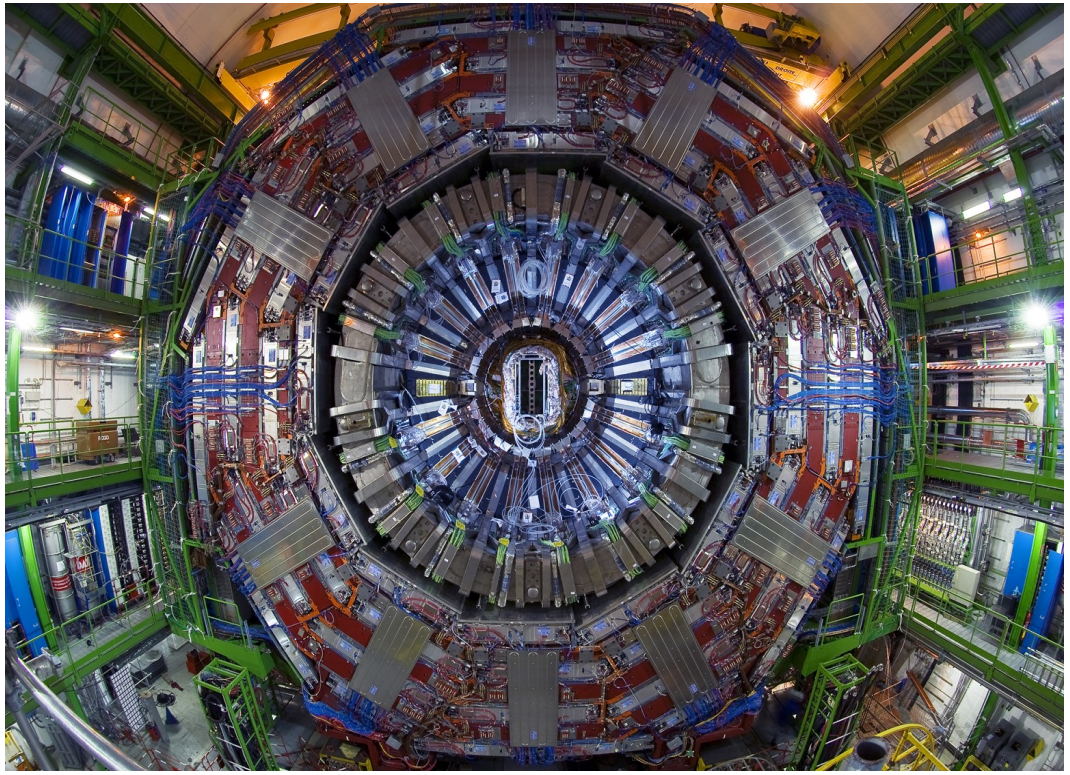
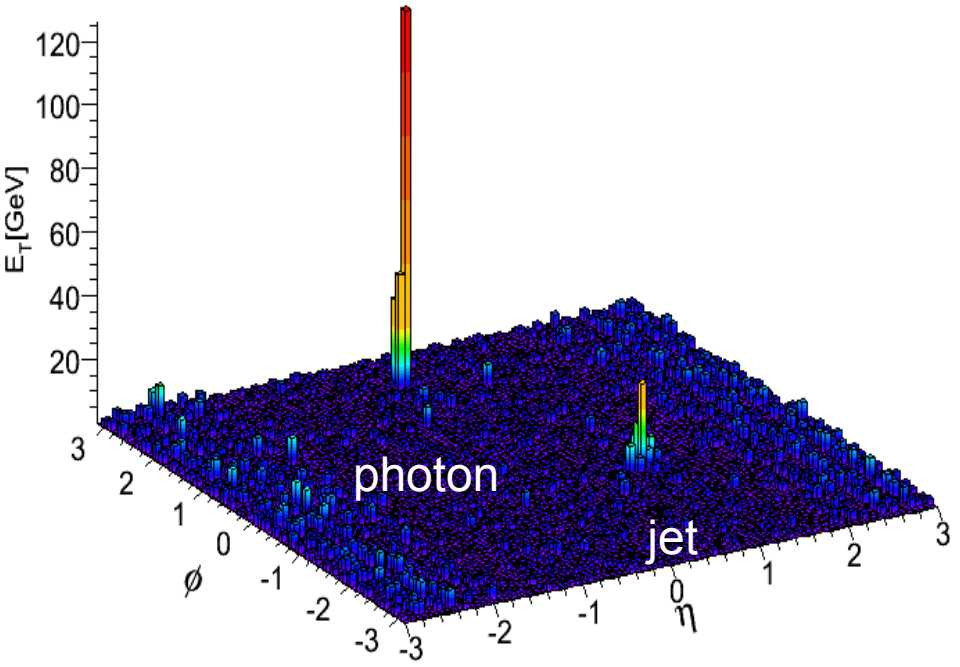
Jet Quenching in Heavy-Ion Collisions with CMS

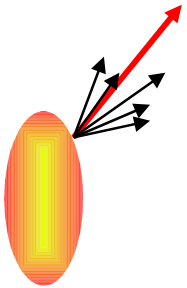
Yen-Jie Lee (MIT)
for the CMS Collaboration

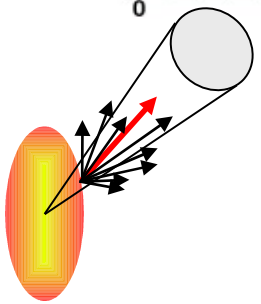




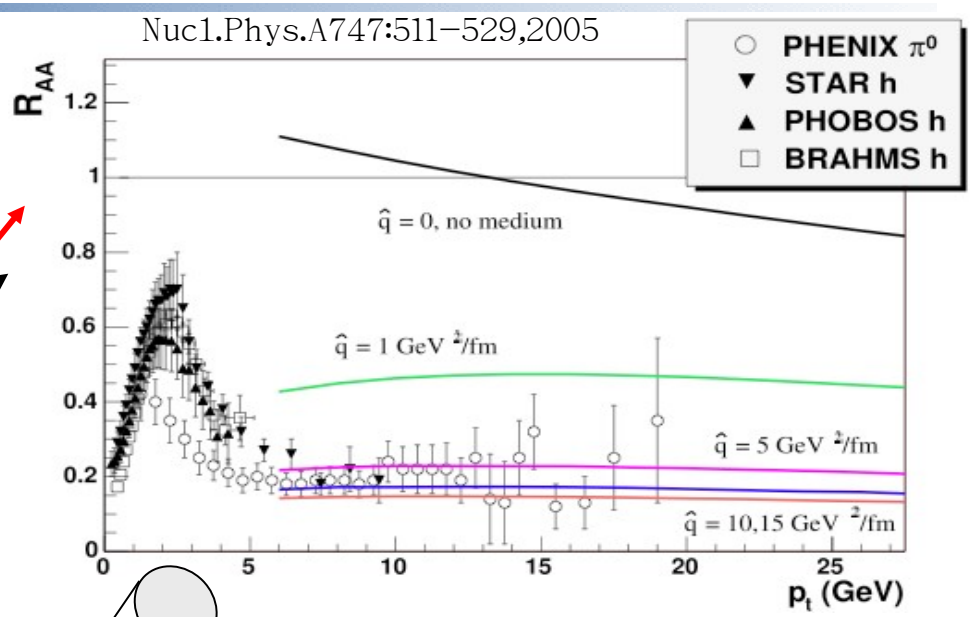
Jet quenching: RHIC vs LHC

- At RHIC, suppression of **leading particles**
  - Interpreted by "parton energy loss" models
  - Surface bias dominates yield at high p_T
- Measure Jet Quenching effect:
  - R_{AA} (Vasu's talk)
  - Fragmentation function
- At LHC, jet cross sections large enough to copiously produce high-E_T jets :
  - Use **jets** to characterize initial partons event-by-event
  - Measure how the "energy loss" is distributed inside the jet fragmentation cone





Nuc1.Phys.A747:511–529,2005



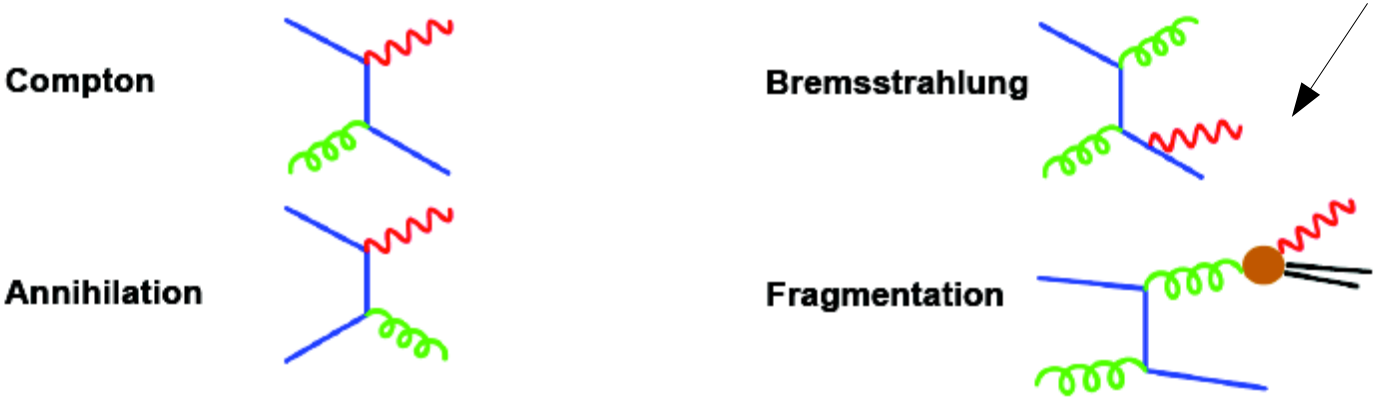
$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta}$$

Ratio of AA/pp scaled by # of binary NN collisions

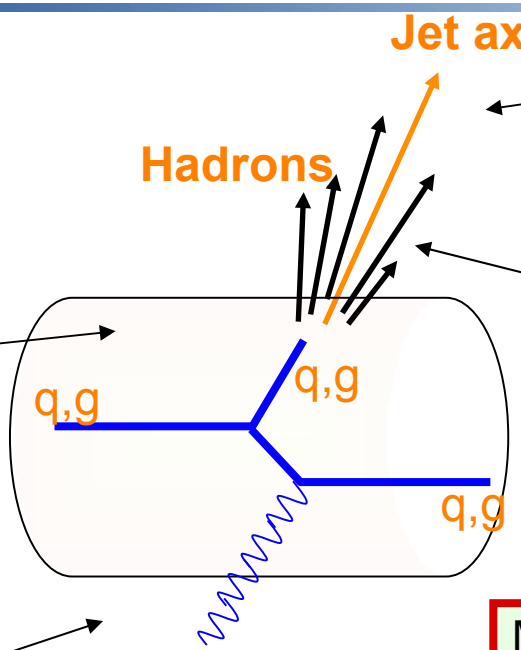
Photon energy tag

- Use the photon to tag parton energy
  - Goal: Best correlation of parton and photon energy
  - Ideal: Use the leading order photons
  - In Practice: Use the isolated photons to select events with good correlation of parton and photon energy

Background photons usually associated with jets, remove them by isolation cut in data analysis



Photon-tagged jet fragmentation functions



3.Jet axis provides parton direction

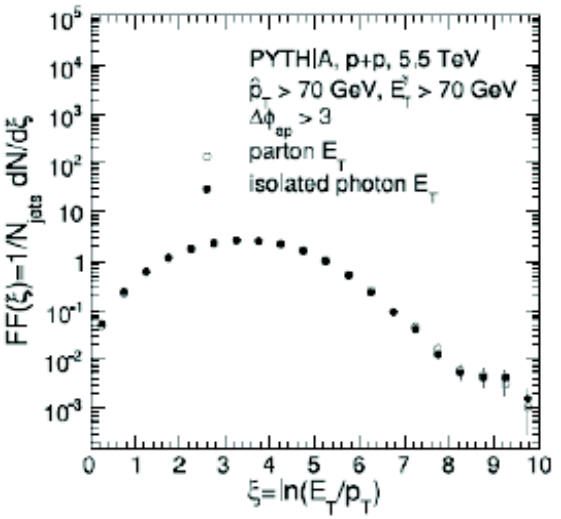
1.Multiplicity and flow measurements characterize density, path length

4.Charged hadron tracks used to calculate

$z = p_T/E_T$

2.Photon energy tags parton energy E_T

Measure jet fragmentation function:
$dN/d\xi$ with $\xi=-\log z$



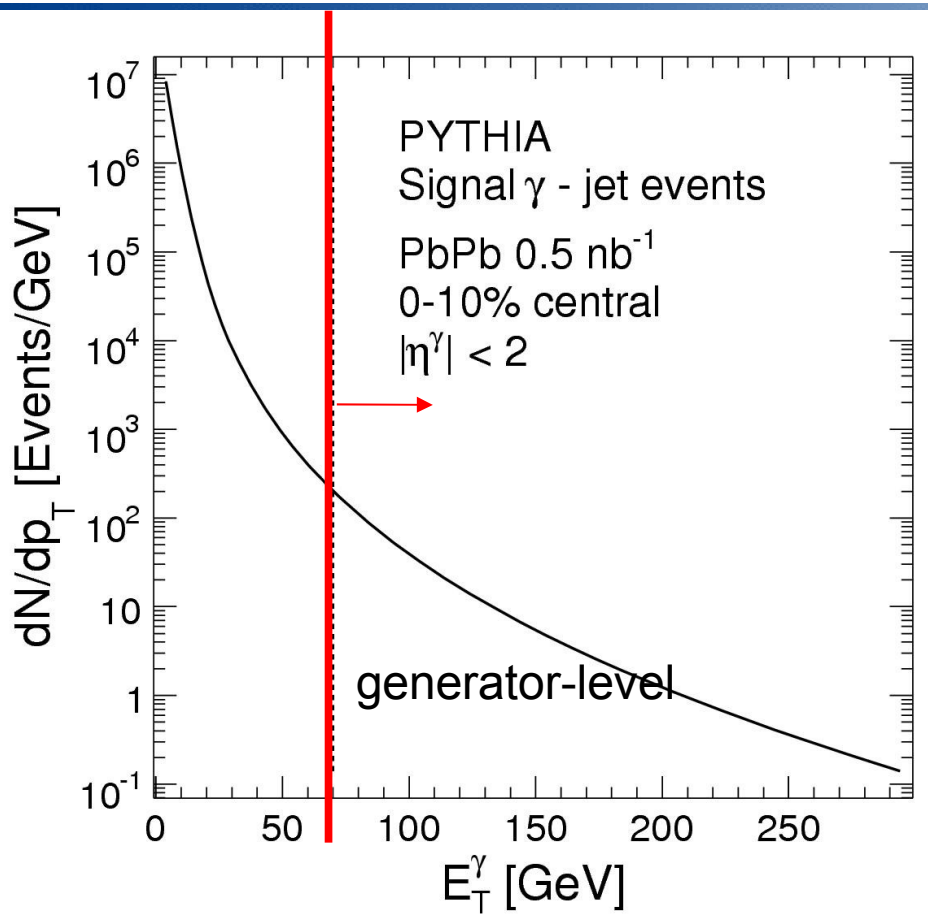
Main advantage

- Photon unaffected by the medium
- Avoids measurement of absolute jet energy

Event generation

- Study two scenarios
  - **No Quenching**: PYTHIA signal and QCD background (p+p) events mixed with central unquenched Pb+Pb HYDJET events
    - No high-p_T particle suppression
    - Leads to high background rates
  - **Quenching**: PYQUEN signal and QCD background (p+p) events mixed with central quenched Pb+Pb HYDJET events
    - Suppression of high-p_T particles
    - Energy loss radiated out of jet cone
    - Challenging for jet finder

Signal and background statistics



- Study for one nominal LHC Pb+Pb run "year"
  - 10^6 sec, 0.5nb^{-1}, 3.9 x 10^9 events
- Use 0-10% most central Pb+Pb
  - $dN/d\eta|_{\eta=0}$~2400
- Simulate signal and background QCD (p+p) events
  - Mix into simulated Pb+Pb events (~1000 events)

Data set	p_T [GeV/c]	signal γ-jet	π^0	$\pi^{\pm}$	η	η′	ω
unquenched	>70	4288	23675	47421	12267	8194	30601
unquenched	>100	1216	4422	9103	2357	1567	5975
quenched	>70	4209	7569	14616	3825	2445	9235
quenched	>100	1212	1562	3000	829	515	2051

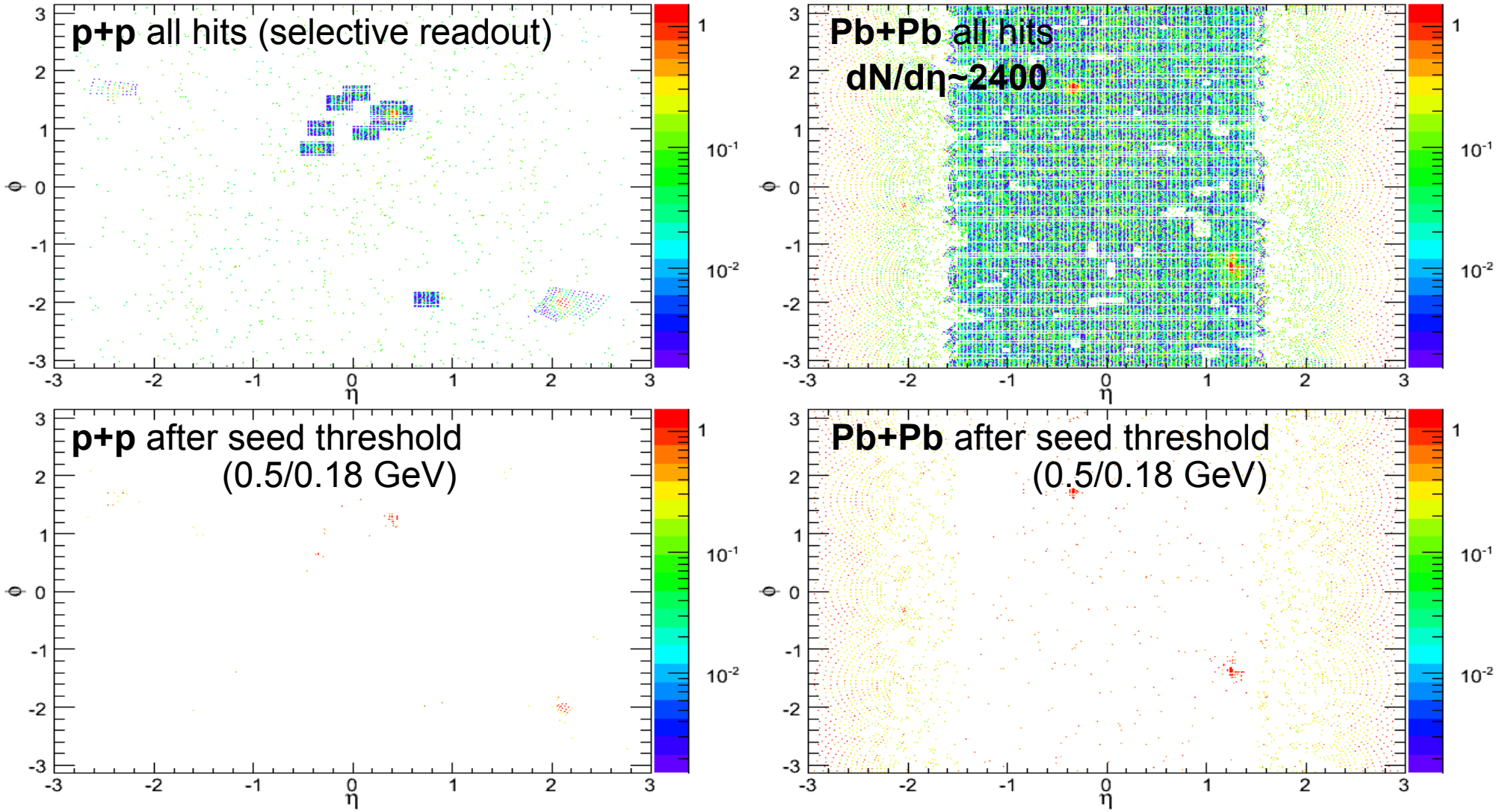
Reconstruction

- Tracking
  - Low p_T cutoff at 1GeV/c
  - Efficiency (algorithmic + geometric) ~ 50-60%
  - Fake rate ~ few %
- Jet axis finding
  - Iterative cone algorithm with underlying event subtraction (R=0.5)
  - Performance studies on away-side jet finding (see later)
- Photon ID
  - Reconstruction of high-E_T isolated photons
  - New for this analysis (see next slides)

Tracking: NIM A566 (2006) 123

Jet finding: Eur. Phys. J. 50 (2007) 117

ECAL response in p+p and Pb+Pb

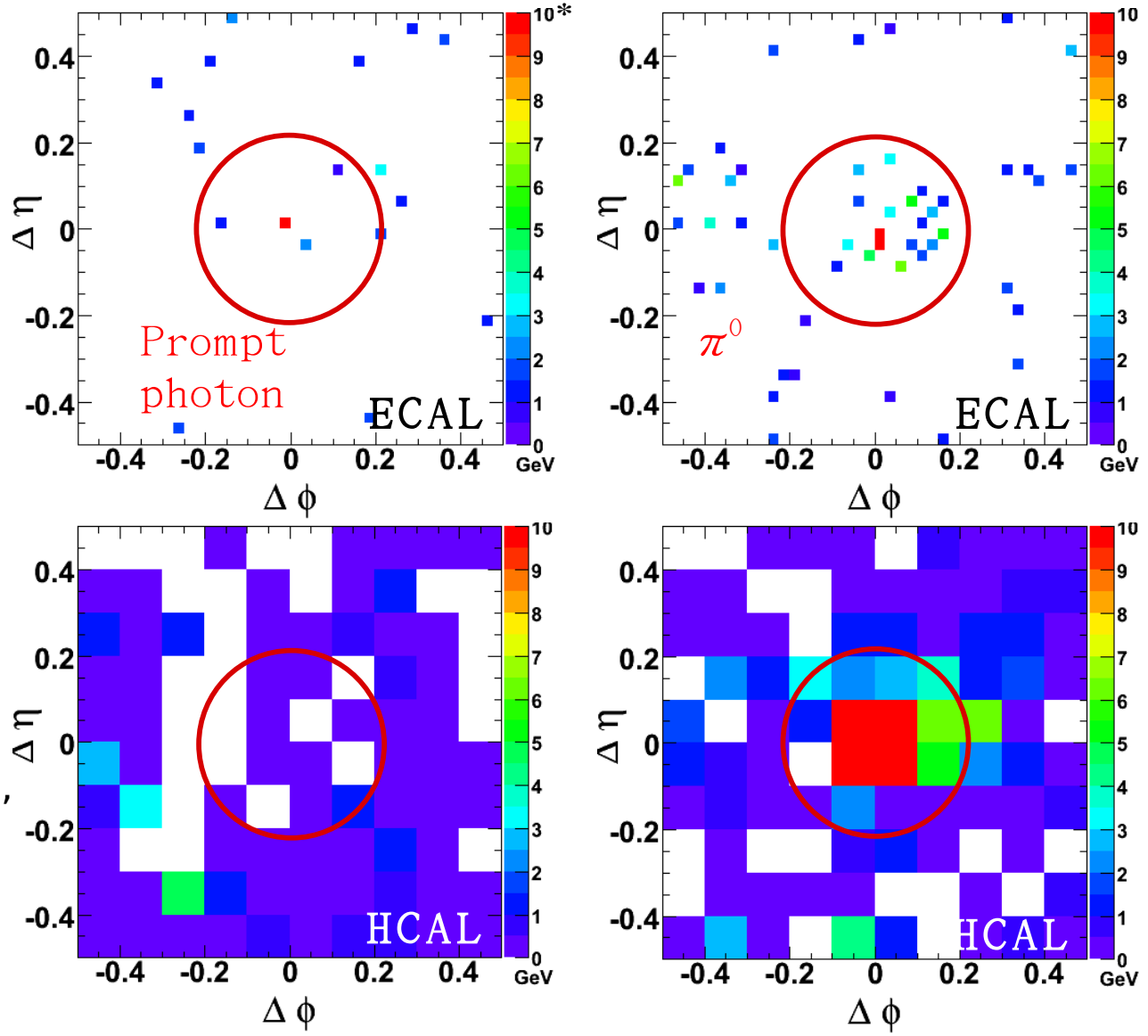


ECAL reconstruction chain used with standard p+p settings

NB: The two p+p (QCD) events are not the same.

Photon ID: Isolation and cluster shape cuts

- Identification
  - 10 cluster shape variables
    - based on ECAL
  - 10 isolation variables
    - based on ECAL/HCAL
  - Track-based cut
- Selection
  - Total of 21 variables grouped into 3 sets (photon ID, Calo Isolation, track isolation)
  - Linear discriminant analysis (Fisher) and cut optimization using TMVA

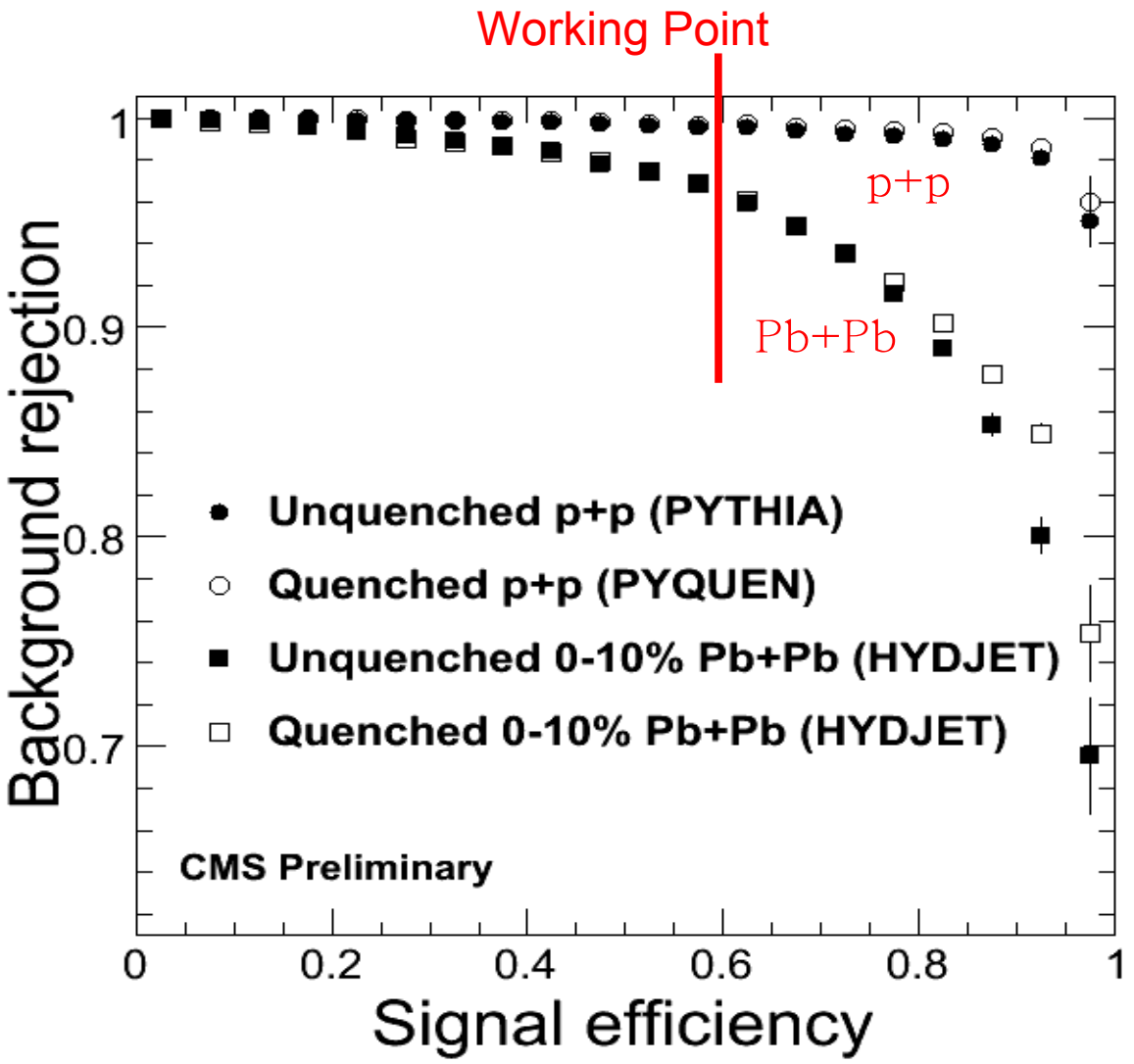


TMVA: http://tmva.sourceforge.net

*) Maximum set to 10

Photon identification performance

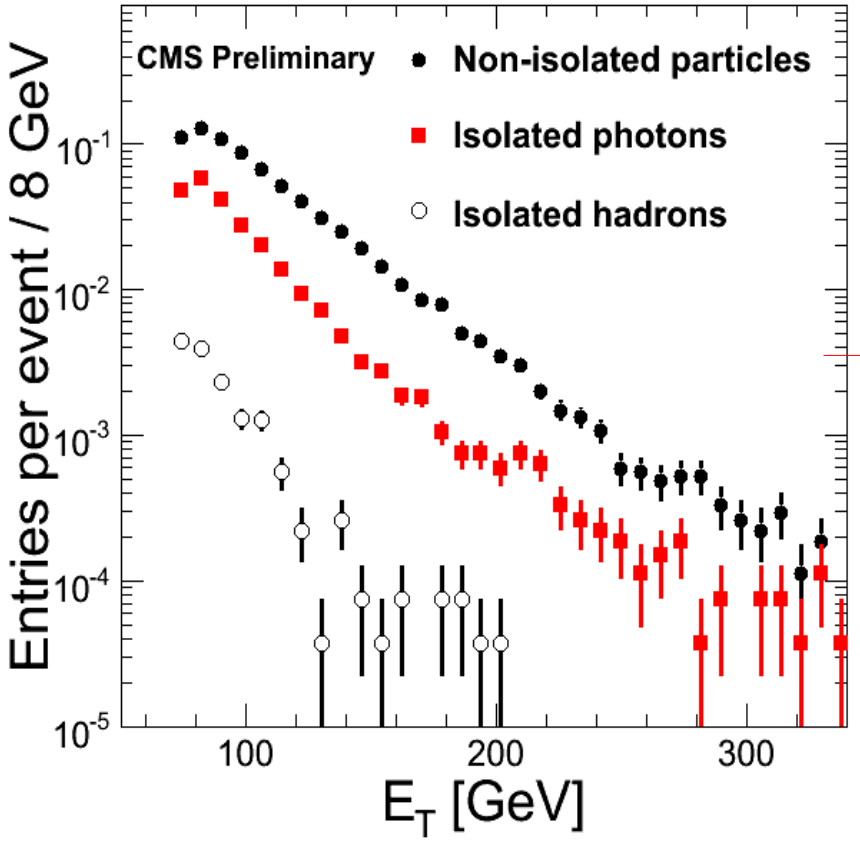
- Set working point to 60% signal efficiency
- Leads to 96.5% background rejection
- Training is done on unquenched samples only



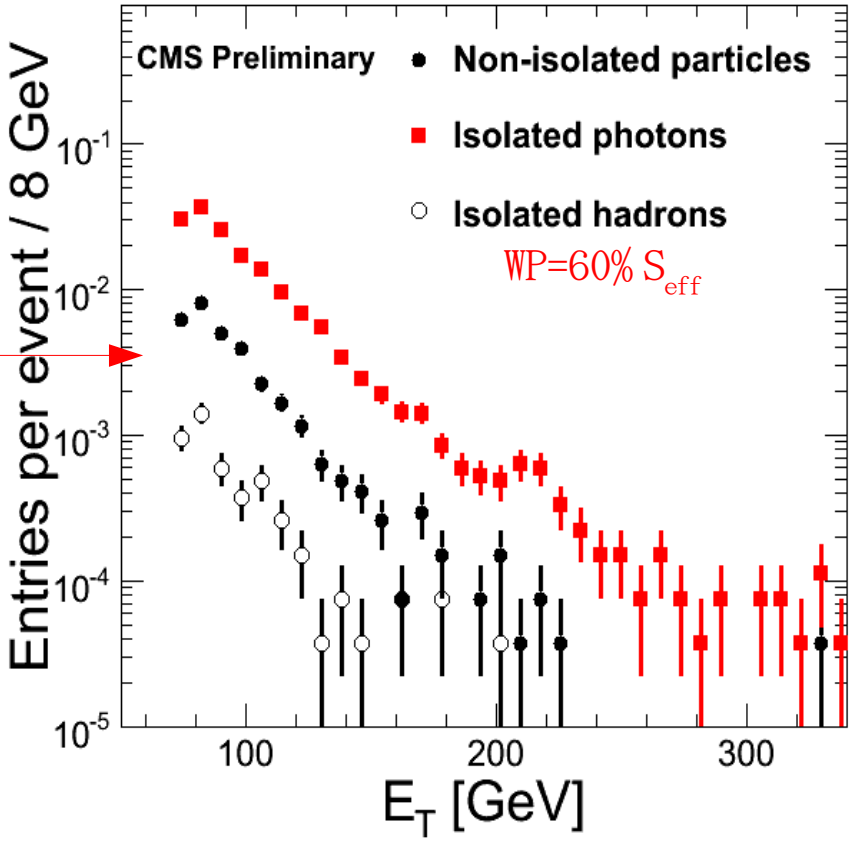
Photon identification performance

Quenched Pb+Pb

Before cuts: S/B=0.3



After cuts: S/B=4.5

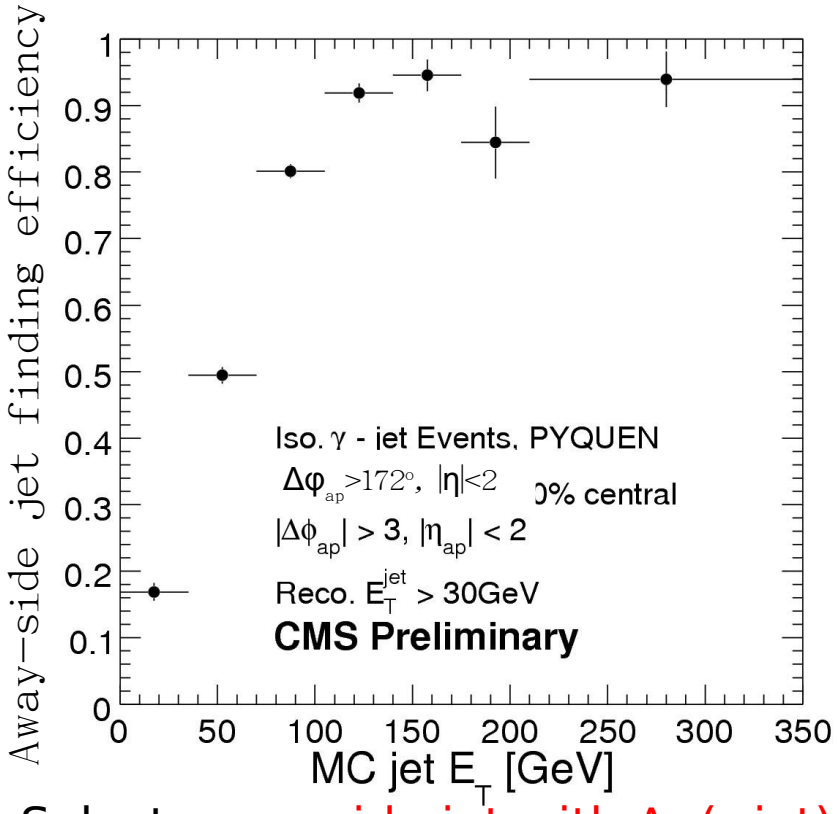


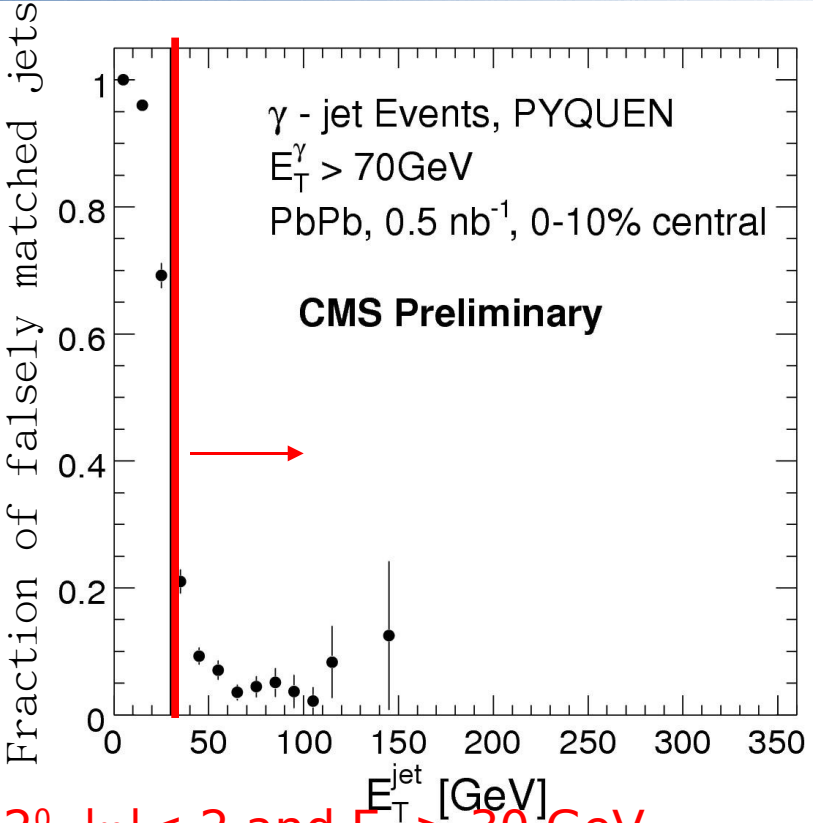
E_T^{γ} >70GeV

Photon isolation and shape cuts improve S/B by factor ~15

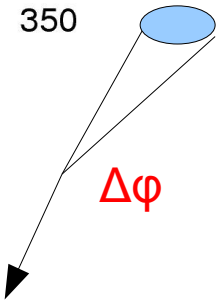
Jet finding (away-side)

Quenched Pb+Pb



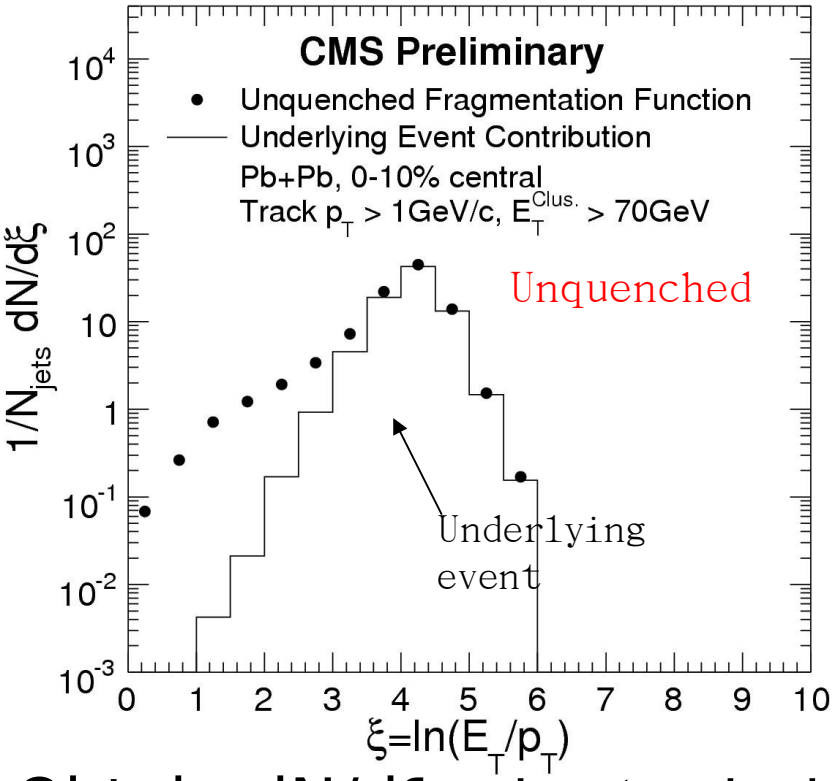


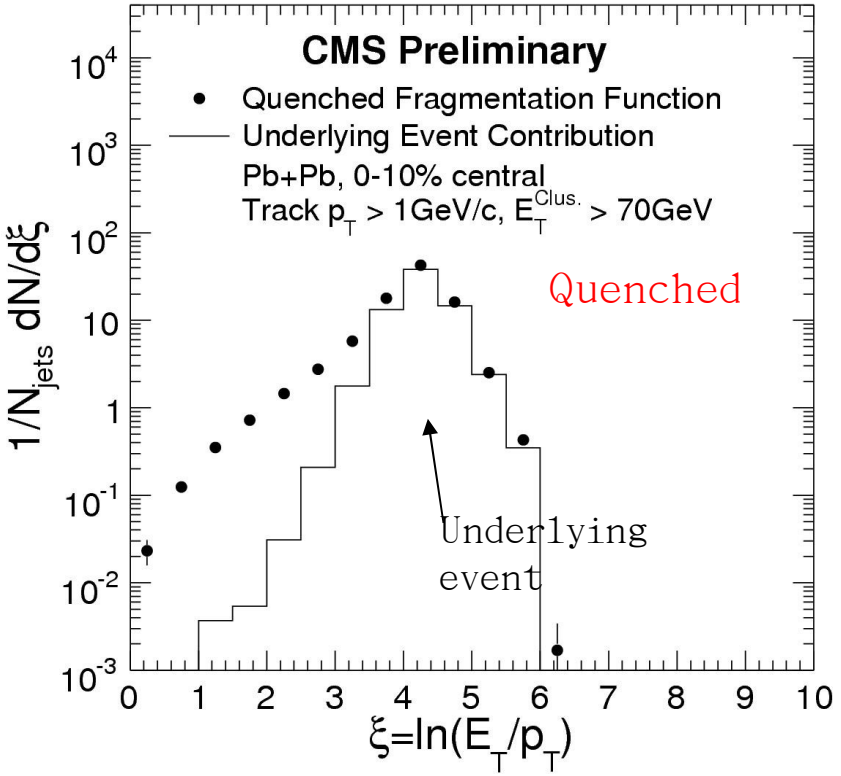
- Select away-side jet with $\Delta\varphi(\gamma,\text{jet}) > 172^0$, $|\eta| < 2$ and $E_T > 30$ GeV
  - The energy cut reduces the false rate to 10% level
    - Analysis does not use jet energy otherwise
  - Jet finding efficiency rises sharply between 30-100 GeV MC jet E_T
    - Main source of systematic uncertainty in reconstructed FFs



Algorithm: CMS NOTE 2006/050
Authors: O. Kodolova, I. Vardanyan, A. Nikitenko, A.Oulianov.
Eur. Phys. J. C 50 (2007) 117 123

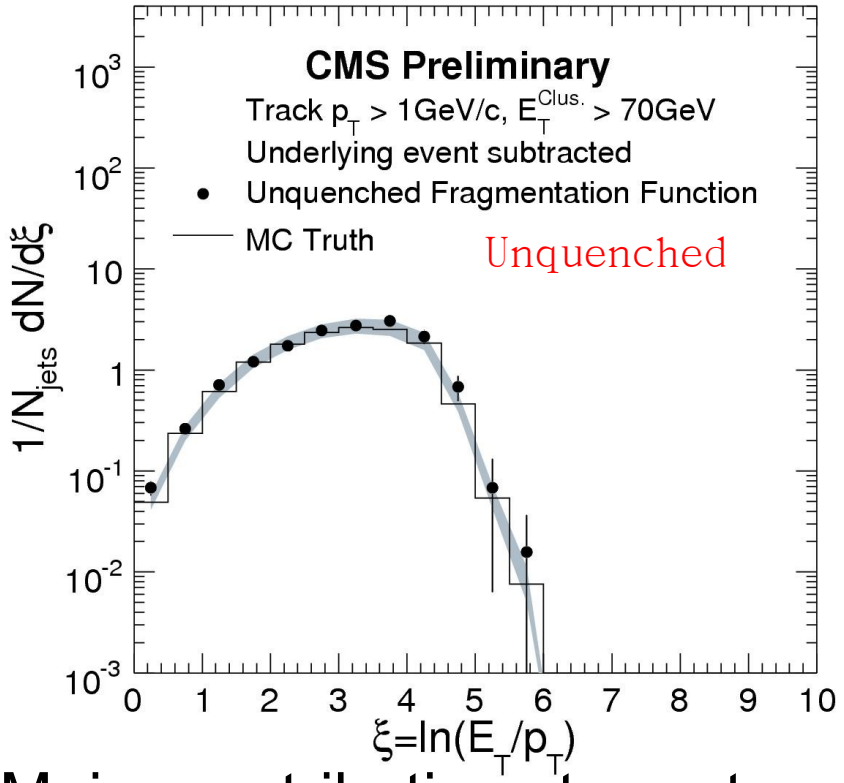
Fragmentation Functions

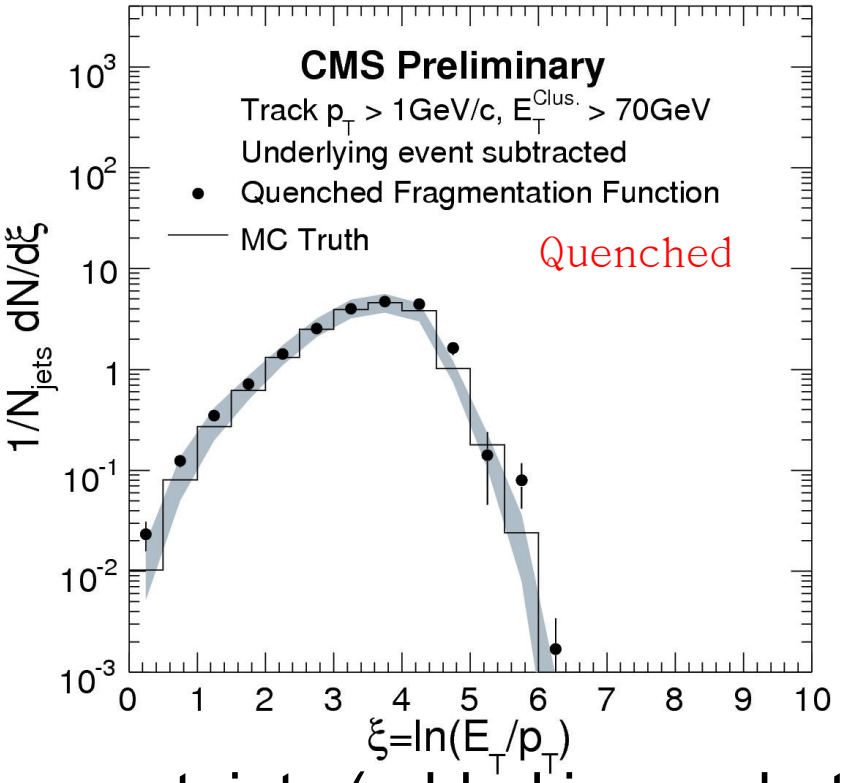




- Obtain dN/dξ using tracks in R=0.5 cone around jet axis
- For ξ>3 (~p_T<4GeV/c) dN/dξ dominated by underlying Pb+Pb event
  - Estimate background using R=0.5 cone rotated in φ by 90º relative to jet
  - Sum event-by-event backgrounds and subtract

Reconstructed fragmentation functions



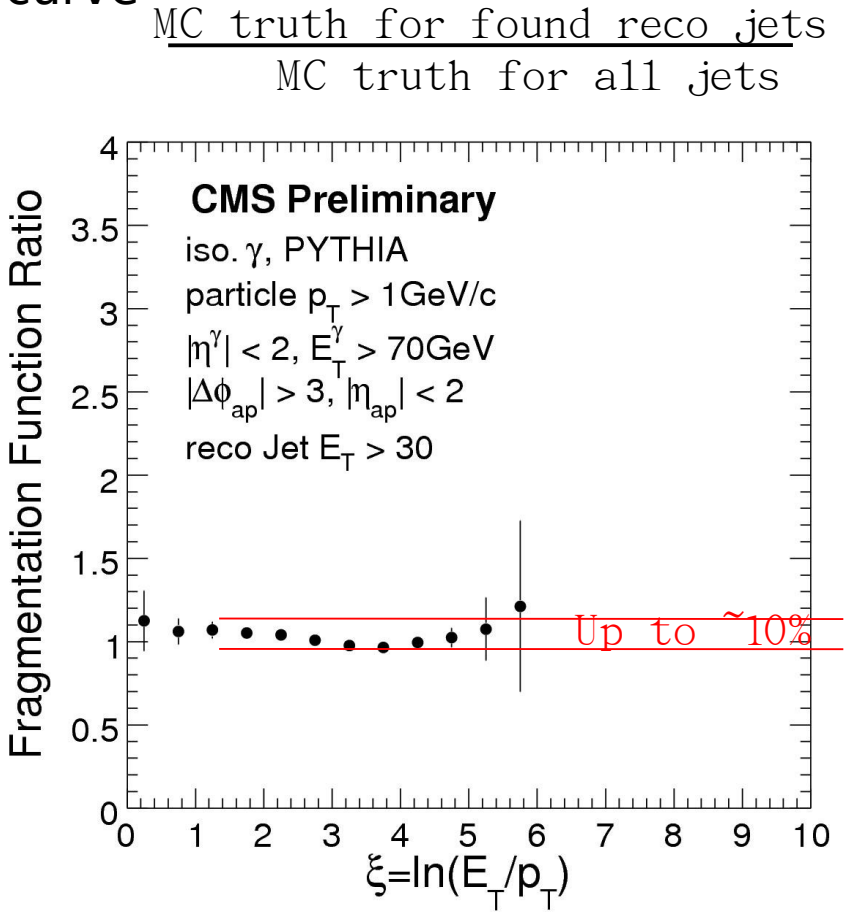


- Major contributions to systematic uncertainty (added in quadrature)
  - Photon selection and background contamination (15%)
  - Track finding efficiency correction (10%)
  - Wrong/fake jet matches (10%)
  - Jet finder bias (10-30%, largest contribution in quenched case, see next slide)

} No or small ξ dependence

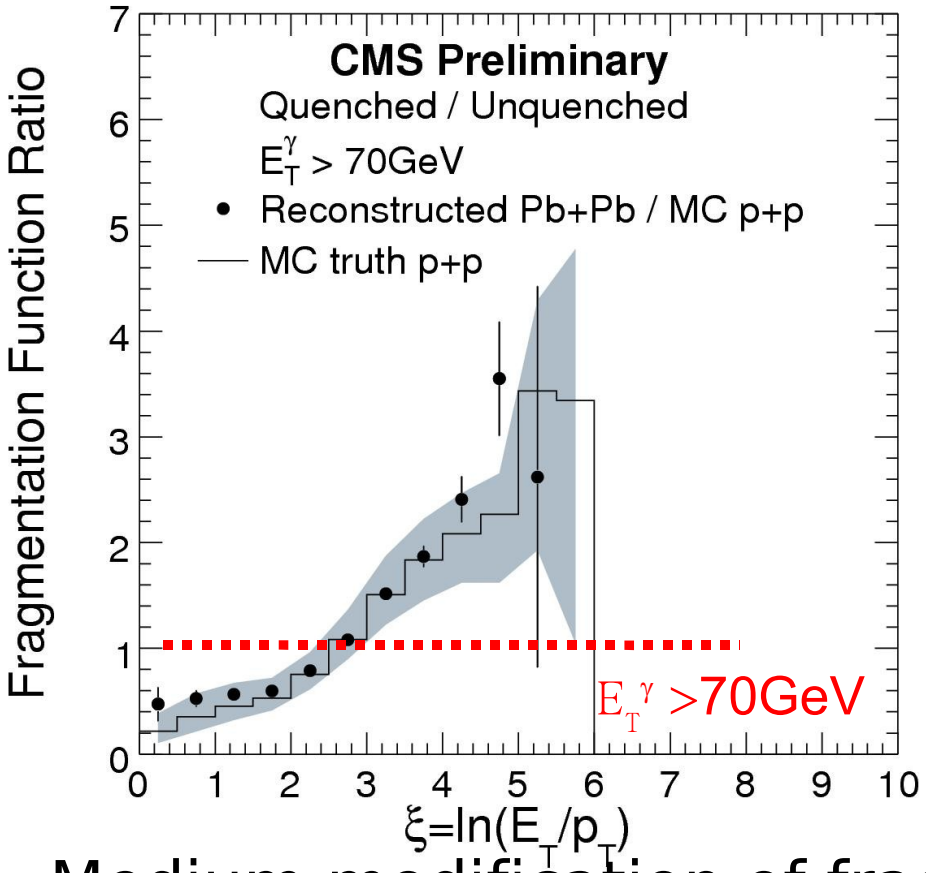
Jet finder bias

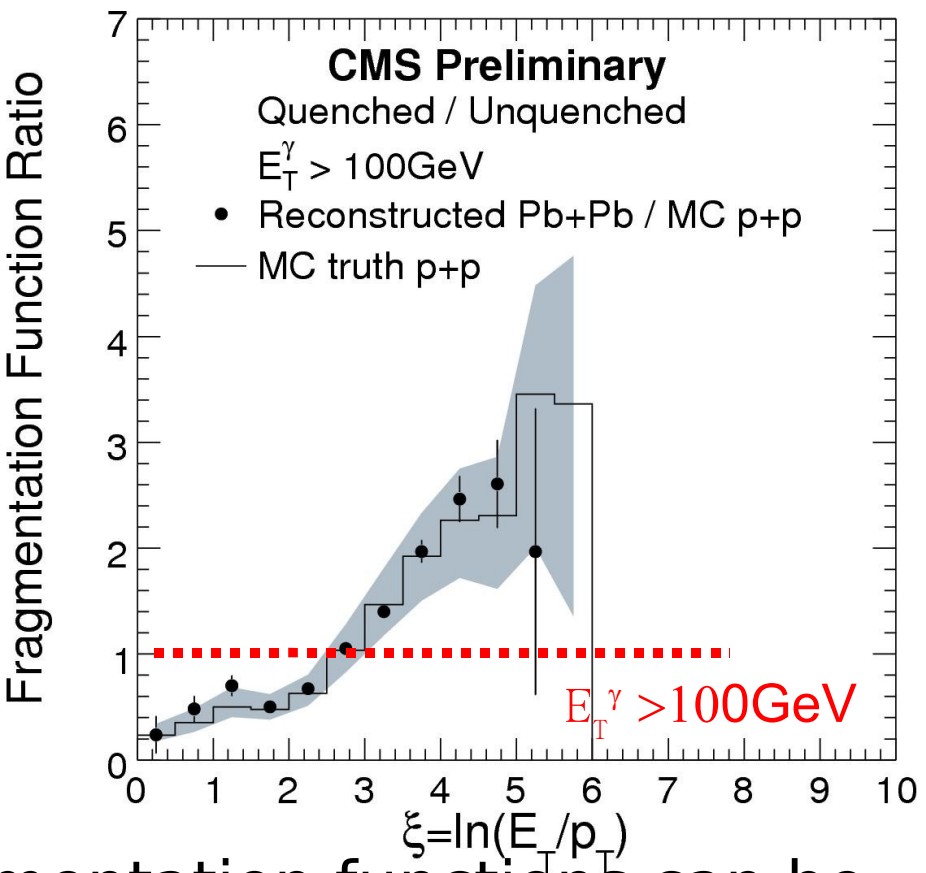
- Jet finder bias leads to about 30% in quenched case
  (10% for unquenched case)
- It has two contributions
  - 1)FFs and jet finding efficiency depend on parton E_T
    - Can be corrected with known turn-on curve (not done here)
  - 2)For a given parton E_T, jet finding probability depends on parton fragmentation pattern
    - The jet finder is more likely to find a jet with few high p_T particles than jets with many soft particles
    - MC based correction might be possible (not done here)
- MC studies suggest that 2) dominates



Fragmentation function ratio

Reconstructed quenched Pb+Pb / MC unquenched p+p





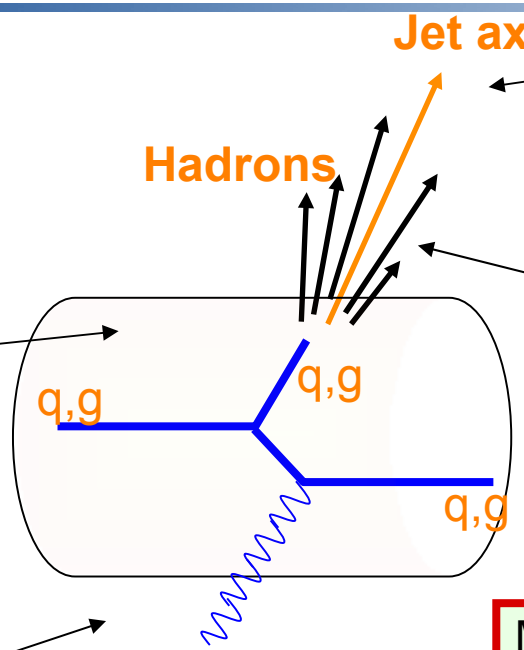
- Medium modification of fragmentation functions can be measured
  - High significance for $0.2 < \xi < 5$ for both, E_T^γ >70GeV and E_T^γ >100GeV

Summary

- Complete study of in-medium fragmentation functions using photon-tagged jet events
  - Two scenarios: Unquenched and quenched cases
    - Pythia and Pyquen (+ Hydjet)
- Key features of the study
  - Full statistics expected for nominal one-year CMS Pb+Pb run at LHC
  - Full detector simulations of signal and background
  - Complete reconstruction chain
    - Track finding
    - Jet finding
    - Photon isolation
    - Underlying event subtraction
  - Analysis of systematic errors
    - Uncertainty dominated by jet finder bias
- Measurement of expected strong medium modification of fragmentation functions can be done reliably in central Pb+Pb

Backup Slides

Photon-tagged jet fragmentation functions



3.Jet axis provides parton direction

1.Multiplicity and flow measurements characterize density, path length

4.Charged hadron tracks used to calculate $z = p_T/E_T$

2.Photon energy tags parton energy E_T

Measure jet fragmentation function: $dN/d\xi$ with $\xi=-\log z$

Main advantage

- Photon unaffected by the medium
- Avoids measurement of absolute jet energy

Ingredients:

- Event/Centrality selection
- Reaction plane determination
- Vertex finding
- Track reconstruction
- Jet finding
- Photon identification

All results based on full GEANT-4 simulations using full reconstruction algorithms on expected one run-year statistics