Heavy ion physics with CMS

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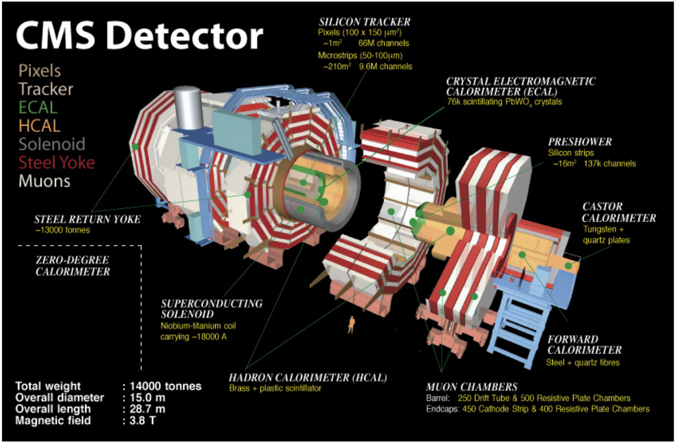
Outline

- **Introduction**: detector, data taking and centrality
- **Pb+Pb** (selected) results
  - **global observables :** charged particle multiplicity, energy and transverse energy
  - **control probes :** isolated photons, electroweak bosons
  - **modified probes :** jet quenching, γ+jet, hadrons and jets R_{AA}, quarkonia
- **Summary**



- inner **tracking** system ($|\eta| < 2.5$)
- **calorimeters** (electromagnetic: $|\eta| < 3$, hadronic: $|\eta| < 5$)
- **muon** system ($|\eta| < 2.4$)
- **forwards** detectors (CASTOR: $-6.6 < \eta < -5.2$ and ZDC: $|\eta| > 8.3$)
- magnetic field of 3.8 T

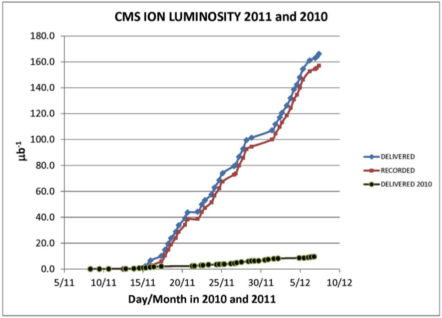
- PbPb: $\sim$ 8.7 [150] μb^{-1} in 2010 [2011]
- pp (at 2.76 TeV): $\sim$ 230 nb^{-1} in 2011
- comparing PbPb results to pp reference

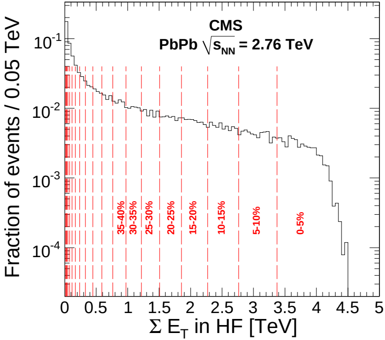
  $R_{AA} = \frac{1}{N_{coll}} \cdot \frac{N_{AA}}{N_{pp}}$

  N_{coll}: number of elementary NN collisions or

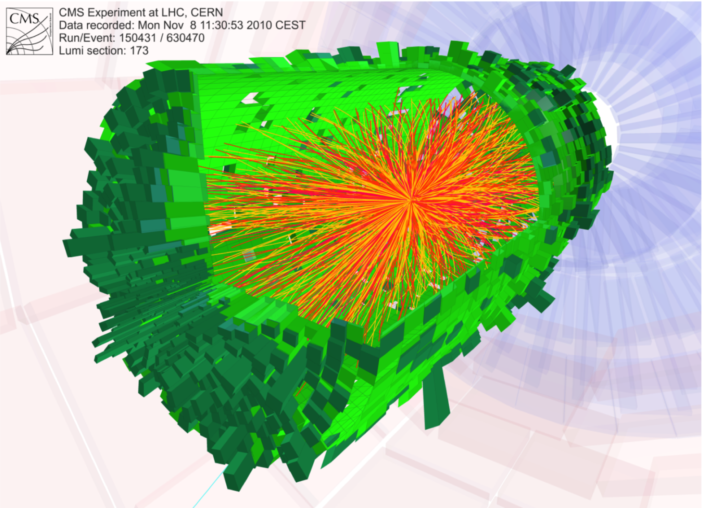
  $T_{AA} = N_{coll}/\sigma_{pp}$

- centrality concept: Pb ions are extended objects, particle production depends on the impact parameter
- reflects the geometrical overlap of the two colliding nuclei
- energy deposit in forward calorimeters



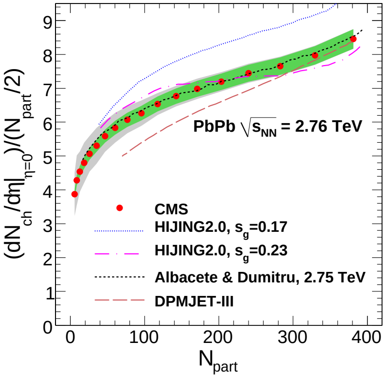


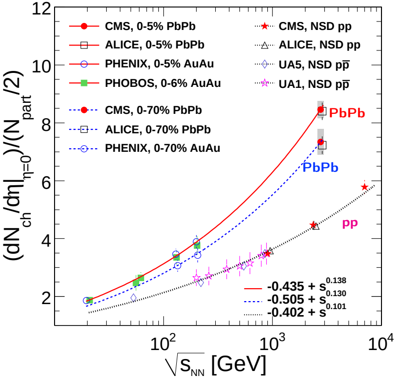
Introduction | Event display



Global observables
$\hookrightarrow$ **basic information on the created system**

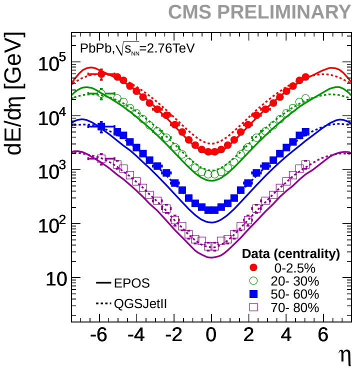
- **hadron** rapidity **density** $\propto$ number of **initially** released **partons** at a given η: reduced multiplicity in saturation models

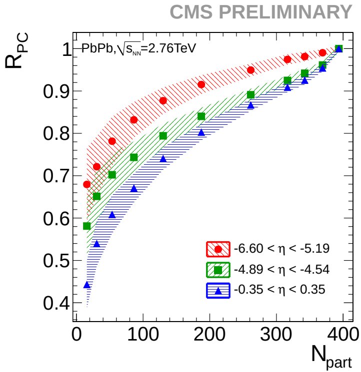




- charged hadron density for 0-5% collisions: 1612$\pm$55
- $dN_{ch}/d\eta$ is $\sim$ flat over $|\eta|$ <2.5 ($<$ 10% variation)
- similar N_{part} dependence for all $\sqrt{s_{NN}}$
- good description of the data by a parton saturation approach
- $\sqrt{s_{NN}}$ dependence follows power law behavior with exponent $s^{0.13}$

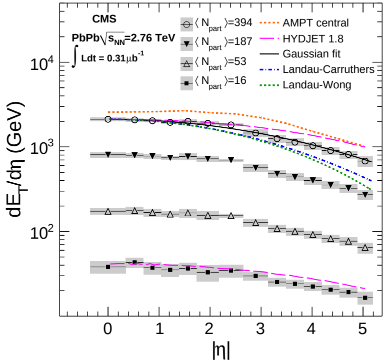
- CASTOR coverage up to η=-6.6 (y_{beam} ~8); peak of the $dE/d\eta$
- HYDJET 1.8 and EPOS-LHC: good agreement for central data
- QGSJetII.3: describe better peripheral data; AMPT: quantitative agreement to the data

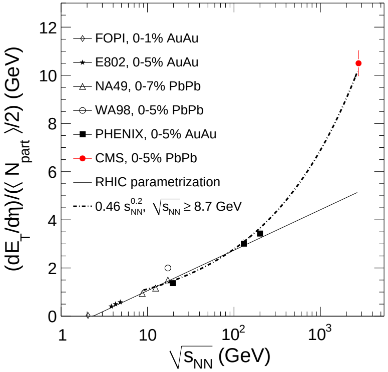




- $R_{pc} = \frac{\langle E\rangle(\eta,N_{part})}{\langle E\rangle(\eta,N_{part}^{max})} \cdot \frac{N_{part}^{max}}{N_{part}}$
- shape change in the forward η; flattening region for central events at high η
- data is challenging for models

- initial distribution of partons (via N_{part}) and hydrodynamic flow that builds up after thermalization (via η); energy density via Bjorken's formula $\epsilon_{\rm BJ} = \frac{dE_T}{dy} \cdot \frac{1}{\tau_0 \pi R^2}$

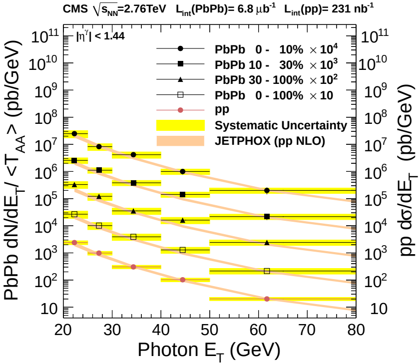


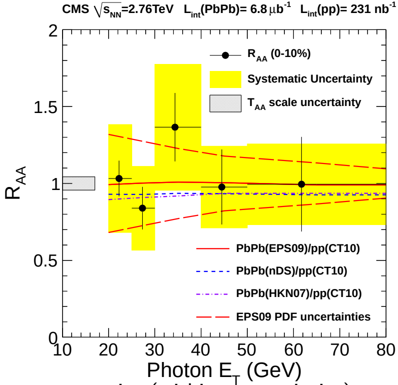


- $\sim$ 2.1 TeV at $\eta = 0$; at least 3 times larger than at RHIC
- shape consistent with a Gaussian with $\sigma_\eta = 3.4 \pm 0.1$: larger than predicted by Landau hydro but narrower than given by HYDJET; AMPT overestimates
- $(dE_T/d\eta)/(0.5\langle N_{part}\rangle)$ increases with N_{part} for all η
- for $\tau_0 = 1$ fm/c and $R = 7.1$ fm: energy density of ≈ 14 GeV/fm^3
- for $\sqrt{s_{NN}} \geq 8.7$ GeV, E_T at $\eta = 0$ reproduced by a power-law dependence $s_{\rm NN}^n$ with $n \approx 0.2$

Control probes
$\hookrightarrow$ **not affected by the medium**

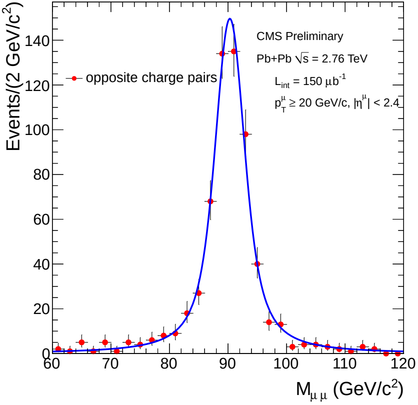
- sources of high-p_T photons:
  - isolated (direct): blind to the created medium
  - not-isolated (fragmentation, meson decay,...): affected by the medium
- first adaptation of p+p photon identification methods to heavy ion experiment
- photons are measured for $|\eta| < 1.44$, E_T of 20–80 GeV in 3 centrality bins
- significant background: mainly from neutral mesons

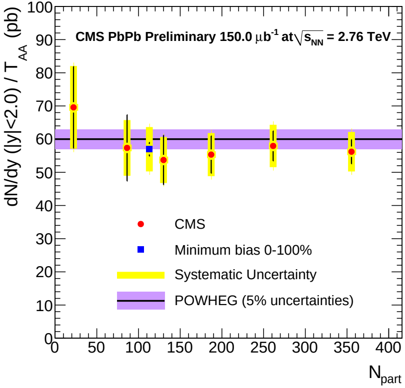




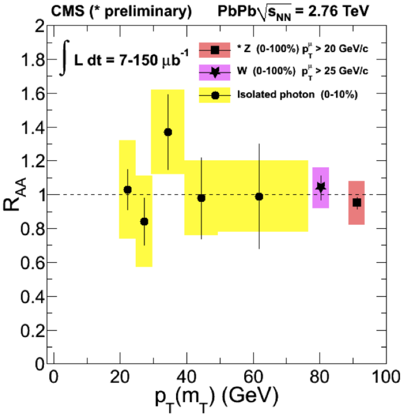
- consistent with the NLO calculation at all transverse energies (within uncertainties)
- R_{AA} vs E_T is flat
- no dependence of R_{AA} on N_{part}

- for the mass range 60-120 GeV/c^2: 616 events with opposite-sign muons; no events with same-sign muons
- very low pp statistics for 2.76 TeV: comparison to POWHEG generator (well tested at Tevatron and LHC at 7TeV)





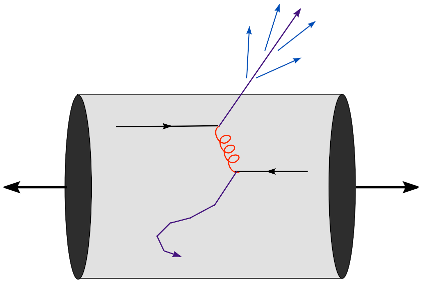
- $R_{AA} = 0.95 \pm 0.03 \pm 0.13$

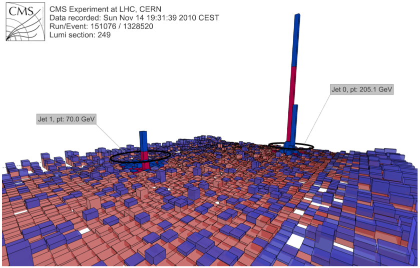


- also W $\rightarrow \mu\nu$ studies **[PLB 715 (2012) 66]**
- electroweak bosons are not affected by the medium (within uncertainties)
- confirmation of the validity of the binary (N_{coll}) scaling
- more precision: access to the nuclear PDFs

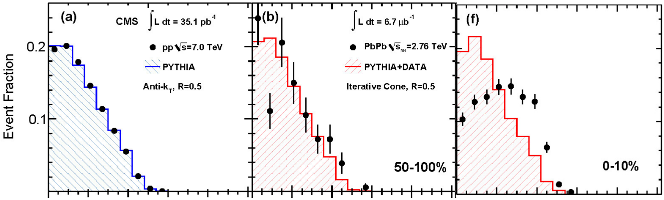
Modified probes
$\hookrightarrow$ **affected by the medium**

- jets are produced at the initial impact
- radiative energy loss when they travel through the QGP
  - sensitive to the energy density of the medium
  - depends on the path length
  - azimuthal correlations between produced jets: for p+p or p+A peak at $\Delta\phi$=180°
  - for A+A important modification of the azimuthal correlations: the away side jets are suppressed
- investigating modification of jets: very useful tool for probing the QGP properties

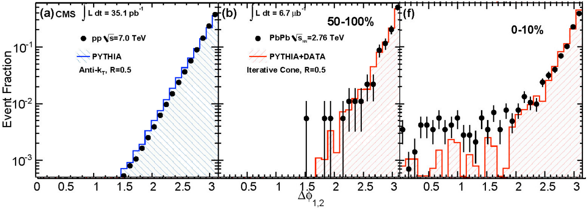




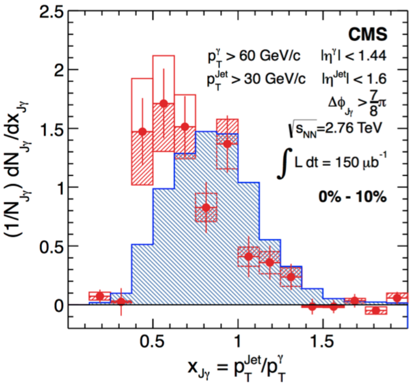
- dijet asymmetry: $A_J = \frac{p_{T,1}-p_{T,2}}{p_{T,1}+p_{T,2}}$ ($p_{T,1}$ for leading, $p_{T,2}$ for sub-leading)
- here only calorimeter dijets: leading p_T >120 GeV, sub-leading p_T >50 GeV
- p_T imbalance (i.e. A_J) increases with the centrality

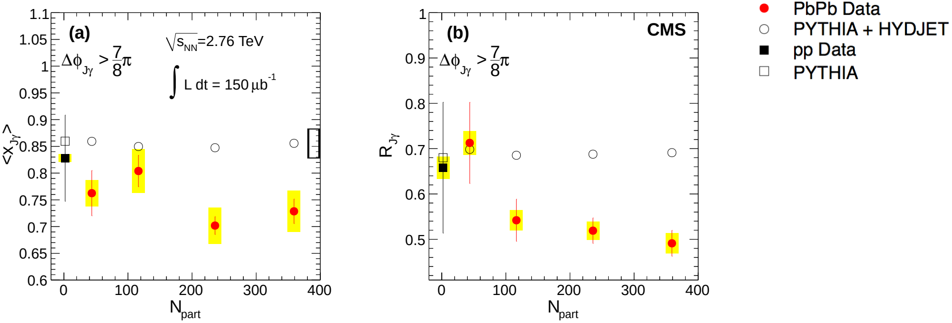


- azimuthal decorrelation $\Delta\phi_{1,2}$: back-to-back ($\Delta\phi_{1,2} \sim \pi$) for all centralities



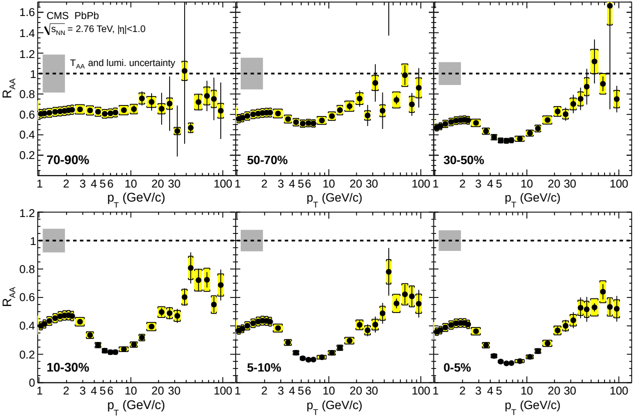
- at LO photons produced back-to-back with an associated parton (jet): $p_T^{\gamma} \sim p_T^{Jet}$
- transverse momentum balance $x_{J\gamma} = \frac{p_T^{Jet}}{p_T^{\gamma}}$
- when increasing the centrality of the collision
  - shift of the $x_{J\gamma}$ distribution towards lower values
  - reduction of the fraction of photons with an associated jet





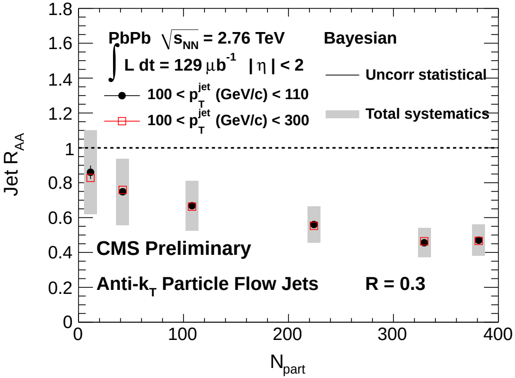
- average γ-jet p_T balance decreases by ∼14% compared to pp
- fraction of γ with an associated jet partner drops by ∼20%

- using jet trigger to enhance p_T reach (up to 100 GeV/c) and decrease fake rate

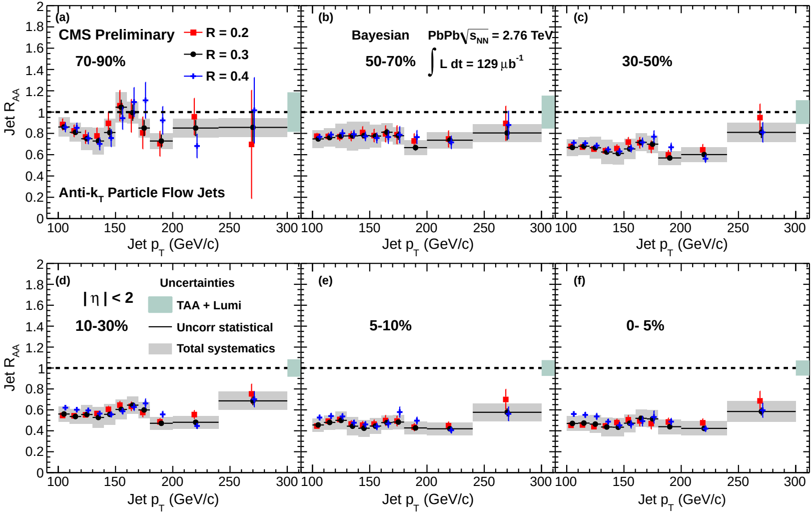


- large suppression of charged particles above a few GeV/c

- online PbPb jet trigger threshold of 80 GeV/c; offline: $p_T > 100$GeV/c and $|\eta| < 2$

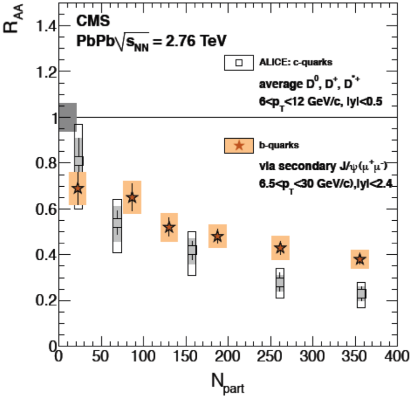


- suppression factor of ∼0.5 in central PbPb when comparing to pp
- no suppression (within uncertainties) in the most peripheral PbPb
- R_{AA} is approximately independent of p_T in the measured range



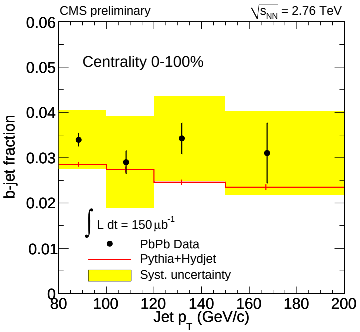
- no change in level of suppression due to jet cone size

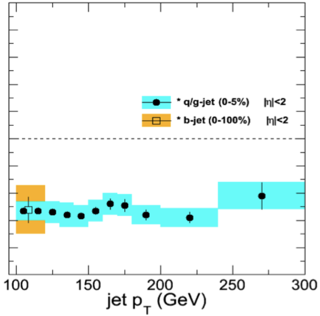
- b from non-promt J/ψ: produced at large distance from the primary vertex; p_T <30 GeV/c
- the identification of J/ψ coming from B hadron decays relies on the measurement of a secondary $\mu^+\mu^-$ vertex displaced from the primary collision vertex. The distance between the $\mu^+\mu^-$ vertex and the primary vertex is measured in the plane transverse to the beam direction.
- D's from ALICE



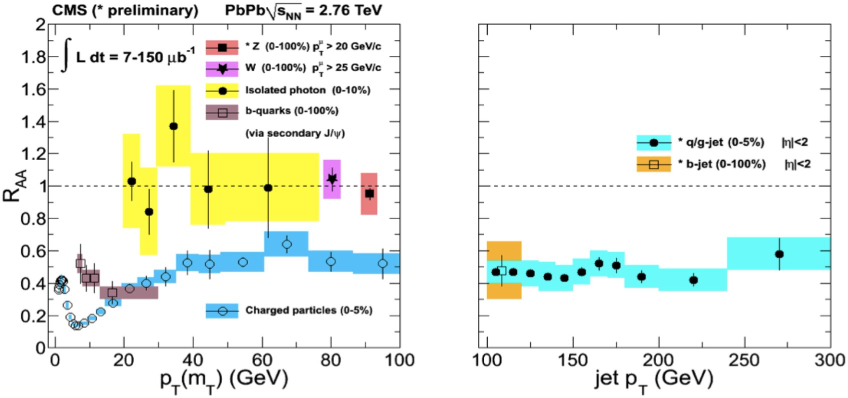
- in theory: energy loss depends on the quark mass
- $R^b_{AA} > R^c_{AA}$: b-quarks are less suppressed than c-quarks

- jets tagged by cutting on discriminating variables:
  - Simple Secondary Vertex High Efficiency (SSVHE): based on the flight distance significance of reconstructed SV
  - Jet Probability (JP)
- p_T >100 GeV/c; first b-jet identification in heavy ion collisions

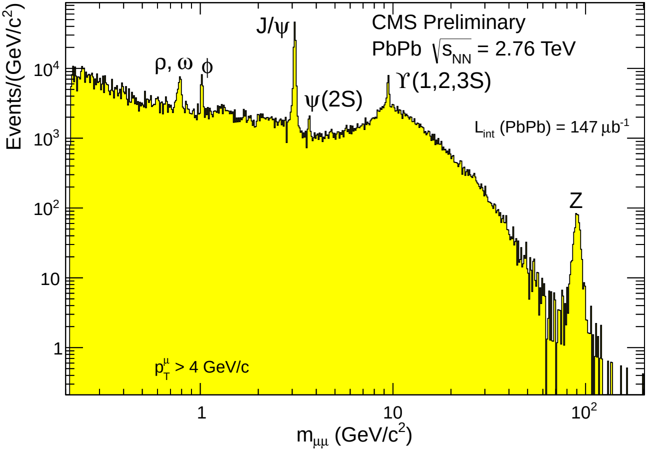


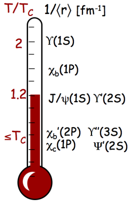


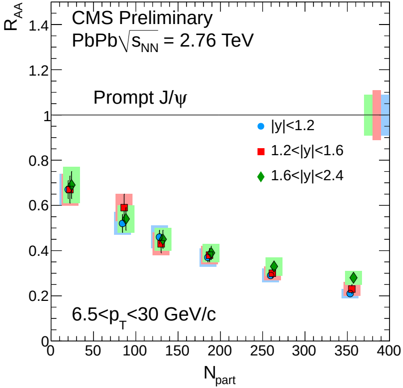
- pp and PbPb b-jet fraction are the same: consistent with MC
- $R_{AA} < 1$


CMS (* preliminary)
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
$\int$ L dt = 7-150 μb^{-1}
* Z (0-100%) p_T^μ > 20 GeV/c
W (0-100%) p_T^μ > 25 GeV/c
Isolated photon (0-10%)
b-quarks (0-100%)
(via secondary J/ψ)
Charged particles (0-5%)
R_{AA}
$p_T(m_T)$ (GeV)
* q/g-jet (0-5%) |η|<2
* b-jet (0-100%) |η|<2
jet p_T (GeV)

- **color screening** of static potential between heavy quarks
- quarkonia **melting** depending on the binding energy: **thermometer** of the medium

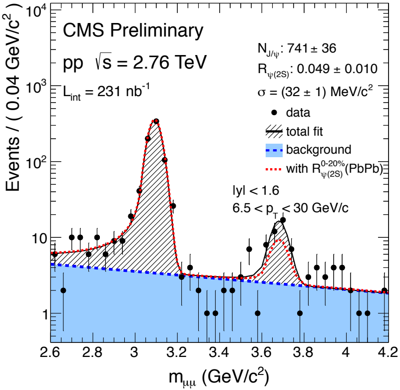






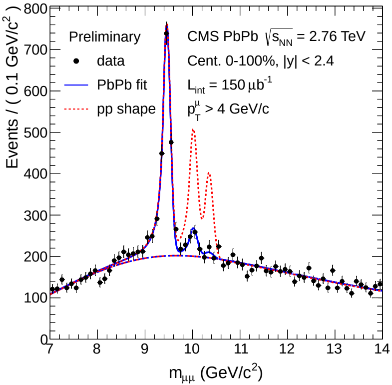
- 6.5$<p_T<$30 GeV/c: no rapidity dependence
- central collisions: suppression by factor ~5
- high y: low p_T suppressed less than high p_T

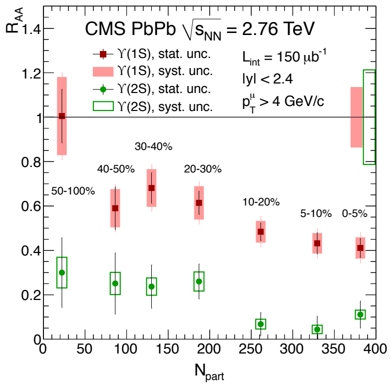
- first look at $\psi(2S)$; raw ratios: $R_{\psi(2S)} = N_{\psi(2S)}/N_{J/\psi}$
- red curves: PbPb fit
- $|y|$ <1.6 and 6.5< p_T <30 GeV/c



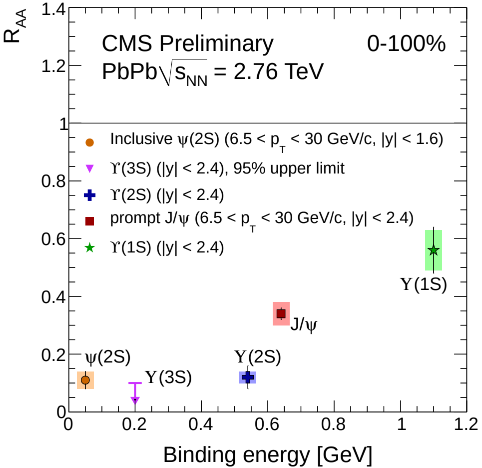
- relatively less $\psi(2S)$ than J/ψ
- $R^{PbPb}_{\psi(2S)} \sim 0.5\ R^{pp}_{\psi(2S)}$

- excellent mass resolution ($\sim$1%): clear separation; acceptance down to $p_T = 0$ GeV/c
- centrality-integrated $R_{AA}(\Upsilon(nS))$





- $R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08 \pm 0.07$
- $R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04 \pm 0.02$
- $R_{AA}(\Upsilon(3S)) <0.1$ (95% CL)
- ordered suppression



- centrality-integrated R_{AA} vs binding energy seems ordered: looser bound states are more suppressed
- but has to be done with more data: centrality dependence, feed-down contributions, cold nuclear matter effects (pA)

Summary

- Pb+Pb data taking periods were very successful !
- CMS collected a significant amount of data

  thanks to CERN for fantastic LHC performance!

- detailed measurements of global properties of medium in Pb+Pb collisions
- measurement of control probes (γ, Z and W): unmodified as expected
- jet quenching ... including b !!!
- quarkonium suppression
- looking forward for pA data ...

- much more results not discussed here :
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN