Measurement of J/ψ production at the LHC with the ALICE experiment

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and Related Subjects
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Outline

- Physics motivation(s)
- The ALICE detector
- p-p results at $\sqrt{s}$ = 7 TeV
  - $J/\psi \rightarrow e^+e^-$ ($p_T > 0$, $|y| < 0.88$)
  - $J/\psi \rightarrow \mu^+\mu^-$ ($p_T > 0$, $-4 < y < -2.5$)
- Conclusions
- Heavy-ion analysis: status and prospects

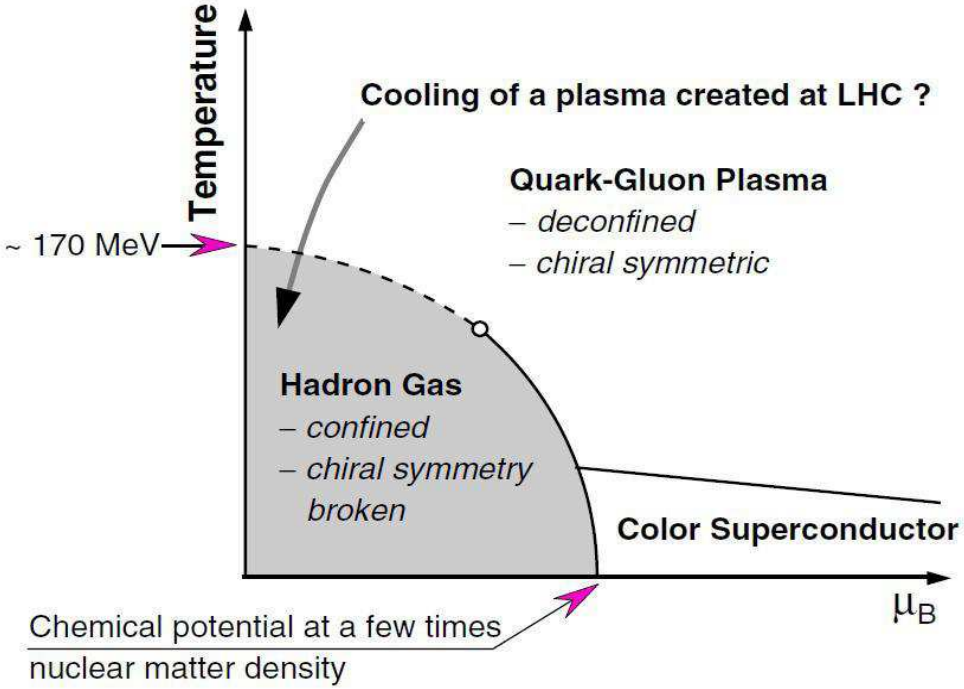
The ALICE physics goal

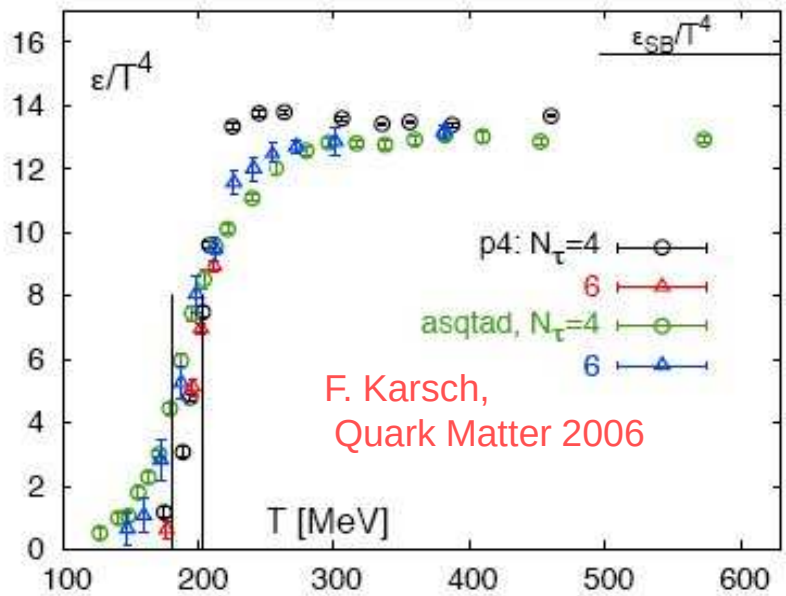
Study the hot and dense medium formed in **ultra-relativistic heavy-ion collisions** at the LHC

QCD asymptotic freedom -> transition to a **deconfined state of nuclear matter** with partonic degrees of freedom (**Quark Gluon Plasma**, QGP)

Lattice QCD predicts transition at T ~ 170 MeV ($\varepsilon \sim 0.7$ GeV/fm^3)

Early indications of QGP formation came from experiments at RHIC and SPS



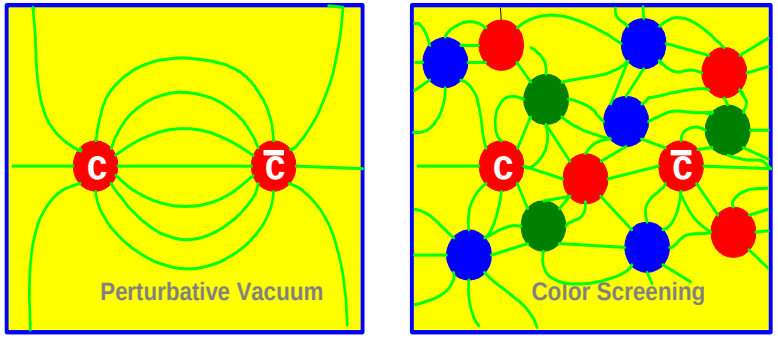


F. Karsch,
Quark Matter 2006

Why heavy quarkonia?

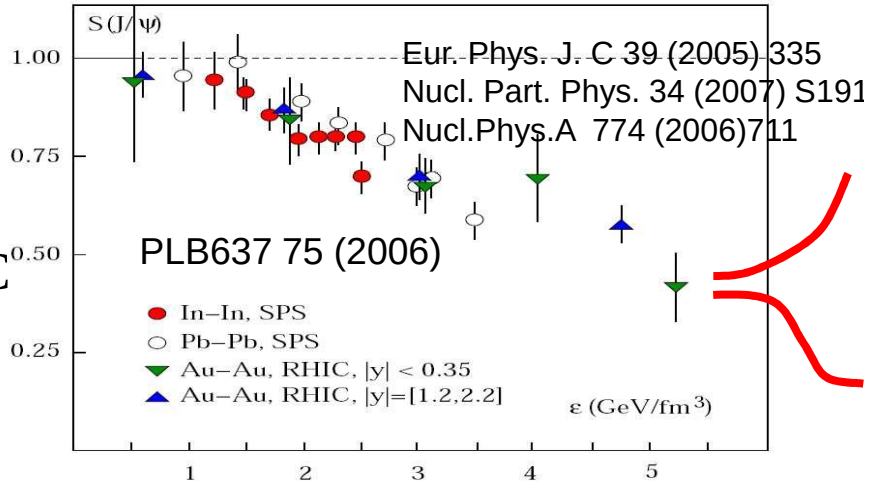
Resonance melting by colour screening: one of the first proposed signatures of deconfinement.

More tightly bound resonances melt at higher temperatures -> “thermometer” of the plasma



Same amount of J/ψ suppression at SPS and RHIC. Two main hypotheses:

- Suppression of ψ’ and χ_C feed down, survival of direct J/ψ at both SPS and RHIC -> **full melting of J/ψ at LHC?**
- Interplay between J/ψ suppression and regeneration by charm pair recombination at RHIC -> **J/ψ enhancement at LHC?**



p-p collisions

- Reference for heavy-ion analysis
- Test of pQCD and quarkonium production models at LHC energies

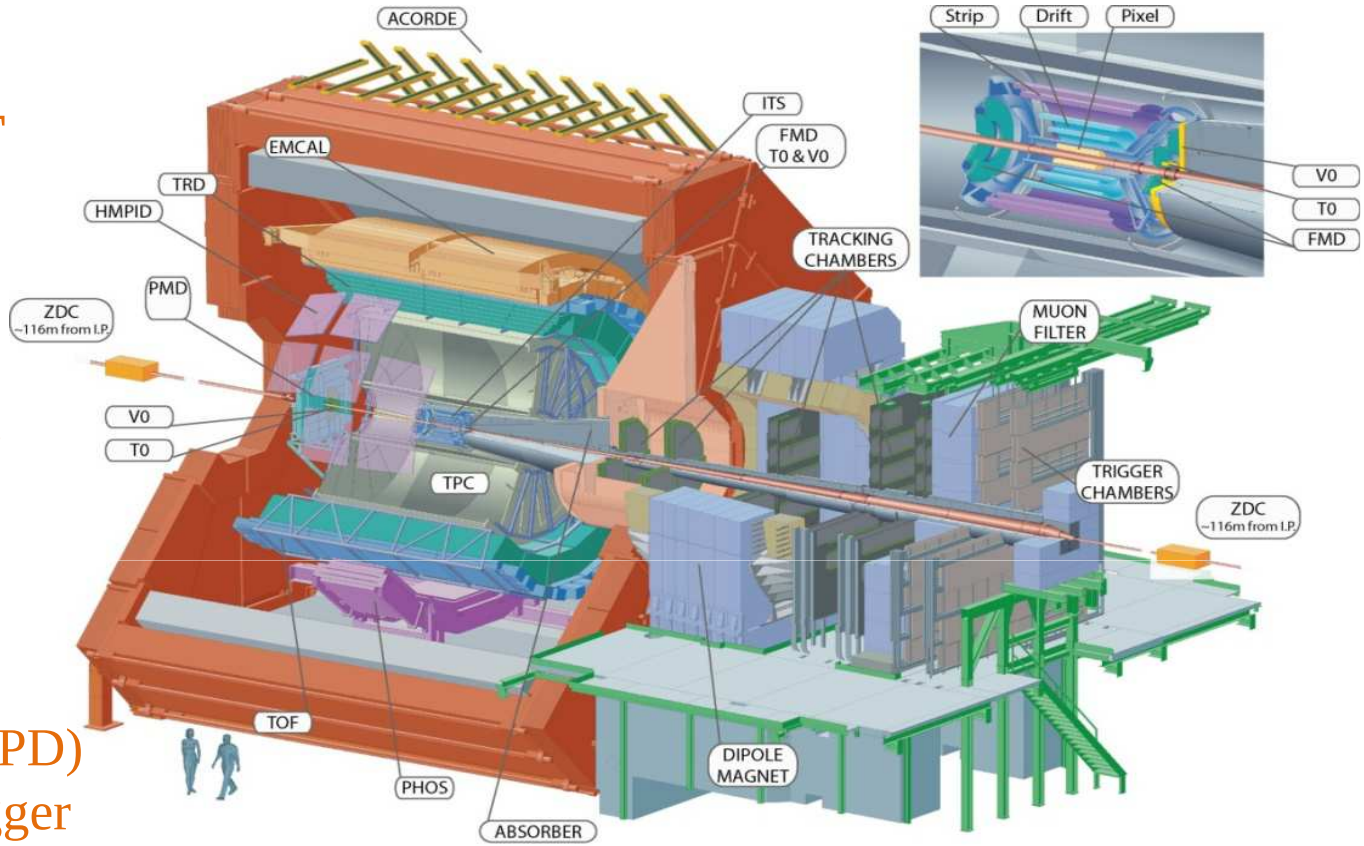
Detectors

Central barrel
$|\eta| < 0.9$

Solenoidal magnet 0.5 T

Inner Tracking System
(ITS)
-6 layers of silicon Pixel, Drift and Strip detectors
- 4 to 44 cm from IP
- primary and secondary vertexing
- low-p_T tracking
- two innermost layers (SPD) enter minimum-bias trigger

Time Projection Chamber
(TPC)
- 90 m^3 active volume, 72 MWPC read-out chambers
- main tracking detector
- particle identification via dE/dx



Muon spectrometer $-4<\eta<-2.5$
(will be described separately)

V0 detector
- two scintillator arrays on both sides of the IP
- enters minimum-bias trigger
- luminosity normalisation

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

$(p_T > 0, |y| < 0.88)$

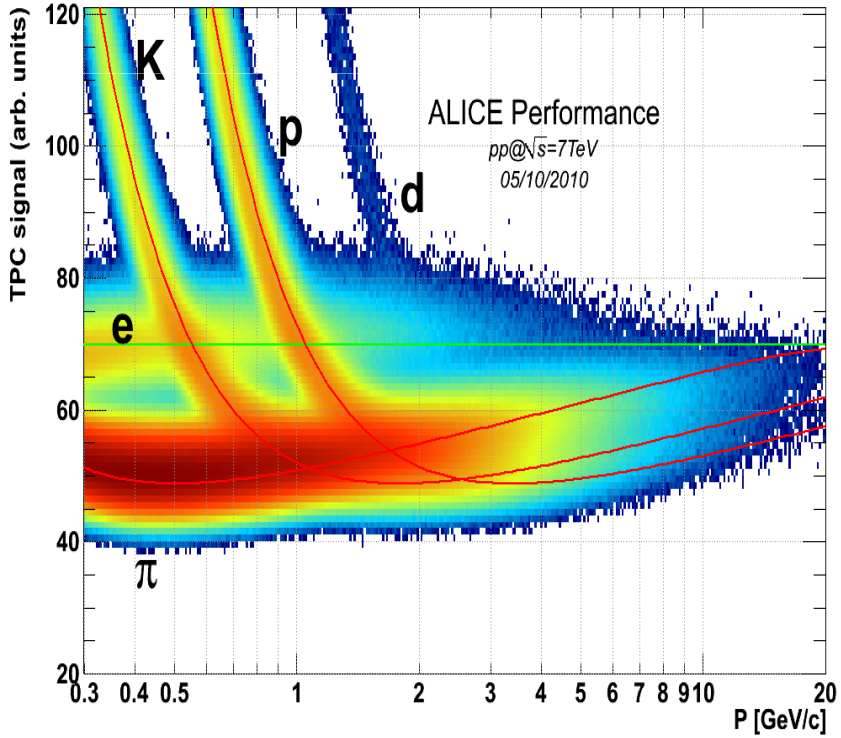
$J/\psi \rightarrow e^+e^-$: electron identification and track selection

- Minimum-bias trigger

- Electron identification via TPC dE/dx
  (TPC dE/dx resolution: 5.5%):
  - 3σ inclusion cut around the electron Bethe-Bloch line
  - 3σ exclusion cut around the pion Bethe-Bloch line

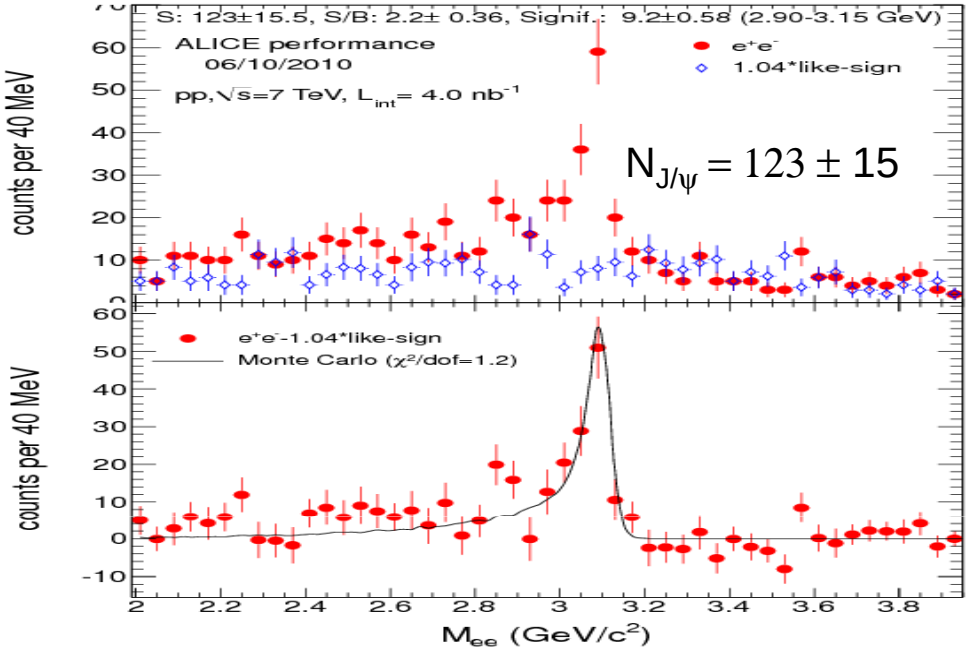
- Kinematical cuts:
  - $|\eta^{e+,e-}|<0.88$
  - $|y^{J/\psi}|<0.88$
  - $p_T^{e+,e-} > 1$ GeV/c

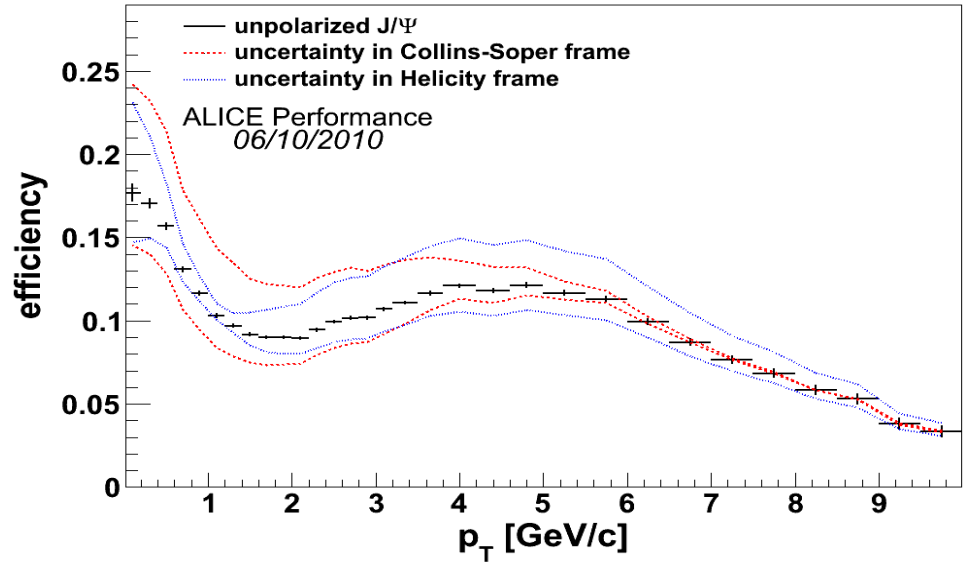
- Quality cuts:
  - reconstructed vertex
  - number of clusters in TPC
  - no weak decay candidate
  - a hit in one of the first two ITS layers (SPD, radii = 3.9 and 7.6 cm): minimise the impact of γ conversions



$J/\psi \rightarrow e^+e^-$: signal extraction and efficiency factors

- Inclusive J/ψ: no separation of B-mesons feed-down (yet)
- Signal extraction: bin-counting above like-sign background in $2.9 < M_{e+e-} < 3.15$ GeV/c^2
- Efficiency evaluated via simulation:
  - Kinematical cuts
  - Reconstruction
  - PID
  - Signal extraction range
- Strong effect of unknown J/ψ polarisation on acceptance (-25% ÷ +10%): assume no polarisation and quote polarisation-related uncertainty separately
- Non-vanishing acceptance at $p_T = 0$!





J/ψ –> e^+e^-: results and systematic uncertainties

Luminosity normalisation

- Reference process: coincidence of V0 hits on both sides of the IP (V0and)
- Measured in van der Meer scans

Sources of systematic uncertainty

Kinematics	<1%
Track quality, #clusters TPC	10%
PID cuts	10%
Signal extraction range	4%
Luminosity normalisation	10 %
Total systematic error	**18 %**

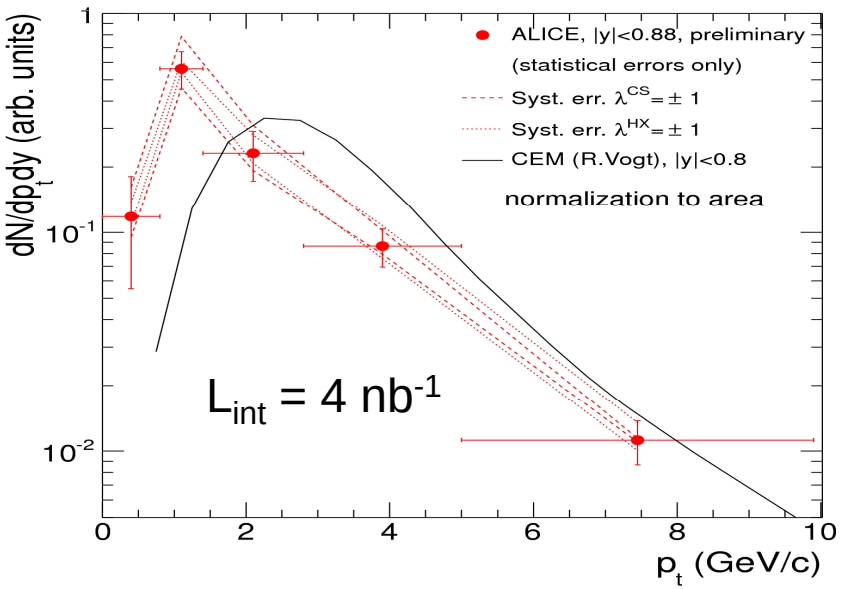
Inclusive J/ψ cross section in |y| < 0.88

Using best calibrated subset of data (L_{int} = 1.5 nb^{-1}):

$d\sigma_{J/\psi}/dy = 7.36 \pm 1.22 \pm 1.32 {}^{-1.84}_{+0.88}\ \mu b$

stat. syst. syst. pol.

p_T spectrum



Systematics evaluation and normalisation of the full data set ongoing -> $d\sigma/dp_T$

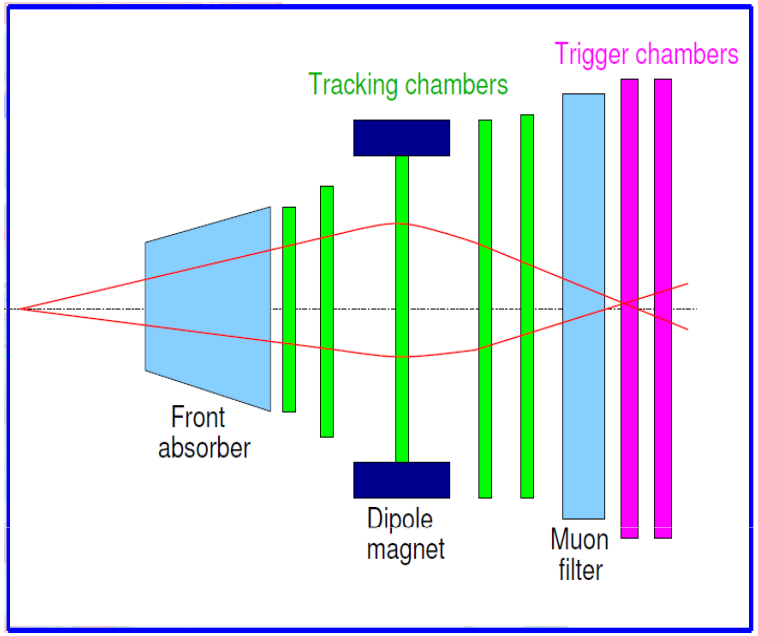
$J/\psi \rightarrow \mu^+\mu^-$

$(p_T > 0, -4<y<-2.5)$

$J/\psi \rightarrow \mu^+\mu^-$: muon detection and event selection

Muon spectromer:

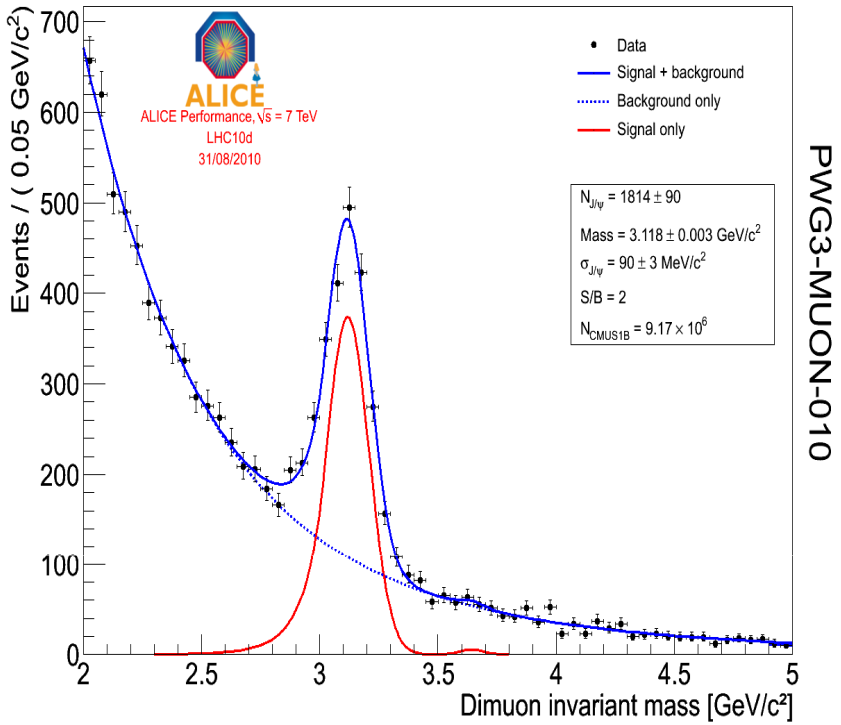
- Dipole magnet (0.7 T)
- 5 tracking stations (Cathode Pad Chambers)
- Trigger system with variable muon p_T cut (Resistive Plate Chambers)
- Front absorber (10 λ_{int})
- Muon filter before trigger chambers (7 λ_{int})
- Momentum resolution with current alignment: 12% at p_T ~10 GeV/c

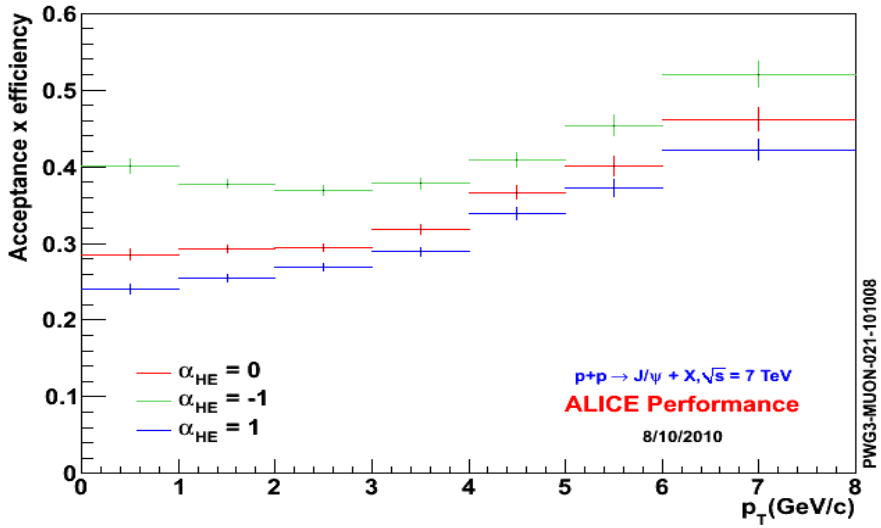


- Trigger: minimum bias & (single μ, $p_T > 0.5$ GeV/c)
- Cuts:
  - reconstructed vertex
  - trigger-tracking matching for at least one muon track: rejection of hadron contamination (muon filter)
  - Radial coordinate at exit of absorber $R_{abs} > 17.5$ cm: reject muons travelling long distances in the beam pipe + shielding
  - $4 < y^{\mu+,\mu-} < -2.5$: limit edge effects on acceptance

$J/\psi \rightarrow \mu^+\mu^-$: signal extraction and efficiency factors

- Inclusive J/ψ (no B separation)
- Signal extraction:
  Crystal Ball function (MC-tuned) + double exponential for background
- Statistics for total cross section:
  1909 ± 78 J/ψ in $2.9 < M_{\mu+\mu-} < 3.3$
- Tracking and trigger efficiency evaluated by simulation (realistic kinematics and detector configuration)
- Strong effect of unknown J/ψ polarisation on acceptance (-21% ÷ +12%): assume no polarisation and quote separately the polarisation-related uncertainty
- Non-vanishing acceptance at $p_T = 0$!





$J/\psi \rightarrow \mu^+\mu^-$: results and systematic uncertainties

Luminosity normalisation

- Single muon cross section relative to minimum-bias (using V0and for absolute normalisation)

Sources of systematic uncertainty

Signal extraction	7.5 %
p_T and y shapes used in the MC	p_T: +2 -1.3%, y: +1.4 -1.3%
Trigger efficiency	4%
Tracking efficiency	2%
Luminosity normalization	10 %
Total systematic error	**13.5 %**

Integrated J/ψ cross section in -4 < y < -2.5:

$$7.25 \pm 0.29 \pm 0.98 \; {}^{-1.50}_{+0.87} \; \mu b$$

stat. syst. syst. pol.

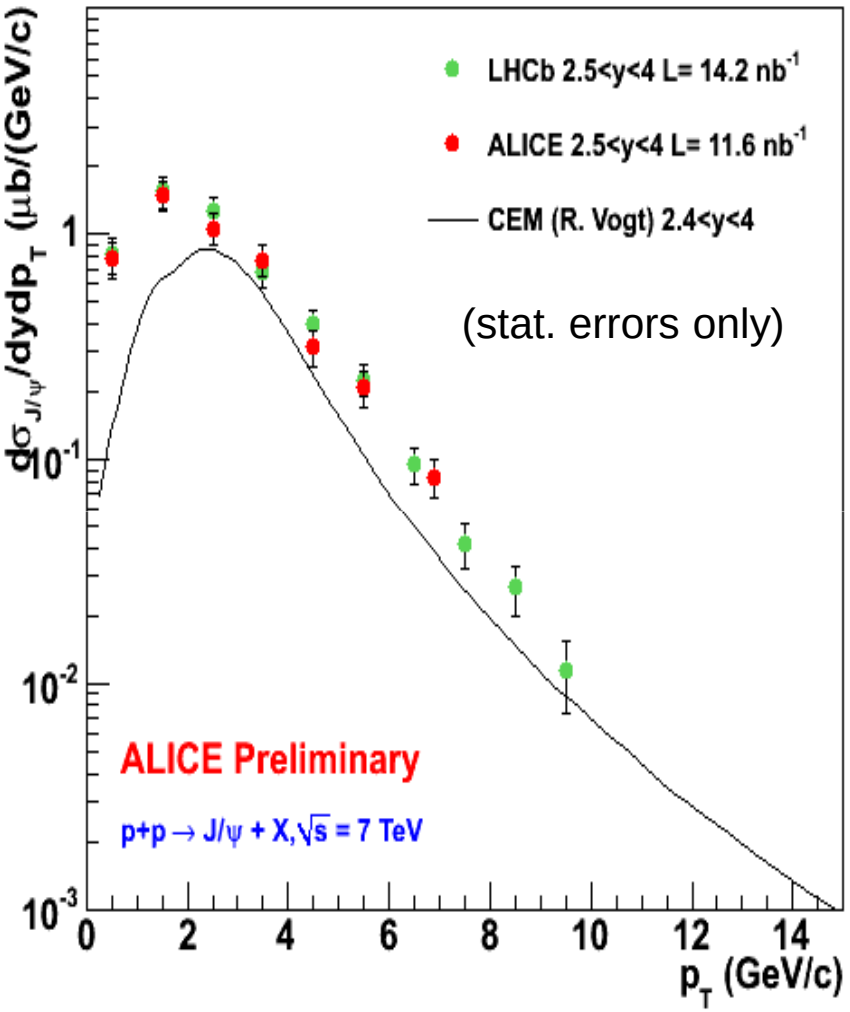
- Obtained with L_{int} = 13.6 nb^{-1}
- Good agreement with **LHCb result** in the same rapidity window:

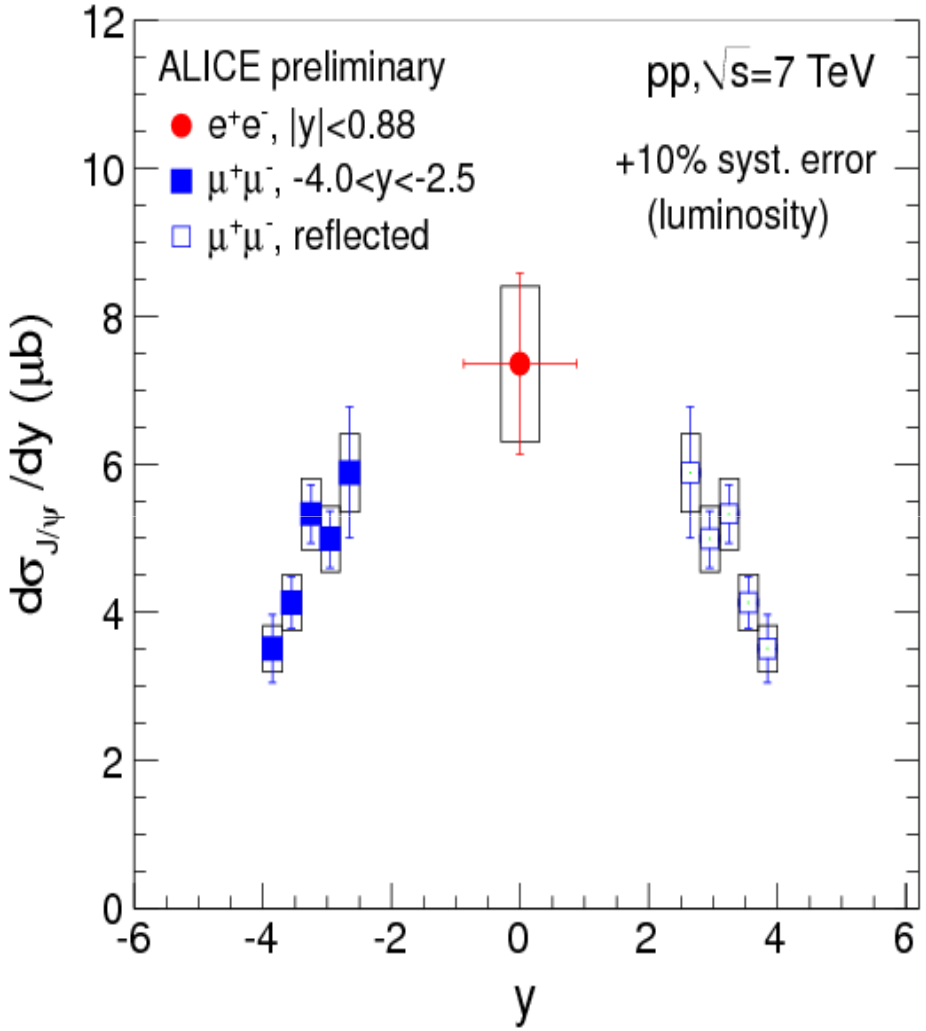
$$7.65 \pm 0.19 \pm 1.10 \; {}^{-1.27}_{+0.87} \; \mu b$$

(preliminary, ICHEP 2010)

- p_T and rapidity differential cross sections have also been measured (next slide)

Differential inclusive J/ψ cross sections

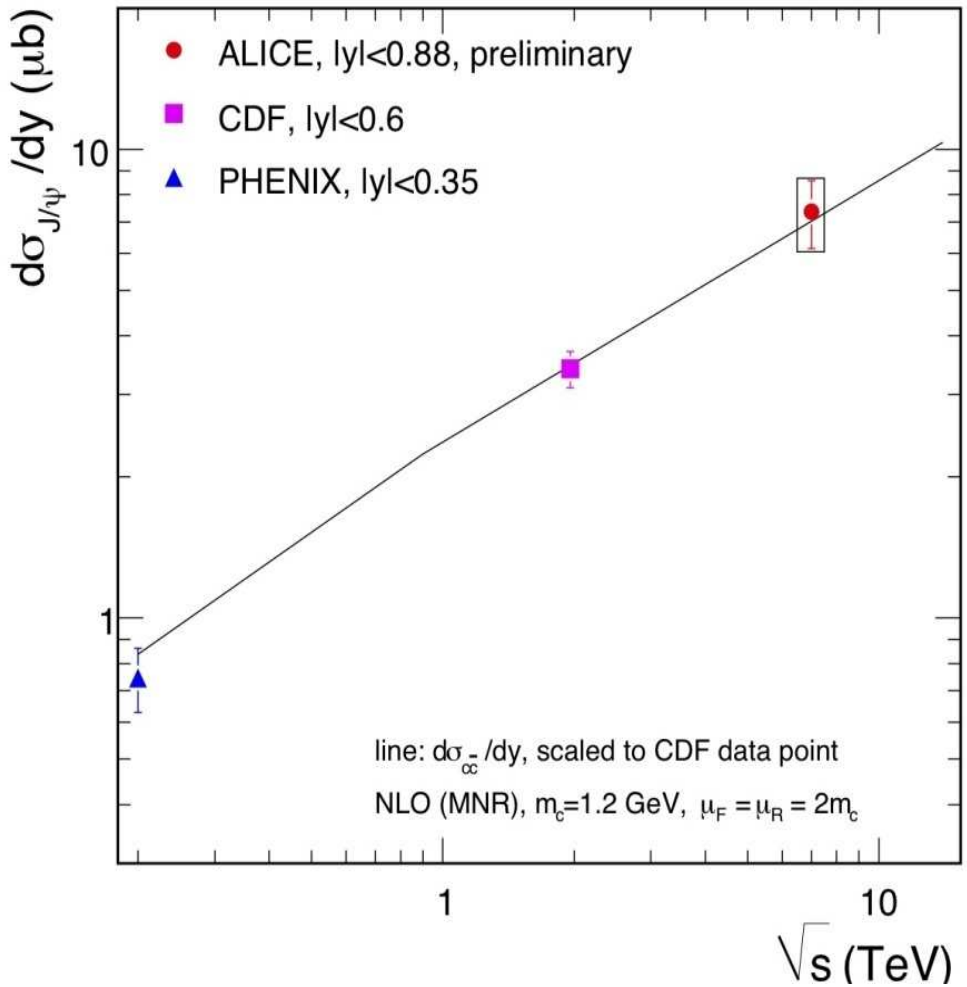




- Point-to-point systematic error: 3-10%, mainly related to signal extraction and acceptance correction (evaluation ongoing)

Conclusions and outlook

- ALICE in good shape during 2010 p-p run
- Preliminary results on J/ψ in p-p are available
- Paper under Collaboration review:
  - increased statistics:
    4 nb^{-1} in the electron channel
    16 nb^{-1} in the muon channel
  - extend p_T reach of $d\sigma/dp_T$ measurement in the muon channel (improved alignment)
  - $d\sigma/dp_T$ in the electron channel
  - reduced luminosity uncertainty (using final beam intensity values)



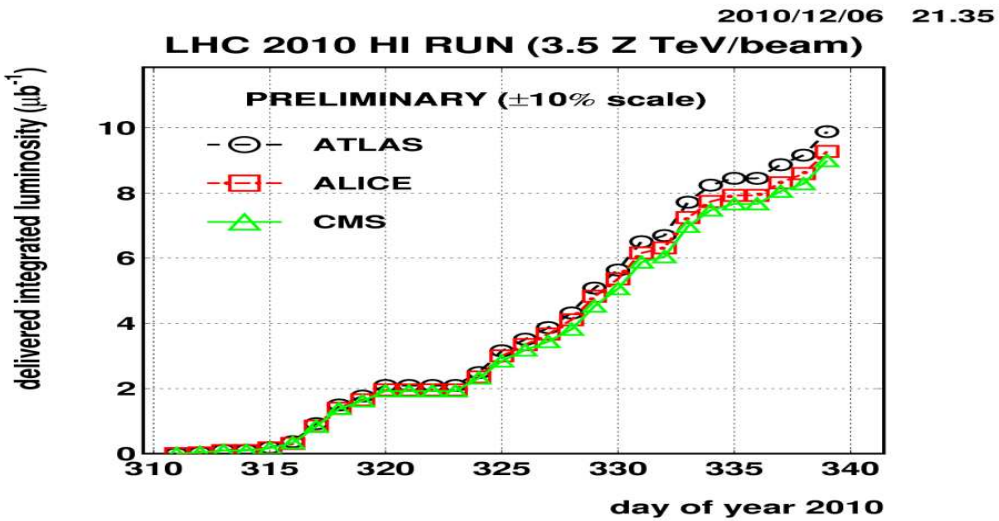
- Longer term:
  - J/ψ polarisation in the muon channel
  - B feed-down separation in the electron channel
  - improve electron PID (Time Of Flight, Transition Radiation Detector)
  - data-driven techniques for muon background subtraction

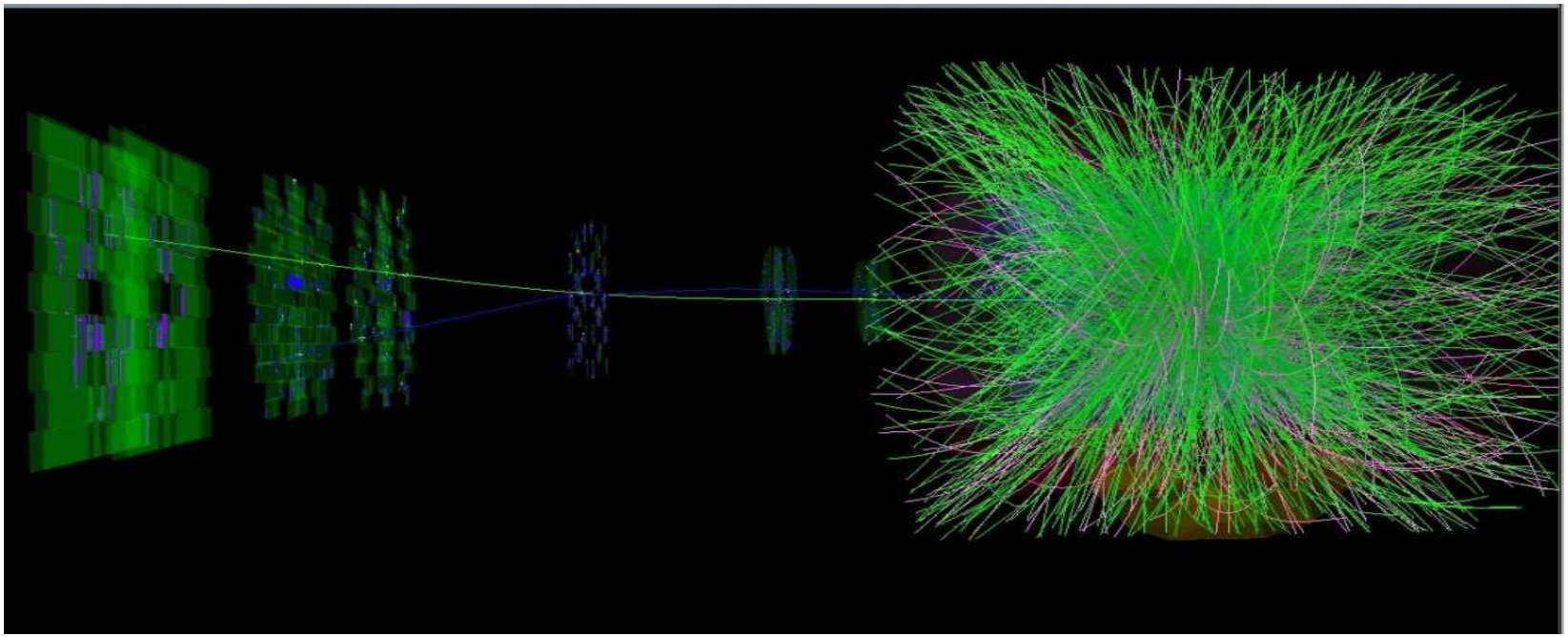
Pb-Pb collisions

1 month running time
10 μb^{-1} delivered luminosity

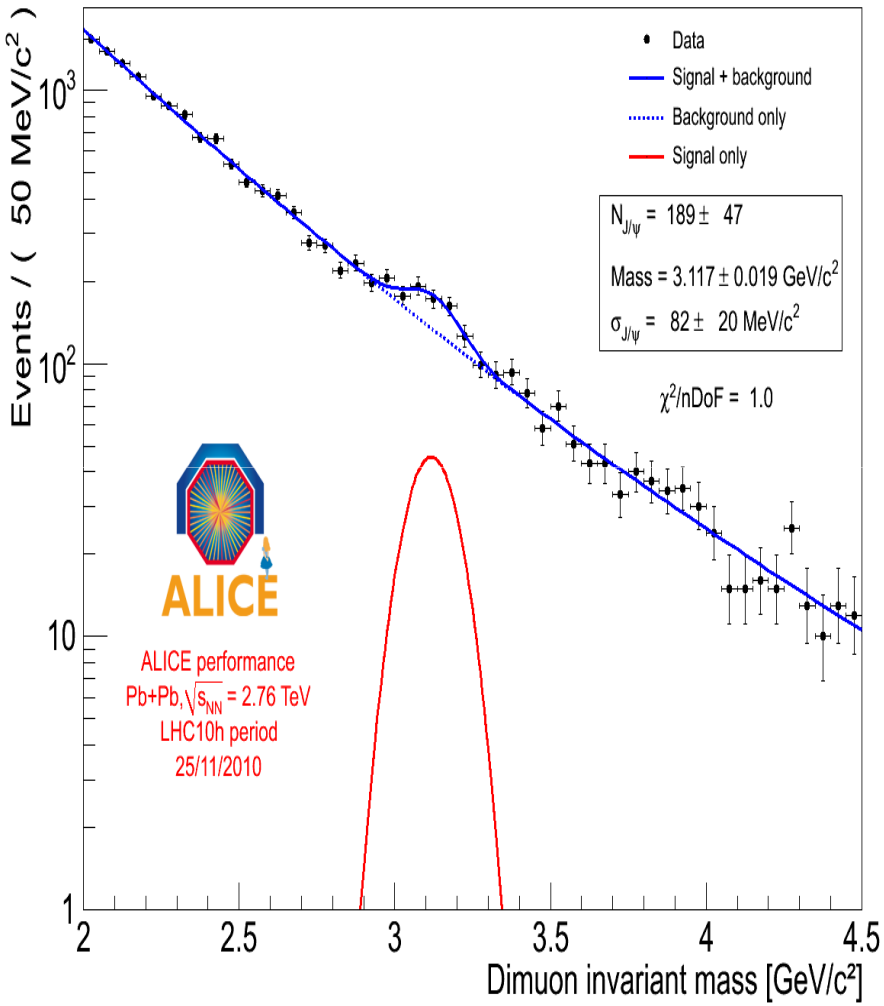
$$\sqrt{s}_{NN} = 2.76\ TeV$$

$$\frac{dN_{ch}}{d\eta} \approx 1600$$ (central collisions)





Status of J/ψ analysis in Pb-Pb collisions



First J/ψ –> $\mu^+\mu^-$ signal

2.6 M minimum-bias events

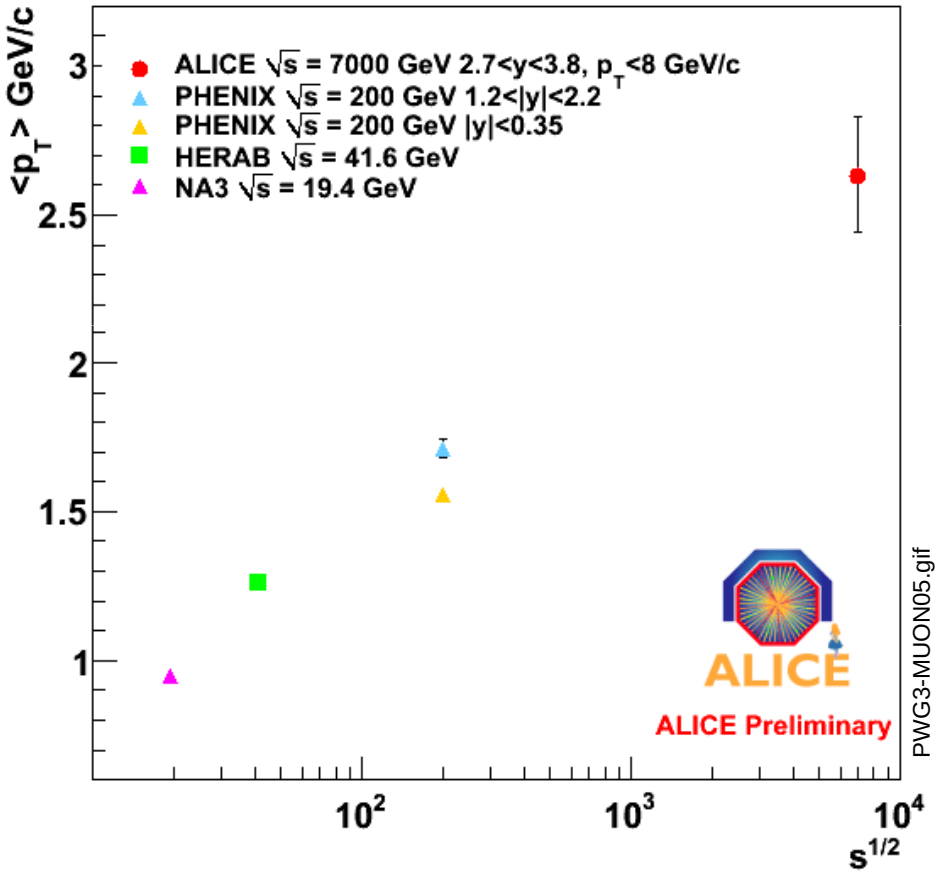
- Analysis focuses on the muon channel
- Low luminosity (~10^{25} Hz/cm^2)
  -> no dedicated muon trigger needed
- About 30 M minimum-bias events on tape
- Analysis of pt-integrated (p_T>0) nuclear modification factor in progress
- Need p-p reference at $\sqrt{s}$ = 2.76 TeV

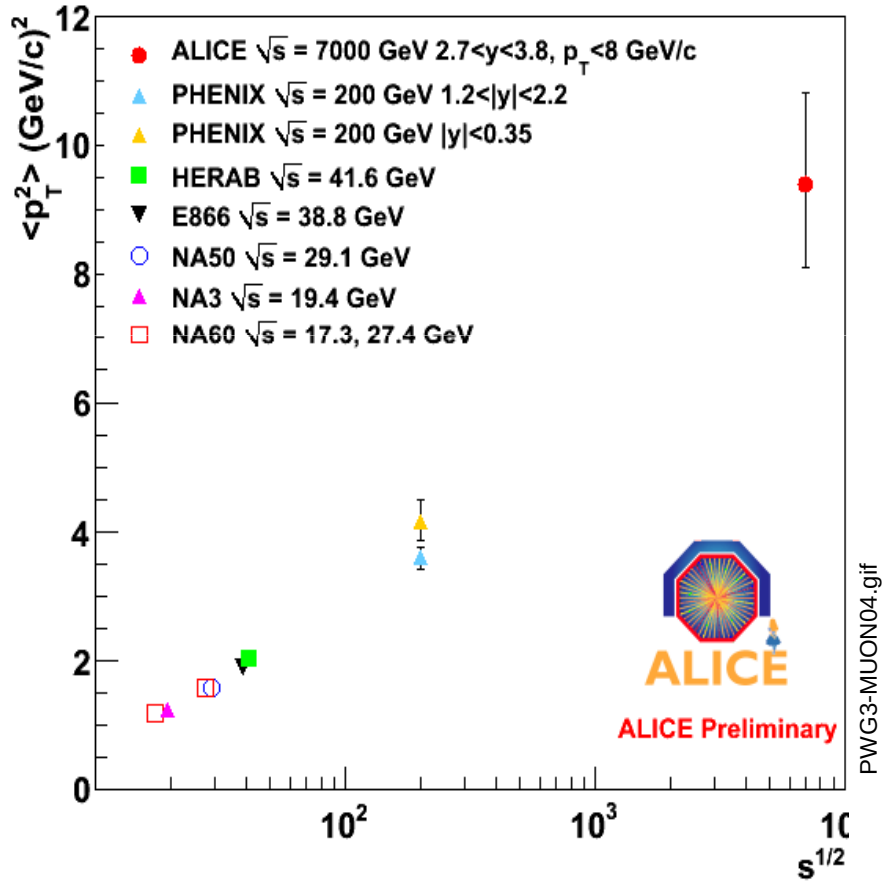
  Two strategies:
  - direct measurement in p-p collisions at 2.76 TeV in March 2011: 34h data-taking - 9M muon triggers
  - energy interpolation (arXiV:1103.2394)

Backup

$J/\psi \rightarrow \mu^+\mu^-$: $\langle p_T \rangle$ and $\langle p_T^2 \rangle$

Fitting the p_T differential distribution the $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ are computed and compared with lower energy experiments





$$\langle p_T^2 \rangle = 9.4^{+1.4}_{-1.3} (stat. + syst. errors)(GeV/c)^2$$