



# Charm Quarks as a probe of matter produced in relativistic nucleus-nucleus collisions

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For NA61/SHINE Collaboration

International Conference on New Frontiers in Physics  
28 August 2013 to 5 September 2013  
Kolymbari, Crete, Greece

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# Introduction

- Direct measurement of hadrons containing charm quark carries important information about the initial stage of the nucleus-nucleus collision at relativistic energies.
- A feasibility study of  $D^0 \rightarrow K^- \pi^+$  (BR=3.9%) channel in central Pb+Pb collisions at the CERN SPS energies will be presented. The study is done for 158 AGeV and 40 AGeV.
- The NA61/SHINE requires upgrade with a new vertex detector that will allow precise track and vertex reconstruction at the target proximity.

# Why Charm?

- An ideal probe for studying QGP
- Charm quarks created at early stage of Heavy Ion Collision

How to measure Charm?

Reconstruction via hadronic decay channels

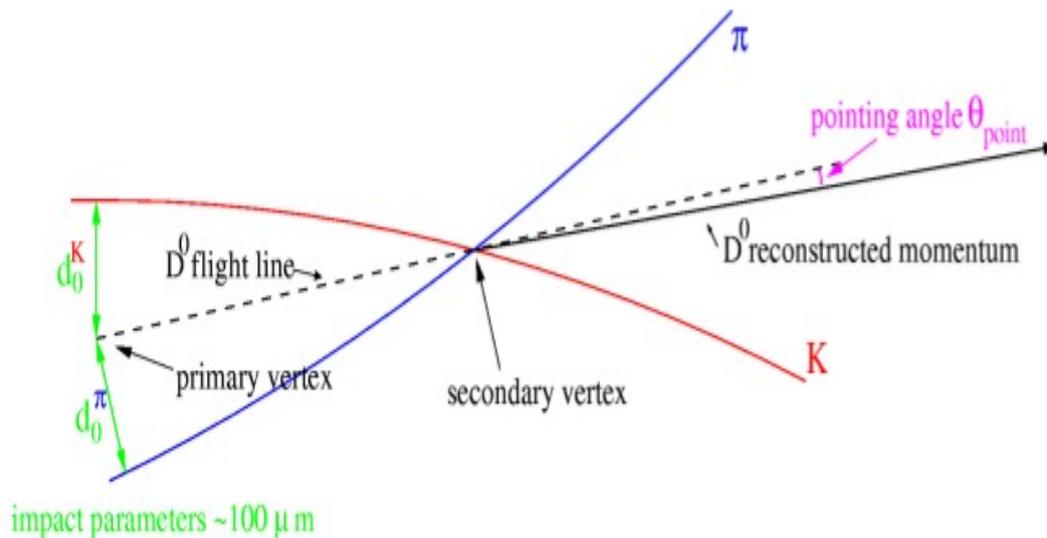
$$D^0 \rightarrow K^- + \pi^+ \quad (3.91\%) \quad c\tau = 123 \mu\text{m}$$

$$D^{*+} \rightarrow D^0 + \pi^+ \quad (61.9\%)$$

Semi-leptonic decay channels

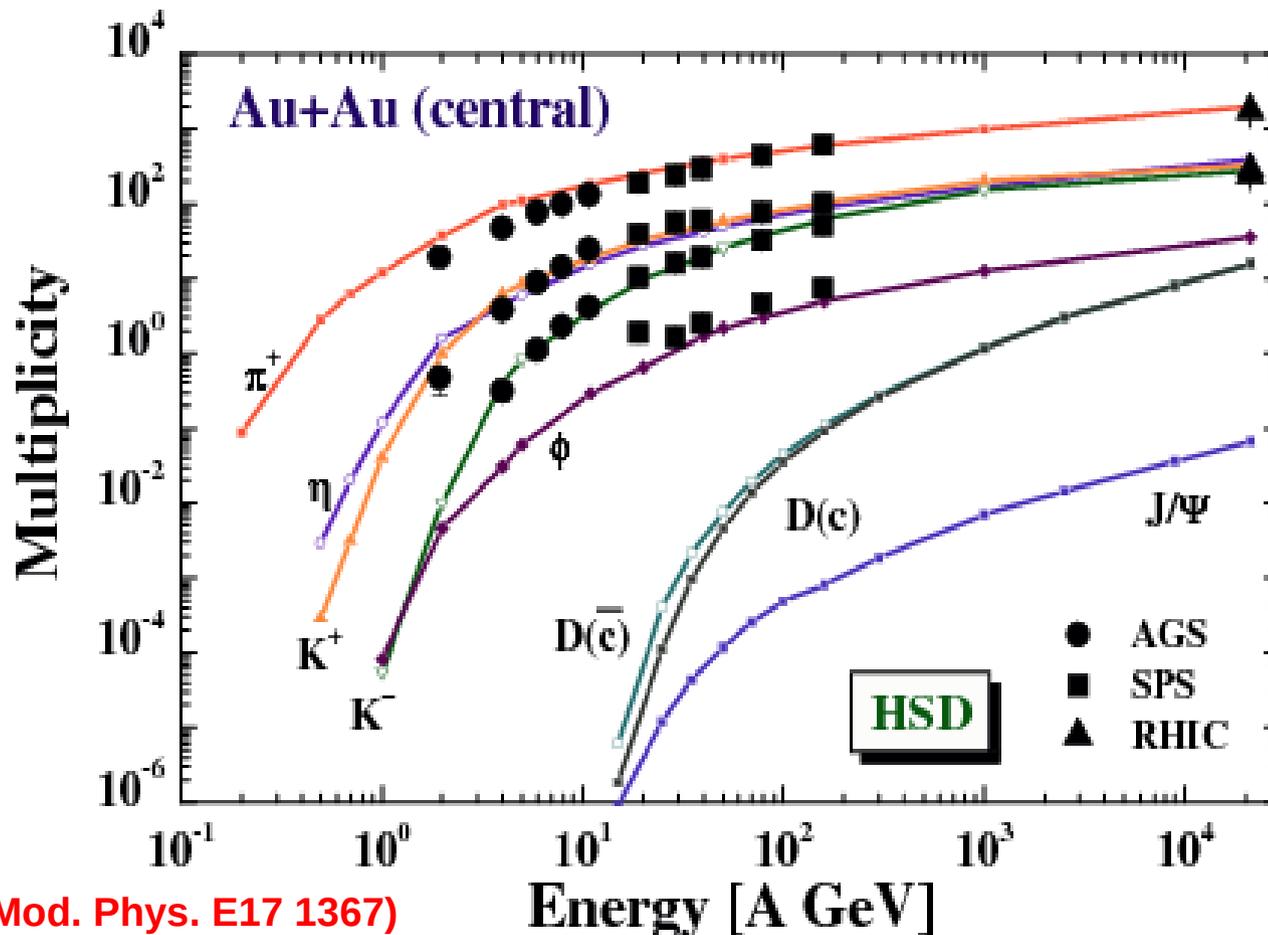
$$D^0 \rightarrow e + X \quad (6.9\%)$$

$$D^+ \rightarrow e + X \quad (17.2\%)$$



# Physics motivation

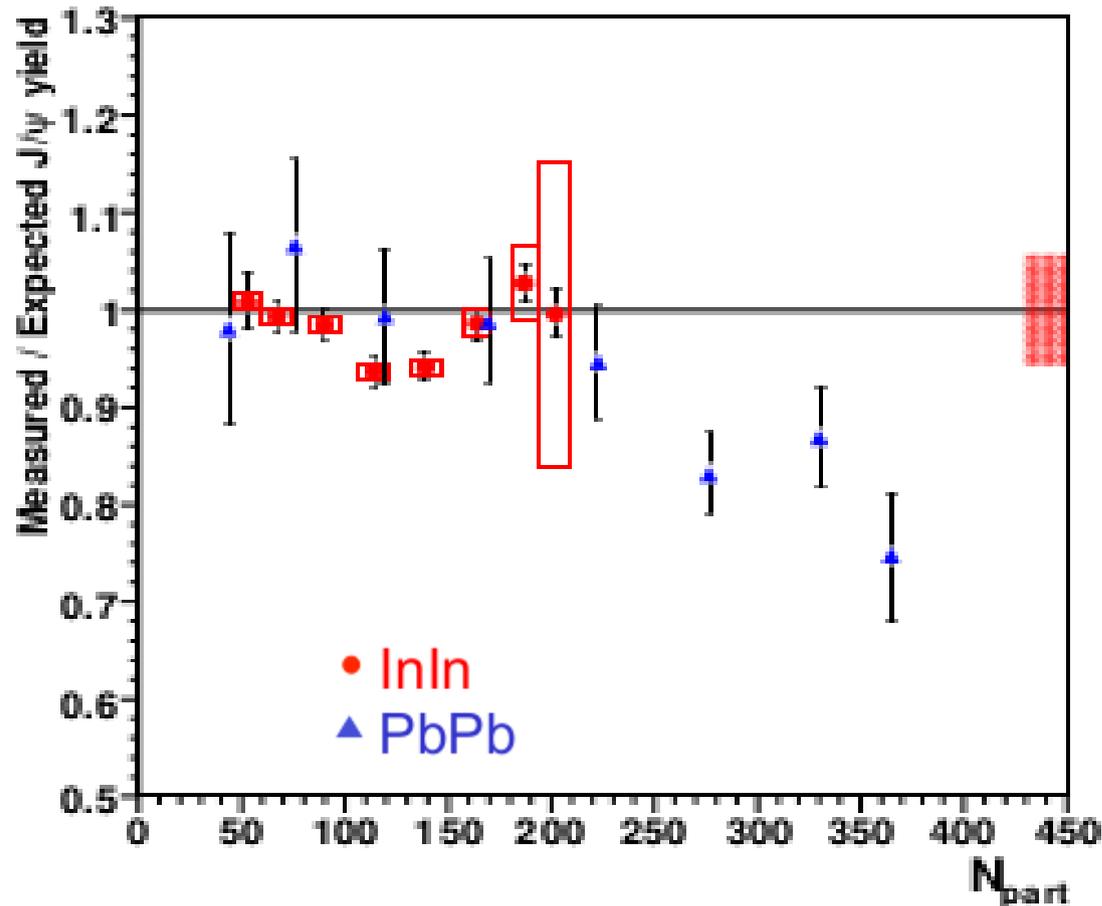
- So far no direct open charm measurements at SPS energies
- But there are experimental initiatives which measure charmonia states at SPS energies (Town Meeting "Relativistic Heavy-Ion Collisions" Fleuret and Usai)
- Simultaneous measurements of charmonia and open charm
  1. are needed to construct charm observables that are model independent.
  2. will allow to disentangle between initial and final state effects( Satz. Rep. Prog. Phys. 63 1511 2000 )



(Int. J. Mod. Phys. E17 1367)

# Physics motivation cnt.

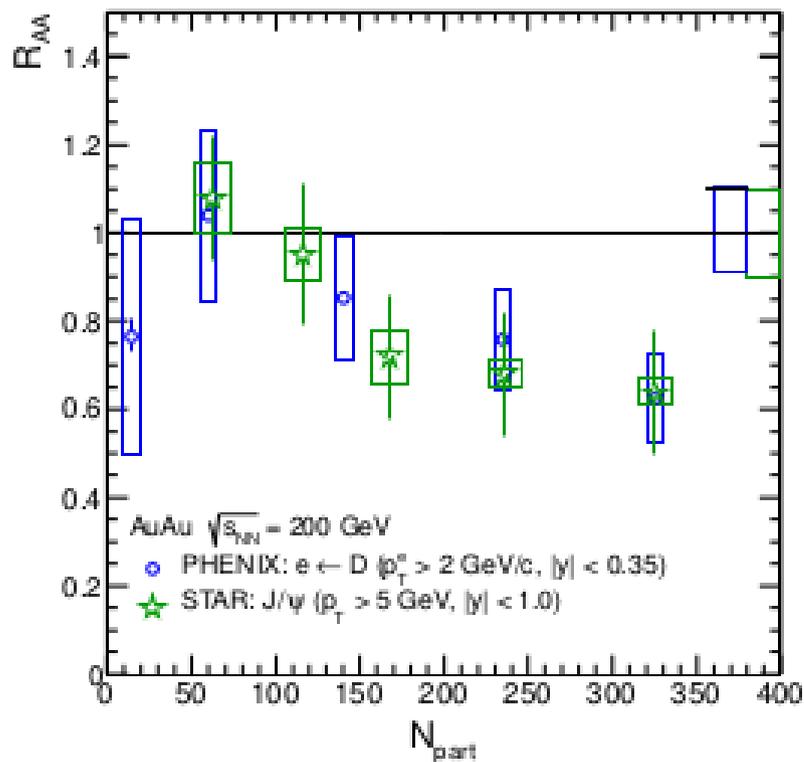
- Measurement of  $J/\psi$  at top SPS energy (NA50,NA60) was performed
- Anomalous suppression of  $J/\psi$  for central A+A collisions ( $N_{\text{part}} > 200$ ).
- Attributed to QGP formation but other scenarios can not be ruled out.
- Measurement of charm production in open charm channel is requested (**Phys. Lett. B 178 416 1986**)
- if anomalous behavior of charm production is present in the open charm channel we will be able to characterize this effect versus centrality and energy.



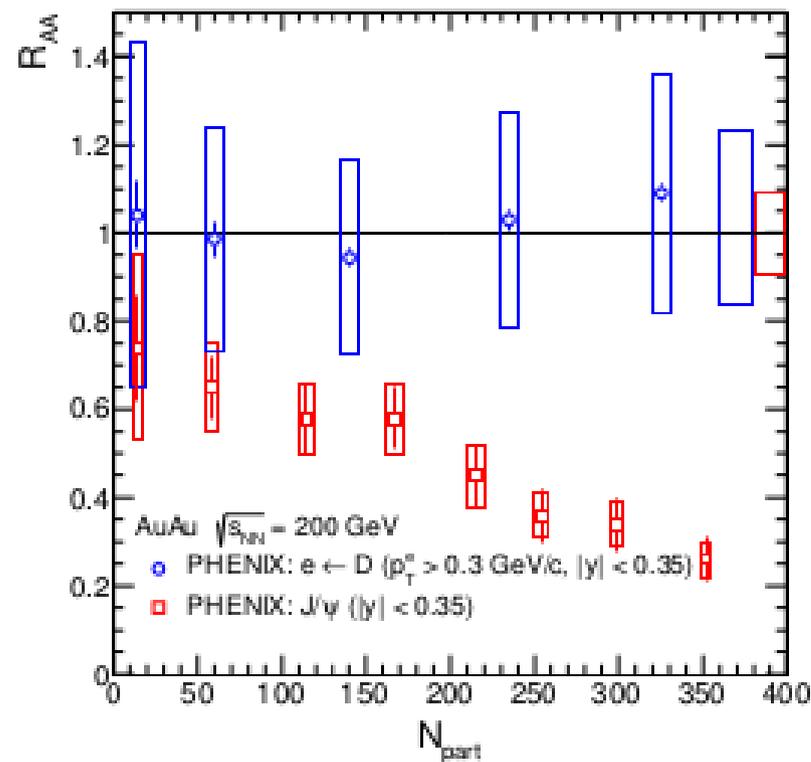
(arXiv 0907. 3682 v2 [nucl-ex] 2009)

# Comparison of hidden and open charm

## $R_{AA}$ at high and low $p_T$



At high  $p_T$   $R_{AA}$  for  $J/\psi$  and  $D$  mesons are consistent  
 → no final (medium) state effects  
 (initial state effects are the same)

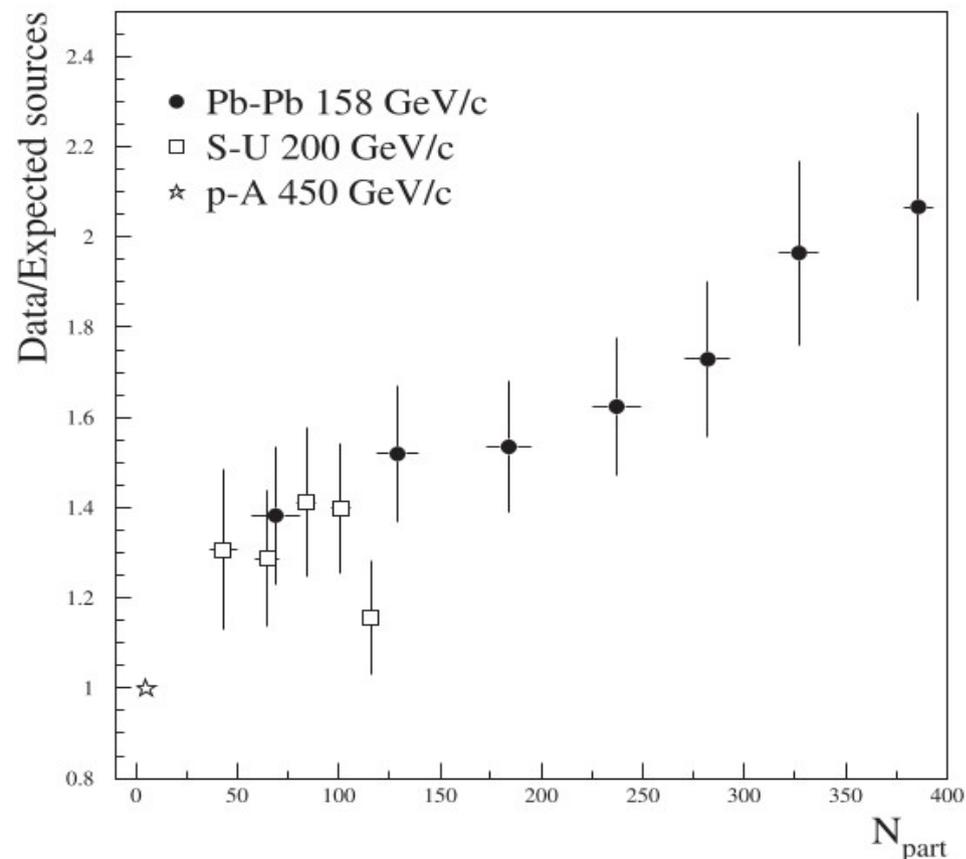


At low  $p_T$   $R_{AA}(J/\psi)$  shows significant suppression increasing with centrality whereas  $R_{AA}(D)$  is consistent with unity

→ studying both hidden and open charm allows separation of final and initial state effects!!!

# Direct open charm measurements → conclusion

- The NA50 and NA38 experiments have studied muon pair production in p-A and nucleus-nucleus collisions at the CERN SPS.
- The p+A results are described in terms of Drell-Yan process and semi-leptonic decays of charmed mesons.



→ The A+A data → enhancement of dimuons in the invariant mass region (IMR) between  $\Phi$  and  $J/\psi$  meson masses.

→ The nature of the described phenomenon encountered in dimuon production in the IMR can be finally concluded by :

→ Only a direct measurement of open charm production in nucleus-nucleus collisions at SPS energies.<sub>8</sub>

# NA61/SHINE Experiment



**NA61/SHINE at the CERN SPS**

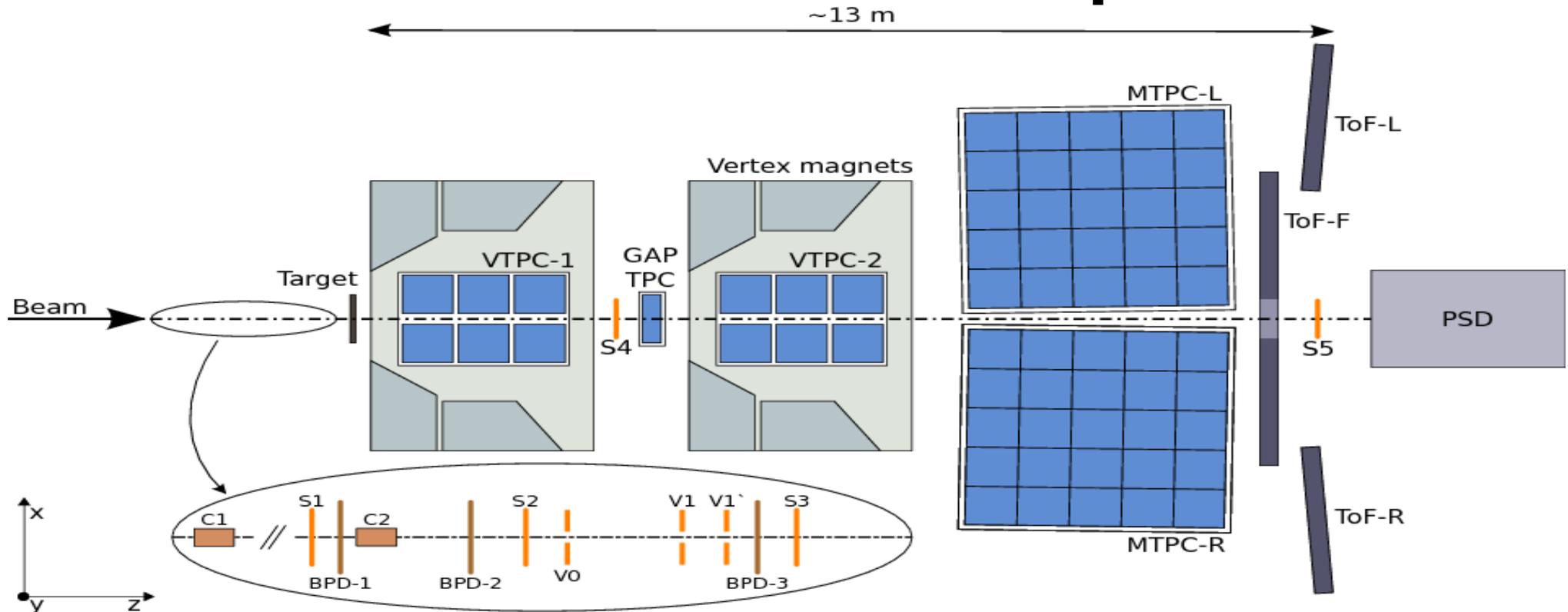


# NA61/SHINE physics goals

SHINE = SPS Heavy Ion and Neutrino Experiment

- Search for the critical point of strongly interacting matter.
- Study the properties of the onset of deconfinement in nucleus-nucleus collisions.
- Hadron production reference measurements for neutrino (T2K) and cosmic-ray (Pierre Auger Observatory, KASCADE-Grande and KASCADE) experiments.
- Study of high transverse momentum phenomena in proton-nucleus and proton-proton interactions.

# NA61/SHINE detector - Top view



**Beam detectors and triggering** → A set of upstream scintillator and Cherenkov counters and beam Position detectors provides timing reference, charge and position measurements

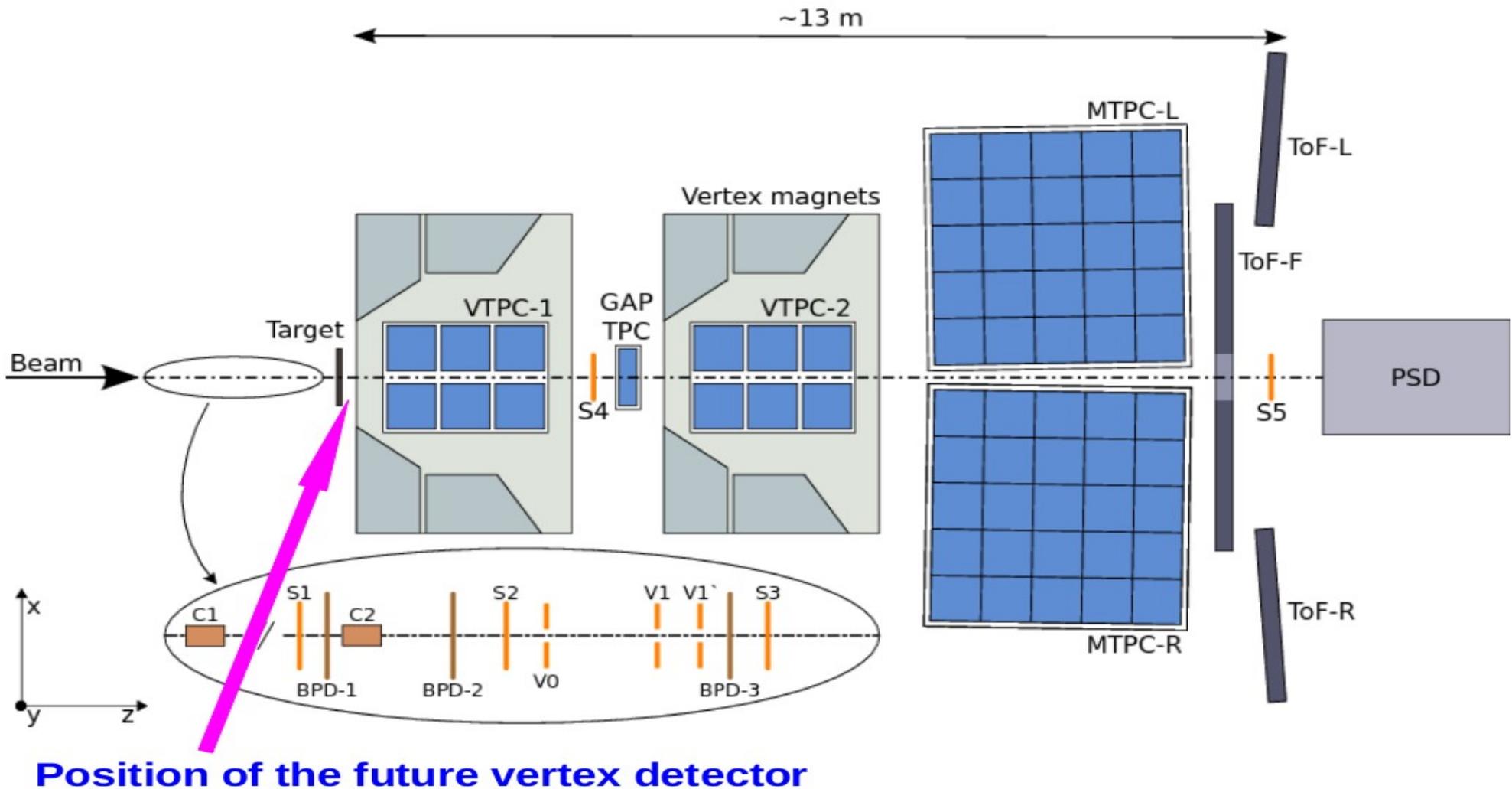
**Time Projection chambers** → Four large volume TPC's serve as tracking detectors

**Time of Flight walls** → Mainly used for Hadron Identification

**Projectile Spectator Detector(PSD)** → A Calorimeter which is positioned downstream of the time of flight detectors measure energy of projectile fragments.

# NA61/SHINE detector - Top view

## Vertex detector Position



# Feasibility Studies

# Physical Input

- AMPT (A MultiPhase Transport model) event generator used to generate 200k Pb+Pb events at 158 AGeV for 0-10% centrality
- AMPT predicts **0.01** of  $\langle D0 \rangle + \langle \bar{D0} \rangle$  per central Pb+Pb event. this seems to be under-predicted value.
- The prediction of the HSD model is  $\sim 0.2$ . HSD model was tuned to properly describe available p+A and  $\pi$ +A charm production data at SPS energies. (**Nucl. Phys. A 691, 753 (2001)**).
- HSD (Hadron String Dynamic) Model predictions are consistent with scaled PYTHIA → We scaled AMPT predictions to be consistent with HSD and PYTHIA.

# Physical Input cnt.

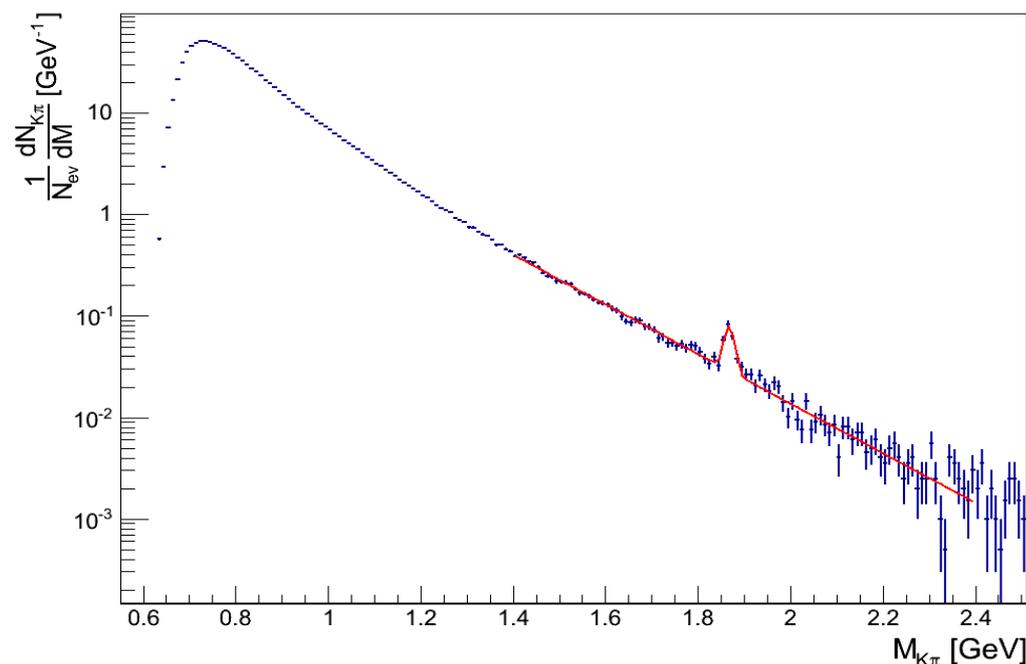
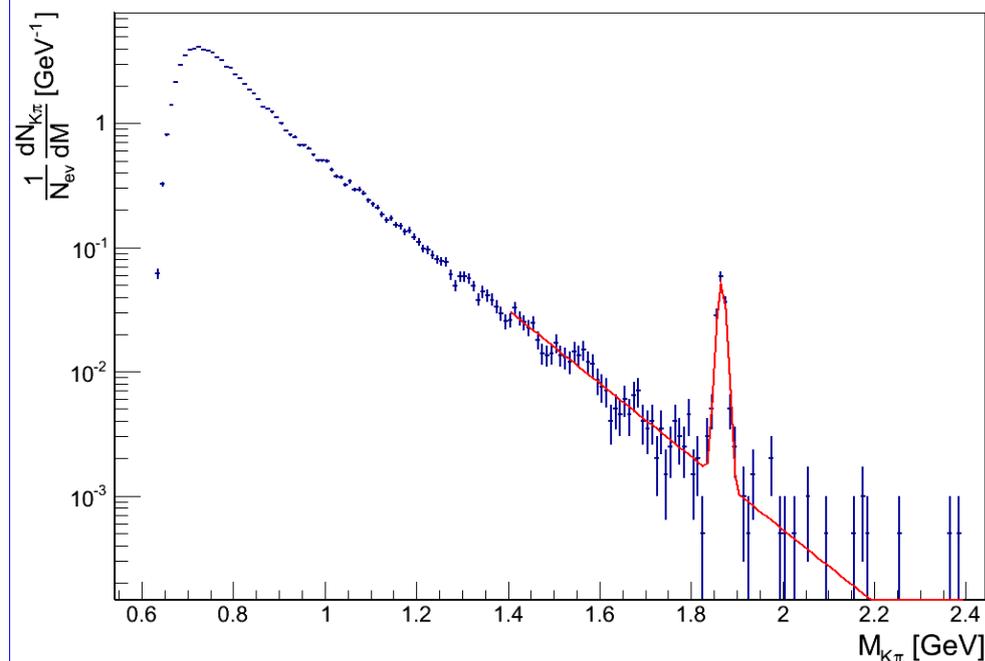
- AMPT does not generate “Open Charm” at 40 AGeV.
- Width of the rapidity distribution and Invariant mass slope parameter does not change by more than 10% for Kaons while going from 158 AGeV to 40 AGeV
- We assumed similar changes for D0 as we observe for Kaons and its yield as predicted by HSD model.

AMPT : **(Phys.Rev.C72:064901, 2005)**

HSD : **(Int. J. Mod. Phys. E17 1367)**

PYTHIA: **(T. Sjostrand etal., Comput. Phys. Commun. 135, 238 (2001))**

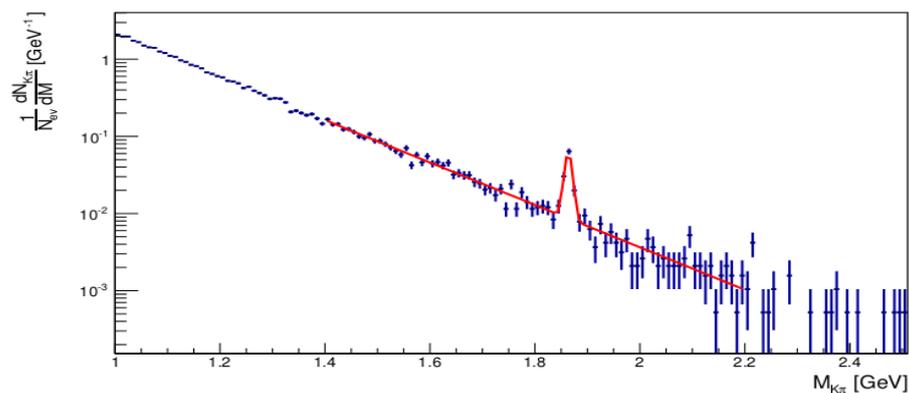
# Open Charm measurements → feasible with a dedicated vertex detector



- **S/B = 17**
- **SNR(@50M) = 246**
- **64300 detected  $D^0+D^0$ bar mesons in 50M central Pb+Pb (PID)**

**158 AGeV**

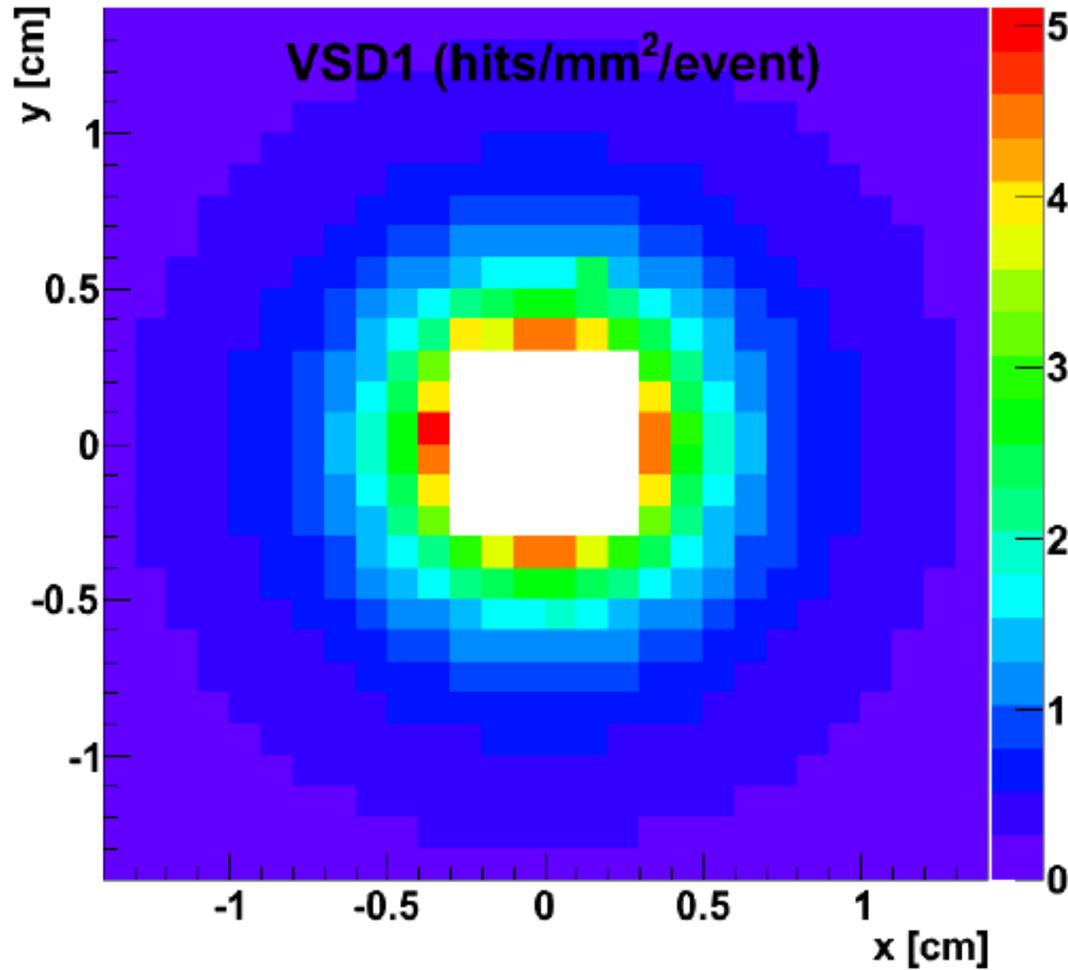
- **S/B = 1**
- **SNR(@50M) = 197**
- **64300 detected  $D^0+D^0$ bar mesons in 50M central Pb+Pb (PID)**



- **S/B = 1.0**
- **SNR(@50M) = 11.3**
- **2000 detected  $D^0+D^0$ bar mesons in 50M central Pb+Pb (PID)**

**40 AGeV**

# We used developed simulation to determine requirements for the detector which are:



→ We can expect very high hit occupancy on the level of 5 hit/mm<sup>2</sup>/event in the most inner part of the vertex detector.

→ It suggests that silicon pixel sensors would provide a good solution for us.

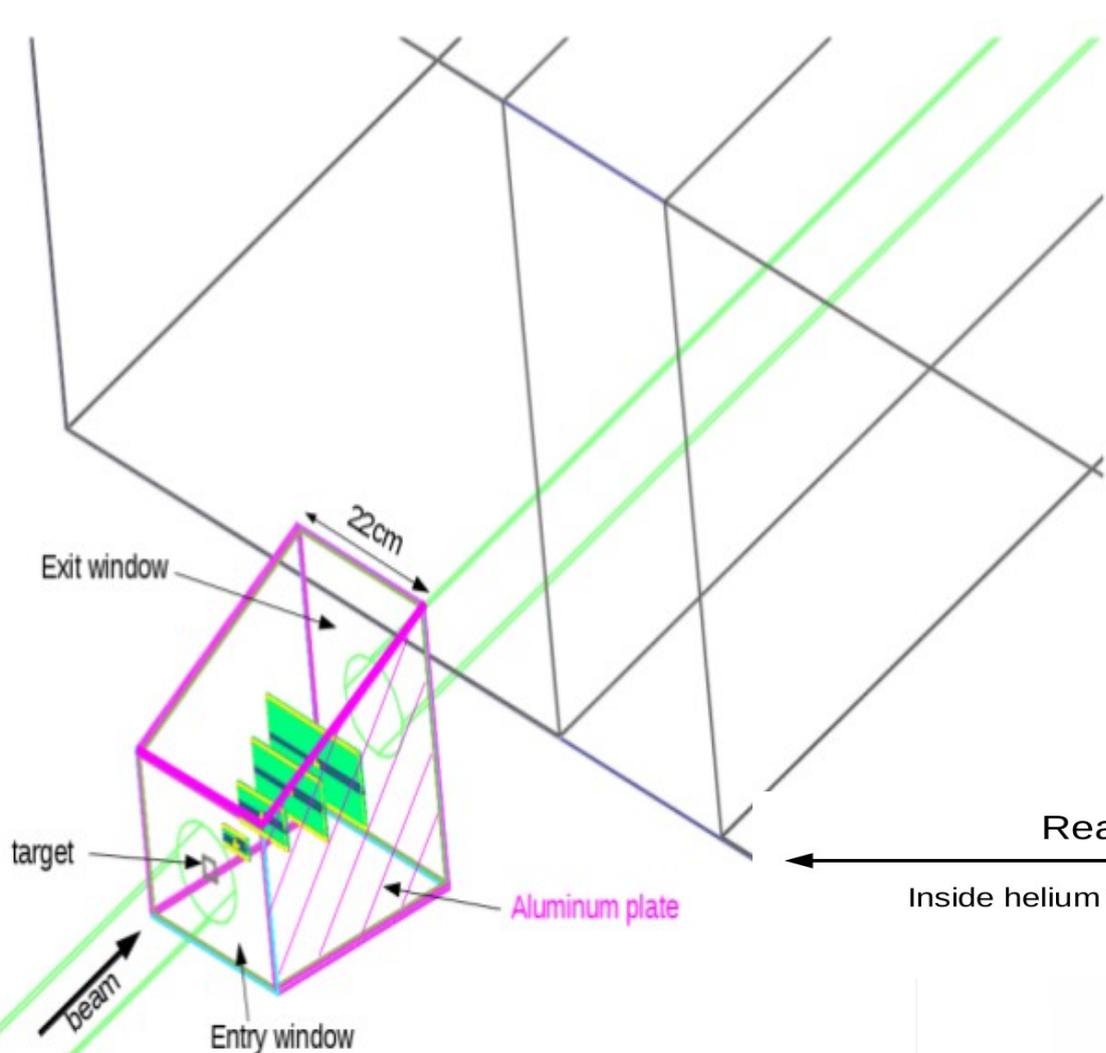
Charged particles produced in Pb+Pb 0-10%  
central interactions

# Estimates of NA61/SHINE requirements and limits for different chip technologies

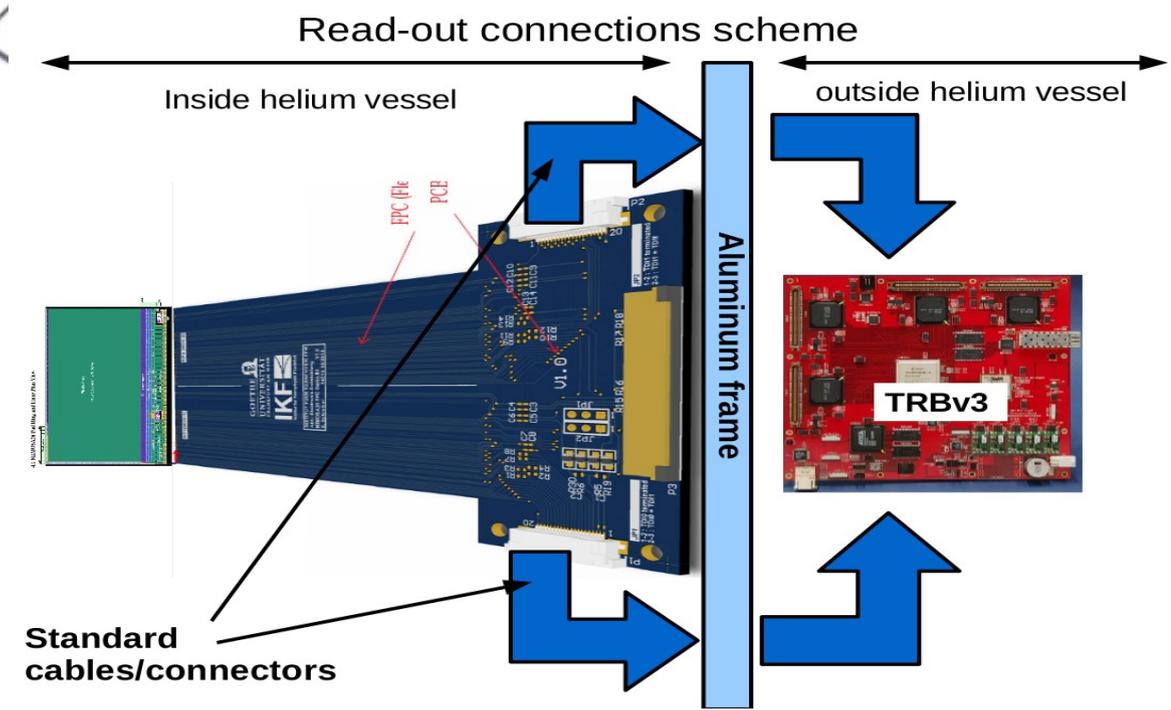
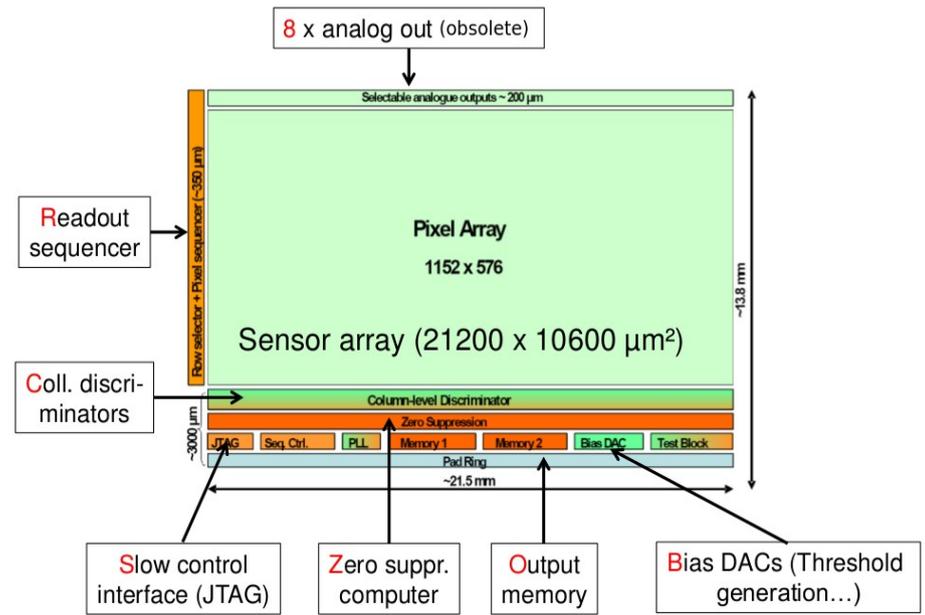
	NA61	Hybrid	CCD	MIMOSA
Resolution	< 5 $\mu\text{m}$	30 $\mu\text{m}$	< 5 $\mu\text{m}$	< 3.5 $\mu\text{m}$
Mat. Budg.	Few 0.1 $X_0$	$\sim 1\% X_0$	$\sim 0.1\% X_0$	$\sim 0.05\% X_0$
Rad. Tol (1)	$3 \times 10^{10}$ neq/cm <sup>2</sup>	$> 10^{14}$ neq/cm <sup>2</sup>	$< 10^9$ neq/cm <sup>2</sup>	$> 10^{13}$ neq/cm <sup>2</sup>
Rad. Tol (2)	$\sim 1$ krad	$\sim 10$ Mrad	$\sim 1$ Mrad	$\sim 300$ krad
Time resolution	$\sim 100$ $\mu\text{s}$	$\sim 20$ $\mu\text{s}$	$\sim 100$ $\mu\text{s}$	$\sim 115.2$ $\mu\text{s}$

Rad. Tol (1) and (2) refers to non ionizing and ionizing dose per week beam on Target

→ MIMOSA-26 seems to be very much feasible device

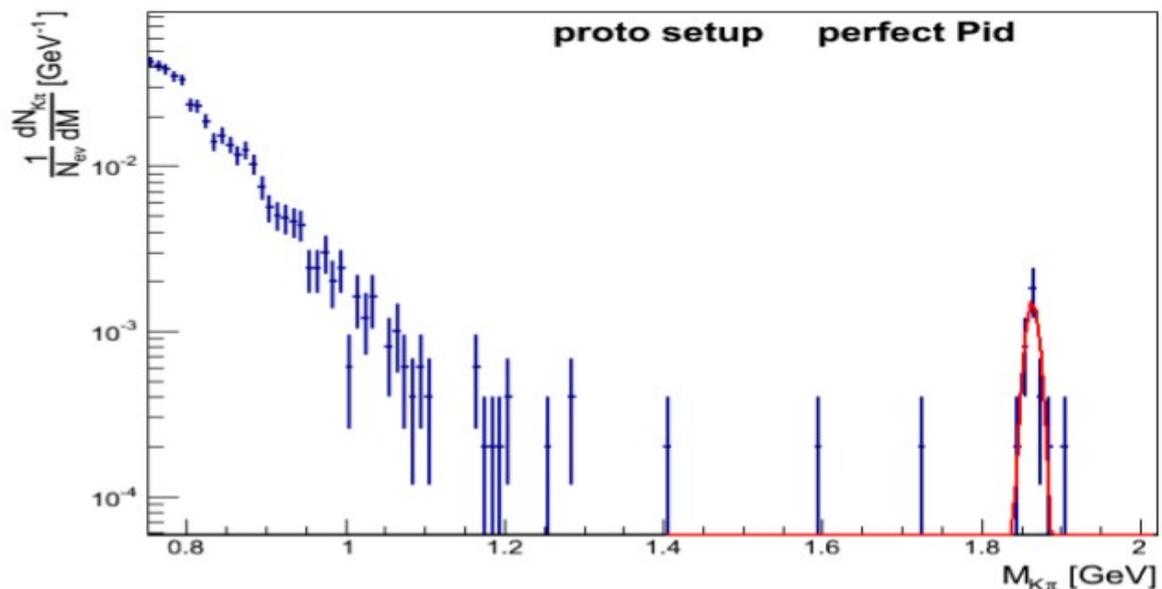


## Block diagram of MIMOSA-26



# Test of Prototype in 2015 ( Ar + Ar/Ca )

Simulation results: prototype setup geometry

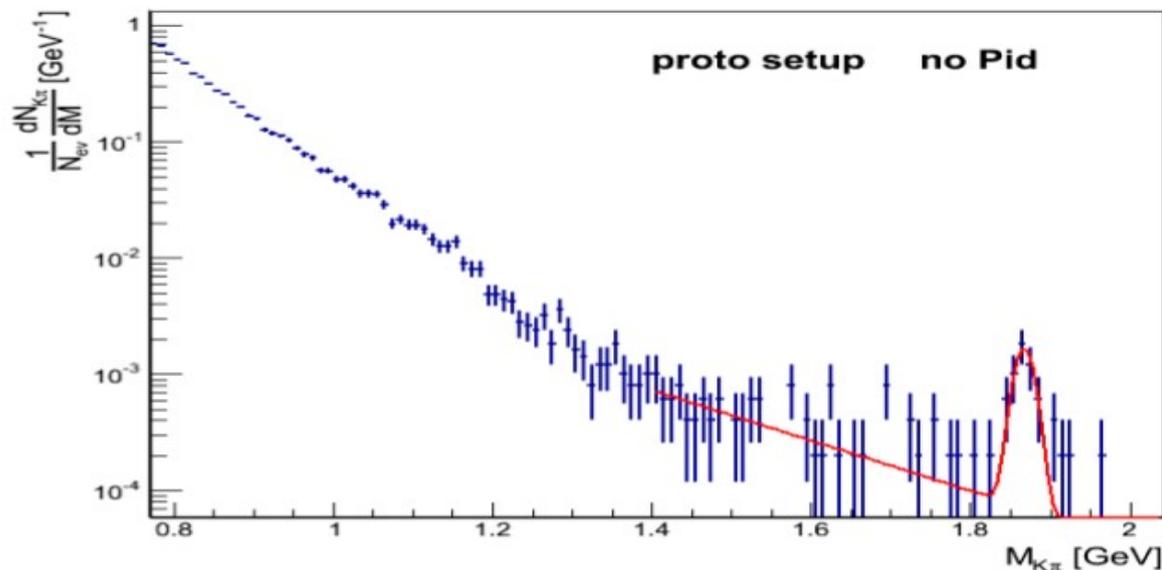


500k 0-10% central  
Ar+Ar at 158 GeV

Again cuts are optimized to  
central Pb+Pb at 158 AGeV  
(cuts may be relaxed for  
Ar+Ar/Ca)

~ 20  $D^0 + D^0\text{bar}$

For “no Pid” analysis S/B=11  
and SNR= 4.6



**Measurement with the  
setup geometry seems to  
be feasible if we collect  
~500k central events  
(and if HSD yields are not  
significantly over-  
predicted)**

# Summary

→ Measurement of heavy flavor mesons → better understanding → nucleus-nucleus reactions at relativistic energies.

→ Upgradation of the NA61/SHINE experiment with a dedicated vertex detector equipped with MIMOSA-26 sensors as detection units → feasible for open charm measurements .

→ Building Prototype and Tests (on beam) to show that keeping sensors in flowing and conditioning helium will ensure reasonably low and stable sensor temperature (to keep fake hits low)

→ Differential measurements for open charm

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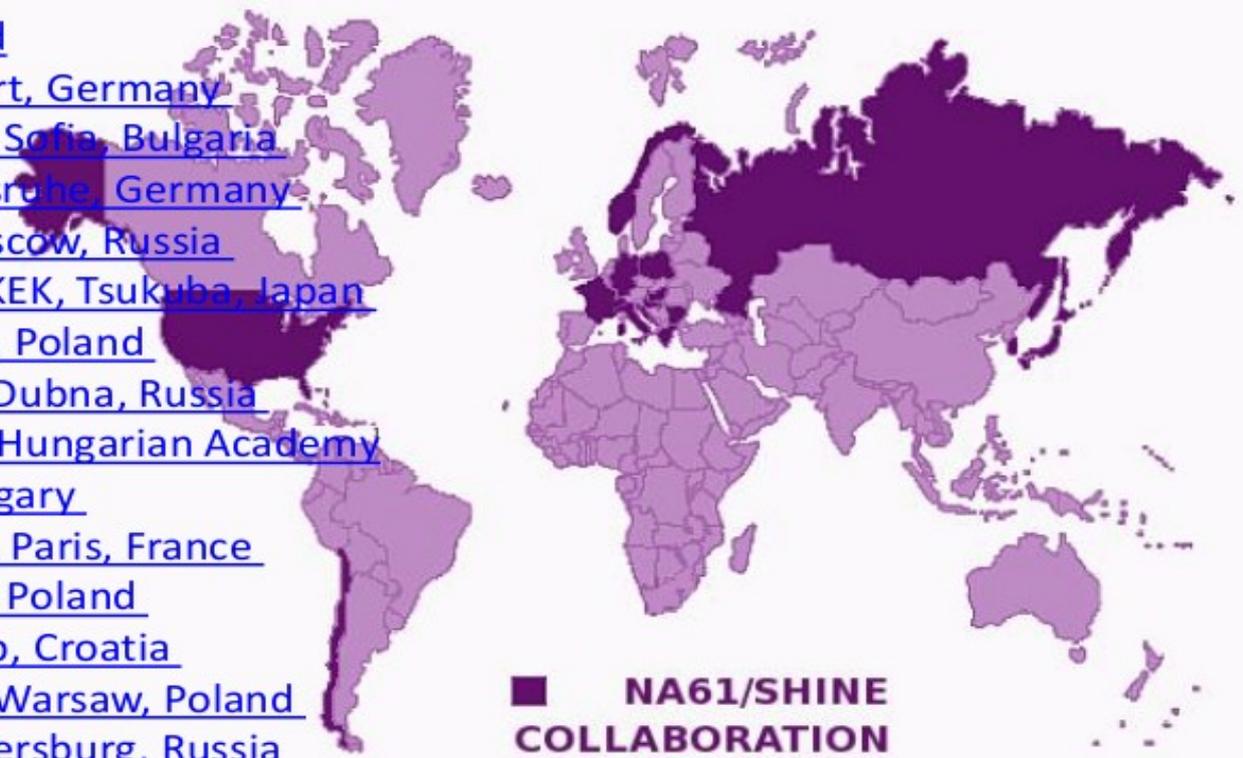
[University of Geneva, Geneva, Switzerland](#)

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[Warsaw University of Technology, Warsaw, Poland](#)

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[University of Belgrade, Belgrade, Serbia](#)



**~ 150 Participants**  
**16 Countries**

**THANK YOU!**

# Acknowledgments

- We acknowledge the support by the Foundation for Polish Science - MPD program, co-financed by the European Union within the European Regional Development Fund.
- NA61 Collaboration

# NA61/SHINE Experiment



**NA61/SHINE at the CERN SPS**



**BACK UP SLIDES**

# Other Ideas: sequential dissociation

If similar anomalous feature is visible in open charm we will be able to characterize it in a wide range of SPS energies:

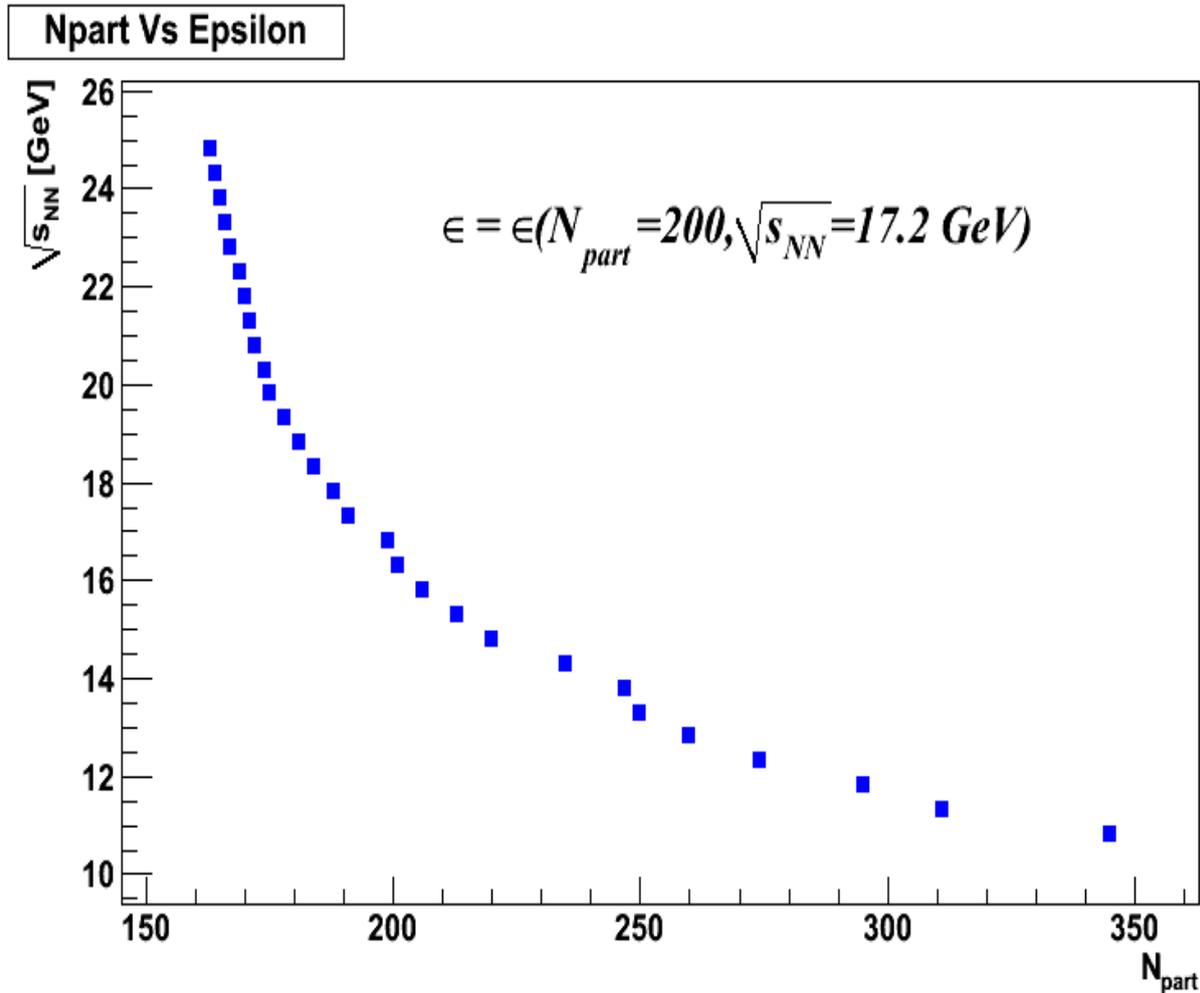
Journal of Physics: Conference Series **5** (2005) 17

**Table 2.** Average values of  $dN_{ch}/d\eta / (0.5N_p)$  at different  $\sqrt{s_{NN}}$ . An additional 5% error should be added to columns 17.2 GeV through 4.8 GeV for the uncertainty related to recalculation to the C.M.S..

$N_p$	200 GeV RHIC aver.	130 GeV RHIC aver.	62.4 GeV PHENIX prelim.	19.6 GeV PHENIX/ PHOBOS	17.2 GeV SPS aver.	8.7 GeV SPS aver.	4.8 GeV E806/E917 combined
375	3.92±0.13	3.41±0.10			1.97±0.12	1.26±0.11	0.92±0.14
350	3.81±0.13	3.31±0.10	2.77±0.21	1.91±0.11	1.93±0.12	1.22±0.11	0.89±0.13
325	3.72±0.12	3.22±0.10	2.68±0.20	1.89±0.11	1.90±0.14	1.20±0.11	0.85±0.13
300	3.65±0.12	3.16±0.10	2.60±0.20	1.88±0.11	1.88±0.15	1.18±0.10	0.81±0.12
275	3.56±0.12	3.11±0.09	2.54±0.19	1.87±0.11	1.83±0.16	1.17±0.10	0.78±0.12
250	3.51±0.12	3.07±0.09	2.48±0.19	1.87±0.12	1.80±0.17	1.16±0.10	0.76±0.11
225	3.45±0.12	3.04±0.10	2.43±0.19	1.85±0.12	1.78±0.17	1.16±0.10	0.75±0.11
200	3.38±0.11	3.00±0.09	2.37±0.19	1.83±0.12	1.75±0.17	1.14±0.10	0.74±0.11
175	3.34±0.12	2.96±0.10	2.30±0.19	1.81±0.12	1.72±0.17	1.14±0.09	0.72±0.11
150	3.27±0.12	2.89±0.10	2.23±0.20	1.76±0.13	1.69±0.17	1.14±0.09	0.71±0.11
125	3.20±0.12	2.83±0.10	2.13±0.20	1.72±0.14	1.66±0.16	1.14±0.09	0.70±0.11
100	3.14±0.13	2.73±0.11	2.02±0.22	1.68±0.15	1.66±0.23	1.14±0.09	0.67±0.14
75	3.03±0.13	2.65±0.11	1.89±0.24	1.62±0.19	1.61±0.21		0.64±0.18
50	2.73±0.13	2.53±0.12			1.54±0.19		0.63±0.21
25	2.78±0.43	2.36±0.30			1.45±0.13		

# Other Ideas: sequential dissociation

If similar anomalous feature is visible in open charm we will be able to characterize it in a wide range of SPS energies:

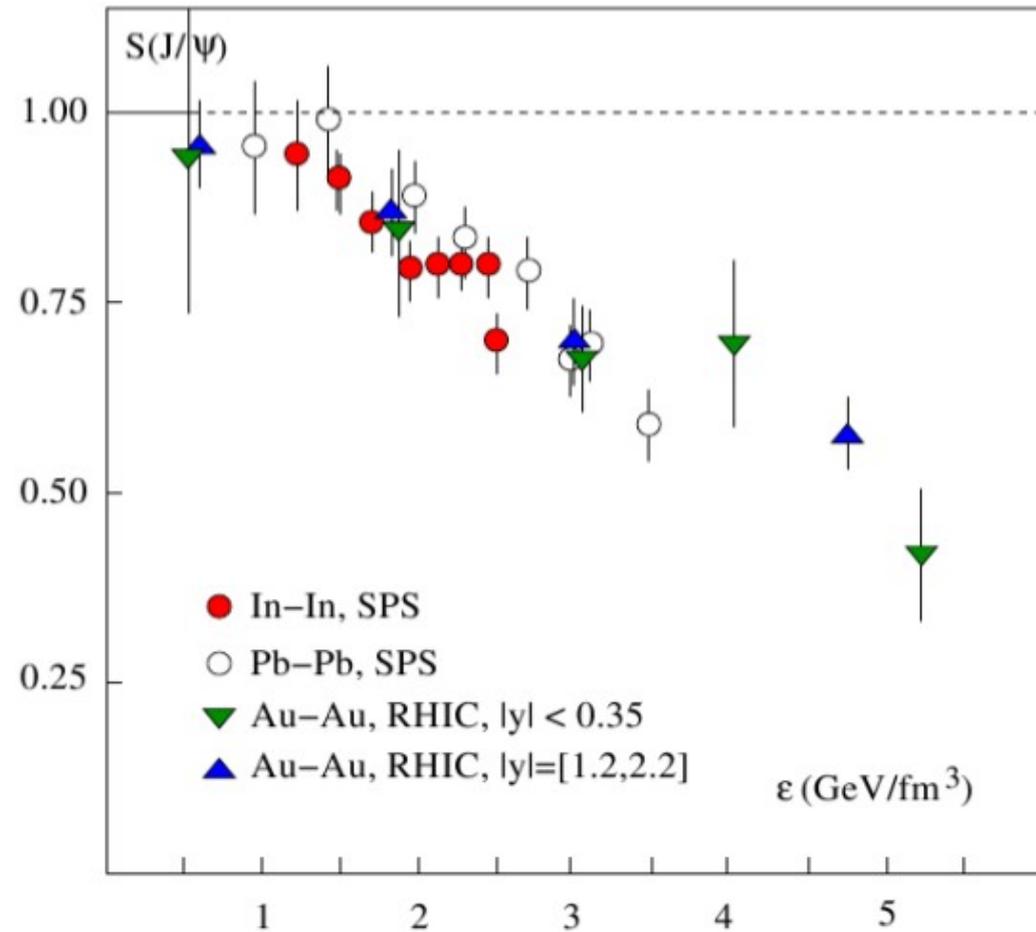


Same energy density as that at top SPS and  $N_{part} \sim 200$  can be obtained at 30 AGeV but at most central collisions

It was shown that measurements are feasible at 40 AGeV  $\rightarrow$  energy scan

$\rightarrow$  Anomalous behavior of bulk hadronic observables

# Other Ideas: sequential dissociation



Karsch, Kharzeev, Satz (2006):  
 →  $J/\psi$  can survive up to  $1.5T_c$ ,  
 however and are dissociated just  
 above  $T_c$

→  $J/\psi$  suppression due to  
 sequential dissociation at given  
 energy density

→ energy density from Bjorken  
 formula,  $N_{\text{part}} \rightarrow$  centrality →  
 overlapping surface

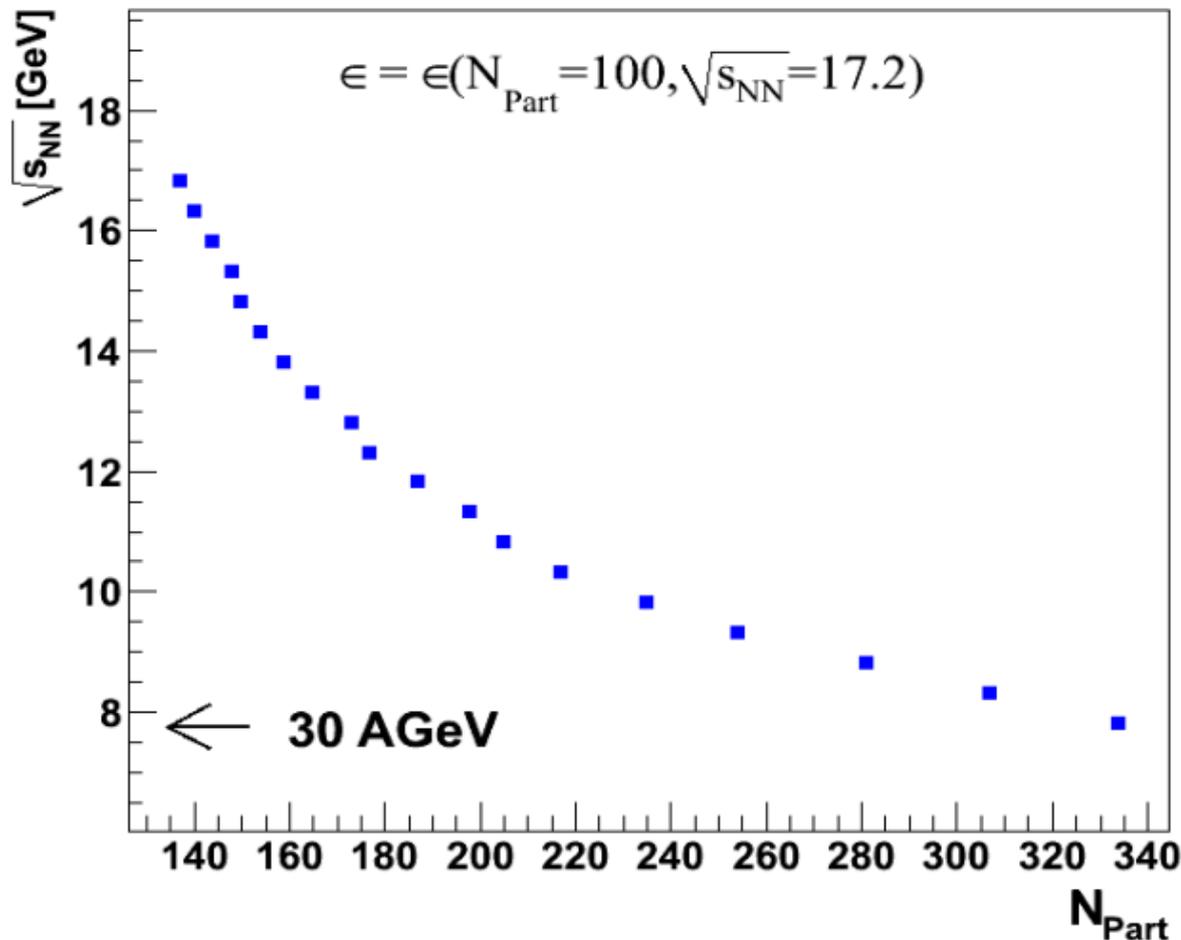
SPS and RHIC data on  $J/\psi$   
 production are re consistent when  
 plotted versus energy density !!!

$$\varepsilon = \frac{3}{2} \times \frac{\langle E_t \rangle}{\pi R^2 \tau_0} \times \frac{dN_{ch}}{d\eta}$$

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**Npart Vs Epsilon**



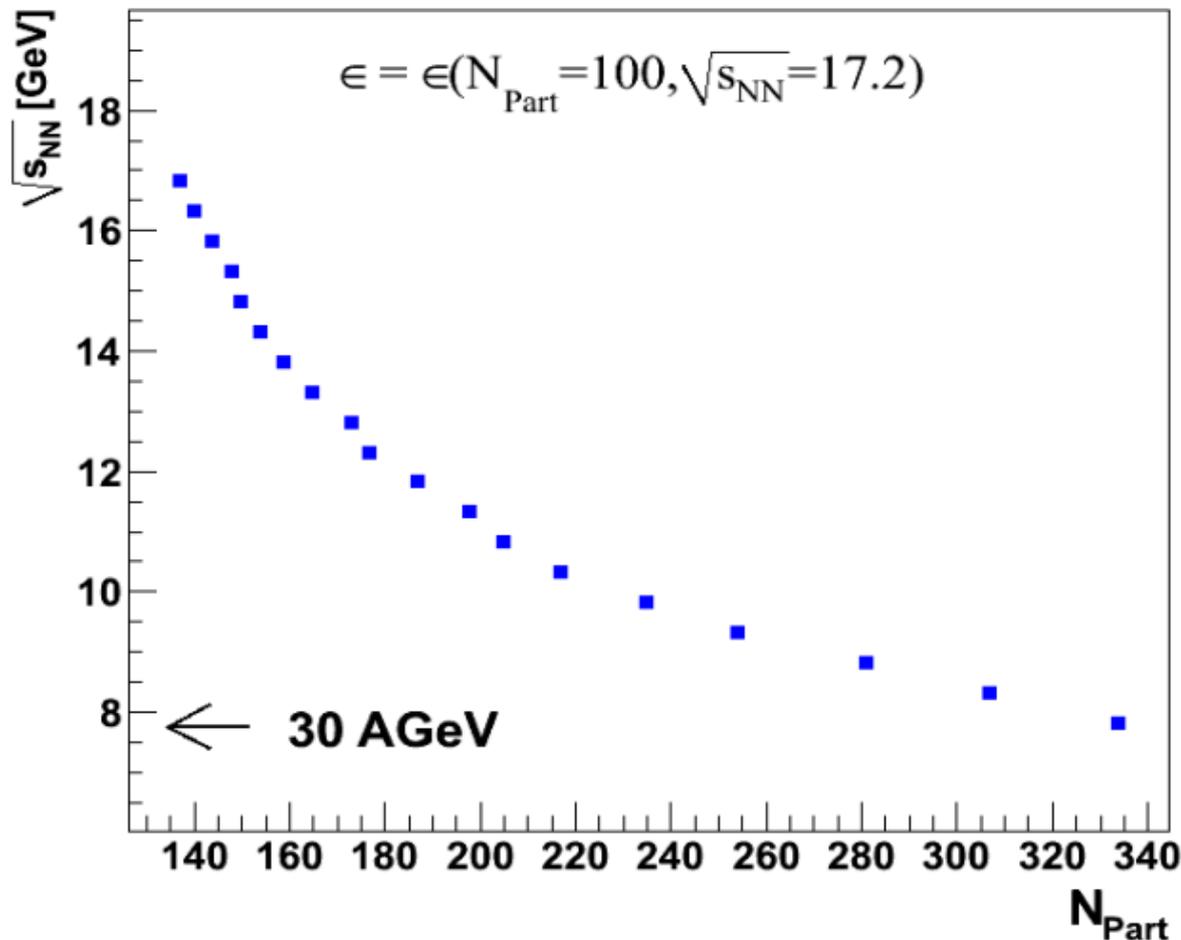
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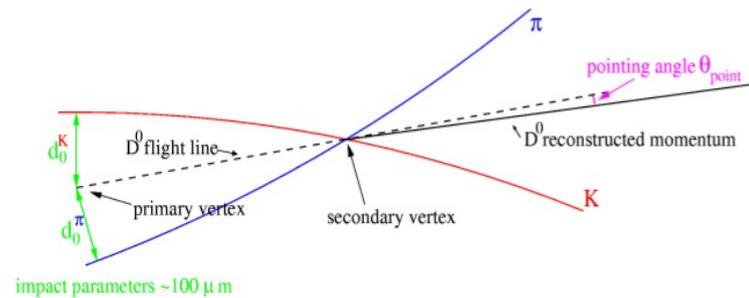


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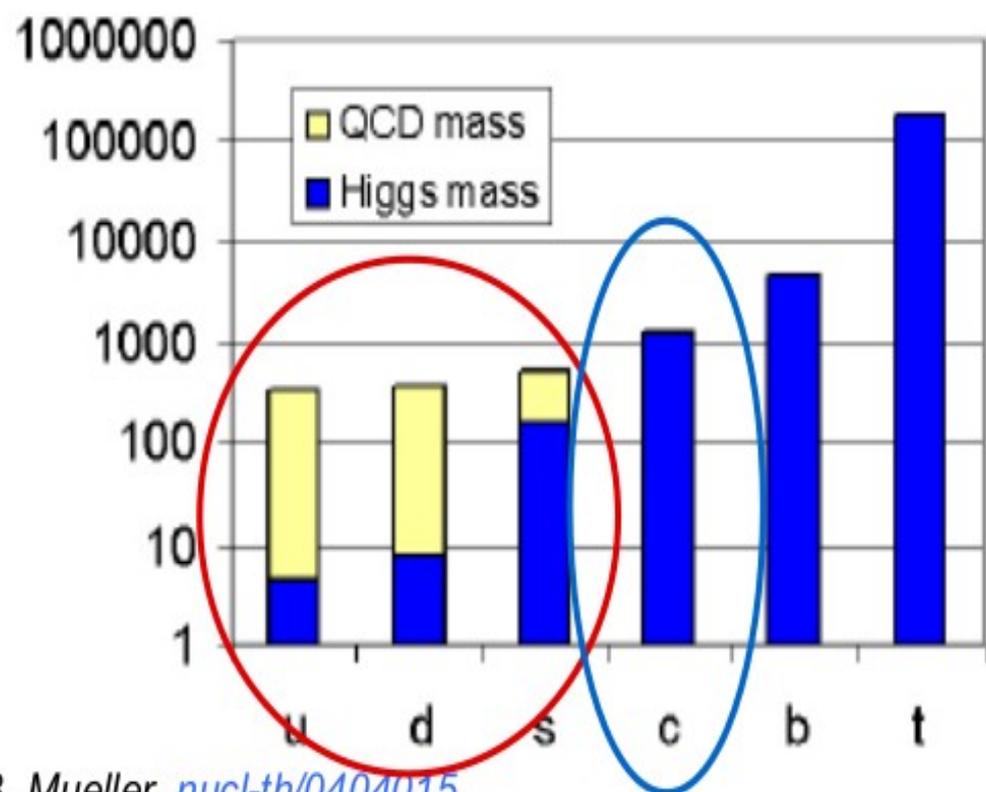
# Detection Strategy

→ *Distance between interaction Point and decay point is measurable*



Meson	Decay Channel	$c\tau$	Branching Ratio
$D^0$	$D^0 \rightarrow K^- + \pi^+$	$122.9\mu\text{m}$	$(3.91 \pm 0.05)\%$
$D^0$	$D^0 \rightarrow K^- + \pi^+ + \pi^+ + \pi^-$	$122.9\mu\text{m}$	$(8.14 \pm 0.20)\%$
$D^+$	$D^+ \rightarrow K^- + \pi^+ + \pi^+$	$311.8\mu\text{m}$	$(9.2 \pm 0.25)\%$
$D_s^+$	$D_s^+ \rightarrow K^+ + K^- \pi^+$	$149.9\mu\text{m}$	$(5.50 \pm 0.28)\%$
$D^{*+}$	$D^{*+} \rightarrow D^0 + \pi^+$	-----	$(61.9 \pm 2.9)\%$

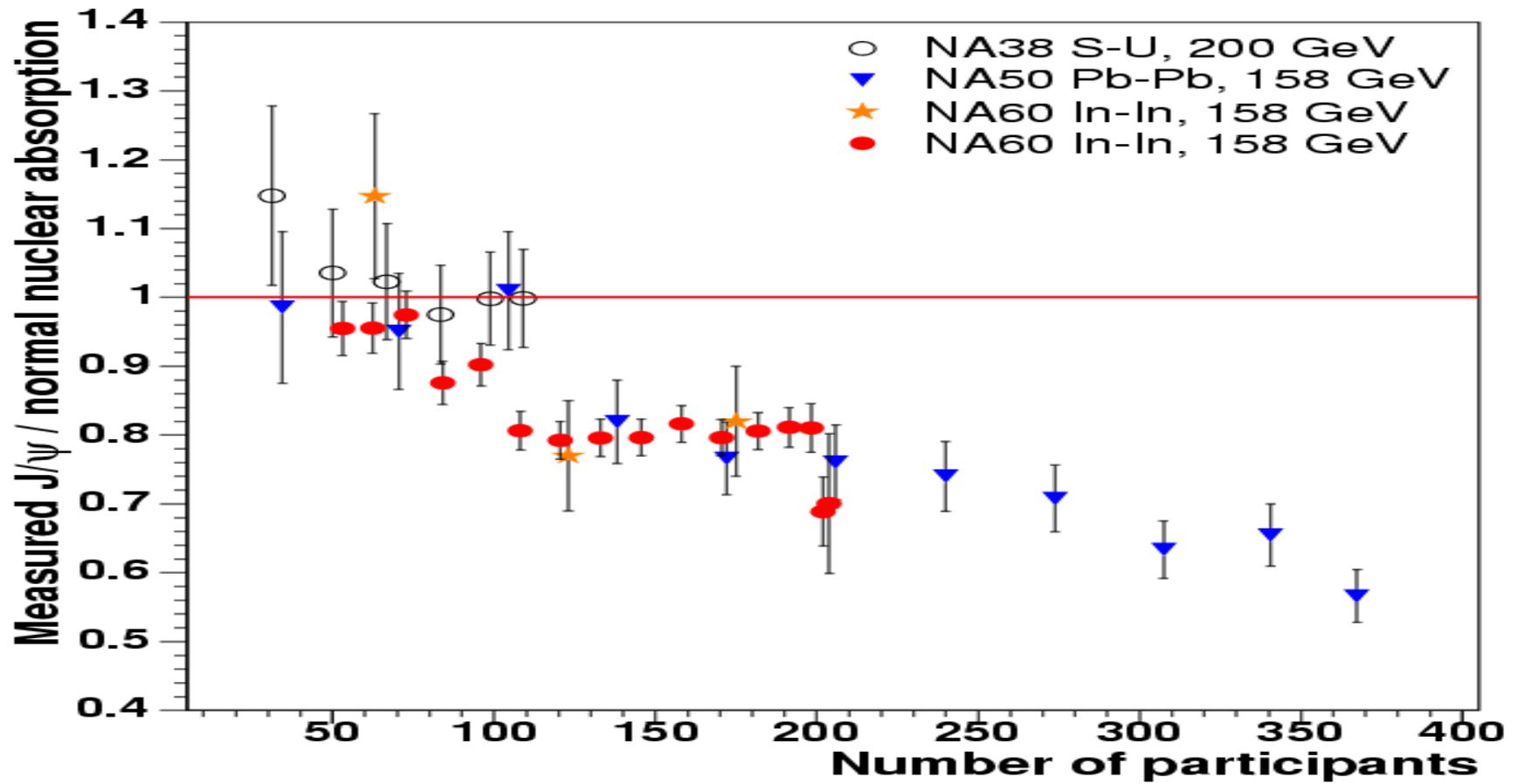
# Why Charm? – an ideal probe for studying QGP



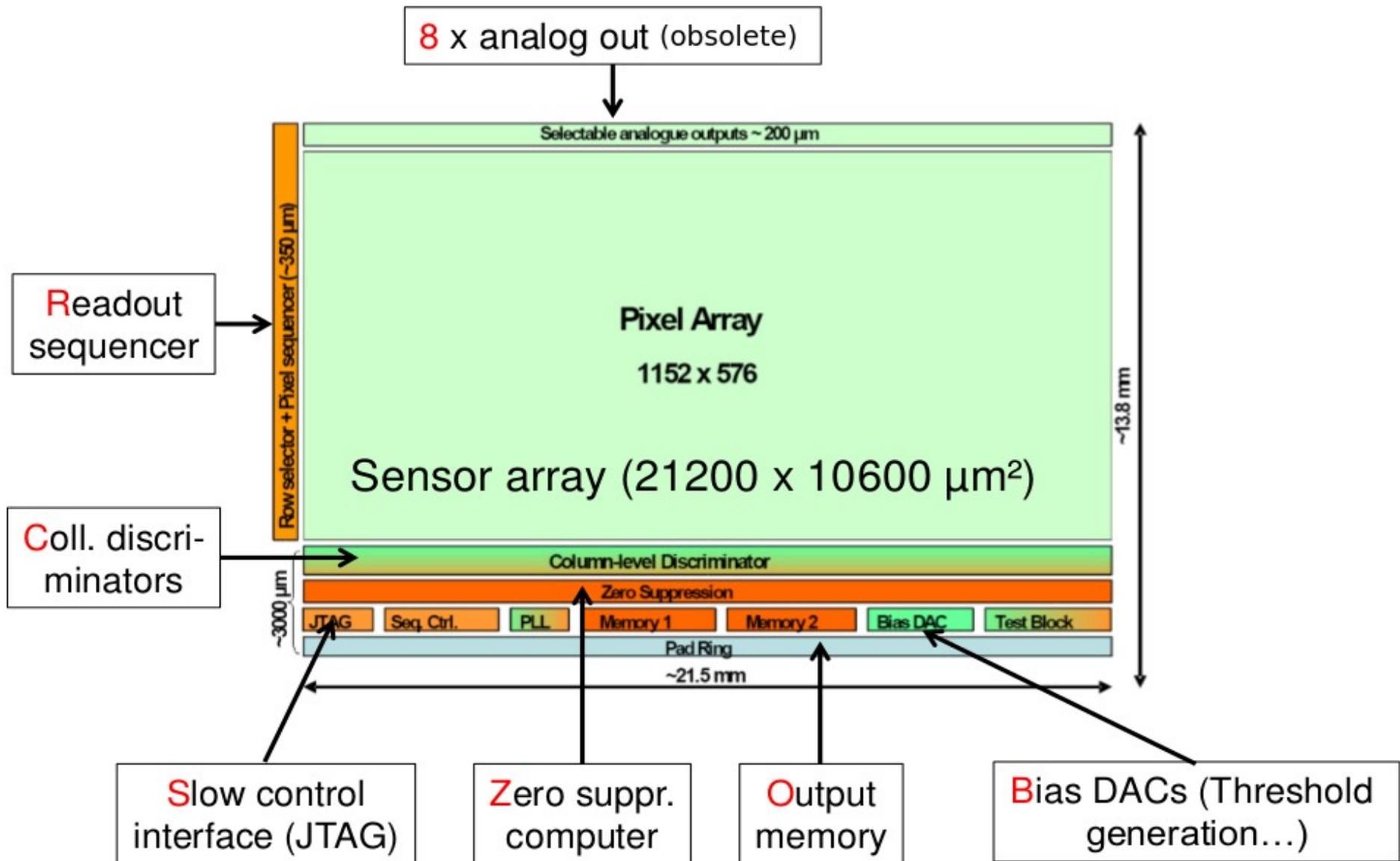
B. Mueller, [nucl-th/0404015](https://arxiv.org/abs/nucl-th/0404015)

## *Heavy !*

- Charm quarks created at early stage of HIC
  - total yields scaled by  $N_{\text{bin}}$
- Sensitive to the partonic rescatterings
- Collectivity, flow
  - indication of light flavor thermalization (to some degree)

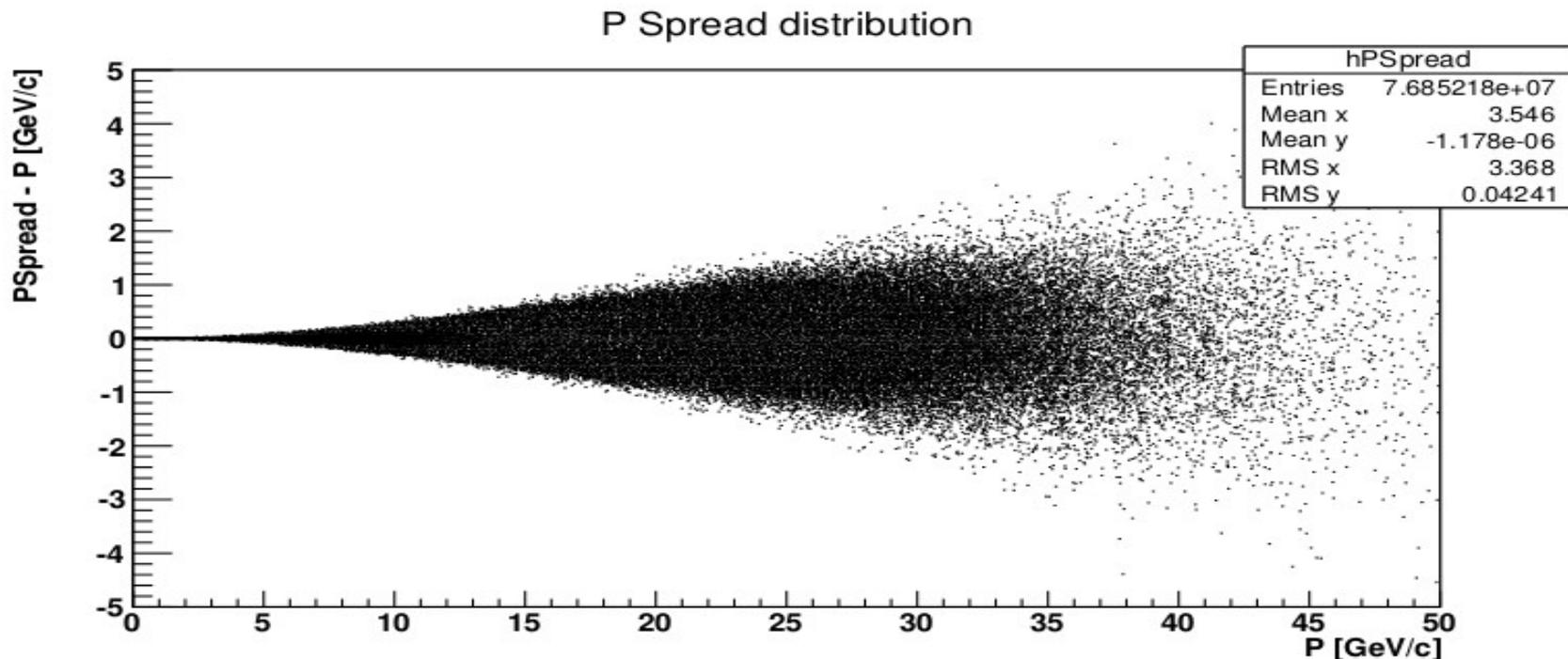


# Block diagram of MIMOSA-26

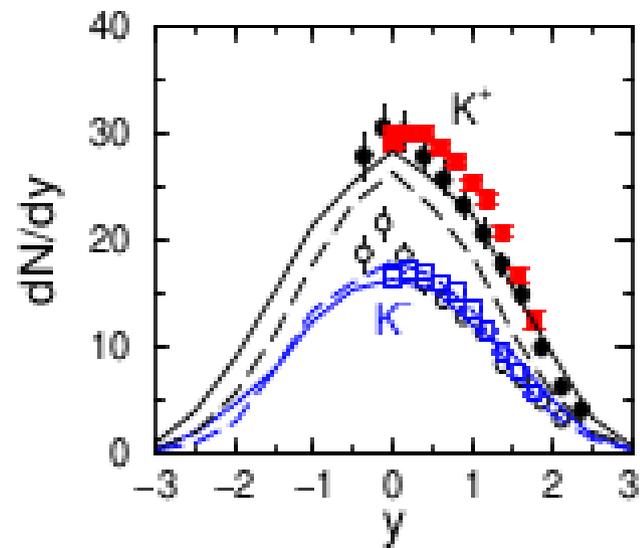
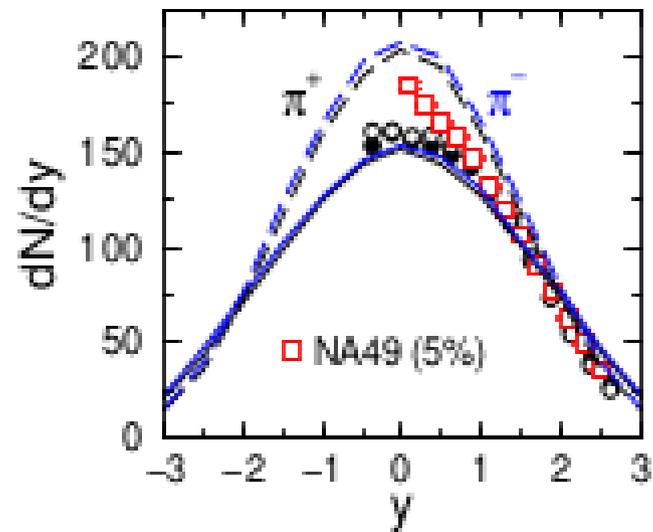
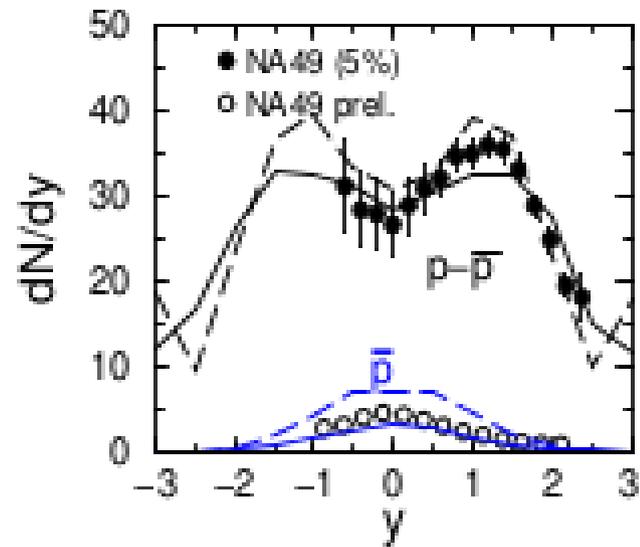
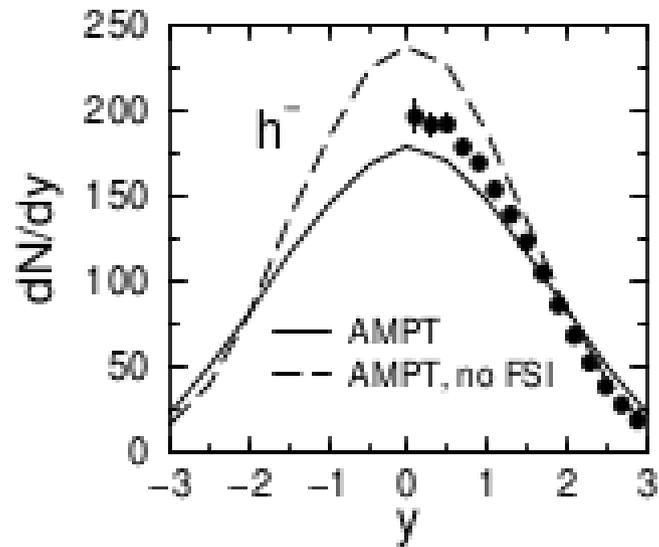


# Reconstruction

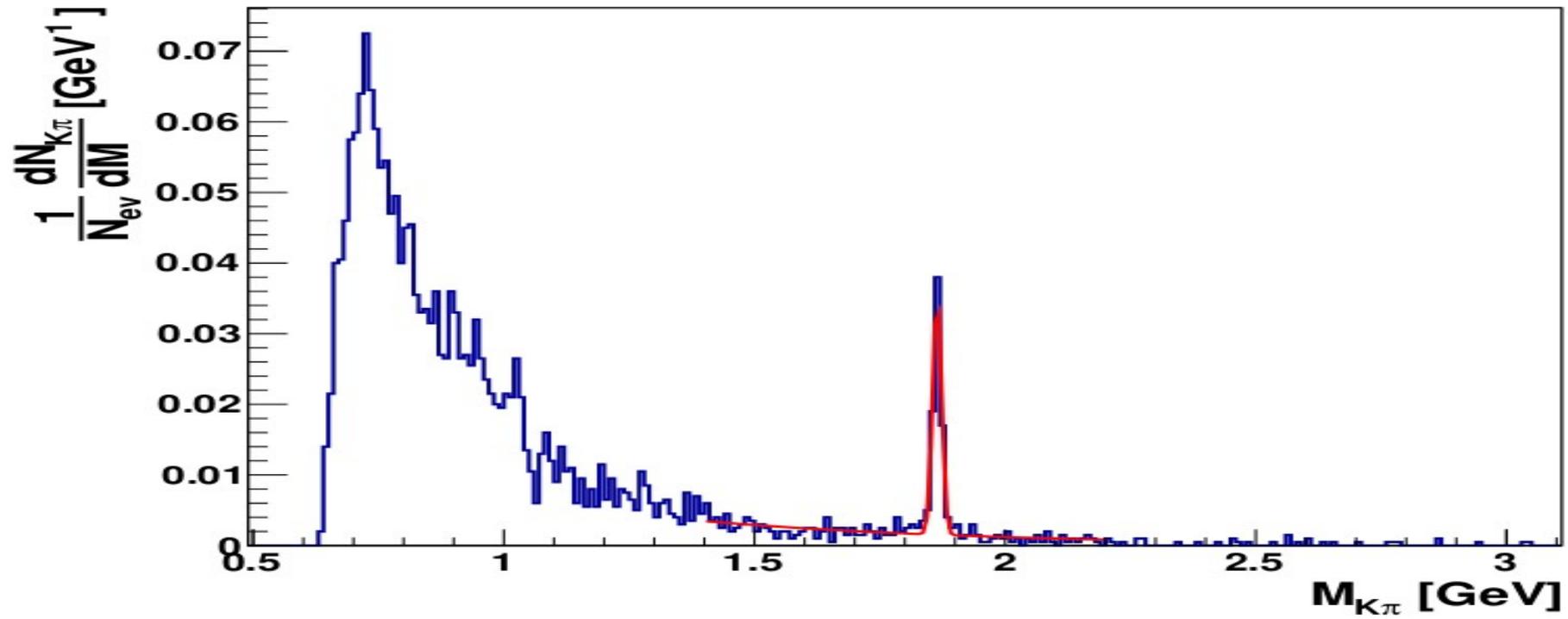
- Track distance in VTPC1 + VTPC2 > 1m
- Require hit at least in the three Vertex detector stations
- NA61/SHINE Momentum resolutions is assumed
  1. momentum resolution  $dp/p^2 = 7.0 \times 10^{-4}(\text{GeV}/c)^{-1}$  ([Nuclear Instruments and Methods in Physics Research A 430 \(1999\) 210 - 244](#))
  2. position resolution is  $10 \mu\text{m}$  → hits are spread in y and x around geant hit according to the Gaussian distribution ( $\sigma = 10 \mu\text{m}$ ). Track line is taken from the fit to the spread points



# AMPT-MODEL



# Reconstructed yield for $D^0 \rightarrow K^+ \pi^-$ , 200k 0-10% cent. Pb+Pb at 158 AGeV

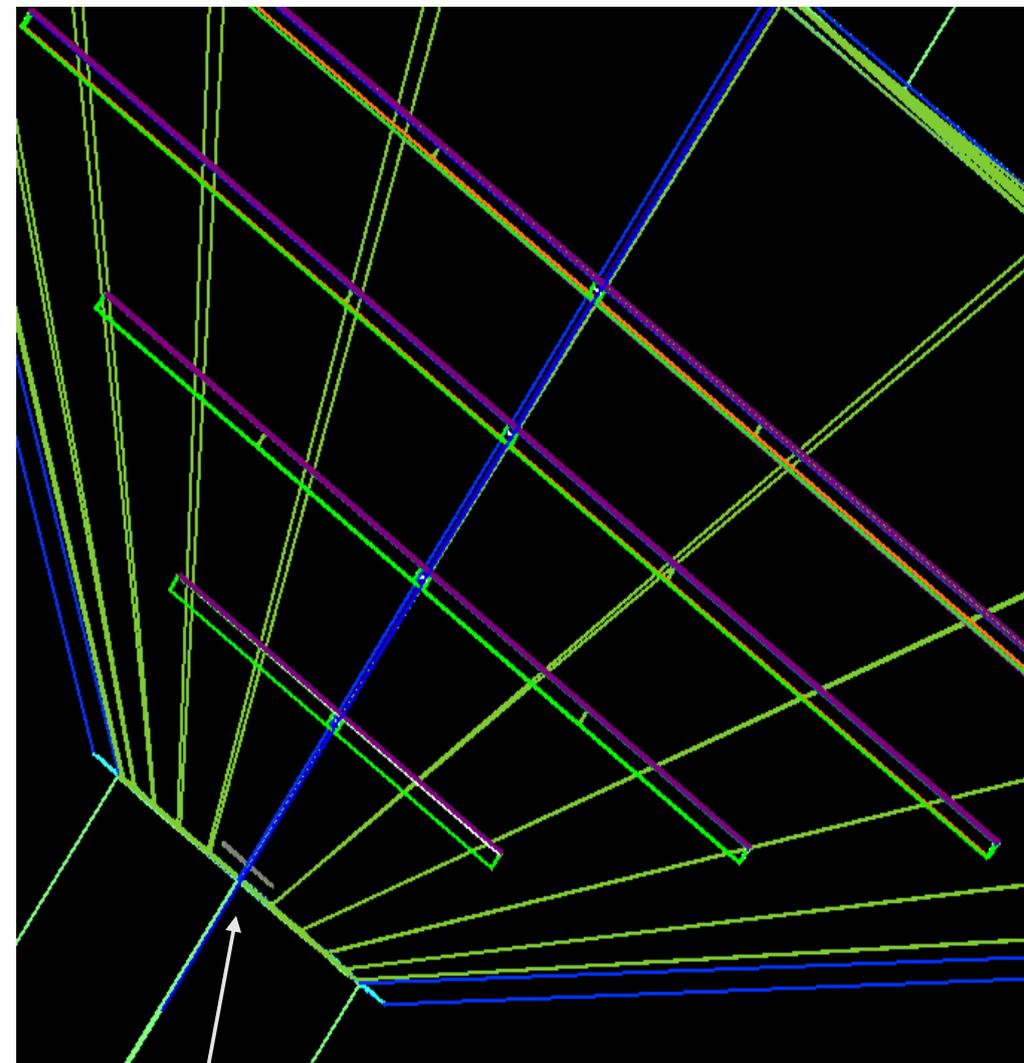
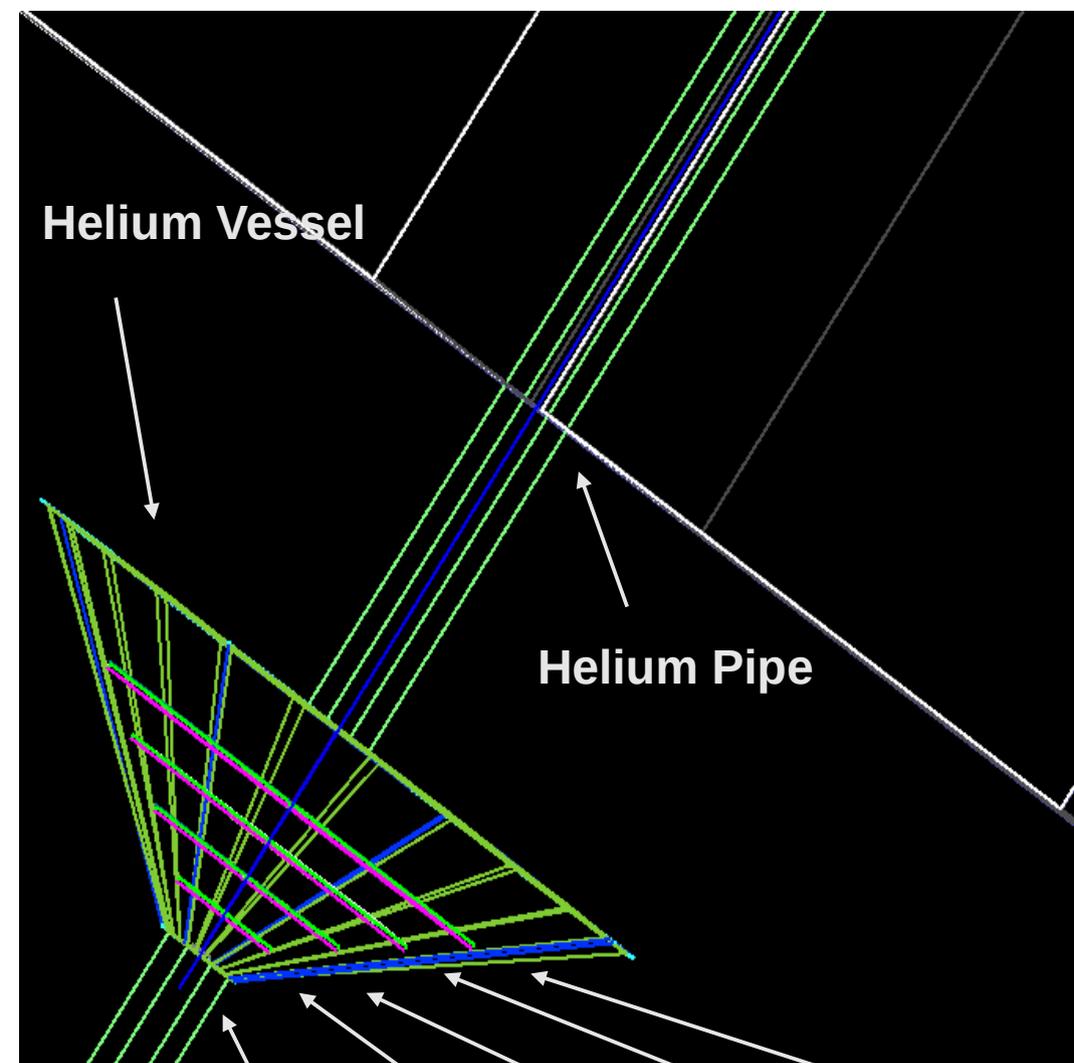


Pos. Res ( $\mu\text{m}$ )	10	10	15	15
Beam hole(mm)	2.5	3.0	2.5	3.0
$S/B$	9.6	10.0	4.5	6.5
Signal Significance (SNR) ★	209.6	199.4	175.4	174
$\langle D^0 \rangle + \langle \bar{D}^0 \rangle$ ★	48K	43K	37K	36K

★ Results Extrapolated to 50M Events

# Design of the Future Vertex Detector

Zoom in



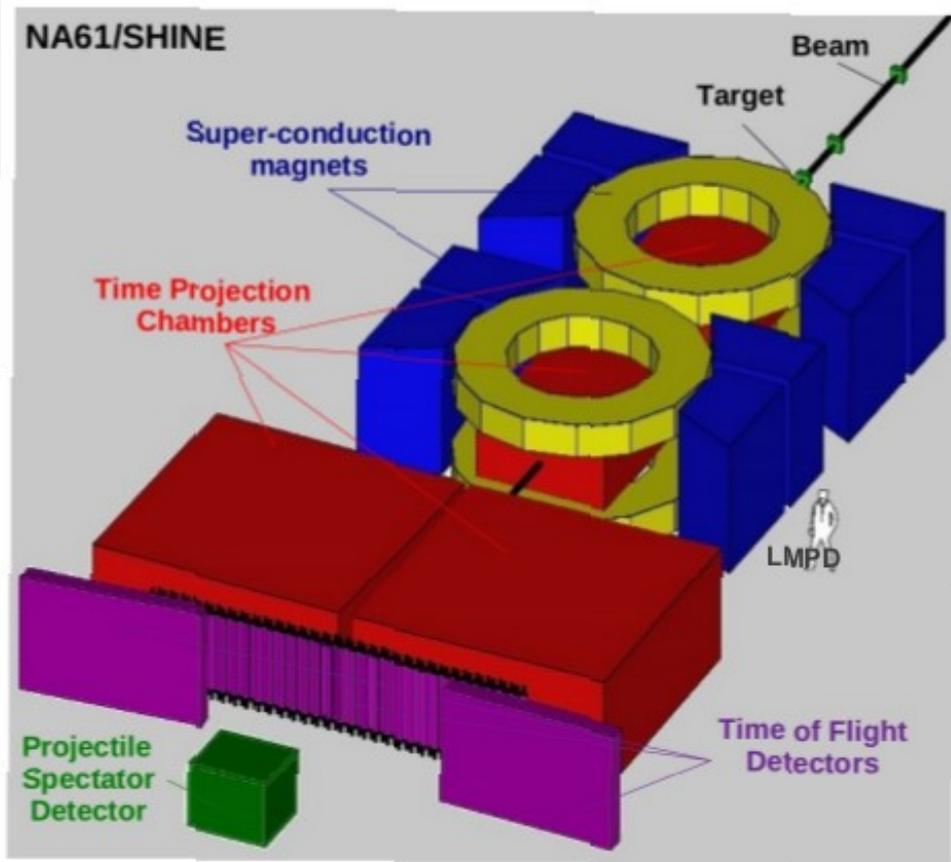
VDS1 VDS2 VDS3 VDS4

Pb target

beam pipe

VDS Stations are located at the distance of 5, 10, 15 and 20 cm respectively from the Target

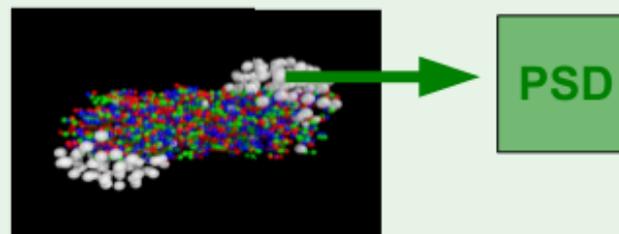
# NA61/SHINE detector



- Large acceptance:  $\approx 50\%$
- High momentum resolution:  
 $\sigma(p)/p^2 \approx 10^{-4}(\text{GeV}/c)^{-1}$  (at full  $B=9 \text{ T}\cdot\text{m}$ )
- ToF walls resolution:  
ToF-L/R:  $\sigma(t) \approx 60 \text{ ps}$ ; ToF-F:  $\sigma(t) \approx 120 \text{ ps}$
- Good particle identification:  
 $\sigma(dE/dx)/\langle dE/dx \rangle \approx 0.04$ ;  $\sigma(m_{inv}) \approx 5 \text{ MeV}$
- High detector efficiency:  $> 95\%$
- Event rate: 70 events/sec

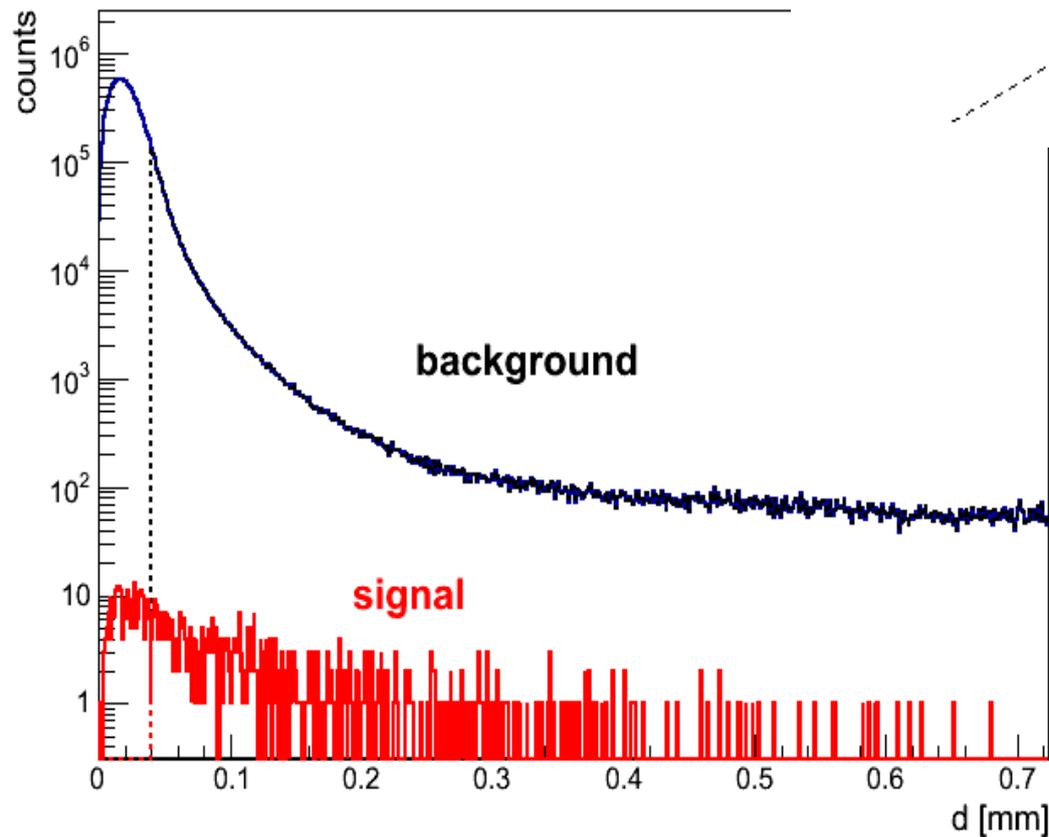
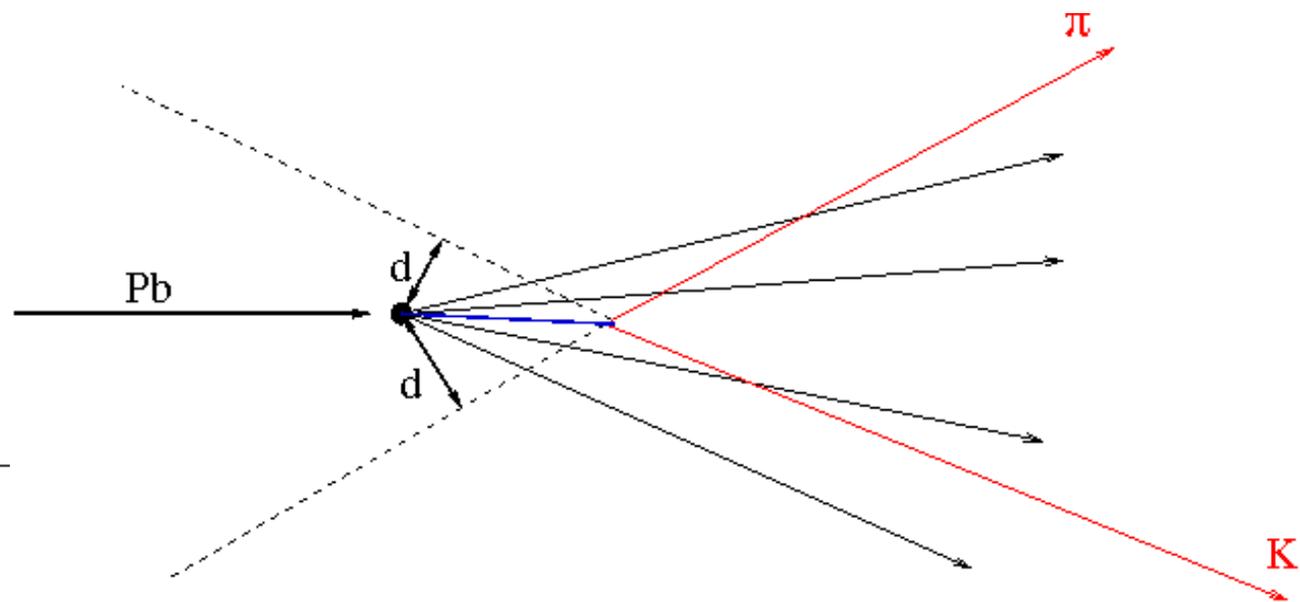
- Four large volume **Time Projection Chambers (TPCs)**: VTPC-1, VTPC-2 (inside superconducting magnets), MTPC-L, MTPC-R; measurement of  $dE/dx$  and  $p$ . **Time of Flight (ToF)** detector walls.

- **Projectile Spectator Detector (PSD)** for centrality measurement (energy of projectile spectators) and determination of reaction plane; **resolution of 1 nucleon (!)** in the studied energy range (important for fluctuation analysis).



- **Helium beam pipes** inside VTPC-1 and VTPC-2 (to reduce  $\delta$ -electrons).
- **Z-detector** (measures ion charge for on-line selection of secondary ions, **A-detector** (measures mass composition of secondary ion beam).
- Low Momentum Particle Detector (**LMPD**) for centrality determination in  $p+A$ ; measures target nucleus spectators.

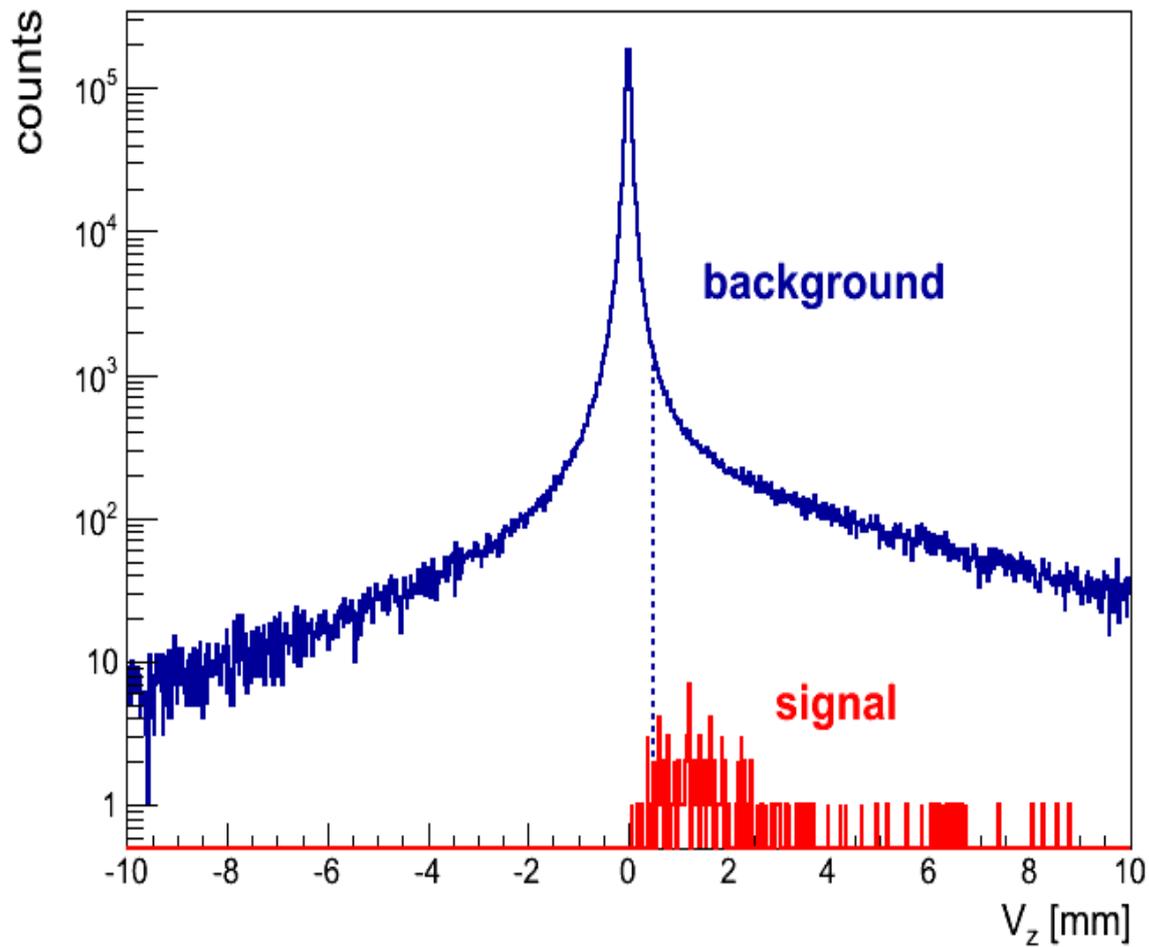
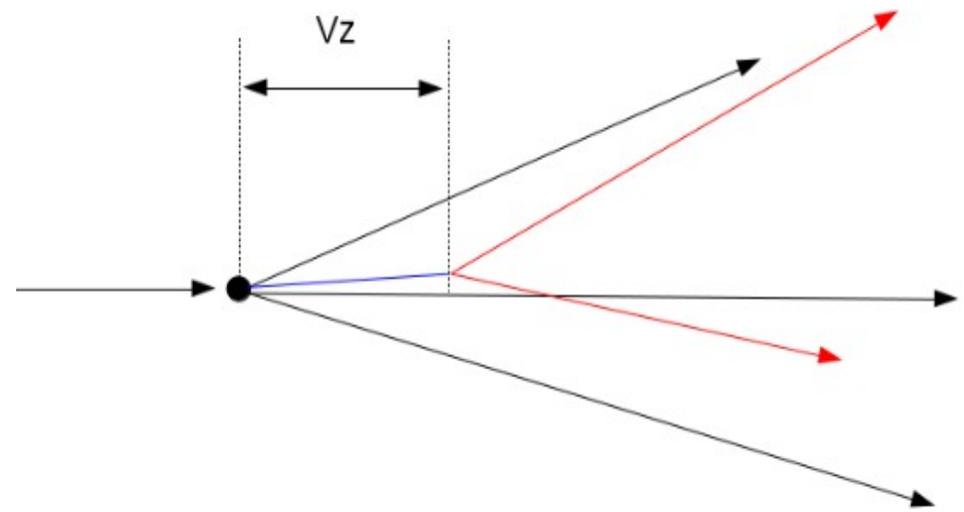
## 2. Cut on d



Relatively smooth shape of background at  $\sim 0$  is due to uncertainty in reconstruction of track position and angle. Some uncertainty comes from multiple scattering.

→ cut on  $d < 40 \mu\text{m}$  as indicated

# 4. cut on $V_z$



→ cut on  $V_z < 500 \mu\text{m}$  as require

## Parameters for 40 AGeV

40 AGeV energy the whole phase space (physical input) was

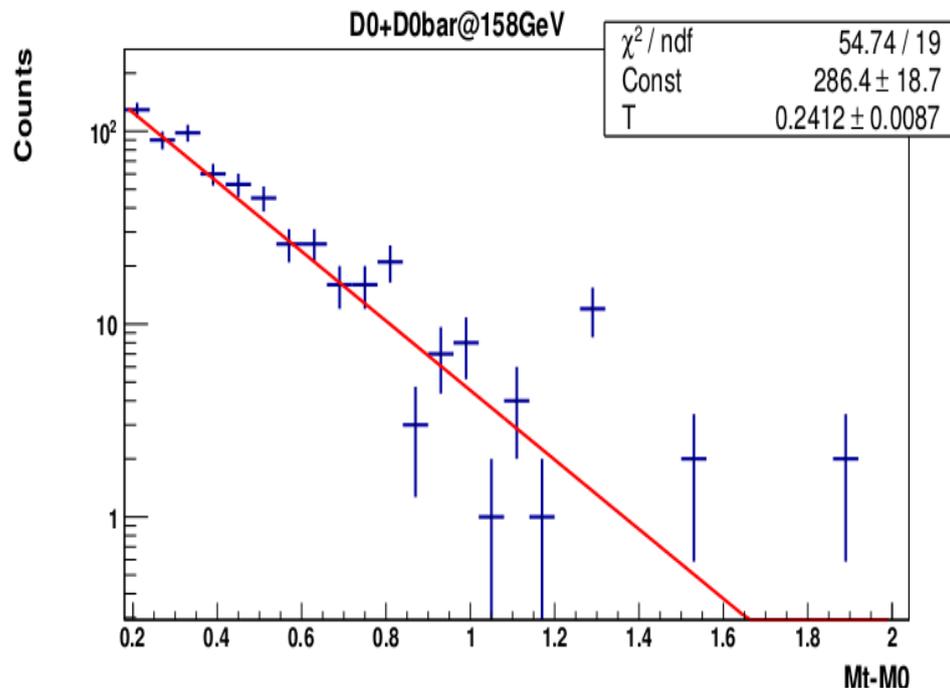
not available by AMPT even

rapidity distributions for kaons at both energies 40 and 158

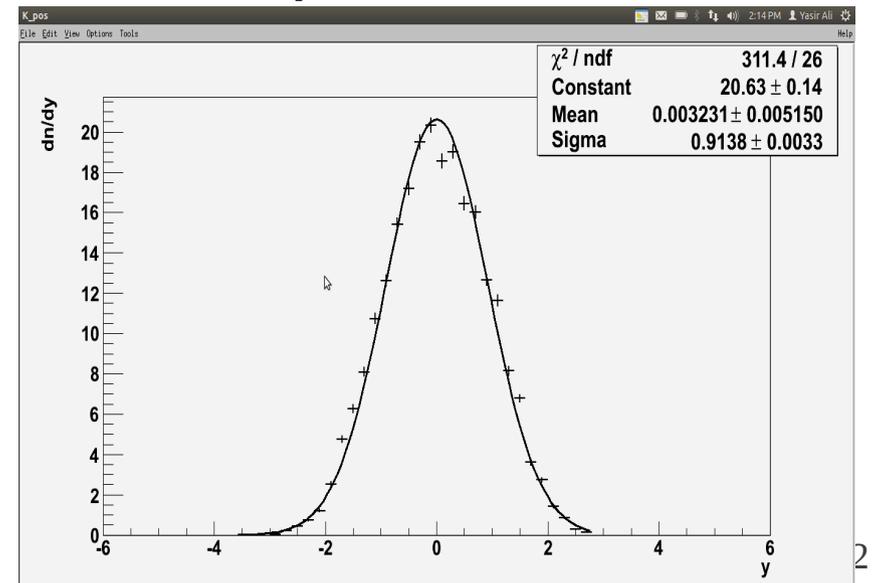
AGeV and for D0 meson at 158

$$R_D(40) = \text{Sigma D}(158)/\text{Sigma D}(40)$$

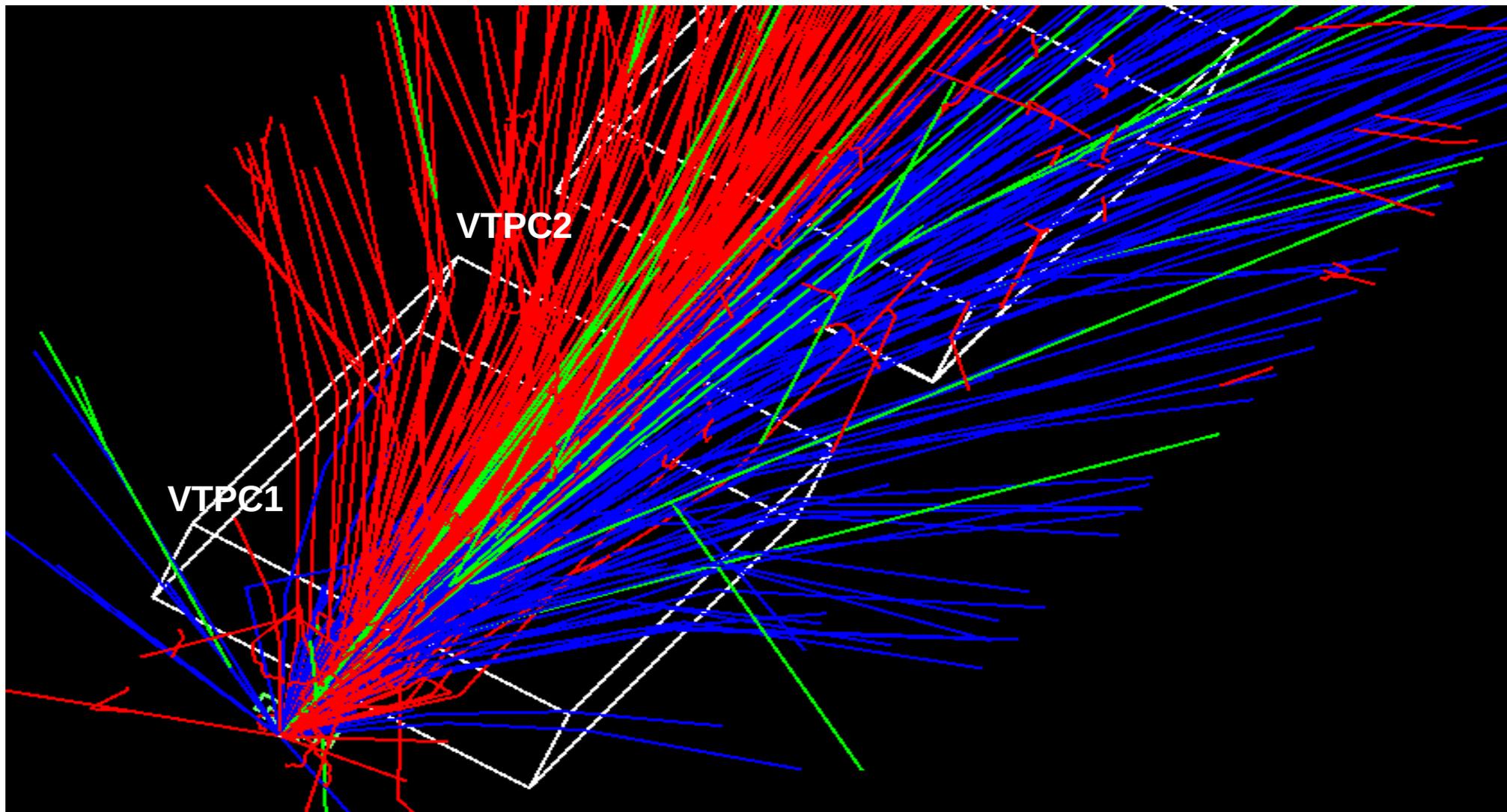
transverse mass distributions By Fitting  
Exponential Function  $A \text{Exp}(-m_T/T)$



## Kplus @ 40 AGeV

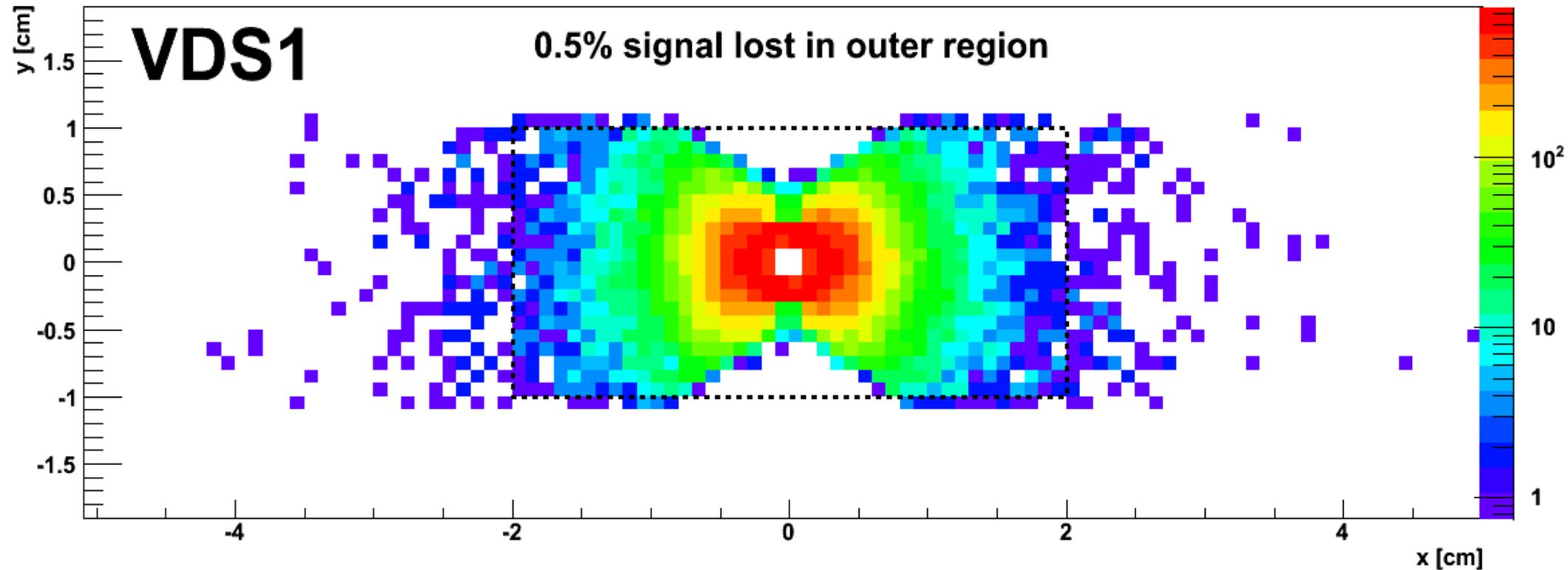


## Detector overview in GEANT simulation



- VTPCs filled with Ar-CO<sub>2</sub> mixture, location and dimensions as in Na61 setup.
- Uniform magnetic field: 1.5 T in VTPC1 and 1.1 T in VTPC2

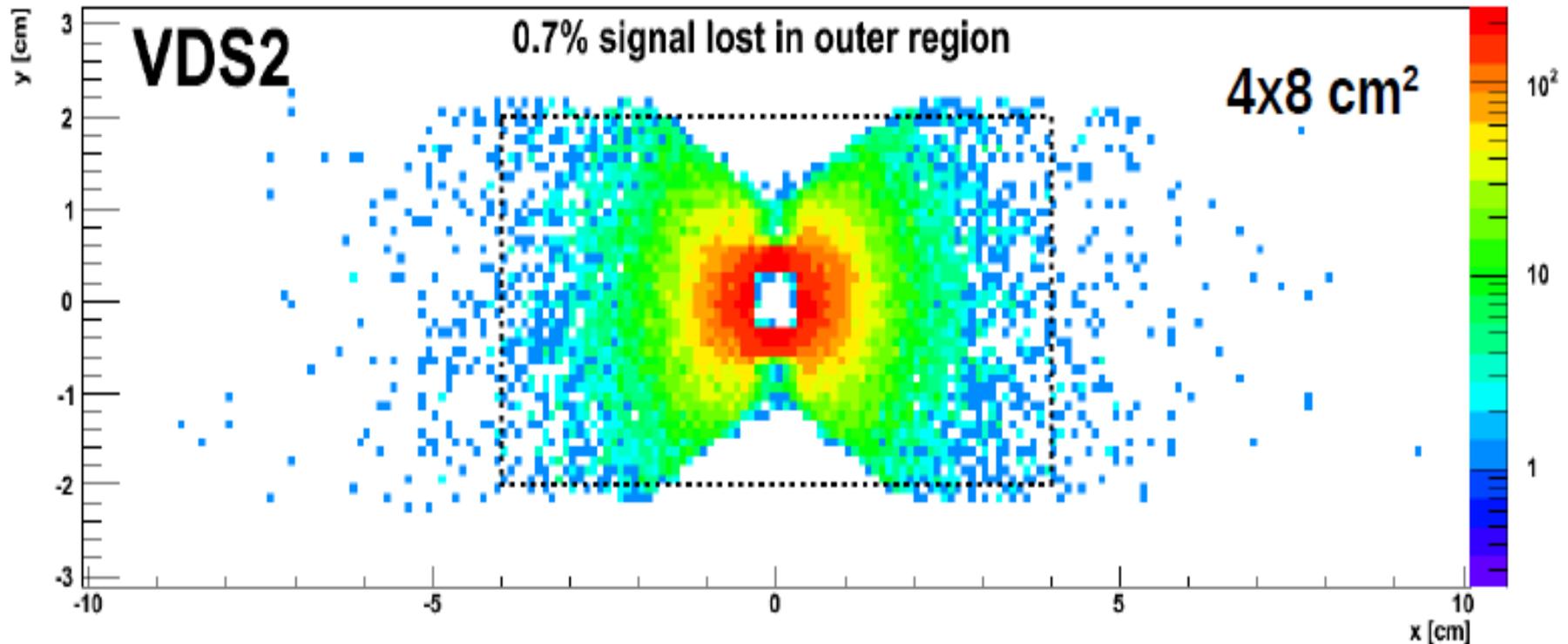
# Signal track distribution at 158 AGeV in VDS1



The figure shows hits (x,y) distribution generated by signal tracks in Vds1. The dashed boxes represent the cuts. We found that  $\sim 99.5\%$  of signal tracks is localized within the box  $2 \times 4 \text{ cm}^2$

As we can see, to cover the remaining 0.5% we would need to extend the cut in the x direction for almost factor of 2.

## Signal track distribution at 158 AGeV in VDS2

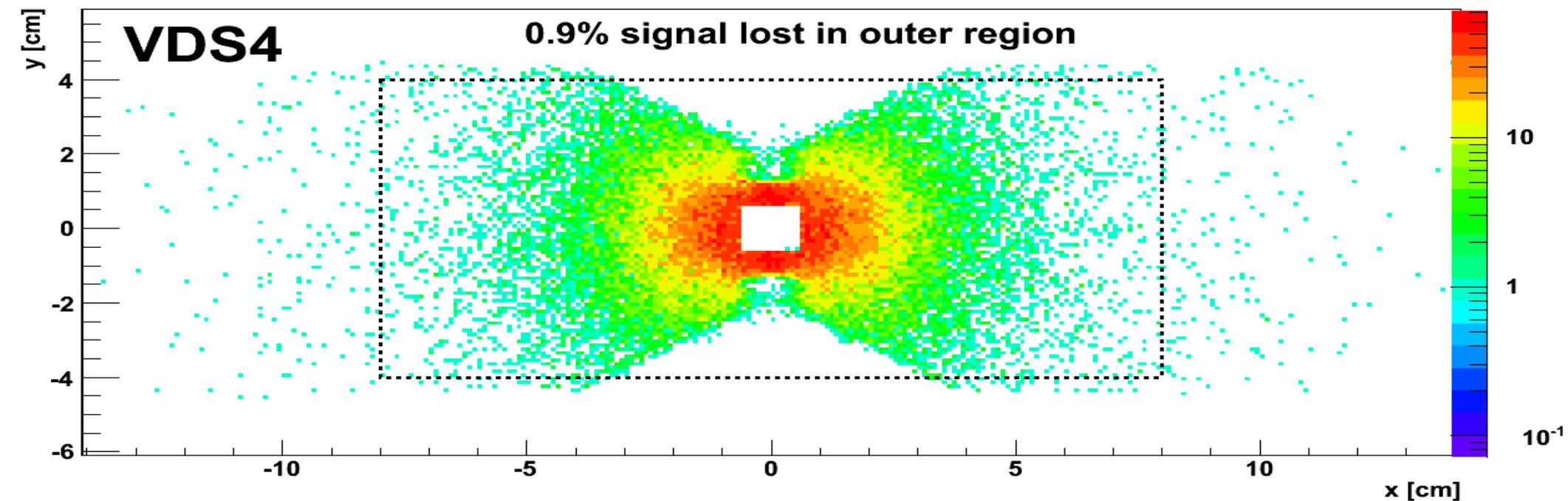
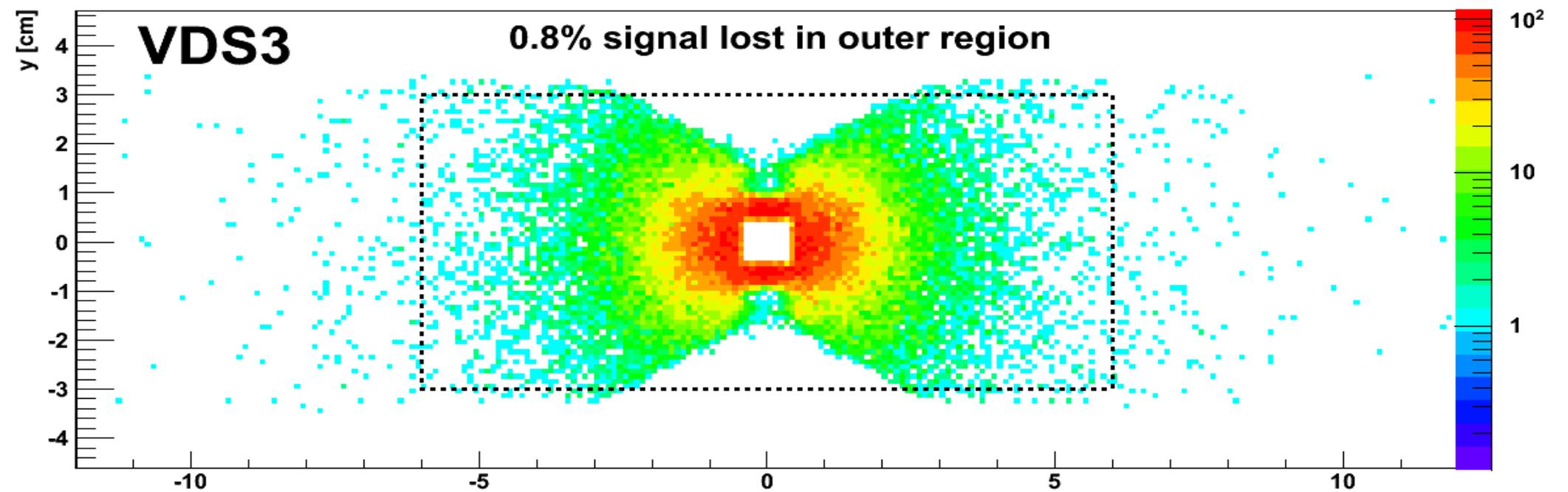


For stations Vds2-Vds4 we just extend size of the boxes in proportion to their distance from the target. So we got dimensions: 4x8 cm<sup>2</sup>, 6x12 cm<sup>2</sup> and 8x16 cm<sup>2</sup>

For Vds2, Vds3 and Vds4, respectively. The signal lost is kept below 1 % for each station.

For Pb+Pb at 40 AGeV the signal lost is on the level of 4% for the same cuts.

# Signal track distribution at 158 AGeV in VDS3 and VDS4



## Background suppression strategy (Need to discuss)

List of cuts in the order they are applied

### Single particle cuts:

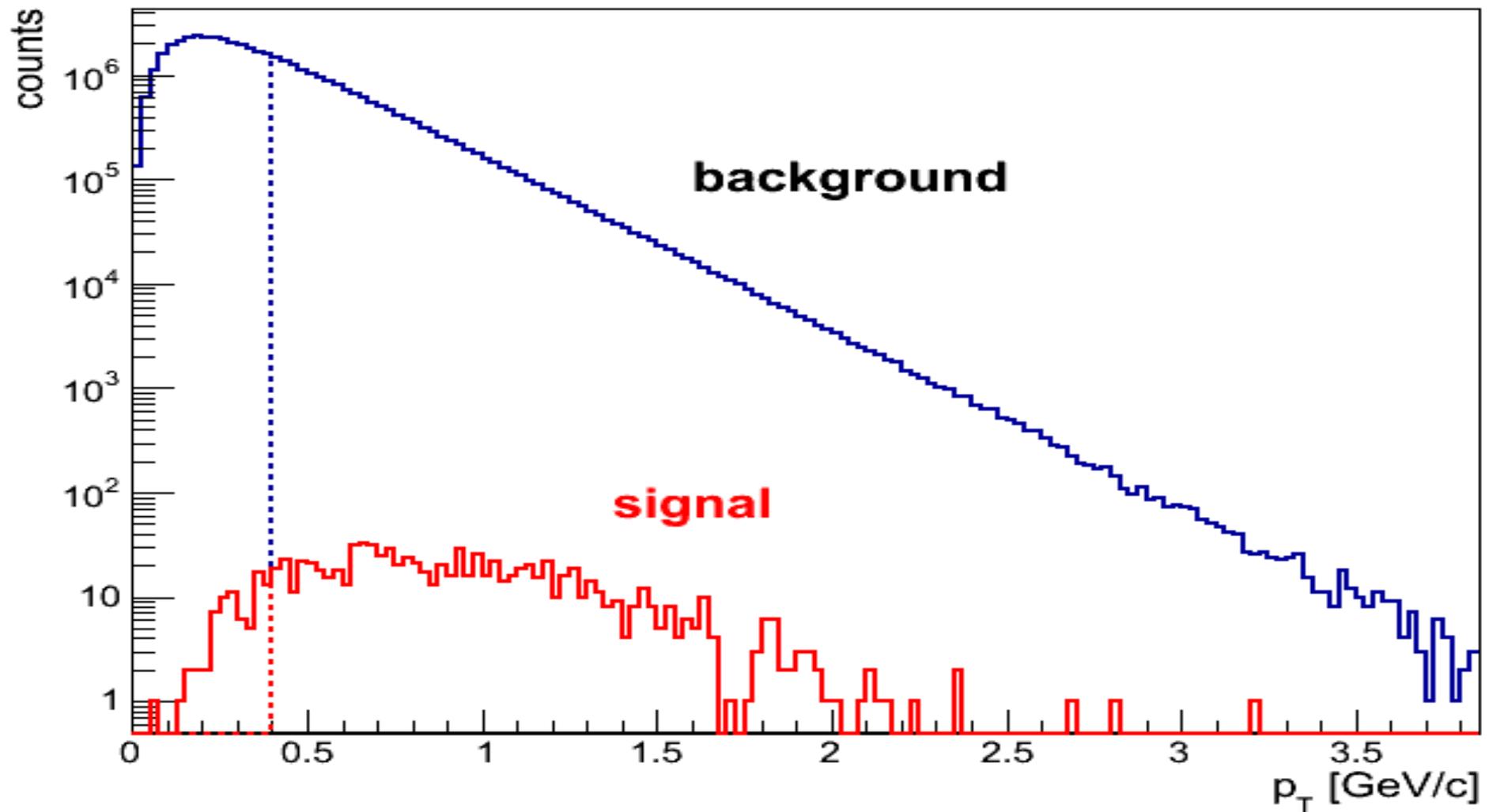
1. track  $p_T$  cut
2. track  $d$  cut (track impact parameter)

### Two particle cuts:

3. cuts in Armenteros-Podolanski space to remove background from Ks and  $\Lambda$
4. two track vertex cut  $V_z$
5. reconstructed parent impact parameter cut  $D$

The average multiplicity for 158 AGeV is  $0.01 * 1/0.0378 = 0.26$  (consistent with HSD)  
for 40 AGeV it is 0.01

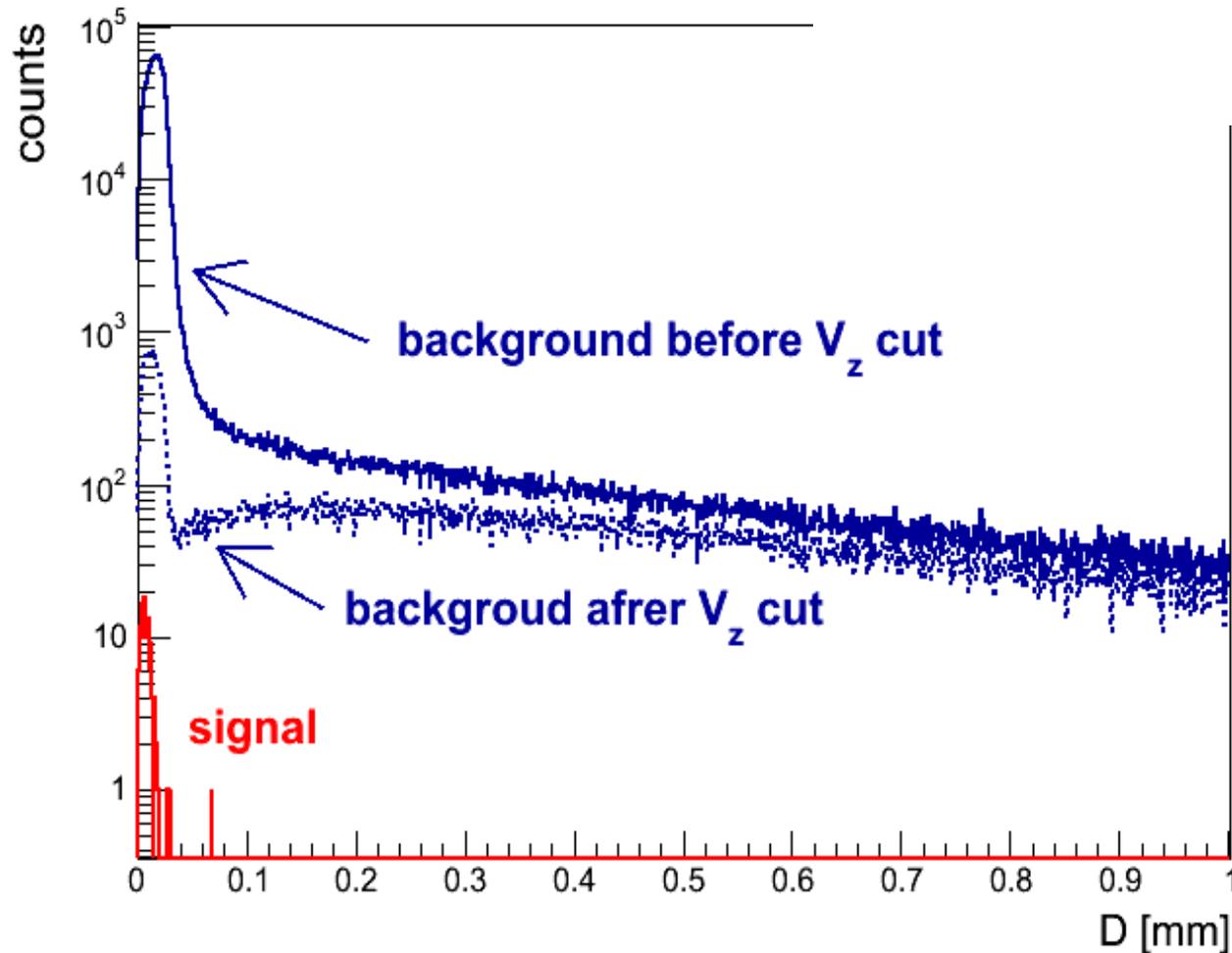
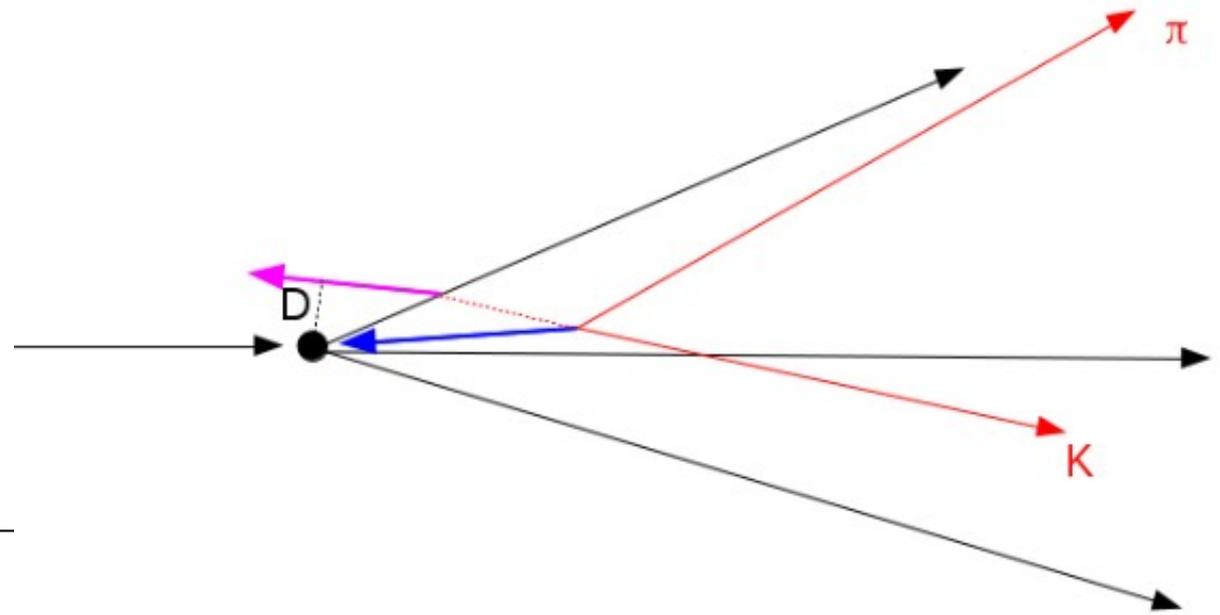
# 1. cut on $p_T$



Background  $p_T$  spectrum has maximum around  $\sim 0.2 \text{ GeV}/c$ , whereas maximum of signal distribution is at around 1  $\text{GeV}/c$

→ cut on  $p_T < 0.4$  as indicated

### 3. cut on **D**



$V_z$  cut reduces background at  $D \sim 0$ , where the signal is located  $\rightarrow V_z$  and  $D$  cuts are nicely complementary to each other

$\rightarrow$  cut on  $D > 0.022$  mm

# Charged Particle Fluxes

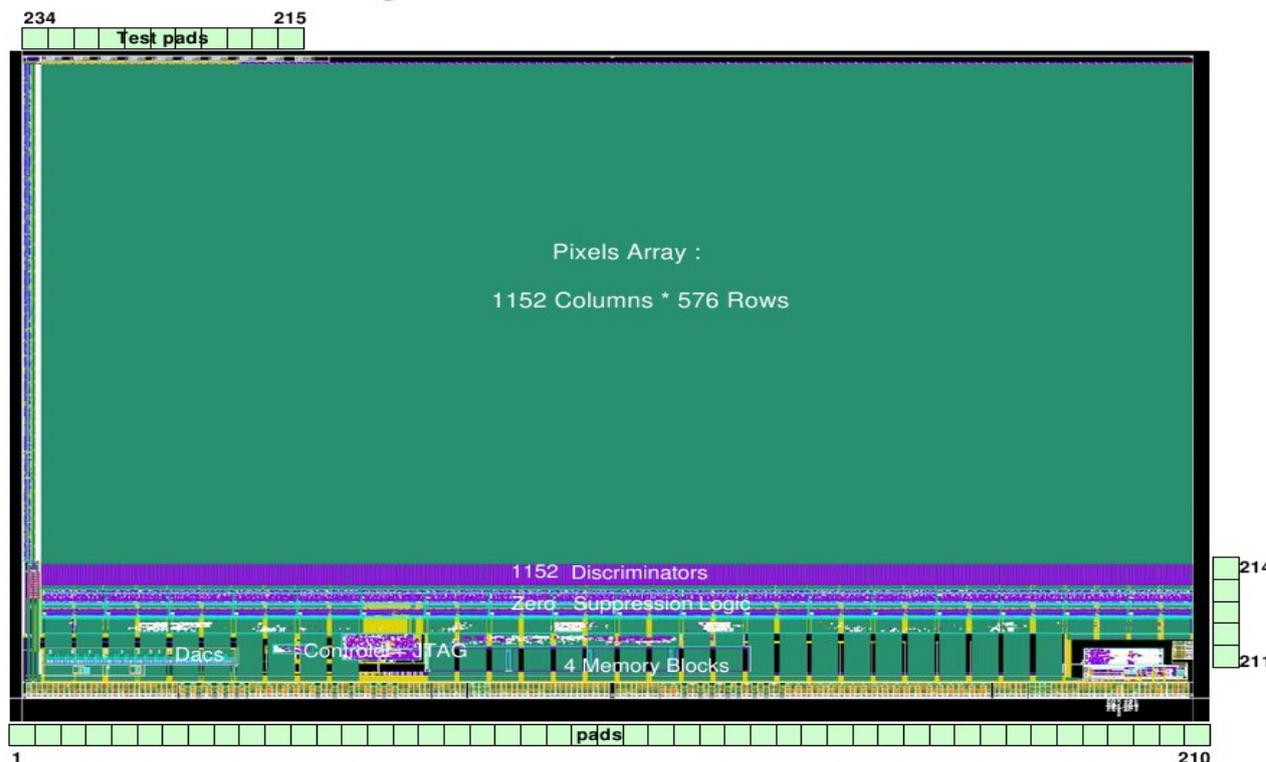
## Sources of particles hitting VD:

1. Charged particles produced in Pb+Pb interactions.
    - during spill the anticipated beam intensity is 10<sup>5</sup> Pb ions per second.
    - for 200  $\mu\text{m}$  Pb target interaction probability is 0.5% which leads to 500 Hz interaction rate
    - used AMPT to generate 100k min. bias Pb+Pb at 158 AGeV
  2. Delta electrons produced mostly in target
    - study 10k Pb ions passing through the lead target
    - soft particles – surrounding material might be important
    - production threshold cut in geant4: minimum distance that produced particle will travel in a given material  $\rightarrow$  translates to cut on energy
      - If the distance is (too) small** – a lot of soft particles is produced (CPU consumption)
      - If the distance is (too) large** – important component might not be described
- $\rightarrow$  the influence of the production threshold cut has to be studied

# MIMOSA-26

▫ The following conceptual drawings are based on MIMOSA-26 chip hosting sensitive area of about  $1.06 \times 2.12 \text{ cm}^2$  with the pixel pitch equal  $18.4 \mu\text{m}$  ( $\sim 663.5\text{k}$  pixels/chip):

## 4.1 MIMOSA26 Pad Ring and Floor Plan View



These pads are for testing purpose and can be removed

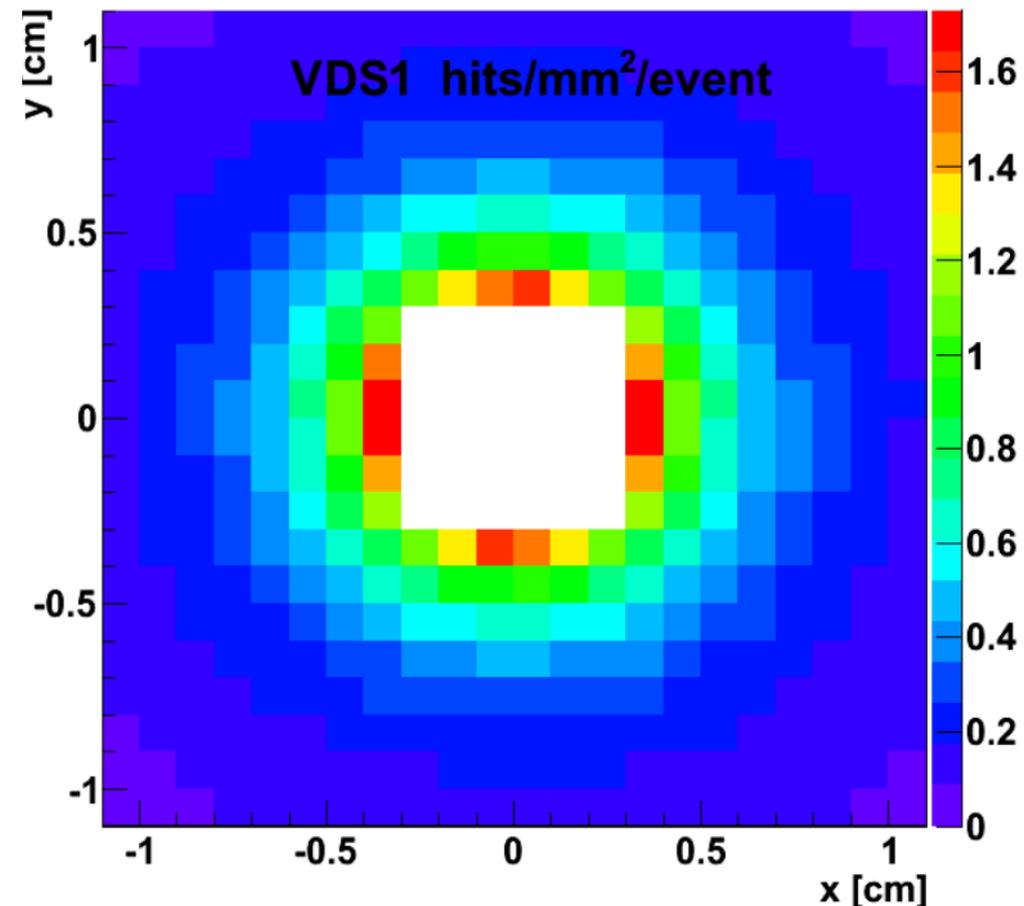
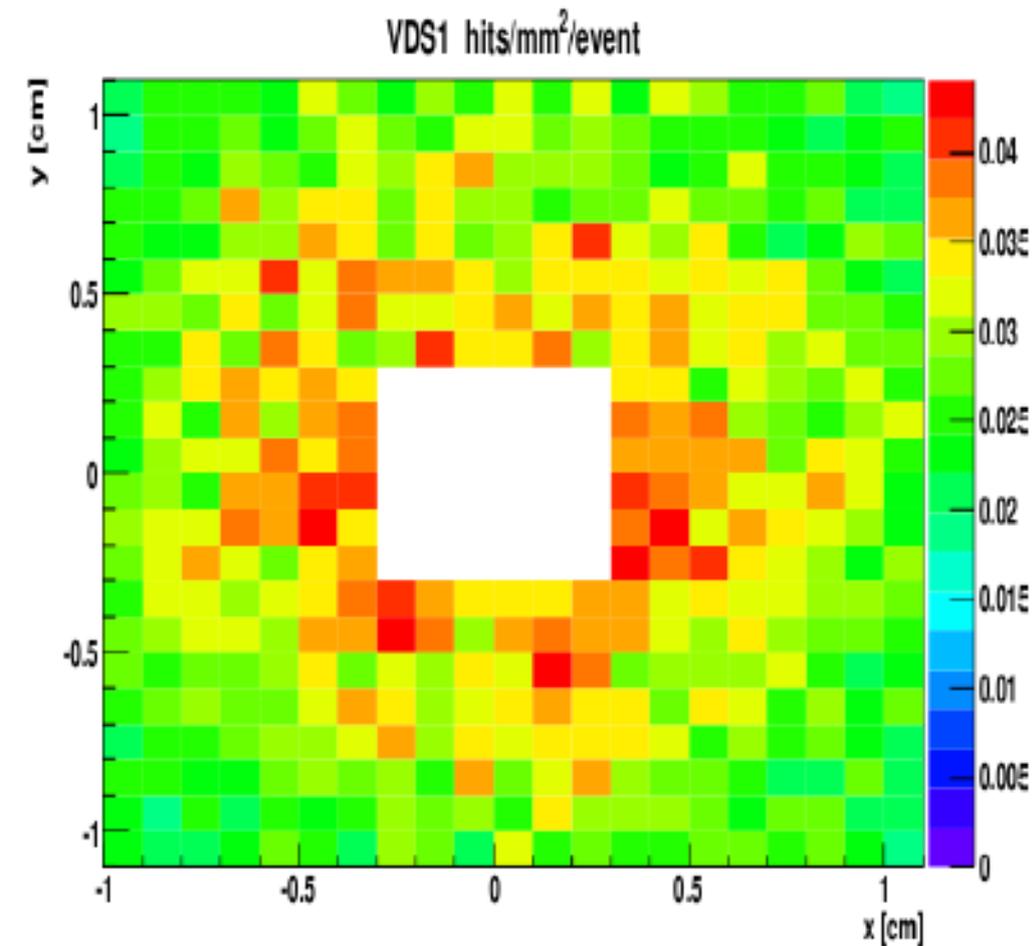
▫ The readout speed of the whole fame in  $\sim 100 \mu\text{s}$  (10 kHz), zero suppression circuit.

▫ The chips are available. We can just buy them from IPHC (Institut Pluridisciplinaire Hubert Curien), Strasbourg

# $\delta$ -electrons and charge particles produced in Pb+Pb interaction

Delta electrons  
(averaged over 10k Pb events)

Charged particles produced in  
Pb+Pb interactions



## Particle Flux:

- During spill the anticipated beam intensity is 105 Pb ions per second.
- For 200  $\mu\text{m}$  Pb target interaction probability is 0.5% which leads to 500 Hz interaction rate

### **Hadronic interactions:**

$$\begin{aligned}\text{flux} &= (105 * 0.005) \text{ event/s} * 1.6 \text{ particles/mm}^2/\text{event} = \\ &= 800 \text{ particles/mm}^2/\text{s} = 800 \text{ Hz/mm}^2\end{aligned}$$

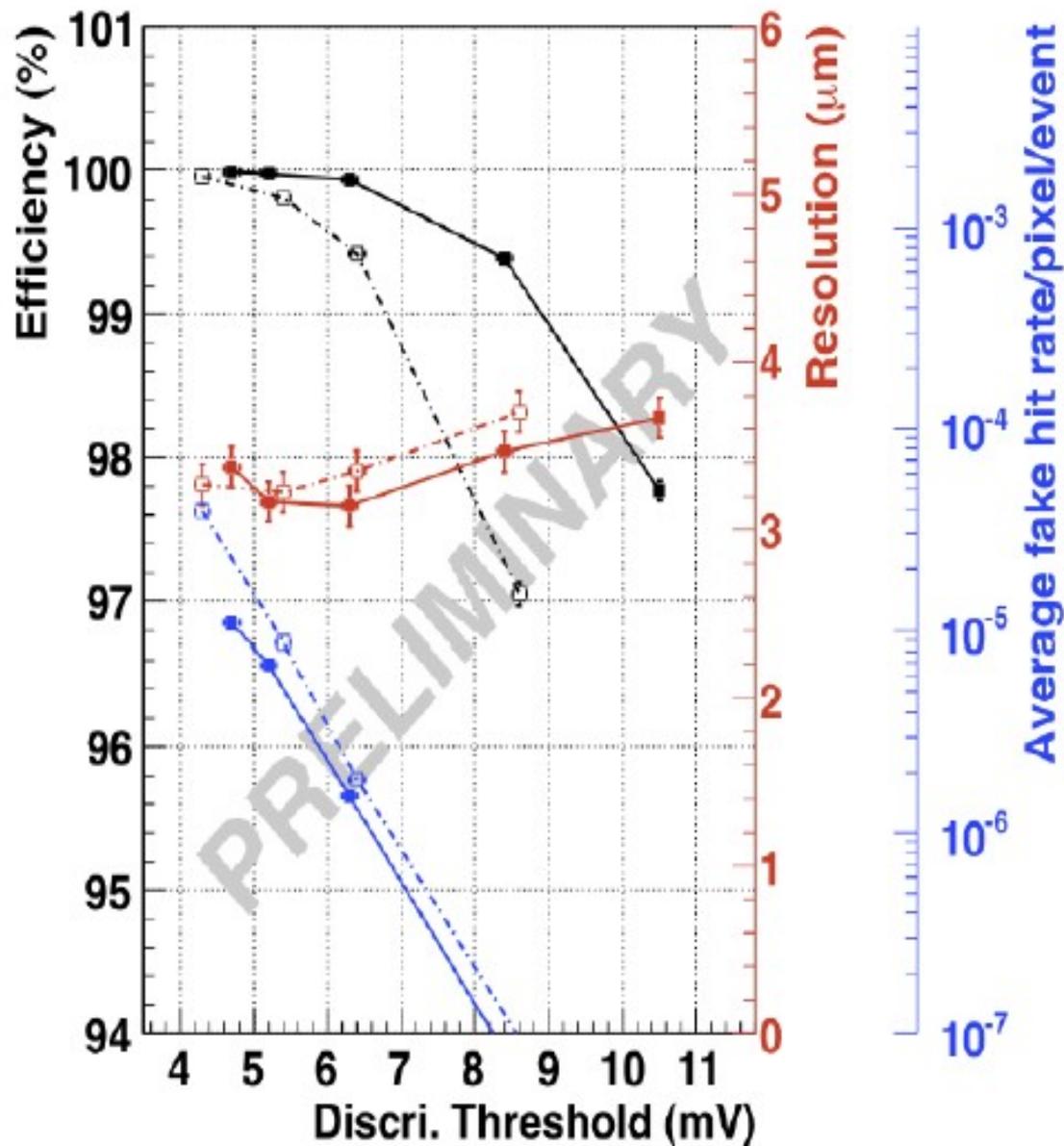
### **Electromagnetic interactions ( $\delta$ -electrons):**

$$\begin{aligned}\text{flux} &= 105 \text{ event/s} * 0.04 \text{ particles/mm}^2/\text{event} = \\ &= 4000 \text{ Hz/mm}^2\end{aligned}$$

□ Rate of Flux is not critical, for the future detectors

# Fluence estimates

# Performance of MIMOSA-26 → test on beam



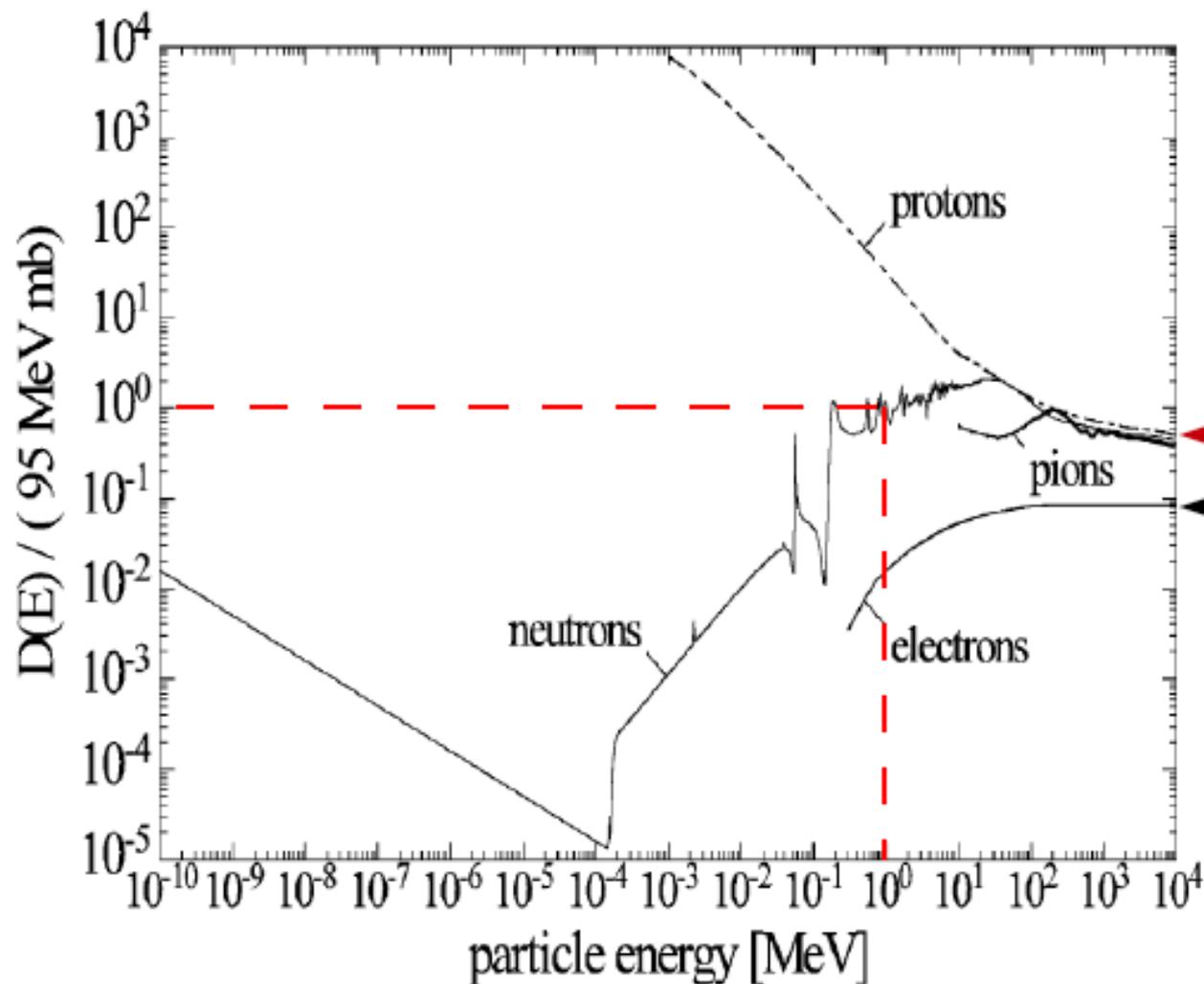
Temperature: + 30<sup>0</sup> C  
 Readout Time: 125 μs  
 Pitch size : 20.7 μm  
 Irradiated with to  
**fluence = 3 x 10<sup>12</sup> n<sub>eq</sub>/cm<sup>2</sup>**

For disc. Threshold= 5 mV:  
 detection efficiency ~ 99.8%,  
 fake hits < 10<sup>-4</sup>  
 resolution ~ 3.5 μm

(M.Winter, CBM Progress Report 2010)

# Displacement Damage Function

Bulk damage exclusively depends upon non ionizing energy lose (NIEL). This is described by the displacement damage functions  $D(E)$



Hadronic interactions:  
flux =  $(105 * 0.005)$   
event/s \* 1.6  
particles/mm<sup>2</sup>/event =  
**800 Hz/mm<sup>2</sup>**

0.62  
0.62/  
5

Electromagnetic  
interactions ( $\delta$  -  
electrons):  
flux = 105 event/s \*  
0.04  
particles/mm<sup>2</sup>/event =  
4000 Hz/mm<sup>2</sup>

(A. Vasilescu, ROSE Internal Note ROSE/TN/97-2  
(1997))

## Fluence Calculations

$\Phi_{eq} 1\text{MeV} = \kappa\Phi$        $\kappa$  - radiation hardness parameter

$\kappa = 0.62/5$  for electrons

$\kappa = 0.62$  for particles from hadronic interactions

Fluence for electrons in [for 1 month] (upper limit):

$$= 4 \times 10^5 \text{ /cm}^2\text{/sec} * 0.62/5 * 2592000 \text{ sec} = 1.28 * 10^{11} \text{ neq/ cm}^2$$

For Spill of the beam (20%) =  $2.57 * 10^{10} \text{ neq/cm}^2$

→  $\Phi$  for charge Particles = 800 Hz/mm<sup>2</sup>

Fluence for charged particles [for 1 month] (upper limit):

$$= 8 \times 10^4 \text{ /cm}^2\text{/sec} * 0.62 * 2592000 \text{ sec} = 1.28 * 10^{11} \text{ neq/ cm}^2$$

For Spill of the beam (20%) =  $2.57 * 10^{10} \text{ neq/cm}^2$

**Factor of 40 below the tested range**

# Pixel Occupancy

## Pixel occupancy

▫ As usually looking at the most critical area of Vds1 where the track occupancies are:

1. **5** tracks/mm<sup>2</sup>/event for central Pb+Pb collisions
2. **1.6** tracks/mm<sup>2</sup>/event from averaging over minimum bias Pb+Pb collision
3. **0.04**  $\delta$ -electrons/mm<sup>2</sup>/event for Pb ion on 200  $\mu$ m target

$P(0) = 95\%$  - empty frame

$P(1) = 4.7\%$  - single event

$P(2) = 0.12\%$  (pile-up  $P(2)/P(1) = 2.5\%$ )

Beam intensity of 100kHz will lead to 10 ions in 100  $\mu$ s

**Single Pixel Occupancy = 0.25%** (+0.01% contribution from fake hits)

→ Not very dense environment → probability of overlap low, however we need full simulation to prove the reconstruction feasibility

# Charmonium as a probe for the properties of the QGP & Charmonium suppression

The main idea: implant charmonia into the QGP and observe their modification, in terms of suppressed (or enhanced) production in nucleus-nucleus collisions with or without plasma formation.

original proposal: H. Satz and T. Matsui, Phys. Lett. B178 (1986) 416

assumptions:

- **all** charmonia are produced before QGP formation
- suppression takes place in QGP
- some charmonia might survive beyond  $T_c$   
→ sequential suppression pattern due to feeding

actually, in 1978, Edward Shuryak investigated gluonic destruction of charmonium,

$$gJ/\psi \rightarrow \bar{c}c$$

and concluded that it would not survive the gluon-rich plasma

E. V. Shuryak, Phys. Lett. B 78, 150 (1978) [Sov. J. Nucl. Phys. 28, 408.1978 YAFIA,28,796 (1978 YAFIA,28,796-808.1978)].