Open charm mesons measurement in ALICE

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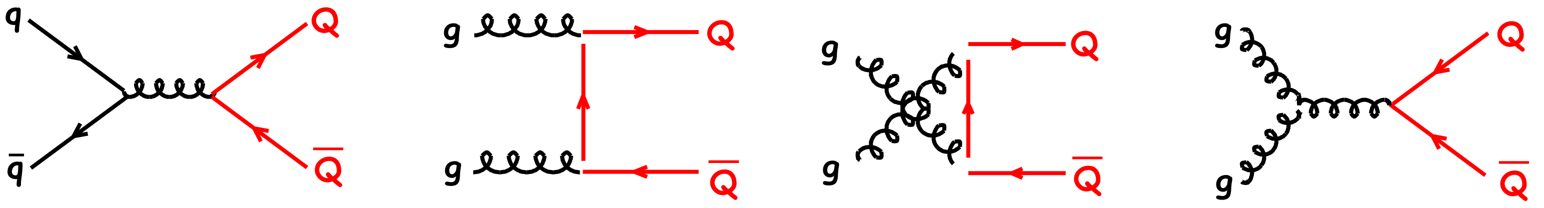
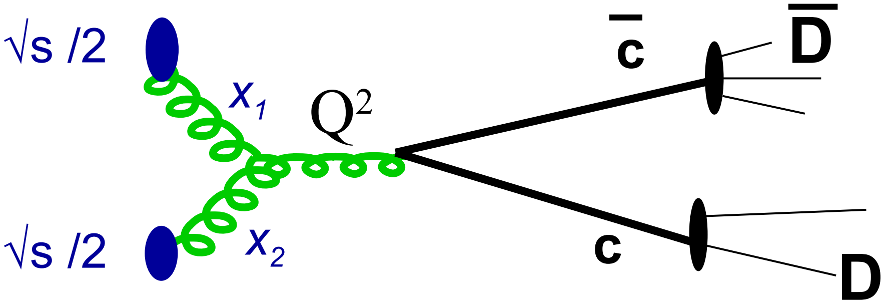
Physics motivation

Charm production: pp collisions

- Hard partonic processes (q-qbar annihilation, gluon fusion)
  - pQCD phenomenon taking place on short time-scale (≈1/m_Q)



- Factorized pQCD approach



$$\sigma_{hh\to Dx} = PDF(x_a)PDF(x_b)\otimes\sigma_{ab\to c\bar{c}}\otimes D_{c\to D}(z_c)$$

cross-section at hadron level

Parton Distribution Functions x_a , x_b= momentum fraction of partons a, b in hadrons

cross-section at parton level

fragmentation
$z = p_D / p_c$

Charm production: AA collisions

- Hard primary production in parton processes (pQCD)
  - Binary scaling for hard process yield:

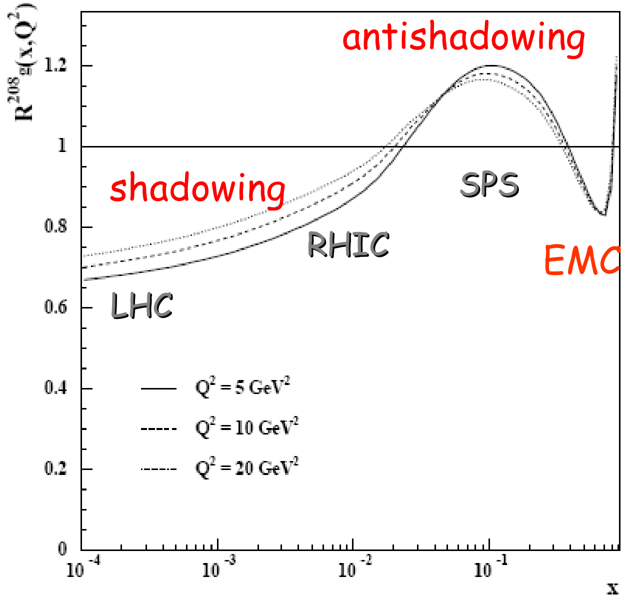
$$\mathrm{d}N_{AA}/\mathrm{d}p_T = N_{coll} \times \mathrm{d}N_{pp}/\mathrm{d}p_T$$

  - long lifetime of charm quarks allows them to live through the thermalization phase of the QGP and be affected by its presence
- Secondary (thermal) c-cbar production in the QGP
  - m_c (≈1.2 GeV) only 10%-50% higher than predicted temperature of QGP at the LHC (500-800 MeV)
  - Thermal yield expected much smaller than hard primary production
    - ✓ ***can be observed if the pQCD production in A-A is precisely understood***

Binary scaling break-up

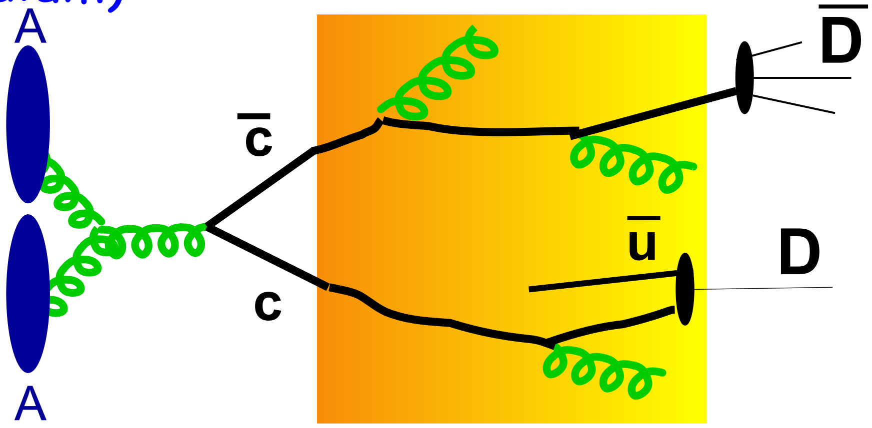
- Initial state effects
  - PDFs in nucleus different from PDFs in nucle
    - ✓ ***Anti-shadowing and shadowing***
  - k_T broadening (Cronin effect)
  - Parton saturation (Color Glass Condensate)

Present also in pA (dA) collisions
Concentrated at lower p_T



- Final state effects (due to the medium)
  - Energy loss
    - ✓ ***Mainly by gluon radiation***
  - In medium hadronization
    - ✓ ***Recombination vs. fragmentation***

Only in AA collisions
Dominant at higher p_T



Final state effects: energy loss

- BDMPS formalism for radiative energy loss
  - Baier et al., Nucl. Phys. B483 (1997) 291)

$$\langle \Delta E \rangle \quad \alpha_s \; C_R \;\; q \;\; L^2$$

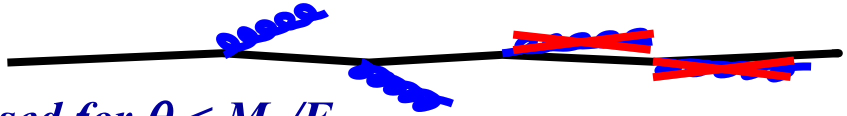
average energy loss

Casimir coupling factor

transport coefficient of the medium

distance travelled in the medium

- Energy loss for heavy flavours is expected to be reduced by:
  - Casimir factor
    - ✓ ***light hadrons originate predominantly from gluon jets, heavy flavoured hadrons originate from heavy quark jets***
    - ✓ ***C_R is 4/3 for quark-gluon coupling, 3 for gluon-gluon coupling***
  - Dead-cone effect



- ✓ ***gluon radiation expected to be suppressed for $\theta < M_Q/E_Q$***
  - Dokshitzer & Karzeev, Phys. Lett. **B519** (2001) 199
  - Armesto et al., Phys. Rev. D69 (2004) 114003

Experimental observables

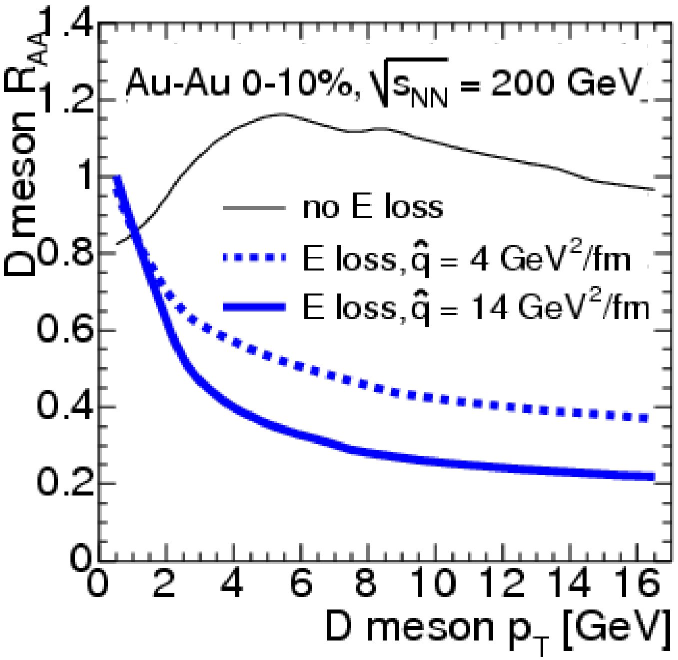
Observables: R_{AA}

- Nuclear modification factor

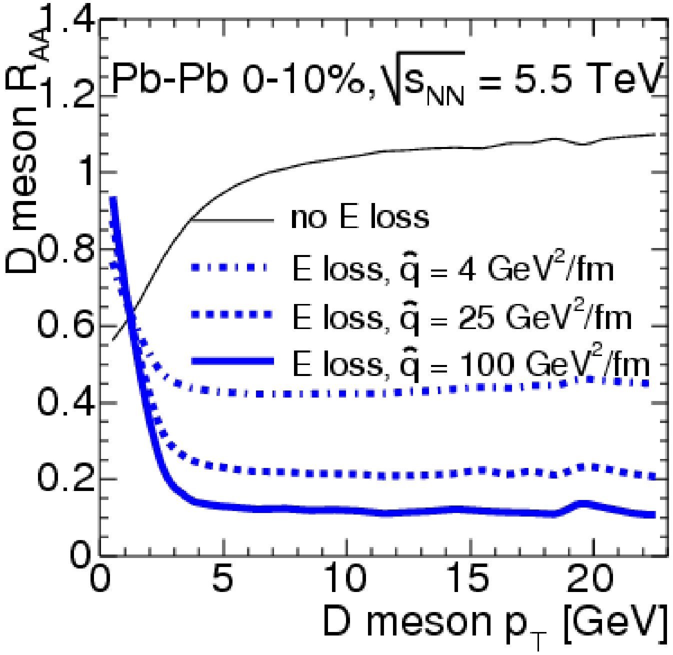
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

  - $R_{AA} \neq 1$ ⇨ binary scaling violation
    - ✓ ***Low p_T → main effect = nuclear shadowing***
    - ✓ ***High p_T → main effect = energy loss***

RHIC

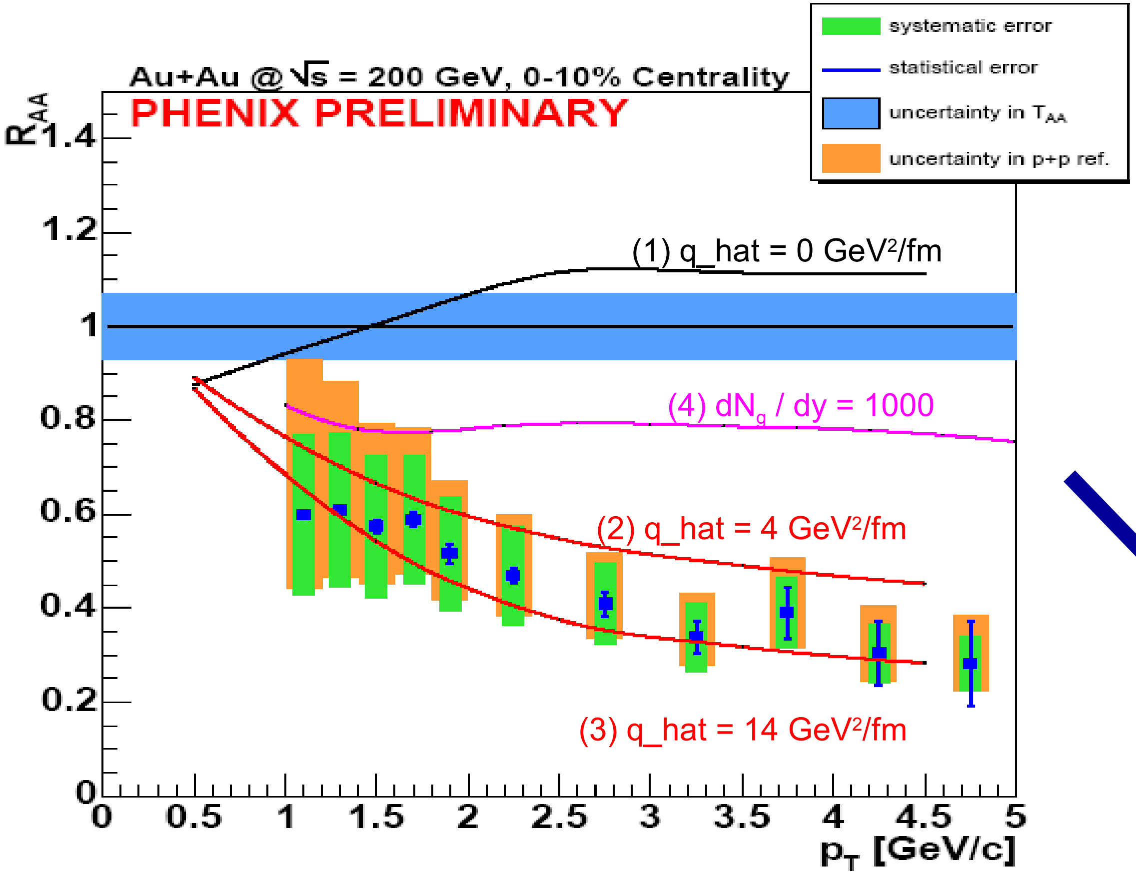


LHC



RHIC results: non-photonic electrons

Nuclear modification factor



The medium is so dense that c quarks lose energy (by gluon radiation)

Charm in ALICE

Charm at the LHC (I)

	SPS	RHIC	LHC
$\sqrt{s}$ (GeV)	17.2	200	5500
N_{cc}	≈ 0.2	≈10	≈100-200
x (at $y=0$)	≈ 10^{-1}	≈ 10^{-2}	≈ 10^{-4}

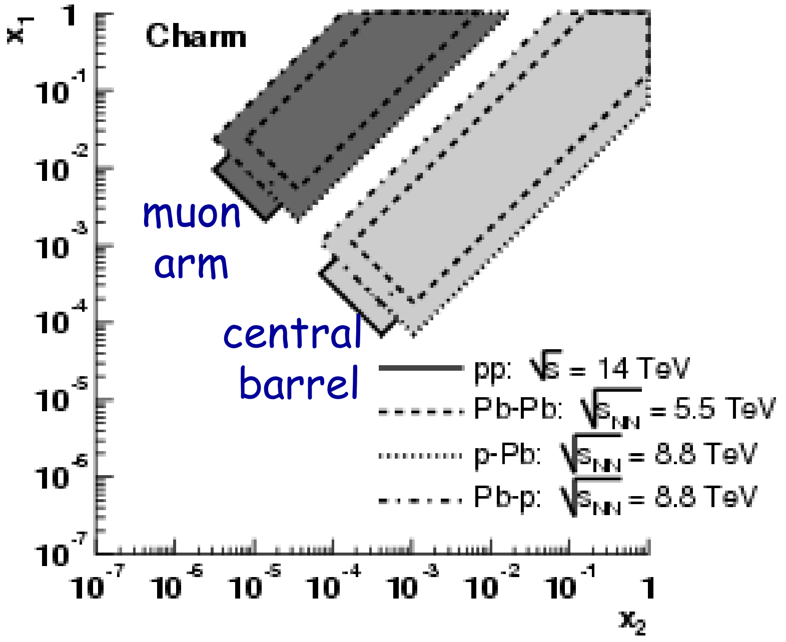
- Large cross-section
  - Much more abundant production with respect to SPS and RHIC

$$\sigma_{LHC}^{c\bar{c}} \approx 10-20\times\sigma_{RHIC}^{c\bar{c}}$$

- Small x

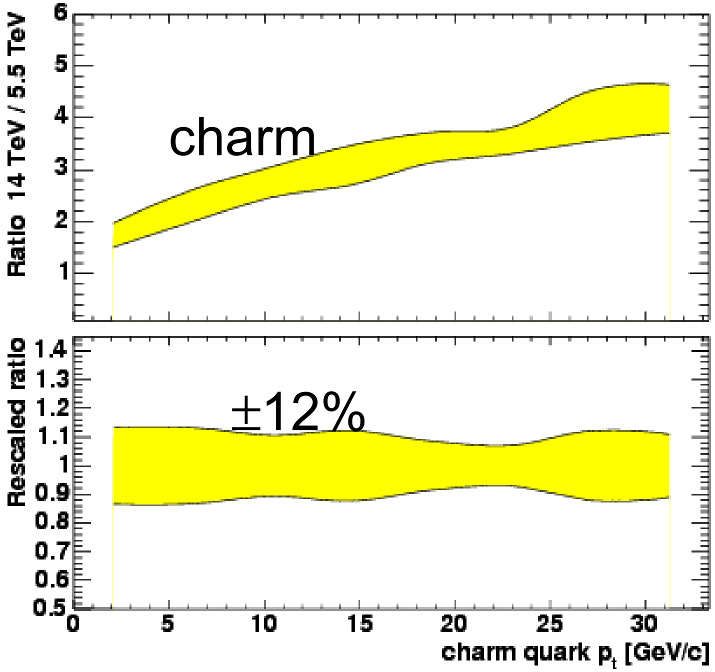
$$x_1 = \frac{A_1}{Z_1}\frac{M_{c\bar{c}}}{\sqrt{s}_{pp}}e^{y_{c\bar{c}}} \qquad x_2 = \frac{A_2}{Z_2}\frac{M_{c\bar{c}}}{\sqrt{s}_{pp}}e^{-y_{c\bar{c}}}$$

  - unexplored small-x region can be probed with charm at low p_T and/or forward rapidity
    - ✓down to $x \sim 10^{-4}$ at $y=0$ and $x \sim 10^{-6}$ in the muon arm



Charm at the LHC (II)

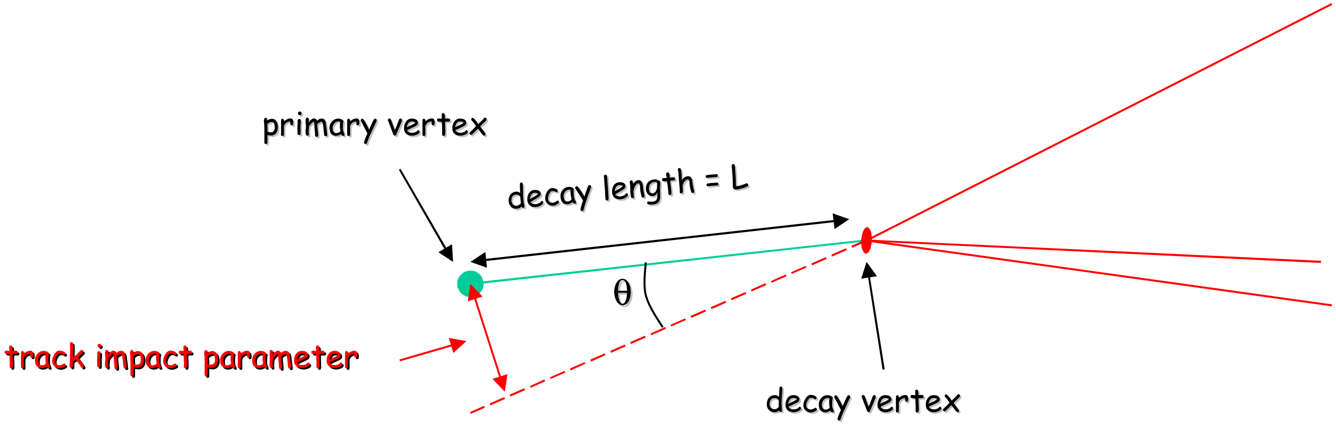
- p-p collisions
  - Test of pQCD in a new energy and x regime
  - Reference for Pb-Pb (necessary for R_{AA})
- p-Pb collisions
  - Probe nuclear PDFs at LHC energy
  - Disentangle initial and final state effects
- Pb-Pb collisions
  - Probe the medium formed in the collision
- ***WARNING:*** pp, pPb and PbPb will have different $\sqrt{s}$ values
  - Need to extrapolate from 14 TeV to 5.5 TeV to compute R_{AA}
    - *Small (≈ 10%) theoretical uncertainty on the ratio of results at 14 and 5.5 TeV*



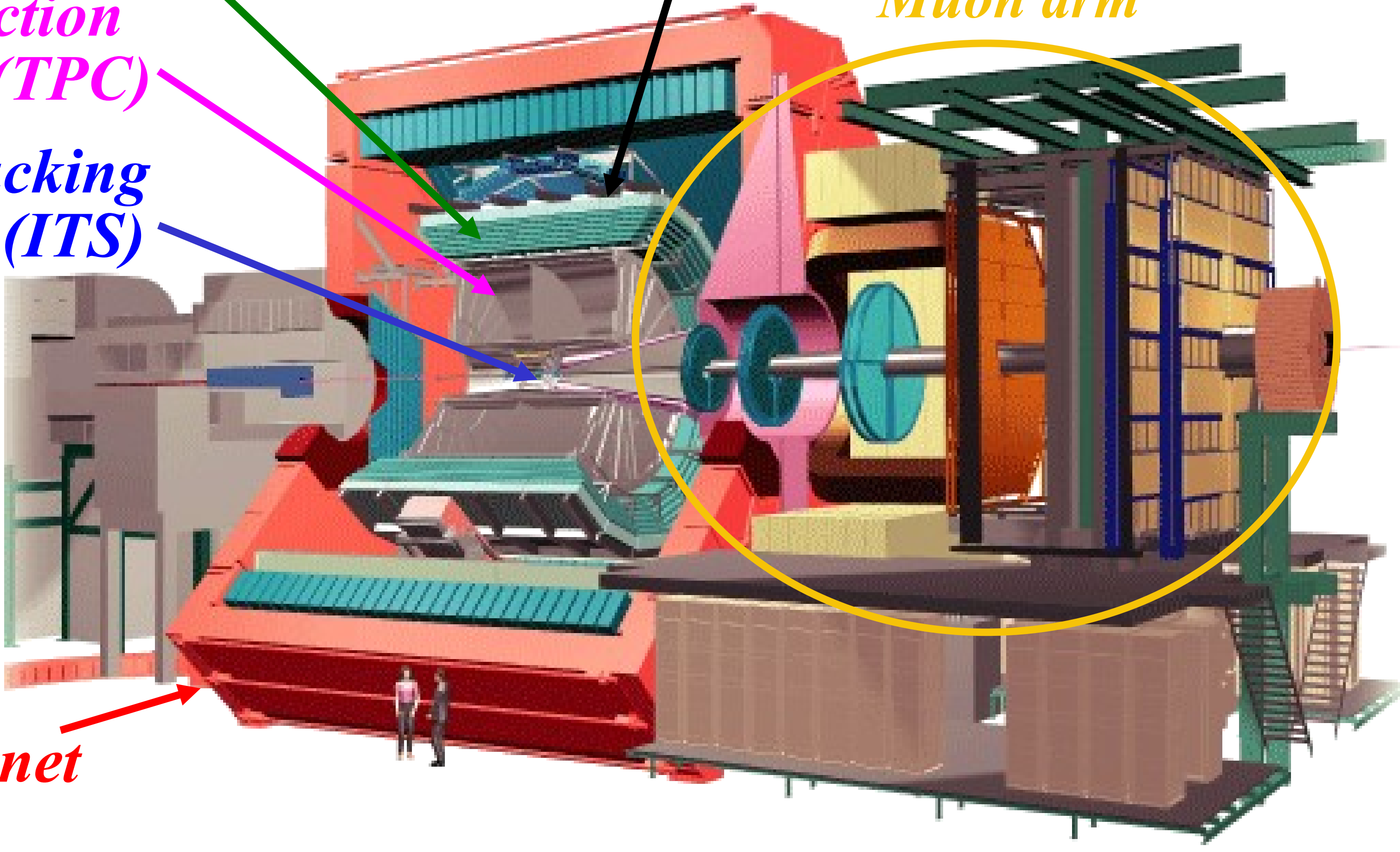
Charmed mesons and baryons

- Weakly decaying charm states
  - Mean proper length ≈ 100 μm
- Main selection tool: displaced-vertex
  - Tracks from open charm decays are typically displaced from primary vertex by ≈100 μm
  - Need for high precision vertex detector (resolution on track impact parameter ≈ tens of microns)

Meson	**Mass (MeV)**	**$c\tau$ (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



ALICE at the LHC



Time Of Flight (TOF)

Transition Radiation Detector (TRD)

Time Projection Chamber (TPC)

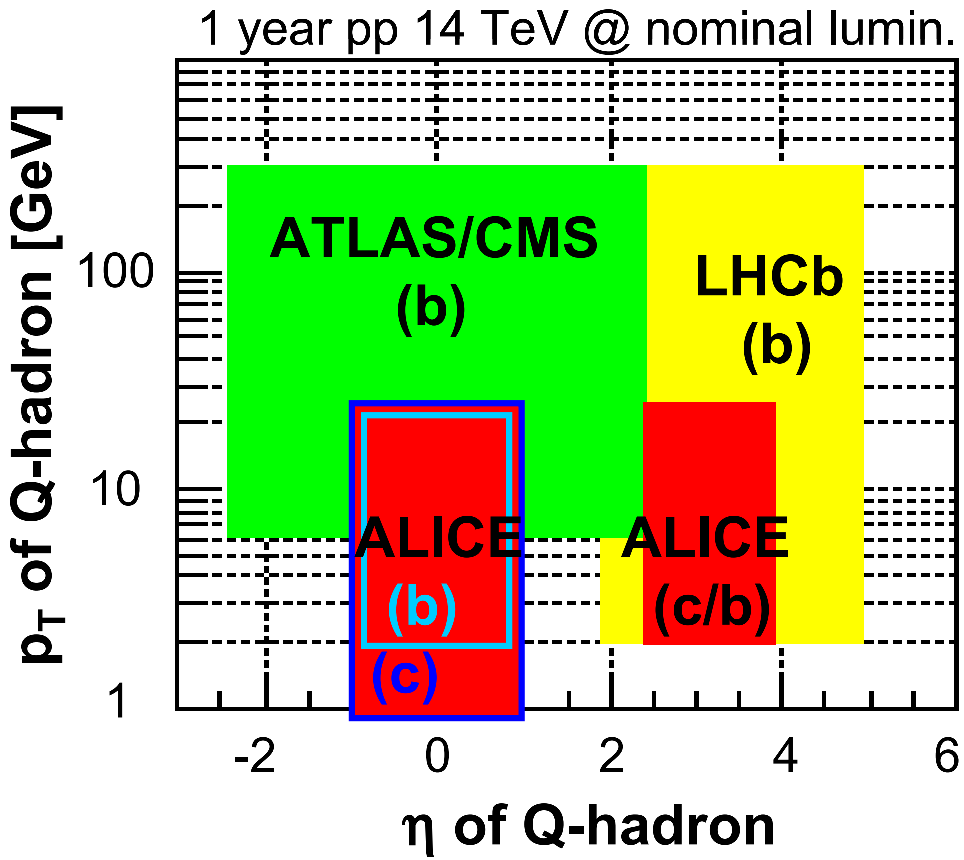
Muon arm

Inner Tracking System (ITS)

L3 magnet

Heavy-flavours in ALICE

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

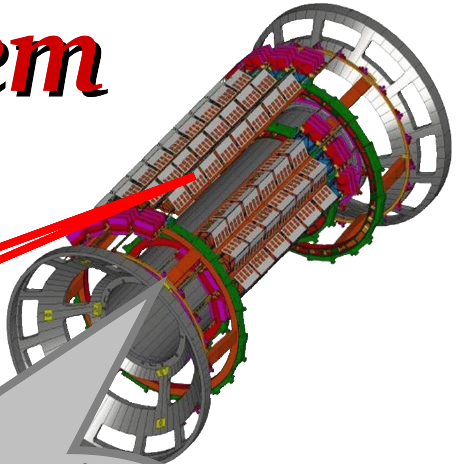


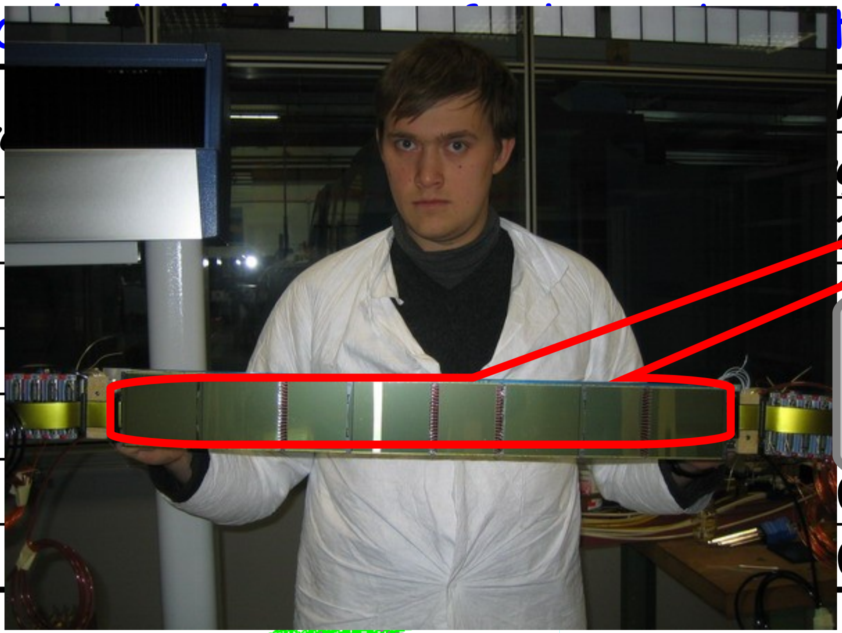
Inner Tracking System

- 6 c tors:

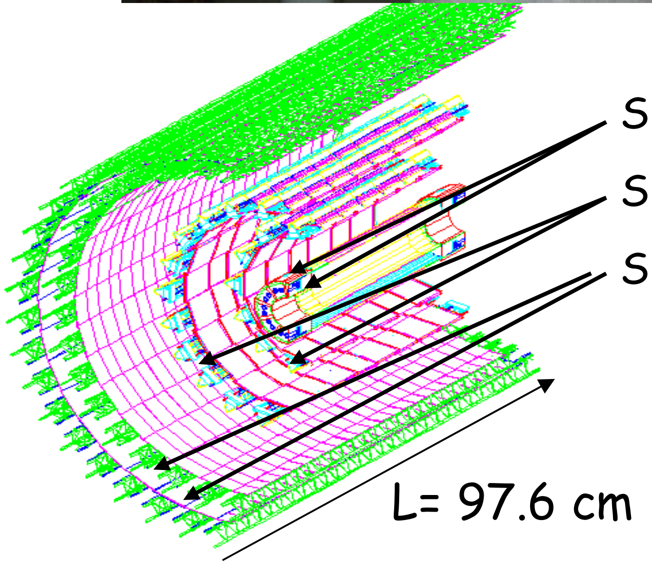
Lay	ial resolution (μm)	
	ϕ	z
1	2	100
2		
3		
4		
5	0	830
6	0	830

de also
x for
particle
idetification





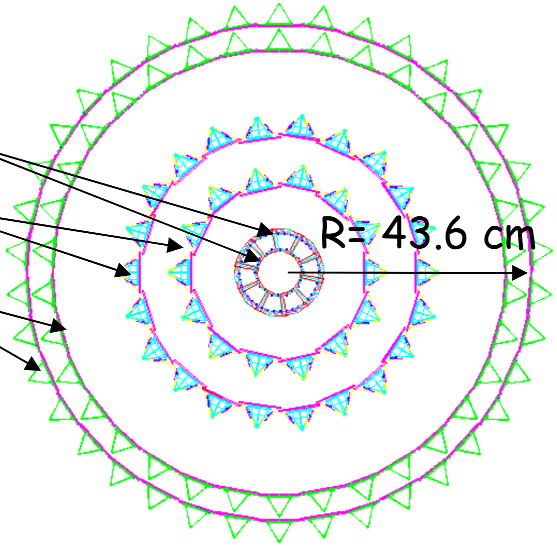
Made in Turin (SDD)



Silicon Pixel Detectors (2D)

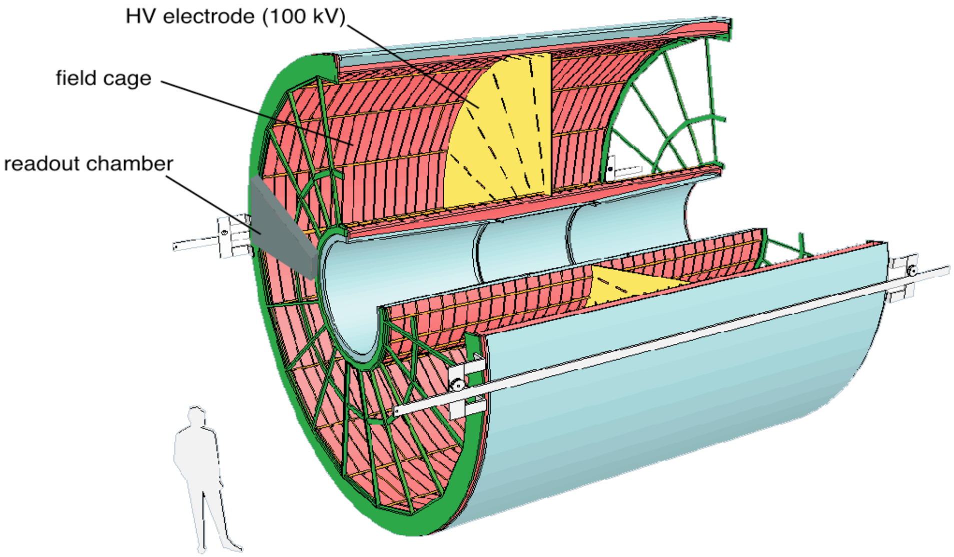
Silicon Drift Detectors (2D)

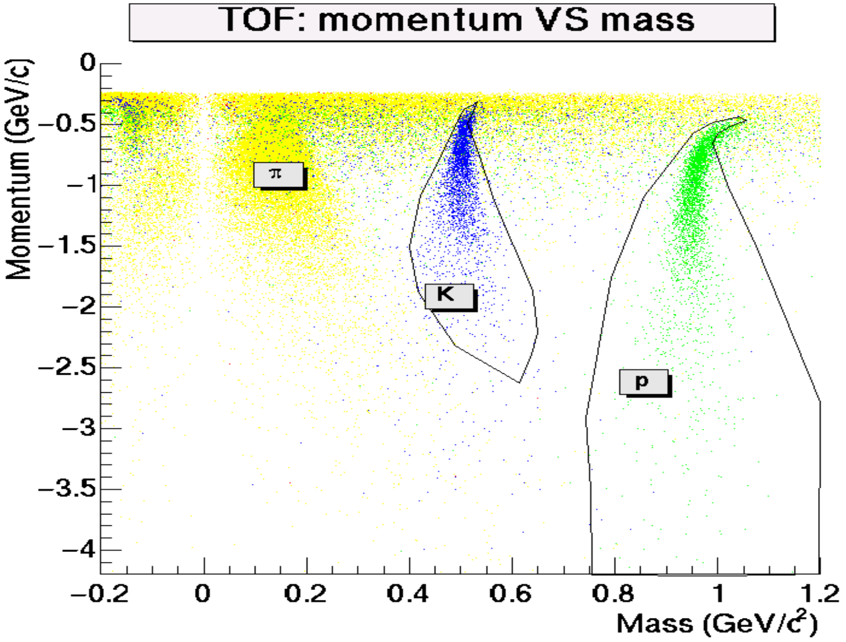
Silicon Strip Detectors (1D)



Time Projection Chamber and Time Of Flight

- TPC Provides:
  - Many 3D points per track
  - Tracking efficiency > 90%
  - Particle identification by dE/dx
    - ✓ in the low-momentum region
    - ✓ in the relativistic rise





- TOF 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

D mesons simulation and reconstruction

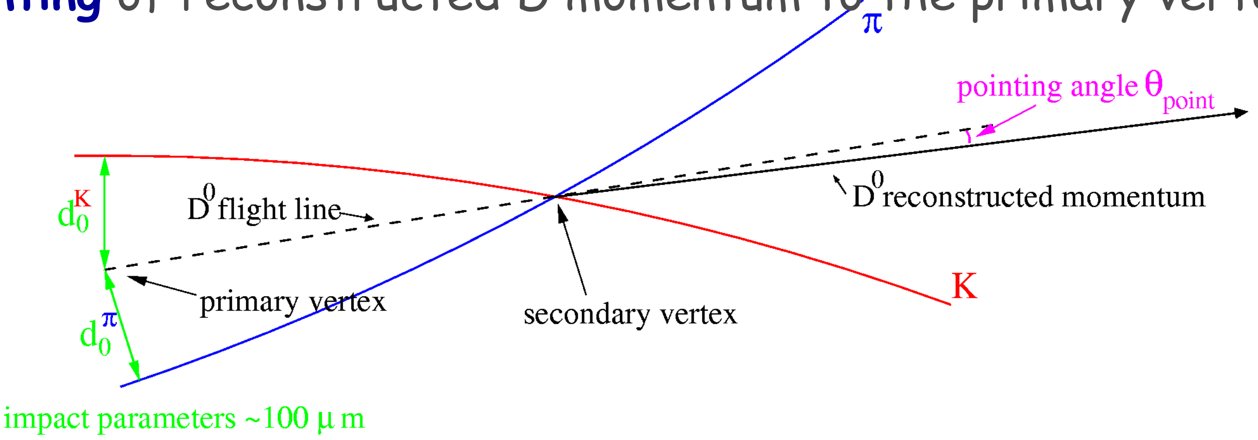
D mesons: hadronic decays

- Most promising channels for exclusive charmed meson reconstruction

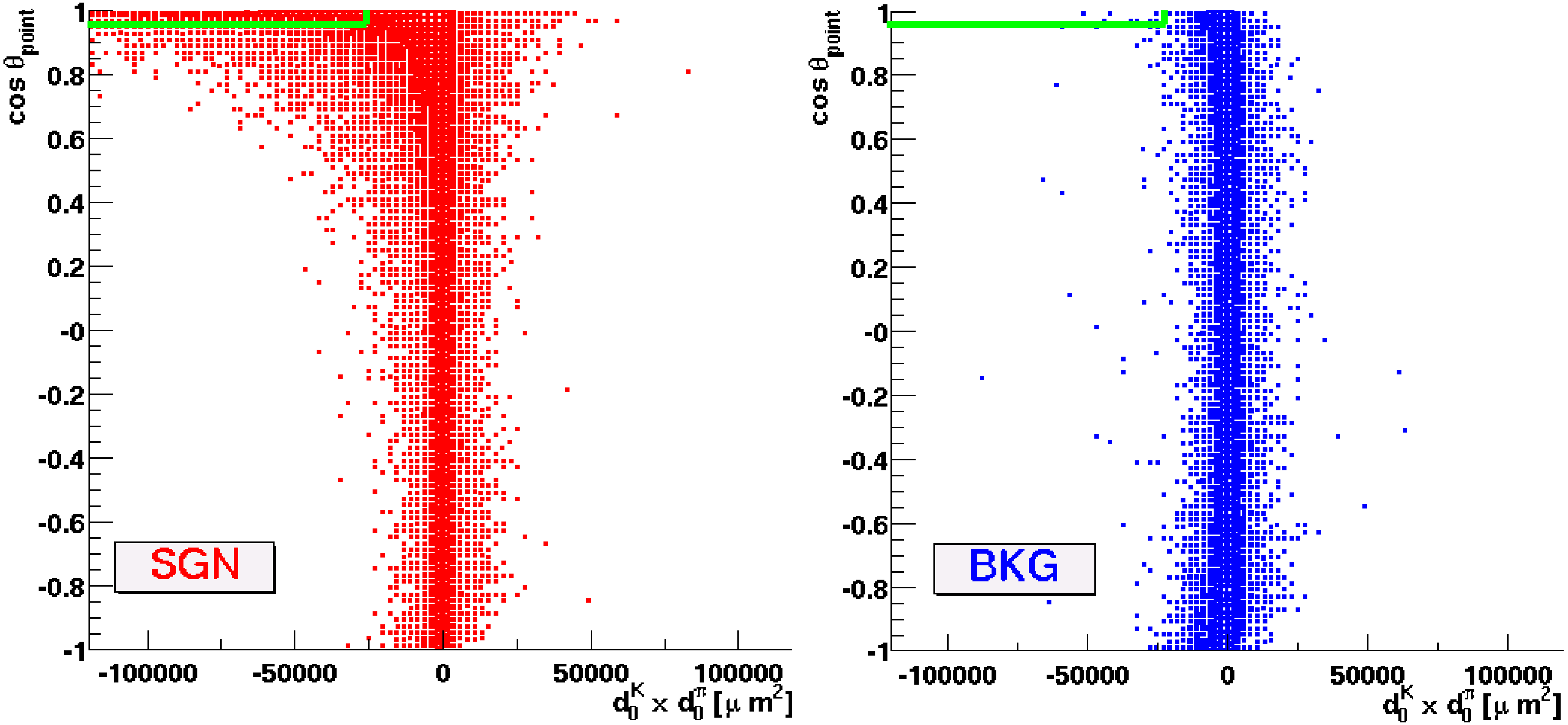
Meson	*Final state*	*# charged bodies*	*Branching Ratio*	
D^0	$\rightarrow K^-\pi^+$	2	**3.8%**	
	$\rightarrow K^-\pi^+\pi^+\pi^-$	4	**Total**	**7.48%**
			Non resonant	1.74%
			$D^0 \rightarrow K^-\pi^+\rho^0 \rightarrow K^-\pi^+\pi^+\pi^-$	6.2%
D^+	$\rightarrow K^-\pi^+\pi^+$	3	**Total**	**9.2%**
			Non resonant	8.8%
			$D^+ \rightarrow$ Kbar^{0*}(892)$\pi^+ \rightarrow K^-\pi^+\pi^+$	1.29%
			$D^+ \rightarrow$ Kbar^{0*}(1430)$\pi^+ \rightarrow K^-\pi^+\pi^+$	2.33%
D_s^+	$\rightarrow K^+K^-\pi^+$	3	**Total**	**4.3%**
			$D_s^+ \rightarrow K^+$Kbar$^{0*} \rightarrow K^+K^-\pi^+$	2.0%
			$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$	1.8%

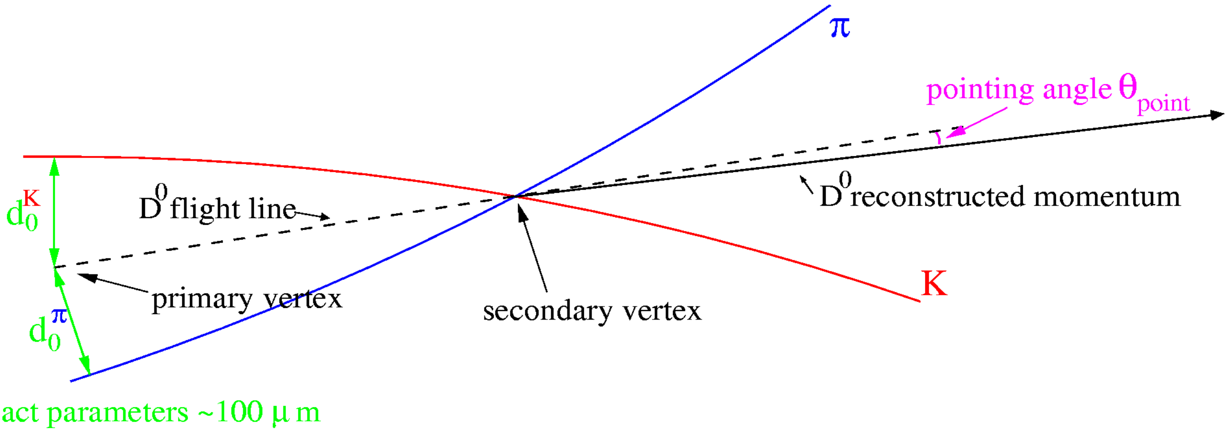
D mesons in central barrel

- No dedicated trigger in the central barrel → extract the signal from Minimum Bias events
  - Large combinatorial background (benchmark study with dN_{ch}/dy = 6000 in central Pb-Pb!)
- SELECTION 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** to tag the decay products
  - calculate the **vertex (DCA point)** of the tracks
  - **good pointing** of reconstructed D momentum to the primary vertex

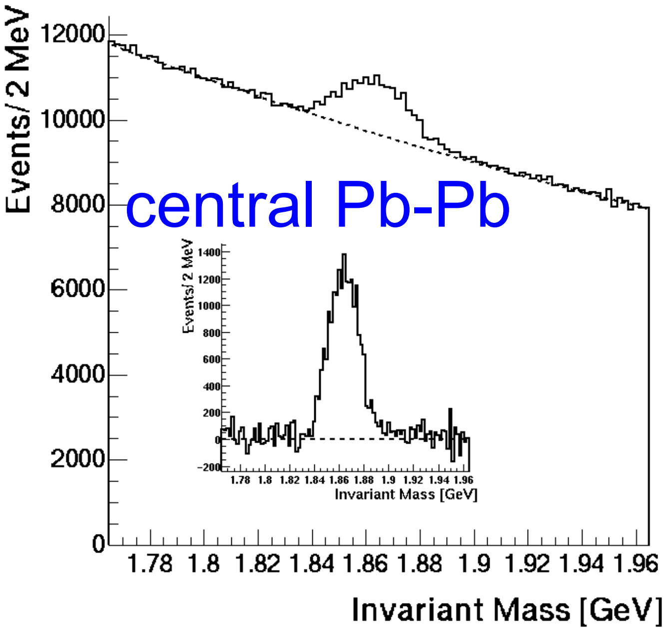


$D^0 \rightarrow K^- \pi^+$: selection of candidates





$D^0 \rightarrow K^-\pi^+$: Results (I)



	S/B initial $(M\pm3\sigma)$	S/B final $(M\pm1\sigma)$	Significance $S/\sqrt{S+B}$ $(M\pm1\sigma)$
Pb-Pb Central $(dN_{ch}/dy = 6000)$	$5 \cdot 10^{-6}$	10%	~35 (for 10^7 evts, ~1 month)
pPb min. bias	$2 \cdot 10^{-3}$	5%	~30 (for 10^8 evts, ~1 month)
pp	$2 \cdot 10^{-3}$	10%	~40 (for 10^9 evts, ~7 months)

With $dN_{ch}/dy = 3000$ in Pb-Pb, S/B larger by × 4 and significance larger by × 2

Motivation to study other mesons (D_s & D^+)

- To measure charm yield more precisely we need to measure as many channels as we can
- Study of different ways of hadronization:
  - String fragmentation:

    D_s^+ (cs) / D^+ (cd) ~ 1/3
  - Recombination:

    D_s^+ (cs) / D^+ (cd) ~ N(s)/N(d) (~ 1 at LHC?)

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

Advantages

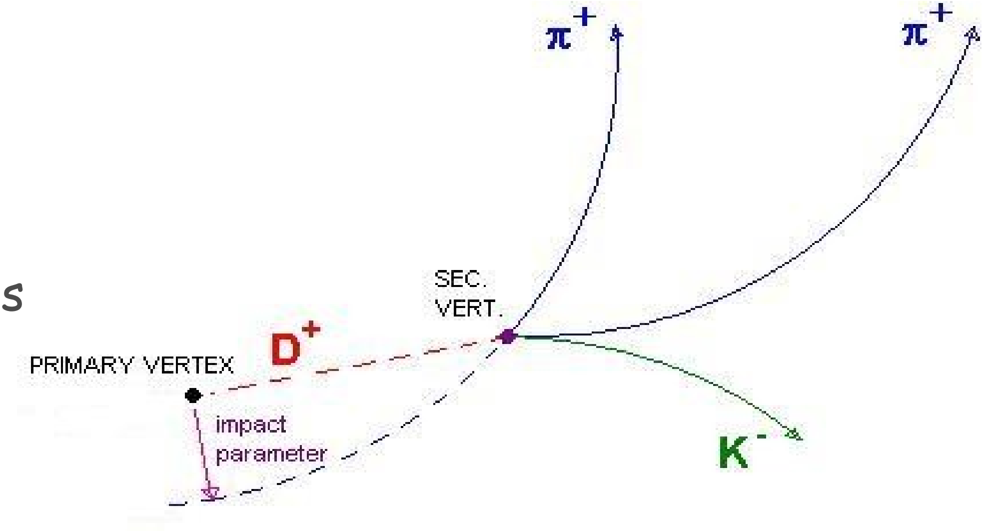
- D^+ has a longer mean proper length ($c\tau$ ~312 μm compared to ~123 mm of the D^0)
- $D^+ \rightarrow K^-\pi^+\pi^+$ has a larger branching ratio (9.2% compared to 3.8% for $D^0 \rightarrow K^-\pi^+$)
- Possibility to exploit the resonant decay through Kbar^{0*} to enhance S/B

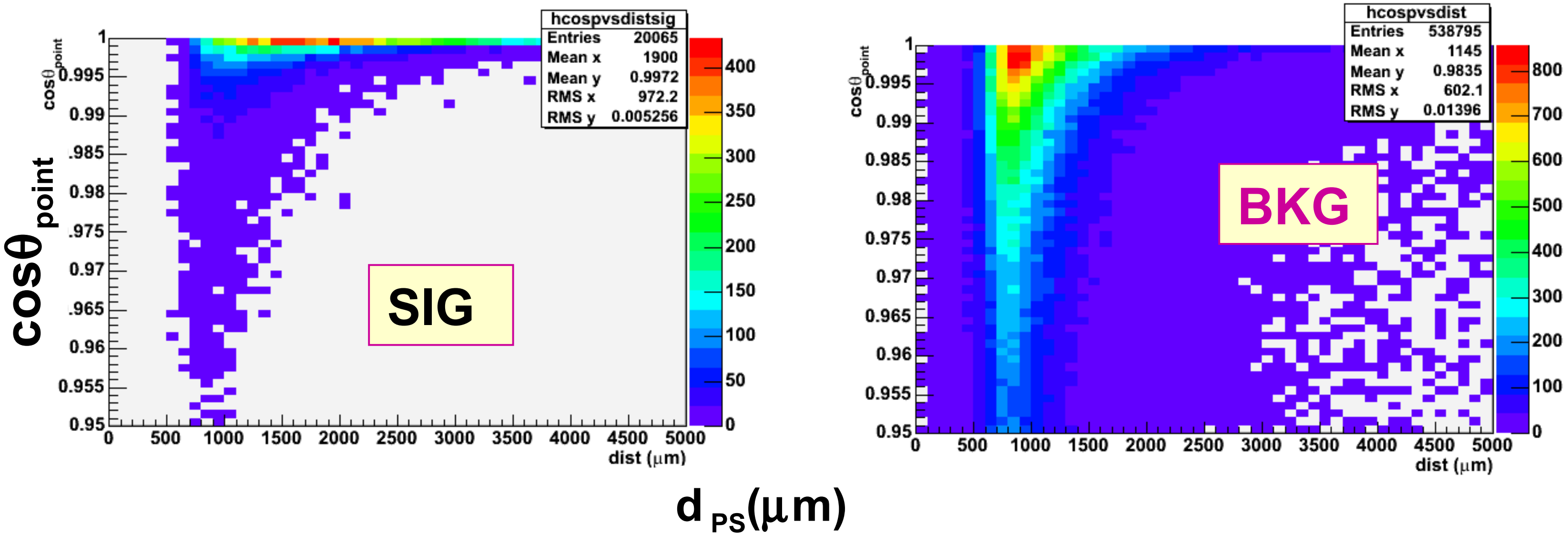
Drawbacks

- Larger combinatorial background (3 decay products instead of the 2 of the $D^0 \rightarrow K^-\pi^+$)
- Smaller $\langle p_T \rangle$ of the decay products (~ 0.7 GeV/c compared to ~ 1 GeV/c of the D^0 decay products)
- D^+ less abundant than D^0 (factor 2-3)

D^+ final selection steps (I)

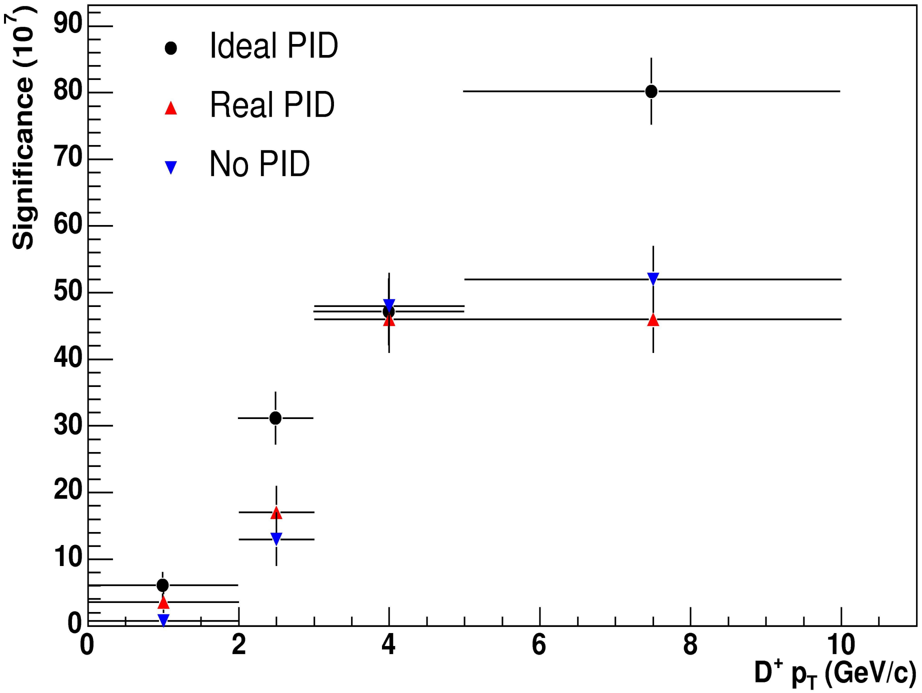
- Four selection variables:
  - Distance between primary and secondary vertex (d_{PS})
  - $\cos\theta_{point}$
  - Sum of squared impact parameters $s = d_{01}^2+d_{02}^2+d_{03}^2$
  - Max. p_T among the 3 tracks $p_M=Max\{p_{T1},p_{T2},p_{T3}\}$

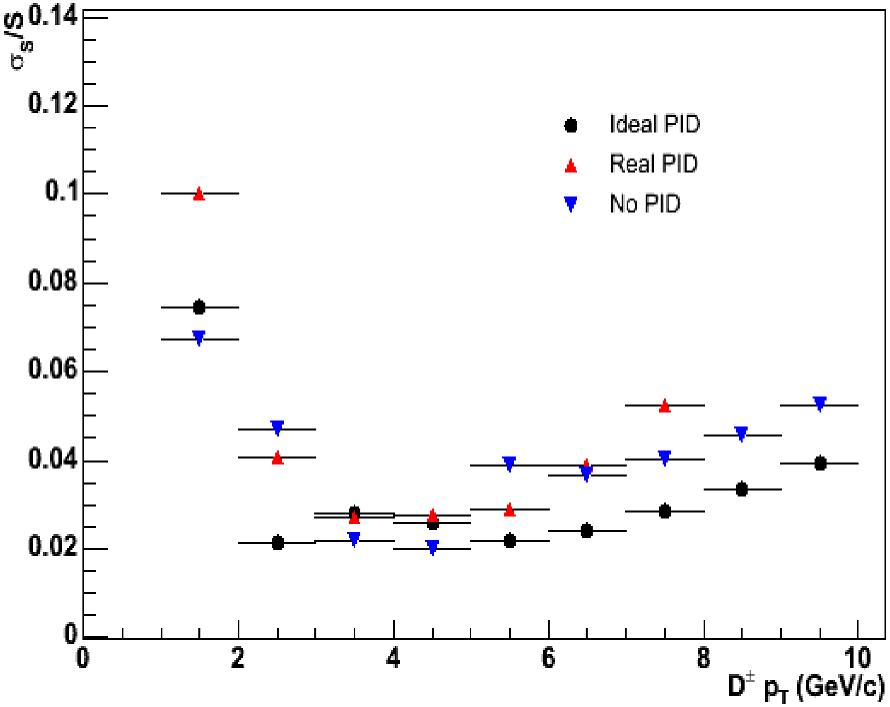




D^+ Results: PbPb (I)

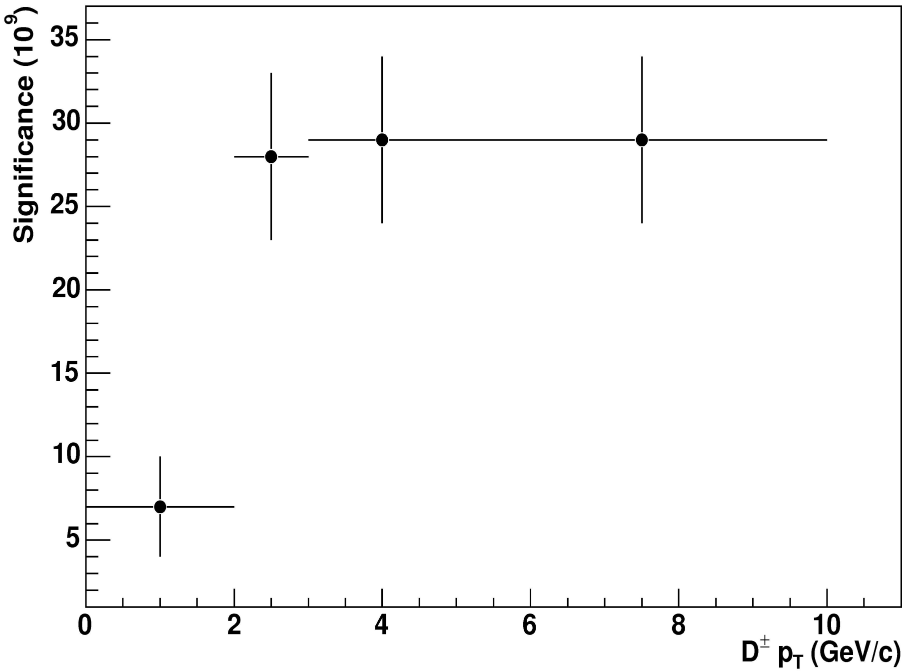
- Significance and relative statistical error vs. D^+ p_T
  - $S/ev \sim 10^{-3}$, $B/ev \sim 10^{-4}$
  - Significance and relative statistical error ($=1/\sqrt{S}$) normalized to 10^7 central PbPb events

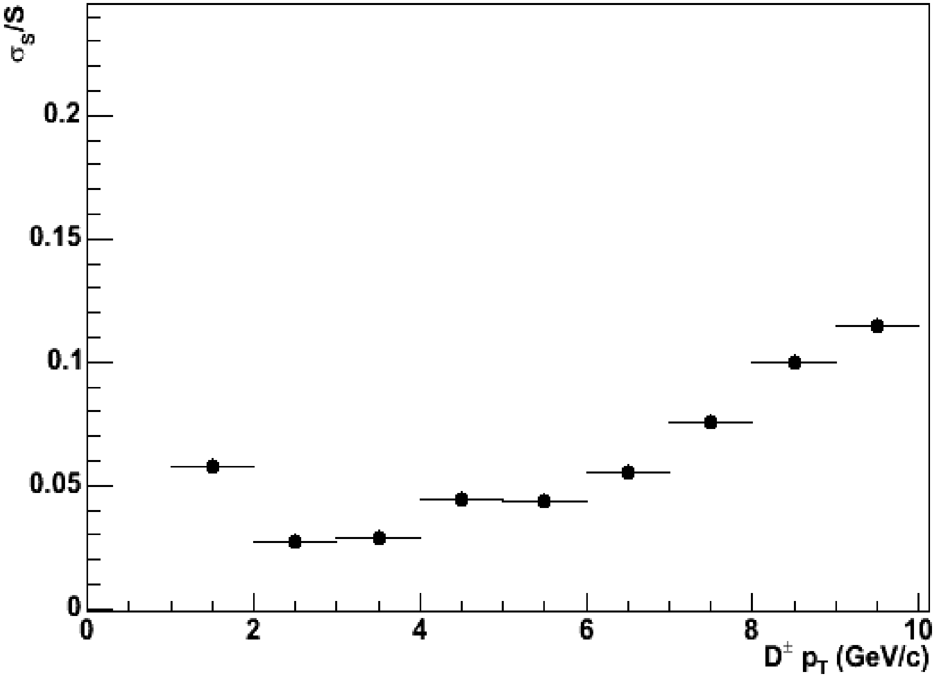




D^+ Results: pp (I)

- Significance and relative statistical error vs. D^+ p_T
  - S/ev~5 10^{-6} , B/ev ~5 10^{-6}
  - Significance and relative statistical error (=1/√S) normalized to 10^9 pp Minimum Bias events





$D_s^+ \rightarrow K^+K^-\pi^+$ vs. $D^+ \rightarrow K^-\pi^+\pi^+$

Advantages

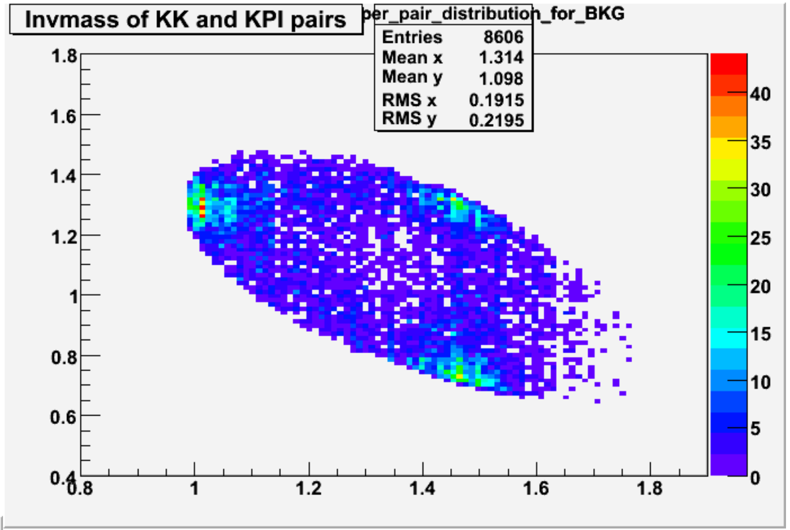
- Smaller combinatorial background if particle identification is efficient (kaons are less abundant than pions)
- Larger fraction of $D_s^+ \rightarrow K^+K^-\pi^+$ from resonant decays (through Kbar0* or ϕ) with respect to D^+

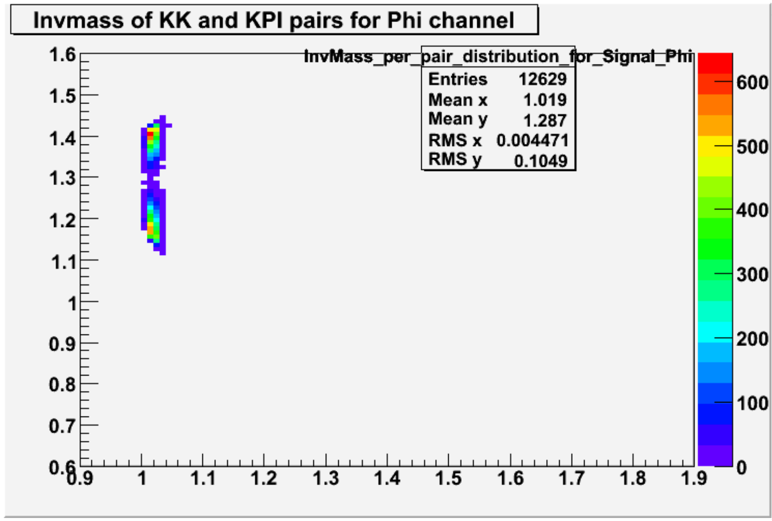
Drawbacks

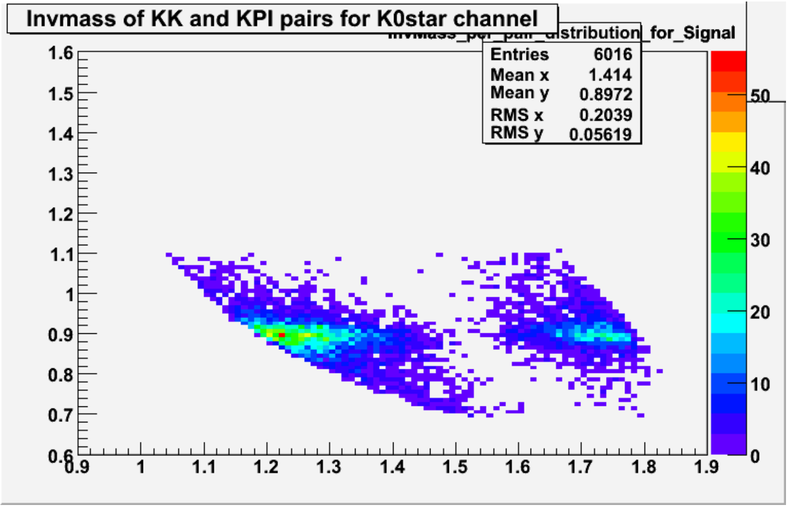
- D_s^+ has a smaller mean proper length ($c\tau$ =147 μm compared to 312 μm of the D^+)
- $D_s^+ \rightarrow K^+K^-\pi^+$ has a smaller Branching Ratio (4.3%) with respect to $D^+ \rightarrow K^-\pi^+\pi^+$ (BR=9.2%)

D_s: Resonances channels separation

- Calculation of the invariant mass of the KK and Kπ pairs
- Comparing them to m(φ) and m(K0*)


Invmass of KK and KPI pairs

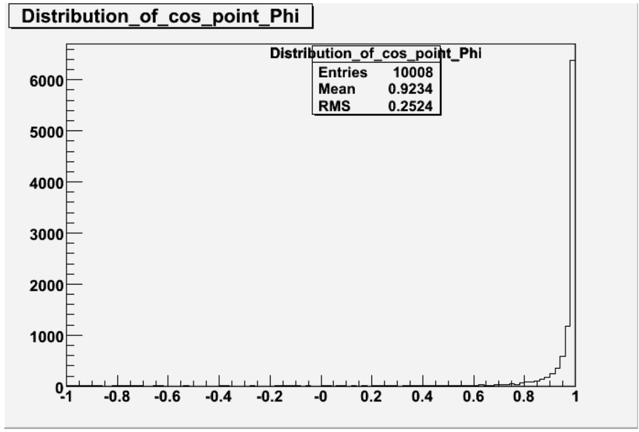

Invmass of KK and KPI pairs for Phi channel

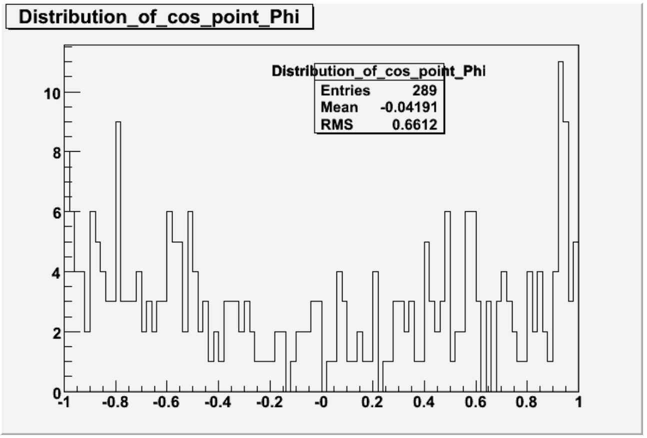

Invmass of KK and KPI pairs for K0star channel

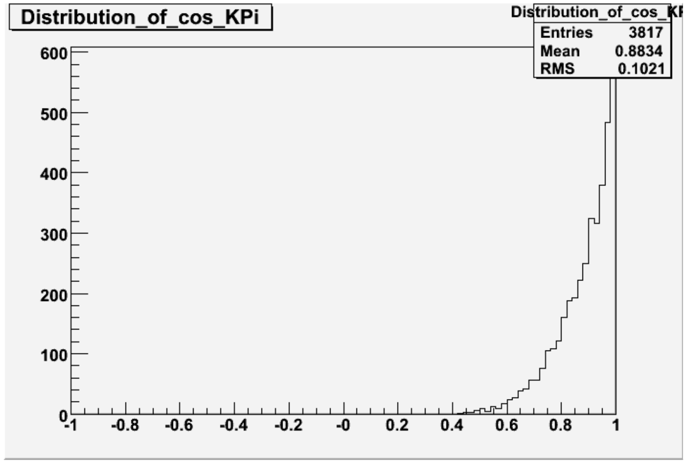
D_s: Final triplet multicut

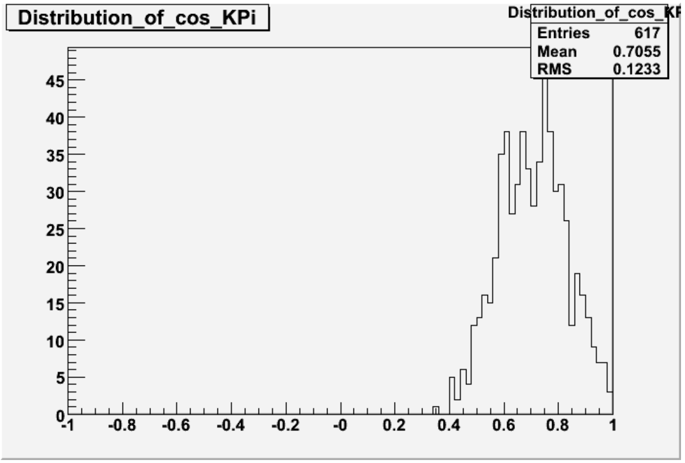
(under development)

- 4 variables
  - Cosine of pointing angle
  - Cosine of opening angle
  - Sum of impact parameters squared
  - Distance between primary and secondary vertex









Perspective for D^0 D^+ energy loss

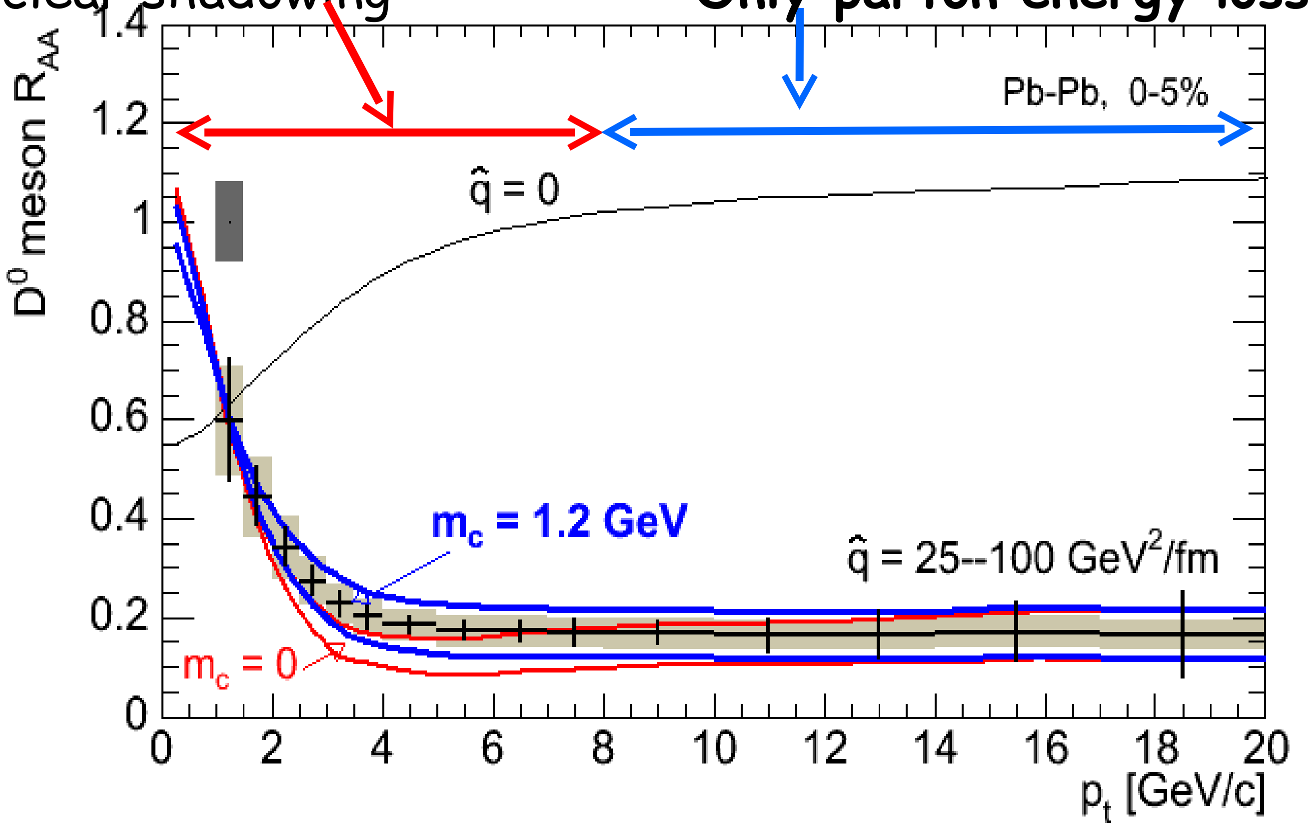
$D^0 \to K^-\pi^+$: R_{AA}

- 1 year at nominal luminosity
  - 1 month → 10^7 central Pb-Pb events
  - 10 months → 10^9 pp events

$$R_{AA}^{D}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}^{D}/dp_t}{dN_{pp}^{D}/dp_t}$$

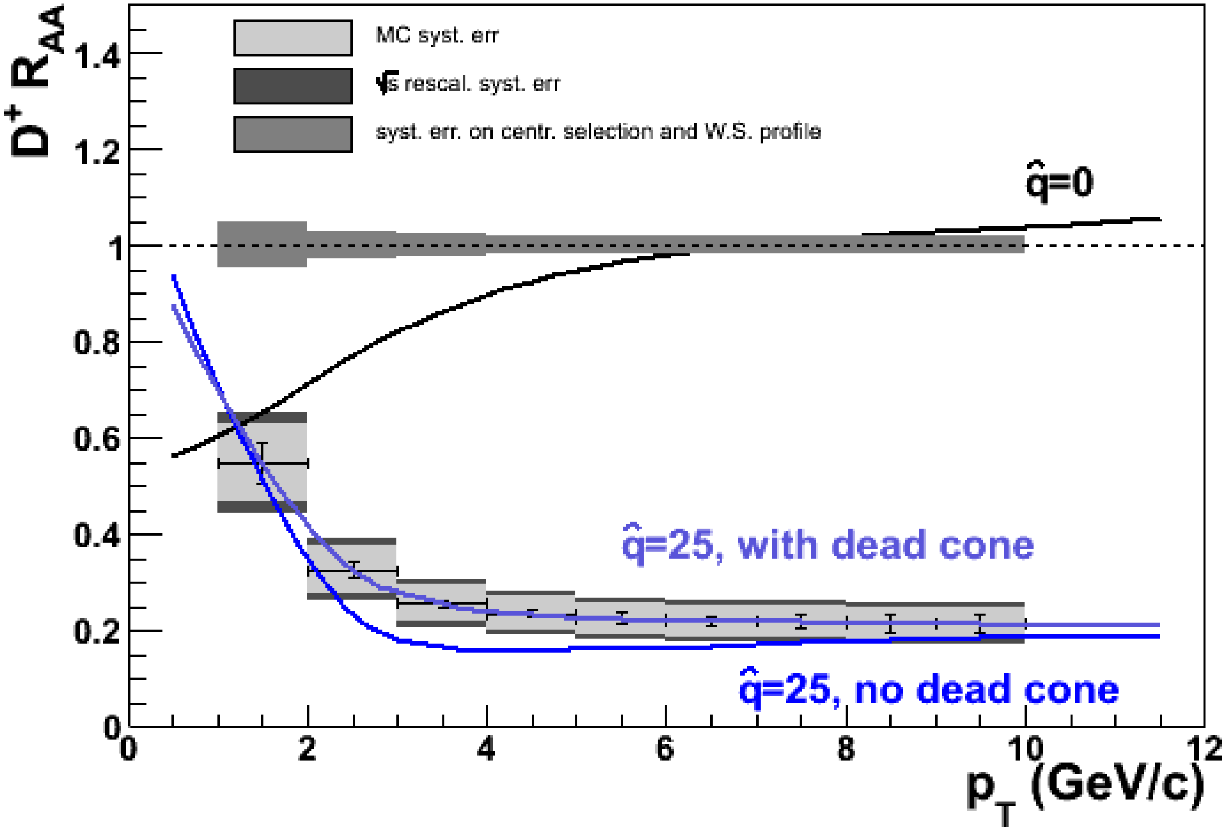
Low p_T (< 6–7 GeV/c)
Also nuclear shadowing

'High' p_T (6–15 GeV/c)
Only parton energy loss



$D^+ \rightarrow K^-\pi^+\pi^+$: R_{AA}

- Statistical error bars from 10^9 pp Min. Bias events and 10^7 central PbPb events (1 year of data taking)
  - Statistical error smaller than the syst. errors up to 10 GeV/c



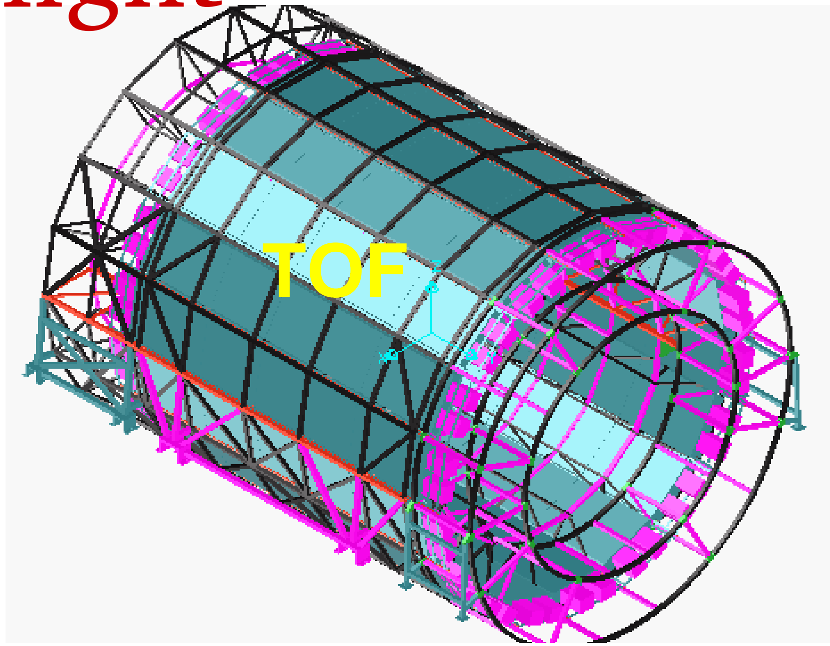
Backup

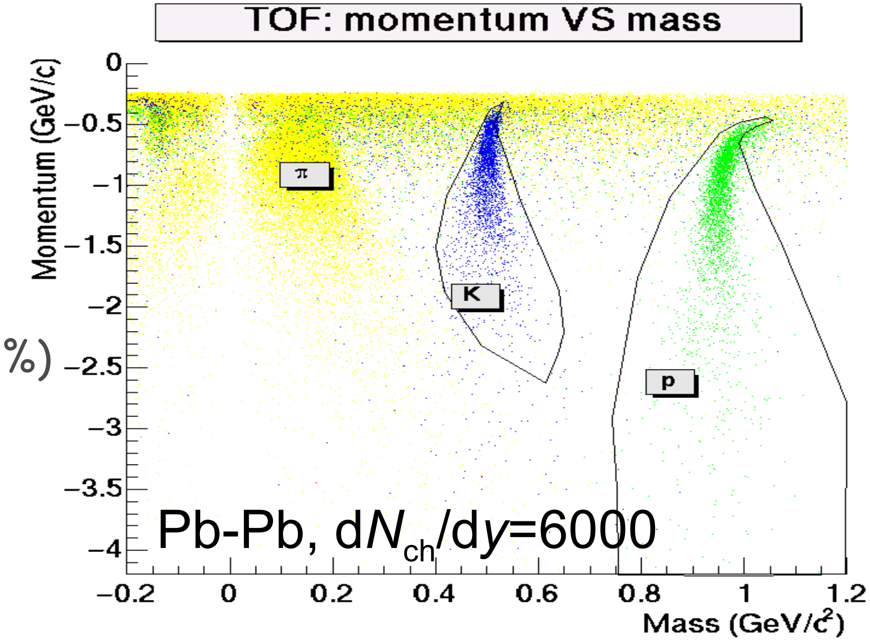
Time Of Flight

- 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





Charm production at the LHC

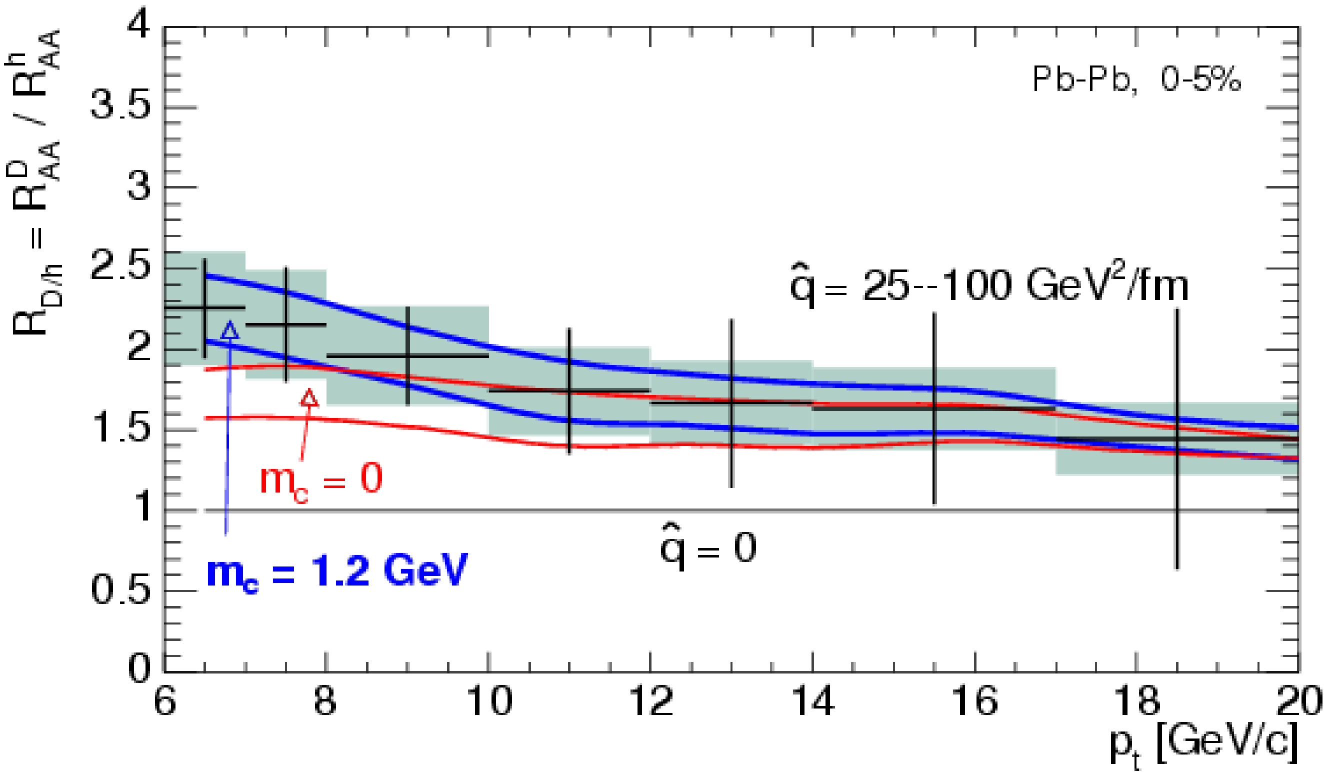
- ALICE baseline for charm cross-section and p_T spectra:
  - NLO pQCD calculations (Mangano, Nason, Ridolfi, NPB373 (1992) 295.)
    - ✓ Theoretical uncertainty = factor 2-3
  - Average between cross-sections obtained with MRSTHO and CTEQ5M sets of PDF
    - ✓ ≈ 20% difference in σ_{cc} between MRST HO and CTEQ5M
  - Binary scaling + shadowing (EKS98) to extrapolate to p-Pb and Pb-Pb

System	*Pb-Pb (0-5% centr.)*	*p-Pb (min. bias)*	*pp*
$\sqrt{s_{NN}}$	**5.5 TeV**	**8.8 TeV**	**14 TeV**
σ^{cc}_{NN} **w/o shadowing**	6.64 mb	8.80 mb	11.2 mb
$C_{shadowing}$ (EKS98)	0.65	0.80	1.
σ^{cc}_{NN} **with shadowing**	4.32 mb	7.16 mb	11.2 mb
N^{cc}_{tot}	115	0.78	0.16
D^0+D^0bar	141	0.93	0.19
D^++D^-	45	0.29	0.06
$D_s^++D_s^-$	27	0.18	0.04
$\Lambda_c^++\Lambda_c^-$	18	0.12	0.02

$D^0 \rightarrow K^-\pi^+$: heavy-to-light ratios

- 1 year at nominal luminosity
  - 1 month → 10^7 central Pb-Pb events
  - 10 months → 10^9 pp events

$$R_{D/h}(p_t) = R^D_{AA}(p_t) / R^h_{AA}(p_t)$$



Perspective for D^+ v_2

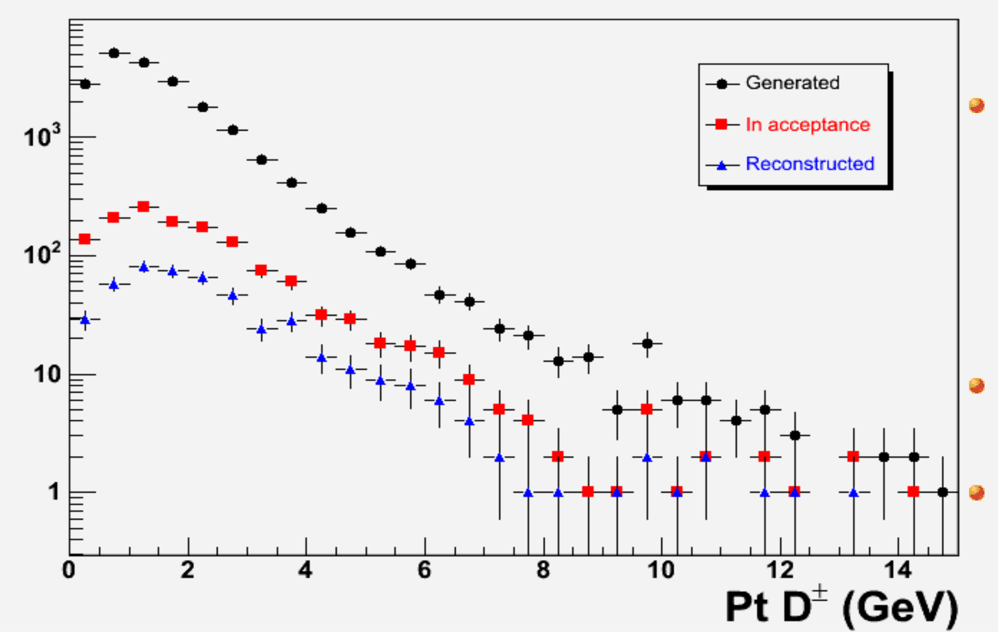
Motivation and method

- GOAL: Evaluate the statistical error bars for measurements of v_2 for $D^\pm$ mesons decaying in $K\pi\pi$
  - v_2 vs. centrality (p_T integrated)
  - v_2 vs. p_T in different centrality bins

- TOOL: fast simulation (ROOT + 3 classes + 1 macro)
  - Assume to have ***only signal***
  - Generate $N^{D\pm}(\Delta b, \Delta p_T)$ events with 1 $D^\pm$ per event
  - For each event
    - ☐ ***Generate a random reaction plane***
    - ☐ ***Get an event plane (with correct event plane resolution)***
    - ☐ ***Generate the D^+ azimuthal angle (φ^D) according to the probability distribution $p(\varphi) \propto 1 + 2v_2 \cos[2(\varphi-\Psi_{RP})]$***
    - ☐ ***Smear φ^D with the experimental resolution on $D^\pm$ azimuthal angle***
    - ☐ ***Calculate $v'_2(D^+)$, event plane resolution and $v_2(D^+)$***

$D^{\pm}$ statistics

b_{min}-b_{max} (fm)	σ (%)	N_{events} (10^6)	N_{cc} / ev.	$D^{\pm}$ yield/ev.
0-3	3.6	0.72	118	45.8
3-6	11	2.2	82	31.8
6-9	18	3.6	42	16.3
9-12	25.4	5.1	12.5	4.85
12-18	42	8.4	1.2	0.47



- N_{events} for $2 \cdot 10^7$ MB triggers
- N_{cc} = number of c-cbar pairs
  - MNR + EKS98 shadowing
  - Shadowing centrality dependence from Emelyakov et al., PRC 61, 044904
- $D^{\pm}$ yield calculated from N_{cc}
  - Fraction $N^{D\pm}/N_{cc}$ (≈0.38) from tab. 6.7 in chapt. 6.5 of PPR
- Geometrical acceptance and reconstruction efficiency
  - Extracted from 1 event with 20000 $D^{\pm}$ in full phase space
- B. R. $D^{\pm} \rightarrow K\pi\pi$ = 9.2 %
- Selection efficiency
  - No final analysis yet
  - Assume ε=1.5% (same as D^0)

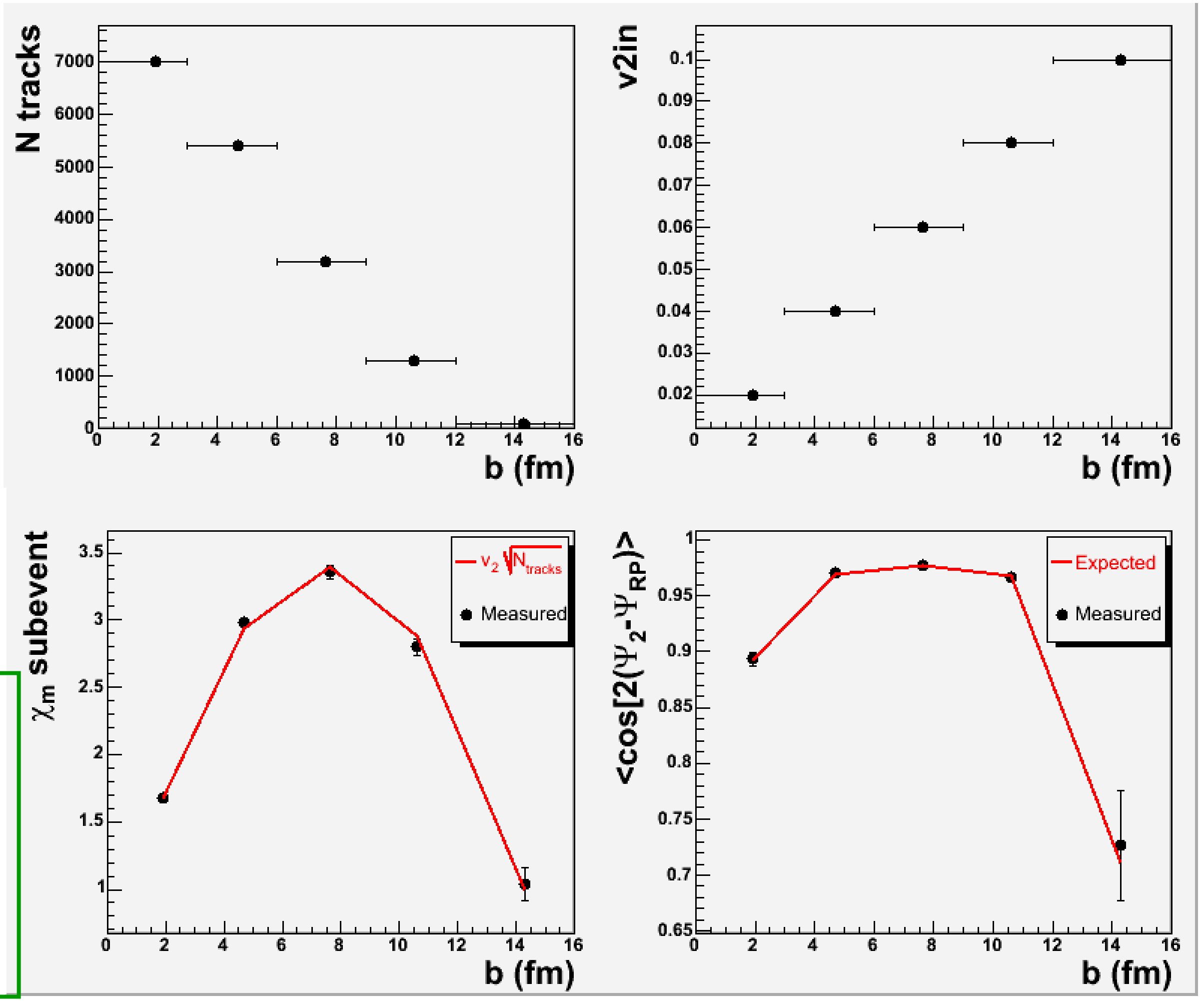
Event plane resolution scenario

- Event plane resolution depends on v_2 and multiplicity

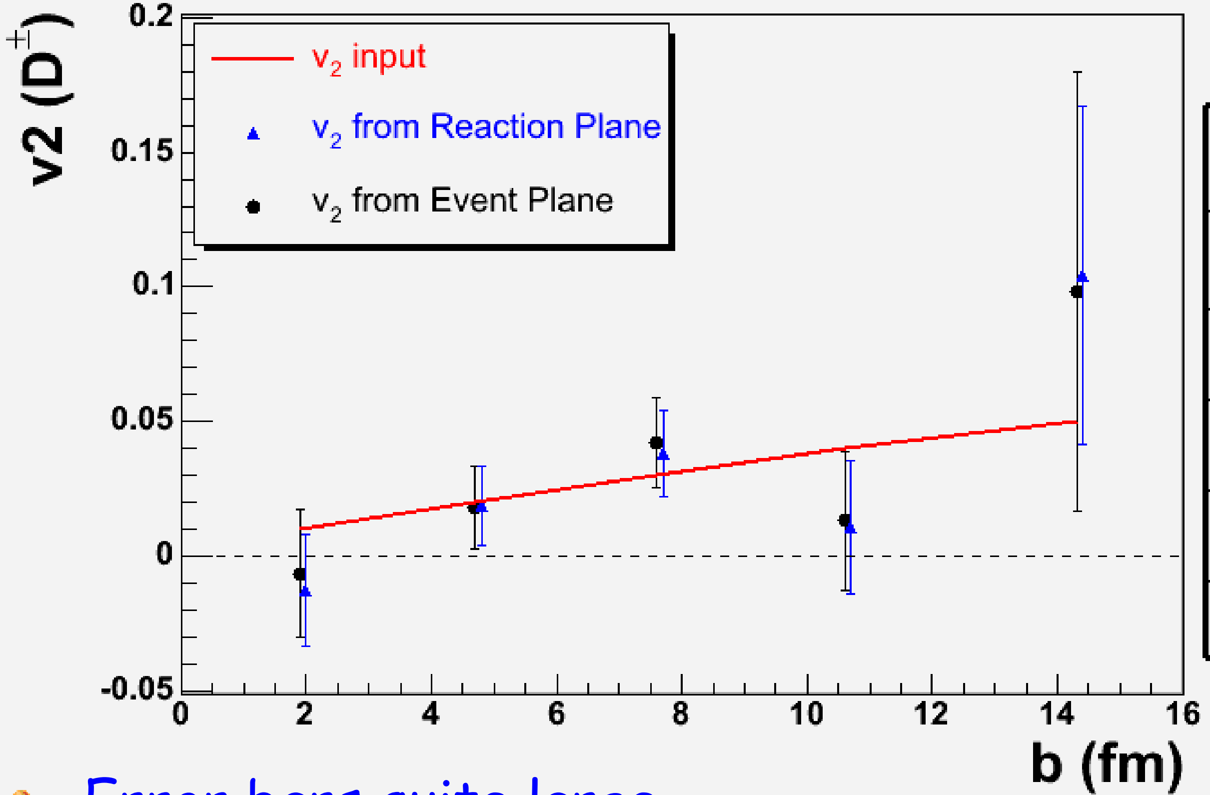
b_{min}-b_{max}	<b>	N_{track}	v_2
0-3	1.9	7000	0.02
3-6	4.7	5400	0.04
6-9	7.6	3200	0.06
9-12	10.6	1300	0.08
12-18	14.1	100	0.10

N_{track} = number of π, K and p in AliESDs of Hijing events with b = <b>

Hadron integrated v_2 input values (chosen ≈ 2 × RHIC v_2)



Results: v_2 vs. centrality



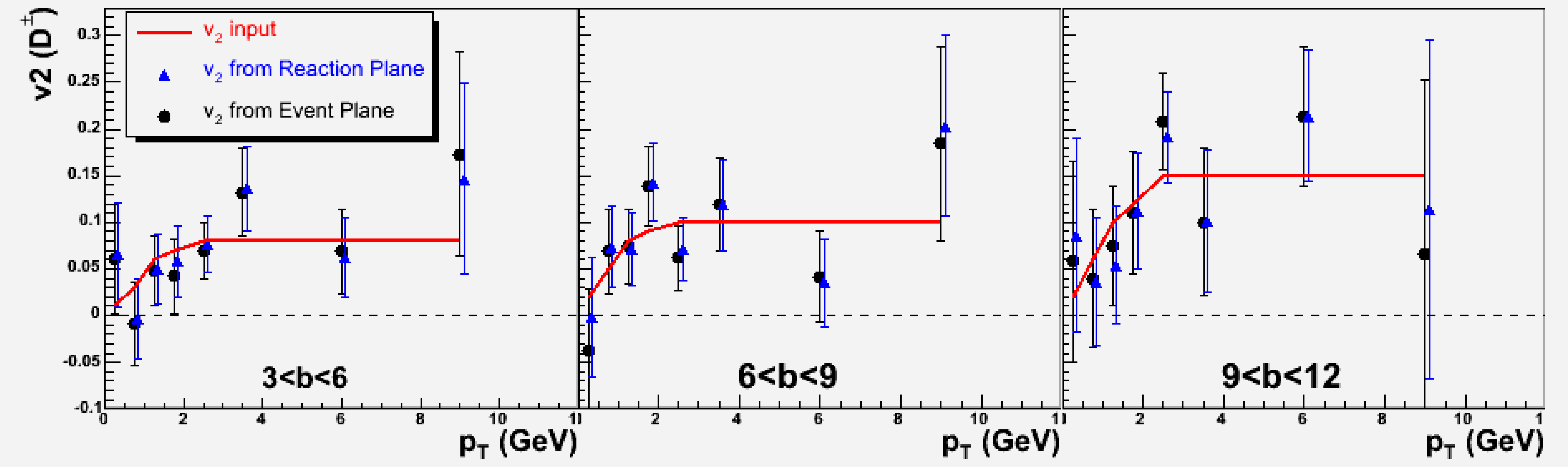
$2 \cdot 10^7$ MB events

b_{min}-b_{max}	$N(D^{\pm})_{selected}$	$\sigma(v_2)$
0-3	1070	0.024
3-6	2270	0.015
6-9	1900	0.016
9-12	800	0.026
12-18	125	0.09

- Error bars quite large
  - Would be larger in a scenario with worse event plane resolution
  - May prevent to draw conclusions in case of small anisotropy of D mesons

Results: v_2 vs. p_T

$2 \cdot 10^7$ MB events



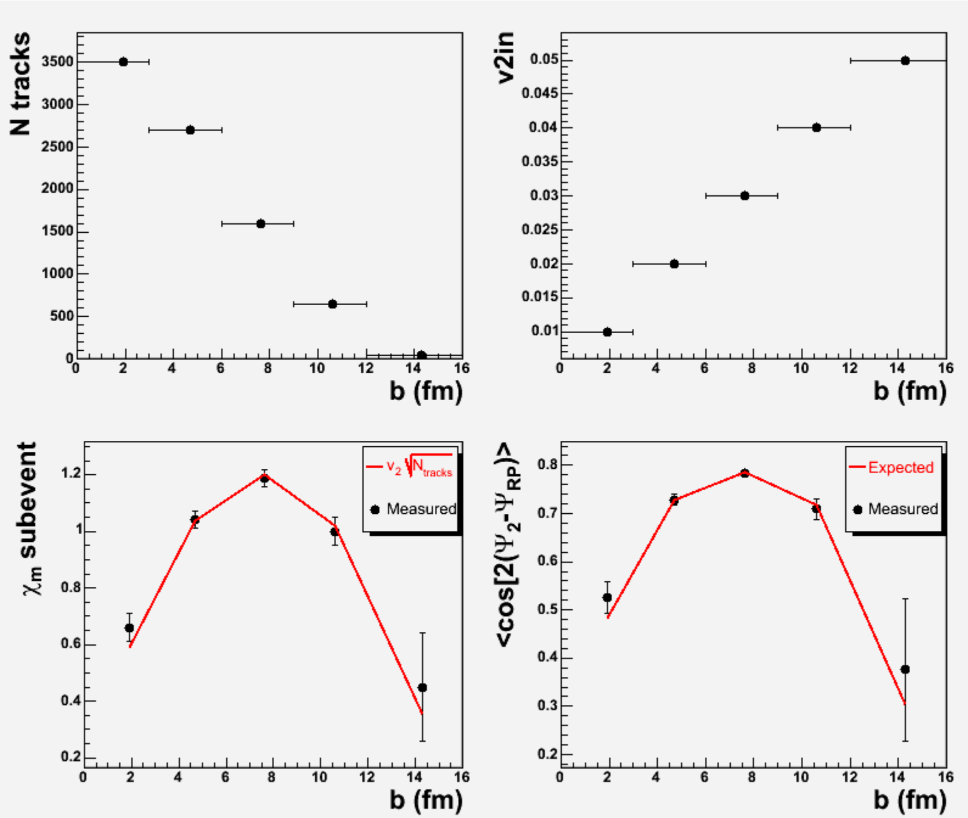
p_T limits	$N(D^{\pm})_{sel}$	$\sigma(v_2)$
0-0.5	140	0.06
0.5-1	280	0.04
1-1.5	390	0.04
1.5-2	360	0.04
2-3	535	0.03
3-4	250	0.05
4-8	265	0.05
8-15	50	0.11

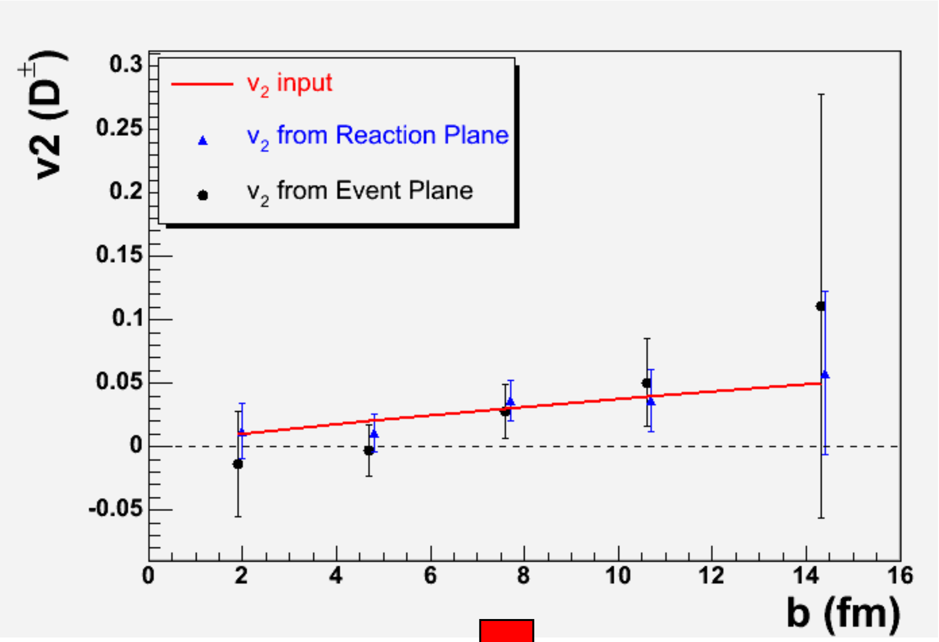
p_T limits	$N(D^{\pm})_{sel}$	$\sigma(v_2)$
0-0.5	120	0.06
0.5-1	230	0.05
1-1.5	330	0.04
1.5-2	300	0.04
2-3	450	0.03
3-4	210	0.05
4-8	220	0.05
8-15	40	0.11

p_T limits	$N(D^{\pm})_{sel}$	$\sigma(v_2)$
0-0.5	50	0.10
0.5-1	100	0.07
1-1.5	140	0.06
1.5-2	125	0.06
2-3	190	0.05
3-4	90	0.07
4-8	95	0.07
8-15	20	0.15

Worse resolution scenario

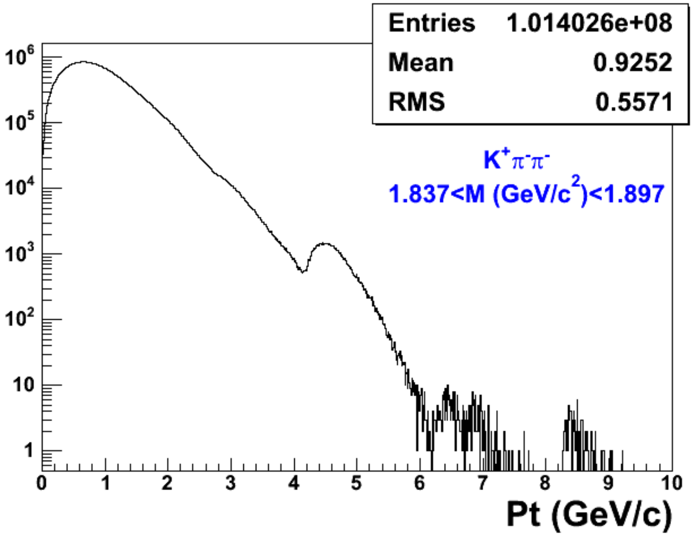
- Low multiplicity and low v2

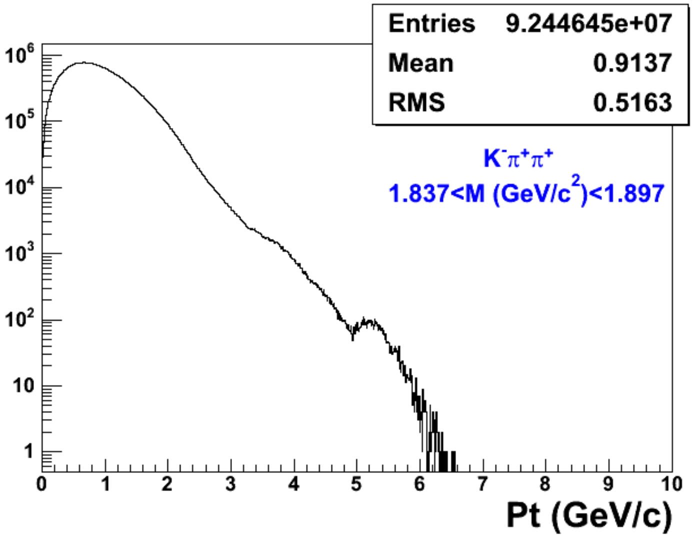




Large contribution to error bar on v_2 from event plane resolution

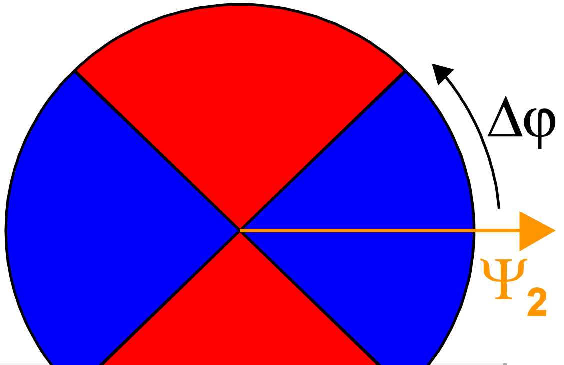
Combinatorial background



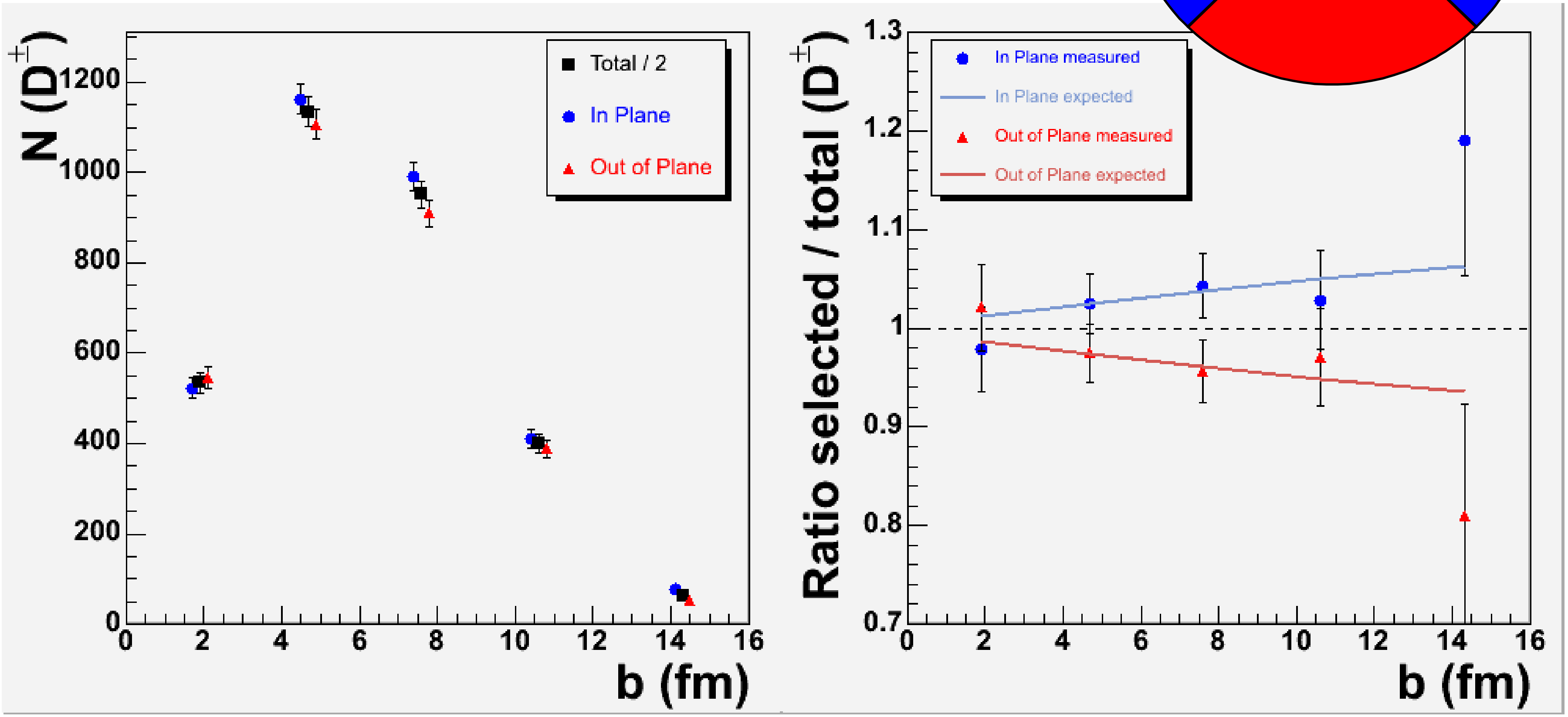


- Huge number ($\approx 10^{10}$) of combinatorial $K\pi\pi$ triplets in a central event
  - $\approx 10^8$ triplets in invariant mass range $1.84<M<1.90$ GeV/c^2 ($D^\pm$ peak $\pm 3\sigma$)
    - ✓ ***Final selection cuts not yet ready***
  - Signal almost free from background only for $p_T>5$-6 GeV/c
  - Need to separate signal from background in v_2 calculation
- FIRST IDEA: sample candidate $K\pi\pi$ triplets in bins of azimuthal angle relative to the event plane ($\Delta\varphi = \varphi - \Psi_2$)
  - Build invariant mass spectra in bins of $\Delta\varphi$ and centrality / p_T

Analysis in bins of Δφ (I)

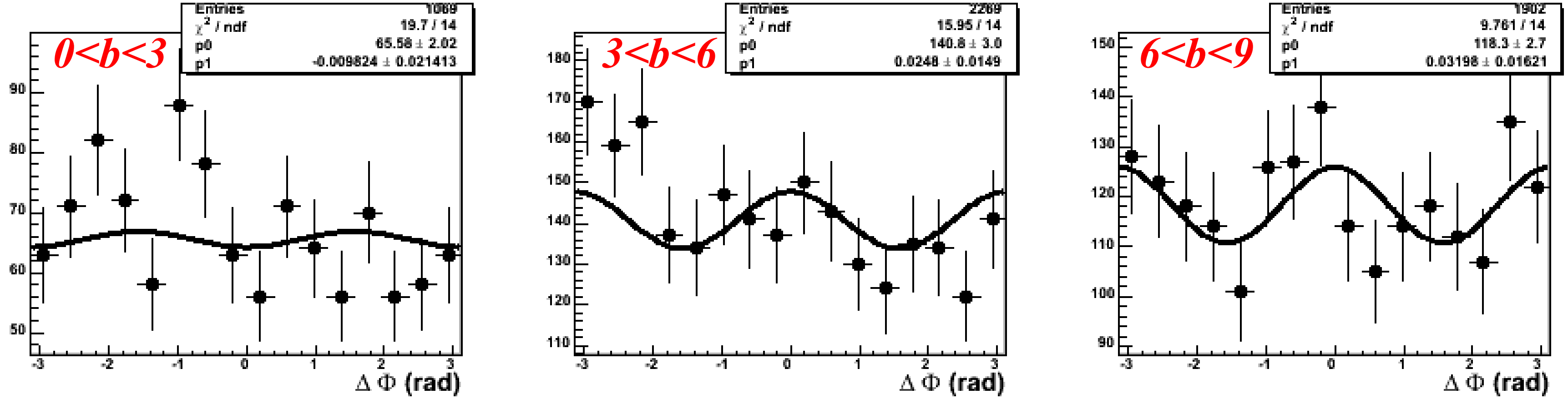


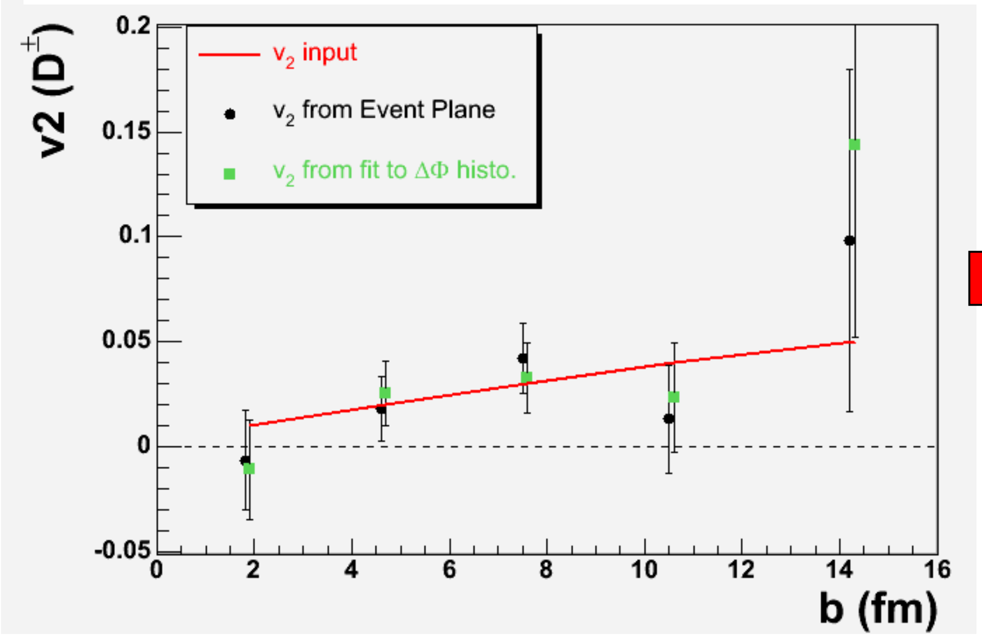
- Extract number of $D^\pm$ in 90° "cones":
  - in-plane ($-45<\Delta\varphi<45 \cup 135<\Delta\varphi<225$)
  - out-of-plane ($45<\Delta\varphi<135 \cup 225<\Delta\varphi<315$)



Analysis in bins of Δφ (II)

- Fit number of D± vs. Δφ with $A[1 + 2v_2\cos(2\Delta\varphi)]$





v_2 values and error bars compatible with the ones obtained from $\langle\cos(2\Delta\varphi)\rangle$

Other ideas for background

Different analysis methods to provide:

- Cross checks
- Evaluation of systematics

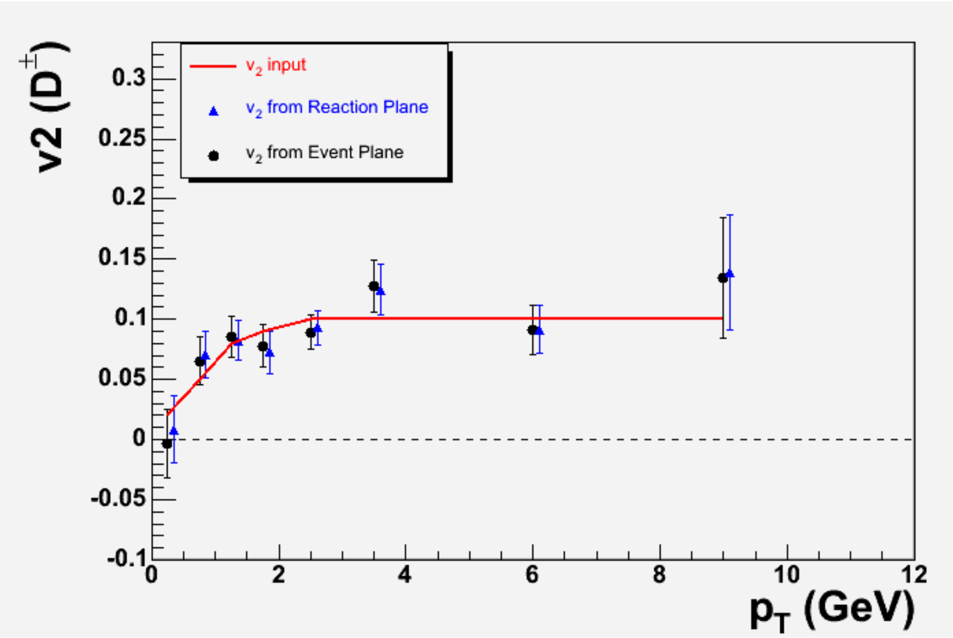
- Apply the analysis method devised for Λs by Borghini and Ollitrault [PRC 70 (2004) 064905]

$$N_{\text{pairs}}(M) = N_b(M) + N_\Lambda(M). \longrightarrow \begin{aligned} N_{\text{pairs}}(M) v_{c,n}(M) &= N_b(M) v_{c,n}^{(b)}(M) + N_\Lambda(M) v_{c,n}^{\Lambda}, \\ N_{\text{pairs}}(M) v_{s,n}(M) &= N_b(M) v_{s,n}^{(b)}(M) + N_\Lambda(M) v_{s,n}^{\Lambda}. \end{aligned}$$

  - To be extended from pairs (2 decay products) to triplets (3 decay products)
- Extract the $\cos[2(\varphi-\Psi_{RP})]$ distribution of combinatorial $K\pi\pi$ triplets from:
  - Invariant mass side-bands
  - Different sign combinations (e.g. $K^+\pi^+\pi^+$ and $K^-\pi^-\pi^-$)

Conclusions on v_2

- Large stat. errors on v_2 of $D^{\pm} \rightarrow K\pi\pi$ in $2 \cdot 10^7$ MB events
- How to increase the statistics?
  - Sum $D^0 \rightarrow K\pi$ and $D^{\pm} \rightarrow K\pi\pi$
    - ✓ *Number of events roughly ×2 → error bars on v_2 roughly $/\sqrt{2}$*
    - ✓ *Sufficient for v_2 vs. centrality (p_T integrated)*
  - Semi-peripheral trigger
    - ✓ *v_2 vs. p_T that would be obtained from $2 \cdot 10^7$ semi-peripheral events (6<b<9)*



p_T limits	$N(D^{\pm})_{sel}$	$\sigma(v_2)$
0-0.5	645	0.03
0.5-1	1290	0.02
1-1.5	1800	0.017
1.5-2	1650	0.018
2-3	2470	0.015
3-4	1160	0.02
4-8	1225	0.02
8-15	220	0.05

Glauber calculations (I)

- N-N c.s.:

$$\sigma_{NN}^{inel} = 60\,mb$$

$$\sigma_{NN}^{c\bar{c}} = 6.64\,mb$$

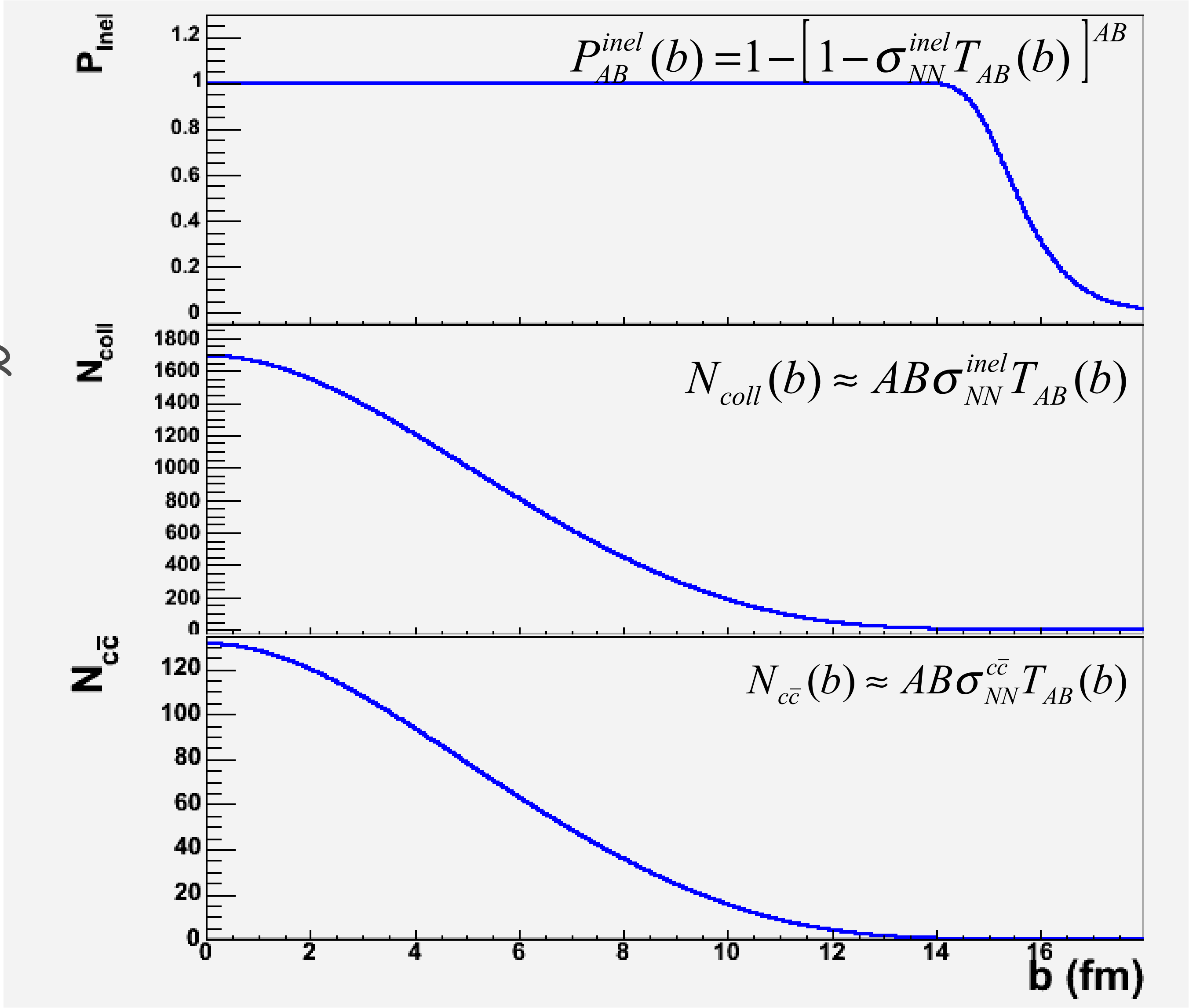
  - σ^{cc} from HVQMNR
  - + shadowing
- Pb Woods-Saxon

$$\rho(r) = \frac{\rho_0}{1 + e^{\frac{r - r_0}{d}}}$$

$$\rho_0 = 0.16\ fm^{-3}$$

$$r_0 = 6.624\ fm$$

$$d = 0.549\ fm$$



Glauber calculations (II)

- N-N c.s.:

$$\sigma_{NN}^{inel} = 60\,mb$$

$$\sigma_{NN}^{c\bar{c}} = 6.64\,mb$$

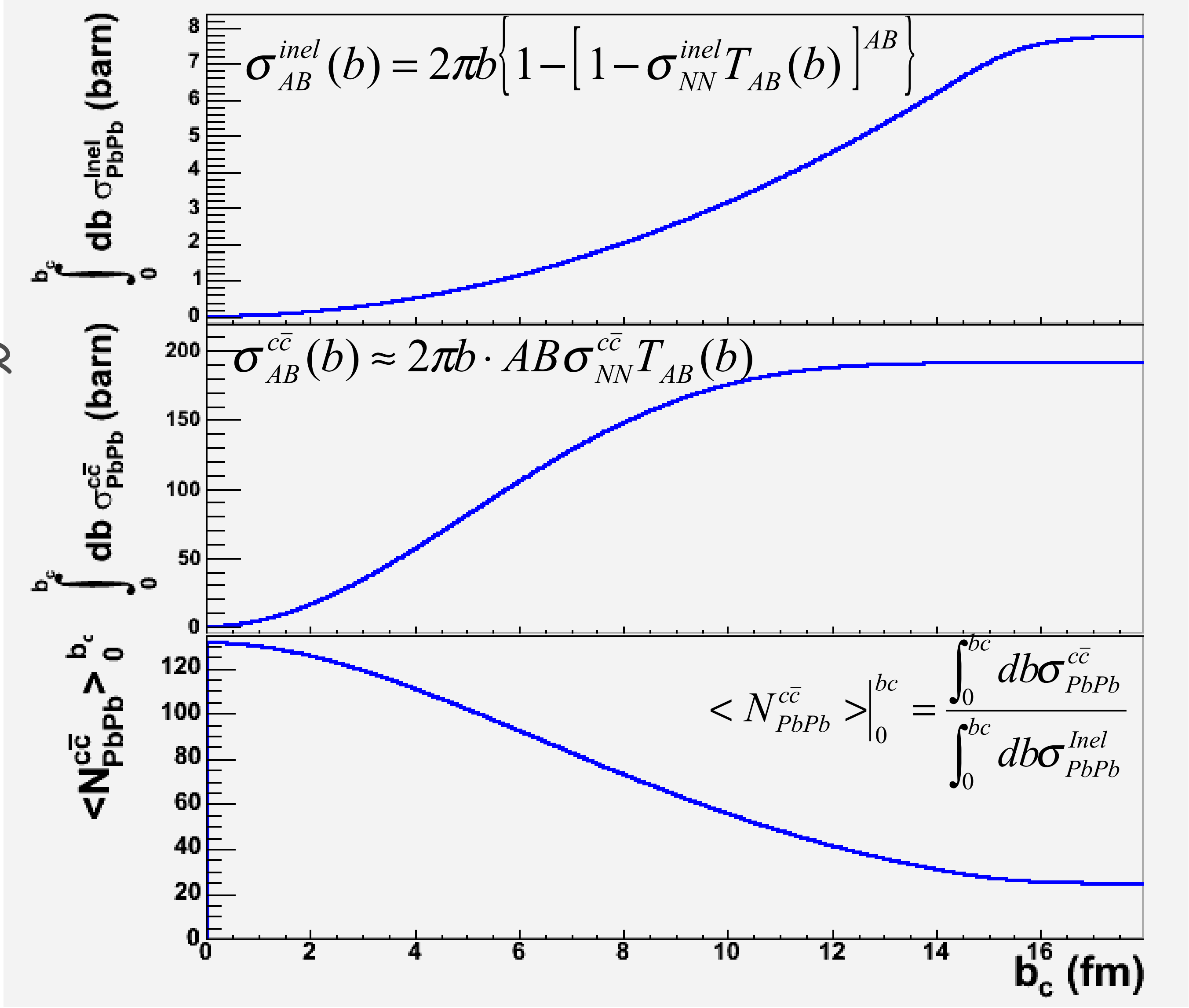
  - σ^{cc} from HVQMNR
  - + shadowing
- Pb Woods-Saxon

$$\rho(r) = \frac{\rho_0}{1+e^{\frac{r-r_0}{d}}}$$

$$\rho_0 = 0.16\ fm^{-3}$$

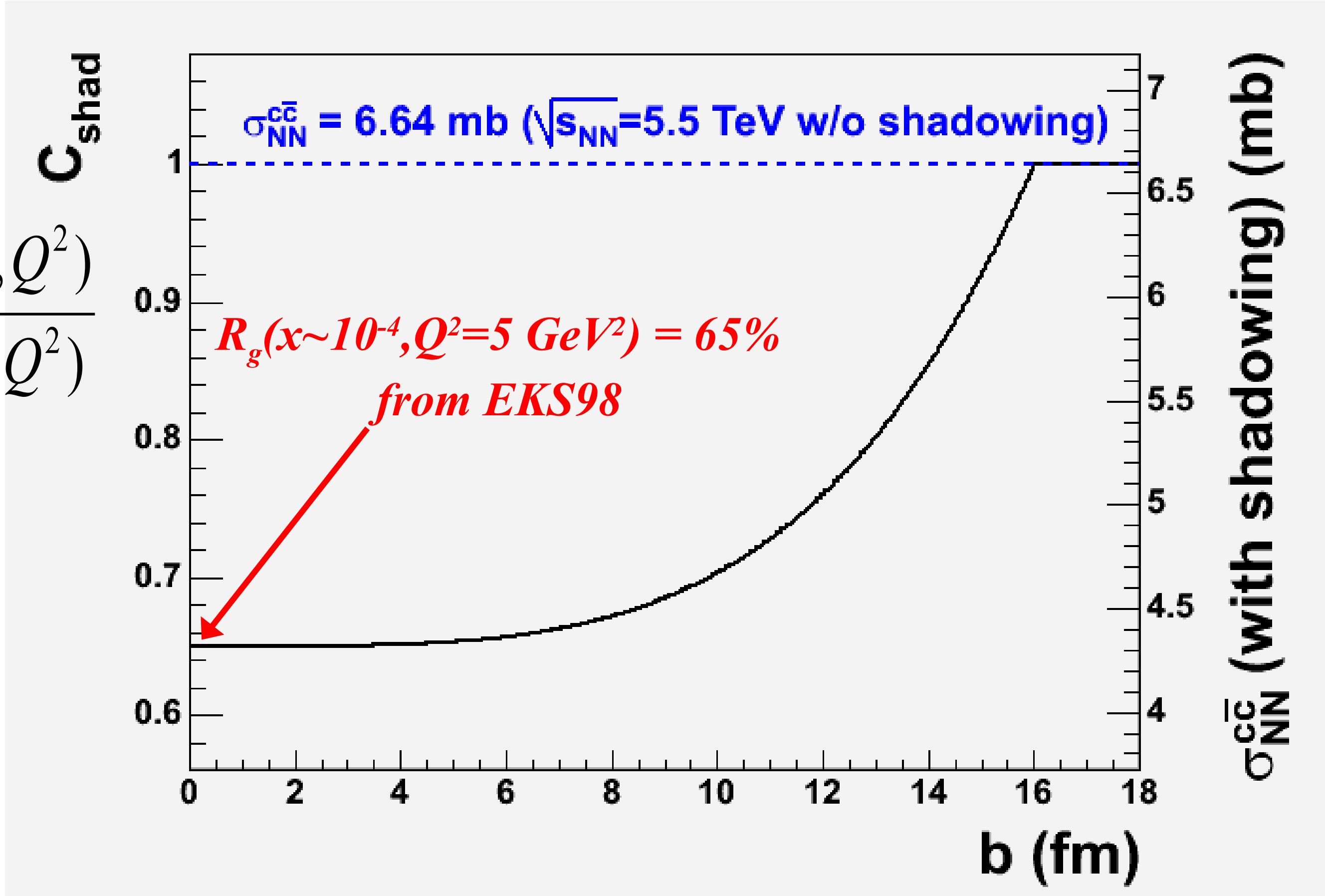
$$r_0 = 6.624\ fm$$

$$d = 0.549\ fm$$



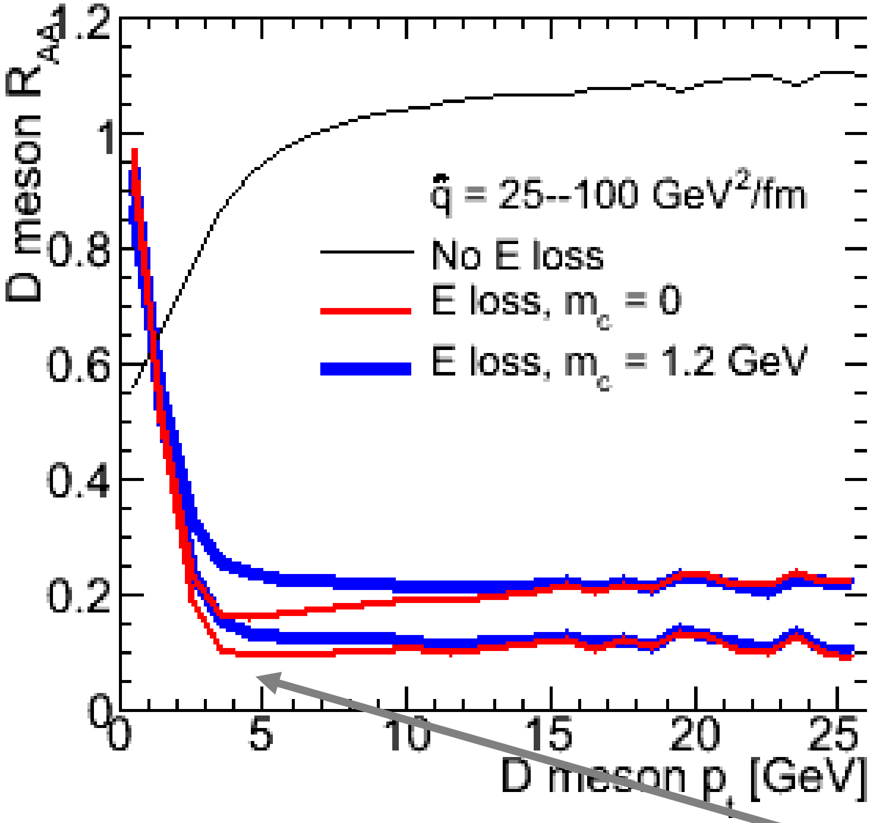
Shadowing parametrization

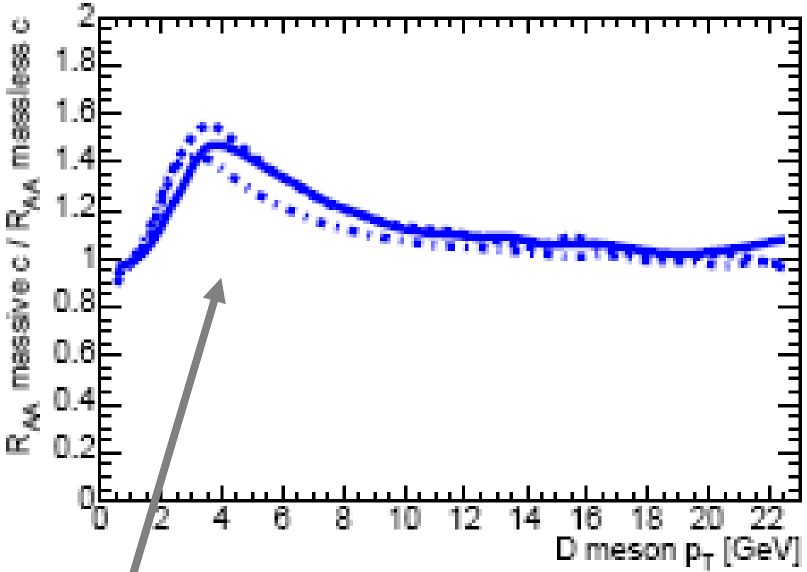
$$C_{shad} = \frac{f_g^{Pb}(x,Q^2)}{f_g^{p}(x,Q^2)}$$



- Eskola et al., Eur. Phys. J C 9 (1999) 61.
- Emel'yanov et al., Phys. Rev. C 61 (2000) 044904.

Effect of charm mass at the LHC





mass effect visible only for p_T<10 GeV

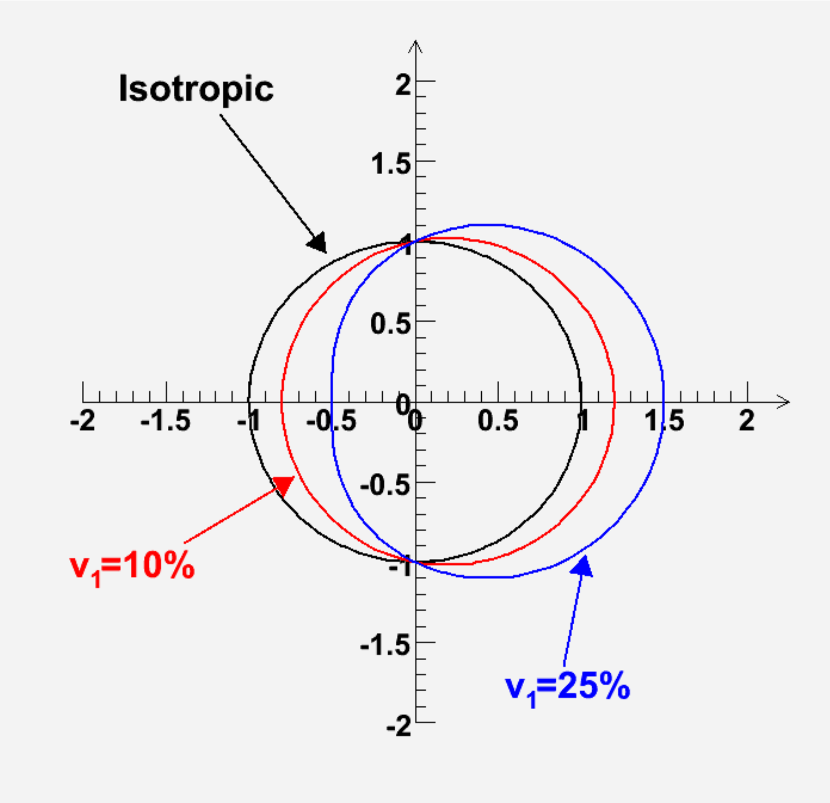
where other competing processes are in

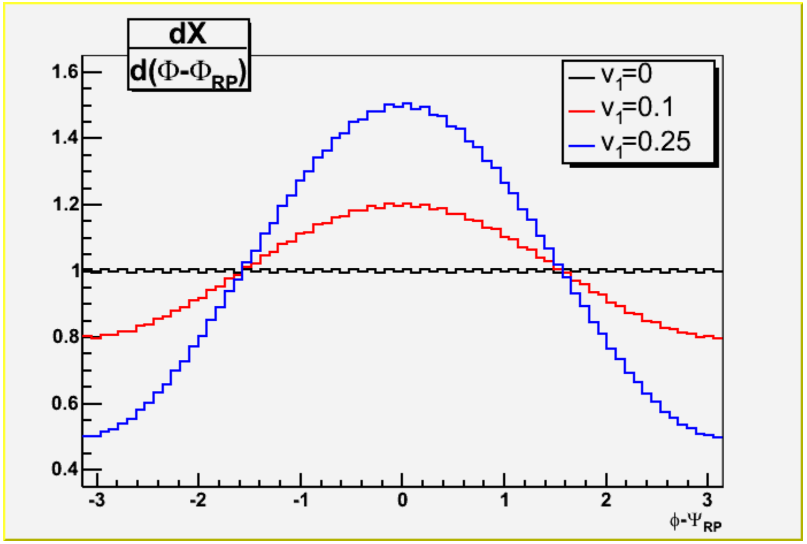
Directed flow

$$\frac{dX}{d\varphi} = \frac{X_0}{2\pi}\left(1 + \boxed{2v_1}\cos(\varphi - \Psi_{RP}) + 2v_2\cos\left(2\left(\varphi - \Psi_{RP}\right)\right) + \ldots.\right)$$

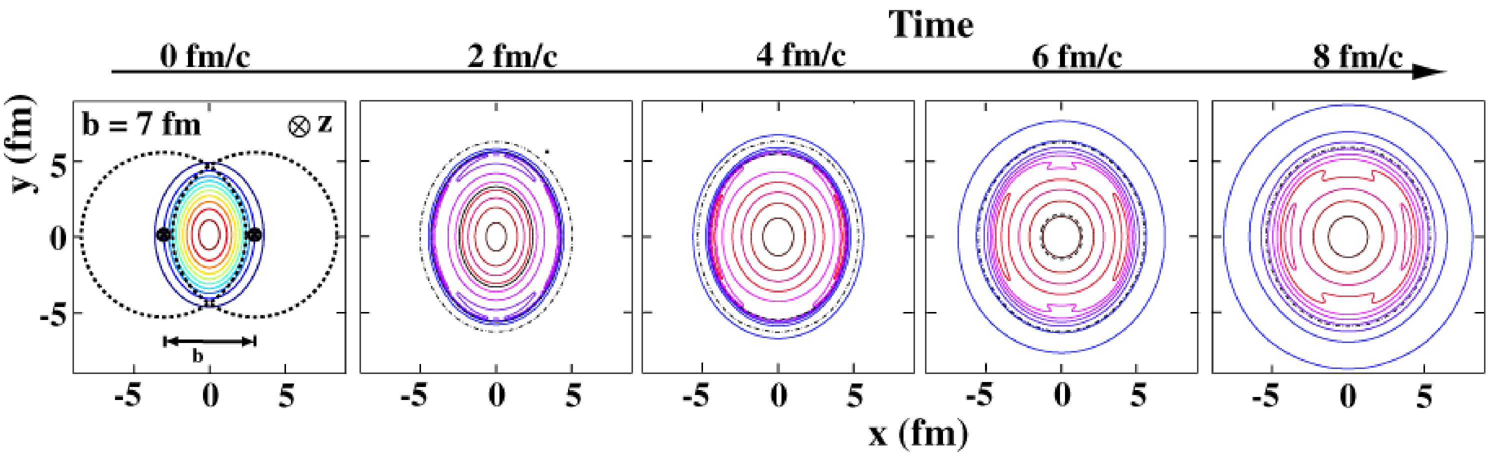
Directed flow coefficient

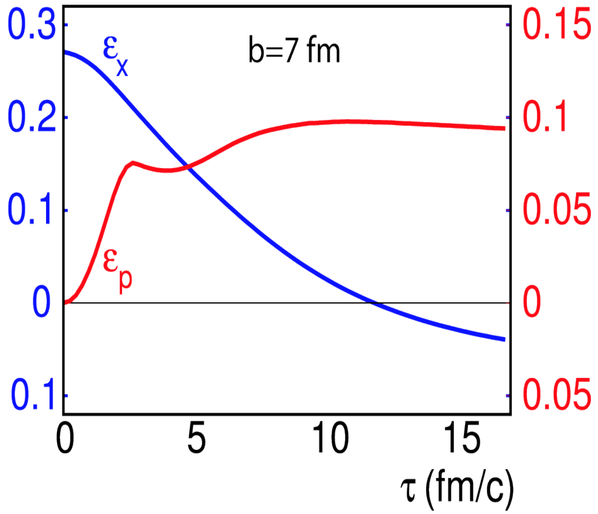
$$v_1 = \left\langle \cos\left(\varphi - \Psi_{RP}\right)\right\rangle$$





Why elliptic flow ?





- At t=0: geometrical anisotropy (almond shape), momentum distribution isotropic
- Interaction among consituents generate a pressure gradient which transform the initial spatial anisotropy into a momentum anisotropy
  - Multiple interactions lead to thermalization → limiting behaviour = ideal hydrodynamic flow
- The mechanism is self quenching
  - The driving force dominate at early times
  - Probe Equation Of State at early times

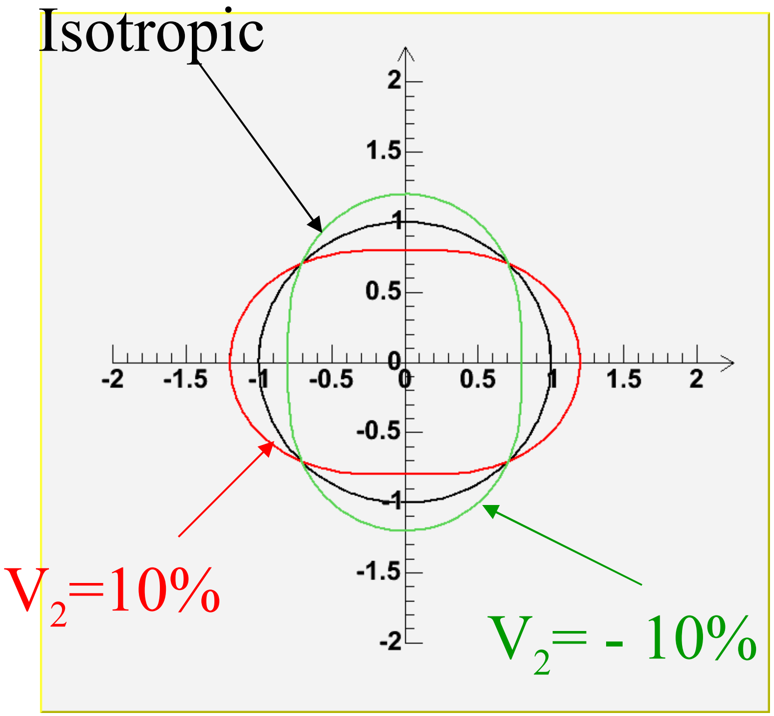
In-plane vs. out-of-plane

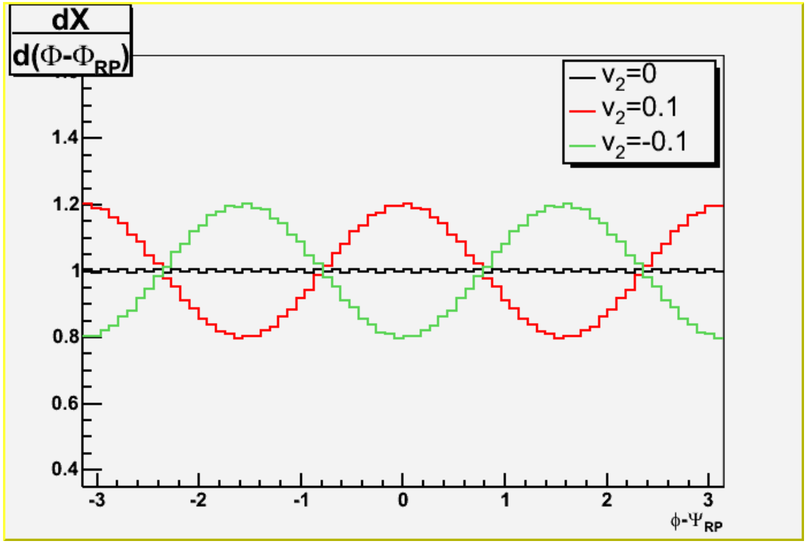
$$\frac{dX}{d\varphi} = \frac{X_0}{2\pi}\left(1 + 2v_1\cos(\varphi - \Psi_{RP}) + \boxed{2v_2}\cos\left(2\left(\varphi - \Psi_{RP}\right)\right) + ...\right)$$

Elliptic flow coefficient:

$v_2>0$ In plane elliptic flow

$v_2<0$ Out of plane elliptic flow





"Glauber" calculations

- Optical approximation
   Czyz and Maximon, Annals Phys. 52 (1969) 59.

Nucleus thickness functions

$$T_A(\vec{s}) = \int_{-\infty}^{\infty} \rho_A(\vec{s}, z_A)\, dz_A \qquad T_B(\vec{s}-\vec{b}) = \int_{-\infty}^{\infty} \rho_B(\vec{s}-\vec{b}, z_B)\, dz_B$$

Nucleus-nucleus thickness function

$$T_{AB}(\vec{b}) = \int T_A(\vec{s})\, T_B(\vec{s}-\vec{b})\, ds^2$$

Nucleon-nucleon collision probability

$$P(1, \vec{b}) = T_{AB}(\vec{b})\, \sigma_{in.} \rightarrow P(n, \vec{b}) = \binom{AB}{n} \left(T_{AB}(\vec{b})\, \sigma_{in.}\right)^n \left(1 - T_{AB}(\vec{b})\, \sigma_{in.}\right)^{AB-n}$$

$$\text{Part} = \int \{A\, T_A[1-(1-\sigma_{in}\, T_B)^B] + B\, T_B[1-(1-\sigma_{in}\, T_A)^A]\}\, ds^2$$

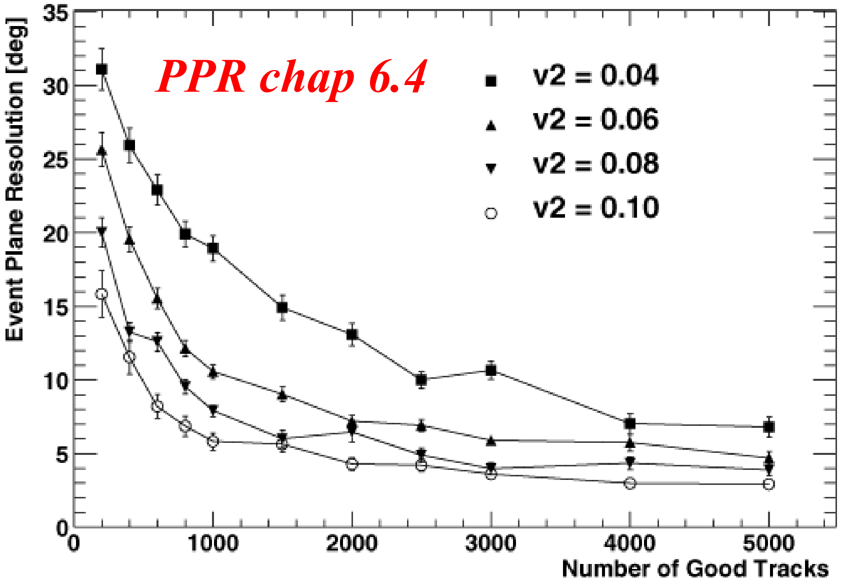
$$\text{Coll} = A\, B\, T_{AB}\, \sigma_{in}$$

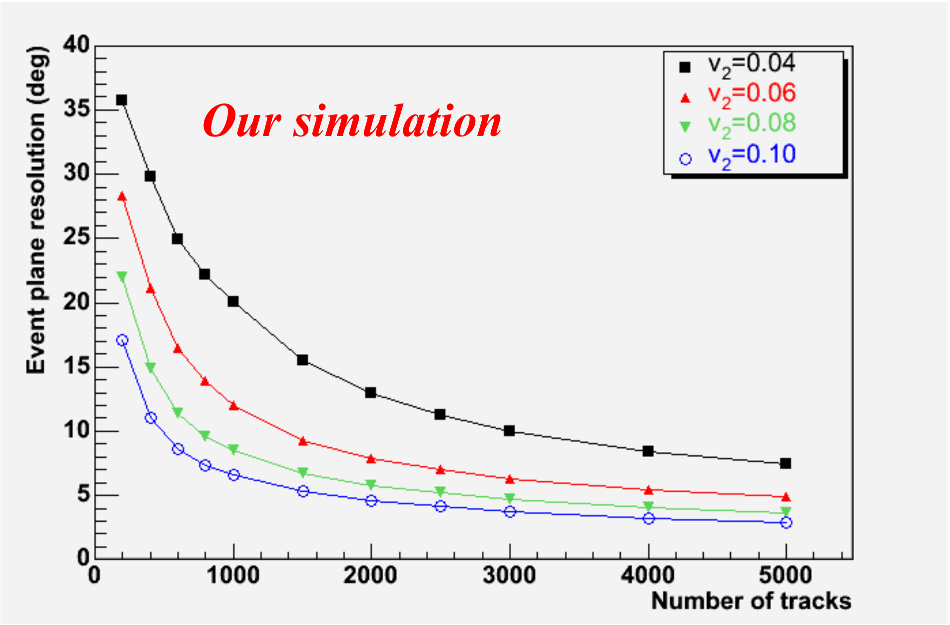
Event plane simulation

- Simple generation of particle azimuthal angles (φ) according to a probability distribution

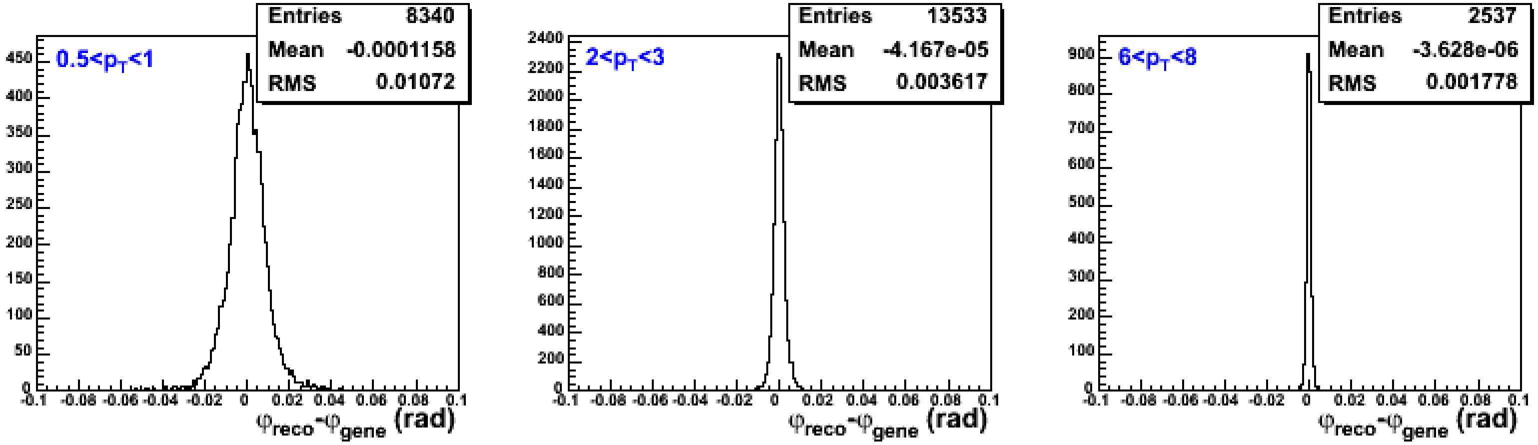
$$\frac{dN}{d\varphi} = 1 + 2v_2 \cos(\varphi - \Psi_{RP})$$

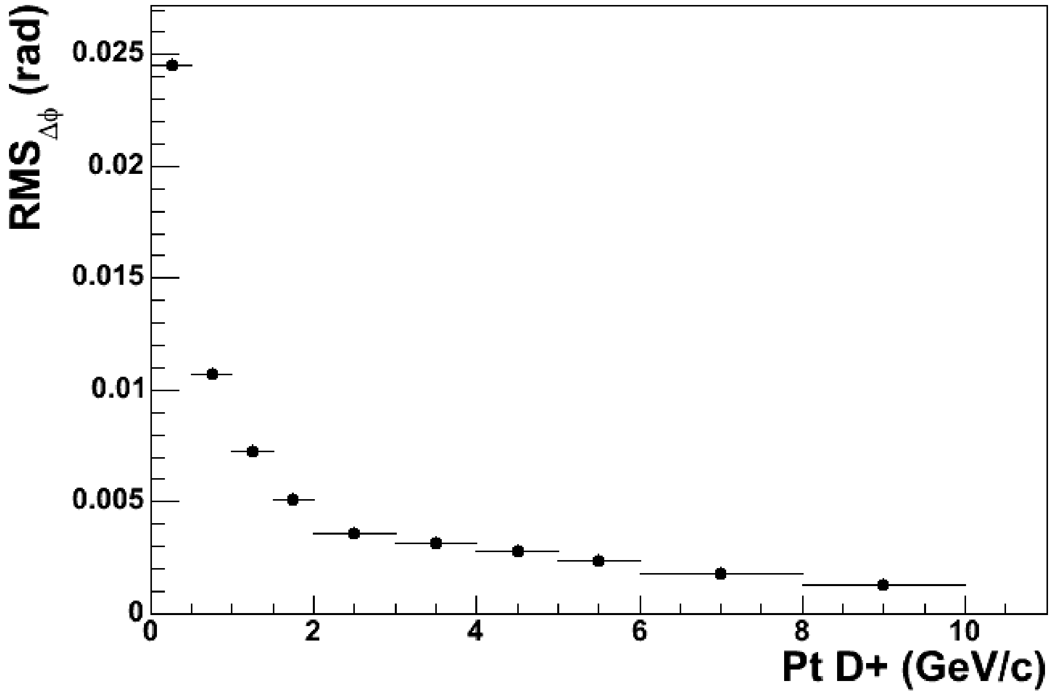
  - Faster than complete AliRoot generation and reconstruction
  - Results compatible with the ones in PPR chapter 6.4





$D^{\pm}$ azimuthal angle resolution





- From 63364 recontructed D+
  - 200 events made of 9100 D^+ generated with PYTHIA in $-2<y<2$
- Average φ resolution = 8 mrad = 0.47 degrees