Open heavy flavors in ALICE

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ALICE, Junior Day, March 15th 2012

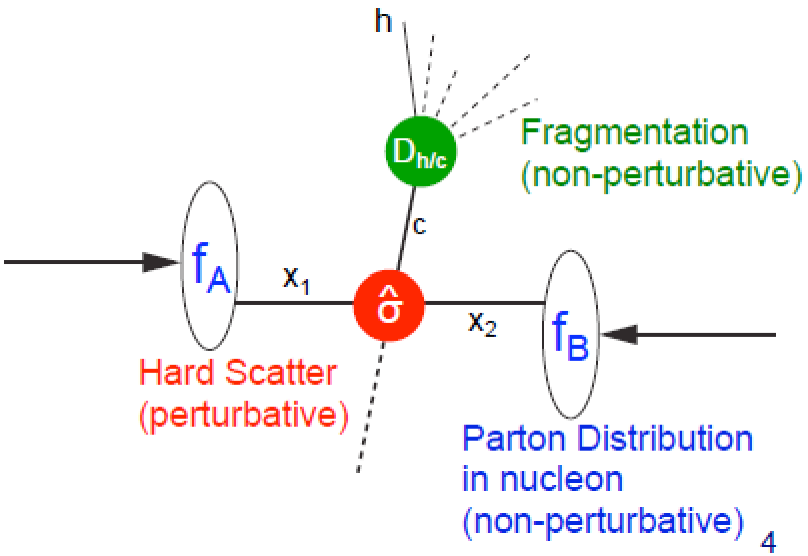
Physics Motivation

HF in ALICE physics programme

- A-A collisions
  - ⇨ Heavy Flavours are a powerful tool to 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
- p-A collisions
  - ⇨ Address initial state effects (Cronin enhancement, nuclear PDFs)

The reference: heavy flavour in pp

- Hadron production cross section in pp can be calculated in pQCD.
- Assumptions:
  - ⇨ **Factorization** between the hard part and the non perturbative PDF and fragmentation function $D_{q\to H}$
  - ⇨ **Universal** fragmentation and PDFs
    - ✓ ***(e.g PDF from ep, fragmentation from ee, but used in pp data)***



$$\sigma_{hh\to Hx} = PDF(x_a,Q^2)PDF(x_b,Q^2) \otimes \sigma_{ab\to q\bar{q}} \otimes D_{q\to H}(z_q,Q^2)$$

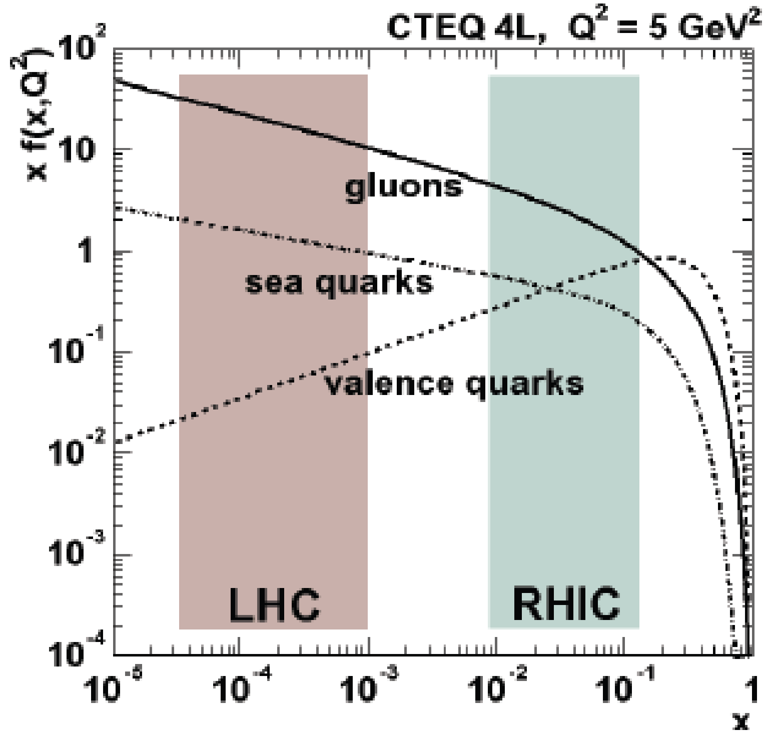
Parton Distribution Functions x_a, x_b → fraction of the momentum carried by the a,b partons in the hadron

Partonic σ computed in pQCD

Fragmentation of quark q into the hadron H

Parton Distribution Functions

- PDFs: probability of finding a parton with a fraction x of the proton momentum, in a hard scattering with momentum transfer (virtuality) Q^2
  - ⇨ PDFs are obtained by means of a global fit to experimental data, for one or more physical processes which can be calculated using pQCD, such as deep inelastic scattering and the Drell-Yan process
  - ⇨ PDFs depends on the Q^2 value
  - ⇨ The Q^2 evolution can be calculated in pQCD, using the DGLAP equations



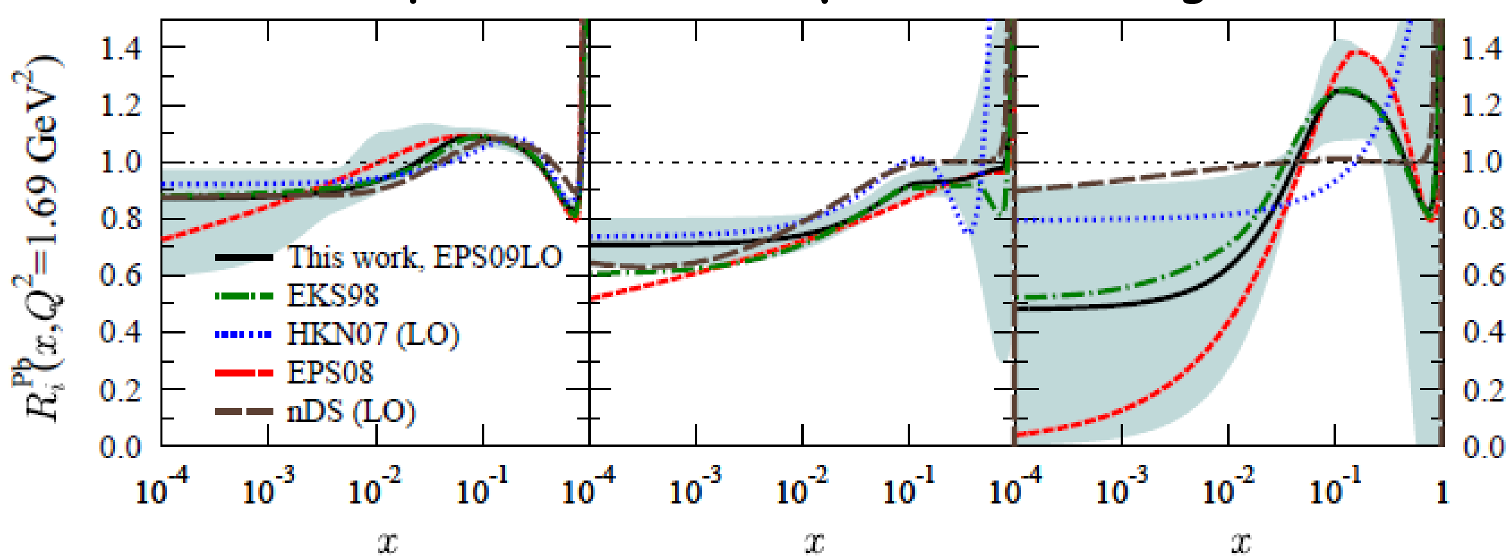
PDF in nuclei

- Parton distributions in nuclei are modified with respect to those in a free nucleon
  - ⇨ First observed by EMC experiment in 1983
- Nuclear modification depends on:
  - ⇨ Fraction x of the hadron momentum carried by the parton
  - ⇨ Momentum scale Q^2
  - ⇨ Mass number of the nucleus

$$R_i^A(x,Q^2) = \frac{f_i^A(x,Q^2)}{f_i^p(x,Q^2)}$$

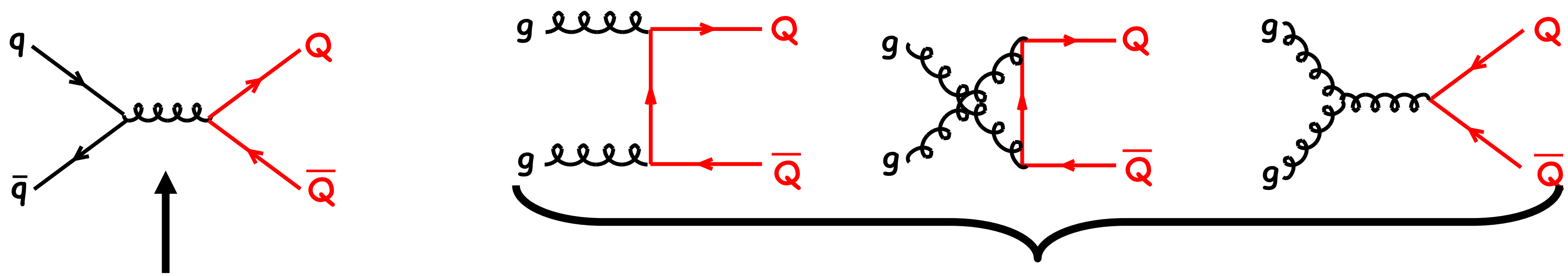
- Different parameterizations are available to convert free nucleon distributions into the nuclear one

valence quarks **sea quarks** **gluons**



Partonic cross section

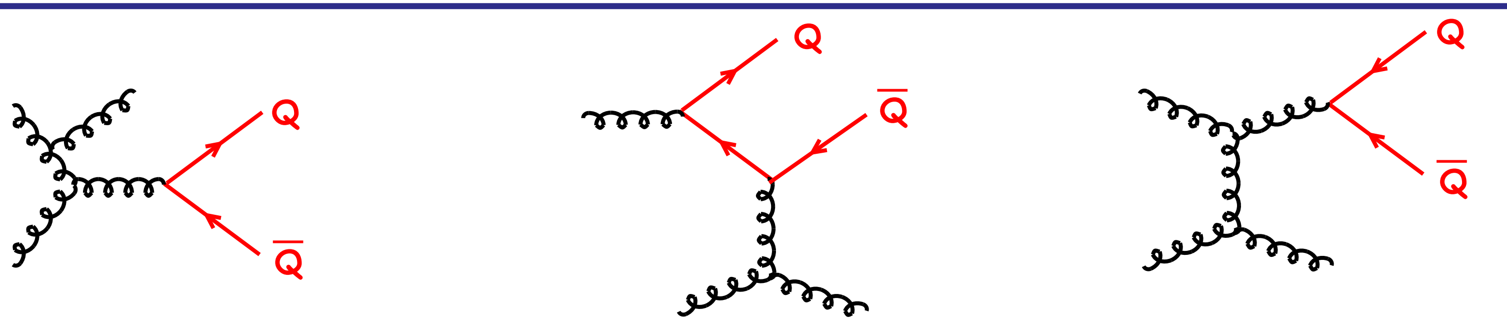
- Perturbative expansion in powers of α_S
  - ⇨ State of the art: FONLL = Fixed Order calculation (at NLO) + resummation of next to leading logs
- Leading order diagrams ($\propto \alpha_S^2$)



q-qbar annihilation

gluon fusion

- Next to leading order additional diagrams ($\propto \alpha_S^3$)



higher order terms in pair creation

flavour excitation

gluon splitting

Fragmentation function

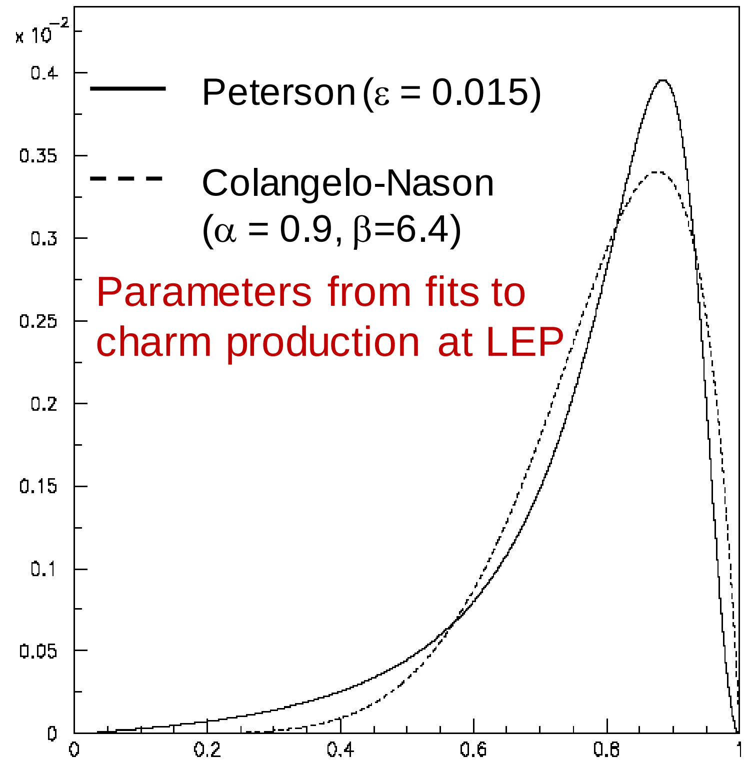
- Fragmentation fucntion $D_{q\to H}(z,Q^2)$ gives the probability that a quark q produces an hadron H carrying a fraction z of the quark momentum ($p_H = zp_q$)
  - ⇨ Usually extracted from e^+e^- data and used in other collision systems
- In case of heavy quark fragmentation, the D/B meson takes a large fraction z of the quark momentum
  - ⇨ Fragmentation function shows a peak for z close to 1 (-> hard fragmentation function)
  - ⇨ Example of parameterizations:

Peterson

$$D_{D/c}(z) \propto \frac{1}{z[1-1/z-\varepsilon/(1-z)]^2}$$

Colangelo-Nason

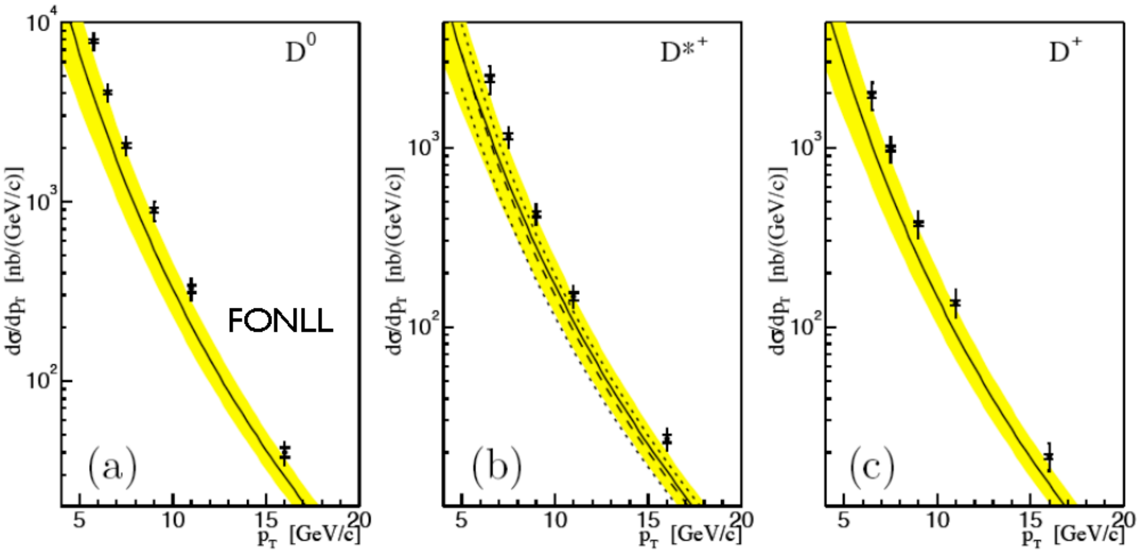
$$D_{D/c}(z) \propto (1-z)^{\alpha} z^{\beta}$$



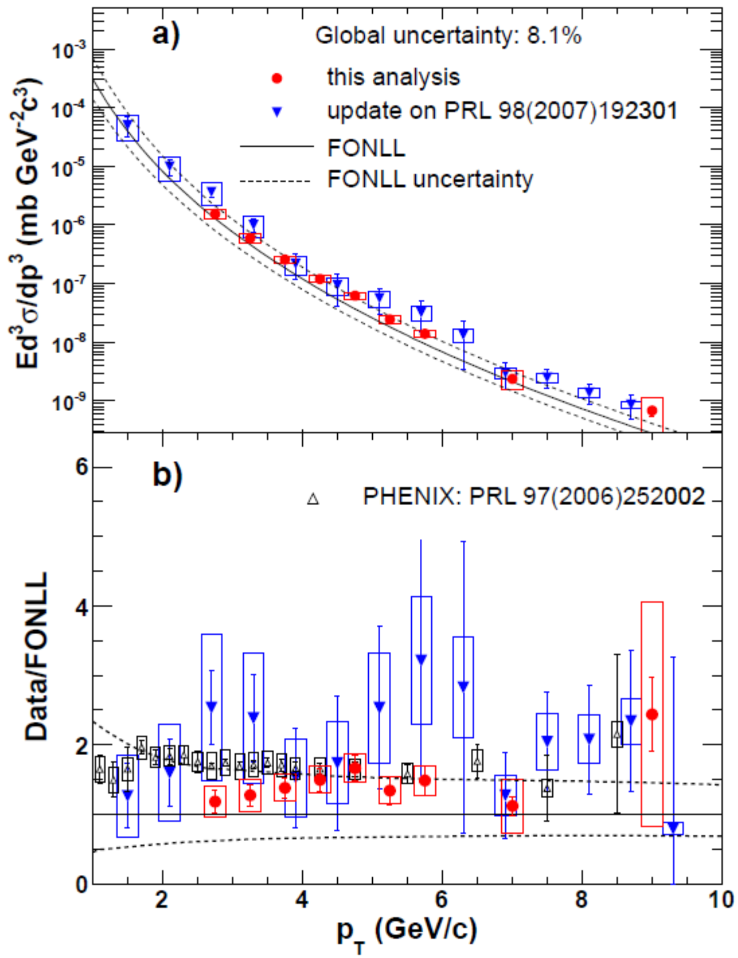
Charm production in p-p

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

CDF, $\sqrt{s}$=1.96 TeV, PRL 91:241804 (2003)



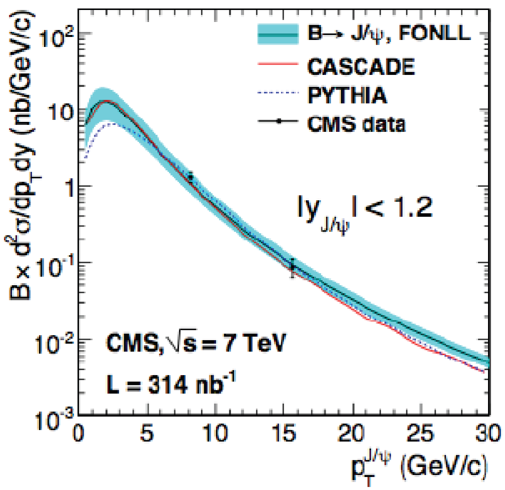
RHIC, $\sqrt{s}$=200 GeV
arXiv:1102.2611

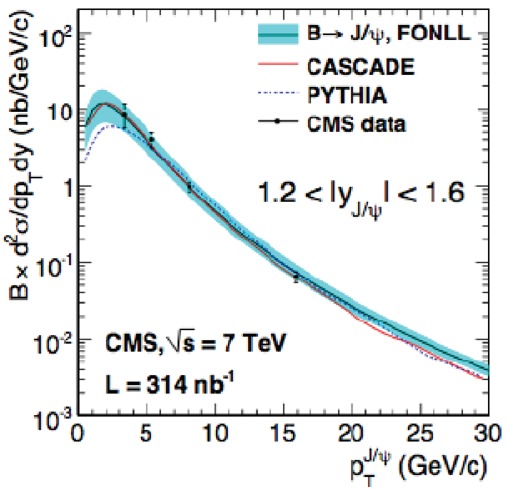


Beauty production in pp

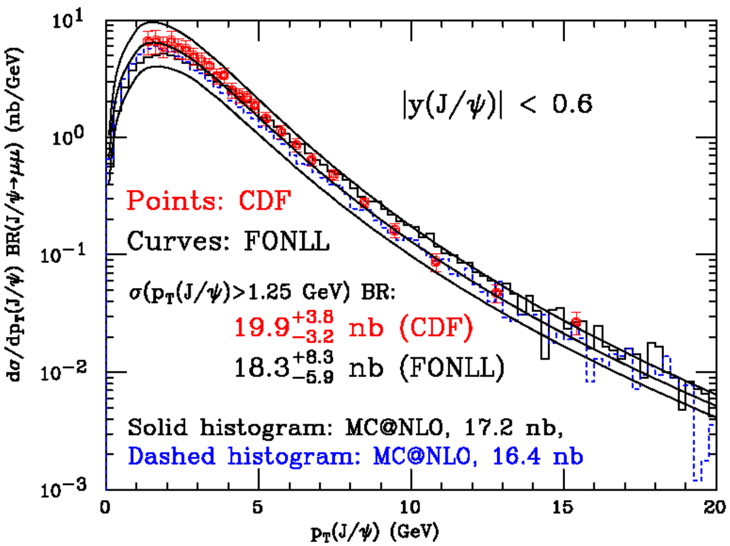
- Beauty differential cross section at Tevatron and LHC well reproduced by pQCD calculations

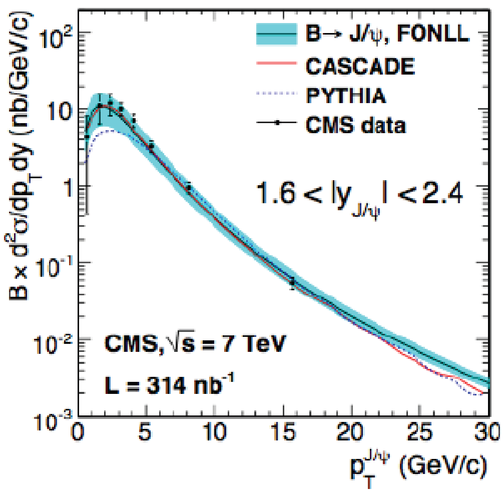
CMS, arXiv:1011.4193





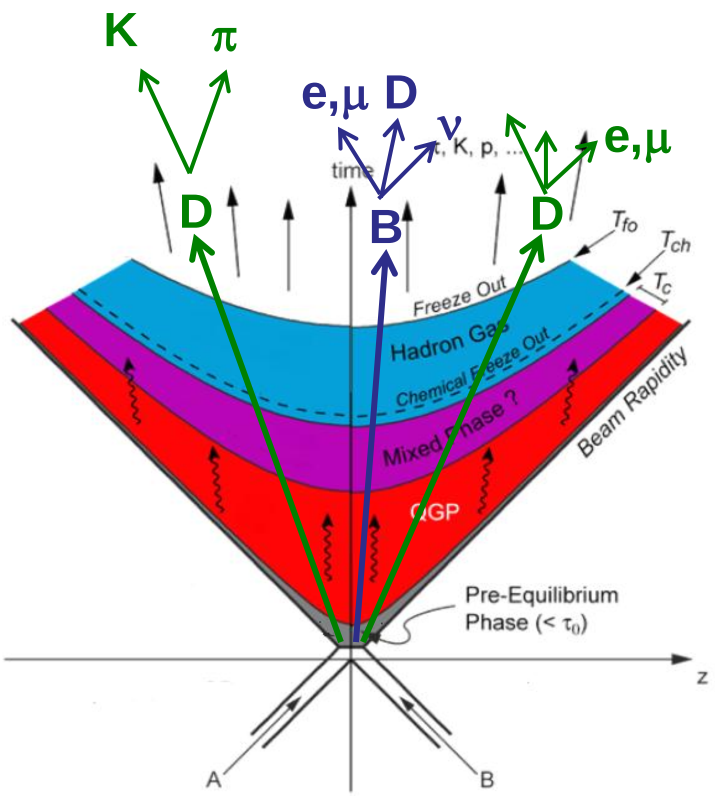
CDF: b->B->J/ψ





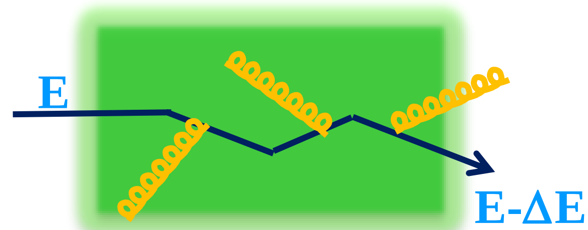
Heavy Quarks as QGP probes

- Heavy (c, b) quarks produced in high-virtuality scatterings occurring the first instants of the collision
  - ⇨ Experience the full evolution of the medium
  - ⇨ Production can be computed with pQCD -> calibrated probe
- Heavy quarks interact with the medium
  - ⇨ Energy loss, via radiative and collisional mechanisms
    - ✓ ***Heavy quarks provide a benchmark for energy loss models***
  - ⇨ Do charm (and beauty) quarks thermalize with the medium and participate to the collective motion (flow)?

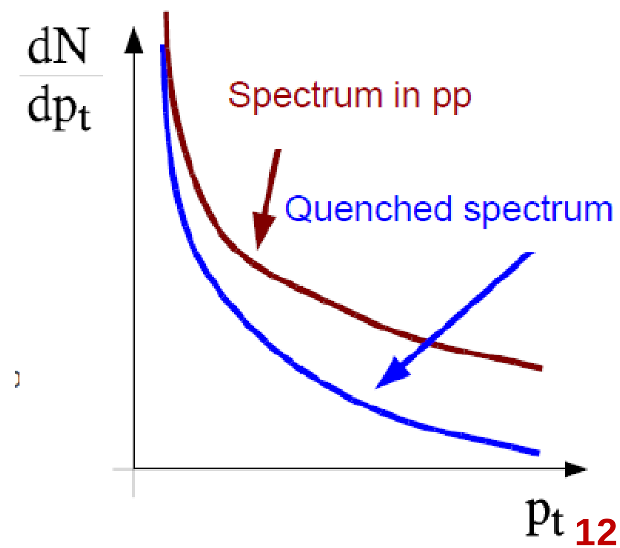


Energy loss in colored medium

- Partons are expected to lose energy while traversing a deconfined medium via gluon radiation and elastic collisions with partonic constituents
  - ⇨ see, e.g. arXiv:0902.2011[nucl-ex], arXiv:1002.2206v3[hep-ph]
- Basic experimental observable: **nuclear modification factor** R_{AA}



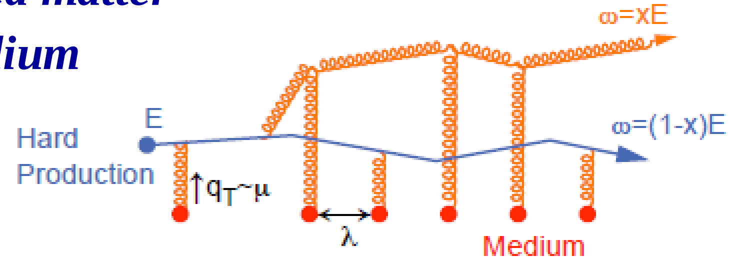
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$



⇨ The reduction in the parton energy translates to a reduction in the average momentum of the produced hadron, i.e. to a reduction of the yield at high p_T wrt pp collisions -> R_{AA}<1

Radiative energy loss

- Gluon radiation expected to be the main mechanism of energy loss
  - ⇨ The amount of energy lost is sensitive to:
    - ✓ ***the medium properties (density)***
    - ✓ ***the path-length (L) of the parton in deconned matter***
    - ✓ ***the properties of the parton probing the medium***
  - ⇨ Several models are available
  - ⇨ e.g. in BDMPS approach:



$$\langle \Delta E \rangle \propto \alpha_s C_r \hat{q} L^2$$

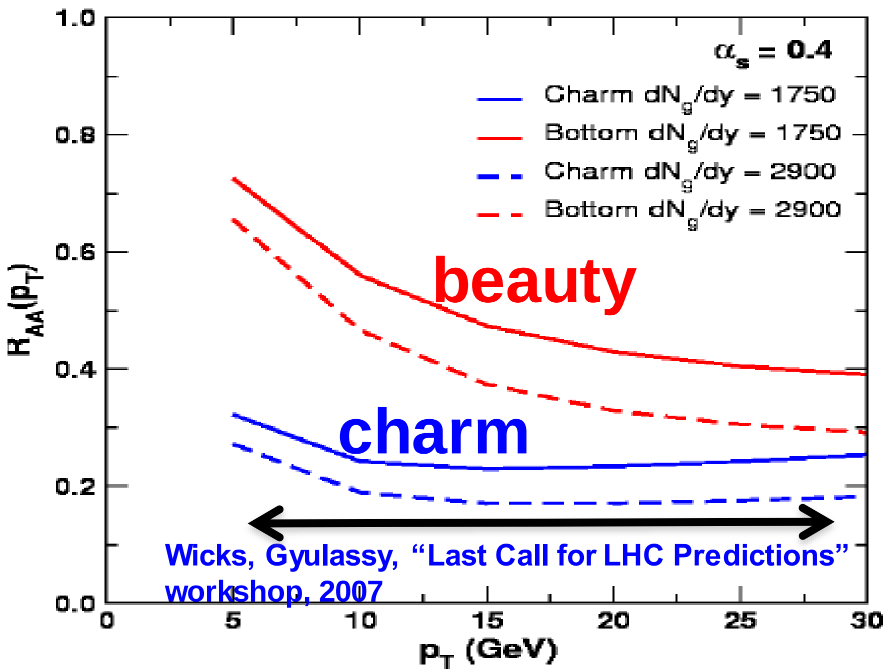
Casimir factor
→ 3 for gg interactions
→ 4/3 for qg interactions

En. loss is proportional to L^2, taking into account the probability to emit a breemstrahlung gluon and the fact that radiated colored gluons can interact themselves with the medium

$\hat{q}$ = transport coefficient, related to the medium characteristics and to the gluon density dN_g/dy

Heavy quark energy loss

- Radiative energy loss of charm and beauty quarks expected to be smaller (-> higher R_{AA}) wrt light hadrons due to:
  - ⇨ Casimir factor (**color charge** dependence)
    - ✓ *Cr = 3 for gg interactions, 4/3 for qg interactions*
    - ✓ *heavy hadrons are mainly produced from heavy quarks jet (while light hadrons are produced from gluon jets)*
  - ⇨ Dead cone effect (**mass dependence**)
    - ✓ *Gluon radiation is suppressed for angles $\vartheta < M_Q/E_Q$*



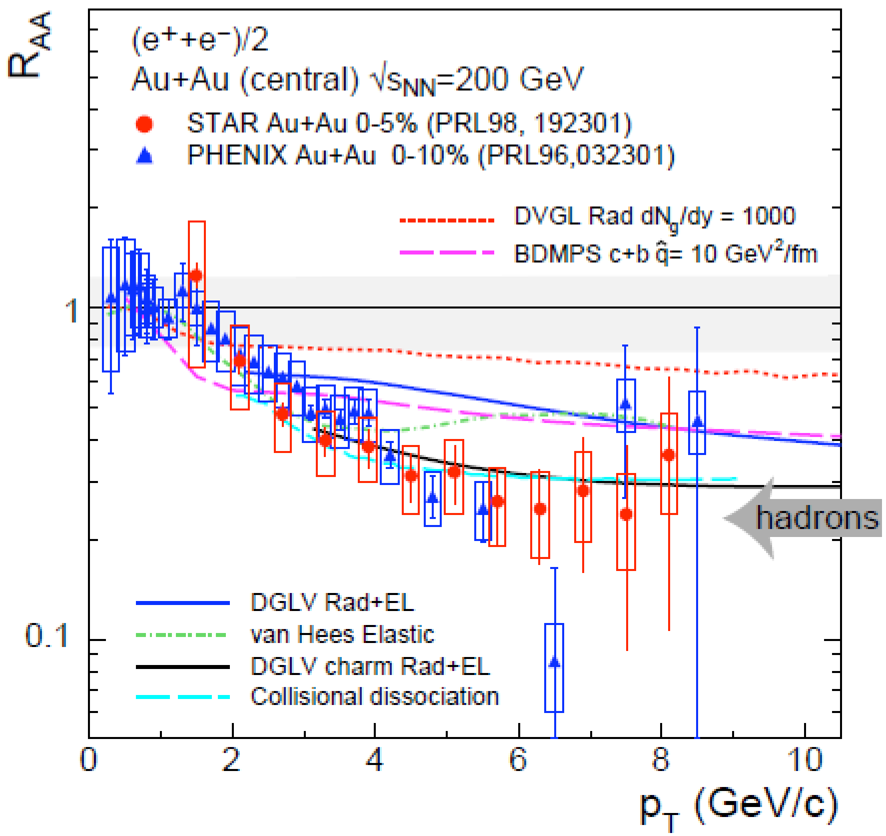
$$\Delta E_{quark} < \Delta E_{gluon}$$

$$\Delta E_{massive\ quark} < \Delta E_{light\ quark}$$

$$\Downarrow$$

$$R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$$

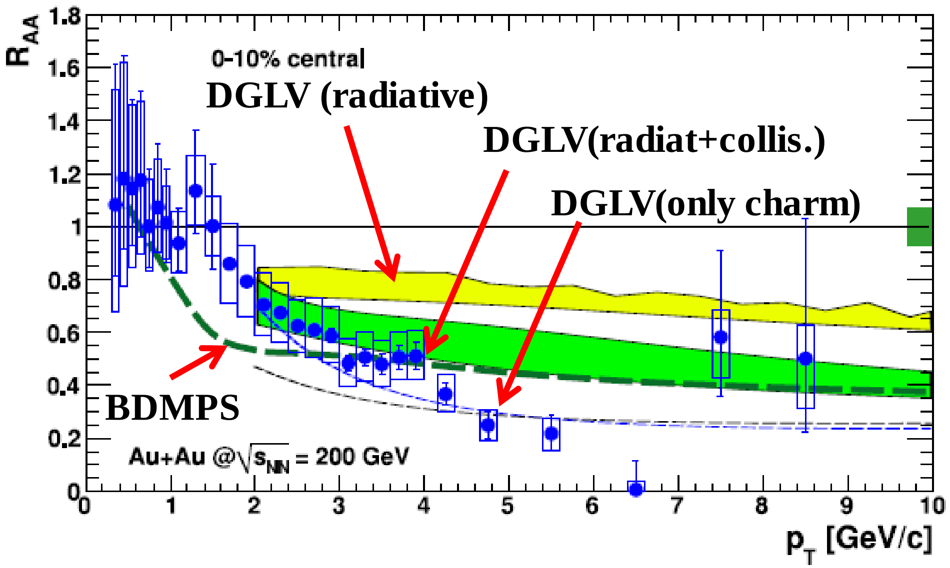
RHIC results: R_{AA}

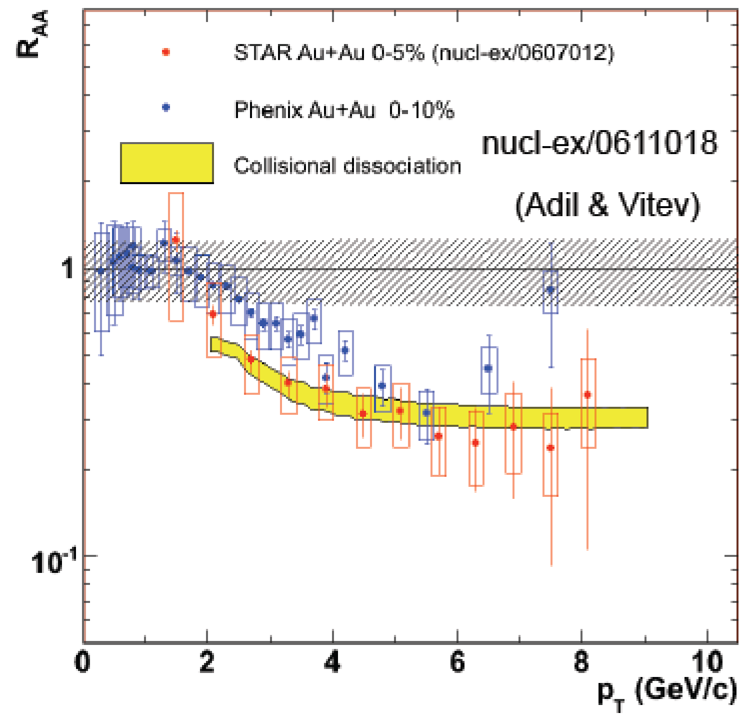


- Measurement based on non-photonic electrons
  - Start from identified electron spectra
    - ***STAR: dE/dx in TPC + TOF at low pt, EMC at high pt***
    - ***PHENIX: combined RICH and E/p (with E from EM cal)***
  - Reject non-heavy-flavour electrons, mainly "photonic"
    - ***Gamma conversions***
    - ***Dalitz decay of π^0 and η***
  - STAR also did exlusive reconstruction of D0 from hadronic decays

- Non-photonic electrons show suppression similar to that of light hadrons
  - A challenge for theory: models that work for light hadrons overestimate RAA of non-photonic electrons

R_{AA} at RHIC: interpretations





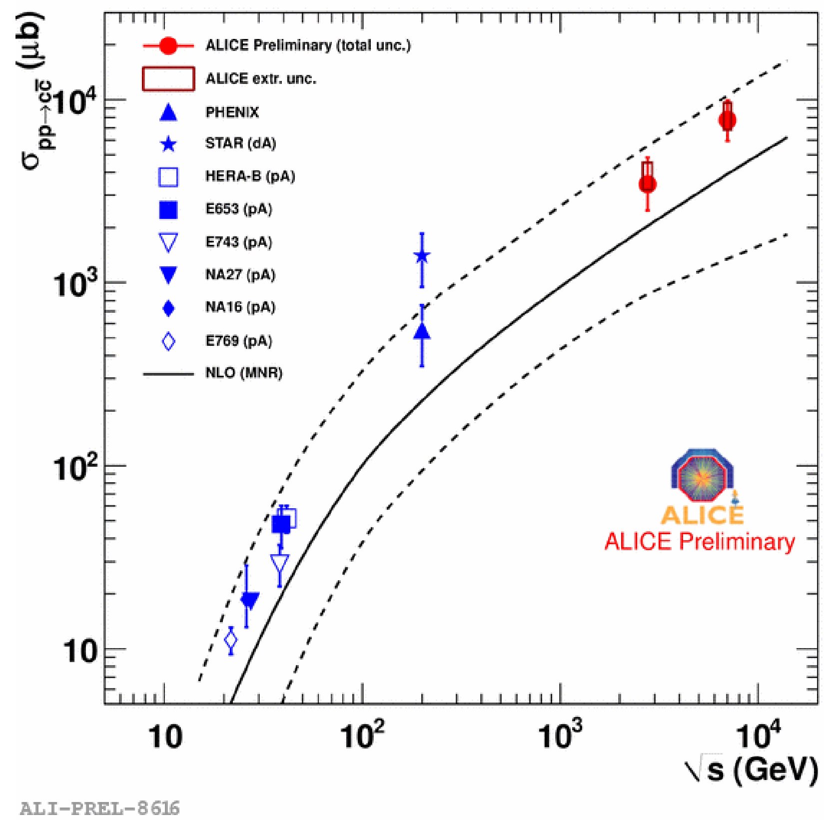
- Collisional energy loss to be taken into account?
- Energy loss models sensitive to the B/D admixture
  - ⇨ Important to establish b and c contributions, since their energy loss should be different
- Collisional dissociation of D/B mesons formed in the medium early after hard scattering?

What can we learn at the LHC

- Higher c and b cross sections:
  - ⇨ More abundant heavy flavour production
  - ⇨ Better precision (reduced errors)

$$\sigma_{LHC}^{c\bar{c}} \approx 10 \cdot \sigma_{RHIC}^{c\bar{c}}$$
$$\sigma_{LHC}^{b\bar{b}} \approx 100 \cdot {}_{RHIC}^{b\bar{b}}$$

- High precision vertex detectors
  - ⇨ Background removal
  - ⇨ Separate c and b



Heavy flavour measurements in ALICE

Heavy flavour hadrons

- Lower mass heavy flavour hadrons decay weakly:
  - Lifetimes ≈ 0.5-2 ps
  - $c\tau \approx$ 100-500 μm
  - Decay vertices of open heavy flavour hadrons displaced by hundreds of microns from the interaction (primary) vertex

Hadron	Mass (MeV)	cτ (μm)
$D^+(c\bar{d})$	1869	312
$D^0(c\bar{u})$	1865	123
$D_s^+(c\bar{s})$	1968	147
$\Lambda_c^+(udc)$	2285	60
$\Xi_c^+(usc)$	2466	132
$\Xi_c^0(dsc)$	2472	34
$\Omega_c^0(ssc)$	2698	21

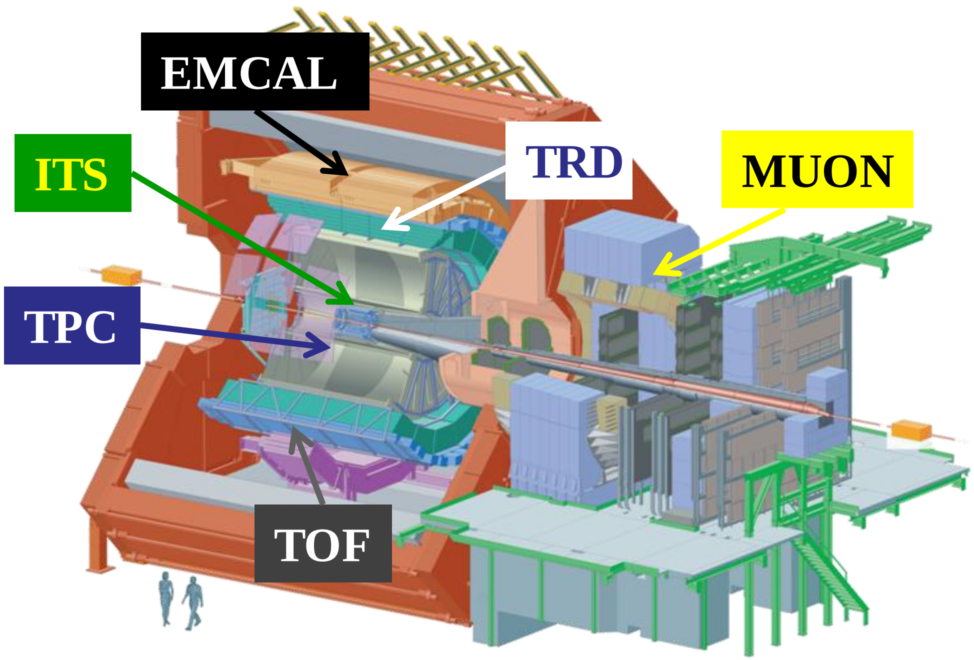
Hadron	Mass (MeV)	cτ (μm)
$B^+(u\bar{b})$	5279	501
$B^0(d\bar{b})$	5279	460
$B_s^0(s\bar{b})$	5370	438
$B_c^0(c\bar{b})$	≈ 6400	$100-200$
$\Lambda_b^0(udb)$	5624	368

Decay modes

- Large semi-leptonic branching ratio, tipically 10%
  - ~10% of heavy flavour hadrons gives $e^{\pm}$ in final state (and ~10% $\mu^{\pm}$)
- Charm hadrons have large branching ratios to kaons
  - e.g. $D^0 \to K^- + X$ BR~55%
  - Golden channels for exclusive reconstruction

Meson	Final state	# charged bodies	Branching Ratio
D^0	$\to K^-\pi^+$	2	3.87%
	$\to K^-\pi^+\pi^+\pi^-$	4	8.07%
D^+	$\to K^-\pi^+\pi^+$ (non-resonant or via $K^*(892)^0\pi^+$)	3	9.13%
D^{*+}	$\to D^0\pi^+ \to K^-\pi^+\pi^+$	3	67.7% * 3.87%
D_s^+	$\to K^+K^-\pi^+$ (via $\phi\pi^+$ or $K^+K^*(892)^0$)	3	5.49%
Λ_c^+	$\to pK^-\pi^+$ (non-resonant or via Δ^{++}, $\Lambda(1520)$ $K^*(892)^0$)	3	5.0%

Heavy flavors with ALICE

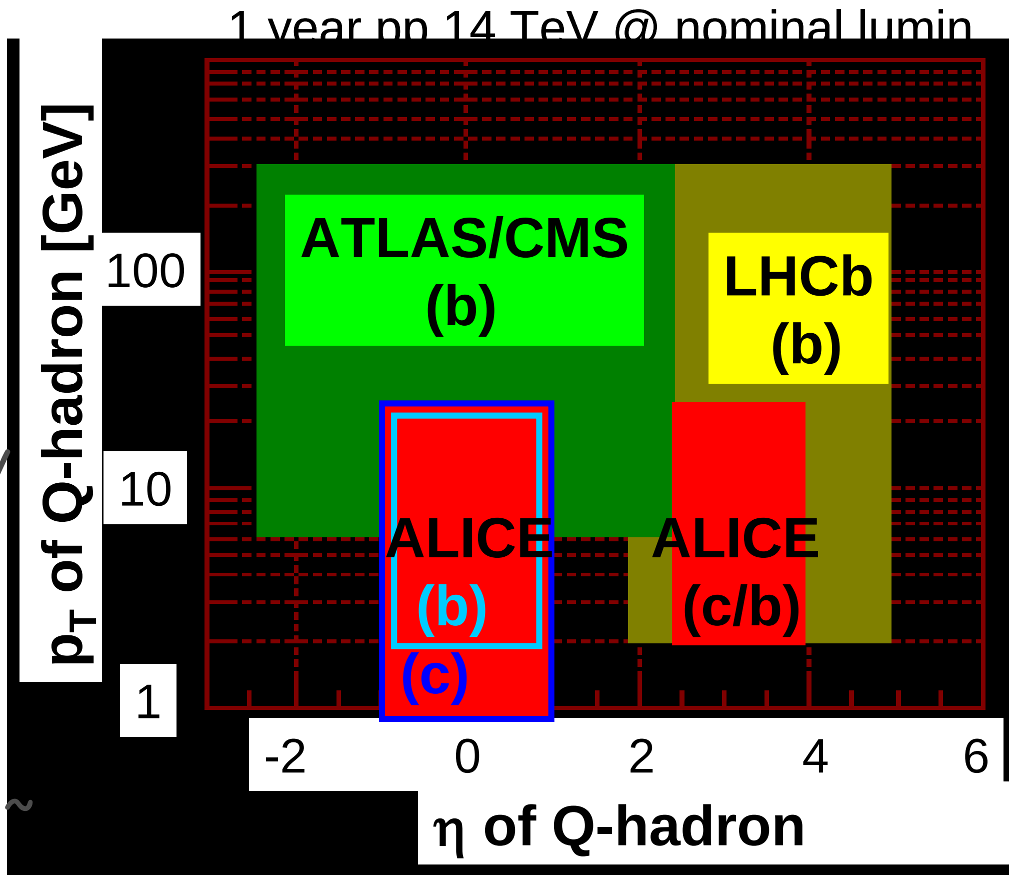


ITS: vertexing + tracking
TPC: tracking + PID (π, K, e)
TOF: PID (π, K, p)
TRD: PID (π, e)
EMCAL: PID (e)
MUON: μ tracking + PID

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

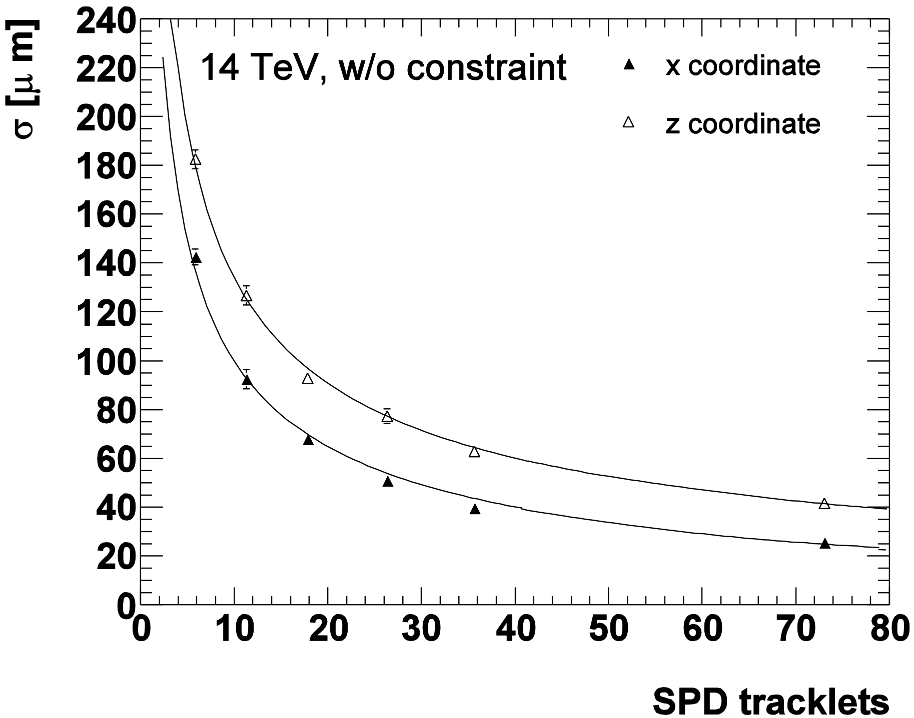
Heavy-flavours in ALICE

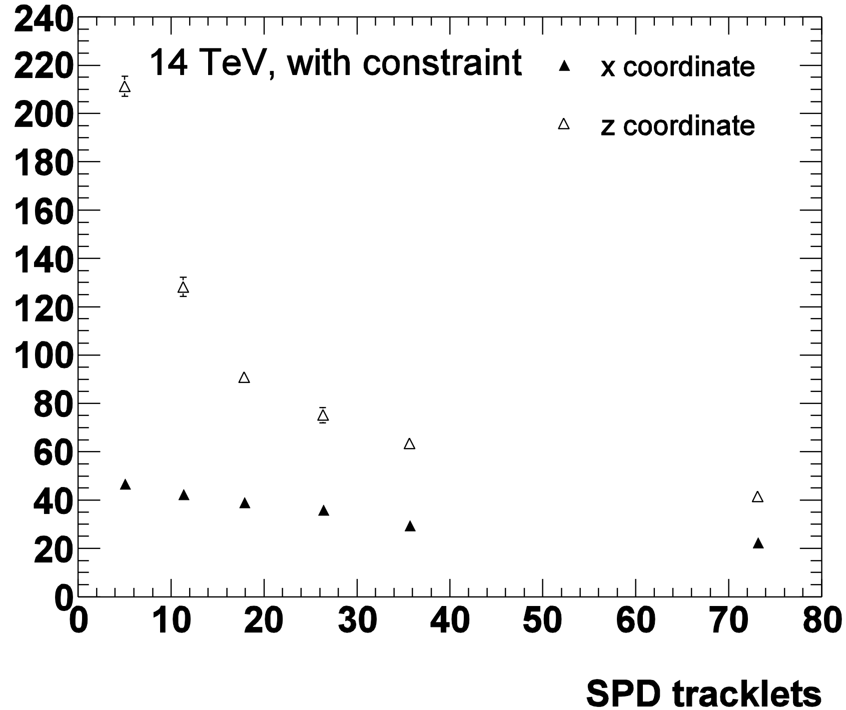
- ALICE channels:
  - ⇨ electronic ($|\eta|$<0.9)
  - ⇨ muonic ($-4<\eta<-2.5$)
  - ⇨ hadronic ($|\eta|$<0.9)
- ALICE specific features:
  - ⇨ low-p_T region
  - ⇨ central and forward rapidity regions
  - ⇨ Both c and b
  - ⇨ Precise vertexing in the central region to identify D ($c\tau$ ~ 100-300 μm)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



Tools: primary vertex reconstruction

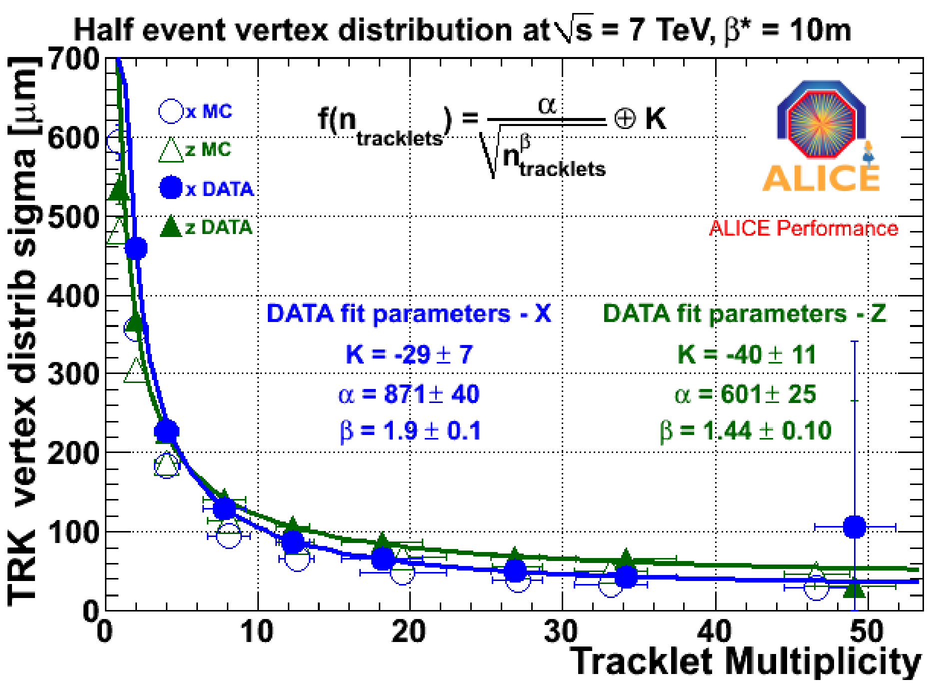
- 3D reconstruction from tracks of primary (interaction) vertex position with full error-matrix treatment
  - ⇨Resolution on vertex position depends on multiplicity.
  - ⇨Important for
    - ✓ *Impact parameter resolution (in p-p low multiplicity events)*
    - ✓ *Separation of secondary vertices from the primary*
    - ✓ *Determination of the pointing angle*

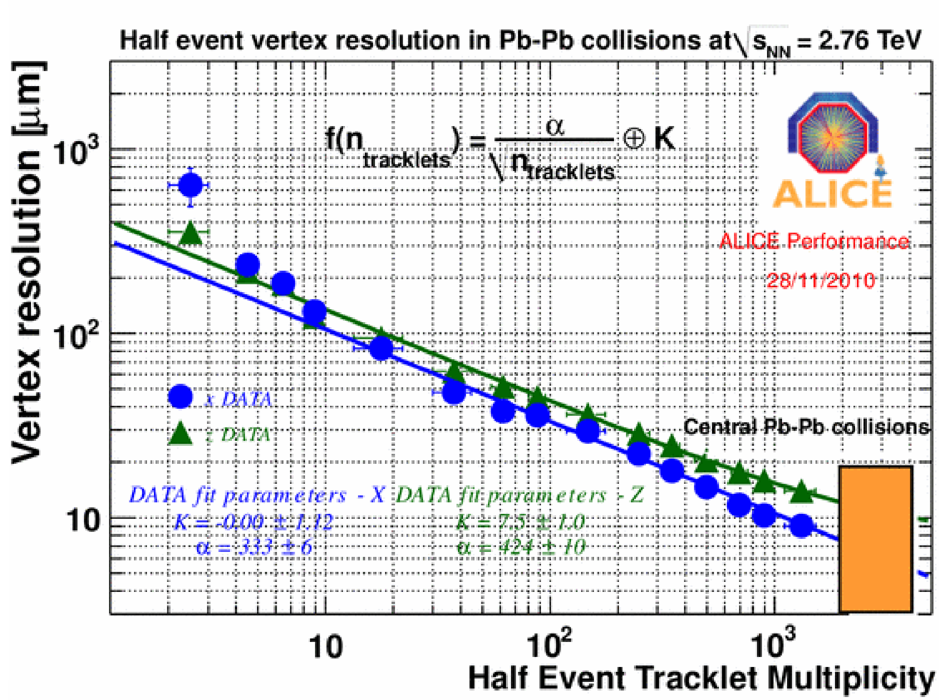




Tools: primary vertex reconstruction

- Estimate resolution on data using half events
  - ⇨ Split tracks in 2 sub-samples and build residuals between reconstructed coordinates from the 2 half-events





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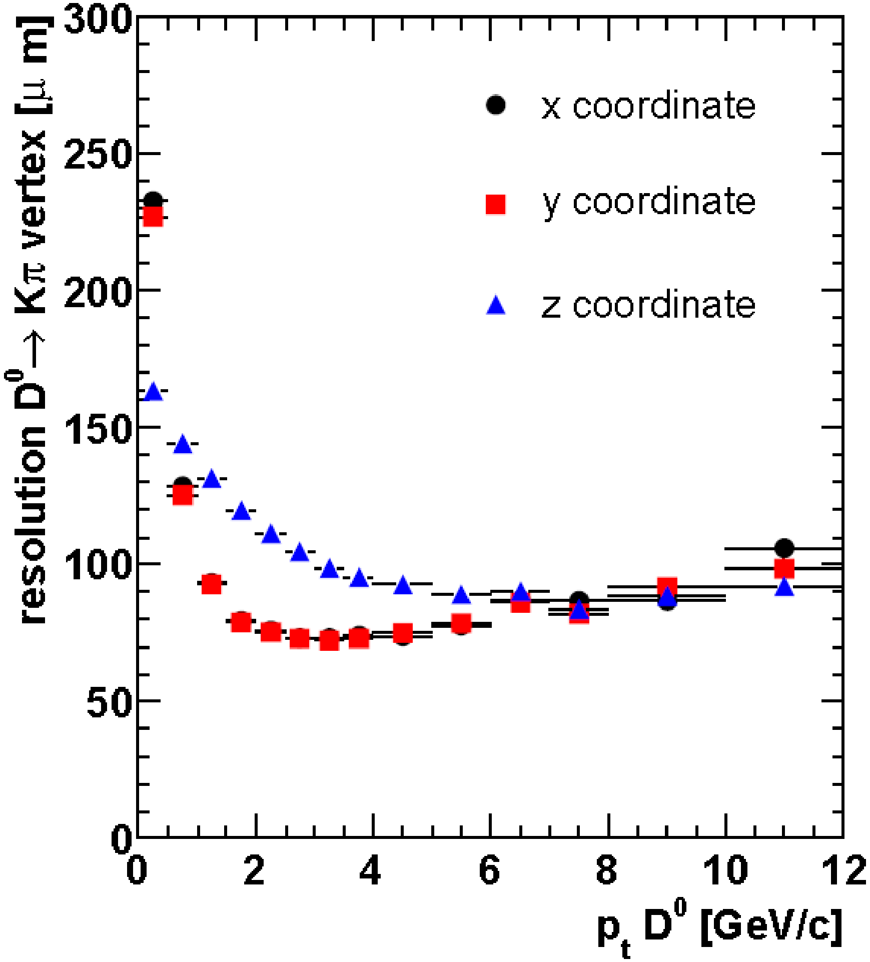
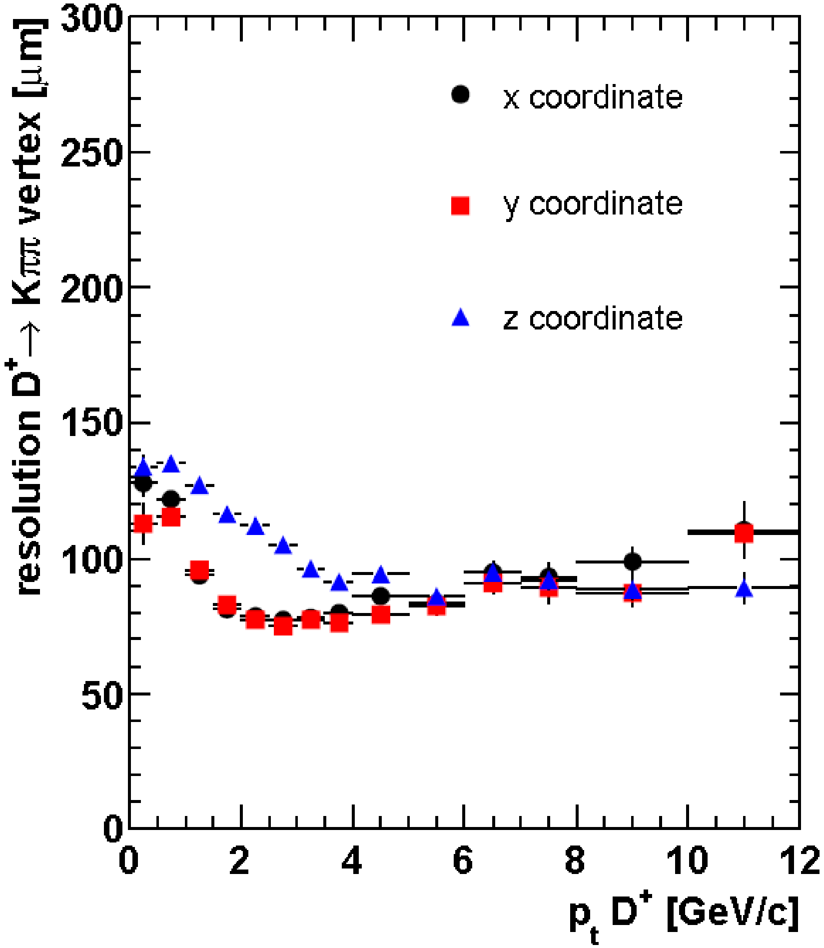
Tools: secondary vertices

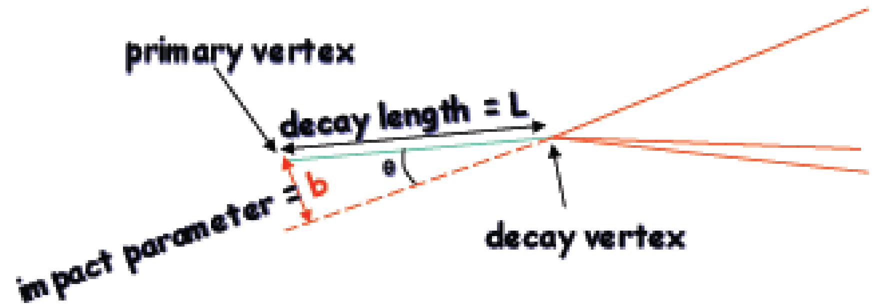
- Precise determination of secondary vertices is the crucial ingredient for open charm analyses based on the reconstruction of displaced (by ~100 μm) decay topologies

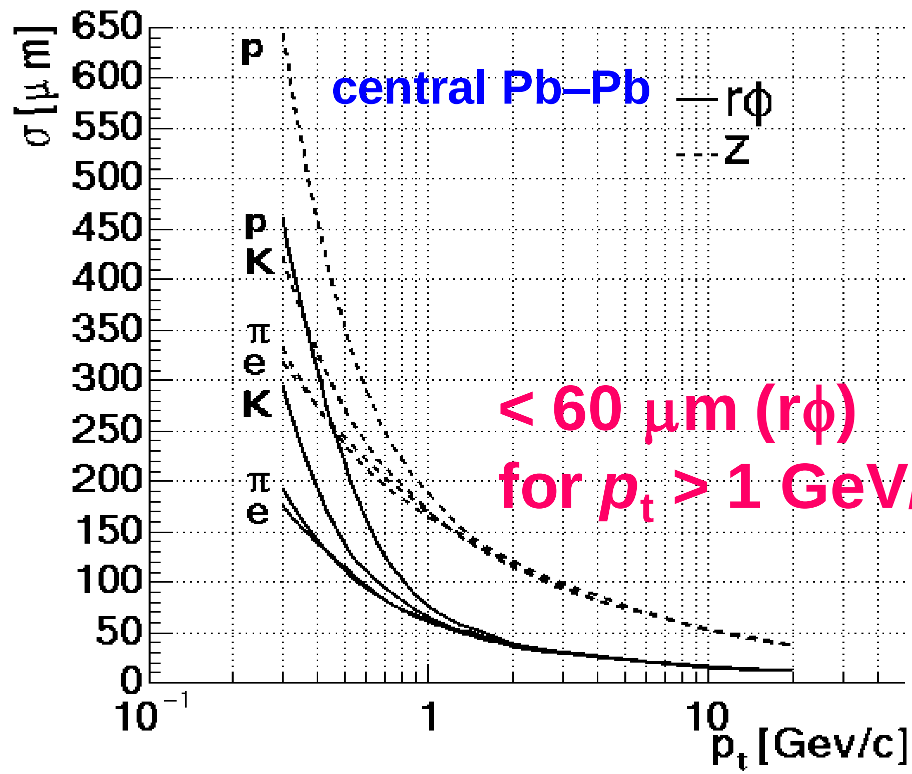




Tools: impact parameter

- Track impact parameter = distance of closest approach of a track to the interaction (primary vertex)
  - ⇨ High resolution provided by the Inner Tracking system (ITS) and in particular by the SPD points (high precision and close to the beam axis
  - ⇨ Resolution determined by:
    - ✓ *Resolution on primary vertex (worse in pp)*
    - ✓ *Resolution on particle trajectory, which has two components: detector spatial resolution and p_T (β) dependent multiple scattering.*



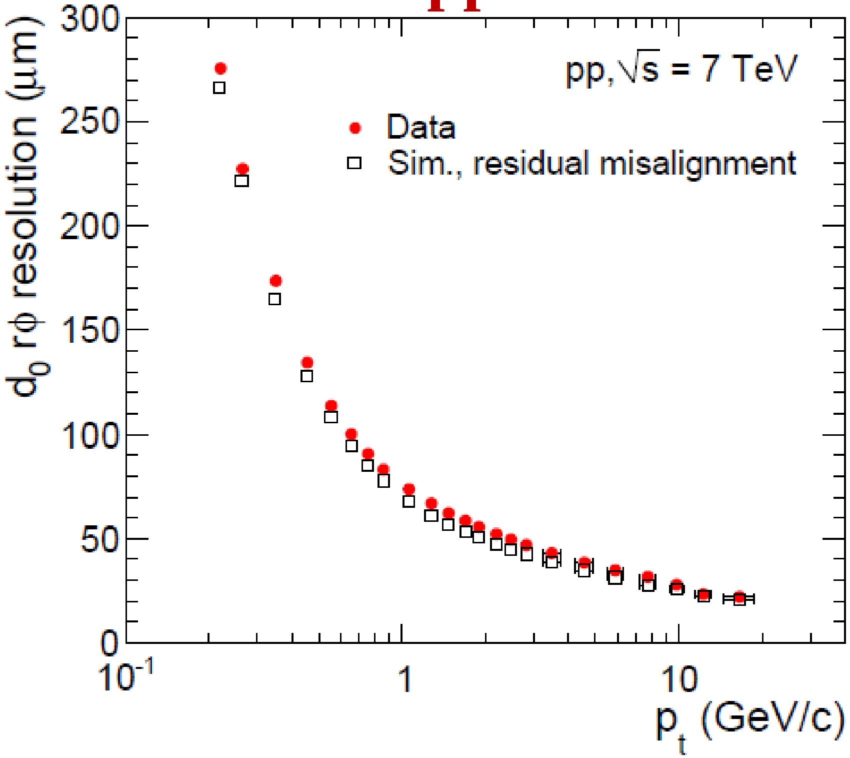


< 60 μm (rϕ) for p_t > 1 GeV/c

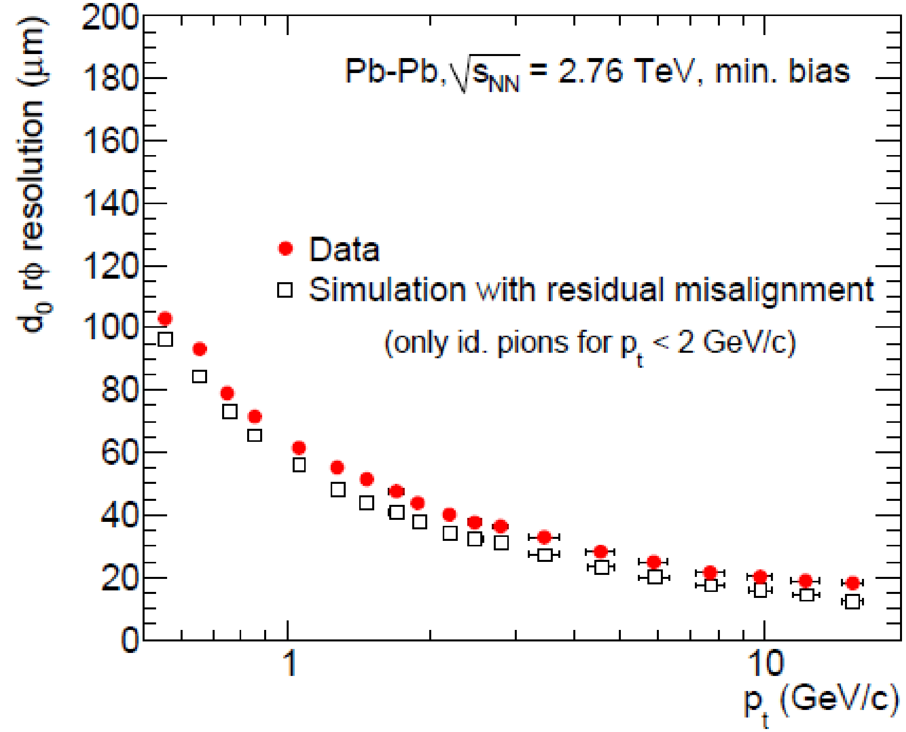
Tools: impact parameter

- Track impact parameter ~75(65) μm at 1 GeV/c in pp(PbPb) , well described in MC
  - ⇨ Difference between pp and PbPb due to resolution on the primary vertex (improving with increasing multiplcity)

pp



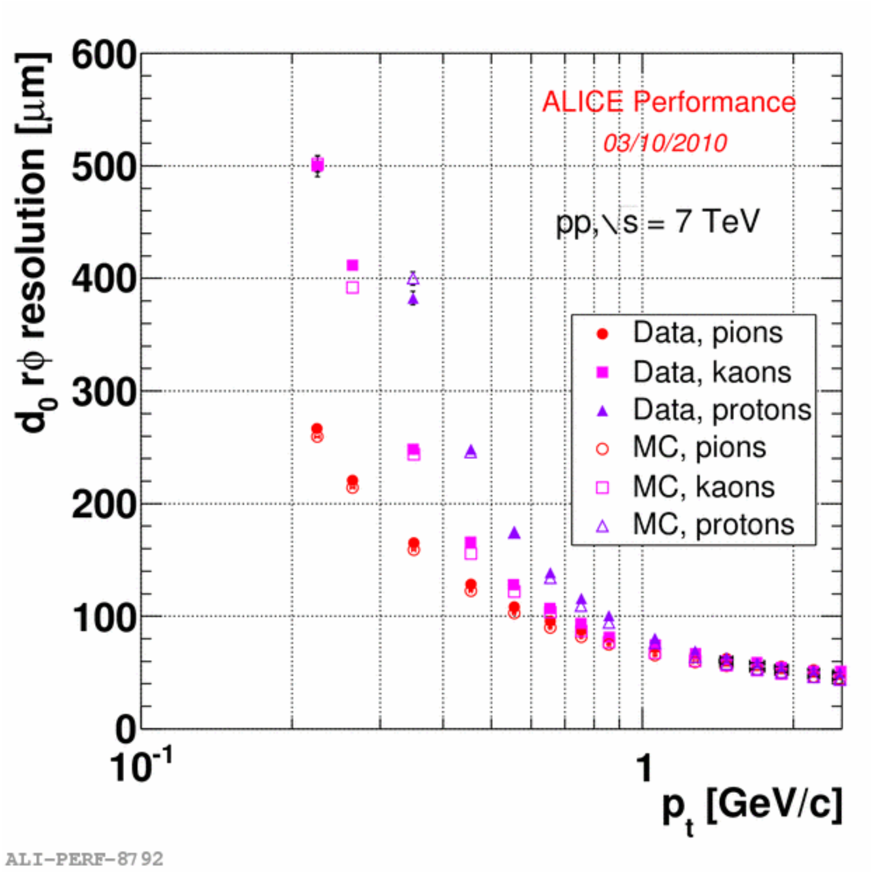
PbPb



Tools: impact parameter

- Also the mass dependence is well understood

pp



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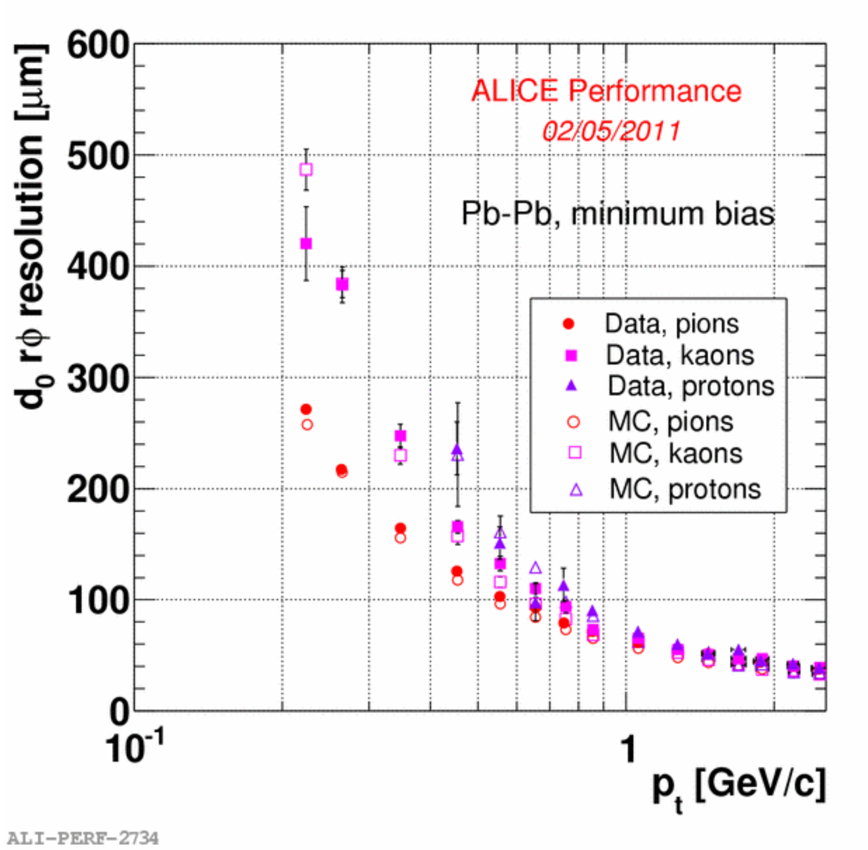
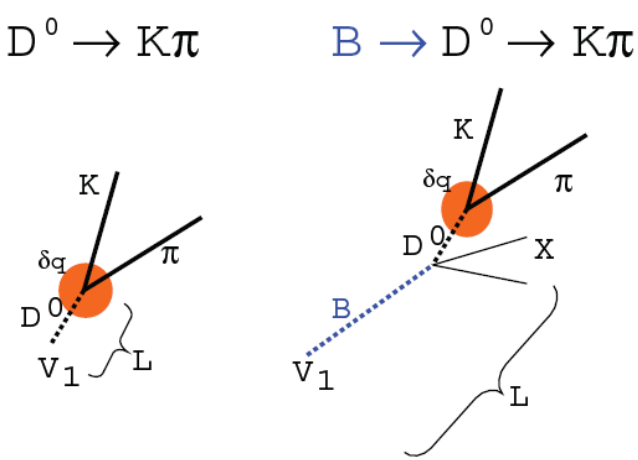
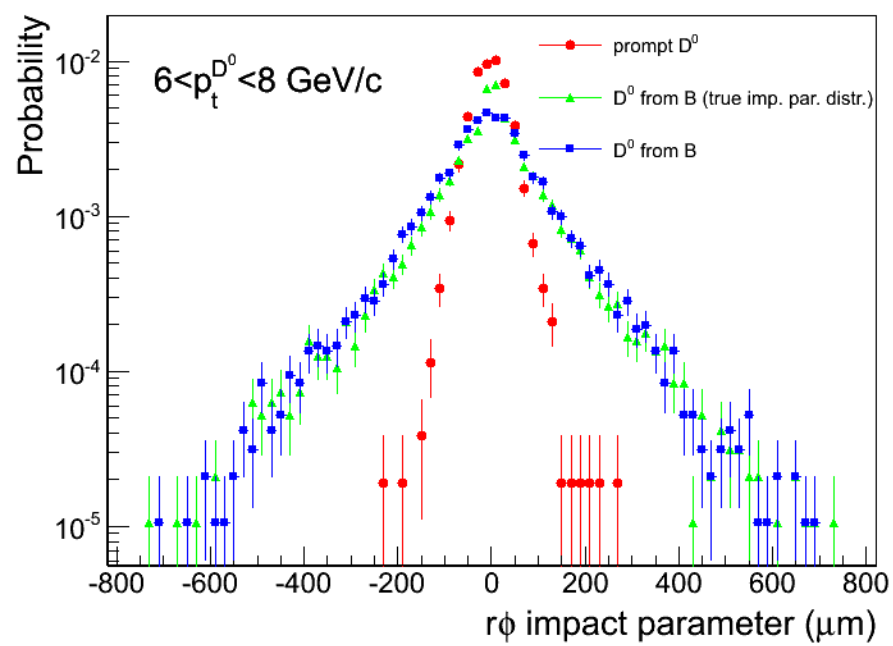


Charm vs. beauty

- A significant fraction (~10-20%) of the measured yield of heavy flavour leptons (electrons or muons) and D mesons comes from B decays (feed-down)
- Due to large B lifetime, leptons, D mesons and J/ψ's from B decays are more displaced from the primary vertex
  - ⇨ Wider impact parameter distribution
- Can use this feature to separate charm and beauty:
  - ⇨ By cutting on impact parameter to enhance beauty
  - ⇨ By fitting the impact parameter distribution to extract prompt (charm) and displaced (beauty) contributions





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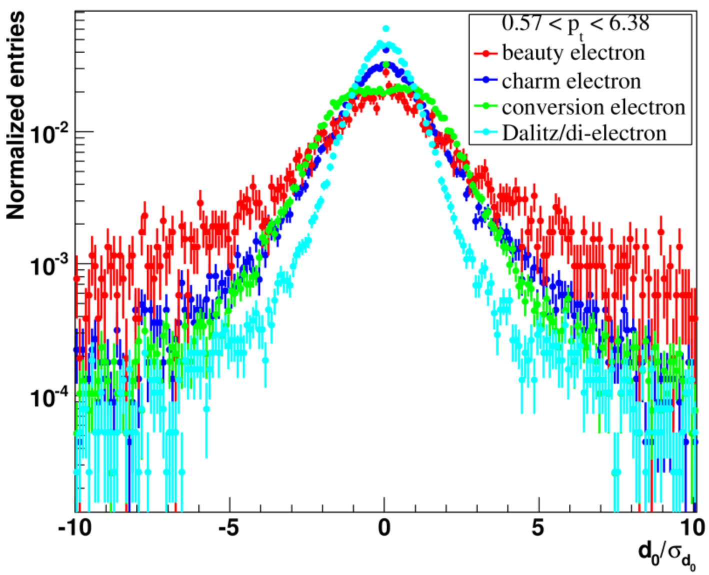
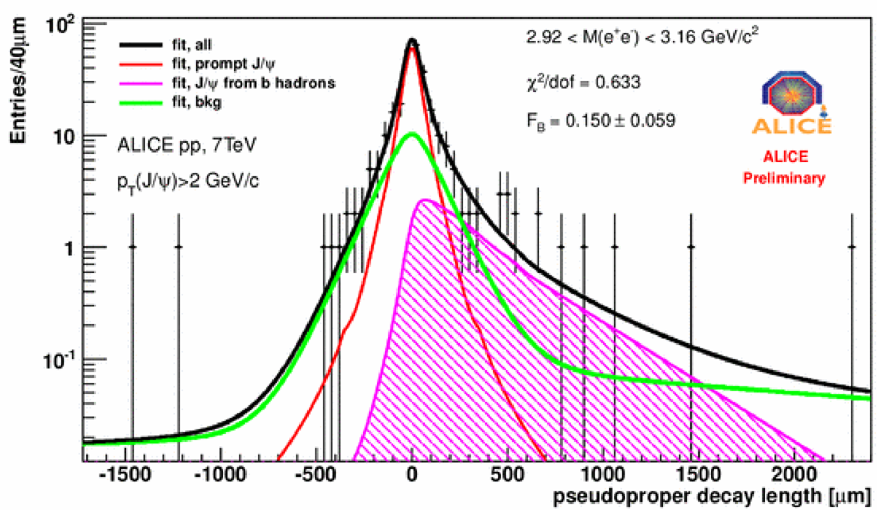
  - ⇨ By fitting the impact parameter distribution to extract prompt (charm) and displaced (beauty) contributions

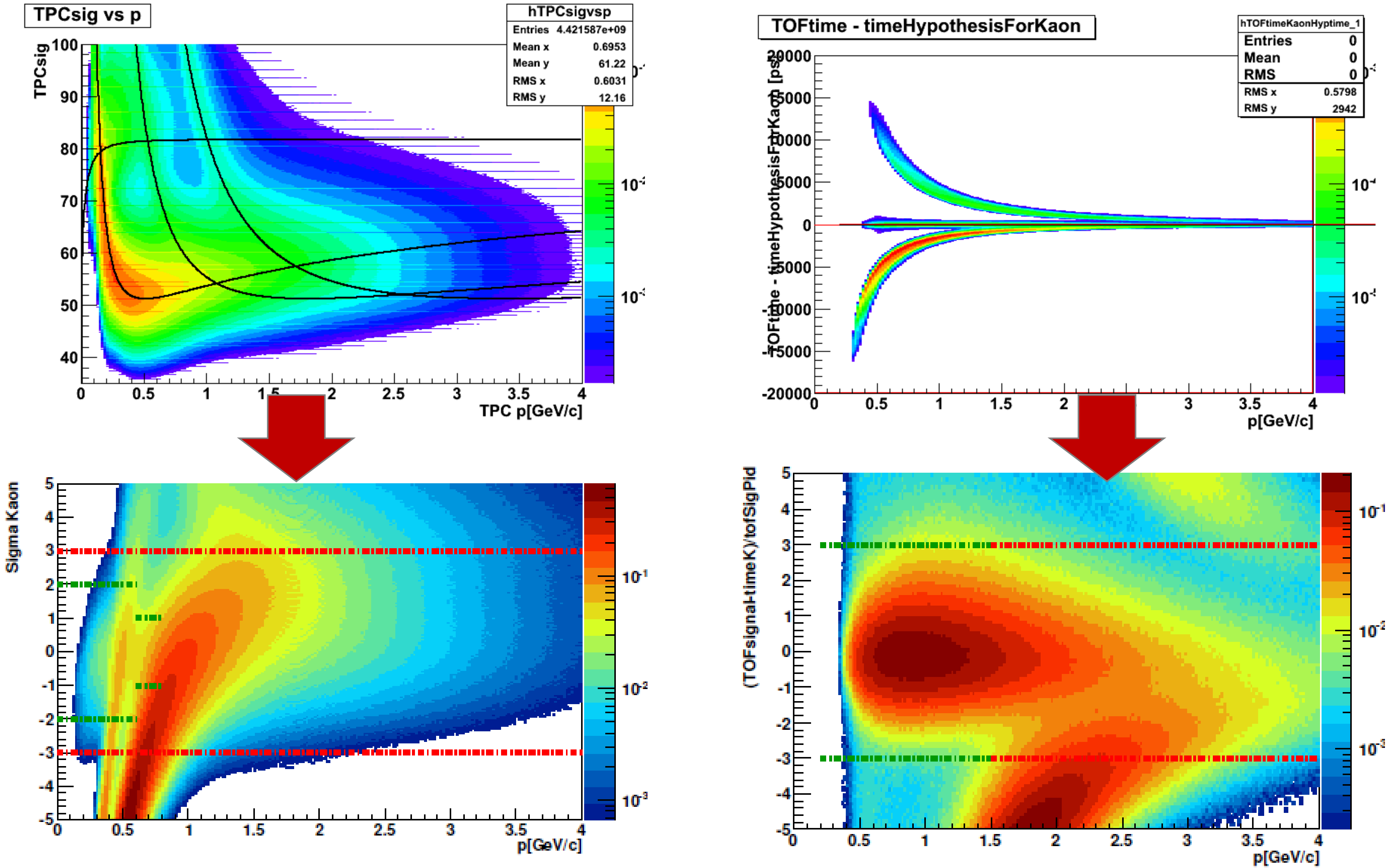




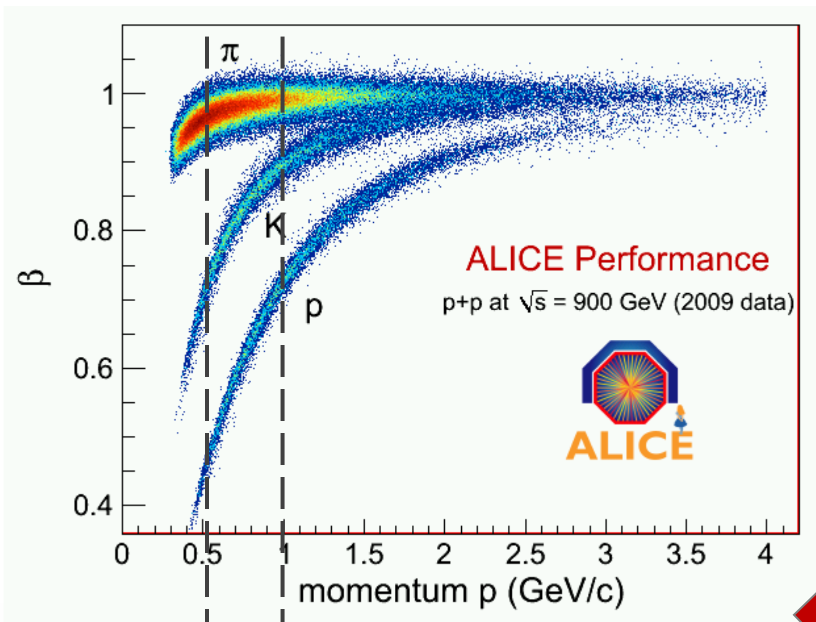
ALI-PREL-9929

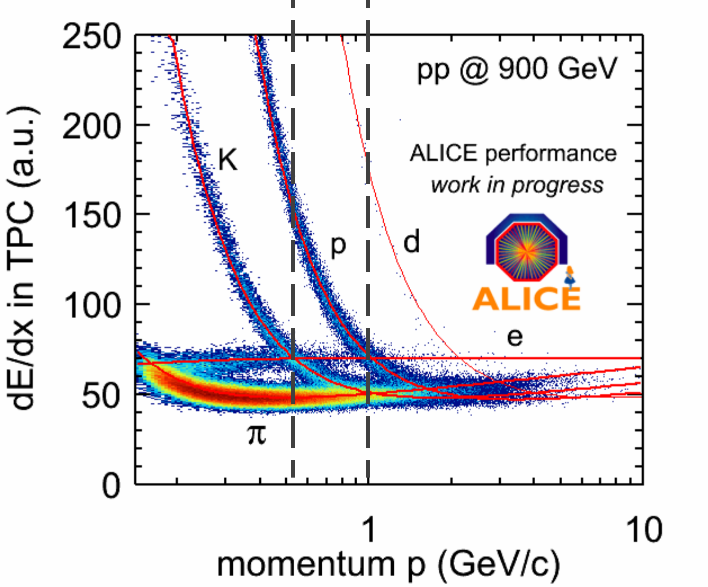
Tools: PID

- Proton, kaon and pion separation using dE/dx in TPC and TOF information

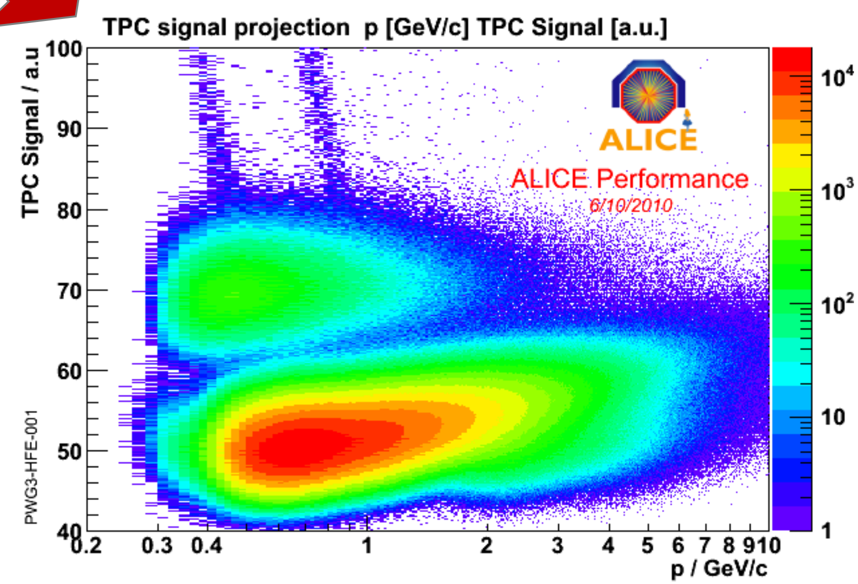


Tools: electron identification

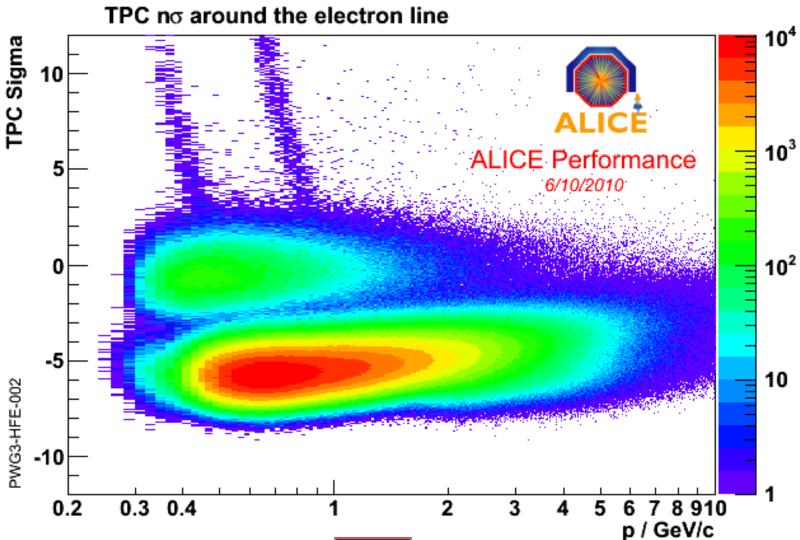




- Strategy based on TOF and TPC
  - ⇨ TOF resolves momentum regions where electron dE/dx in TPC crosses kaon and proton curves
  - ⇨ Effective for p_t<4 GeV/c
- TOF rejects kaons for p<1.5 GeV/c and protons for p<3 GeV/c
- Further hadron rejection with TPC
  - ⇨ n. sigma cut with respect to electron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



Tools: electron identification



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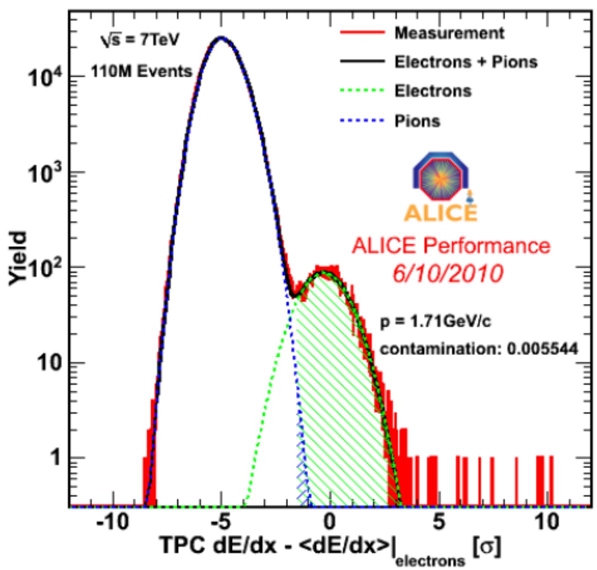
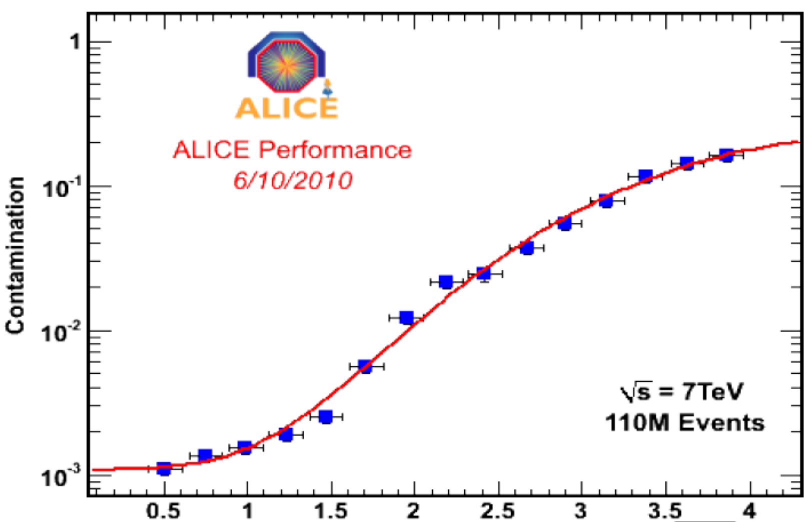
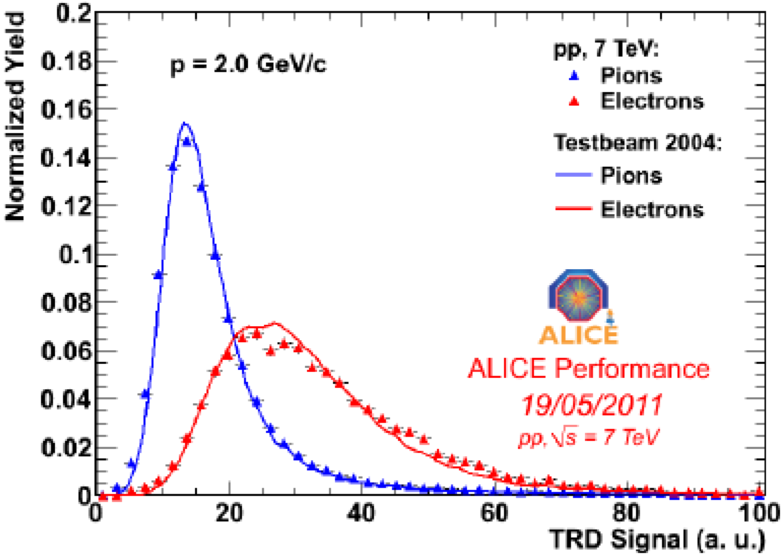
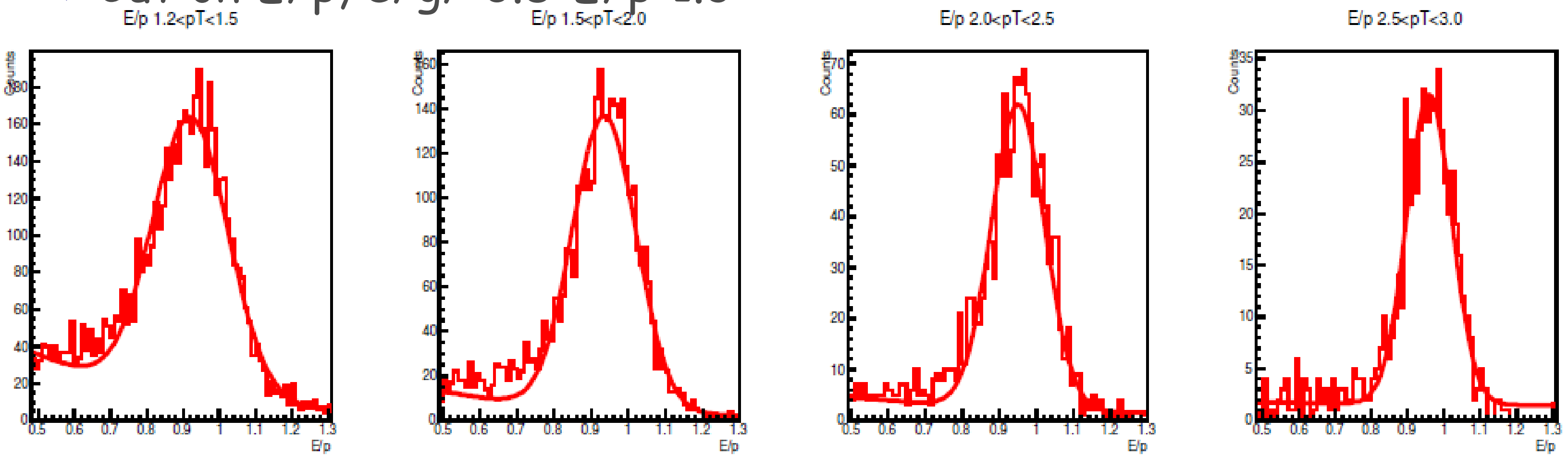




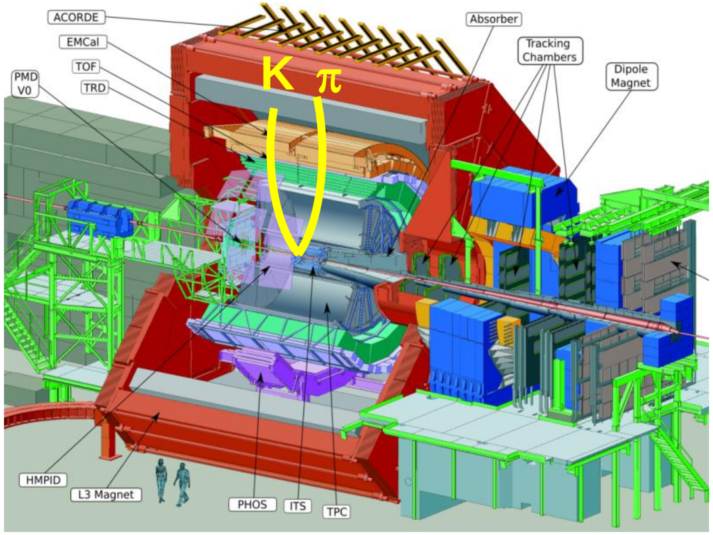
Tools: electron identification



- TRD
  - Extend measurement to higher pt
  - Energy deposit (dE/dx) + absorption of Transition Radiation photons
  - Cut at 80% of electron efficiency
- EMCAL
  - dE/dx from TPC, momentum (p) from track fit
  - Energy (E) from the EMCAL cluster matched to the track
  - Compatibility of dE/dx with election energy loss (-> remove hadrons)
  - Cut on E/p, e/g/ 0.8<E/p<1.3

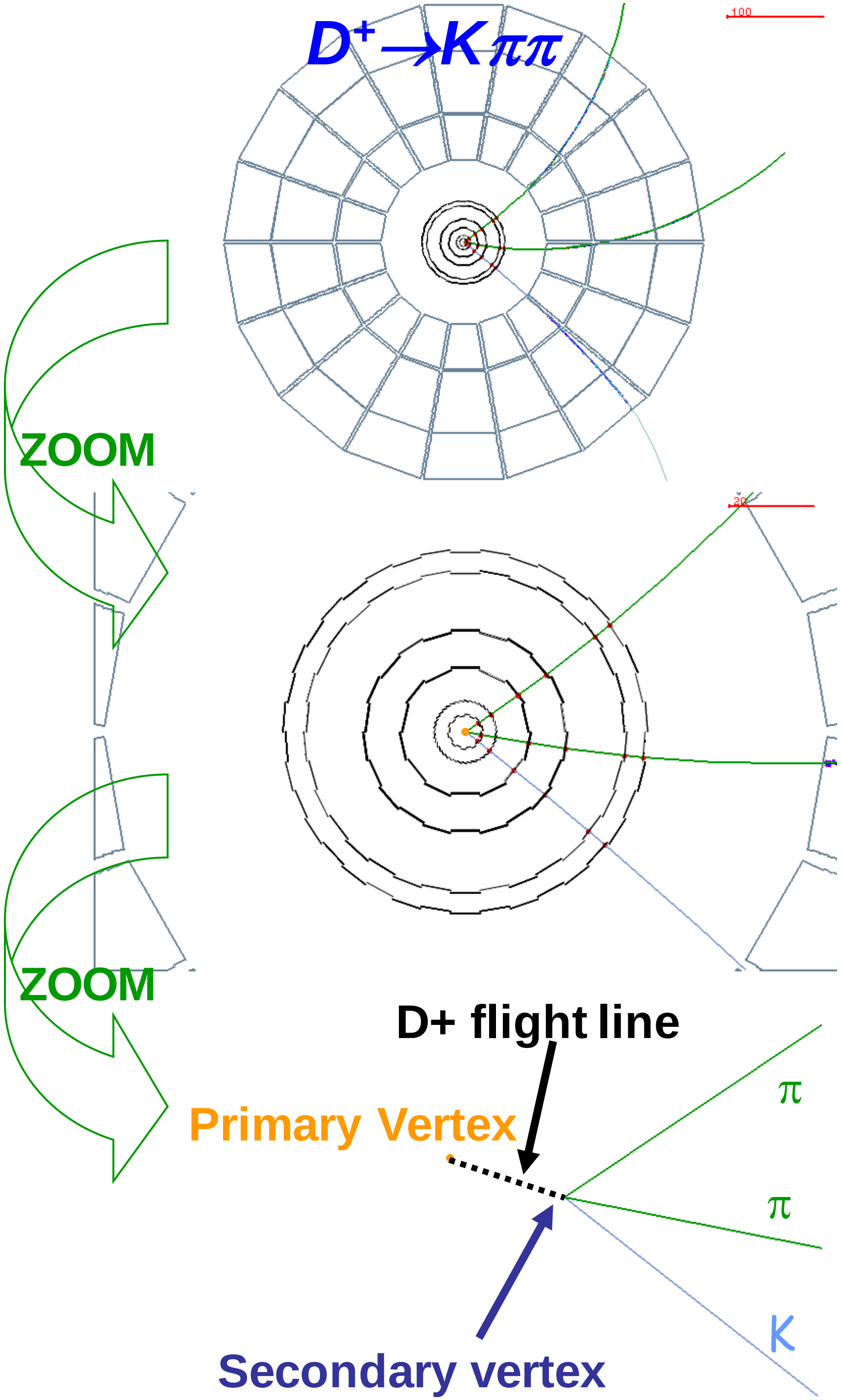


More details on D → hadrons



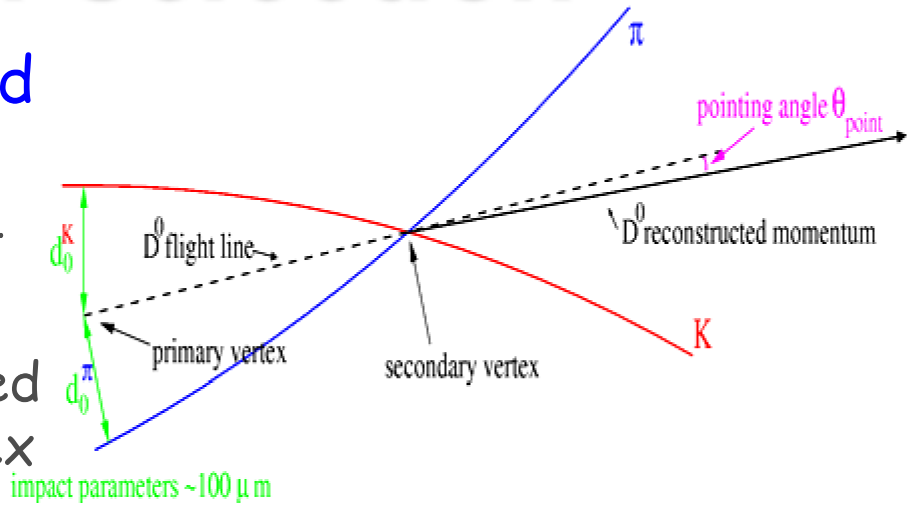
D meson reconstruction

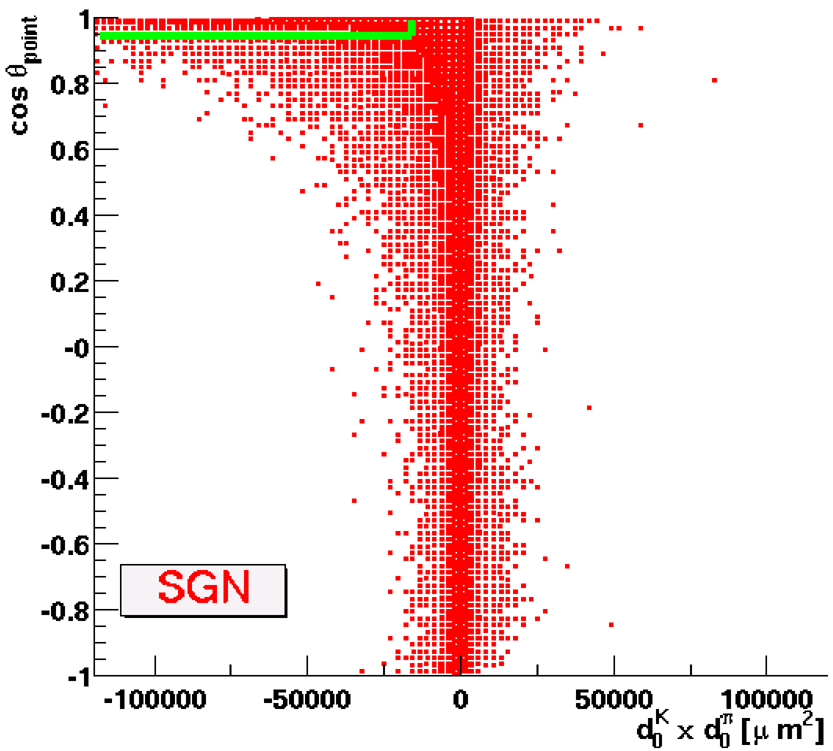
- STRATEGY: invariant-mass analysis of fully-reconstructed topologies originating from displaced vertices
  - build pairs/triplets/quadruplets of tracks with **correct combination of charge signs** and **large impact parameters**
  - **particle identification** from TPC and TOF to reject background (at low pt)
  - calculate the **vertex (DCA point)** of the tracks
  - require **good pointing** of reconstructed D momentum to the primary vertex

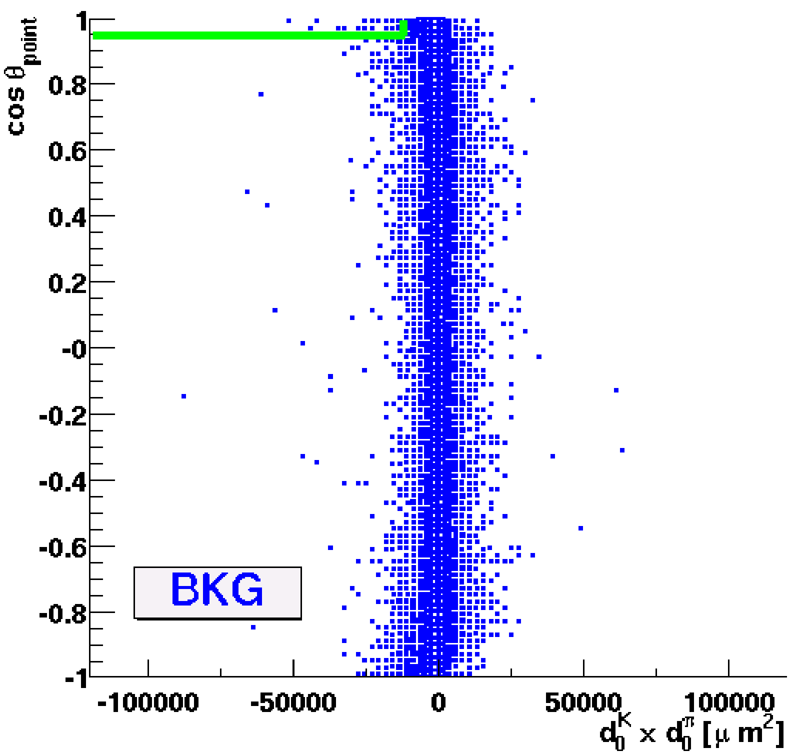


$D^0 \to K^-\pi^+$: selection

- Pair of opposite sign charged tracks
  - ⇨ large and opposite sign impact parameter
  - ⇨ Good pointing of reconstructed D momentum to primary vertex

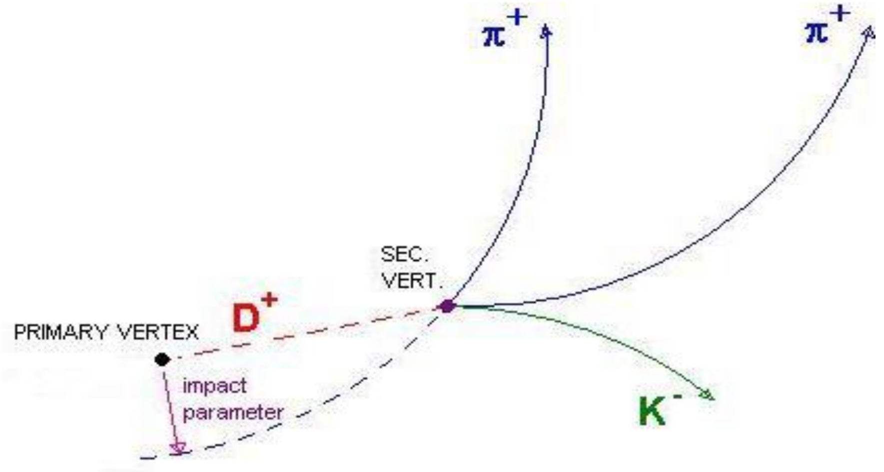


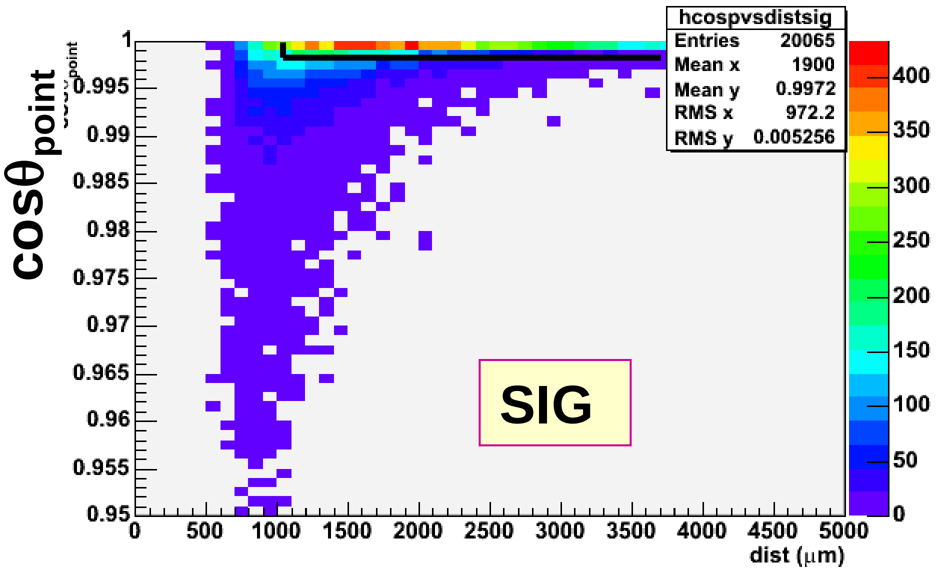


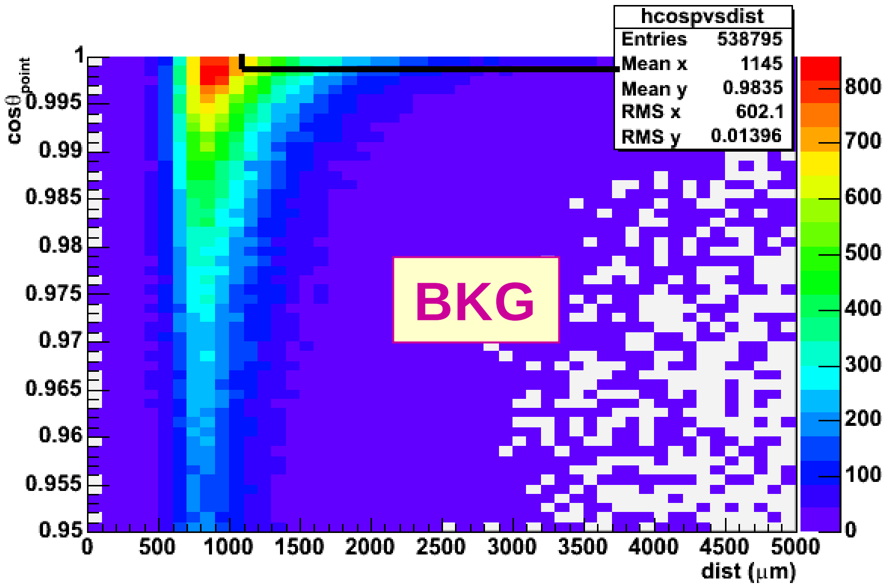


$D^+ \rightarrow K^- \pi^+ \pi^+$: selection

- Triplet of charged tracks
  - ⇨ Large distance between primary and secondary vertex ($c\tau$ = 310 μm)
  - ⇨ Good pointing of the reconstructed D momentum to the primary vertex



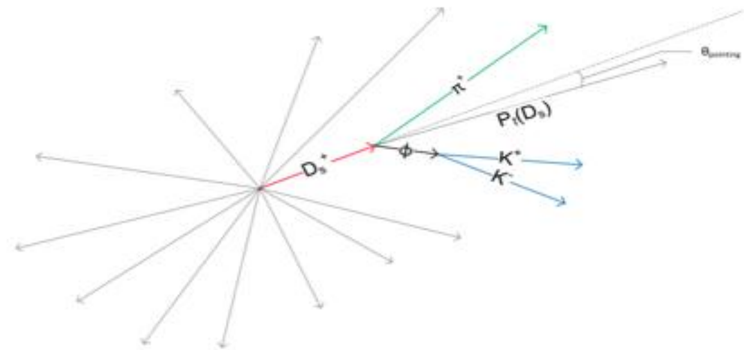


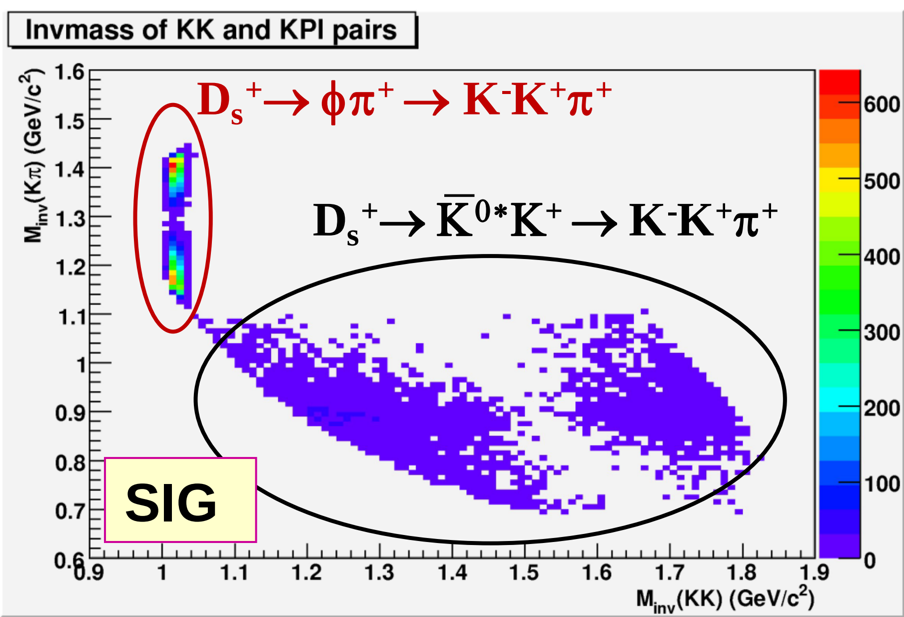


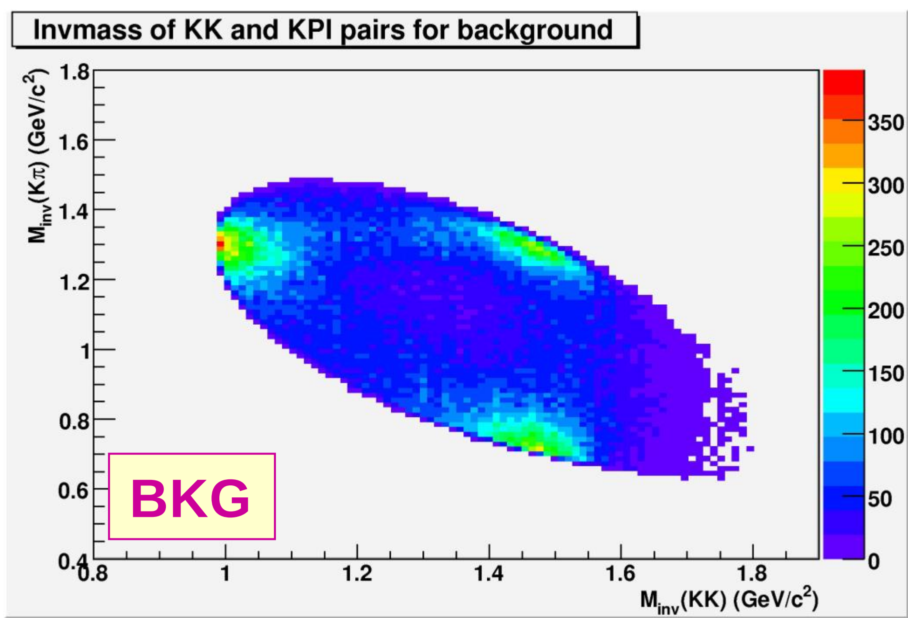
$d_{PRIM\text{-}SEC}$ (μm)

$D_s^+ \to K^-K^+\pi^+$ selection

- D_s has shorter lifetime than D+
  - ⇨ Looser topological cuts
  - ⇨ PID cuts more background (2 tracks should be compatible with Kaon hypothesis)
  - ⇨ Exploit resonant intermediate state: M(KK) compatible with phi mass

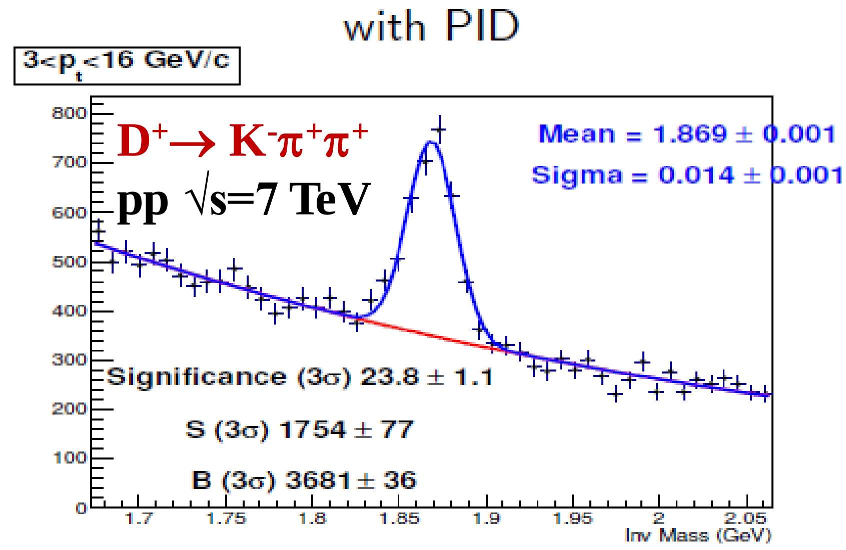


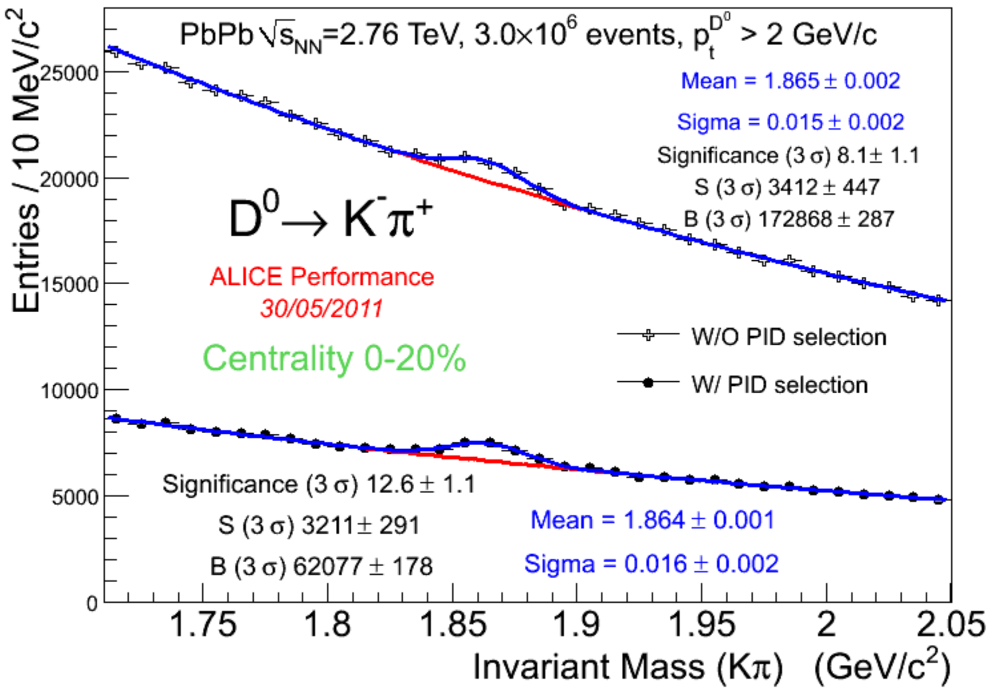


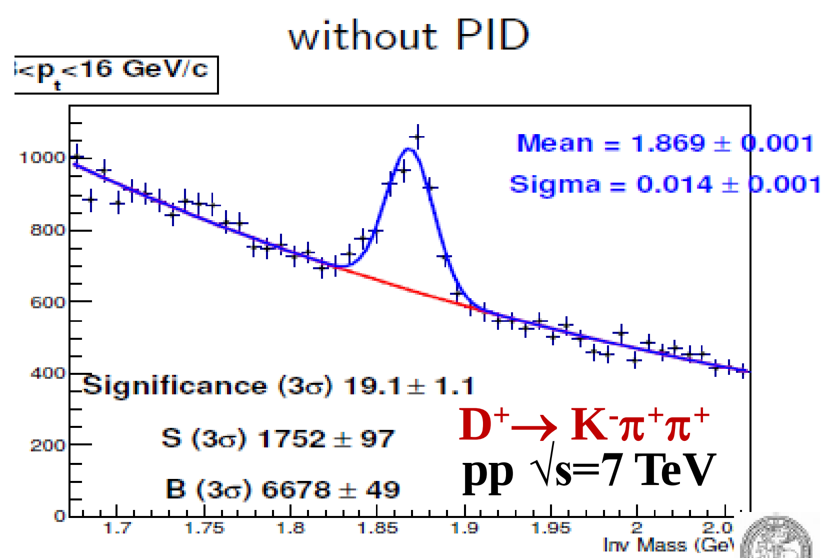


The power of PID

- PID strategy:
  - ⇨ Conservative PID: 3s cuts on TPC dE/dx and TOF signal
  - ⇨ Preserve close to 100% of the signal and remove background



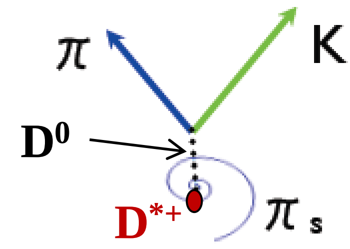




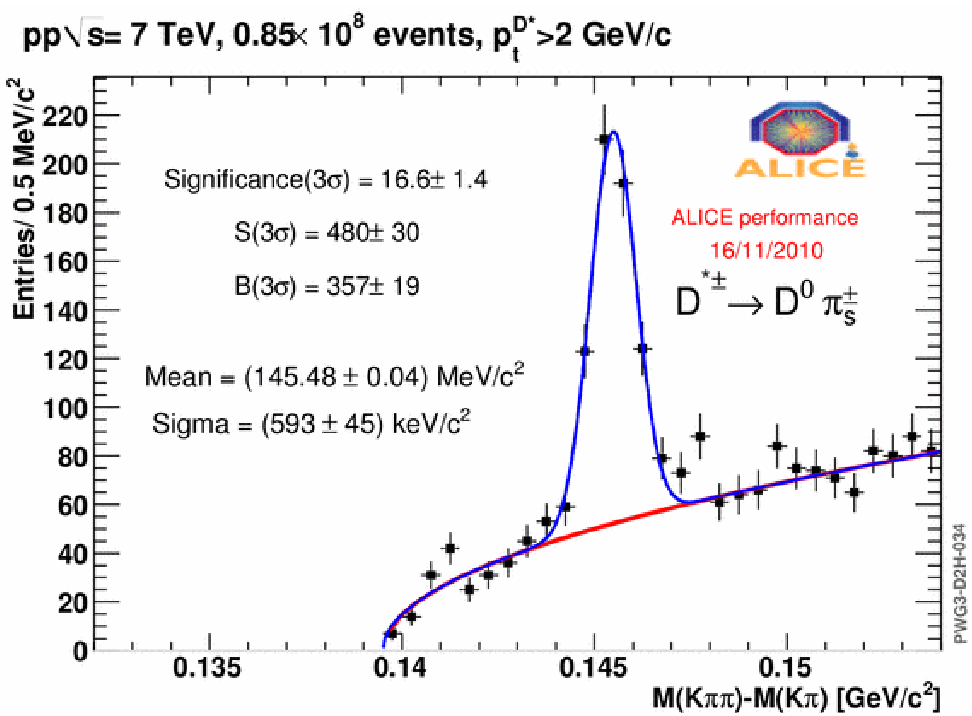
$D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$ selection

$D^{*\pm} \rightarrow D^0\ \pi_s^\pm$ (BR = 67.7%)

$D^0 \rightarrow K\ \pi$ (BR = 3.89%)



- Strong decay
  - Topological selection of D daughters
  - Attach a pion to D^0 candidates
    - ✓ ***Low momentum (soft) pion***
  - Exploit narrow signal in $\Delta M = M(K\pi\pi) - M(K\pi)$ at the edge of phase space
    - ✓ ***High S/B***



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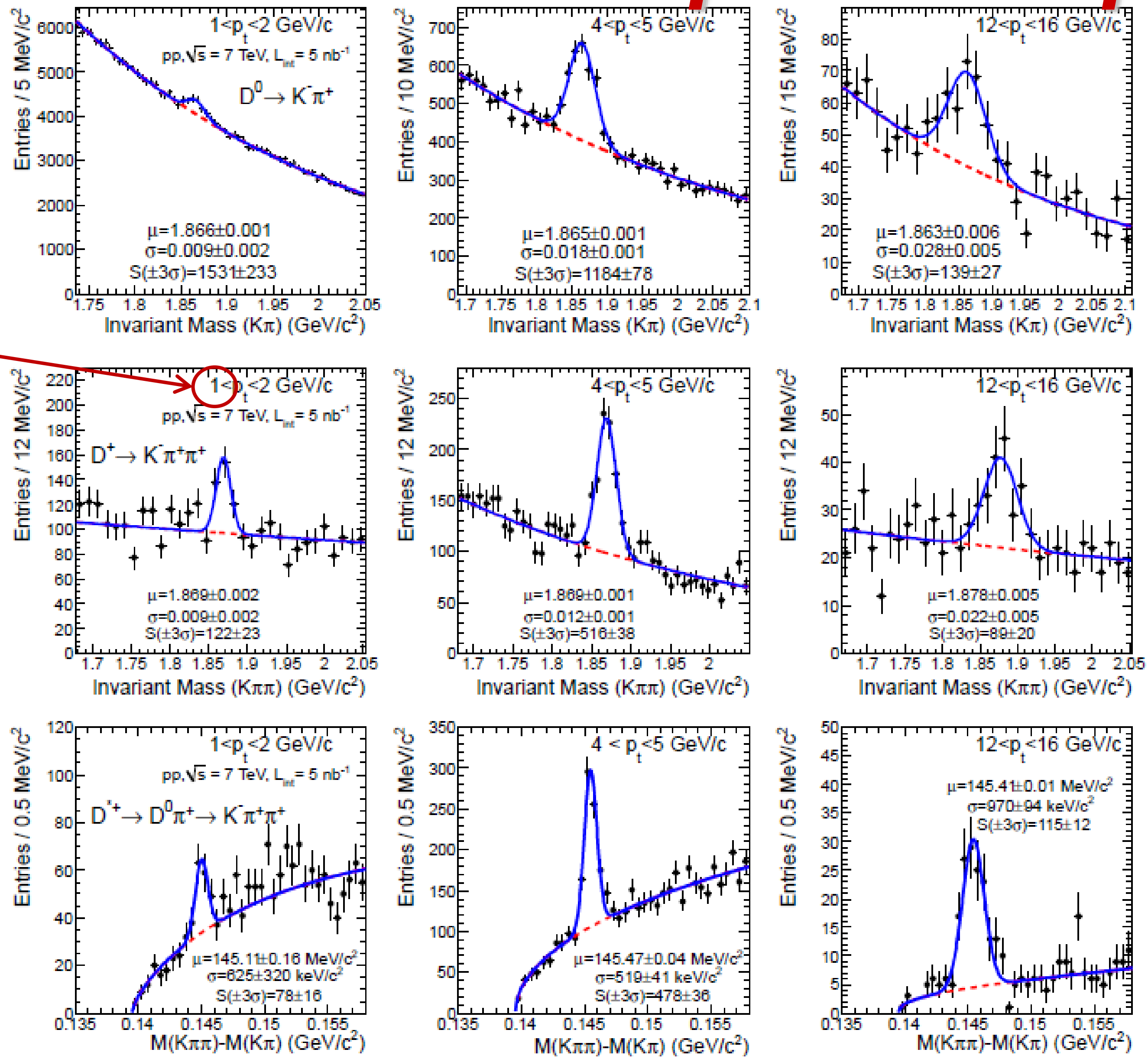
Invariant mass spectra in pp

D^0

Down to p_t=1 GeV/c

D^+

D^{*+}



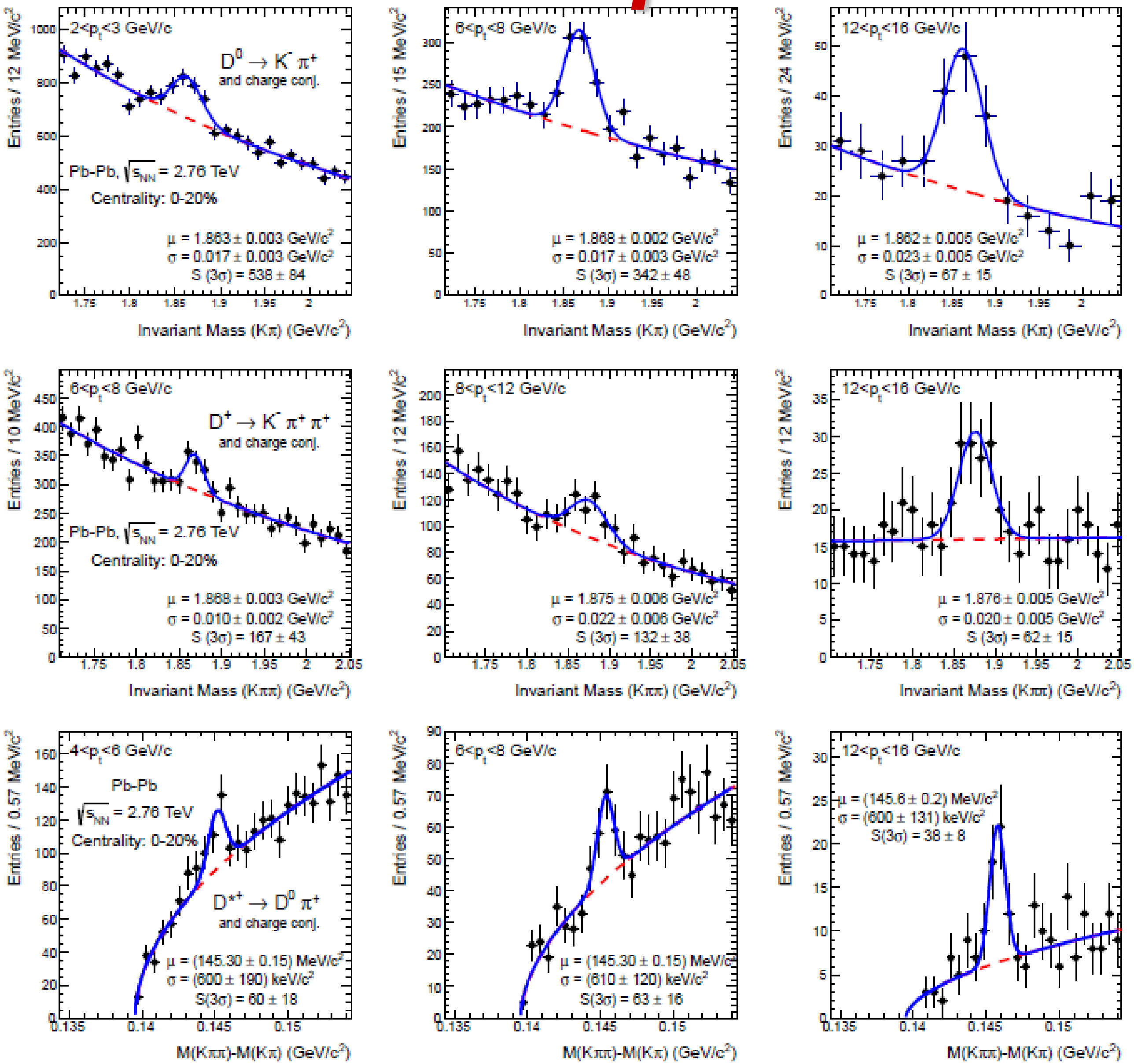
Increasing pt

Invariant mass spectra in PbPb

D0

D+

D*+



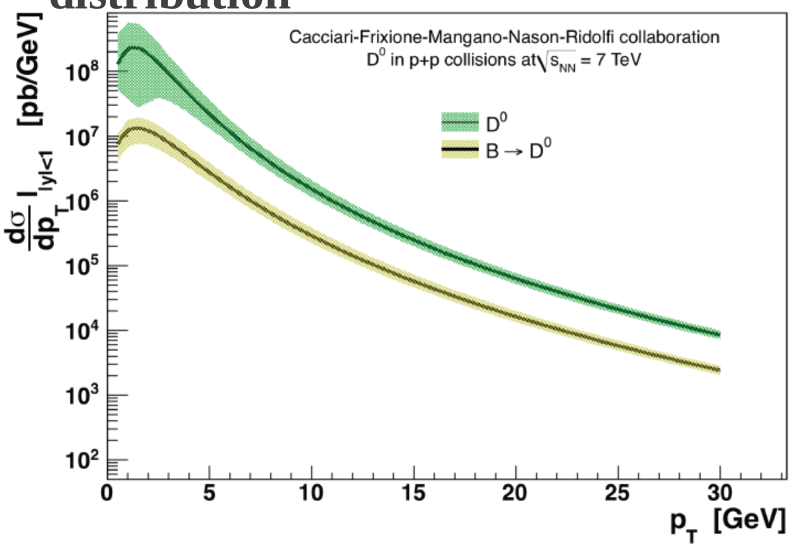
Increasing pt

From signals to cross-sections

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

Correction for B→D feeddown:

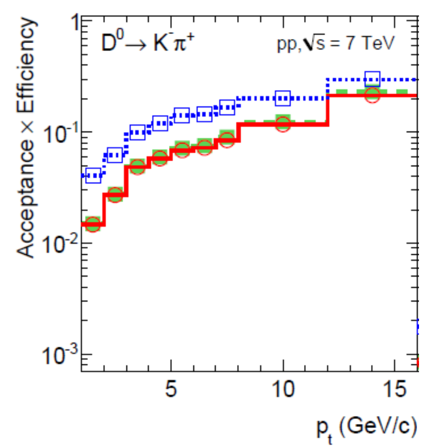
- **From FONLL predictions + selection efficiencies from MC**
- **Check with data driven method based on fit to D meson impact parameter distribution**



From fits to invariant mass spectra

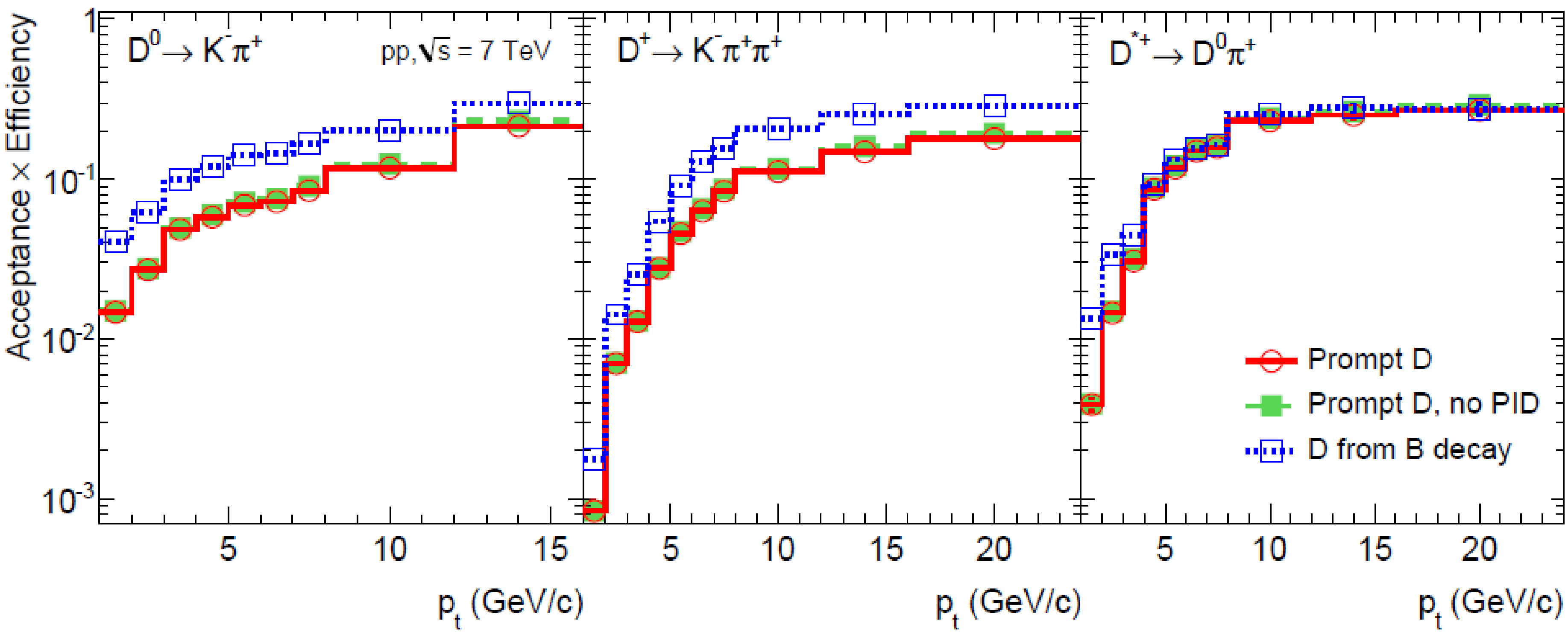
Correction for reconstruction and selection efficiency:

- **From MC simulations**



B feed-down subtraction: why

- Different efficiency for prompt and secondary D mesons
  - ⇨ D from B feed-down are more displaced from primary vertex -> higher efficiency of topological cuts

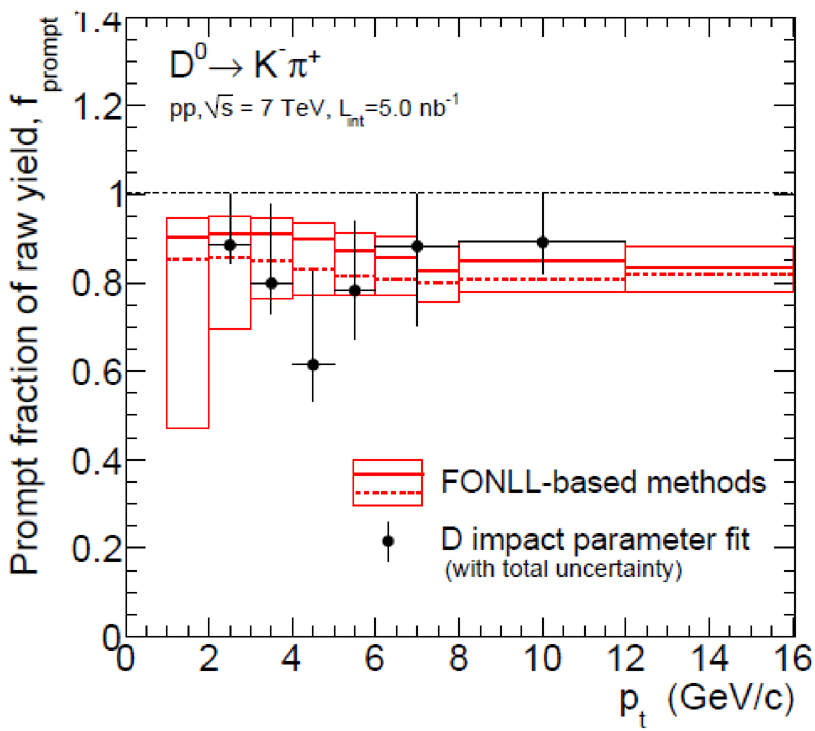


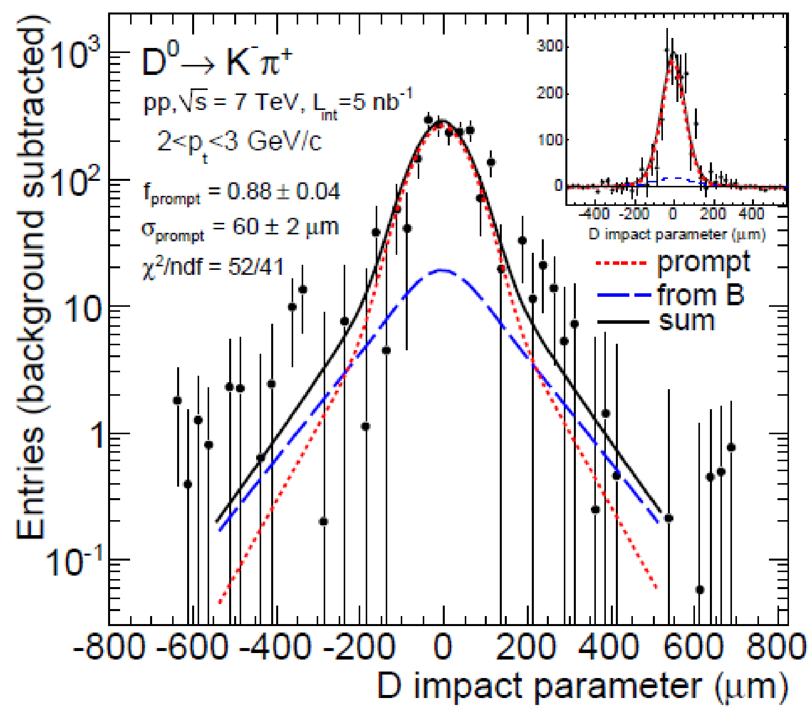
B feed-down subtraction: how

- Contribution to yield from feed-down B using FONLL prediction for B mesons, decayed with EvtGen to D mesons, multiplied by the reconstruction efficiency for feed-dwon D mesons

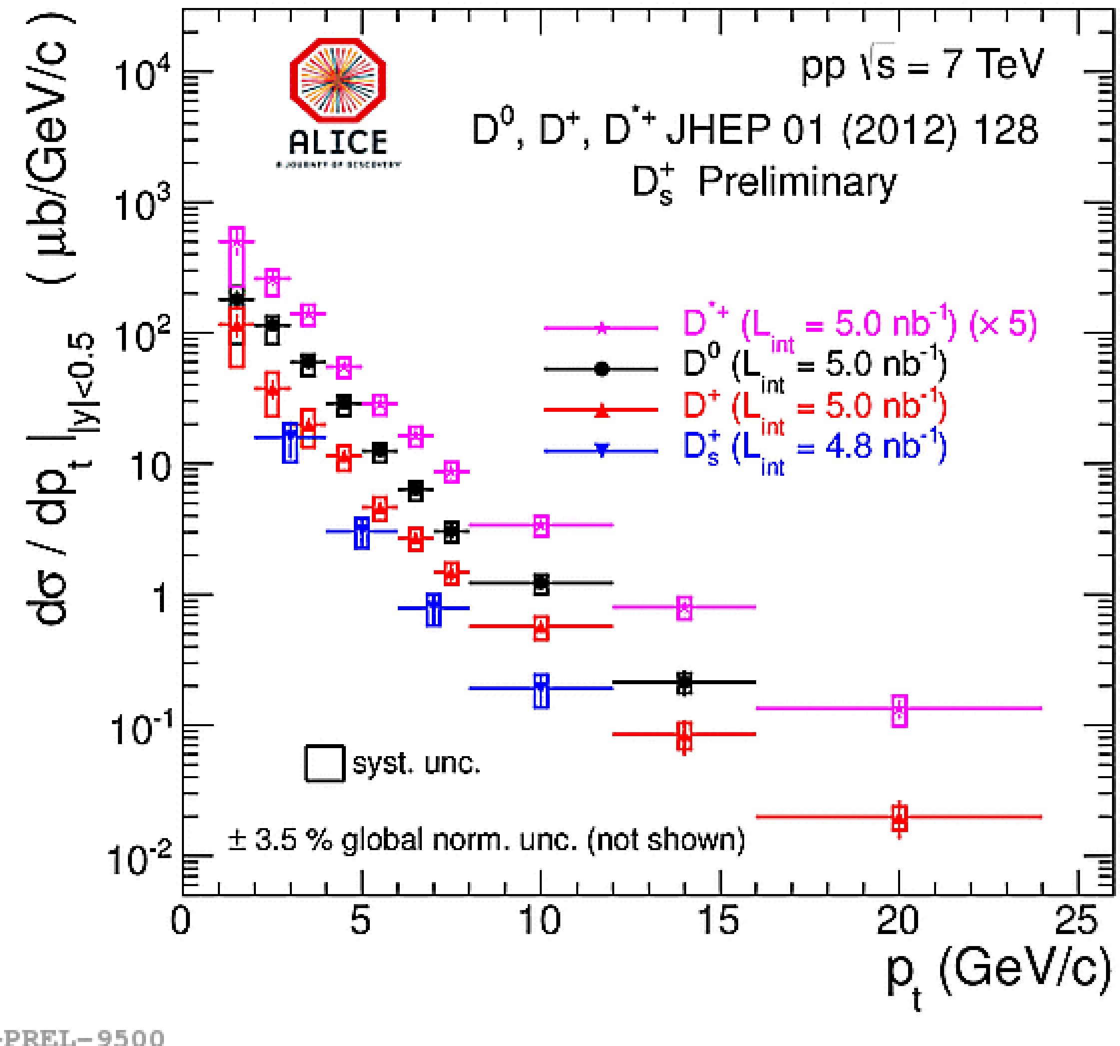
$$f_{\text{prompt}} = 1 - \left(N^{\text{D}^\pm \text{ from B raw}} / N^{\text{D}^\pm \text{ raw}}\right)$$

$$N^{\text{D}^\pm \text{ from B raw}}\Big|_{|y|<y_{\text{fid}}} = 2 \left.\frac{d\sigma^{\text{D}^+ \text{ from B}}_{\text{FONLL}}}{dp_{\text{t}}}\right|_{|y|<0.5} \cdot \Delta y \Delta p_{\text{t}} \cdot (\text{Acc} \times \varepsilon)_{\text{feed-down}} \cdot \text{BR} \cdot L_{\text{int}} \cdot$$



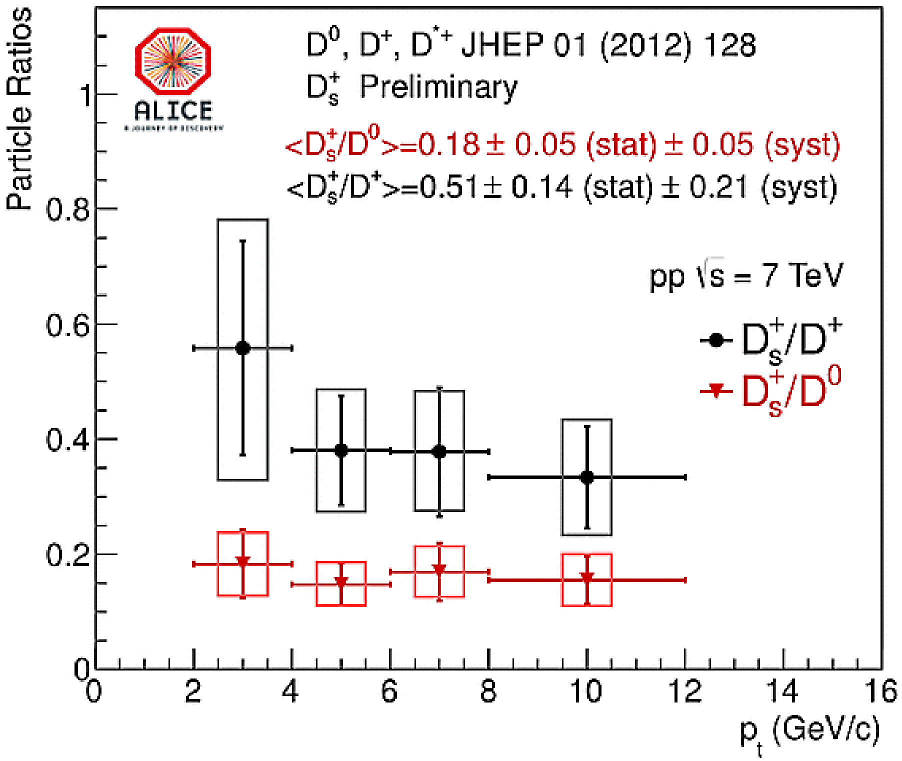


p_t differential cross sections



- From an integrated luminosity of 5 nb^{-1}
  - ⇨300M MB triggers from 2010 data sample

Particle ratios



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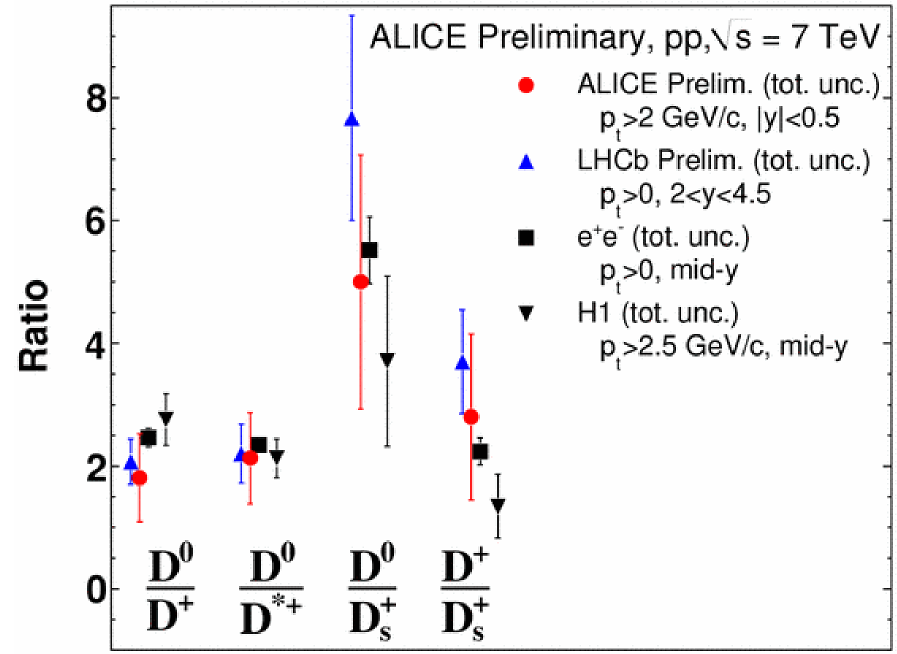
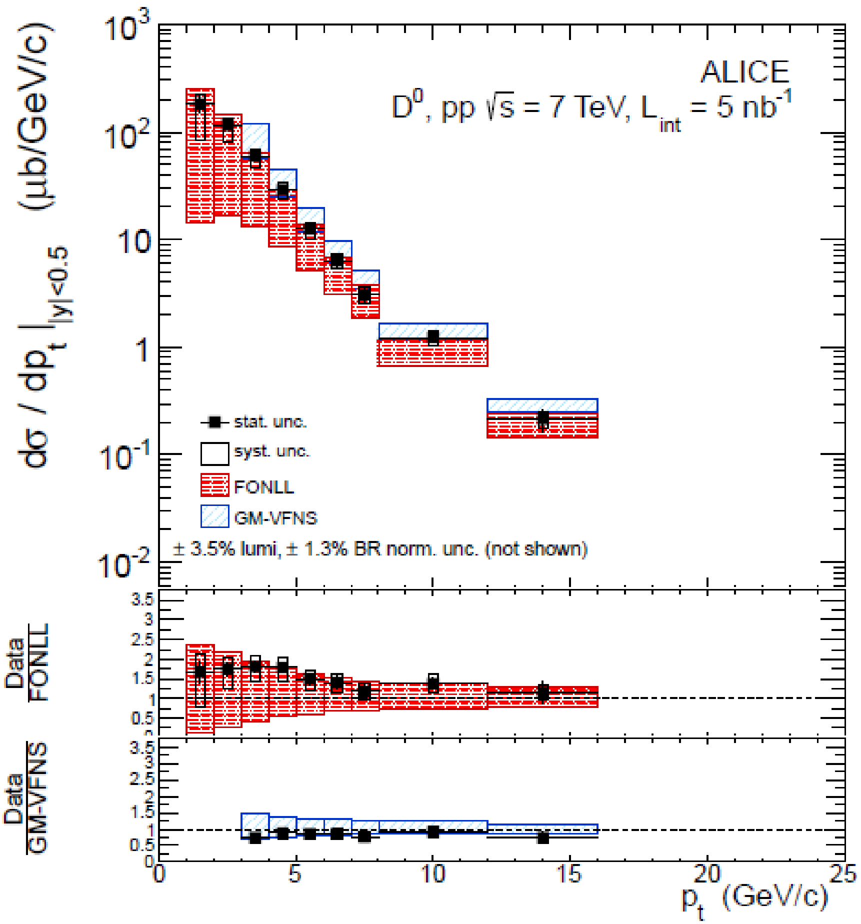
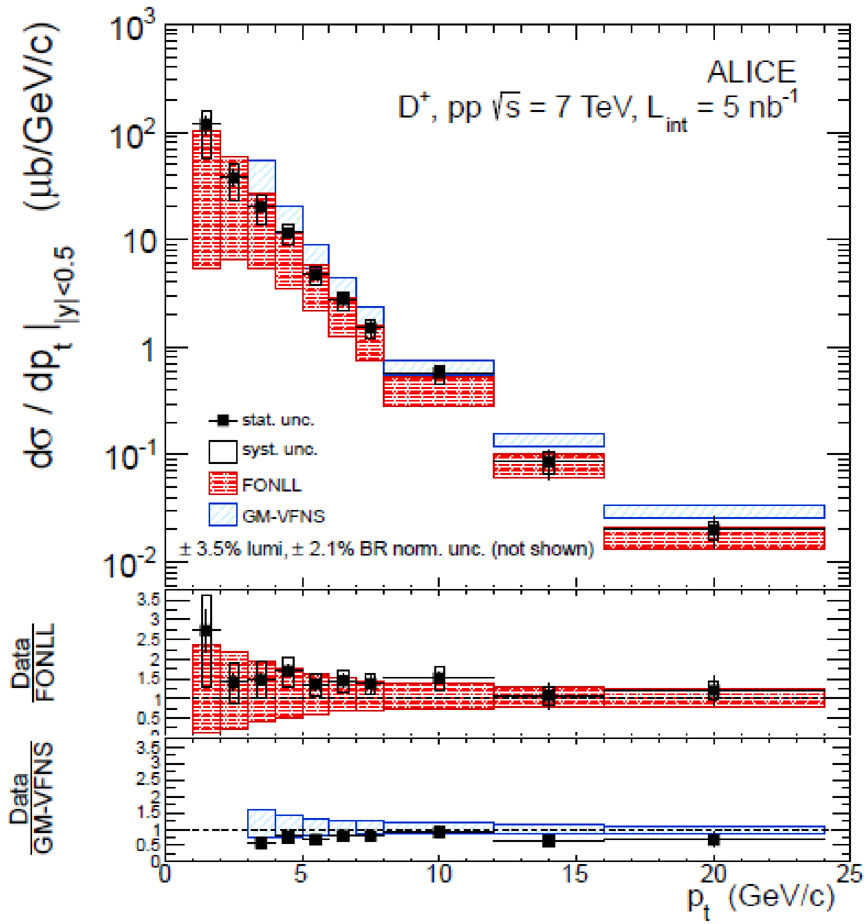


ALI-PREL-9458

- Looking at these ratios in PbPb can provide information on hadronization mechanism and strangeness enhancement
  - ⇨ Ds expected to be enhanced in PbPb in case of hadronization via recombination
- Λ_c under study: would allow to study baryon/mesons in the charm sector

Comparison to pQCD

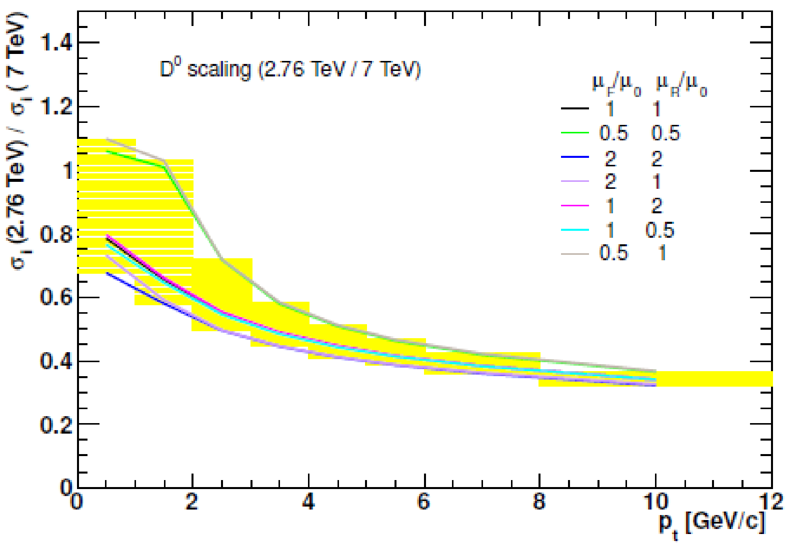


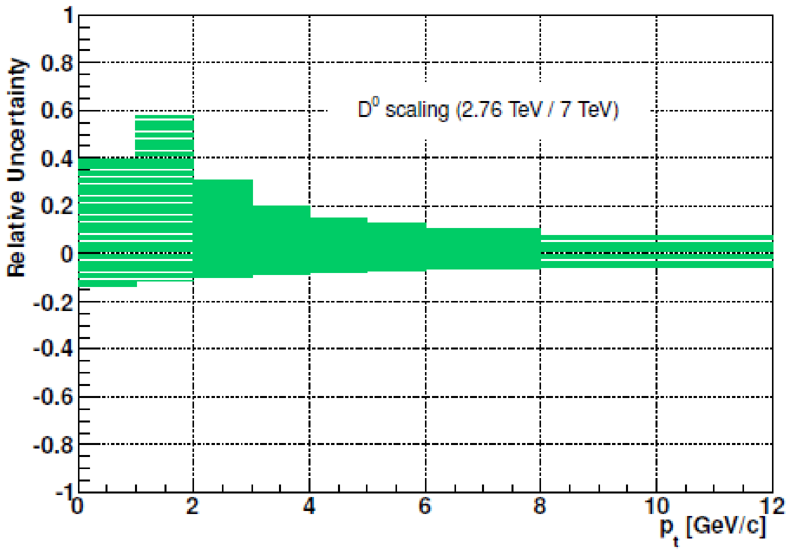


- Data compatible with pQCD prediction within uncertainties
  - ⇨ As observed al lower energies, data are on the upper edge of FONLL uncertainty band

Towards R_{AA}: pp reference

- pp data sample at $\sqrt{s}$=2.76TeV: too small statistics for measuring D meson cross section with enough precision in the same p_t intervals used in PbPb
- Solution: scale the pt differential cross section measured at $\sqrt{s}$=7 TeV
  - Scaling factor defined for each D meson species from the ratio of the cross-sections from FONLL at 2.76 and 7 TeV
  - Validated scaling to $\sqrt{s}$=1.96TeV and comparing with CDF data
  - Checked against ALICE measurement at 2.76 TeV



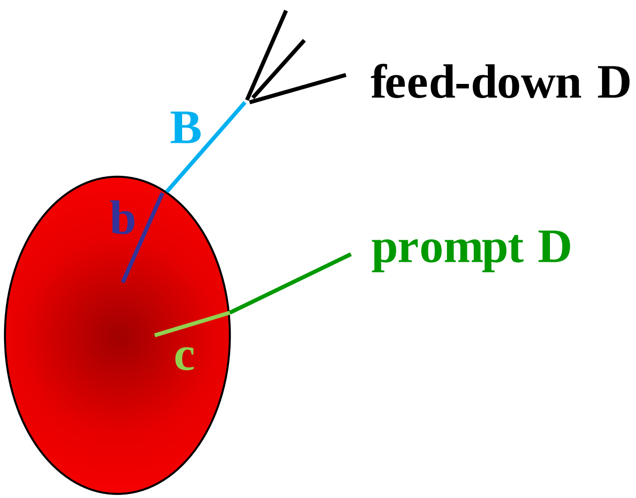


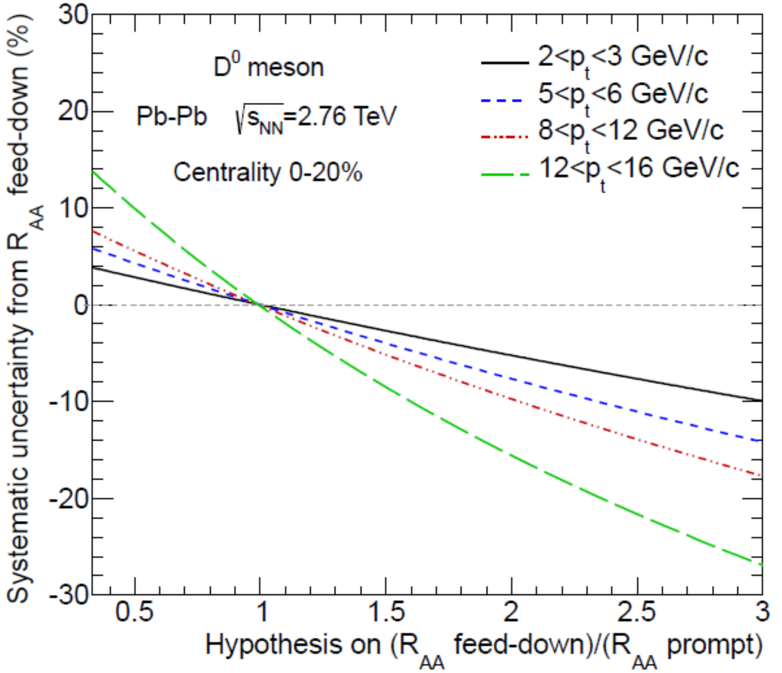
B feed-down in PbPb

- Hypothesis on RAA of D mesons from B decays needed
  - ⇨ B decays outside the medium: in case of D mesons from B feed-down, the quark crossing the medium is the b
  - ⇨ Energy loss of beauty expected different from that of charm

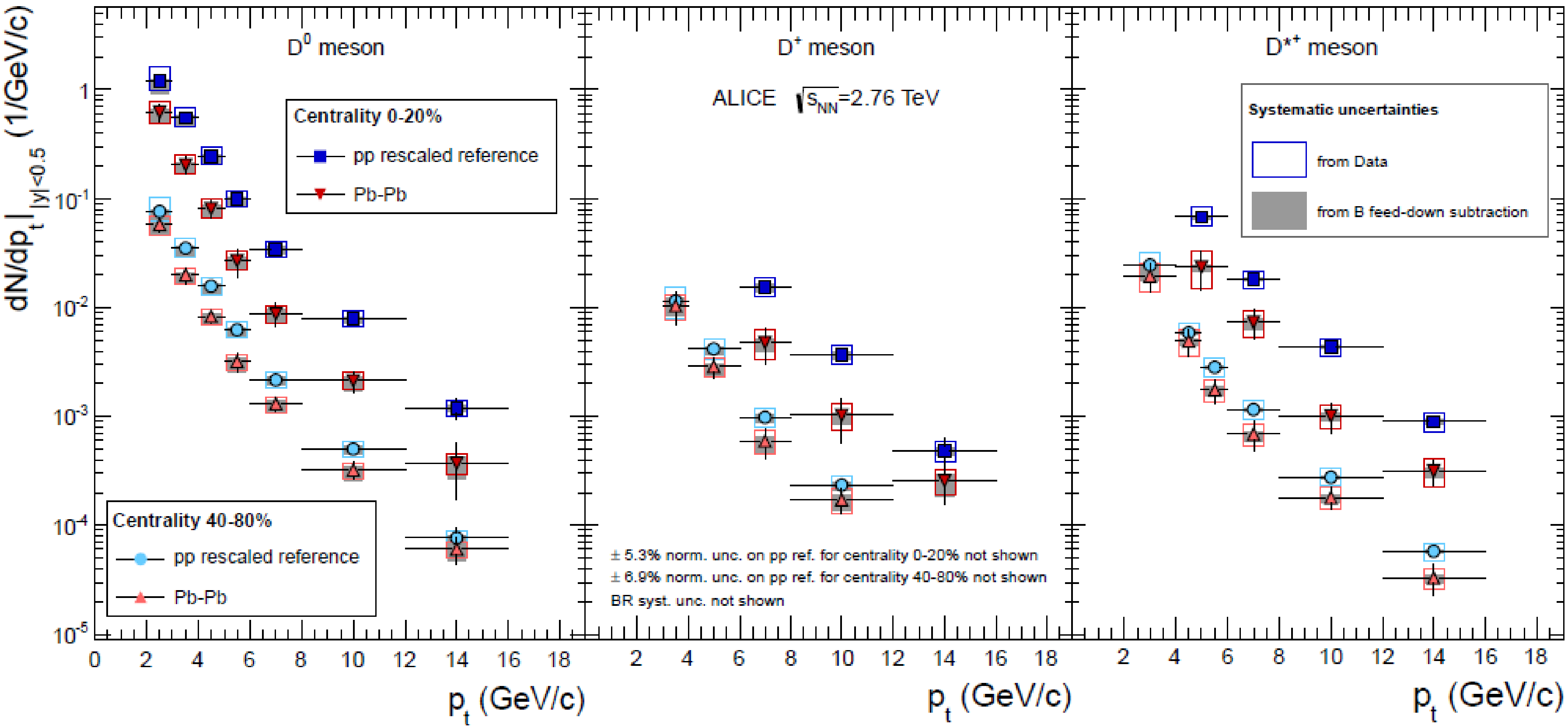
$$f_{\text{prompt}} = 1 - (N^{\text{D feed-down raw}} / N^{\text{D raw}}) =$$

$$= 1 - \langle T_{\text{AA}} \rangle \cdot \left(\frac{d^2\sigma}{dy\, dp_t} \right)^{\text{FONLL}}_{\text{feed-down}} \cdot \boxed{R_{\text{AA}}^{\text{feed-down}}} \cdot \frac{(\text{Acc} \times \varepsilon)_{\text{feed-down}} \cdot \Delta y \Delta p_t \cdot \text{BR} \cdot N_{\text{evt}}}{N^{\text{D raw}} / 2}$$



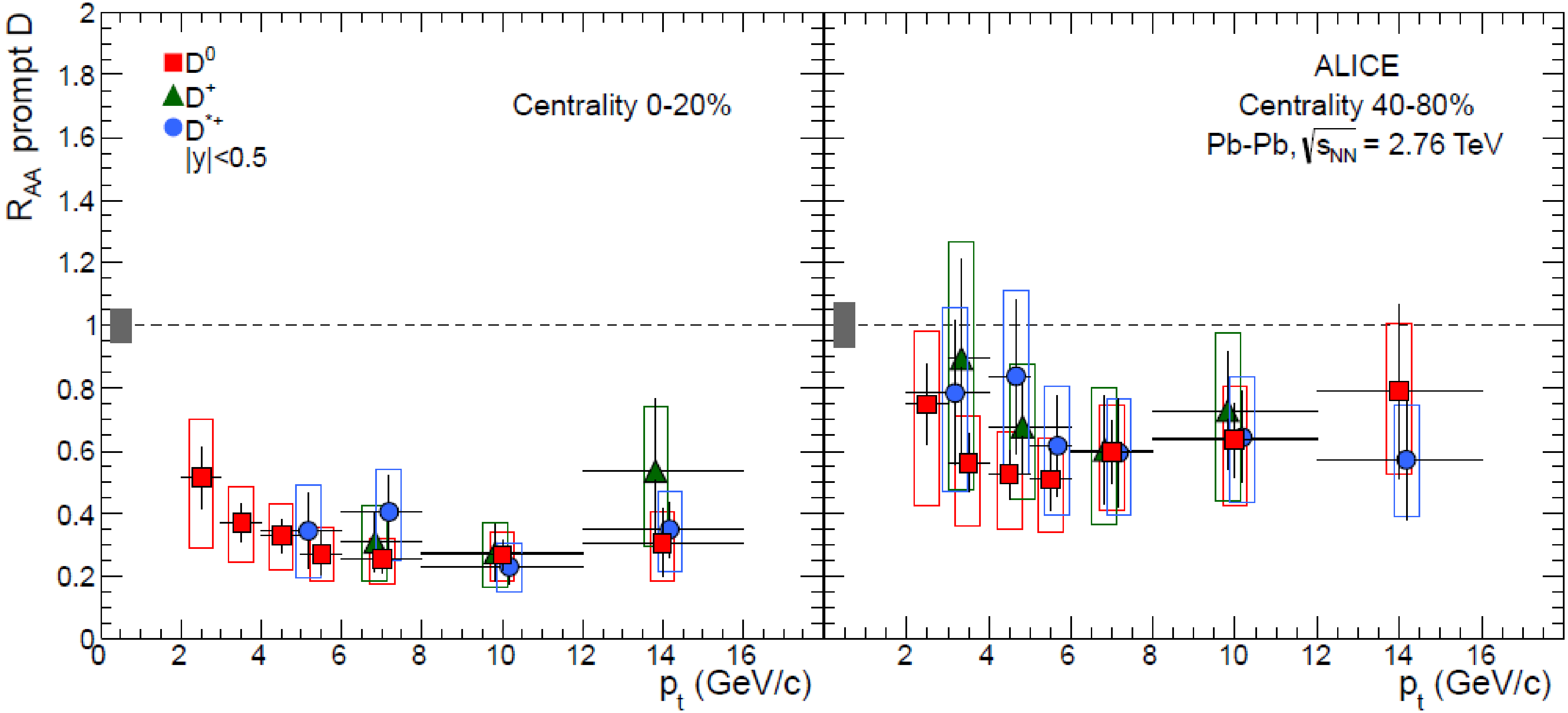


dN/dpt: PbPb vs. pp



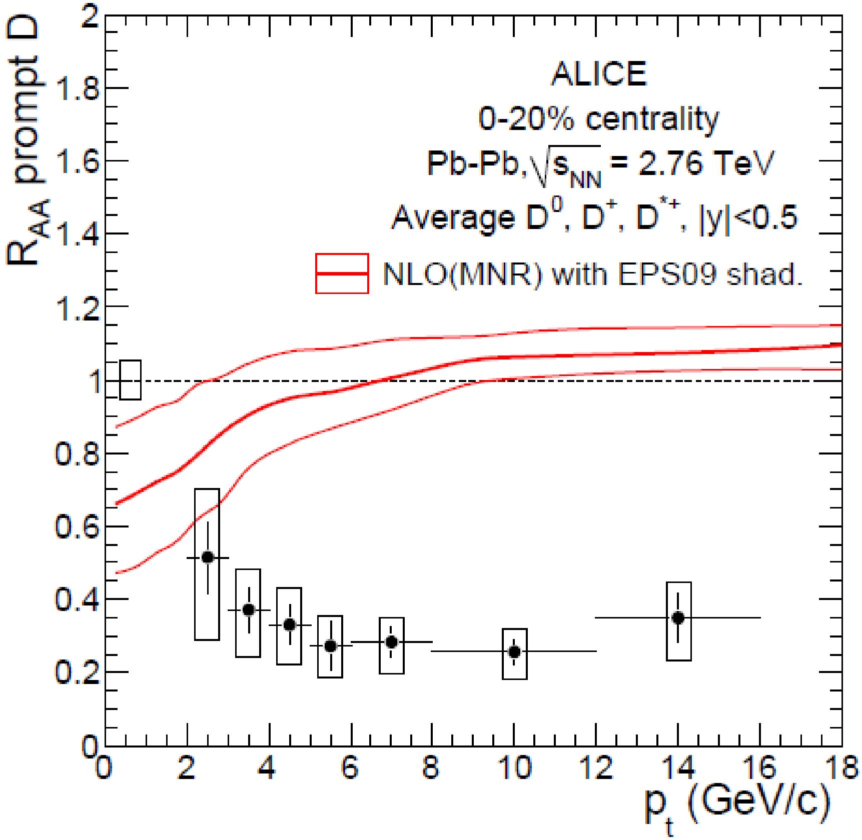
- Suppression of prompt D mesons in central (0-20%) PbPb collisions by a factor 4-5 for p_T>5 GeV/c
  - ⇨ Little shadowing at high p_T → suppression is a hot matter effect
  - ⇨ Similar suppression for D mesons and pions
  - ⇨ Maybe a hint of $R_{AA}^D > R_{AA}^\pi$ at low p_T

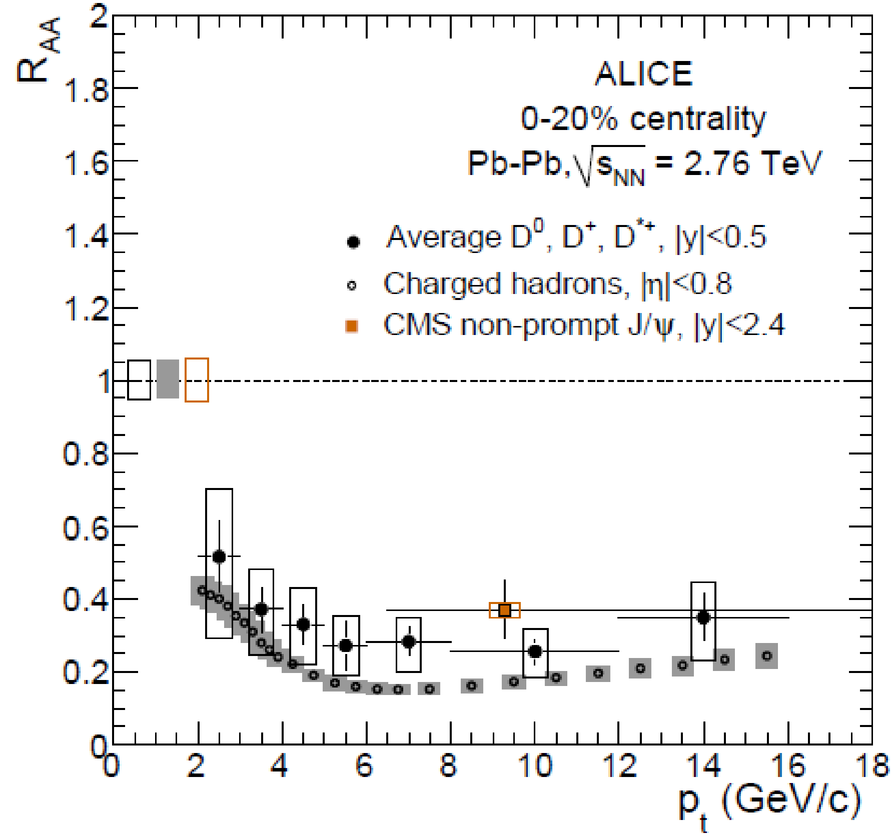
Prompt D meson R_{AA}



- Suppression of prompt D mesons in central (0-20%) PbPb collisions by a factor 3-4 for p_T>5 GeV/c
  - ⇨ Smaller suppression for peripheral events

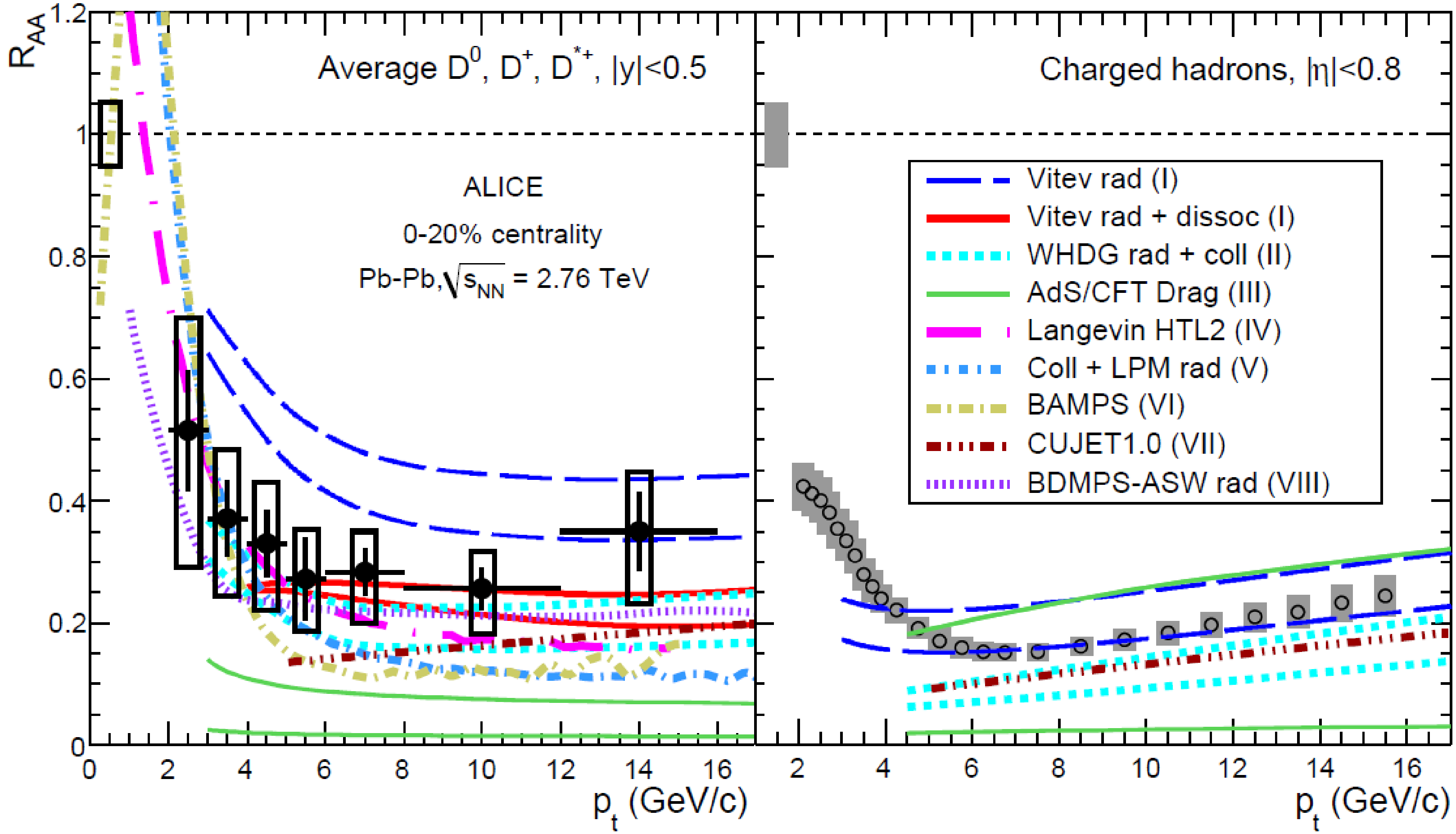
Prompt D meson R_{AA}





- Little shadowing at high p_T → suppression is a hot matter effect
- Similar suppression for D mesons and pions
  - ⇨ Hint of $R_{AA}^D > R_{AA}^{\pi}$ at low p_T
  - ⇨ CMS measurement of displaced J/ψ (from B feeddown) indicate $R_{AA}^B > R_{AA}^D$

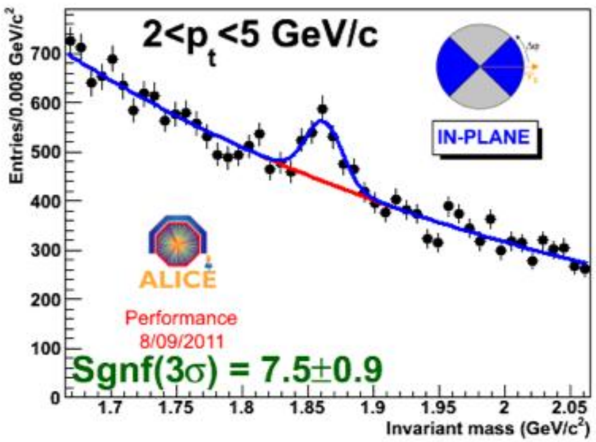
Prompt D meson R_{AA}

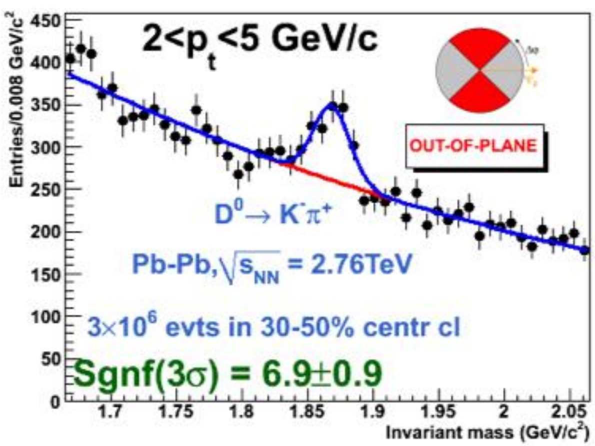


- Comparison to theoretical predictions
  - ⇨ Several models on the market
  - ⇨ Only few have predictions for D mesons and light hadrons

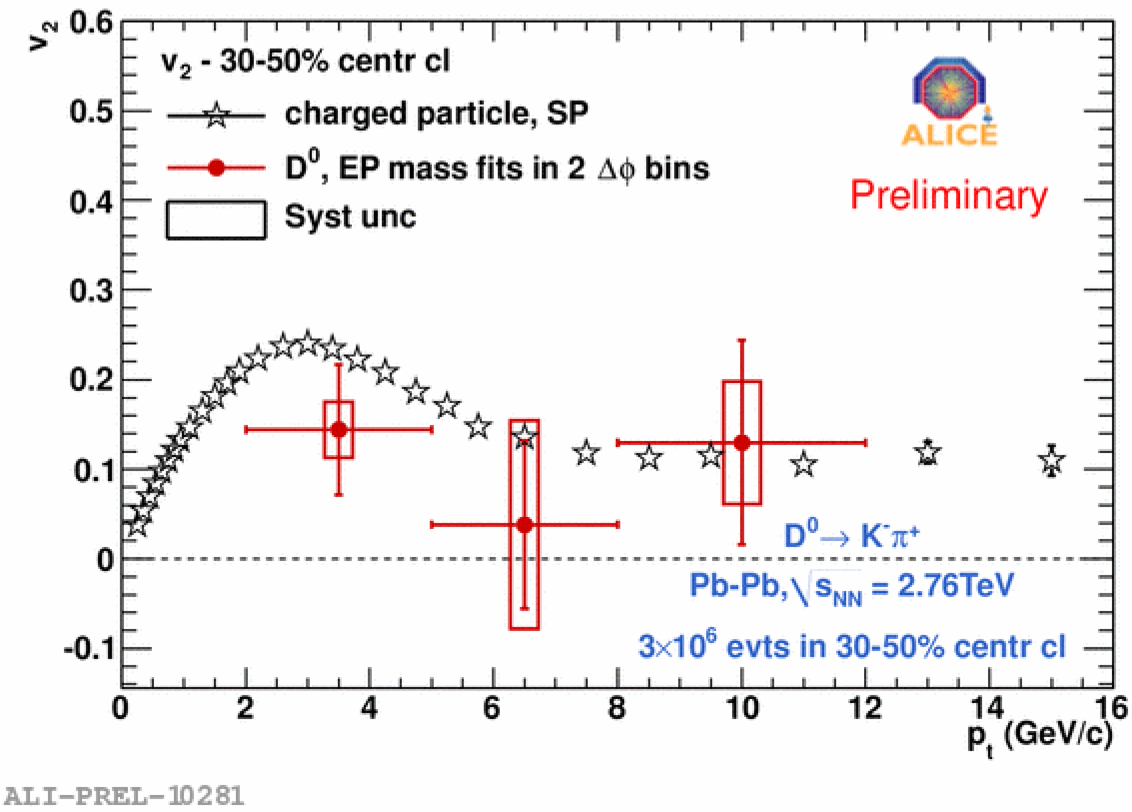
D^0 elliptic flow

- First direct measurement of D flow in heavy-ion collisions
- Yield extracted from invariant mass spectra of $K\pi$ candidates in 2 bins of azimuthal angle relative to the event plane





$$v_2 = \frac{\pi}{4} \frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$

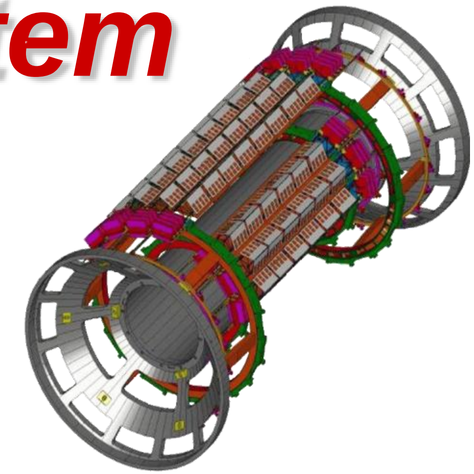


Final remarks...

- Heavy flavours are a powerful tool to investigate the medium produced in heavy ion collisions
- ALICE is particularly suited for these studies due to
  - ⇨ Excellent vertexing and impact parameter resolution
  - ⇨ PID capabilities: crucial for electrons, very important also to remove background for D mesons
- D meson analysis
  - ⇨ R_{AA} of D mesons measured for the first time as a function of pt and centrality
  - ⇨ v_2 of D mesons measured for the first time
  - ⇨ What next?
    - ✓ *High statistics PbPb data of 2011 -> extend to higher pt, improve precision of flow measurement*
    - ✓ *Reduce systematic errors from B feeddown subtraction in PbPb using data driven approach*
    - ✓ *Measure D_s in PbPb and Λ_c in pp*
- Many more ongoing and published analyses not shown here:
  - ⇨ Single muons and single electrons in pp and PbPb
  - ⇨ Heavy flavour production vs. multiplicity in pp
  - ⇨ Correlations (e-hadron, D-hadron, D-electron ...)

Backup

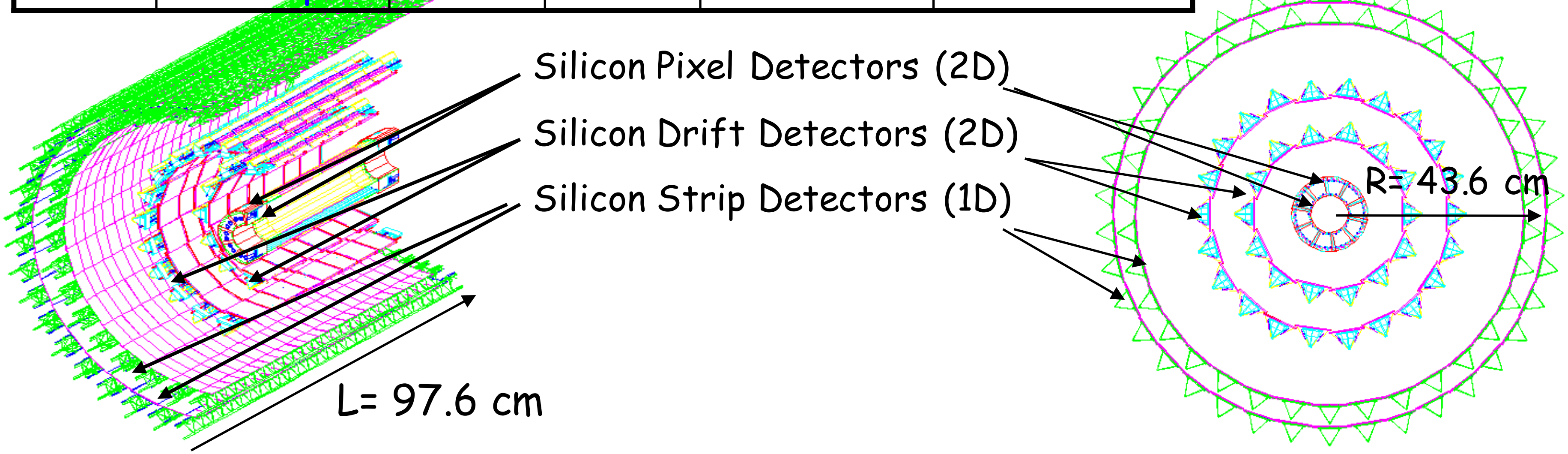
Inner Tracking System



- 6 cylindrical layers of silicon detectors:

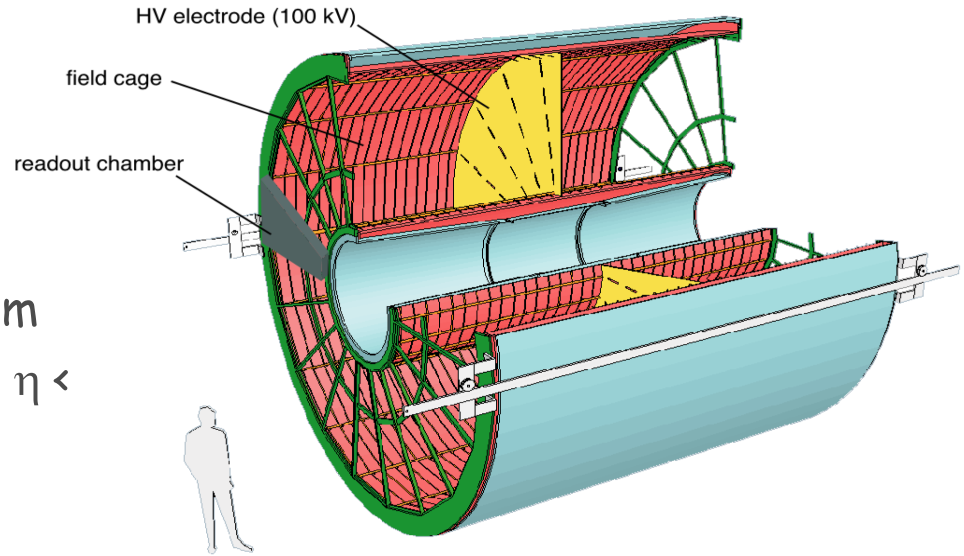
Layer	Technology	Radius (cm)	±z (cm)	Spatial resolution (μm)	
				$r\phi$	z
1	Pixel	4.0	14.1	12	100
2	Pixel	7.2	14.1	12	100
3	Drift	15.0	22.2	38	28
4	Drift	23.9	29.7	38	28
5	Strip	38.5	43.2	20	830
6	Strip	43.6	48.9	20	830

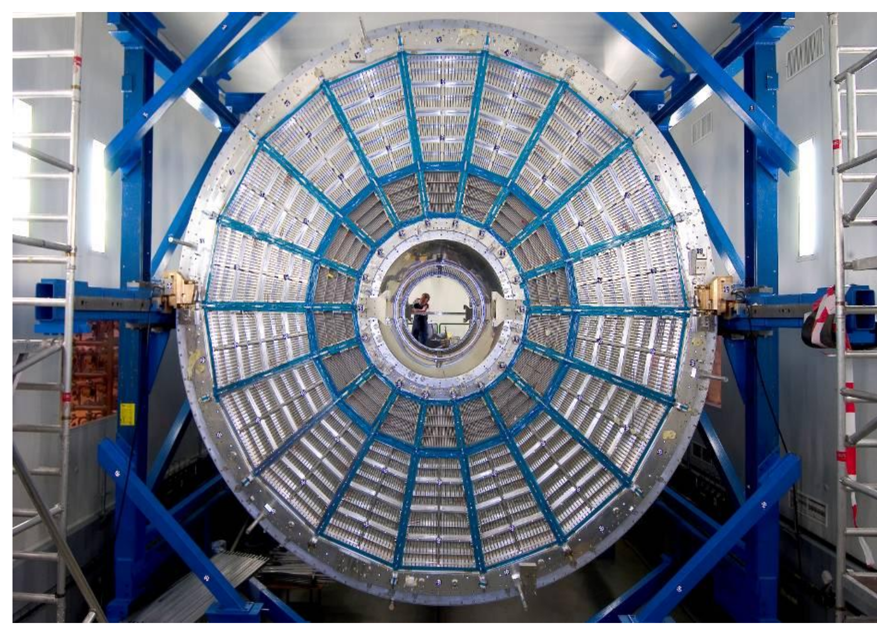
provide also dE/dx for particle idetification



Time Projection Chamber

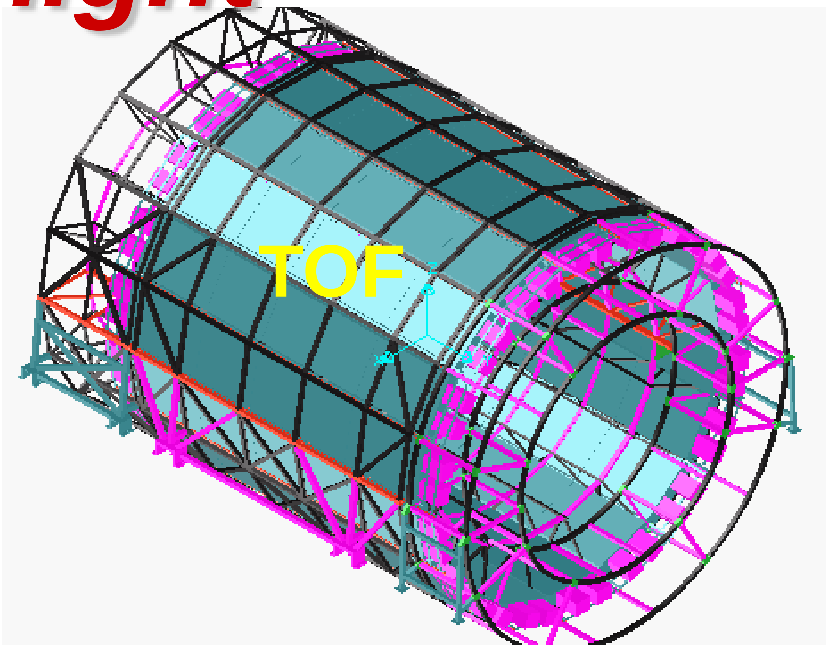
- Main tracking detector
- Characteristics:
  - ⇨R_{in} 90 cm
  - ⇨R_{ext} 250 cm
  - ⇨Length (active volume) 500 cm
  - ⇨Pseudorapidity coverage: $-0.9 < \eta < 0.9$
  - ⇨Azimuthal coverage: 2π
  - ⇨# readout channels ≈560k
  - ⇨Maximum drift time: 88 μs
  - ⇨Gas mixture: 90% Ne 10% CO_2
- Provides: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

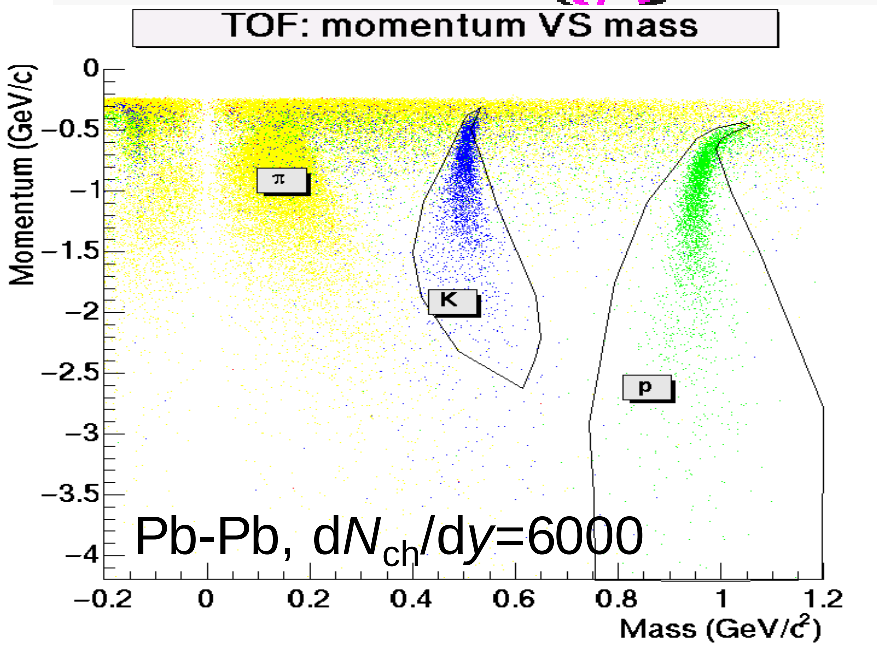




Time Of Flight

- 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





More on B feed-down

The feed down contribution from B decays is estimated from FONLL and B and D efficiencies. 2 methods to estimate feed-down:

$$f_c:\ f_{\text{prompt}} = 1 - \frac{N^{D^{\pm}\,\text{raw}}_{\text{from B}}}{N^{D^{\pm}\,\text{raw}}_{\text{all}}}$$

$$N_b:\ f_{\text{prompt}} = \left(1 + \frac{\epsilon_{\text{from B}}}{\epsilon_{\text{prompt}}} \frac{\left.\frac{d\sigma^{D^+\,\text{from B}}_{\text{FONLL}}}{dp_t}\right|_{|y|<0.5}}{\left.\frac{d\sigma^{D^+}_{\text{FONLL}}}{dp_t}\right|_{|y|<0.5}}\right)^{-1}$$

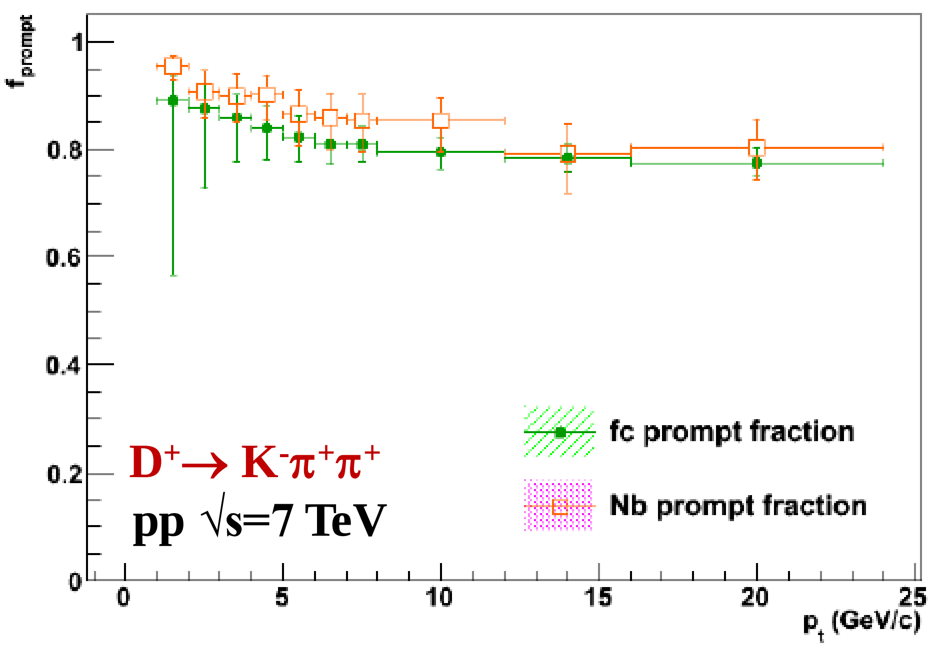
FONLL parameters varied to estimate uncertainties:

$0.5 < \frac{\mu_{F/R}}{m_T} < 2$,

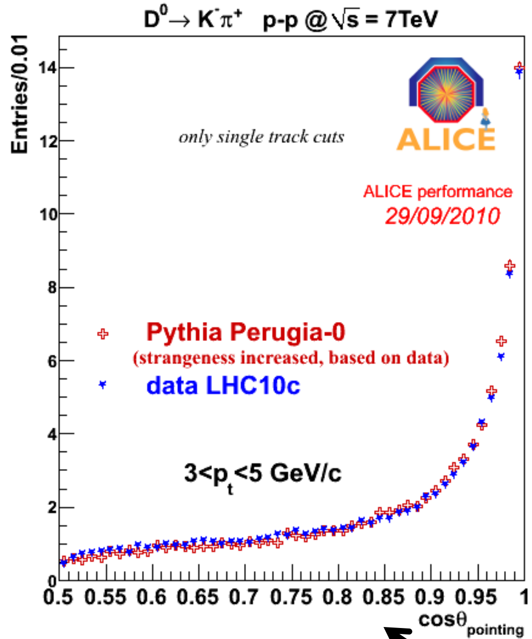
$0.5 < \frac{\mu_F}{\mu_R} < 2$,

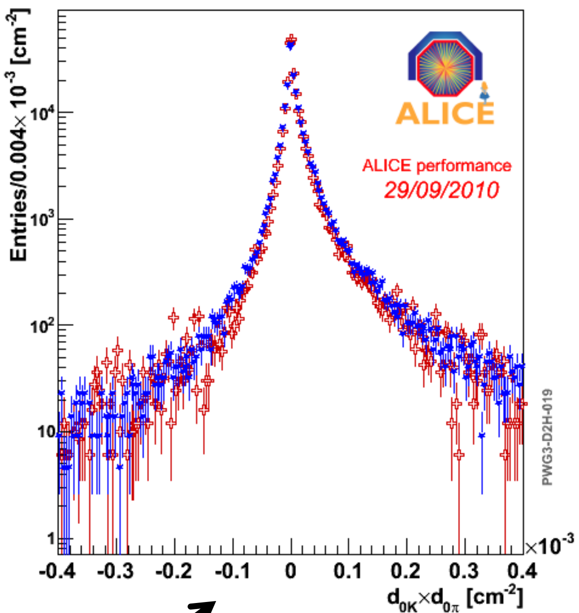
$4.5 < m_b < 5$ GeV,

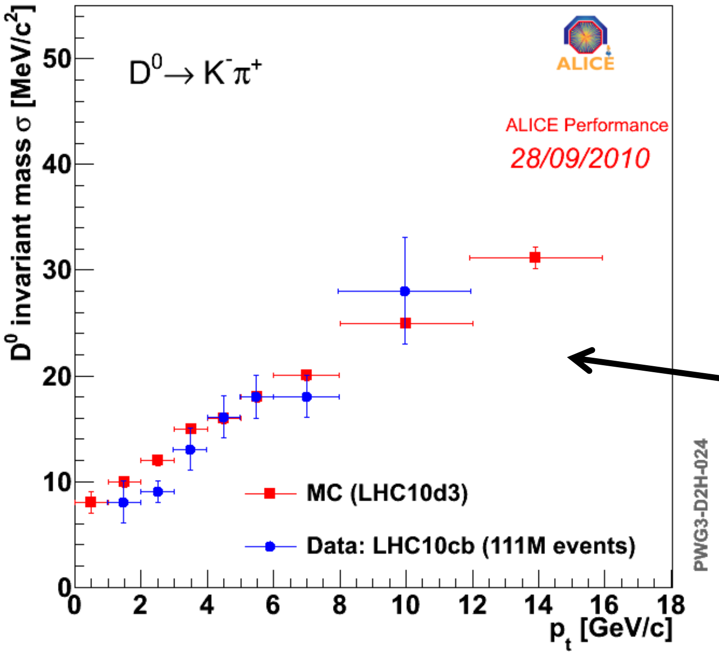
$1.3 < m_c < 1.7$ GeV



D^0: data vs. MC



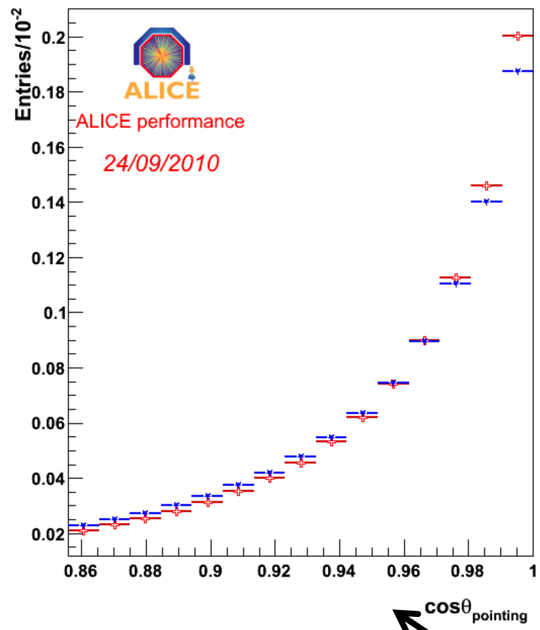


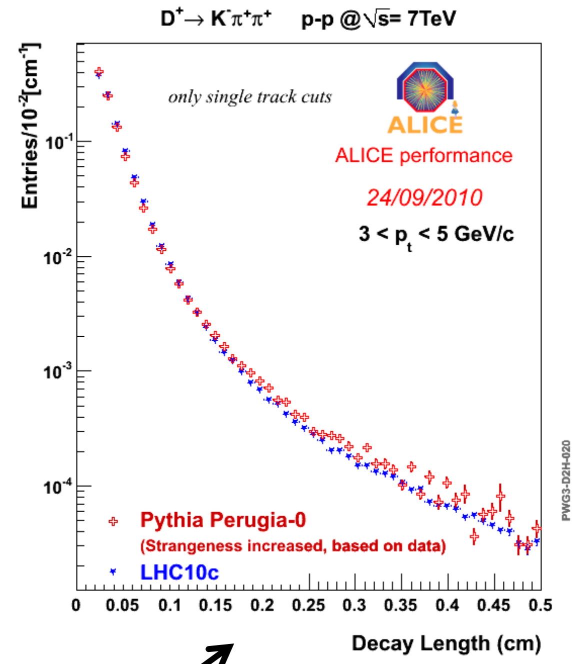


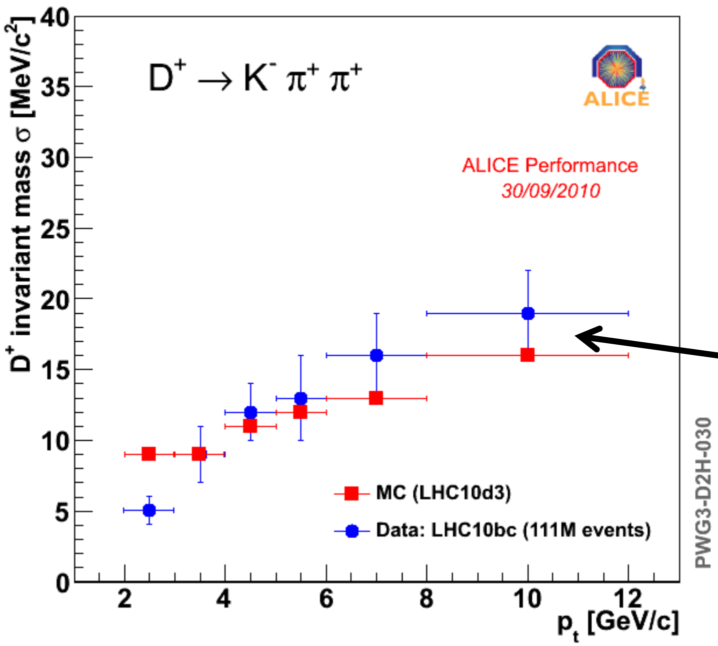
Distributions of cut variables

Sigma of invariant mass peak

D^+: data vs. MC



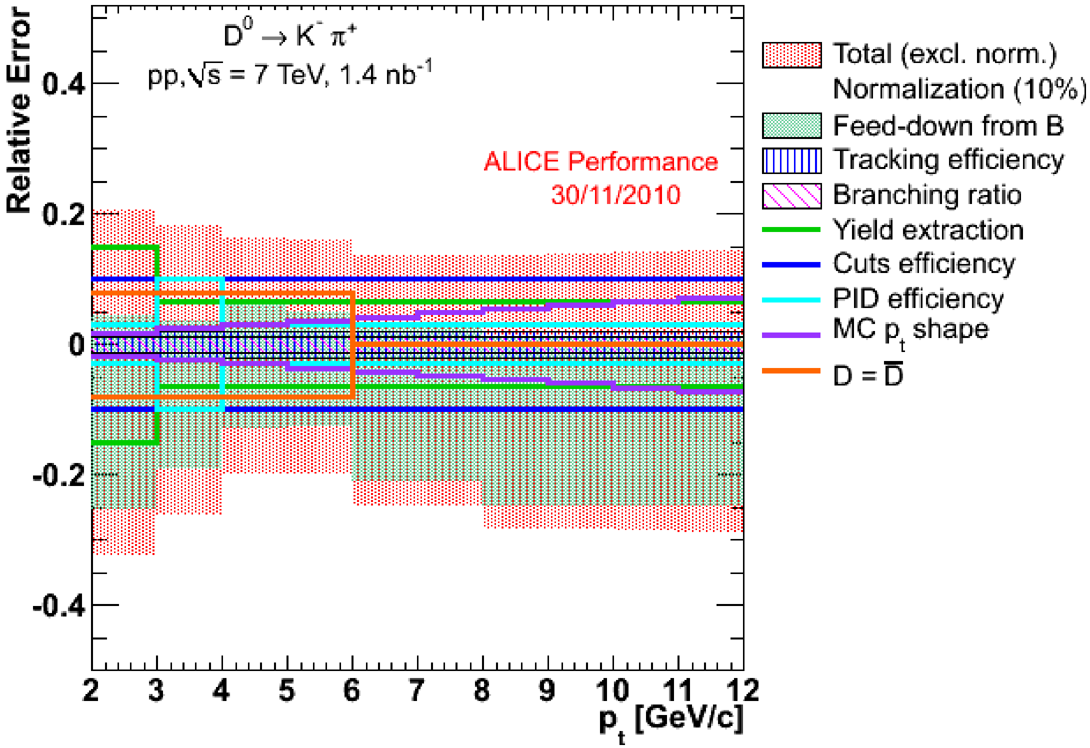


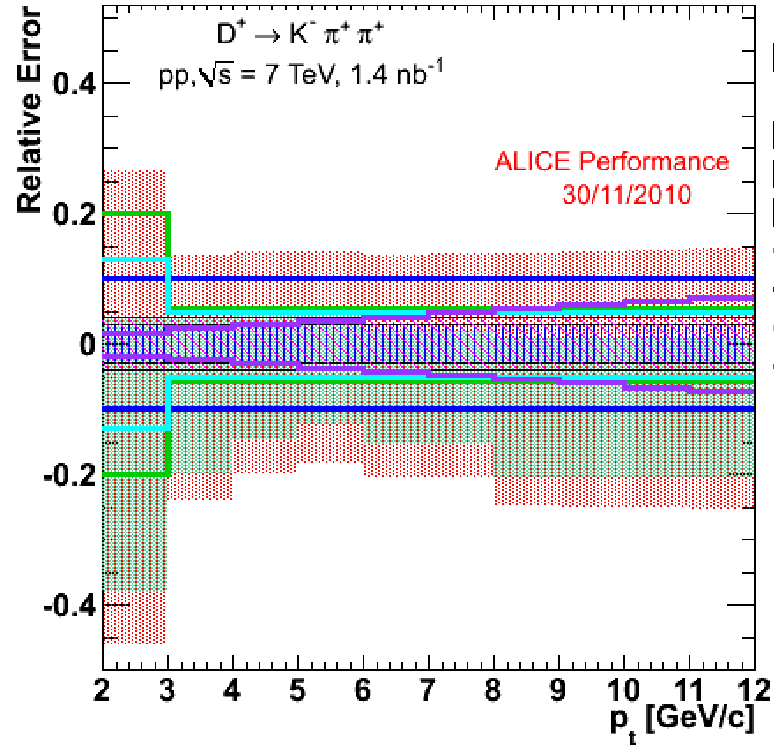


Distributions of cut variables

Sigma of invariant mass peak

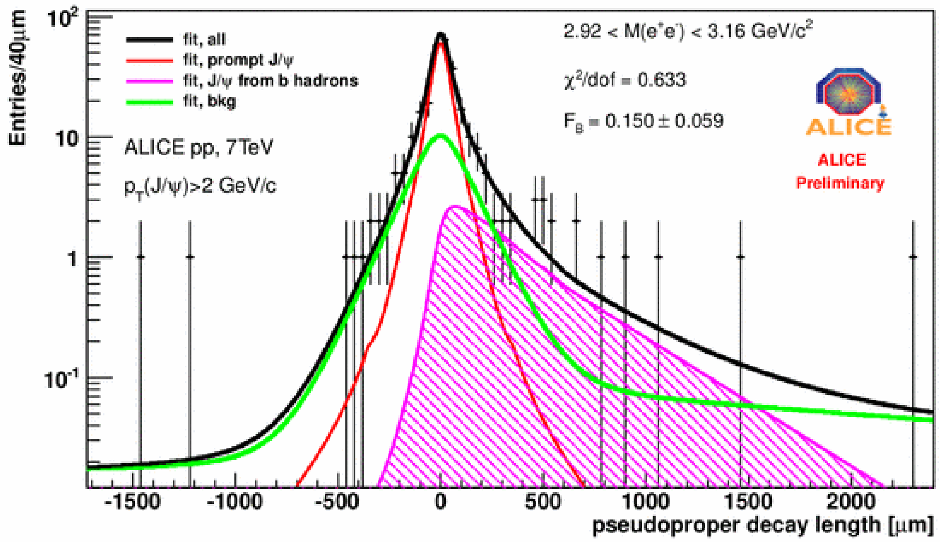
D^0 and D^+: systematics





- 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

Pseudo-proper decay length



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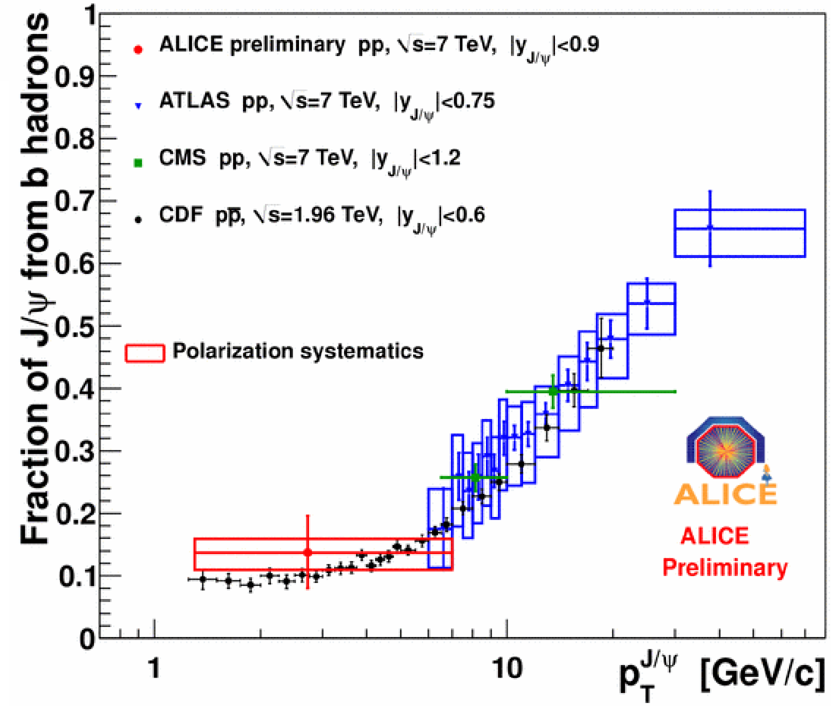
$$x = \boxed{L_{xy}(J/\psi)} \cdot \frac{M_{J/\psi}}{p_T(J/\psi)}$$

$$L_{xy}(J/\psi) = \boxed{\vec{L}} \cdot \frac{\vec{p}_T(J/\psi)}{|\vec{p}_T(J/\psi)|}$$

$$\vec{L} = \vec{r}_{\text{vtx}}^{\,\text{sec}} - \vec{r}_{\text{vtx}}^{\,\text{prim}}$$

- Method from CDF, D. Acosta et al Phys. Rev. D 71 (2005) 032001



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