Quarkonium and heavy flavour physics with ALICE at the LHC

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for the ALICE collaboration

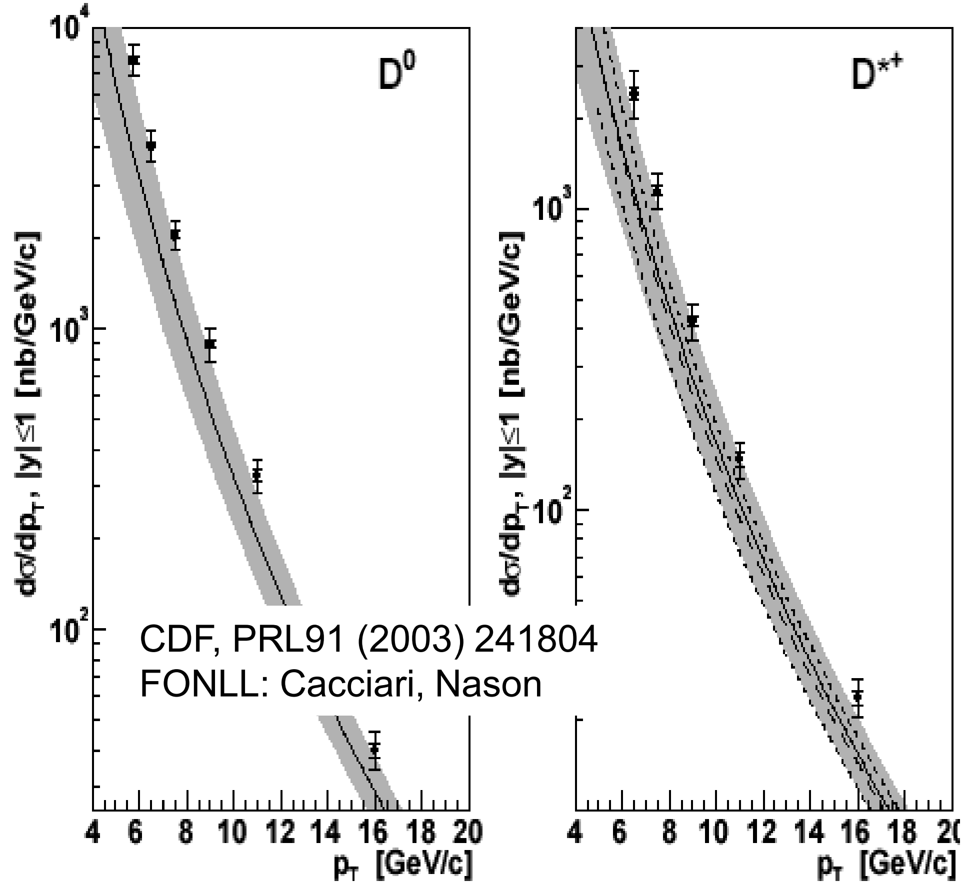
Workshop on discovery physics at the LHC
Kruger National Park (SA) 06/12/2010

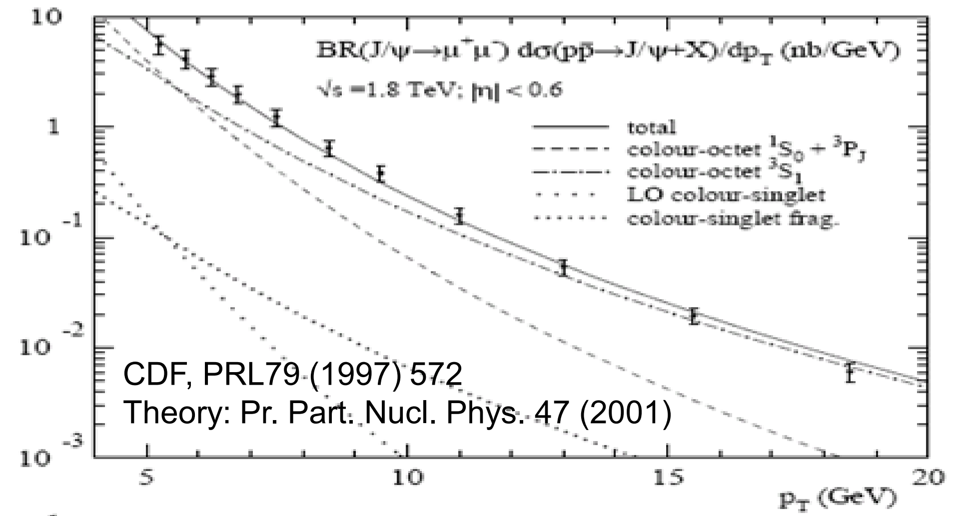
Outline

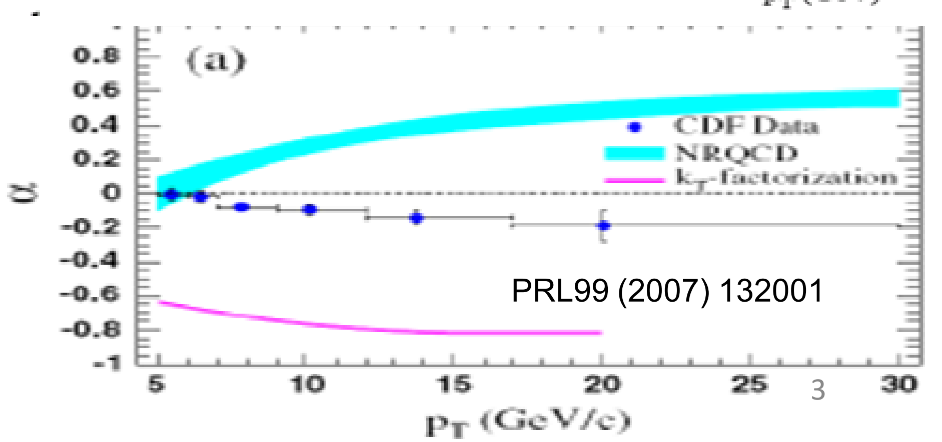
- Physics motivation(s)
- The ALICE experiment
- p-p physics performance and results on
  - Heavy flavour via semi-muonic decays
  - Heavy flavour via semi-electronic decays
  - Heavy flavour via hadronic decays
  - $J/\psi \to \mu^+\mu^-$
  - $J/\psi \to e^+e^-$
- Conclusions
- A glimpse of heavy ions

Physics motivation: p-p

- Test of c, b production in pQCD in new energy domain
  (data lie on top edge of FONLL band at Tevatron and RHIC)
- Test quarkonia production models
  (NRQCD predicts cross section but misses polarisation; CSM?)
- Reference for heavy ion physics







Physics motivation: heavy ions

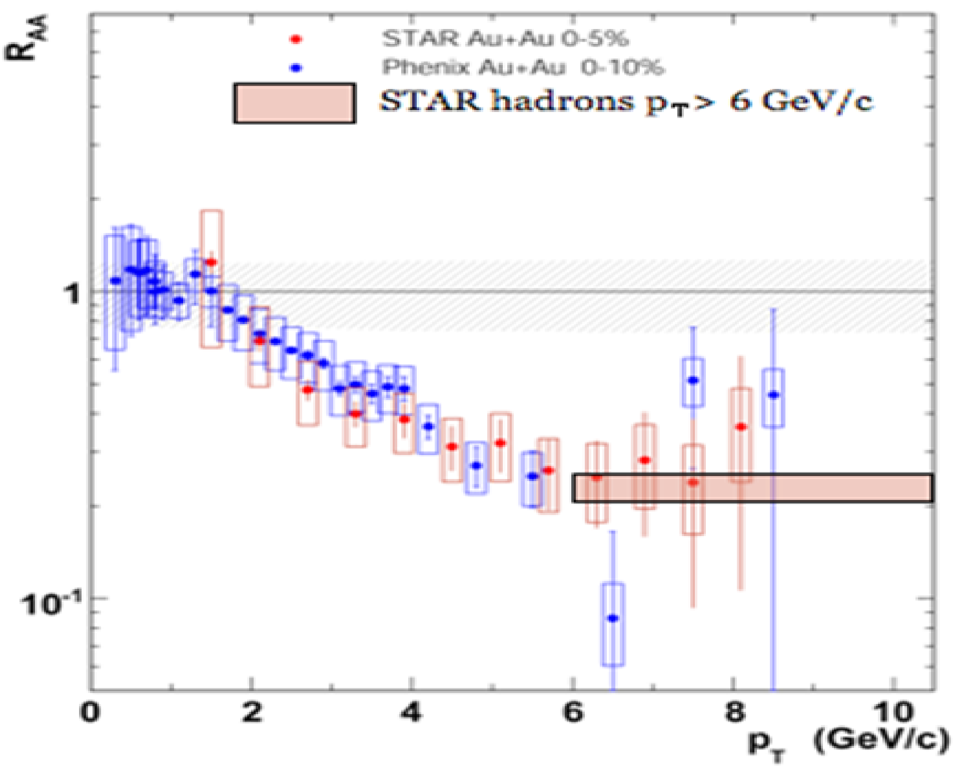
Heavy flavour produced on a "hard" scale in early stages of collision
-> ideal probe of strongly interacting phase

Open heavy flavour:

- Study the properties of hot, high density medium through:
  - energy-loss
  - modification of fragmentation functions
- Important reference for quarkonia studies
- Need to disentangle "cold" initial state effects (p-A)
- More items:
  - charm flow
  - heavy quark jets

$$R_{AA}(p_T) \equiv \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

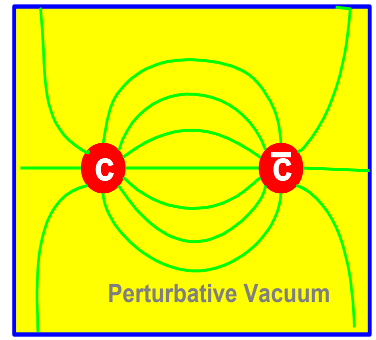
STAR : PRL98, 192301 (2007)
PHENIX : PRL98, 172301 (2007)

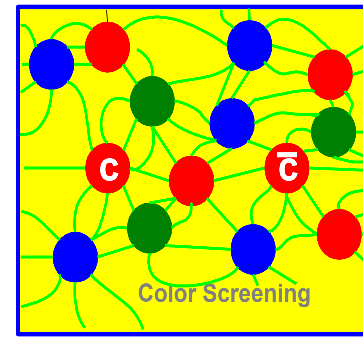


Physics motivation: heavy ions

Heavy flavour produced on a "hard" scale in early stages of collision
-> ideal probe of strongly interacting phase

Quarkonia:

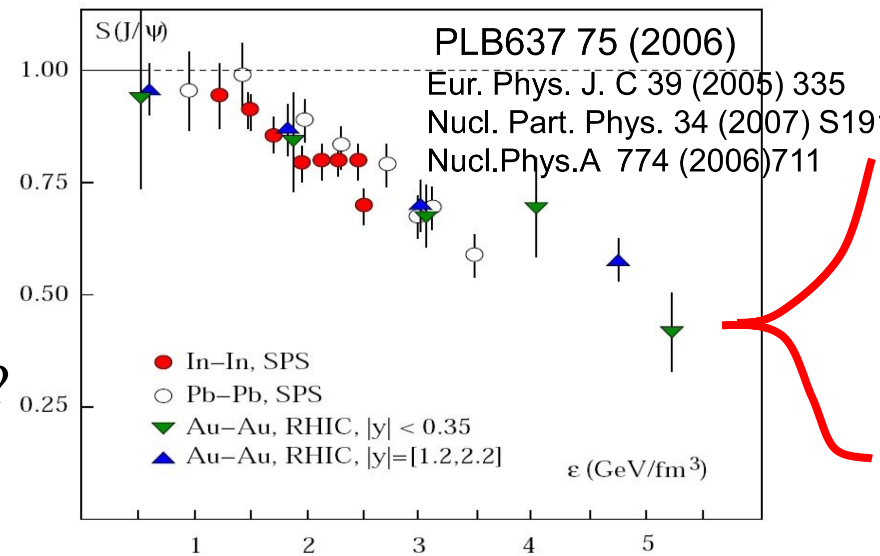




- Resonance melting by colour screening: one of the first proposed signatures of deconfinement

- Need to disentangle cold nuclear matter effects (p-A)

- Same amount of suppression at SPS and RHIC. Two main hypotheses:



- Melting of ψ' and χ at SPS and RHIC (suppression of feed down)? -> melting of primary J/ψ at LHC?

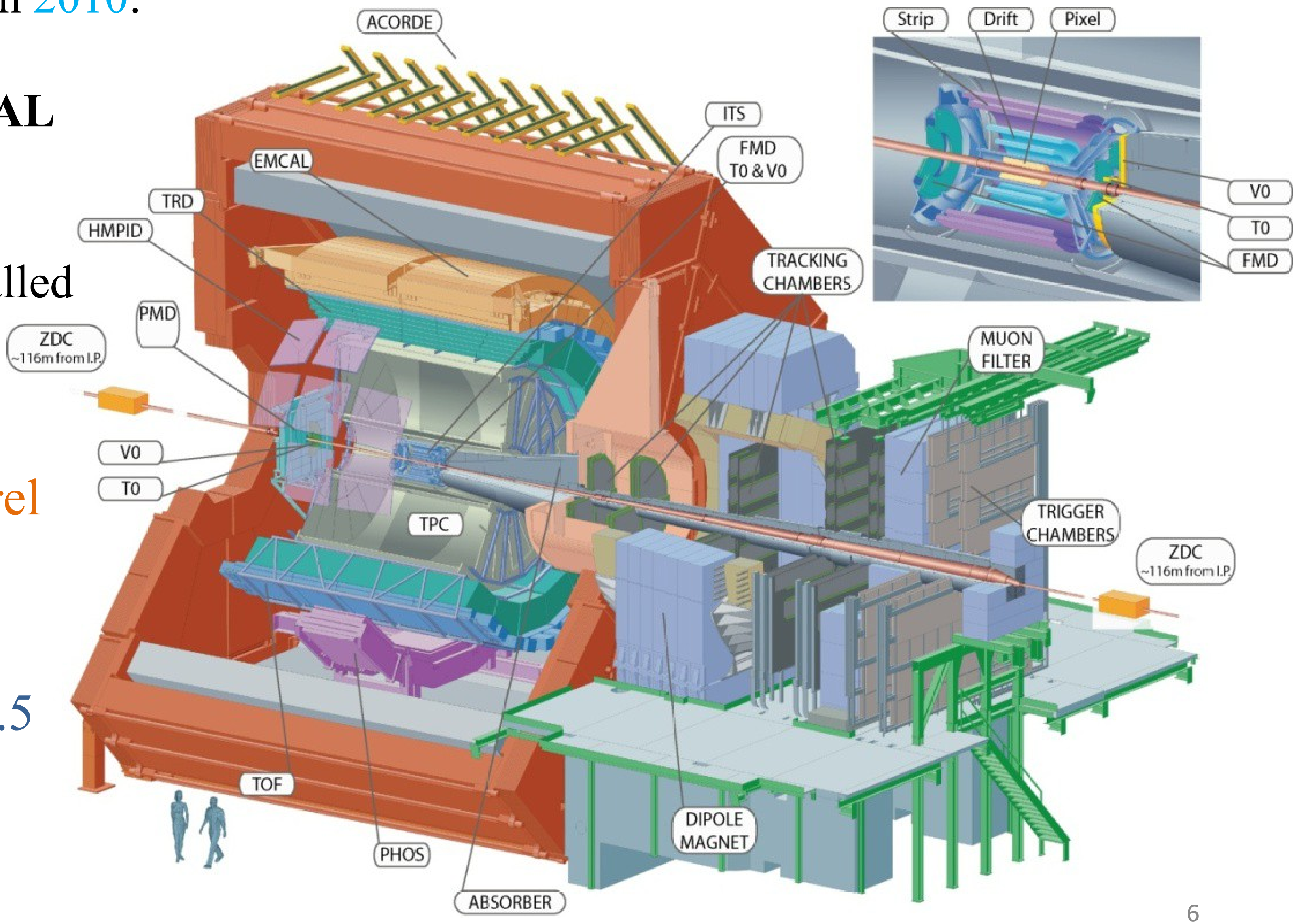
- Interplay between J/ψ suppression and regeneration at RHIC? -> enhancement at LHC?

The ALICE experiment

Configuration 2010:
- **7/18 TRD**
- **4/12 EMCAL**
- **3/5 PHOS**
- Others:
  100% installed

Central barrel
$|\eta| < 0.9$

Muon arm
$-4 < \eta < -2.5$

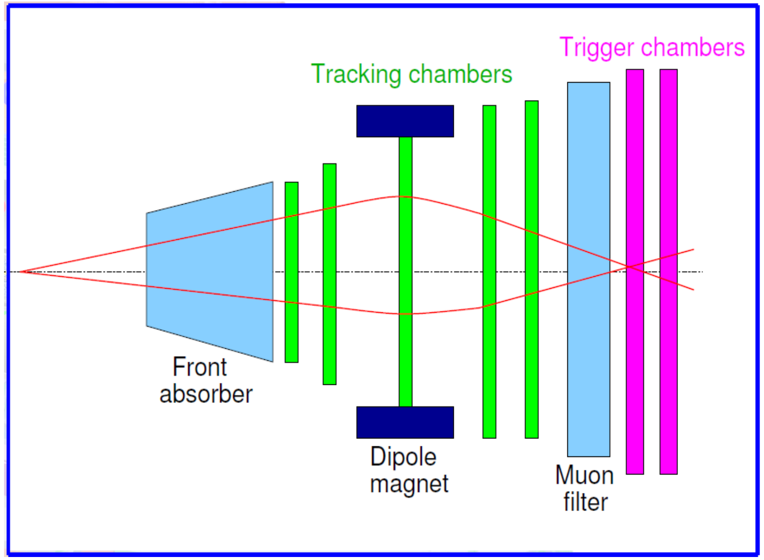


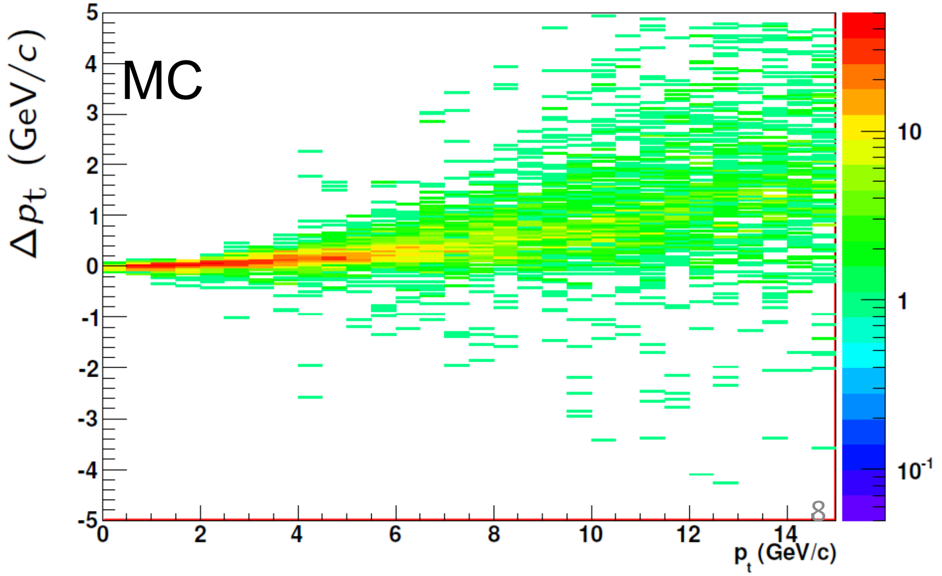
Open heavy flavour

Heavy flavour via semi-muonic decays

Measurement of the muon spectrum

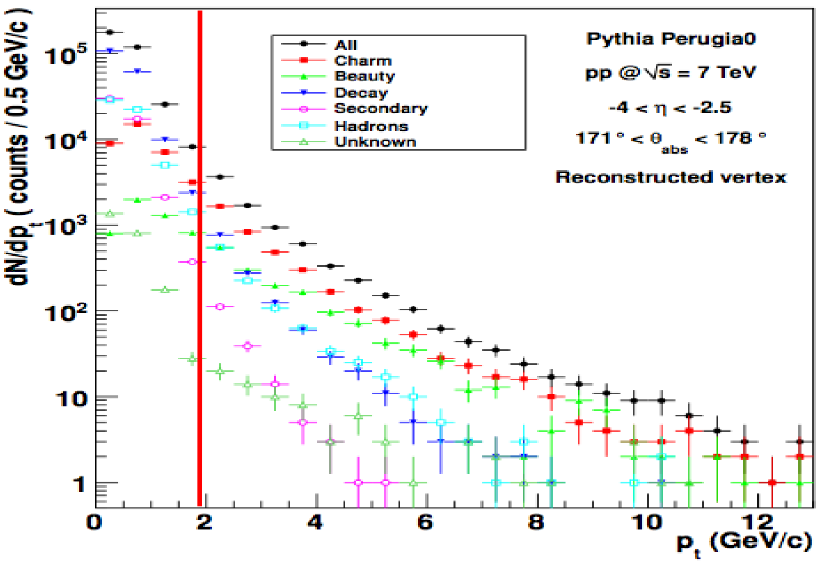
- ALICE muon spectrometer: $-4 < \eta < -2.5$
- tracking chambers (MWPC) $\sigma_x \sim 100\ \mu m$
  Alignment not yet ideal:
  - $\Delta p_T/p_T \sim$ 12% at $p_T \sim 10$ GeV/c
  - 2% p_T syst. error on dN/dp_T
- dedicated muon trigger (RPC)
  programmable p_T cut
  (~ 0.5 GeV/c for this run)
- Front absorber: 10 λ_{int}, 90 cm from IP
- Muon filter (7 λ_{int})
  in front of trigger chambers
  -> matching with trigger
  for residual hadron rejection

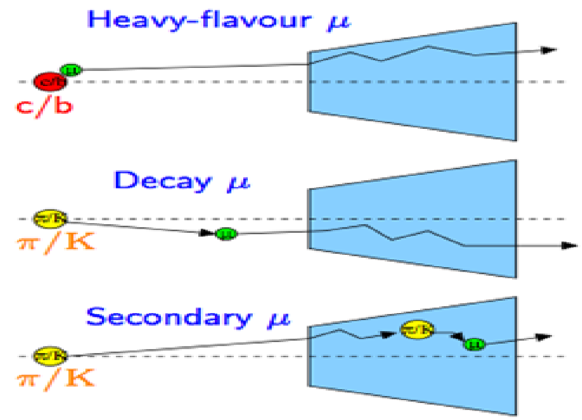


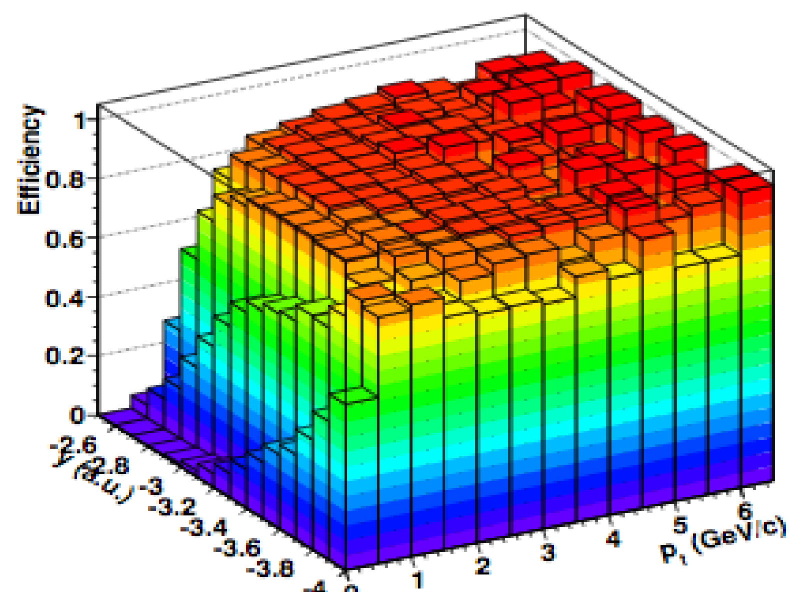


Heavy flavour via semi-muonic decays

Subtraction of known sources and efficiency correction



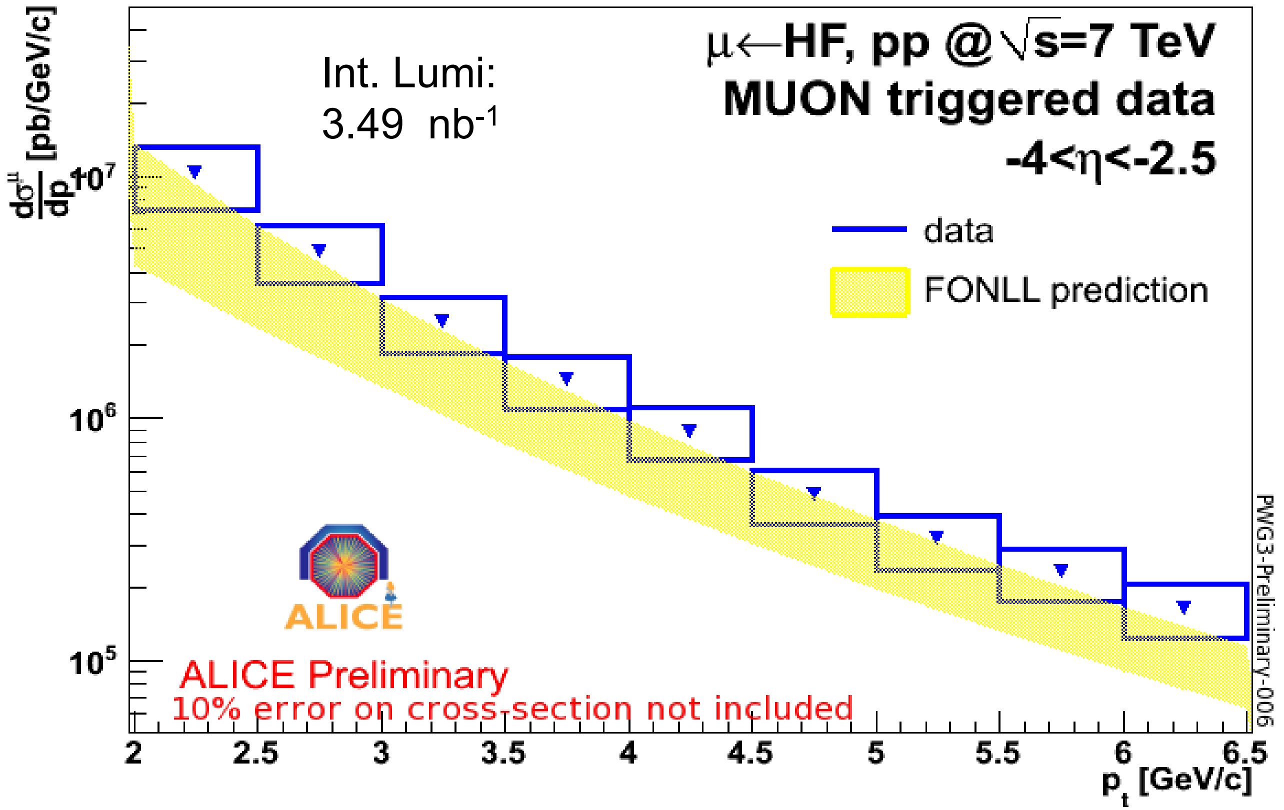




- Analysis in $p_T > 2$ GeV/c
  (low secondary contribution ~3%)
- Fix decay contribution at low p_T (< 1 GeV/c)
- Vary Pythia tune and secondary yield
  to evaluate systematics
- Full MC to evaluate 2D efficiency matrix
- Integrated efficiency ~ 87%
- Overall systematic error: 30% to 20% from low to high p_T

Heavy flavour via semi-muonic decays

Combined charm and beauty cross section



Good agreement with pQCD prediction (FONLL)

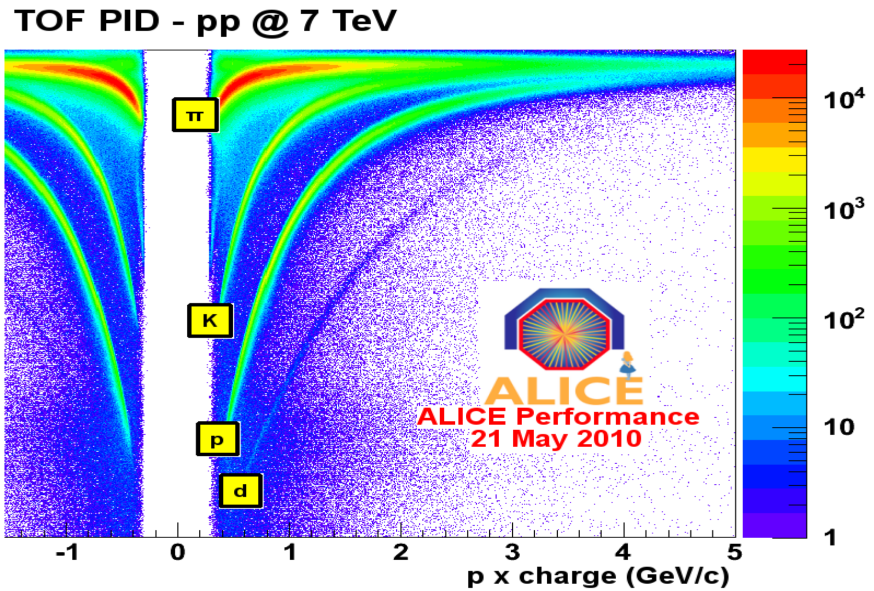
Next:

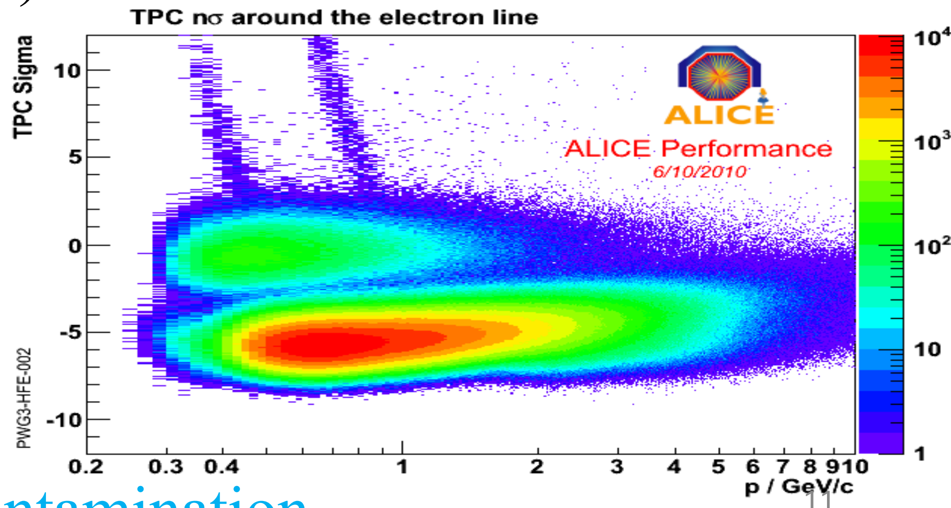
- data-driven methods for background subtraction (DCA, vertex z-position)
- B-D separation via pQCD fit
- New alignment available -> will soon extend p_T reach

Heavy flavour via semi-electronic decays

Measurement of the electron spectrum

- To minimise conversions, request 1 hit in Silicon Pixel Detector inner layer (radius 3.9 cm)
- Tracking: ITS, TPC
- Electron identification:
  - 3σ cut with Time Of Flight detector (resolution 130 ps): clean rejection of p (up to 3 GeV/c) and K (up to 1.5 GeV/c)
  - e/π with dE/dx in TPC (resolution 5-6%): 5σ upper cut and momentum-dependent lower cut around the Bethe-Bloch line
  - double gaussian fit for residual contamination



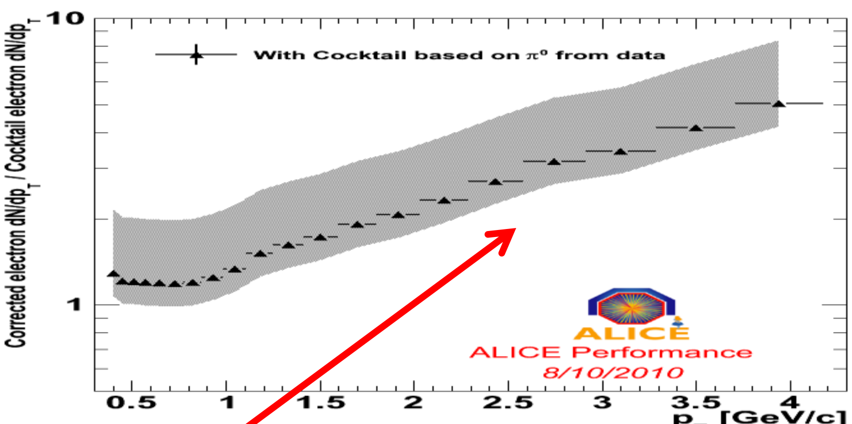


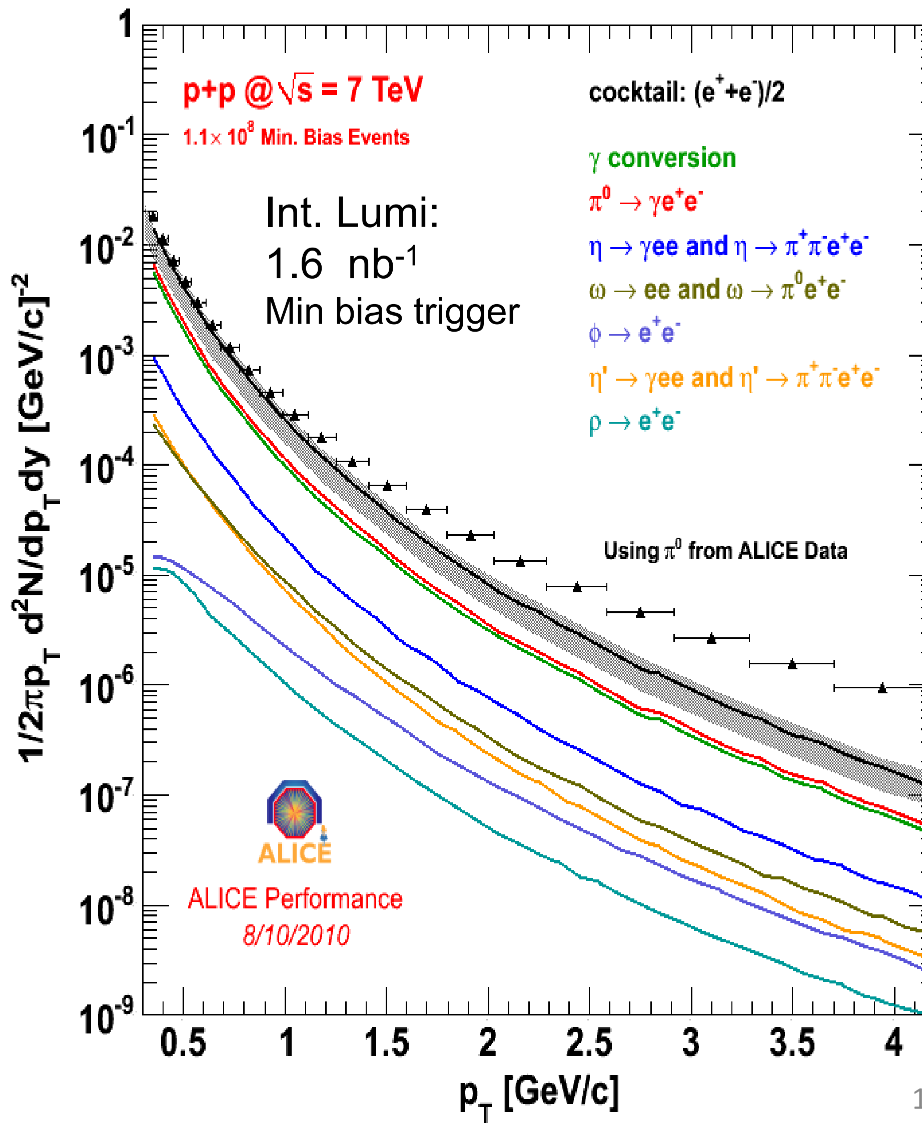
Heavy flavour via semi-electronic decays

Subtraction of known sources via electron cocktail

Current cocktail components:

- Dalitz decays of π^0 (measured via γ conversions)
- Decays of other light vector mesons: η, ρ, ω, ϕ, η’ (m_T scaling)
- γ conversions in material



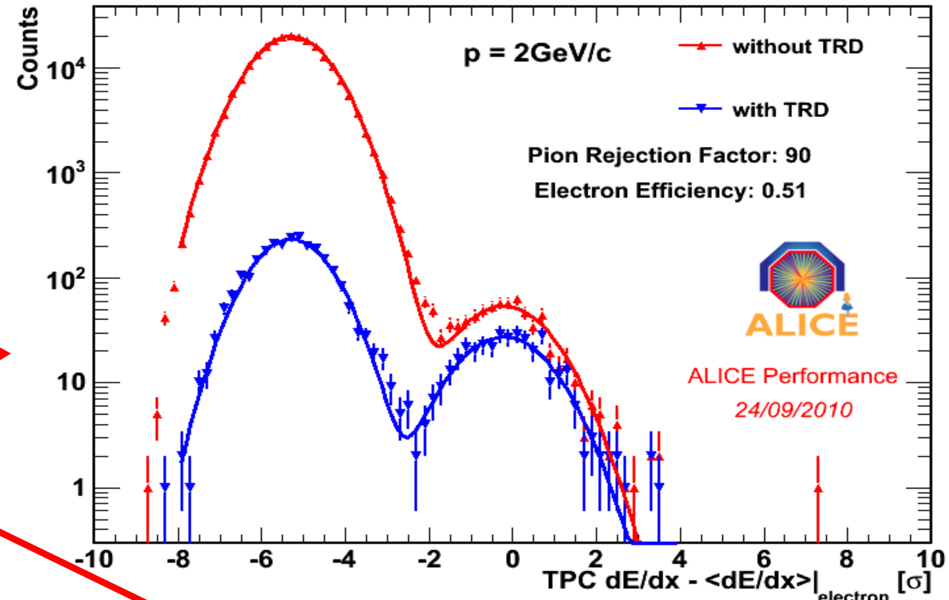


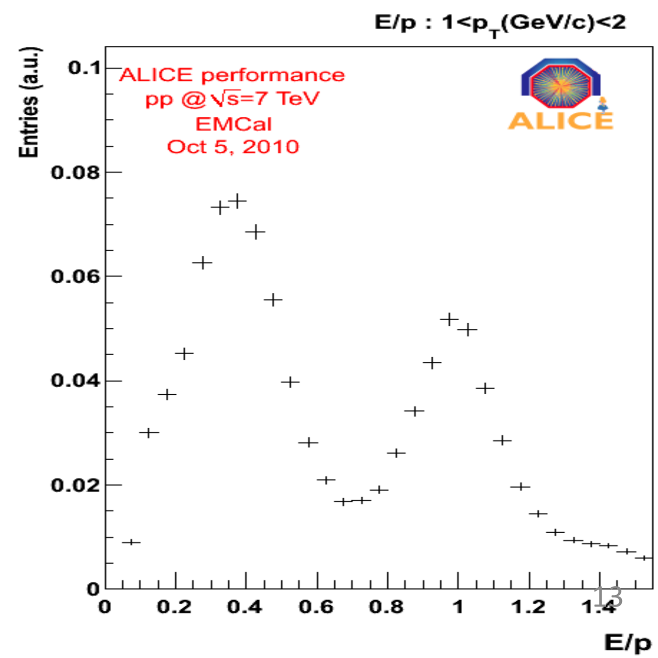
Excess wrt cocktail: heavy flavour and direct radiation

Heavy flavour via semi-electronic decays

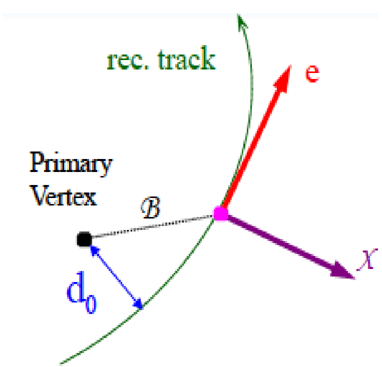
Coming up next:

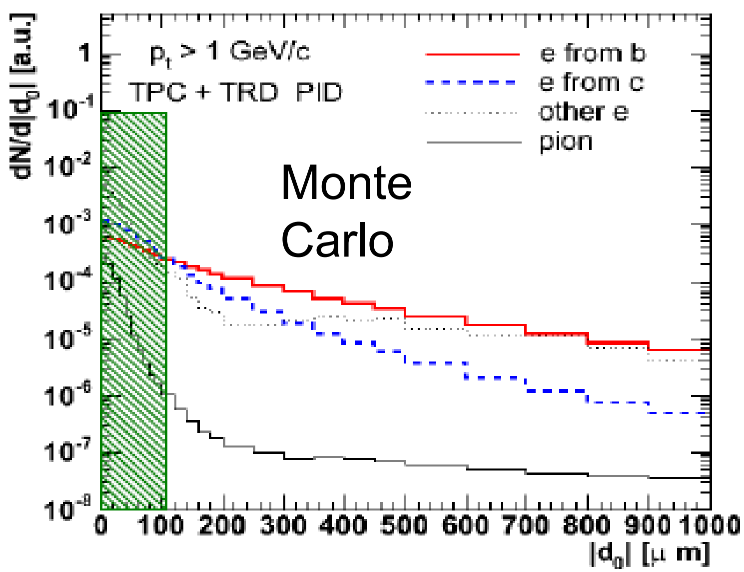
- Evaluation of systematics and normalisation -> cross section
- Extend electron identification with TRD and EMCAL





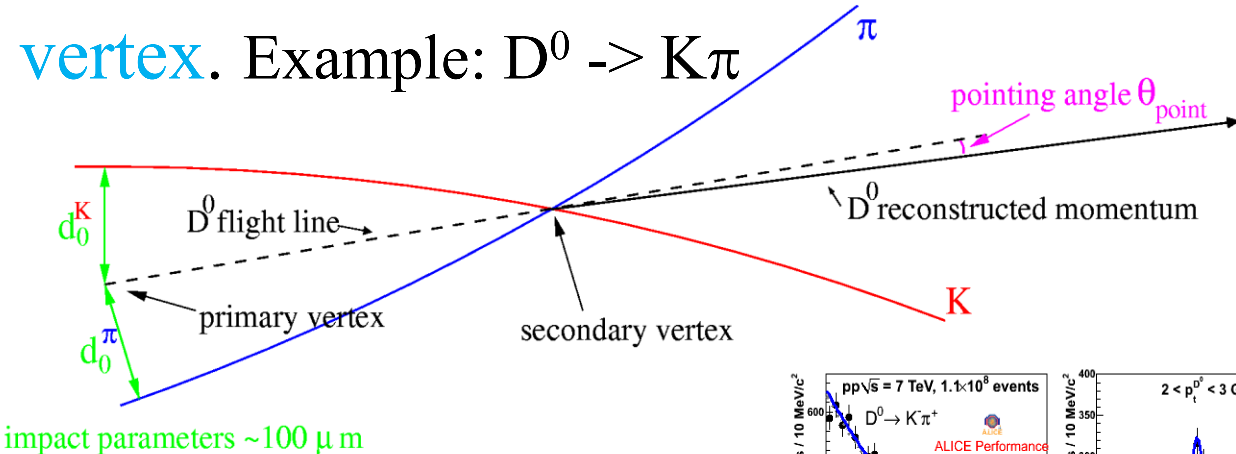
- Displaced vertex analysis -> beauty separation



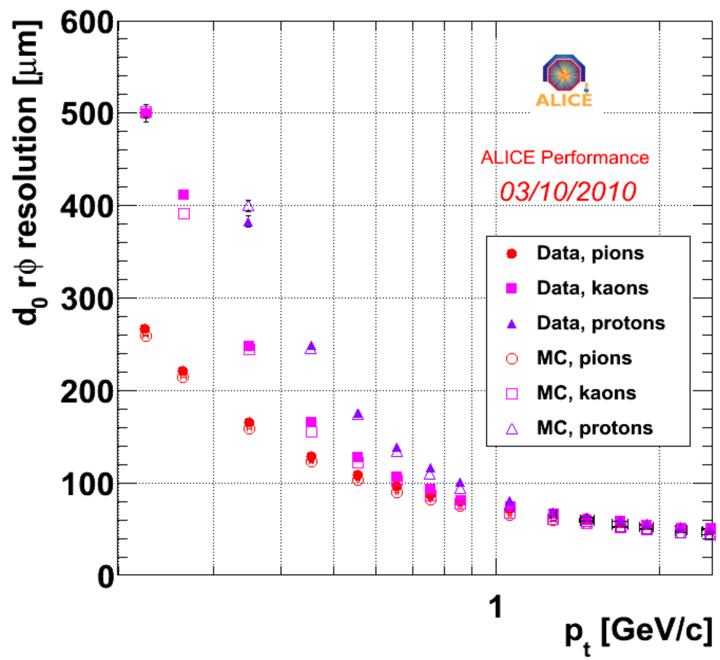


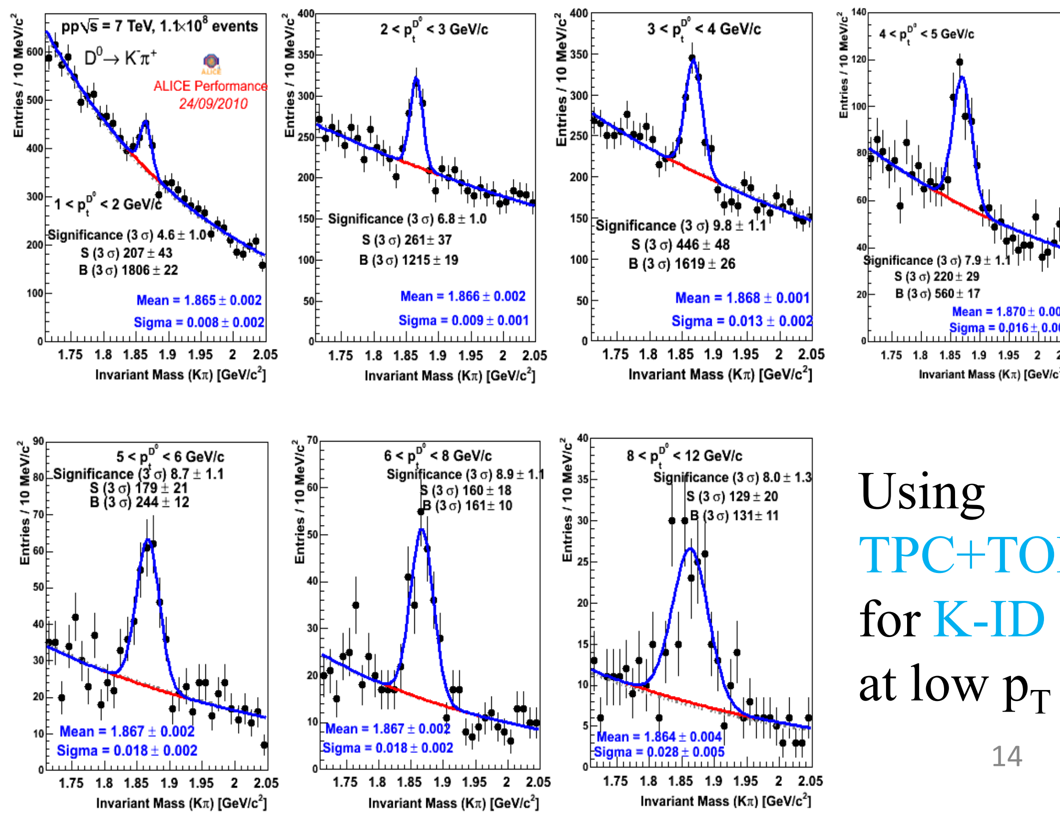
Heavy flavour via hadronic decays

Full invariant mass reconstruction on events with displaced vertex. Example: $D^0 \to K\pi$



Vertexing and tracking resolution crucial (current SPD spatial resolution: 14 μm)





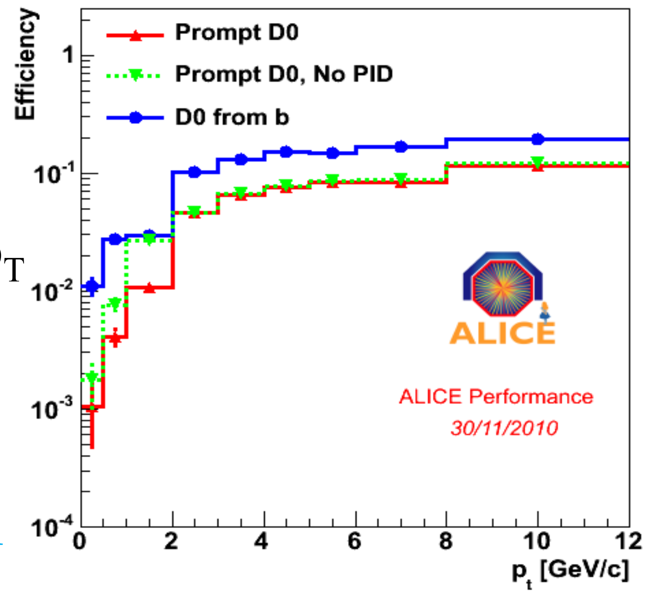
Using TPC+TOF for K-ID at low p_T

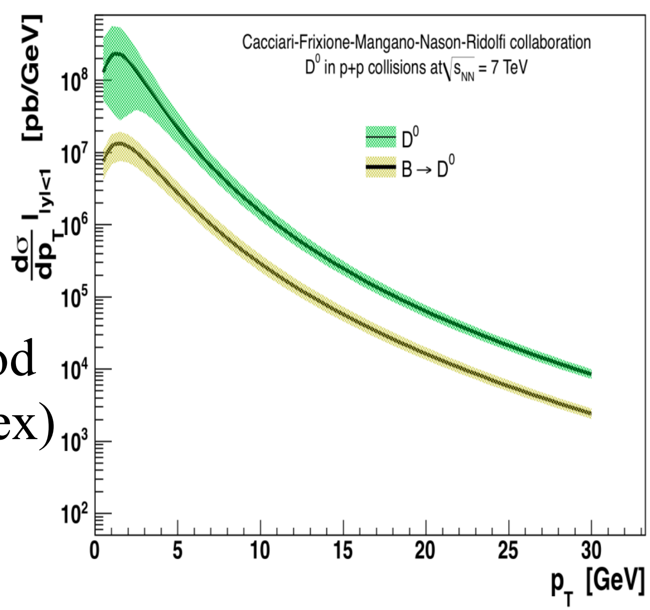
Heavy flavour via hadronic decays

Corrections:

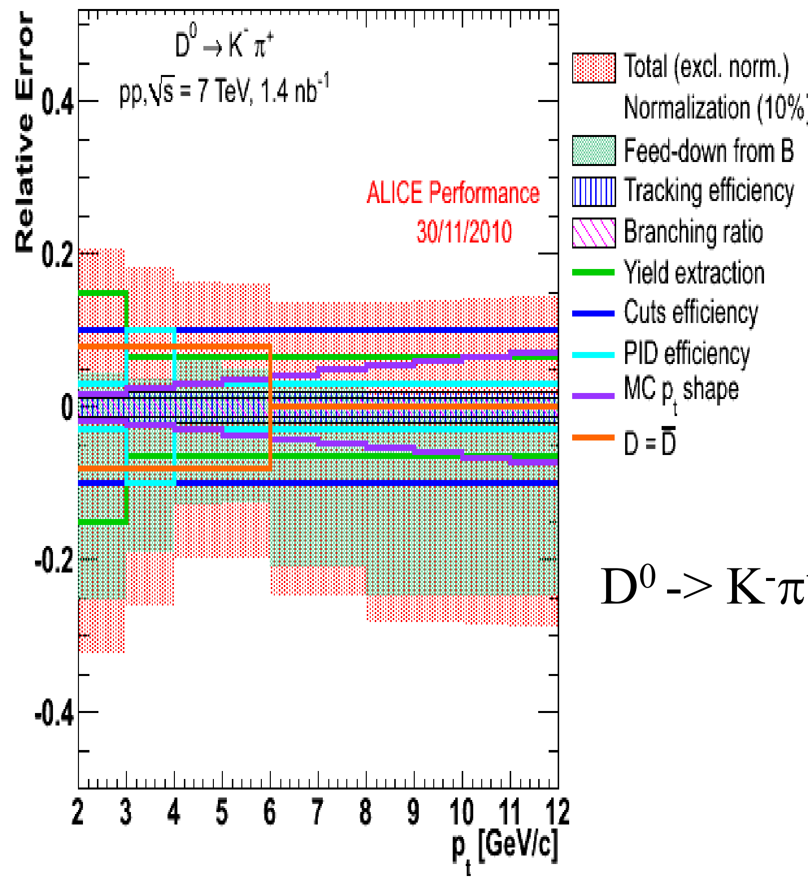
- **Efficiency:** 1% to 10% from low to high p_T. Factor two higher for D mesons from B feed-down
- **B feed-down subtraction:** 20-25% using FONLL. Next: implement data-driven method (D displaced vertex)

$D^0 \to K^-\pi^+$





Systematics

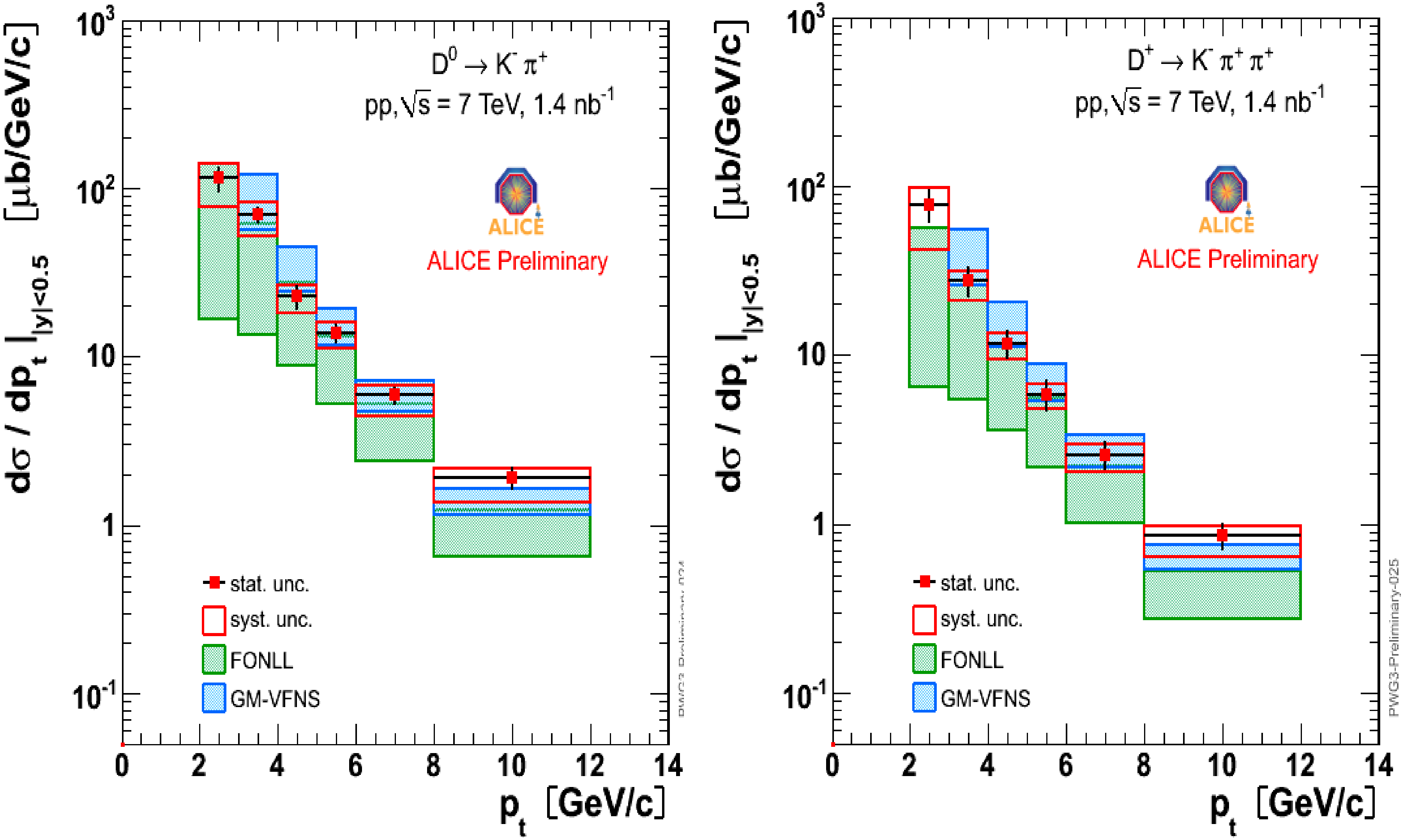


$D^0 \to K^-\pi^+$

Main contribution to error comes from B feed–down subtraction: error obtained by varying subtraction method and FONLL input

Heavy flavour via hadronic decays

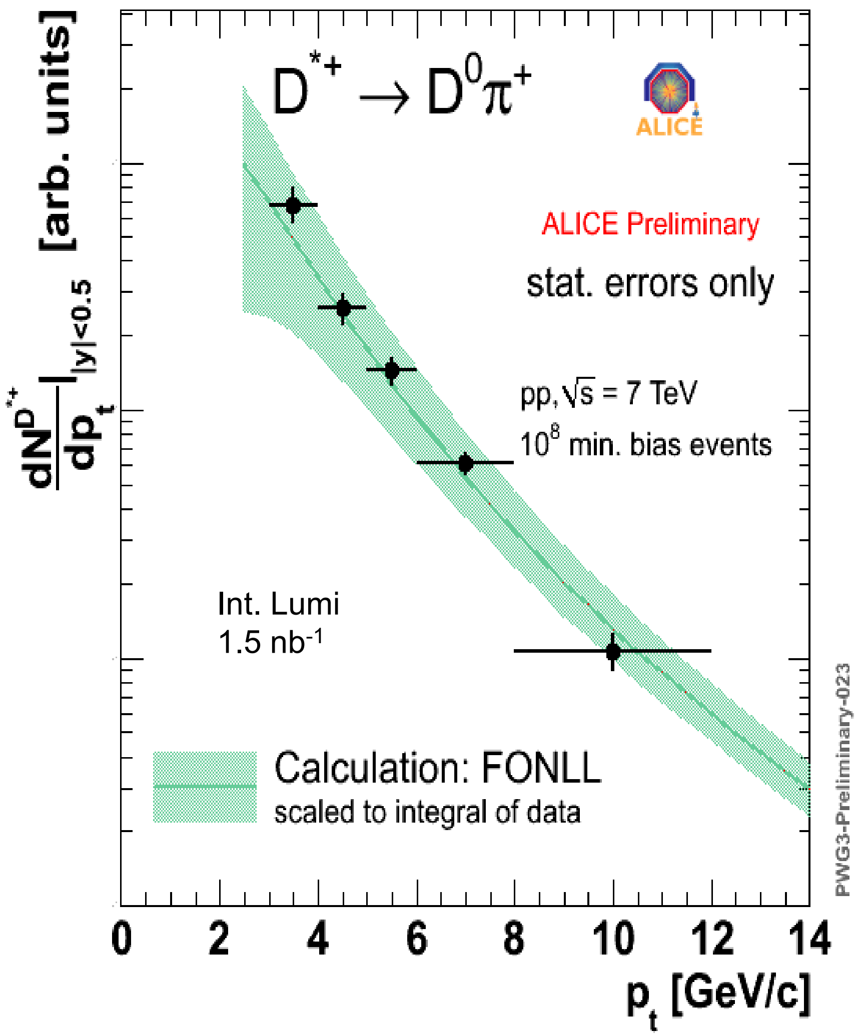
$d\sigma/dp_T$ in $|y| < 0.5$ for D^0 and D^+



Good agreement with pQCD predictions (both shape and yield)

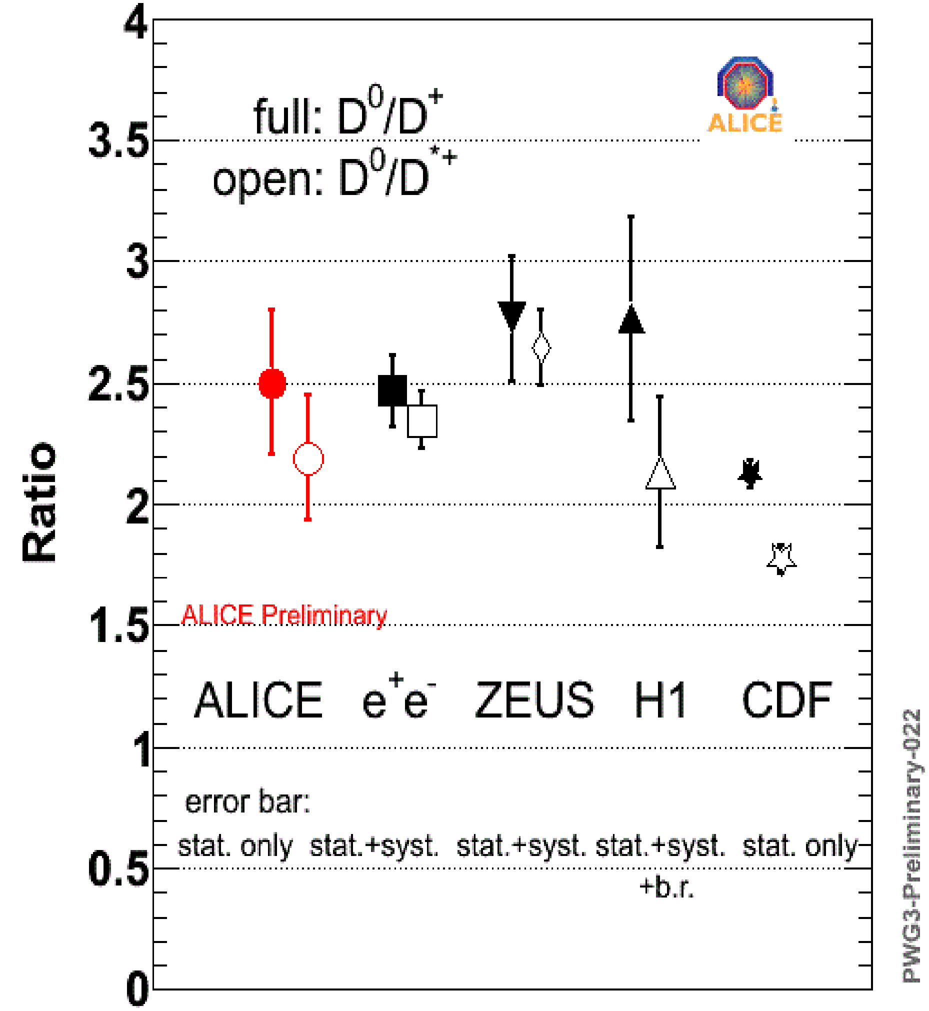
Heavy flavour via hadronic decays

dN/dp_T for D^{*+}



Shape of p_T spectrum agrees with FONLL
Normalisation ongoing to get cross section

D^0/D^+ and D^0/D^{*+} ratios



Agreement with measurements at lower energies

Heavy flavour via hadronic decays

More ongoing analyses:

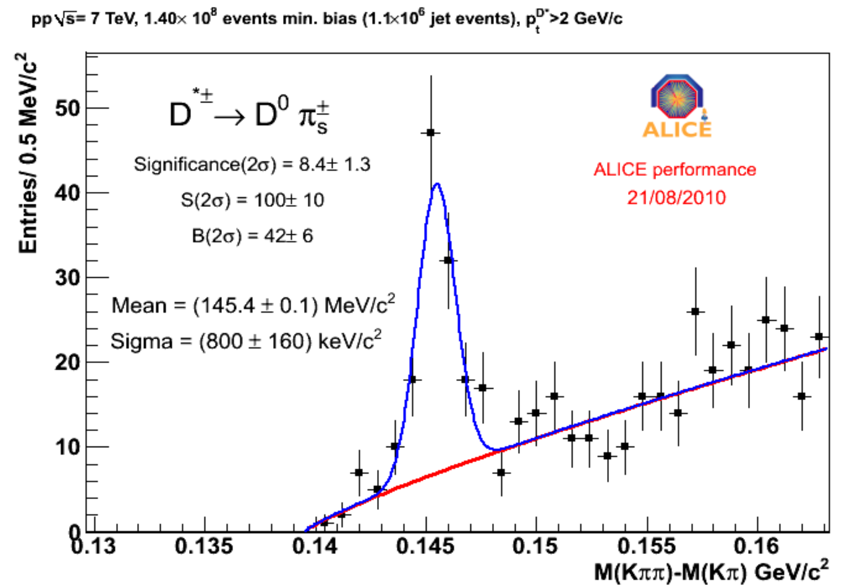
$D^0 \to K^-\pi^+$ at low p_T

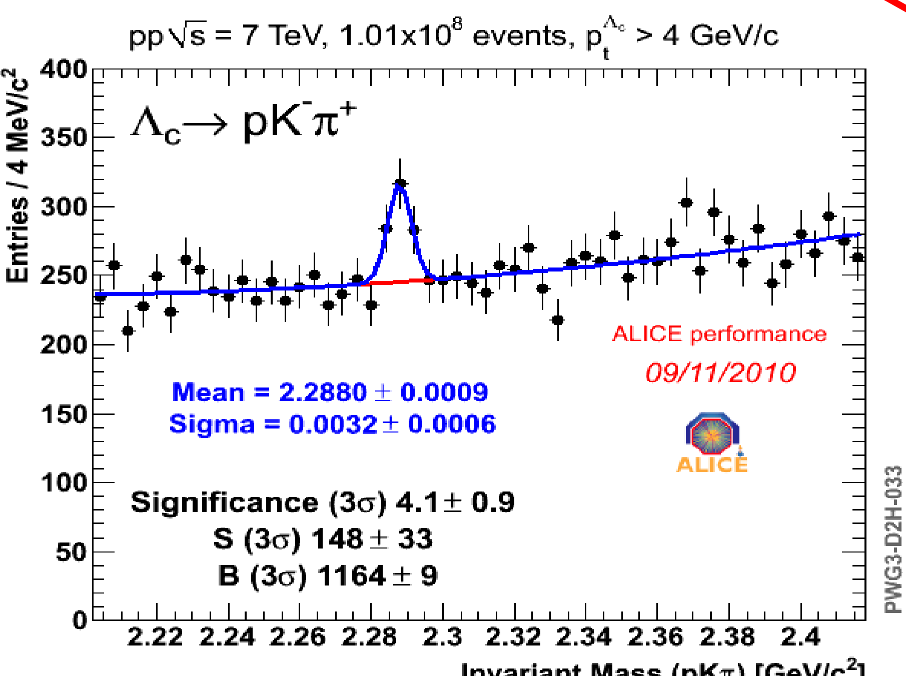
$D^0 \to K^-\pi^-\pi^+\pi^+$

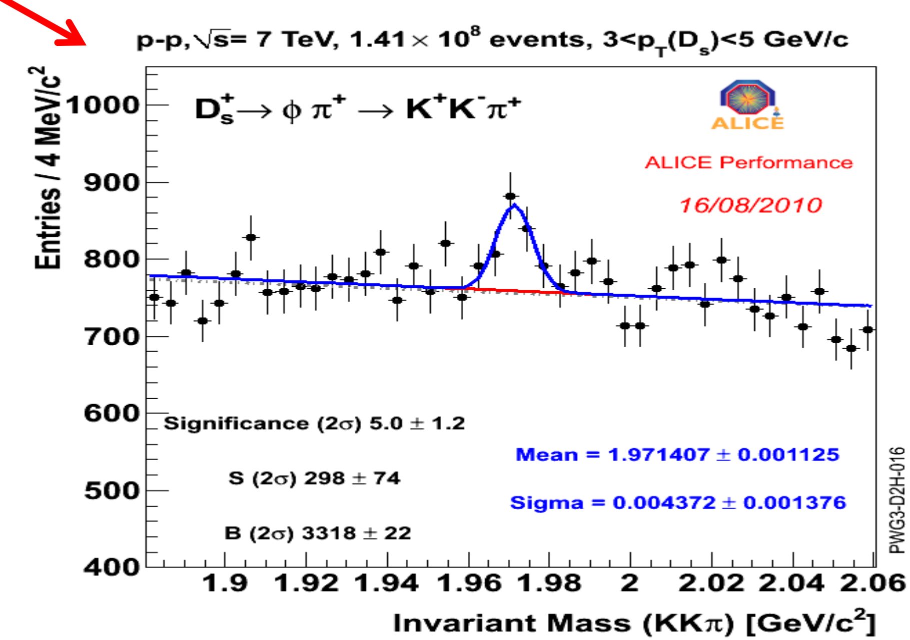
D^* in jets

$D^+_S \to \phi\pi^+ \to K^+K^-\pi^+$

$\Lambda_c \to pK^-\pi^+$







J/ψ

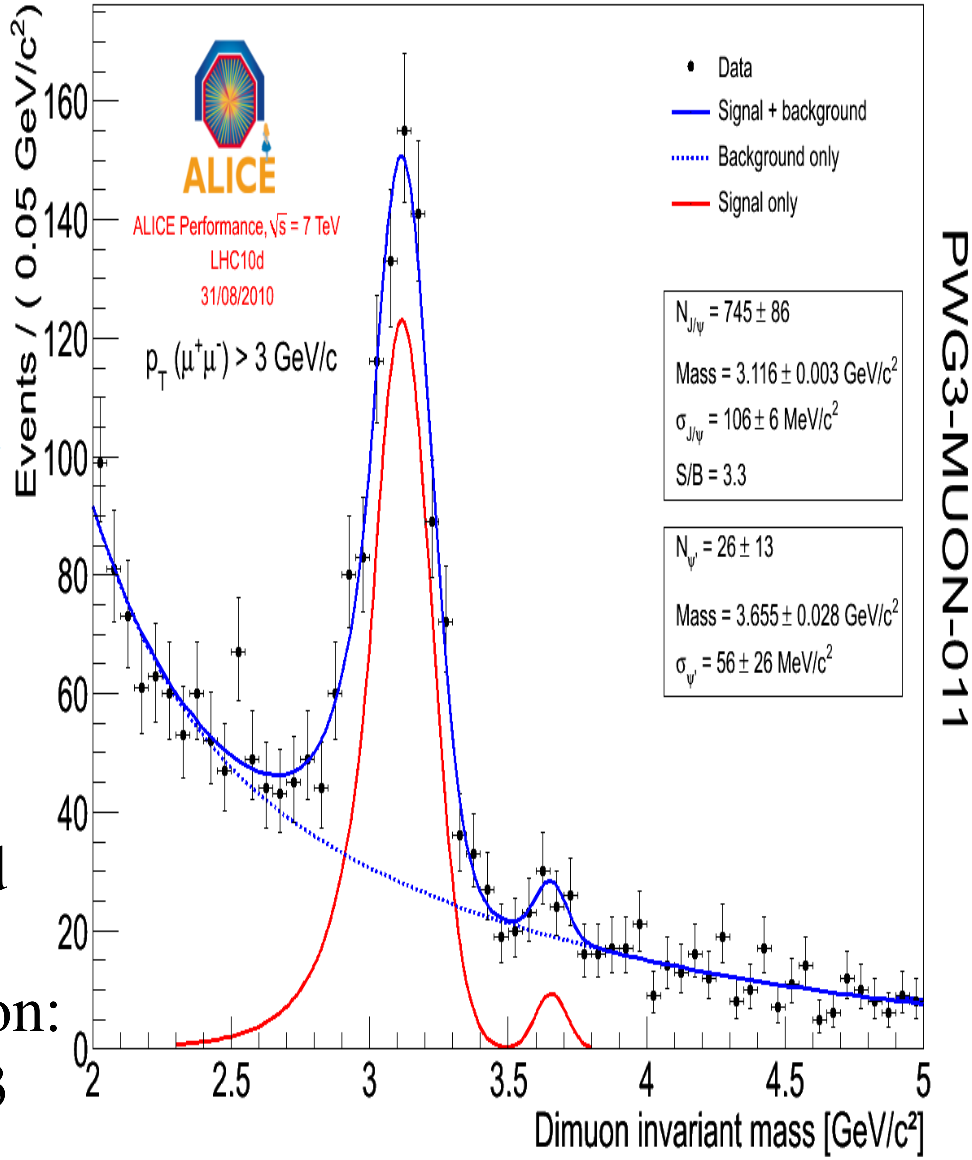
$J/\psi \to \mu^+\mu^-$

- Muon triggered events (Int-Lumi = 13.6 nb^{-1})
- Inclusive J/ψ (no B separation)
- $-4 < y^{J/\psi} < -2.5$

-Track selection:
at least one vertex in SPD
at least one muon matching trigger
cut on the track position
at the end of the front absorber

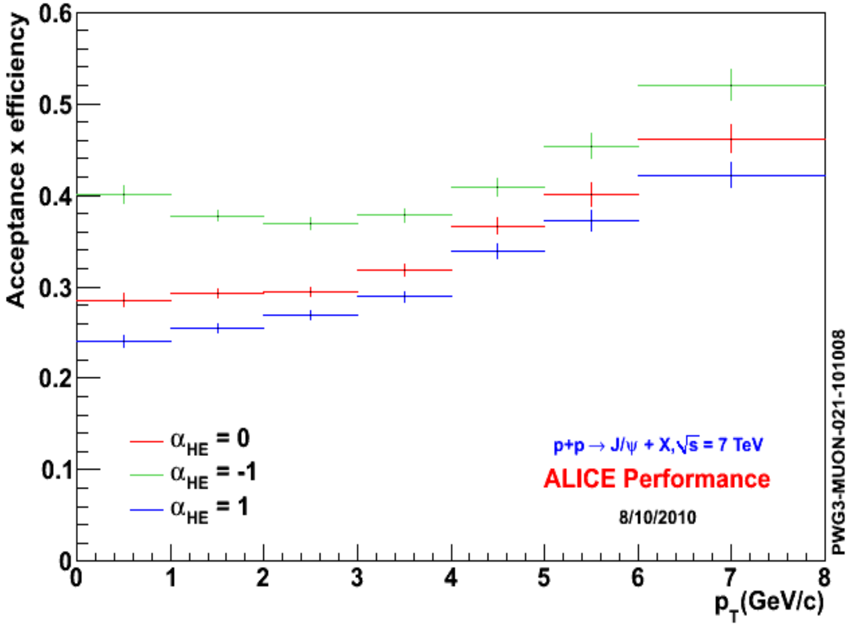
- Signal extraction: Crystal Ball function for signal, double exponential for background

- Statistics used for total cross section:
1909 ± 78 J/ψ in $2.9 < M_{\mu+\mu-} < 3.3$



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

Acceptance x efficiency evaluated via MC with realistic kinematic distributions and detector configuration



Overall systematic error (polarisation excluded): 13.5%

Main contribution: luminosity normalisation (10%)

Polarisation effect on acceptance: -21% +12% syst. error

Integrated cross section:

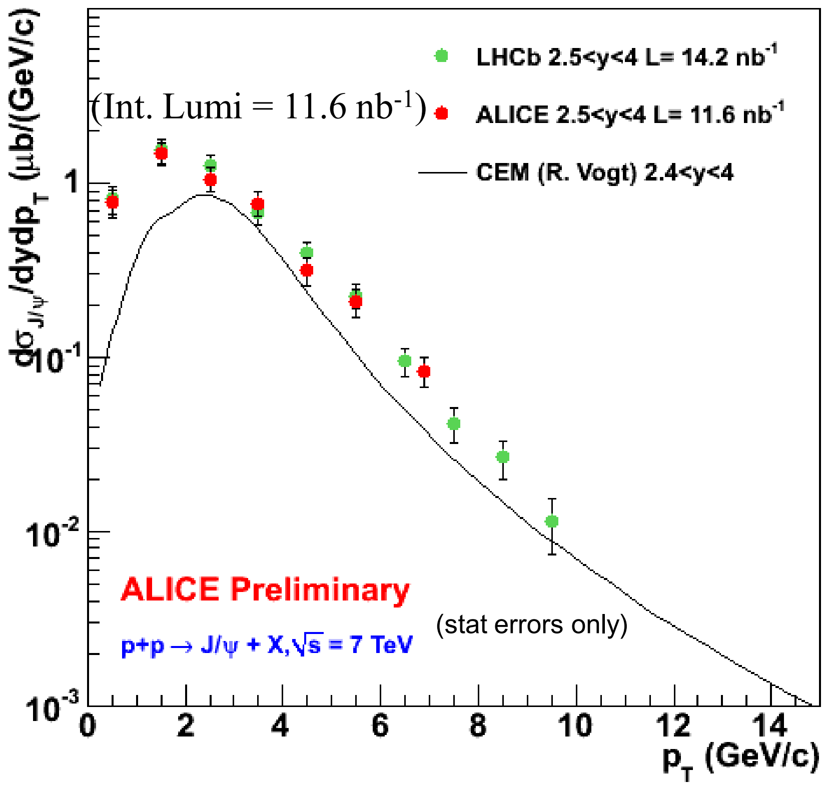
$$\sigma_{J/\psi}(2.5 < y < 4) = 7.25 \pm 0.29\,(stat) \pm 0.98\,(syst)\,^{+0.87}_{-1.50}\,(syst.pol.)\ \mu b$$

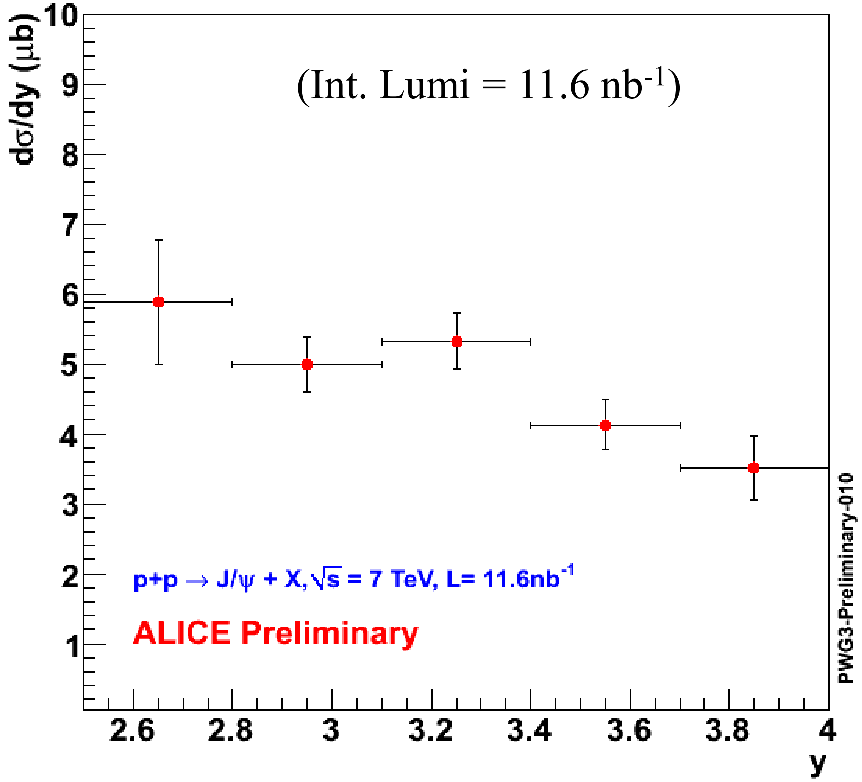
Very good agreement with the corresponding LHCb result (ICHEP2010):

$$\sigma_{J/\psi}(2.5 < y < 4) = 7.65 \pm 0.19(stat) \pm 1.10(syst)^{+0.87}_{-1.27}(syst.pol.)\ \mu b$$

J/ψ –> $\mu^+\mu^-$

Differential cross sections





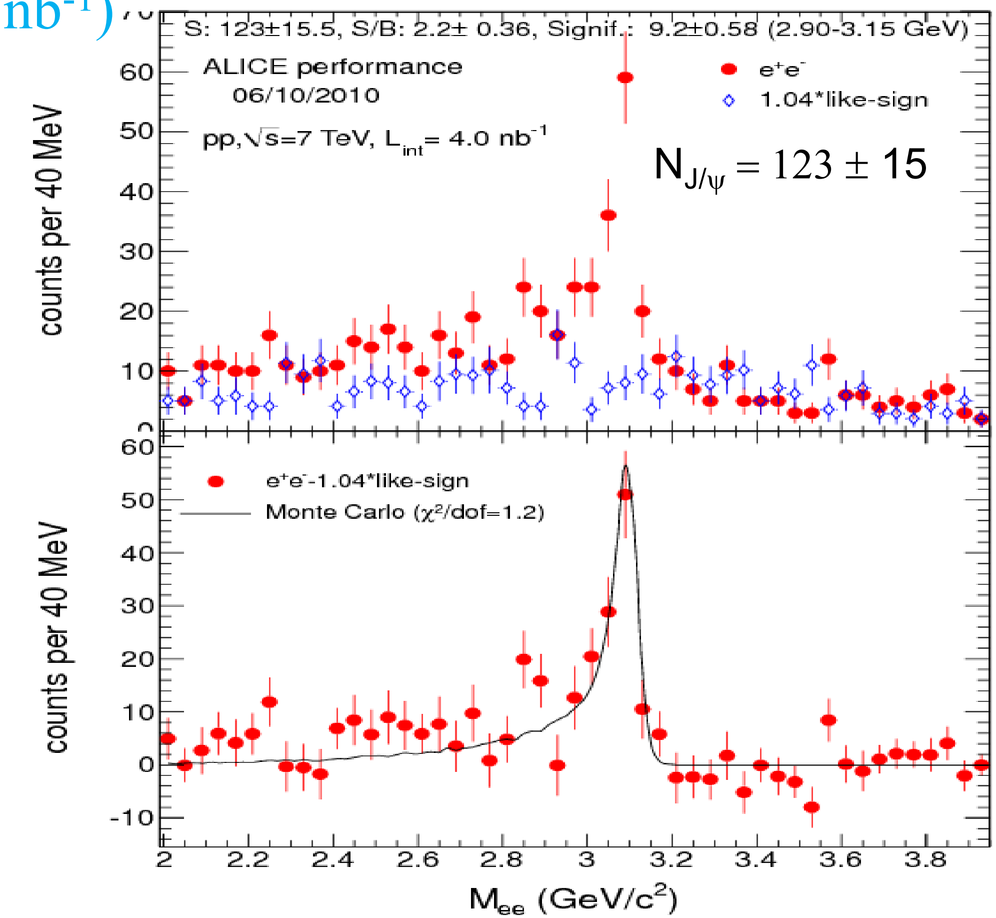
- Point-to-point systematic error: 3-10%, mainly related to signal extraction and acceptance correction (not fully evaluated yet)
- p_T distribution: softer than CEM, good agreement with LHCb
- Analysis of angular distribution (<--> polarisation) ongoing

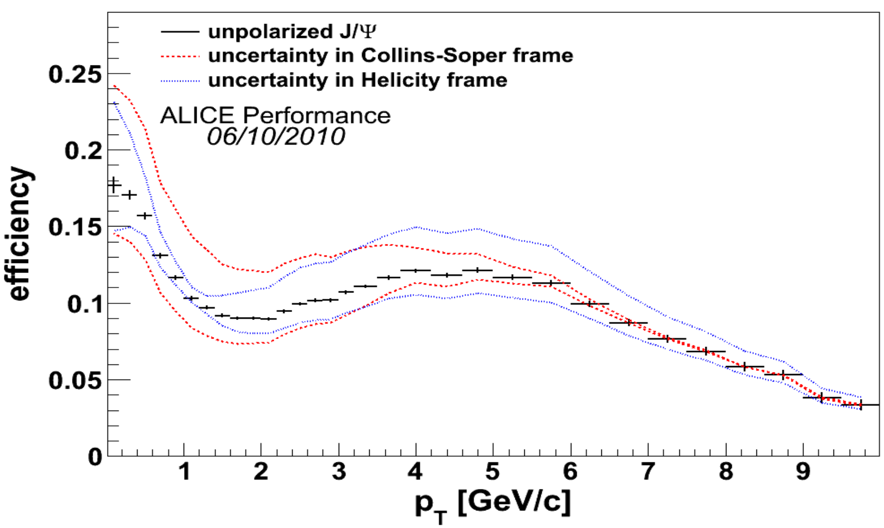
J/ψ –> e^+e^-

- Minimum bias events (Int-Lumi = 4 nb^{-1})
- Inclusive J/ψ (no B separation yet)
- Tracking: ITS + TPC
- PID: TPC dE/dx
- Track selection:

  $|\eta^{e+,e-}|<0.88$ and $|y^{J/\psi}|<0.88$

  $p_T^{e+,e-} > 1$ GeV/c
- Signal extraction: bin-counting above like-sign background in M_{e+e-} =2.9 -3.15 GeV/c^2



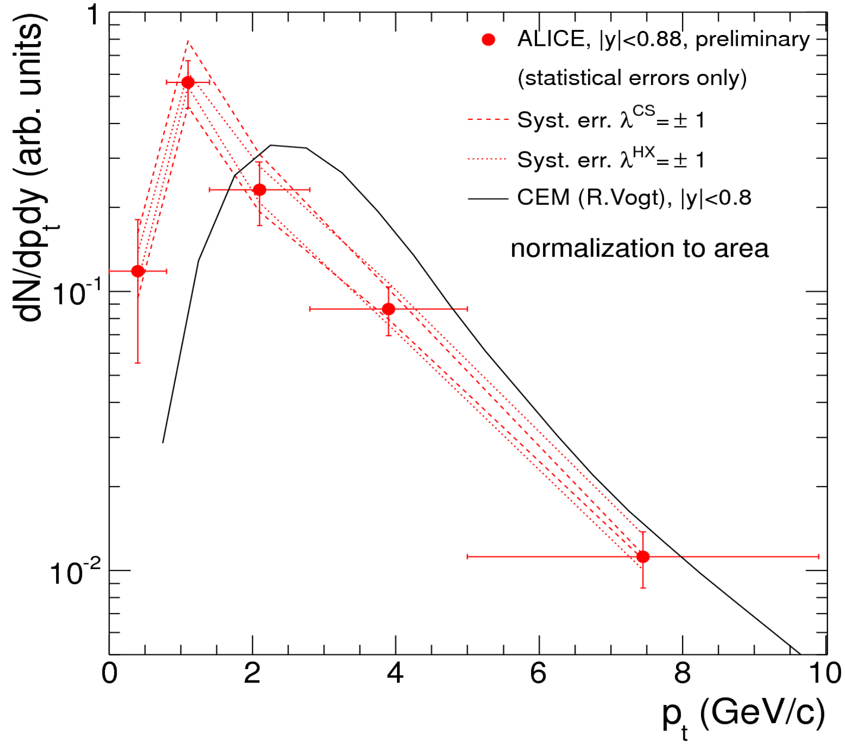


Systematic errors:

- 14.5% from efficiency corrections
- 10% from lumi normalisation
- -25% +10% from polarisation

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

p_T spectrum



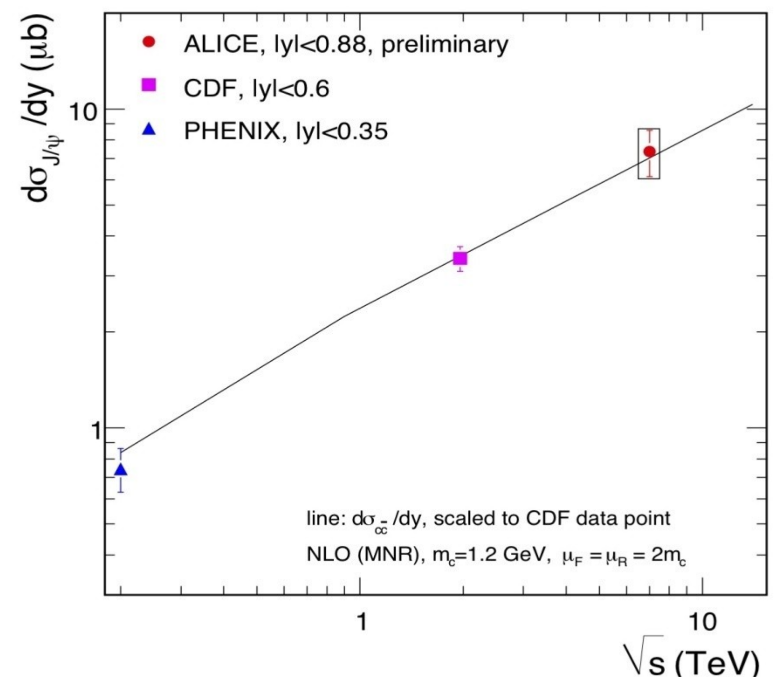
- Obtained with full data sample
- Softer than Colour Evaporation Model prediction
- Analysis for normalisation of the full data set and cross section ongoing

Integrated 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.



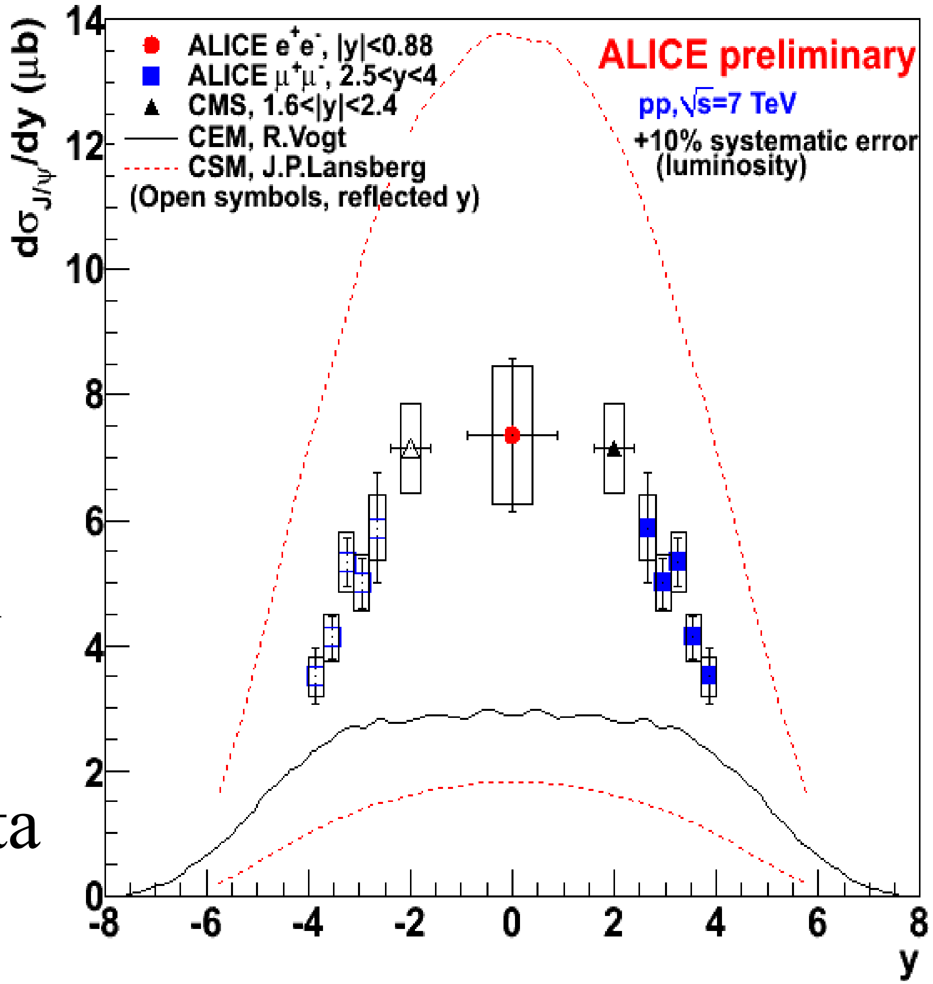
Conclusions

- ALICE in good shape during 2010 p-p run

- Preliminary results on heavy flavour in p-p are available

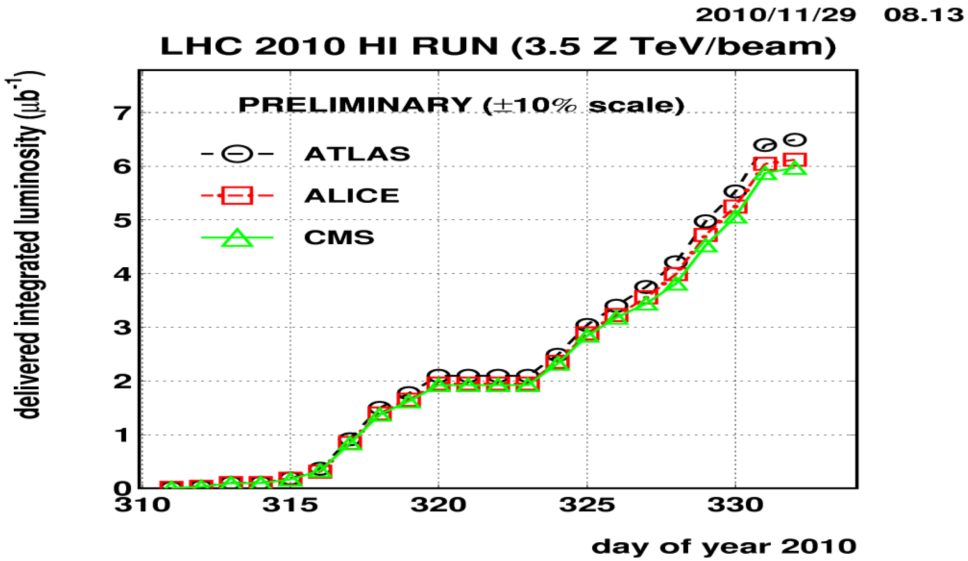
- More results to come soon

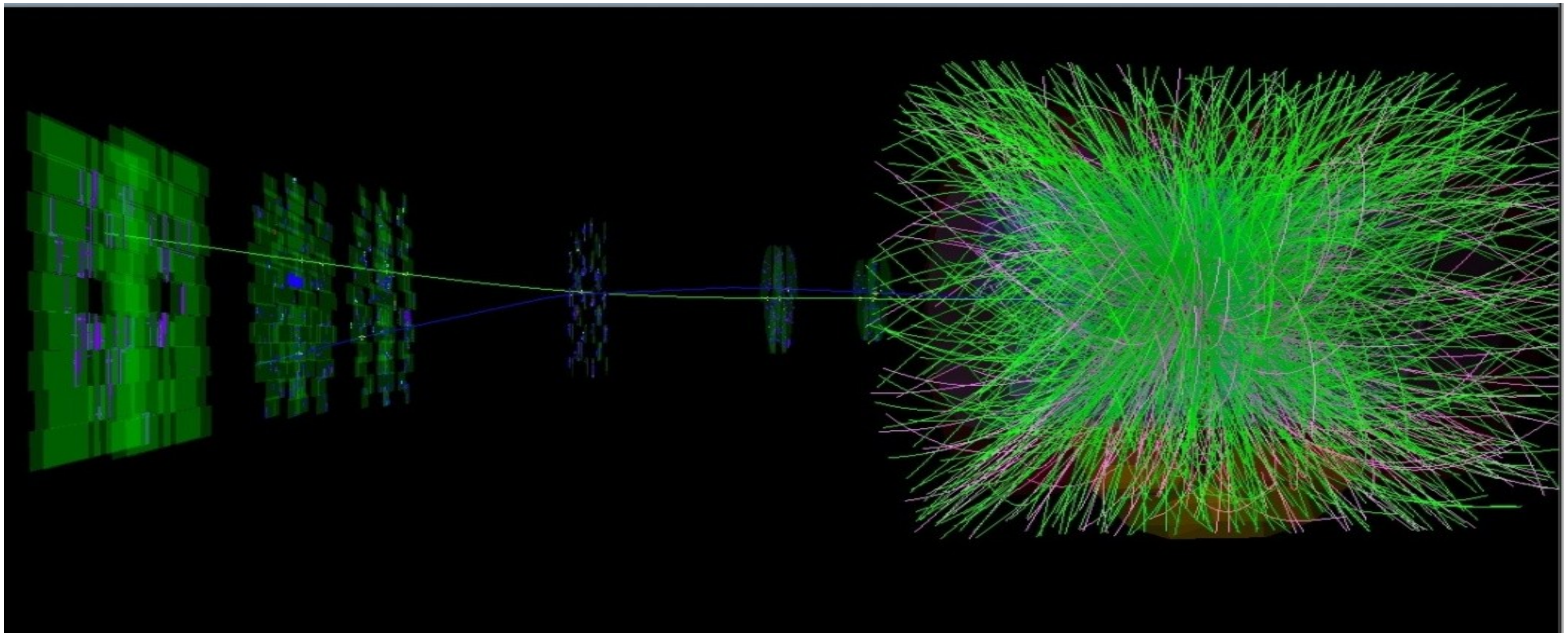
- Challenge: use p-p as a reference for heavy ion data



and now ....

Heavy ion collisions!

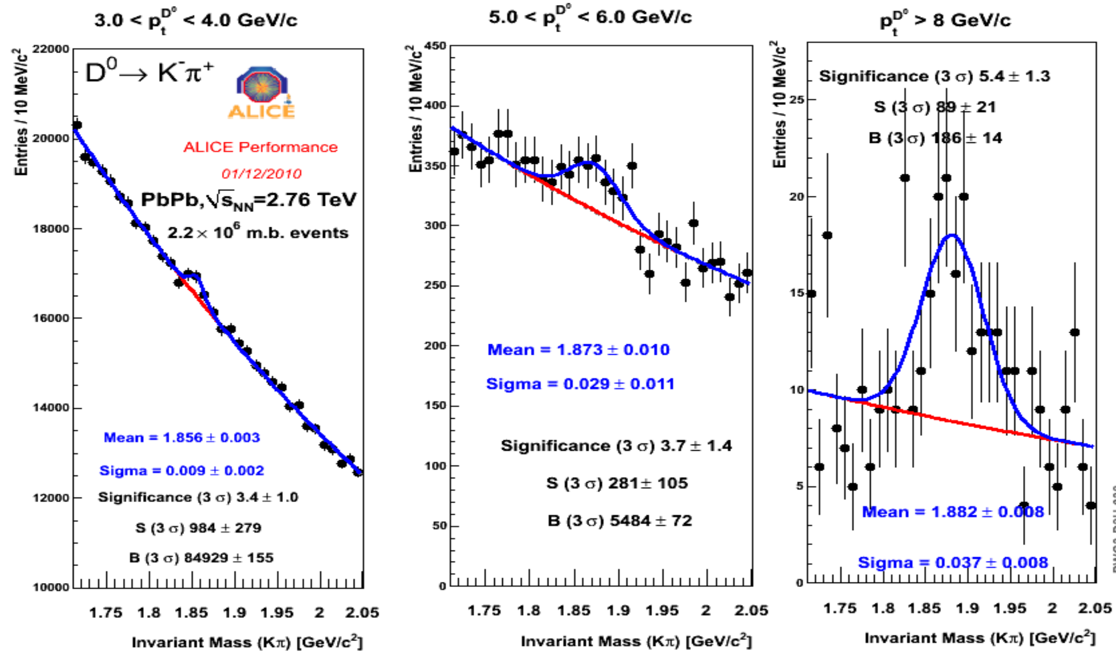




First heavy flavour signals in Pb-Pb collisions

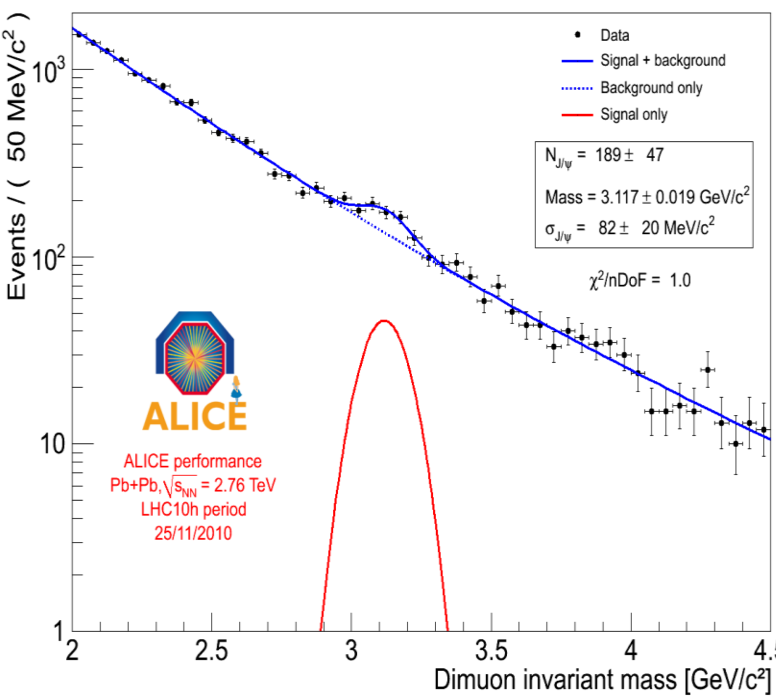
$D^0 \to K^- \pi^+$ →

2.2 M min bias events



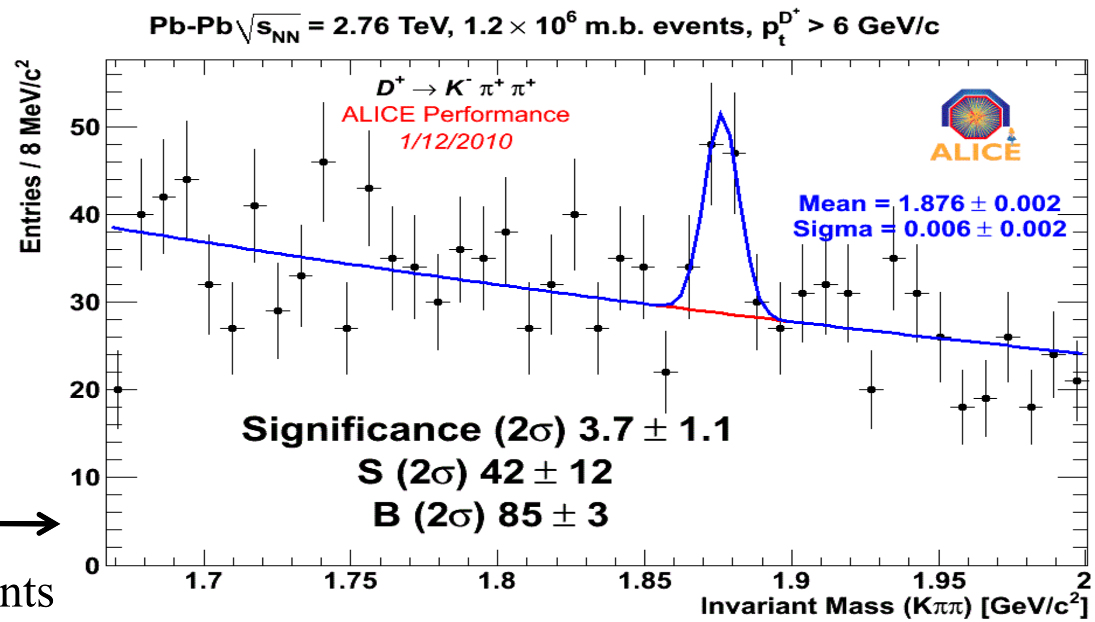
$J/\psi \to \mu^+\mu^-$

2.6 M mb events ↓



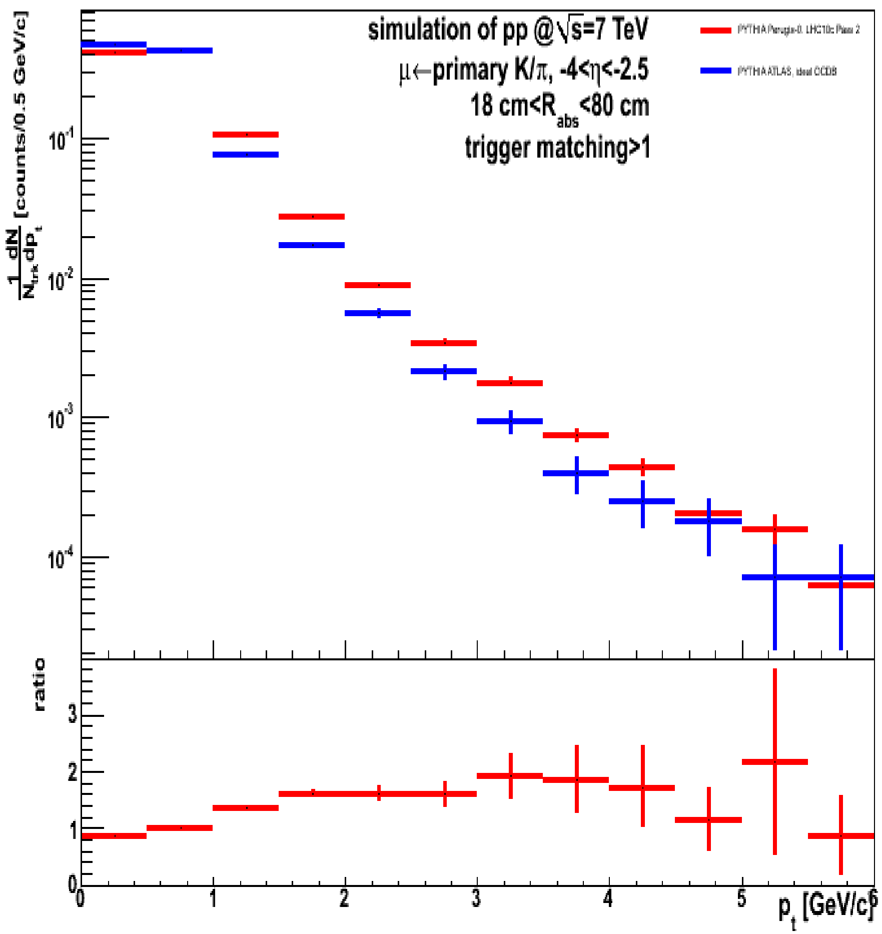
$D^+ \to K^- \pi^+ \pi^+$ →

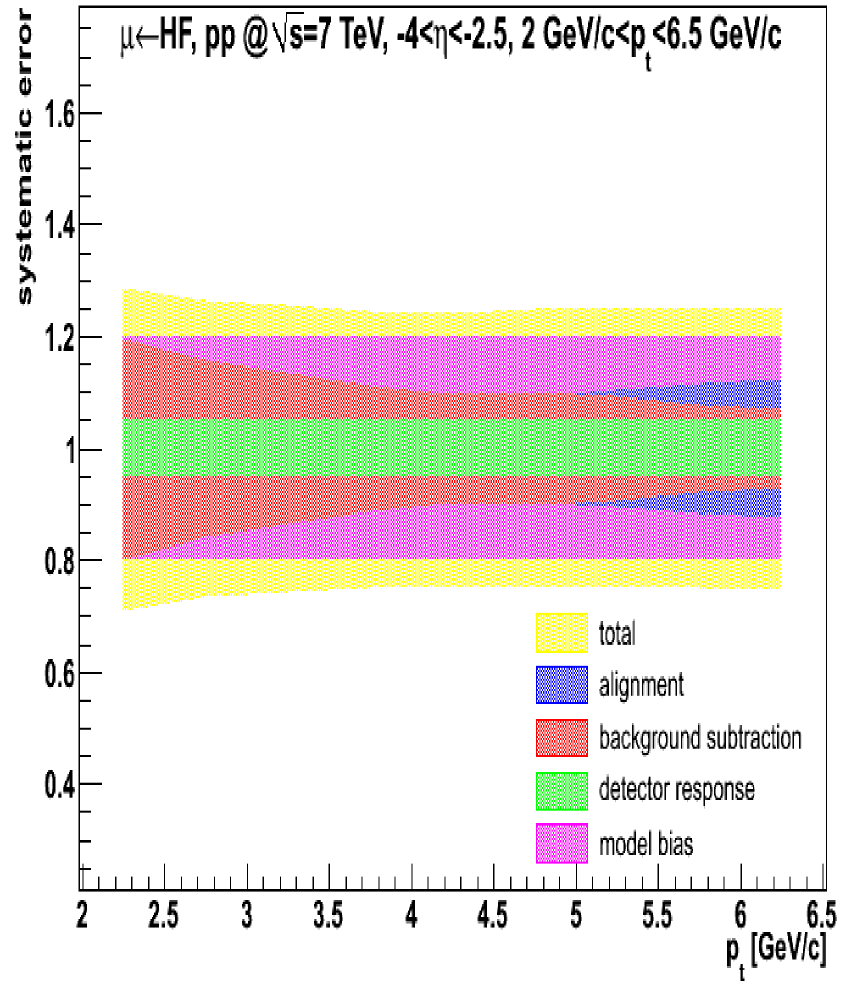
1.2 M min bias events



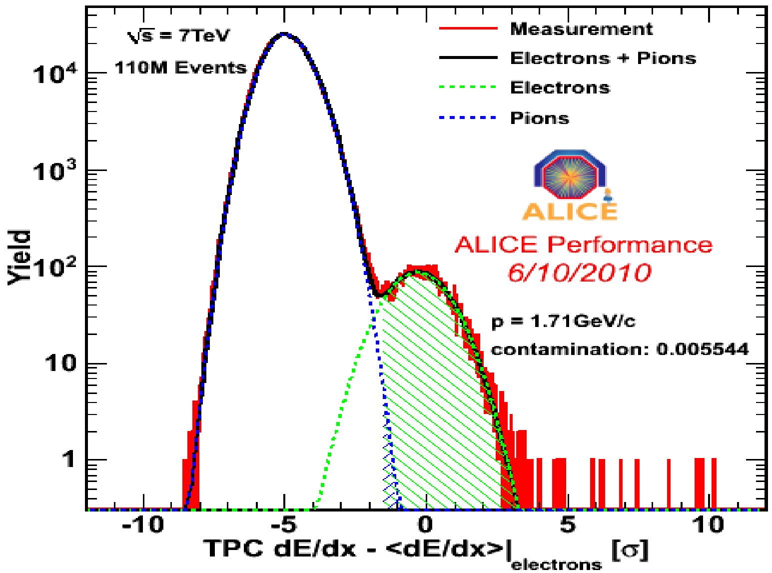
Backup

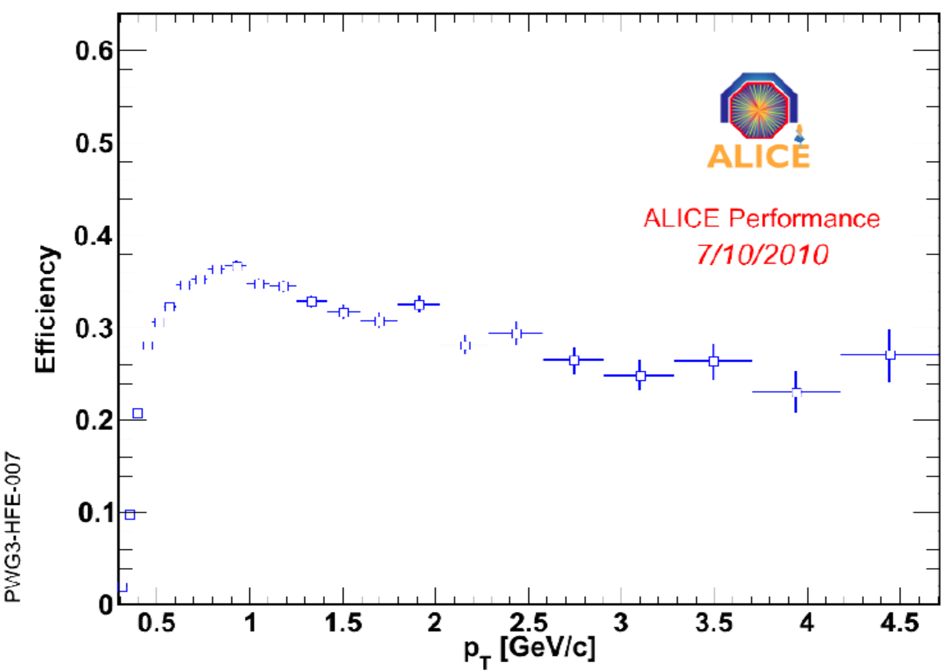
Heavy flavour via semi-muonic decays

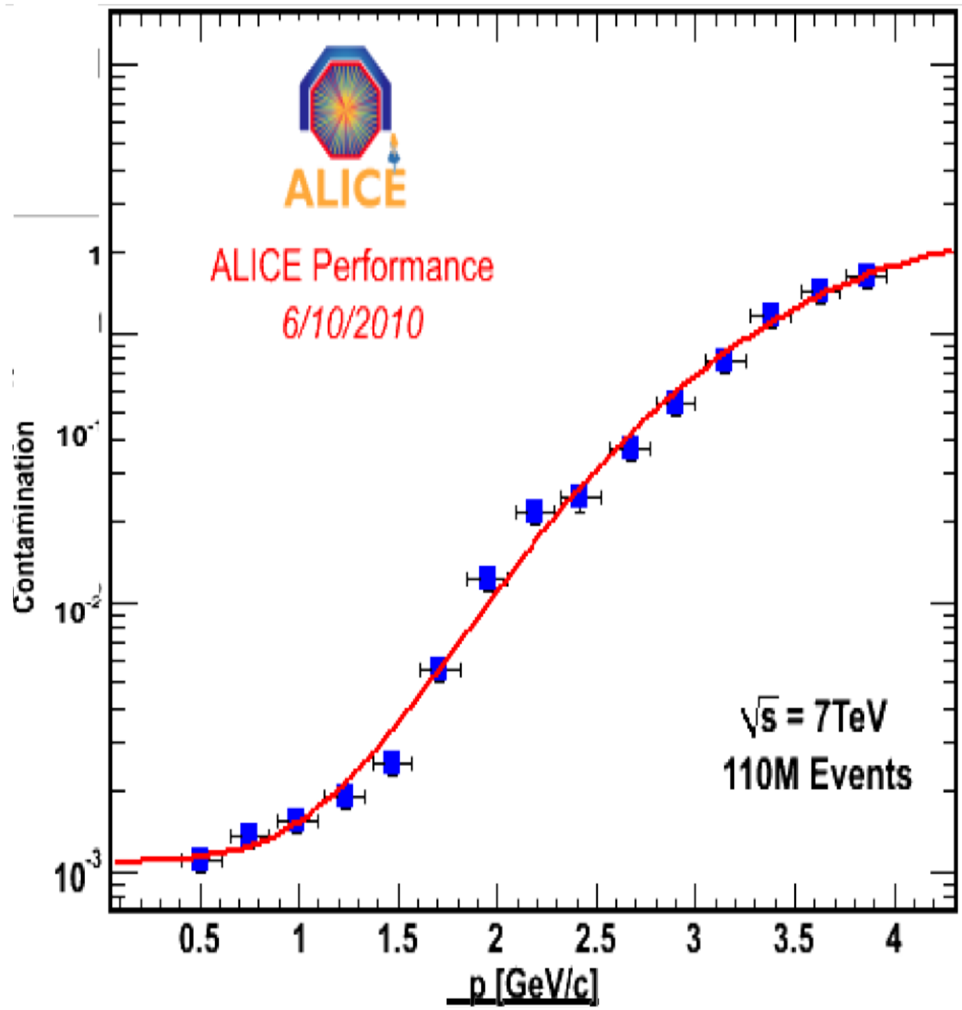




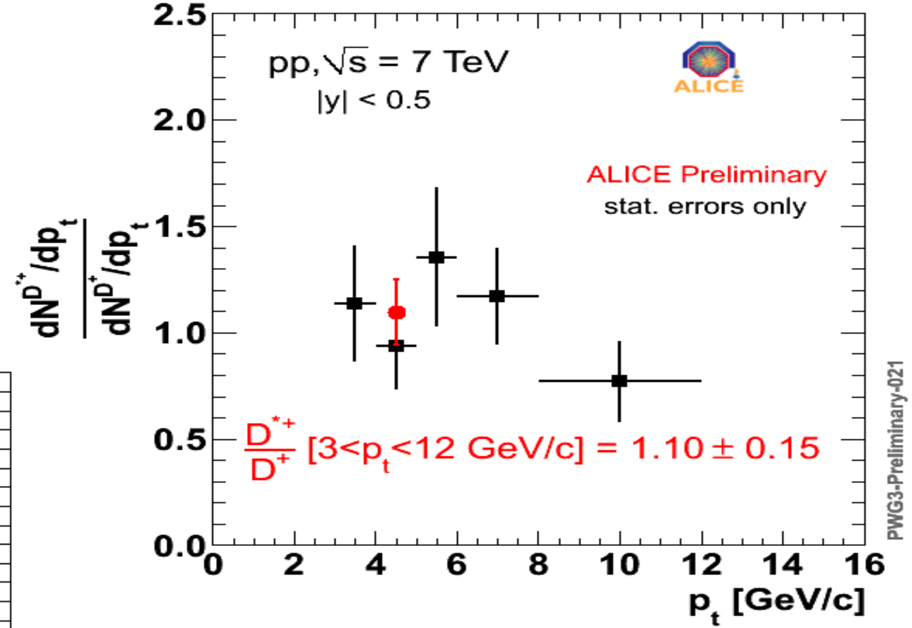
Heavy flavour via semi-electronic decays

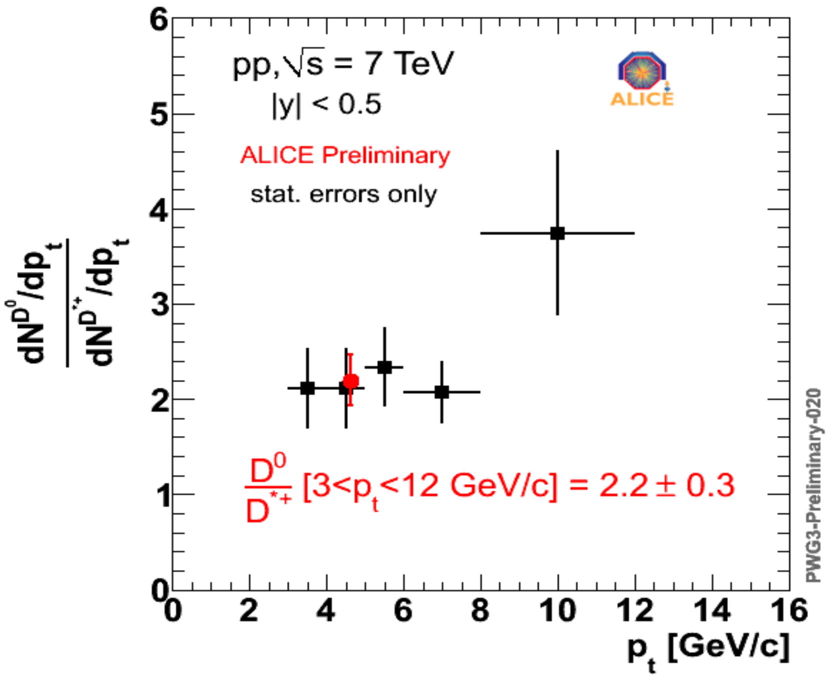


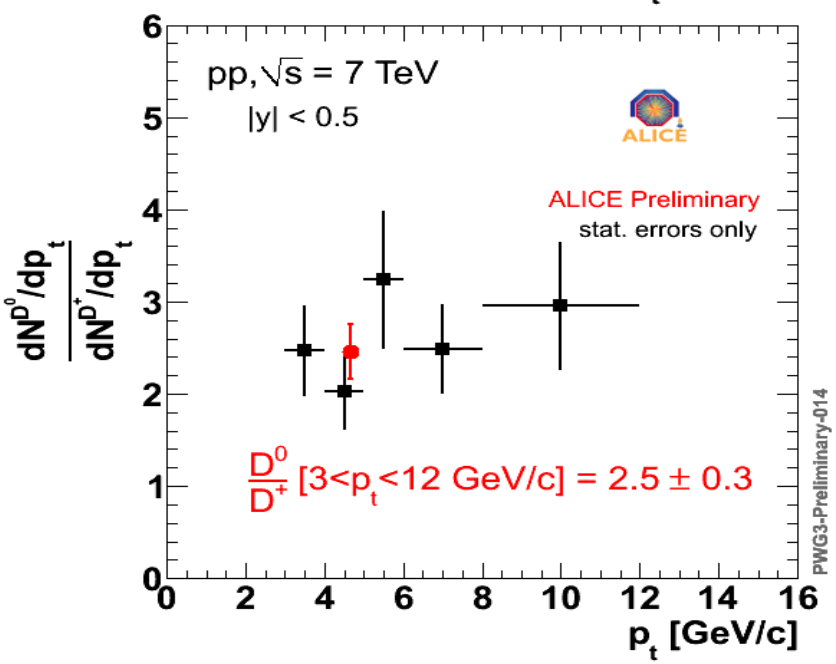




Heavy flavour via hadronic decays

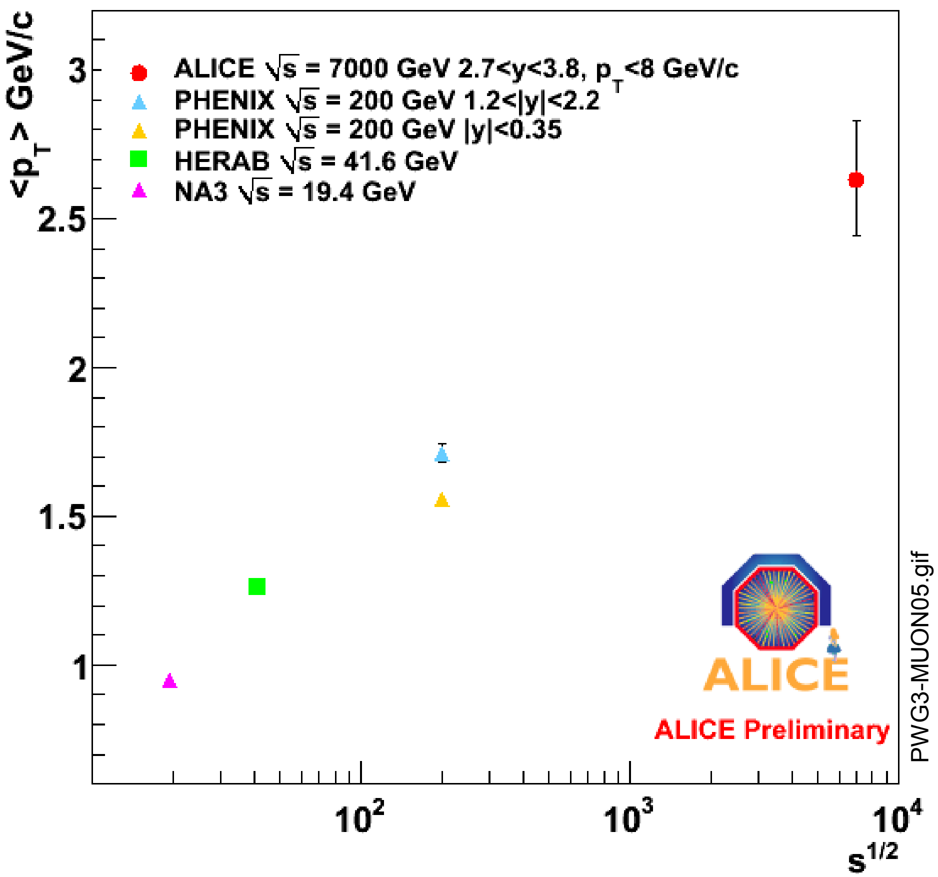


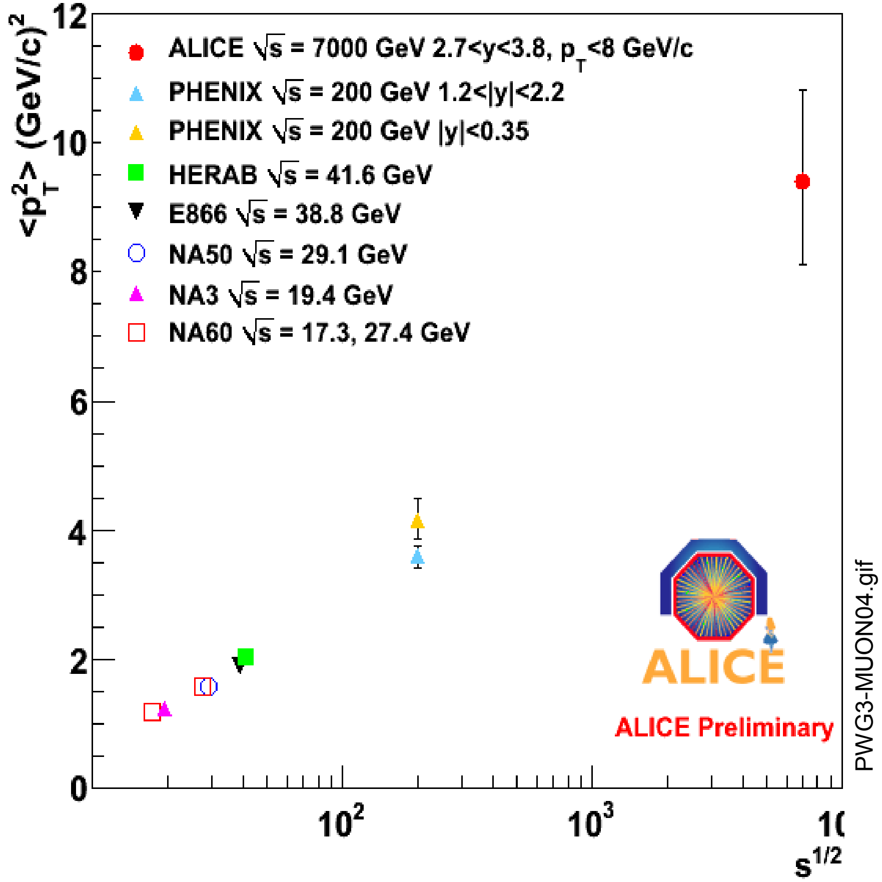




$J/\psi \rightarrow \mu^+\mu^-$: $\langle p_T \rangle$ and $\langle p_T^2 \rangle$

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





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

$J/\psi \rightarrow \mu^+\mu^-$: syst. errors on cross section

Source of systematic error	
Uncertainty on 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%
Normalization	10 %
Total systematic error	**13.5 %**

Polarization (helicity frame)	**+12 -20.7 %**

Large systematic error from luminosity
→ to be improved with next LHC Van der Meer scans

$J/\psi \rightarrow e^+e^-$: syst. errors on cross section

Source of syst. error	
Kinematics	<1%
Track quality,#clusters TPC	10%
PID cuts	10%
Signal extraction range	4%
Normalization	10 %
Total systematic error	**18 %**