Feasibility study of open charm elliptic flow in CBM

Sélim SEDDIKI [1,2,3] and Fouad RAMI [2]

Physics motivation

Goal and strategy of the simulations

Reconstruction of the reaction plane

Feasibility of v_2 measurements for D^+ mesons (only statistical errors)

Summary and conclusion

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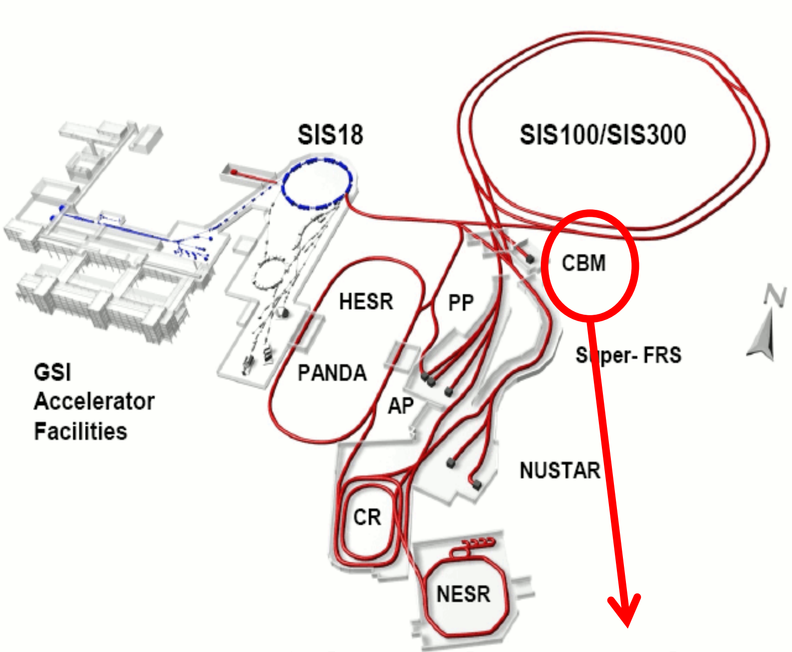
(3) Helmholtz Research School, Frankfurt am Main

School of Collective dynamics in High Energy Collisions, Berkeley, 09.06.10

The CBM experiment at FAIR

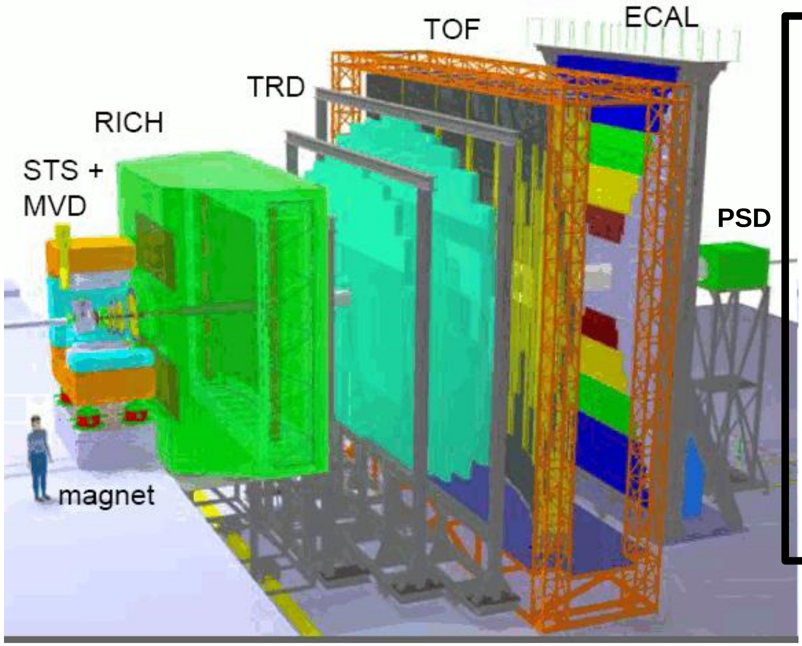


Facility for Anti-proton and Ion Research (FAIR) at GSI-Darmstadt:

→ **extremely high intensity HI beam synchrotron SIS100/300**

→ **ex: up to $10^{8\text{-}9}$ Au / s @ 45 A.GeV**

CBM: one of the major experiments



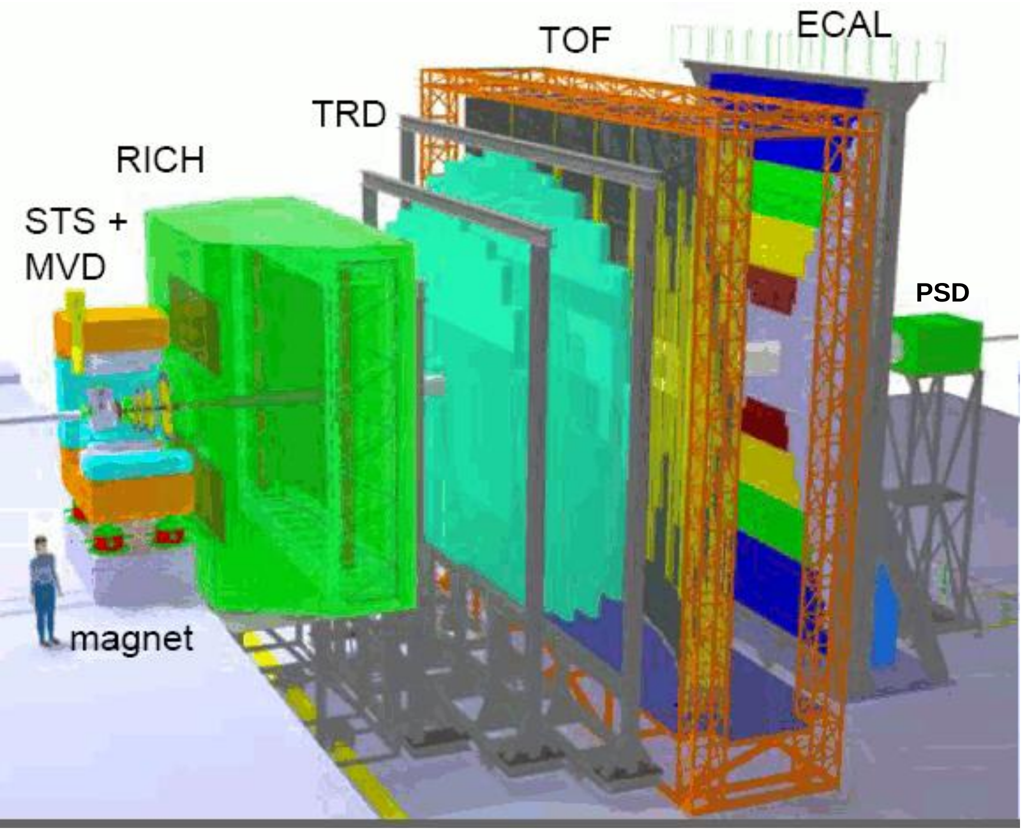
Compressed Baryonic Matter experiment (CBM):

→ **Explore the nuclear matter phase diagram at high baryonic density**

→ **Experimental challenge : measure rare probes**
- Ξ, Ω, low-mass ρ, ω, ϕ-mesons,
- **J/Ψ, Ψ', open charmed particles near the threshold energy (E_c = 15 AgeV)**

→ **Extremely fast and radiation-hard experiment**

The CBM experiment at FAIR (2)



Track reconstruction and p-determination:
Silicon Tracking System (STS)

Hadron ID:
STS + Time Of Flight (TOF)

Vertex reconstruction and open charm ID:
Micro-Vertex Detector (MVD)
→ close to interaction point
→ operate in vacuum

Event characterisation :
Projectile Spectator Detector (PSD)

Electron ID / pion suppression:
RICH, TRD, ECAL

Photon detection:
ECAL

Muon detection:
RICH → muon set-up with absorbers

A rich panel of observables foreseen for CBM

↔ Cross-check with independent observables

Deconfinement phase transition at high ρ_B

- excitation function and flow of strangeness (K, Λ, Σ, Ξ, Ω)
- excitation function and flow of charm (J/ψ, ψ', D_0, $D^\pm$, Λ_c)
- melting of J/ψ and ψ'

QCD critical endpoint

- excitation function of event-by-event fluctuations (K/π,...)

The equation-of-state at high ρ_B

- collective flow of hadrons
- particle production at threshold energies (open charm?)

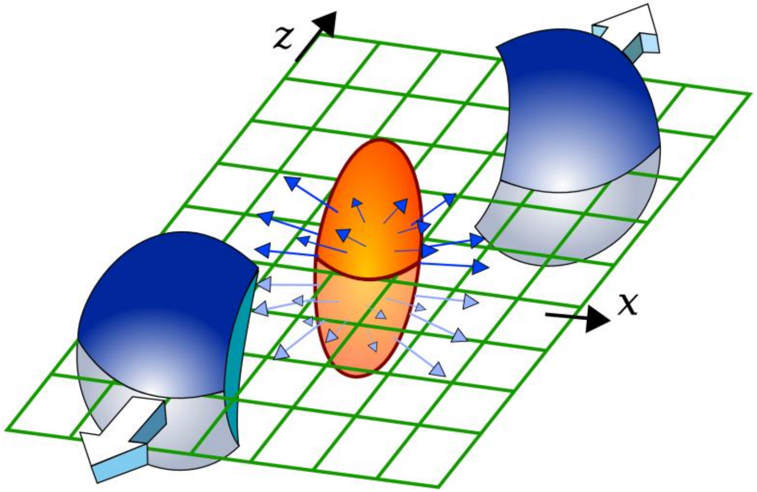
Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$, D)

- Excitation functions of bulk and rare observables!
- Bulk observables with “unlimited” statistics
- Systematic studies of rare observables (charm, dileptons) with excellent statistics

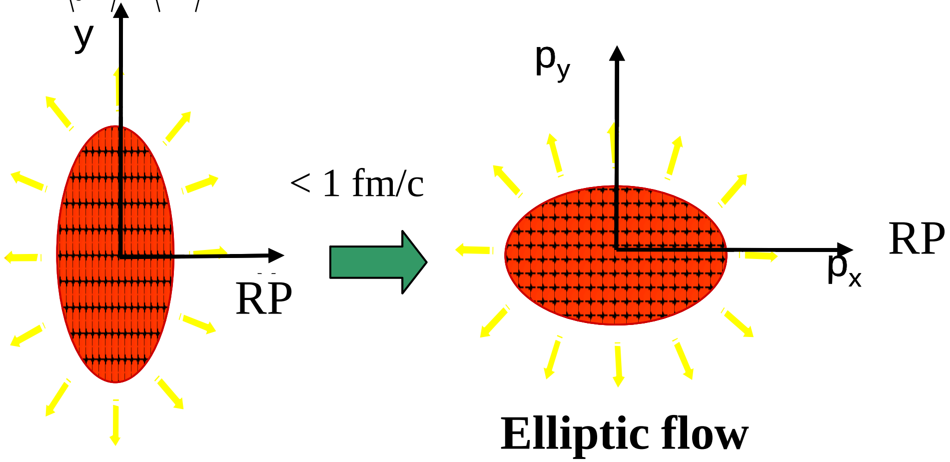
Just a reminder about elliptic flow …

Reaction plane (RP)



$$e = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

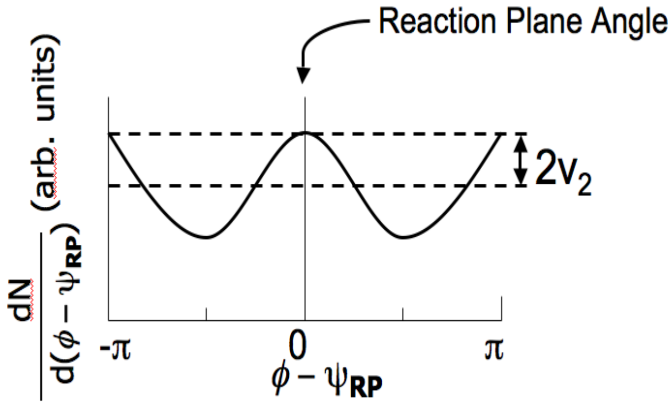
$$v_2 = \frac{\langle p_x^2 \rangle - \langle p_y^2 \rangle}{\langle p_x^2 \rangle + \langle p_y^2 \rangle} = <\cos(2 \times (\phi_i - \Psi_{RP}))>$$



Elliptic flow

- Initial spatial anisotropy of participants in transverse plane for non-central collisions
- Via the re-scattering processes in the participant region, pressure gradients appear, higher along the reaction plane, which leads to …
- A collective flow, preferably « in-plane » (no "squeeze-out" for $E_{beam} > 5$ A.GeV)

→ Sensitive to
the nuclear matter **compressibility** (soft/hard EOS?)
its **transport properties** (speed of sound, viscosity, etc)
its **effective dof** (QGP and HRG have ≠ transport properties)



$$\frac{dN}{d\Delta\Theta} = \frac{1}{2\pi} \sum_n (1 + 2v_n \cos n\Delta\Theta)$$

Elliptic flow as a probe of the deconfinement phase transition at FAIR energies

At FAIR energy regime, a **1^{st} order phase transition** is predicted by LQCD to occur in HI collision (for $20 < E_{beam} < 45$ A.GeV ?):

- predicted collapse of proton v_2 around mid-rapidity at beam energy $E_{lab} \sim 40$ A.GeV
  (Stoecker et al., CPOD07_025)

  → indication of this collapse from NA49 data at 40 A.GeV
  → extrapolation from AGS data leads to a collapse of proton v_1 around same energy
  → predicted collapse of proton v_1 at 10 A.GeV by hydro + 1^{st} phase transition (only!)

- disappearance of the number of valence quark scaling of v_2
  (and localisation of the QCD critical point via an energy scan)

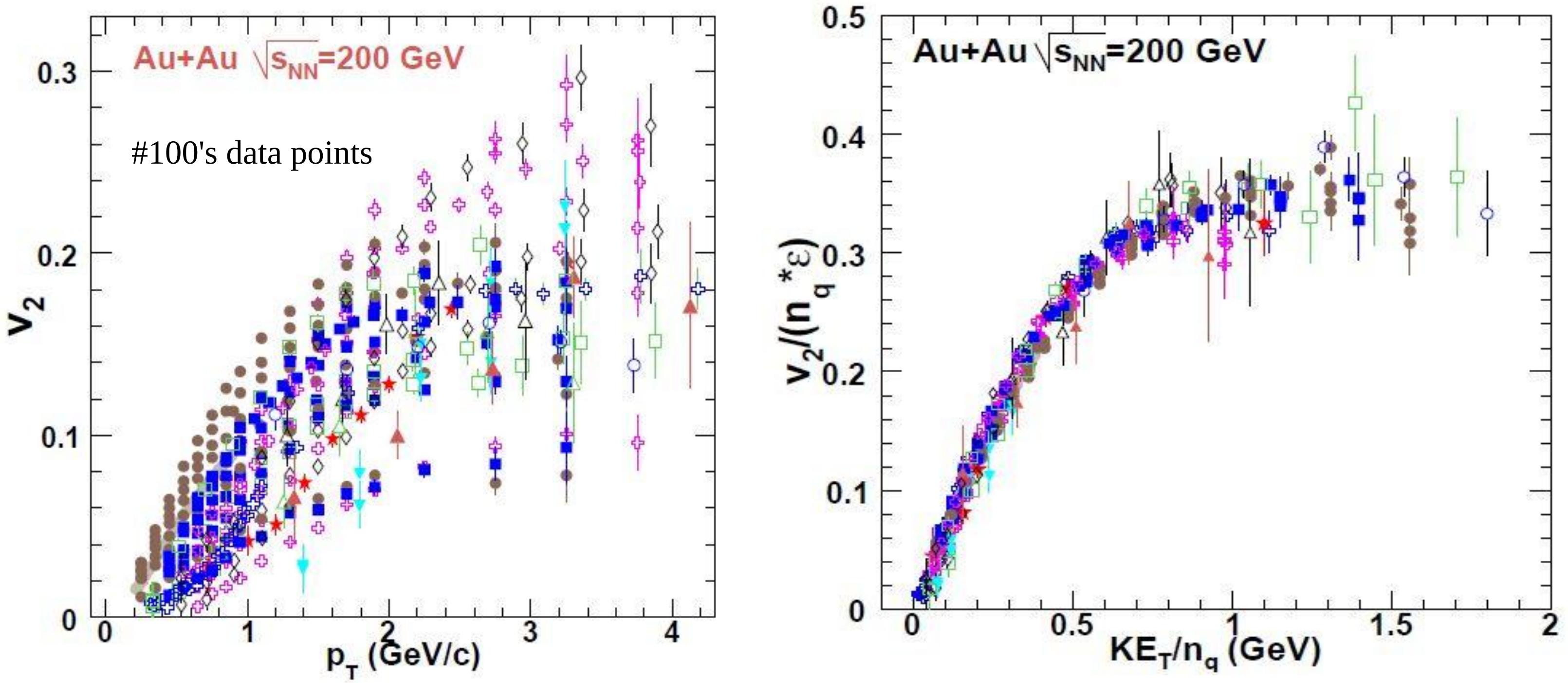
- "large/small" open-charm v_2 ?

→ **all these signals require a high precision of the v_2 measurement!**

Disappearance of v2 CQN scaling as a probe of the phase transition at FAIR energies

- The **Constituent Quark Number (CQN) scaling** of the elliptic flow is one of the strong indications for the **formation of a QGP** (RHIC)

RHIC data, R.Lacey and A.Taranenko, arXiv:nucl-ex/0610029v3

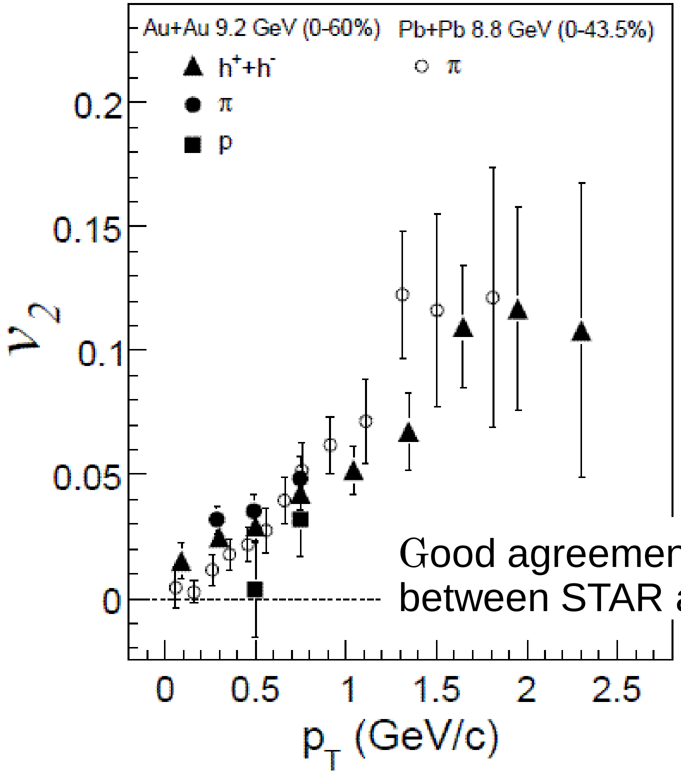


#100's data points

- Search for the **disappearance of this scaling at FAIR energies**
  → 1st order phase transition ↔ sharp signal
  → energy scan → constrain on the localisation of the QCD critical point

Bulk v2 existing measurements at FAIR energies

ArXiv: 0909.4131v1



Good agreement within error bars between STAR and NA49 data's

V_2 as function of p_T for charged hadrons (solid triangles), π (solid circles), and p (solid squares)
in 0-60% Au-Au collisions at √s = 9.2 GeV (STAR).
(only statistical errors are shown)

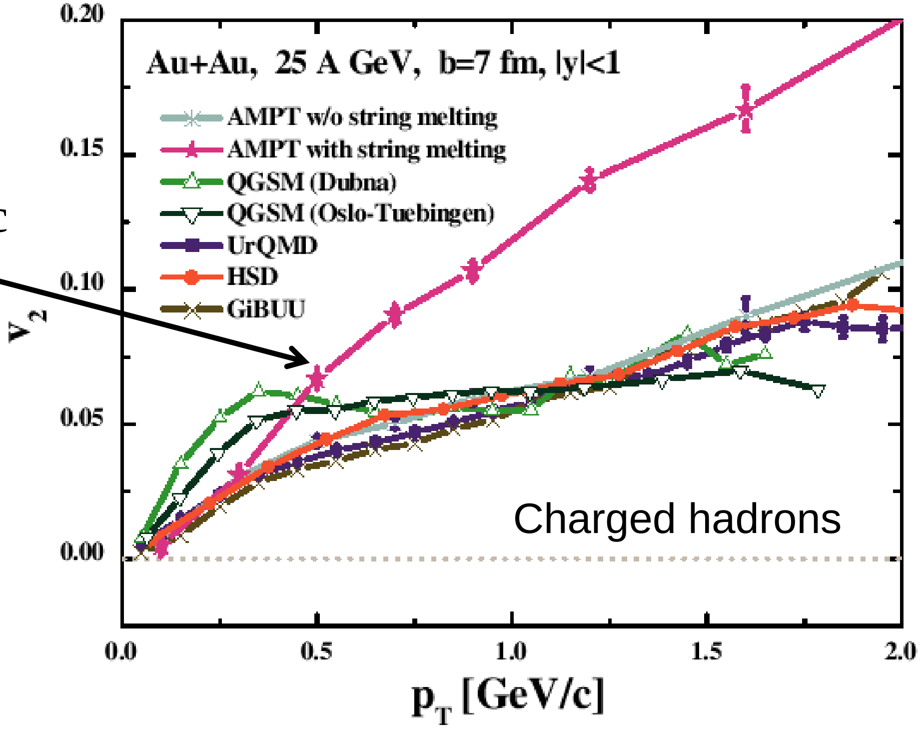
For comparison,
$V_2(p_T)$ for π (open circles) from NA49 in 0-43.5% Pb-Pb collisions at √s = 8.8 GeV.

- Existing measurements at RHIC (low energy scan) and SPS, close to FAIR energy regime √s ~ 7 GeV
- But insufficient statistics to study the scaling behaviour of the collective flow of particles at √s ~ 9.2 GeV (recent data taking – 2010 with higher statistics!)
- The FAIR intense beam intensity will allow for very high statistics studies
- It will give access to the collective flow of rare probes at these energies, namely open charmed particles

Open charm v2 as a probe of the phase transition at FAIR energies

- The deconfinement phase transition should be visible in the **magnitude of the elliptic flow**

The string melting mimic
the partonic dof.



CBM physics book
Submitted to Lecture
Notes in Physic

- The observed v2 may be bigger in case an early partonic medium contributes to the rescattering process
- **Same argument for open charm v_2** (no prediction so far at FAIR energies):
  → **its magnitude is a particularly sensitive to the formation of a QGP**
  → one of the most challenging differential analysis at FAIR energy regime!

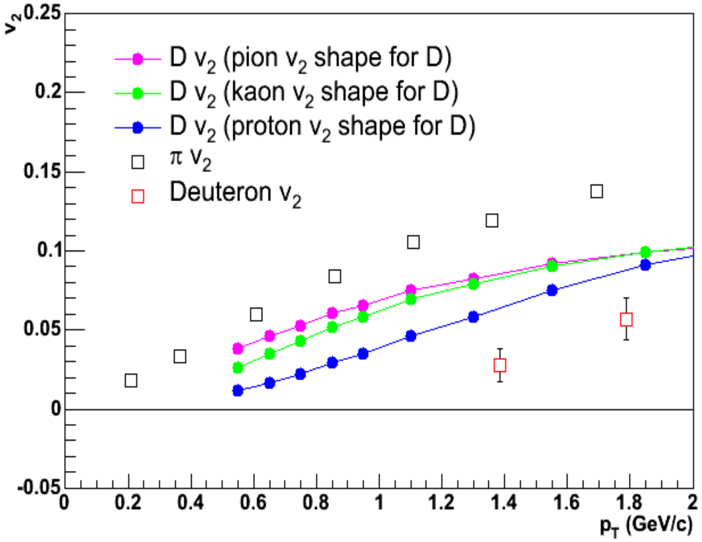
Existing open charm v2 measurements

- The open charm v2 has only been measured via the indirect method using non-photonic electrons:

→ the estimation may suffer from large systematic errors and is model dependant

- A direct measurement of open charm v2 is one of the motivations for the future Heavy Flavor Tracker (STAR) and Micro-Vertex Detector (CBM)

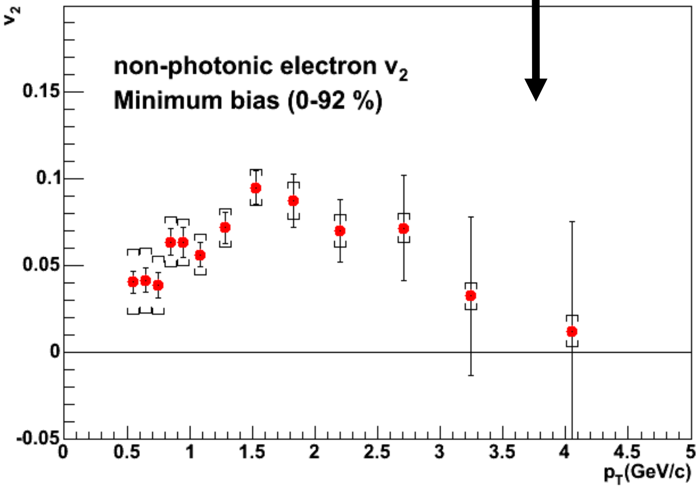
D $V_2(p_T)$ simulation



Shingo Sakai (PHENIX) (J. Phys G 32, S 551)

- Different assumptions for the shape of D meson V_2(pt): π,K and p v2(pt)
- All non-photonic electrons (p_T < 2.0 GeV/c) were assumed to come from the D decay
- D-> e, p_T spectrum constrained by the data

Phenix measurements



Open charm measurement with CBM

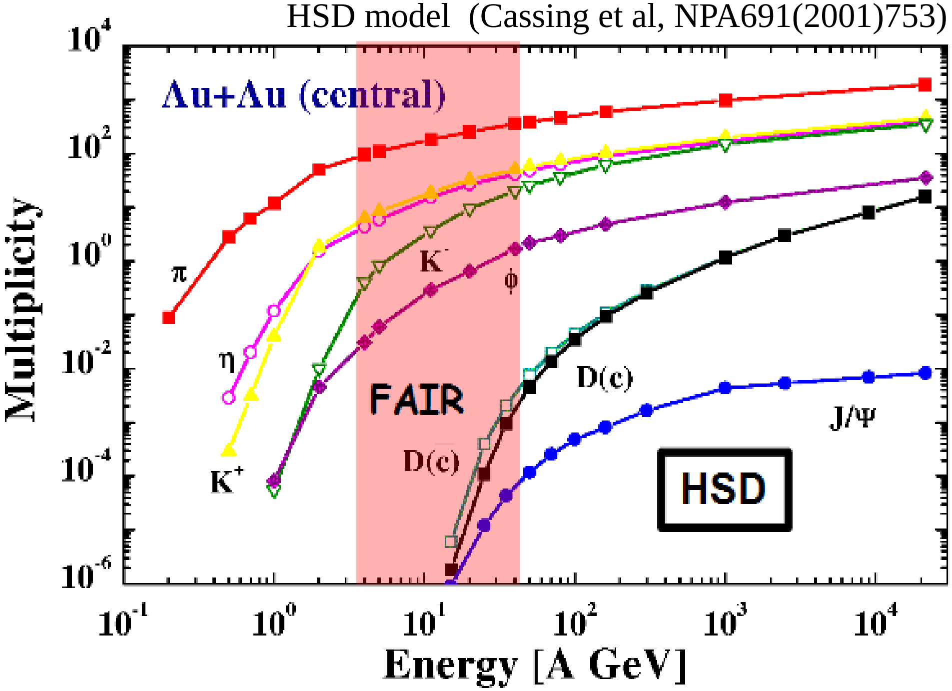
FAIR energies are at the kinematical threshold of open charm production:

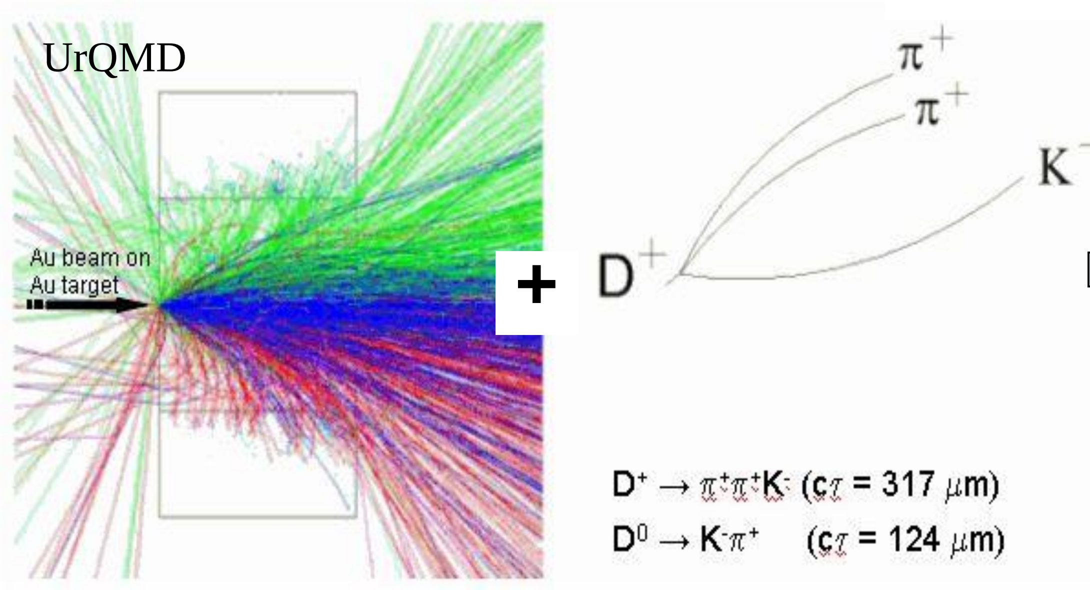
$M_{D+} \sim 10^{-5}$ among ~ 1000 part./coll in central Au-Au coll.

→

The Micro-Vertex Detector (MVD) will allow to disentangle open charmed and bulk particles

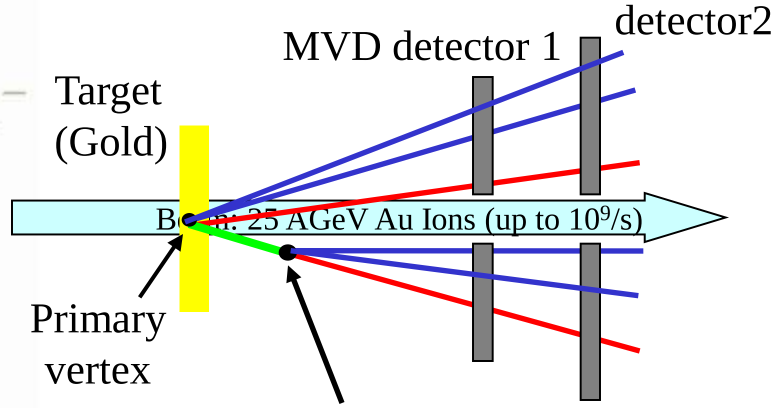
HSD model (Cassing et al, NPA691(2001)753)





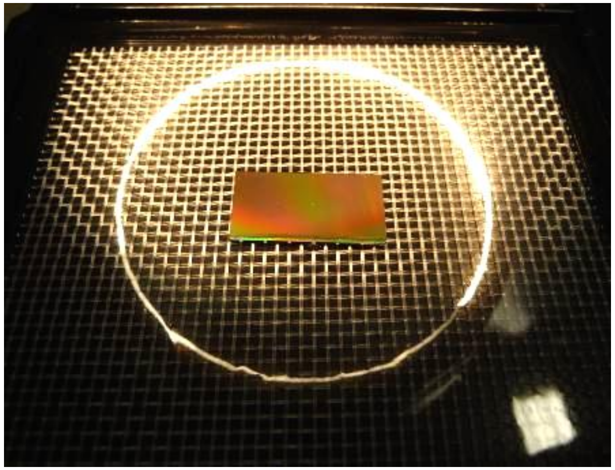
$D^+ \rightarrow \pi^+\pi^+K^-$ ($c\tau$ = 317 μm)

$D^0 \rightarrow K^-\pi^+$ ($c\tau$ = 124 μm)



Displaced decay vertex of open charmed part.

MAPS sensors for the MVD – R&D



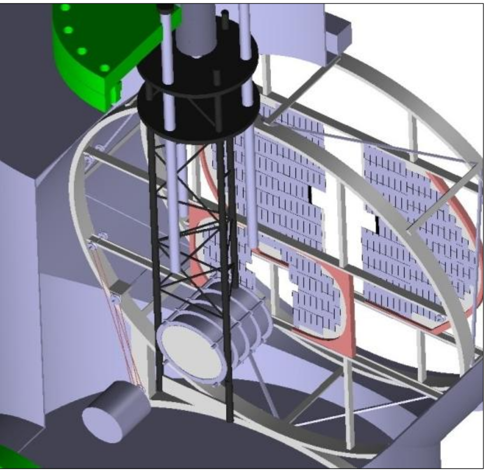
Monolithic Active Pixel Sensors
(MAPS, CMOS-based sensors)

- Invented by industry (digital camera)
- Modified for charged particle detection since 1999 by IPHC Strasbourg
- Also foreseen for ILC, STAR…

Rad. hard. and speed optimization on-going →

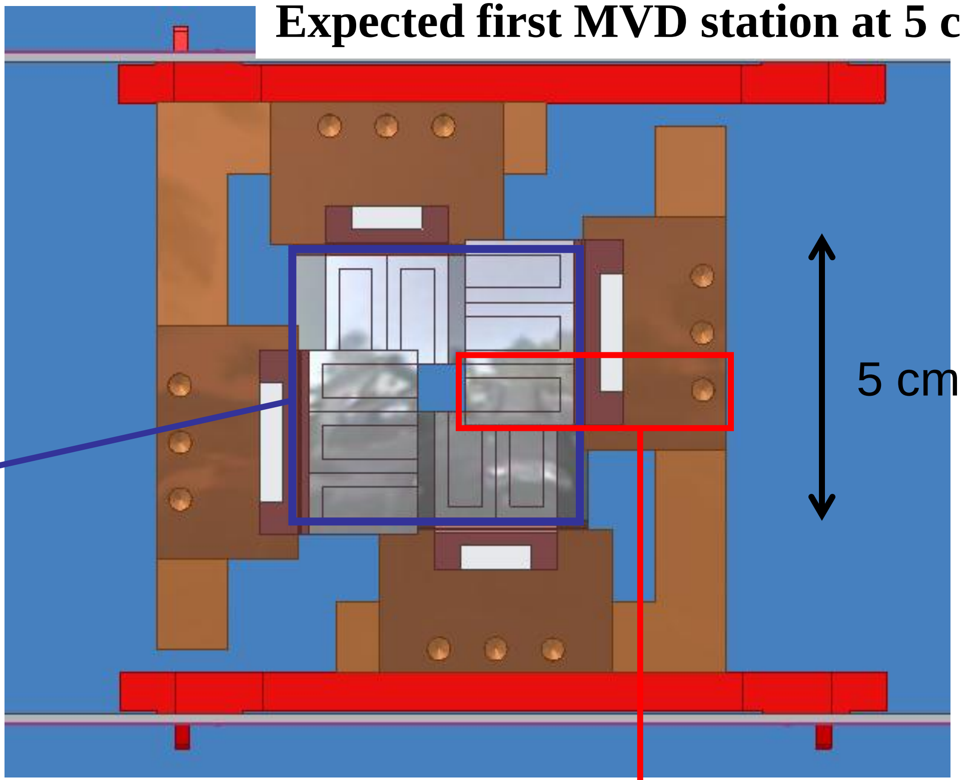
	CBM wish list	**MAPS* (2003)**	**MAPS* (2009)**	**MIMOSA-26 Binary, ∅**
Single point res.	~ 5 µm	1.5 µm	1 µm	4 µm
Material budget	$< 0.3\%\ X_0$	$\sim 0.1\%\ X_0$	$\sim 0.05\%\ X_0$	$\sim 0.05\%\ X_0$
Rad. hard. non-io.	$>10^{13}\ n_{eq}$	$10^{12}\ n_{eq}/cm^2$	$>3 \times 10^{13}\ n_{eq}$	few $10^{12}\ n_{eq}$
Rad. hard. io	> 3 Mrad	200 krad	> 1 Mrad	> 300 krad
Time resolution	< 30 µs	~ 1 ms	~ 25 µs	110 µs

MAPS sensors for the MVD – integration

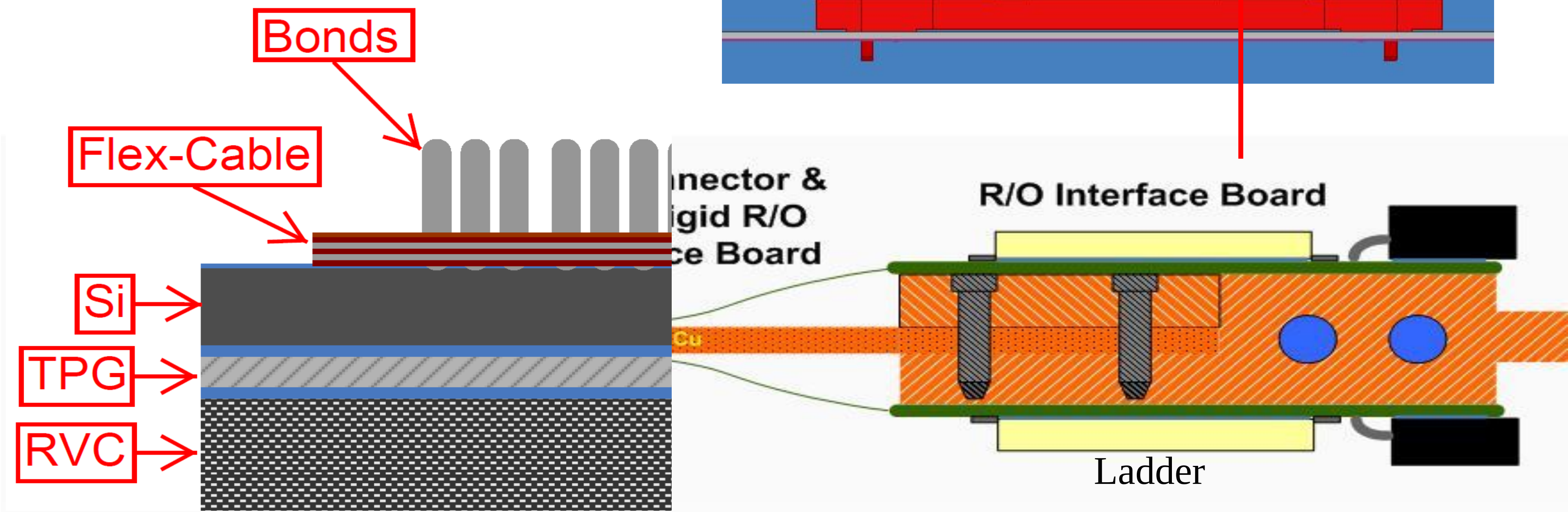


IKF - Frankfurt

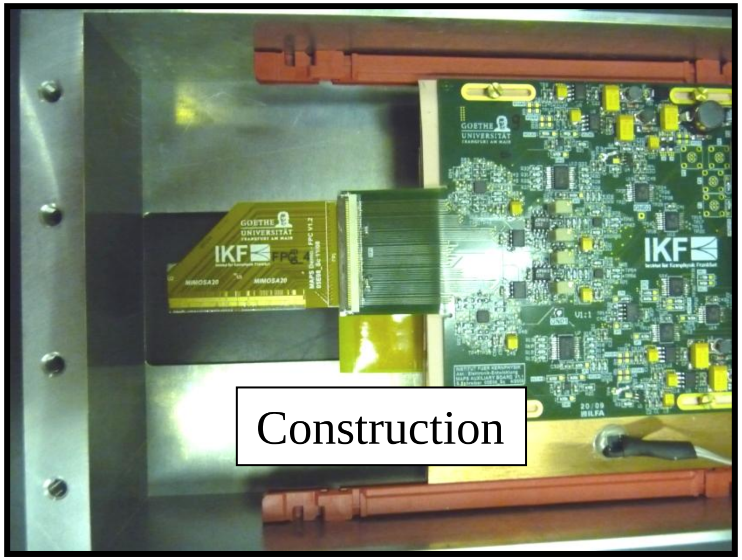
Expected first MVD station at 5 cm

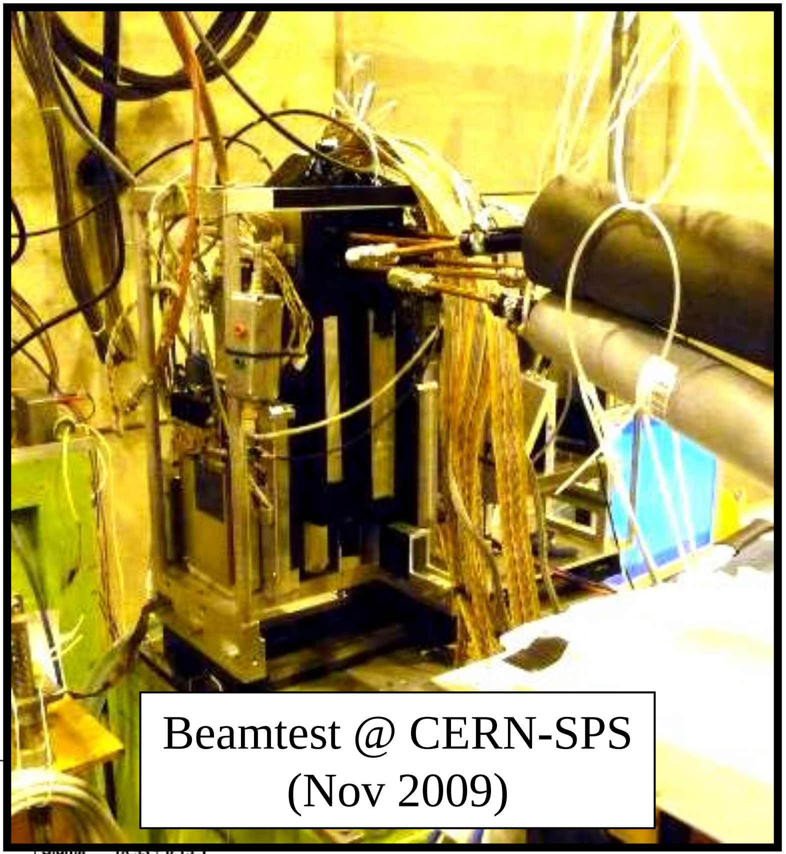


CBM-Acceptance
Low material



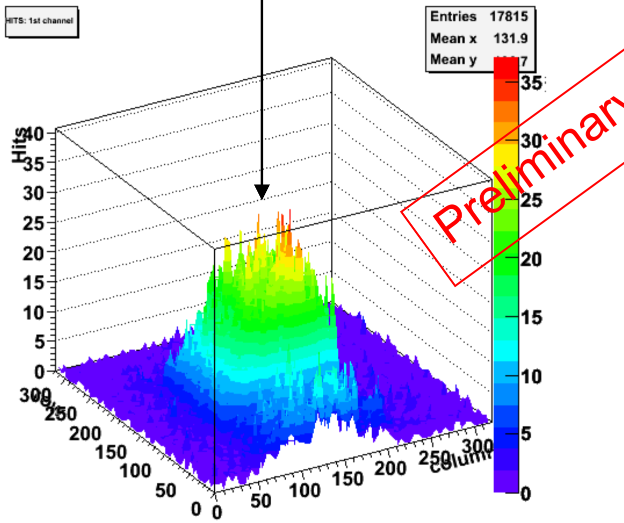
MAPS sensors for the MVD – integration (3)



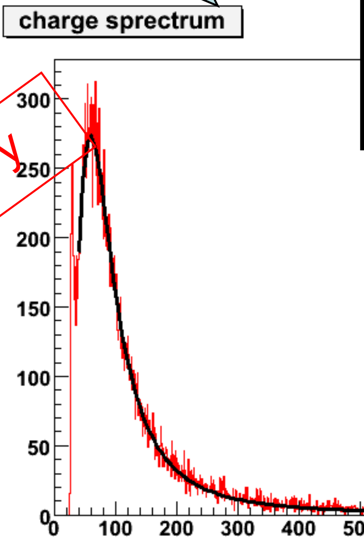


S. Amar-Youcef

Shadow of trigger scintillator



charge sprectrum



signal (a.u.)

Achievements:

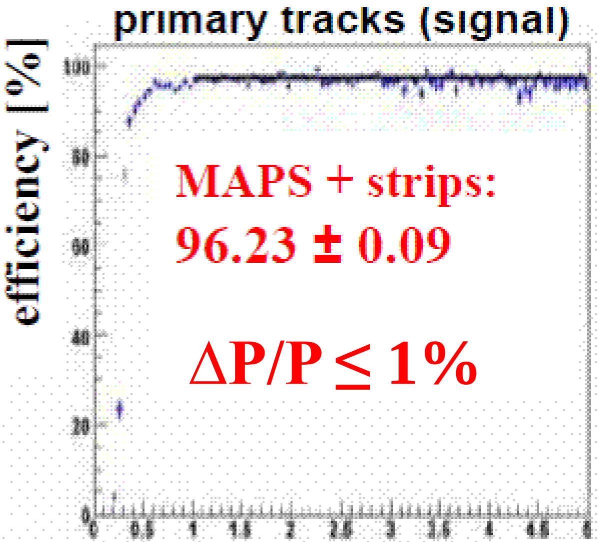
System design validated

Good noise: 21 e^- ENC

Spatial res.: < 6µm

Open charm measurement with CBM in the simulation

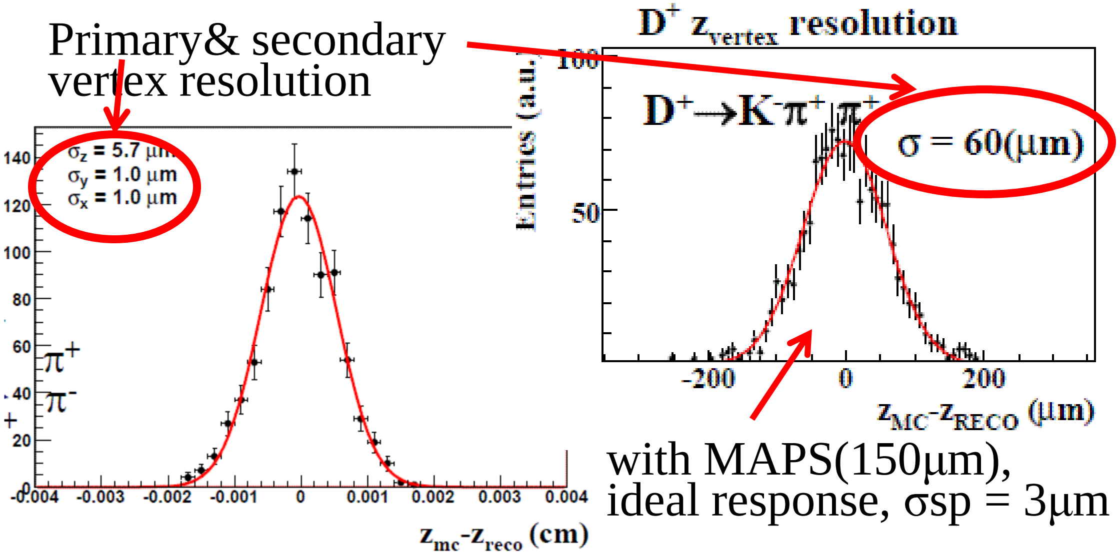
Tracking performances:



MAPS + strips: 96.23 ± 0.09

$\Delta P/P \leq 1\%$

Primary& secondary vertex resolution

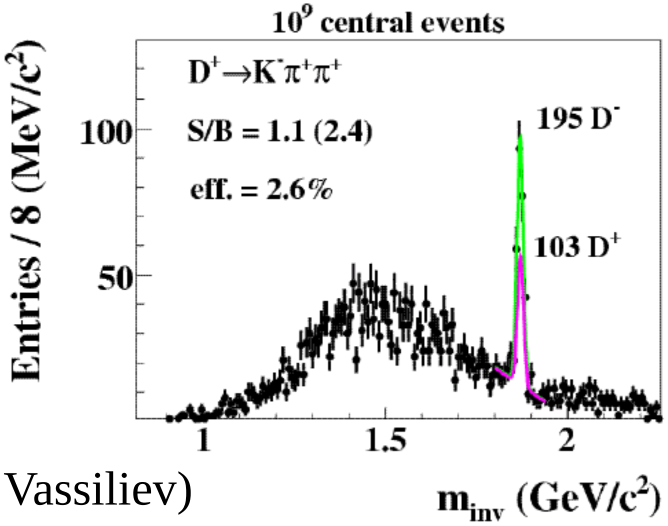


with MAPS(150μm), ideal response, σsp = 3μm

Topological cuts:

Track impact parameter

Vertex position, chi2

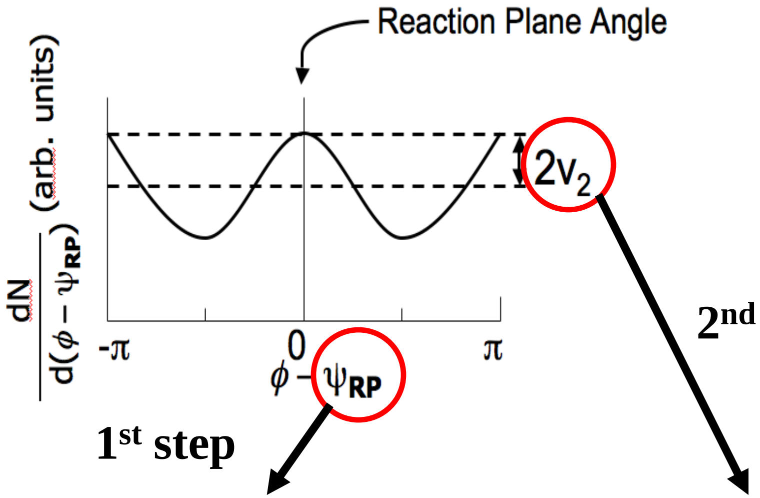


(I. Vassiliev)

Central Au-Au @ 25 AGeV → several 10^4 open charm particles per month (10^{11} central coll.)

Main steps of the v2 measurement capability study with CBM

What is the expected precision for the measurement of open charm elliptic flow with CBM?
→ 2 limitations: **the reaction plane resolution**
the limited statistics of open charm particles



1st step

2nd step

Evaluation of the reaction plane resolution:

- Use Au(25AGeV)-Au minimum bias events
  → transport through the appropriate detector(s)
- Systematic study of the reaction plane resolution
  → **b and Ebeam dependence**

Reconstruction of v_2 for the D^+ :

Assume the reaction plane resolution evaluated in the 1st step

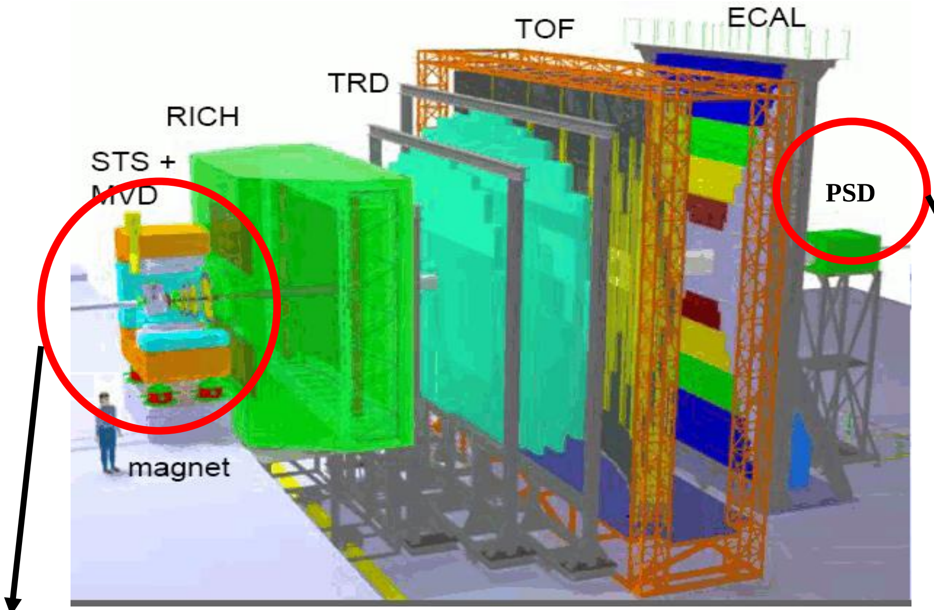
this will give a estimate of the v_2 statistical error!

$\sigma_{\Phi_{RP}}$

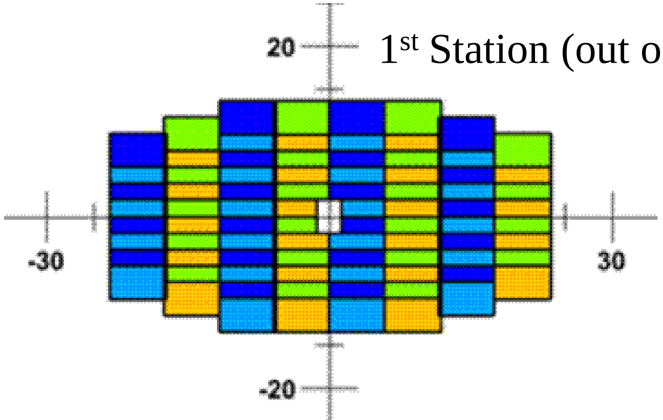
$M_D \sim 10^{-5}$ for 25 AGeV Au-Au central coll.

Reconstruction of the reaction plane

- Experimental set-up -



Silicon Tracking System (STS)

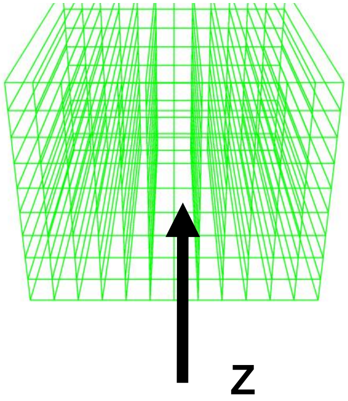


1st Station (out of 8)

Heuser, ULISI, Feb 2010

Projectile Spectator Detector (PSD)

CBM-PSD-note-2006-001

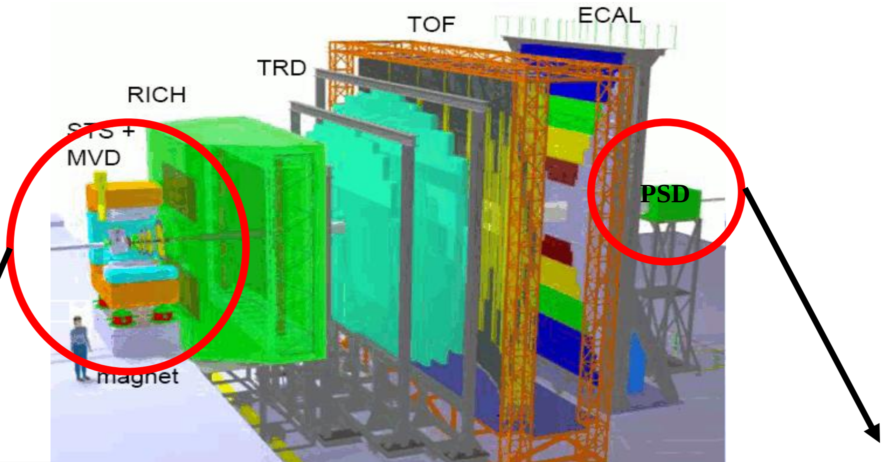


2 independent sub-detectors to measure the event plane

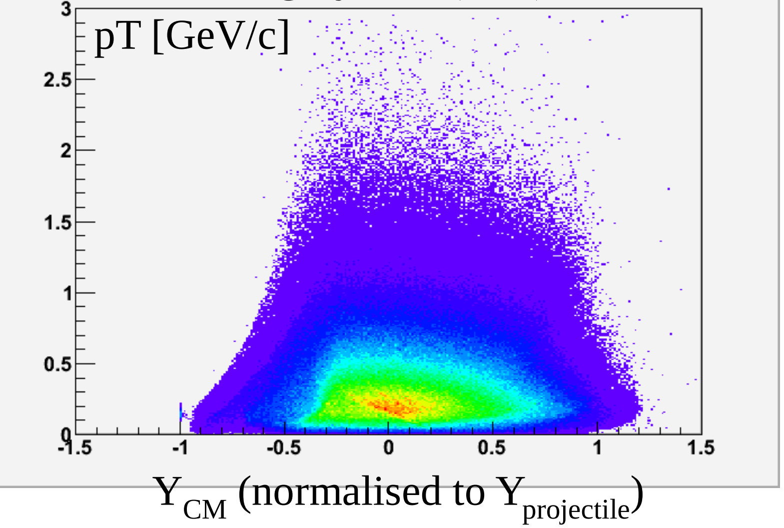
↔ cross-check of several estimates of v2!

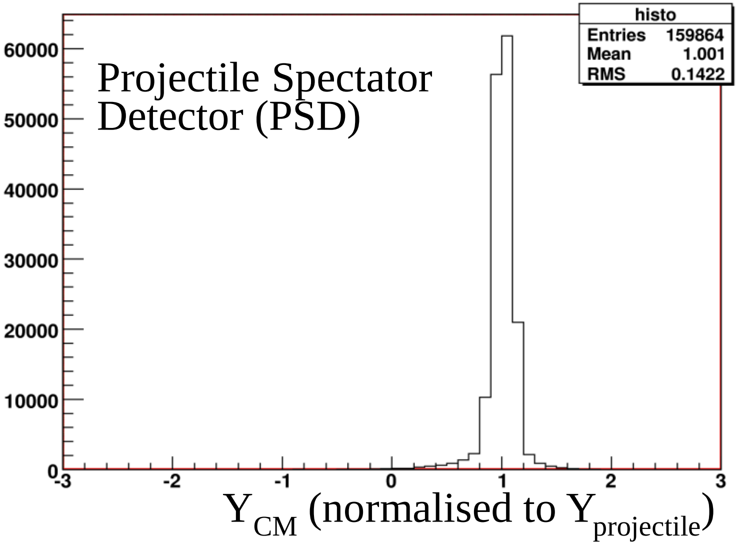
Reconstruction of the reaction plane

- Detector acceptance -



Silicon Tracking System (STS)





STS → mid-Y / forward-Y coverage → n = 2 and 1

PSD → forward-Y coverage → n = 1

Reconstruction of the reaction plane

- Simulation set-up -

1Tm magnetic field dipole

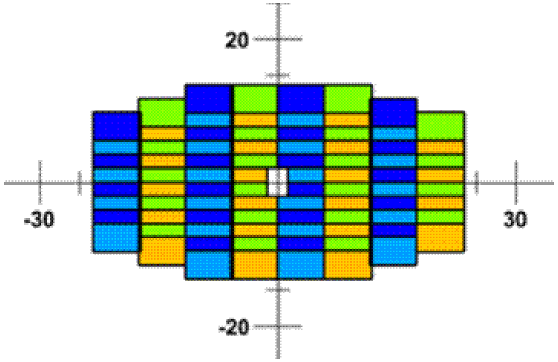
PSD – 15m

MVD + STS
- 5 cm – 1m

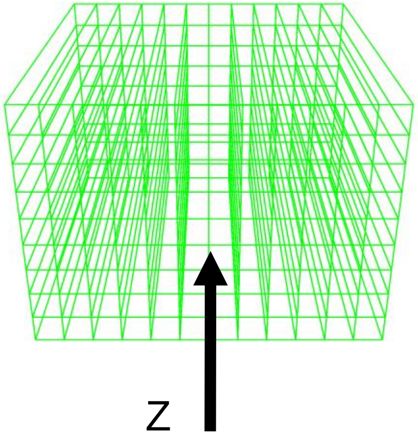
Target

Z

- UrQMD : Au(25AGeV)-Au minimum bias
- RP plane randomly distributed



Transport with GEANT



Reconstruction of the reaction plane

- Method for the STS -

Poskanzer and S. Voloshin, arXiv:nucl-ex/9805001

Flow vector Q:

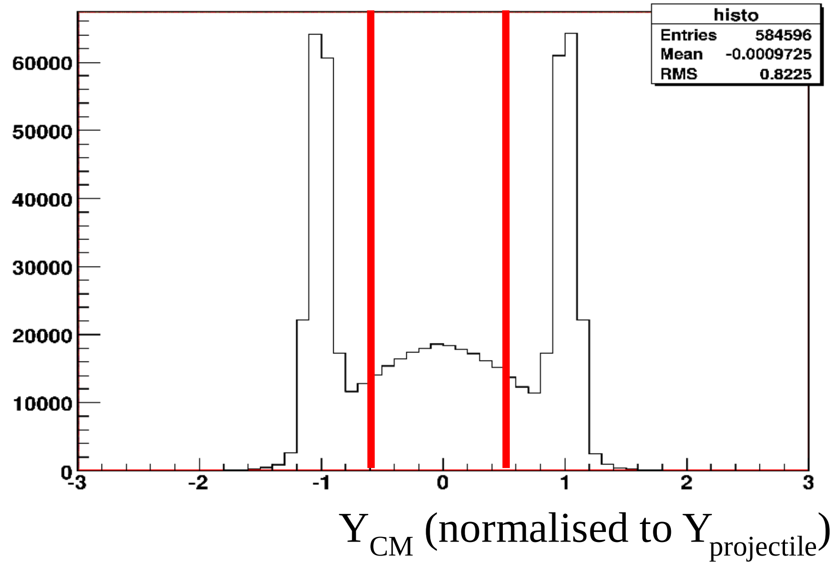
$$Q_x = \Sigma_i\, w^i \,.\, p_T^i \,.\, \mathrm{Cos}(n \,.\, \Phi^i)$$

$$Q_y = \Sigma_i\, w^i \,.\, p_T^i \,.\, \mathrm{Sin}(n \,.\, \Phi^i)$$

$$\longrightarrow \Phi_{RP}^{reco} = 1/n \,.\, \tan^{-1} (Q_y \,/\, Q_x)$$

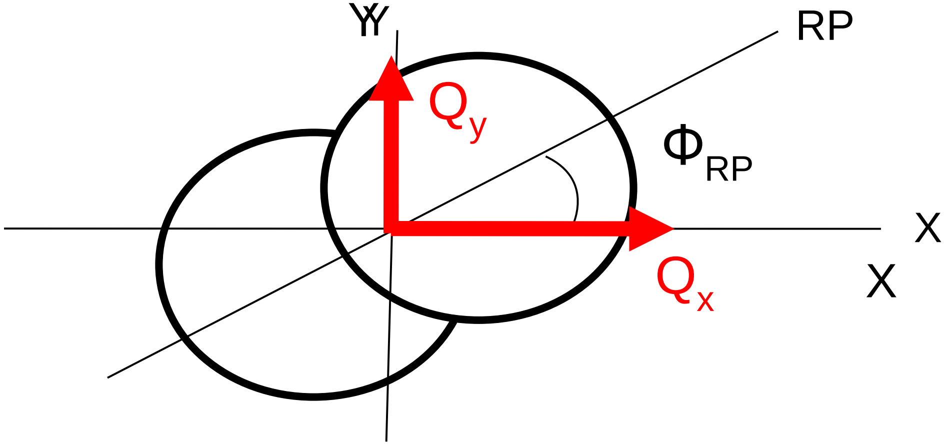
p_T^i: transverse momentum of part. i

Φ^i: azimuth of the part. i



For n = 1: W = -1 0 1

For n = 2: W = 1



Also: anti-flow of pions

For n = 1: $\Phi_{pion} \rightarrow \Phi_{pion} + \pi$

Reconstruction of the reaction plane

- Method for the PSD -

Flow vector Q:

Gravity center of the energy deposited in the PSD modules:

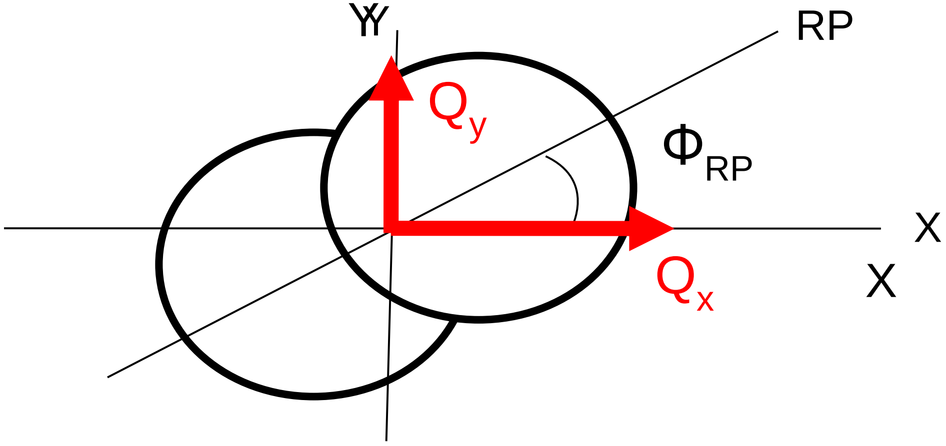
$$\left.\begin{array}{l} Q_x = \Sigma_i\, R^{i}_{module} \,.\, E^{i}_{module} \,.\, \mathrm{Cos}(\Phi^{i}_{module}) \\ Q_y = \Sigma_i\, R^{i}_{module} \,.\, E^{i}_{module} \,.\, \mathrm{Sin}(\Phi^{i}_{module}) \end{array}\right| \longrightarrow \Phi_{RP}^{\ reco} = \tan^{-1}(Q_y / Q_x)$$

Poskanzer and S. Voloshin, arXiv:nucl-ex/9805001

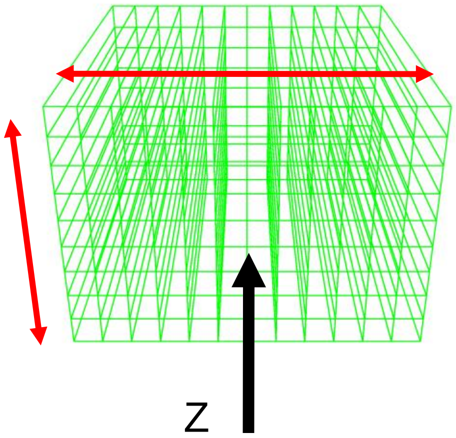
E^{i}_{module} : deposited energy in module I

R^{i}_{module} : radius of module I ↔ distance from (0, 0)

Φ^{i}_{module} : azimuth of the module i



12 × 9 modules, 120 cm long



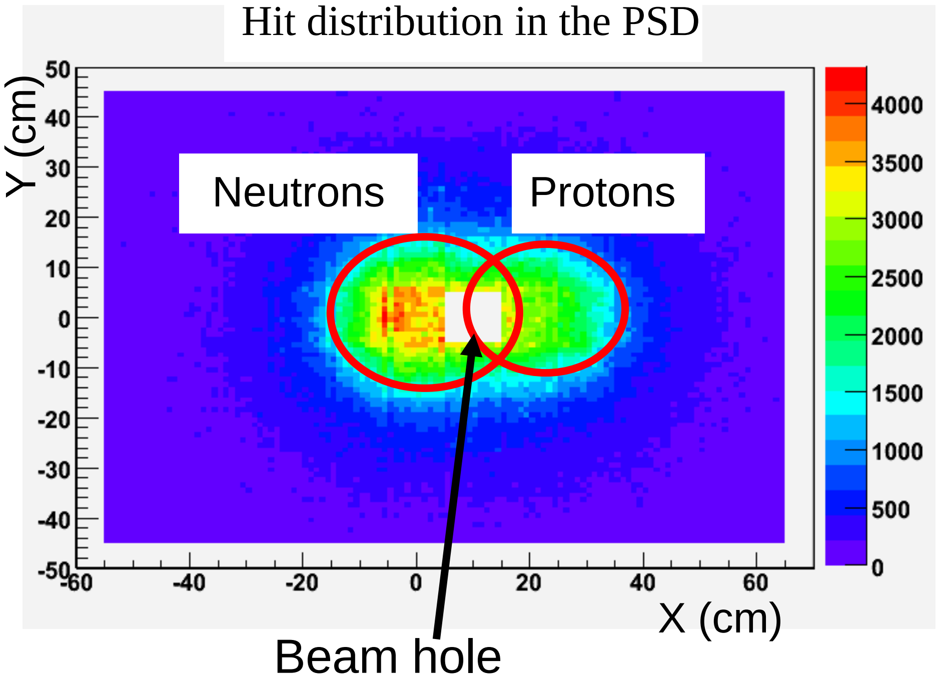
Reconstruction of the reaction plane

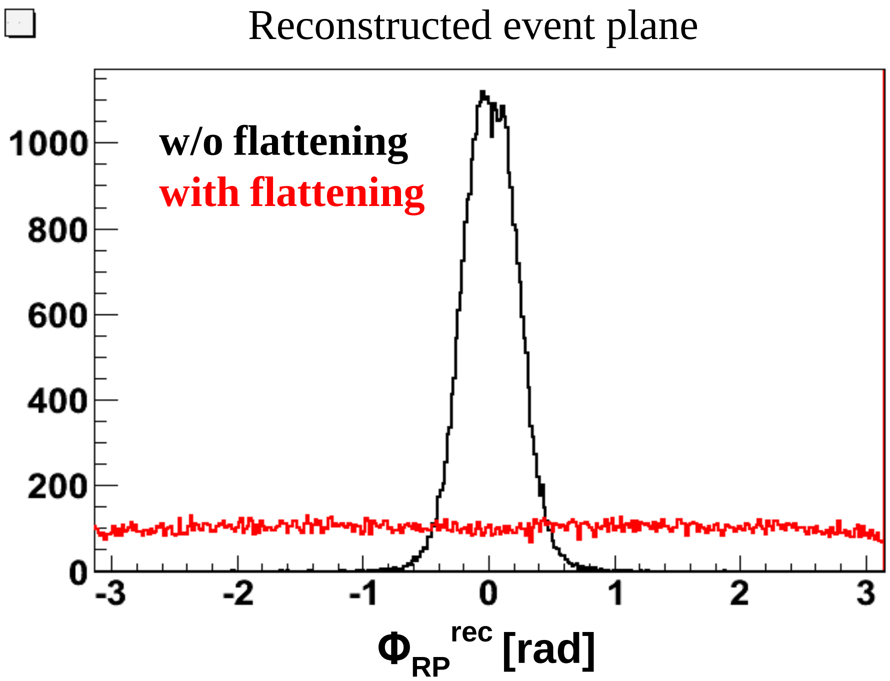
- PSD azimuthal asymmetry and shift of the protons-

- The PSD is shifted along X > 0 to place the **beam hole** at the beam spot position
- **The spectator protons are deflected by the magnetic dipole field**
- We used one of the simplest technique to **flatten the reconstructed event plane distribution**:

  $Q_x = \Sigma_i \, E_{module} \,.\, X_{module} - < \Sigma_i \, E_{module} \,.\, X_{module} >$
- The phi weight method has been used but not conclusive results ...
- Other flattening methods: shifting method, etc

  (A. Poskanzer and S. Voloshin, arXiv:nucl-ex/9805001, J. Barrette et al. arXiv:nucl-ex/9707002)


Hit distribution in the PSD


Reconstructed event plane

Reconstruction of the reaction plane

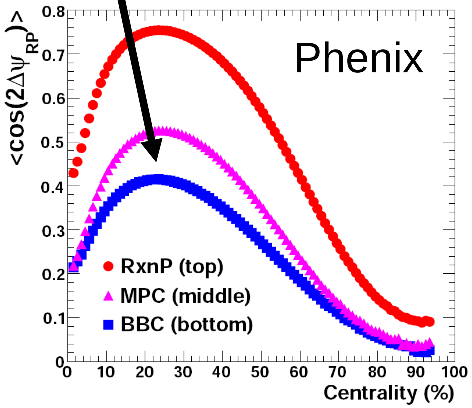
- $\Delta\Phi_{RP} = \Phi_{RP}^{reco} - \Phi_{RP}^{true}$ distribution for the PSD event plane -

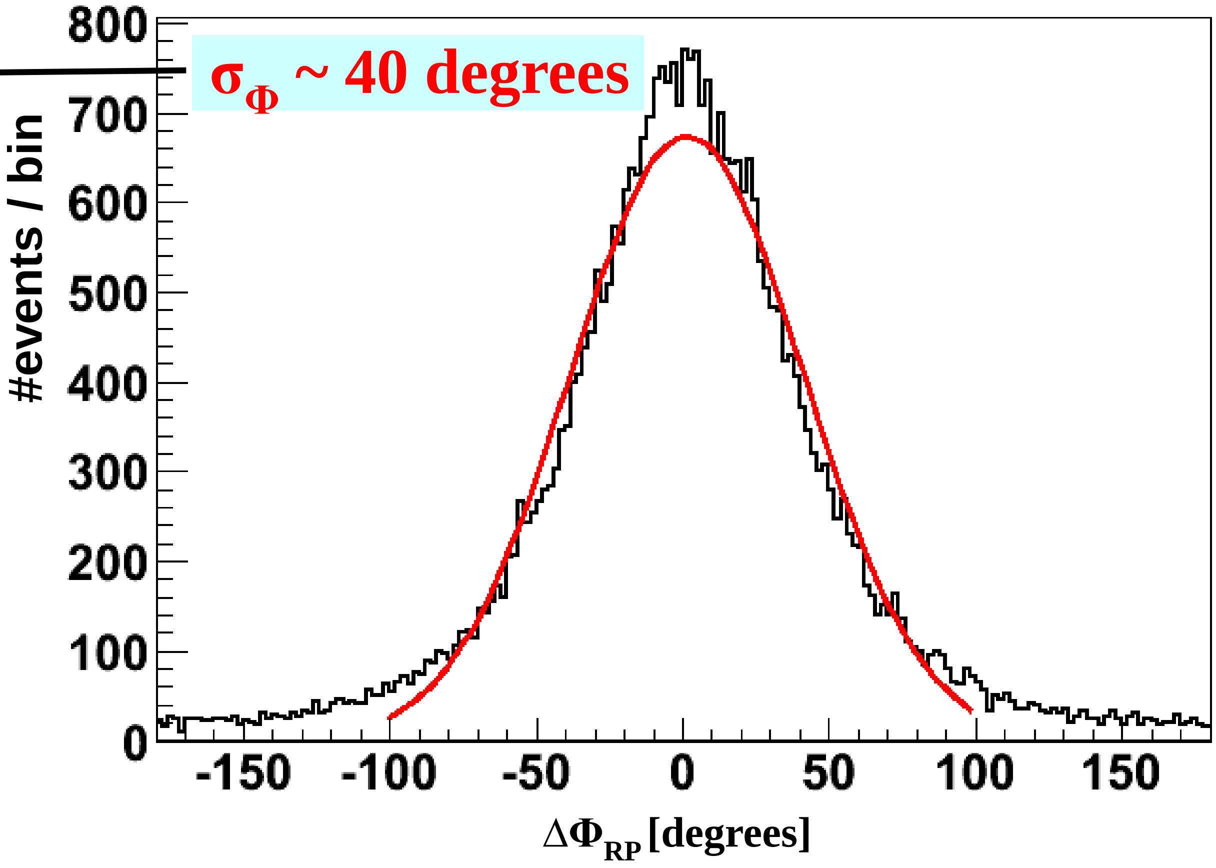
- Au(25AGeV)-Au with b between 6 and 9 fm
- $\Delta\Phi_{RP}$ ~ Gaussian (0, σ_{Φ})

$< \cos(2\,\Delta\boldsymbol{\Phi}_{RP}) >_{event}$ ~ 0.3

For comparison:

arXiv : 0806.0475





σ_{Φ} ~ 40 degrees

Reconstruction of the reaction plane

Ideal calculation of v2:

True reaction plane

$$v_2 = \frac{\langle p_x^2 \rangle - \langle p_y^2 \rangle}{\langle p_x^2 \rangle + \langle p_y^2 \rangle} = < \cos(2 \times (\phi_i - \Psi_{RP})) >$$

Real calculation of v2:

Measured event plane (of order n)

$$v_2 obs = < \cos(2 \times (\phi_i - \Psi_n)) >$$

Correction:

$$< \cos(2 \times (\phi_i - \Psi_n)) > = < \cos(2 \times (\phi_i - \Psi_{RP})) > < \cos(2 \times (\Psi_{RP} - \Psi_n)) >$$

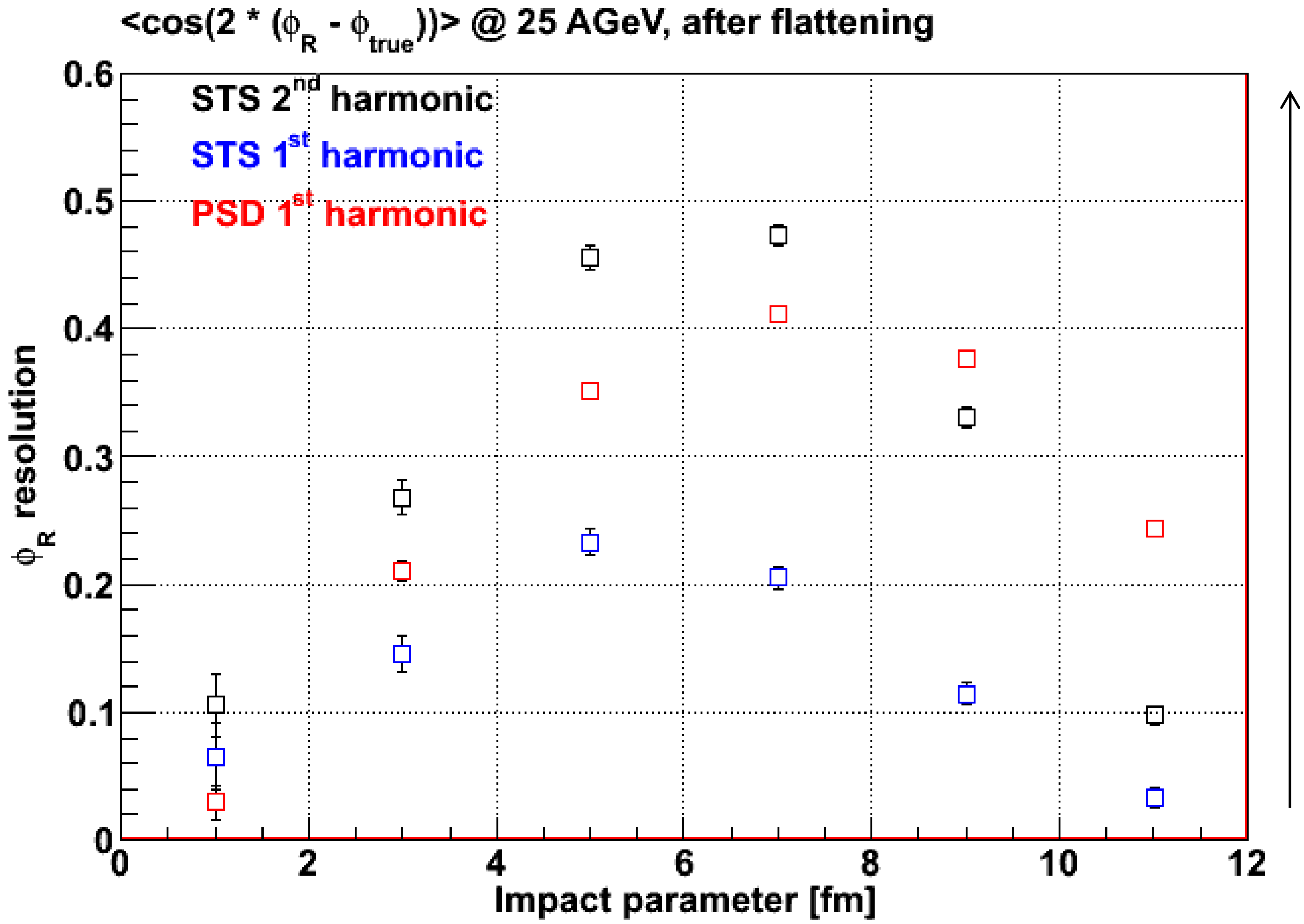
$$\longrightarrow \underbrace{< \cos(2 \times (\phi_i - \Psi_{RP})) >}_{\text{True v2}} = \underbrace{< \cos(2 \times (\phi_i - \Psi_n)) >}_{\text{v2}_{\text{obs}}} / \boxed{< \cos(2 \times (\Psi_{RP} - \Psi_n)) >}$$

Now on, reaction plane resolutions expressed in terms of < cos(2 x (Ψ_{RP} - Ψ_n)) >

Side remark: the statistical error on the true v2 is proportional to 1/<cos((2 x (Ψ_{RP} - Ψ_n))>

Reconstruction of the reaction plane

- Impact parameter (b) dependance of the event plane resolution -



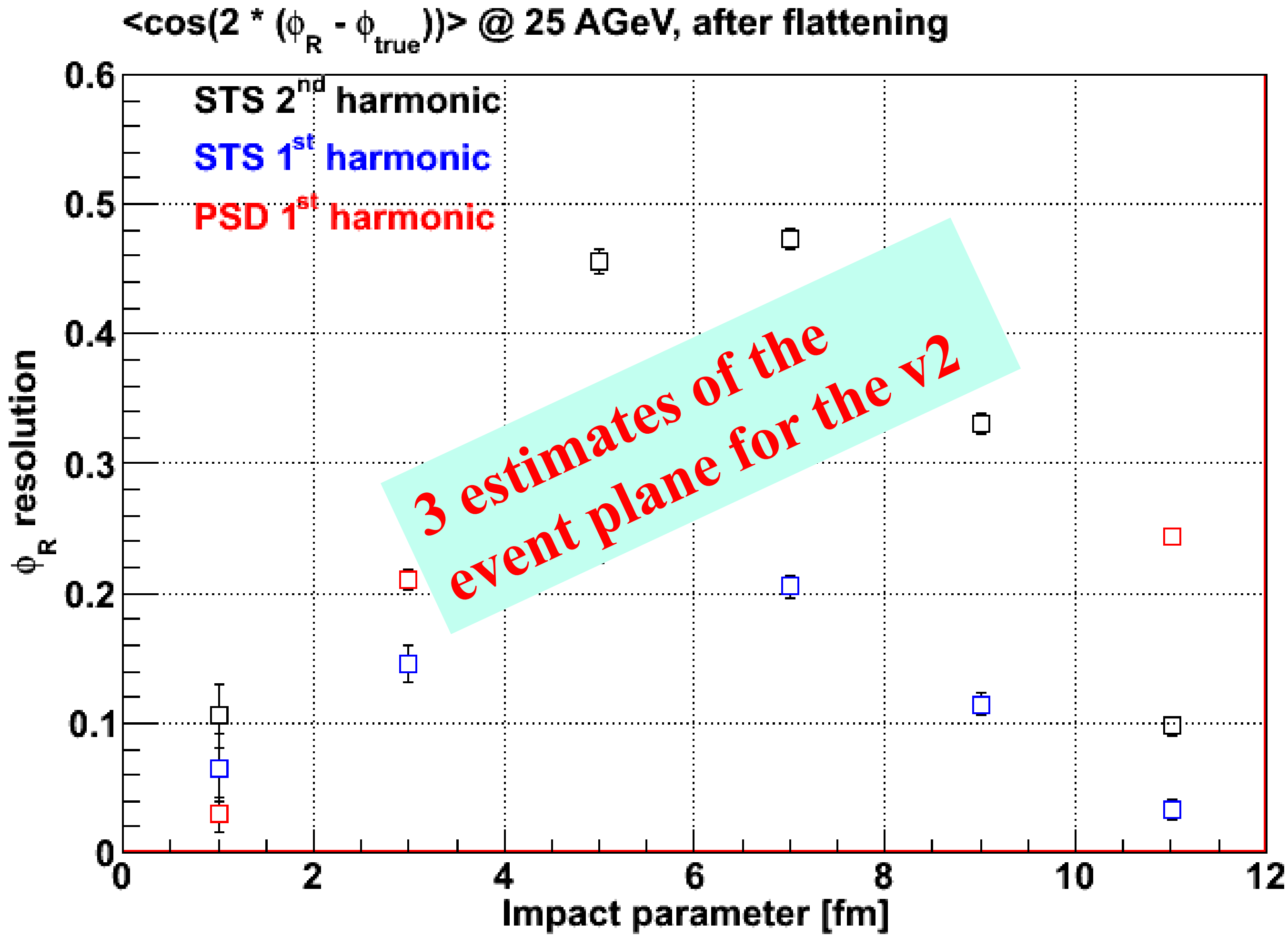
Close to 1
↔ good RP resolution
↔ don’t increase dramatically the v2 statistical error

Toward central coll.
→ low initial eccentricity
↔ low anisotropy in P devpt

Toward peripheral coll.
→ low energy density (low P devpt)
→ for STS: low acceptance

Reconstruction of the reaction plane

- Impact parameter (b) dependance of the event plane resolution -



3 estimates of the event plane for the v2

Close to 1
↔ good RP resolution
↔ don't increase dramatically the v2 statistical error

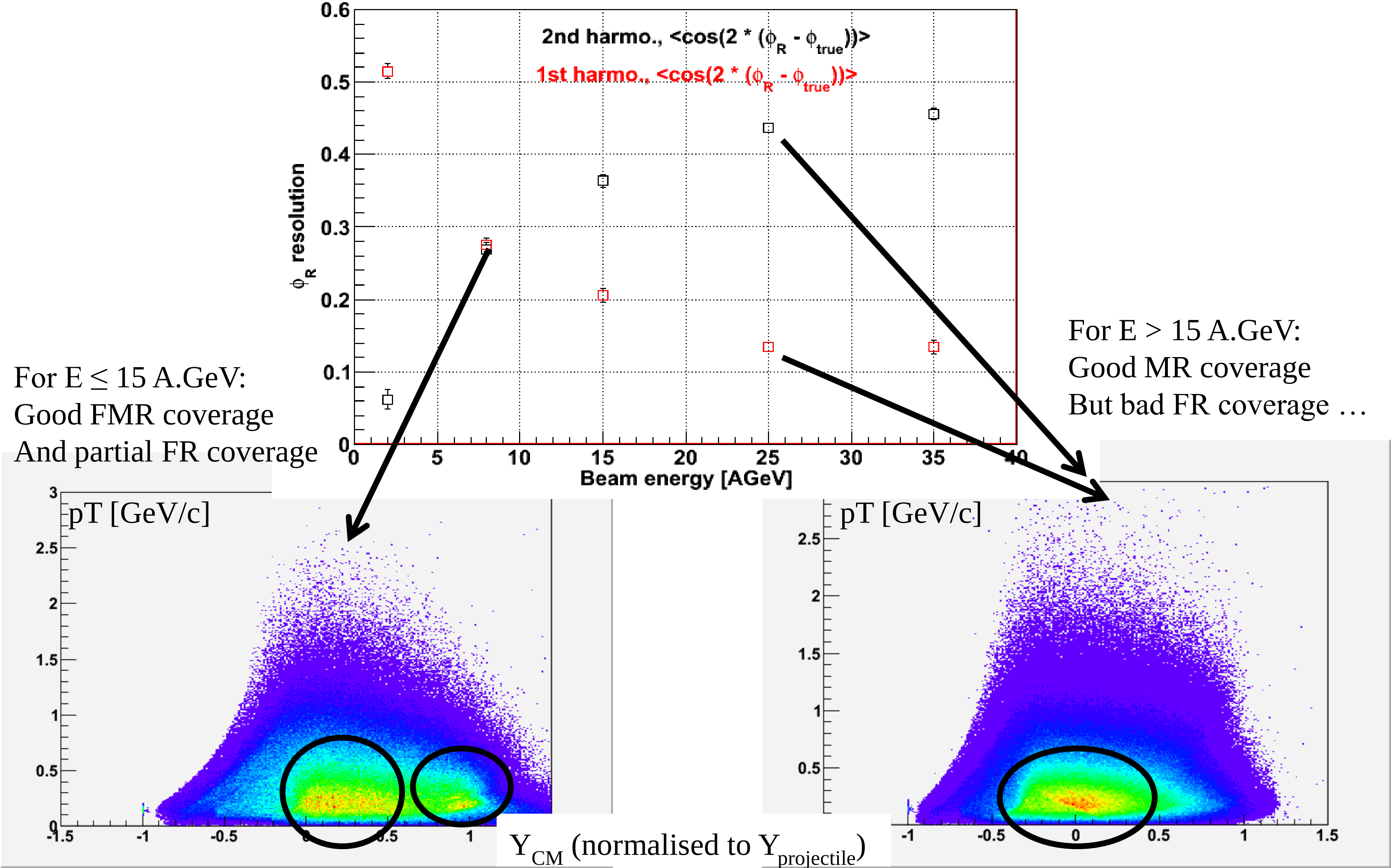
Toward central coll. → low initial eccentricity
↔ low anisotropy in P devpt

Toward peripheral coll. → low energy density (low P devpt)
→ for STS: low acceptance

Reconstruction of the reaction plane

- Beam energy (Ebeam) dependance for the STS event plane resolution -

Acceptance ↔ 4 hits in STS



For E ≤ 15 A.GeV:
Good FMR coverage
And partial FR coverage

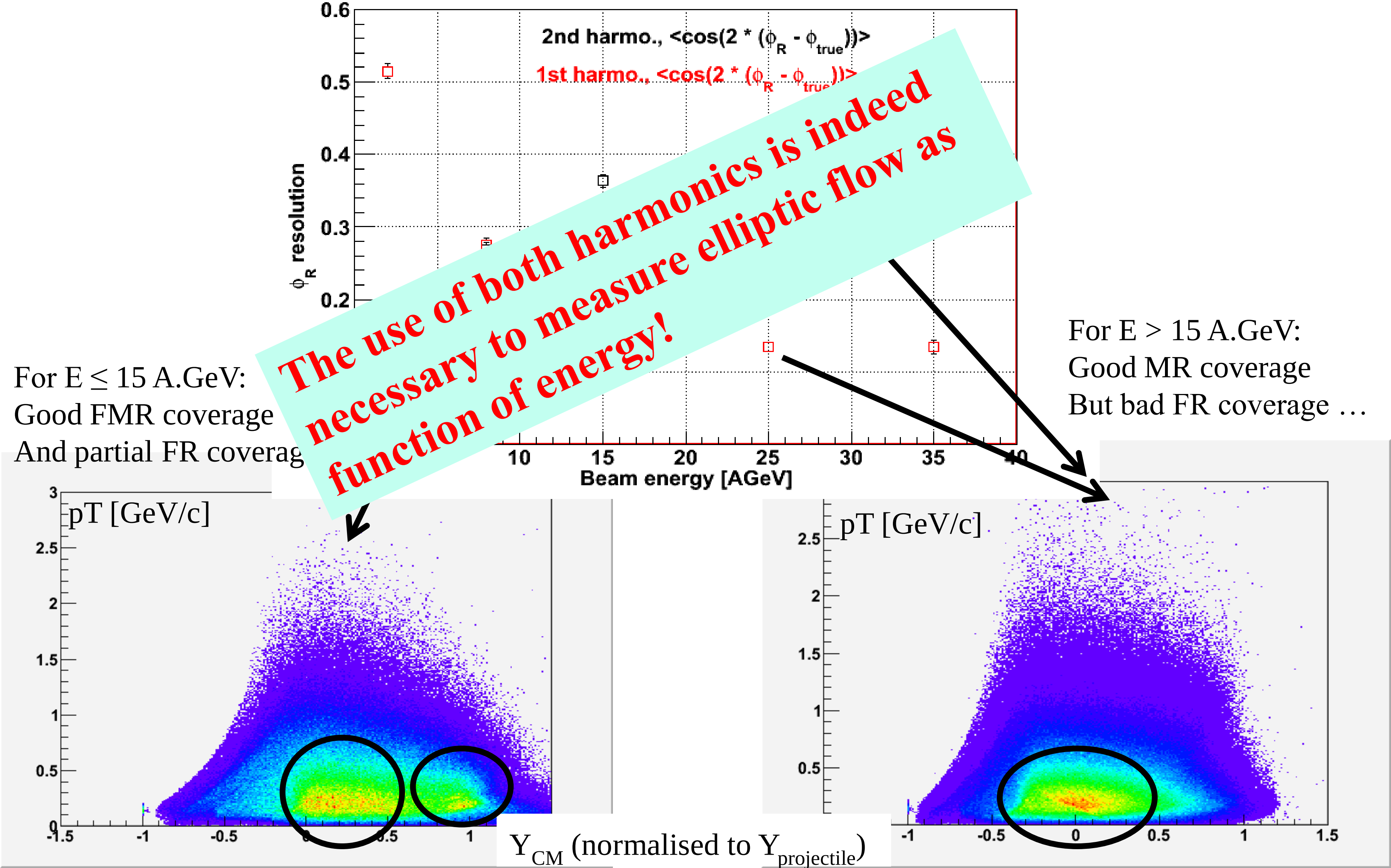
For E > 15 A.GeV:
Good MR coverage
But bad FR coverage …

Y_{CM} (normalised to $Y_{projectile}$)

Reconstruction of the reaction plane

- Beam energy (Ebeam) dependance for the STS event plane resolution -

Acceptance ↔ 4 hits in STS



The use of both harmonics is indeed necessary to measure elliptic flow as function of energy!

For E ≤ 15 A.GeV:
Good FMR coverage
And partial FR coverag

For E > 15 A.GeV:
Good MR coverage
But bad FR coverage …

Reconstruction of the reaction plane

- Experimental evaluation – sub-event method -

- Create 2 sub-events with equal multiplicity
- Calculate the event plane for each of them
- Flatten the 2 resulting event planes …
- And use the correlation between them → $\langle \cos[n(\Psi_n^a - \Psi_n^b)] \rangle$

- The resolution of each sub-event plane is:

$$\mathrm{resSub} \equiv \langle \cos(n(\Psi_n^a - \Psi_{RP})) \rangle = \sqrt{\langle \cos(n(\Psi_n^a - \Psi_n^b)) \rangle}$$

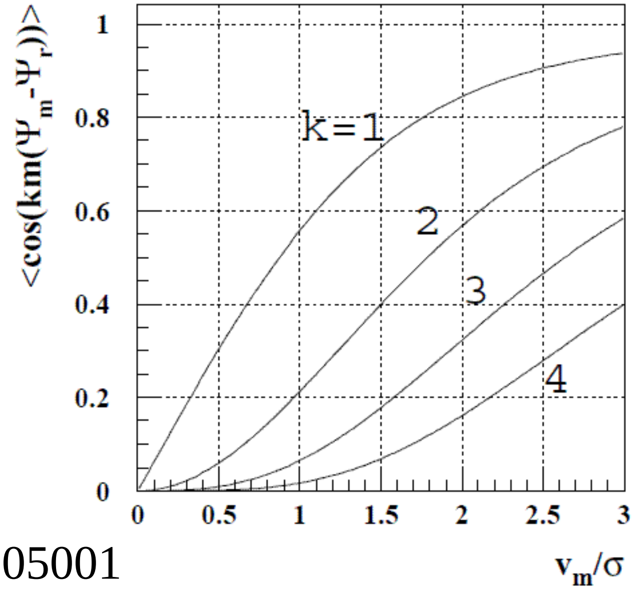
- This can be used in 1st approx. to evaluate the resolution of the full event plane (used to determine the v2 parameter):

$$\mathrm{res} \equiv \langle \cos(n(\Psi_n - \Psi_{RP})) \rangle \leq \sqrt{2}\,\mathrm{resSub}$$

- Other method:

$$\frac{N_{events}(m|\Psi_m^a - \Psi_m^b| > \pi/2)}{N_{total}} = \frac{e^{-\chi_m^2/4}}{2}$$

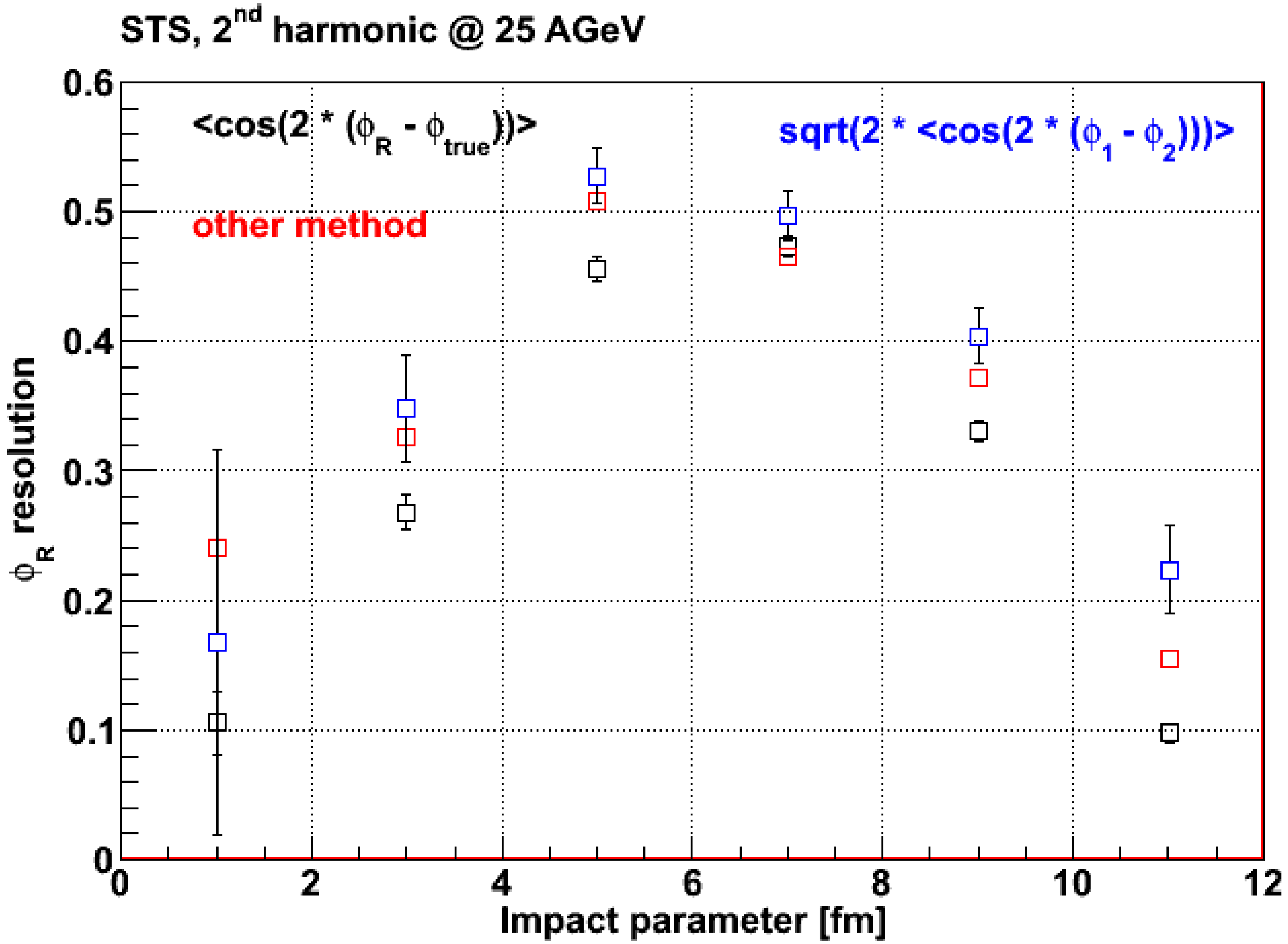
$$\chi_m = v_m\sqrt{2N}$$



A. Poskanzer and S. Voloshin, arXiv:nucl-ex/9805001

Reconstruction of the reaction plane

- Experimental evaluation – sub-event method -

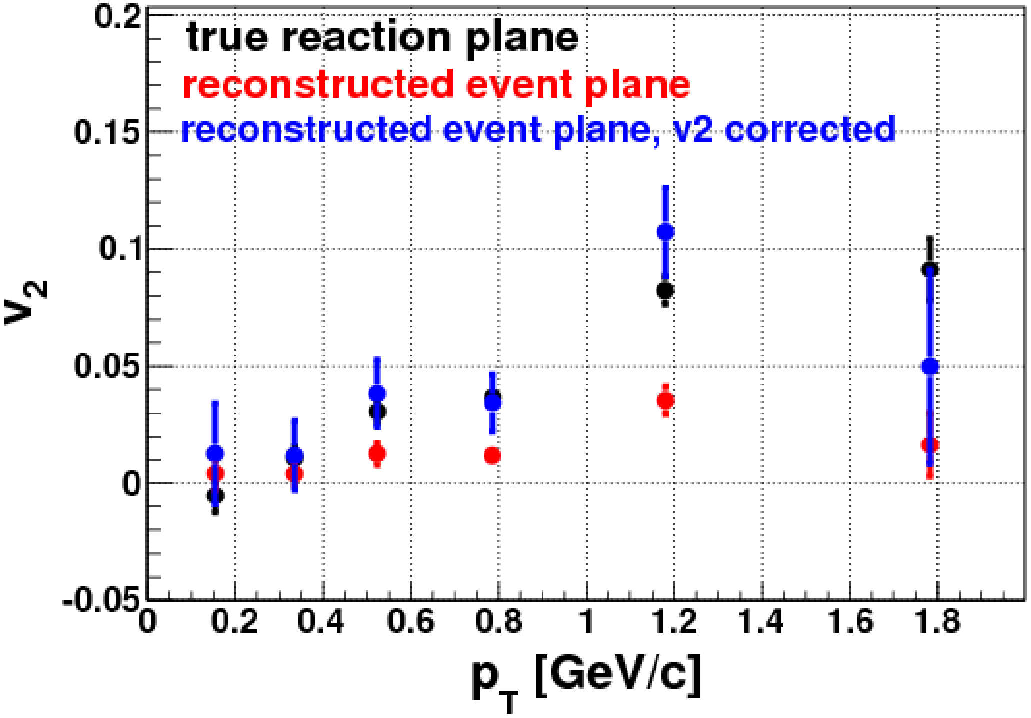


- The experimentally determined event plane resolution should coincide with the actual event plane resolution reasonably well

Elliptic flow of bulk particles (protons, pions)

- For each event with b in [6, 9] fm:
  - ➢ the event plane is evaluated with the PSD
  - ➢ v_2 of bulk particles is calculated with the MVD+STS: here the protons at mid-rapidity ($|Y| < 0.3$)
- The azimuthal distribution of the particles is taken relative to the reconstructed event plane
- $v_2 = \langle\cos\{2(\Phi - \Phi_{RP}^{reco})\}\rangle$
- $v_2^{corr} = v_2 / Corr$ $\quad$ $Corr = \langle\cos\{2(\Phi_{RP}^{reco} - \Phi_{RP}^{true}\}\rangle \sim 0.3$
- After a correction is applied, the v_2 reconstructed values fit the true values within statistical errors

UrQMD, Au+Au @ 25 AGeV, protons, |Y| < 0.3



Only 20K minimum bias events in the simulation!

v_2 reconstruction for the D^+

- Simulation method -

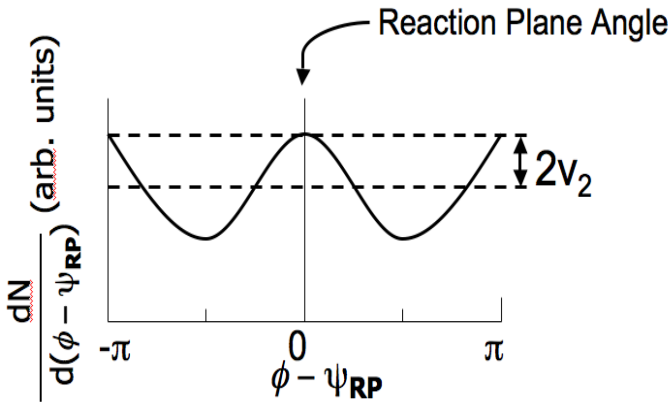
- Generate D^+ mesons **at mid-rapidity**
- Assume this sample to be reconstructed D^+

  → **very large coverage at mid-rapidity with CBM (confirmed by simulations)**
  → **very low backgroung contamination**

- Thermal distribution: $P(p_T) = p_T \,.\, e^{-\sqrt{m_t^2}/T}$, T = 200 MeV, $m_{D+} = 1.87\ \mathrm{GeV}/c^2$
- Assume p_T linear dependance of v_2: $v_2 = \mathbf{0.03} \times p_T$, $v_2 = \mathbf{0.05} \times p_T$, etc
- Azimuthal anisotropy

  → $\Phi - \Phi_{RP}$ distributed according

  to the function $dN/d\Phi$



- **Reconstructed event plane uncertainty**

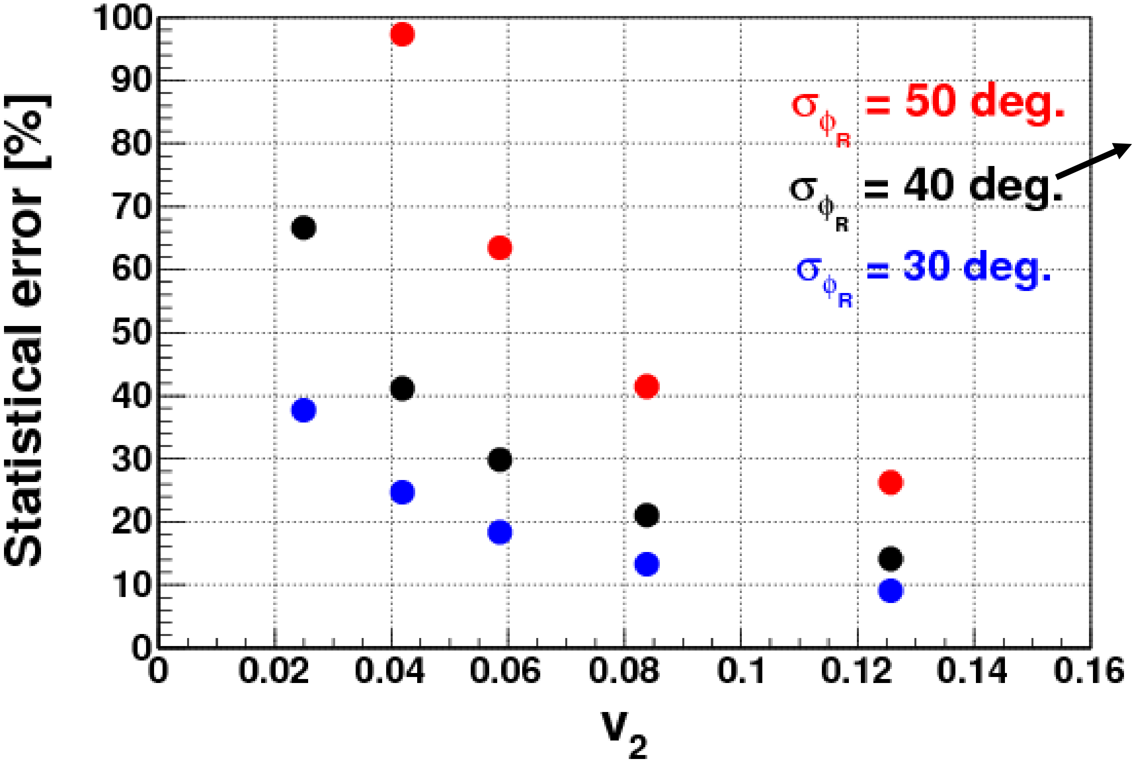
  → $\Delta\Phi_{RP} \sim \mathrm{Gaus}(0, \sigma_{RP})$, σ_{RP} = 40 degrees

Current expectation

v_2 reconstruction for D^+

- Statistical errors on integrated v_2 -

We consider a sample of 10K reconstructed D^+ meson (~ one month of data taking)



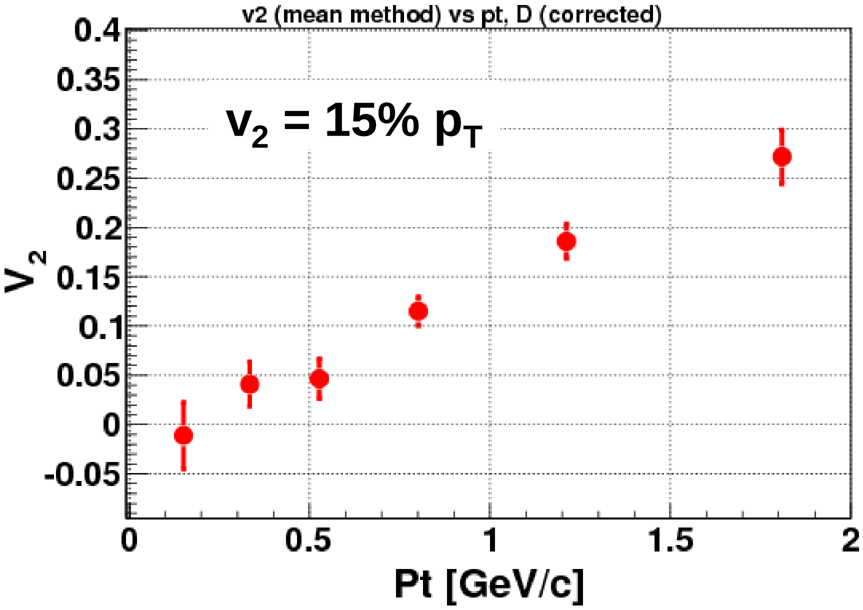
Current expectation

- **A quite good accuracy on the integrated v_2 is obtained, even for a moderate elliptic flow magnitude**
- There is still room for improving the reaction plane resolution, which would reflect in a significantly more accurate measurement

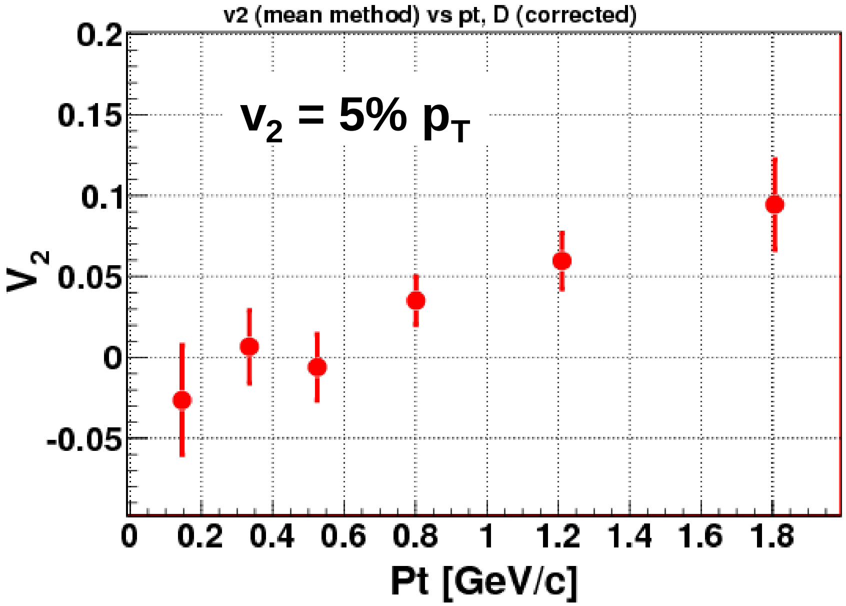
v_2 reconstruction for D-Mesons

- Differential $v_2(p_T)$ -

- We assume 50K reconstructed D-mesons (D^+, D^-, D^0, D^0bar, etc) (~ one month of data taking)
- A reaction plane resolution of 40 degrees



Strong charm elliptic flow
→ small statistical errors



Moderate charm elliptic flow
→ quite large statistical errors

Still, the two scenarios can be distinguished

Summary and Conclusion

Elliptic flow is one of the most promising probes of deconfinement transition, but is also one of the most challenging differential analysis at FAIR energy regime.

A simulation of the reaction plane reconstruction has been performed with the CBM set-up and **a fairly good accuracy has been found for semi-peripheral collisions**.

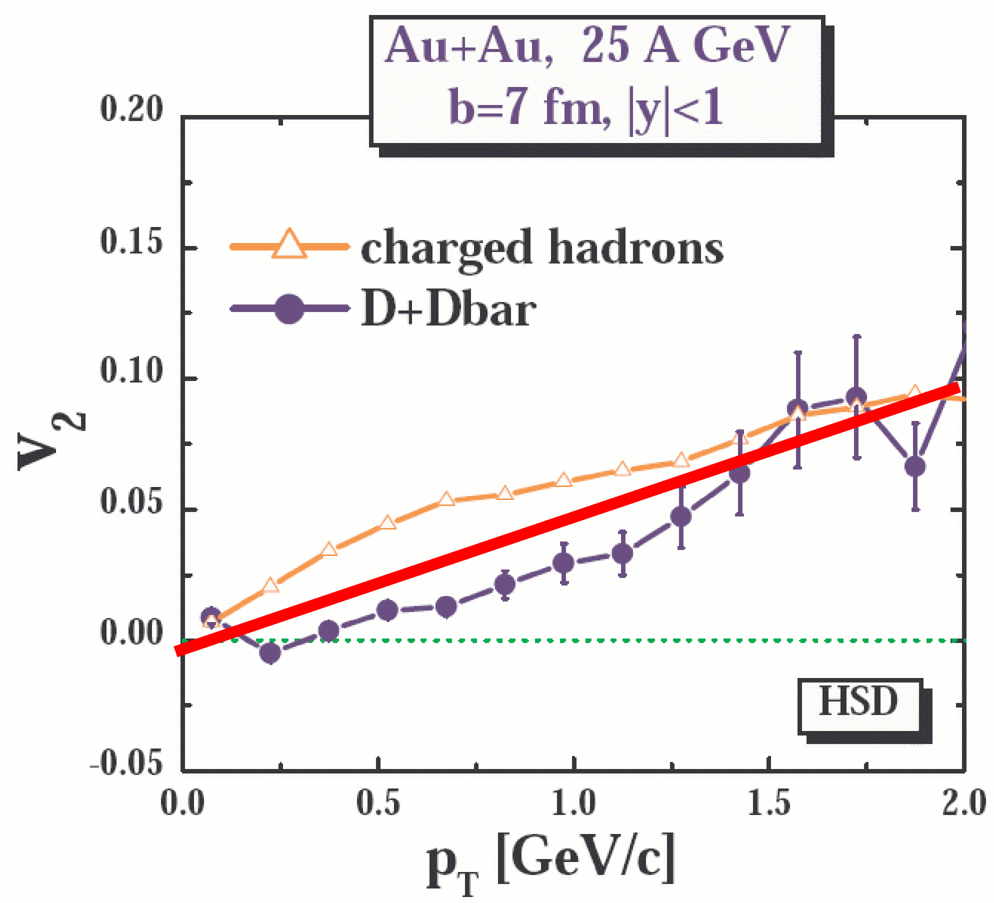
A first indicative feasibility study of open charm elliptic flow reconstruction has been conducted, and concluded that **the integrated v_2 of individual species will be measurable with a good statistical precision, already after 1 month of data taking, even for a moderate v_2 magnitude**.

The differential elliptic flow measurement for D-mesons (including all species) has been found to be feasible with a reasonable statistical precision, after only 1 month of data taking.
A longer running period would allow a detailed study of individual species.

Back-up

V_2 reconstruction for the D^+

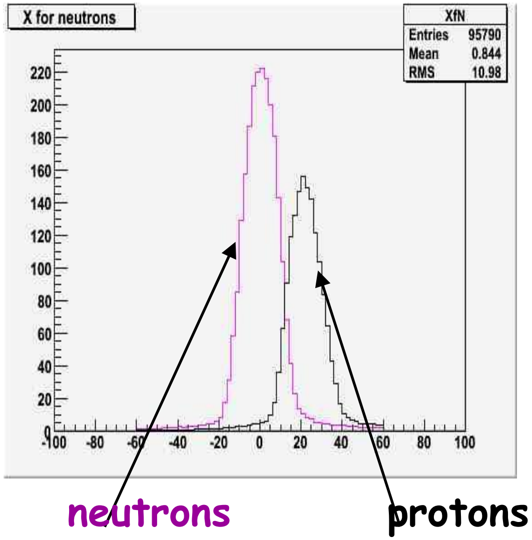
- V_2(pt) prediction from HSD at FAIR energies -



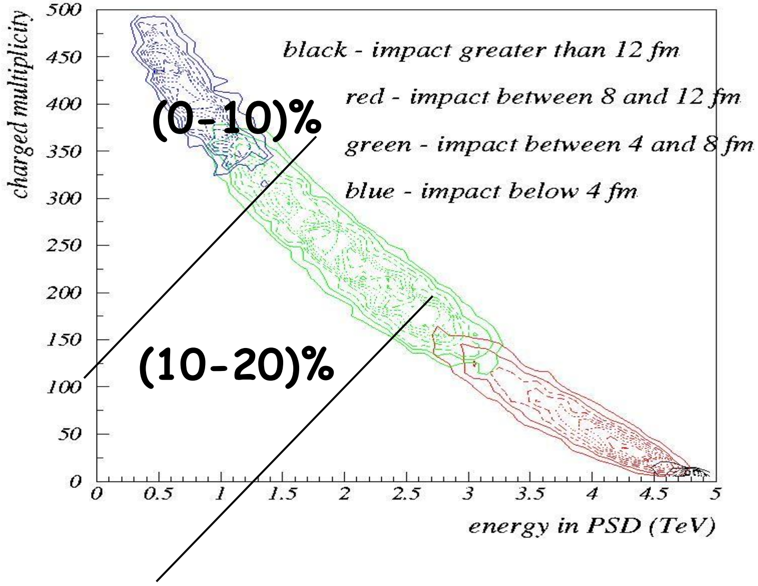
Linear approximation

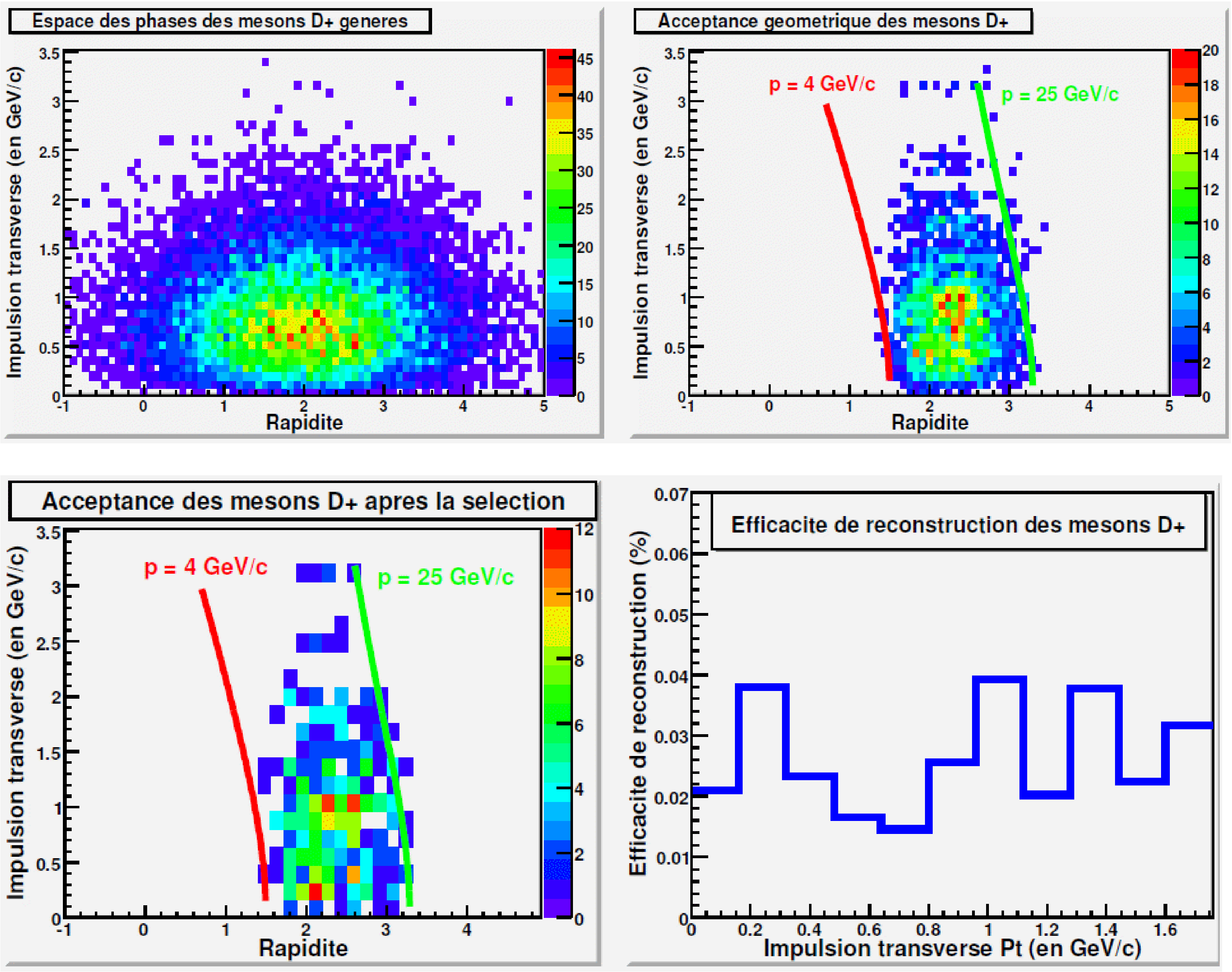
V_2^{true} = 0.05 x pt for D^+ mesons is assumed for the V_2 reconstruction feasibility study

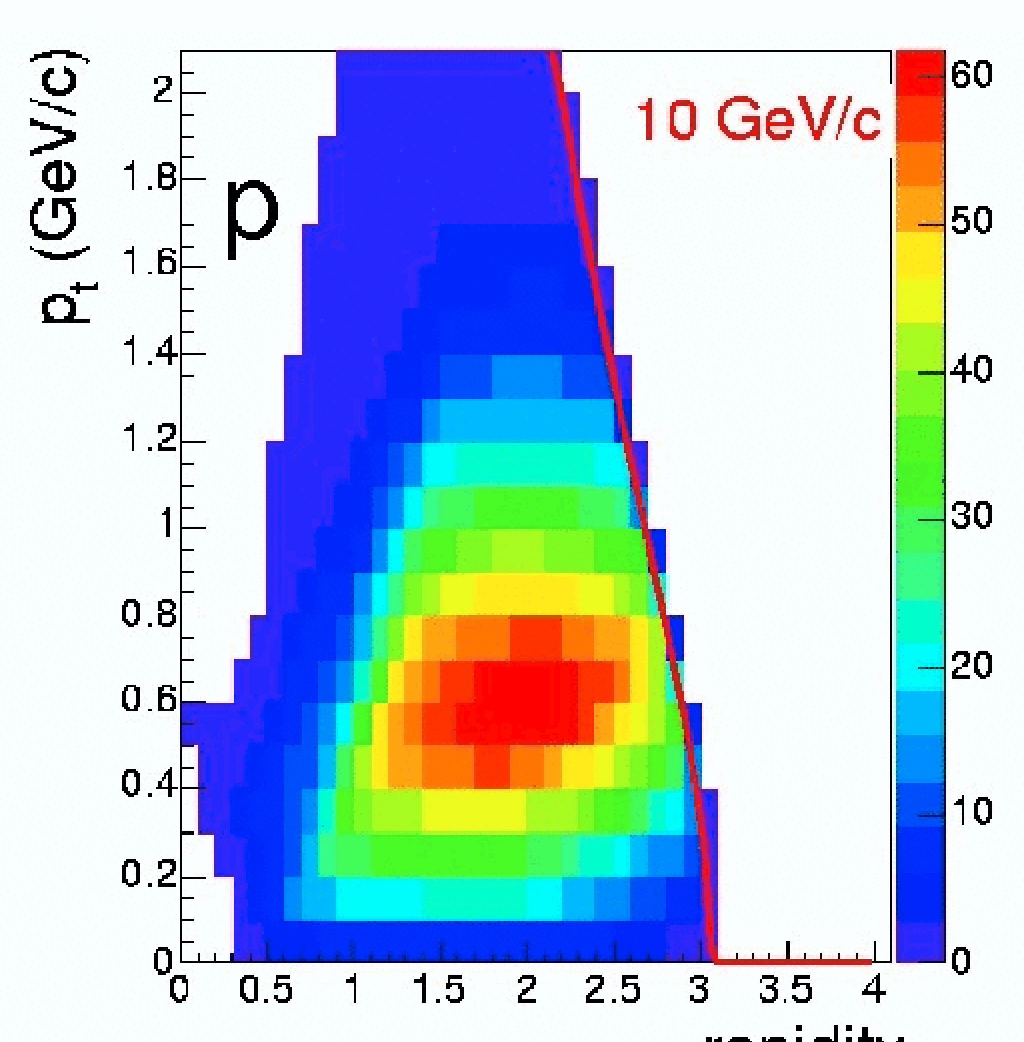
PSD centered at X=8.9 cm (pass 25 GeV beam)



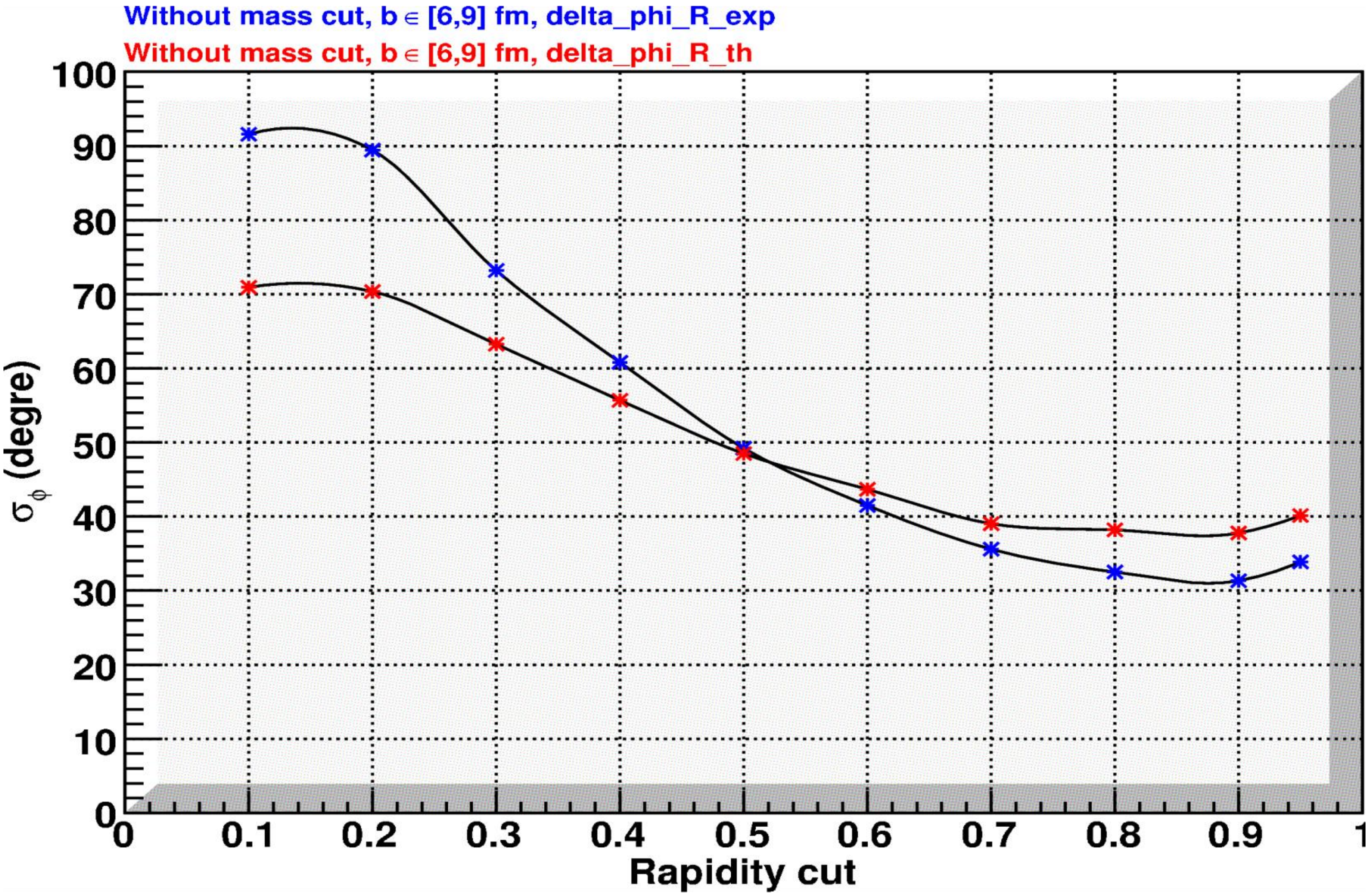
radius	mean energy in circle band (GeV
2.5 – 7.5	330 (4-8fm) 680 (8-12fm)
7.5 – 12.5	520 (1040)
12.5 – 17.5	540 (1040)
17.5 – 22.5	410 (710)
22.5 – 27.5	260 (340)




Espace des phases des mesons D+ generes
Impulsion transverse (en GeV/c)
Rapidite
Acceptance geometrique des mesons D+
p = 4 GeV/c
p = 25 GeV/c
Impulsion transverse (en GeV/c)
Rapidite
Acceptance des mesons D+ apres la selection
p = 4 GeV/c
p = 25 GeV/c
Impulsion transverse (en GeV/c)
Rapidite
Efficacite de reconstruction des mesons D+
Efficacite de reconstruction (%)
Impulsion transverse Pt (en GeV/c)


p_t (GeV/c)
p
10 GeV/c
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60

Results : σ_Φ versus rapidity cut – theoretical an experimental

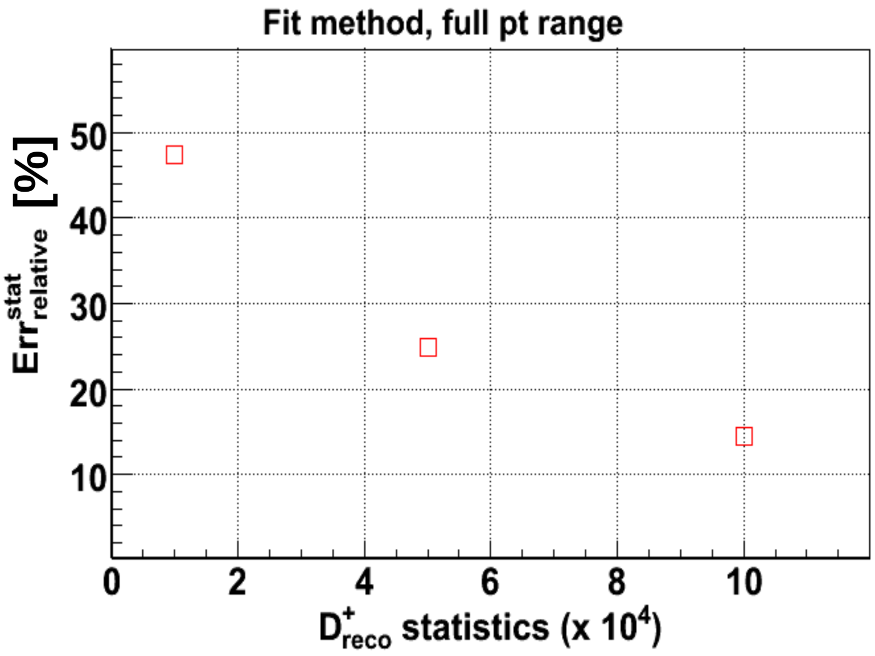


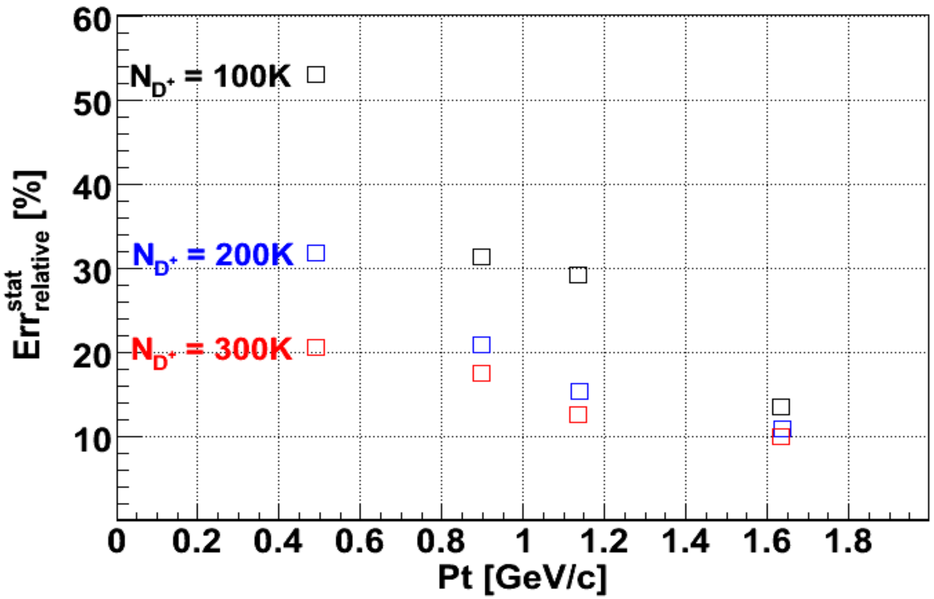
σ_{exp} : Ψ_{RP}^{reco} from 2 sub-events with equal multiplicity : ($\Psi_{RP}^{reco1} - \Psi_{RP}^{reco2}$) / 2 ~ σ_Φ if σ_Φ relatively small !!

V_2 reconstruction for the D^+

- Results -

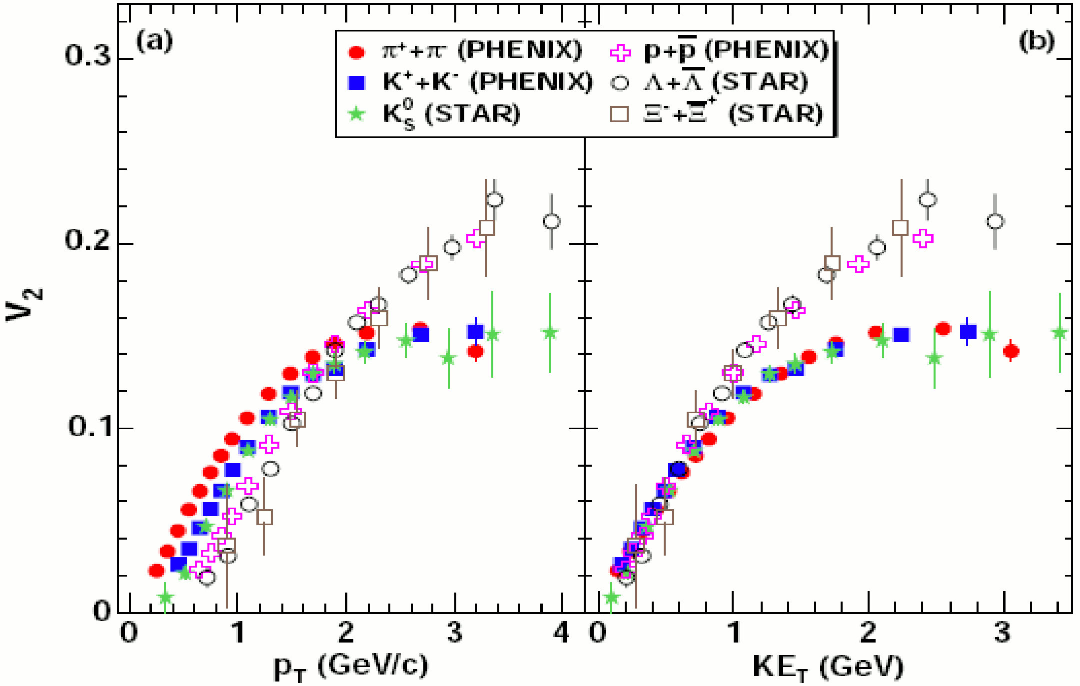
Integrated and differential V_2 (Pt) for **V_2 = 0.05 x Pt** and **σ_{RP} = 40 degrees**



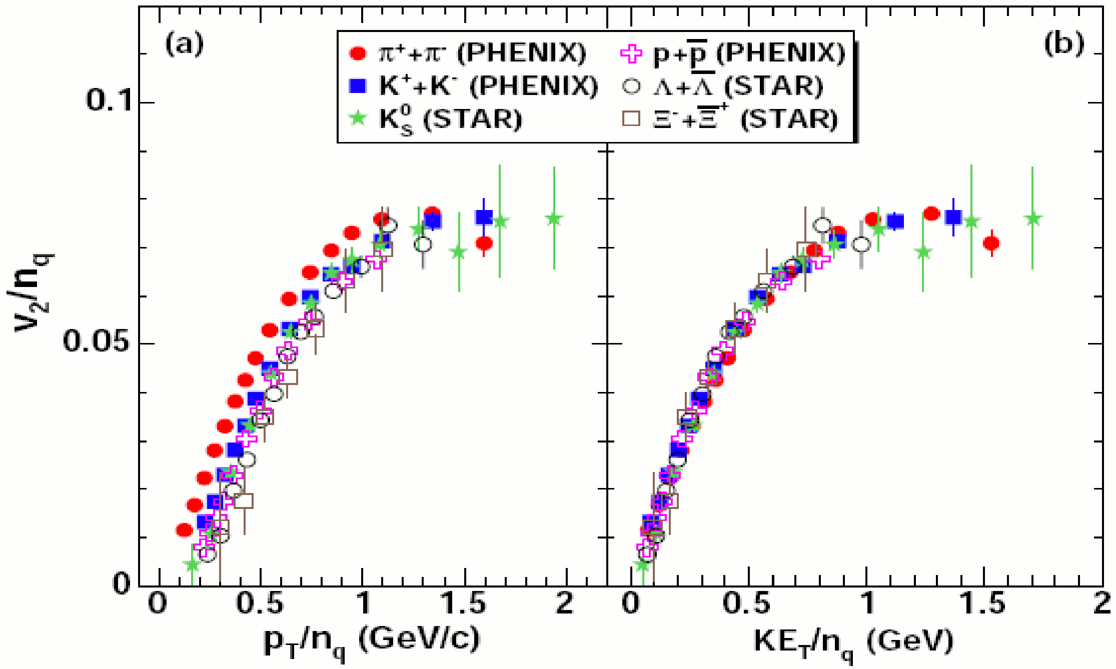


Need ~ 70 000 D^+

Need ~ 300 000 D^+

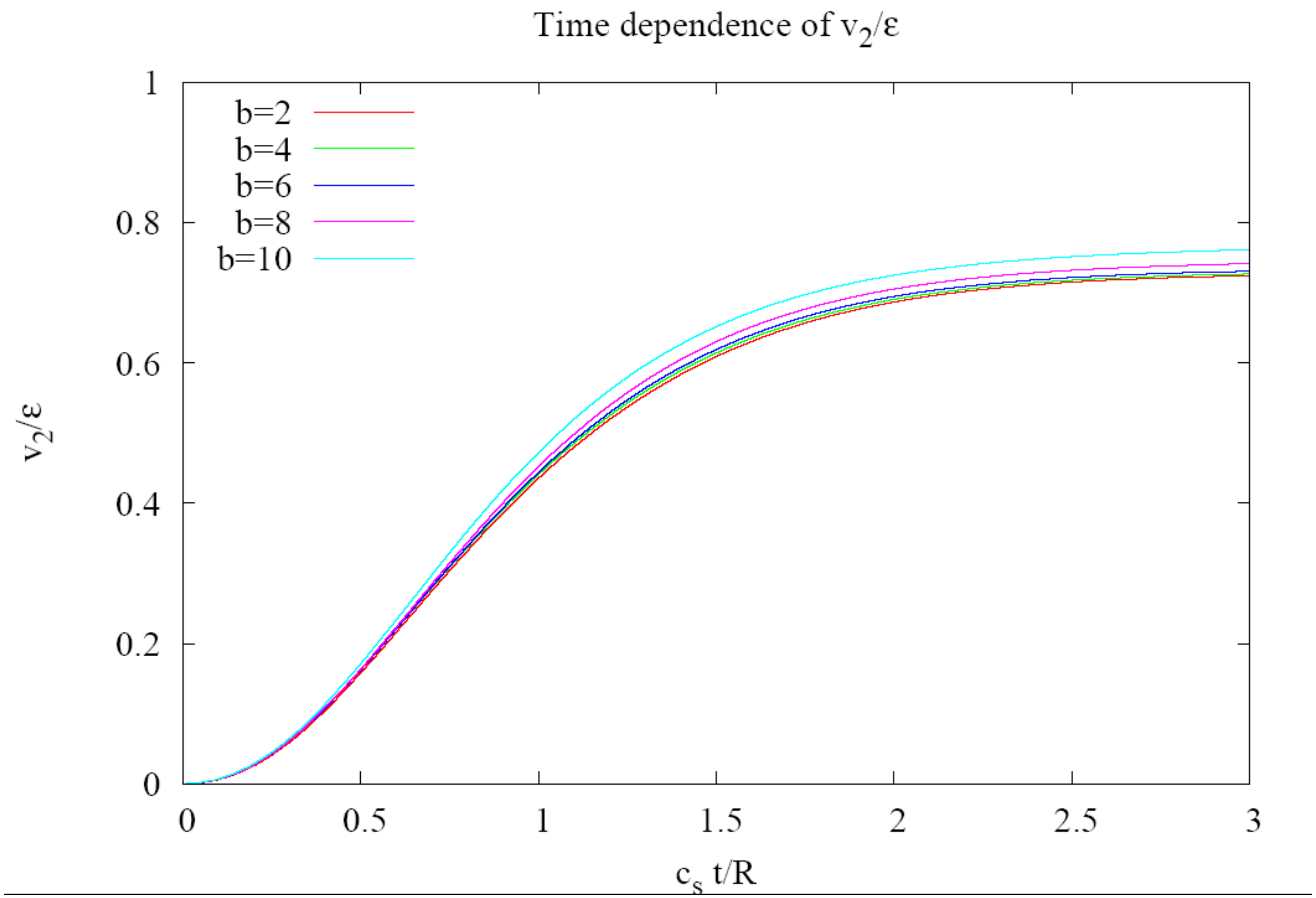


arXiv:nucl-ex/0608033v1

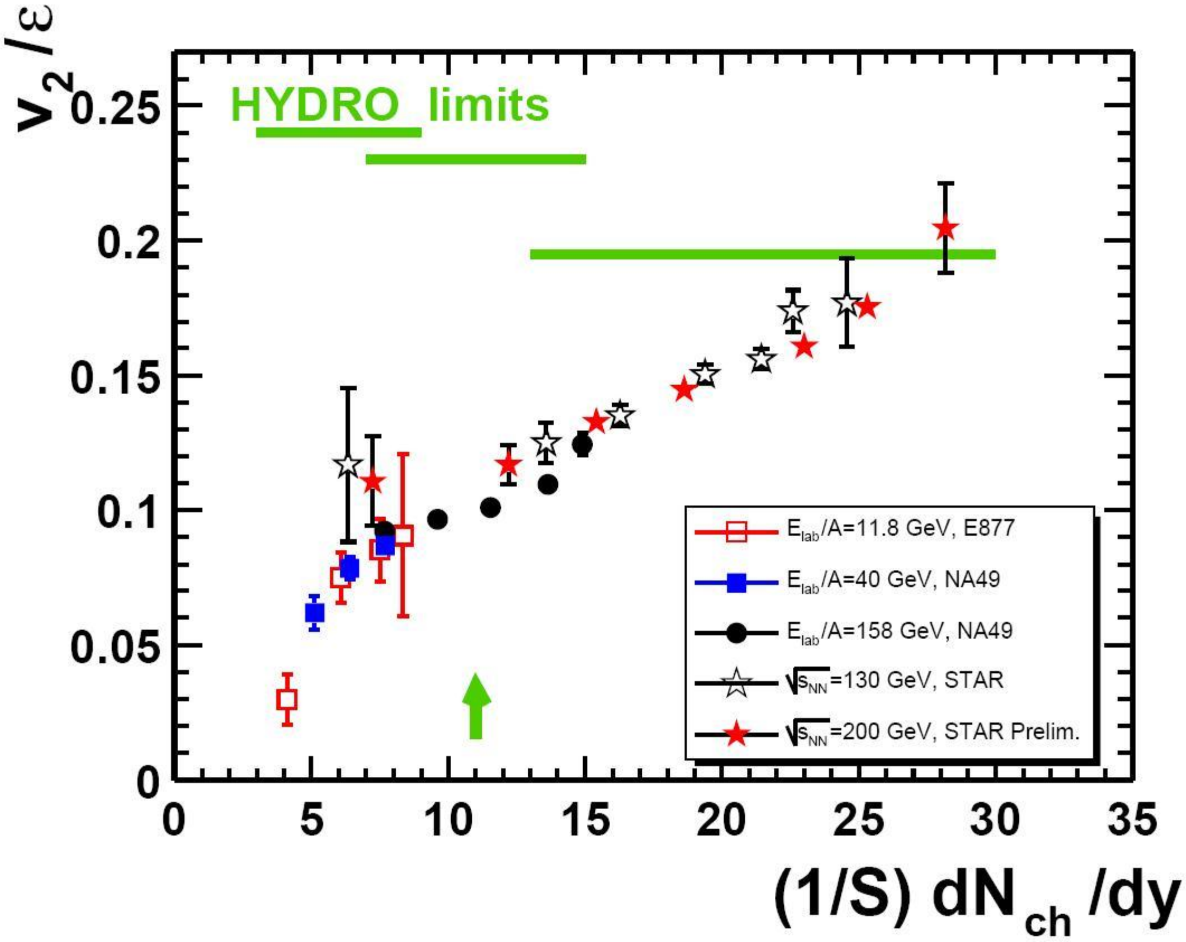


1. When is v_2 created?

At a time ~R/c_s, where $R=(1/\langle x^2\rangle+1/\langle y^2\rangle)^{-1/2}$



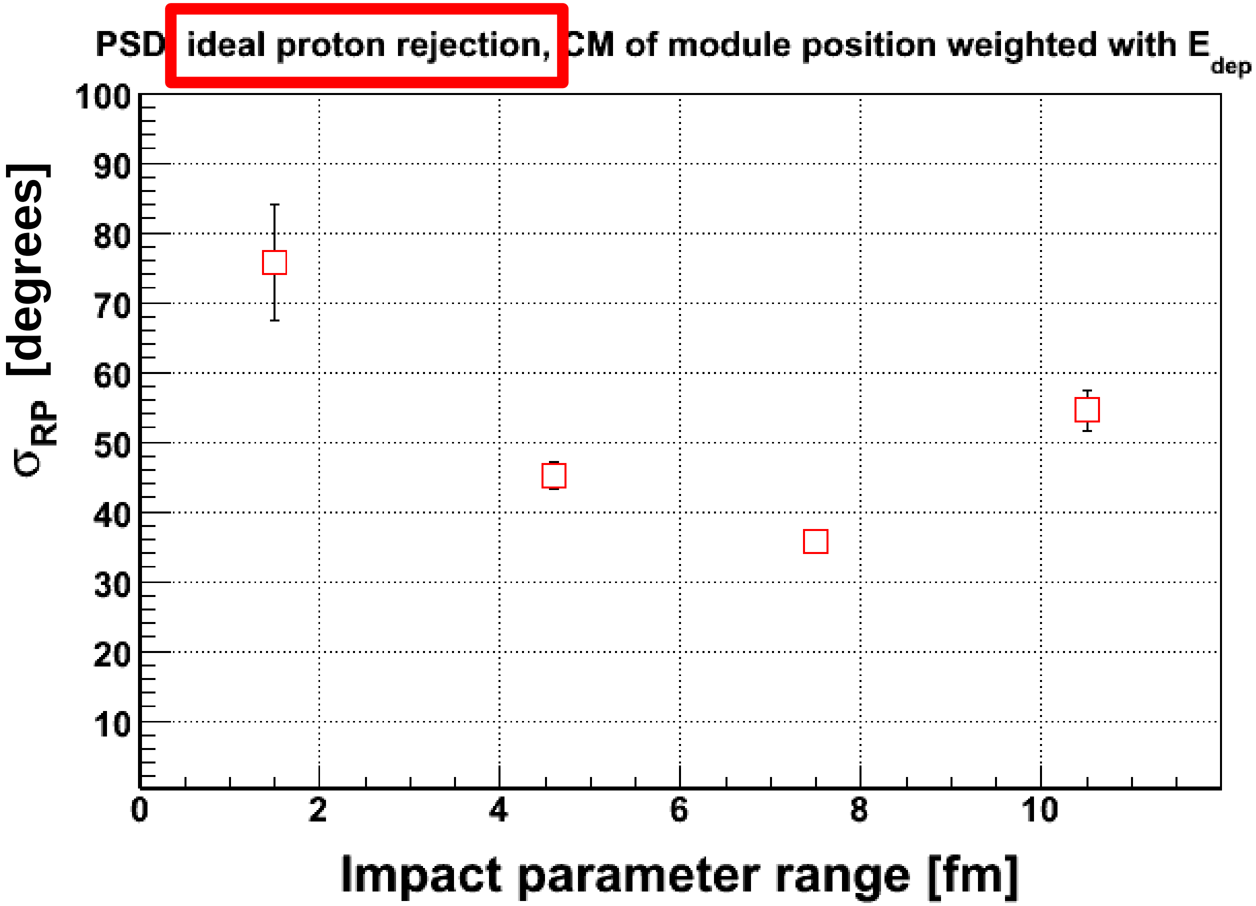
v_2/ε: Data from SPS and RHIC



Hydrodynamical evolution at RHIC energy regim square(s) ~ 200 GeV

Reconstruction of the reaction plane

- Systematic study -

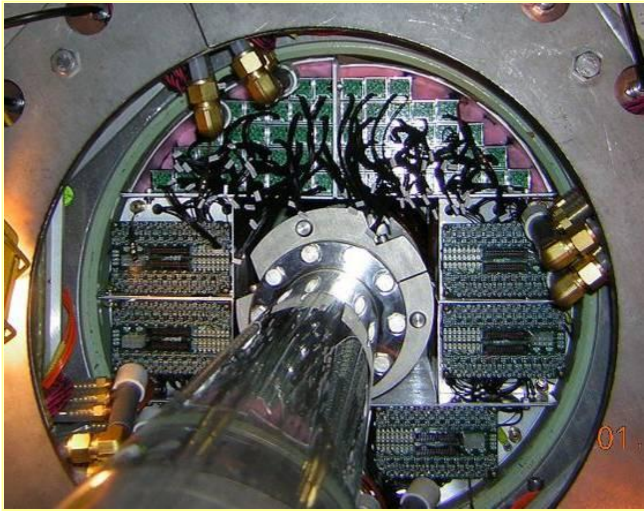


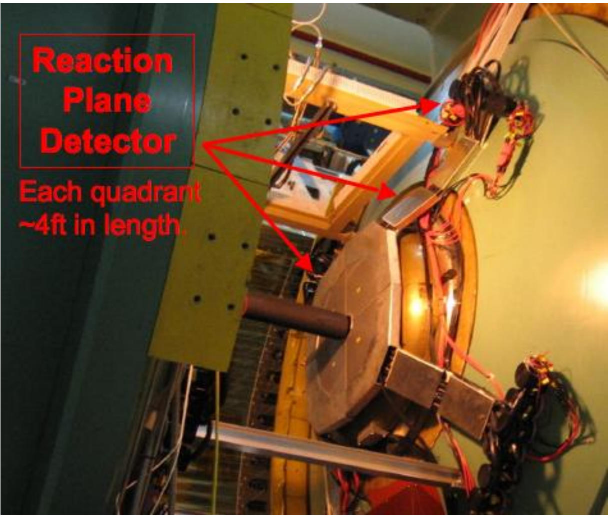
The best reaction plane resolution is obtained for b between 6 and 9 fm

σ_{RP} ~ 40 degrees is used for the feasibility study of v_2 reconstruction

Reaction Plane Measurement with PHENIX

Beam-Beam Counters (BBC)
- Quartz Cherenkov radiators
- 64 elements in 3 rings
- $3.0 < |\eta| < 4.0$
- All Runs





Reaction Plane Detector (RxnP)
- plastic scintillators @ $38<|z|<40$cm
- 12 segments in ϕ
- 2 segments in η
  - $1.0 < |\eta| < 1.5$
  - $1.5 < |\eta| < 2.8$
- Pb converter
- Run 7+

Muon Piston Calorimeter (MPC)
- $PbWO_4$ PHOS crystals
- 192 towers
- $3.1 < |\eta| < 3.7$
- Run 6+

Multiple overlapping and complementary measurements

Starting from 2007, PHENIX uses two new Reaction Plane Detectors (RxnP) (see Fig. 1) to measure the reaction plane of each collision following methods described in [13, 14]. It improves the reaction plane resolution, and thus gives a correction $\sigma_{RP} = \langle\cos(2\Delta\psi_{RP})\rangle$ twice better than what was achieved previously with the Beam Beam Counters (BBC), or what can be measured with the Muon Piston Calorimeters (MPC) (see Fig. 2).

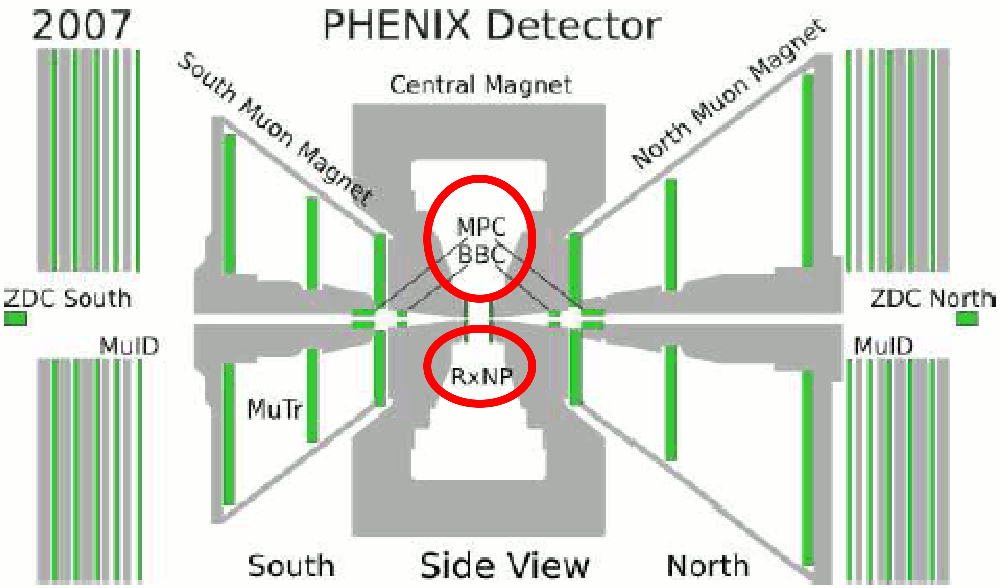


Figure 1. PHENIX detector during 2007 data taking with the RxnP detector near the collision vertex.

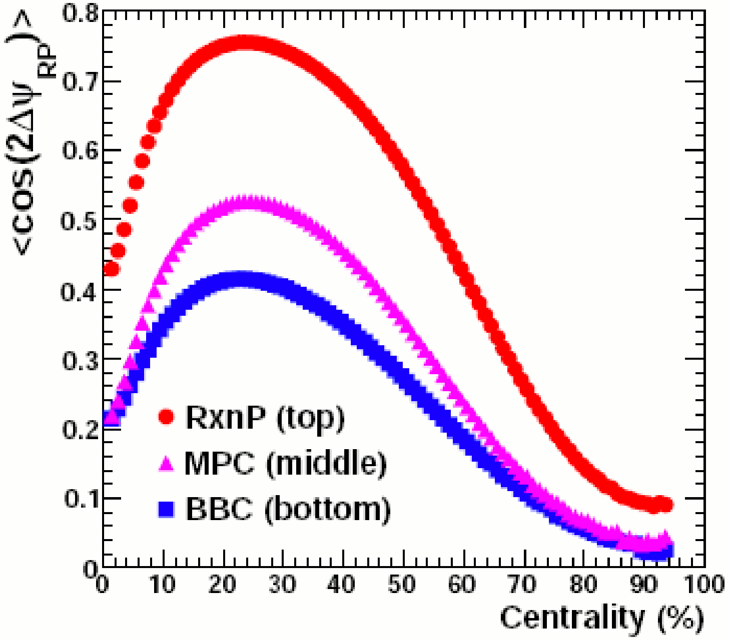


Figure 2. Reaction plane resolution as a function of centrality, measured with the RxnP (top), the MPC (middle), or the BBC (squares).

“Shifting Method” in PHENIX

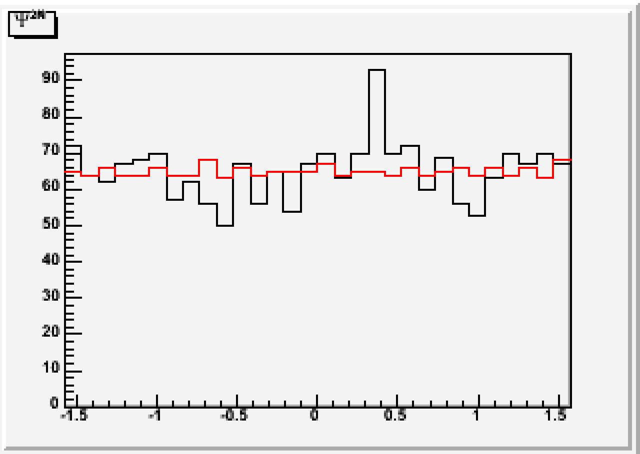
$$\Psi_1' = \Psi_1 + \Delta\Psi_1 .$$

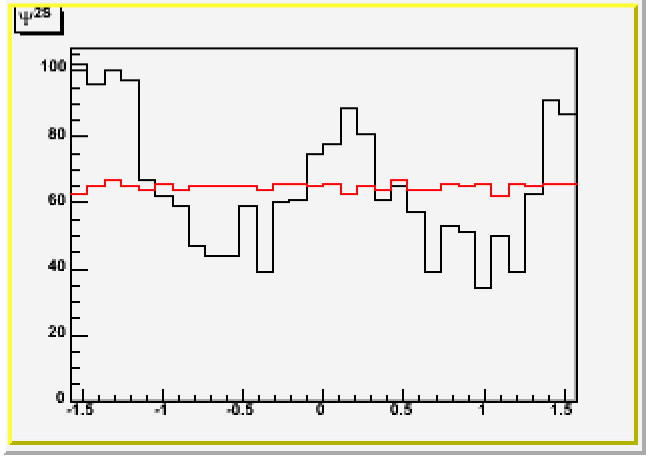
$$\Delta\Psi_1 = \sum_n (A_n \cos(n\Psi_1) + B_n \sin(n\Psi_1))$$

$$B_n = \frac{2}{n}\langle\cos(n\Psi_1)\rangle,$$

$$A_n = -\frac{2}{n}\langle\sin(n\Psi_1)\rangle,$$

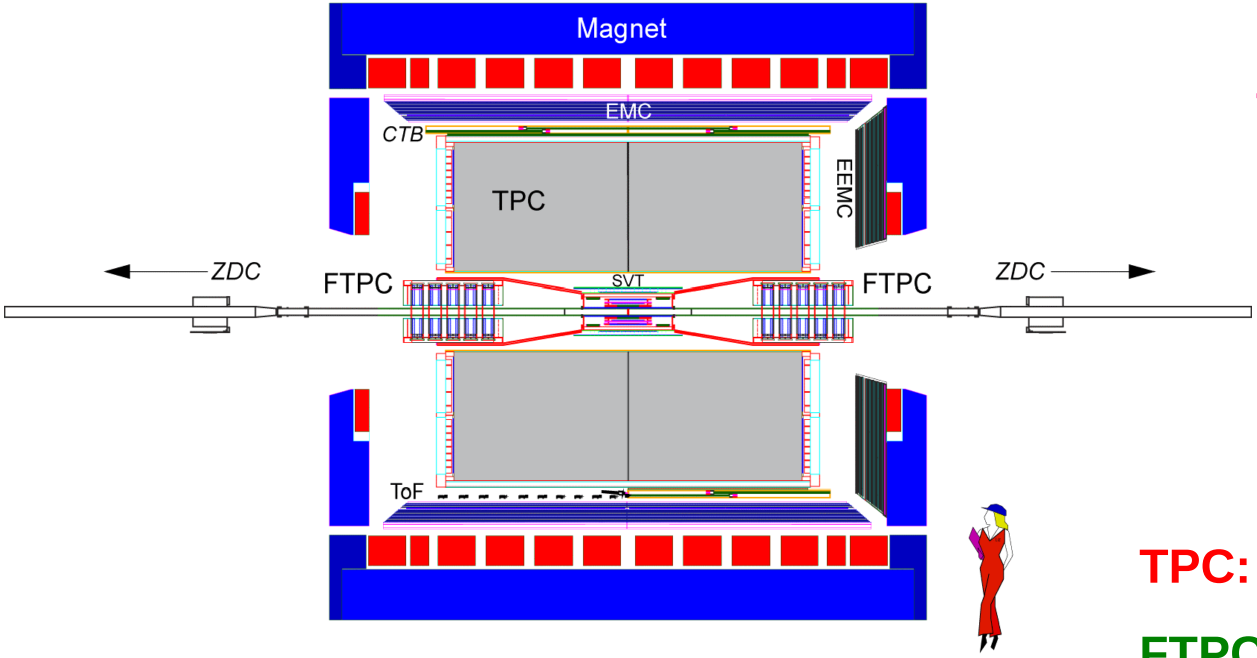
Usually 1 <= n <= 32





$$\Psi_1' = \Psi_1 + \sum_n \frac{2}{n}\left(-\langle\sin(n\Psi_1)\rangle \cos(n\Psi_1) + \langle\cos(n\Psi_1)\rangle \sin(n\Psi_1)\right)$$

Reaction Plane Determination in STAR



TPC or FTPC

reaction-plane

TPC: $-1.0 < \eta < 1.0$

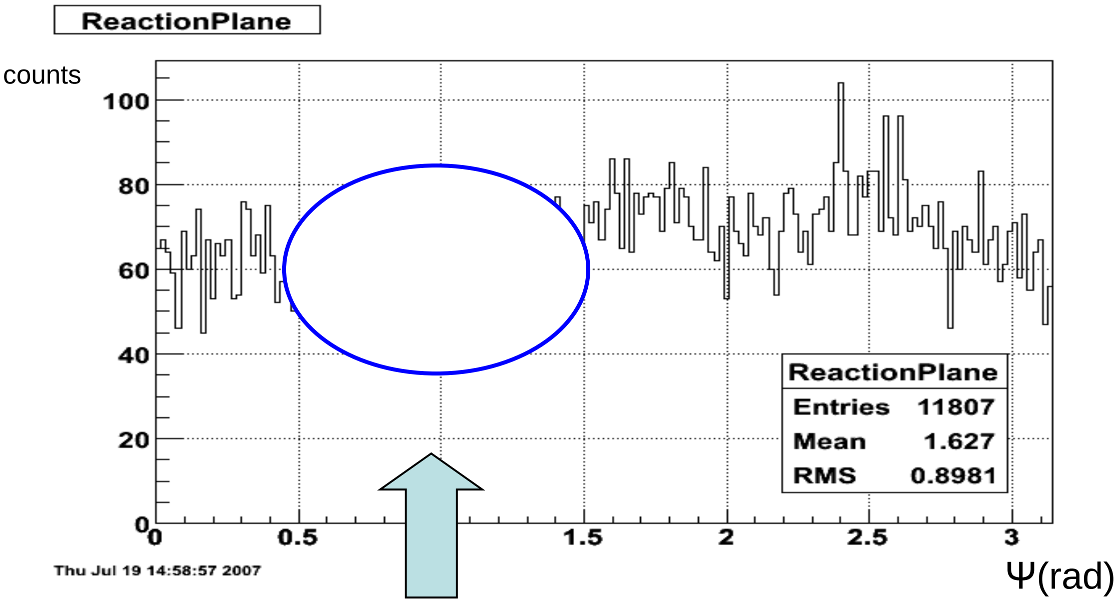
FTPC: $2.8 < |\eta| < 3.8$

Why we use FTPC reaction-plane?

1. The non-flow correlation and auto correlation effects are smaller from FTPC reaction-plane

2. Comparing the v_2 results from FTPC reaction-plane with TPC reaction-plane can help us understand the non-flow effects.

Shifting Corrections in STAR

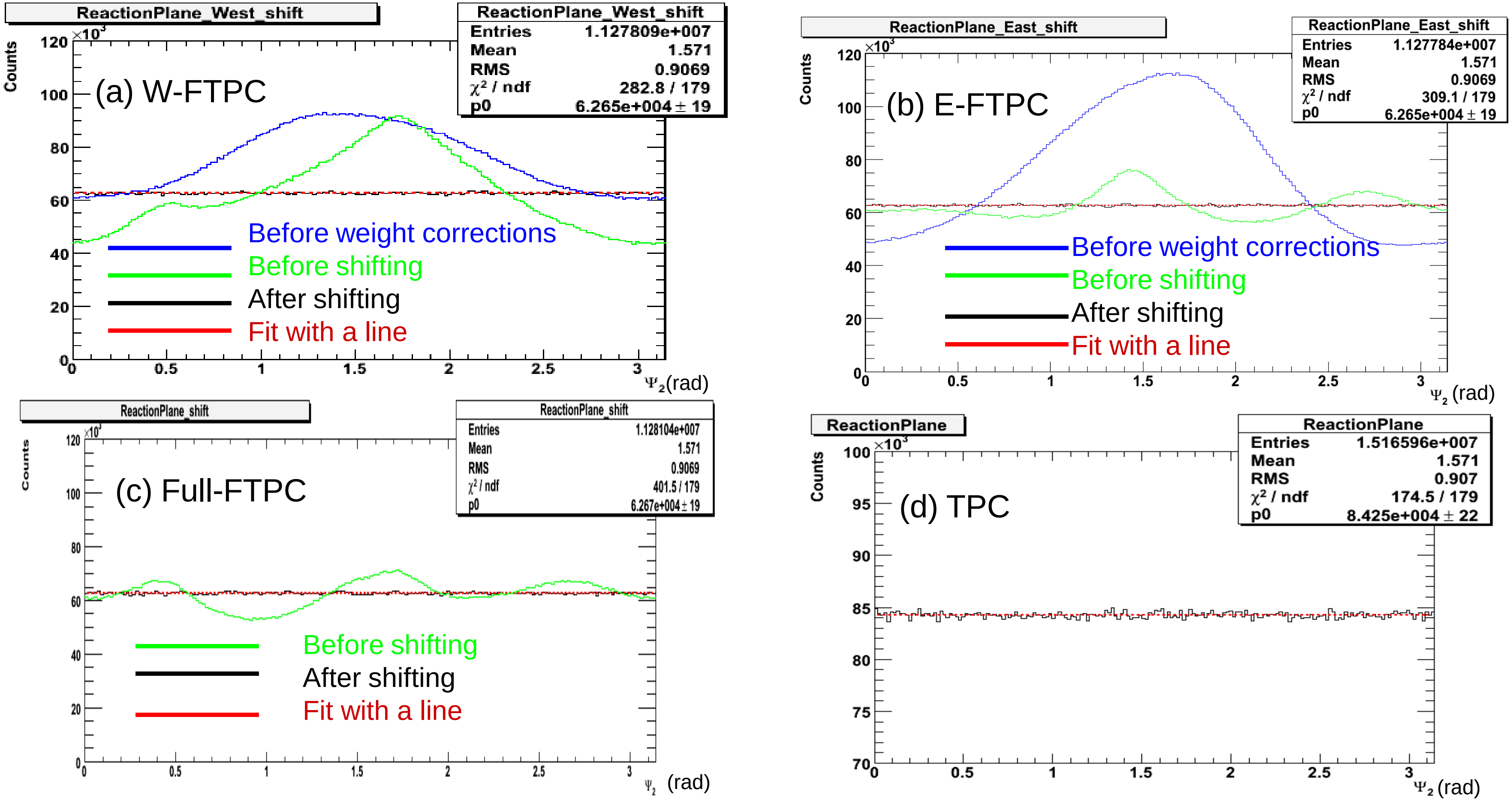


Even with the weighting method, the event plane distribution from FTPC we obtain isn't isotropic. We can flatten that distribution by shifting:

$$\Psi' = \Psi + \sum_{n} \frac{1}{n}(- < \sin 2n\Psi > \cos 2n\Psi + < \cos 2n\Psi > \sin 2n\Psi)$$

J. Barrette et al. Phys.Rev. C56, 3254(1997), *nucl-ex/9707002*

Reaction Plane from FTPC and TPC inSTAR



Full-FTPC: cos(2∆Ψ):0.335

TPC: cos(2∆Ψ): 0.604

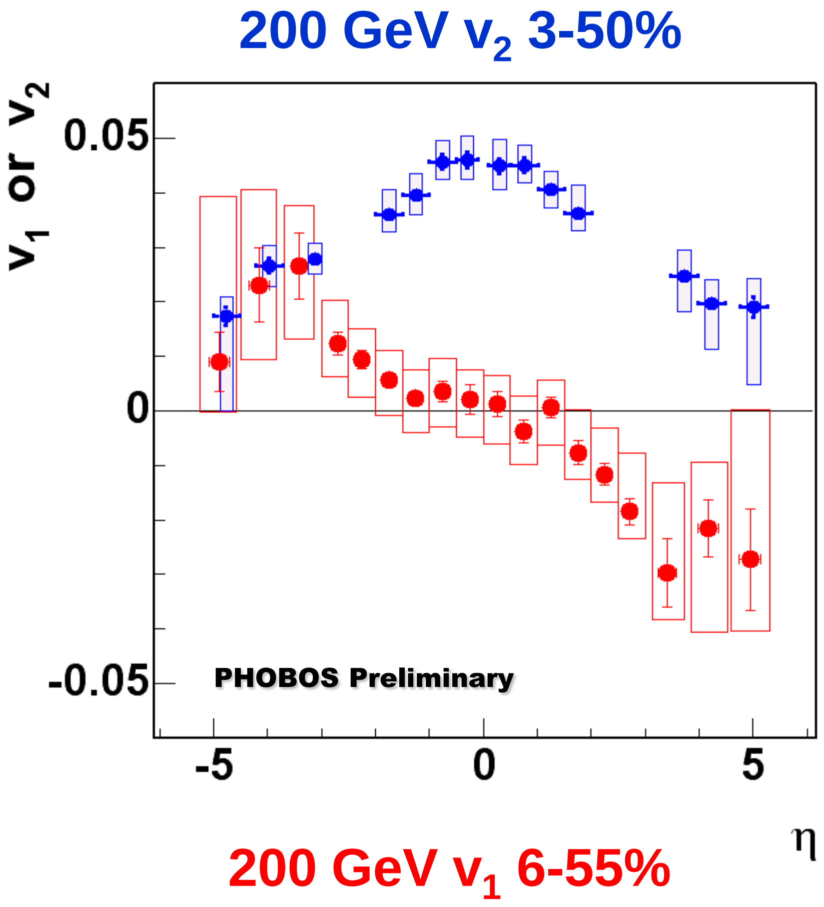
DNP Meeting October,
11th, 2007

X.H.Shi

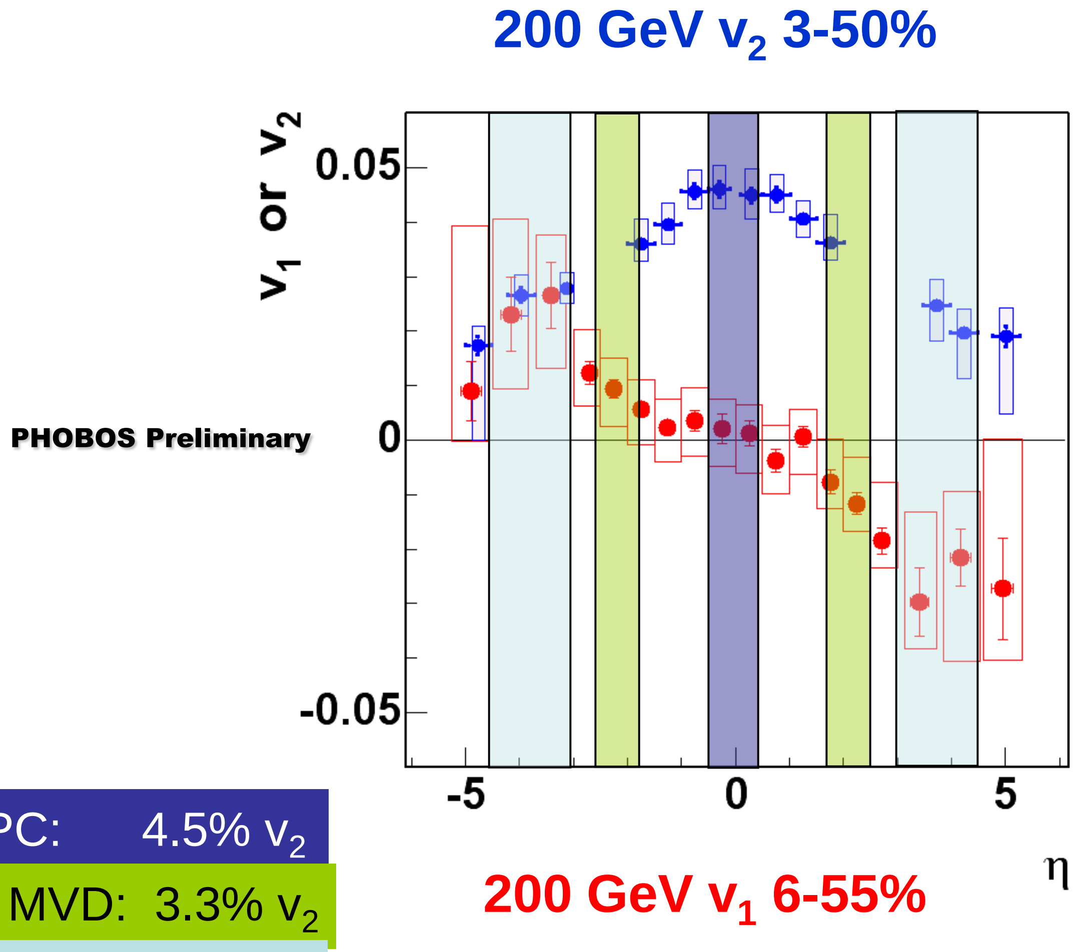
In 2007!!

How much asymmetry?

- v_1, v_2 measure asymmetry of system
- Forget flow for now
- effects are at the few % level
  - nontrivial measurement
  - must understand asymmetric efficiency/ acceptance/ background



How much asymmetry? ctd



v_2 decreases with η

v_1 increases with η

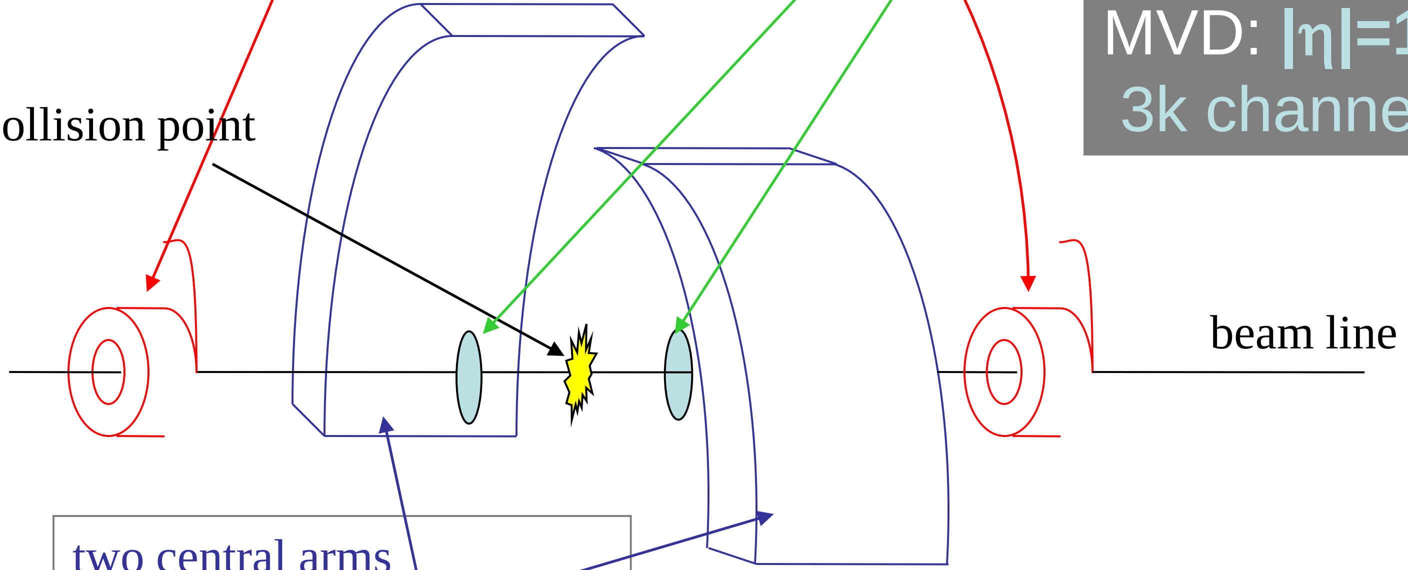
MVD sees somewhat stronger v_2 signal than BBC

STAR TPC:	4.5% v_2
PHENIX MVD:	3.3% v_2
PHENIX BBC:	2.8% v_2

BBC and MVD in PHENIX

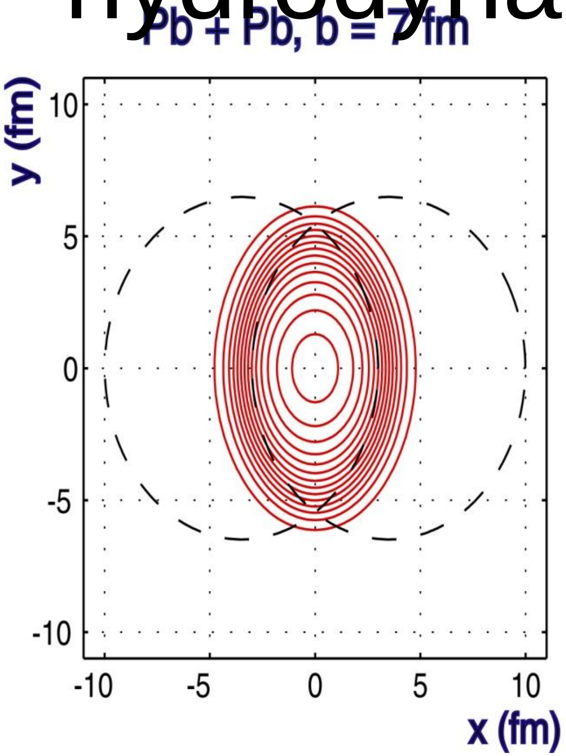
Beam-beam counter
(BBC) |η|=**3~4**
64pmts in each BBC
charged particles

MVD: **|η|=1.8-2.6**
3k channels per side!



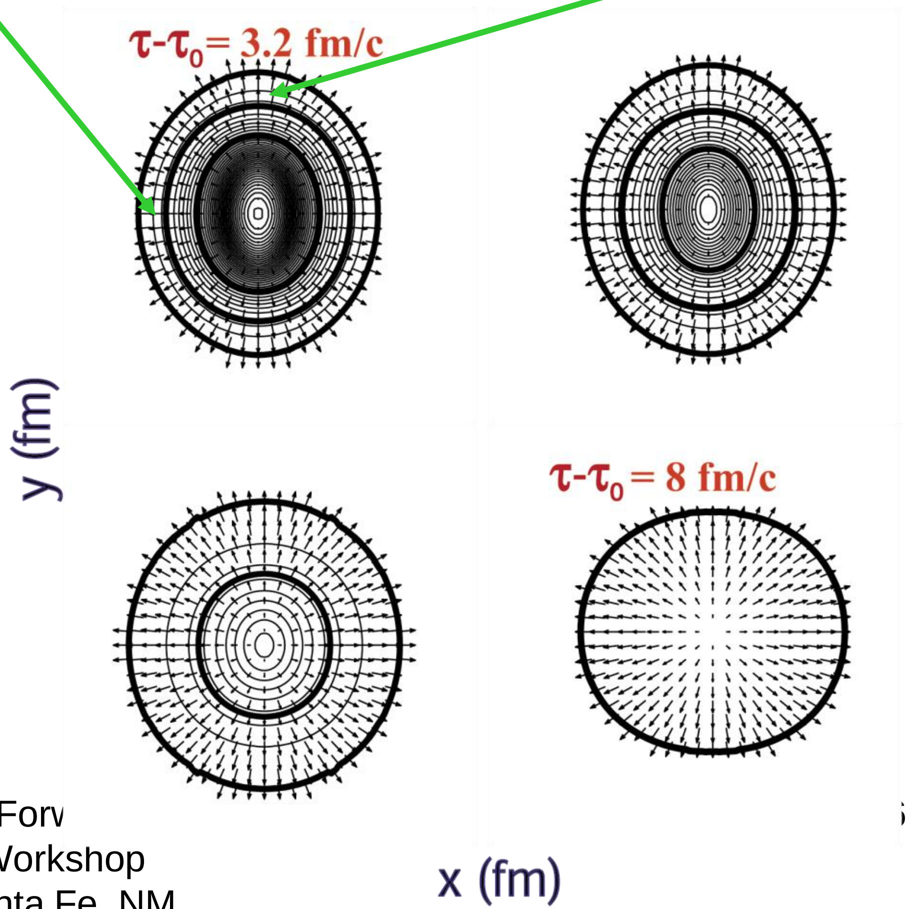
two central arms
(CNT) |η|<**0.35**
Dch,PCs,TOF,EMCAL
tracking, momentum, PID

Time evolution in a ideal hydrodynamic model calculation



dn/dr (dP/dr) higher

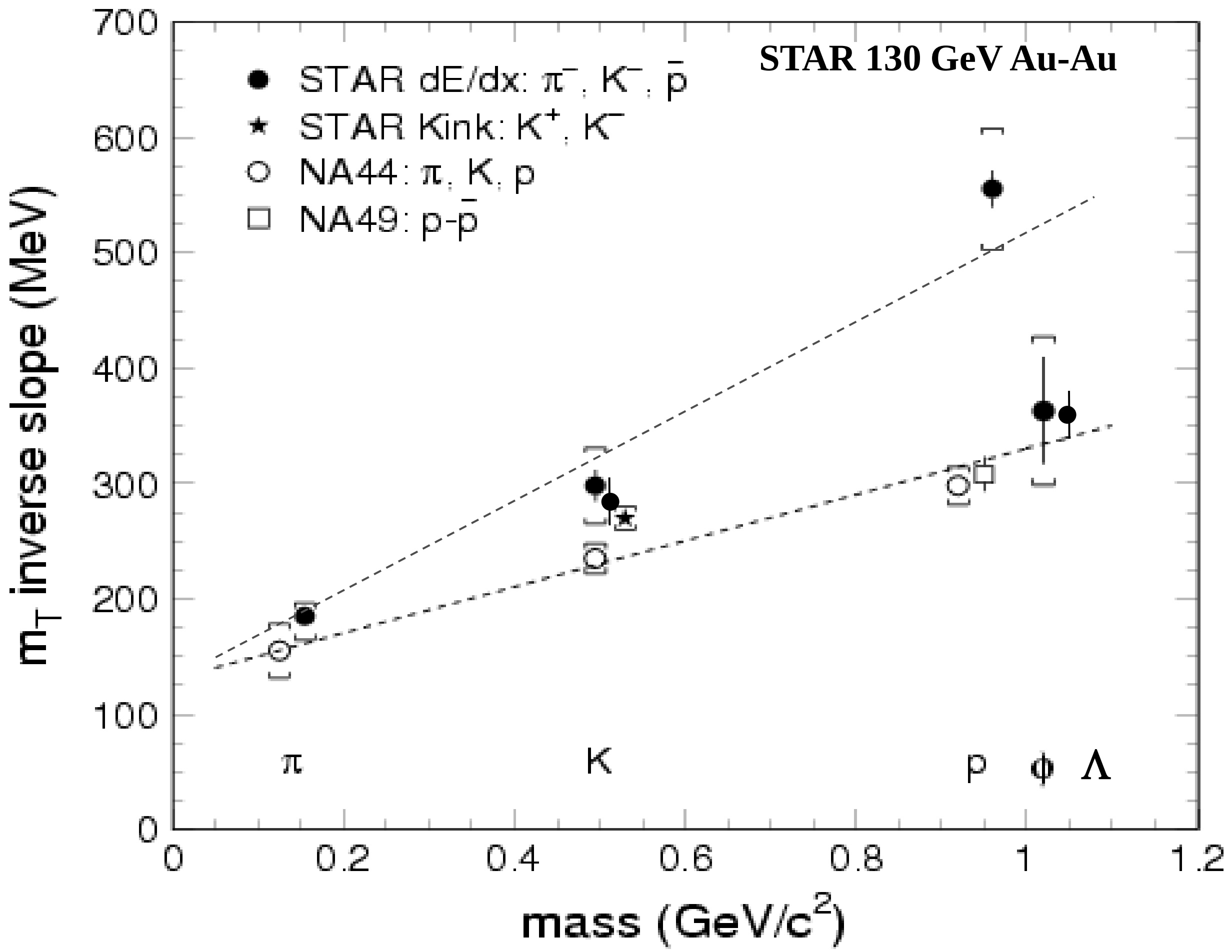
dn/dr (dP/dr) lower



- Elliptic Flow reduces spatial anisotropy -> shuts itself off

“PV = nRT” ➔ $dP \sim dn$

Mass dependence of m_T slope - Radial Flow



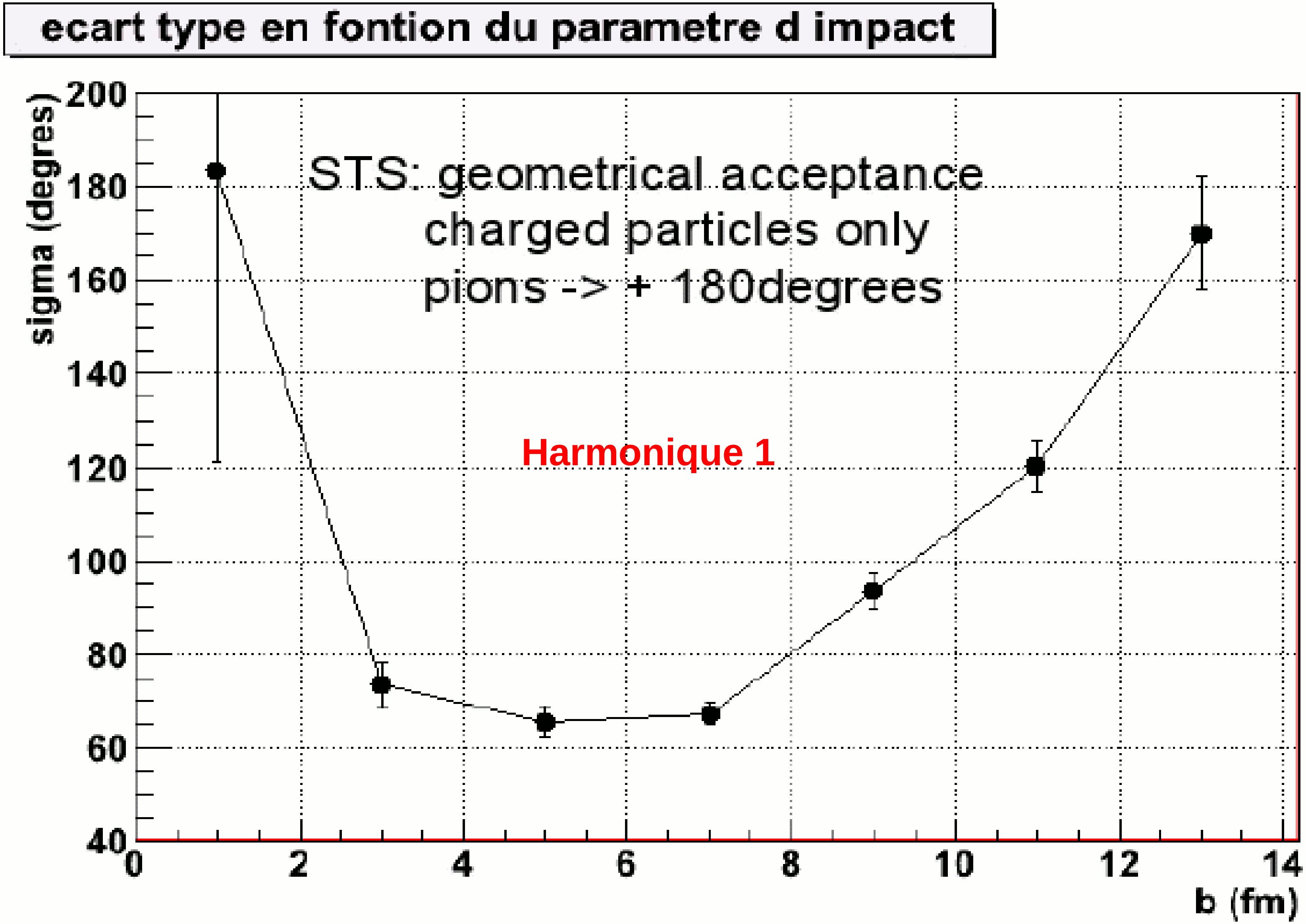
- The different m_T slopes indicate that the slope should not be interpreted as a simple thermal temperature.

- It also has a component from collective radial velocity.

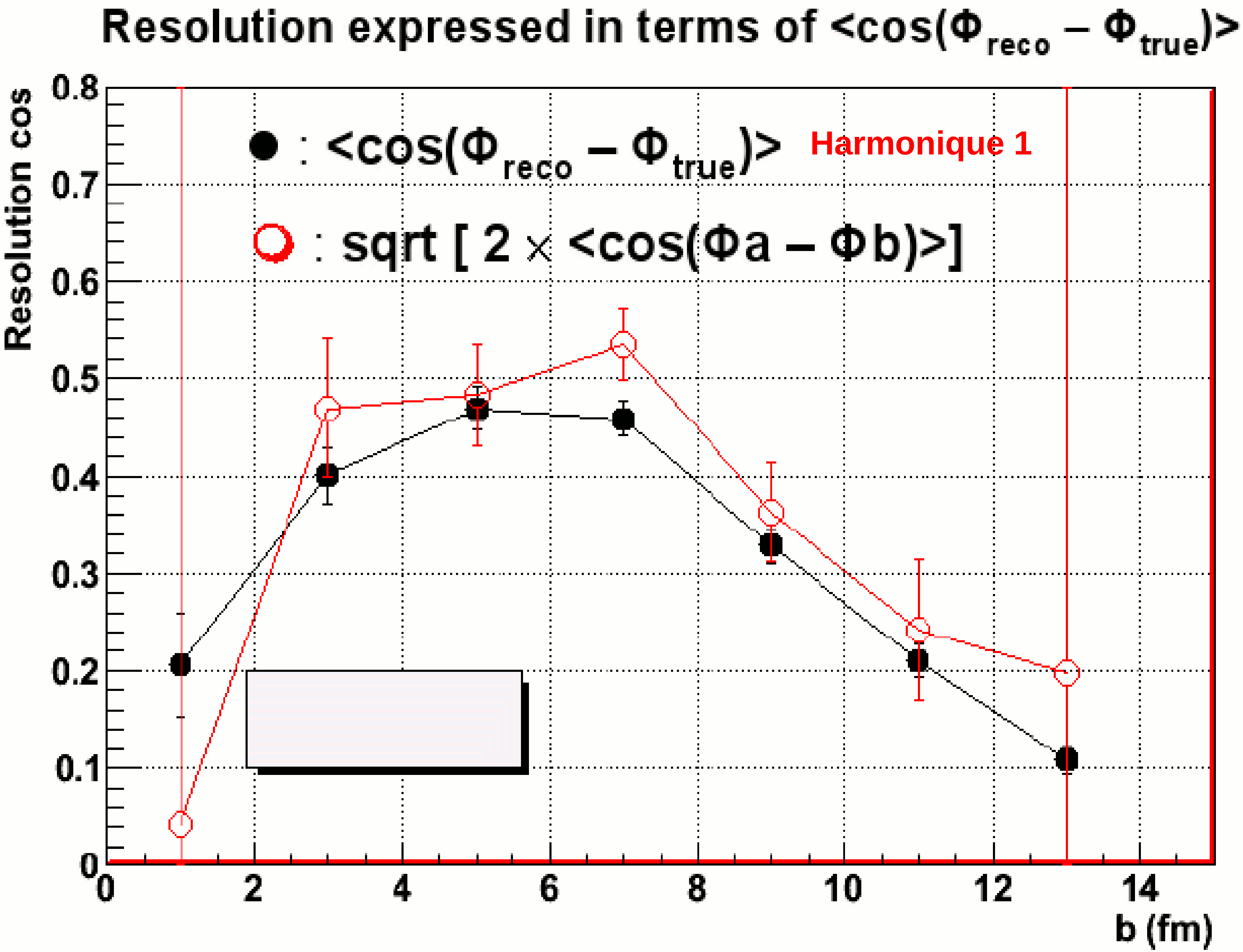
$$\frac{1}{m_T}\frac{d^2N}{dm_T\,dy} \quad e^{-\frac{(m_T - m)}{T}}$$

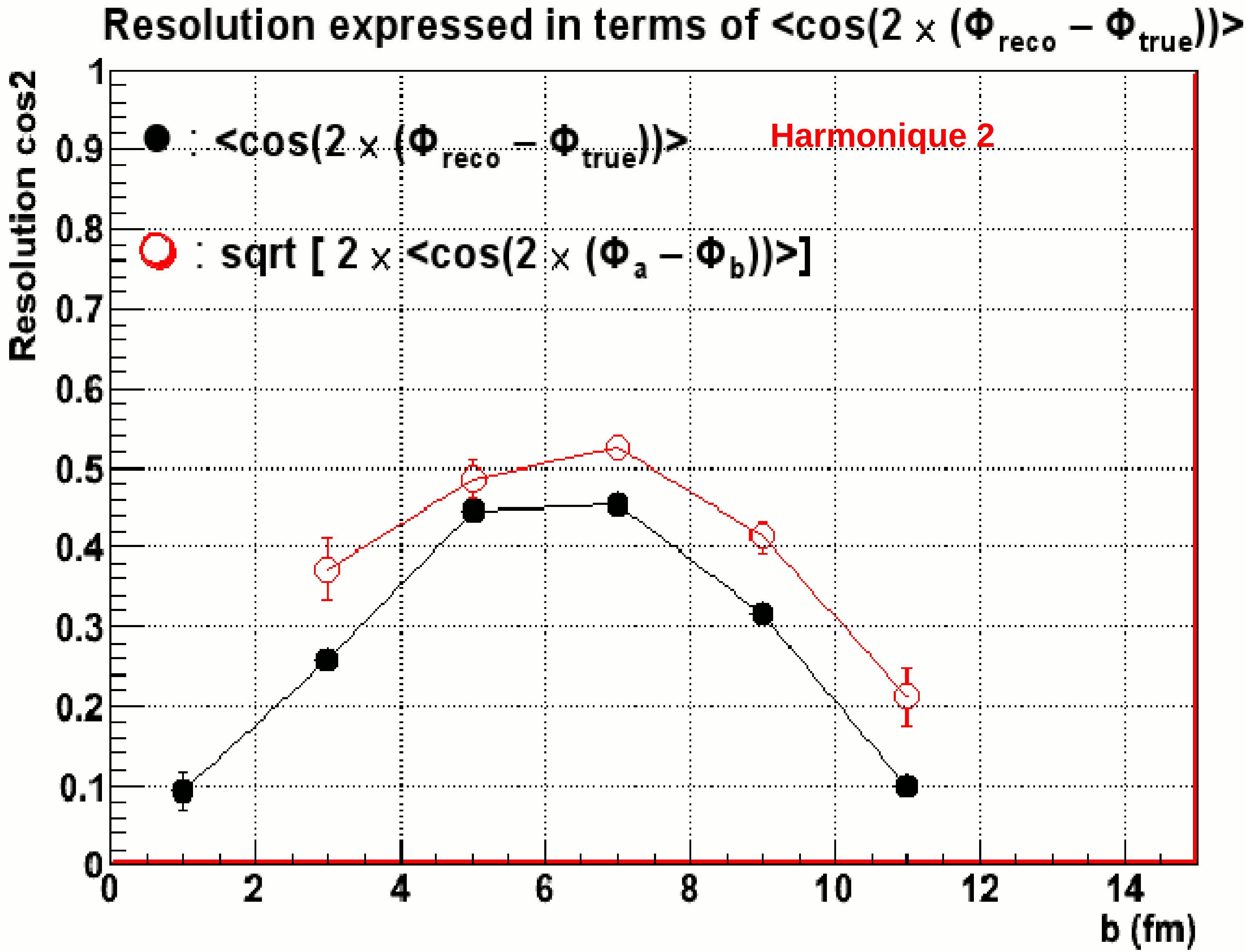
$$T = T_{Th} + m\beta^2$$

Resolution expressed in terms of $\sigma(\Phi_{reco} - \Phi_{true})$



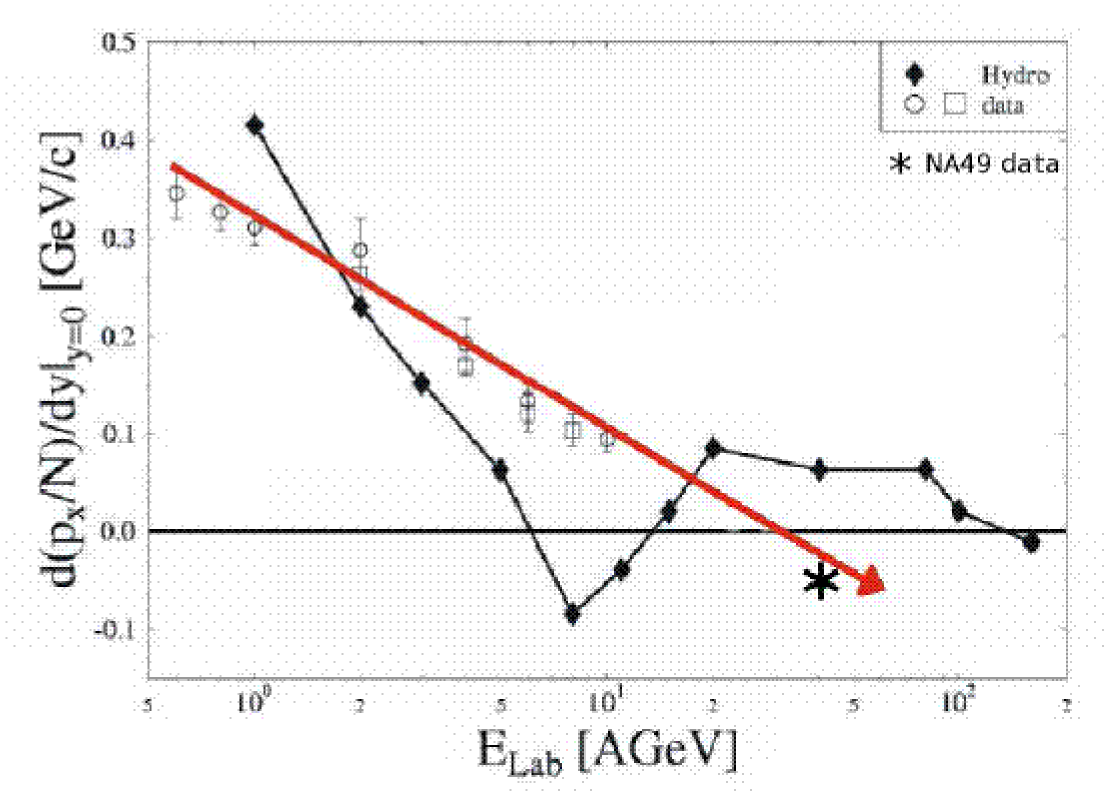
Harmonique 1


Resolution expressed in terms of $\langle\cos(\Phi_{reco} - \Phi_{true})\rangle$
Resolution cos
● : $\langle\cos(\Phi_{reco} - \Phi_{true})\rangle$
Harmonique 1
○ : sqrt [2 × <cos(Φa – Φb)>]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
b (fm)



Resolution expressed in terms of $<\cos(2 \times (\Phi_{reco} - \Phi_{true}))>$

Collapse of proton v2 as a probe of the 1st order phase transition at FAIR energies (1)



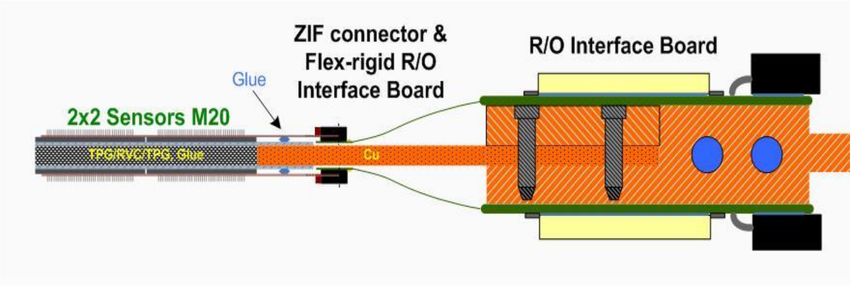
Prediction at FAIR energy (around 30 – 40 A.GeV)

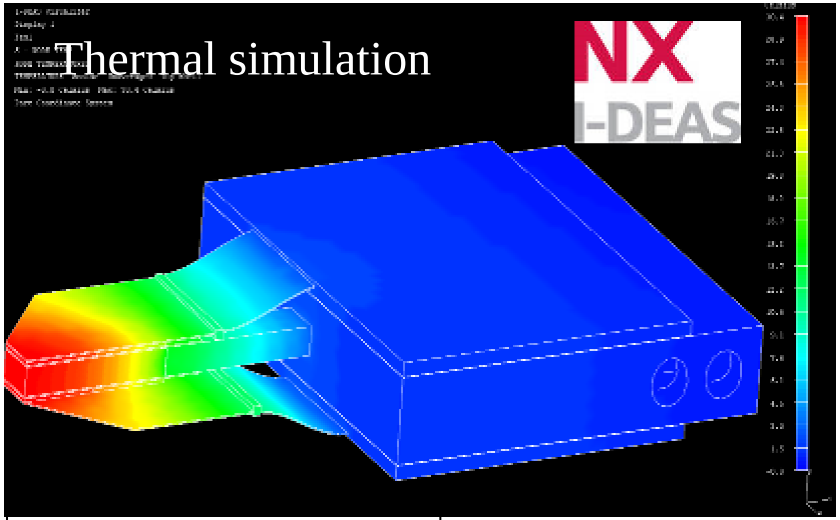
- Collapse of proton v2

- also: Wiggle of v1 at mid-rapidity

MAPS sensors for the MVD – integration (2)

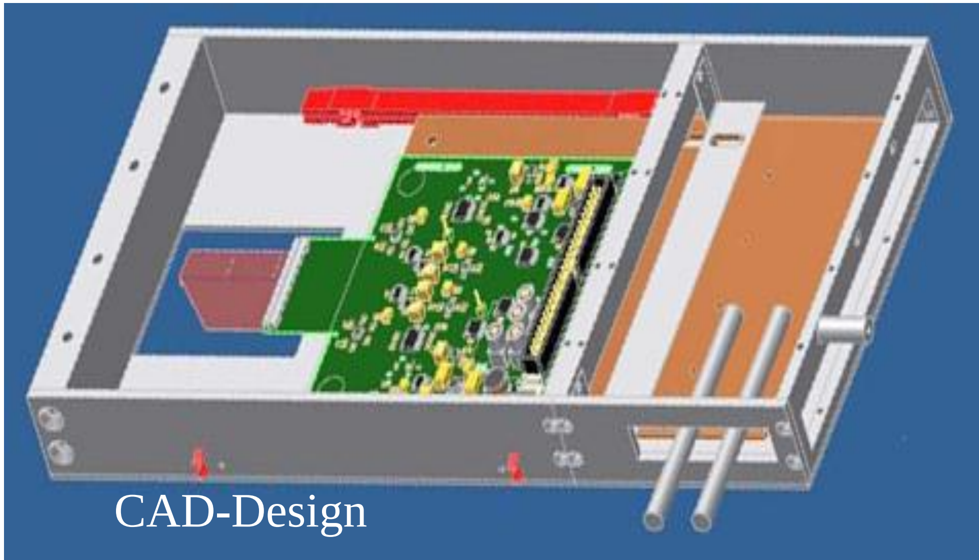
Ladder



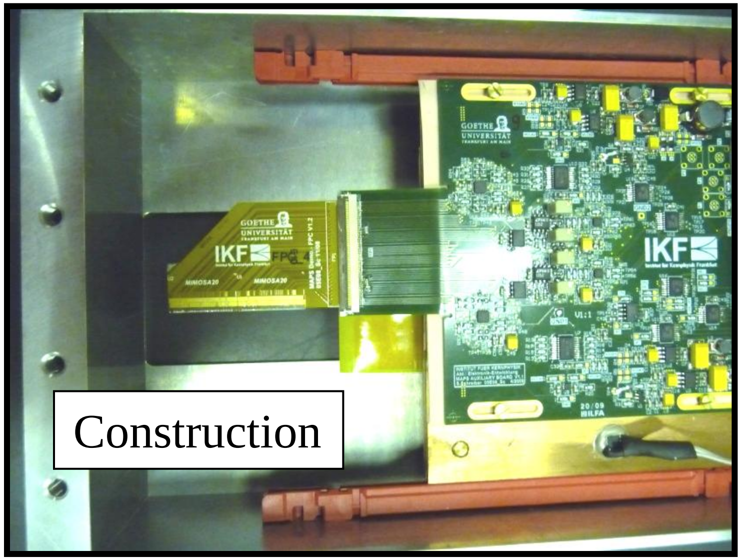


Thermal simulation

Power: ~ 1W /cm²



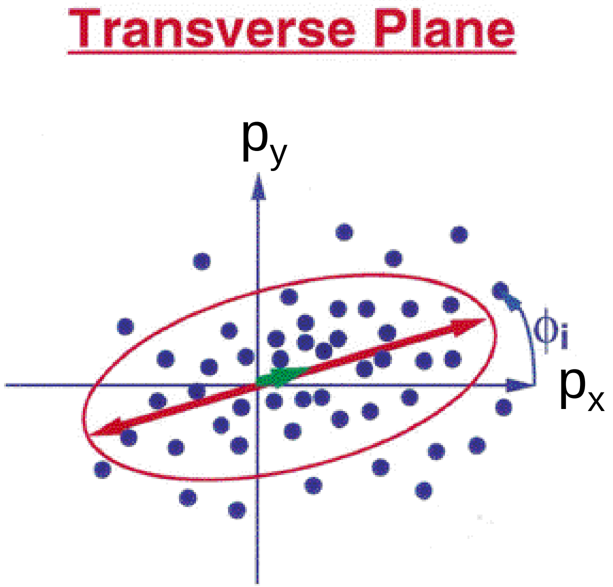
CAD-Design



Construction

Flow analysis

Several flow analysis methods: cumulant, Lee-Yang zero method, here: **Event Plane Method**



$$\Psi_{plane} = \tan^{-1}\frac{\Sigma \sin(\phi_i)}{\Sigma \cos(\phi_i)}$$

$$2\,\Psi_{ellipse} = \tan^{-1}\frac{\Sigma \sin(2\phi_i)}{\Sigma \cos(2\phi_i)}$$

$$Q_n \cos(n\Psi_n) = \sum[w_i \cos(n\phi_i)]$$
$$Q_n \sin(n\Psi_n) = \sum[w_i \sin(n\phi_i)]$$

Φi : azimuth of part. in lab.
w_i : weight: pT,
opposite signe for/backward
rapidity in case n = 1

S. Voloshin and Y. Zhang,

Z. Phys. C 70, 665 (1996)

The event plane resolution depends on:

- the magnitude of the flow of order n
  → **beam energy** (Ebeam) and **impact parameter** (b) dependant
- the event multiplicity → idem
- the **detector acceptance** and **azimuthal symmetry**