Heavy flavour and Quarkonium measurements with ALICE at LHC

Javier Castillo

for the

ALICE Collaboration

Outline

- Physics motivations
- ALICE experiment
- ALICE capabilities
  - Open heavy flavour
  - Quarkonia
- First results from 7 TeV p-p collisions
- Conclusions

- Disclaimer:
  - muon spectrometer biased
  - other heavy flavour results in
    - G. Bruno, session 05 - 22/7
    - A. Grelli, session 05 - 22/7
    - R. Bailhache, session 05 - poster

Heavy flavours

- In Pb-Pb collisions: probe the properties of the medium
  - created in the hard initial collisions
    - experience the whole collision history
  - possible comparison heavy quarks/light partons
    - energy loss:

$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

dead cone effect (mass)

Casimir factor (colour charge)

$$R_{AA}^{H}(p_t) = \frac{1}{N_{coll}} \frac{dN_{AA}^{H}/dp_t}{dN_{pp}^{H}/dp_t}$$

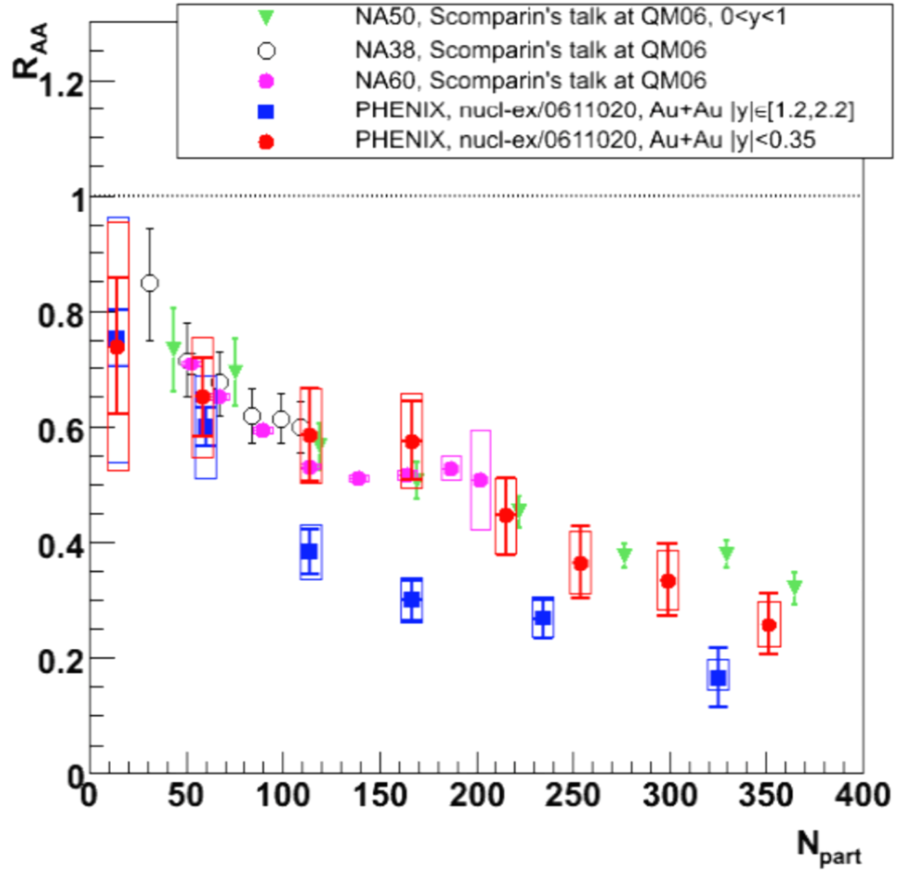
medium density and size

$$R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B}$$

- In p-p collisions:
  - baseline for Pb-Pb
  - measure charm and beauty cross section
  - compare to pQCD predictions

Quarkonia, heavy ions and the QGP?

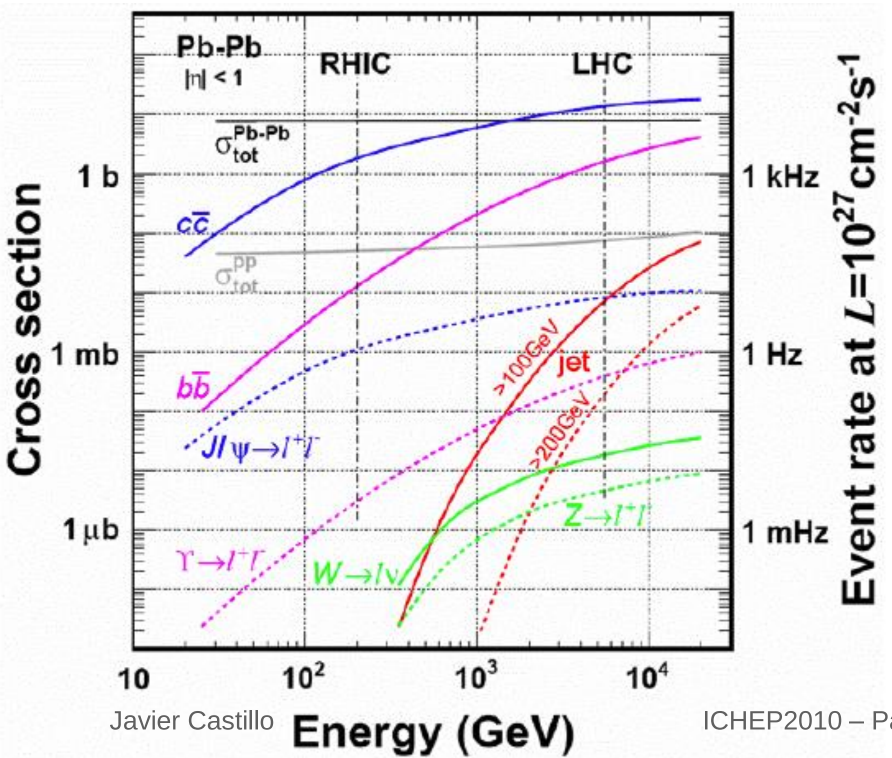
- A long lasting story…
  - 1986, Matsui and Satz: J/ψ suppression as a QGP signature
  - NA38, NA50, NA60 at SPS
  - PHENIX, STAR at RHIC
- … and many open questions
  - similar suppression at RHIC and at SPS
  - larger suppression at larger rapidities
  - cold nuclear matter effect (still) weakly constrained
  - statistical hadronization, recombination?

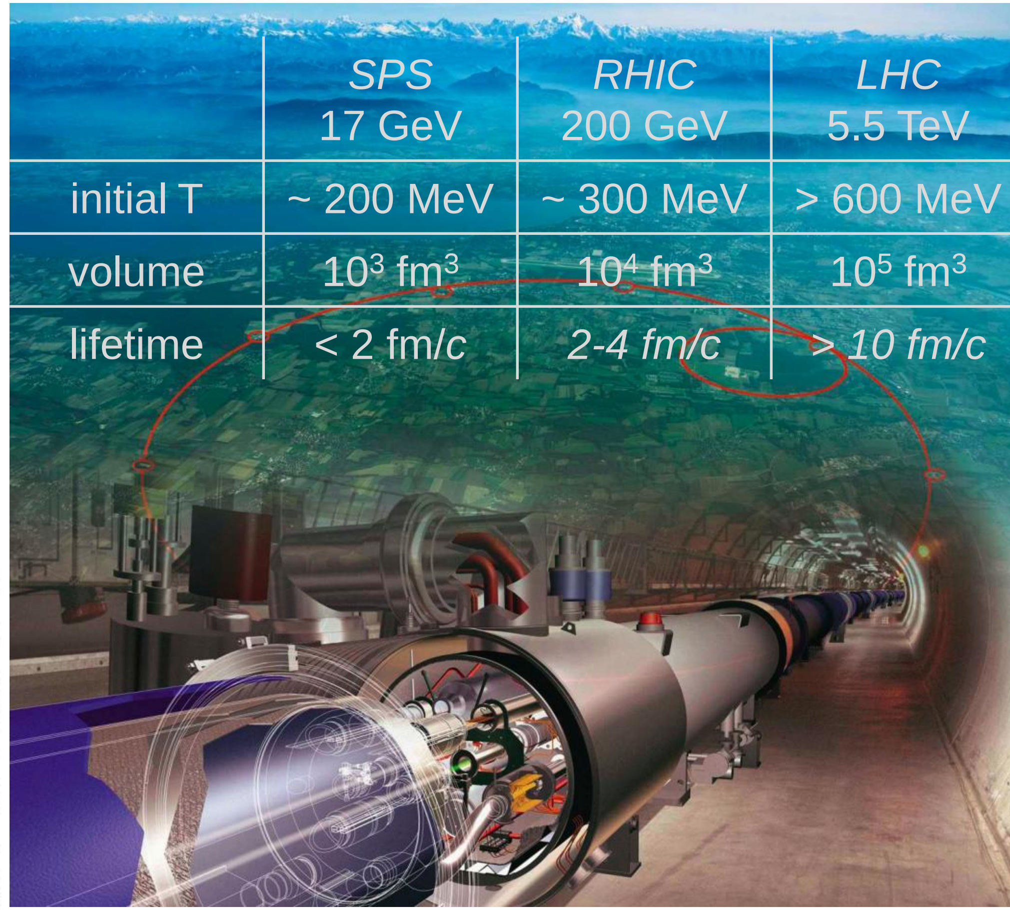


… and then??
The LHC might enlighten us …

The LHC and its features

- Large energy step (RHIC x30)
  - A QGP that will be
    - hotter,
    - bigger,
    - longer lived,
    - earlier thermalized.
  - Large hard probe production cross-sections





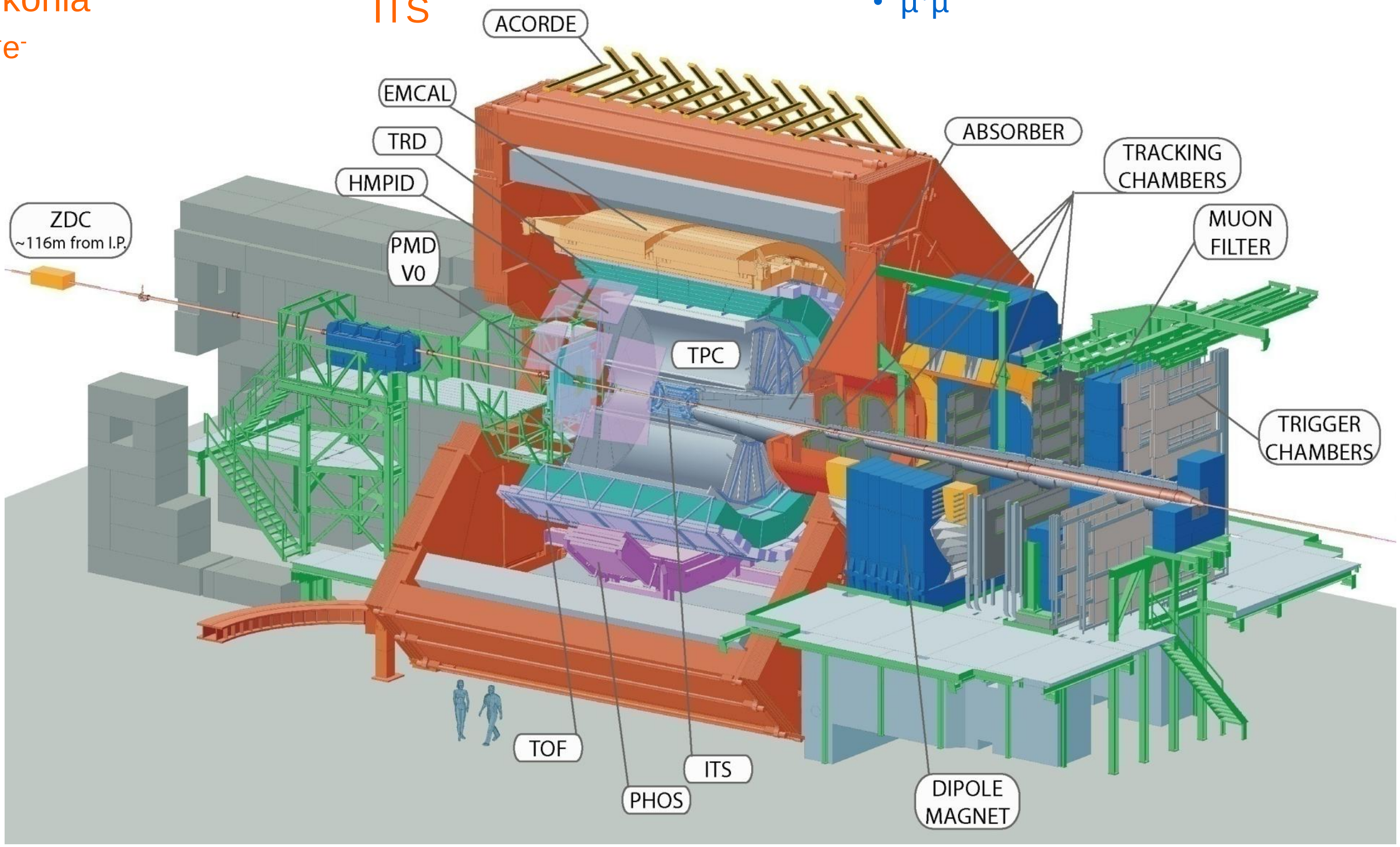
	SPS 17 GeV	RHIC 200 GeV	LHC 5.5 TeV
initial T	~ 200 MeV	~ 300 MeV	> 600 MeV
volume	10^3 fm^3	10^4 fm^3	10^5 fm^3
lifetime	< 2 fm/c	2-4 fm/c	> 10 fm/c

	SPS PbPb Cent	RHIC AuAu Cent	LHC pp	LHC pPb	LHC PbPb Cent
cc	0.2	10	0.2	1	**115**
bb	-	0.05	0.007	0.03	**5**

At top energies

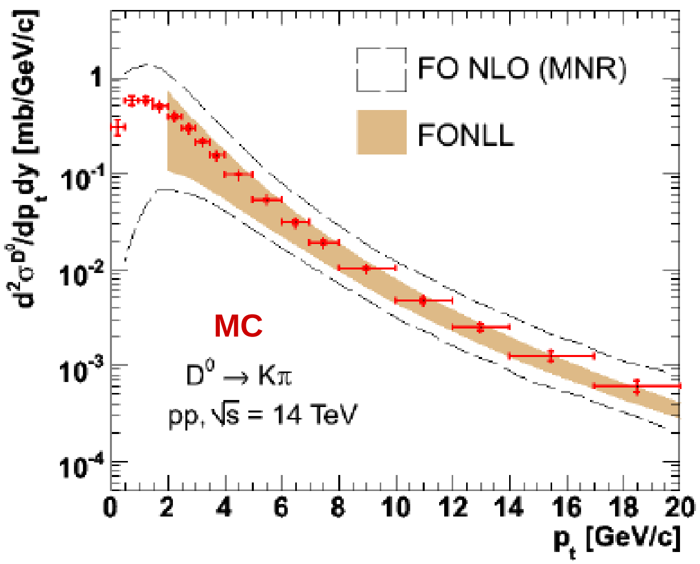
ALICE

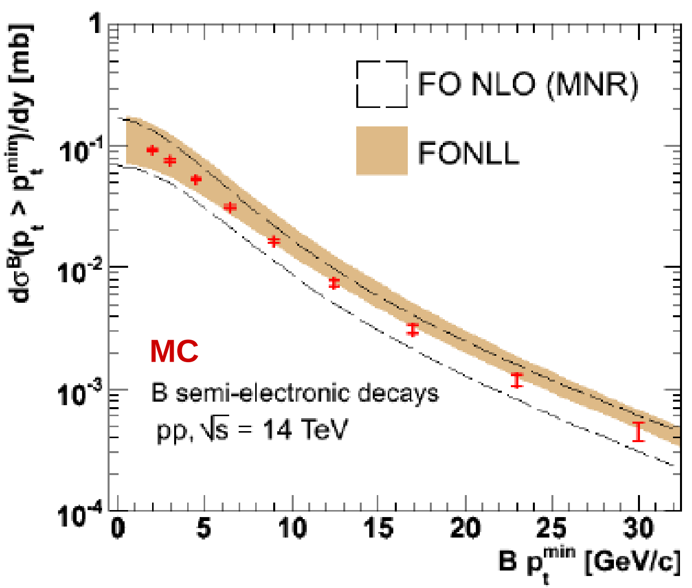
- Central barrel (|η|<0.9)
  - Open heavy flavour
    - hadronic channel
    - semi-leptonic decays (e)
  - Quarkonia
    - e^+e^-
  - Tracking: ITS+TPC+TRD
  - PID: TPC+TRD+TOF
  - Secondary vertexing: ITS
- Muon spectrometer (-4.0<η<-2.5)
  - Open heavy flavour
    - semi-leptonic decays (μ)
  - Quarkonia
    - $\mu^+\mu^-$
  - Absorber
  - Tracking chambers
  - MUON Trigger



Heavy flavour measurement potential

Comparison with pQCD

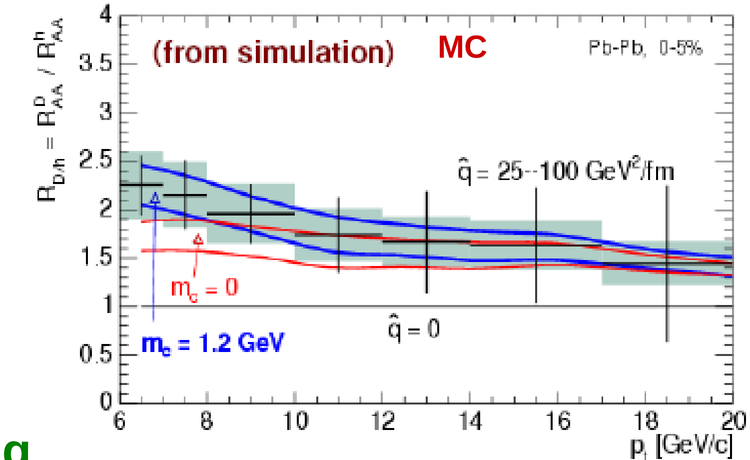




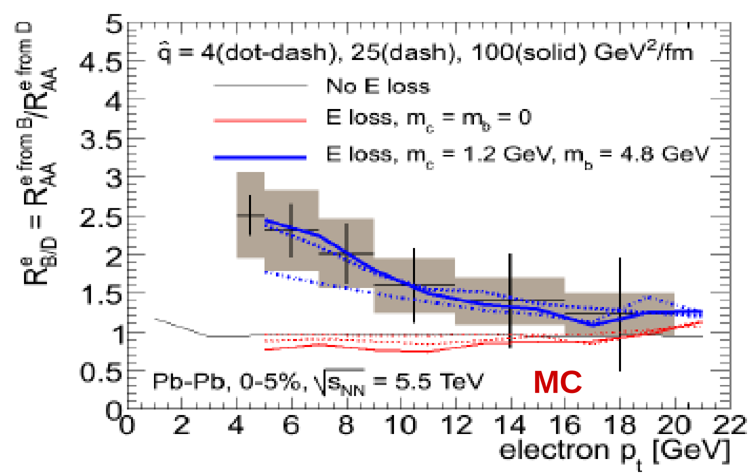
Good discriminating power!

Energy loss studies

$$R_{D/h}(p_t) = R_{AA}^{D}(p_t) / R_{AA}^{h}(p_t)$$



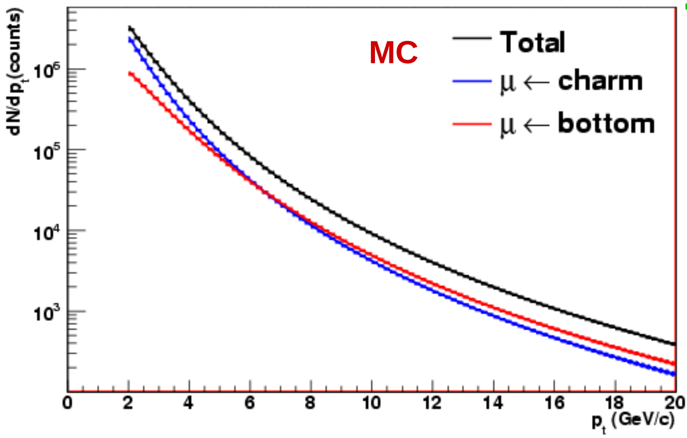
$$R_{B/D}(p_t) = R_{AA}^{\text{e from B}}(p_t) / R_{AA}^{\text{e from D}}(p_t)$$



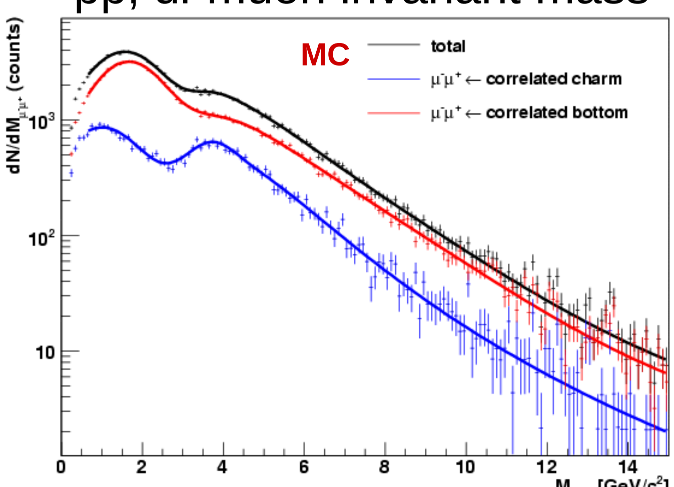
Muons from charm at forward rapidity

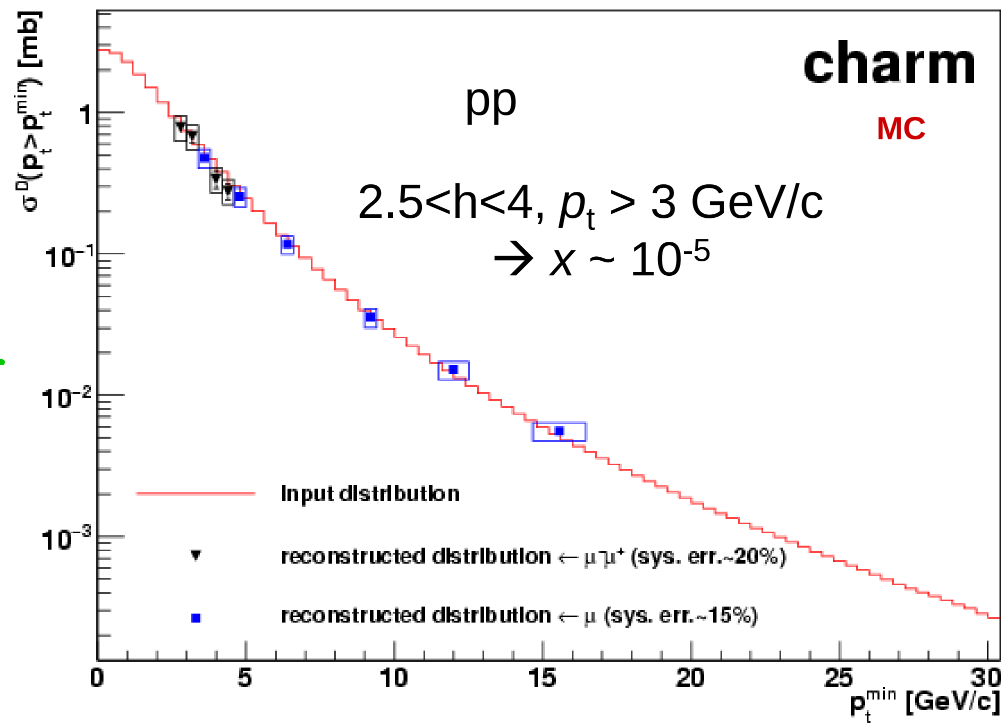
- Unfold single muon p_t and dimuon invariant mass spectra
- No dca cuts → use large statistics to constrain the fits

pp, single muon p_t



pp, di-muon invariant mass

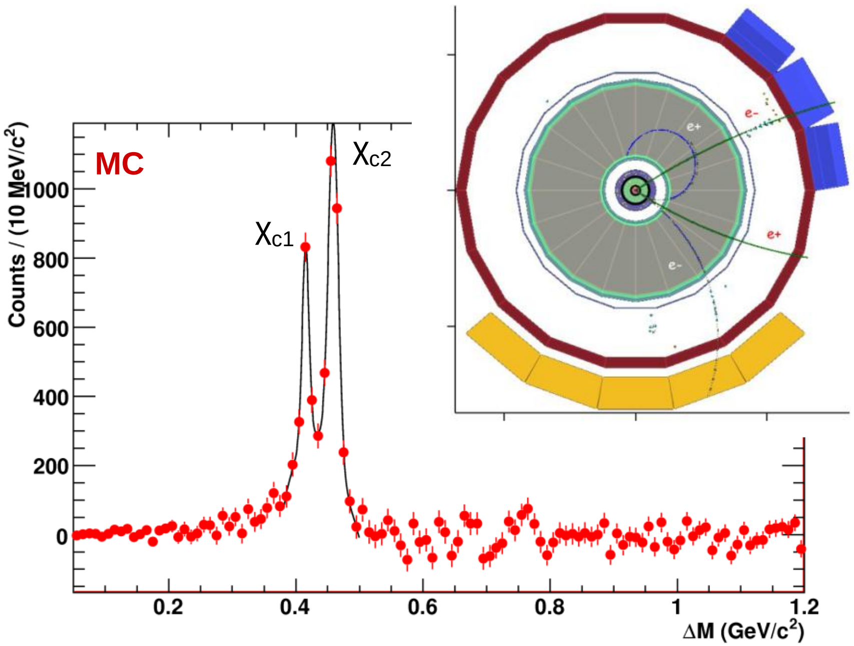




1 month at reduced luminosity
(10^{30} $cm^{-2}s^{-1}$, 7 x 10^{10} pp events)

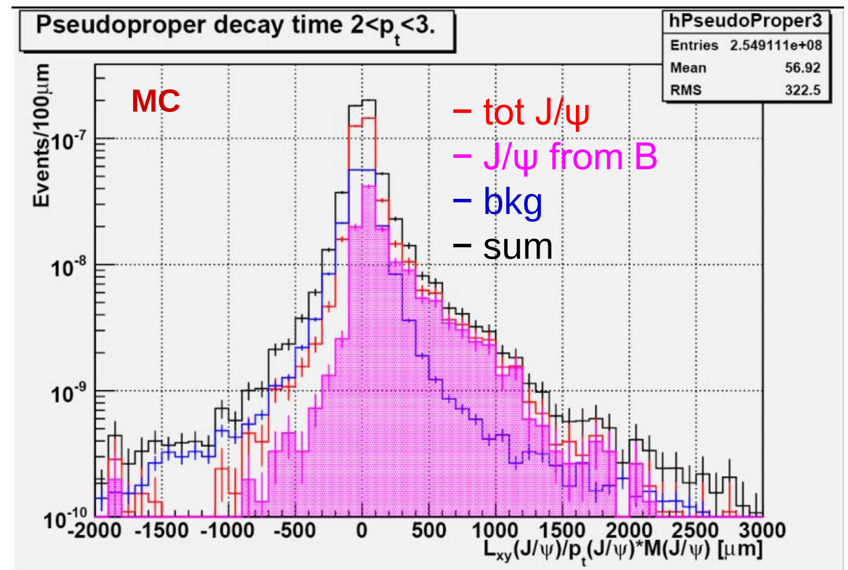
Secondary J/ψ

- χ_c: contribution ~30%
  - $\chi_c \rightarrow J/\psi + \gamma$
    - J/ψ in dielectron channel
    - γ in γ-conversion



  - feasible in pp collisions
    - ~7k χ_c but requires a trigger strategy which is under study
- ψ': contribution ~10%
  - challenging

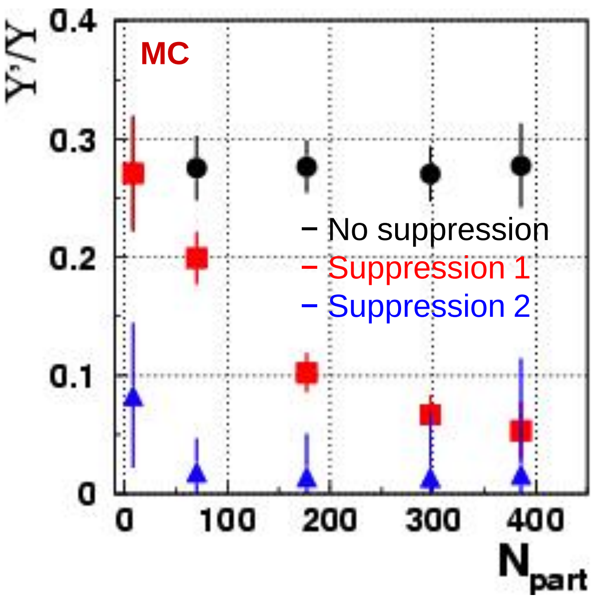
- B mesons: contribution ~20%
  - $B \rightarrow J/\psi + X$
    - Non photonic electrons
    - à la CDF: simultaneous fit
      - Invariant mass distribution
      - Pseudo proper decay time



  - In muon arm
    - method using 3 muon events is under study

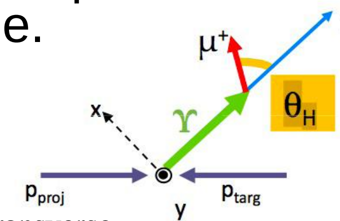
Quarkonia: what could be achieved

- Upsilon measurements
  - Separation of family states is possible (100 MeV resolution)

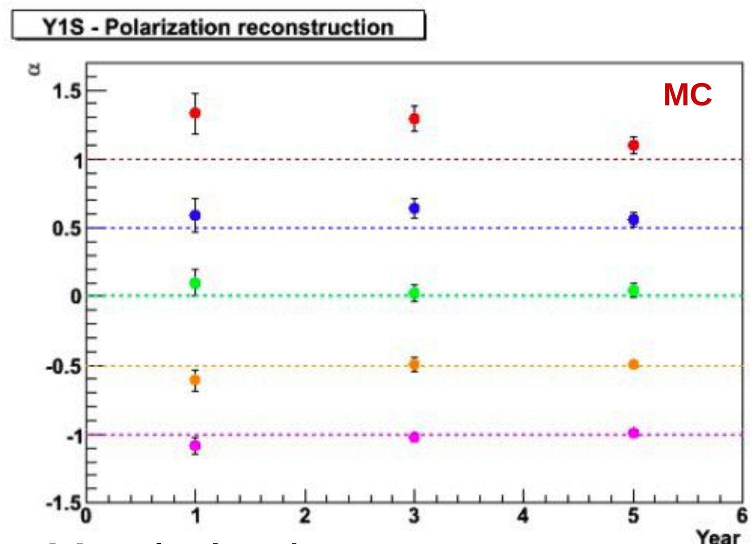


  - Good sensitivity to "suppression" scenarii
    - Suppression 1: T_C = 270 MeV; T_D/T_C = 4.0 (1.4) for ϒ(ϒ');
    - Suppression 2: T_C = 190 MeV; T_D/T_C = 2.9 (1.1) for ϒ(ϒ');

- Polarization
  - Angular distribution of μ+ in the quarkonium rest frame.

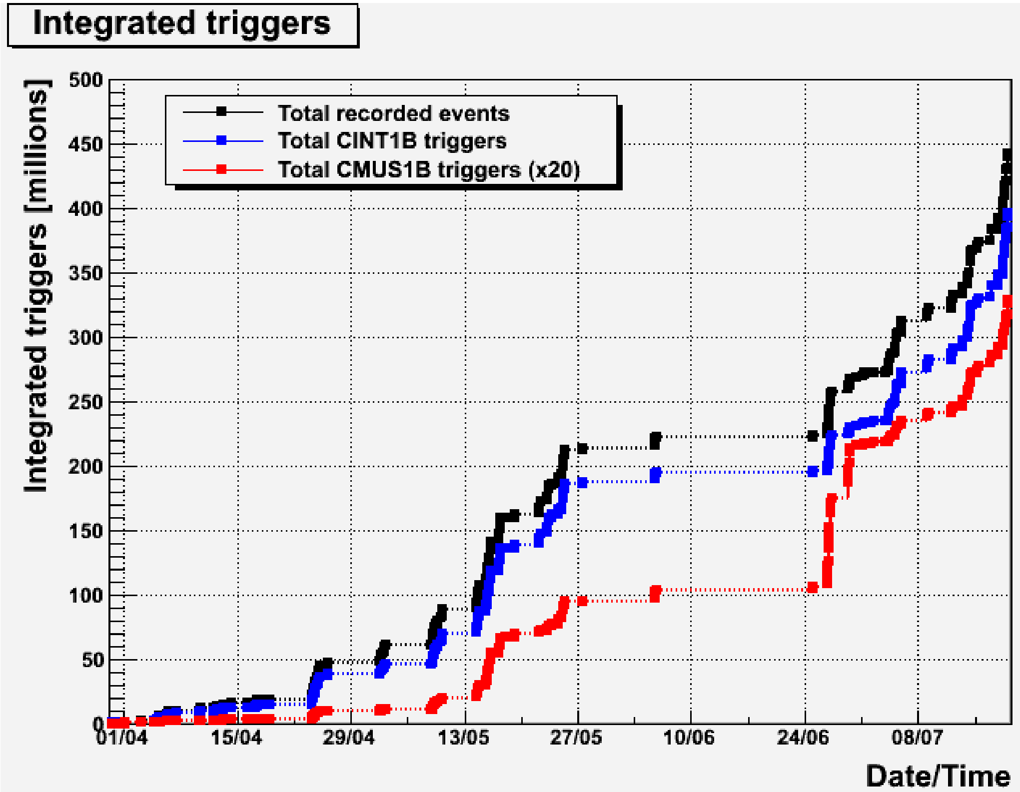


    - $\frac{d\sigma}{d\cos\theta_H} \propto 1 + \alpha\cos^2\theta_H$
    - $\alpha = \frac{\sigma_T - 2\sigma_L}{\sigma_T + 2\sigma_L} \Rightarrow \begin{cases} 1 & \text{transverse} \\ 0 & \text{no polarization} \\ -1 & \text{longitudinal} \end{cases}$



  - Y polarization
    - 1 nominal year for integrated studies
    - Several years for differentials

First results from 7 TeV p-p collisions



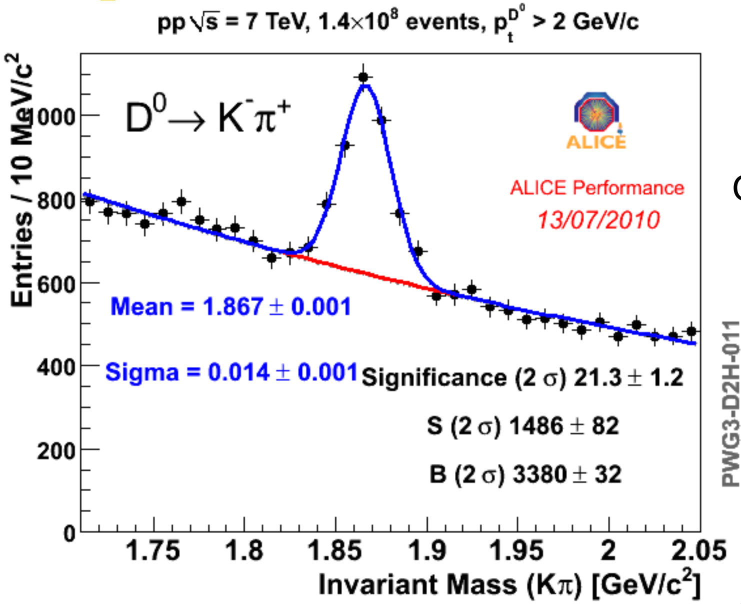
- **CINT1B**: interaction trigger
  - at least one charged particle in 8 η units
- **CMUS1B**: single-muon trigger:
  - forward muon in coincidence with interaction trigger

Further background-event rejection is performed offline by selecting events which:

1. have the correct event type (physics);
2. trigger on bunch crossings;
3. fulfill at least -one- of the three following conditions:
   a) 2 fired chips in the SPD*
   b) 1 fired chip in the SPD* and a beam-beam flag in either V0A or V0C**
   c) beam-beam flags on both sides V0A and V0C**;
4. are not flagged as beam-gas by either V0A or V0C**.

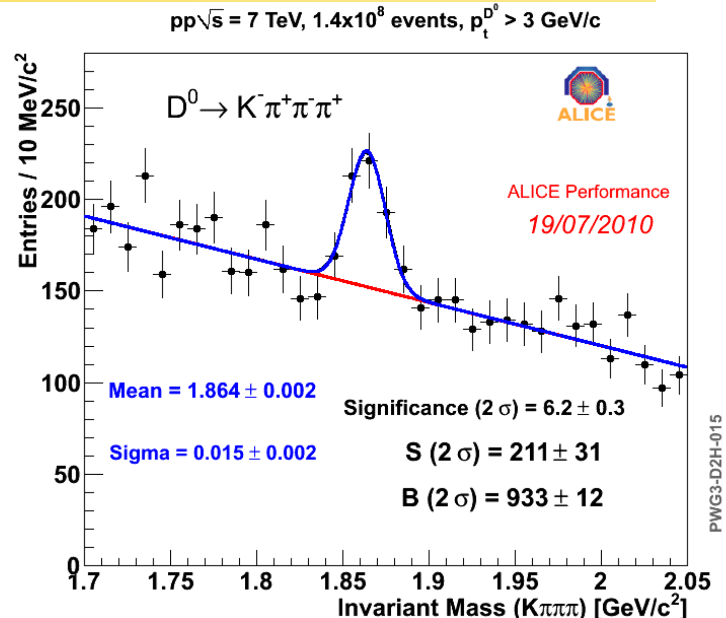
* calculated offline from reconstructed clusters
** calculated offline from the V0 signals

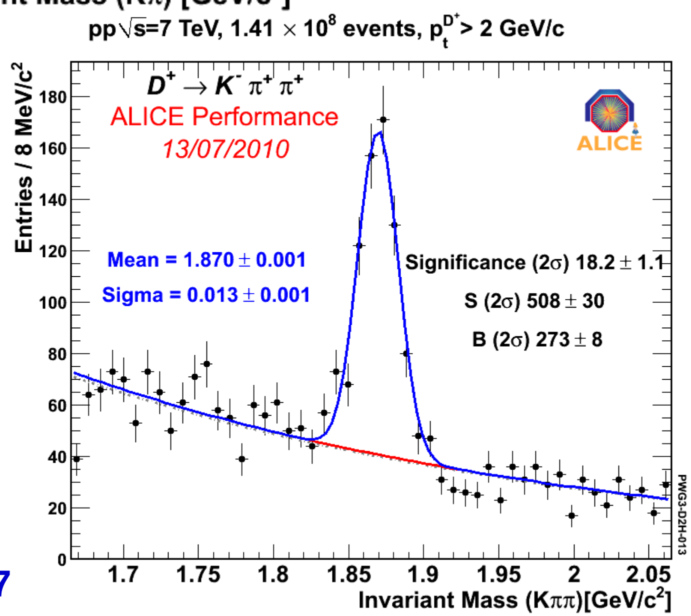
Open heavy flavour: D mesons

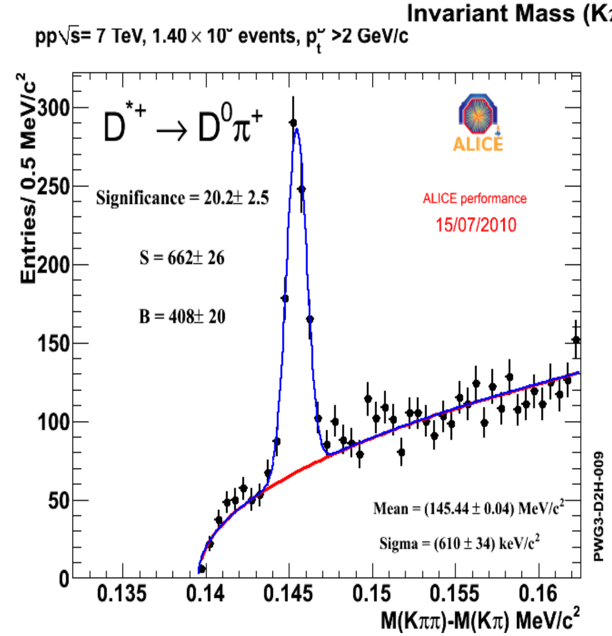


Observed differentially in p_T

- up to p_T=12 GeV/c
- down to 1 GeV/c for D^0





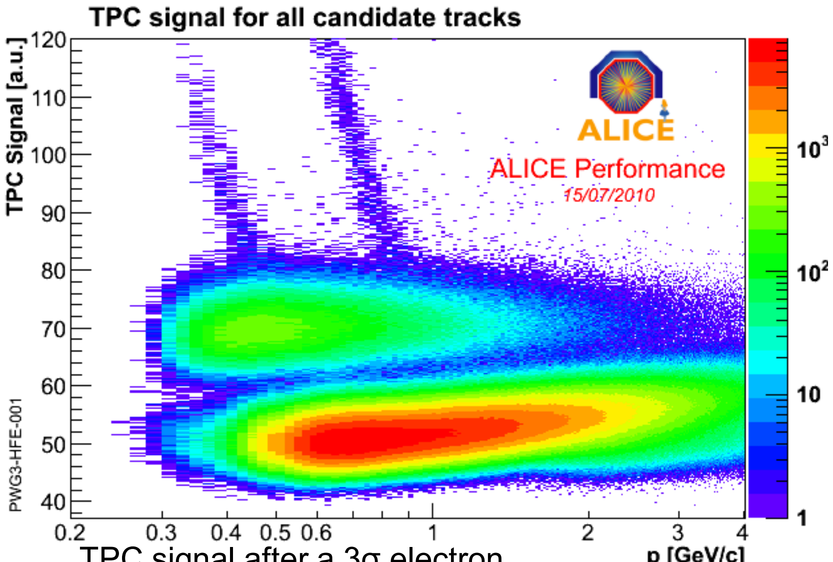


Expected to cover
$0.5 < p_T < 15$ GeV/c
with 10^9 events

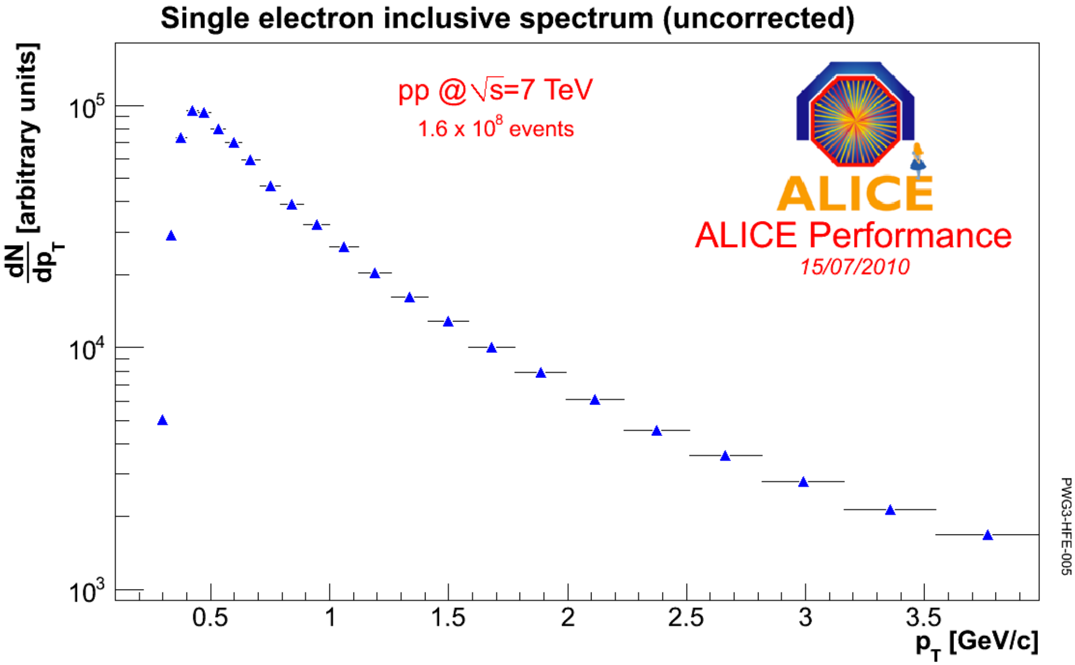
See A. Grelli
Session 05 – 24/7

Open heavy flavour in the electron channel

- Compute the inclusive cross section using electrons
- For high p_T, the contribution from charm and beauty becomes dominant
- Essential ingredient for the analysis: electron Identification
  - For the moment: TPC + TOF
  - Hard work to add the TRD is going on!
  - EMCAL will also contribute



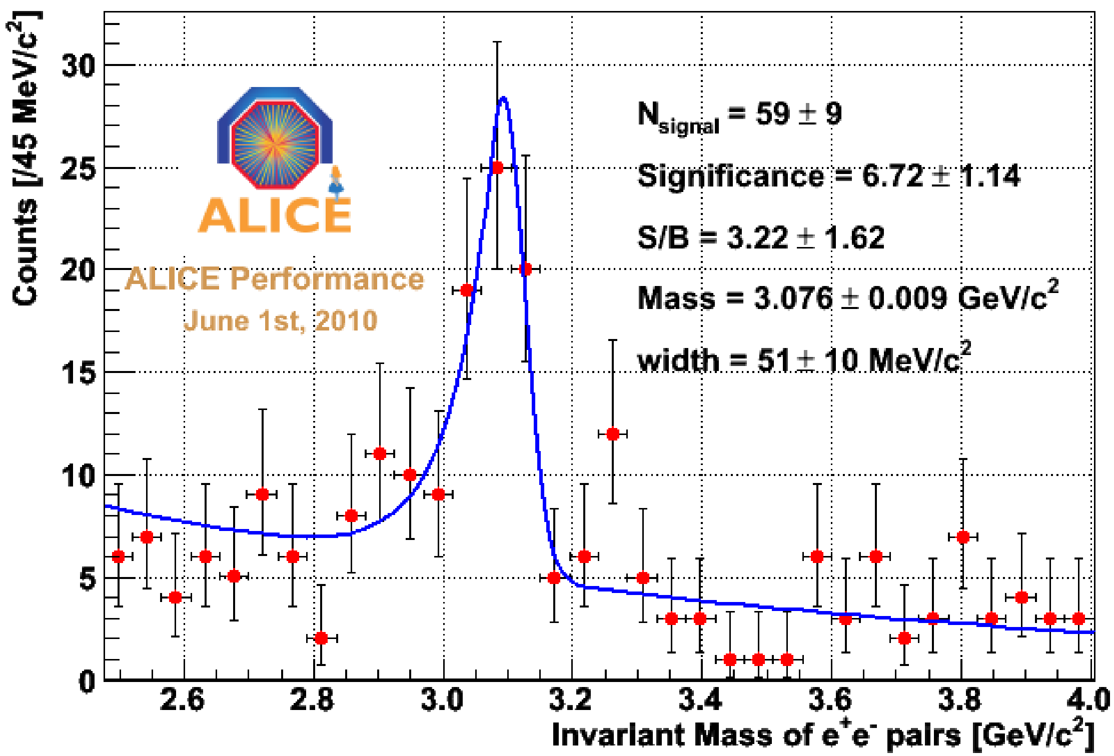
TPC signal after a 3σ electron selection from TOF signal



See R. Bailhache
Session 05 – Poster

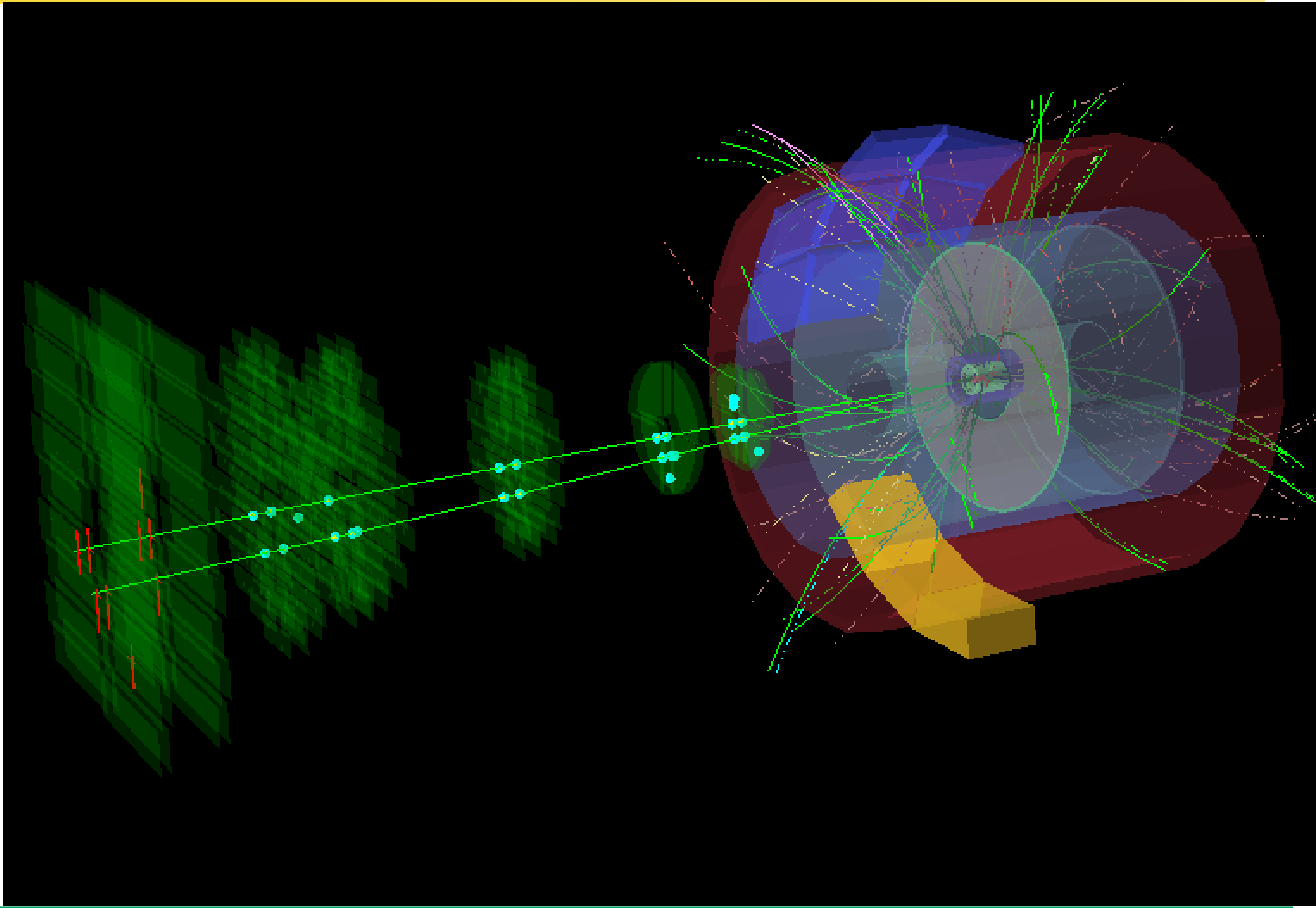
J/ψ in the di-electron channel

- 110M p-p events at 7 TeV
  - 1/3 of available statistics
- Track reconstruction
  - TPC + ITS
- Electron identification (and pion rejection)
  - TPC
  - TRD could be included later
- Fit with a Cristal Ball function
- |η|<0.9



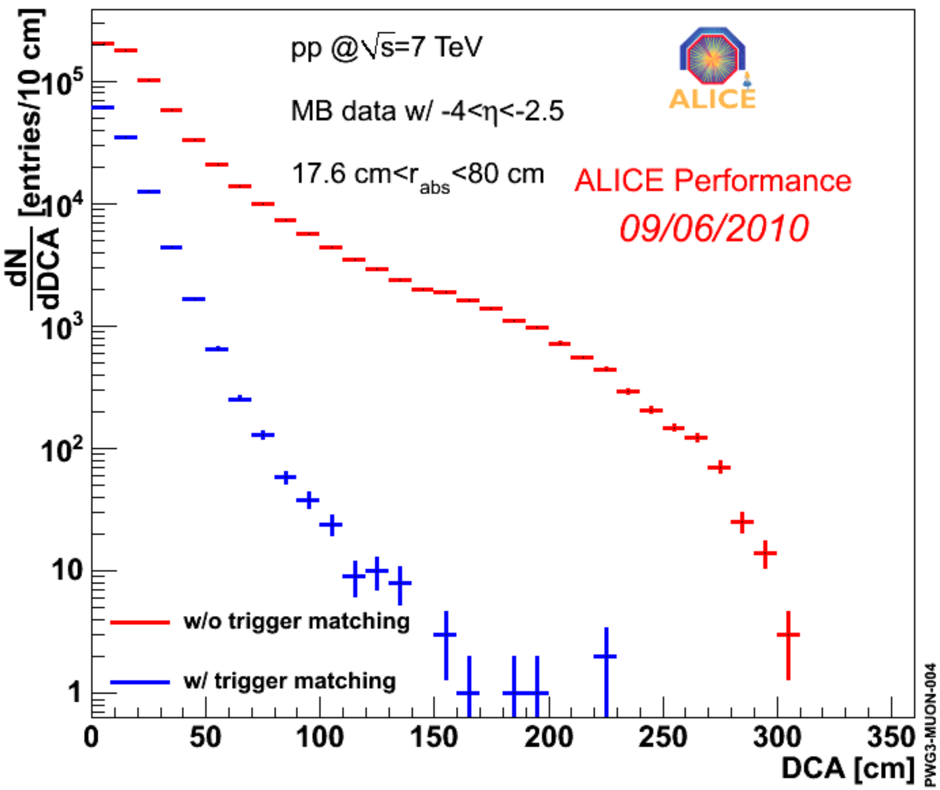
See G. Bruno
Session 05 – 22/7

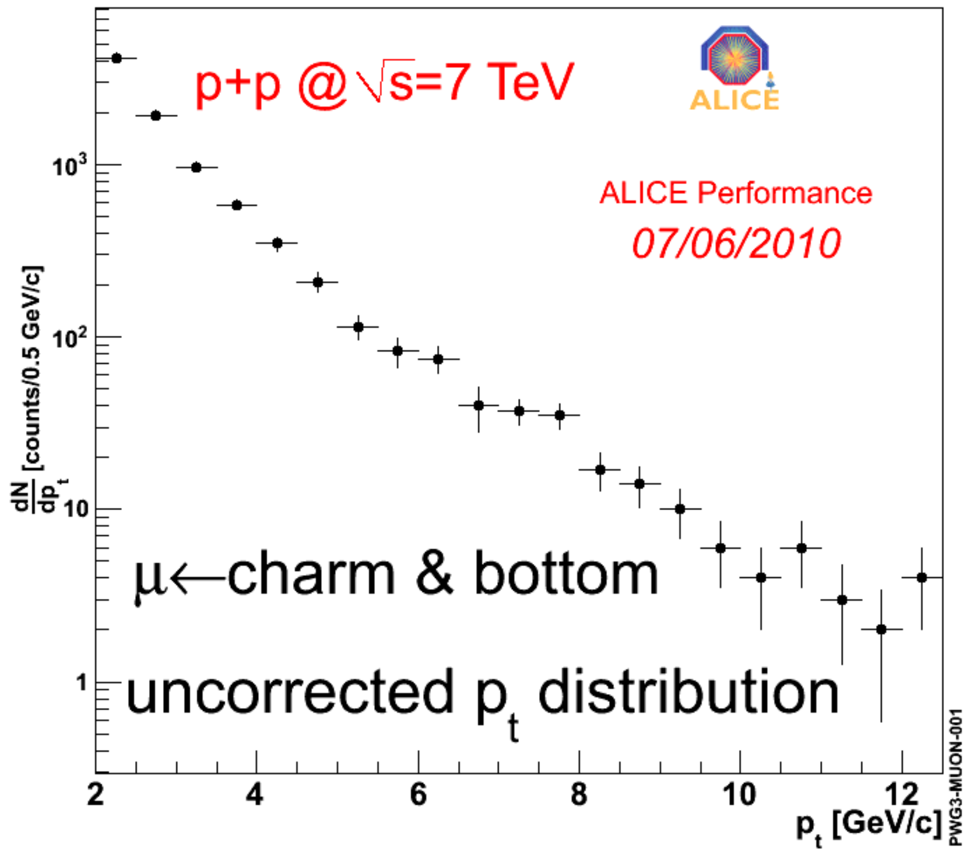
Measurements with the forward muon spectrometer



Open heavy flavour from single muons

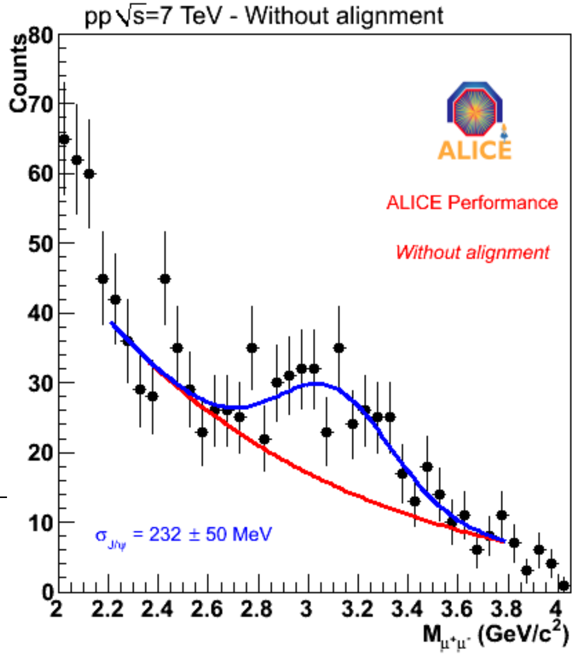
- Trigger matching
  - Iron wall stop hadrons produced in the absorbers
- Distance of Closest Approach
  - Could be used to separate c and b signal from π and K background (using simulations)

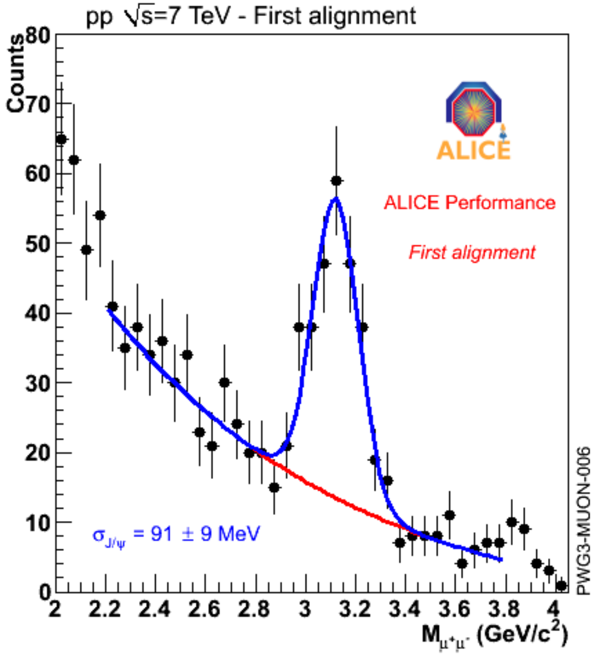


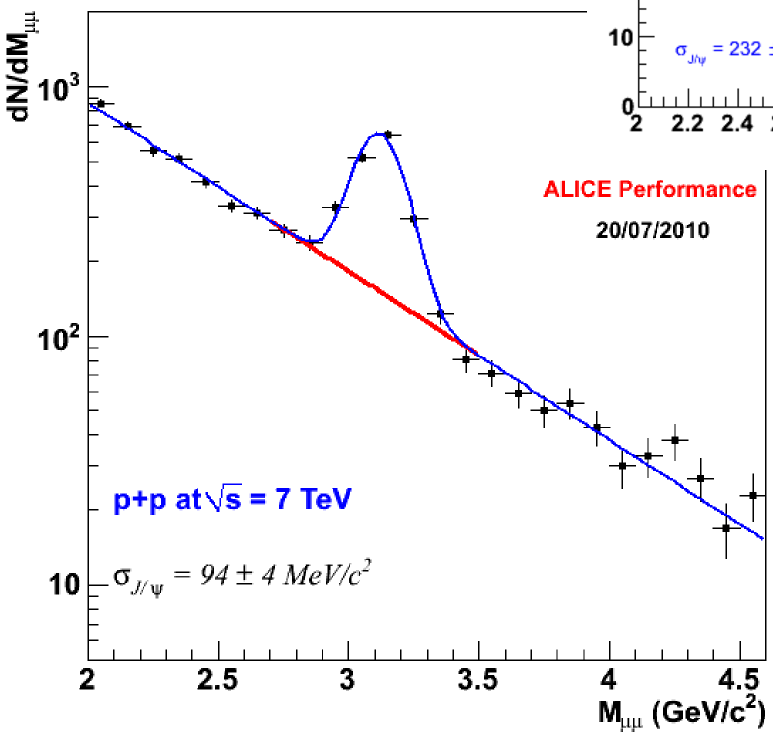


- π and K contribution
  - subtracted using Pythia simulations normalized at low p_T
- c and b contribution
  - dominates for p_T>2 GeV/c

J/ψ in the di-muon channel



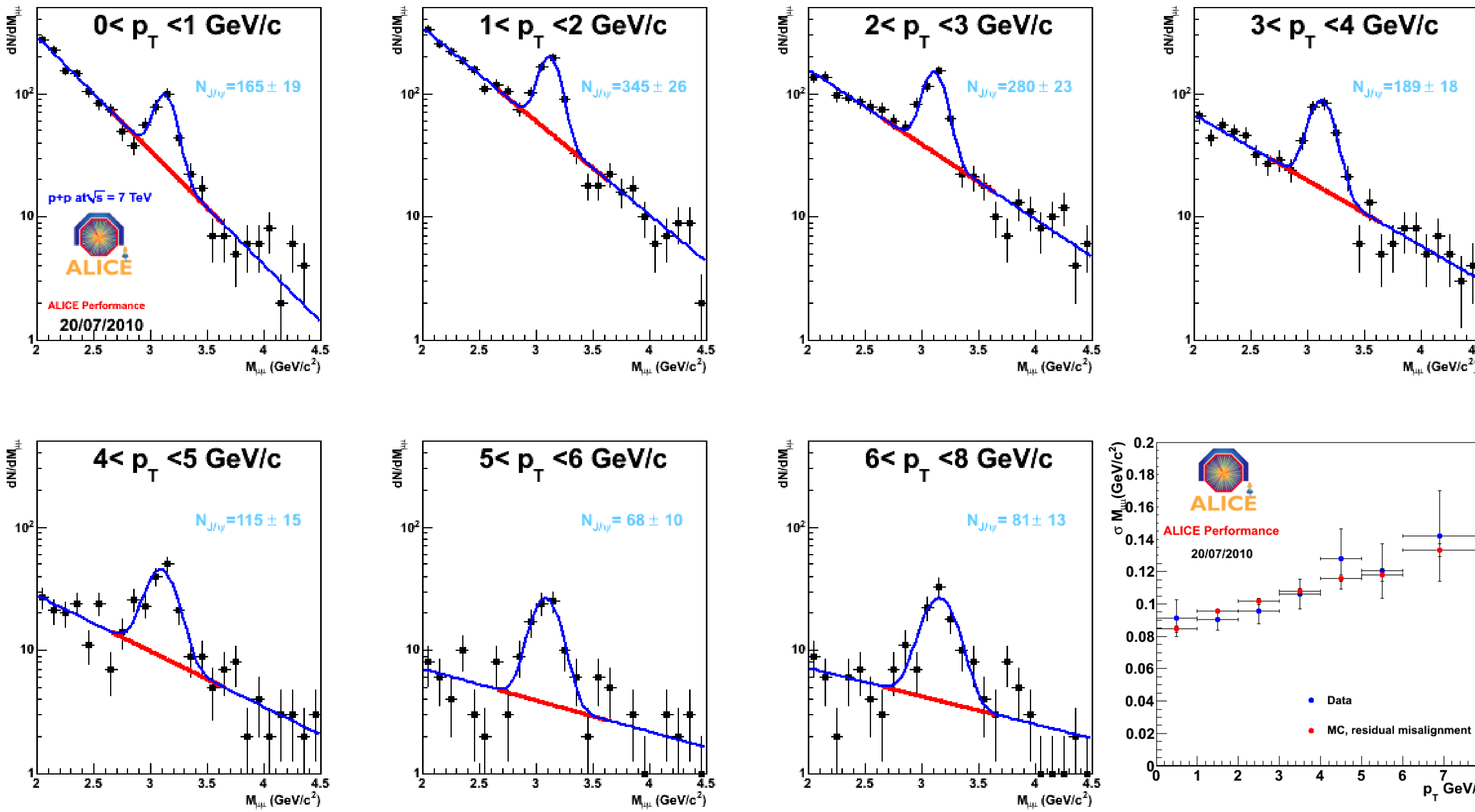




- The alignment of the tracking chambers is a critical step for the J/ψ measurements
  - First alignment: straight tracks from B=0 T data

	$\sigma_{J/\psi}$ (MeV)
Without alignment	230
First alignment	90
Target	70

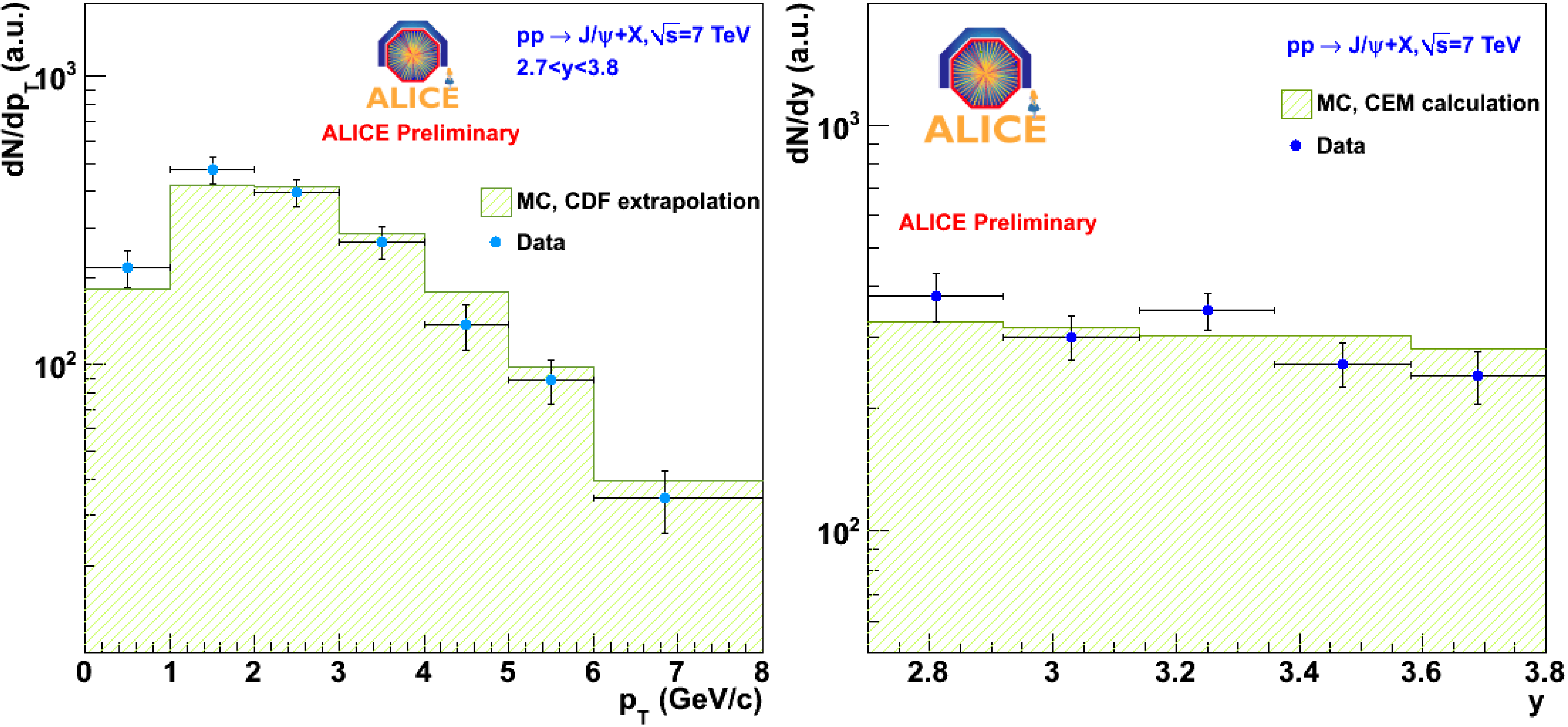
Transverse momentum dependence



The width of the J/ψ peak is well reproduced by our Monte Carlo including residual misalignment and other realistic conditions!

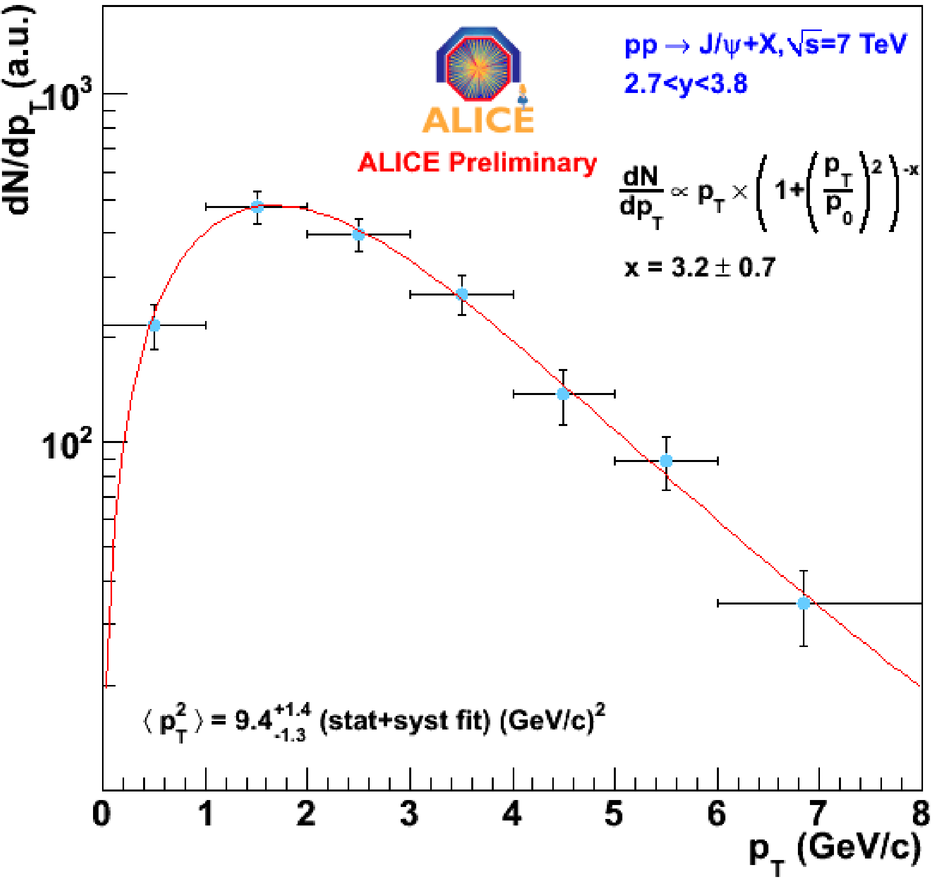
Monte Carlo comparison

The acceptance and efficiency corrected distributions are compared to generated MC distribution

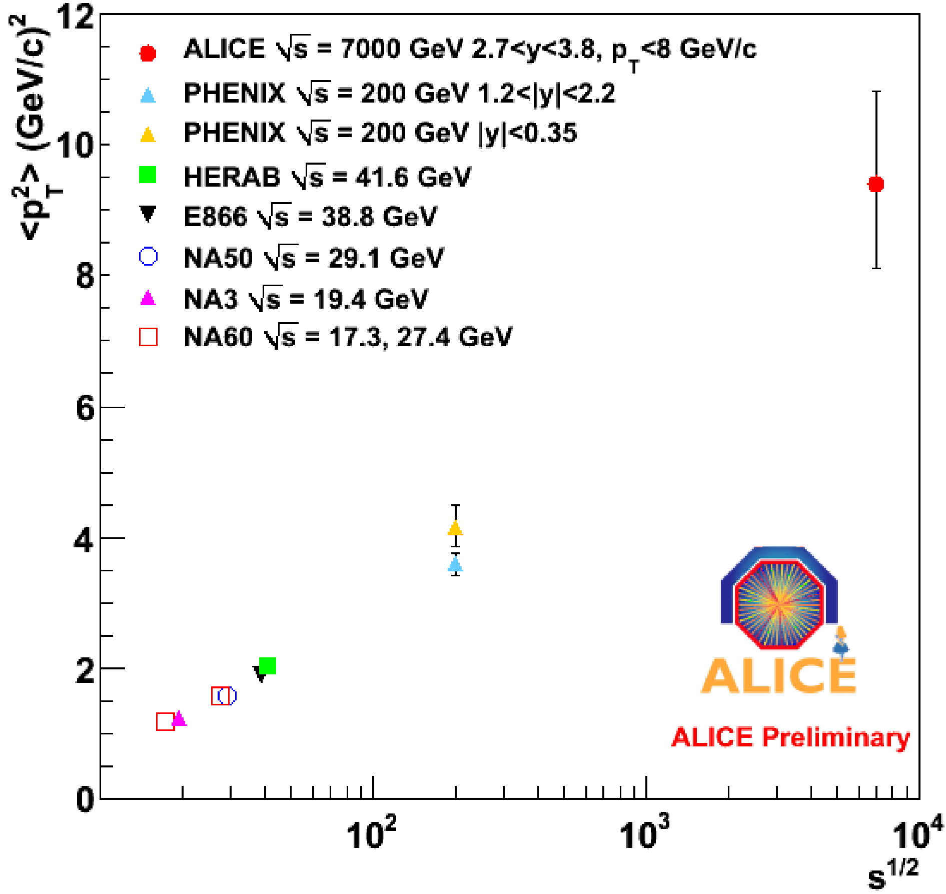


- “CDF pp 7TeV” parameterization
  - p_T extrapolated from CDF results
  - y obtained from CEM calculations
  - No polarization (λ = 0)

Transverse momentum distribution



To extract $\langle p_T^2 \rangle$ we use the fit function first proposed by Yoh et al., PRL 41 (1978) 684 and also used by previous experiments



- Quoted uncertainties include systematics from the fit function
- Full systematic uncertainties are being evaluated

Conclusion

- The LHC provides a new and promising environment for the study of open heavy flavour and quarkonium production
- ALICE is well suited for the study of heavy flavours
  - Two rapidity domains
- Exciting results from first pp data at 7 TeV
  - J/psi transverse momentum distribution
- Coming soon
  - J/ψ differential cross-section
  - Corrected open heavy flavour measurements
- Looking forward for Pb-Pb data et the end of the year

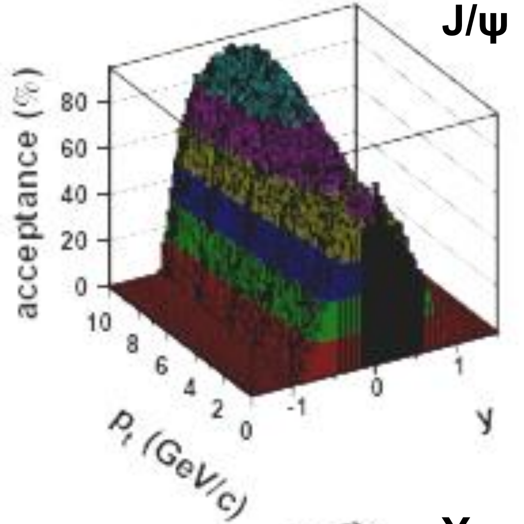
Back-Up

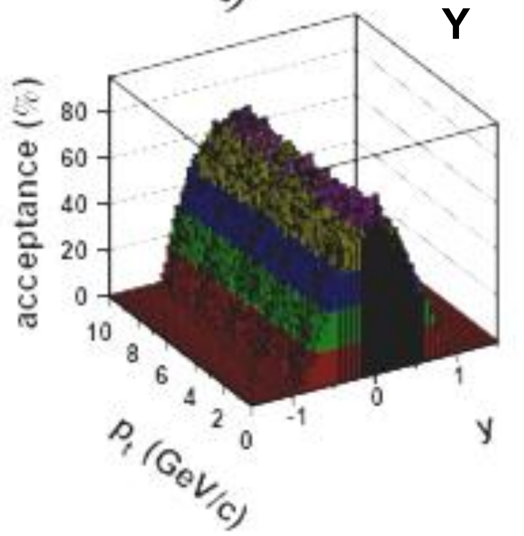
The LHC and its other "features"

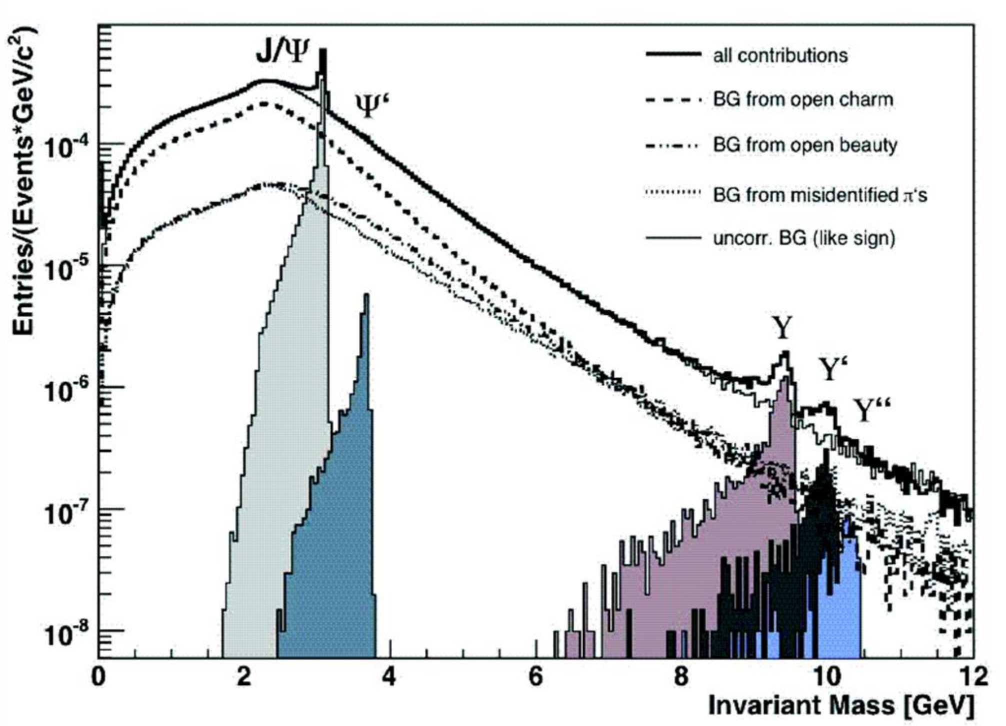
- Only 1 month per year for the heavy ion program
  - Including pA or lighter ions
- Lead beam luminosity is limited by the magnets "quench limit" due to EM processes induced by PbPb collisions;
- Large contribution from B-hadron decays to charmonia yields
  - ~20% for J/ψ
- Cold nuclear matter effects are not well under control
  - Could try different normalizations
  - Will be measured with pA runs

- Heavy Ion running plan (1 month per year)
  - First 5 years: 1 PbPb low luminosity, 2 PbPb runs at nominal luminosity, 1 pPb and 1 lighter ion runs
  - Next 5 years (based on results): lower energies, pp at 5.5 TeV, other AA or pA, more stat …

Quarkonia in dielectron channel

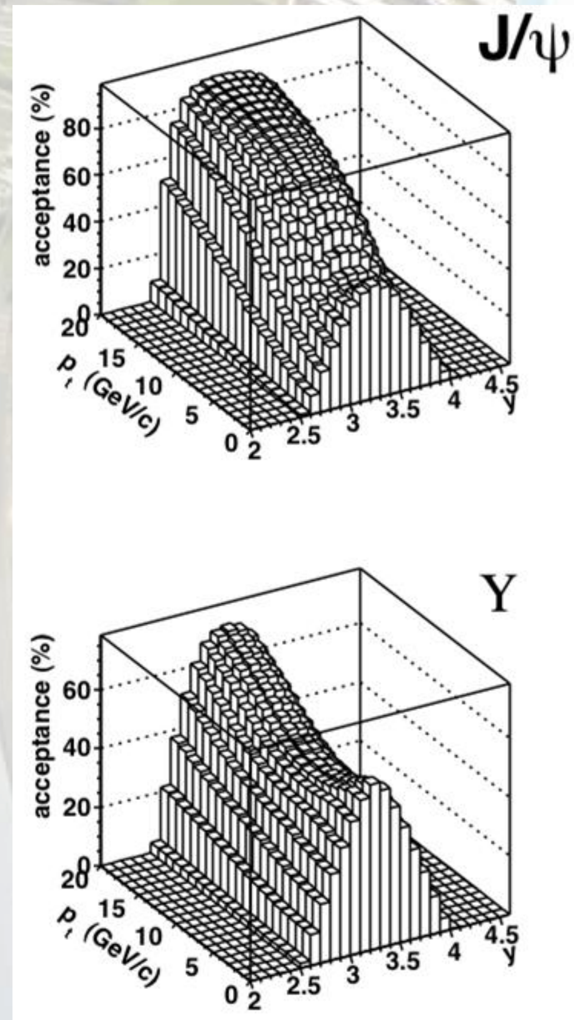


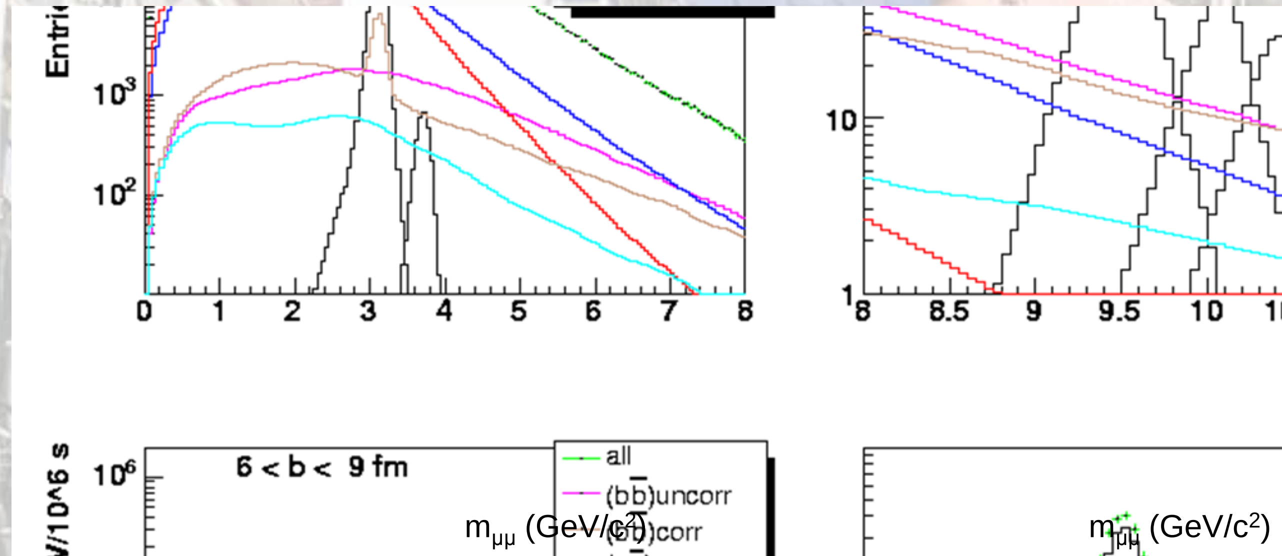




	J/ψ	*Υ*
Mass resolution	~30 MeV/c^2	~90 MeV/c^2
Signal/Noise	1.2	1.0
Counts (nominal PbPb year) 10%	120k	*900*

Quarkonia in dimuon channel





	J/ψ	Y
Mass resolution	~70 MeV/c²	~100 MeV/c²
Signal/Noise	0.3	2.5
Counts (nominal PbPb year) MB	680k	*6000*

ALICE performances in $\mu^+\mu^-$

0<b<3 fm

State	S[10^3]	S/B	$S/(S+B)^{1/2}$
J/Ψ	130	0.20	150
Ψ'	3.7	0.01	6.7
ϒ(1S)	1.3	1.7	29
ϒ(2S)	0.35	0.68	13
ϒ(3S)	0.20	0.48	8.1

6<b<9 fm

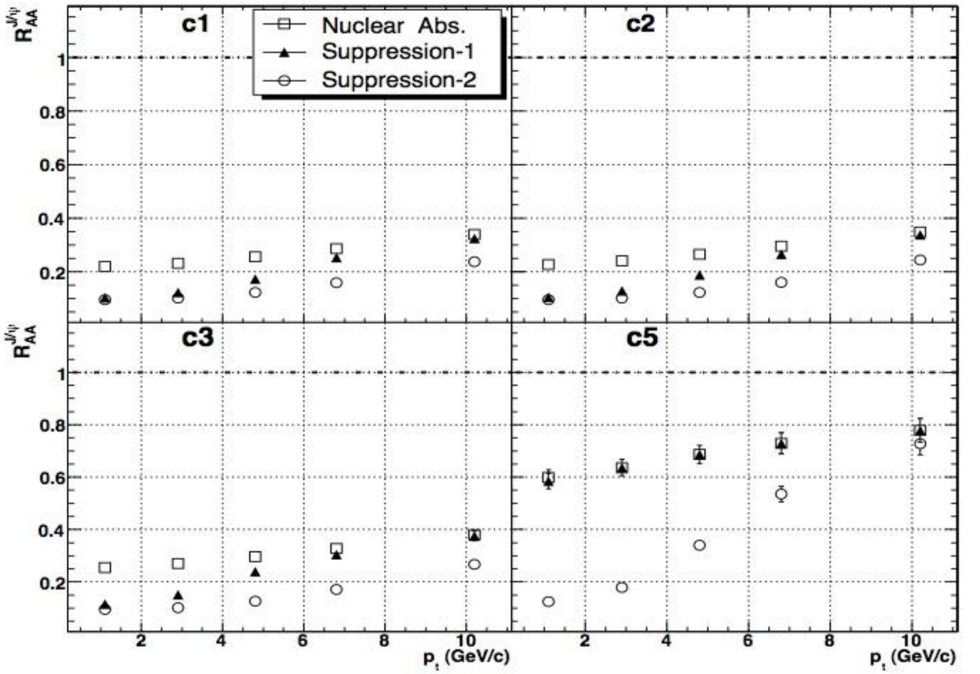
State	S[10^3]	S/B	$S/(S+B)^{1/2}$
J/Ψ	200	0.49	250
Ψ'	5.5	0.03	13
ϒ(1S)	2.0	3.6	39
ϒ(2S)	0.52	1.4	18
ϒ(3S)	0.28	0.95	12

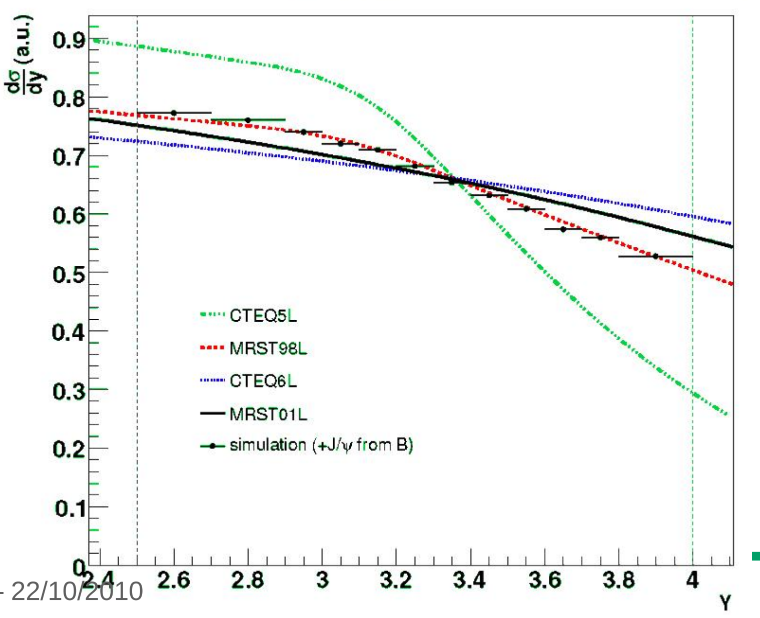
b>12 fm

State	S[10^3]	S/B	$S/(S+B)^{1/2}$
J/Ψ	22	3.14	130
Ψ'	0.6	0.18	9.7
ϒ(1S)	0.21	9.5	15
ϒ(2S)	0.06	3.6	6.5
ϒ(3S)	0.03	1.9	4.2

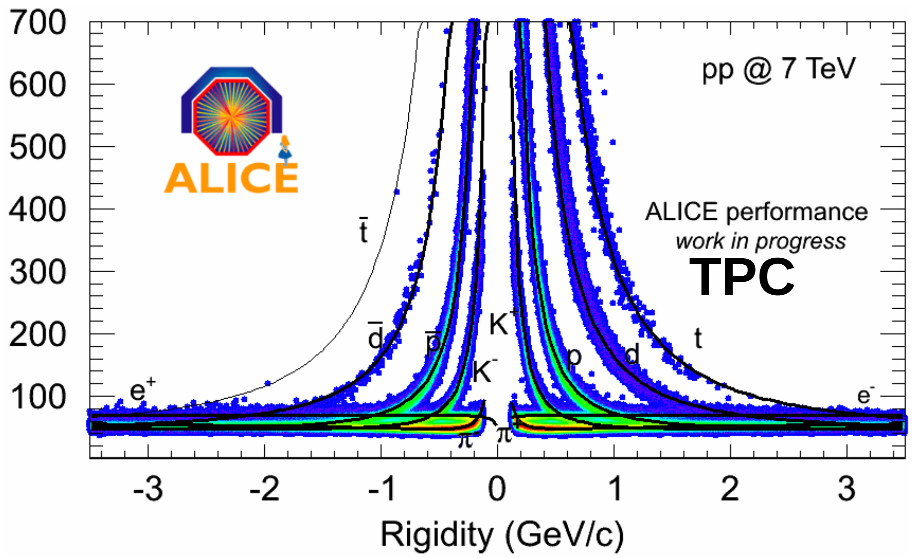
Quarkonia: what will be done

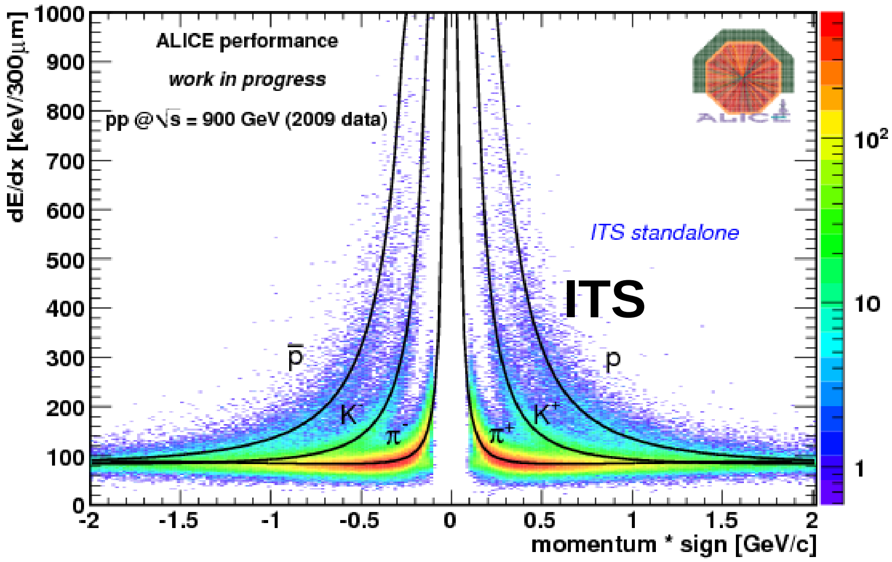
- The bread and butter of J/ψ
  - Production yields, cross-sections
    - High statistics
    - From p_T = 0 GeV/c
  - Detailed "suppression" studies
    - With respect to
      - Beauty
      - pp (R_{AA})
    - As a function of
      - Centrality
      - Transverse momentum (0-20 GeV/c)
      - Rapidity (two domains)
  - Precise pp measurement
    - 3.10^6 J/ψ in nominal pp run
    - Sensitivity to low x-Bjorken
      - probing gluon distribution at $x_{Bj} = 2x10^{-4} – 4x10^{-6}$;

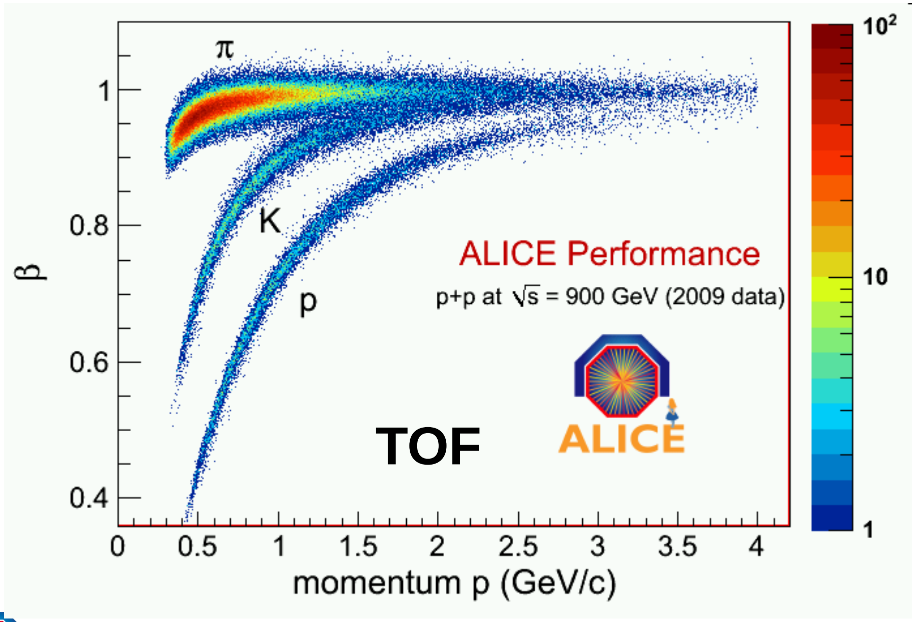




Particle Identification

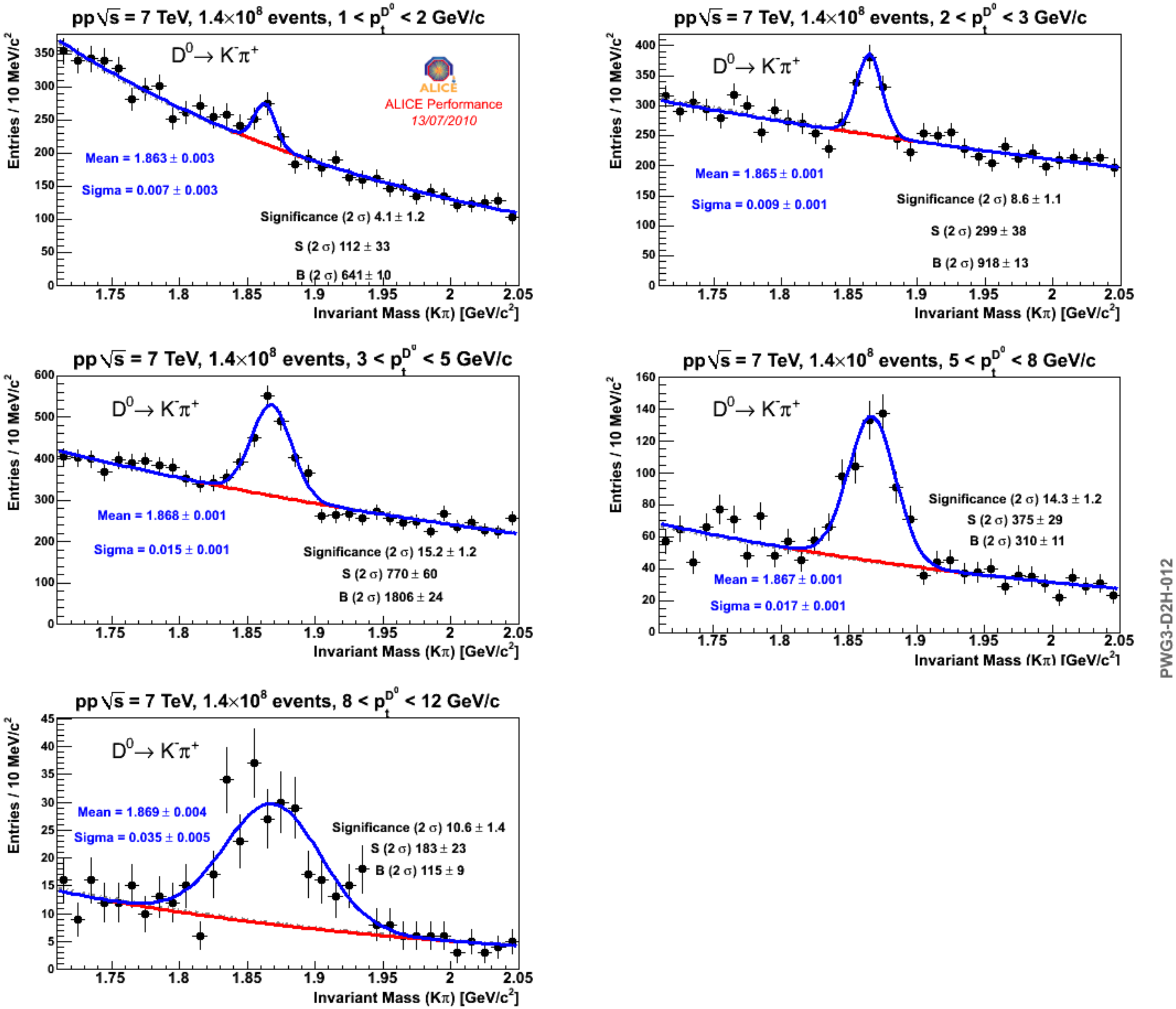




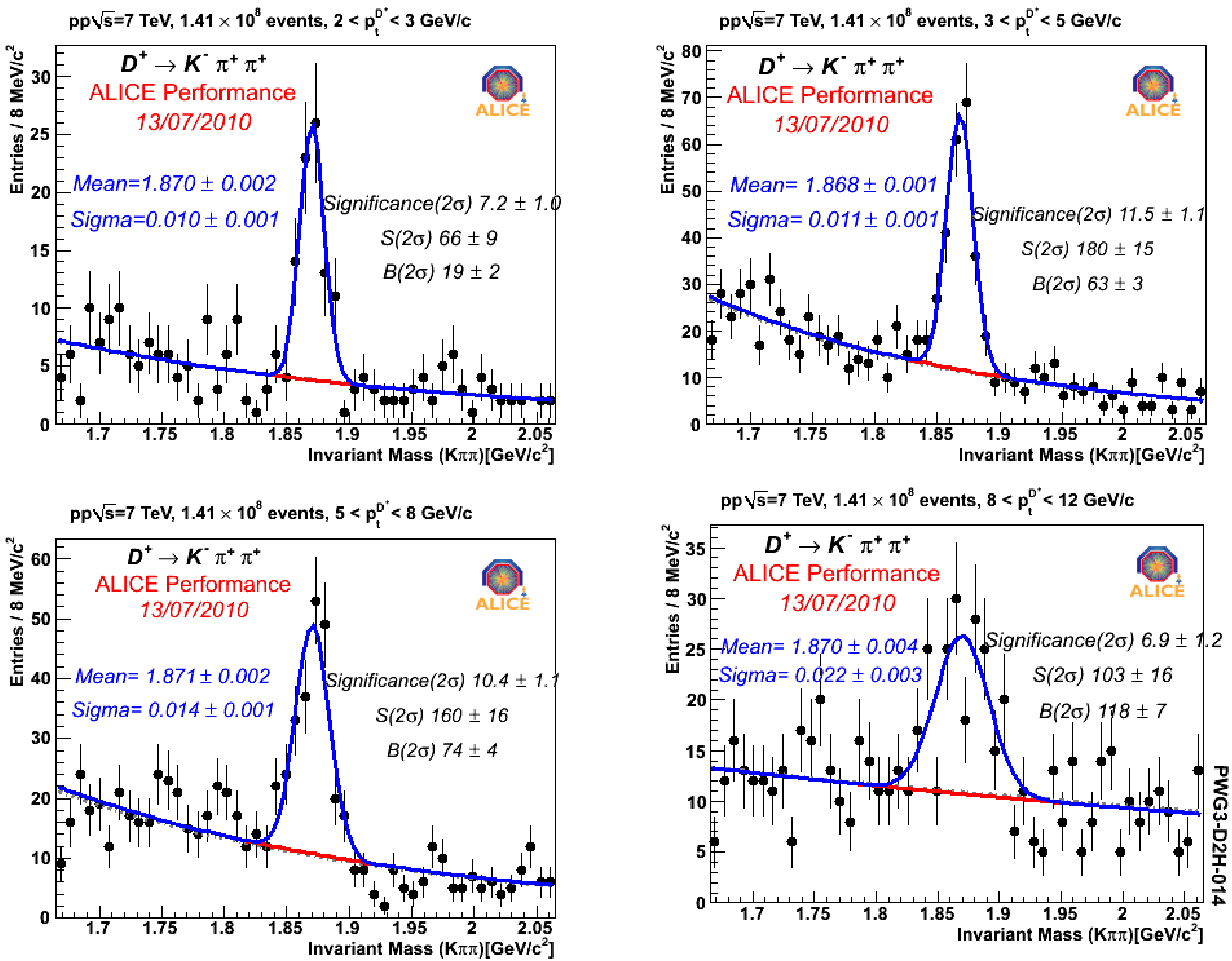


Complementary momentum coverage

D^0 Invariant Mass Spectra in p_T bins



D^+ Invariant Mass Spectra in p_T bins



D* Invariant Mass Spectra in p_T bins