Detection of jets and photons at ATLAS

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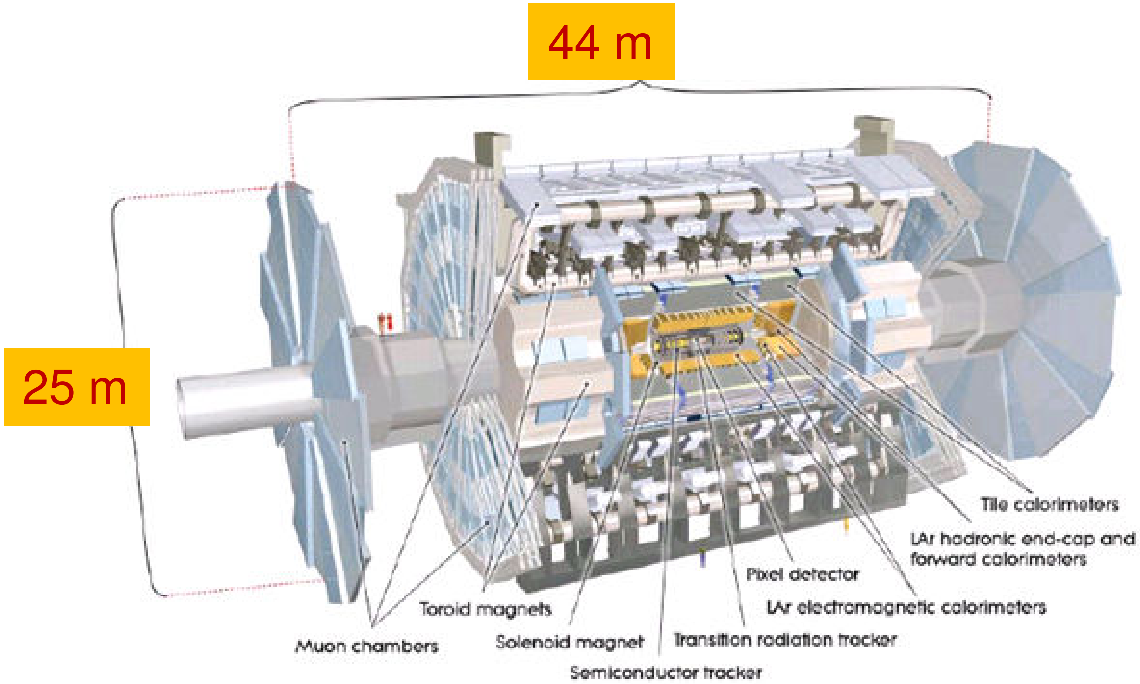
Outline

I. Introduction
II. (New) Physics related with Jets and Photons
III. Reconstructions and calibration of photons and jets
IV. Photon Conversion
V. Direct photon cross-section measurement
VI. Summary

One page about ATLAS detector

- **Inner detector (ID)**
  Pixel detector,
  Semiconductor tracker (SCT)
  Transition radiation tracker (TRT)
  Tracking $|\eta| < 2.5$
  $\sim 0.05\% p_T(\text{GeV}) + 0.1\%$
- **Calorimetry**
  - Lar EM Cal.
    - Barrel $|\eta|<1.475$
    - End Cap $1.375<|\eta|<3.2$
    - $\sigma/E \sim 10\%/\sqrt{E(\text{GeV})} + 0.7\%$
  - Hadronic Cal.
    - Barrel $|\eta|< 1.7$
    - End Cap $1.5<|\eta|<3.2$
    - $\sigma/E \sim 50\%\sqrt{E(\text{GeV})} + 3\%$
  - Forward Cal. $3.1<|\eta|<4.9$
- **Magnet system**
  - Central solenoid (surrounds ID) : 2T
  - Barrel toroid
  - Two end cap toroid
- **Muon Spectrometer**
  - Barrel $|\eta|<1$
  - Two end cap $1<|\eta|<2.7$
  - $\sigma/p_T \sim 2\text{-}7\%$



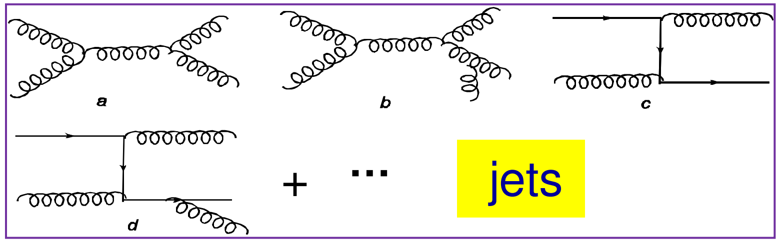
In summary :
Calorimetry coverage: $|\eta|<4.9$
Precise measurement: $|\eta|<2.5$
Typically:
for 50 GeV photons, the resolution ~0.8 GeV
for100 GeV jets, the resolution ~5.8 GeV

Introduction

- Di-jet has the highest cross-section of LHC:
  - Measurement of di-jet can help to test coupling constant α_s and constrain parton density function.
  - di-jet may also be the resonance of some new physics.
  - Measurement needs good jet reconstruction.
- Direct photon is second largest production at LHC.
  - The background of photon related physics
  - help to estimate parton density function with less uncertain due to jet reconstruction.
- Di-photon:
  - Di-photon is the second largest resource of photons
  - Di-photon is the dominant background of $H\rightarrow\gamma\gamma$
  - Has born and box process.
  - Photon/Jet separation is one the major work for photon study.
  - Photon conversion needs serious treatment.

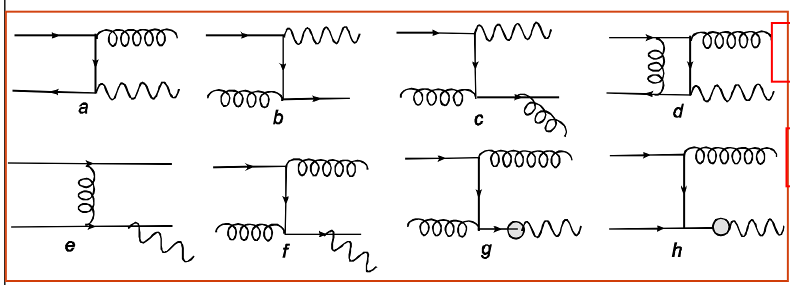
Relevant processes and cross-sections

Process	σ calculator	Cuts	σ(pb)
$q\bar{q}, qg \to \gamma\gamma x$	ResBos/ DIPHOX	$80 < m_{\gamma\gamma} < 150$ GeV $p_{T\gamma} > 25$ GeV, $\lvert\eta\rvert < 2.5$	20.9
$gg \to \gamma\gamma$	ResBos	$80 < m_{\gamma\gamma} < 150$ GeV $p_{T\gamma} > 25$ GeV, $\lvert\eta\rvert < 2.5$	8.0
γj	JETPHOX	$p_{T\gamma} > 25$ GeV	$180 \cdot 10^3$
jj	NLOJET++	$p_T > 25$ GeV	$477 \cdot 10^6$



Di-jet and direct photon have highest and second highest cross-section at LHC.

- For $\gamma\gamma$, ResBos and DIPHOX agreement better than 10%.
- For γj: $\sigma_{JETPHOX}/\sigma_{PYTHIA} \sim 2.1$
- For jj: $\sigma_{NLOJET}/\sigma_{PYTHIA} \sim 1.3$

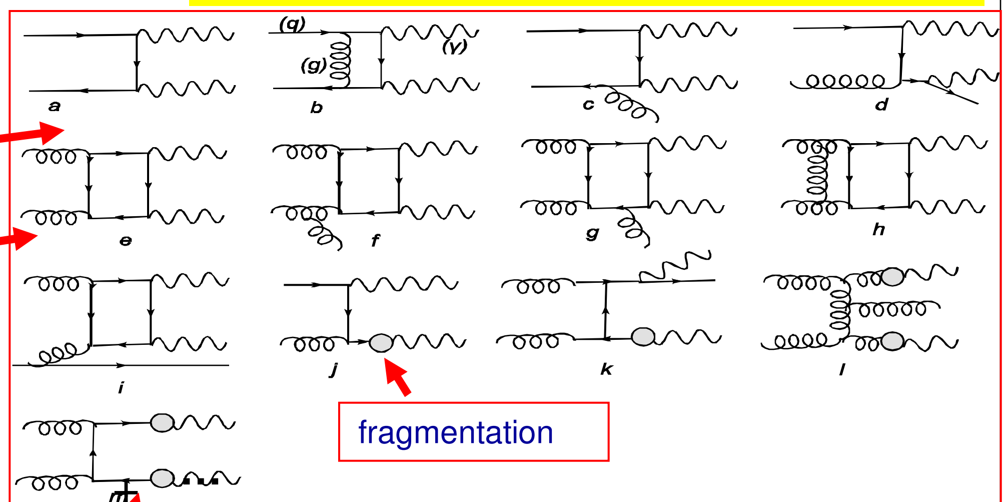


Direct photon

Di-photon: Born and Box

Born

Box



fragmentation

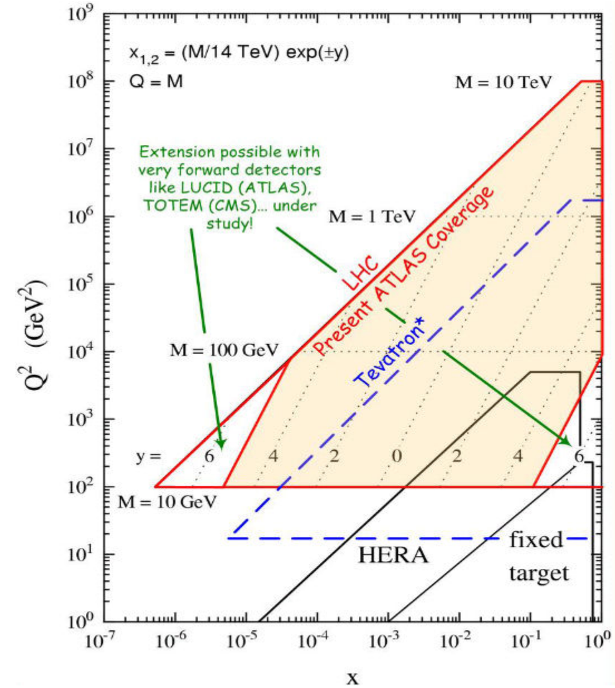
\+ ...

fragmentation

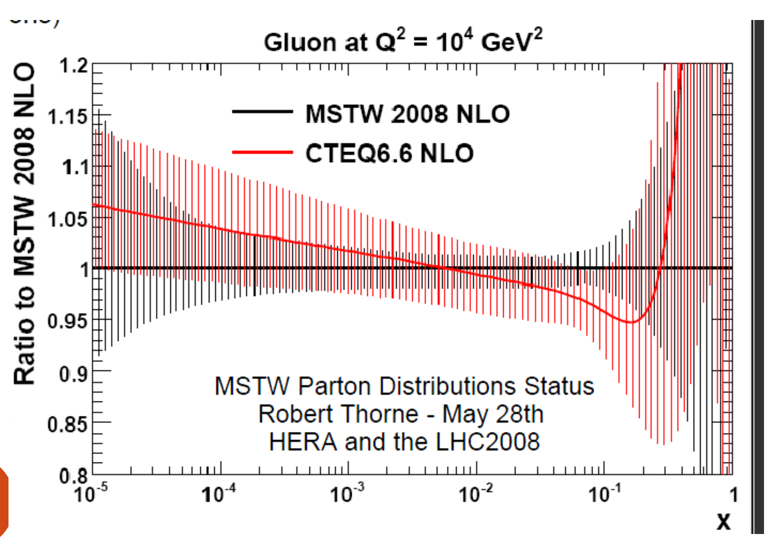
\+ ...

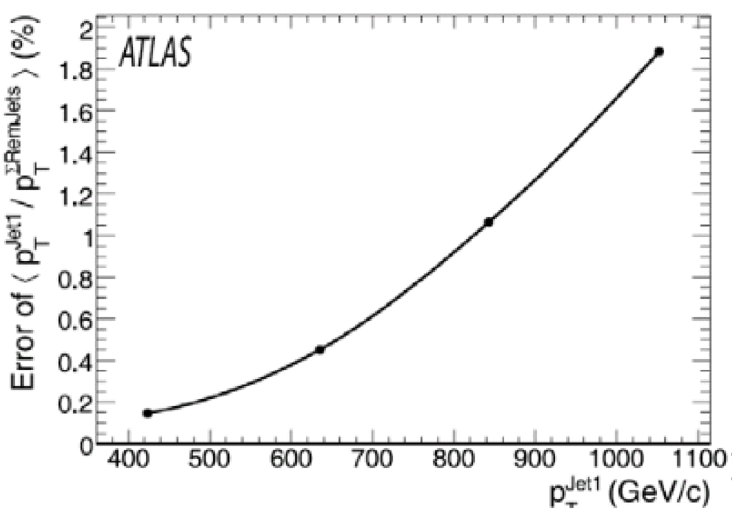
New Physics related with di-jet at ATLAS

- ➢LHC has wider phase-space with respect to other experiments.
- ➢Interesting dijet –Resonances: q*→qg, axigluon, coloron, graviton, W', Z' etc.
- ➢ Issue to take into account : theory uncertainty at high x and jet energy scale uncertainty goes higher for high pt jet.

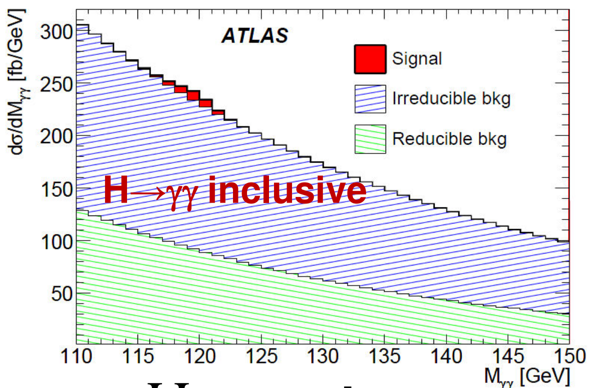


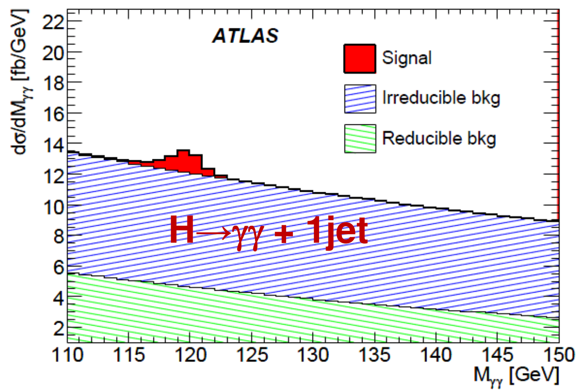
W. Stirling, LHC Workshop “”Theory of LHC Processes” (1998)

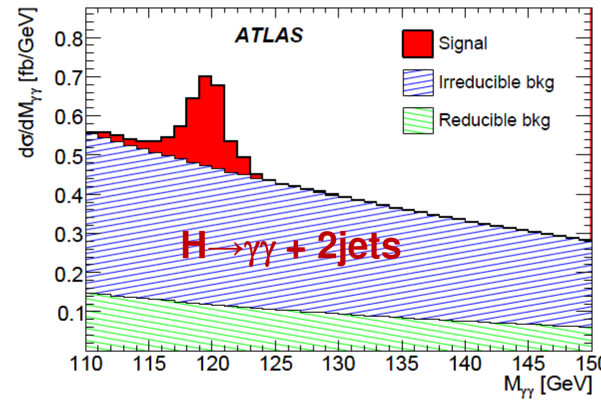




Physics related with photons at ATLAS





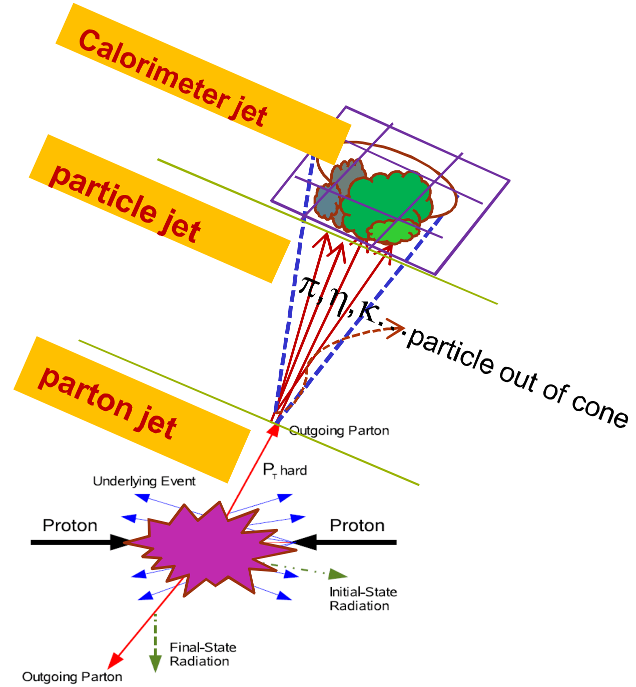


- H→γγ：
  - Sensitive at $114 < M_H < 150$GeV and robust with sideband.
  - Challenge: good energy and angular resolution ($\sigma/M_H \sim 1.0\%$) and QCD rejection larger than 10^3 per jet.
  - Combination of H→γγ associated with jets can enhance the sensitivity (~25% at 10 fb^{-1}).
- Graviton→γγ .
- Signature of Zγ from Higgs, toponium, Z', techiparticle etc.
- GMSB SUSY with signature di photon+missing ET and Zγ+missing ET.

Jet Reconstruction and calibration

❑Quark/gluon produced from pp interaction.
❑Fragment of parton into hadrons.
❑Jets clustering algorithm.
❑Calibration:

detector effect : Calorimeter non-compensation, noise, losses in dead material and crack, particle deflection in magnetic field etc.
physics effect : Fragmentation, out of cone ,ISR and FSR, Underlying events etc.



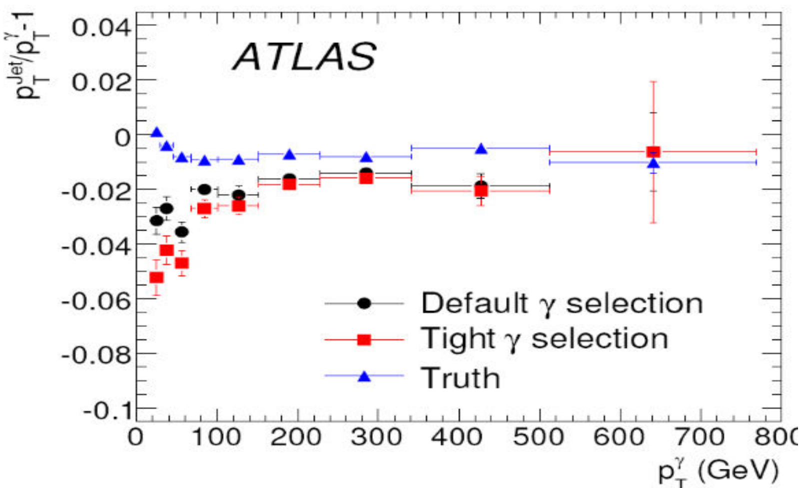
✓The calibration to the Truth Jet

- Minimize :

$$\chi^2 = \sum_e \left(\frac{E^{(e)} - E_{truth}^{(e)}}{E_{truth}^{(e)}}\right)^2$$

✓ In-situ study:
absolute energy scale

- γ-jet (can go to high pt)
- di-jet (different eta regions)
- multi-jets (two low pt jets balanced with a high pt jet)

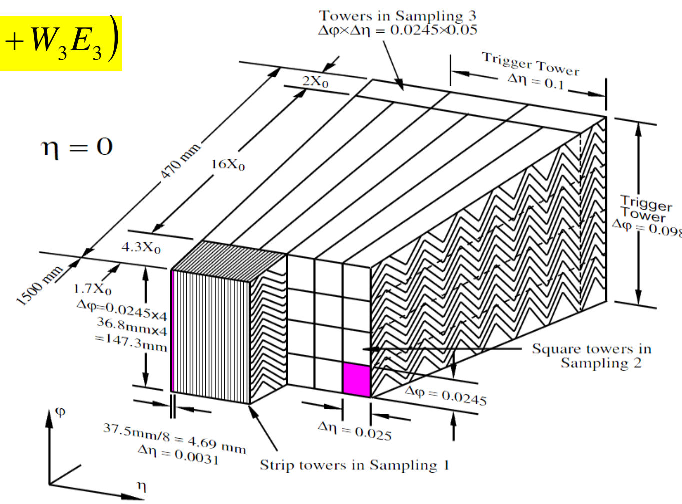


Calibration and vertex correction for Photons

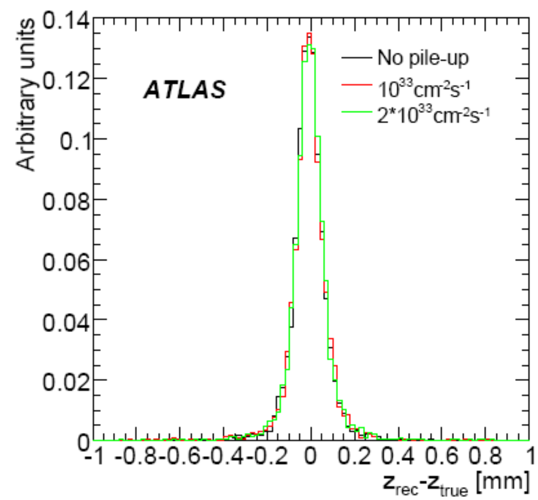
- Calibration
  - Longitudinal weights calibration: $E_{rec} = s(b + W_0 E_{pres} + E_1 + E_2 + W_3 E_3)$
    - 3x5 cluster for unconverted photon
    - 3x7 cluster for converted photon (from electron)
  - Calibration hit: with special simulations (calibration hits), correlate energy deposits with measurable quality
  - Refined energy correction:

    Lateral leakage and ϕ/η modulation
  - Refined position correction:

    S-shape (η correction) and Phi-offset

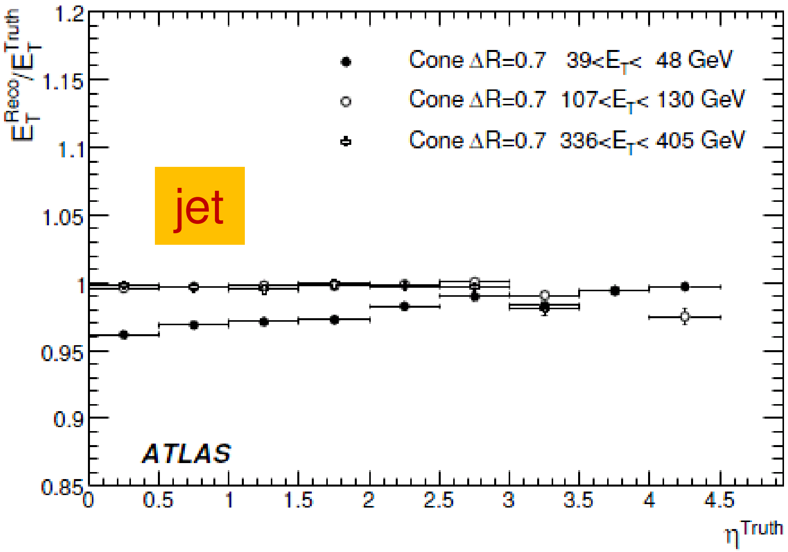


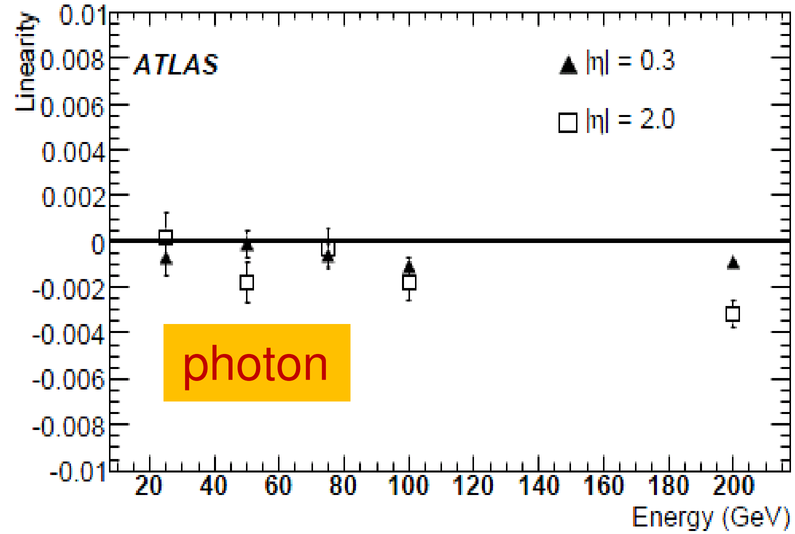
- Vertex correction (important for $H \to \gamma\gamma$):
  - Precise measurement of Z vertex is very important to improve the Higgs mass resolution.
  - Method : a linear fit of multi-layer centers of the EM shower + event vertex
    - The best Higgs boson position accuracy is achieved, with a Gaussian width 0.07 mm (see plot). A likelihood method is used to distinguish the hard scattering vertices from pile-up vertices.

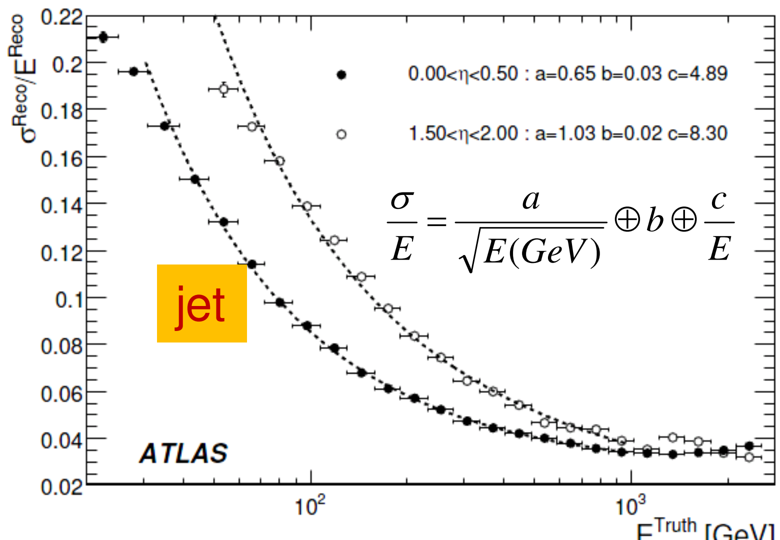


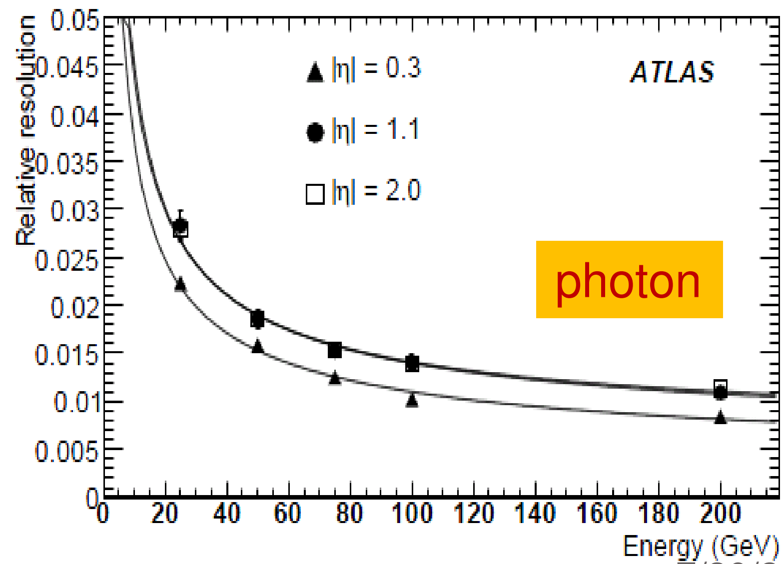
Performance after calibration for jet and photon

Good linearity and expected resolution obtained after calibration









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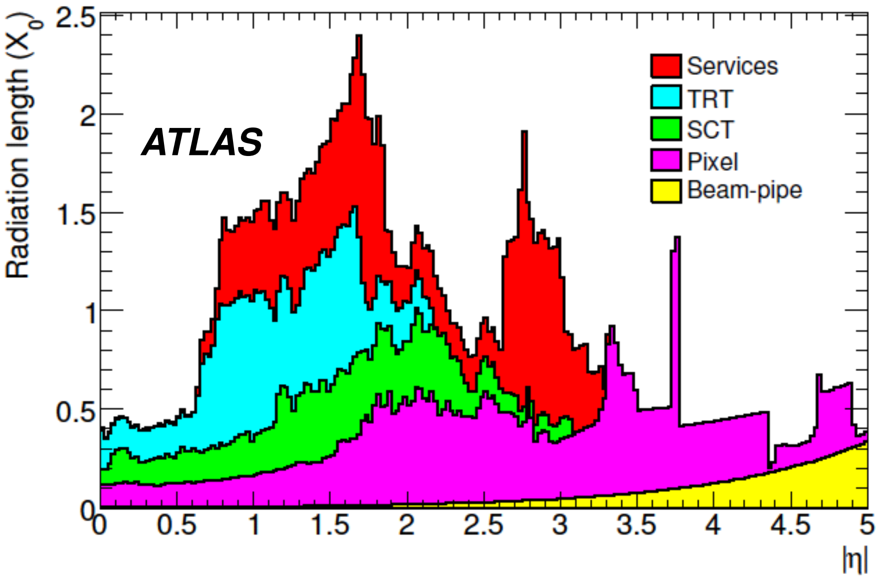
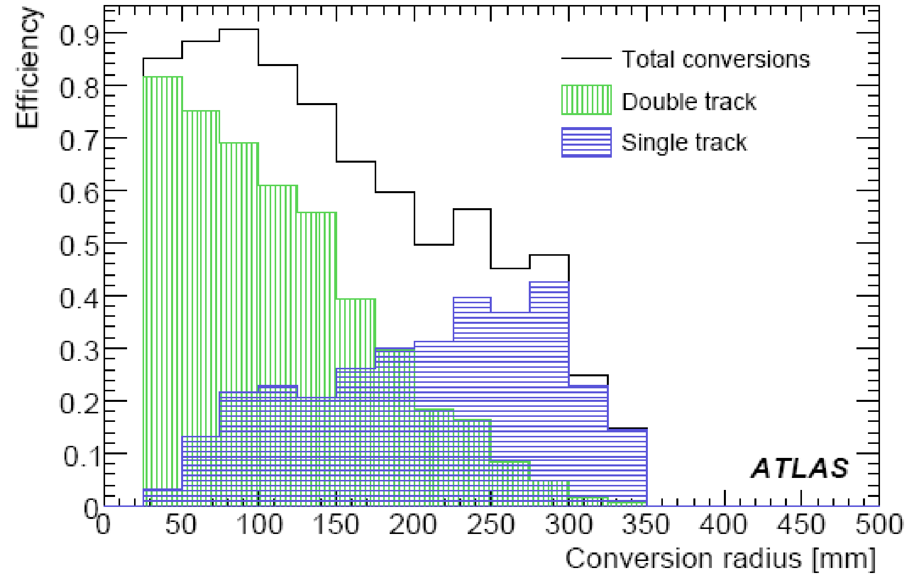
Photon Conversion

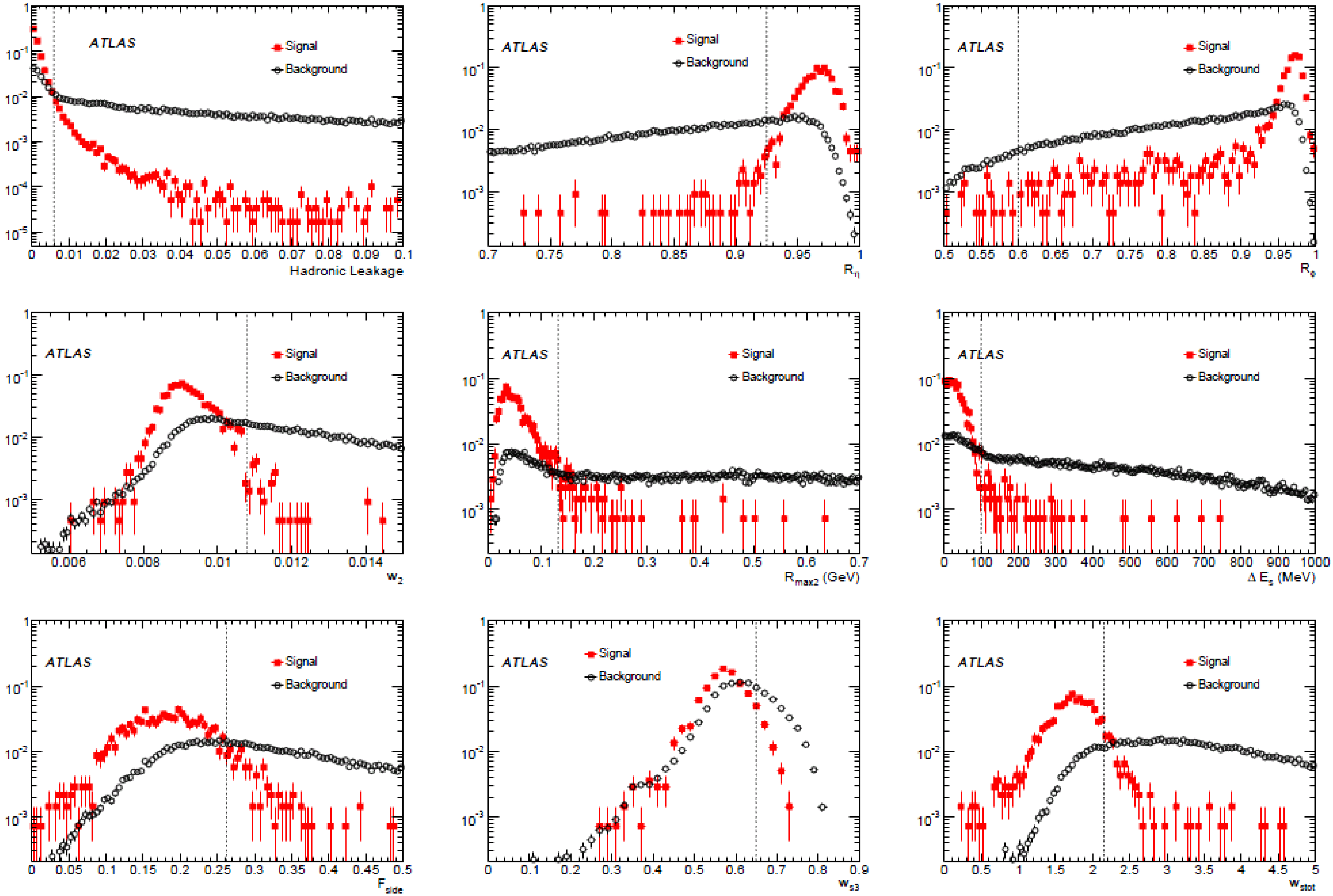




Photons can converted into e+e- pairs while traveling within material.
Photons left after traveling Δx: $$N_\gamma = N_{0,\gamma} e^{\frac{-\Delta x}{9X_0/7}}$$

- Around 57% selected H→γγ events have at least one true conversion with a radius smaller than 80 cm.
  - We don't want a converted photon to be regarded as an electron.
- Recovery of early converted photon (R<35 cm) is crucial.
- An algorithm tagging early converted photons based on reconstructed single/double tracks has a high tagging efficiency for those photons (left plot).

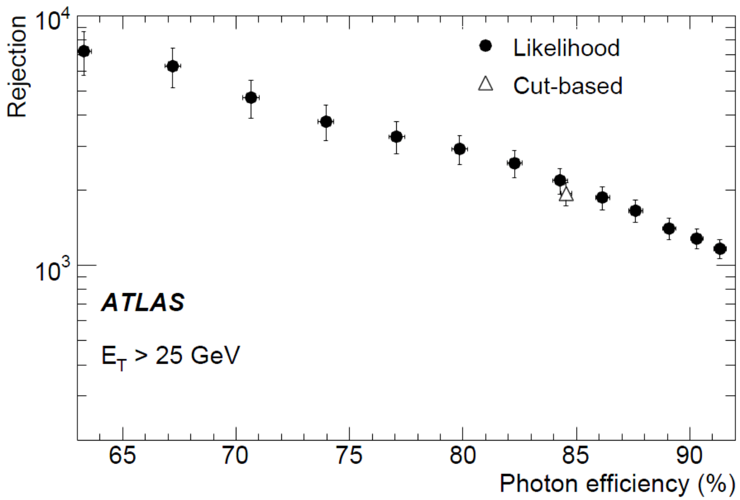
Photon/jet separation: Discriminating variables

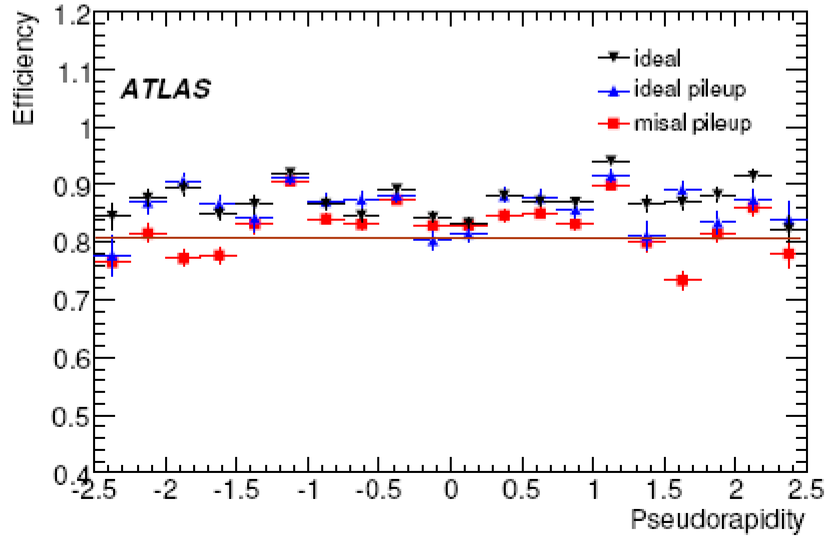


9 EM calorimeter based variables in addition to track isolation so far are used for photon ID.

Photon ID and jet rejection

- Three photon id methods:
  - Cut based : implement
  - Likelihood ratio algorithm
  - Hmatrix

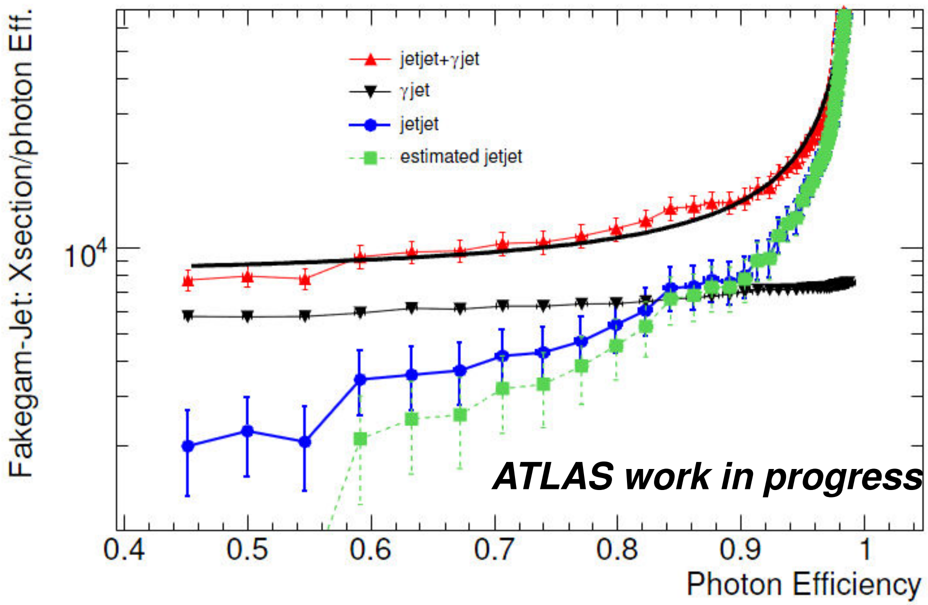




	All	quark-jet	gluon-jet
Rejection (before isolation)	5070±120	1770±50	15000±700
Rejection (after isolation)	8160±250	2760±100	27500±2000

- ➢ Similar photon/jet separation performance can be seen from likelihood ratio method.
- ➢ Rejection of gluon-initiated jets is much higher than that of quark-initiated jets.
- ➢ After photon identification, the fake photons are dominated by π^0 .

Data driven: measurement direction photon from di-jet



Purpose :

estimate the jet-jet from γ-jet in signal like region.

Method :

- Use heavy pre-scaled triggers for single jet for different P_T thresholds.
- Apply the Photon ID requirement on the accompanying jet that was not used to issue trigger.
- Estimating γ-jet(e.g. γ-jet+jet-jet sample) at low photon efficiency. It should be asymptotically close to the black curve (can be extracted from fit) (Note, Y-Axis is σ/photon eff).
  - photon eff. can be extracted from $Z \rightarrow l^+l^-\gamma$ or from electron at early data.
- Subtract estimated γ-jet from red curve and then one can get the green curve which is **estimated di-jet**.

Result:

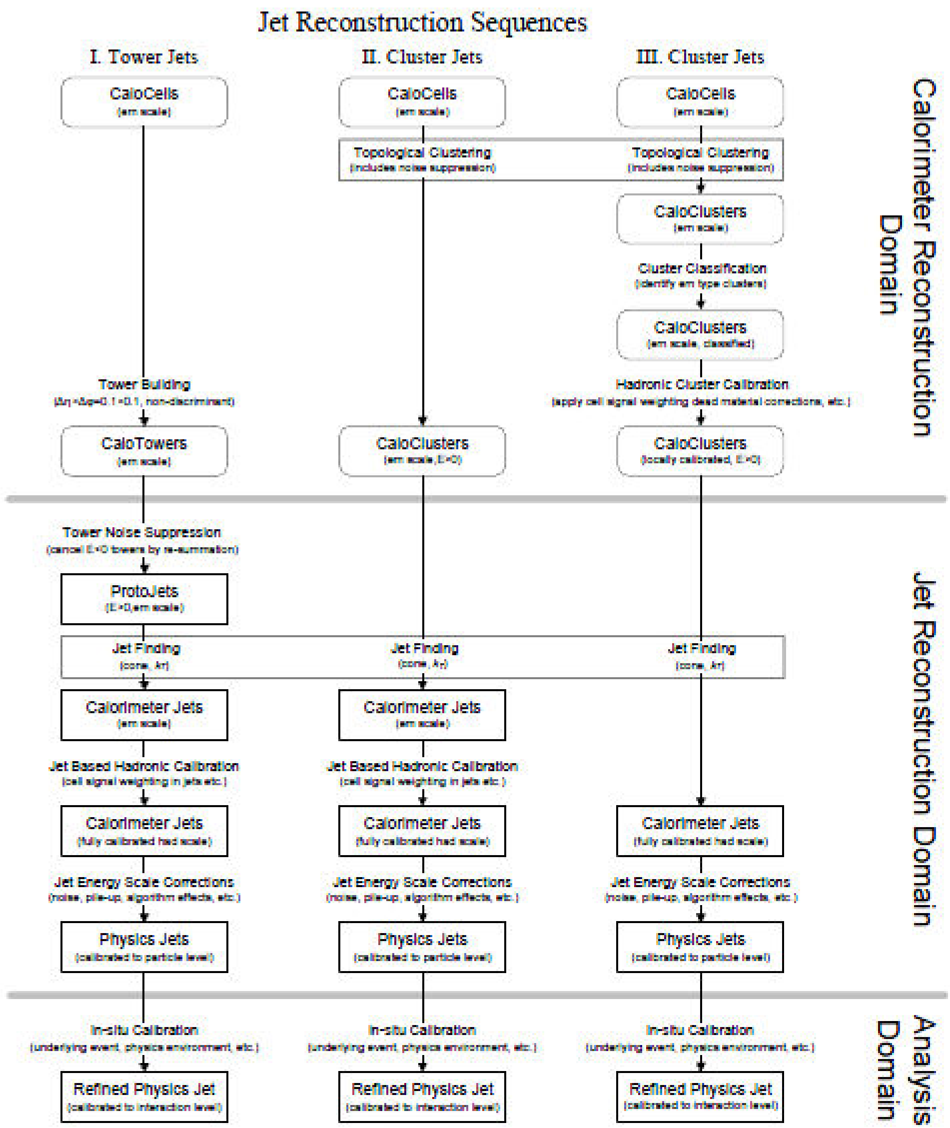
- In the signal like region (80%<Eff.<90%), the green curve is close to the expected jet-jet (blue curve).
- Can also apply this method to di-photon and direct photon separation.

Conclusions

- The LHC is preparing the first data this year.
  - Wider phase space can be exploited.
  - First high pt data taking will be di-jet and direct photon.
- The finely segmented calorimeter allows the well measurement of photons and jets.
  - expected resolution and linearity for photon and jets can be accessed.
  - dedicated design of the calorimeter and track system can provide needed γ/jet separation for physics such as $H \rightarrow \gamma\gamma$.
  - Photon conversion has been considered seriously. The algorithm tagging converted photon can effectively recover those photons.
  - Some method about γ-jet measurement is discussed.
- Eager to see the first event.

Thank you for your attention !

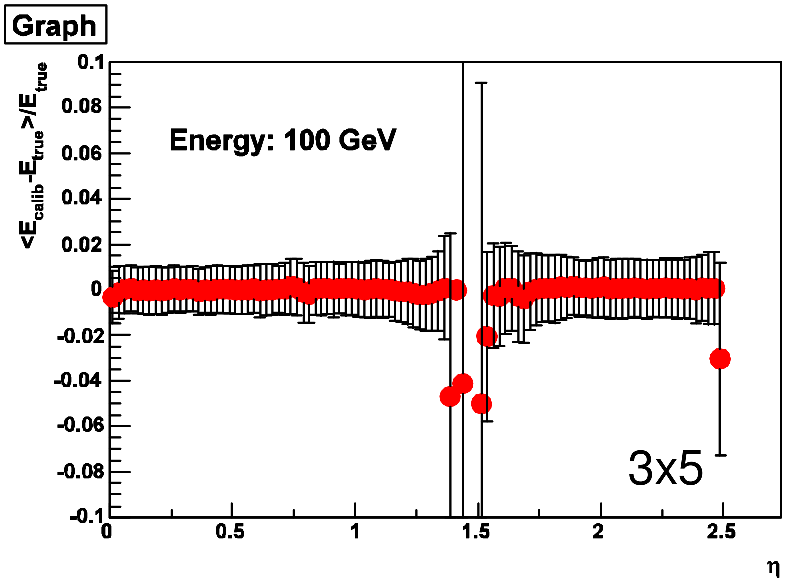
Backup Slides

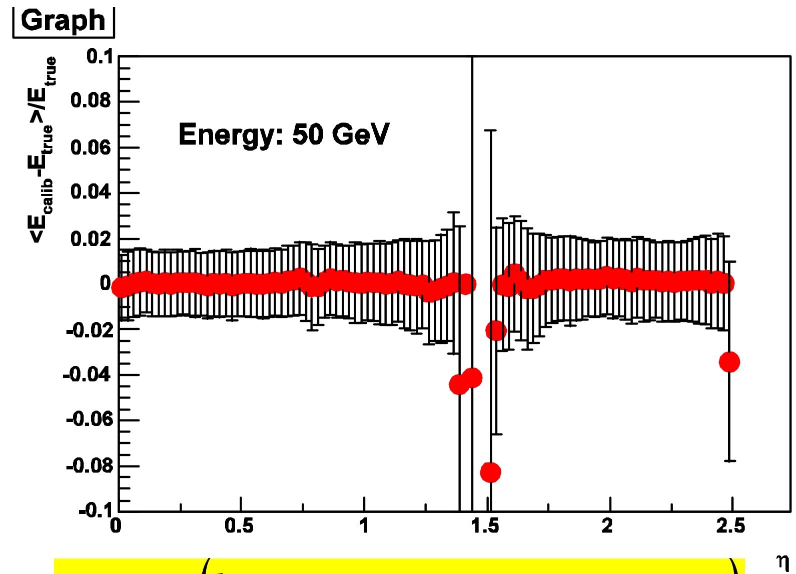


Jet Reconstruction Sequences
I. Tower Jets
II. Cluster Jets
III. Cluster Jets
CaloCells (em scale)
CaloCells (em scale)
CaloCells (em scale)
Topological Clustering (includes noise suppression)
Topological Clustering (includes noise suppression)
CaloClusters (em scale)
Cluster Classification (identify em type clusters)
CaloClusters (em scale, classified)
Tower Building
Hadronic Cluster Calibration (apply cell signal weighting dead material corrections, etc.)
CaloTowers (em scale)
CaloClusters
CaloClusters
Calorimeter Reconstruction Domain
Tower Noise Suppression (cancel E<0 towers by re-summation)
ProtoJets
Jet Finding
Jet Finding
Jet Finding
Calorimeter Jets (em scale)
Calorimeter Jets (em scale)
Jet Based Hadronic Calibration (cell signal weighting in jets etc.)
Jet Based Hadronic Calibration (cell signal weighting in jets etc.)
Calorimeter Jets (fully calibrated had scale)
Calorimeter Jets (fully calibrated had scale)
Calorimeter Jets (fully calibrated had scale)
Jet Energy Scale Corrections (noise, pile-up, algorithm effects, etc.)
Jet Energy Scale Corrections (noise, pile-up, algorithm effects, etc.)
Jet Energy Scale Corrections (noise, pile-up, algorithm effects, etc.)
Physics Jets (calibrated to particle level)
Physics Jets (calibrated to particle level)
Physics Jets (calibrated to particle level)
Jet Reconstruction Domain
In-situ Calibration (underlying event, physics environment, etc.)
In-situ Calibration (underlying event, physics environment, etc.)
In-situ Calibration (underlying event, physics environment, etc.)
Refined Physics Jet (calibrated to interaction level)
Refined Physics Jet (calibrated to interaction level)
Refined Physics Jet (calibrated to interaction level)
Analysis Domain

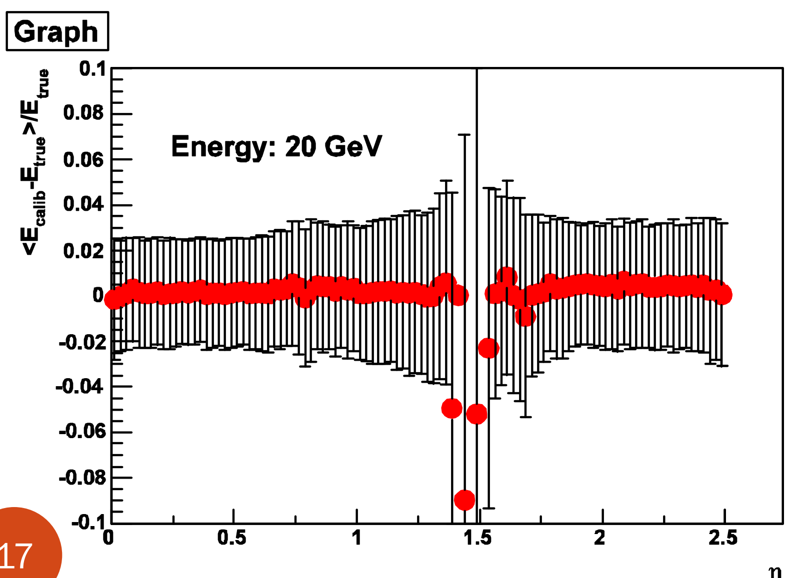
Calibration with longitudinal weights

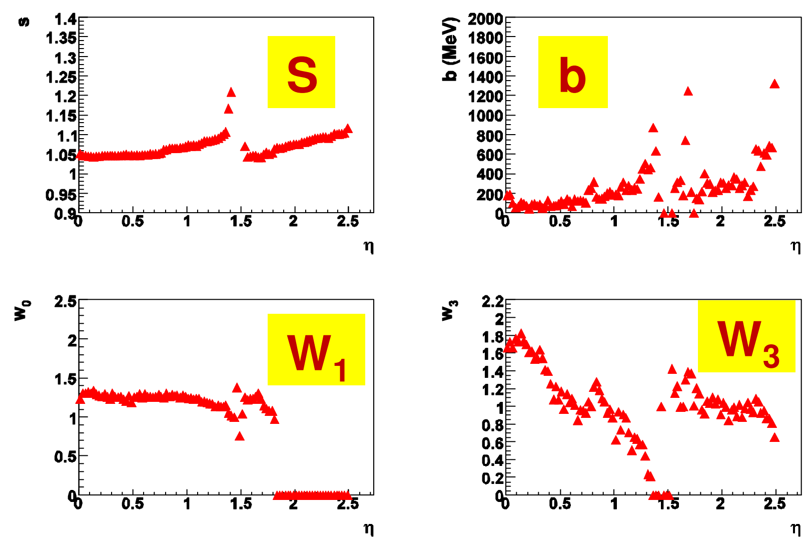
Linearities and resolutions after applying the weights.





$$E_{rec} = s\left(b + W_0 E_{pres} + E_1 + E_2 + W_3 E_3\right)$$





Jetphox results for high order and fragmentation