open heavy flavor production in ALICE and its connection to quarkonium production

- $\sqrt{s}$ = 7 and 2.76 TeV pp data:
  - measurement of hadronic decays of charmed hadrons
  - extraction of total charm cross section
  - measurement of electrons and muons from semi-leptonic decays of heavy flavor hadrons
- $\sqrt{s_{NN}}$ = 2.76 TeV PbPb collisions:
  - open charm and beauty from hadronic decays
  - and from heavy flavor electrons and muons
- perspectives

EMMI Workshop 'Quarkonia in Deconfined Matter'
Acitrezza, September 29, 2011

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why open heavy flavor?

- cross section in pp interesting in its own right, can be computed in pQCD

- in PbPb collisions
  - cross section and gluon shadowing, probes nuclear gluon distributions
  - heavy quark energy loss in hot QGP and thermalization via R_{AA} and elliptic flow?
  - do spectra exhibit radia flow?

- reference for quarkonia

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best reference for charmonia?

- NA38/NA50: Drell-Yan

- has several disadvantages: large stat. error, completely diff. production mechanism

- as a consequence proposal by H. Satz, K. Sridhar, PRD50 (1994) 3557 to use open charm instead much smoother sqrt(s) dependence

- for statistical hadronization model open charm is the only physical reference, only free parameter for prediction for yield of charmonia (J.S., P. Braun-Munzinger, PLB490 (2000) 196)
  - but due to quadratic dependence strong sensitivity to uncertainty in charm cross section

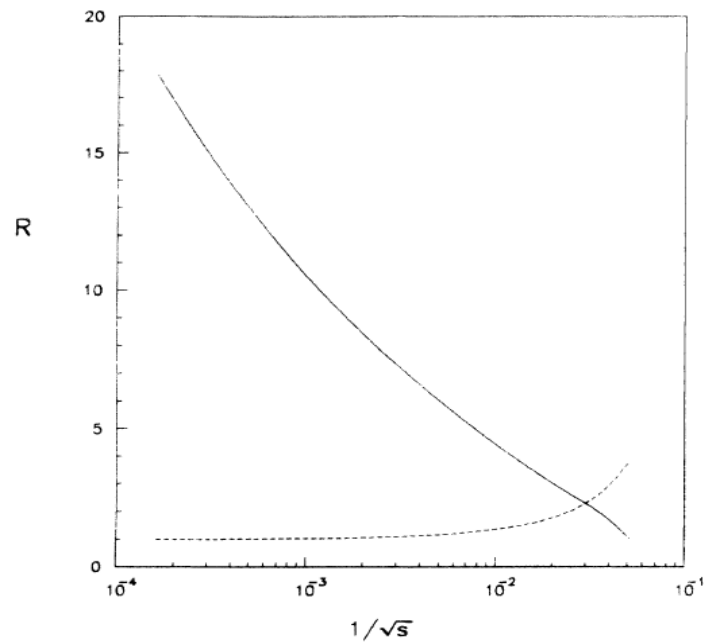

FIG. 2. The variation with incident energy $\sqrt{s}$ of the ratio of J/ψ to open charm-quark production, normalized to its value at $\sqrt{s} \to \infty$ (dashed line), and of the ratio of J/ψ to Drell-Yan production (solid line), normalized to its value at $\sqrt{s} = 20$ GeV.

- need really accurate open charm measurement to have predictive power!

- R_{AA} not the holy grale either, since shadowing enters, still need open charm

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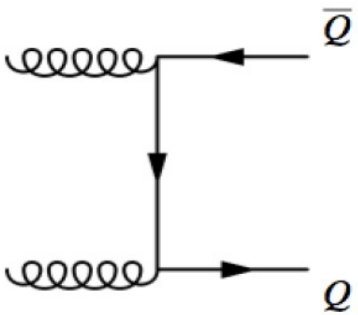
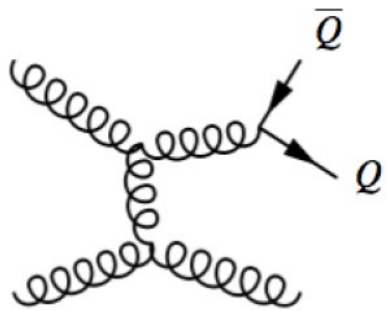
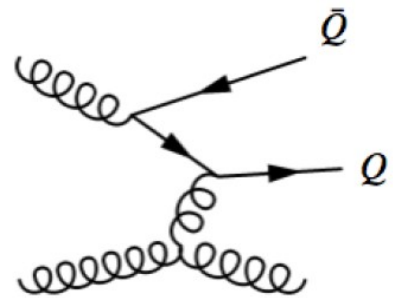
production of charm quarks at LHC energies



pair production



gluon splitting



flavor excitation

and higher orders...

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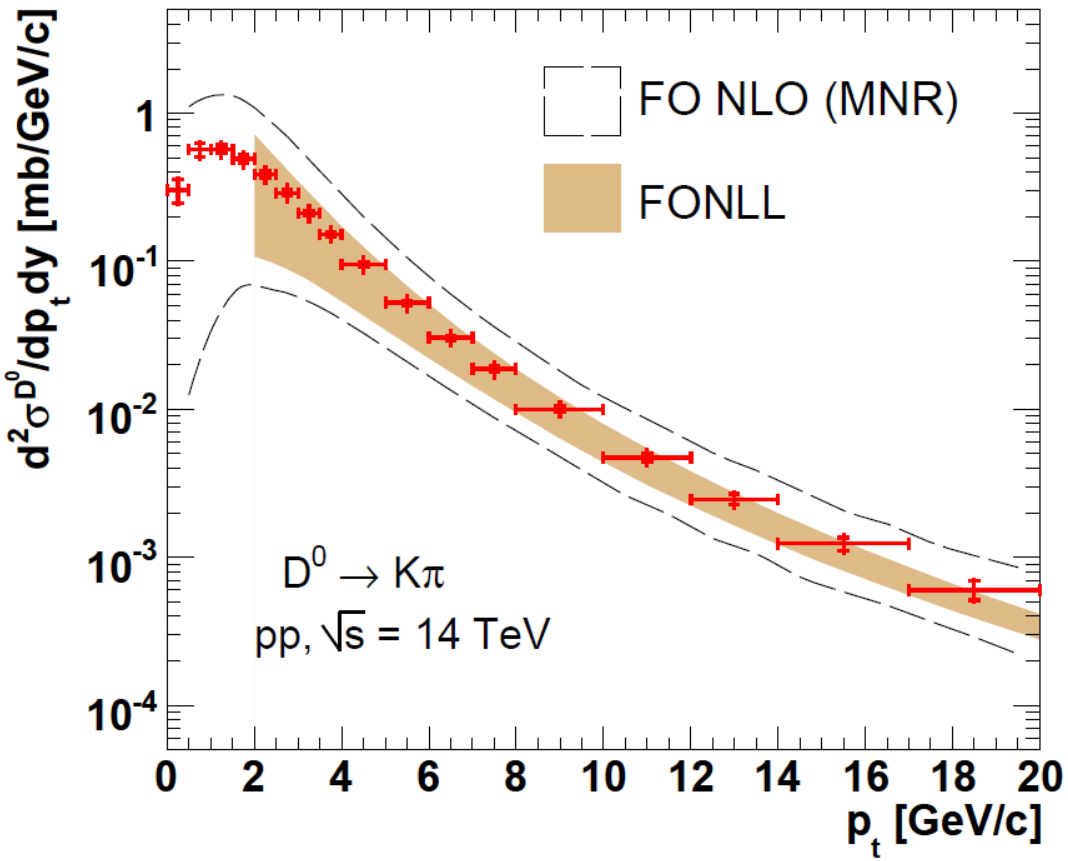
production of charm in pQCD

Calculations of cross section and spectra in pQCD

FO NLO Mangano, Nason, Ridolfi, Nucl. Phys. B373 (1992) 295

FONLL Cacciari, Frixione, Mangano, Nason, Ridolfi, JHEP 0407 (2004) 033
and priv. comm.

significant uncertainties due to charm mass (used range 1.3 – 1.7 GeV and fragmentation and renormalisation scales (μ_F and μ_R 0.5 – 2)
less in FONLL
(see talk by Ramona Vogt for details)



A. Dainese, Nuovo Cim. B123 (2008) 369

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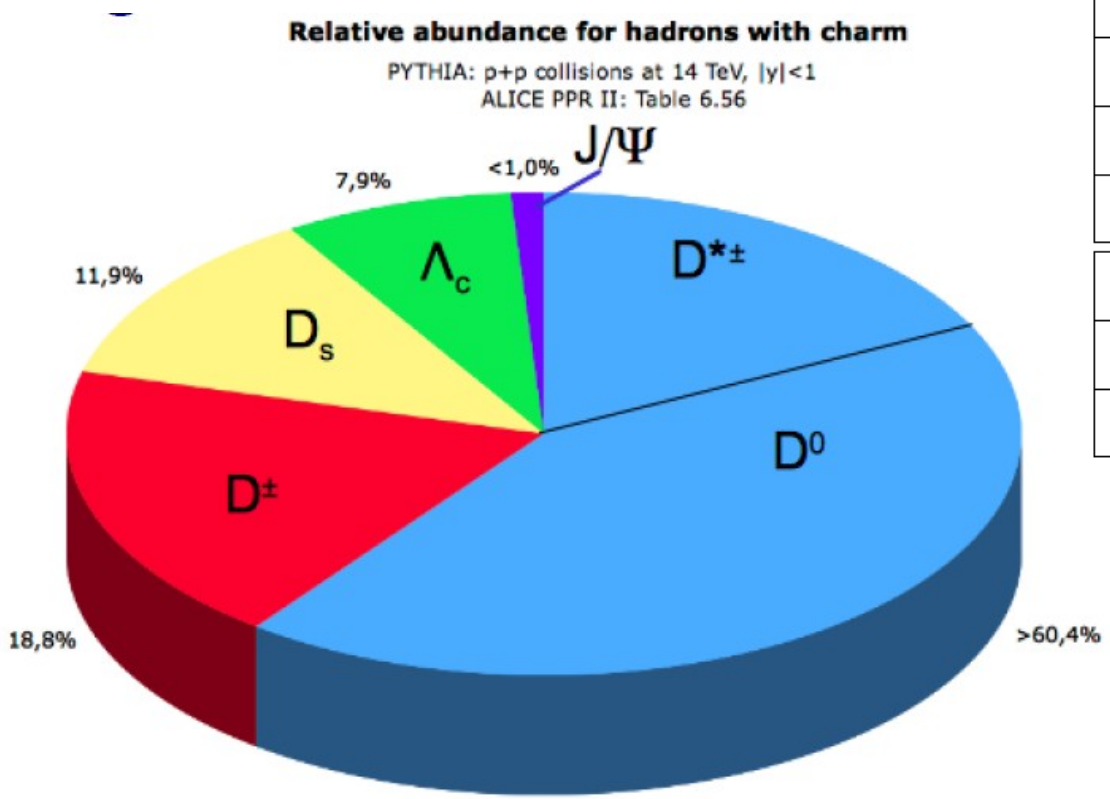
fragmentation of charm quarks into hadrons



	LEP data		
	stat.$\oplus$syst.		br.
$f(c \to D^{*+})$	0.235	± 0.007	± 0.003
$f(c \to D^{+})$	0.222	± 0.010	± 0.009
$f(c \to D_s^{+})$	0.087	± 0.009	± 0.005
$f(b \to D^{*\pm})$	0.175	± 0.020	± 0.001
$f(b \to D^{\pm})$	0.227	± 0.016	± 0.010
$f(b \to D_s^{\pm})$	0.140	± 0.016	± 0.008

thermal population very similar, see below

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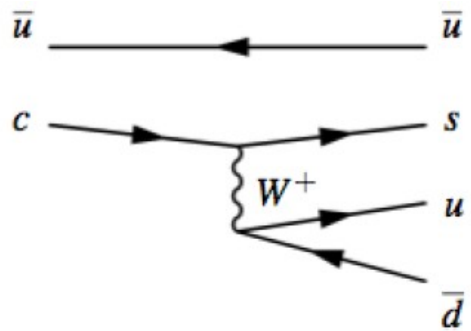
measurement of open charm via hadronic decays

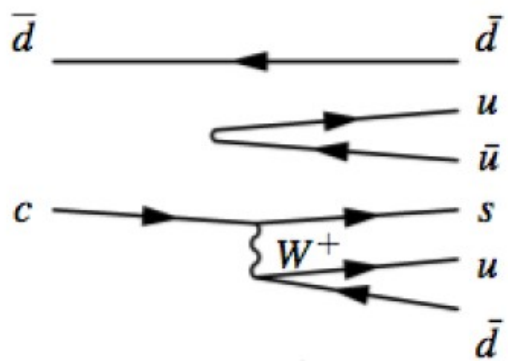
$D^0 \rightarrow K^- + \pi^+$

BR = 0.0389 ± 0.0005



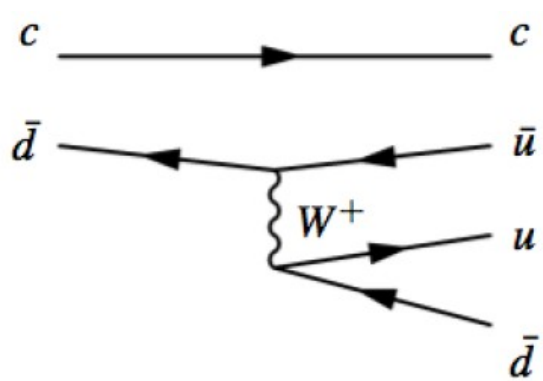
$D^+ \rightarrow K^- + \pi^+ + \pi^+$

BR = 0.094 ± 0.004



$D^{*+} \rightarrow D^0 + \pi^+$

BR = 0.677 ± 0.005



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measurement of charm and beauty via semi-leptonic decays

$D^+ \rightarrow e^+/\mu^+ + \text{anything}$

BR = 0.161 ± 0.003

$B^+ \rightarrow e^+/\mu^+ + \text{anything}$

BR = 0.110 ± 0.003

$D^0 \rightarrow e^+/\mu^+ + \text{anything}$

BR = 0.065 ± 0.001

$B^0 \rightarrow e^+/\mu^+ + \text{anything}$

BR = 0.103 ± 0.003

$D_s^+ \rightarrow e^+/\mu^+ + \text{anything}$

BR = 0.065 ± 0.004

$B_s^0 \rightarrow e^+/\mu^+ + D_s^- + \text{anything}$

BR = 0.079 ± 0.024

and charmonium modes

$B \rightarrow J/\psi + \text{anything}$

BR = $O(10^{-3})$

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open heavy flavor measurements in ALICE

rely on good tracking and vertexing performance
and good particle identification (PID)

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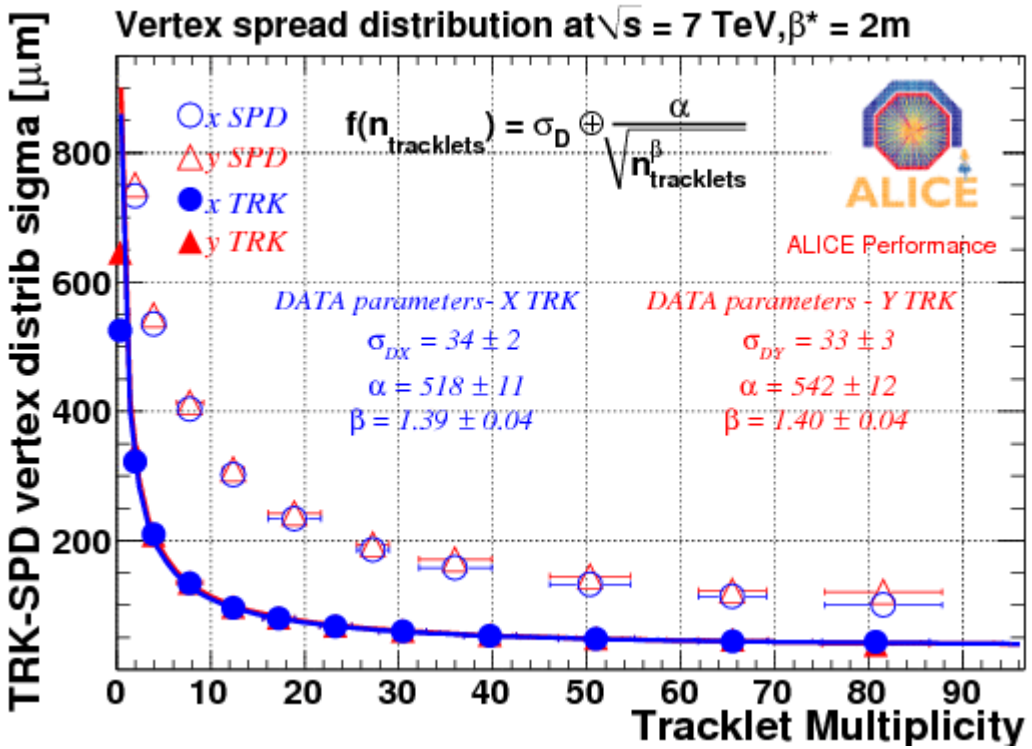
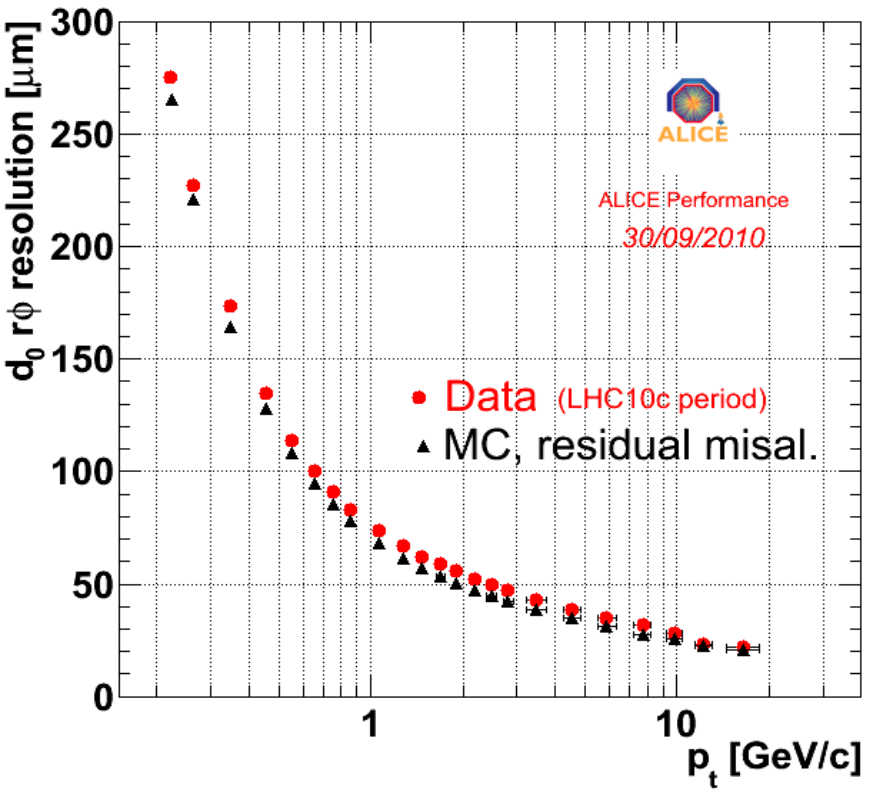
tracking performance – ITS system





after careful alignment of Silicon Pixel Detectors
expected vertex and impact parameter resolution already nearly reached

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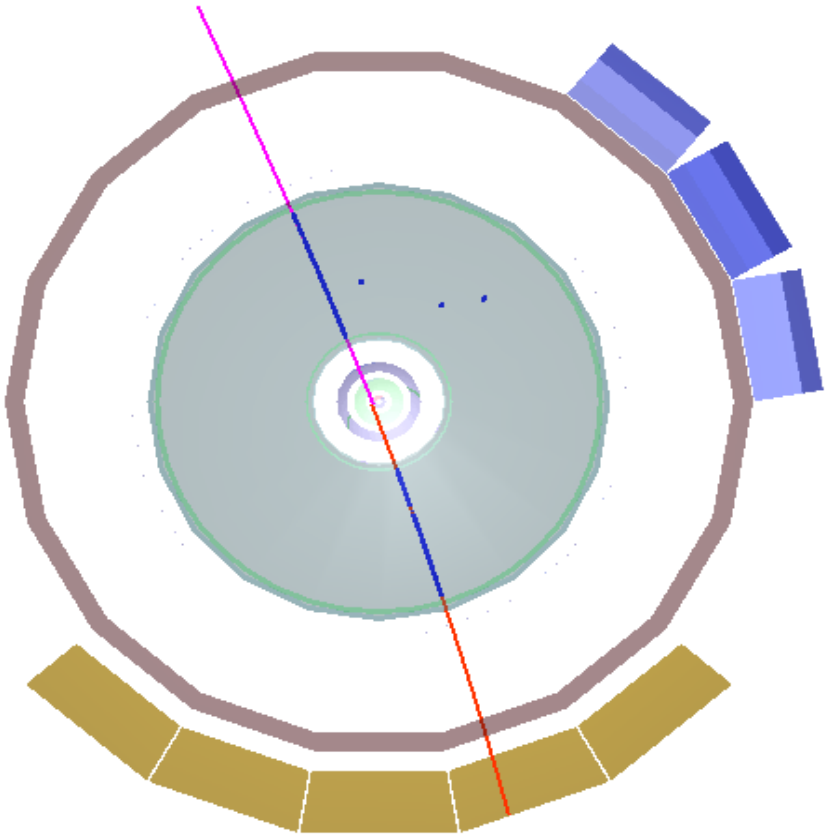
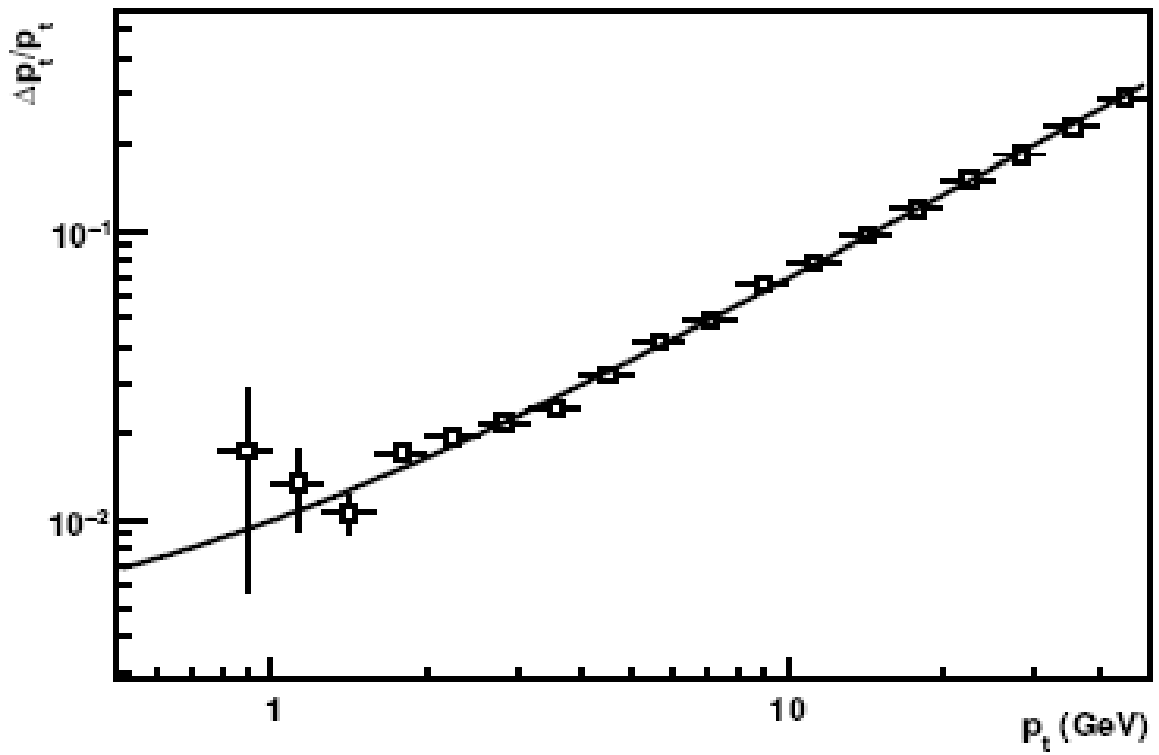
measured TPC stand-alone momentum resolution

tracking cosmic rays in magnetic field



resolution from two halfs of a cosmic ray track: already at this stage 7% at 10 GeV/c



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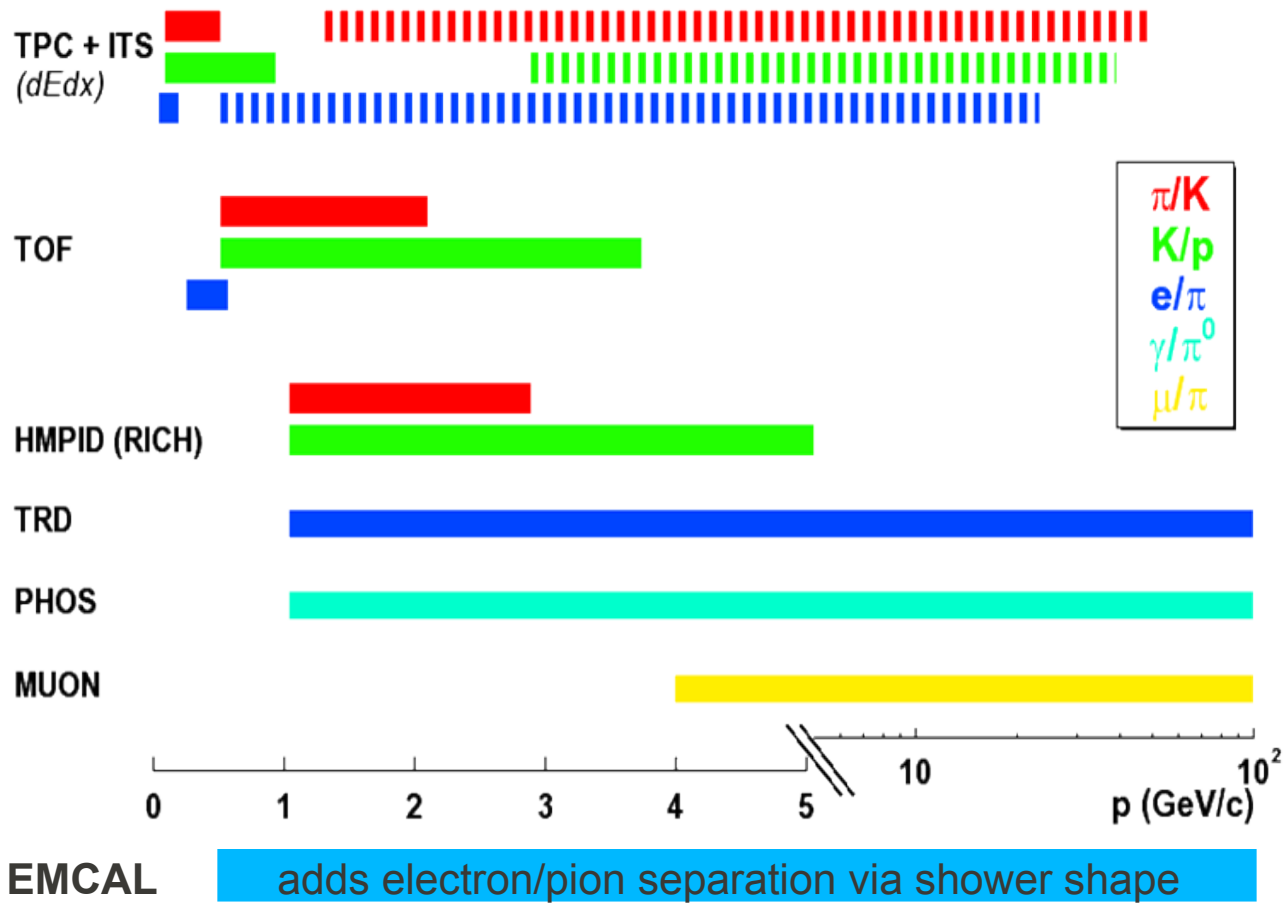
Particle Identification in ALICE

ALICE has PID over large momentum range



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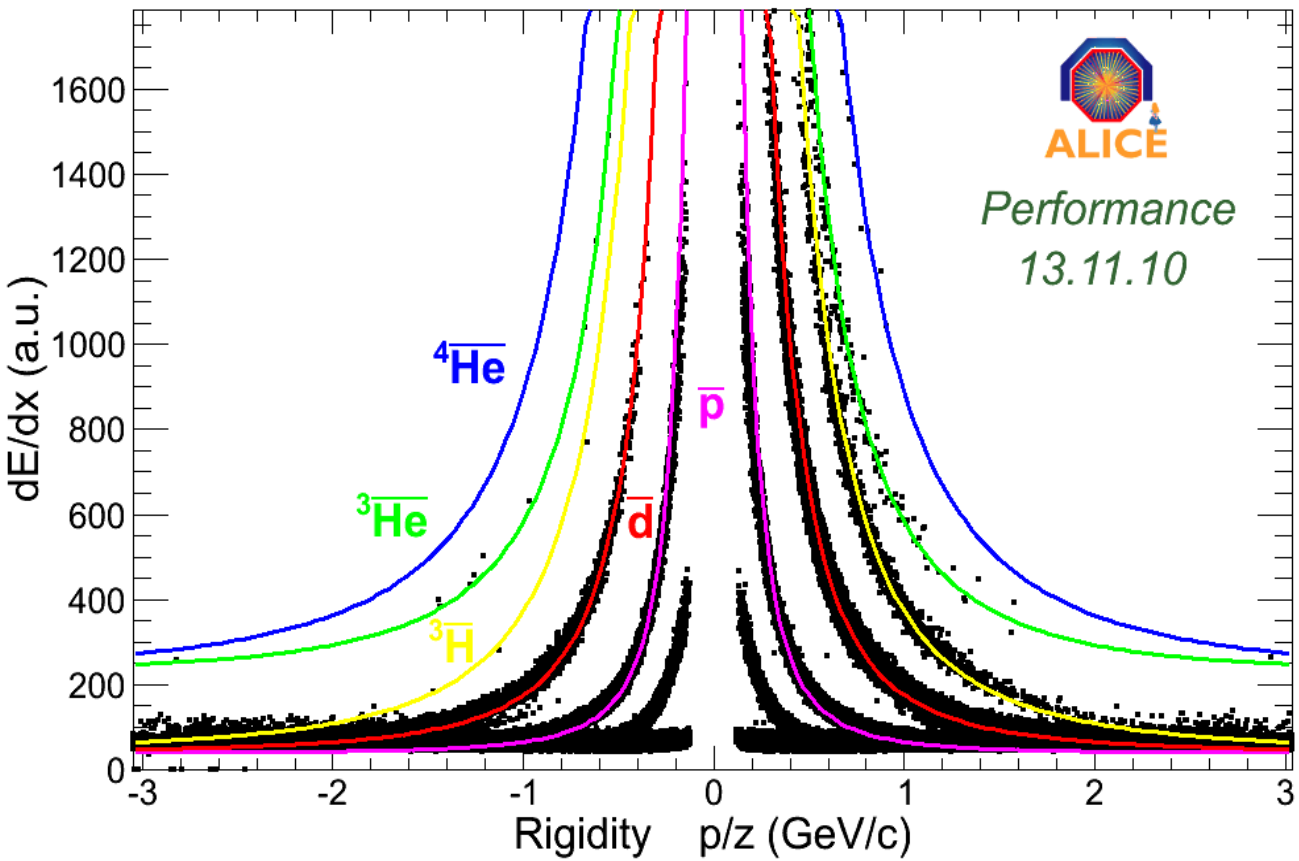
ALICE PID Performance 1 – Energy Loss in TPC



excellent PID with TPC
dE/dx resolution 5 %
close to theoretical limit

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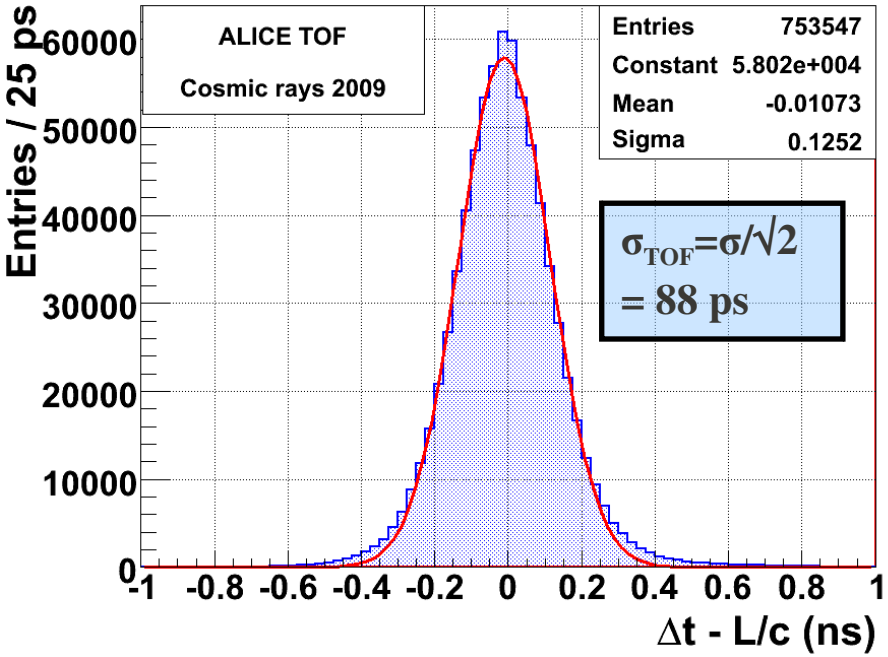
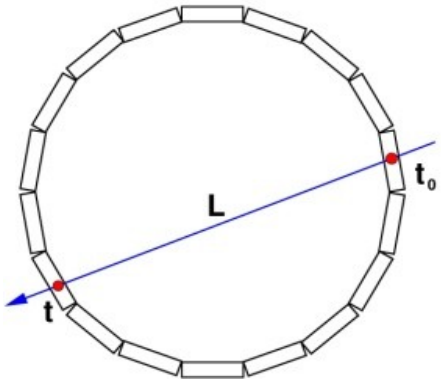
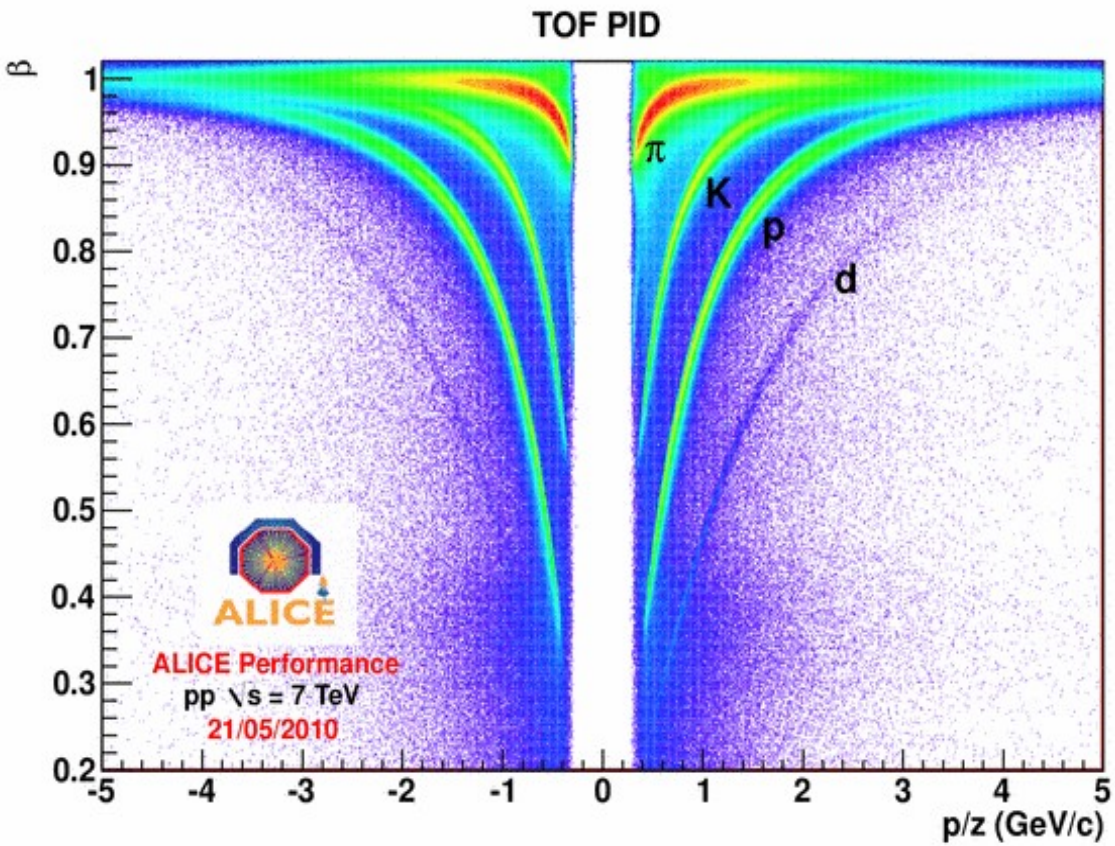
ALICE PID performance 2 – time-of-flight (TOF)







ALI-PERF-4517

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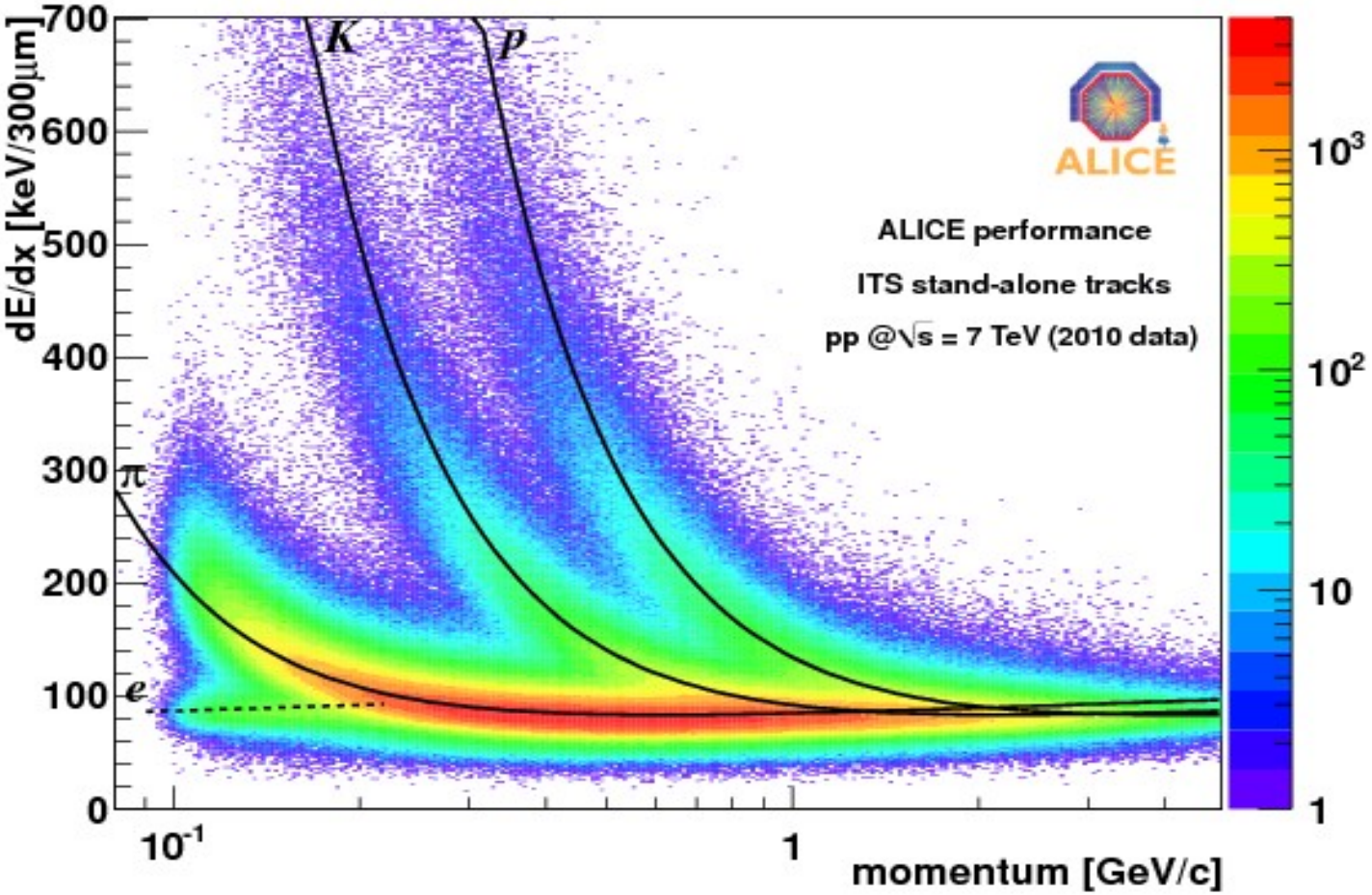
ALICE PID performance 3 – energy loss in ITS



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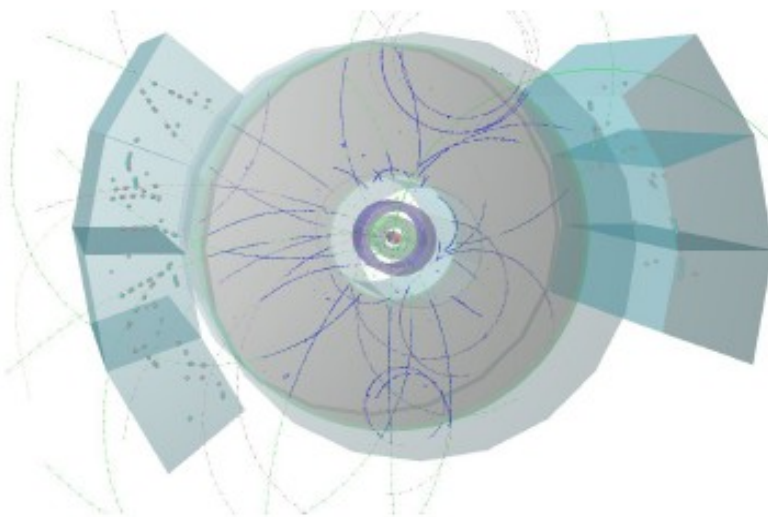
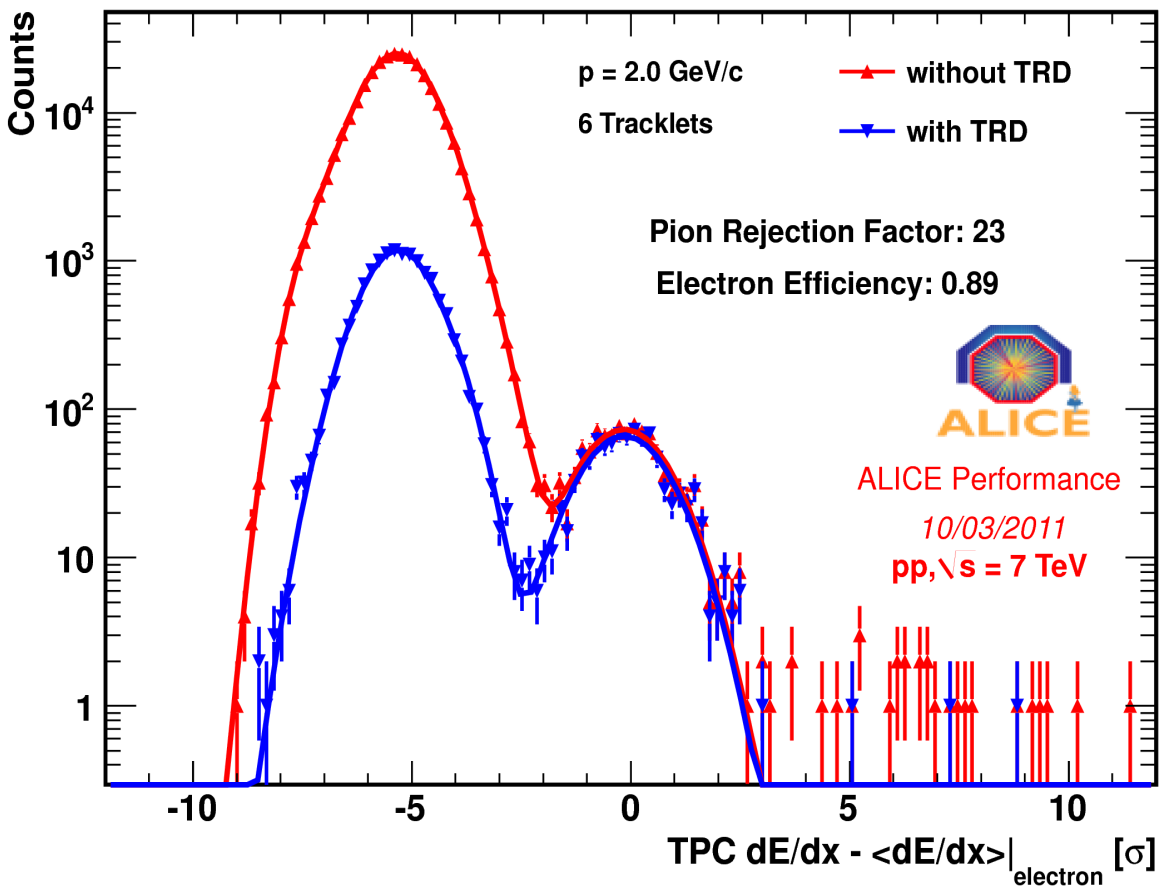
ALICE PID Performance 4 - Transition Radiation in TRD

Transition Radiation Detector

- Electron/pion discrimination
- Electron trigger
  (high pT, particle ID)





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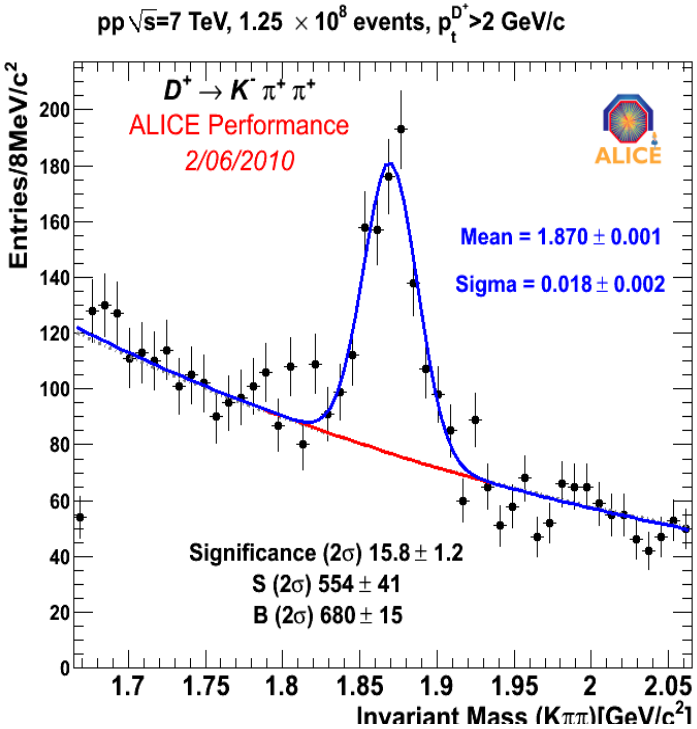
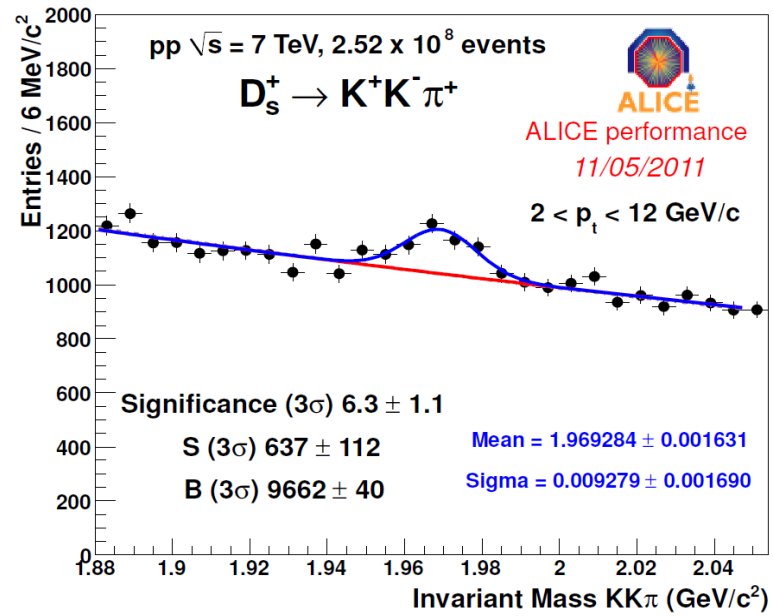
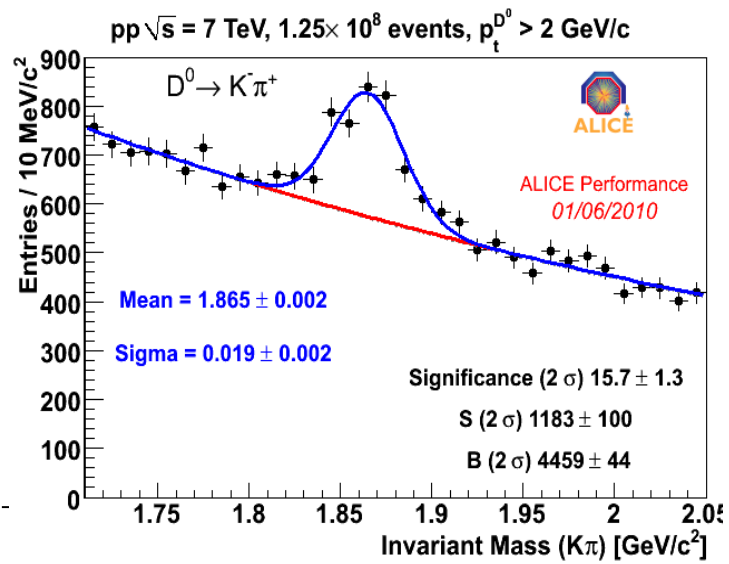
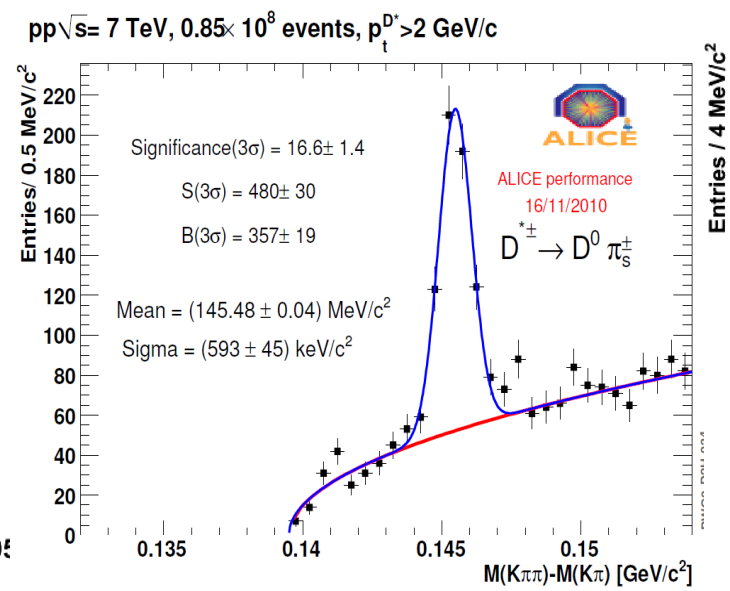
D^0, $D^{\pm}$, $D_s^{\pm}$ and $D^{*\pm}$ in 7 TeV pp data

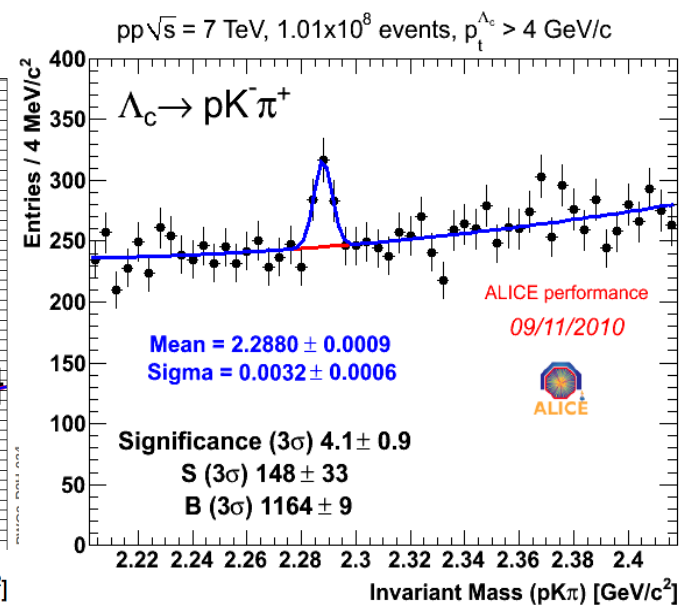


$D^{\pm}$, D^0, $D_s^{\pm}$, $D^{*\pm}$ reconstructed in ALICE central barrel tracking ITS/TPC sec vertexing ITS PID TPC/TOF Λ_c anal. just starting

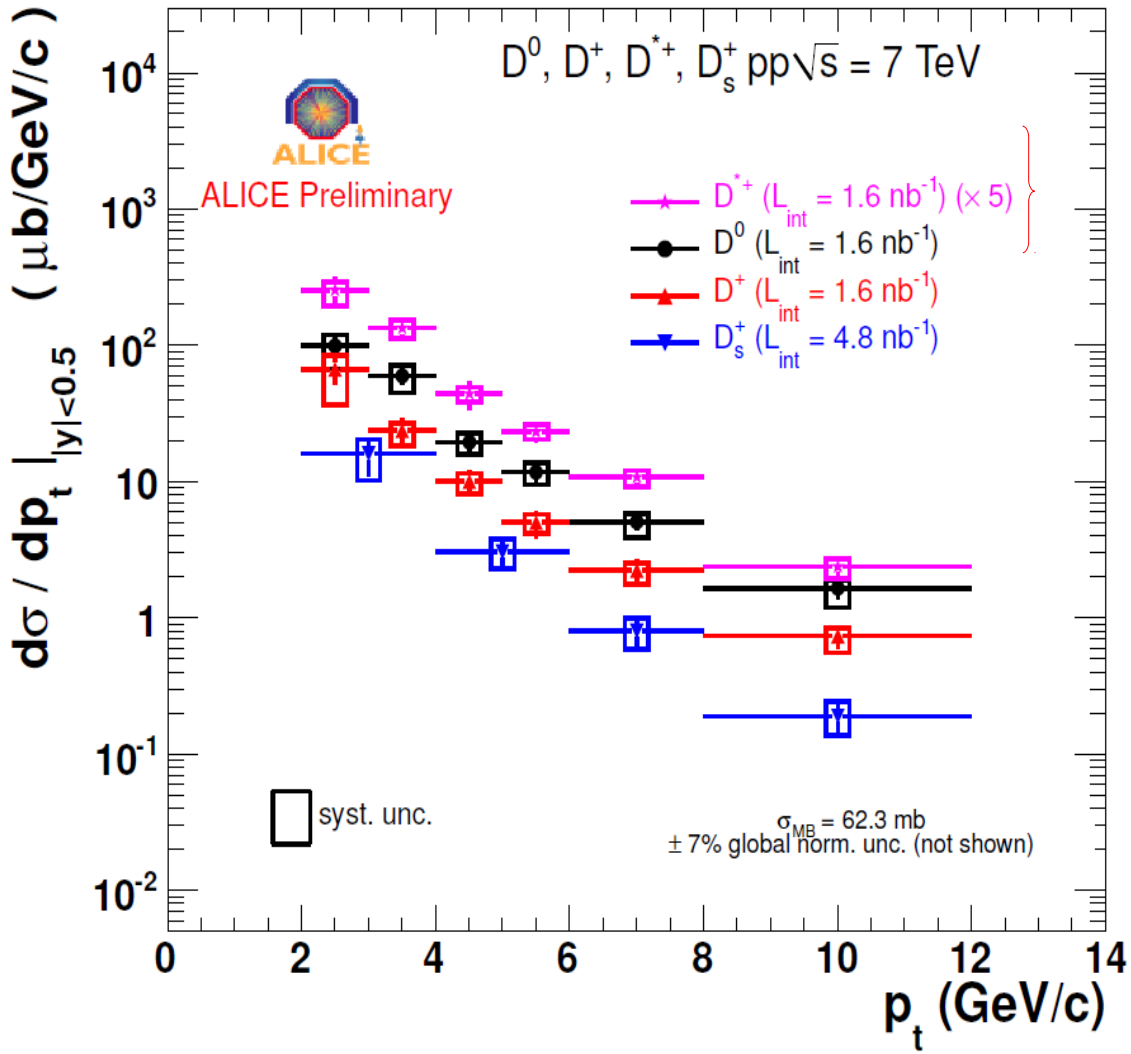








D meson spectra in pp collisions



currrent analysis with 1/3 of 2010 statistics: spectra from 2 to 12 GeV/c expect to cover open charm for p_t = 1 - 20 GeV/c with full statistics

data also available for 2.76 TeV for D+, D0, D*+

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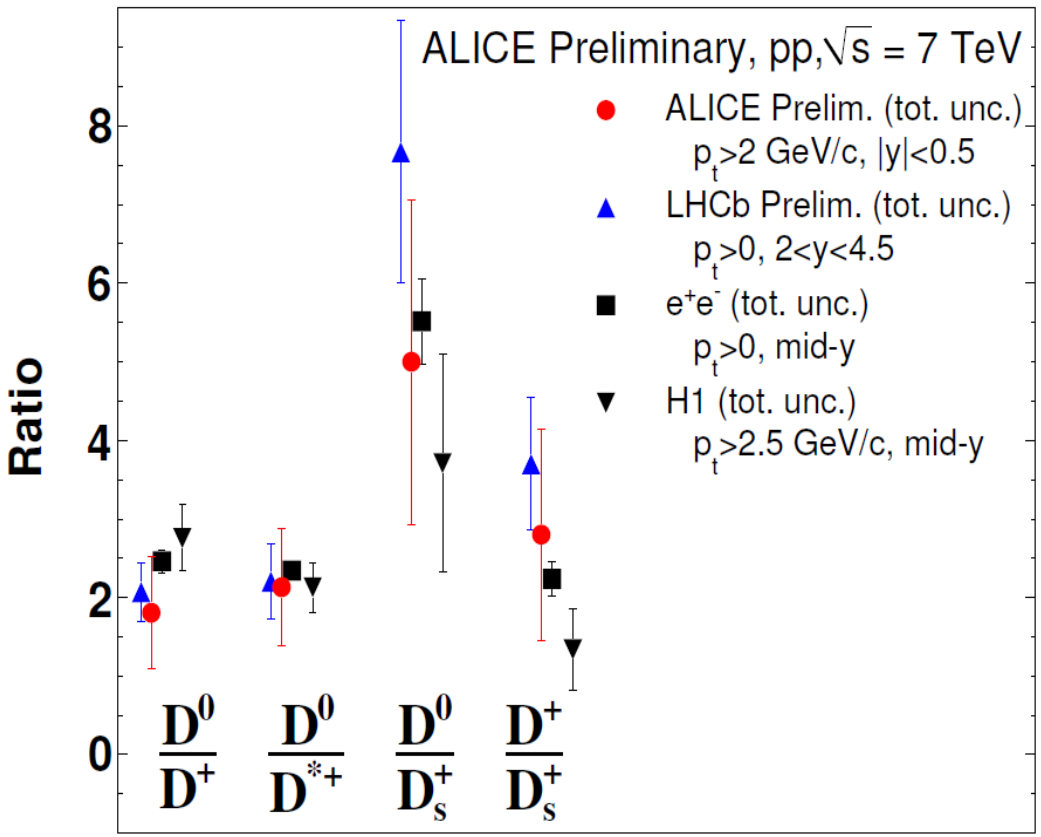
population of various D states



in good agreement with systematics observed in e+e-, ep, and pp
errors will be reduced in future

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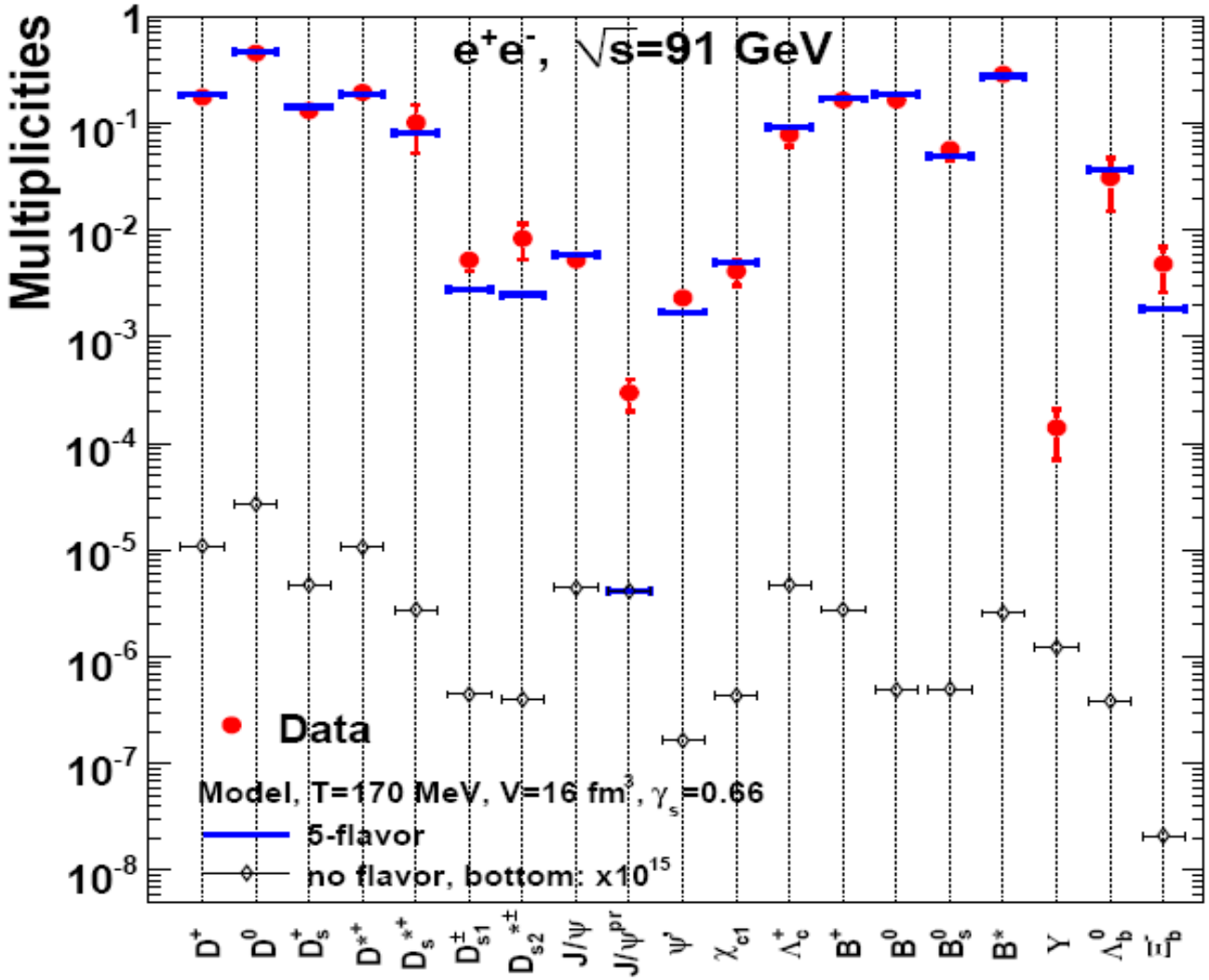
in fact fragmentation very close to thermal (except quarkonia)



5-flavor: use population of the 5 quark flavors following weak isospin

Andronic, Beutler, Braun-Munzinger, Redlich, Stachel., PLB678 (2009) 350

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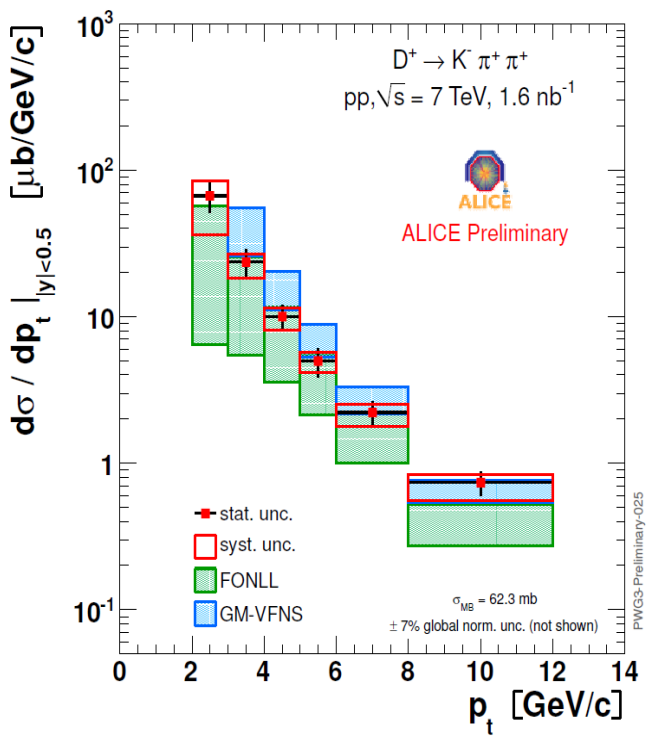
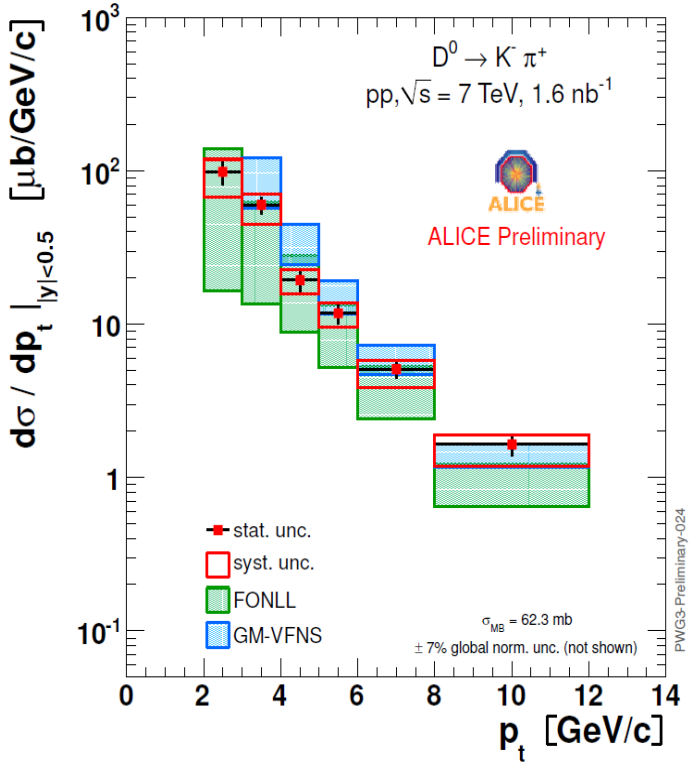
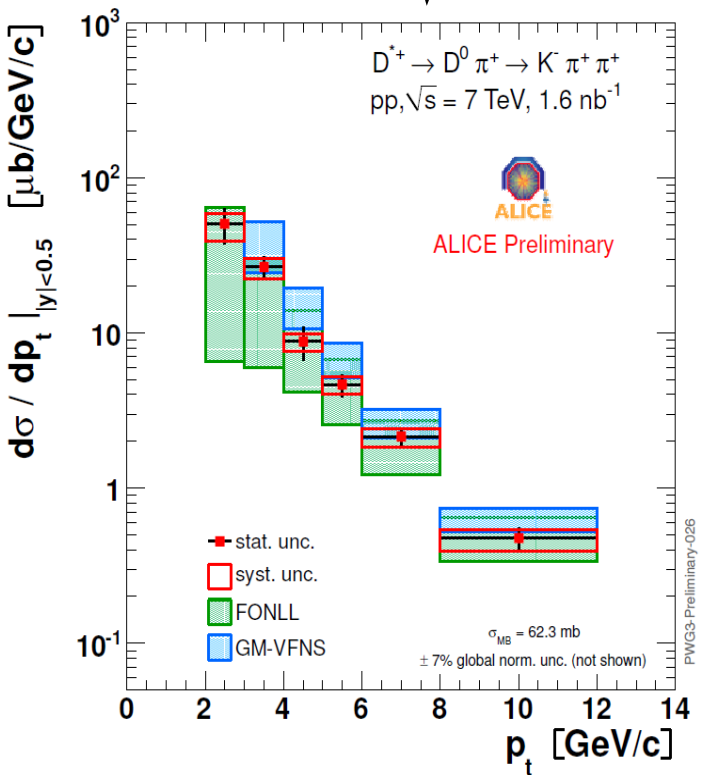
Measurements agree well with state of the art pQCD calculations





for illustration, sofar only statistical error



spectra measured between 2 an 12 GeV/c
can use good agreement with pQCD in measured range to extrapolate to charm production in full phase space

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from measured D-meson spectra to a total charm cross section

ALICE: D0, D+-, D*+-

$2 < p_t < 12$ GeV corresponds to about 40% of full spectrum

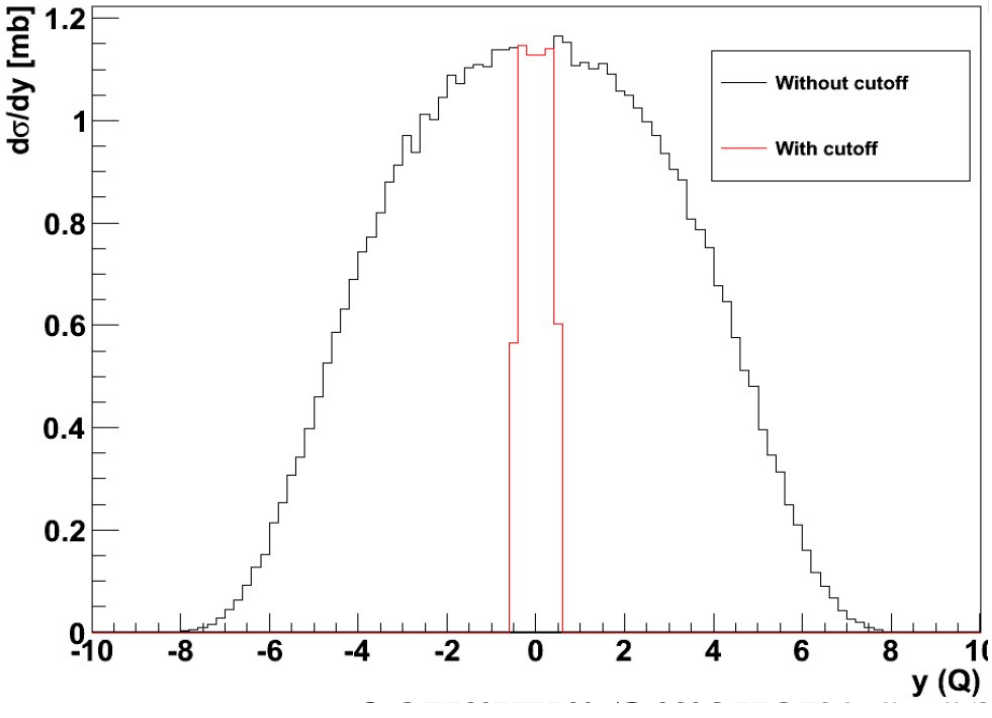
$|y| < 0.5$ about 12% of rapidity distribution of FONLL

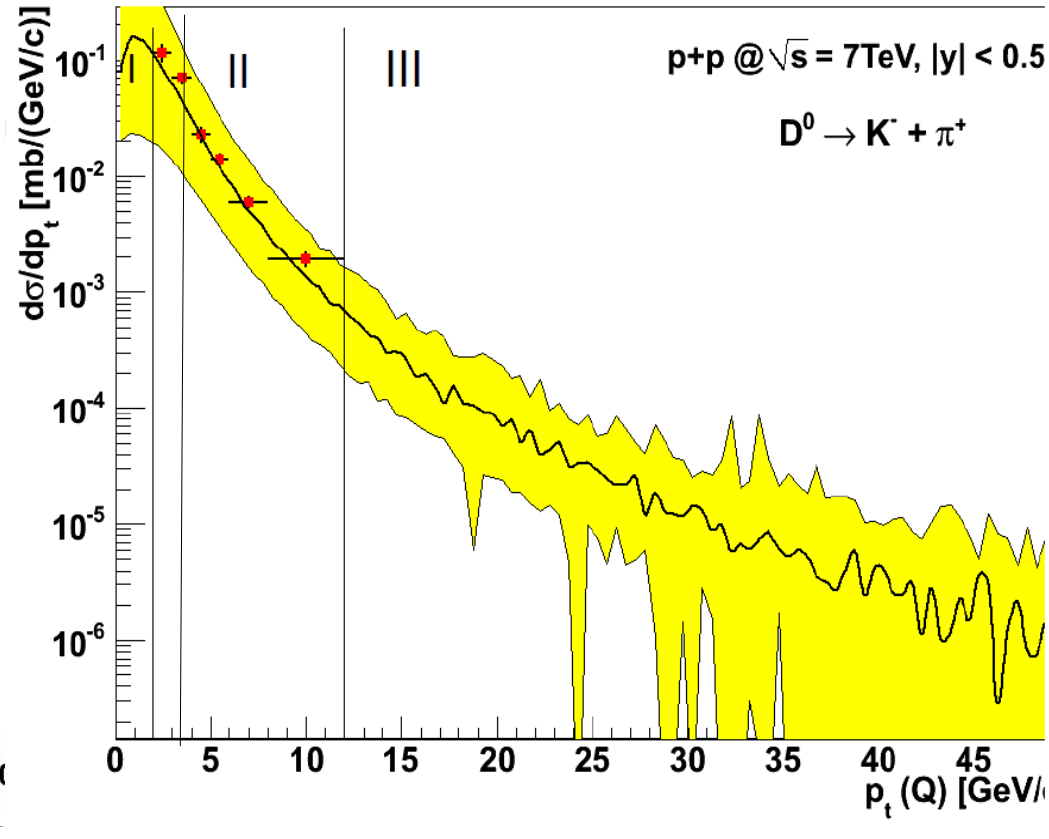
ATLAS: D+-, D*+-, Ds+-

ATLAS-CONF-2011-017

$p_t > 3.5$ GeV/c corresponds to 1/7 of full spectrum

$|\eta| < 2.1$





systematic errors of total charm cross section

in addition to statistical and systematic error of the measured D-meson spectra and error in luminosity measurement
theoretical error due to PDF, c-mass and pQCD scales enters via extrapolation

<u>example:</u>
present preliminary ALICE data

$$\sigma^{vis}(D^0) = 206 \pm 20(\text{stat.})^{+25}_{-48}(\text{syst.}) \pm 14(\text{lum.}) \pm 3(\text{br.})\mu\text{b}$$

+ 17 %
- 26 %

– extrapolation factor is 1/(0.4 x 0.12) = 20.7
from FONLL

D^0 central:	19.507	
Scales:	+5.600	-2.719
Mass:	+0.109	-0.618
PDF:	+0.780	-1.03
Overall:	+5.655	-2.973

+ 29 %
- 15 %

this will improve (has already)

best way to improve: increase measured fraction (lower p_t)

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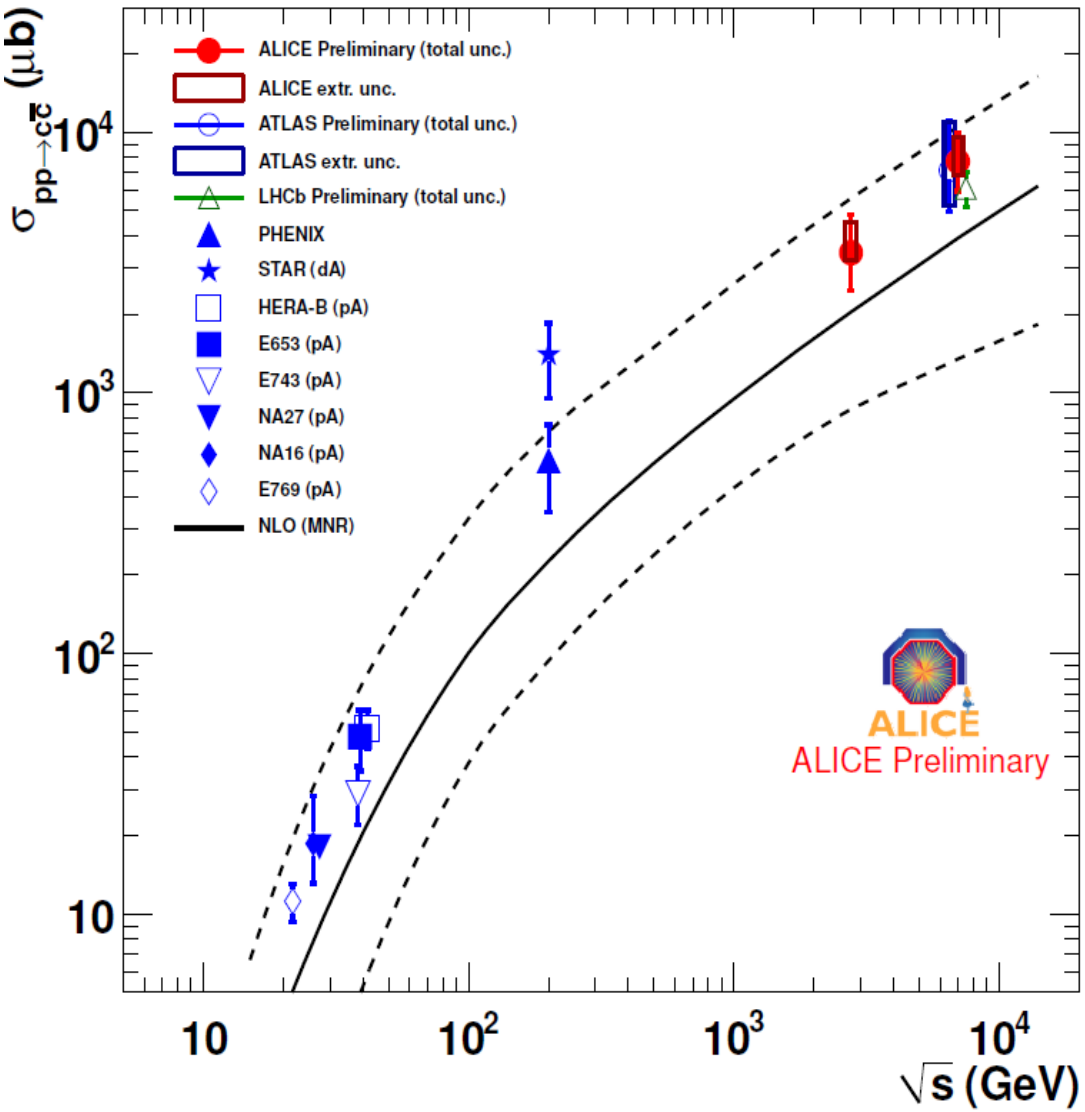
a first try at the total ccbar cross section in pp collisions



- good agreement with ATLAS and LHCb
- data factor 2 ± 0.5 above central value of FONLL but well within uncertainty
- beam energy dependence follows well FONLL

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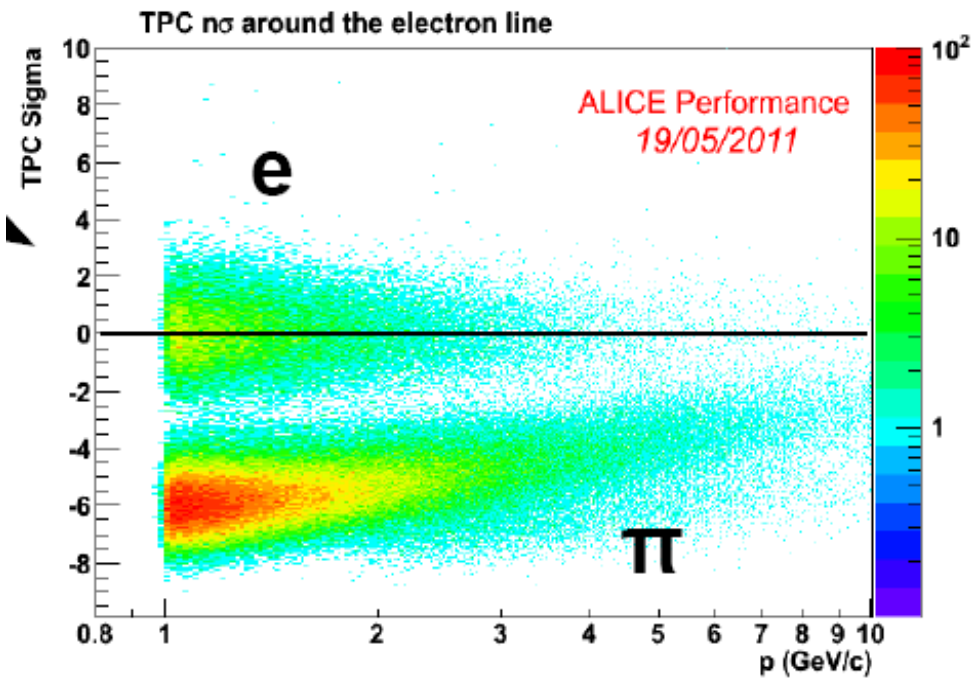
electrons from semileptonic decays of charm and beauty hadrons

- **TOF:** $\pm 3\ \sigma$ around expectation for electrons
  → remove K and p at low momenta
- **TRD:** use the energy deposit + TR for electron only
  cut fixed at 80% electron efficiency
  → supress pions
  (not yet used in Pb-Pb analysis)
- **TPC:** lower cut in the middle of dE/dx distribution
  50% electron efficiency
  → Remove further pion contamination



- **pp: $0.5 < p_T < 10$ GeV/c**

→ less than 5% hadron contamination

- **Pb-Pb: $1.5 < p_T < 6$ GeV/c**

→ less than 10% hadron contamination

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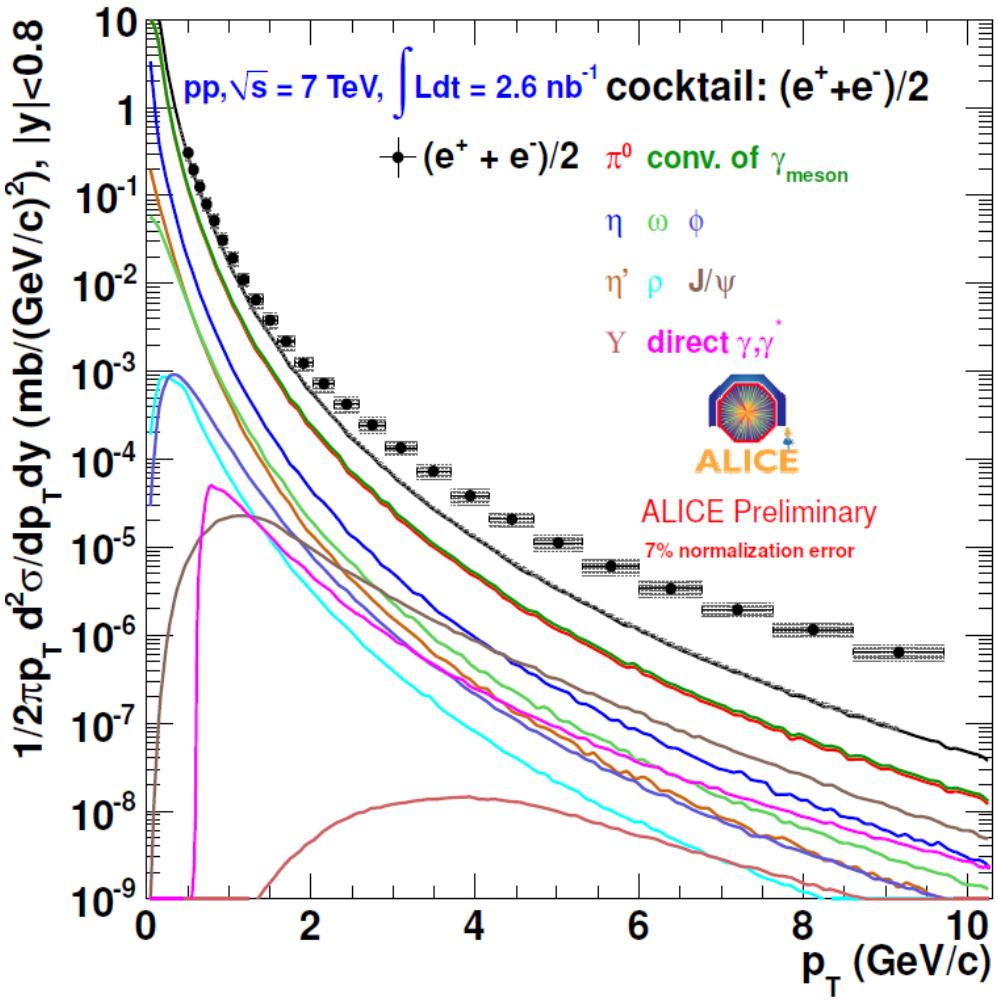
inclusive electron spectrum



Inclusive electron spectrum

electron ID with TOF-TRD-TPC

Cocktail of known background e

- γ conversion in the detector material
- π^0, η, η' Dalitz-decays
- ρ, ω , ϕ decays
- J/ψ, Υ decays
- Direct γ, γ^* (based on NLO, W. Vogelsang)

- **measured π^0 as input**
- **heavier mesons: m_T scaling**
- **J/ψ, Υ: ALICE and CMS measurements**
- **ratio Conversions/Dalitz: from the known material budget**

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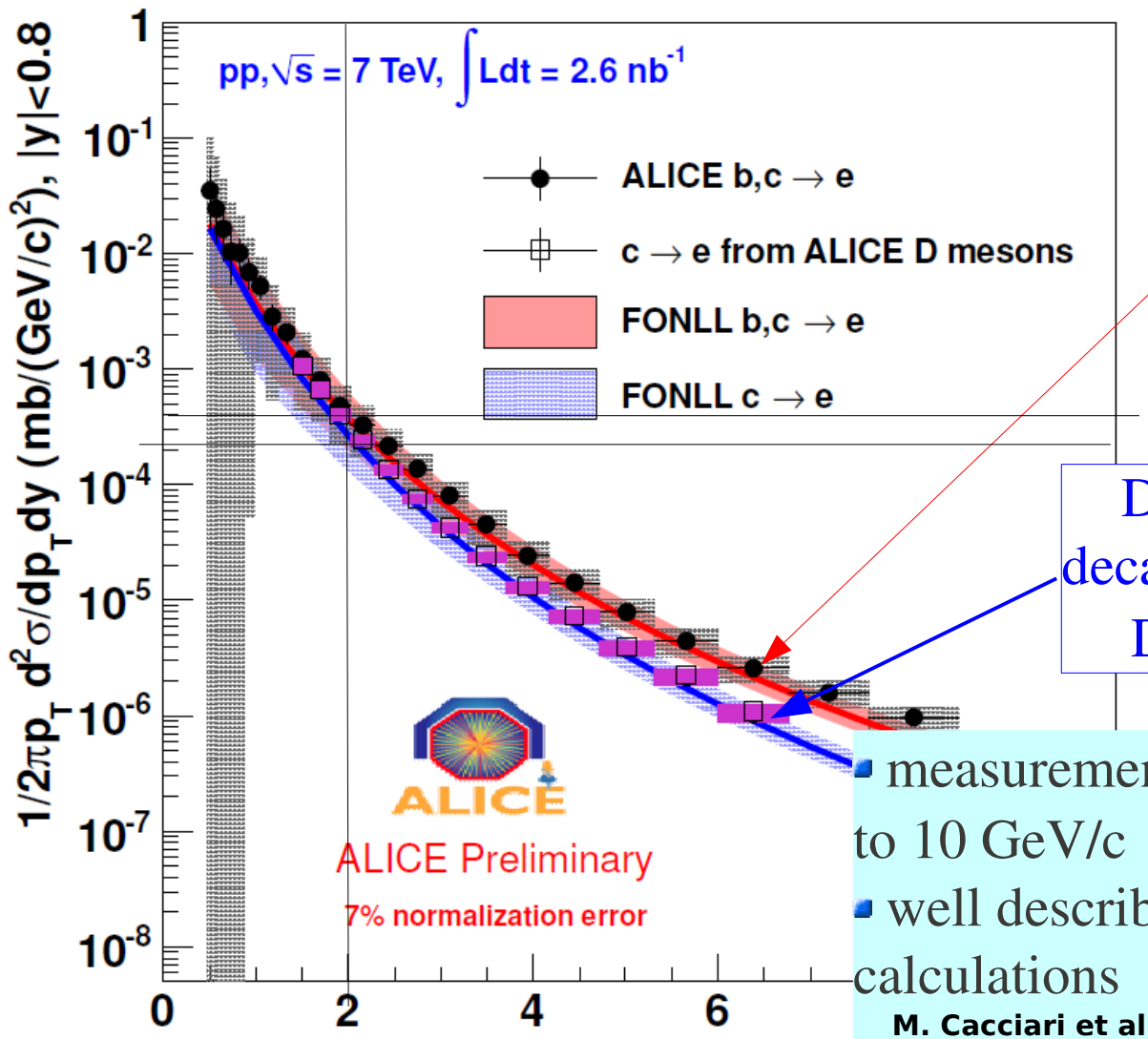
D,B → e + X



inclusive electrons - cocktail = D,B → e + X

D mesons + decay kinematics D → e + X

- measurement of D,B → e + X from 0.8 to 10 GeV/c (TPC+TOF+TRD)
- well described by FONLL calculations

M. Cacciari et al., arXiv:hep-ph/980340, hep-ph/0102134

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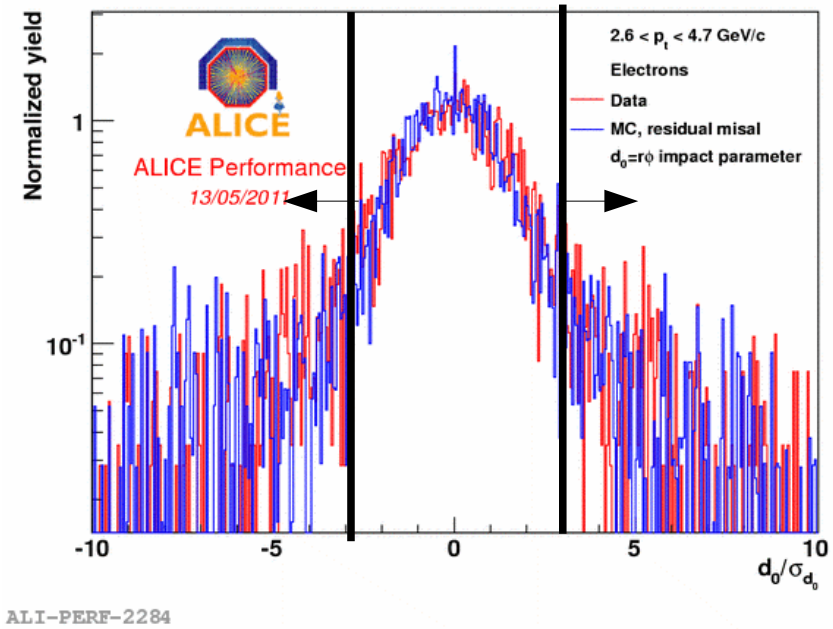
electrons from B decays

large b mass and cτ of 500 μm combined with good impact parameter resolution allow cut on impact parameter in transverse plane d_0



subtraction of remaining background

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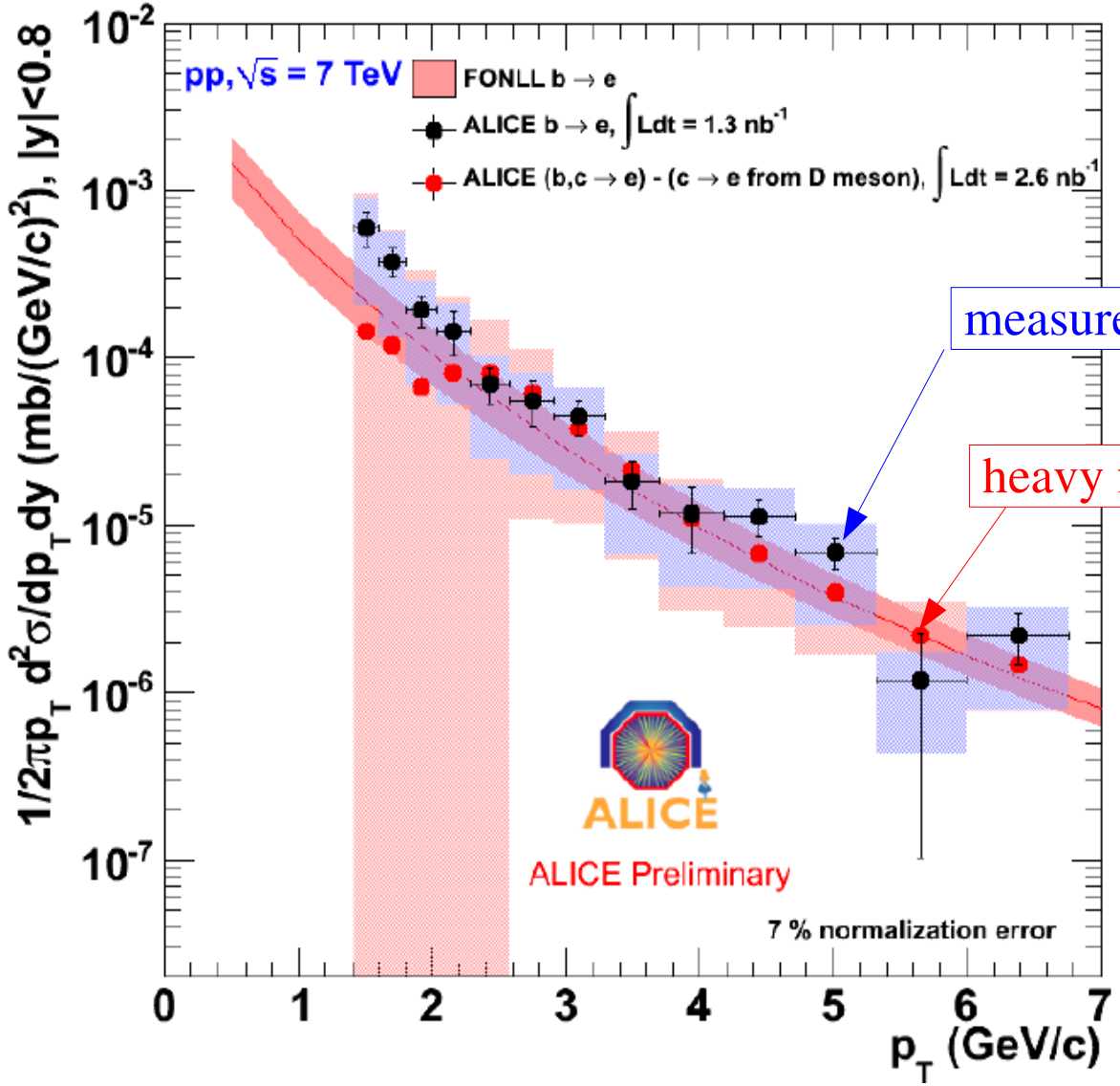
B → e + X



measurement of beauty electrons for 1.4 – 6.8 GeV/c

measurement via impact parameter cut

heavy flavor electrons – charm from D mesons

- excellent agreement of 2 methods to determine electrons from B-decays
- good agreement with FONLL calc.

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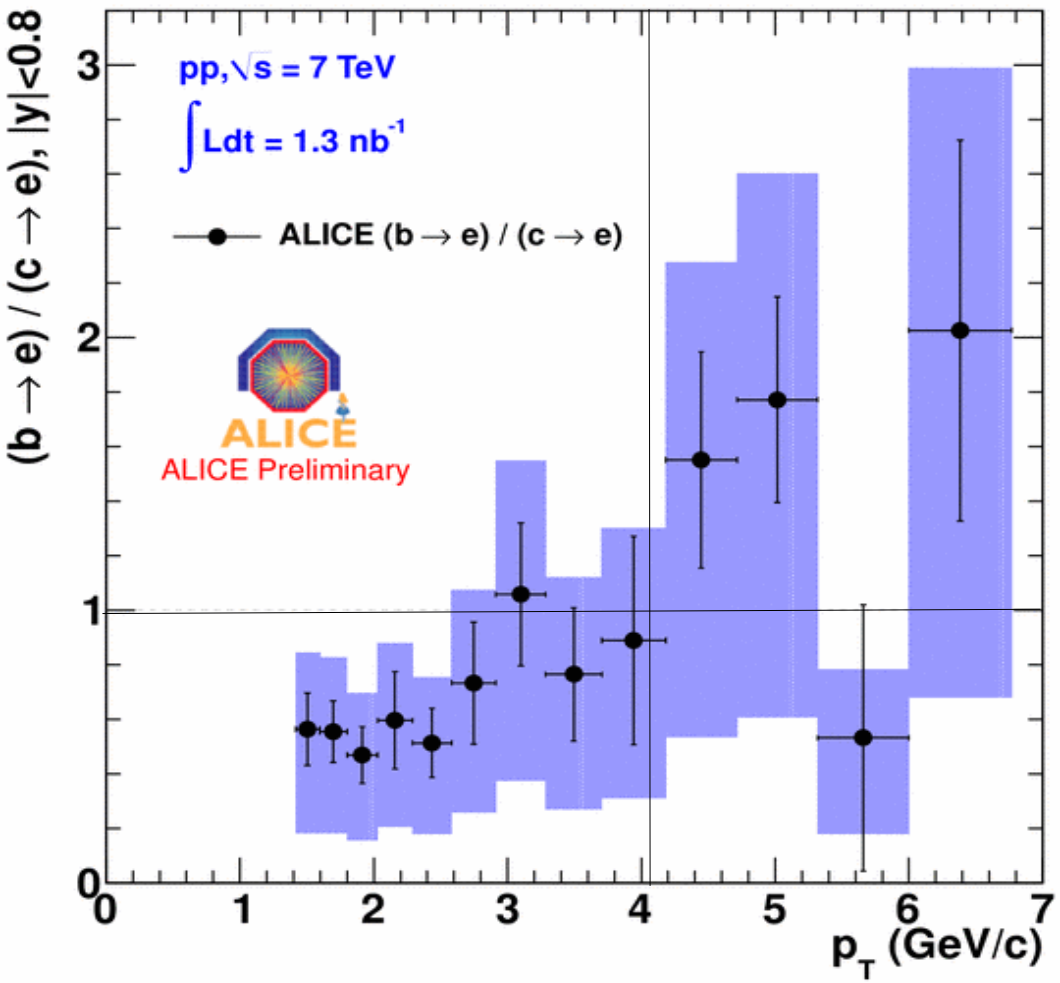
Electrons from beauty relative to electrons from charm



ALI-PREL-4010

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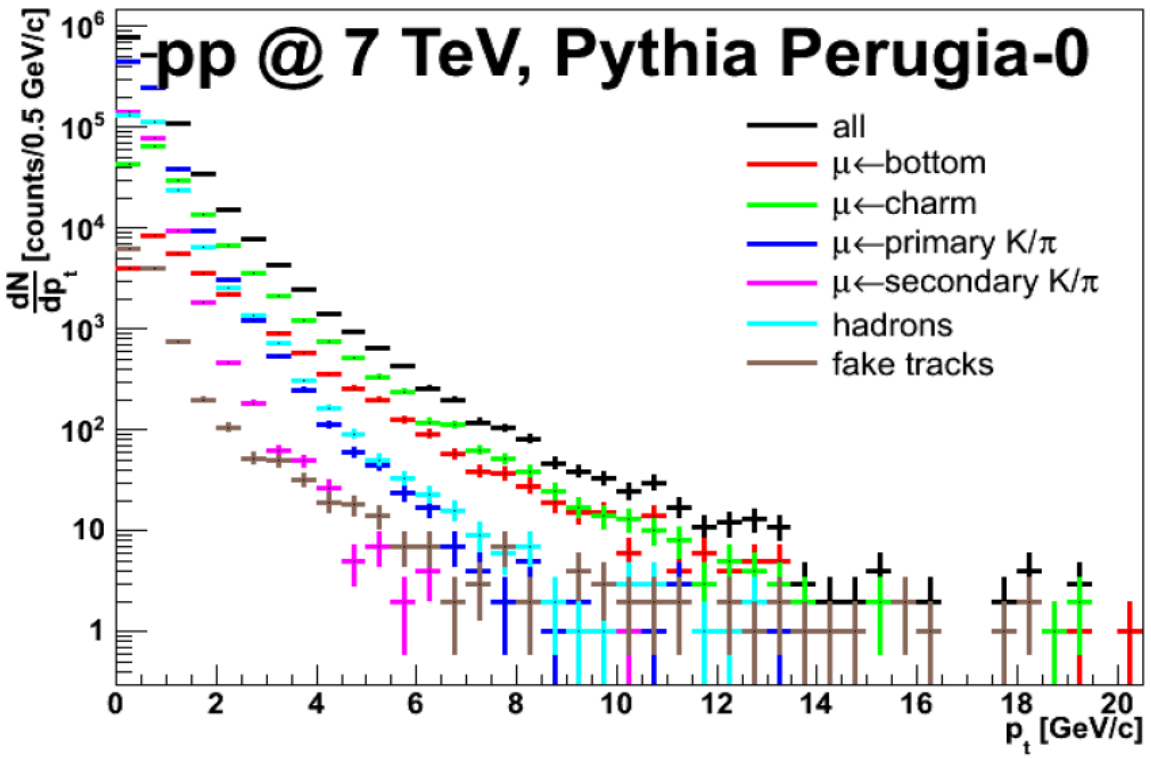
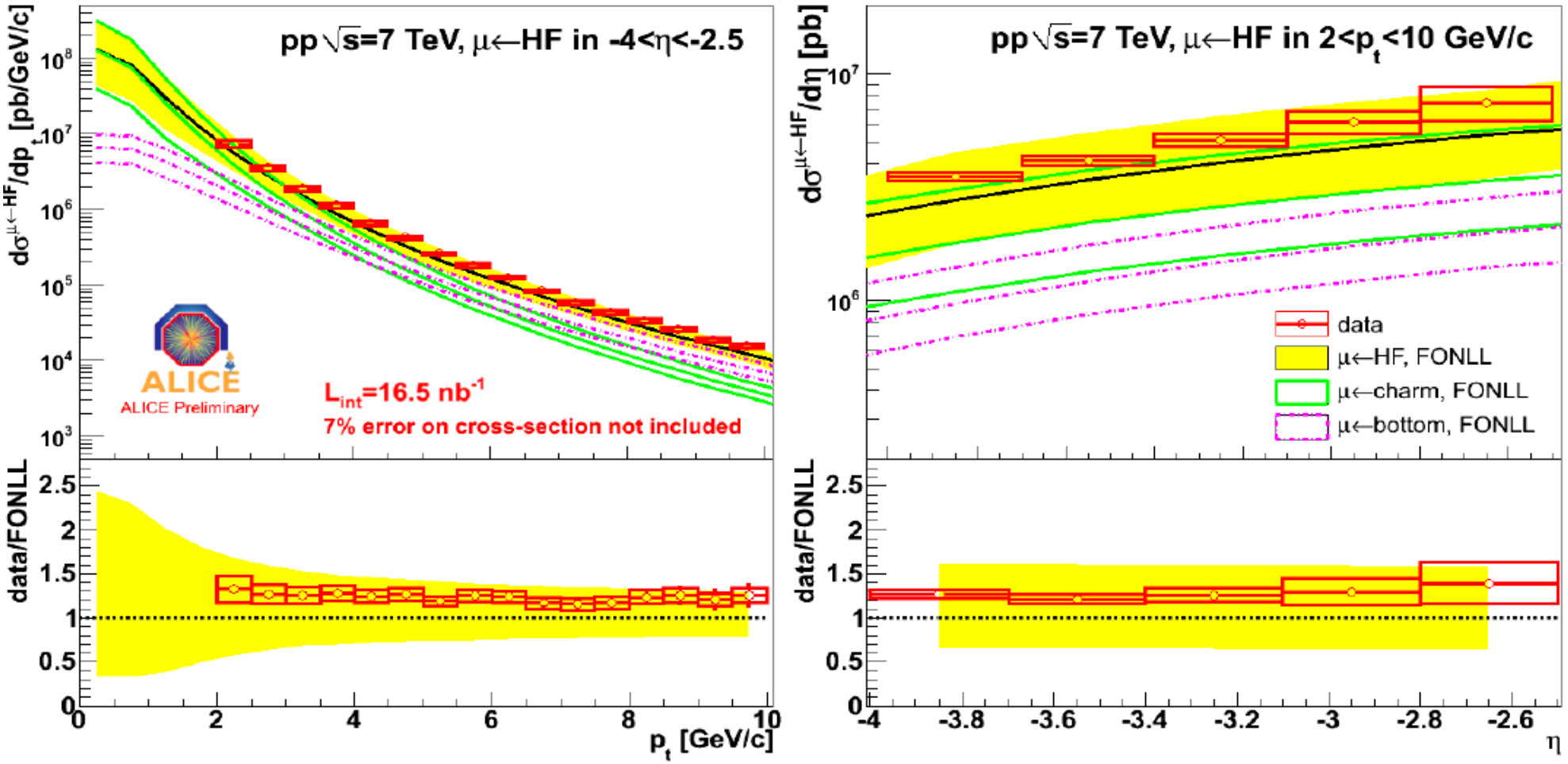
heavy flavor production in semi-muonic decays

- in acceptance -4 < eta < -2.5
- background from decays of primary pion and kaon before absorber
  from decay of secondary pion and kaon in absorber
  from punch-through through absorber
  reduced by cuts and remaining background subtracted
- data corrected for efficiency and acceptance
- systematic error contains beyond correction uncertainties the error of background subtraction alignment and overall cross section error



muons from semi-leptonic charm and beauty decays in pp



for p_t = 2-10 GeV integrated yield of semi-leptonic muon data/FONLL = 1.24

starts to constrain scales - see talk by Ramona Vogt

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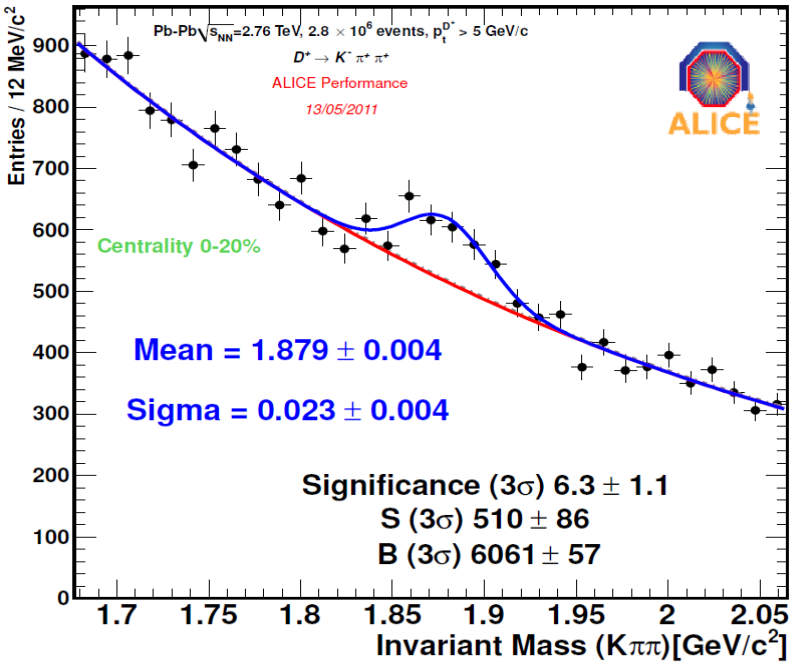
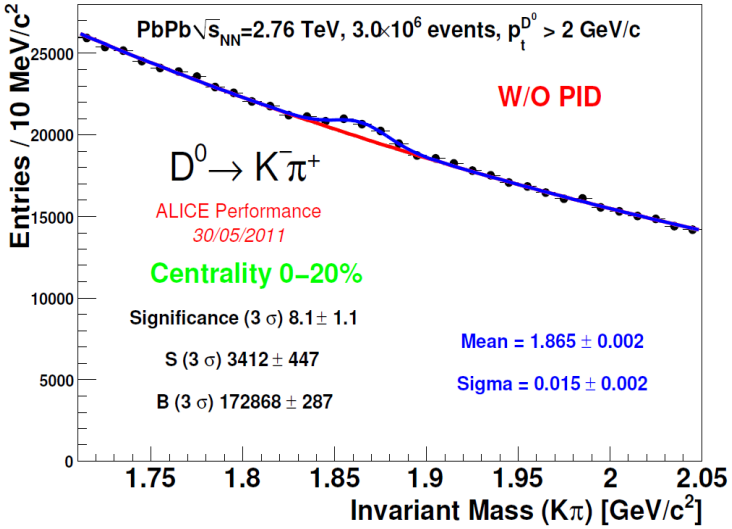
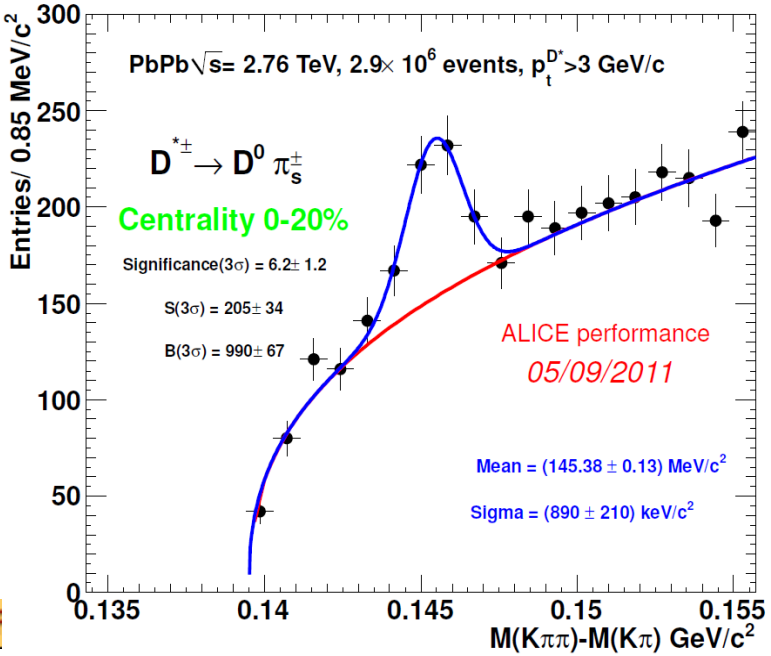
Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV







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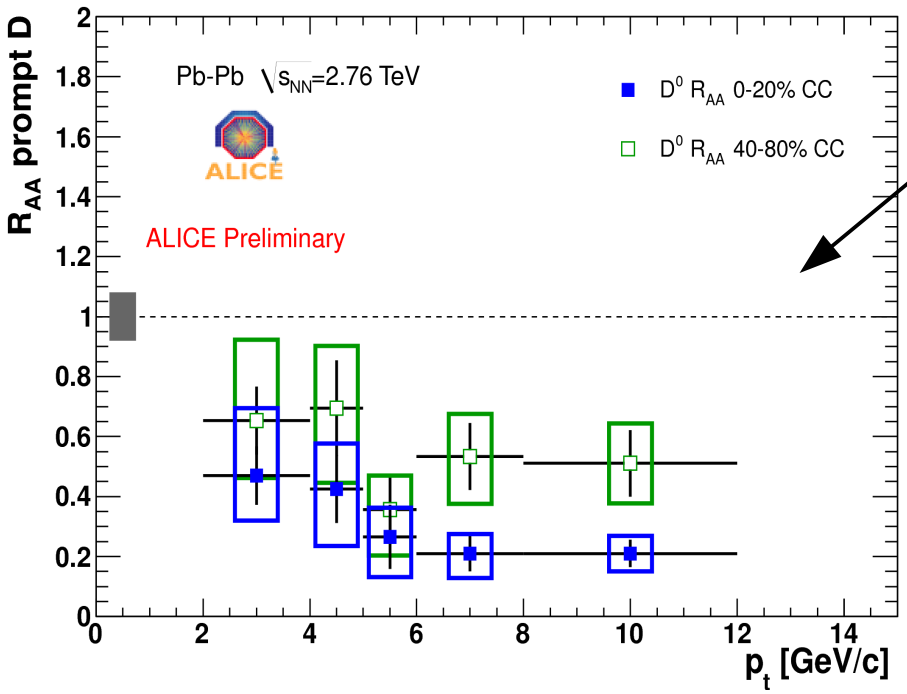
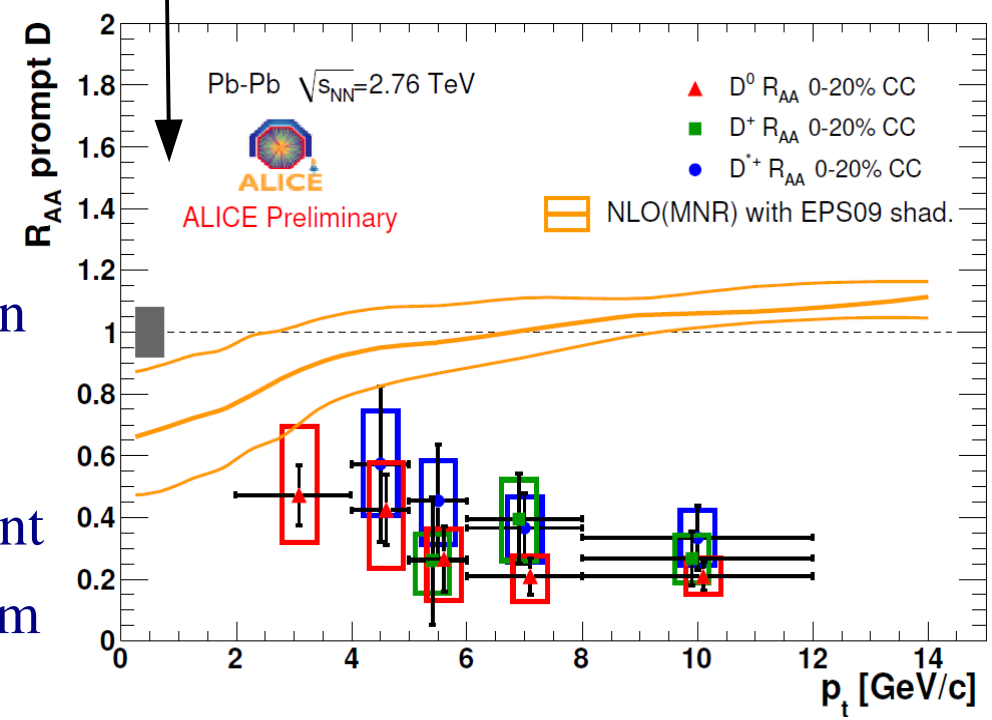
R_{AA} for D mesons in PbPb collisions



with increasing centrality significant suppression observed for D^0

and with somewhat larger errors but in good agreement also for $D^{\pm}$ and D^*



how much of it is due to gluon shadowing in nuclear collisions?

no measurement yet

estimates show: at small p_t this could account for data, at $p_t > 5$ GeV/c genuine hot medium effects

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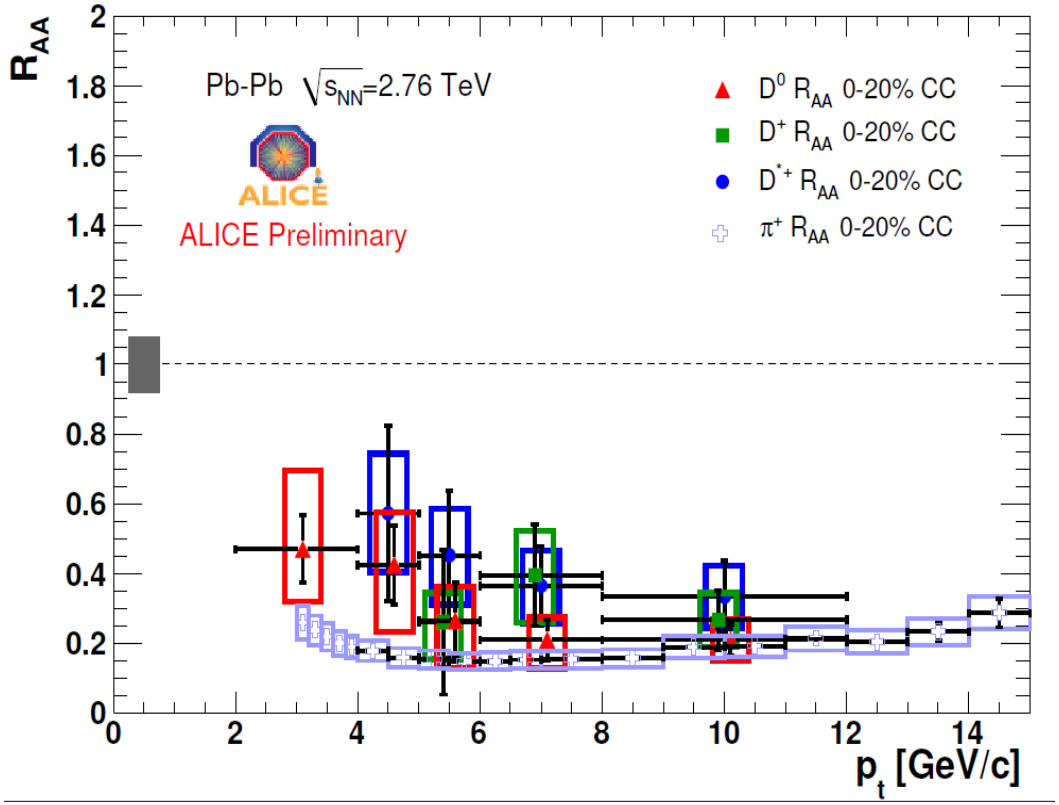
suppression of D mesons relative to pions



comparable

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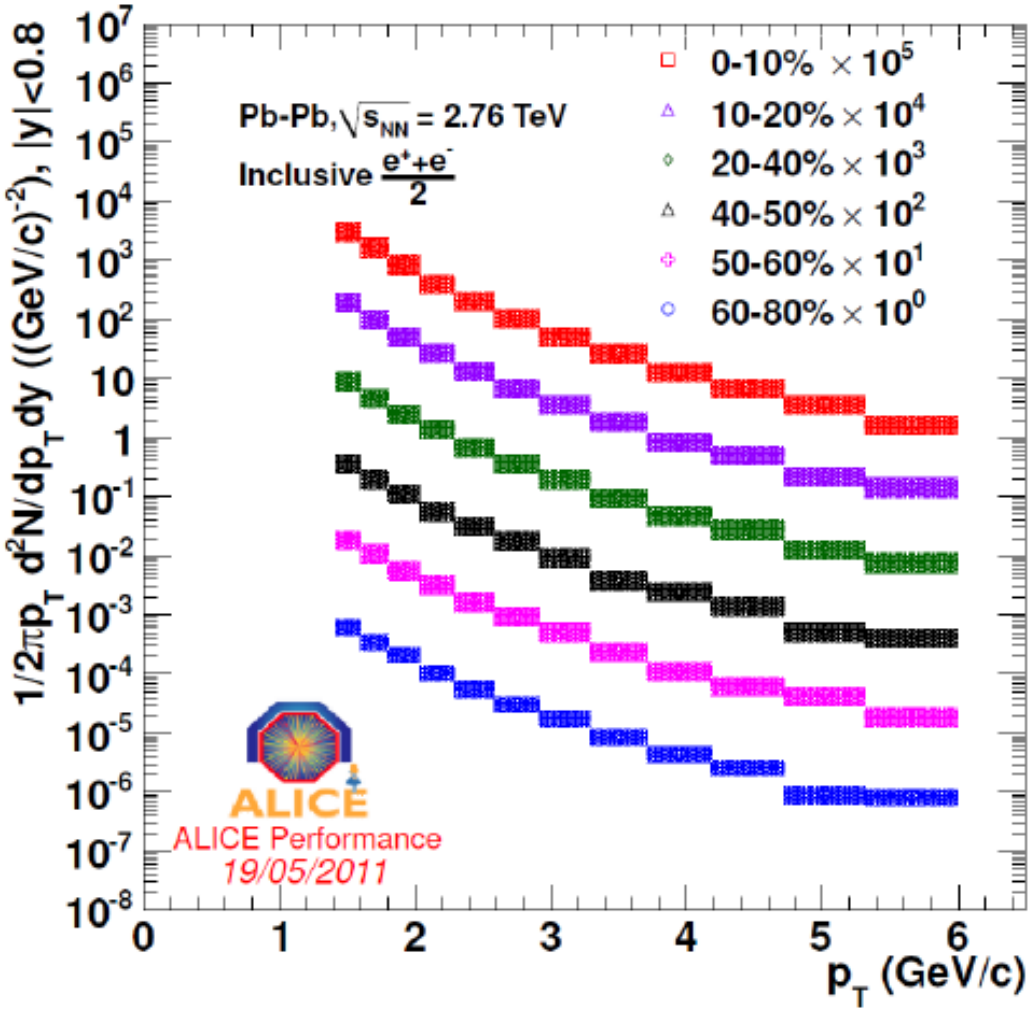
Inclusive electron spectrum as function of centrality



PID with TOF and TPC
systematic error ±35%
dominated by PID

cocktail similar as for pp:
systematic error ±25%

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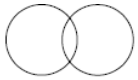
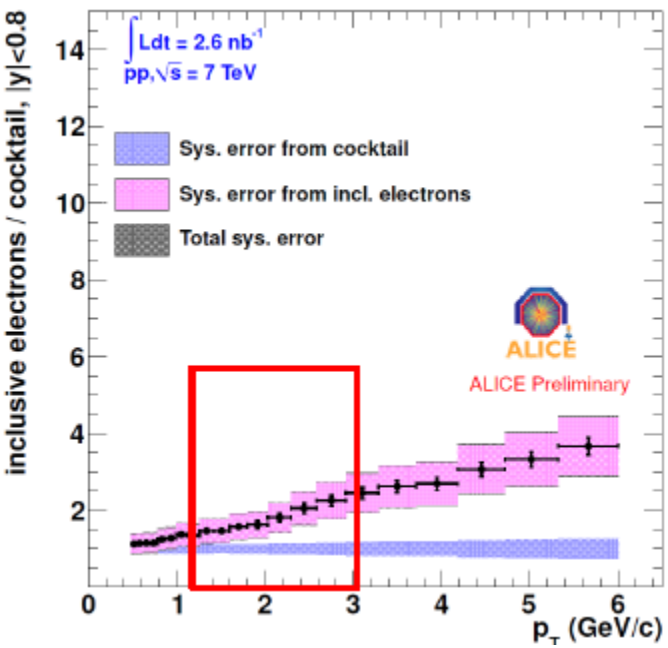
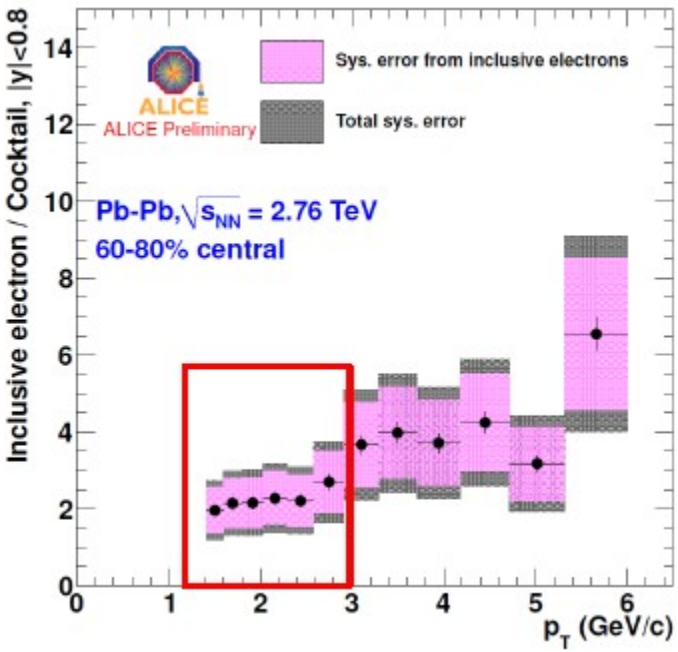
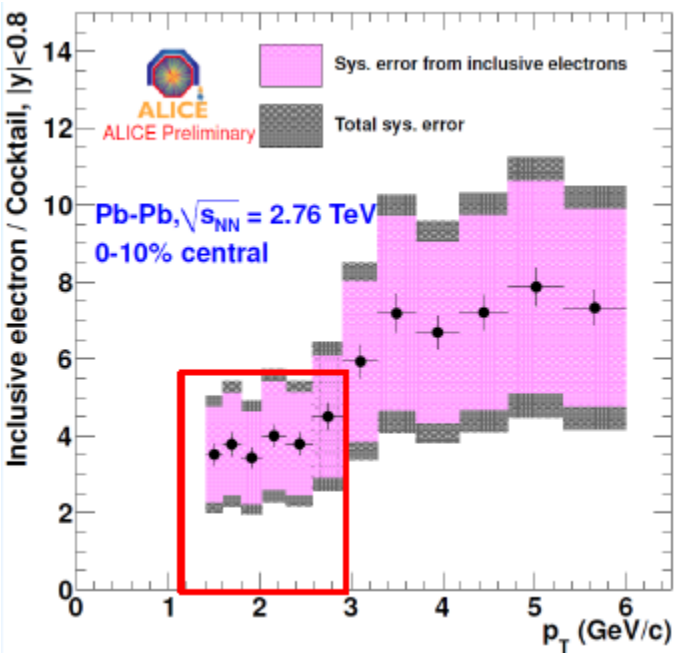
ratio inclusive electrons to decay cocktail

pp 7 TeV **Pb-Pb**  **0-80%** **Pb-Pb**  **-10%**







in PbPb a hint for an electron excess at low p_T, increasing with centrality

thermal radiation? (measured by PHENIX in central collisions)

thermal charm production? See talk by Krzysztof Redlich

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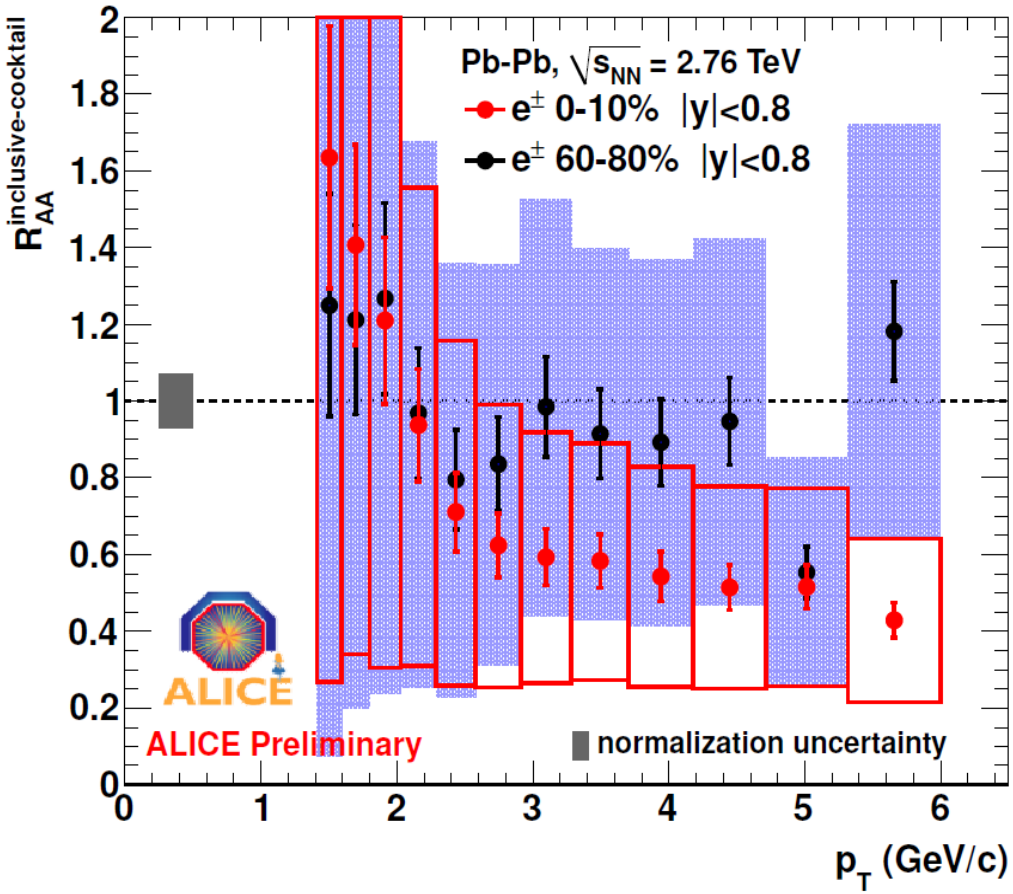
R_{AA} for electrons from charm and beauty decays



- for central collisions significant suppression of heavy flavor electrons (dominate beyond 3.5 GeV/c)
- separation into charm and beauty to come

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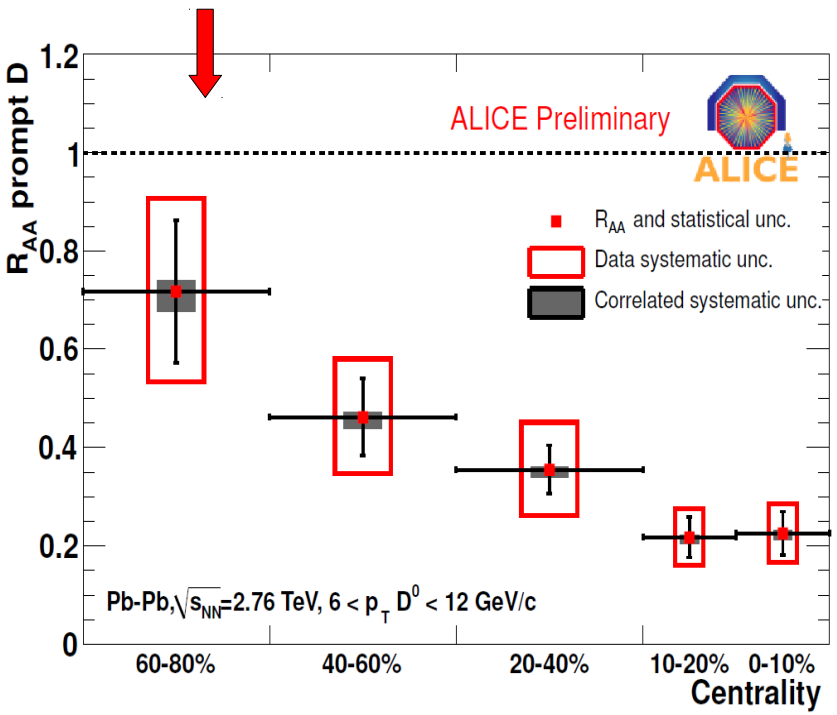
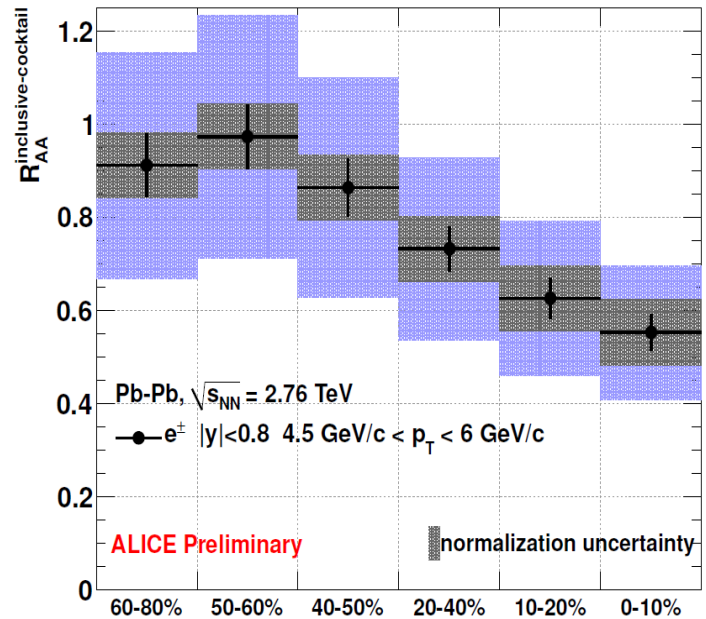
open heavy flavour suppression vs centrality

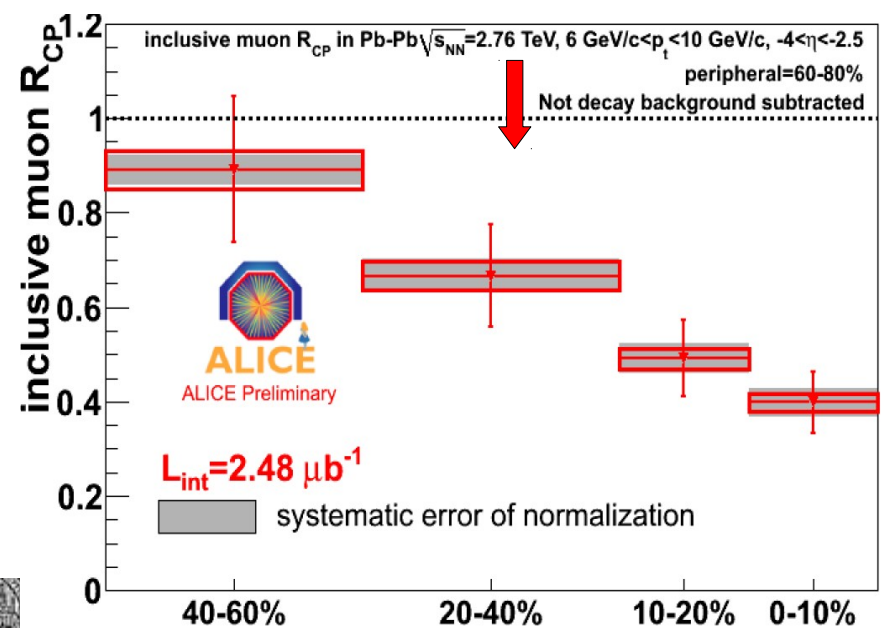
D mesons

electrons





muons



all measures of open charm and beauty indicate significant energy loss of heavy quarks in central nuclear collisions

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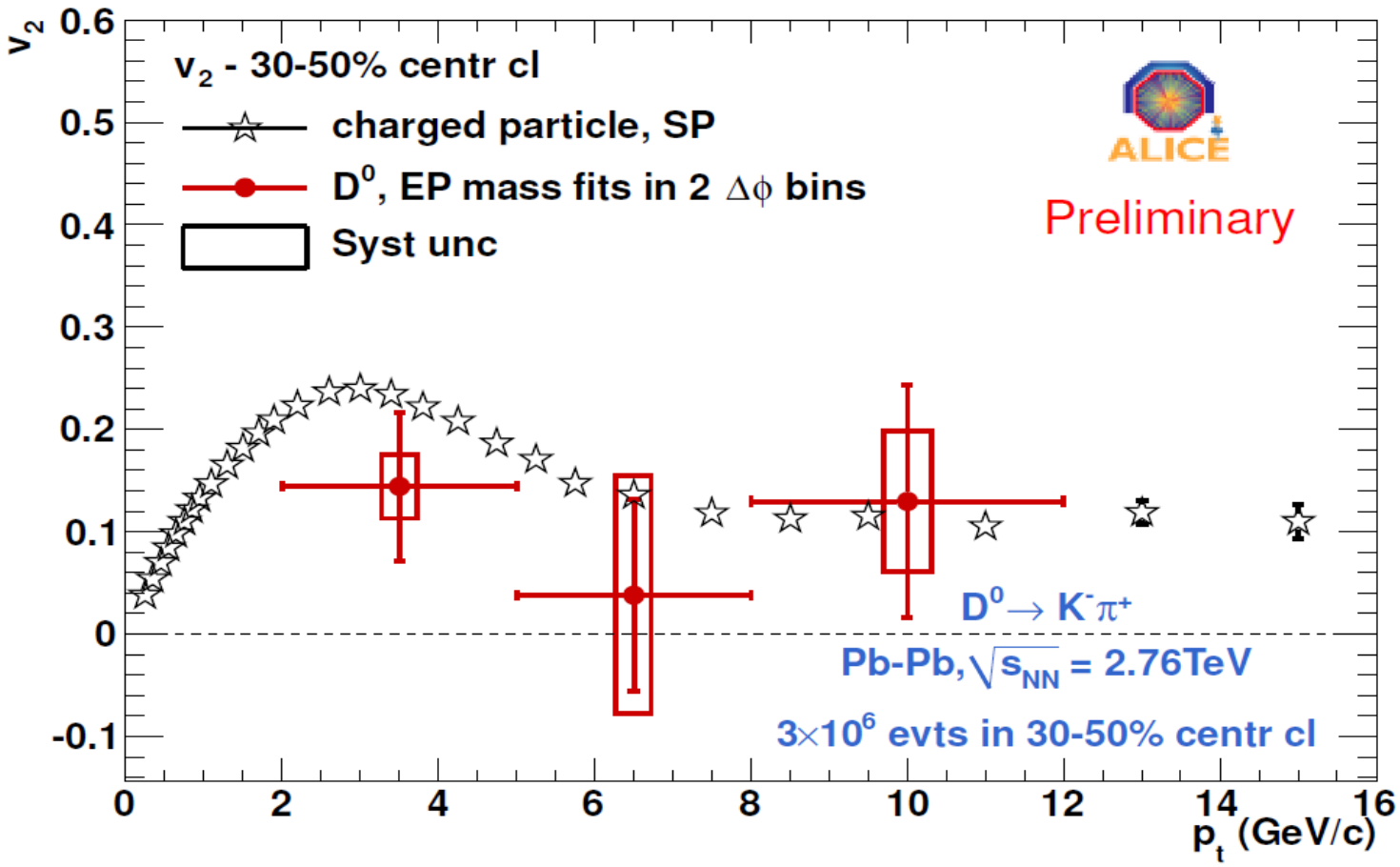
elliptic flow of D mesons

event plane from charged particle tracks in the TPC



SP: scalar product method

$D^0 \rightarrow K\pi$ in 2 bins in and out of plane background subtraction with side-band method

looking forward to more statistics with 2011 data

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summary

Open charm measured in pp via hadronic D decays and semi-leptonic electron and muon decaysa at 7 and 2.76 TeV

Errors will still be reduced by adding more statistics and improving systematics

First measurement of b production via semi-electronic B decays
J/psi from B just starting

Errors still too large to constrain J/psi to open charm ratio

In PbPb open charm and beauty are on the way, will benefit a lot from improved luminosity of 2011 run

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