Heavy Quark production at ALICE/LHC

Raphaelle Bailhache
on behalf of the ALICE collaboration

Outline

- Introduction
  - Motivations and predictions at the LHC
  - The ALICE experiment

- Heavy-flavour results in proton-proton at $\sqrt{s}$=7 TeV
  - D meson p_T distributions and D^0/D^+ ratio
  - Heavy-flavour electrons at mid-rapidity
  - Heavy-flavour muons at forward-rapidity
  - J/ψ production cross section at mid- and forward rapidity

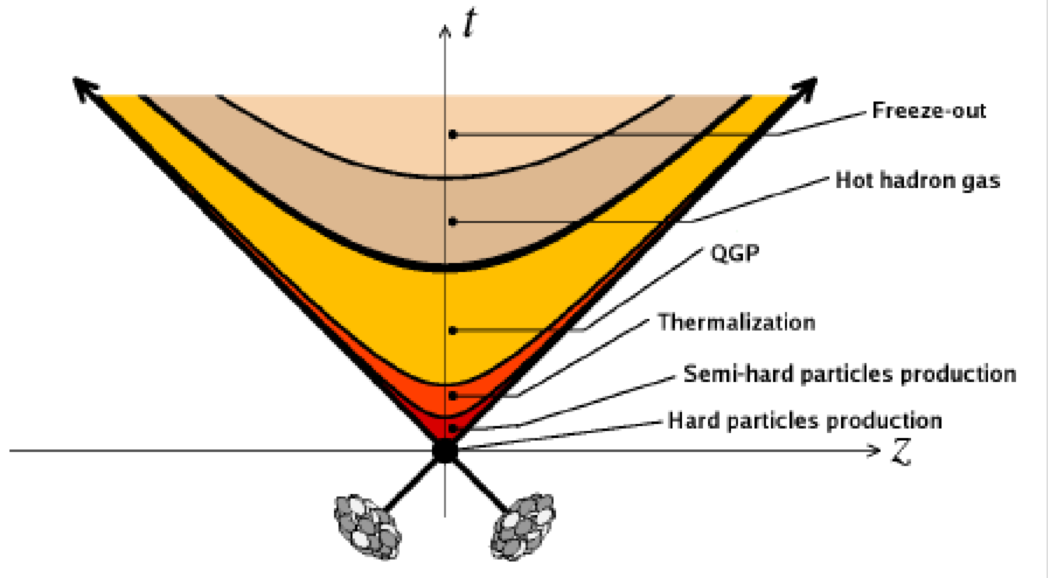
- First look at Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

Motivation

to measure Charm and Beauty production cross-sections

In heavy-ion collisions:

- Produced at the beginning of the collision (large Q^2)
- Experience the evolution of the fireball (large $c\tau$)
- Interact strongly with the medium (parton energy-loss)



In proton-proton collisions:

- Test of pQCD
- Baseline for studies in heavy-ion collisions

Why heavy Quarks in pp at the LHC?

Test pQCD in a new energy domain (3.5-7x$\sqrt{s}_{Tevatron}$)

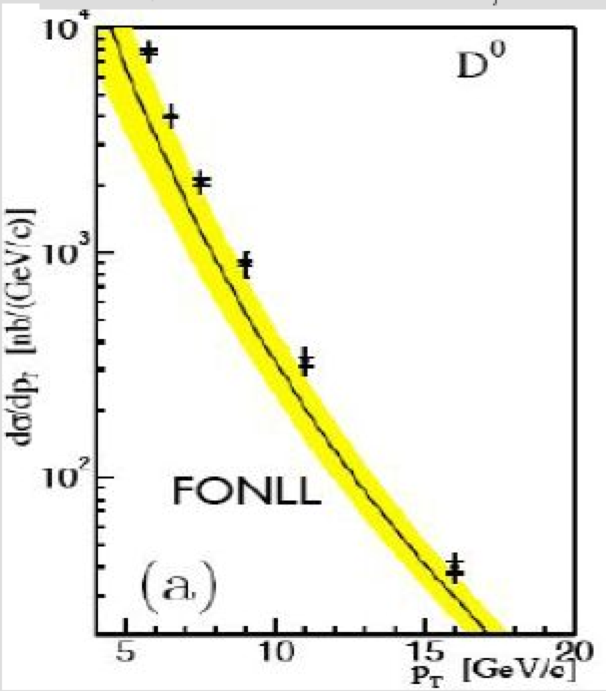
Charm production

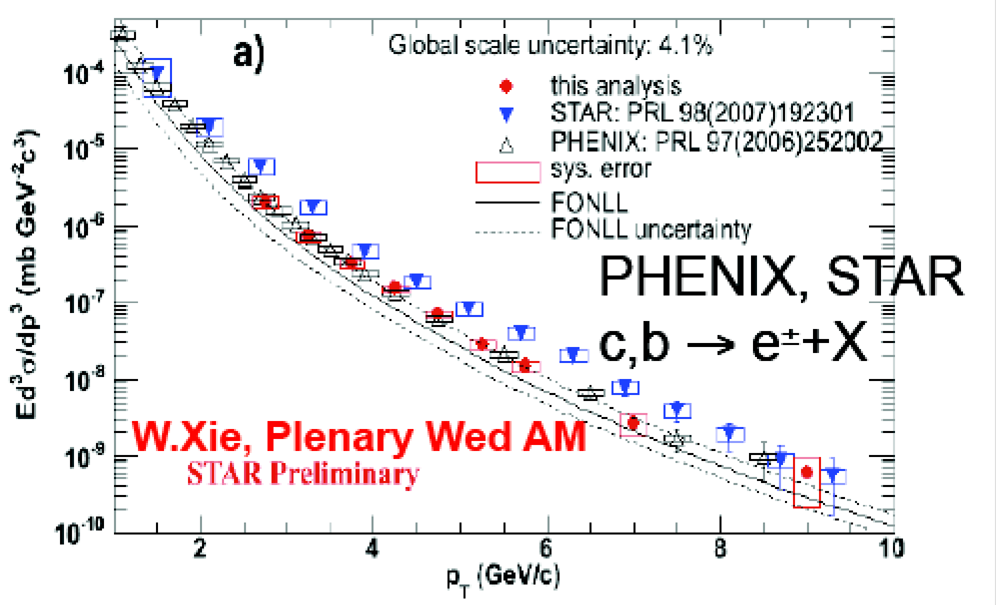
Measurements on the upper edge of prediction

at Tevatron in ppbar at √s=1.96TeV

at RHIC in pp at √s=200GeV

CDF data PRL 91:241804,2003



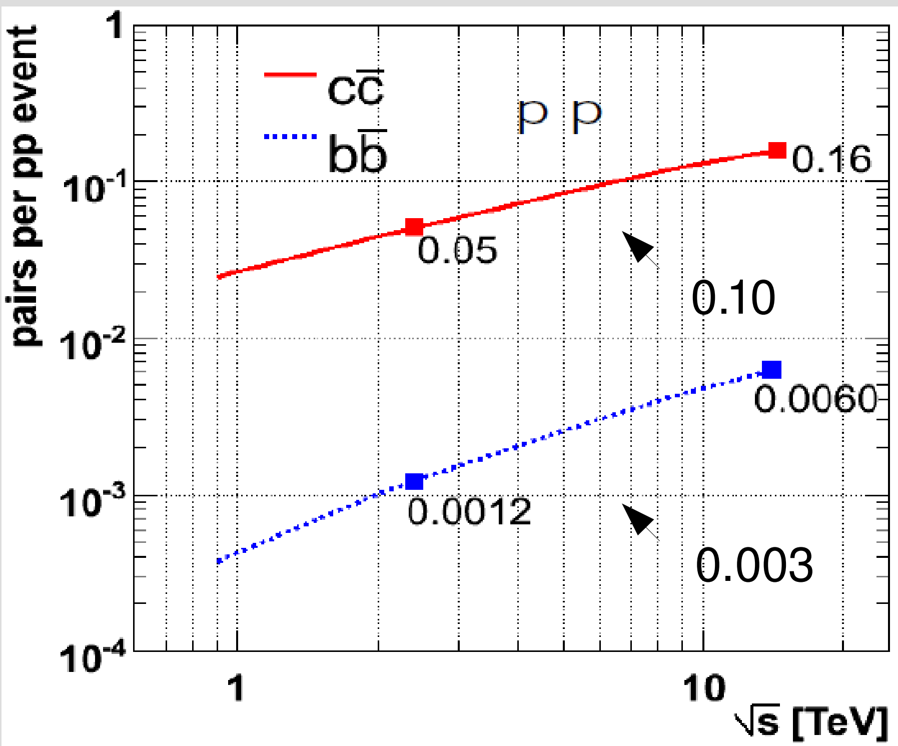


Beauty production

Fairly well reproduced by NLO calculations

Heavy Quarks production: predictions in pp

Mangano,Nason,Ridolfi, NPB373 (1992) 295



LHC production much higher than at RHIC

- $\sigma^{c\bar{c}}_{LHC} \approx 10 \cdot \sigma^{c\bar{c}}_{RHIC}$
- $\sigma^{b\bar{b}}_{LHC} \approx 50 \cdot \sigma^{b\bar{b}}_{RHIC}$

Still a factor 2 uncertainty

Probe unexplored small-x region

-> Need a measurement at these energies

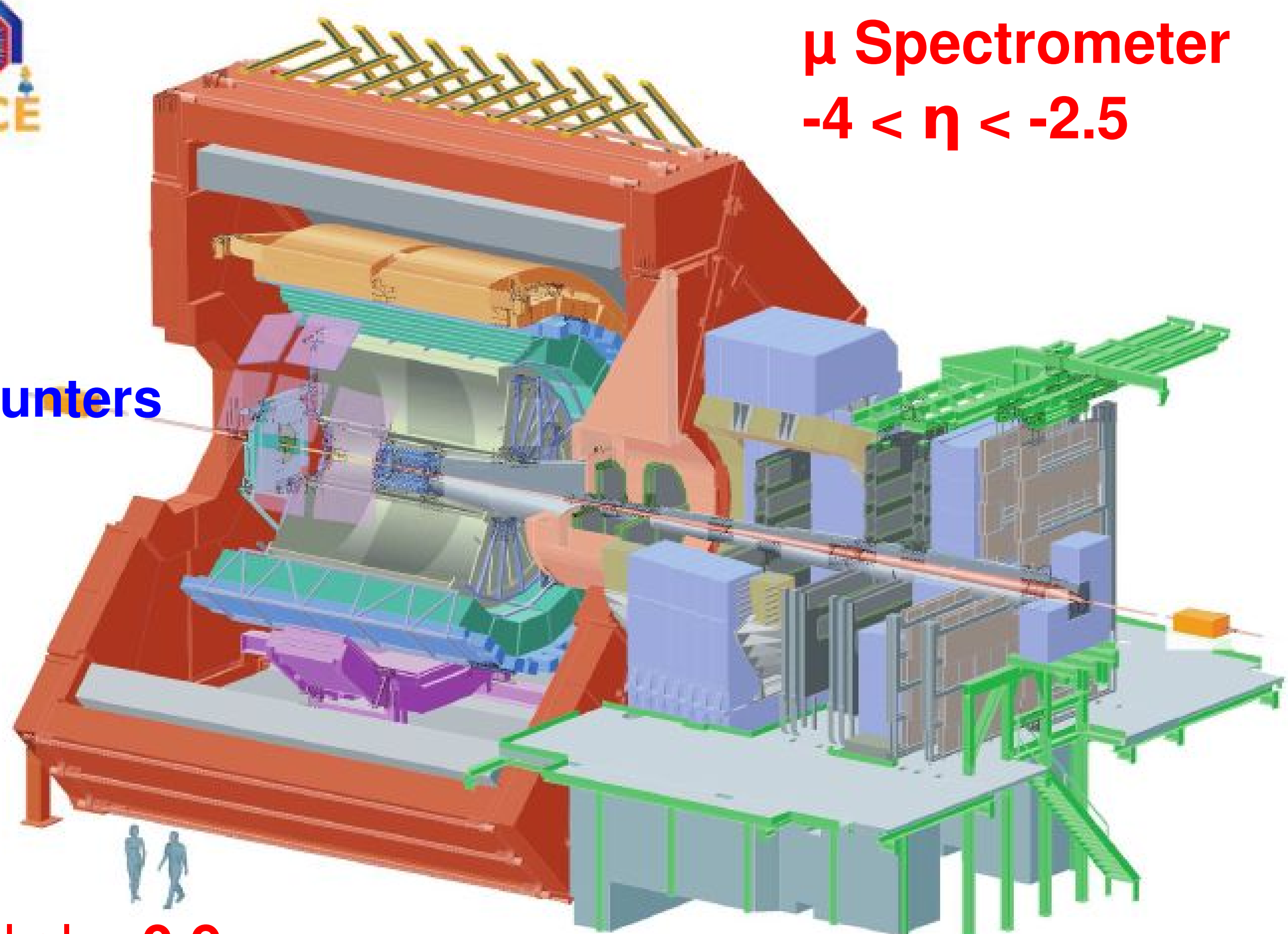
ALICE Experiment

μ Spectrometer
$-4 < \eta < -2.5$

Trigger detectors:

central barrel:
- VZERO scintillator counters
- 2 pixel layers (ITS)

μ spectrometer:
- + μ trigger chambers



Central Barrel $|\eta| < 0.9$

ALICE Experiment

Central Barrel

$|\eta| < 0.9$

D meson decays

D^0 -> $K\pi$

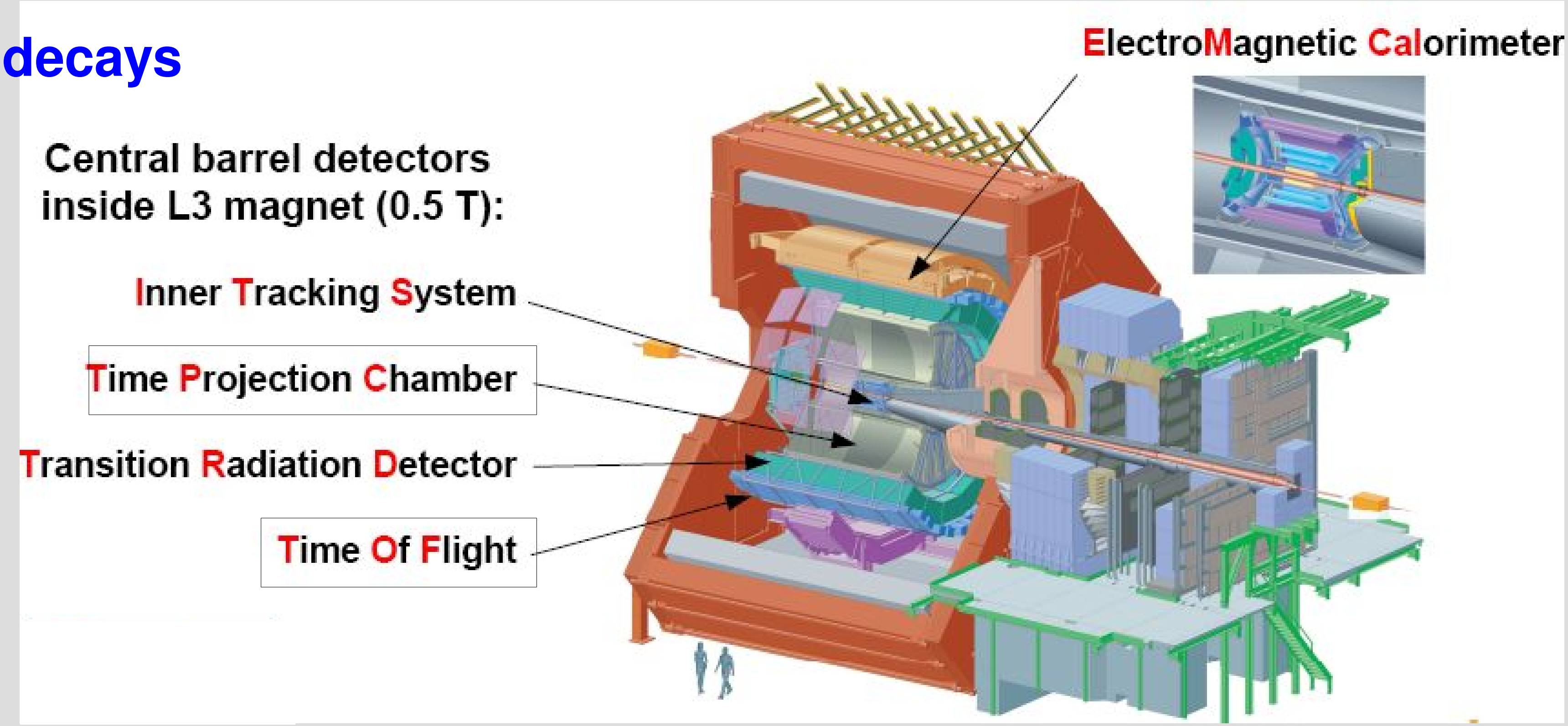
$D^{\pm}$->$K\pi\pi$

$D_S^{\pm}$->$KK\pi$

D^*->$D^0\pi$

D^0->$K\pi\pi\pi$

Λ_c->πKp



b/c -> hadrons (D mesons)

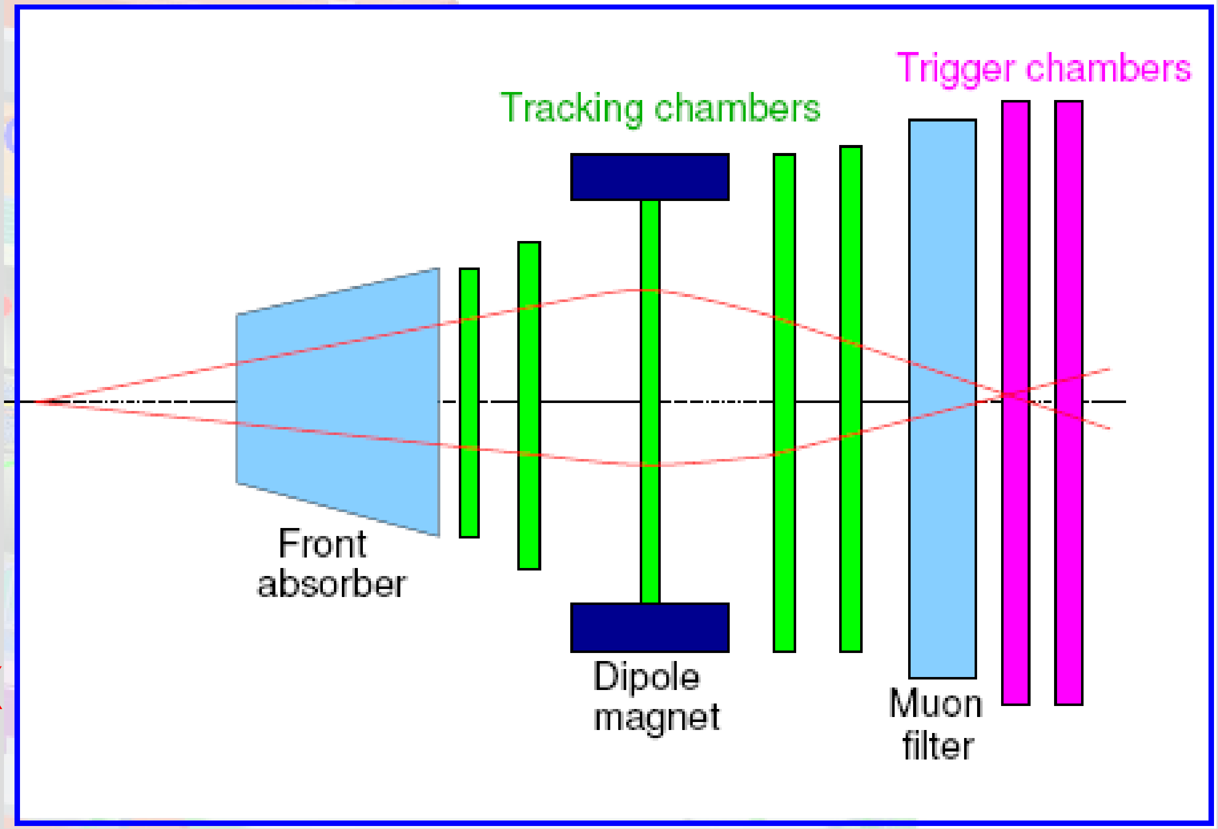
b/c -> e + X

J/ψ -> e^+e^-

ALICE Experiment

μ Spectrometer

$-4 < \eta < -2.5$



$b/c \rightarrow \mu + X$

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

Trigger system with programmable p_T cuts: lowest in 2010 $p_T^{\mu} > 0.5$ GeV/c

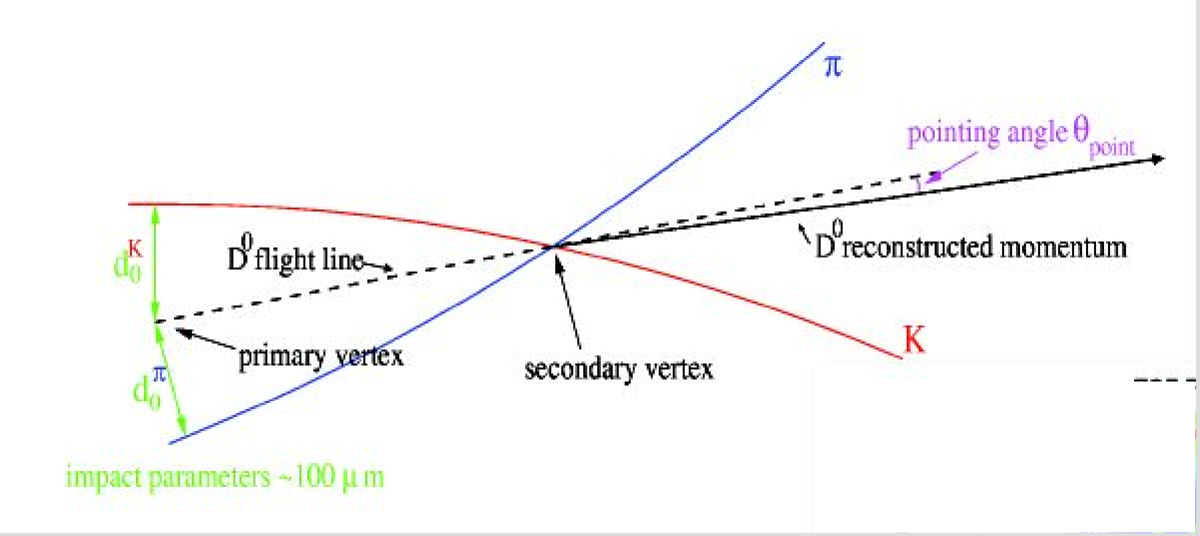
Heavy-flavour results in pp at $\sqrt{s}$=7 TeV

b/c -> hadrons (D mesons)

D meson reconstruction

- Main selection: displaced-vertex topology (ITS)
- Example: D^0->$K\pi$
  - Good pointing of reconstructed D^0 momentum to primary vertex
  - Pair of opposite charged tracks with large impact parameters
- Kaon PID with TPC + TOF to reduce background at low p_T

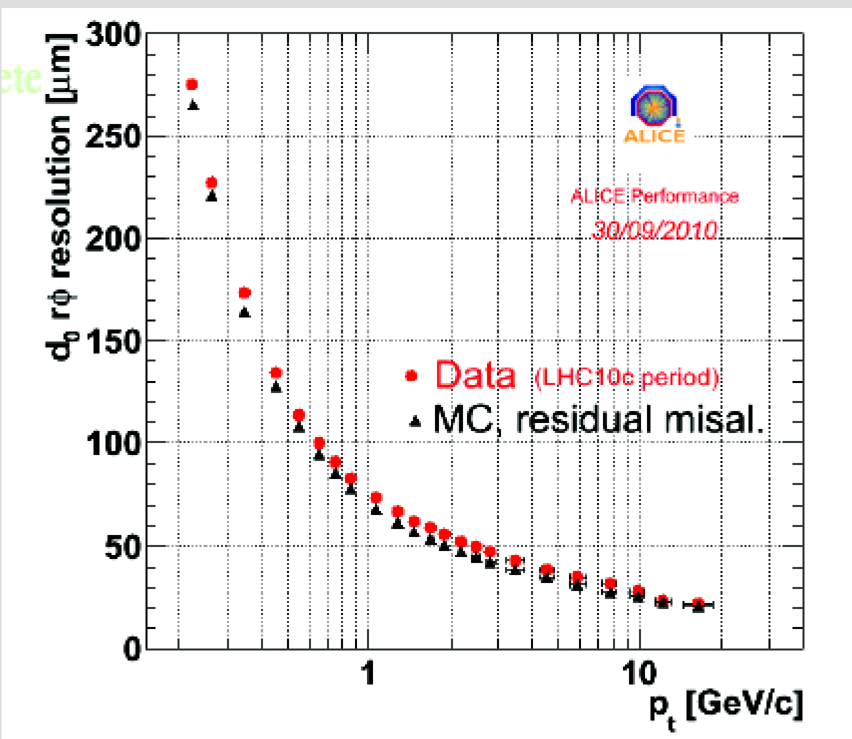
D^0: $c\tau$ = 122.9 μm
$D^{\pm}$: $c\tau$ = 311.8 μm
$D_S^{\pm}$: $c\tau$ = 149.9μm

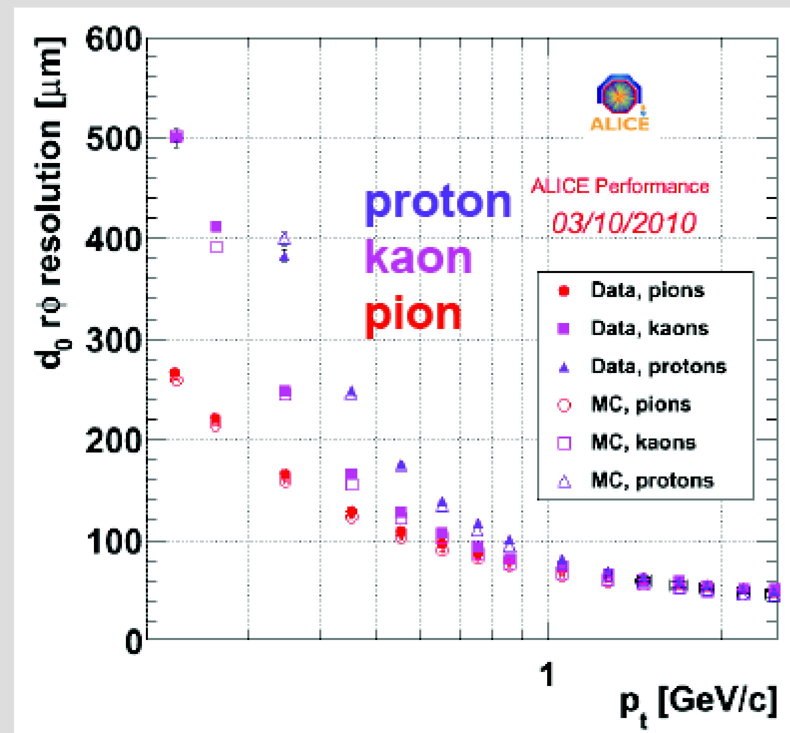


D meson reconstruction

Detector performances

- Tracking and vertexing precision crucial
- Inner Tracking System (ITS) with 6 layers: two pixel layers at 3.8 cm and 7 cm
- ITS aligned using cosmics and collisions: pixel resolution 14 µm (nominal ~11µ m)

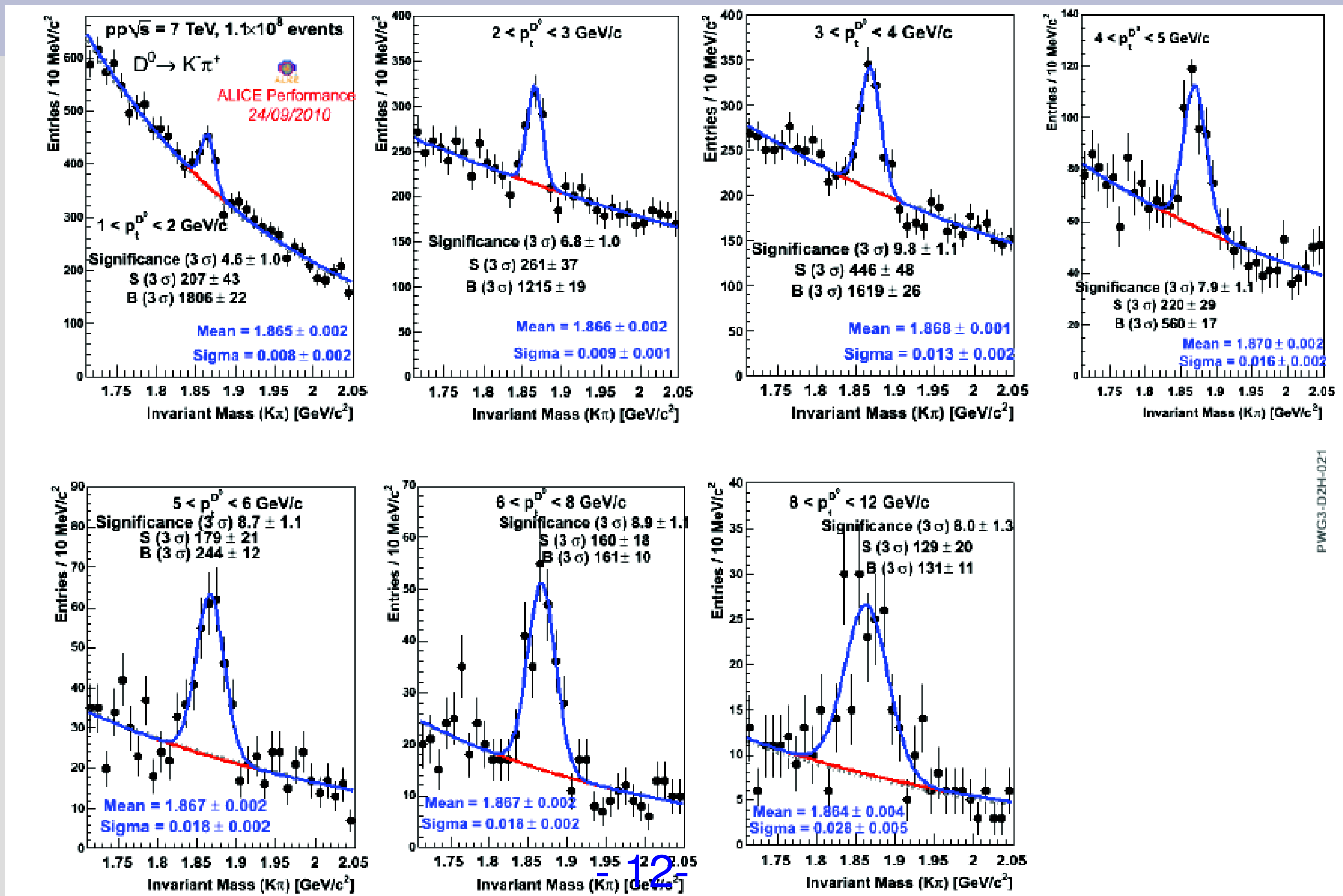




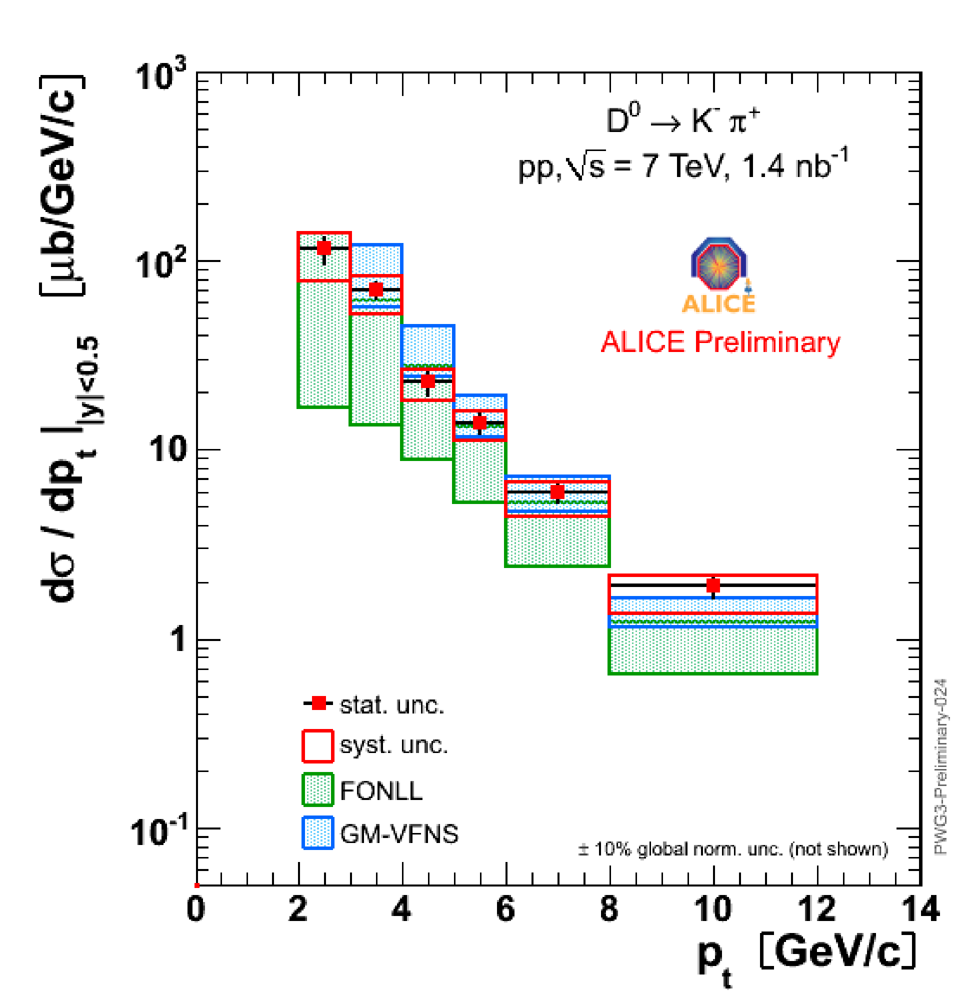
Signal extraction

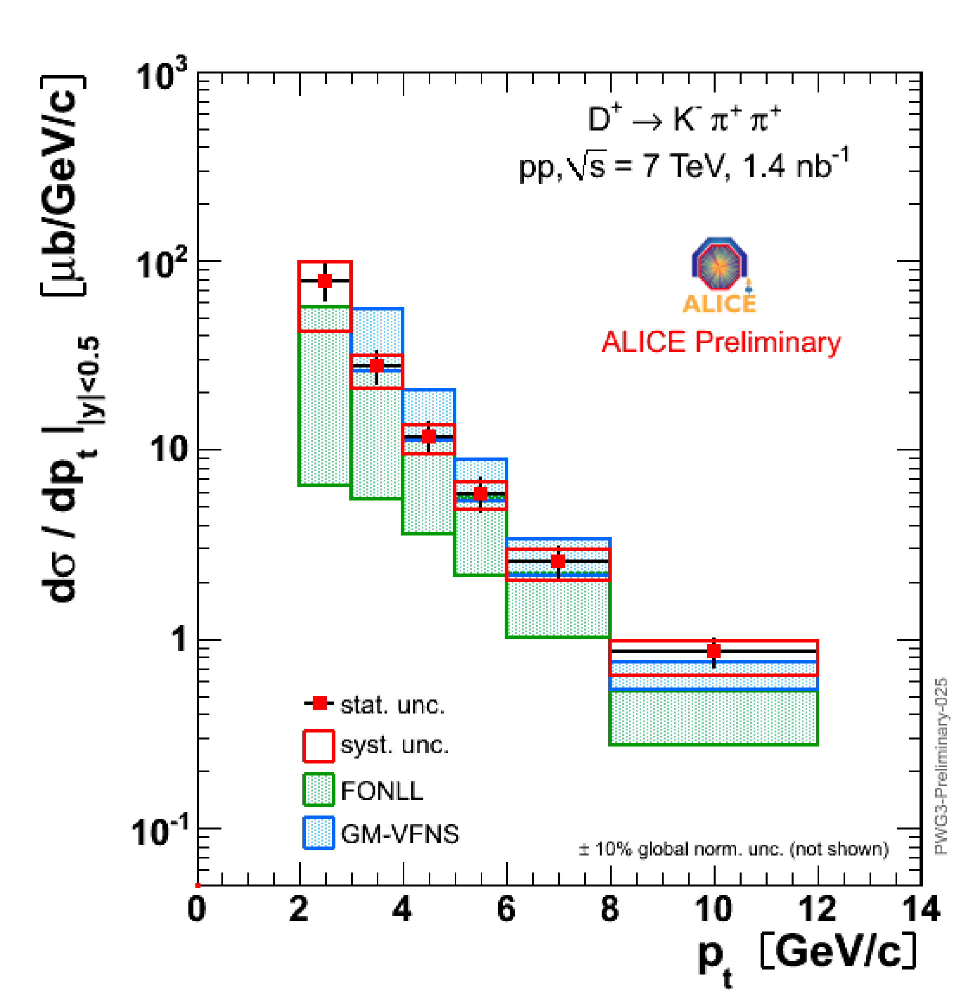
$D^0 \rightarrow K^-\pi^+$

10^8 events; 1-12 GeV in 7 bins

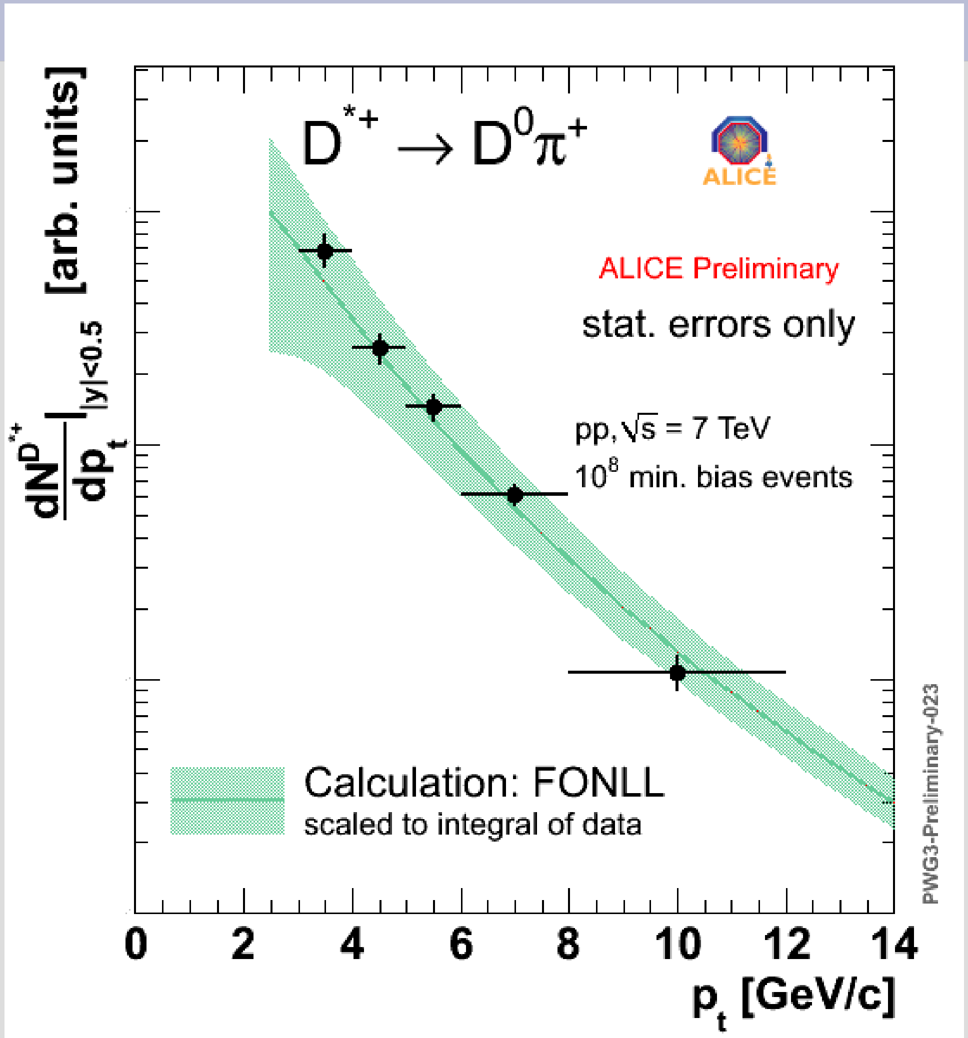


D^0 and D^+ $d\sigma/dp_T$



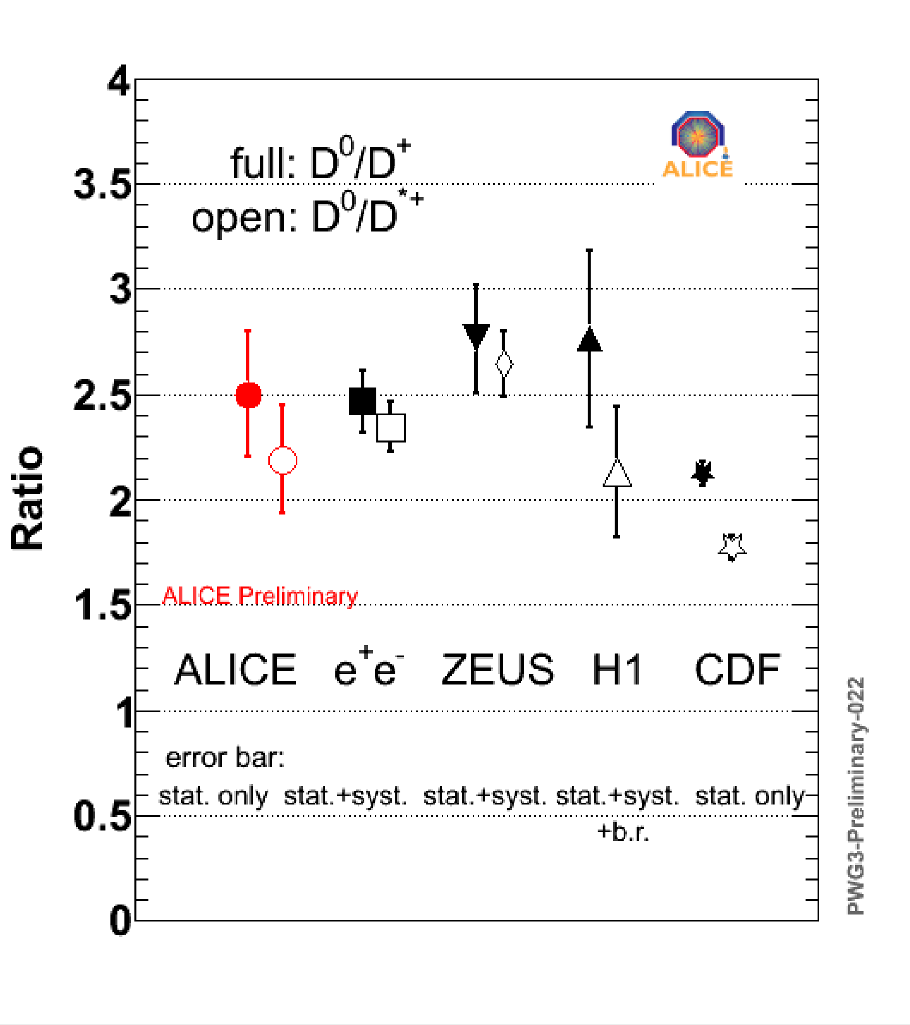


D^{*+} dN/dp_T



$D^{*+} \rightarrow D^0\pi^+$
ALICE
ALICE Preliminary
stat. errors only
pp, $\sqrt{s}$ = 7 TeV
10^8 min. bias events
Calculation: FONLL
scaled to integral of data
PWG3-Preliminary-023
$\frac{dN^{D^{*+}}}{dp_t}\Big|_{|y|<0.5}$ [arb. units]
0
2
4
6
8
10
12
14
p_t [GeV/c]

Integrated D^0/D^+ and D^0/D^{+*} ratio



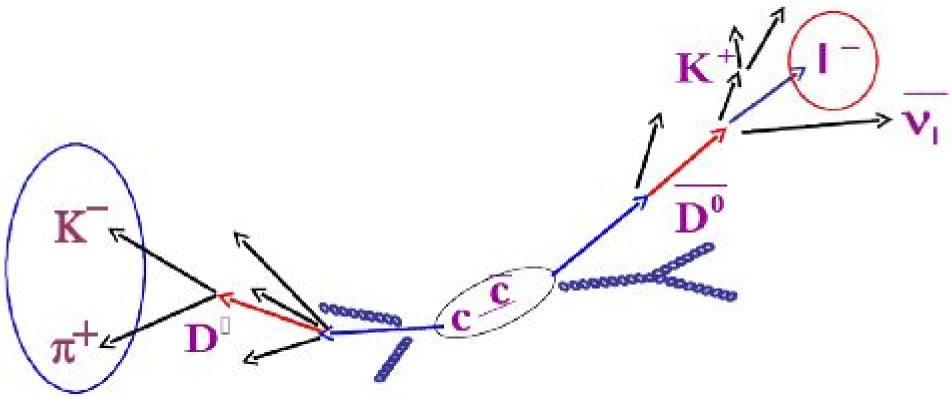
Heavy-flavour results in pp at $\sqrt{s}$=7 TeV

Heavy-flavour electrons at mid-rapidity

b/c -> e + X

Heavy-flavour electrons at mid-rapidity

Measure the Charm and Beauty production cross sections through semi-electronic decays of open charm and open beauty hadrons



Branching Ratios:

$c \rightarrow e + X$ $\mathcal{O}$ (9.6%)

$b \rightarrow e + X$ $\mathcal{O}$ (11%)

$b \rightarrow c \rightarrow e + X$ $\mathcal{O}$ (10%)

- Select electrons with large displacement to primary vertex

-> reconstruct beauty cross-section ($c\tau_{\text{(B hadrons)}} \approx$400-500 μ m)

- Measure inclusive electron spectrum

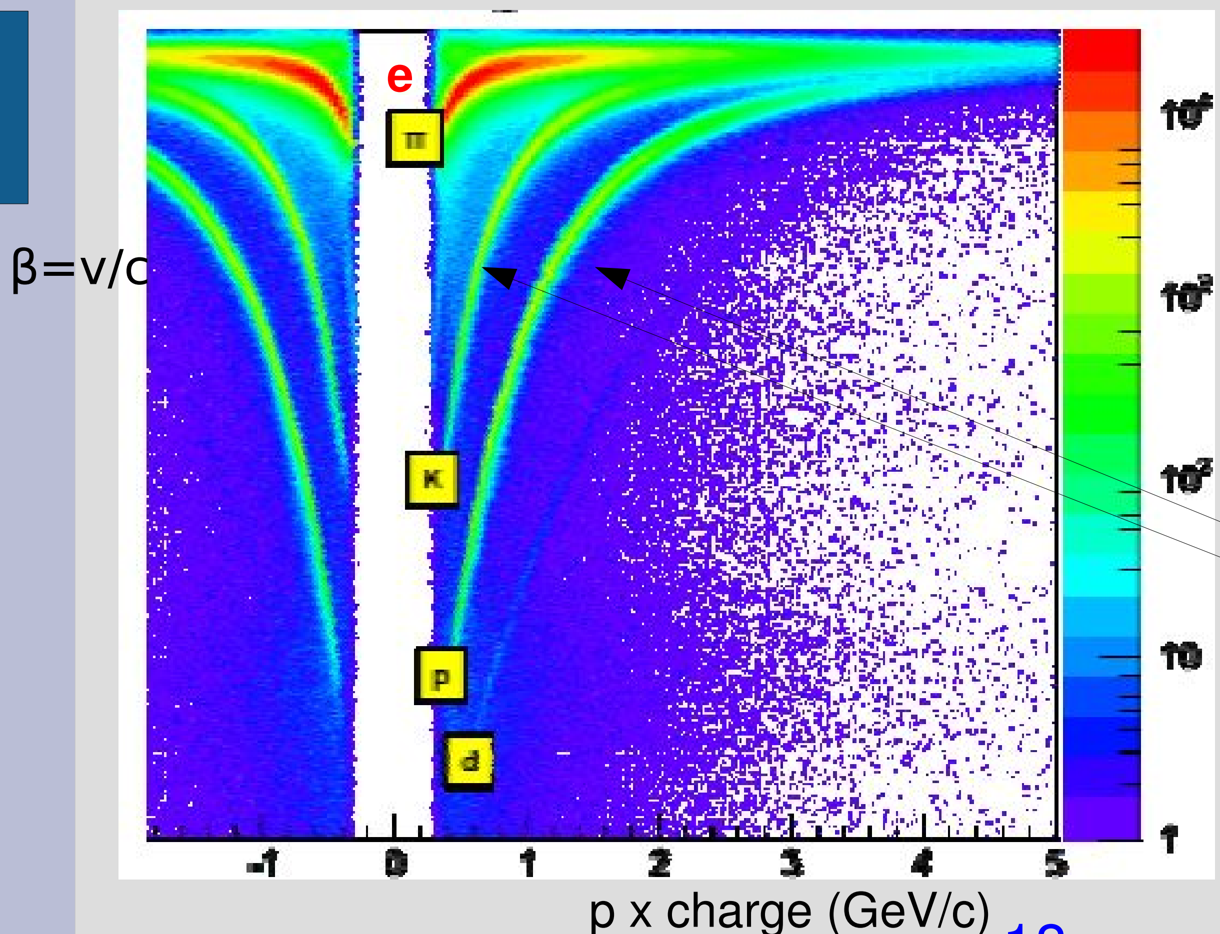
-> subtract a cocktail describing the background electron sources

-> reconstruct charm + beauty cross-section

Electron identification

withTOF and TPC

TOF PID in pp at 7 TeV

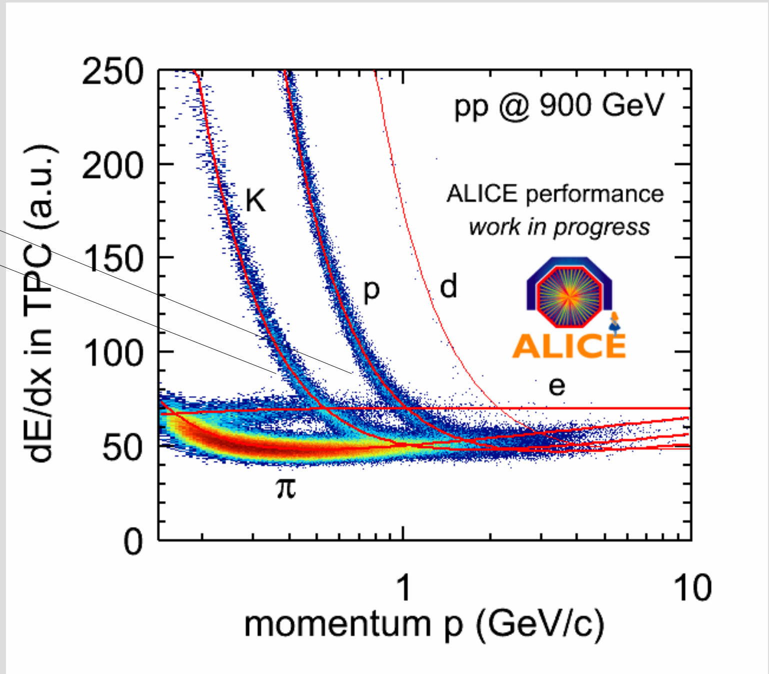


- $\pm 3\ \sigma$ TOF inclusion cut for $e^{\pm}$

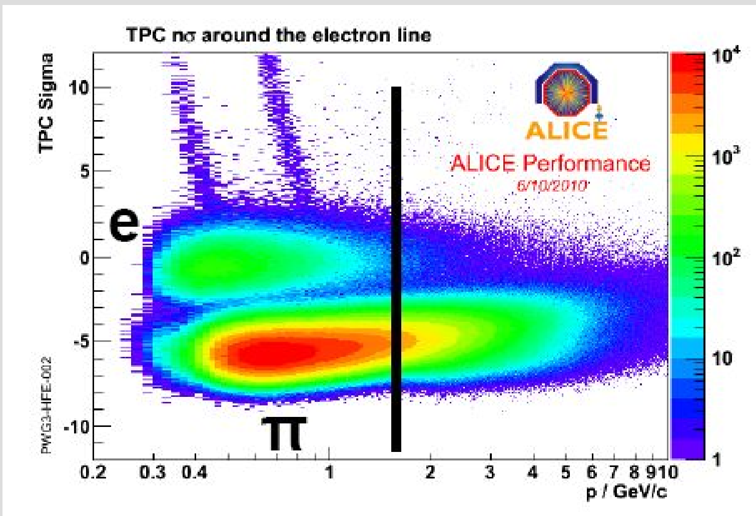
Rejection of kaons ($p < 1.5$ GeV/c) and protons ($p < 3$ GeV/c)

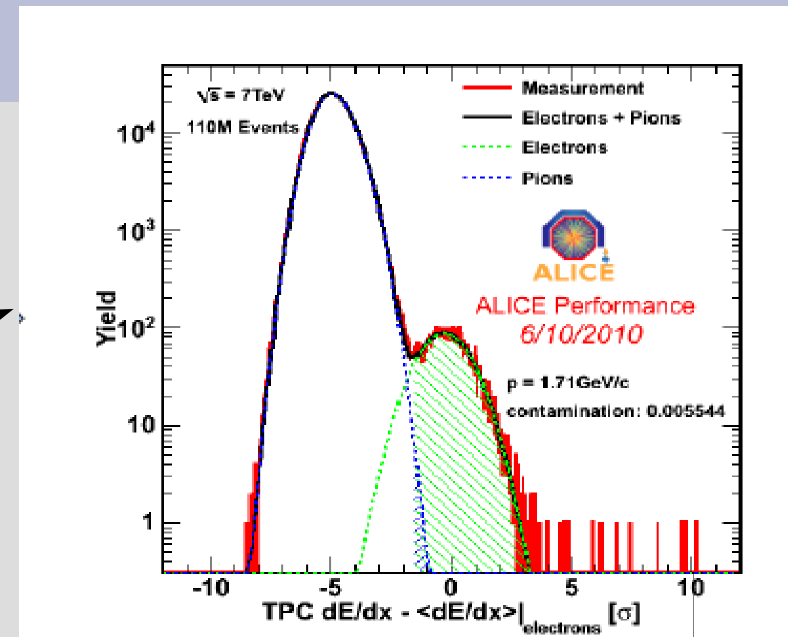
- TPC momentum dependent cut

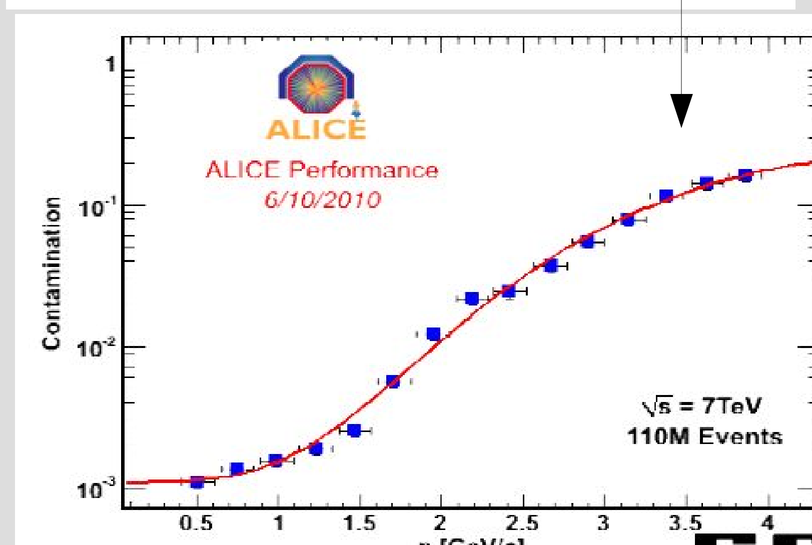
Rejection of pions



Hadron contamination





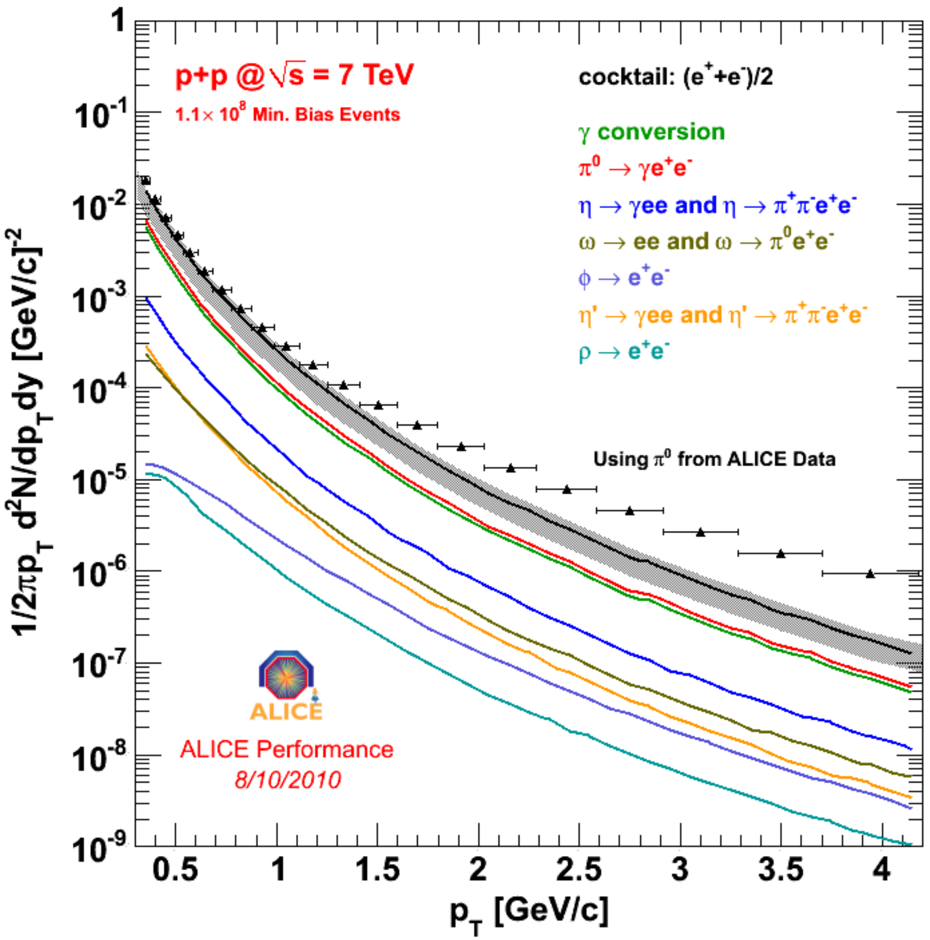


Gaussian fits of dEdx of TPC after TOF cut in momentum slices

-> Determine the hadron contamination
as function of p

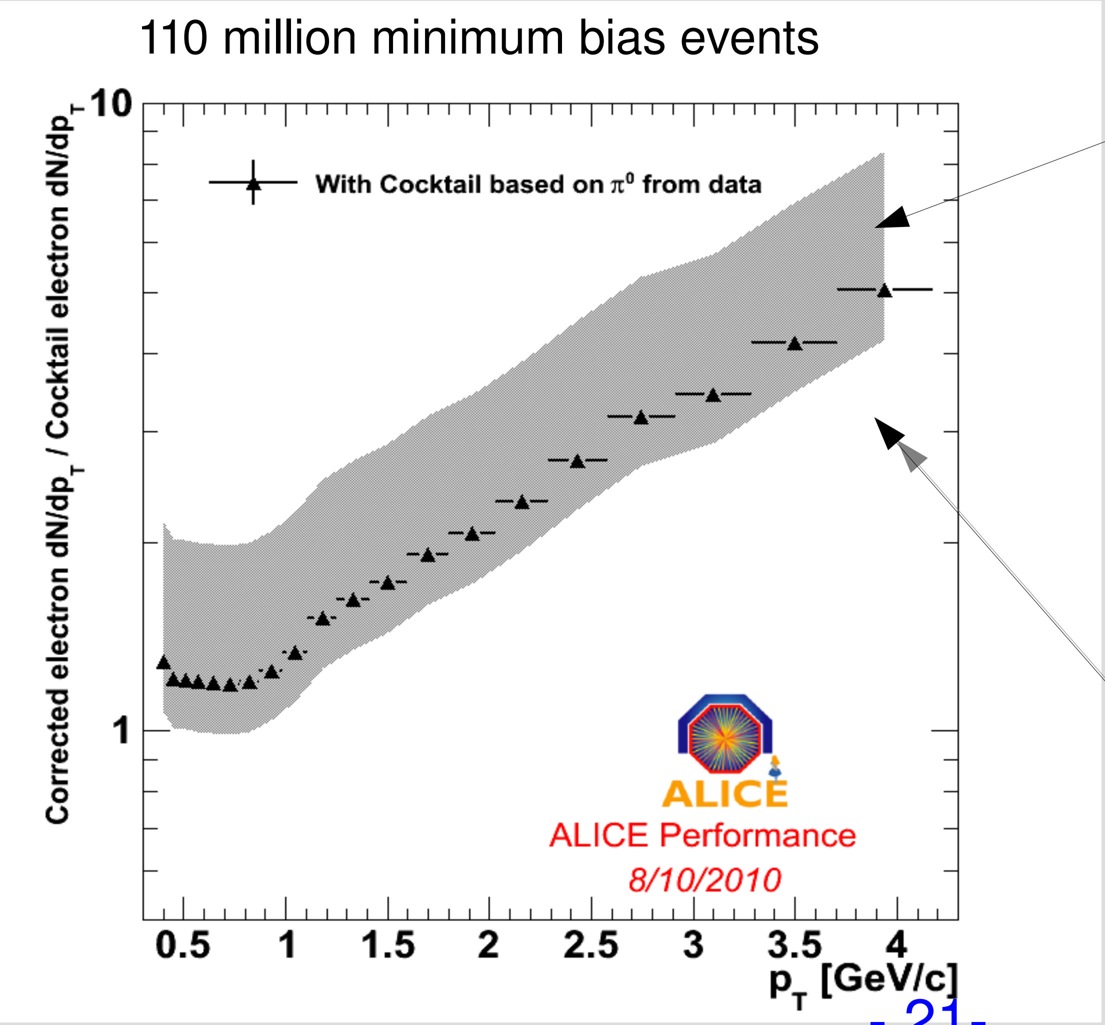
Comparison cocktail and inclusive electron spectrum

110 million minimum bias events



- Inclusive electron spectrum corrected for
  - Hadron contamination
  - Detector efficiency and acceptance
  - p_T resolution (due to Bremsstrahlung)
- Compared to cocktail based on π^0 cross section measured from double conversion reconstruction
- Large D and B decay electrons in ratio to cocktail

Ratio inclusive electron spectrum to cocktail



(now much smaller systematic error on input π^0)

The significant excess of electrons comes from charm and beauty, semileptonic decays, J/ψ, direction radiation

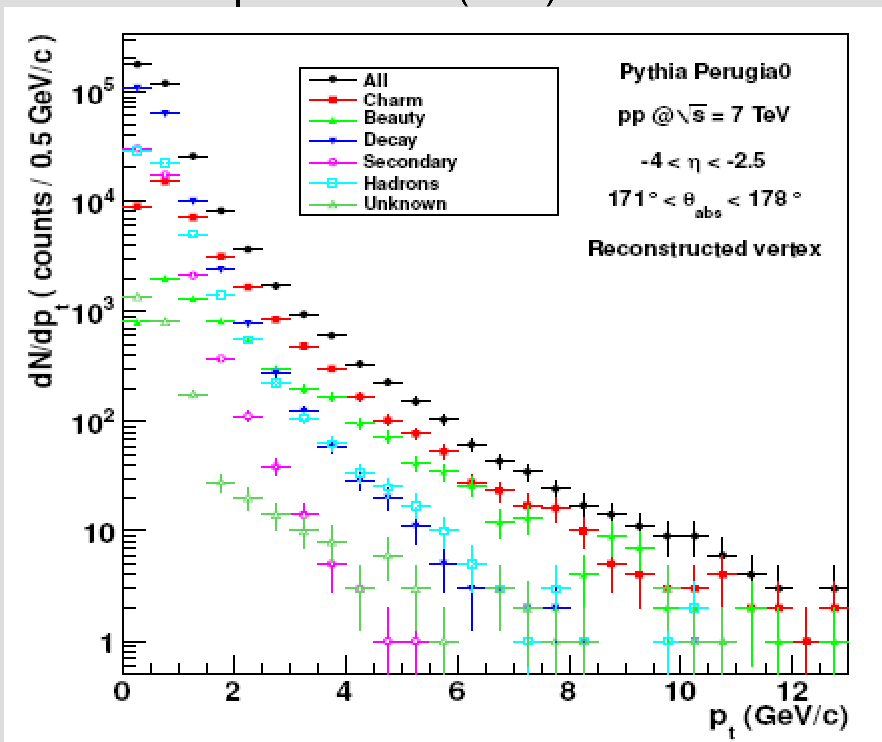
Heavy-flavour results in pp at $\sqrt{s}$=7 TeV

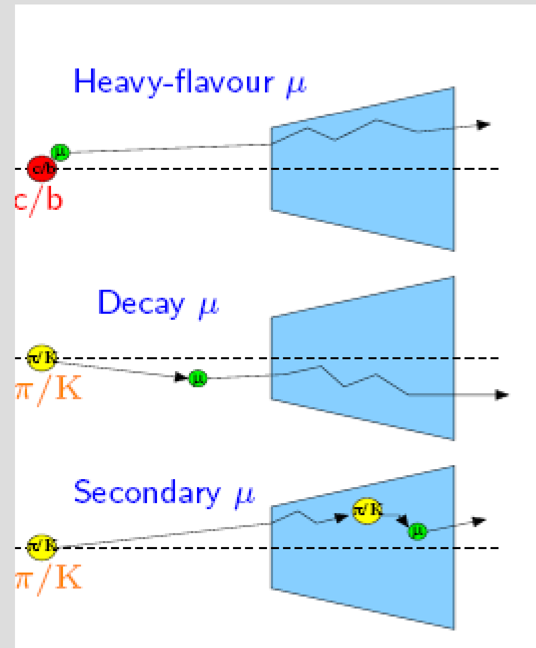
Heavy-flavour muons at forward-rapidity

b/c -> μ + X

Heavy-flavour muons at forward-rapidity

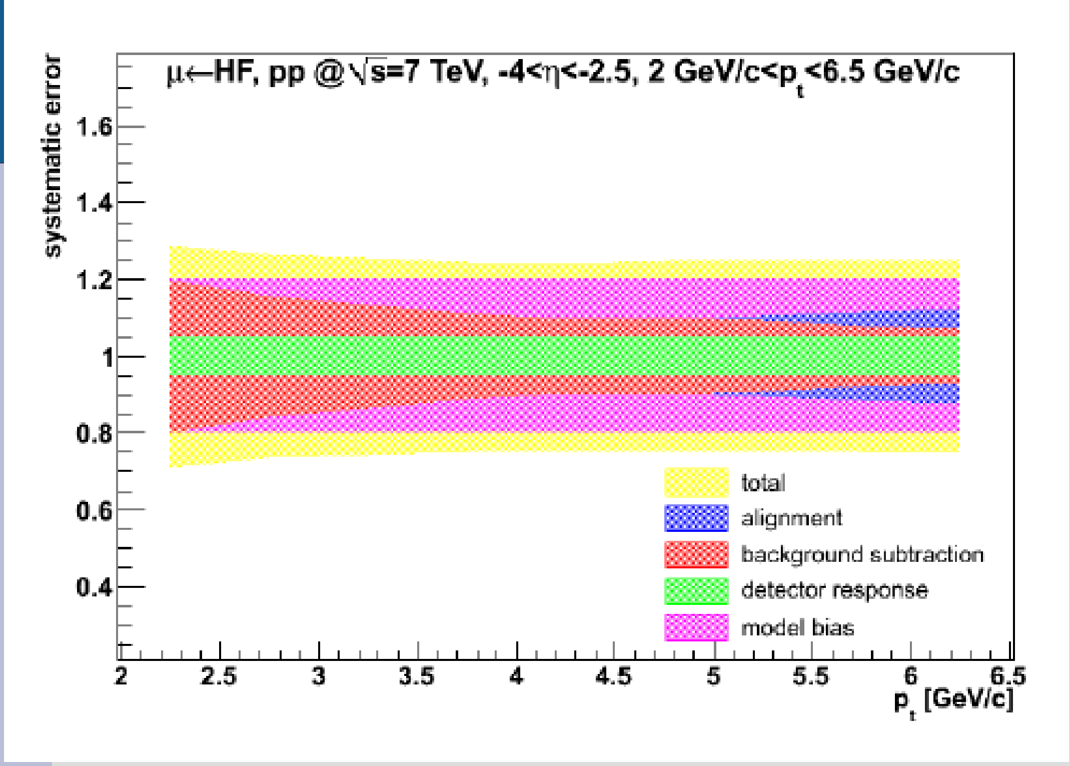
μ sources (MC)





- Remove hadrons and low-p_T secondary μ by requiring a μ trigger signal
- Remove decay μ by subtracting MC dN/dp_T normalized to data at low p_T
  - Alternative method: use μ distance of closest approach to primary vertex
- **What is left are muons from charm and beauty**

Systematic errors



Background substraction

• Above p_T > 2 GeV/c, secondary μ contribution low (< 10%)

Taken from MC and varied by 100%

• Main source of background: decay μ

Subtract the contribution using two different MC Pythia tunes

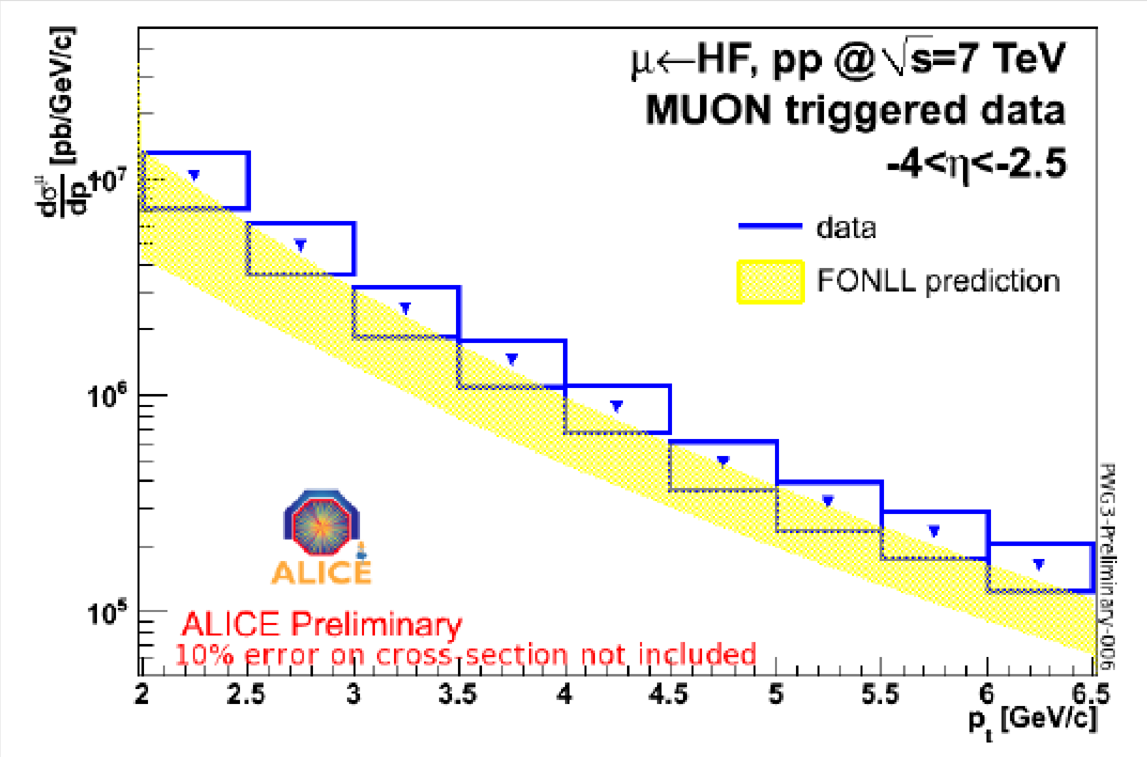
-> 20% systematic model bias errors

Efficiency

About 87% above 2.5 GeV/c

5% systematic errors

$d\sigma/dp_T$ of D and B muons



Next step: use the µ distance of closest approach to primary vertex to reduce systemactic errors from secondary µ background subtraction

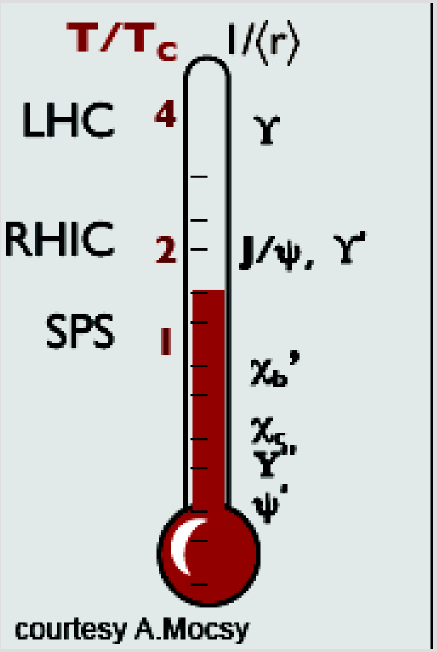
Heavy-flavour results in pp at $\sqrt{s}$=7 TeV

J/ψ production cross section at mid- and forward rapidity

J/ψ -> e^+e^- and J/ψ -> $\mu^+\mu^-$

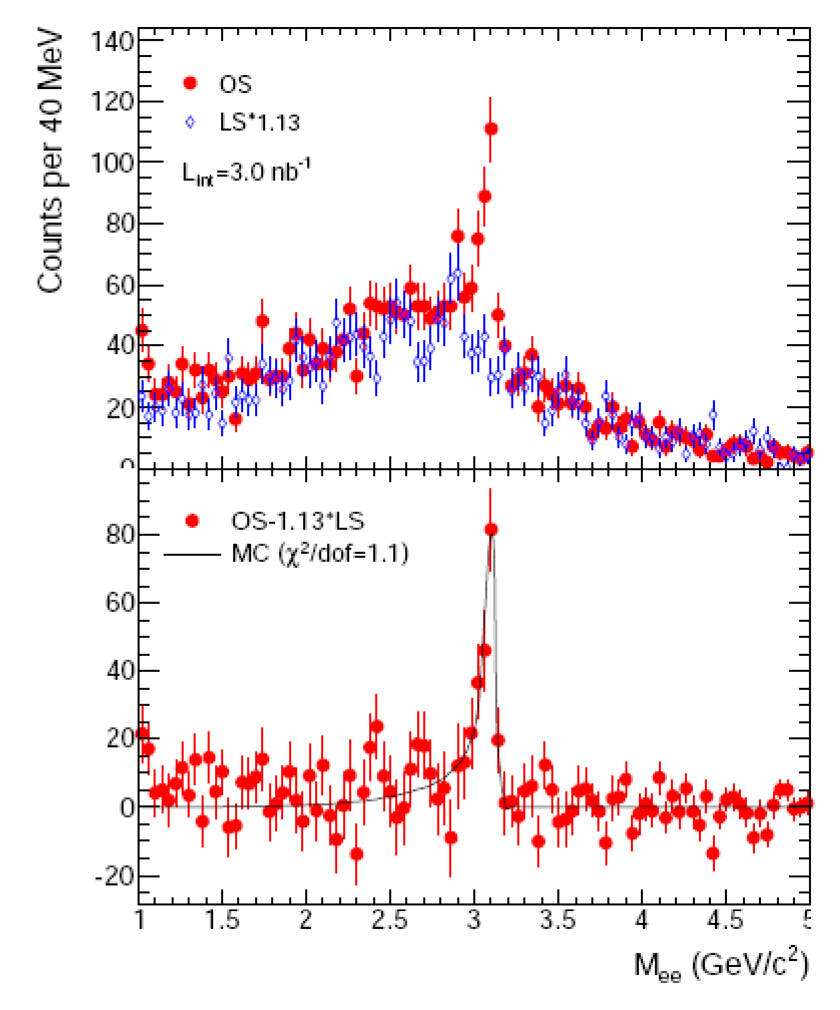
Quarkonia at the LHC

- Quarkonia dissociation due to colour screening
- Dissociation pattern depends on binding energy T_D and medium temp. T
  - Υ would dissociate only at LHC
  - Υ' T_D ~ J/ψ T_D



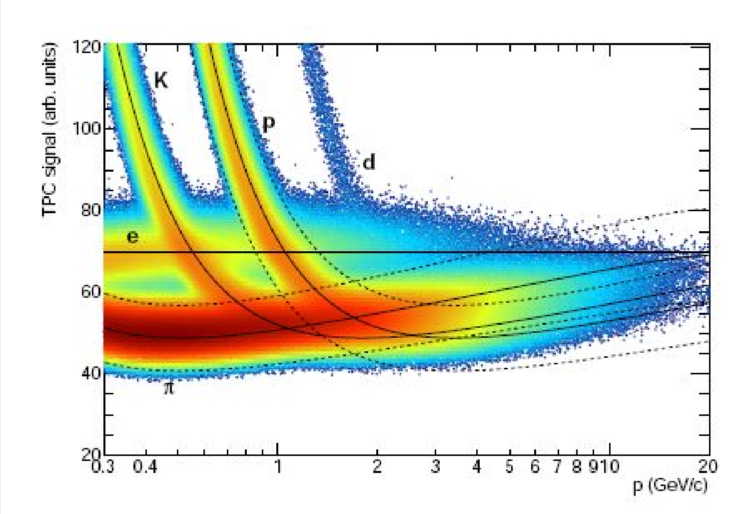
- Expected regeneration for charmonia due to amount of charm quarks in the medium

J/ψ -> e^+e^- at mid-rapidity



- Identify electrons with TPC
  - ±3 σ inclusion cut for electrons
  - ±3 σ exclusion for pions and protons

- Invariant mass distributions for like-sign (LS) and opposite sign (OS) electron pairs
  - Match the LS to OS in mass interval 3.2-5.0 GeV/c^2



J/ψ -> e^+e^- at mid-rapidity systematic errors

Channel	e^+e^-	
Signal extraction	8	
Acceptance input	1	
Trigger efficiency	0	
Reconstruction efficiency	10	
Luminosity		10
B.R.		1
Polarization	$\lambda = -1$	$\lambda = 1$
CS	+25	–12
HE	+20	–10

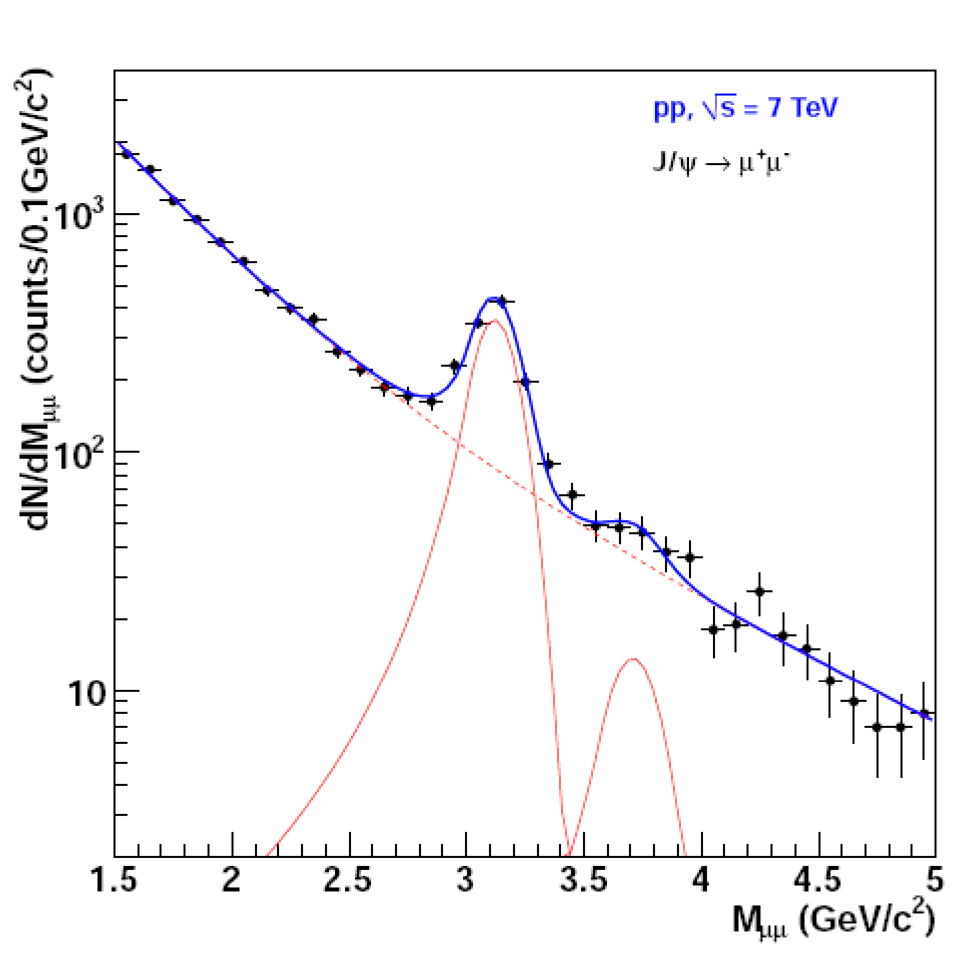
The unknown polarization dominates the systematic errors

CS = Collins-Soper
HE = helicity reference frames

λ= -1 longitudinal polarization
λ= 1 transverse polarization

$N_{J/\psi}$= 218 ± 26(stat.) ± 17(syst.) for L = 3.0 nb^{-1}

$J/\psi \to \mu^+\mu^-$ at forward-rapidity



- Single μ trigger (p_T^{μ} > 0.5 GeV/c)
- Invariant mass distributions for opposite sign muon pairs
- Extract the signal with a fit in 1.5-5 GeV/c^2 region
  - Crystal Ball functions for J/ψ and ψ
  - Sum of two exponentials for background

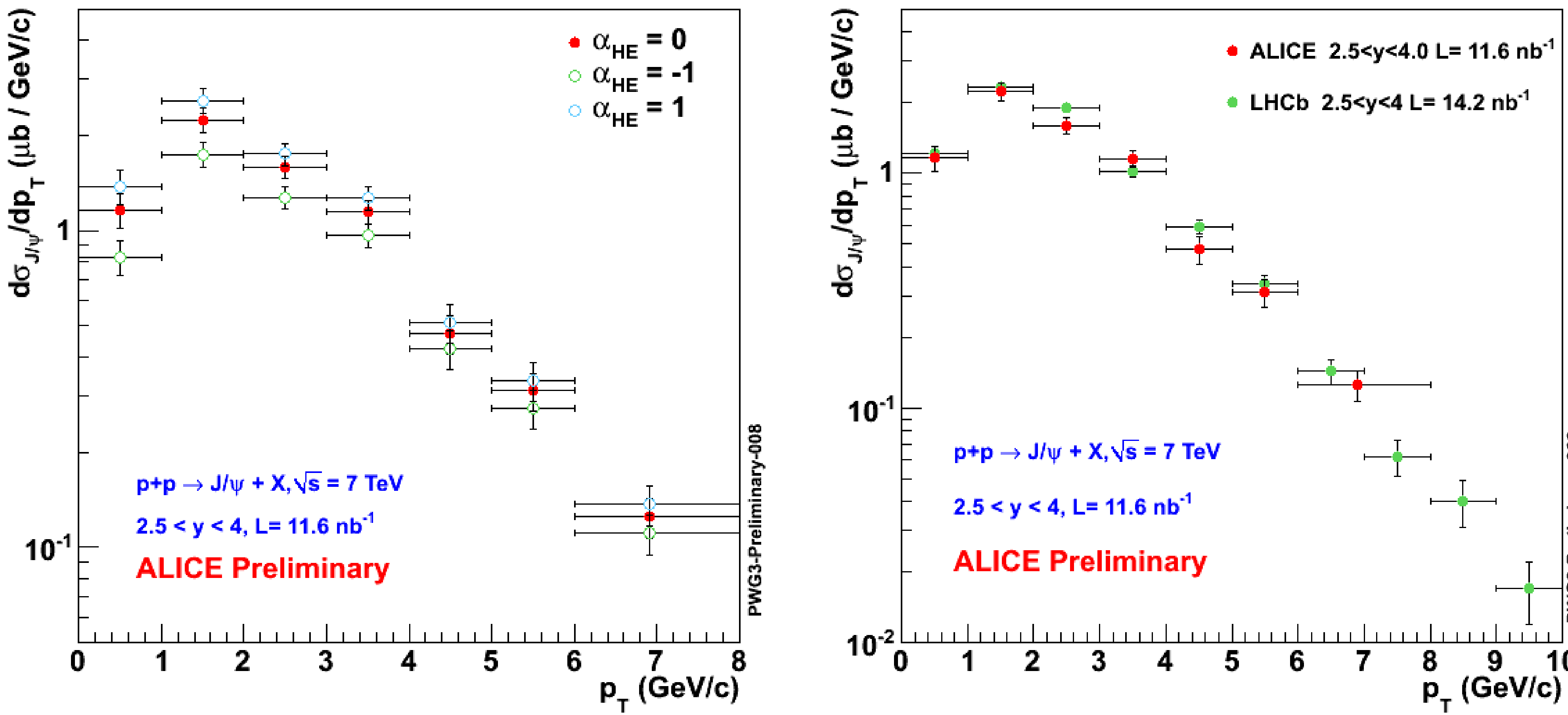
Sub-period with $N_{J/\psi}$ = 957 ± 56

$J/\psi \rightarrow \mu^+\mu^-$ at forward-rapidity Systematic errors

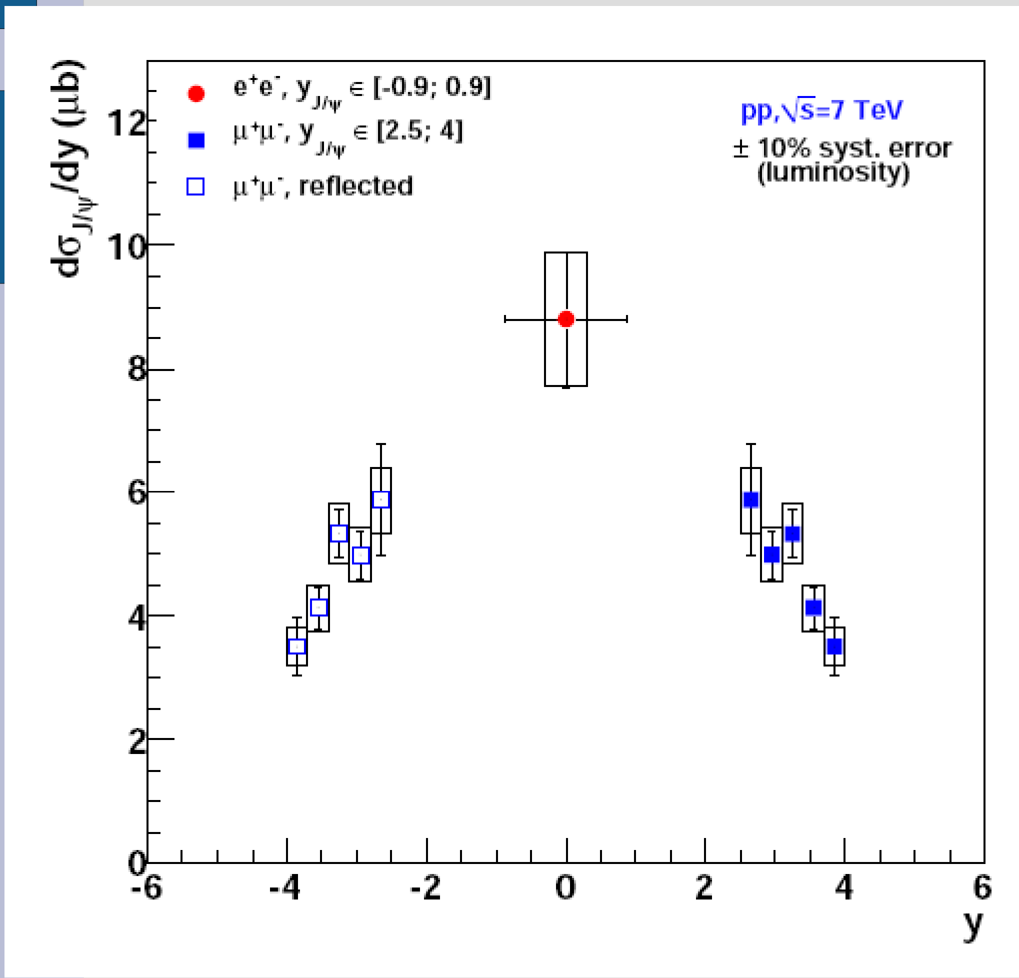
Channel	e^+e^-		$\mu^+\mu^-$	
Signal extraction	8		7.5	
Acceptance input	1		2	
Trigger efficiency	0		4	
Reconstruction efficiency	10		2	
Luminosity	10			
B.R.	1			
Polarization	$\lambda = -1$	$\lambda = 1$	$\lambda = -1$	$\lambda = 1$
CS	+25	−12	+31	−15
HE	+20	−10	+22	−10

$N_{J/\psi} = 1924 \pm 77(\text{stat.}) \pm 144(\text{syst.})$ for $L = 13.6\ \text{nb}^{-1}$

$J/\psi \to \mu^+\mu^-$ at forward-rapidity $d\sigma/dp_T$ spectrum



J/ψ dσ/dy spectrum



This measurement = direct J/ψ + radiative decay of higher-mass charmonium

Next: separate the different contributions

-> Central barrel:

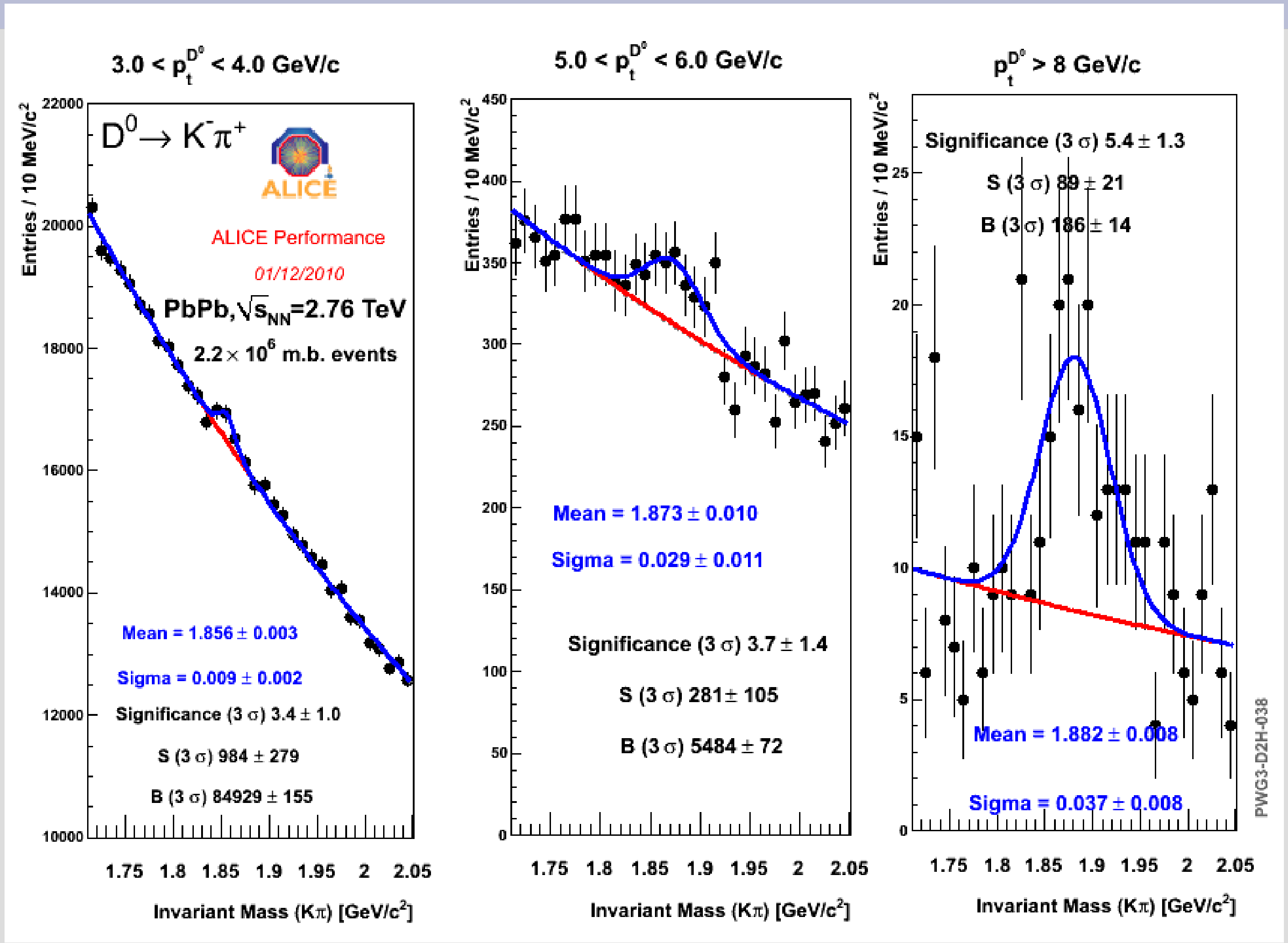
- J/ψ from b via pseudo-proper time distribution
- $\chi_c \rightarrow J/\psi + \gamma$ decay measurement

-> forward-rapidity:

- Contribution from b-decays estimated from the measured beauty cross section via single μ

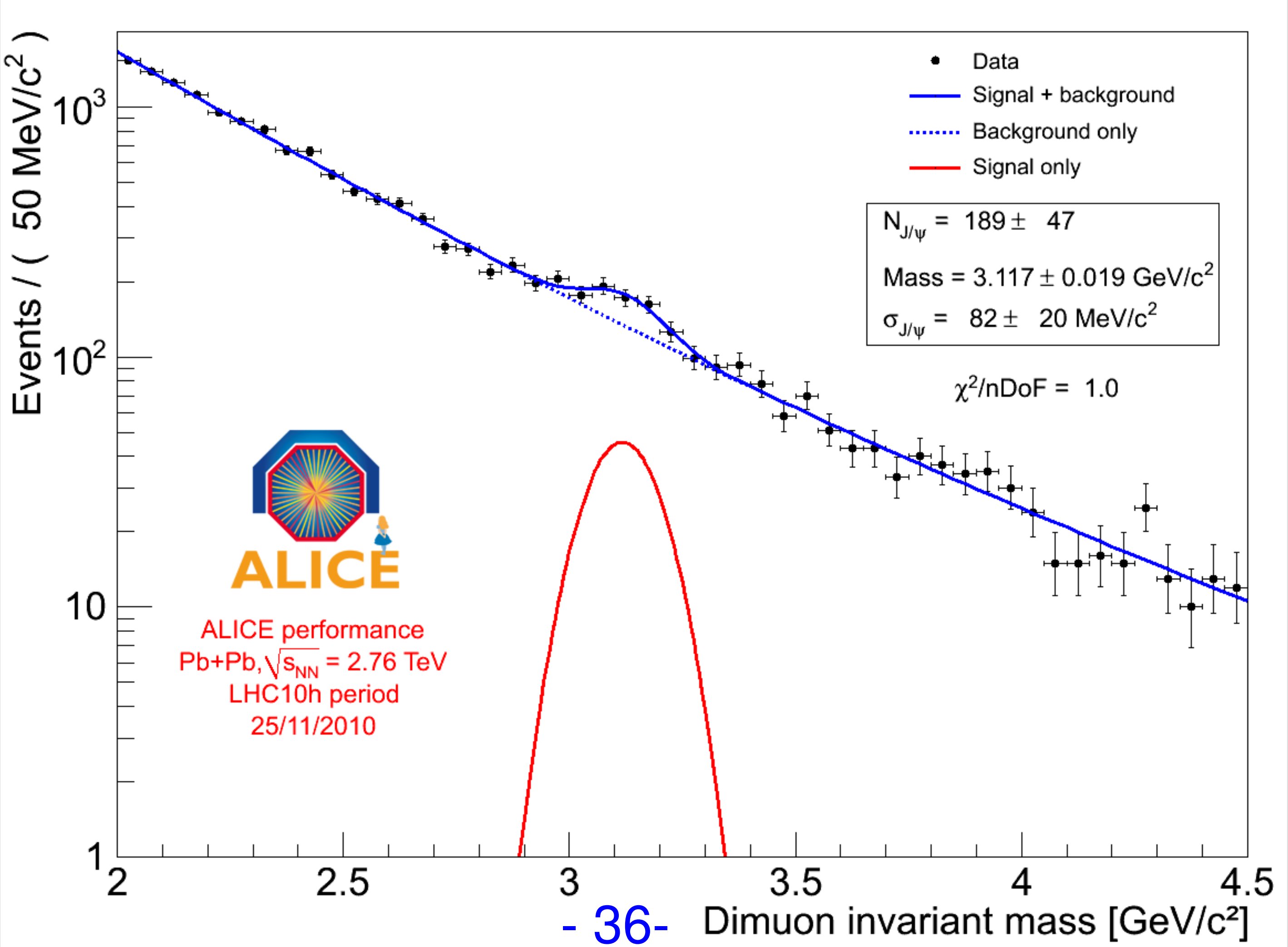
First look at Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

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



3.0 < $p_t^{D^0}$ < 4.0 GeV/c
$D^0 \to K^-\pi^+$
ALICE
ALICE Performance
01/12/2010
PbPb, $\sqrt{s_{NN}}$=2.76 TeV
2.2 × 10^6 m.b. events
Mean = 1.856 ± 0.003
Sigma = 0.009 ± 0.002
Significance (3 σ) 3.4 ± 1.0
S (3 σ) 984 ± 279
B (3 σ) 84929 ± 155
Entries / 10 MeV/c^2
Invariant Mass (Kπ) [GeV/c^2]
5.0 < $p_t^{D^0}$ < 6.0 GeV/c
Mean = 1.873 ± 0.010
Sigma = 0.029 ± 0.011
Significance (3 σ) 3.7 ± 1.4
S (3 σ) 281 ± 105
B (3 σ) 5484 ± 72
$p_t^{D^0}$ > 8 GeV/c
Significance (3 σ) 5.4 ± 1.3
S (3 σ) 89 ± 21
B (3 σ) 186 ± 14
Mean = 1.882 ± 0.008
Sigma = 0.037 ± 0.008
PWG3-D2H-038

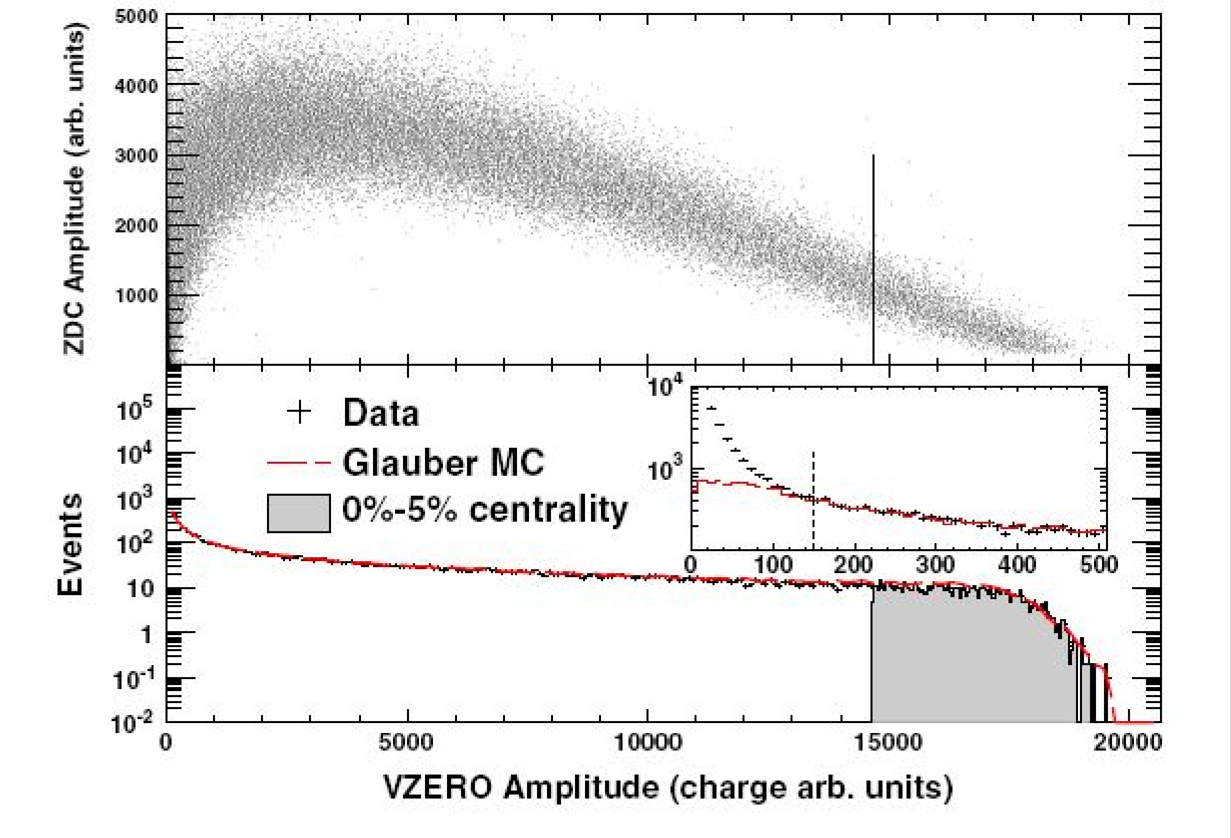
J/ψ -> $\mu^+ \mu^-$



Data
Signal + background
Background only
Signal only
N J/ψ = 189 ± 47
Mass = 3.117 ± 0.019 GeV/c²
σ J/ψ = 82 ± 20 MeV/c²
χ²/nDoF = 1.0
ALICE
ALICE performance
Pb+Pb, √sNN = 2.76 TeV
LHC10h period
25/11/2010
Events / (50 MeV/c²)
Dimuon invariant mass [GeV/c²]

Next: centrality selection R_{AA} or R_{CP}

nucl-ex arXiv:1011.3916



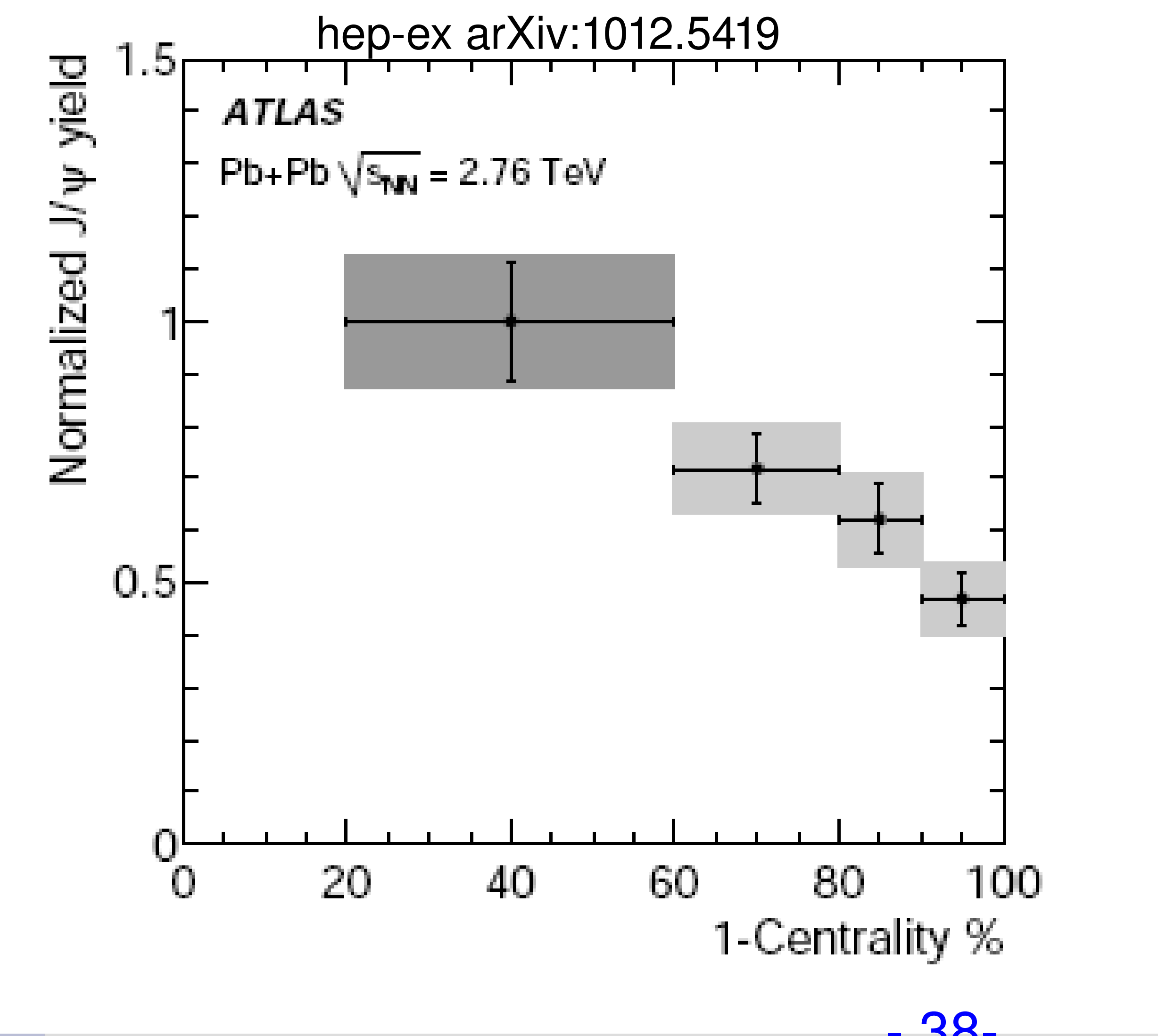
- Zero Degree Calorimeter

- Sum of amplitudes in the VZERO scintillator tiles

-> fit of Glauber calculation to the data

(low amplitude dominated by electromagnetic the processes not taken in the fit)

ATLAS results



- J/ψ -> μ μ
  $|\eta_\mu| < 2.4$
  $p_{T\mu} > 3$ GeV/c

corrected for efficiency per centrality bins

- Centrality from the total transverse energy measured in the forward calorimeter

- $R_{CP} = N_c^{corr}/(N_{40\text{-}80\%}^{corr} \times N_{coll})$

Summary and outlook

- ALICE Heavy-flavour results in proton-proton at $\sqrt{s}$=7 TeV
  - D meson p_T distributions and D^0/D^+ ratio
  - Heavy-flavour electrons at mid-rapidity
  - Heavy-flavour μs at forward-rapidity
  - J/ψ production cross section at mid- and forward rapidity

Most of them on the upper edge of prediction
but in agreement within errors

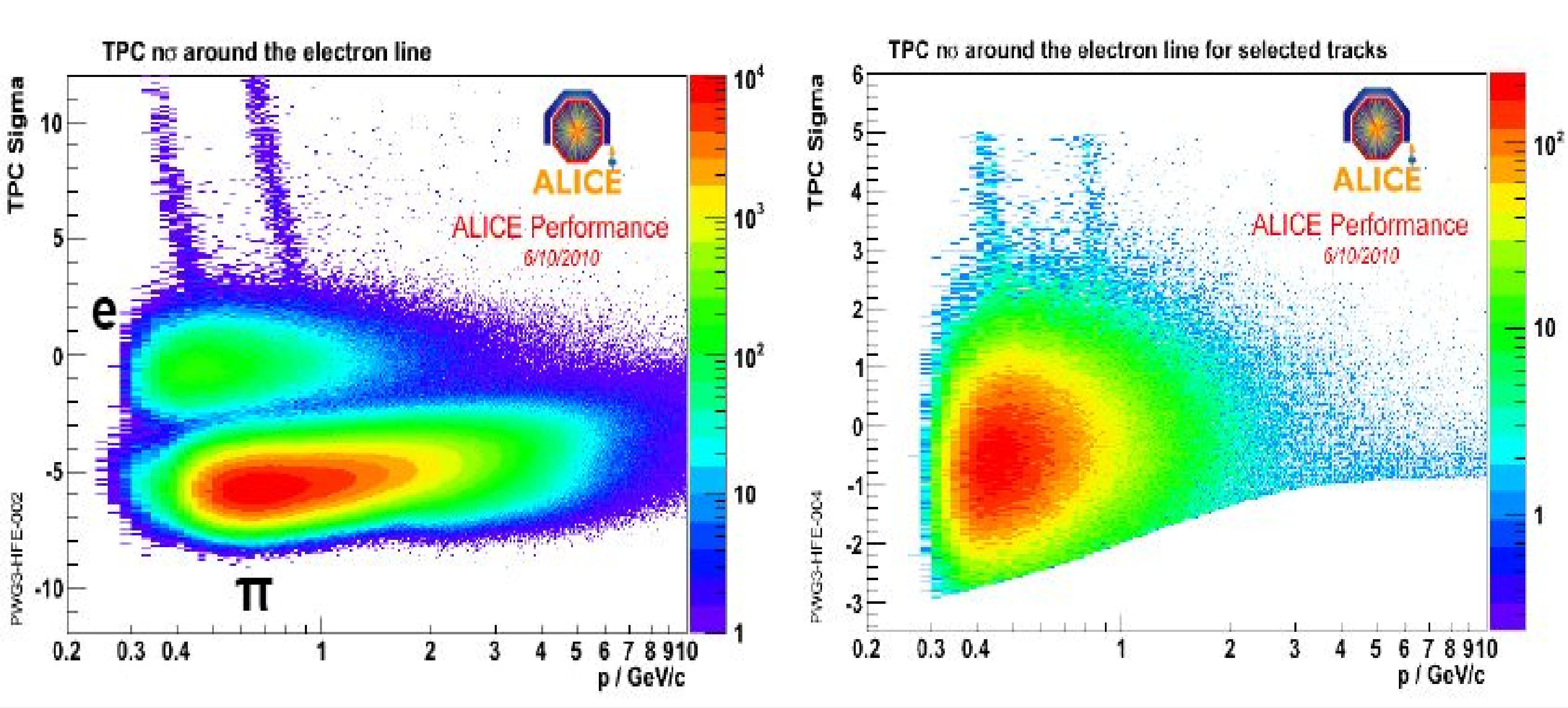
- Working on PbPb collisions!

THANK YOU

Electron identification

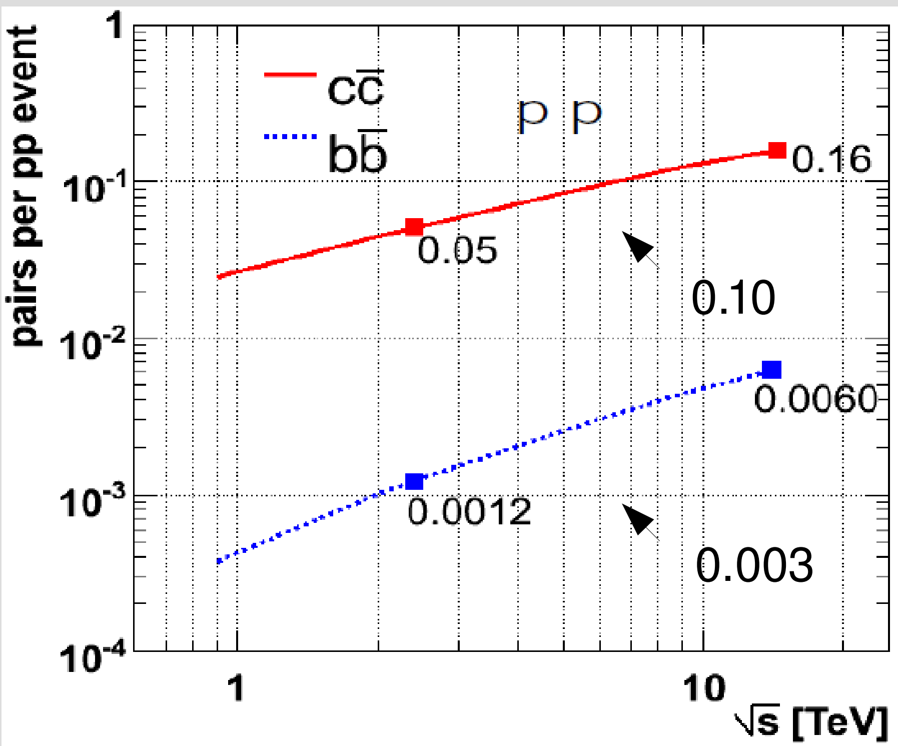
π± rejection with TPC

TPC PID after TOF PID in pp at 7 TeV



Heavy Quarks production: prediction in pp and features

Mangano,Nason,Ridolfi, NPB373 (1992) 295



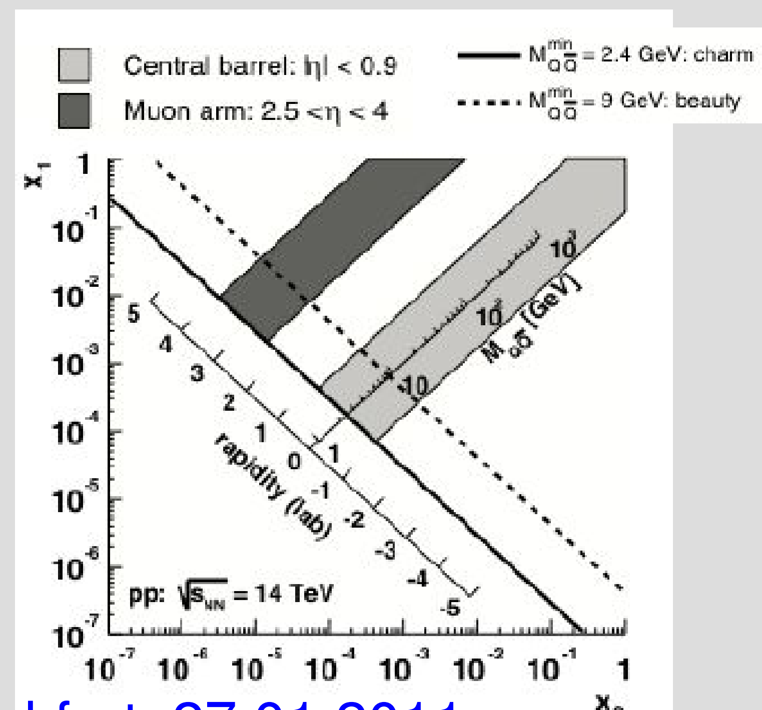
-> Need a measurement at these energies

LHC production much higher than at RHIC

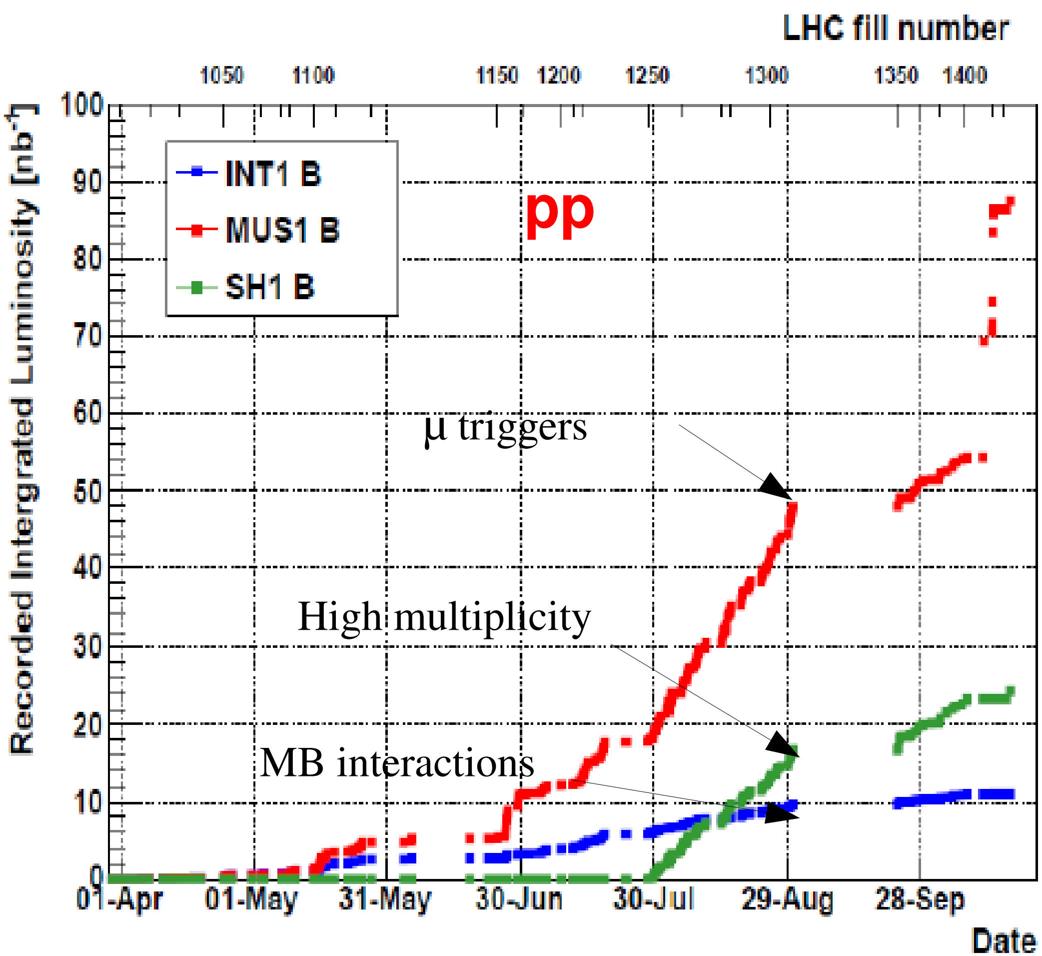
- $\sigma^{c\bar{c}}_{LHC} \approx 10 \cdot \sigma^{c\bar{c}}_{RHIC}$
- $\sigma^{b\bar{b}}_{LHC} \approx 50 \cdot \sigma^{b\bar{b}}_{RHIC}$

Still a factor 2 uncertainty

Probe unexplored small-x region



Data Taking in ALICE



INT1B: minimum-bias trigger

- Signals from two beam πck-up counters
- AND a hit in:
  - One of the VZERO scintillator hodoscopes
  - OR one of the two πxels layers

MUS1B: µ trigger

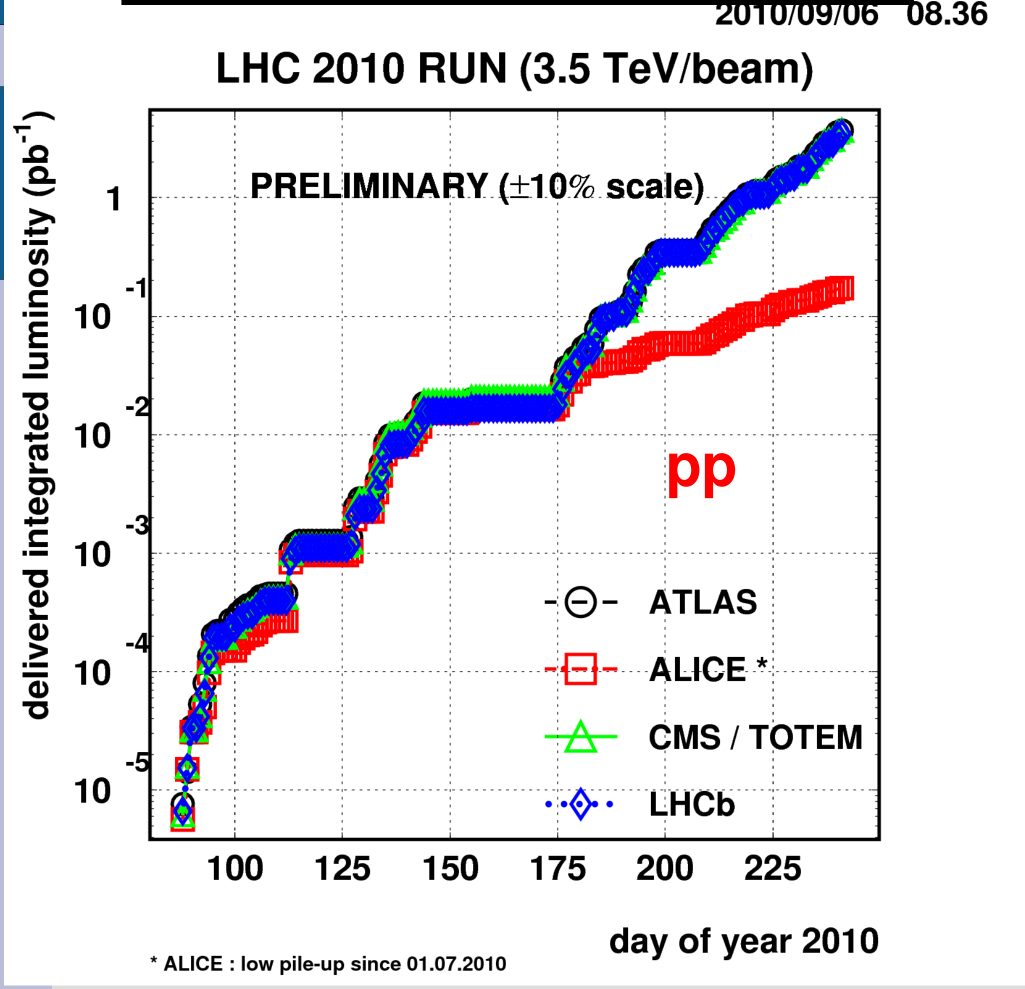
- Single µ trigger

Additional event selection

•offline minimum bias trigger
•beam-gas events excluded by VZERO
• primary vertex reconstruction

Large Hadron Collider

Reduced luminosity since 01/07 for ALICE (displaced beams)



pp collisions

- $\sqrt{s}$=900 GeV (2009 & 2010)
- $\sqrt{s}$=2.36 TeV (not all detectors in ALICE ON 2009)
- **$\sqrt{s}$=7 TeV (2010)**

PbPb collisions

- $\sqrt{s_{NN}}$=2.76 TeV (startet on 8th nov 2010 until 5th dec)

Back-up slices

Inclusive p_T electron spectum and an 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, Y)

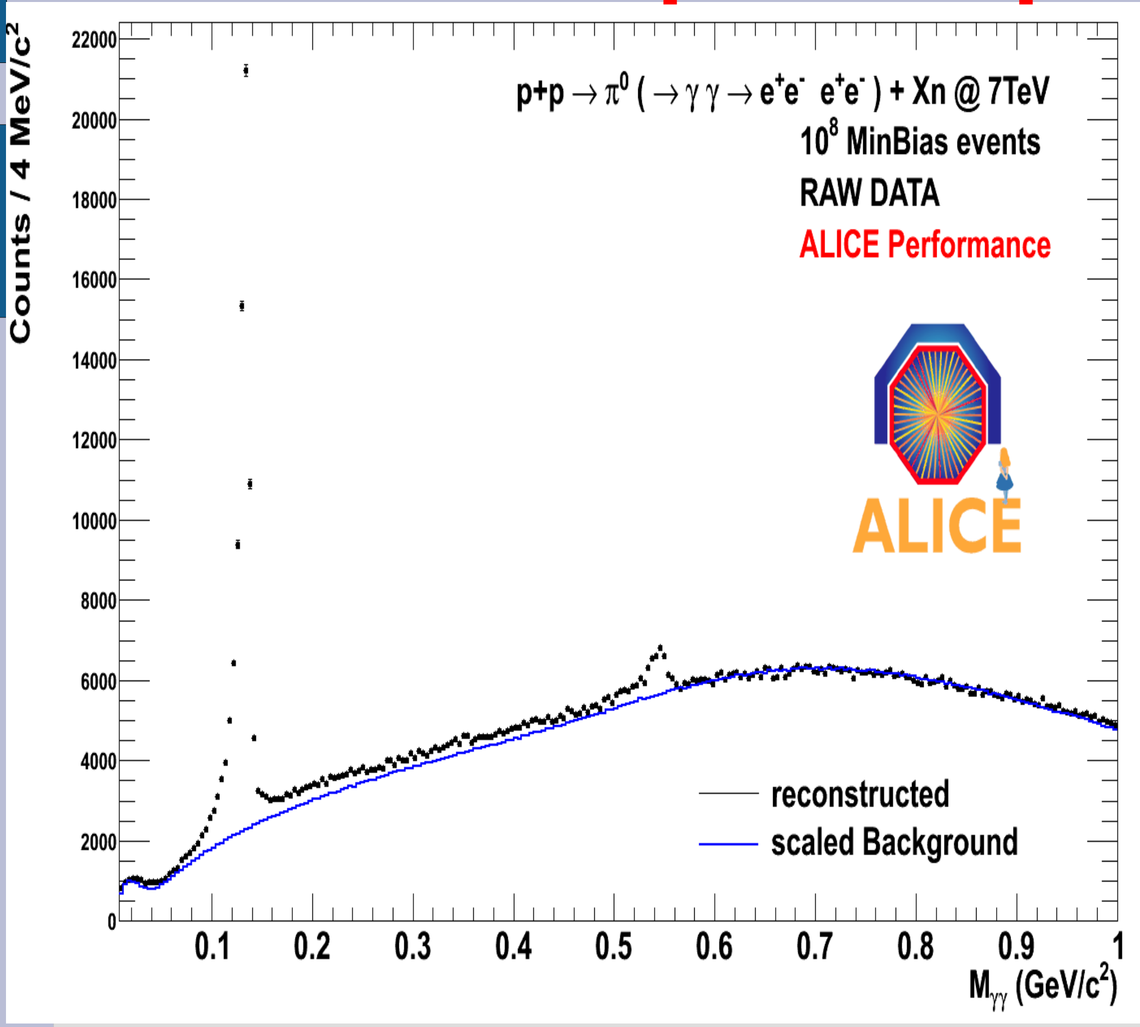
Current cocktail ingredients used to interpret the data:

- Neutral πs (based on the measured π_0 spectrum!)
- Heavier mesons: η, ρ, ω, φ, η'
- Photon conversions
- J/ψ not official yet (based on data)

Back-up slices

Cocktail ingredients:

The input Π^0 spectrum data



- Π^0 (and ŋ) reconstructed via photon conversion in the detector material
  $\gamma \rightarrow e^+e^-$

$$M_{\gamma\gamma} = \sqrt{2E_{\gamma 1}E_{\gamma 2}(1-\cos\theta_{\gamma 1\gamma 2})}$$

- With 9.5×10^7 Minimum Bias collisions:
  - π^0 measured from p_T = 0.4 GeV/c to p_T= 7 GeV/c
  - η measured from p_T = 0.6 GeV/c to p_T = 6 GeV/c

- Important to know the detector budget and the probability for a photon to convert (about 8,6%)

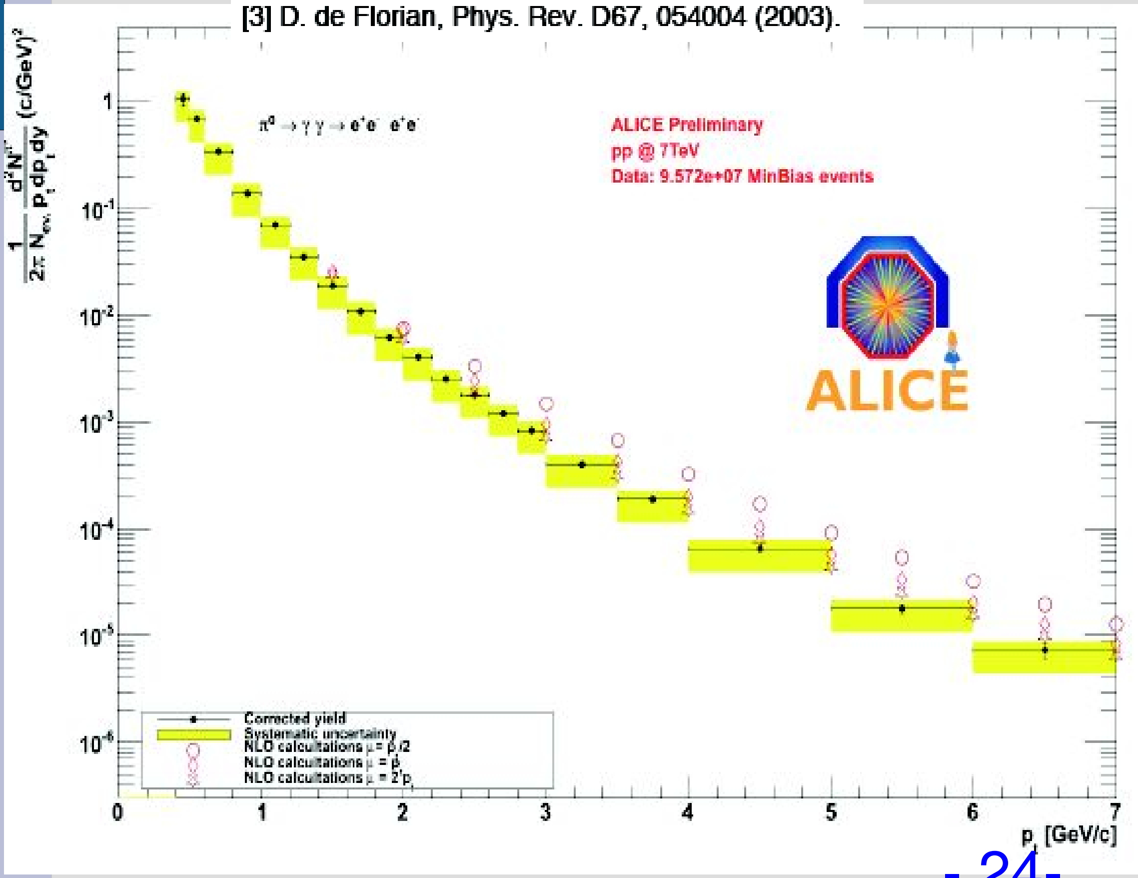
Back-up slices

Cocktail ingredients:

The input Π^0 spectrum data

NLO calculations from Werner Vogelsang

[1] F. Aversa et al., Nucl. Phys. B327, 105 (1989).
[2] B. Jäger et al., Phys. Rev. D67, 054005 (2003).
[3] D. de Florian, Phys. Rev. D67, 054004 (2003).



- Results in agreement with two other methods using:
  - the PHOS calorimeter to measure photons
  - A combination: one photon via conversion, the other via PHOS

- Smaller uncertainties today

Back-up slices
Cocktail ingredients:
Π⁰ Dalitz decays and heavier mesons decays

- Electrons from Dalitz π^0 decays:

Π^0 Spectrum fitted with the Hagedorn function, decay kinematics used to produce $e^\pm$

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

- Heavier mesons decays contributions (η, η', ρ, ω, φ):
    - Use m_T scaling for the shape (verified with η)

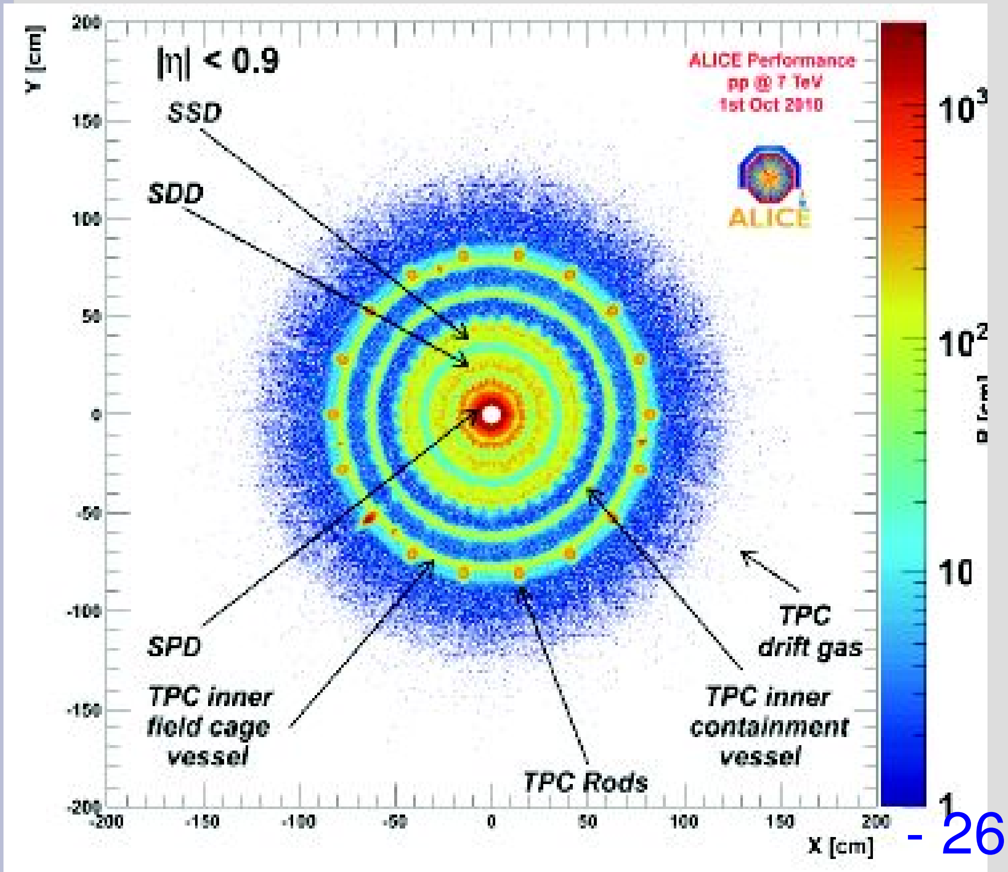
$$E\frac{d^3\sigma}{dp^3} = \frac{c \times \frac{meson}{pion}}{\left(p_0 + \frac{\sqrt{m_T^2 - m_\pi^2}}{p_1}\right)^n}$$

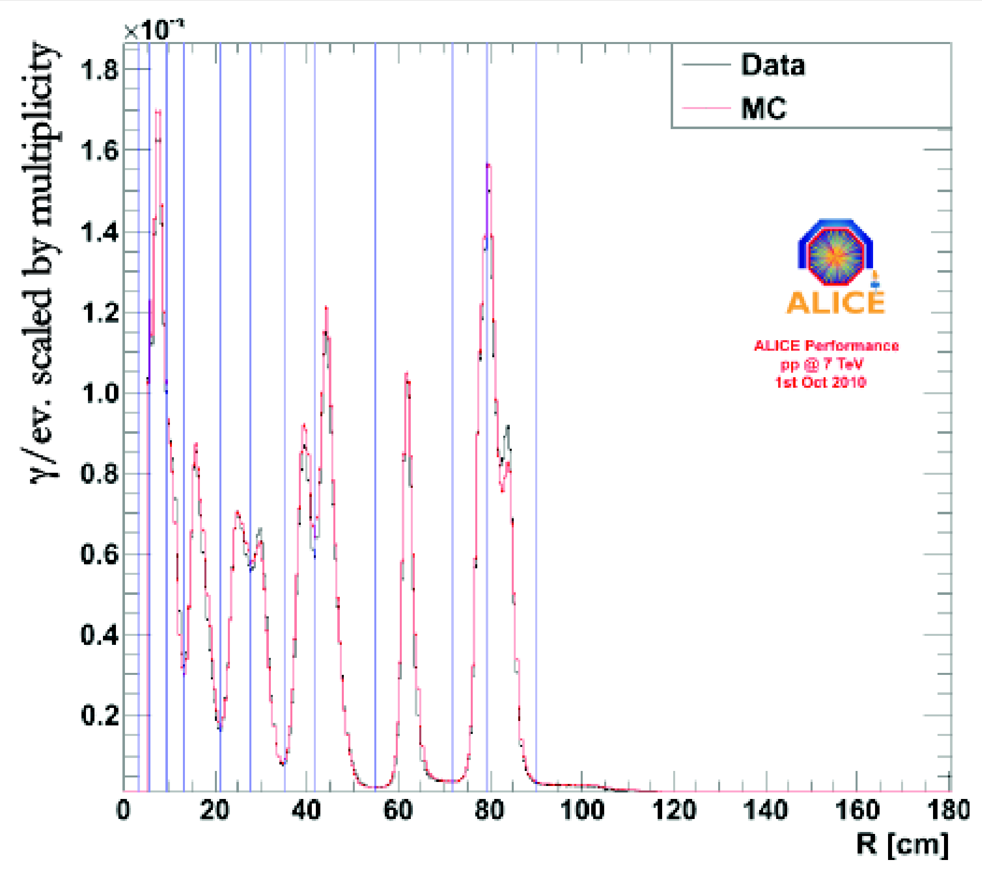
    - Use ratio at high p_T for the normalisation

Back-up slices

Cocktail ingredients: electrons from photon conversion

Conversions provide a γ-ray tomography of ALICE
Very useful tool to check the material budget
Well known down to ±6% accuracy





Back-up slices

Cocktail ingredients: electrons from photon conversion

•To know the material budget is not enough!
-> Need to know the fraction of electrons from conversion not rejected by the track quality cuts (One hit in the first πxel layer)

• Material budget to be considered:

beam πpe + a fraction x of the first πxel layer

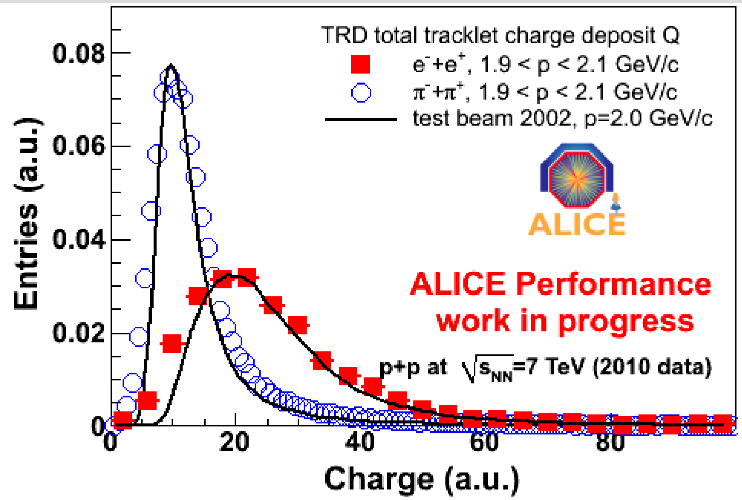
x determined via three different methods

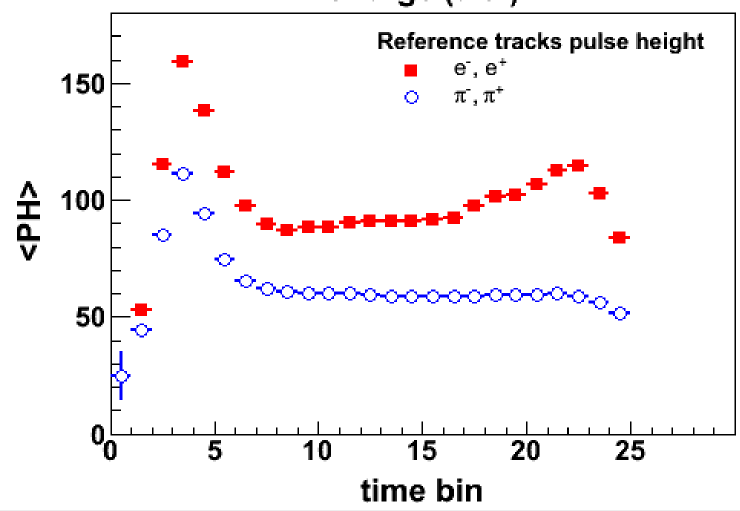
- from the material budget map (material and sensor position)
- from the simulations: check for conversions in the first layer if a hit was produced
- from simulations (and/or data): use the ratio of conversion electron spectra with hit in first layer vs second layer

$x = 0.45 \pm 0.05$

Back-up slices

Electron identification with the TRD

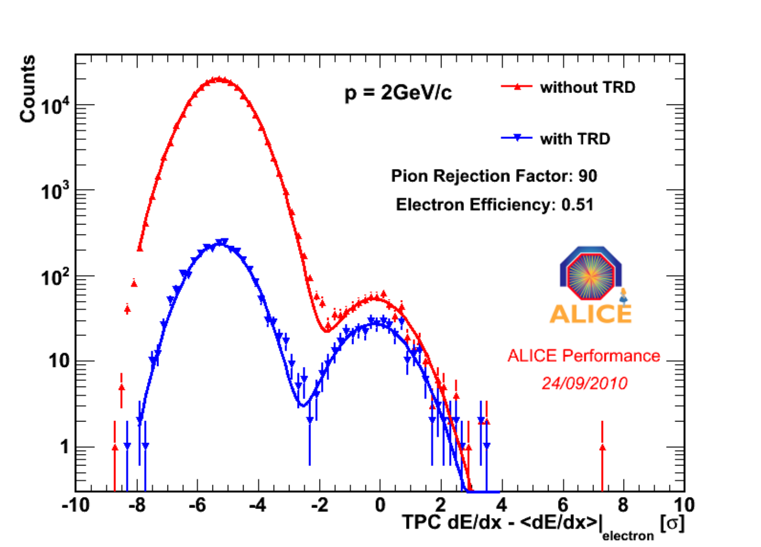




•Identify in pp collisions pure samples of electrons and πs independently from the TRD detector via V0 technics:

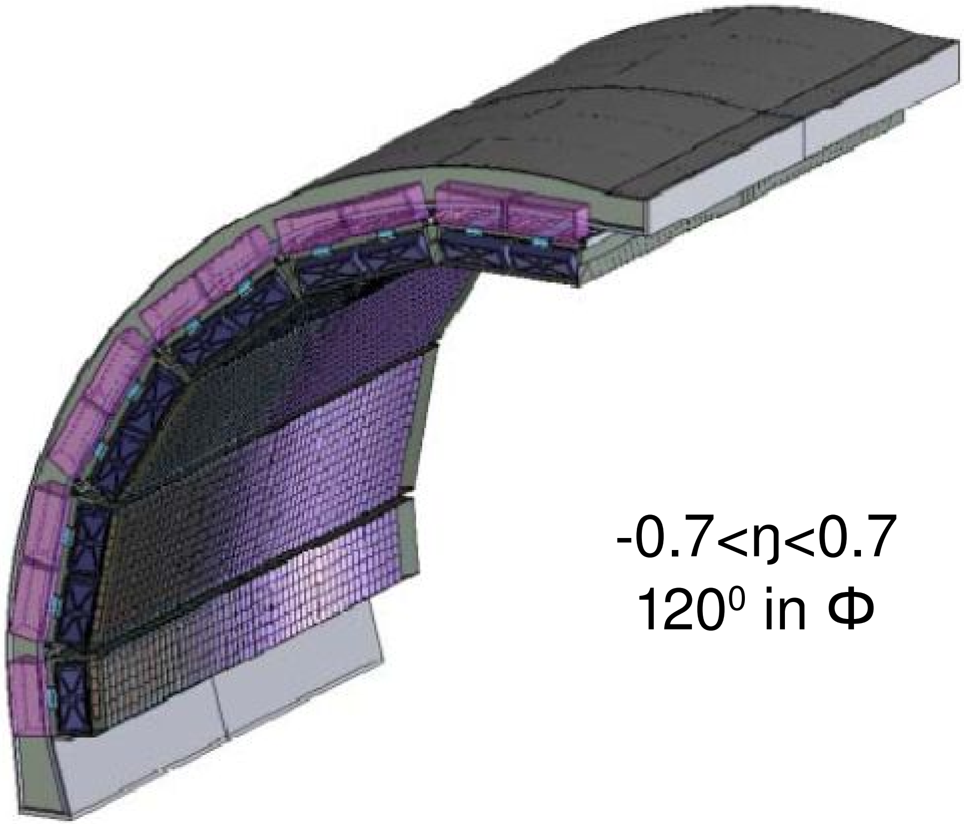
- K_0 -> $\pi^+\pi^-$
- Photon conversion in material: γ -> e^+e^-

•Compare the deposited energy of this particles with the distributions obtained with test-beam data in 2002



Back-up slices

Electron identification with EMCAL



-0.7<ŋ<0.7
120^0 in Φ

36% installed in 2010

Electro Magnetic Calorimeter

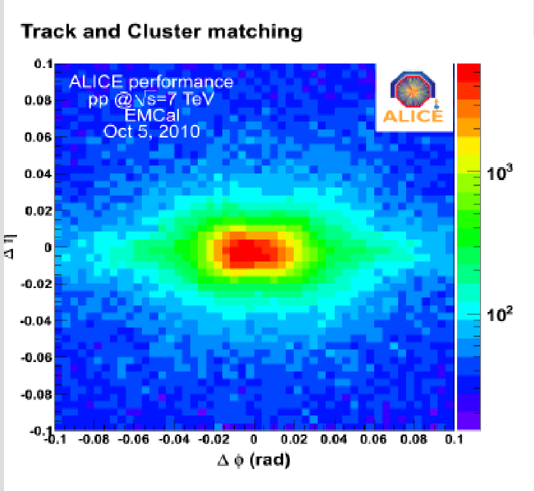
- Sampling calorimeter:
  - Layers of Pb to produce showers
  - Layers of scintillators to detect

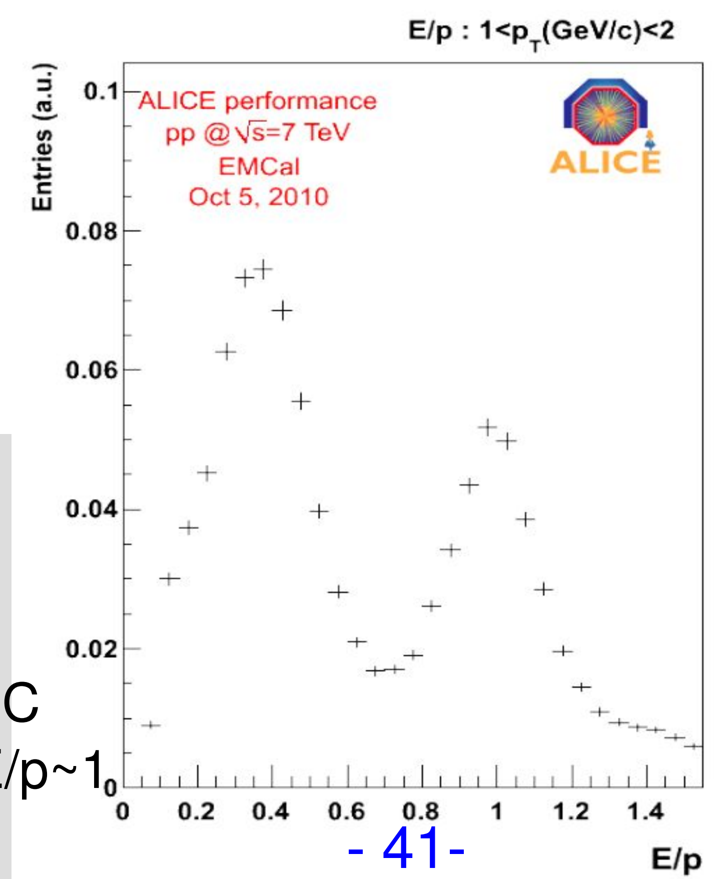
- High momenta electron identification until 200 GeV/c

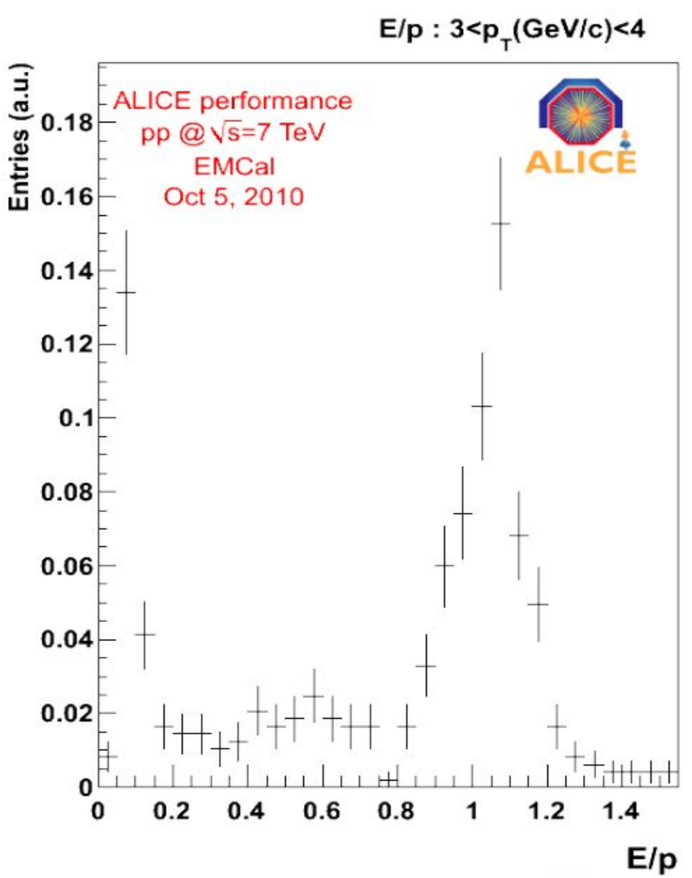
Back-up slices

Electron identification with EMCAL

Electrons candidates (TPC dE/dx), EMCAL clusters assigned:

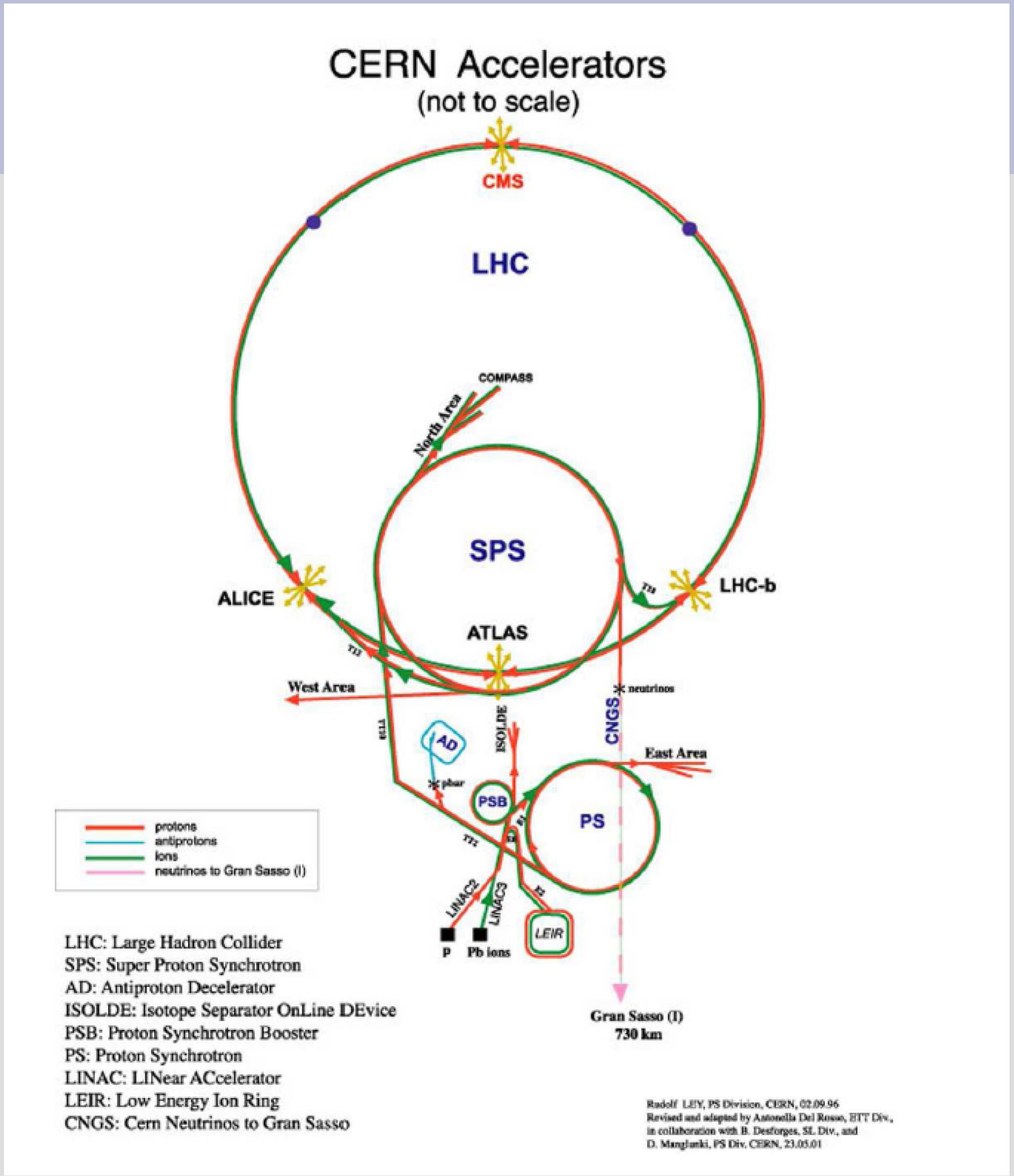






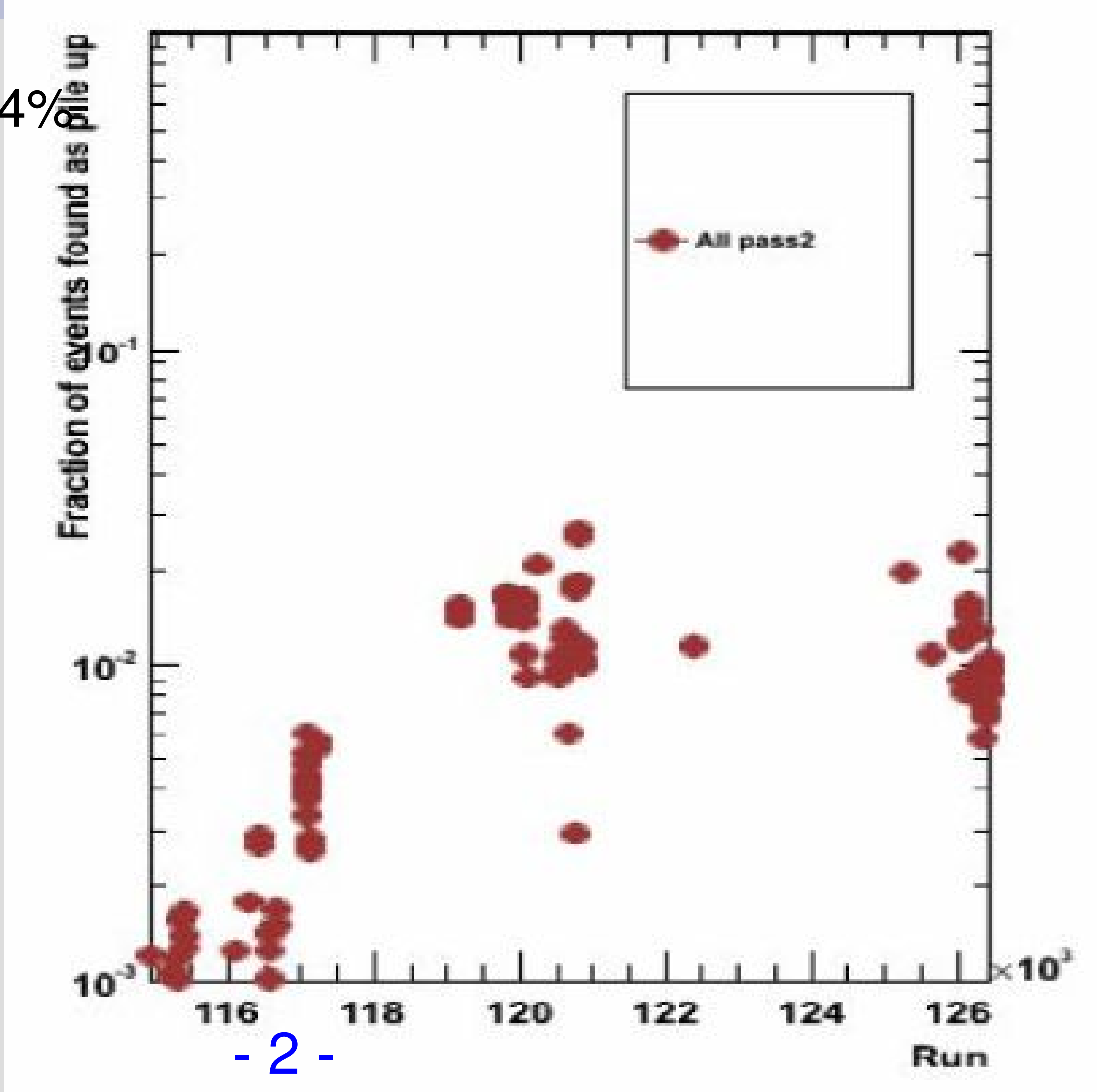
After matching with TPC
Select electrons with E/p~1

Back-up slices

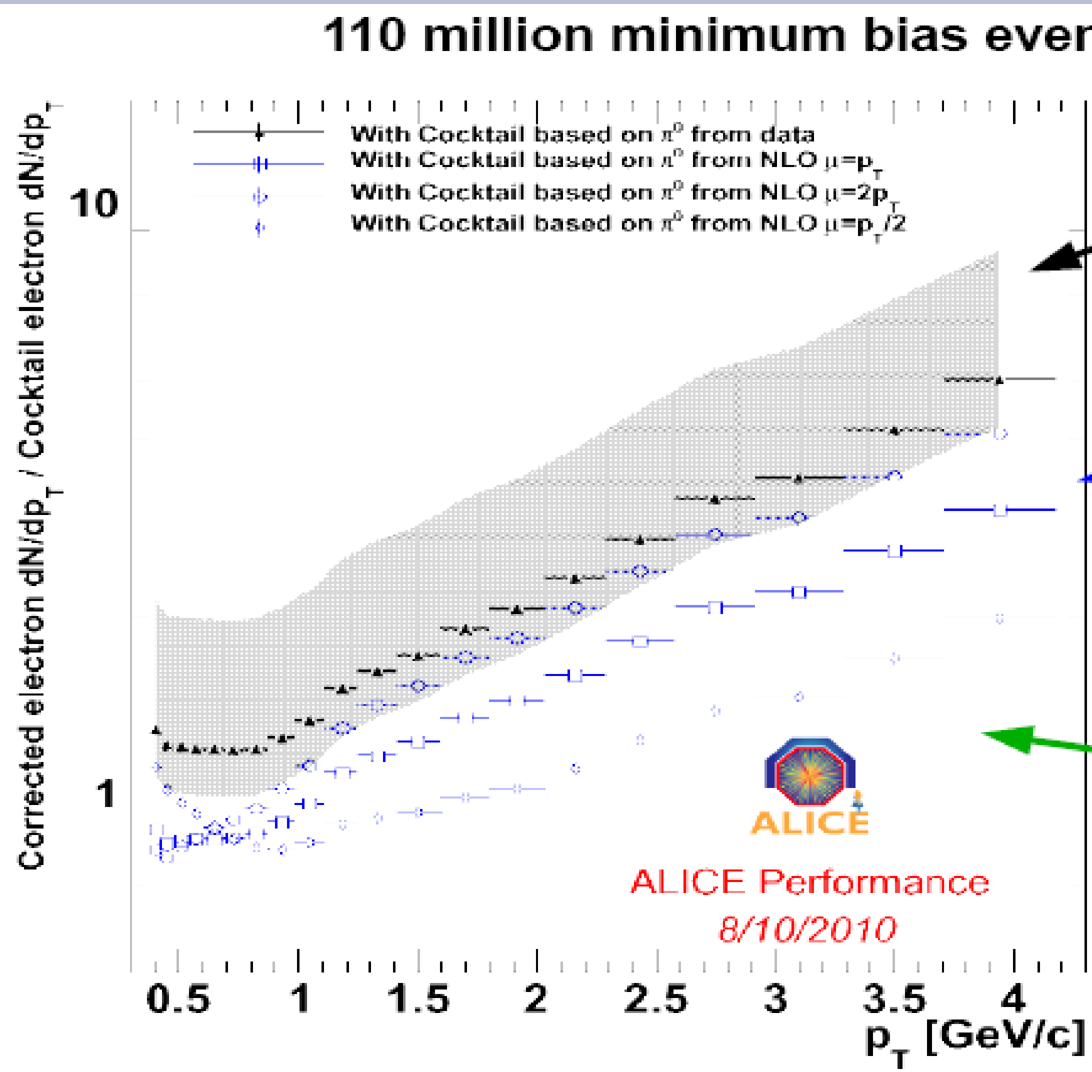


Back-up slices

Efficiency to reject πle up
of about 0.7% -> maximum 4%



Back-up slices



Systematic error on input π^0 spectrum from conversions: + 20%

- 40%

Variation of the NLO prediction between the 2 extreme scales:

$p_T/2$ and $2p_T$

The significant excess electrons come from charm and beauty semileptonic decays and from direct radiation