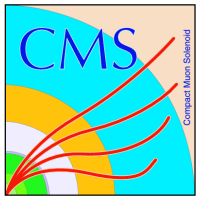
Hard Probes at LHC (CMS)



Gunther Roland
(MIT)
for the CMS Collaboration

EMMI Workshop
"Prospects and Challenges for Future Experiments in Heavy Ion Collisions"
GSI Feb 15-16, 2013

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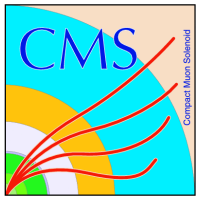

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LHC timeline

- Phase 0: 2010-2012
  - PbPb @ 2.76TeV: 160/μb
  - pPb @5TeV: 30/nb
  - pp @ 2.76 TeV: 5/pb

- Phase 1: 2014-2018 (up to LS2)
  - PbPb @ 5.5 TeV: 1.5/nb
  - pPb and pp @ 5.5 TeV equivalent statistics (50/pb pp)
  - smaller nucleus

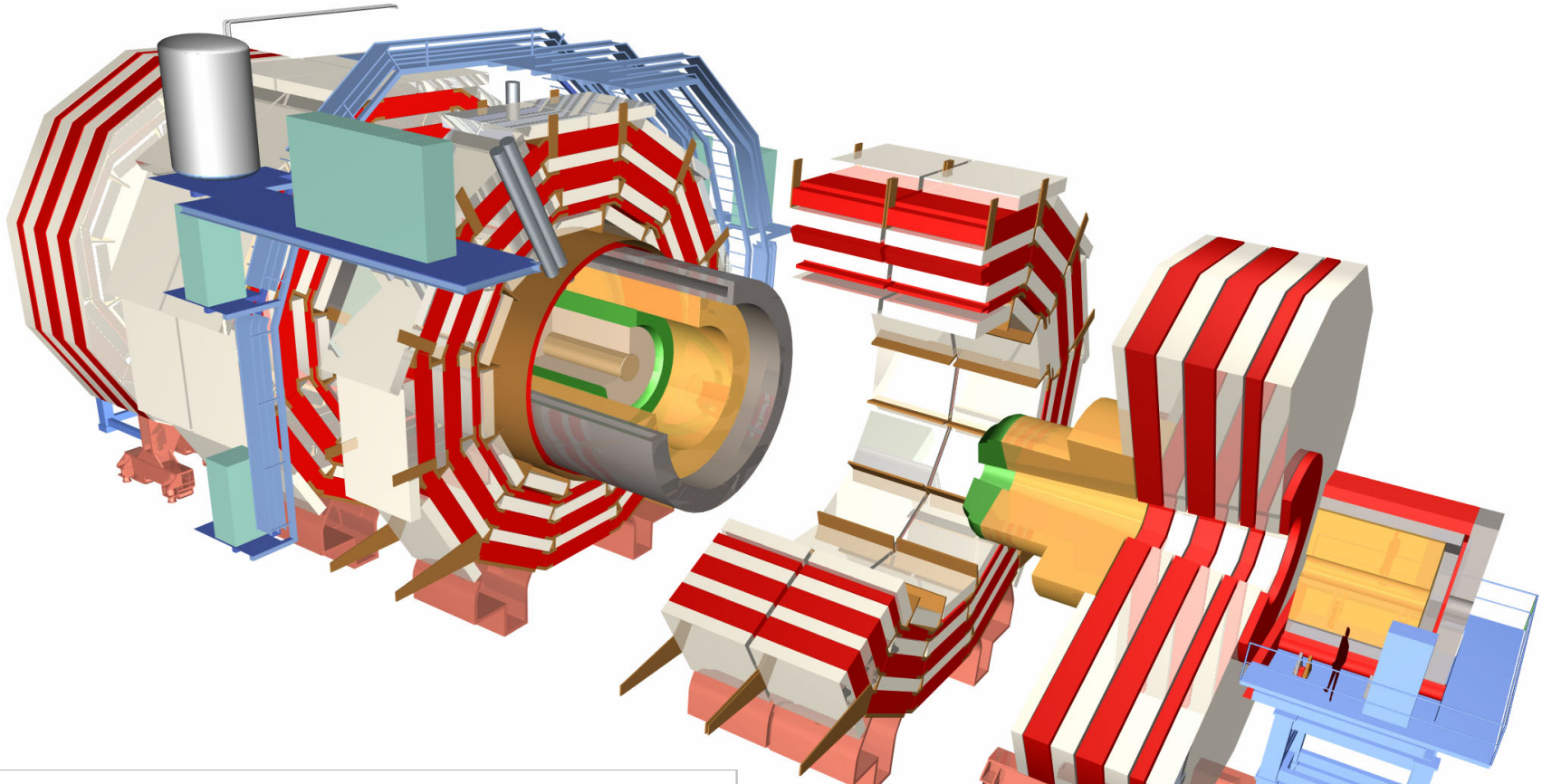
- Phase 2: 2020- (LS2 and beyond)
  - PbPb @ 5.5 TeV: increase total L_{int} to 10/nb
  - additional nuclei
  - pp equivalent statistics (500/pb)

Now

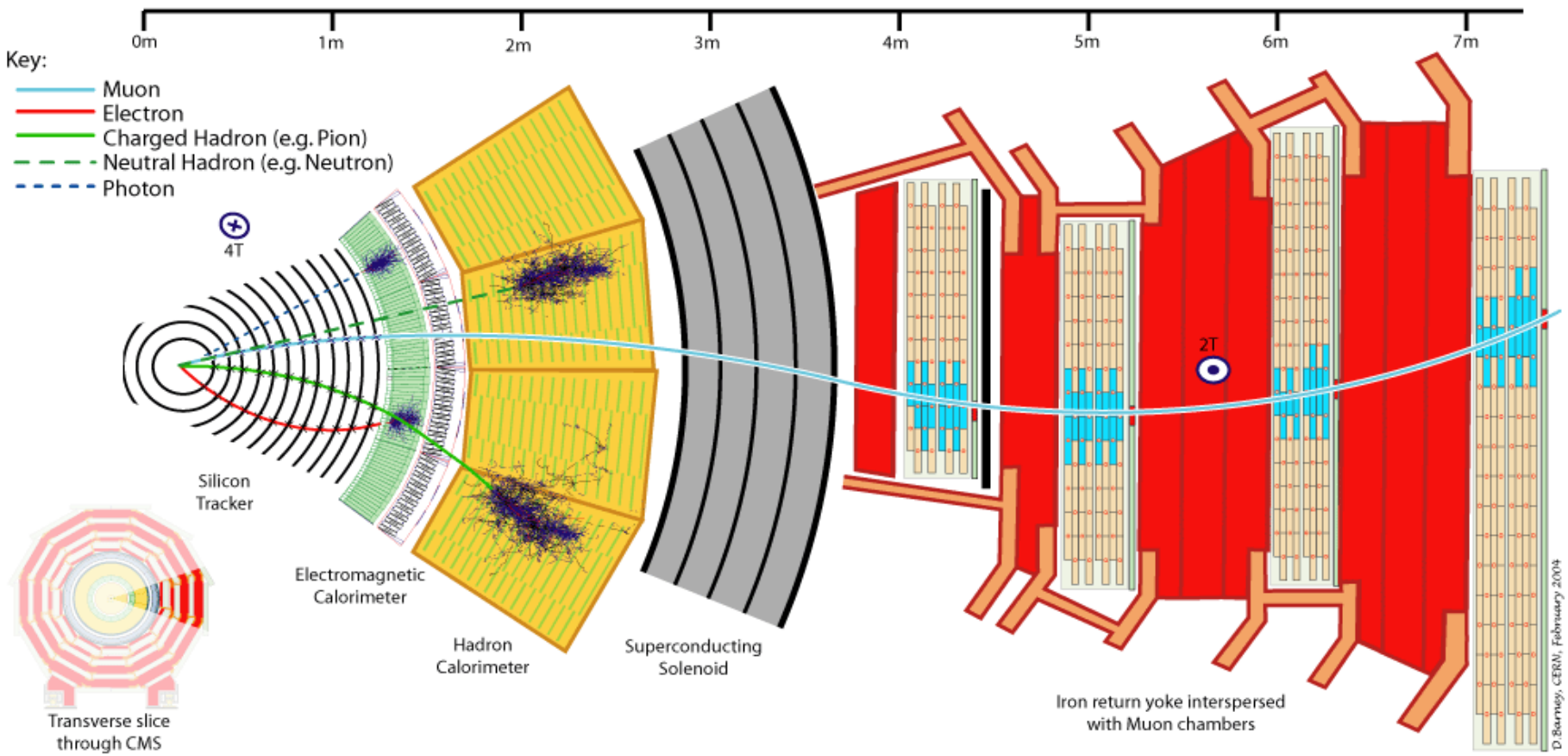
x10

x100

CMS Detector



Hard Probes in CMS



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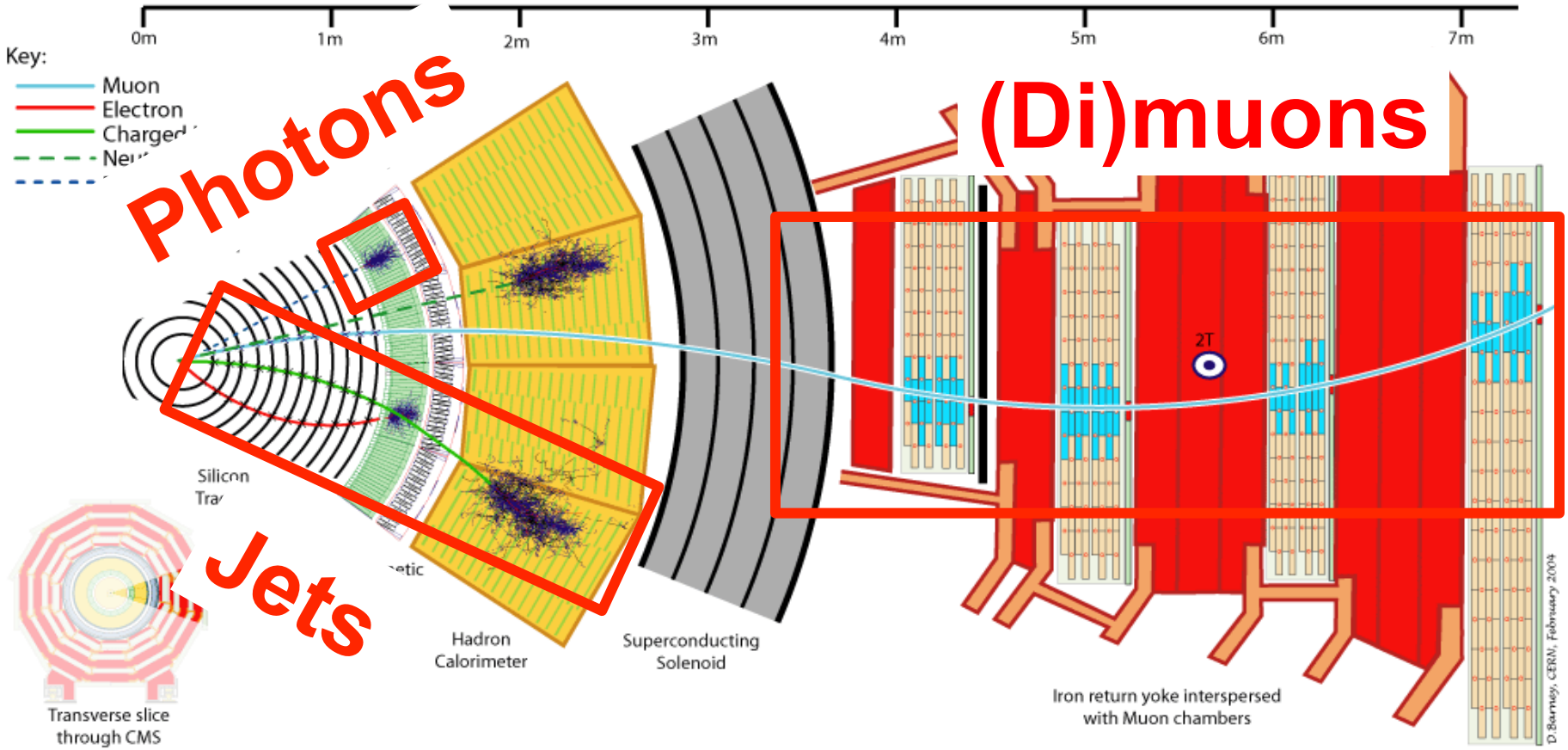

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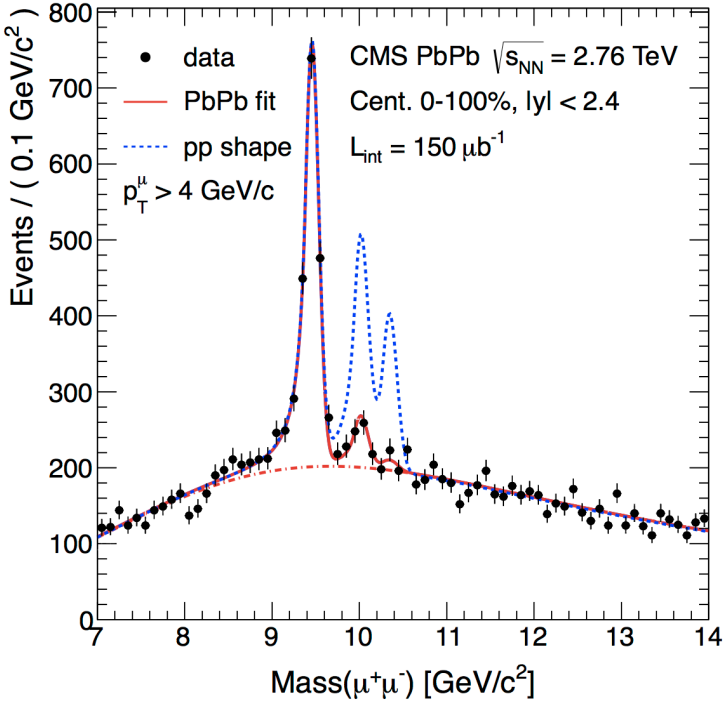
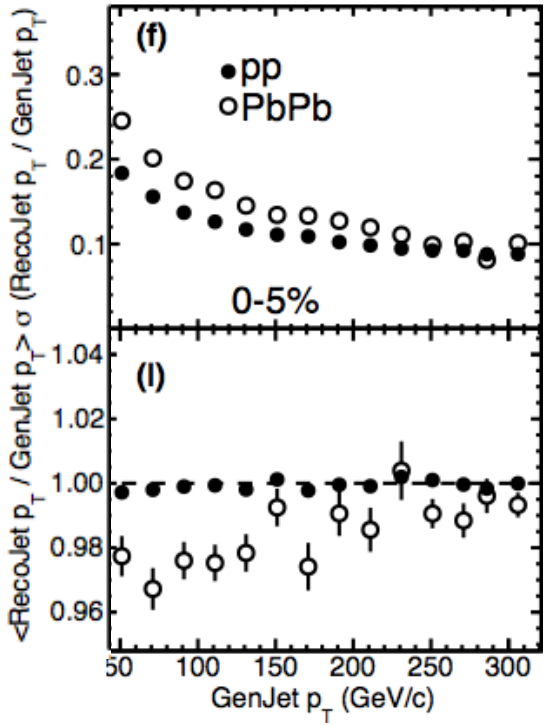


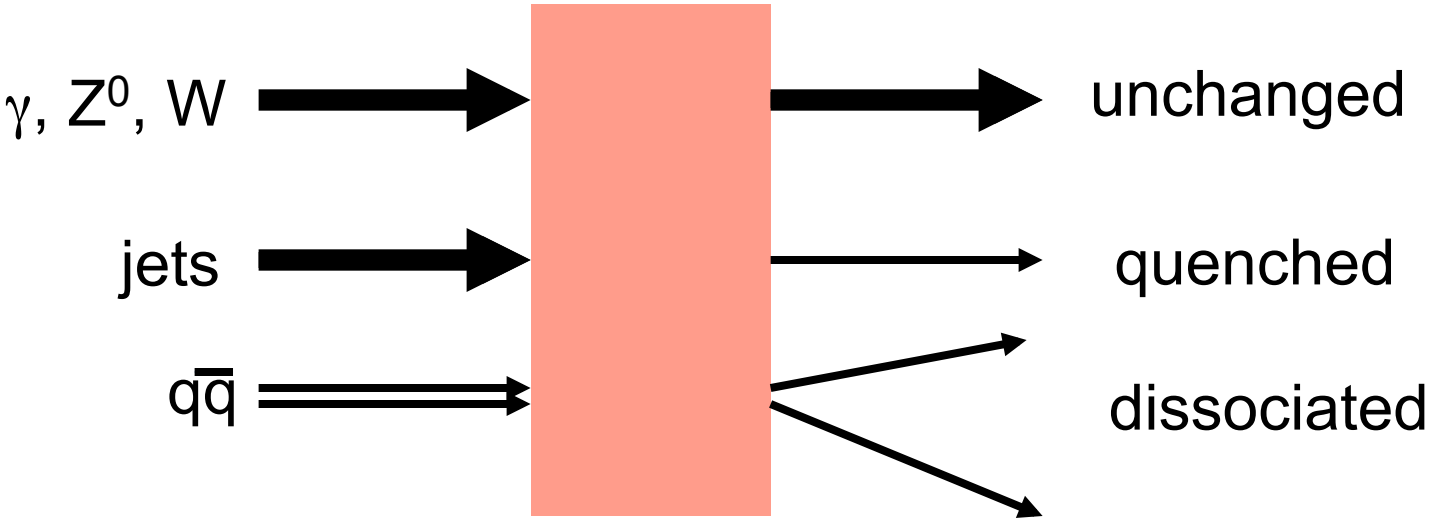
Dimuon resolution essentially identical in pp and PbPb



Moderate to small degradation of jet performance in PbPb

CMS detector performance for hard probes:
PbPb ≈ pp + minor perturbation

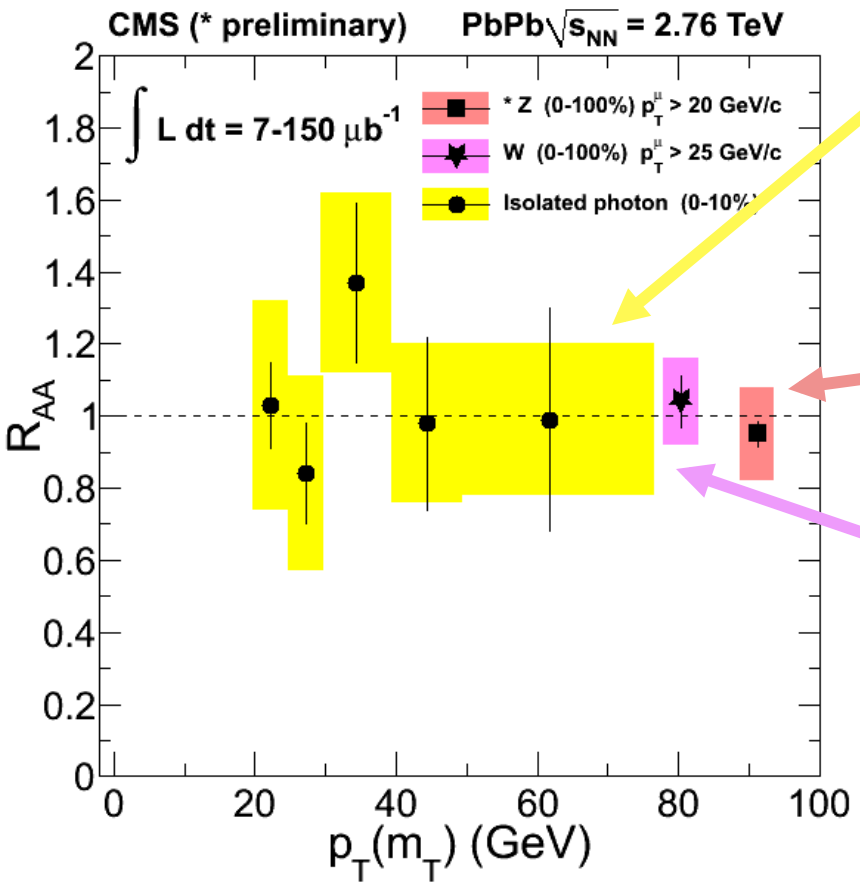
Hard Probes



(Non-) Suppression of colorless probes

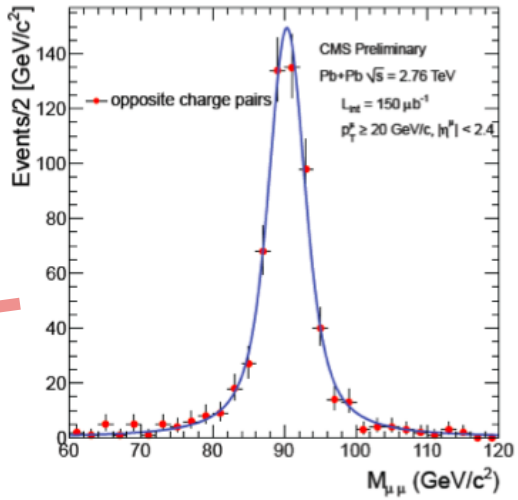
Isolated photon R_{AA} with 2.76 TeV pp reference

PLB 710 (2012) 256

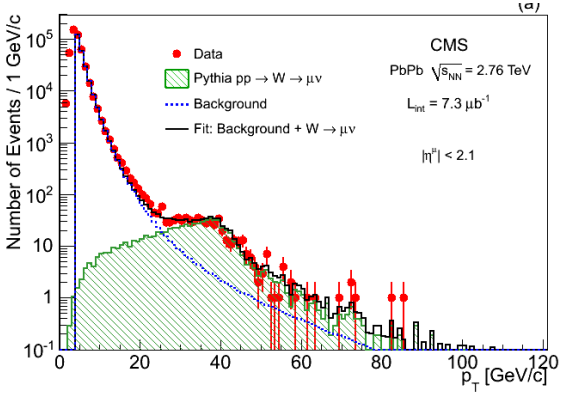


$Z^0 \rightarrow \mu^+\mu^-$

CMS-PAS HIN-12-008



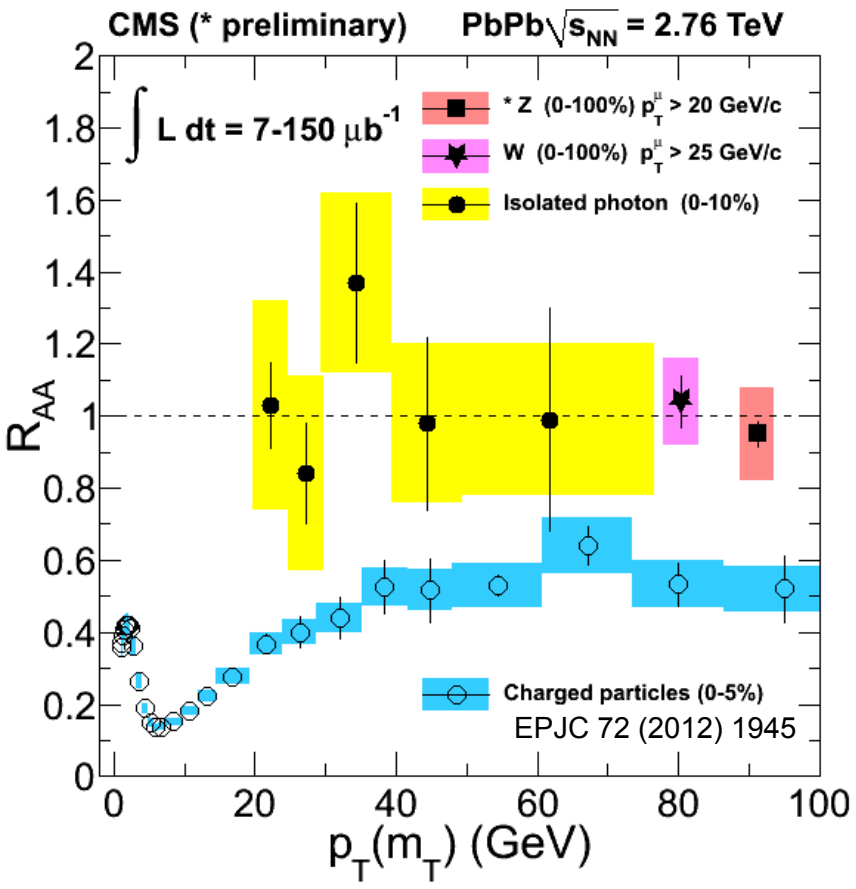
$W \rightarrow \mu\nu$ using single muon recoil against missing p_T



PLB 715 (2012) 66

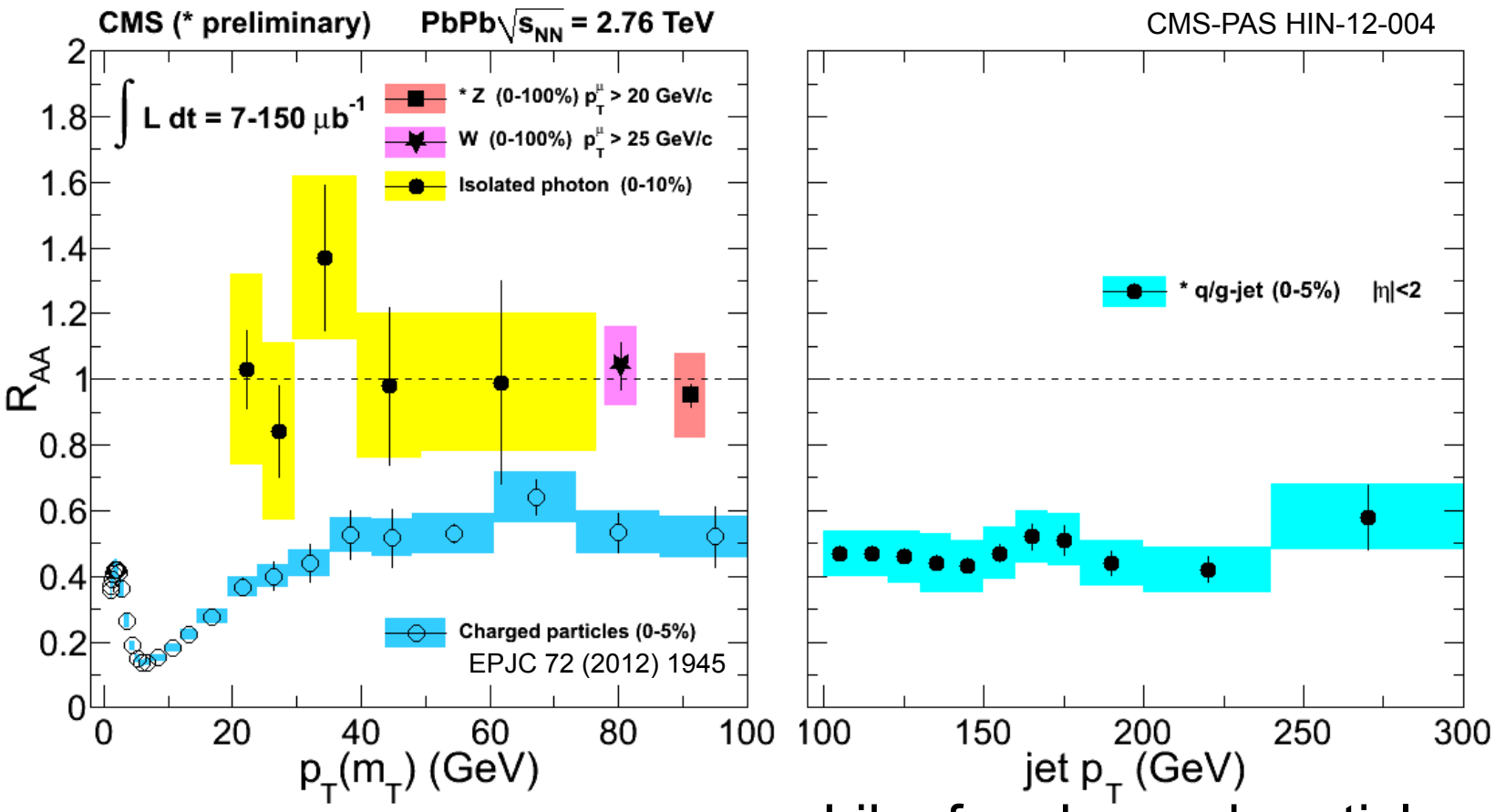
N_{coll} scaling confirmed

Suppression of inclusive jets



Suppression of inclusive jets

Fully unfolded inclusive jet R_{AA}
pp 2.76 TeV reference

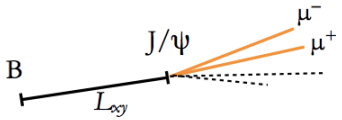


Like for charged particles, high-p_T jet R_{AA} flat at ≈ 0.5

B-tagging in PbPb

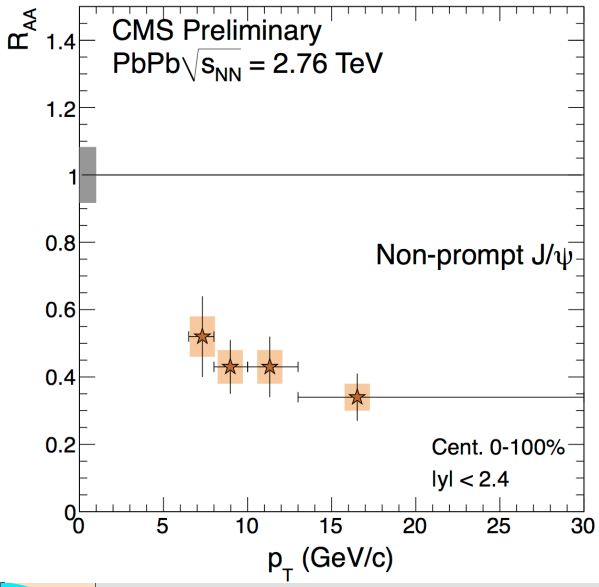
Study quark mass dependence of energy loss

$6.5 < p_T < 30$ GeV:
Displaced J/ψ → μμ



Obtain *B* R_{AA}

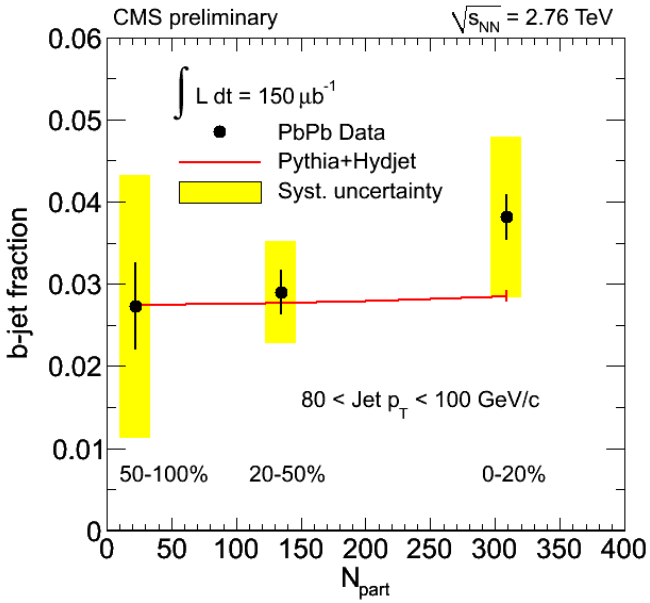
CMS-PAS HIN-12-014



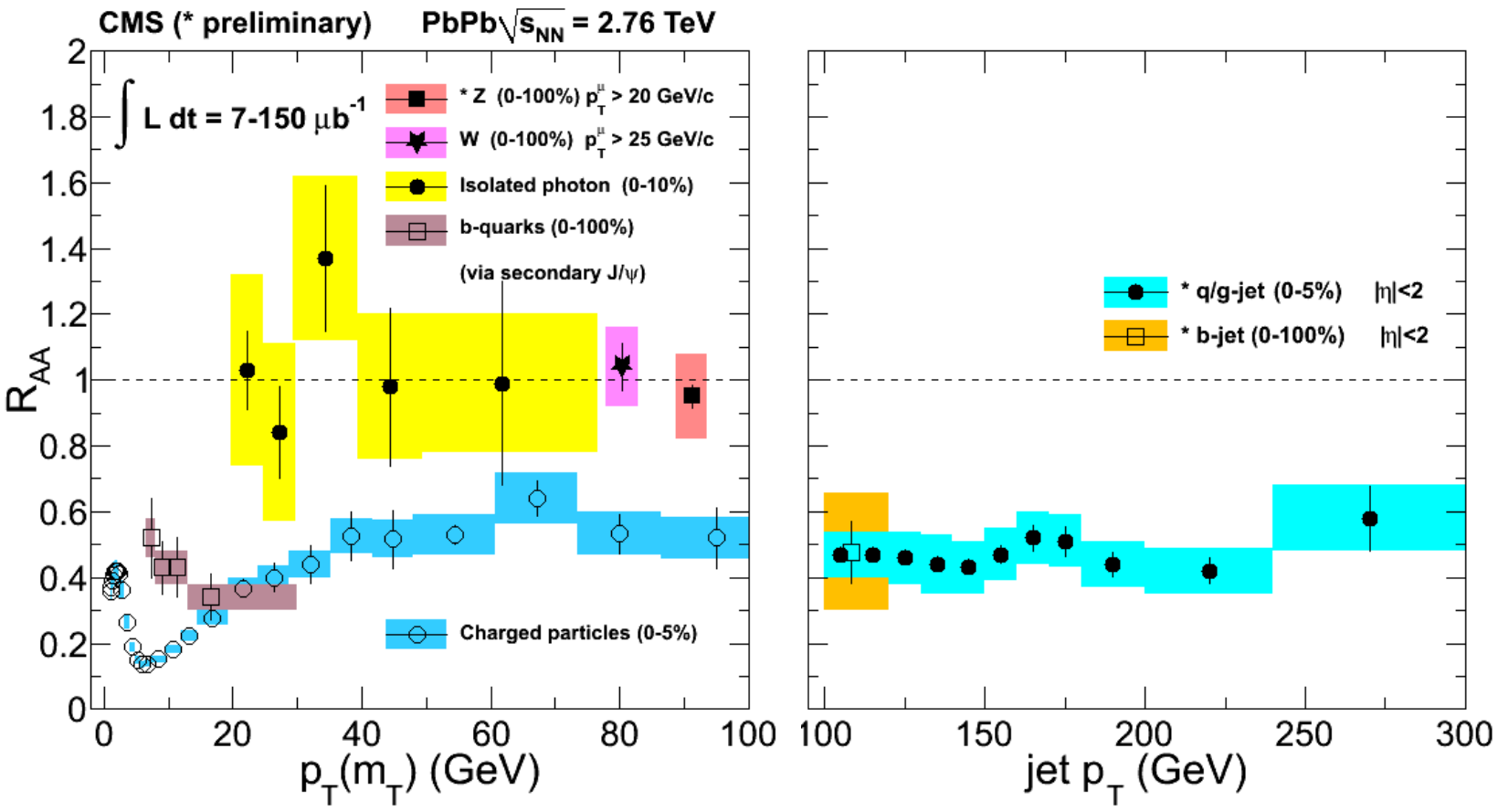
$p_T > 80$GeV:
Jet + high mass
secondary vertex

Obtain *b-jet fraction*

CMS-PAS HIN-12-003

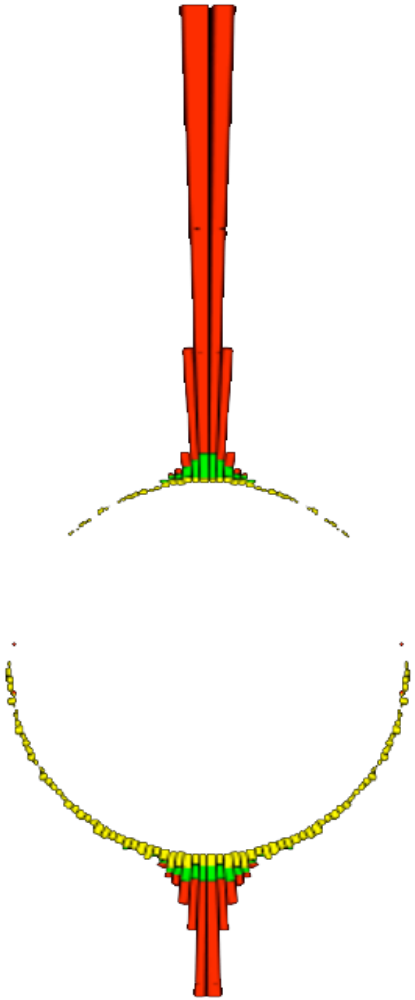


Jet Suppression Mass Dependence



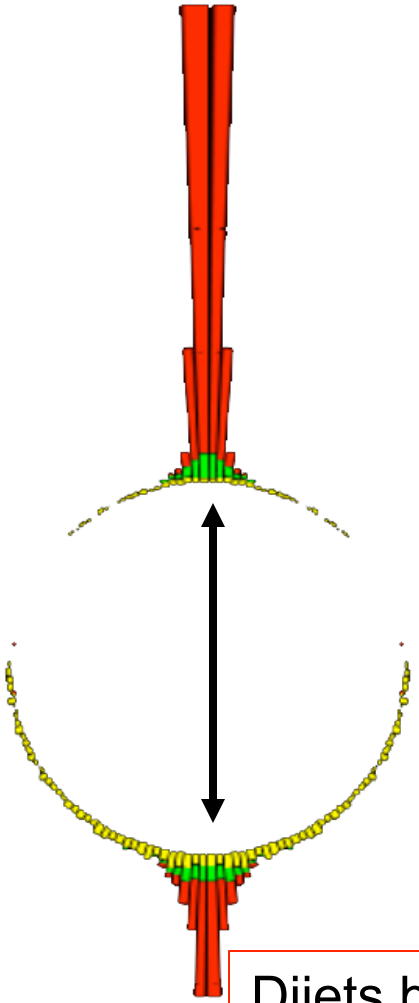
PbPb dijet phenomenology

Leading jet (p_T>120GeV/c)



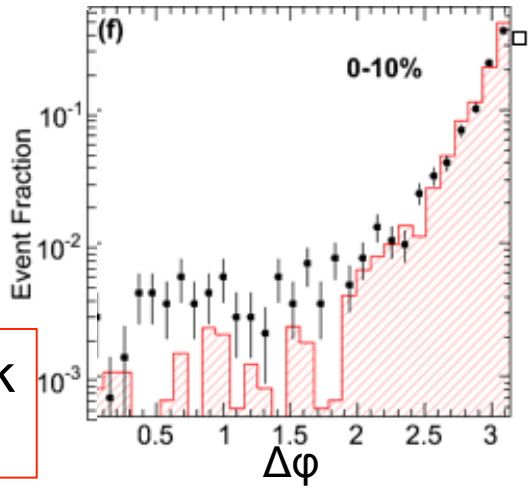
Subleading jet (p_T>30GeV/c)

PbPb dijet phenomenology



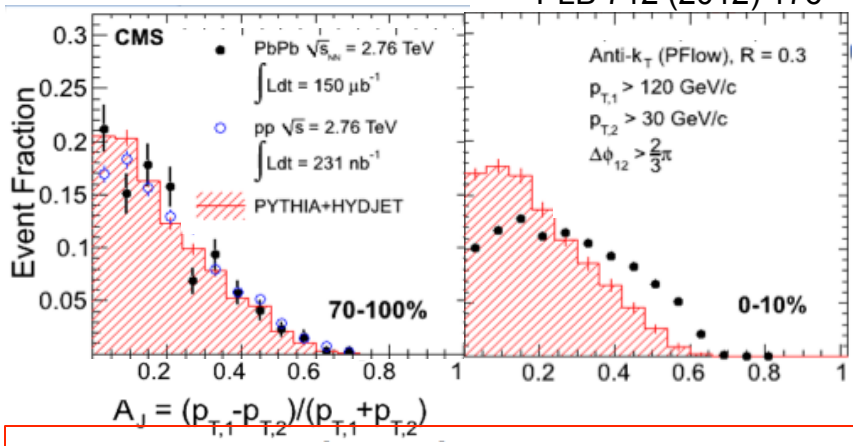
Dijets back-to-back in central PbPb

PRC 84 (2011) 024906

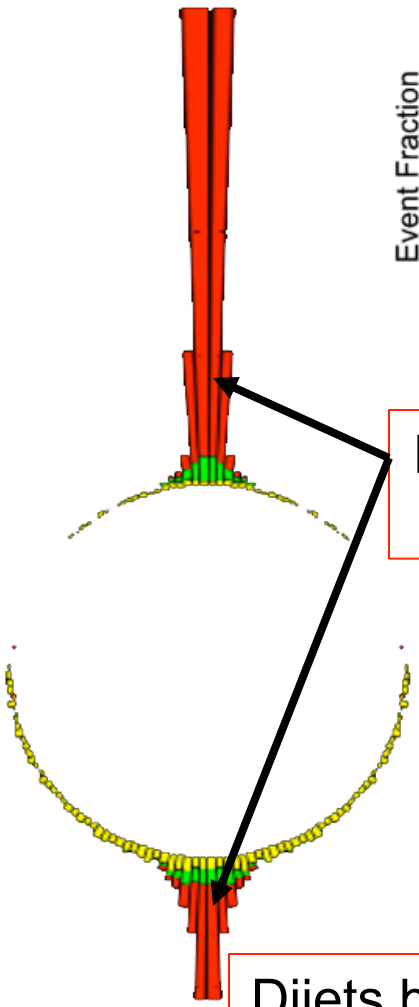


PbPb dijet phenomenology

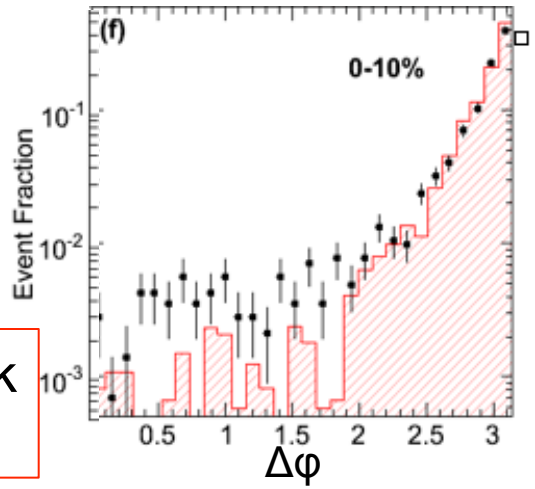
PLB 712 (2012) 176



Large dijet momentum asymmetry in central PbPb



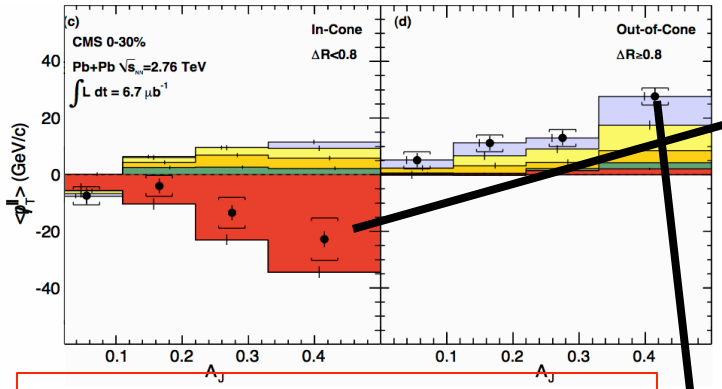
PRC 84 (2011) 024906



Dijets back-to-back in central PbPb

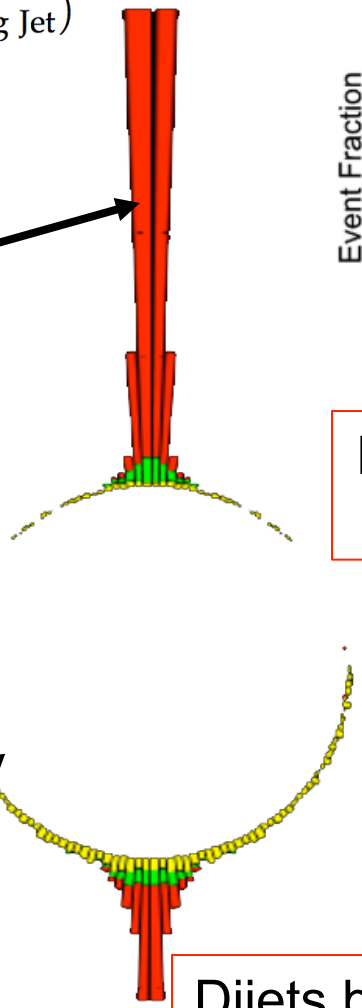
PbPb dijet phenomenology

$$\not{p}_{\mathrm{T}}^{\parallel} = \sum_{\text{Tracks}} -p_{\mathrm{T}}^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$

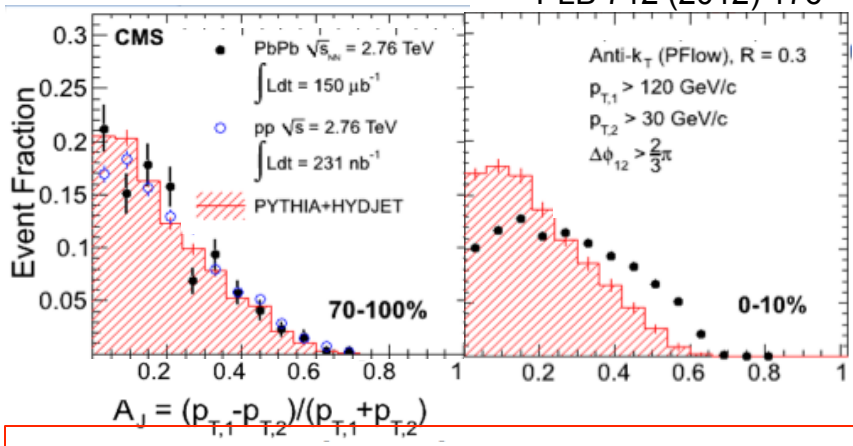


Jet asymmetry balanced by soft particles at large angles

PRC 84 (2011) 024906



PLB 712 (2012) 176



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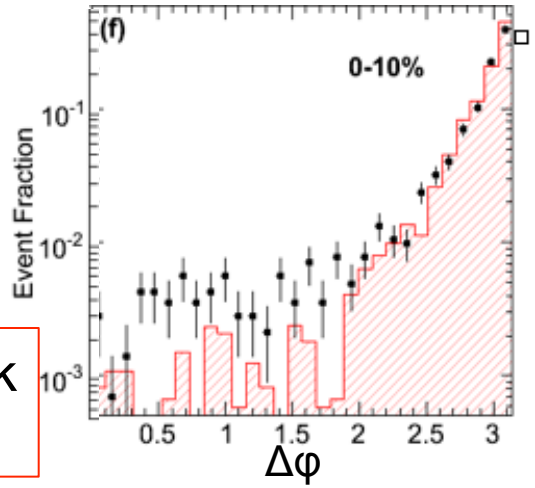
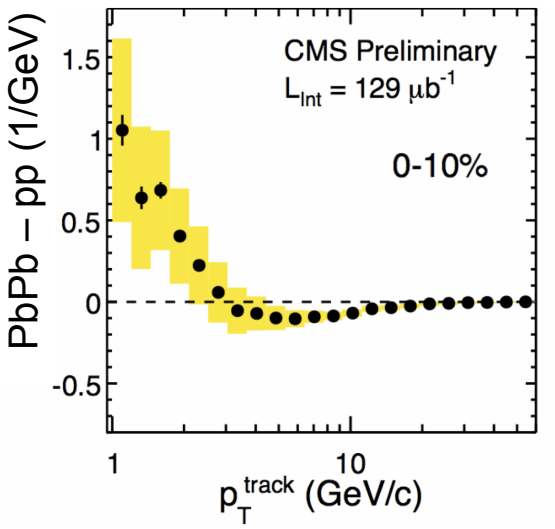
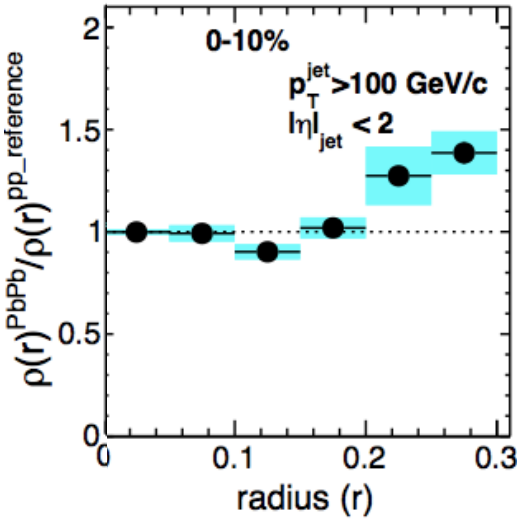


Dijets back-to-back in central PbPb

Jet anatomy

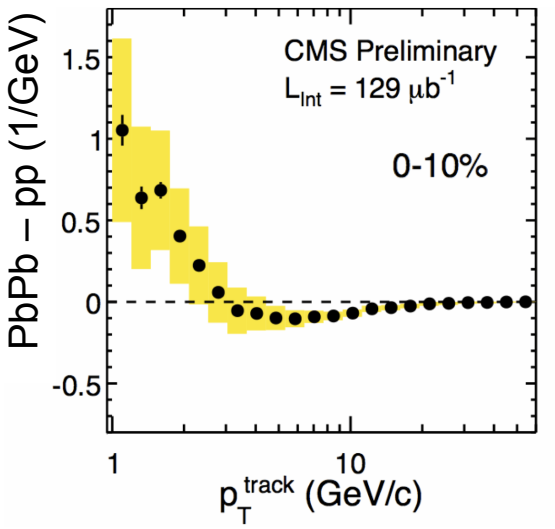


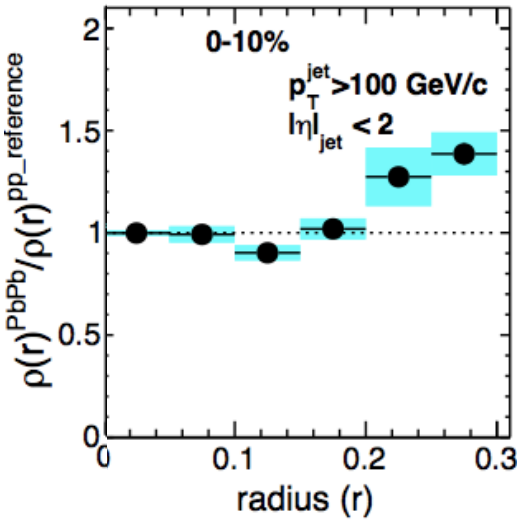
Fragmentation function difference (PbPb – pp):
Shows redistribution of particles in p_T



Jet shape ratio (PbPb/pp):
Shows redistribution of energy in *r* from jet axis

Jet anatomy





Fragmentation function difference (PbPb – pp):
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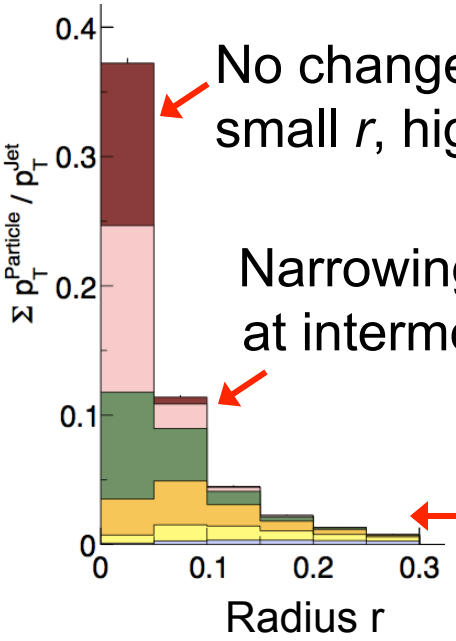


No change at small *r*, high p_T

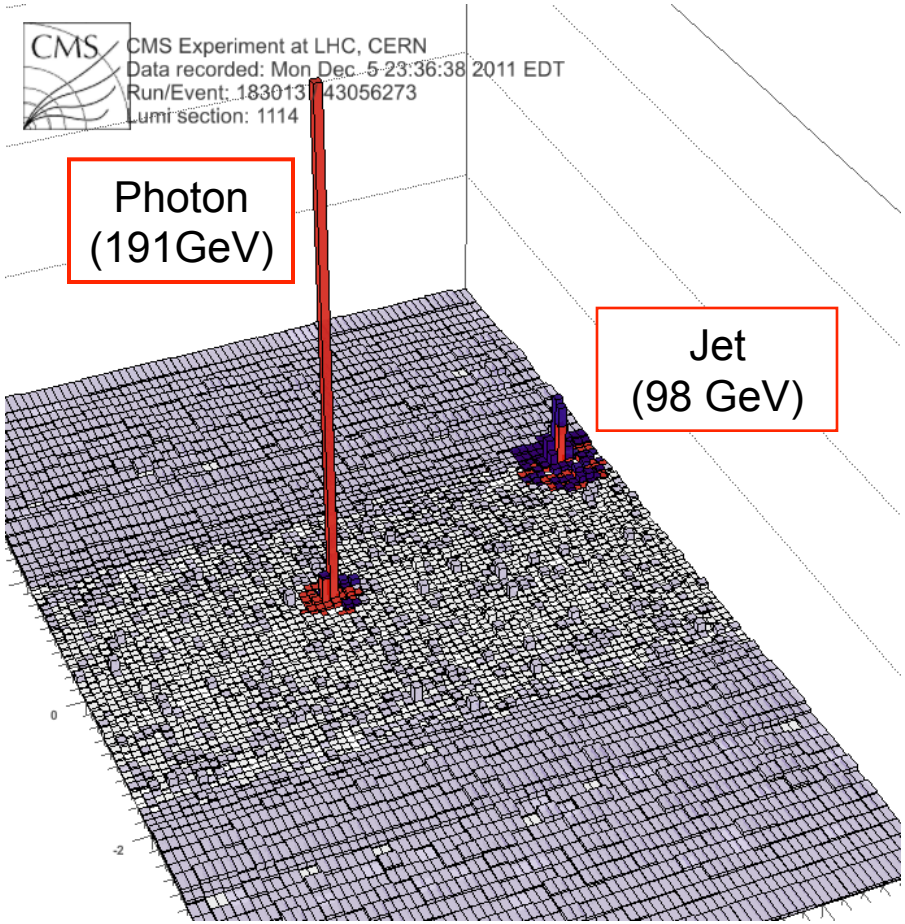
Narrowing/depletion at intermediate *r*, p_T

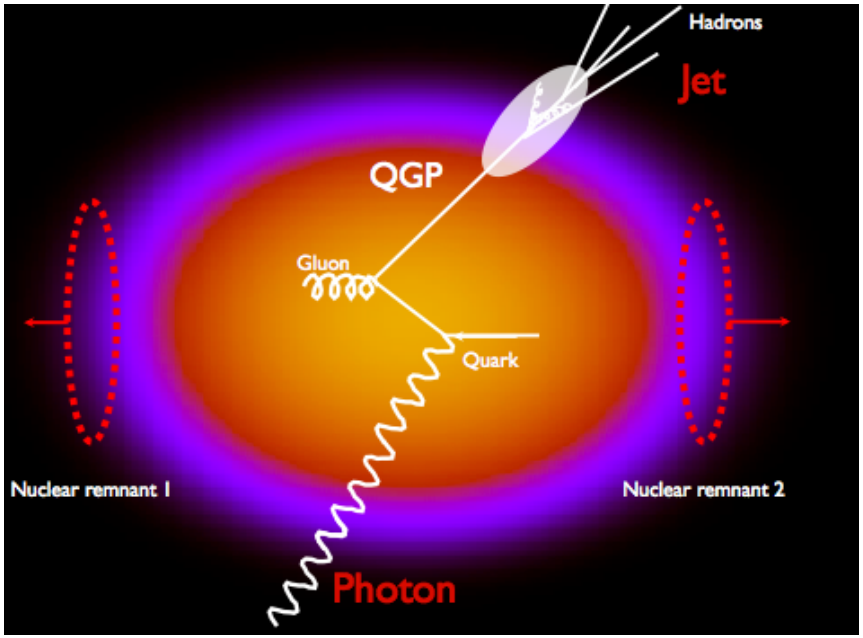
Broadening/excess at large *r*, low p_T

(3-5% of jet energy)

Jet shape ratio (PbPb/pp):
Shows redistribution of energy in *r* from jet axis

γ+jet: u,d quark energy loss



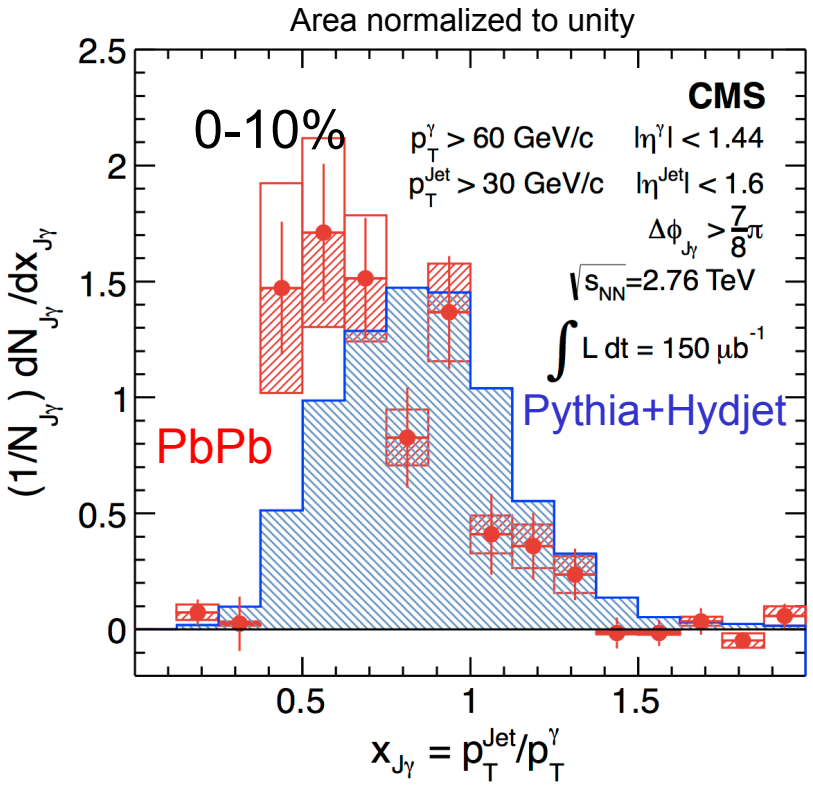


Photon tag:

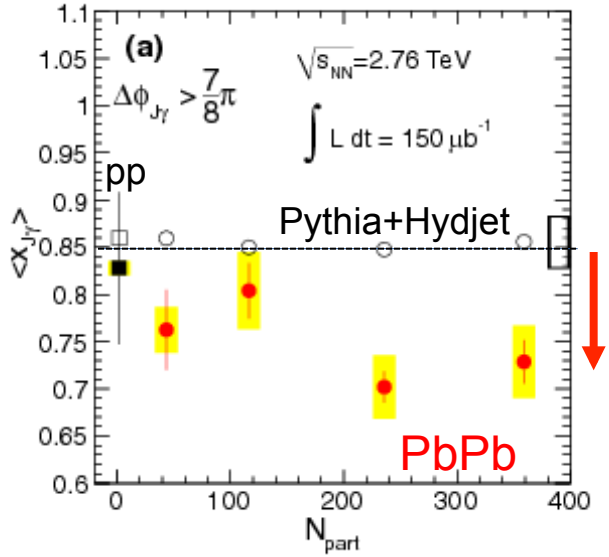
- Identifies jet as u,d quark jet
- Provides initial quark direction
- Provides initial quark p_T

γ+jet: u,d quark energy loss

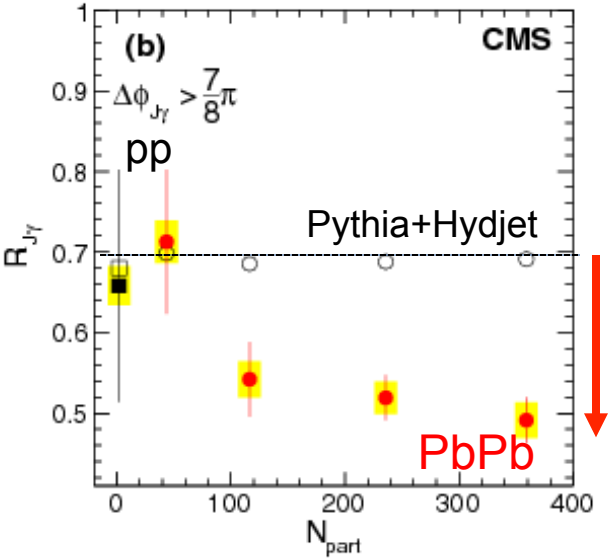
PLB 718 (2013) 773



Photon-jet momentum balance

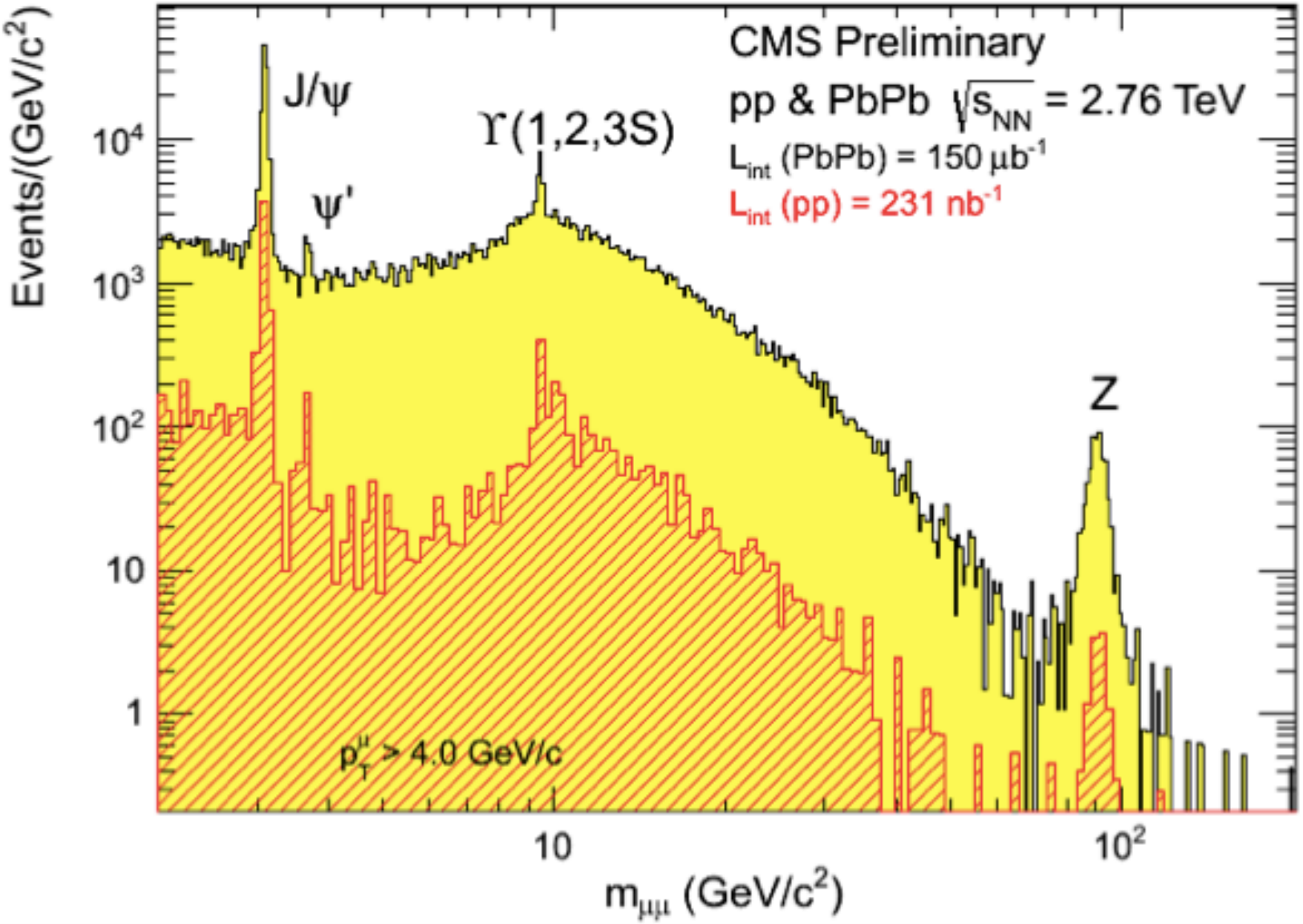


Jet-photon p_T balance drops by 14%



20% of photons lose jet partner

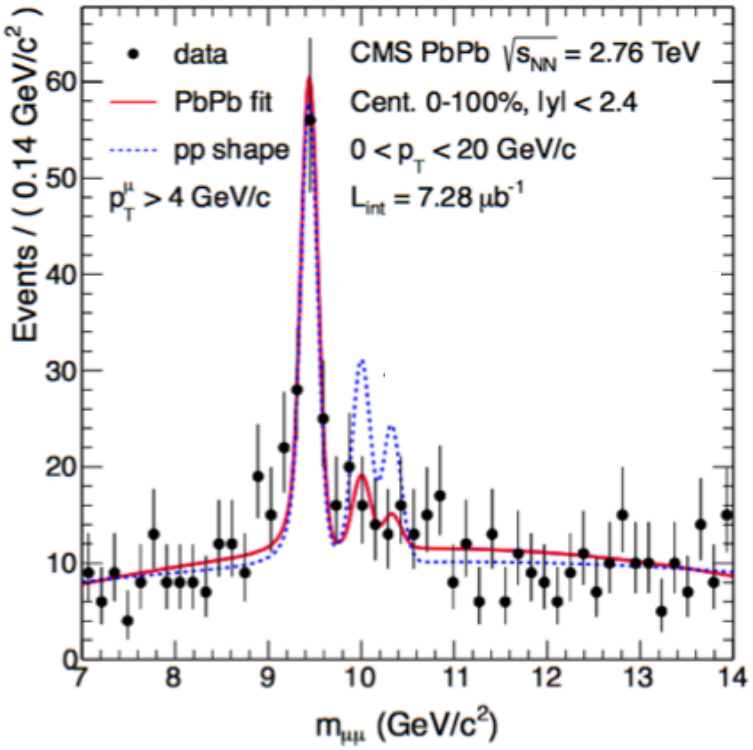
Di-muon invariant mass



Sequential Upsilon suppression

2010 data

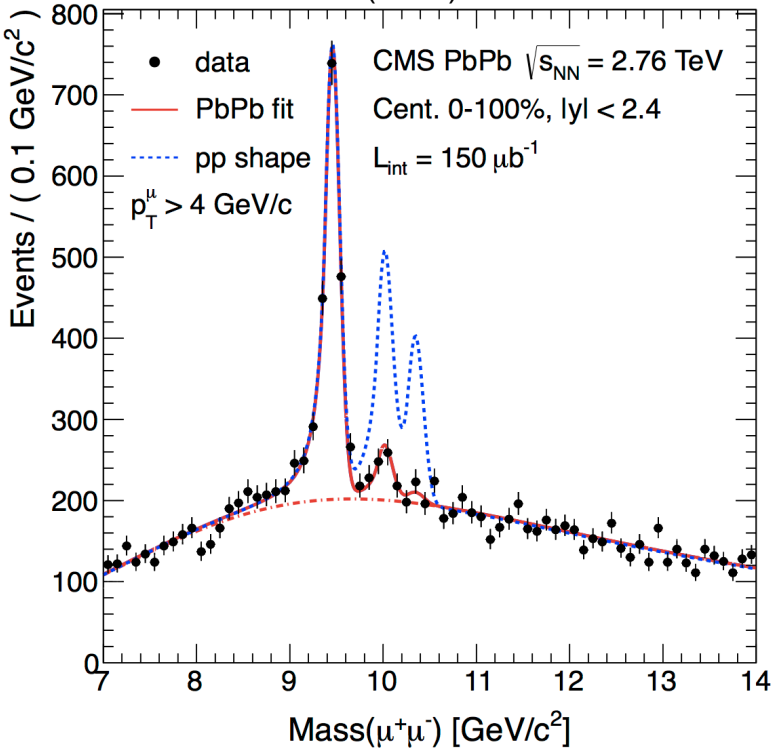
PRL 107 (2011) 052302



Indication of suppression of (Y(2S)+Y(3S)) relative to Y(1S)
→ 2.4σ significance

2011 data

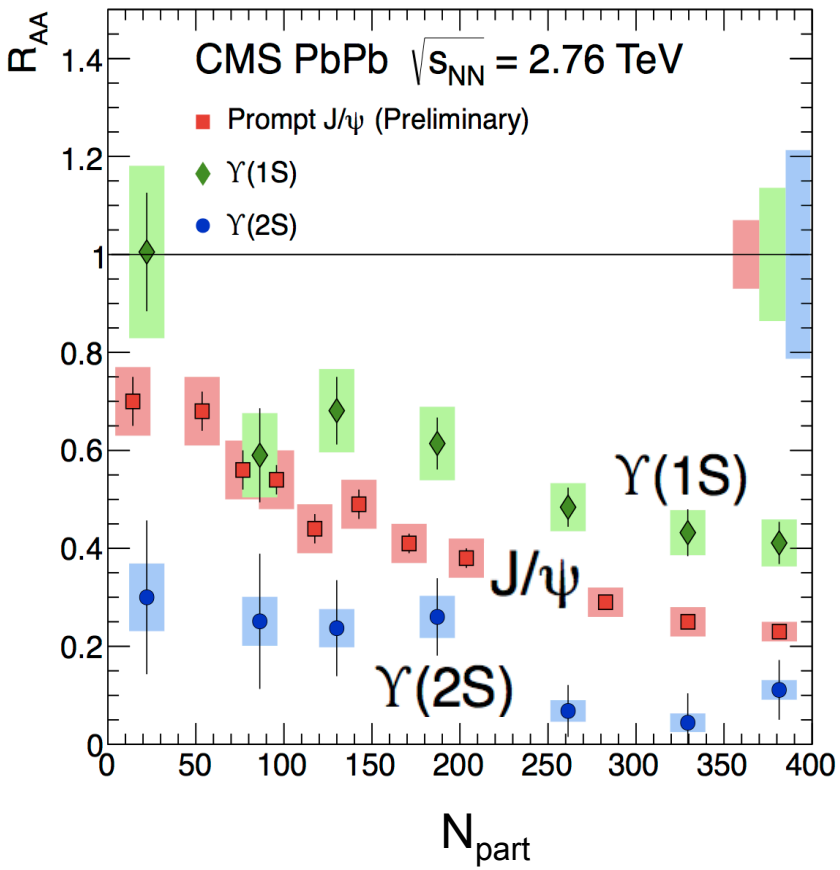
PRL 109 (2012) 222301



Observation of sequential suppression of Y family
→ Detailed studies

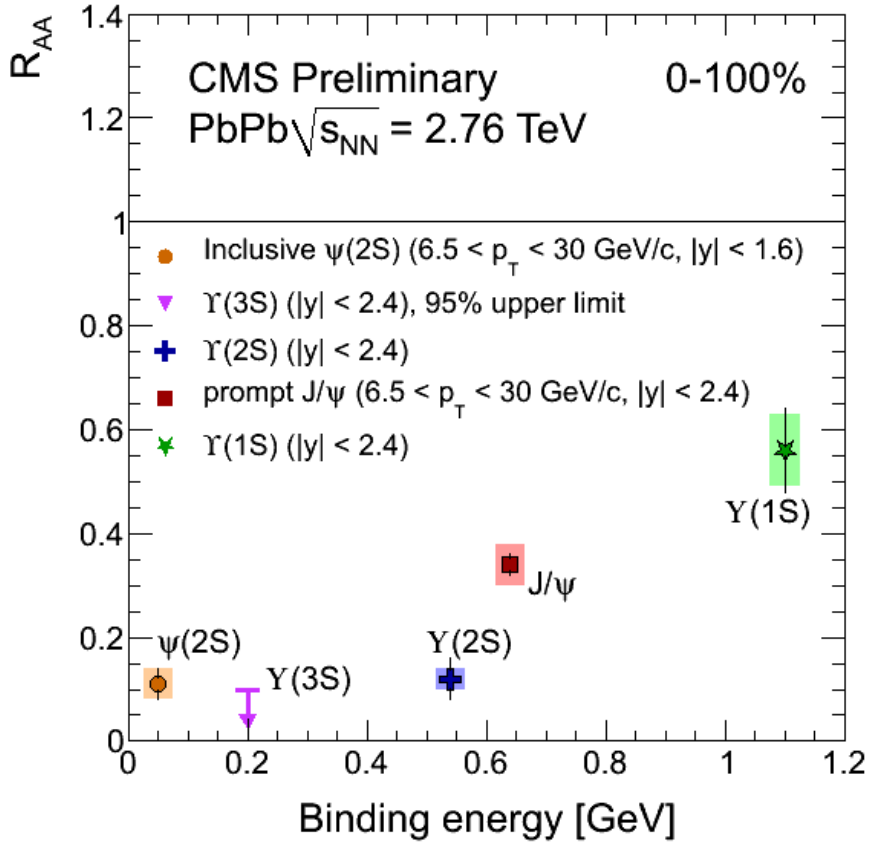
Building a quarkonium-thermometer

CMS-PAS HIN-11-011



Clear hierarchy in R_{AA} of different quarkonium states

Note: $6.5<p_T<30$ GeV for J/ψ and ψ(2s)



Expected in terms of binding energy

CMS-PAS HIN-12-014, HIN-12-007

Challenges and prospects

- Phase 0: 2010-2012
  - PbPb @ 2.76TeV: 160/μb
  - pPb @5TeV: 30/nb
  - pp @ 2.76 TeV: 5/pb

- Phase 1: 2014-2018 (up to LS2)
  - PbPb @ 5.5 TeV: 1.5/nb
  - pPb and pp @ 5.5 TeV equivalent statistics (50/pb pp)
  - smaller nucleus

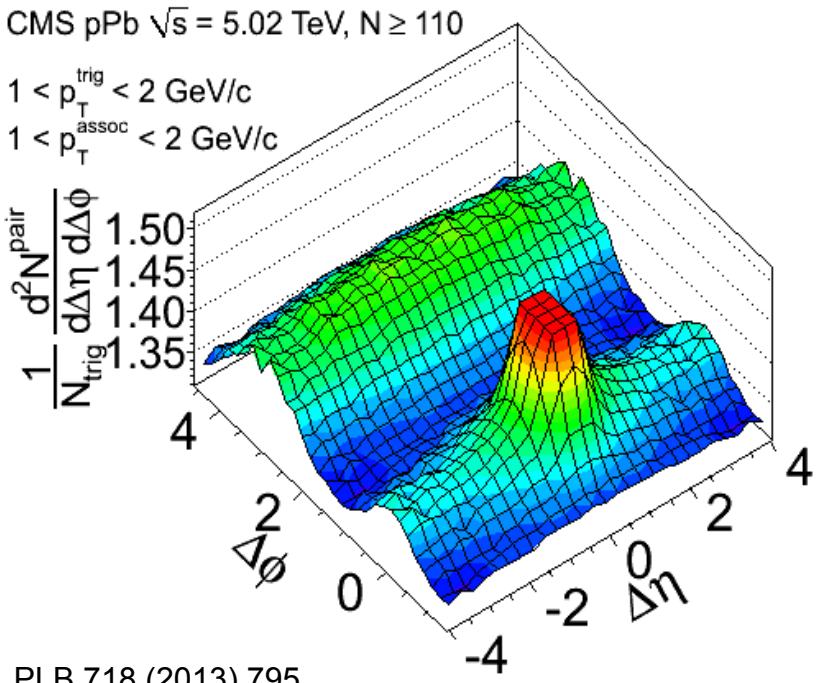
- Phase 2: 2020- (LS2 and beyond)
  - PbPb @ 5.5 TeV: increase total L_{int} to 10/nb
  - additional nuclei
  - pp equivalent statistics (500/pp)

Now

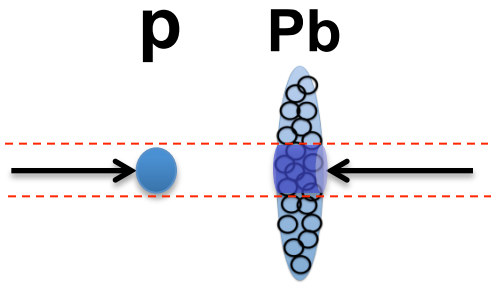
x10

x100

Now: What's the matter in pPb?

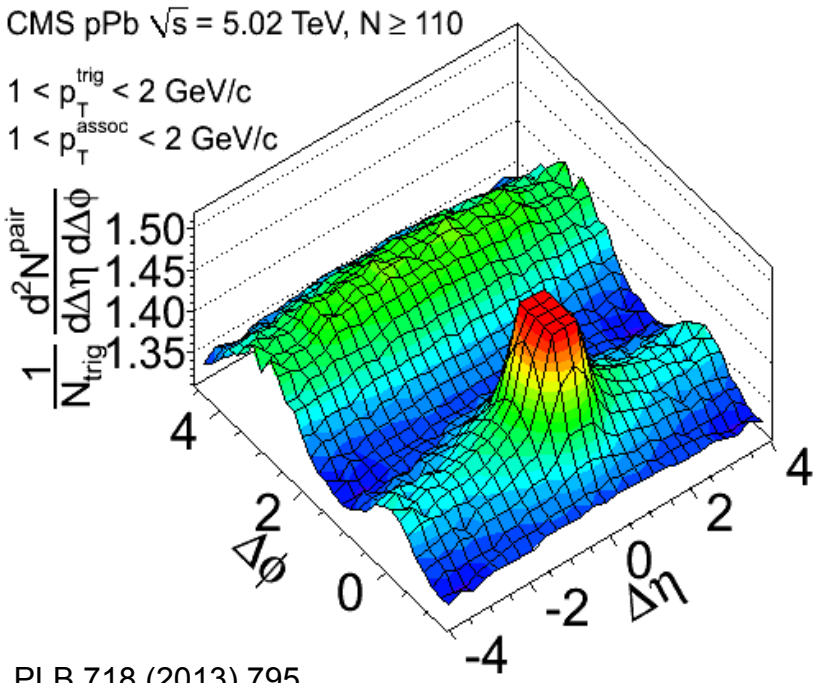


PLB 718 (2013) 795

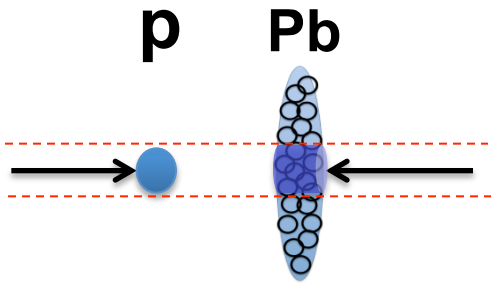


Clear evidence of collective behavior in pPb (and pp)

Now: What's the matter in pPb?



PLB 718 (2013) 795



Clear evidence of collective behavior in pPb (and pp)

Do we see other "matter" effects? (jets, quarkonia)

Yes → ?

No → ?

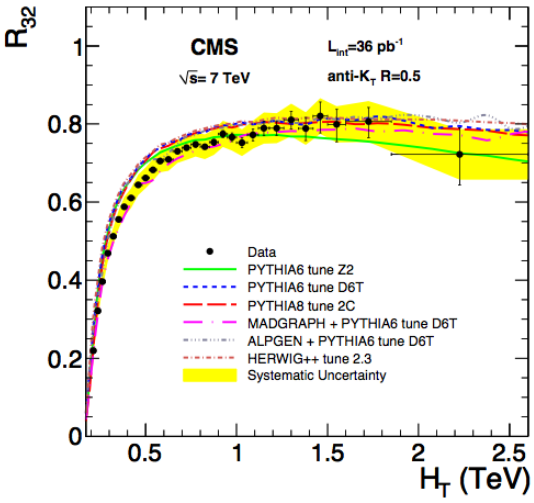
expect answers before summer…

After LS1: Precision + Accuracy

- For now, “Golden channels” suffer from limited statistics
  - γ+jet, Z^0+jet, Υ(nS) vs N_{part}
- Expect further increase in luminosity
  - Machine predictions have been very conservative
- Key issue in CMS: Selectivity of L1 trigger
  - PbPb input rate for high level trigger limited to < 3kHz
  - E.g. 50kHz PbPb requires 95% rejection at L1
    - Current configuration limited to 50% for jet triggers
    - requires background subtraction at L1
- L1 upgrade proposal approved by CMS
  - (Moderate) funding request for 2013-15 (HEP+NP)

LS2 and beyond: New Frontiers

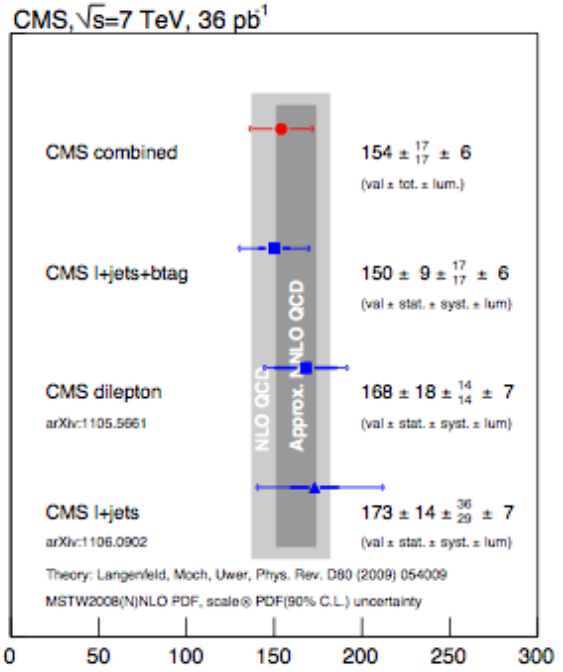
- CMS upgrade for HL-LHC
  - Trigger/DAQ ready for highest conceivable PbPb rates
  - Major upgrades for silicon tracker, calorimeters, trigger
- 10/nb PbPb corresponds to several 100/pb pp



Multi-jet ratios!

Statistics to pursue sophisticated QCD measurements

Full arsenal of pp heavy-flavor analyses (b-physics, top)



Top quarks?

Summary

- CMS has delivered a wide range of results for hard probes in HI collisions at the energy frontier
- Selective trigger is key component
  - L1 upgrade
- Strong physics program for x10 and x100 increase in integrated luminosity (2014-2018 and 2020-)
  - From "First observation" to "Precision measurement"
    - photon-jet, Z^0-jet, sequential quarkonium suppression,….
  - Beyond "single particles"
    - Correlations of rare probes with bulk properties (system size, flow)
    - Differential multi-object measurements
  - Use full arsenal of pp observables/analysis techniques
    - Particle flow, missing p_T, b-tagging, life-time fits, top quark ID,…