Direct Photons from RHIC to the LHC

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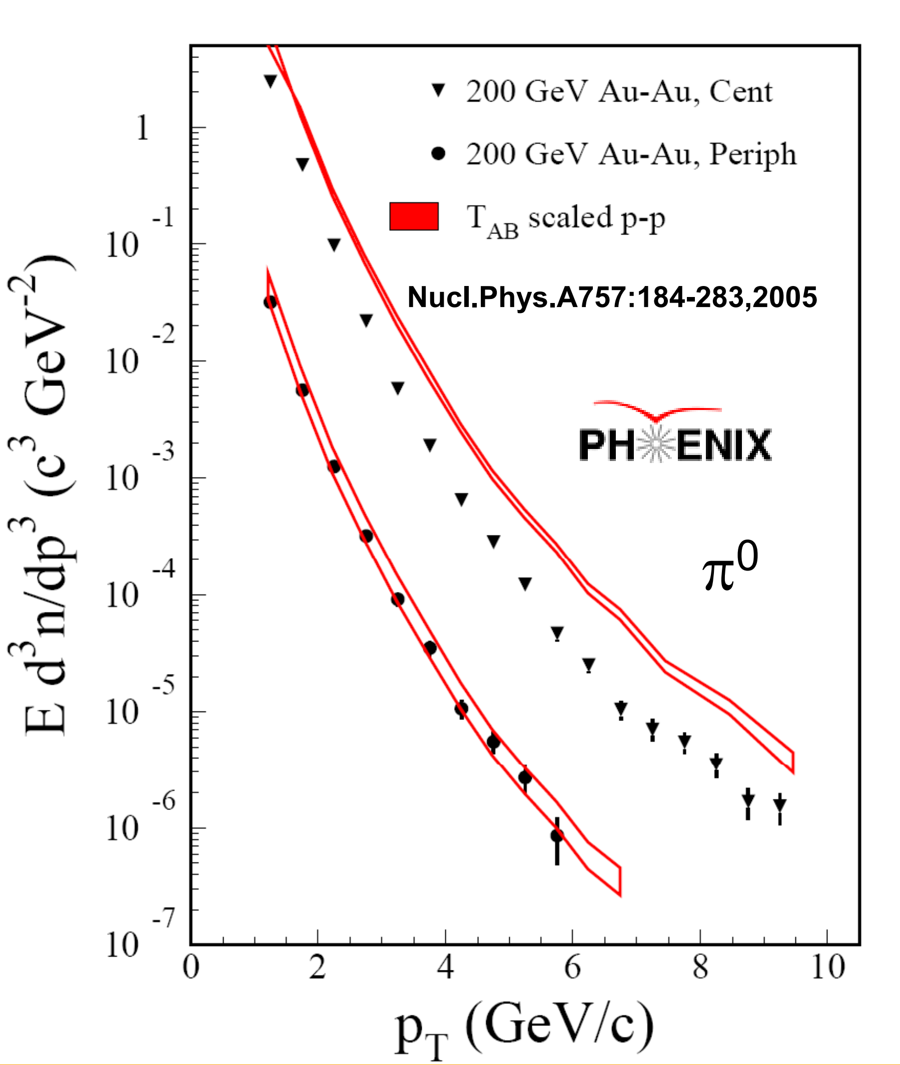
RBRC

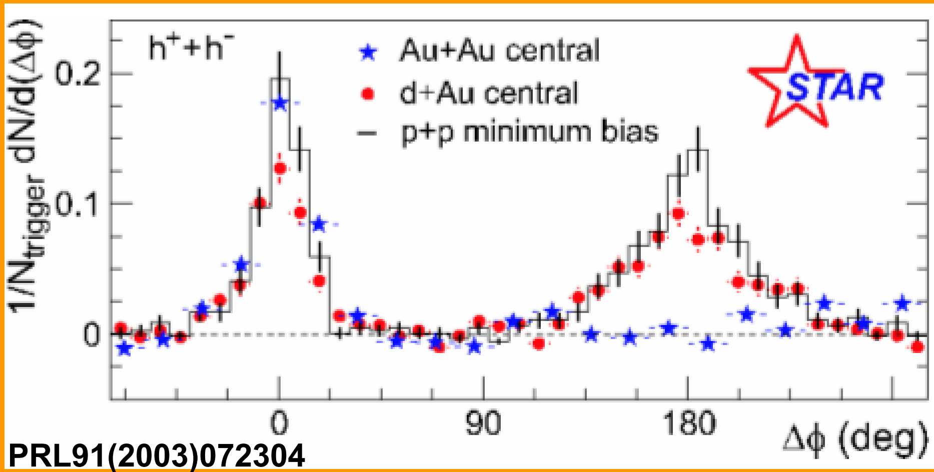
Nuclear Physics Seminar
BNL, August 19, 2008

What I will do in this talk
- a disclaimer -

- I’ll talk little about RHIC physics
- I’ll talk some about LHC physics
- I’ll talk much about LHC calorimeters

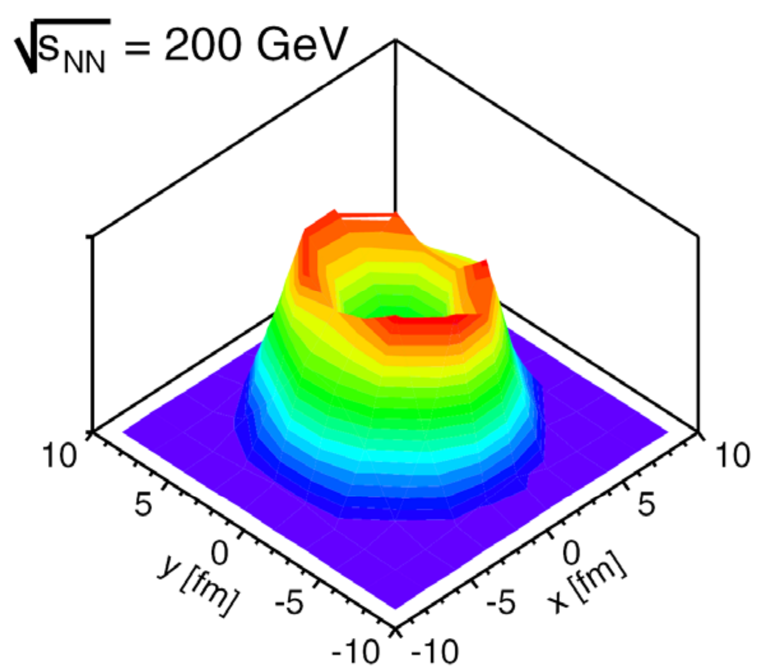
RHIC Key Physics Result





- High-pT hadron suppression
- E loss of partons in medium

Surface Bias



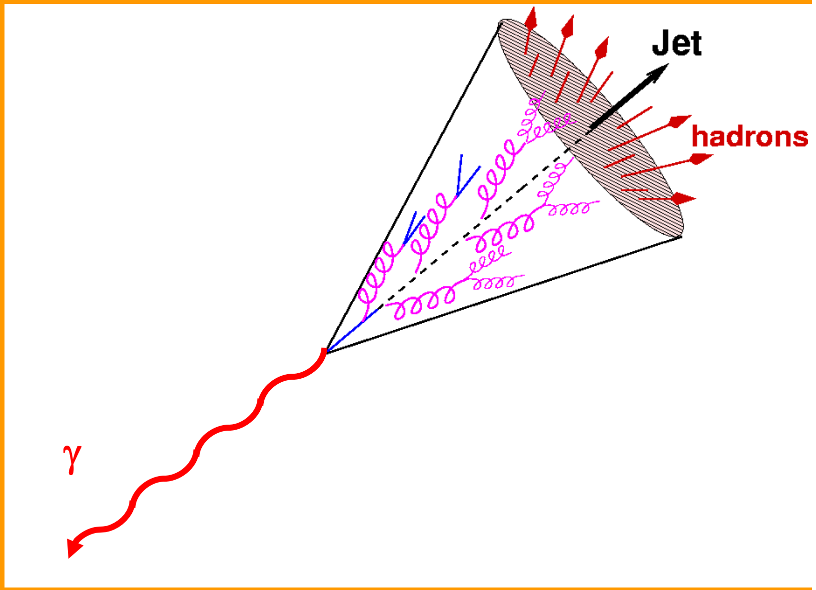
Dainese et al., Eur. Phys. J. C 38, 461 (2005)

Origin of partons that produce 5 GeV hadrons in central Au+Au

- Strong suppression (factor 5)
- Dominated by surface emission (black probe)
- Difficult to learn about suppression mechanism

How can we learn more?

- **"[Almost]** everything you want to know about jets can be found in 2-particle correlations." Mike Tannenbaum
- "**Almost**": Shape of x_E distribution not sensitive to FF
  - ♦ Reason: trigger bias
- Trigger bias can be overcome by
  - ♦ γ-h correlations (also overcomes surface bias!)
  - ♦ Full jet reconstruction (difficult, but higher rate)
- So what does γ-jet help vs. γ-h?
  - ♦ Jet angle easy to measure
  - ♦ Expect multiple scattering in medium even w/o E loss



Jet Measurements in HI Collisions

Challenge: background!

In cone of $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

there is $E = \pi R^2 dE_T / (d\phi d\eta)$

$= R^2 / 2 * dE_T / d\eta$

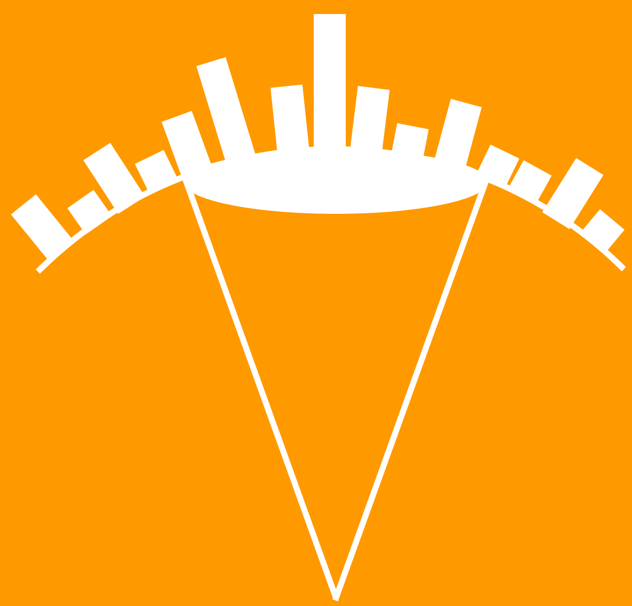
$dE_T/d\eta$ in central Au+Au at RHIC is 600 GeV*

*** Phys. Rev. C 71, 034908 (2005)**

→E= 300 GeV in cone with R=1

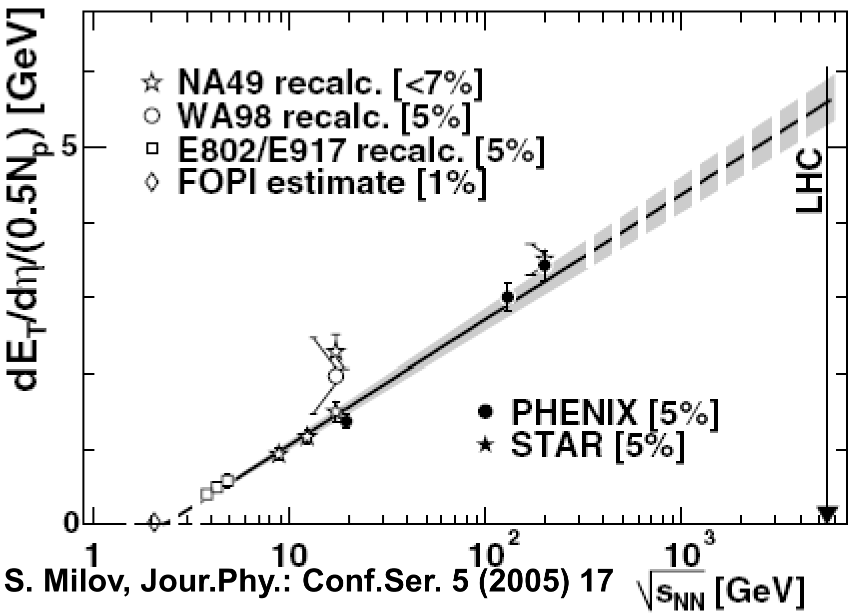
75 GeV in cone with R=0.5

Compare to maximum jet energy: 100 GeV



Jet measurement in HI at RHIC difficult!

Jet Measurements at LHC



S. Milov, Jour.Phy.: Conf.Ser. 5 (2005) 17

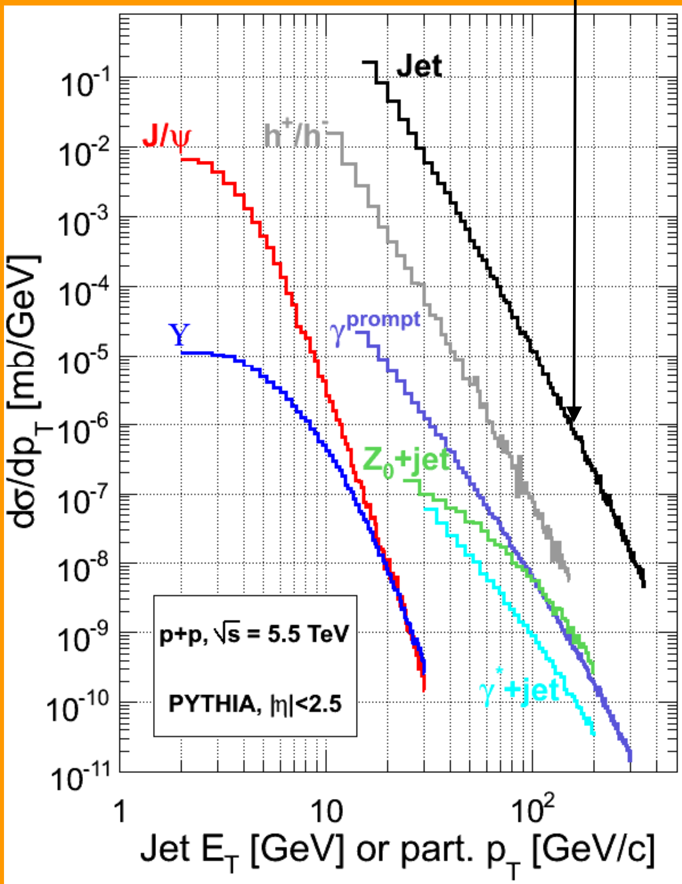
***Logarithmic extrapolation of √s dependence of (*$dE_T/d\eta$*)/(*$N_{part}/2$*) from SIS to LHC**

- **Jet measurement in HI at LHC still challenging**
  - **eliminate b fluctuations (large acceptance)**

$dE_T/d\eta$ in central Pb+Pb at LHC ≈ 1200 GeV*
→E= 600 GeV in cone with R=1
150 GeV in cone with R=0.5
Compare to: - maximum jet energy: 2750 GeV
- typical jet energy: 100-200 GeV

RHIC to LHC

Pb+Pb design lumi:
One Jet with 150 GeV/s

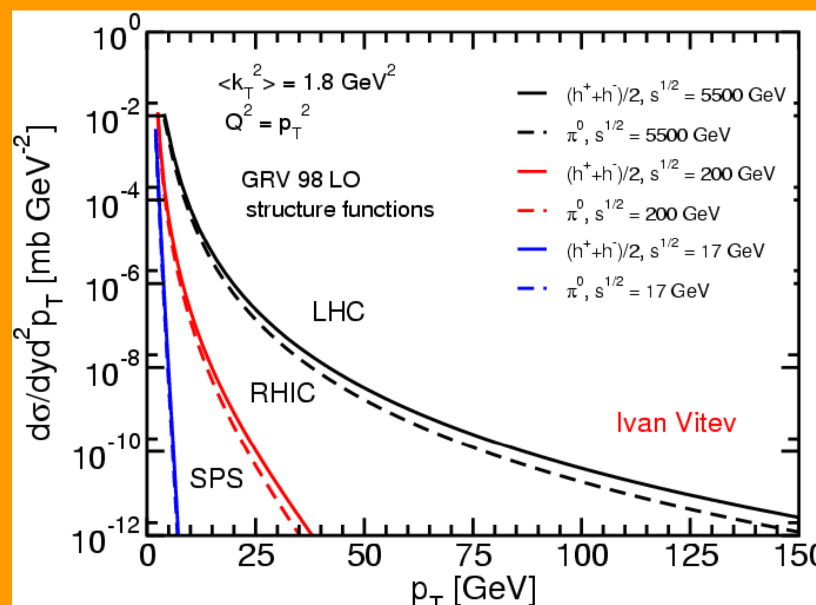


G. Roland, Hard Probes 2008

- $\sqrt{s}$: 0.2 TeV → 5.5 TeV (x 27.5)
- Relative rates (e.g. γ/π^0) ~ scale with x_T
  - ♦ e.g. γ fraction = 10%, 3 GeV at RHIC
    90 GeV at LHC

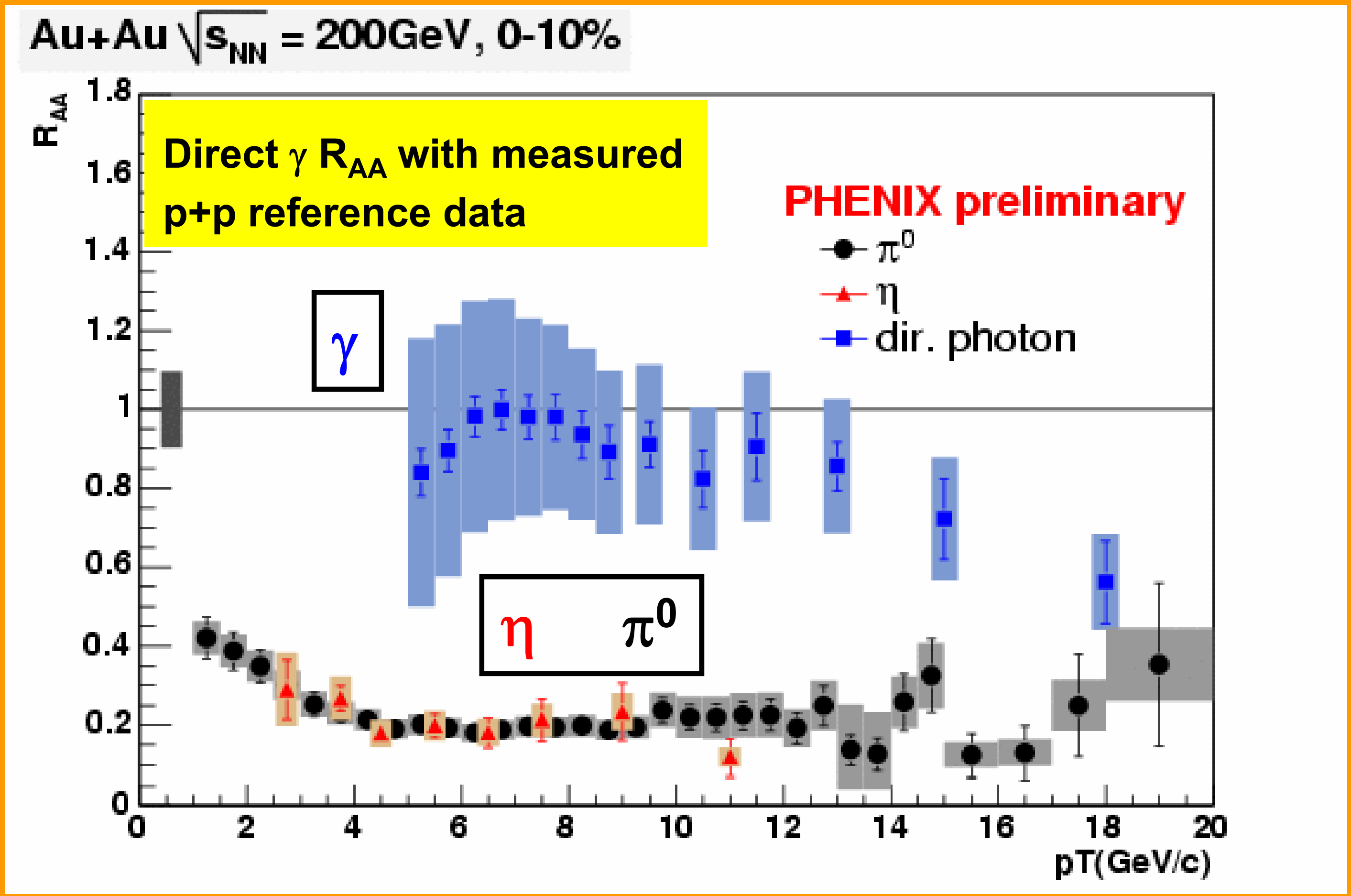
Experimental limit at RHIC

- σ_{hard} increases by orders of magnitude
- Accessible p_T range ~ 20-200 GeV (x10)
- New probes available
  - ♦ Jets, direct γ-jet correlations



Detailed study of hard scattering

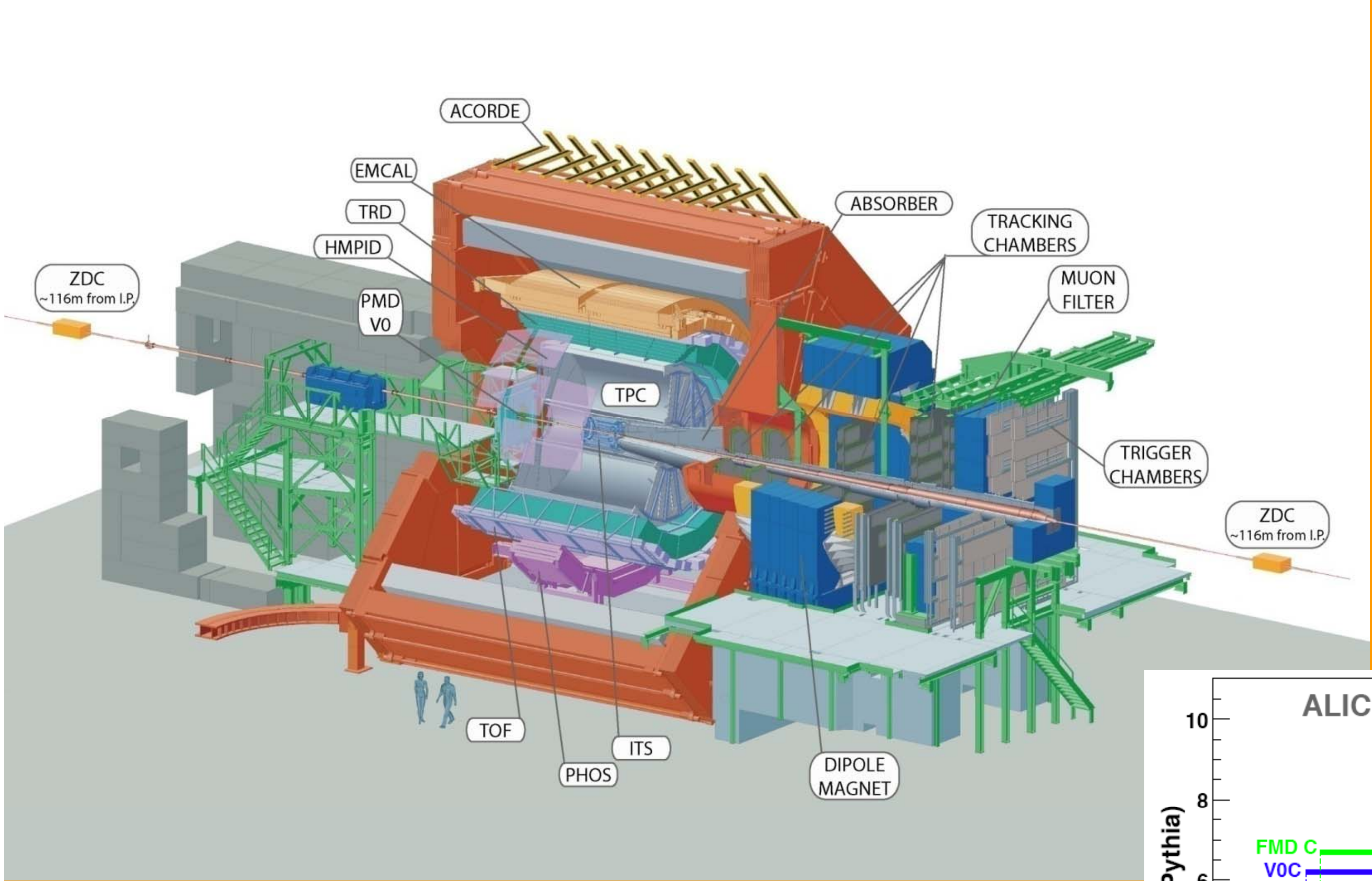
Caveat



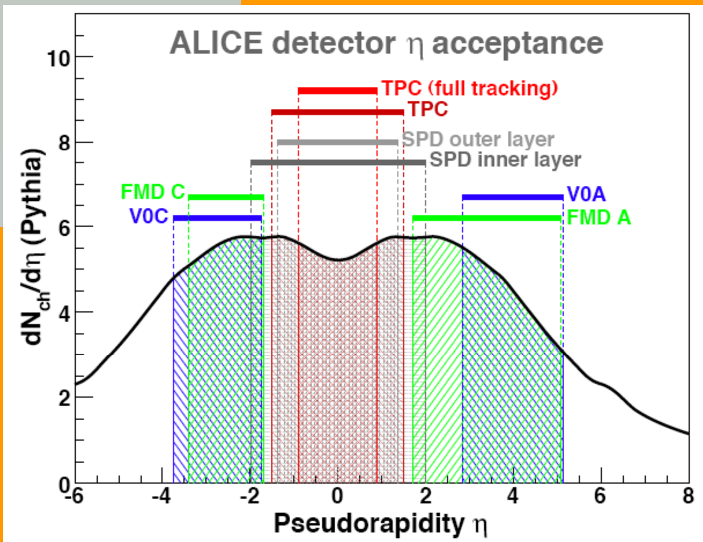
- "If energy loss is low-p_T phenomenon, LHC will have nothing to measure." (Mike Tannenbaum)


Time Projection Chamber
Particle Identification Detector
High-Momentum Particle Identification Detector
Absorber
Dipole Magnet
L3 Magnet
Muon Chambers
Photon Spectrometer
Inner Tracking System
Alice

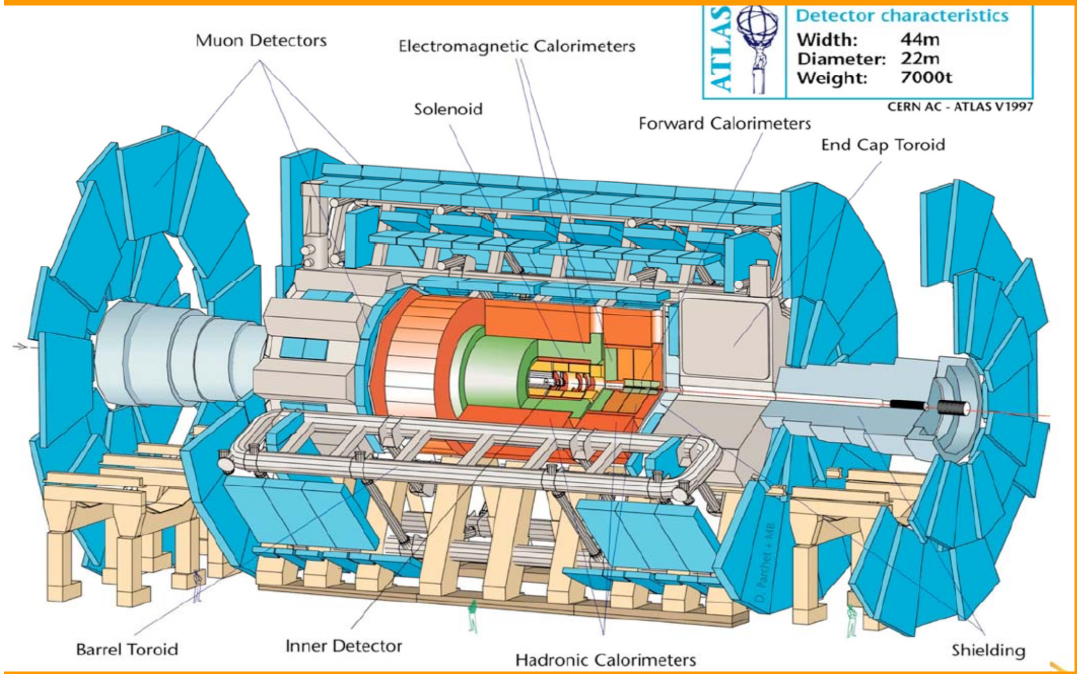
The ALICE Detector: dedicated to HI



Capabilities
Hadrons: 2π * 1.8 units η (dE/dx + ToF)
Leptons (dE/dx, TOF, transition radiation)
Photons (high resolution EM calorimetry, conversions)
Tracking and PID p_T range: 100 MeV/c -100 GeV/c



The ATLAS Detector



- Inner tracking
- EM and Hadronic calorimeters
- External muon spectrometers
- Full azimuthal acceptance in all detectors
- Large pseudorapidity coverage

Capabilities

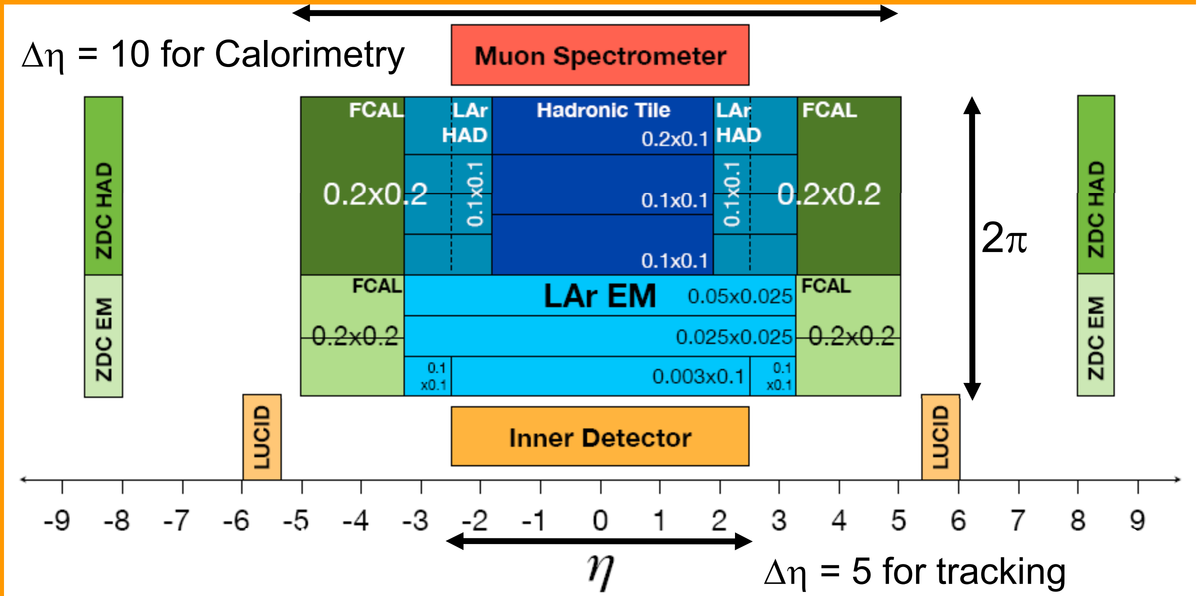
High-precision tracking $|\eta| < 2.5$

Muon identification $|\eta| < 2.5$

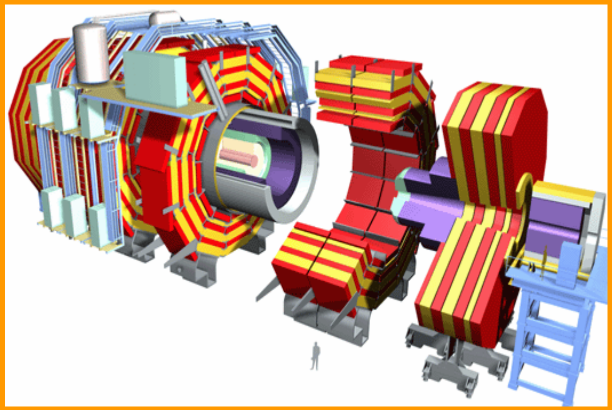
Highly segmented calorimetry $|\eta| < 5$

Forward coverage

Large bandwidth: DAQ + Trigger

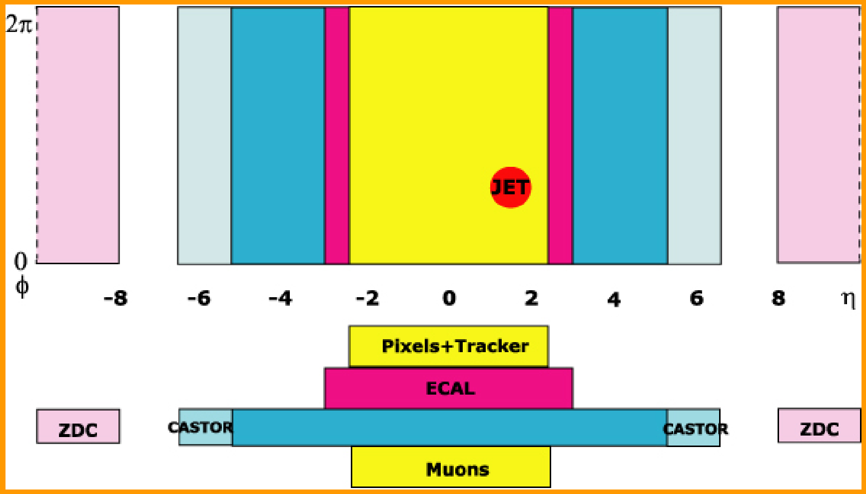


The CMS Detector



$\Delta\eta$ = 10 for Calorimetry

$\Delta\eta$ = 5 for Si tracker



Capabilities

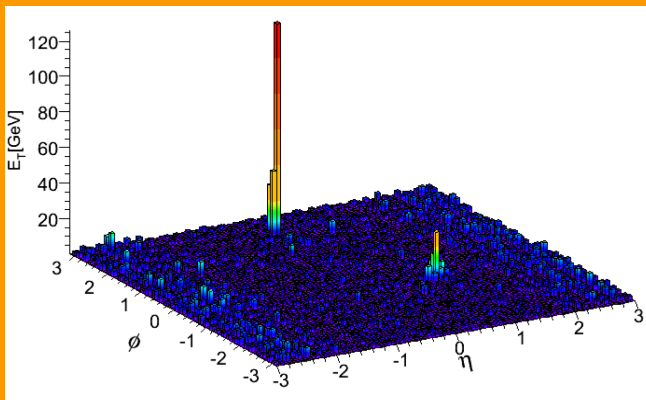
High-precision tracking over $|\eta| < 2.5$
Muon identification over $|\eta| < 2.5$
High resolution calorimetry over $|\eta| < 5$
Forward coverage
Large bandwidth: DAQ + Trigger

Very well suited for HI environment

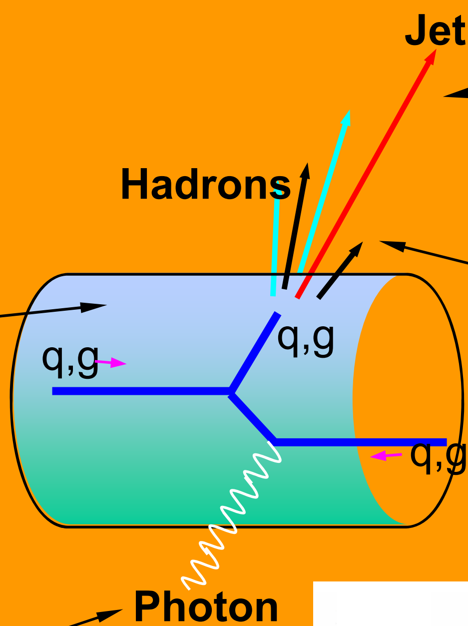
J.Phys.G34:2307-2455,2007

- Large (mid-rapidity) acceptance (tracker and calorimetry)
- DAQ+HLT will inspect every single Pb+Pb event
- Large statistics for rare probes

Measuring γ-Jet Correlations



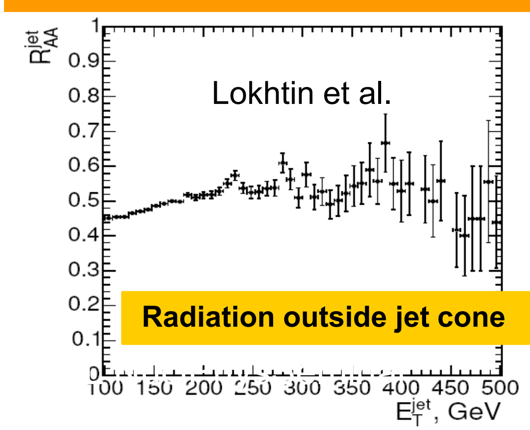
1) Multiplicity, <p_T> and flow measurements characterize density, path length



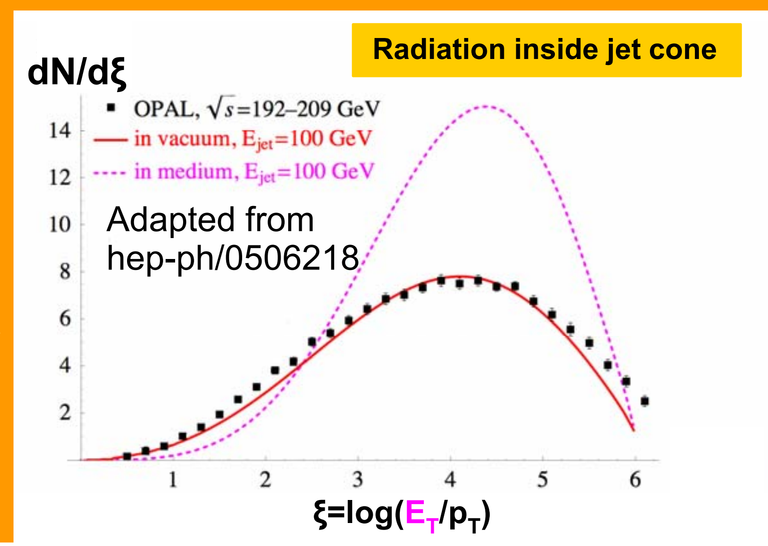
3) Jet axis provides parton direction

4) Charged hadron tracks used to calculate $z = p_{T(track)}/E_T^{\gamma}$

2) Photon energy tags parton energy E_T

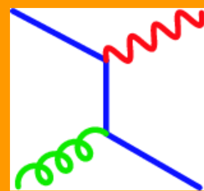


Collisional/non-perturbative vs. radiative E loss

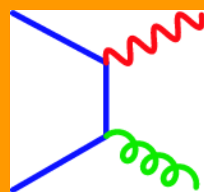


Photon Energy Tag

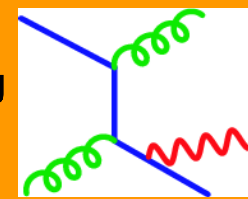
Compton



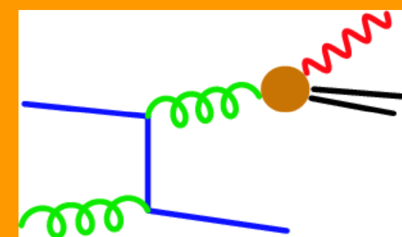
Annihilation



Bremsstrahlung



Fragmentation



Use photon to tag parton energy

Goal: Best correlation of photon and parton energy

Ideal: Use leading order photons

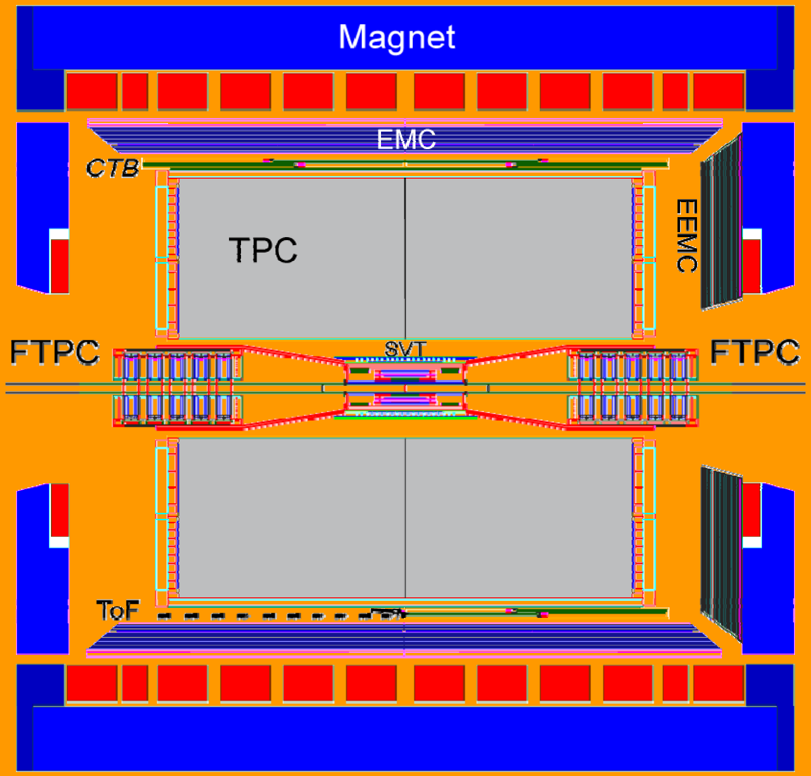
In practice: **Isolated** photons to select events with good correlation of photon and parton energy

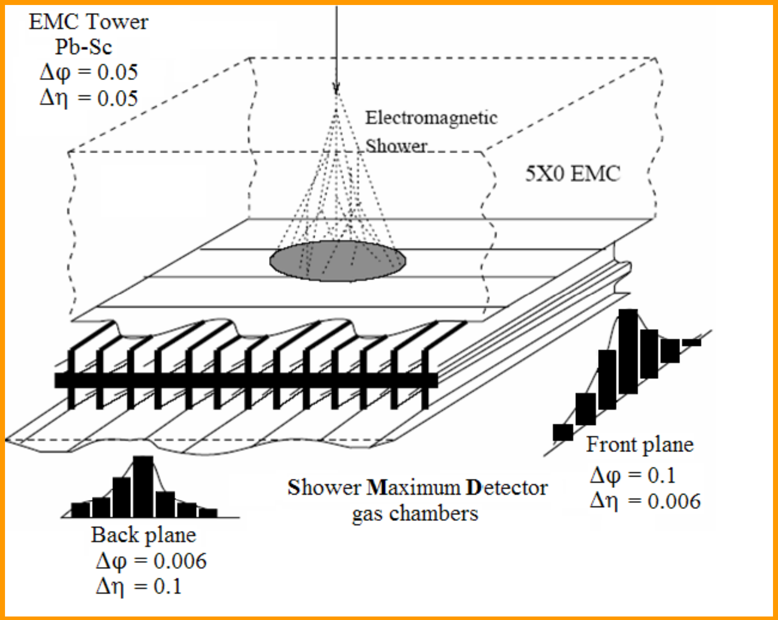
Background photons usually associated with jets

Remove using isolation cuts in data analysis **and** calculations

RHIC Calorimeters

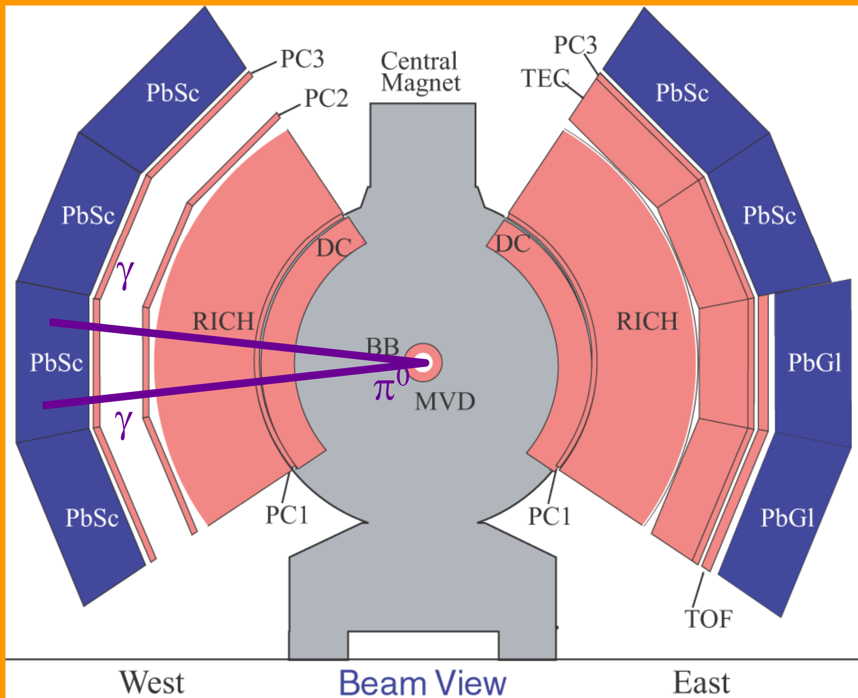
STAR Calorimeter

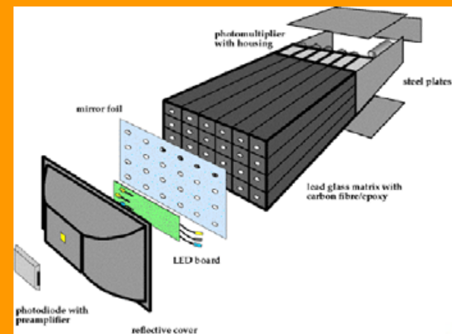


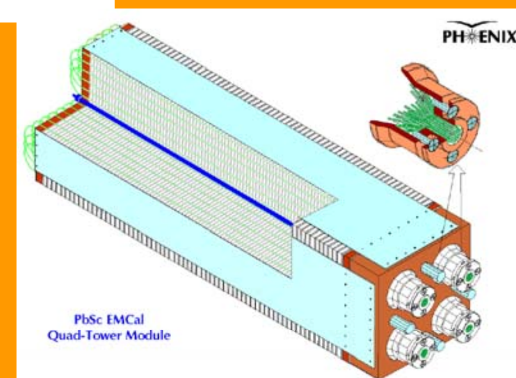


- Similar to LHC calorimeters
  - large coverage
  - high resolution in Shower Max for neutral hadron rejection
  - lower resolution in Towers for π^0 measurement

PHENIX Calorimeter

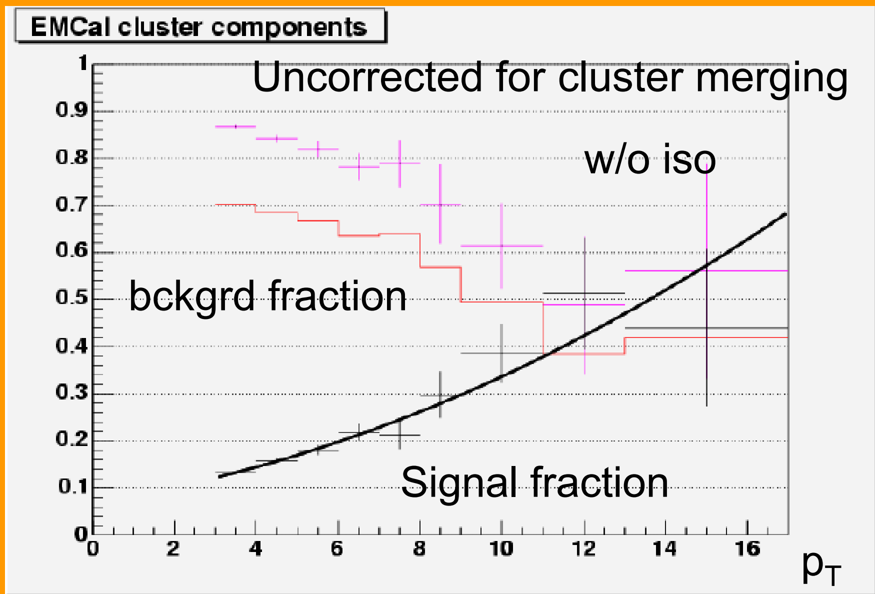


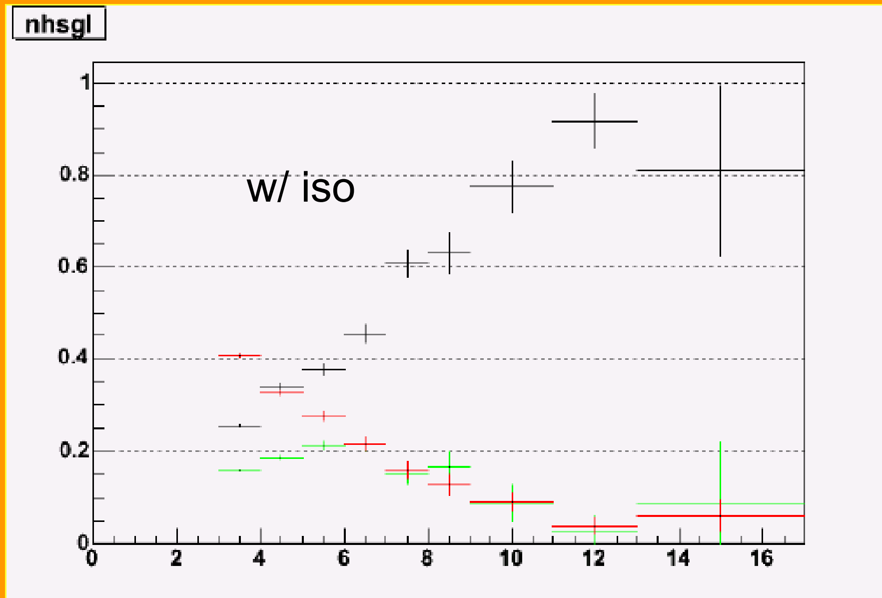




- Two calorimeters: PbSc (sampling); PbGl (homogenous)
- Spatial resolution: $\Delta\eta x \Delta\varphi$ = 0.01x0.01
- Energy resolution: $\sigma(E)/E = [1\text{-}2]\% \oplus [6\text{-}8]\%/\sqrt{E}$
- Virtually complete background rejection for p_T< 25 GeV through reconstruction of neutral hadrons

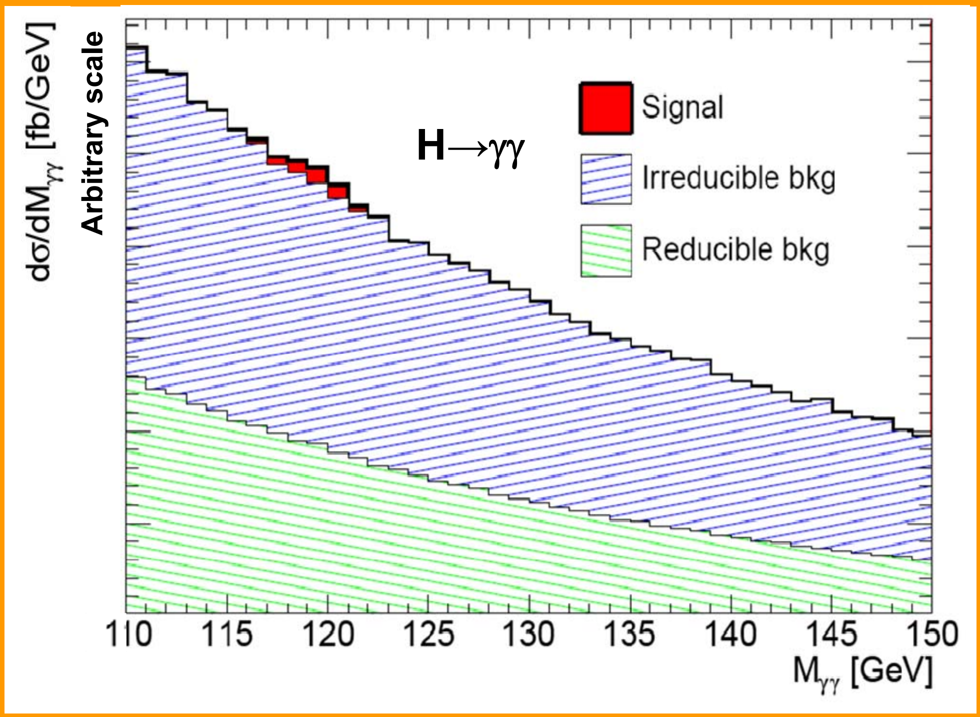
PHENIX Isolation Cut in p+p





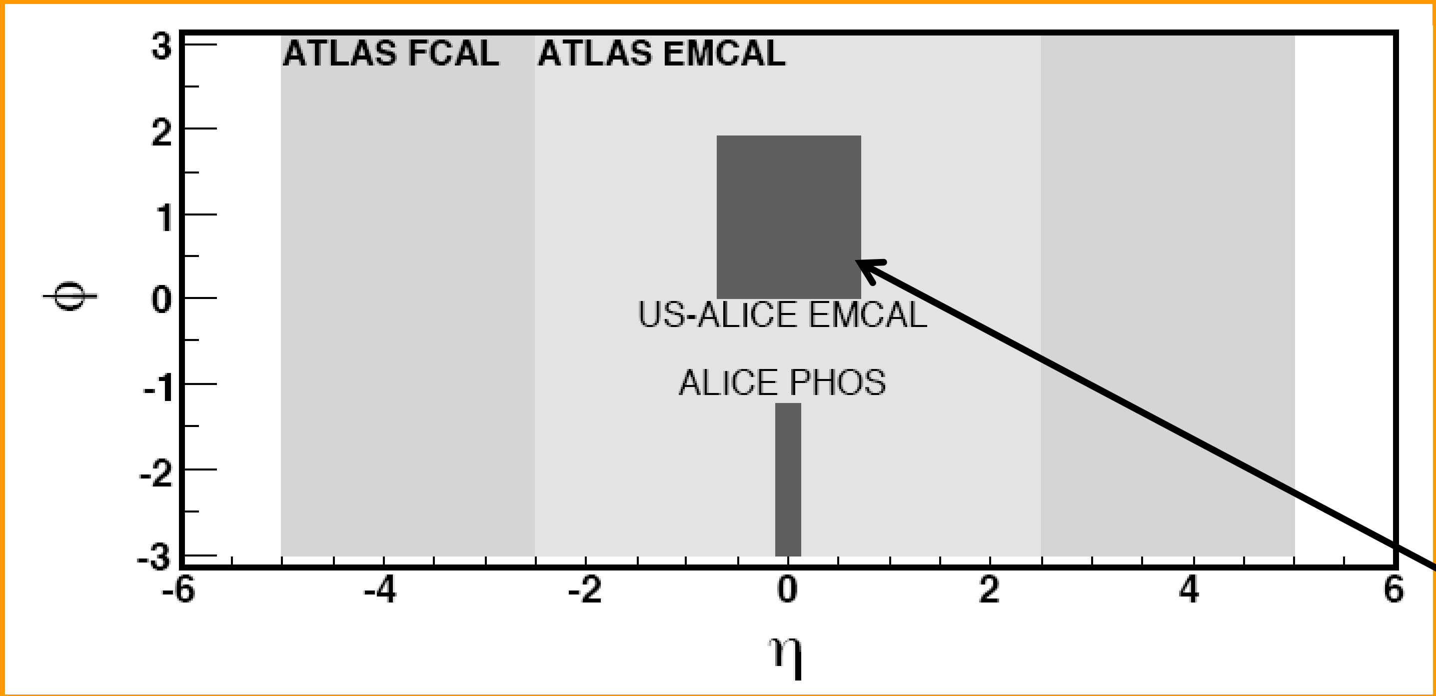
- Why does isolation cut only suppresses background by factor 5 at 10 GeV?
- Small acceptance?---Small effect.
- More likely due to underlying event

The Higgs: driving the design of LHC calorimetry



- Higgs capabilities depend on
  - Rejection (ATLAS: lateral, longitudinal segmentation)
  - E Resolution (CMS: crystal)

Coverage and Other Differences



From 2010

- ALICE: 1000 scientists, 1000 HI
- ATLAS: 2500 scientists, ~35+ HI (11 inst.), photon experts
- CMS: 2600 scientists, ~100 HI (25 inst.)

Photon Detectors at LHC

Exp.	ATLAS		CMS		ALICE		
Name	LAr Barrel	LArEndCap	ECAL(EB)	ECAL(EE)	PHOS	EMCal	Barrel
Structure	Liquid Argon		PWO+APD		PWO+APD	Pb+APD	TPC+ITS+ TRD+TOF
Coverage	$0<\|\eta\|<1.4$ 2π	$1.4<\|\eta\|<3.2$ 2π	$0<\|\eta\|<1.5$ 2π	$1.5<\|\eta\|<3.$ 2π	$0<\|\eta\|<0.12$ 0.6π	$0<\|\eta\|<0.7$ 0.6π	$(0<\|\eta\|<0.9$ $2\pi)*$ 7% X/X_0
Granularity $\Delta\eta$ x$\Delta\phi$	**0.003x0.100 0.025x0.025 0.025x0.050**	**0.003x0.100 0.025x0.025 0.025x0.050**	**0.017x0.017**	**0.017x0.017 to 0.05x0.05**	**0.004x0.004**	**0.014x0.014**	**3.10^{-4}x 2.10^{-4} (resolution)**
Resolution	$10\%/\sqrt{E} \oplus 0.5\%$	$10\%/\sqrt{E} \oplus 0.5\%$	$2.7\%/\sqrt{E} \oplus 0.55\%$	$5.7\%/\sqrt{E} \oplus 0.55\%$	$3.3\%/\sqrt{E} \oplus 1.1\%$	$7\%/\sqrt{E} \oplus 1.5\%$	2% low p_T 5% high p_T

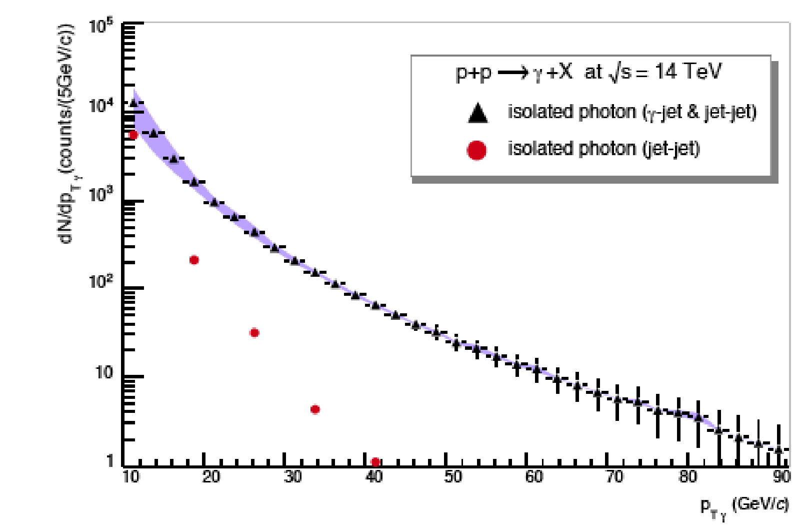
A. Marin, Hard Probes 2008

ALICE

Identifying prompt γ in ALICE (PHOS)

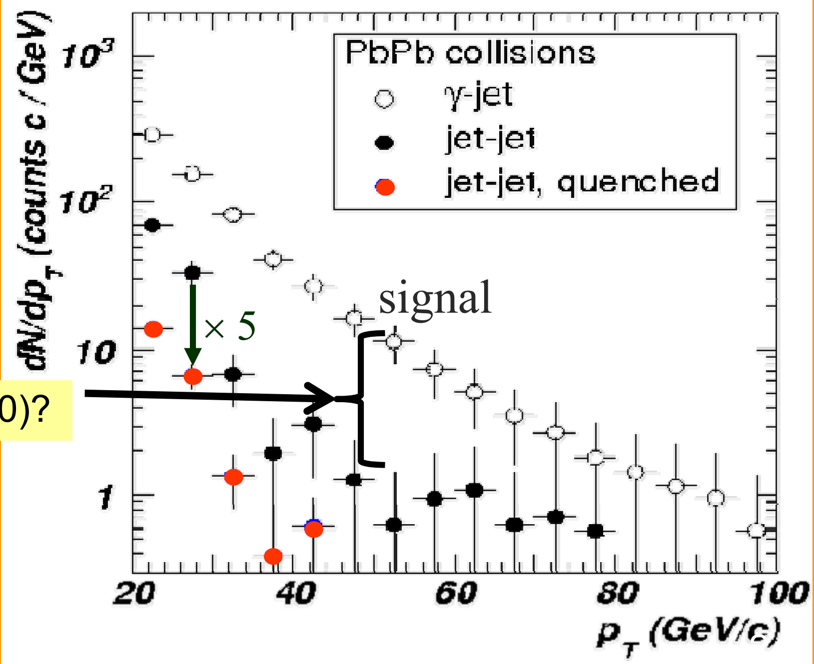
Y. Mao, Poster QM2008, ALICE-INT-2007-021

- p+p
  - $R = 0.3$, $\Sigma p_T < 2$ GeV/c
  - Efficiency: 69%
  - Background rejection: 1/170
  - First year (10 pb^{-1})
    - 3000 γ ($E\gamma > 20$ GeV)



- Pb+Pb
  - $R = 0.2$, $p_T^{thresh} = 2$ GeV/c
  - Efficiency: 50%
  - Background rejection: 1/14
  - One month of running
    - 2000 γ ($E_\gamma > 20$ GeV)

Why S/B so good (100)?

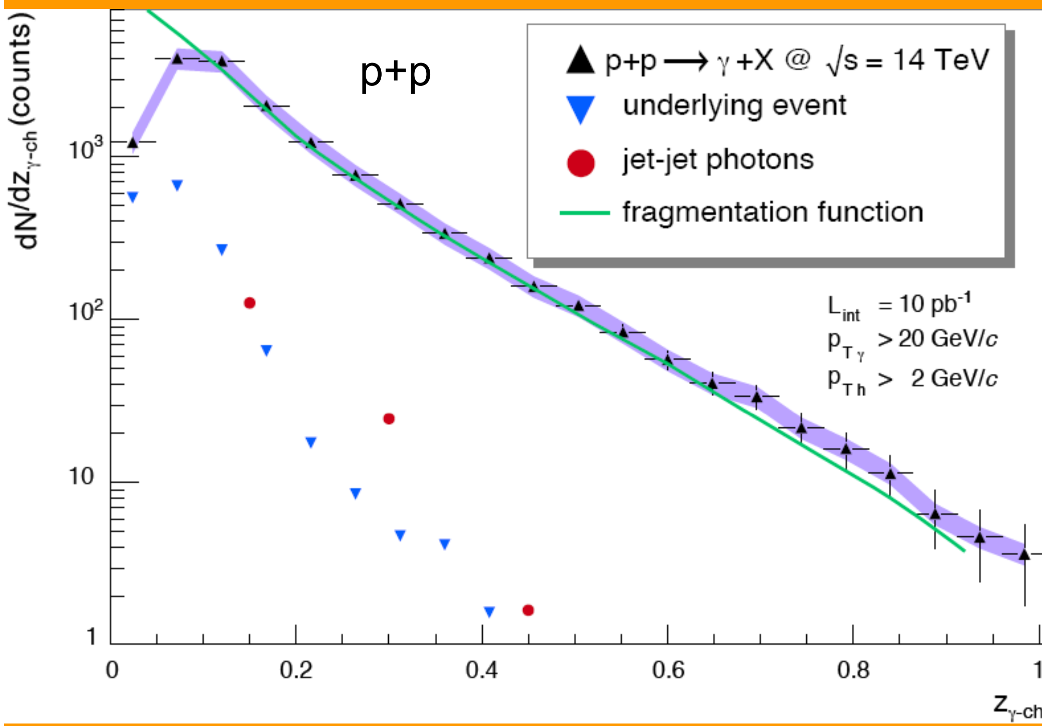


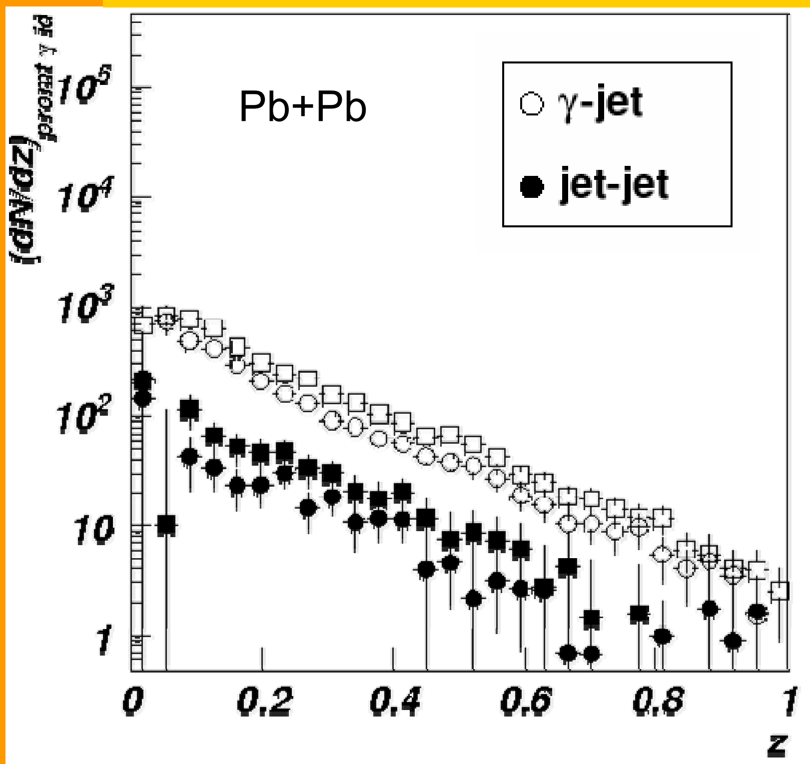
G. Conesa et al., NIM A 580(2007) 1446, NIM A 585(2008) 28

ALICE: Photon-Tag Jets Fragmentation Function

Y. Mao, Poster QM2008, ALICE-INT-2007-021

G. Conesa et al., NIM A 580(2007) 1446, NIM A 585(2008) 28





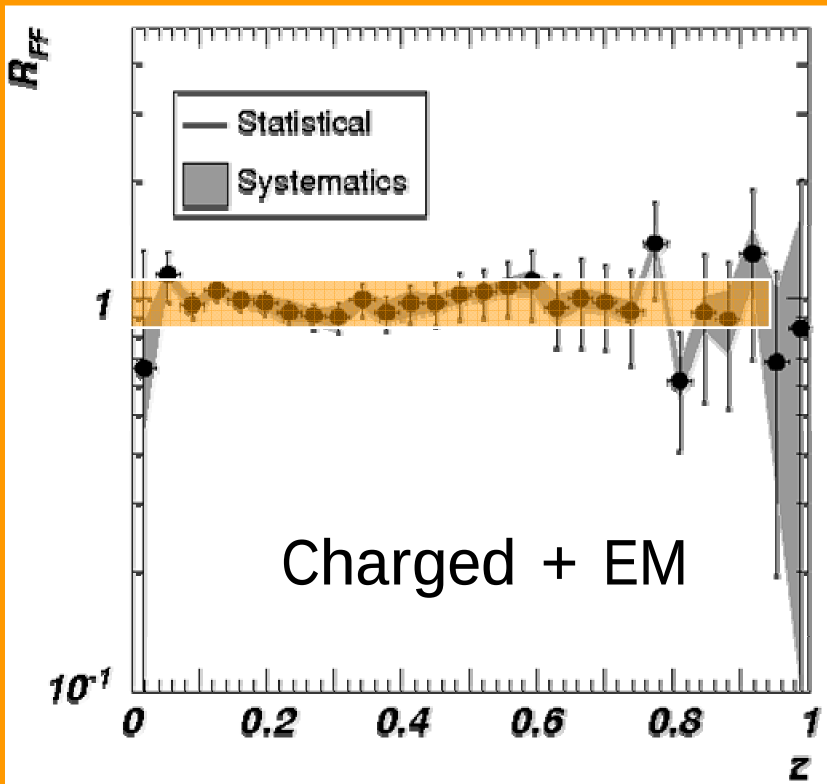
Imbalance distribution

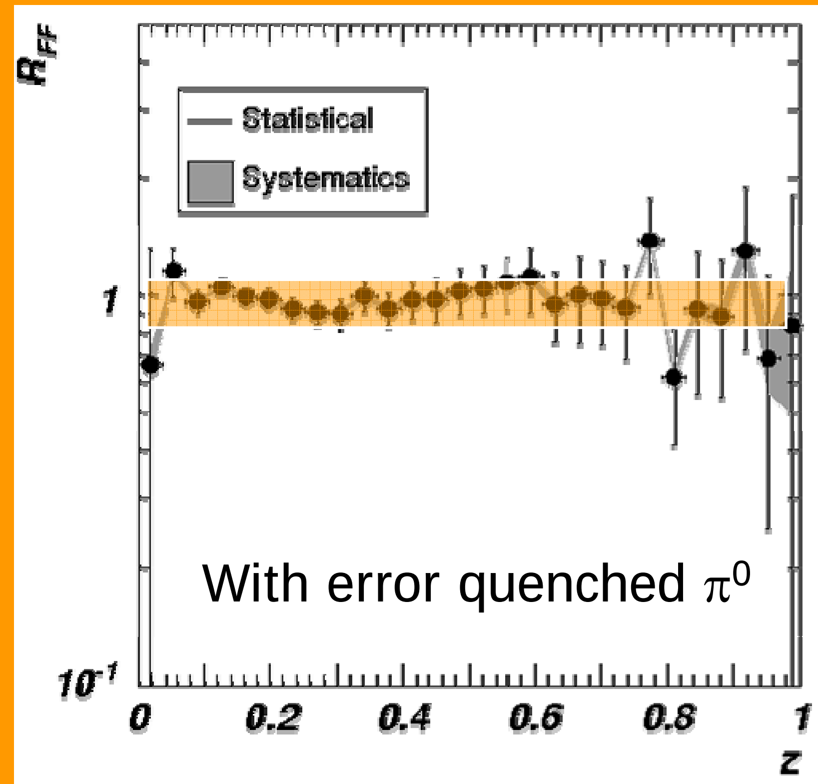
Isolated photons and background subtracted

ALICE: γ-tagged FF R_{AA}

Systematic errors due
to jet(π^0)-jet background

G. Conesa et al., NIM A 580(2007) 1446,
NIM A 585(2008) 28



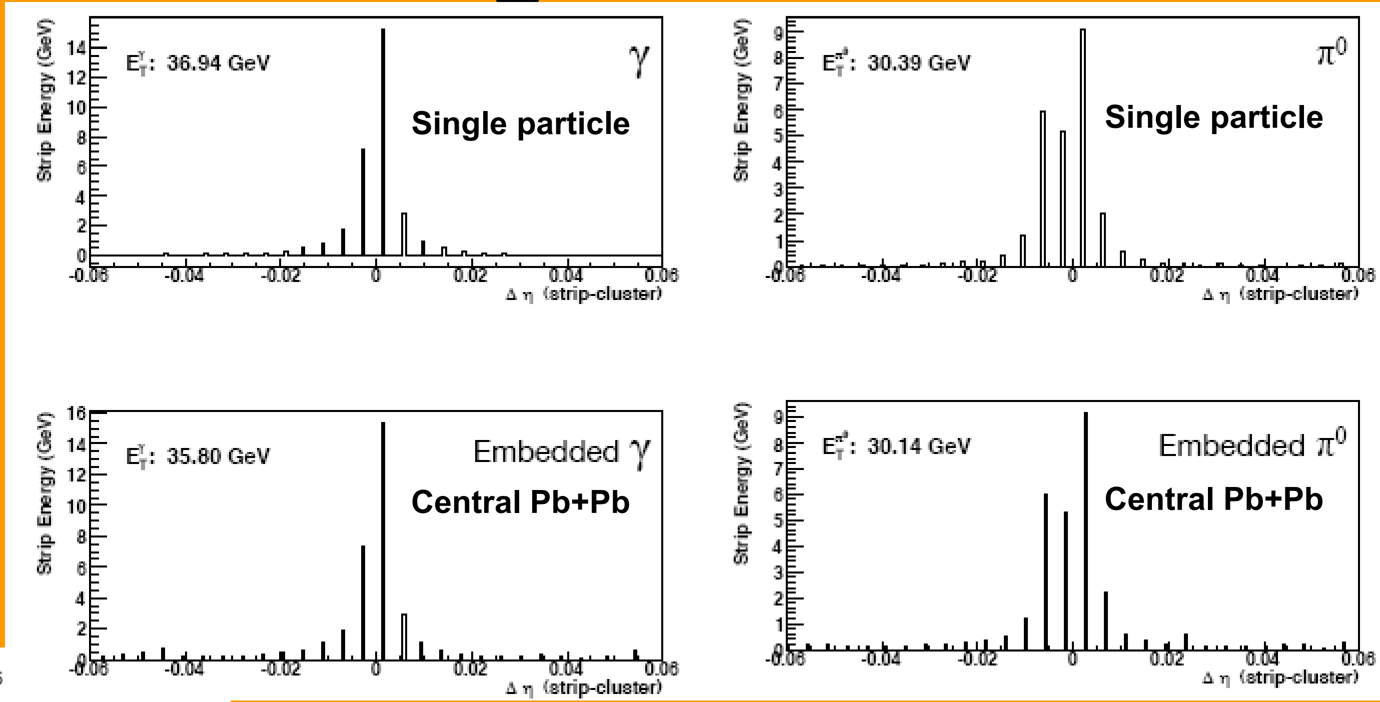


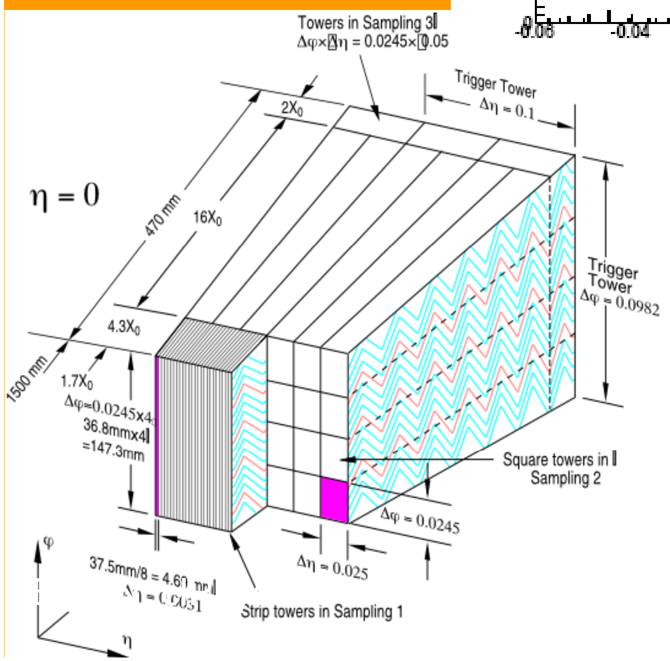
Sensitive to medium modifications at low z

if larger than ~5%.

ATLAS

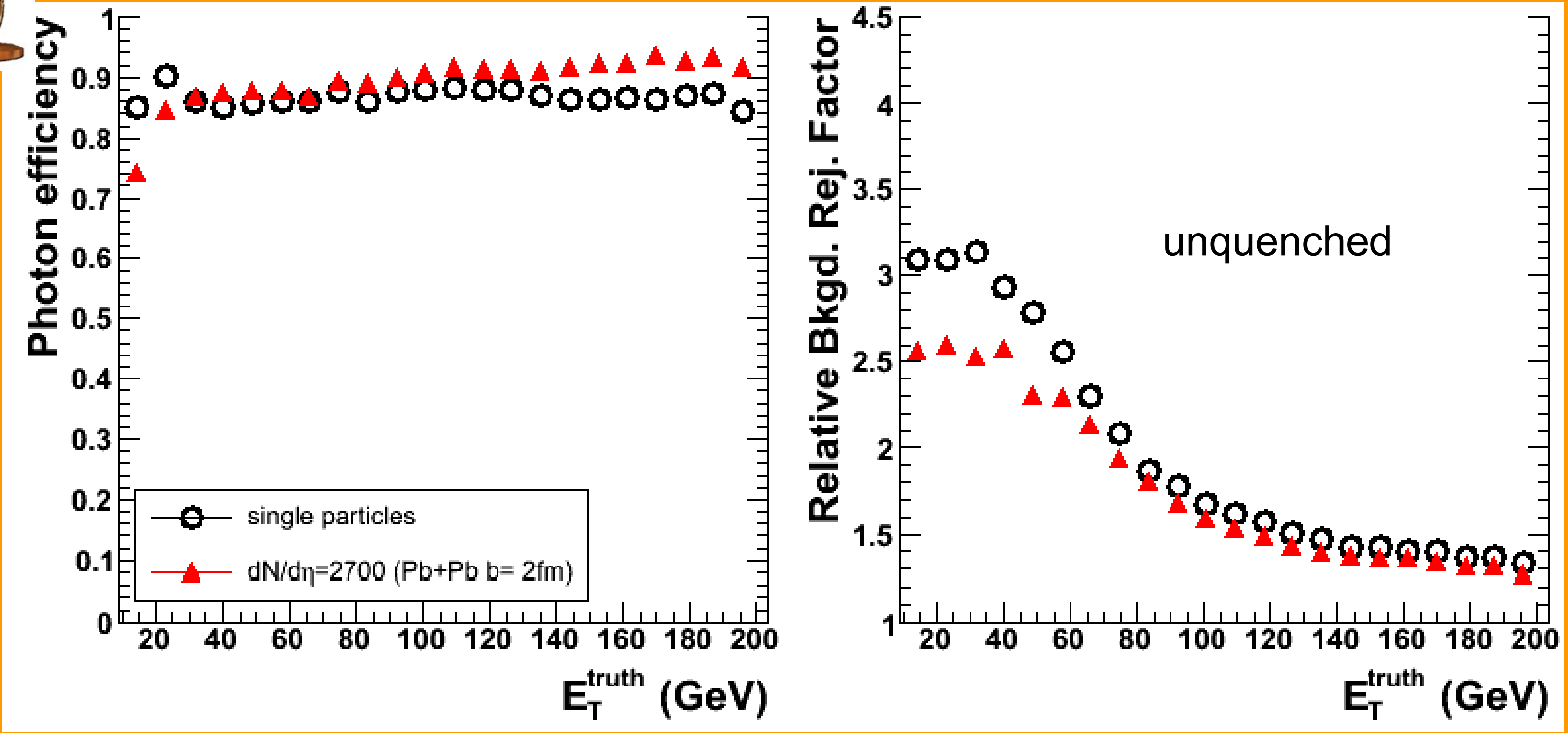
Lateral Segmentation





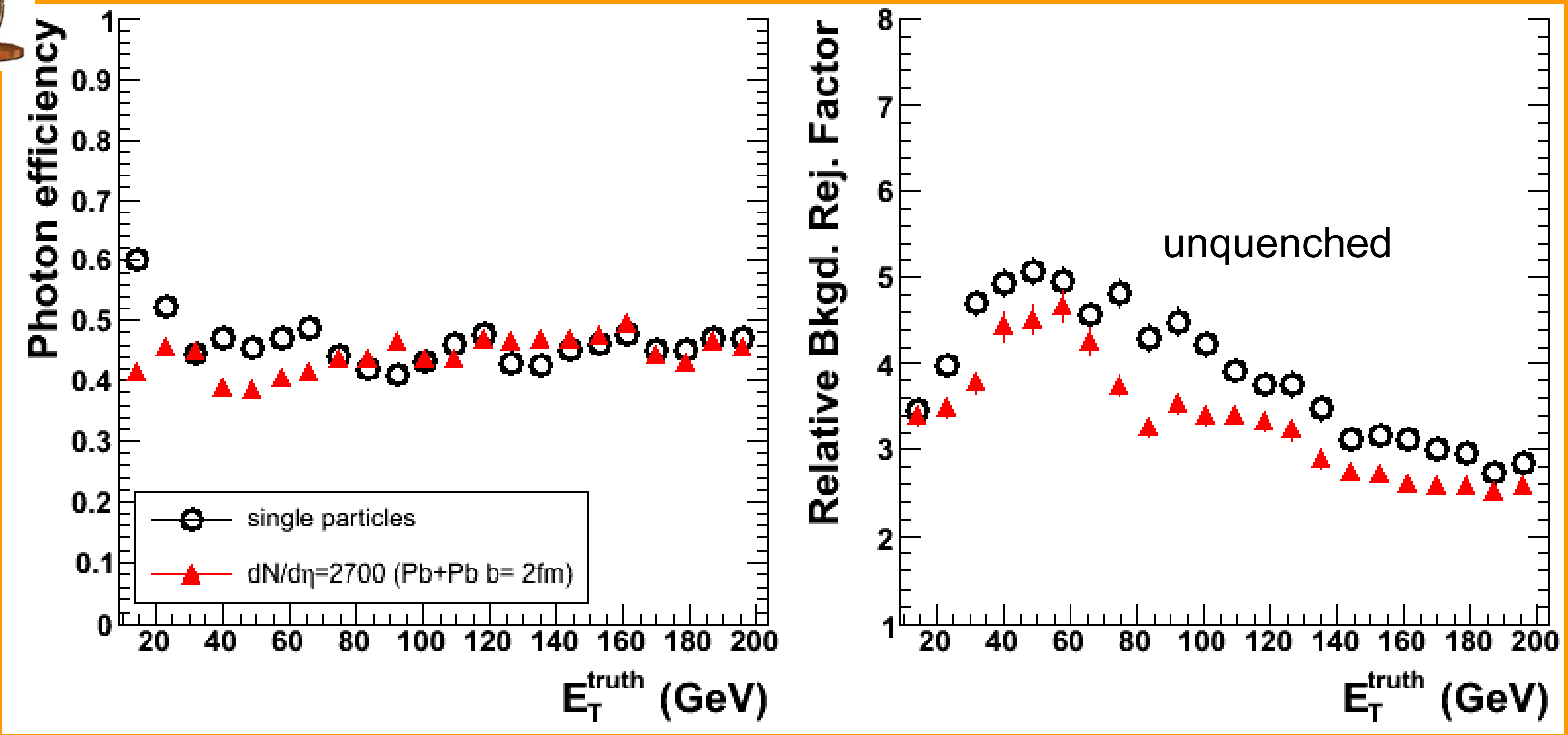
- First EMCal layer has high separation in η
- Low occupancy even in central Pb+Pb
- π^0 rejection for $E_T \leq 70$ GeV

Photon ID: Loose Cuts



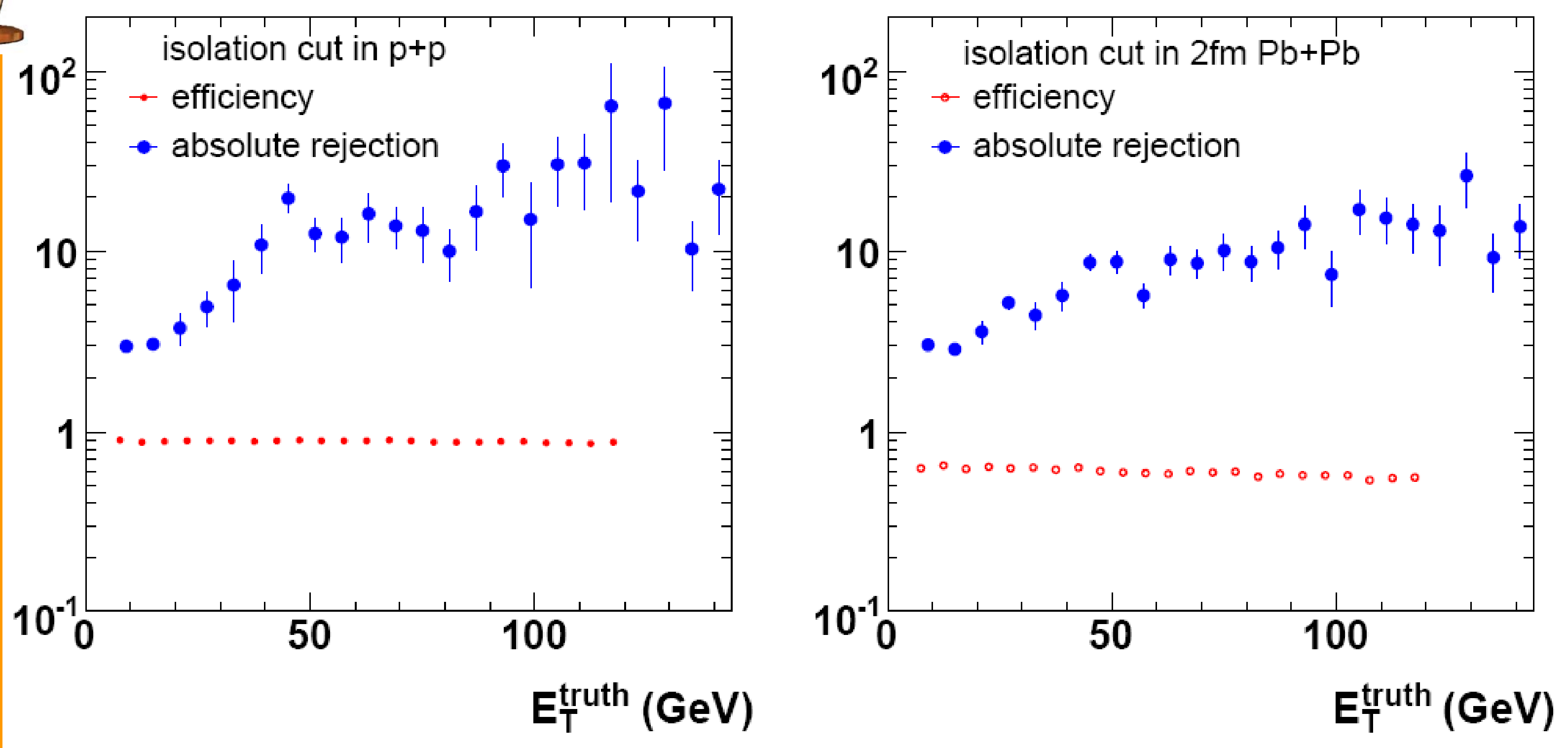
- Relative rejection of 2 at 85% efficiency with loose photon ID cuts below ~ 50 GeV

Photon ID: Tight Cuts



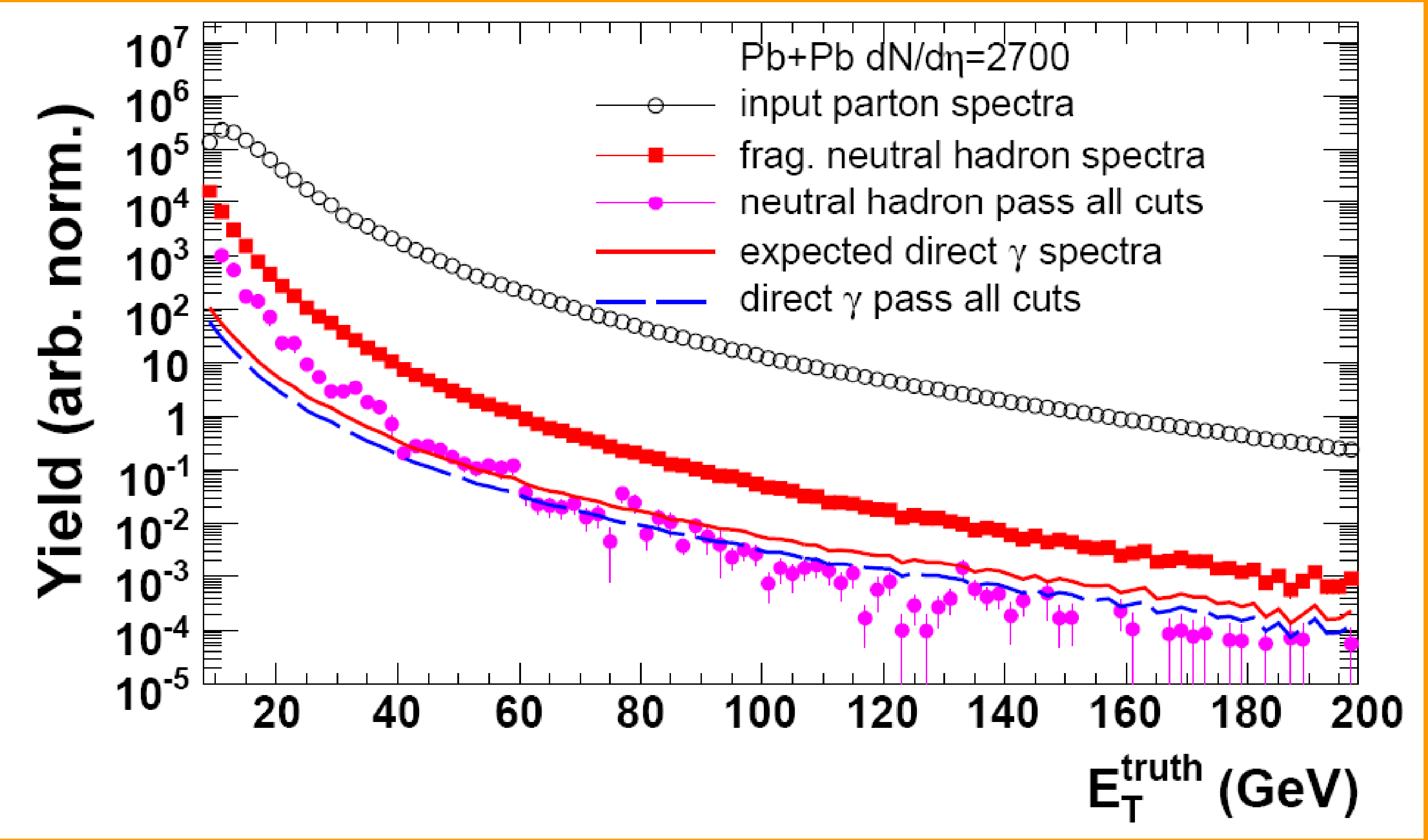
- Relative rejection of 1.5-2.2 at ~50% efficiency with tight photon ID cuts

Isolation Cut



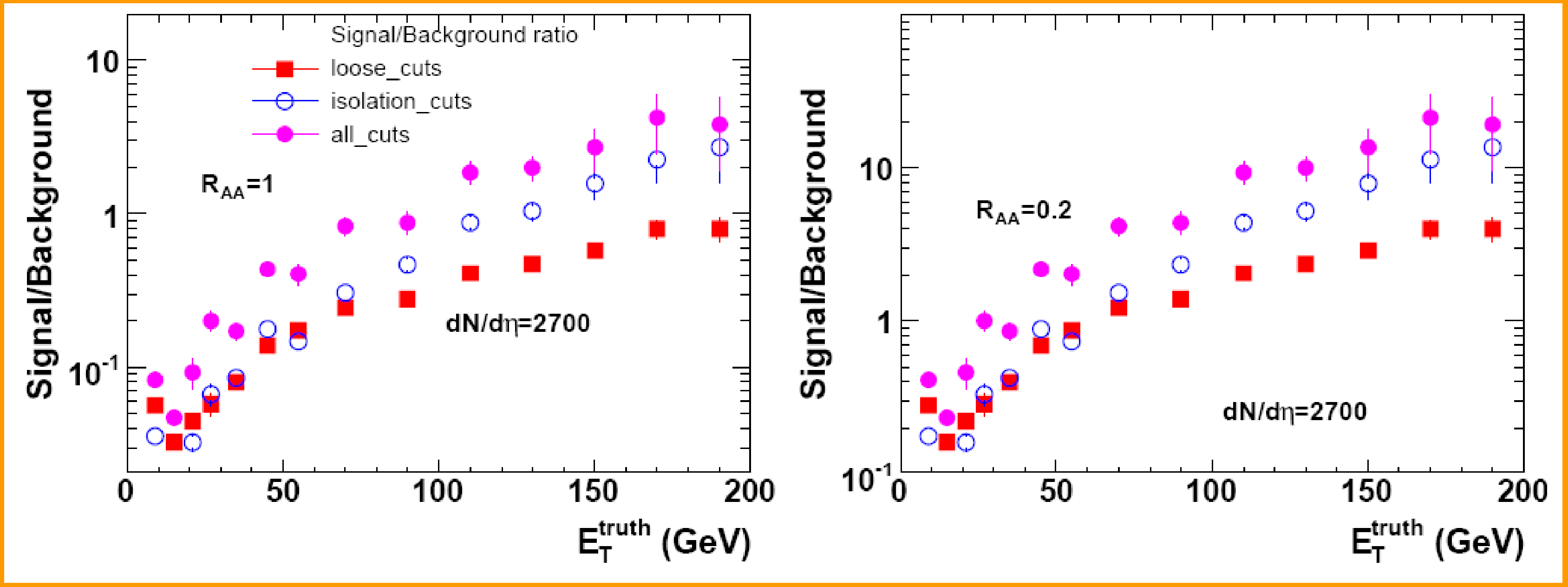
- Relative rejection of 5 at ~60% efficiency in unquenched Pb+Pb

Photon Spectrum



- S/B > 1 for E_T > 70 GeV in unquenched central Pb+Pb
- Relative rejection factor ~ 15

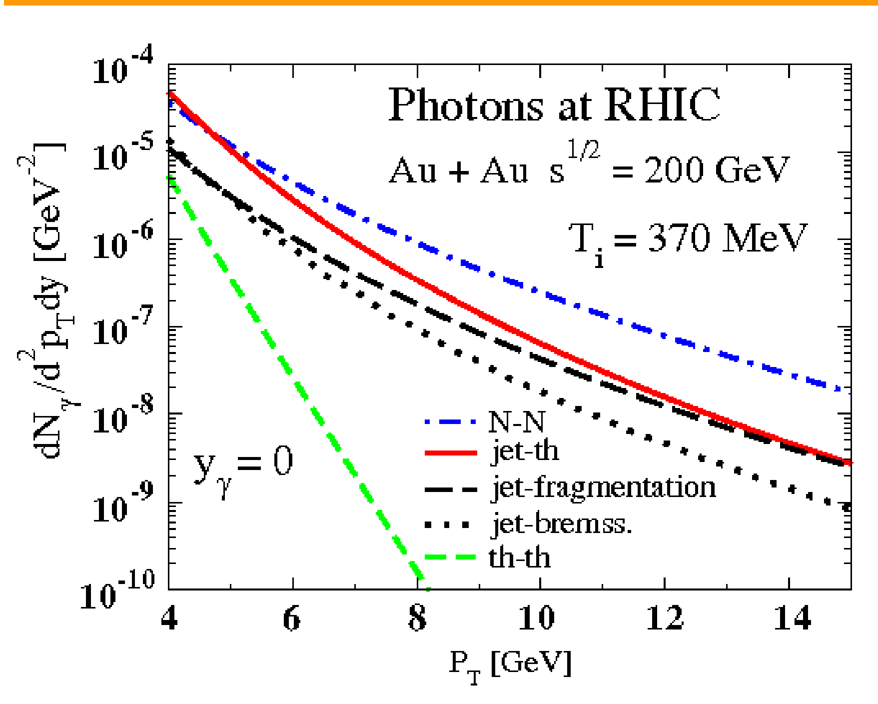
S/B

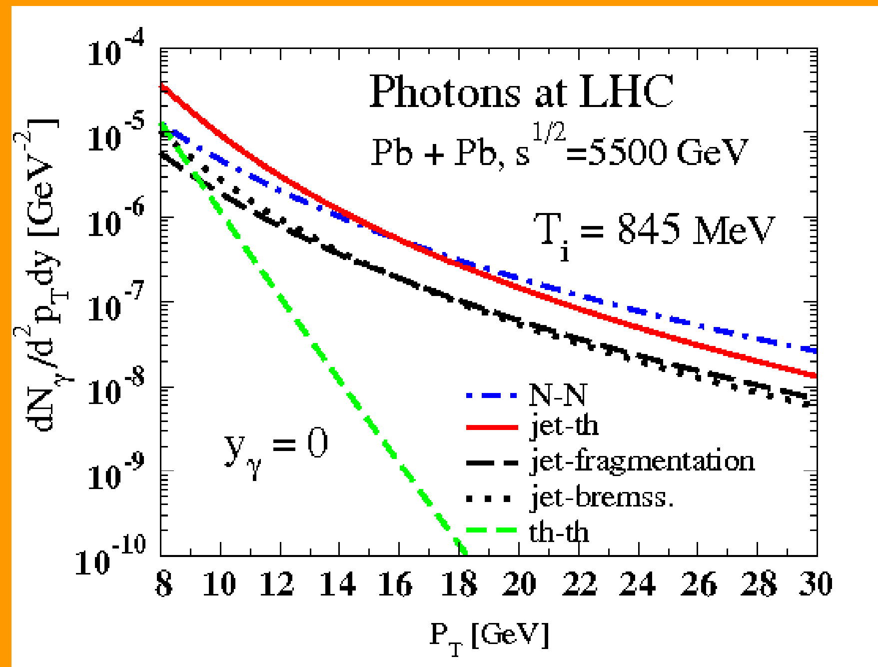


- S/B = 1 at E_T = 70 GeV for unquenched Pb+Pb
- S/B ~ 4 at E_T = 70 GeV for quenched Pb+Pb

Medium Photons

Turbide, Gale, Jeon, and Moore
PRC (2004) 014906

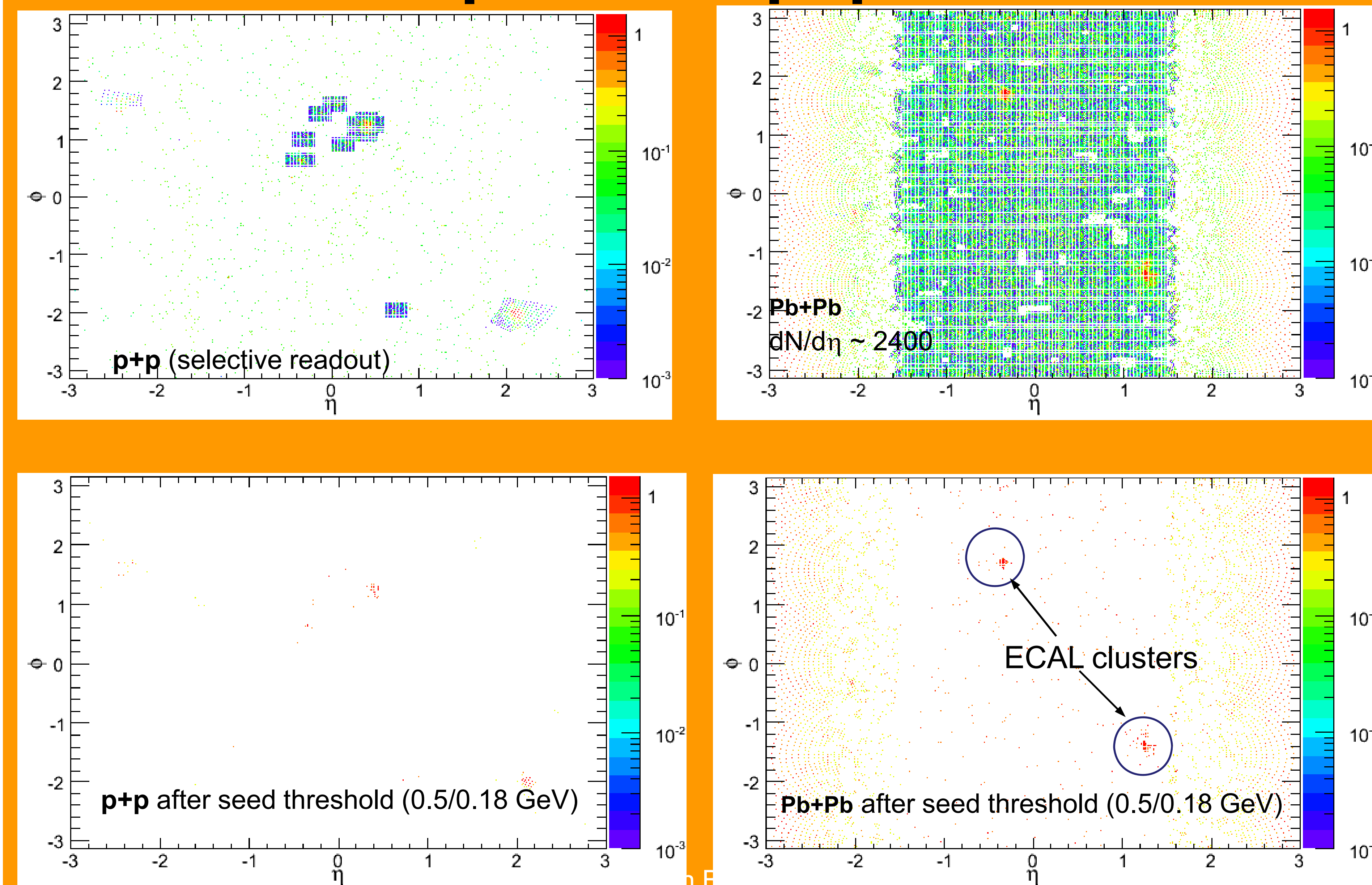




- Photons are abundantly produced at LHC
- Jet-photon conversion in the plasma dominates $8<p_T<14$ GeV
- Prompt hard NN scattering dominant for $p_T>20$GeV at LHC
- ATLAS better suited than CMS

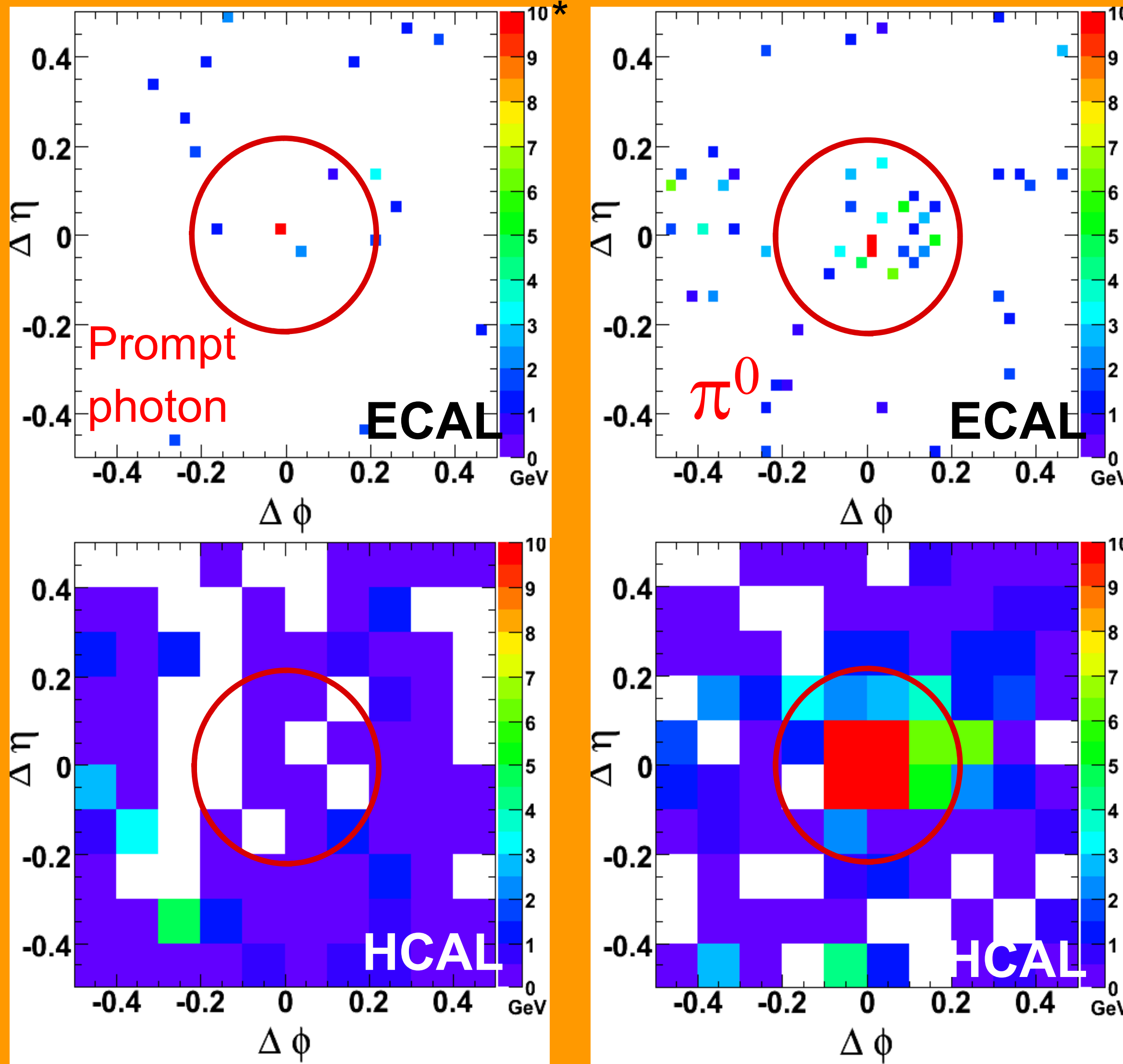
CMS

ECAL Response in p+p and Pb+Pb



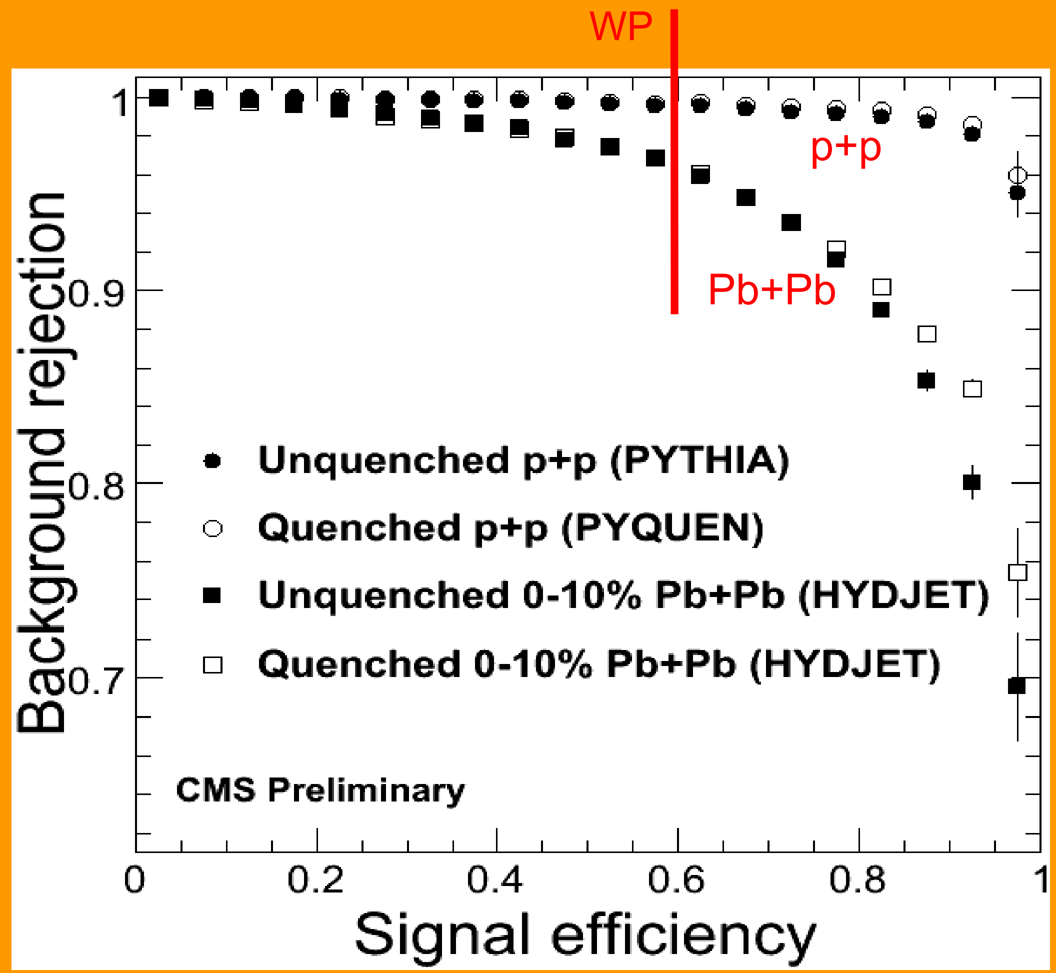
Photon Selection

- Selection variables
  - ♦ Cluster shape in ECAL
  - ♦ HCAL/ECAL energy ratios
  - ♦ Track isolation
- 21 variables total
  - ♦ Linear discriminant analysis to select optimal cuts
- Large acceptance essential for effective cuts w/o loss of signal



Photon identification performance

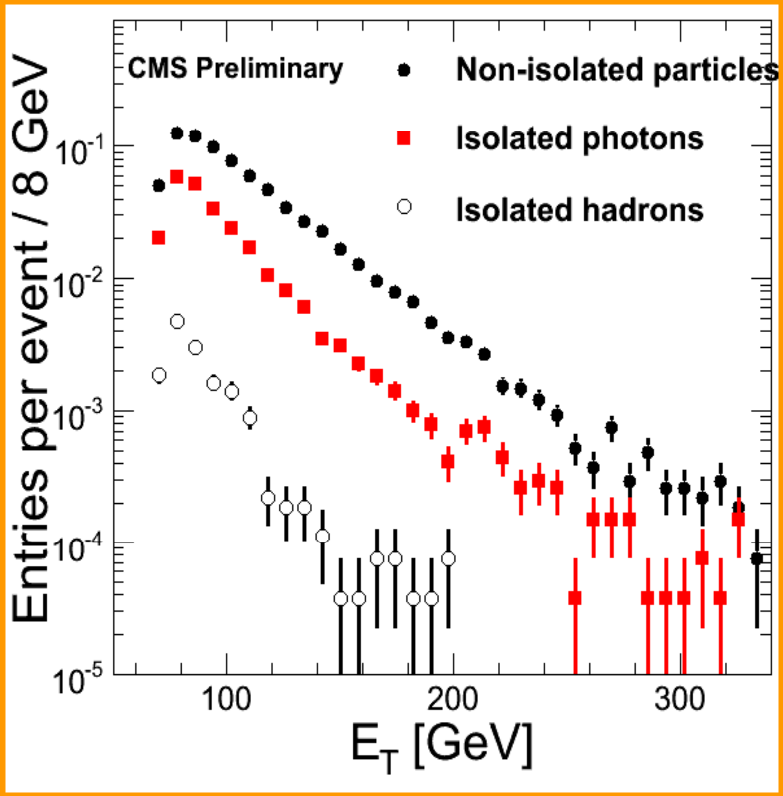
- Set working point to **60%** signal efficiency
- Leads to **96.5%** background rejection
- Training is done on unquenched samples only



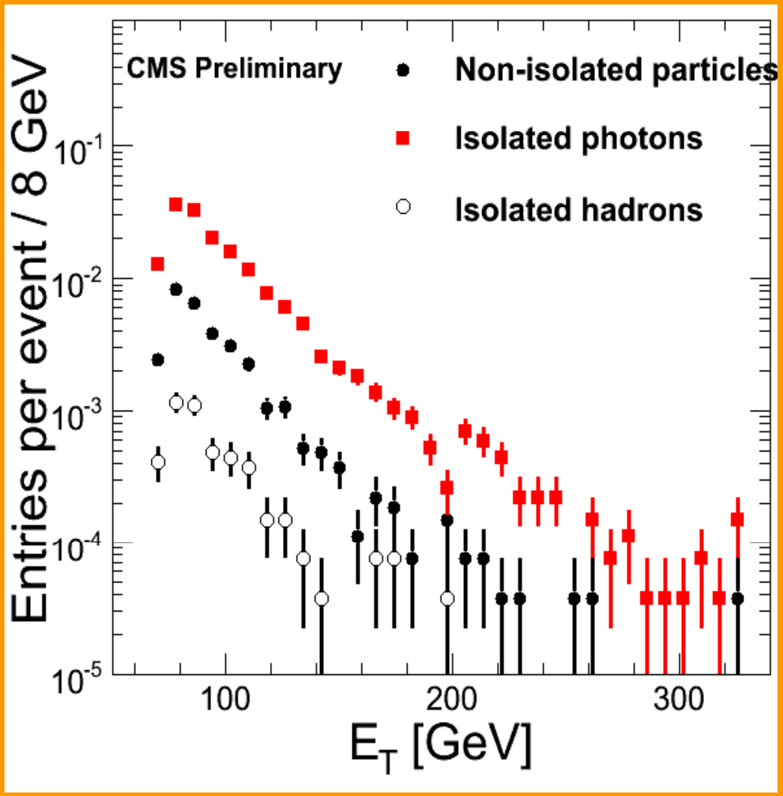
Photon Selection Performance

PYQUEN/quenched Pb+Pb

Before cuts: **S/B=0.3**



After cuts: **S/B=4.5**



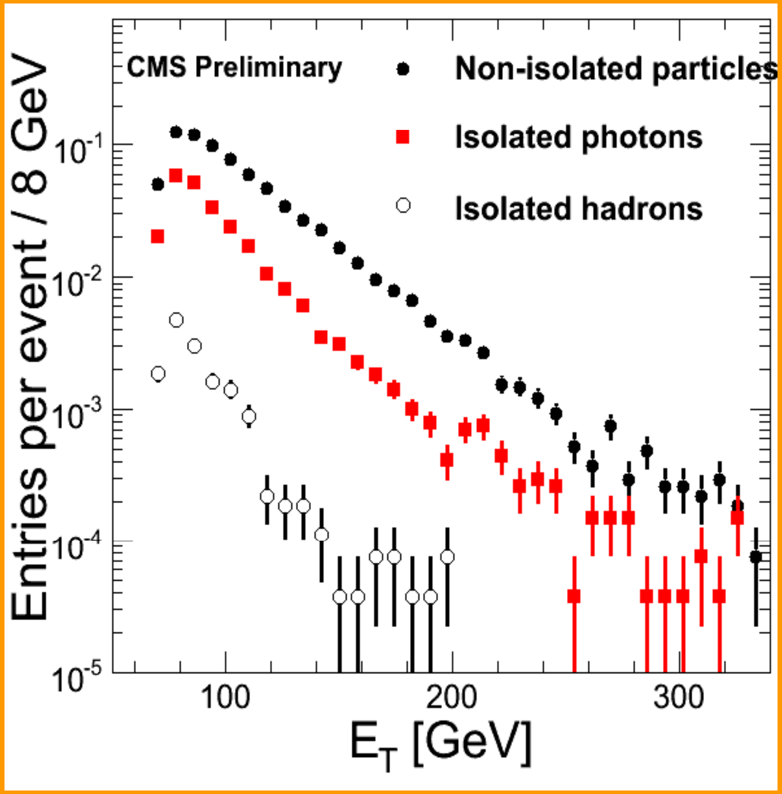
C. Loizides nucl-ex/0804.3679v1

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

(at 60% signal acceptance, 97% background rejection)

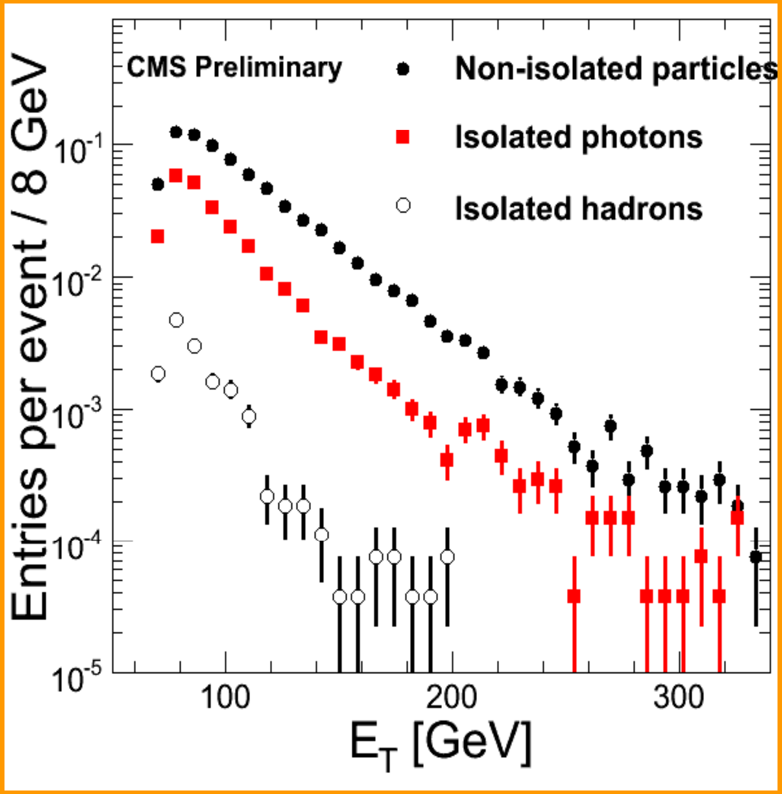
Photon Selection Performance

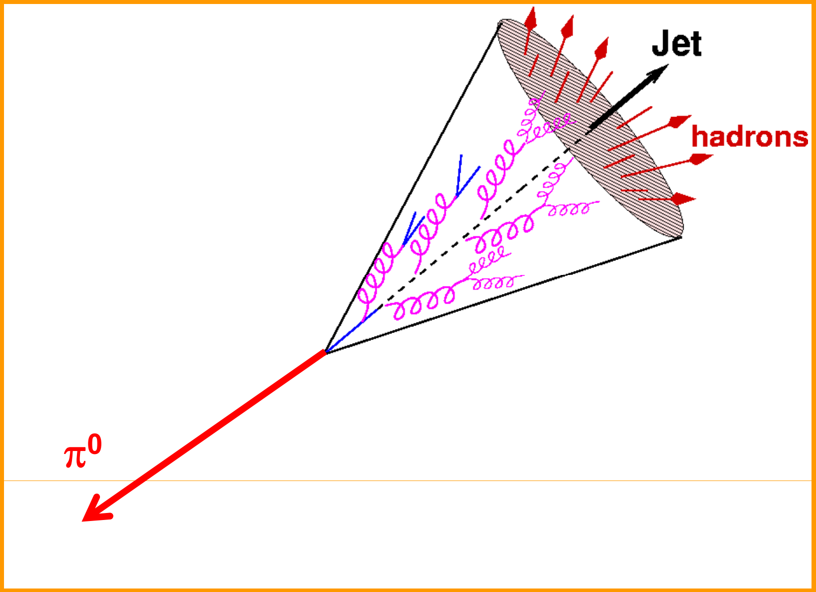
Before cuts: **S/B=0.3**



Photon Selection Performance

Before cuts: **S/B=0.3**



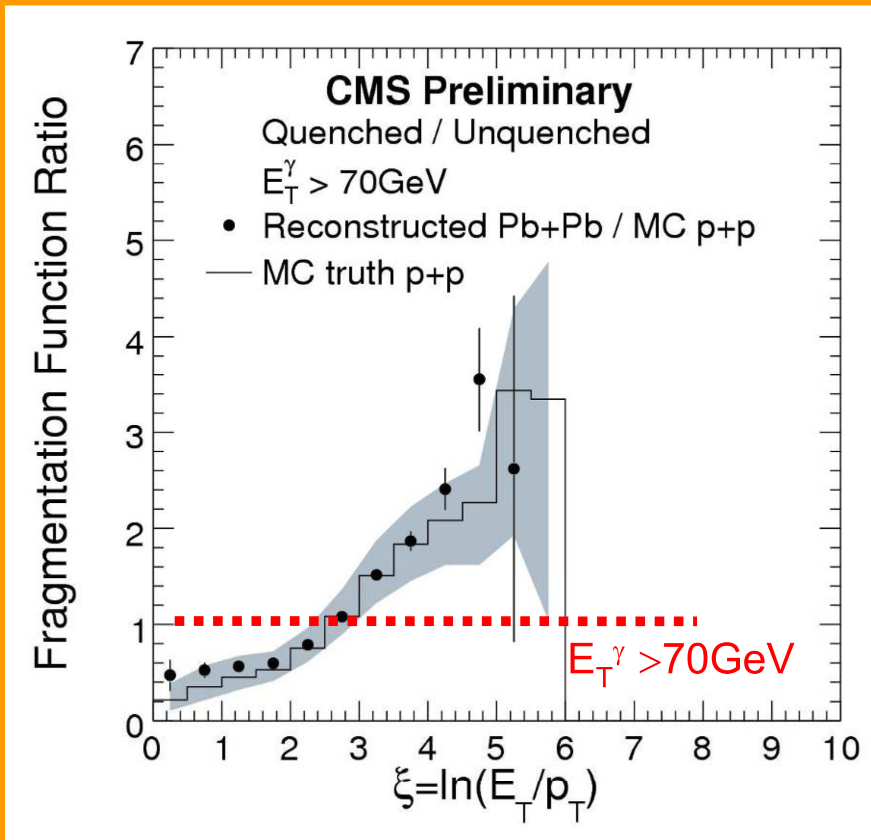


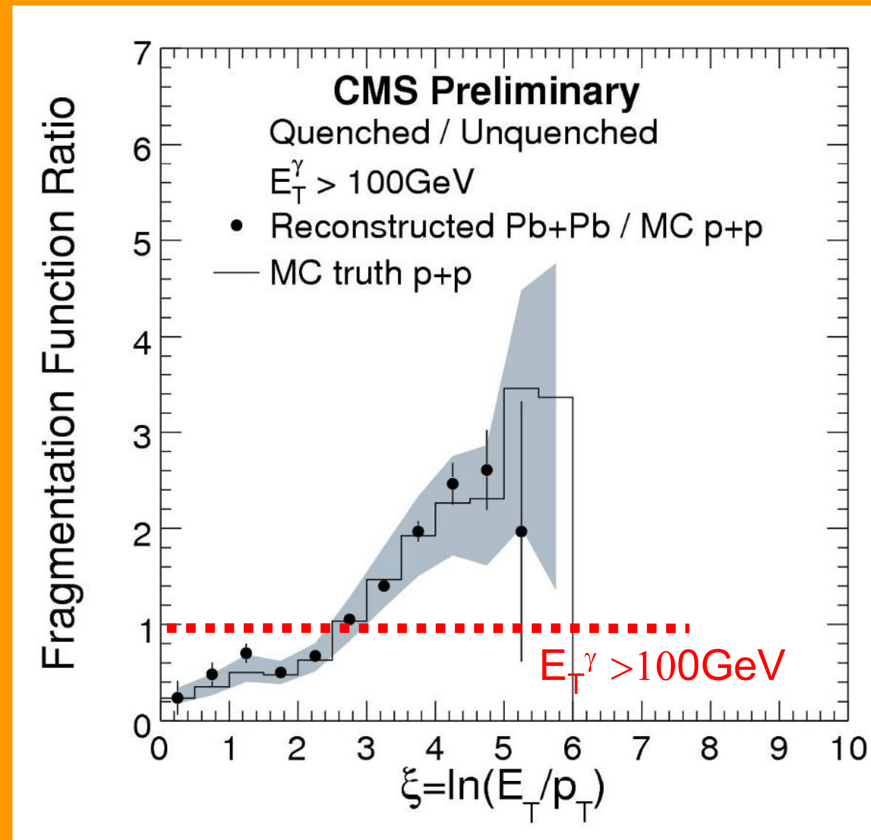
Main background: high-z neutral hadrons

- Why γ/π^0 flat (and not rising)?

Fragmentation function ratio

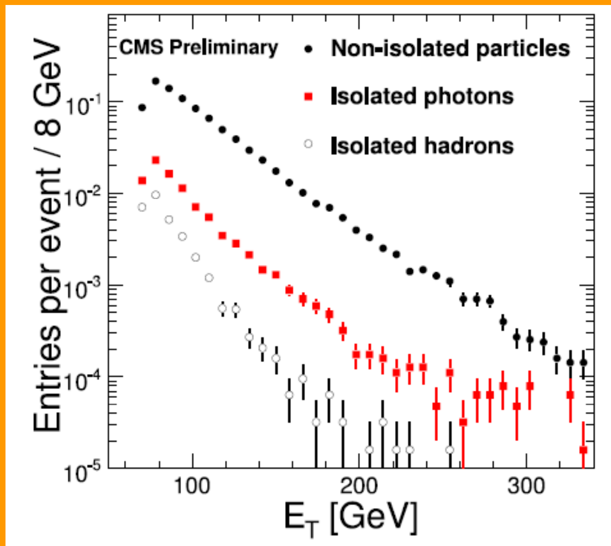
Reco quenched Pb+Pb / MC unquenched p+p

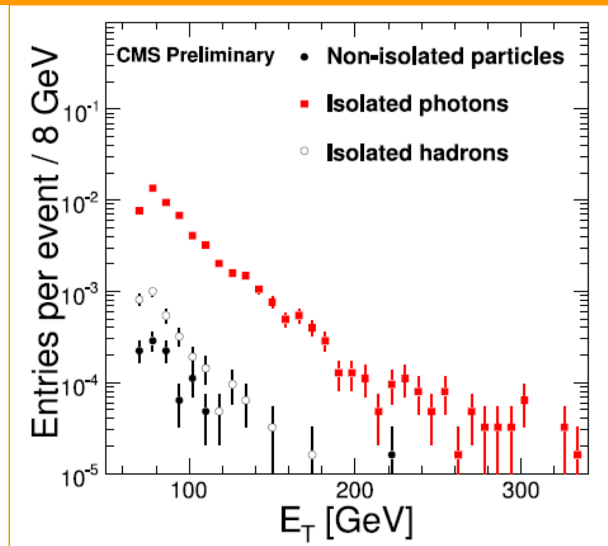




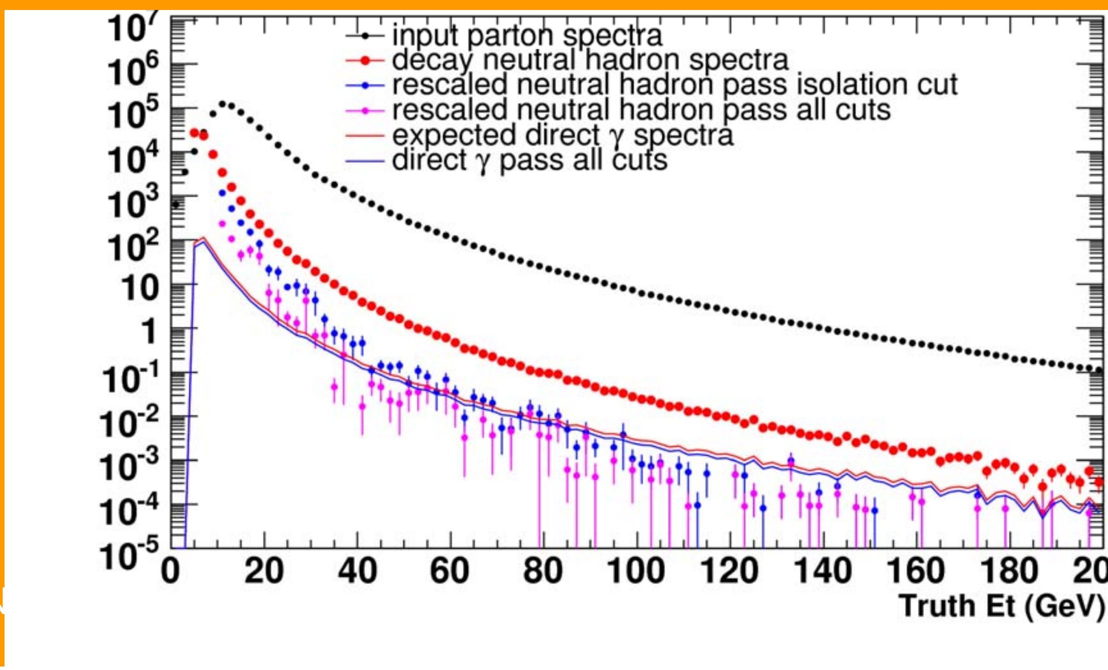
- Medium modification of fragmentation functions can be measured
  - High significance for $0.2 < \xi < 5$ for both, E_T^γ >70GeV and E_T^γ >100GeV

Discrepancy in p+p





- CMS: factor 200 background rejection
- S/B = 10 after cuts

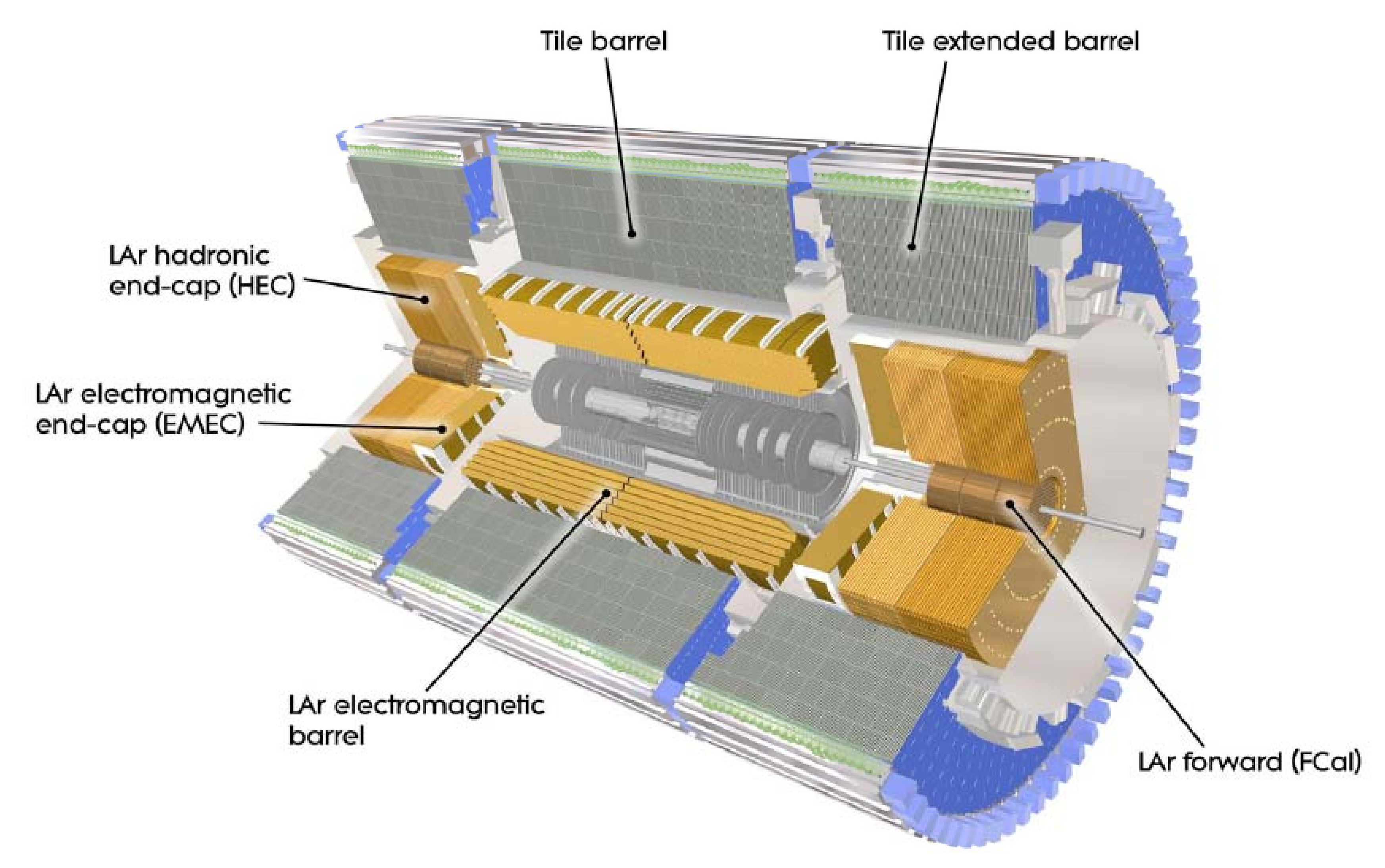


- ATLAS: factor 15 rejection
- S/B = 1 after cuts at (70 GeV)

Summary

- LHC gives access to new regime of HI physics
- High rates for hard scattering
- New observables: jets, direct photon-jet
- One dedicated HI experiment (ALICE)
- Two large-acceptance HEP experiments (ATLAS, CMS) with excellent HI capabilities
- ATLAS and CMS calorimeters ideally suited for jet measurement

ATLAS Calorimeter I



ATLAS Calorimeter II