High p_T with ATLAS and CMS in Heavy-Ion Collisions @ 2.76TeV

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HCP 2011, Paris

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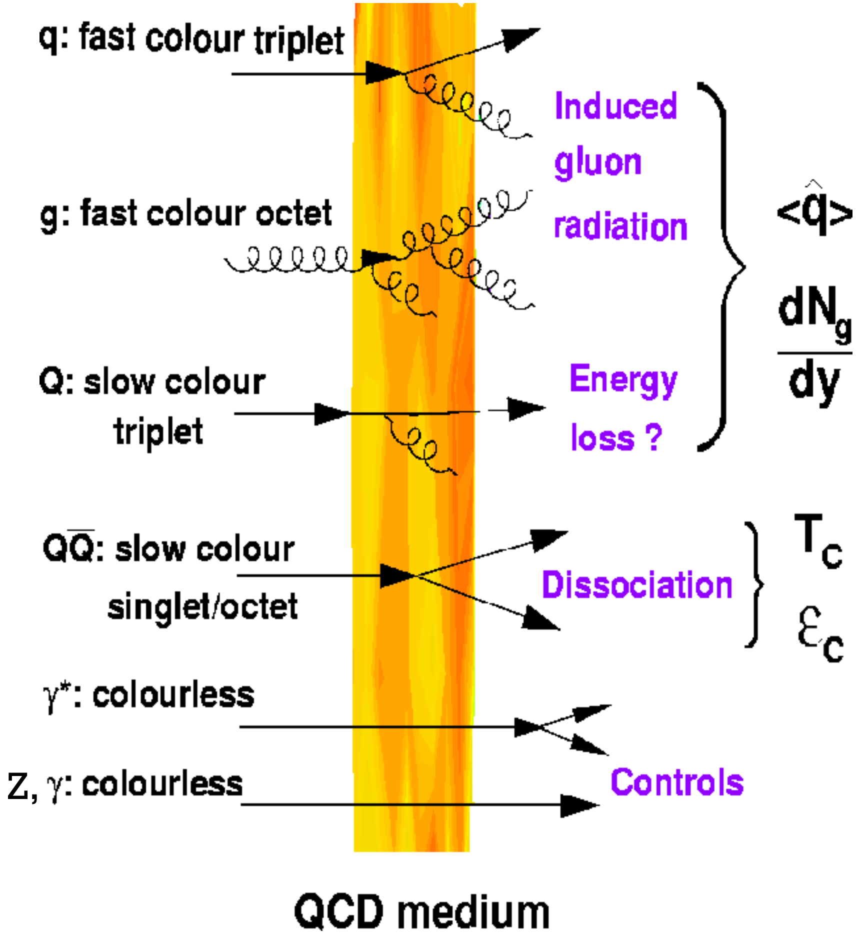
+ Outlook

- Introduction : hard probes
- Strongly interacting pQCD probes of QGP
  - Jet measurement and fragmentation function
  - High p_T charged hadrons
  - Quarkonia
- Weakly interacting pQCD probes of QGP
  - W and Z bosons
  - Isolated photons
- Conclusion

+ Introduction

- Hard probes of QCD matter: high momentum/virtuality >> Tc (jets, γ, $Q\bar{Q}$ ...)
  - well controlled experimentally and theoretically (pQCD)
- Produced very early in collision at τ< ~ 0.1 fm/c
- Tomographic probes of the medium
- Medium effects are quantified by calculating the
  - Nuclear modification factor



$$R_{AA} = \frac{1/N_{evnts} d^2N_{PbPb}/dydp_T}{<T_{AB}> d^2\sigma_{pp}/dydp_T}$$

Hot&dense QCD Medium / QCD Vaccum like

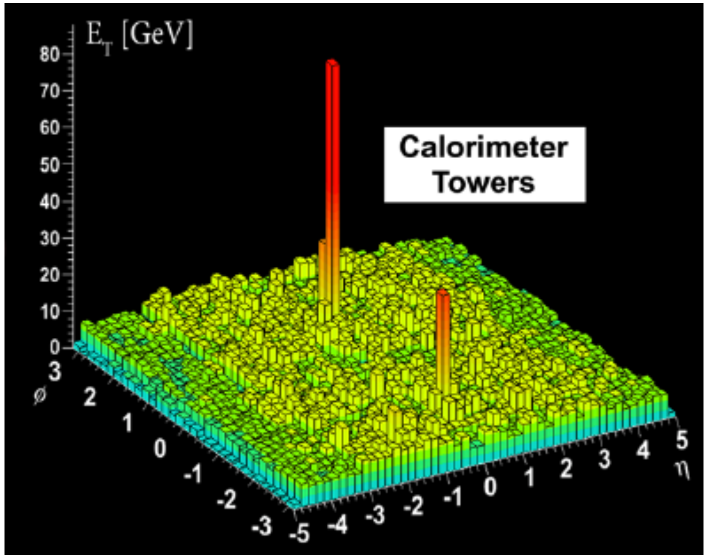
- $R_{cp} = \frac{\text{Production yield at central collisions}}{\text{Production yield at peripheral collisions}}$ → ≃ pp like

Strongly interacting pQCD probes of QGP

- Jet measurement. Fragmentation function
- High p_T charged hadrons
- Quarkonia

+ Dijet imbalance

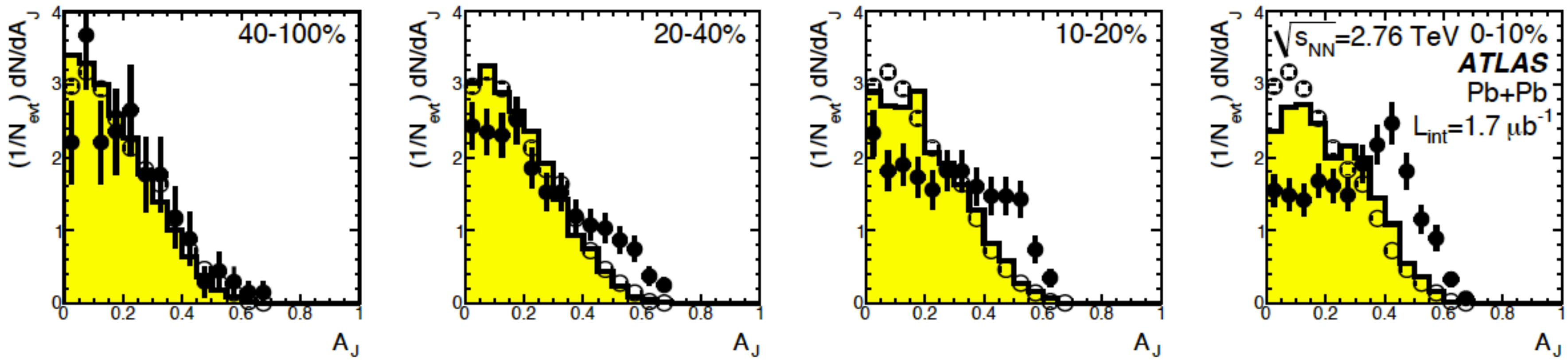
- Dijet selection
  - Leading jet p_T > 100 GeV/c
  - Subleading jet p_T > 25 GeV/c



- Quantify dijet imbalance by asymmetry ratio

$$A_j = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

ATLAS, Phys. Rev. Lett **105** (2010) 252303



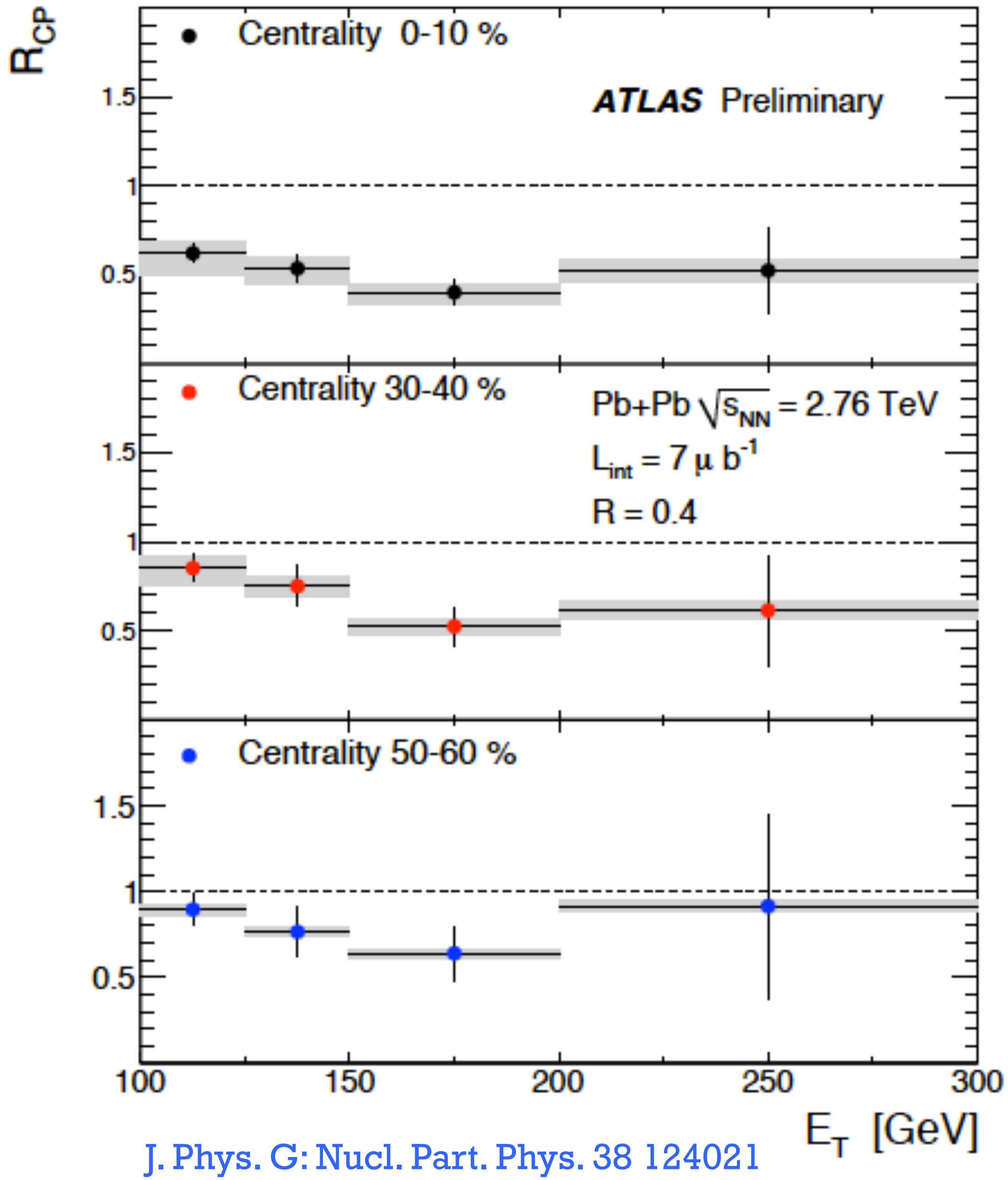
- Larger imbalance in central collisions, but not in peripheral collisions, with respect to pp reference
- Parton energy loss is observed as pronounced energy imbalance in reconstructed dijets

Single jet yield ratios: central vs. peripheral

- $$R_{cp} = \frac{\frac{1}{N_{coll}^{cent}} \frac{1}{N_{evt}^{cent}} \frac{dN_{jet}^{cent}}{dE_T}}{\frac{1}{N_{coll}^{60-80}} \frac{1}{N_{evt}^{60-80}} \frac{dN_{jet}^{60-80}}{dE_T}}$$

A factor 2 suppression is observed in central (0-10%) collisions relative to peripheral (60-80%)

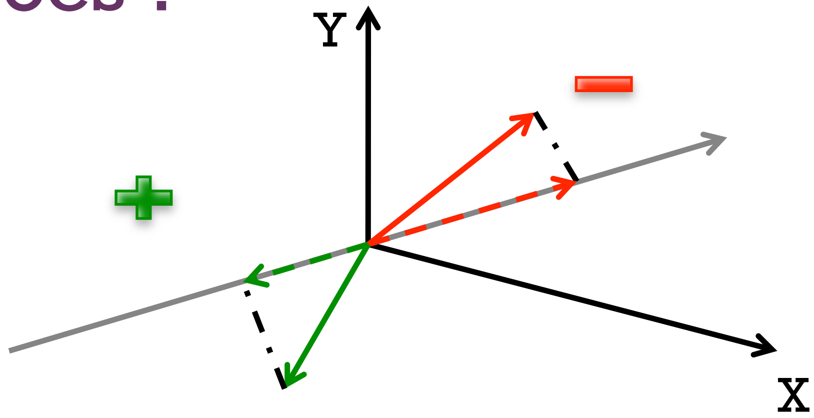
The suppression is independent of jet E_T within uncertainties



J. Phys. G: Nucl. Part. Phys. 38 124021

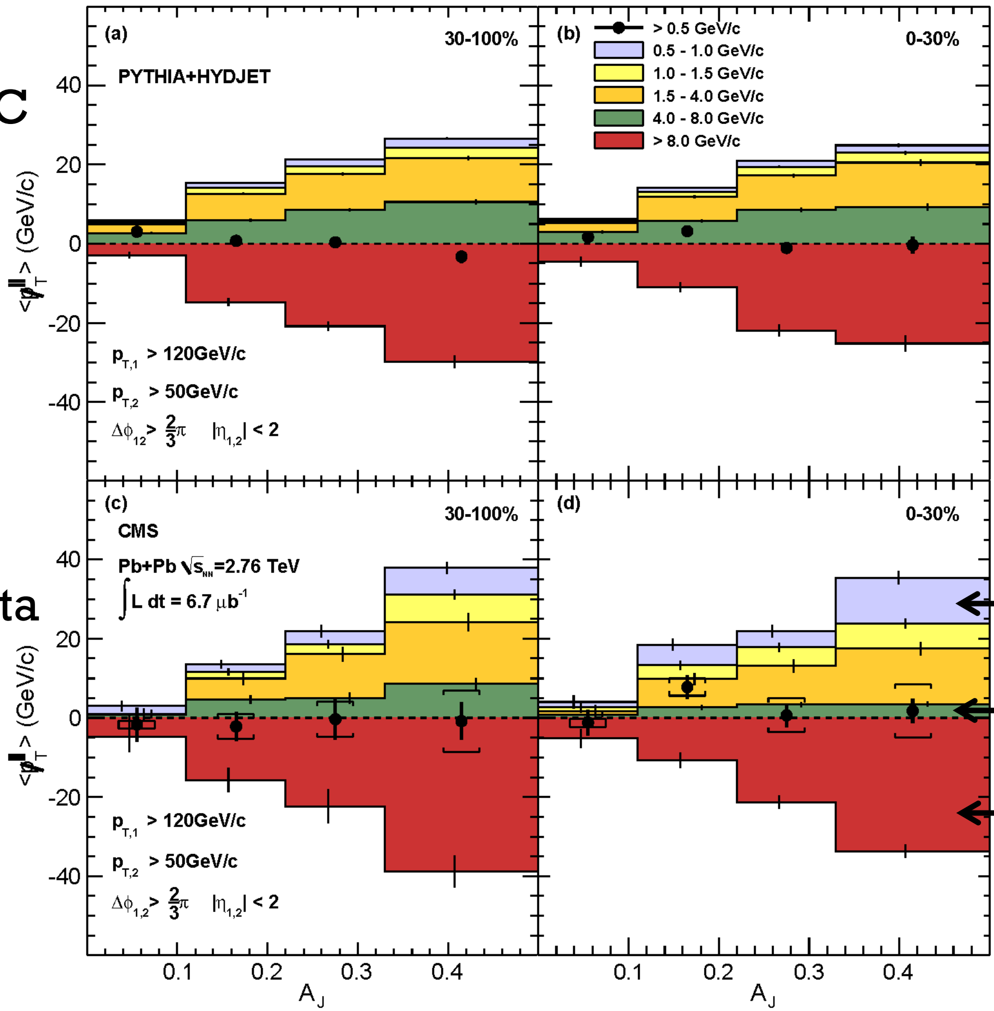
Where does the missing p_T goes ?

$$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$



MC

Data



0.5 – 1.0 GeV/c
1.0 – 2.0 GeV/c
2.0 – 4.0 GeV/c
4.0 – 8.0 GeV/c
> 8.0 GeV/c

Low p_T excess away from leading jet

Overall balance !

High p_T excess towards leading jet

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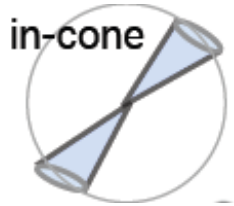
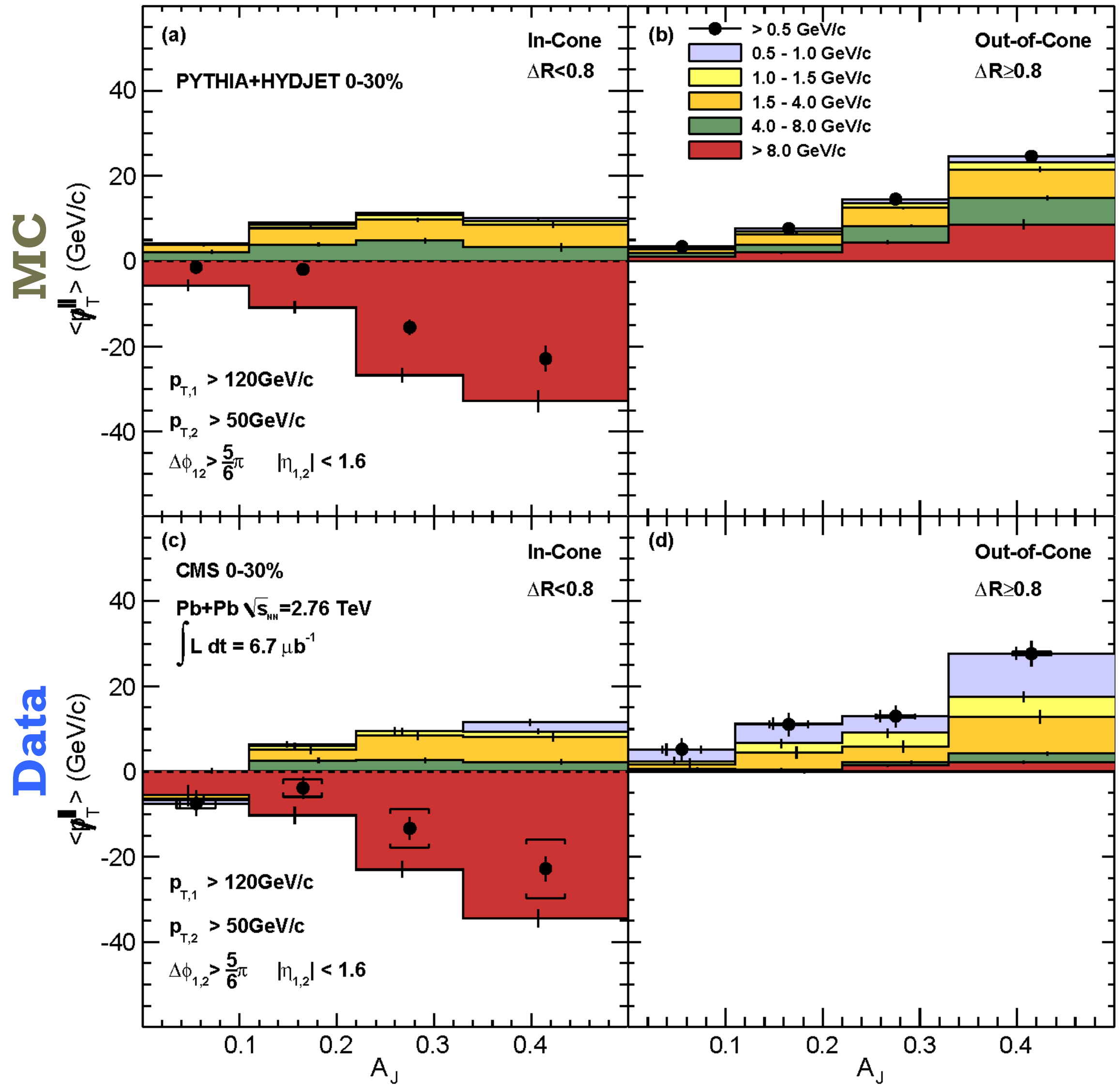
Where does the missing p_T goes ?



- In **PYTHIA**, balance is found out-of-cone as well, but at higher p_T (3^{rd} jets)

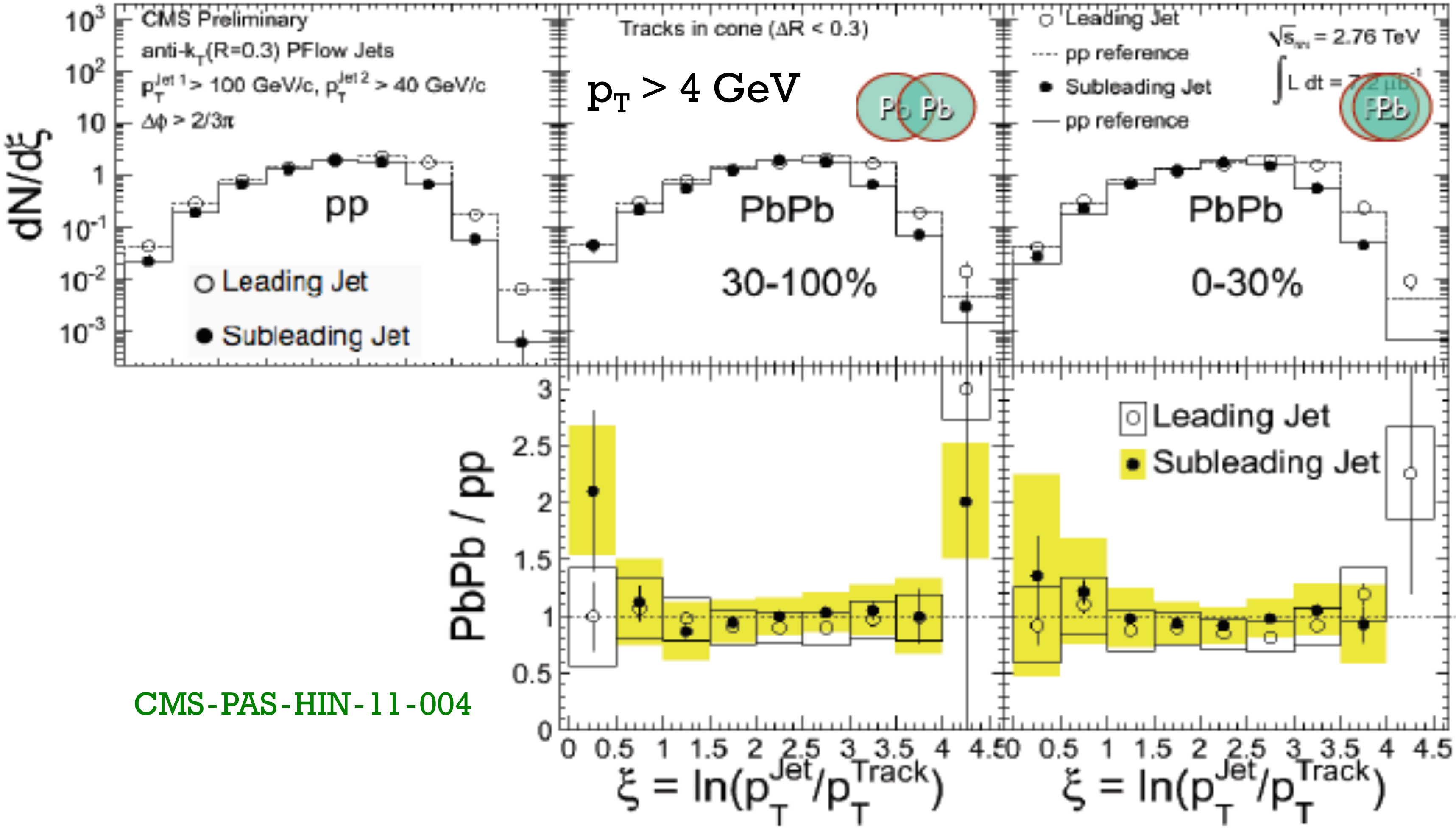


PbPb **Data**, in-cone excess of high-p_T tracks is balanced by out-of-cone low-p_T tracks

Phys.Rev.C84:024906,2011

Fragmentation function (hard component)

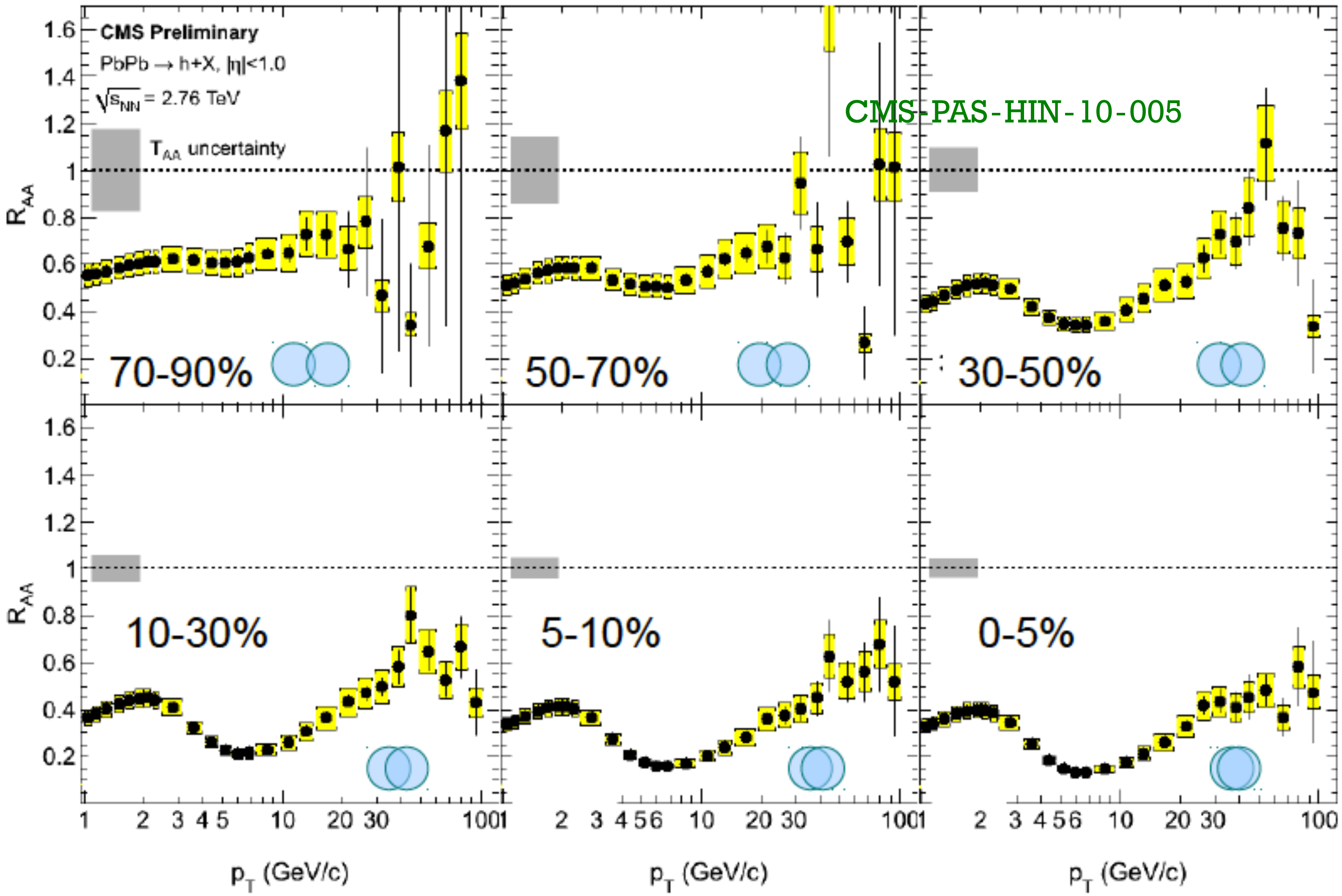
- Fragmentation function represents the energy fraction carried by a particular hadron out of the total energy of the parent parton



CMS-PAS-HIN-11-004

Leading and subleading jets in PbPb fragment like jets of a corresponding energy in pp collisions

+ R_{AA} of charged hadrons



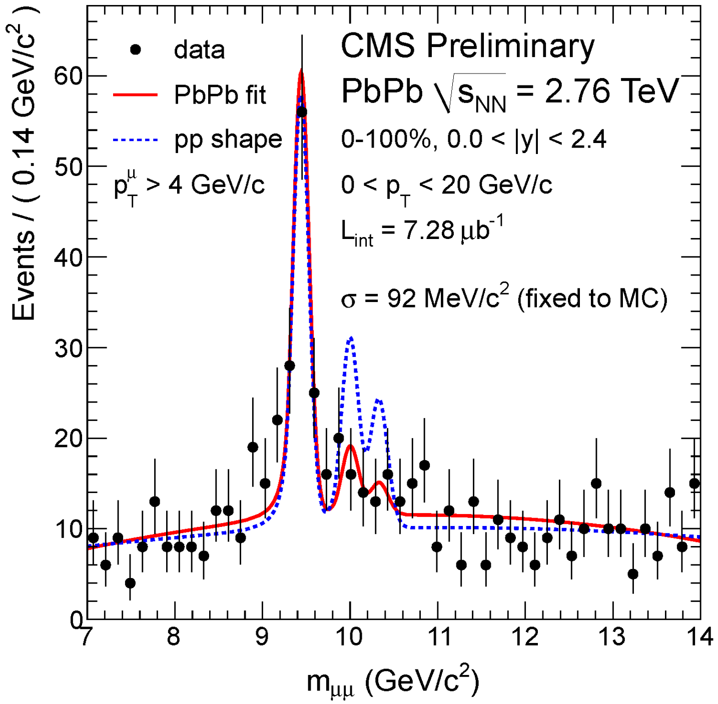
- R_{AA} for central collisions: minimum near 10 GeV/c, then increases for larger p_T
- Strong constraint on the parton energy loss

+ Υ Excited states

- Compare Υ(2S+3S) production relative to Υ(1S) in pp and PbPb
- Single Ratio
  - Insensitive to overall cross section for theoretical comparison

  Note: Sensitivity to acceptance difference between excited and ground state. (p_T>4 GeV/c cut)
- Double Ratio
  - Acceptance and efficiency cancels

Phys.Rev.Lett.107:052302,2011



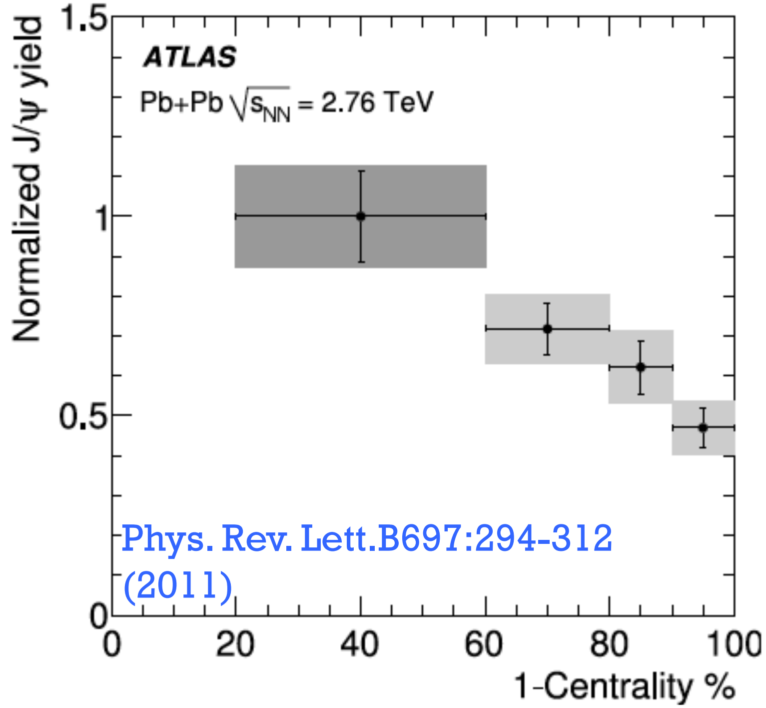
$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02 \qquad \Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$

$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

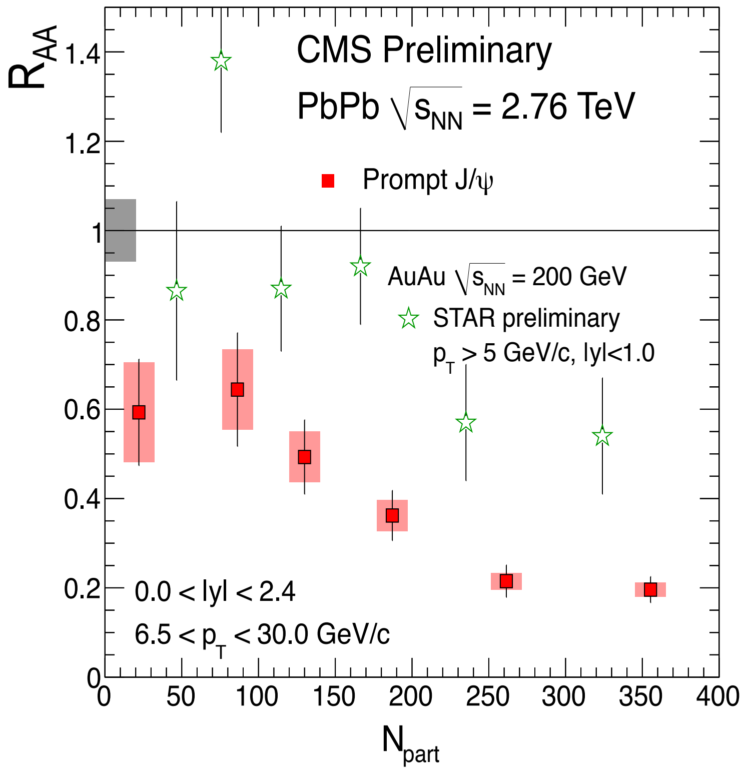
- In PbPb, the ratio of Upsilon excited-to-ground states is much lower than in pp
- Significance of the suppression 2.4 σ

+ R_{AA} and R_{cp} of J/ψ

- High p_T J/ψ production is more suppressed in central compared to peripheral events
- Stronger high p_T J/ψ suppression seen in CMS and ATLAS than at STAR
- High p_T J/ψ tendency to survive at RHIC (and SPS) is not seen at the LHC



Phys. Rev. Lett.B697:294-312 (2011)



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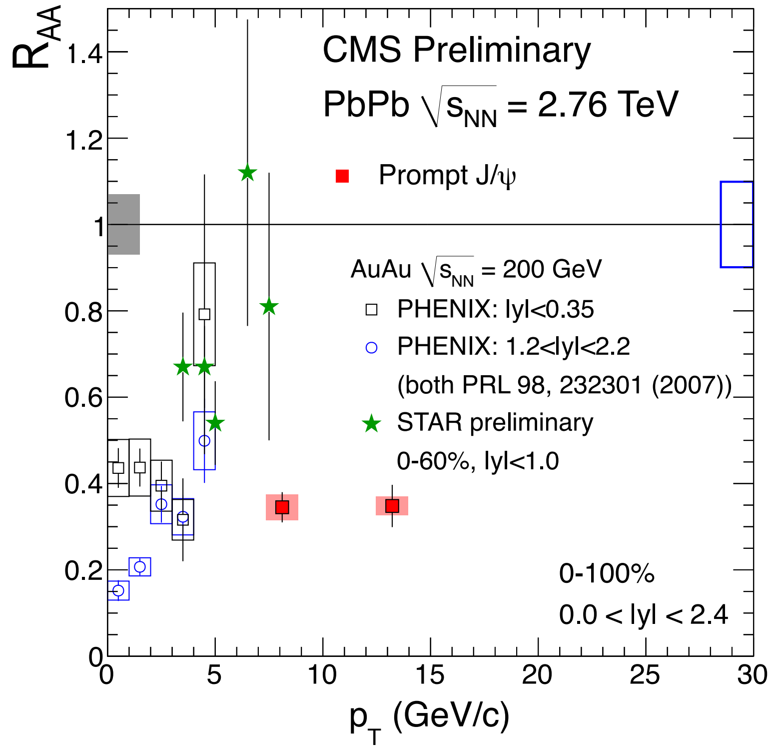
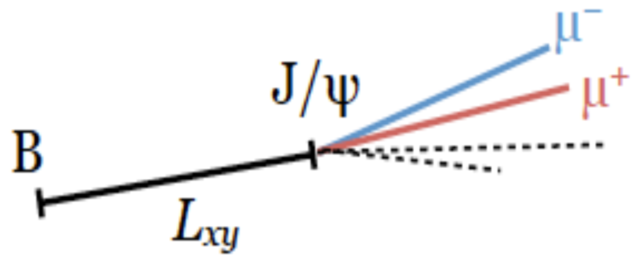
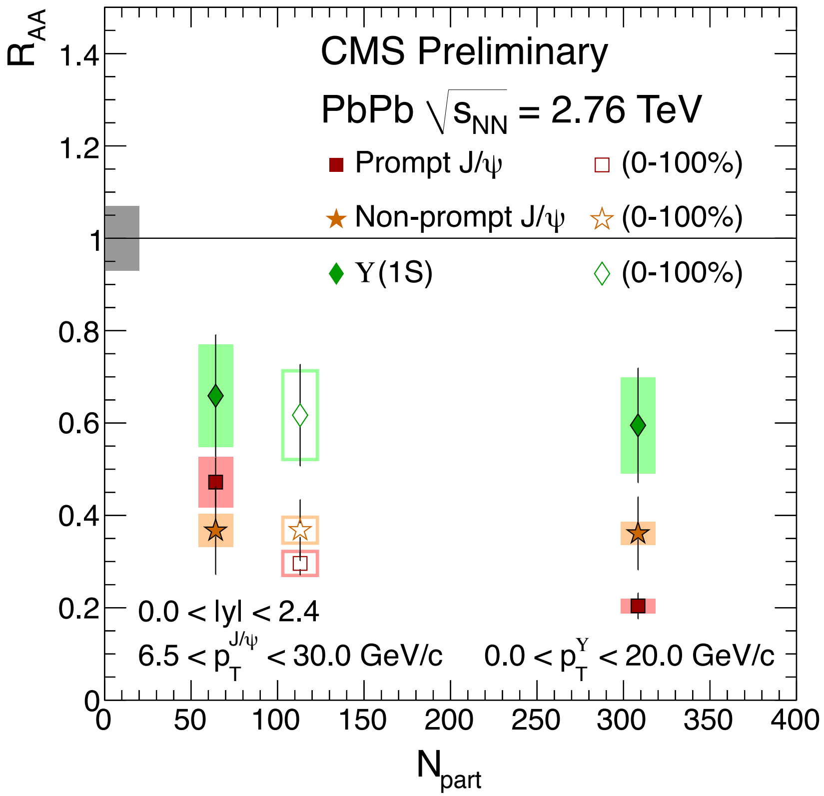


B → J/ψ

Inclusive J/ψ → Prompt J/ψ → Direct J/ψ; Feed-down from ψ' and χ_c

Inclusive J/ψ → **Non-Prompt J/ψ from B decays**





- non-prompt J/ψ are less suppressed than prompt J/ψ
- First indication of b-quark energy loss

PAS HIN-10-006

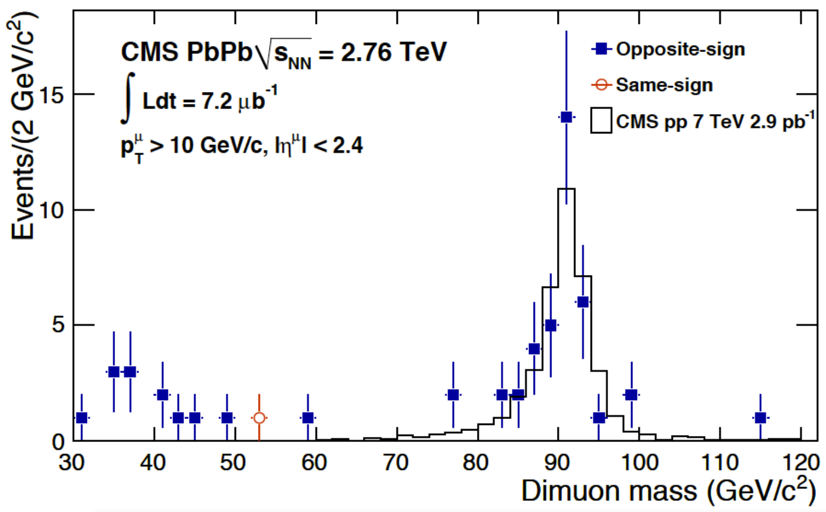
+ Weakly interacting pQCD probes of QGP

- W and Z bosons
- Isolated photons

Z boson

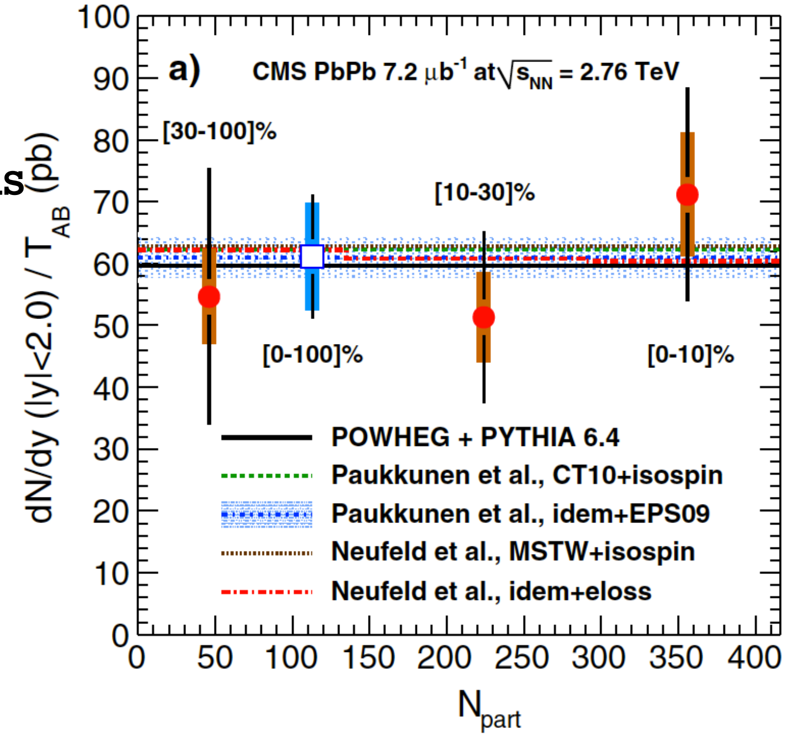
- Around 40 Z candidates in both
  ATLAS Phys. Lett. B **697** (2011) 294-312
  CMS PRL 106, 212301 (2011)
  - Almost background free (one like sign count only)

Heavy ion run @2.76 TeV



- Z production scales with the number of NN collisions

- Comparaison to different theoretical predictions



- Using POWHEG cross-section:

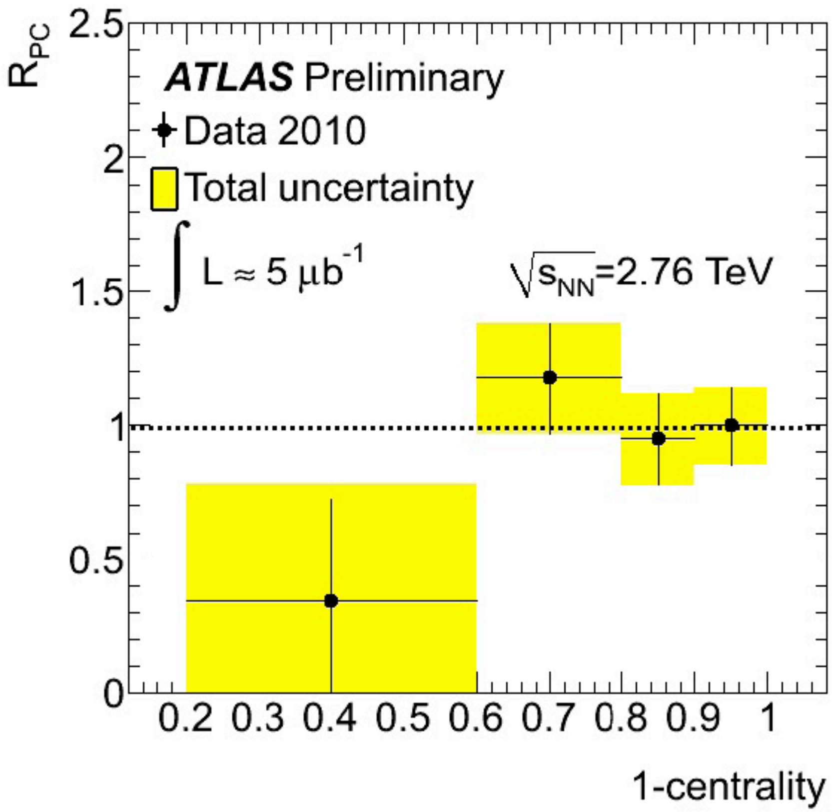
- $d\sigma_{pp}/dy$ = 59.6pb in $|y|<2$

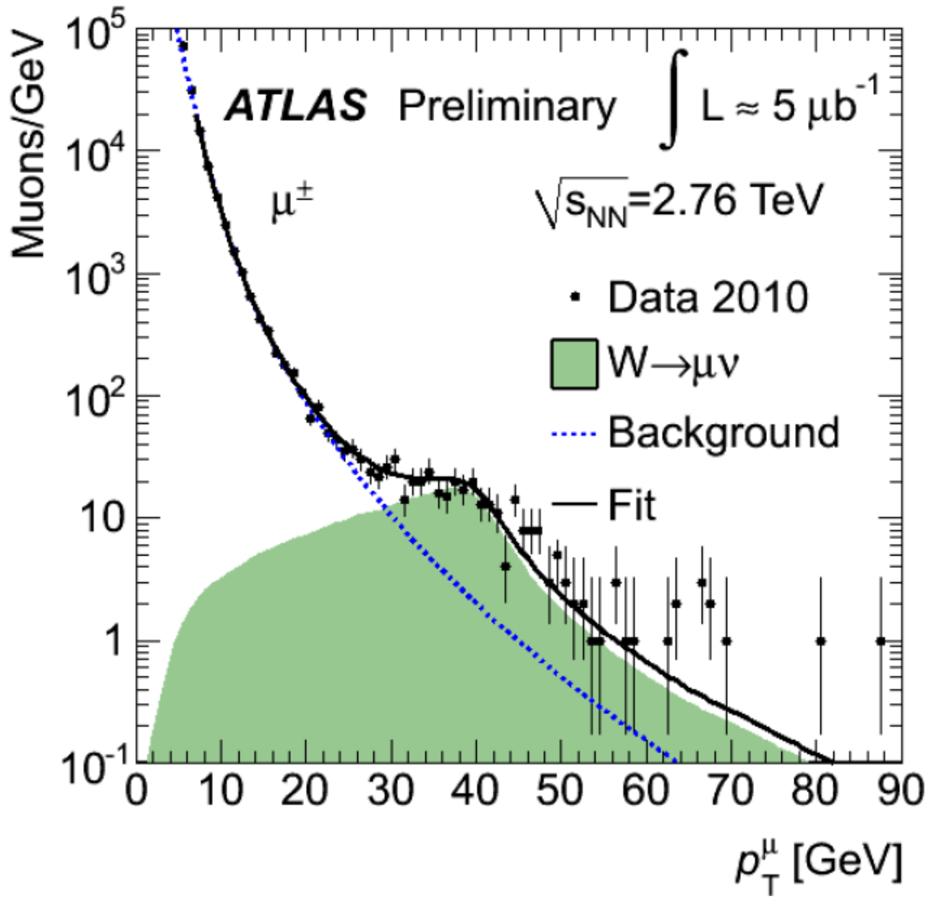
The resulting R_{AA} is: $dN_{AA}/(T_{AB}\, d\sigma_{pp})$

$= 1.00 \pm 0.16 \pm 0.14$

W boson

- W signal: built a template from $W \rightarrow \mu\nu$ decays
  - Use MC @ $\sqrt{s}$ = 2.76TeV
- Use a function to describe background and find the best estimate of number of W with fitting signal + background to data



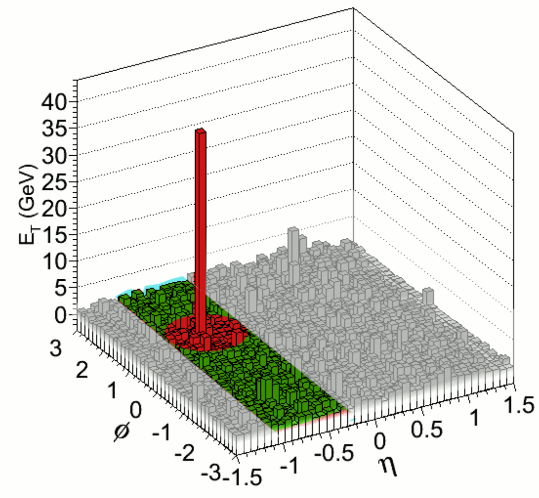


The results are consistent with no suppression

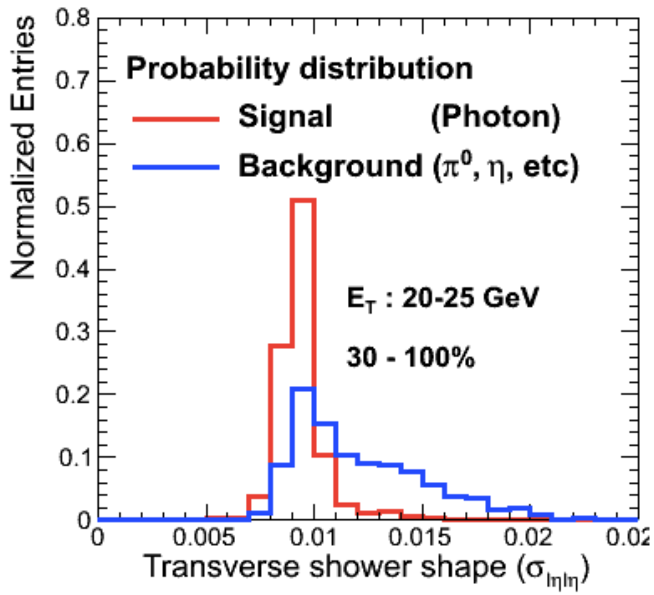
$R_{W/Z}$ =10.5 ± 2.3 : in agreement with standard model prediction

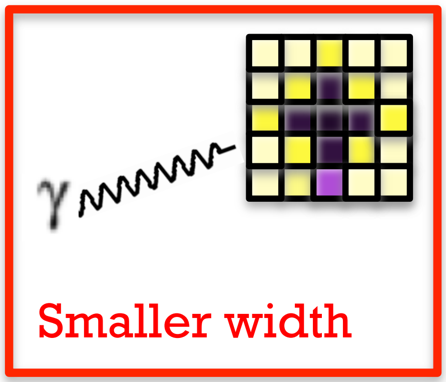
J. Phys.G: Nucl. Part. Phys. 38 124133

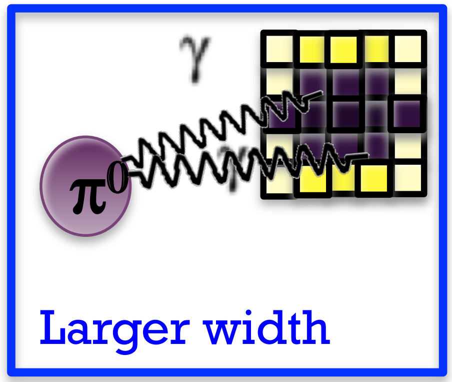
Isolated photons : How do we isolate photons in CMS ?



- Isolation cut rejects such jets : $E_{Hcal}/E_{Ecal} < 0.2$ and ΣE_T of particles in cone around candidates measured $\Sigma E_T < 5$GeV
- Background energy subtraction event-by event
- Isolation cuts are not sufficient (isolated π^0 and η remain)
- Statistical approach used: quantify transverse extent of ECAL shower

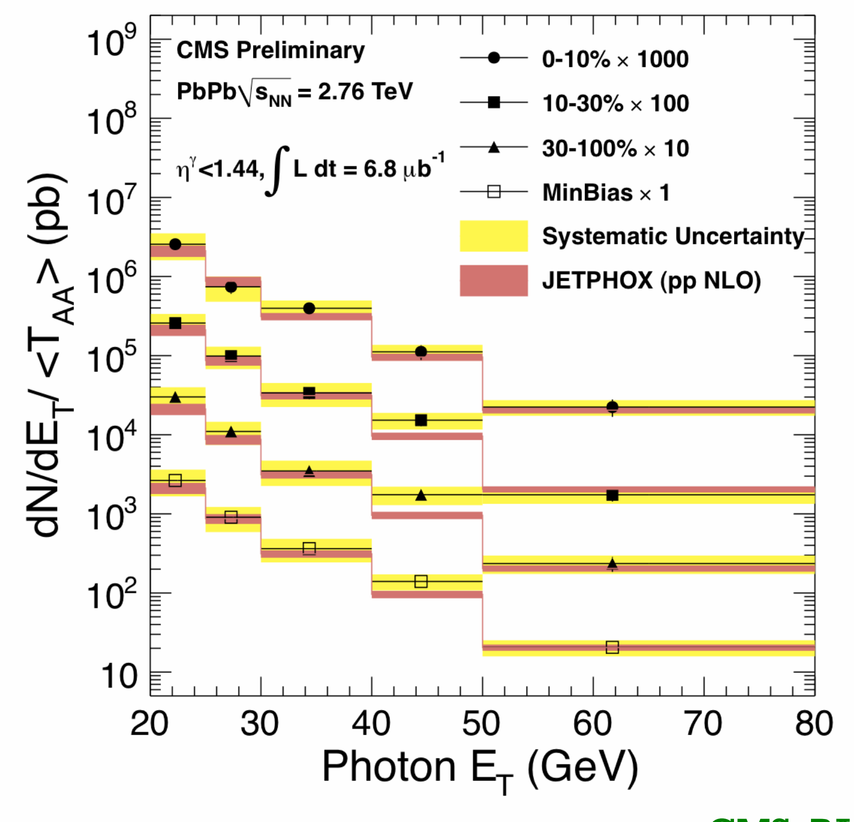


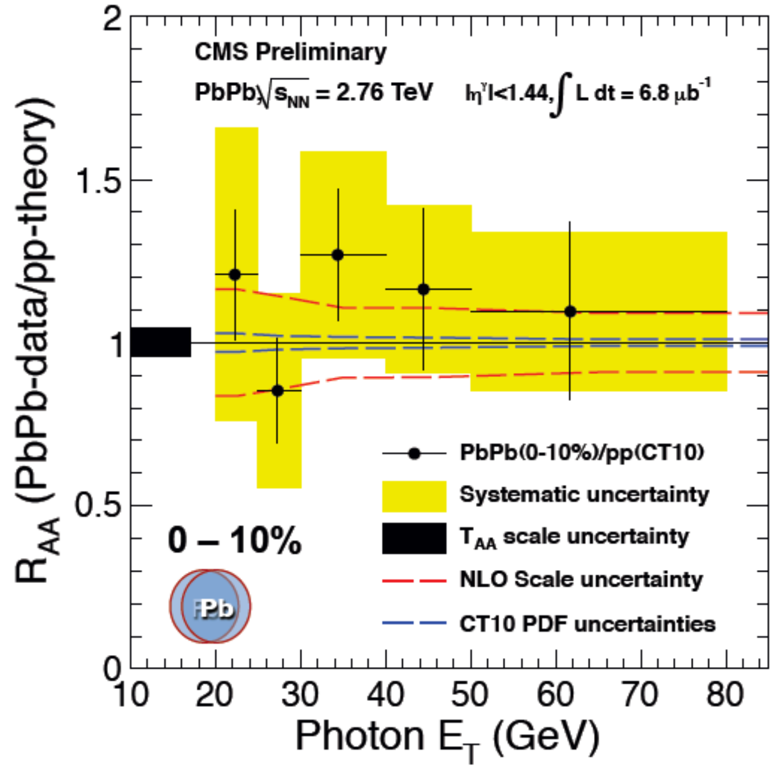




+ Isolated photons

- dN/dE_T is scaled by T_{AA}
  - T_{AA} : tickness factor, the cross-section of N-N inside PbPb collision





CMS-PAS-HIN-11-002

R_{AA} of isolated photons vs E_T and vs centrality is consistent with unity

Conclusion

+ Strongly interacting pQCD probes of QGP

- The momentum difference in the dijet is balanced by low p_T particles at large angles relative to the away side jet axis
- Leading and subleading jet in PbPb fragment like jets of a corresponding energy in pp collisions and the fragmentation pattern independent of energy lost in the medium is consistent with parton fragmenting in vacuum
- R_{AA} rises to about 0.5 at high p_T in the most central events. Strong constrain on the parton energy loss models
- High p_T prompt J/ψ is significantly suppressed at LHC
- non-prompt J/ψ is suppressed in Pb-Pb collisions
  - First observation of B-hadron suppression, likely connected to b-quark energy loss.
- $\Upsilon(2S)+\Upsilon(3S)$ excited states are suppressed (relative to $\Upsilon(1S)$) in PbPb colllisions at $\sqrt{s}$ =2.76TeV

Conclusion
Weakly interacting pQCD probes of QGP

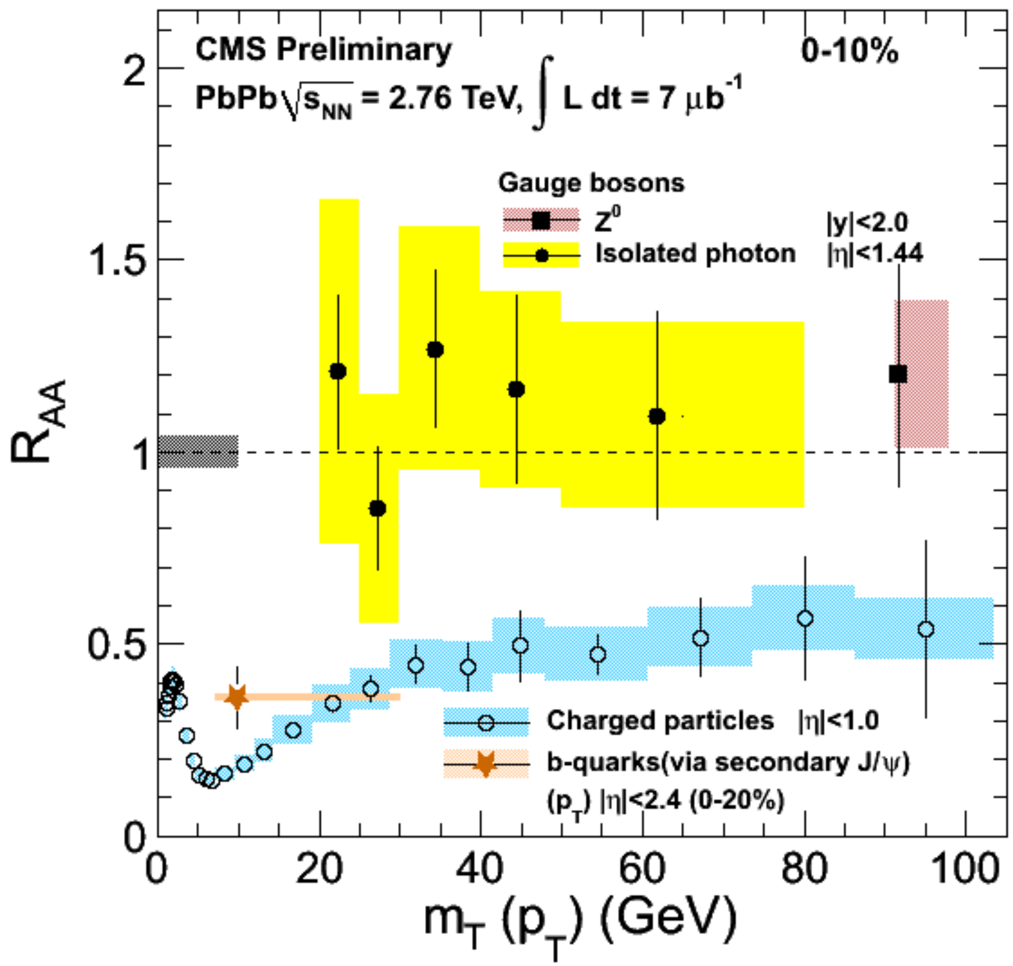
- The Z boson yield has been measured inclusively and as a function of rapi transverse momentum and centrality and within uncertainties no modifica observed with respect to theoretical NLO pQCD p-p cross sections scaled elementary nucleon-nucleon collisions

- The observation of no suppression for W-bosons confirms that they are produced at the initial phase of the collisions and don't interact with the medium

- The ratio of W/Z production in Pb+Pb collisions agree with Standard Model predictions

- First ever measurement of isolated photon spectra in heavy ion collision experiment shows no evidence of any modification in the initial state of the particle production process in heavy ion collision

+ Summary



CMS Preliminary
0-10%
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV, $\int L\,dt$ = 7 μb^{-1}
Gauge bosons
Z^0 |y|<2.0
Isolated photon |η|<1.44
Charged particles |η|<1.0
b-quarks(via secondary J/ψ)
(p_T) |η|<2.4 (0-20%)
R_{AA}
m_T (p_T) (GeV)
0
0.5
1
1.5
2
0
20
40
60
80
100

Back-up