ALICE heavy quarks

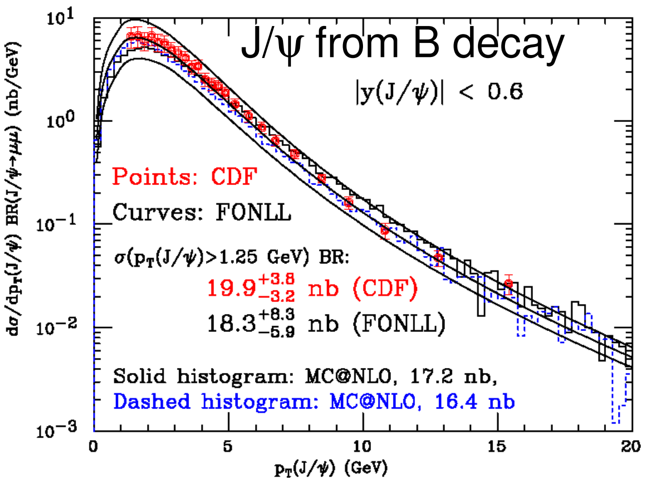
Andrea Rossi, Padova Univ. & INFN
on behalf of the ALICE collaboration

Contents

- Heavy Flavour targets in ALICE
- ALICE detector and 2010 data taking conditions
- J/ψ production cross section at forward and mid-rapidity
- Cross section for heavy flavour decaying into muons
- Heavy flavour electron signal at central rapidity
- D mesons dN/dp_t and D spectra ratios
- Summary

Heavy-flavour physics target in pp collisions for ALICE

- **Measure total and pt-differential cross section for charm and beauty production**

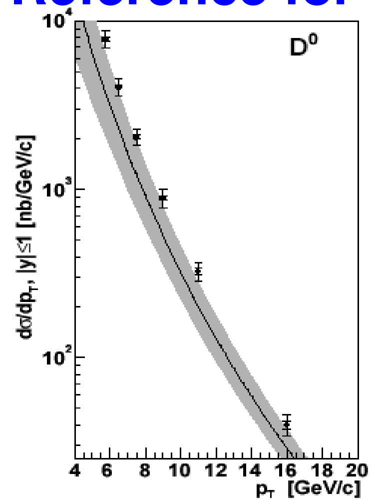


FONLL, MC@NLO:
Cacciari, Frixione, Mangano,
Nason and Ridolfi,
JHEP0407 (2004) 033

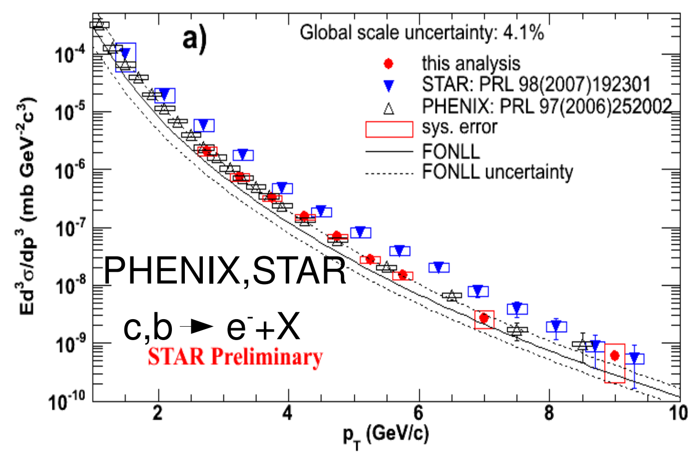
- **Important test of pQCD in a new energy domain**

  c production on the upper edge of predictions at Tevatron and RHIC

- **Reference for Pb-Pb collisions**



CDF, PRL91 (2003) 241804
FONLL: Cacciari, Nason



from W. Xie talk at Hard Probes (STAR Preliminary)

- **Measure total and pt-and y- differential cross section for quarkonia production**
  - **Mechanism of quarkonia production not fully understood yet**
  - **Charmonium and bottomonium sensitive probe of deconfinement in Pb-Pb**

Heavy-flavour production at the LHC

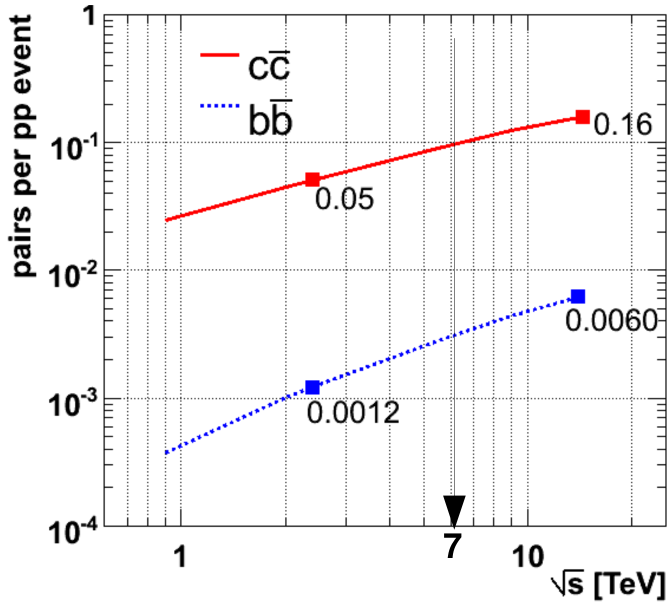
NLO predictions (ALICE baseline for **charm** & **beauty**)

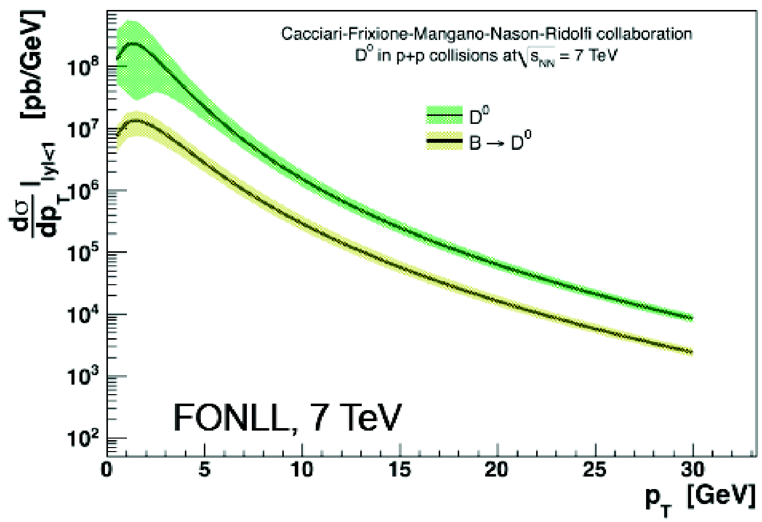
MNR code (FO NLO): Mangano, Nason, Ridolfi, NPB373 (1992) 295.

Shadowing (Pb-Pb), EKS98, EPS08: Eskola et al., EPJC9 (1999) 61; JHEP07 (2008) 102

system, √s	pp, 7 TeV	pp, 14 TeV	Pb-Pb (0-5%), 2.76 TeV	Pb-Pb (0-5%), 5.5 TeV
$\sigma_{NN}^{Q\bar{Q}}$ [mb]	6.9 / 0.23	11.2 / 0.5	2.1 / 0.075	3.4 / 0.14
$N_{tot}^{Q\bar{Q}}$	0.10 / 0.003	0.16 / 0.007	56 / 2	90 / 3.7

(Factor 2 uncertainty from pQCD scales and mass choices)



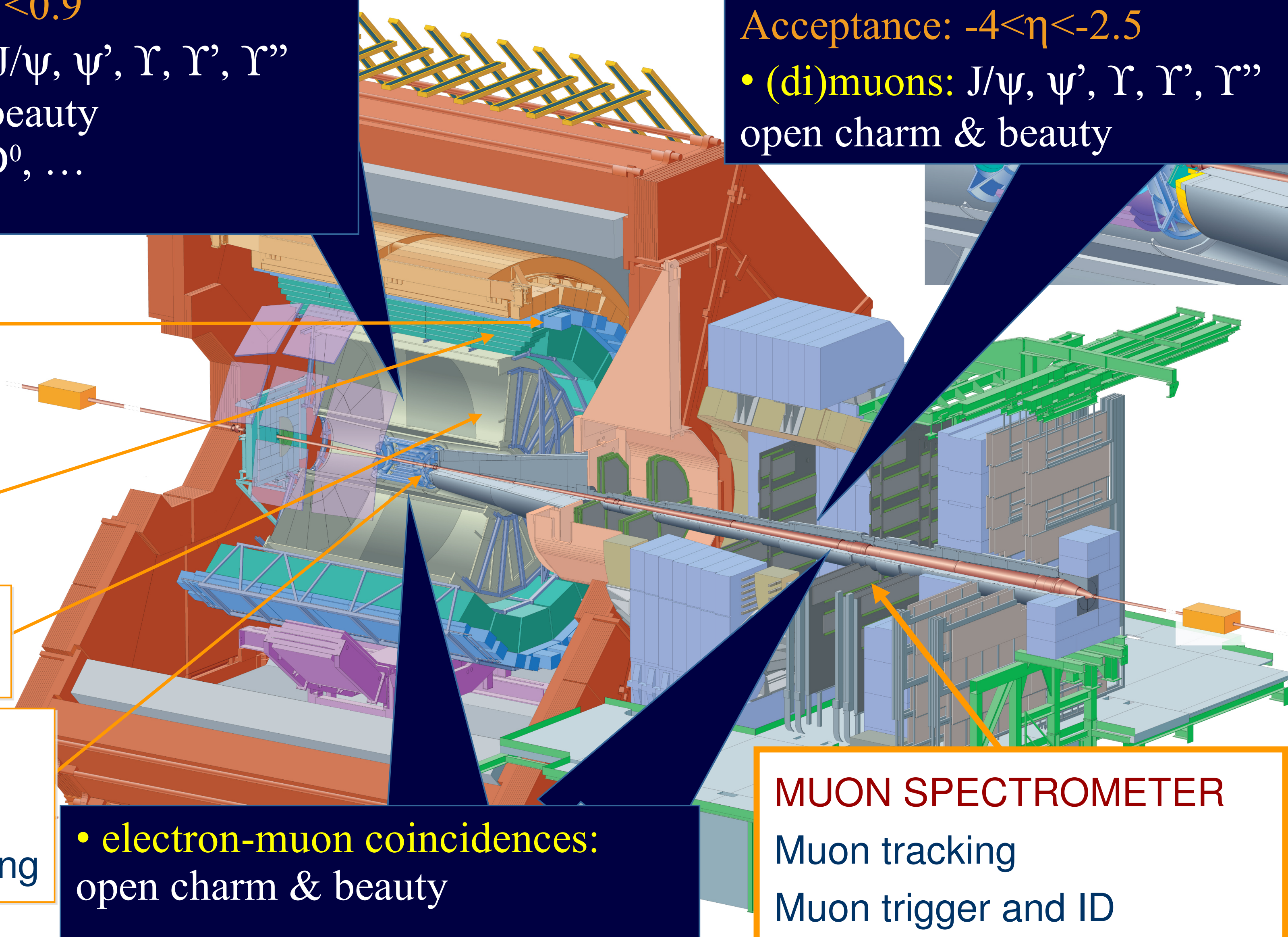


The ALICE detector

more details on H. Caines talk yesterday

Acceptance: |η| <0.9
- (di)electrons: J/ψ, ψ', ϒ, ϒ', ϒ" open charm & beauty
- hadrons: $D^{\pm}$, D^0, …

Acceptance: -4<η<-2.5
- (di)muons: J/ψ, ψ', ϒ, ϒ', ϒ" open charm & beauty



TOF
PID

TRD
Electron ID

TPC
Tracking, dE/dx

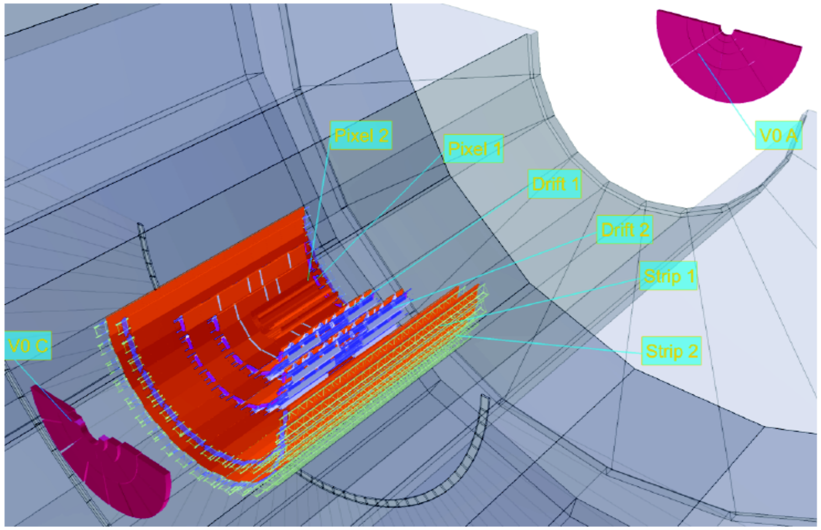
ITS
Vertexing,
Low p_t tracking

- electron-muon coincidences: open charm & beauty

MUON SPECTROMETER
Muon tracking
Muon trigger and ID

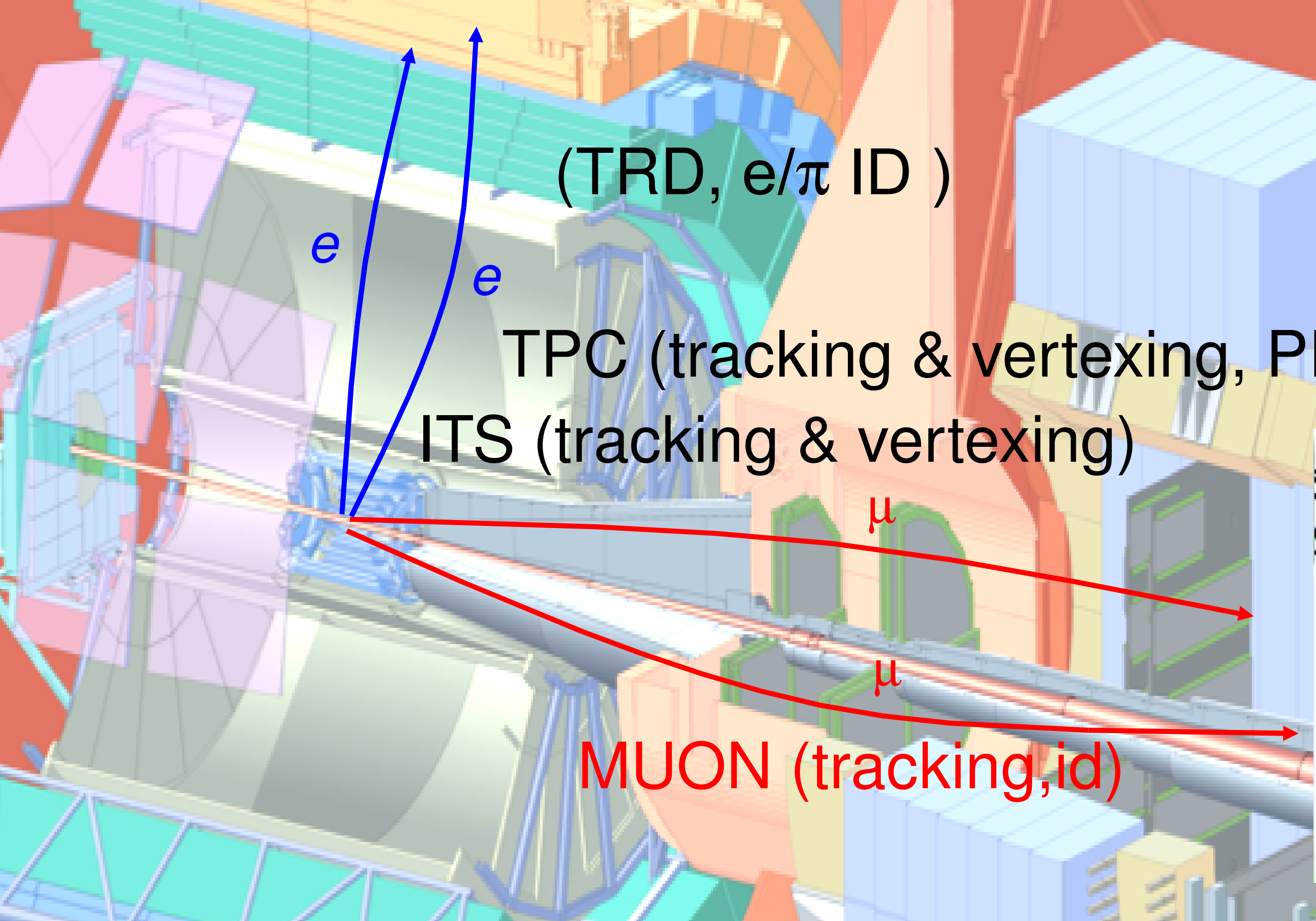
Trigger and Data sample

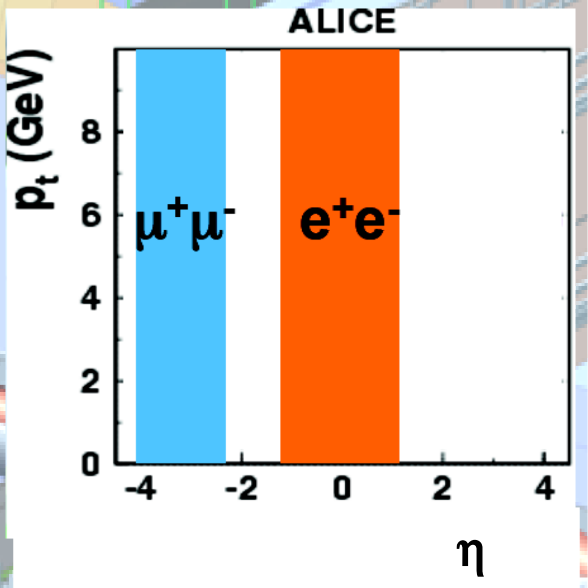
- "**Minimum bias**", based on interaction trigger:
  - SPD or V0-A or V0-C
    - at least one charged particle in 8 η units
    - ~95% of σ_{inel}
  - read out all ALICE
- **Single-muon trigger:**
  - forward muon in coincidence with Min Bias
  - read out MUON, SPD, V0, FMD, ZDC
- Both activated in coincidence with the BPTX beam pickups
- Since March 31st 2010, collected
  - ~8×10^8 minimum bias triggers
  - ~1.3×10^8 muon triggers



- Results presented on this talk based on:
  - ~10^8 minimum bias triggers
  - ~10^7 muon triggers

Quarkonia



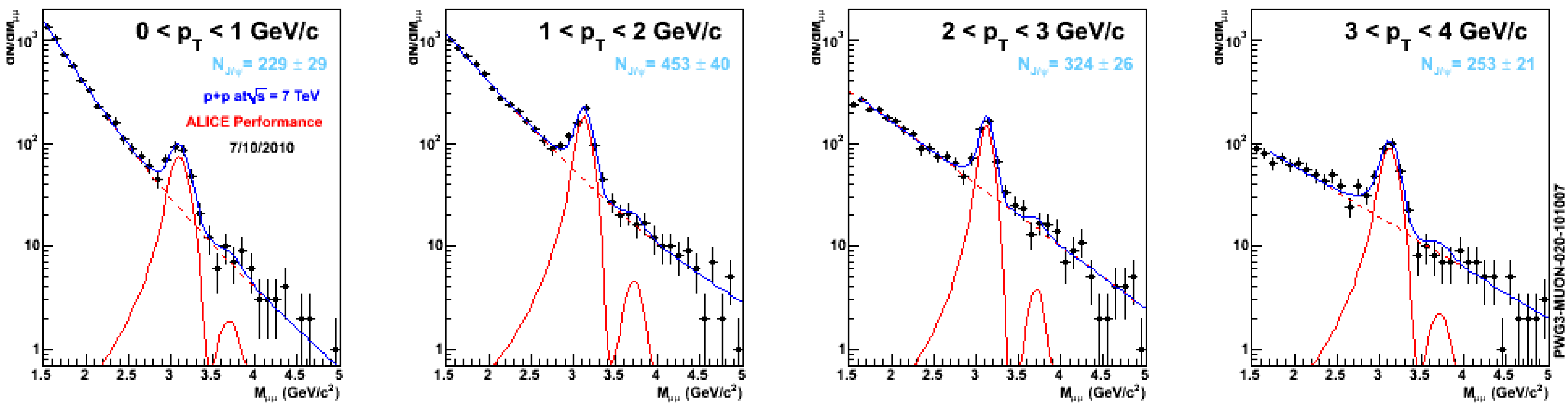


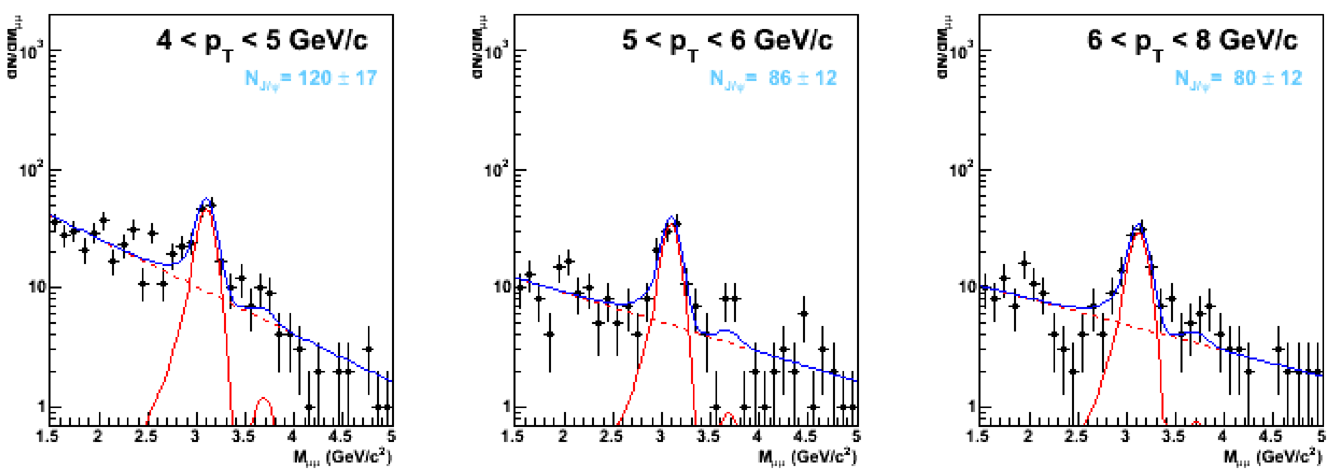
Measured both in the di-electron (midrapidity, TRD) and di-muon (forward rapidity, MUON) channel

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

Data sample: L = 11.6 nb-1

Differential distributions studied in 7 p_t-bins (0-8 GeV/c) and 5 y-bins (2.5 < y< 4)



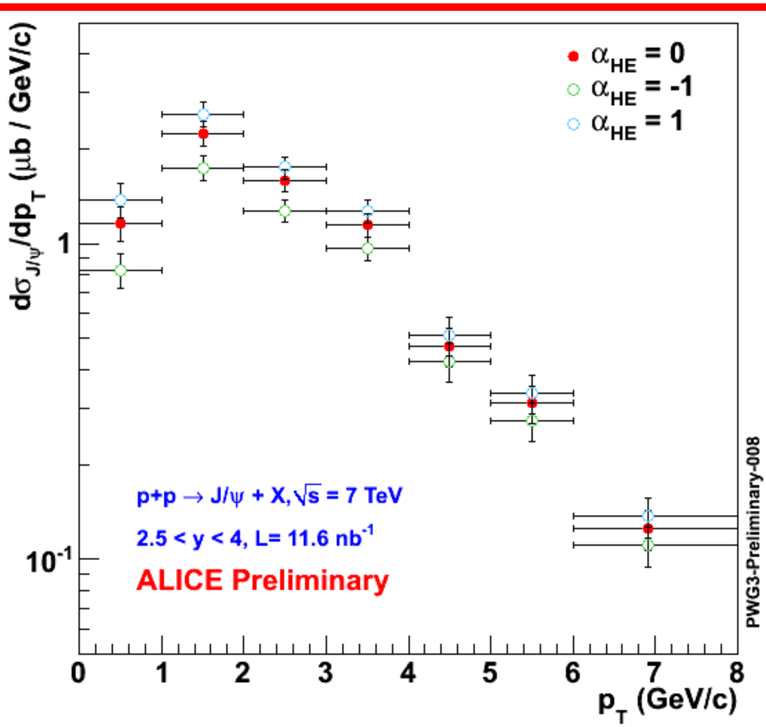


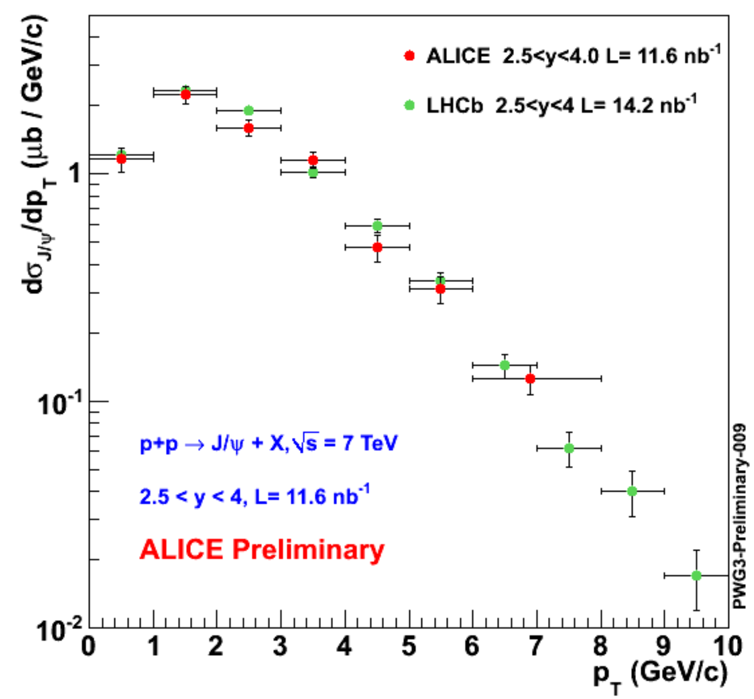
2 Crystal Ball fit functions
+ 2 exponential functions
for the background

J/ψ -> μ⁺μ⁻: Results

- Main systematic errors:
  - unknown polarization -> -21 +12% (from α=±1 in the helicity frame)
  - cross section normalization: 10%
- Integrated cross section:

$$\sigma_{J/\psi}(2.5<y<4)=7.25\pm0.29(stat.)\pm0.98(syst.)^{+0.87}_{-1.50}(syst.\ pol.)\mu b$$





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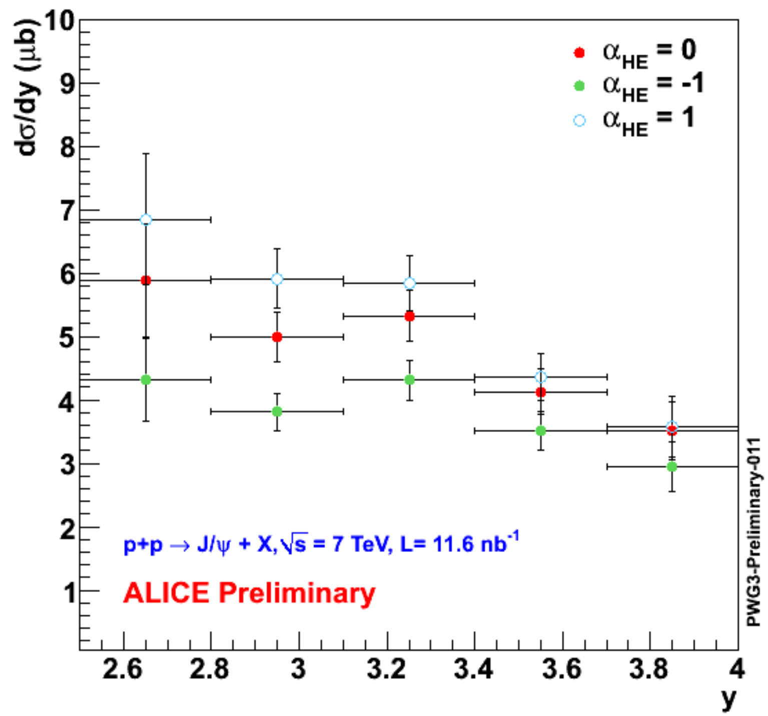
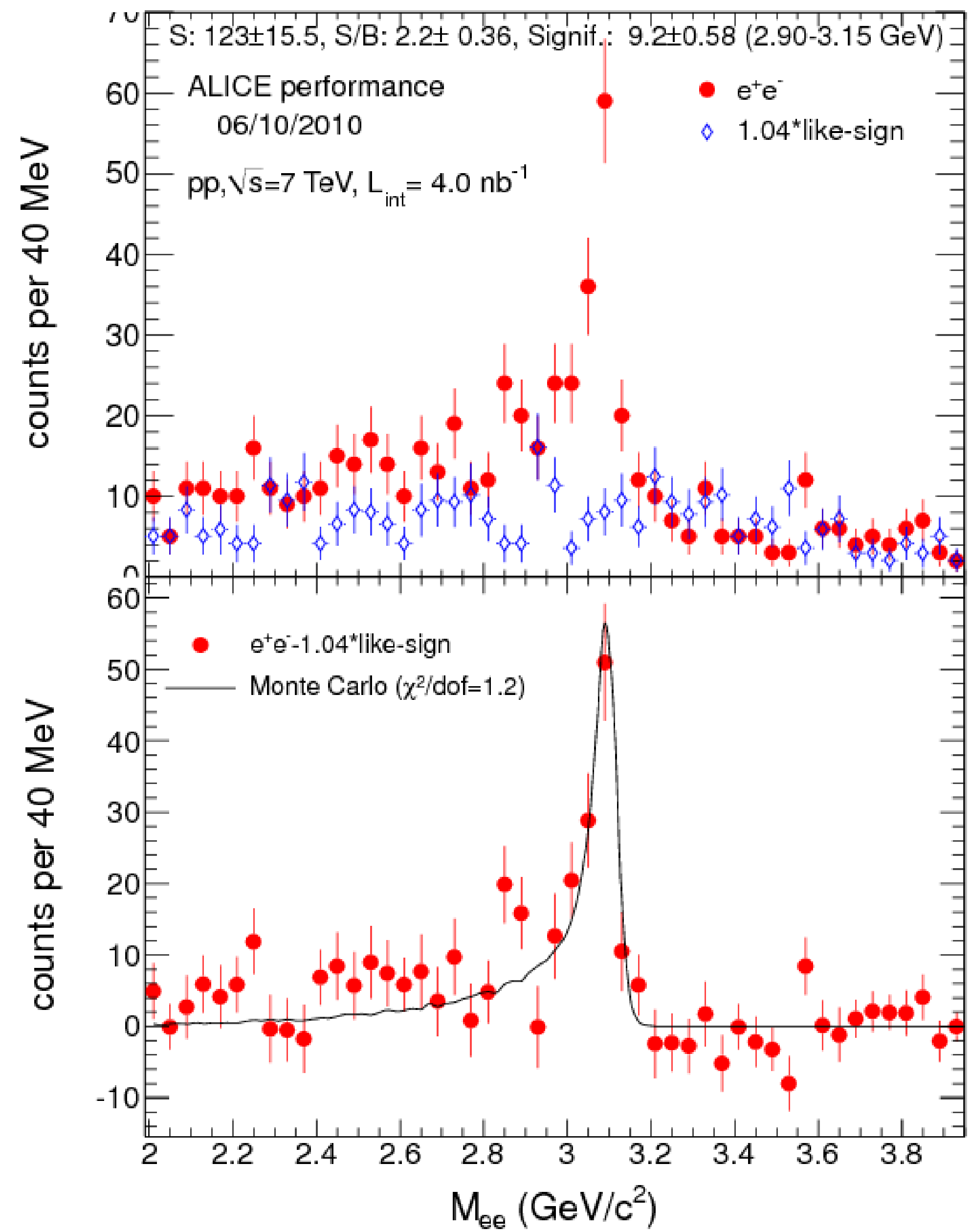


J/ψ ->e^+e^-: *Analysis*

- High quality tracks in TPC and ITS
  - point in pixels to reduce γ conversions
- e PID from TPC dE/dx
  - next: exploit TOF, TRD
- Inclusive J/ψ:
  - No correction for B feed-down
- Data sample
  - ~ $3 \cdot 10^8$ min. bias ev. -> L~4.0 nb^{-1}
- Signal extraction:
  - bin counting after like-sign back. subtraction ($N_{J/\psi}$=123±15)



$J/\psi \to e^+e^-$: Results

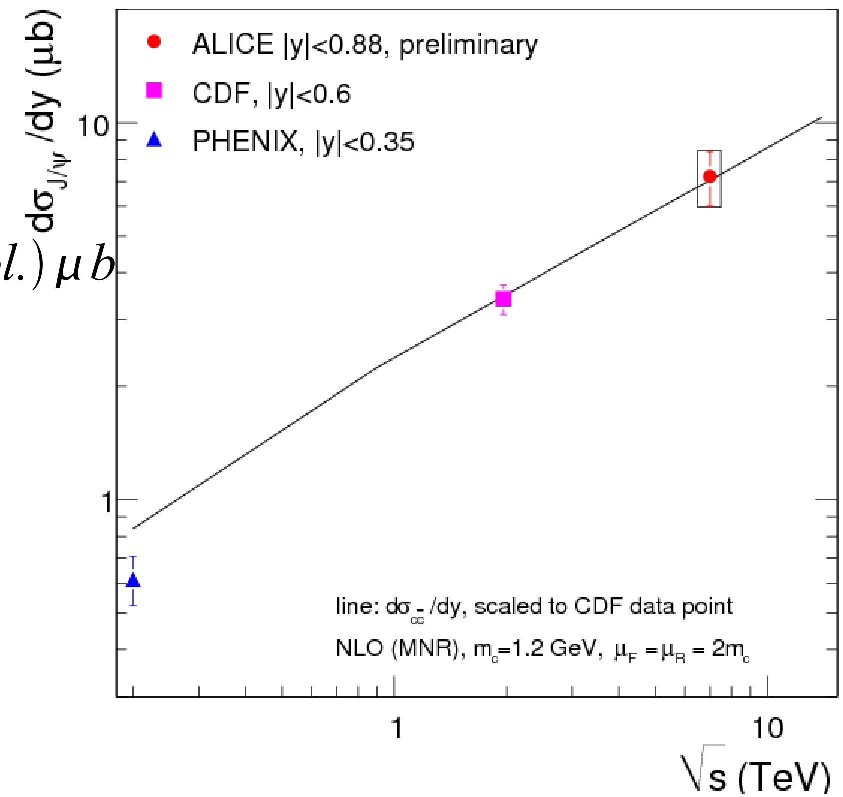
p_t-integrated cross-section

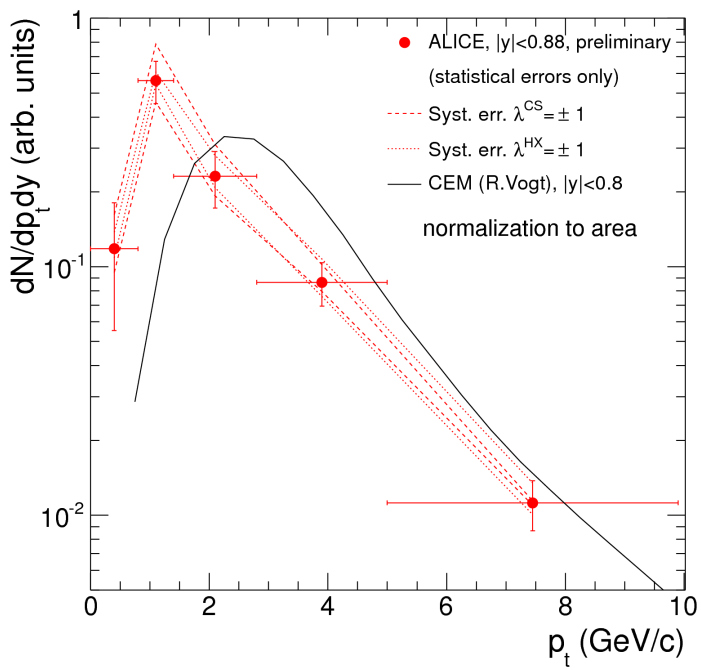
(10^8 events from a well calibrated sample)

$$\left.\frac{d\sigma_{J/\psi}}{d\,y}\right|_{|y|<0.88} = 7.36 \pm 1.22\,(stat.) \pm 1.32\,(syst.)^{+0.88}_{-1.84}\,(syst.\ pol.)\,\mu b$$

Systematic errors:

- 14.5 % from efficiency corrections (tracking, PID)
- 10% normalization
- -25% + 10% polarization



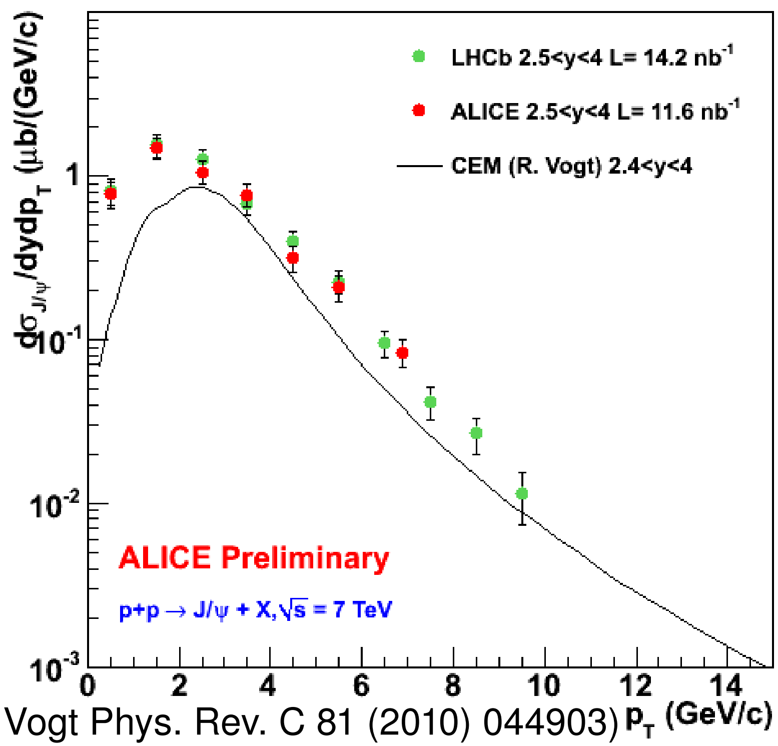


dN/dp_t from a larger sample (~300M events) with partial calibration

- shape compared to theory
- $d\sigma/dp_t$ down to p_t=0 coming soon

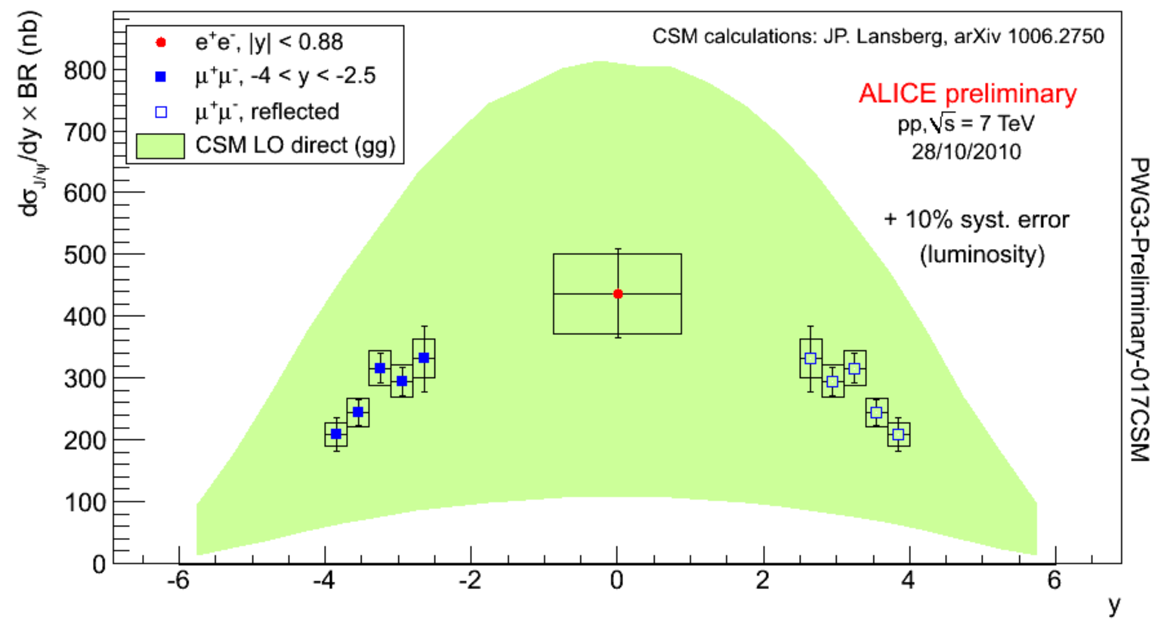
J/ψ: comparison with predictions

dσ/dp$_t$ at forward rapidity



(R.Vogt Phys. Rev. C 81 (2010) 044903)

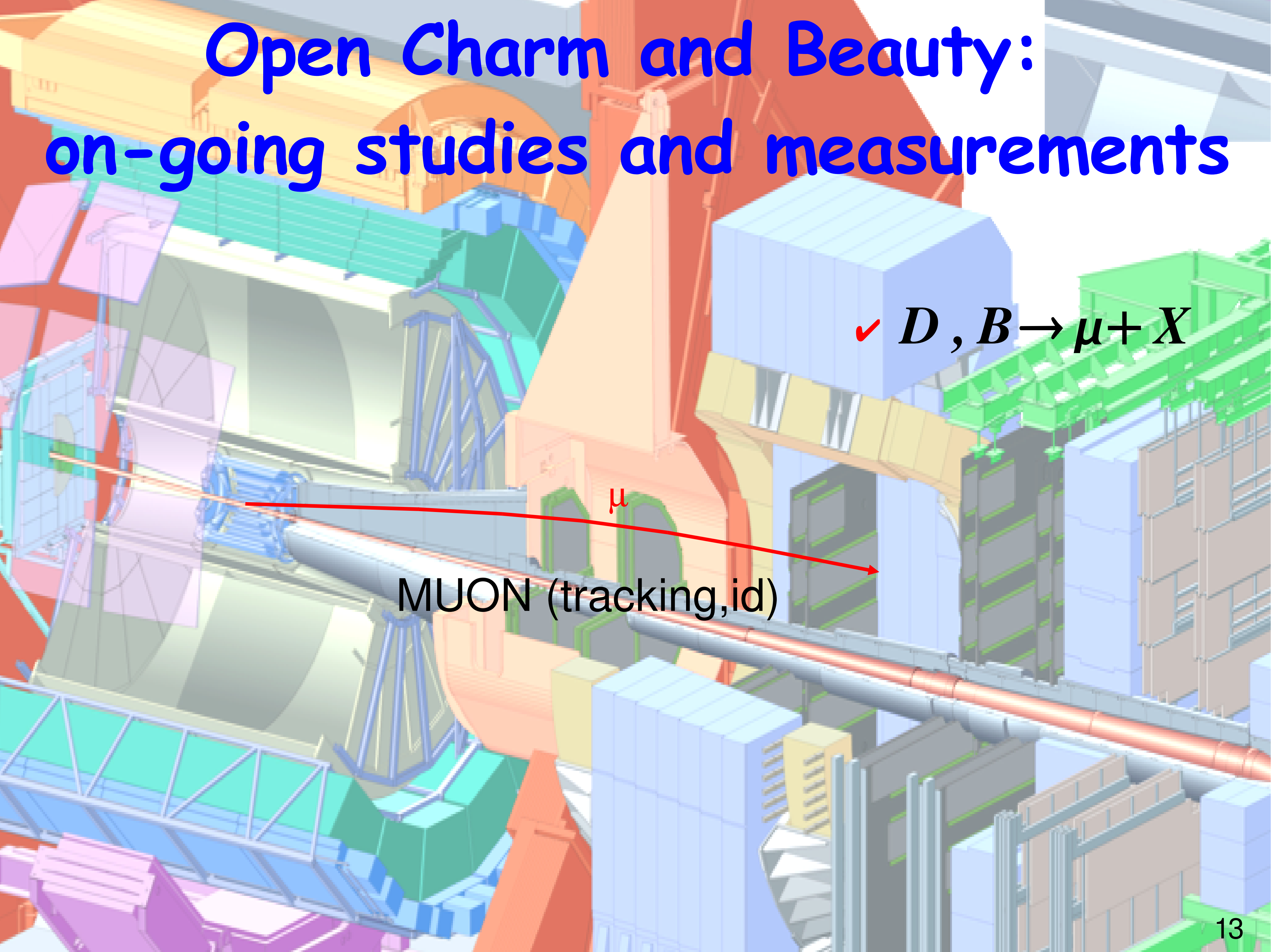
dσ/dy in -4 <y <0.9 rapidity range



Next step for J/ψ analsis:

- Measure polarization
- Extend high p$_t$ coverage
- Measure ψ' at forward rapidity

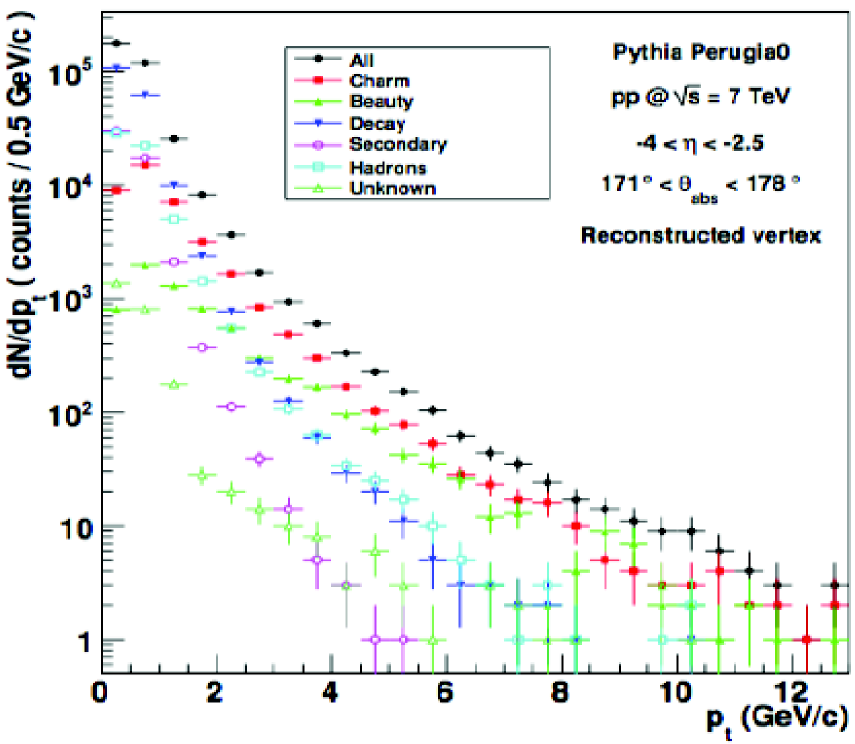
Open Charm and Beauty: on-going studies and measurements

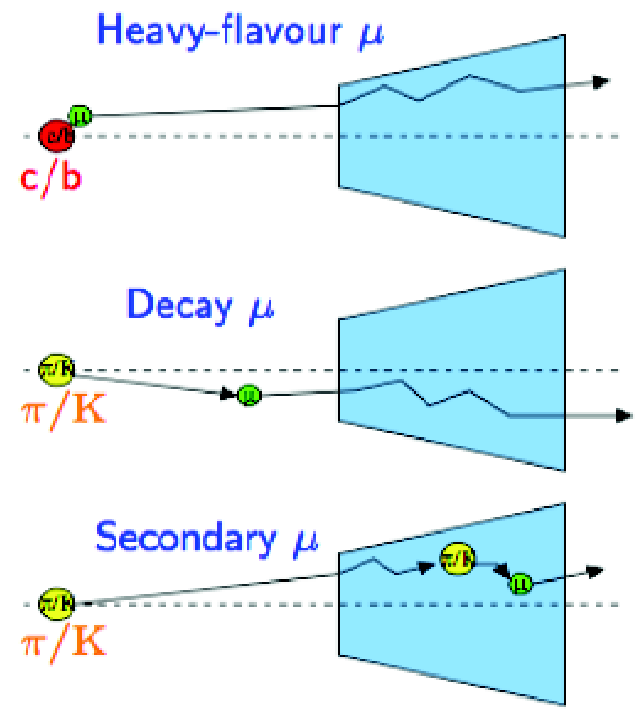


✔ $D, B \rightarrow \mu + X$

Forward single Muons from HF: analysis

Muon sources:

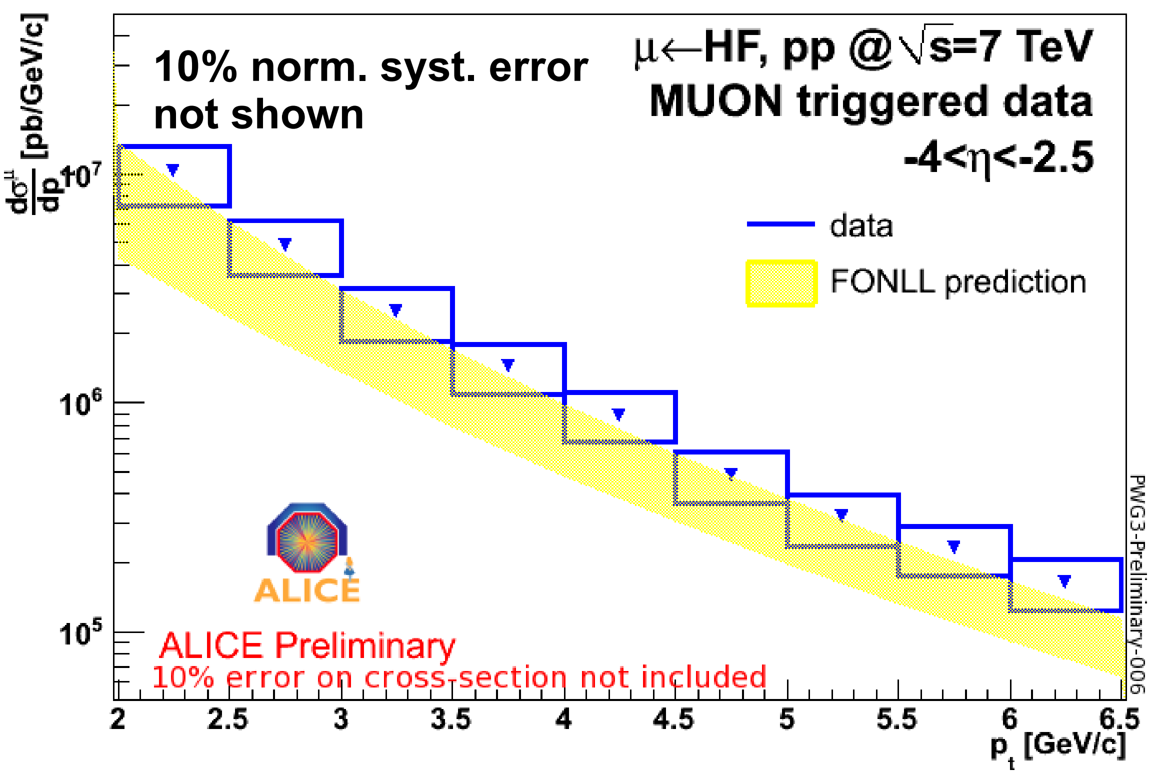




- remove hadrons and low-pt secondaries by requiring a muon trigger signal
- remove decay muons by subtracting MC dN/dp_t normalized to data at low pt
  - ✓ alternative method: use muon distance of closest approach to the primary vertex
- what is left are muons from charm and beauty
- apply corrections for efficiencies

Forward single Muons from HF: results

- $d\sigma/dp_t$ for D and B decay muons in the range $2 < p_t < 6.5$ GeV/c
- Data agree with FONLL prediction in shape and normalization



Most delicate step:

Subtraction of residual secondary and decay muons from π,K (30% to 20% syst. error from low to high p_t)

Next

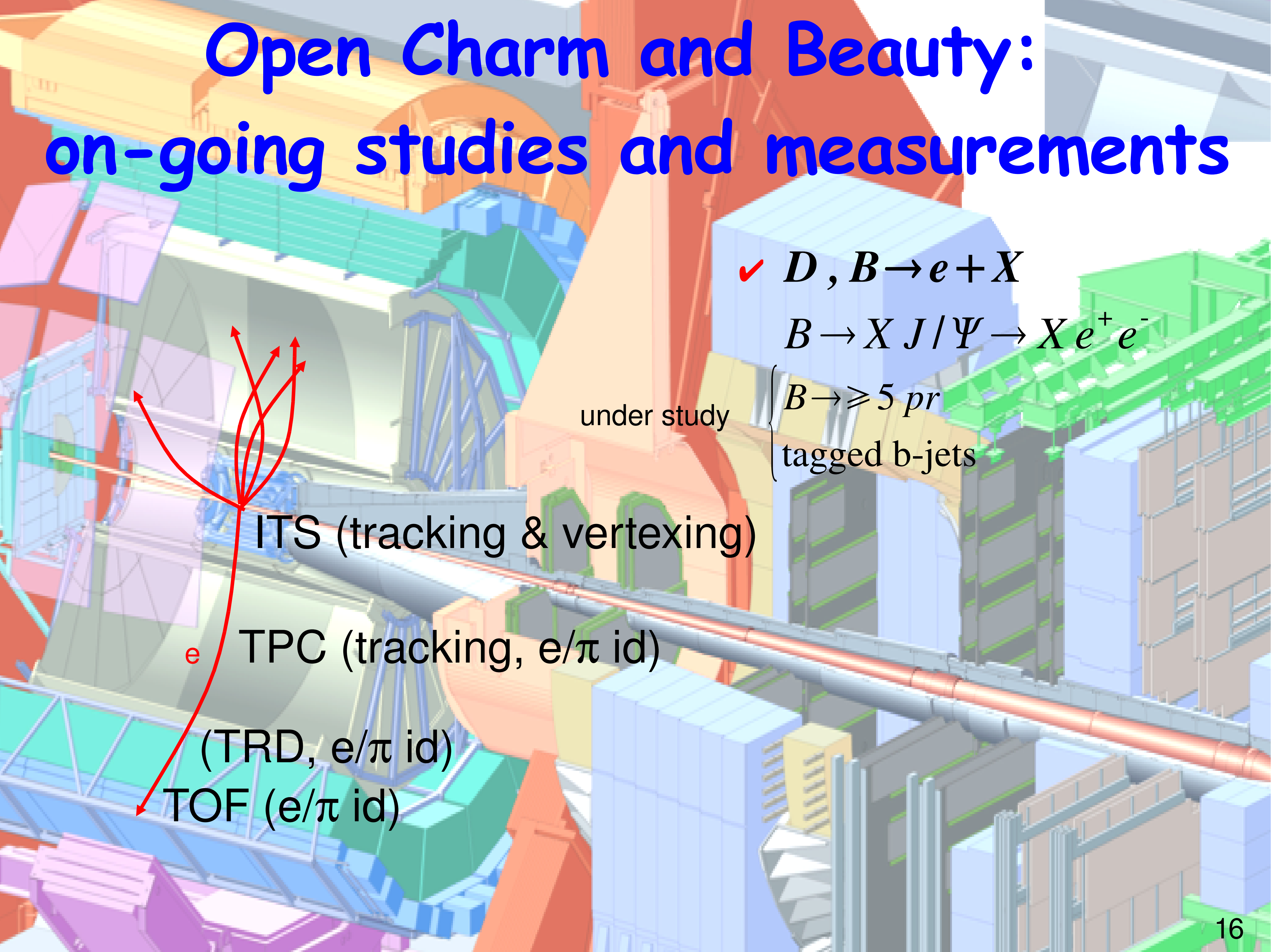
- Use DCA to reduce syst. error due to background subtraction
- Improved spectrometer alignment already deployed -> extend to higher p_t
- D and B separation by fitting with pQCD shapes

Open Charm and Beauty: on-going studies and measurements

✔ $D, B \rightarrow e + X$

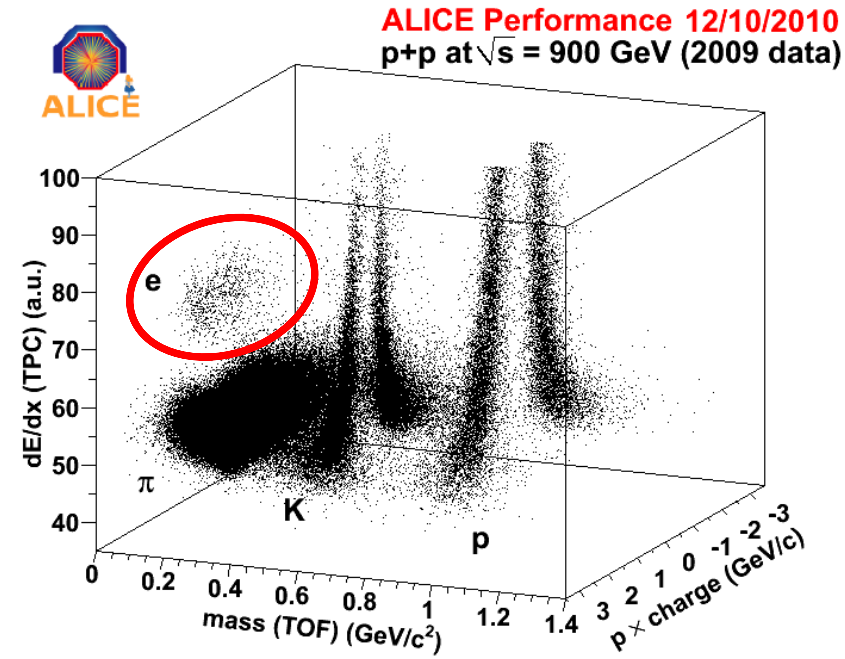
$B \rightarrow X\, J/\Psi \rightarrow X\, e^{+} e^{-}$

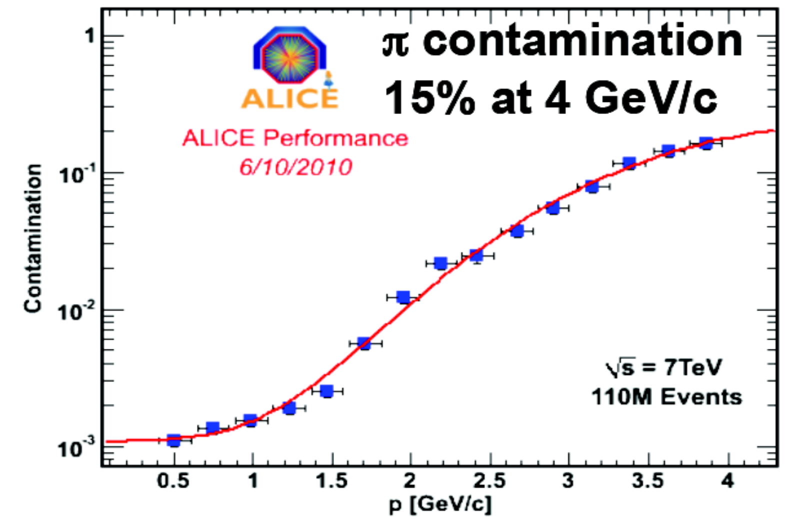
under study:
- $B \rightarrow \geqslant 5\ pr$
- tagged b-jets



Single Electrons: analysis

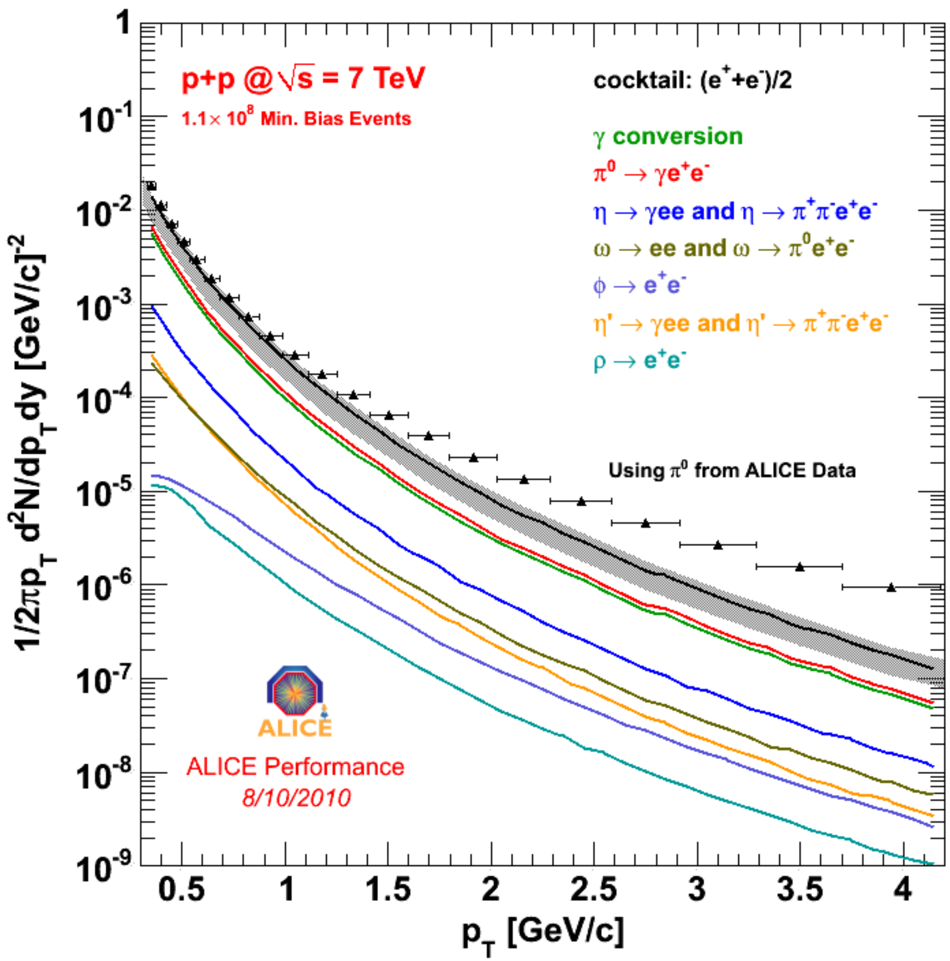
- High quality tracks in TPC+ITS
  - Hit in the innermost ITS layer to reduce γ–conversions (beam pipe + ~1/3 in the first SPD layer, 0.5% X_0)
- Electron identification: TOF + TPC-dE/dx
  - TOF rejects K (<1.5 GeV/c) and protons (<2 GeV/c)
  - TPC: asymmetric cut around electron Bethe-Bloch
    - measure π contamination by fitting the dE/dx with a double Gaussian
- Two procedures to get HF electrons spectrum:
  - subtract "cocktail" of photonic electron sources (à la RHIC, *next slide*)
  - cut on impact parameter w.r.t. primary vertex to pick out electrons from B (i*n progress*)





Single Electrons: performance results

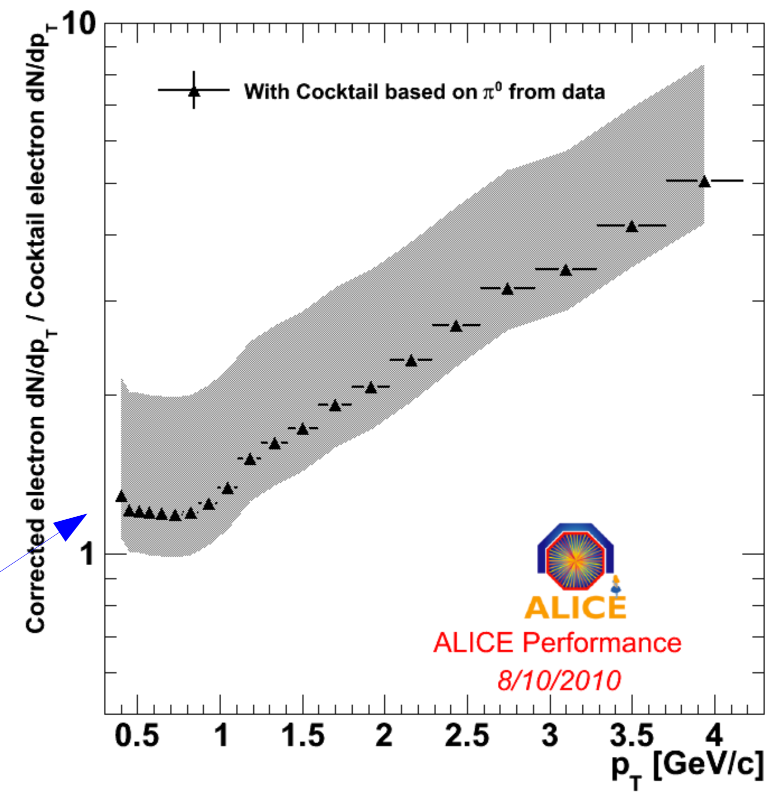
dN/dp_t in $0.4 < p_t < 4$ GeV/c



Spectrum corrected for:

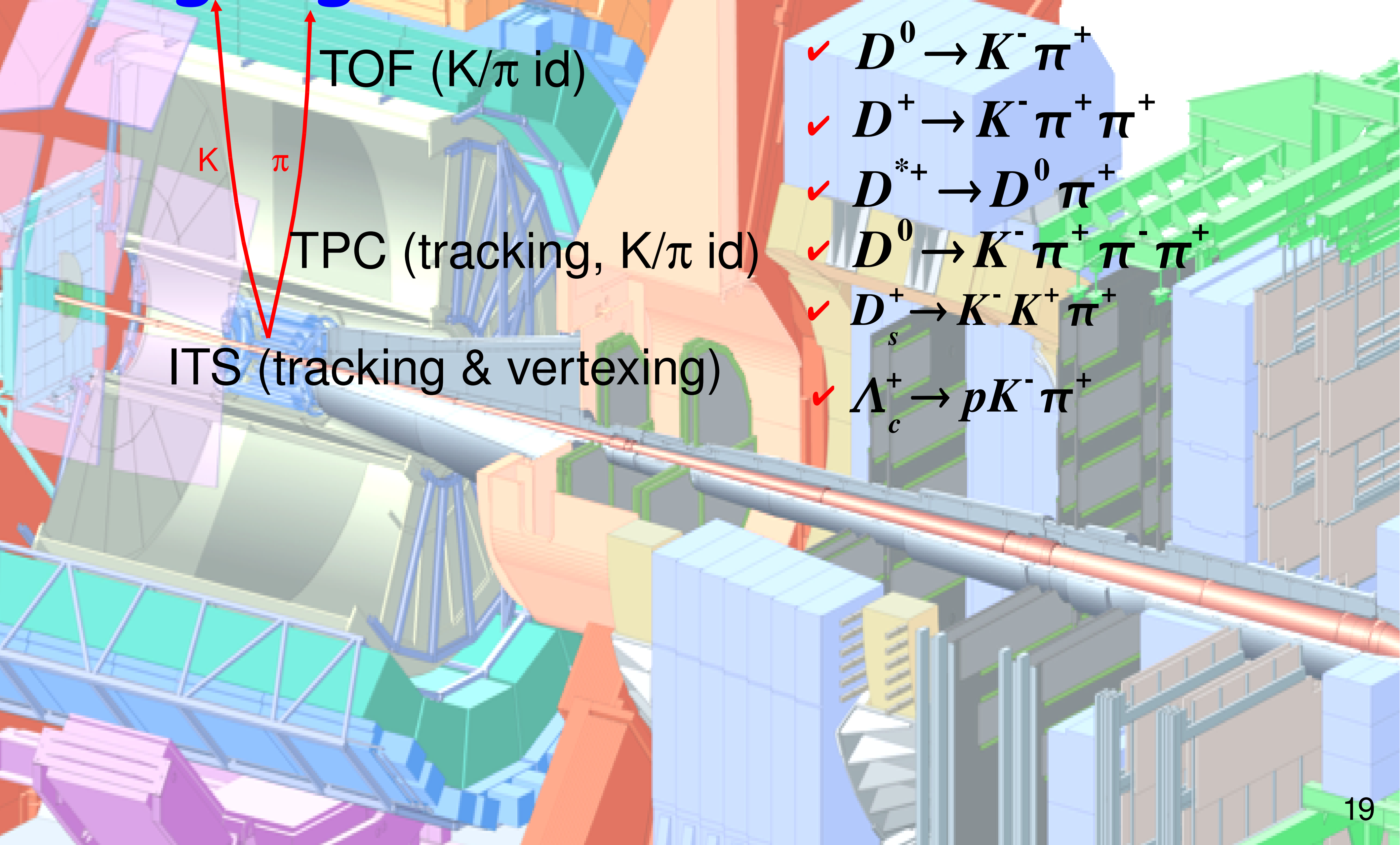
- residual hadron contamination (subtracted)
- efficiency and acceptance (from MC)
- p_t unfolding for e^- bremsstrahlung

Cocktail based on π^0 cross-section measured from double γ conversion reconstruction



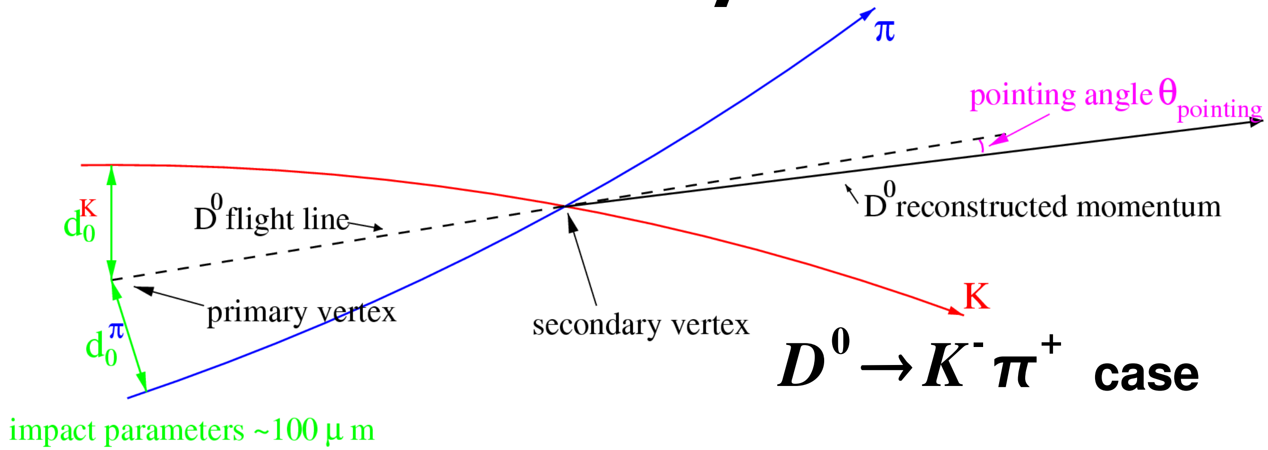
Large signal from D and B decay electrons in ratio to cocktail

Open Charm and Beauty: on-going studies and measurements



- ✔ $D^0 \rightarrow K^- \pi^+$
- ✔ $D^+ \rightarrow K^- \pi^+ \pi^+$
- ✔ $D^{*+} \rightarrow D^0 \pi^+$
- ✔ $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$
- ✔ $D_s^+ \rightarrow K^- K^+ \pi^+$
- ✔ $\Lambda_c^+ \rightarrow p K^- \pi^+$

D mesons: analysis strategy

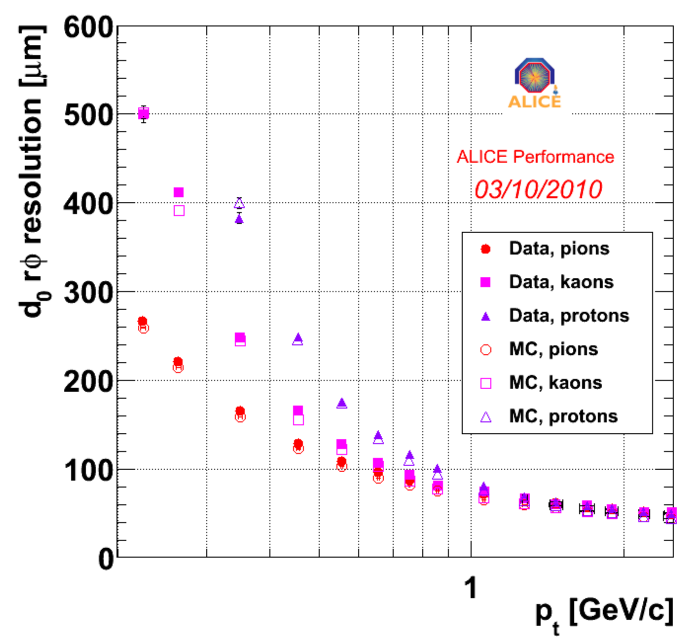


$D^0 \rightarrow K^- \pi^+$ **case**

Main selection strategy

Displaced secondary vertices topology (-> ITS)

- (e.g. $D^0 \rightarrow K^- \pi^+$) : pair of opposite charge tracks with large impact parameters
- good pointing of reconstructed D momentum to the primary vertex
  - ➔ Tracking and vertexing performance is crucial!



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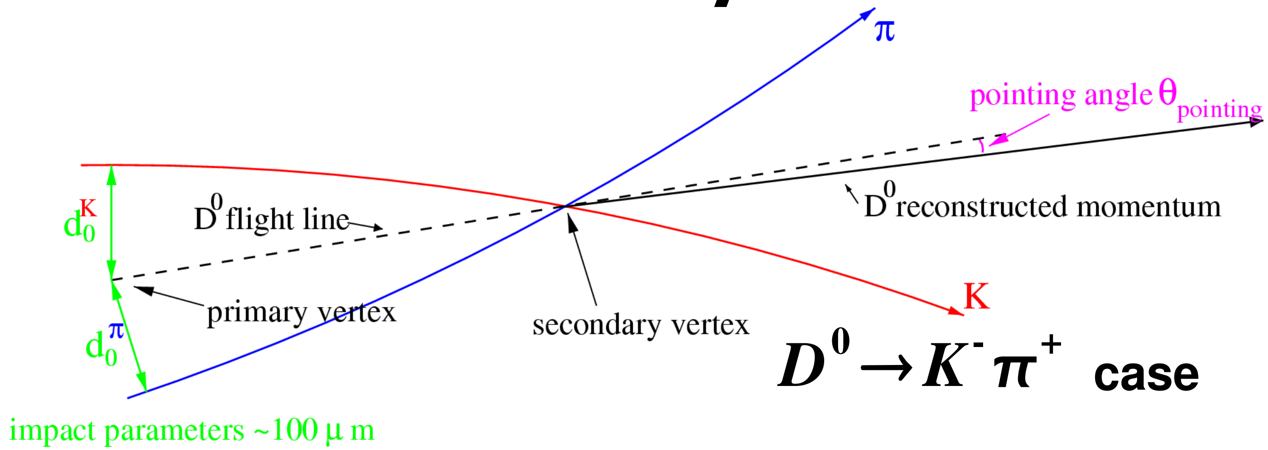

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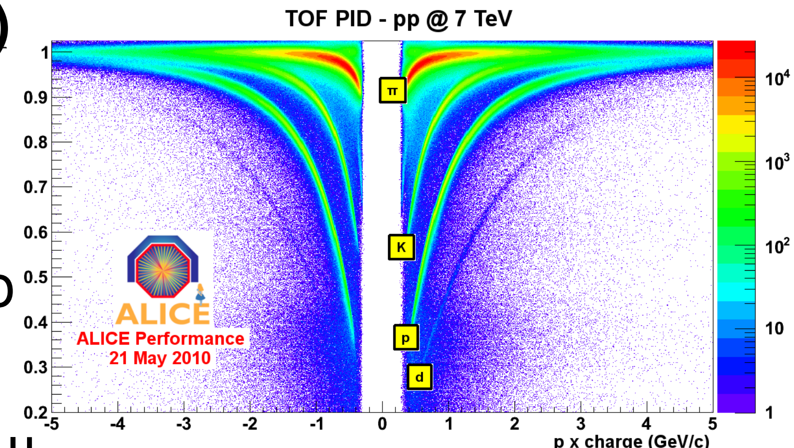
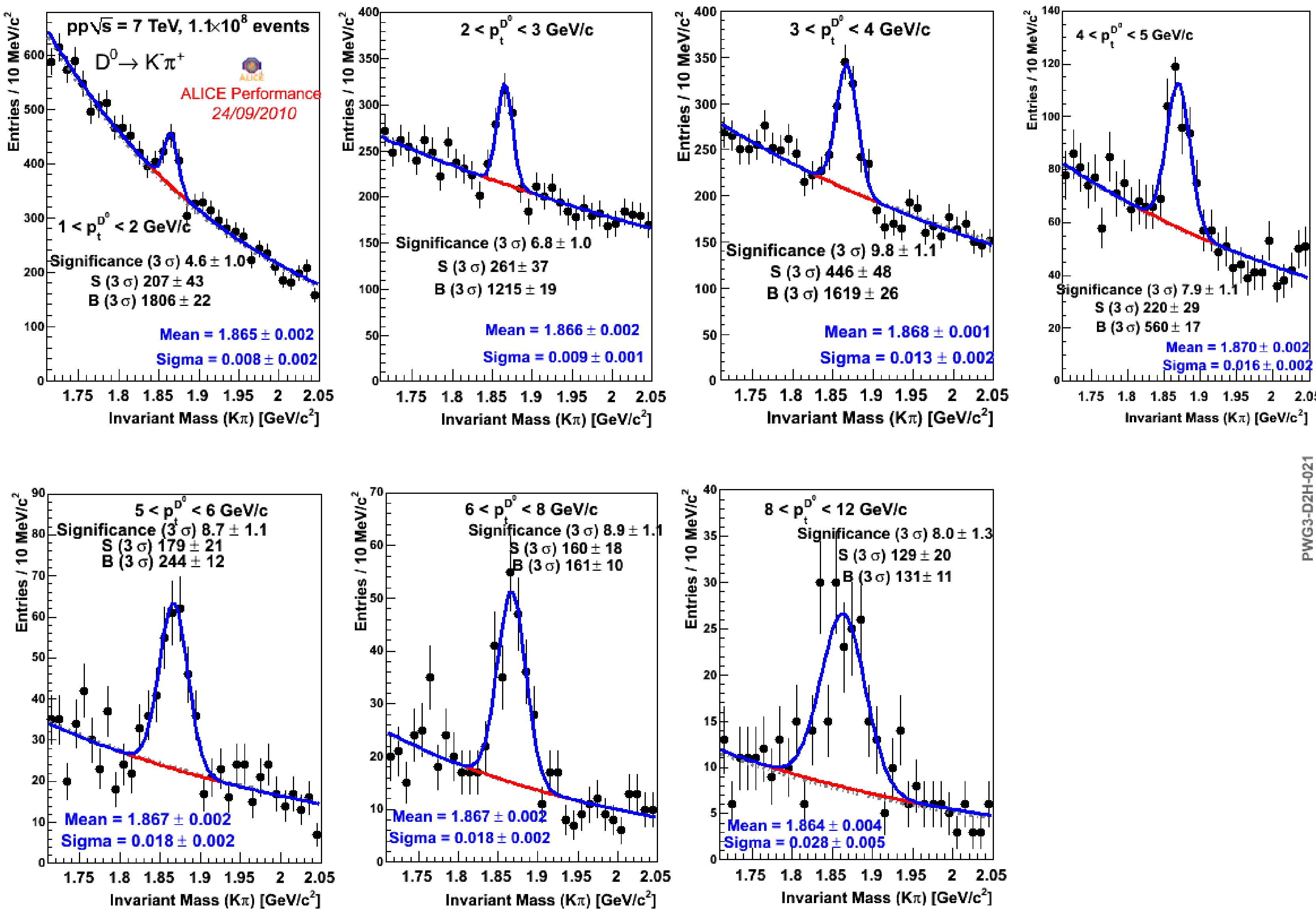


PID selection (TOF+TPC) to reduce background (mainly via K identification)

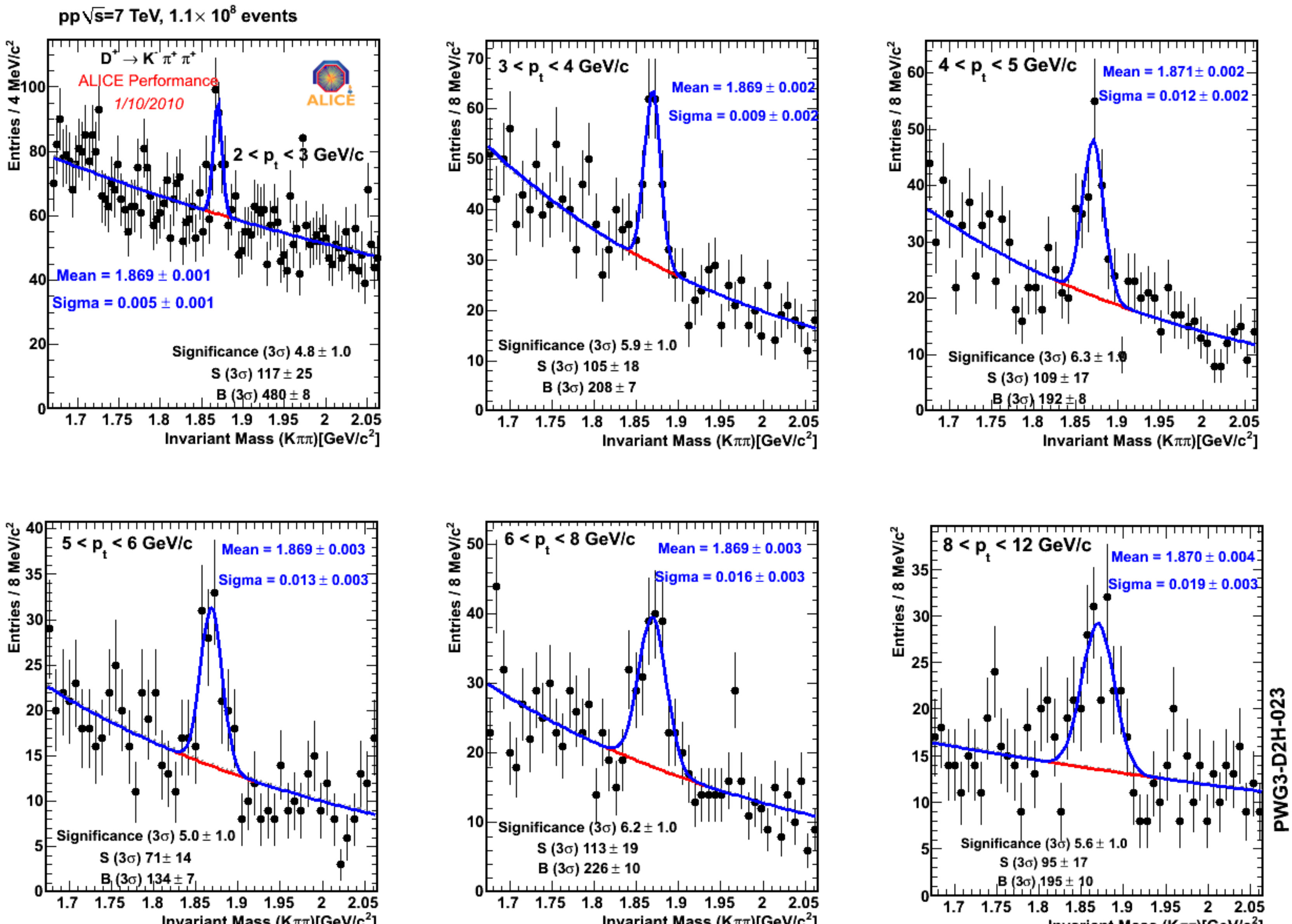
D meson signals: $D^0 \to K^- \pi^+$

~10^8 events, 1- 12 GeV/c (7 bins)



D meson signals: $D^+ \rightarrow K^- \pi^+ \pi^+$

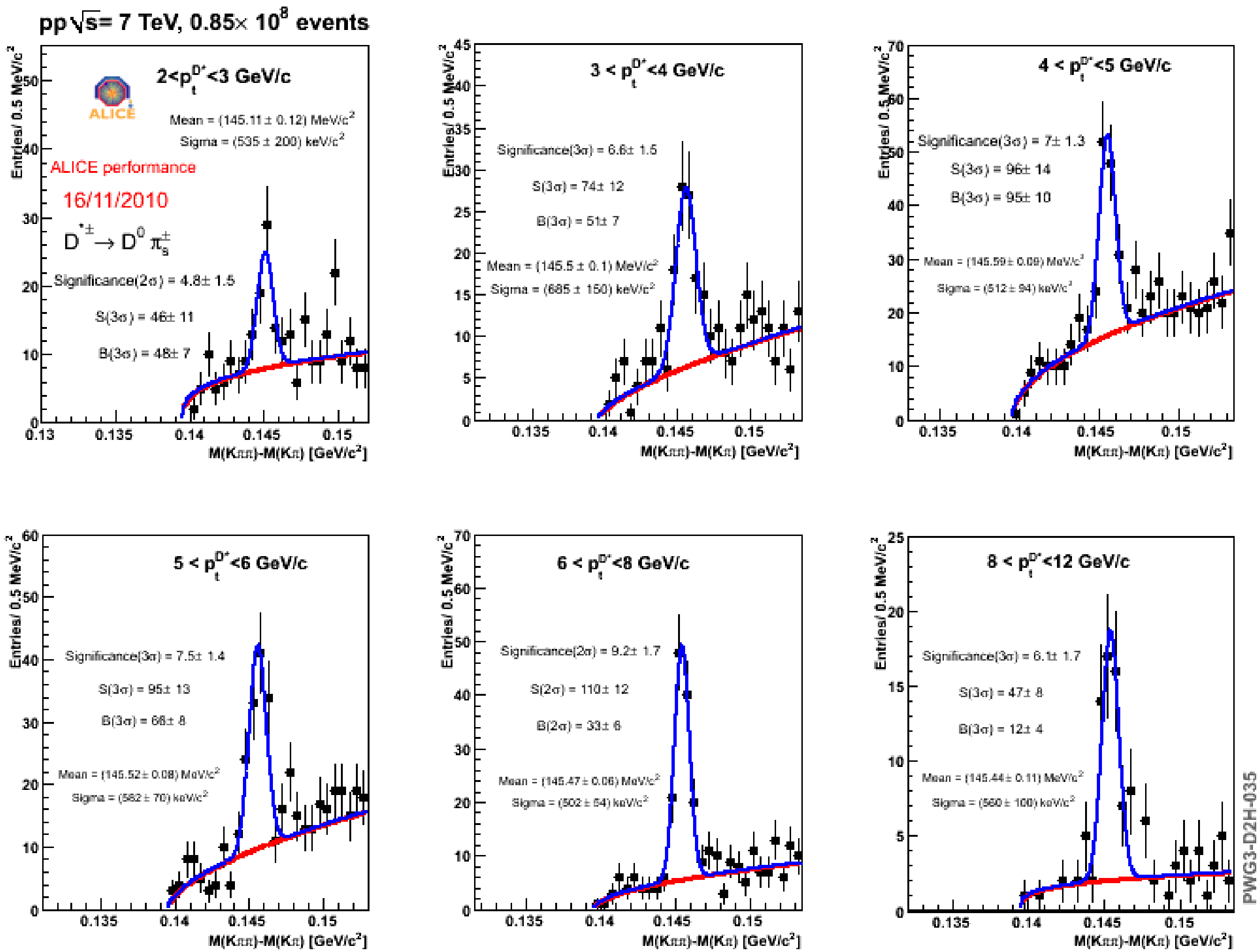
~10^8 events, 2- 12 GeV/c (6 bins)



D meson signals: $D^{*+} \rightarrow D^0 \pi^+$

~1.4·10^8 events, 2-18 GeV/c (5 bins)

ITS standalone tracking crucial for the low-p_t D^{*+} bins

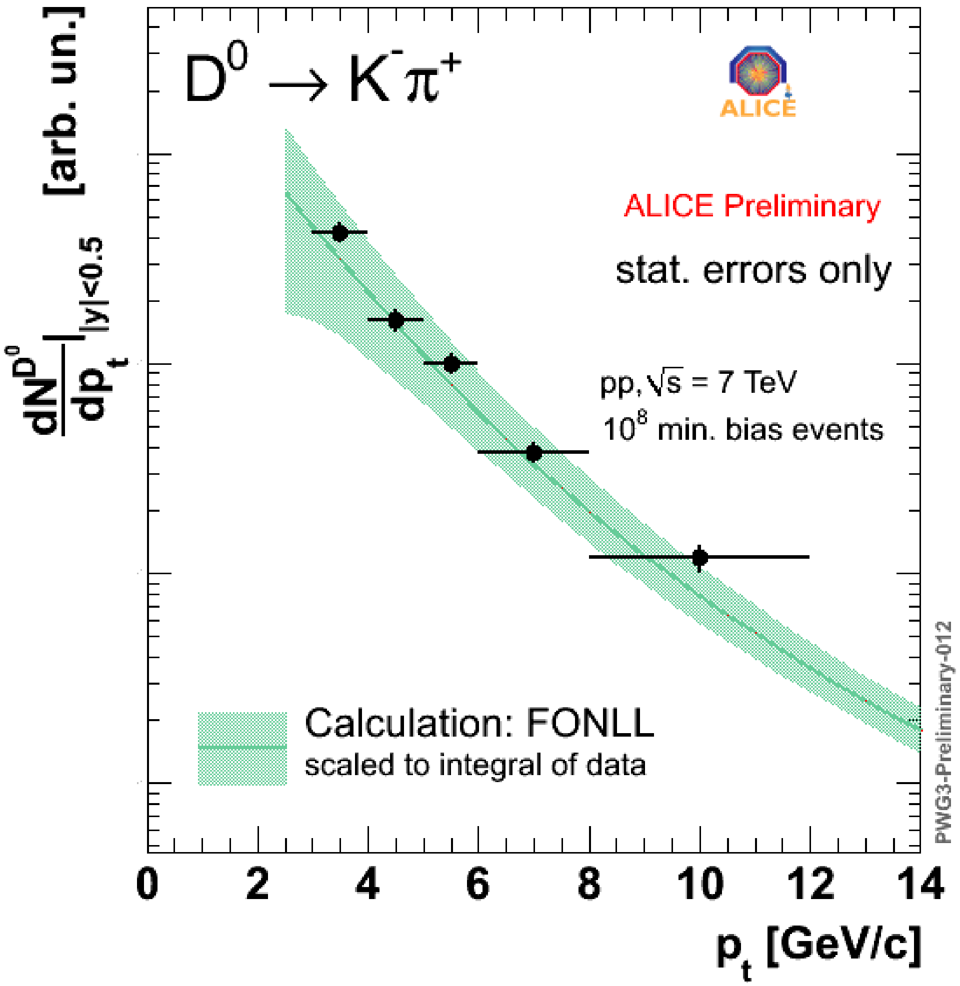


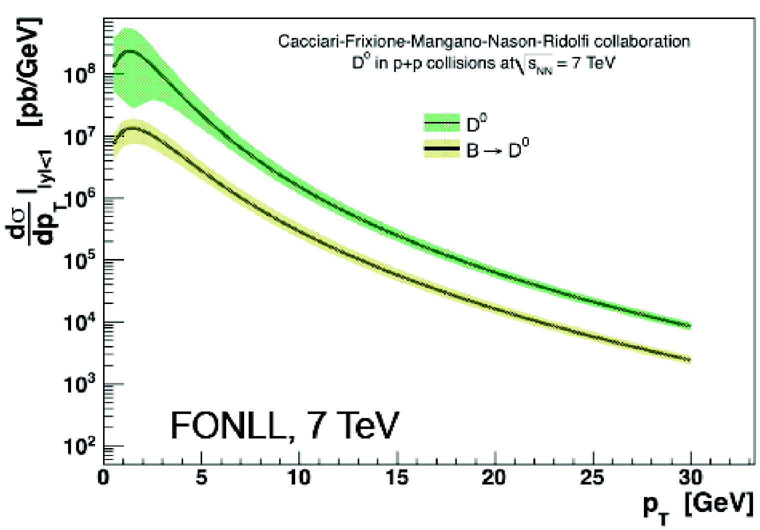
D mesons: corrected spectra

dN/dp$_t$ spectra in |y|< 0.5 corrected for:

- MC efficiency and acceptance
- B feed-down (from 15% to 25%)
  - presently subtracted using FONLL predictions
  - next: extract from data exploiting D meson impact parameter distribution (à la CDF)

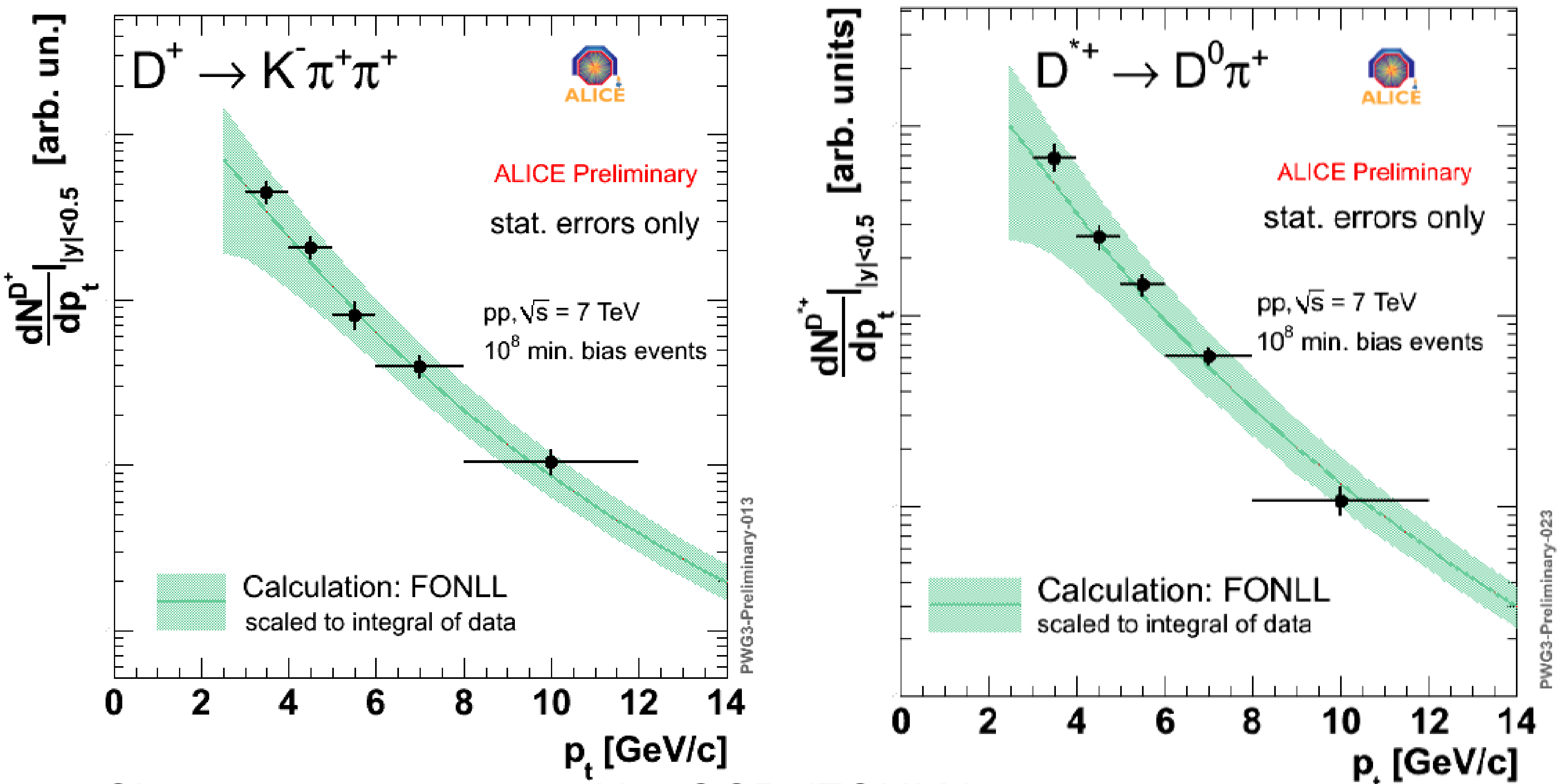
Statistical errors only





D mesons: corrected spectra

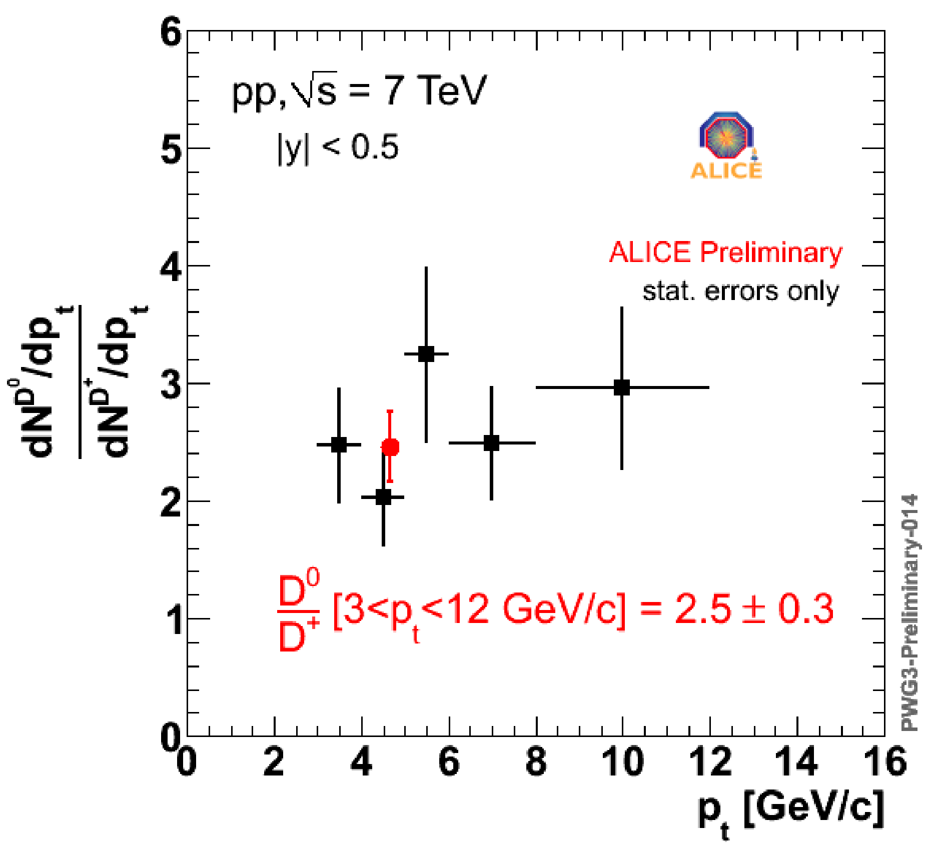
dN/dp_t spectra in $|y|< 0.5$ statistical errors only

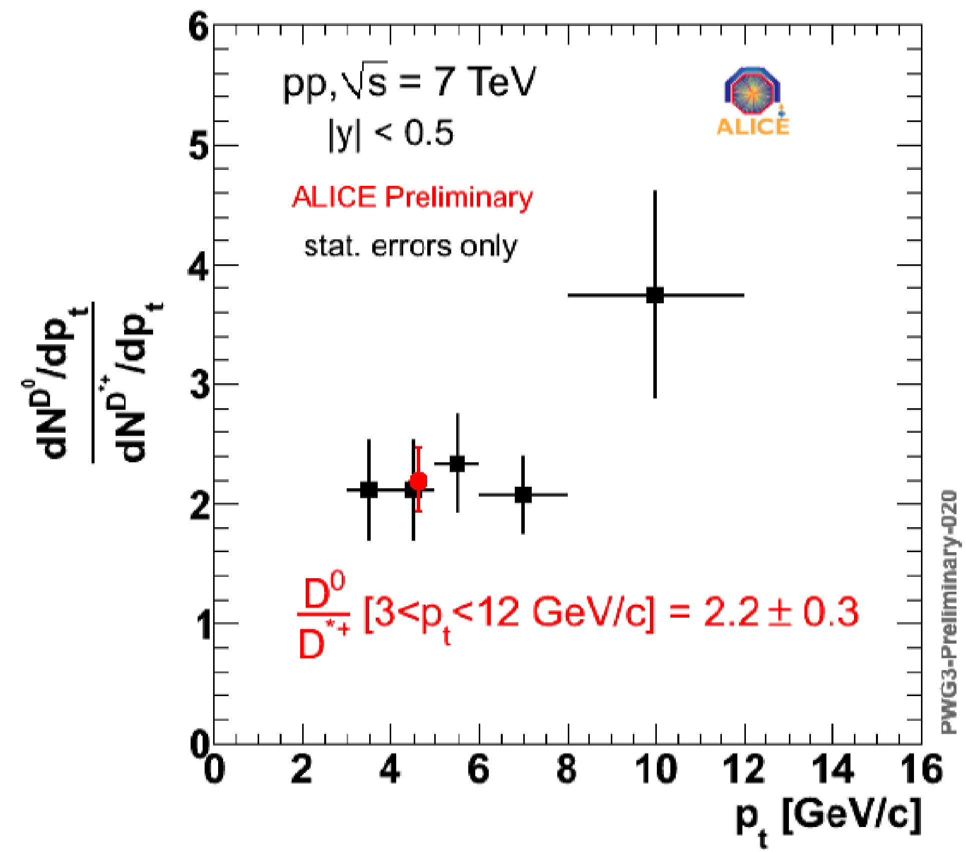


Shape compares well with pQCD (FONLL)

Ongoing: extension at lower and higher p_t and absolute normalization

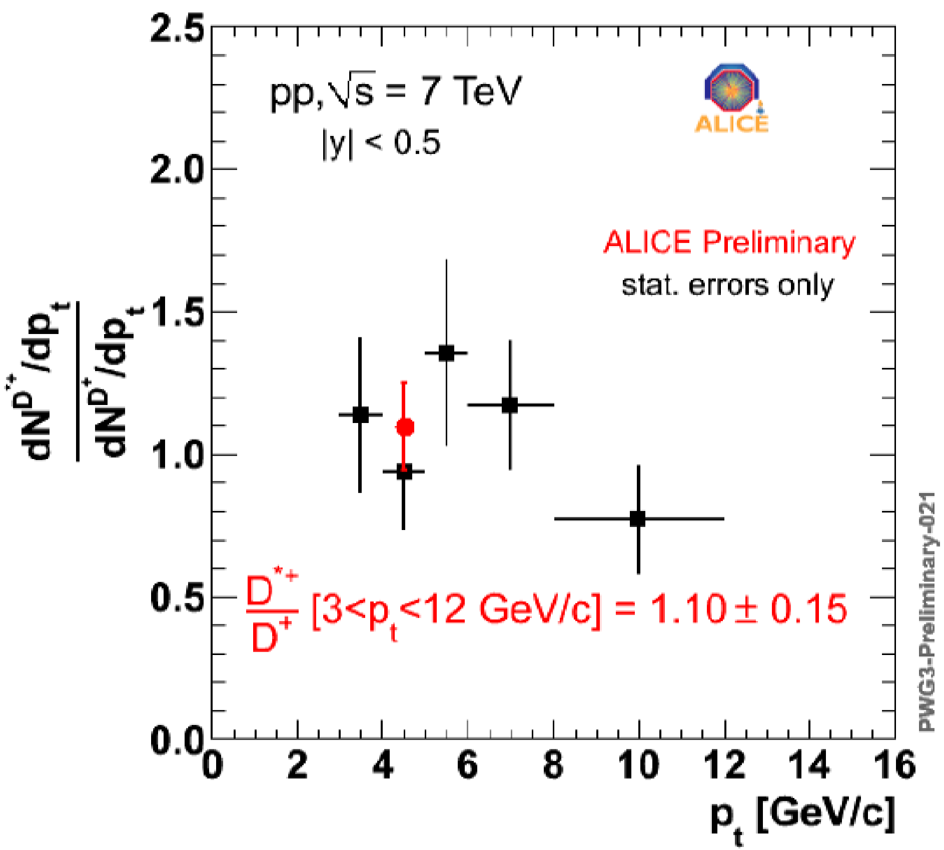
D meson ratios

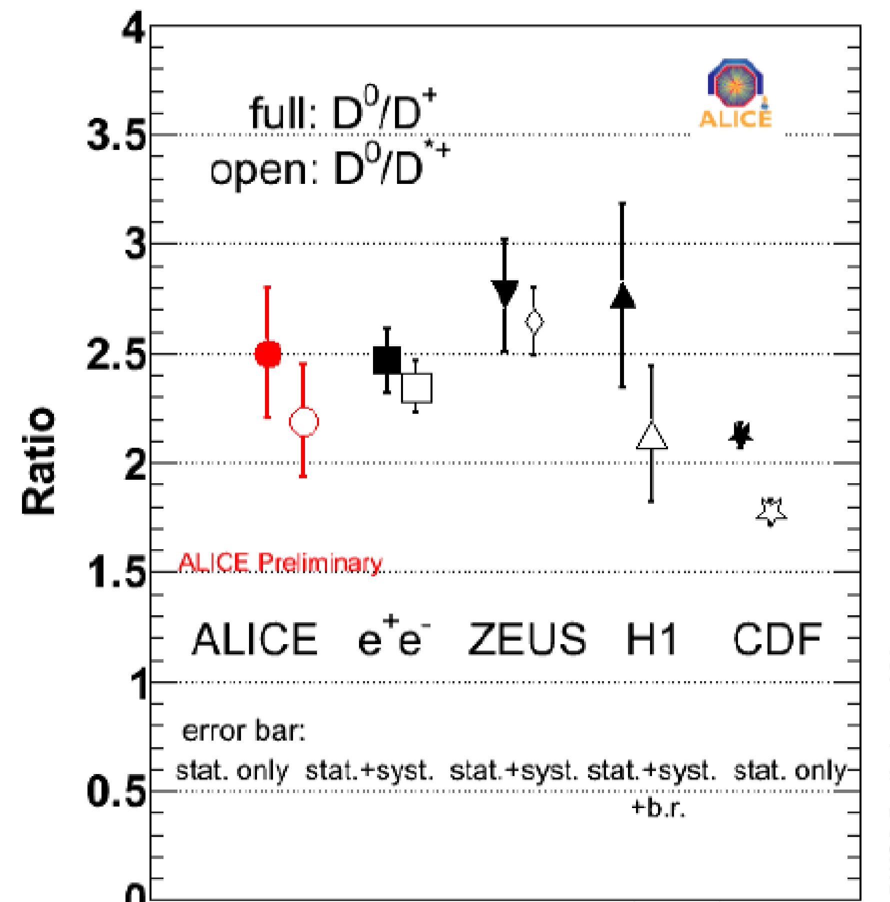




- p_t independent in the range 3-10 GeV/c

D meson ratios





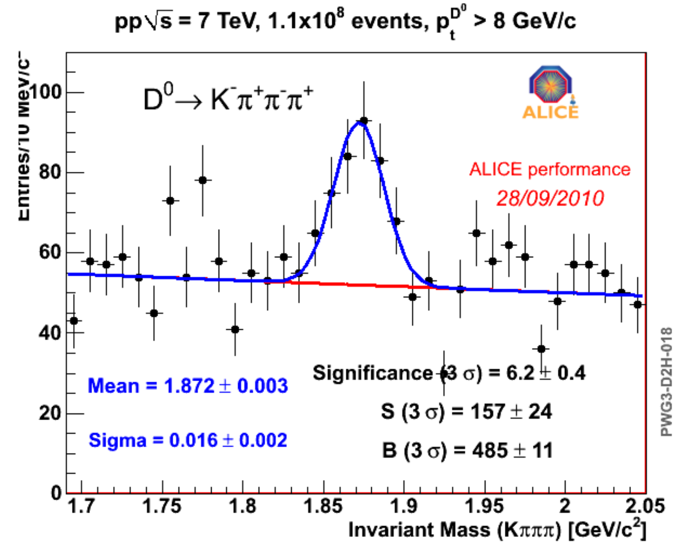
ee, H1, ZEUS: JHEP07 (2007) 074
CDF: PRL 91 (2003) 241804

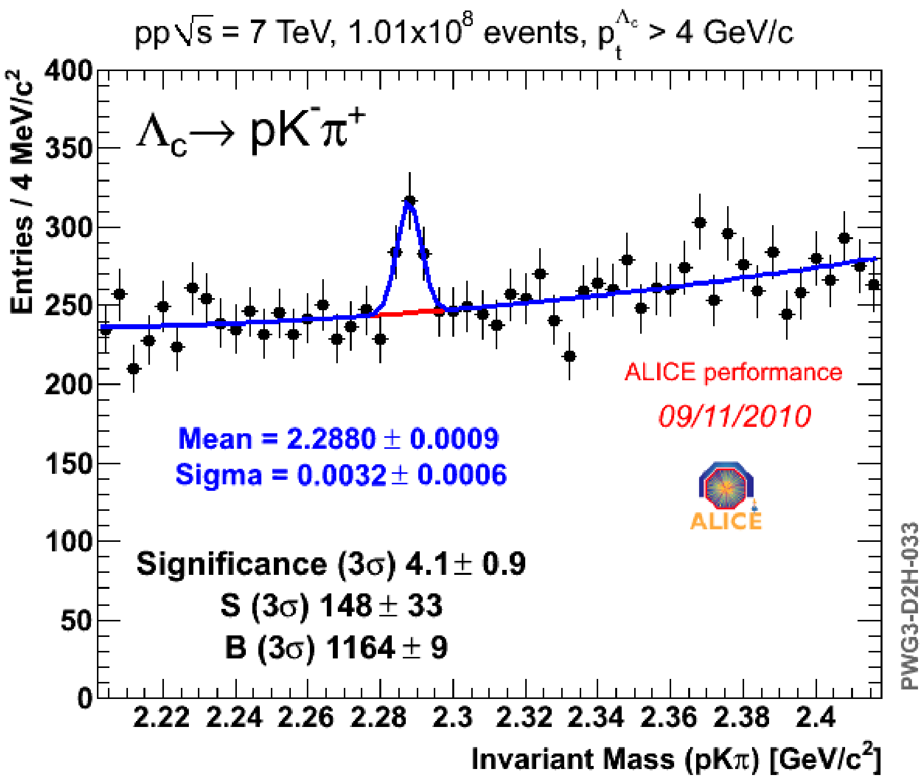
- p_t independent in the range 3-10 GeV/c

- **in agreement with previous experiments**

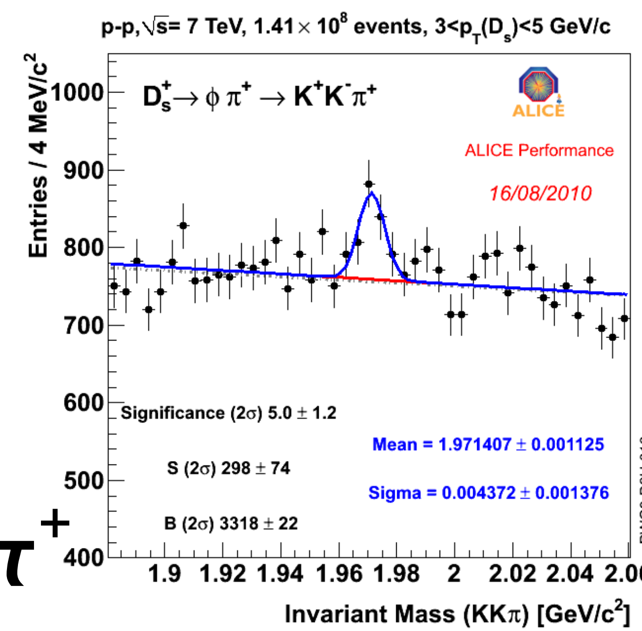
Other charm hadron ongoing analyses

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





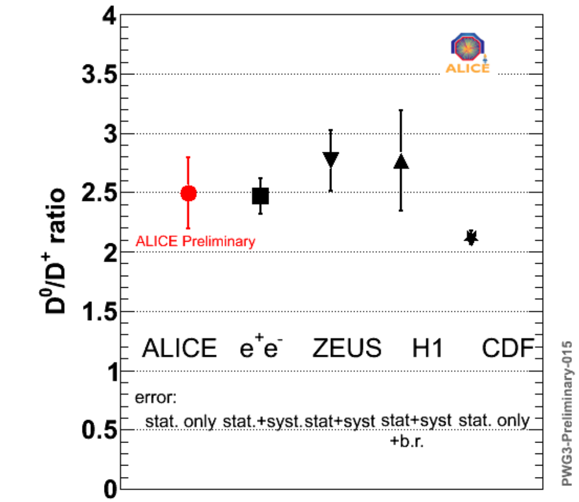
$$\Lambda_c^+ \rightarrow pK^- \pi^+$$

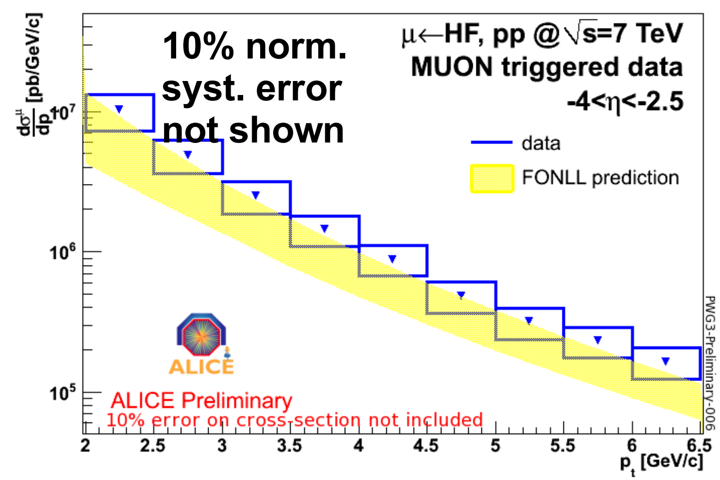


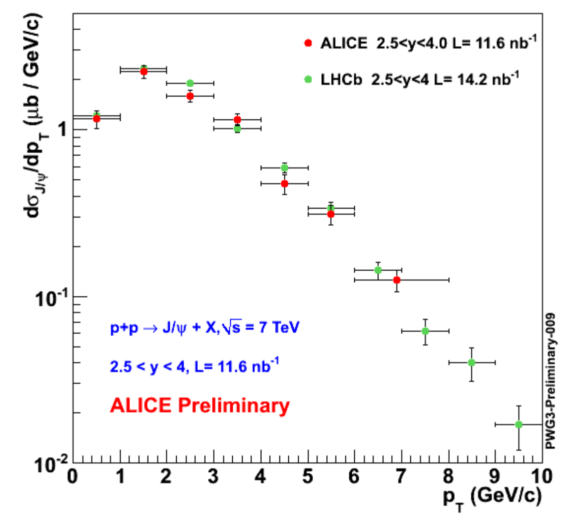
$$D_s^+ \rightarrow K^- K^+ \pi^+$$

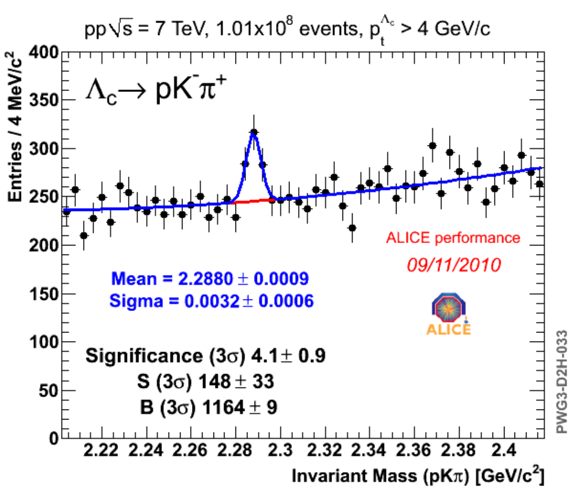
Summary

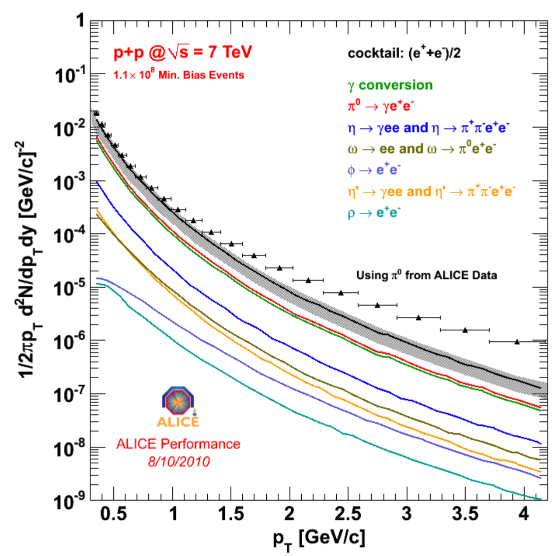
ALICE started to deliver heavy flavour physics results...

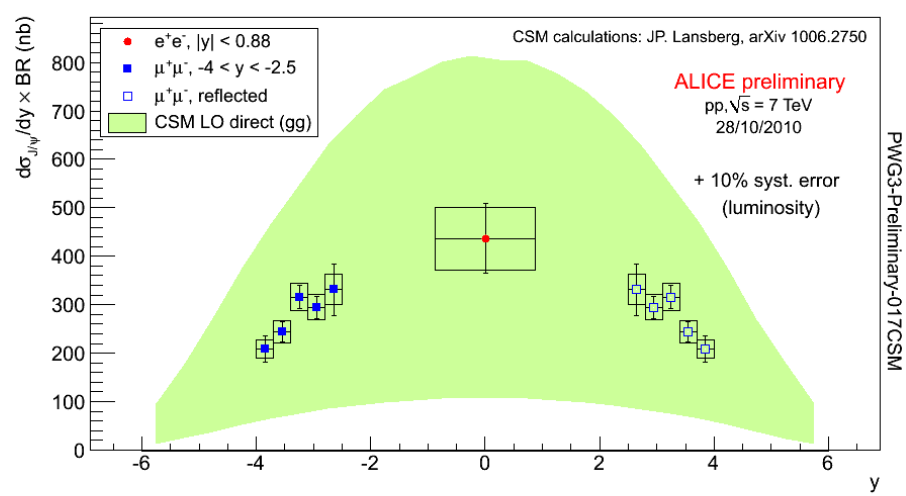




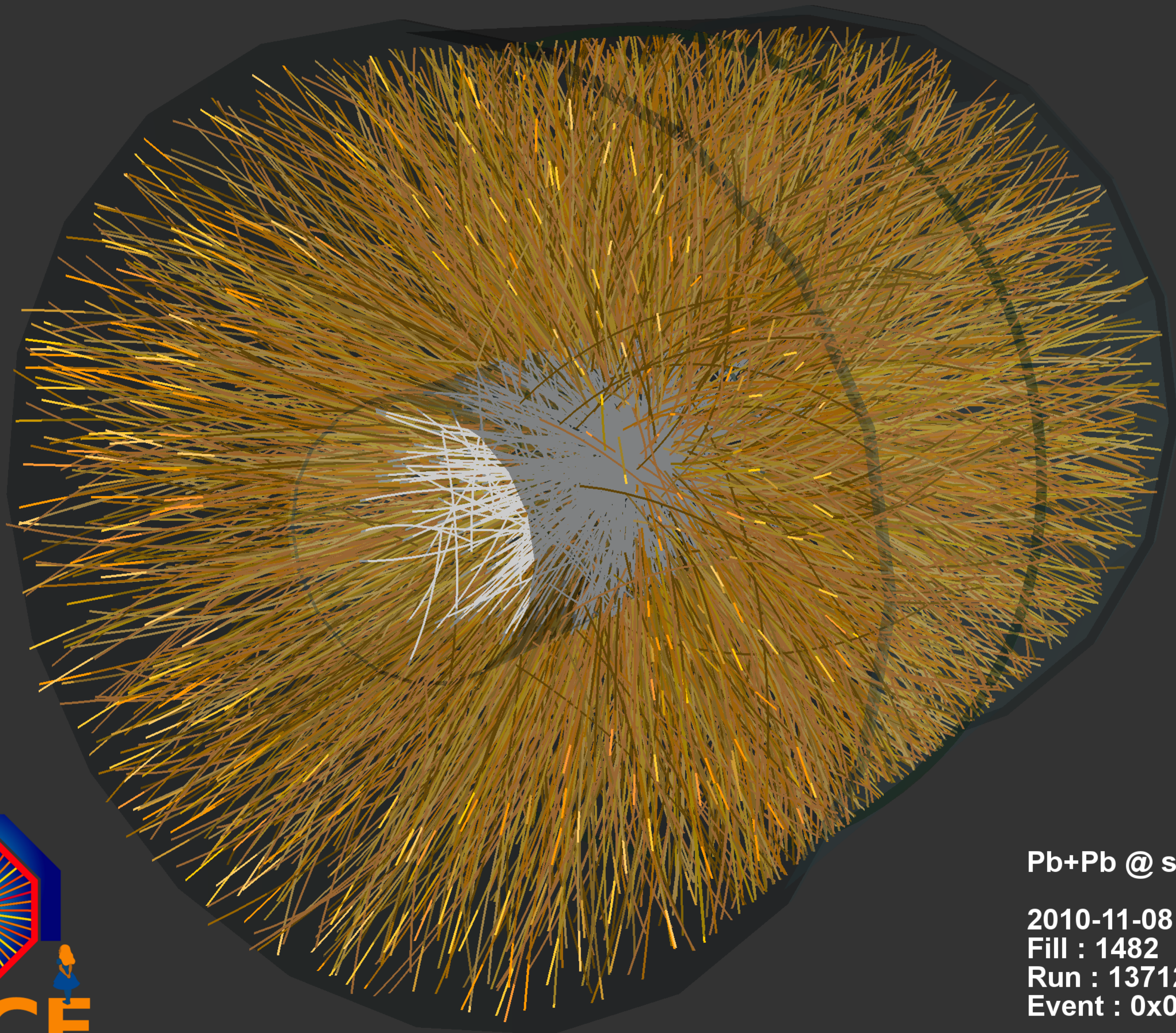








...many others coming soon!



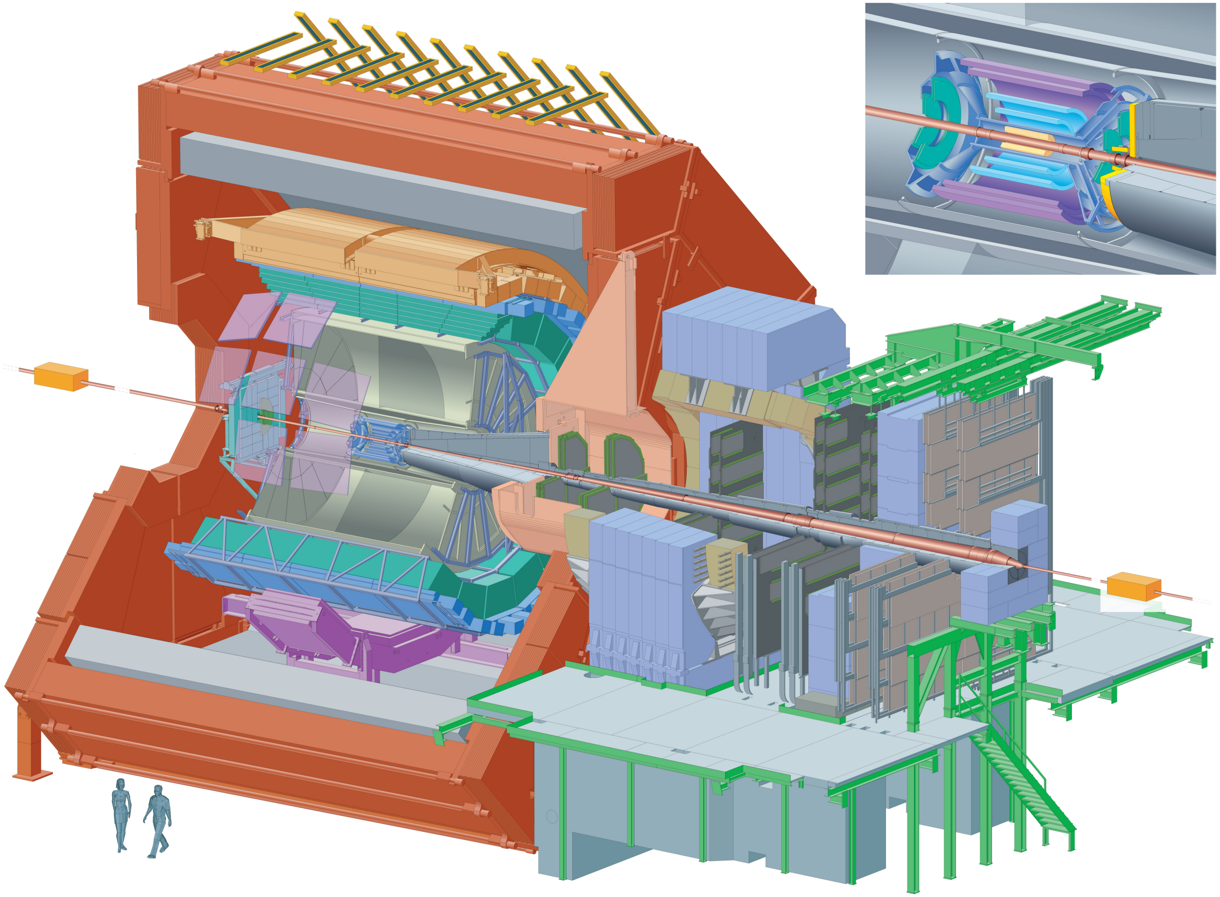
Pb+Pb @ sqrt(s) = 2.76 ATeV

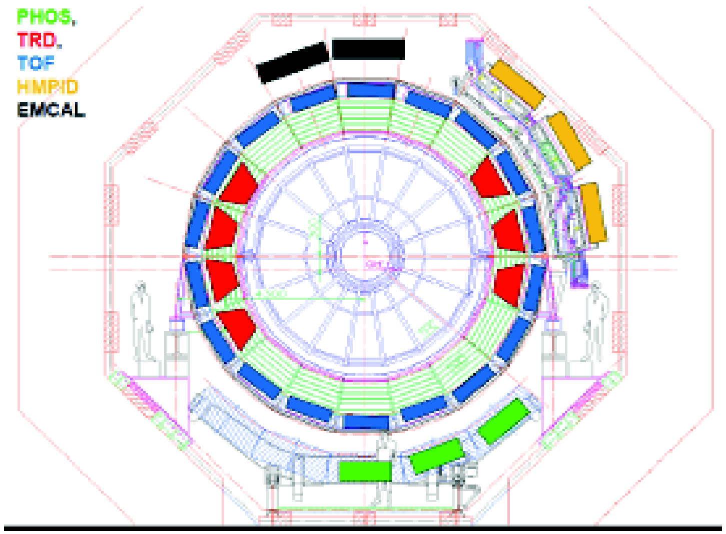
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

Extra

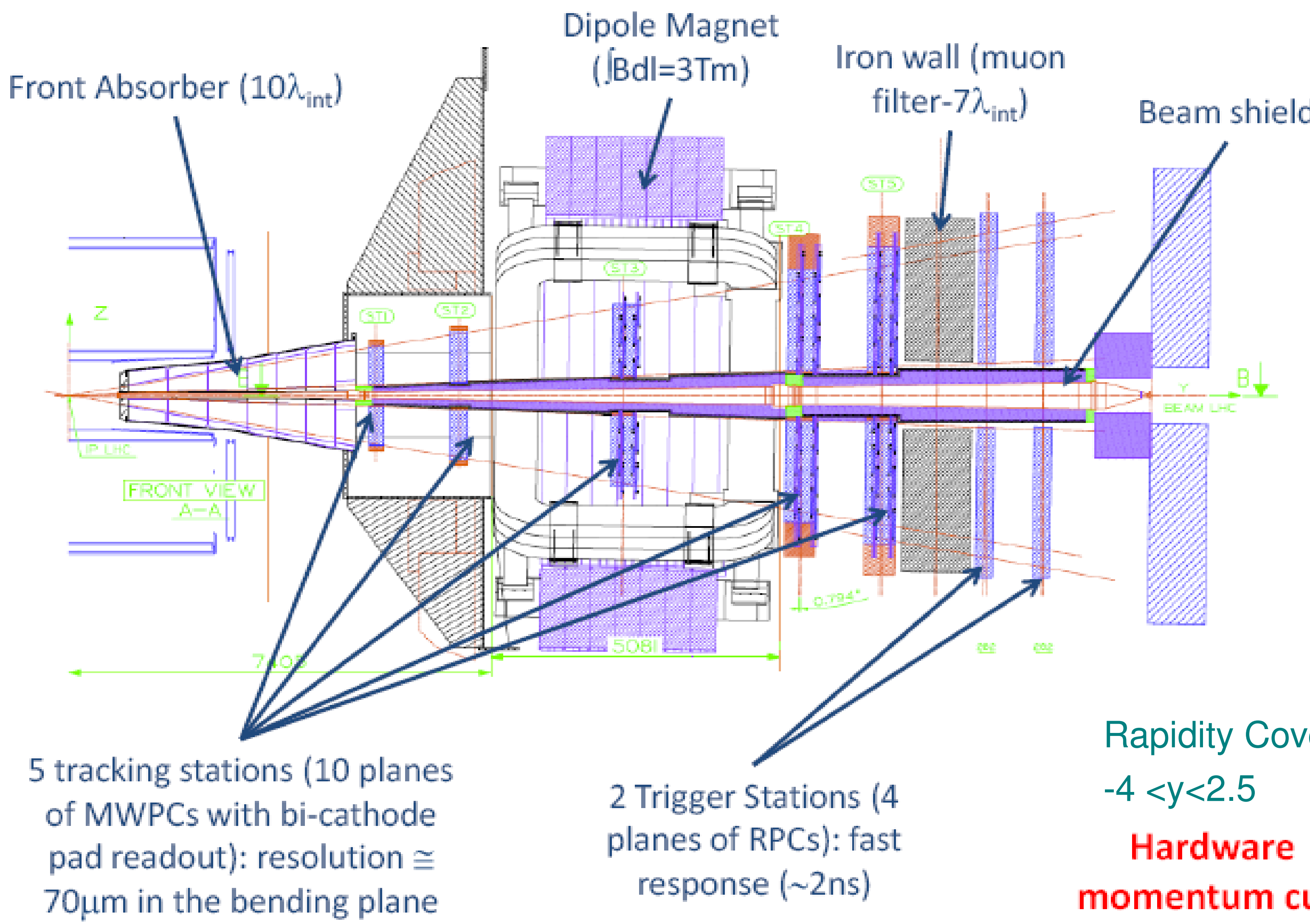
ALICE detector configuration in 2010

- ITS, TPC, TOF, HMPID, MUON, V0, T0, FMD, PMD, ZDC (100%)
- TRD (7/18)
- EMCAL (4/12)
- PHOS (3/5)





The forward muon spectrometer



Rapidity Coverage:

-4 <y<2.5

Hardware momentum cut:
p_{μ} = 4 GeV/c

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

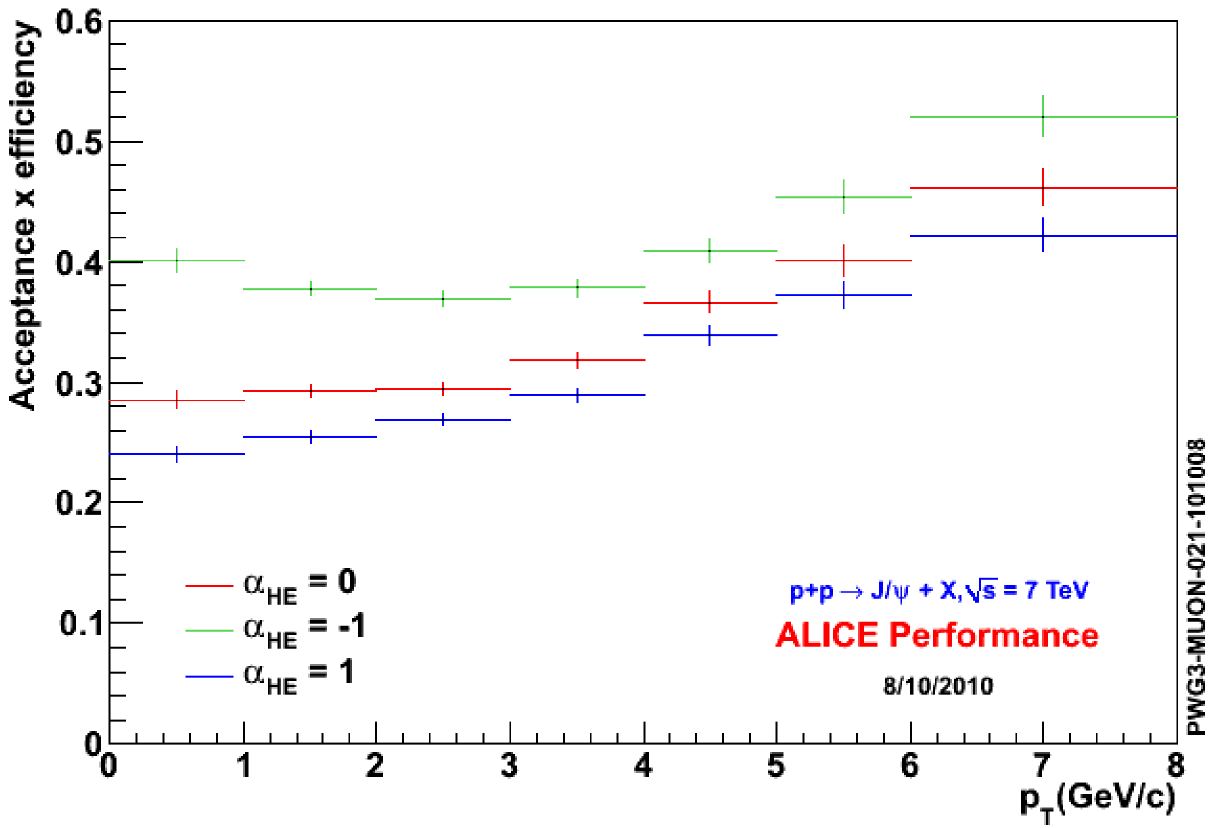
$J/\psi \rightarrow \mu^+\mu^-$: acceptance x efficiency

- Based on simulations performed separately for each LHC period, in order to reproduce in a realistic way, the detector status
  - Realistic y and p_T J/ψ distributions

p_T ->CDF extrapolation

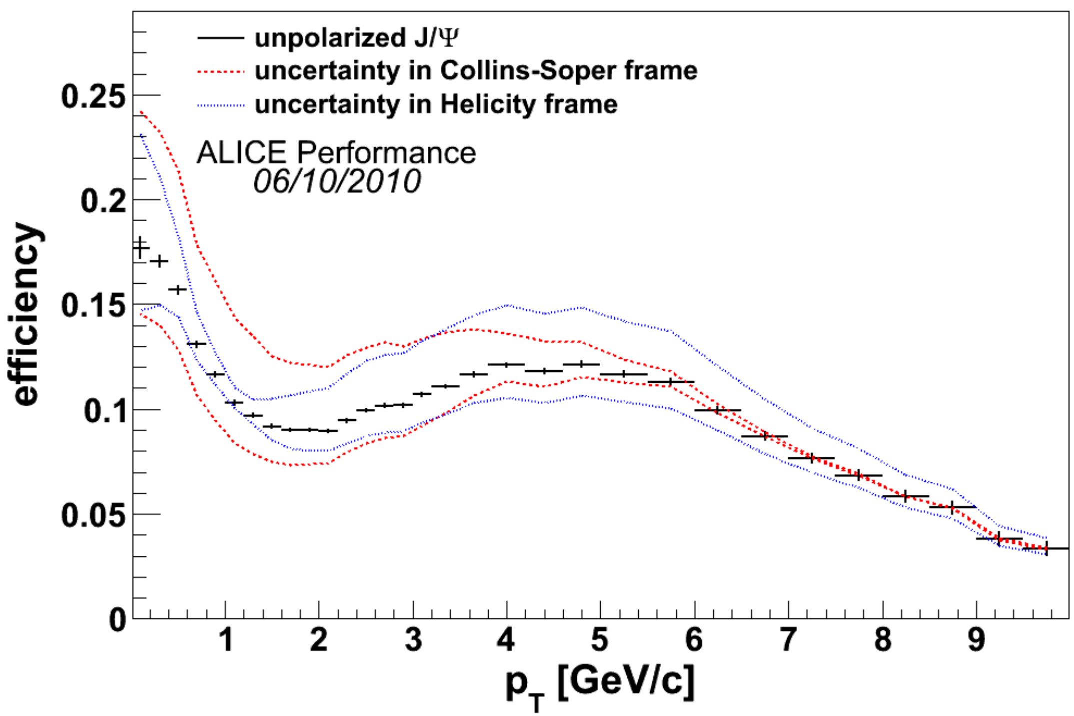
y ->CEM calculation

- 1D correction has been adopted for the study of differential distributions



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

Acceptance x efficiency:



Systematic error evaluation based on checks on the stability of the cuts applied in the analysis.

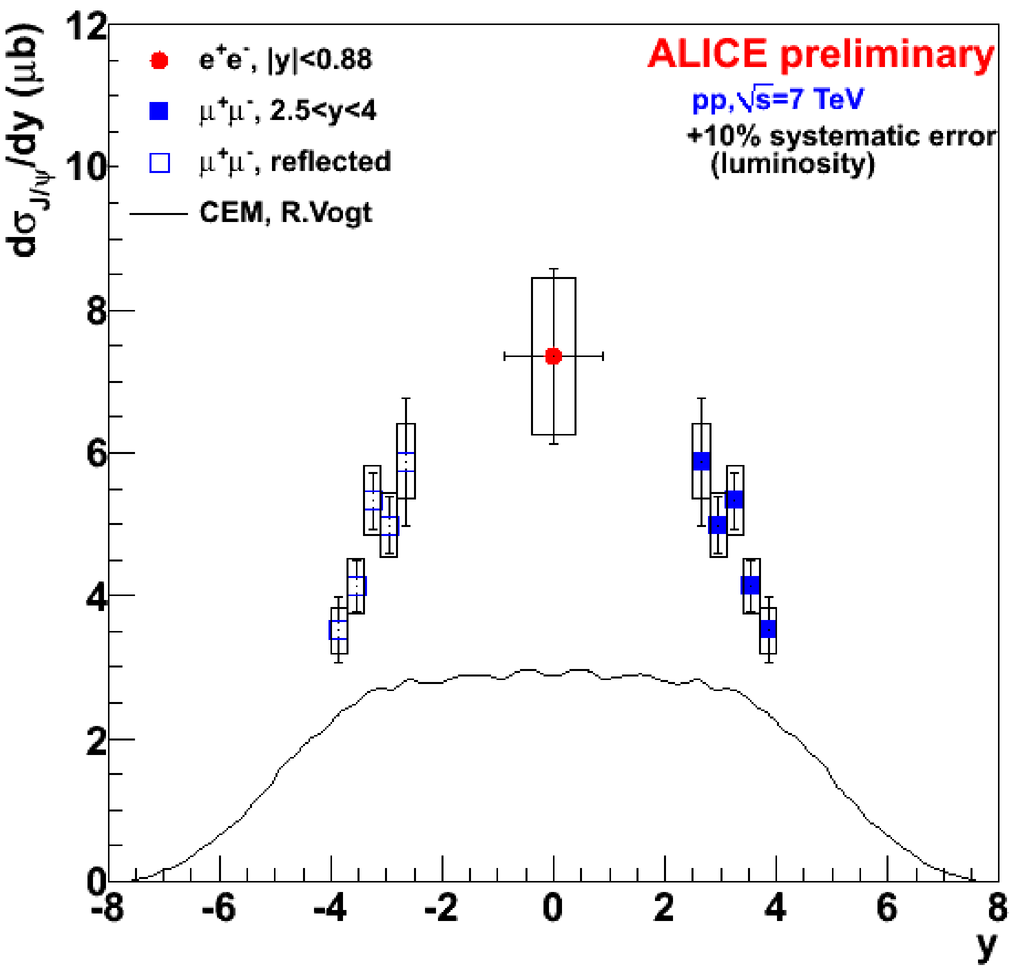
Dependence on polarization evaluated separately

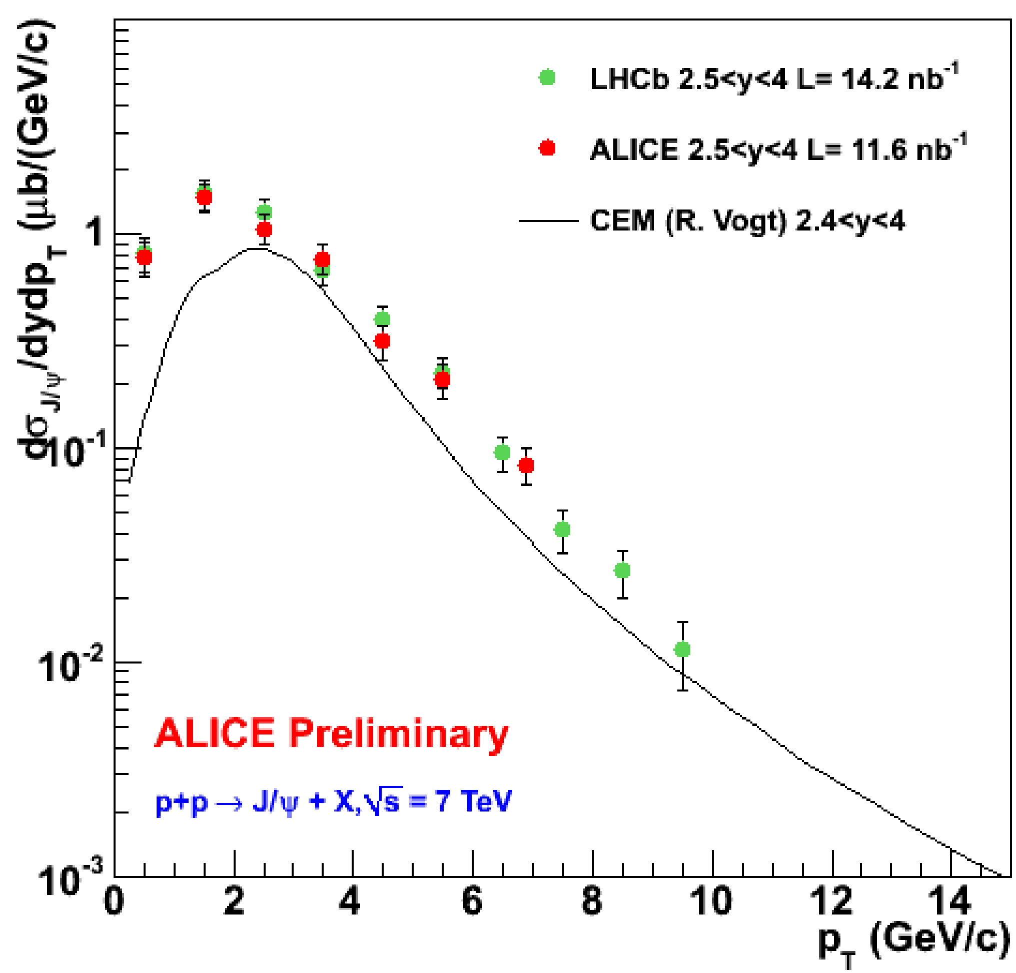
Systematic errors:

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

polarization	α=-1	α=1
Helicity	-24.8	11.9
Collins-Soper	-19.7	9.7

J/ψ: comparison with CEM





CEM prediction refers to prompt J/ψ

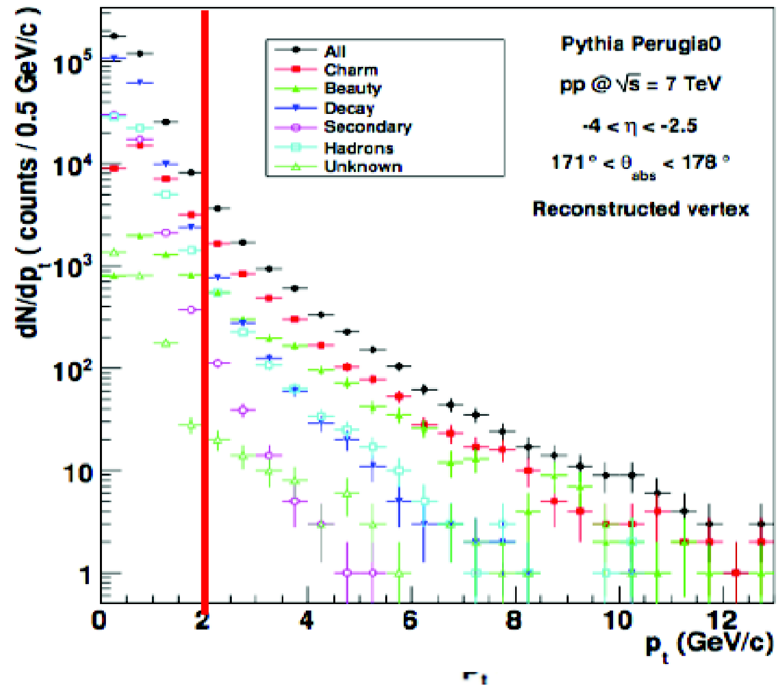
R.Vogt Phys. Rev. C 81 (2010) 044903

Forward single Muons from HF: analysis

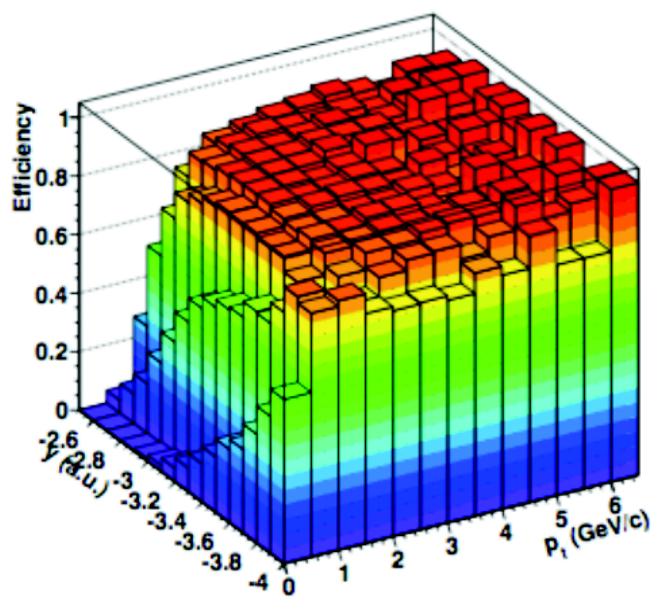
<u>Most delicate step:</u>

- Subtraction of residual secondary and decay muons from π,K
  - p_t>2 GeV/c secondary contribution small (<10%)
    - from MC and varied by 100%
  - subtract decay muons by using two different PYTHIA tunes (Perugia-0 and ATLAS-CSC)

➔ Resulting systematic errors on HF muons:
  - 30% -> 20% from low to high pt



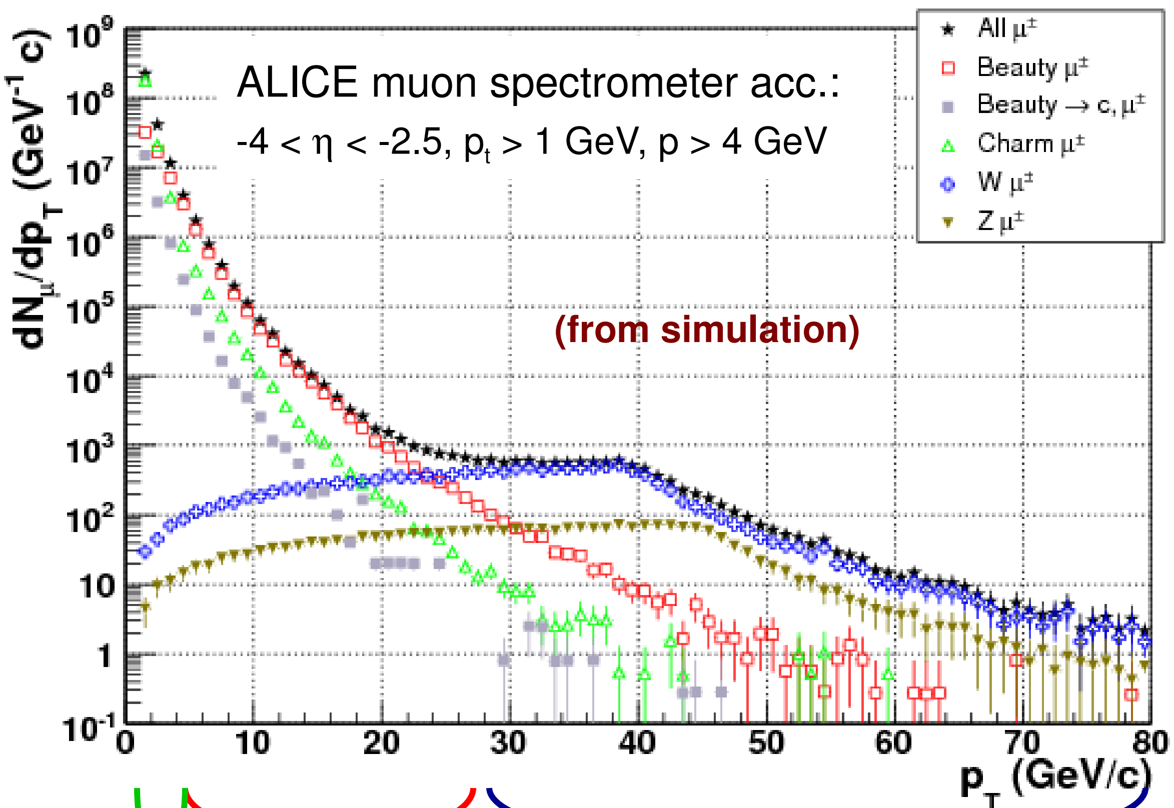
<u>Efficiency</u> >87% for pt >2.5 GeV/c



ALICE's forward muons

Muons identified in the forward spectrometer ($-4 < \eta < -2.5$)

Pb-Pb 0-5% 5.5 TeV: single muon statistics for ~1 month (~4 x 10^8 events)



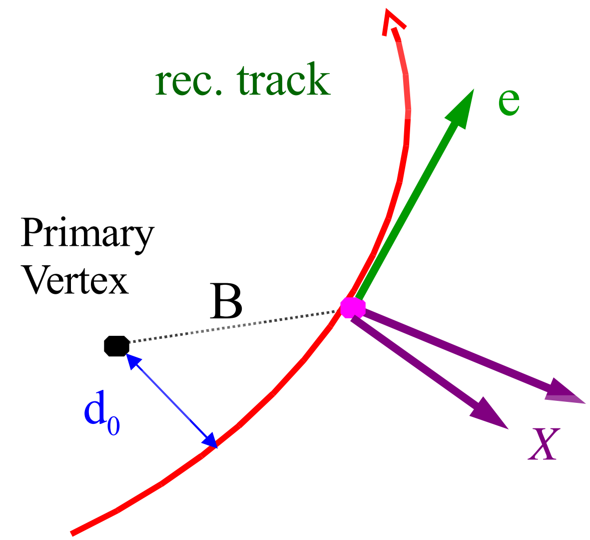
c dominates for $1 < p_t < 3$ GeV/c

b dominates for $3 < p_t < 25$ GeV/c

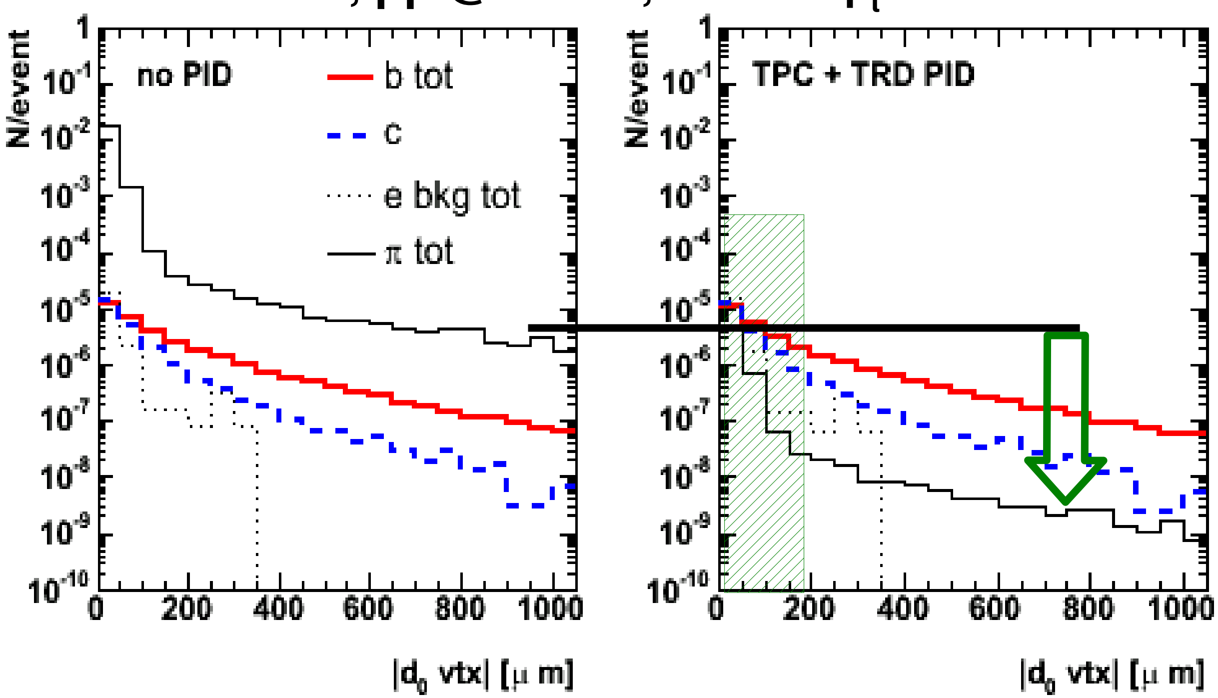
$W \rightarrow \mu$ (medium-blind reference) dominates for $p_t > 25$ GeV/c

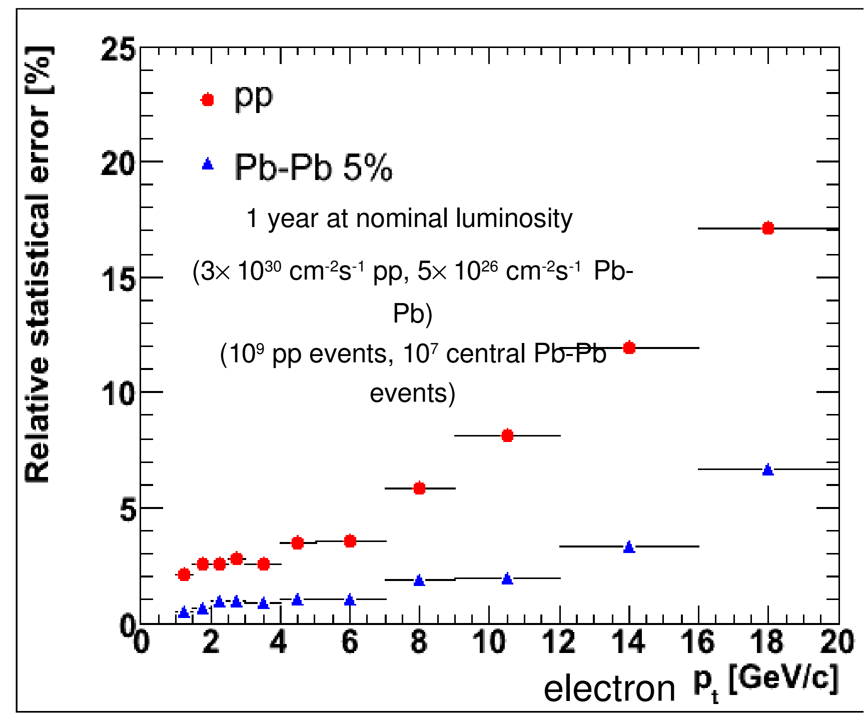
Beauty in the barrel: $B \rightarrow e + X$

1) Electron PID (TPC+TRD): reject most of the hadrons
2) d_0 cut: reduces charm and bkg electrons (Dalitz, γ conv.)
3) Subtract (small) residual background (ALICE data + MC)



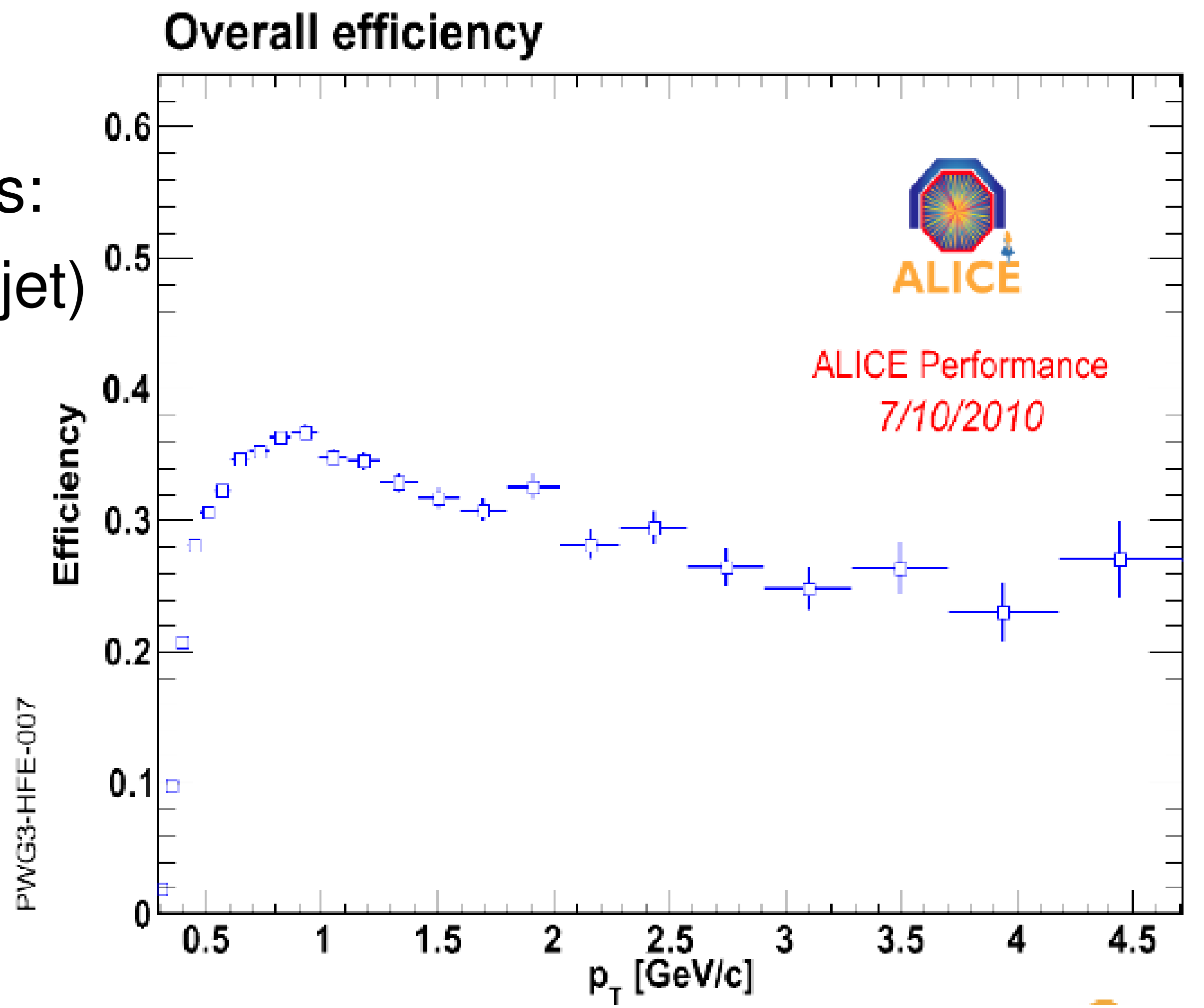
simulation, pp @14 TeV, electron p_t > 3 Gev/c





Heavy Flavour electrons: efficiency

Efficiency and acceptance correction using simulations:
Minimum bias (Pythia+Phojet)



The electron cocktail

All sources of electrons:

- **Dalitz decays of light neutral mesons** *(π^0, η, ω, η', $\varphi \rightarrow \gamma e^+e^-$)*
- **Photon conversions in material**
- **Direct radiation** *(direct photon conversions, virtual photons $\gamma^* \rightarrow e^+e^-$)*
- **Weak kaon decays** *(e.g. $K^\pm \rightarrow \pi^0 e^\pm \nu_e$)*
- **Dielectron decays of vector mesons** *(ρ, ω, $\varphi \rightarrow e^+e^-$)*
- **HEAVY FLAVOR DECAYS** *(open charm and beauty, J/ψ, Υ)*

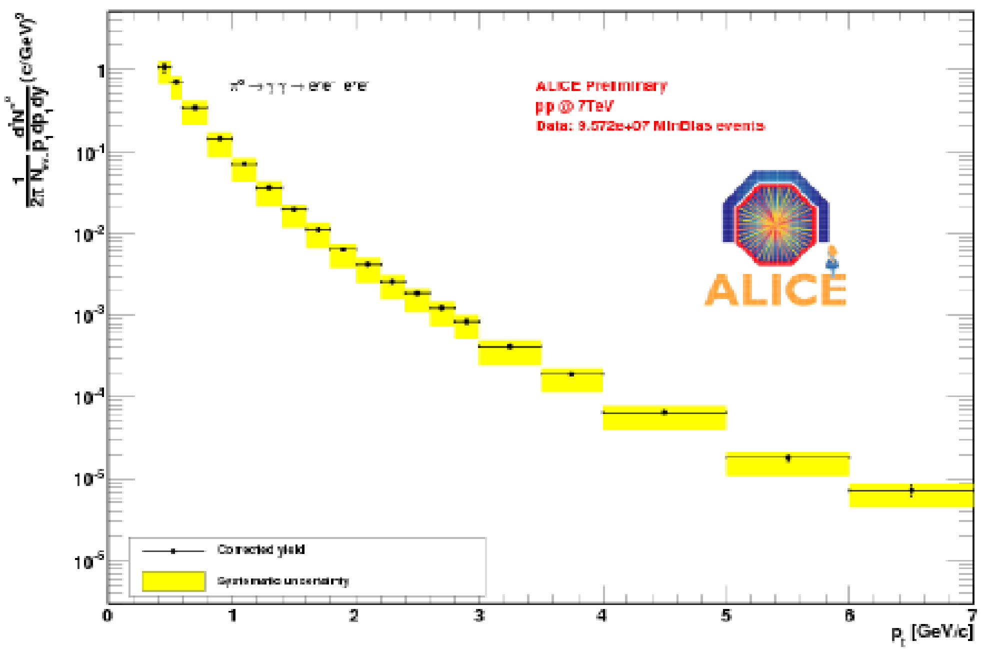
Current cocktail ingredients:

- **Neutral pions (based on the measured π^0 spectrum!)**
- **Heavier mesons: η, ρ, ω, φ, η'**
- **Photon conversions**

The electron cocktail

- **DATA: ALICE measured π^0 spectrum**

  reconstructed with photon conversions



OR

- **NLO prediction for π^0**

  B.Jager, A. Schaefer, M. Stratmann, W. Vogelsang

  Phys. Rev. D67 (2003) 054005

Spectra are fit with the Hagedorn function:

$$E\frac{d^3\sigma}{dp^3} = \frac{c}{\left(p_0 + {p_T}/{p_1}\right)^n}$$

The electron cocktail

Heavier mesons:

- Included: **η, η', ρ, ω, φ**
- Implemented via **m_T scaling**

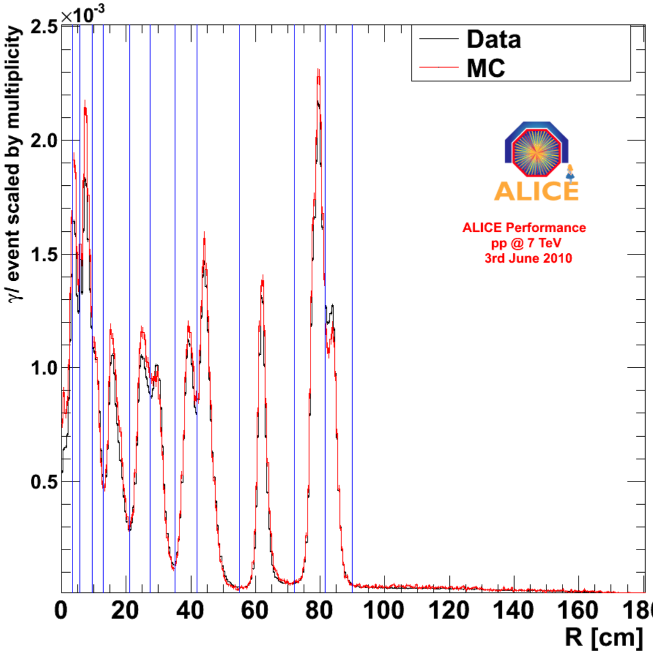
$$E\frac{d^3\sigma}{dp^3} = \frac{c \times {}^{meson}\!/\!_{pion}}{\left(p_0 + \sqrt{m_T^2 - m_\pi^2}\,/\,p_1\right)^n}$$

Verified for η in ALICE !

Electrons from photon conversions

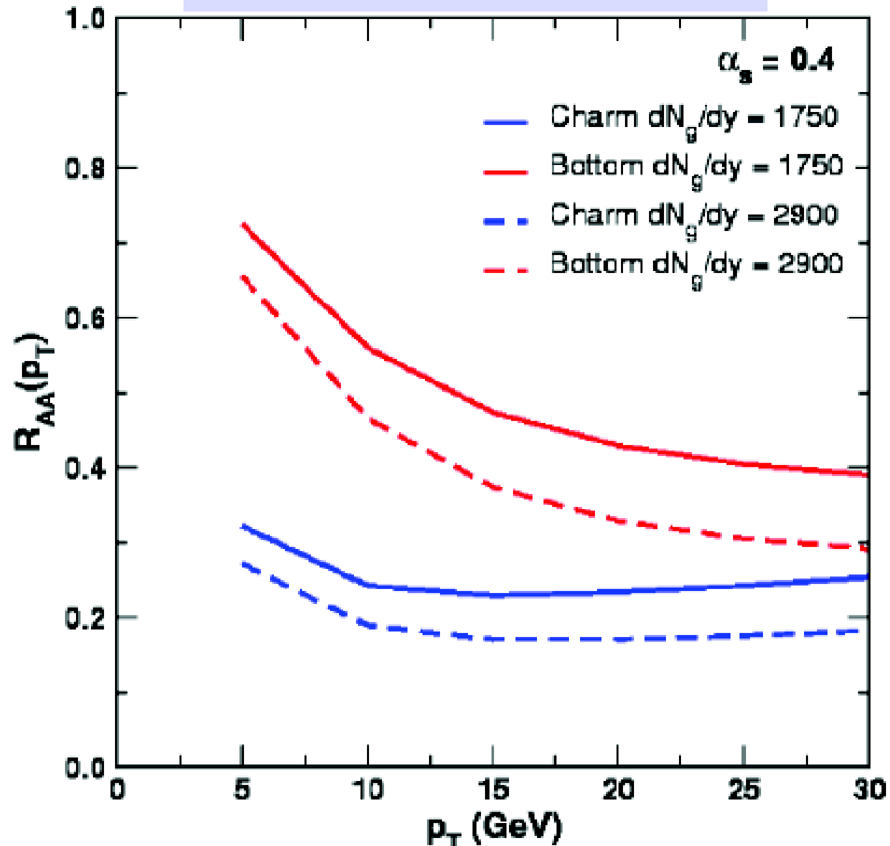
- Not rejected: those from the beam pipe and ~1/3 of first pixel layer (≈0.5 % X_0)
- Ratio of conversions to Dalitz electrons:

$$\frac{Conv.}{Dalitz} = \frac{BR^{\gamma\gamma} \times 2 \times \left(1 - e^{-7/9 \times X/X_0}\right) \times 2}{BR^{Dalitz} \times 2} = 0.739$$



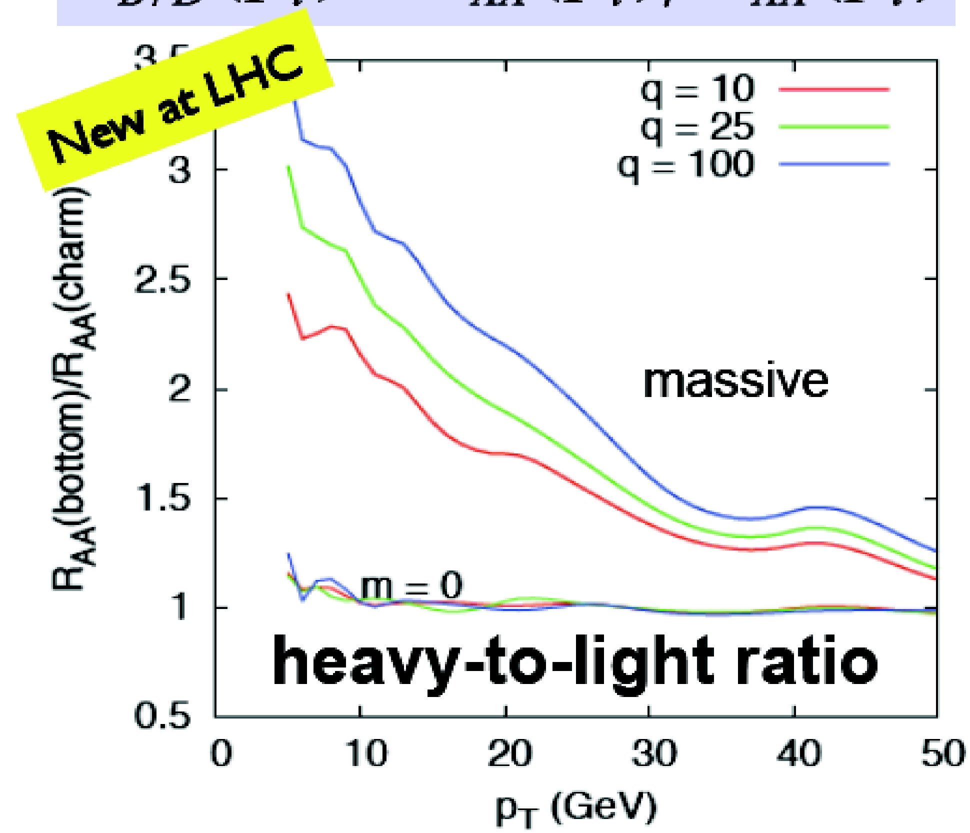
Heavy Flavour in pp as a reference for PbPb

$R^B_{AA}(p_t)\ vs.\ R^D_{AA}(p_t)$



Wicks, Gyulassy, "Last Call for LHC Predictions" workshop

$R_{B/D}(p_t) = R^B_{AA}(p_t)/R^D_{AA}(p_t)$

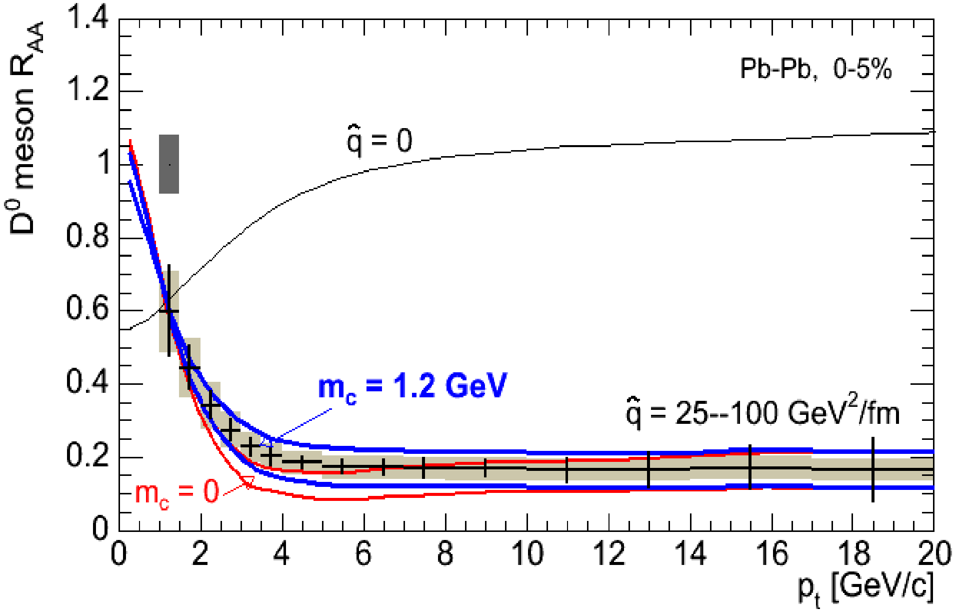


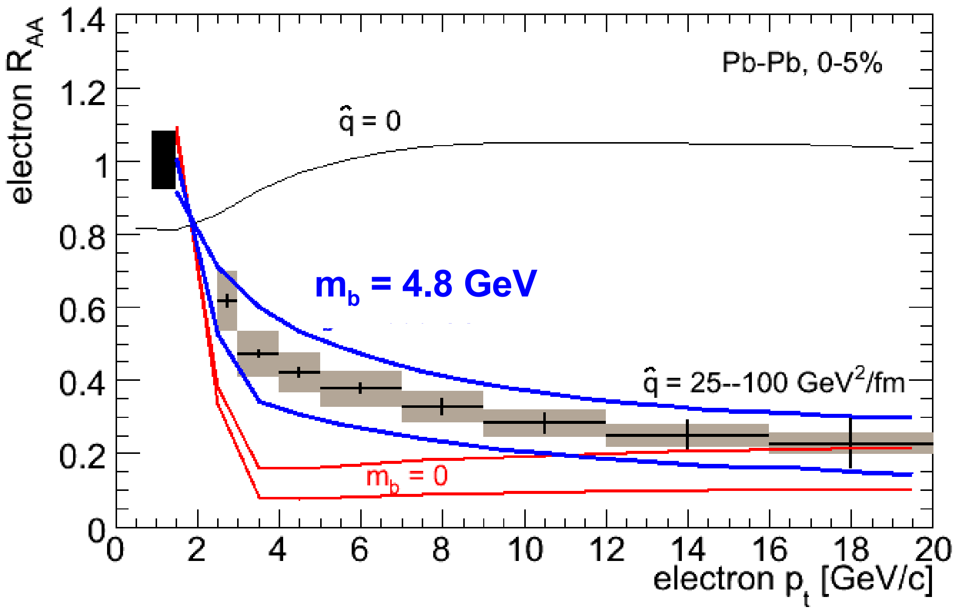
Armesto, et al, "Last Call for LHC Predictions" workshop

Expected performance for Heavy Flavour R_{AA}

$$R^{D}_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{D}_{AA}/dp_t}{dN^{D}_{pp}/dp_t}$$

$$R^{e}_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{e}_{AA}/dp_t}{dN^{e}_{pp}/dp_t}$$





simulation, 1 year at nominal luminosity
(10^7 central Pb-Pb events, 10^9 pp events)

Beauty energy loss expected lower due to dead cone effect

Study of energy loss mechanisms

Expected: $\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$ $\oplus$ "Dead cone" effect

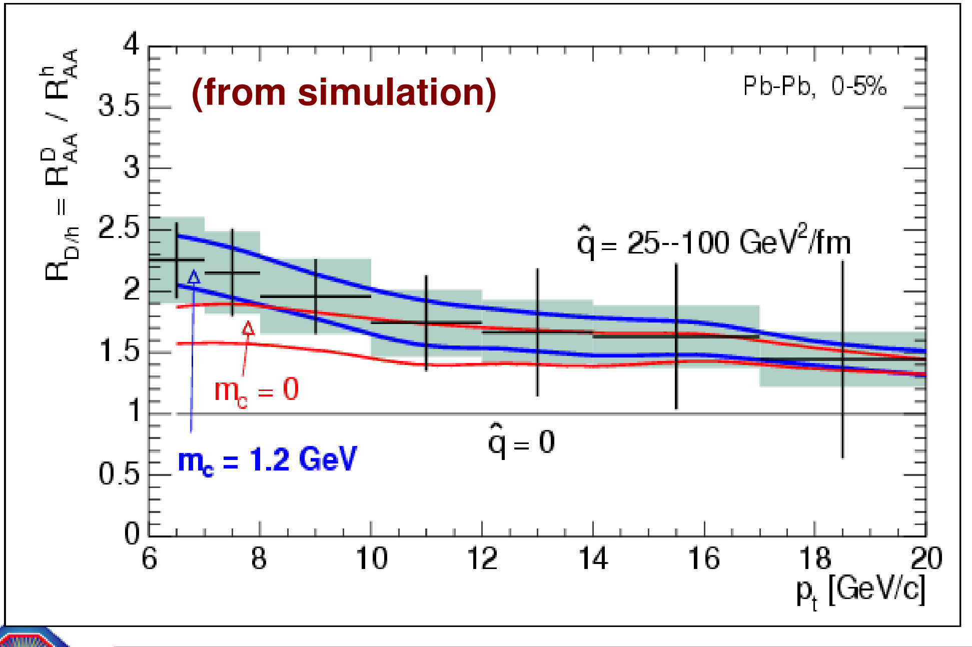
$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

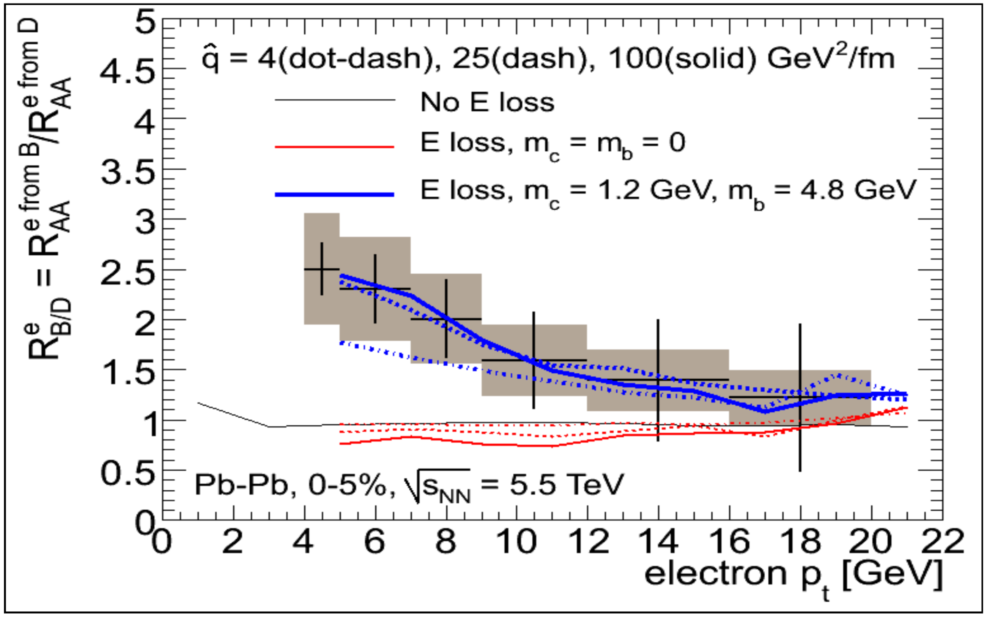
colour charge dependence

mass dependence

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

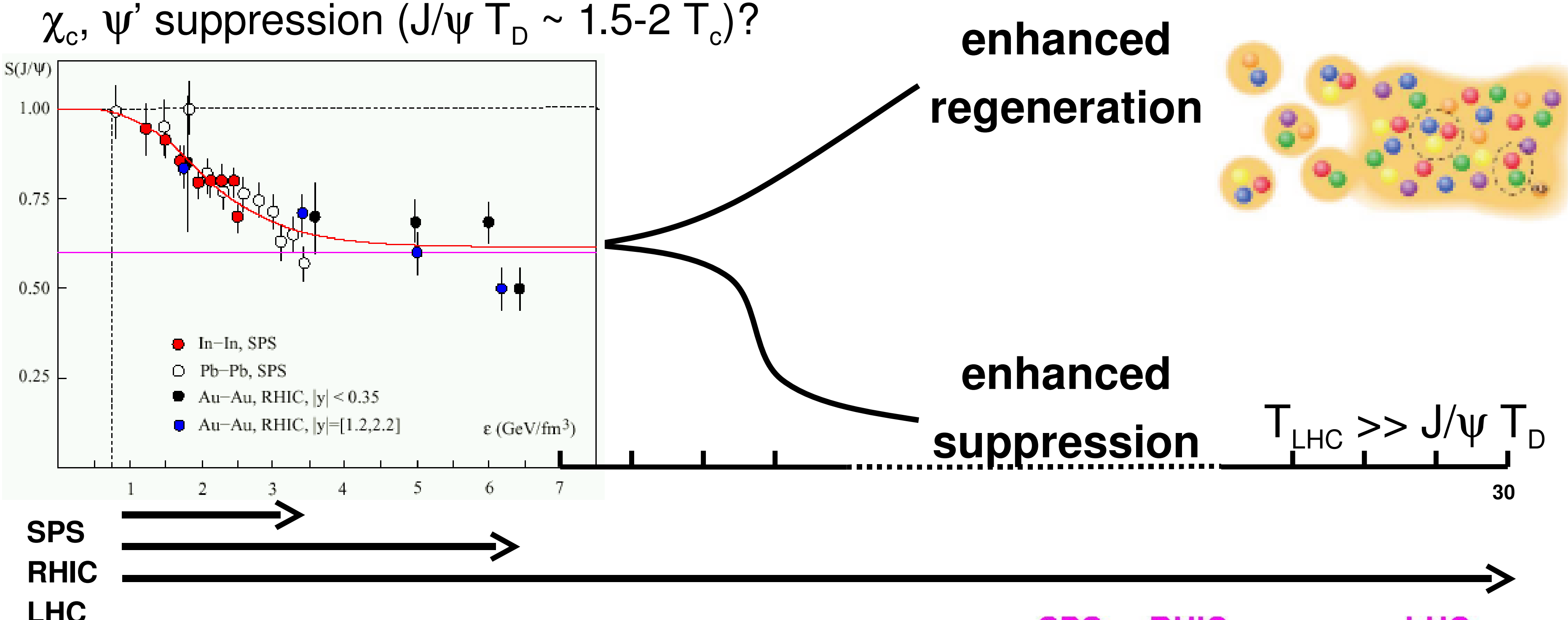
$$R_{B/D}(p_t) = R_{AA}^{\text{e from B}}(p_t) / R_{AA}^{\text{e from D}}(p_t)$$



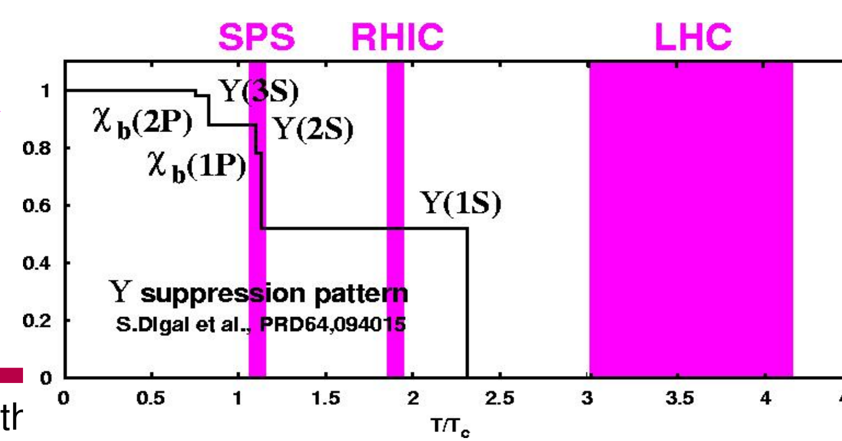


Quarkonia at the LHC

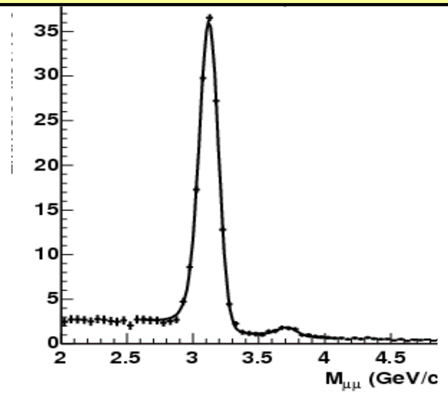
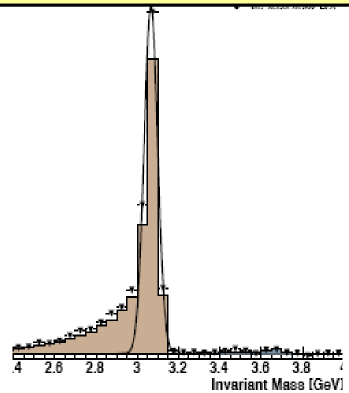
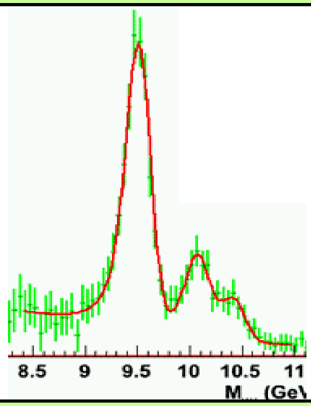
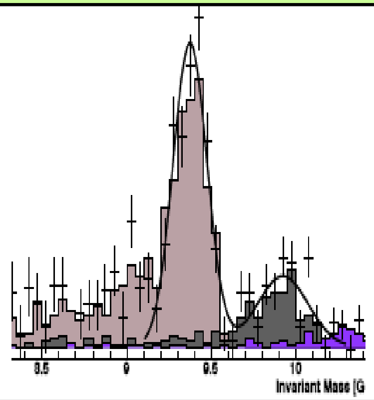
- Charmonium and bottonium production <u>sensitive probe of deconfinment</u> (~Debye screening)
  - J/ψ suppression & regeneration?
  - χ_c, ψ' suppression (J/ψ T_D ~ 1.5-2 T_c)?



- Υ "melts" only at LHC
- Υ' T_D ~ J/ψ T_D
- Small Υ regeneration
  - →Υ' can unravel J/ψ suppression VS regeneration



Quarkonia performances in PbPb

Particle	Charmonia $\mu^+\mu^-$	Charmonia e^+e^-	Bottonia $\mu^+\mu^-$	Bottonia e^+e^-
Bkg-subtracted mass plot				
acc. η	$-4 < \eta < -2.5$	$\|\eta\| < 0.9$	$-4 < \eta < -2.5$	$\|\eta\| < 0.9$
M res.	65 MeV	35 MeV	90 MeV	90 MeV
$\frac{S}{\sqrt{S+B}}$	**J/ψ 150, ψ' 7**	**J/ψ 245**	**ϒ 30, ϒ' 12, ϒ'' 8**	**ϒ 21, ϒ' 8**
perf.	ψ, ?ψ'	ψ, ??ψ'	ϒ, ϒ', ?ϒ''	ϒ, ?ϒ', no ϒ''
p_t	J/ψ 0-20 GeV	J/ψ 0-10 GeV	ϒ 0-8 GeV	--

Bkg input: dN_{ch}/dy=4000 in central Pb-Pb. $S/\sqrt{S+B}$ for 1 month