Open heavy flavour measurements with the ALICE experiment at the LHC

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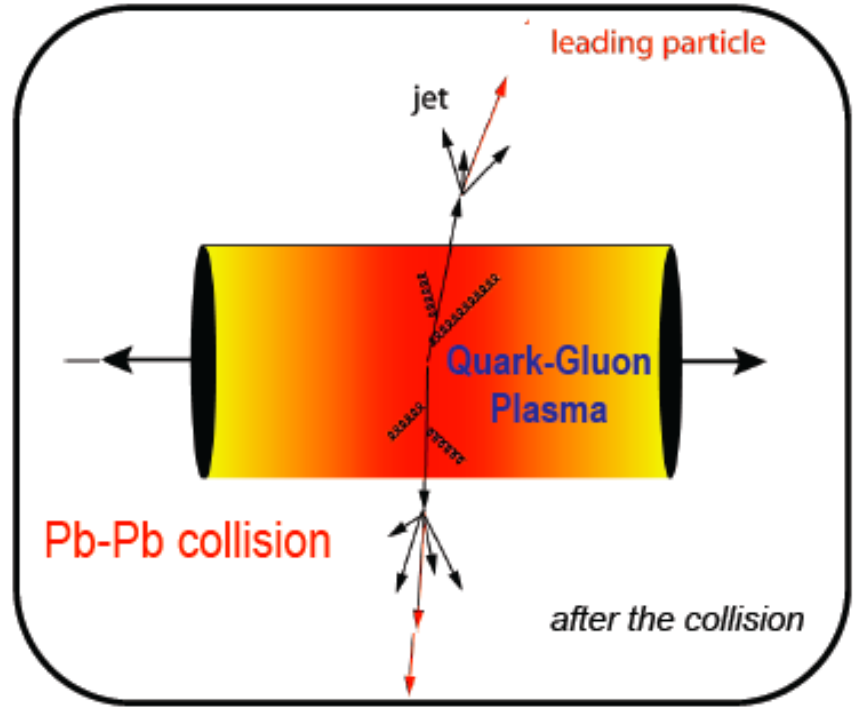
Outline:

- motivations
- measurements in pp at √s=7 TeV
  - D meson reconstruction
  - HF→ e+X, μ+X
  - *charmonium measurements*
- outlook to PbPb
- conclusions

Motivations

- No needs to motivate the study of charm and beauty production in pp collisions with such an audience
- I will concentrate on the peculiarities of heavy ion physics

Probing hot and dense QCD matter



- How to establish the properties of a system ?
  - calibrated probe
  - calibrated interaction
  - suppression pattern tells about density profile
- Heavy-ion collisions
  - hard processes serve as calibrated probe (pQCD)
  - traversing through the medium and interact strongly
  - suppression provides density measurement
  - General picture: energy loss via medium induced gluon radiation and collisional energy loss

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA}) d^2N^{AA}/dydp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp}) d^2N^{pp}/dydp_T}$$

Charm & Beauty as probes

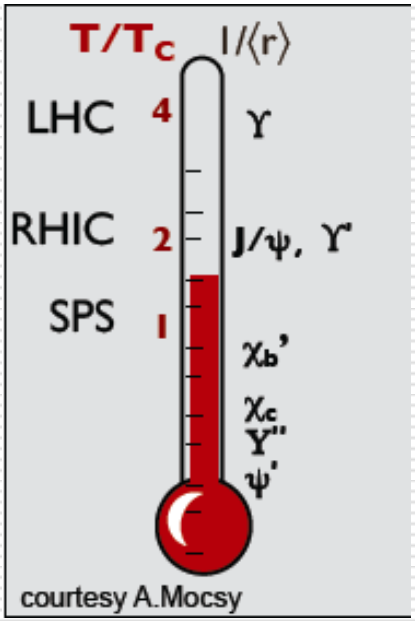
- calculable in pQCD; calibration measurement from pp
  - → rather solid ground
    - caveat: modification of initial state from pp to AA
      - shadowing (for pt <5-7 GeV/c)
      - saturation?
    - pA reference fundamental!
- produced essentially in initial impact
  - → probes of high density phase
- no extra production at hadronization
  - → probes of fragmentation
    - e.g.: independent string fragmentation vs recombination

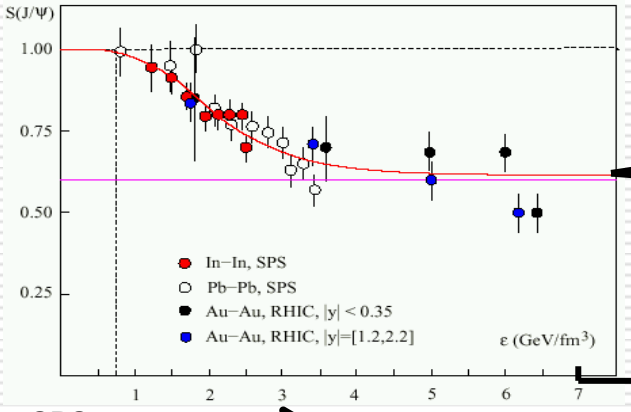
Probing the medium

- quenching vs colour charge
  - heavy flavour from quark (C_R = 4/3) jets
  - light flavour from (p_T-dep) mix of quark and gluon (C_R = 3) jets
- quenching vs mass
  - heavy flavour predicted to suffer less energy loss
    - gluonstrahlung
    - collisional loss
  - beauty vs charm

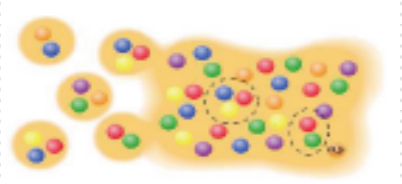
Quarkonia at LHC

- Quarkonia dissociation due to colour screening
- Dissociation pattern depends on binding energy T_D and medium temp. T → quarkonia as a thermometer
  - Υ would dissociate only at LHC
  - $\Upsilon' T_D \sim J/\psi T_D$
- Expected regeneration for charmonia due to in-medium coalescence of charm quarks





enhanced regeneration

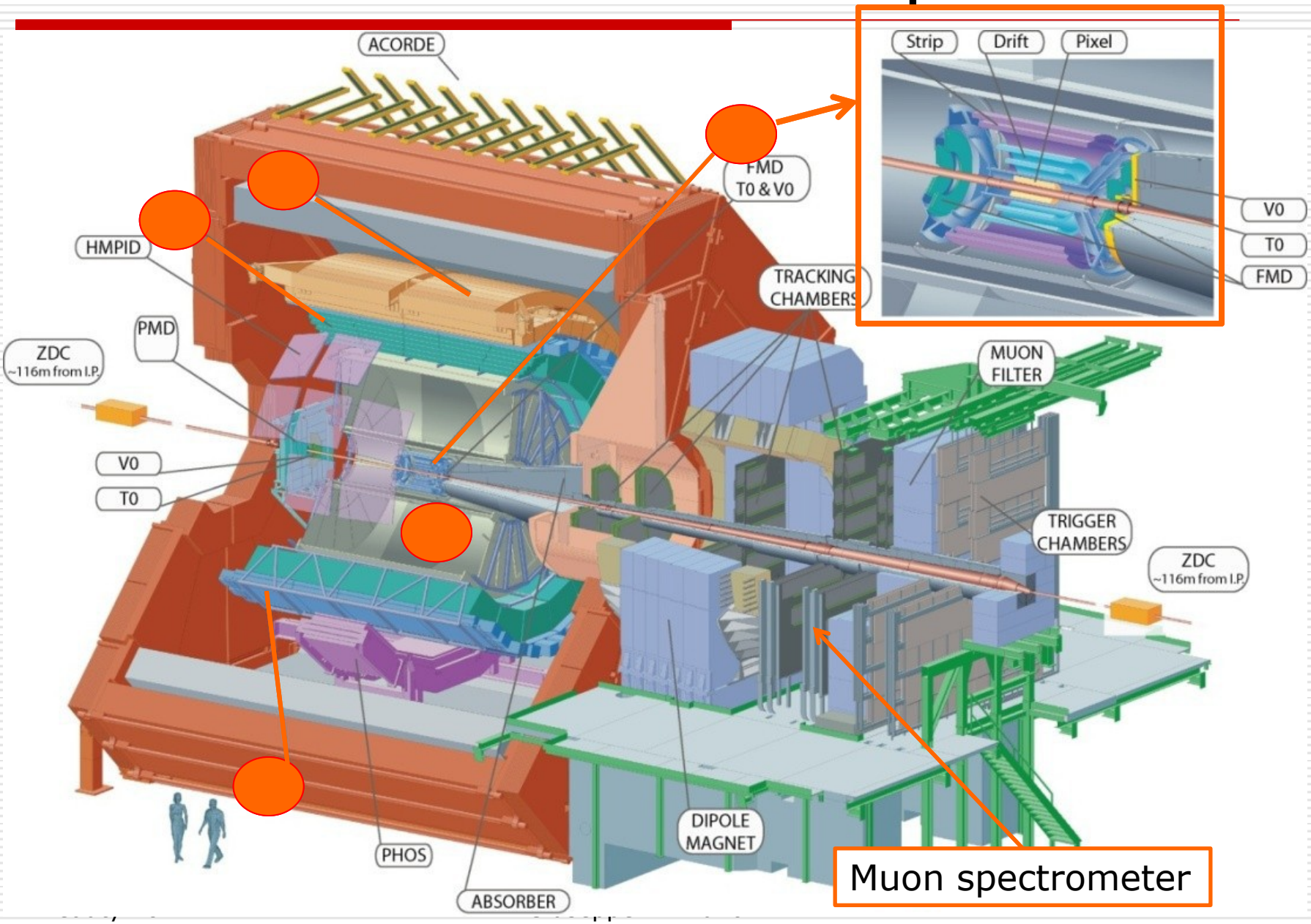


enhanced suppression

$T_{LHC} >> J/\psi\ T_D$

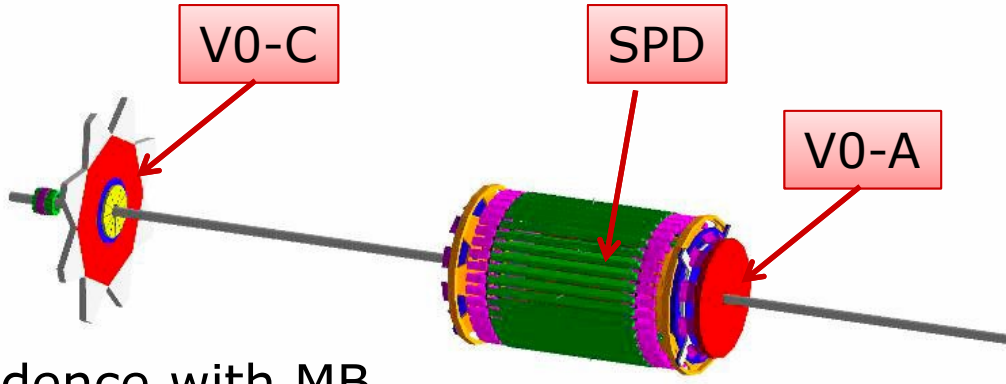
SPS
RHIC
LHC

ALICE schematic setup



Trigger and data sample: pp

- **Minimum bias** (MB) based on interaction trigger:
  - SPD(pixels) or V0-A(scintillators) or V0-C(scintillators)
  - At least one charged particle in 8 η units
  - 95% efficient on σ_{inel}



- **Single muon** trigger:
  - Forward Muon in coincidence with MB
  - read out MUON, SPD, ZDC, V0, FMD

- A total of 8×10^8 min. bias events and 1.3×10^8 muon events were recorded in the 2010 pp run.

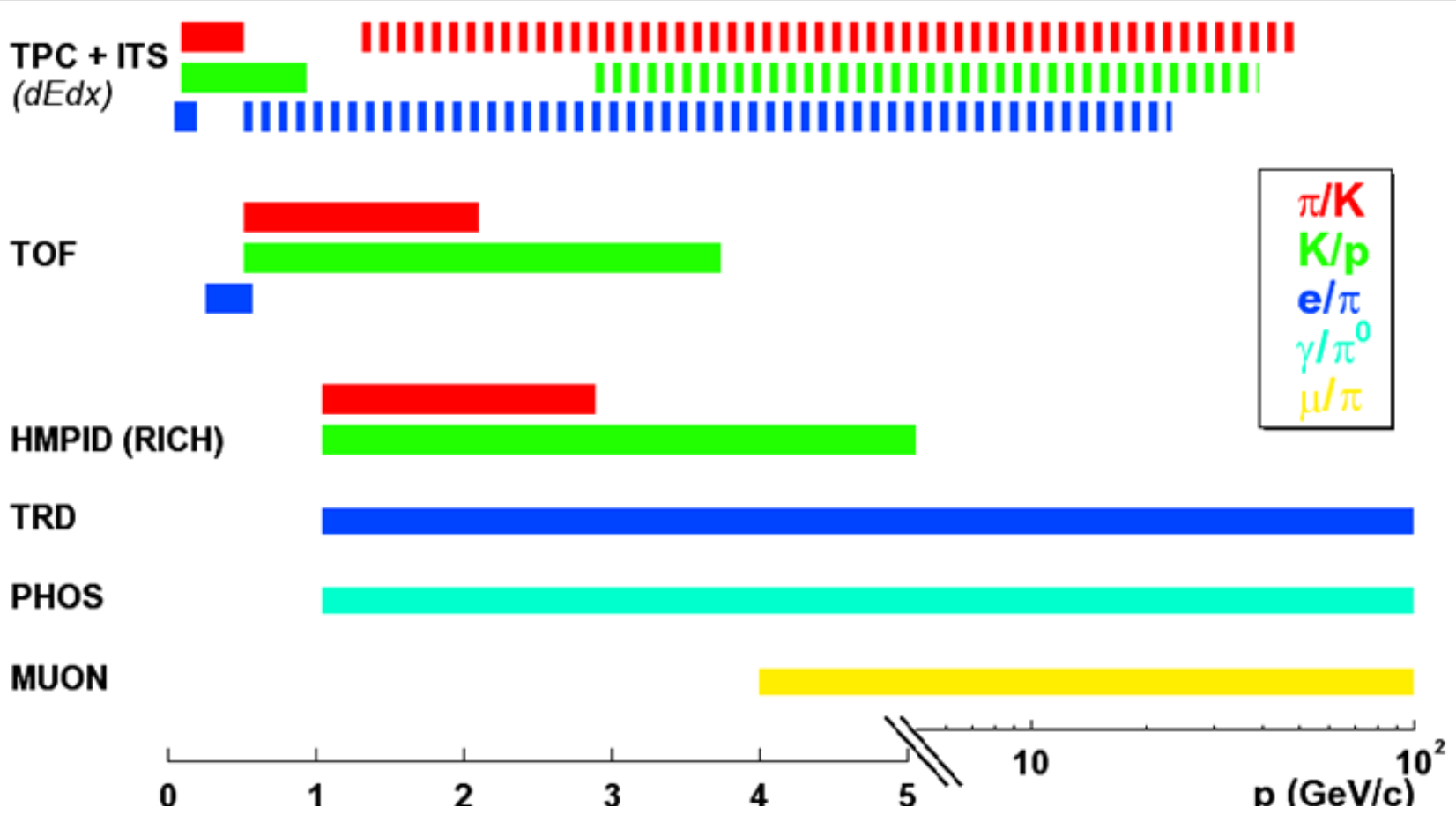
Trigger and data sample

PbPb

- Triggering with SPD and V0:
  - 2 out of 3 trigger signals:
    - 2 SPD fired chips in the outer layer
    - V0A
    - V0C
  - V0-A and V0-B
    - more efficient for electromagnetic interaction suppression
  - 95% efficient on σ_{inel}

Year	Collision system	Energy (TeV)	# of MB events
2009	pp	0.9	$3x10^5$
2009	pp	2.36	$4x10^4$
2010	pp	0.9	$8x10^6$
2010	pp	7.0	$8x10^8$
2010	Pb-Pb	2.76x208	$3x10^6$
2011	pp	2.76	$9x10^7$

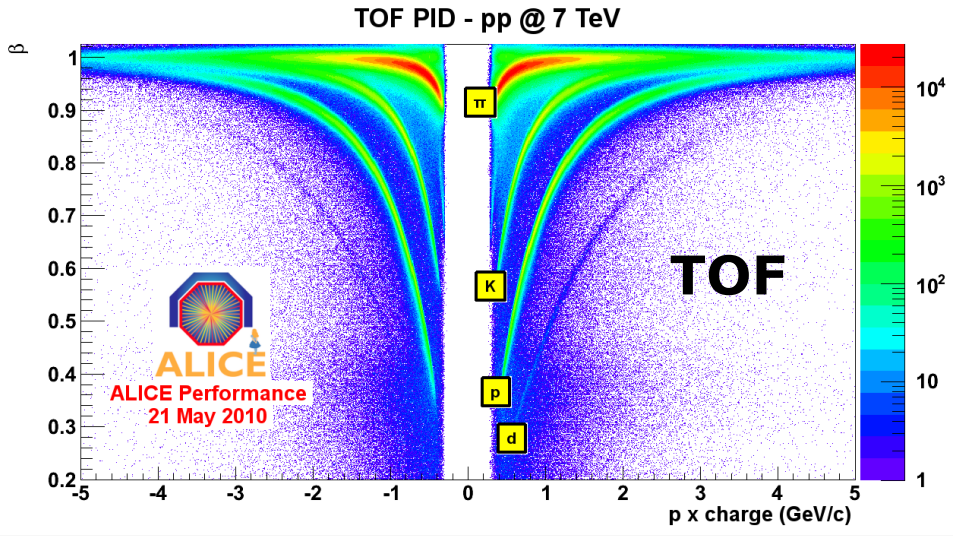
PID: one of ALICE's strengths

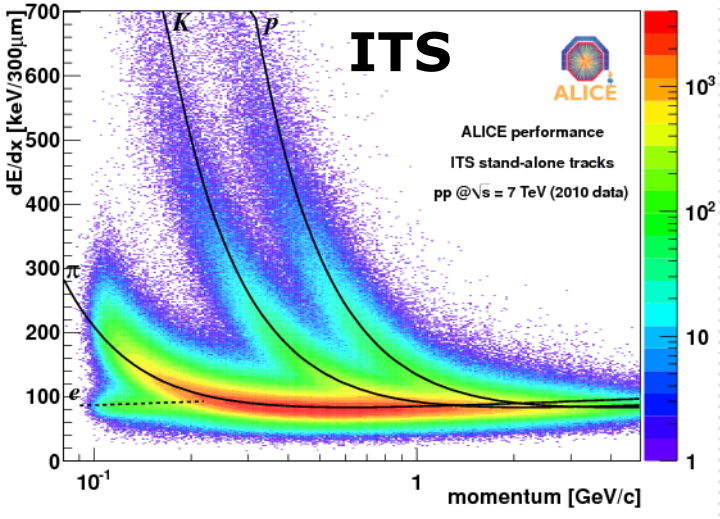


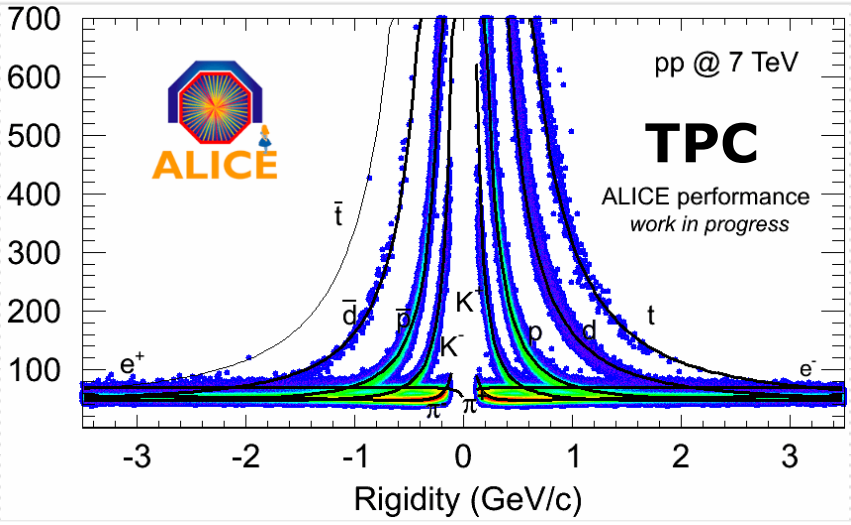
EMCAL adds electron/pion separation via shower shape

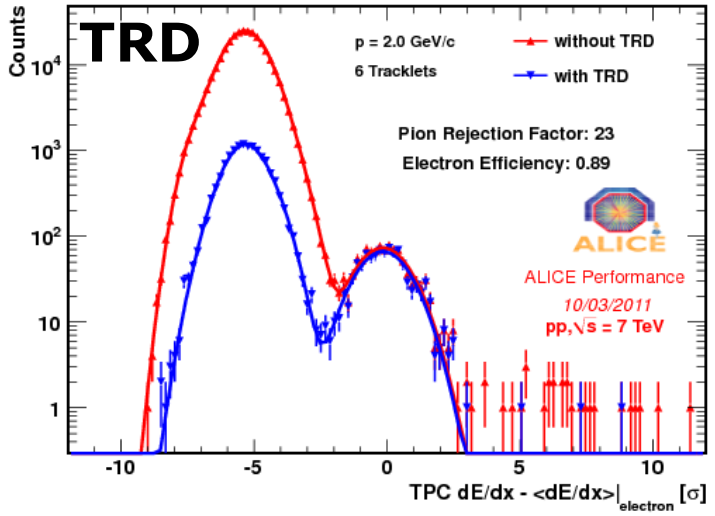
- ALICE has PID over large momentum range

PID performance



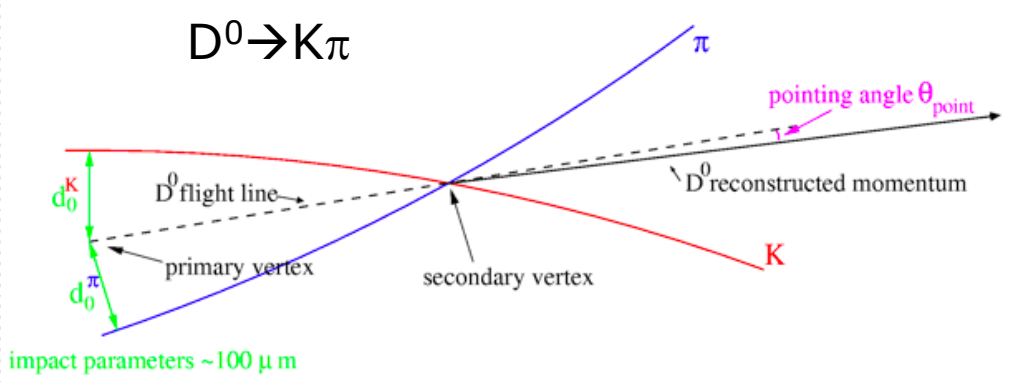






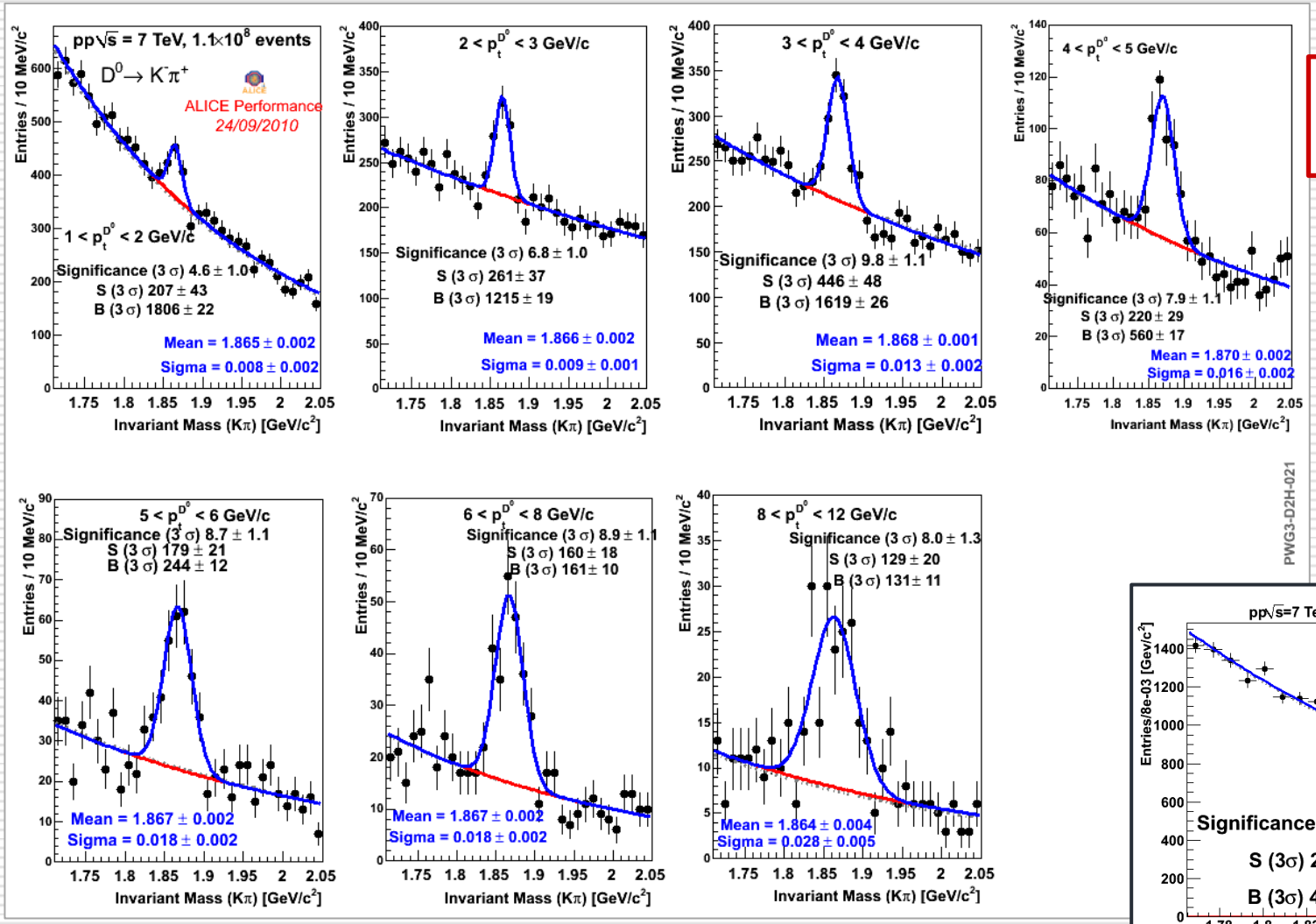
Exclusive charm decays

- Analysis based on decay topology and invariant mass technique
- Essential selection cuts:
  - impact parameter
  - distance of closest approach
  - pointing angle
- High precision tracking (ITS+TPC)
- K and □ identification (TPC+TOF) → to reduce background at low p_T



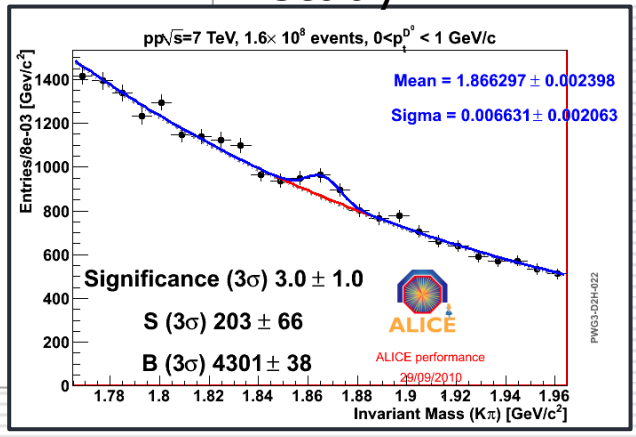
- Studied channels:
  - $D^0 \rightarrow K^-\pi^+$
  - $D^+ \rightarrow K^-\pi^+\pi^+$
  - $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$
  - $D^{*+} \rightarrow D^0(\rightarrow K^-\pi^+)\,\pi^+$
  - $D_s^+ \rightarrow K^-K^+\pi^+$
  - $\Lambda_c \rightarrow pK^-\pi^+$

$D^0 \rightarrow K^-\pi^+$ signals in p_T bins

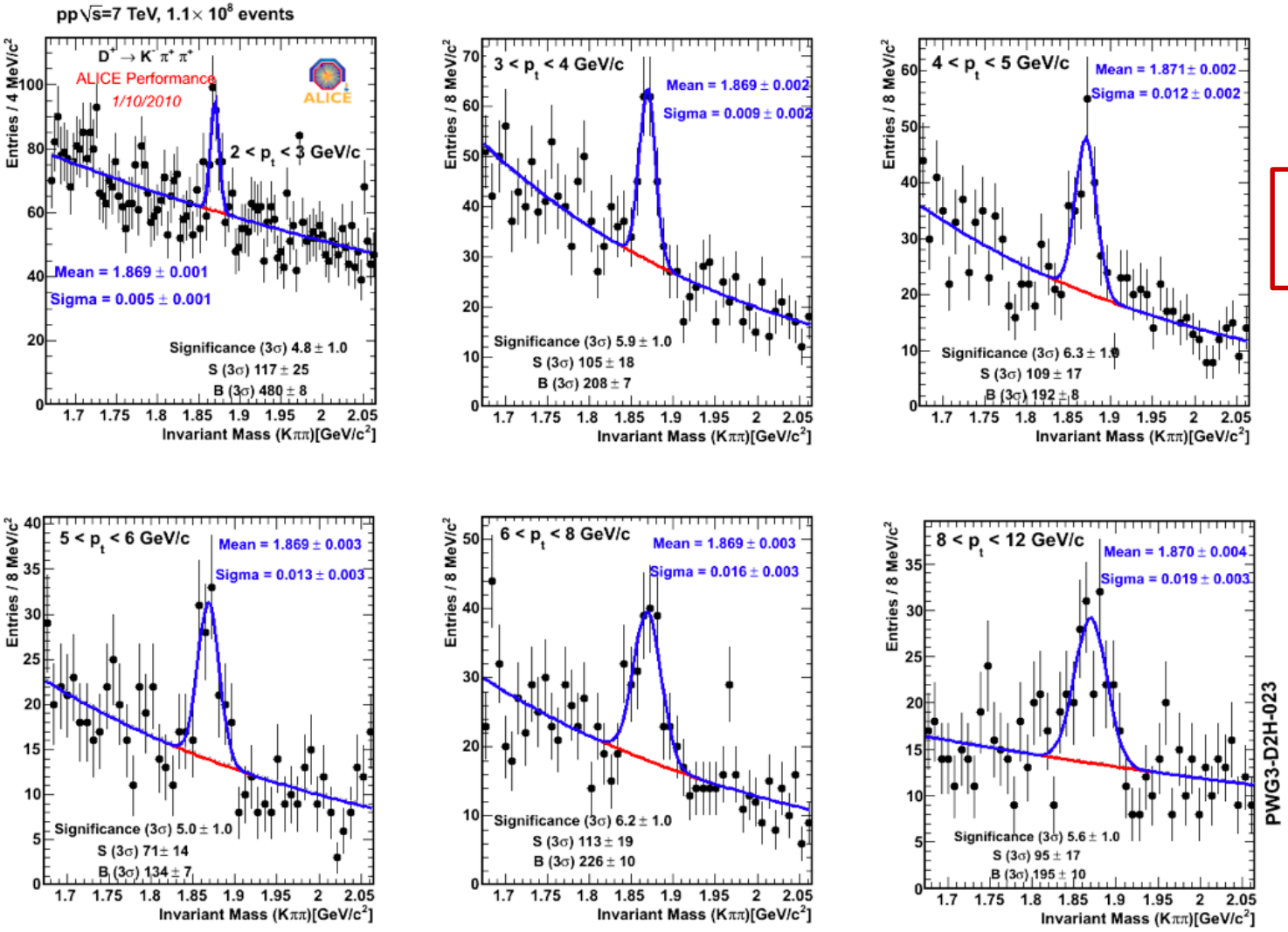


~10^8 events
$1<p_T<12$ GeV/c

Signal at very low p_T under study

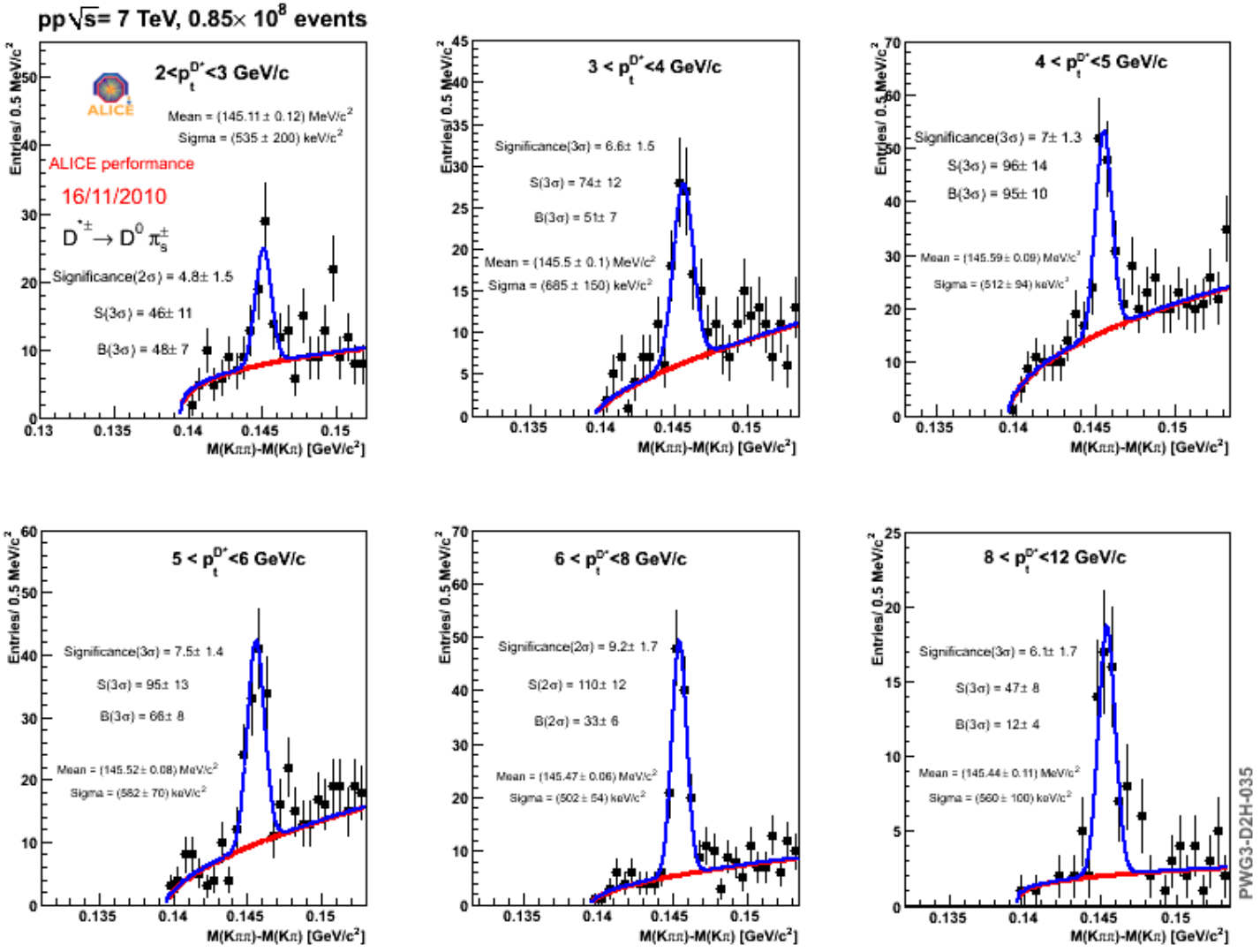


$D^+ \rightarrow K^-\pi^+\pi^+$ signals in p_T bins



~10^8 events
$2<p_T<12$ GeV/c

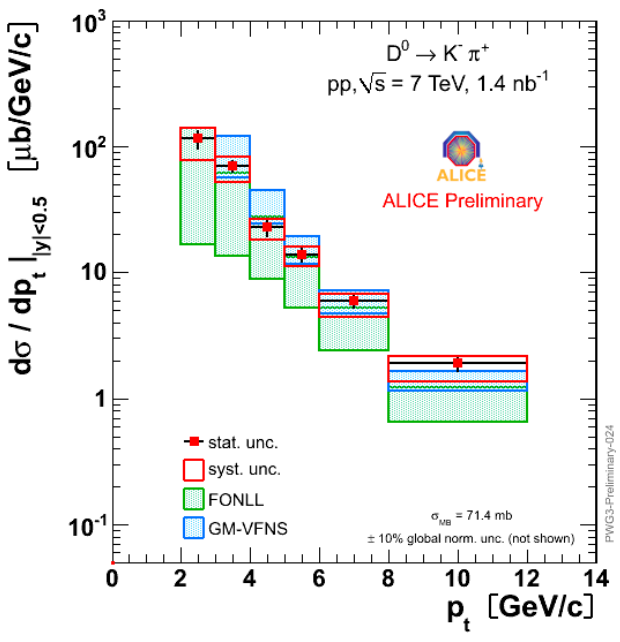
$D^{*+} \rightarrow D^0(\rightarrow K^-\pi^+)\,\pi^+$ signals in p_T bins

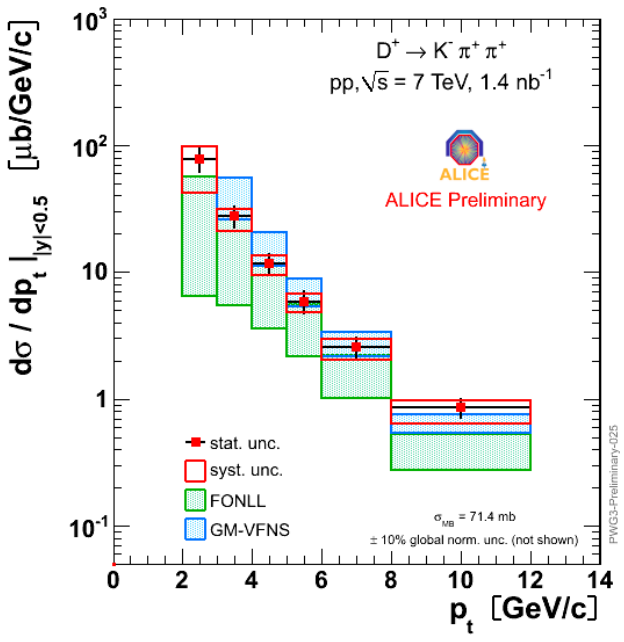


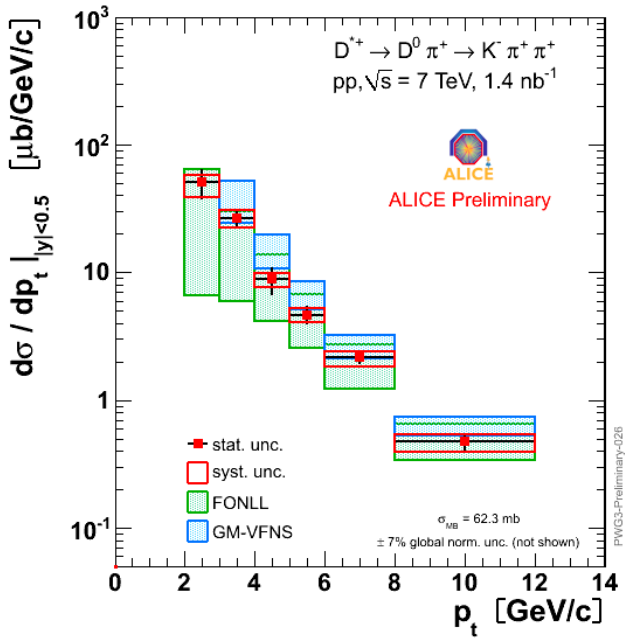
~10^8 events
$2<p_T<12$ GeV/c

ITS standalone tracking fundamental for the soft π reconstruction

Prompt D meson cross sections in |y|<0.5

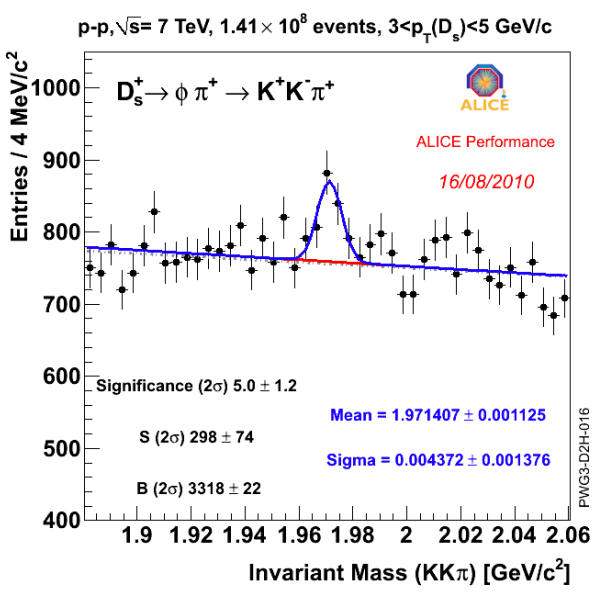


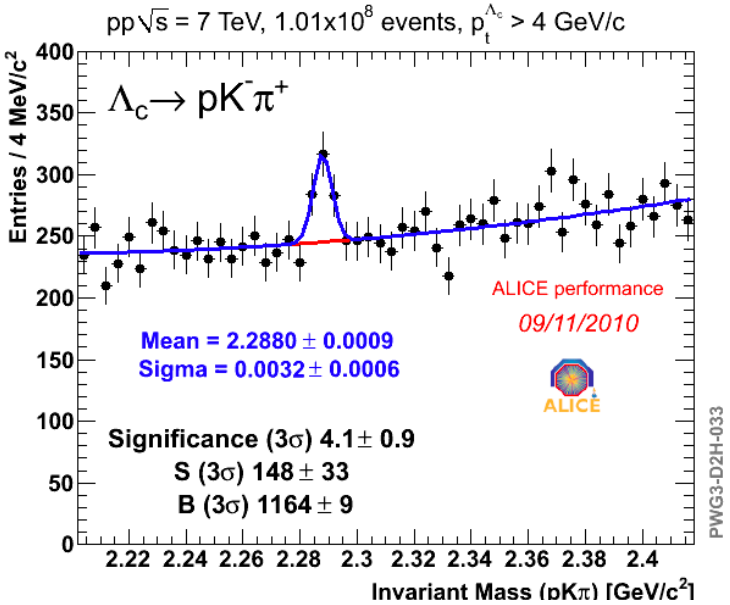


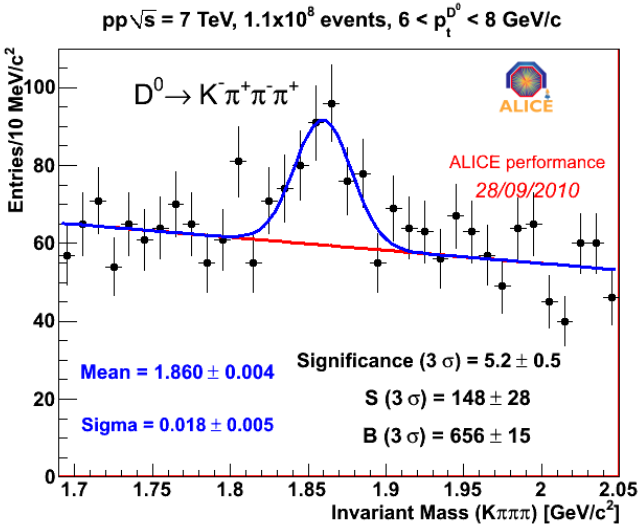


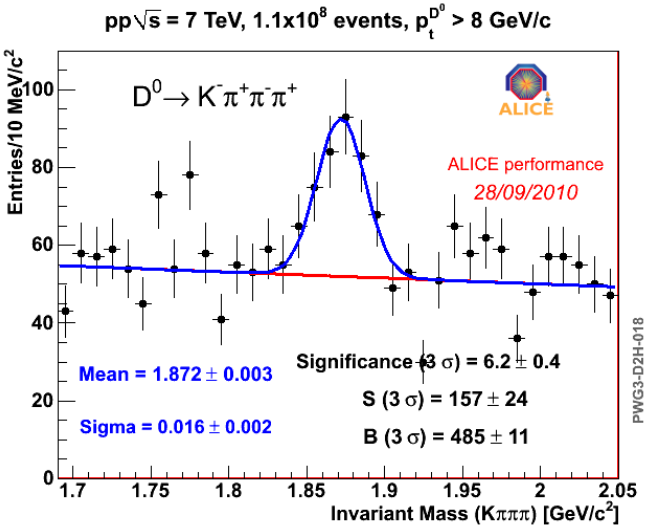
- B feed-down calculated from theory (10-15%) and subtracted
- pQCD calculations describe well our data
- Current p_T range (20% of the 2010 statistics): 2-12 GeV/c
- next:
  - extension to lower and higher p_T
  - B feed-down subtraction from data-driven methods

Other charm signals in 7 TeV p-p

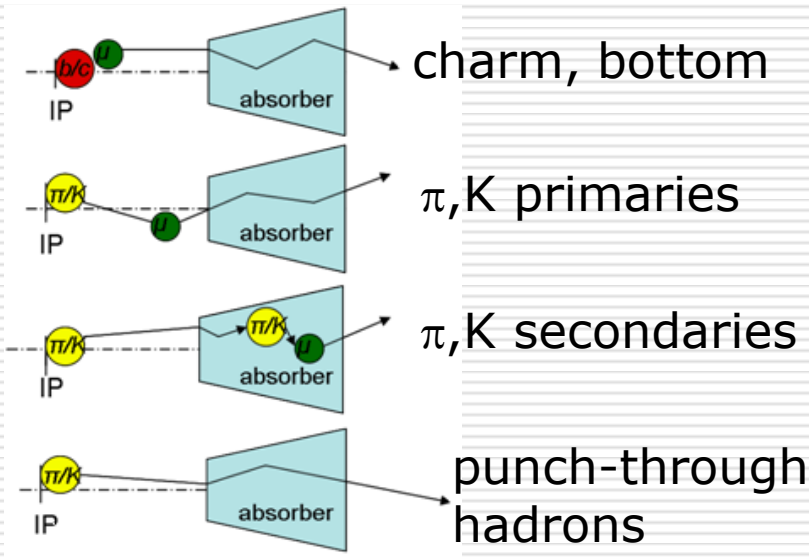


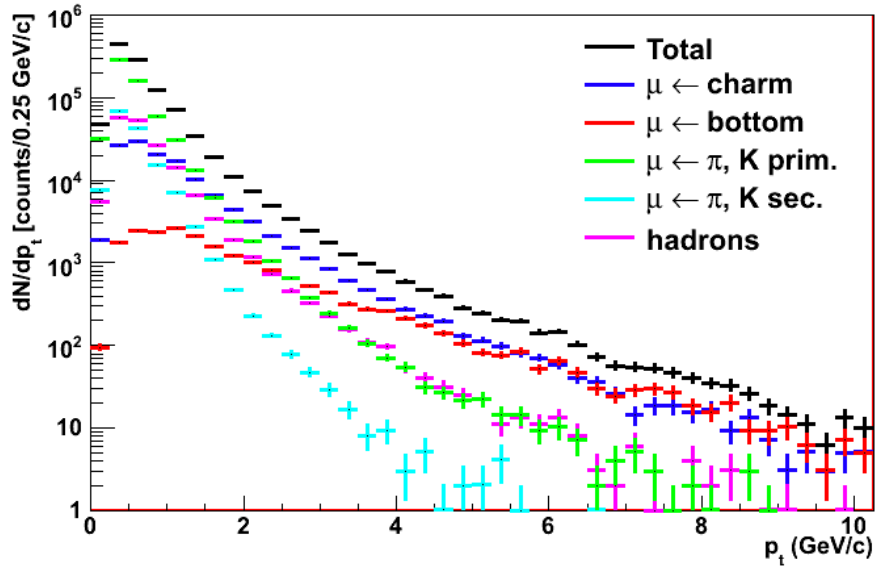






Single μ at forward rapidity

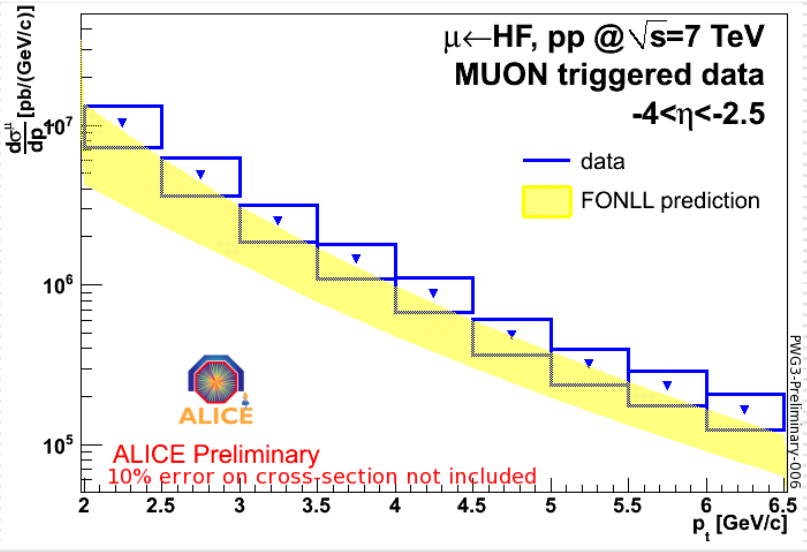


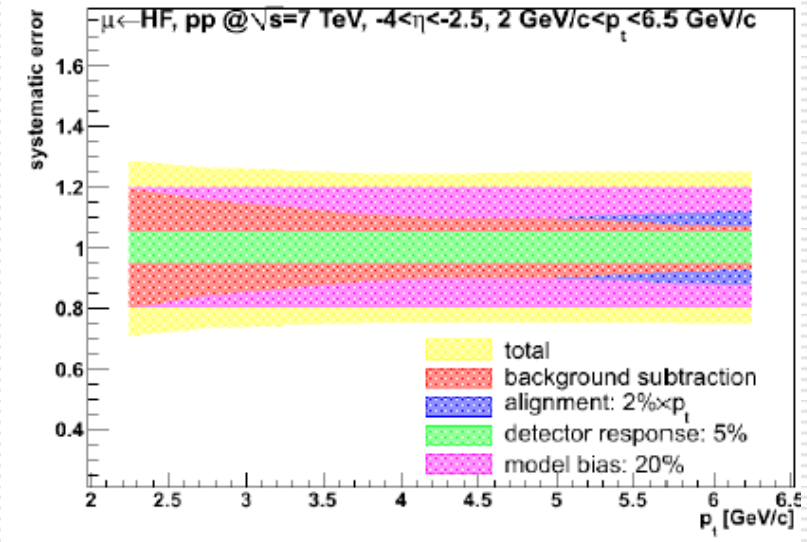


Analysis strategy

- Remove hadrons and low-pT μ (secondary □/K) by requiring μ tracking-trigger
- Remove decay μ (primary □/K) by subtracting MC dN/dp_T normalized to data at low p_T (< 2 GeV/c)
- Remaining contribution are μ from charm and bottom
- Corrections for acceptance x efficiency (~80% for p_T > 2 GeV/c)

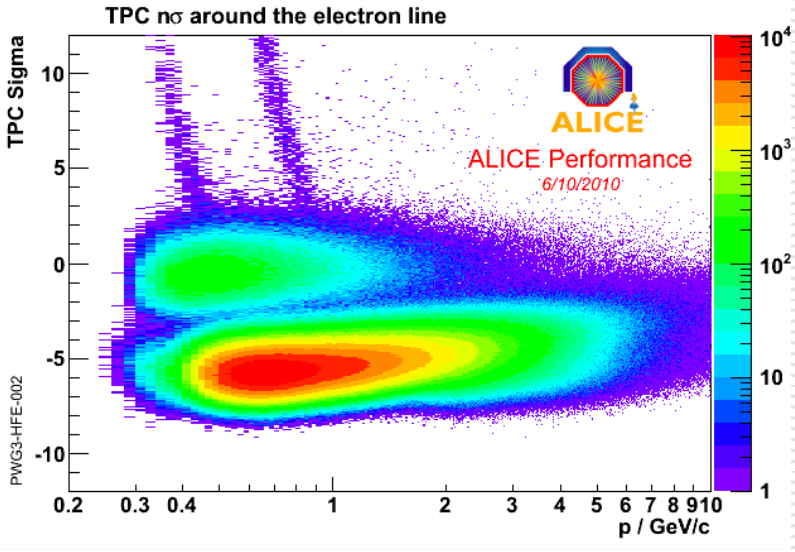
Single μ at forward rapidity

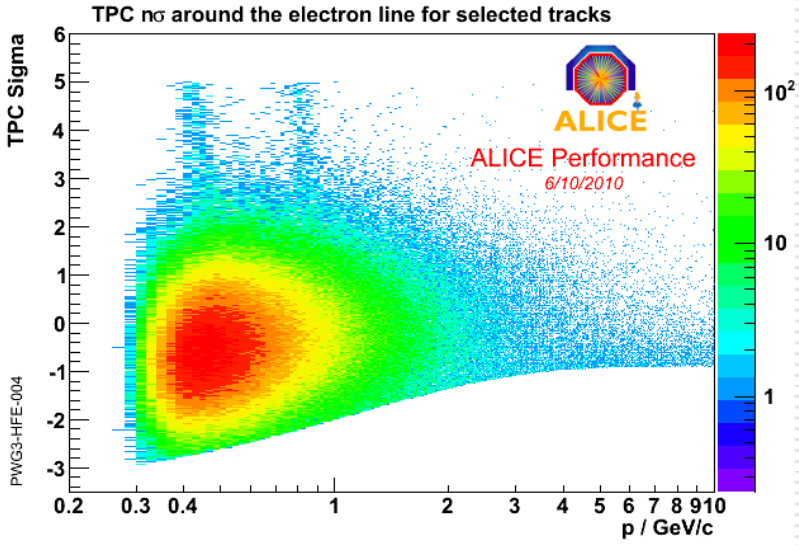




- Good agreement with FONLL within (large) errors
- 20-25% systematic uncertainties
- Will be extended to 15 GeV/c with more statistics and improved spectrometer alignment
- Reference for single muon R_{AA}

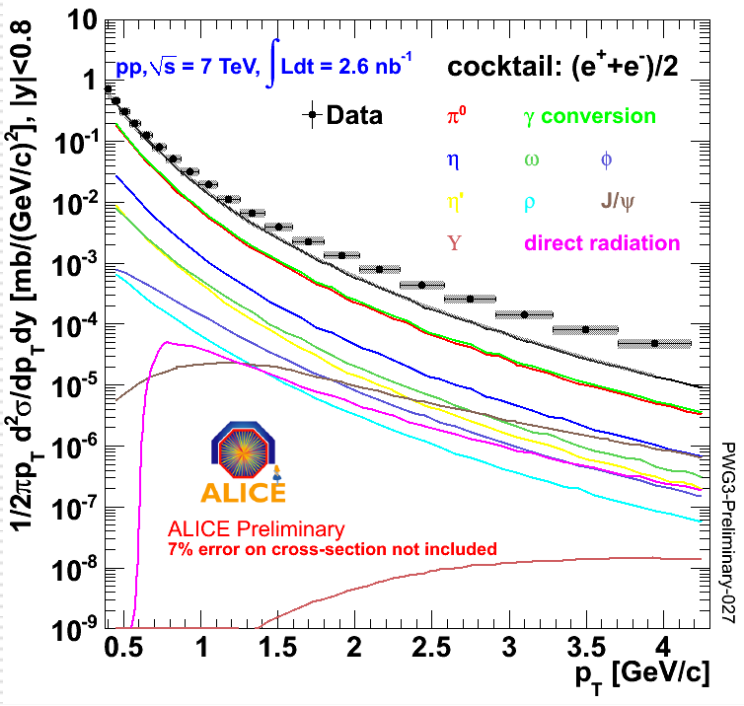
Single *e* at central rapidity

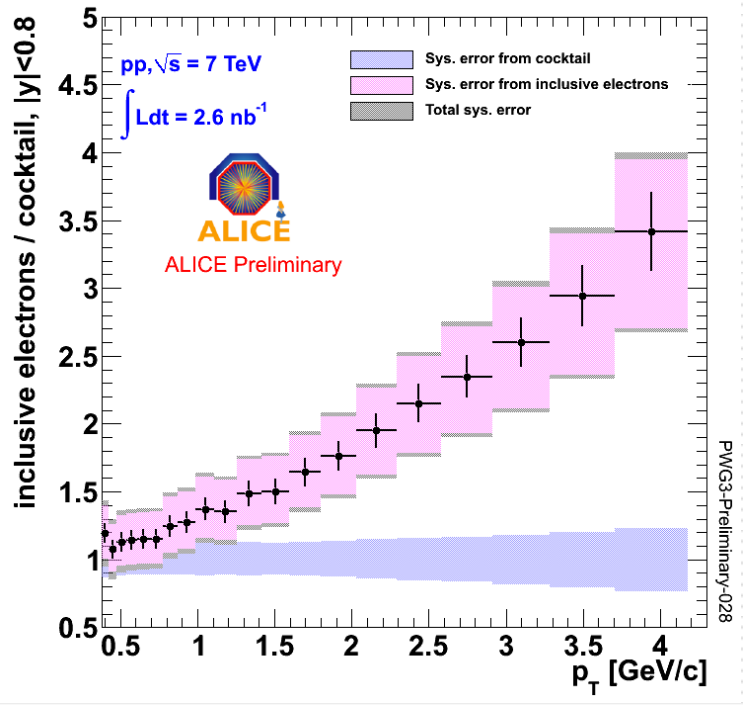




- High quality tracks in TPC and ITS
  - hit in innermost ITS layer to reduce © conversions
- Electron identification using TOF and TPC
  - TOF to reject Kaons (<1.5 GeV/c) and protons (<3 GeV/c)
  - TPC: asymmetric cut around the electron Bethe-Bloch curve
  - measure contamination by fitting dE/dx with a double Gaussian distributions

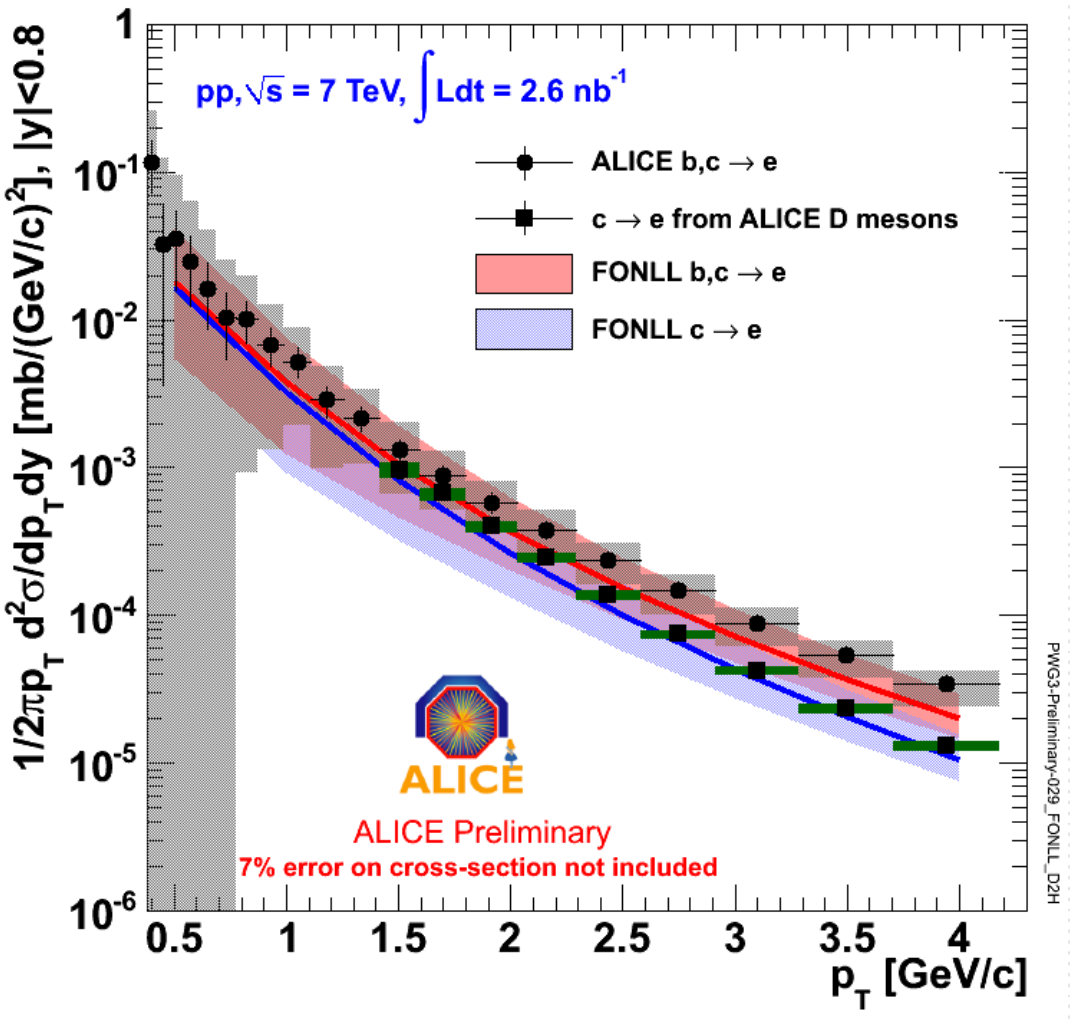
Single *e* at central rapidity





- Efficiency correction and corrections for electron Bremsstrahlung
- Cocktail based on neutral pion cross section measured in PHOS and from double conversion reconstruction in TPC
- Excess of inclusive/cocktail ratio at high-p_T, arising from D and B decay electrons

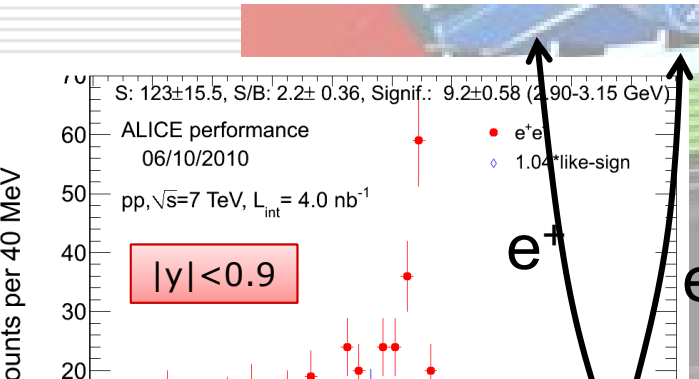
Single *e* at central rapidity



- Total systematic uncertainty is 16-20% (p_T dependent) plus 7% from L_{int}
- Single electrons in agreement with expectations from D mesons
- FONLL calculation describes well our data
- p_T range will be extended with EMCAL and TRD

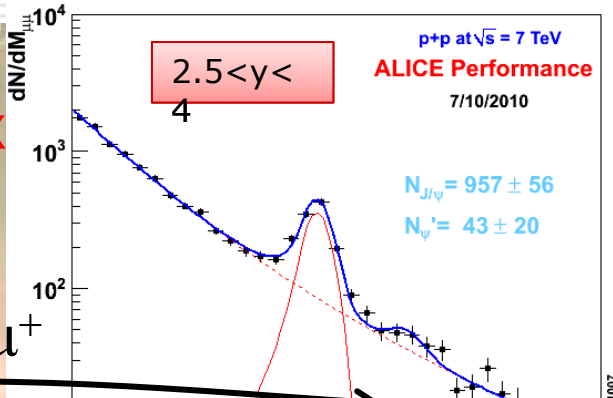
Charmonium measurements

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



ITS (vertexing)
TPC (tracking, dE/dx
TOF (e/K, e/p id)
TRD,EMCAL (e/π id)

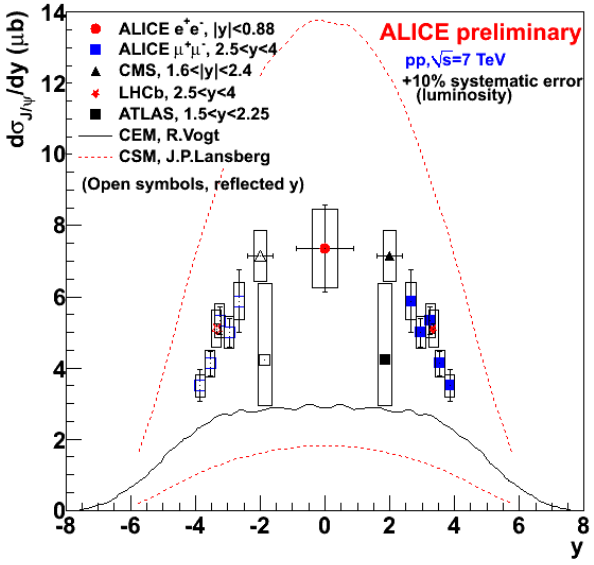
e^+
e^-

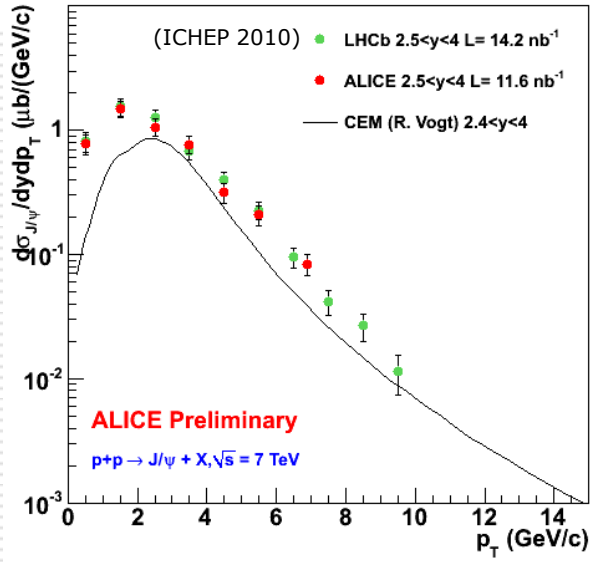


μ^+
μ^-

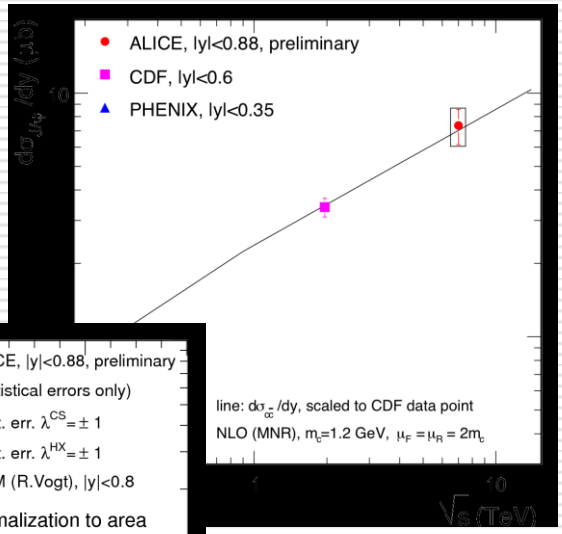
MUON (tracking,id)

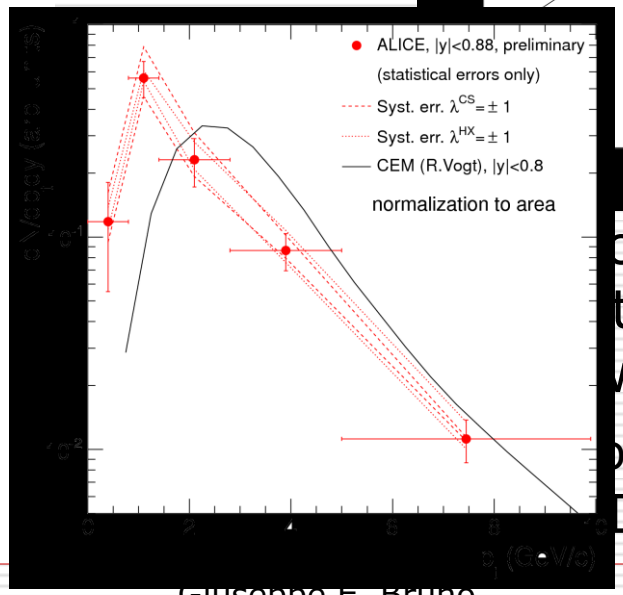
Charmonium results





- Data within uncertainty range of CSM calculations
- dσ/dy of CEM has different shape, the p_T spectrum is harder



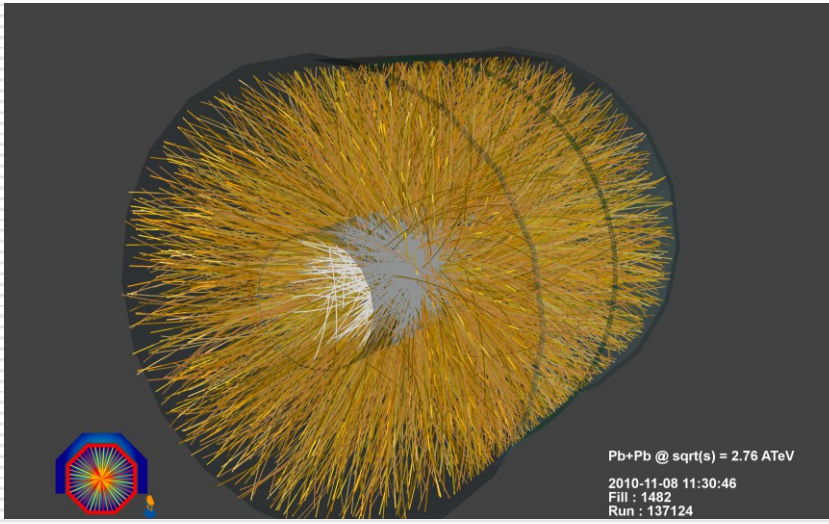


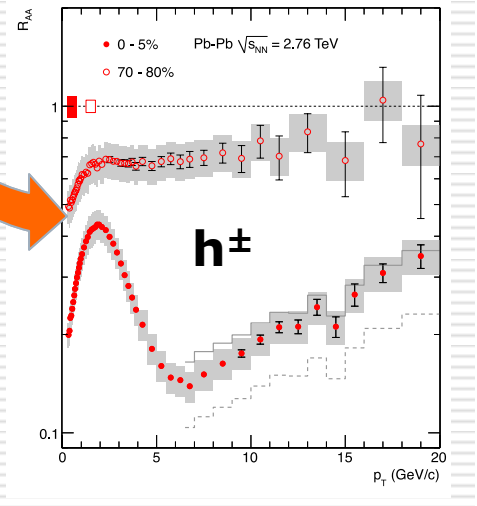
oss-section at mid-
the trend of $c\bar{c}$ cross-
ver energies

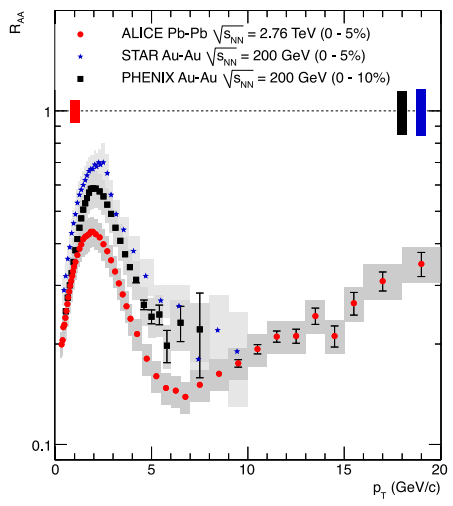
om NLO code scaled to
DF point

Outlook to Pb-Pb

- Pb-Pb collision at 2.76x208=0.57 PeV
  - jump in collision energy by a factor of ~15 compared to RHIC
  - first measurements:
    - ✓multiplicity density of primary charged particles
      Phys. Rev. Lett. 105, 252301 (2010), arXiv:1011.3916
      Phys. Rev. Lett. 106, 032301 (2011), arXiv:1012.1657
    - ✓ elliptic flow of primary charged particles
      Phys. Rev. Lett. 105, 252302 (2010), arXiv:1011.3914
    - ✓ Bose—Einstein correlations
      Phys. Lett .B 696 (2011) 328-337, arXiv:1012.4035
    - ✓ p_t spectra of primary charged particles and R_{AA}
      Phys. Lett .B 696 (2011) 30-39, arXiv:1012.1004



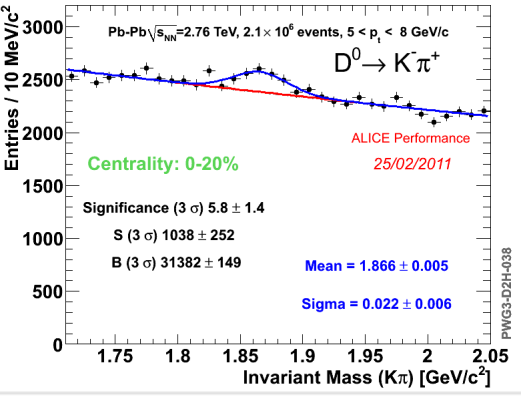


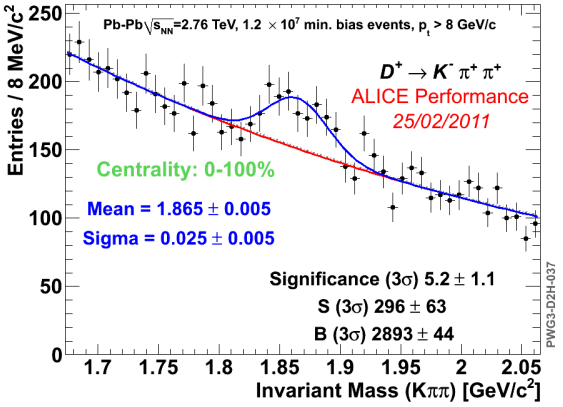


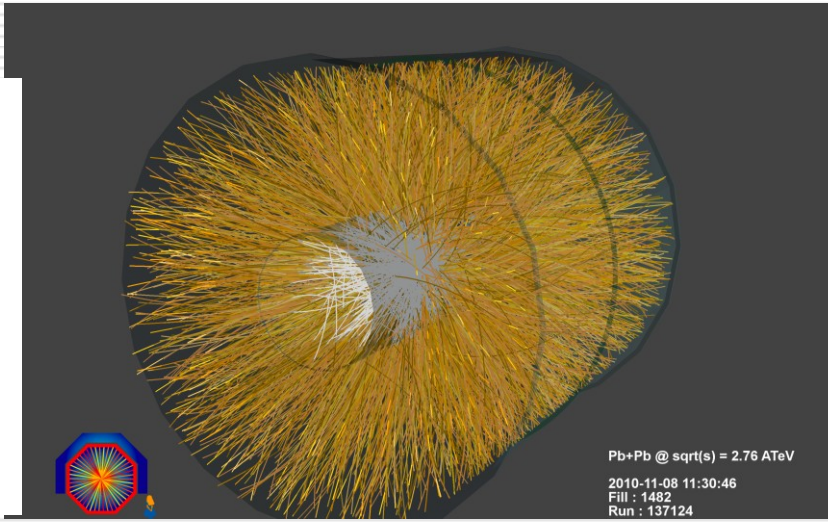
- Are HF hadrons suppressed as charged (light) hadrons?

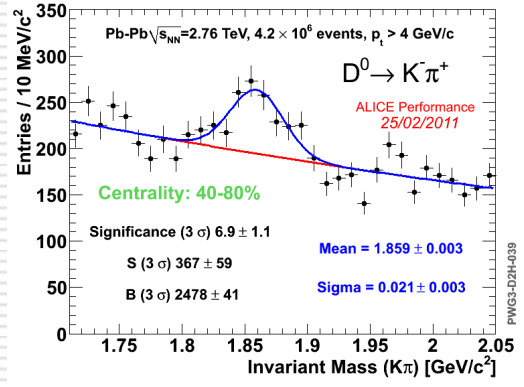
Outlook to Pb-Pb

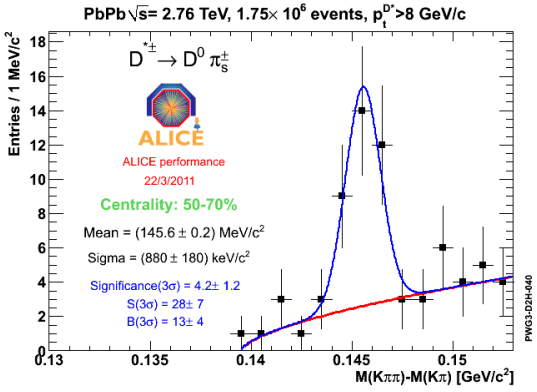
- Pb-Pb collision at 2.76x208=0.57 PeV
  - jump in collision energy by a factor of ~15 compared to RHIC
  - first signals of HF detected

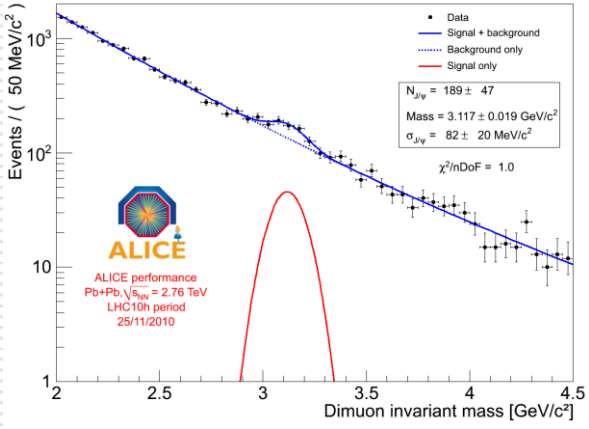












Summary

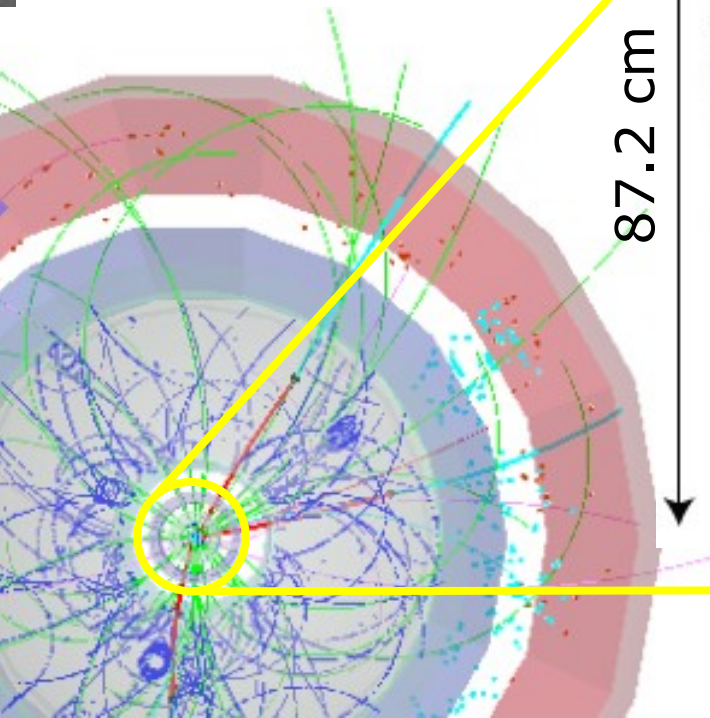
- HF production in 7 TeV p-p collisions:
  - cross-section of single muons, electrons and D mesons measured up to p_T = 6.5, 4 and 12 GeV/c, respectively
    - data described by pQCD predictions
  - J/ψ production cross-section measured at mid and forward rapidity
    - Measurement down to $p_T^{J/\psi}=0$ at all rapidities
- HF in heavy-ion collisions
  - detailed understanding of:
    - energy loss mechanisms
    - hadronization mechanism
    - thermalisation and hydrodynamic expansion of QGP

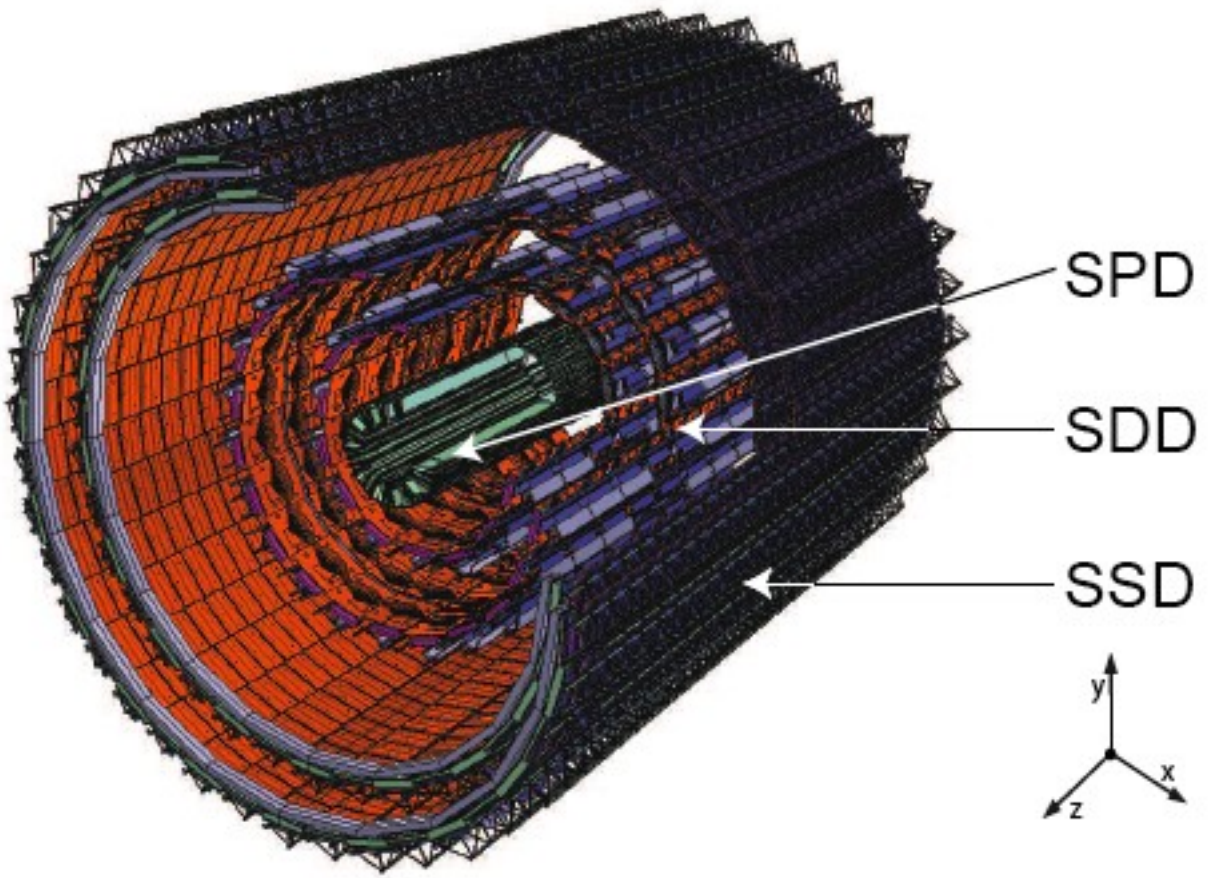
Many more to come

Spares

The inner tracking system

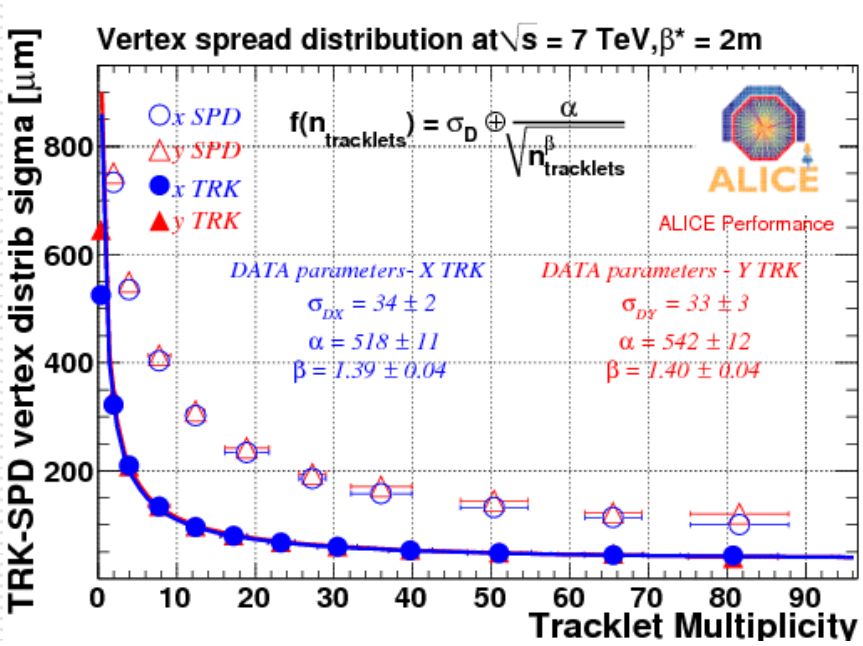
- Six layers of silicon detectors
- Three technologies
  - Pixels (SPD)
  - Drift (SDD)
  - Strips (SSD)





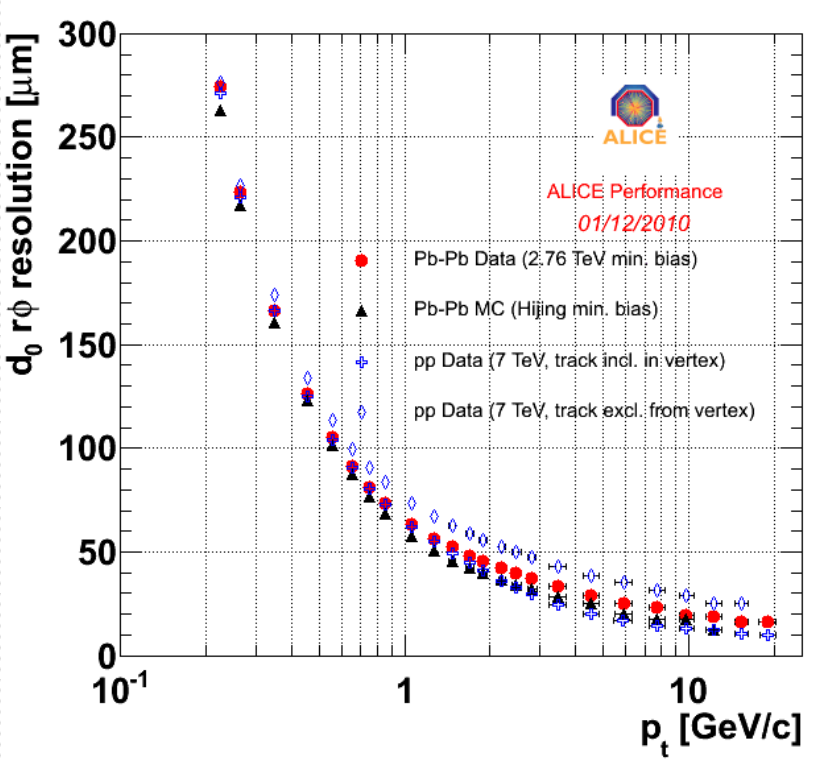
ITS performance

- Vertex resolution



Primary vertex from tracks with at least 4 points in ITS

- Impact parameter resolution

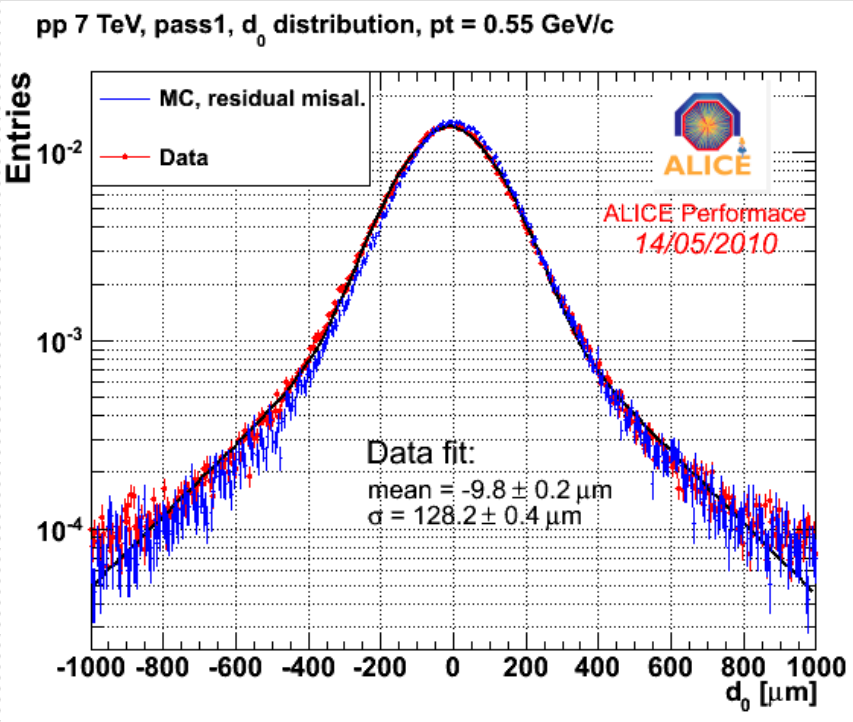


- very low material budget: lowest p_T reach at y≈0 at LHC

Track impact parameter resolution

- Track selection: standard TPC cuts + **both SPD points**

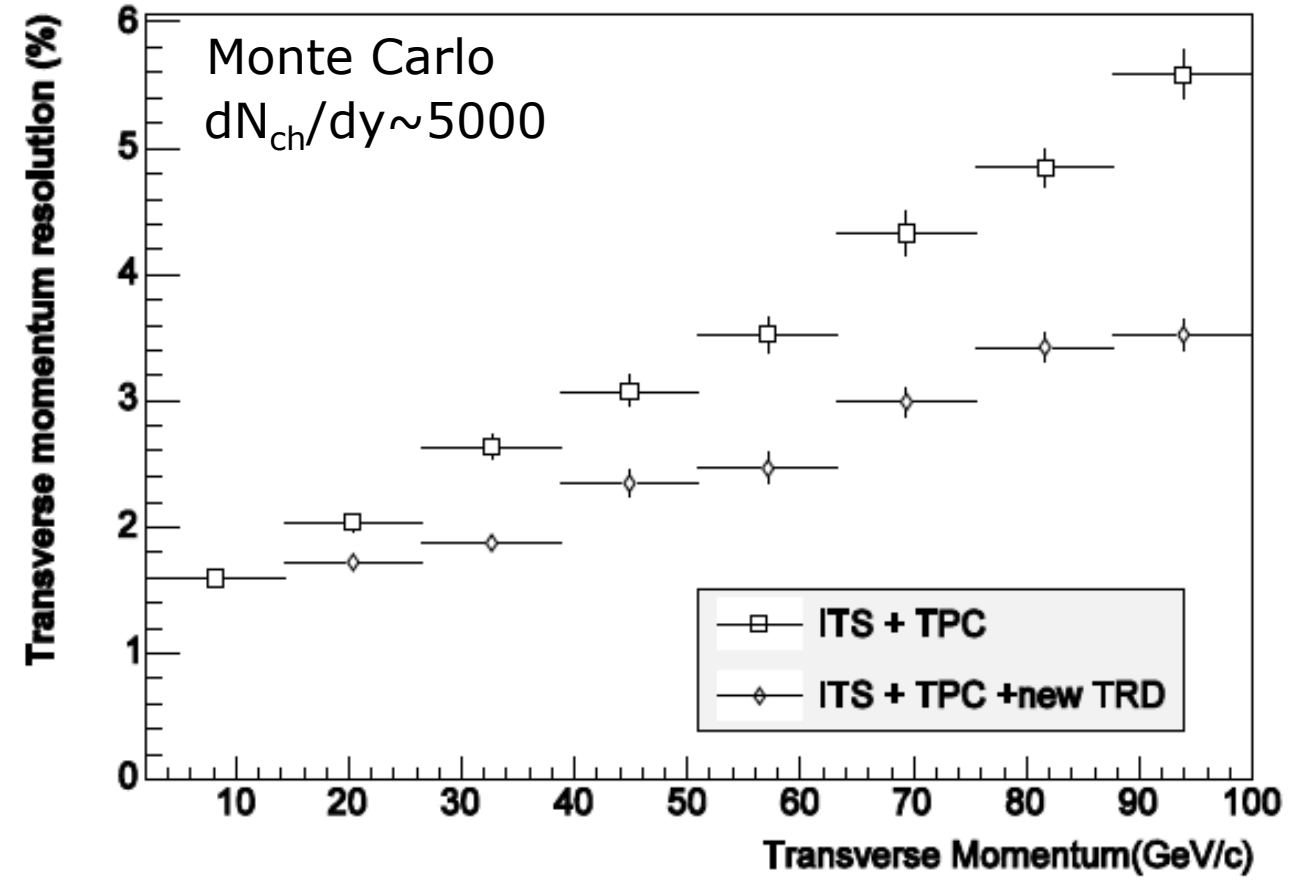
- Method:
  - d_0 distribution w.r.t. primary vertex from tracks without the current track
  - Gaussian fit distribution in ± 2 RMS (negligible contribution of secondaries)
    - *Gaussian+Exp-tails fit under study (looks more stable)*
  - Check sigma and mean



The resulting resolution is the convolution of the track-position and the primary-vertex resolutions

Combined Momentum Resolution in ALICE Central Barrel in Pb-Pb collisions

- resolution ~ 3% at 100 GeV/c
- still excellent performance in hard region!



LHC

- Running conditions:

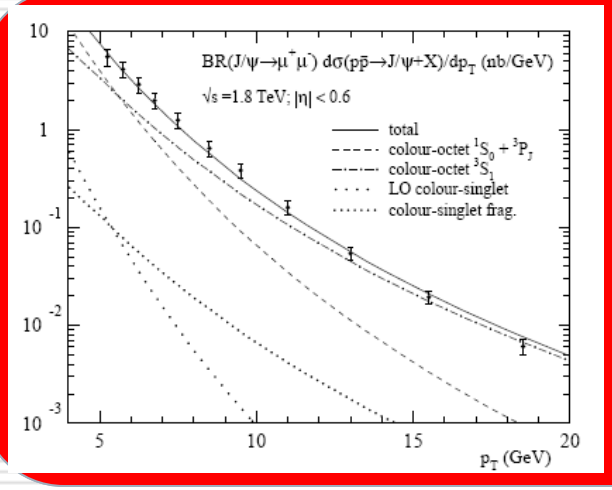
Collision system	$\sqrt{s_{NN}}$(TeV)	L_0 ($cm^{-2}s^{-1}$)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{34} *	10^7	0.07
PbPb	5.5	10^{27}	10^6 **	7.7
pPb	8.8	10^{29}	10^6	1.9
ArAr	6.3	10^{29}	10^6	2.7

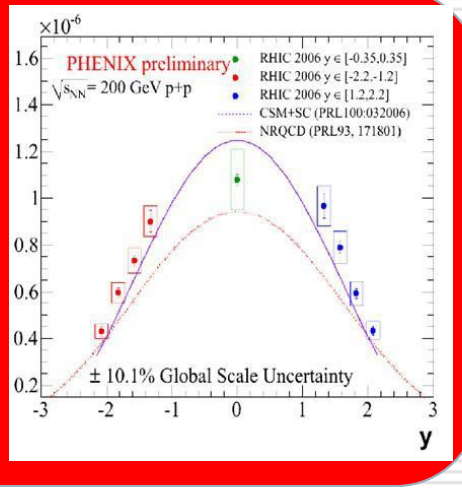
$\mathcal{L}_{max}$ (ALICE) = 10^{31}** * $\mathcal{L}_{int}$ (ALICE) ~ 0.5 nb^{-1}/year**

- + other ions (Sn, Kr, O) & energies (e.g.: pp @ 5.5 TeV)

Quarkonium production in p-p collisions: motivations

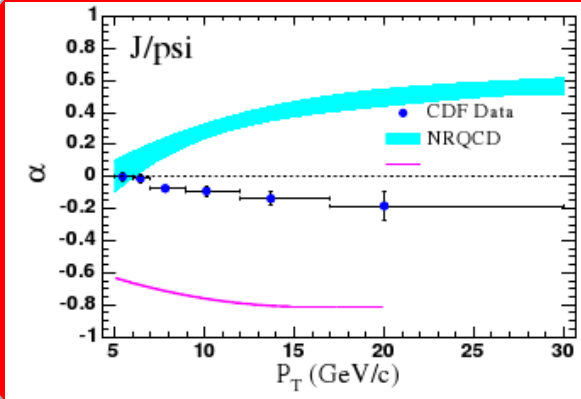
- Several production mechanisms: CEM, CSM, NRQCD (COM)

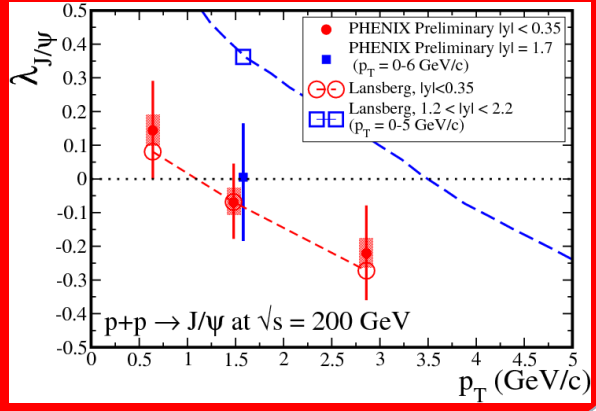




- NRQCD well reproduces CDF data
- PHENIX preliminaries of dσ/dy are better reproduced by CSM (+s-channel cut) at forward rapidities

- NRQCD fails in predicting polarization (CDF Run II).
- At mid-rapidity PHENIX preliminaries are well reproduced by CSM + s-channel cut (still problems at high y)



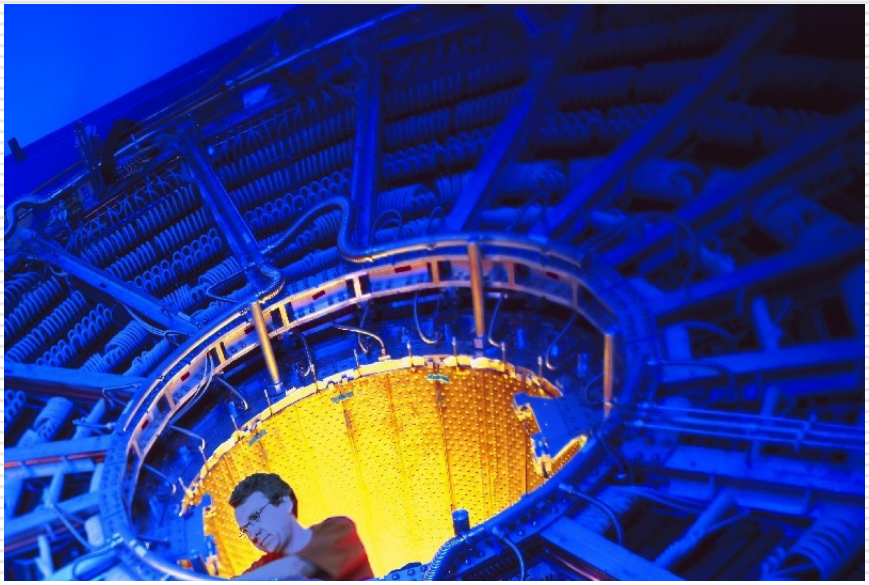


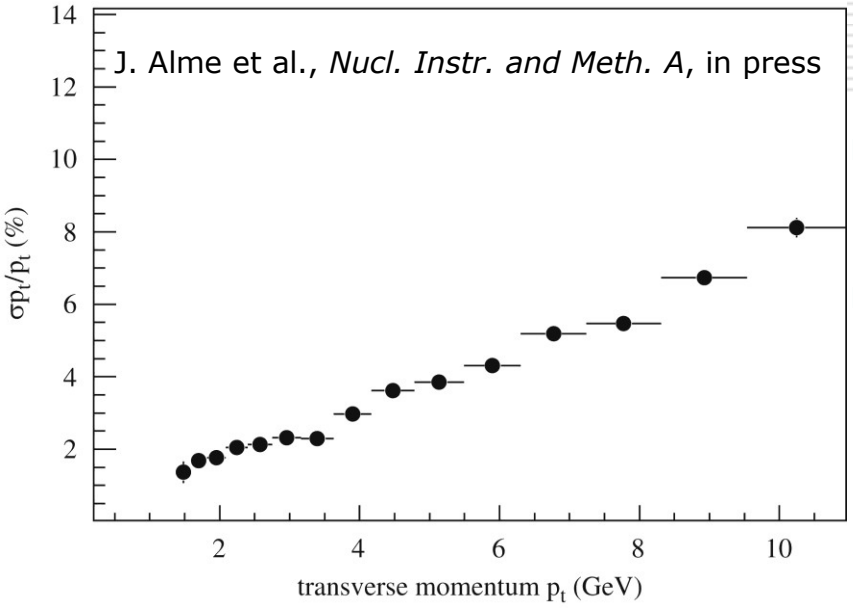
Analysis strategy for quarkonium in the ALICE barrel

- good tracks from the primary vertex
  - tracking with ITS + TPC (+ TRD)
- electron identification
  - dE/dx in TPC
  - time-of-flight for low momentum electrons from TOF
  - transition radiation signature from TRD
- cuts to maximize the peak significances
- determination of combinatorial background
- J/□ from B-decay: secondary vertexing with ITS

Tracking with TPC: 3D reconstruction of up to 15 000 charged tracks per event

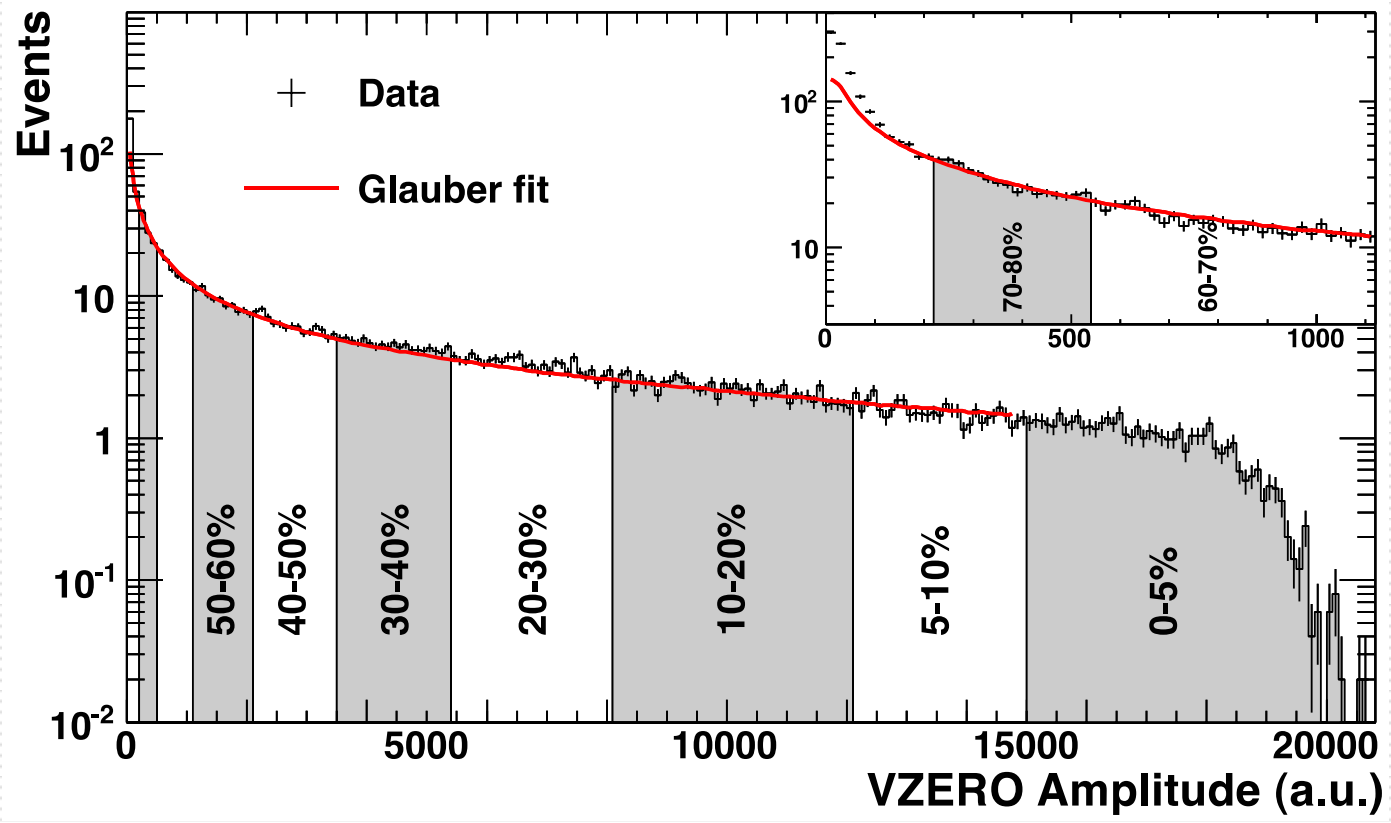
- with 95 m^3 the largest TPC ever
- precision better than 500 □m in all 3 dim.
- 160 space and charge points per track





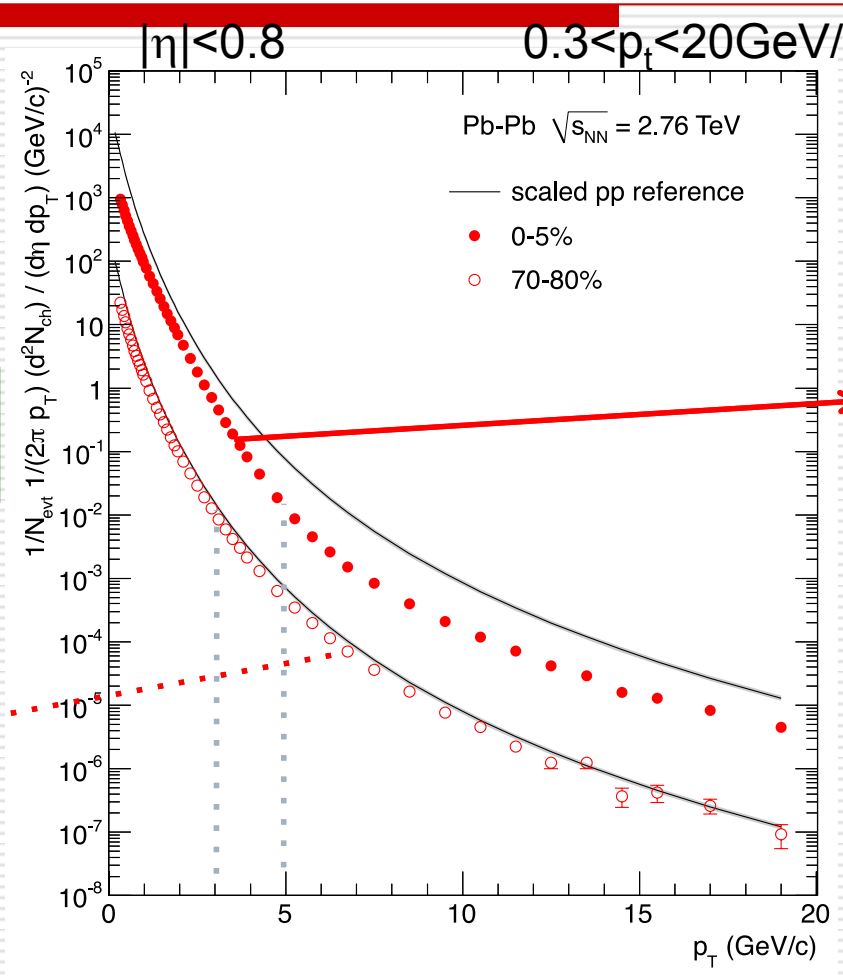
- match two segments of cosmic tracks
- momentum resolution very close to detector design:
  - 7% at 10 GeV/c
  - < 1% at p_T< 1 GeV/c confirmed from K^0_s measurement

Centrality determination



Glauber fit of **V0 amplitude distribution** above an anchor point corresponding to 88% of the hadronic cross-section, where trigger is fully efficient and background negligible

p_t spectra of primary charged particles



Analysis on 2.3M events:
- $|z_{vtx}|<10$ cm
- ITS+TPC tracks

Exponential

Power law

Peripheral events and scaled pp reference have same p_t dependence

- pp reference at 2.76 TeV: main approach
  - ✓ interpolation of ALICE measurements in p_t bins (at 0.9 and 7 TeV), assuming a power law for the increase of the yield with $\sqrt{s}$