Observation of jet quenching in γ-jet in CMS

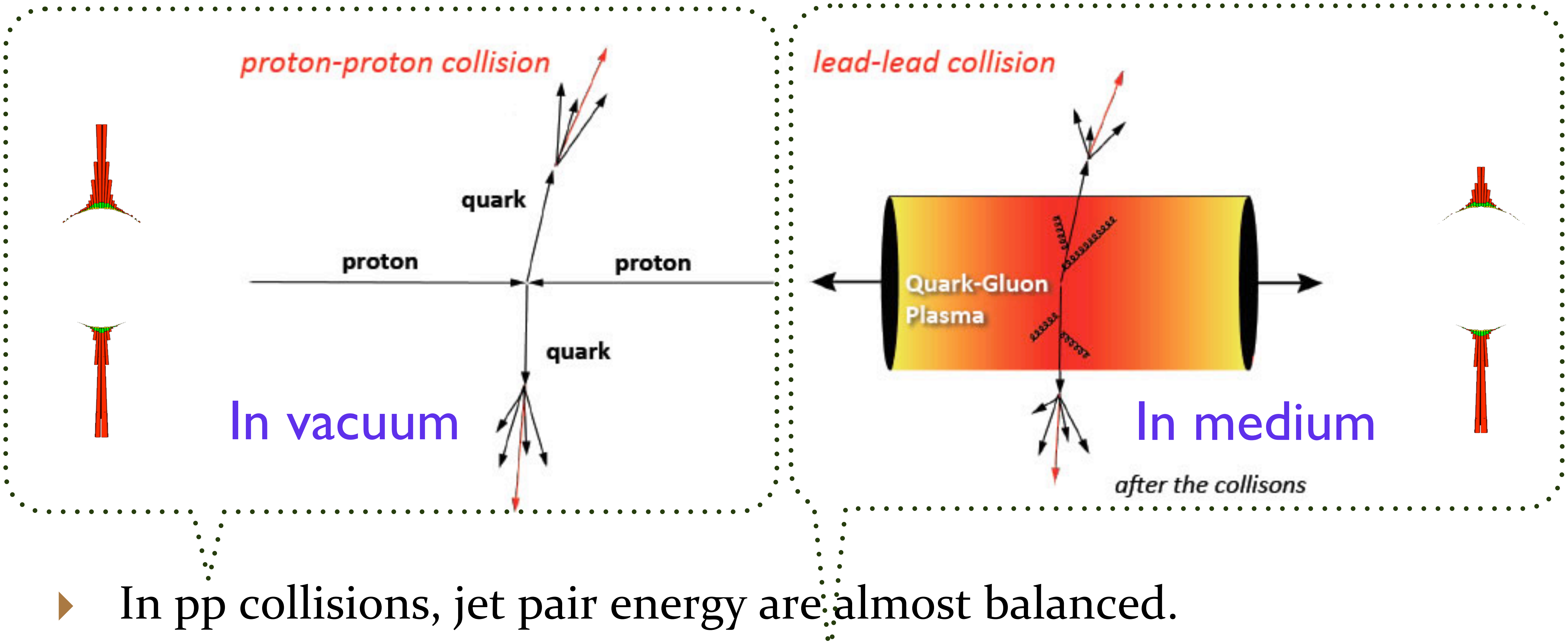
Yeonju Go
(Korea University)
for the CMS collaboration
07 Dec. 2013

Outline

- ✓ Introduction
  - Physics motivation
- ✓ Photon-Jet
- ✓ Analysis Techniques
  - CMS detector
  - Jet reconstruction
  - Isolated photon identification
- ✓ Results
- ✓ Summary

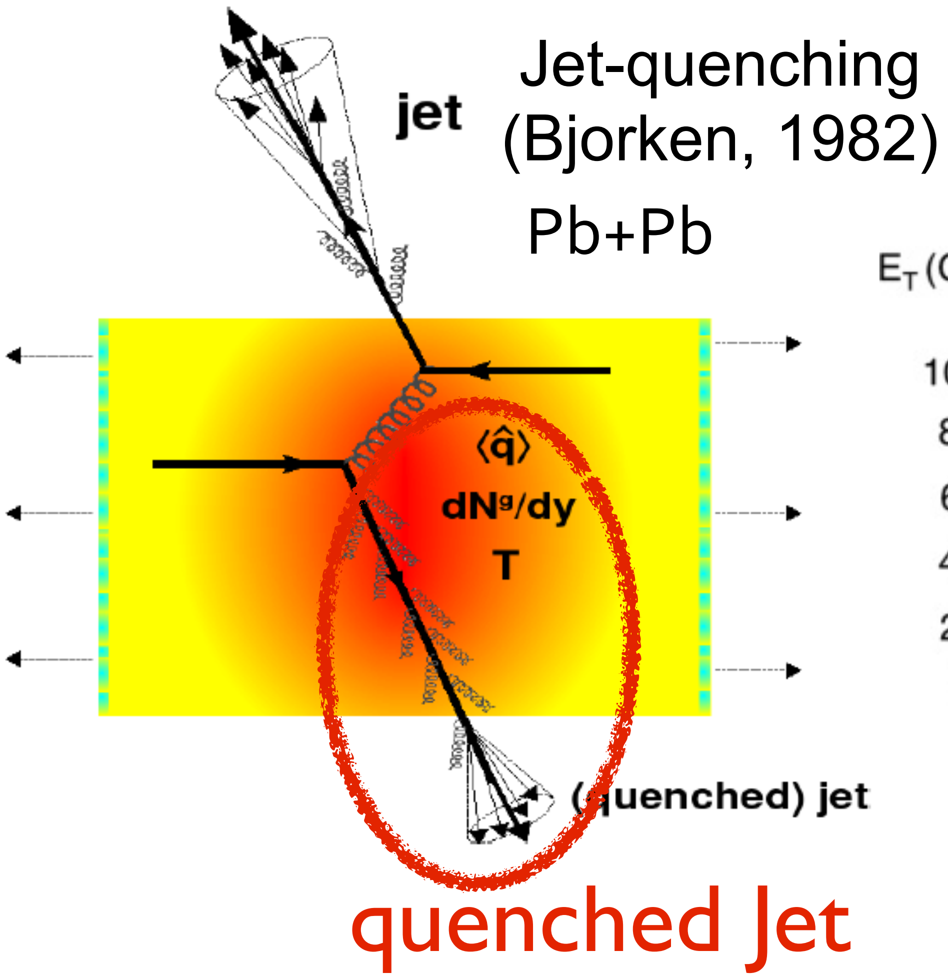
Motivation

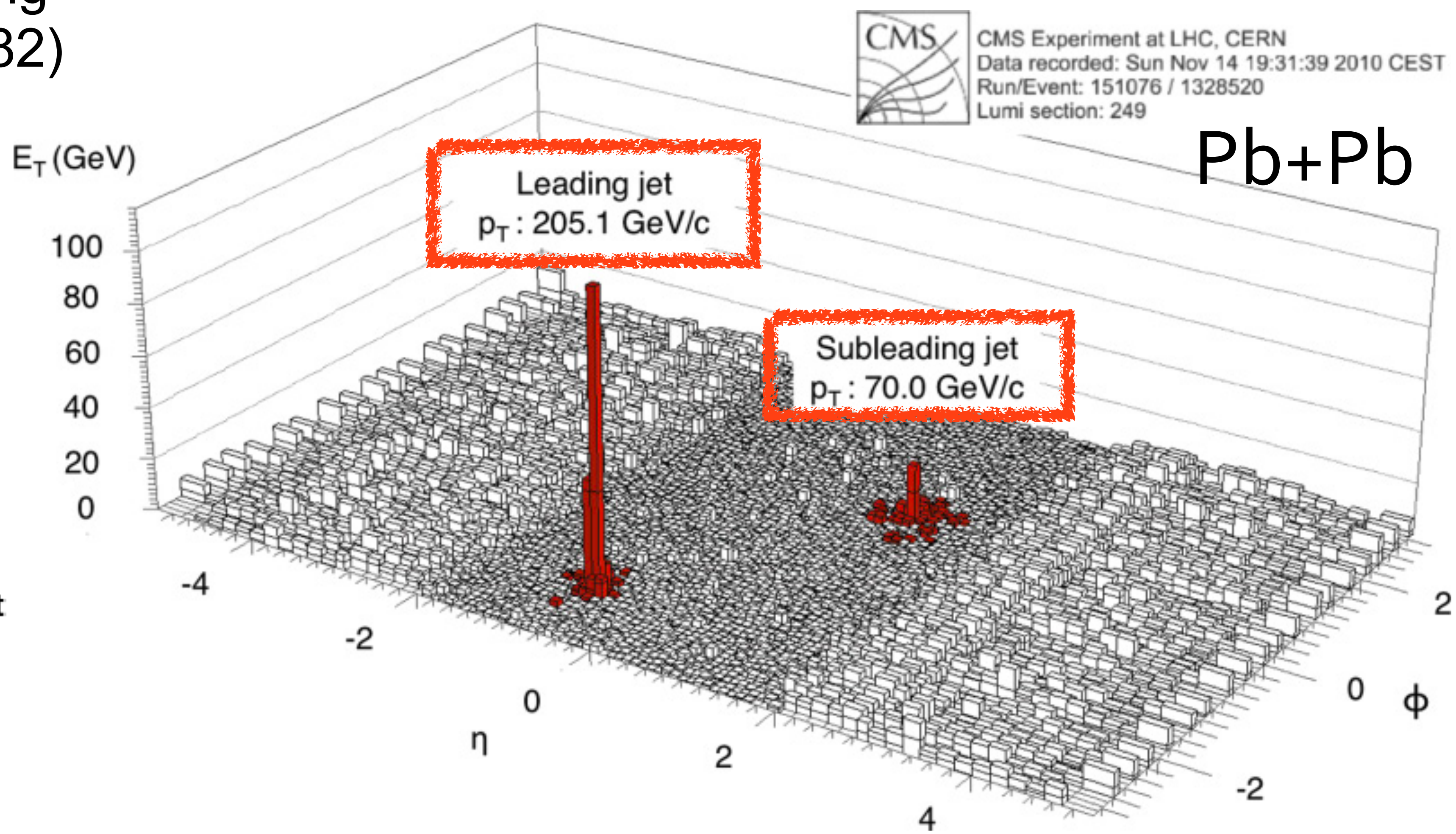
Definition of Jet : the collimated set of hadronic decay products of a high energy parton(quark or gluon) in high energy collision.



- In pp collisions, jet pair energy are almost balanced.
- In hot and high dense matter(QGP), partons lose energy by radiating gluons : **Jet Quenching**

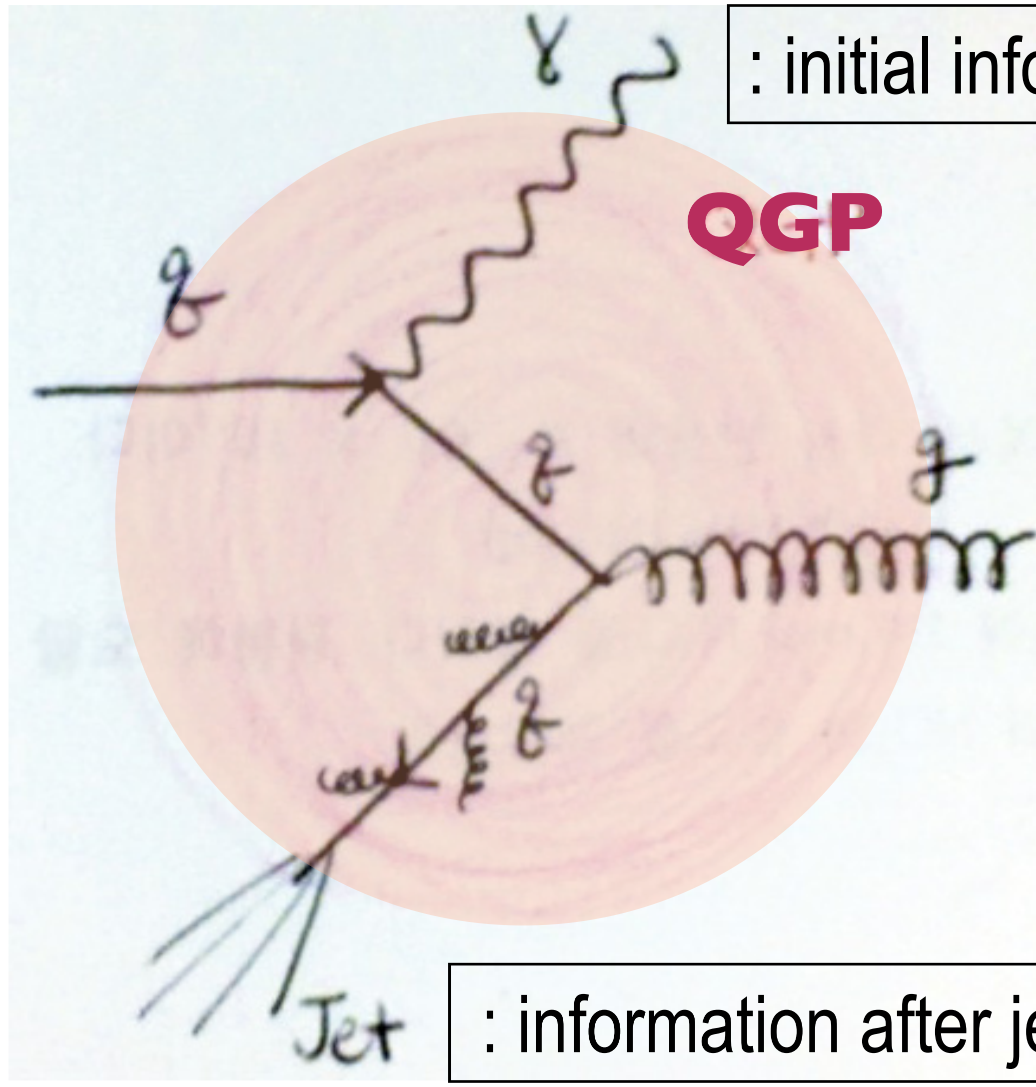
Dijet





- Energy loss by passing through medium(QGP) : qeunching
- Different path lengths ⟶ Di-jet E asymmetry

Photon-Jet



: initial information before jet quenching

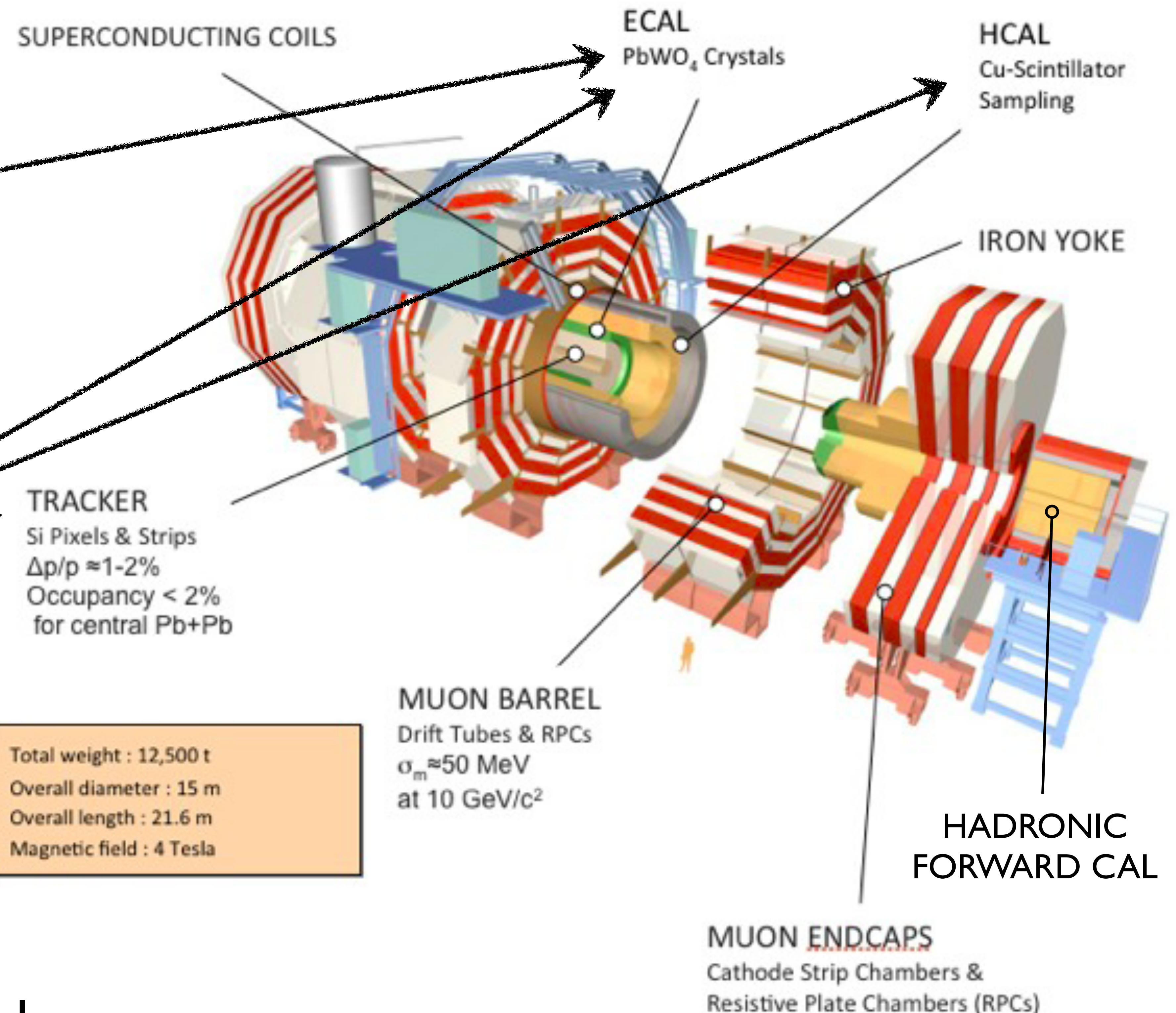
: information after jet quenching

- Photon does not have any color charge.
  : without strong interaction
  : it can be a reference for the initial momentum of jet

CMS detector

photon reconstructed here!

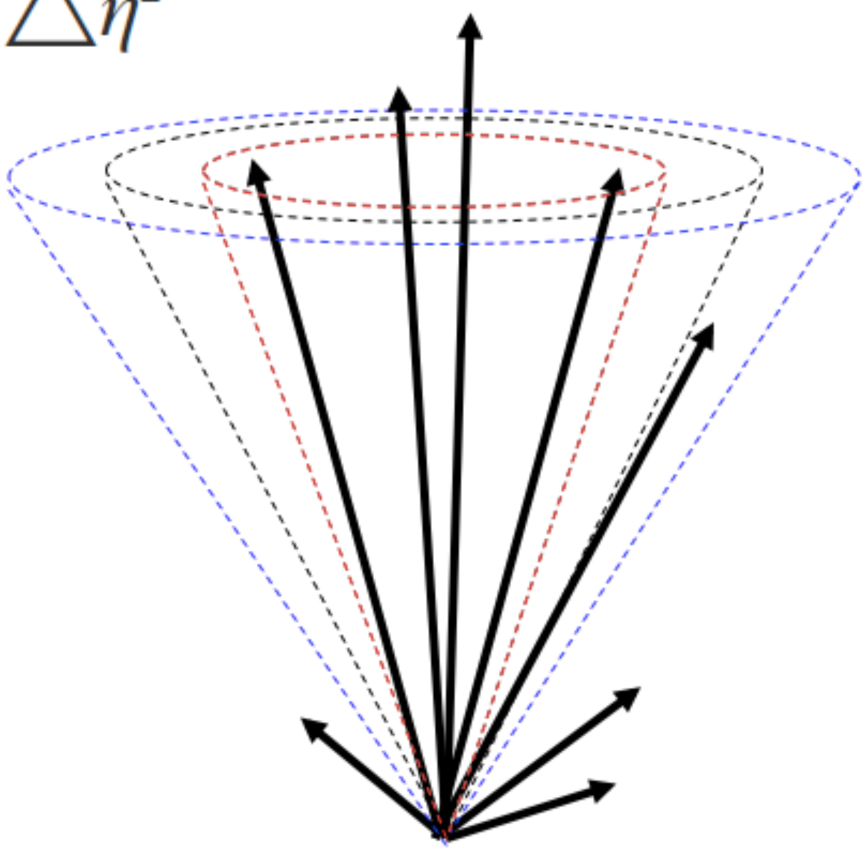
jet reconstructed here!



Compact Muon Solenoid

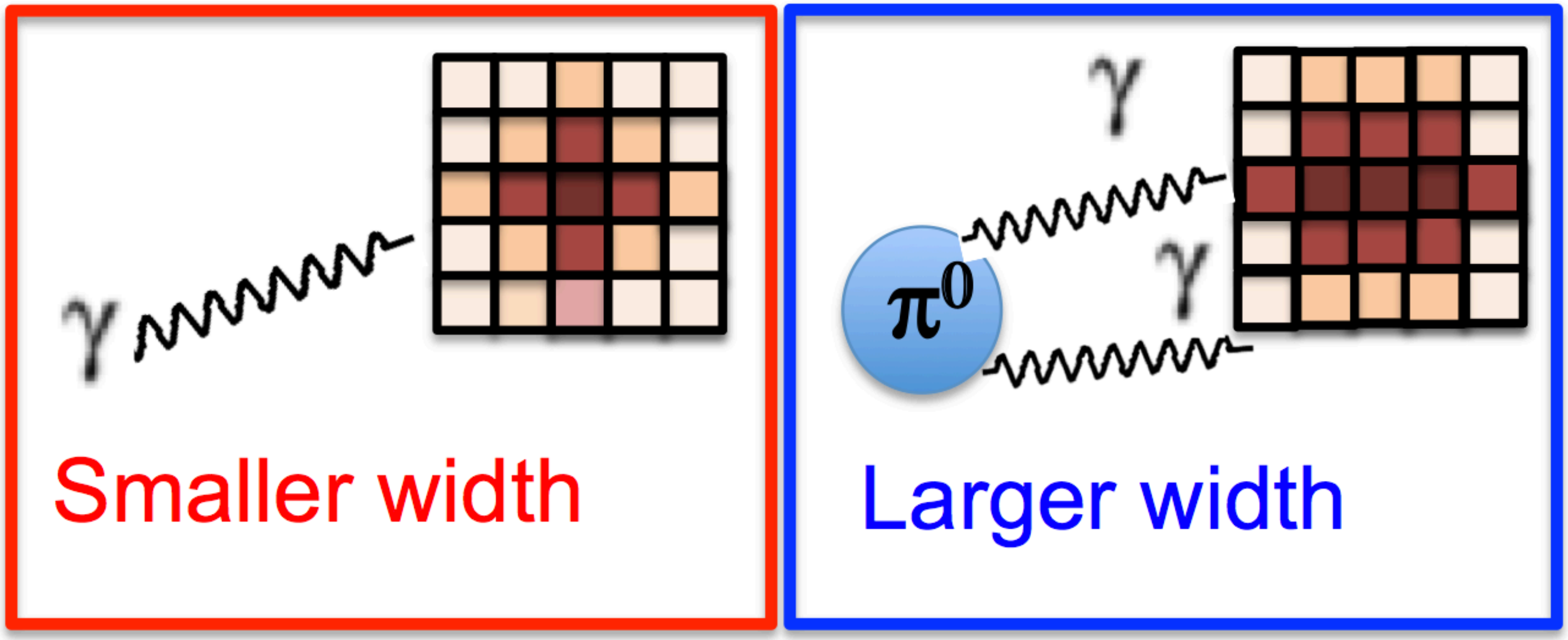
Jet Reconstruction

- Anti-k_T sequential recombination algorithm
- Underlying-Event Subtraction
- Cone size $\Delta R < 0.3$ $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$
- $|\eta| < 1.6$



Anti-k_T jets with
R = 0.2, 0.3, 0.4

Isolated Photon Identification



- H/E < 0.1
- Photon isolation variable : $\text{SumIso}^{\text{UE-sub}} < 1$ GeV
- Purity calculation : shower shape method
- $|\eta| < 1.44$ (barrel region of the Ecal)

Recent results of γ-jet exp.

Monte Carlo Simulation

- Use of MC
  : reference of the data
  : systematic uncertainty calculation
  (such as efficiency, resolution ...)

==== WHAT we measured & used DATA SETs ==================

- PbPb and pp were measured at the same CM energy
- pPb were also measured to understand the cold nuclear matter effect
  and MC was used as the reference

PYTHIA + HYDJET : Pb+Pb MC
PYTHIA + HIJING : p+Pb MC
Smeared pp reference : by the relative jet energy resolution in order to account the underlying event fluctuation when compared to PbPb data.

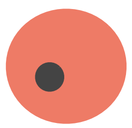
Angular Correlation : $\Delta\phi_{J\gamma}$

p_T^{γ} →

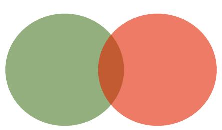
40 GeV<P_T^{γ}<50 GeV | 50 GeV<P_T^{γ}<60 GeV | 60 GeV<P_T^{γ}<80 GeV | P_T^{γ}>80 GeV

$$\Delta\phi_{J\gamma} = |\phi^{\mathrm{Jet}} - \phi^{\gamma}|$$

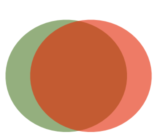
p+Pb

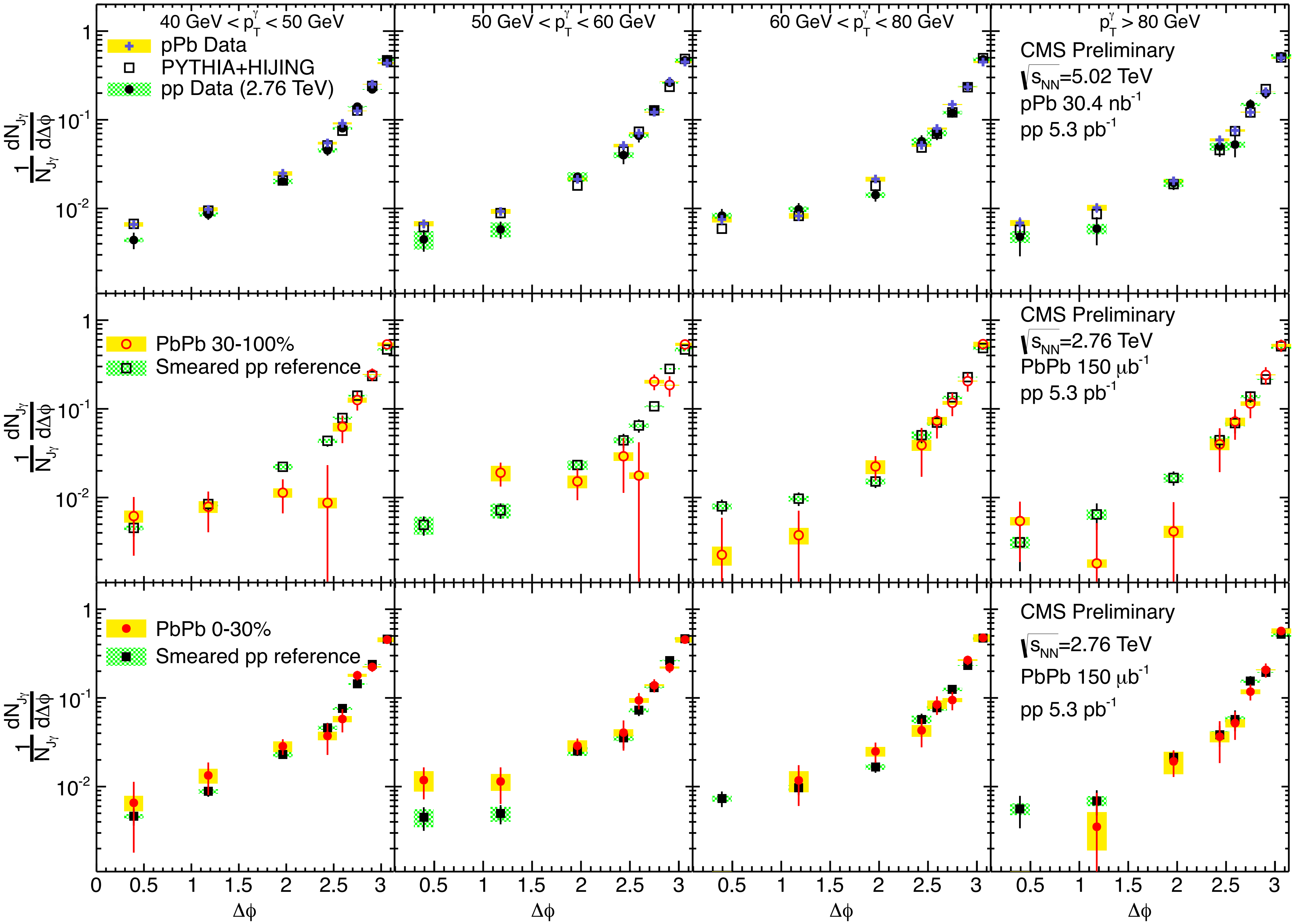


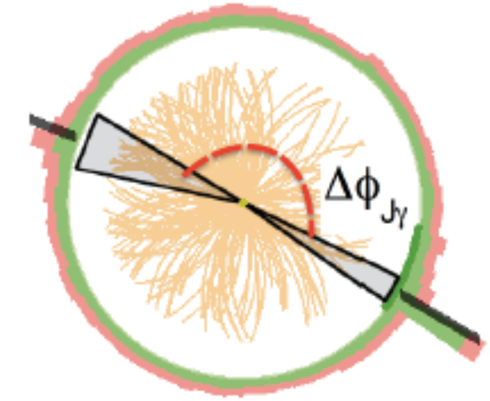
Pb+Pb



centrality ↓







CMS PAS HIN-13-006

- PbPb, pPb, pp are consistent with each other
- clear peak at $\Delta\phi_{J\gamma} = \pi$ (back-to-back)

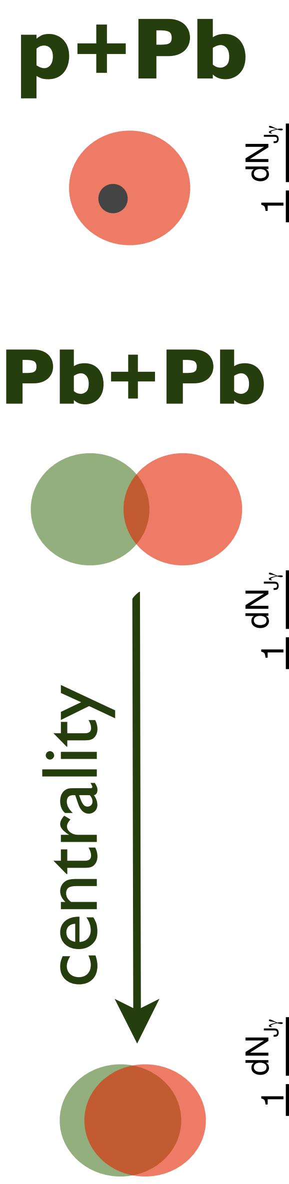
Momentum fraction : $x_{J\gamma}$

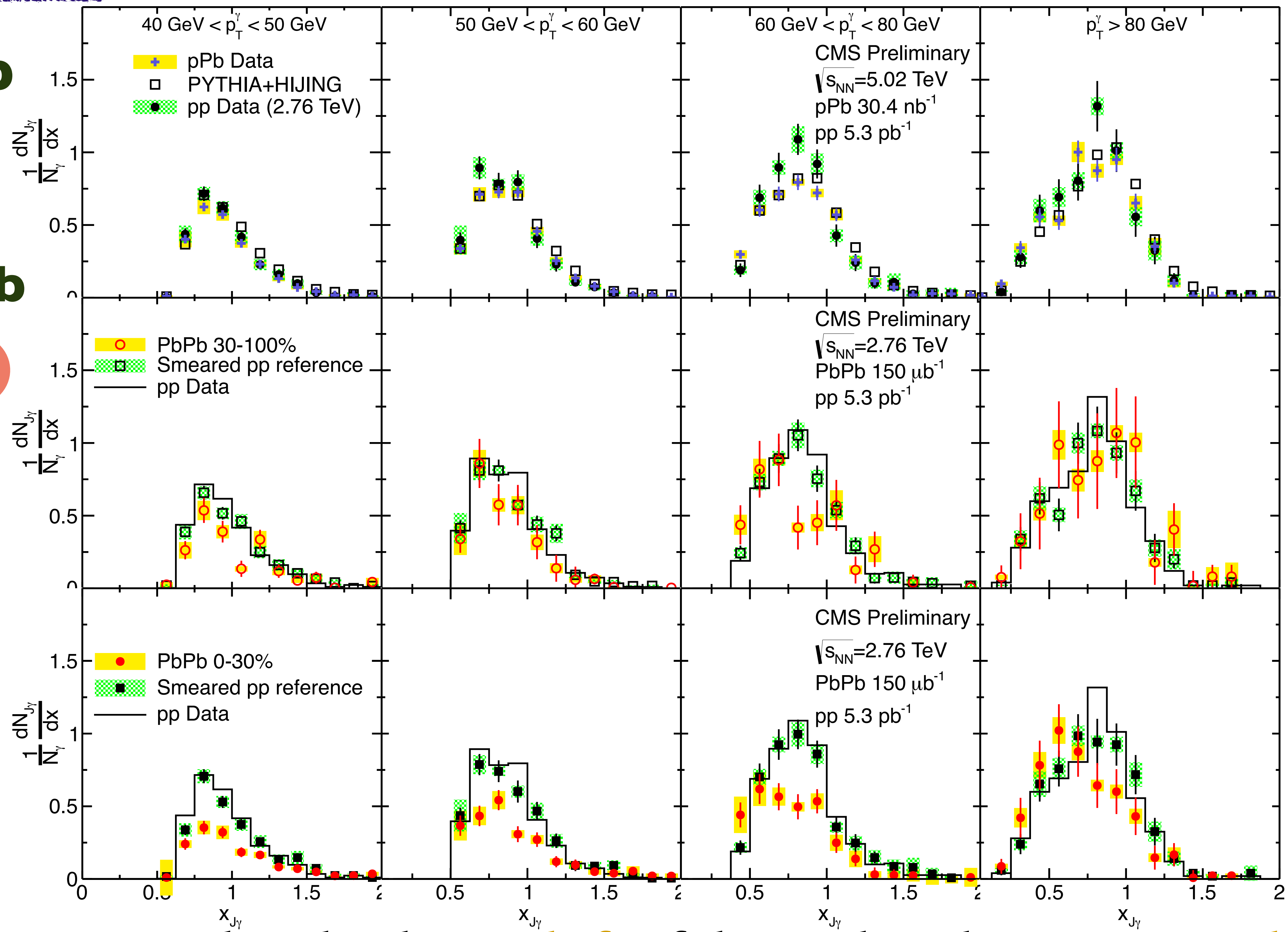
$$x_{J\gamma} = p_T^{Jet} / p_T^{\gamma}$$

p_T^{γ} →

CMS PAS HIN-13-006

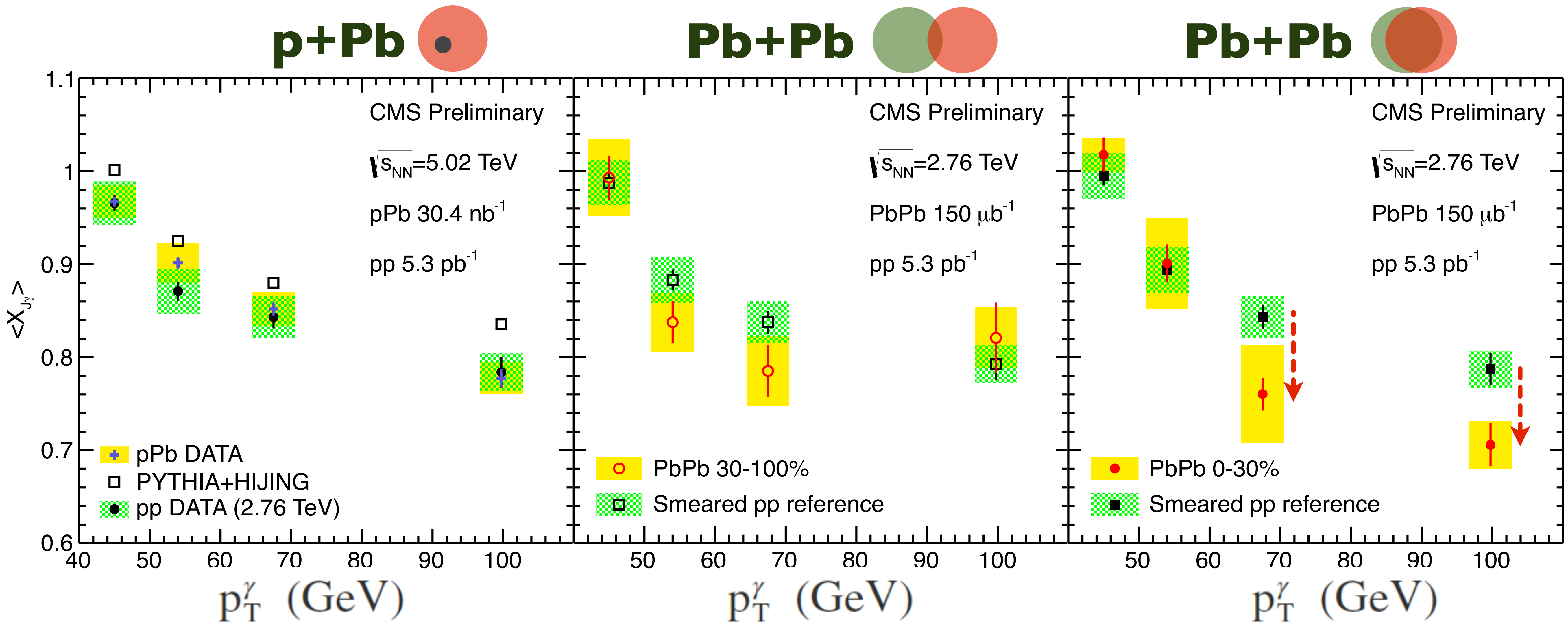
40 GeV<P_T^{γ}<50 GeV | 50 GeV<P_T^{γ}<60 GeV | 60 GeV<P_T^{γ}<80 GeV | P_T^{γ}>80 GeV





- Parton energy loss lead to a shift of the $x_{J\gamma}$ distribution towards left.

Mean $X_{J\gamma}$



CMS PAS HIN-13-006

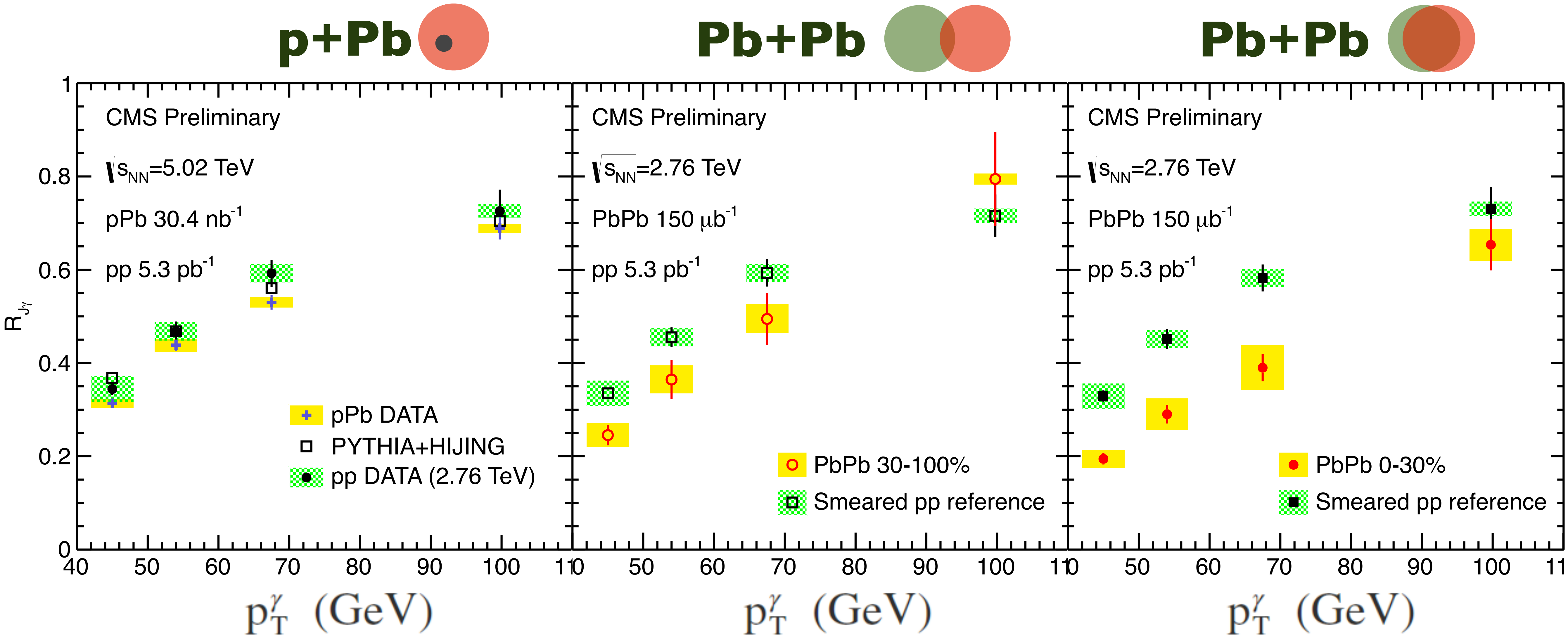
- No strong deviation b/w p+p and p+Pb
- Significant modification with respect to the smeared pp reference is observed in 0–30% PbPb collisions

$R_{J\gamma}$: (# of γ-jet)/(# of γ)

$$R_{J\gamma} = \frac{\text{Number of associated jets}}{\text{Number of triggering } \gamma\text{'s}}$$

: the probability to find jet when leading photon is triggered.

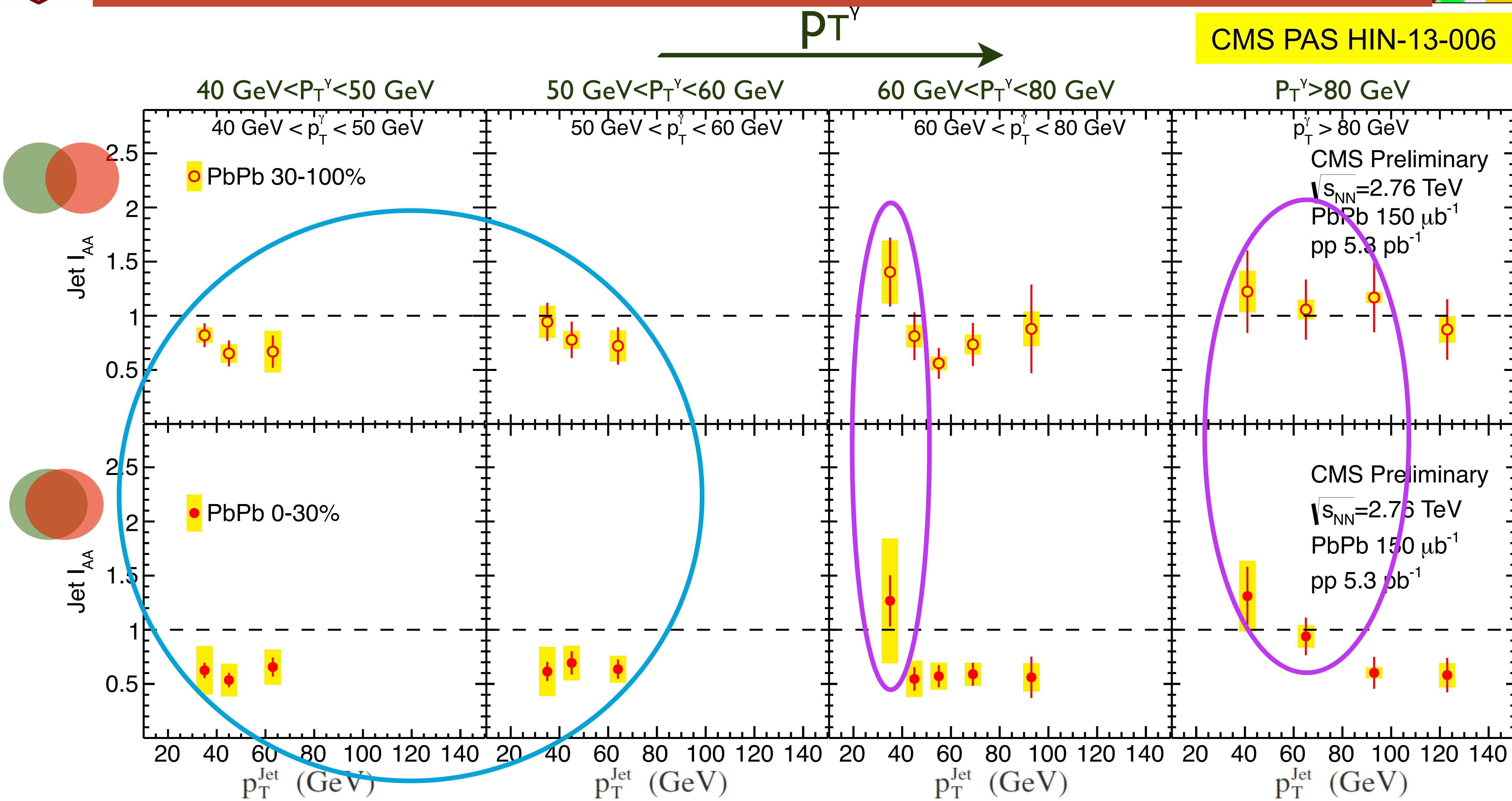
- **Parton energy loss** can cause jet to **disappear.**



CMS PAS HIN-13-006

Jet I_{AA}

CMS PAS HIN-13-006



Jet I_{AA} = Ratio of jet yield in PbPb to smeared pp.

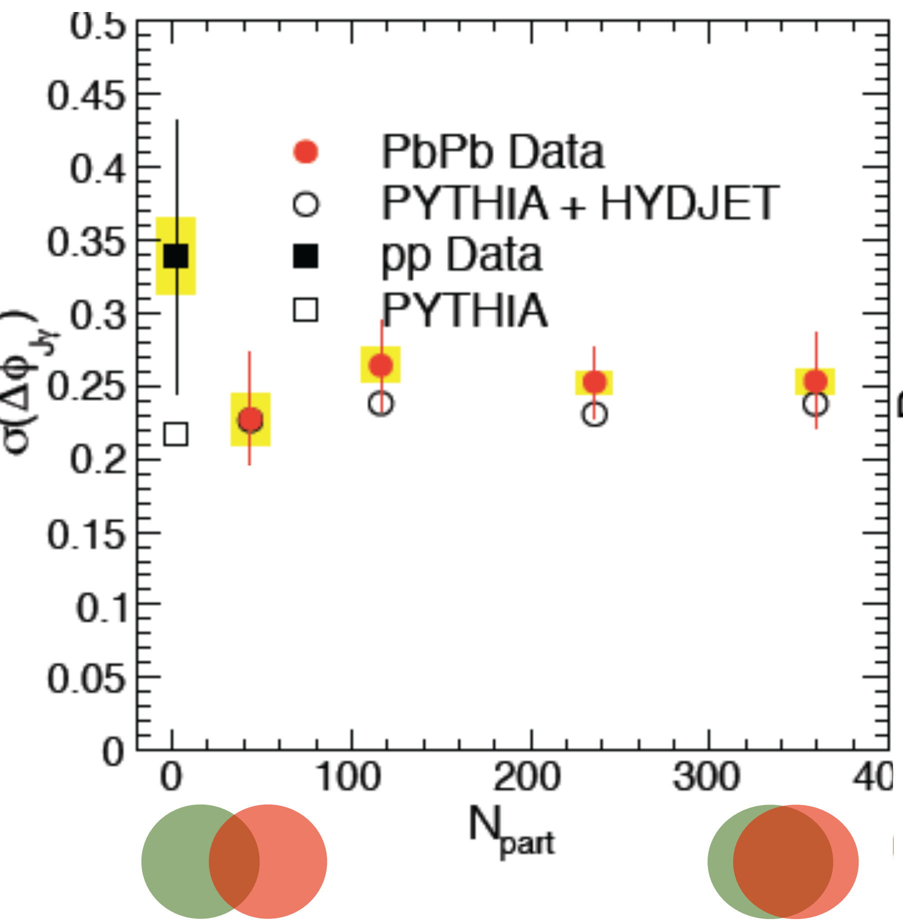
In the low p_T^γ, the yields in PbPb are smaller than in pp for all $p_{T,jet}$ bins.

As p_T^γ increases, yields at low $p_{T,jet}$ are greater in PbPb than pp.

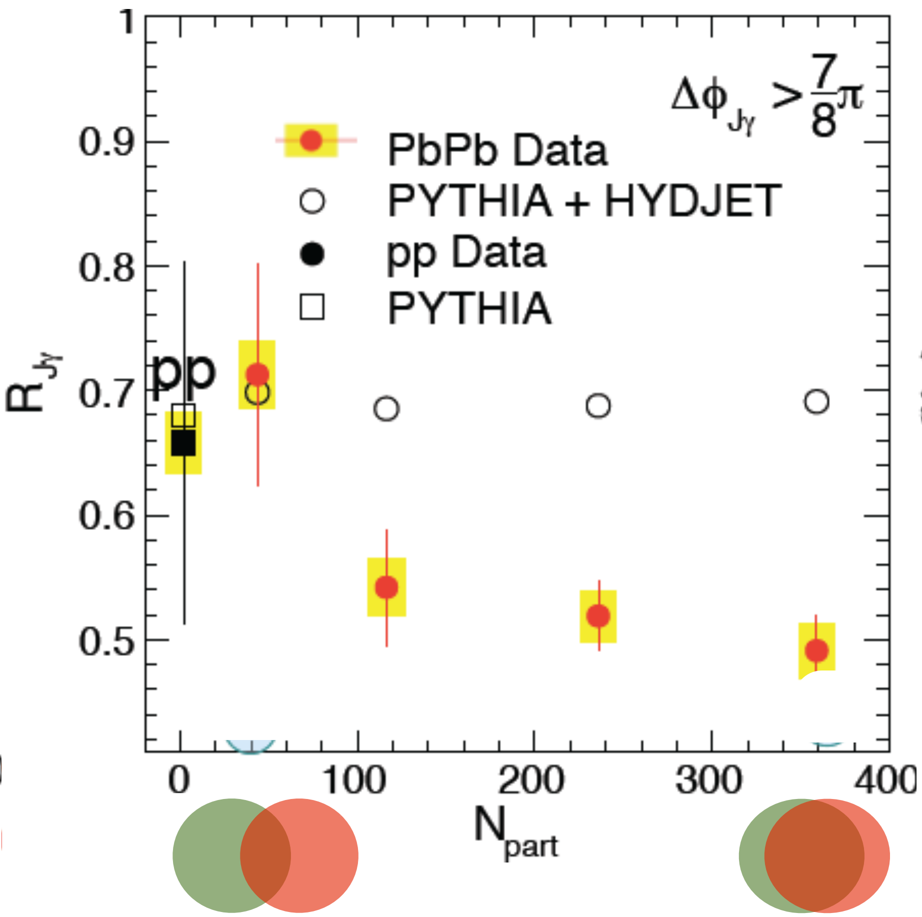
Centrality dependence of γ-jet correlation

old results

PLB 718 (2013) 773

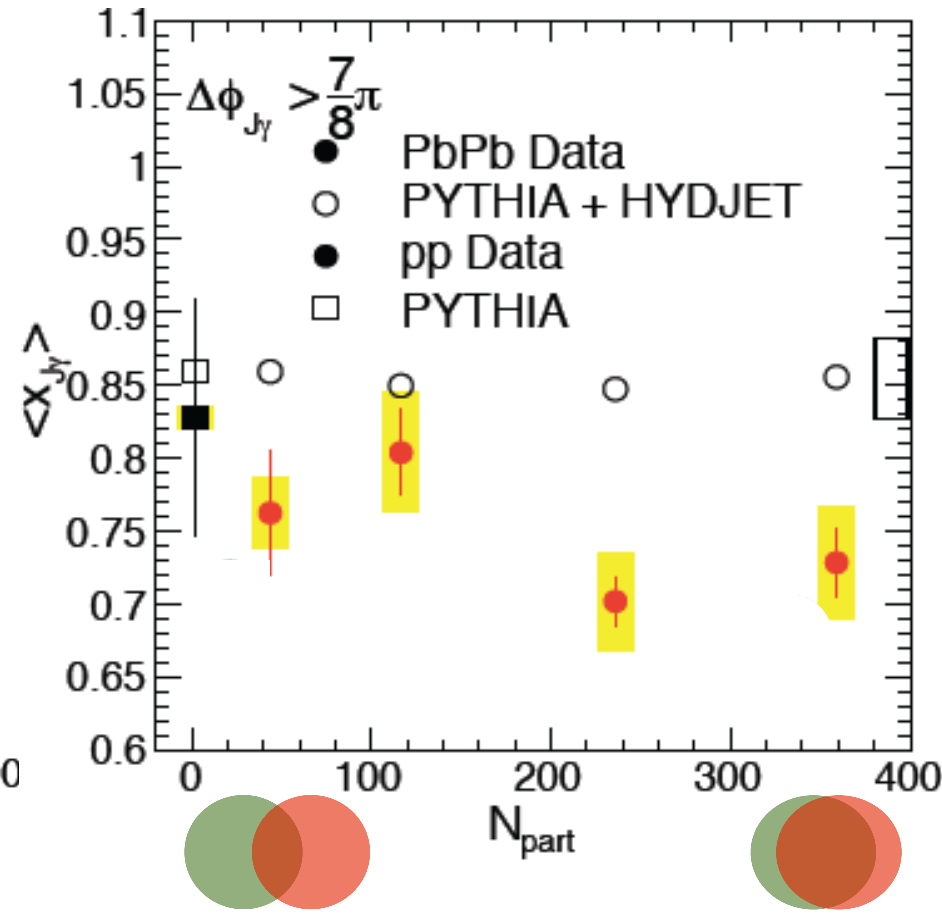


Δphi and sigma(Δphi) are almost the same with pp and PbPb



$R_{J\gamma}$ in PbPb are more smaller value than in pp

→ Jet Quenching



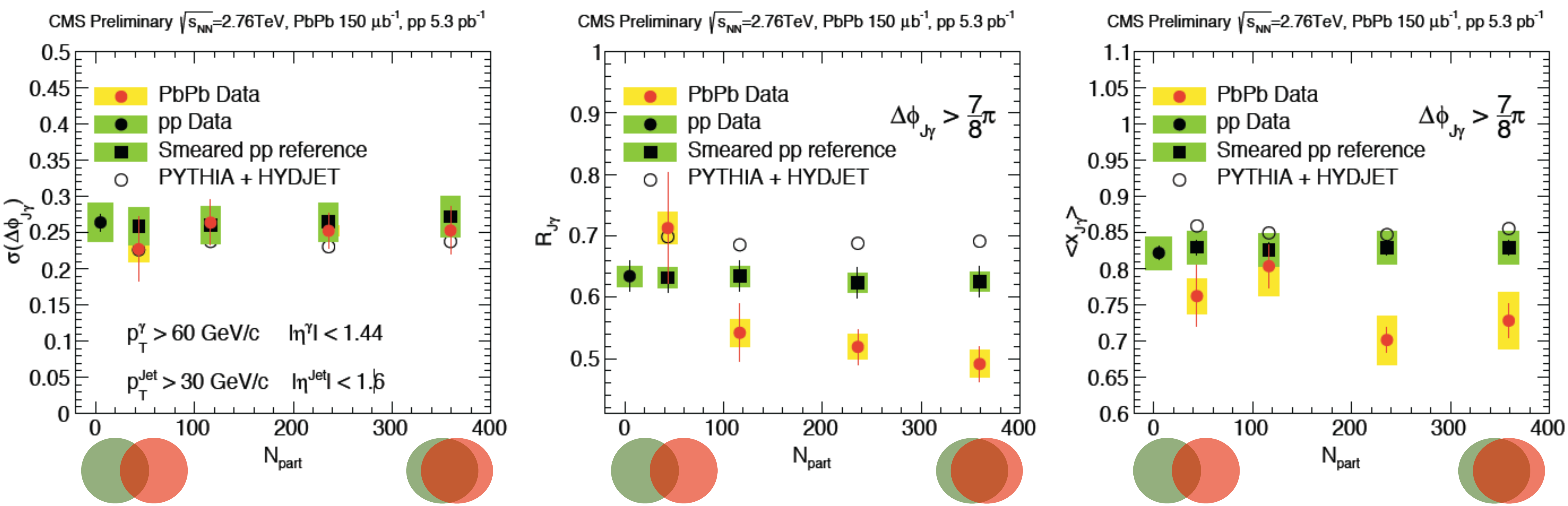
$\langle x_{J\gamma} \rangle$ of PbPb are more smaller value than in pp

→ Jet Quenching

Centrality dependence of γ-jet correlation

recently updated results : high luminosity pp data

CMS PAS HIN-13-006



Δphi and sigma(Δphi) are almost the same with pp and PbPb

$R_{J\gamma}$ in PbPb are more smaller value than in pp
→ Jet Quenching

$\langle x_{J\gamma} \rangle$ of PbPb are more smaller value than in pp
→ Jet Quenching

Summary

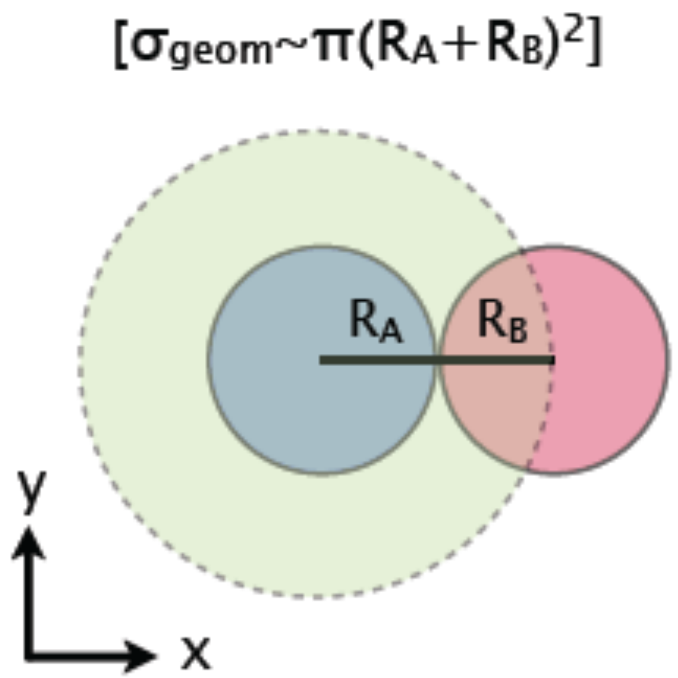
✓ We measured $\Delta\phi_{J\gamma}$, $x_{J\gamma}$, $R_{J\gamma}$, and Jet I_{AA} in p+p, p+Pb, and Pb+Pb collisions for the γ-jet events.

✓ In the central Pb+Pb collisions, there are significant modifications as compared to the p+p
  - Jet Quenching

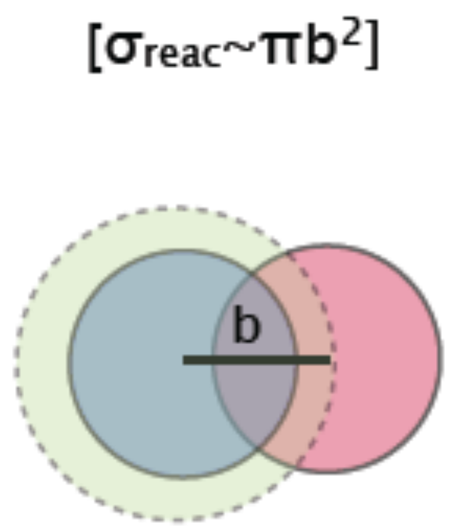
✓ The p+Pb data are consistent with p+p and MC.
  - It confirms that the γ-jet momentum imbalance did **not** originate from **initial-state effects** in cold nuclear matter.

BACK UP

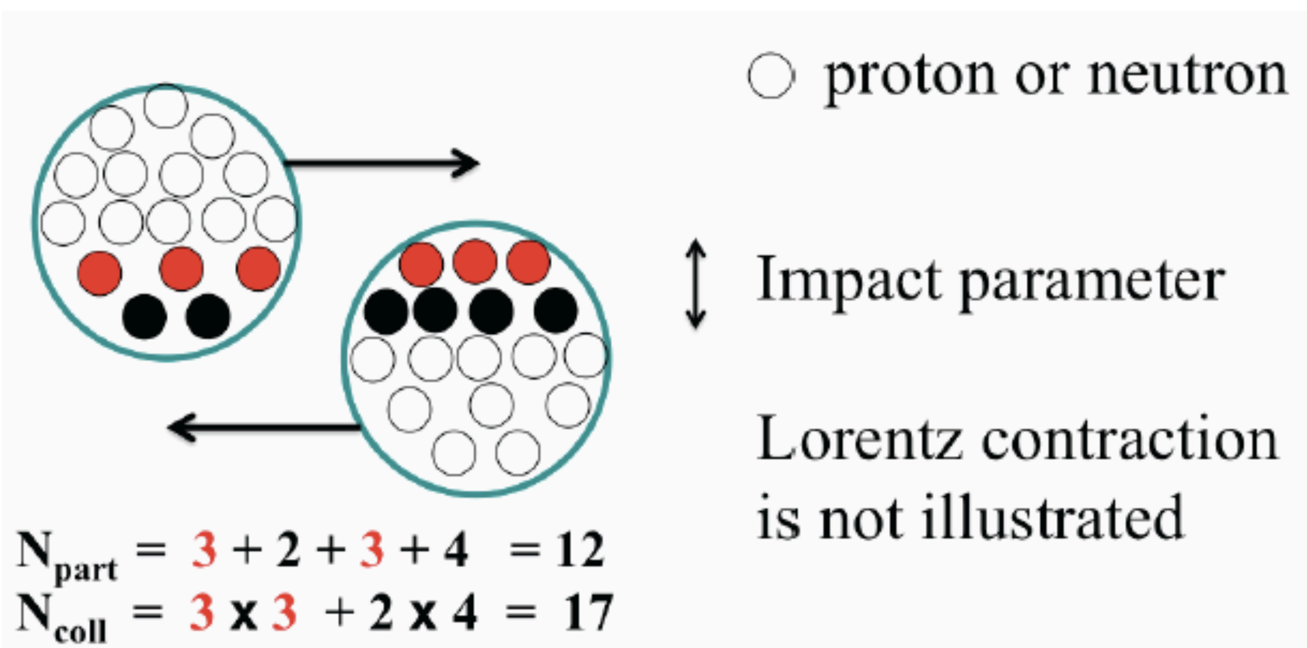
Centrality



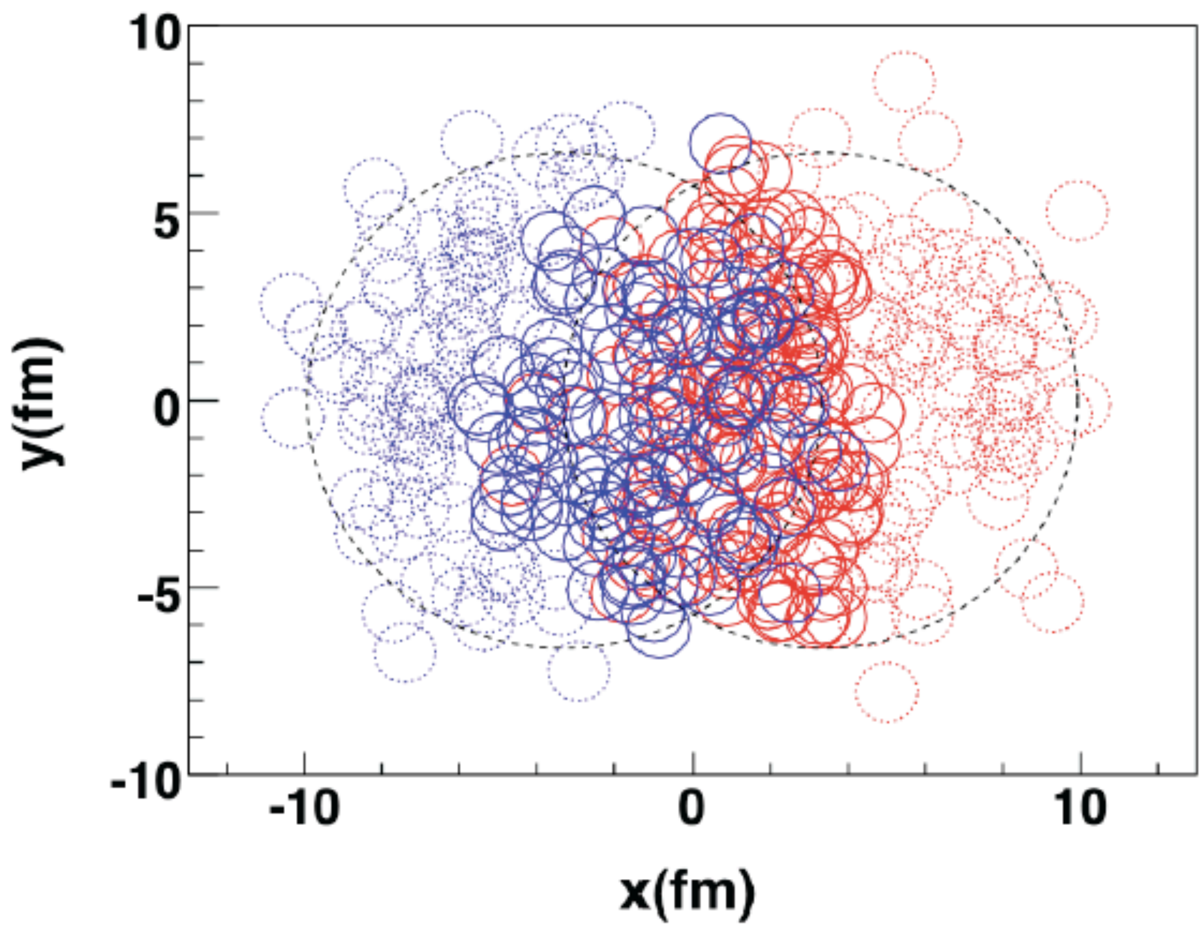
[σgeom~π(RA+RB)2]
RA
RB
y
x



[σreac~πb2]
b



proton or neutron
Impact parameter
Lorentz contraction
is not illustrated
Npart = 3 + 2 + 3 + 4 = 12
Ncoll = 3 x 3 + 2 x 4 = 17

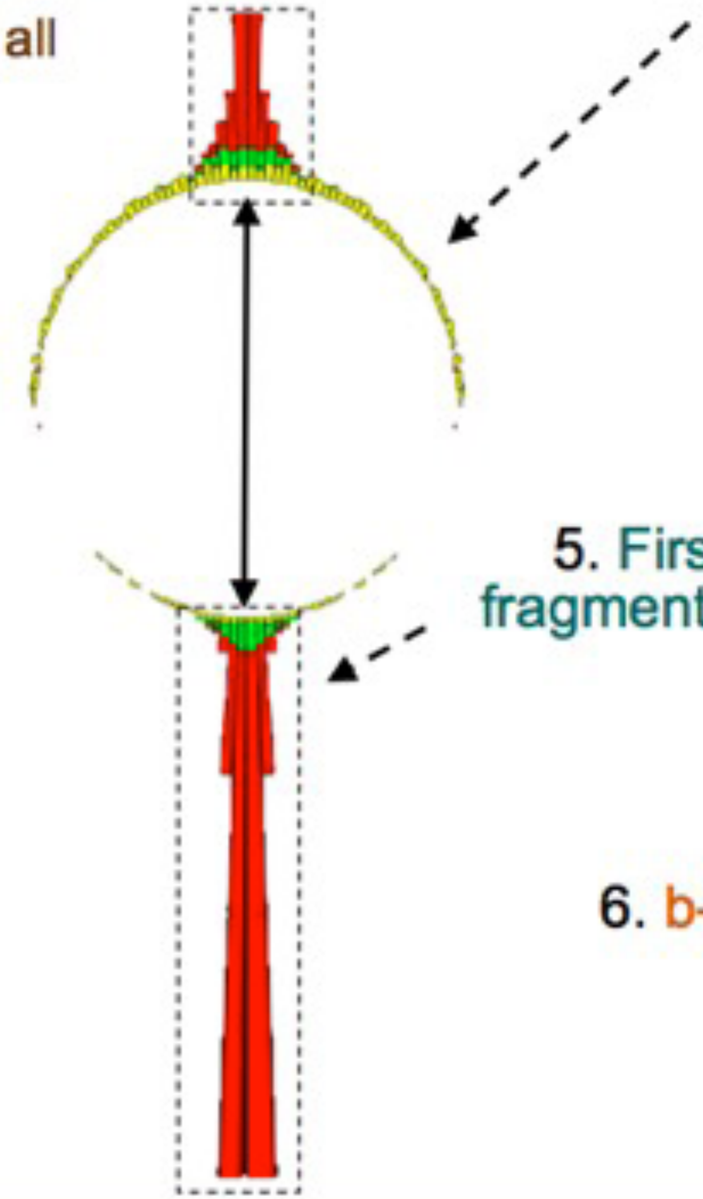


10
5
0
-5
-10
y(fm)
-10
0
10
x(fm)

Anatomy of jet in PbPb

1. High p_T jet suppression
→ΔR = 0.2 - 0.5 doesn't capture all the radiated energy

4. p_T difference found at low p_T particles far away from the jets



2. Large average dijet and photon-jet p_T imbalance

5. First observation of modified fragmentation function and jet shape

6. b-jets are also quenched

3. Angular correlation of jets not largely modified

challenges to theory community!

Anti-k_{T} algorithm

1. Find particles having high p_{T}ãbove a certain threshold and set them as seeds of clusters.

2. Starting from the seed of highest p_{T}; calculate the distance measures and find the smaller one between

$$d_{ij} = \min(k_{it}^{-2}, k_{jt}^{-2}) \frac{\Delta R_{ij}^2}{R^2} \tag{2.1}$$

   and

$$d_{iB} = k_{it}^{-2} \tag{2.2}$$

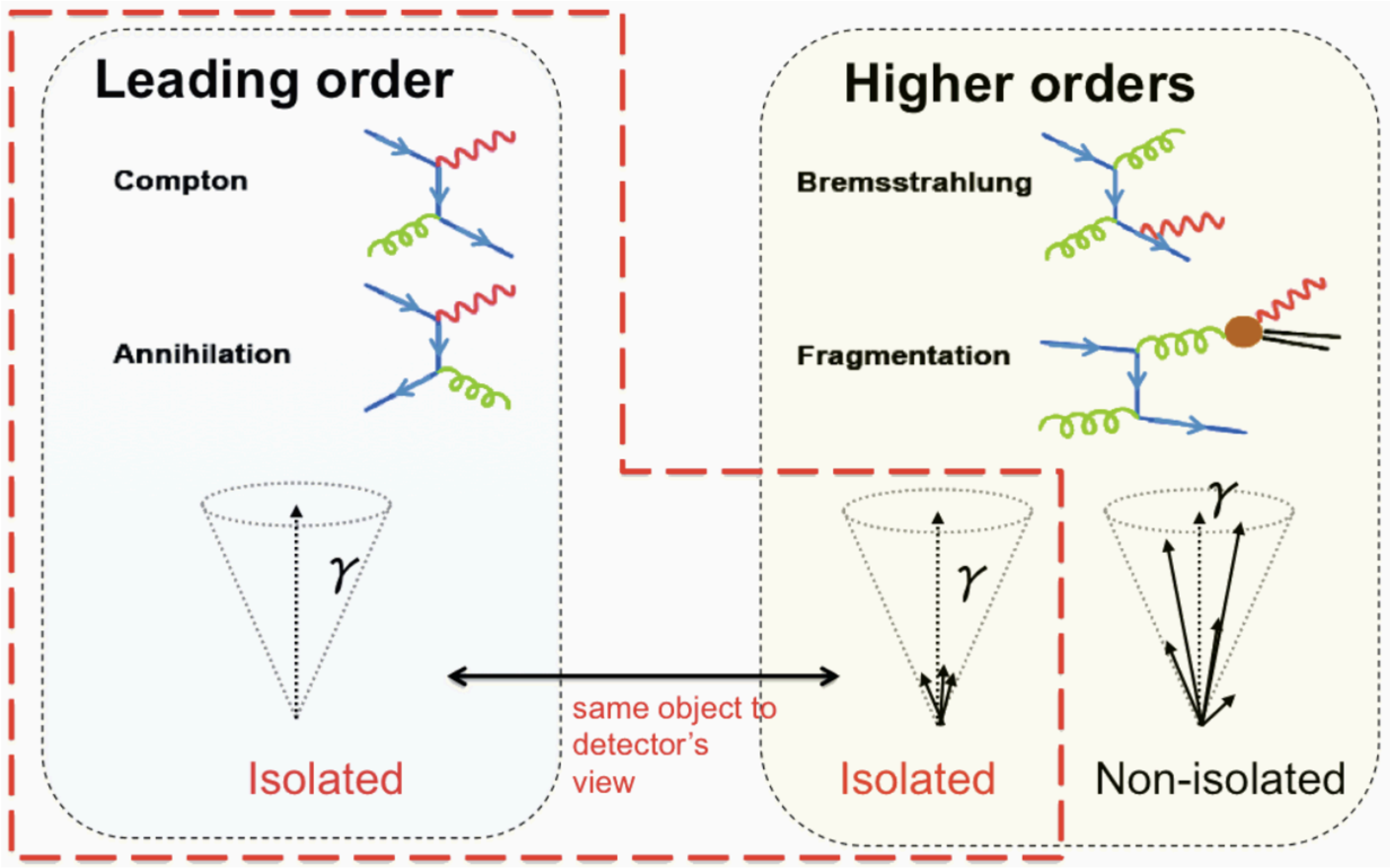
   where, k_{it} and k_{jt} are the transverse momentum of the seed and searching particles respectively and ΔR is the distance defined as

$$\Delta R_{ij} = \sqrt{(y_i - y_j)^2 + (\phi_i - \phi_j)^2} \tag{2.3}$$

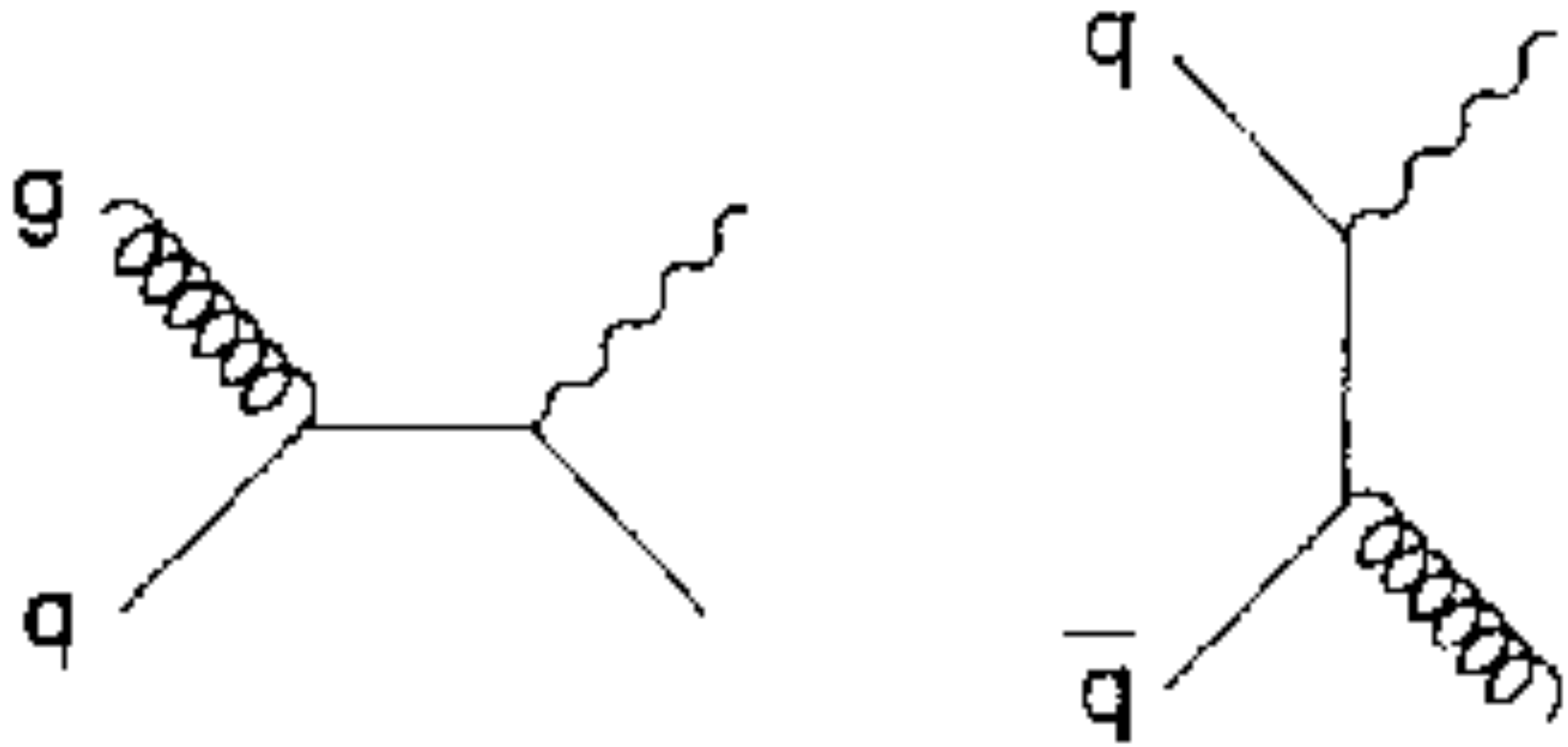
3. If d_{ij} is smaller than d_{iB} the searching particle is merged into the seed jet. In the other case, it is dropped from the jet entities.

4. Step 2 and 3 are repeated until there is no seed remaining.

Isolated Photon & LO



Jet Quenching



Feynman diagram

- In pp collisions, jet pair energy are almost balanced.
- In hot and high dense matter(QGP), partons lose energy by radiating gluons : Jet Quenching

Jet Production

Jets detected in calorimeter

↑

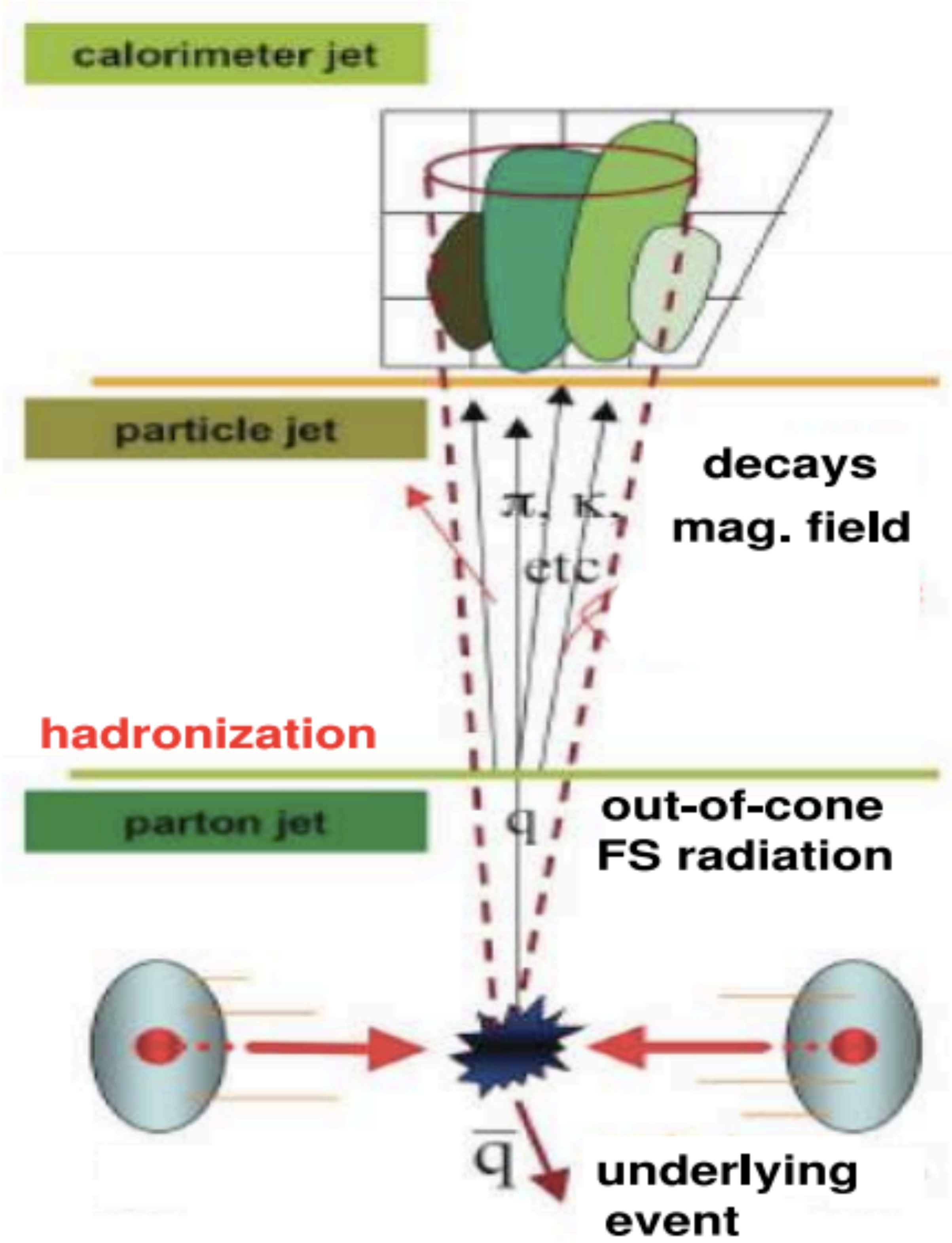
Hadronization
(makes mesons and baryons)

↑

Collective high pT partons
(quarks or gluons)

↑

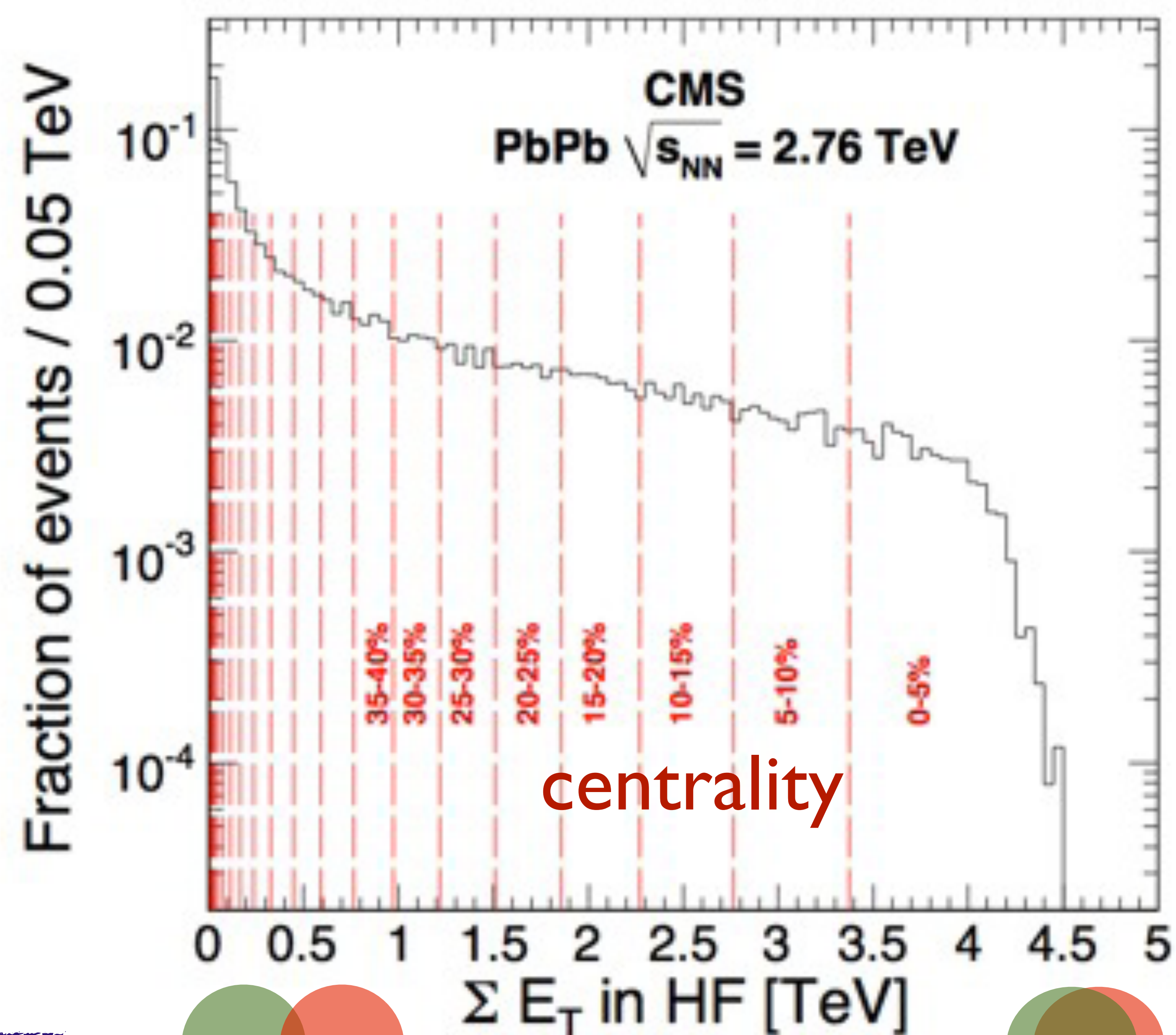
QCD hard scattering
(large momentum transfer)

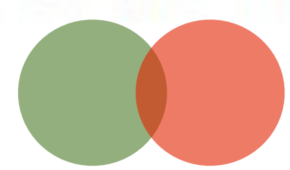


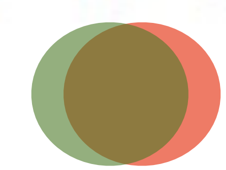
Centrality

- **Centrality** : whether the overlap of the two colliding nuclei is large or small.
- **N_{part}** : the number of nucleons which experienced at least one inelastic collision (with N_{part} = 2 for pp)
- Peripheral case is found to approach that for the pp events.

$$centrality(\%) = \frac{\sigma_{reac}}{\sigma_{geom}} \times 100$$







small ⟵ N_{part} ⟶ large

peripheral ⟷ central

Event Selection

CMS case

L1(Level1) trigger → HLT (High Level Trigger) → Offline event selection

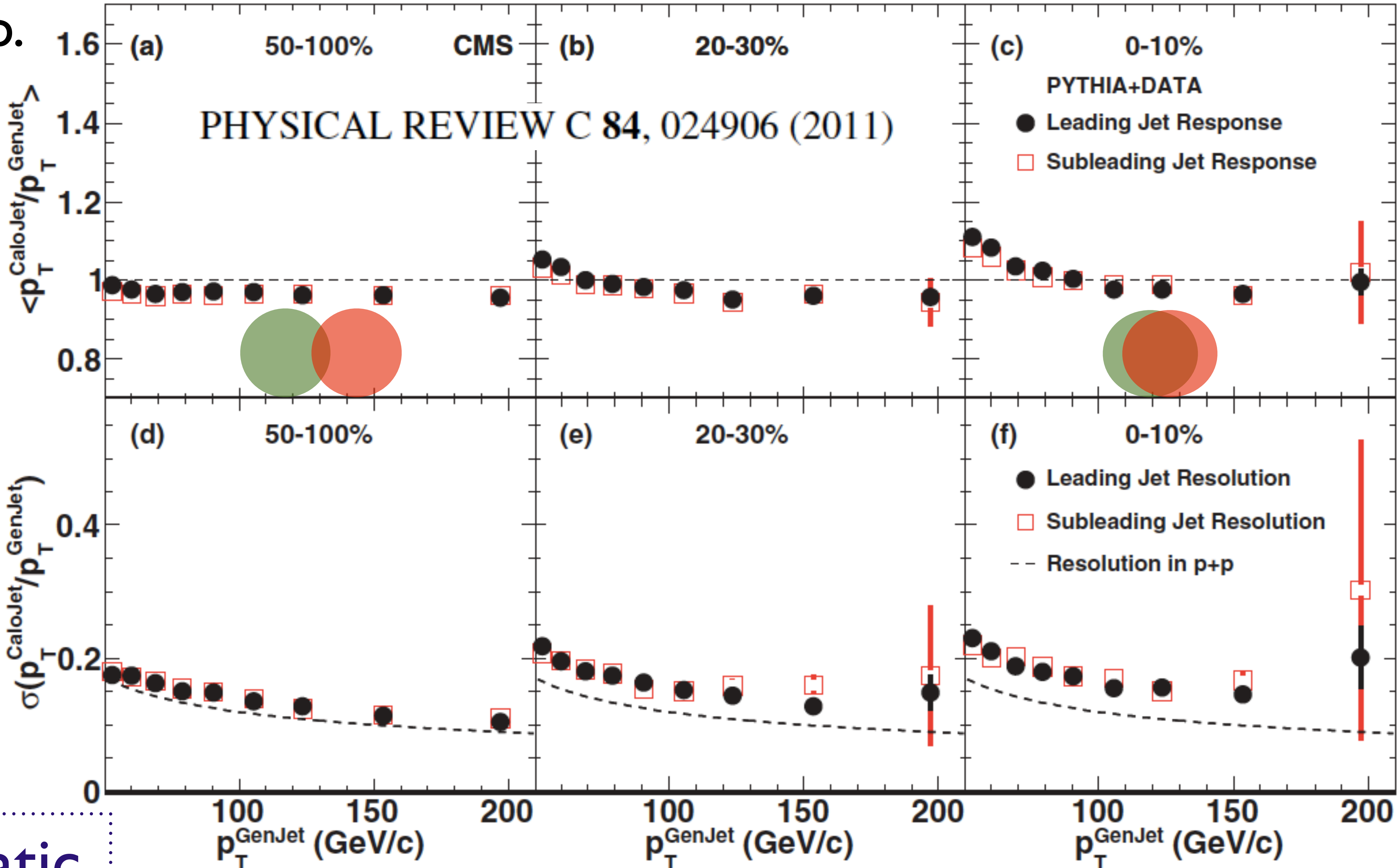
- Single-photon-candidate were triggered in L1
- HLT use a clustering algorithm from calorimeter towers
- Further offline selections were applied to the triggered event sample. (such as removing 'ultra peripheral collision events' and non-collision beam backgrounds and so on..)

Energy Scale & Resolution

Di-jet exp.

Jet Energy Scale

Jet Energy Resolution



Systematic uncertainty!

These are determined using PYTHIA + HYDJET