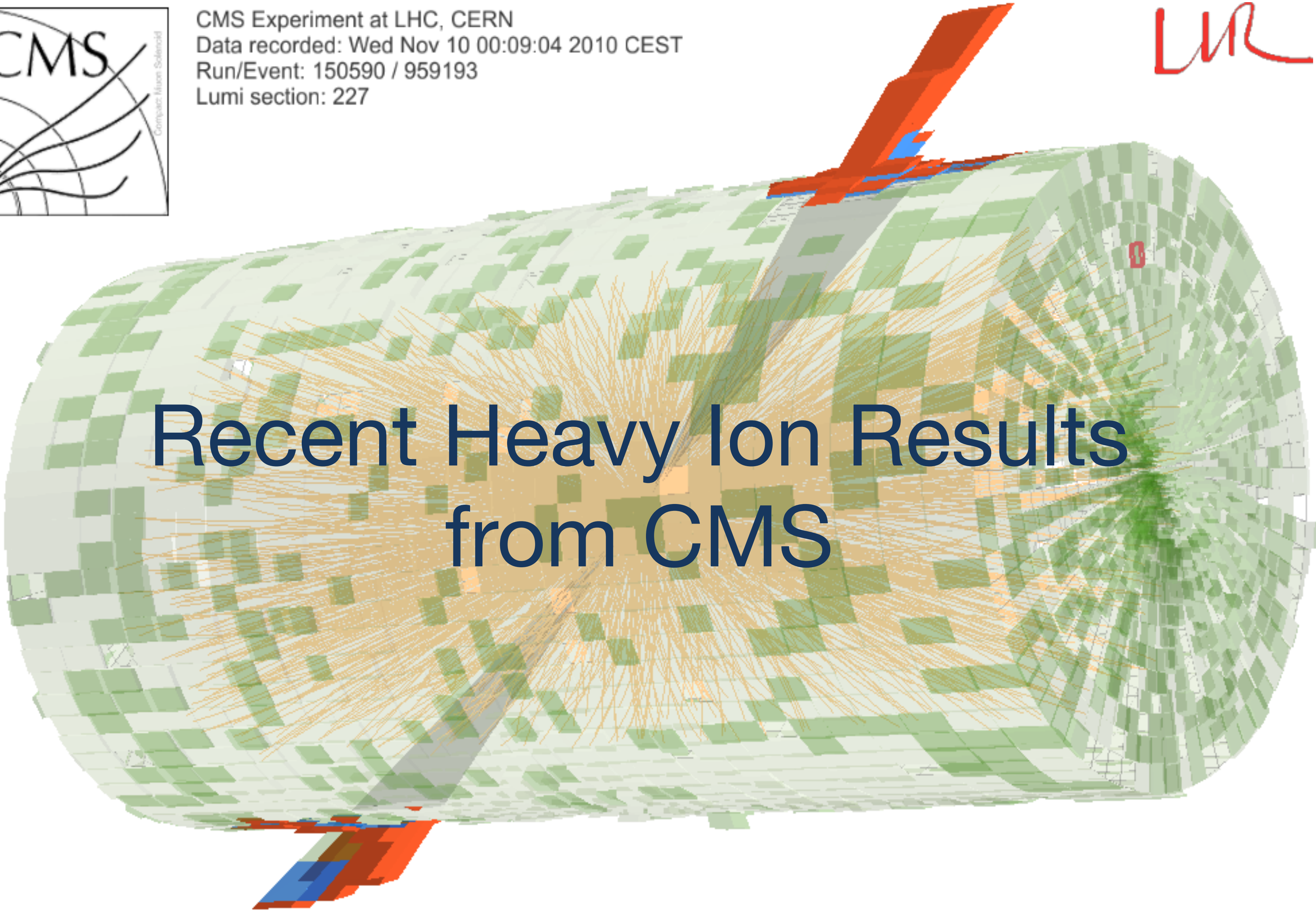
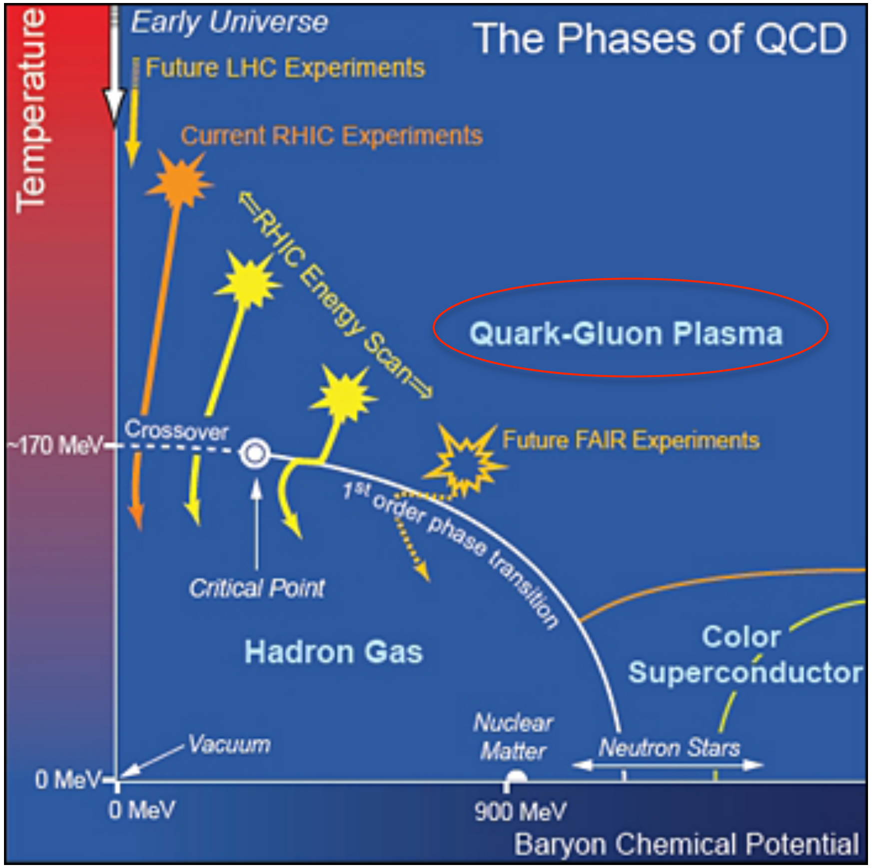
Recent Heavy Ion Results from CMS



Matt Nguyen, LLR—Ecole Polytechnique 26-11-13

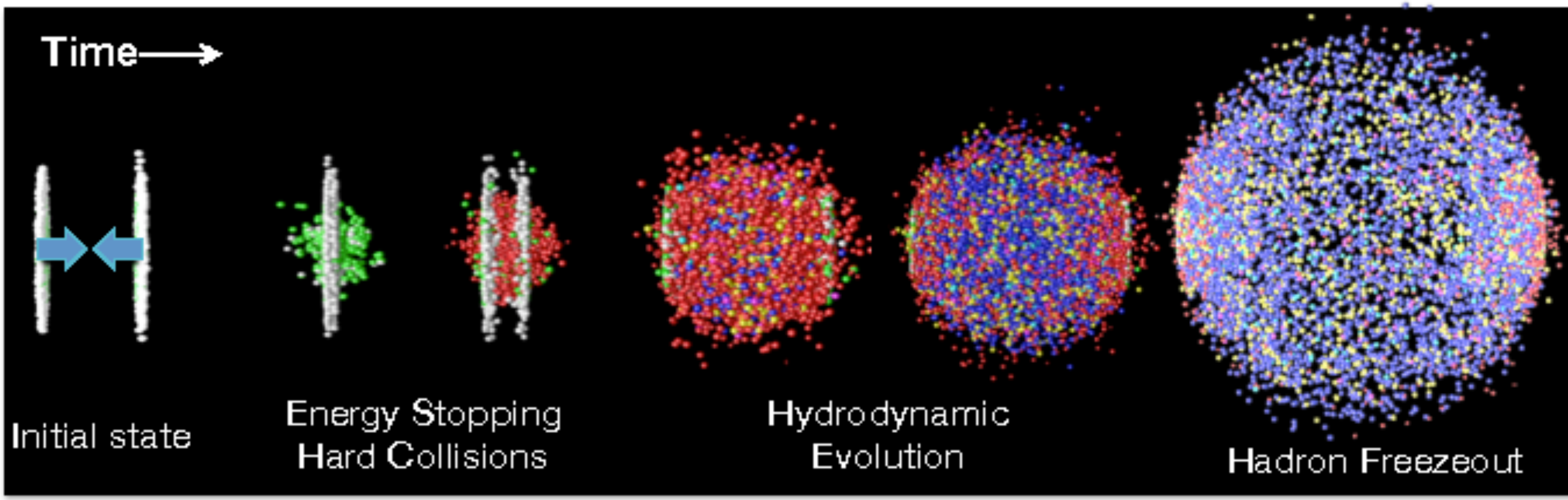
Exploring hot QCD w/ heavy ions

- Lattice QCD predicts a phase transition near T = 170 MeV
- High T regime accessible w/ high-energy HI collisions
- Replicates conditions of the early universe



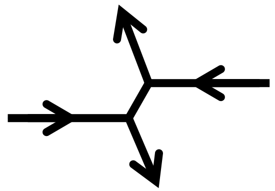
source: www.bnl.gov

Evolution of a HI collision

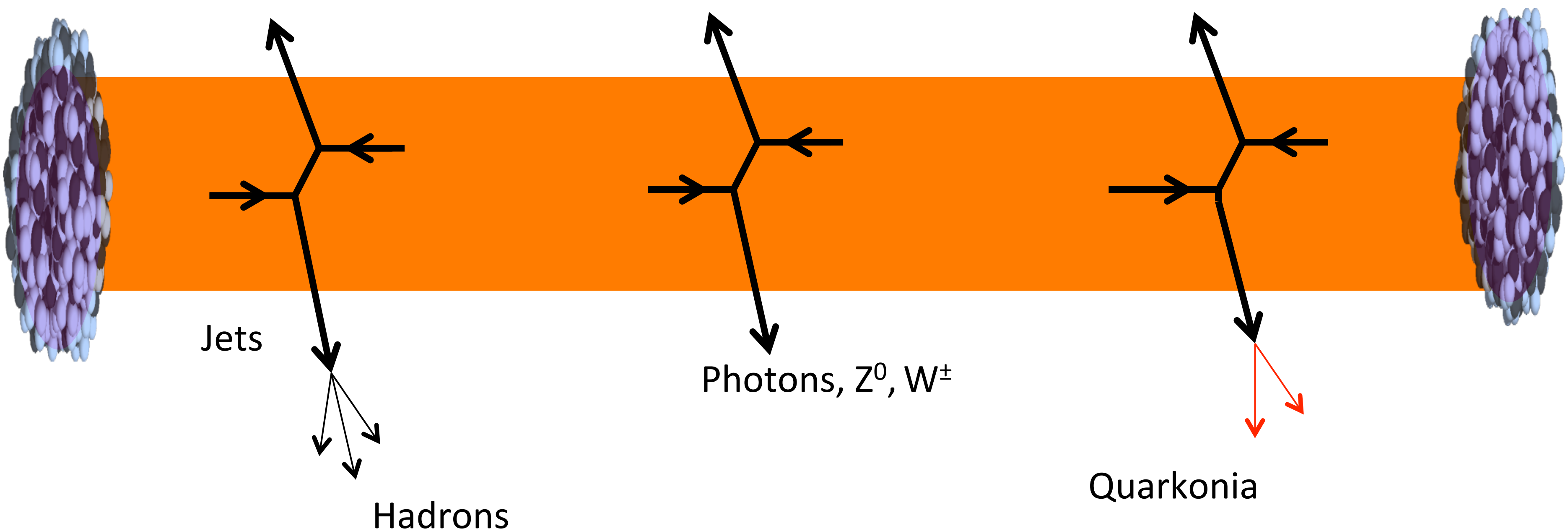


- Soft/global observables, e.g., multiplicity, particle correlations
- Hard probes, e.g., jets, EW bosons, quarkonia

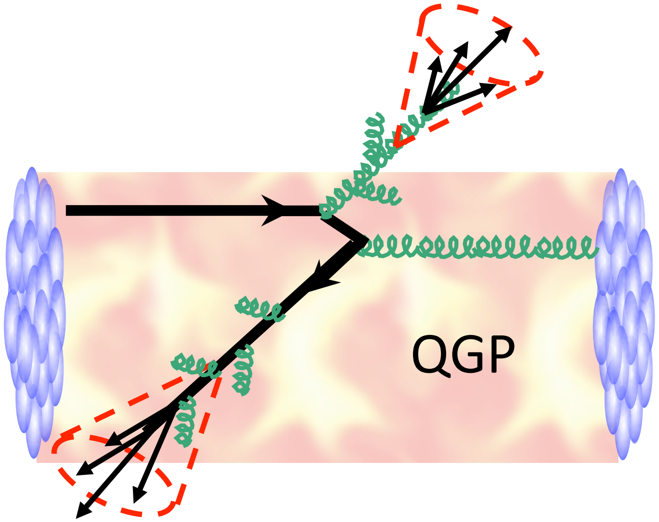
The hard probes paradigm

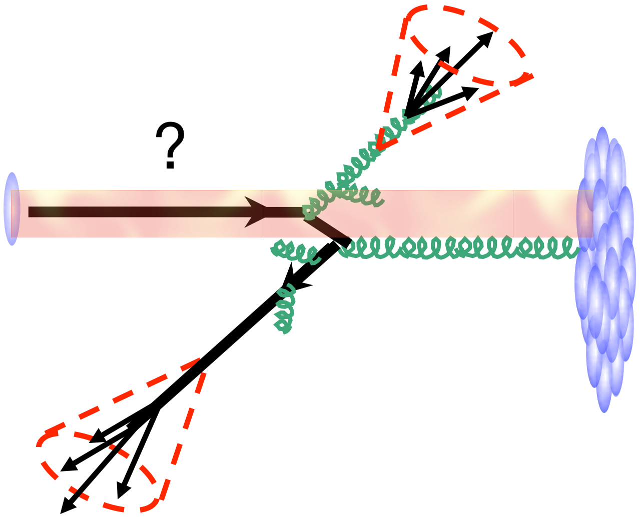


- Hard scattering in vacuum
  - Well understood in pQCD
  - Measurable in pp collisions
- How does picture change w/ a hot QCD medium?

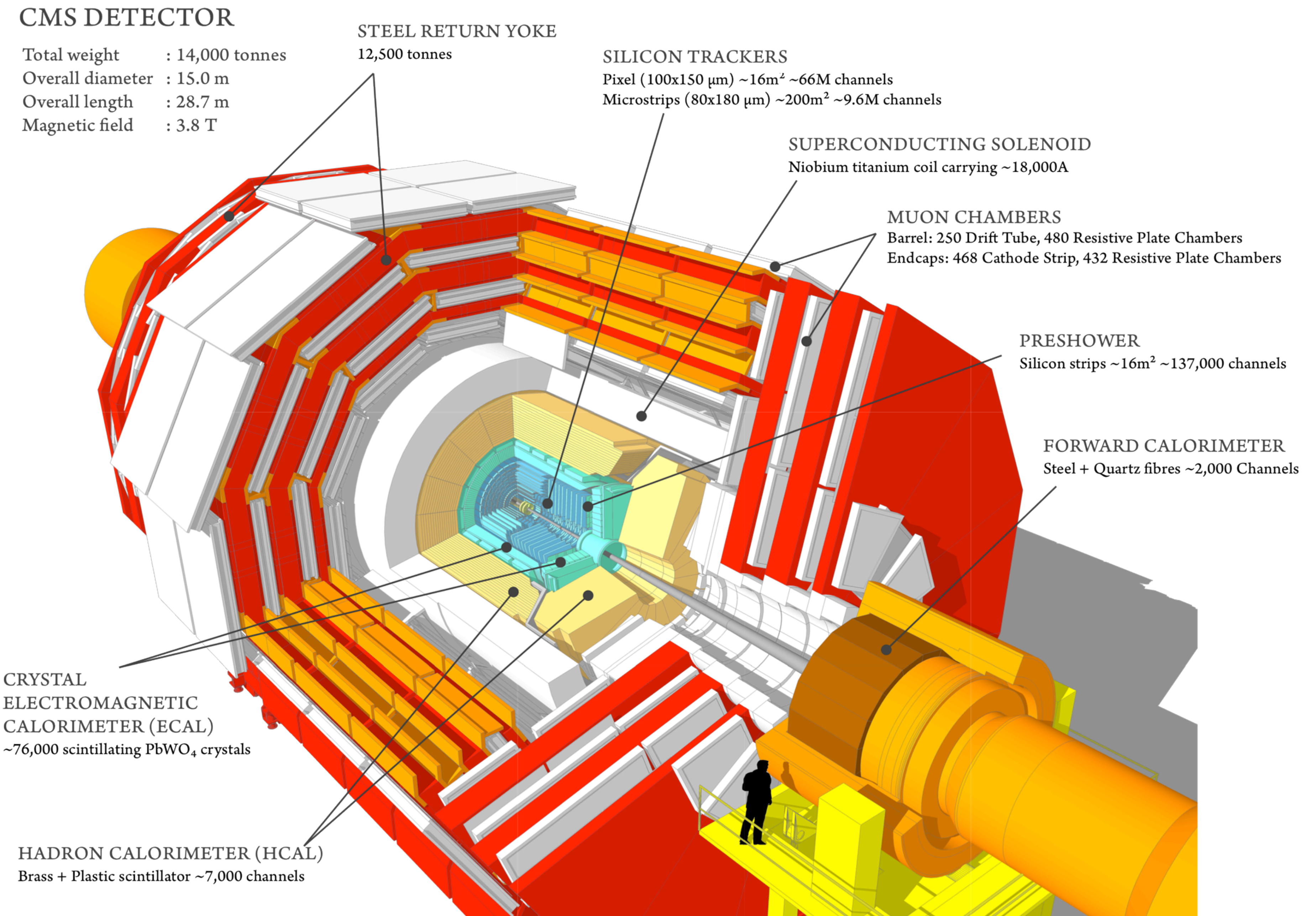


Proton-lead collisions

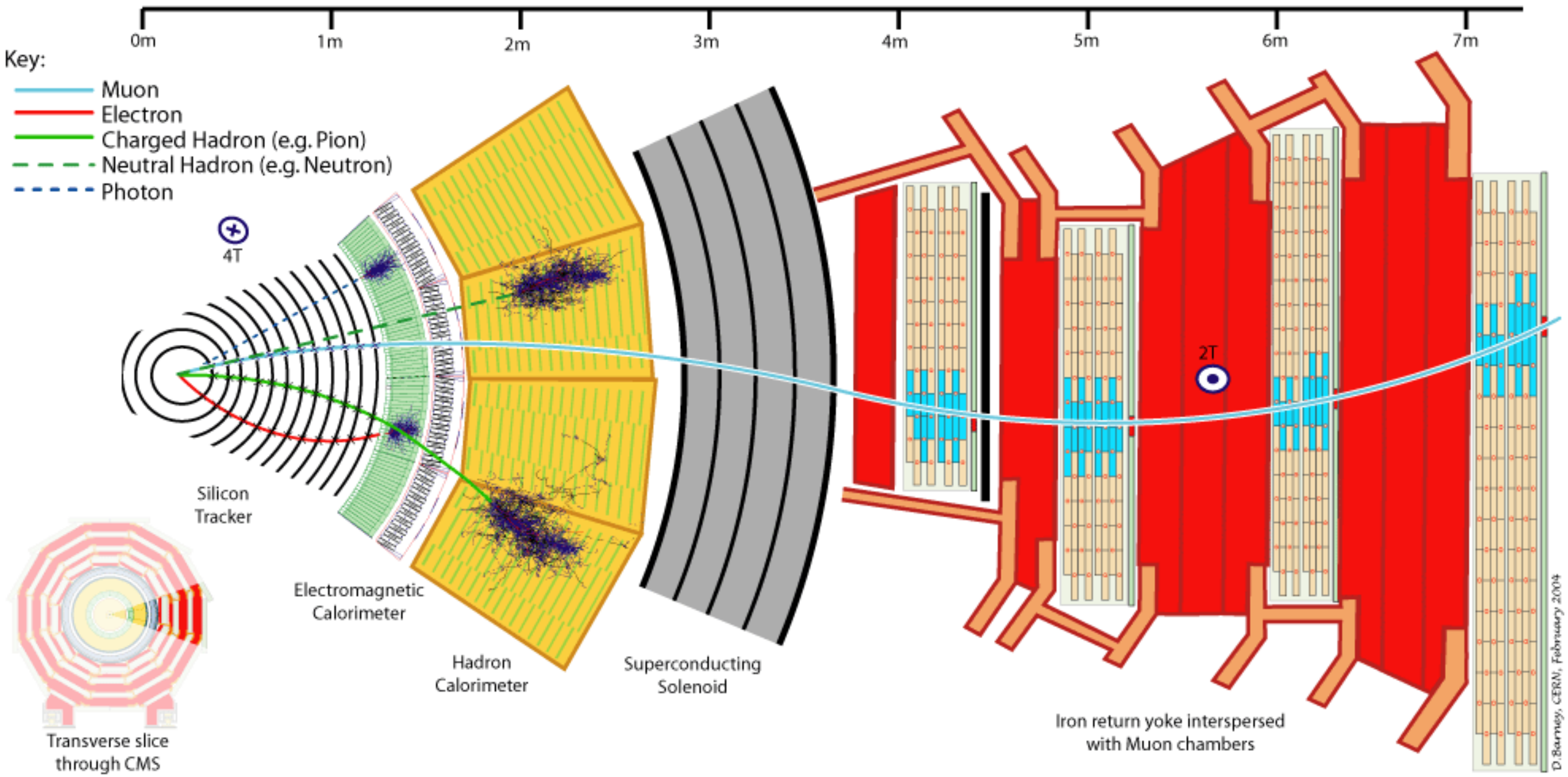




- Investigate initial state nuclear effects, e.g., nuclear modification to the PDFs (nPDF)
- Final-state effects in cold nuclear matter (mostly) expected to be small w.r.t. QGP effects
- Is there evidence for HI-like effects in p-Pb?

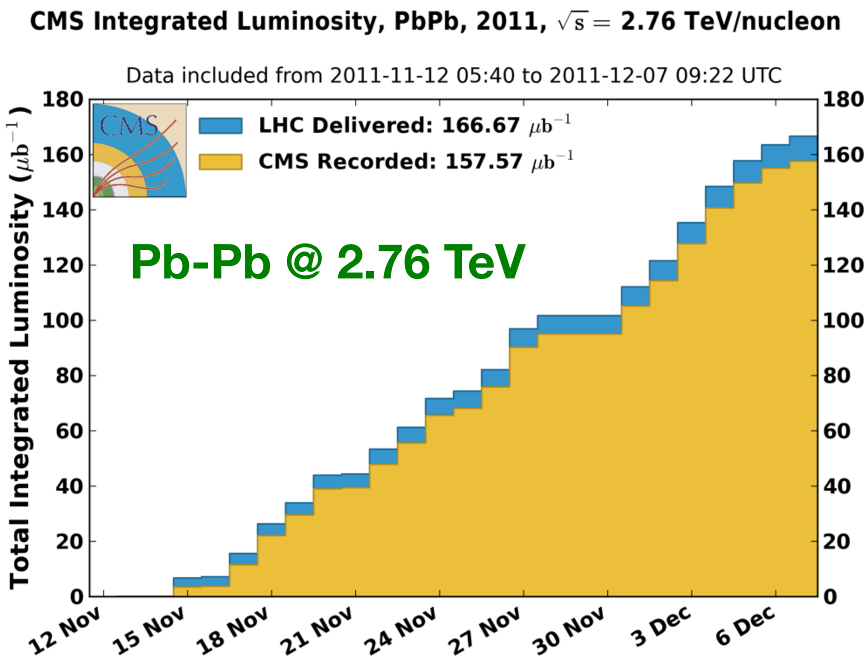

CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

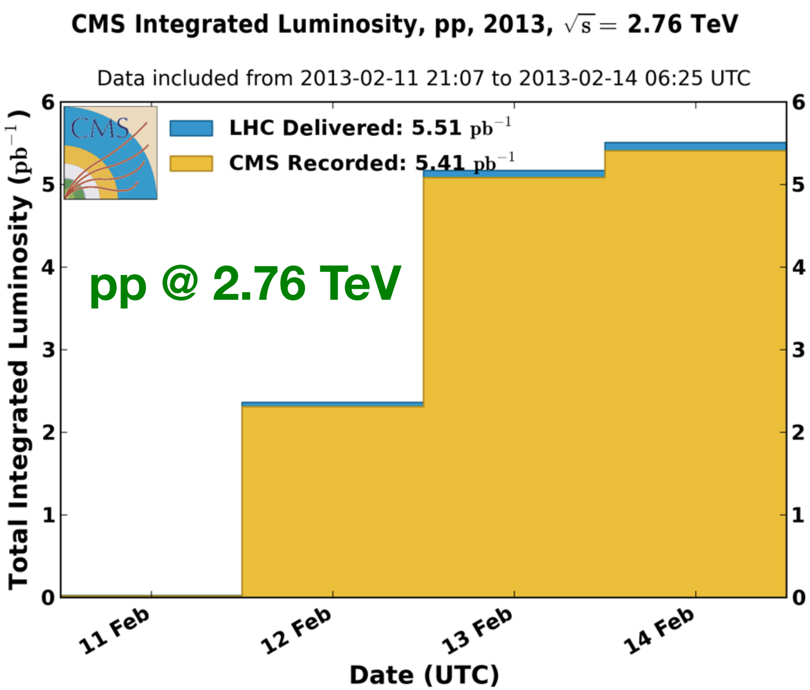
Particle ID in CMS

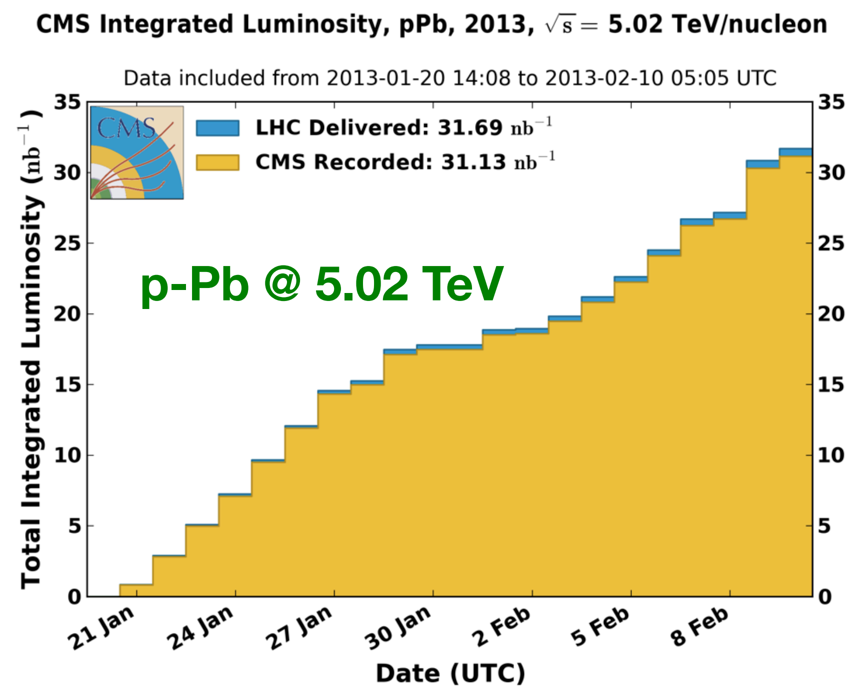


LHC Run 1

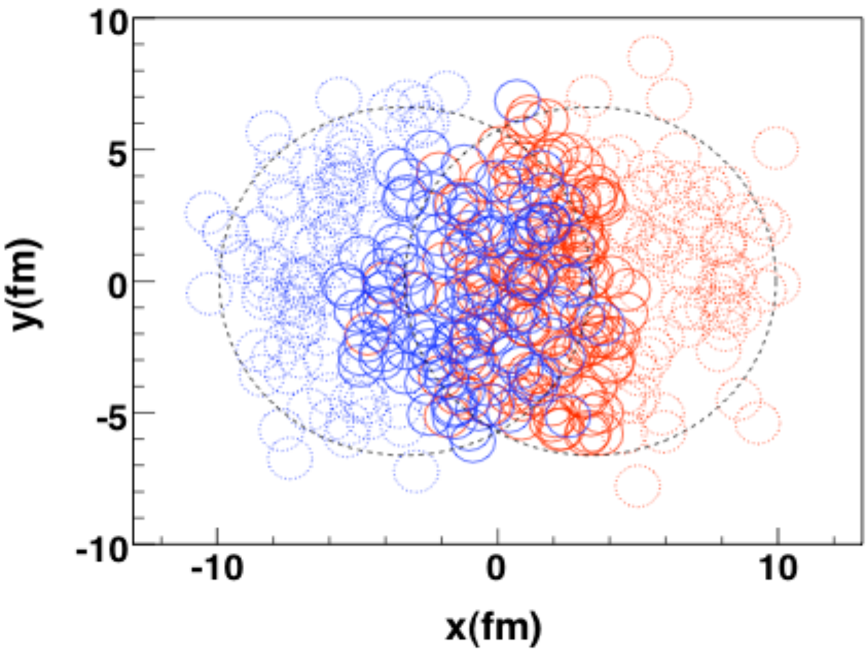
Comparable statistics for rare probes in all 3 systems





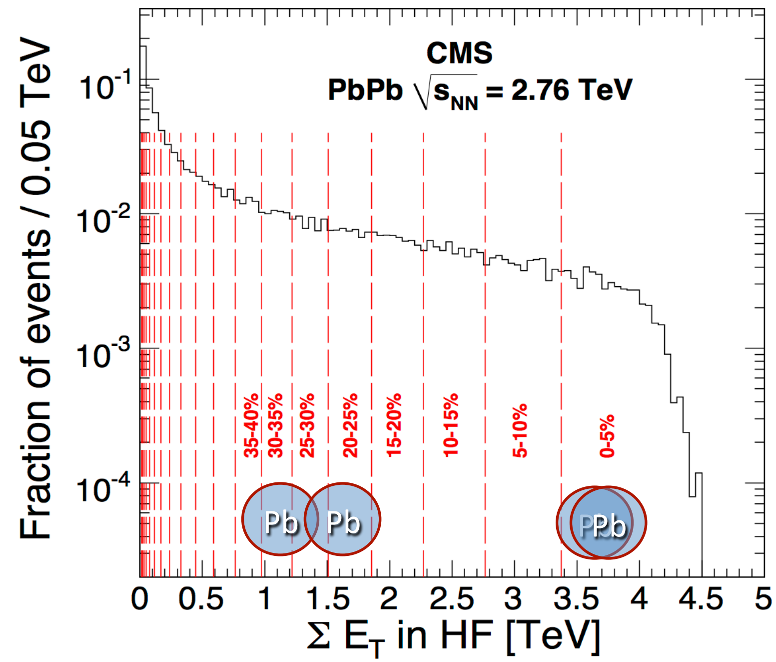


Collision centrality



Nuclear effects dependent strongly on collision impact parameter

JHEP 08 (2011) 141



Centrality: classify events according to some measure of overall activity

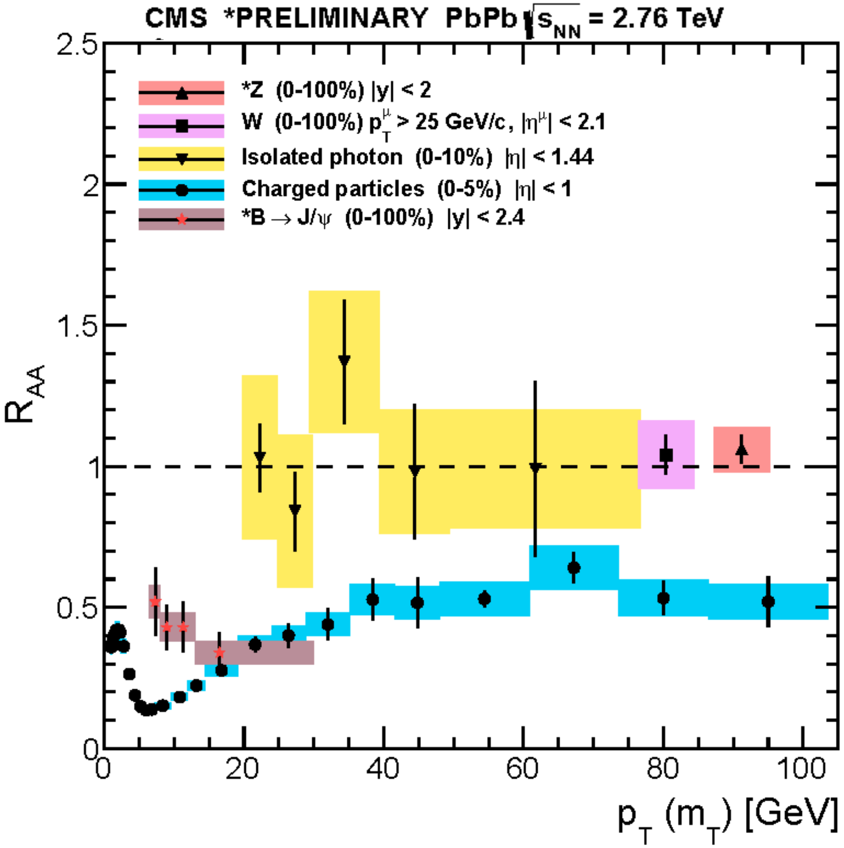
Typically use forward detectors, well separated from region we want to study

Using a Glauber model, centrality is translated into collision properties: Impact parameter, # of participating nucleons (N_{part}), # of collisions (N_{coll}), etc.

Nuclear modification factor (R_{AA})

$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta} = \frac{\text{Yield in AA}}{\text{Yield expected from pp}}$$

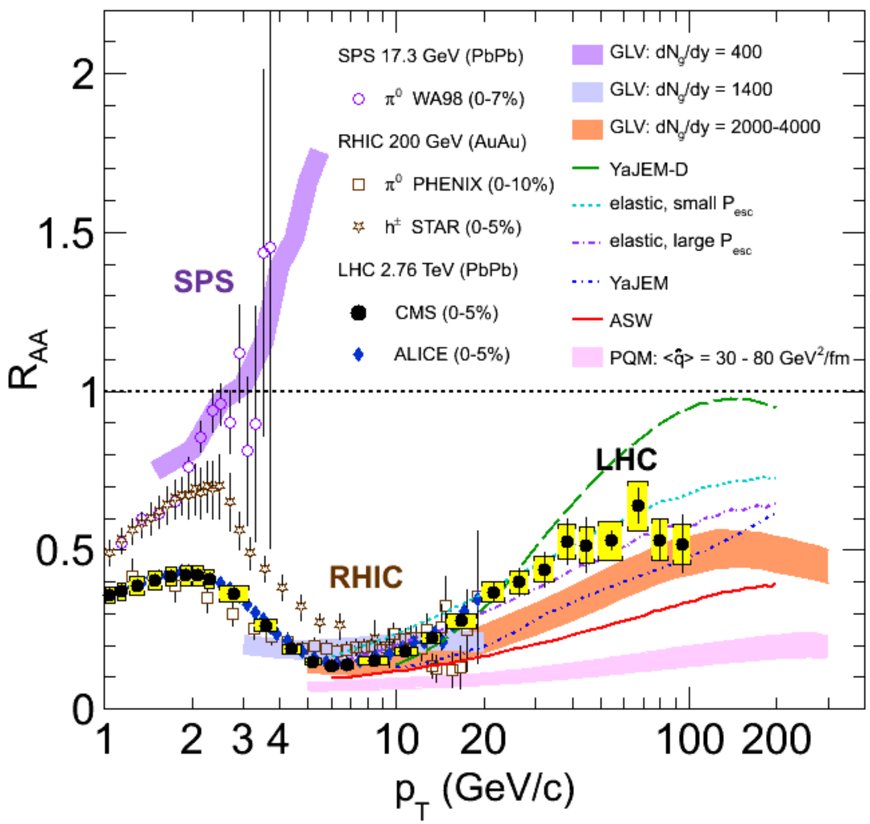
- R_{AA} quantifies departure from expectation based on pp collisions
- Colorless probes are free-streaming
- Rate of high p_T charged particles is strongly suppressed → jet quenching
- So are hadrons from heavy flavor



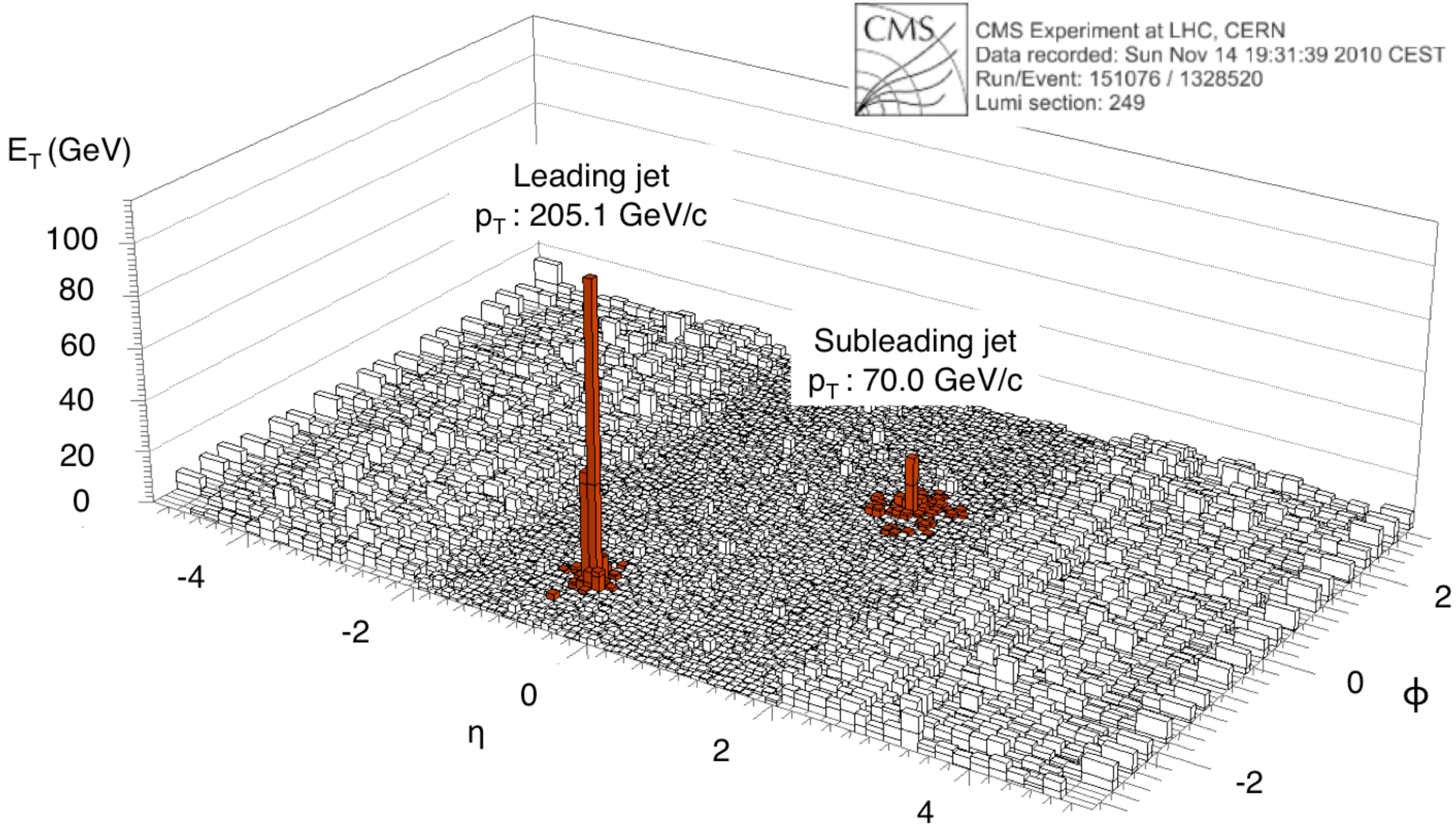
Charged particle suppression

- Turn-on of suppression from SPS to LHC
- Constrains models of parton energy loss
- Limitations:
  - Path length biased
  - Convoluted with FF
- Reconstructed jets provide a more direct window into the dynamics of parton-medium interactions

EPJC 72 (2012) 1945



Dijet in a Pb-Pb collision

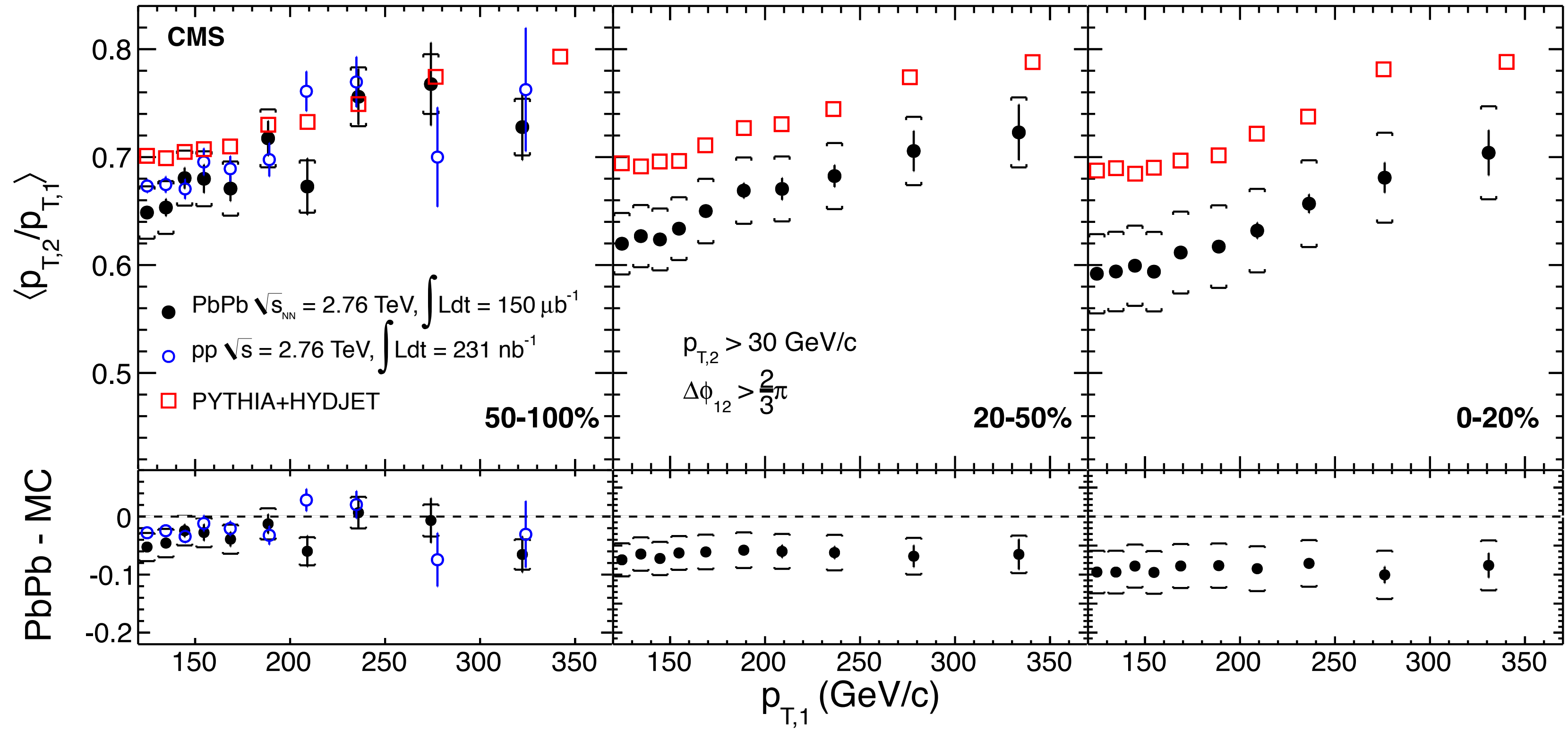


- Clean access to jets in HI possible for the 1st time at the LHC
- Jet quenching manifest as large p_T asymmetry visible e-by-e
- Subtraction of Pb-Pb underlying event is non-trivial

Dijet p_T imbalance

Subleading jet p_T / leading jet p_T

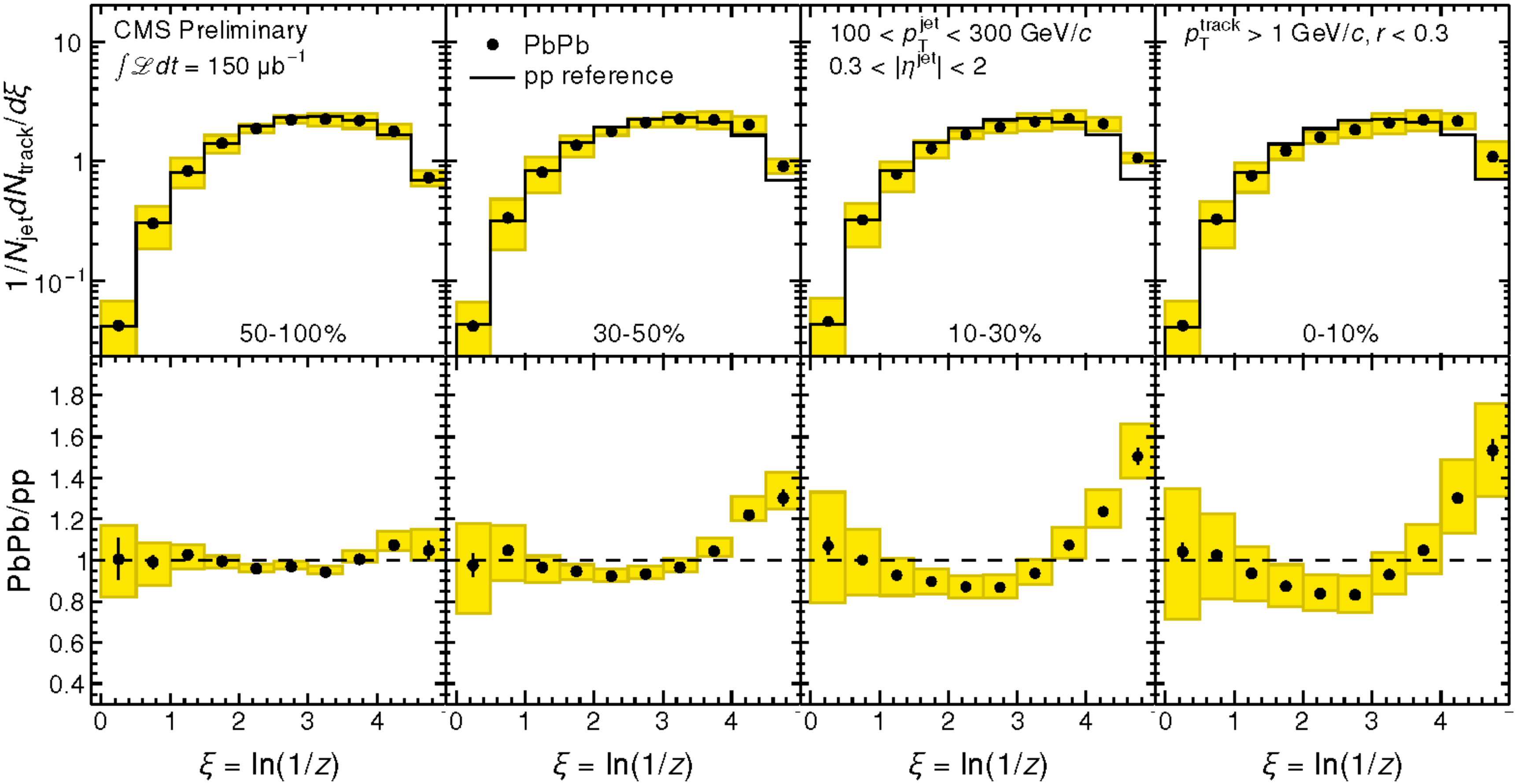
PRL 109 (2012) 022301



- Gradual turn on of quenching with increased collision centrality
- Effect persists out to largest values of jet p_T
- Difference in ratio between data and MC does not depend strongly on p_T
- Caveat: Not corrected for jet resolution effects

"Fragmentation functions"

z = track p_T / **reconstructed** jet p_T (R=0.3) CMS-PAS-HIN-12-013



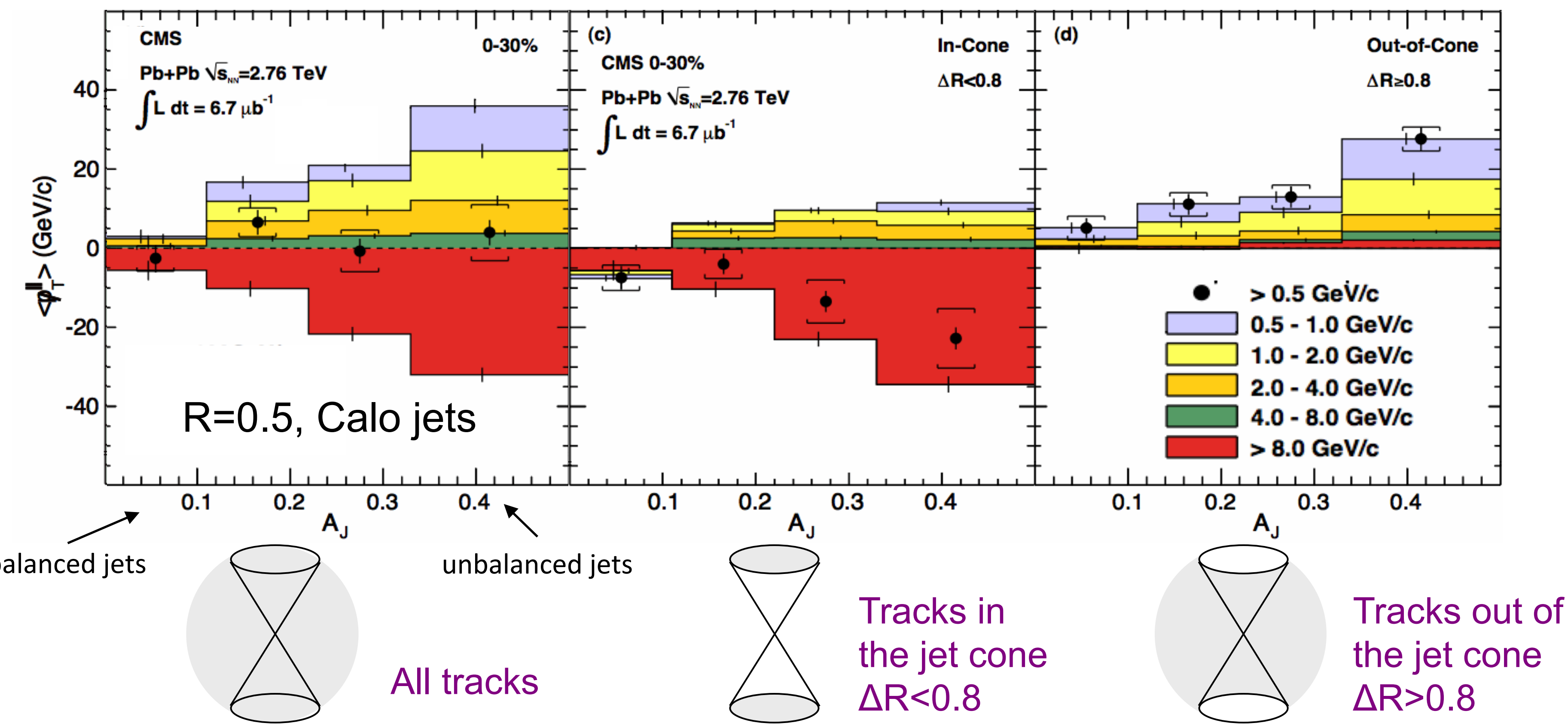
Relatively mild distortion of the jet fragmentation pattern inside the jet cone

Missing $p_T^{||}$

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

PRC84 (2011) 024906

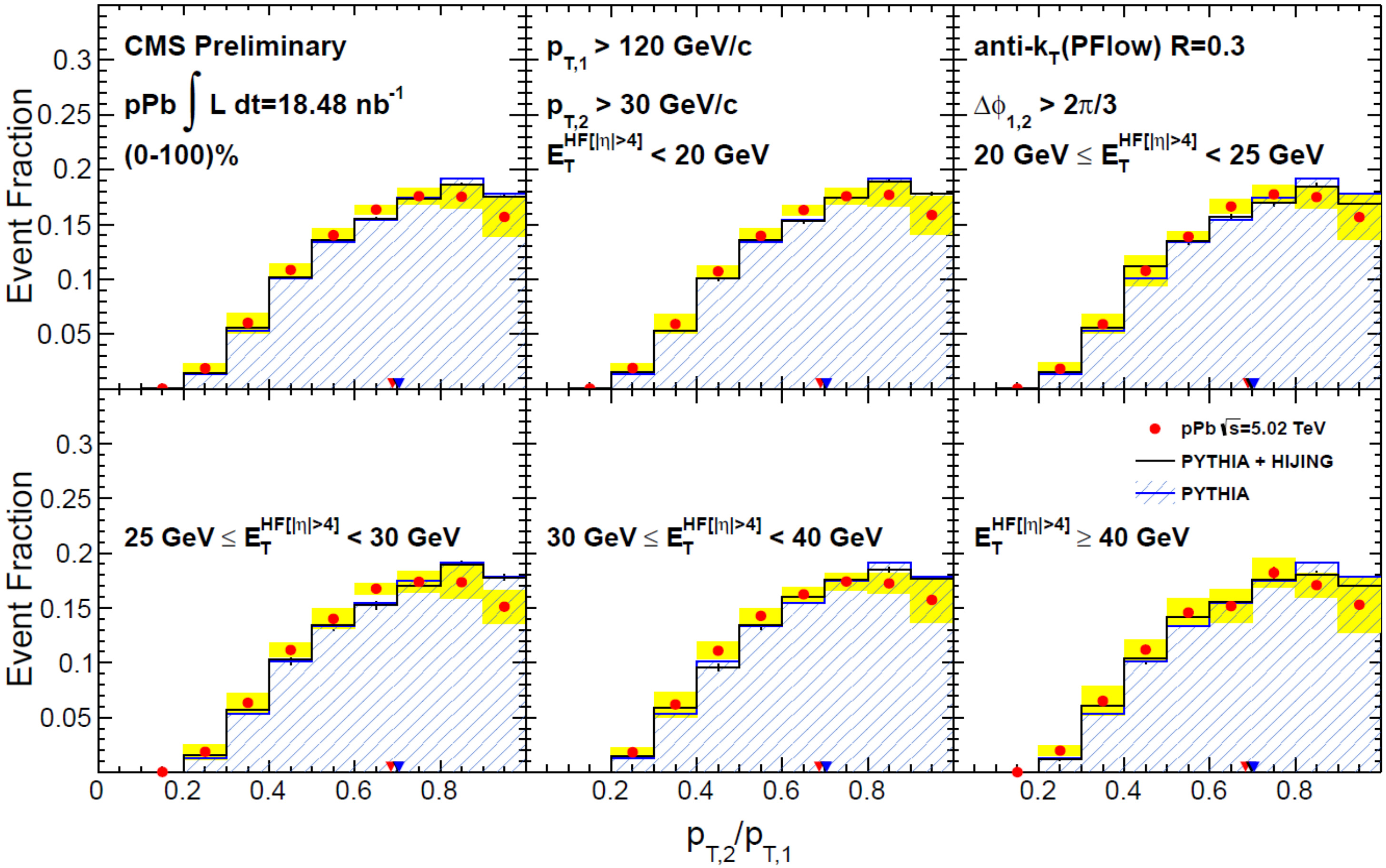
0-30% Central PbPb



The momentum difference in the dijet is balanced by low p_T particles outside the jet cone

Dijets in p-Pb

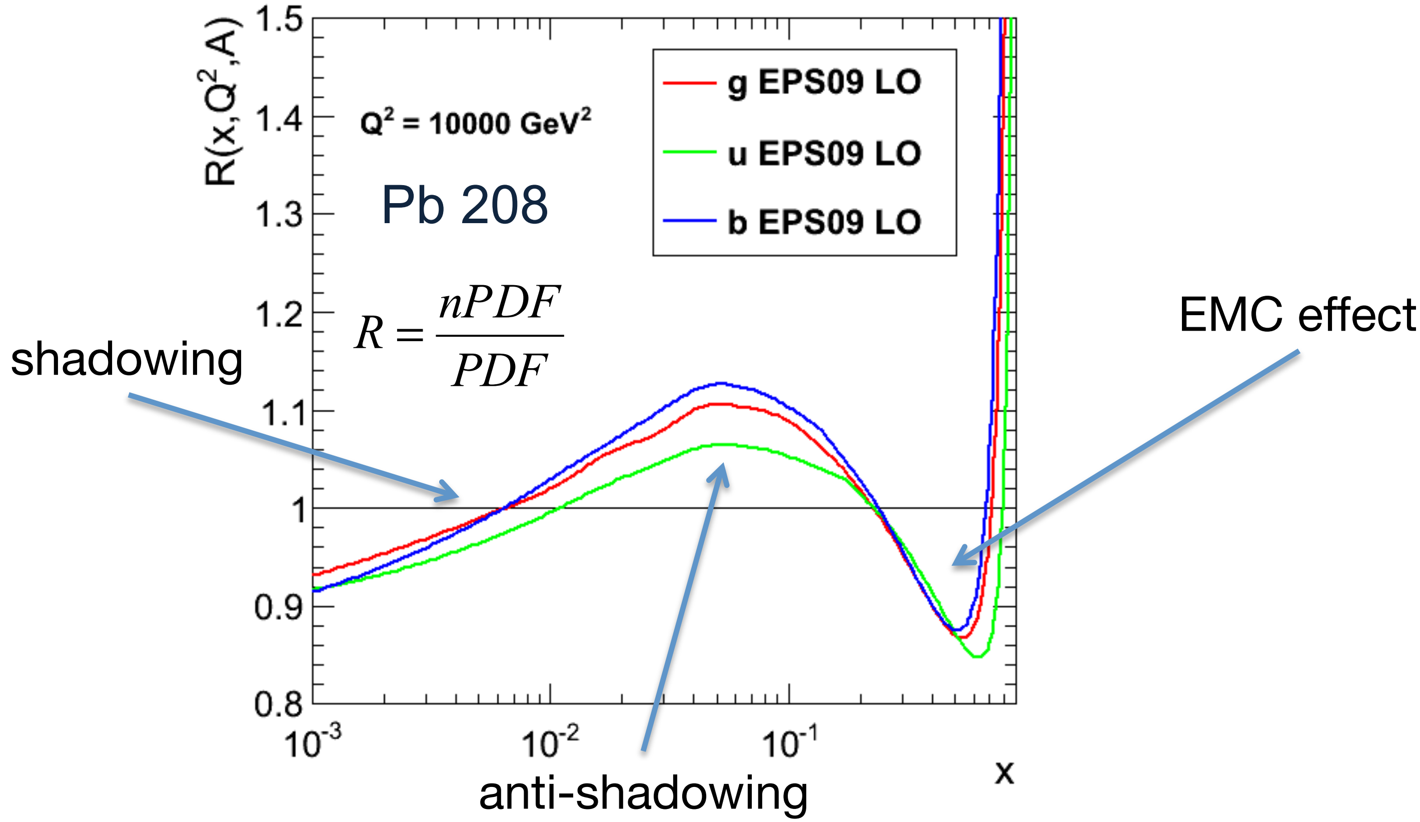
CMS-PAS-HIN-13-001



No evidence of jet quenching even in the events with the largest activity in the HF

Nuclear parton distributions

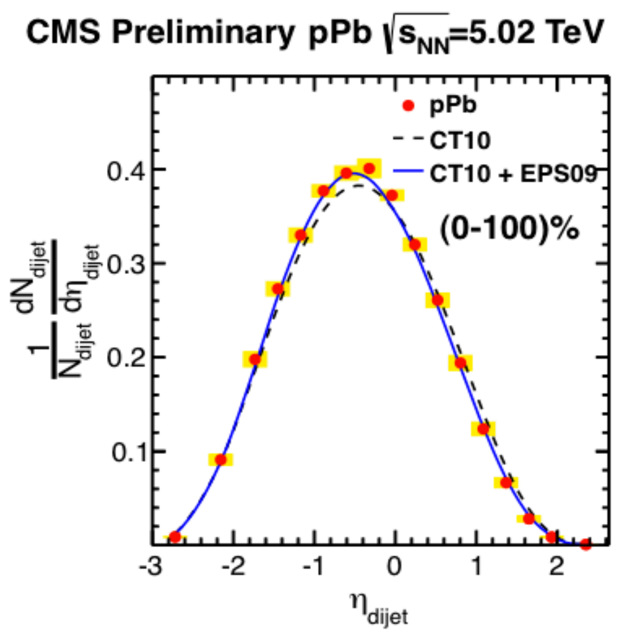
Source: François Arleo and Jean-Philippe Guillet http://lapth.cnrs.fr/npdfgenerator/



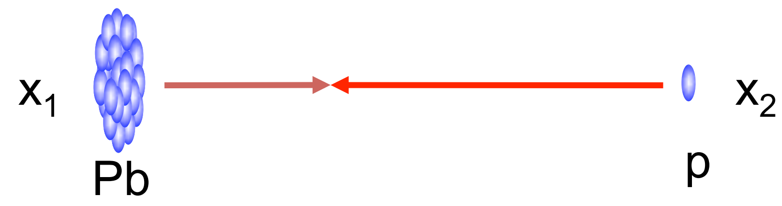
- Distributions of partons in nuclei are modified by ~10% for the relevant Q^2
- Poor agreement among various global fit analyses

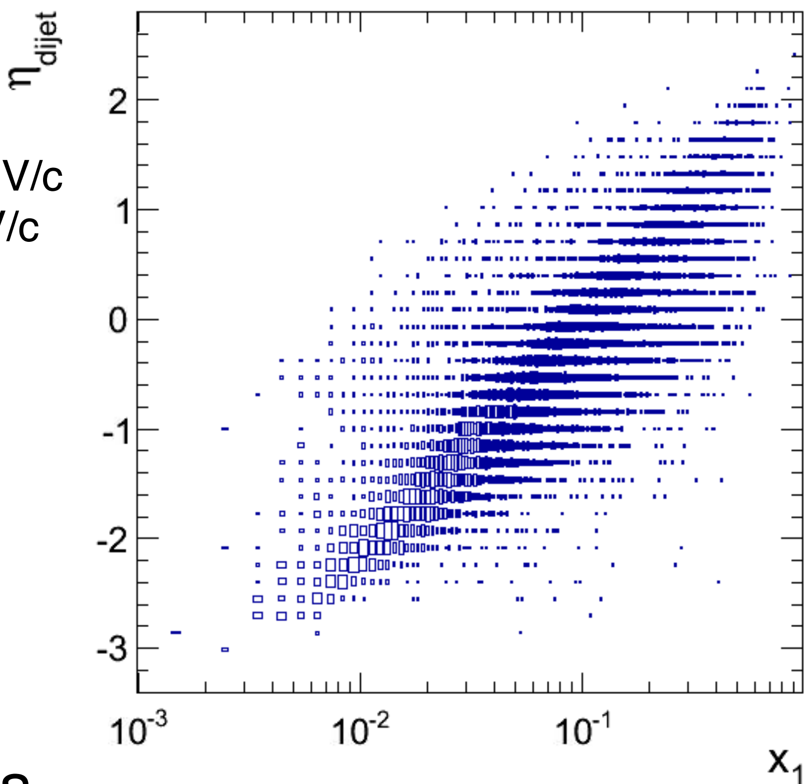
Dijet pseudorapidity

CMS-PAS-HIN-13-001



$p_{T,1} > 120$ GeV/c
$p_{T,2} > 30$ GeV/c
$|\Delta\phi_{12}| > 2\pi/3$

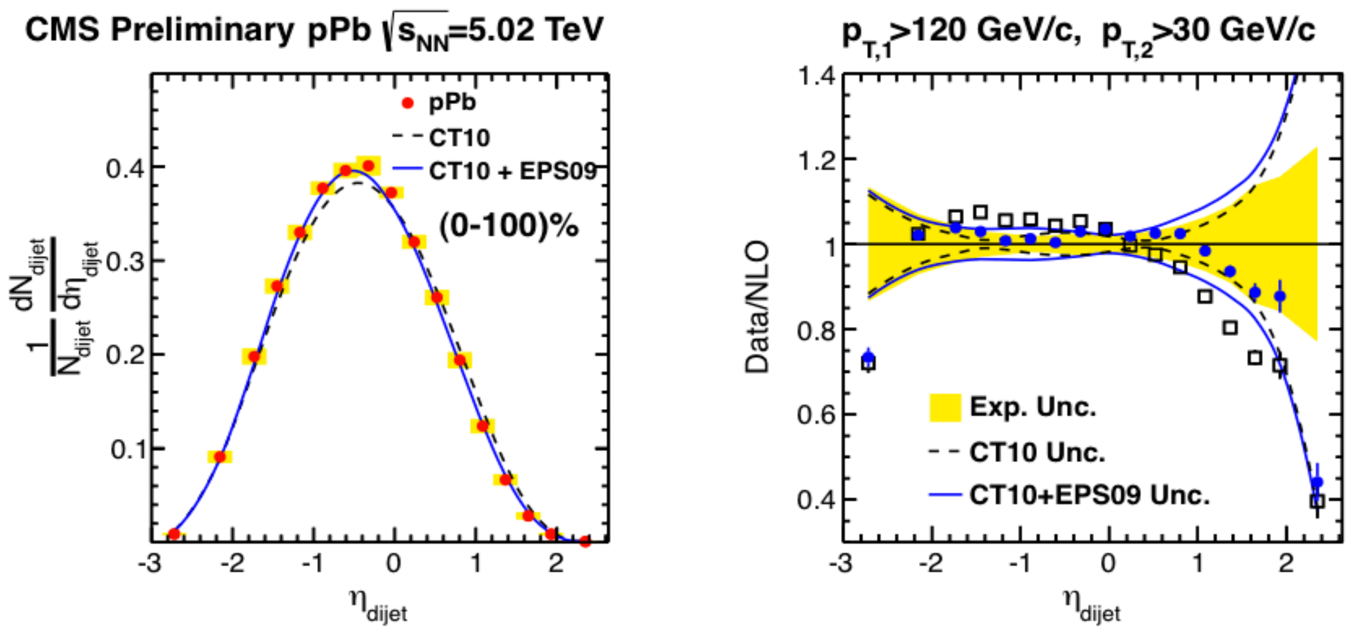




- The dijet η distribution is sensitive to nuclear effects
- Probes shadowing, anti-shadowing and EMC regimes

Dijet sensitivity to nPDF

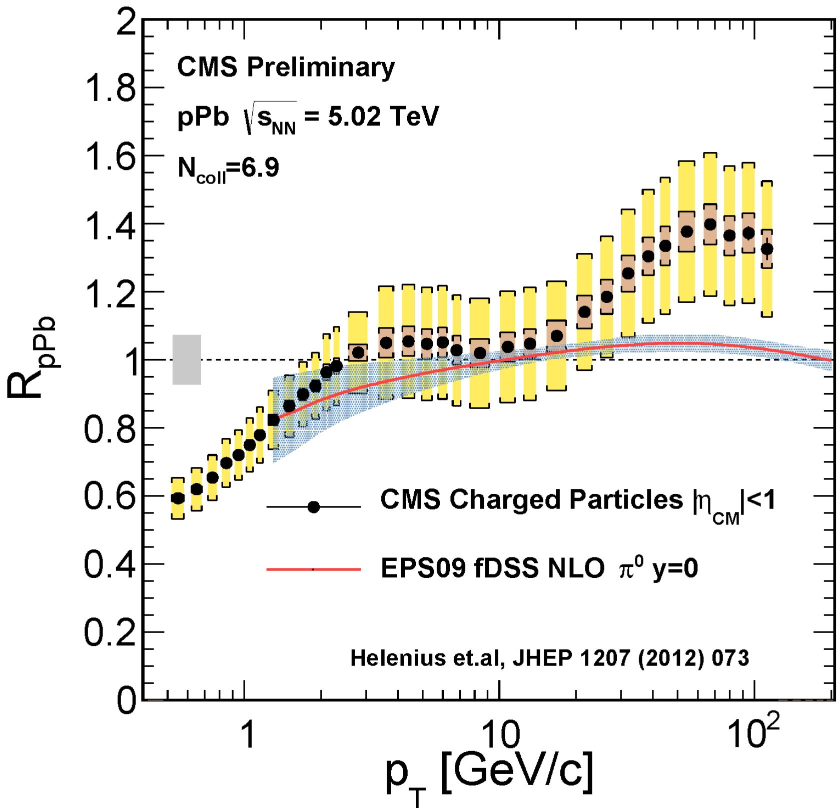
CMS-PAS-HIN-13-001



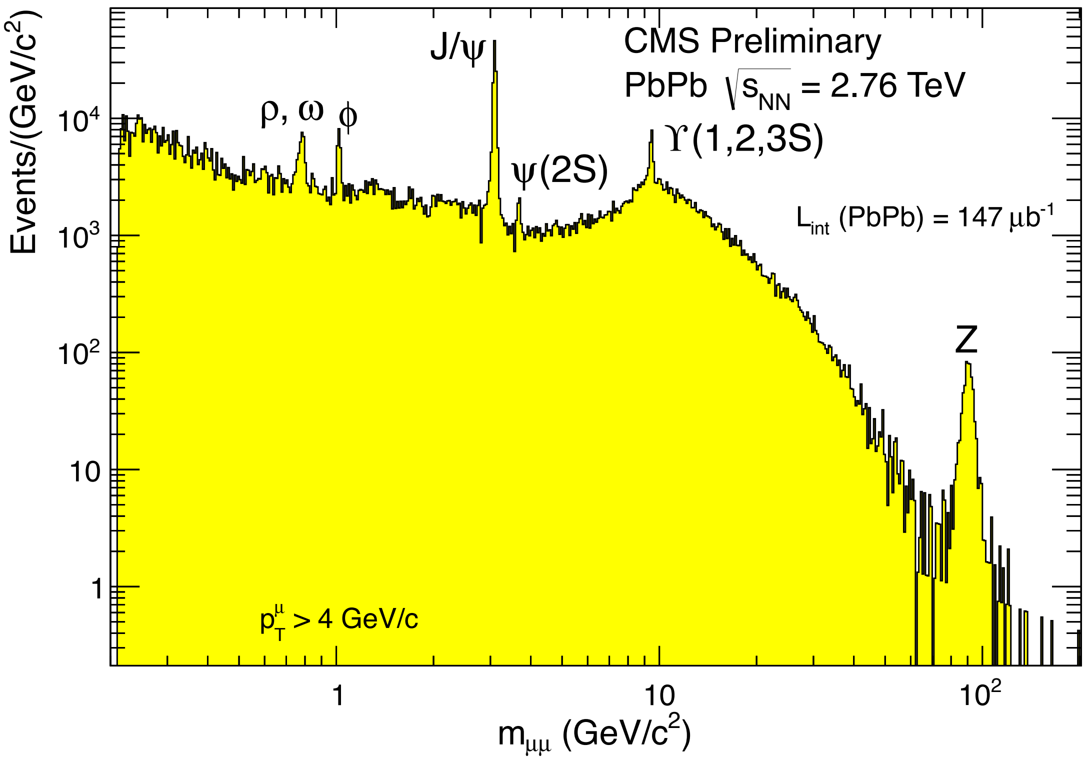
- Compared to NLO w/ CT10 (pp), vs including nuclear effects w/ EPS09
- Shape comparison only

Charged particle RpA

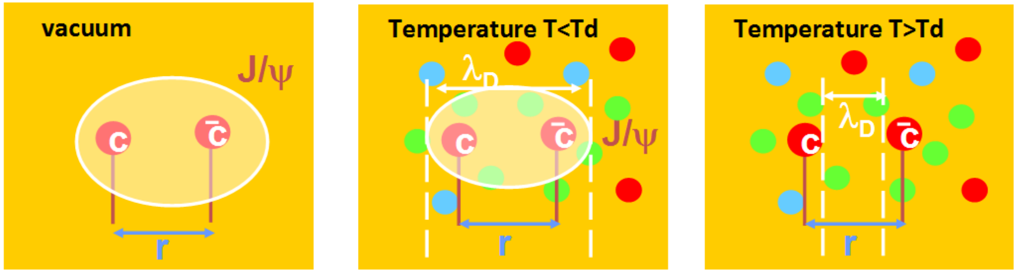
- Larger enhancement than expected from anti-shadowing
- Some tension with ATLAS jet results



Dimuons in CMS

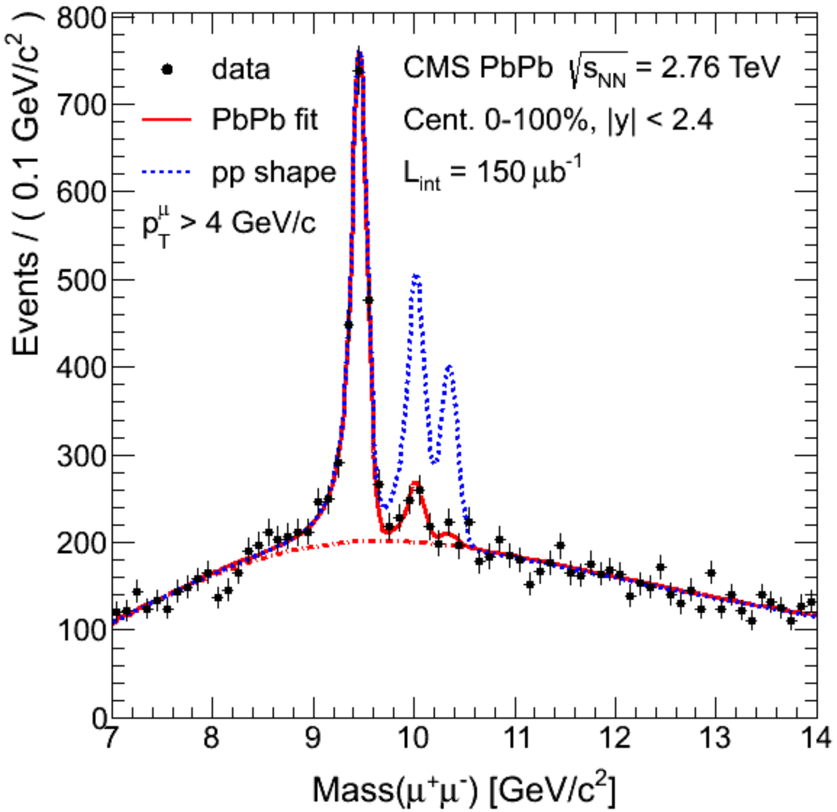


Quarkonium Dissociation

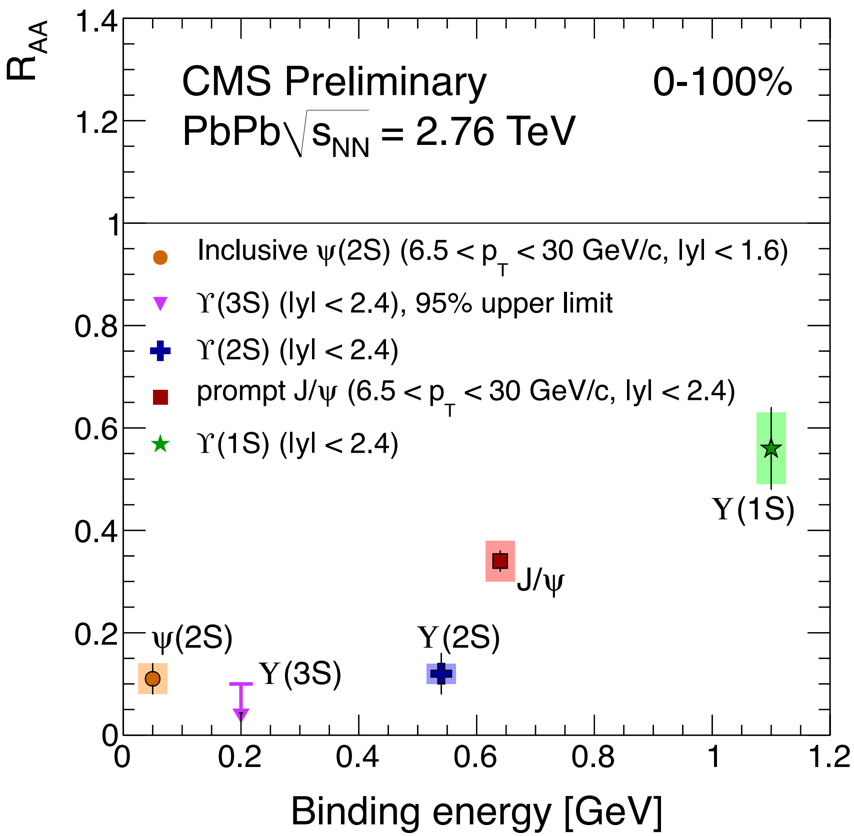


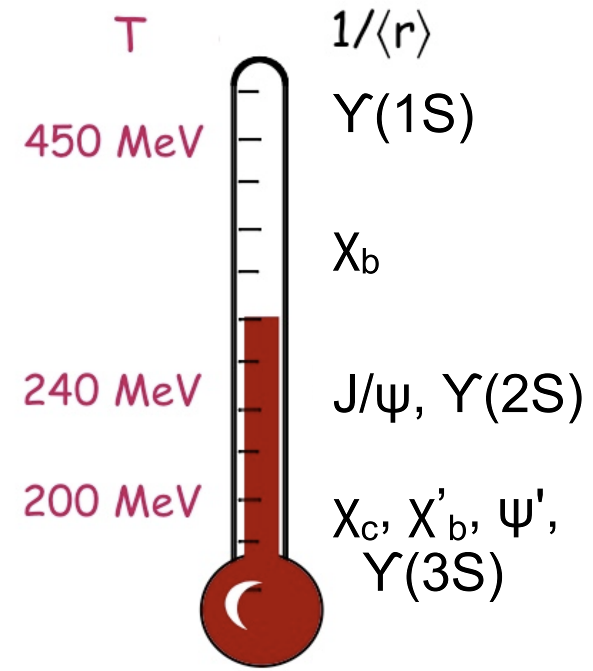
- Onia states thought to melt due to color screening
- Melting temperature depends on binding energy
  - ~ T_c for ϒ(2s), ϒ(3s)
  - ~ 4 T_c for ϒ (1s)
- Lineshape in Pb-Pb shows increase in ϒ(1s)/[ϒ(2s)+ϒ(3s)]

PRL 109 (2012) 222301



Sequential Melting?



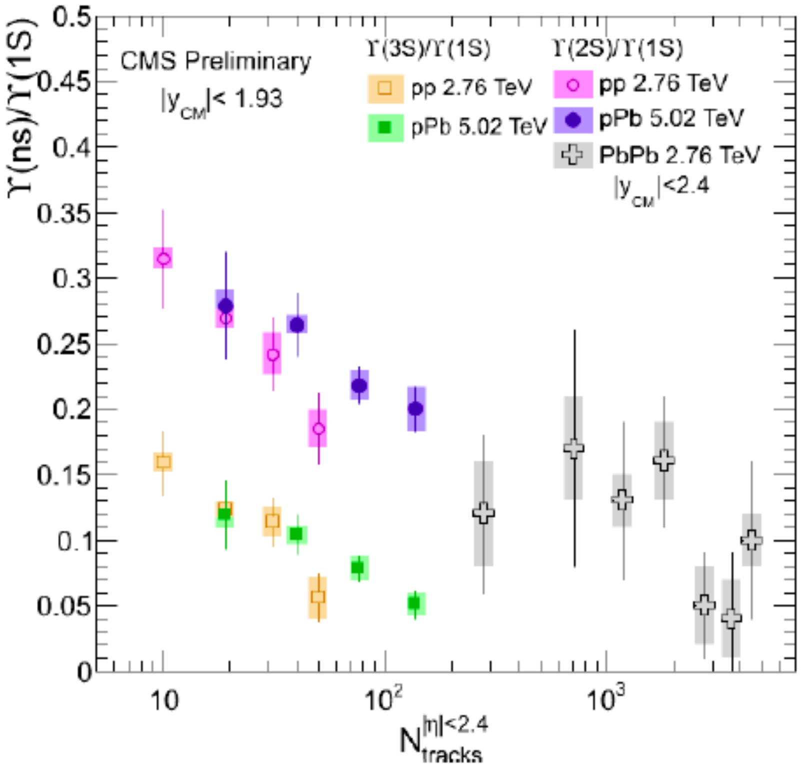


Mocsy, EPJC61 (2009) 705

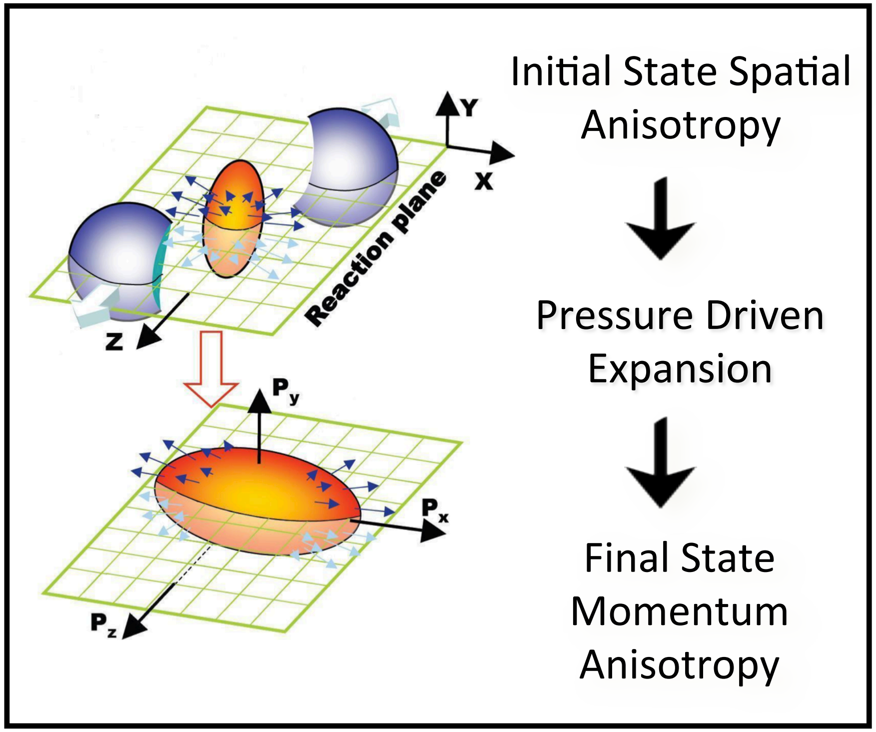
- Large suppression of excited states
- Ground states unmelted, except for feed-down?

Upsilon in p-Pb

- Ratio of states shows surprising dependence on multiplicity in pp/p-Pb
- Need more Pb-Pb data to see if trend varies smoothly
- Not yet clear what impact multiplicity dependence has on interpretation of Pb-Pb



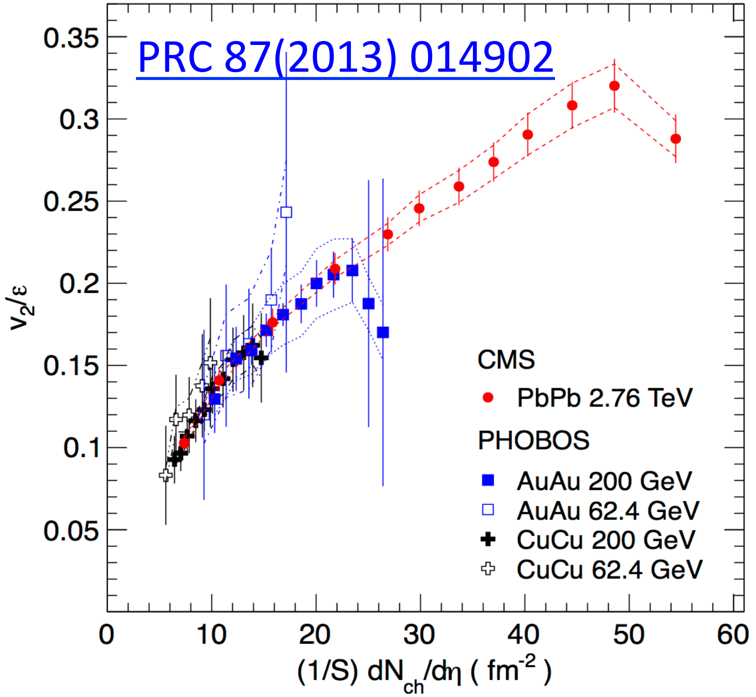
Azimuthal Flow



Azimuthal dependence of particle yield w.r.t. to reaction plane is expanded in a Fourier series:

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\varphi - \Psi_R\right)\right]\right)$$

- Ψ_R is the 'reaction plane angle'
- v_2 is known as 'elliptic flow'



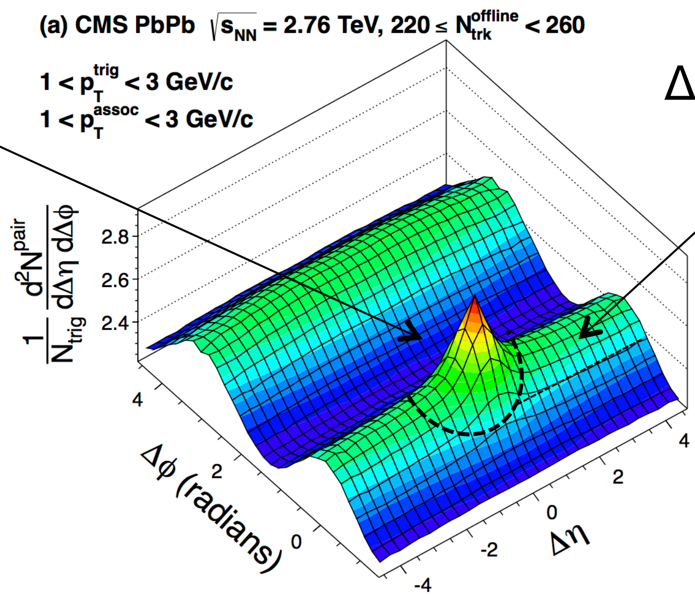
- v2/ε sensitive to shear viscosity of system
- Only weak dependence on √s via EOS
- Elliptic flow scales with charged particle density → close to hydro limit, low visc.

Long-range correlations (Pb-Pb)

PLB 724 (2013) 213

Jet-like correlations

Δη correlation, “the ridge”



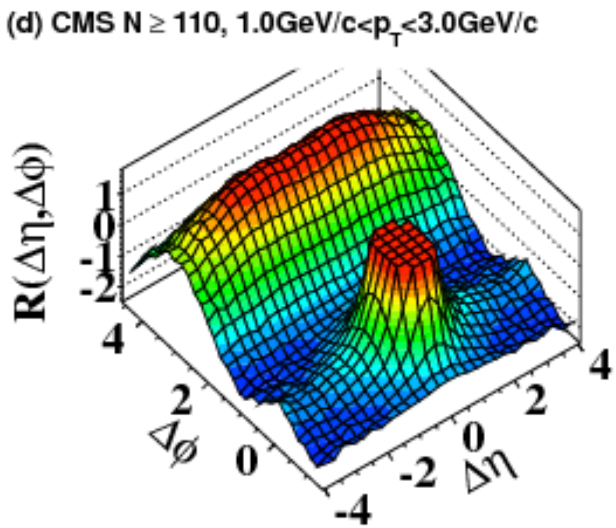
- Large acceptance permits correlations studies over broad range
- Long-range correlations must correspond to early times
- Require hydro. flow to propagate to final state (and/or CGC)

Ridgeology

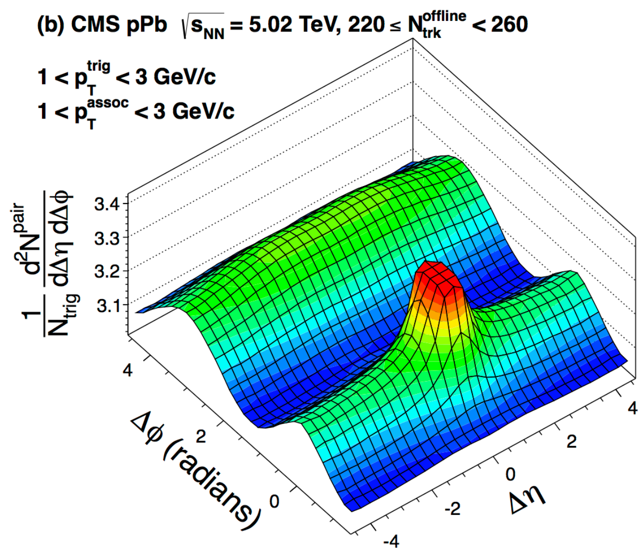
PLB 724 (2013) 213

PLB 718 (2013) 795

High multiplicity pp



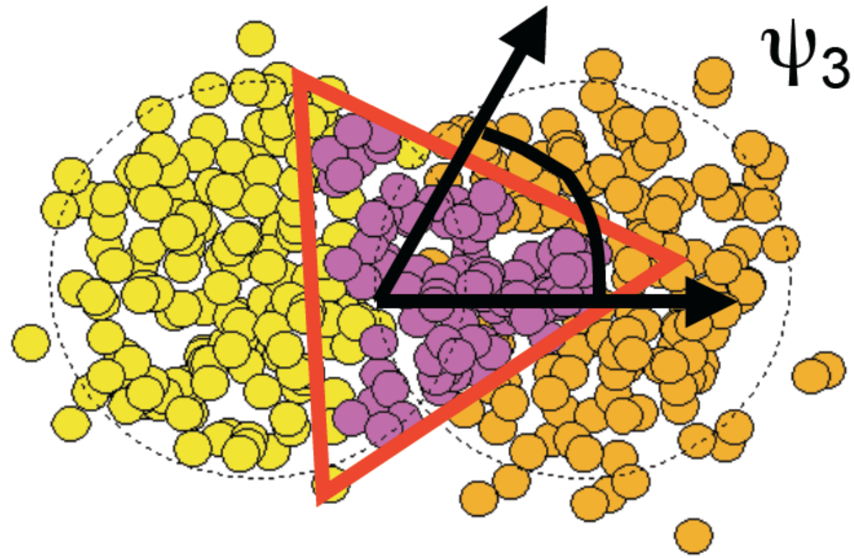
High multiplicity p-Pb

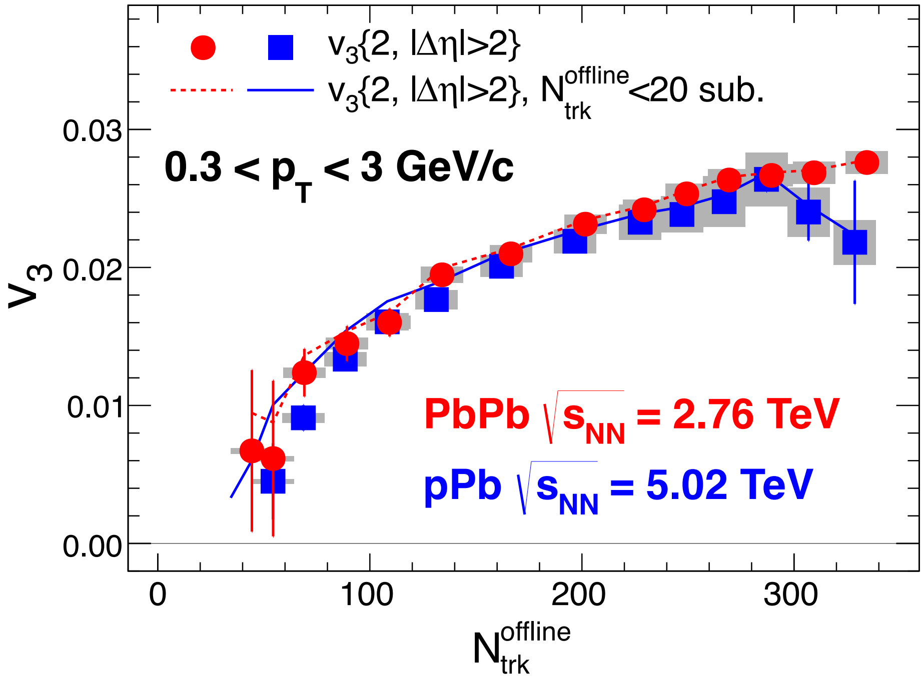


- CMS has dedicated triggers for high multiplicity events
- Ridge in high multiplicity pp collisions one of the most surprising results from the LHC so far
- Also seen in high multiplicity pPb collisions
- Are these systems really big enough to thermalize?
- If so, can we find evidence for QGP-like effects?

Triangular Flow

- Fluctuations in overlap shape give rise to triangular flow component
- As with v2, requires hydro to propagate to final state
- Surprisingly large in p-Pb ridge and scales with overall multiplicity
- Evidence of hydro-like behavior, but hard to reproduce w/ models



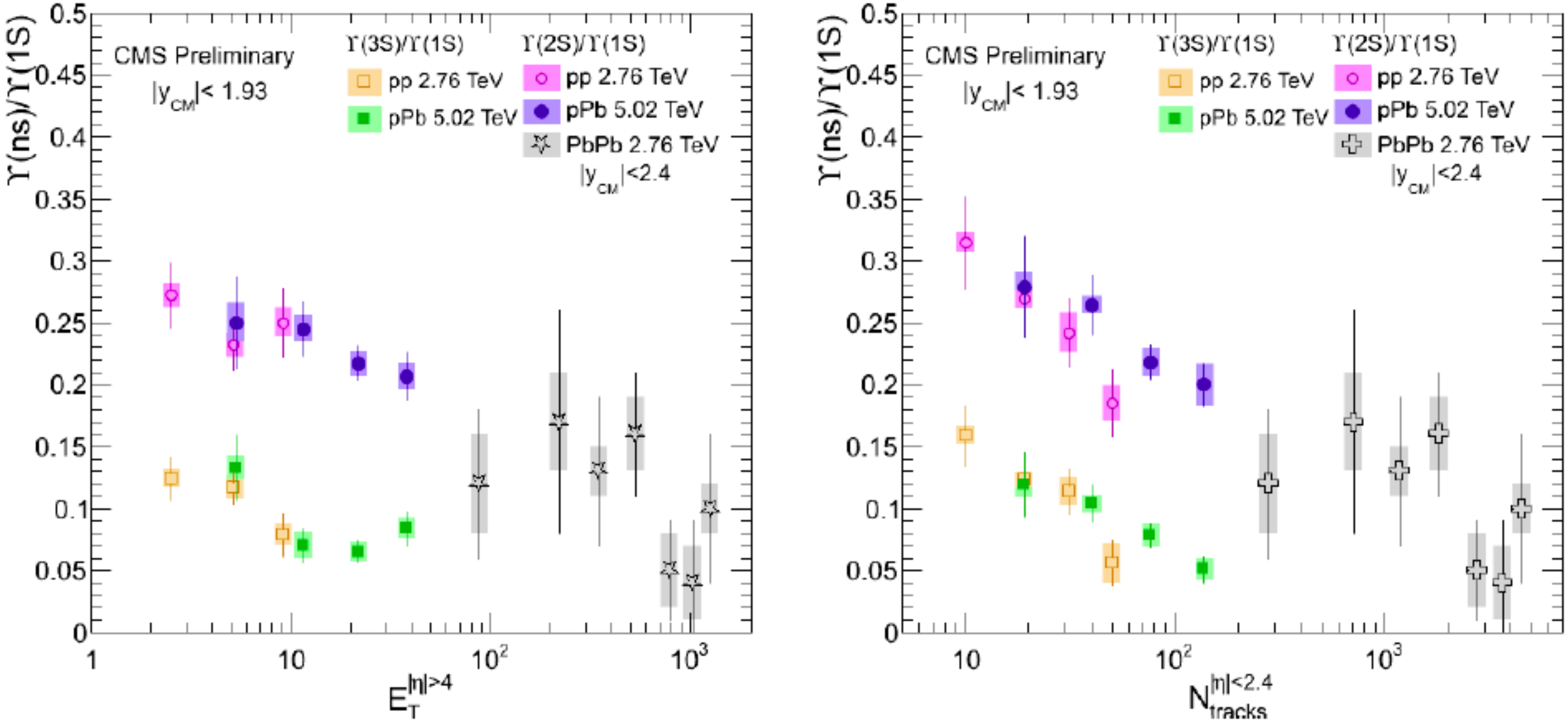


Conclusions

- LHC Run 1 has brought new opportunities to HI
  - Clean jet measurements
  - Access to bottomonia (and open beauty)
  - Long-range correlations
  - Lots more I did not discuss …
- Lots of information about the QGP to digest
- Latest p-Pb data
  - Constrains nPDFs and cold nuclear matter effects
  - Opens new puzzles with surprisingly HI-like behavior
- Much more to come after LS1with an order of magnitude more data expected!

Backup

Onia in p-Pb (N_{tracks} vs HF E_T)



Charged particle η asymmetry in p-Pb