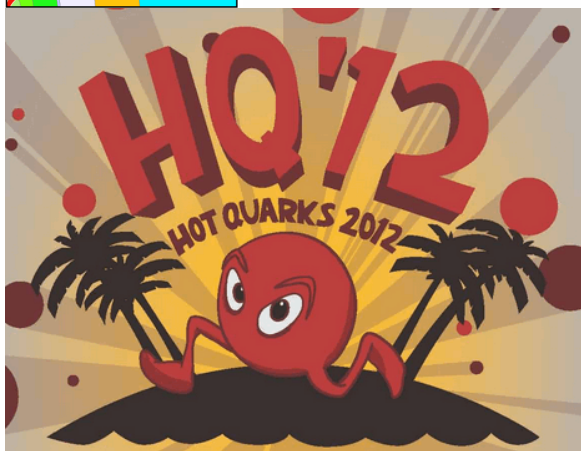
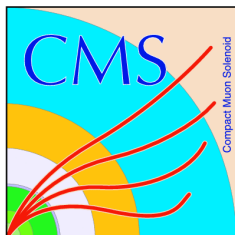


Study of jet quenching using jets and photons in PbPb collisions at 2.76TeV with CMS



Yongsun Kim (MIT)
CMS collaboration
Hot Quarks 2012

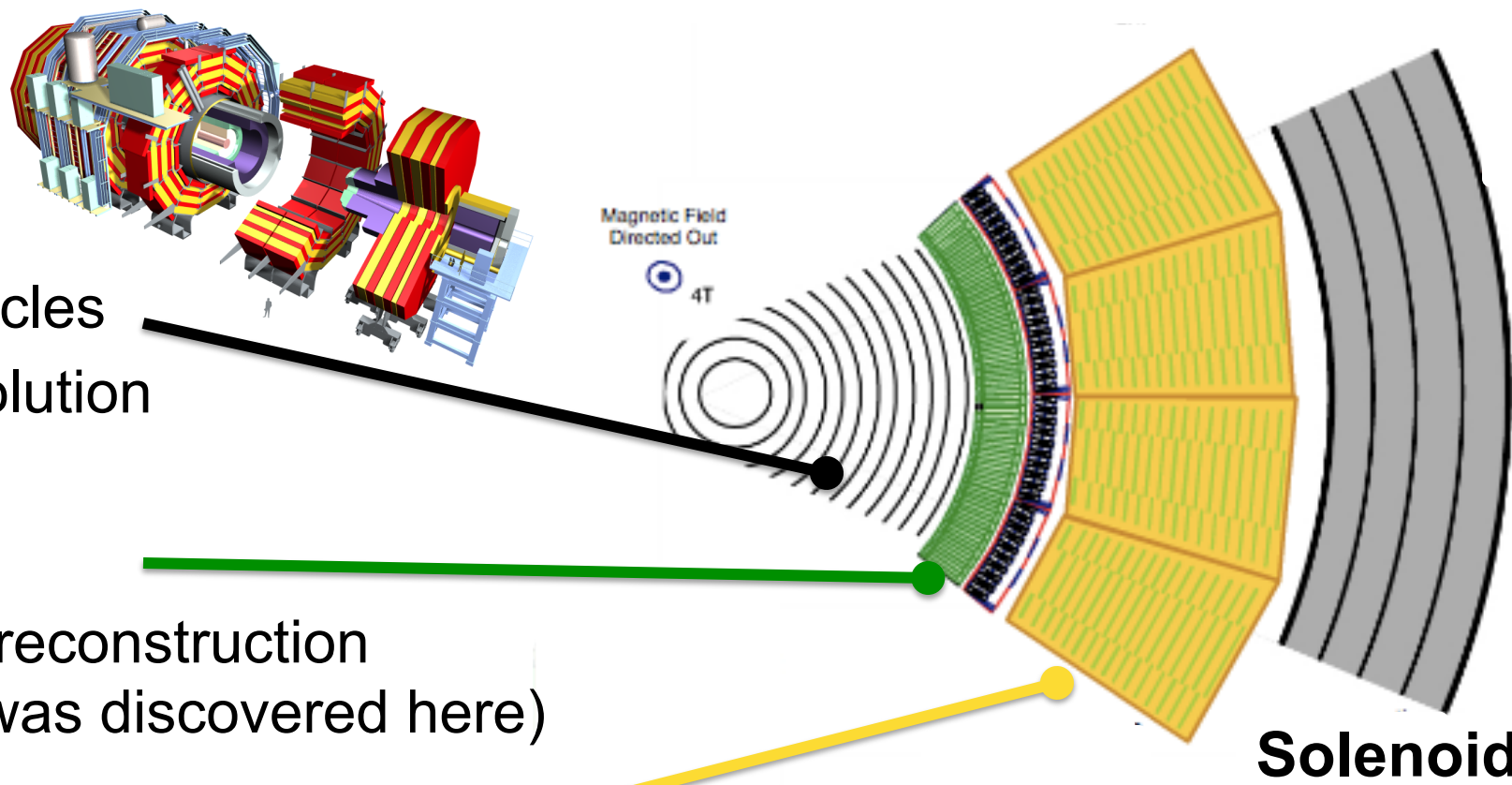
Questions to be discussed

- How does a high p_T parton interact with hot and dense matter?
 - How much energy is lost?
 - Is the jet fragmentation modified in the medium?

Questions to be discussed

- In this talk, CMS results of hard probes will be presented to help us to answer this question
 - How much energy is lost?
 - R_{AA} of hadrons and jets
 - Photon-jet correlations to quantify the energy loss
 - Is the jet fragmentation modified in the medium?
 - Jet fragmentation function
 - Jet shape

CMS – Excellent for high p_T observables



Si tracker

Charged particles
O(1)GeV resolution

Ecal

Photon reconstruction
(Higgs was discovered here)

Hcal

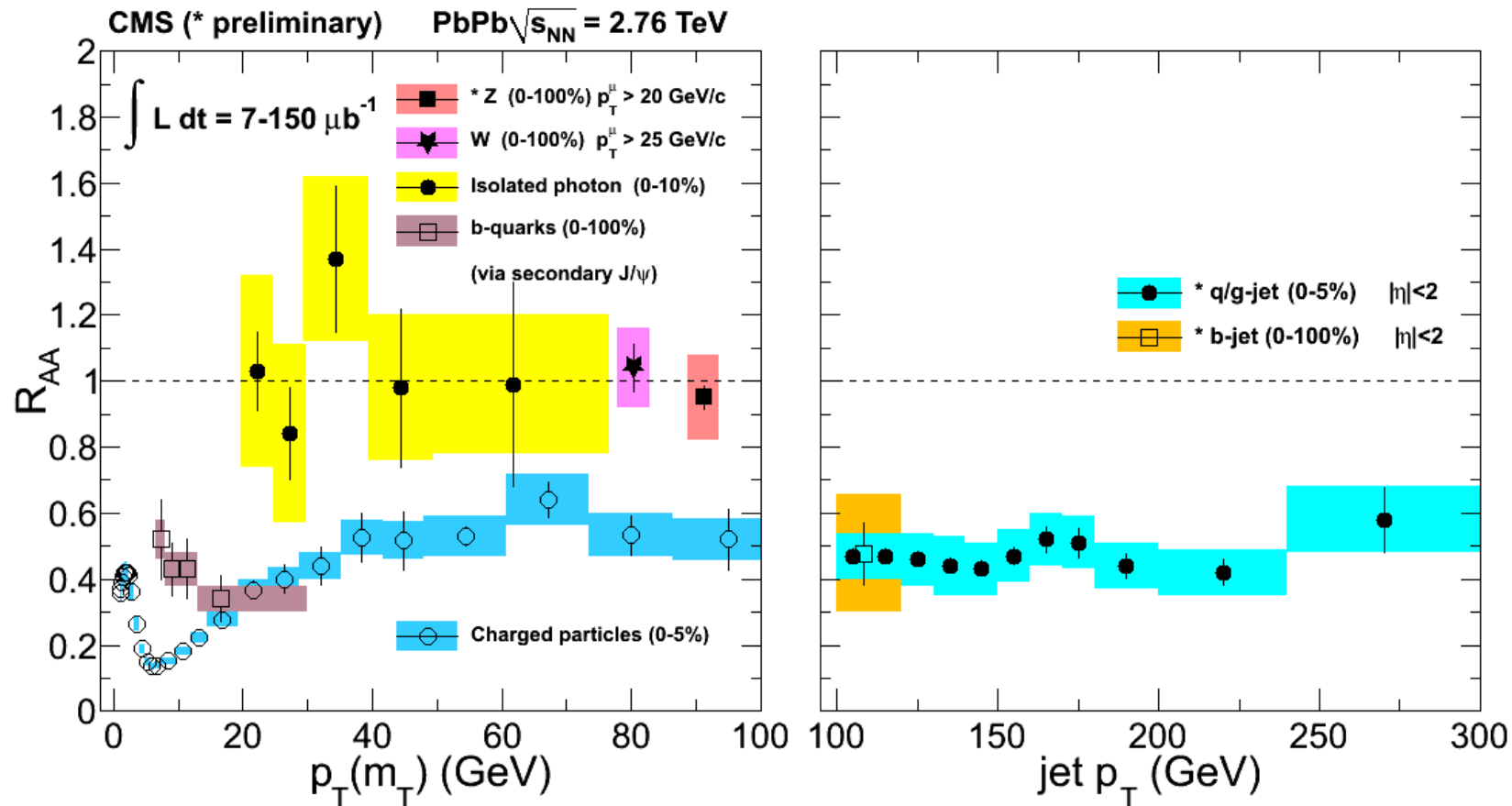
Jet reconstruction

Almost 4π coverage

All components are used to ensure photon isolation

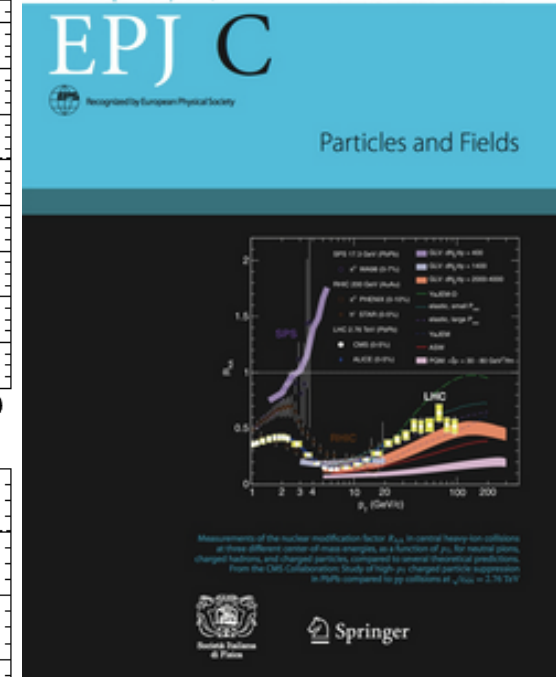
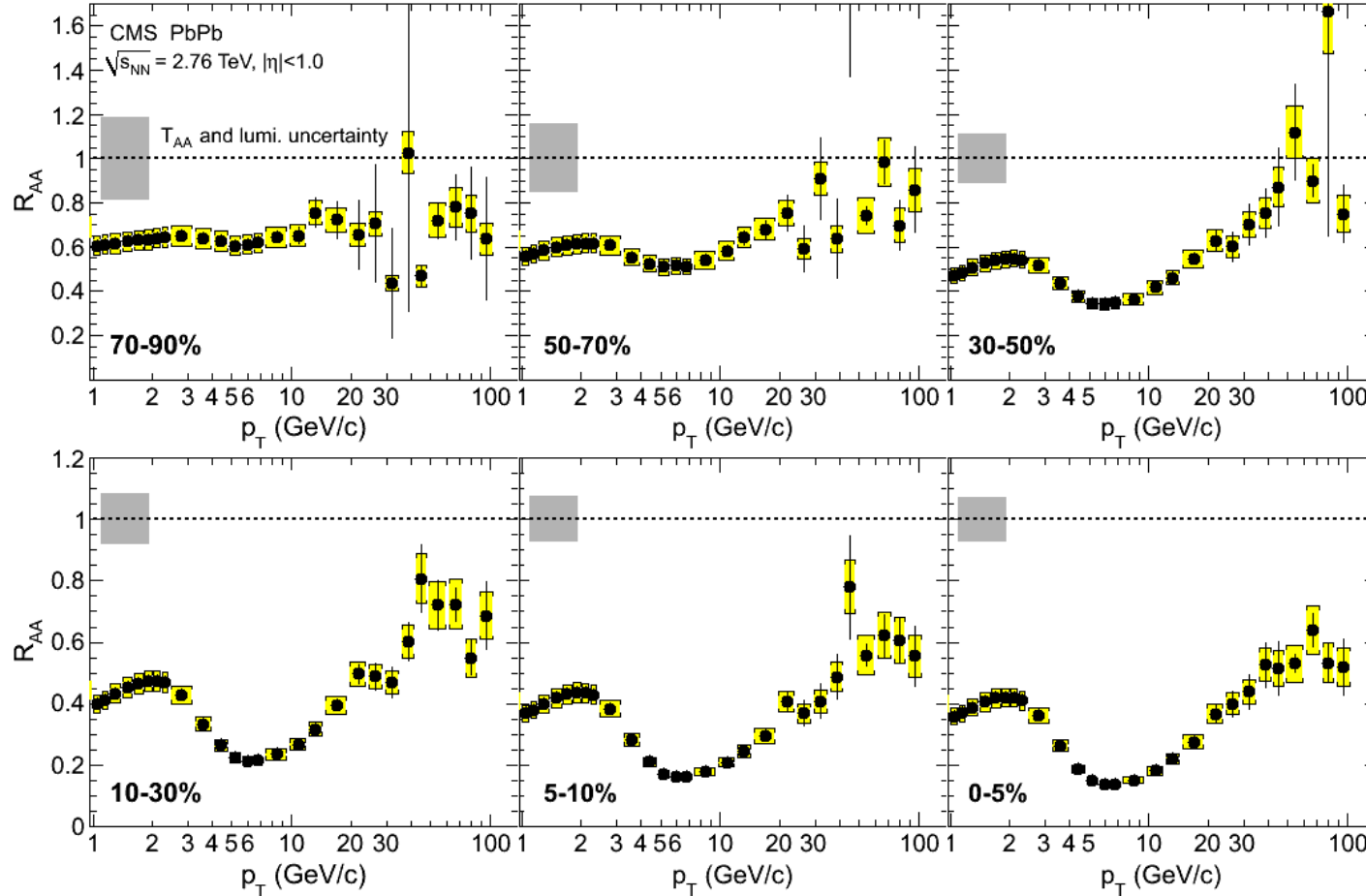
Welcome to the zoo of R_{AA}

- R_{AA} – traditional quantization of jet quenching



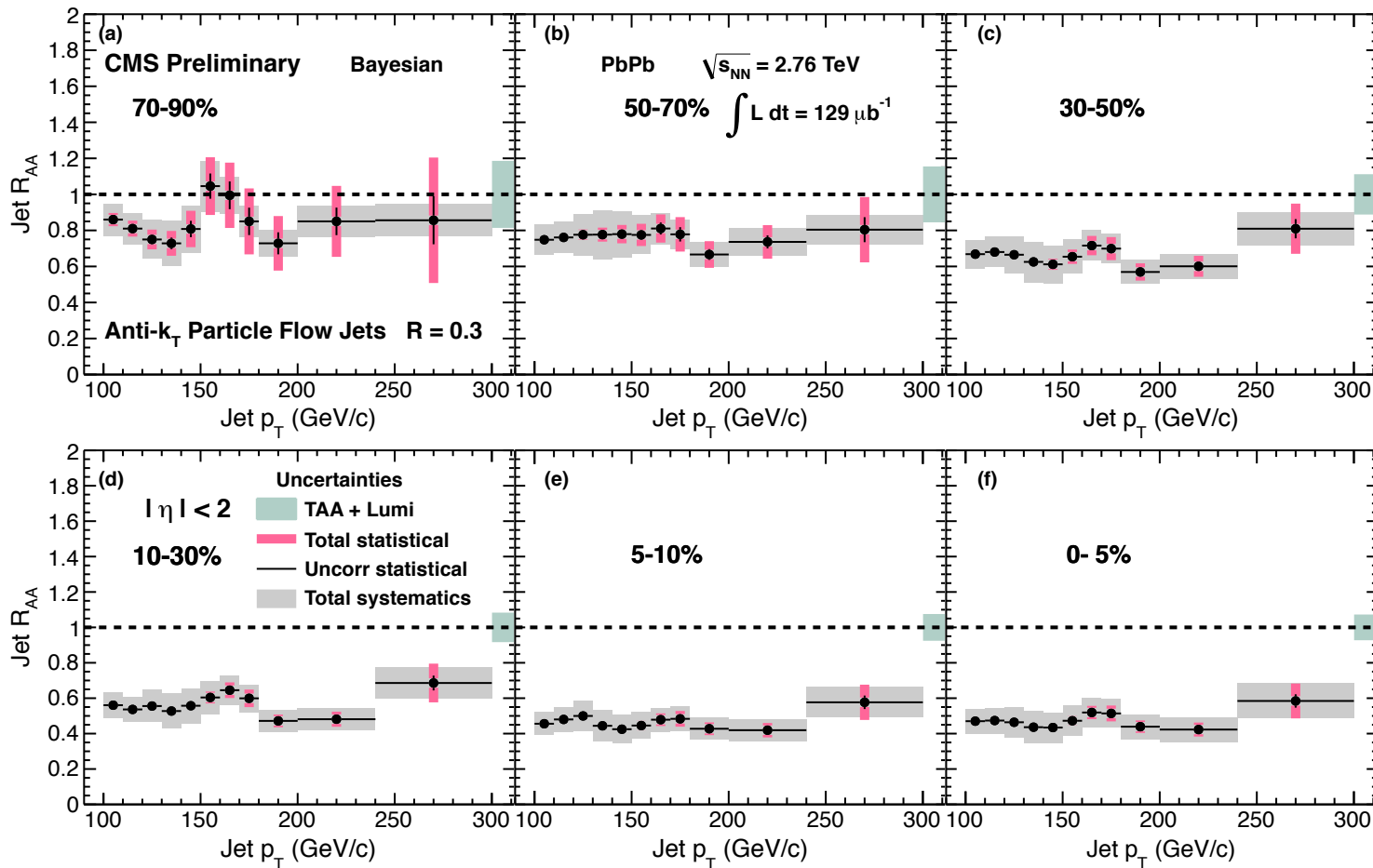


$R_{AA} - 1$: Charged hadron



- Charged hadrons ($|\eta| < 1$)
 - Featured in EPJC for providing strong constraints
 - Flat R_{AA} for $p_T > 30$ GeV

R_{AA}^{-2} : Jet



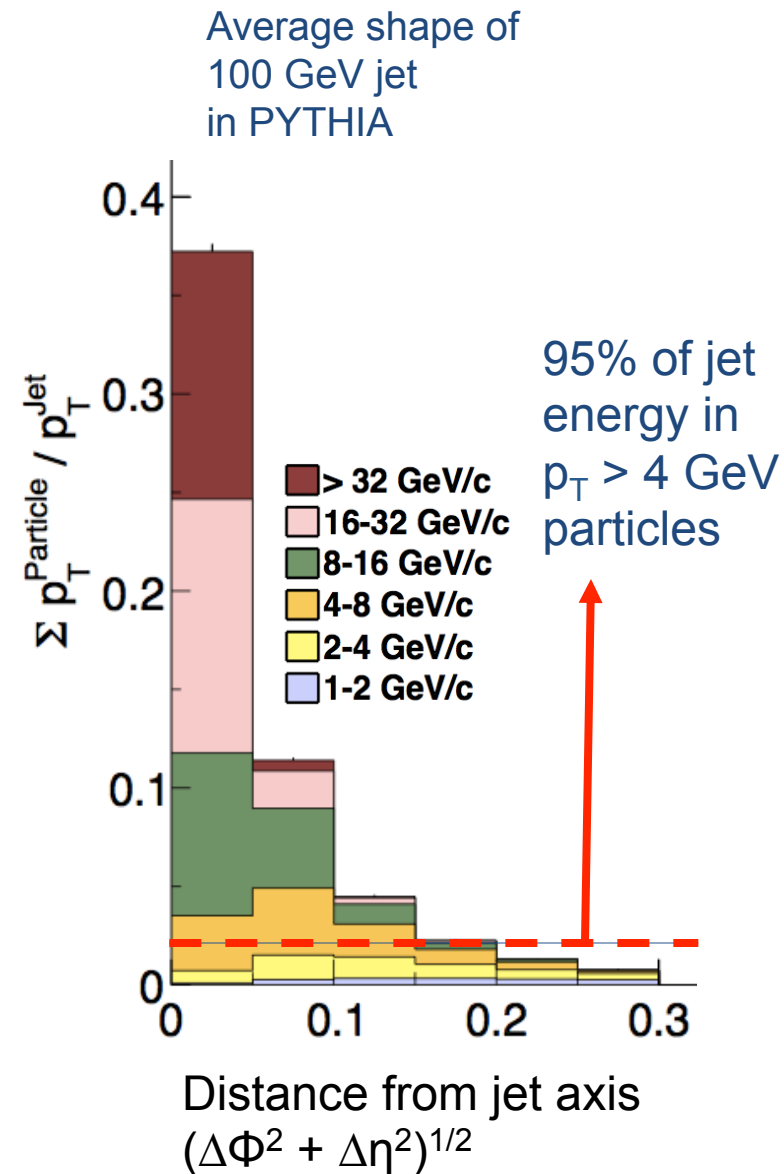
- Inclusive Jet ($|\eta| < 2$, $p_T > 100$ GeV)
 - Anti- k_T algorithm with $R = 0.3$
 - Flat R_{AA} in the most central events

Connection between jet and hadron R_{AA}

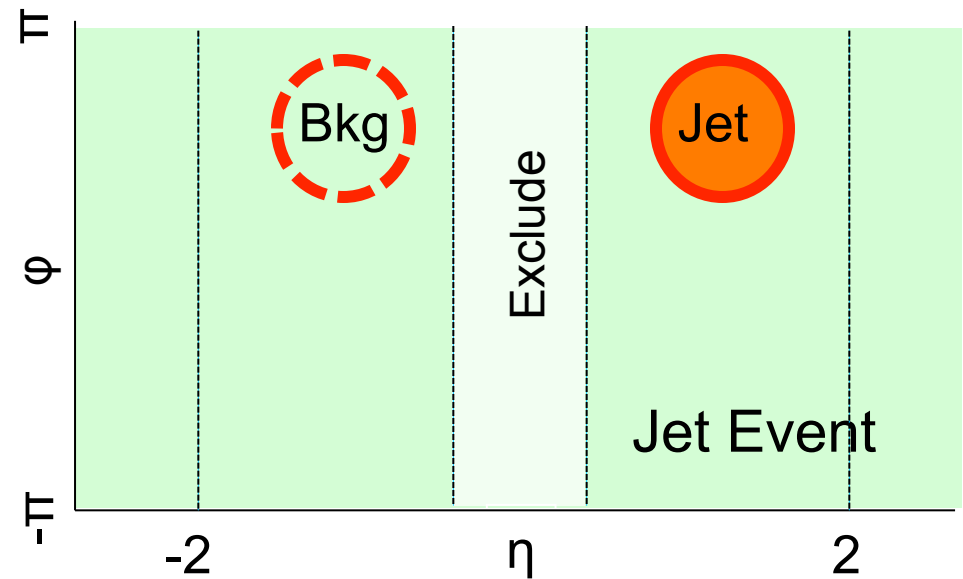
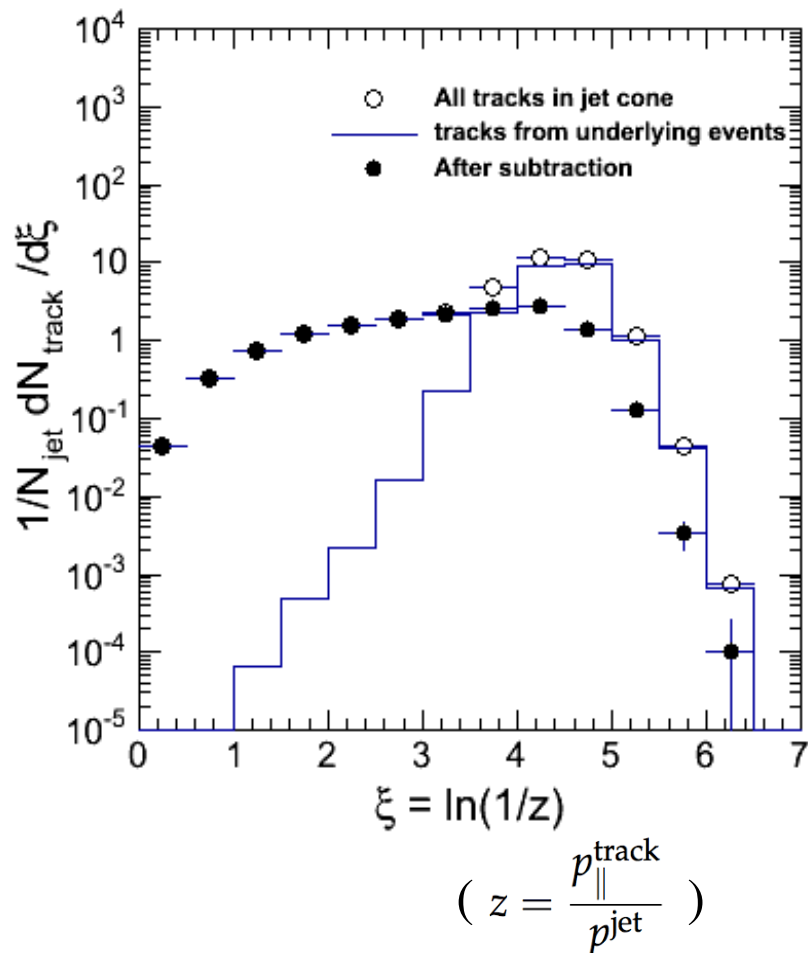
- Flatness (at 0.5) of high p_T jet and hadron R_{AA}
 - Implies that the **high p_T hadronization of a parton** in medium is **similar to that in vacuum**
- What about soft part?

Connection between jet and hadron R_{AA}

- Flatness (at 0.5) of high p_T jet and hadron R_{AA}
 - Implies that the **high p_T hadronization of a parton** in medium is **similar to that in vacuum**
- To investigate soft part of jet fragmentation, jet-track correlations were studied
 - Large background from underlying events
 - Careful subtraction required

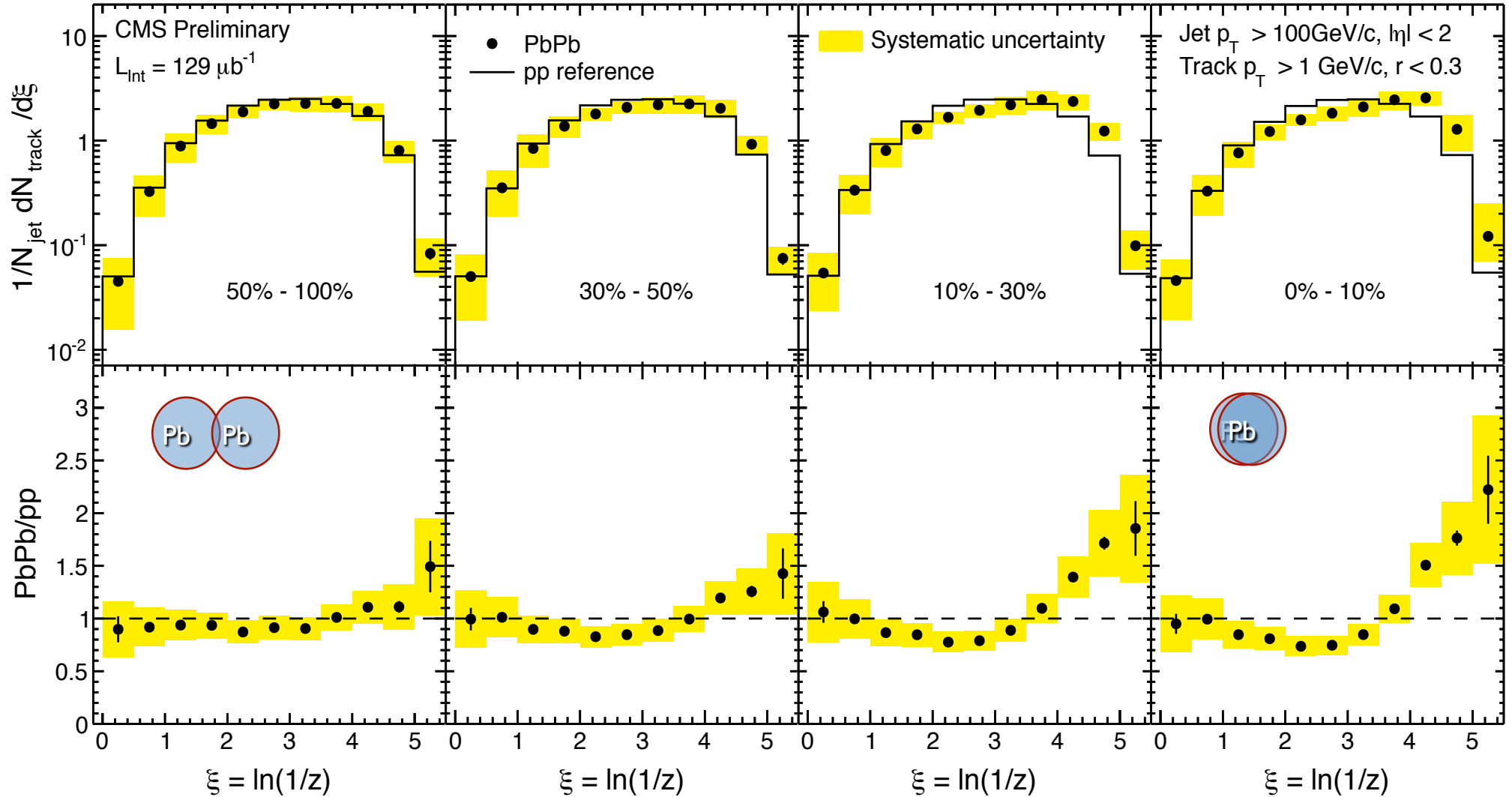


Underlying event subtraction



Background from underlying events estimated from reflected η cone

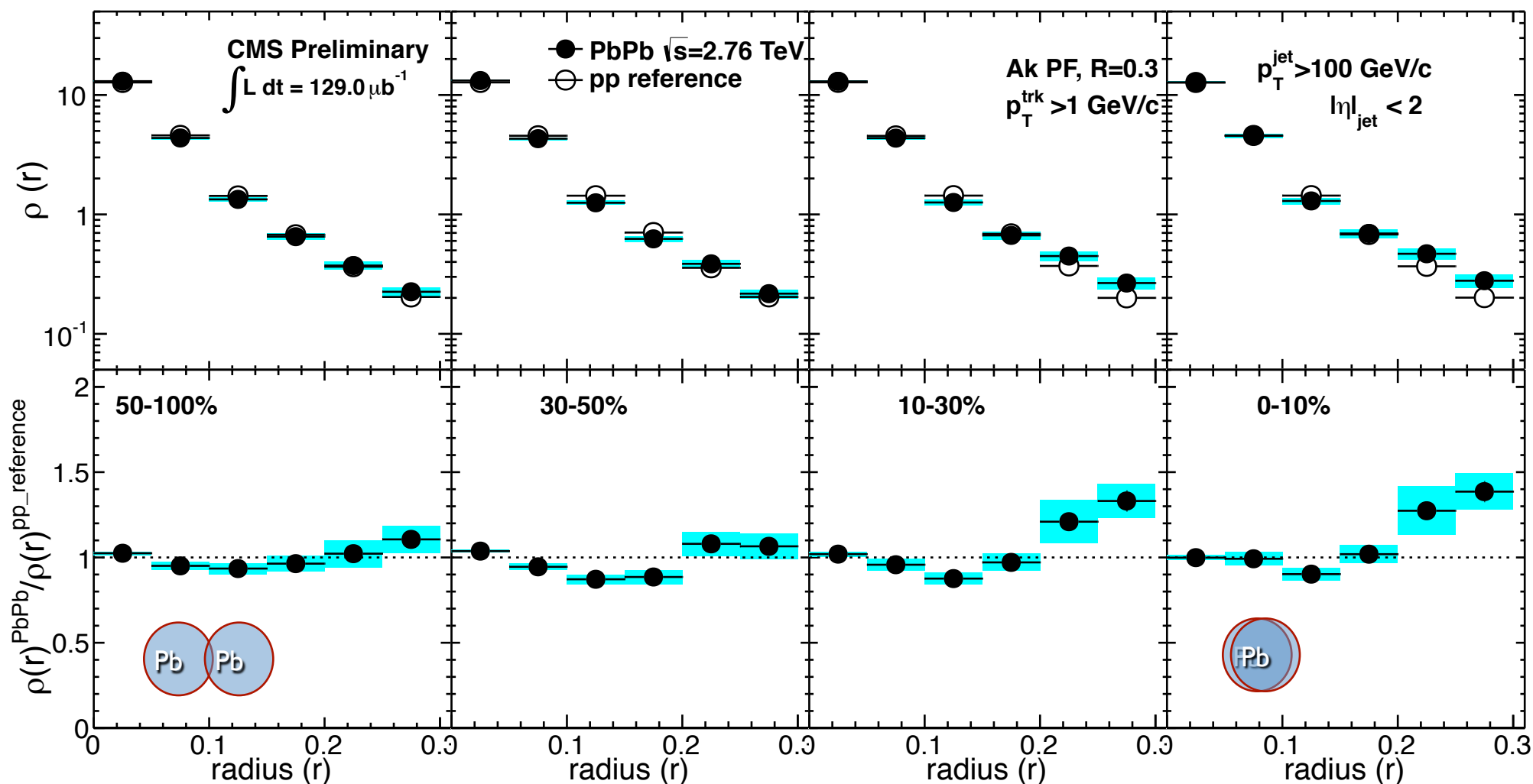
Modification of Jet Fragmentation Function



- High p_{T} particles in jet unmodified (as expected)
- **Significant excess** of low p_{T} particles
- **Deficit** of fragmentation probability for intermediate p_{T} particles

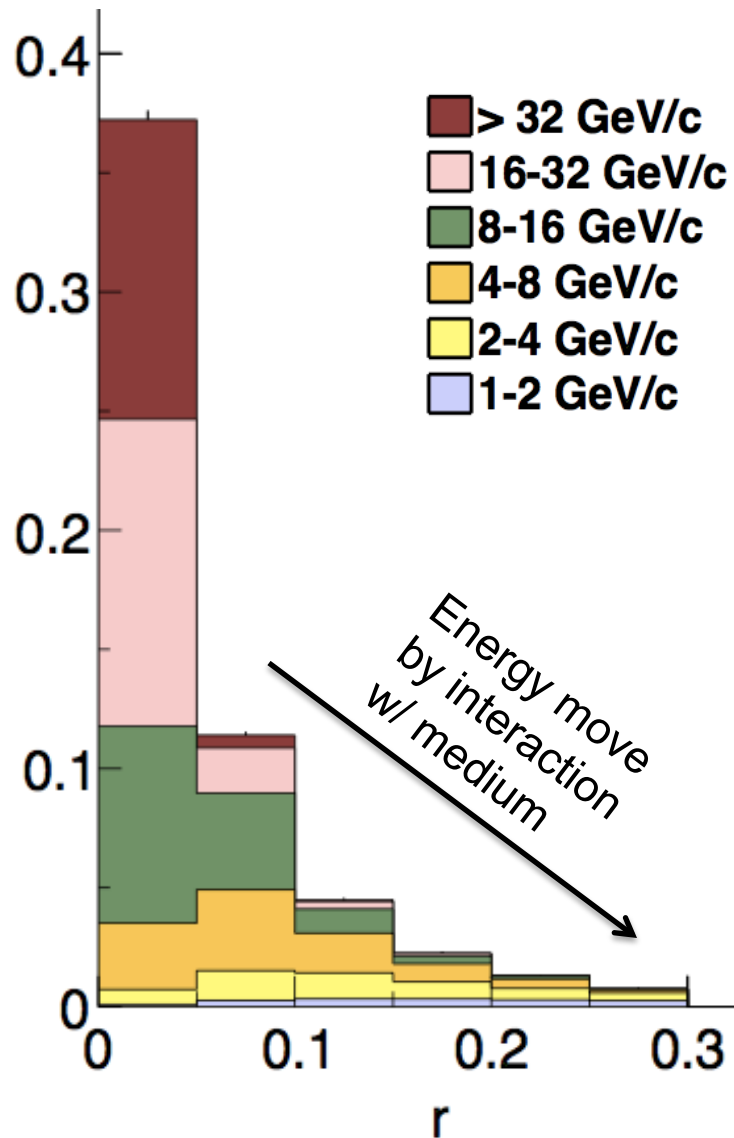
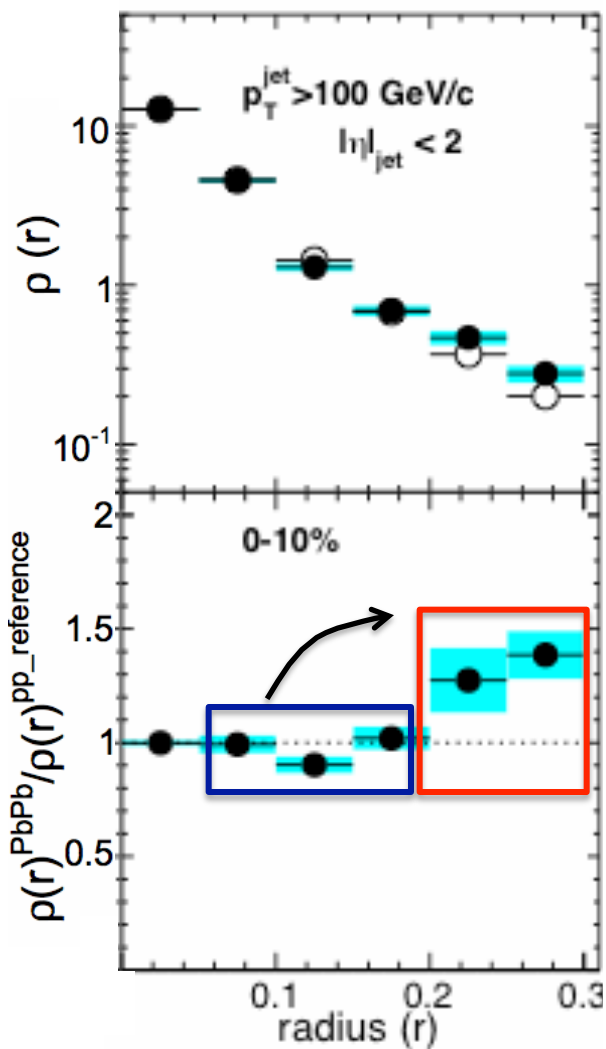
$$\left(z = \frac{p_{\parallel}^{\text{track}}}{p^{\text{jet}}} \right)$$

Modification of Jet Shape

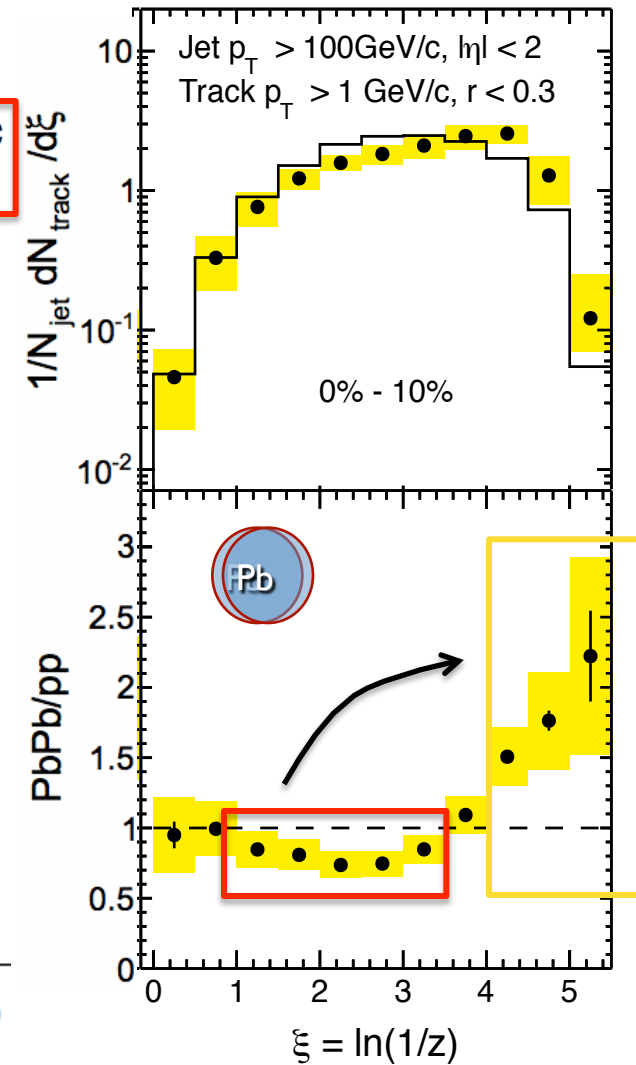
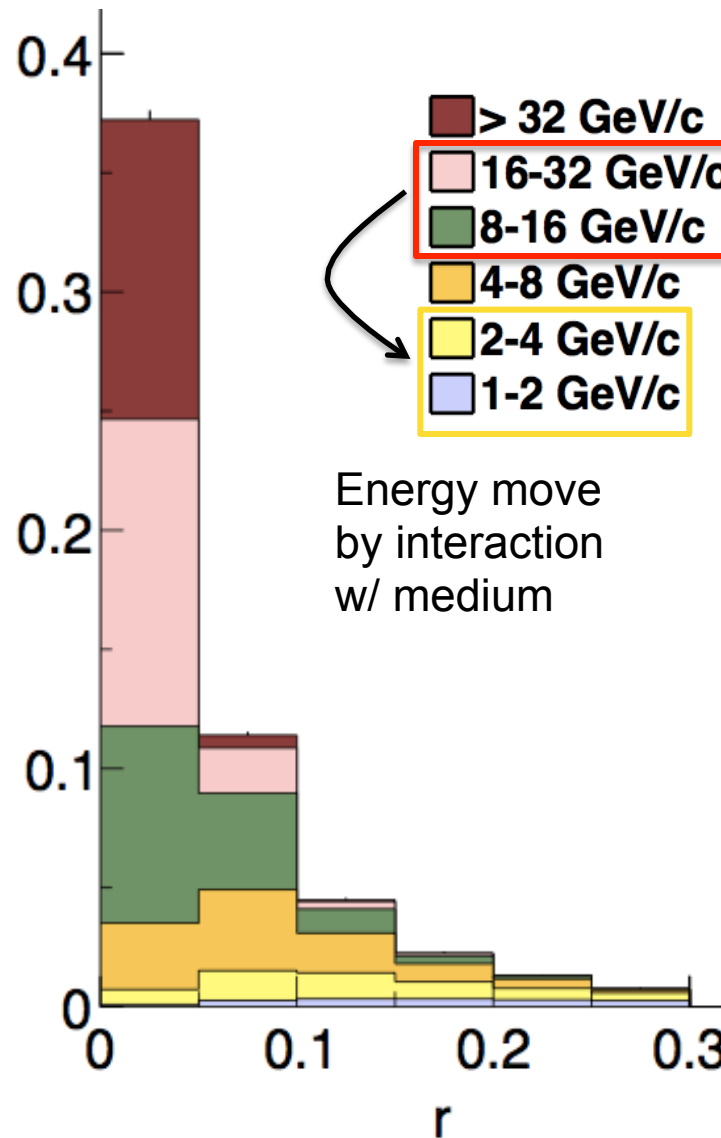


- Jet shape : radial distribution of energy around the jet axis
- Significant modification of energy distribution for $r > 0.2$

Review of jet track correlation - 1/2

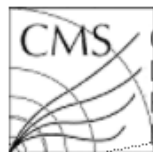


Review of jet track correlation - 2/2



- We used reconstructed jet energy in PbPb collision to study the quenching and fragmentation function modification
- However, the reconstructed jet already lost the information of initial hard scattering because of the interaction with medium
- Can we recover history of parton before energy loss?

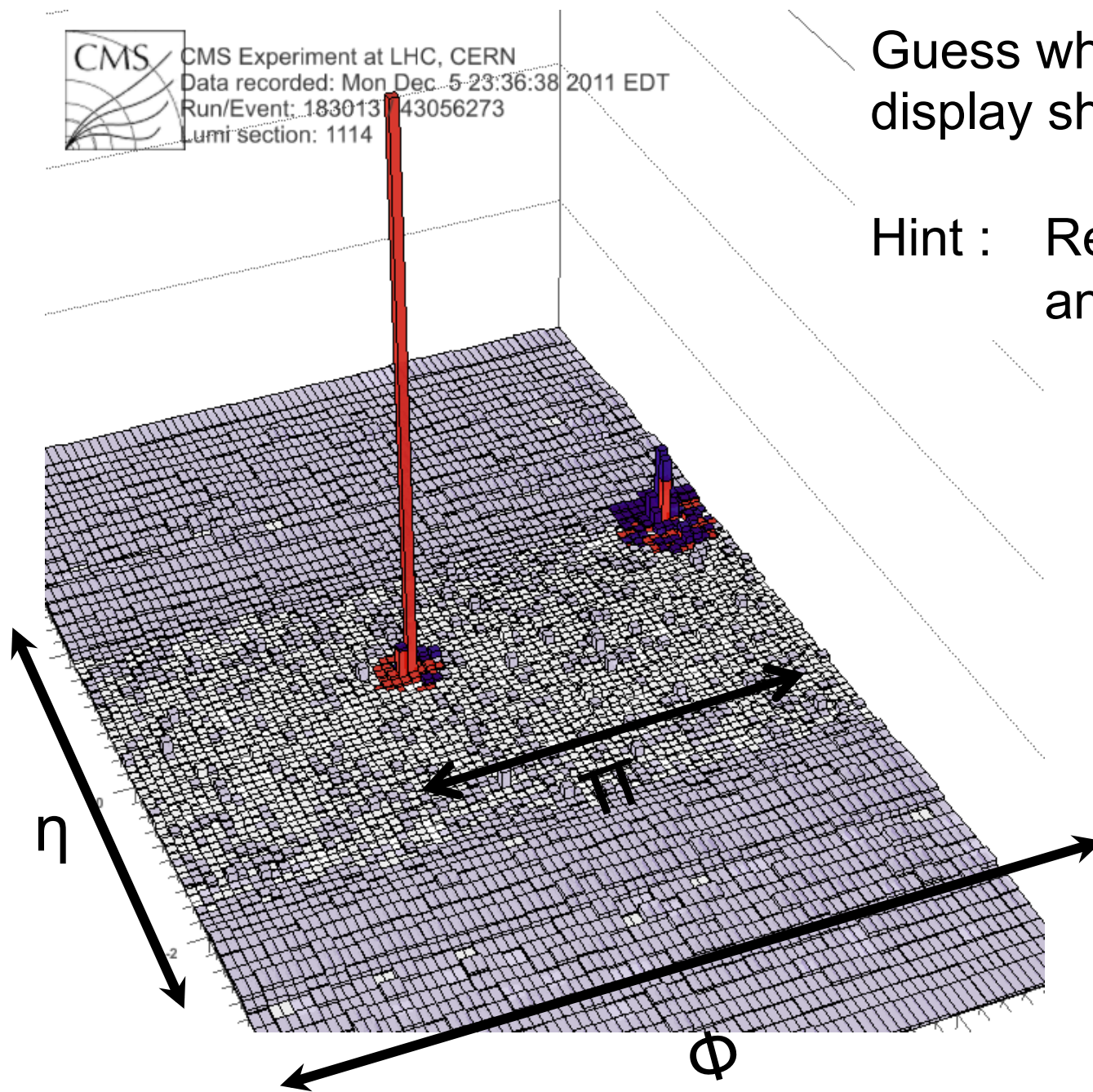
More direct measurement of jet quenching



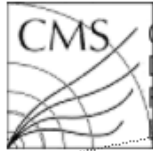
CMS Experiment at LHC, CERN
Data recorded: Mon Dec 5 23:36:38 2011 EDT
Run/Event: 183013/43056273
Lumi section: 1114

Guess what this CMS event display shows?

Hint : Red brick is **EMcal** energy and blue is **Hcal** energy



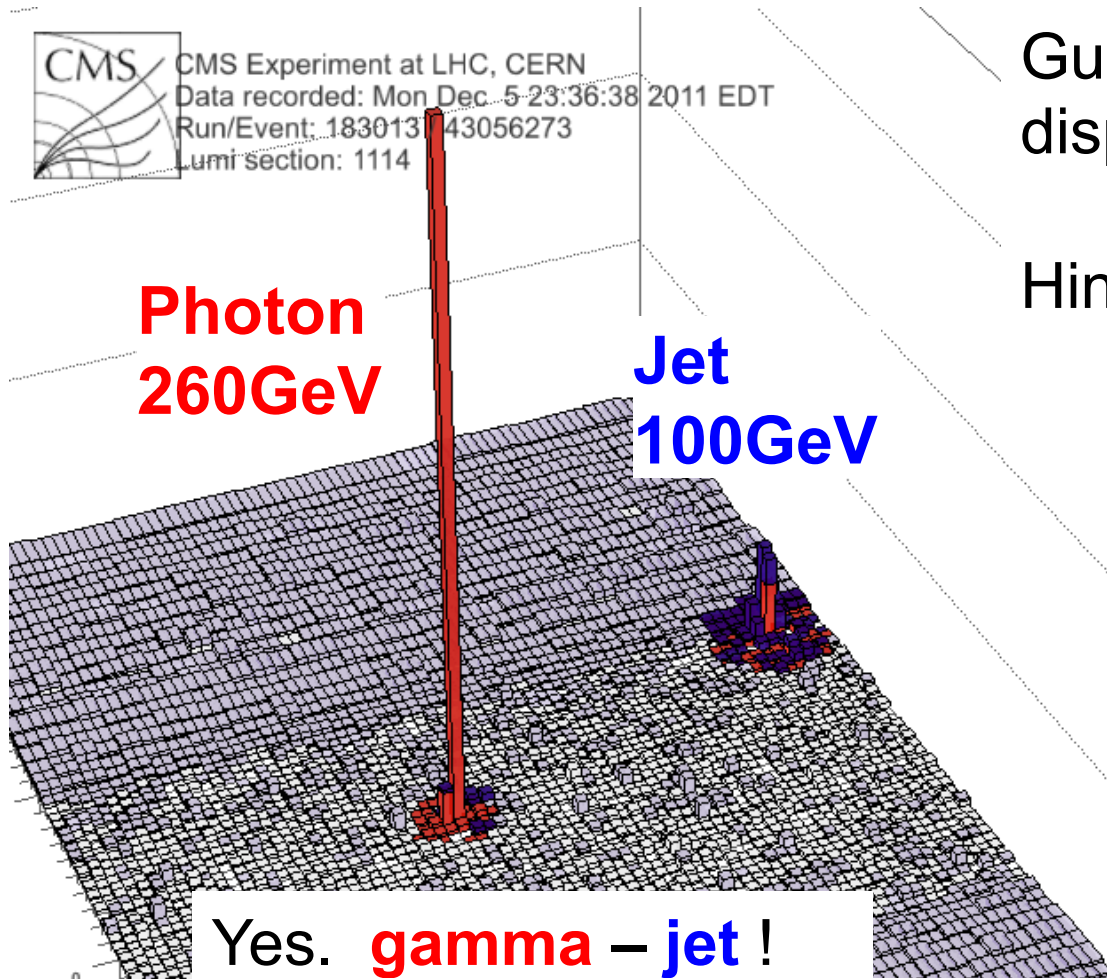
More direct measurement of jet quenching



CMS Experiment at LHC, CERN
Data recorded: Mon Dec 5 23:36:38 2011 EDT
Run/Event: 183013/43056273
Lumi section: 1114

Photon
260GeV

Jet
100GeV



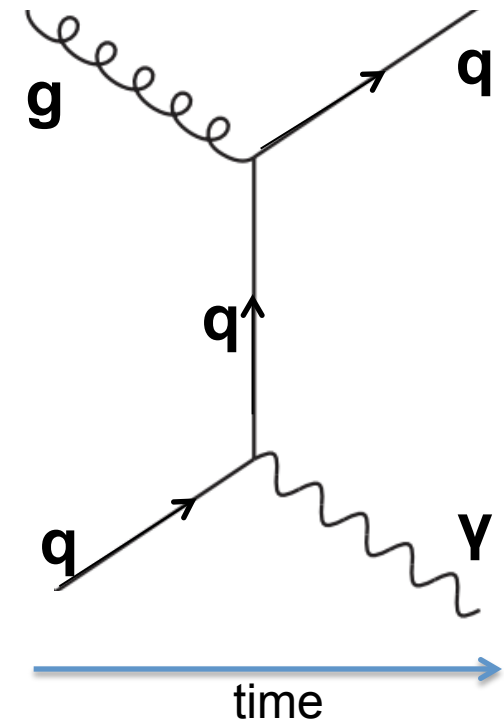
Guess what this CMS event display shows?

Hint : Red brick is **EMcal** energy and blue is **Hcal** energy

Yes. **gamma** – **jet** !

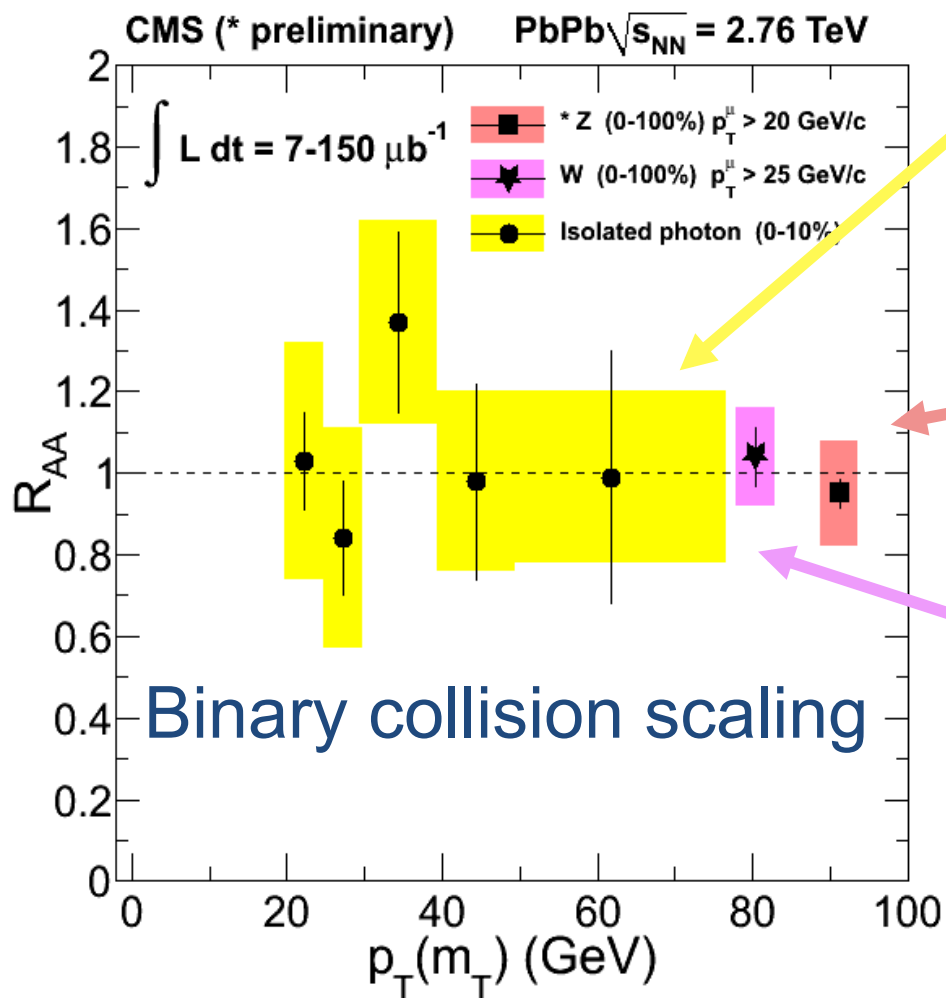
Photon is **colorless** so it is blind to QCD matter.

Therefore it keeps the initial hard scattering information.



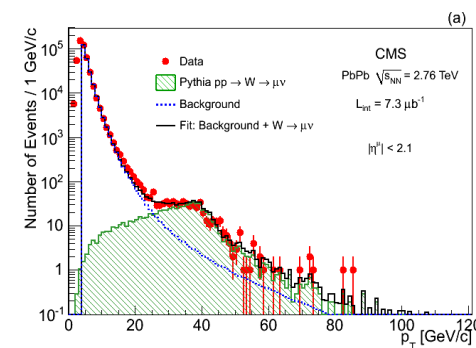
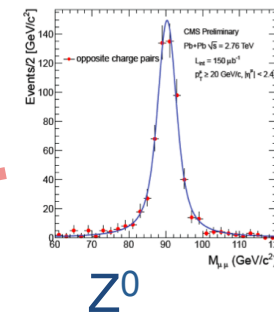
Non-quenching of Colorless probes was proven

Isolated photon R_{AA}
with 2.76 TeV pp
reference



R_{AA} : ratio of cross section between heavy ion
to pp collision after binary collision scaling

CMS-PAS HIN-12-008

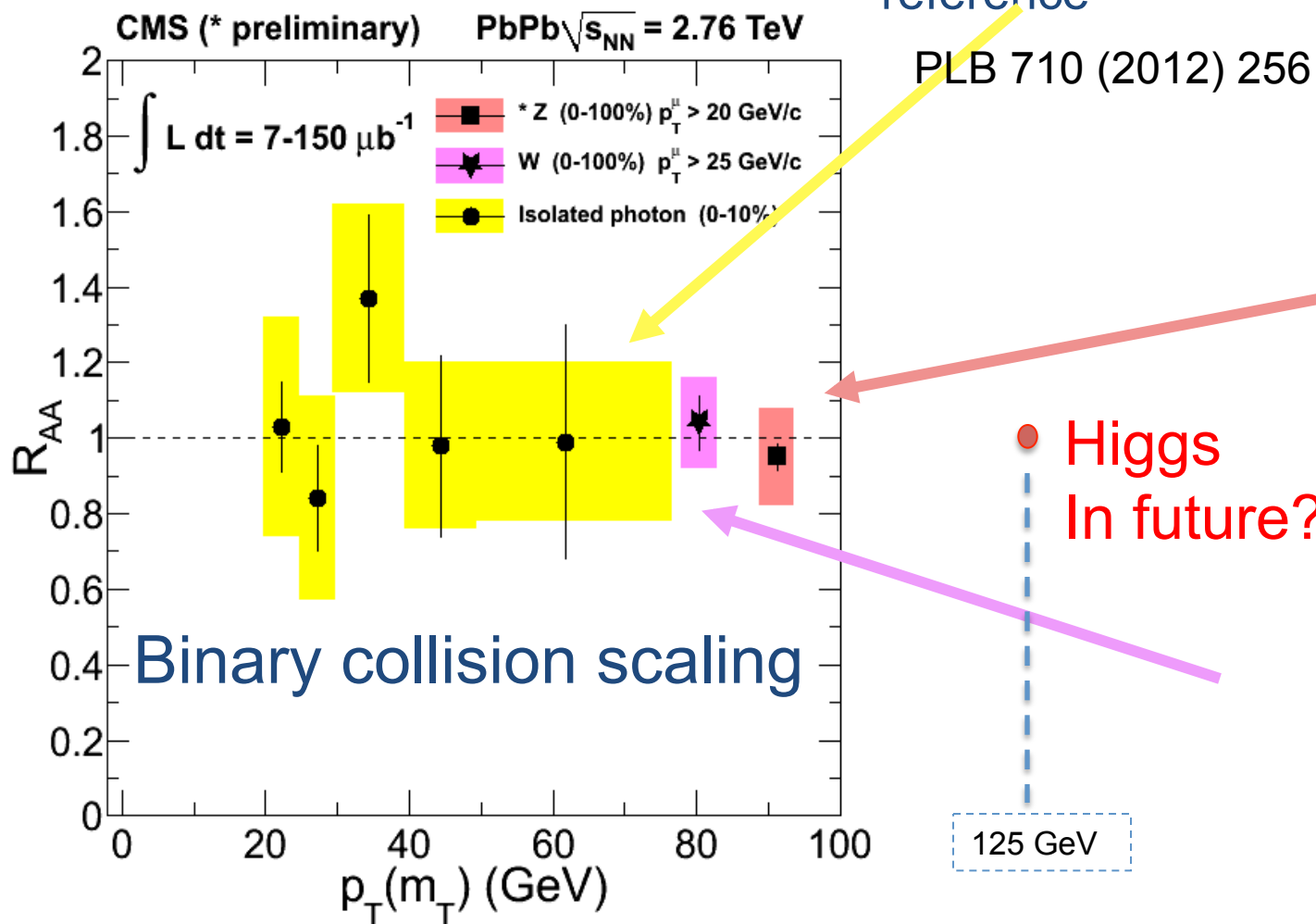


W^+ & W^-

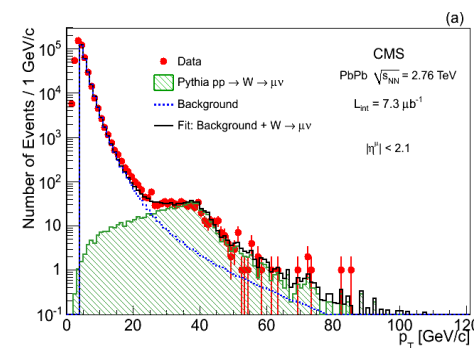
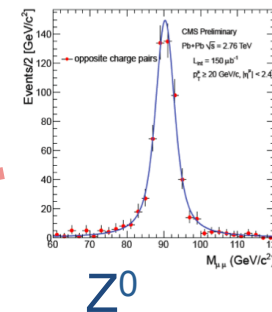
arXiv:1205.6334
Accepted by PLB

Non-quenching of Colorless probes was proven

Isolated photon R_{AA}
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CMS-PAS HIN-12-008



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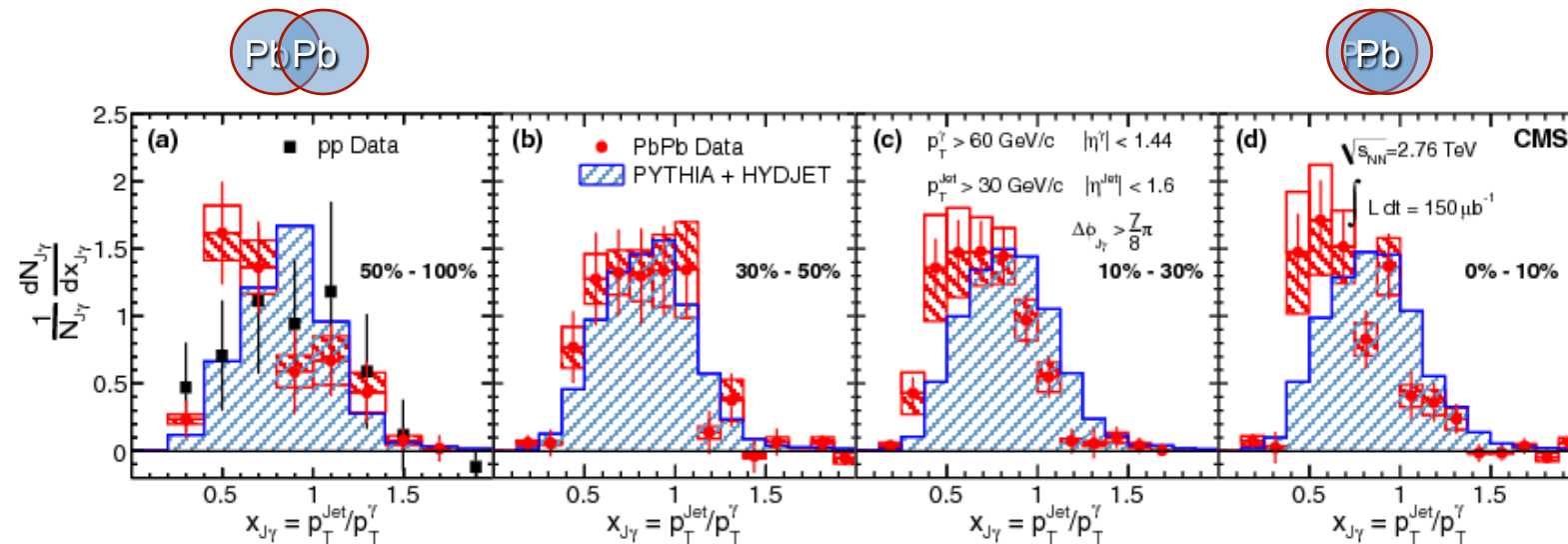
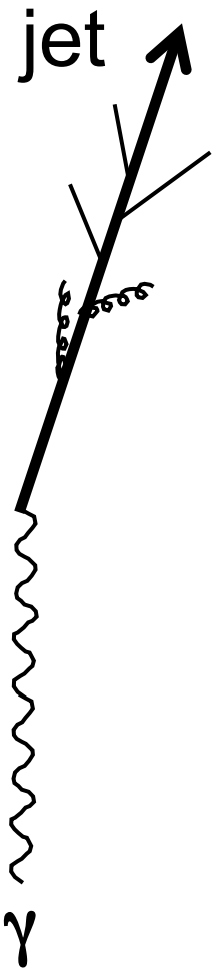
γ -jet correlations

- Ratio of the p_T of jets to photons ($x_{J\gamma} = p_T^{\text{jet}}/p_T^\gamma$) is a **direct measure** of the jet energy loss

Photon $p_T > 60\text{GeV}$

jet $p_T > 30\text{GeV}$

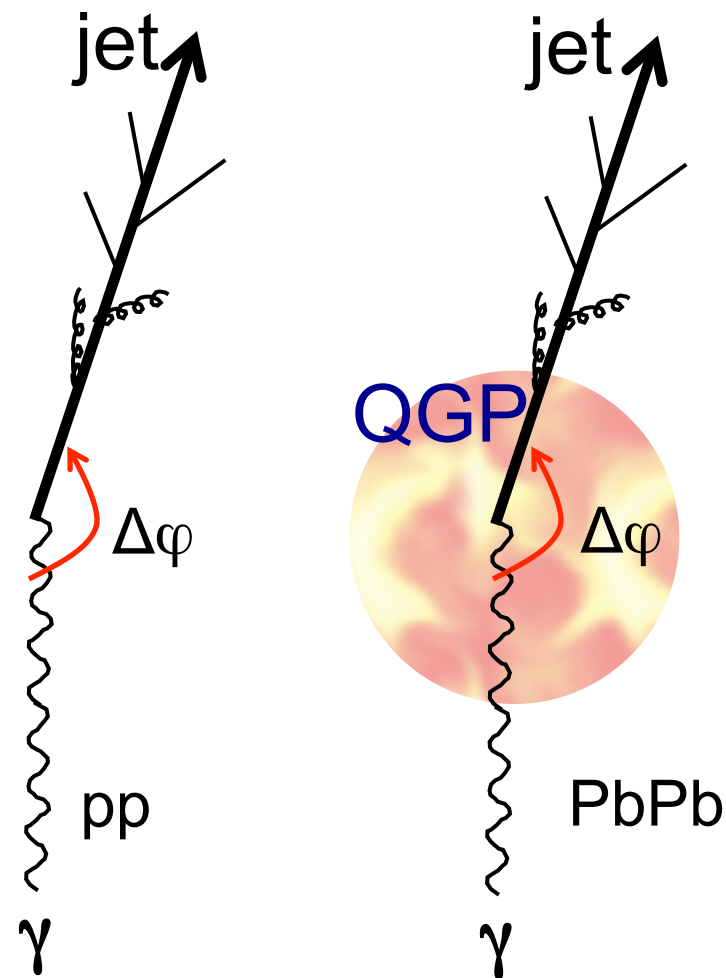
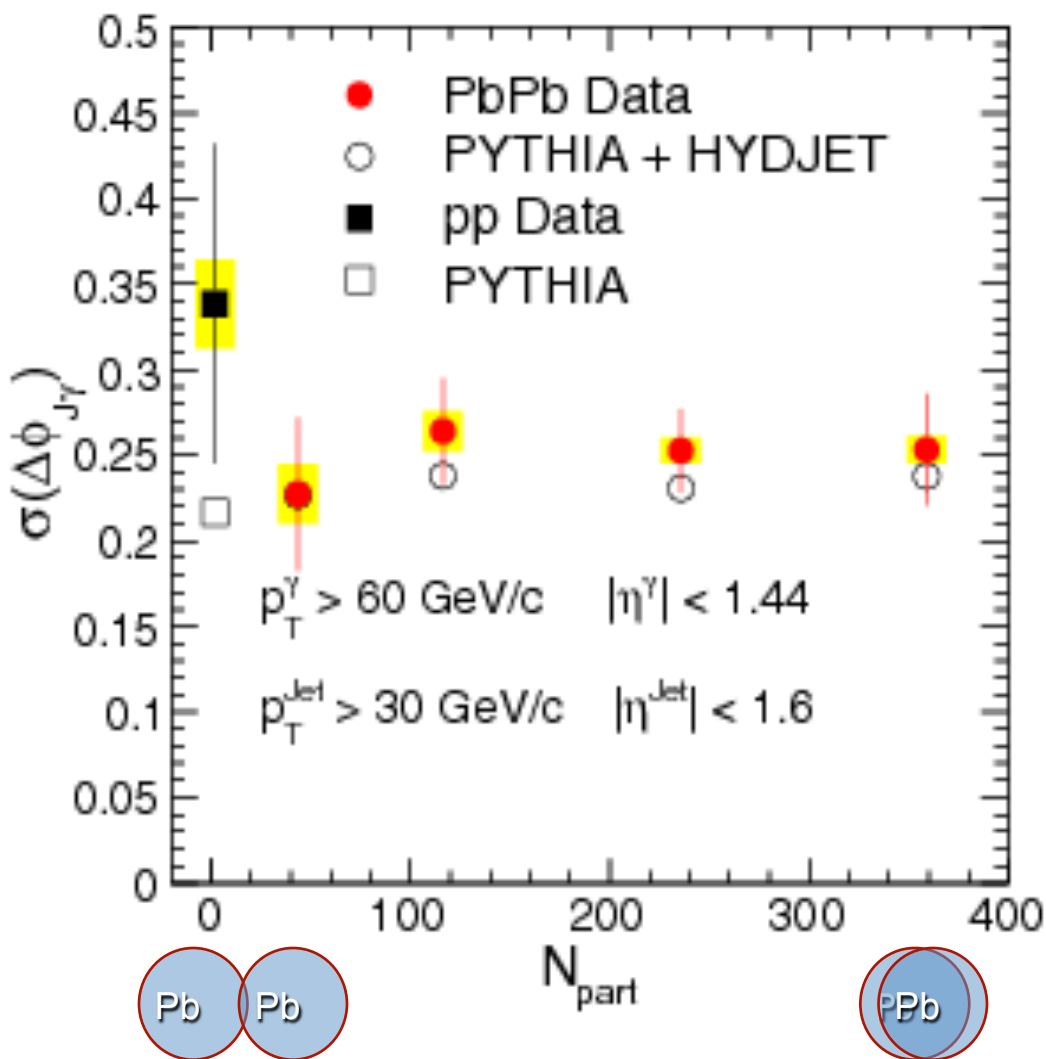
Back-to-back requirement ($d\phi > 7\pi/8$)



arXiv:1206.0206

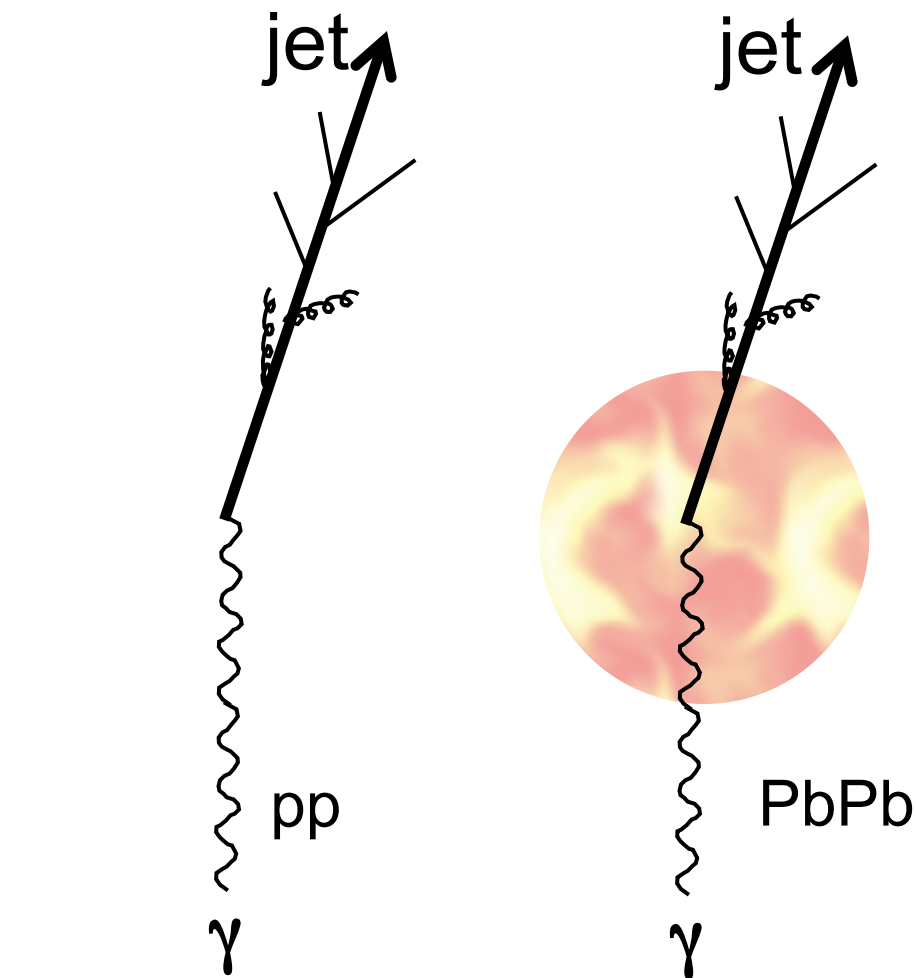
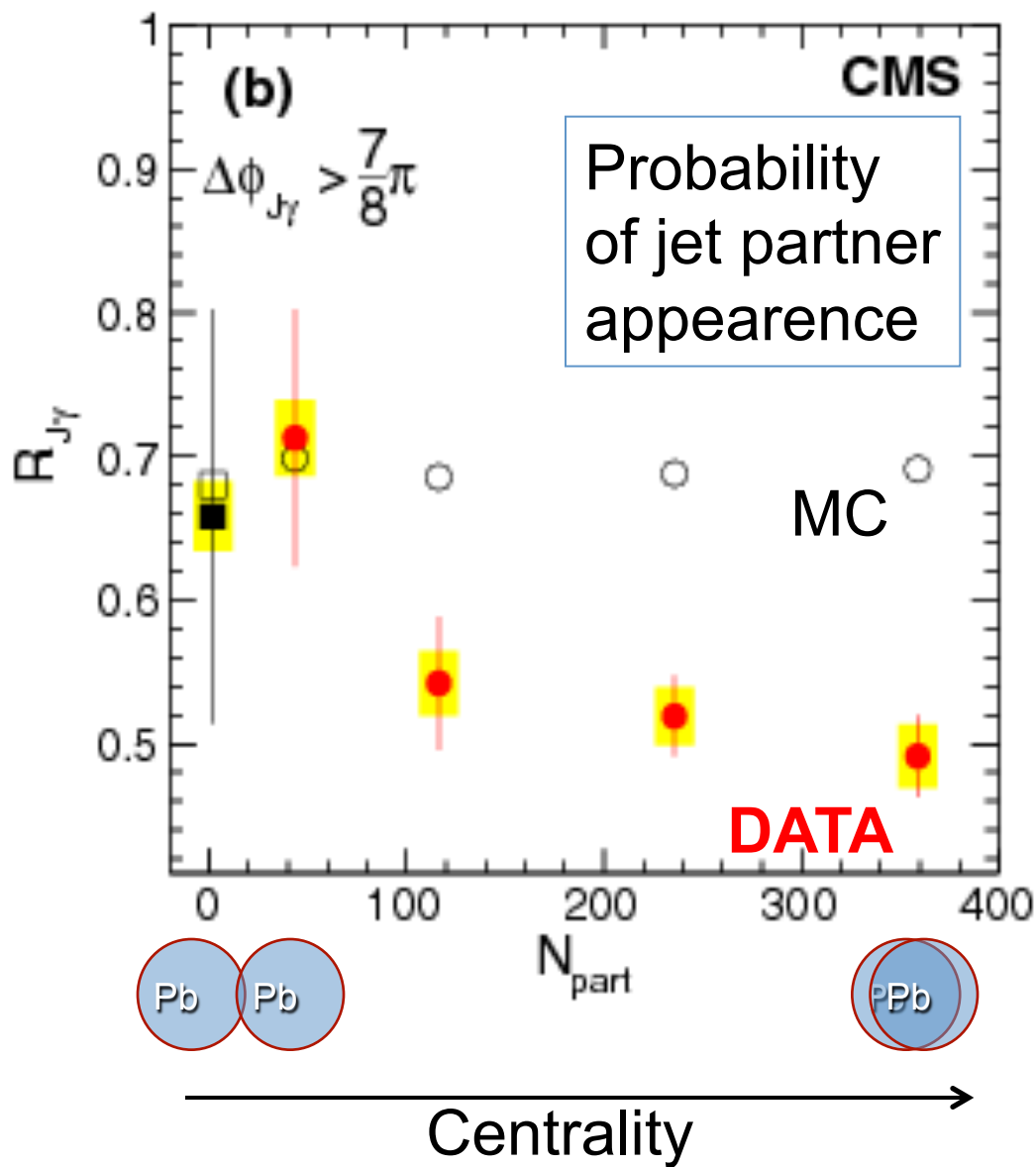
- Gradual **centrality-dependence** of the $x_{J\gamma}$ distribution

γ -jet correlations (1/3) : angular correlation



1. Consistent $\Delta\phi$ distribution for pp and PbPb

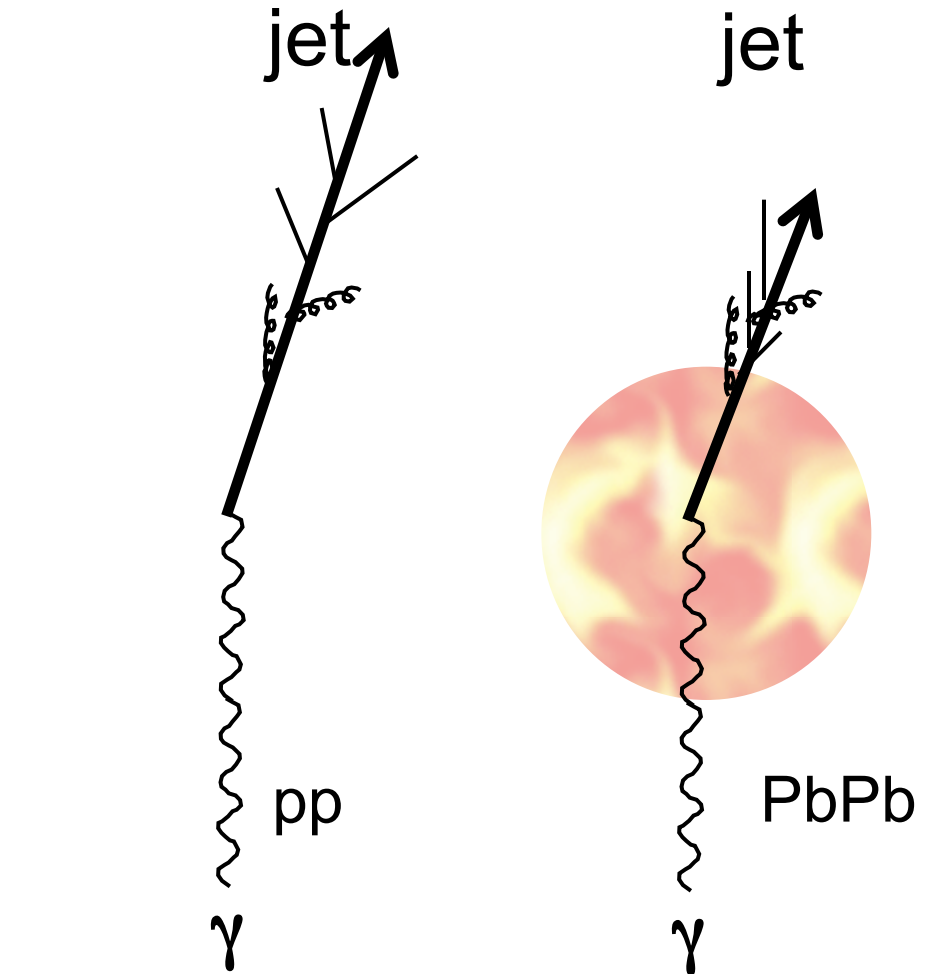
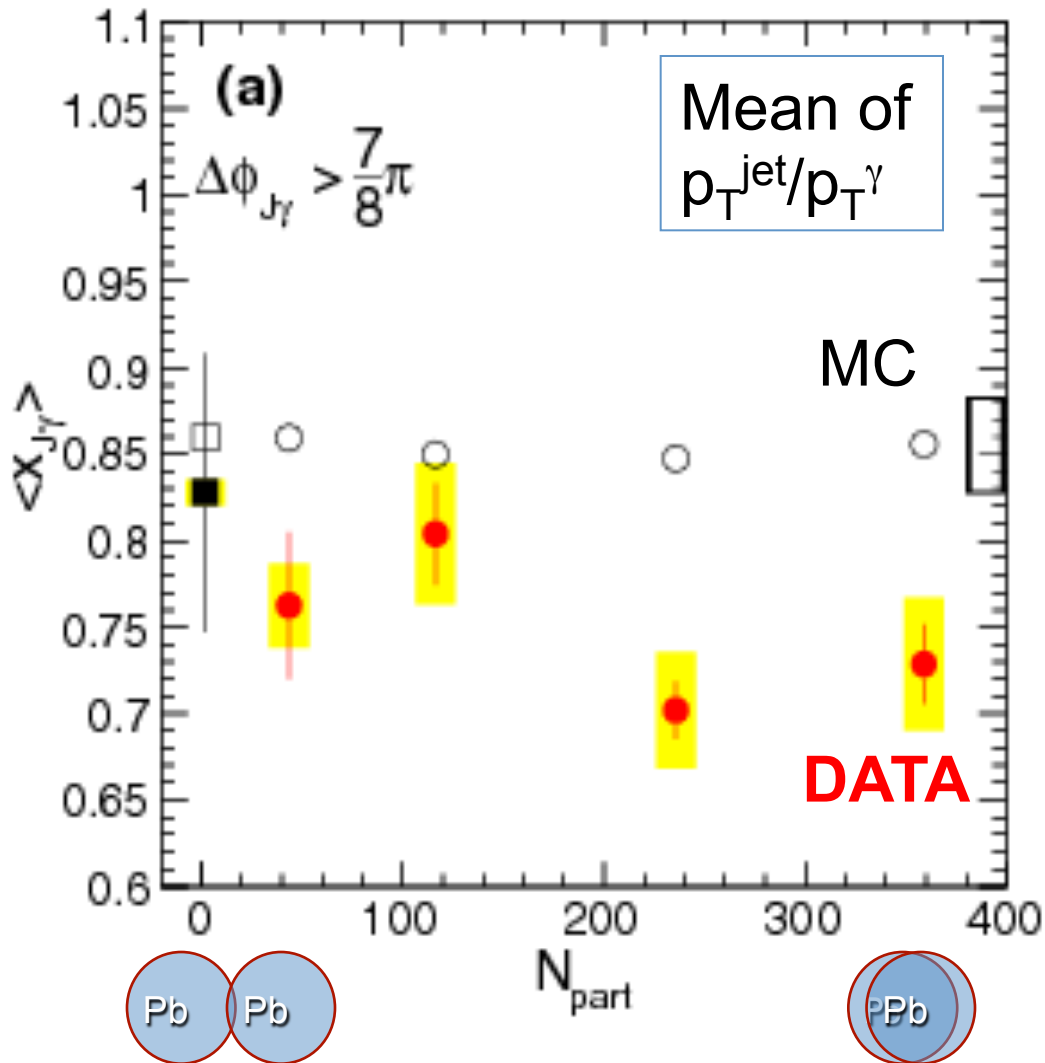
γ -jet correlations (2/3) : jets disappeared



(2) 20% of jet partners are missing in PbPb

($p_T > 30\text{GeV}$)

γ -jet correlations (3/3) : jet energy loss



(3) 14% of jet energy was lost in PbPb

Conclusion

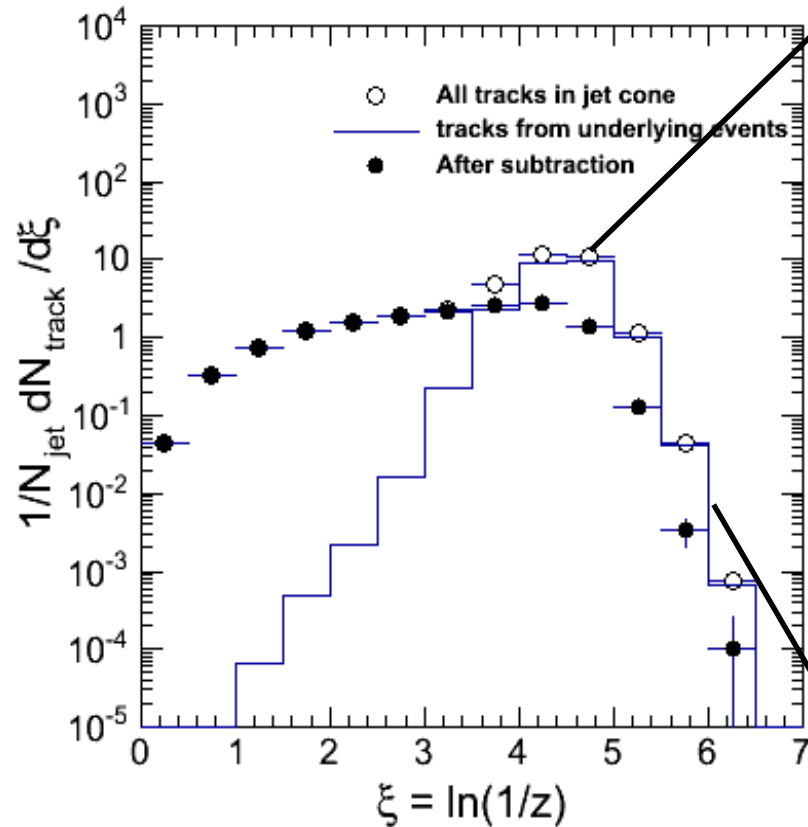
- CMS results show a comprehensive picture of energy loss of high p_T partons in passage of medium
 - Inclusive hadron and jet R_{AA} confirm the quenching effect
 - Fragmentation of parton is modified. More soft particles at farther distance from jet axis
 - γ -jet, a novel channel, quantifies the jet quenching by directly correlating initial and final energy information extracted from γ and jet respectively.

Thank you very much for your attention!

- backup

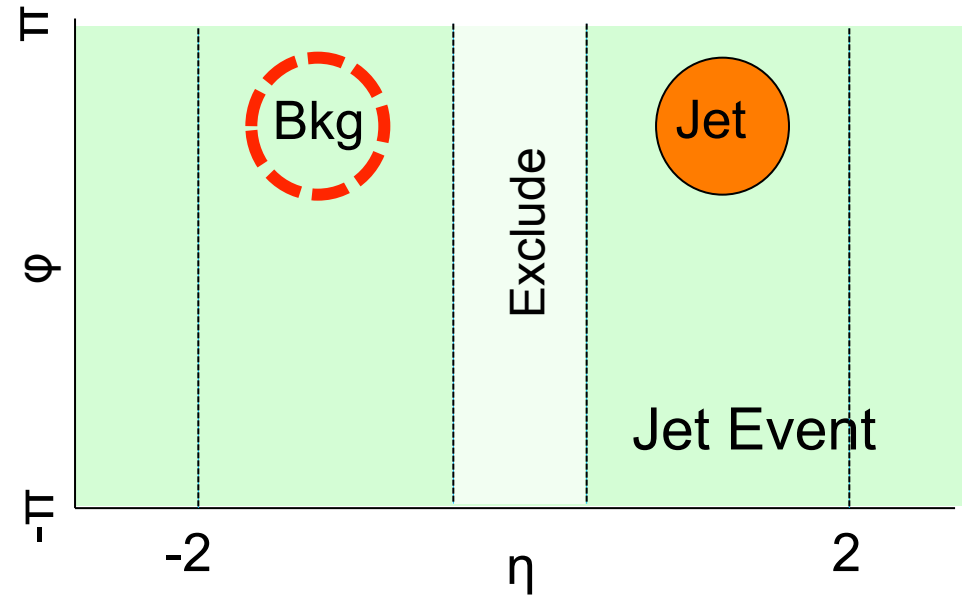
FF – underlying event subtraction

Background subtraction for fragmentation function



(1) Plot raw FF in jet cone

○ All tracks in jet cone

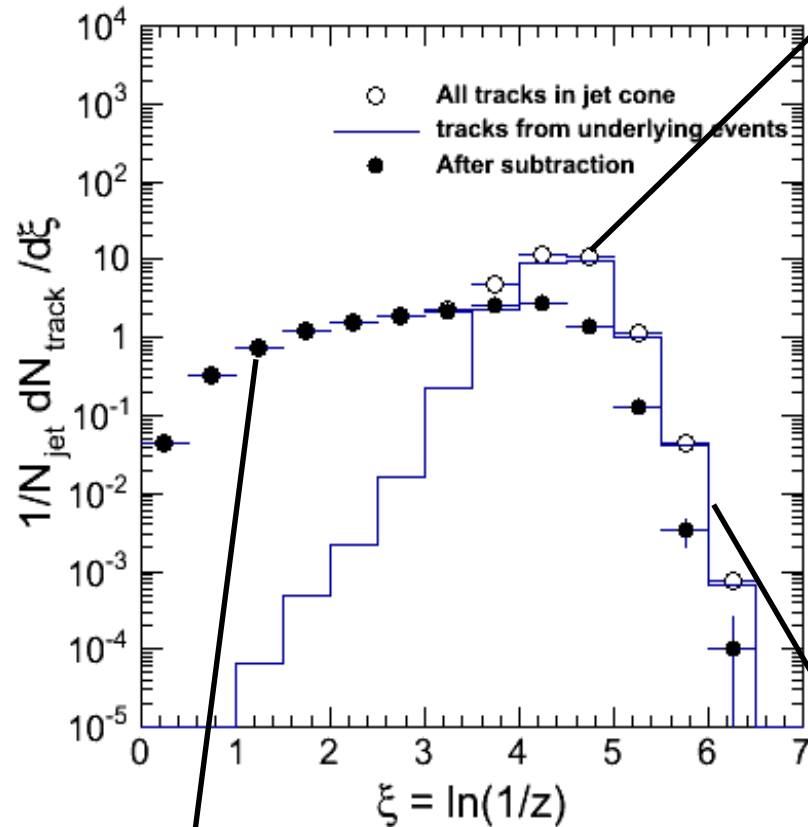


(2) Obtain FF contribution from heavy ion background using η reflected cone.

— tracks from underlying events

FF – underlying event subtraction

Background subtraction for fragmentation function

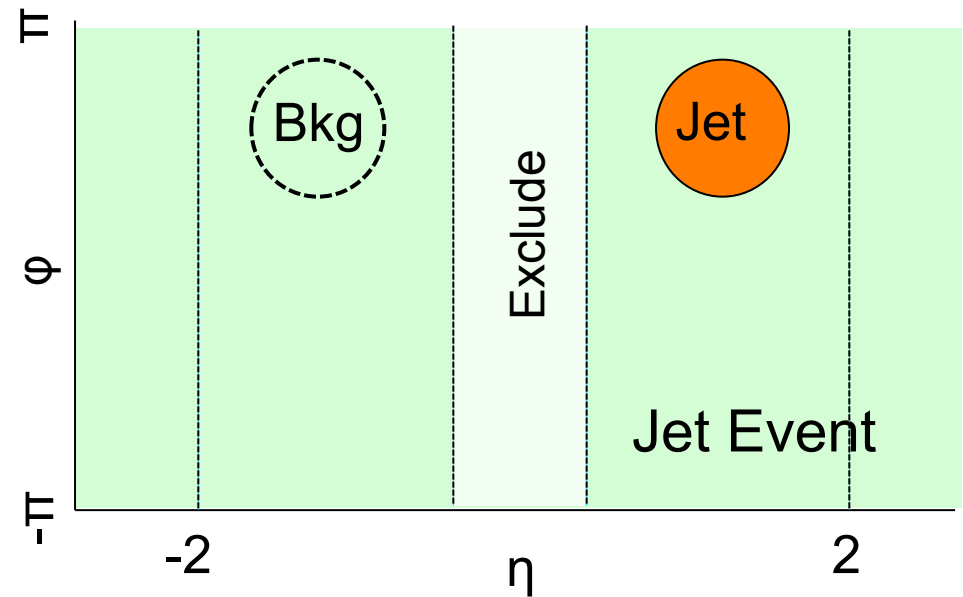


(3) Subtract (2) from (1)

● After subtraction

(1) Plot raw FF in jet cone

○ All tracks in jet cone



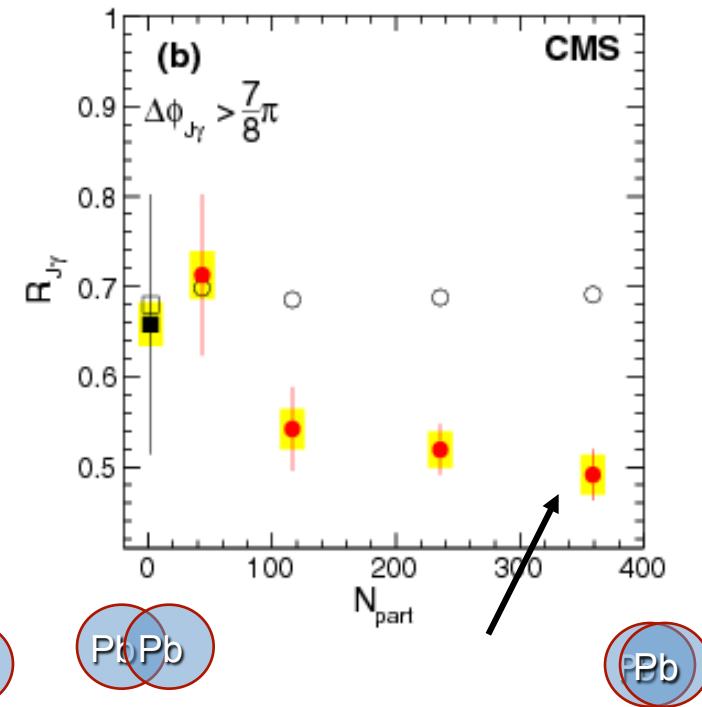
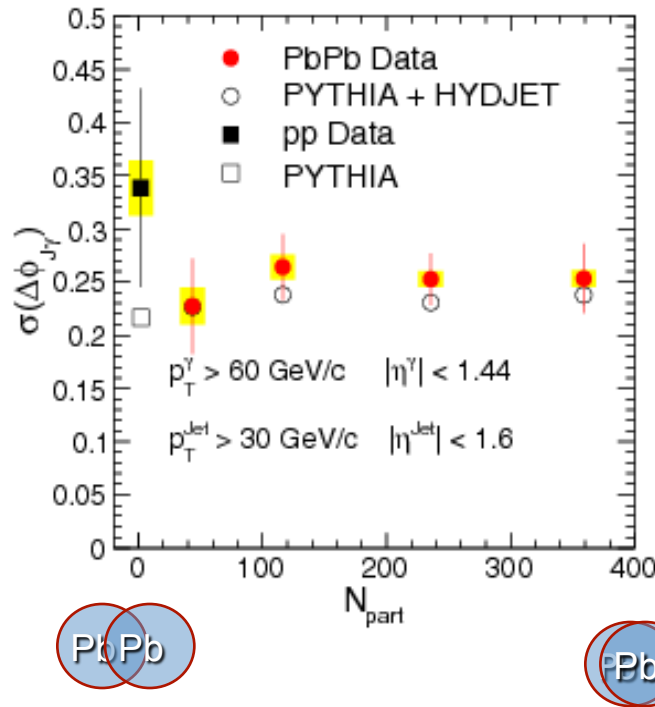
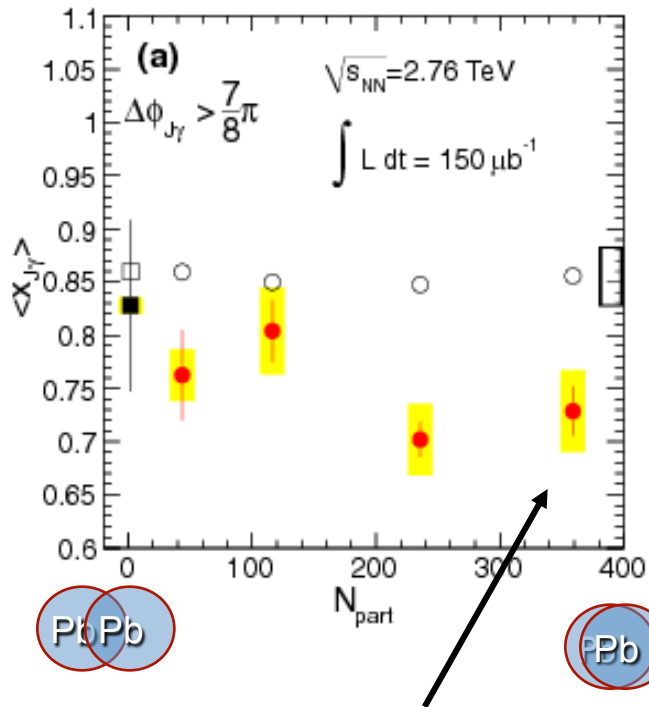
(2) Obtain FF contribution from heavy ion background using η reflected cone.

— tracks from underlying events

γ -jet correlations

$$x_{J\gamma} = p_T^{\text{jet}} / p_T^{\gamma}$$

$R_{J\gamma}$ = fraction of photons with jet partner > 30 GeV/c



No φ -decorrelation