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Future Vertex Detector For Open Charm Measurements with NA61/SHINE Experiment at CERN-SPS

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JAGIELLONIAN UNIVERSITY IN KRAKOW

SHINE NA61

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Introduction

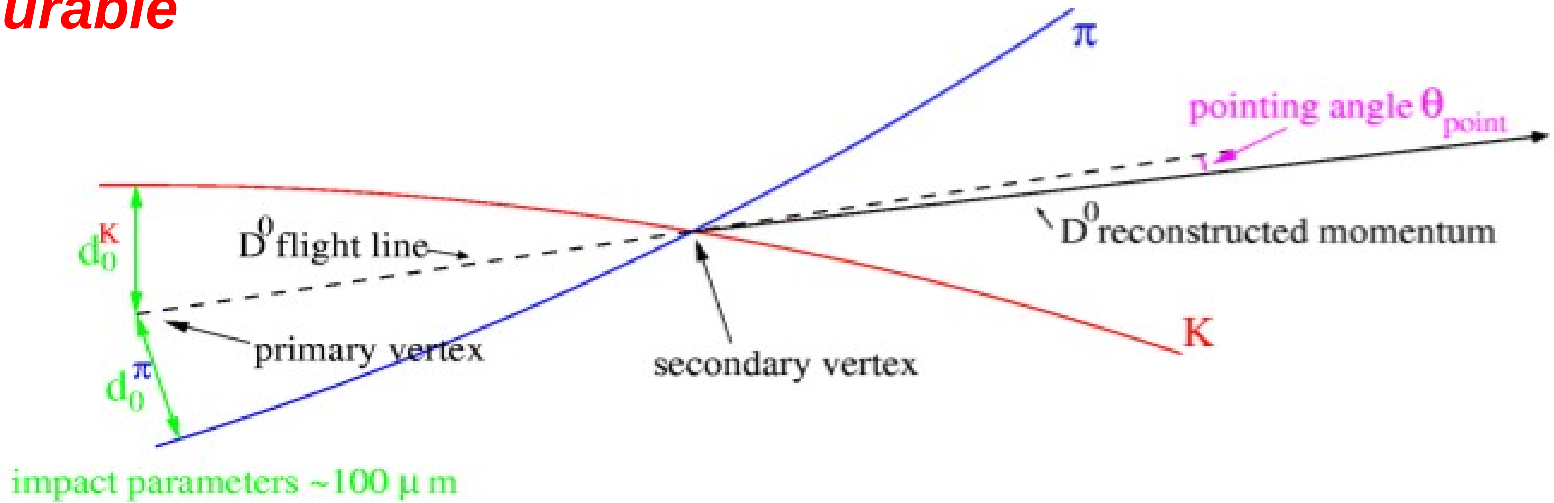
→ A feasibility study of D0 → K+ π- (BR=3.87%) channel in central Pb+Pb collisions at the CERN SPS energies will be presented. The study is done for 158 AGeV and 40 AGeV.

→ The NA61/SHINE requires upgrade with a new vertex detector that will allow precise track and vertex reconstruction at the target proximity.

→ The obtained results based on the predicted yields of D0 mesons and vertex detector optimization regarding its geometry and applied detection technologies

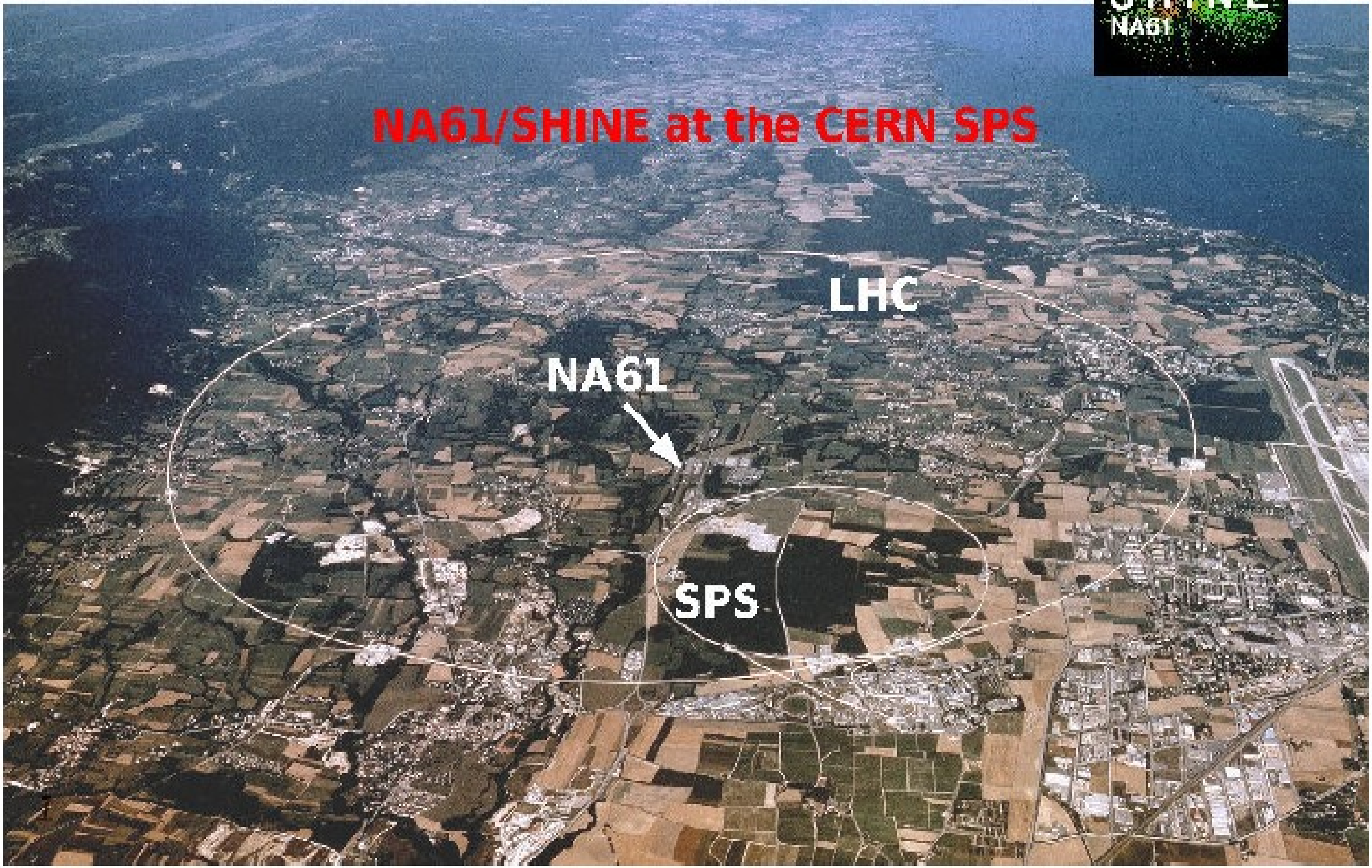
Detection Strategy

→ Distance between interaction Point and decay point is measurable



Meson	Decay Channel	Cτ	Branching Ratio
D^0	$D^0 \rightarrow K^- + \pi^+$	122.9μm	(3.91±0.05)%
D^0	$D^0 \rightarrow K^- + \pi^+ + \pi^+ + \pi^-$	122.9μm	(8.14±0.20)%
D^+	$D^+ \rightarrow K^- + \pi^+ + \pi^+$	311.8μm	(9.2±0.25)%
D^+_s	$D^+_s \rightarrow K^+ + K^- \pi +$	149.9μm	(5.50±0.28)%
D^{*+}	$D^{*+} \rightarrow D^0 + \pi^+$	---------	(61.9±2.9)%

NA61/SHINE Experiment



Physics motivation

→ So far no direct open charm measurements at SPS energies

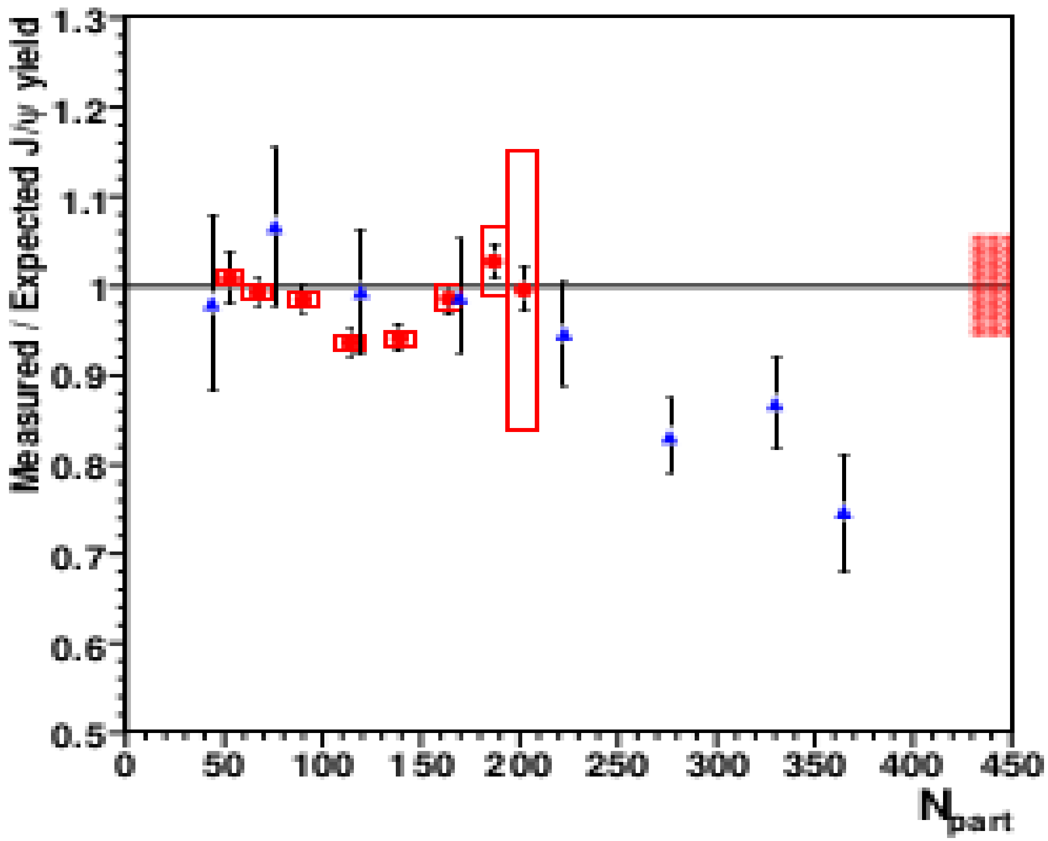
→ Only J/Ψ has been measured at top SPS energy by (NA50 and NA60) experiments

→ Open charm measurement provides unique opportunity to test the validity of pQCD based and statistical models of nucleus-nucleus collisions at higher energies

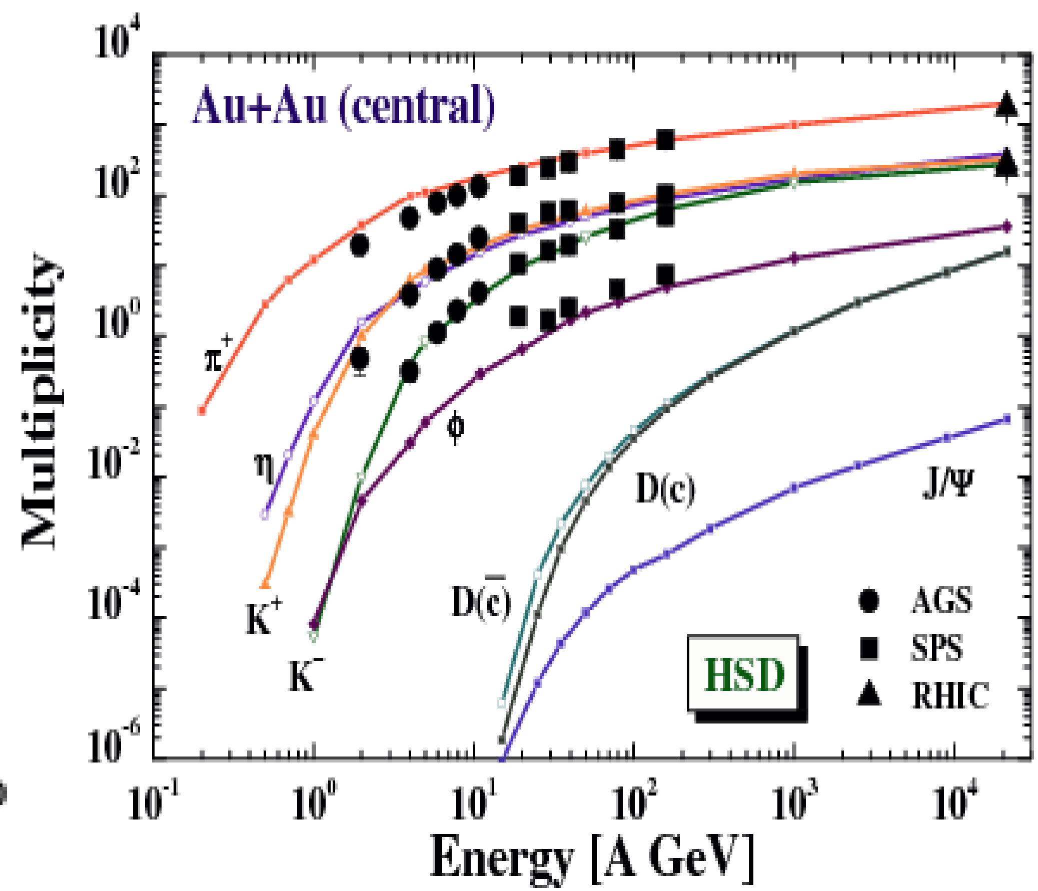
(Acta. Phy. Pol. B Vol 31 (2000))

→ Differential measurements for open charm

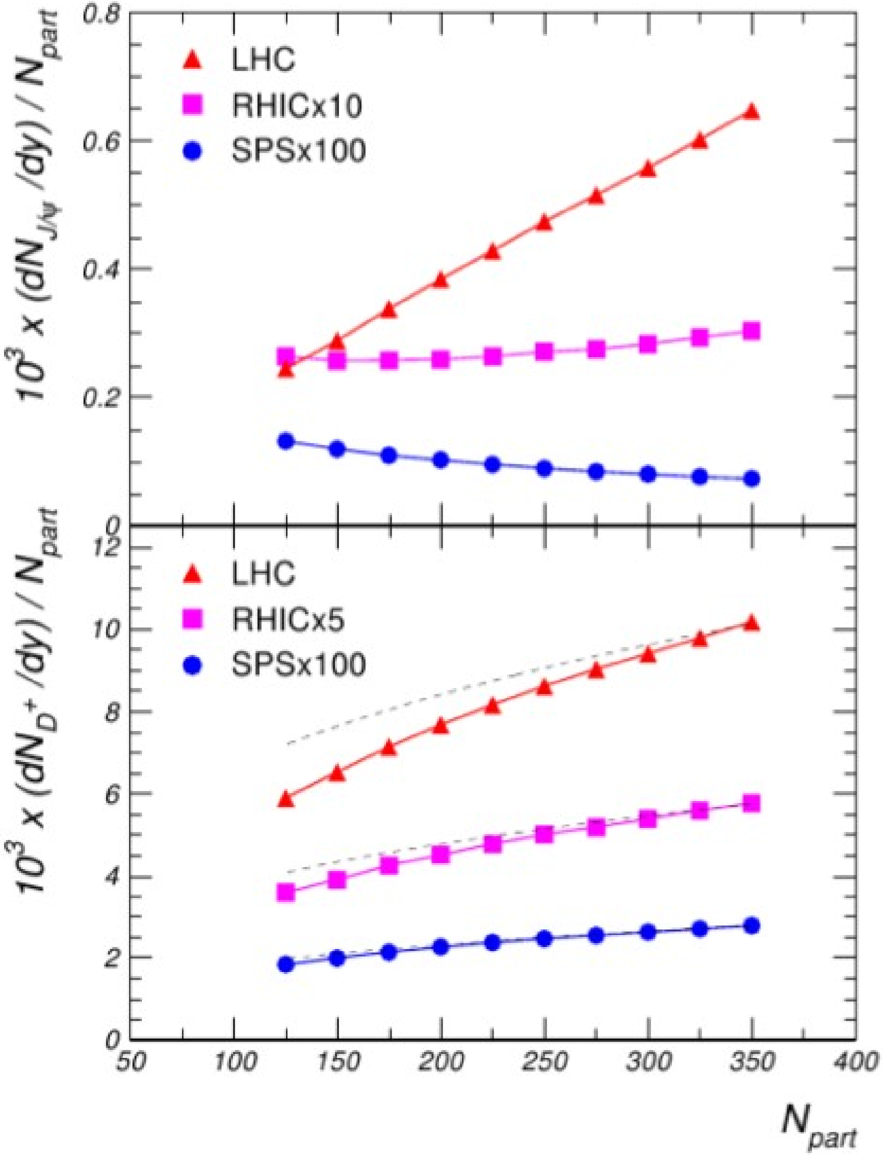
(arXiv 0907. 3682 v2 [nucl-ex] 2009)



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



Statistical Hadronization Model – predictions for J/ψ and open charm



Note different scale factors for SPS-LHC

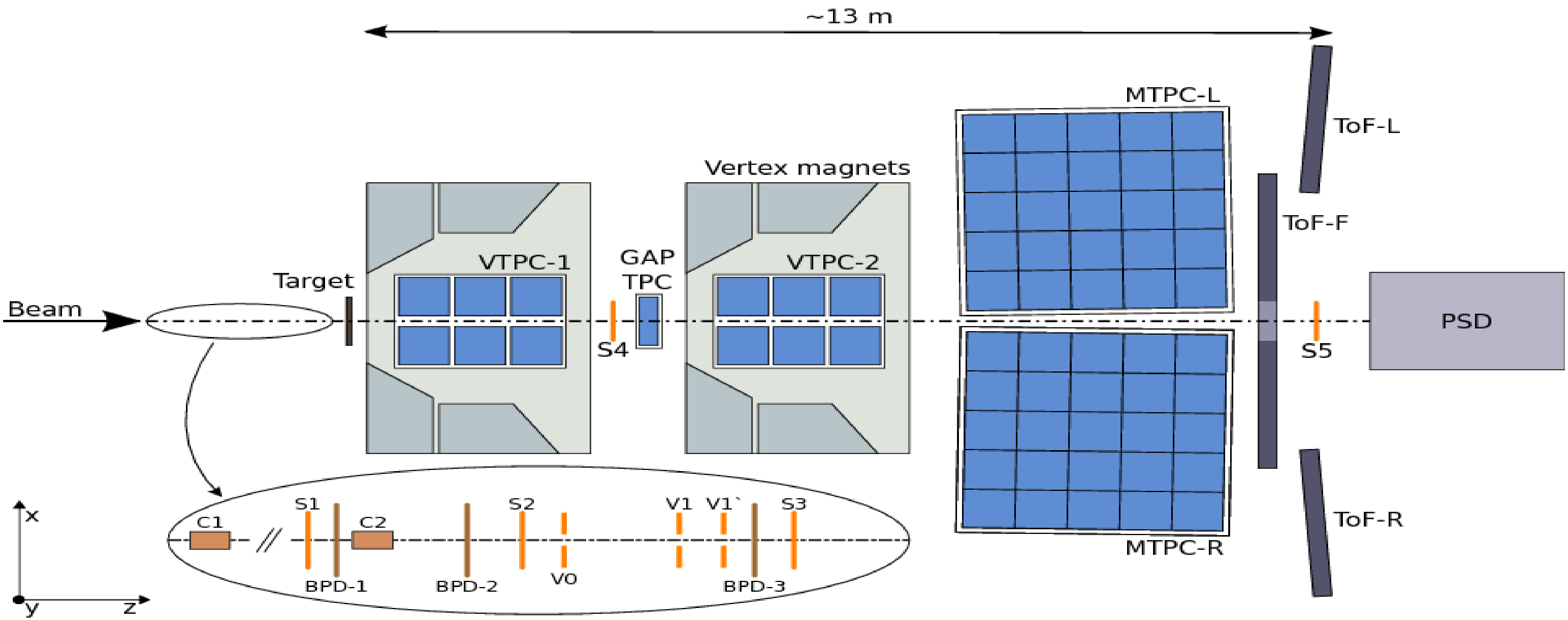
Quality of charm measurement not sufficient to desintangle among different models

→ needs more precise data
→detector upgrade

We know that both STAR and ALICE (also CMS) are working on vertex detector to improve heavy flavor measurement

We can be part of the story if we succeed to build vertex detector for NA61/SHINE

NA61/SHINE detector – Top view



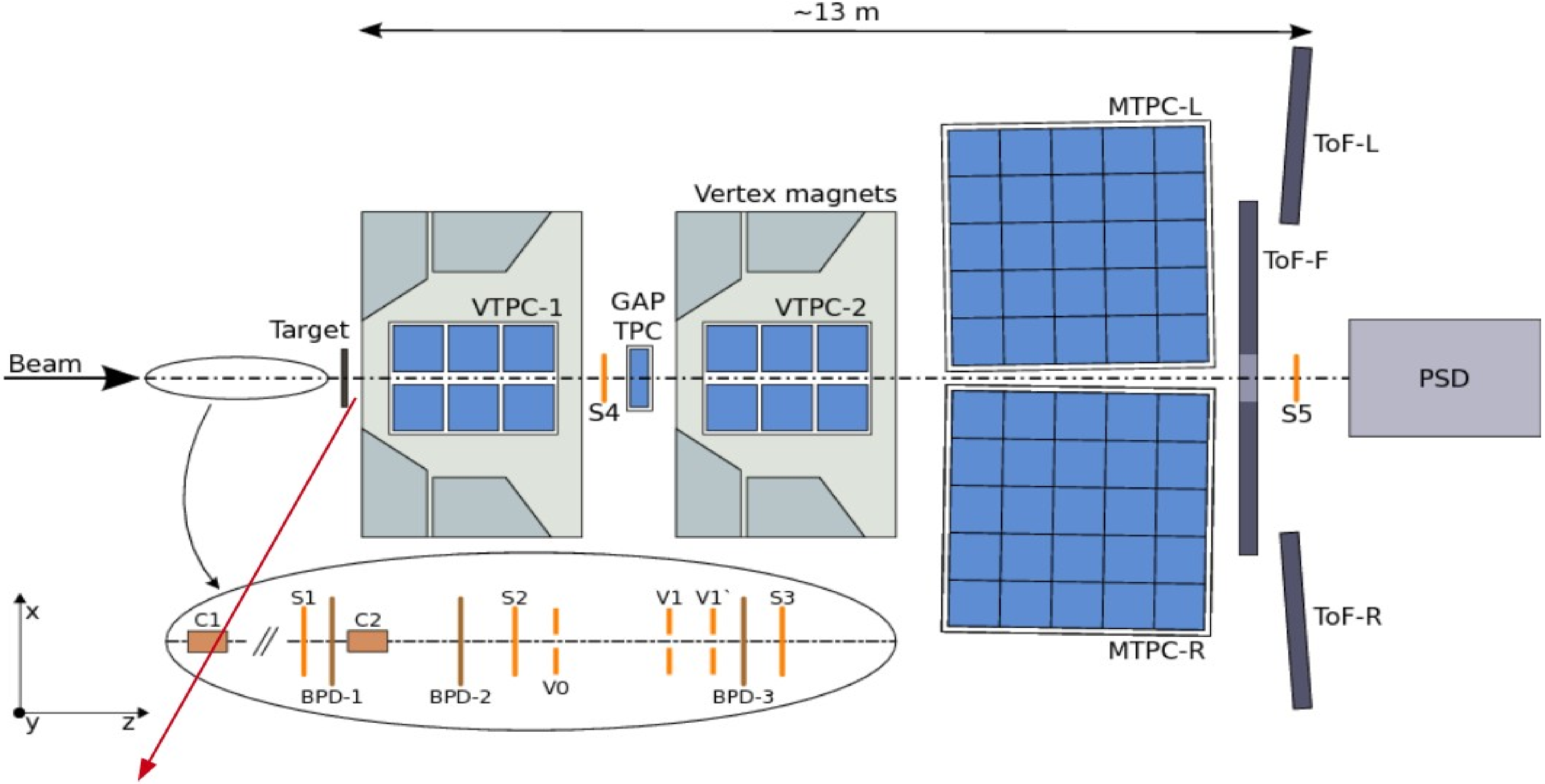
Beam detectors and triggering → A set of upstream scintillator and Cherenkov counters and beam Position detectors provides timing reference, charge and position measurements

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



Position of the Future Vertex Detector

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 <D0> + <$\overline{D0}$> per central Pb+Pb event. this seems to be under-predicted value, e.g. PYTHIA run for N-N and scaled to central Pb+Pb gives 0.21 **(P. Braun-Munzinger, J. Stachel, PLB 490 (2000) 196)**

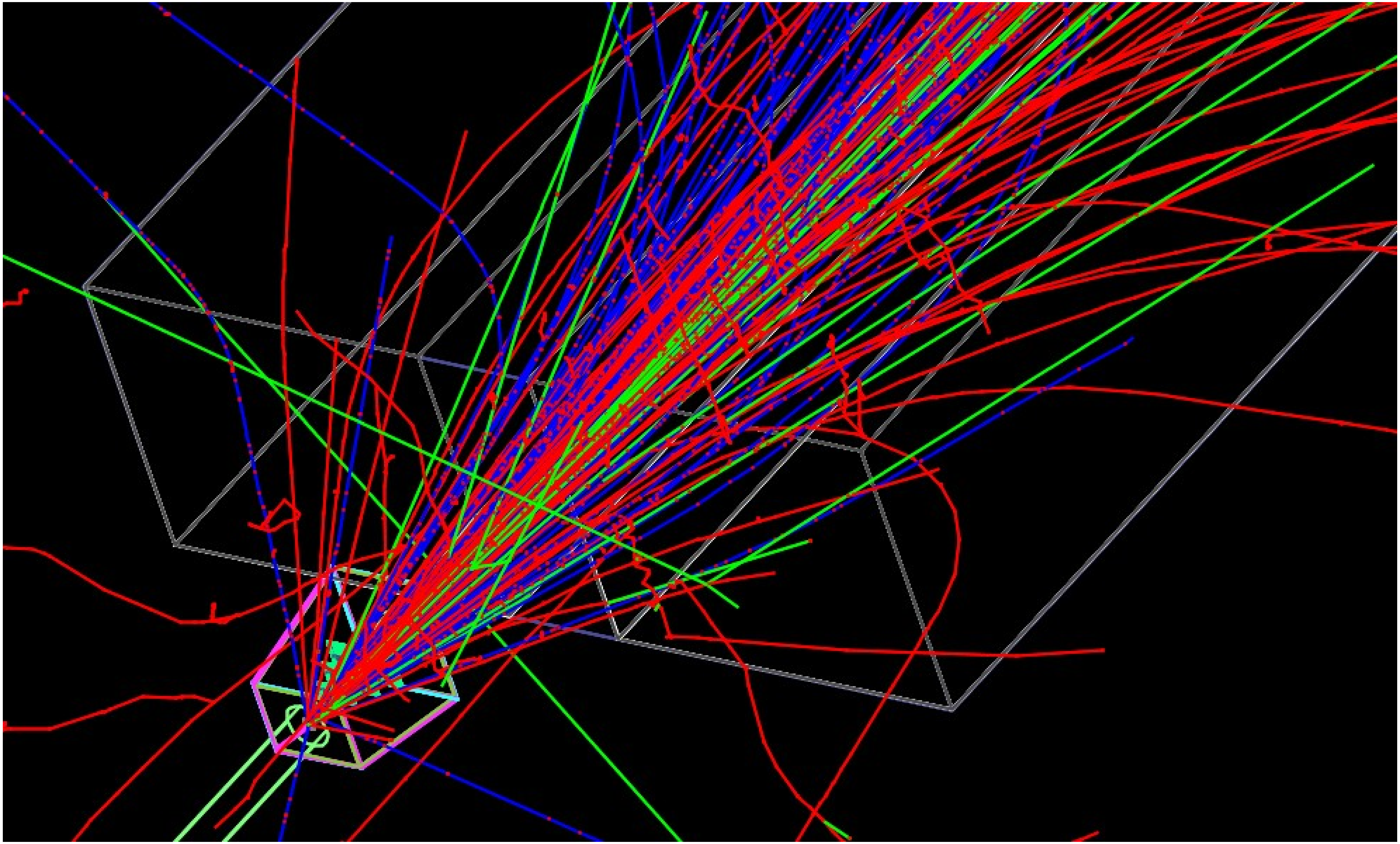
→ HSD (Hadron String Dynamic) Model predictions are consistent with scaled PYTHIA → We scaled AMPT predictions to be consistent with HSD and PYTHIA.

→ AMPT does not generate “Open Charm” at 40 AGeV, We assume open charm phase space distribution characteristic same as for 158 AGeV and yields as predicted by HSD model.

→ Rapidity distribution and Invariant mass slope parameter does not change more than 10% for Kaons while going from 158 AGeV to 40 AGeV

AMPT : **(Phys.Rev.C72:064901, 2005)**
HSD : **(Int. J. Mod. Phys. E17 1367)**
PYTHIA : **(T. Sjostrand etal., Comput. Phys. Commun. 135, 238 (2001))**

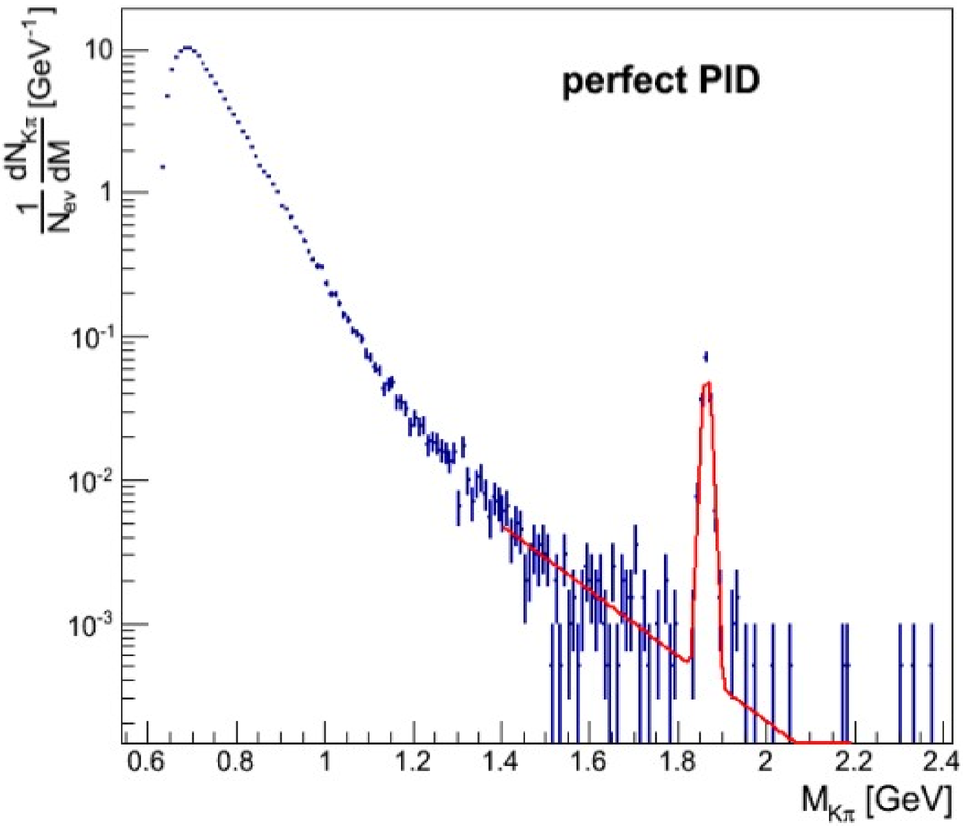
AMPT Event: Pb+Pb at 158 AGeV

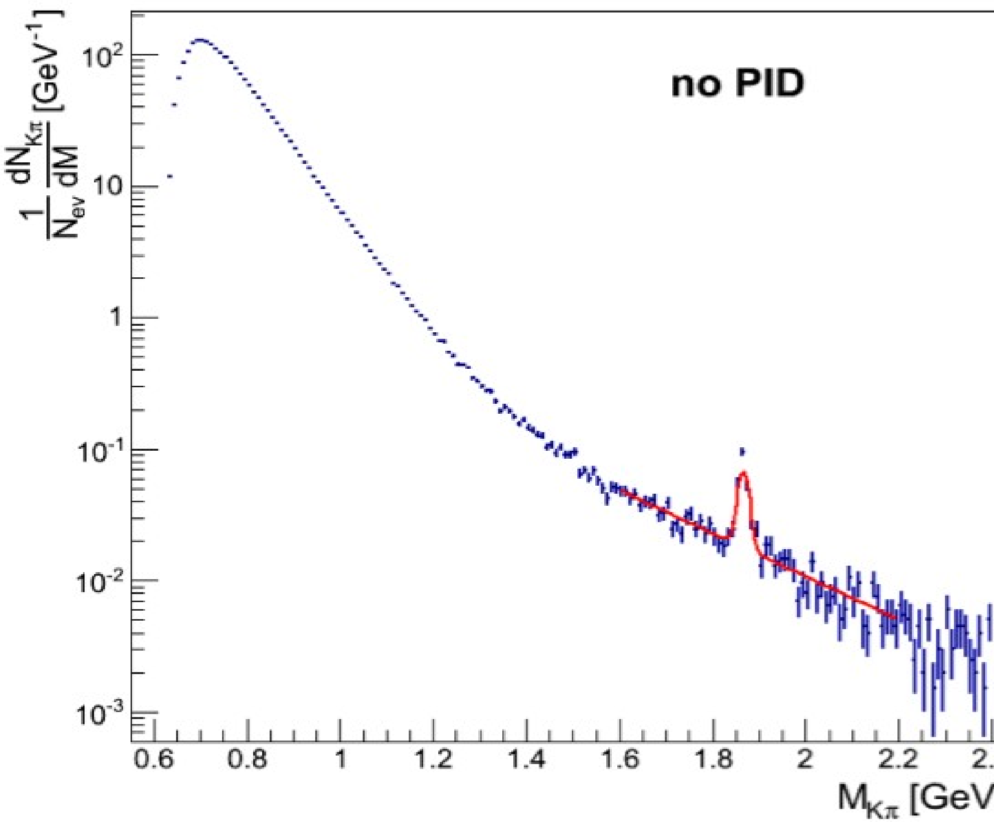


→ **VTPCs filled with Ar-CO² mixture, location and dimensions as in NA61/SHINE experimental setup.**

→ **Uniform magnetic field: 1.5 T in VTPC-1 and 1.1 T in VTPC-2**

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

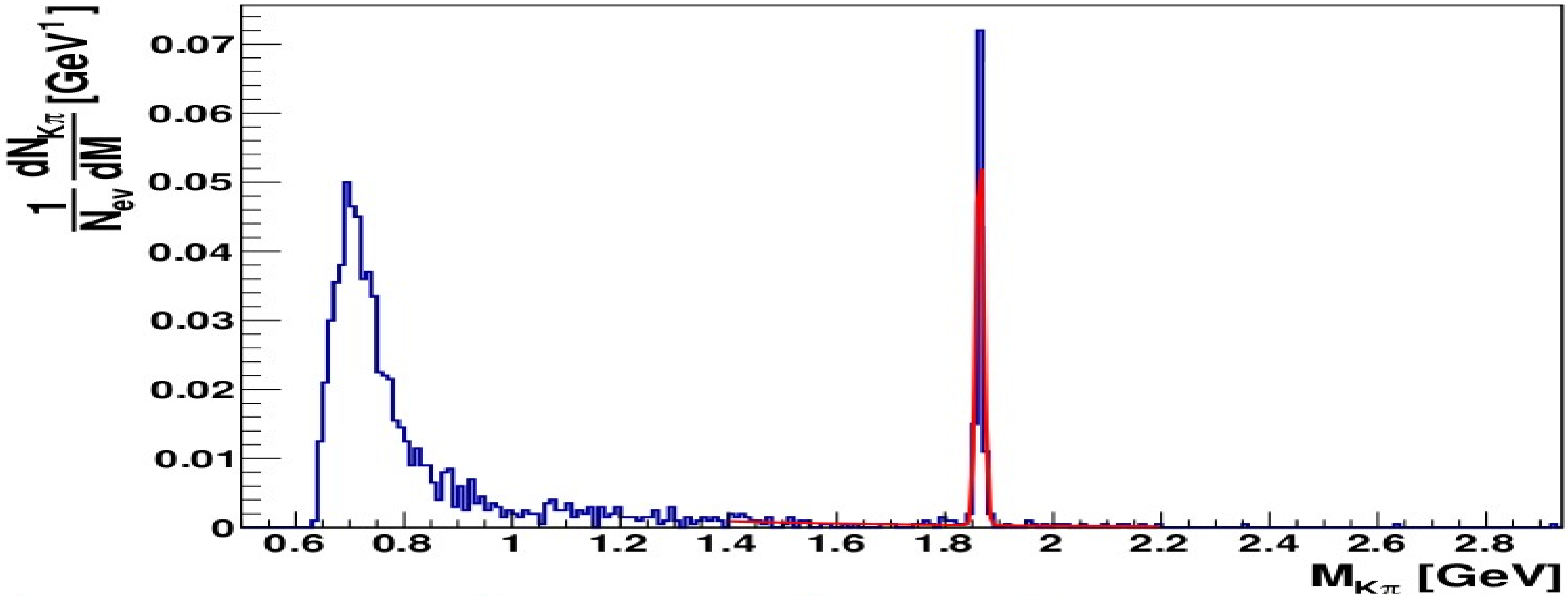




→ S/B = 66
→ SNR (@50M) = 276
→ 77800 detected D^0+D^0bar mesons in 50M central Pb+Pb

→ S/B = 2
→ SNR (@50M) = 249
→ 77800 detected D^0+D^0bar mesons in 50M central Pb+Pb

Reconstructed yield for D0→ K+ π-, 200k 0-10% cent. Pb+Pb at 40 AGeV

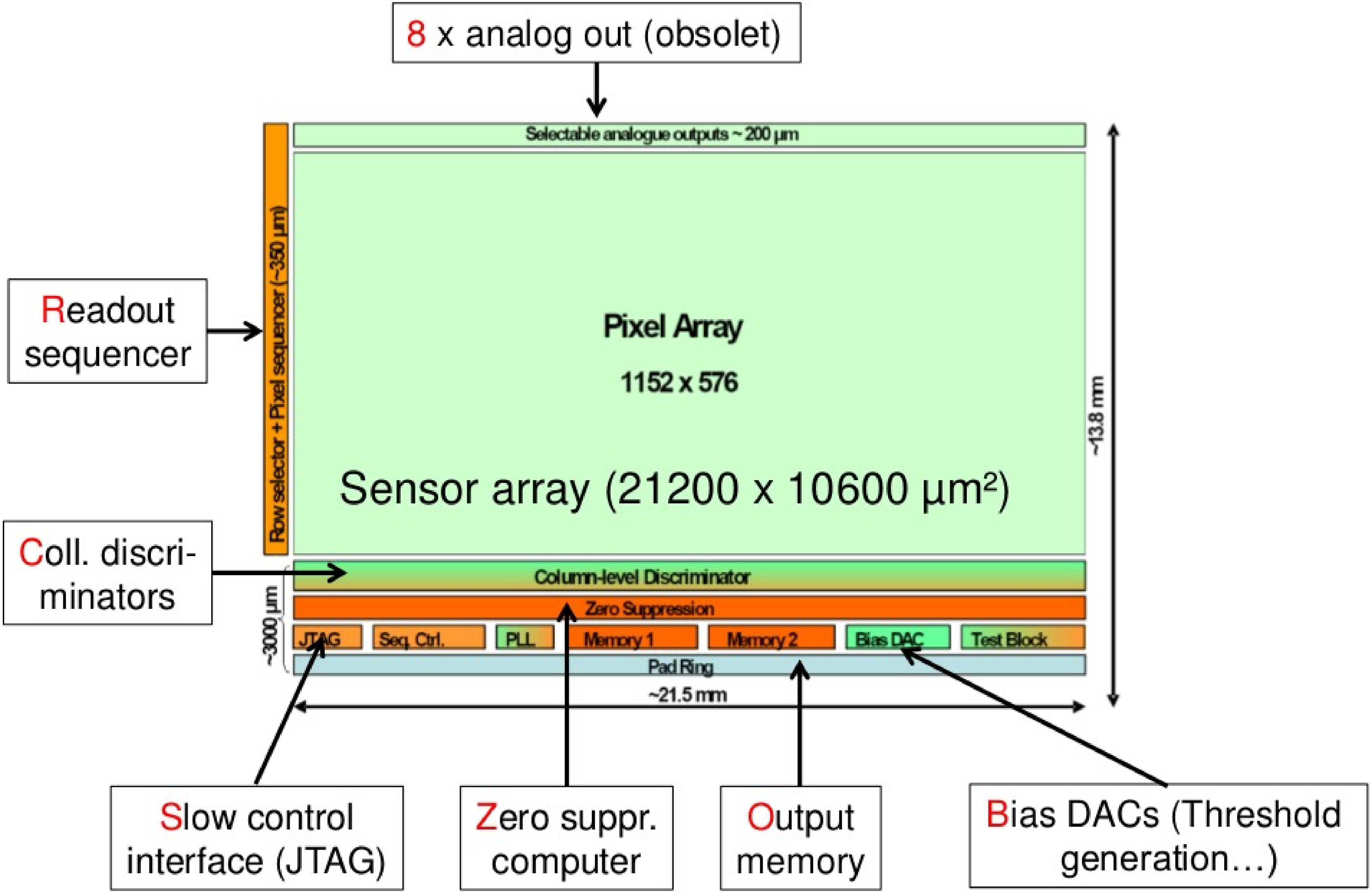


Pos. Res (μm)	10	10	15	15
Beam hole(mm)	2.5	3.0	2.5	3.0
S/B	1.5	2.0	1.0	1.5
Signal Significance (SNR) ★	33.3	32.7	8.0	7.3
$\langle D^0 \rangle + \langle \overline{D^0} \rangle$ ★	1846	1759	1769	1692

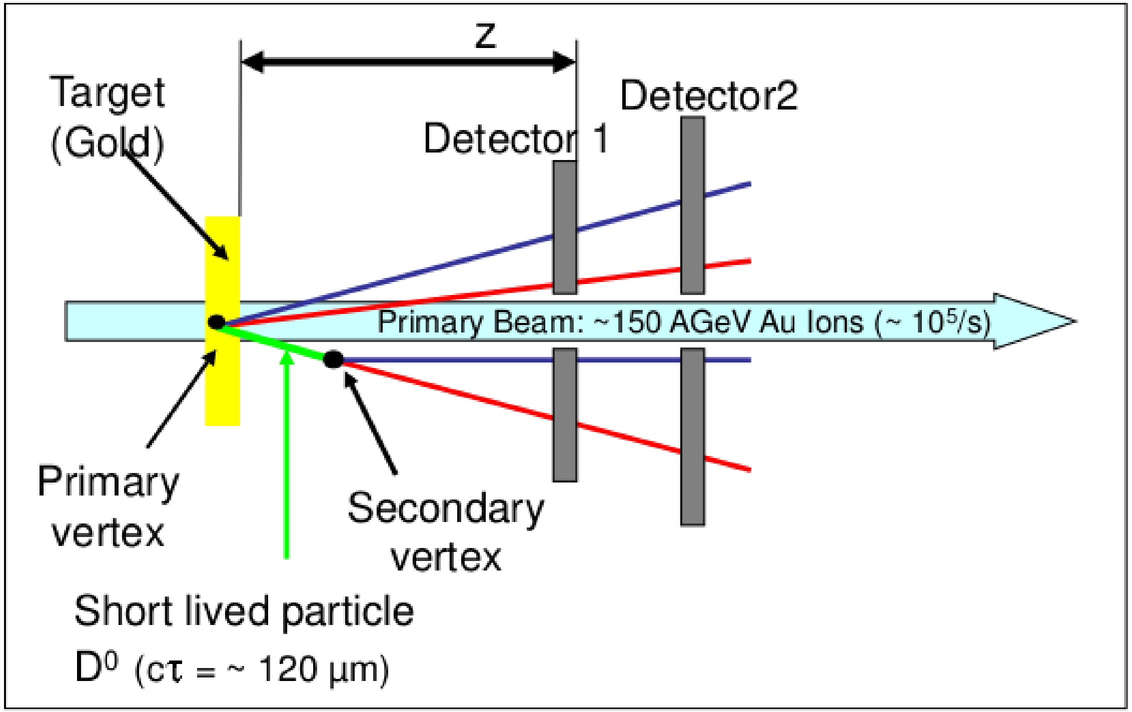
★ Results Extrapolated to 50M Events

Which Device Should we Use to measure open charm ???

Block diagram of MIMOSA-26



Requirements of Reconstruction



All numbers extrapolated from CBM simulations

Reconstructing open charm requires:

- Excellent secondary vertex resolution (~ 50 µm)

=> Excellent spatial resolution (~5 µm)

=> Very low material budget (few 0.1 % X_0)

- Good radiation tolerance
- Time resolution to separate 2000 coll/s => ~ 100 µs

Is MIMOSA-26 suited to measure open charm with NA61/SHINE?

Requirements vs. sensors

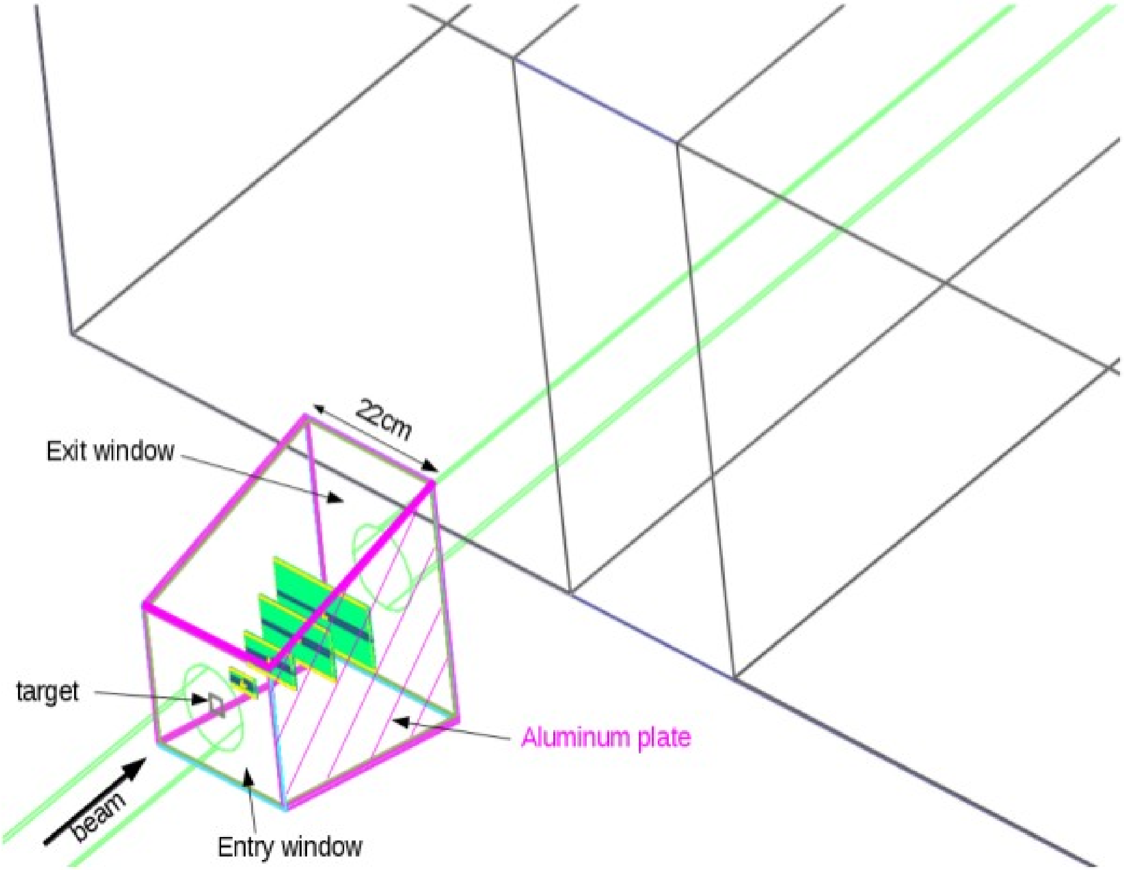
	NA-61	Hybrid	CCD	MIMOSA-26
Resolution	< 5 µm	30 µm	<5 µm	3.5 µm
Material Budget	few 0.1 X_0	~ 1% X_0	~0.1% X_0	0.05% X_0
Rad. Tol. (1)	$3x10^{10} n_{eq}/cm^2$	$>10^{14}$ n_{eq}/cm^2	$<10^9$ n_{eq}/cm^2	$>10^{13}$ n_{eq}/cm^2
Rad. Tol. (2)	~1 krad	>10 Mrad	~1 Mrad	> 300krad
Time res.	~100 µs	20 ns	~ 100 µs	115.2 µs

(1) non ionizing dose per week beam on target
(2) ionizing dose per week beam on target

All numbers extrapolated from CBM simulations assuming 2000 Au+Au coll./s

Vertex Detector

VD in geant4



VDS1 : 5 cm
VDS2: 10 cm
VDS3: 15 cm
VDS4: 20 cm

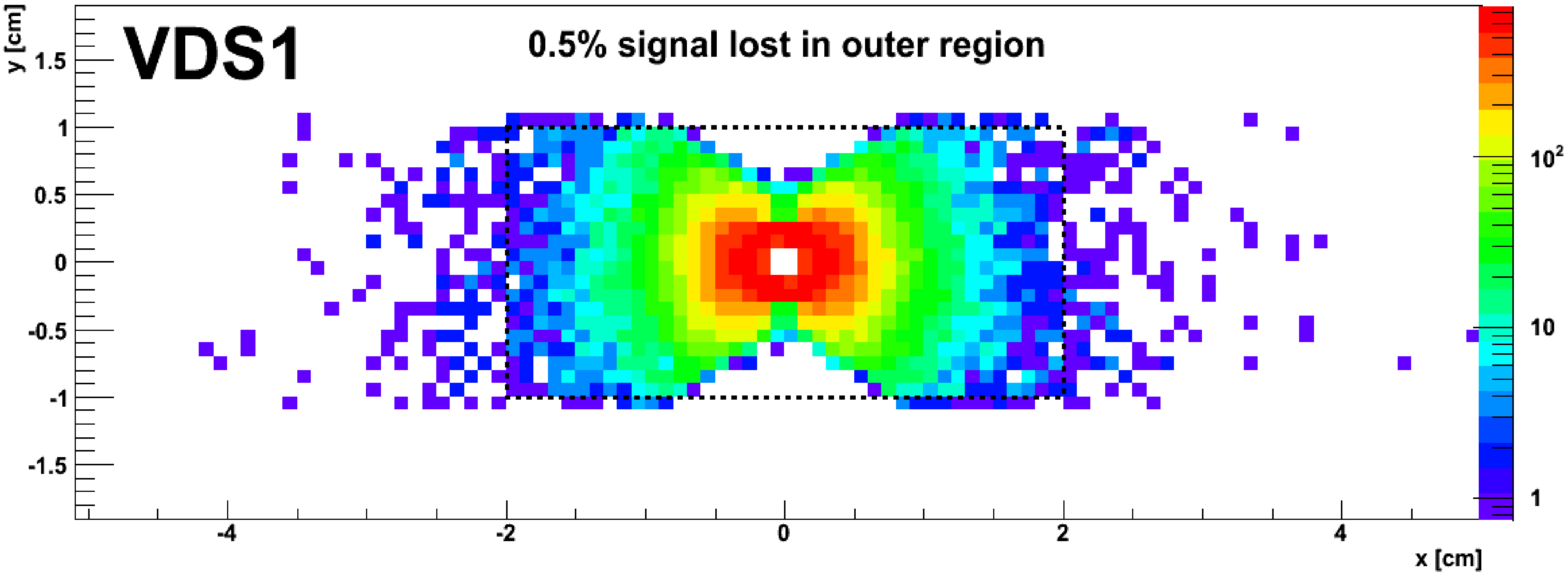
MIMOSA-26 sensors
Carbon fiber support
Water cooling tubes

Vessel:
Rectangular top/bottom plates
Trapezoidal left/right plates

→ same length of carbon leader
→ similar distance between top/bottom plates and VDS1-VDS4

→ flat micro cables variation in length +/- 2cm

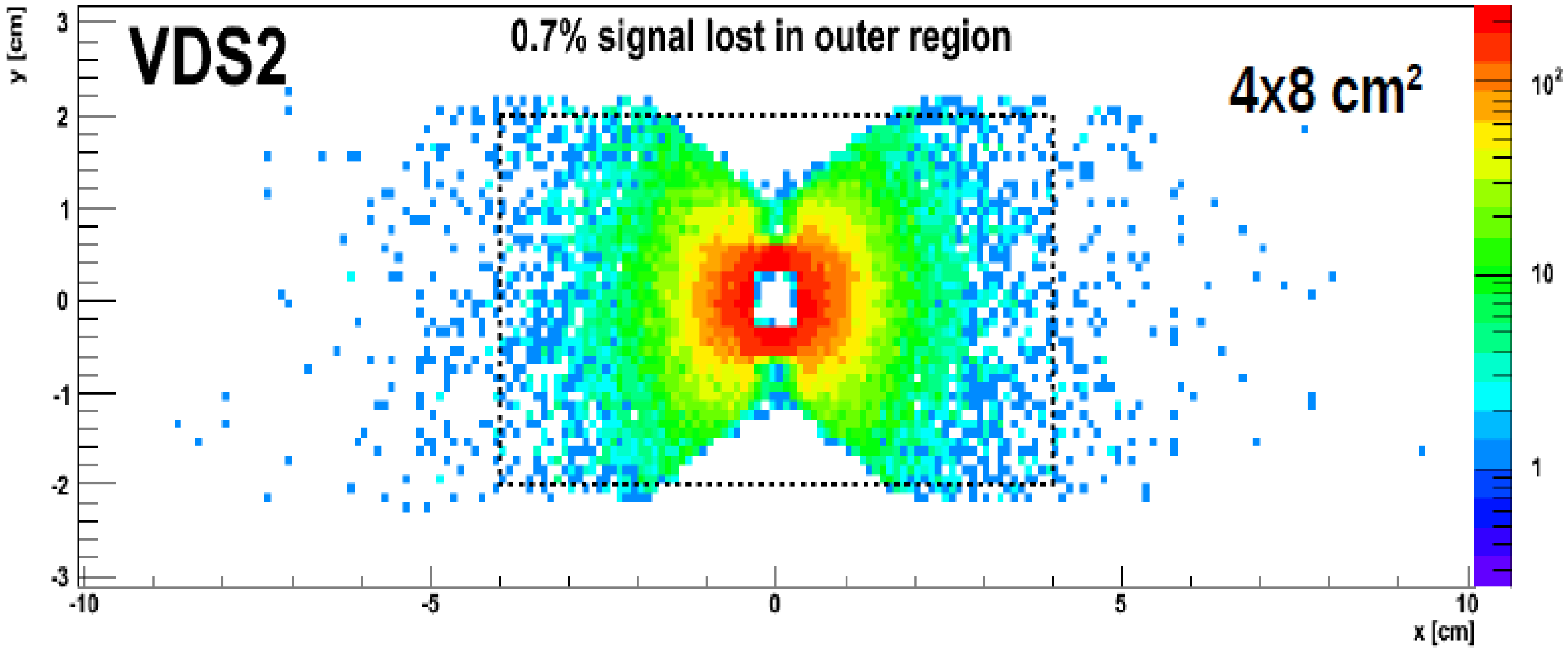
Signal track distribution at 158 AGeV in VDS1



The figure shows hits (x,y) distribution generated by signal tracks is Vds1. The dashed boxes represent the cuts. We found that ~99.5% of signal tracks is localized within the box 2x4 cm^2

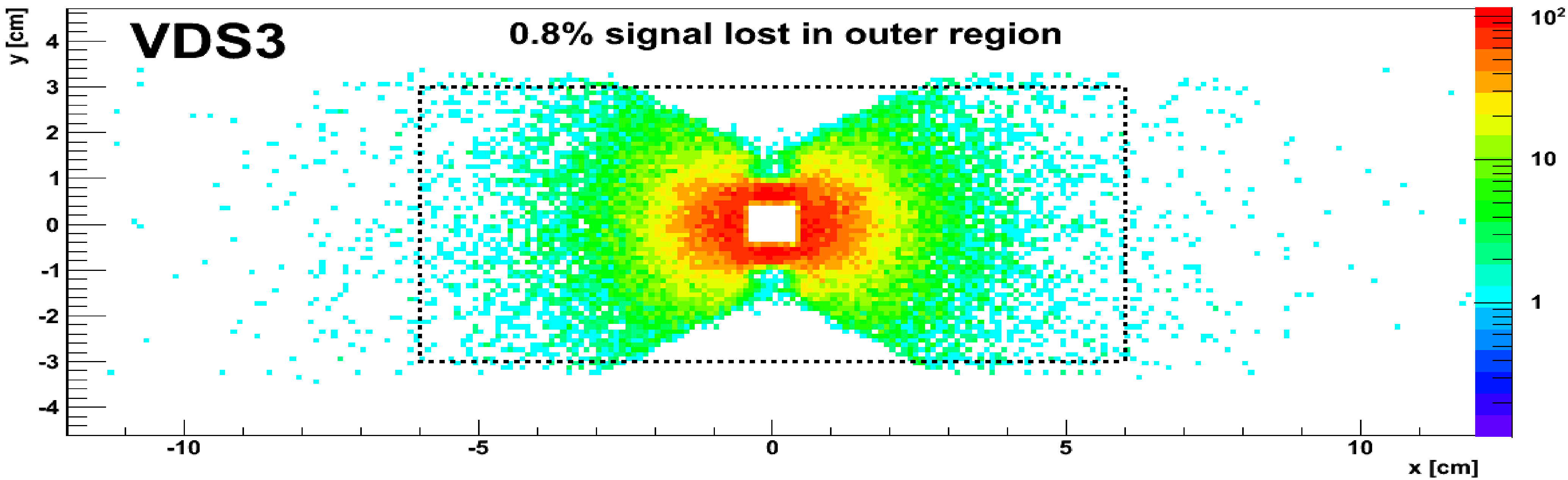
As you can see, to cover the remaining 0.5% we would need to extend the cut in the x direction for almost factor of 2.

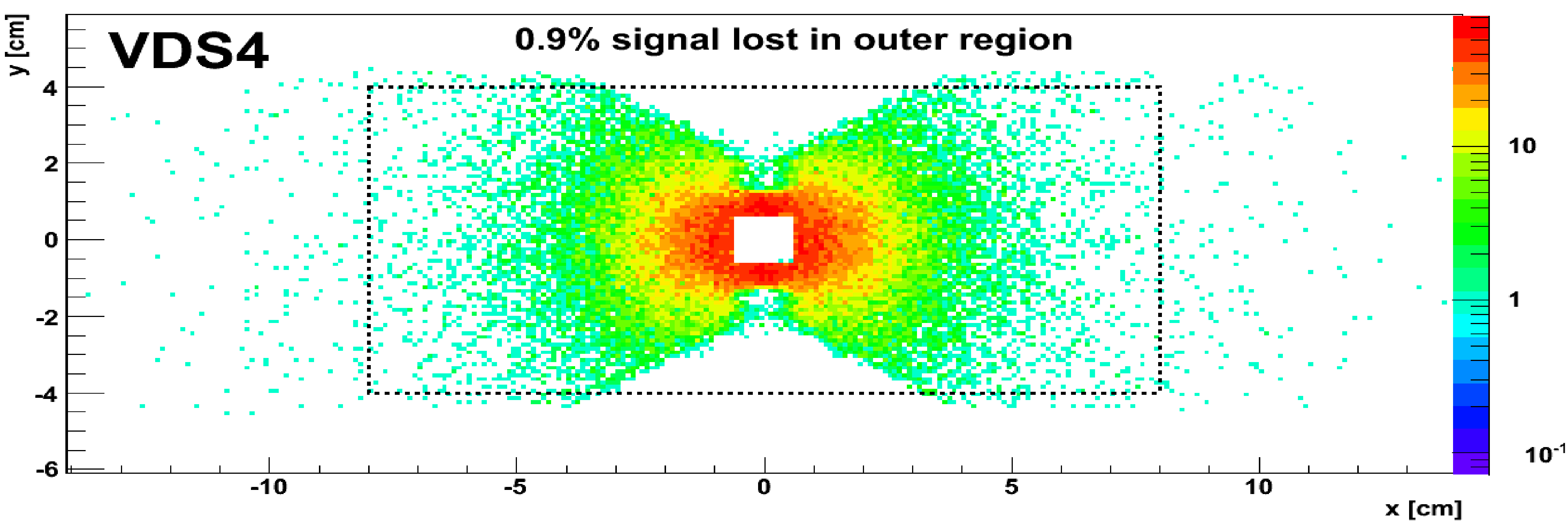
Signal track distribution at 158 AGeV in VDS2



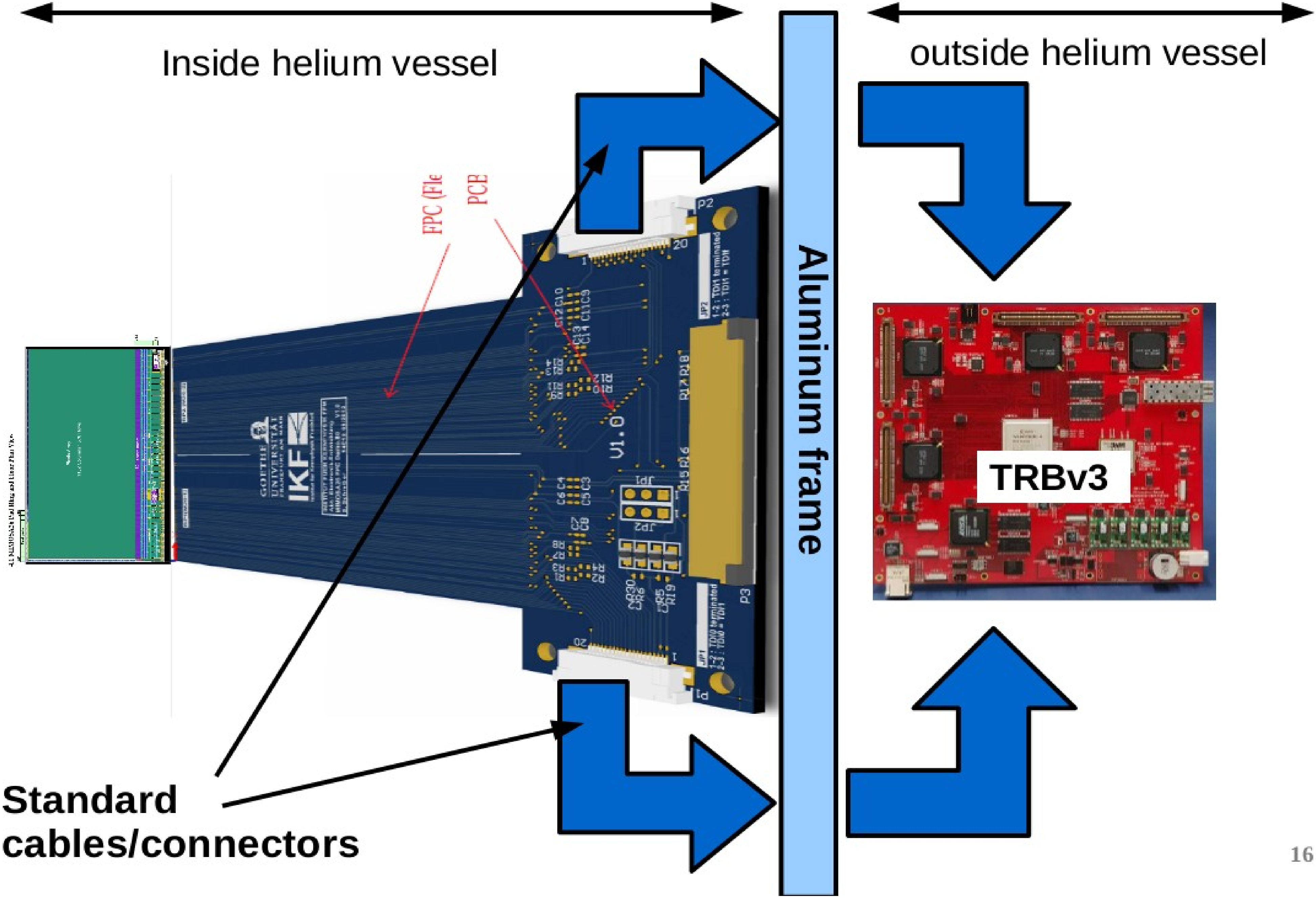
For stations Vds2-Vds4 we just extend size of the boxes in proportion to their distance from the target. So we got dimensions: 4x8 cm^2, 6x12 cm^2 and 8x16 cm^2
For Vds2, Vds3 and Vds4, respectively. The signal lost is kept below 1 % for each station.
For Pb+Pb at 40 AGeV the signal lost is on the level of 4% for the same cuts.

Signal track distribution at 158 AGeV in VDS3 and VDS4





Read-out connections scheme



Summary

The simulations have shown that the measurements of the D0 and $\overline{D0}$ mesons in NA61 experiment with a dedicated vertex detector is feasible.

In the next stage of the study, need to include :

1. Full simulation:
Realistic track reconstruction in VD & matching with VTPC (on going)

2. 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)

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→ NA61 Collaboration

Thank you!


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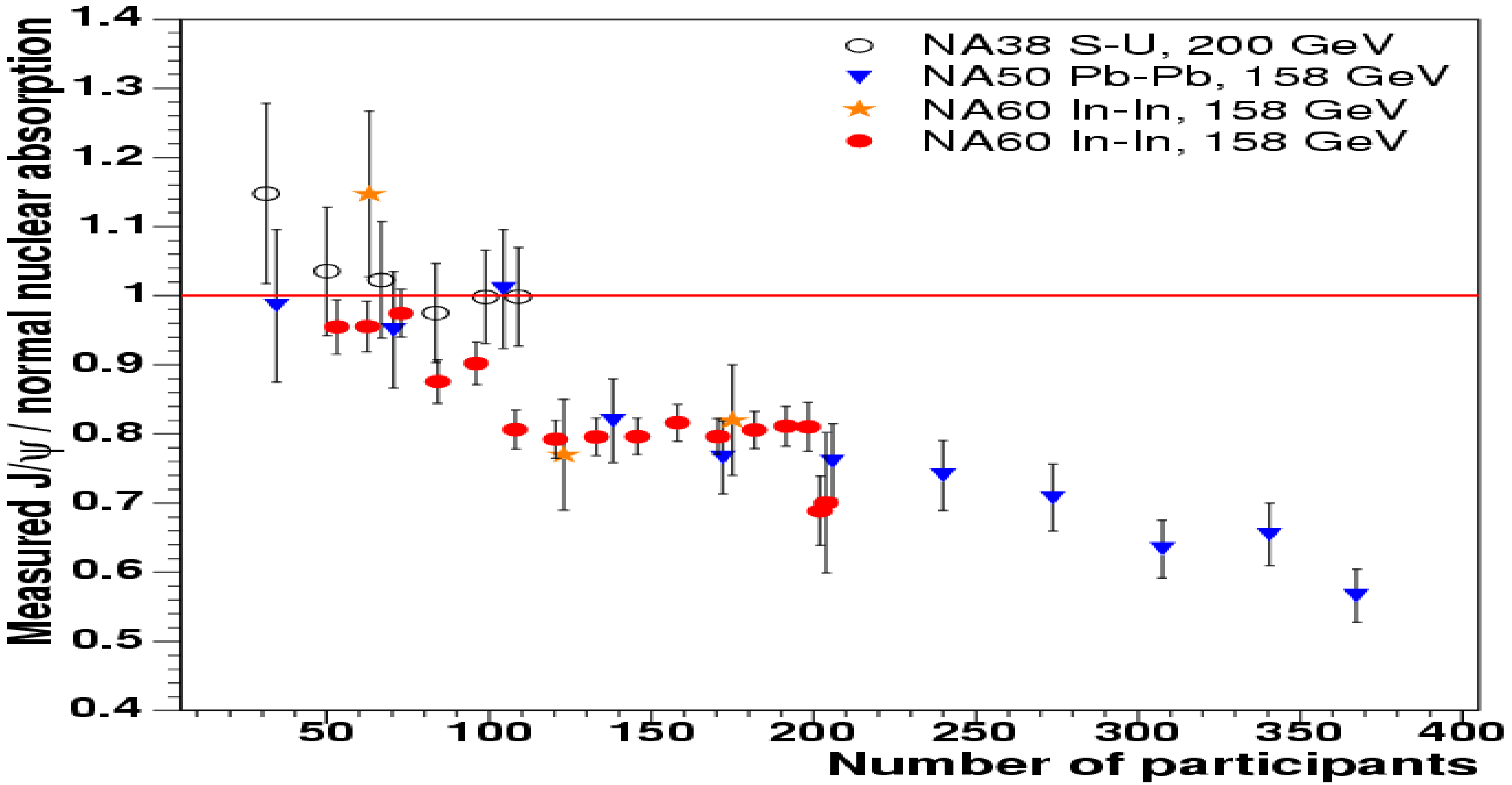
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
University of Warsaw, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
The Universidad Tecnica Federico Santa Maria, Valparaiso, Chile

BACK UP SLIDES



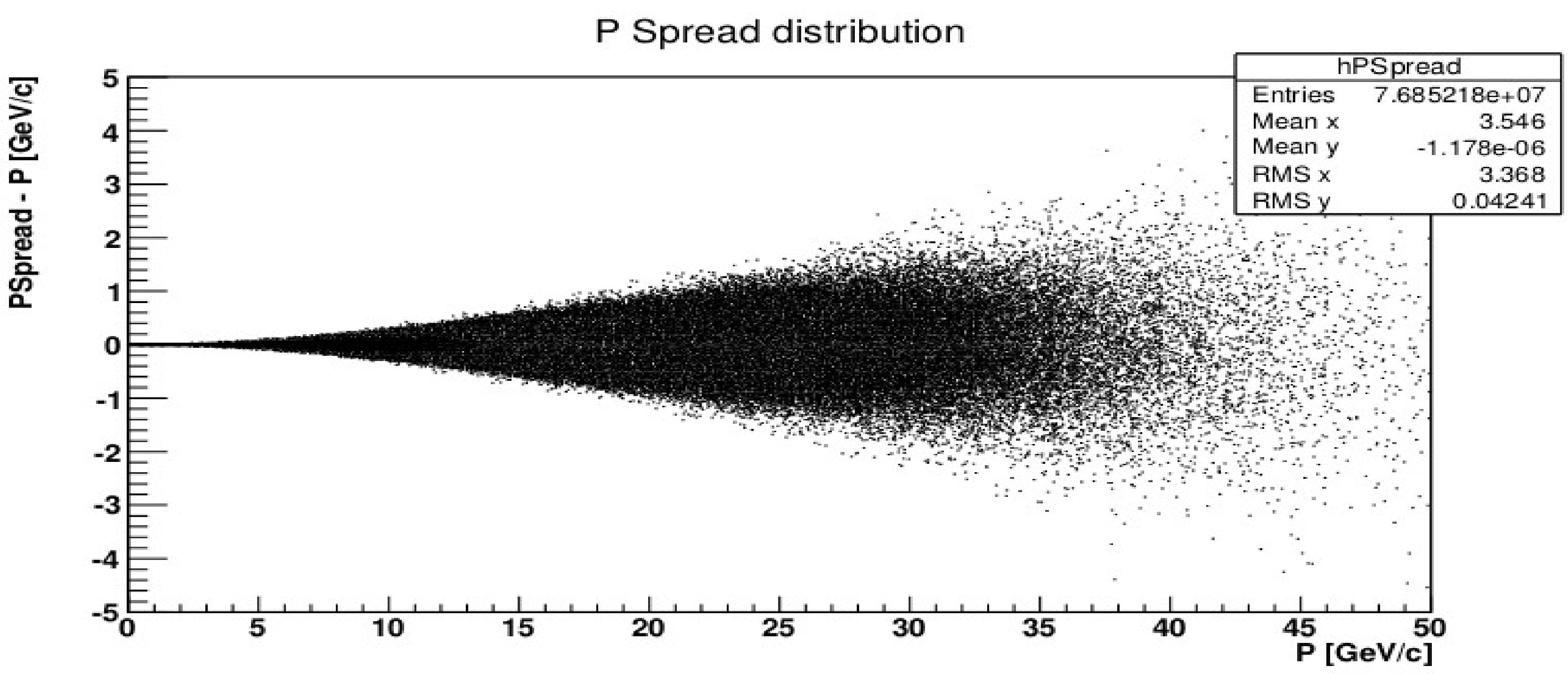
Measured J/ψ / normal nuclear absorption
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
50
100
150
200
250
300
350
400
Number of participants
NA38 S-U, 200 GeV
NA50 Pb-Pb, 158 GeV
NA60 In-In, 158 GeV
NA60 In-In, 158 GeV

Reconstruction

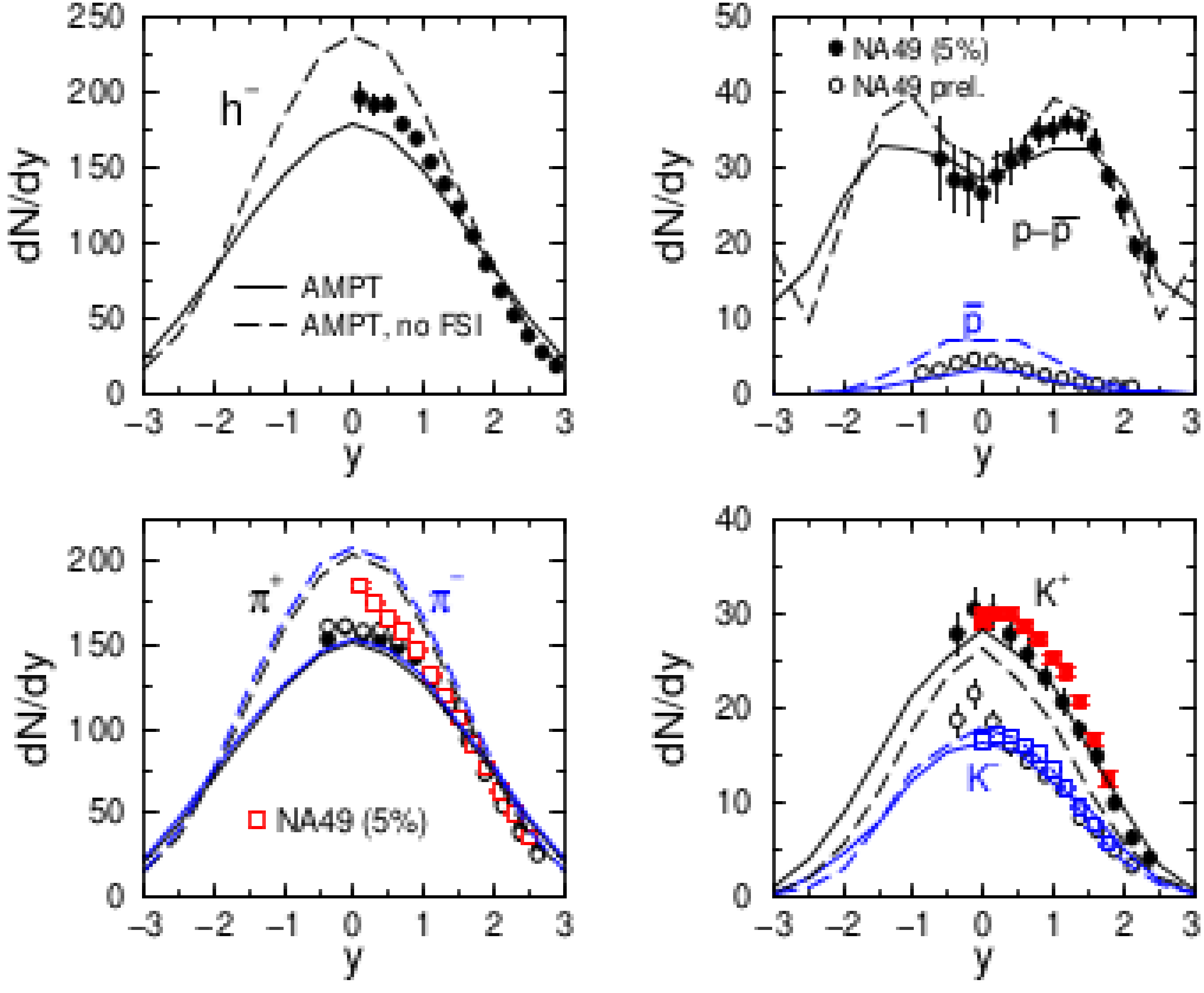
- → Track distance in VTPC1 + VTPC2 > 1m
- → Require hit at least in the three Vertex detector stations
- → NA61/SHINE Momentum resolutions is assumed

1. momentum resolution dp/p2 = 7.0 X 10-4(GeV/c)-1 **(Nuclear Instruments and Methods in Physics Research A 430 (1999) 210 - 244)**

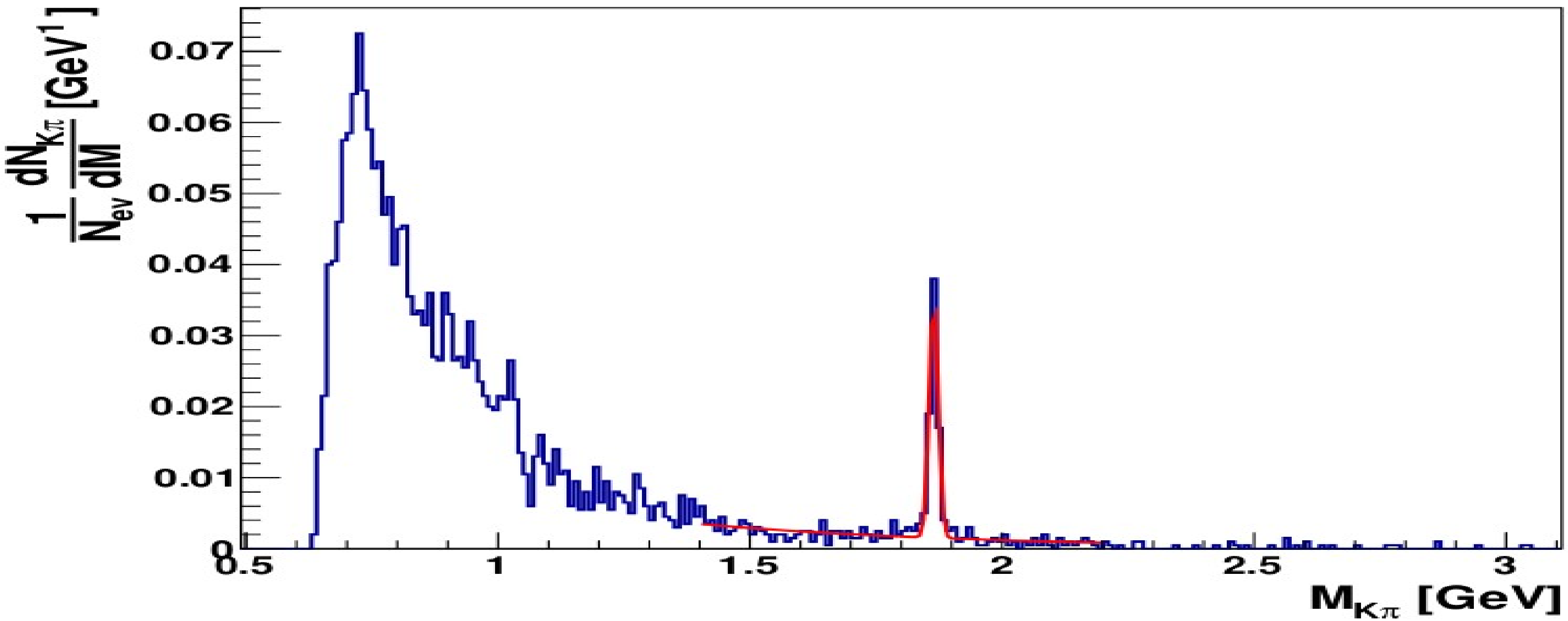
2. position resolution is 10 μm → hits are spread in y and x around geant hit according to the Gaussian distribution (σ = 10 μm).Track line is taken from the fit to the spread points



AMPT-MODEL



Reconstructed yield for D0→ K+ π-, 200k 0-10% cent. Pb+Pb at 158 AGeV

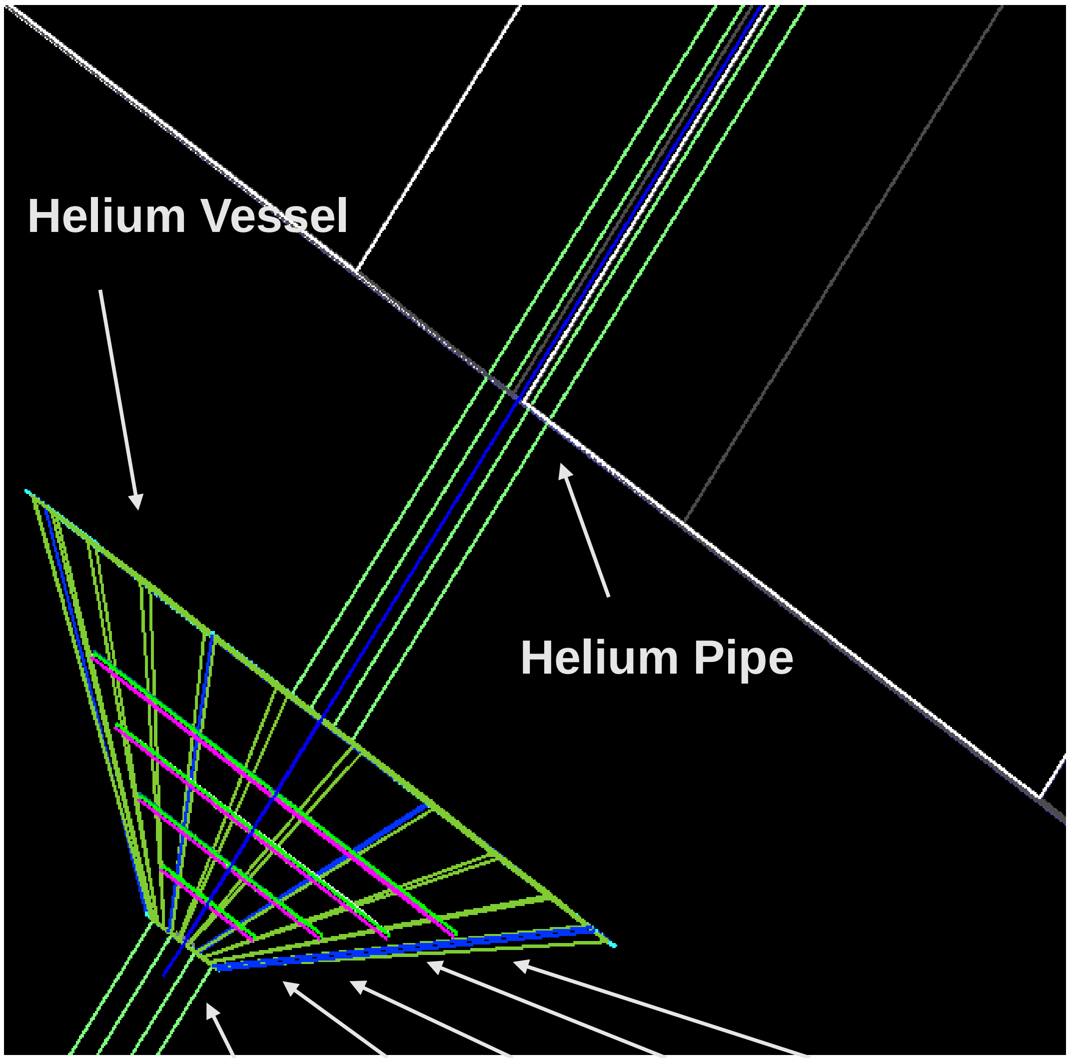


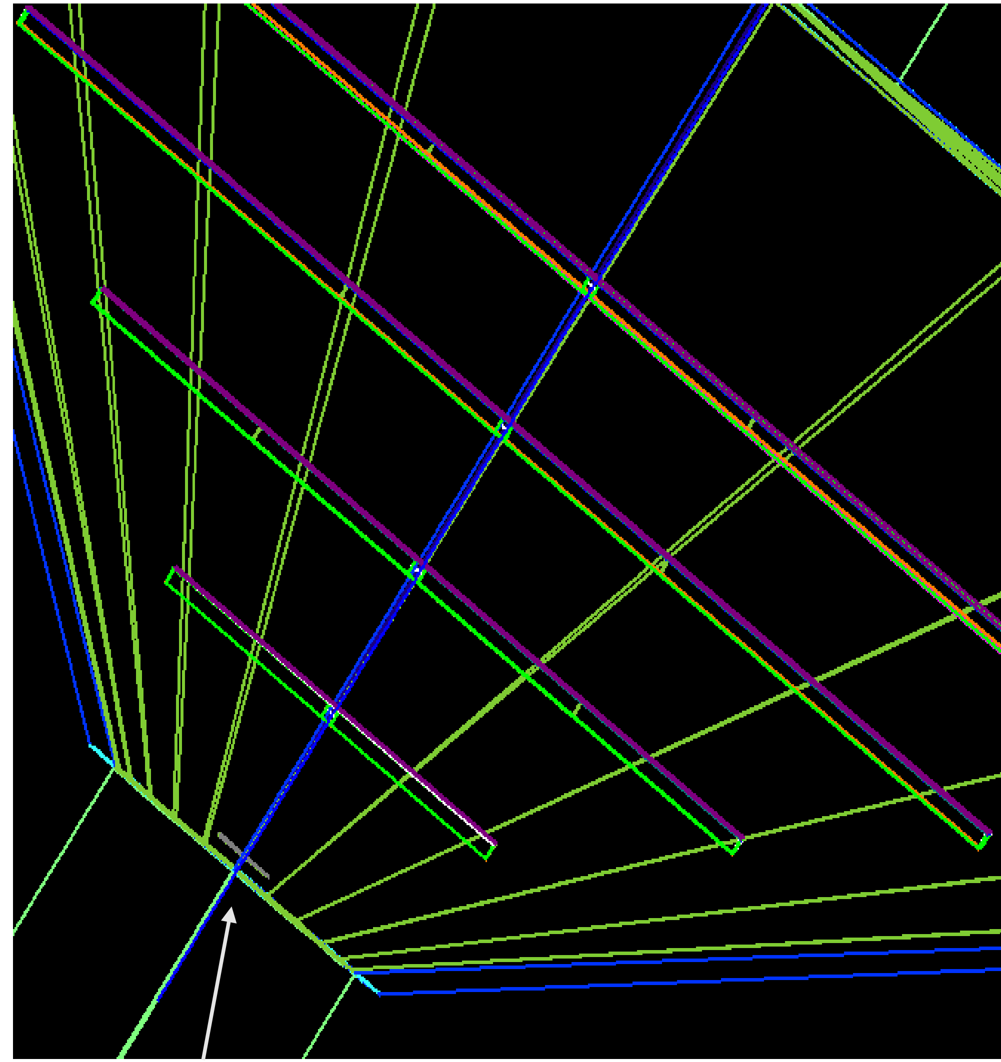
Pos. Res (μm)	10	10	15	15
Beam hole(mm)	2.5	3.0	2.5	3.0
S/B	9.6	10.0	4.5	6.5
Signal Significance (SNR) ★	209.6	199.4	175.4	174
$\langle D^0 \rangle + \langle \overline{D^0} \rangle$ ★	48K	43K	37K	36K

★ Results Extrapolated to 50M Events

Design of the Future Vertex Detector

Zoom in





VDS1 VDS2 VDS3 VDS4

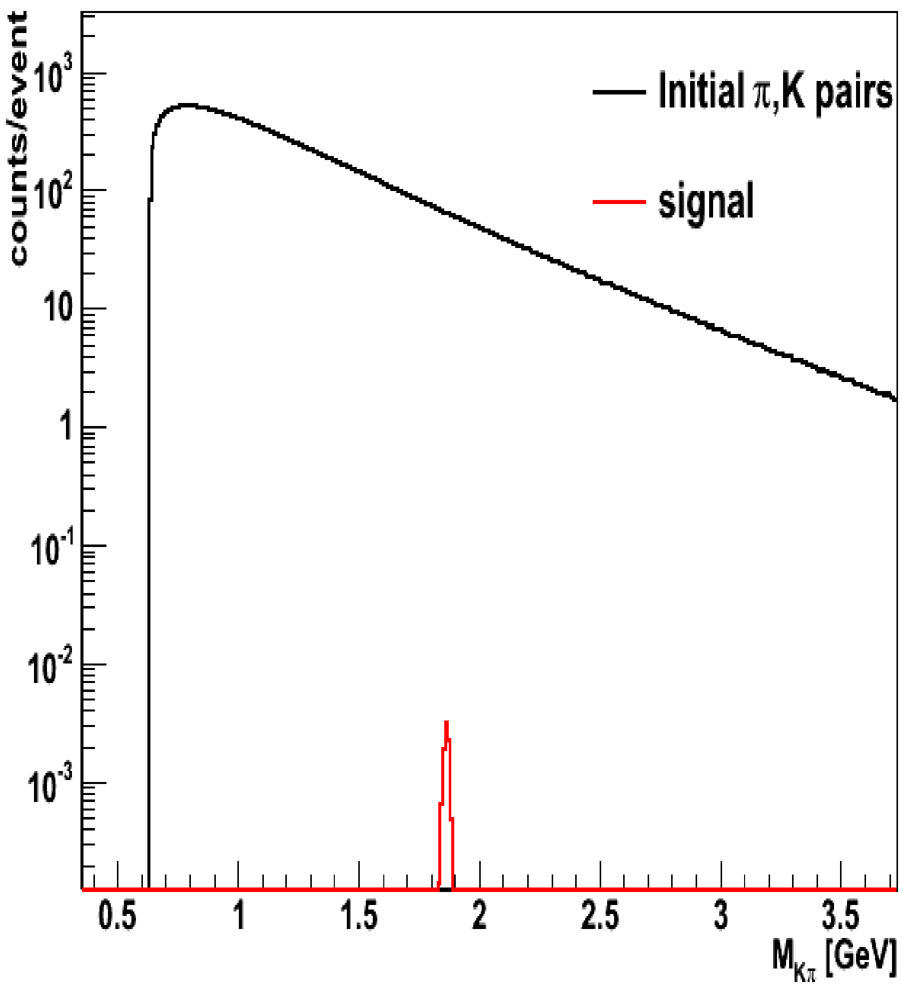
Pb target

beam pipe

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

Background Suppression strategy

→ Combinatorial background is very large → need to apply background suppression cuts.
→ Optimized to assure good signal Acceptance.



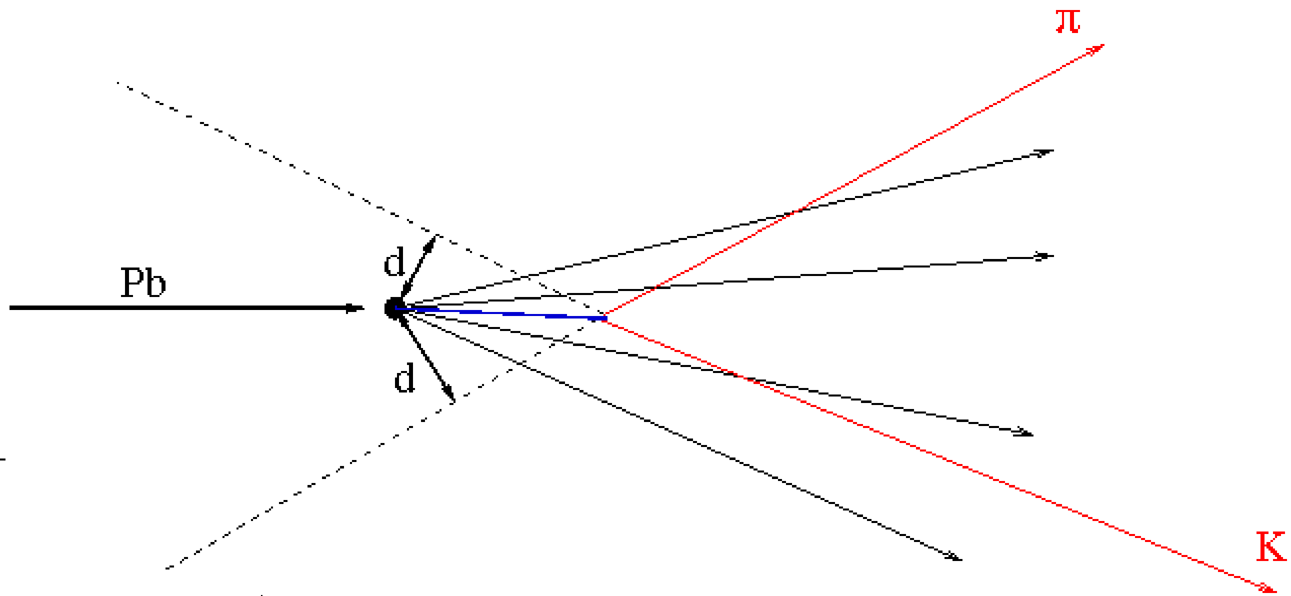
Single particle cuts:

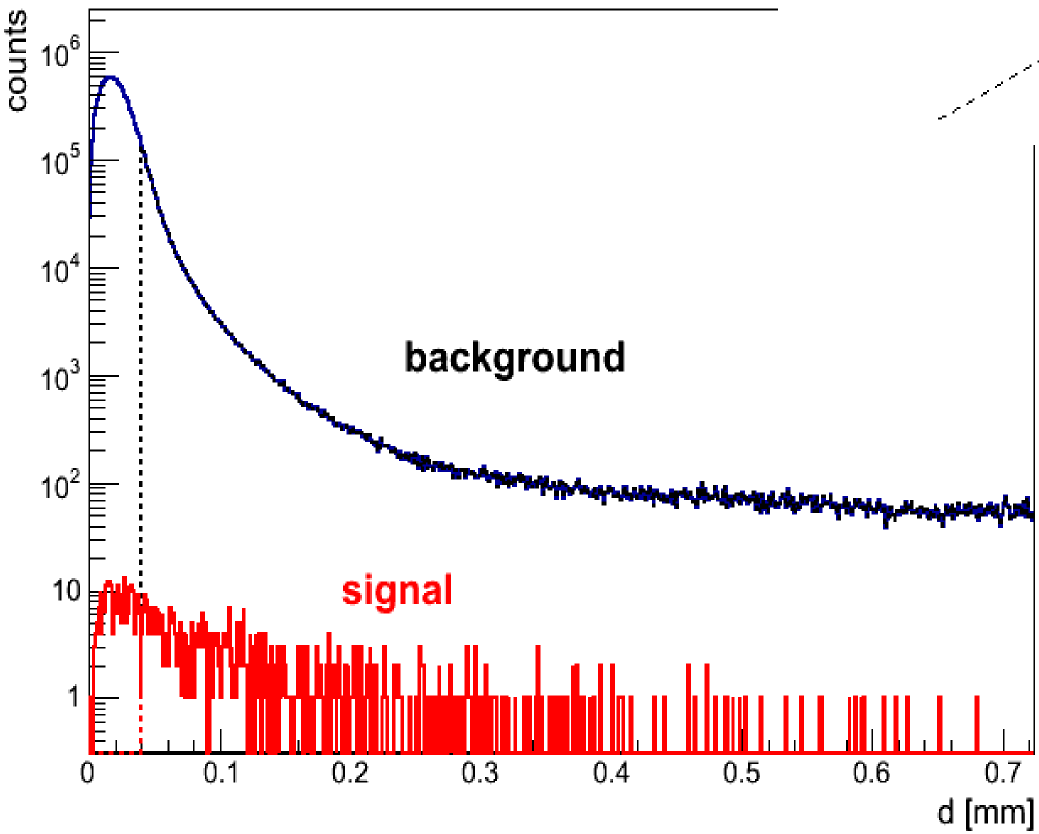
1. cut on **pT** (< 0.4)
2. cut (track impact parameter **d** (< 40µm)

Two particle cuts:

3. Cuts in Armenteros-Podolanski space to remove background from Ks and Λ
4. Two track vertex cut **Vz** (< 500µm)
5. Reconstructed parent impact parameter cut **D** (> 22µm)

2. Cut on **d**

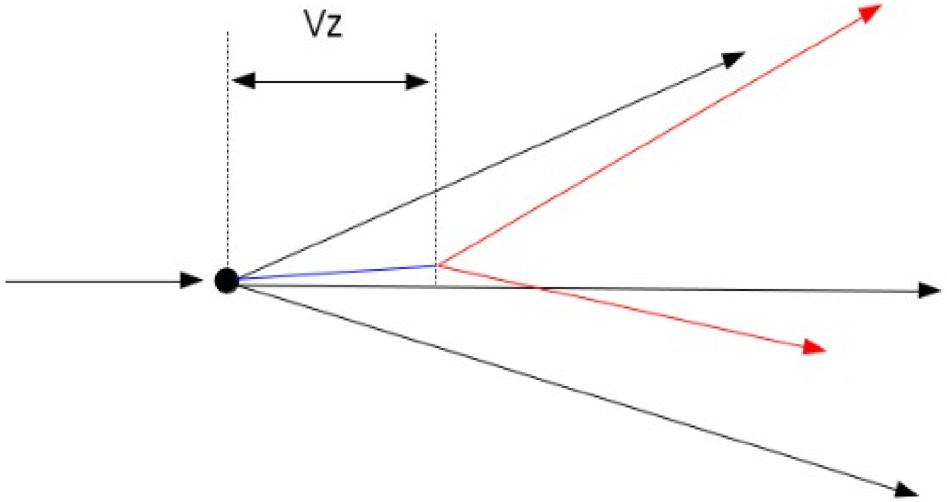


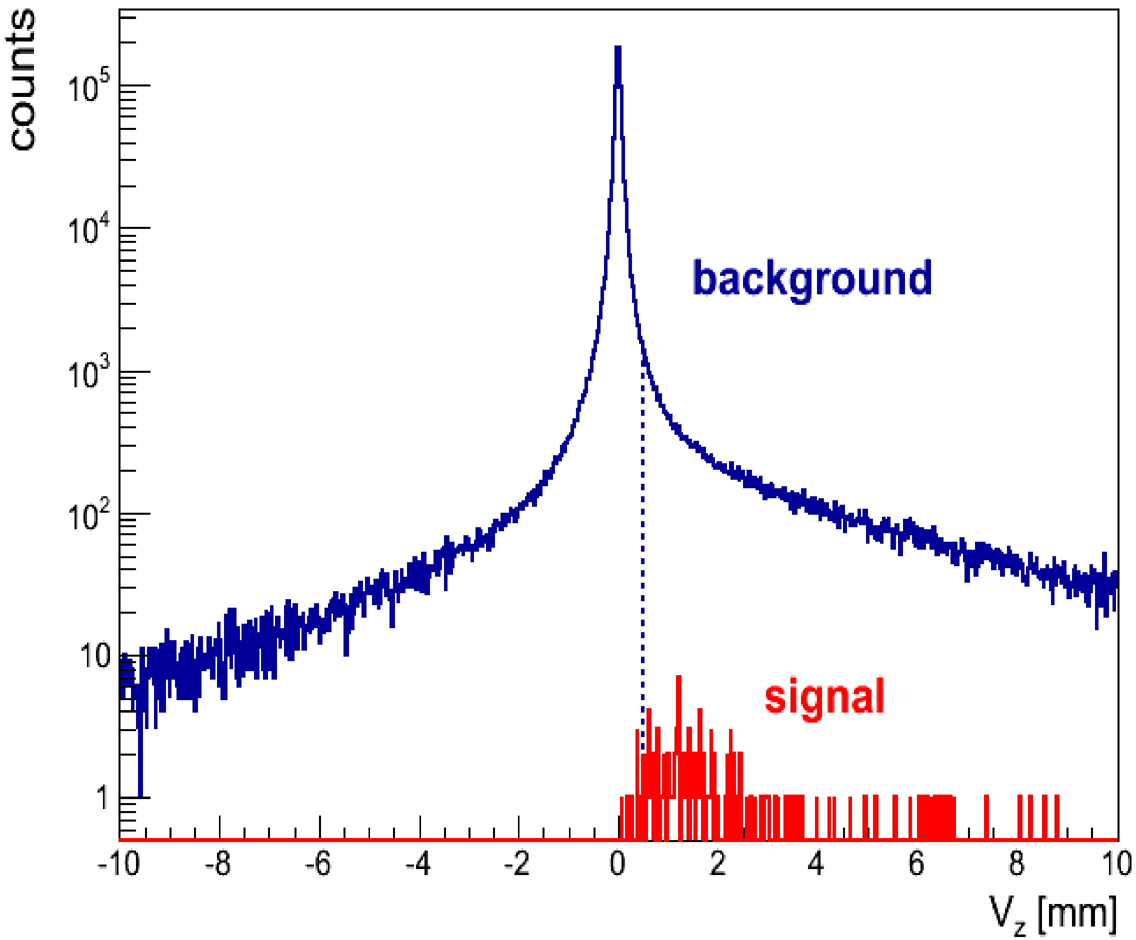


Relatively smooth shape of background at ~ 0 is due to uncertainly in reconstruction of track position and angle. Some uncertainly comes from multiple scattering.

→ cut on d < 40 μm as indicated

4. cut on **Vz**

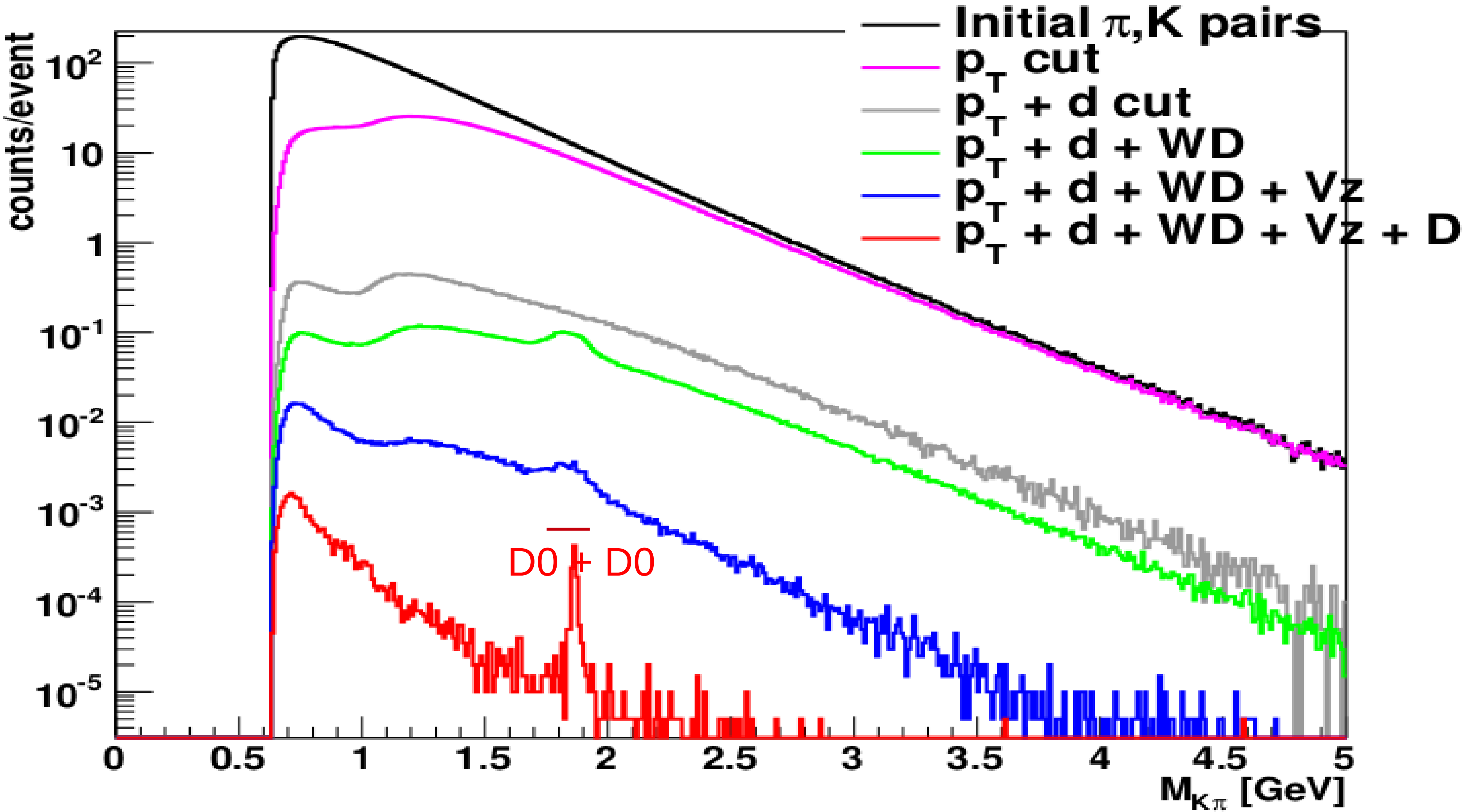




→ cut on **Vz** < 500 µm as require

Spectrum after selection Cuts

Reduction of Background ≈ 106
Reduction of Signal ≈ 3



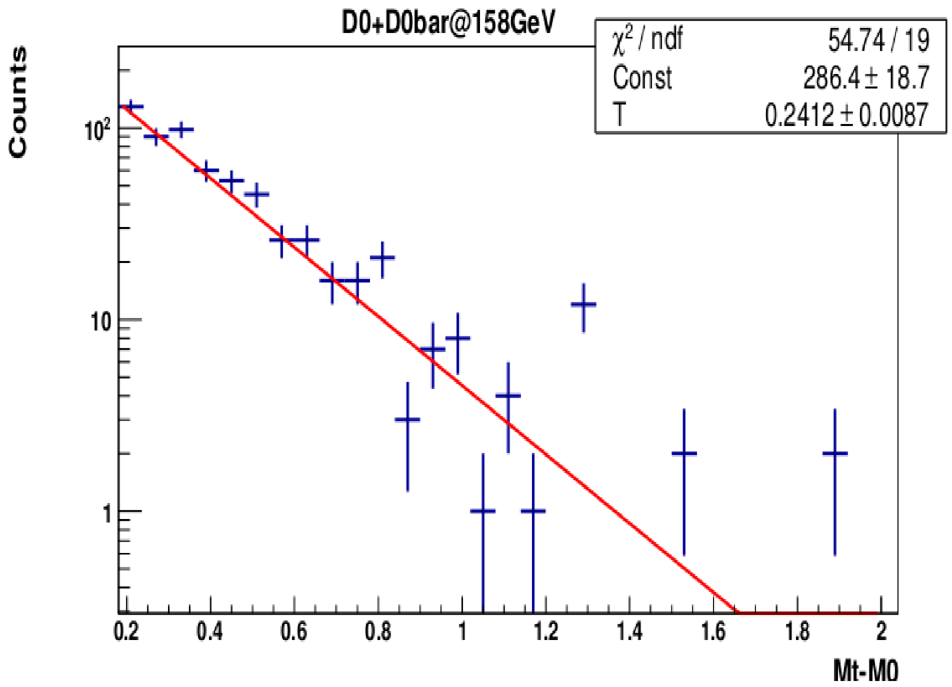
Parameters for 40 AGeV

AGeV energy the whole phase space (physical input) was not available by AMPT even

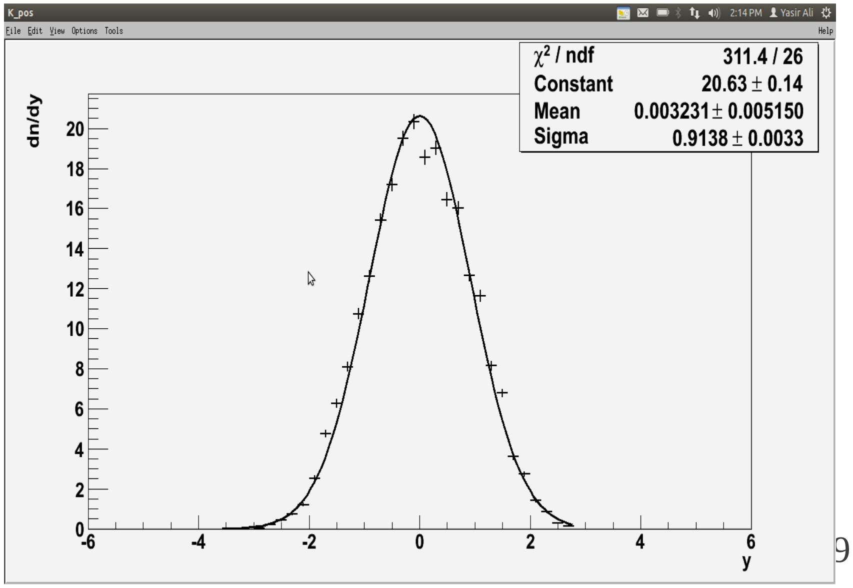
pidity distributions for kaons at both energies 40 and 158 AGeV and for D0 meson at 1

(40) = Sigma D(158)/Sigma D(40)

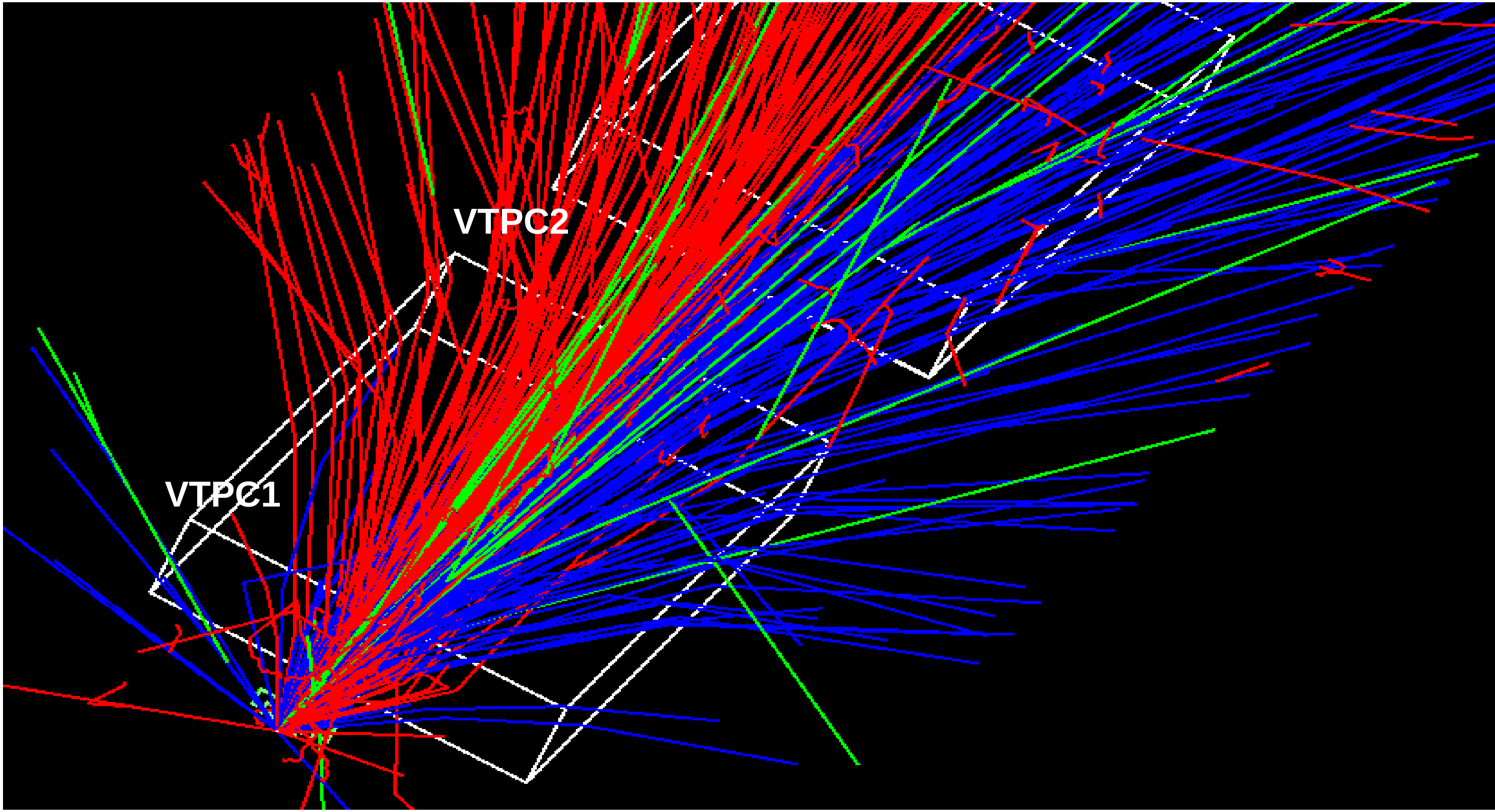
ansverse mass distributions By Fitting
ential Function A Exp(-mt/T)



Kplus @ 40 AGeV



Detector overview in GEANT simulation



→ VTPCs filled with Ar-CO2 mixture, location and dimensions as in Na61 setup.

→ Uniform magnetic field: 1.5 T in VTPC1 and 1.1 T in VTPC2

Background suppression strategy (Need to discuss)

List of cuts in the order they are applied

Single particle cuts:

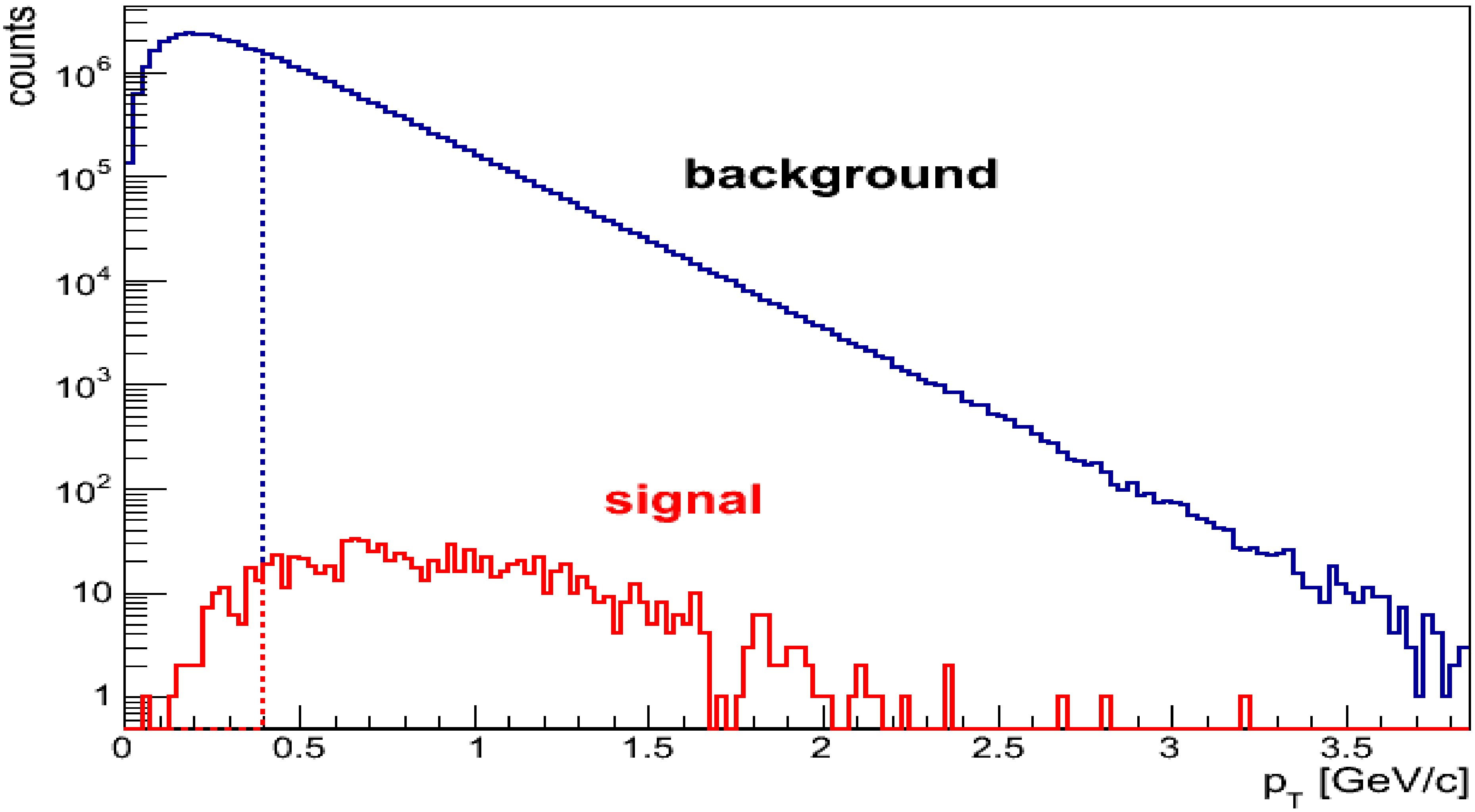
1. track **pT** cut
2. track **d** cut (track impact parameter)

Two particle cuts:

3. cuts in Armenteros-Podolanski space to remove background from Ks and Λ
4. two track vertex cut **Vz**
5. reconstructed parent impact parameter cut **D**

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

1. cut on **pT**



Background pT spectrum has maximum around ~ 0.2GeV/c, wheres maximum of signal distribution is at around 1 GeV/c

→ cut on pT<0.4 as indicated

Charged Particle Fluxes

Sources of particles hitting VD:

1. Charged particles produced in Pb+Pb interactions.
   - during spill the anticipated beam intensity is 105 Pb ions per second.
   - for 200 μm 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 → 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

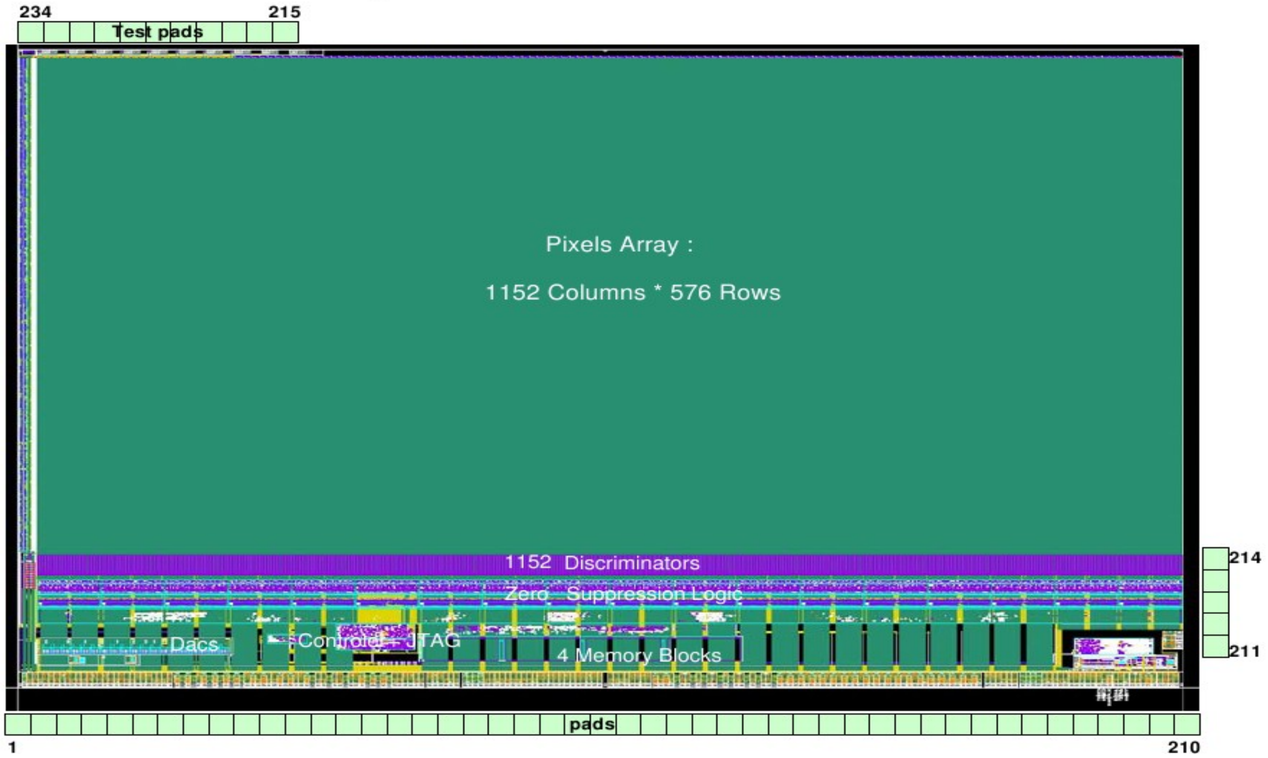
→ the influence of the production threshold cut has to be studied

MIMOSA-26

- The following conceptual drawings are based on MIMOSA-26 chip hosting sensitive area of about 1.06 x 2.12 cm2 with the pixel pitch equal 18.4 µm (~663.5k pixels/chip):

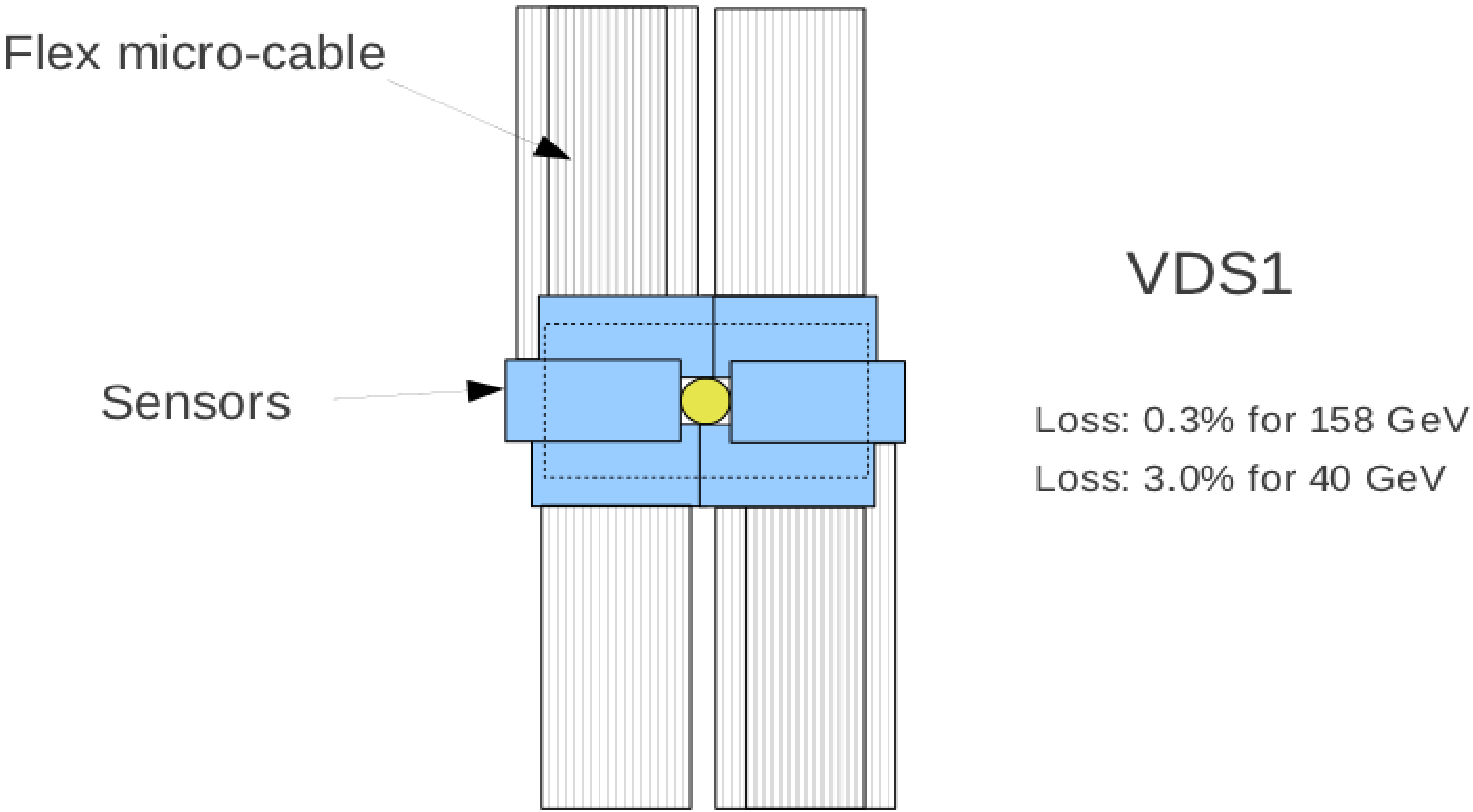
These pads are for testing purpose and can be removed

4.1 MIMOSA26 Pad Ring and Floor Plan View



- The readout speed of the whole fame in ~100 µs (10 kHz), zero suppression circuit.
- The chips are available. We can just buy them from IPHC (Institut Pluridisciplinaire Hubert Curien), Strasbourg

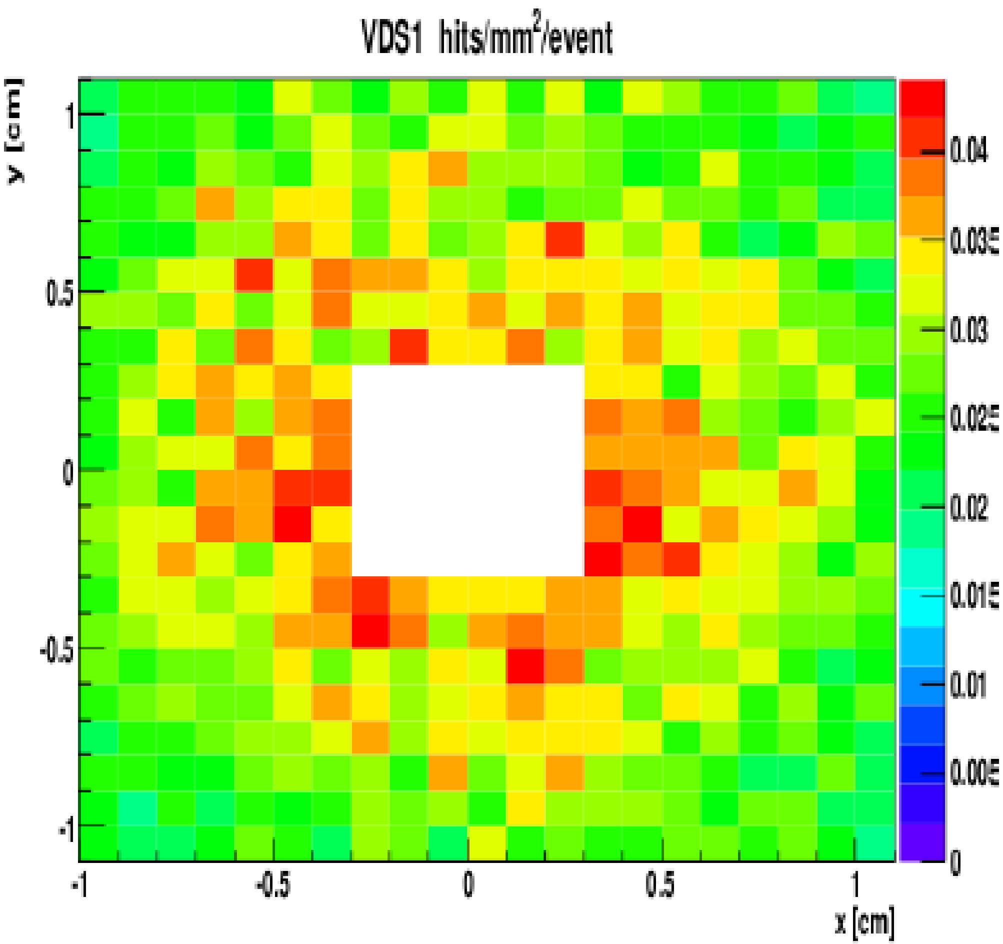
Preliminary design of the 1st station



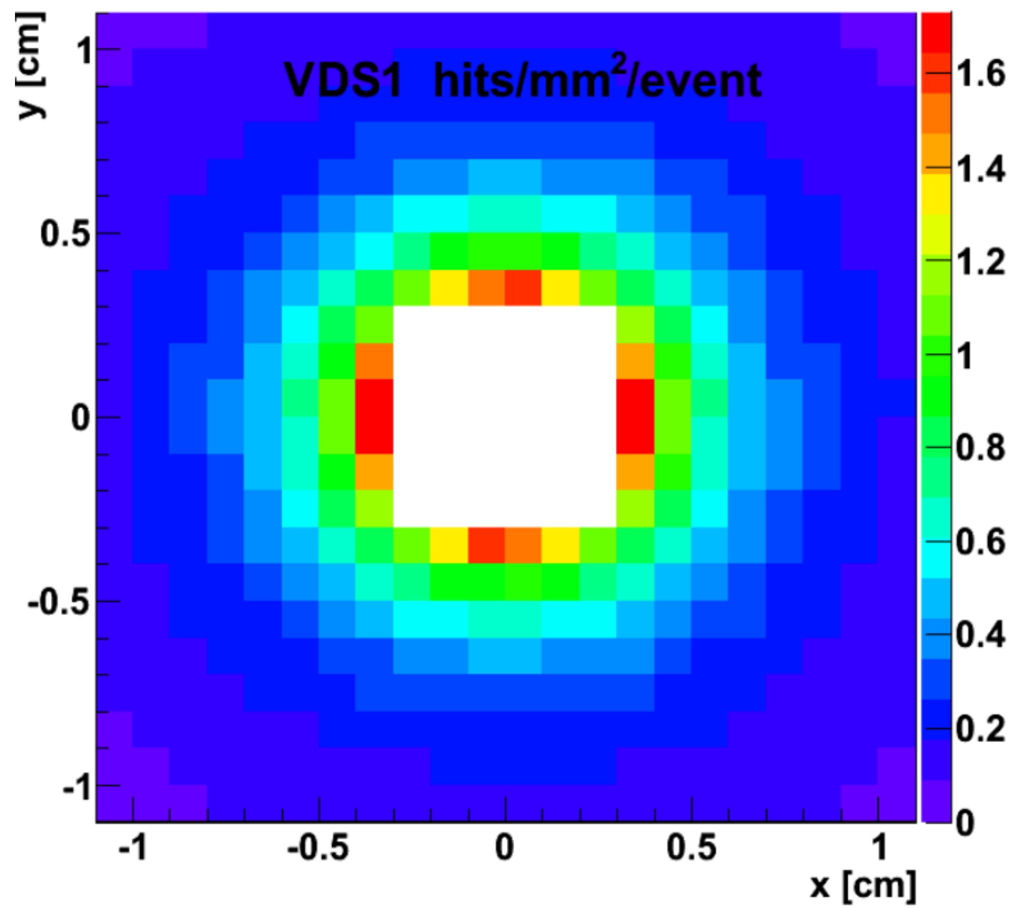
- Drawn blue boxes have dimensions of the sensitive area of MOMOSA-26 sensor (~1x2 cm2)
- Size of the dashed box is ~ 2x4 cm2. We have to cover this area to loose less than 0.3% / 3% of signal particles for 158 / 40 GeV

δ-electrons and charge particles produced in Pb+Pb interaction

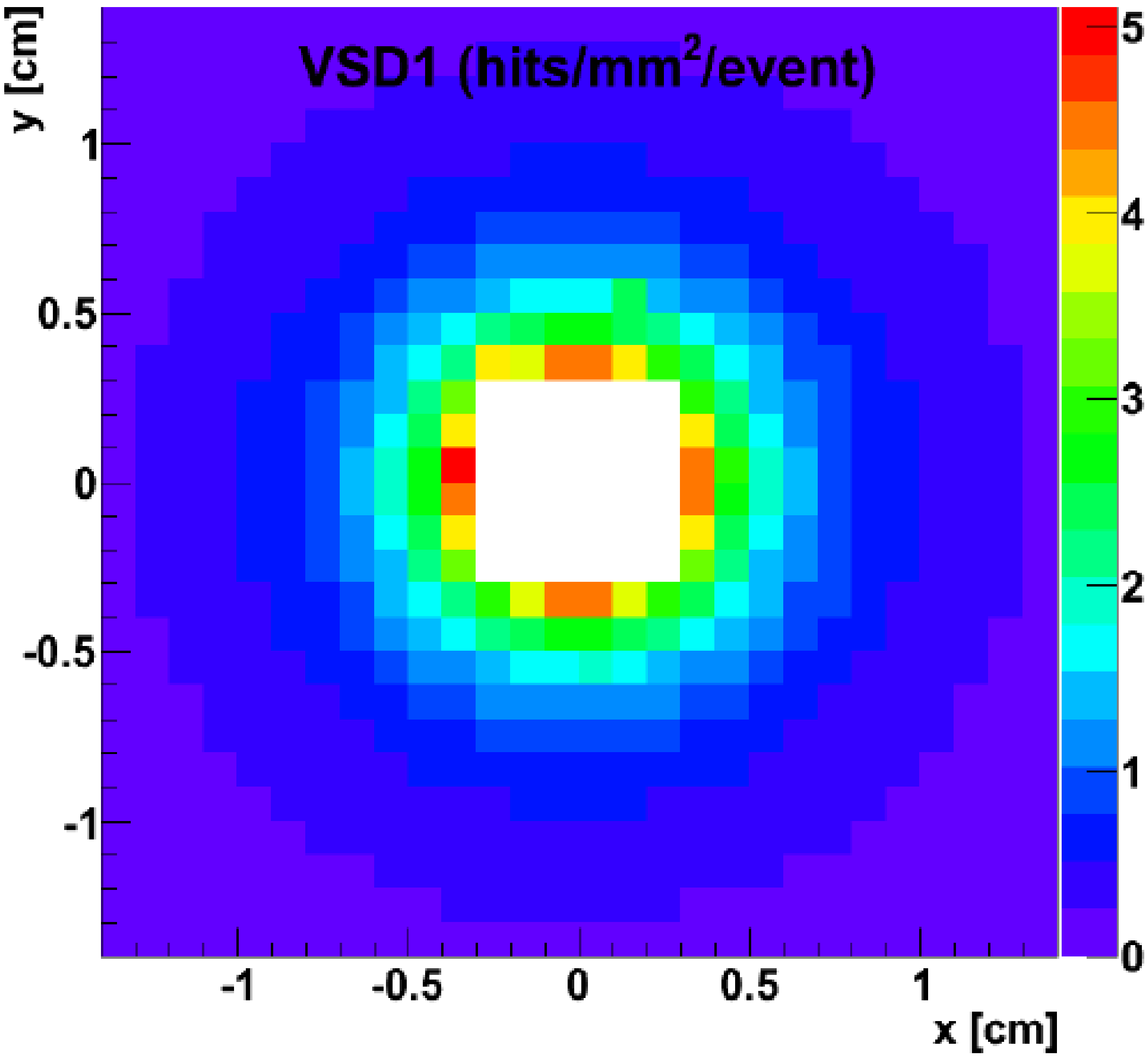
Delta electrons
(averaged over 10k Pb events)



Charged particles produced in
Pb+Pb interactions



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



- We can expect very high hit occupancy on the level of 5 hit/mm2/event in the most inner part of the vertex detector.

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

Particle Flux:

- During spill the anticipated beam intensity is 105 Pb ions per second.
- For 200 μm Pb target interaction probability is 0.5% which leads to 500 Hz interaction rate

Hadronic interactions:

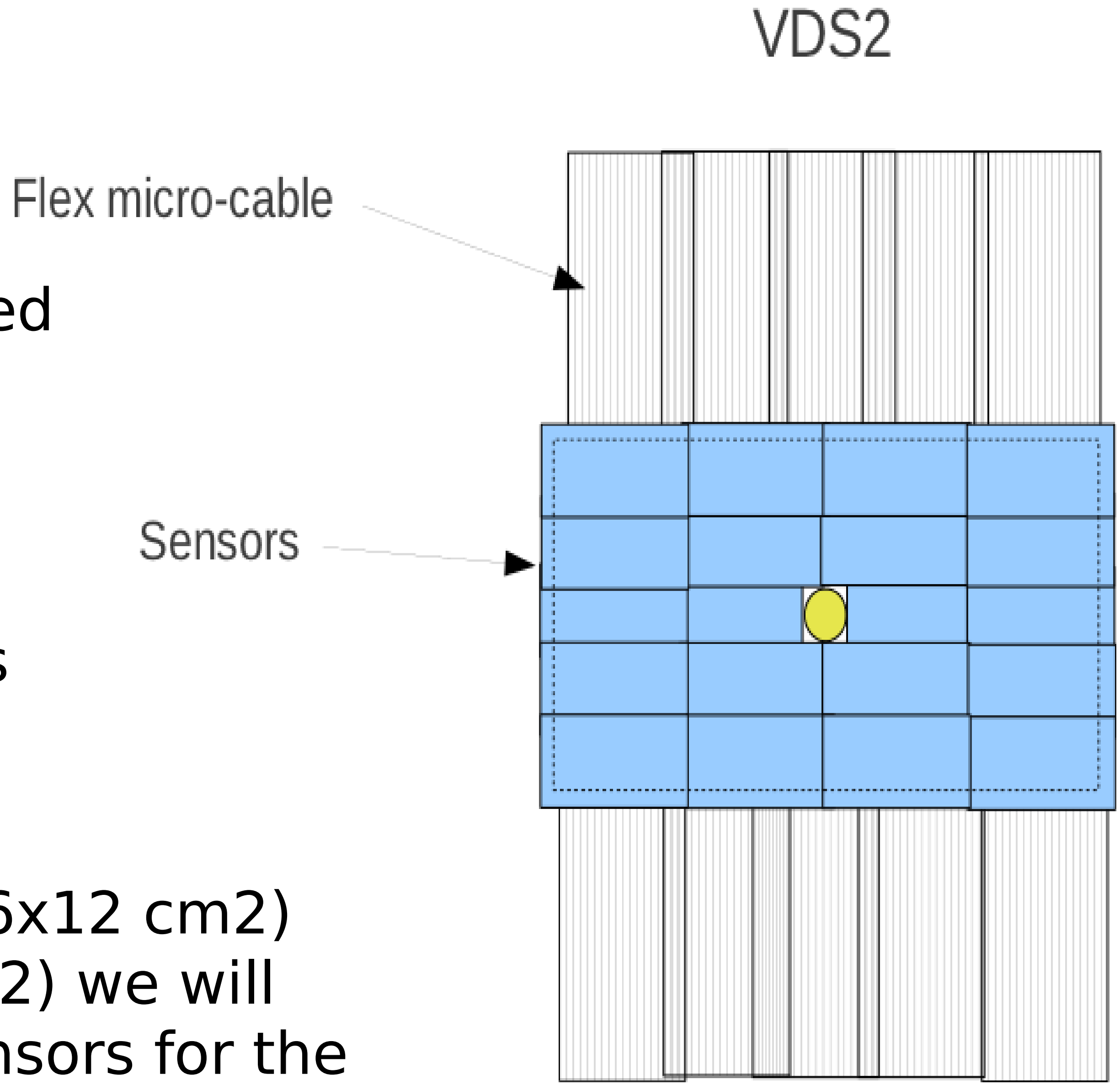
flux = (105 * 0.005) event/s * 1.6 particles/mm2/event =
= 800 particles/mm2/s = 800 Hz/mm2

Electromagnetic interactions (δ-electrons):

flux = 105 event/s * 0.04 particles/mm2/event =
= 4000 Hz/mm2

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

Preliminary design of the 2nd station

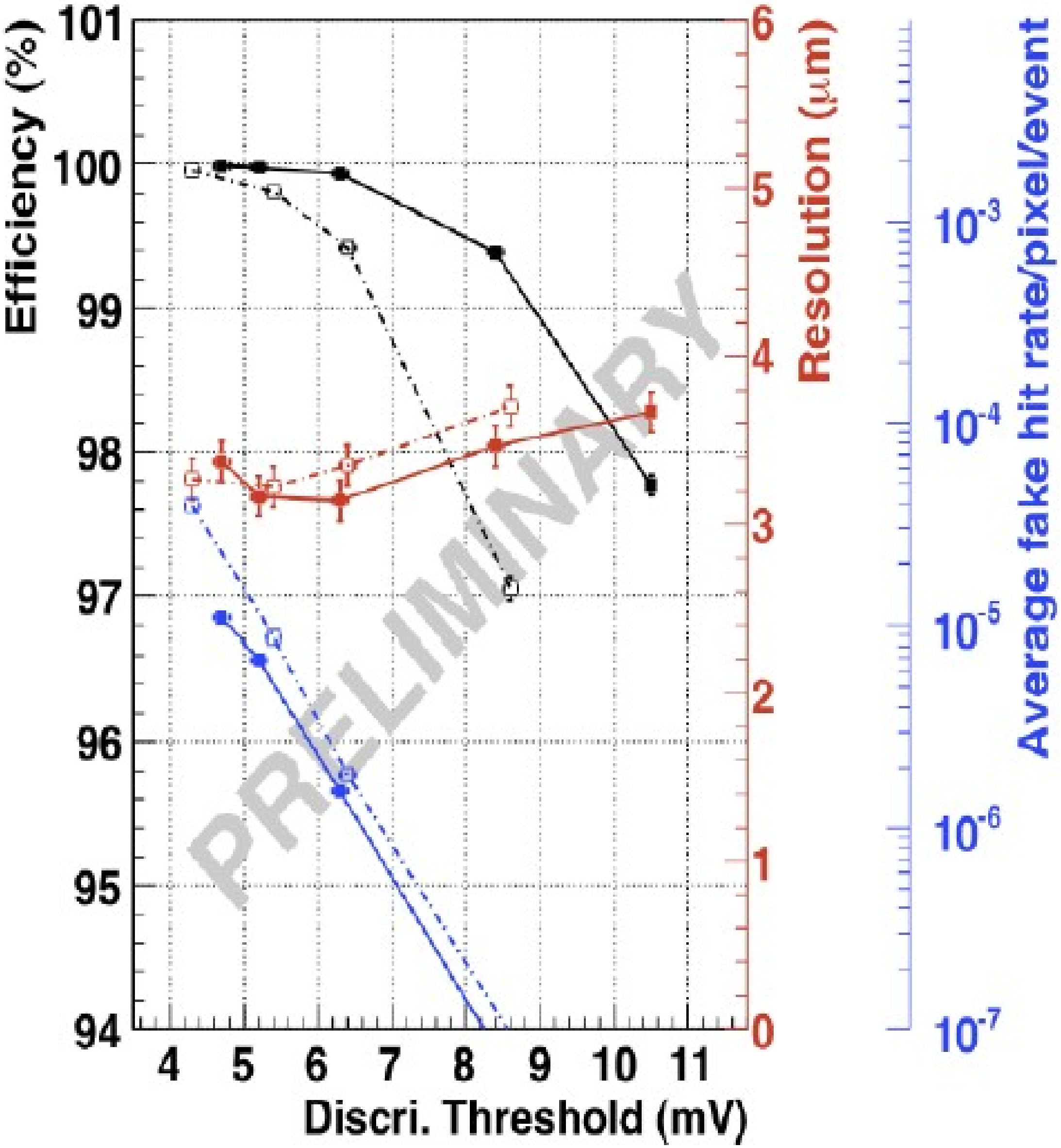


- Size of the dashed box is ~ 4x8 cm2
- full coverage of Vds2 area with MOMOSA-26 requires 20 sensors

- Including Vds3 (6x12 cm2) and Vds4 (8x16 cm2) we will need about 120 sensors for the whole detector.

Fluence estimates

Performance of MIMOSA-26 → test on beam



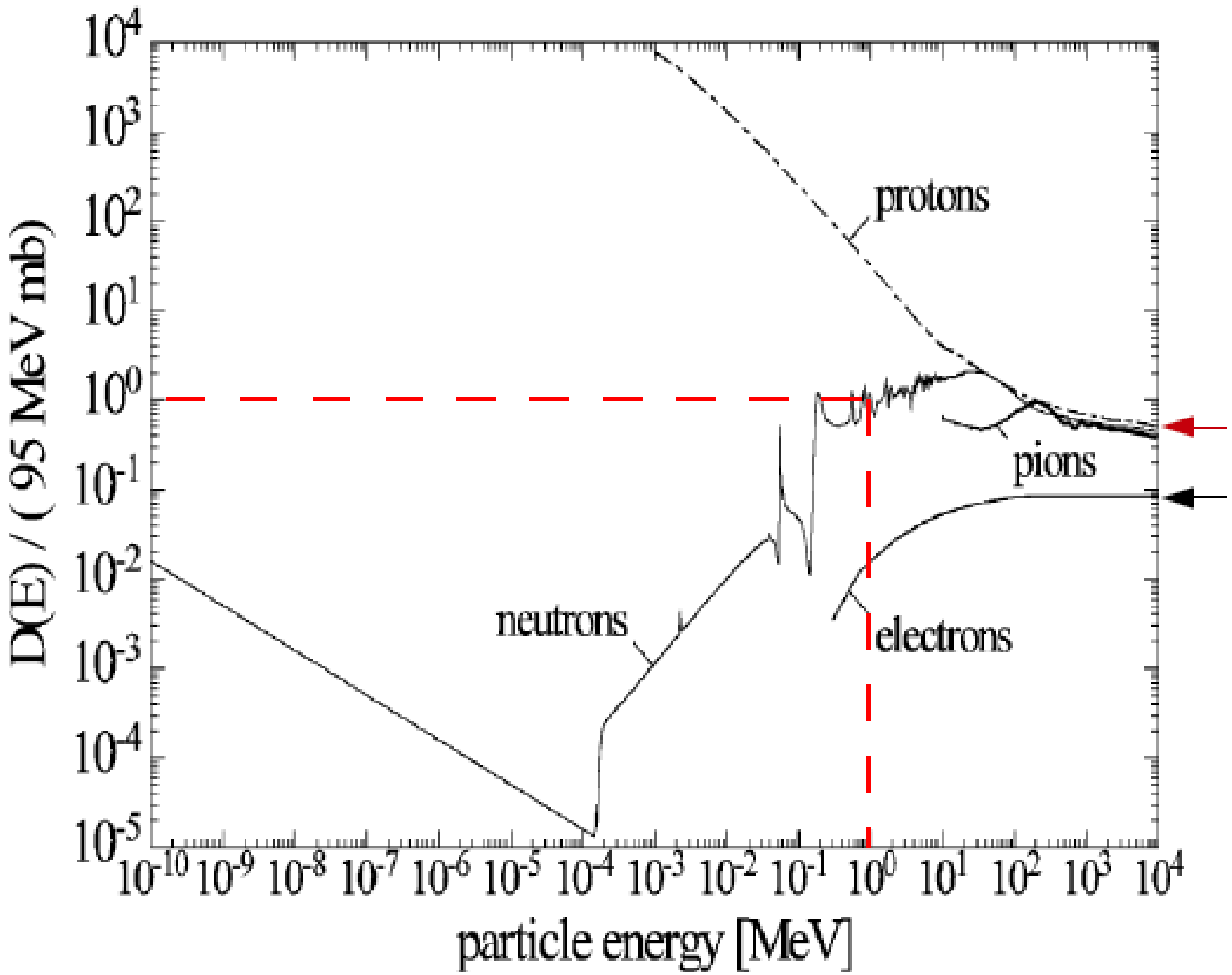
Temperature: + 30^0 C
Readout Time: 125 μs
Pitch size : 20.7 μm
Irradiated with to
fluence = 3 x 10^{12} n$_{eq}$/cm^2

For disc. Threshold= 5 mV:
detection efficiency ~ 99.8%,
fake hits < 10^{-4}
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/mm2/event = 800 Hz/mm2

Electromagnetic interactions (δ - electrons):
flux = 105 event/s * 0.04 particles/mm2/event = 4000 Hz/mm2

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

Fluence Calculations

Φeq 1MeV = ϰΦ ϰ - radiation hardness parameter

ϰ = 0.62/5 for electrons

ϰ = 0.62 for particles from hadronic interactions

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

= 4 x 105 /cm2/sec * 0.62/5 * 2592000 sec = 1.28 * 1011 neq/ cm2

For Spill of the beam (20%) = 2.57 * 1010 neq/cm2

→ Φ for charge Particles = 800 Hz/mm2

`

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

= 8 x 104 /cm2/sec * 0.62 * 2592000 sec = 1.28 * 1011 neq/ cm2

For Spill of the beam (20%) = 2.57 * 1010 neq/cm2

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/mm2/event for central Pb+Pb collisions
2. 1.6 tracks/mm2/event from averaging over minimum bias Pb+Pb collision
3. 0.04 δ-electrons/mm2/event for Pb ion on 200 μm 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 μs
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