The status of open charm measurements

in NA61/SHINE experiment

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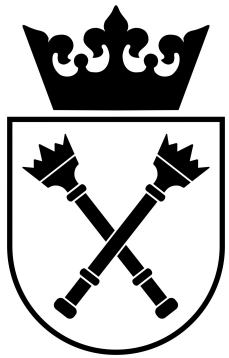
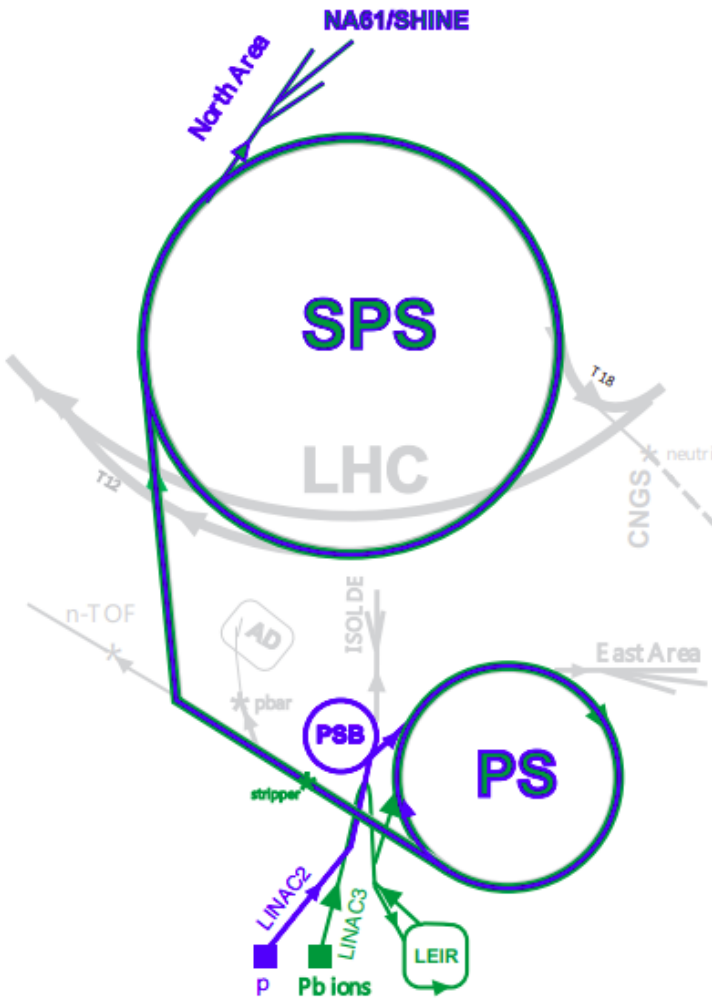
Zakopane



Experiment NA61/SHINE (the experimental setup and physics program)



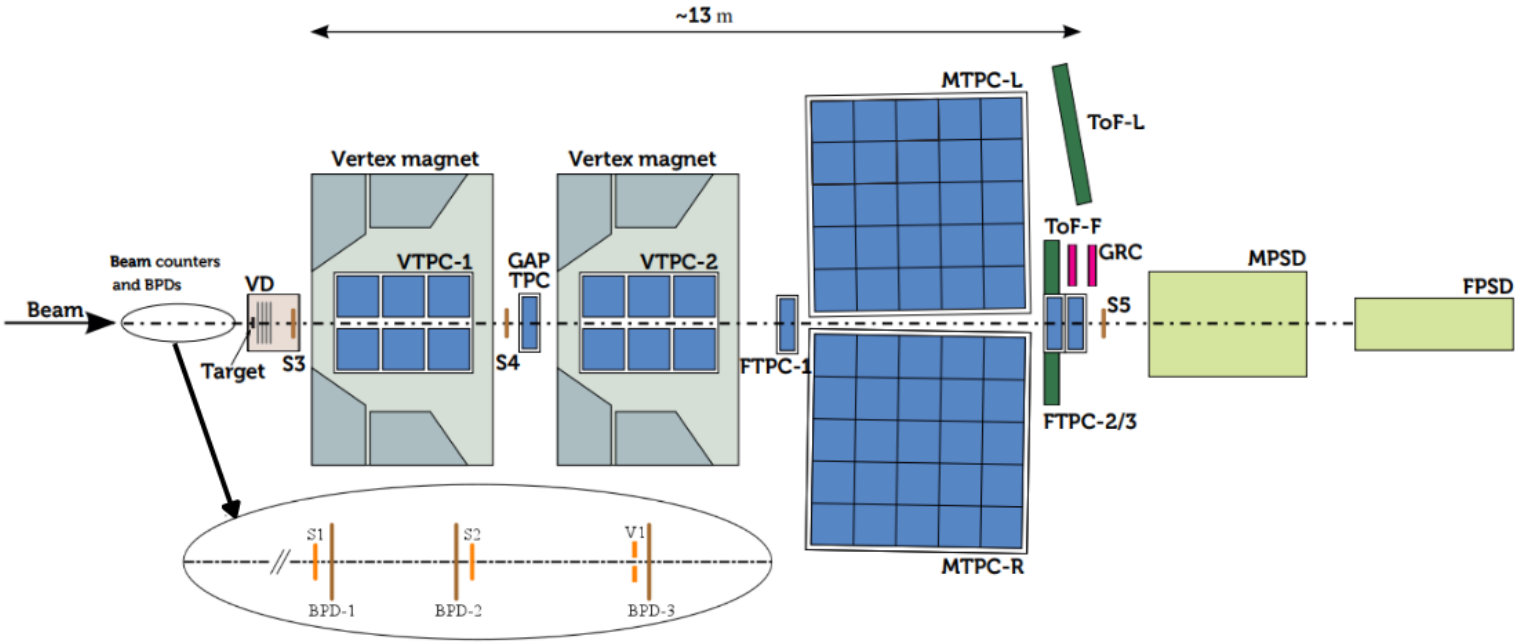
SHINE (**S**PS **H**eavy **I**on and **N**eutrino **E**xperiment) is a fixed-target experiment located on the H2 beamline of the CERN SPS (**S**uper **P**roton **S**ynchrotron) accelerator.

It was optimized to study hadron production in hadron-proton, hadron-nucleus, and nucleus-nucleus collisions. This experiment is a successor to the NA49[1] experiment from which several components are used.

The main goal of the experiment is to study the diagram of strongly interacting matter, including i.a.:

- charm hadron production,
- quark-gluon plasma signature,
- location of the critical point.

[1] S. Afanasiev et all., *The NA49 large acceptance hadron detector*, volume 430, pages 210-244, 1999, Nuclear Instruments and Methods in Physics Research Section A



Beam detectors - a set of scintillators, Cherenkov counters, and beam position detectors (BPD) that provide information about the charge, transverse position, and flight time of beam particles.

Time Projection Chambers (TPC) - four large and four small TPCs used as particle tracking detectors. They also provide information about momentum and allow particle identification.

Time of Flight - identification of hadron.

Projectile Spectator Detector (PSD) - the hadronic calorimeter provides information about the centrality of the reaction from the measurement of the spectator's energy.

Vertex Detector (VD) - precise reconstruction of particle tracks close to the target.

The charm production

The intention

The mechanism of charm production is one of the crucial topics in the relativistic collision of heavy ions. **This study will allow us to discriminate between models** that contain different mechanics of charm production like statistical and dynamical models.

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The goal[1]

- What is the mechanism of charm production?
- How does the onset of deconfinement in the nucleus-nucleus collision impact charm production?

[1] A. Aduszkiewicz et all., *Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS: Early Post-LS2 Measurements and Future Plans*, CERN, Geneva, 2018, SPS and PS Experiments Committee

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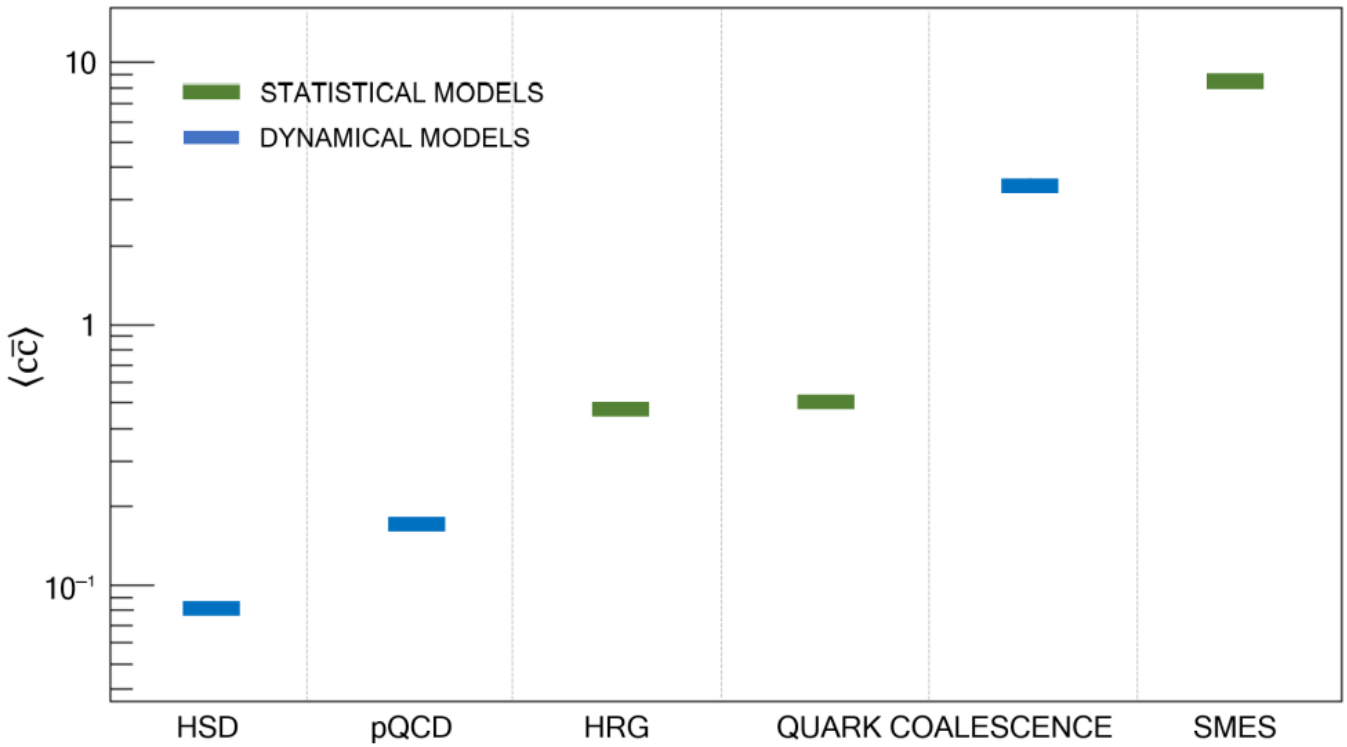
[1] A. Aduszkiewicz et all., *Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS: Early Post-LS2 Measurements and Future Plans*, CERN, Geneva, 2018, SPS and PS Experiments Committee

Models predicting the production of $\langle c\bar{c} \rangle$ in central Pb+Pb collisions at 150 GeV/c momentum



Hadron String Dynamics (HSD) [O. Linnyk, E. Bratkovskaya, W. Cassing, Int. J. Mod. Phys. E 17 (2008), 1367-1439]

perturbative QCD (pQCD) [P. Braun-Munzinger, J. Stachel, Phys. Lett. B 490 (2000), 196-202]

Hadron Resonance Gas (HRG) [A. Kostyuk, M. I. Gorenstein, H. Stoecker, W. Greiner, Phys. Lett. B 531 (2002), 195-202]

Statistical Quark Coalescence [A. Kostyuk, M. I. Gorenstein, H. Stoecker, W. Greiner, Phys. Lett. B 531 (2002), 195-202]

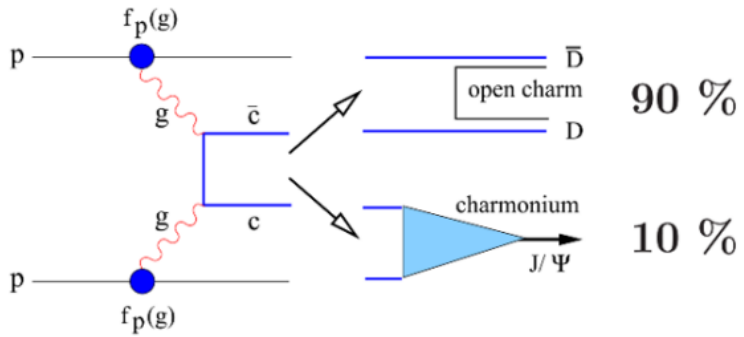
Dynamical Quark Coalescence [P. Levai, T. Biro, P. Csizmadia, T. Csorgo, J. Zimanyi, J. Phys. G 27 (2001), 703-706]

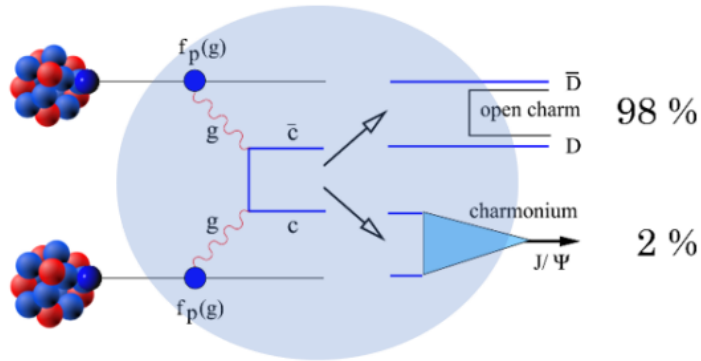
Statistical Model of the Early Stage (SMES) [M. Gazdzicki, M. I. Gorenstein, Acta Phys. Polon. B 30 (1999), 2705]

Two ways

The $c\bar{c}$ pairs can hadronize in two ways:

- **open charm** - charm hadrons (usually mesons) will be formed, i.e. charm quark (antiquark) and a light antiquark (quark).
- **hidden charm** - a bound $c\bar{c}$ system (charmonium).





Helmut Satz, *Calibrating the In-Medium Behavior of Quarkonia*, Advances in High Energy Physics, vol. 2013, Article ID 242918, 6 pages, 2013.

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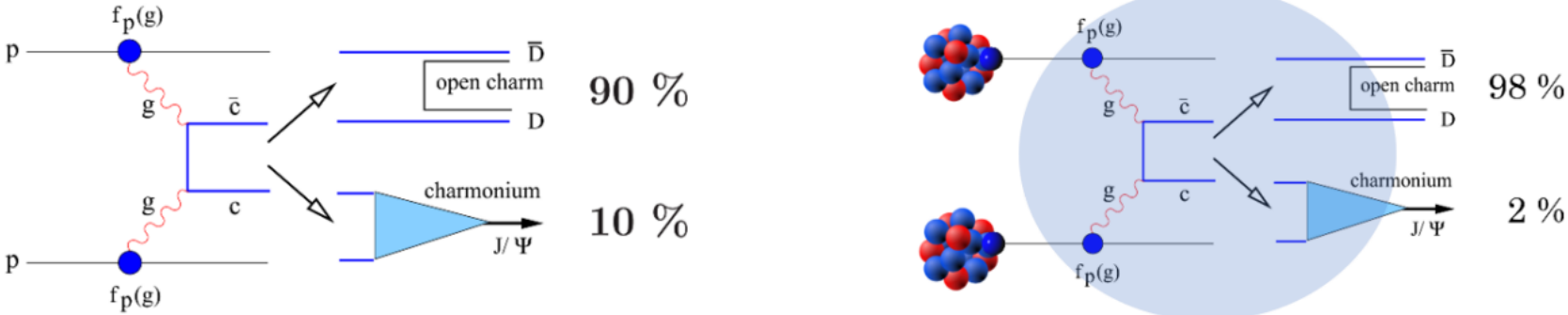

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J/ψ suppression (as a signal of deconfinement)

In A+A color screening reduces charmonia production $\rightarrow$ reduction of fraction of $c\bar{c}$ pairs going into charmonia with respect to p+p at the same collision energy.

The medium effect on $c\bar{c}$ pairs binding can be determined by comparing the ratio:

$$P(c\bar{c} \to J/\psi) \equiv \frac{\langle J/\psi \rangle}{\langle c\bar{c} \rangle} \equiv \frac{\sigma_{J/\psi}}{\sigma_{c\bar{c}}}$$

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in A+A to that in p+p collisions. **For this purpose, the measurement of open charm in A+A is needed(!).**

Hadron	Mass [MeV]	Channel decay	$c\tau$ [μm]	Branching ratios [%]
D^0	1864.83 $\pm$ 0.05	$\pi^+ + K^-$	122.9	3.950 $\pm$ 0.031
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D^+	1869.65 $\pm$ 0.05	$\pi^+ + \pi^+ + K^-$	311.8	9.38 $\pm$ 0.16
D^-	1869.65 $\pm$ 0.05	$\pi^- + \pi^- + K^+$	311.8	8.22 $\pm$ 0.28
D_S^+	1968.34 $\pm$ 0.07	$\pi^+ + K^- + K^+$	151.2	5.39 $\pm$ 0.15
Λ_c	2286.46 $\pm$ 0.14	$p + \pi^+ + K^-$	60.7	6.28 $\pm$ 0.32

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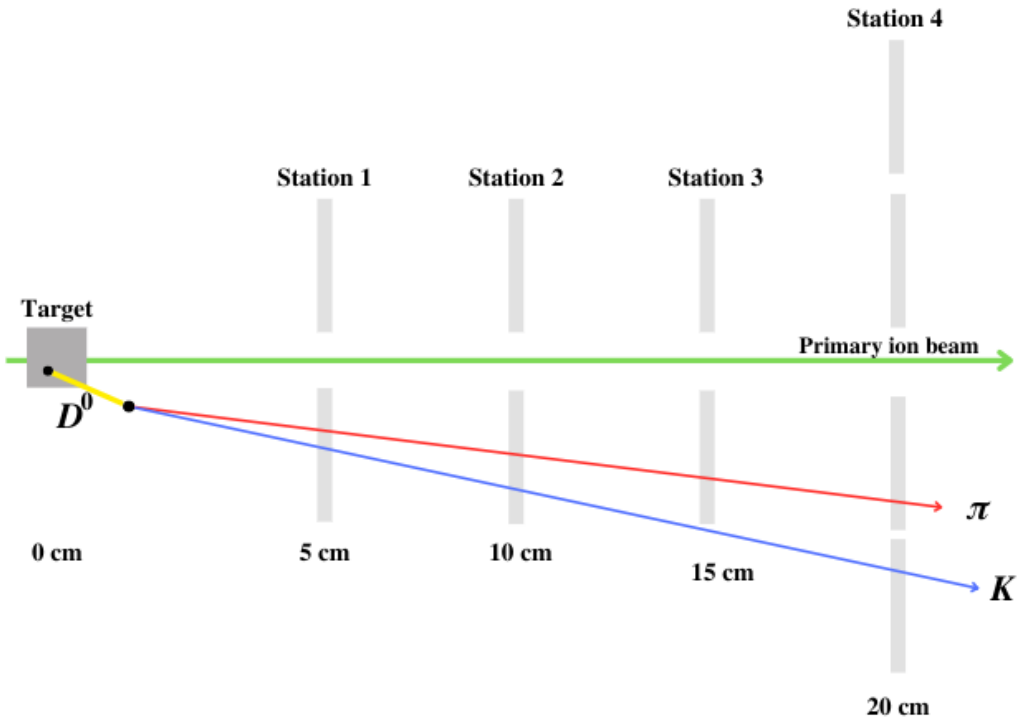
SAVD - Small Acceptance Vertex Detector



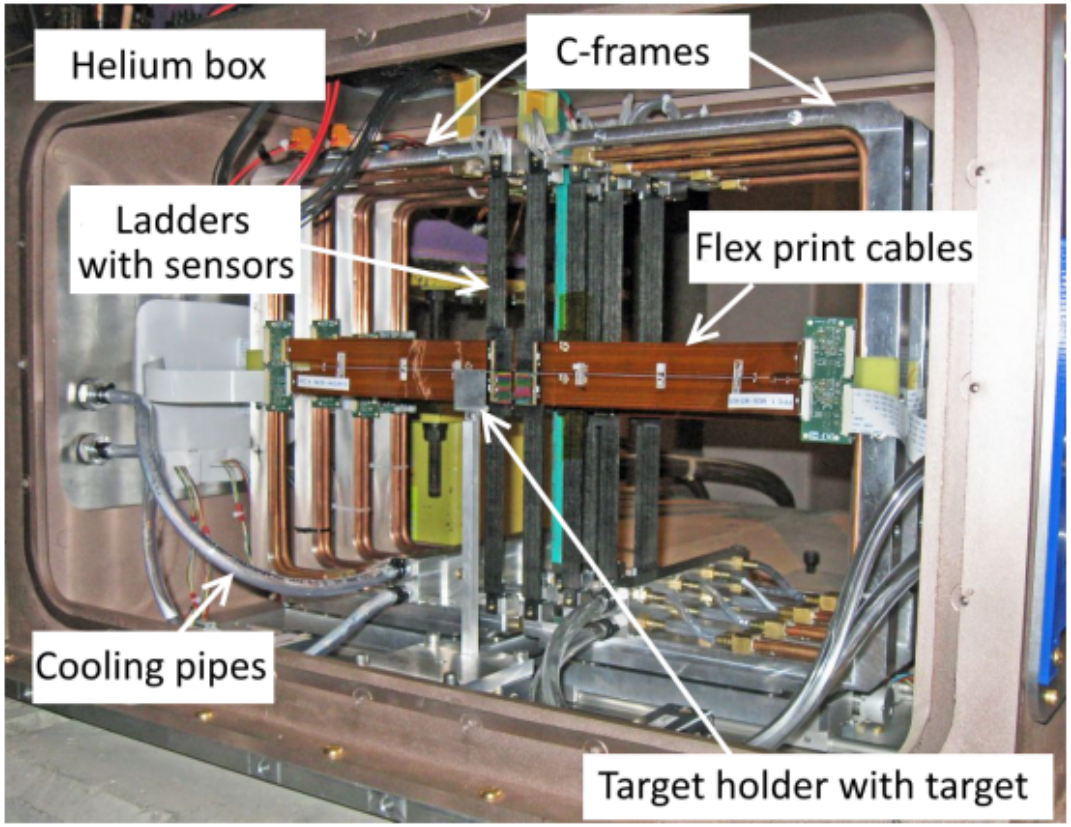
- The D^0 lifetime $\sim$ 410 fs in CM ($c\tau \approx 123\ \mu$m).
- The reconstruction of the D^0 meson is possible based on the decay particles. The most interesting is the two-body decay:

$$D^0 \to K^+ + \pi^-, \qquad \overline{D}^0 \to K^- + \pi^+$$

- In experiments with a fixed target, thanks to Lorentz time dilation (typical value $\gamma \approx 10$), the average distance traveled by the D^0 meson will be:

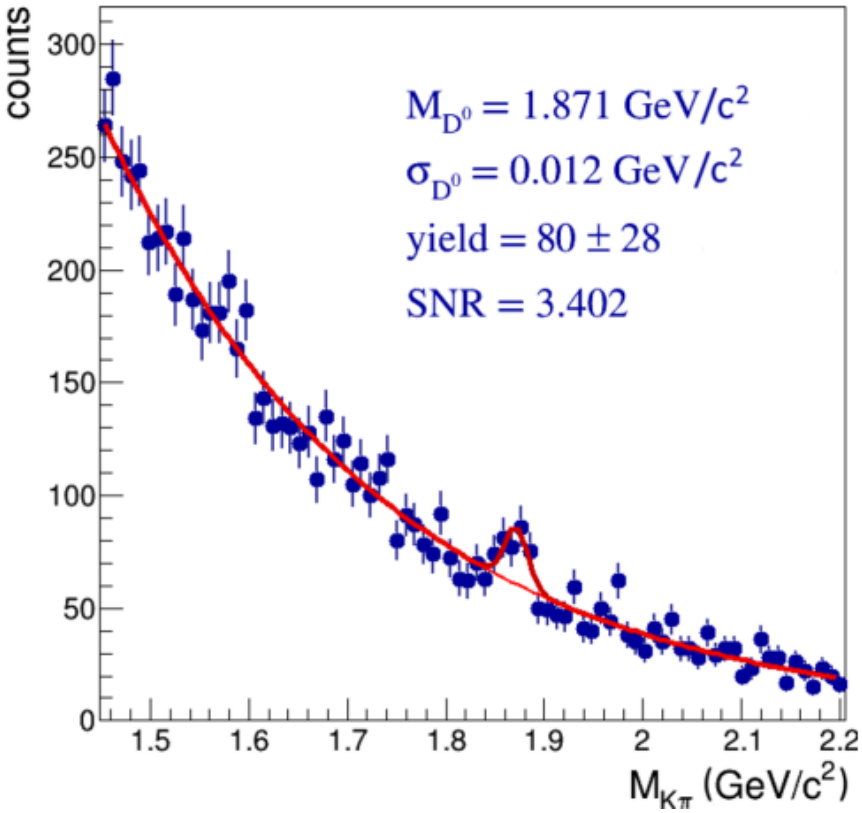
$$c\tau \cdot \gamma > 1 \text{ mm}$$

- The reconstruction of D^0 mesons is achieved by reconstructing its decay point (*secondary vertex*) relative to the point of primary interaction (*primary vertex*). For this, the **Vertex Detector** is needed.



The detector configuration

The SAVD consists of two arms (Jura and Saleve). Each of the arms has 4 stations located respectively 5, 10, 15, and 20 cm downstream of the target. On each arm are located MIMOSA-26AHR Monolithic Active Pixel Sensors (MAPS) pixel detectors based on CMOS (Complementary Metal-Oxide-Semiconductors) technology.



Data (Xe+La 150A GeV/c)[1]
0.11 ± 0.04 AMPT(b) + PHSD(s)
0.12 ± 0.05 EPOS(b) + PHSD(s)

Predictions (Xe+La 150A GeV/c)[1]
0.042 (PHSD)
0.19 (NA60, dynamical scaling)
0.25 (NA60, statistical scaling)
3.9 (SMES)

The measurement result of the D meson (SAVD)

Invariant mass distribution[2] for all combinations of particles with opposite charge, assuming that one of these particles is K and the other π. Data collected for the Xe+La collision with a beam momentum of 150 GeV/c performed in 2017 and refer to 1.86 million collisions with a centrality of 0-20%.

[1] A. Merzlaya, I. C. Arsene, *Status of the K^0s and D^0 analysis using SAVD*, NA61/SHINE Collaboration Meeting at CERN, 12-16.09.2023

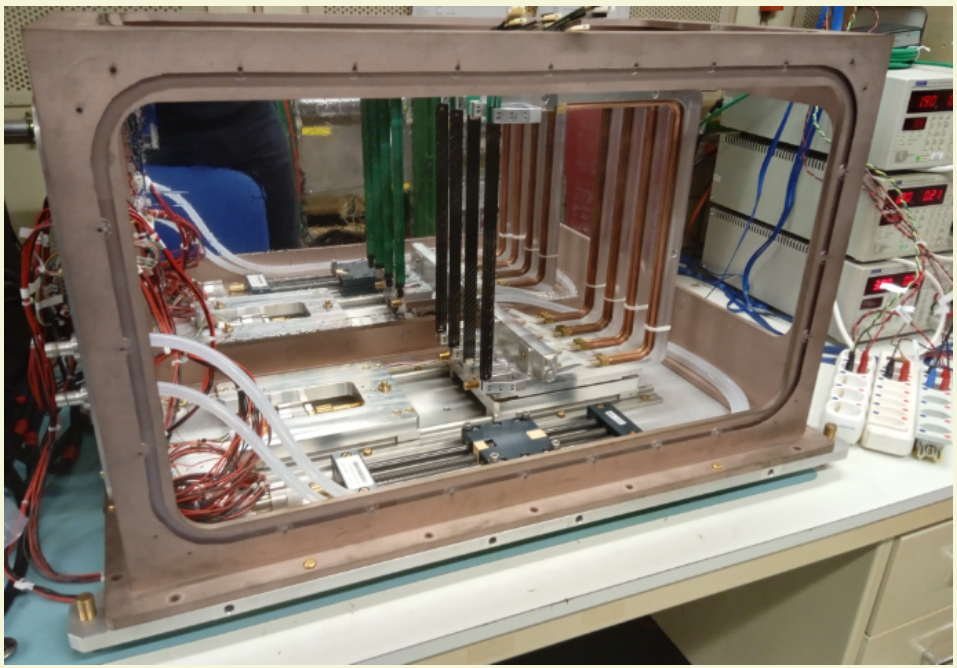
[2] A. Aduszkiewicz, M. Bajda, M. Baszczyk, et all. *A high-resolution pixel silicon Vertex Detector for open charm measurements with the NA61/SHINE spectrometer at the CERN SPS.* Eur. Phys. J. C 83, 471 (2023).

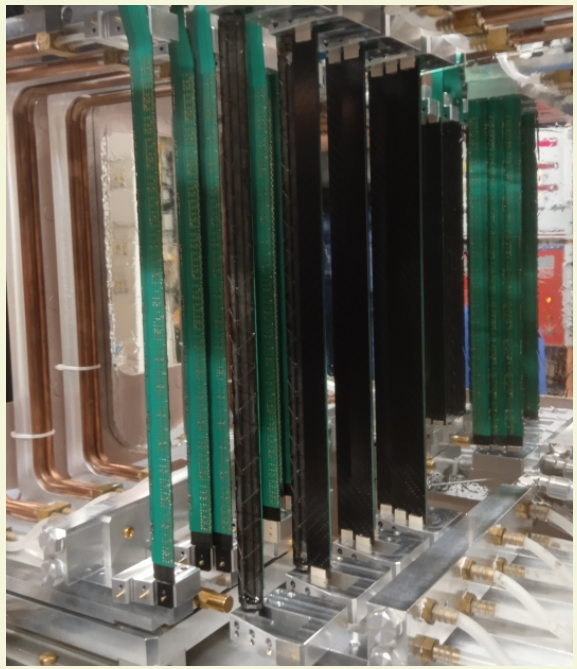
Upgraded Vertex Detector

The main improvements

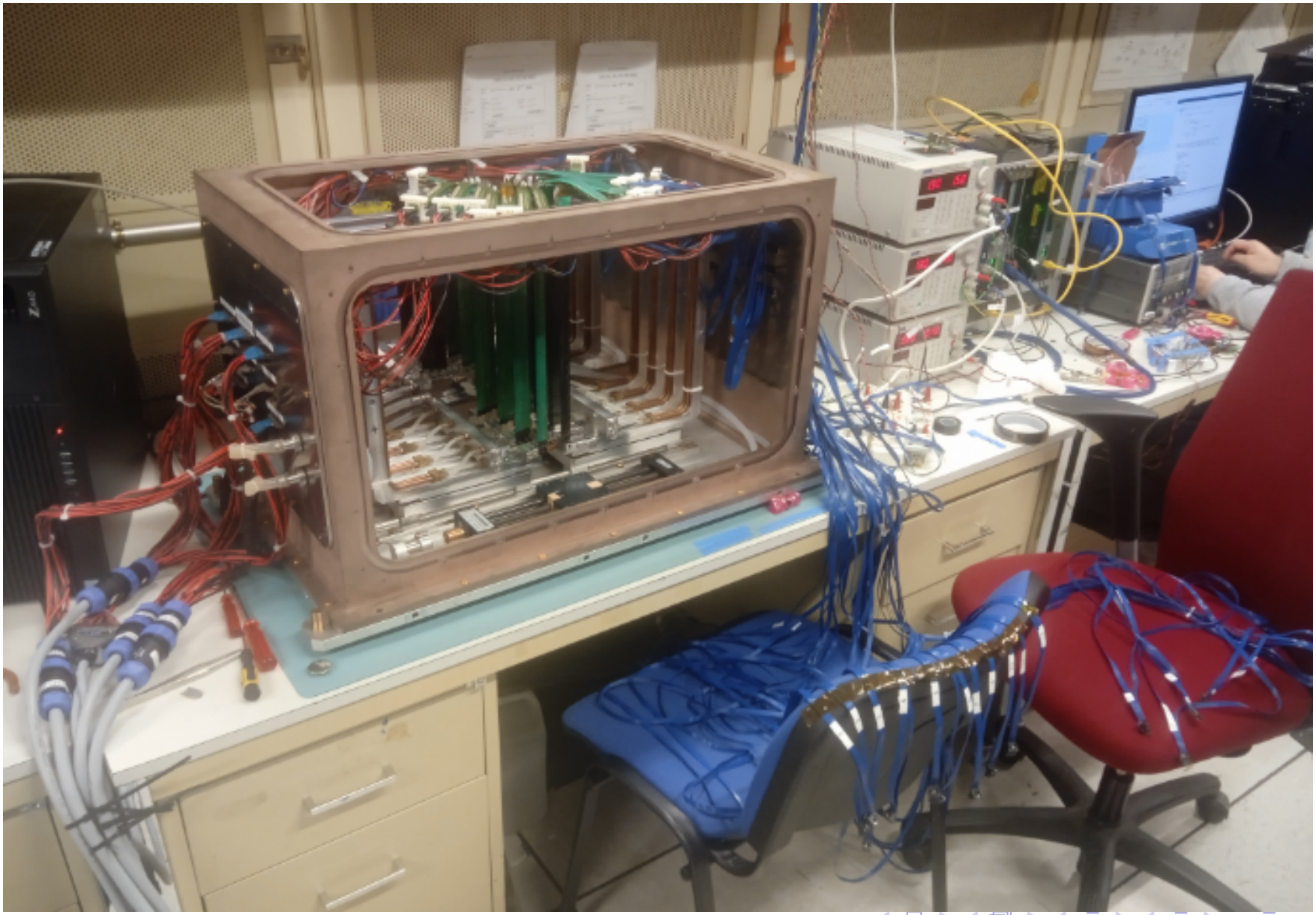
During the Long Shutdown 2 (LS2) at CERN the detection system of the NA61/SHINE experiment was significantly upgraded[1].

- Replacement of TPC (Time Projection Chamber) readout electronics to increase the speed of data readout and reduce the noise.
- Exchange of the Vertex Detector (VD) configuration by employing ALPIDE silicon sensors to i.a. increase geometrical acceptance.



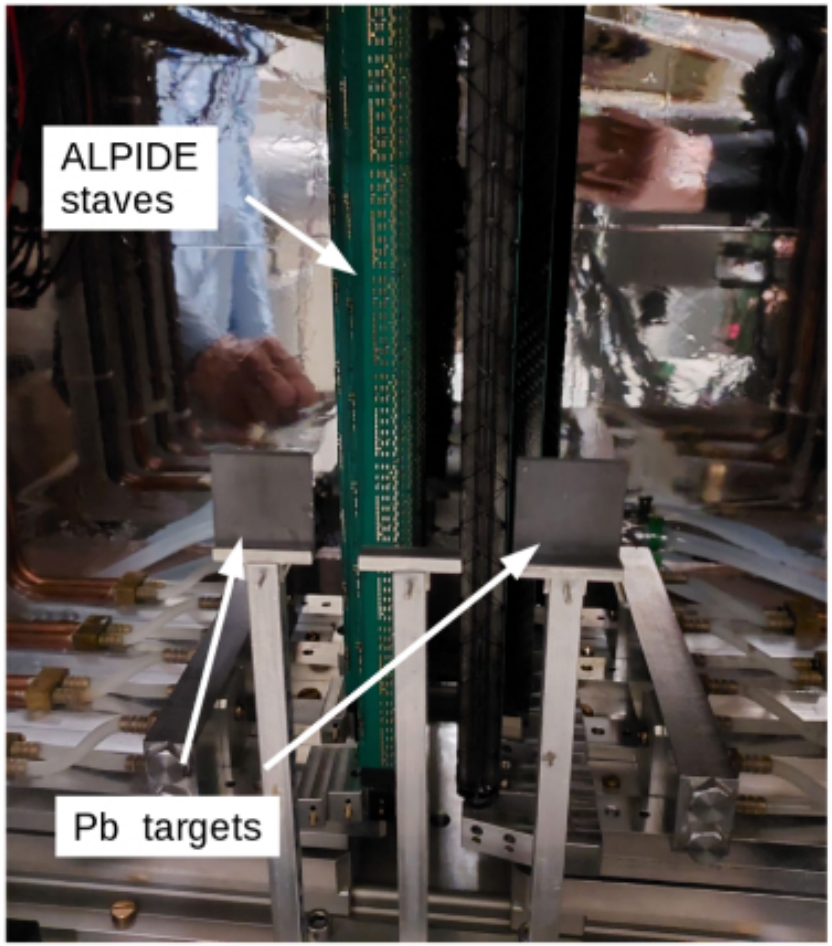


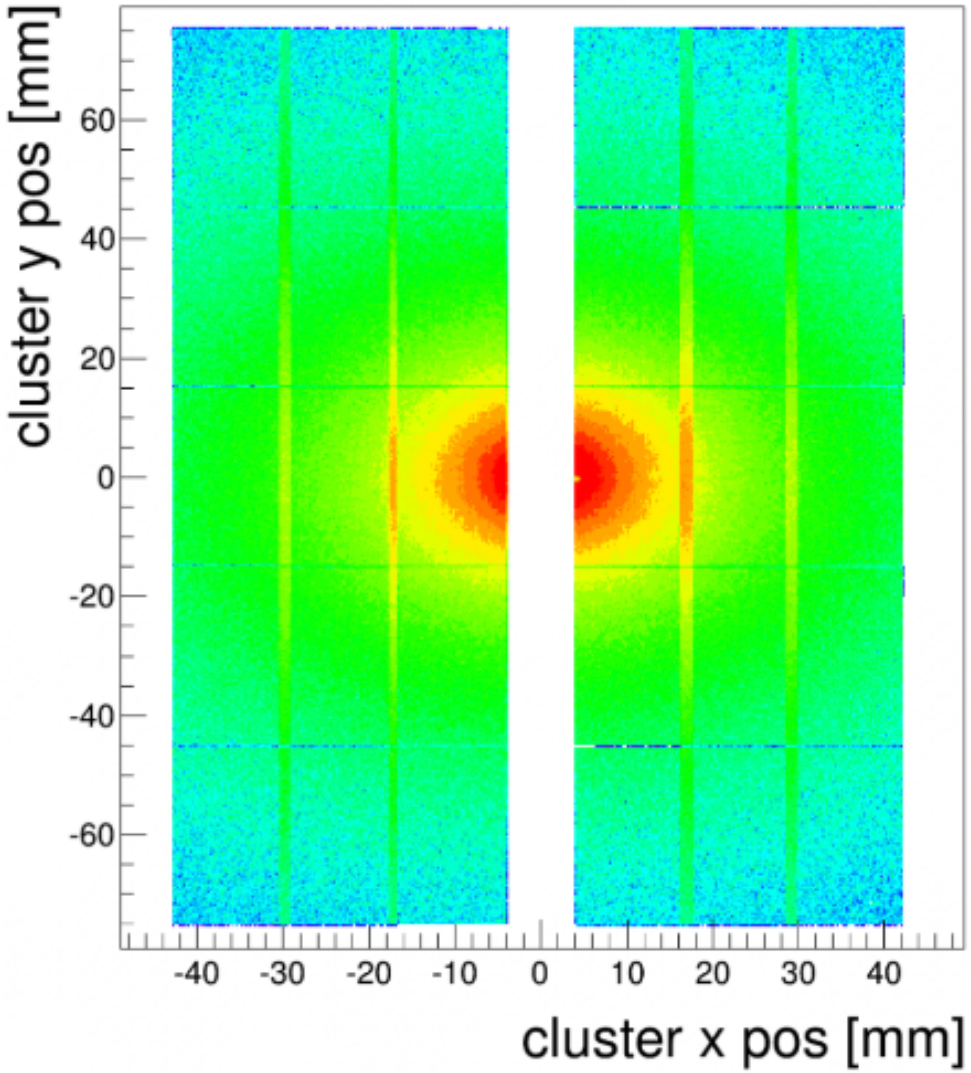
[1] A. Rybicki and A. D. Marino, *Report from the NA61/SHINE experiment at the CERN SPS*, SPS and PS Experiments Committee, Technical report, CERN, Geneva, 2022,



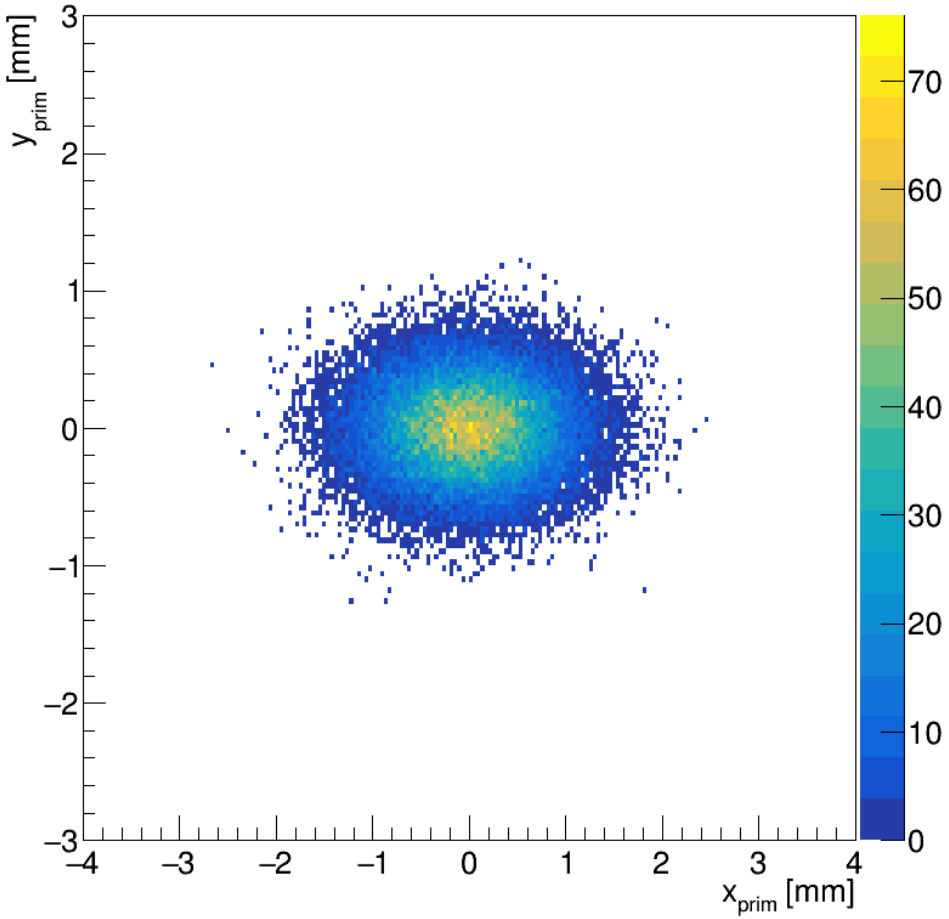
Data reconstruction

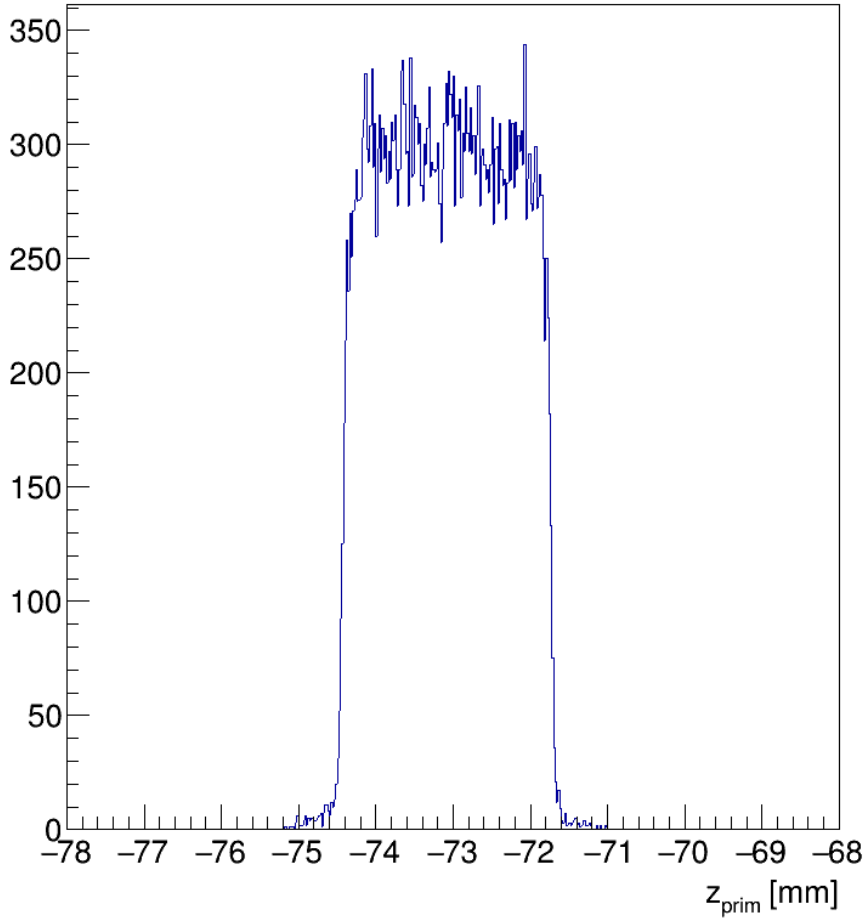
Result from testing upgraded VD in 2022[1]

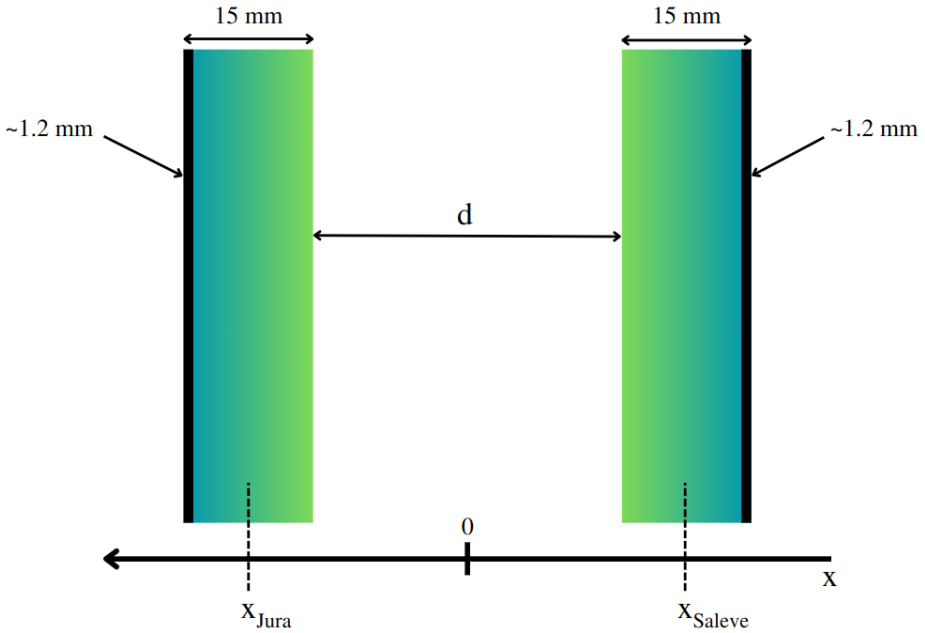


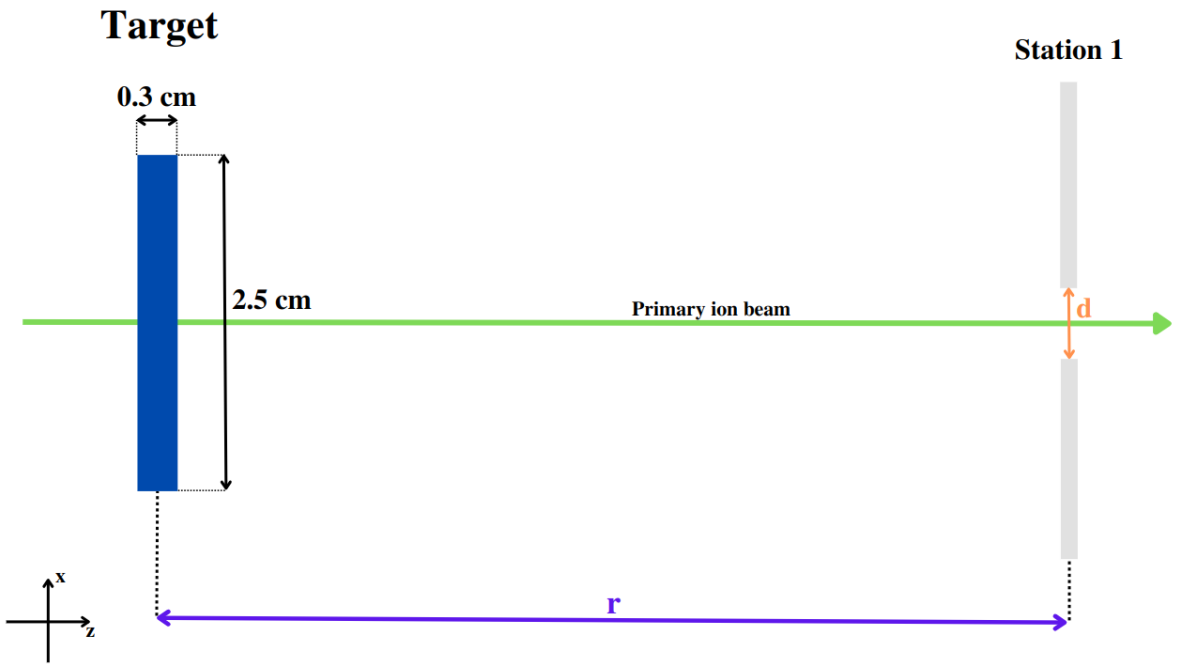


[1] P. Podlaski, P. Staszel, *Hunting for charm with lead and SHINE*, Newsletter of the EP department, https://ep-news.web.cern.ch/content/hunting-charm-lead-and-shine

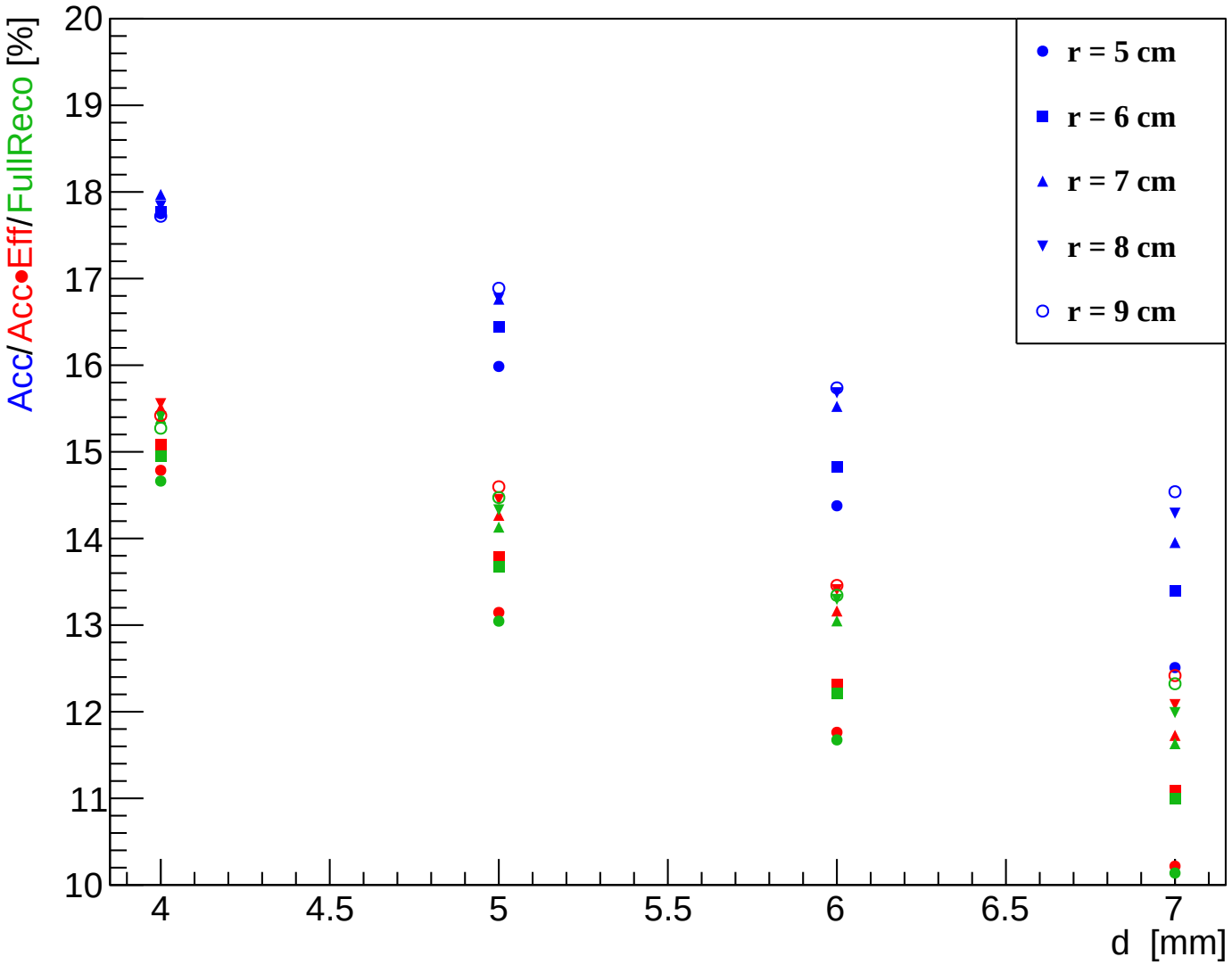

y_{prim} [mm]
x_{prim} [mm]
3
2
1
0
−1
−2
−3
−4
−3
−2
−1
0
1
2
3
4
70
60
50
40
30
20
10
0


z_{prim} [mm]
350
300
250
200
150
100
50
0
−78
−77
−76
−75
−74
−73
−72
−71
−70
−69
−68


15 mm
15 mm
~1.2 mm
~1.2 mm
d
0
x
x_{Jura}
x_{Saleve}


Target
Station 1
0.3 cm
2.5 cm
Primary ion beam
d
r
x
z

Acceptance and reconstruction efficiency of D^0 (VD+TPC)



Thank you for attention!