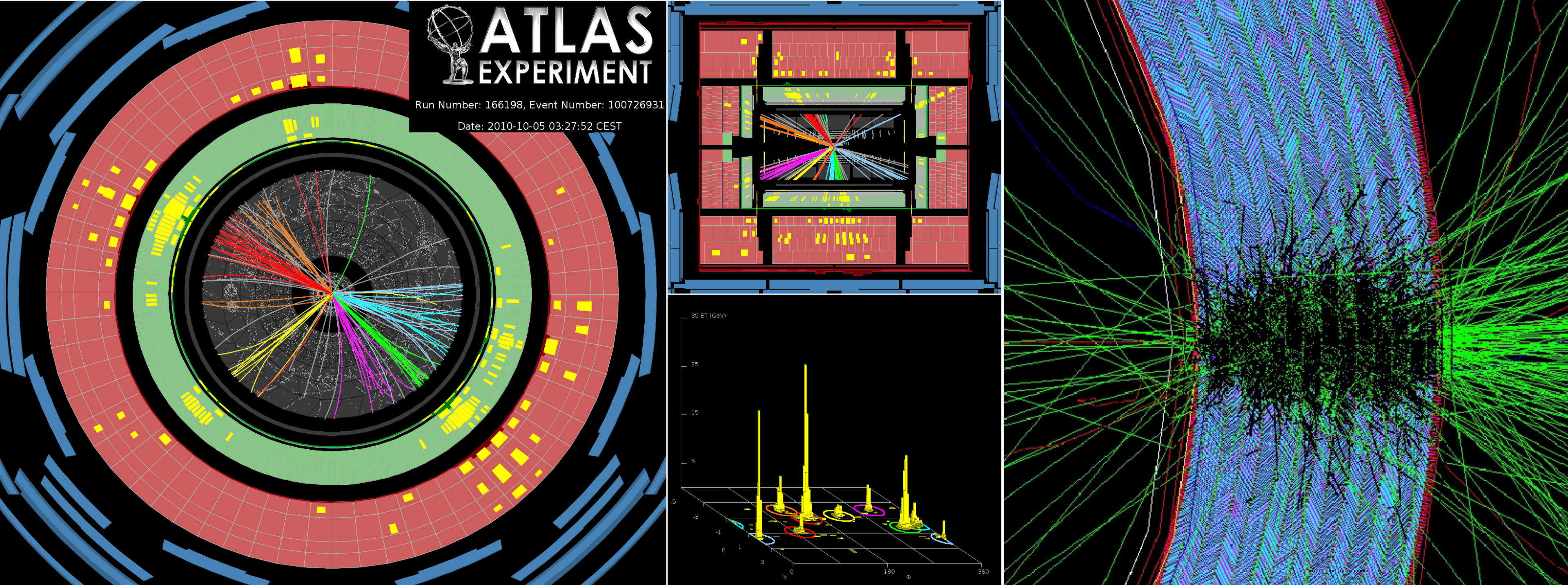
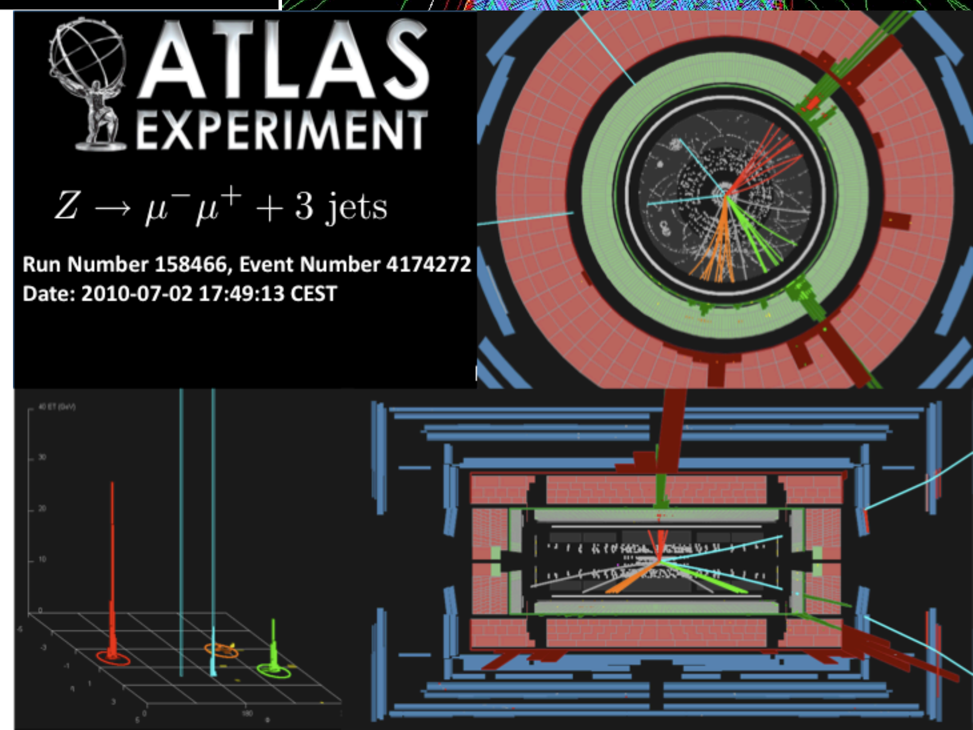


ATLAS Data/MC Comparisons in Hadronic Physics

Zach Marshall (LBL)
For the ATLAS Collaboration

Second LPCC Simulation Workshop
18 March 2014



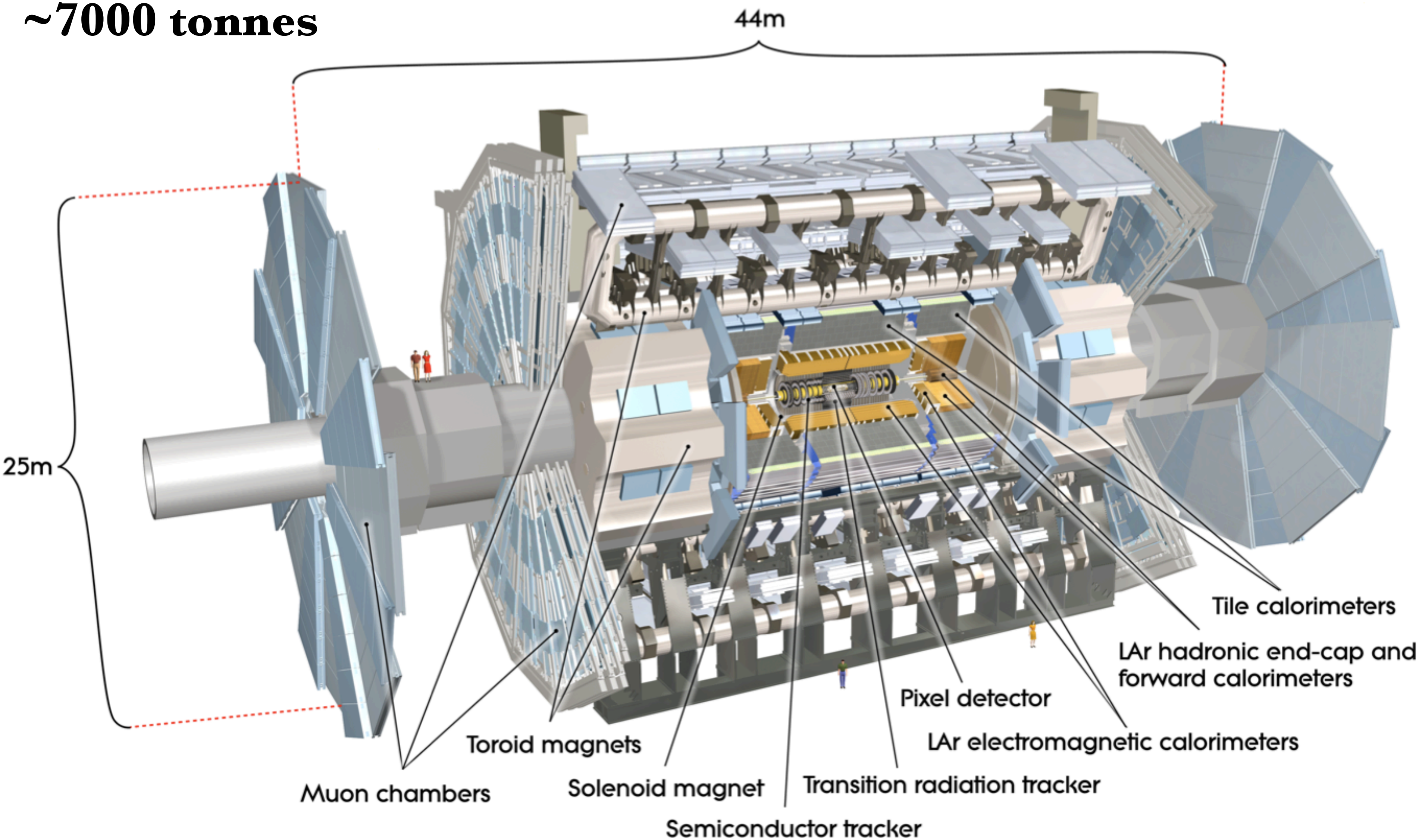
Overview

- Some reminders about the ATLAS calorimetry
- In situ single particle measurements
  - Inclusive isolated hadron response in situ
  - Identified isolated hadron response in situ
- More complex variables and topologies
  - Jet resolution
  - Missing energy
- Fast Simulation

- ATLAS MC simulation is described in this paper
- ATLAS generator tuning is described in this note
- Updating from last time

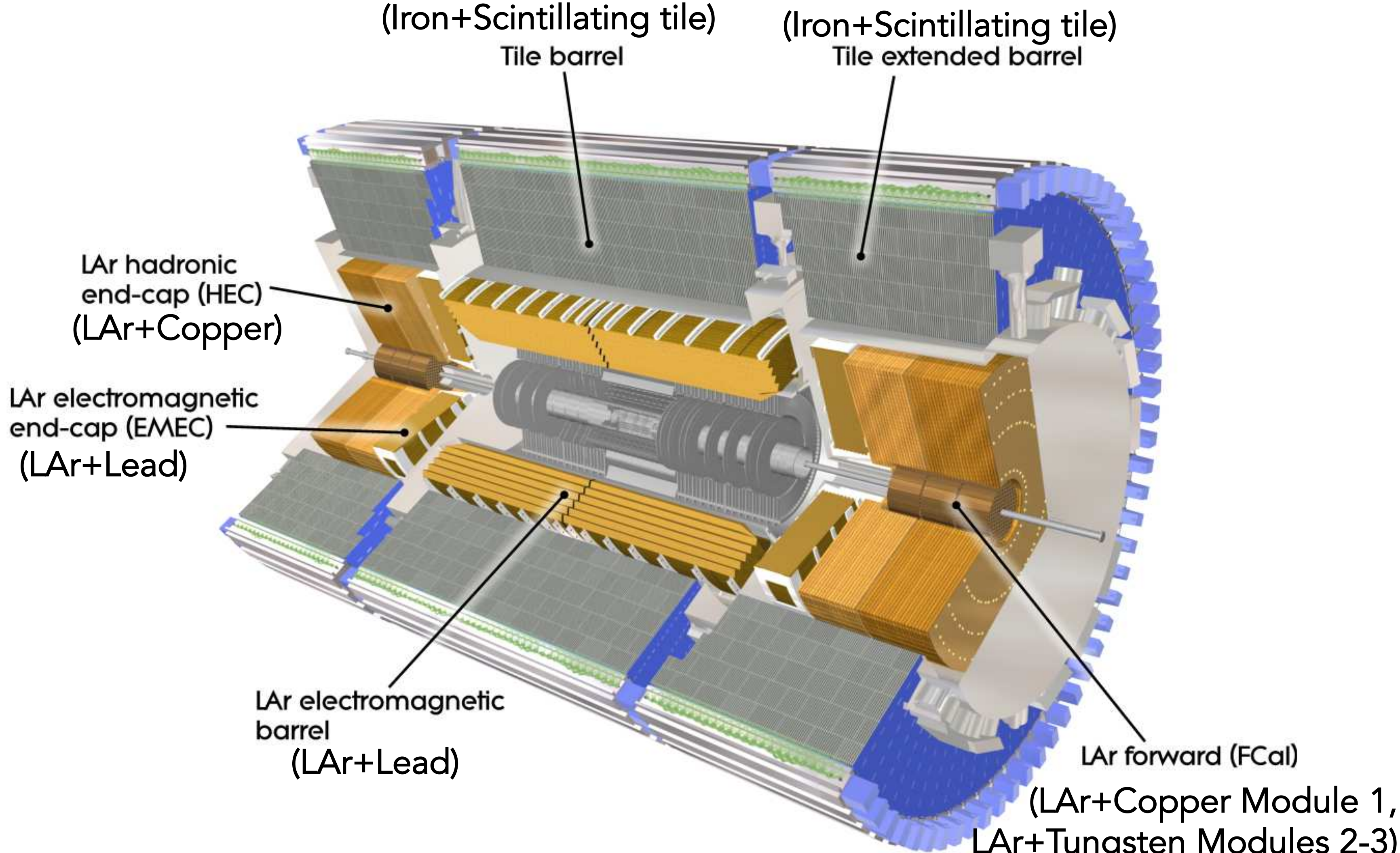
ATLAS

~7000 tonnes



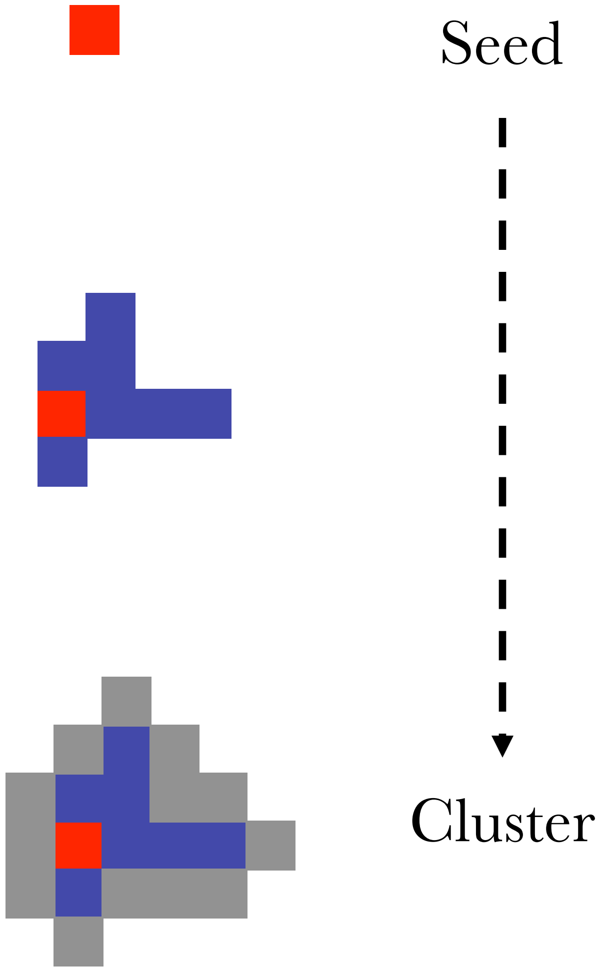
ATLAS Calorimetry

- Designed for hermeticity (to $|\eta|=4.9$), 1% jet energy scale uncertainty, $50\%/\sqrt{E} \oplus 3\%$ central jet resolution, and $50\% \times \sqrt{(\Sigma E_T)}$ MET resolution

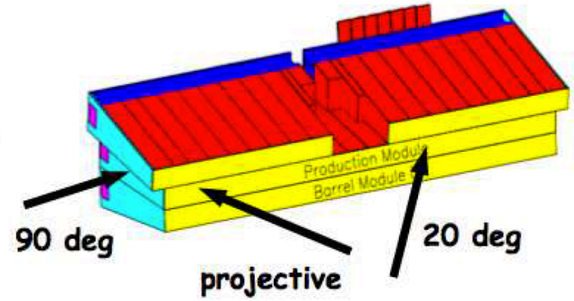


Calorimetry Reminders

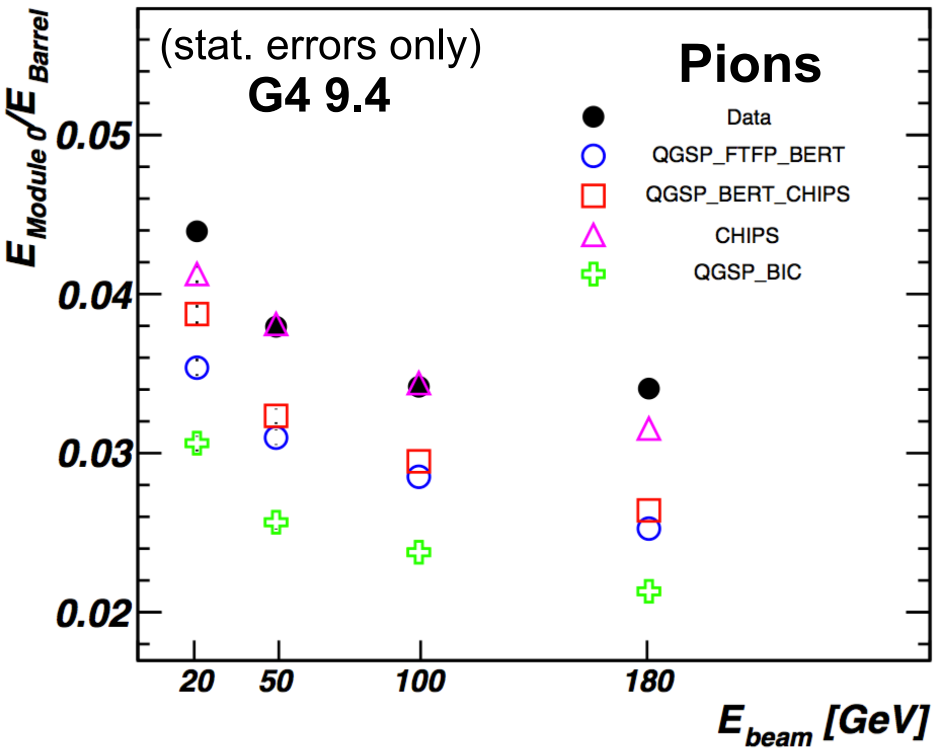
- ATLAS uses a three-step clustering algorithm
  - Our way to deal with noise
  - Seed with $|E_{cell}|>4\sigma$
  - Add cells with $|E_{cell}|>2\sigma$
  - Final layer to improve resolution
  - Rough claim: 1 cluster = 1 particle
    - Breaks down in some cases
    - Classify clusters as "EM" or "Hadronic" – more on this later
- We *almost never* measure the energy that G4 deposited
  - More or less because of noise, clustering effects, and backgrounds
  - Shower shapes are *cluster* shapes!
  - Must check test beam for this

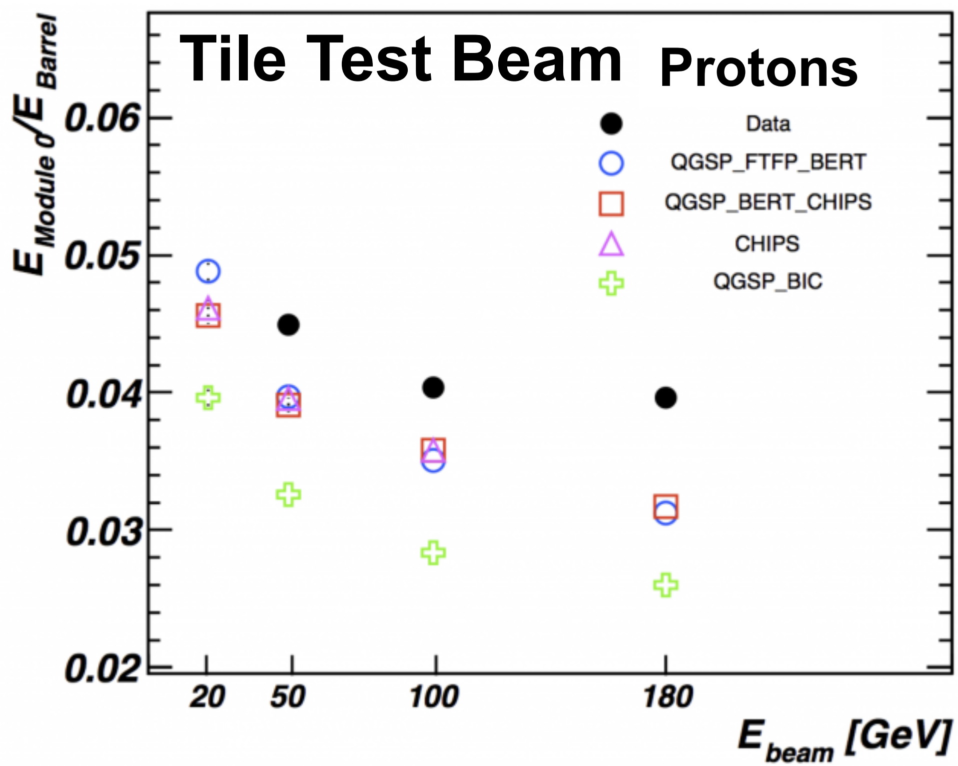


Test Beams



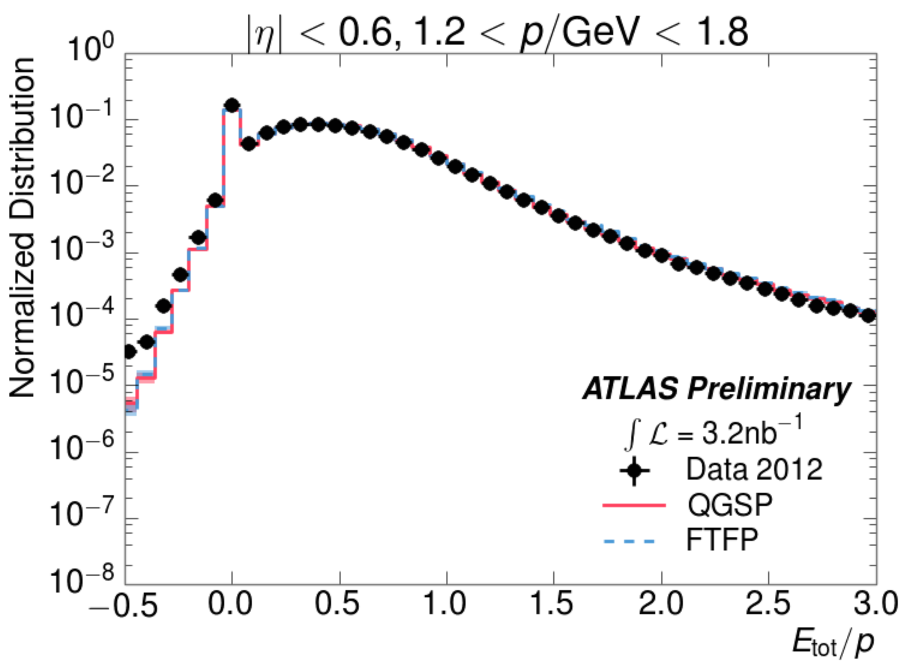
- We recognize the importance of our calorimeter test stands for validating G4 hadronic physics
- We are working to update the results with the test beams, but there is no new news today
- We will make an effort to test both G4 9.6 and G4 10.Y

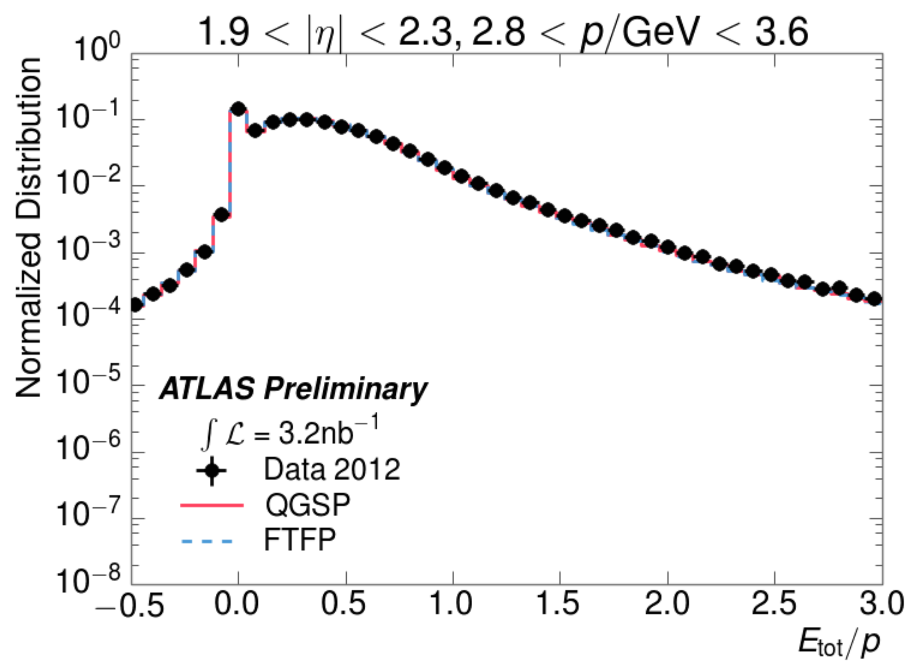




Calorimeter Response

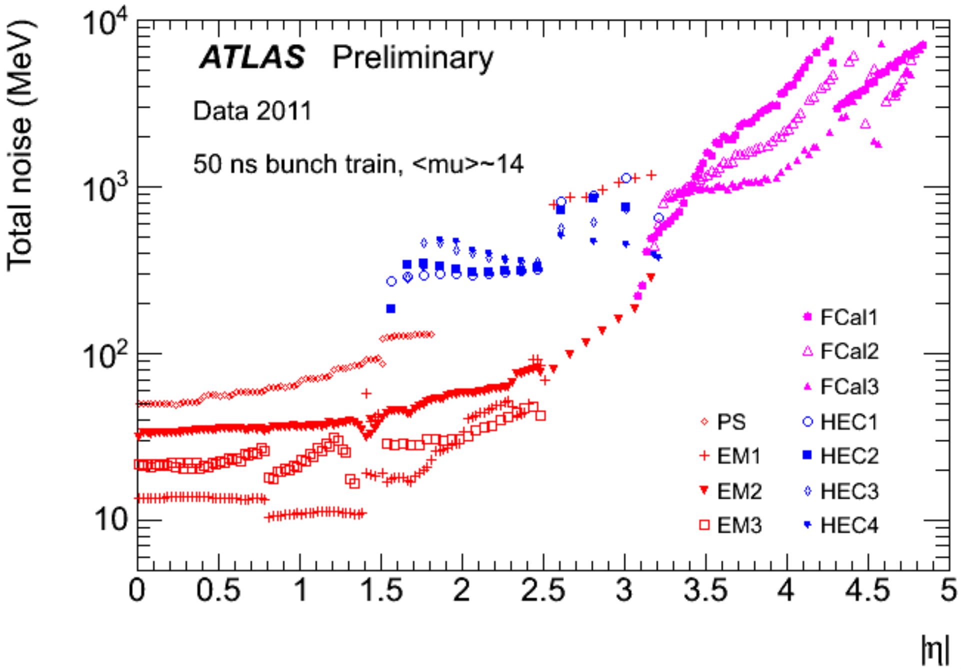
- We can look at *inclusive isolated tracks* to check calorimeter response
  - This is done in **2012 data** with very low pileup – new G4, new geometry, etc
- Raw distributions below with G4 9.4 (G4 9.6 results to be completed)
  - High tail due to neutral backgrounds
  - Low tail due to noise (and little or no energy deposit in the calorimeter)
- Some possible issues with our noise description visible on the left, but at a quite low level; generally this is very well described

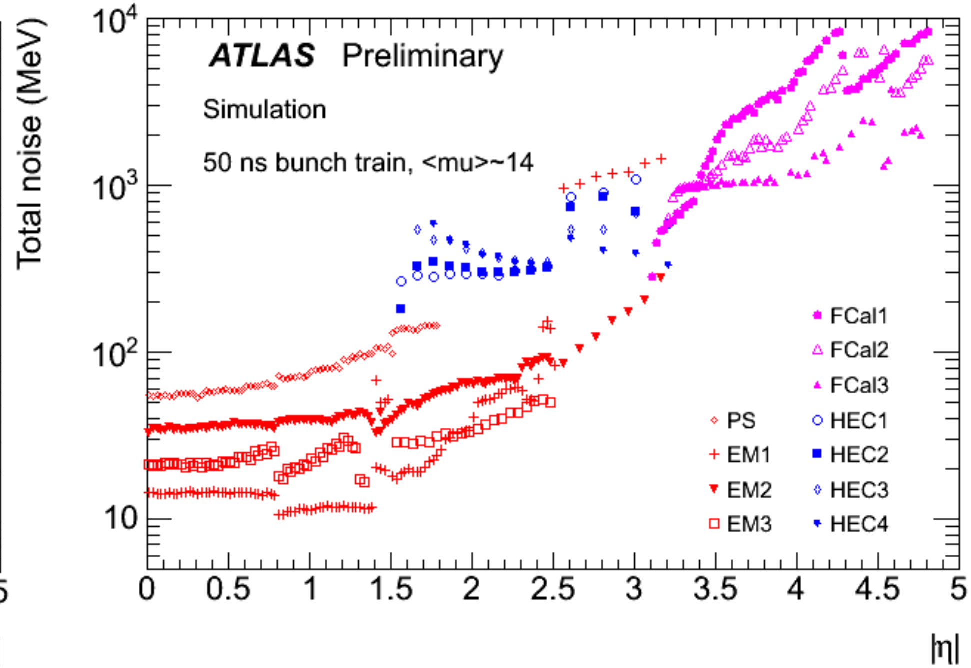




Calorimeter Noise

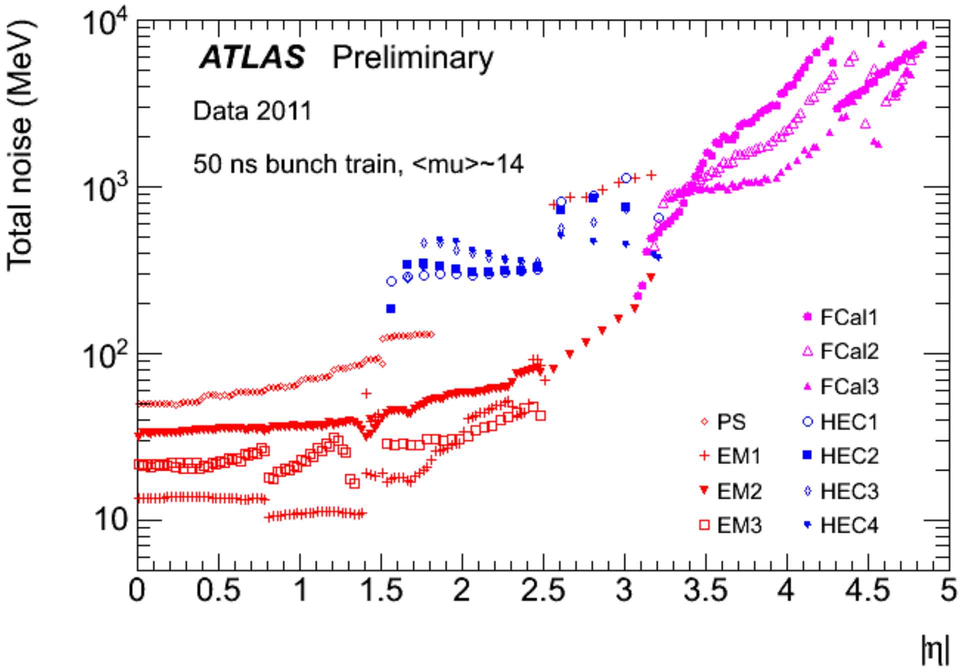
- The calorimeter noise description is quite good, even with moderate to high pile-up (below an average of 14 MB interactions per crossing)
  - The simulation follows the structure of the data quite well
- Some departure in the forward region, particularly deep in the FCAL
  - Origin of the difference is unclear – this could "just" be physics!
  - Considerable improvement in the description of the forward region in the last year, though the detector description may still be an area of some concern – no tracking here to provide constraints / help

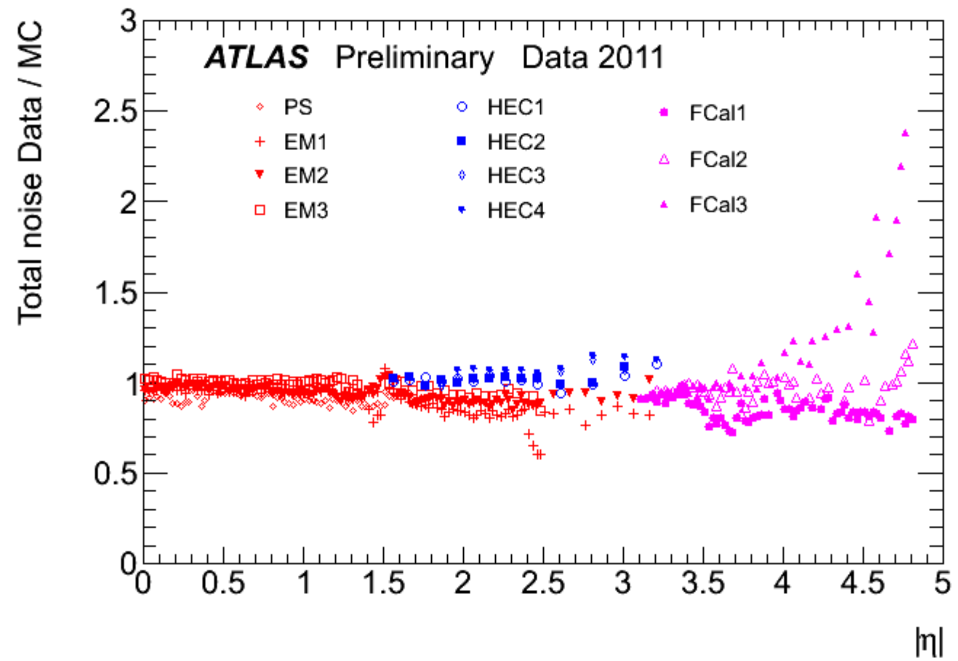




Calorimeter Noise

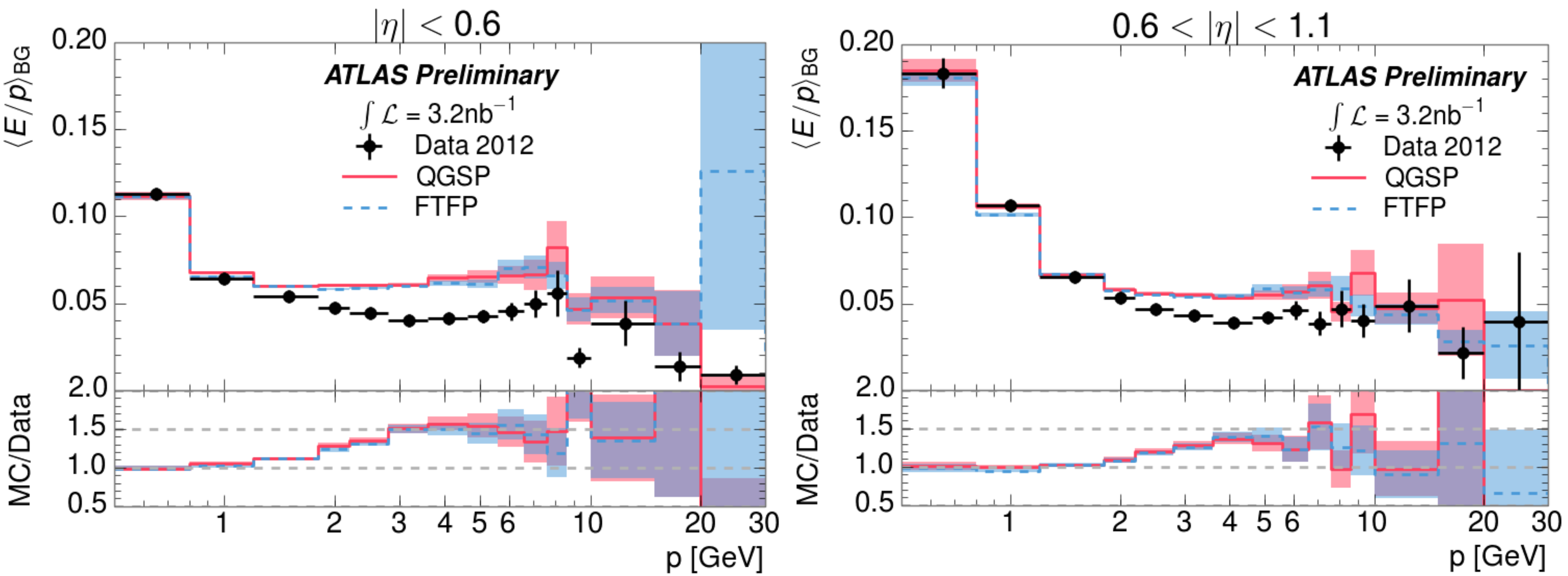
- The calorimeter noise (electronic and physics) description is good, even with moderate pile-up (below for 14 MB interactions per crossing)
  - The simulation follows the structure of the data quite well
- Some departure in the forward region, particularly deep in the FCAL
  - Origin of the difference is unclear – this could "just" be physics!
  - Considerable improvement in the description of the forward region in the last year, though the detector description may still be an area of some concern – no tracking here to provide constraints / help





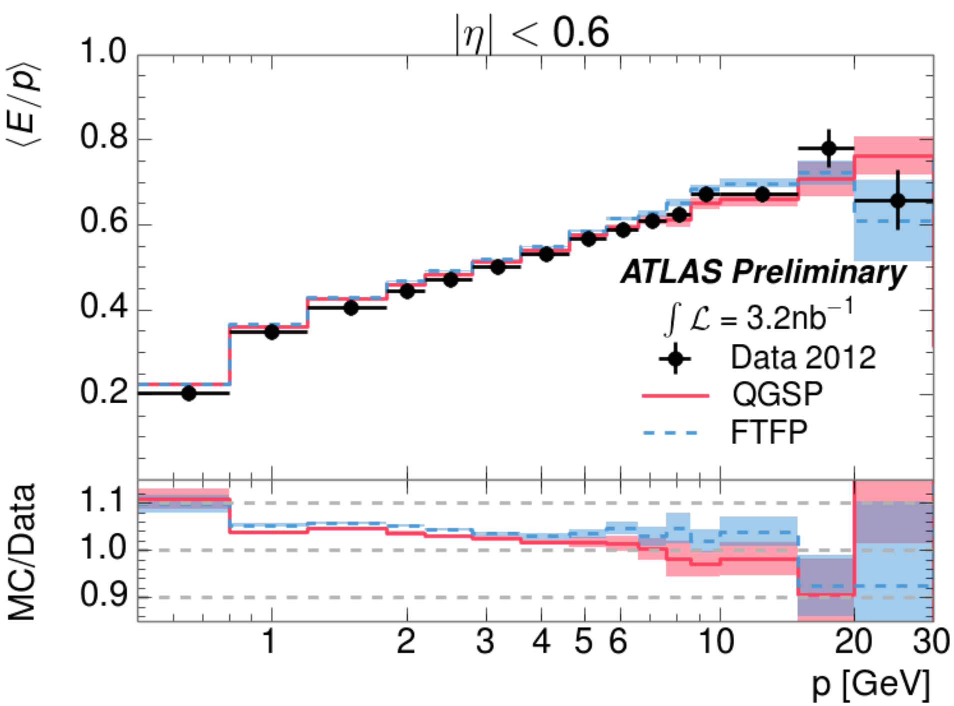
Background Subtraction

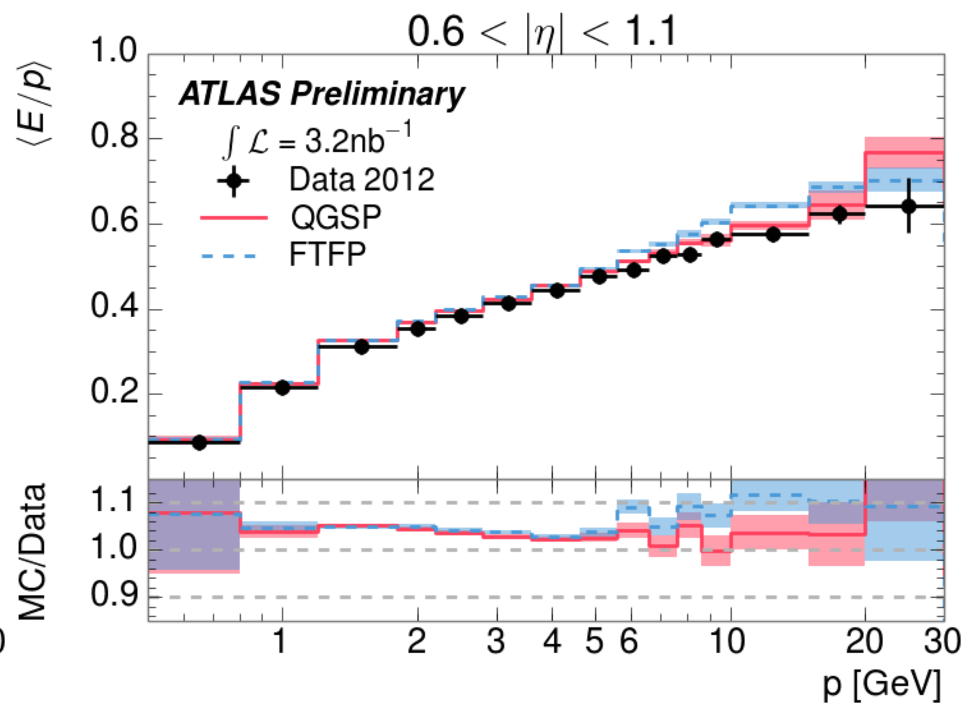
- We can measure and subtract the neutral background (background E, “signal” track p) by finding particles that do not shower in the EM calorimeter and only shower in the hadronic calorimeter
  - Random cone estimation here would miss coherence, which is important
  - This still has issues with threshold effects, which could be important
- Background is not well modeled by the MC, but this is Pythia’s “fault”
  - We can still subtract it and try to get at what G4 is doing



Corrected Response

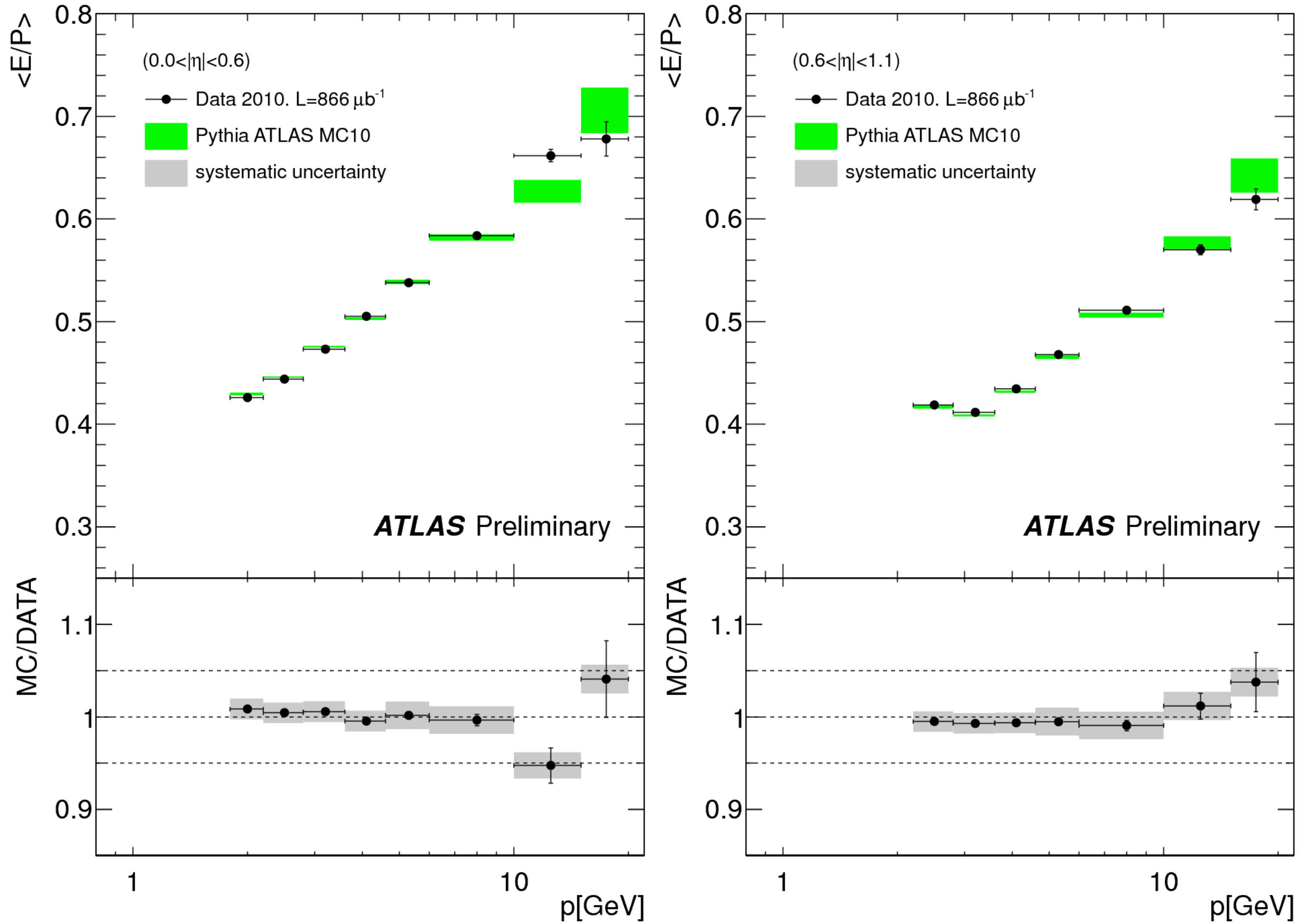
- New this time through: the inclusive response does not agree so well
- Some significant over-estimation at low momenta for inclusive tracks
- High-momenta tracks suffer from low statistics (note low lumi), but the data and MC are roughly consistent
- Low-momenta tracks dominate jets, and show some unfortunate disagreement! We will come back to this in a few slides, of course.





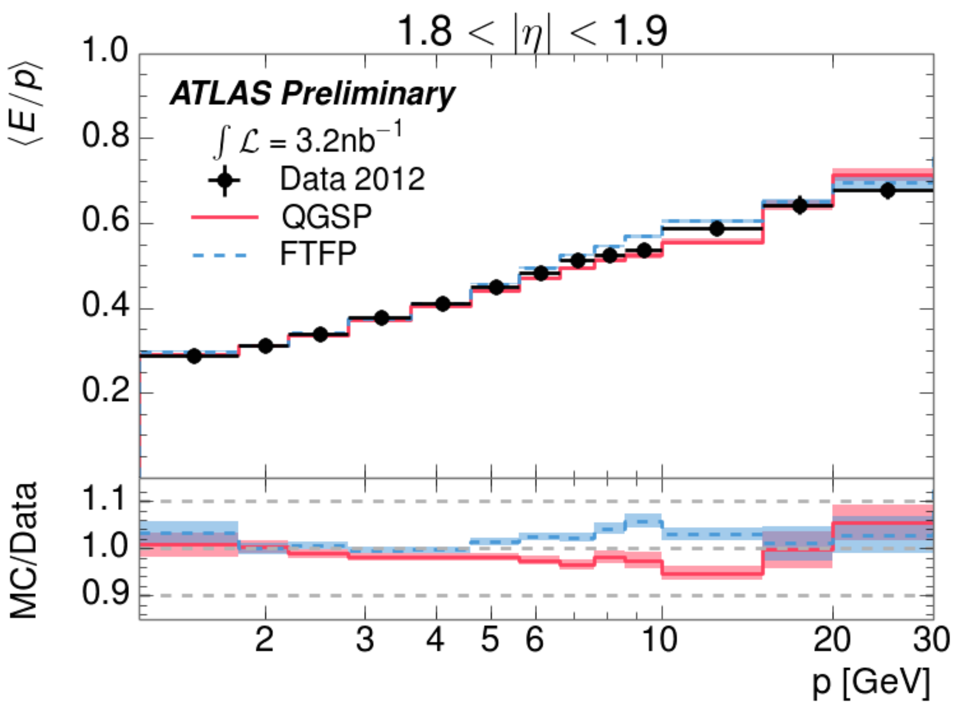
Reminder

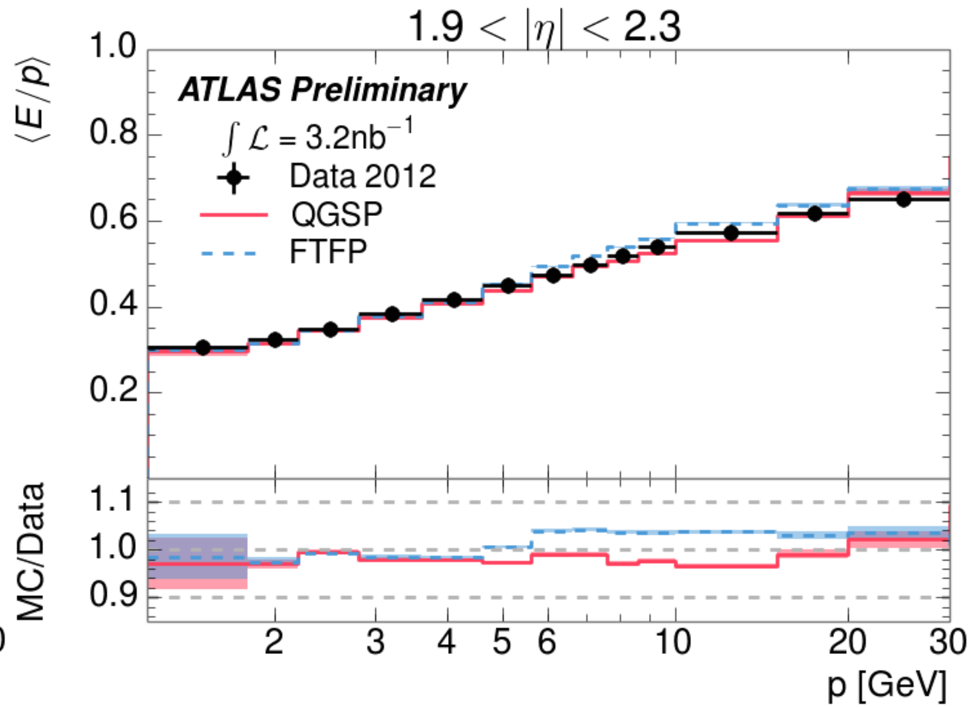
- This was our result for 2010 – extraordinarily good agreement!



Different Regions

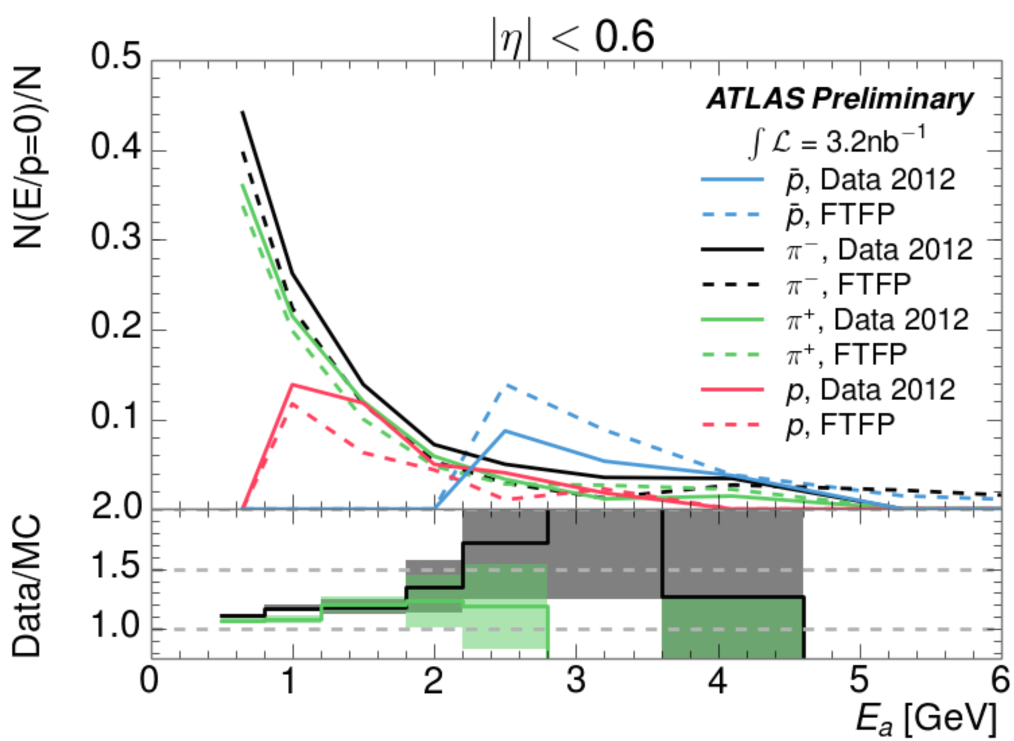
- In more forward regions we see much better agreement between the data and the MC
  - Without access to the lowest momenta bins, since this is more forward
  - Perhaps a geometry issue? But that seems crazy! Background residual?
- Note the appearance of the famous QGSP_BERT dip on these two plots – looks like the data actually prefer something in between QGSP_BERT and FTFP_BERT





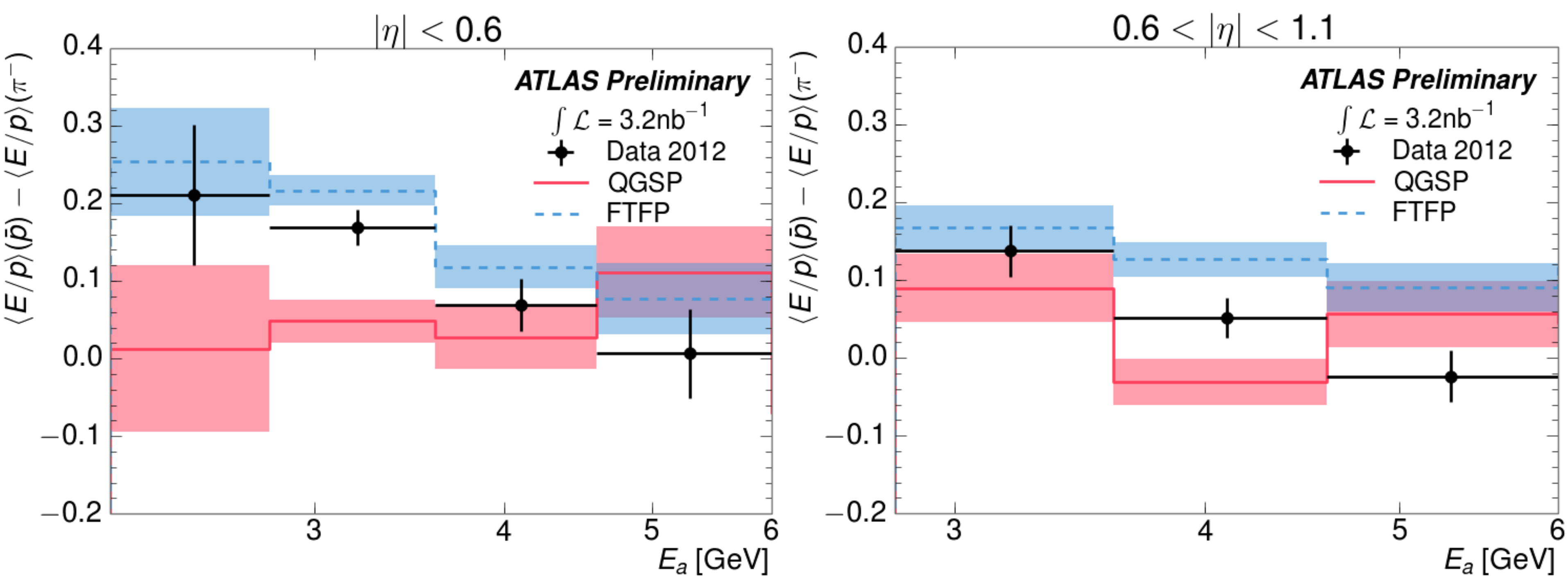
Identified Particles

- Now use well known particle decays for response
  - K_S to get pions, Λ to get protons and anti-protons
  - Protons look like pions, but anti-protons look *very* different
  - Binning in E_a, "Available Energy": KE (ps), KE+m (πs), or KE+2m (anti-ps)
- Now we can look at the fraction of particles *by species* that have E=0 in the calorimeter and see how data and MC compare
- Under-estimation in MC
- Most clear at low p (better stats)
- Points to a geometry problem
- One major source of data/MC discrepancy
- Note that this hits "signal" and "background" differently, so could also be partially responsible for the background disagreement shown earlier
- Version with newest Geant4 release (9.6) still to come



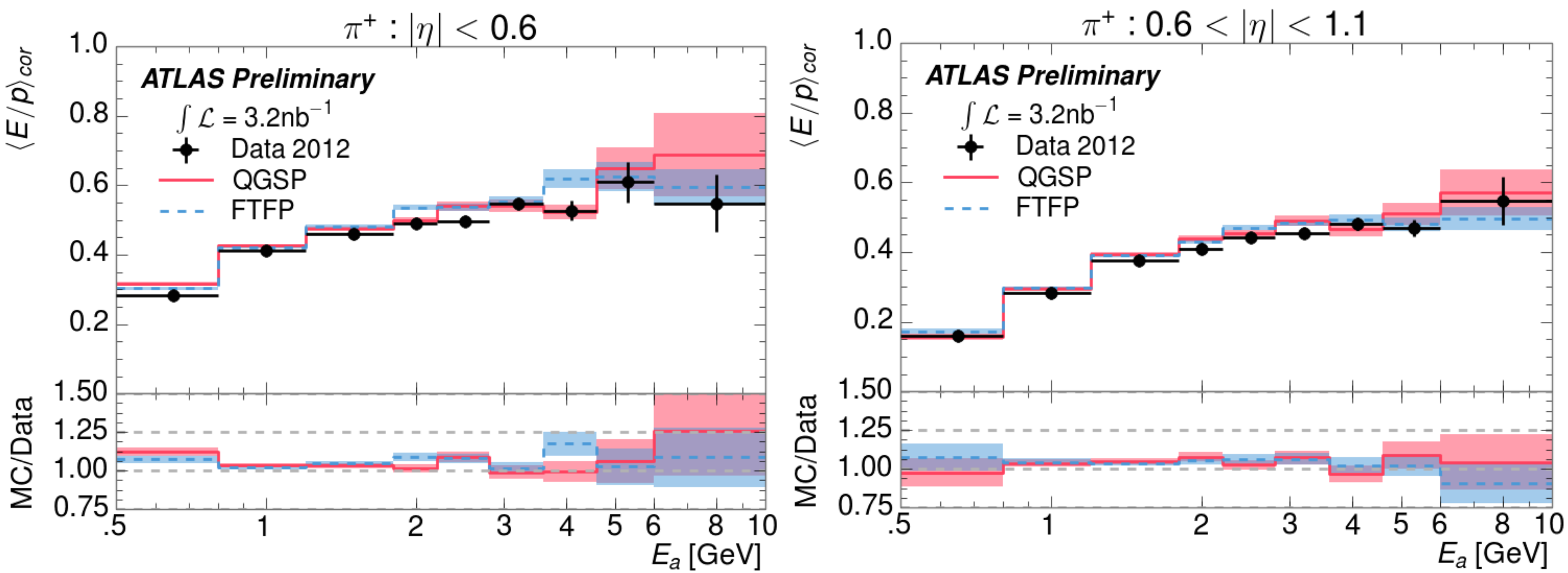
Response Differences

- Old story of anti-proton miss-modeling appears to be improved with FTFP_BERT in G4 9.4
  - Admittedly we need higher stats to say with certainty!
- The disagreement between QGSP_BERT and data on the bottom left was what we lived with a couple of years ago
- Still, this is encouraging



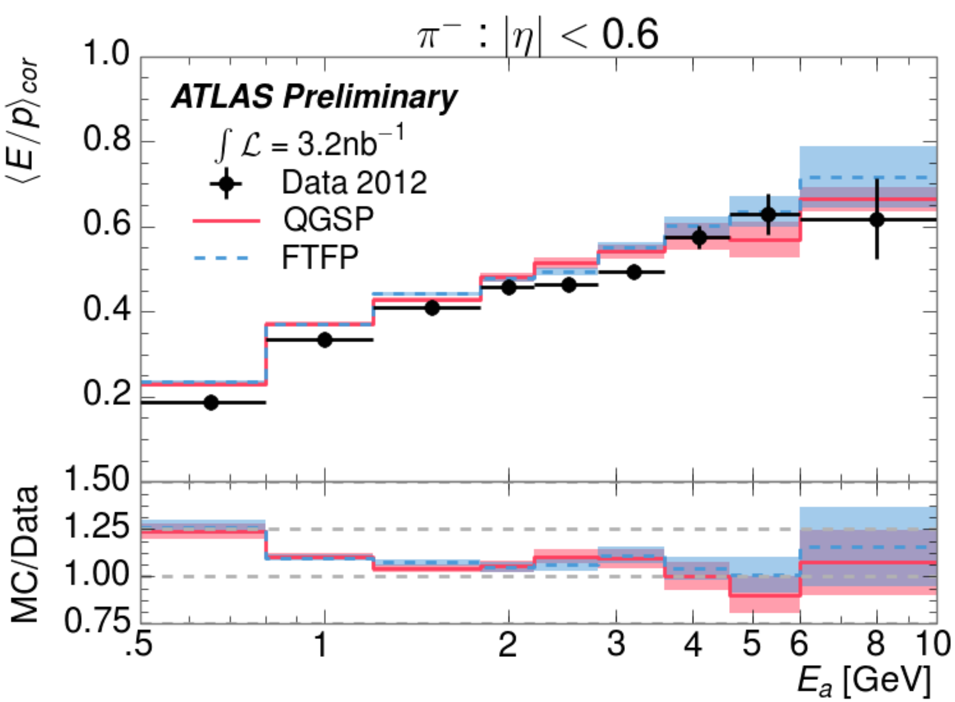
Identified Particle Response

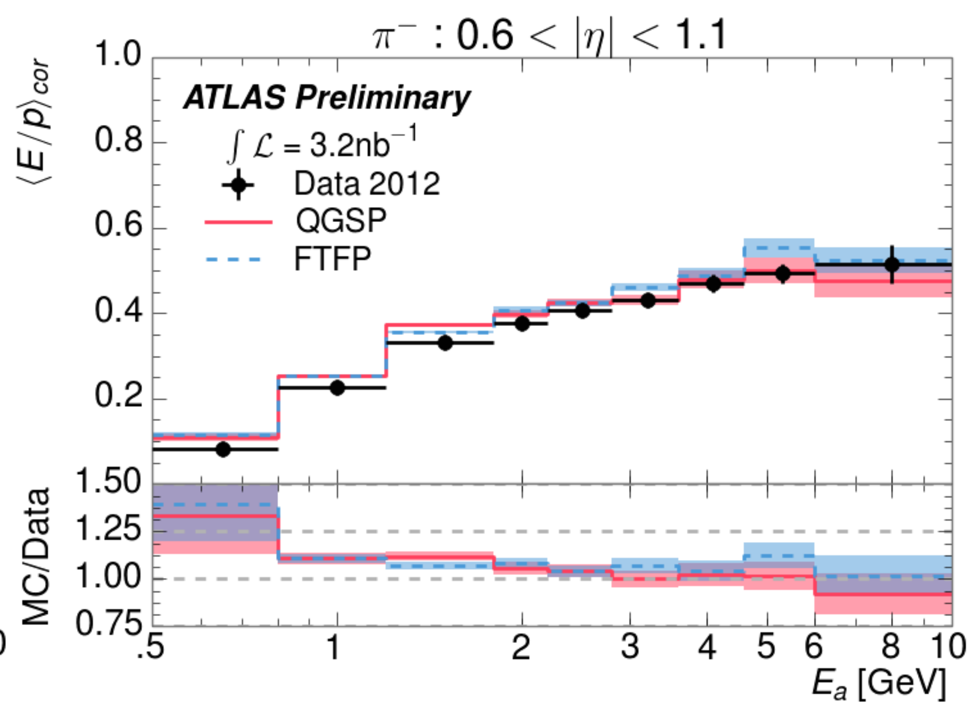
- First for ATLAS: trying to apply the background estimation from earlier to the identified particles
- Requires the assumption that backgrounds are the same for all particles
  - Might not be bad at low momenta, as the decays are wide-angle
- For positively charged pions, below, quite good agreement in the central region – seems this cannot be the source of the earlier disagreement



Identified Particle Response (II)

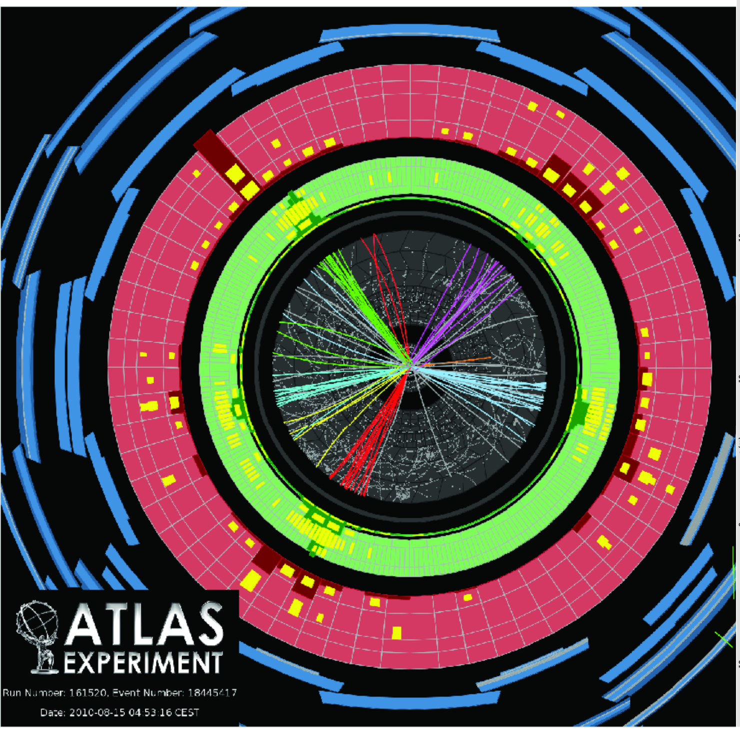
- Negatively charged pions (below) show larger discrepancy
  - Mostly at low momenta – at high momenta this is not a major issue
- Appears that this, along with the difference in zero fraction (which may be correlated) lead to the difference in inclusive E/p that is observed
- The difference is *not* yet well-understood, and is being investigated
- Will also be tested with G4 9.6 to see how the story changes

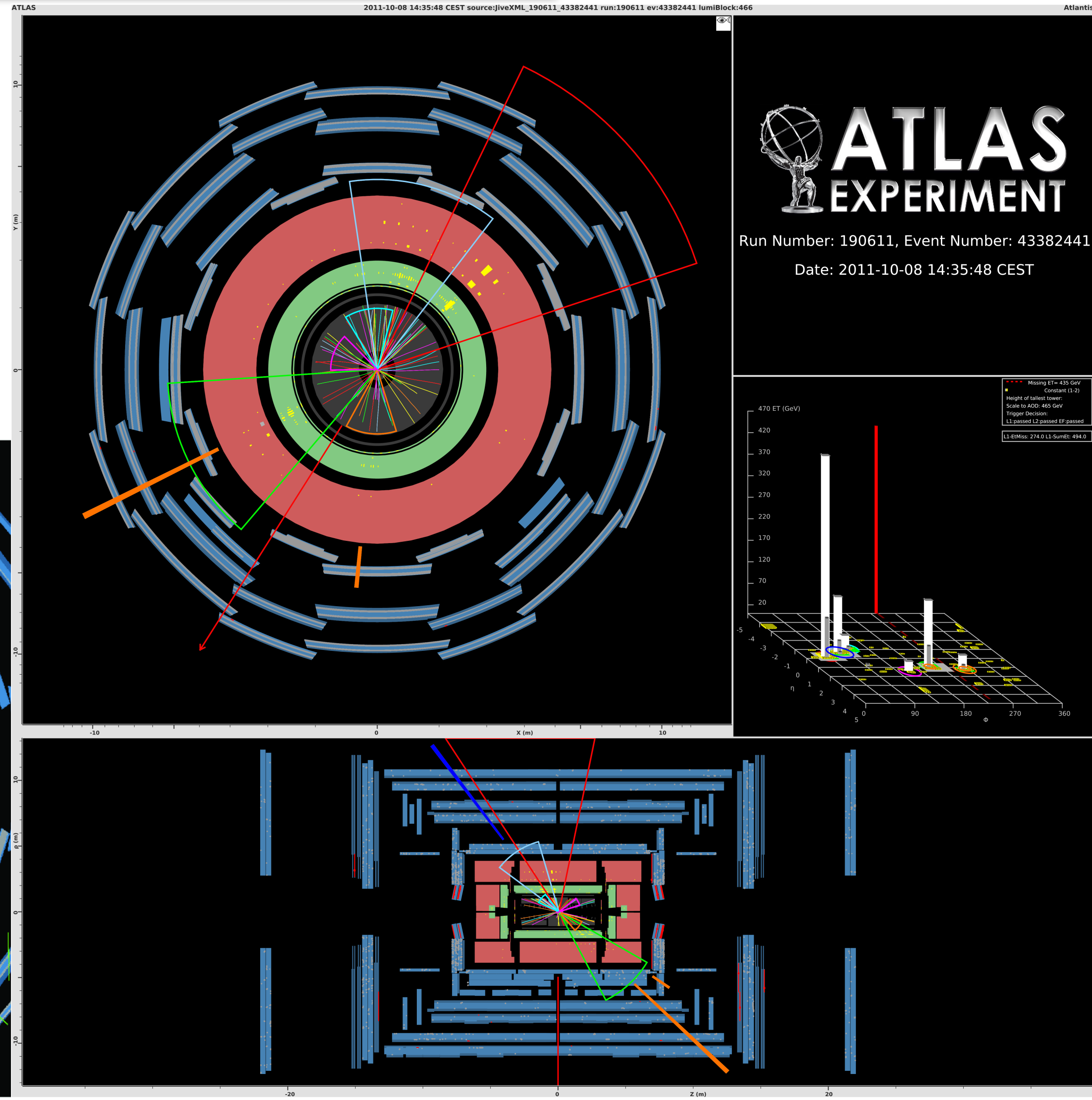




Extrapolation

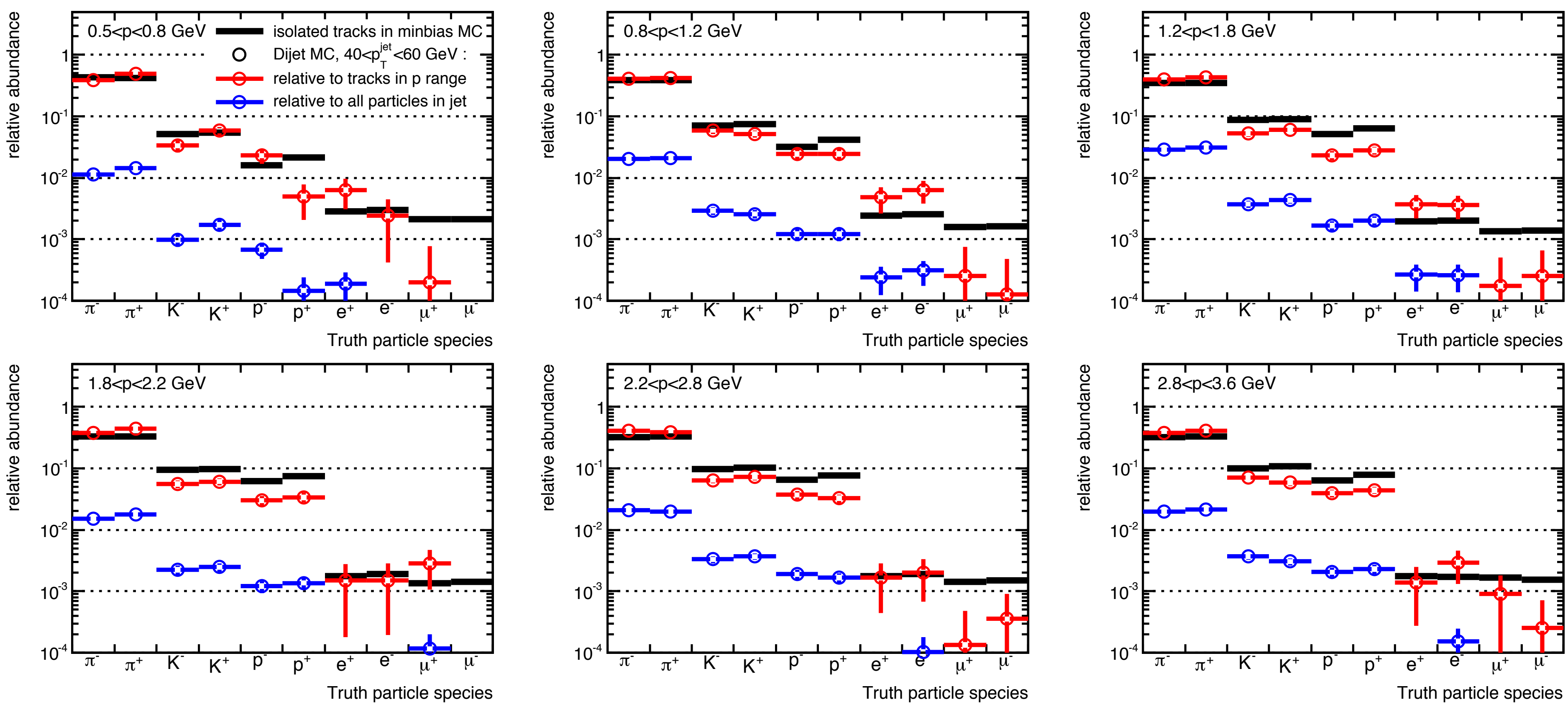
It's a long way from single particles to finding SUSY…





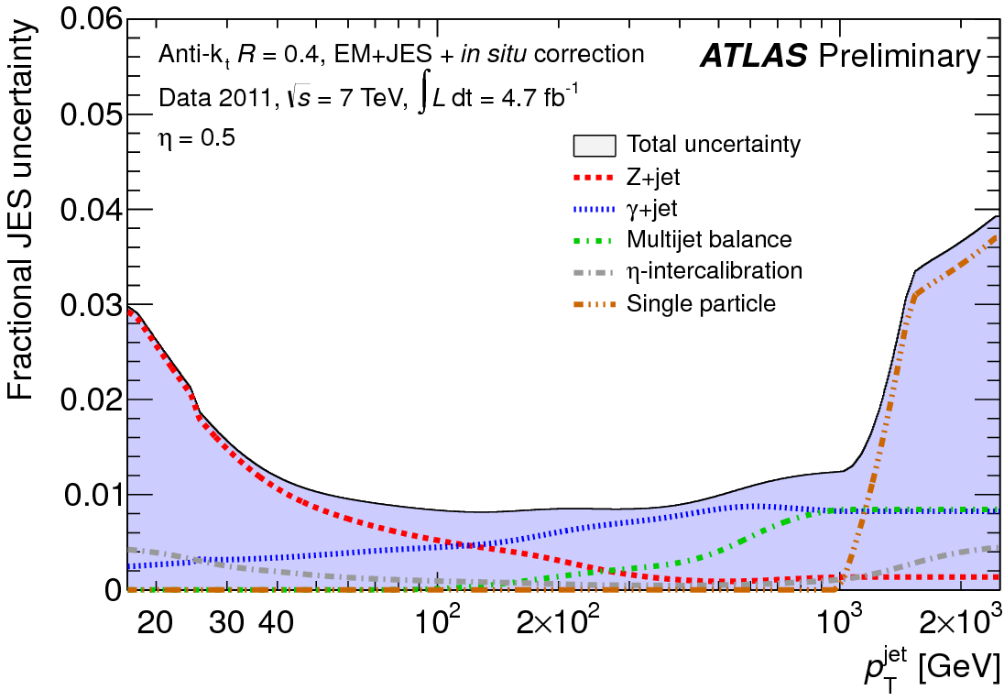
Extrapolating to Jets

- What changes when we move to jets?
  - If we can measure all the components and how those components go together, we will have great confidence in jet physics
- The particle composition might! Is the spectrum of particles we measure in E/p a fair representation of the particles we find in a jet?
  - Yes! Those in a jet may be high energy, so we extrapolate or use test beam



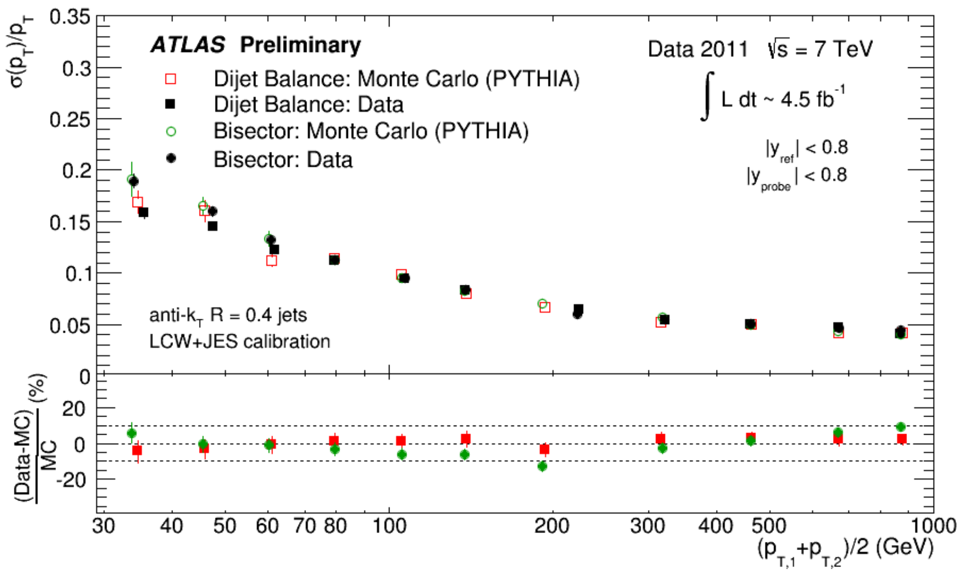
So Much in Single Particles?

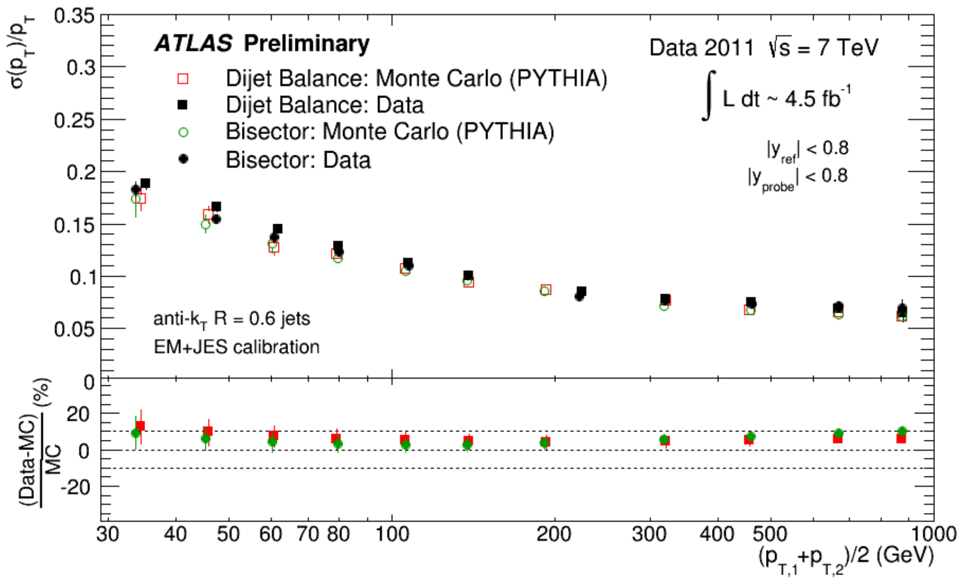
- Single particle response measurements actually drive our JES uncertainties at high momenta
- Can't convincingly get at that energy with in situ techniques
- 1-1.5 TeV seems like a lot now, but at 14 TeV it won't be!
- Limited largely by the high-p_T single-particle response from test beam, but test beam has large uncertainties to extrapolate to the detector
- Effort ongoing to improve this and squeeze the uncertainty



Resolution

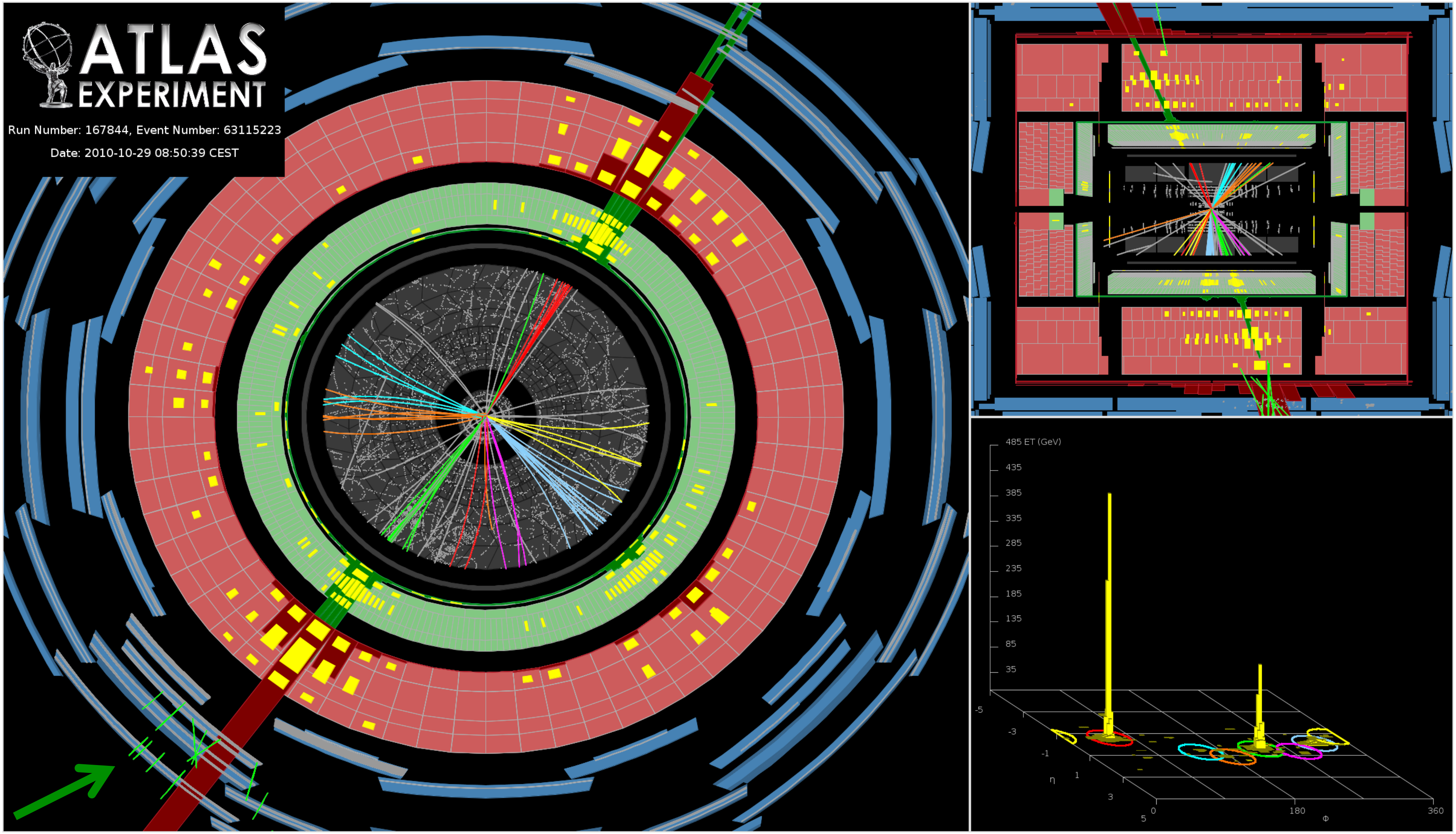
- Jet resolution looks much better in the full 2011 dataset (bottom) than we had feared at the last workshop
  - This is G4 9.4 with QGSP_BERT; picture might change with 9.6 / FTFP
- This doesn't mean that single particle resolution is a solved problem, of course, but it is not something we'll be able to get at from here
- Will revisit this issue with the full 2012 dataset soon, when we'll have more data to cover an even wider range of momenta





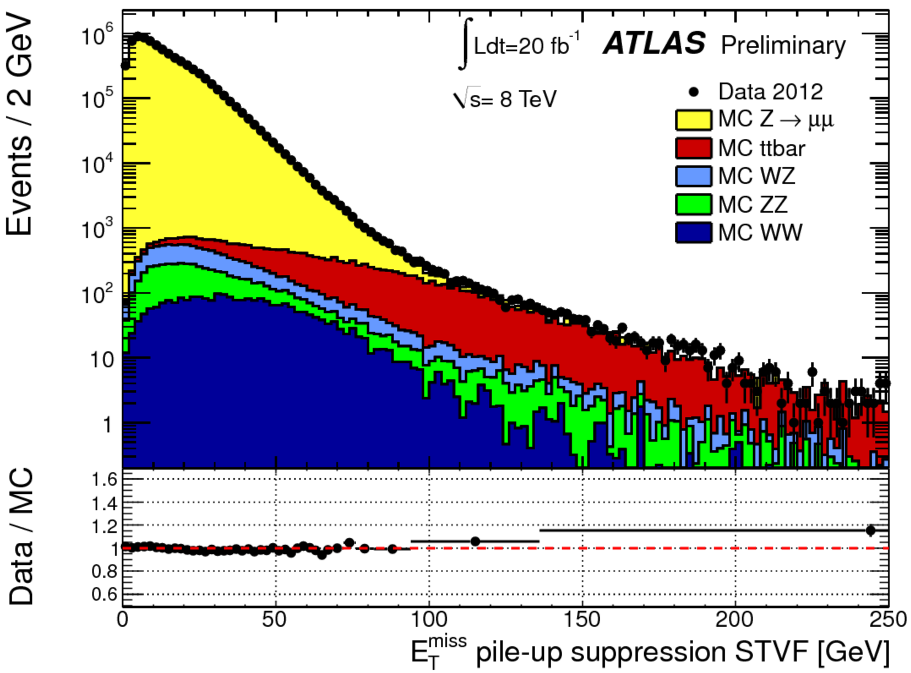
Punch-Through

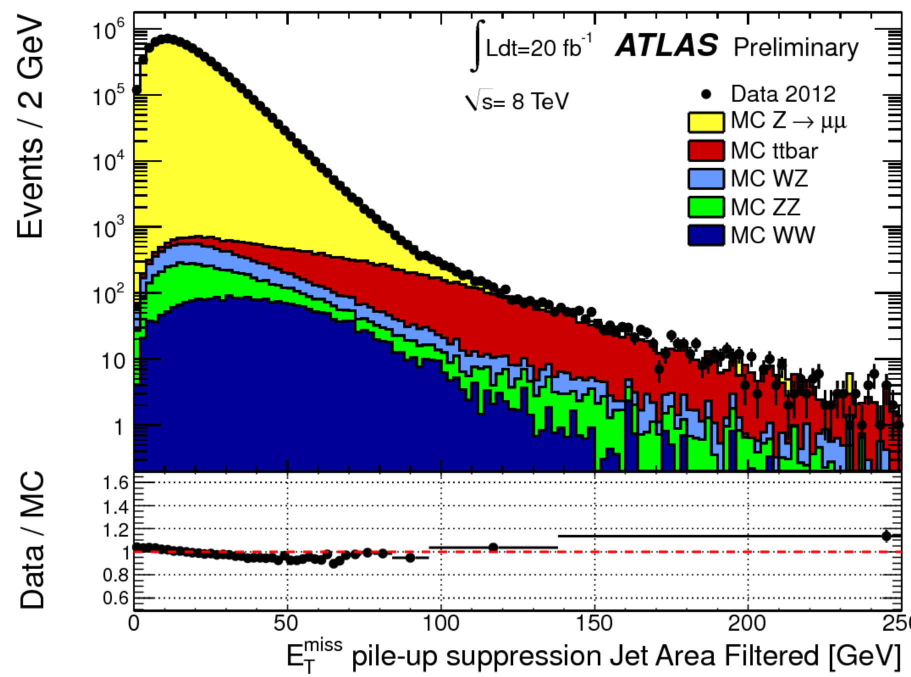
- Geant4 seems to do an excellent job of describing even difficult events, despite reasonable concerns that it might not. Much more on this soon.



Missing Energy

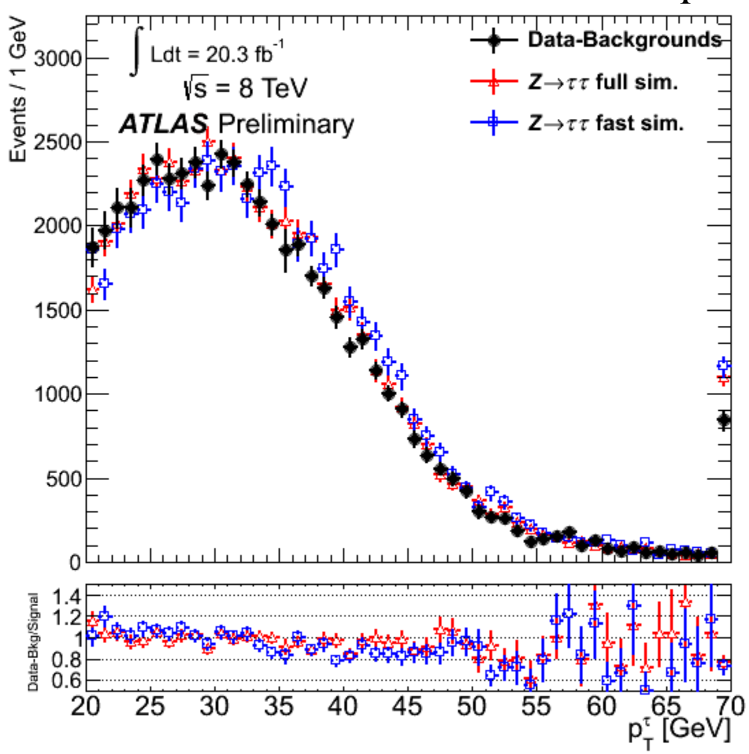
- Missing energy and ΣE_T are, of course, *very* complicated variables, with many effects entering
- Still, excellent agreement with data, in both the core and tails, in events with and without true MET
- Builds more confidence in our modeling of all aspects of the data
- Much (most?) remaining discrepancy that's visible could be down to generator issues, pile-up issues, etc. rather than simulation issues

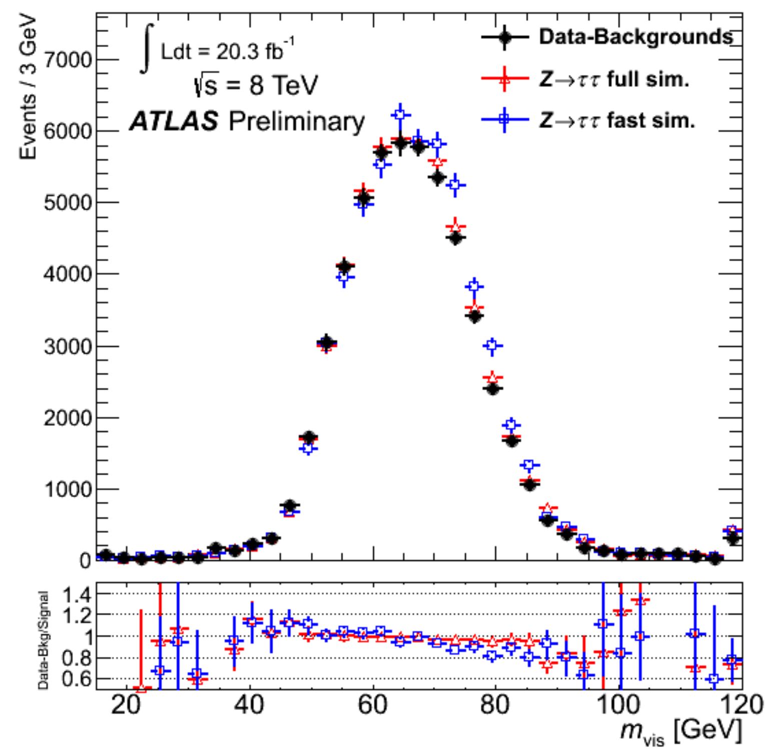




Fast Simulation

- We rely heavily on fast simulation (below for $Z \rightarrow \tau\tau$)
- Our current fast simulation treats all hadrons as identical
  - Of course there is E and η binning, but it doesn't know π from p
- Means some variables aren't super well modeled – but close enough
  - Some are even better than full simulation, though
  - Most details are final-state dependent; more detail in Robert's talk





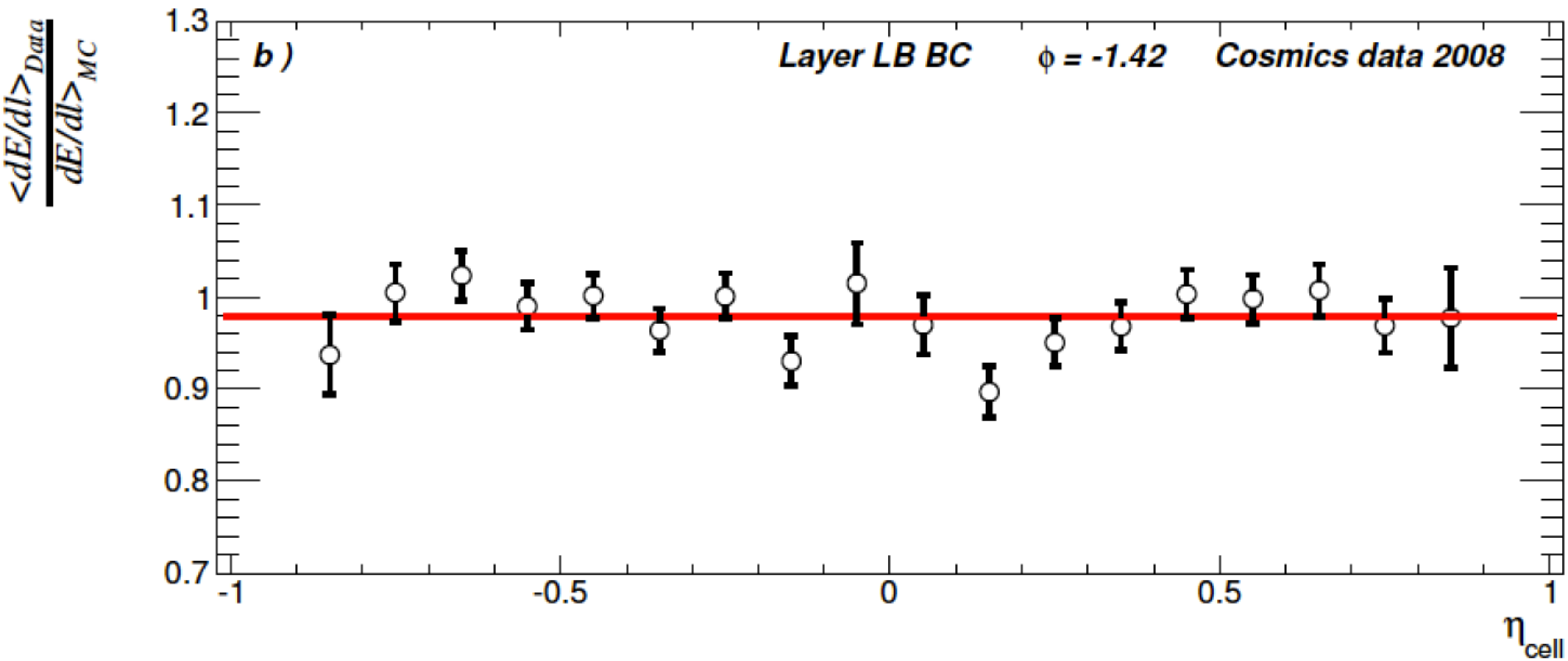
Summary and Conclusions

- Geant4 is doing a pretty good job describing hadronic physics in ATLAS, over a broad range of topologies, energies, and materials
- The picture is slightly different from that of the last workshop
  - Inclusive single particle looks somewhat worse – not yet clear why this is
  - Anti-protons and jet resolution both look better
- We know there are many measurements to update with the latest MC version (G4 version and geometry version for us!), and some new measurements and properties that we are working hard to understand
  - Test beam is very important to all of us
  - Performance work always takes a little more time to publish than a search for new physics, but this documentation will come
  - We'll keep working to try to extract information that is interesting to the simulation community, not just the generator tuning community, of course, but this is a bit of a trick for very complex final states and variables
  - Expect to also hear quite a bit about the successes (and failures) of fast simulation in the coming months, as that will be a bit story for 2015!
- Moving to G4 9.6 and FTFP_BERT now – no showstoppers yet, and we hope that the picture will be even better

BACKUPS

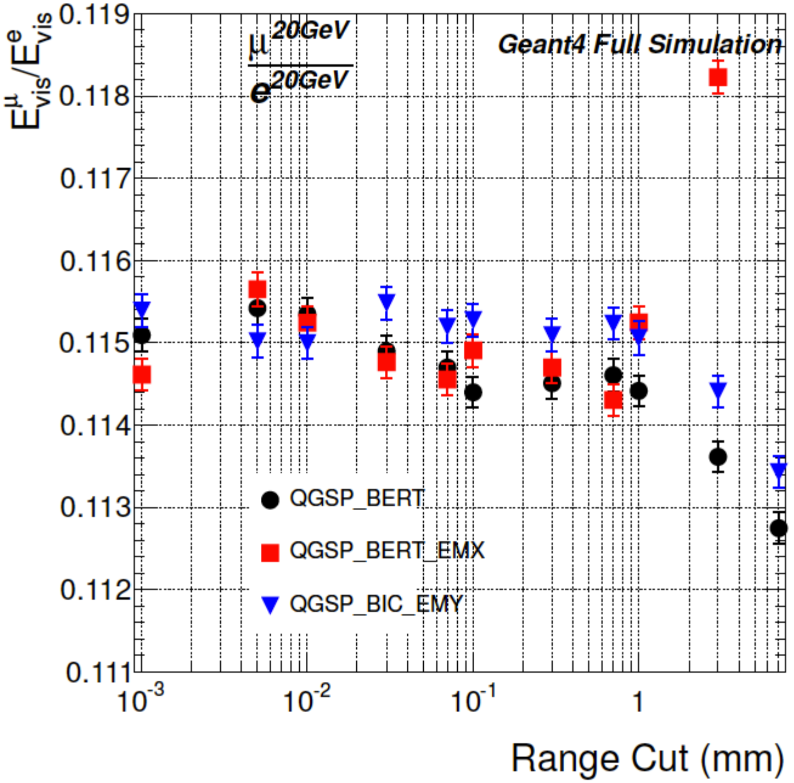
Sampling Fractions

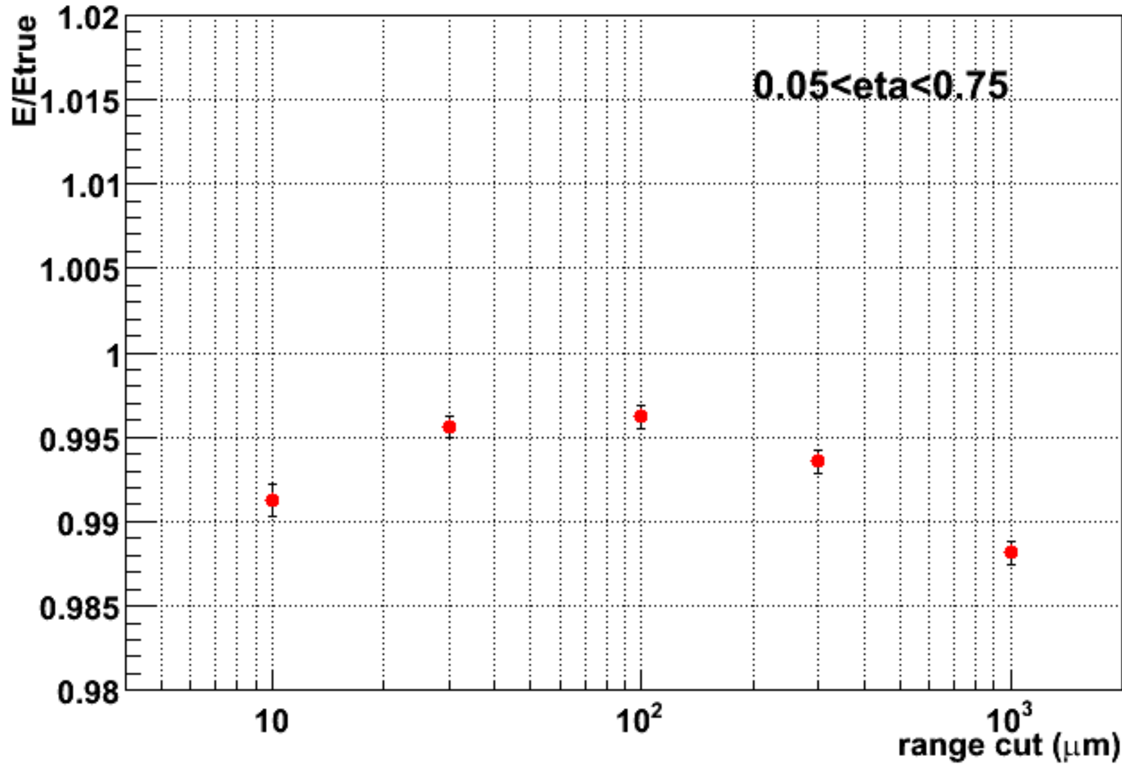
- Measure LAr and Tile sampling fractions several ways
  - Cosmics, Z->ee, any other handle we can find…
  - In LAr, sensitive to temperature - monitor temp carefully!
    - Can’t compare well to test beam (no temperature measurement)
- Calibrate constantly in situ with a cesium source



Sampling Fractions

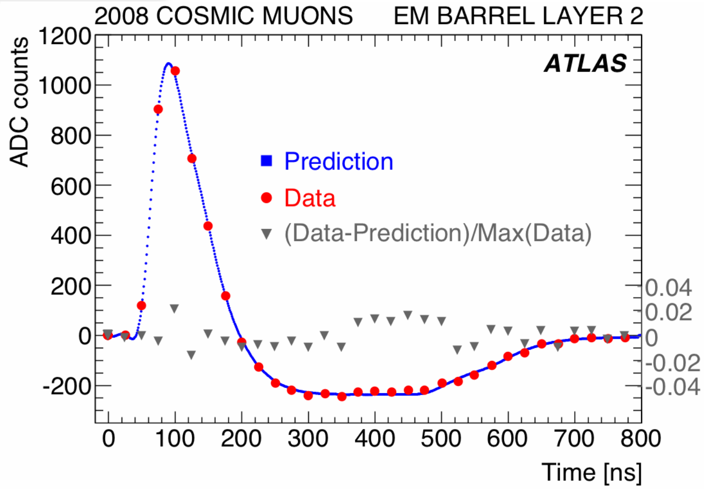
- Varies with range cuts (left: tile; right: LAr)
- Need to be in the stable band (where we claim independence)
  - For us, this means range cuts significantly at least a factor of two smaller than the smallest detector feature (e.g. LAr gap width)
  - Only stable with "new" (range-limiting / non-EMV) multiple scattering
  - Noticeable CPU effects, so watching this is a good idea

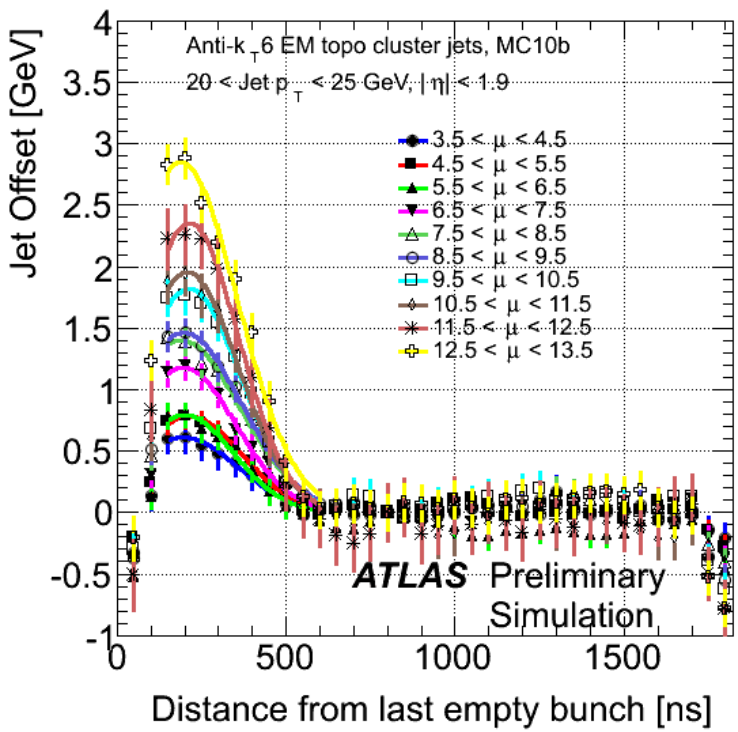


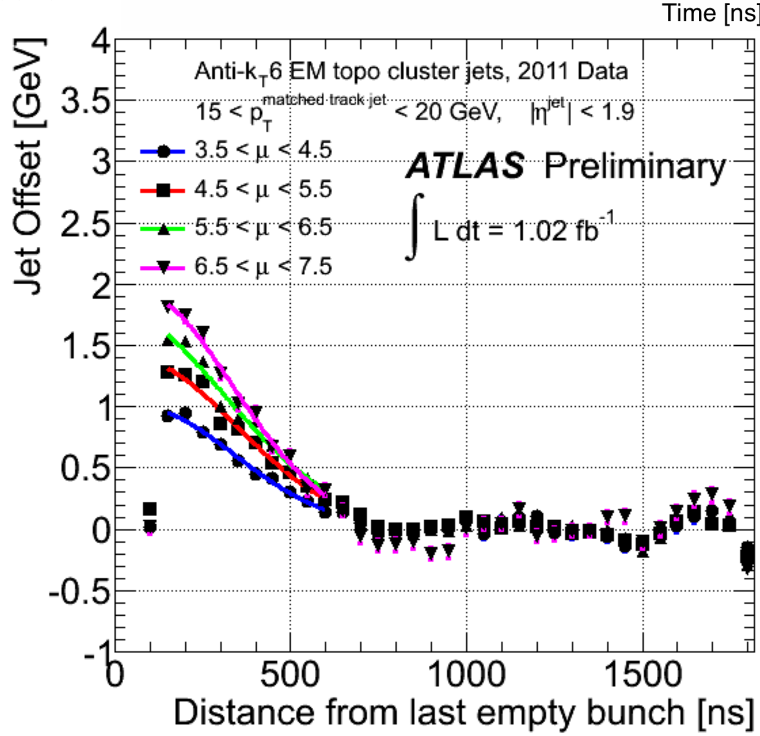


Pile-Up

- Pulse shaping in the liquid argon calorimeter is included in the simulation
- Jet offsets from pile-up is modeled to <50%
  - Remaining differences from bunch-to-bunch current variation not modeled in the MC
  - Could be included in the future – see talk from John Chapman in tomorrow's session



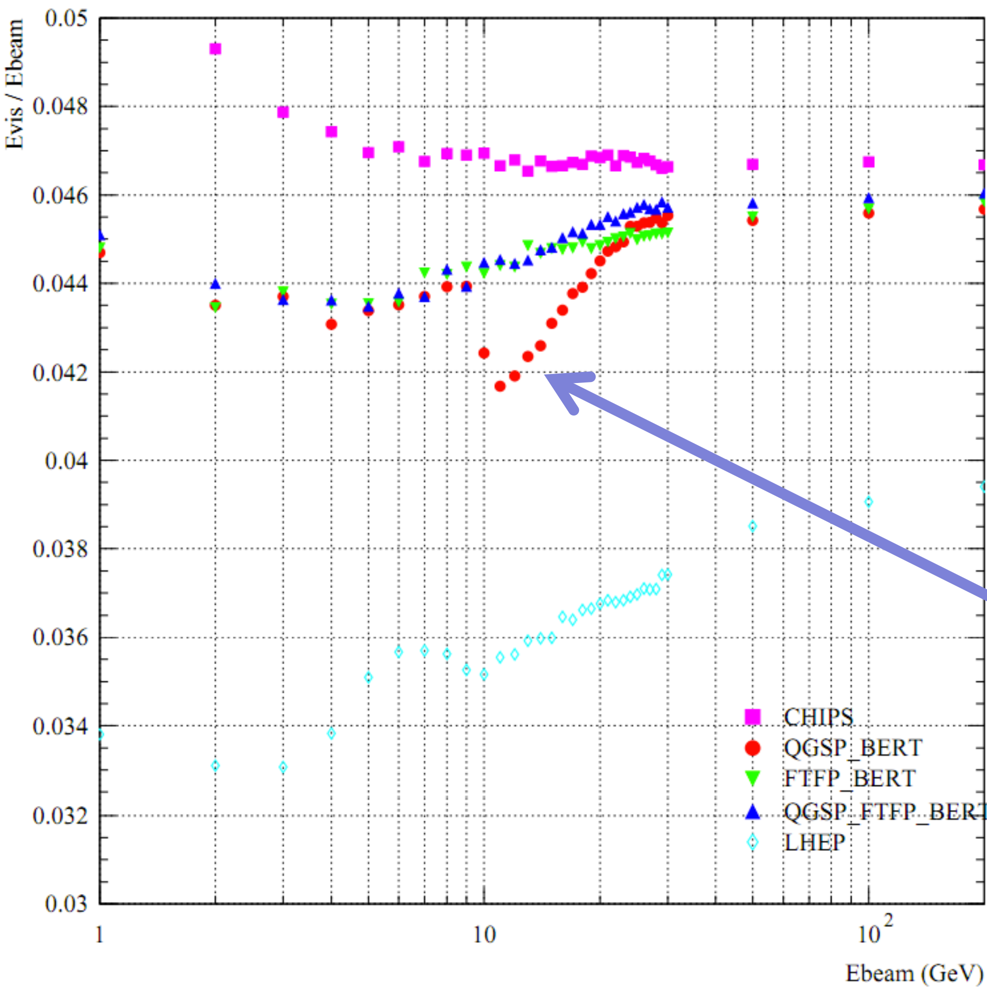


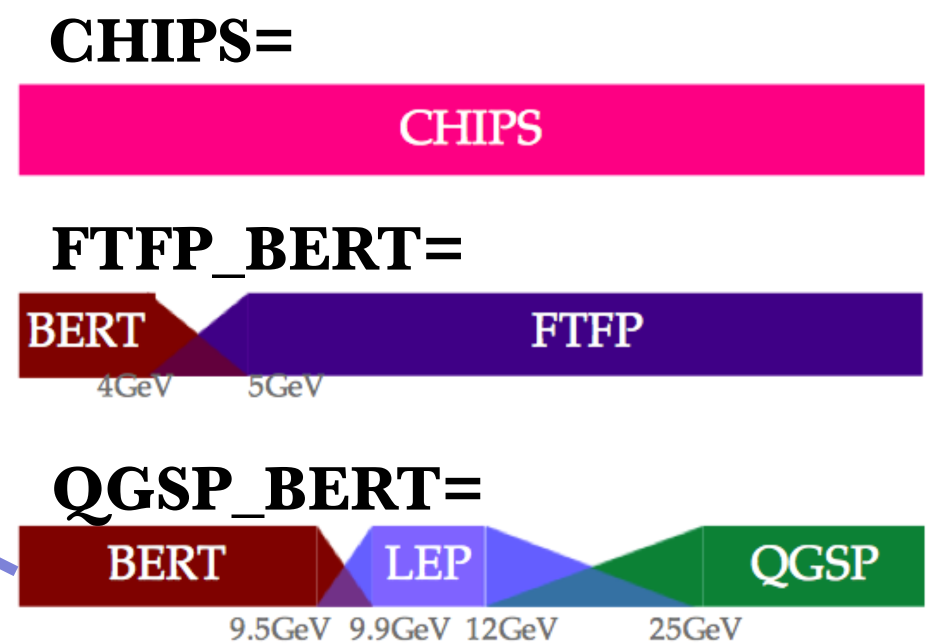


Response Discontinuity

- We knew about that one: entirely to do with transitions between different models!

Evis / Ebeam vs. Ebeam simplified Cu-LAr pi- G4 9.3.p01





Described in detail in an [LCG Simulation Note]