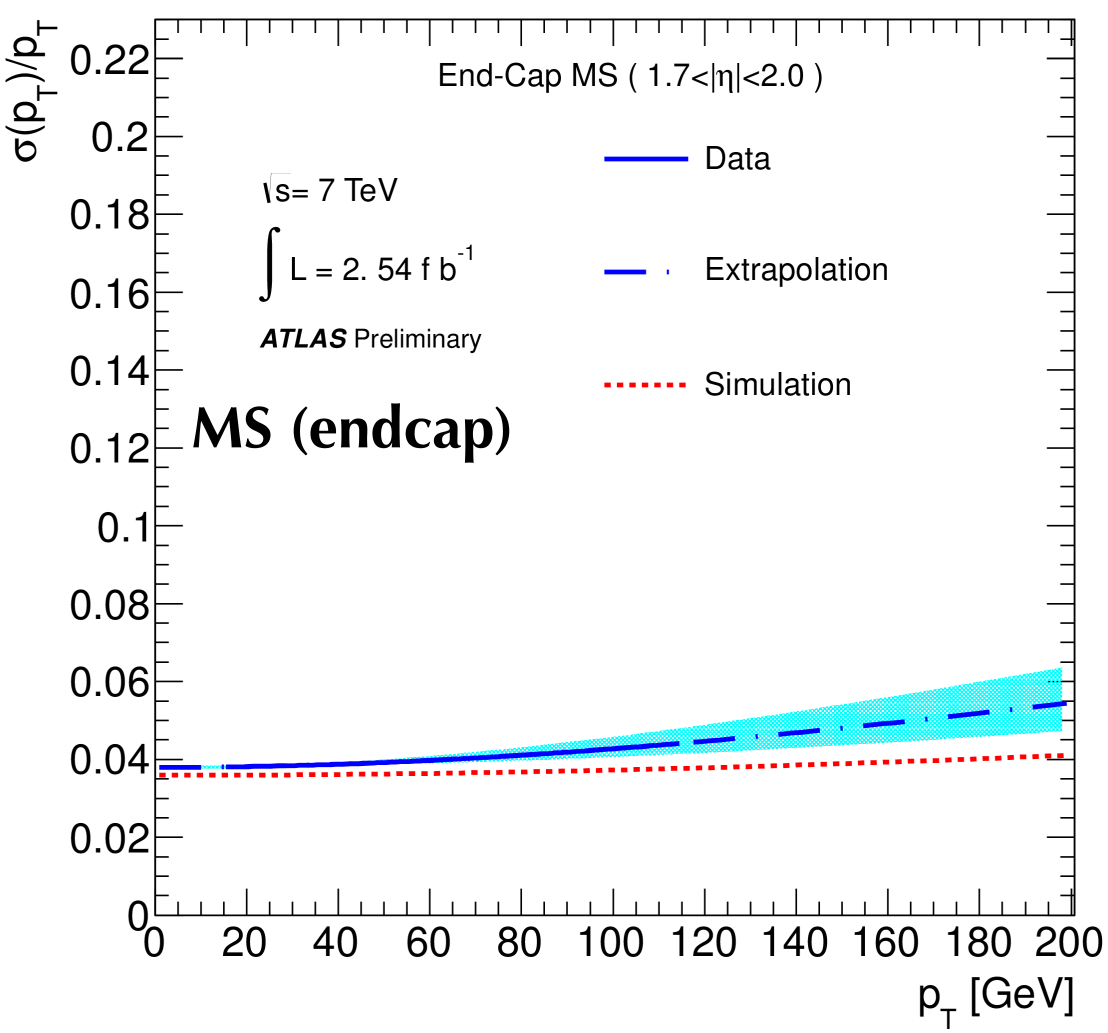
acceptance loss: MS partially equipped with chambers to provide space for services of ID and calos

- MS reco efficiency from T&P in resonances dimuon decays
  - J/Ψ (low-p_T) and Z→μμ (high-pT)
    - tag = Combined (CB) muon (MS+ID track-combination)
    - probe = ID-track matched to a CB or segment-tagged muon
      - tagged muons allow to recover "geometrical" inefficiencies

Momentum resolution







- MS-only momentum resolution
  - constrained by $Z\rightarrow\mu\mu$ line-shape and ID-vs-MS measurements from $W\rightarrow e\nu$
  - $\sigma(p_T)/p_T < 5\%$ for $p_T(\mu) \in [20; 200]$ GeV

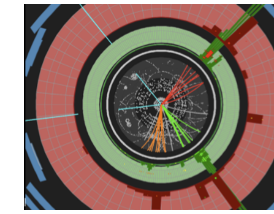
$$\frac{\sigma(p_T)}{p_T} = \frac{p_0^{MS}}{p_T} \oplus p_1^{MS} \oplus p_2^{MS} \cdot p_T$$

Energy loss (p_0^{MS})

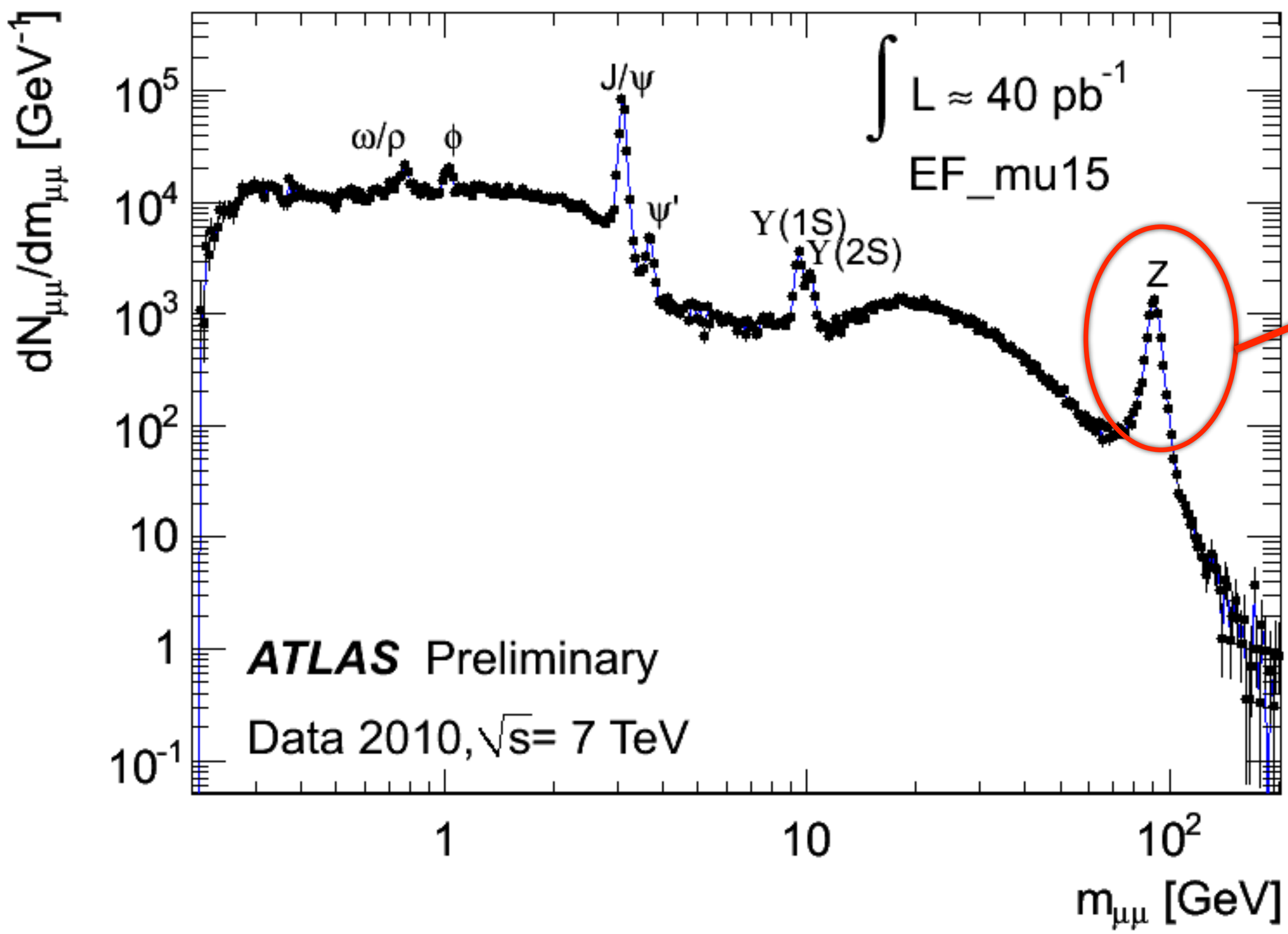
Multiple scattering (p_1^{MS})

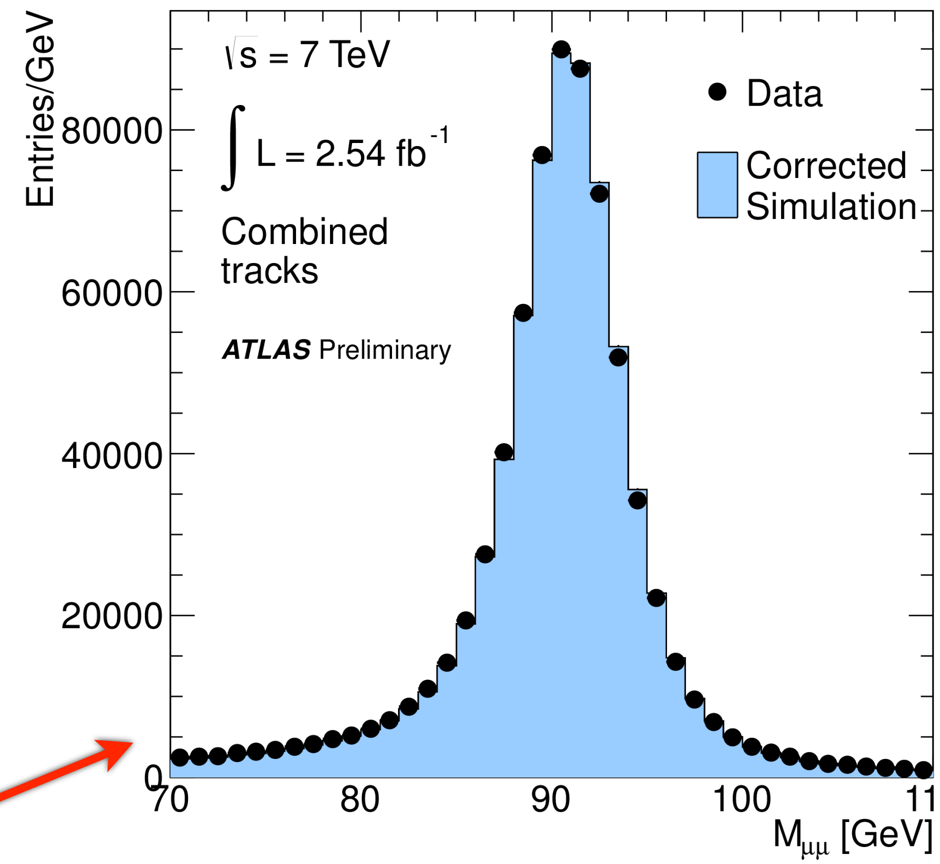
Intrinsic resolution (calibration + alignment) (p_2^{MS})

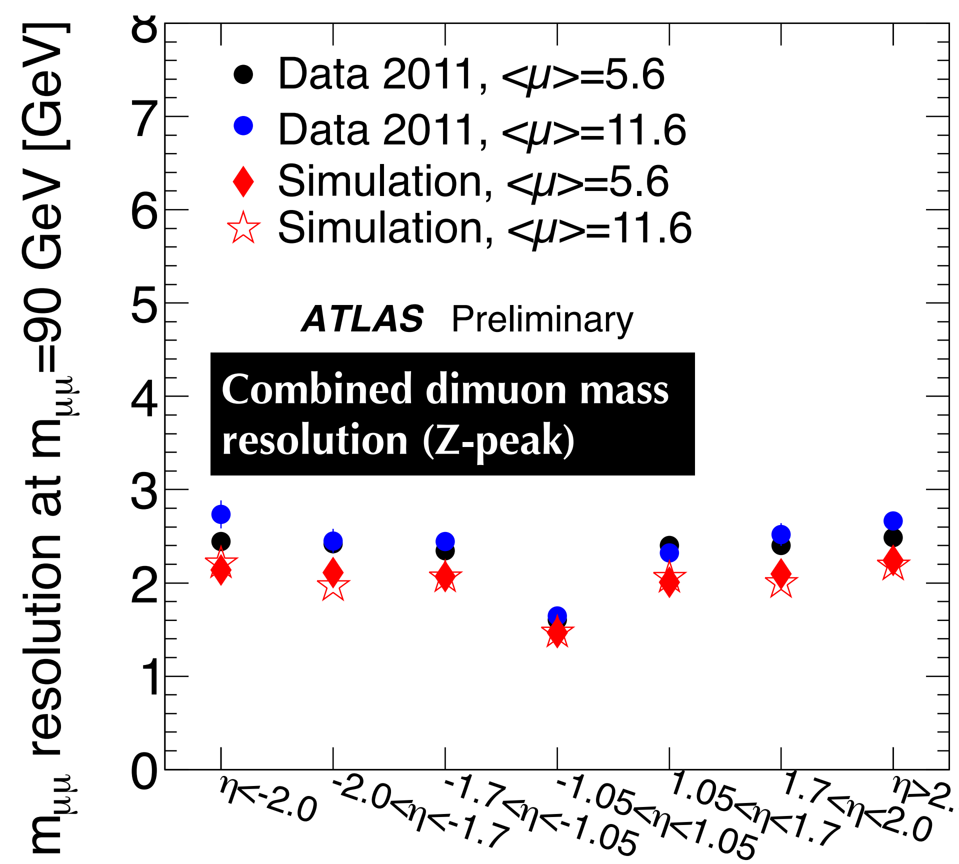
Combined ID+MS dimuon mass resolution

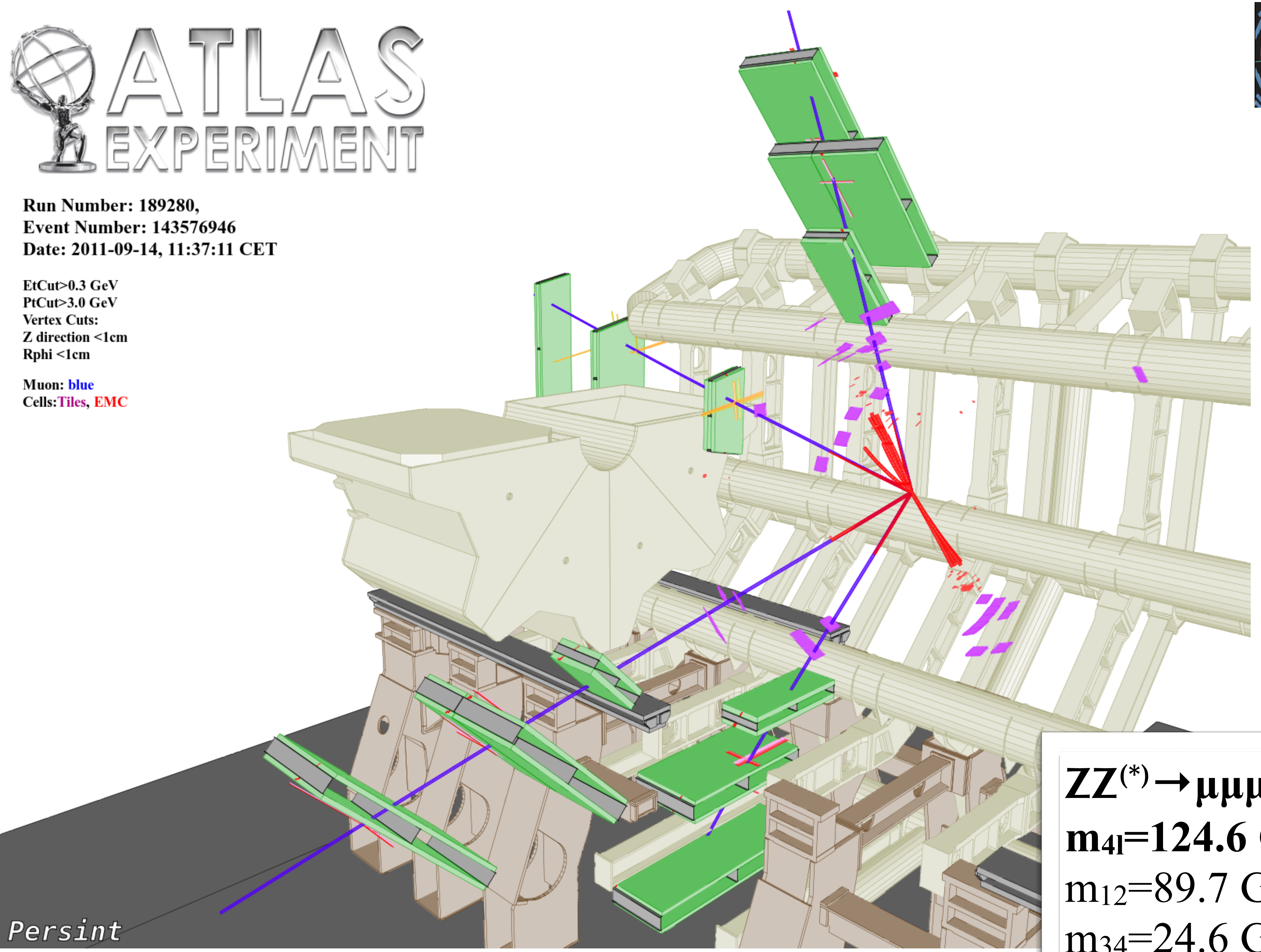


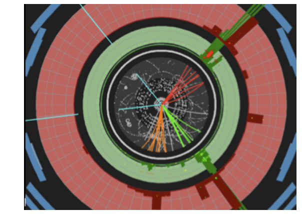
Dimuon inclusive invariant mass spectrum











$ZZ^{(*)} \rightarrow \mu\mu\mu\mu$

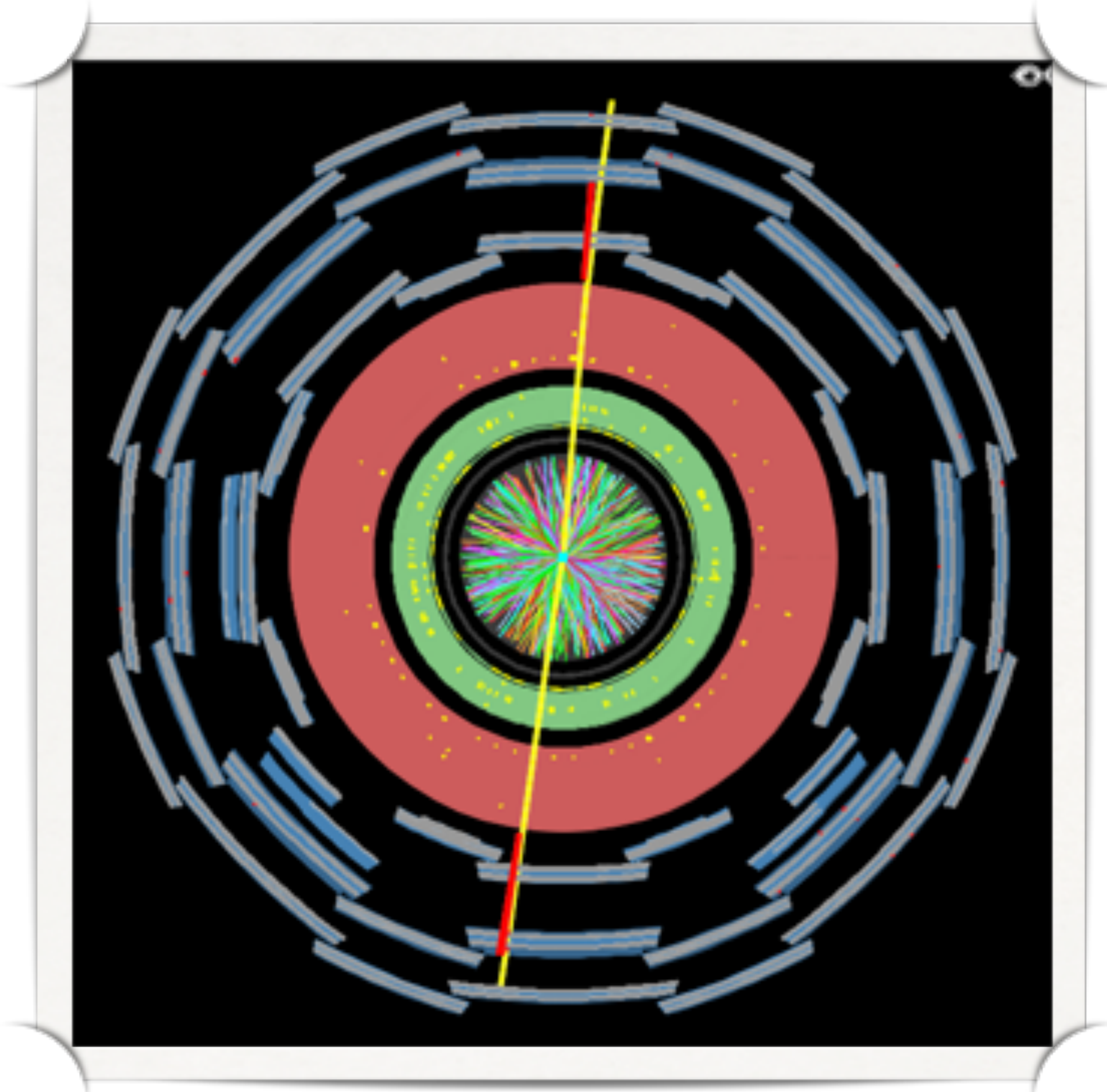
m_{4l}=124.6 GeV

m_{12}=89.7 GeV

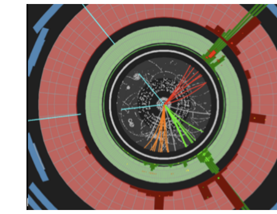
m_{34}=24.6 GeV

2.- Performance

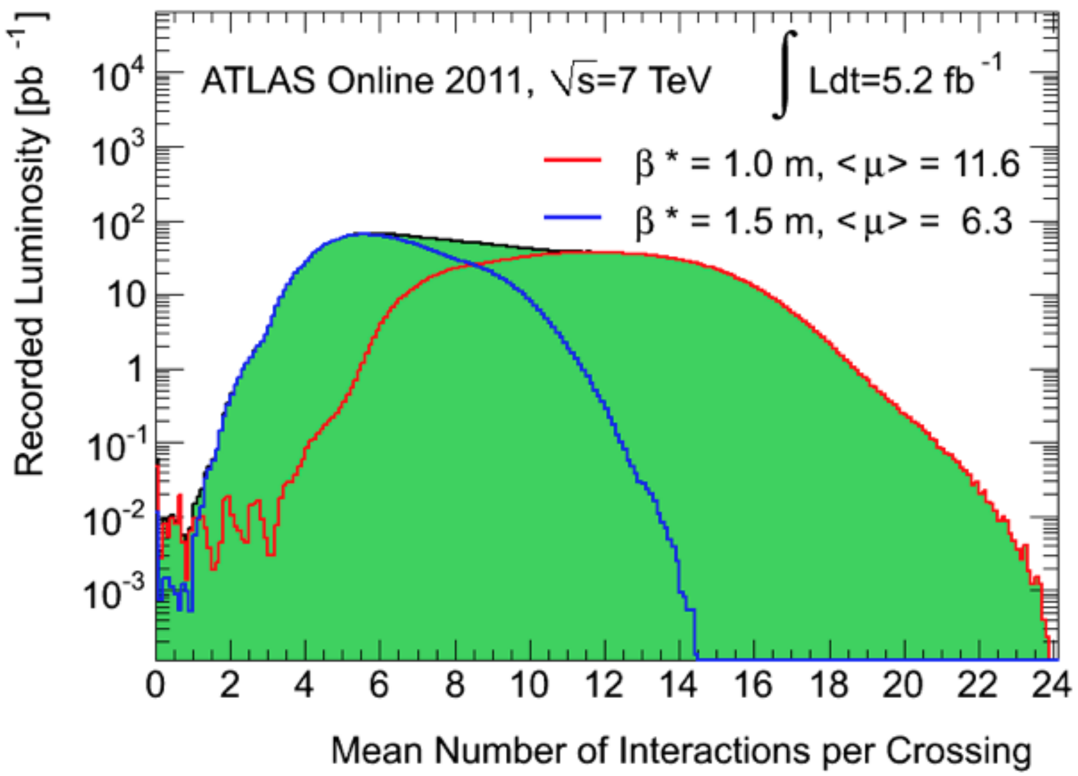
2.4.- Pileup

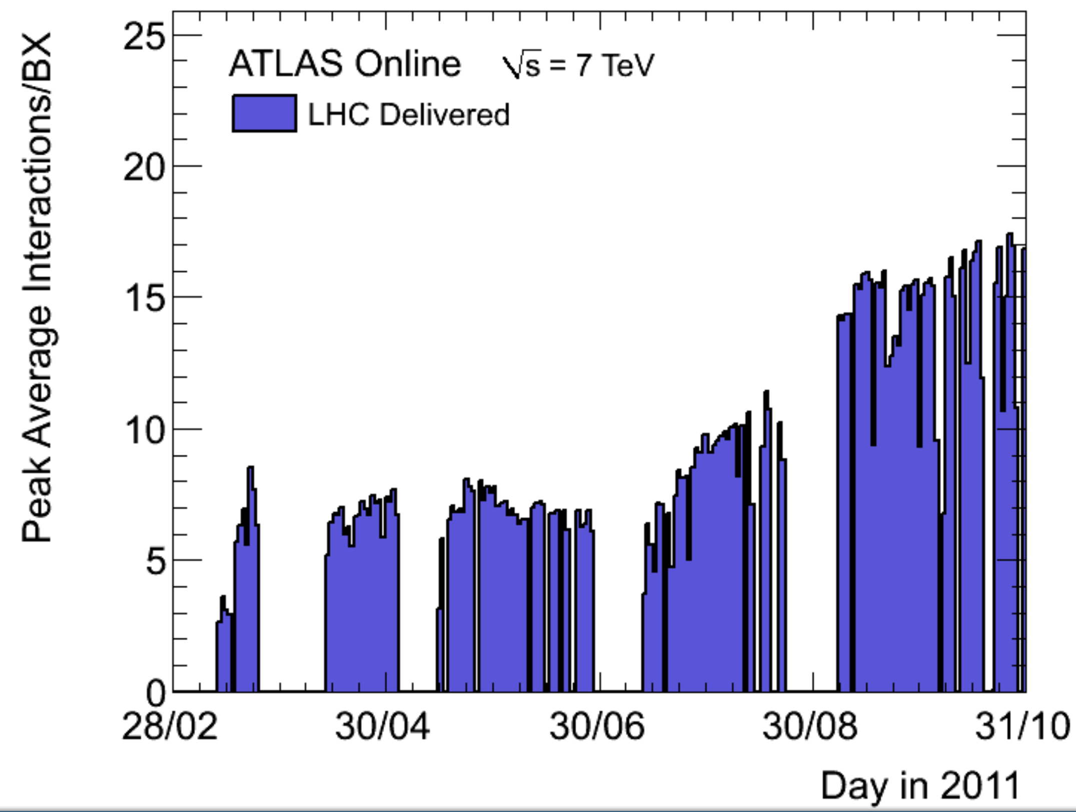


Pile-up



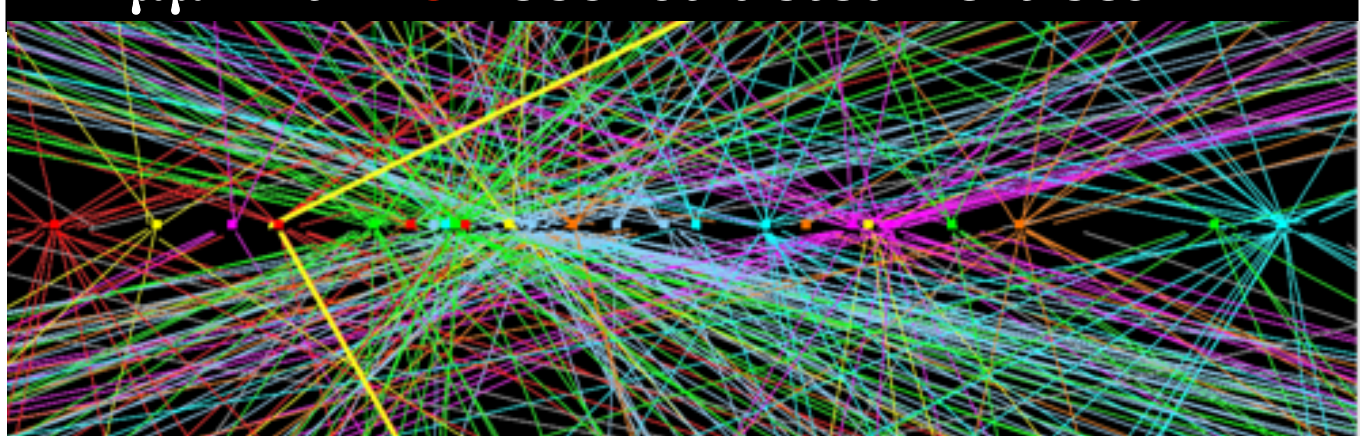
2011



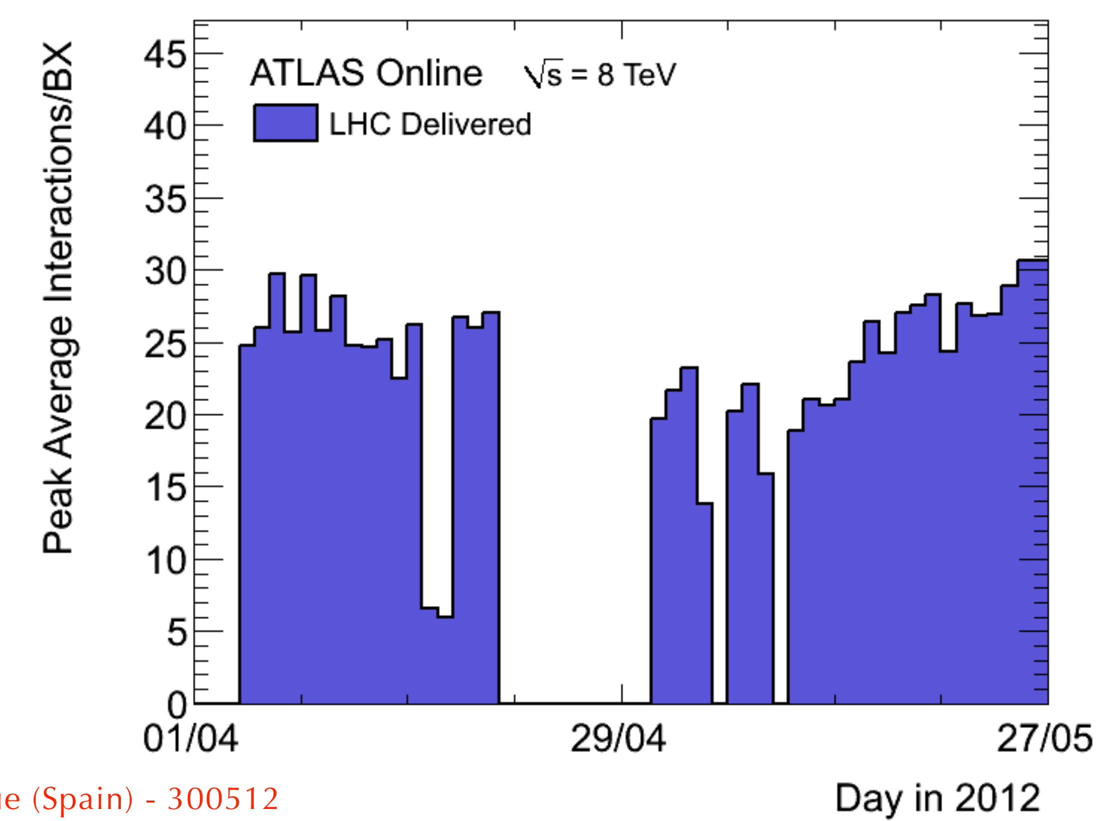


2012

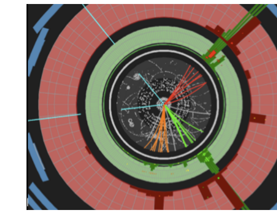
Z→μμ with 25 reconstructed vertices



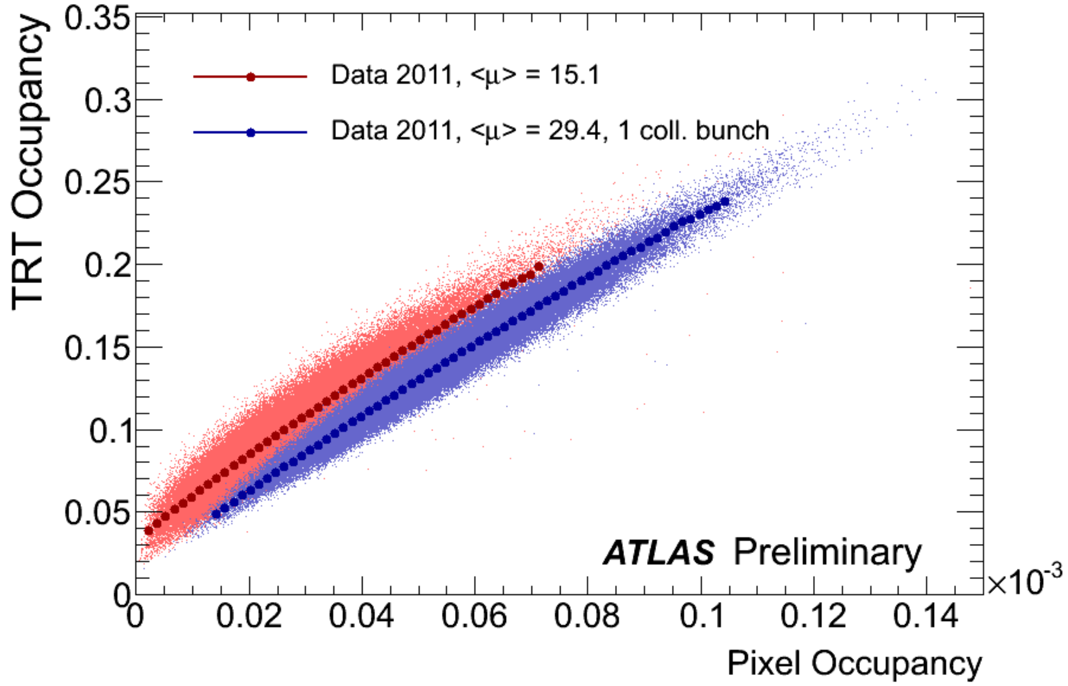
Run: 201289, event: 24151616 (15th April 2012)

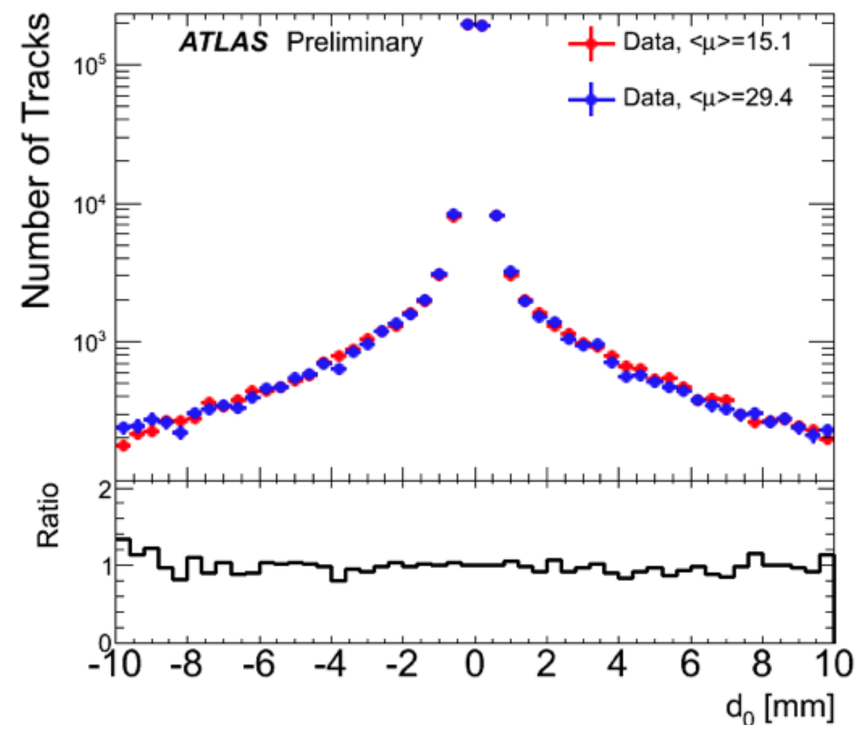


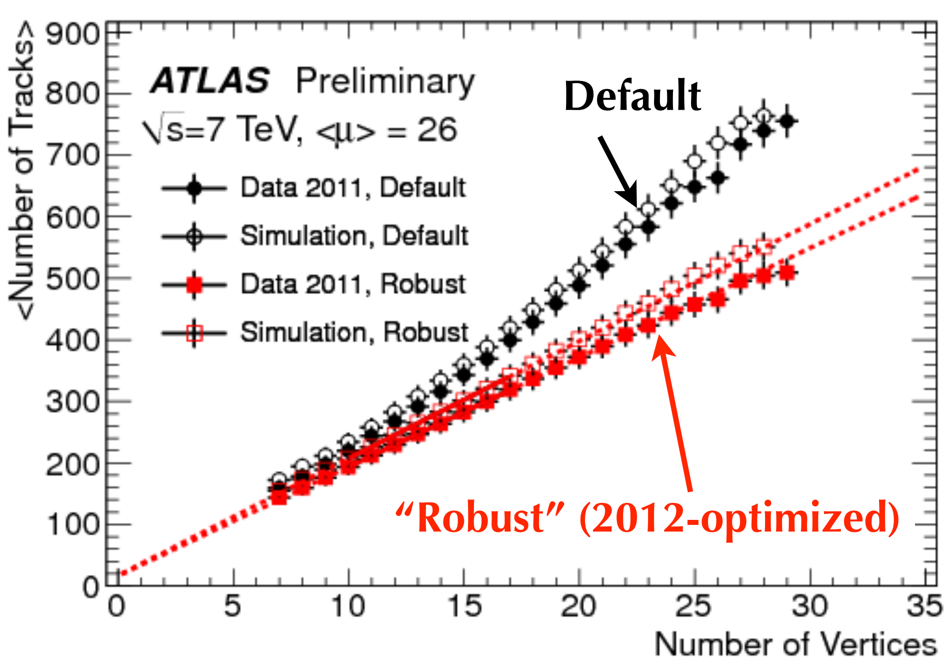
Tracking performance with pile-up

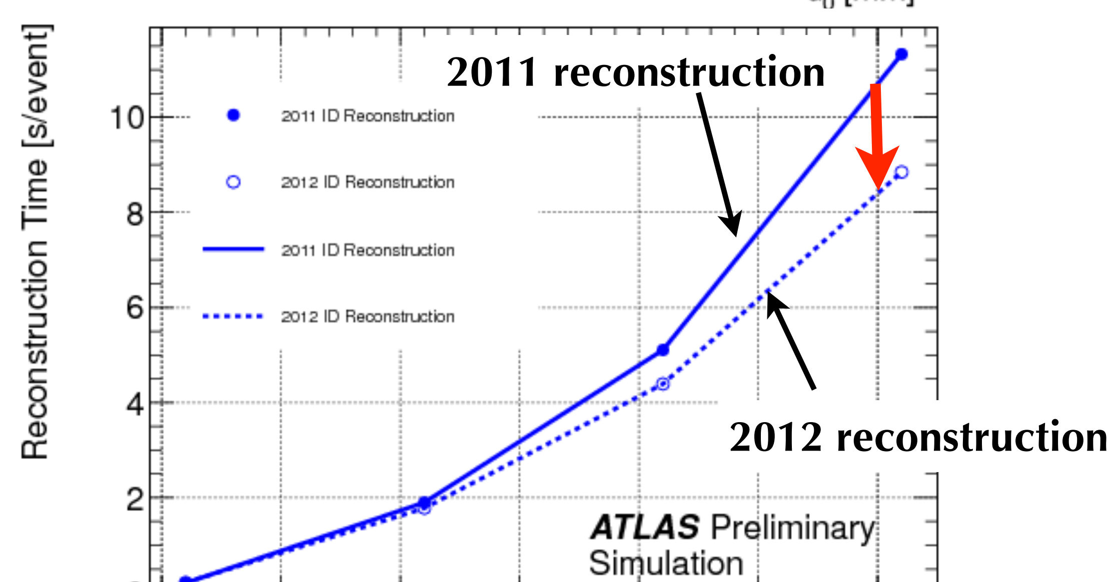


- Performance from runs with medium (<μ>=15) and high pile-up (<μ>=30)
  - no saturation effects observed yet at these luminosities
  - no significant increase in the fake-rate observed
  - linear relation between <number of tracks> and vertices preserved at high pileup

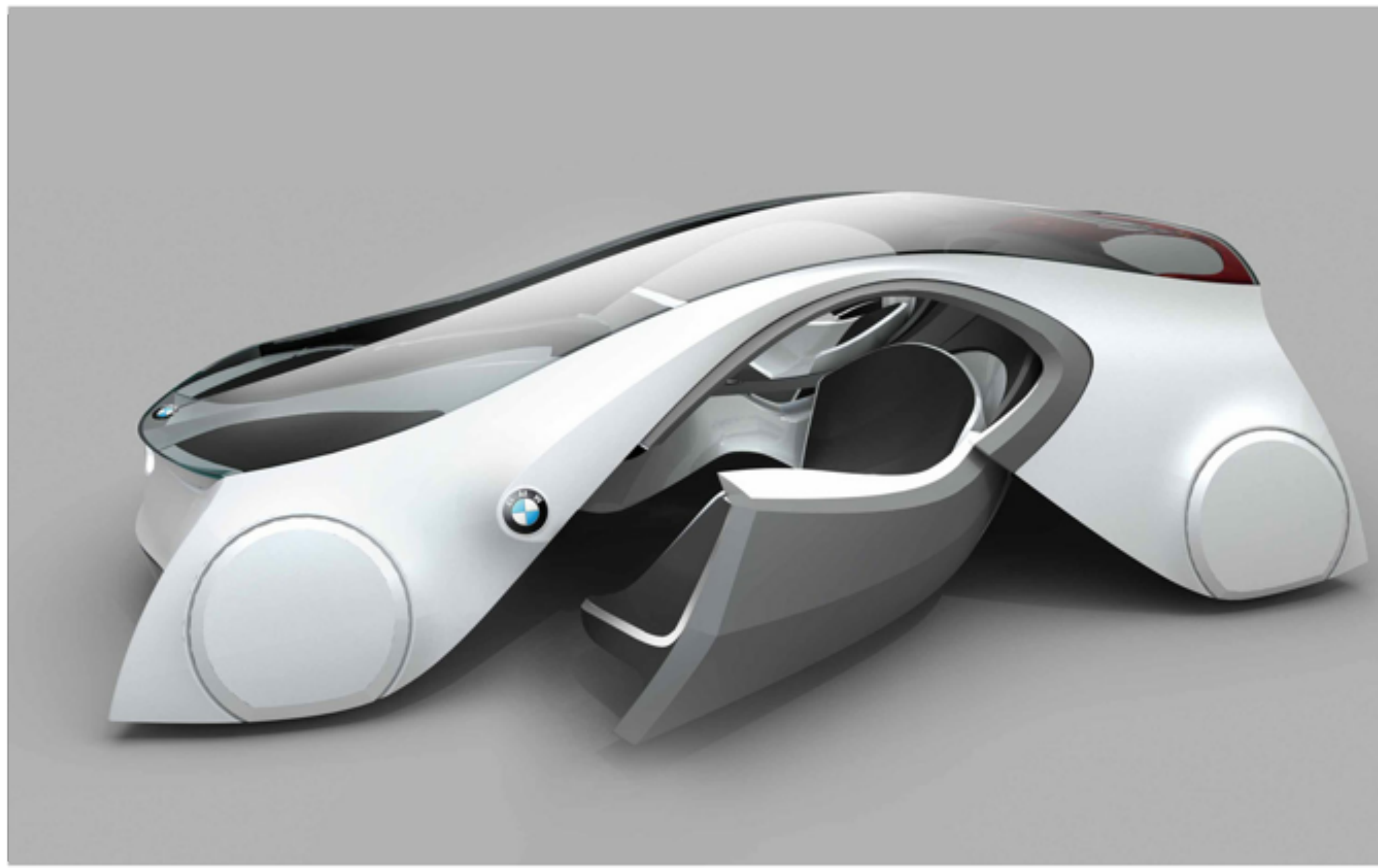




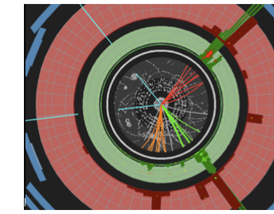


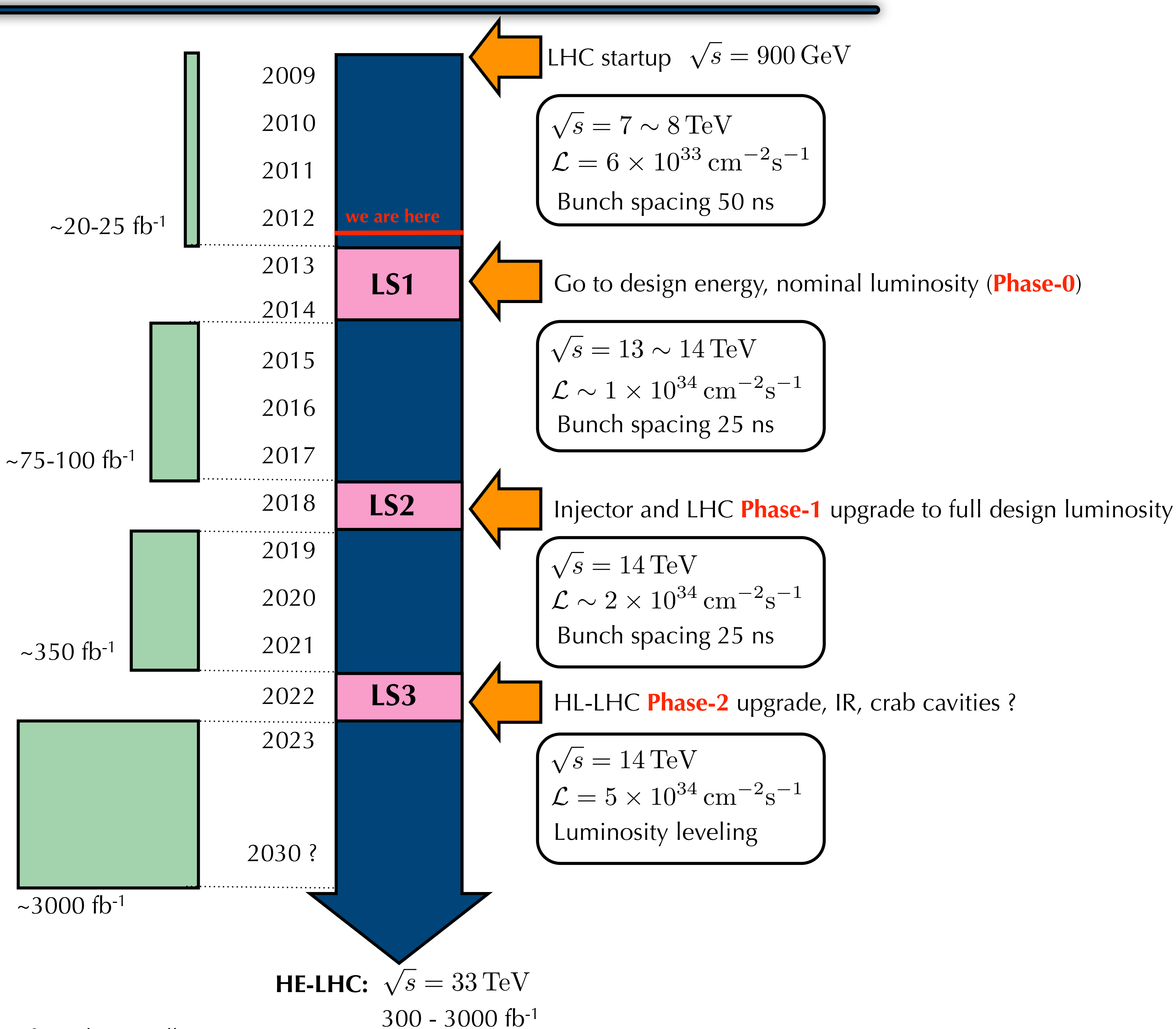


3.- ATLAS Upgrade

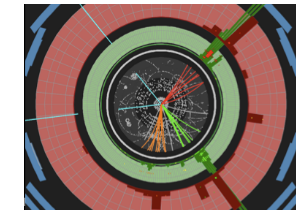


High-Luminosity LHC (HL-LHC)

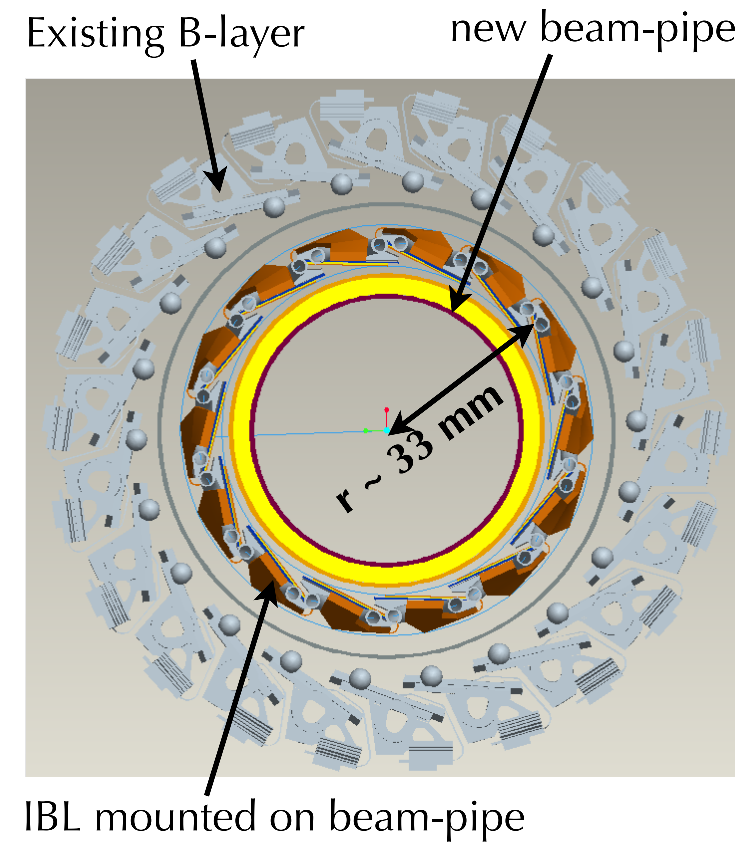


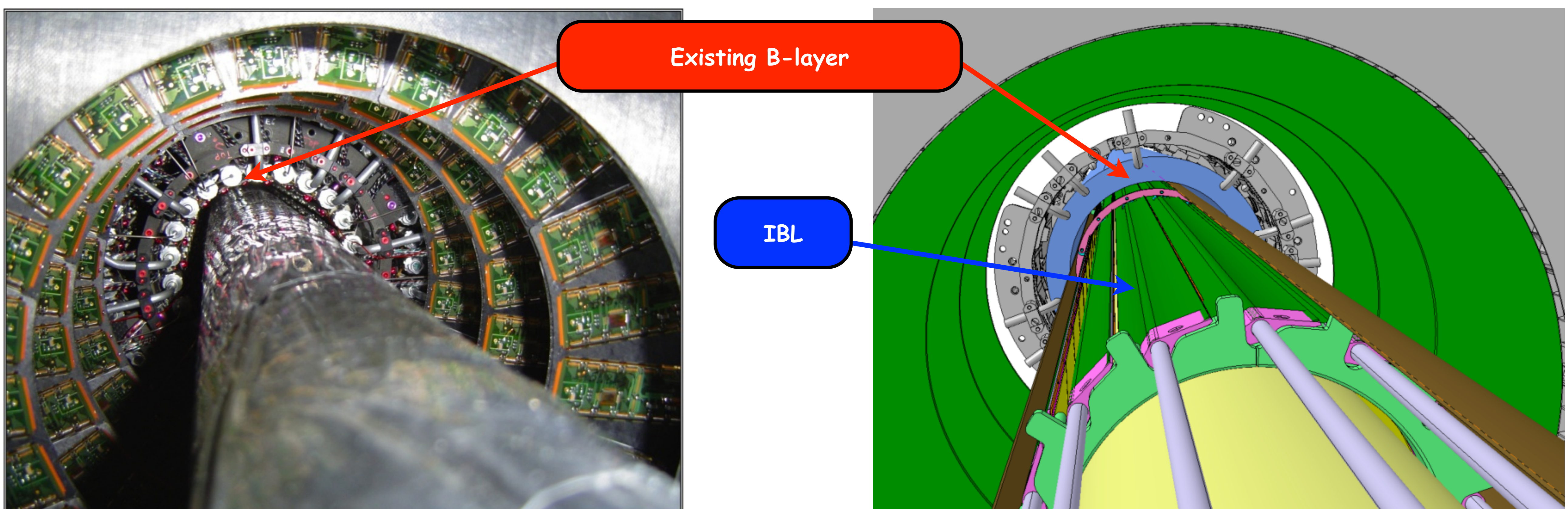


Phase-0: Insertable B-layer

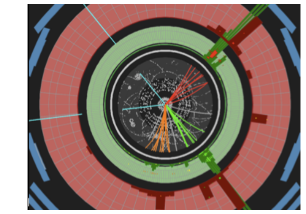


- 4th Pixel layer, mounted directly on beam-pipe
- Maintain and improve physics performance until the HL-LHC
  - new sensor technologies
  - closer to IP: 50.5 mm → 32.7 mm
  - new (smaller) Be beampipe (0.7% X0)
    - expensive but significant reduction of the MS background
  - very tight clearance (~14 mm) !!

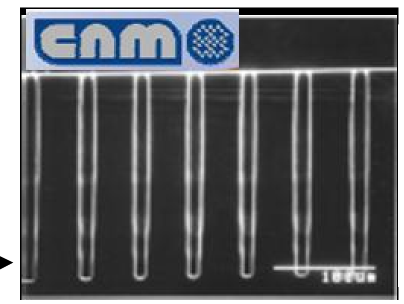


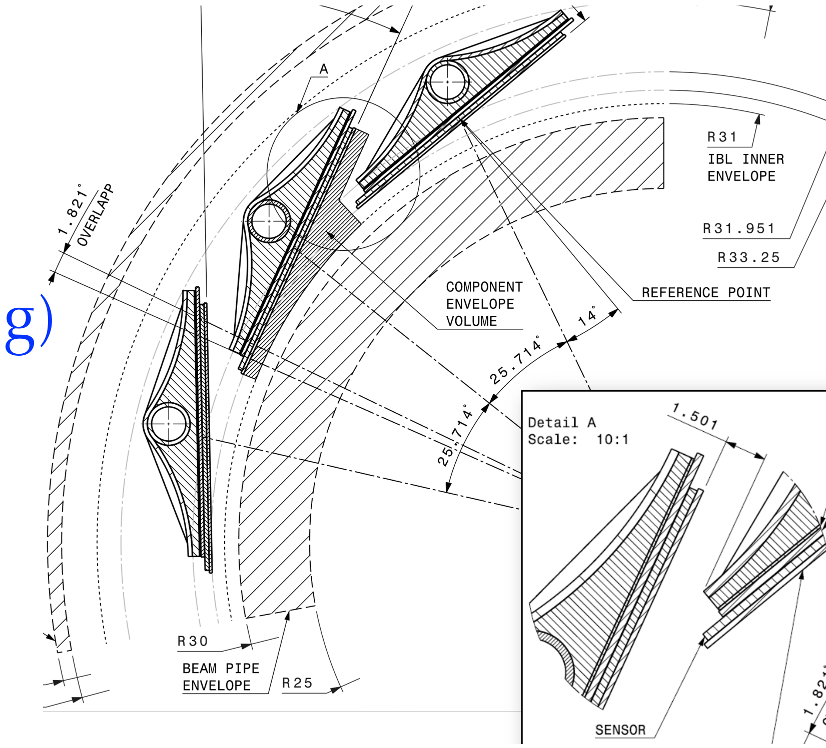


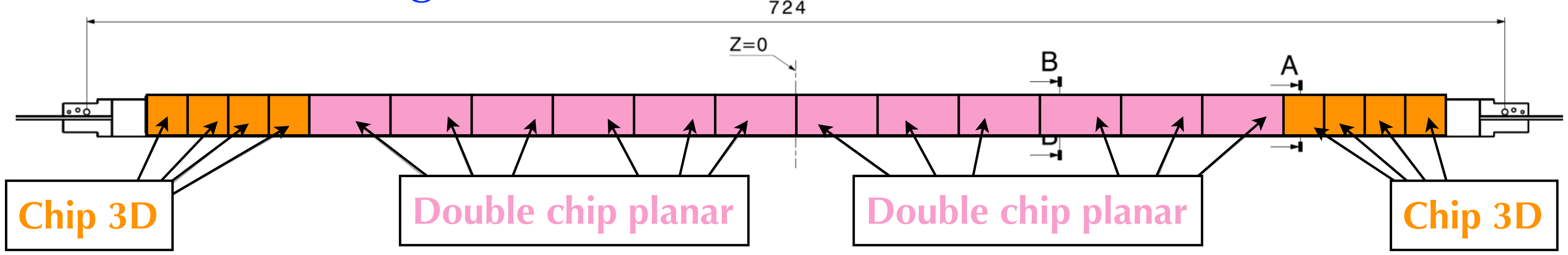
IBL performance



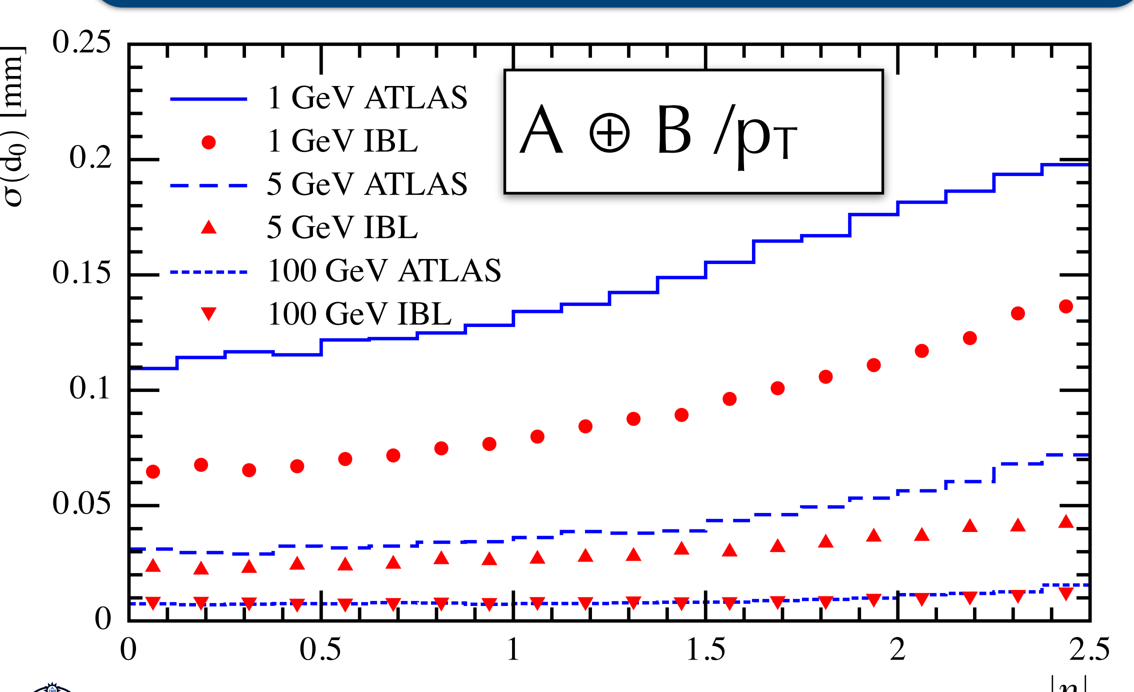
- Layout and specifications:
  - 14 staves, each with 32 FEI4 chips; 50x250 μm^2 pixels
    - 1.8° φ-overlap, <2% gaps in Z
  - Radiation hardness ($5x10^{15}$ n_{eq}/cm^2), -15°C (CO_2 cooling)
- Sensor technology (# per stave):
  - planar n-in-n slim-edge sensors (12)
  - 3D slim-edge sensors (8)



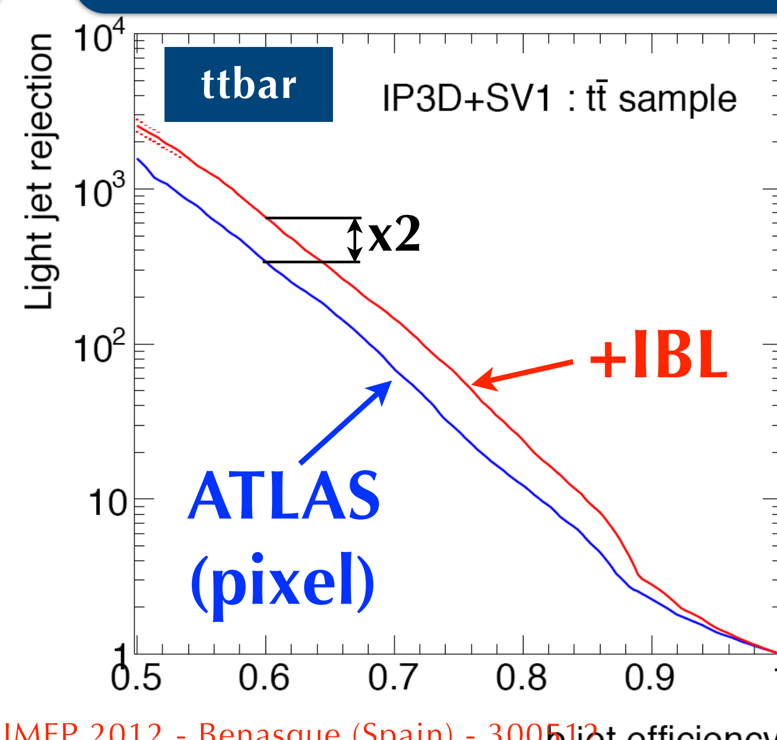


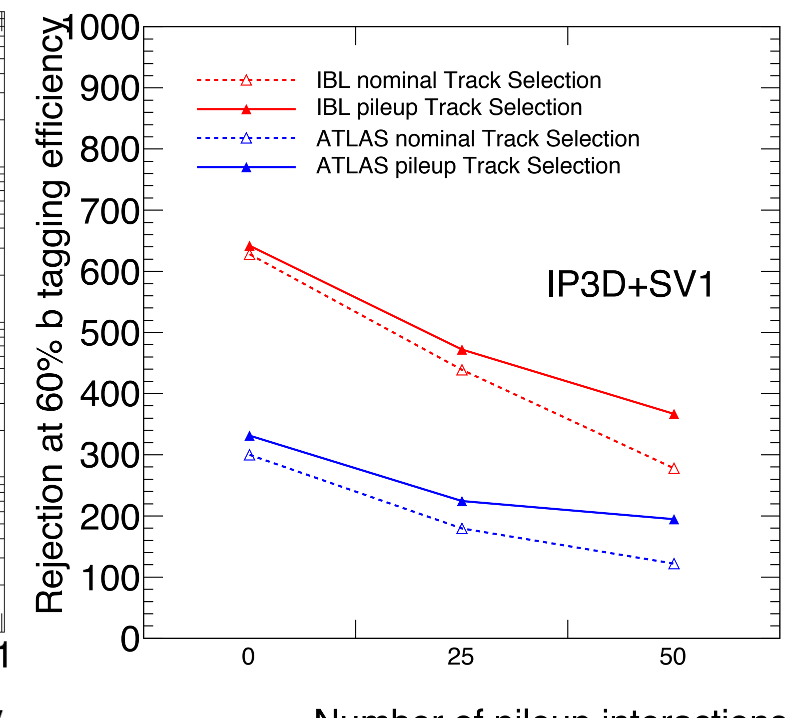


Tracking-performance

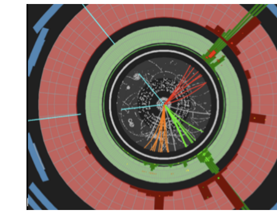


b-tagging

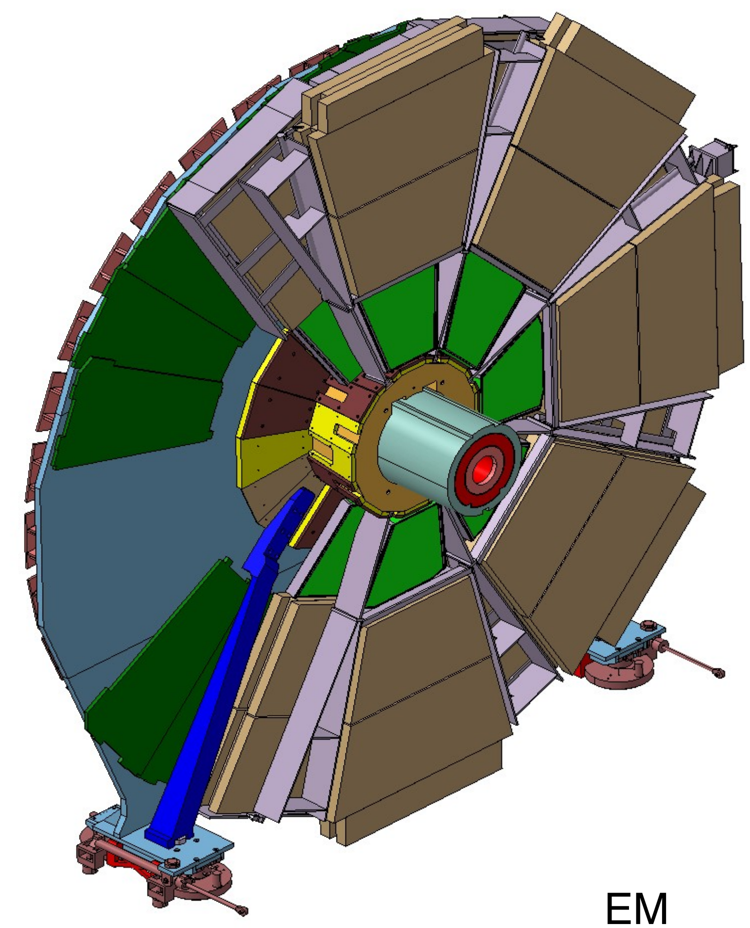




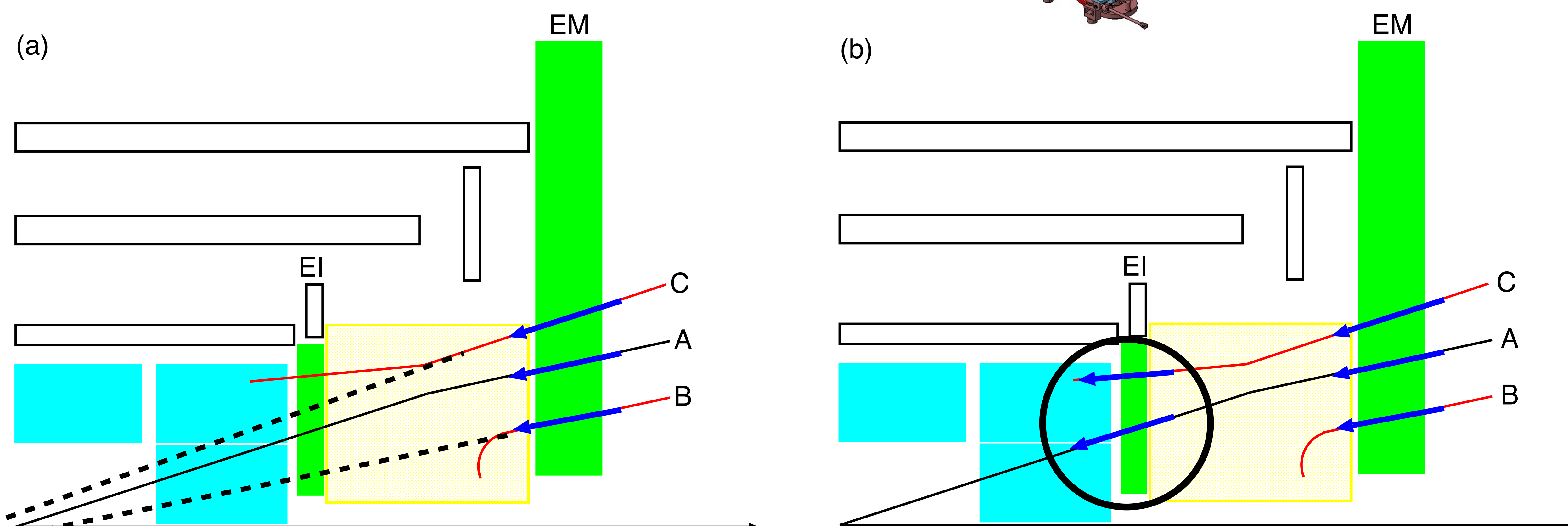
Phase-1: Muon Spectrometer



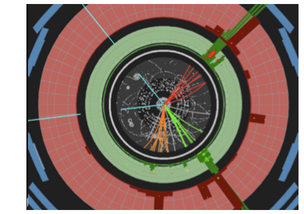
- Replace muon small wheels with improved trigger capabilities
  - need < 1 mrad resolution and associated trigger vector capability
- By requiring an associated pointing segment on EI, background triggers may be eliminated



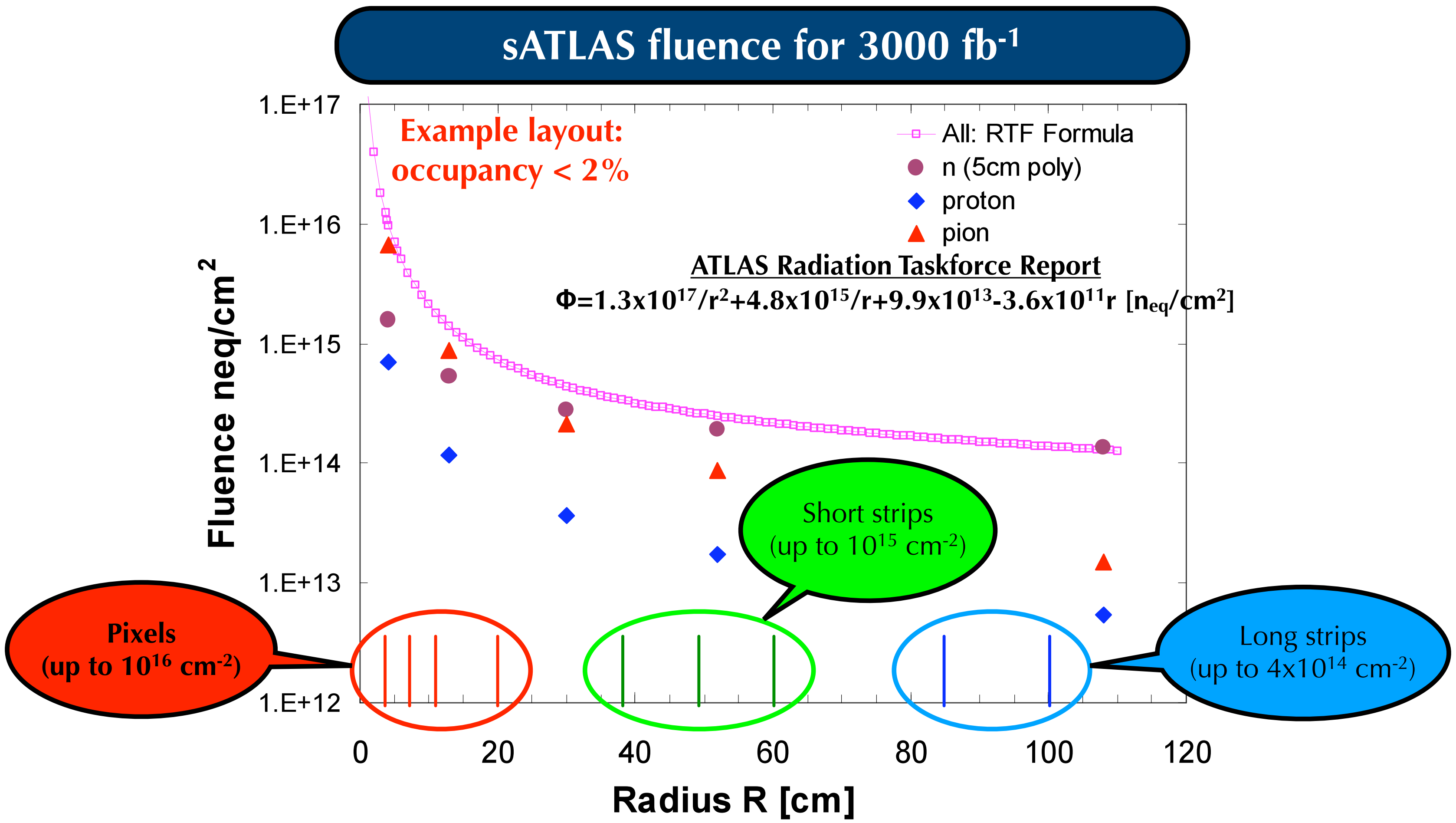
- **A**: high p_T muon coming from the IP
- **B & C**: background segments causing fake triggers

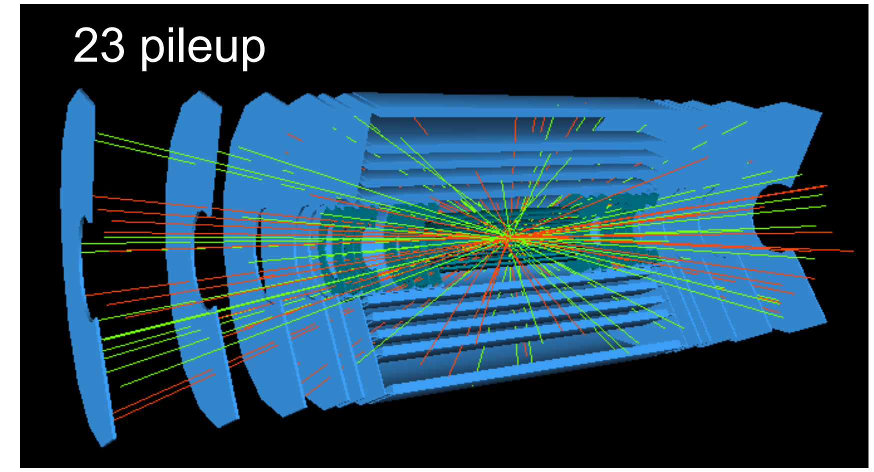


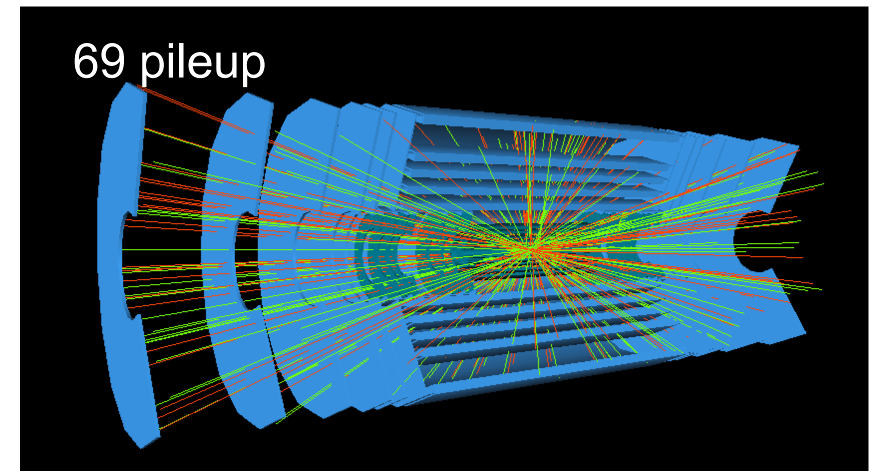
Phase-2: a new ATLAS inner tracker

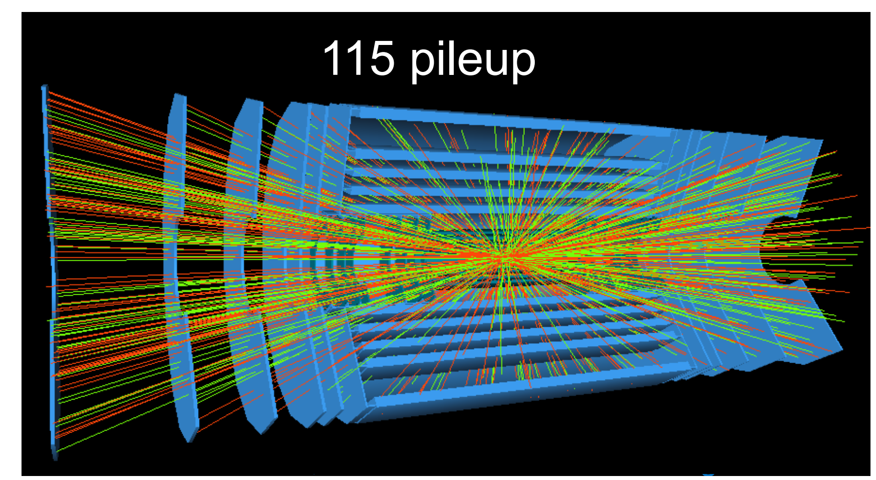


- Increase in pile-up events from ~23 to ~120
  - radiation damage
  - $>10^5$ particles $|\eta|<3.2$ ➡ TRT occupancy ~100%



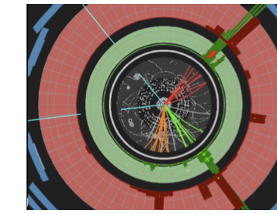


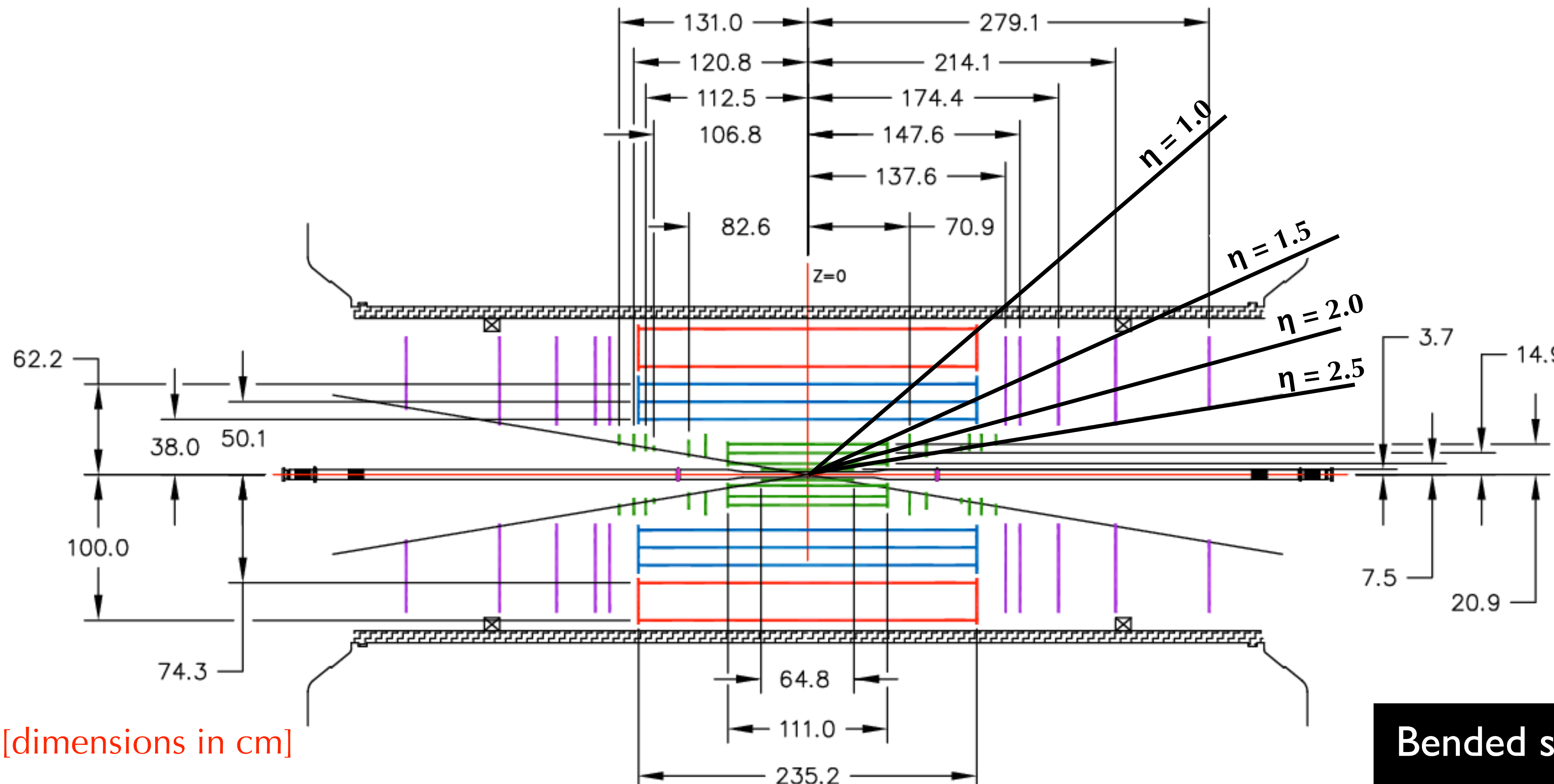




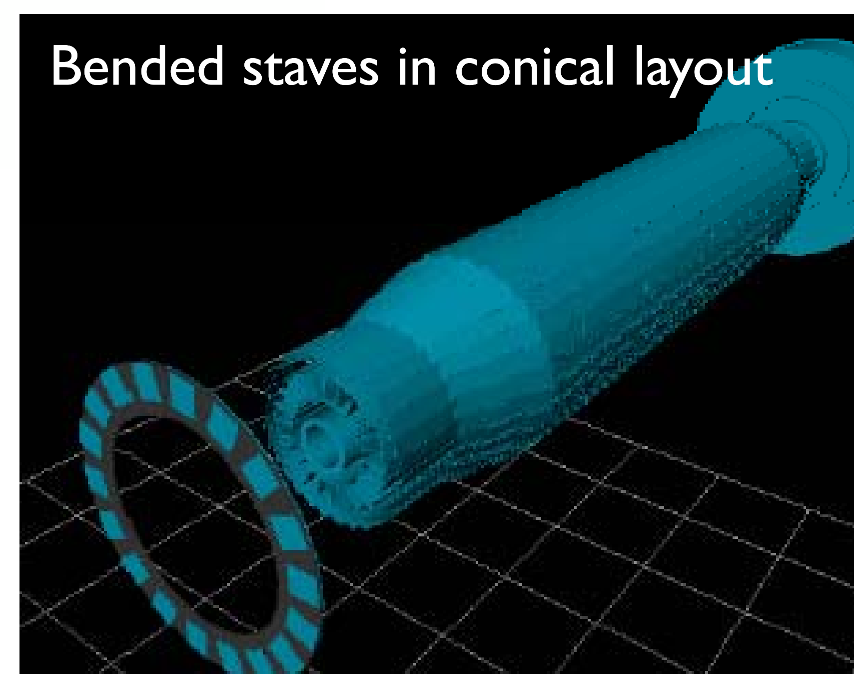
- **A completely new ATLAS Inner Detector !!**
  - Pattern reco, good tracking efficiency + low fake rate, minimize occupancy
    - better detector granularity
    - silicon-based tracker: **pixels** and **strips** (short and long)

(new) Inner detector layout





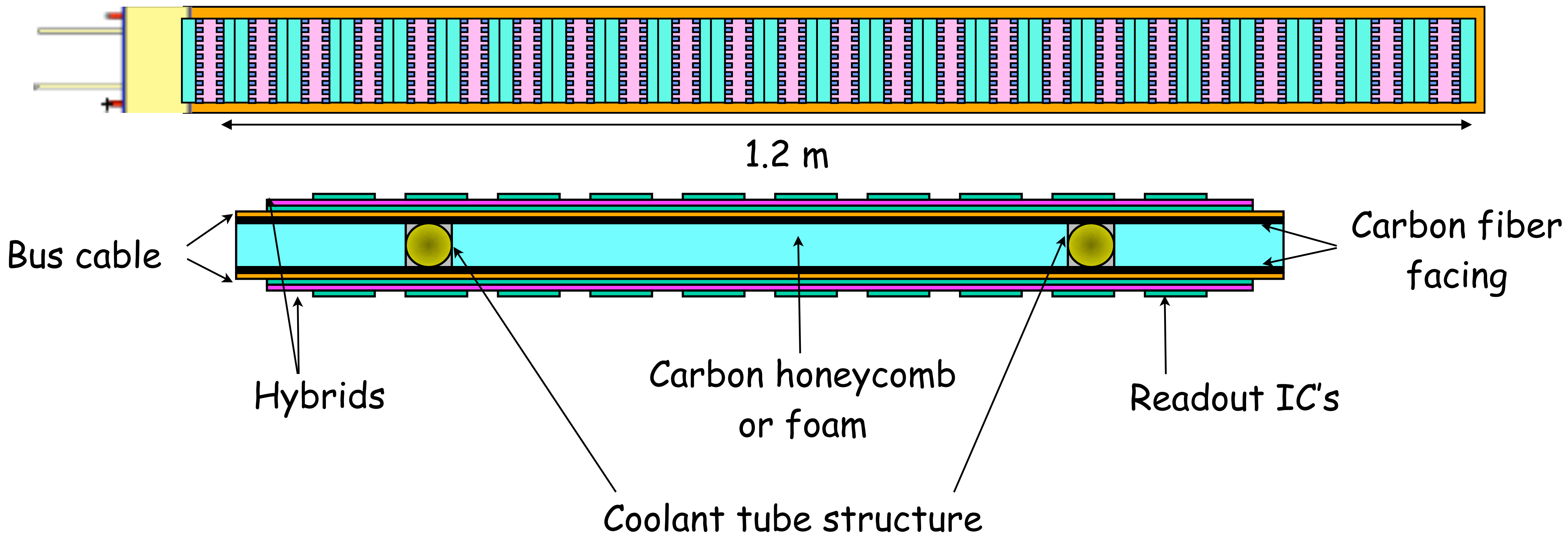
[dimensions in cm]



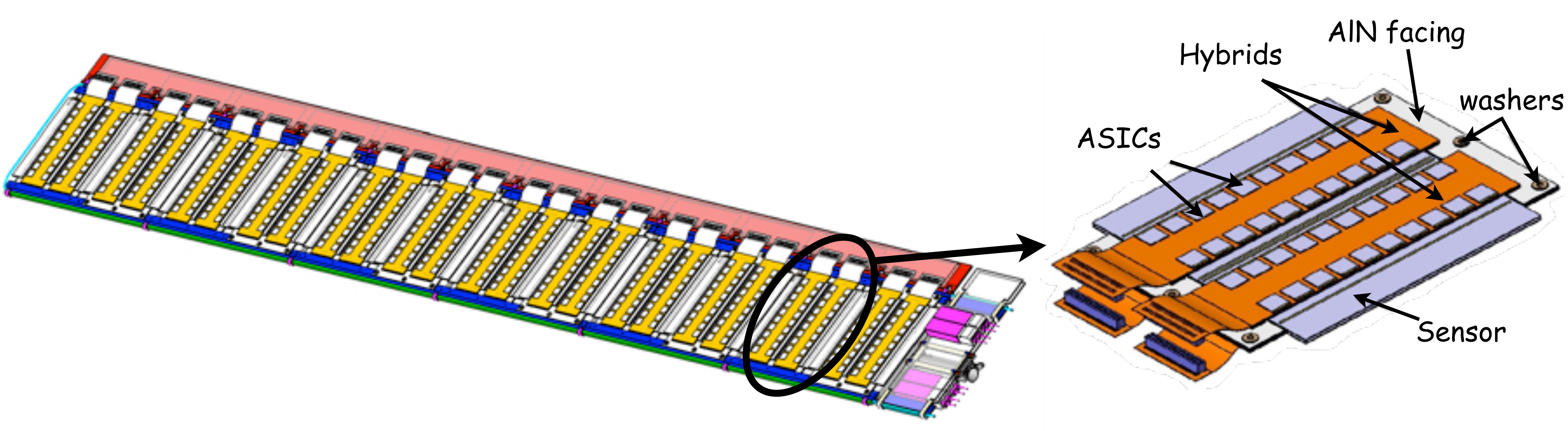
- Pixel-detector
  - 4 barrel layers and 6 end-cap disks
  - investigation of novel layouts
- Strip-detector
  - 5 barrel layers (3 short + 2 long) and 5 end-cap disks

Strip integration concepts: barrel

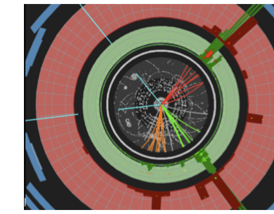
STAVE (single-sided modules)

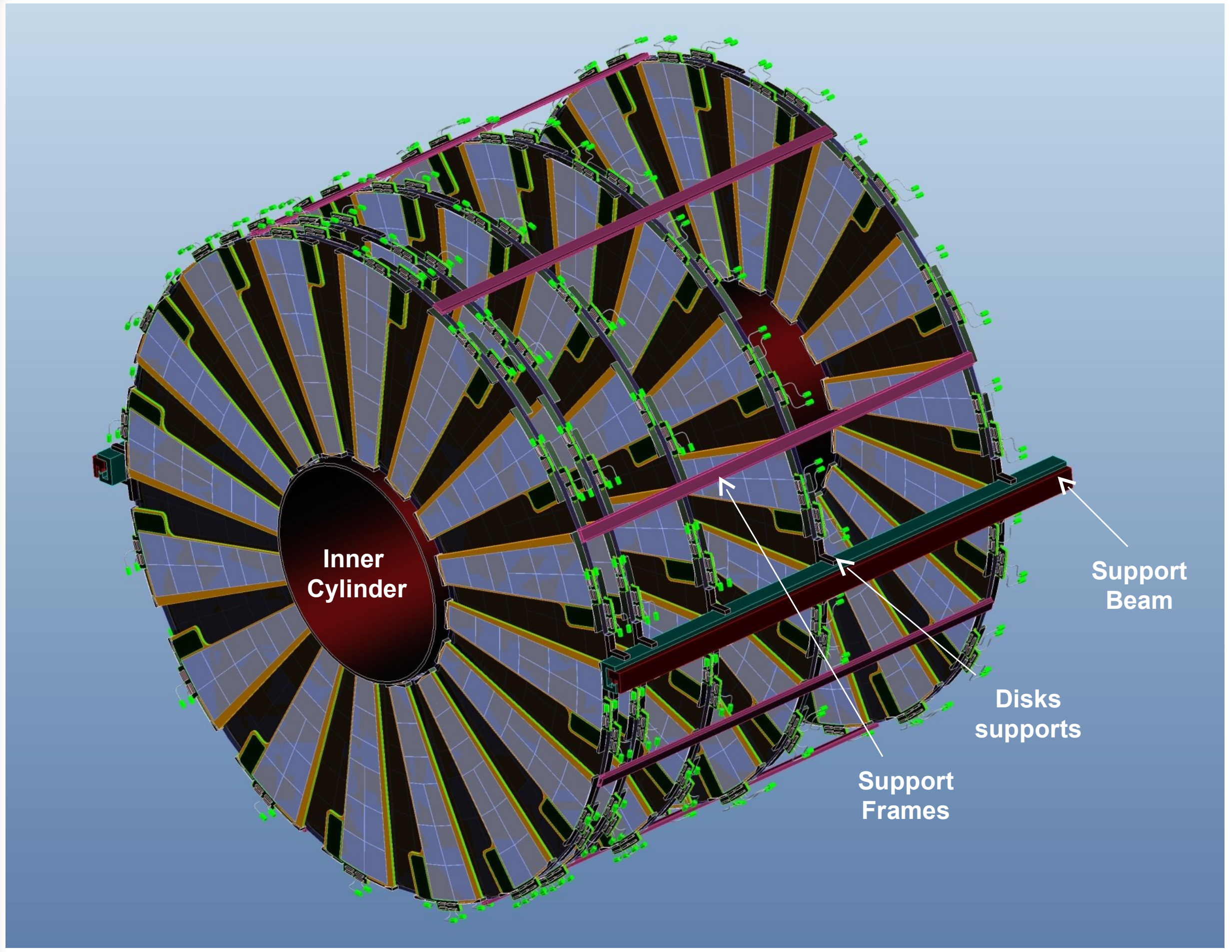


SUPERMODULE (double-sided modules)

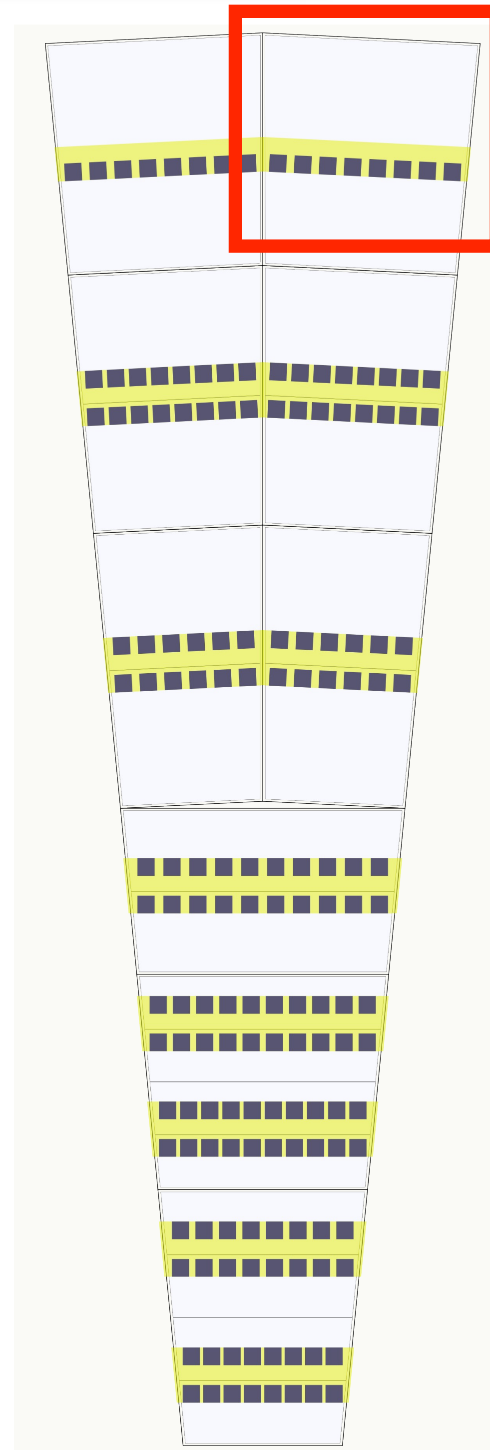


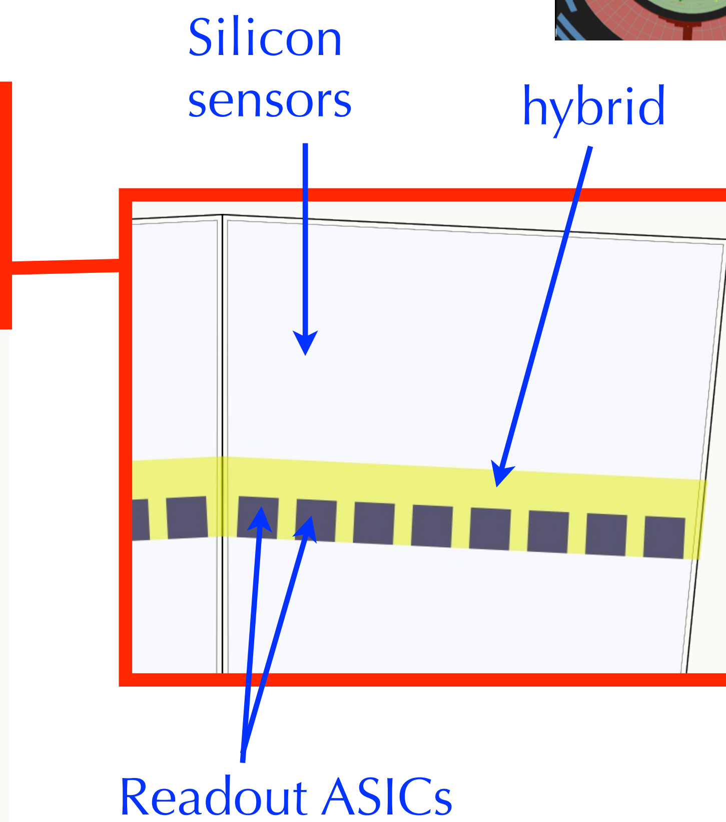
Strip endcaps



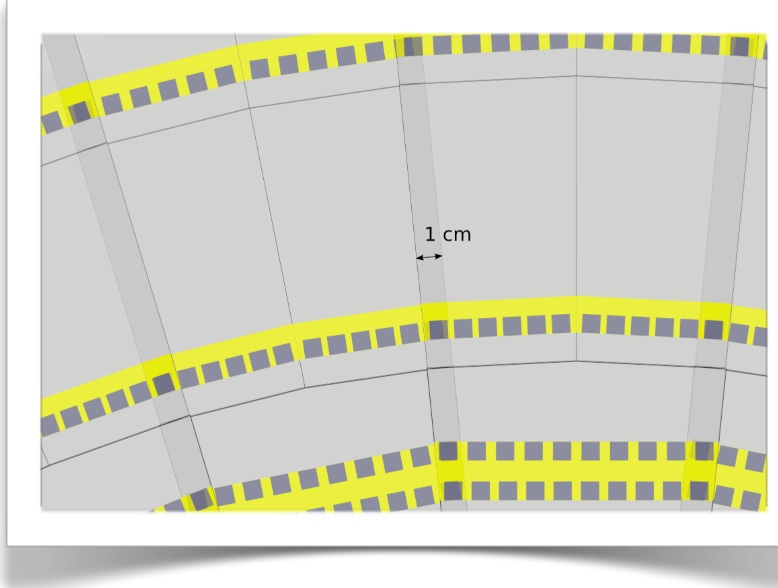


- Sensors mounted on petals and disks made of petals
  - Coverage from R=340 mm to R=950 mm
  - 5 disks
  - 32 petals/disk
  - Large number of sensors/petal

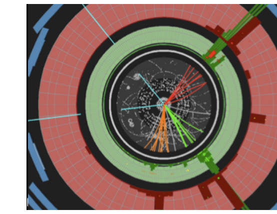




Petals with constant Rϕ overlap along R



Conclusions



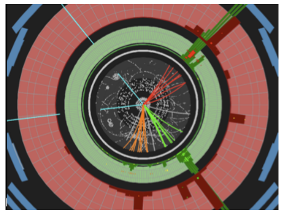
- ATLAS is performing extremely well !!
  - 5.25 fb^{-1} recorded in 2011, 3.15 fb^{-1} in 2012
  - data / MC agreement of the order of few %
- Detector performance
  - Inner detector alignment focused in assessing "weak modes"
  - Momentum resolution of ID and MS very close to design values
  - Prepared for the challenges of 2012 !!
    - reconstruction in a high (increasing) pileup environment
- ATLAS upgrade
  - IBL under assembly and QA, now !!
  - R&D well advanced for Phase-1 and Phase-2
    - prototypes close to final detector under thorough evaluation and testing
- A huge amount of interesting physics results ➡ **see Marcel's talk**
  - and many more to come !!
    - Higgs 2012 ??

More results :

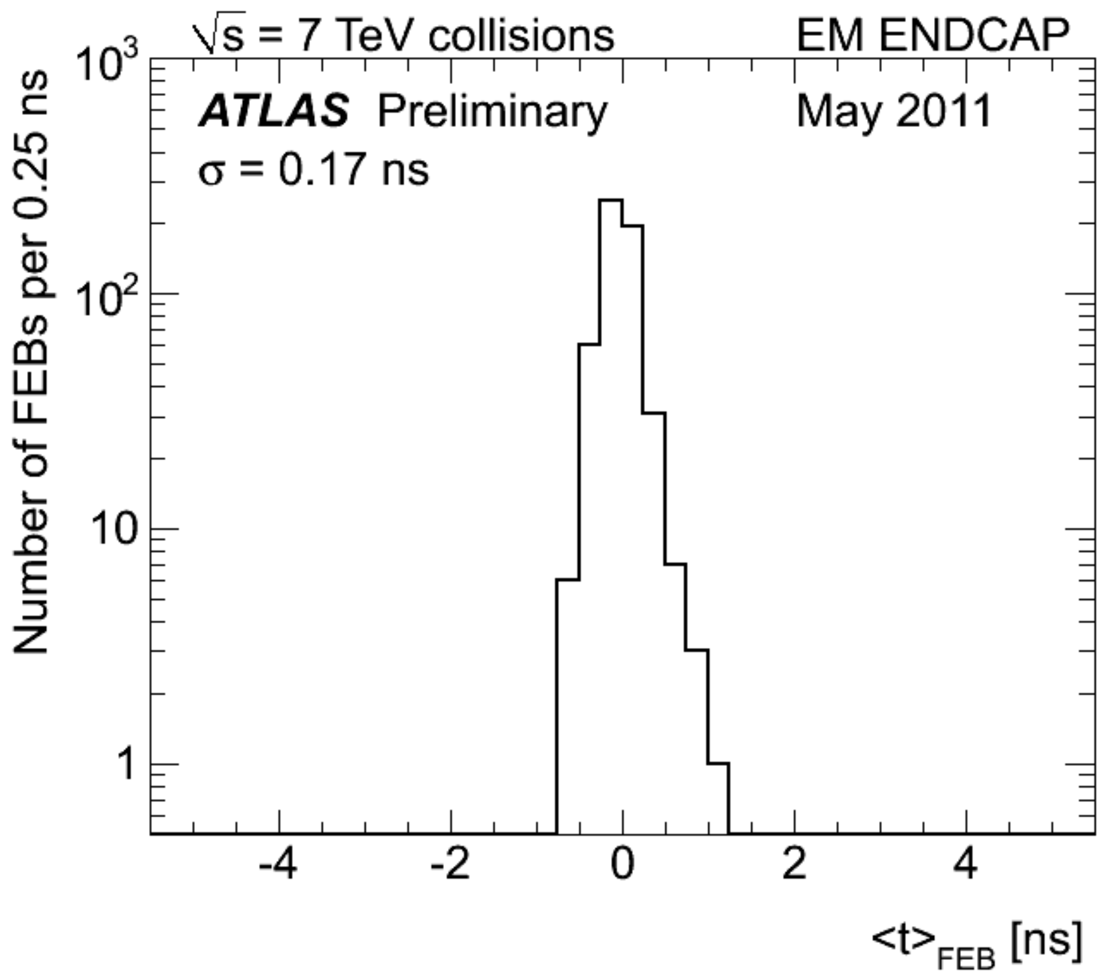
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome

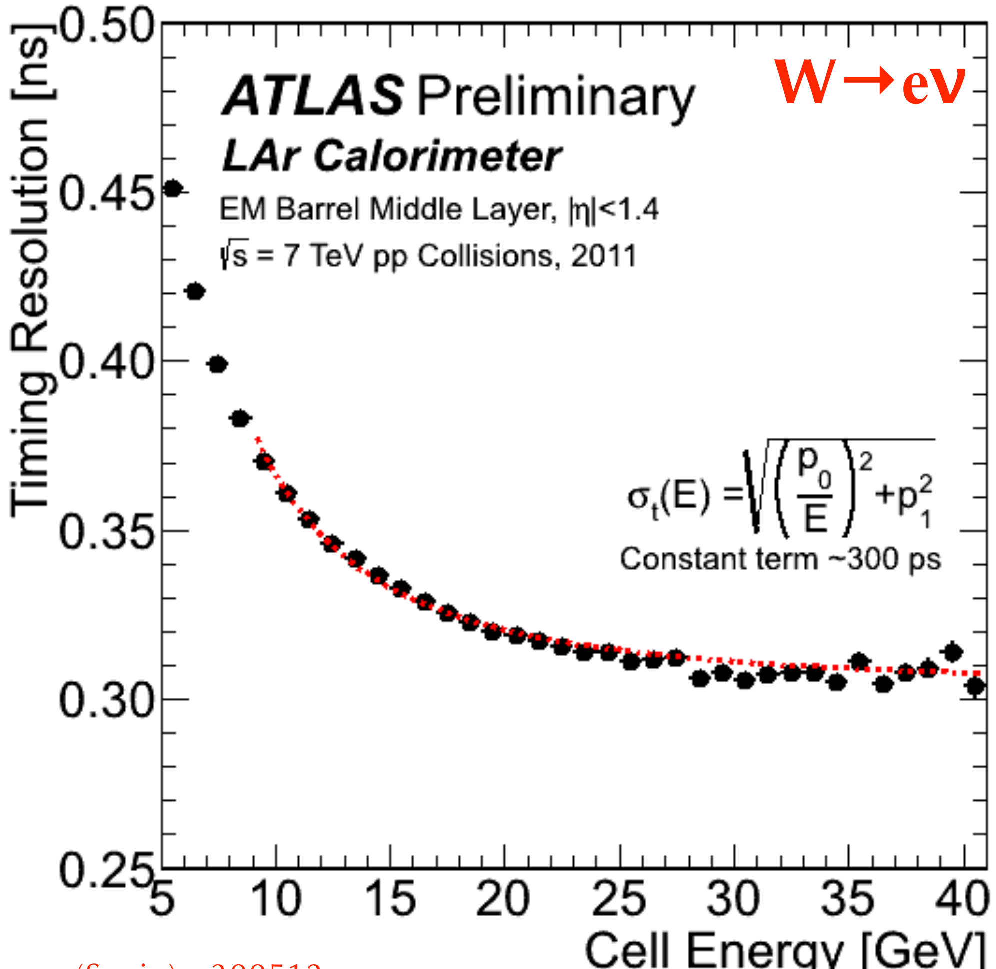
Backup

LAr timing

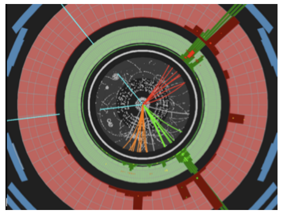


- Timing alignment to synchronize readout clock with BC
  - Distribution of average time / FEB $<t>_{FEB}$
    - FEBs are aligned and centered at zero
    - σ = rms of distribution in a time windows of [-0.5; 0.5] ns
- Timing resolution of ~300 ps achieved for a largre energy deposit in a cell of the EM Barrel
  - resolution includes a ~220 ps correlated contribution from the beam spread as determined from Z→ee studies

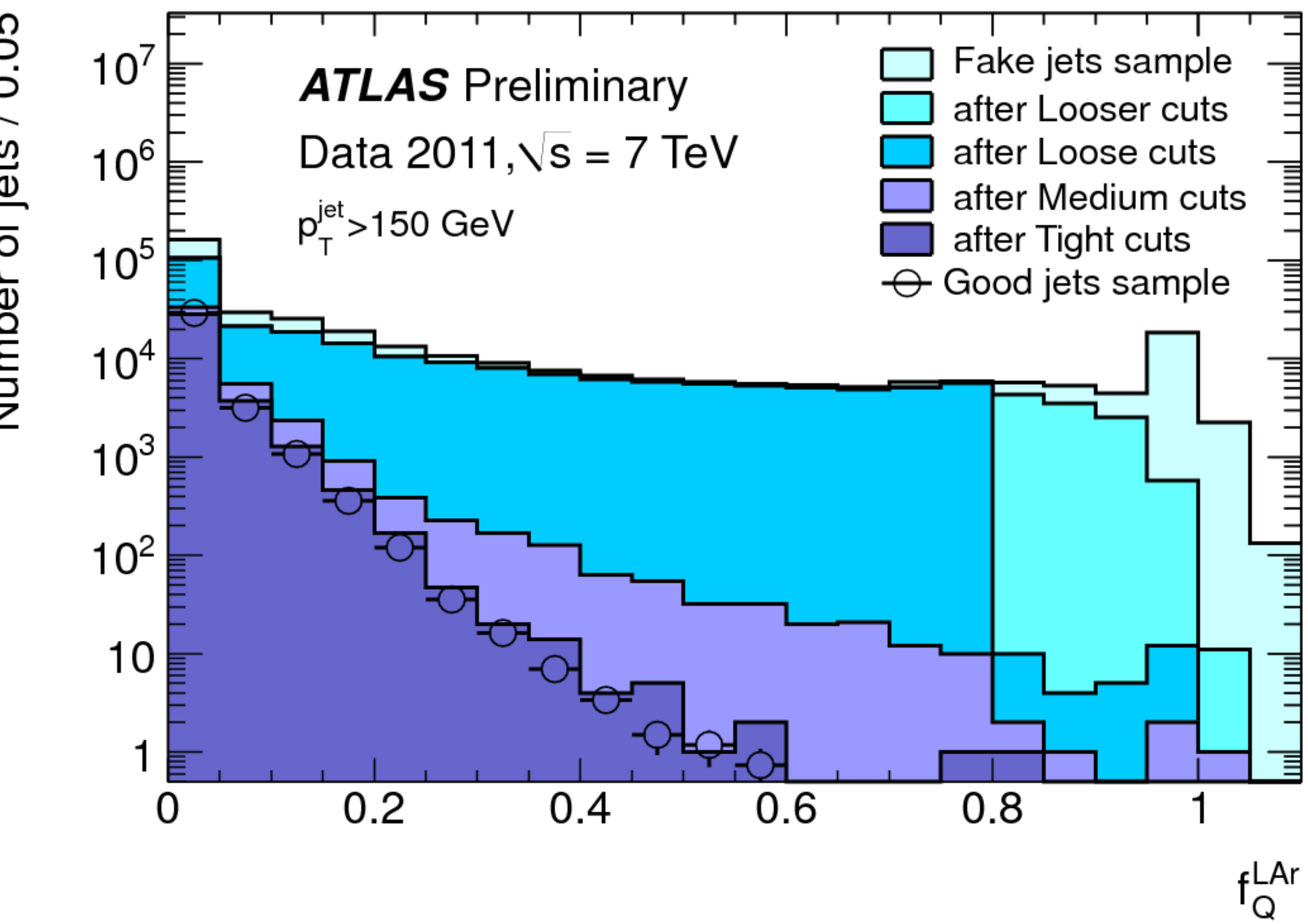


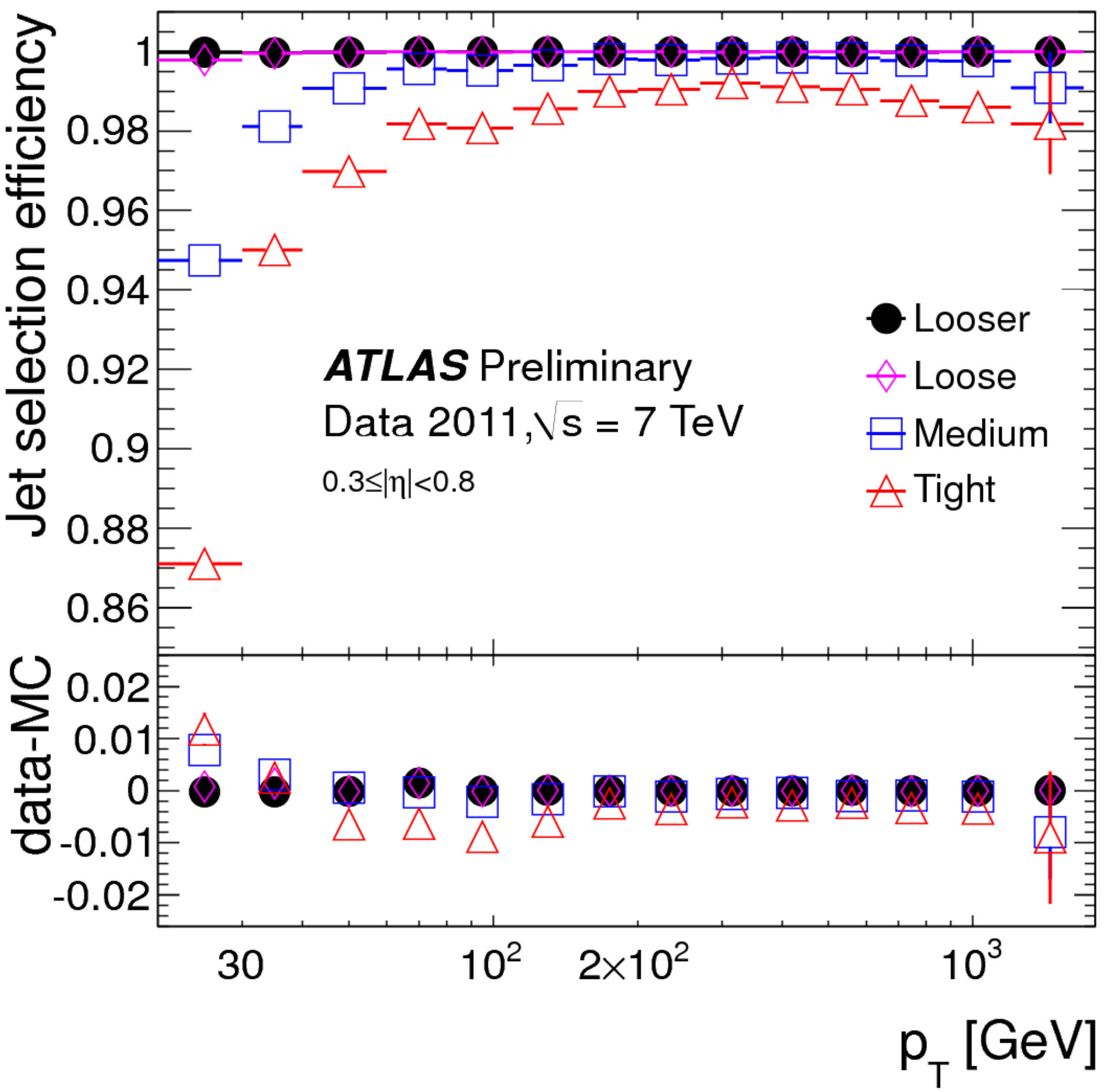


Jet selection

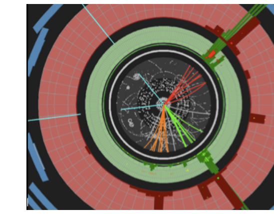


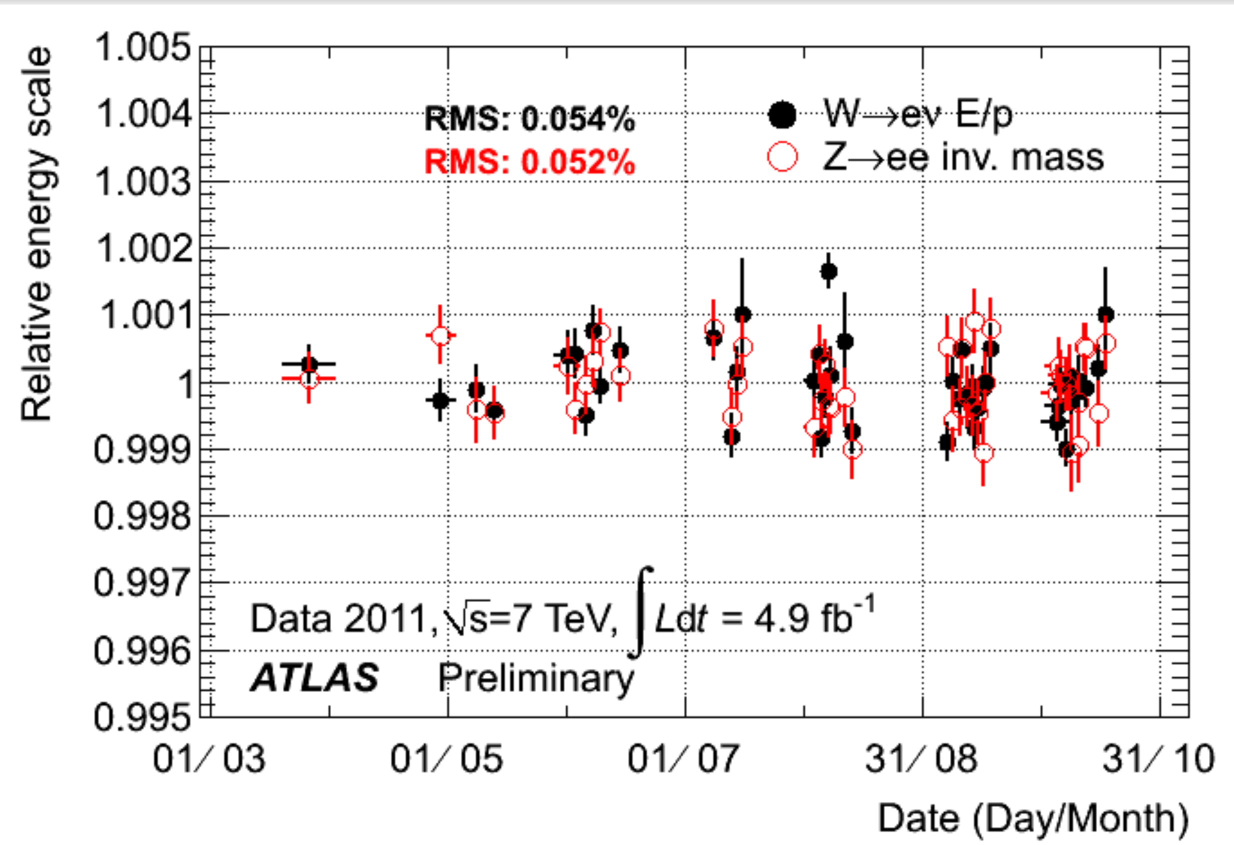
- Main backgrounds to high p_T jets originating from hard-scattering:
  - beam gas, beam halo, cosmic rays (overlapping in-time with pp), calo noise
  - loose selection with ε>99.8% for p_T(jet)>20 GeV (T&P on dijet events)

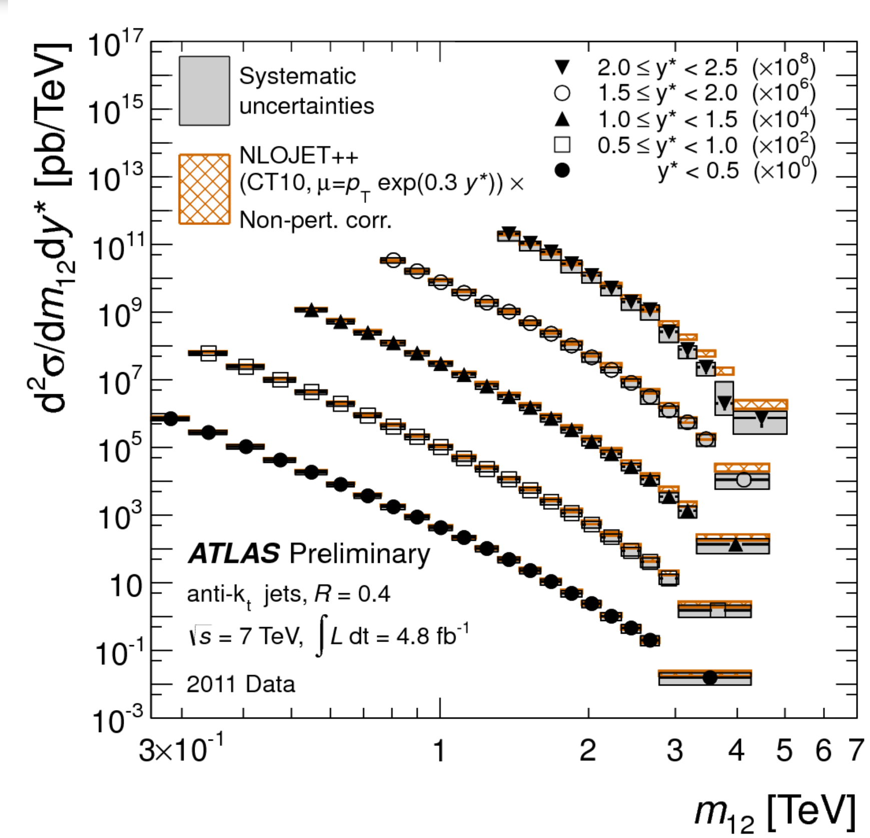




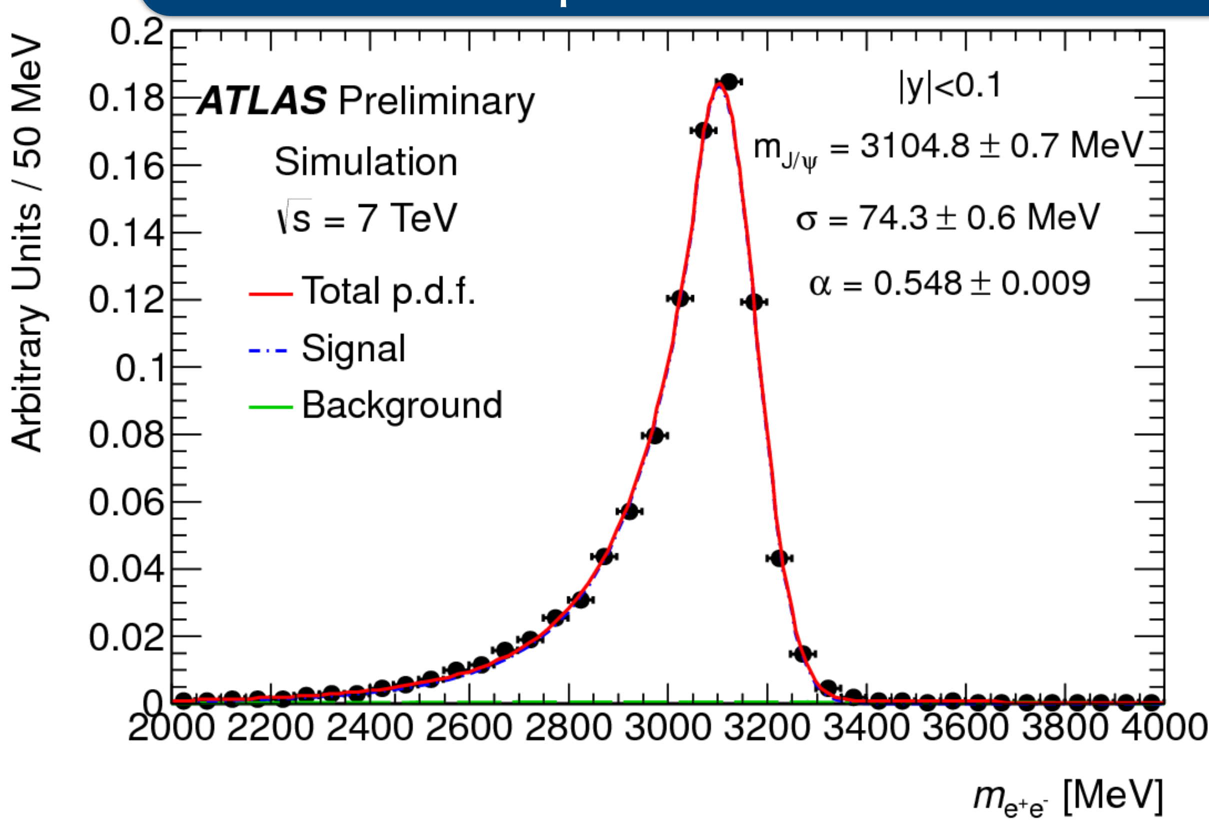
Calo performance

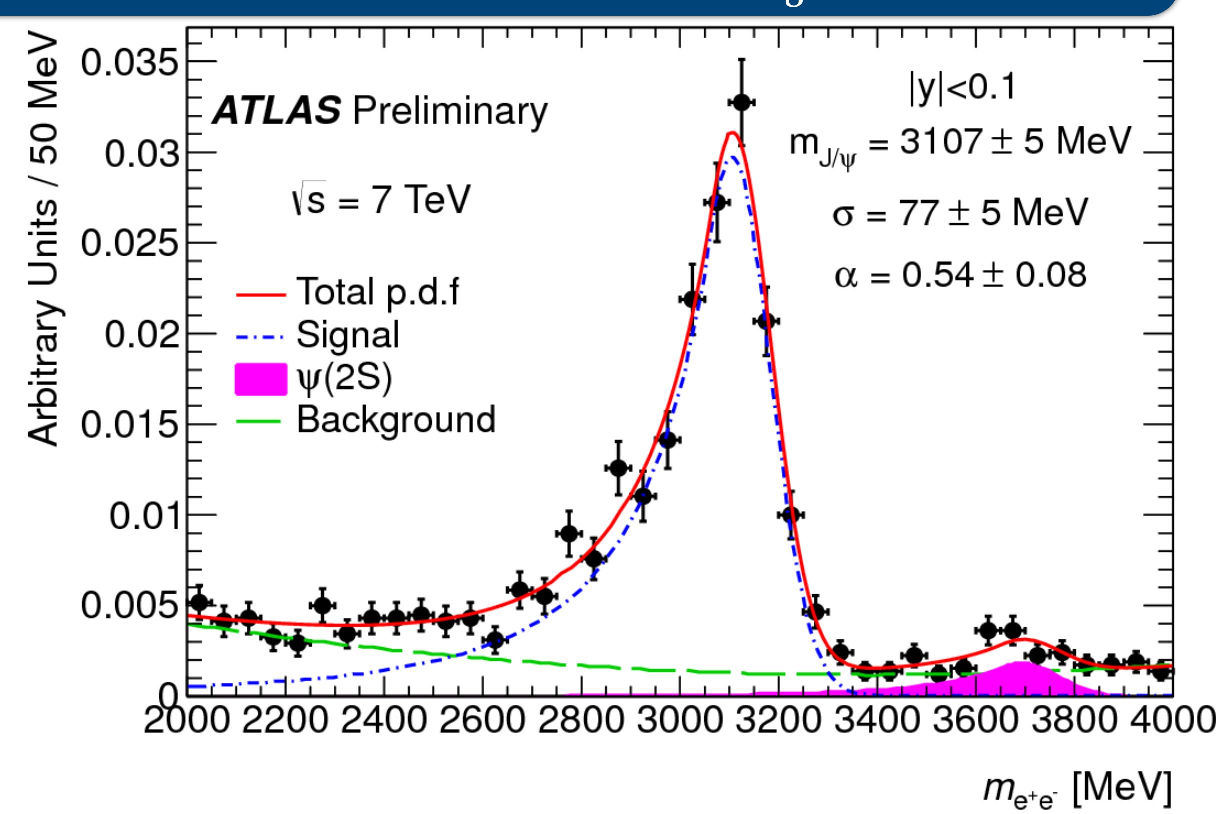




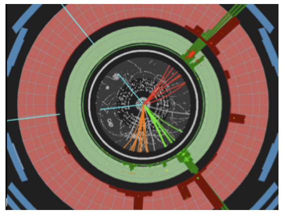


Improved electron reconstruction with Gaussian-Sum-Filter based model for bremmstrahlung

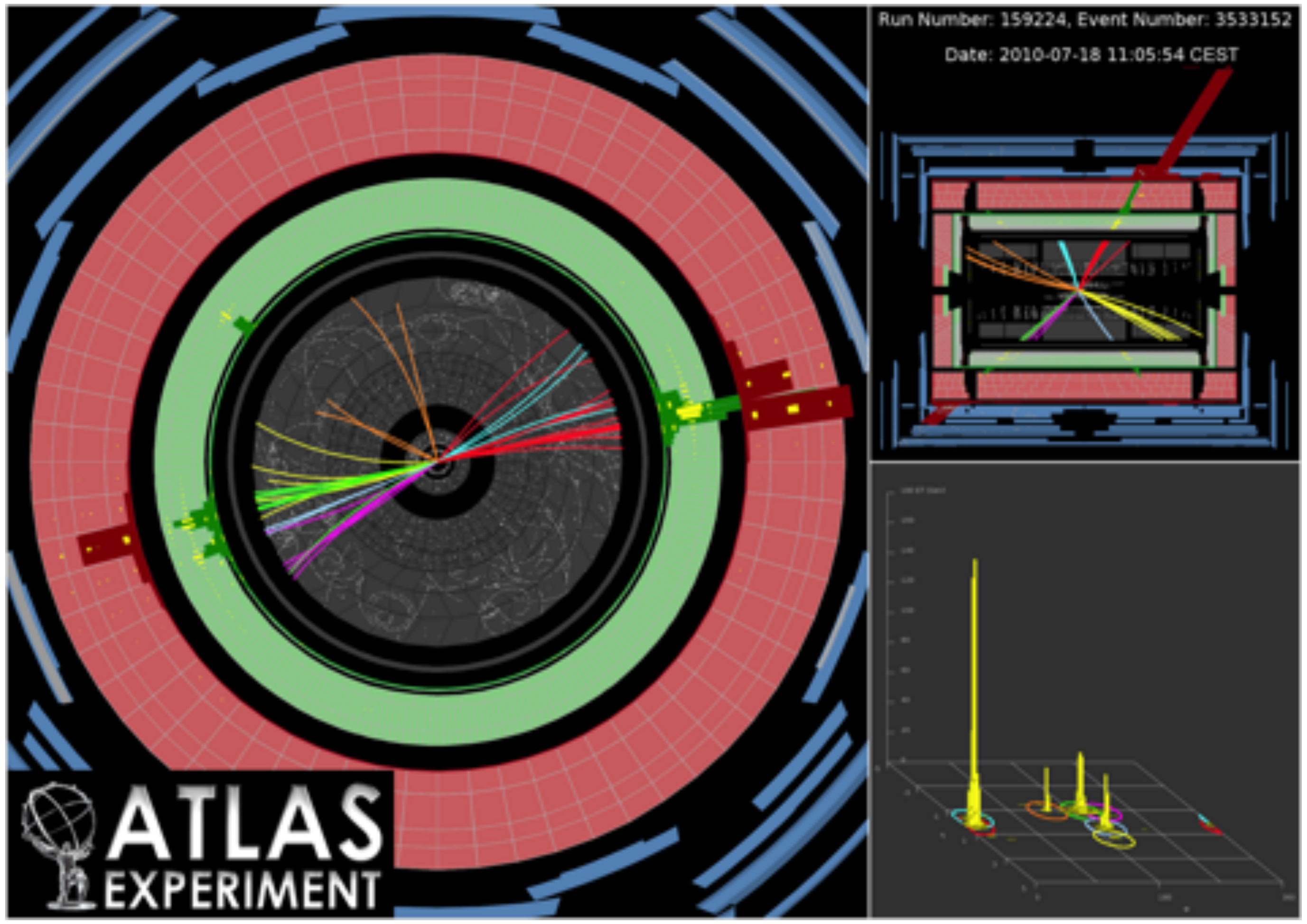


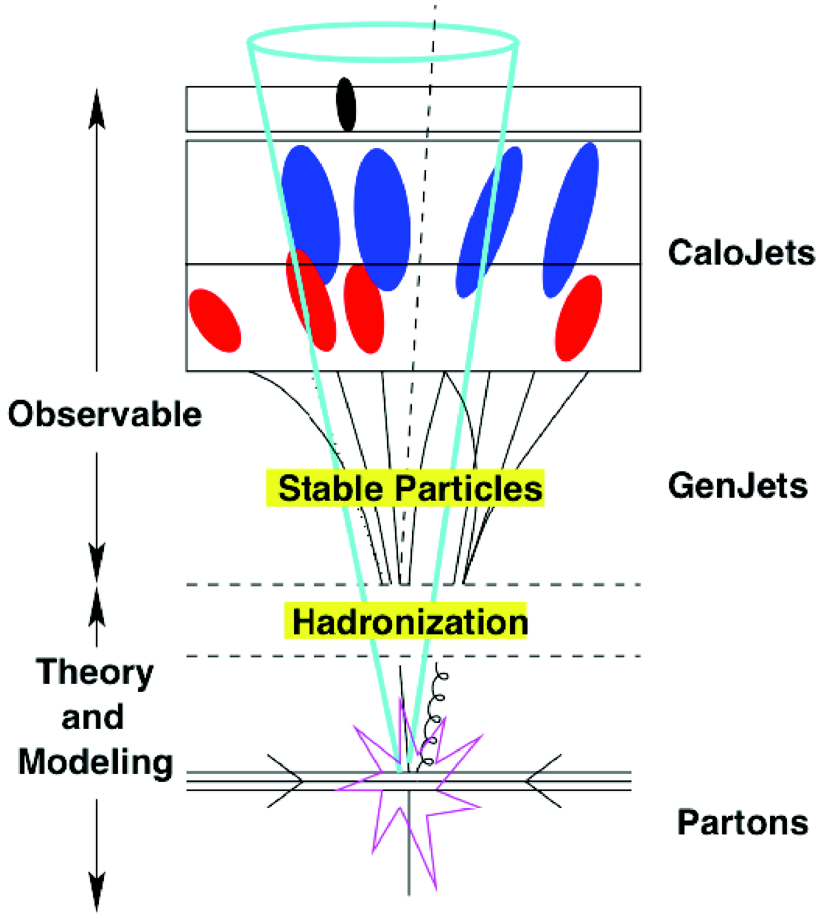


Jet energy scale

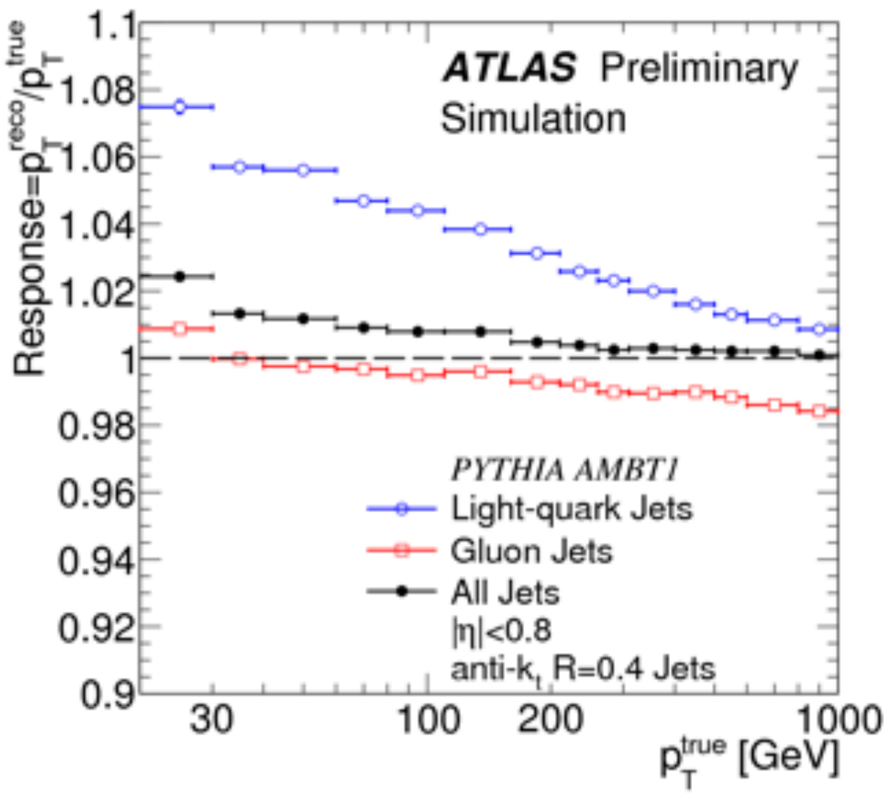


- Jets = showers pf highly collimated stable hadrons
  - from partons (q, g) after fragmentation and hadronization



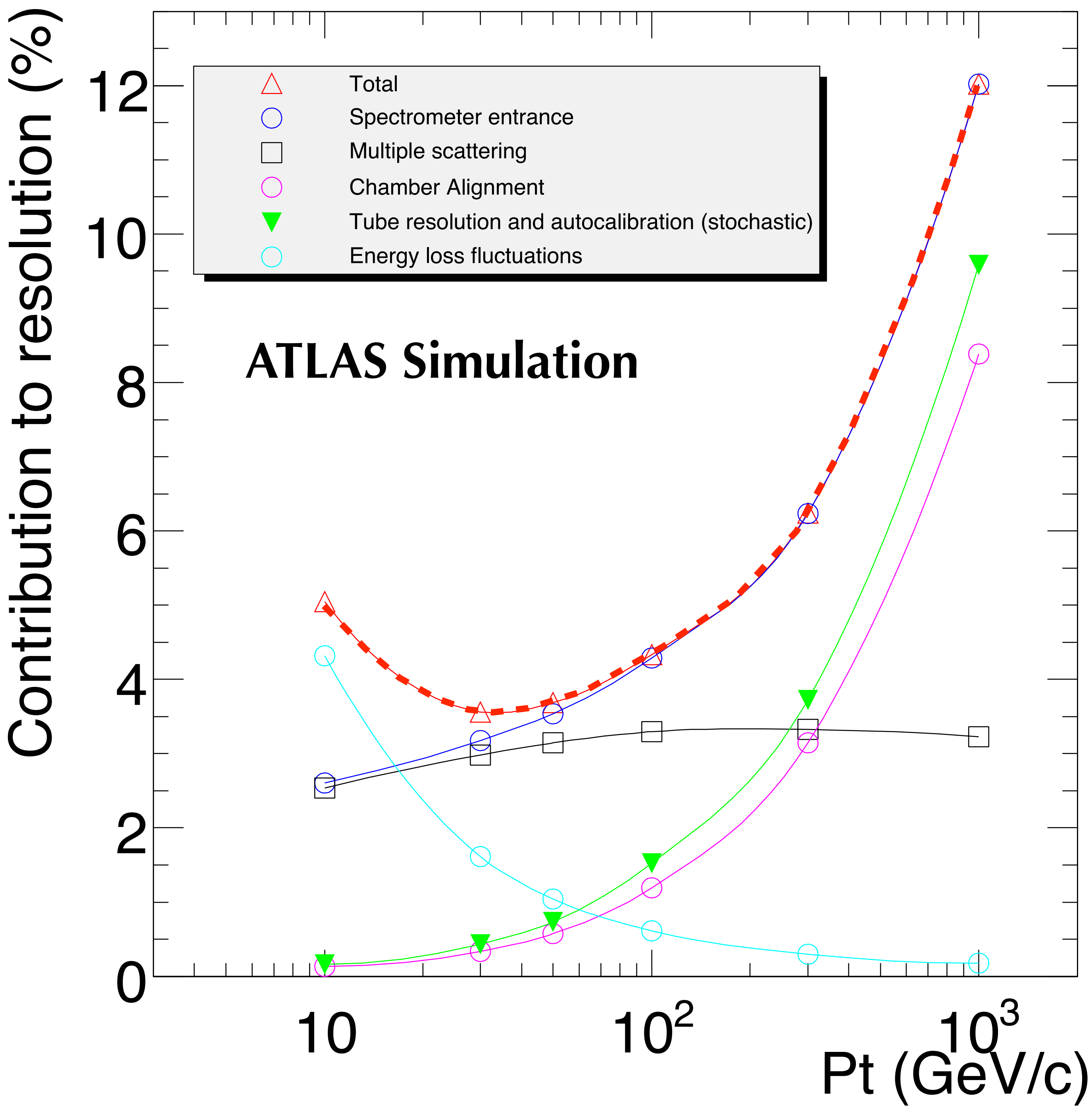


- Measurement of energy deposition in calorimeters ➡ energy of primary parton
  - underlying event contribution
  - response varying with flavours

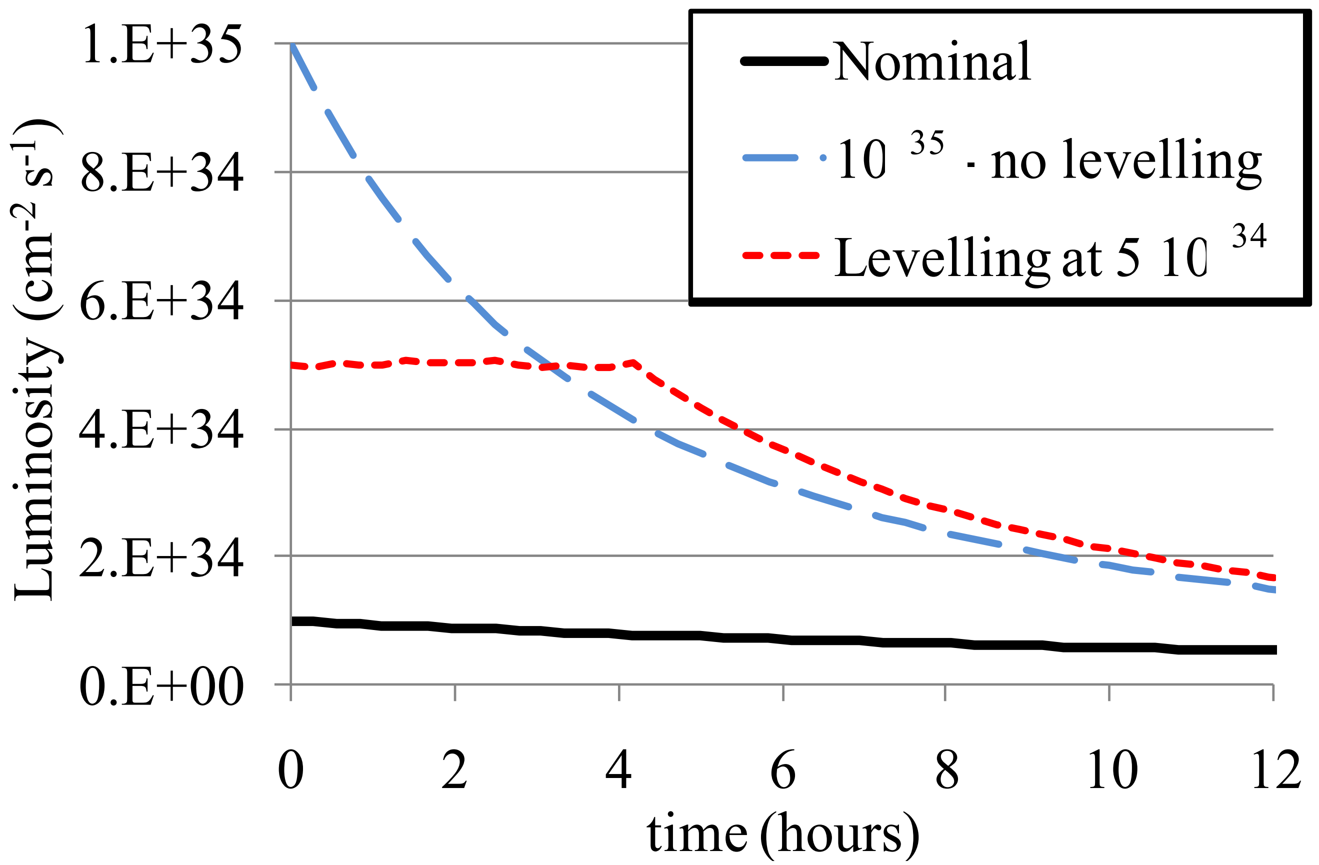


Muon Spectrometer: momentum resolution

- Contributions to the momentum resolution for muons reconstructed in the Muon Spectrometer as a function of transverse momentum
- The alignment curve is for an uncertainty of 30 μm in the chamber positions

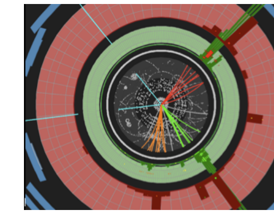


HL-LHC: luminosity levelling

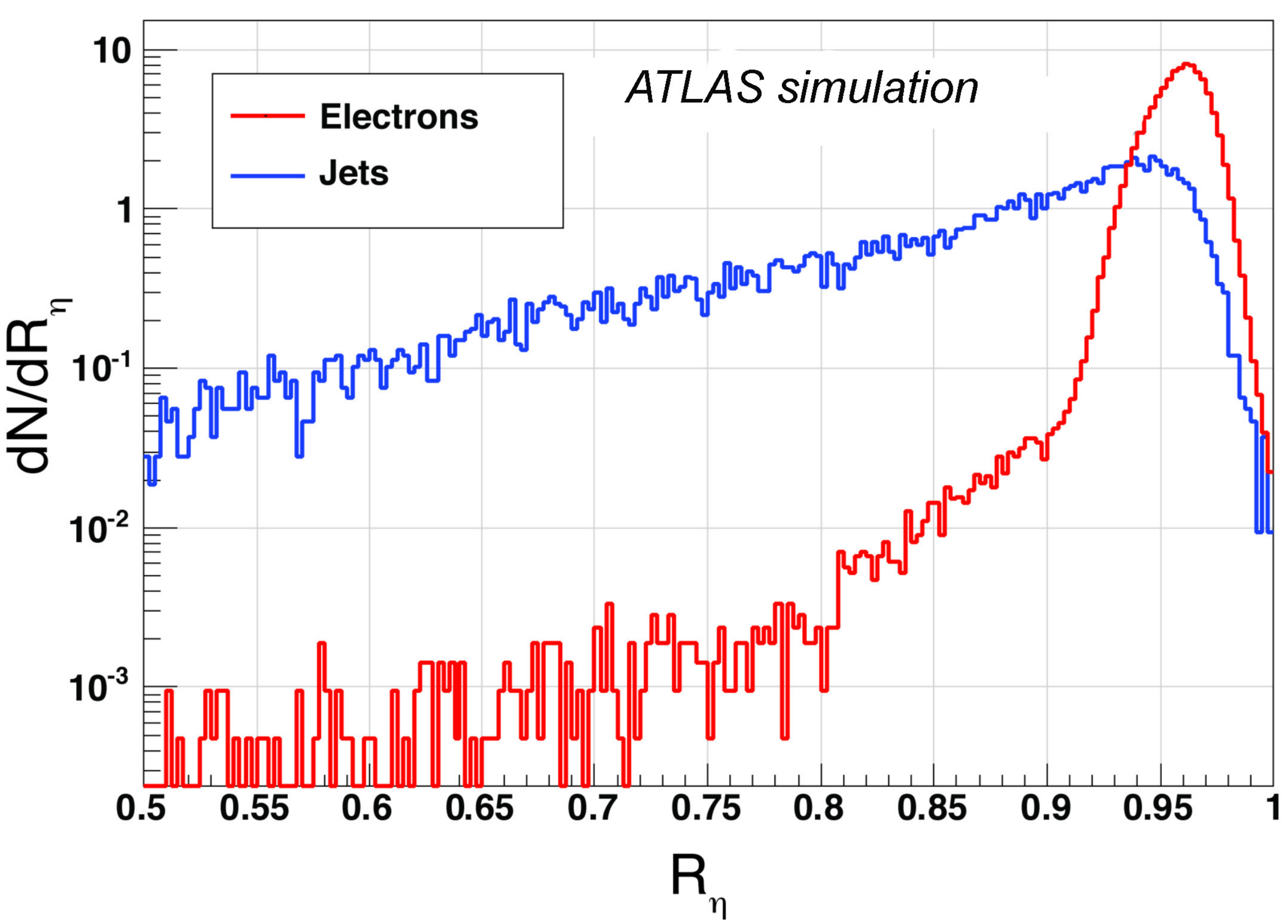


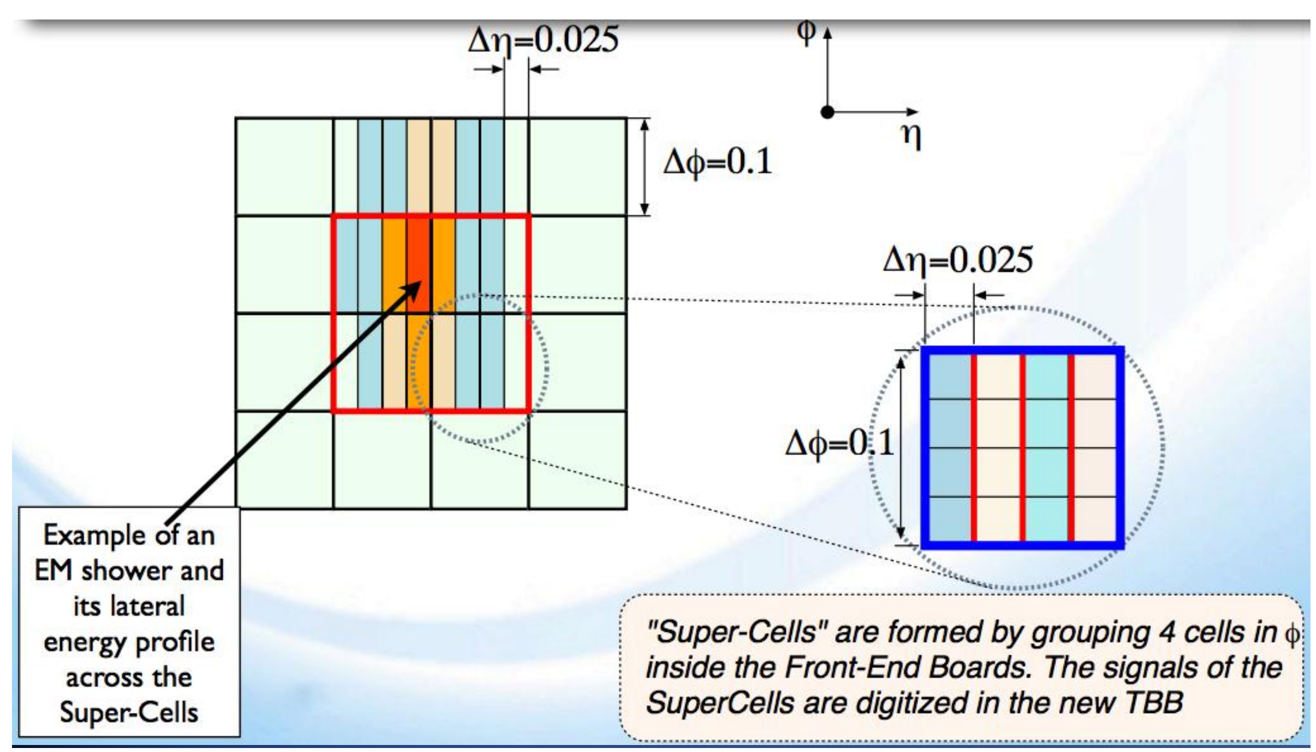
- ~3000 fb^{-1} total IL / 10-12 years ➡ ~250-300 fb^{-1} / year ➡ **~1 fb^{-1} / fill**
- Luminosity decay in storage rings dominated by parasitic effects
  - lifetime recovered with operational experience
  - HL-LHC: unavoidable luminosity decay due to proton burning in the luminous collisions
- **Luminosity levelling**
  - optimize data taking and minimize the required "over-design" of detectors and machine comp.
  - sustained 5×10^{34} $cm^{-2}s^{-1}$ while leveling for 3-5 hours + decay of few hours

Phase-1 upgrade: calorimeters

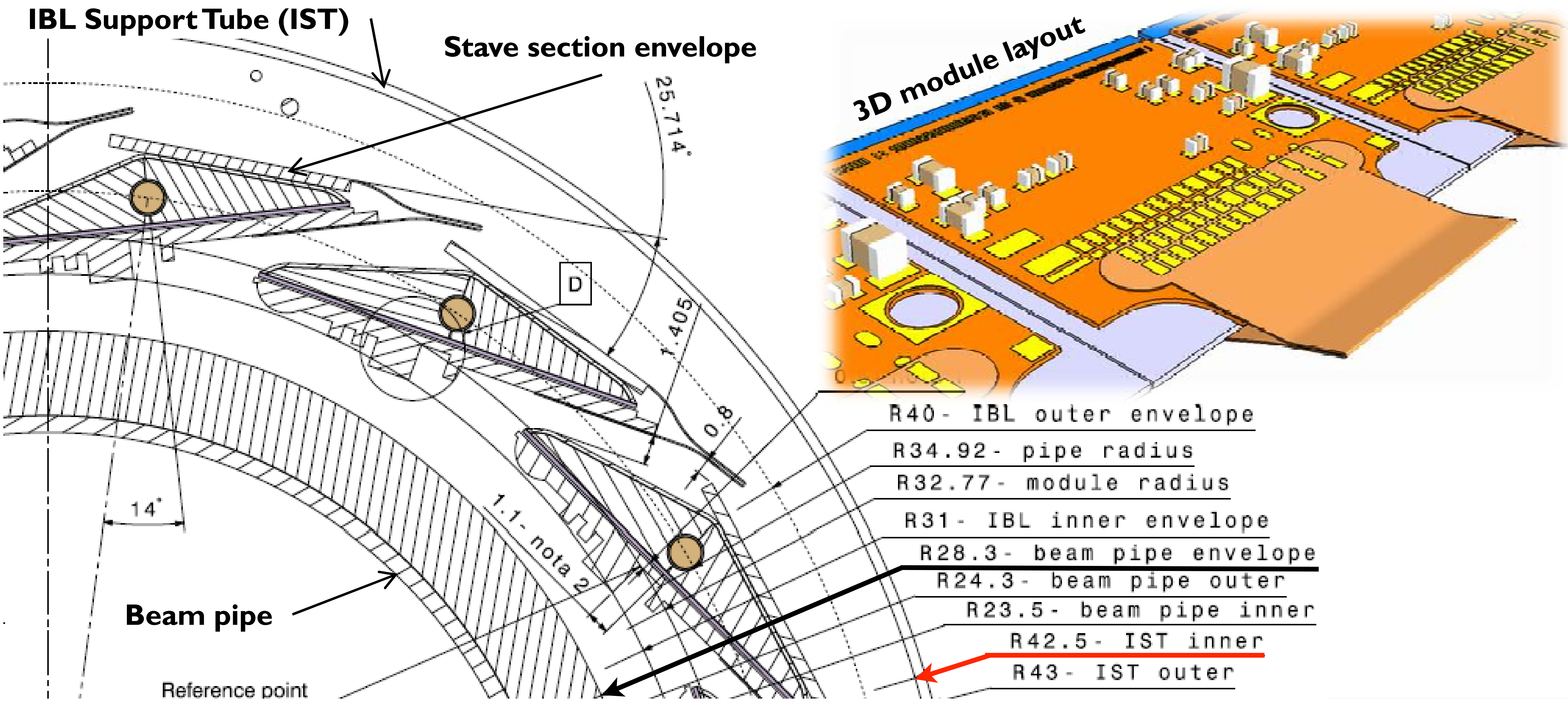


- Goal: preserve un-prescaled LVL1 thresholds fir single electron triggers at p_T~25 GeV for LHC operation beyond the nominal design
  - Phase-1 and HL-LHC (Phase-2)
- Plan to use in the LVL1 trigger all the detector granularity present in LAr
  - new shower shape variables: ratio of energy (2nd layer) in clusters of two-sizes
  - develop new front-end digital chain
    - super-cells with higher granularity are formed in the FE shaper sum ASIC and individually digitized

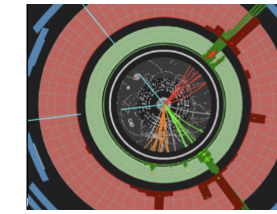




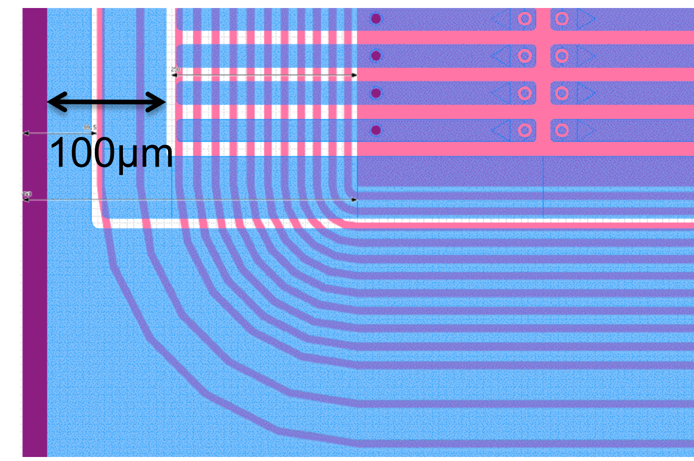
IBL clearances

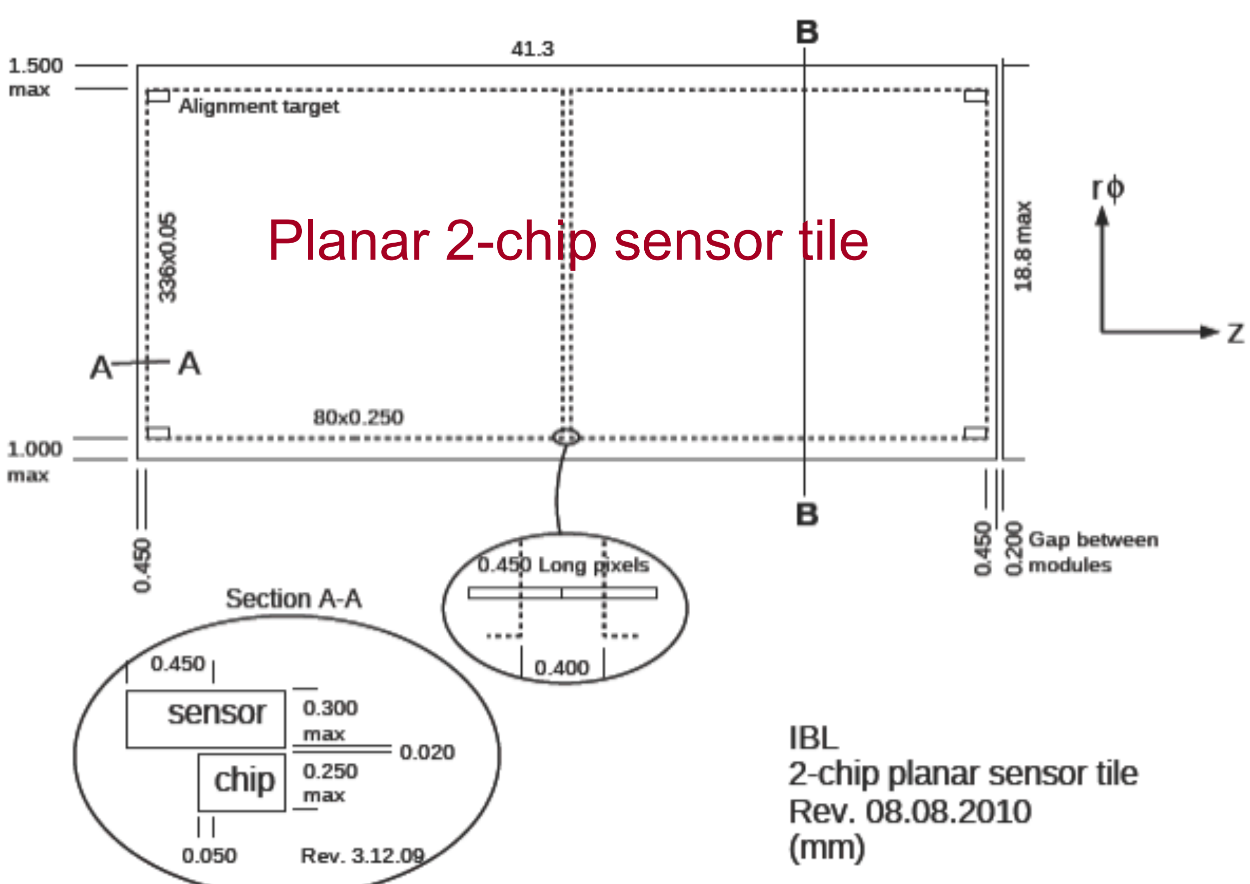


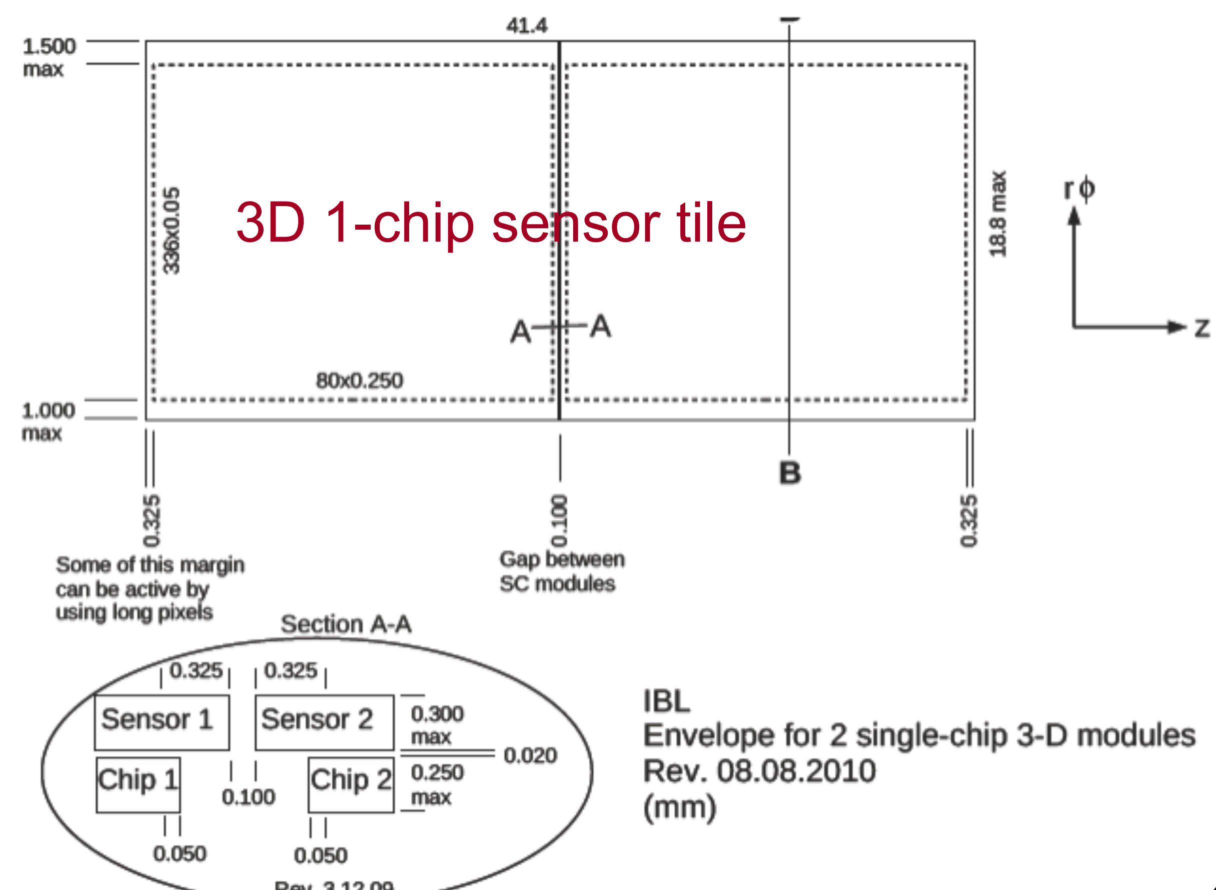
The IBL modules



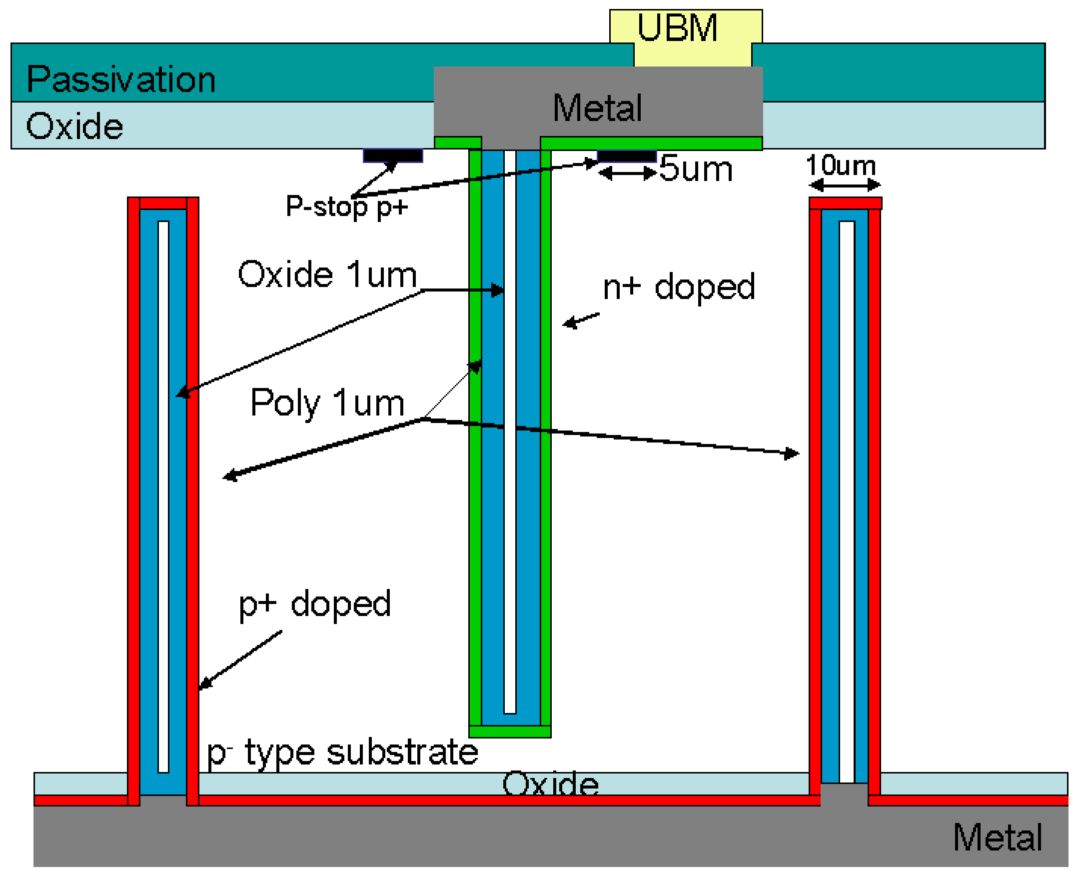
- New readout chip: FE-I4
- Single or double chip module
- Sensor technology independent
  - planar ➡ double-chip module
  - 3D ➡ single chip module
  - diamond

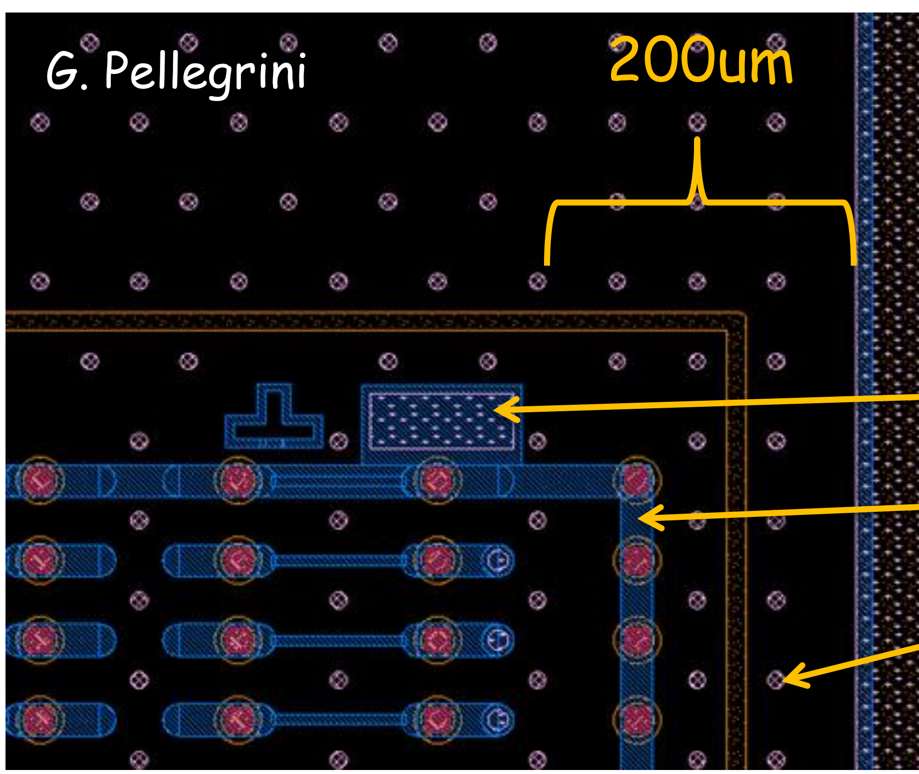






IBL pixel 3D-sensors





CNM 3D IBL sensors:

- 210um columns
- 3D Guard ring + fences (200um)
- Evaluate sensor quality on GR

Probe pad for quality assurance

3D Guard ring

p+ implant (fences)

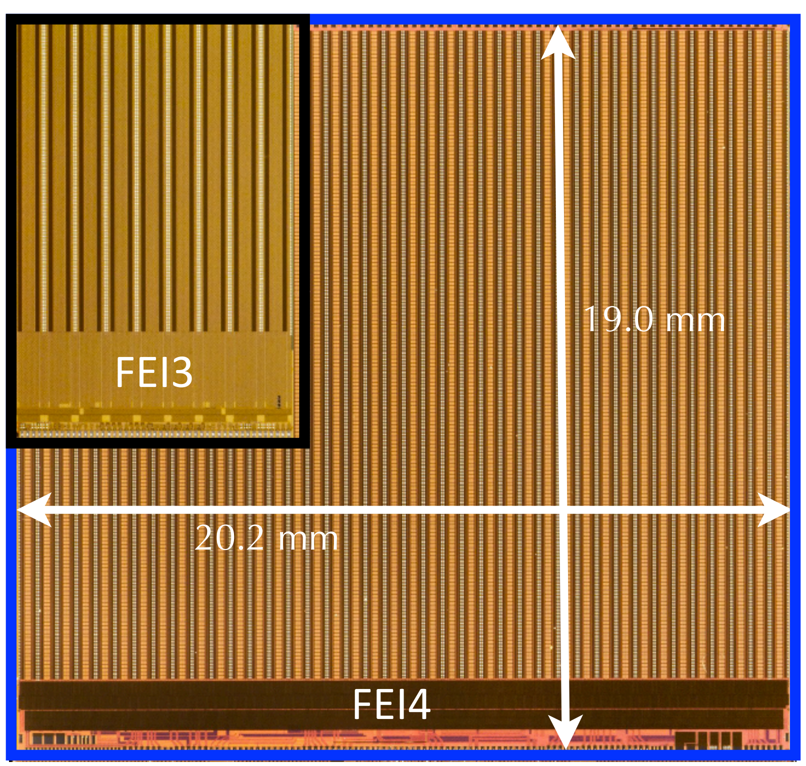
8

S. Grinstein (IFAE) - HSTD 2011

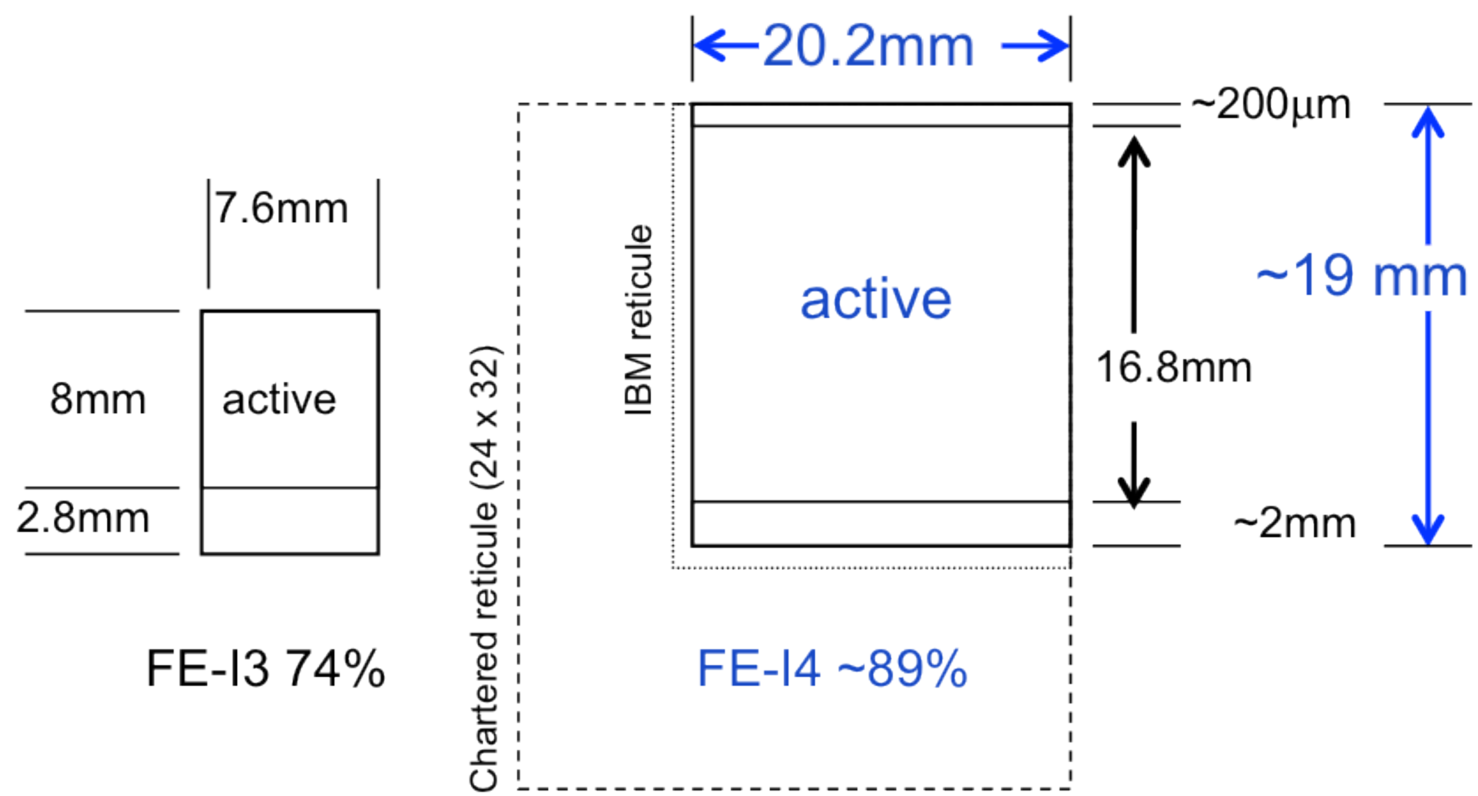
FE-I4

- New readout chip for IBL and outer layers of future upgraded Pixel detector
- Smaller pixel size (50x250 μm^2) and higher rate capabilities (160 MB/s)
- Improved cost effectiveness
  - large chip (20x19 mm^2) with large active area (90%)
- Low power
- Increased radiation tolerance (130 nm)

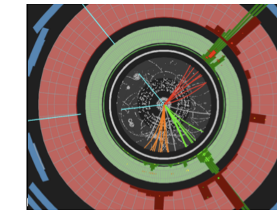
FE-I3: chip used in current Pixel modules



FE-I4: chip used in IBL Pixel modules



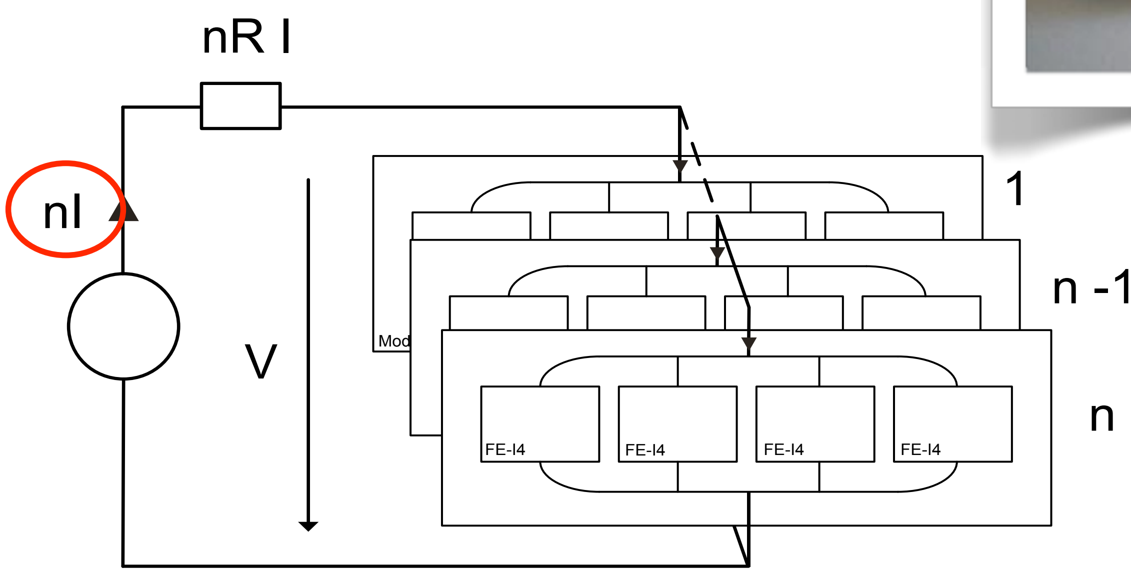
Powering options



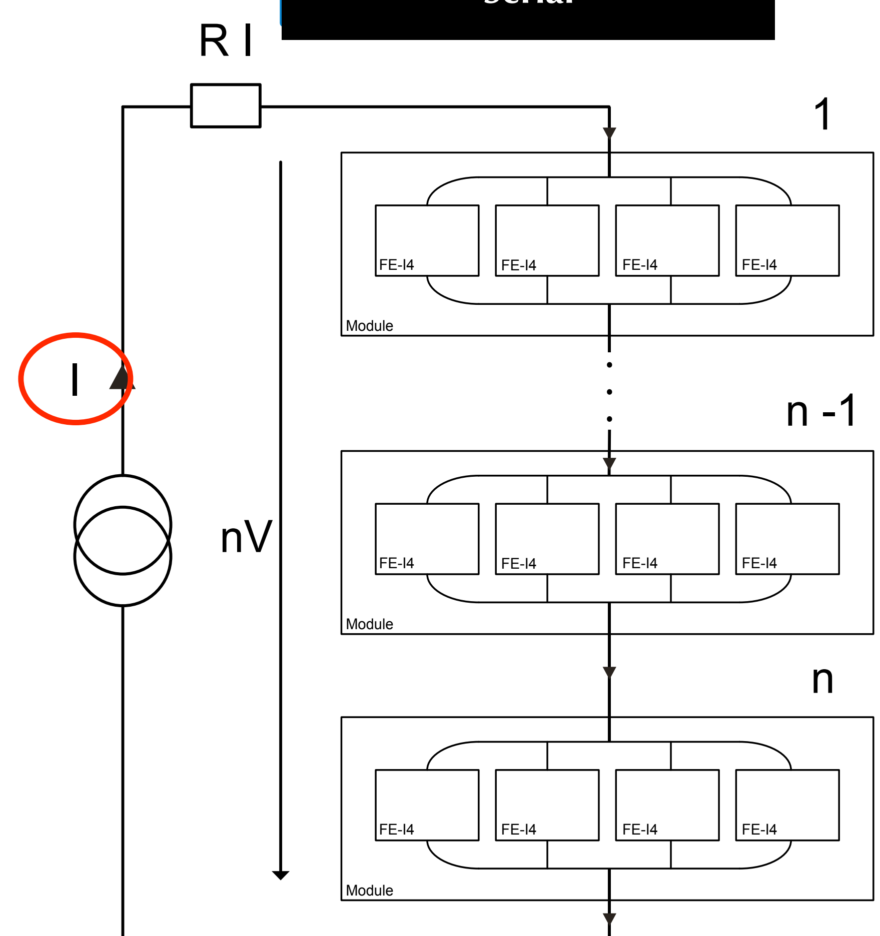
- Current LHC trackers: direct powering
  - high power losses in the cables + significant contribution to material budget

- At the SLHC, assuming 130 nm CMOS ASICS instead of 250 nm
  - almost same total FE power (~ 40-60 kW)…
  - … but 2-4 times higher total current (30-50 kA) with fixed cable cross-section
  - Need to transmit power at lower current
  - Solutions:
    - Serial powering
    - DC-DC conversion

Parallel

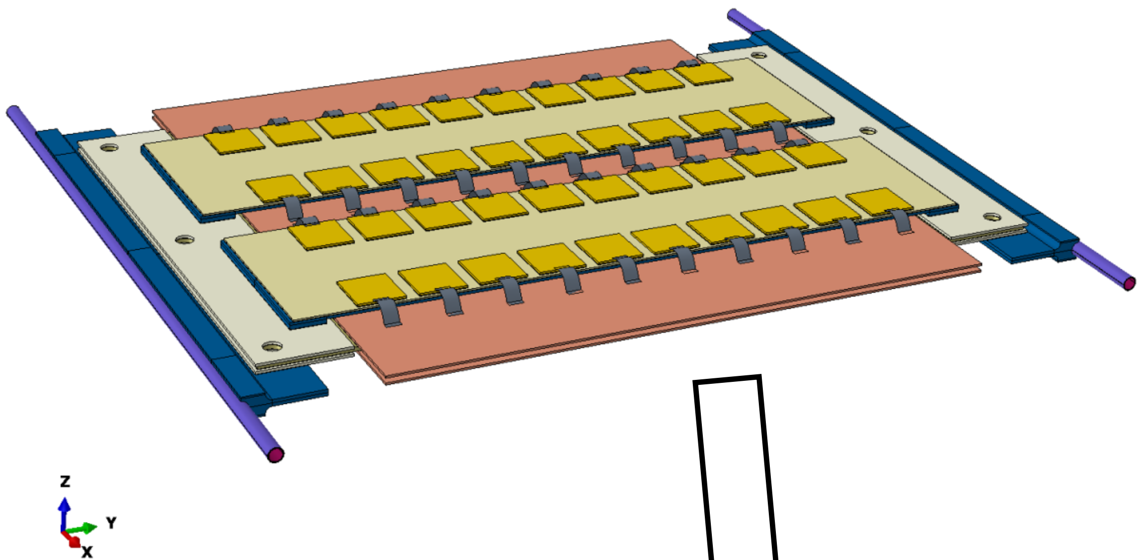


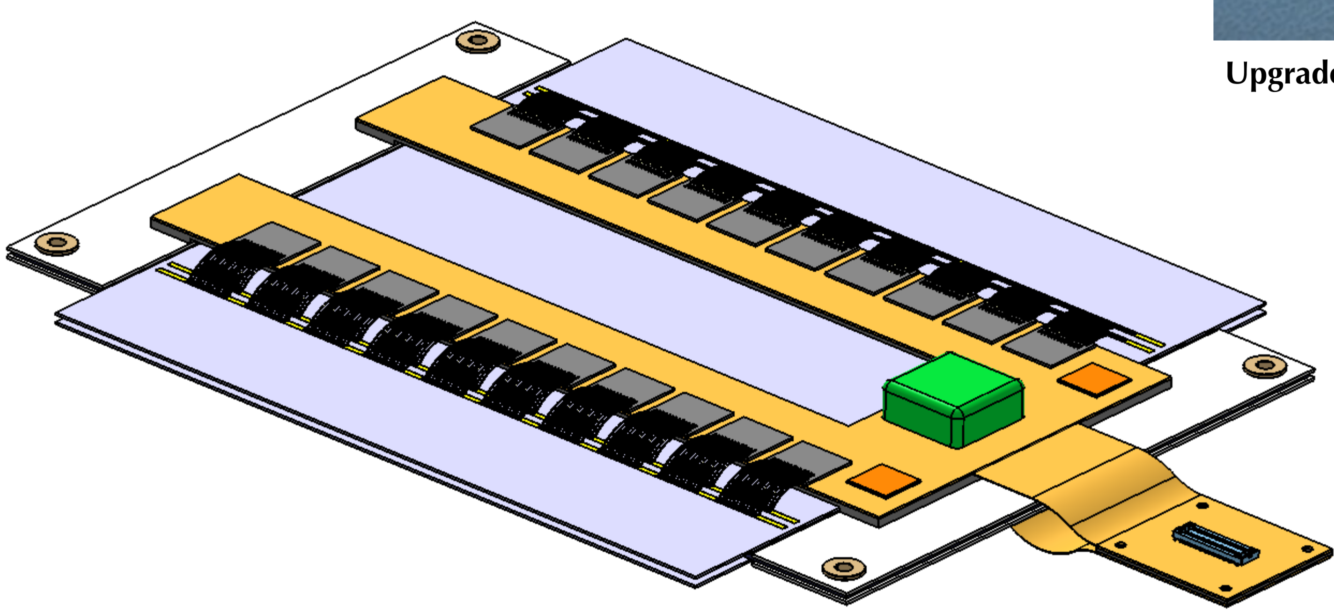
Serial



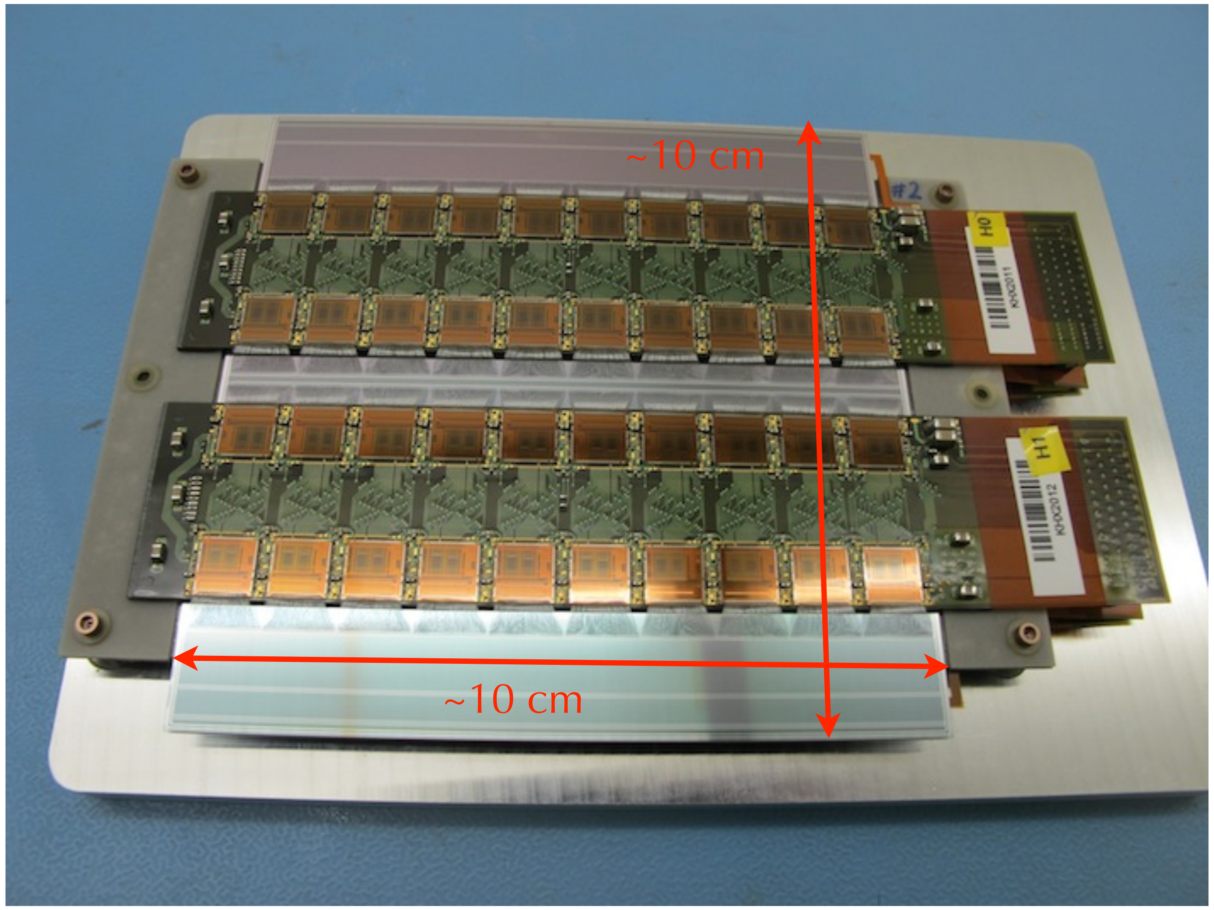
Future module design: ABCN-130

Double-sided module based on ABCN-250
- 80 chips, 128 channels / chip
- 1 DC-DC converter / hybrid





Double-sided module based on ABCN-130
- 40 chips, 256 channels / chip
- 1 DC-DC converter / 2-hybrids



Upgrade Strip double-sided barrel module