Ideas on new NA61/SHINE Vertex Detector Design

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Beyond 2020 -VD NA61 meeting, Geneve University, 26-28 of July 2017

https://indico.cern.ch/event/629968/

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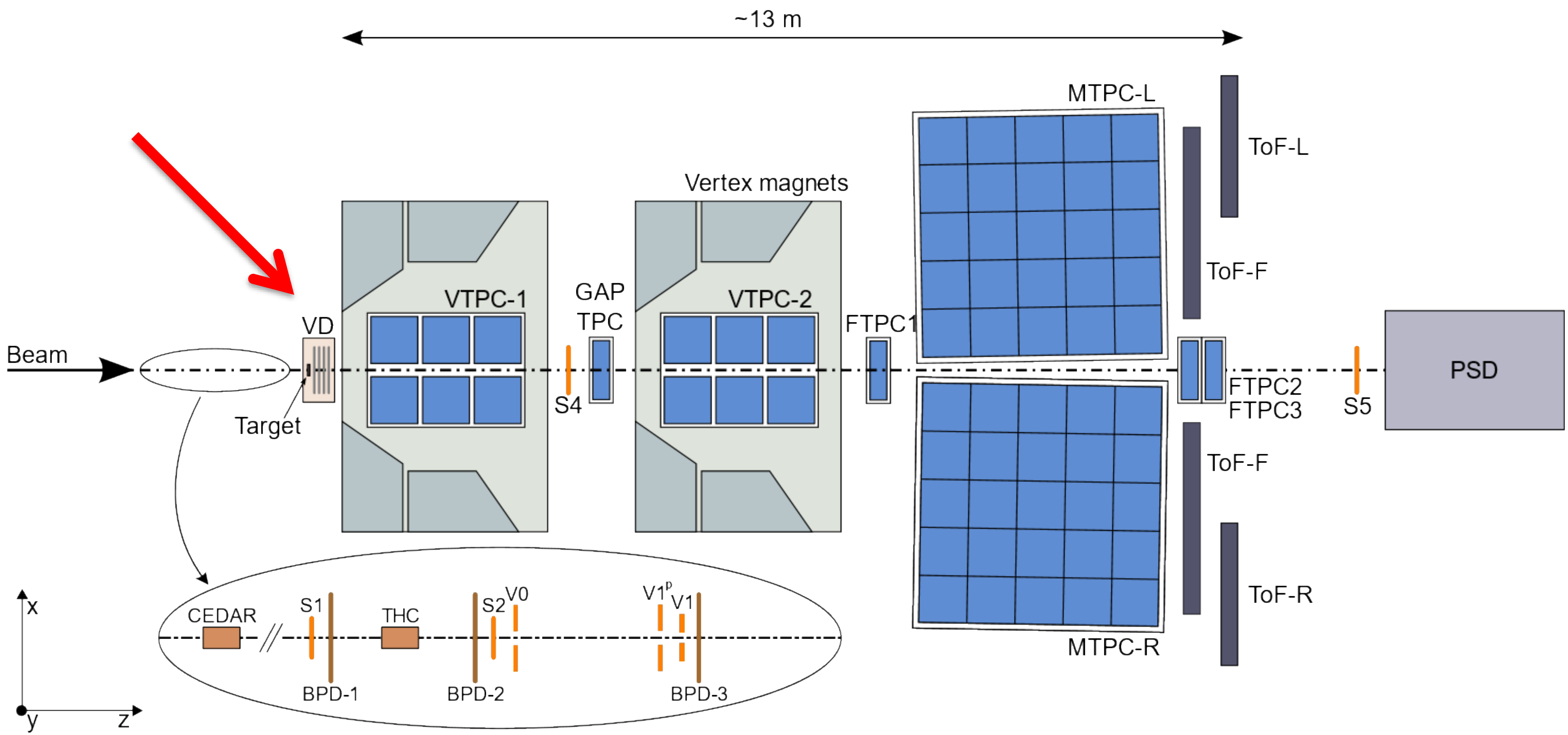
LAYOUT

- Motivations for the new Vertex Detector (VD)
- Challenges to be met and general approach
- The baseline proposal of VD
- Additional options of VD
- Prototyping and the first tests
- Summary

Vertex Detector for NA61



Motivations for the new VD:

1) Open charm [1,2]

[1] **T. Matsui and H. Satz,** Phys. Lett. B 178 (1986) 416.

[2] **Helmut Satz,** Calibrating the In-Medium Behavior of Quarkonia, arXiv: 1303.3493, 12 April 2013

2) **The enhanced relative yield of strange and multi-strange particles** in AA collisions with respect to pp and pA interactions

[1] **J.W. Harris, B. Müller**, Annu. Rev. Nucl. Part. Sci., 46 (1996), p. 71

[2] **J. Rafelski, B. Müller**, Phys. Rev. Lett., 48 (1982) 1066; 56 (1986) 2334.

[3] **J. Rafelski,** Phys. Lett. B, 262 (1991), p. 333

3) Correlations of cumulative particles with strangeness and charm production

[1] ***M.A. Braun, V.V. Vechernin, Theor.Math.Phys. 139, 766 (2004)***

[2] see strangeness production in ***:*** **E.G. Ferreiro, C. Pajares,** J.Phys.G23:1961-1968, (1997)

4) Precise measurements of production of charged pions and kaons out of a replica of the T2K target→ See reports by Matej Pavin and Alain Blondel at this workshop

[1] http://cerncourier.com/cws/article/cern/47836

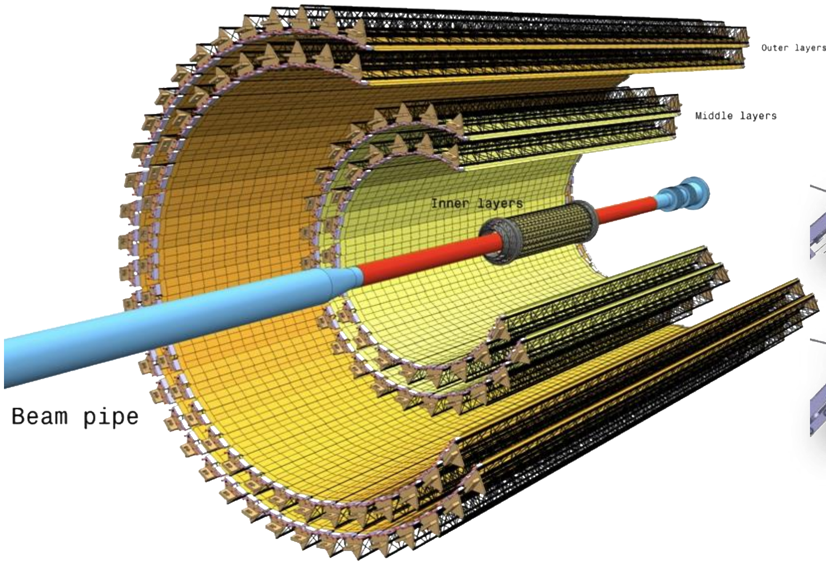
5) Electromagnetic effects in AA collisions → See report by Nikolaos Davis at this workshop

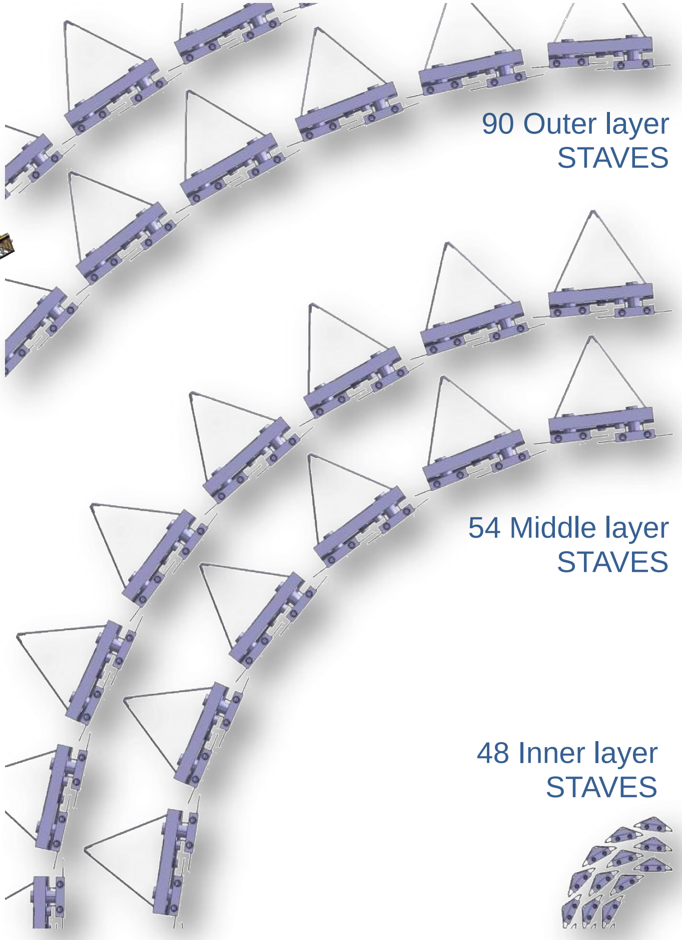
Availability of new detector technologies

New ITS layout(

A Large Ion Collider Experiment

ALICE





- 7-layer barrel based on CMOS sensors
- Radial coverage 22 – 400 mm

Staves length

Inner Layers	290mm
Middle Layers	900mm
Outer Layers	1500mm

Design goals to be met:

CERN-LHCC-2012-013 (LHCC-P-005)

1. **Coverage in transverse momentum to be as complete as possible, in particular down to very low momenta**.

2. Very accurate identification of secondary vertices from decaying charm or beauty (D, J/psi, Λ c, Λ b).

Table 1.1: Comparison of the features of the future ALICE, ATLAS and CMS trackers that are relevant for heavy-flavour measurements [11, 12]. The p range of the ALICE PID reported here refers to the combined PID information of ITS, TPC and TOF. However, it does not include the TPC PID in the relativistic rise.

	current ALICE	ALICE upgrade	ATLAS upgrade	CMS upgrade
innermost point (mm)	39.0	22.0	25.7	30.0
x/X_0 (innermost layer)	1.14%	0.3%	1.54%	1.25%
d_0 res. $r\varphi$ (μm) at 1 GeV/c	60	20	65	60
hadron ID p range (GeV/c)	0.1–3	0.1–3	–	–

PIXEL Chip – General Requirements

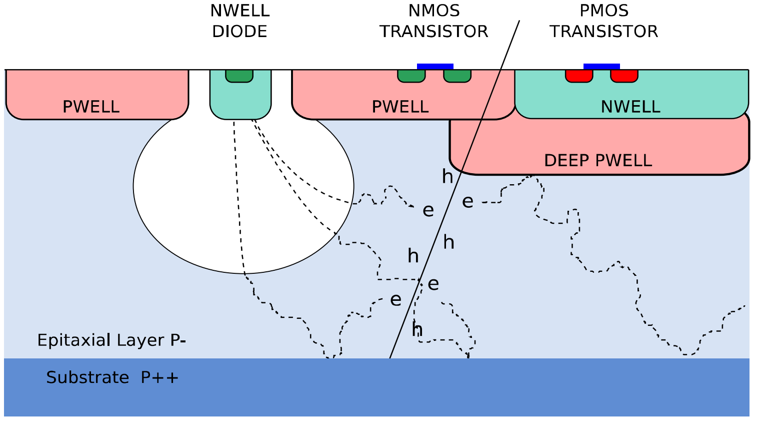
Parameter&	Inner&Barrel&	Outer&Barrel&
Chip size (mm x mm)	15 x 30	
Chip thickness (mm)	50	100
Spatial resolution (mm)	5	10 (5)
Detection efficiency	> 99%	
Fake hit rate	< 10^{-5} evt^{-1} $pixel^{-1}$ (>> ALPIDE)	
Integration time (ms)	< 30 (< 10)	
Power density (mW/cm^2)	< 300 (~35)	< 100 (~20)
TID radiation hardness (krad) (*)	2700	100
NIEL radiation hardness (1MeV n_{eq}/cm^2) (**)	1.7×10^{13}	1.7×10^{12}

(*)

CMOS Pixel Sensor

J. Phys. G: Nucl. Part. Phys. **41** (2014) 087002

CMOS Pixel Sensor using TowerJazz 0.18µm CMOS Imaging Process



Tower Jazz 0.18 µm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

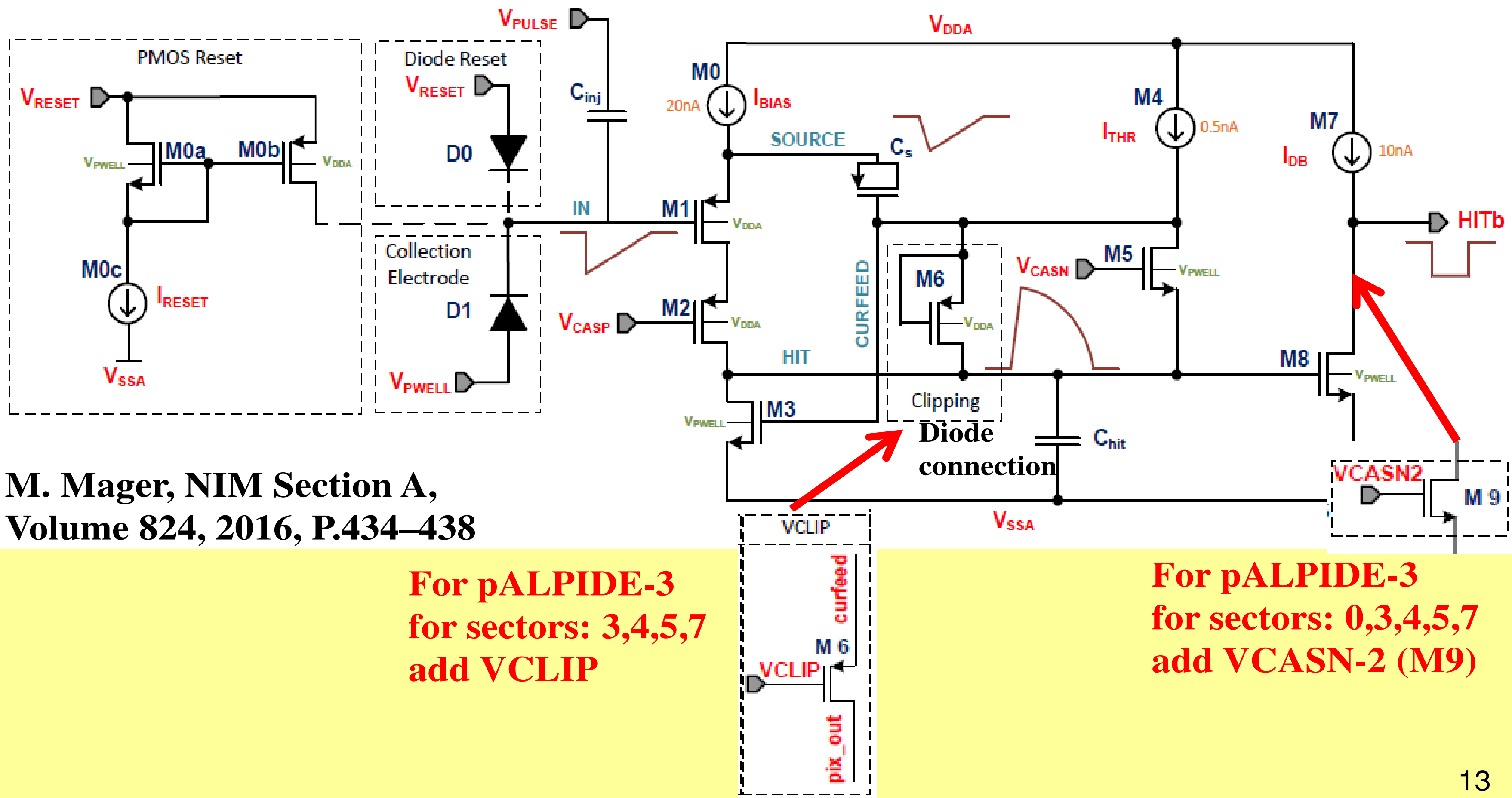
substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

Schematic cross section of a MAPS pixel in the TowerJazz 0.18 µm imaging CMOS with the deep p-well feature.

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25µm) on p-type substrate
- Small n-well diode (2 µm diameter), ~100 <mes smaller than pixel => low capacitance
- Application of (moderate) reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors to allow for full CMOS circuitry within active area

pALPIDE chips -1,2,3

For pALPIDE-1,2



M. Mager, NIM Section A, Volume 824, 2016, P.434–438

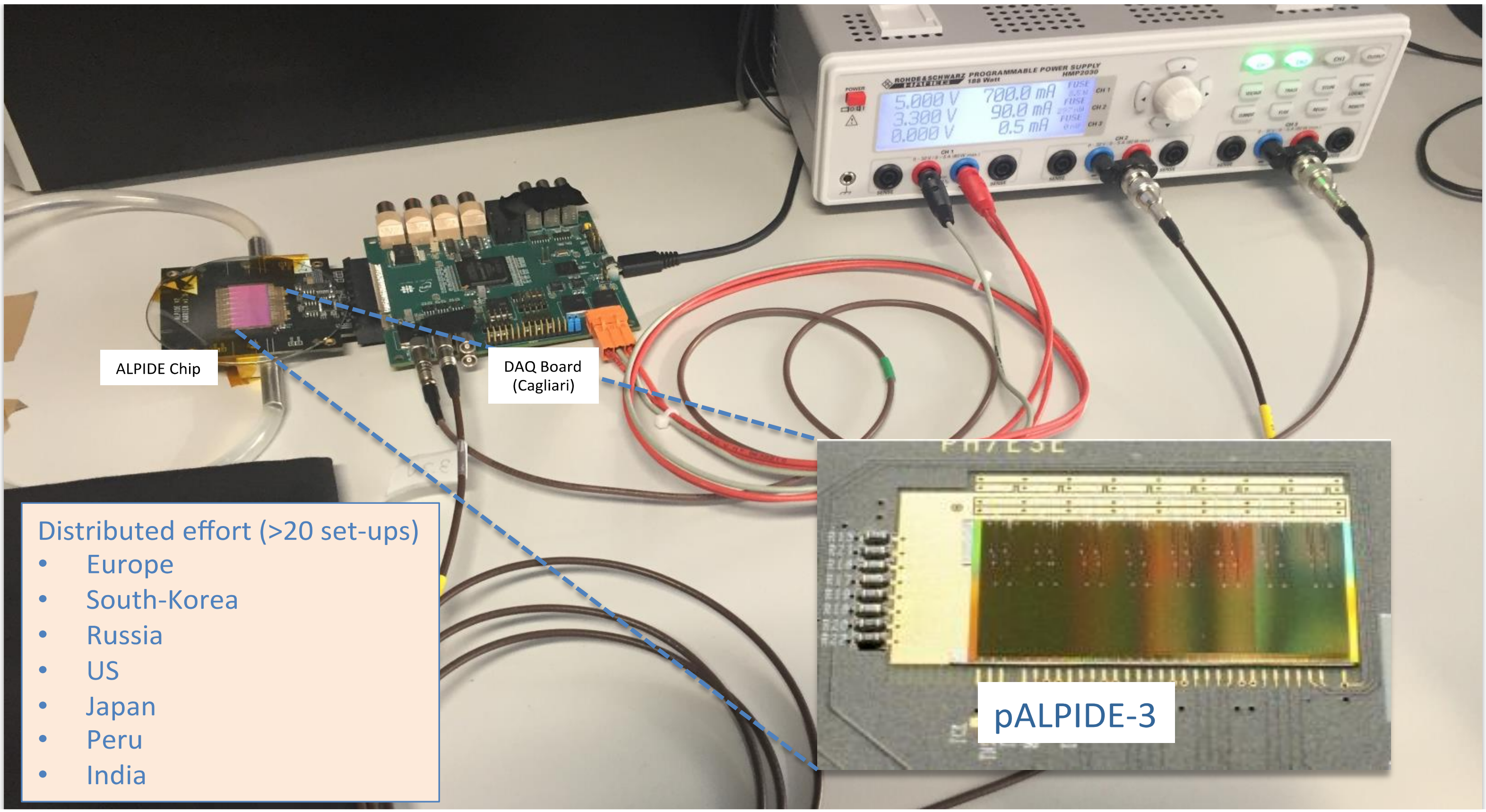
For pALPIDE-3 for sectors: 3,4,5,7 add VCLIP

For pALPIDE-3 for sectors: 0,3,4,5,7 add VCASN-2 (M9)

13

Tests of ALICE pALPIDE chips

Characterization of MAPS: Electrical tests (digital and analogue), noise, thresholds, fake hit rates vs. staring material, temperature, supply voltage, radiation, tests with γ- and β- sources, etc.

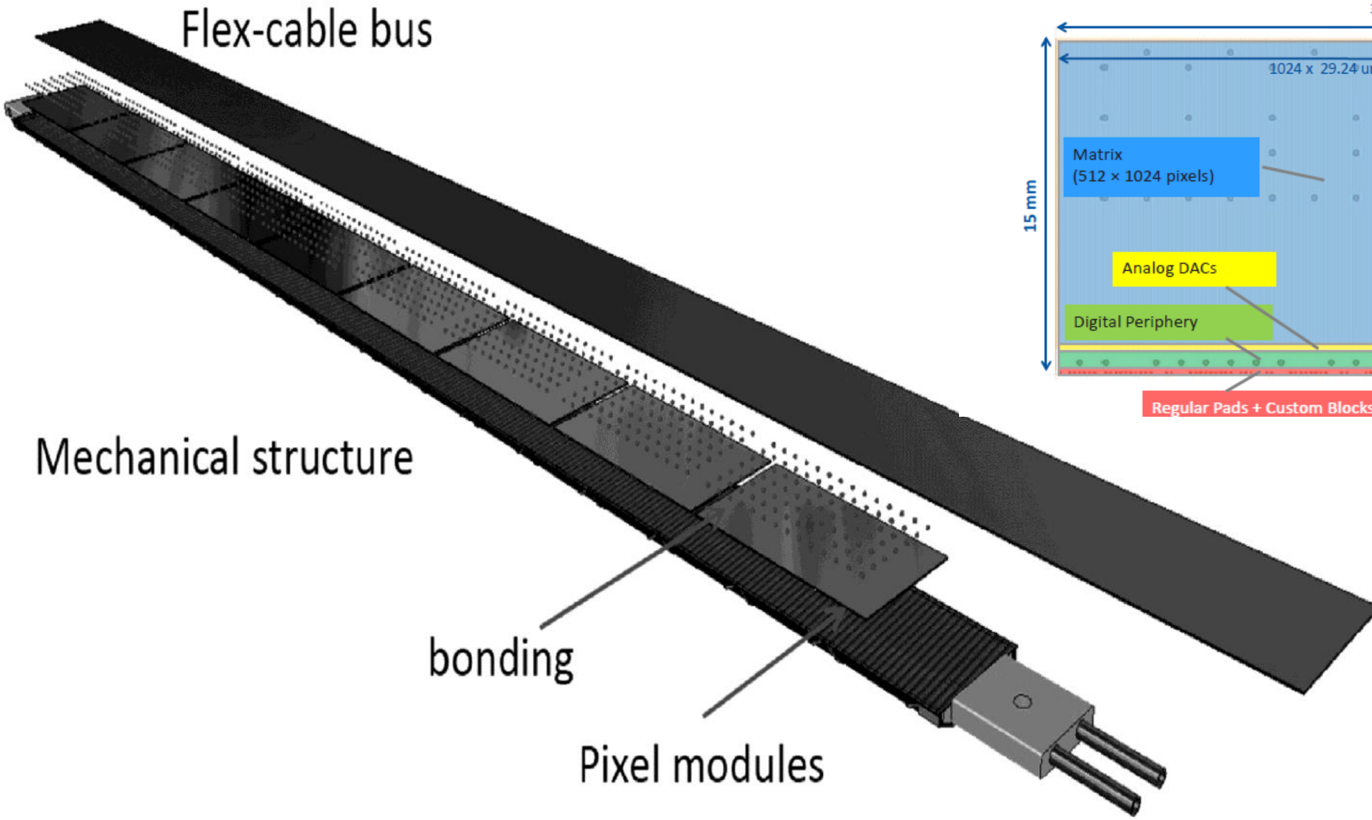


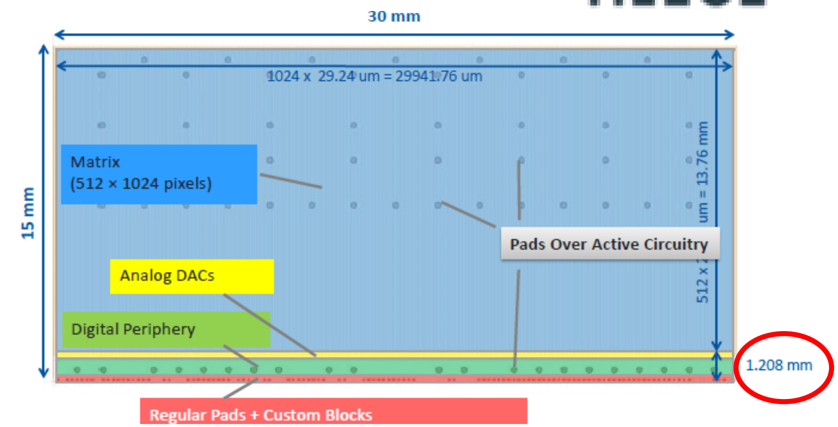
Distributed effort (>20 set-ups)

- Europe
- South-Korea
- Russia
- US
- Japan
- Peru
- India

ALICE technology for ITS:

record level of radiation transparency <0.3% X/Xo

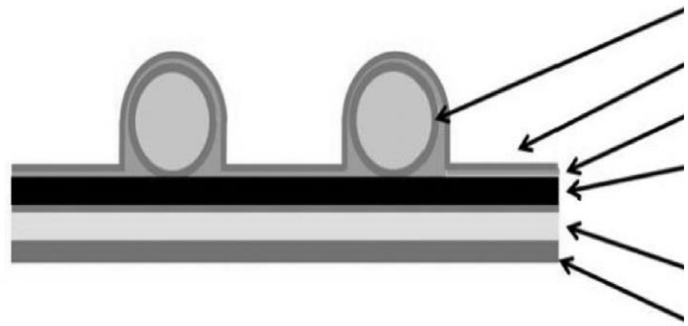




ALPIDE chip

JINST **9** P06005(2014)

Material budget of CF stave for VD NA61

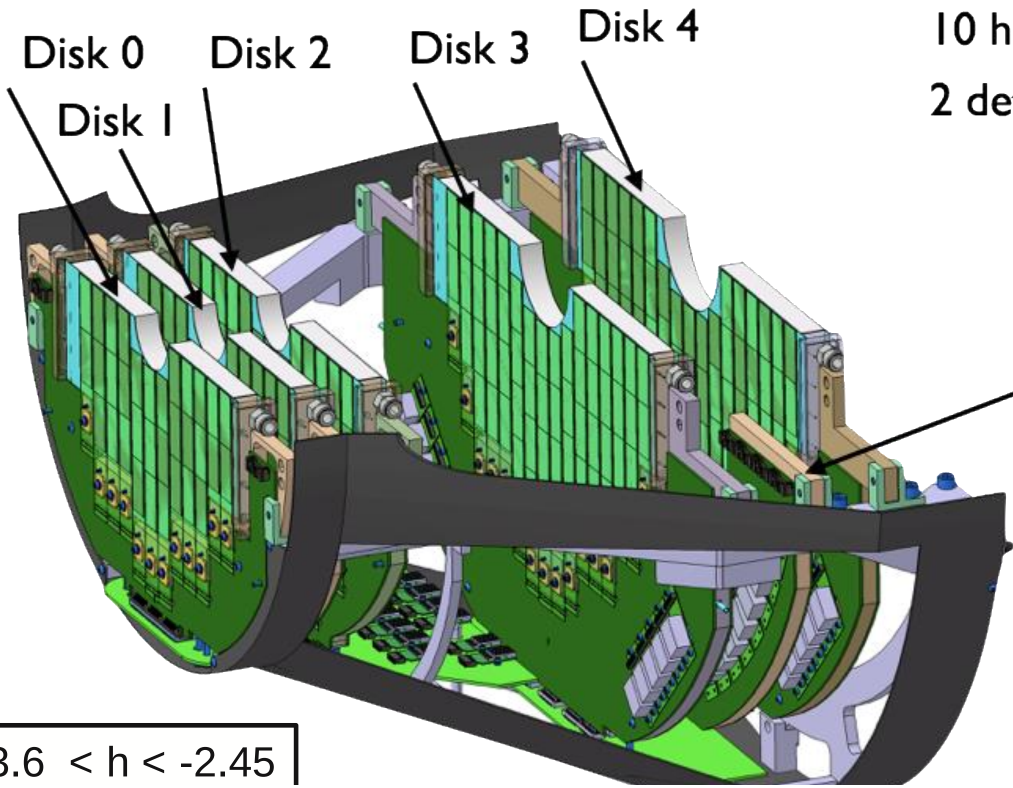


Estimated contributions to the material budget

Material	**Thickness (µm)**	**Xo (cm)**	**X/Xo (%)**
Polyimide cooling pipe wall	25 µm	28.41	0.003
Carbon fleece	40 µm	106.8	0.004
Water	1mm	35.76	0.032
Carbon fiber plate K13D2U	70 µm	26.08	0.027
Graphite foil	30µm	26.56	0.011
Thermal greese (glue)	100µm	44.37	0.023
Si-sensor	50µm	9.36	0.064
Total (without FPC)			**0.154**
Total with FPC			**<0.3**

ALICE technology for MFT: disks with ~ 0.6 X/Xo (reported today by Raphael Tieulent)

928 silicon pixel sensors (0.4 m²) in 280 ladders of 2 to 5 sensors each.



10 half-disks

2 detection planes each

5% of the ITS surface
Twice the ITS inner barrel

-3.6 < h < -2.45

JINST **9** P06005(2014)

Challenges for open charm at SPS

First feasibility studies
for open charm measurements with NA61/SHINE

→ see the next report by Szymon Mateuzh Pulawski at this workshop

NA61/SHINE simulations

Yasir Ali and Pawel Staszel for the NA61/SHINE collaboration, in Proceedings of 14th International Conference on Strangeness in Quark Matter (SQM2013), Journal of Physics: Conference Series **509** 012083(2014).

Yasir Ali, Pawel Staszel, EPJ Web of Conferences, **71**, 00004 (2014).

Yasir Ali, Pawel Staszel, Acta Physica Polonica B Proceedings Supplement **6**, No 4,1081 (2013)

Yasir Ali†, Paweł Staszel, Antoni Marcinek Janusz Brzychczyk, Roman Płaneta, Acta Phys. Pol. B44, 2019(2013).

Based on models:

- AMPT (A Multi-Phase Transport model): Phys.Rev.C72:064901.2005
- HSD(Hadron String Dynamics model) Int.J.Mod.Phys.E17 1367
- PYTHIA: Comput.Phys.Commun.135,238(2001)

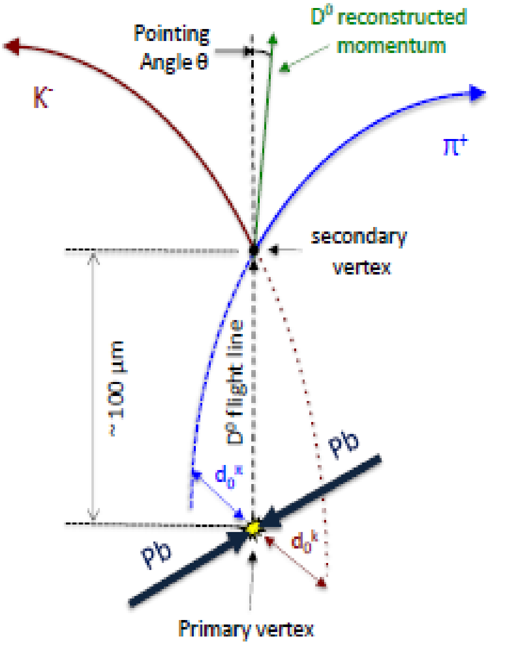
-> Challenges ->

Challenges for open charm measurements

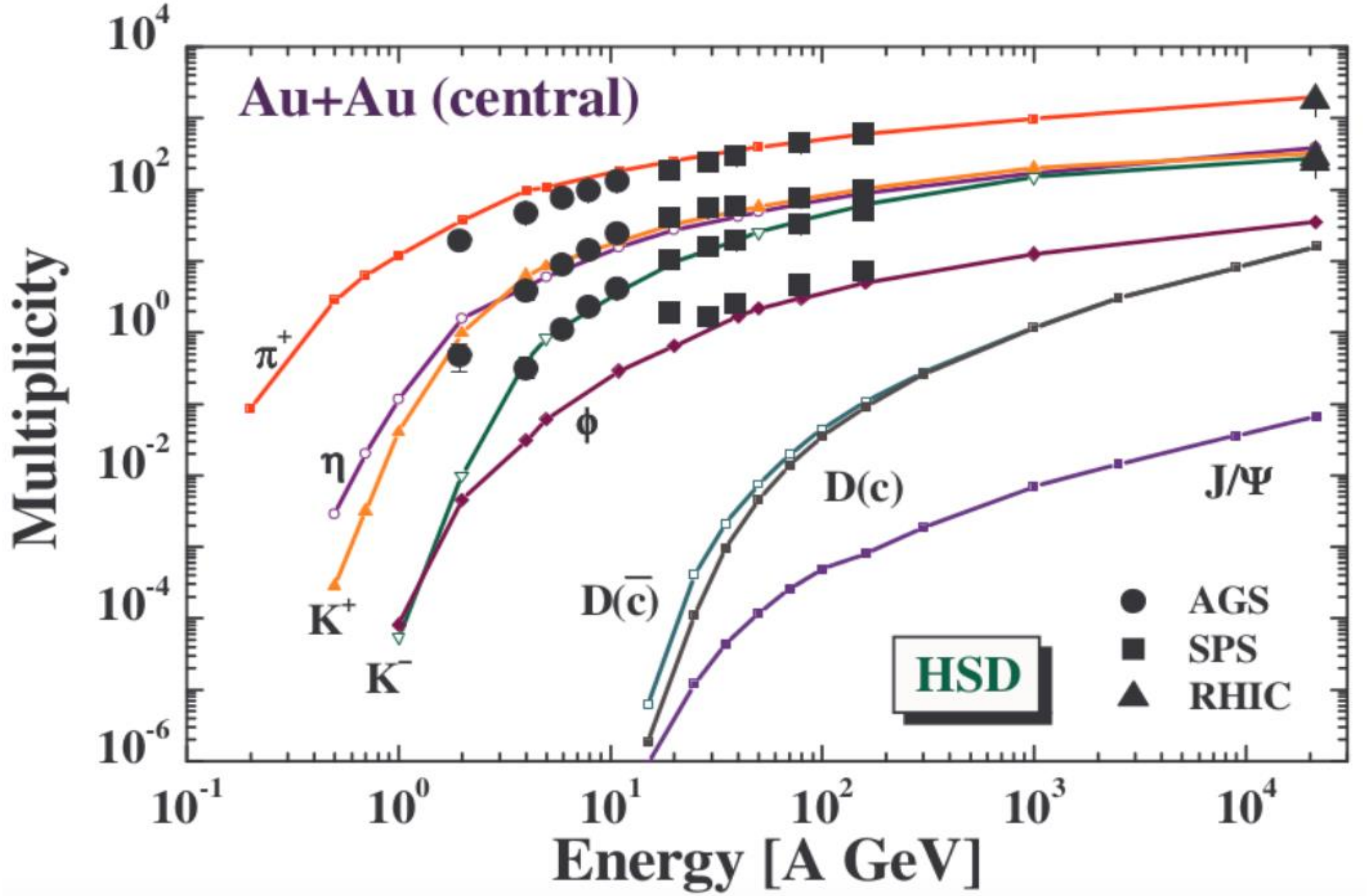
Reconstruction from hadronic decay channels

Challenge-1: Short life-time

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)%



Challenge-2: Low yields



Acta Phys. Pol. B44, (2013) 2019

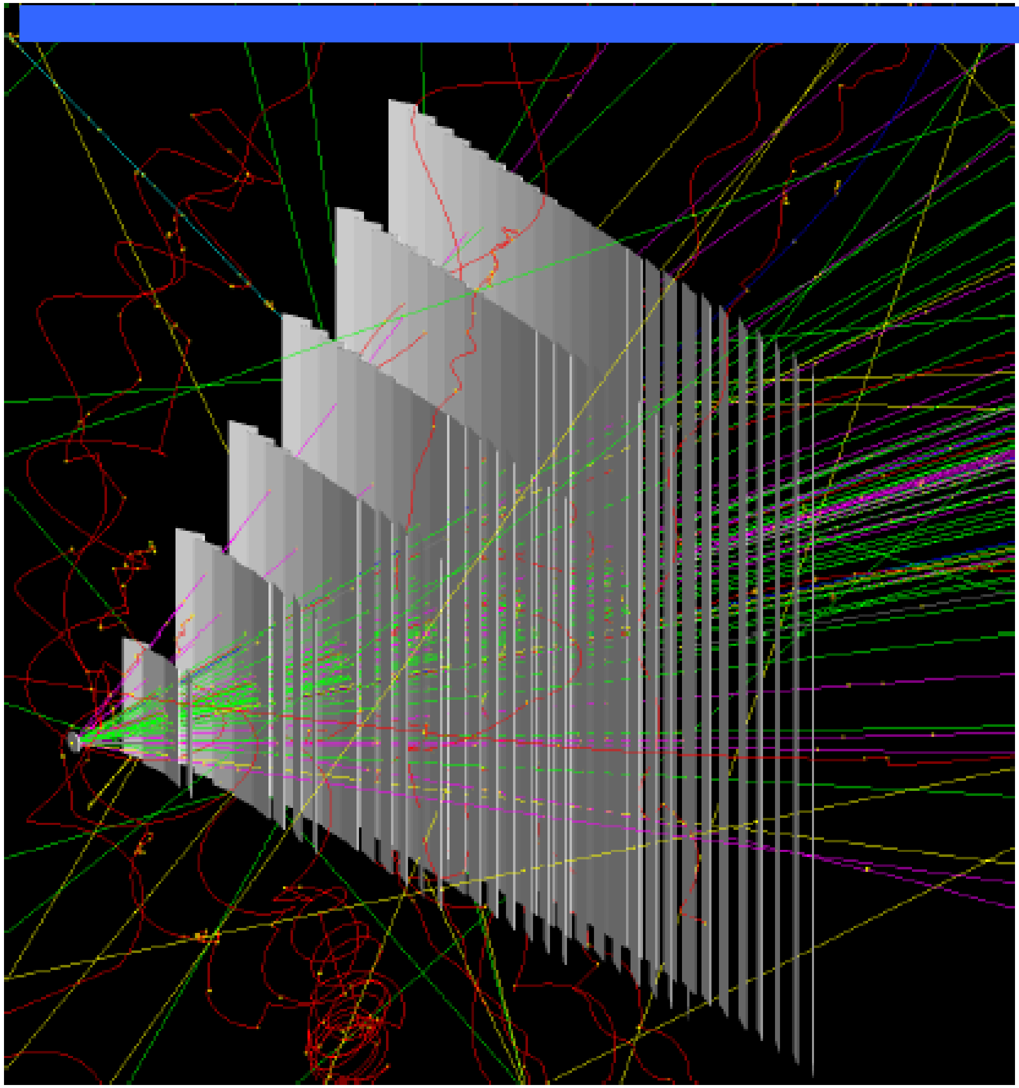
General requirements:

1) Precise vertexing (at the level of better ~20 -30μm for particles with pT> 1 GeV/c)
2) Fast detectors (< 30 μs) with high granularity
3) The low material budget (<0.3% X\Xo)
4) Large acceptance is desirable to accept 100% of the D0s produced and to match the VTPC-1 of NA61/SHINE
5) VD should be considered with the account of various targets (including the Long Target replica for T2K) to be used in future physics programme of NA61/SHINE

→ NA61/SHINE Vertex Detector project is based on CMOS pixel detectors

Baseline proposal:

Large Acceptance VD -- 6 detector planes



➢ Layout is still to be optimized by simulation

PRIORITIES:

➢ the highest granularity

➢ the lowest material budget of the innermost layers

➢ TPC-VD track matching

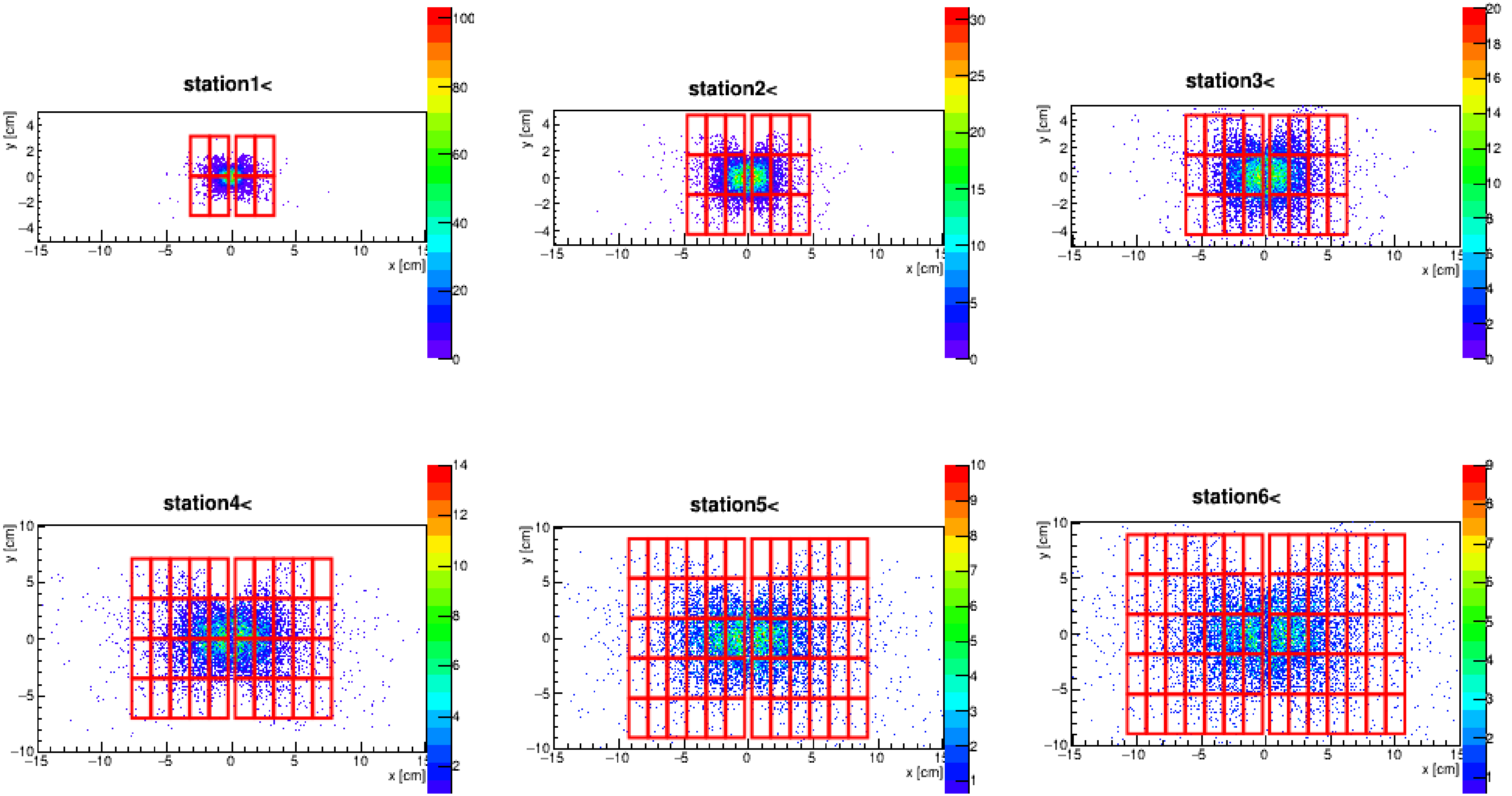
➢ high-precision (~ 10 μ potential capabilities) determination of secondary vertices for open charm

➢ secondary vertices determination for strange and multi-strange particles

→ NA61/SHINE Vertex Detector is based on CMOS pixel detectors

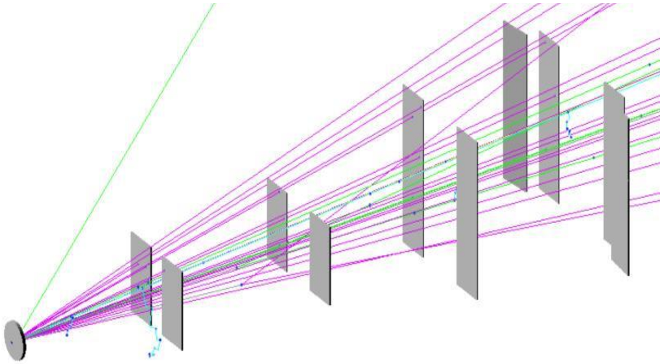
Number of sensors

220 sensors

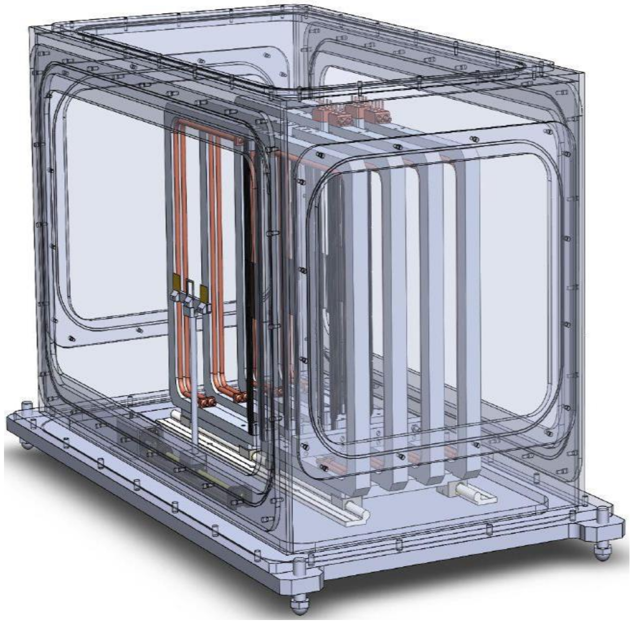


(Anastasiya Merzlaya, 08.05.2017)

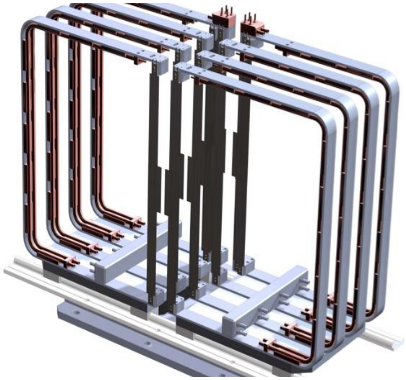
Small Acceptance VD layout



Mimosa-26 sensors mounted
on extra-lighweight CF cooling panels



VD housing box filled with He



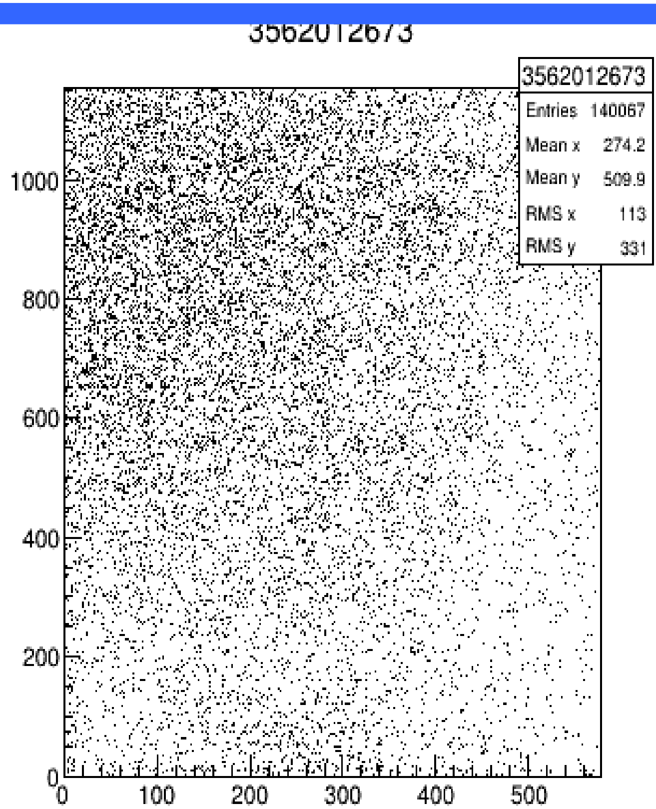
C-shape support frames

Small Acceptance VD at the pilot run at the SPS in 2016

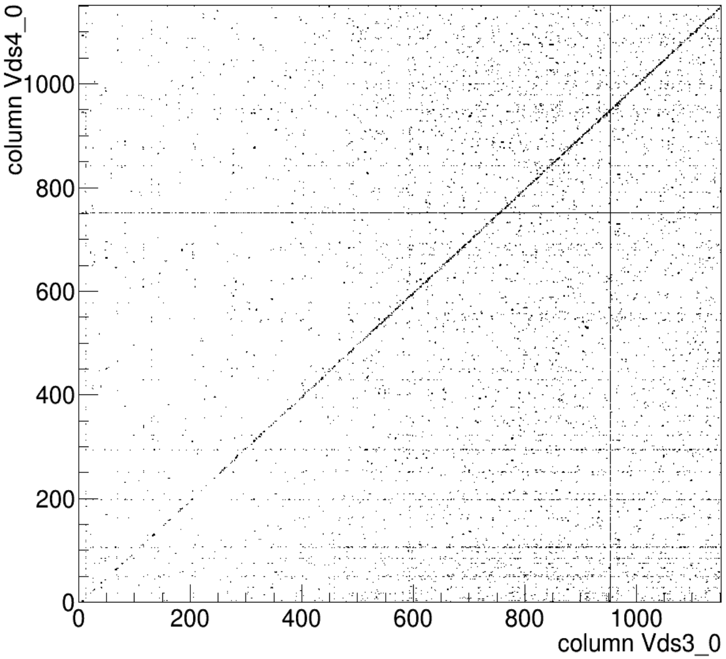
- Left: VD installed between beam pipe and first Vertex TPC (window removed)
- Target to be mounted inside VD enclosure

- Right: close-up of stations/ladders with sensors inside VD
- Sensors attach to feed-throughs in enclosure

July 2016: the 1st in-beam tests of VD telescopes



Accumulated cluster map of one sensor (July 2016)

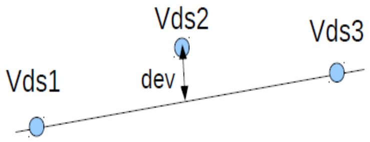


Correlation between hits in sensor columns of stations 3 and 4

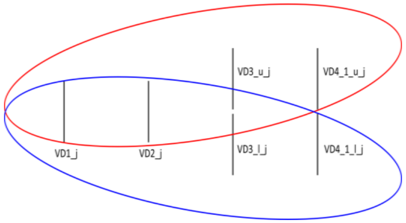
Primary vertex resolution for HighThreshold (HThrs) December 2016 runs

Reconstruction algorithm

- 1 method (PS):
  Based on combinatorial method for 3-hit tracks using deviations; then combine 3-hit tracks to 4-hit tracks and find the primary vertex (for HThrs runs);



- 2 method (AM):
  Based on combinatorial method for 4-hit tracks using residuals from the fit; then find the vertex; for HThrs runs 3-hit tracks are added via Hough Transform, for MF runs - via combinatorial;

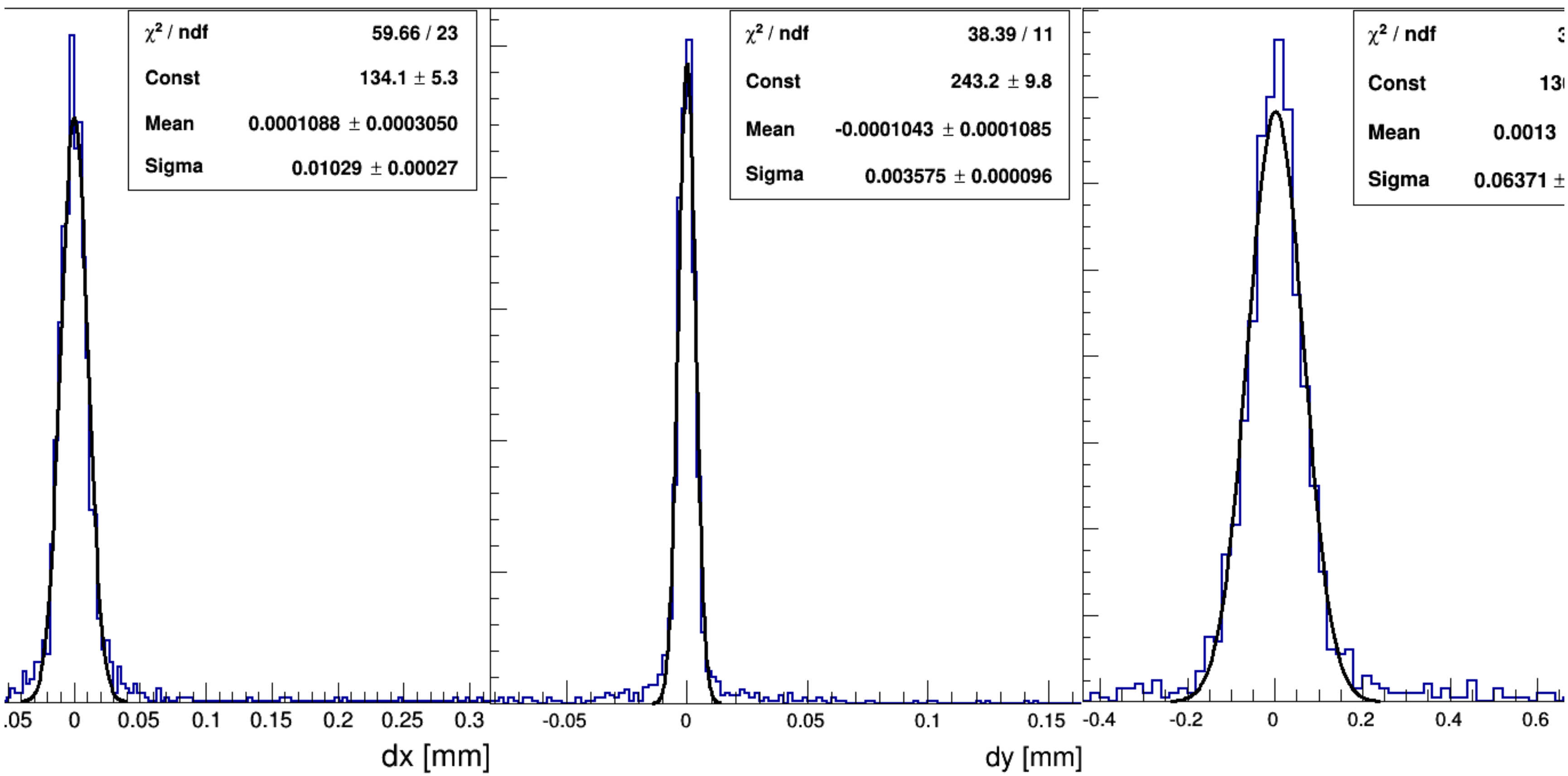


- Methods 1 and 2 give similar results for HThrs runs;
- Having one arm vertex one may reconstruct tracks from another arm;
- For runs with both J&S reconstructed vertices one may find resolution of the vertex.

From the slides on the VD data analysis by Dag Larse and Anastasiya Merzlaya 11.05.2017

Primary vertex resolution December pilot run

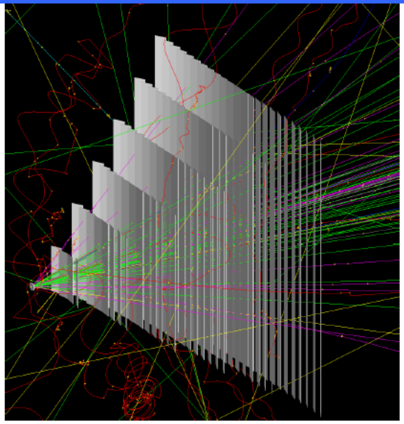
From the slides on the VD data analysis by Pawel Staszel



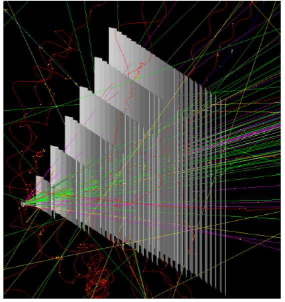
σ_x `10µ σ_y ~ 3 µ σ_z ~ 63µ

Work for D0s is in progergss!

Prototyping for Large Acceptance VD



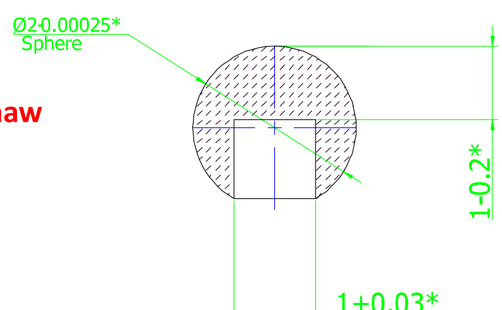
- C-shape frames mounted on the Al-platform



New “Saw” type elements on the C-frame and precise positioning (~10 μ) with ruby balls and fixation

ruby ball

PRECISE POSITIONING of the VD staves with ruby balls



Drilled ball 2mm Ruby Reninshaw
2mm G10 DIN 5401

www.saphirwerk.com

PRECISE POSITIONING on C-SHAPE FRAMES for NA61 VD “PICK-UP” and “RETURN”

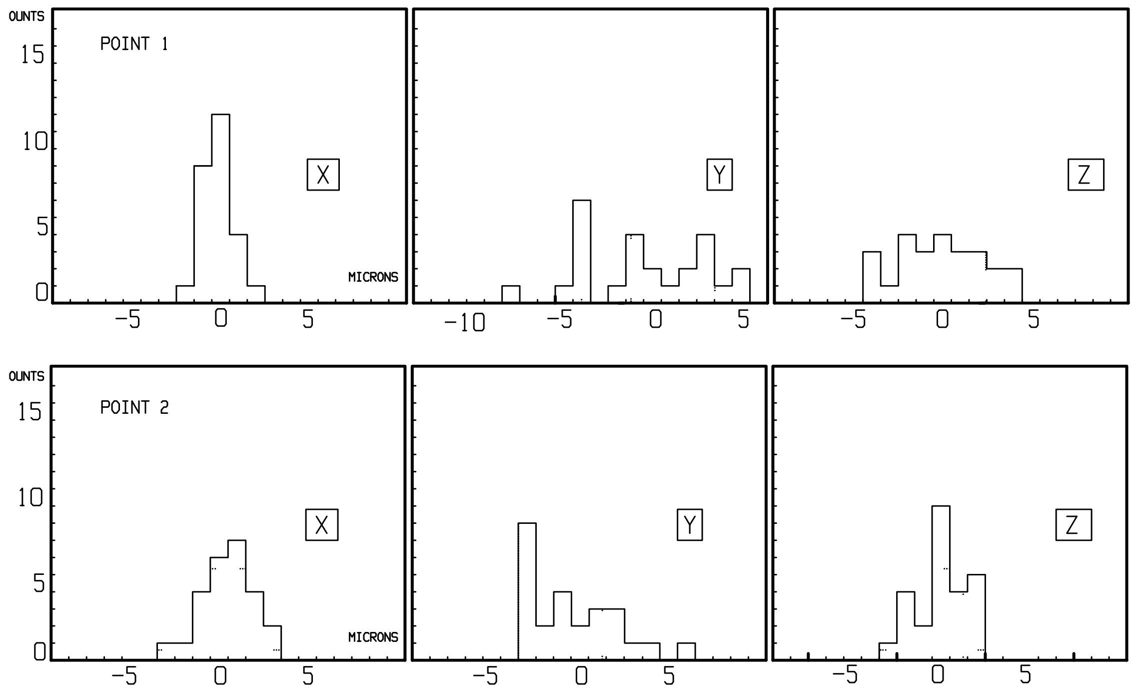
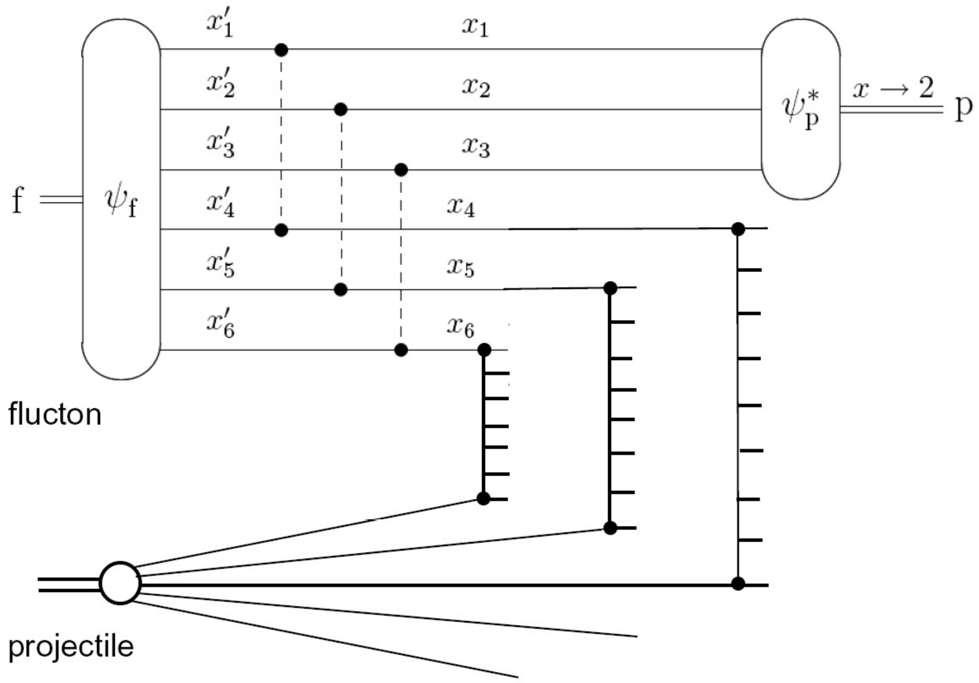


Figure 6.7: Histograms of the distribution of the coordinate of the reference point on the ladder after several ‘pick-up’ and ‘return-back’ operations. The accuracy is better than 10 μm.

From : CERN / LHCC 99–12 ALICE TDR 4, 18 June 1999
ALICE **Technical Design Report of the Inner Tracking System (ITS)**

Future studies of correlations of cumulative particles with strangeness and charm production



Multi-quark configuration in nucleus **(fluctons)** and formation of cumulative proton and of the donor strings (all donors interact with the projectile, strong overlapping strings and string fusion mechanism)

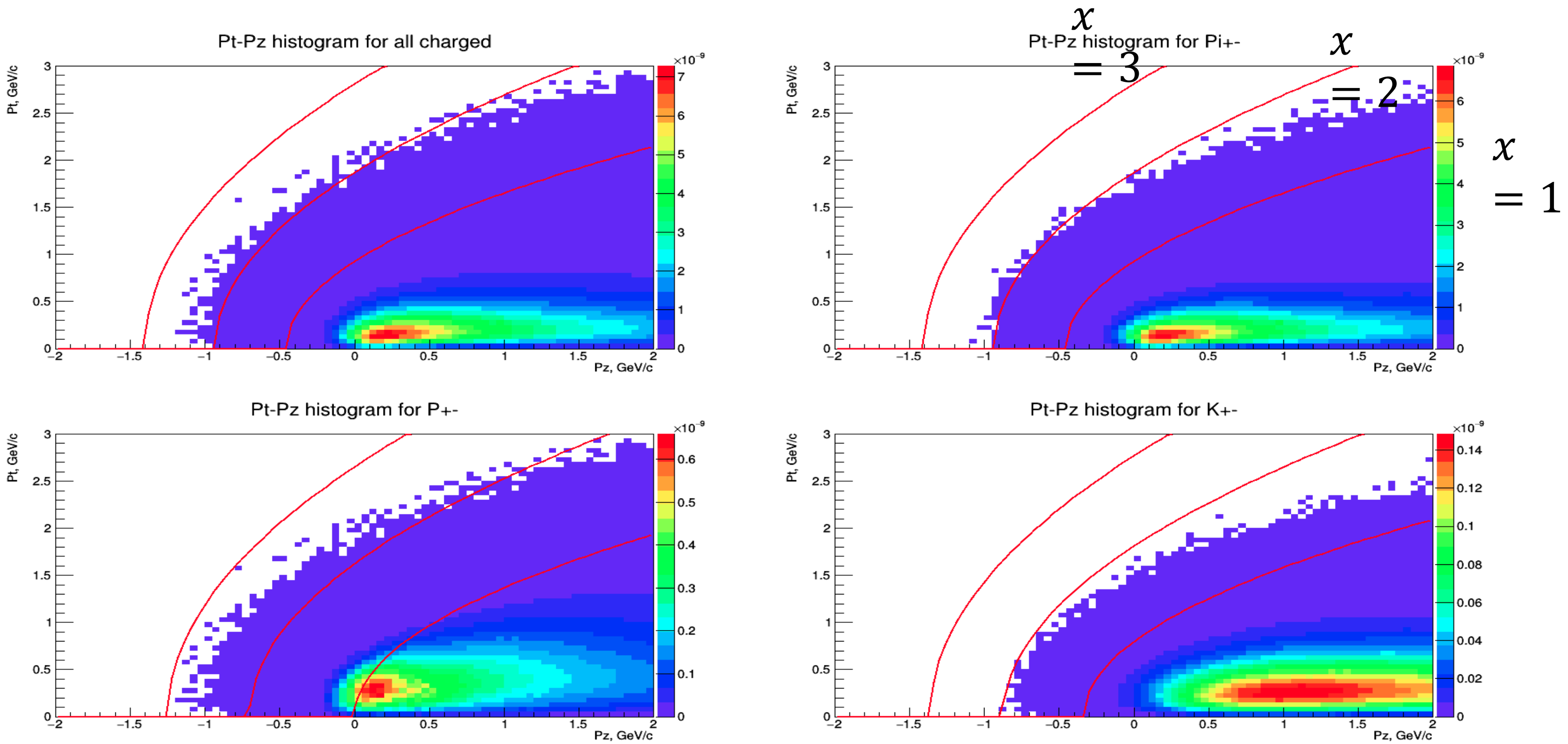
[1] **M.A. Braun, V.V. Vechernin, Phys.Atom.Nucl. 60, 432 (1997)**

[2] [1] ***M.A. Braun, V.V. Vechernin, Theor.Math.Phys. 139, 766 (2004)***

[3] see strangeness production in ***:*** **E.G. Ferreiro, C. Pajares,** J.Phys.G23:1961-1968, (1997)

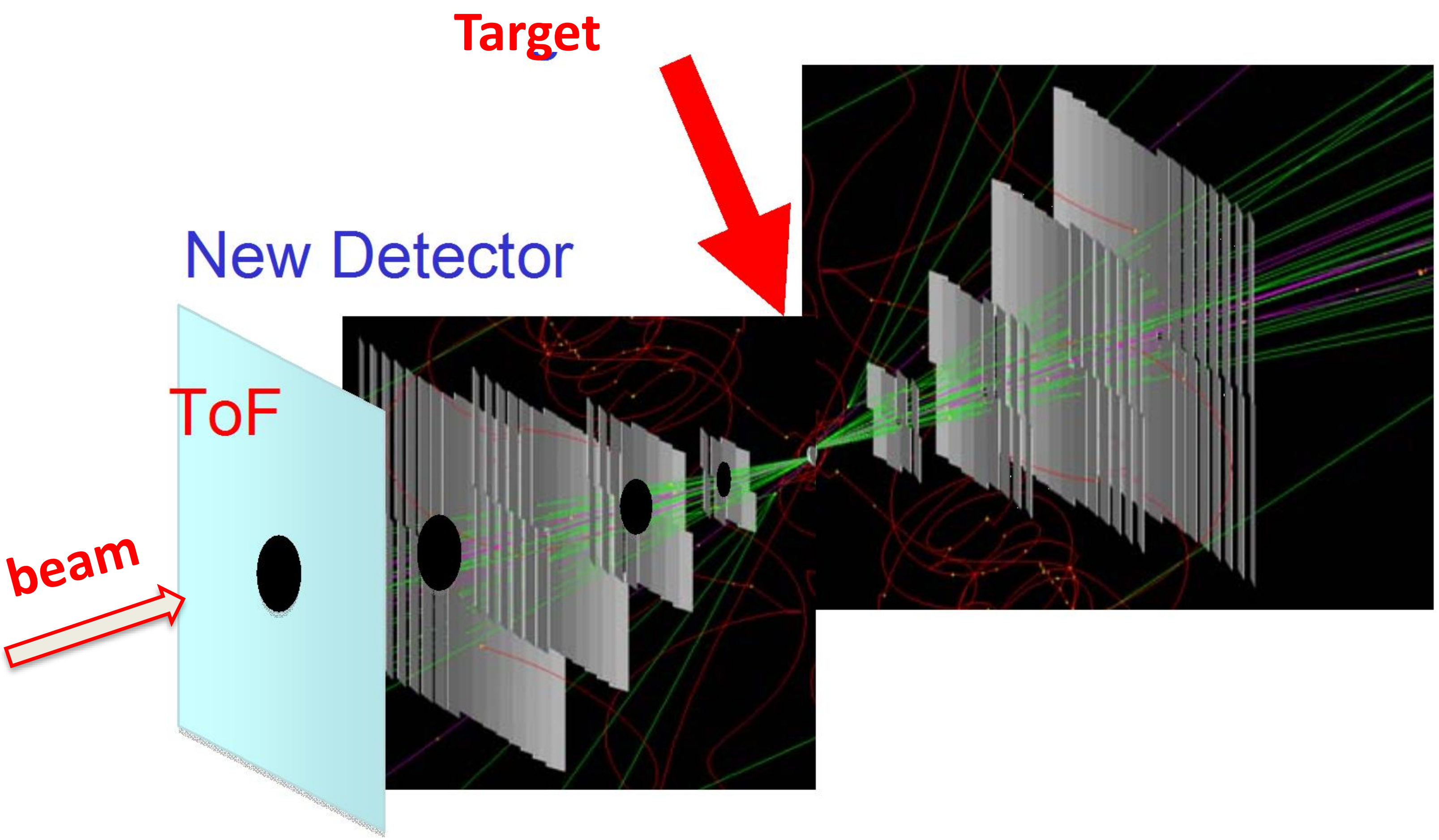
UrQMD simulation of cumulative particles and D mesons in p+C collisions

p-C at plab=400 GeV/c UrQMD default



G.Feofilov, V.Kovalenko, V.Vechernin, **Future studies of correlations between cumulative particles and heavy flavor production in relativistic nucleus-nucleus collisions,** ***Reported by Grigory Feofilov, QFTHEP-2017, Yaroslavl, 28 June 2017***

Concept of new detector for studies of multiquark configurations in nuclei related to strange and multistrange particles, charm and correlations with cumulative particles formation



Summary-1:

1) The ITS/ALICE technology for the NA61/SHINE VD : the record level of radiation transparency <0.3% X/Xo for the innermost layers can be achieved to ensure ~10-20 μ accuracy in secondary vertices determination
2) The ITS/ALICE technology provides the possibility of easy replacement of detector staves and keeping ~10 μ positioning accuracy
3) Flexibility to add layers of detectors
4) Prototyping in the ALICE/ITS technology of the mechanical layout of the LAVD is ongoing. The goal – to provide in October 2017 the setup for application of several ALICE Hybrid Integrated Circuits (HICs) to be used in the NA61/SHINE at the SPS beam tests.

Summary-2:

5) The VD project is well on track.

6) *Small Acceptance VD* is ready and data analysis of the 1st beam tests are ongoing.

7) Development of *Large Acceptance VD* is being continued in 2017
--- To be ready after LongShutdown-2 in 2020

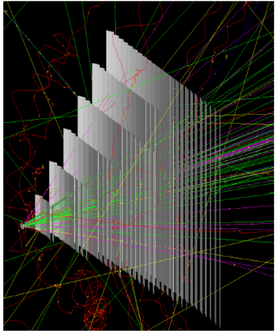
8) Open charm measurements by NA61/SHINE, as well as studies of strange and multistrange particles production in A+A collisions at top SPS energy, are possible after construction of the Large Acceptance Vertex Detector

9) Precise measurements of production of charged pions and kaons out of a replica of the T2K target are being discussed by the collaboration.

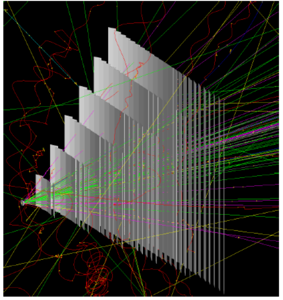
Collaboration list

National Nuclear Research Center, Azerbaijan
Faculty of Physics, University of Sofia, Bulgaria
Ruder Boskovic Institute, Croatia
LPNHE, University of Paris VI and VII, France
Karlsruhe Institute of Technology, Germany
Fachhochschule Frankfurt, Germany
Institut für Kernphysik, Goethe-Universität, Germany
Nuclear and Particle Physics Division, University of Athens, Greece
Wigner RCP, Hungary
Institute for Particle and Nuclear Studies (KEK), Japan
University of Bergen, Norway
Institute of Physics, Jan Kochanowski University, Poland
National Center for Nuclear Research, Poland
Institute of Physics, Jagiellonian University, Poland
Institute of Physics, University of Silesia, Poland
Faculty of Physics, University of Warsaw, Poland
Department of Physics and Astronomy, University of Wroclaw, Poland
Faculty of Physics, Warsaw University of Technology, Poland
Institute for Nuclear Research, Russia
Joint Institute for Nuclear Research, Russia
St. Petersburg State University, Russia
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Russia
University of Belgrade, Serbia
ETH Zürich, Switzerland
University of Bern, Switzerland
University of Geneva, Switzerland
University of Colorado Boulder, USA
Los Alamos National Laboratory, USA
Department of Physics and Astronomy, University of Pittsburgh, USA
Fermilab, Neutrino Division, USA

Back-up slides



Prototyping of the LAVD:
ALPIDE chip with electronics mounted on the first C-shape frame (job in progress)

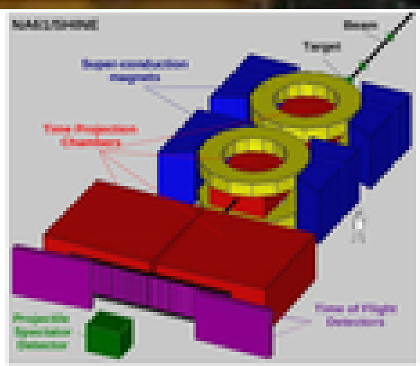


Benefits of the baseline VD design:

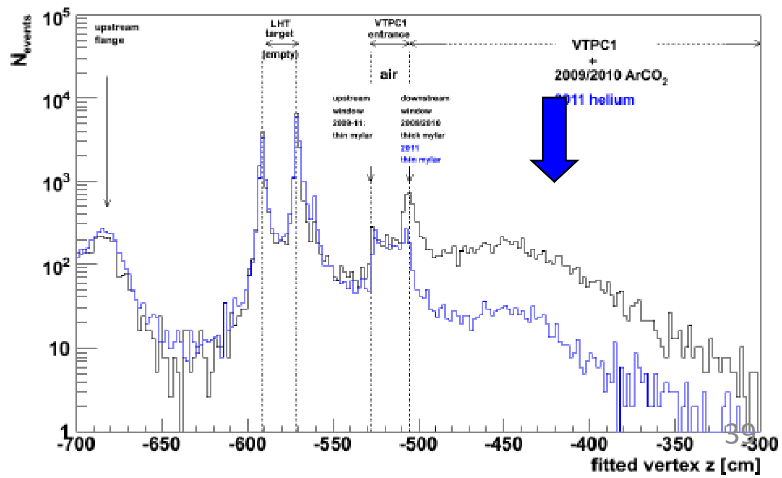
- Record level of radiation transparency (<0.3% X/Xo) of pixel detector layers could be achieved in the ALICE/ITS technology to provide the accuracy of D0's vertex determination at the level of ~ 10μ for tracks with pT>1 Gev/c
- Proved technology
- ALICE ITS IB staves complete compatibility
- Flexibility in station configurations and possibility of stave replacement without loss of precise positioning of staves (~10μ)

Some examples of St.Petersburg University technologies for NA61(SHINE)

Goal: Search for the critical point of strongly interacting matter



- Left: Extra-thin double-wall **He beam pipe** installed in 2012 in the gas volume between two field cages in the VTPC-1 **of NA61(SHINE).**
- This **He beam pipe** reduces the background interactions in the VTPCs by about **a factor of 10.**



He beam pipe for NA61

General design and peculiarities:

1) 2 concentric tubes (pipes) with very thin walls (tedlar, 30 mkm)
2) He is in the central pipe, the protective gap between the 1st and the 2nd pipes is filled with CO2 or N2 Pressure of He –slighly above normal – to keep stability, Pressure of CO2 in the 2nd circuit is slighly above normal but a bit lower pressure of He

$$P_{Ar} < P_{CO2\ (or\ N2)} < P_{He}$$

Motivation-4

precise measurements of production of charged pions and kaons out of a replica of the T2K target (from Alain slides)

The NA61/SHINE experiment at CERN measures the production of charged pions and kaons out of a a replica of the T2K target (a 90-centimetre graphite cylinder) to allow for precise calculations of the initial neutrino fluxes and beam composition at J-PARC [1].

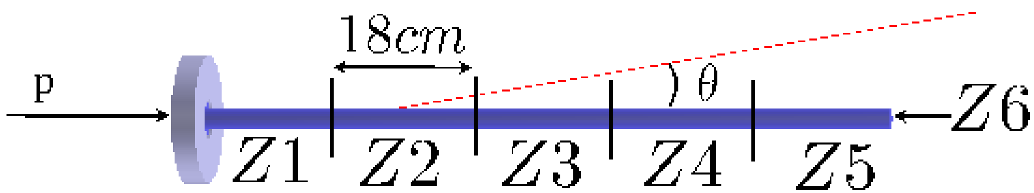
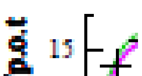


Figure 4.12: Sketch of the longitudinal binning of the target.



- Precise determination of charged particle tracks coming from the Long Target(LT) migh require

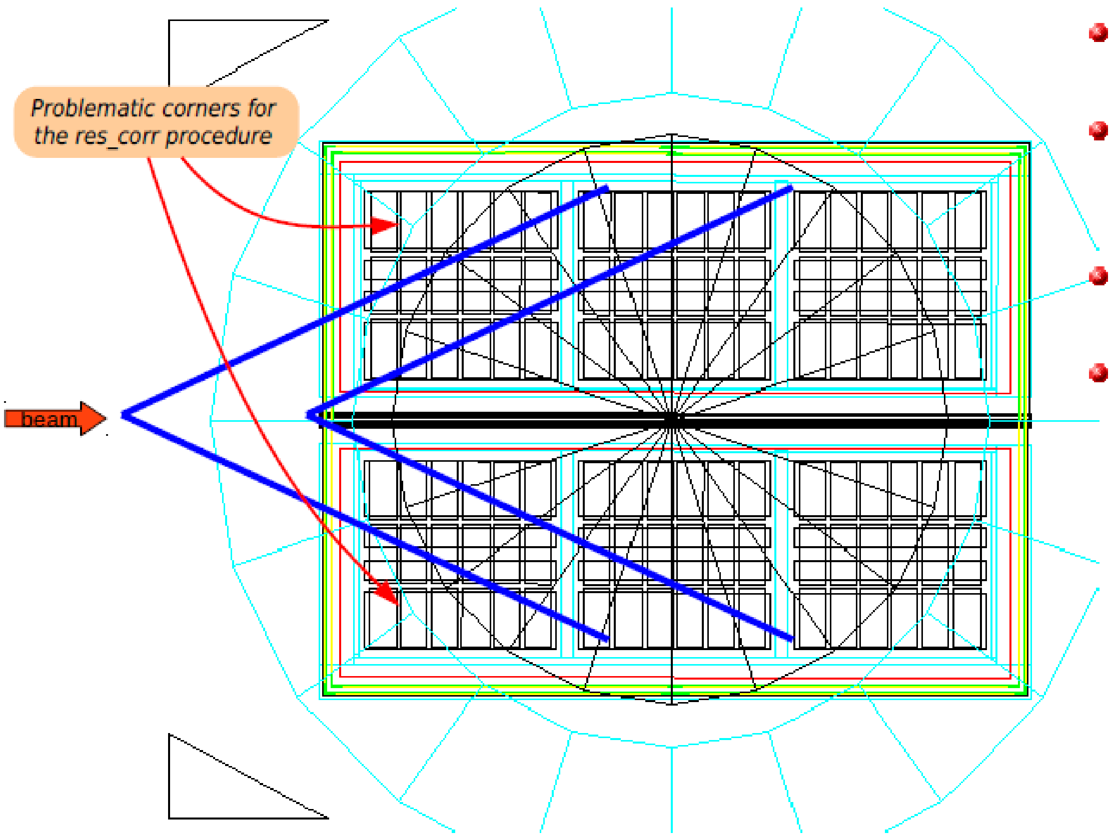
  ----either a new Vertex Detector Layout or

  ----the LT inside the VTPC-1

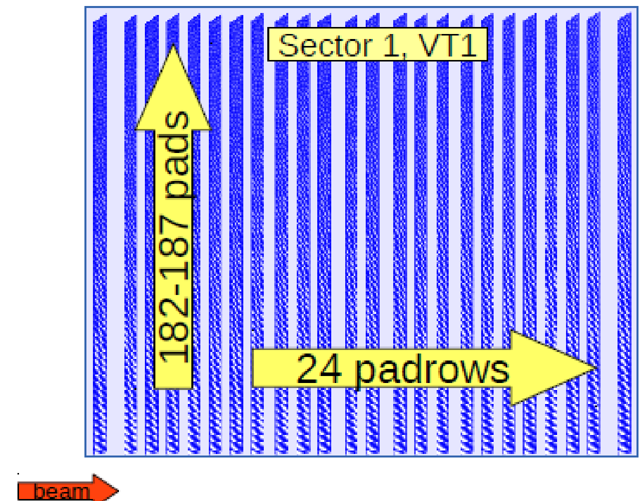
[1] http://cerncourier.com/cws/article/cern/47836

Can we profit in the thin-target analysis?

(from Alain slides)

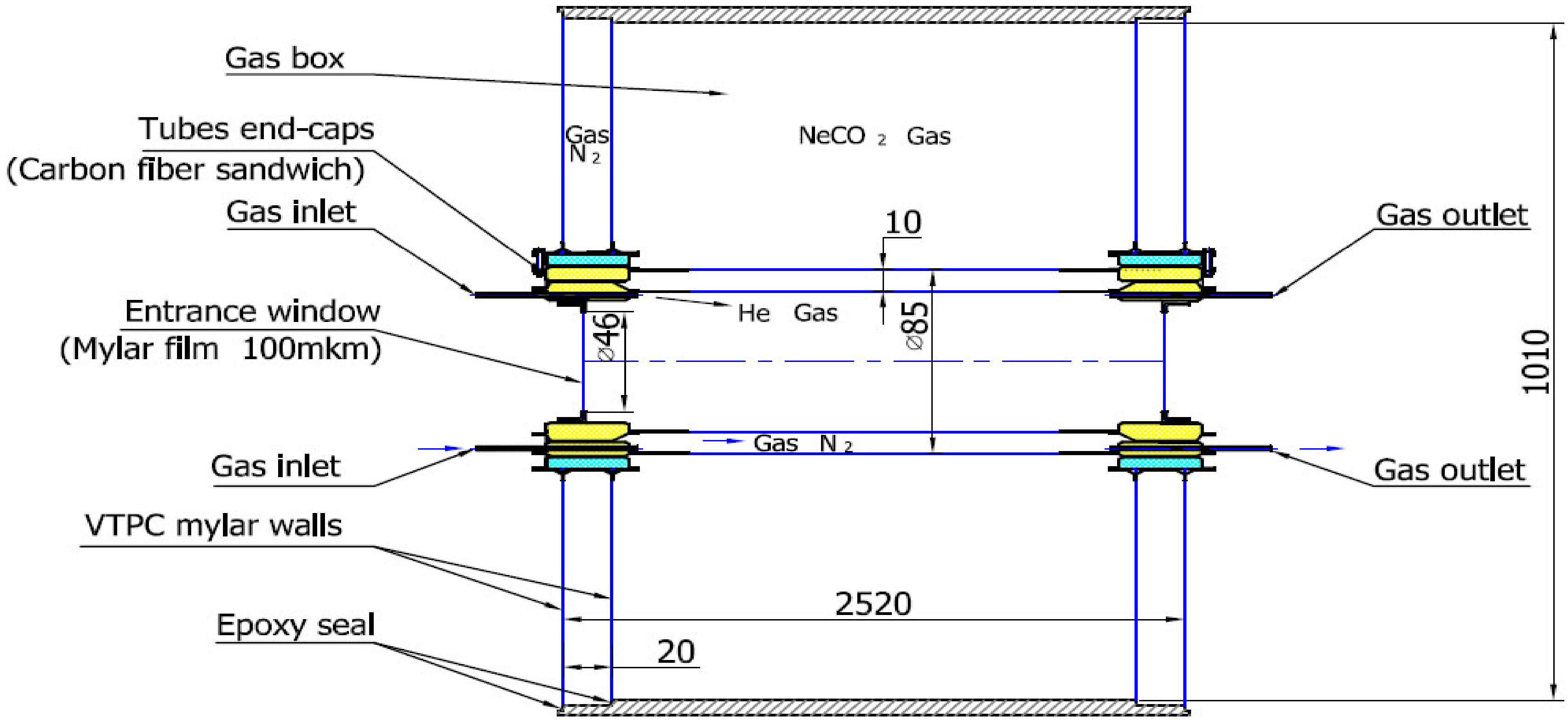


- Thin target can be moved downstream by 70 cm = 1 sector
- For the same angular acceptance corners of VT1 (problematic for res_corr) are not used
- Region of larger magnetic field: 0.02T(z=-5.8m) vs. 0.15T(z=-5m)
- One can also try to reconstruct large angles



9

Thin walls (60 mkm) double layers He beam pipe for NA61 inside the VTPCs-1&2



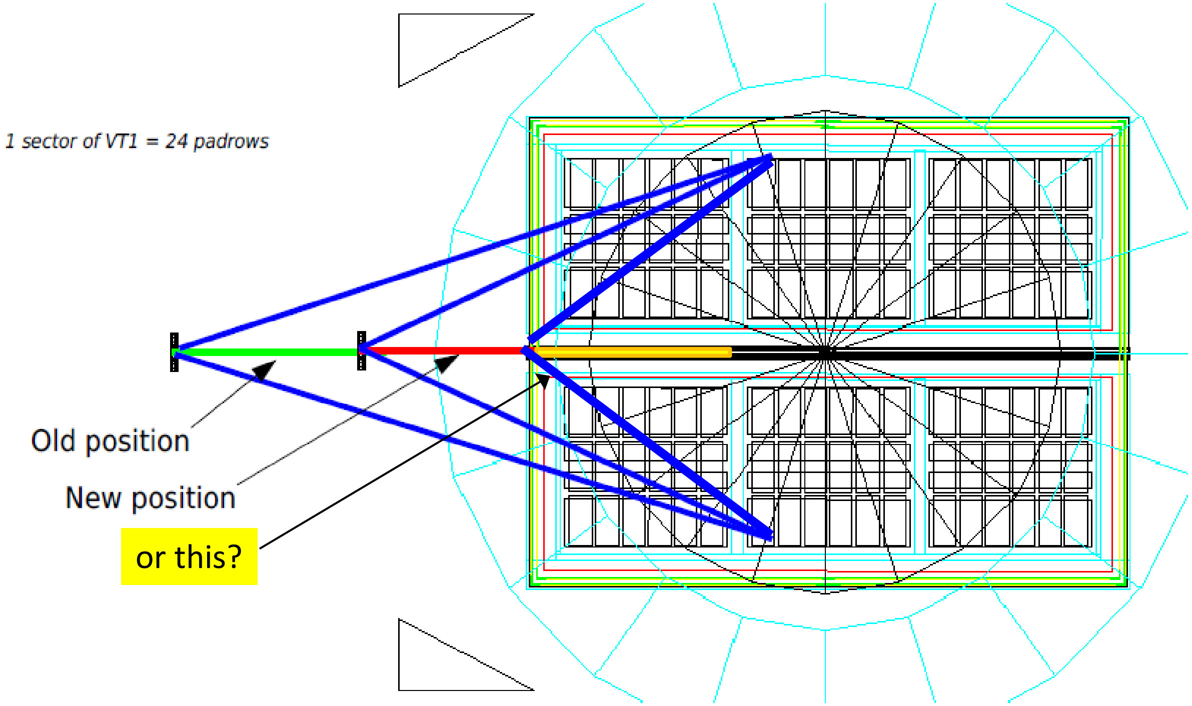
The feasibility of this option-2 for LT inside the VTPC is being discussed: It is NOT so simple just to open/close the beam-pipe for the LongTarget implementation – but it is possible

Additional options of tracking detector relevant to the precise measurements with T2K replica target

Position of Replica of the T2K target ?

slide from Alain Blondel talk 2015

What if we move RT partially into VT1?



Position of Replica of the T2K target ?

Options are being discussed:

- Option-1: tracking to the target by using the MFT disks around the LT, situated in front of the VTPC1
- Option-2: to move the LT is inside the VTPC1

➢ Both options will provide tracking in wider angular acceptance coverage of tracks from the LT (including the backward region)

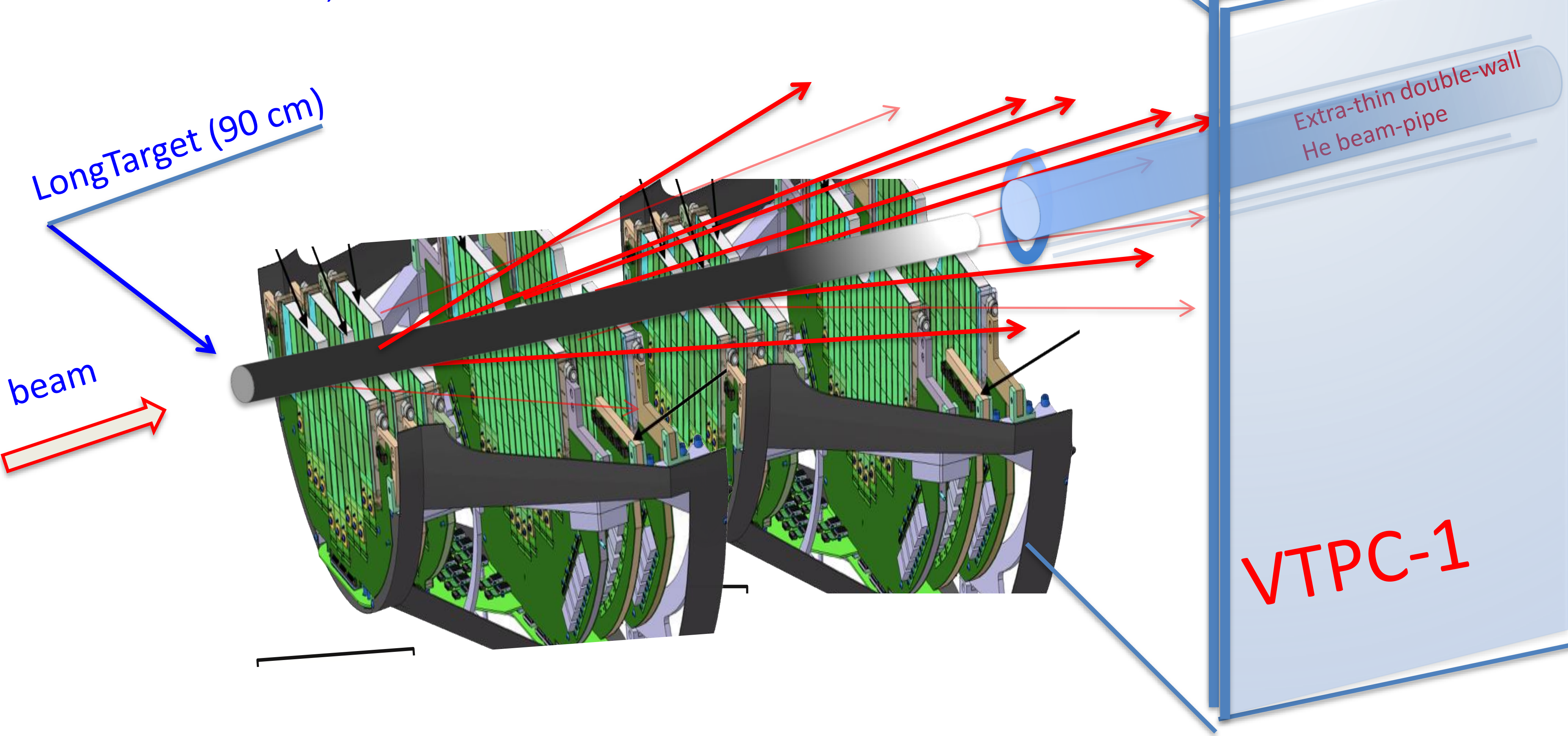
Vertexing for T2K LongTarget (LT) replica ?

Conceptual Option-1

(is still to be checked by simulations)

MFT disks around the LT

disk-1: Rin=25mm, Rout=170mm

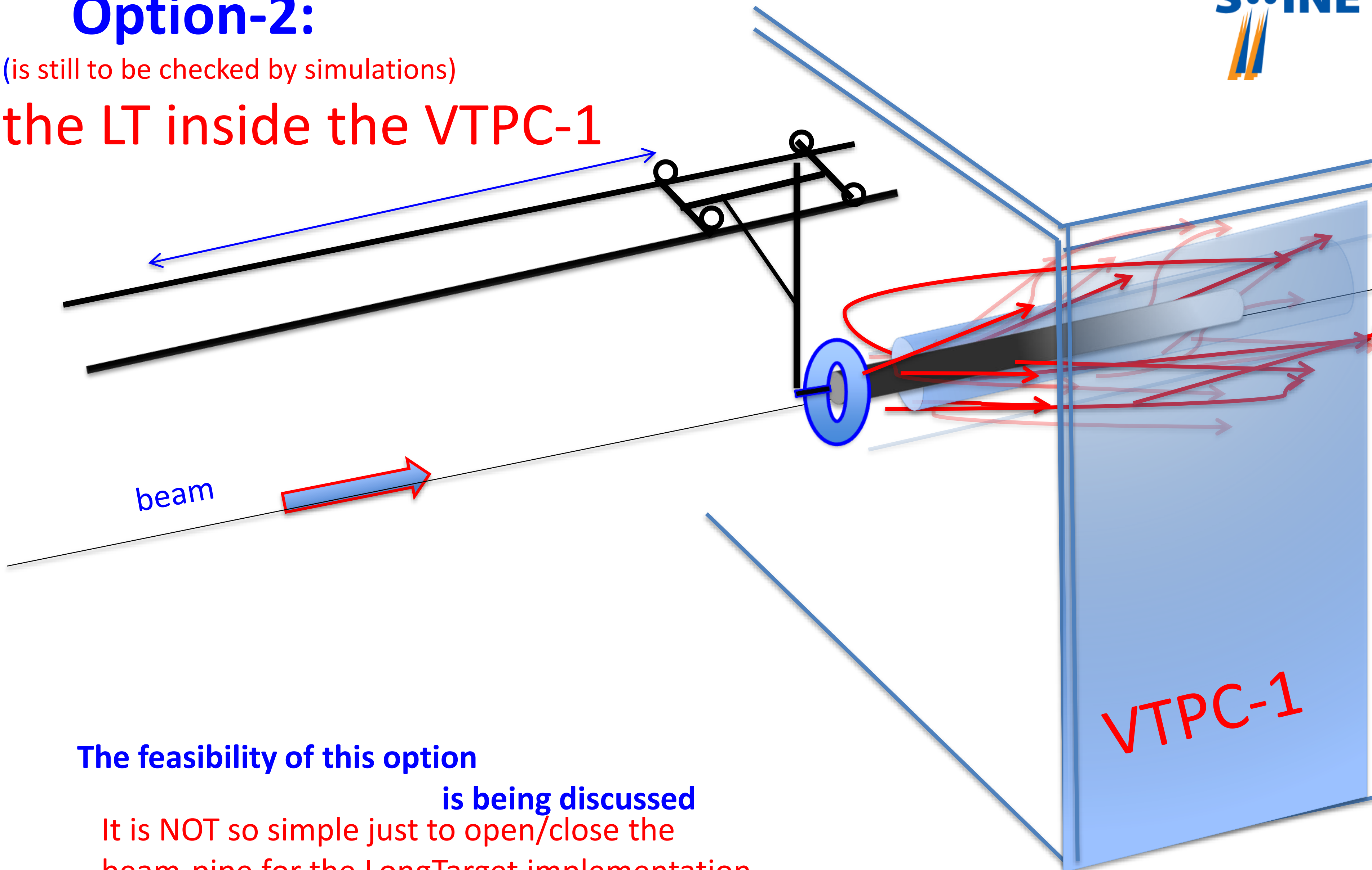


Vertexing for T2K LongTarget (LT) replica ?

Option-2:

(is still to be checked by simulations)

the LT inside the VTPC-1



The feasibility of this option is being discussed

It is NOT so simple just to open/close the beam-pipe for the LongTarget implementation – but it is possible