Production of Direct Photons in ATLAS

Mark Stockton
University Of Birmingham

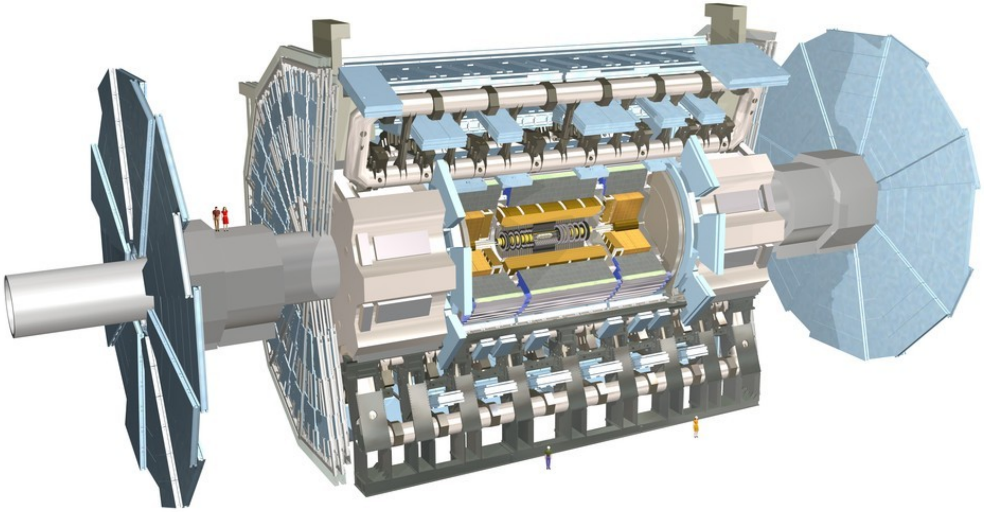
Birmingham Particle Physics Group Seminar
19/11/2008

Outline

- Introduction to the LHC and ATLAS
- Direct Photon Production
- Backgrounds
- Why study direct photons?
- First measurements
- Future measurements
- Summary

ATLAS and the LHC

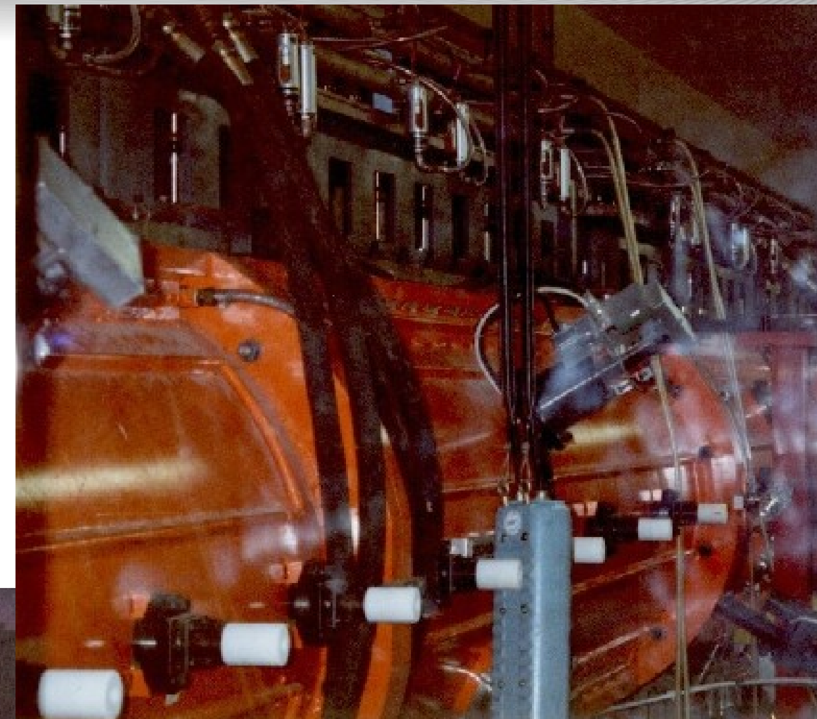
- The LHC is a proton proton collider @ 14TeV
  - Well so far proton collimator/beam gas...
- ATLAS is one of the 2 general purpose detectors, located @ point 1, and consists of:
  - Inner Detector
  - Solenoid
  - Calorimeters
  - Muon system
  - Toroid Magnets



- To give a different view of the LHC here are some personal photos from my many trips to CERN...

Before reaching the LHC

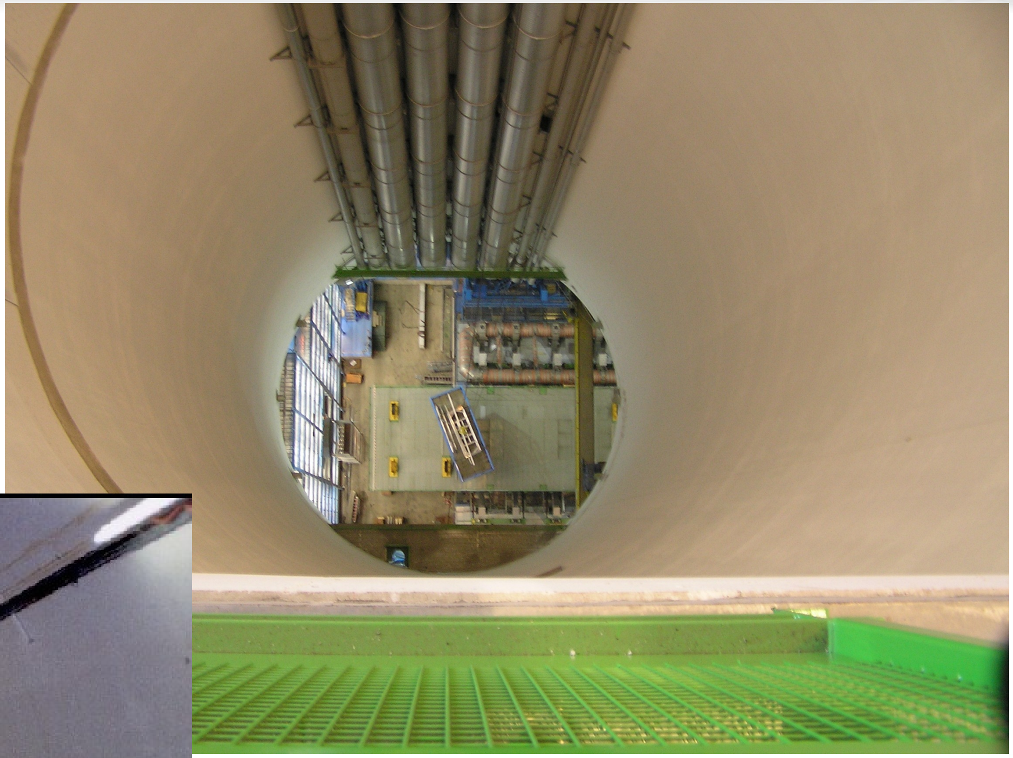
- Protons start their journey to the LHC in the LINAC
- Then they pass through other accelerators getting to 450GeV



Photos from my first visit to CERN during my A levels in 2001

Then reaches the LHC

- Travels 100m underground into the 27km tunnel

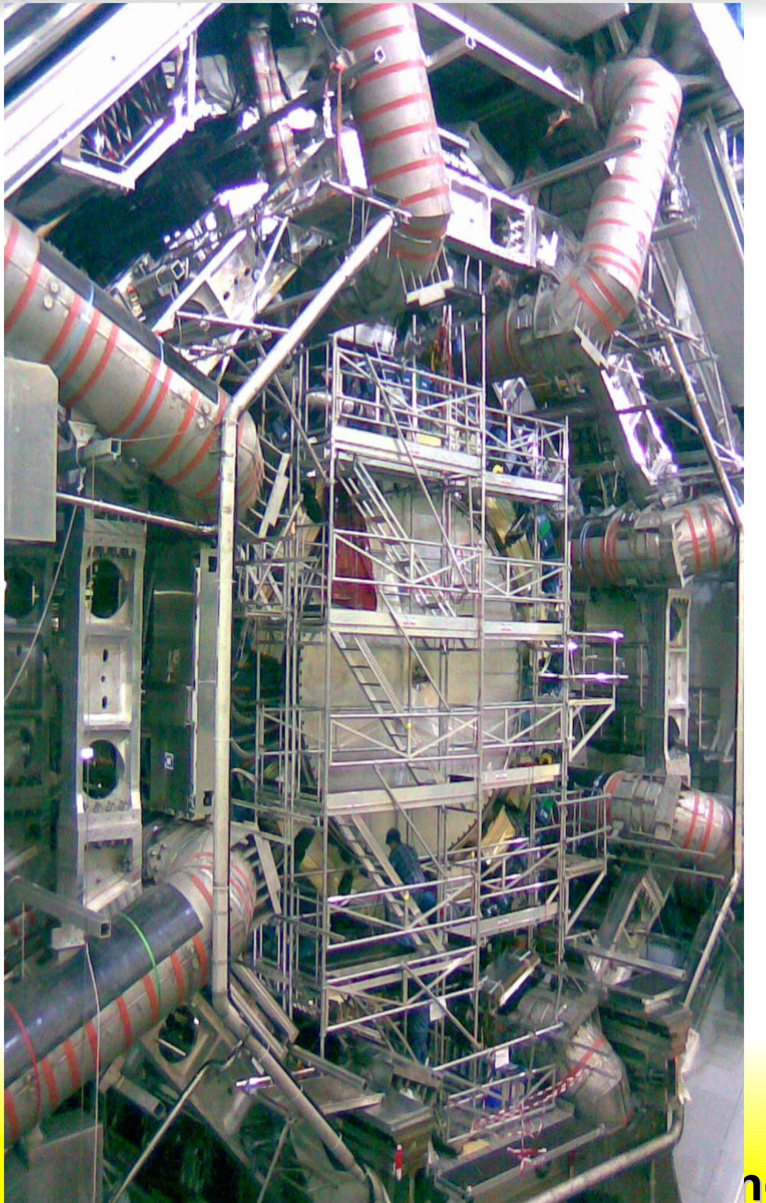


Photos from the PwPPC undergraduate visit to CERN in April 2005

Mark
Stockton

And ATLAS

Time to install

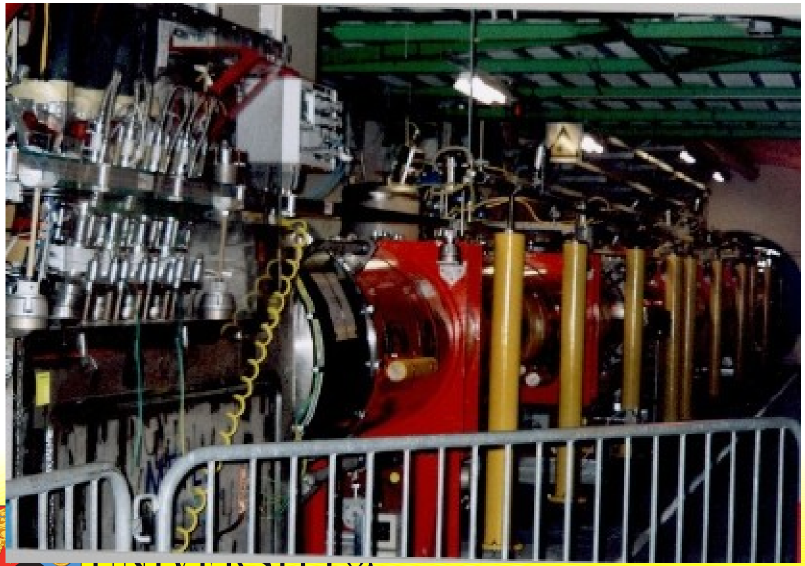


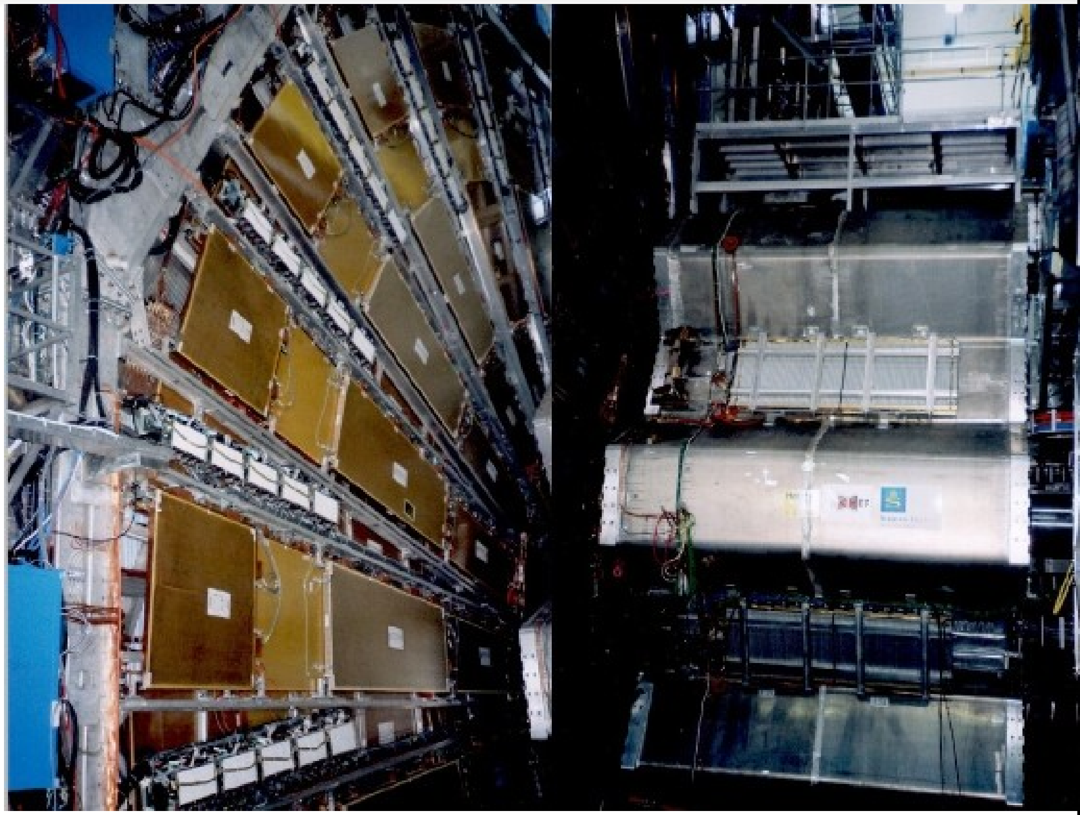
Left: Atlas tour at L1calo joint meeting in Nov 2006

Right: L1calo JEP crate after cabling week April 2007

Mark
Stockton

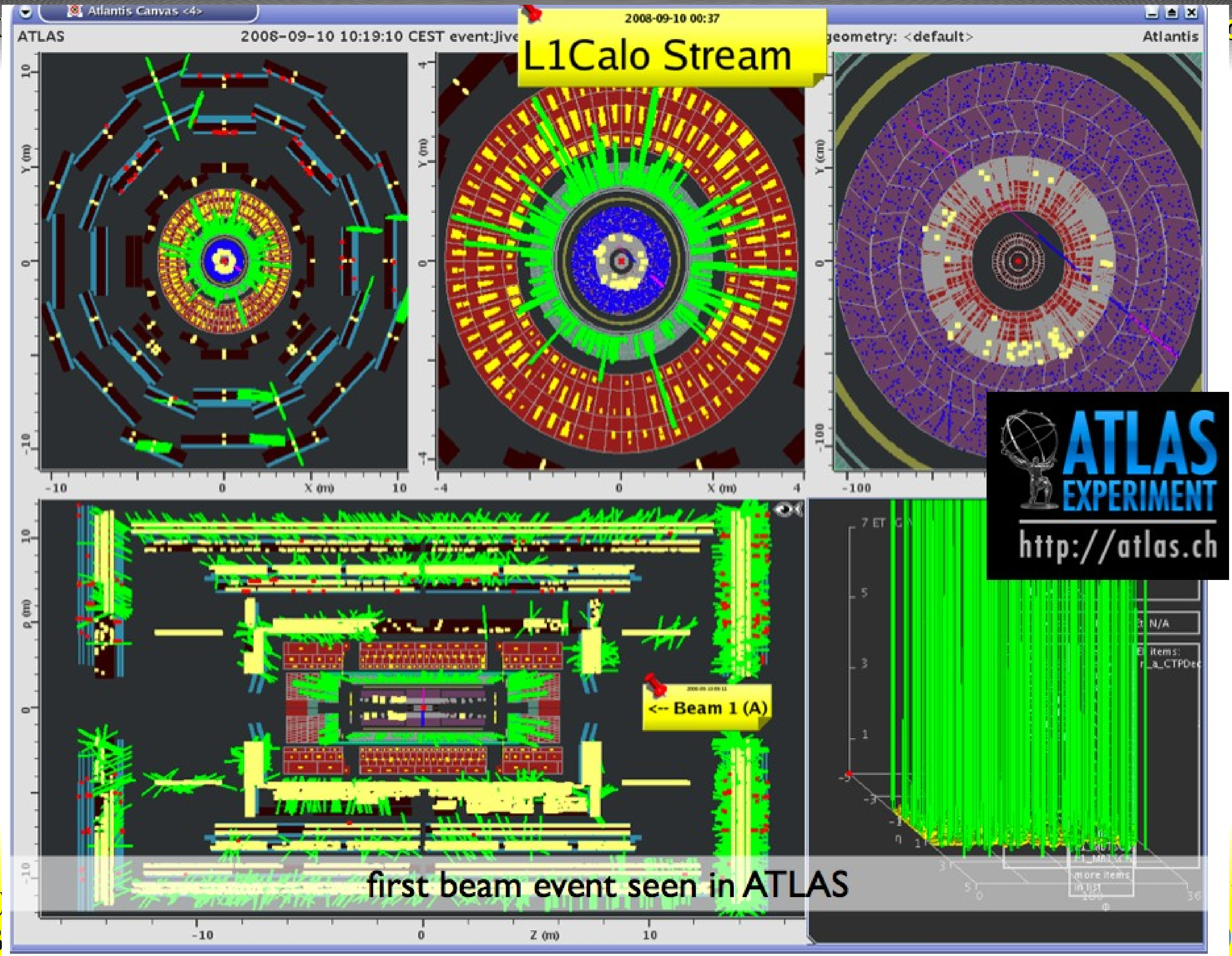
And then it was ready





Photos from the CERN Open Day 2008

Then it took data!

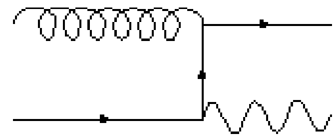


Collision Data

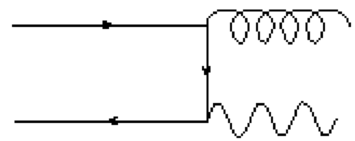
- When the LHC begins taking collision data the first processes we will see are:
  - Minimum Bias (low p_T events)
  - Multi-Jet (many difficulties in jet reconstruction)
  - Direct Photons (possibly the best high p_T events in the world)
- A direct or prompt photon is any photon originating from the hard interaction
- These events are also referred to as “photon jet” as there will also be at least one jet produced

Direct Photons

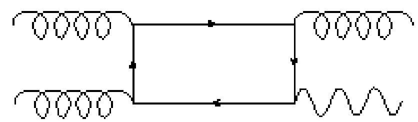
- LO Compton



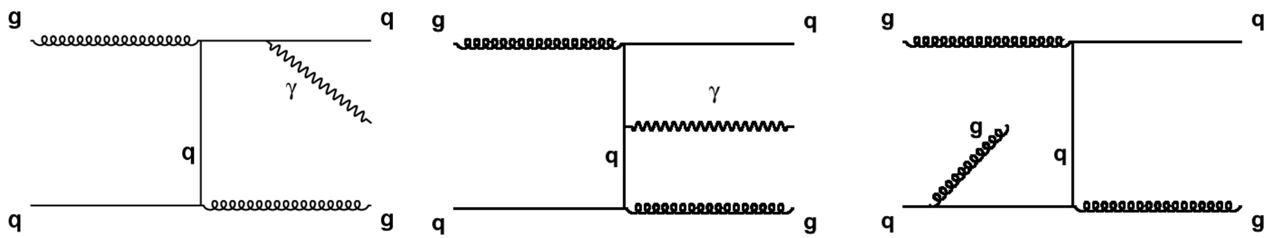
- LO Annihilation



- NLO dual gluon



- Bremsstrahlung

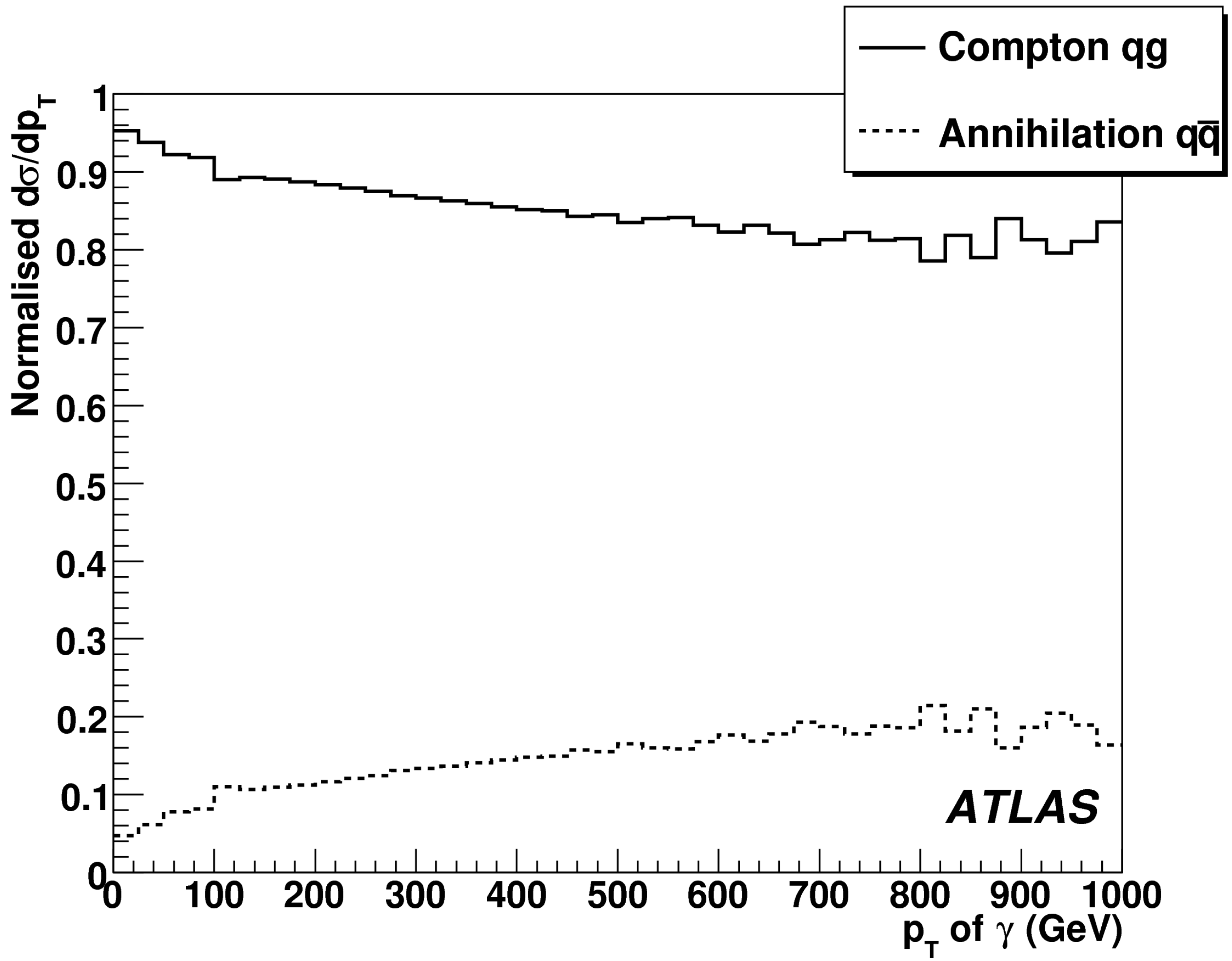


→ Cannot successfully remove these events from the LO sample

→ Have to make an NLO measurement with a well defined isolation requirement

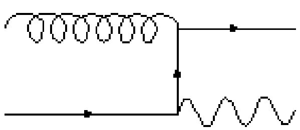
Process importance

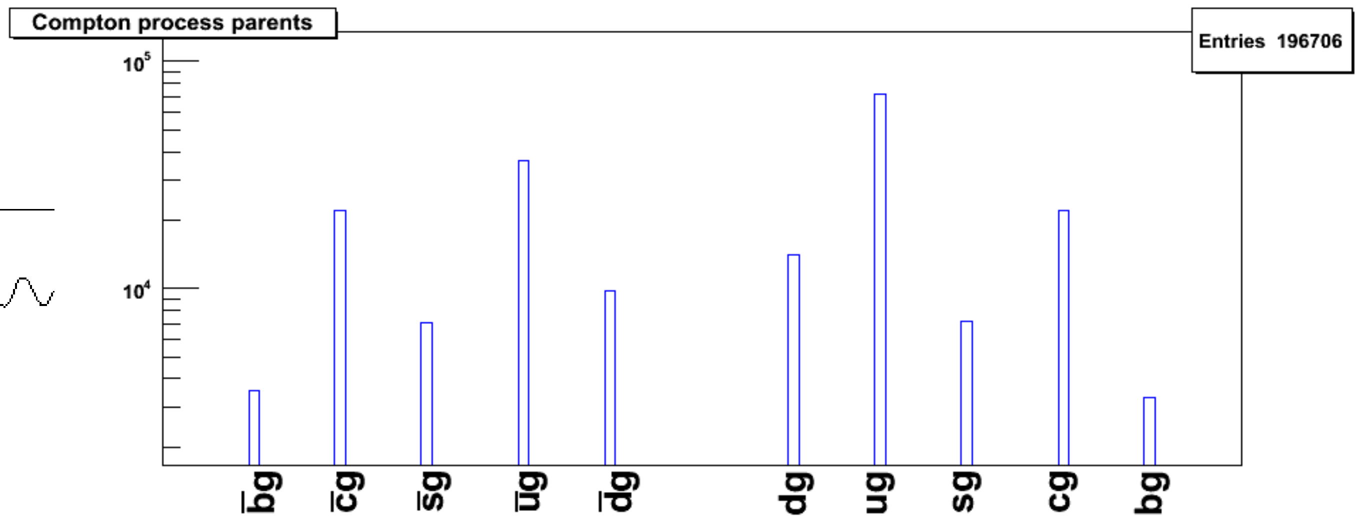
- From generation in Pythia the relative cross sections can be compared for the LO processes

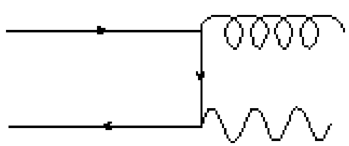


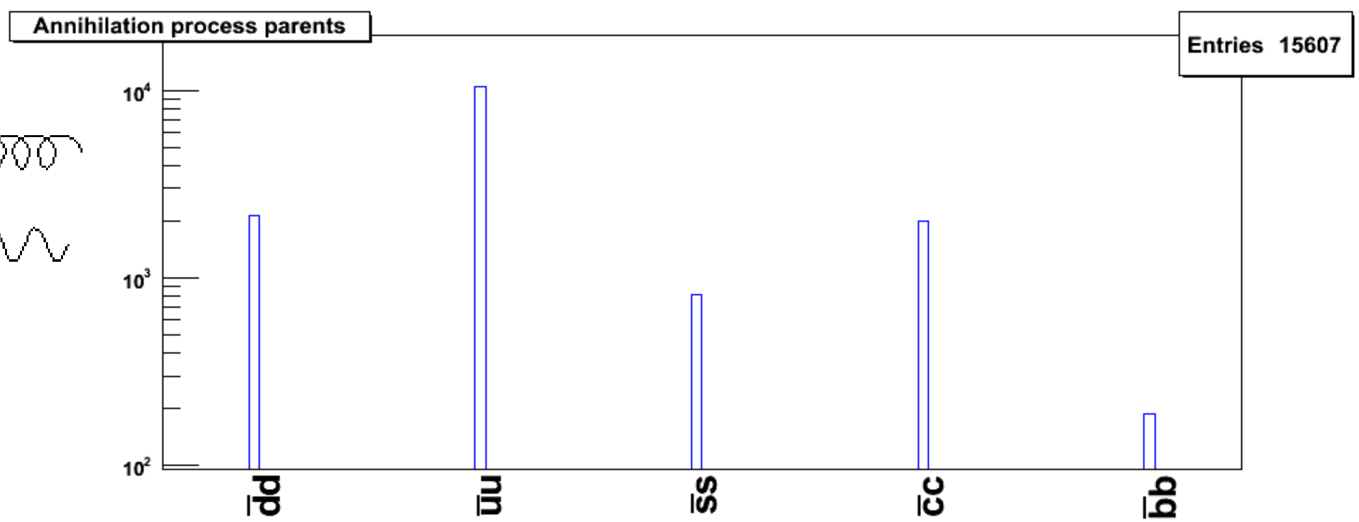
Quark flavours

- The interacting quarks can also be investigated



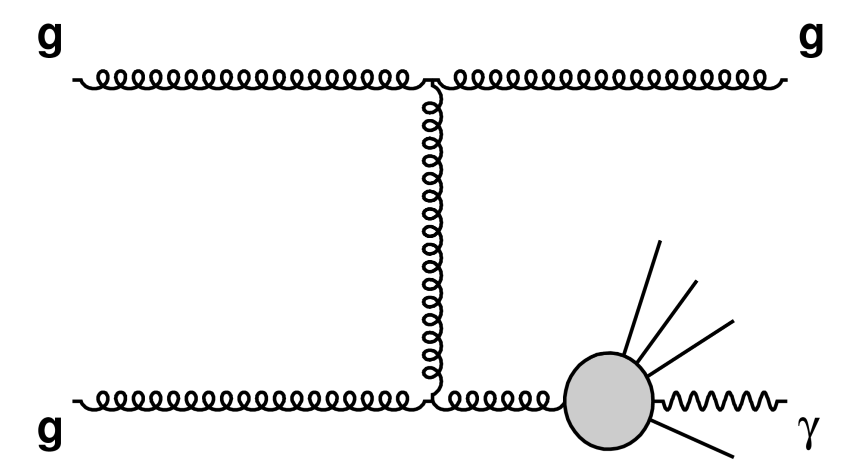




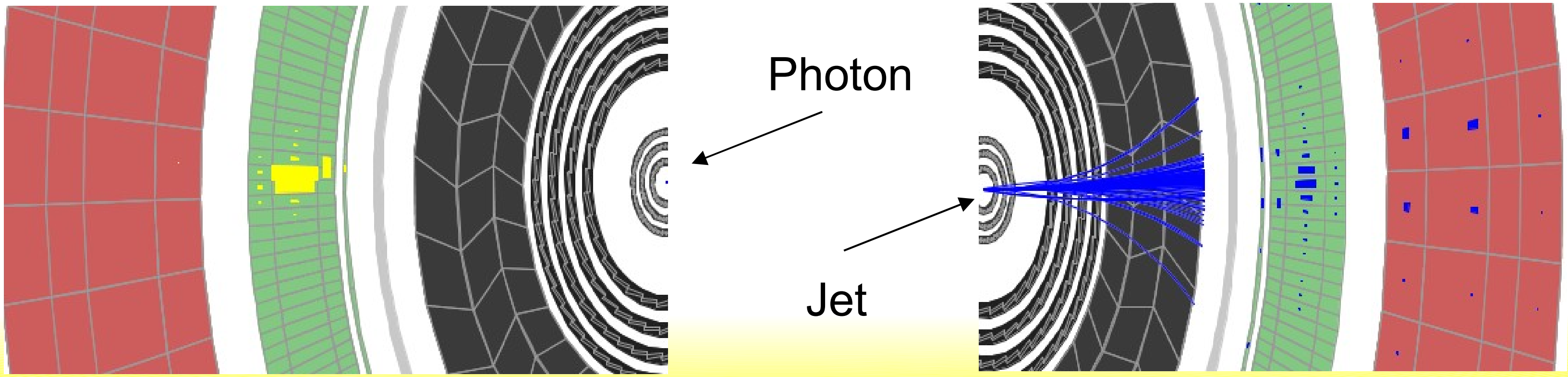


Backgrounds

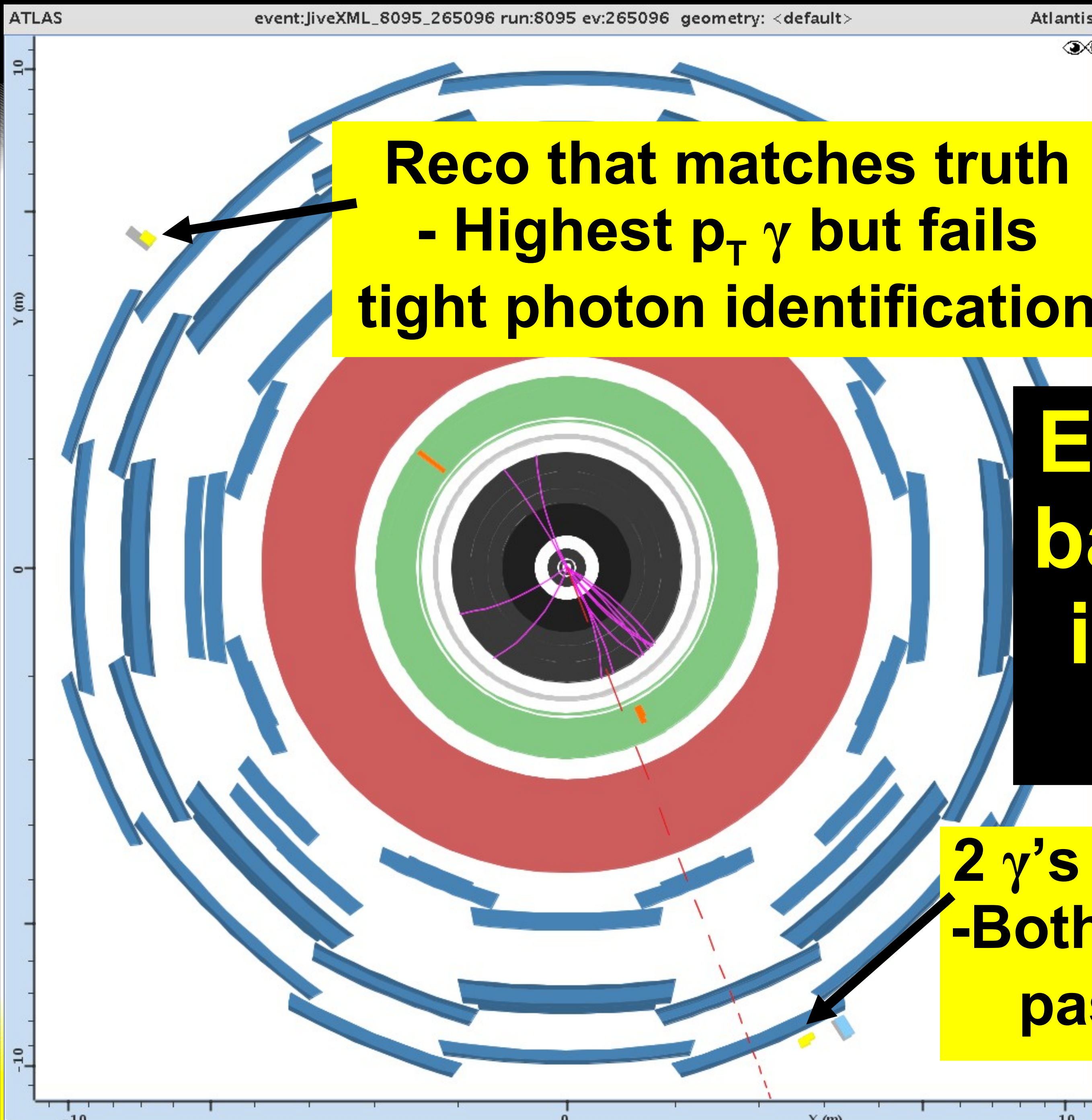
- Main background is from meson decay (mostly π^0) to multiple photons
- Low fake rate but larger cross section



- Should be able to distinguish thanks to the finely segmented calorimeter



Example of background in a signal event



Reco that matches truth
- Highest p_T γ but fails tight photon identification

2 γ's in jet to ignore
-Both lower p_T but 1 passes tight ID

Why study direct photons?

- So there will be lots of these events
- And the calorimeters are designed to effectively remove the background

Why study direct photons?

- So there will be lots of these events
- And the calorimeters are designed to effectively remove the background

- But is there any reason to study these events?

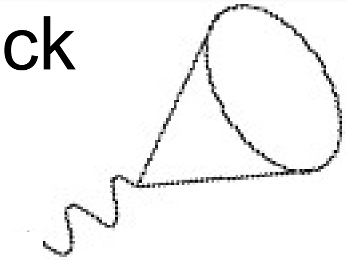
Why study direct photons?

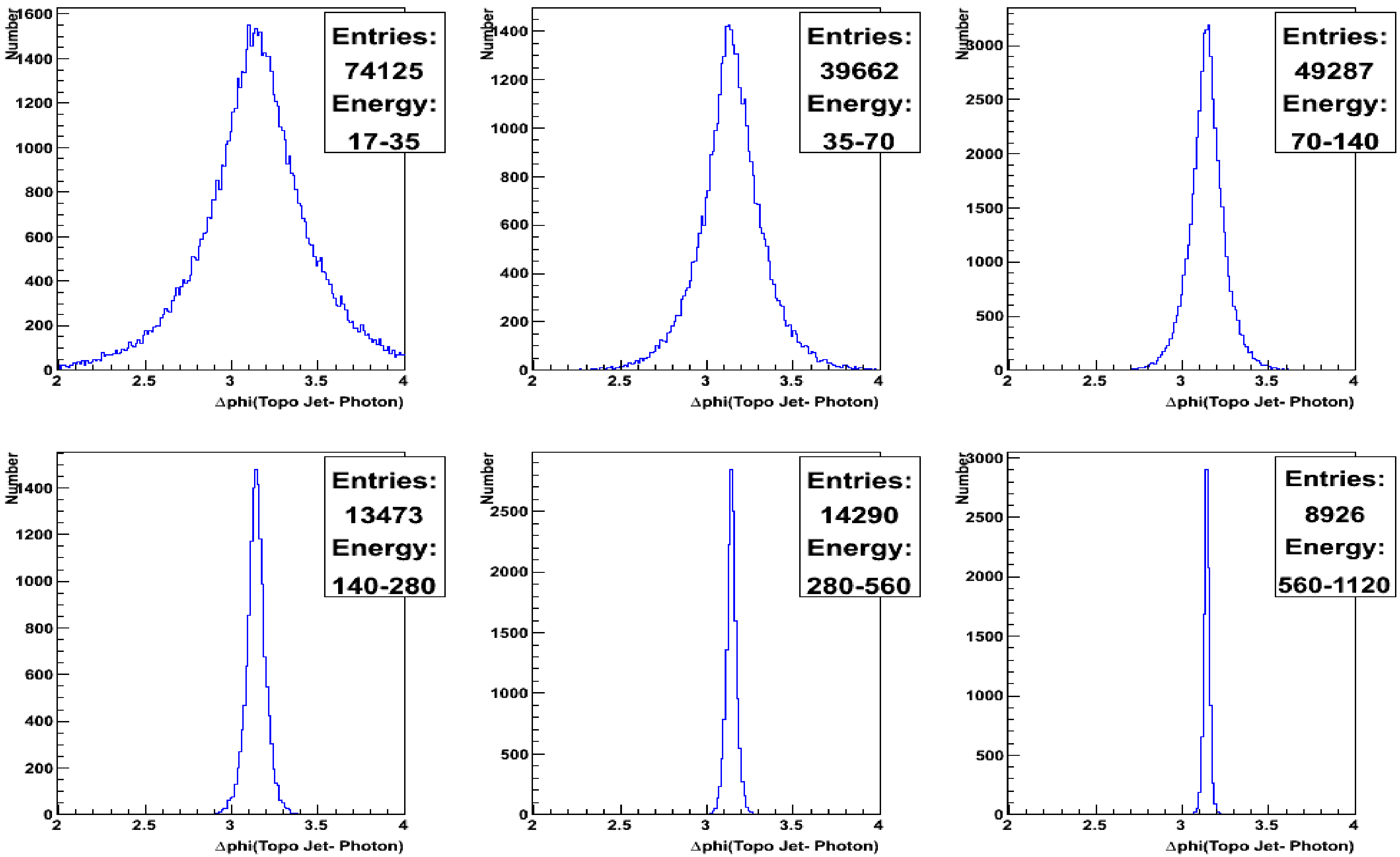
- So there will be lots of these events
- And the calorimeters are designed to effectively remove the background
- But is there any reason to study these events?
- PLENTY!
  - Jet Energy Calibration
  - Background to other processes
  - Gluon PDF
  - (Also an important clean process in heavy ion collisions)

Mark Stockton

Jet Energy Calibration

- The photon and jet should travel back to back in the transverse plane, with energies that should balance

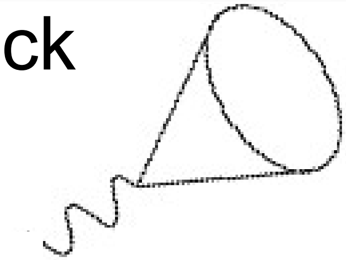


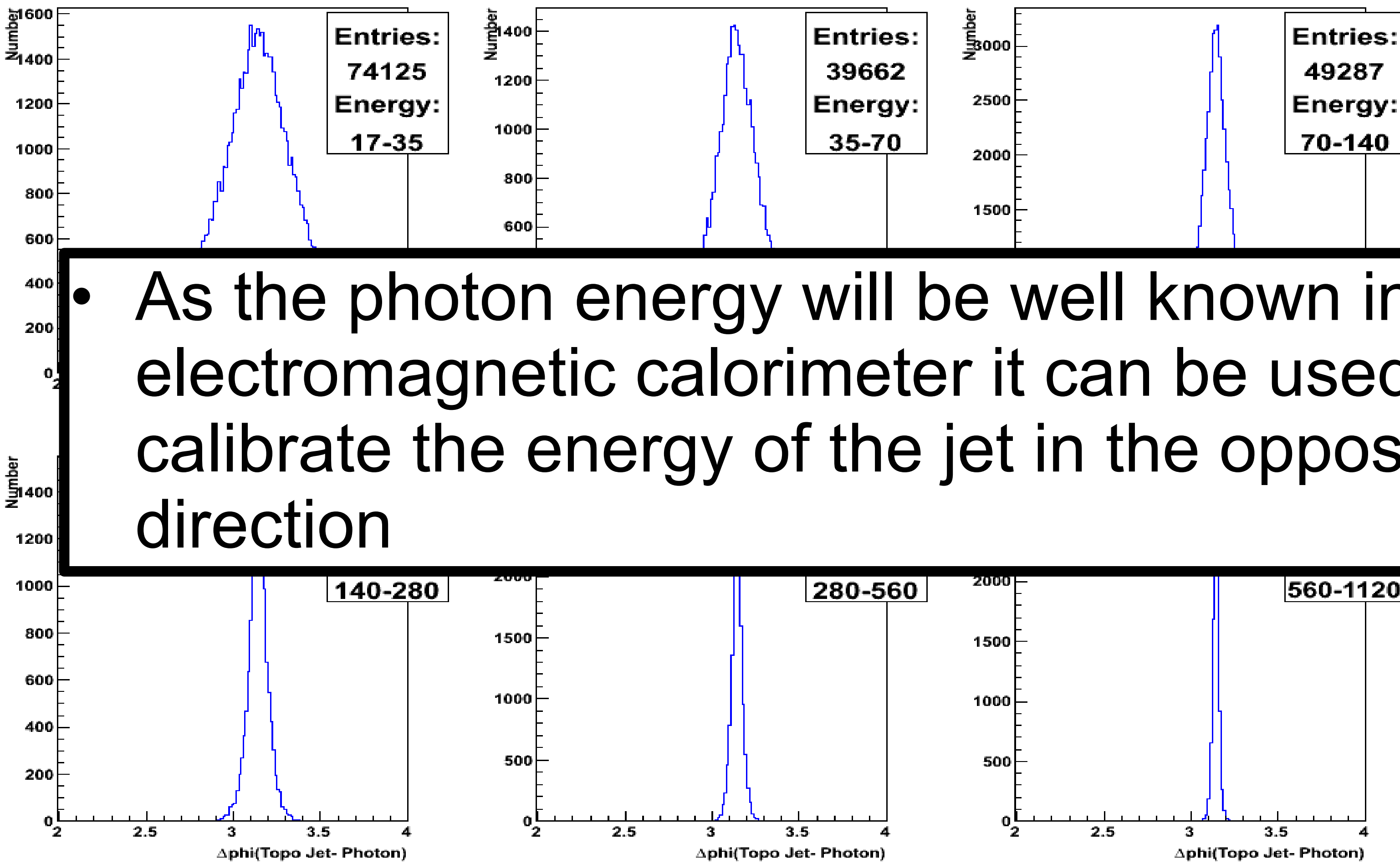


Mark Stockton

Jet Energy Calibration

- The photon and jet should travel back to back in the transverse plane, with energies that should balance





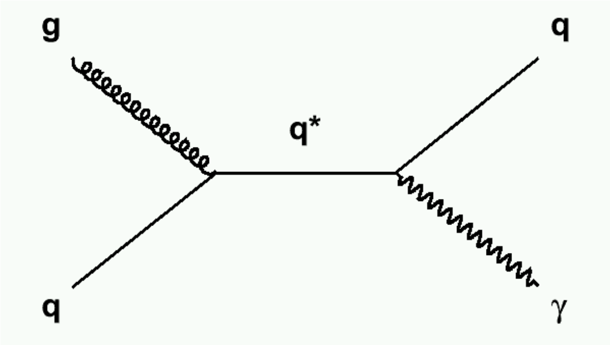
- As the photon energy will be well known in the electromagnetic calorimeter it can be used to calibrate the energy of the jet in the opposite direction

QCD background

- With the process having such a large cross section it means that it will be a background to other processes involving photons
- For example:
  - The Higgs→$\gamma\gamma$ decay will have direct photons as a background if the jet is misidentified as a photon

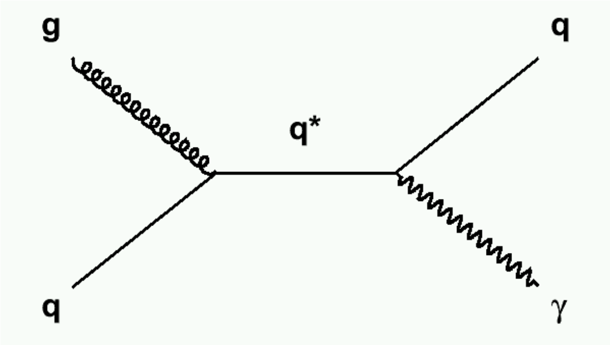
QCD background

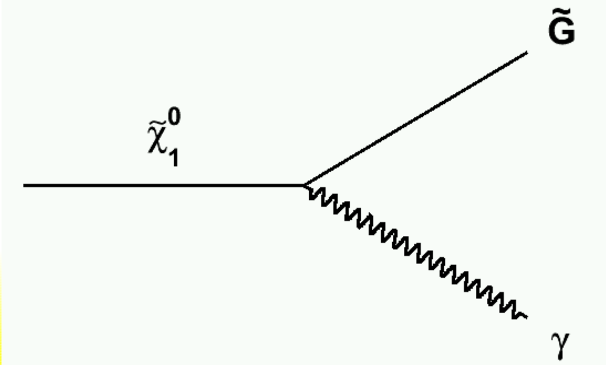
- With the process having such a large cross section it means that it will be a background to other processes involving photons
- For example:
  - The Higgs→γγ decay will have direct photons as a background if the jet is misidentified as a photon
  - An excited quark state would radiate a photon, looking like a direct photon event



QCD background

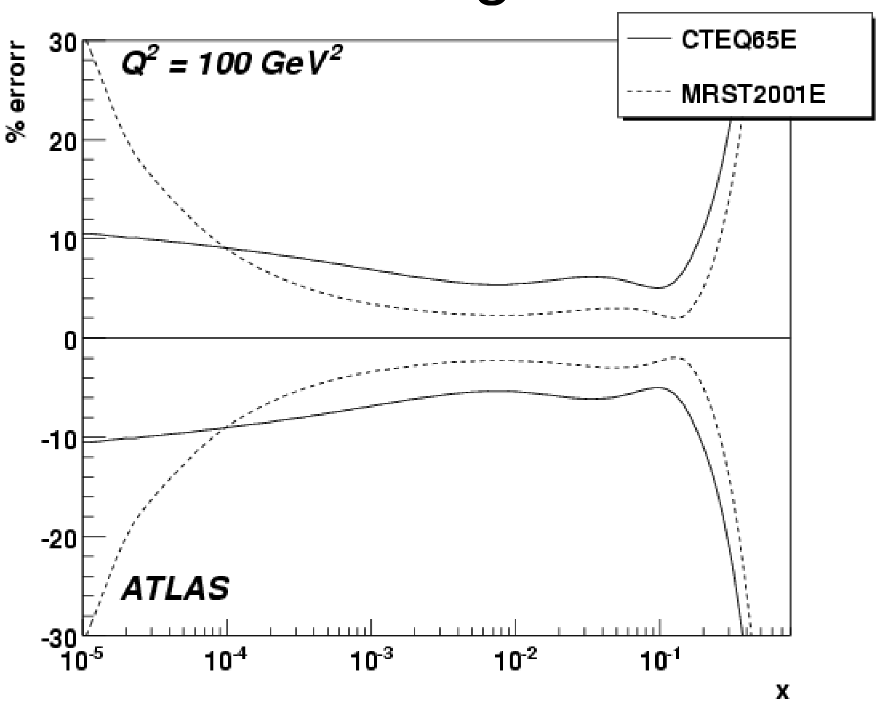
- With the process having such a large cross section it means that it will be a background to other processes involving photons
- For example:
  - The Higgs→γγ decay will have direct photons as a background if the jet is misidentified as a photon
  - An excited quark state would radiate a photon, looking like a direct photon event
  - Delayed/non-pointing photons from SUSY particles will also have direct photons as a large background

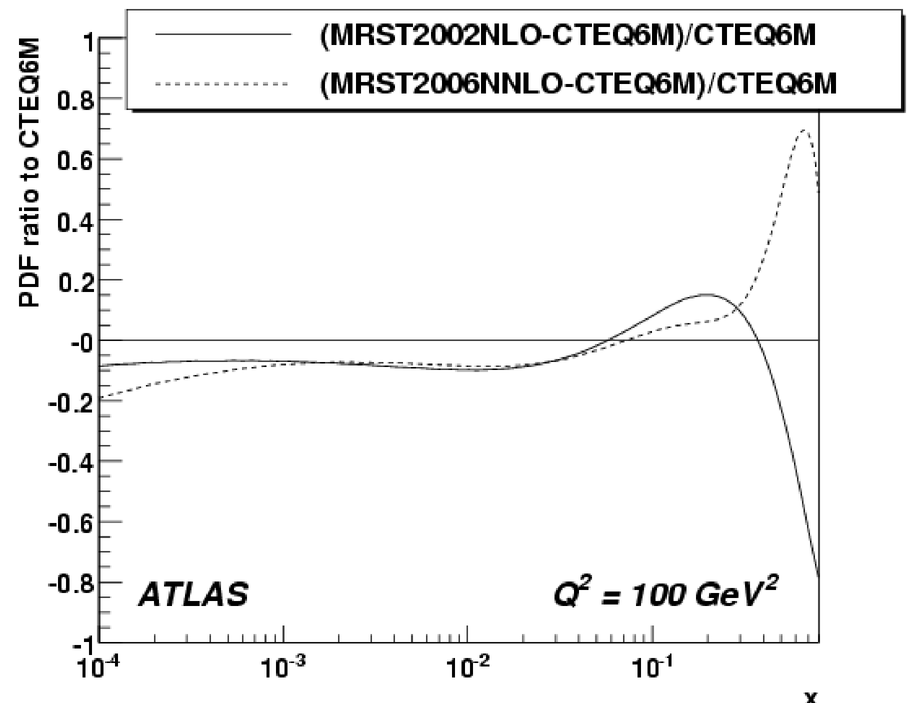




Gluon PDF

- Large uncertainty at high x
  - Important as is discovery region
- At low x:
  - No direct data constraint for $x \leq 10^{-4}$
    - Differences between the PDF sets
  - Does the gluon saturate?

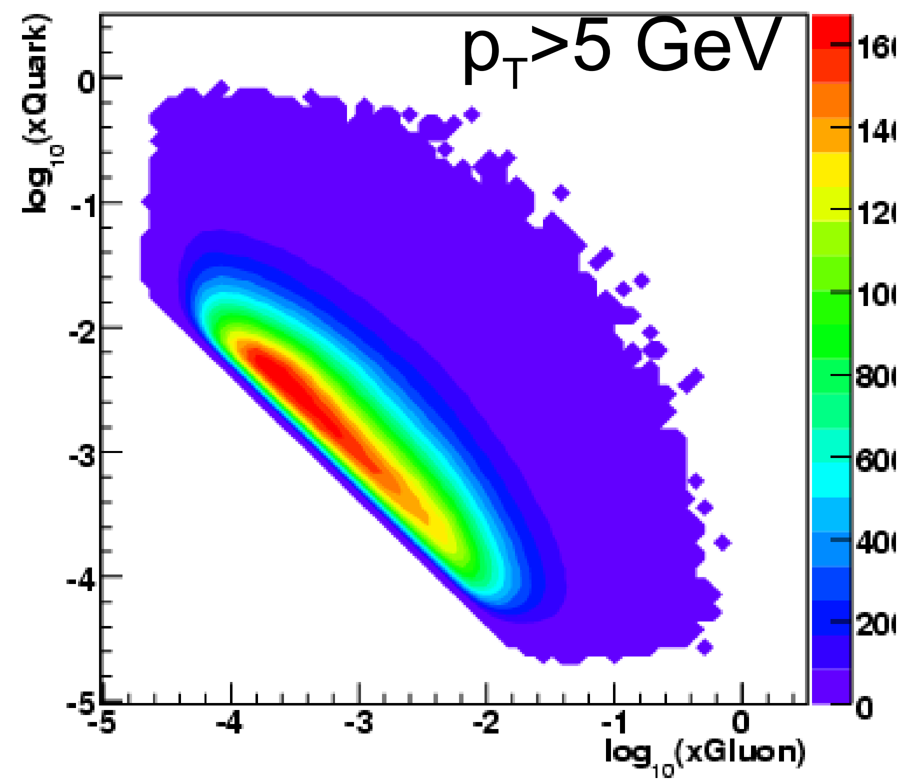




Sensitivity to the low x gluon

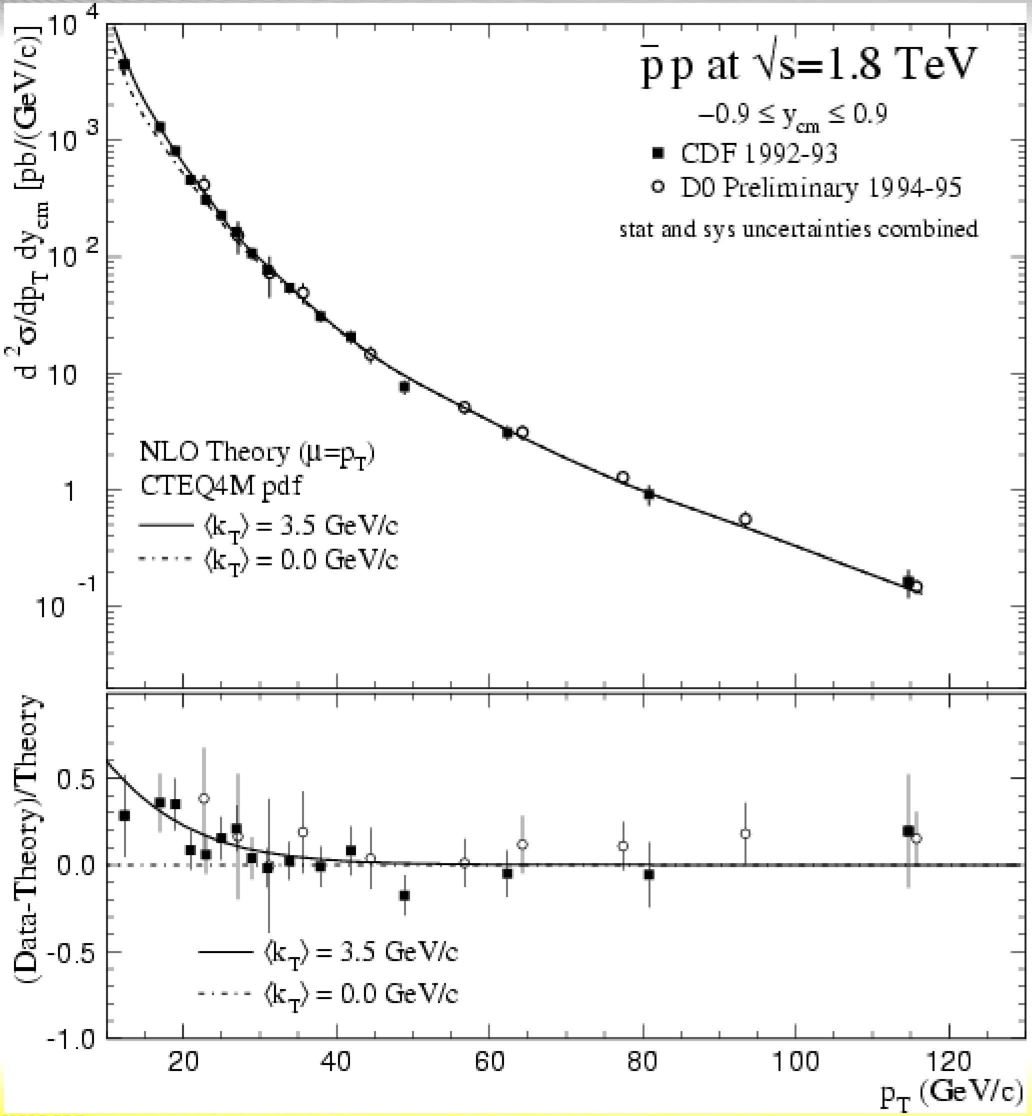
- More often involves low x gluon and high x quark

- Rec of $x_1^{(obs)}$ and $x_2^{(obs)}$:
  - $x_1^{(obs)}=(p_T/\sqrt{s})(e^{\eta jet}+e^{\eta\gamma})$
  - $x_2^{(obs)}=(p_T/\sqrt{s})(e^{-\eta jet}+e^{-\eta\gamma})$
- Direct photons may be useful for this calculation as the γ p_T is well known and only the η of the jet is needed



Mark Stockton

Low PT

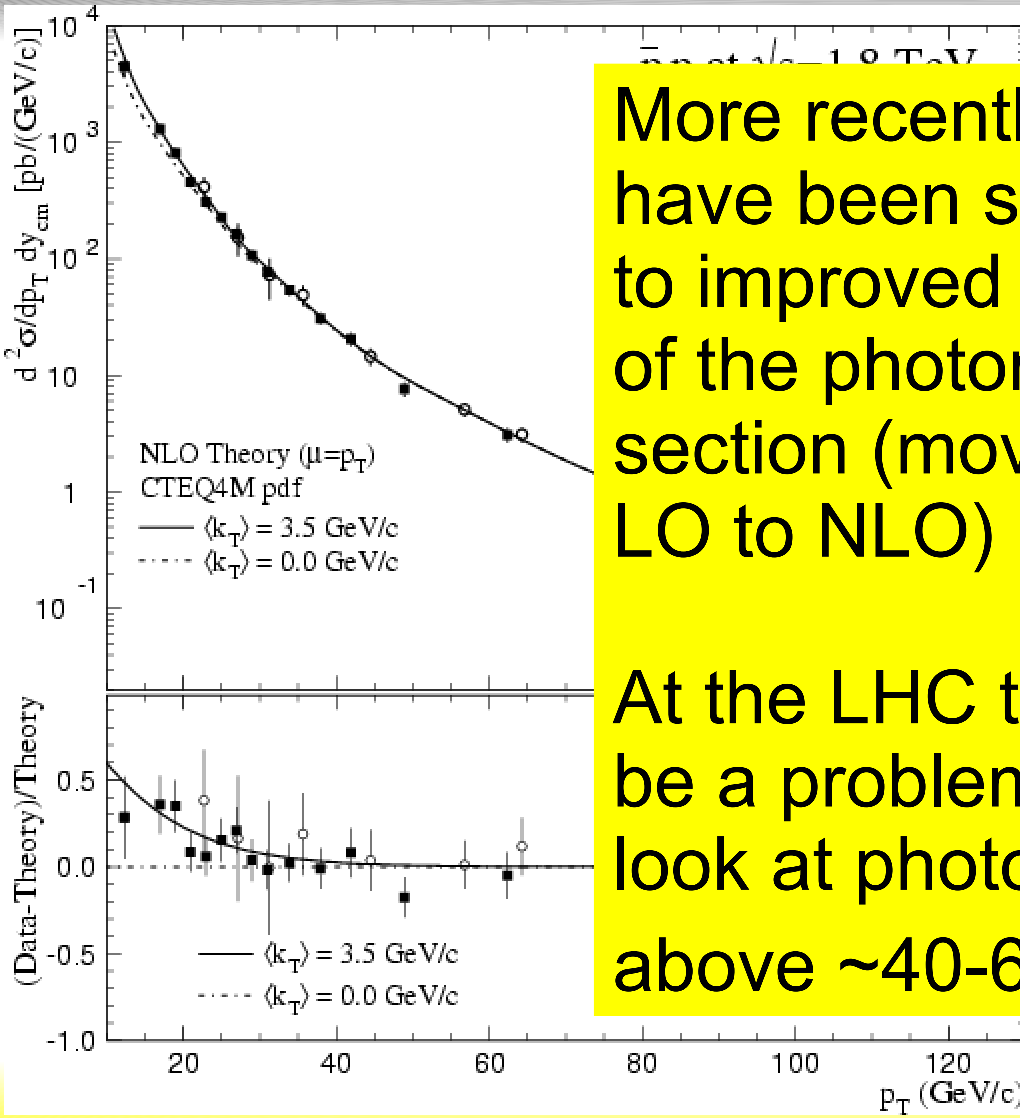


- Previous data taken at the Tevatron is poorly described without intrinsic parton k_T
- Either add k_T factor or is there something else going wrong in the theory?
- Does this suggest that DGLAP evolution is not sufficient?

Apanasevich, L. and others, Phys. Rev. D59 (1999) 074007.

Mark Stockton

Low PT



More recently this may have been solved due to improved definition of the photon cross section (moved from LO to NLO)

At the LHC there won't be a problem if we look at photons with p_T above ~40-60GeV

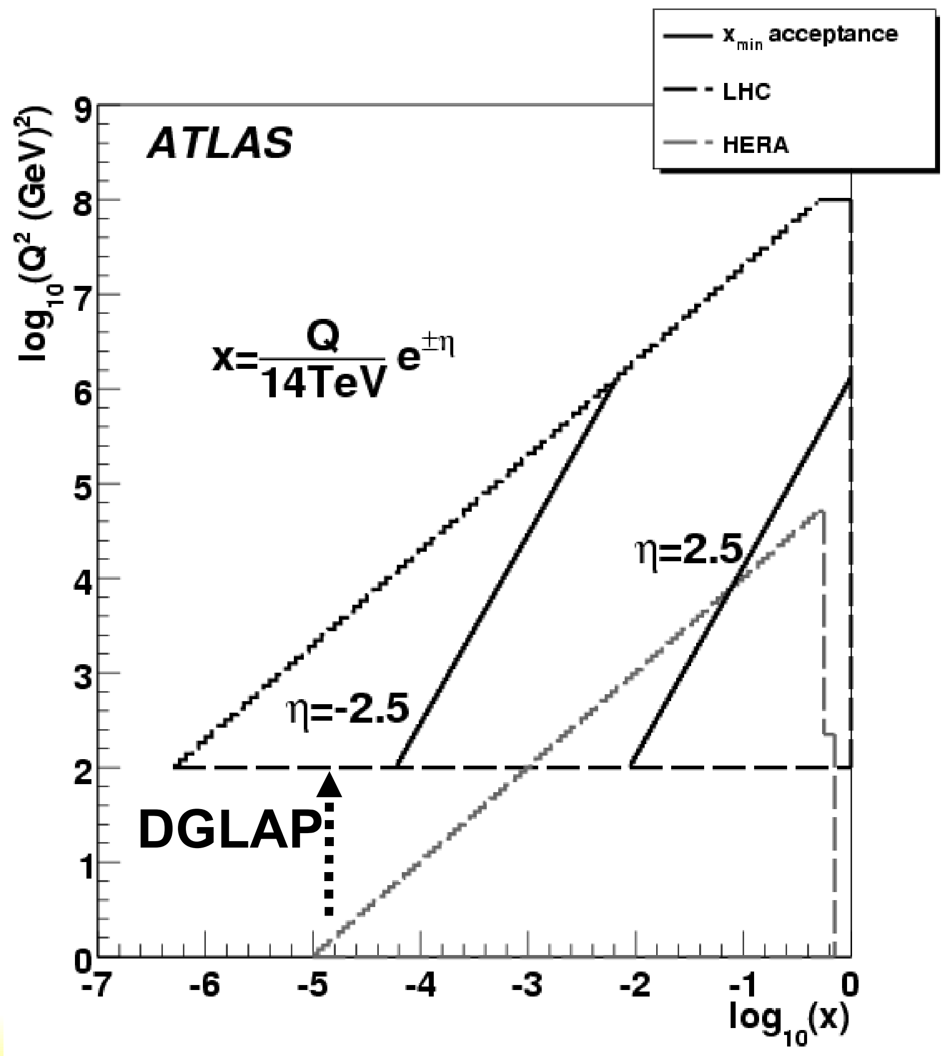
- Previous data taken at …atron is poorly …ed without … parton k_T
- …dd k_T factor or … something …ng wrong in …ry?
- …is suggest that … evolution is …cient?

Apanasevich, L. and others, Phys. Rev. D59 (1999) 074007.

Mark Stockton

Phase space

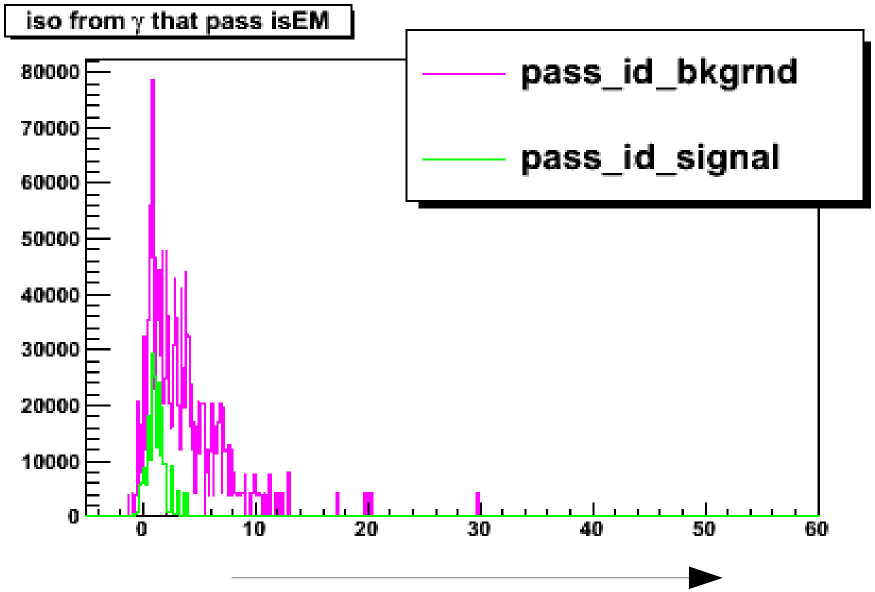
- Covers a wide range of x for a large range of Q^2.
- Most of this area has not been observed before
- Low x region $x<\sim10^{-4}$ accessed at scales where perturbative QCD is clearly applicable for the first time
- To reach even lower x values need lower Q (p_T)
- Will not see saturation but will see evolution from a saturated region



First Measurements

- The first aim would be to measure the cross section... but in early data a method is needed to estimate the amount of background from data

- As the EM calorimeter rejects 2999 out of 3000 fake photons from jets, the remaining fake photons match the shower distributions for real photons, hence why they weren't removed

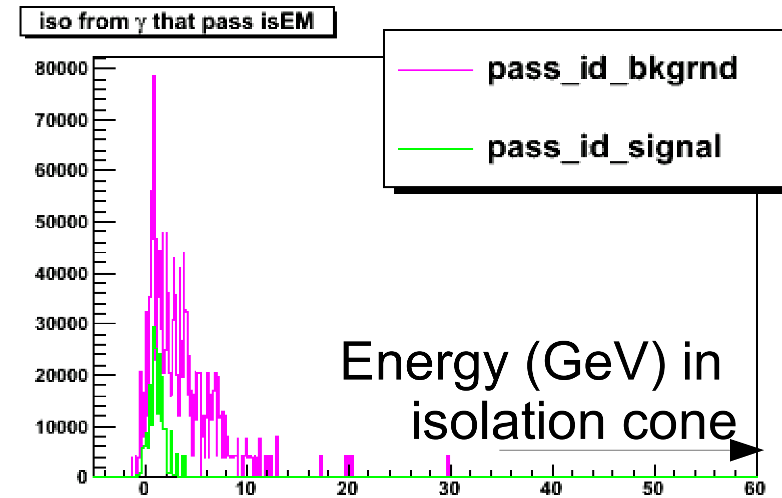


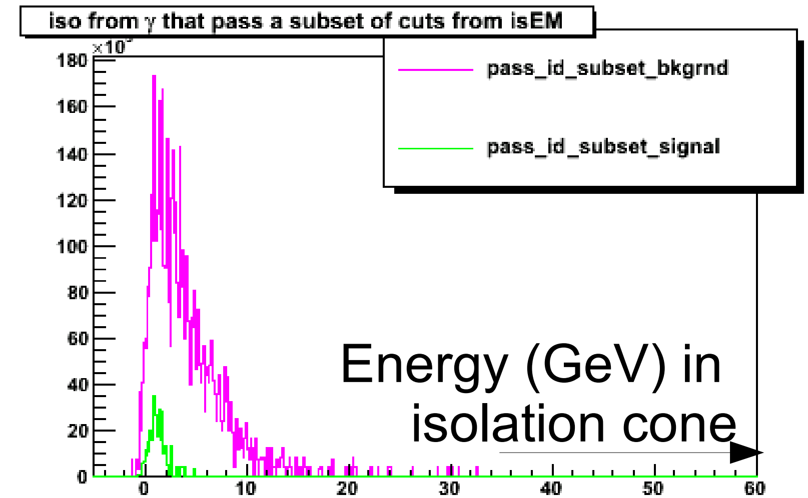
Energy (GeV) in isolation cone
i.e. a cone around the reco photon
(Bkgrnd here includes brem events)

Mark Stockton

Background from data

- As the MC has never been tested at LHC energies, then this number of fakes can't be trusted
- So instead of removing all the background from the sample to study, a looser selection needs to be defined which allows more background to pass the photon identification cuts





Methods

- With more background the normalisations of the MC can be checked by studying the shower shape in the calorimeter
- Example methods include:
  - Extrapolation of the background fraction from a region without signal to a region with signal
  - Make Log Likelihood estimators of individual shower shape variables
  - Use individual cuts to obtain a matrix of number of remaining and predicted efficiencies of each cut

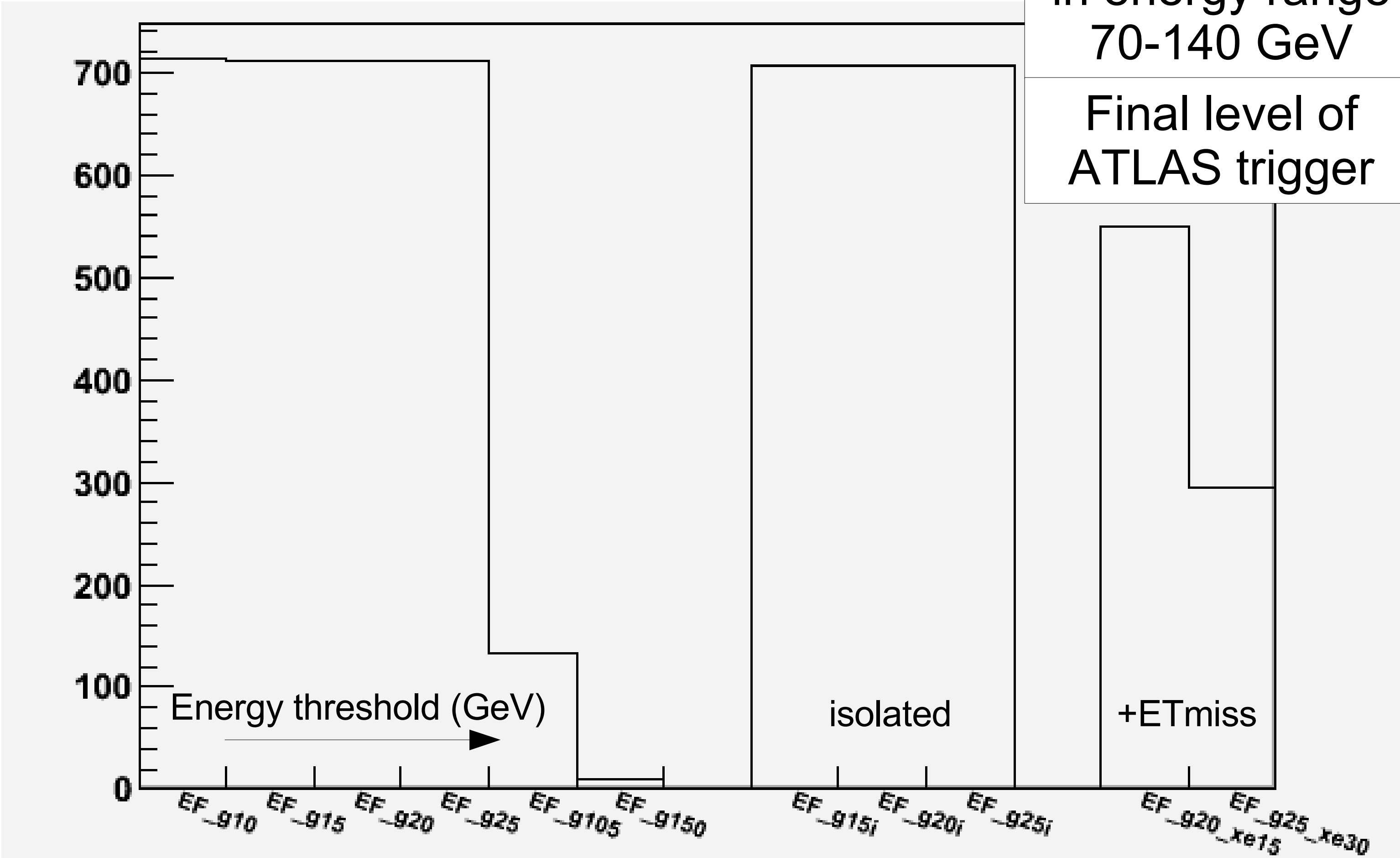
Trigger

- Of course all this work of allowing more background through is undone if the trigger wouldn't write out the data

1000 LO events in energy range 70-140 GeV

Final level of ATLAS trigger

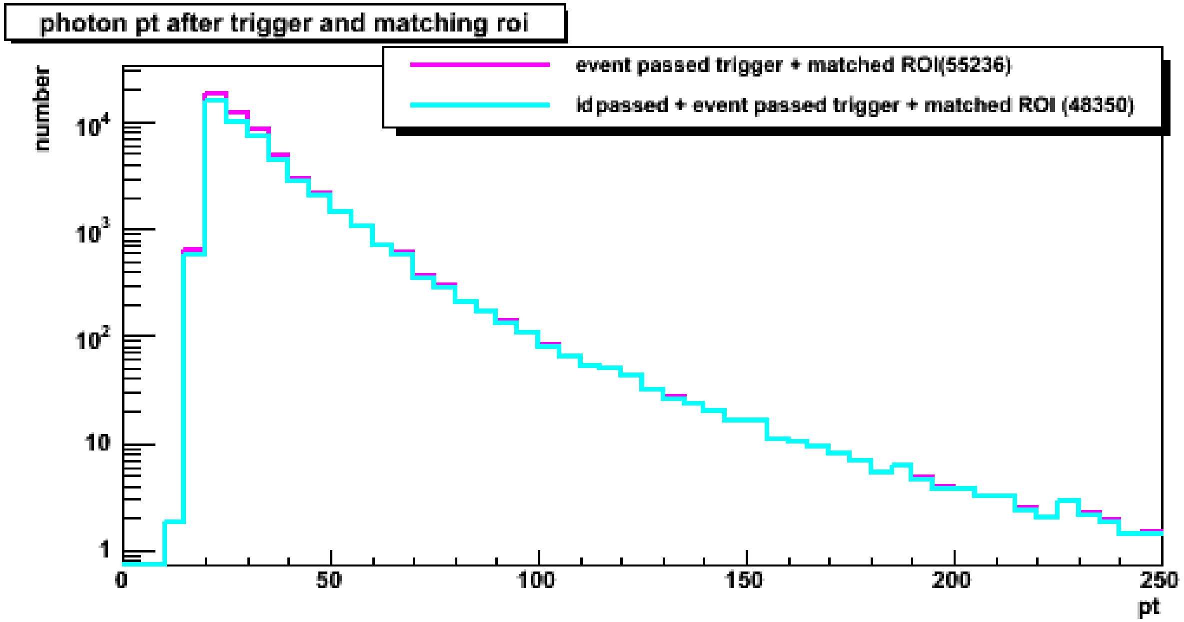
- First study how many events pass trigger:



Mark Stockton

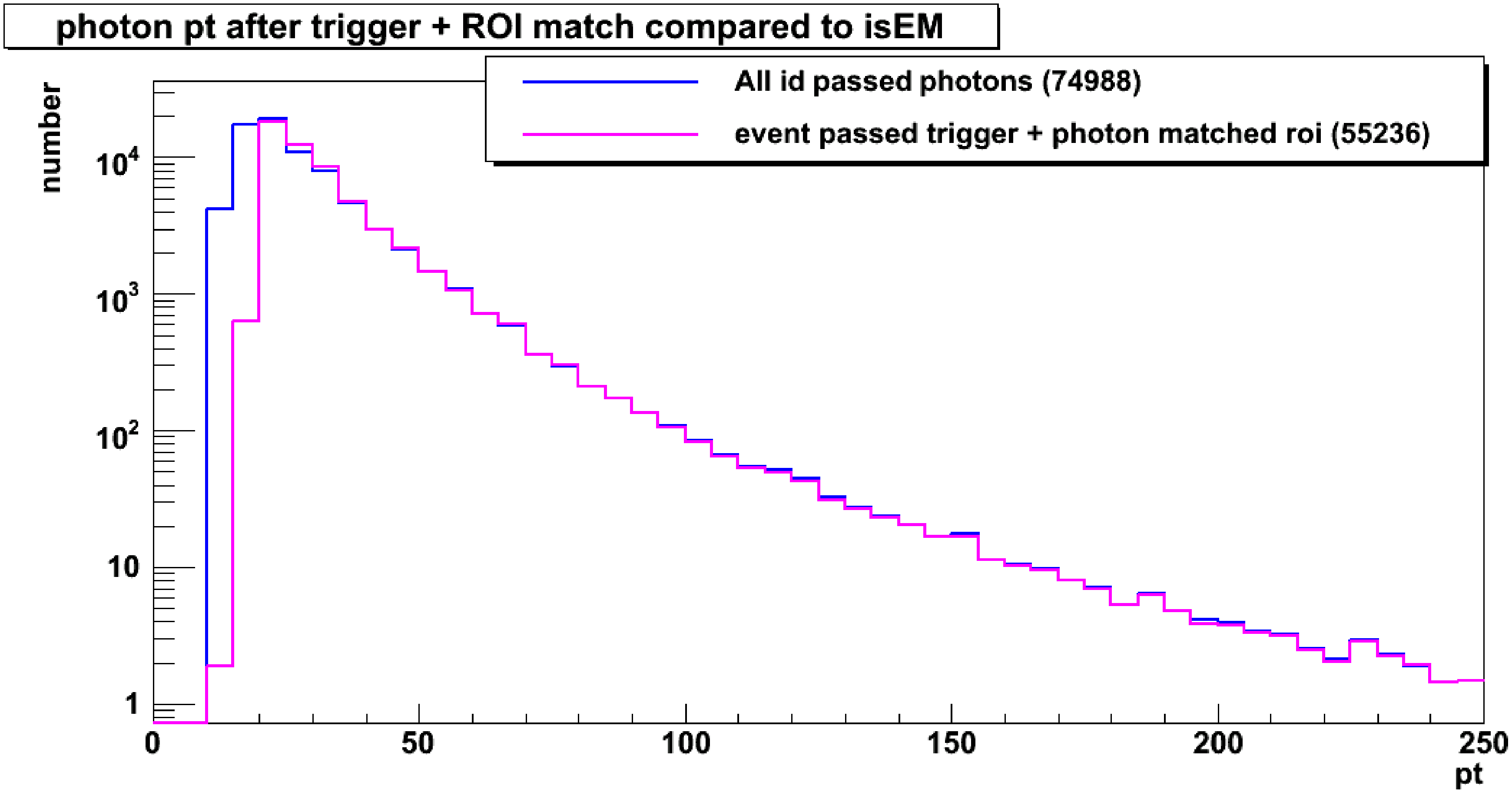
L1 trigger

- Each passed EM trigger item will have an associated Region Of Interest (ROI) produced by the L1 calorimeter trigger
- When looking at reconstructed photons that match this ROI nearly all have passed the tight photon identification



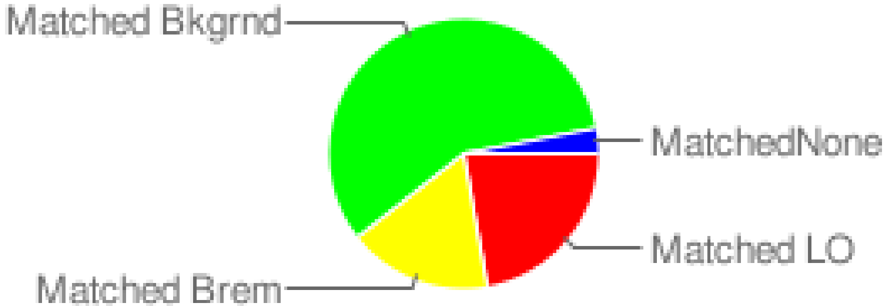
Well done trigger

- Actually the trigger does so well that over the entire p_T distribution it matches the tight ID with no trigger selection:



Event type

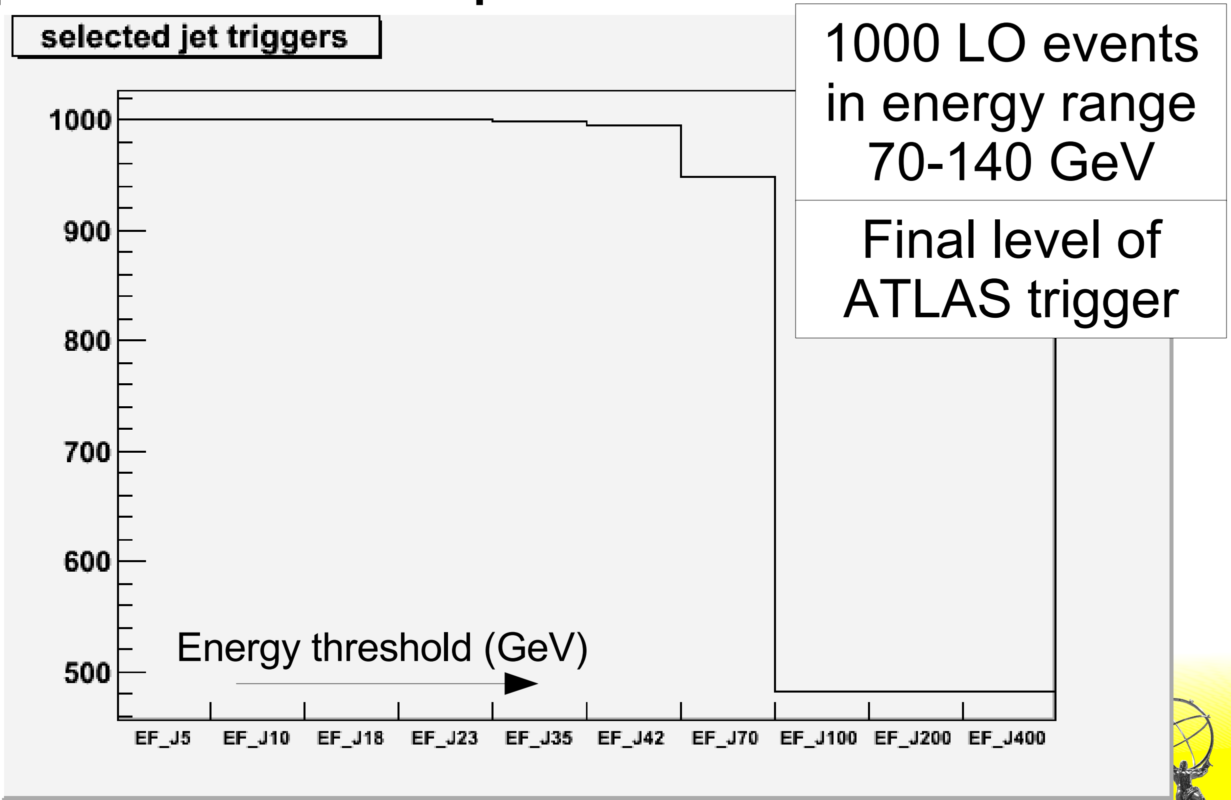
- This was from looking at just LO signal events but what types of photons are matched in combined signal and background samples:



- So some background is selected even though the trigger is performing the tight photon ID
- Would have to apply nearly no offline cut to keep as much background as possible

Alternatives

- A different trigger item definition with a looser selection would allow more background
- Or for the loosest selection it could be a jet item
- This would still pick the direct photon events
- But would now be swamped in background.
- Could get efficiency for photon trigger from within jet sample



Future

- Once the background is well modelled then study:

- Cut Optimisation
- Cross Section
- Reconstruction of the incoming partons

- Study conversions to increase acceptance

- (Also have to consider the effects of pileup and the systematics involved in the measurement)

Cut Optimisation

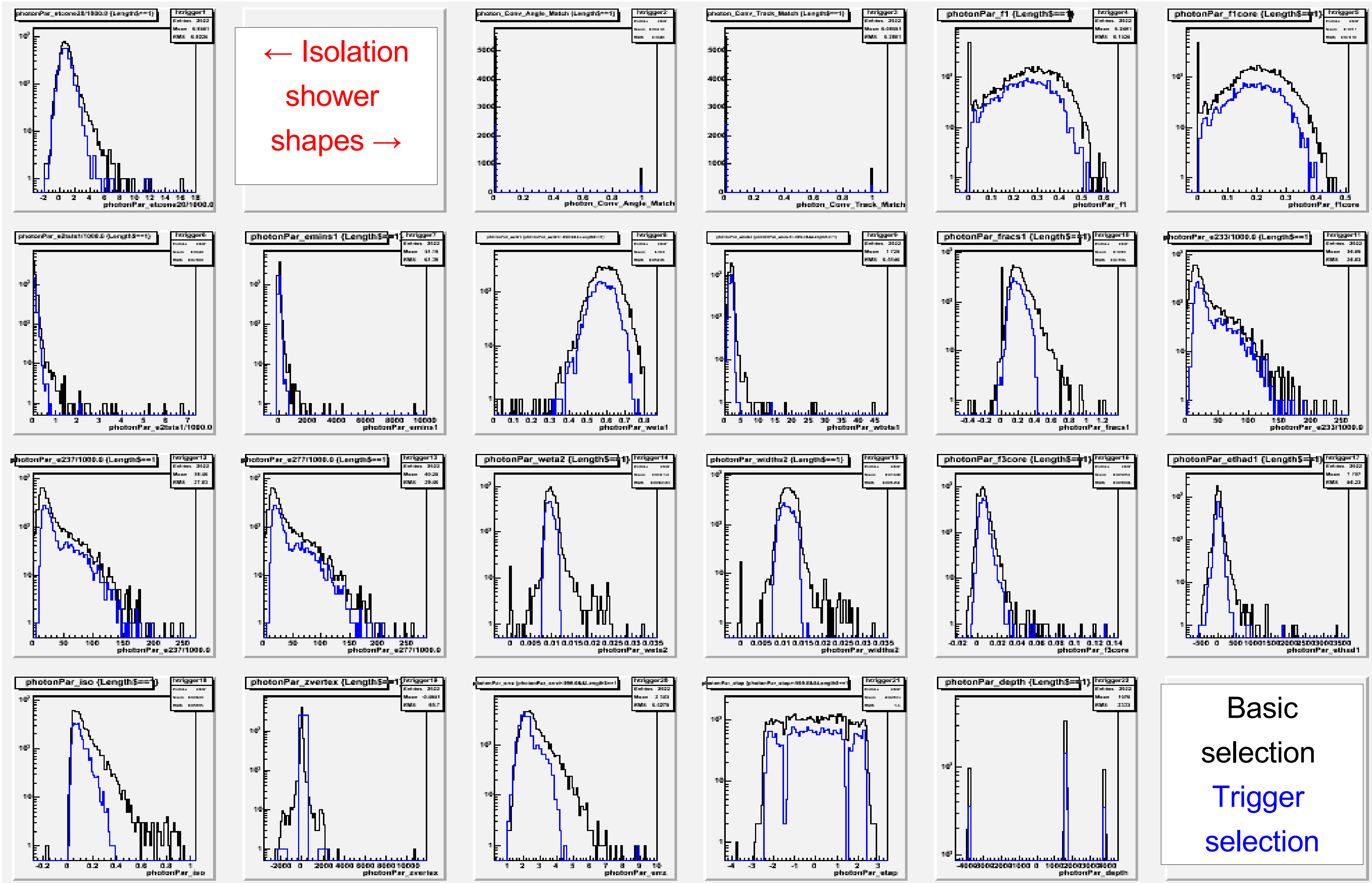
- Have to optimise the selection to have the best signal to background ratio
- Can look at either improving the current identification
- Or can cut on variables not already cut on:
  - Isolation
  - Missing Energy
  - Tracks inside the jet/near the photon

Current ID

- Currently has over 20 shower shape variables to make the tight photon selection, with cuts divided into bins in η and p_T
- Originally designed for low p_T photons for Higgs searches
- Ivan added extra bins in p_T to improve the jet rejection by factors of between 4 and 20
- Martin also investigated this in a later release to investigate which were the most useful cuts
- The best way to perform this is through multi-variate techniques

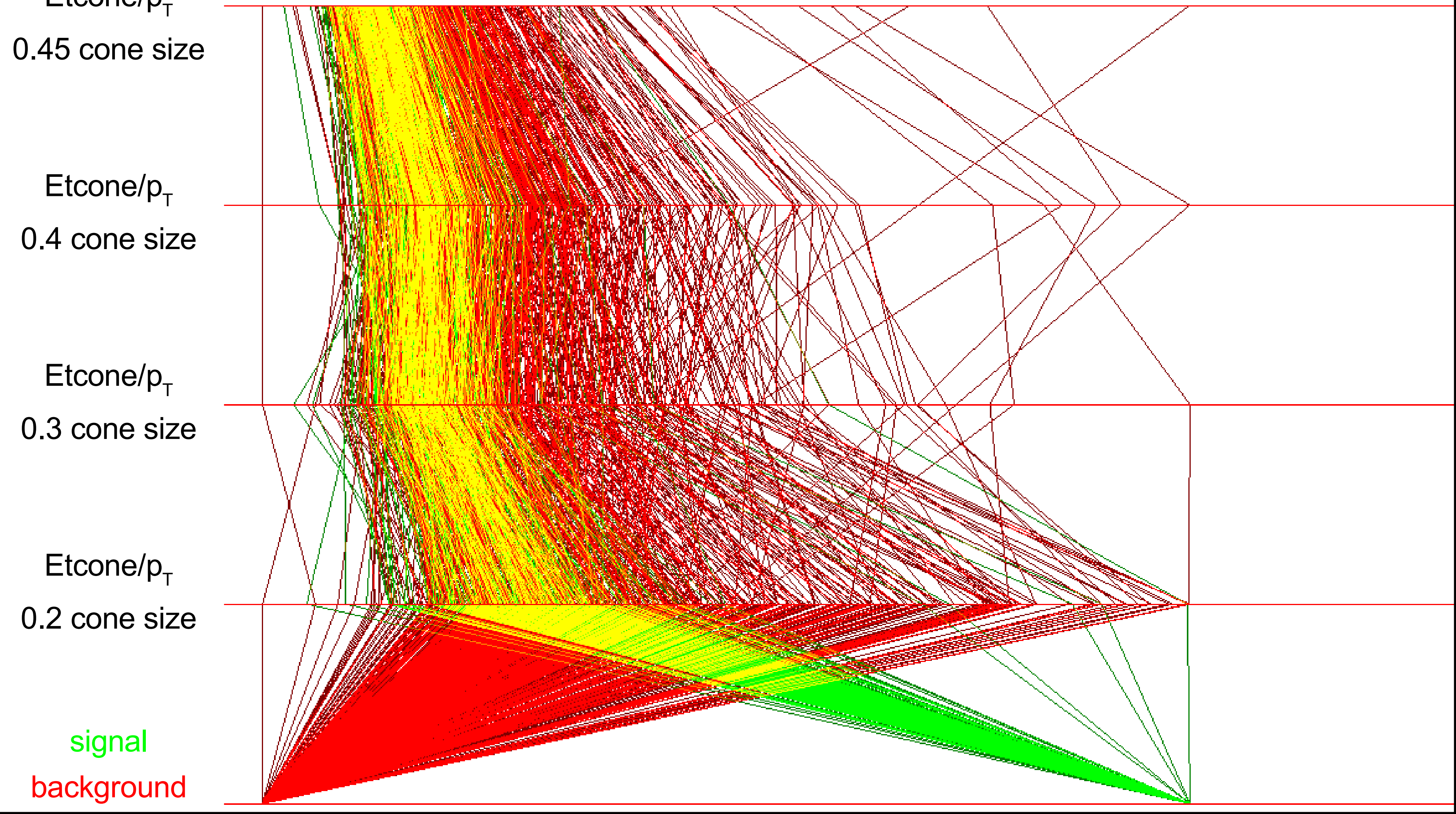
Mark
Stockton

Shower variables



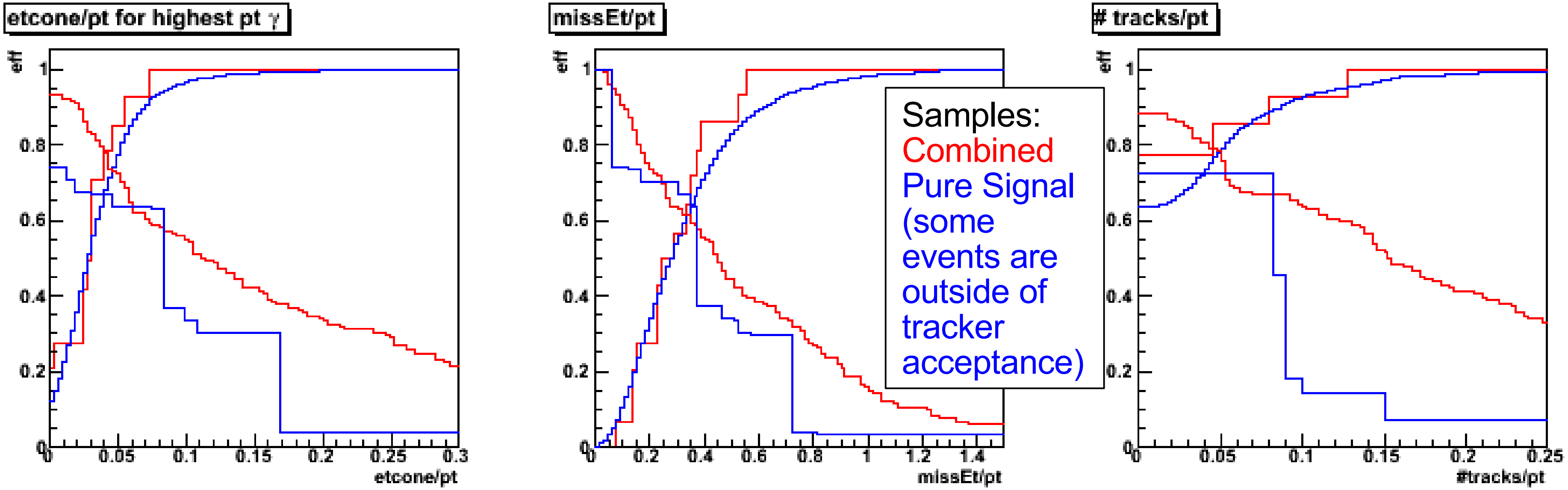
Multivariate analysis

- One example of viewing the relations between these variables is using parallel coordinates



Other variables

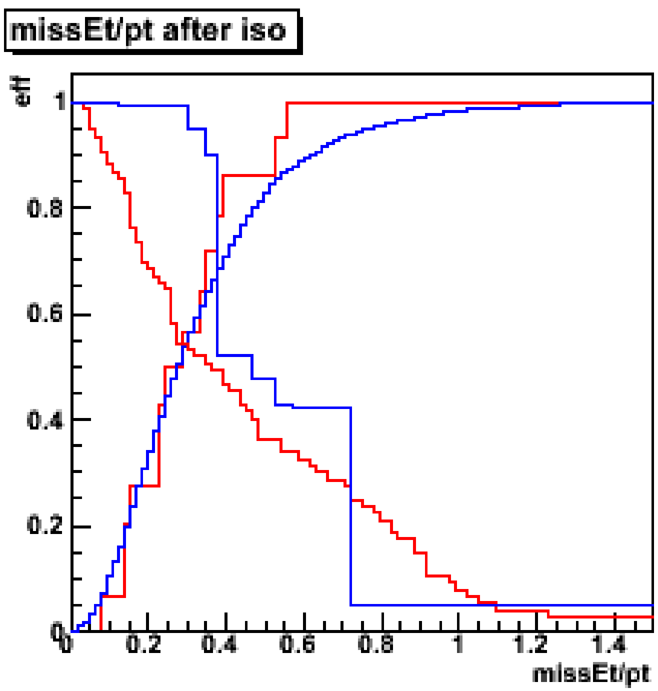
- Etcone = energy in a cone around the photon
- MissEt = should be small as the event should be balanced
- #tracks = number of tracks in the direction of the photon, to remove photons inside a jet

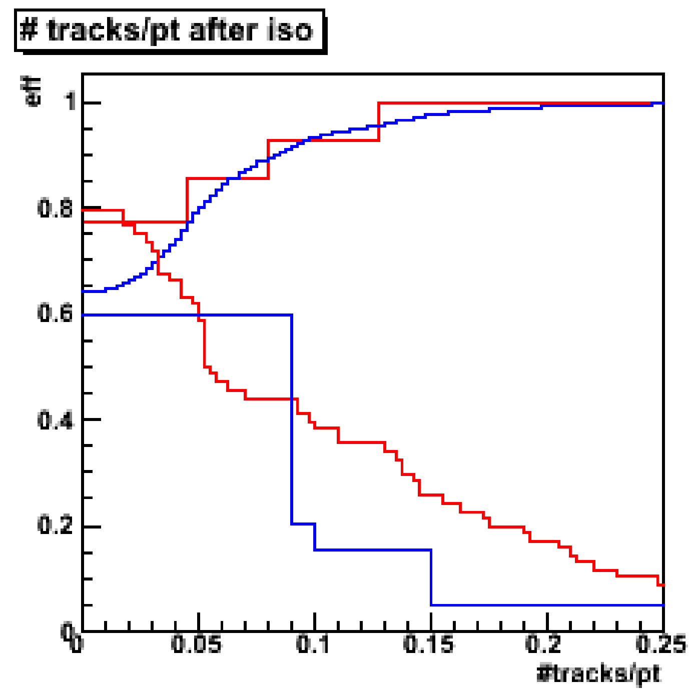


- Scale with p_T so don't need have the cut binned in energy

Apply optimisation

- Also can split into 3 bins: Barrel |η|<1.37, Crack 1.37≤|η|≤1.52 and Endcap 1.52<|η|<2.5
- Still gave the same result that the etcone is most useful
- Apply this and the other cuts are not so useful:





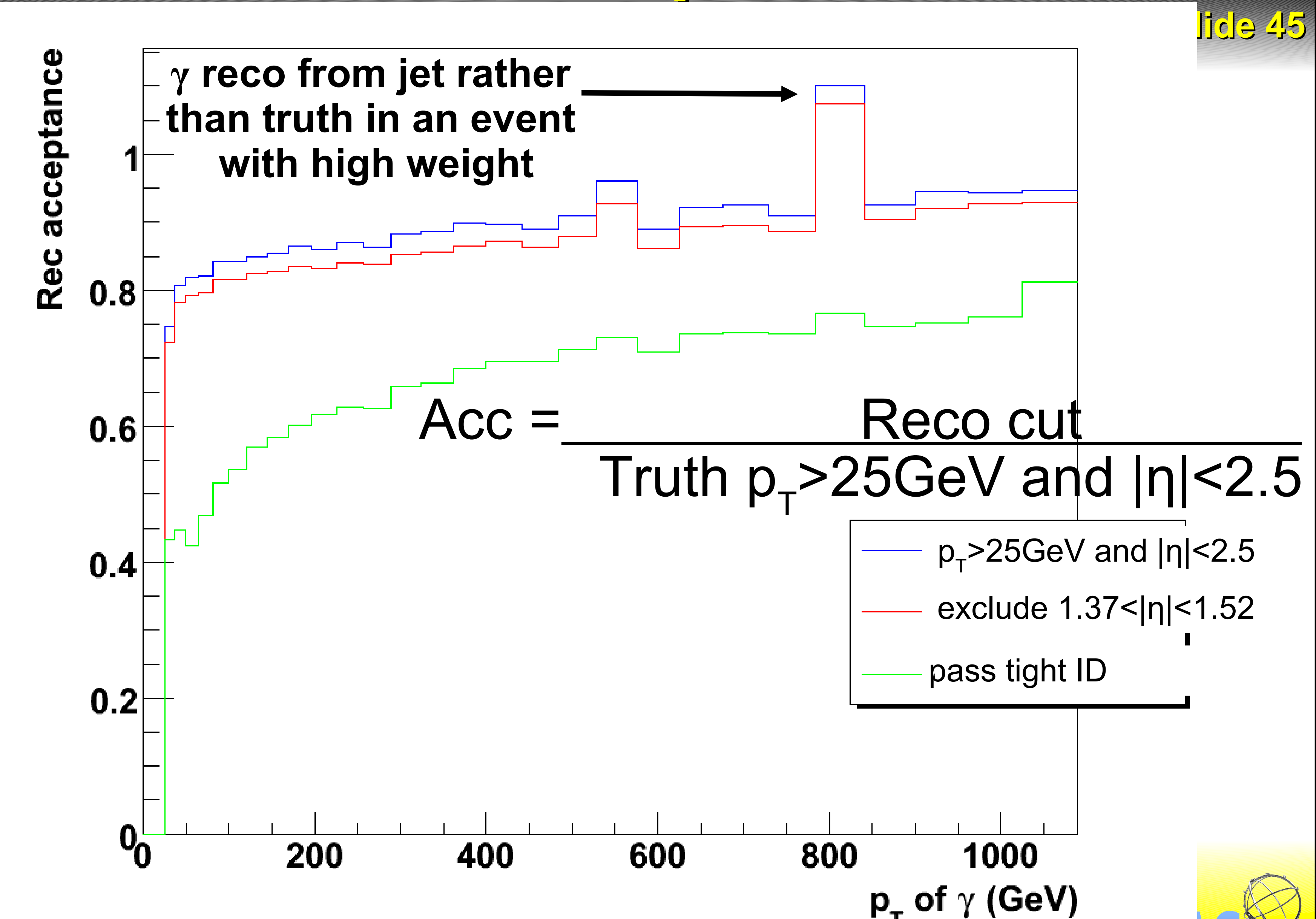
Cross section

- Differential cross section in p_T and η
- η bins will be defined by the detector geometry
- Can be just barrel, crack and endcap or if have more data then can depend on the fine granularity of the EM calorimeter

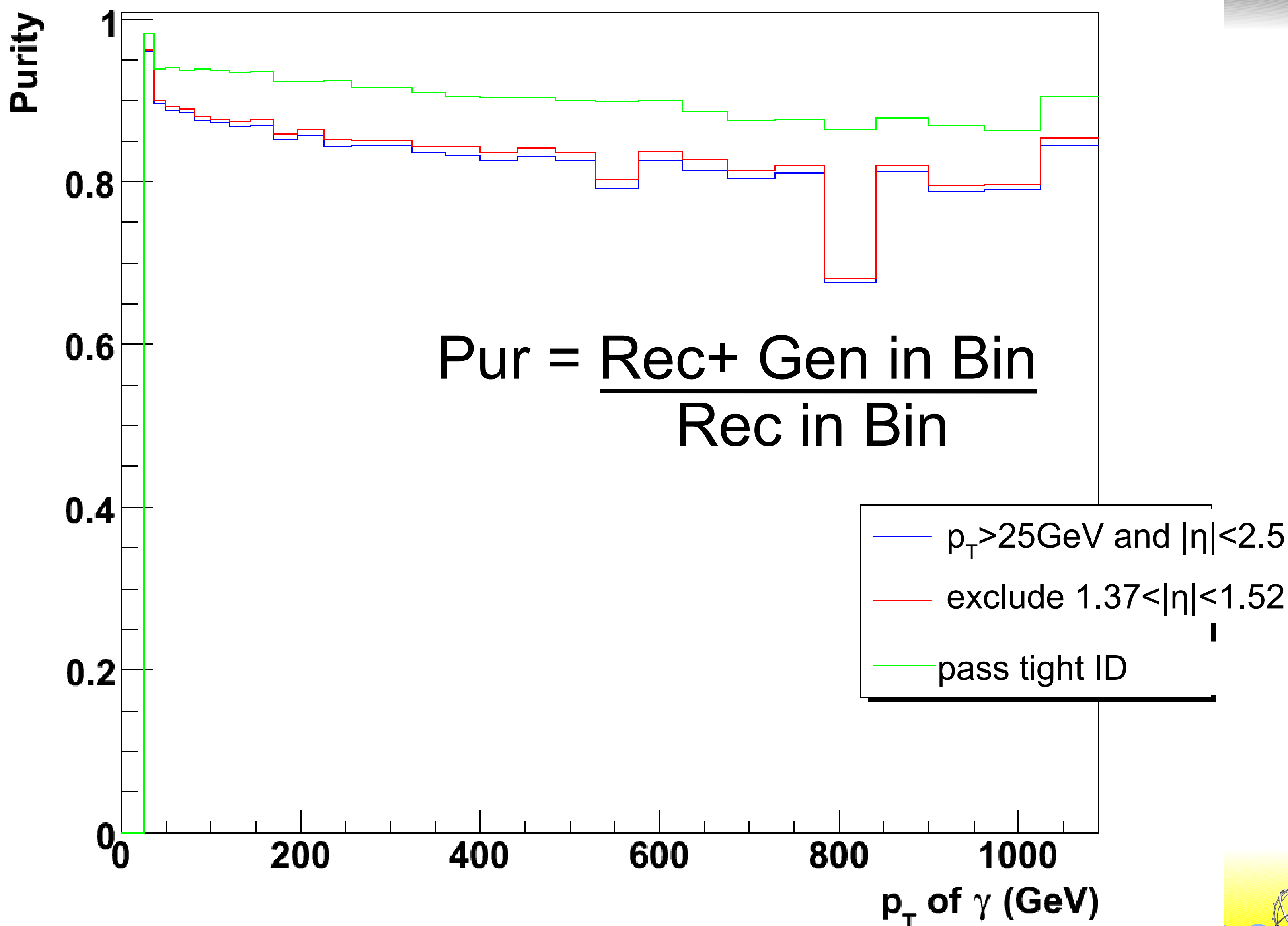
Barrel region granularity $\Delta\eta \times \Delta\phi$		
Presampler	0.025x0.1	$\eta < 1.52$
Calorimeter 1st layer	0.025/8x0.1	$\eta < 1.40$
	0.025x0.025	$1.40 < \eta < 1.475$
Calorimeter 2nd layer	0.025x0.025	$\eta < 1.40$
	0.075x0.025	$1.40 < \eta < 1.475$
Calorimeter 3rd layer	0.050x0.025	$\eta < 1.35$

- The p_T bins will depend on purity and acceptance

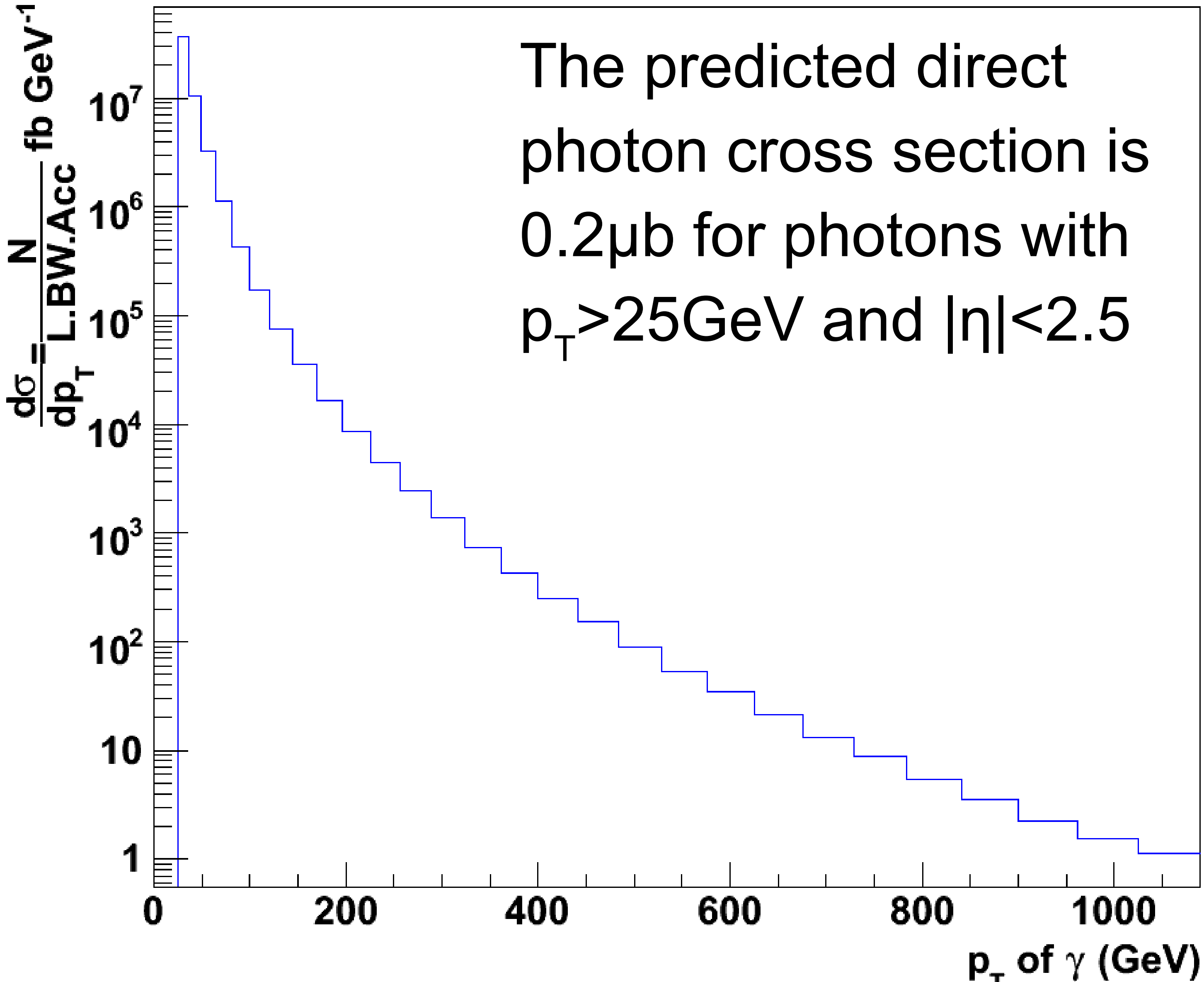
Reco Acceptance



Reco Purity


Purity
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
pT of γ (GeV)
Pur = Rec+ Gen in Bin / Rec in Bin
pT>25GeV and |η|<2.5
exclude 1.37<|η|<1.52
pass tight ID

Signal Cross section

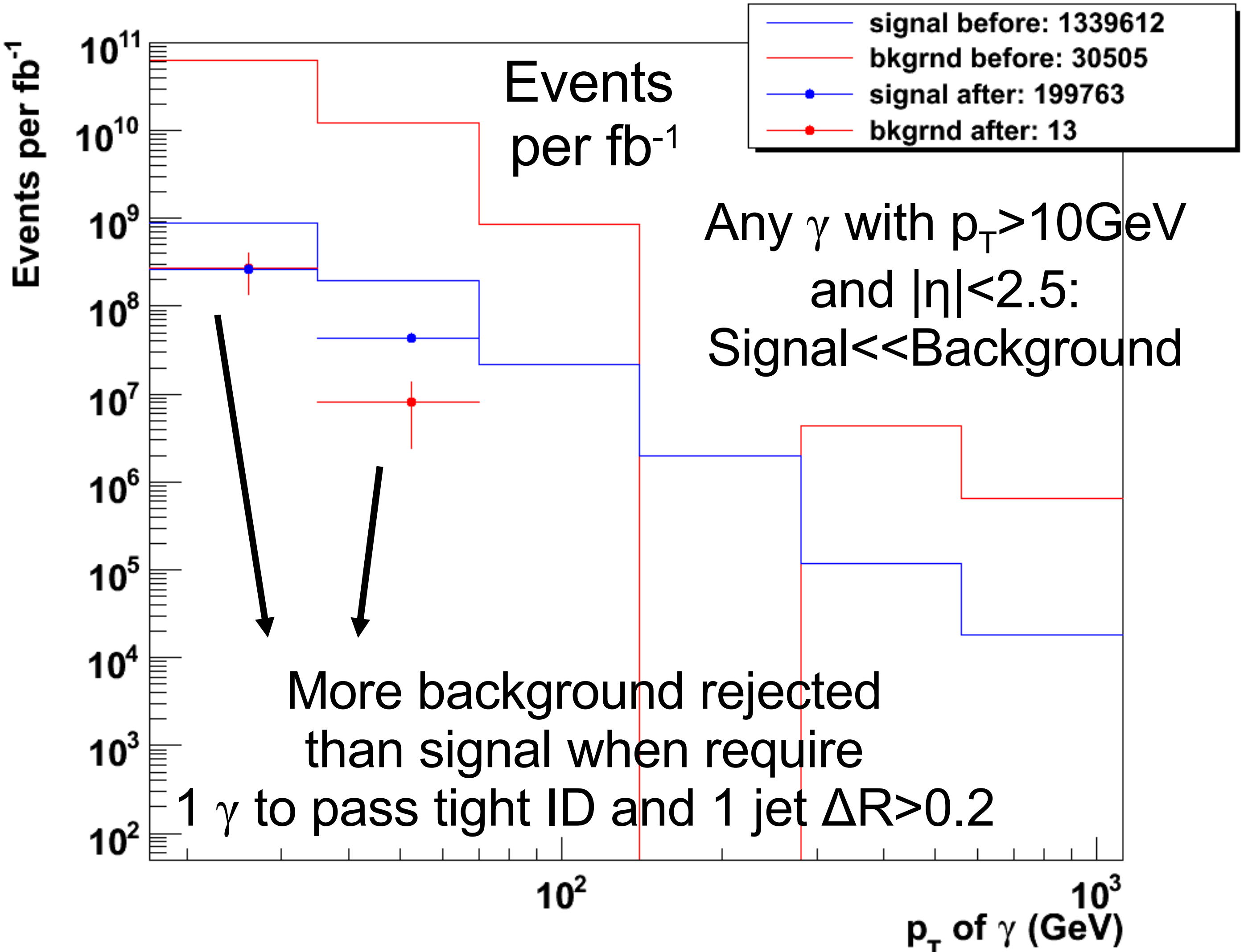


The predicted direct photon cross section is 0.2μb for photons with p_T>25GeV and |η|<2.5

Mark Stockton

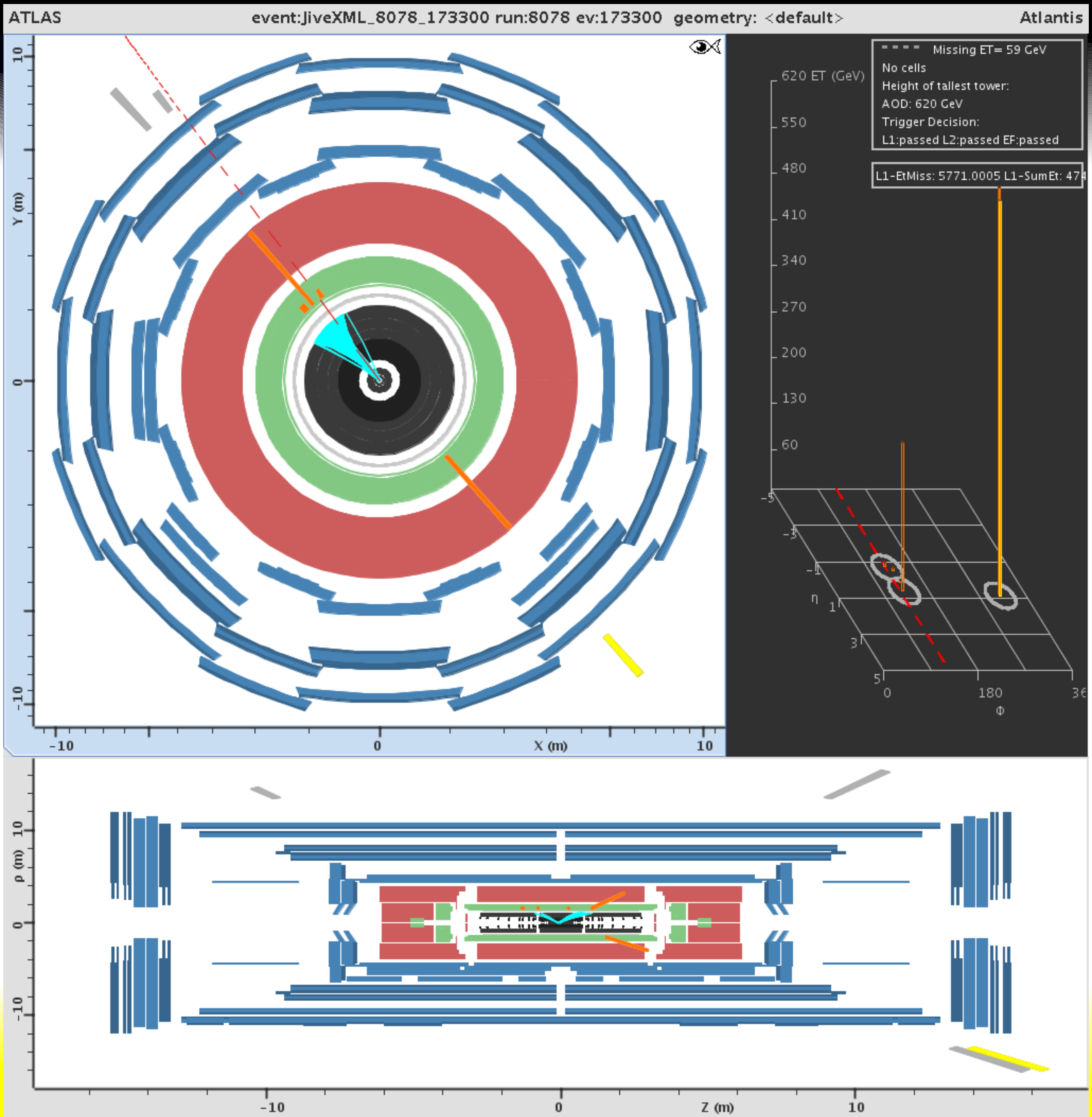
Comparison to background

- A preliminary example of the background rejection



Highest p_T

slide 49



Would be nice to have detailed analysis of one high p_T event as will most likely the highest p_T photons observed in a pp experiment to date

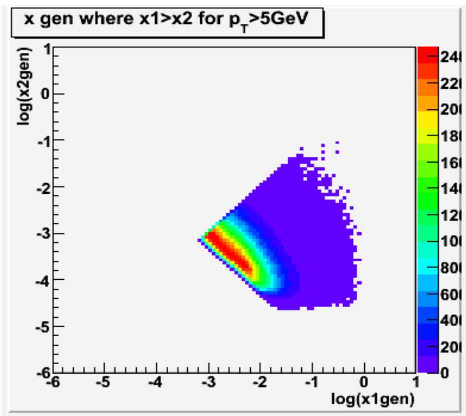
Incoming partons

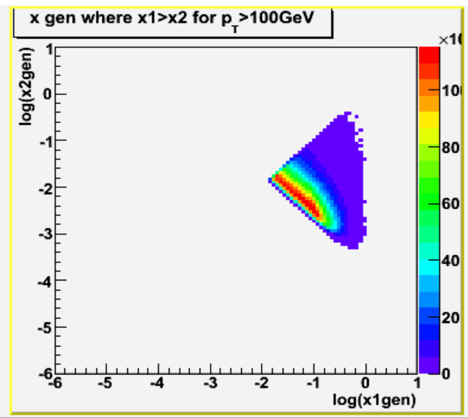
- Once the data is well understood and the cross section has been compared to previous results the work can then look at the low p_T end of the distribution
- This can then involve reconstructing the x fractions of the colliding particles
- I have performed this with the pure MC, truth, and reconstructed data.
- In the reconstruction you can no longer determine the q/g, or which process was involved, so instead the x fractions have to be ordered x1 always greater than x2.
  - Gluon jets are usually wider, but not always
- $x1^{(obs)}$ or $x2^{(obs)} = (p_T/\sqrt{s})(e^{\pm\eta jet} + e^{\pm\eta\gamma})$

Mark
Stockton

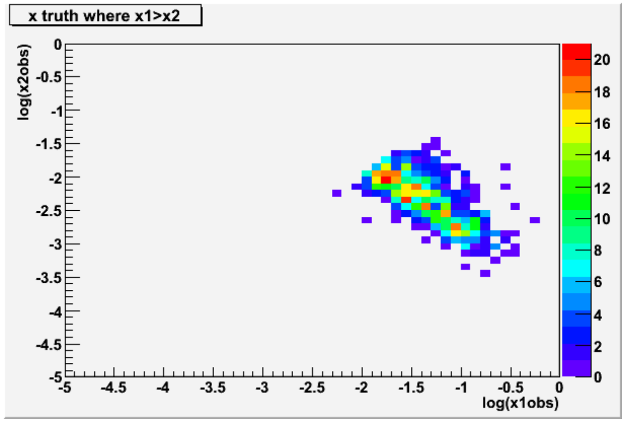
Observed X fractions

Gen

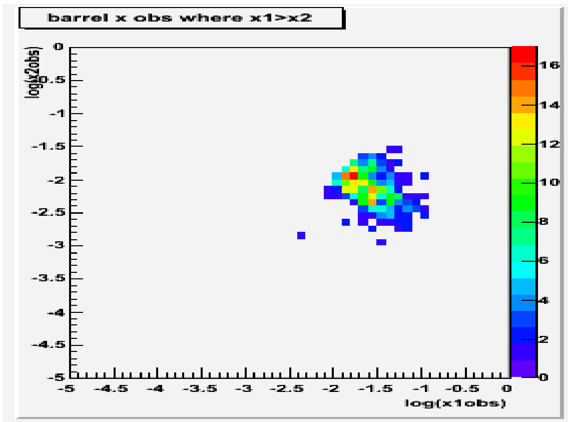


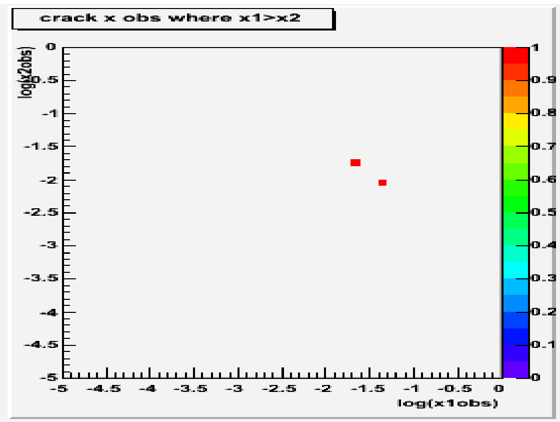


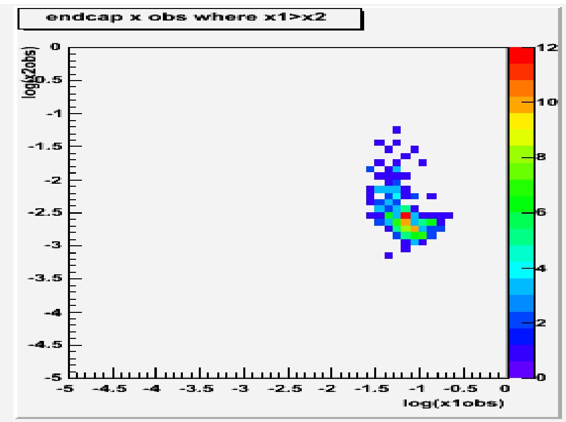
Truth



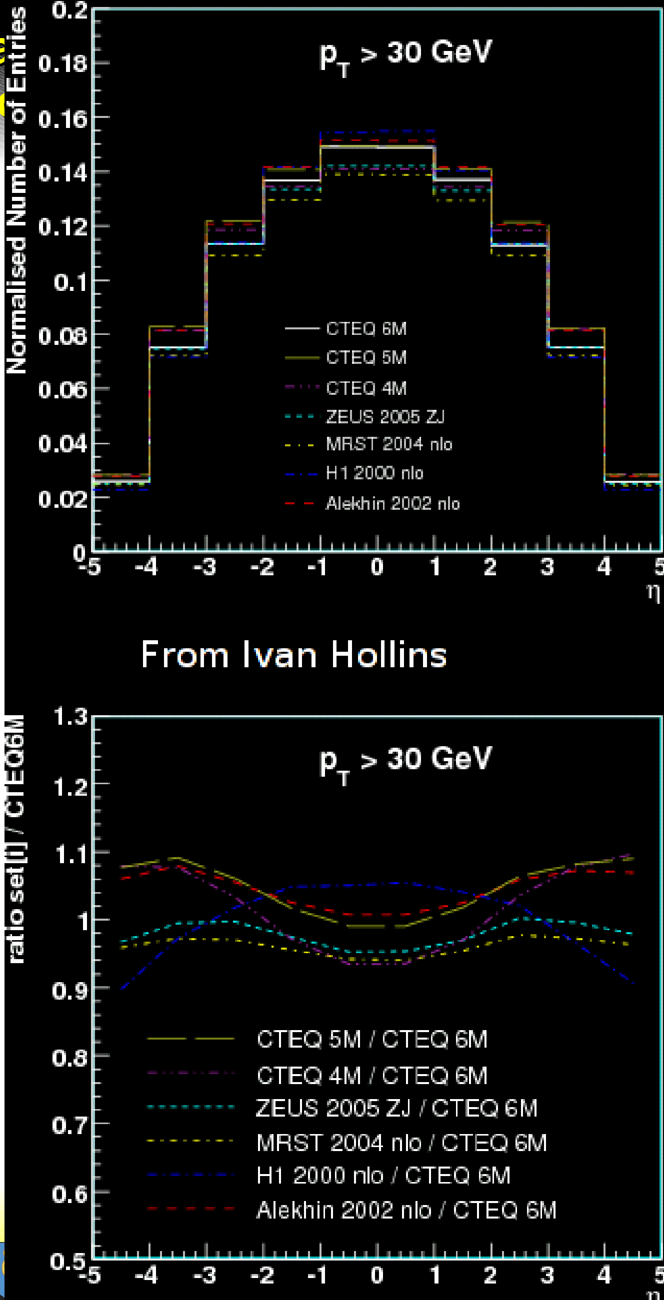
Split above into bins (barrel, crack and endcap) as in reco below:







Outcomes

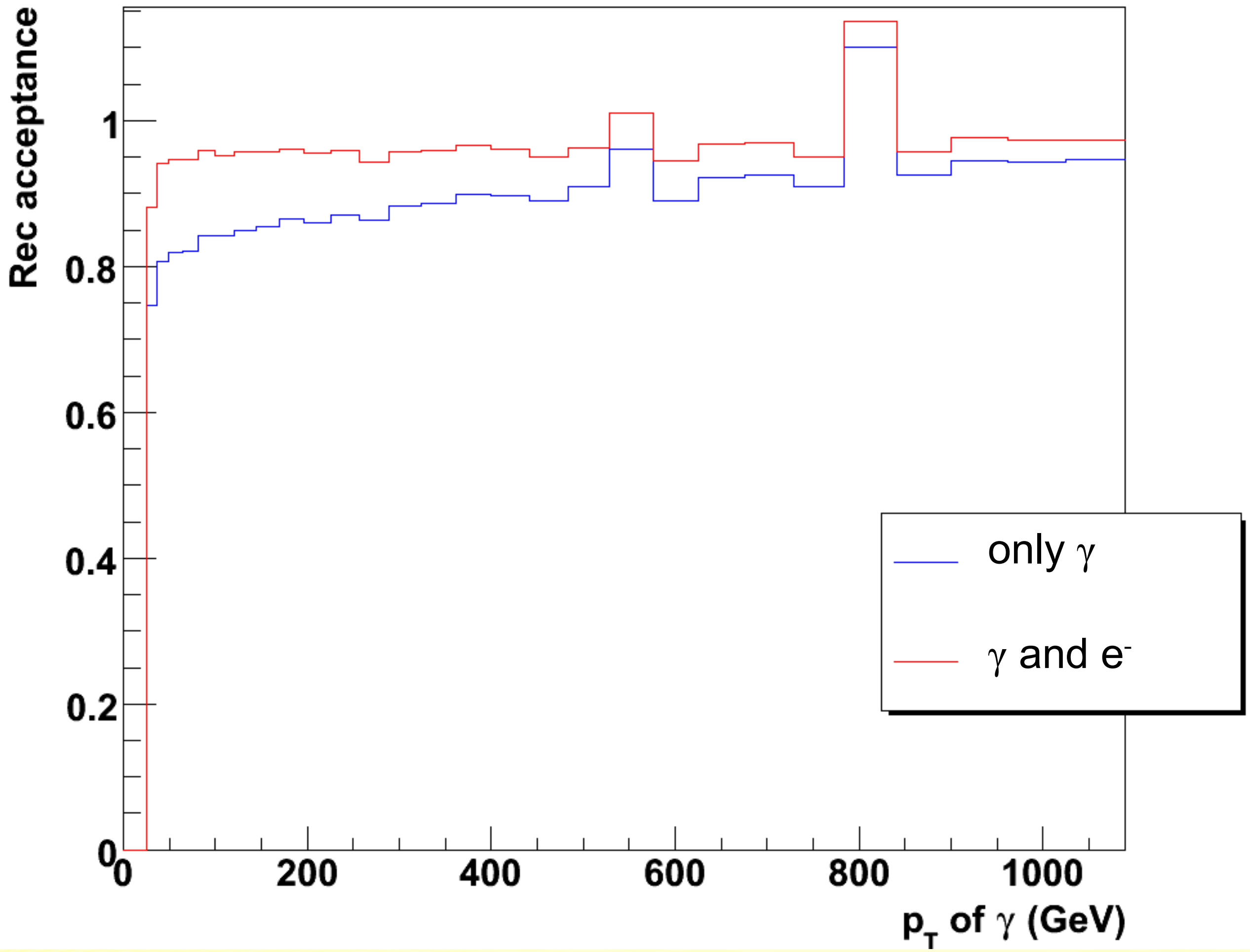


- The aim would be to compare several PDF results
- As done by Ivan the η distribution shows the differences between the PDF's at the 10% level
- With accurate photon measurements these differences should be observed with a relatively small amount of data

Conversions

- The photon coming from the interaction point may convert in the material before hitting the calorimeter.
- In fact 70% do convert but only around 30% convert early enough (i.e. not in the solenoid) to leave a track in the tracker
- This is a loss in photon efficiency which can be recovered using specialised tools or improved photon/electron definitions
- The other conversions should be kept by using the presampler layer of the calorimeters

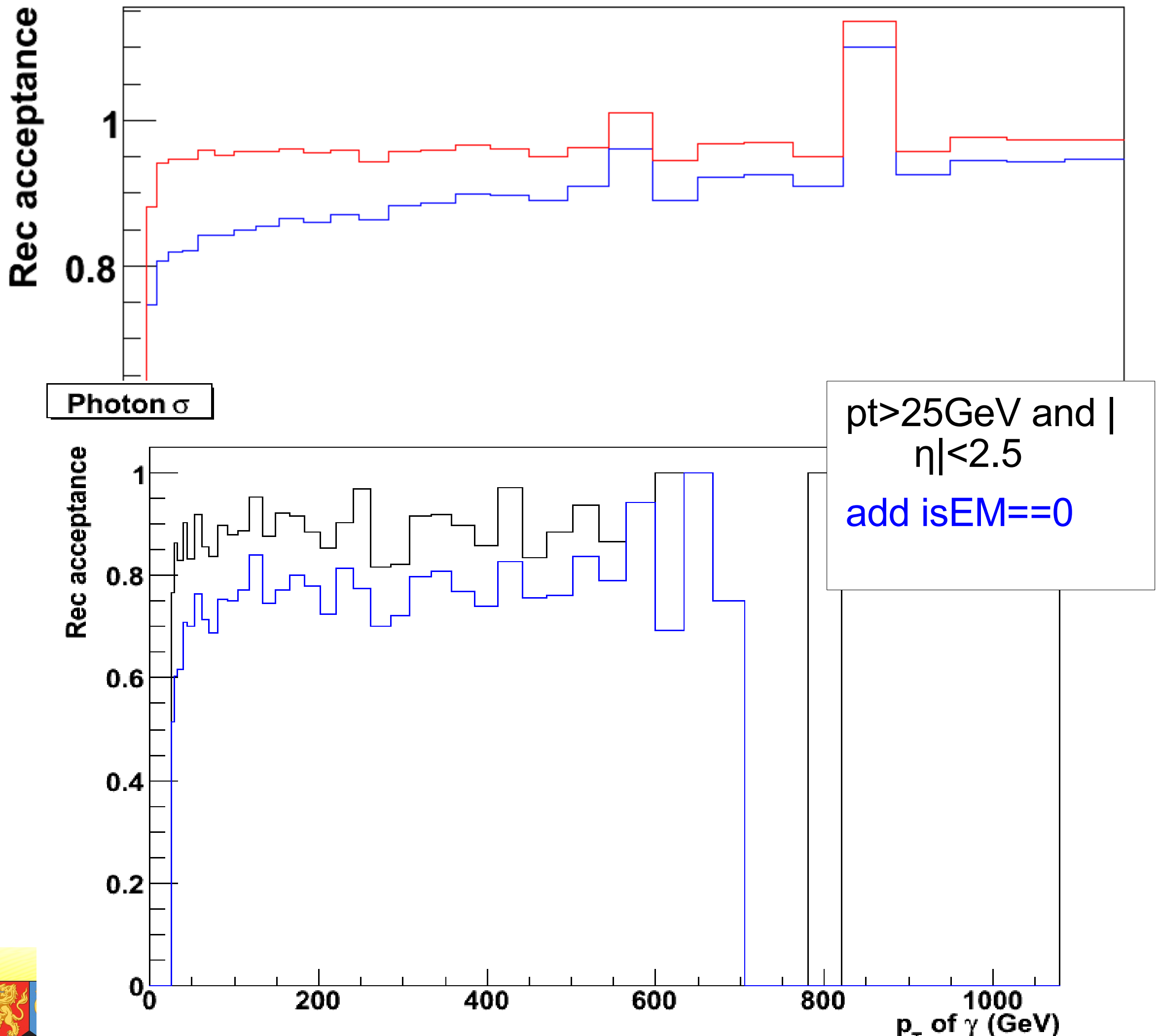
Early conversions



- Before I found asking for an electron when there is no photon kept nearly all events

Mark
Stockton

Early conversions



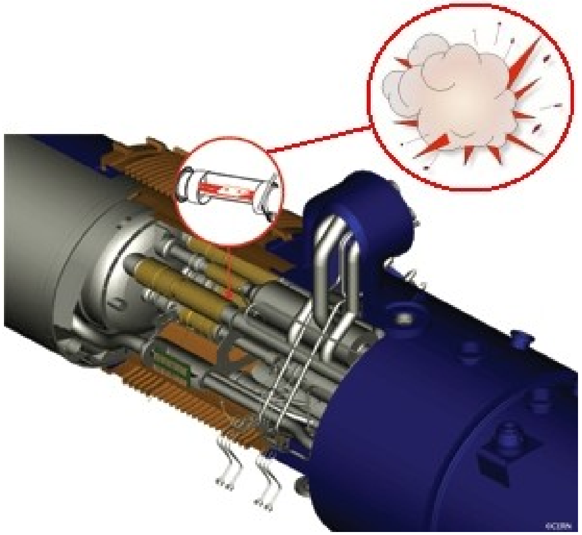
- Before I found asking for an electron when there is no photon kept nearly all events
- But with improved electron/photon definitions in the ATLAS software the photon acceptance is already higher

Status

- My analysis is in good shape

Status

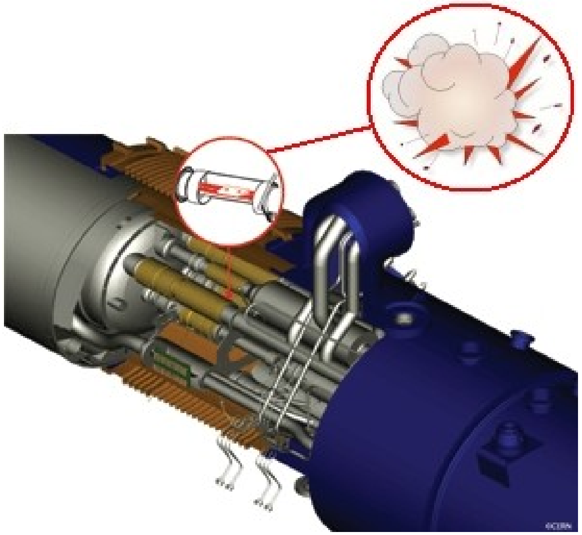
- My analysis is in good shape
- Shame the LHC isn't :(
- For those not in the know the CERN estimate for first colliding beams is roughly end of August
- Nicely timed with the end of my funding



Status

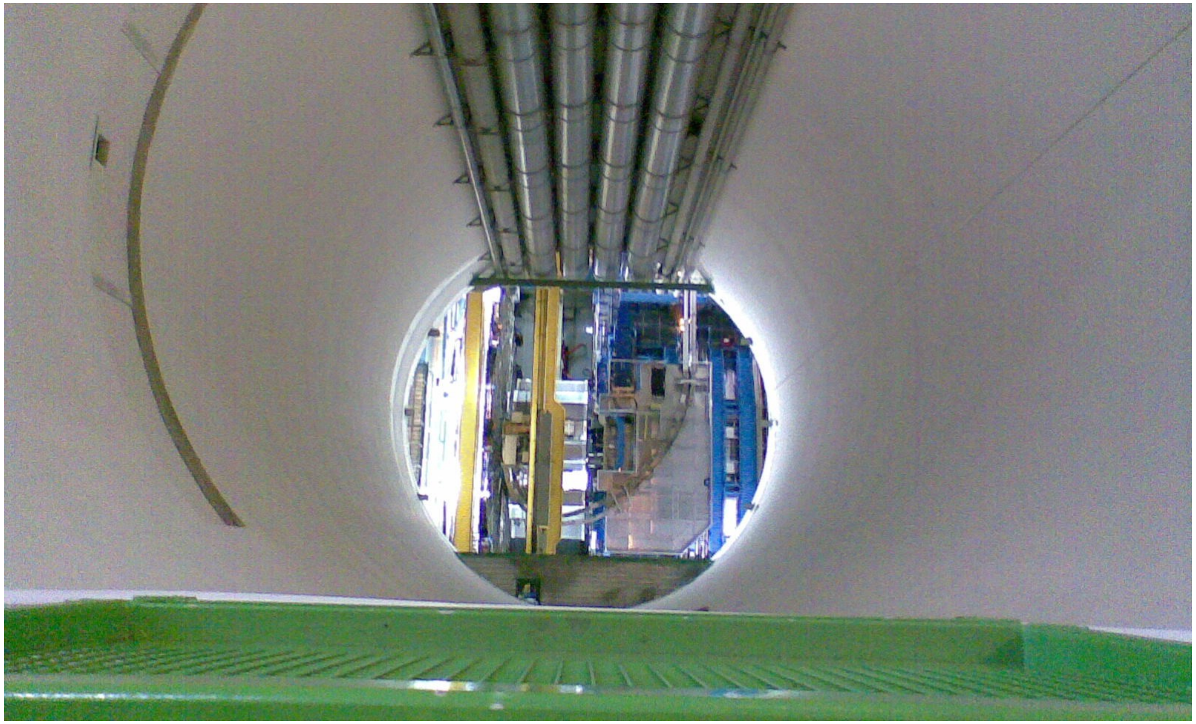
- My analysis is in good shape

- Shame the LHC isn't :(
- For those not in the know the CERN estimate for first colliding beams is roughly end of August
- Nicely timed with the end of my funding



- But to cheer us up...

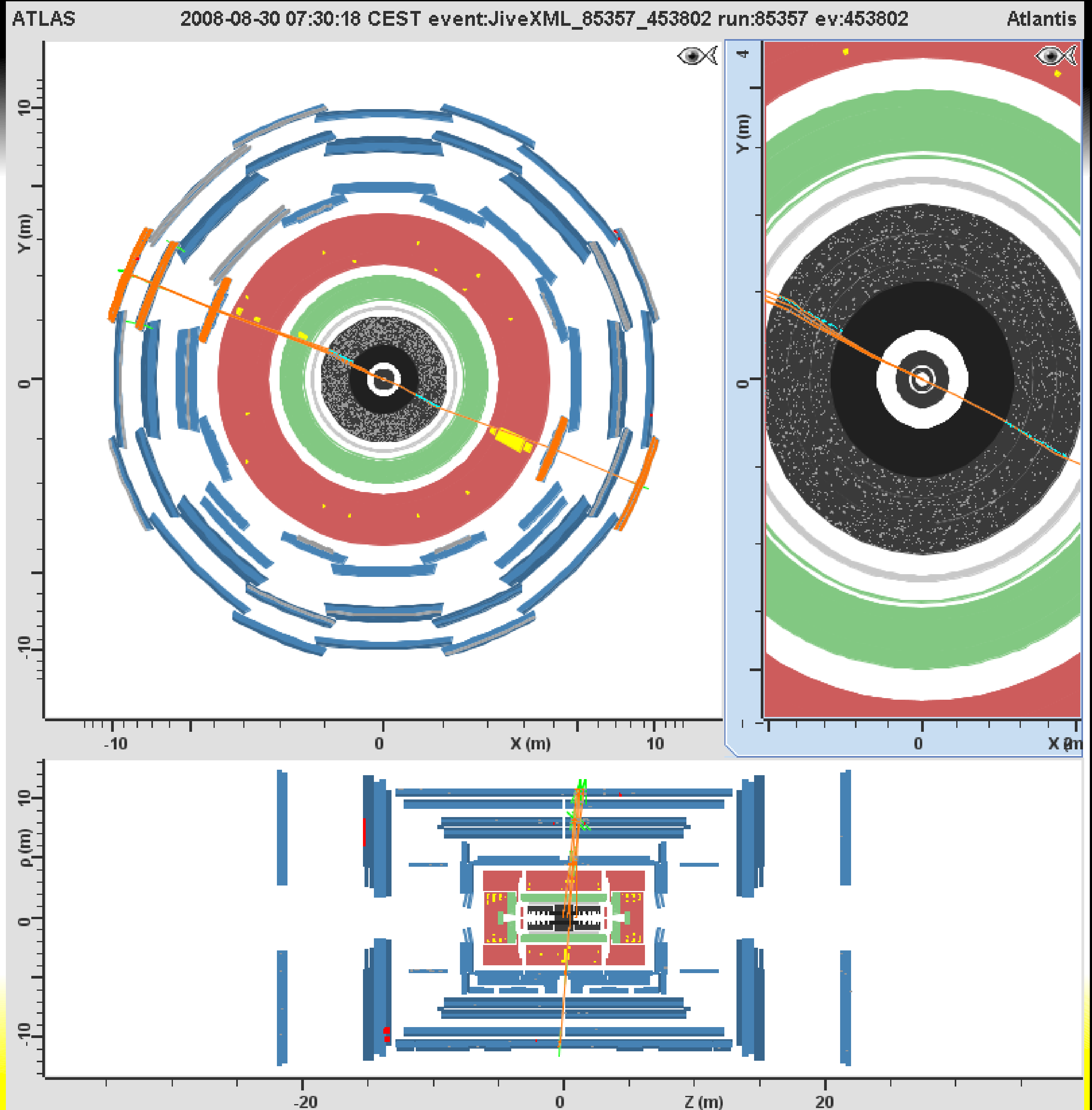
- We got to see ATLAS one last time...



- And we have already taken interesting and useful data
  - Shown here are event pictures from ATLANTIS with colours decided upon here in Birmingham!

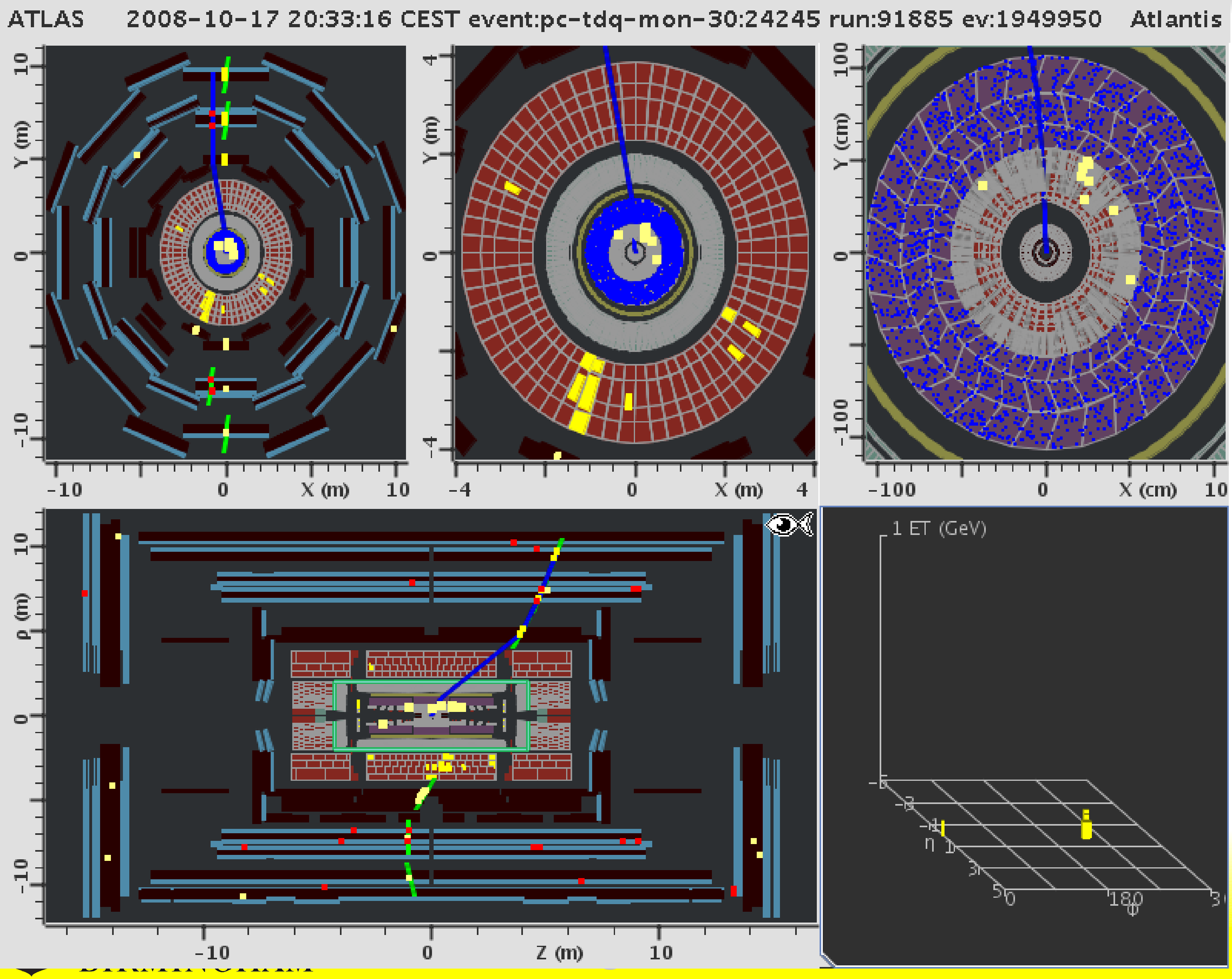
Cosmics

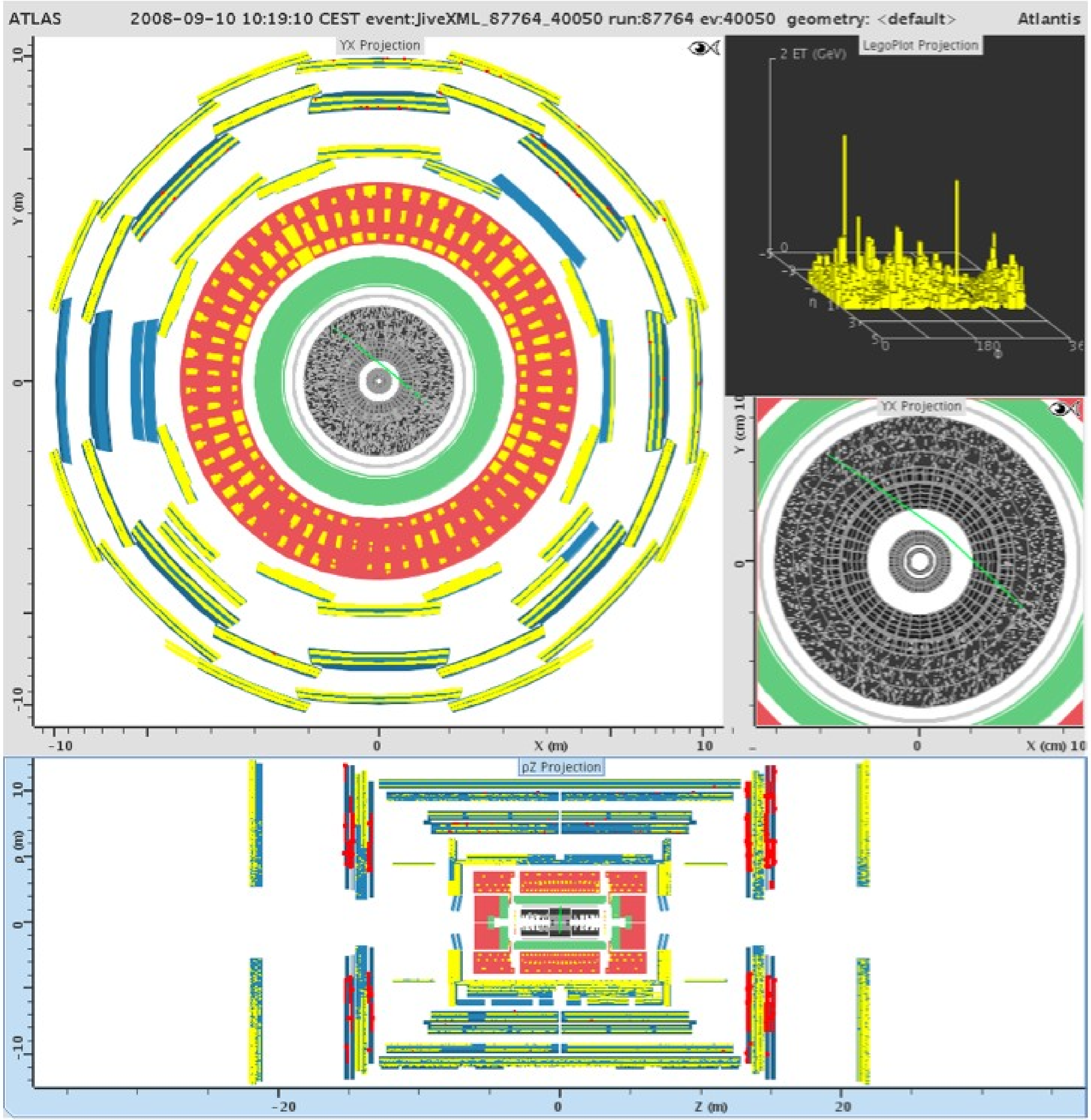
slide 60



UNIVERSITY OF BIRMINGHAM

Cosmics with B field



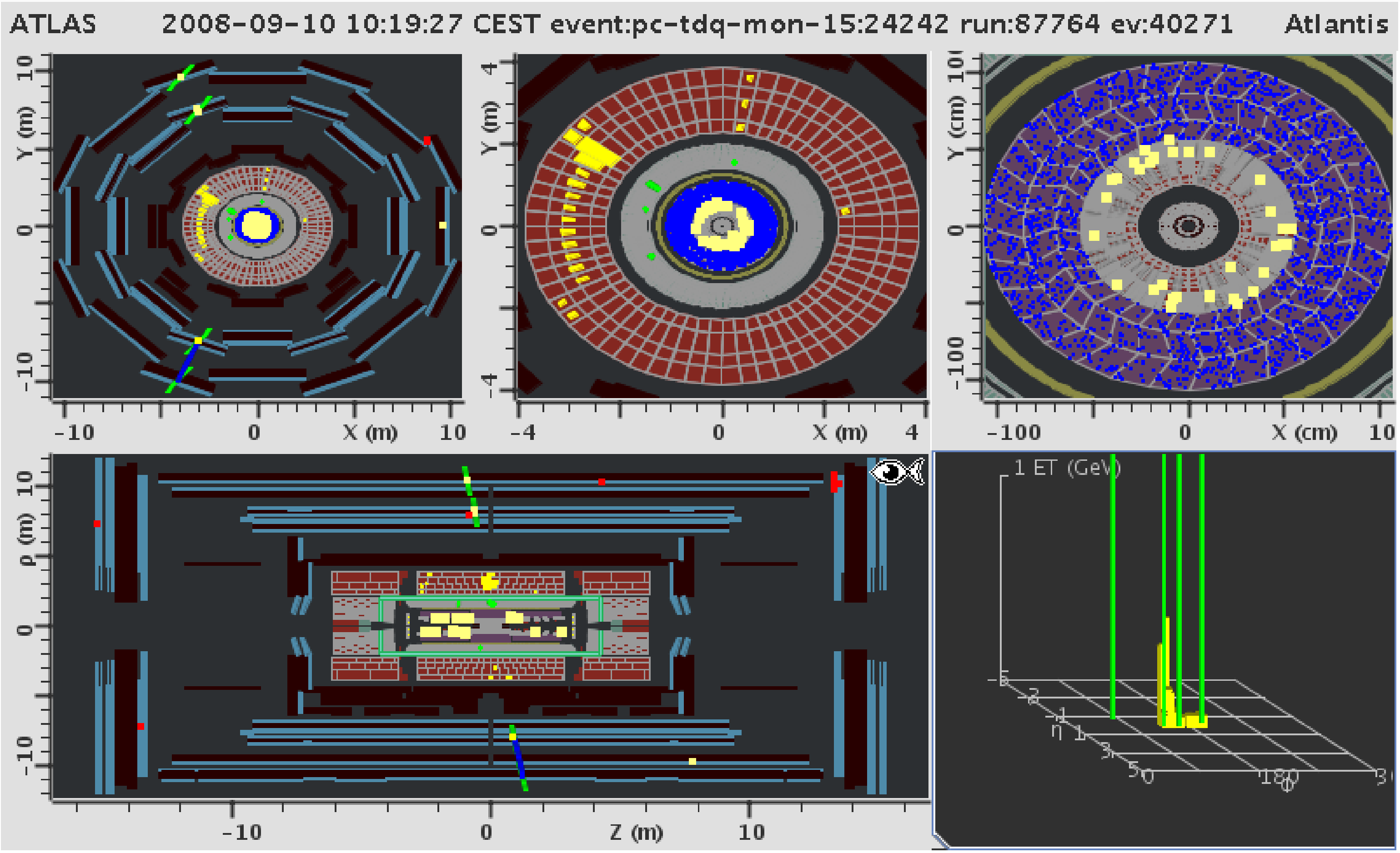


ATLAS EXPERIMENT
http://atlas.ch

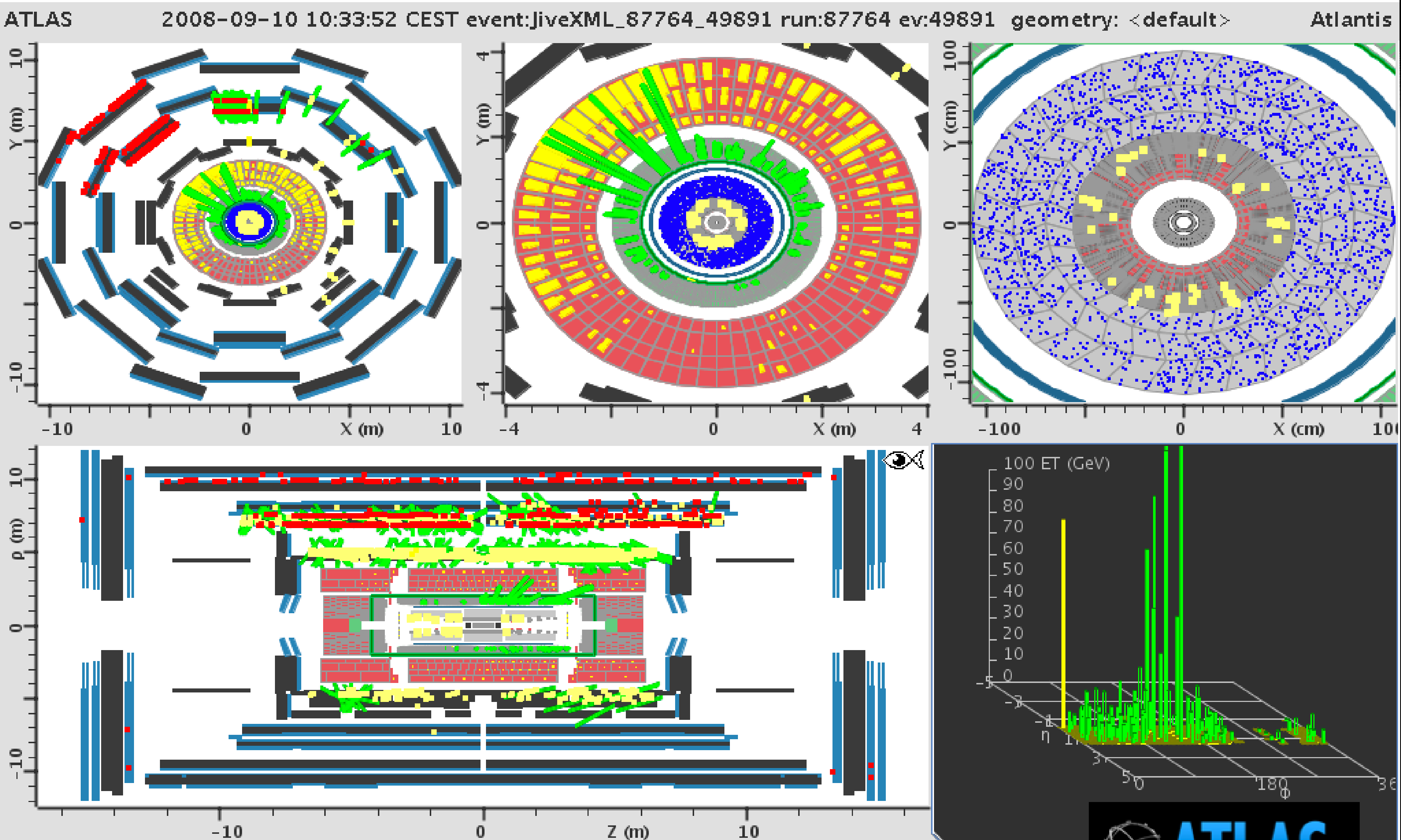
first beam event seen in ATLAS

Mark
Stockton

Then 17 seconds later



- Those in West 316 saw an event triggered by a cosmic



2nd beam event seen in ATLAS

ATLAS EXPERIMENT
http://atlas.ch

Summary

- Direct photons are a useful probe of the gluon PDF, parton evolution and detector calibration
- They need to be well understood before searches can take place as they are a large background
- ATLAS is designed and ready to make the first direct photon measurement when collisions begin

Summary

- Direct photons are a useful probe of the gluon PDF, parton evolution and detector calibration
- They need to be well understood before searches can take place as they are a large background
- ATLAS is designed and ready to make the first direct photon measurement when collisions begin

Thank you for listening

Backup

Mark Stockton

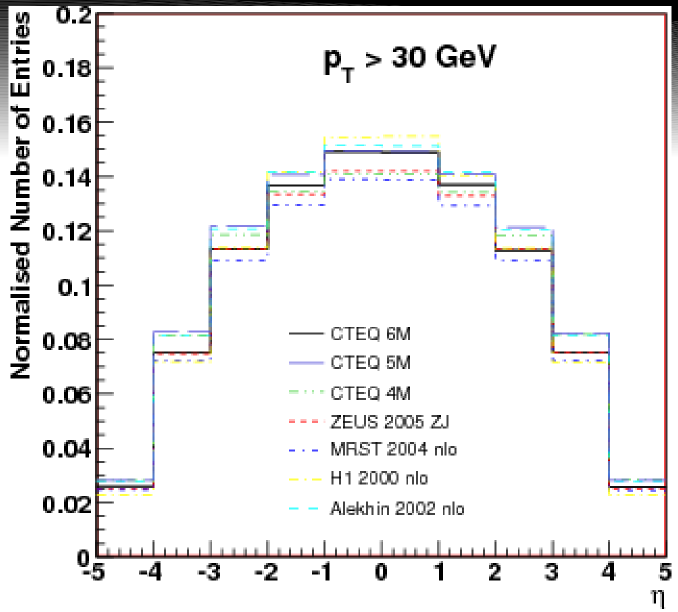
H matrix

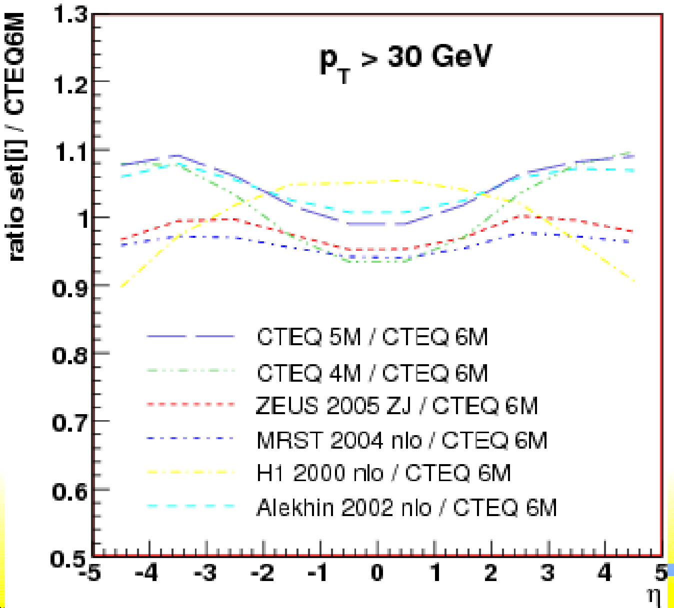
(Known numbers from data in blue)

- Nstart = Nsignal + Nbkgrnd
- Apply 1 cut:
  - Ncut1 = SignalEffCut1*Nsignal + BkgrndEffCut1*Nbkgrnd
- Apply m cuts:
  - .... Ncutm = SignalEffCutm*Nsignal + BkgrndEffCutm*Nbkgrnd
- End with a matrix to solve:

$$\begin{pmatrix} \text{Nstart} \\ \text{Ncut1} \\ \text{Ncutm} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ \text{SignalEffCut1} & \text{BkgrndEffCut1} \\ \text{SignalEffCutm} & \text{BkgrndEffCutm} \end{pmatrix}$$

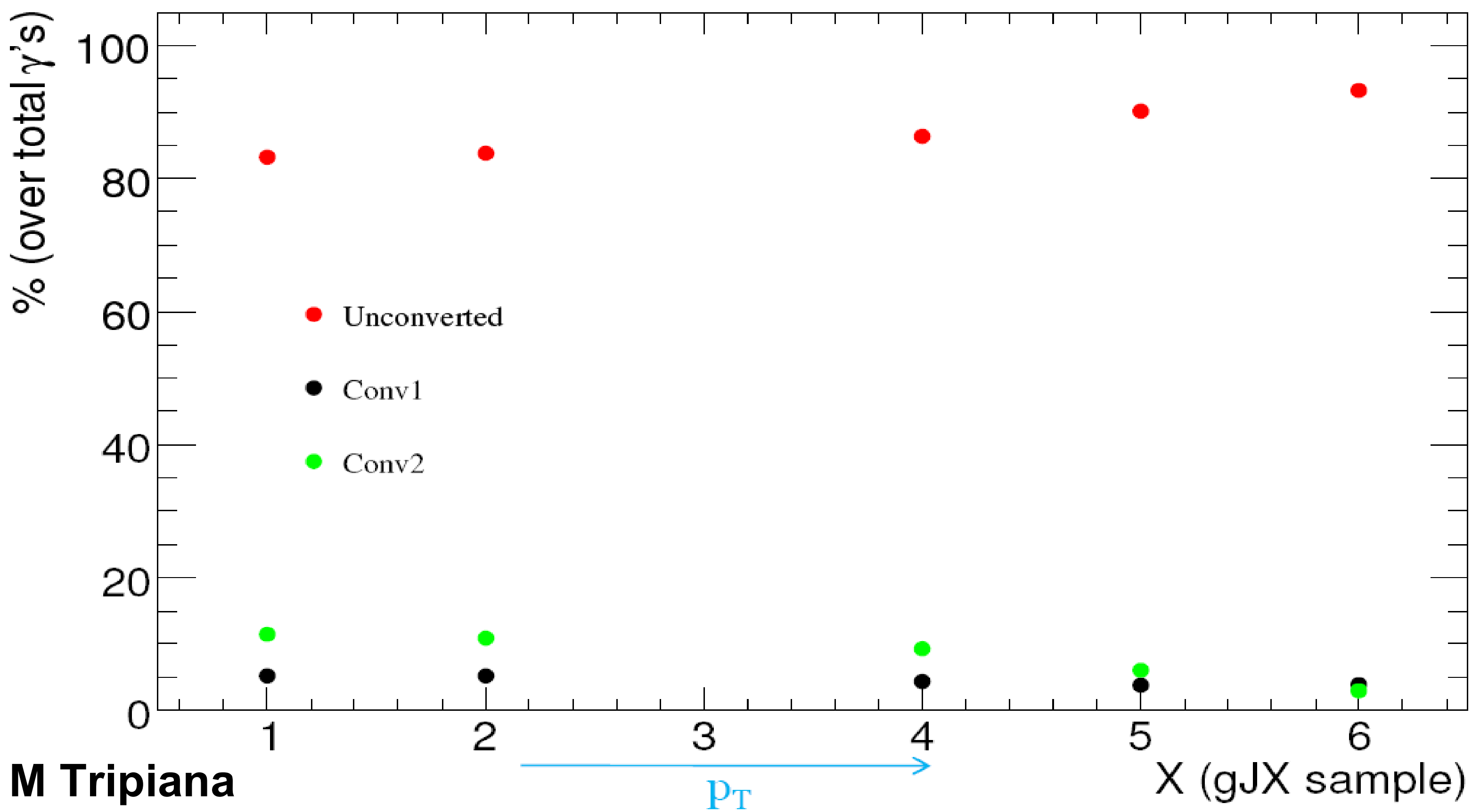
- Ivan's original plot





Early conversion recovery

- Using a tool developed by the Higgs working group
- Unconv photon: unconverted photon / late conversion (i.e no track)
- Conv1/Conv2 photon: converted photons with different requirements from tracking analysis



M Tripiana