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

Yasir Ali

For NA61/SHINE Collaboration

Strangeness in Quark Matter SQM 2013
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JAGIELLONIAN UNIVERSITY IN KRAKOW

SHINE NA61

Contents

Introduction

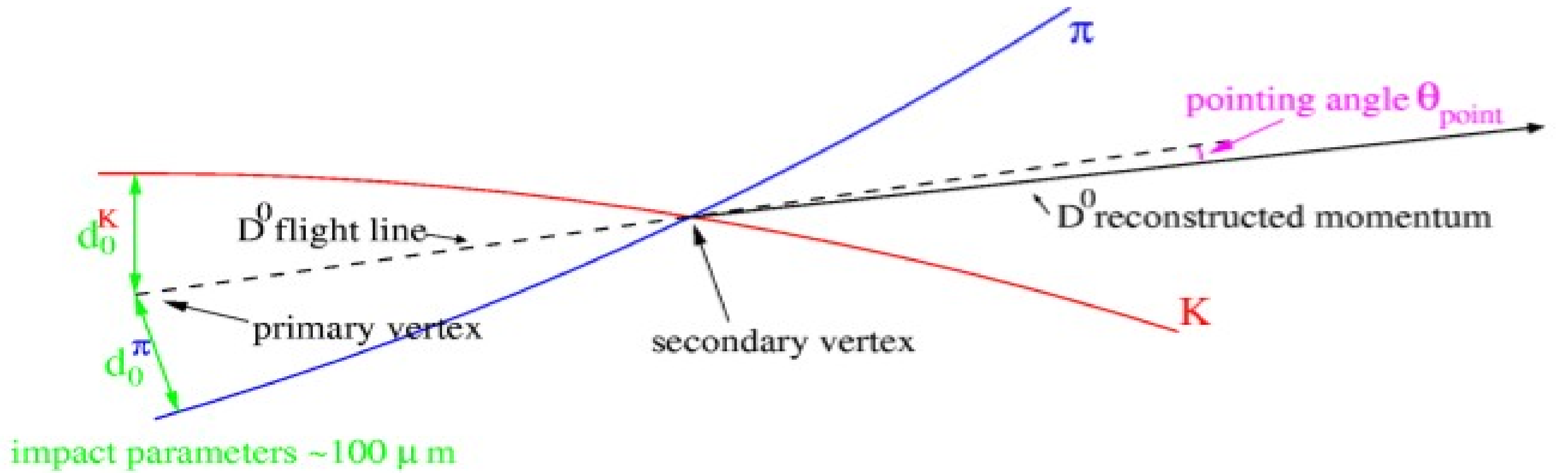
→ A feasibility study of $D^0 \rightarrow K^- \pi^+$ (BR=3.91%) channel in central Pb+Pb collisions at the CERN SPS energies will be presented. The study is done for 158 AGeV and 40 AGeV.

→ 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 D^0 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)%

Physics motivation

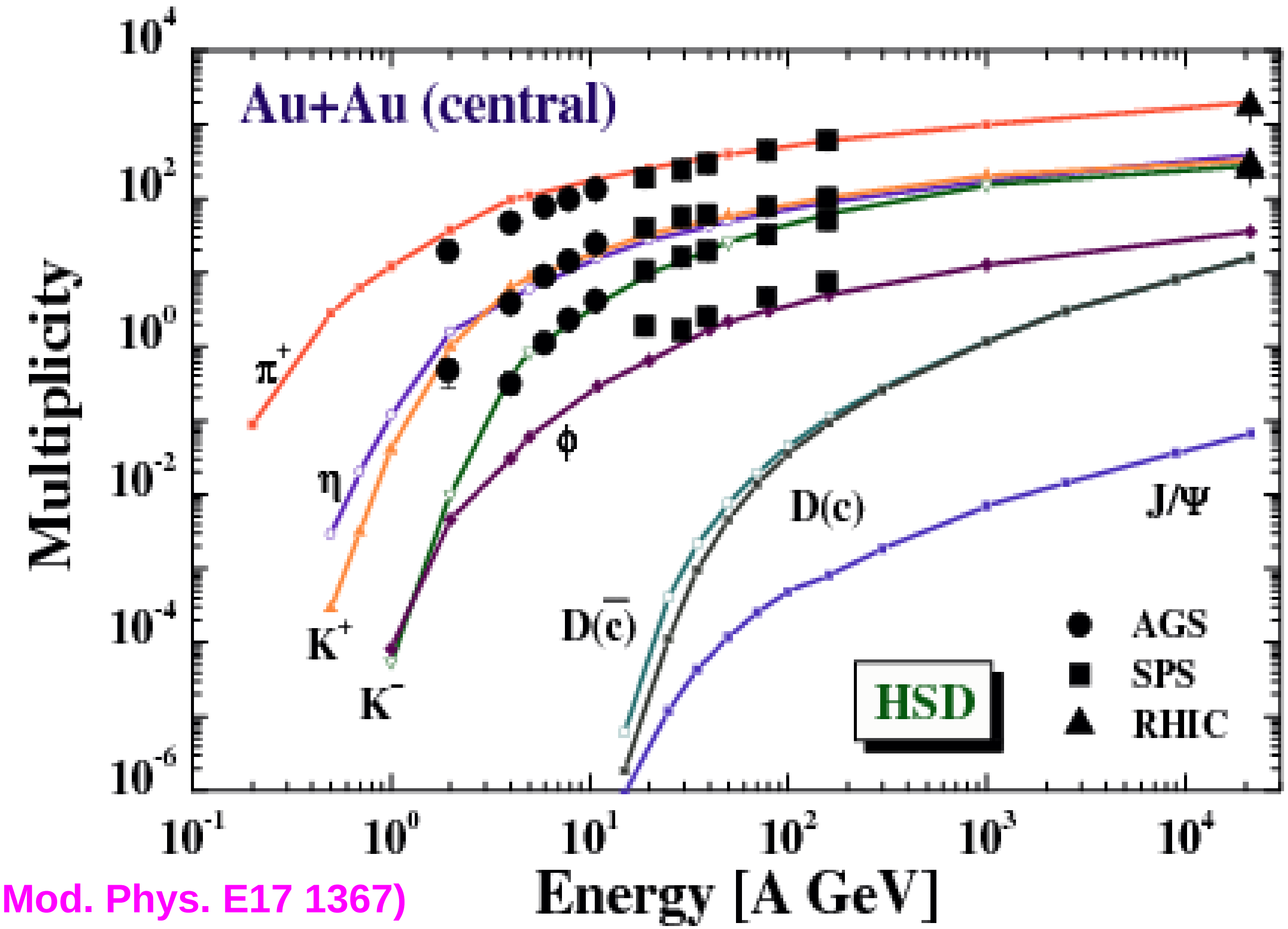
→ So far no direct open charm measurements at SPS energies

→ 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.

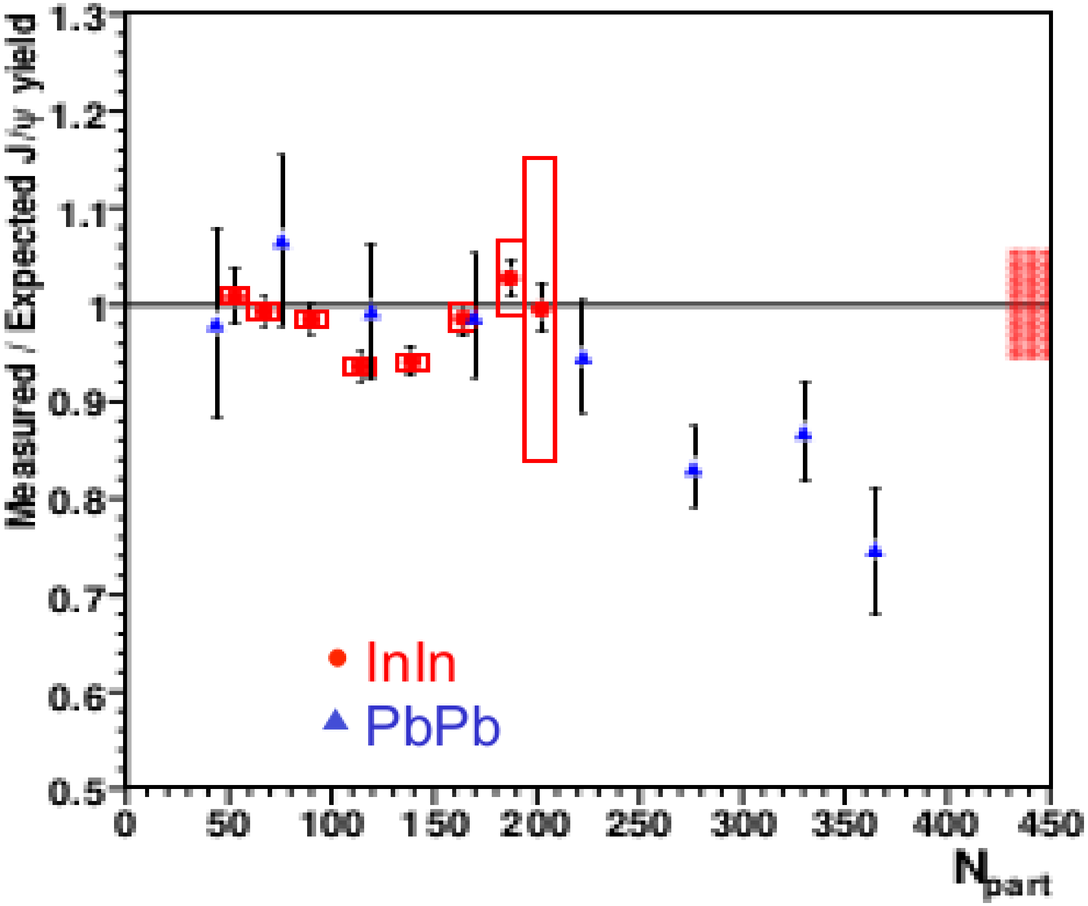
→ Measurement of J/ψ at top SPS energy (NA50,NA60) was performed

→ Anomalous suppression of J/ψ for central A+A collisions (N_{part}>200).

→ Attributed to QGP formation but other scerarious can not be ruled out.

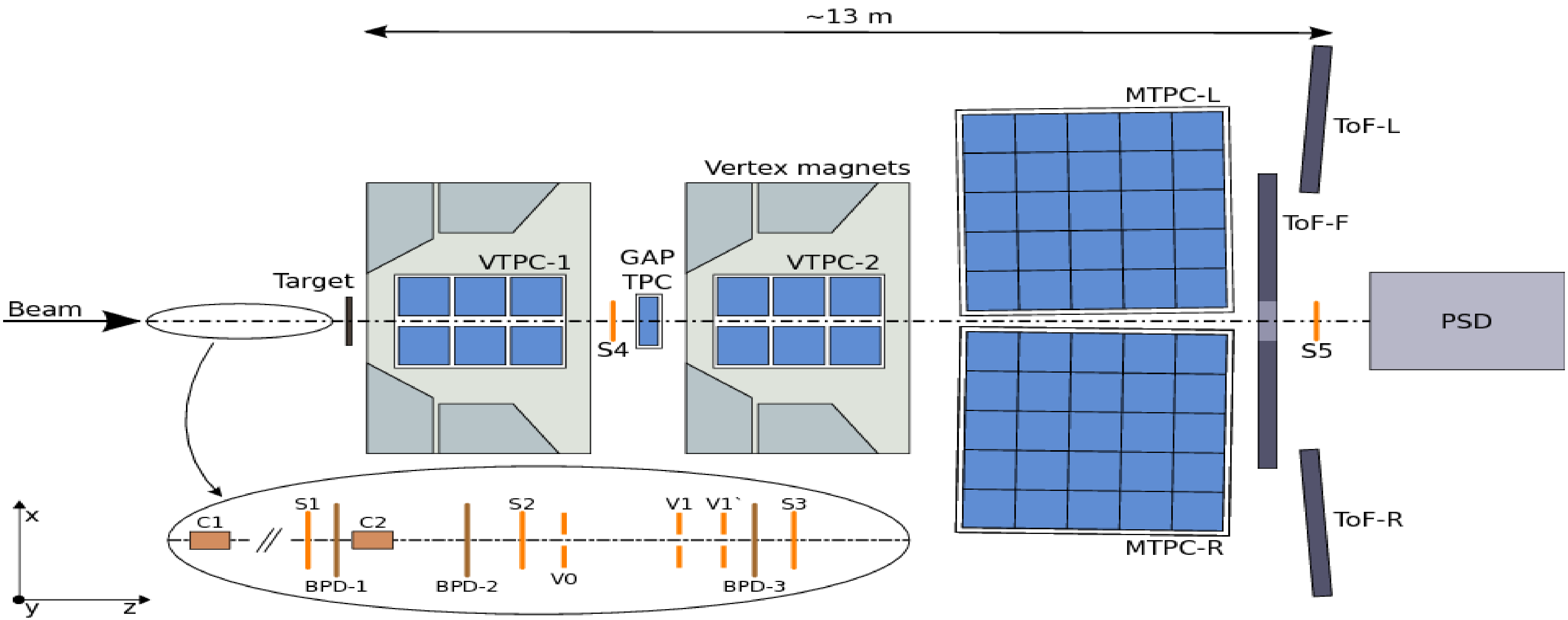
→ Measurement of charm production in open charm channel is requested **(Phys. Lett. B 178 416 1986)**

→ 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)

NA61/SHINE detector – Top view



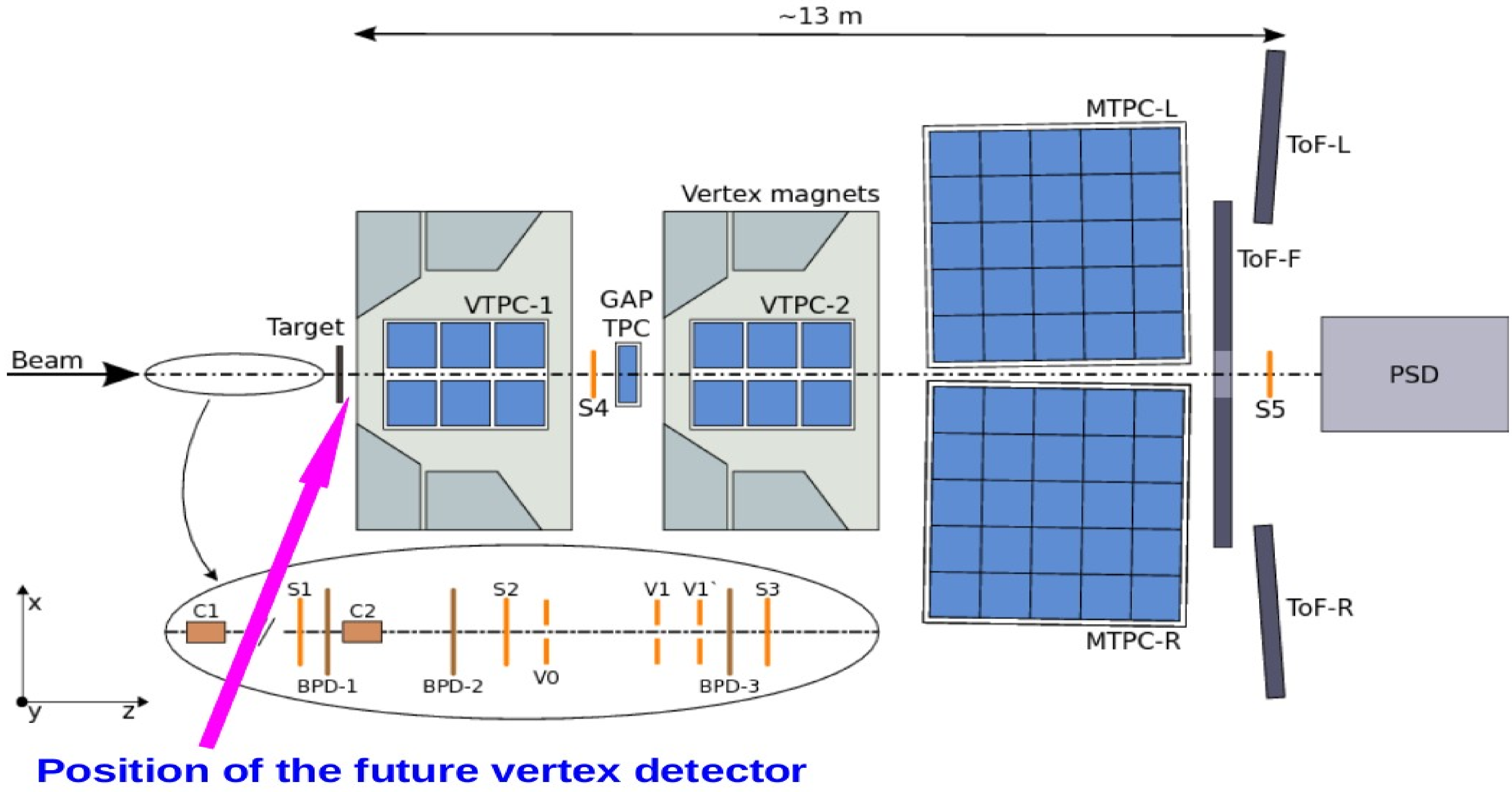
Beam detectors and triggering → A set of upstream scintillator and Cherenkov counters and beam Position detectors provides timing reference, charge and position measurements

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 <D0> + <$\overline{D0}$> per central Pb+Pb event. this seems to be under-predicted value.

→ The prediction of the HSD model is ~0.2. HSD model was tuned to properly describe available p+A and π+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

→ 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

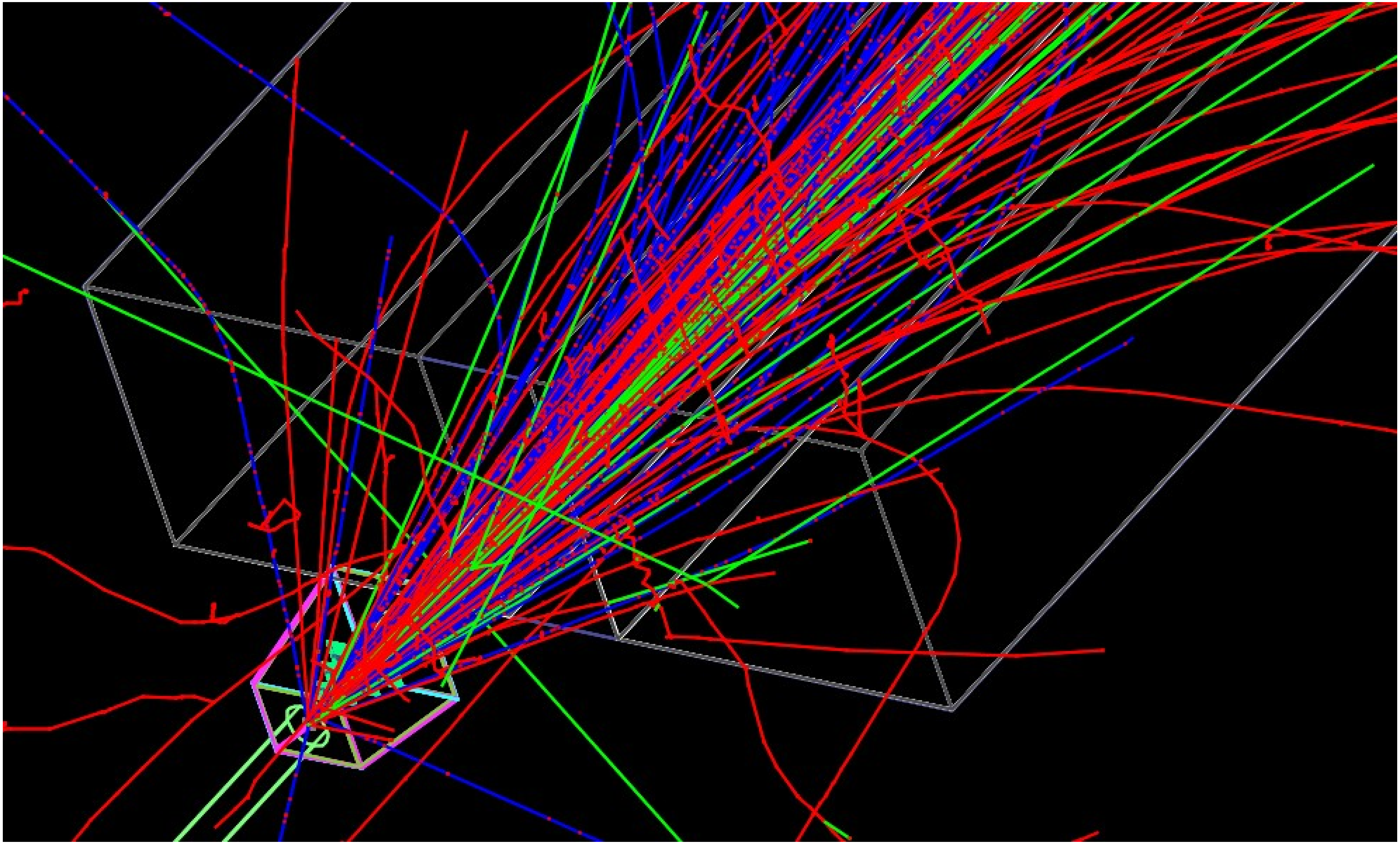
→ We assumed similar changes for D0 as we observe for Kaons and its yield as predicted by HSD model.

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

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

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

AMPT Event: Pb+Pb at 158 AGeV

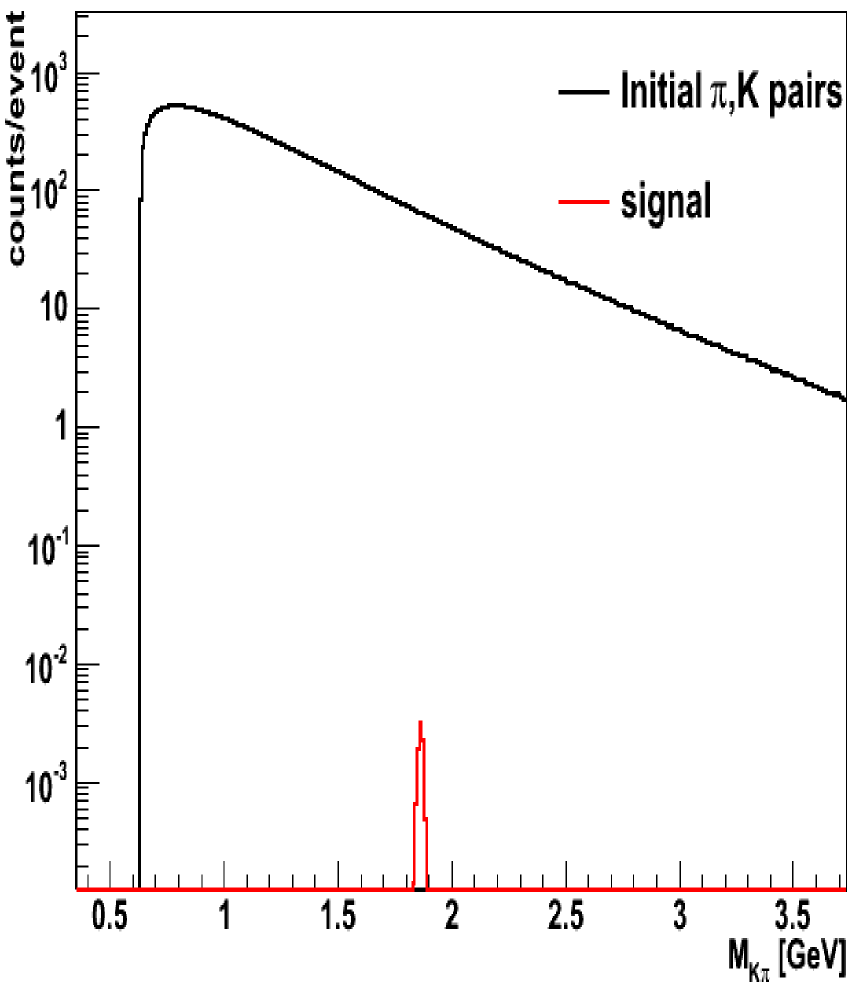


→ **VTPCs filled with Ar-CO_2 mixture, location and dimensions as in NA61/SHINE experimental setup.**

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

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** (< 0.325)
2. cut (track impact parameter **d** (<0.032)

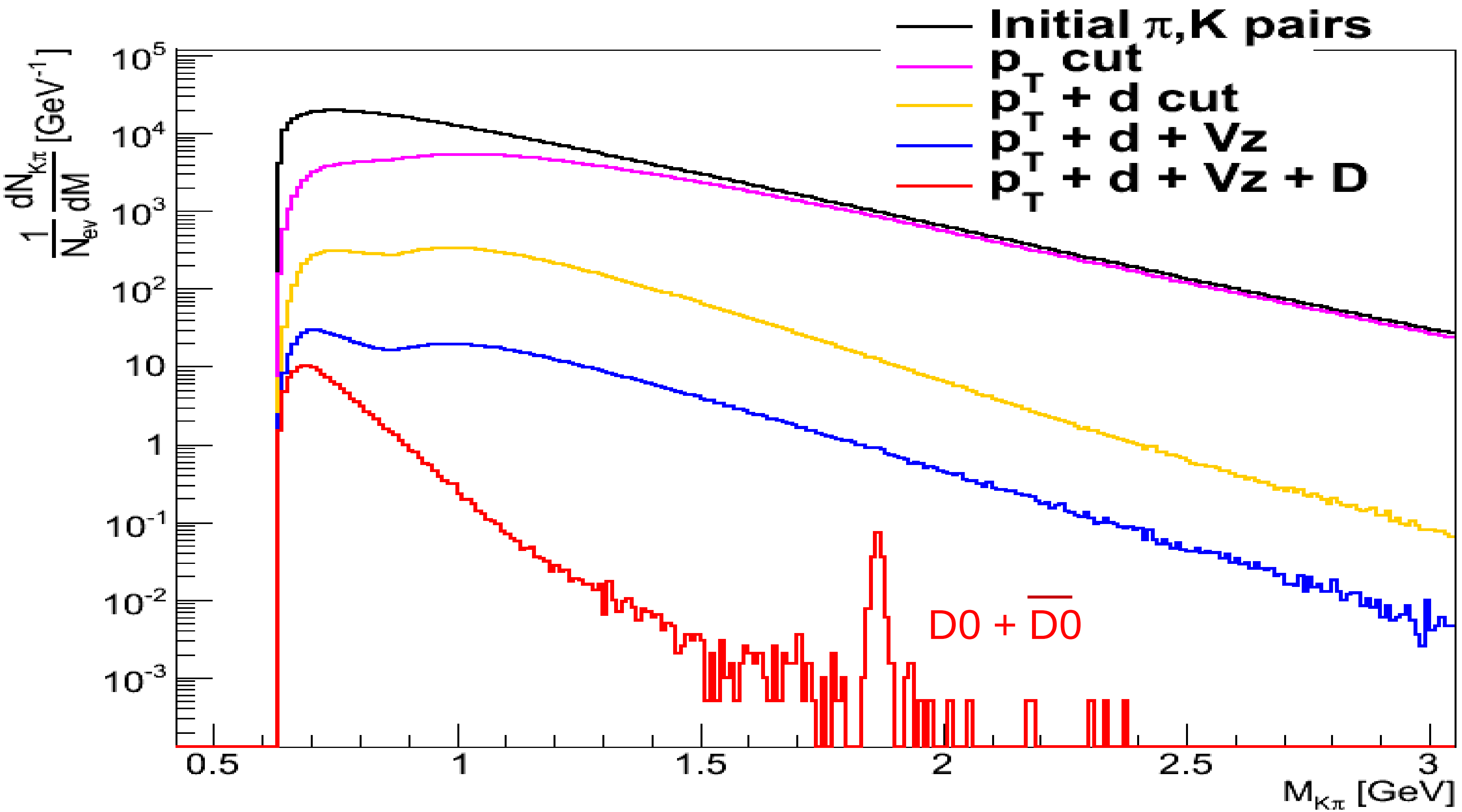
Two particle cuts:

3. Track pair vertex cut $\boldsymbol{V_z}$ (< 0.4)
4. Parent impact parameter cut **D** (> 0.02)

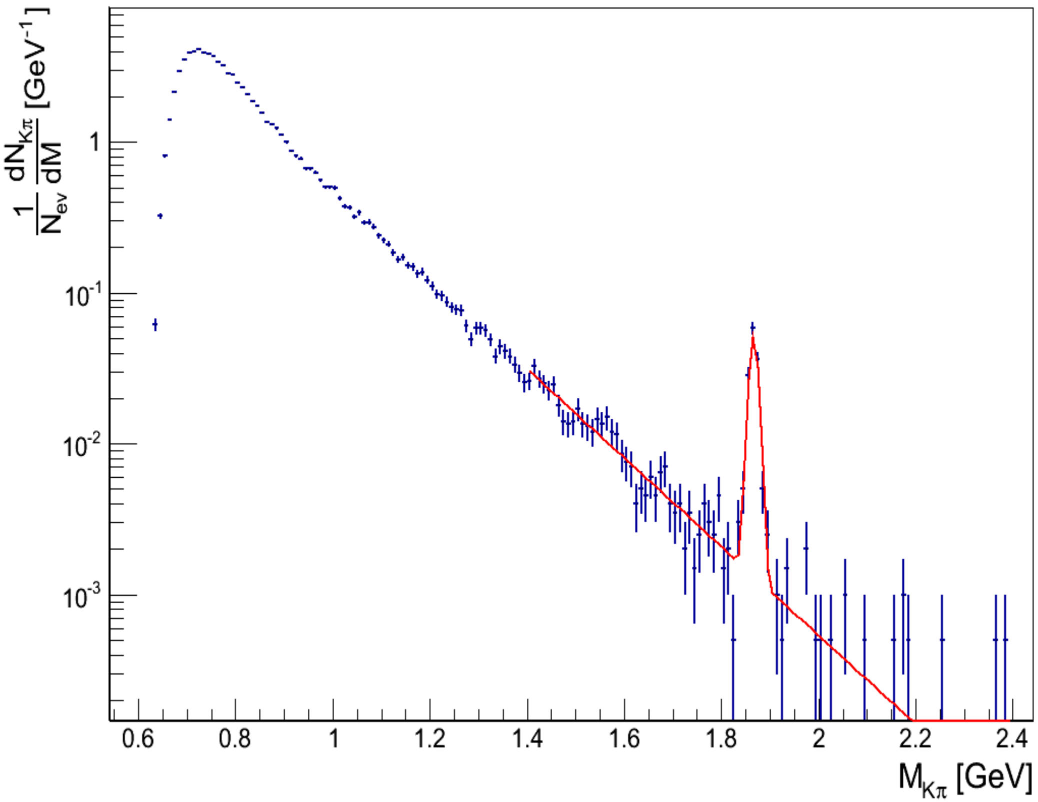
pT in GeV/c
topological cuts are in mm.

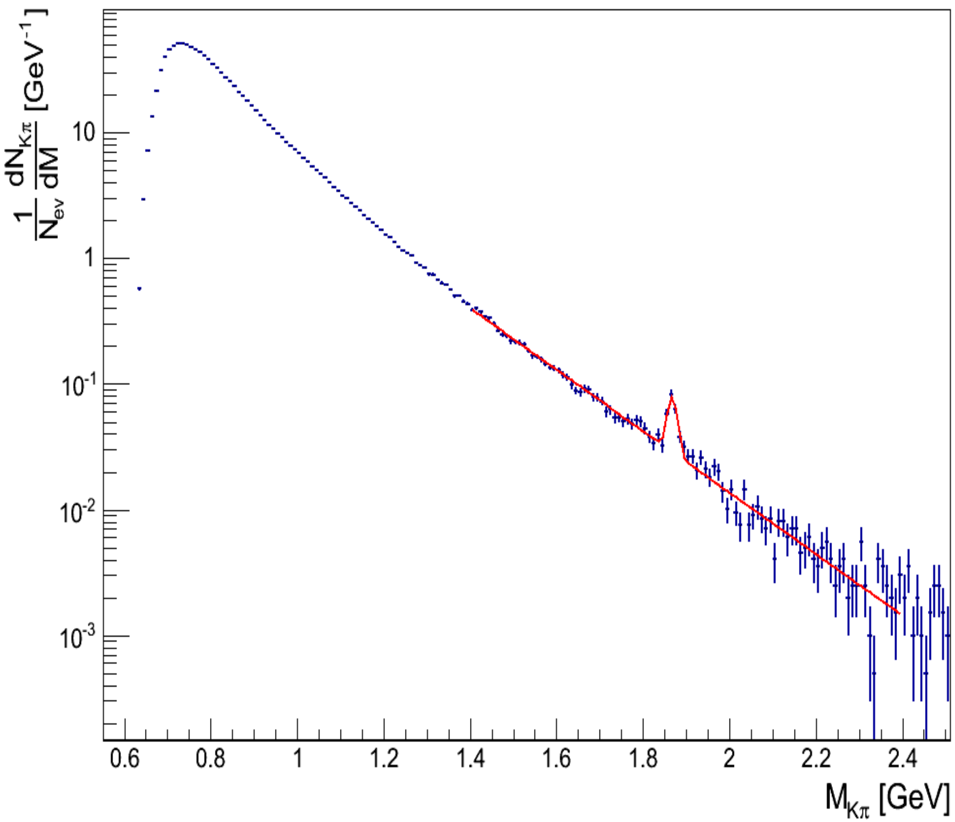
Summary of Cuts

Reduction of Background ≈ 10^6
Reduction of Signal ≈ 1.8



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

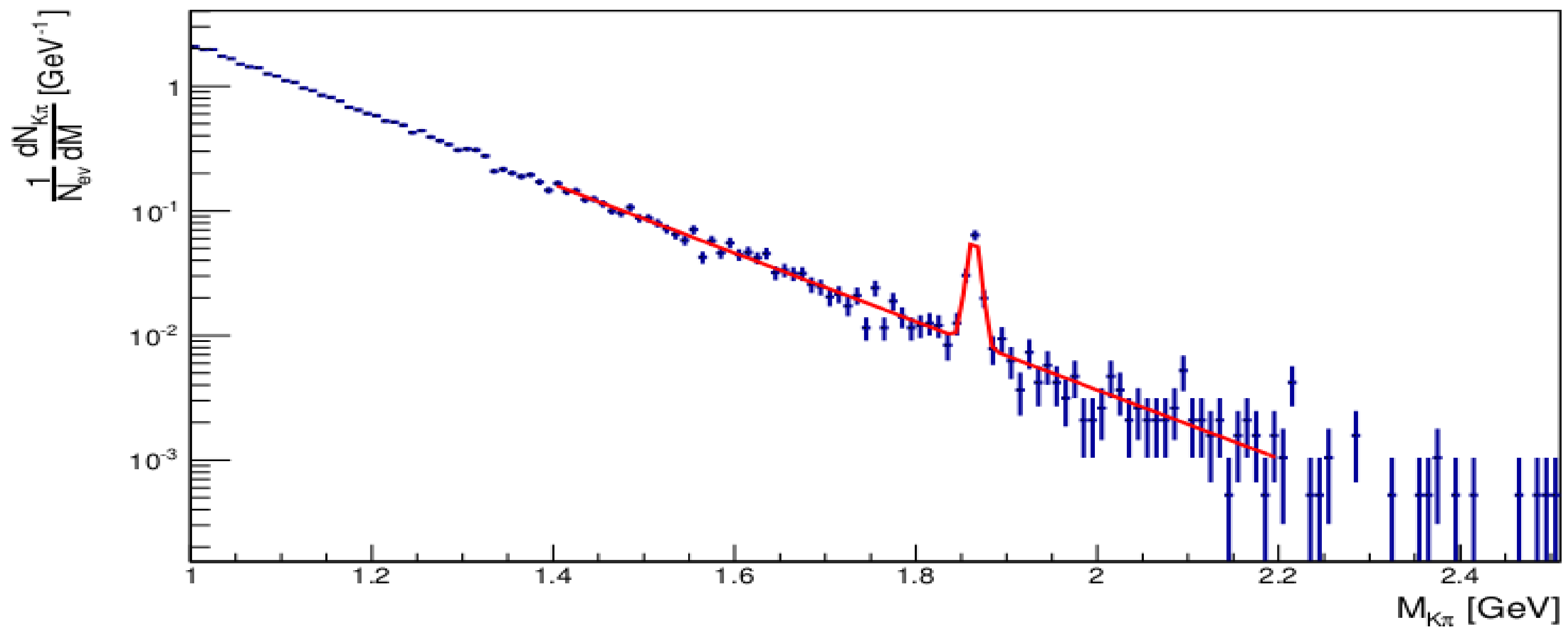




→ **S/B = 17**
→ **SNR(@50M) = 246**
→ **64300 detected D^0+D^0bar mesons in 50M central Pb+Pb (PID)**

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

Reconstructed yield for $D^0 \rightarrow K^- \pi^+$, 200k 0-10% cent. Pb+Pb at 40 AGeV

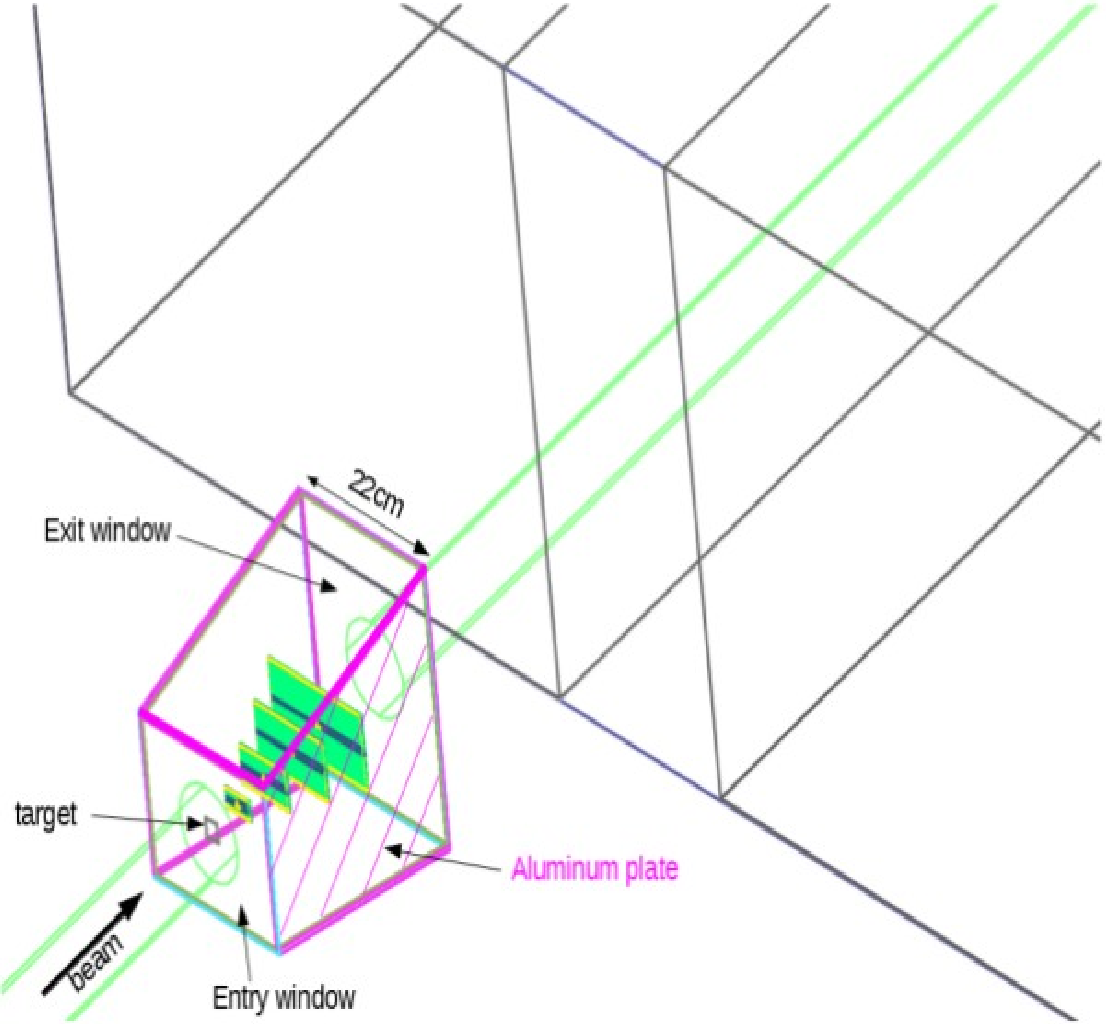


→ **S/B = 1.0**
→ **SNR(@50M) = 11.3**
→ **2000 detected D^0+D^0bar mesons in 50M central Pb+Pb (PID)**

→ **S/B = 0.07**
→ **SNR(@50M) = 2.1**
→ **2000 detected D^0+D^0bar mesons in 50M central Pb+Pb (no PID)**

Vertex Detector studies

VD in GEANT4



MIMOSA-26 sensors

→ Carbon fiber support

→ Water cooling tubes

Vessel:

→ Rectangular top/bottom plates

→ Trapezoidal left/right plates

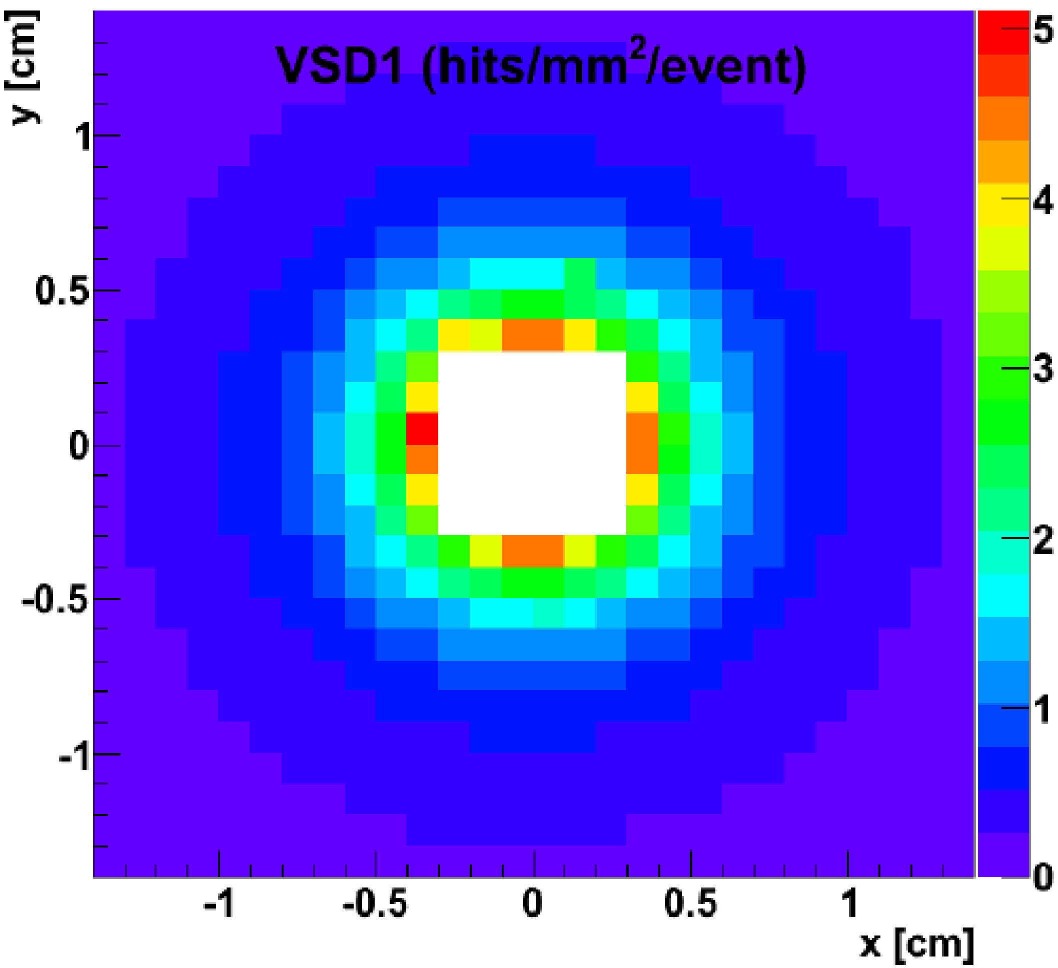
→ same length of carbon ladder

→ similar distance between top/bottom plates and VDS1-VDS4

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

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

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^2/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

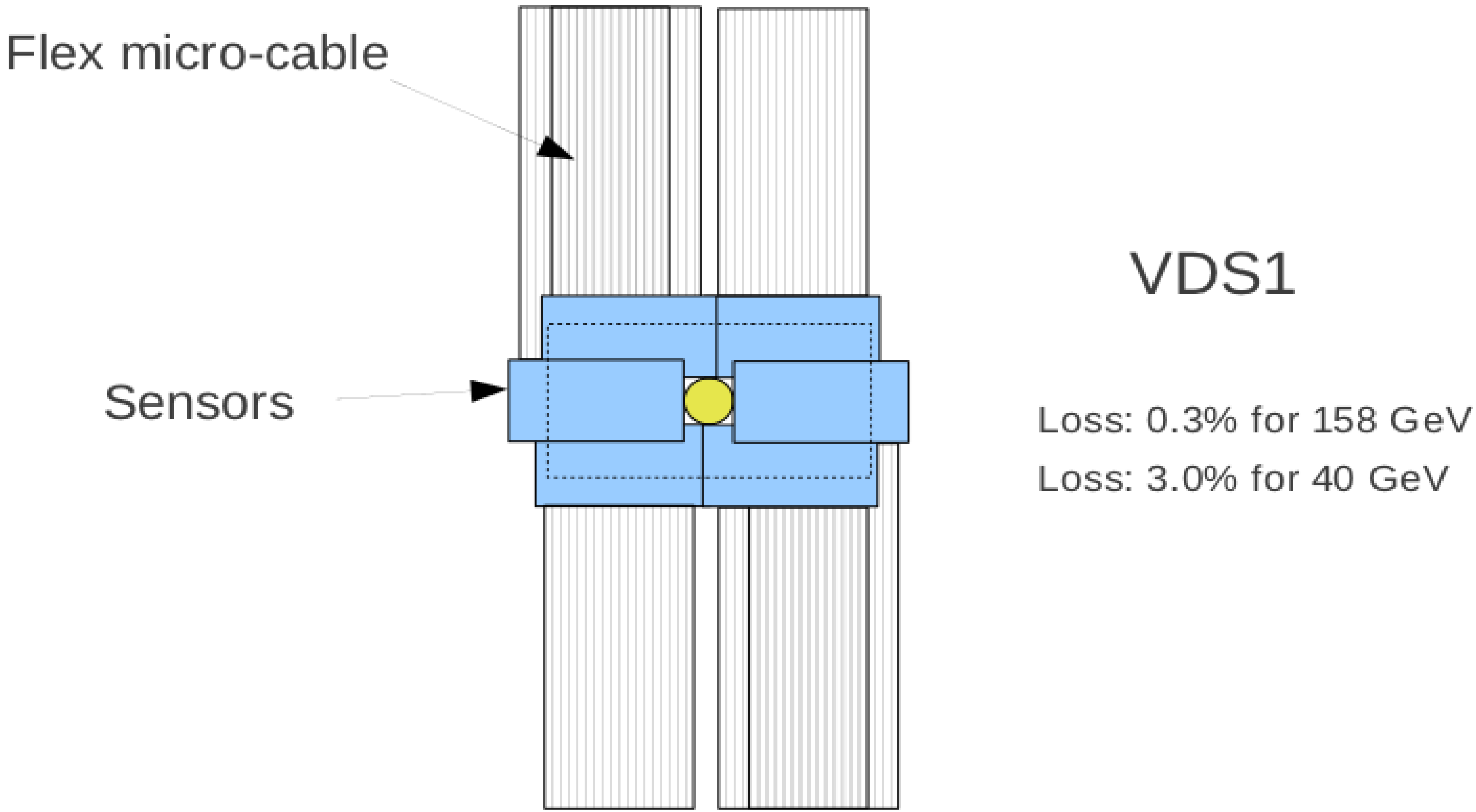
Estimates of NA61/SHINE requirements and limits for different chip technologies

	NA61	Hybrid	CCD	MIMOSA
Resolution	< 5 μm	30 μm	< 5 μm	< 3.5 μm
Mat. Budg.	Few 0.1 X_o	~1% X_o	~0.1% X_o	~0.05% X_o
Rad. Tol (1)	$3x10^{10}$ neq/cm^2	>10^{14} neq/cm^2	<10^9 neq/cm^2	>10^{13} neq/cm^2
Rad. Tol (2)	~1 krad	~10 Mrad	~1Mrad	~300 krad
Time resolution	~100 μs	~20 μs	~100 μs	~115.2 μs

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

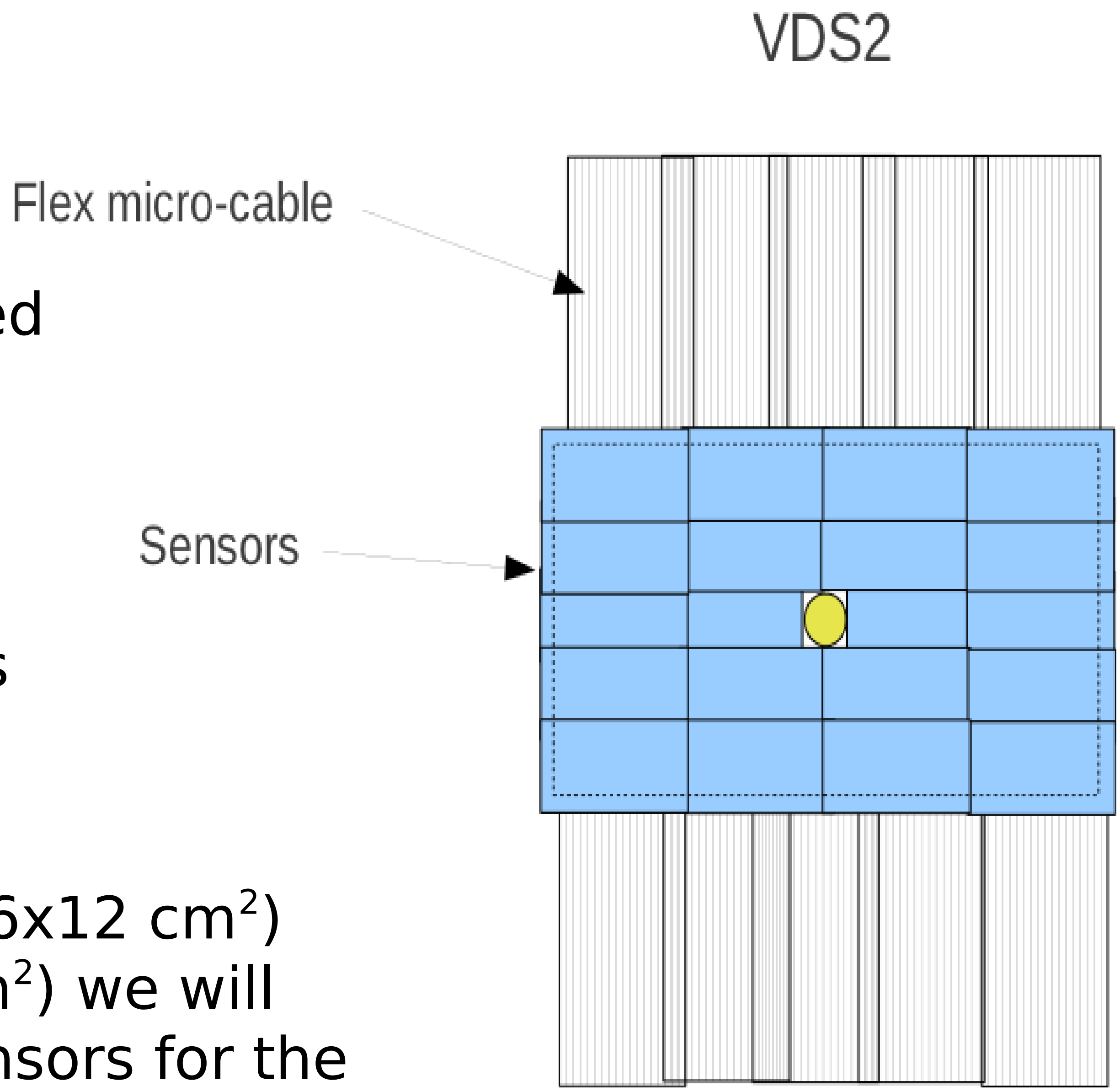
Preliminary design of the 1st station



→ Drawn blue boxes have dimensions of the sensitive area of MOMOSA-26 sensor (~1x2 cm^2)

→ Size of the dashed box is ~ 2x4 cm^2. We have to cover this area to loose less than 0.3% / 3% of signal particles for 158 / 40 GeV

Preliminary design of the 2nd station

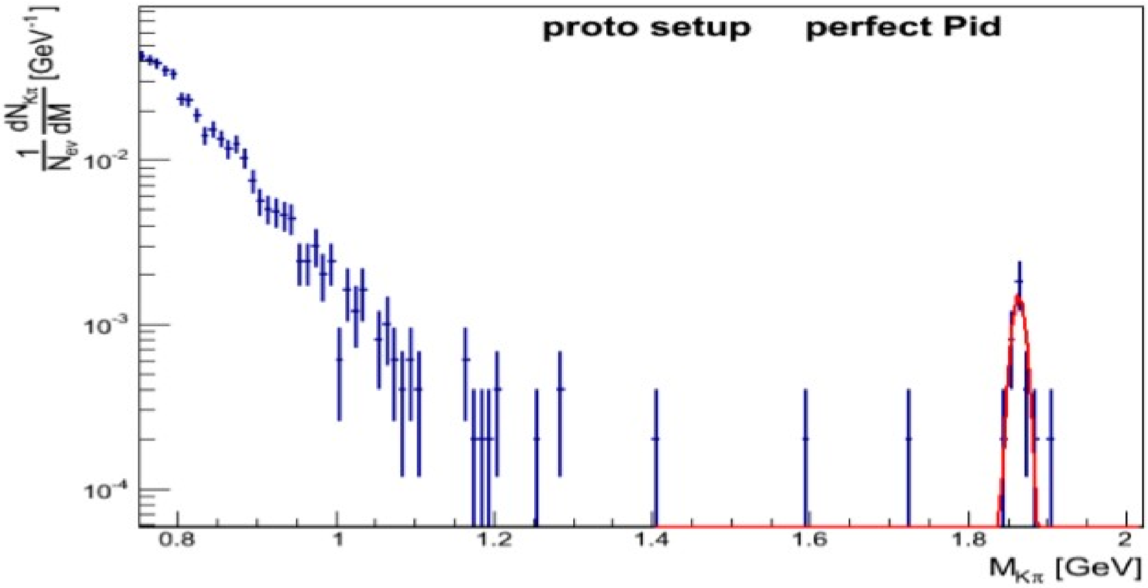


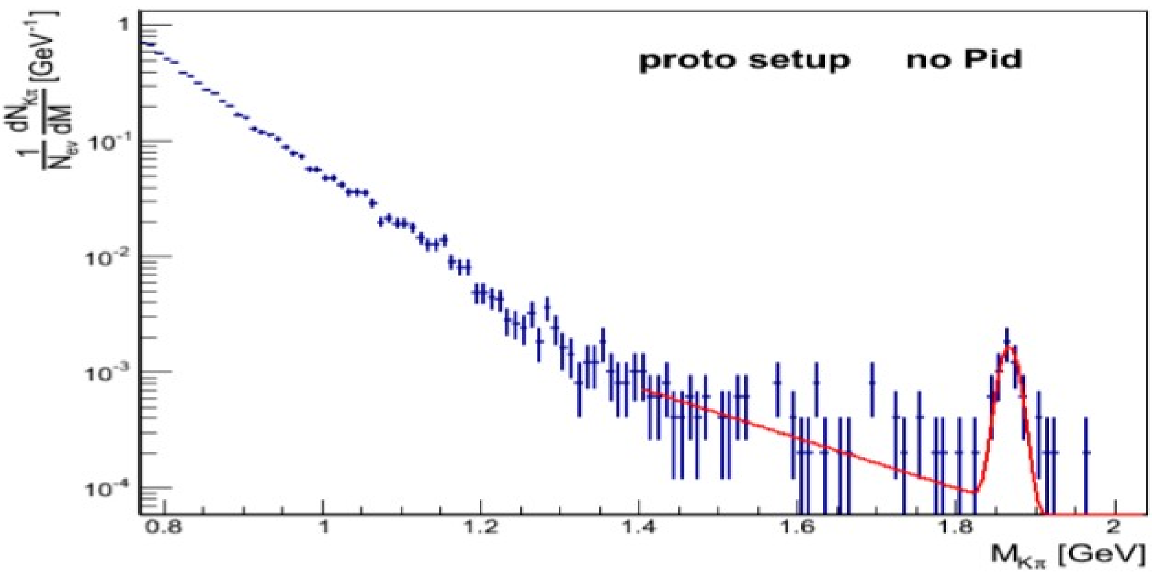
→ Size of the dashed box is ~ 4x8 cm^2
→ full coverage of VDS2 area with MOMOSA-26 requires 20 sensors

→ Including VDS3 (6x12 cm^2) and VDS4 (8x16 cm^2) we will need about 120 sensors for the whole detector.

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

Simulation results: prototype setup geometry





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

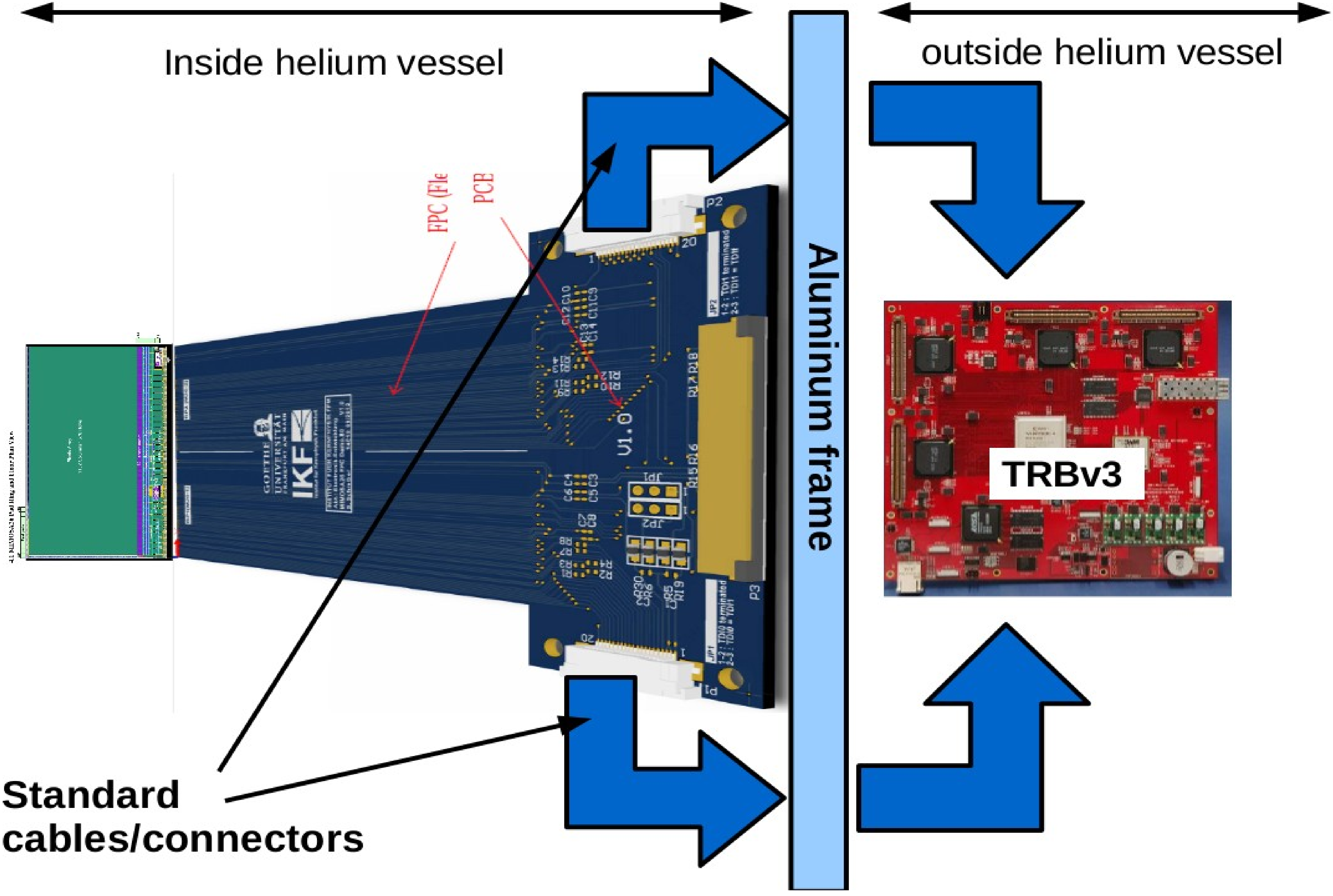
Again cuts are optimized to central Pb+Pb at 158 AGeV (cuts may be relaxed for Ar+Ar/Ca)

~ 20 D^0 + D^0bar

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)

Read-out connections scheme



Summary

→ The measurements of the D0 and $\overline{\mathrm{D0}}$ mesons in NA61 experiment with a dedicated vertex detector equipped with MIMOSA-26 sensors as detection units is feasible.

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

→ 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

Thank you!

NA61/SHINE Collaboration

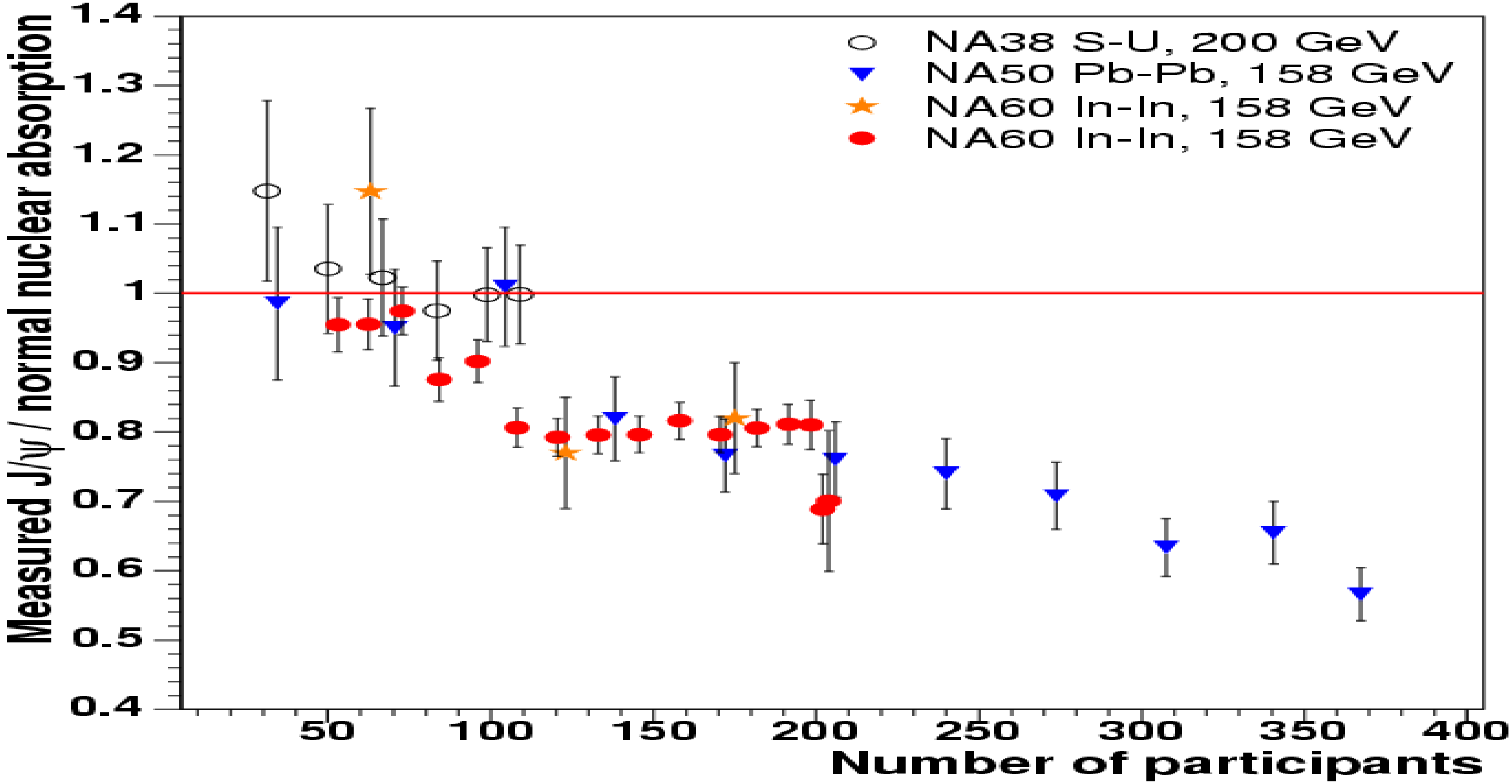
Acknowledgments

→ 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

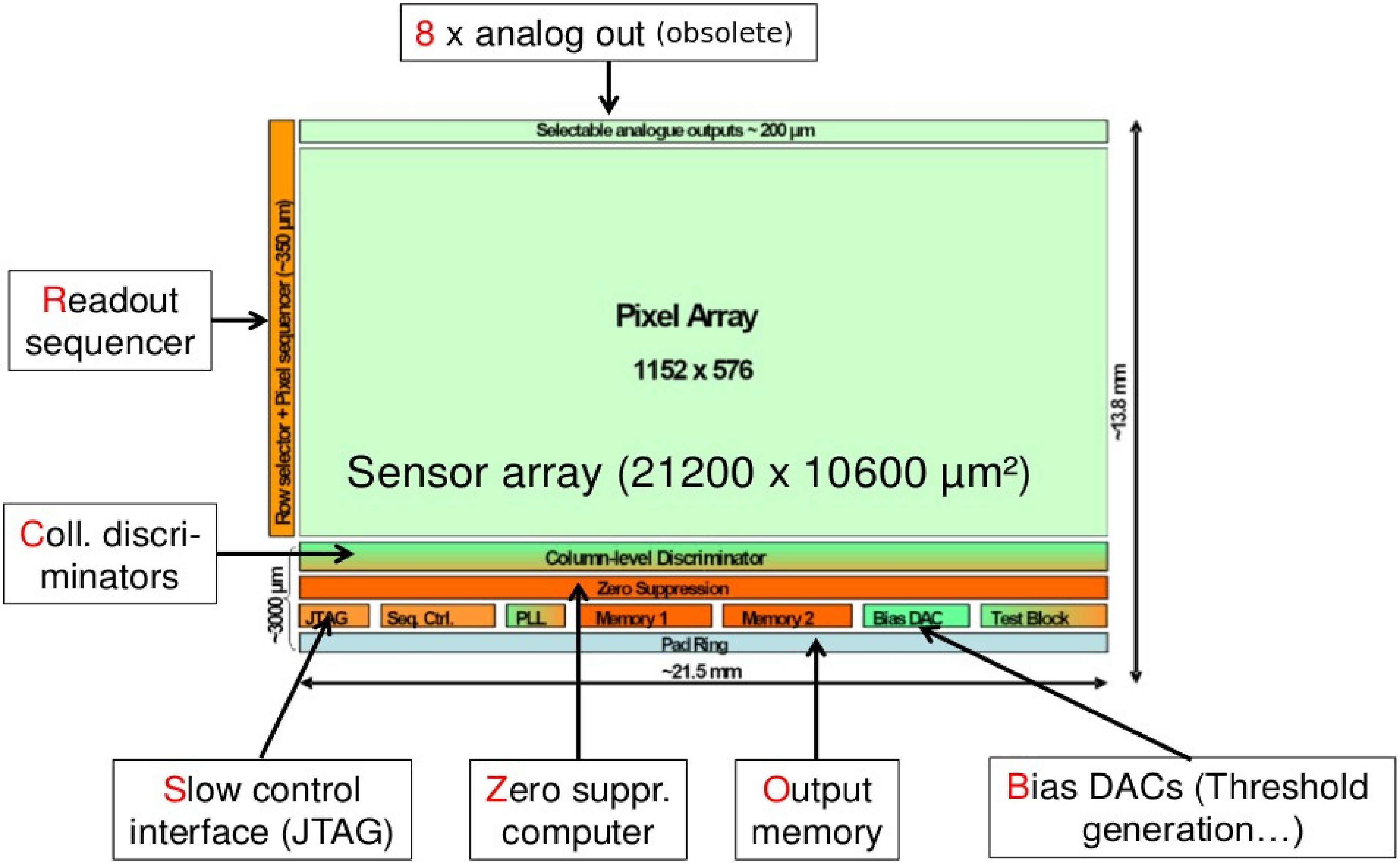
NA61/SHINE Experiment

BACK UP SLIDES



NA38 S-U, 200 GeV
NA50 Pb-Pb, 158 GeV
NA60 In-In, 158 GeV
NA60 In-In, 158 GeV
Measured J/ψ / normal nuclear absorption
Number of participants
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

Block diagram of MIMOSA-26

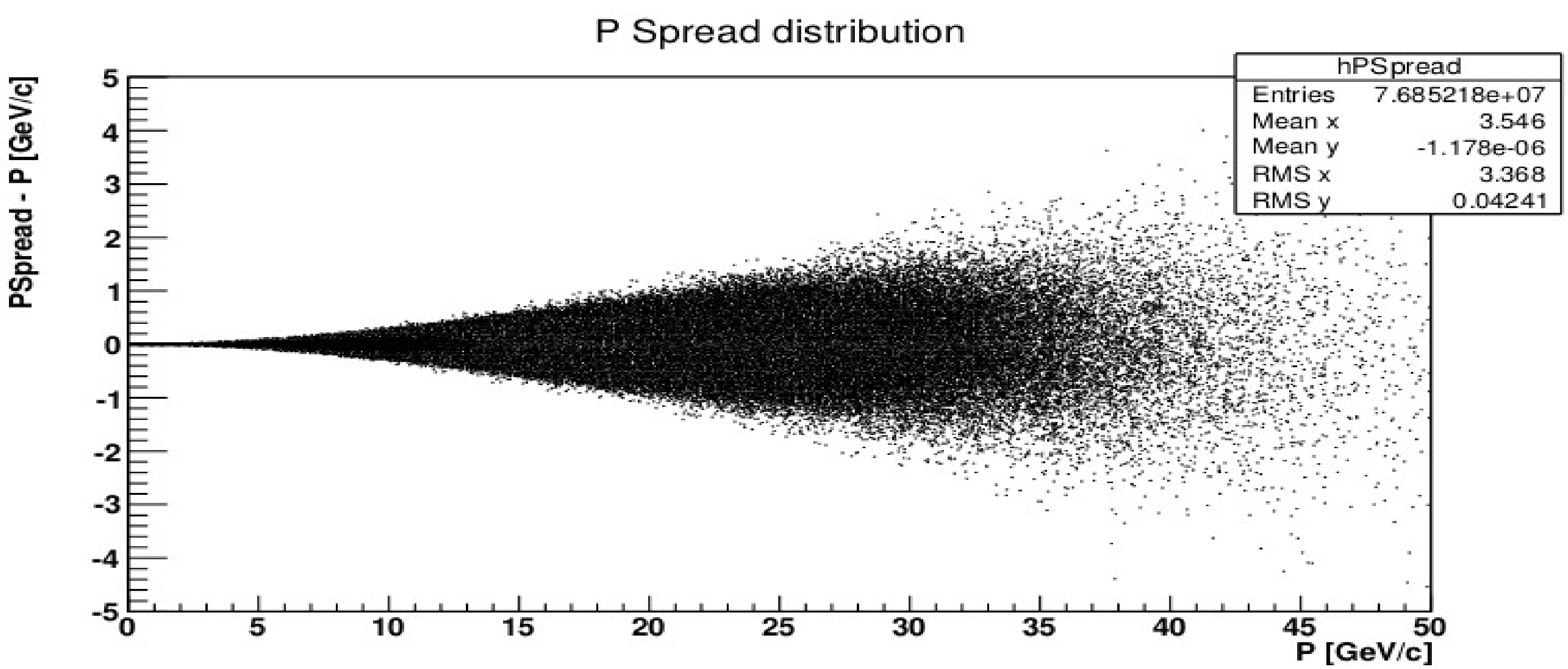


Reconstruction

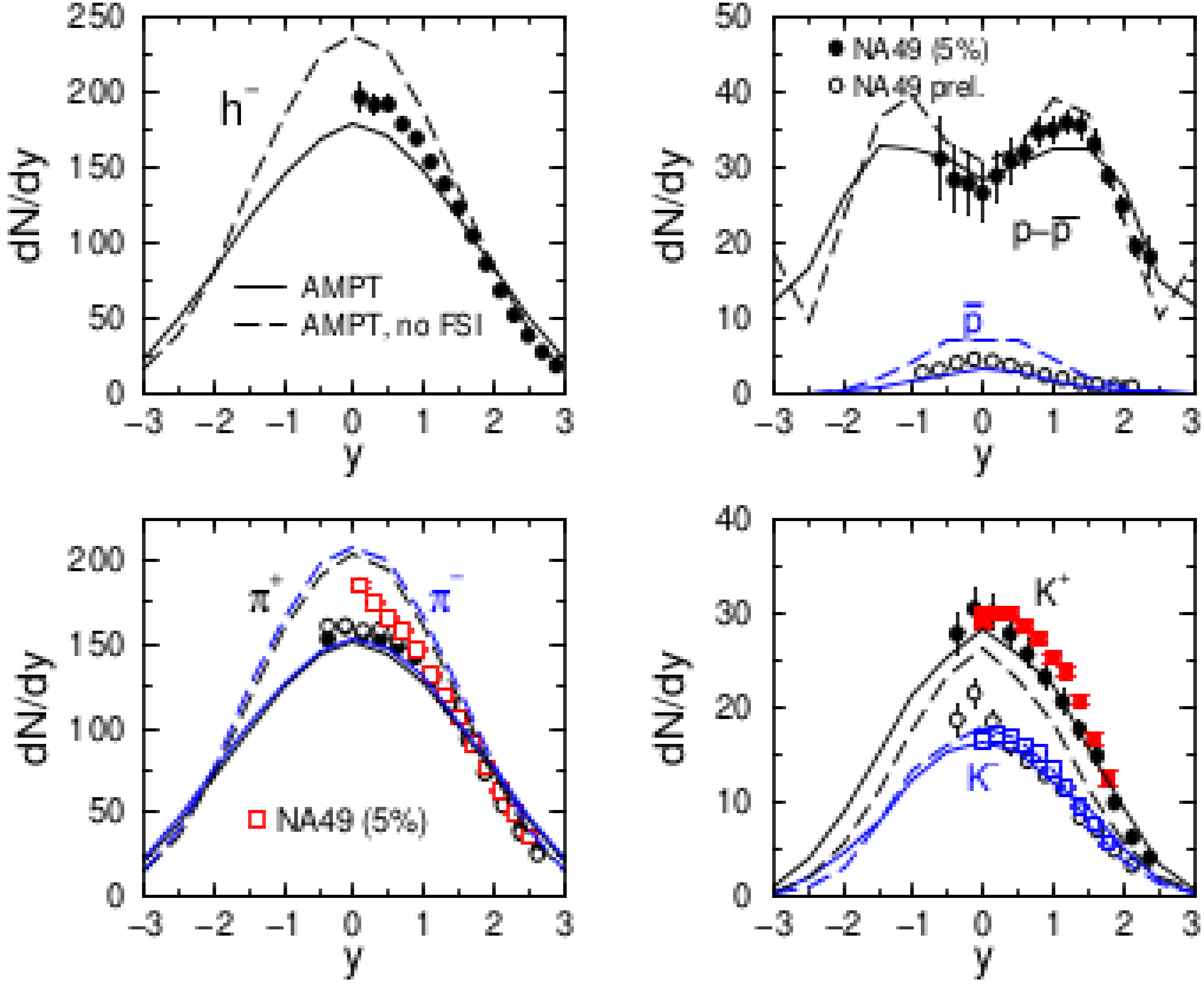
- → Track distance in VTPC1 + VTPC2 > 1m
- → Require hit at least in the three Vertex detector stations
- → NA61/SHINE Momentum resolutions is assumed

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

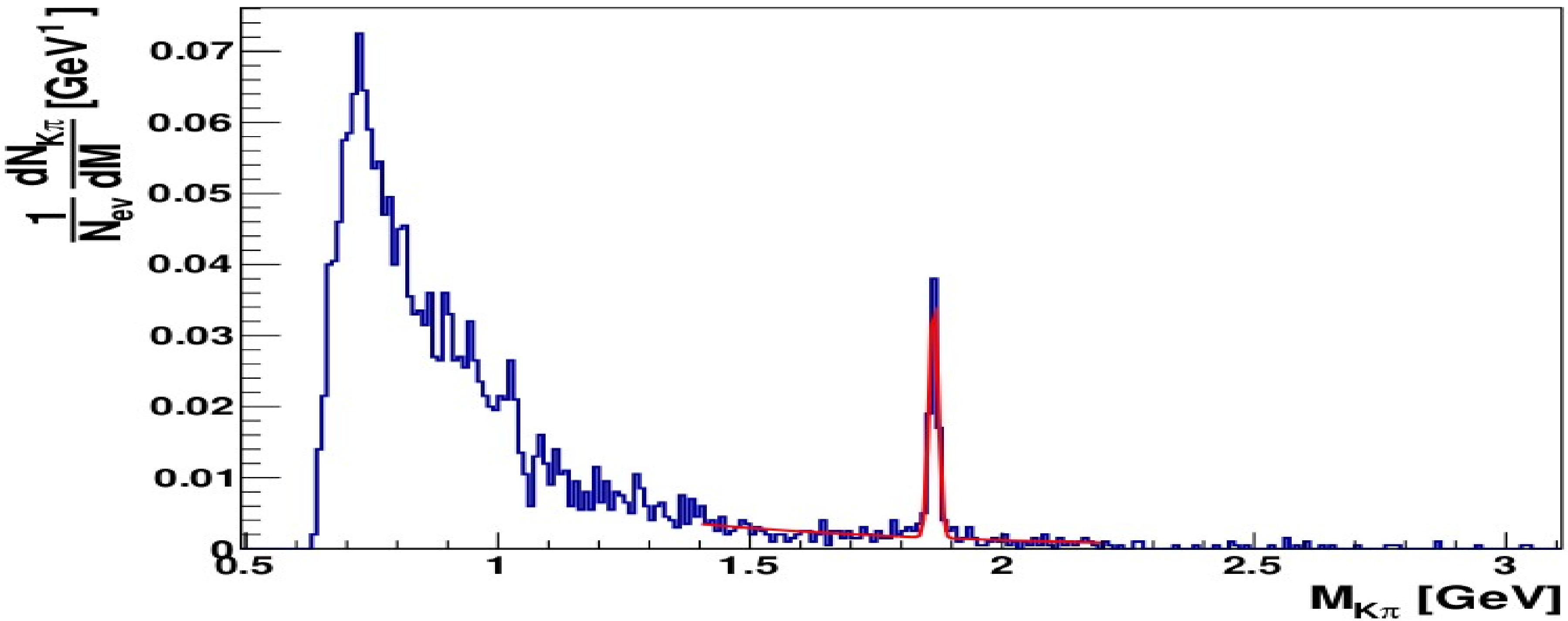
2. position resolution is 10 μm → hits are spread in y and x around geant hit according to the Gaussian distribution (σ = 10 μm).Track line is taken from the fit to the spread points



AMPT-MODEL



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

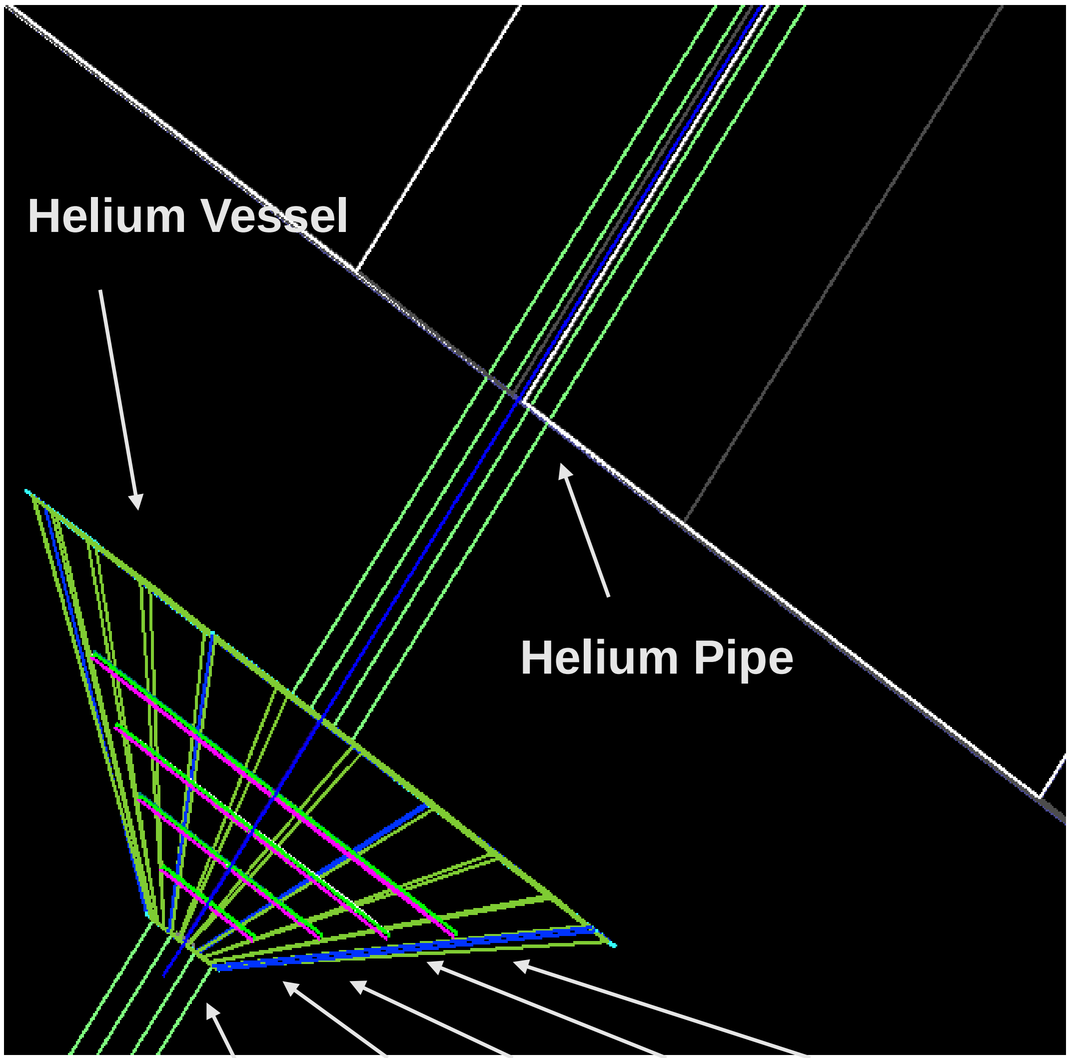


Pos. Res (μm)	10	10	15	15
Beam hole(mm)	2.5	3.0	2.5	3.0
S/B	9.6	10.0	4.5	6.5
Signal Significance (SNR) ★	209.6	199.4	175.4	174
$\langle D^0 \rangle + \langle \overline{D^0} \rangle$ ★	48K	43K	37K	36K

★ Results Extrapolated to 50M Events

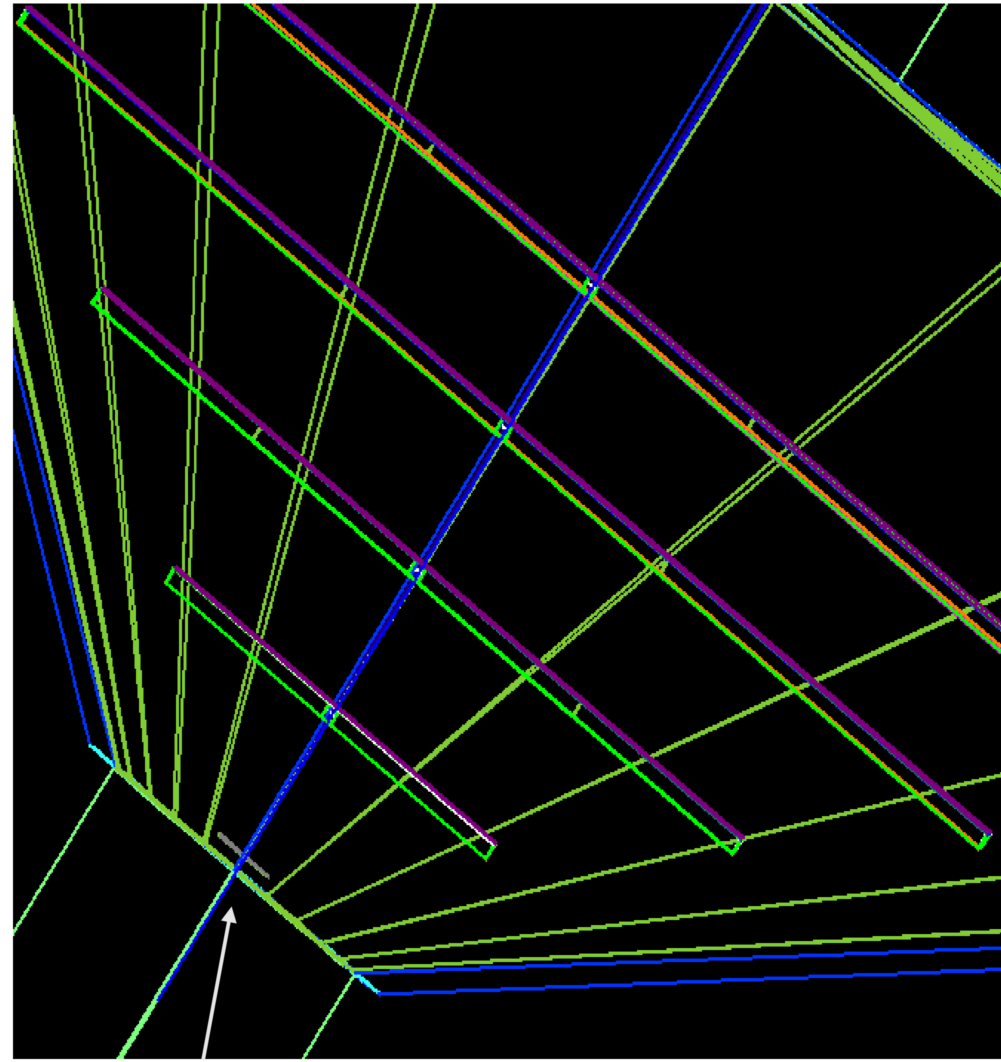
Design of the Future Vertex Detector

Zoom in



VDS1 VDS2 VDS3 VDS4

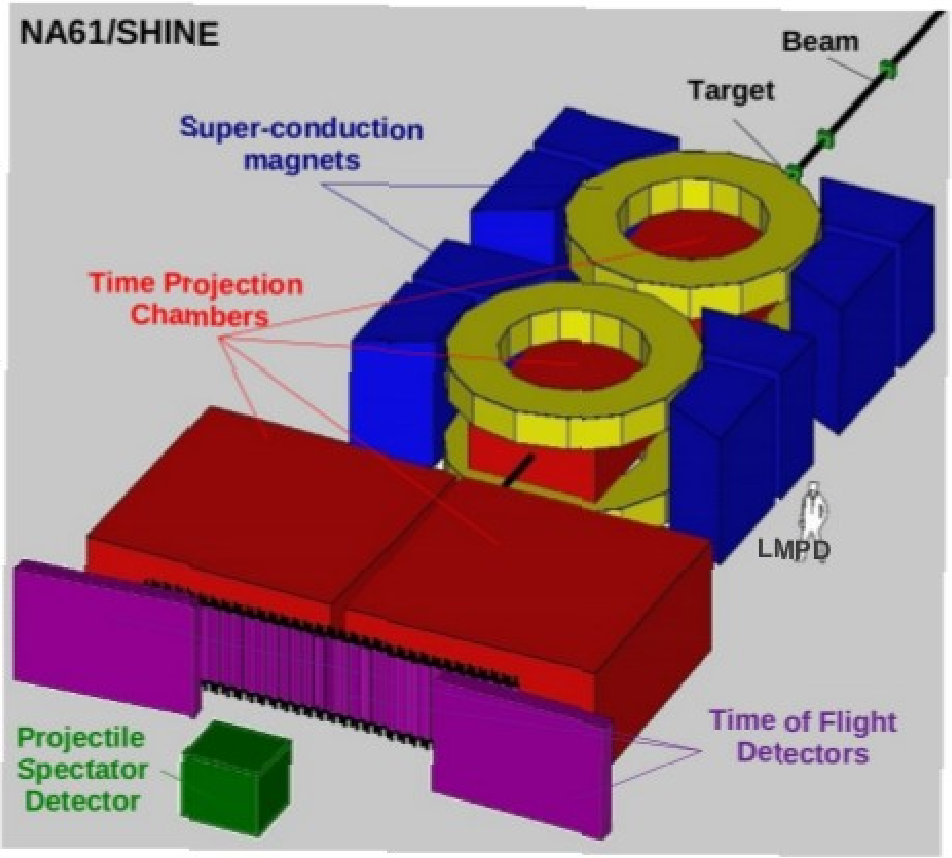
beam pipe



Pb target

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

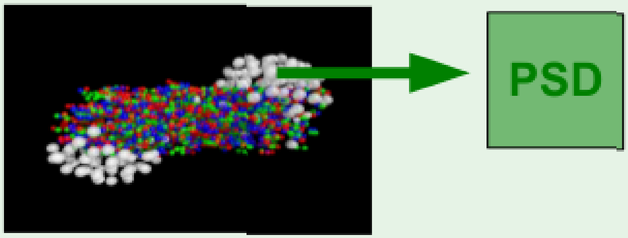
NA61/SHINE detector



- Large acceptance: ≈ 50%
- High momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(\mathrm{GeV}/c)^{-1}$ (at full B=9 T·m)
- ToF walls resolution: ToF-L/R: $\sigma(t) \approx 60$ ps; ToF-F: $\sigma(t) \approx 120$ ps
- Good particle identification: $\sigma(dE/dx)/\langle dE/dx \rangle \approx 0.04$; $\sigma(m_{inv}) \approx 5$ 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).

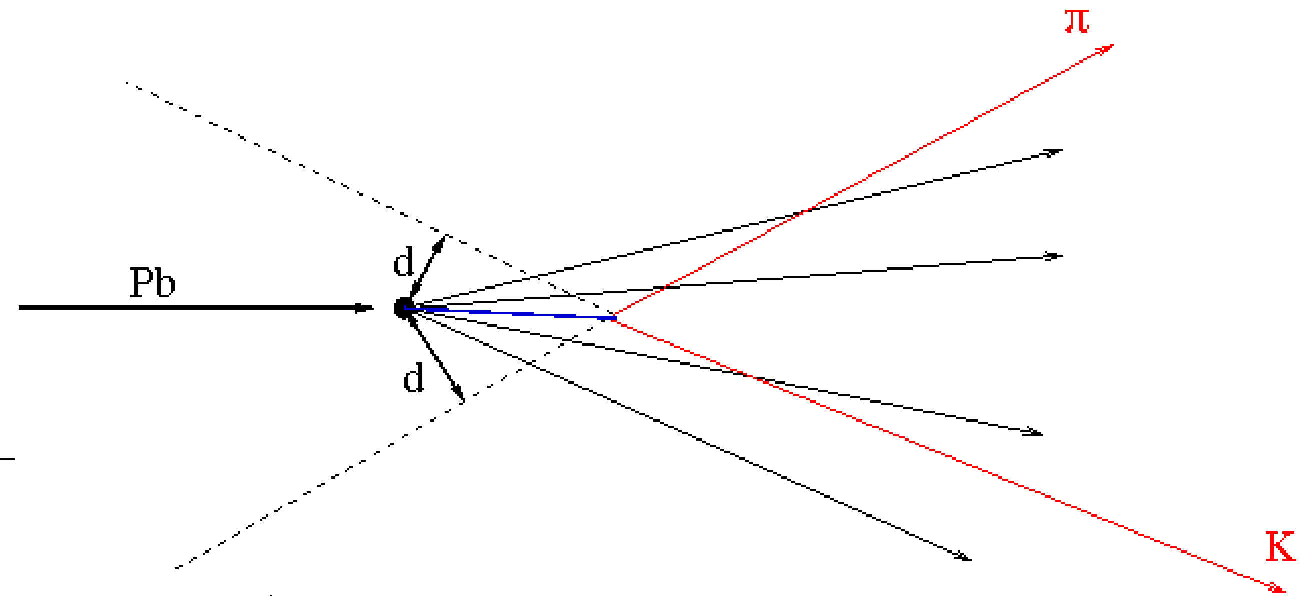


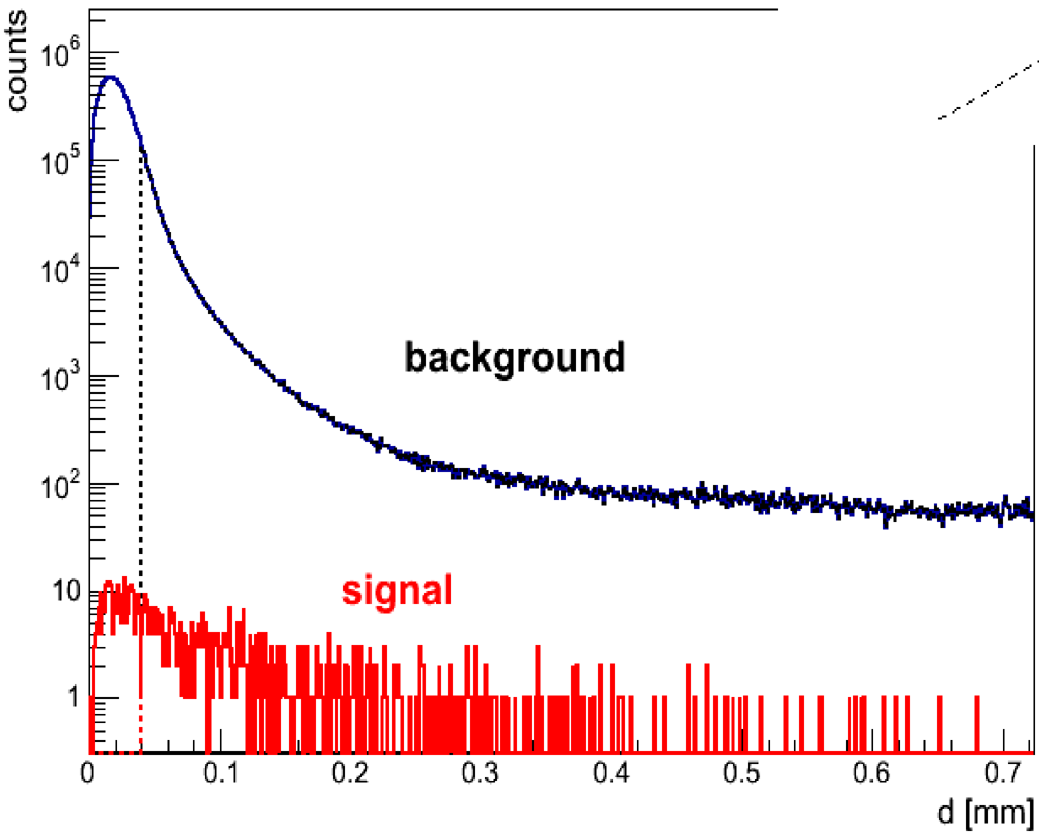
- **Helium beam pipes** inside VTPC-1 and VTPC-2 (to reduce δ-electrons).

- **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**

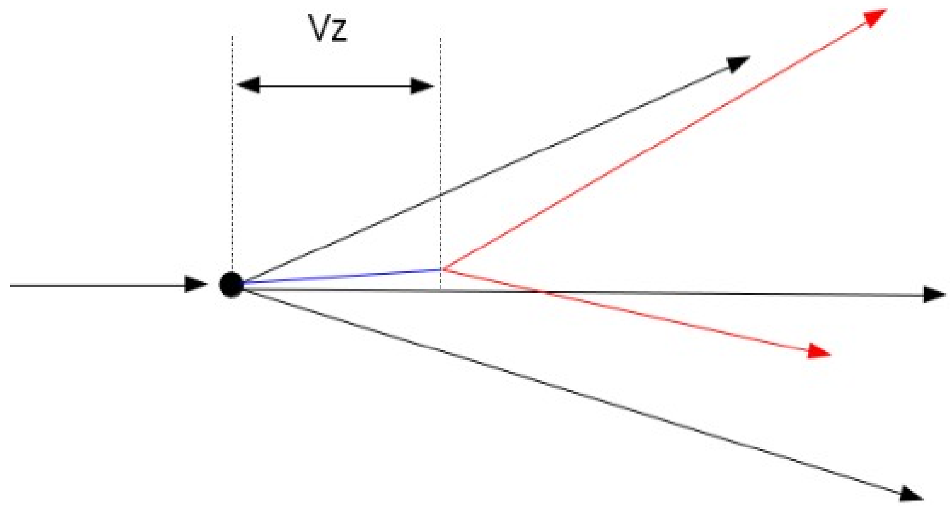


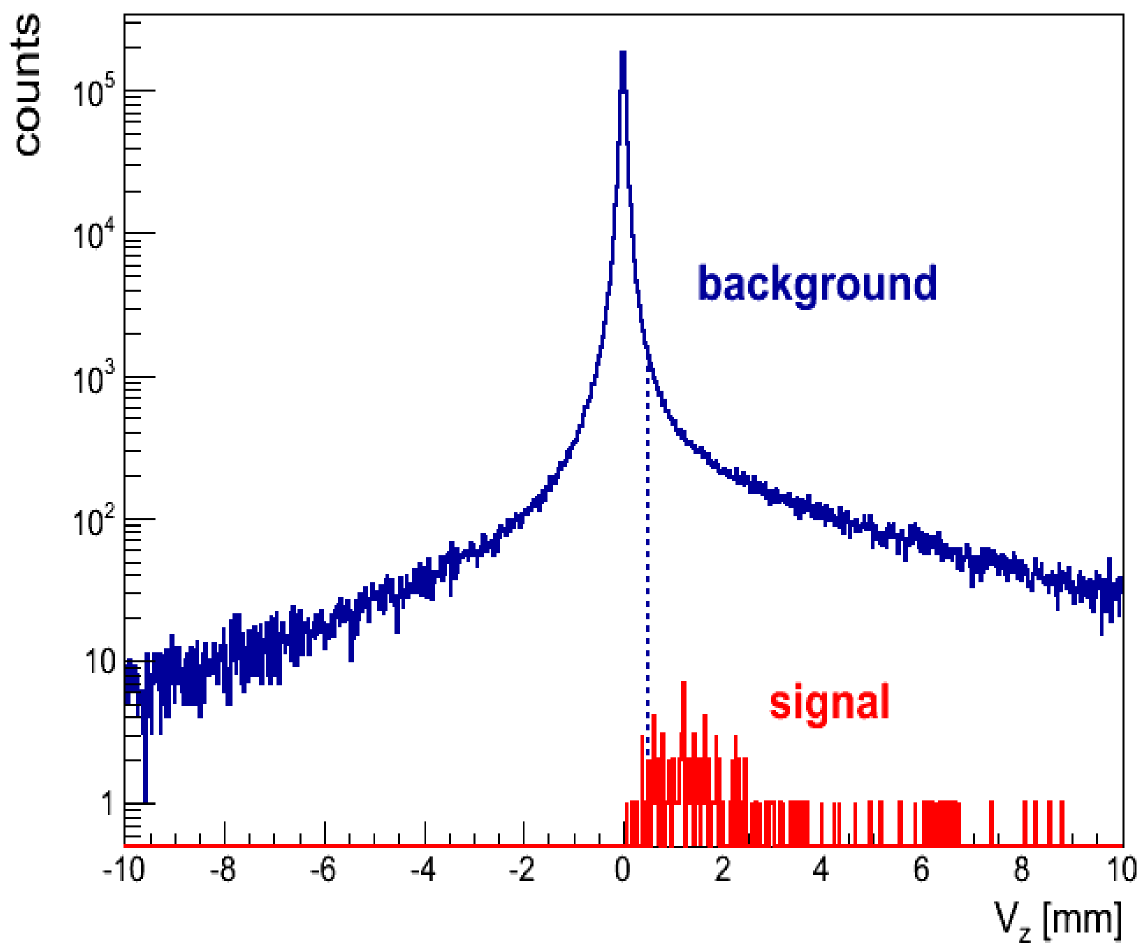


Relatively smooth shape of background at ~ 0 is due to uncertainly in reconstruction of track position and angle.
Some uncertainly comes from multiple scattering.

→ cut on d < 40 μm as indicated

4. cut on **Vz**





→ cut on **Vz** < 500 μm as require

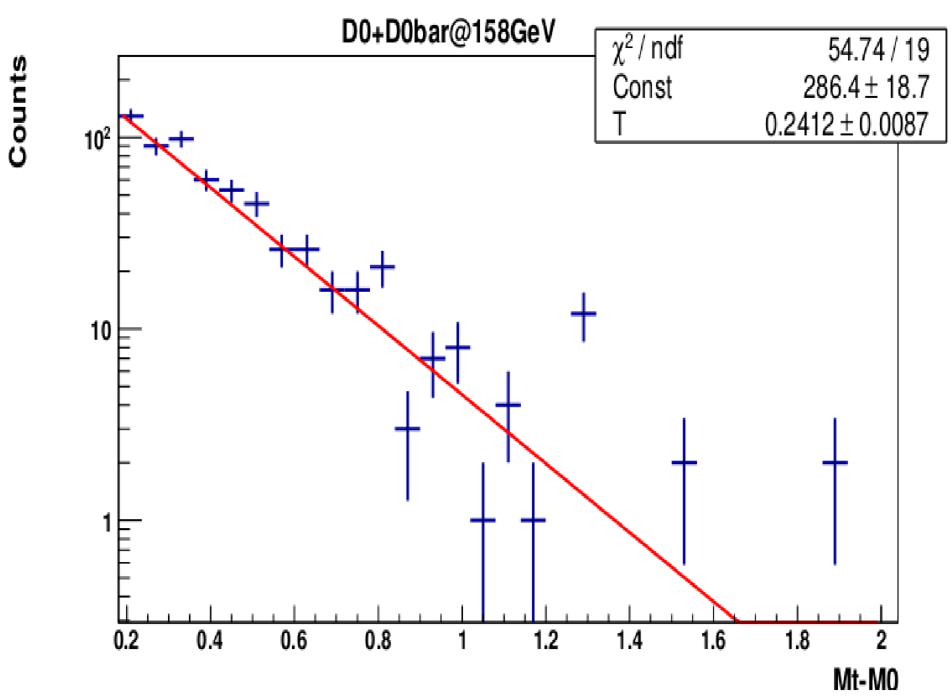
Parameters for 40 AGeV

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

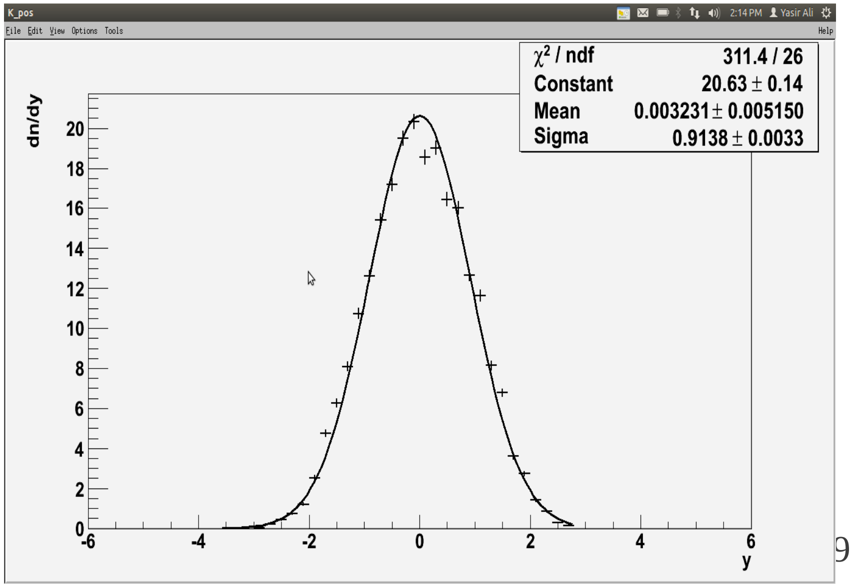
pidity distributions for kaons at both energies 40 and 158 AGeV and for D0 meson at 1

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

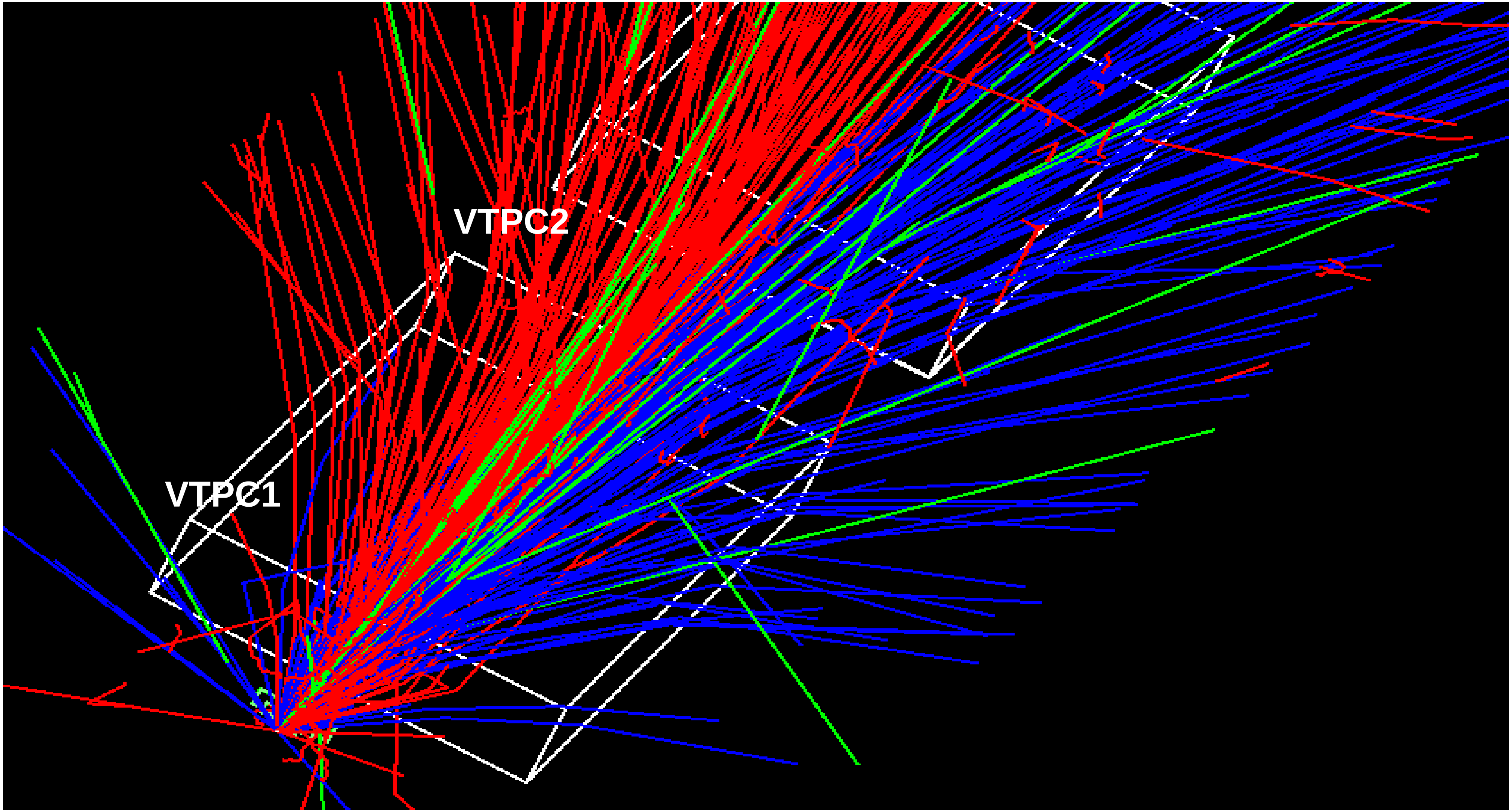
ansverse mass distributions By Fitting
ential Function A Exp(-mt/T)



Kplus @ 40 AGeV



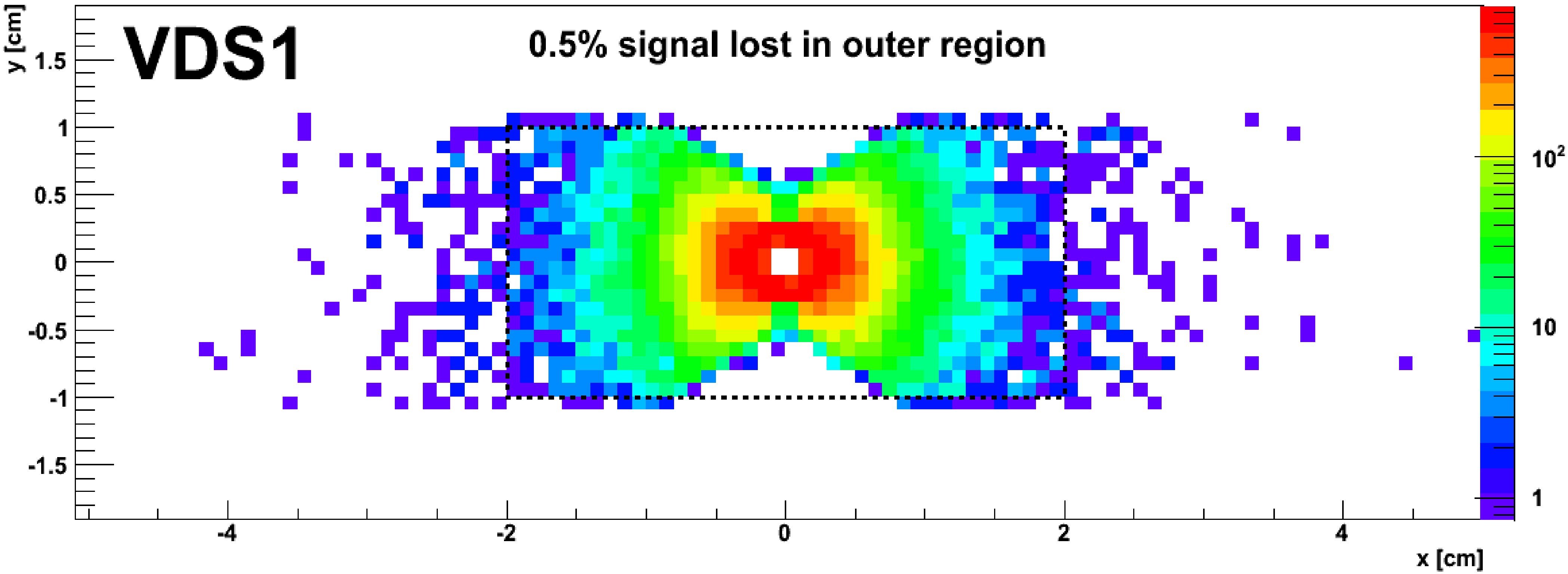
Detector overview in GEANT simulation



→ **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**

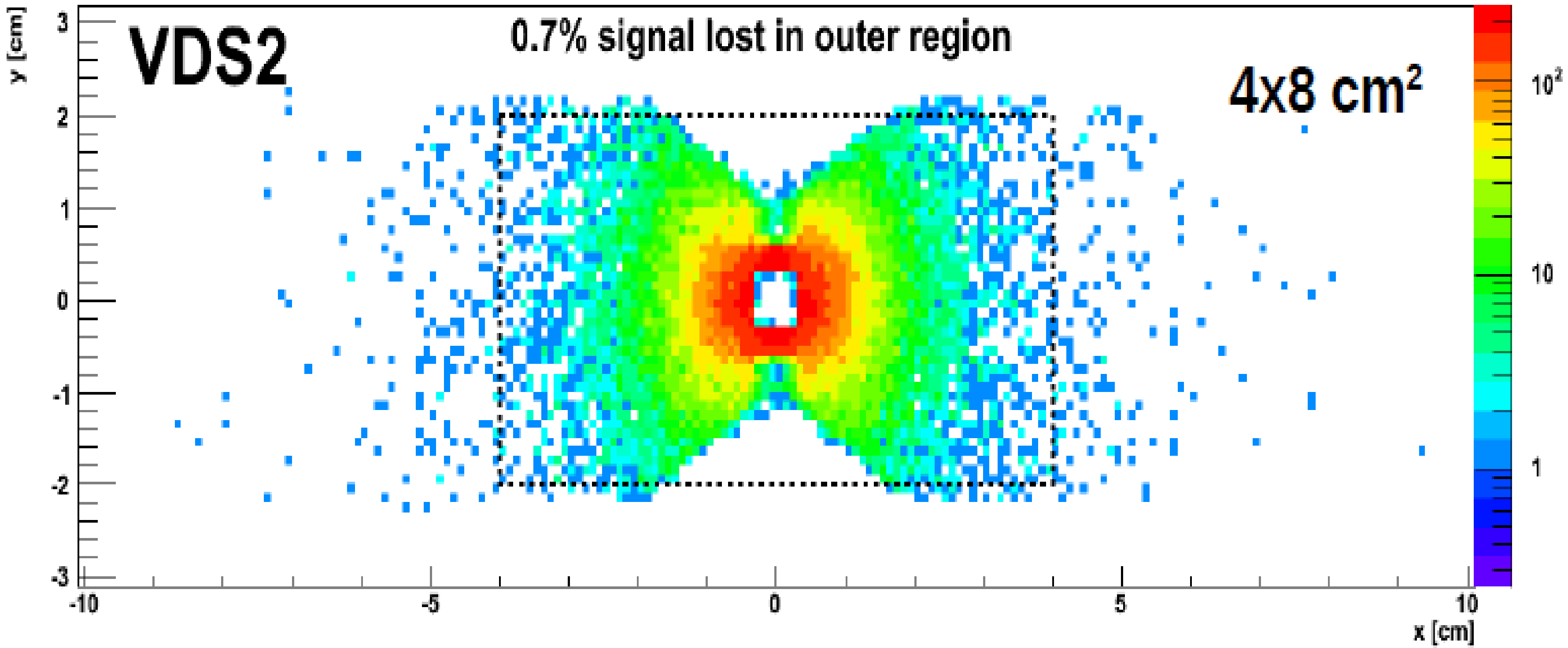
Signal track distribution at 158 AGeV in VDS1



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

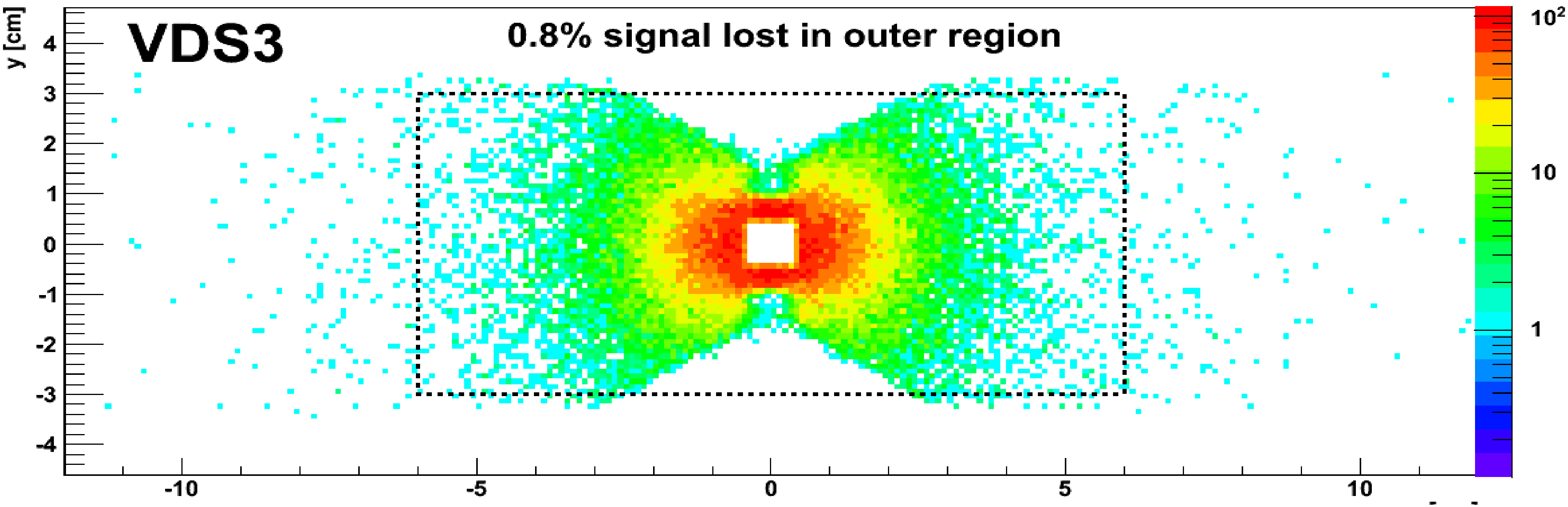
As we can see, to cover the remaining 0.5% we would need to extend the cut in the x direction for almost factor of 2.

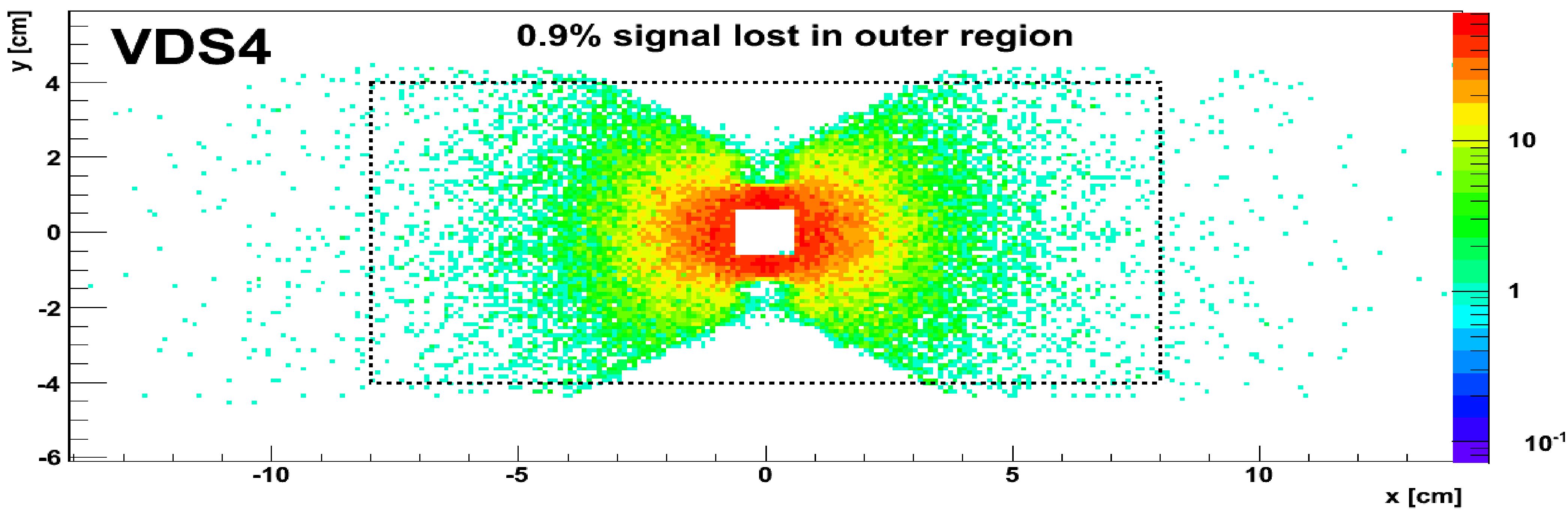
Signal track distribution at 158 AGeV in VDS2



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^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





Background suppression strategy (Need to discuss)

List of cuts in the order they are applied

Single particle cuts:

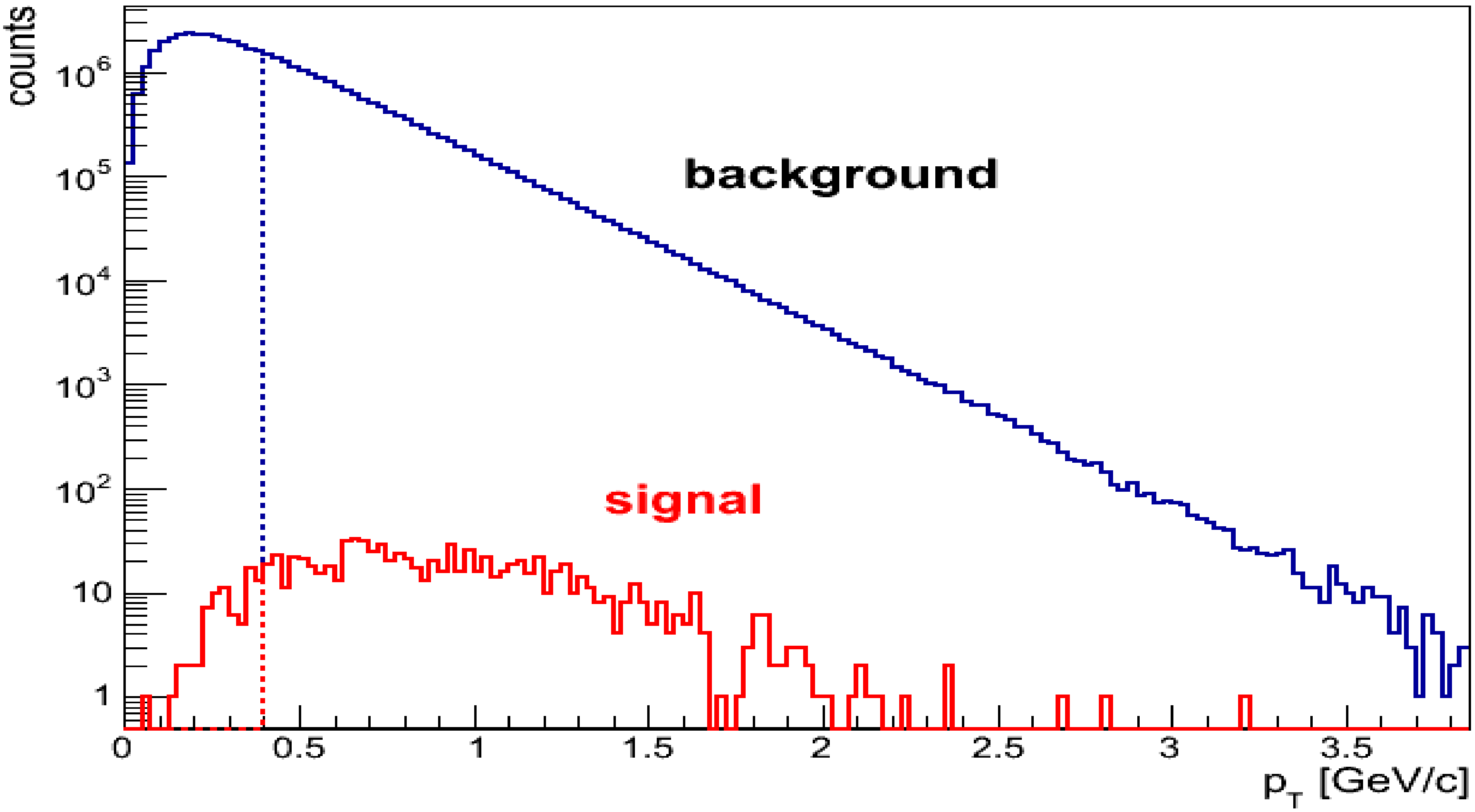
1. track **pT** cut
2. track **d** cut (track impact parameter)

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**

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

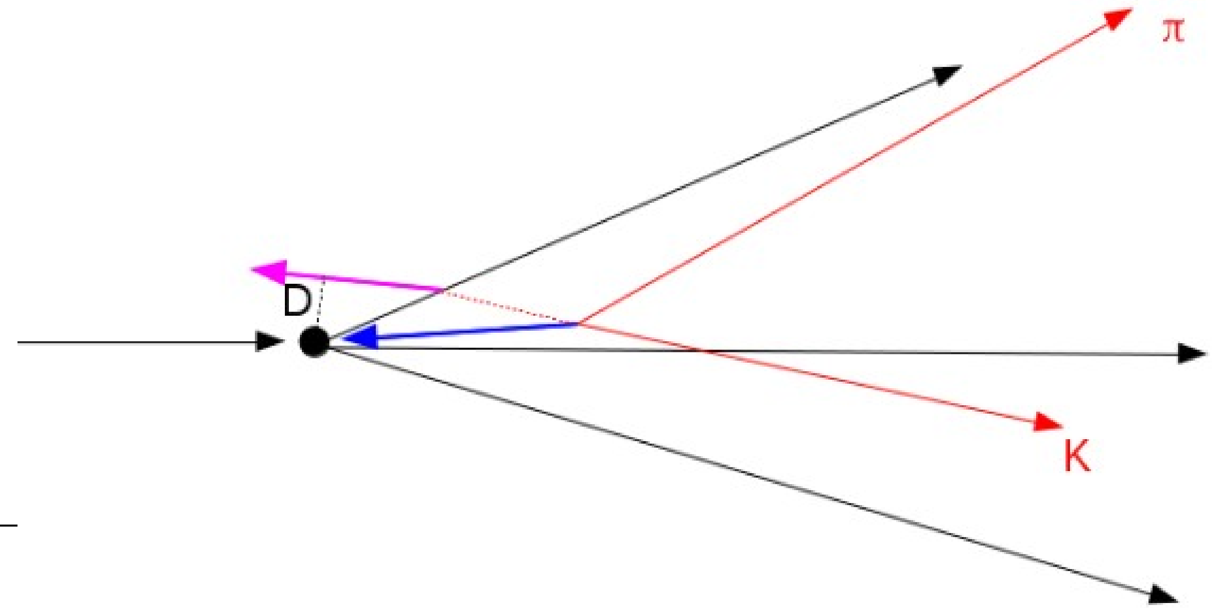
1. cut on **pT**

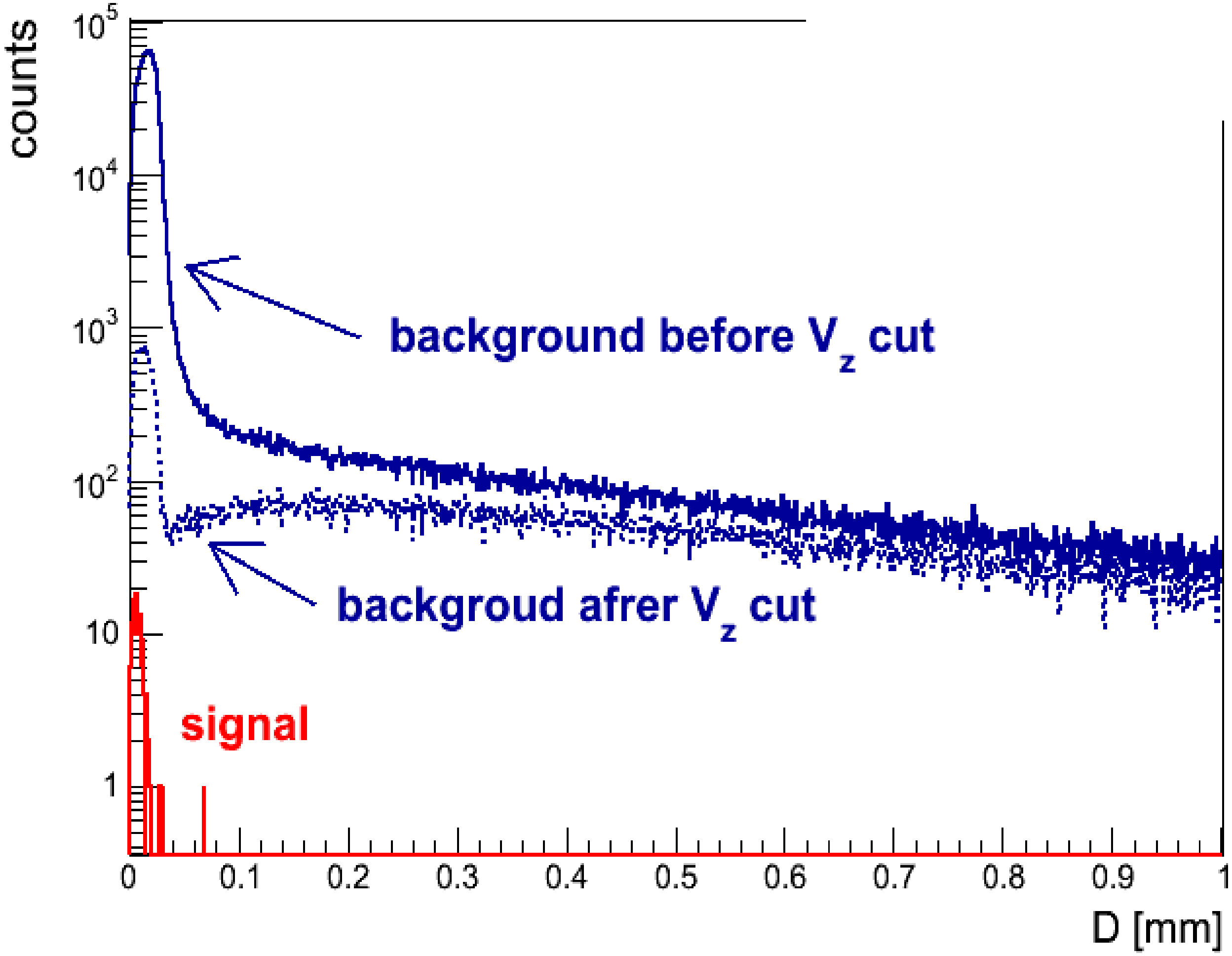


Background pT spectrum has maximum around ~ 0.2GeV/c, wheres maximum of signal distribution is at around 1 GeV/c

→ cut on pT<0.4 as indicated

3. cut on **D**





Vz cut reduces background at D ~ 0, where the signal is located → Vz and D cuts are nicely complementary to each other

→ 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 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)

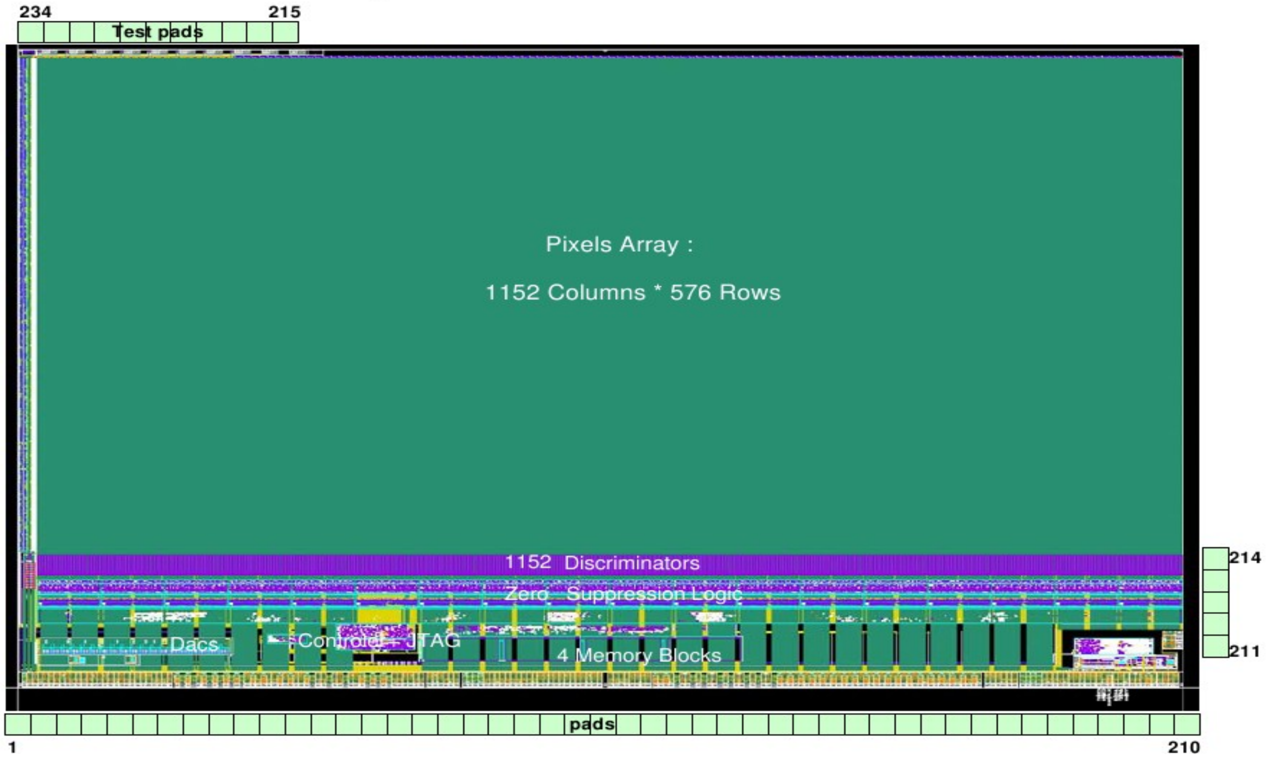
     If the distance is (too) large – important component might not be described

→ 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):

4.1 MIMOSA26 Pad Ring and Floor Plan View



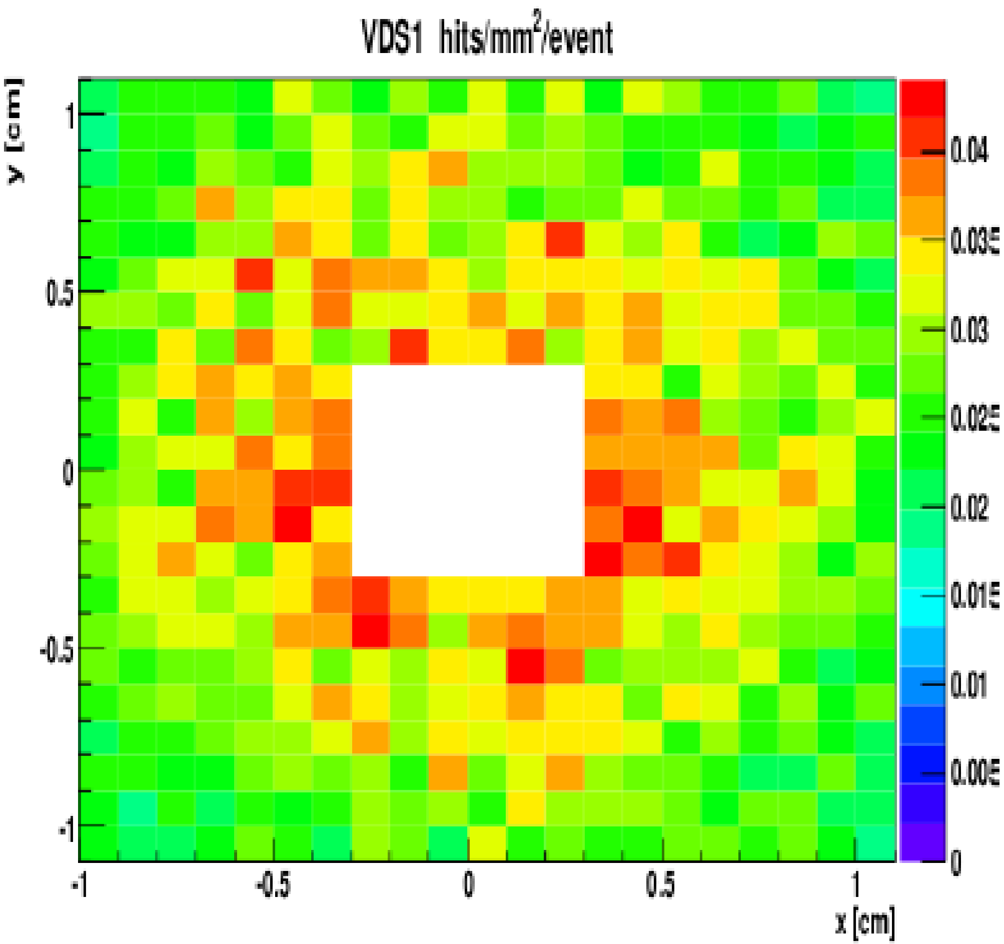
These pads are for testing purpose and can be removed

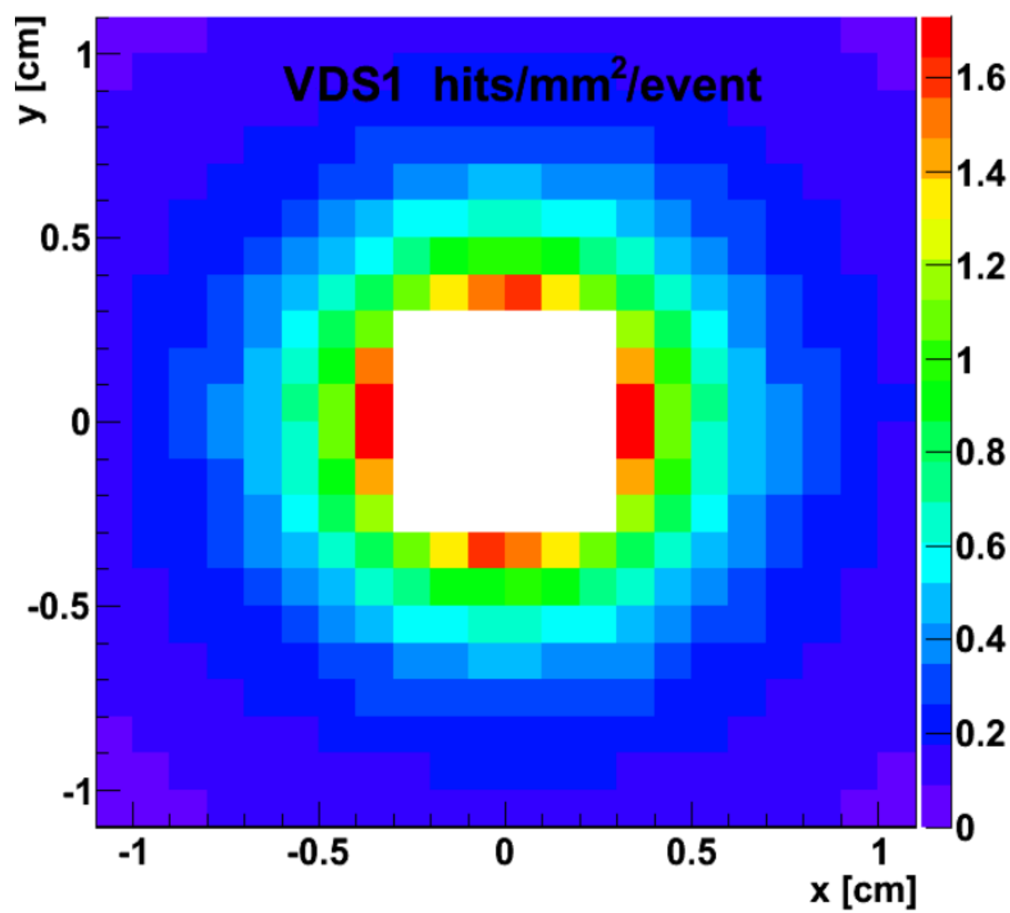
- The readout speed of the whole fame in ~100 µs (10 kHz), zero suppression circuit.
- The chips are available. We can just buy them from IPHC (Institut Pluridisciplinaire Hubert Curien), Strasbourg

δ-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 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

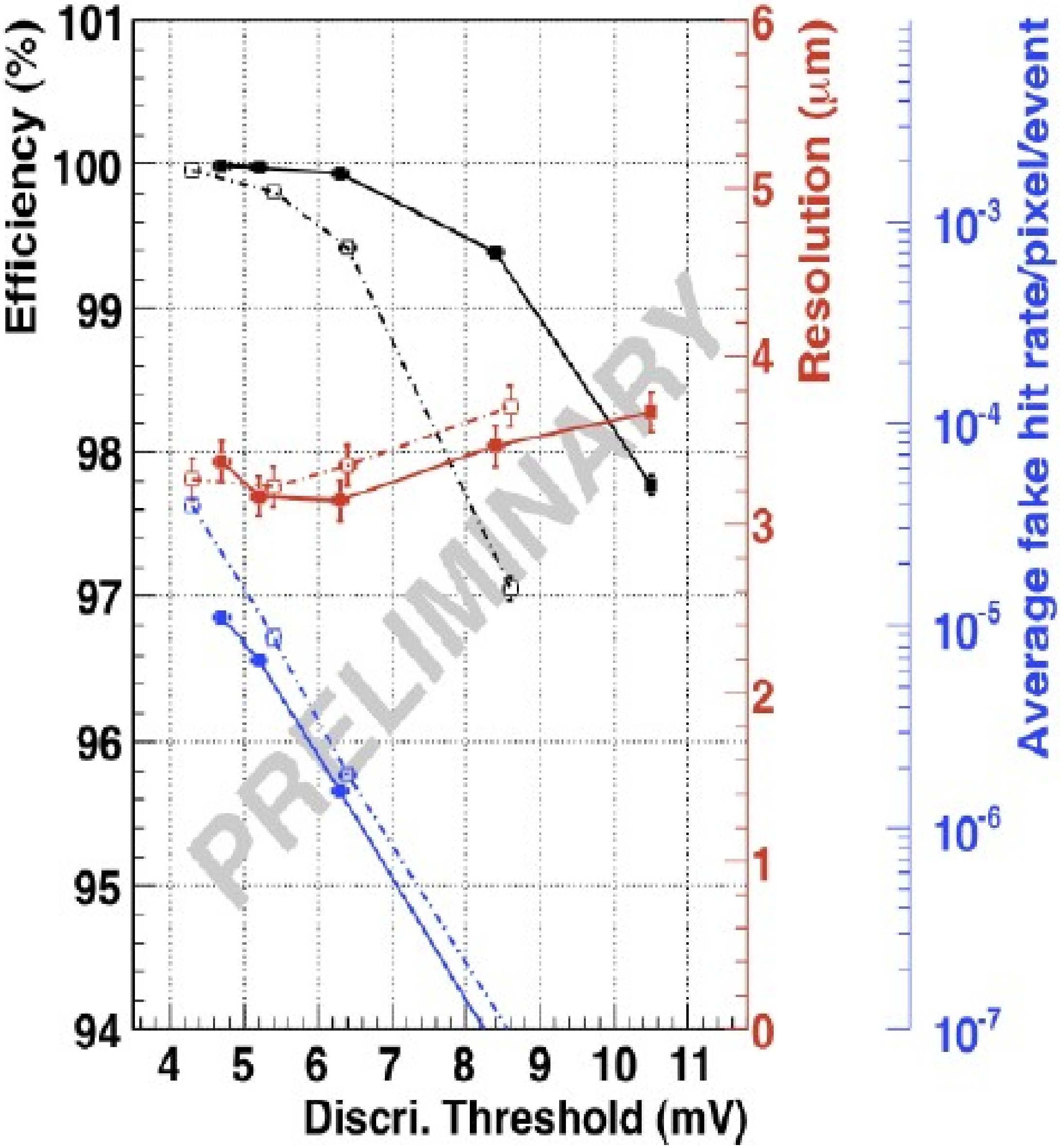
Electromagnetic interactions (δ-electrons):

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

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

Fluence estimates

Performance of MIMOSA-26 → test on beam



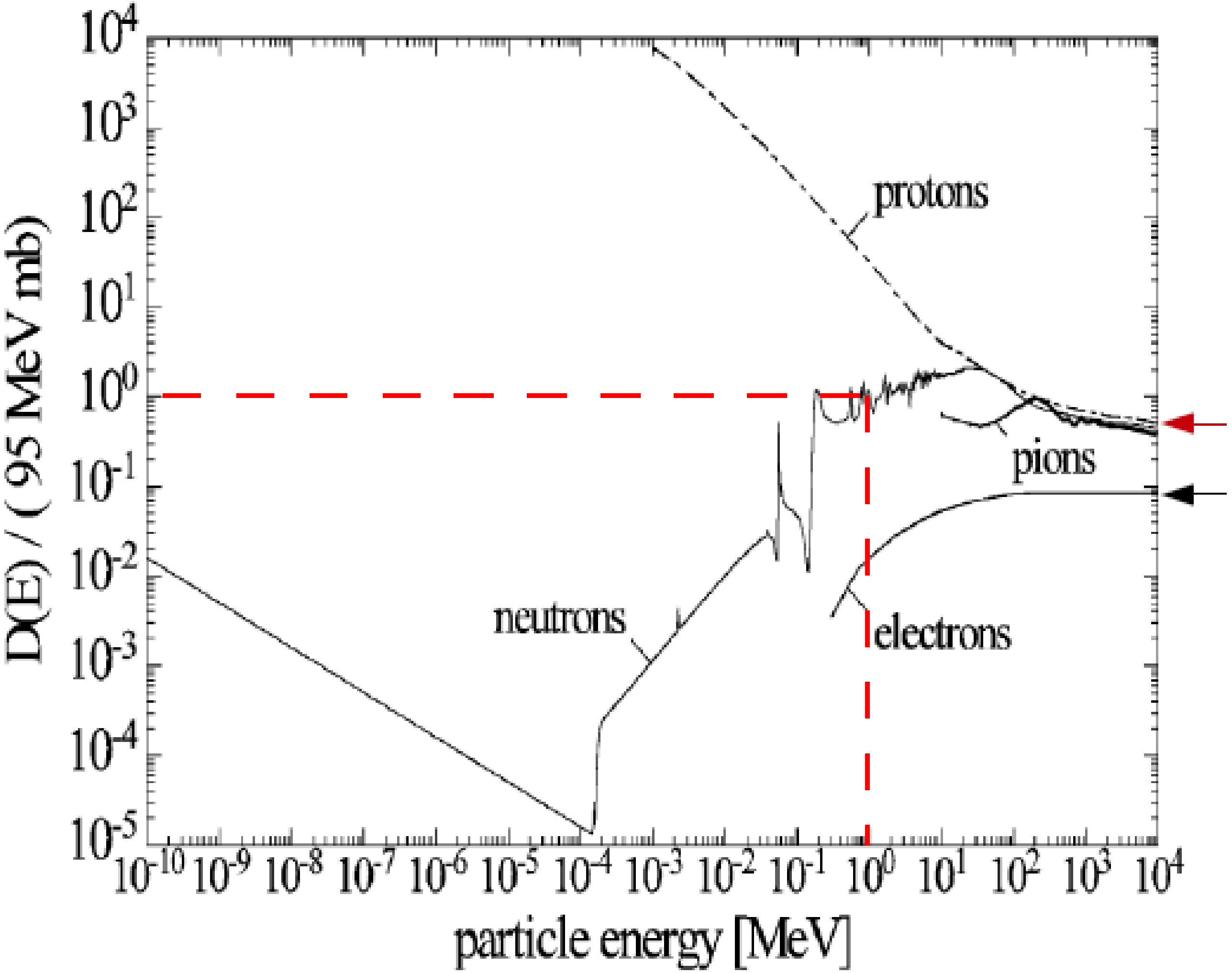
Temperature: + 30^0 C
Readout Time: 125 µs
Pitch size : 20.7 µm
Irradiated with to
fluence = 3 x 10^{12} n_{eq}/cm²

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 = $\varkappa\Phi$ $\varkappa$ - radiation hardness parameter

$\varkappa$ = 0.62/5 for electrons

$\varkappa$ = 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