ALICE technologies proposed for the VD of NA61/SHINE in connection to the future MPD Si tracker

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Saint-Petersburg State University

The NICA days 2019 and IVth MPD Collaboration Meeting,
21-25 October 2019, CZiITT, Warsaw
[*https://indico.cern.ch/event/802303/overview*](https://indico.cern.ch/event/802303/overview)
[*https://indico.cern.ch/event/802303/contributions/3605935//*](https://indico.cern.ch/event/802303/contributions/3605935//)
Reported by Grigory Feofilov, Tuesday, 22.10.2019 ,MPD/NA61 Joint Session, 15:35-15:55

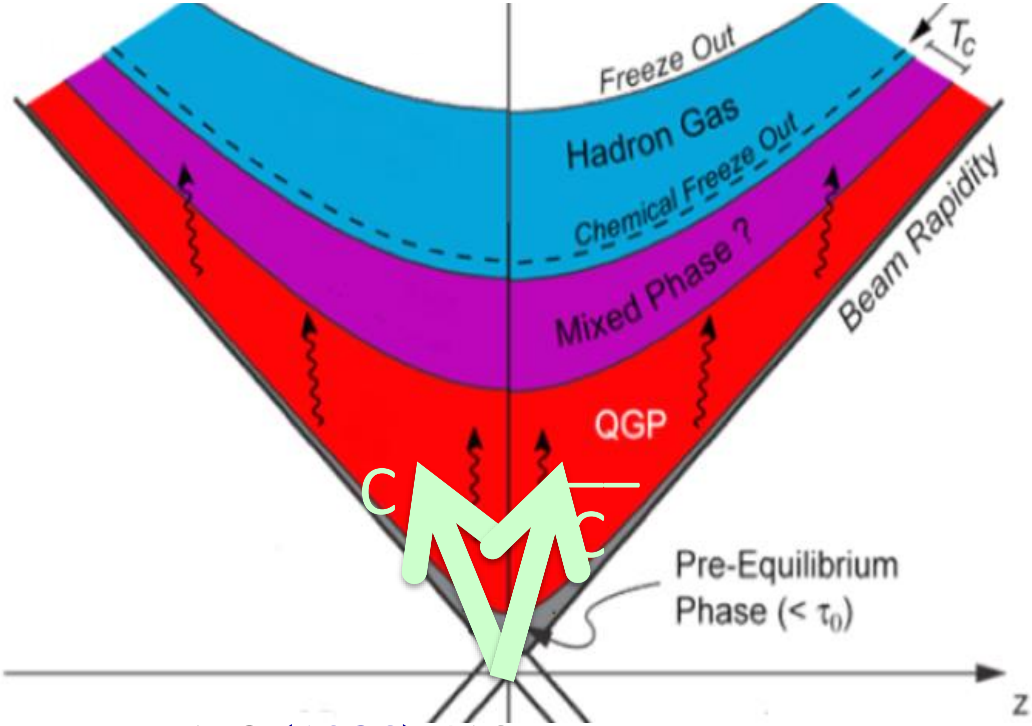
***Job is partially supported by RFBR grant #*18-02-40097**

Why heavy quarks are one of the main motivations?

→ Study the early stages in heavy-ion collisions

→ Probe to study thermalization of Quark Gluon Plasma (QGP)

→ Microscopic insight into transport properties of the medium



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

[3] 2013 -- **Berndt Müller**, arXiv:1309.7616

Challenges
for open charm at SPS and NICA

Physics motivations and the first feasibility studies for open charm measurements with NA61/SHINE

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)

→ see the report by **Pawel Staszel** at this conference

Matter induced changes in the yield of quarkonia

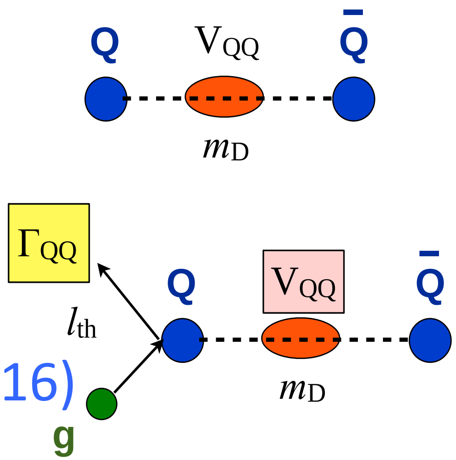
1986 Charmonim suppression in AA collisions
(H.Satz and T.Matsui, Phys.Lett.B178(1986)416):

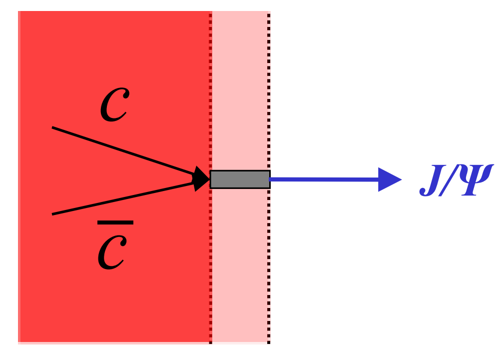
- **All charmonia are produced before QGP formation**
- **Suppression takes place in QGP**
- **Some charmonia may survive beyond Tc**

2013 Mechanisms contributing to matter induced changes in the yield of quarkonia:

Color screening (upper left);
ionization by thermal gluons (lower left);
and recombination (right)

(Berndt Müller,, arXiv:1309.7616)





→ see also the report by **Pawel Staszel at** this conference

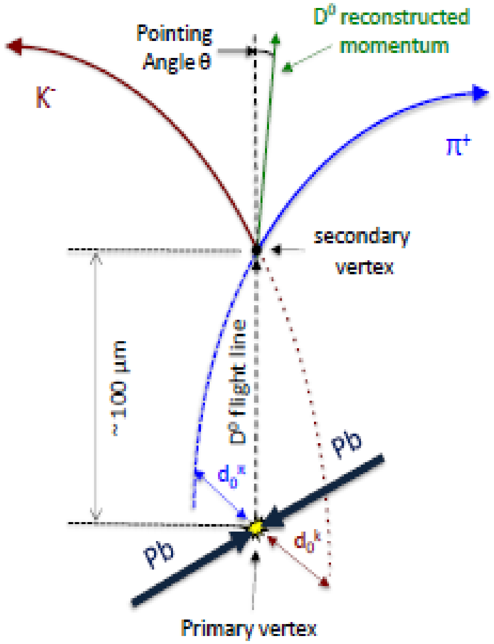
-> Challenges ->

Challenges for open charm measurements

Reconstruction from hadronic decay channels

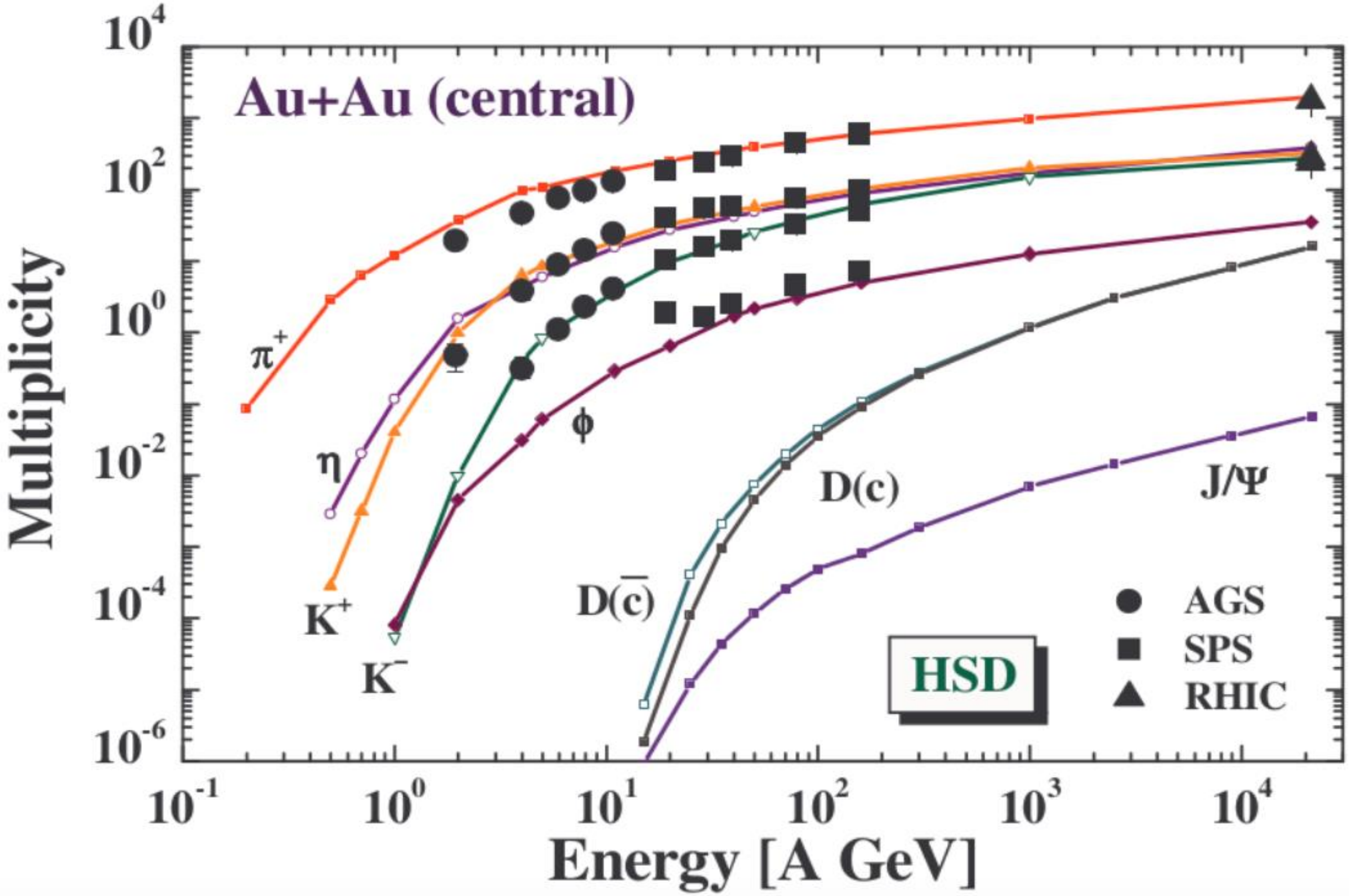
Challenge-1: Short life-time

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)%



Vito Manzari, LXV Conf.Nucl.Phys., 29.0
03.07.2015, SPb

Challenge-2: Low yields



Acta Phys. Pol. B44, (2013) 2019

General requirements for open charm measuremens:

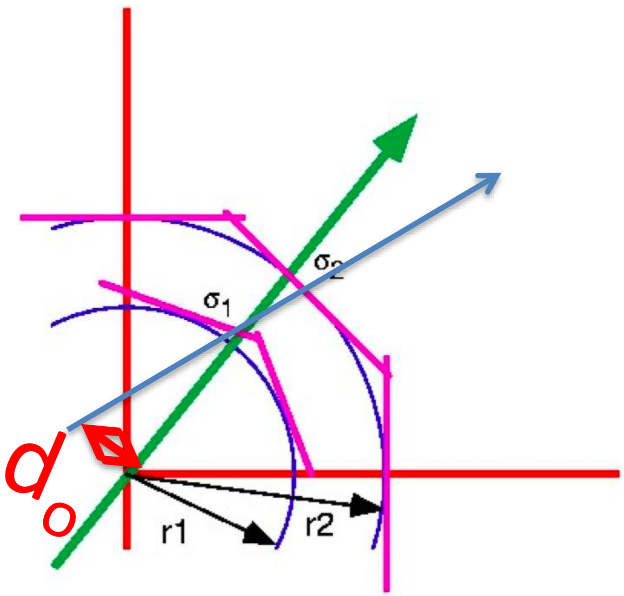
1) Precise vertexing (at the level of better ~20 -30µm for particles with pT~ 1 GeV/c)
2) Fast detectors (< 30 µs) with high granularity
3) The low material budget (<0.3% X\Xo)
4) Large acceptance is desirable to accept 100% of the D0s produced and to match the VTPC-1 of NA61/SHINE

- Vertex Detector projects are based on novel CMOS pixel detectors (Monolyth Active Pixel Sensors – MAPS)

--- see the report by **Vladimir Zherebchevsky** at this conference

Challenges faced by the Vertex Detectors

Impact parameter (d_0) resolution in particle tracking



$$\sigma_{d_0}^2 = \sigma_{MS}^2 + \sigma_{geom}^2$$

Example with two layer setup:

with

$$\sigma_{geom}^2 = \left(\frac{\sigma_1 r_2}{r_2 - r_1}\right)^2 + \left(\frac{\sigma_2 r_1}{r_2 - r_1}\right)^2 \quad \text{and} \quad \sigma_{MS}^2 = \sum_{j=1}^{n_{scatt}} (R_j \Delta\Theta_j)^2$$

Multiple Scattering (MS):

$$\sigma_{d_0} = \frac{r}{p} 13.6\text{MeV} \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \log\left(\frac{x}{X_0}\right)\right]$$

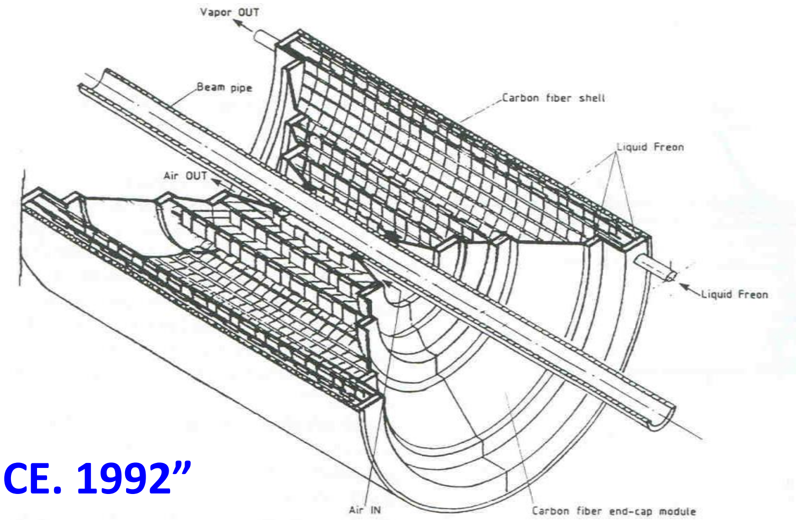
Very important!

- High coordinate resolution sensors are required (minimize σ_1 and σ_2)
- The first layer should be placed close to interaction point (IP) -- decrease r_1
- The multiple scattering should be minimized by the application of low mass, low Z materials to provide the minimal possible X/Xo

Challenges faced by the Inner Tracking System (ITS) desing for ALICE in 1992

The challenges forced the controvercial requirements in 1992(!) :

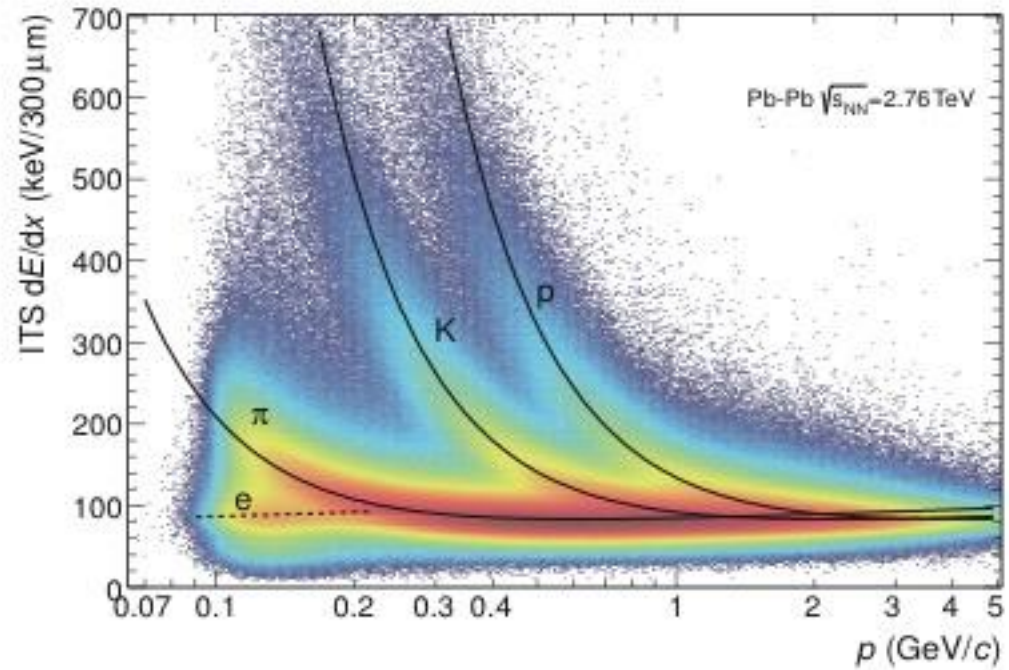
- 10 micron accuracy in positioning of Si-detectors, thermo and mechanical stability
- 10 kW of power drain produced by the front-end electronics
- Ambient operational temperature of the ITS and minimum influence on the temperature field of the surrounding TPC
- *0.1 deg temperature stability of Si-drift detectors (!?)*
- X/Xo per layer ~ 1% (!)



ALICE ITS, " LoI ALICE. 1992"

The ITS-1 performance in 2008-2018

International Journal of Modern Physics A Vol. 29, No. 24 (2014) 1430044



Distribution of the energy-loss signal in the ITS as a function of momentum.

Inner Tracking System (SPD,SDD,SSD – 6 layers between 39 and 430 mm)

10 years of succesful performance!

Minimal material budget of the ITS-1: X/Xo < 1% per layer

- It is a result of the extensive R&D and engineering
in development and application
of the Carbon Fiber Composite technology
for thr extra lightweight, thermo – and mechanically stable
ITS cooling-mechanics-alignment system for ALICE (ITS-CMA)

–

S.N. Igolkin, G.A. Feofilov,
V.M. Dobulevich, O.I.Stolyarov:
RF Patent no. 2396168 and
RF Patent no. **79268 U1 РФ.**
МПК B29C 53/56, 2008

- The improved Carbon Fiber Composite technology
is proposed for the ITS-2 and is being applied
for the NA61/SHINE. It is also proposed for the MPD/NICA.

Design goals that are met for the ITS-2:

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

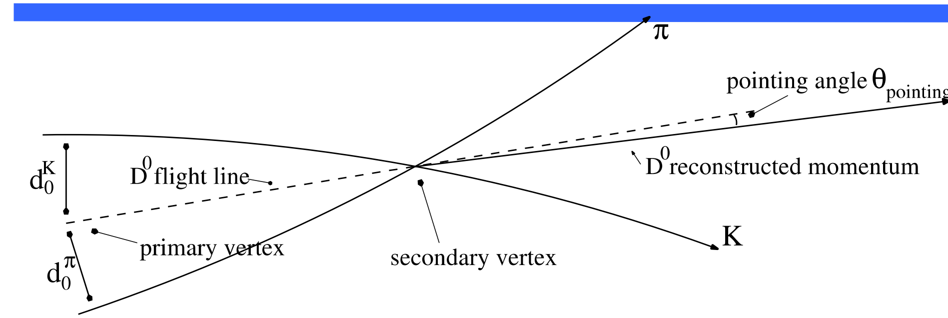
1. Coverage in transverse momentum to be as complete as possible, in particular down to zero momentum

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

Comparison of ALICE,ATLAS and CMS upgrade

	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	–	–

Precise identification of secondary vertices

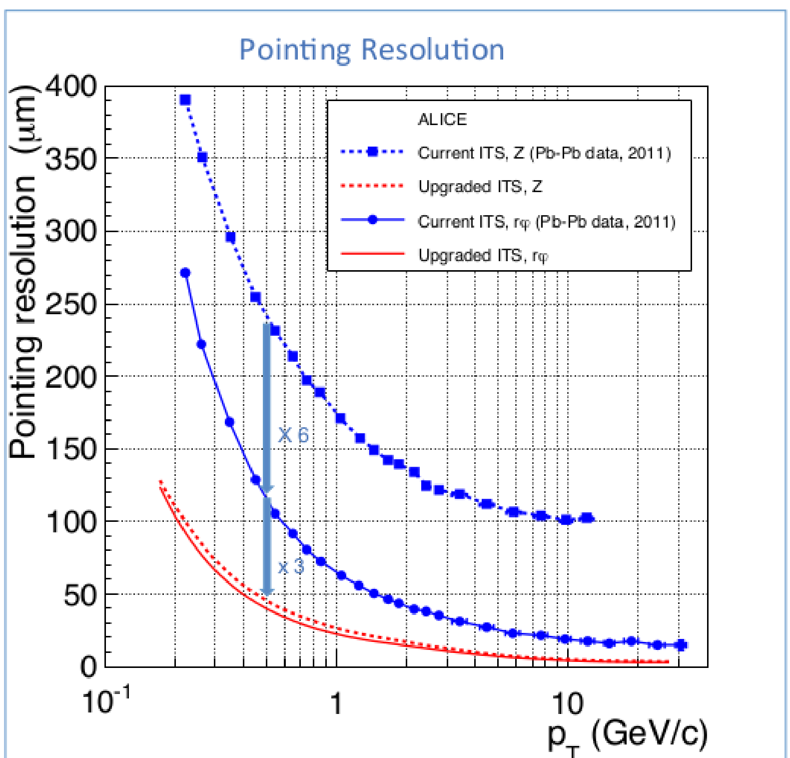


CERN-PH-EP-2012-XXX March 6, 2012

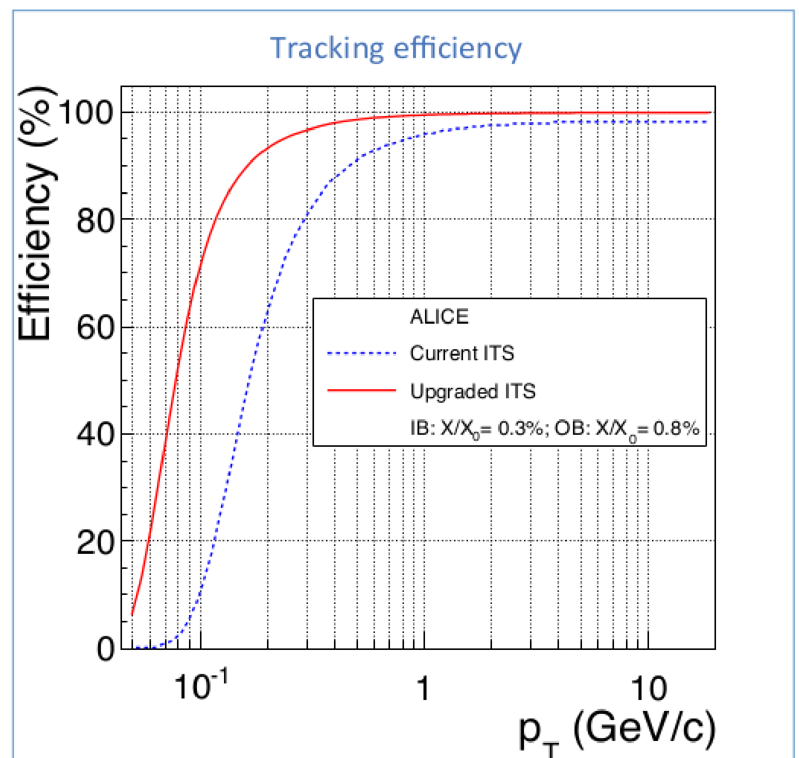
Impact parameter ~100µm

Schematic view of the D0 decay in the **D0 → K−π+** channel.

Impact parameter resolution



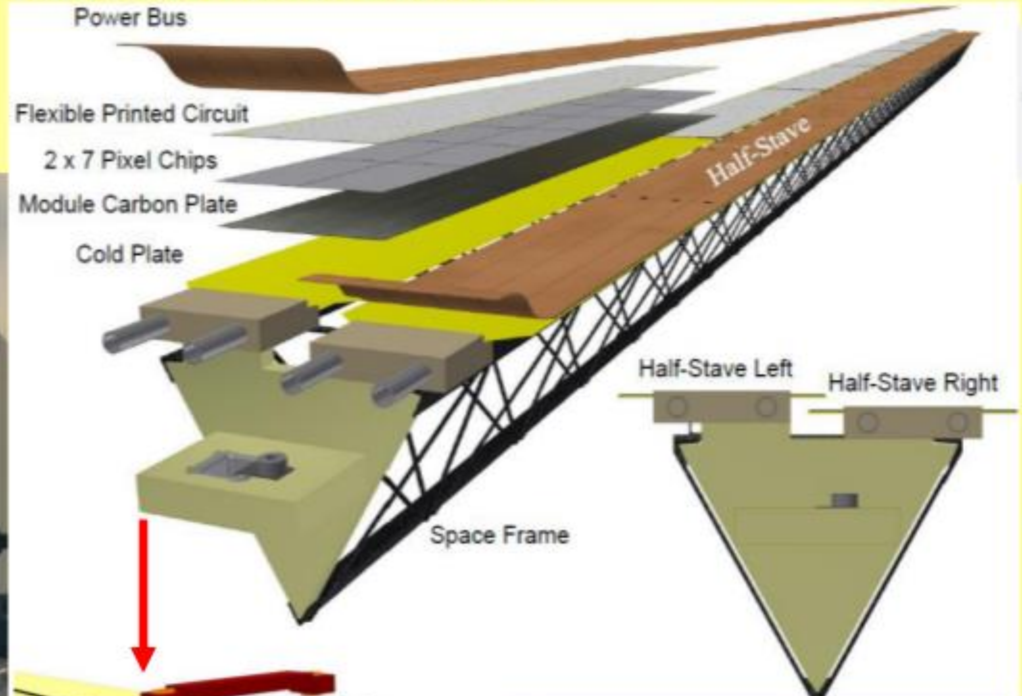
Tracking efficiency (ITS standalone)

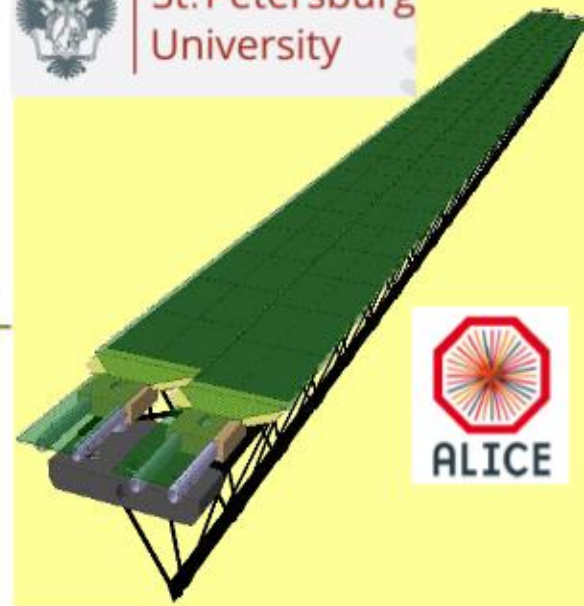


Extra Lightweight Detector Support Structures for a New Generation of Vertex Detectors

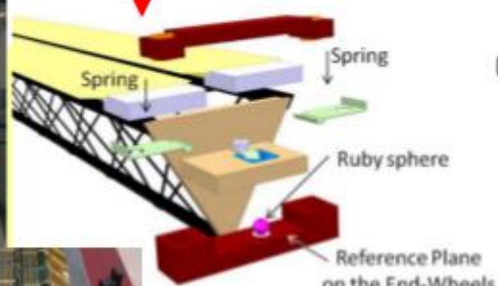
ALICE Outer Barrel Stave

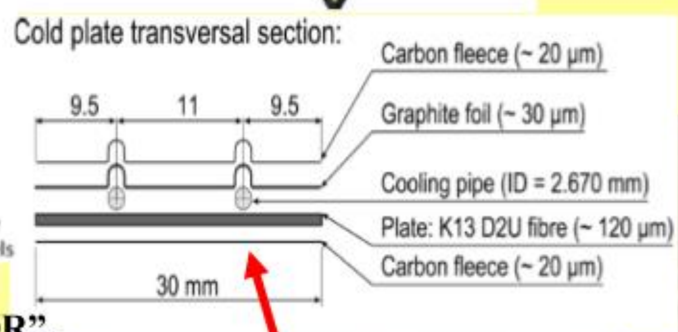
St. Petersburg University



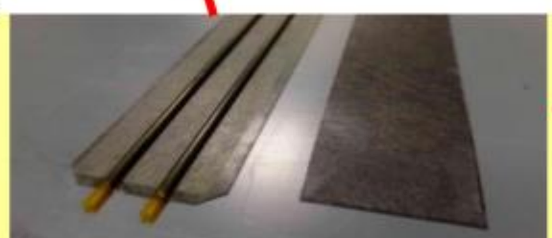


ALICE

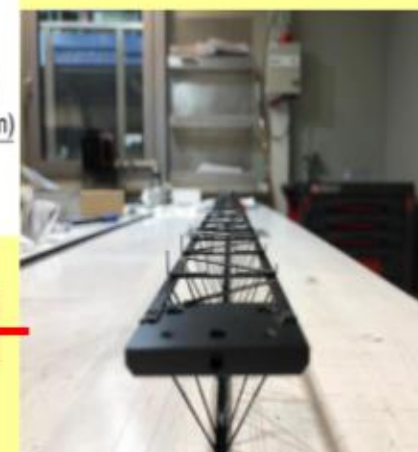




The ALICE **Collaboration: "TDR",** J. Phys. G41 (2014)



Cold plate



Space Frame

ALICE ITS-2 design

Based on high resistivity epitaxial layer Monolithic Active Pixel Sensors (MAPS)

3 Inner Barrel layers (IB)
4 Outer Barrel layers (OB)

Radial coverage: 21-400 mm

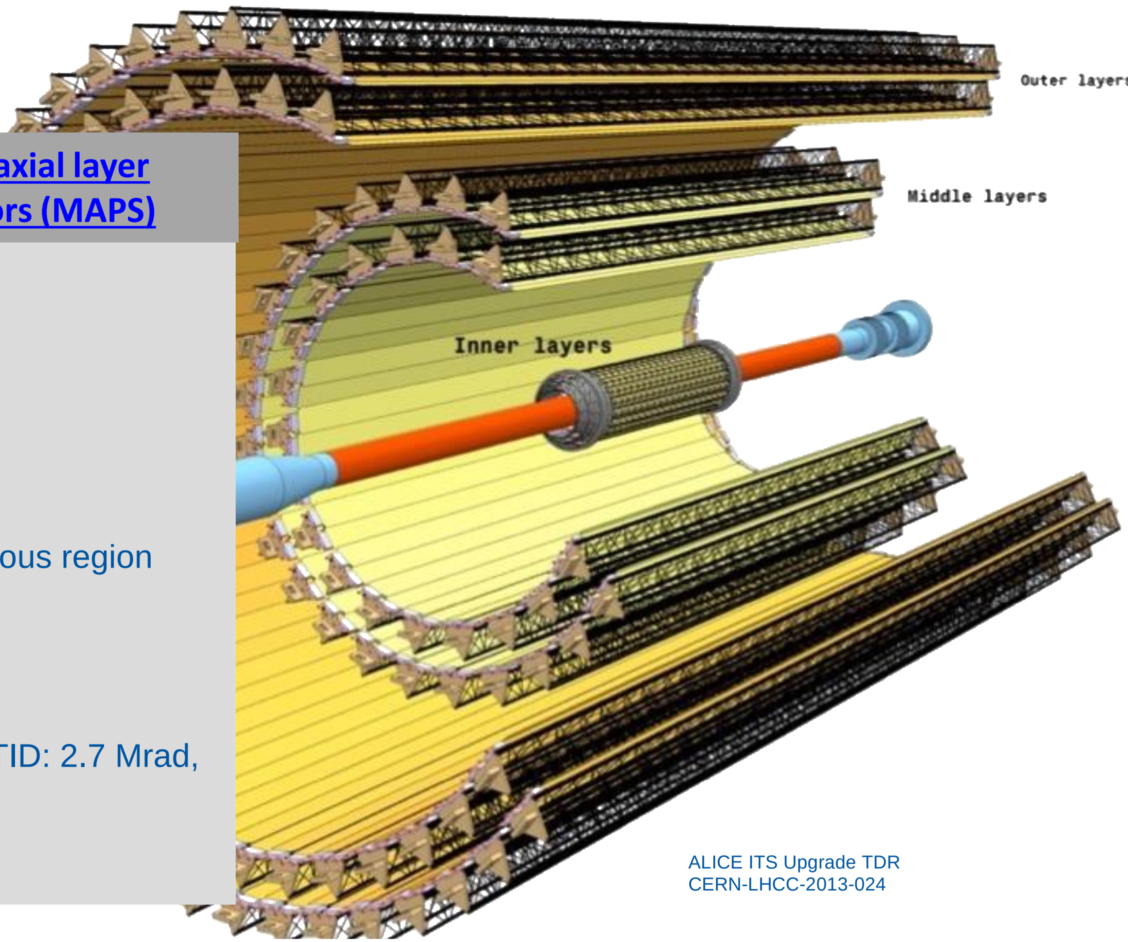
~ 10 m²

|h|<1.22 over 90% of the luminous region

0.3% X_0/layer (IB)
0.8 % X_0/layer (OB)

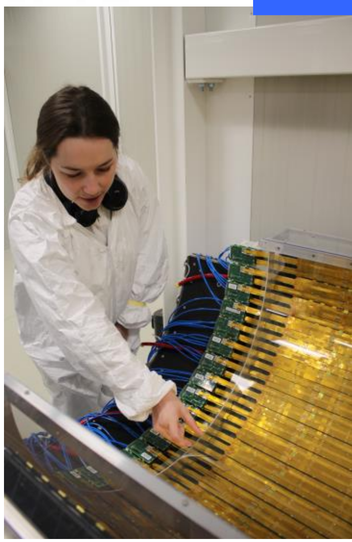
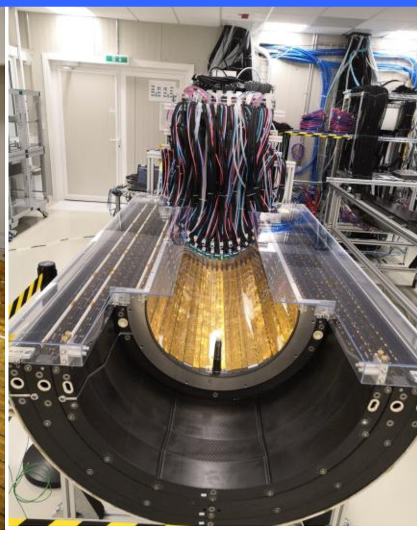
Radiation level (IB, layer 0): TID: 2.7 Mrad, 1.7×10^{13} 1 MeV n_{eq} cm^{-2}

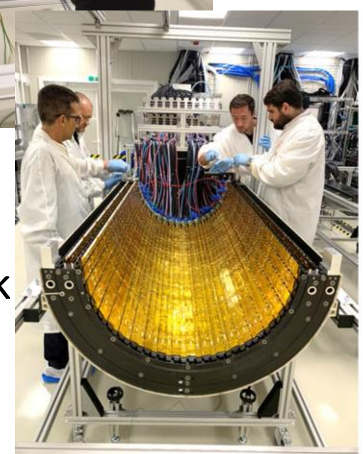
Installation during LS2

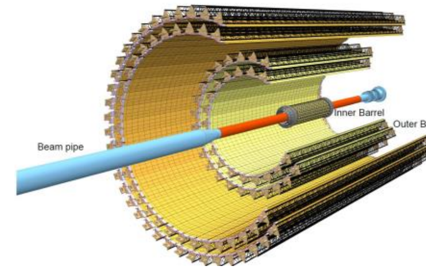


ALICE ITS Upgrade TDR
CERN-LHCC-2013-024

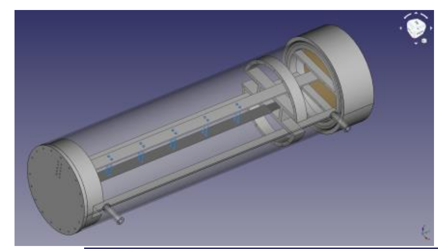
Saint-Petersburg State University in 2019 in assembly and commissioning of the outer layers of the ITS-2

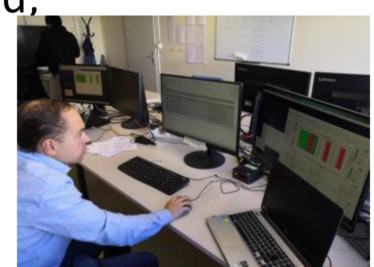





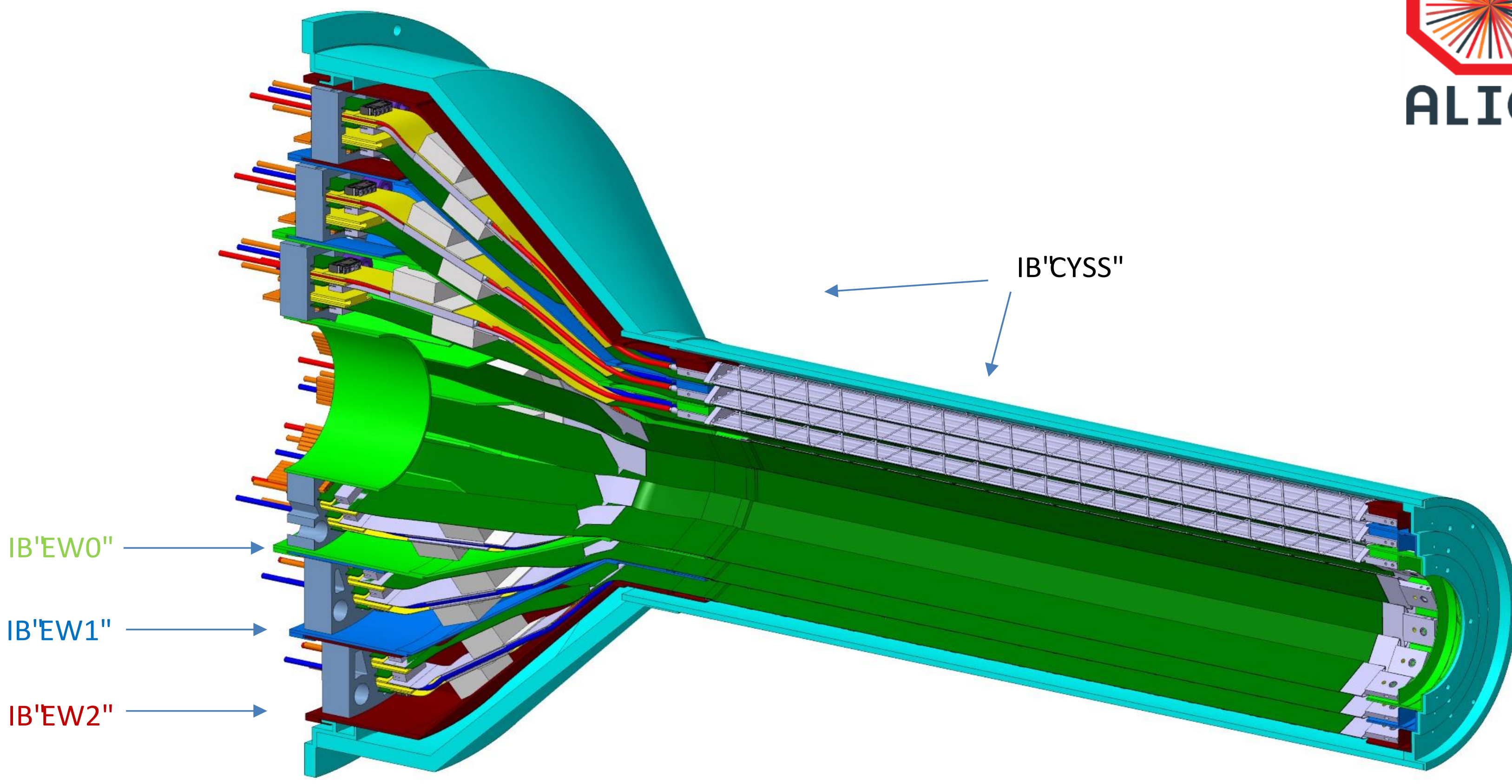
Development of the new test facility for the novel cooling scheme of the future ITS-3 is under preparations at the SPbSU




- Today: assembly and commissioning of the outer layers of the modified ITS-2 –the work is going on in the period January-October 2019 according to the plan. More then 90% modules of the ITS-2 are tested;
- ITS-2 Commissioning Shifts at CERN -- 29 shifts have been done by SPbSU participants



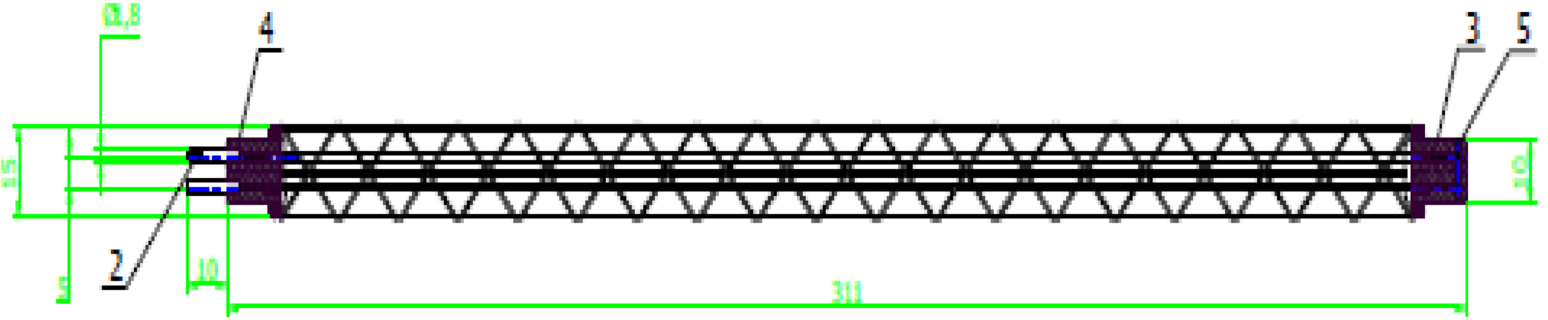
Inner Barrel (ITS-2)

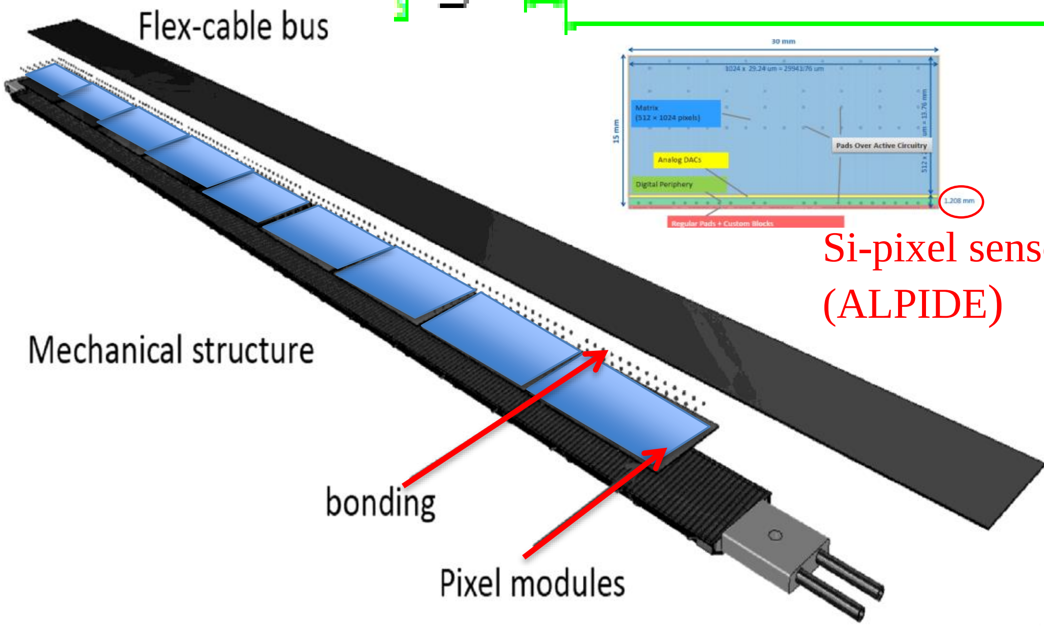


Material thickness per detector layer: ~ 0.3% X_0

ALICE technology for ITS-2 Inner Barrel:

JINST **9** P06005(2014)





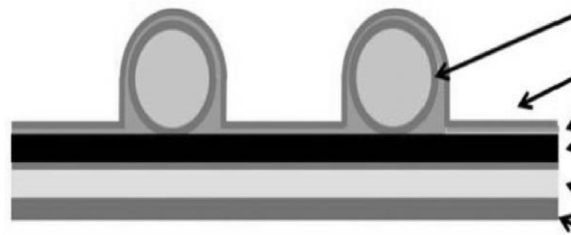
Si-pixel sensor (ALPIDE)

Thickness of detector components in terms of fraction of radiation length X/Xo

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			**<0.3**

- **Record level of radiation transparency X/Xo <0.3%**
- **Technology is proposed and is used for the NA61/SHINE VD and could be used at NICA**

Material budget of CF stave for VD NA61



-- **polyimide** cooling pipe (D=1mm)
-- carbon fleece (20 µm)
-- graphite foil (30µm)
-- carbon fiber plate K13D2U (70 µm)
--- thermal greese
--- Si-sensor (50µm)

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
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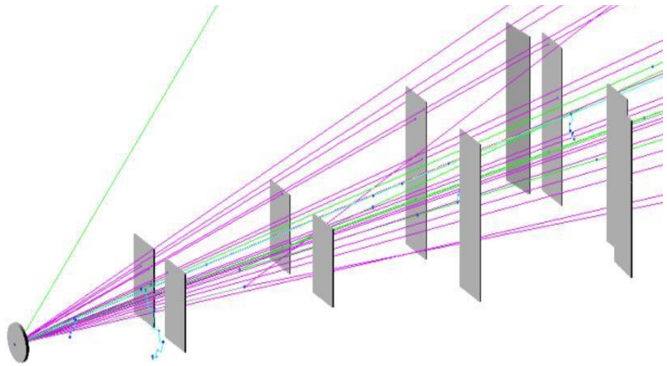
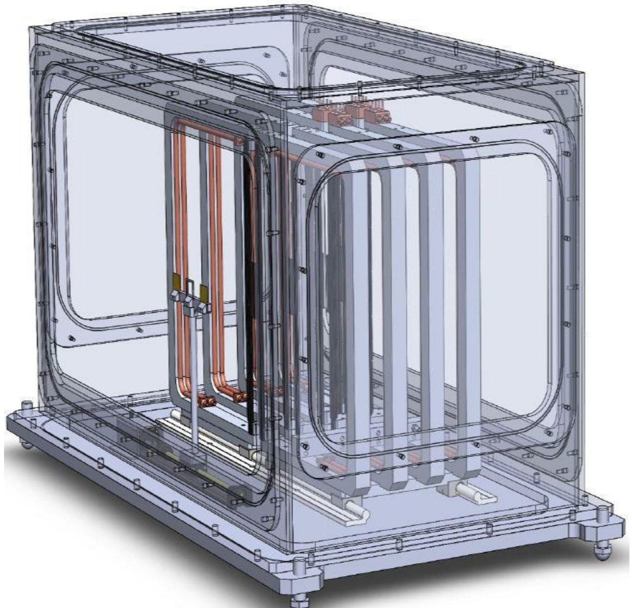
Total (without FPC)			**0.154**
Total with FPC			**<0.3**

- **Technology is proposed for the NA61/SHINE VD**

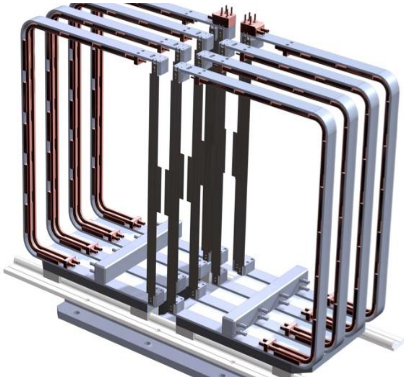
Small Acceptance VD layout



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



VD housing box filled with He



C-shape support frames

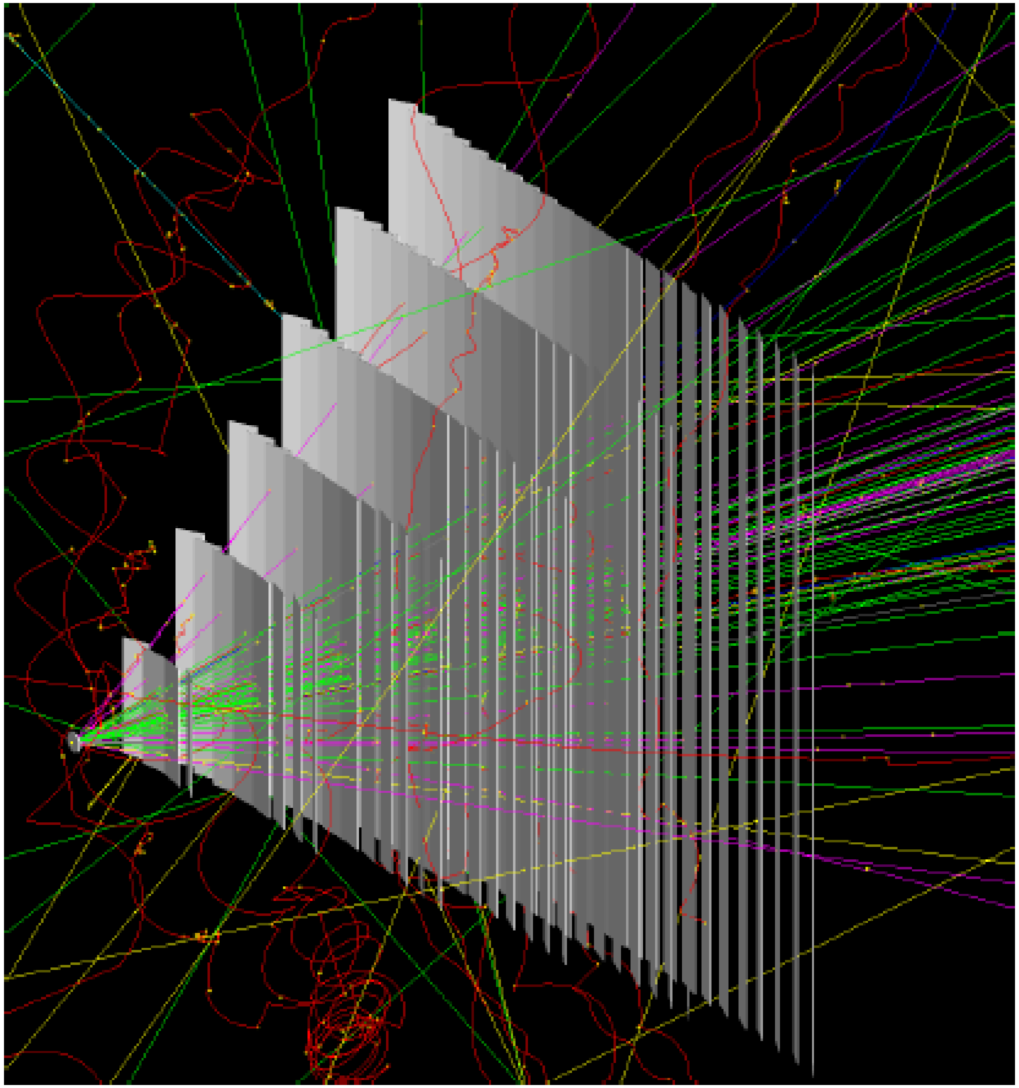
Small Acceptance VD (SAVD) of the NA61/SHINE at the pilot run at the SPS in 2016

- 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

→ see also the reports by **Pawel Staszel at and by** Dariusz Tefelski at this conference

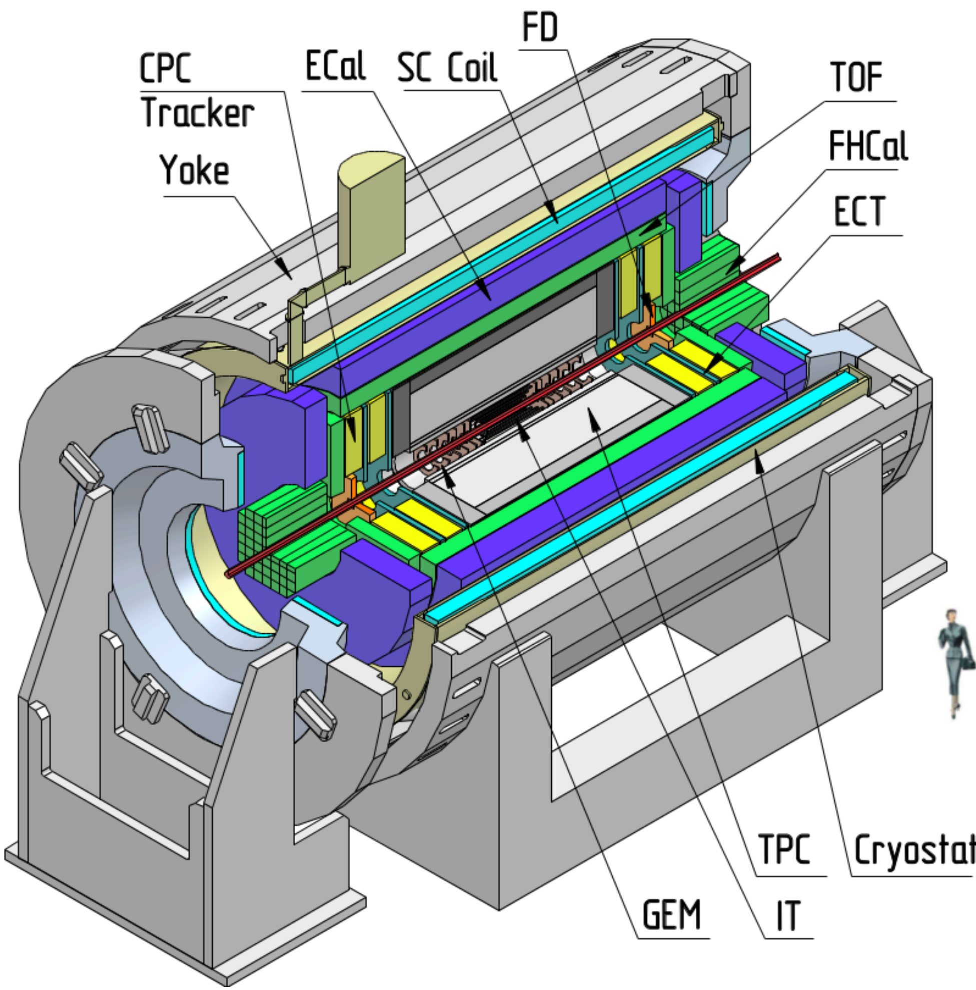
6 planes for NA61 VD/SHINE



PRIORITIES

- The innermost layers (closest to the vertex) should have the highest granularity and the lowest material budget (and low Z materials)
- TPC-VD track matching
- High-precision (~ 10-20 mkm) determination of secondary vertices for D0 , strange and also multi-strange particles…

The setup in preparation for application of ALPIDE sensors to be used in the NA61/SHINE LAVD



MPD/NICA

High vertex resolution Inner Tracker Fast readout (for Au-Au collisions the luminosity will be 10^{27} cm-2s-1)
[4]
Low material budget

Parameter	**ALPIDE Performance**
Silicon thickness	50 µm
Chip dimension	15 mm x 30 mm
Spatial resolution	5 µm
Power density	40 mW/cm$_2$
Max. integration time	10 µs
Detection efficiency	>99%
Fake-hit rate	<<<10_{-6} /event/pixel
Total Ionizing Dose	Up to 500 krad

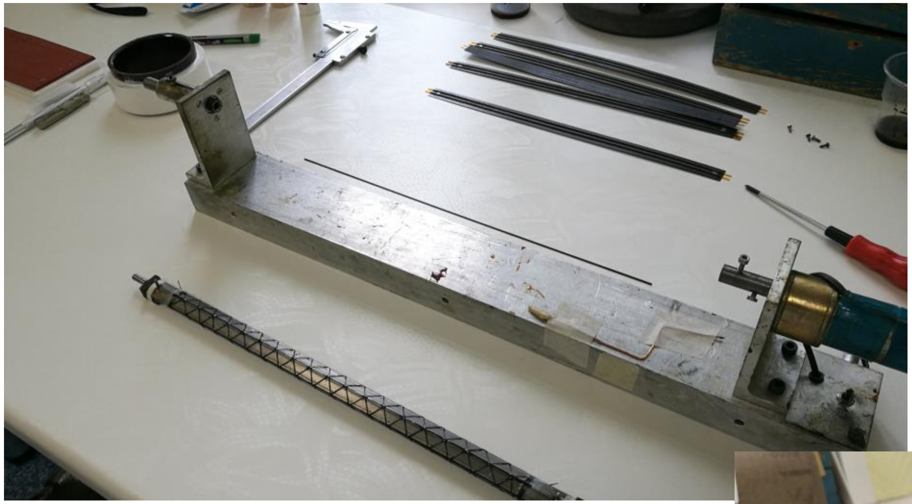
One of the possible solutions:

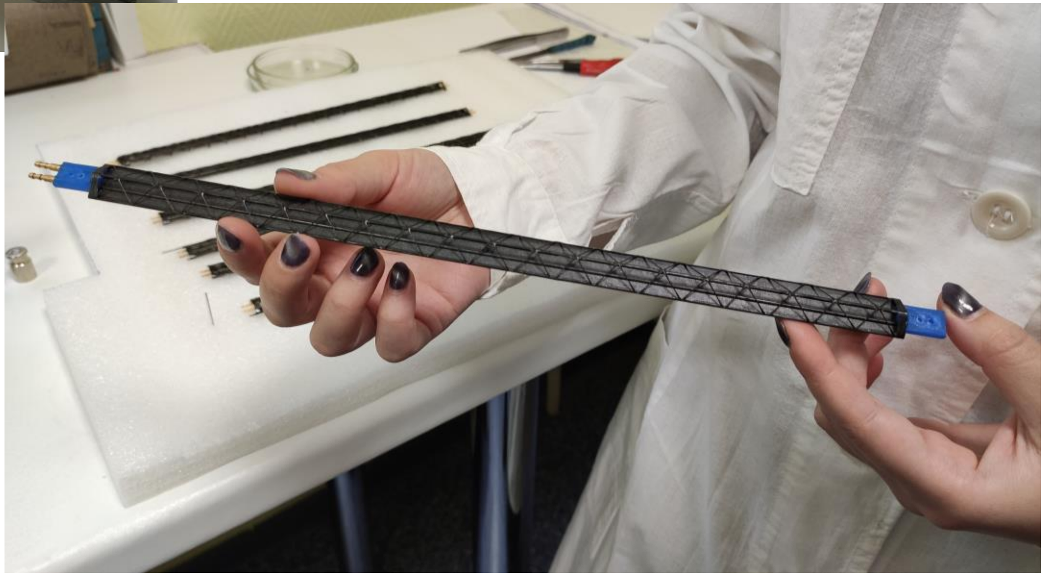
1. Use ALICE MAPS – sensors ALPIDE

2. Use carbon ultra-lightweight support and cooling structures developed for the upgrade of ALICE at the LHC

--- see the report by **Vladimir Zherebchevsky** at this conference

Tooling for Carbon Fiber 30 cm staves production at the SPbSU





ALICE concept for the next generation heavy-ion experiment at the LHC

EoI document, Dec 2018, is submitted to European Strategy for Particle Physics Preparatory Group (arXiv: 1902.01211)

- The aim is to build a nearly massless barrel detector (ITS-3) consisting of truly cylindrical layers based on **Curved wafer-scale ultra-thin silicon sensors with MAPS technology,** featuring an unprecedented low material budget **of 0.05% X/Xo per layer**
- The R&D is started
- High potential for applications at NICA !

Photo: from the report by L. Musa (CERN) – SQM, Bari, 10-15 June 2019

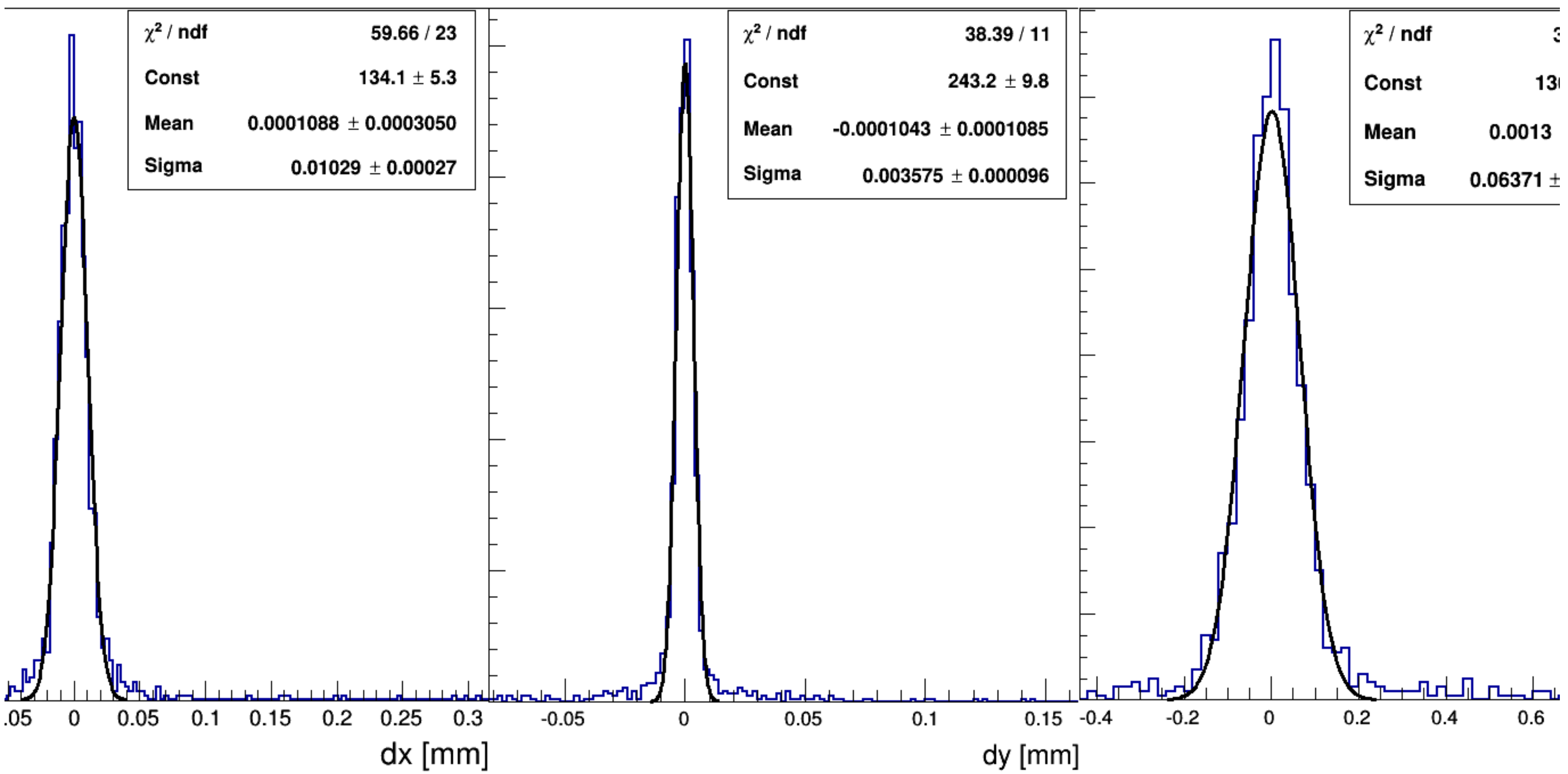
Summary:

1) The ITS/ALICE technology is being applied for the NA61/SHINE VD :
2) 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
3) The ITS/ALICE technology provides the possibility of easy replacement of detector staves and keeping ~10 μ positioning accuracy
4) Flexibility to add layers of detectors
5) Prototyping of the mechanical layout of the LAVD in the ALICE/ITS technology is ongoing.
6) Technology is proposed for NICA experiments

Back-up slides

Primary vertex resolution December pilot run

From the slides on the VD data analysis by Pawel Staszel

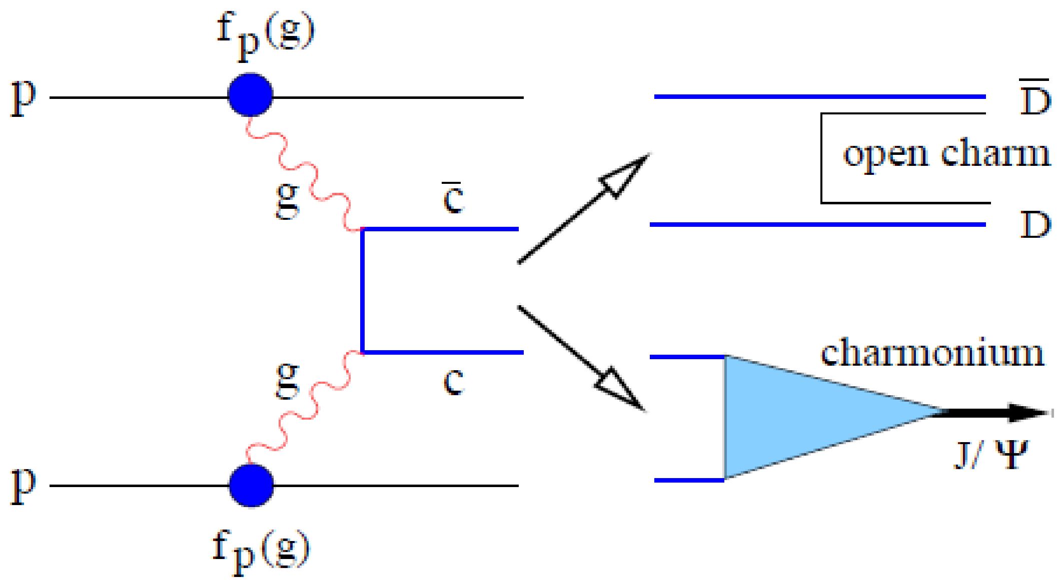


σ_x `10μ σ_y ~ 3 μ σ_z ~ 63μ

Work for D0s is in progerss!

Motivation for open charm

As a tool to study the formation of a deconfined medium formed in high energy AA collisions – to test the color screening effects on binding of charm quarks to color neutral J/ psi production [1]



about 90%

about 10%

charnonia[2]

Fig.1 Schematic view of J/psi production **in pp collisions** (see [2])

AA collisions --?

[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

→ see also the report by **Pawel Staszel at** this conference