Open heavy flavor production in p-p collisions in the ALICE experiment at the LHC

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for the **ALICE COLLABORATION**

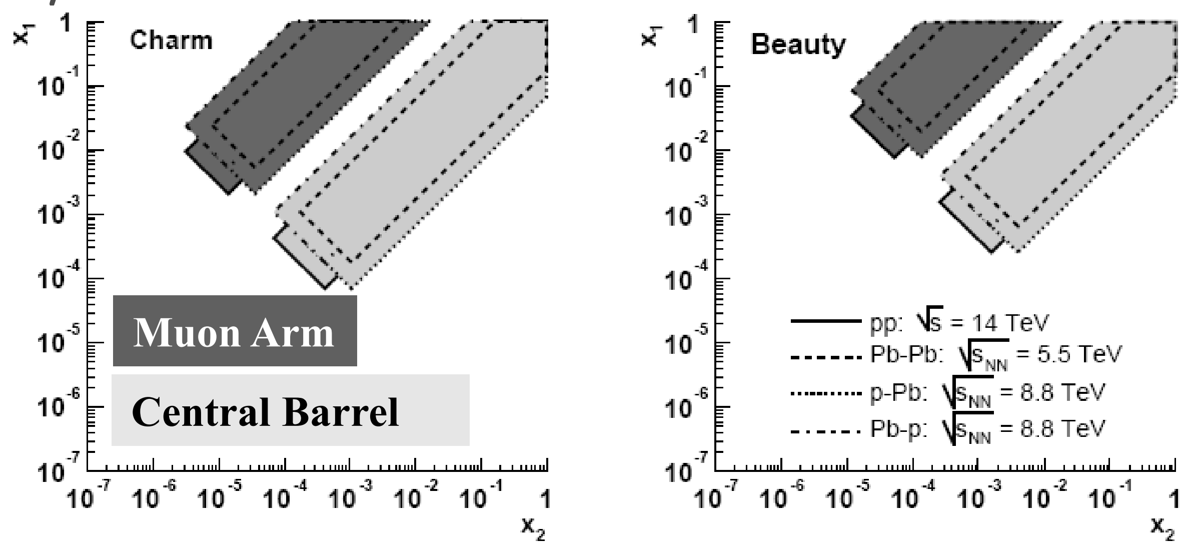
ÉCOLE DE PHYSIQUE des HOUCHES

Winter Workshop on Recent QCD Advances at the LHC

Les Houches, February 13th - 18th, 2011

Heavy flavors in ALICE Physics Motivations

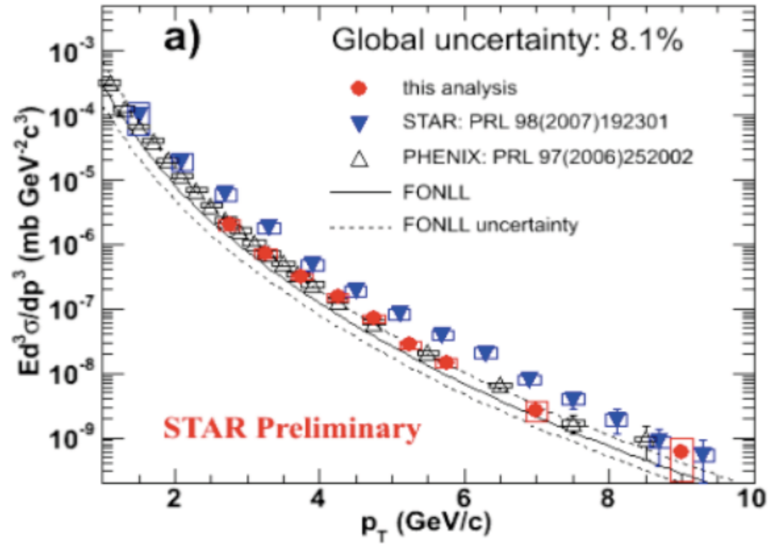
- A-A collisions
  - ⇨ Probe the high density medium via heavy quark energy loss, flow, hadronization mechanism …
- p-p collisions
  - ⇨ Reference for quenching studies in AA
  - ⇨ Test pQCD predictions in a **new energy regime** ($3.5\times\sqrt{s}_{TEVATRON}$)
  - ⇨ Probe an unexplored region of **small Bjorken x** with charm at low p_T and/or forward rapidity
    - ✓ ***Down to $x \approx 10^{-4}$ with low-p_T charmed hadrons in the central rapidity region and down to $x \approx 10^{-6}$ with charm at forward rapidity (y=4)***



- p-A collisions
  - ⇨ Address initial state effects (Cronin enhancement, nuclear PDFs)

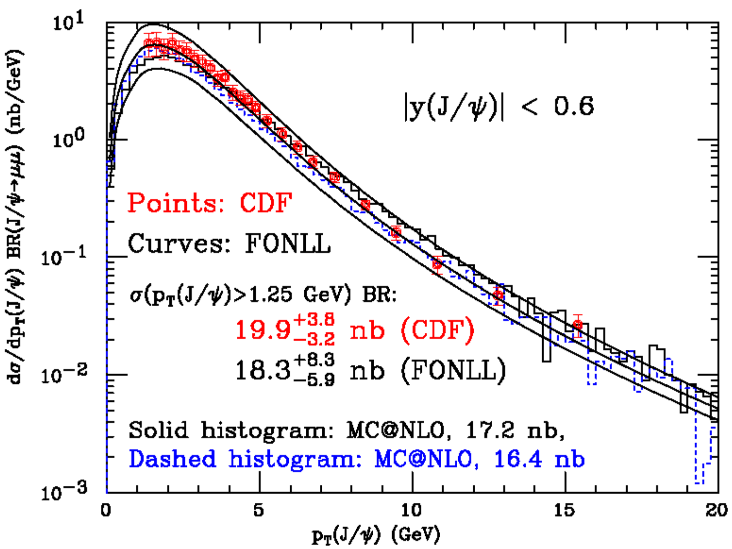
Heavy quarks in p-p

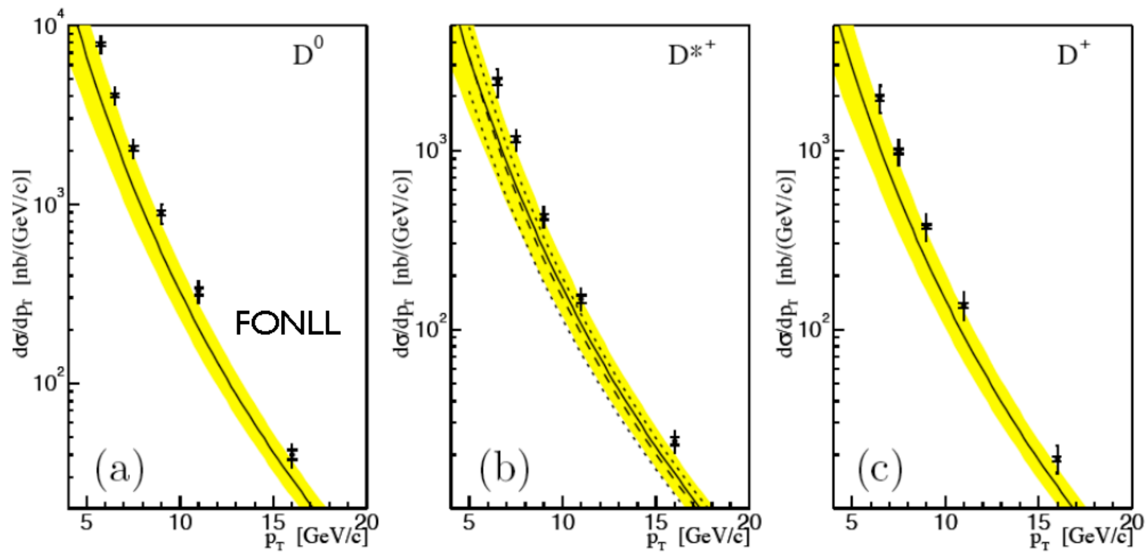
- Charm production on the upper edge of theory predictions at Tevatron and RHIC



- Beauty differential cross section at Tevatron and LHC well reproduced by pQCD calculations

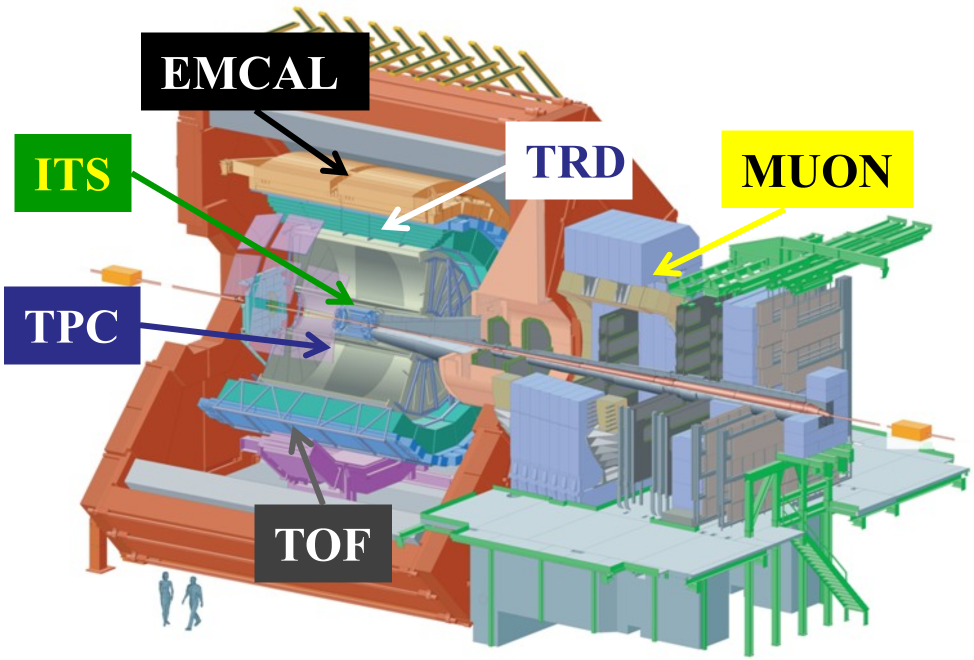
CDF: b->B->J/ψ





CDF RunII: c->D , PRL 91:241804 (2003)

Heavy flavors with ALICE

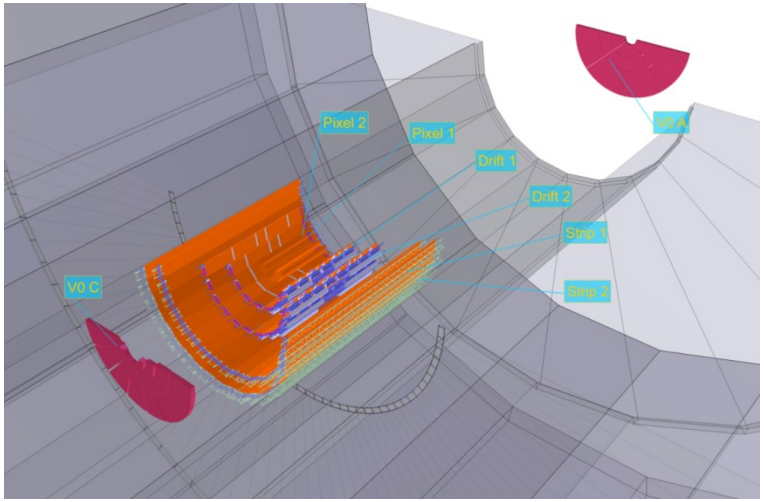


ITS: vertexing + tracking
TPC: tracking + PID (π, K, e)
TOF: PID (π, K, p)
TRD: PID (π, e)
EMCAL: PID (e)
MUON: μ tracking + PID

- Open charm from hadronic decays at central rapidity
  - $D^0 \to K^-\pi^+$
  - $D^+ \to K^-\pi^+\pi^+$
  - $D^{*+} \to D^0\pi^+$
  - $D^0 \to K^-\pi^+\pi^+\pi^-$
  - $D_s \to K^-K^+\pi^+$
  - $\Lambda_c^+ \to pK^-\pi^+$
- Open charm and open beauty from semileptonic decays
  - D, B $\to e^{\pm}$ + X (central rapidity)
  - D, B $\to \mu^{\pm}$ + X (forward rapidity)
- Open beauty from non-prompt J/ψ at central rapidity
  - $B \to J/\Psi \to e^+e^-$

p-p at $\sqrt{s}$= 7 TeV: Trigger and data sample

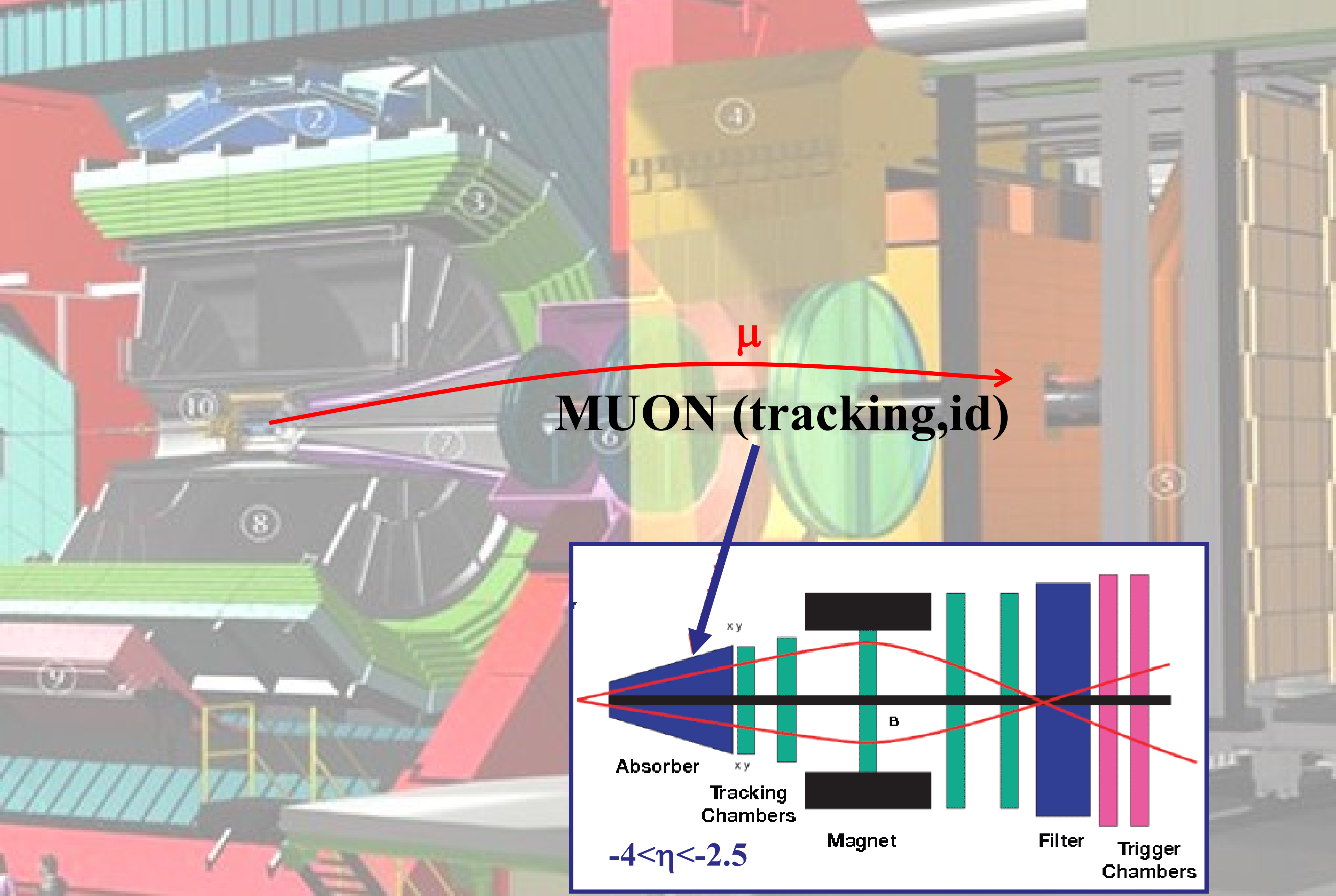
- Minimum bias trigger
  - SPD (Silicon Pixels, $|\eta|<2$) or V0A (Scintillator , $2.8<\eta<5.1$) or V0C (Scintillator, $-3.7<\eta<-1.7$)
    - ✓ ***At least 1 charged particle in 8 units of pseudo-rapidity***
    - ✓ ***95% of σ_{inel}***
  - Activated in coincidence with BPTX beam pickups



- Single muon trigger
  - Forward muons in coincidence with minimum bias trigger

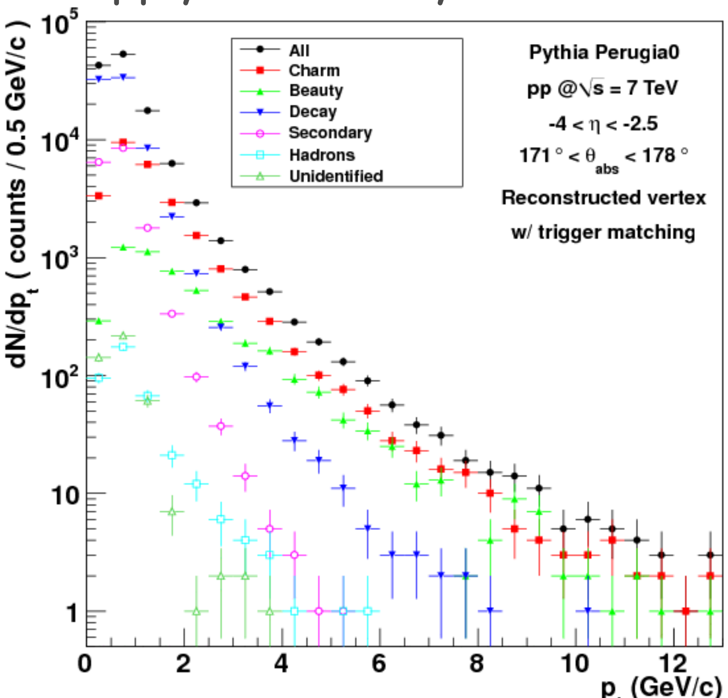
- Data sample
  - ≈$8.5 \cdot 10^8$ Min. Bias events and ≈$1.3 \cdot 10^8$ muon triggers collected in p-p 2010 run
  - Analysis shown here based on 1.4 nb^{-1} for electrons and D mesons, 3.49 nb^{-1} for muons

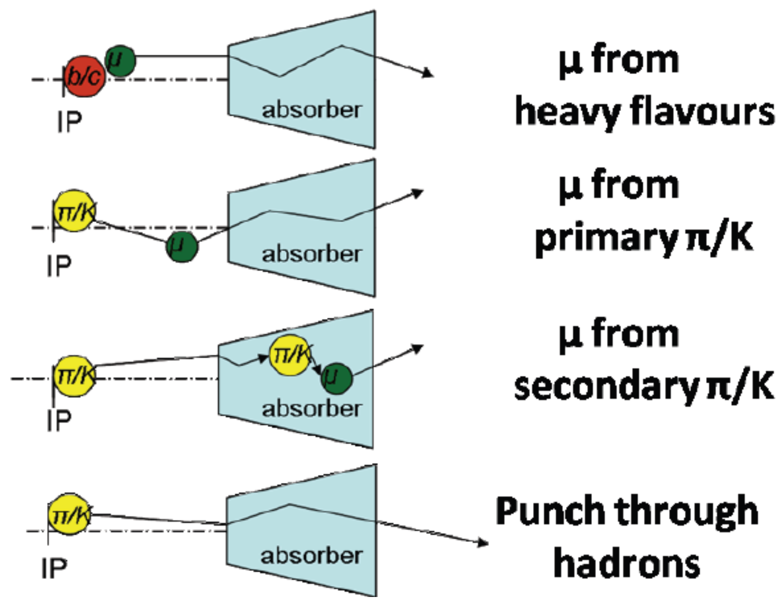
Single muons



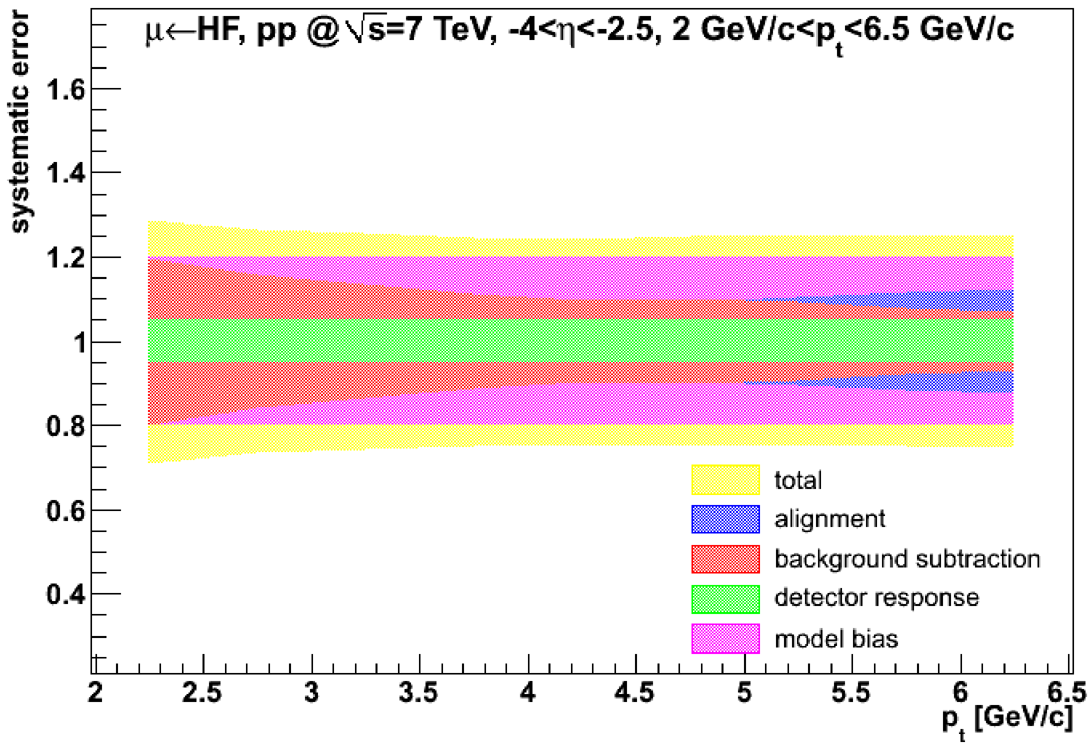
Heavy-flavor single muon

- Analysis strategy
  - Require muon trigger signal to remove hadrons and low p_t secondary muons
  - Remove residual decay muons by subtracting MC dN/dp_t normalized to data at low p_t
    - ✓ *Alternative method: use muon distance-of-closest-approach to primary vertex*
    - ✓ *What is left are muons from charm and beauty*
  - Apply efficiency corrections



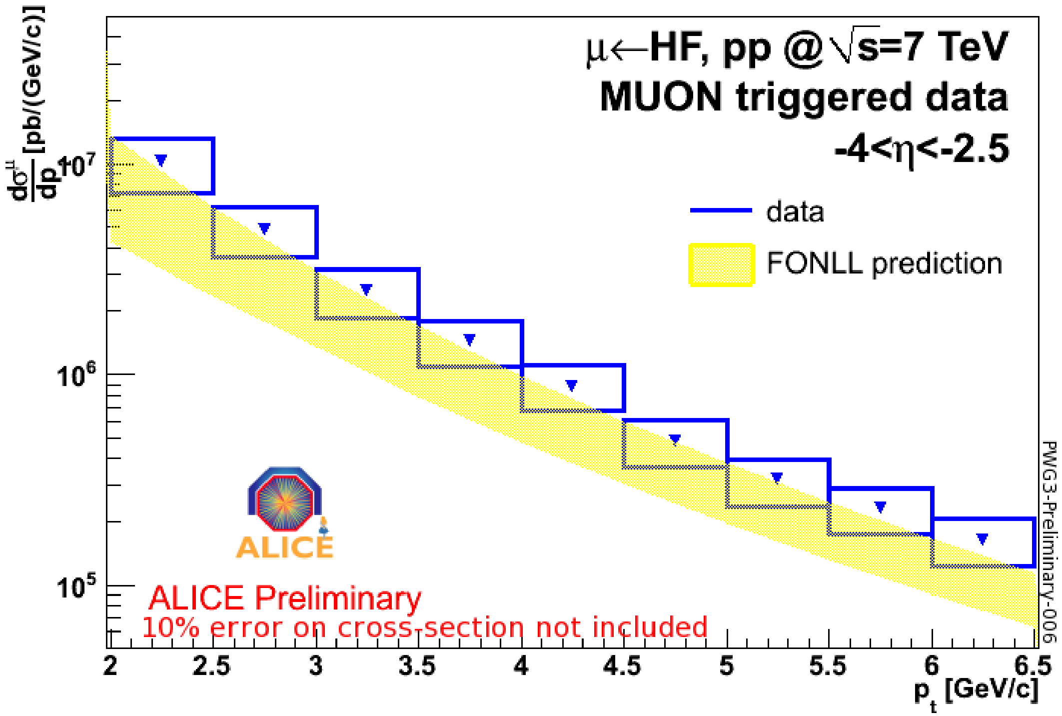


Systematics



- Systematic error from the subtraction of background from decay muons from π and K ≈20%
  - Use different PYTHIA tunes (Perugia-0 vs. ATLAS-CSC) and vary secondary yield to estimate systematic error
- Systematic error from the efficiency correction ≈5%
  - Due to the description of the detector response in the MC and (to a much lower extent) to the p_t shape of the signal used as input in the MC

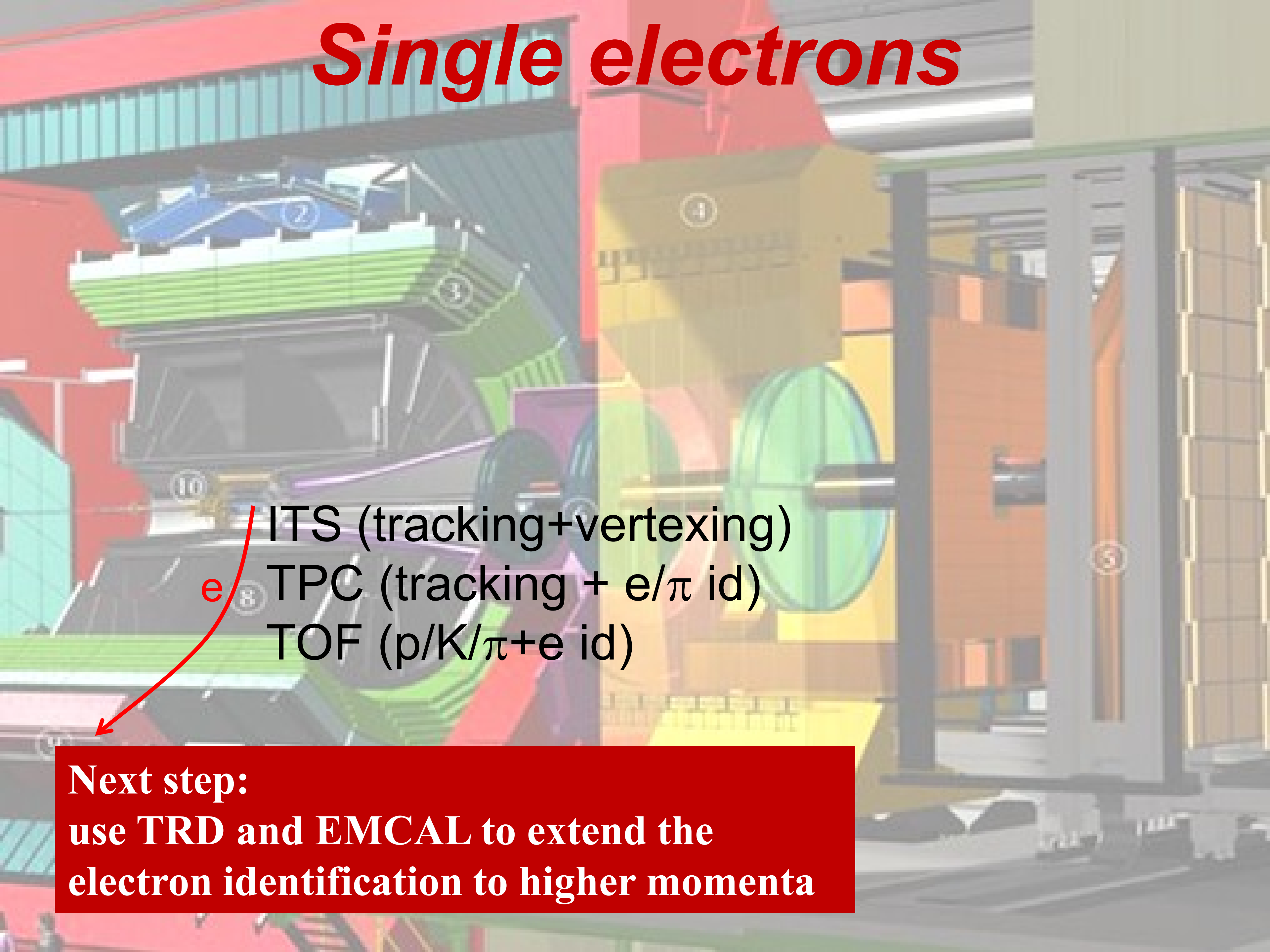
Heavy flavor single muon: $d\sigma/dp_t$



- Integrated luminosity: 3.49 nb^{-1}
- Statistical errors within markers
- 10% systematic error on MB cross section (due to luminosity uncertainty) not included

- p_t differential cross section for muons from B and D decays measured in pt range 2.0-6.5 GeV
  - ⇨ pt reach can be extended (up to 20 GeV/c) with improved alignment and increased statistics
- pQCD prediction (FONLL) reproduces the shape of measured cross section and is in agreement with data within errors

Single electrons



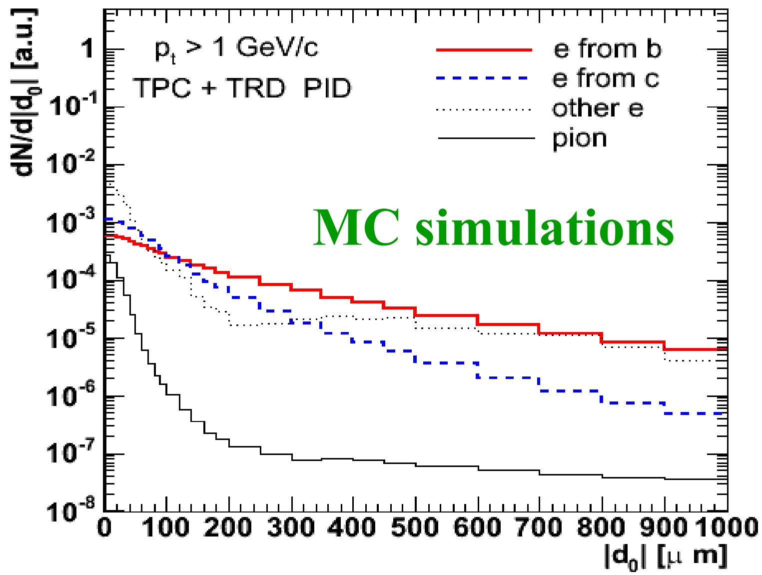
ITS (tracking+vertexing)
TPC (tracking + e/π id)
TOF (p/K/π+e id)

Next step:
use TRD and EMCAL to extend the electron identification to higher momenta

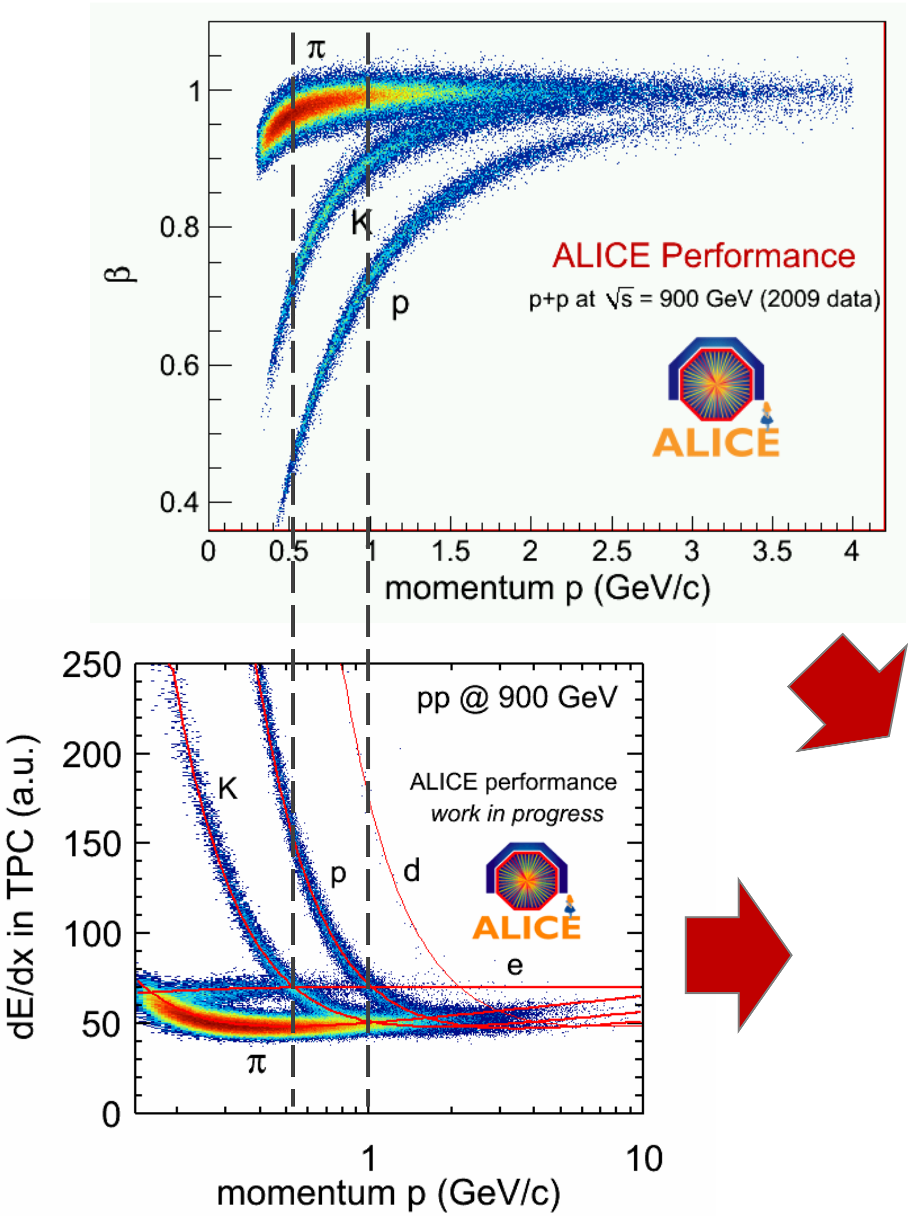
Heavy-flavor electrons

- Present analysis strategy ("the Cocktail")
  - ⇨ Reconstruct inclusive electron transverse momentum spectrum
    - ✓ ***From high quality TPC+ITS tracks, requiring a hit in the innermost ITS layer to reduce contribution from electrons from photon conversion in the material***
    - ✓ ***Electron identification using time-of-flight in TOF and dE/dx TPC***
  - ⇨ Efficiency and acceptance corrections from Monte Carlo simulations
  - ⇨ Extract electrons from heavy flavor decays by subtracting the p_t spectrum of background contributions from an electron cocktail

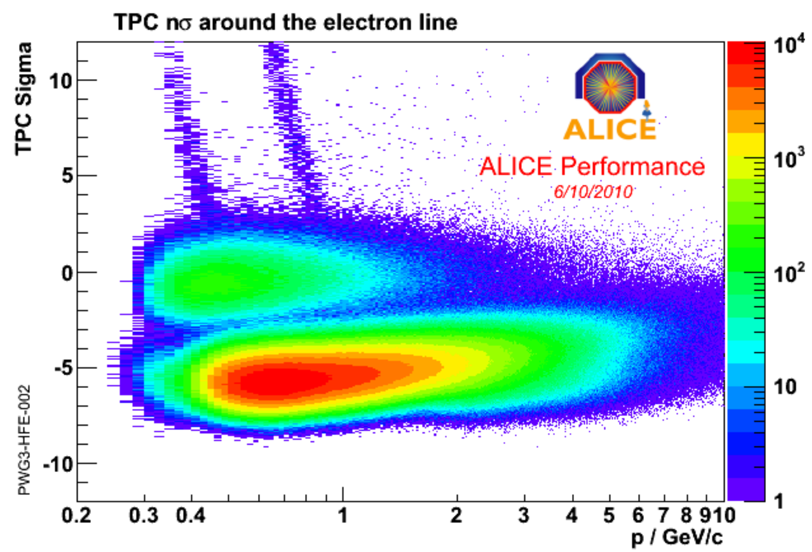
- Next step:
  - ⇨ Exploit the high resolution on track impact parameter to select electrons from heavy flavor decays (beauty in particular)



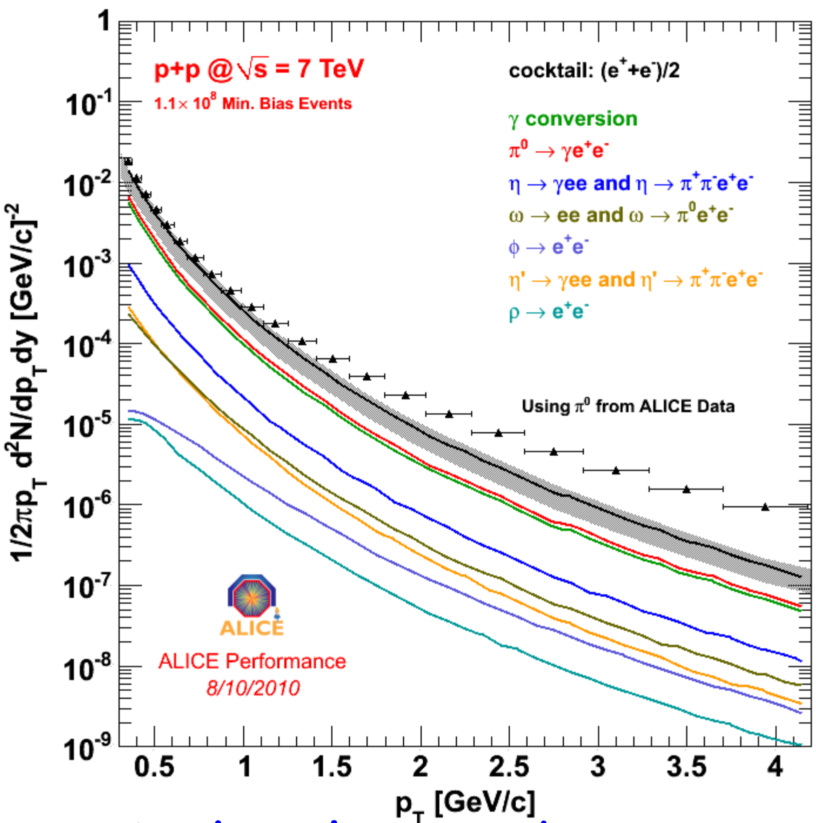
Electron identification

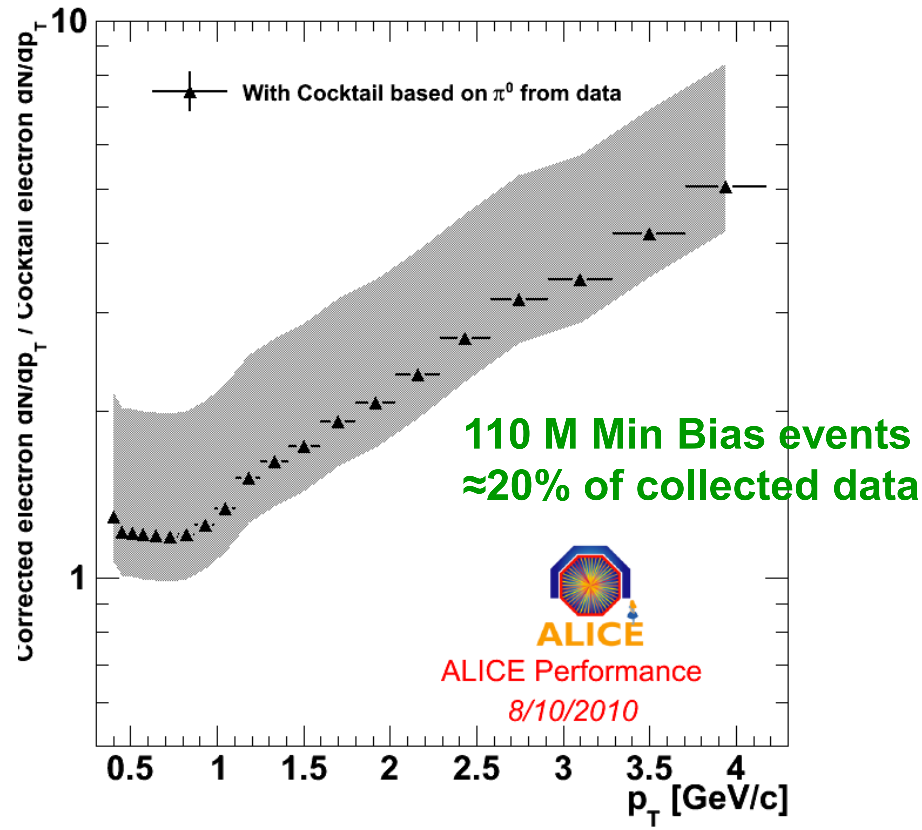


- Present strategy based on TOF and TPC
  - ⇨ TOF resolves momentum regions where electron dE/dx in TPC crosses kaon and proton curves
  - ⇨ Effective for p_t<4 GeV/c
- TOF rejects kaons for p<1.5 GeV/c and protons for p<3 GeV/c
- Further hadron rejection with TPC
  - ⇨ n. sigma cut with respect to electron expected dE/dx
  - ⇨ Remaining hadron contamination estimated from data and subtracted



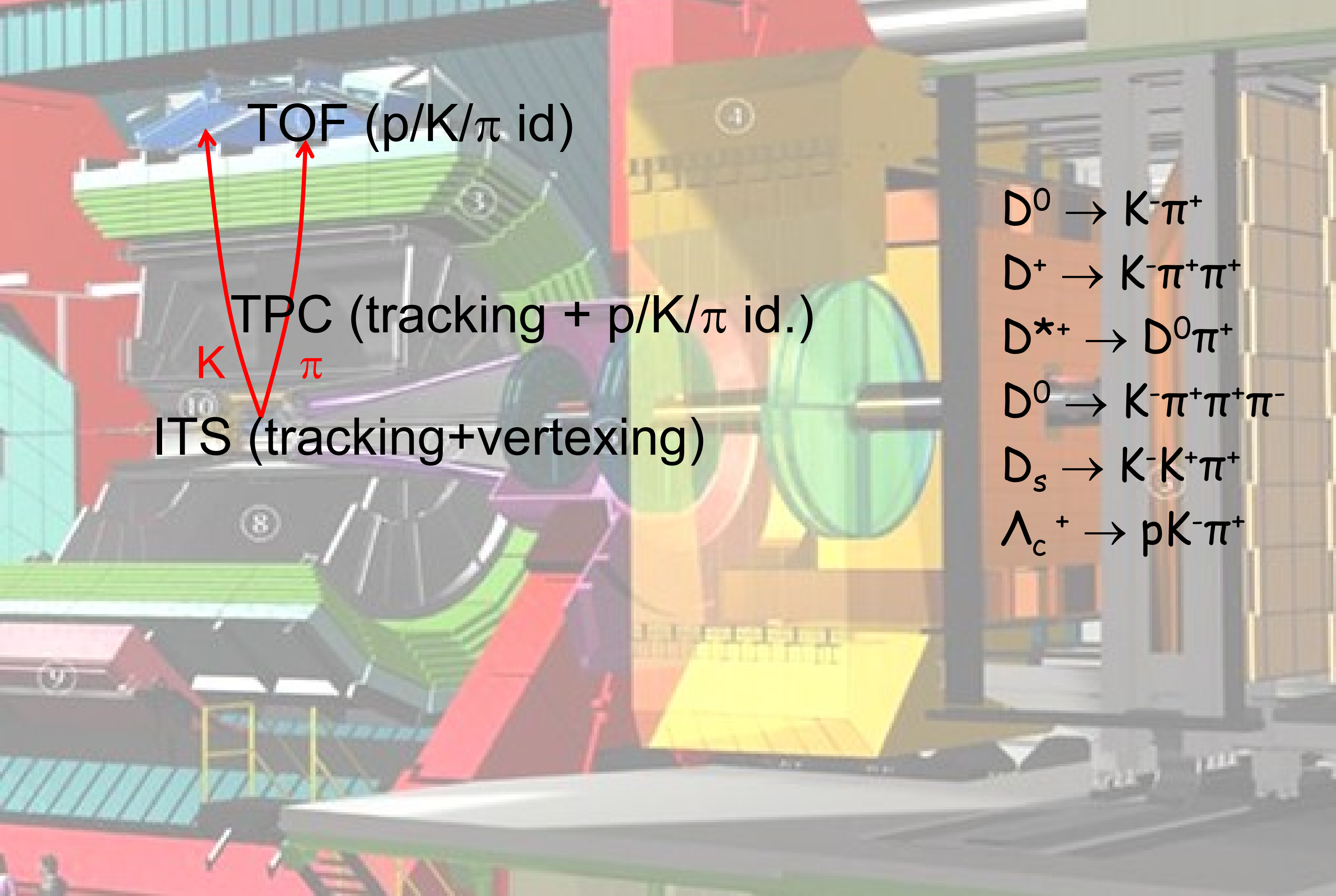
Corrected spectrum and cocktail





- Cocktail ingredients:
  - ⇨ Dalitz decay of neutral pions from measured π^0 spectrum
  - ⇨ Heavier mesons (η, η', ρ, ω, ϕ) implemented via m_T scaling
  - ⇨ Photon conversion (in beam pipe and innermost ITS layer)
- Excess of electrons wrt the cocktail comes from charm and beauty (+ J/ψ and direct radiation)

Hadronic charm



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

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

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

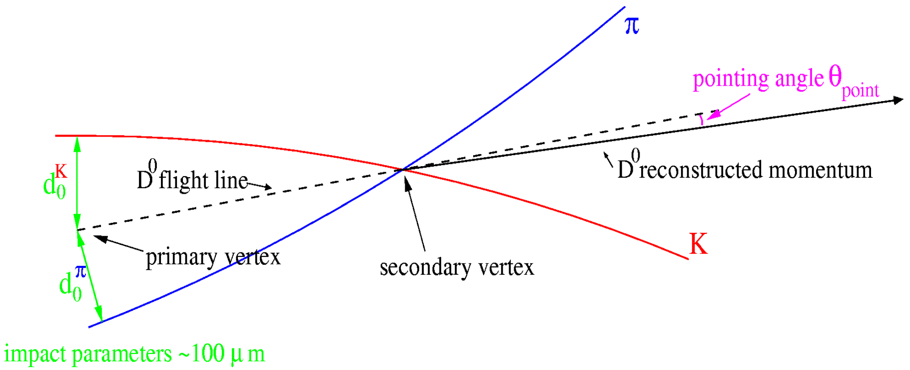
$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$

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

$\Lambda_c^{\ +} \rightarrow p K^- \pi^+$

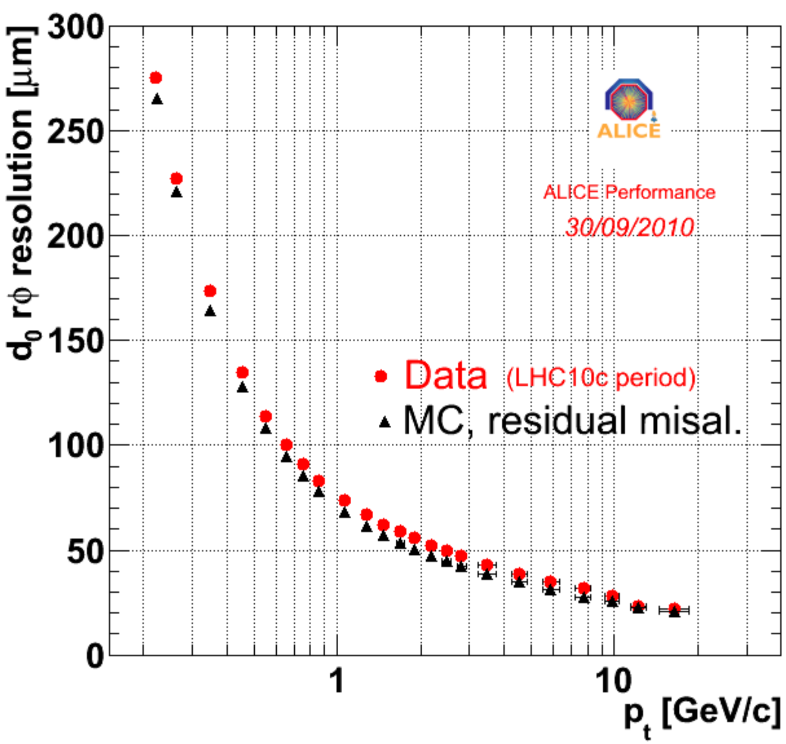
D meson reconstruction

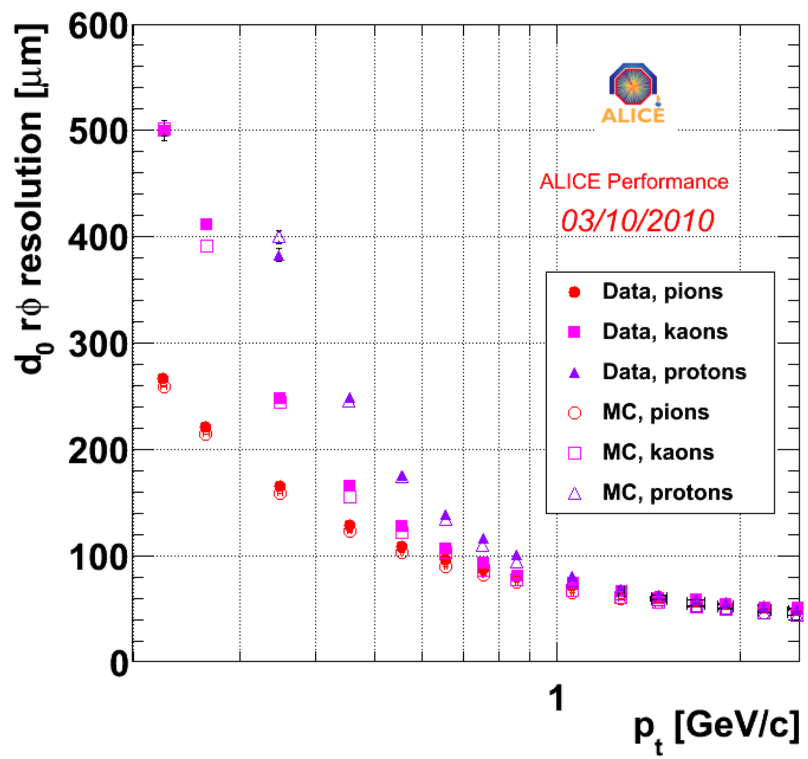
- Analysis strategy: invariant-mass analysis of fully-reconstructed topologies originating from displaced vertices
  - ⇨ Build pairs/triplets/quadruplets of tracks with correct combination of charge signs and large impact parameters
  - ⇨ Particle identification from TPC and TOF to reject background (at low pt)
  - ⇨ Calculate the vertex (DCA point) of the decay tracks
  - ⇨ Require good pointing of reconstructed D momentum to the primary vertex



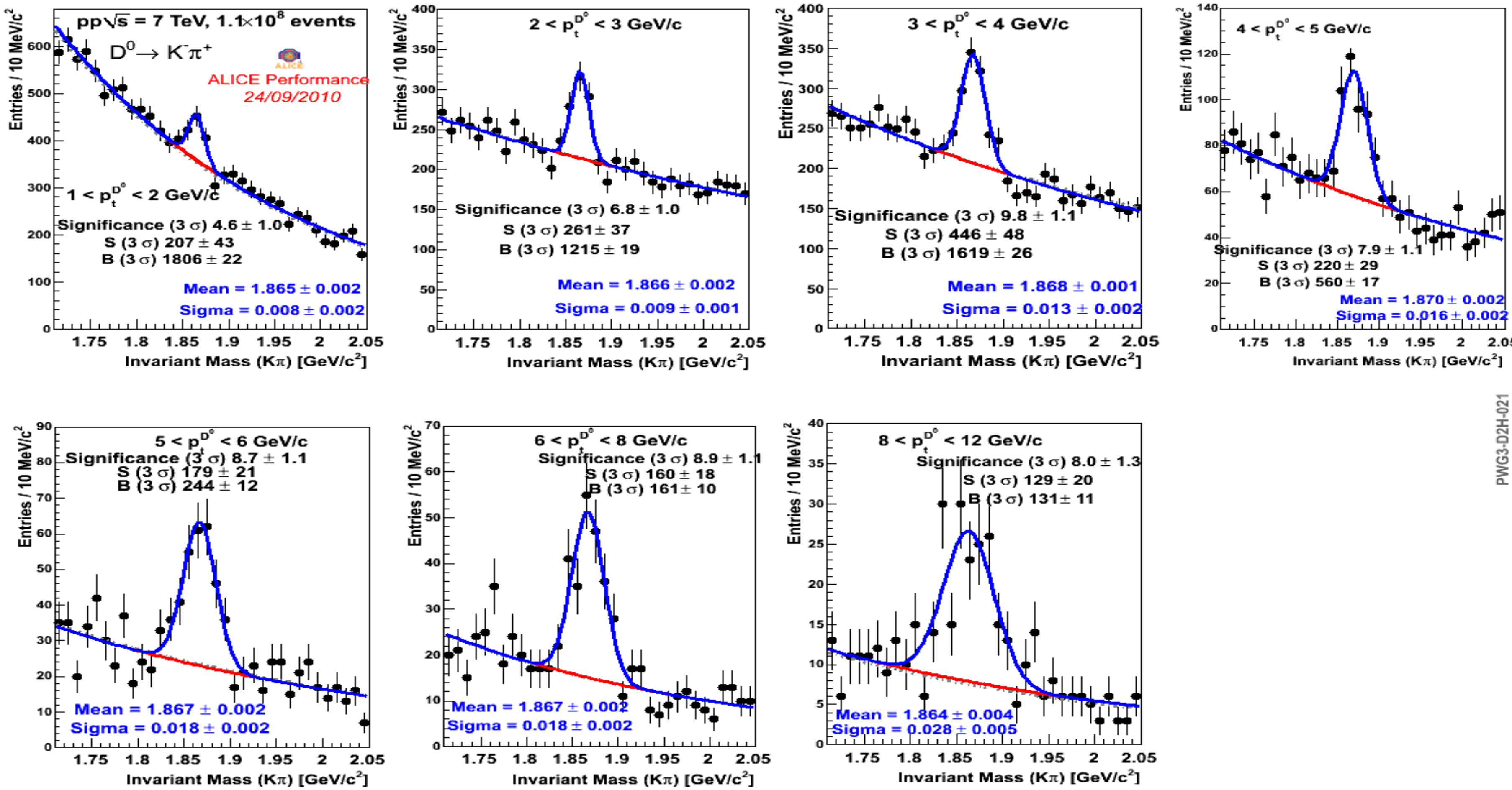
D mesons: selection tools

- Tracking and vertexing performance is crucial
  - Inner Tracking system (ITS) with 6 Si layers
  - Two pixel layers at 3.9 cm (closest barrel layer at LHC) and 7.6 cm.
  - Track impact parameter resolution is 75µm at 1 GeV/c and is well described in MC
    - ✓ *Also the mass dependence is well understood*



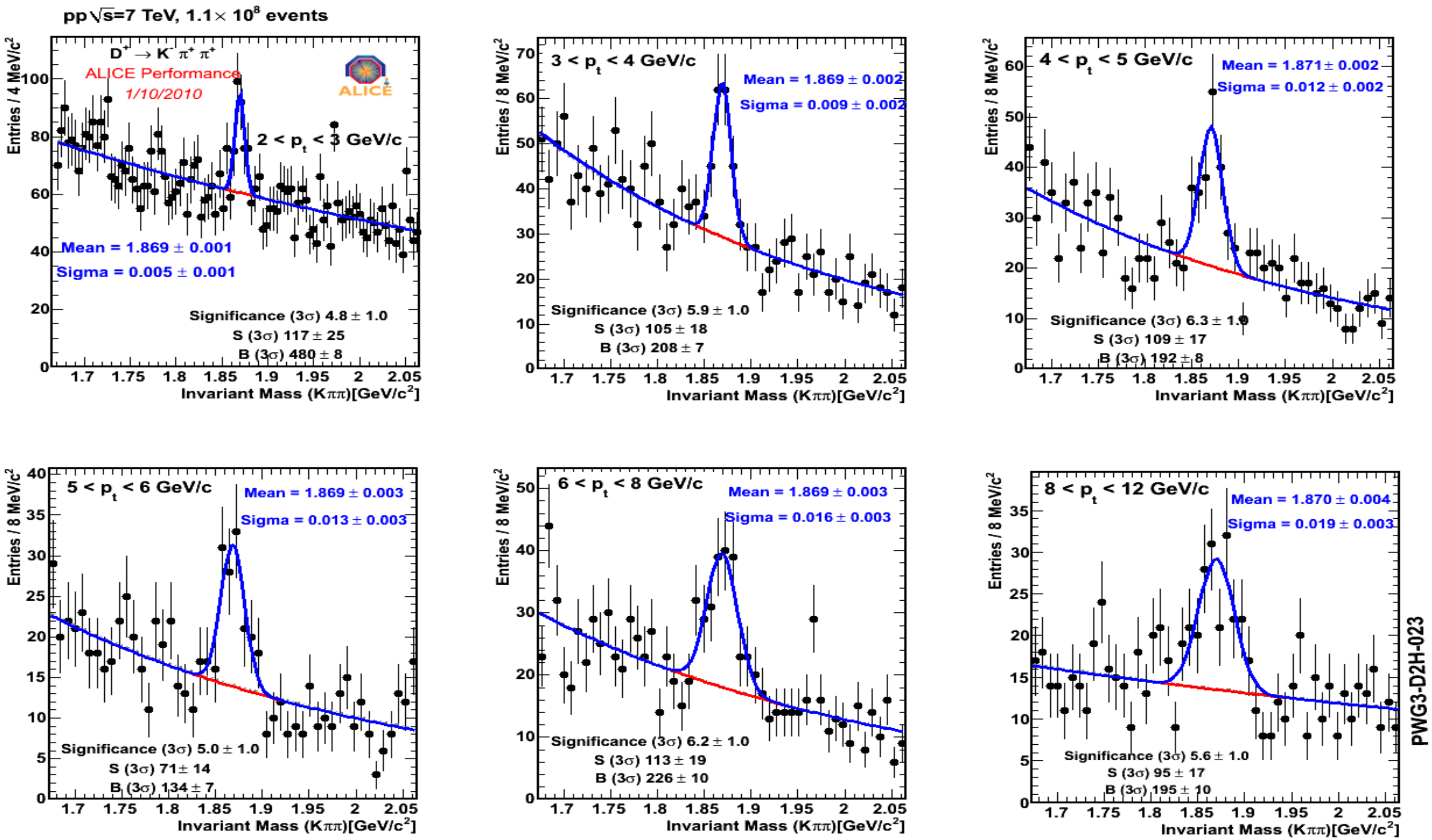


$D^0 \to K^- \pi^+$



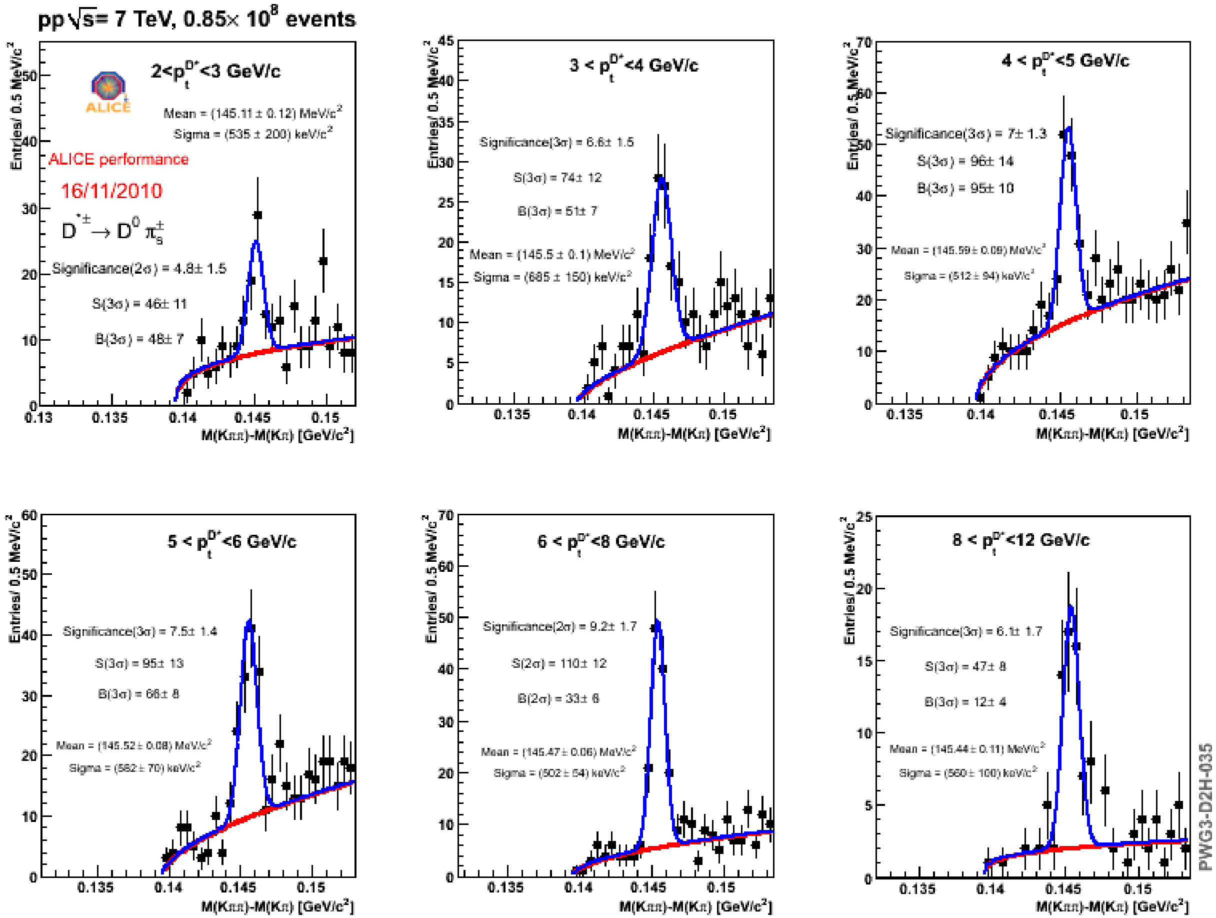
- Signals from 10^8 events
  - ⇨ 7 p_t bins in the range $1<p_t<12$ GeV/c
- Selection based mainly on cosine of pointing angle and product of track impact parameters ($d_0^K \times d_0^\pi$)

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



- Signals from 10^8 events
  - ⇨ 6 p_t bins in the range $2<p_t<12$ GeV/c
- Selection based mainly on cosine of pointing angle and D^+ decay length

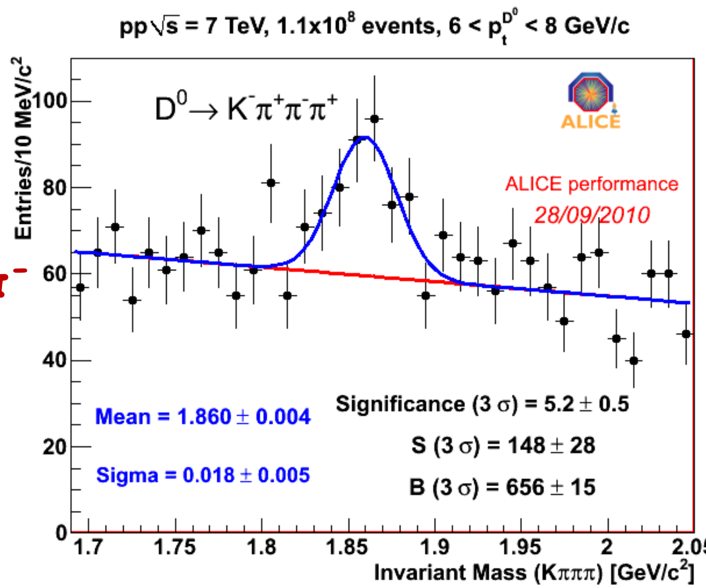
$D^*(2010)^+ \rightarrow D^0 \pi^+$

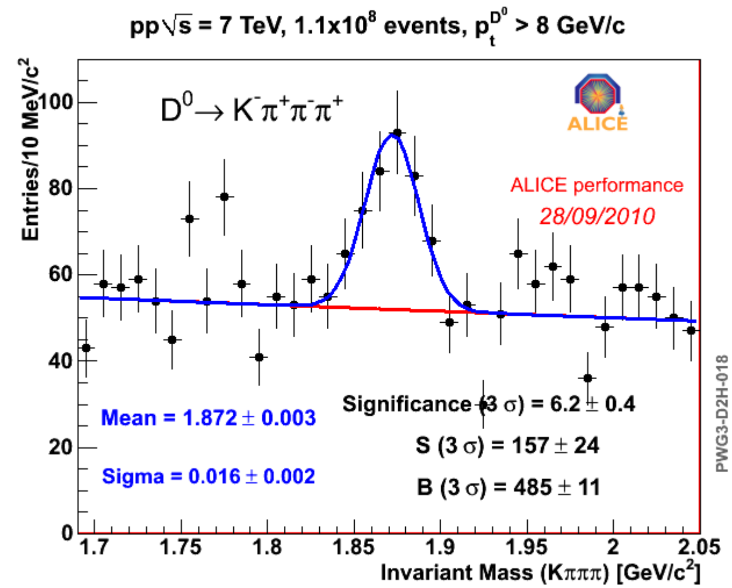


- Signals from $0.85{\cdot}10^8$ events
  - ⇨ 6 p_t bins in the range $2<p_t<12$ GeV/c
- Strategy: topological selection of D^0, attach a pion and build $\Delta m = m_{K\pi\pi} - m_{D0}$ spectra

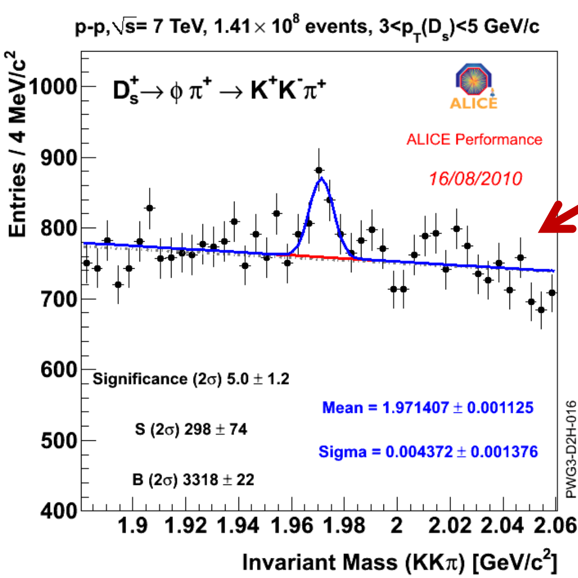
Other channels

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

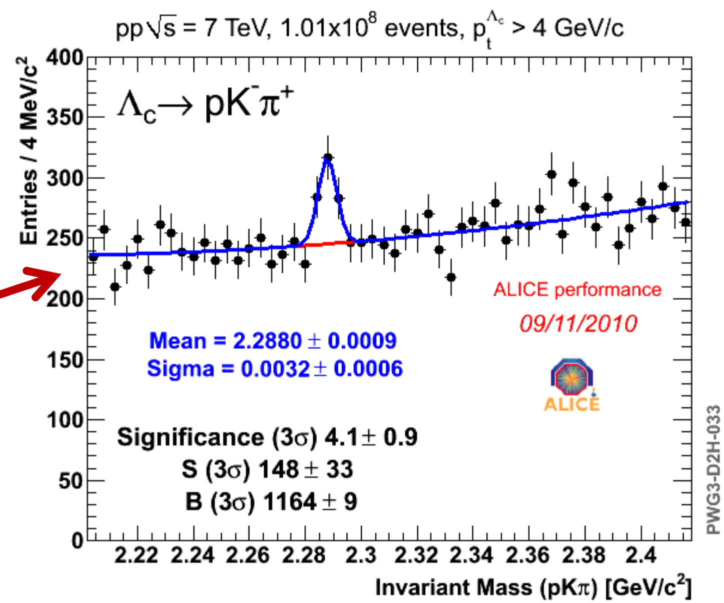




$D_s^+ \rightarrow K^-K^+\pi^+$



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



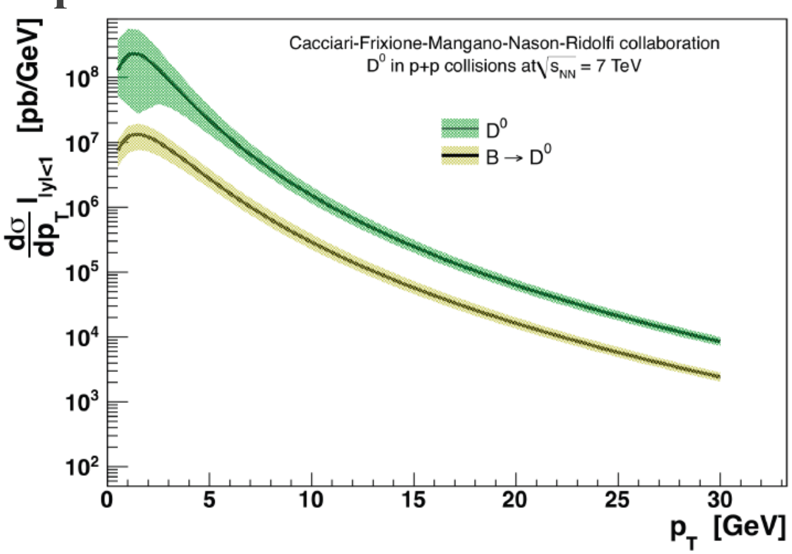
From signals to cross-sections

$$\left.\frac{d\sigma^{D^+}}{dp_t}\right|_{|y|<0.5} = \frac{1}{2}\frac{1}{2y_{acc}\,\Delta p_t}\frac{f_{prompt}\cdot \left. N^{D^\pm\ raw}(p_t)\right|_{|y|<y_{acc}}}{\varepsilon_{prompt}\cdot BR\cdot L_{int}}$$

From fits to invariant mass spectra

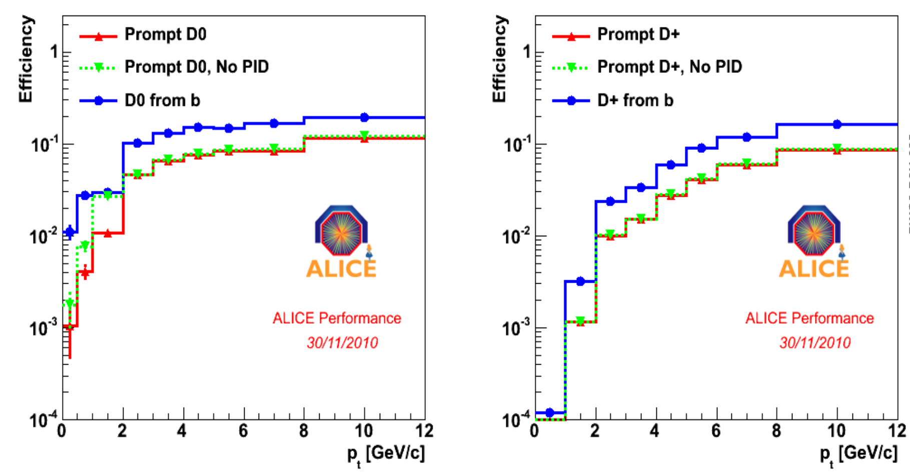
Correction for B→D feeddown:

- Currently from FONLL predictions + selection efficiencies from MC
- Next: from data using impact parameter distribution of D mesons

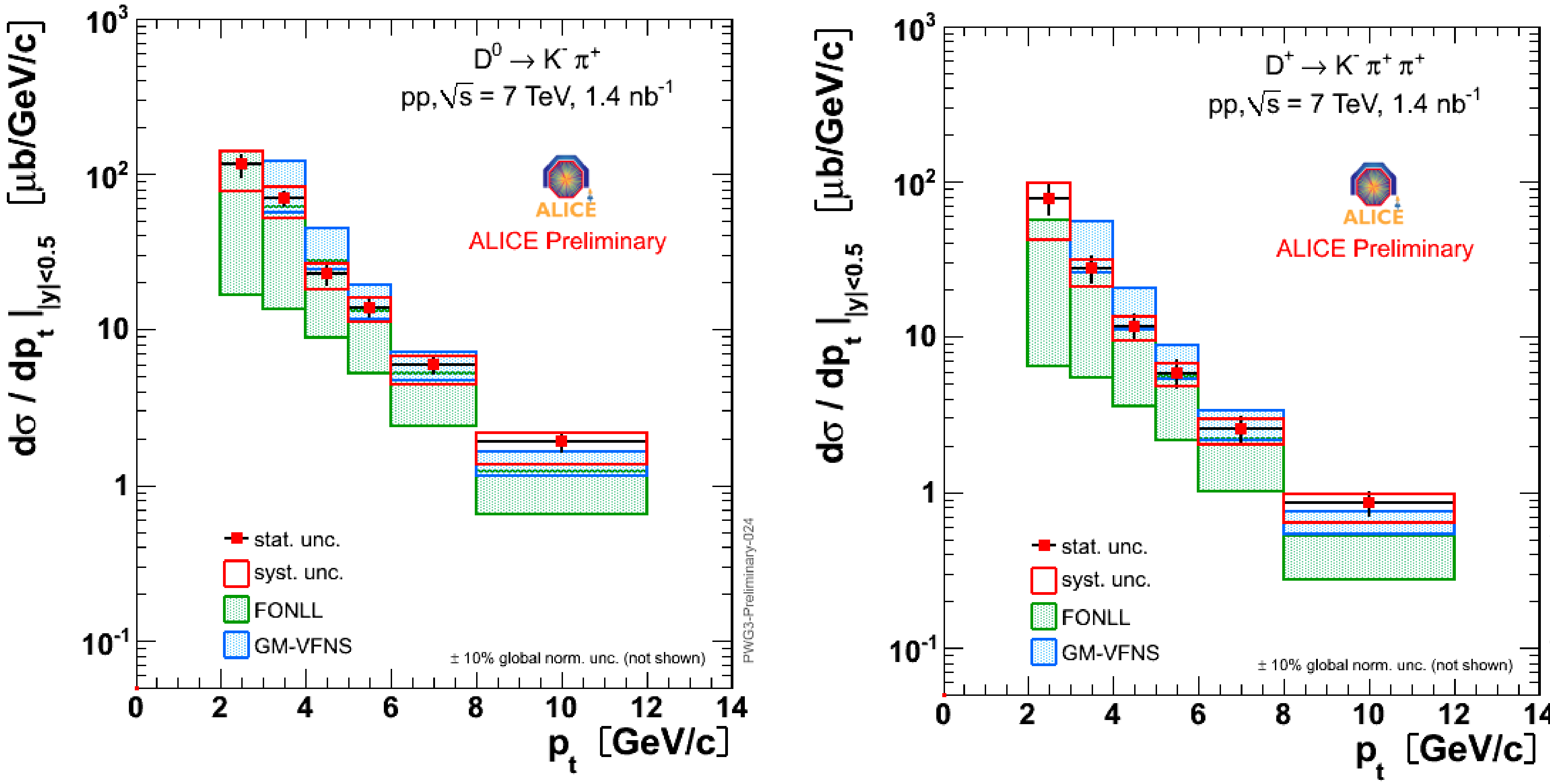


Correction for reconstruction and selection efficiency:

- From MC simulations

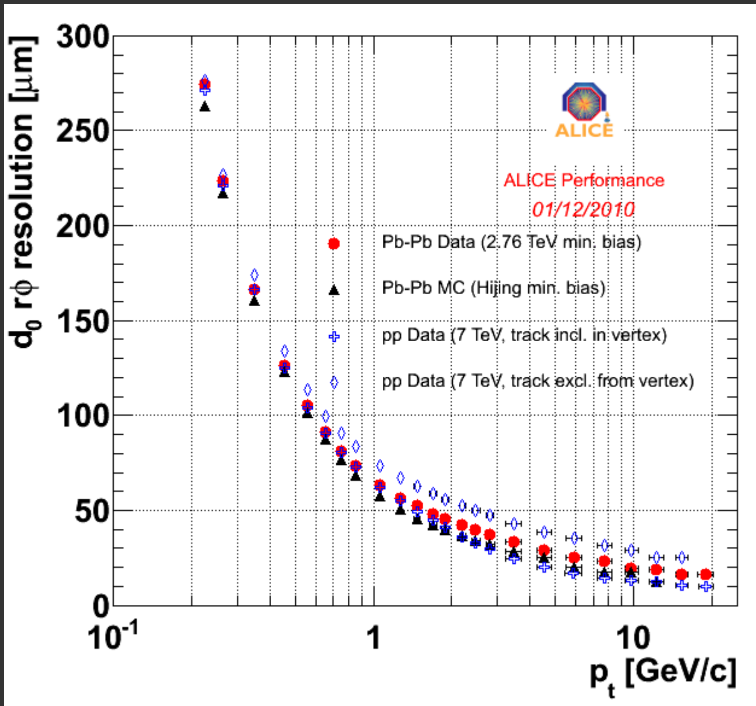


D^0 and D^+: $d\sigma/dp_t$



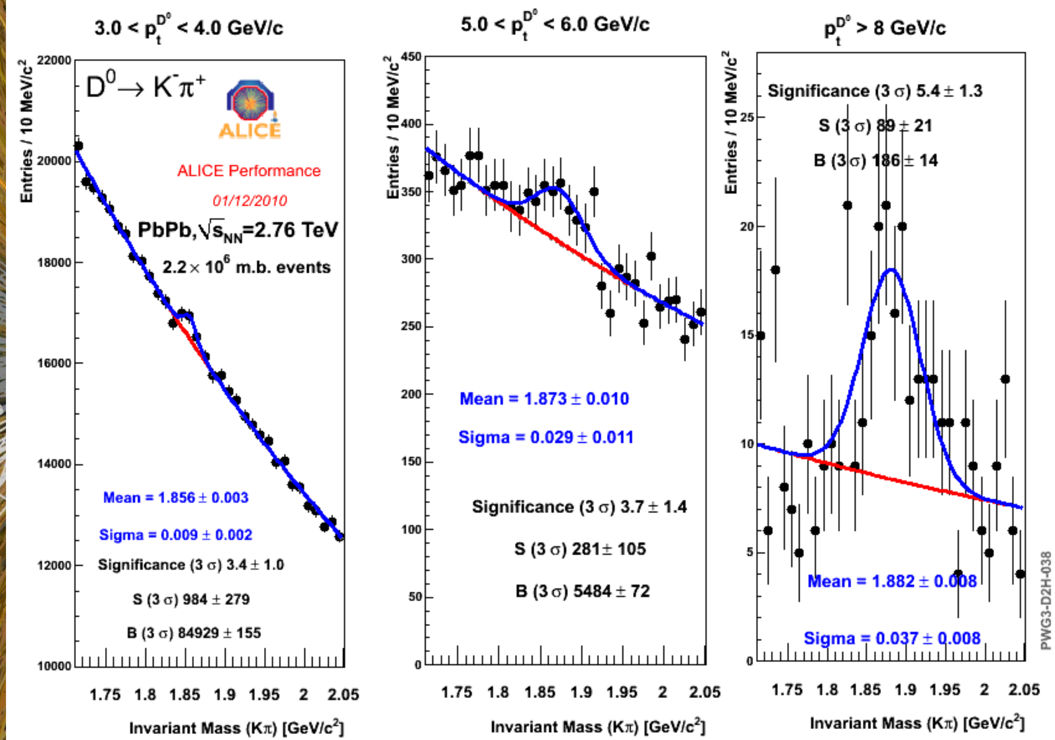
- From an integrated luminosity of 1.4 nb^{-1}
  - ⇨ ~20% of 2010 statistics
- Measured p_t differential cross sections described by pQCD predictions (FONLL and GM-VFNS)

Looking forward to PbPb



Detector is well performing!

First D-meson signals observed!



ALICE

Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:29:52
Fill : 1482
Run : 137124
Event : 0x0000000042B1B693

Conclusions

- ALICE demonstrated excellent capabilities for open heavy flavor physics at the LHC
  - Excellent electron and hadron particle identification
  - High resolution on vertex and track impact parameter
  - Precise tracking down to low pt
- First results on p_t differential cross-sections:
  - muons from c and b at forward rapidity
  - D mesons at midrapidity

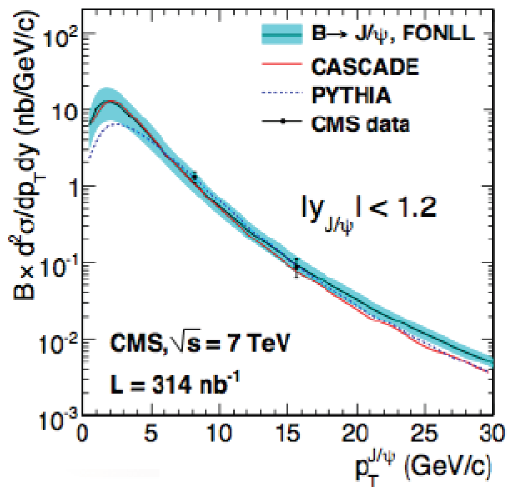
  in agreement with the pQCD predictions
- Ongoing:
  - Study of systematics on the semi-electronic channel
  - Data (impact parameter) based methods to separate charm and beauty contributions in D meson and electron analyses
  - Extension of the measured differential cross-section to lower and higher p_t
  - Analysis of Pb-Pb data sample

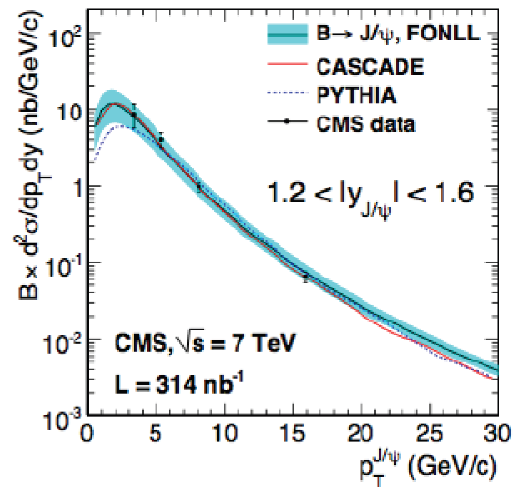
Backup

Beauty at the LHC

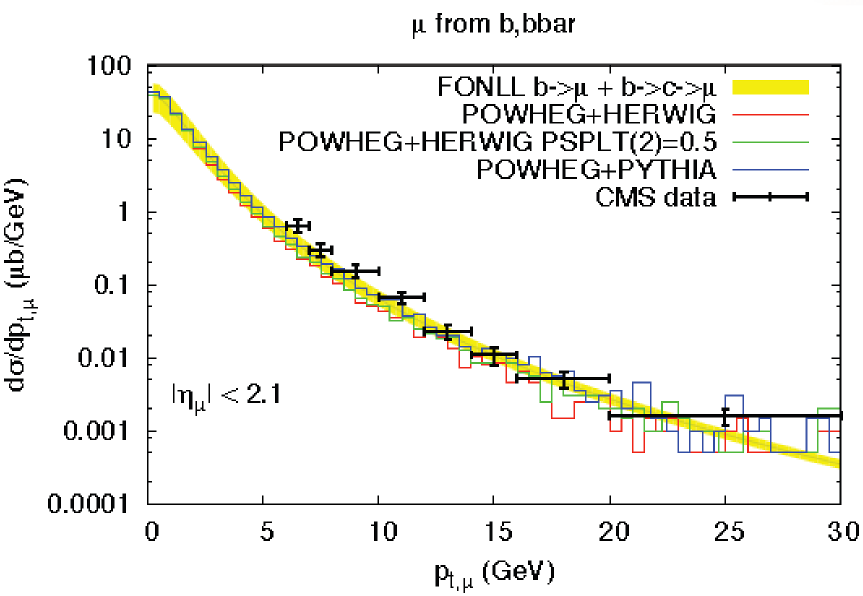
- Beauty production at 7 TeV
  - ⇨ FONLL vs. CMS data: J/ψ and μ from B

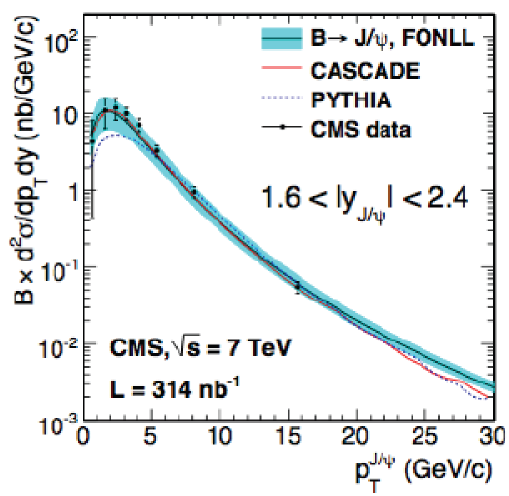
CMS, arXiv:1011.4193





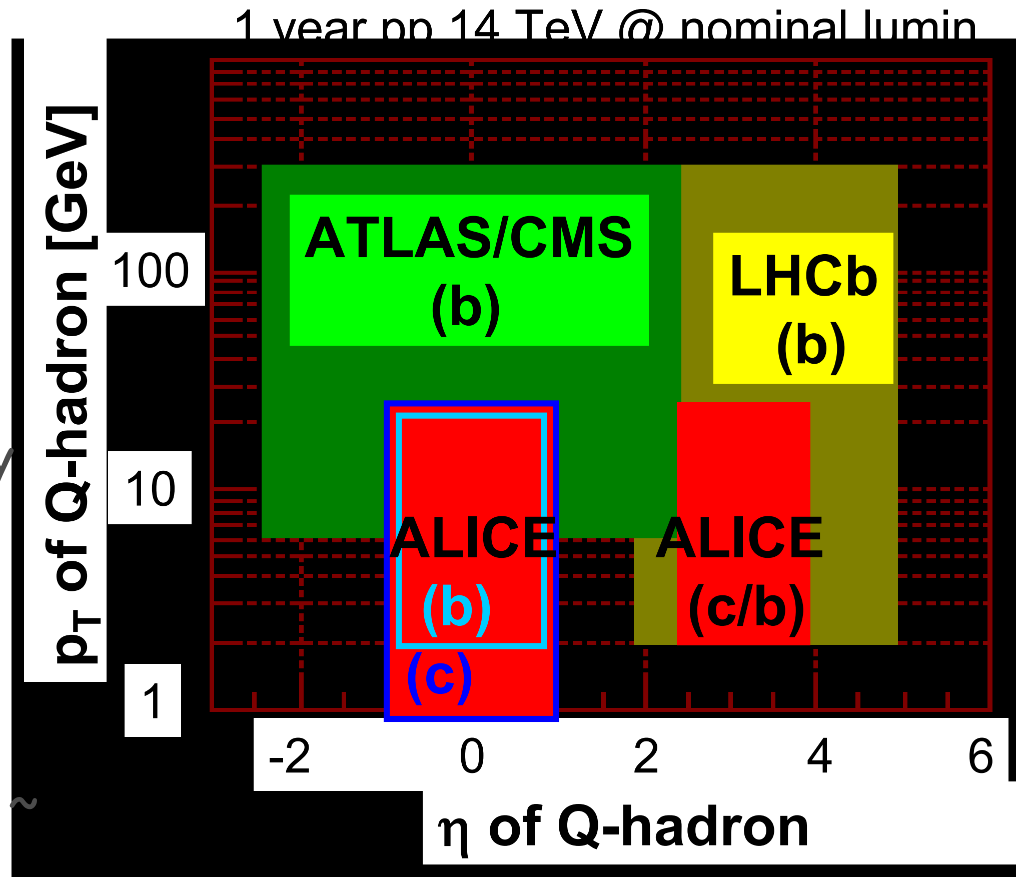
CMS PAS BPH-10-007



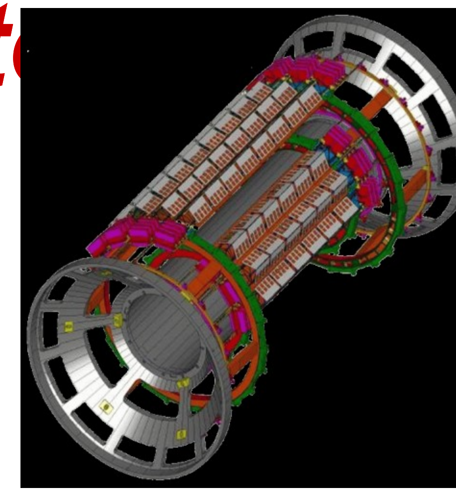


Heavy-flavours in ALICE

- ALICE channels:
  - ⇨ electronic (|η|<0.9)
  - ⇨ muonic (-4<η<-2.5)
  - ⇨ hadronic (|η|<0.9)
- ALICE specific features:
  - ⇨ low-p_T region
  - ⇨ central and forward rapidity regions
  - ⇨ Both c and b
  - ⇨ Precise vertexing in the central region to identify D ($c\tau$ ~ 100-300 μm) and B ($c\tau$ ~ 500 μm) decays



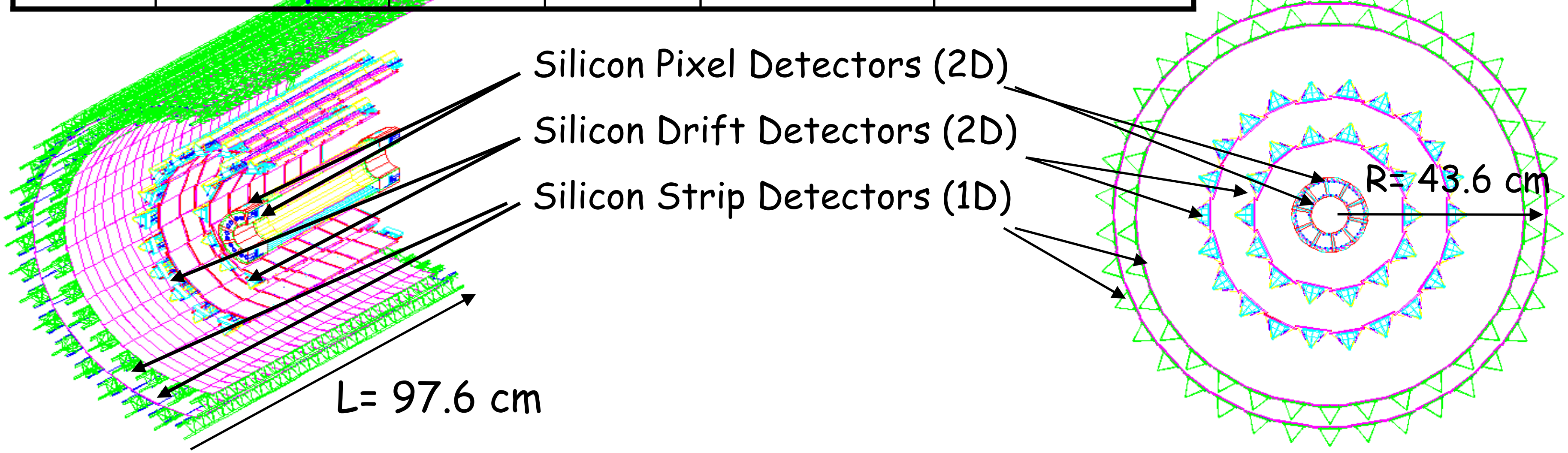
Inner Tracking Syst



- 6 cylindrical layers of silicon detectors:

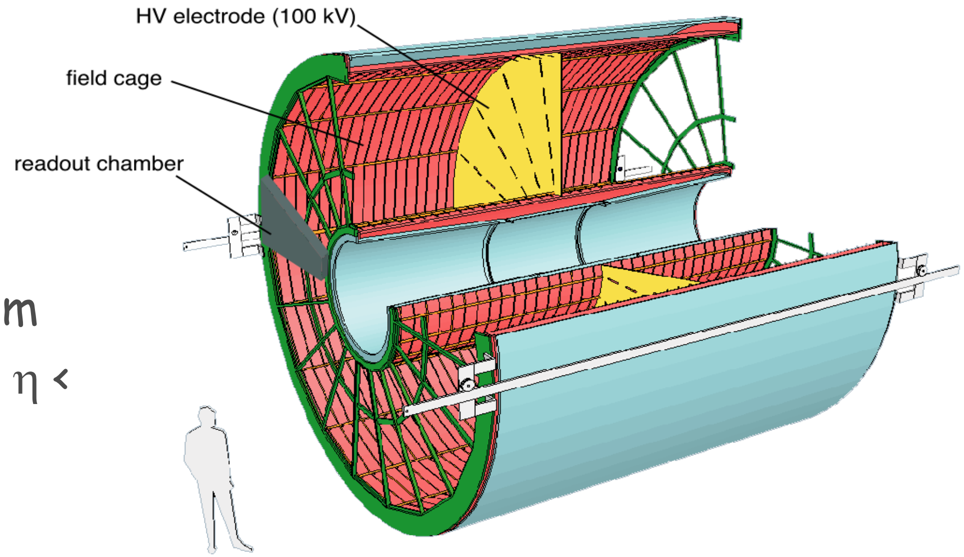
Layer	Technology	Radius (cm)	±z (cm)	Spatial resolution (μm)	
				$r\phi$	z
1	Pixel	4.0	14.1	12	100
2	Pixel	7.2	14.1	12	100
3	Drift	15.0	22.2	38	28
4	Drift	23.9	29.7	38	28
5	Strip	38.5	43.2	20	830
6	Strip	43.6	48.9	20	830

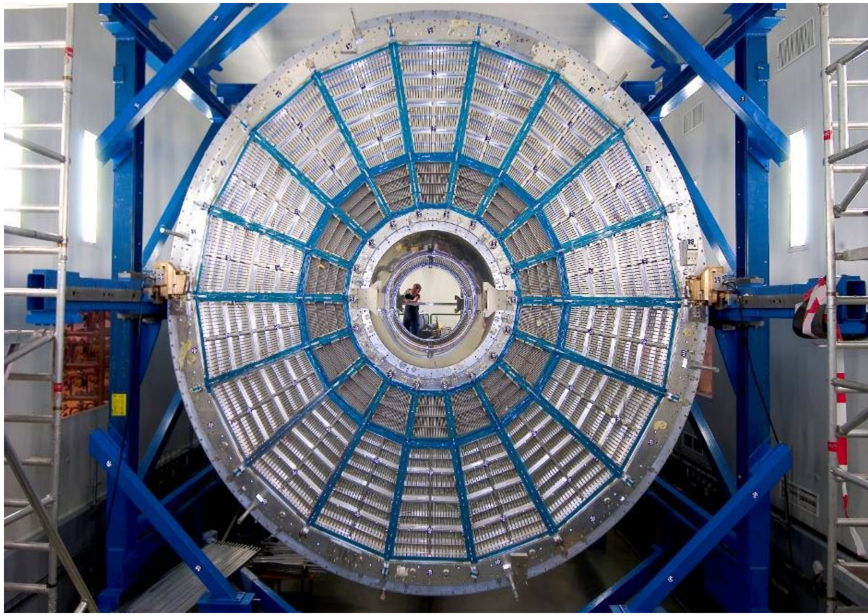
} provide also dE/dx for particle idetification



Time Projection Chamber

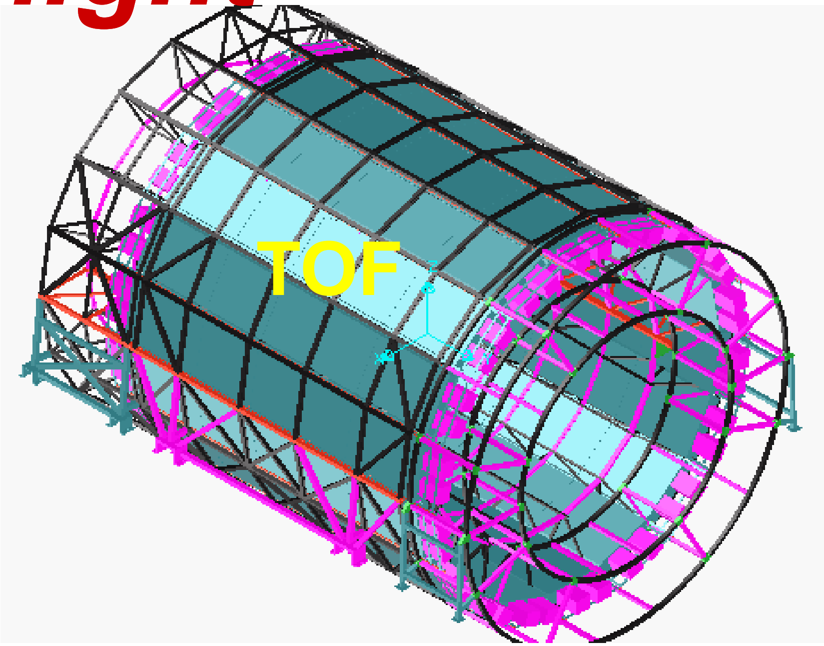
- Main tracking detector
- Characteristics:
  - ⇨ R_{in} 90 cm
  - ⇨ R_{ext} 250 cm
  - ⇨ Length (active volume) 500 cm
  - ⇨ Pseudorapidity coverage: $-0.9 < \eta < 0.9$
  - ⇨ Azimuthal coverage: 2π
  - ⇨ # readout channels ≈560k
  - ⇨ Maximum drift time: 88 μs
  - ⇨ Gas mixture: 90% Ne 10% CO_2
- Provides:
  - ⇨ Many 3D points per track
  - ⇨ Tracking efficiency > 90%
  - ⇨ Particle identification by dE/dx
    - ✓ ***in the low-momentum region***
    - ✓ ***in the relativistic rise***

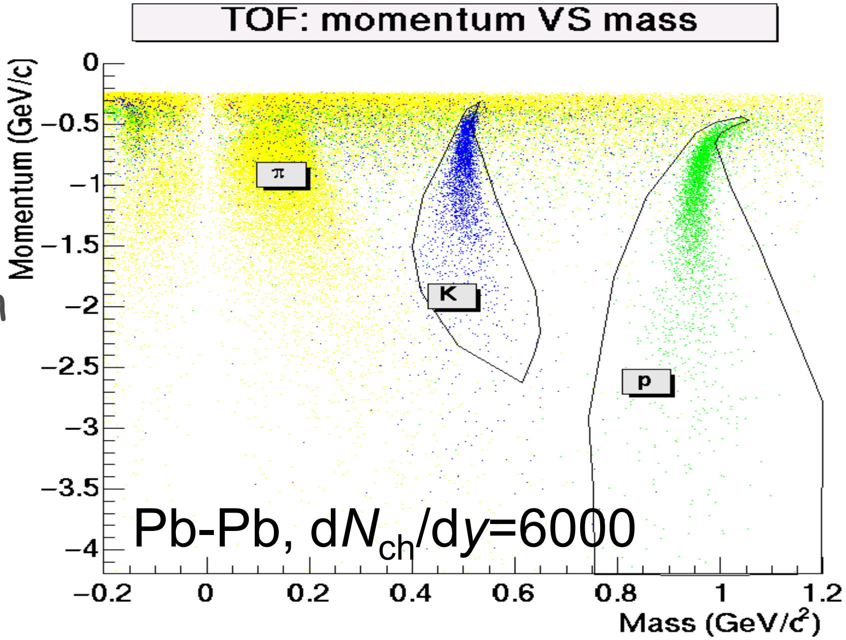




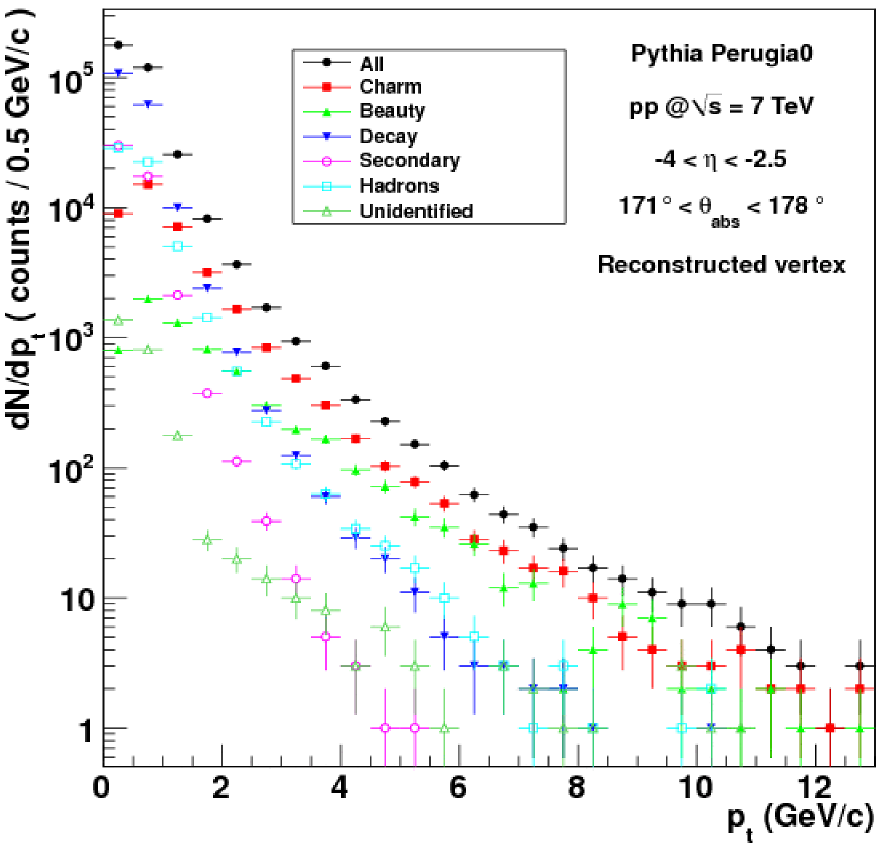
Time Of Flight

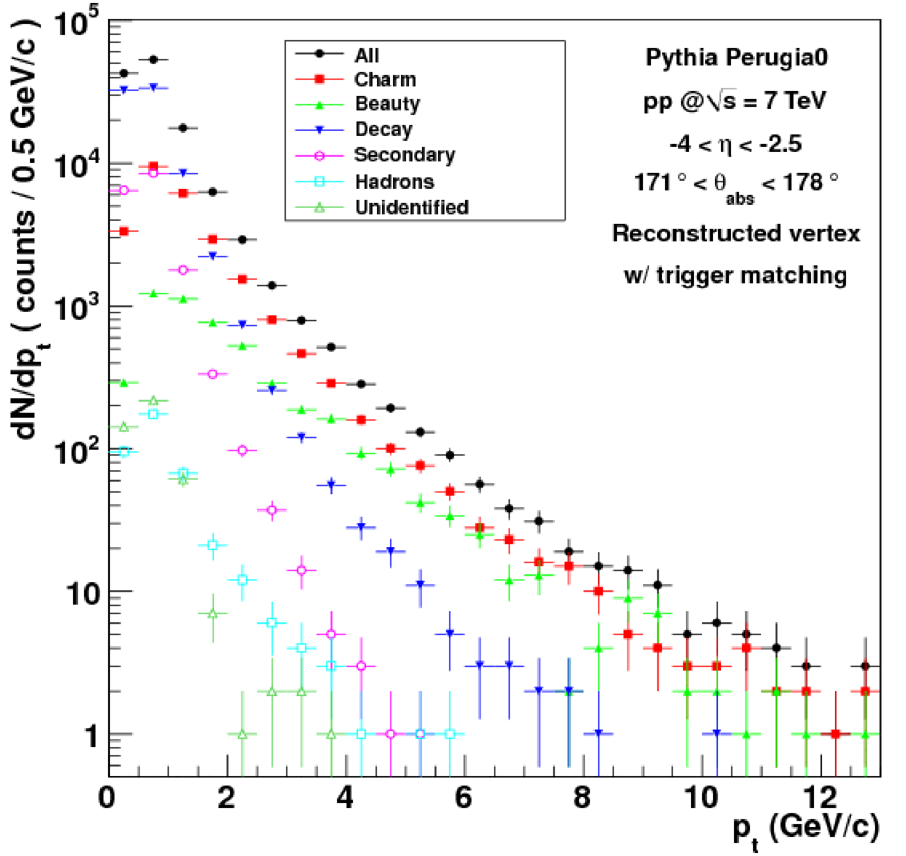
- Multigap Resistive Plate Chambers
  - ⇨ for pion, kaon and proton PID
- Characteristics:
  - ⇨ R_{in} 370 cm
  - ⇨ R_{ext} 399 cm
  - ⇨ Length (active volume) 745 cm
  - ⇨ # readout channels ≈160k
  - ⇨ Pseudorapidity coverage: $-0.9 < \eta < 0.9$
  - ⇨ Azimuthal coverage: 2π
- Provides:
  - ⇨ pion, Kaon identification (with contamination <10%) in the momentum range 0.2-2.5 GeV/c
  - ⇨ proton identification (with contamination <10%) in the momentum range 0.4-4.5 GeV/c



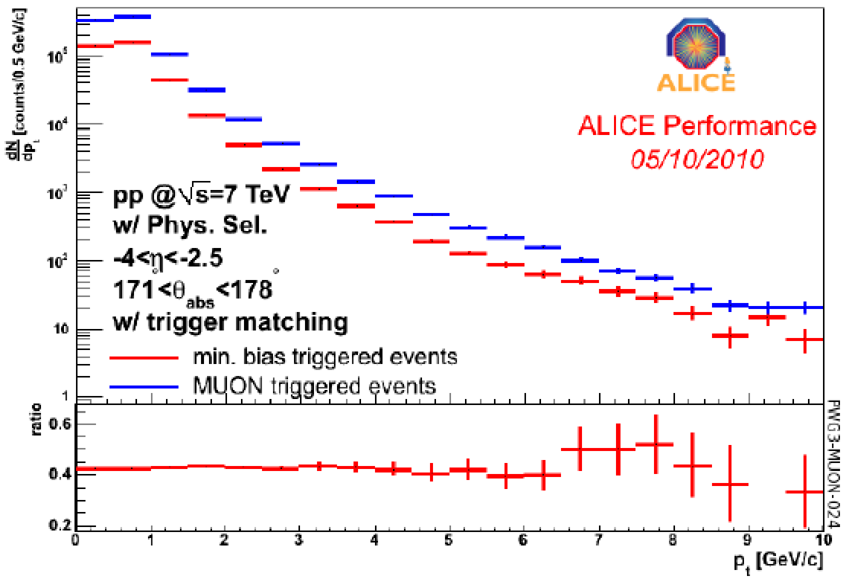


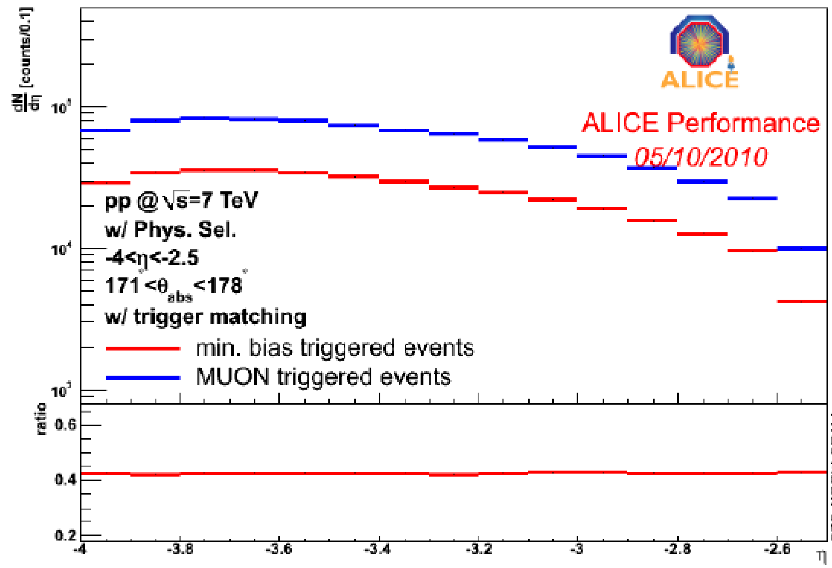
Muon trigger effect





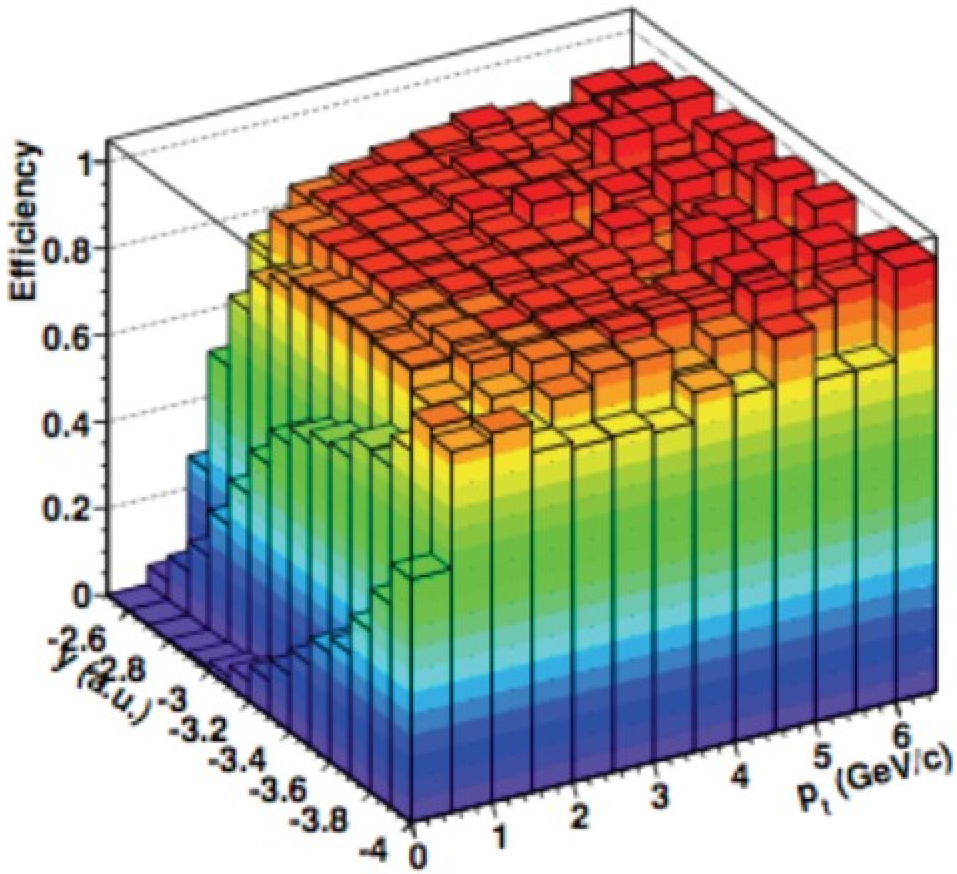
MB vs. muon trigger





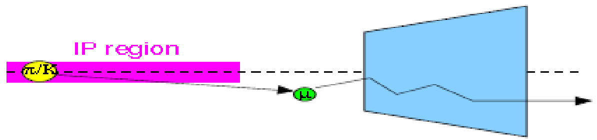
- The shape of spectra (with trigger match) is the same in Minimum Bias (MB) and Muon triggered events
- Using Muon trigger to get larger statistics
- MB triggers used for cross-check and normalization

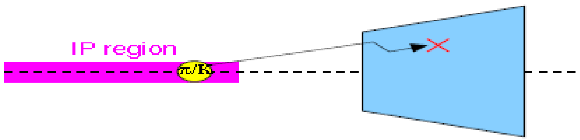
Heavy flavor single muons: efficiency



Efficiency > 87% for p_t>2.5 GeV/c

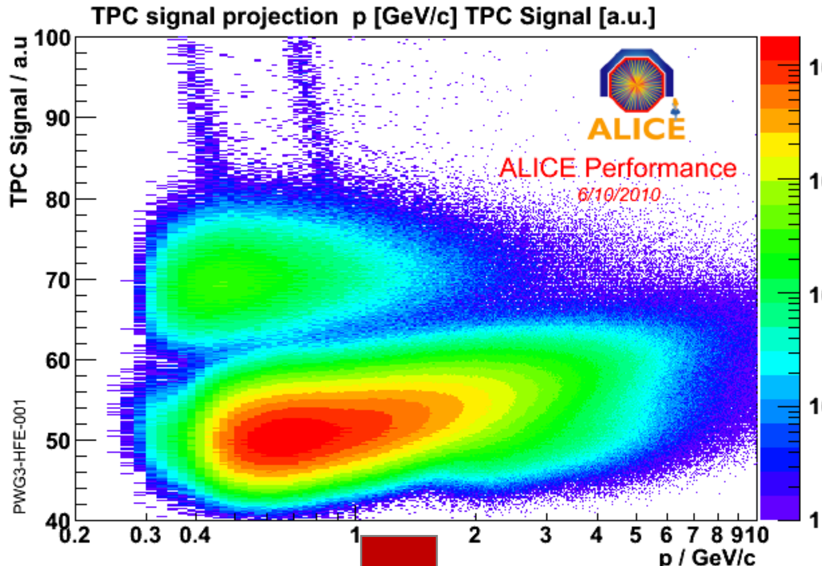
Estimate the fraction of primary muons from data

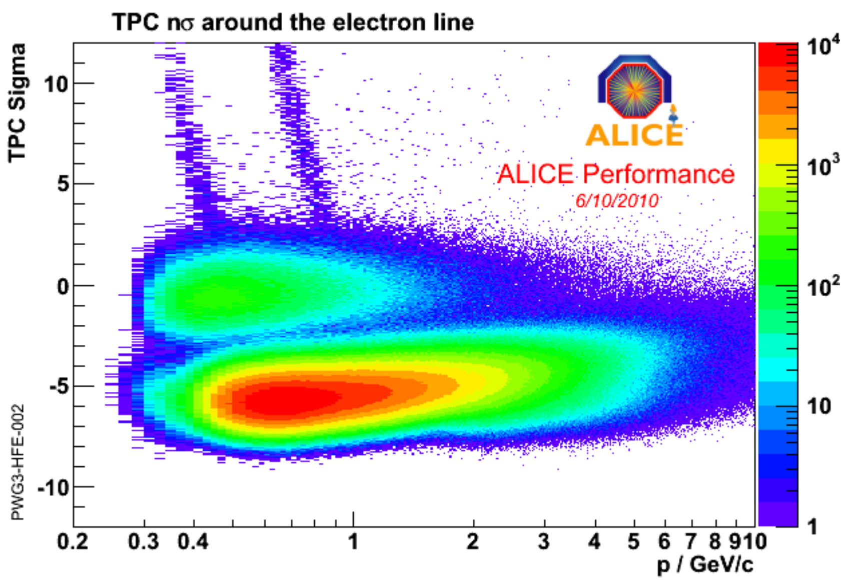


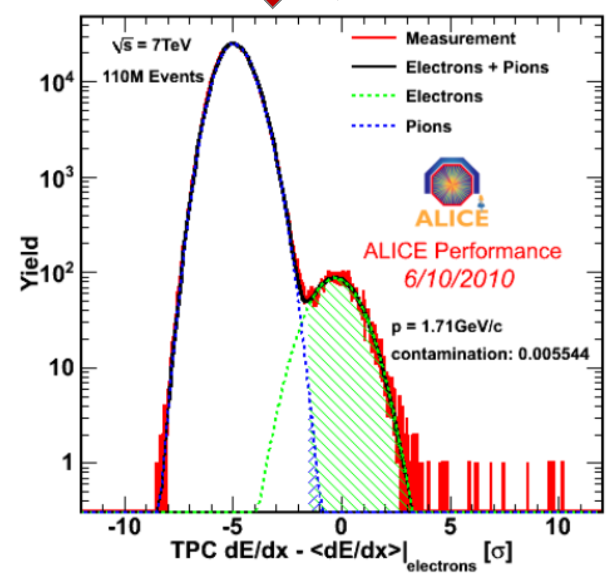


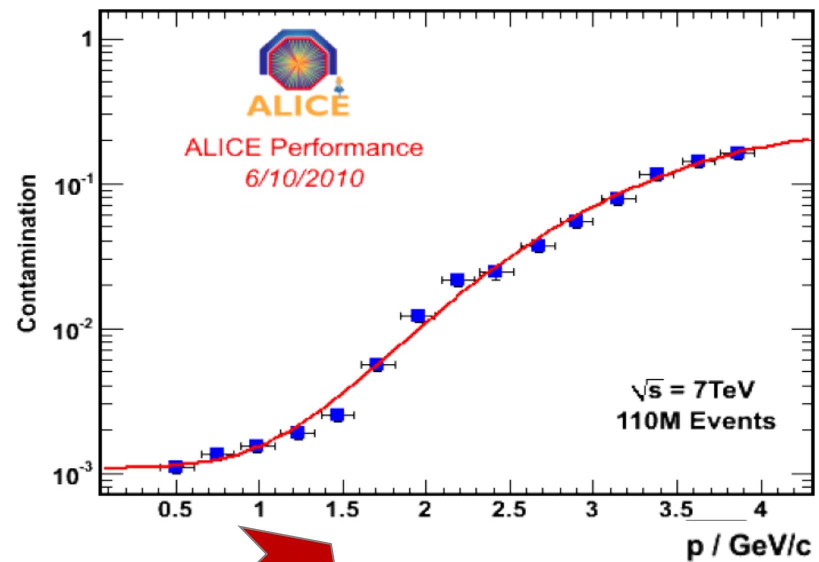
- The collision occurs in the beam crossing region, which has a gaussian profile with
  - Narrow width in the transverse plane ($\sigma_{xy}\approx$50-100 μm)
  - Wider ($\sigma_z\approx$5 cm) along the beam direction
- Exploit the fact that the probability that an hadron decays before reaching the absorber (i.e. the probability of having a decay background muon) is proportional to the distance between the interaction vertex and the absorber

Electron identification in TPC

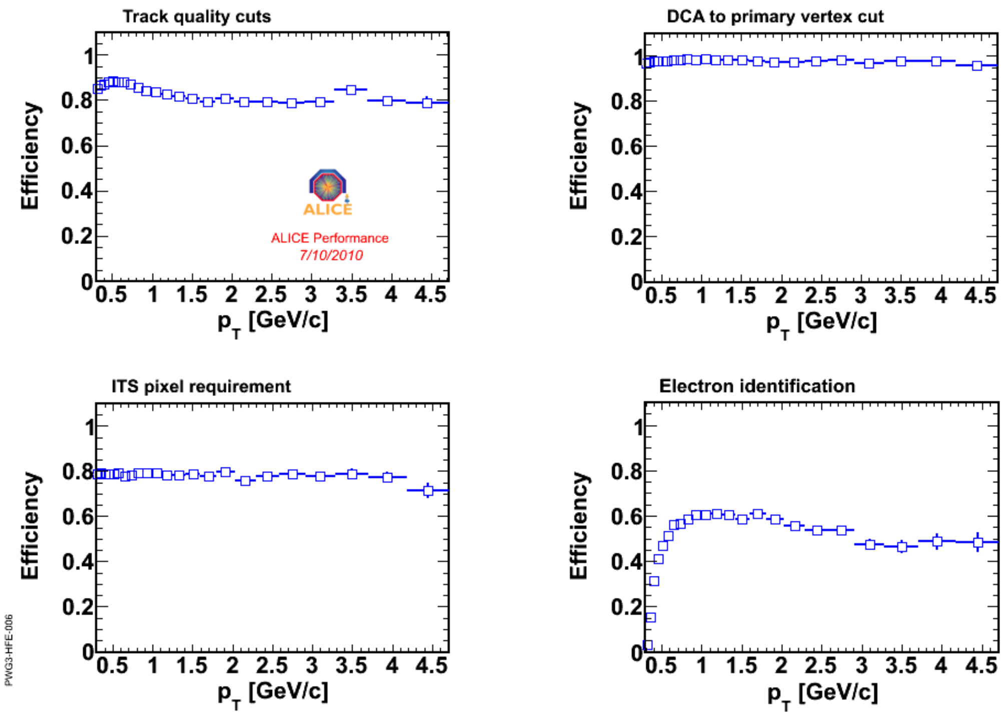


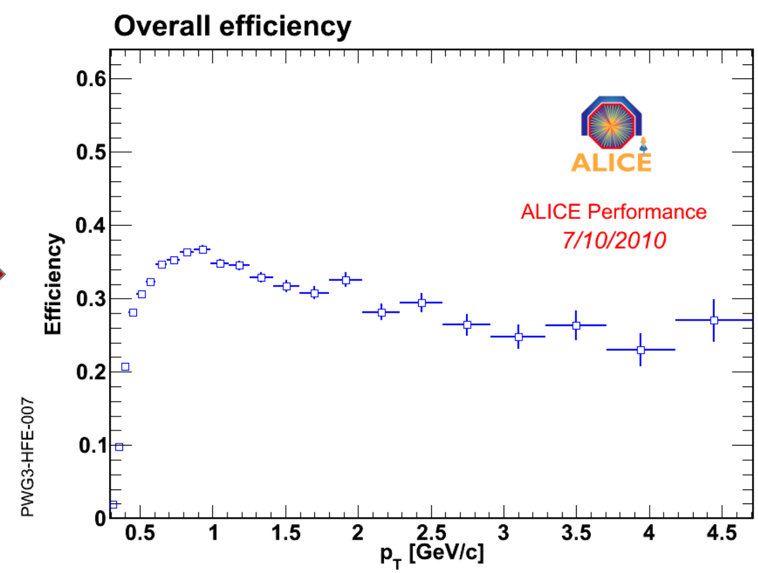




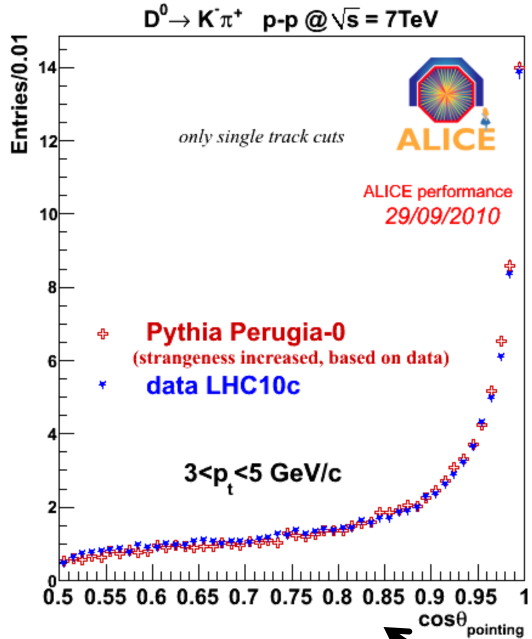


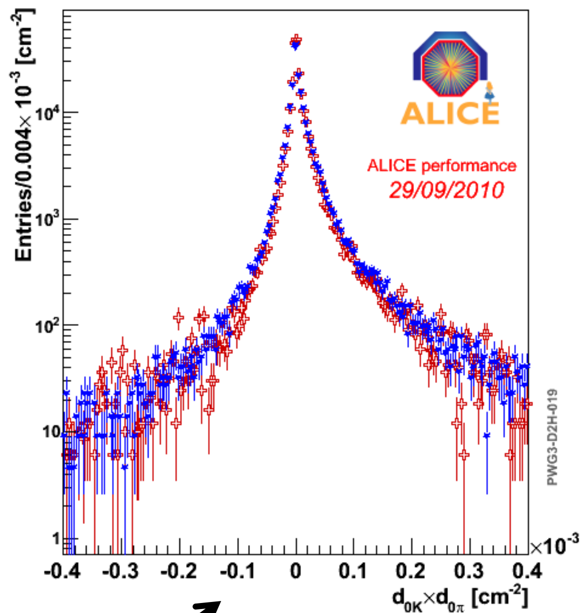
Electron efficiency

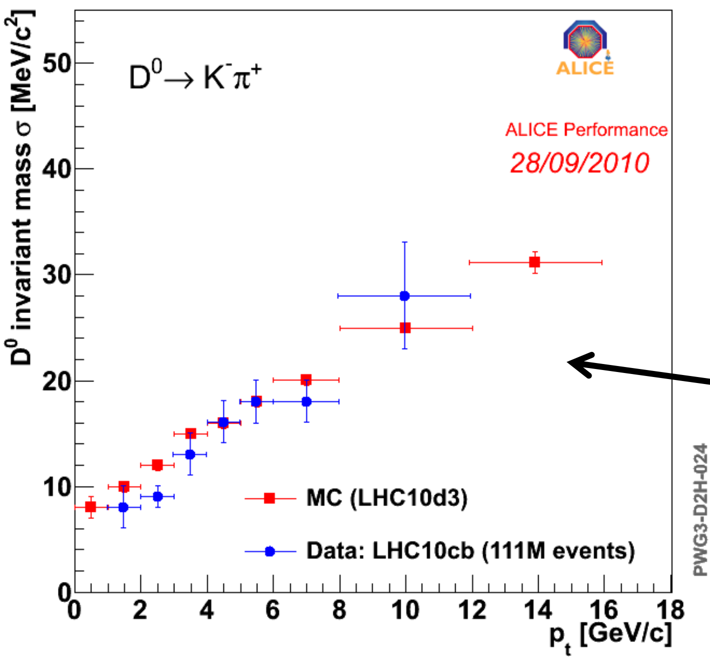




D^0: data vs. MC



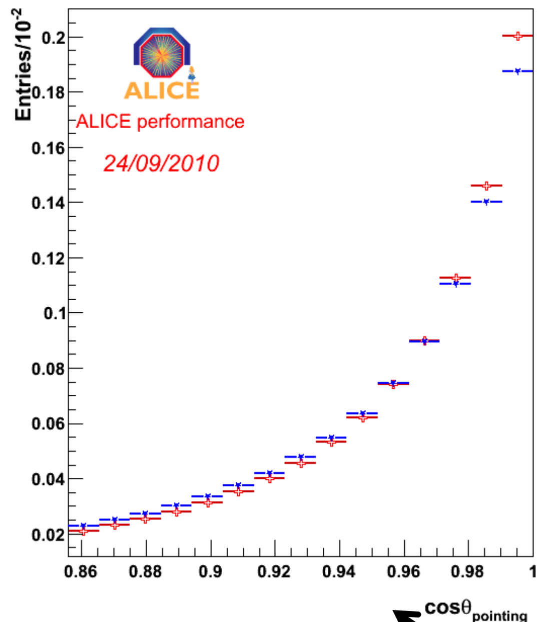


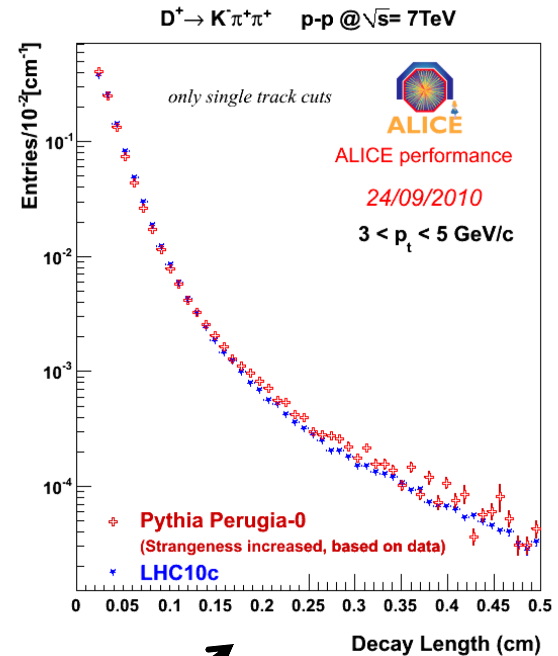


Distributions of cut variables

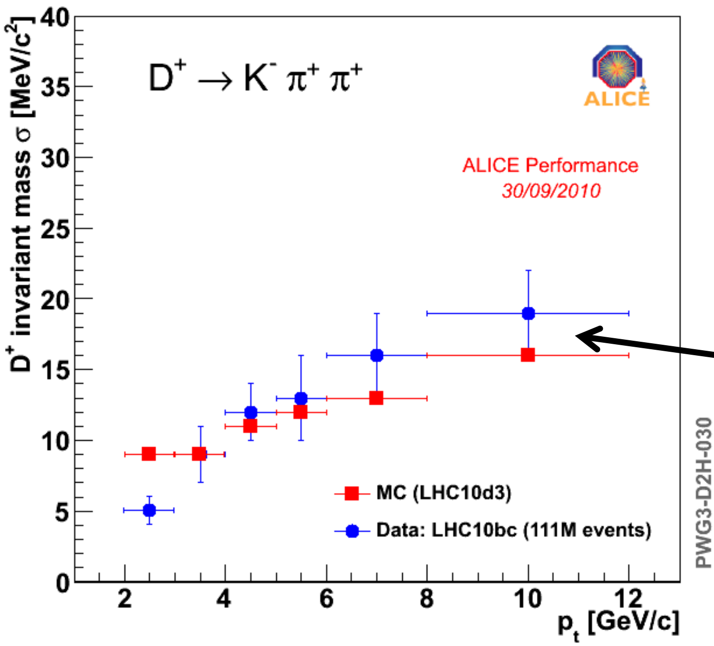
Sigma of invariant mass peak

D^+: data vs. MC



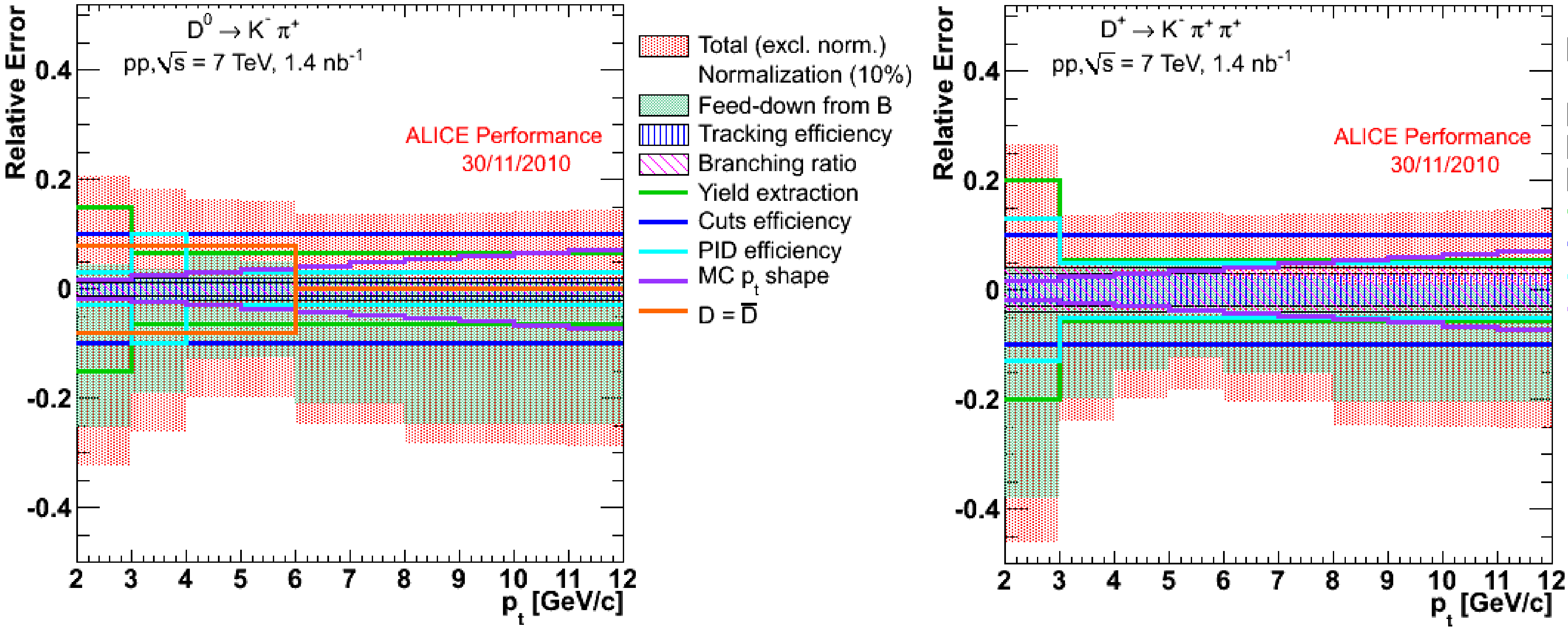


Distributions of cut variables



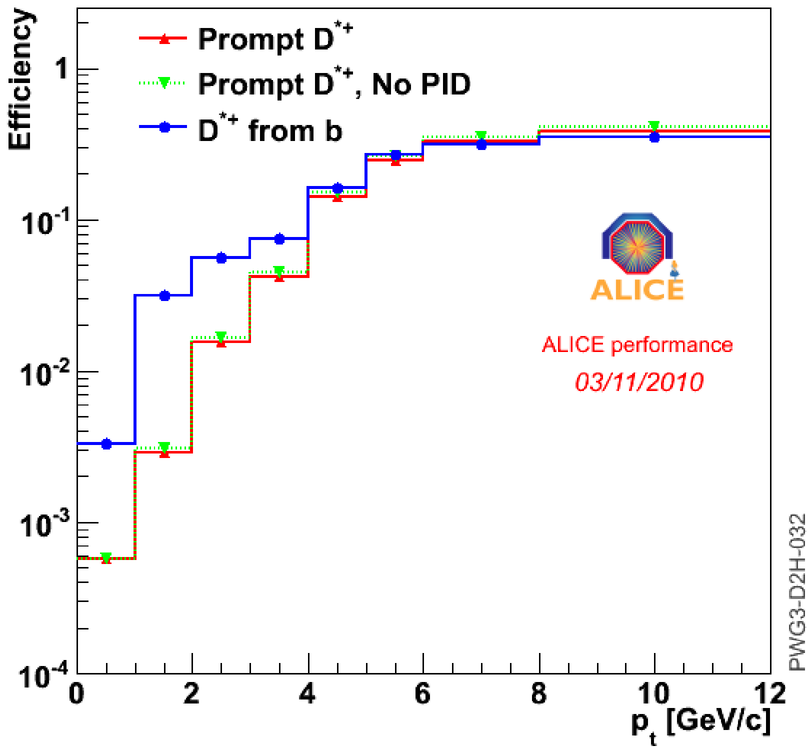
Sigma of invariant mass peak

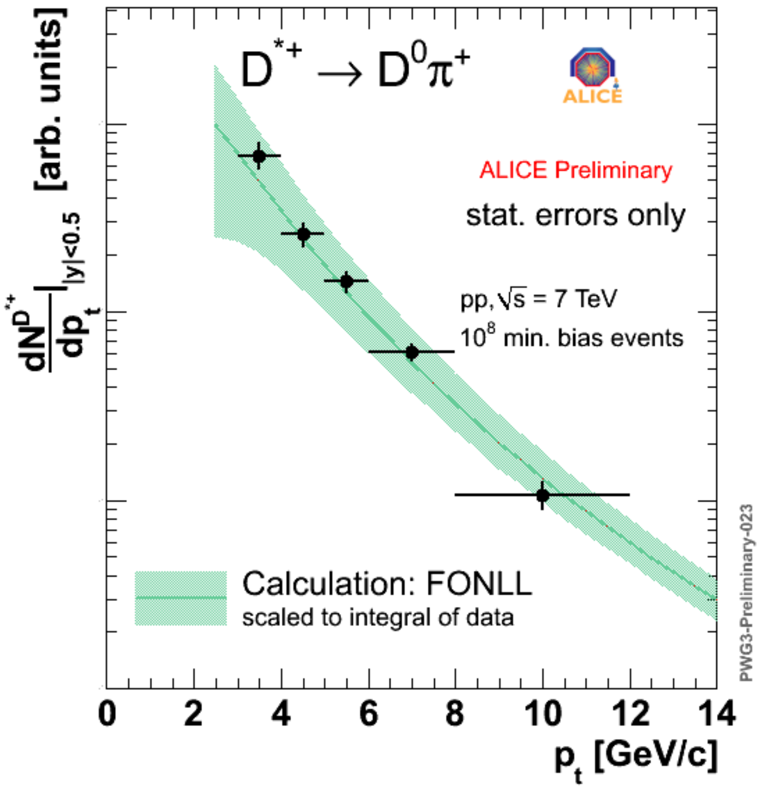
D^0 and D^+: systematics



- Total systematic 20-40% pt-dep. + 10% on normalization.
- Main systematic error: B feed-down from FONLL+MC
  - ⇨ Two methods considered (subtraction of D from B, fraction of prompt D)
  - ⇨ To be reduced using data driven method with full 2010 statistics

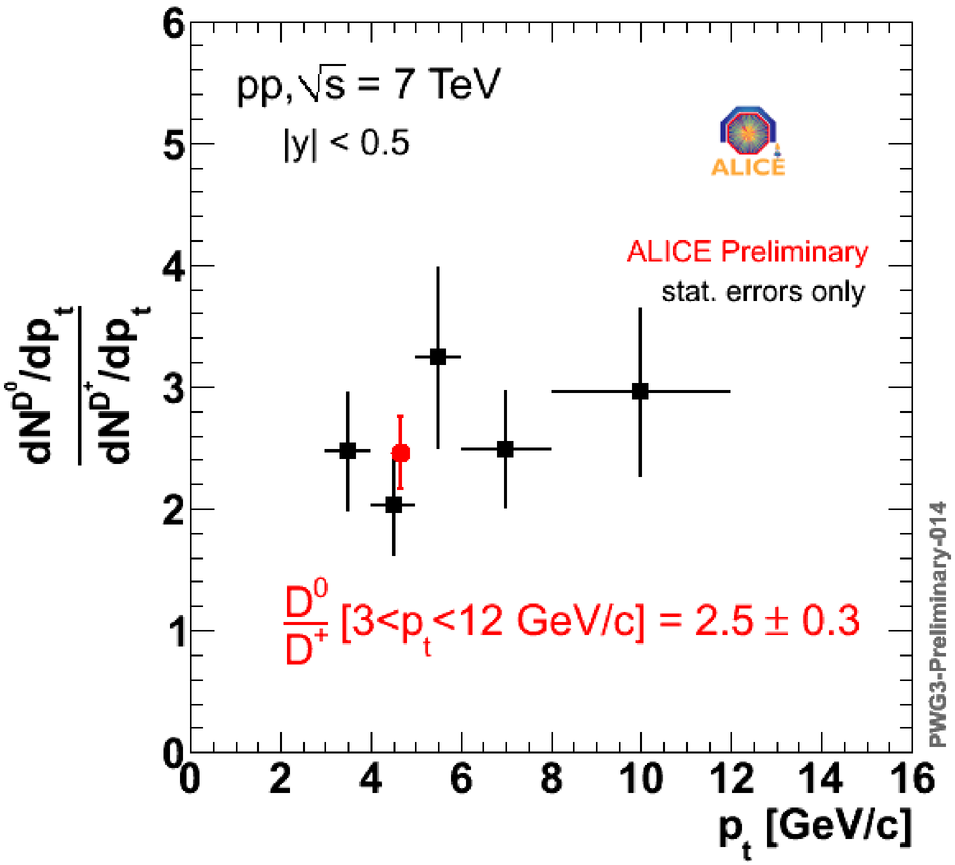
D* efficiency and yield

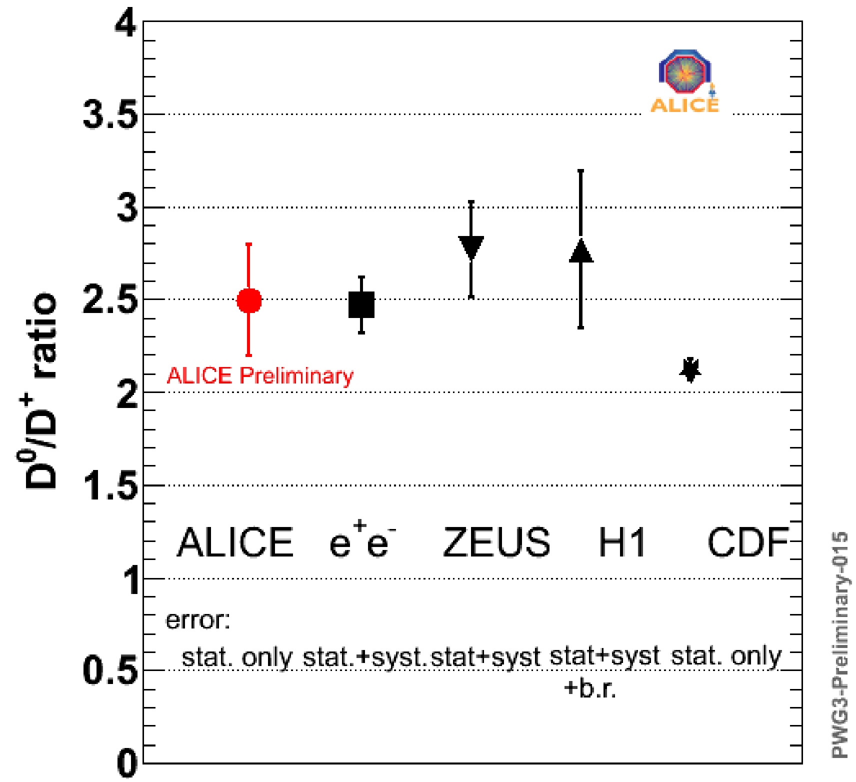




- Only statistical error
- Shape compares well with pQCD (FONLL)

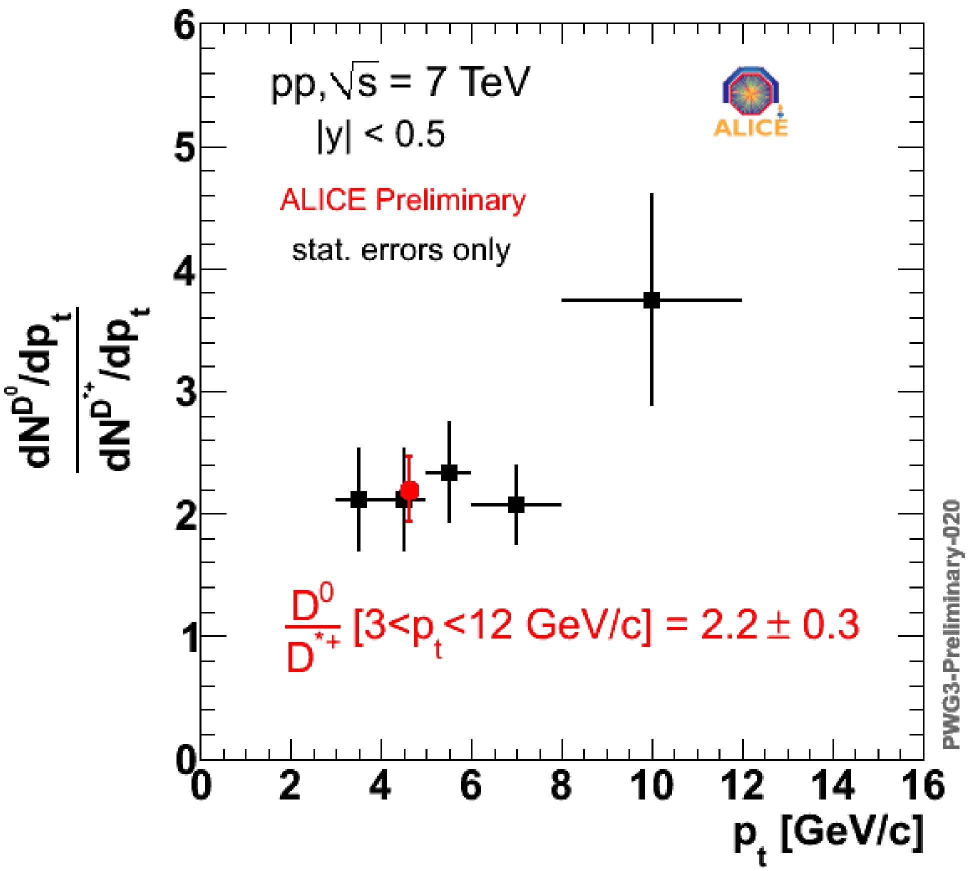
D meson ratios

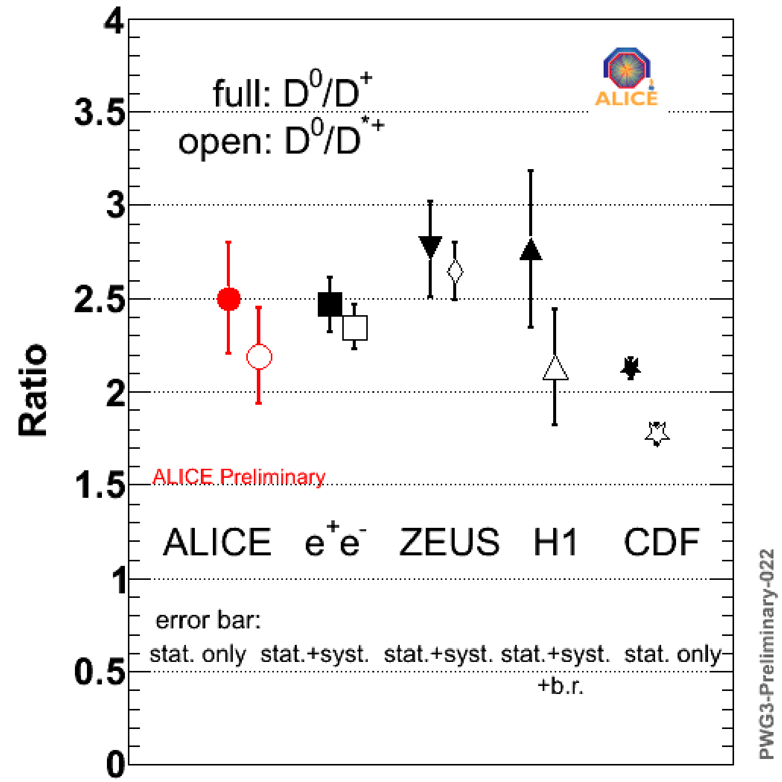




- D^0/D^+ ratio in agreement with previous experiments at lower energy

D meson ratios





- D^0/D^* ratio in agreement with previous experiments at lower energy