Quarkonia and Z Bosons in Heavy Ion Collisions with the CMS Experiment

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on the behalf of the CMS collaboration

Winter Workshop on Recent QCD Advances at the LHC

Les Houches QCD 2011

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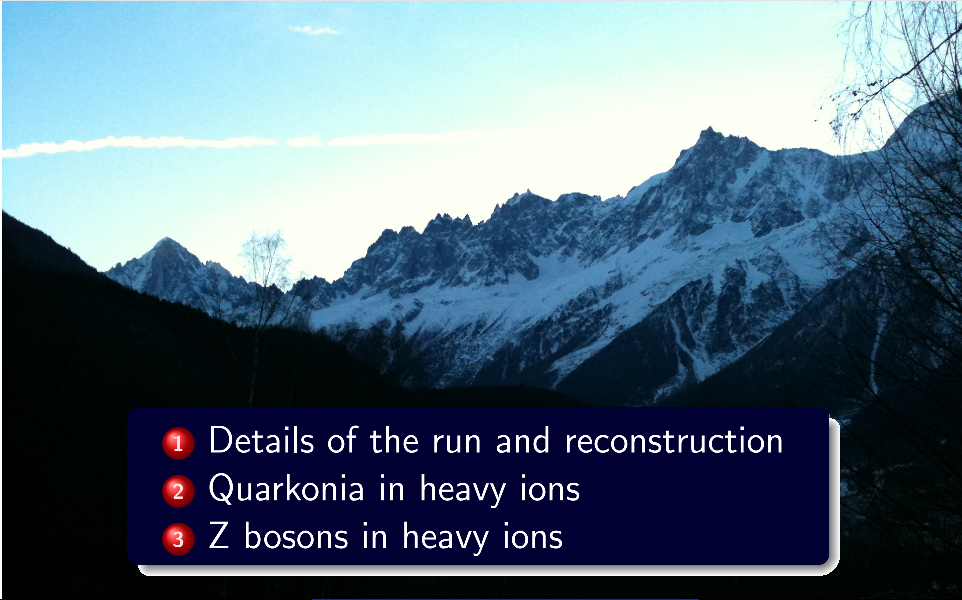
Overview

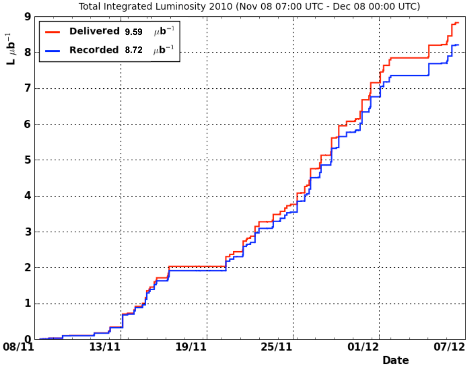


1. Details of the run and reconstruction
2. Quarkonia in heavy ions
3. Z bosons in heavy ions

CMS @ the LHC : 2010 Heavy Ion Run

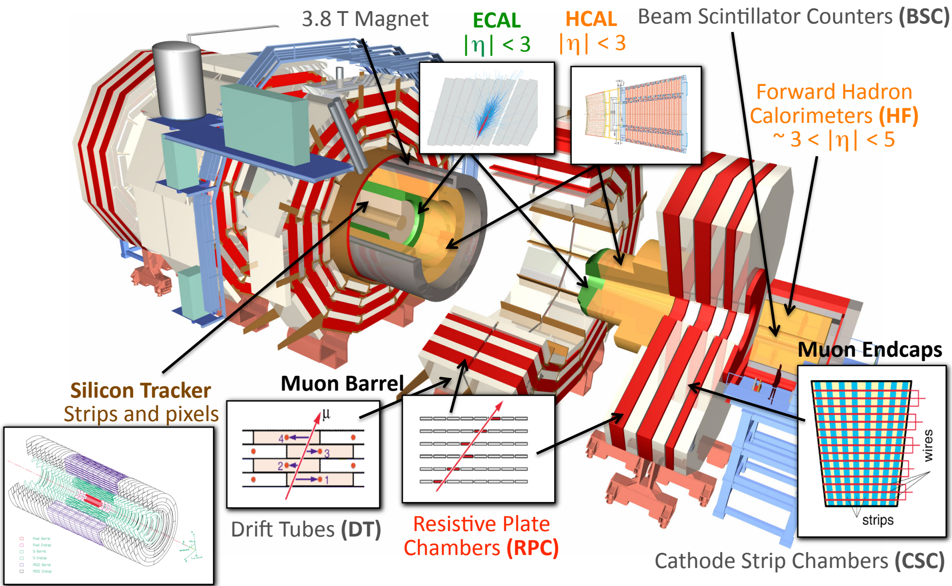
2010 : successful year at LHC

- After delivering over 40 pb^{-1} of p+p data, the LHC delivered over 9 μb^{-1} of Pb+Pb
- For rare processes, this is "equivalent" to $\sim$ 300 nb^{-1} of p+p



Heavy ion quarkonia plots will only show a subset of the available statistics, while the Z boson analysis uses 7.2 μb^{-1}

The Compact Muon Solenoid



Trigger Condition

Minimum bias trigger

- HF or BSC firing in coincidence on both sides
- 97% efficient

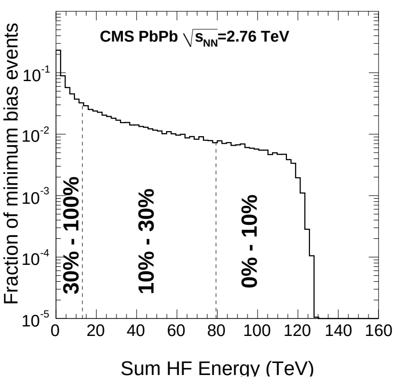
$\Rightarrow$ Z bosons analysis corresponds to 55 milion minimum bias events

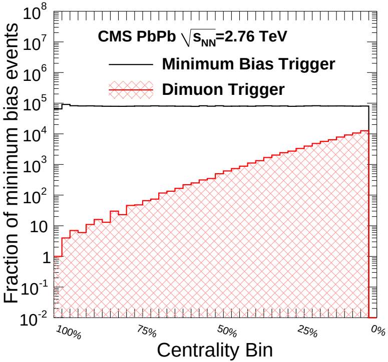
Dimuon trigger

- HLT passthrough of L1
- 94% efficient for dimuons with high p_T muons in HI estimated with a data driven technique

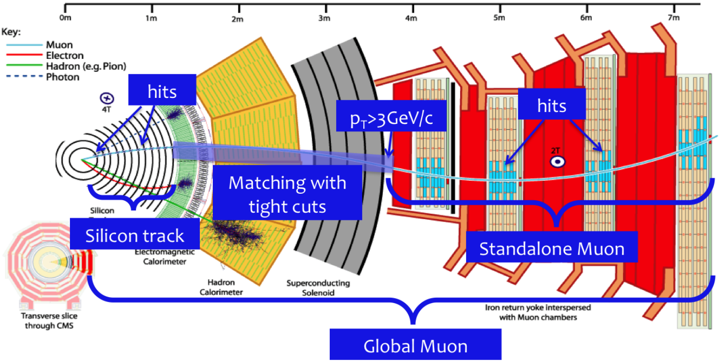
Centrality Determination

Events are classified according to the percentile of the Pb+Pb inelastic cross section based on total deposited HF energy





Muon Reconstruction



Good muon momentum resolution

- Tight matching between the tracks in the muon chambers and in the silicon tracker
- Strong solenoidal magnetic field (3.8T)
- Large rapidity coverage ($|\eta| < 2.4$)

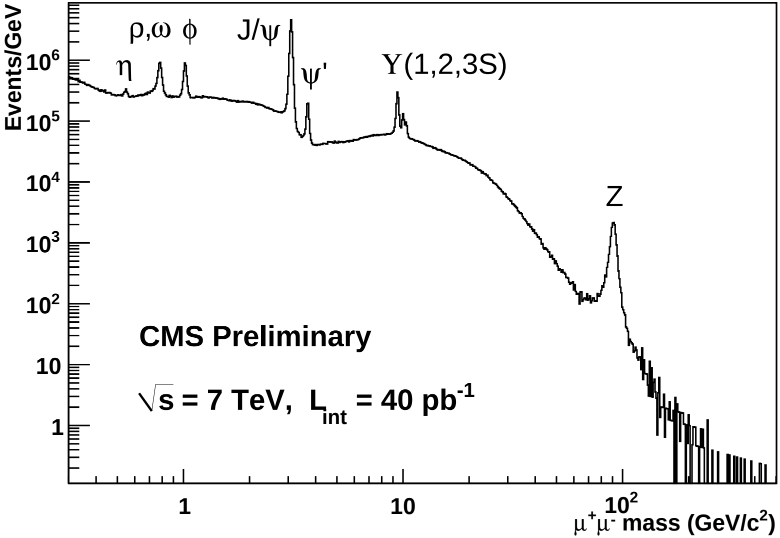
$$p_T = 100 \text{ GeV/c}, \ \sigma_p^\mu \sim 1\%$$

Ideal to measure dimuons

- Excellent dimuon mass resolution: varies as a function of η due to increasing material and of the different lever arm a track has above $\eta \sim 1.6$

$$|\eta| < 2.2, \ \sigma^{pp}_{mass}(\mathrm{J}/\psi) \approx 40 \text{ MeV}/^2$$
$$|\eta| \approx 0, \ \sigma^{pp}_{mass}(\mathrm{J}/\psi) \approx 20 \text{ MeV}/^2$$

The Compact (di-)Muon Solenoid Experiment in pp



Probing the QGP with Quarkonia

Ideal probes

- Large masses and (dominantly) produced at the early stage of the collision, via hard-scattering of gluons.
- Strongly bound (small radius) and weakly coupled to light mesons.

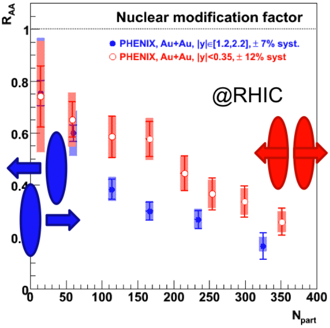
A complex scenario

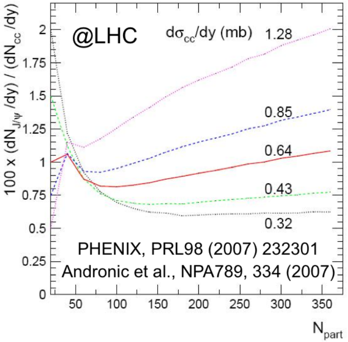
- p+p production mechanism not completely explained
- Interplay of cold nuclear matter effects
- More than just sequential screening can affects the production in the hot medium

Probing the QGP with Quarkonia

Status

- SPS : similar suppression pattern than at RHIC while energies in center of mass 10 times lower !
- RHIC : suppression vs. centrality can be explained by completely different models; pattern vs. rapidity not understood
- LHC : recombination ?

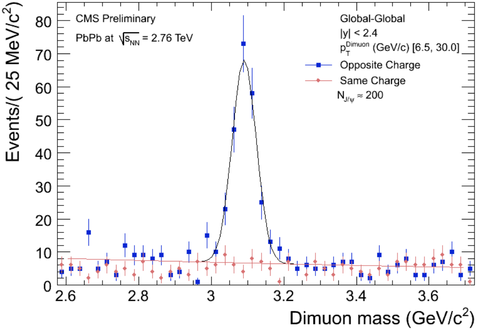




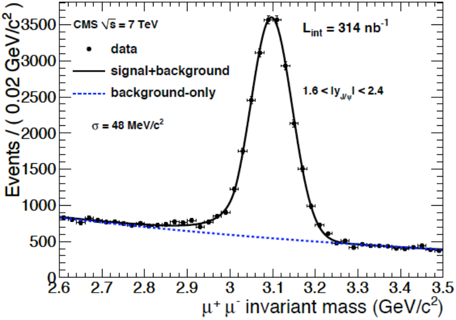
$J/\psi \rightarrow \mu^+\mu^-$

CMS Public Results
+ arXiv:1011.4193
accepted by EPJC

Subset of Heavy Ion run @2.76 TeV



p+p @7 TeV

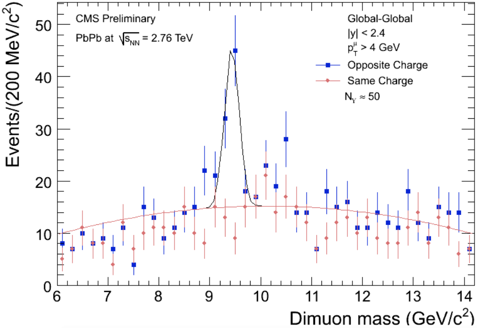


- Note : subset of the statistics in HI, $p_T^{J/\psi} \in [6.5, 30]$ GeV/c^2
- Background in HI already low with basic quality criteria at this p_T
- Very good resolution also in HI collisions

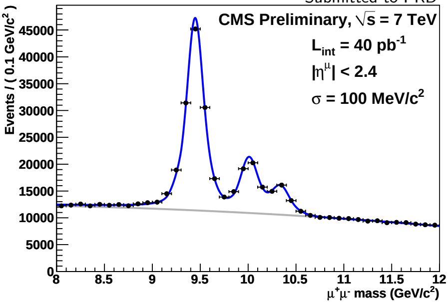
$\Rightarrow$ **Promising studies coming up !**

$\Upsilon \rightarrow \mu^+\mu^-$

Subset of Heavy Ion run @2.76 TeV



p+p @7 TeV CMS Public Results + arXiv:1012.5545 Submitted to PRD



- Note : subset of the statistics in HI, $p_T^\mu > 4$ GeV/c^2
- Background in HI higher than for the J/ψ but statistical significance already showing up
- Good resolution also in HI collisions ! ($\sigma_{pp} = [40 - 100]$ MeV/c^2)

$\Rightarrow$ **Full statistic analysis, with quality criteria, should lead to promising results !**

Z Bosons in Heavy Ion Collisions

Kartvelishvili [arXiv:hep-ph/9505418]
Vogt [arXiv:hep-ph/0011242]
Zhangand [arXiv:hep-ph/0205155]
Paukkunen [arXiv:hep-ph/1010.5392]
Neufeld [arXiv:hep-ph/1010.3708]

A reference for heavy ion collisions

- Probes are modified in the QGP ⇒ A baseline is needed to compare their production (usually pp and pA or dA)

Candle of the initial state in PbPb collisions at the LHC energies

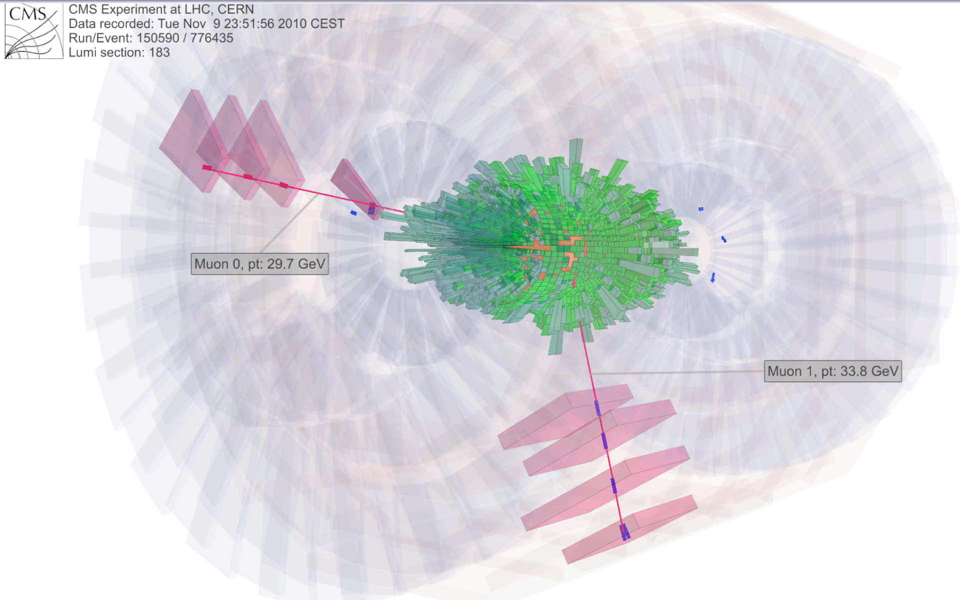
- Z bosons decay within the medium with a life-time of 0.1 fm/c : lepton decays pass freely through the medium

⇒ Reference for quarkonia production and opposite-side jet in a Z-jet process

Z, probe of the initial state

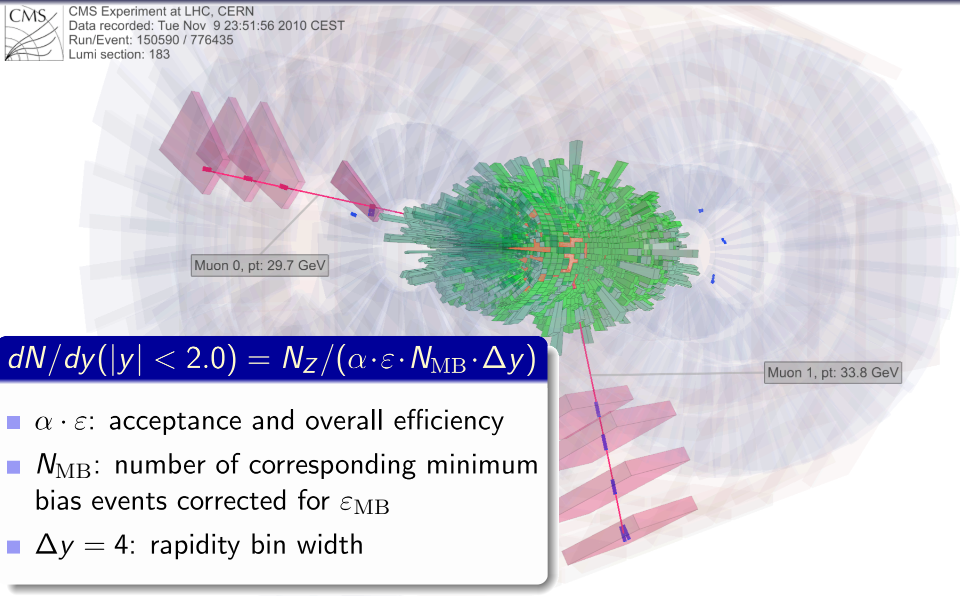
- Shadowing : PDF can be modified (suppressed in the LHC x region) in nuclei $\sim 10-20\%$
- Isospin : Z produced through $q\overline{q} \rightarrow Z$ from low x partons (typically 0.03 at mid-rapidity) and proton and neutron have different quark contents $\sim 3\%$
- Energy loss and multiple scattering of the initial partons $\sim 2\%$

Overview of the Measurement



Overview of the Measurement

Preprint to appear soon

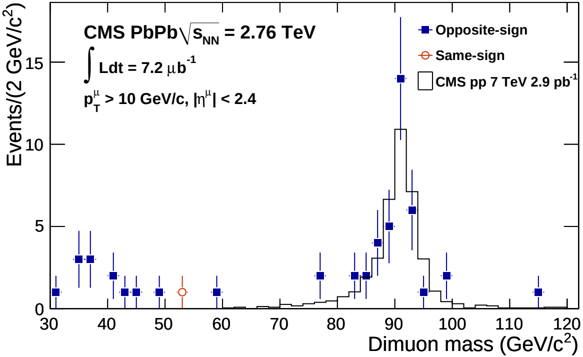


$$dN/dy(|y| < 2.0) = N_Z/(\alpha \cdot \varepsilon \cdot N_{\mathrm{MB}} \cdot \Delta y)$$

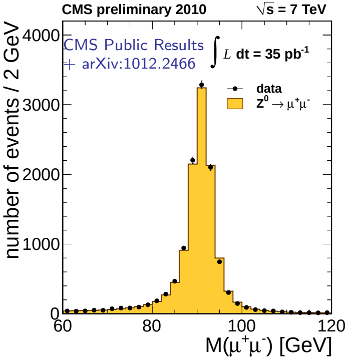
- $\alpha \cdot \varepsilon$: acceptance and overall efficiency
- N_{MB}: number of corresponding minimum bias events corrected for $\varepsilon_{\mathrm{MB}}$
- $\Delta y = 4$: rapidity bin width

Z Bosons

Heavy ion run @2.76 TeV



p+p @7 TeV



- All heavy ion statistics between [30,120] GeV/c^2, with some loose quality criteria
- Only 1 same-sign event for 39 Z
- Resolution comparable to p+p 2.9 pb^{-1} [60,120] GeV/c^2

Corrections

Strategy

- $\alpha \times \varepsilon$ corrections are derived
  - from a Monte Carlo Z sample using a PYTHIA 6.421 simulation with CTEQ6L PDFs
  - embedded in real data at the level of detector hits and with generated vertices matched to the measured ones

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Cross-checks

- Muon characteristics have similar distributions in the data and simulations: number of hits, track fit reduced χ^2, ...
- Alternate reconstructions provide consistent results
  - STA-STA and iterative tracking seeded from muon detectors
- Efficiencies checked with MC truth with hit by hit matching
- Data-driven with a Tag-and-Probe technique
  - Trigger
  - Muon STA reconstruction : probing STA muons with Si tracks
  - Silicon tracking : probing Si tracks with STA muons

Corrections

Dimuon acceptance and efficiencies

- Detector kinematic acceptance : 78%

$$\alpha = \frac{\#(Z)^{|\eta^{\mu}|<2.4, p_T^{\mu}>10\ GeV/c, |y_Z|<2.0, M\in[60,120] GeV/c^2}}{\#(Z)^{|y_Z|<2.0, M\in[60,120] GeV/c^2}}$$

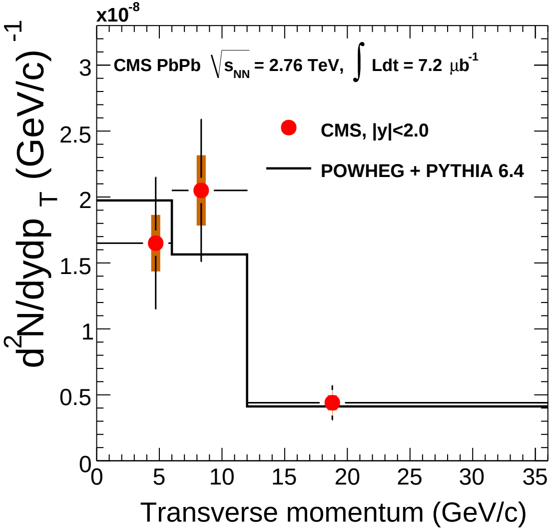
- $\varepsilon_{\text{trigger}} \cdot \varepsilon_{\text{reconstruction}} \cdot \varepsilon_{\text{muon identification}} \simeq 67\%$
  - Trigger efficiency is $\sim$ 94%
  - Silicon tracking efficiency is $\sim$ 76%
    - $\rightarrow$ Lower than pp as it begins with seeds that have at least 3 pixel hits to lower the combinaisons due to high multiplicity.
    - $\rightarrow$ Variation by less than 10% as a function of centrality
  - Stand alone reconstruction and matching are very efficient : $\sim$ 98%

Systematics Uncertainties

Reflect the data precision : 13%

- From the tag-and-probe technique on data
  - **Tracking** : 9.8%
  - **Trigger** : 4.5%
- Extrapolating a fit in [35-60] GeV/c^2
  - **Residual backgrounds** : 4%
- Event-loss from
  - **Muon quality selection** : 2.6%
- Varying Glauber parameters
  - **Minimum bias selection** : 3%
- Varying relative MC shapes vs. p_T and y by 30%
  - **Acceptance** : 3%
- Other (muon reco, embedding, ...) : 1.5%

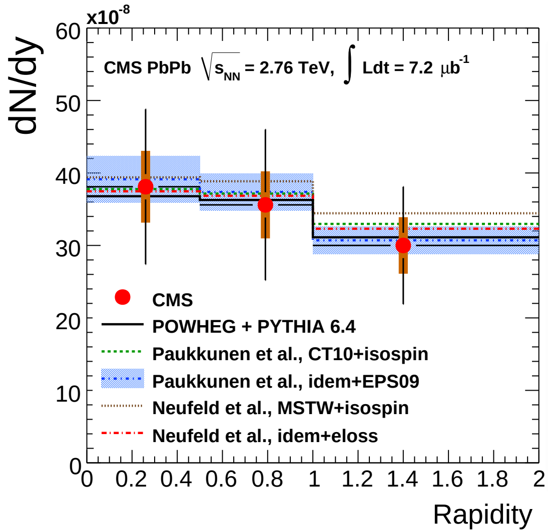
Yield vs. Transverse Momentum



- $dN/dy(|y| < 2.0) = (33.8 \pm 5.5 \pm 4.4) \times 10^{-8}$
- p_T bins: [0,6[[6,12[[12,36[GeV/c
- Bars are statistical and bands systematics
- Compared to NLO multiplied by A^2/σ_{PbPb}

$\Rightarrow$ **No significant deviations from binary scaling are observed**

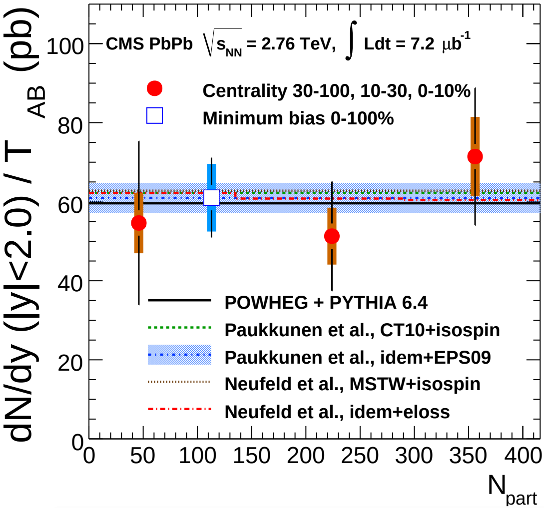
Yield vs. Rapidity



- $|y|$ bins: [0,0.5[[0.5,1[[1,2[
- MC multiplied by A^2/σ_{PbPb}
  - **POWHEG**: no effect
  - **Paukkunen**: isospin + shadowing
  - **Neufeld**: isospin + energy loss
  - More available (PYTHIA, MC@NLO and nDS)

$\Rightarrow$ Within uncertainties none of the subtler effects can be excluded

Normalized Yield vs. Centrality



- $dN/T_{AB} = R_{AA} \cdot d\sigma_{pp}$
- T_{AB} : nuclear overlap function estimated with a Glauber model calculation
- $\sigma_{pp} = 64 \pm 5$ mb at 2.76 TeV
- Marginal centrality dependence is predicted :
  - Eloss prediction drops by 3% from peripheral to central collisions
  - Shadowing is predicted to have negligible impact

$\Rightarrow$ **T_{AB} scaled Z yields are compatible with expectations**

Assuming $d\sigma_{\mathrm{pp}}/dy = 59.6$ pb in $|y| < 2.0$ from POWHEG :

$$R_{\mathrm{AA}} = dN_{\mathrm{AA}}/(T_{AB} \times d\sigma_{\mathrm{pp}}) = 1.00 \pm 0.16 \pm 0.14$$

Summary and Prospects

Quarkonia heavy ions

- J/ψ are measured by CMS in heavy ion collisions with a resolution close to pp
- Υ are already statistically significant
- pp run at $\sqrt{s} = 2.76$ TeV will be a good direct reference if enough stat.

$\Rightarrow$ **Detailed production studies coming up should be promising !**

Z bosons in heavy ions

- Measurement of the Z-boson yield inclusively and as a function of rapidity, transverse momentum and centrality
- Within uncertainties, no modification was observed with respect to the theoretical NLO pQCD pp cross-sections binary-collision scaled

$\Rightarrow$ **Higher luminosity and energy promises it to be a powerful tool**

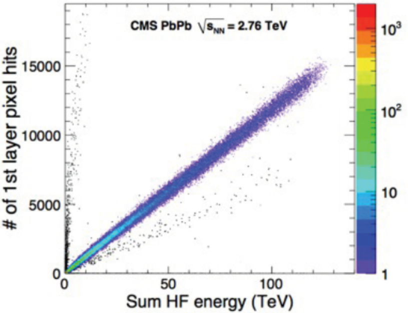
- for final-state HI related signatures : jet quentching, quarkonia suppression
- to study the modification of the PDFs in the initial state

The CMS physics results can be found in https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

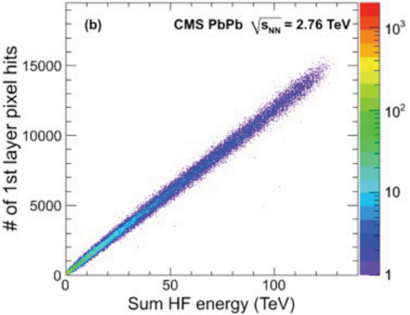
BACKUP

Event Selection

BEFORE



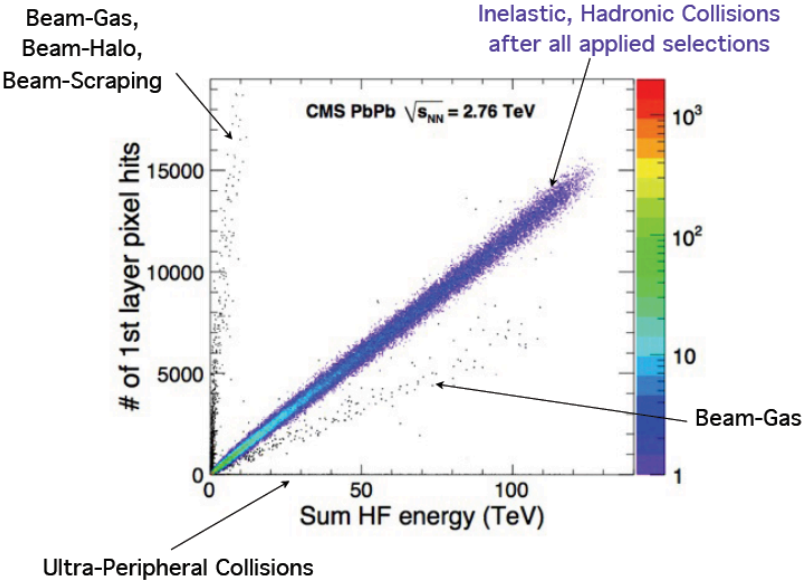
AFTER



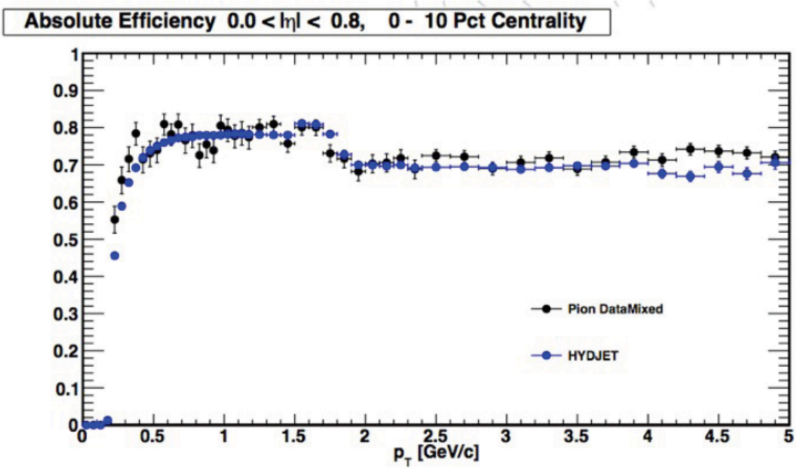
Dimuon triggered events	263 875
No beam halo, based on BSC	206 373
Beam gaz removal	206 121
HF ofine coincidence	205 973
Reconstructed vertex	204 285

204k good dimuon-triggered collision events after all selections

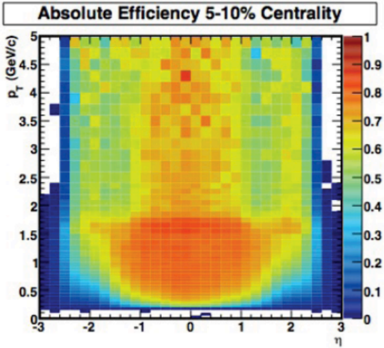
Event Selection

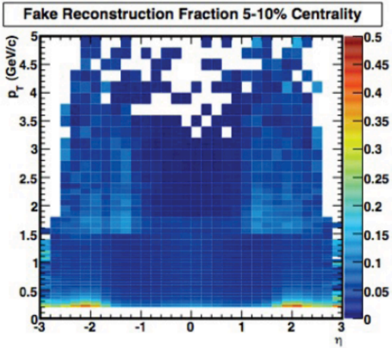


Heavy Ion Tracking Efficiency



Heavy Ion Tracking Performance





J/ψ and Υ Quality Selection in HI

GLB-GLB plots

- $|\eta^{\mu}| < 2.4$
- isGlobal() && isTracker()
- **global track**
  - globalTrack $\chi^2/ndof < 10$
  - globalTrack numberOfValidMuonHits> 0
- **inner track**
  - numberOfValidHits()> 12
  - $p_T^{error}/p^T < 0.05$ (loosen for the Z bosons analysis)
  - $|d_{xy}(prim\_vtx)| < 3$
  - $|d_z(prim\_vtx)| < 15$
  - $\chi^2/ndof < 4$

Z boson Analysis Quality Selection of Global Muons

⇒ Keep as much signal as possible

- Looking at Z embedded in HYDJET

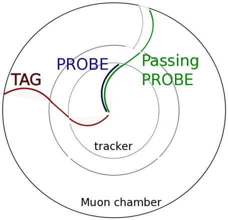
Keeping 97.6% MC signal

$\|\eta\|$	< 2.4
p_T	≥ 10 GeV/c
χ^2_{inner}/ndf	$\leq 4.$
χ^2_{global}/ndf	$\leq 10.$
$d_{xy}(vertex)$	≤ 0.3 mm
$d_z(vertex)$	≤ 1.5 mm
$Validhits_{innertrack}$	≥ 11
$Validhits_{muonstations}$	≥ 1
isTrackerMuon	true
p_T^{error}/p^T	≤ 0.1

The Tag&Probe Method

Data driven method : $\epsilon_{total} = \epsilon_{Track} \times \epsilon_{id|track} \times \epsilon_{trigger|id}$

- Used to estimate the efficiencies of **muon identification** and **triggering**.
- Gives single muon efficiencies corrected by correlations
- It utilizes resonances to identify probe muons objects belonging to resonances (J/ψ, Υ or Z^0) decay.



Method

Given a cleanly identified **tag** muon (generally a global, isolated muon with some p_T cut), estimate number of other muons satisfying or not certain steps of reconstruction (**probes**)

- Pair tags with oppositely charged probes and count the number of signal pairings by fitting the resonance peak (ex J/ψ)
- Process repeated for the case where the probes pass the cut.
- The number of signal pairings in the second case, divided by the number of signal pairings in the first case gives the muon reconstruction efficiency as required : $\epsilon = P_{pass}/P_{all}$

Limitation of the method

- Fit precision
- Correlation between muons (eg: small ΔR)

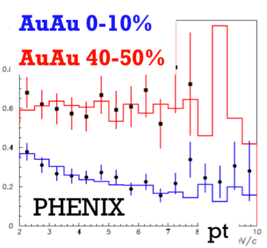
Simulation Pb+Pb avec HYDJET

I.P. Lokhtin, A.M. Snigirev, Eur. Phys. J. C 46 (2006) 211

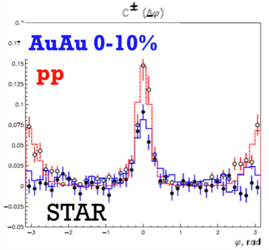
- HYDJET is event generator to simulate jet production, jet quenching and flow effects in ultra relativistic heavy ion AA collisions
- Hydjet code is merging HYDRO (**flow effects**), PHYTHIA6.4 (**hard jet production**) and PYQUEN (**jet quenching**)
  - A fit to PHOBOS η spectra of charged hadrons have been used to fix the particle density at $\eta = 0$ and the maximum longitudinal flow
  - Other parameters have been obtained with a fit to PHENIX p_T spectra of neutral pions

⇒ Reproduces main features of jet quenching observed at RHIC

p_T dependence of $R_{AA}(\pi)$



2 particles correlation



We consider at LHC: $dN/dh_{|\eta|=0}$ ∼2500 for minbias

Dimuon acceptance × efficiency corrections

Peak counting based on embedding MC in real data

$$\alpha \times \varepsilon(p_T^{dimu}, y^{dimu}, cent^{dimu}) = \frac{N^{reco}_{p_T^{\mu}>10, |\eta^{\mu}|<2.4}}{N^{gen}_{|y^{dimu}|<2.4}}$$

- N^{reco} and N^{gen} are the numbers of reconstructed and generated Z respectively. These numbers were computed with the weights to retrieve the p_T and y PYTHIA 6 distributions of the Z from the initial flat distributions: for each event i, the same weight ω_i has been given to the reconstructed and generated distributions
- $\omega_i = \omega_{pythia}(p_T^{gen}, y_Z^{gen}) \cdot N_{coll}$
  - ω_{pythia} is the generator PYTHIA distribution of p_T vs. y
  - N_{coll} is the number of binary collision used to retrieve the proper centrality shape.
- We obtain the following integrated $\alpha \times \varepsilon$ correction :
  - **simulated Z embedded in data:** $\alpha \times \varepsilon = 52.2 \pm 1.2$**%**

Di-electrons in pp