Open charm measurements in NA61/SHINE at the CERN SPS

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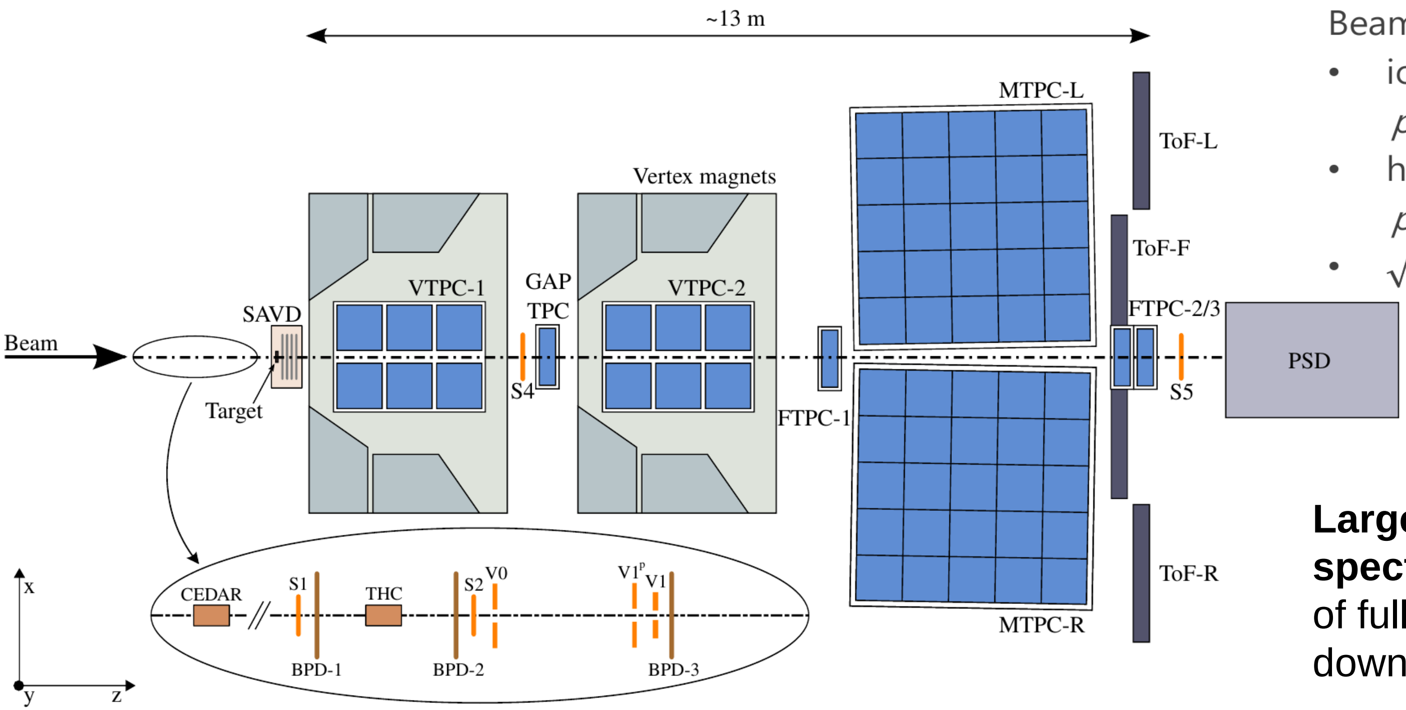
Outline

1. Introduction
2. Physics motivation for Charm measurements
3. Performance of Small Acceptance Vertex Detector
4. Proposed measurements beyond LS2

Introduction

NA61/SHINE Experiment



Beams:

- ions (Be, Ar, Xe, Pb) p_{beam}=13*A*–150*A* GeV/*c*
- hadrons (π, K, p) p_{beam}=13–400 GeV/*c*
- $\sqrt{s_{NN}}$= 5.1–16.8 (27.4) GeV

Large acceptance hadron spectrometer – coverage of full forward hemisphere, down to p_T = 0

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 four small volume TPC's serve as tracking detectors, provide PID

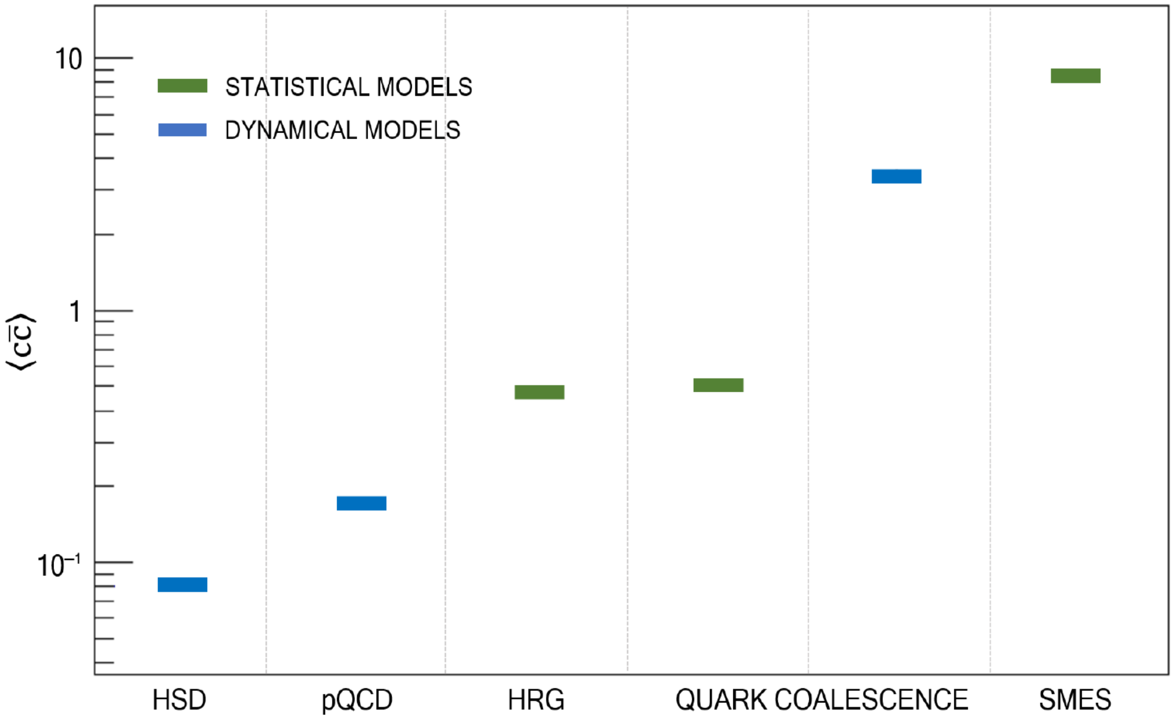
Time of Flight walls → used for hadron identification

Projectile Spectator Detector (PSD) → a calorimeter which is positioned downstream of the time of flight detectors measure energy of projectile fragments.

Small Acceptance Vertex Detector → precise tracking close to the target

Physics motivation

Model predictions for $\langle c\bar{c} \rangle$ in central Pb+Pb at 150A GeV/c



HSD
Linnyk, Bratkovskaya, Cassing, IJMP E17 1367

pQCD
Gavai et al. IJMP A 10 2999
Braun-Munzinger, J. Stachel, PLB 490, 196

HRG, Quark Coalesc. Stat.
Gavai et al. IJMP A10 2999
Braun-Munzinger, J. Stachel, PLB 490, 196

Quark Coalesc. Dyn.
Levai, Biro, Csizmadia, Csorgo, Zimanyi, JP G27, 703

SMES
Gazdzicki, Gorenstein, APP B30, 2705

- Different models differ in predictions of $\langle c\bar{c} \rangle$ by factor ≈ 50
- To discriminate models the $\langle c\bar{c} \rangle$ produced in full phase space is needed
  → measurement of open charm mesons

Measurements of $\langle c\bar{c} \rangle$

0-20% Pb+Pb at 150*A* GeV/*c*

charm conservation

$c = \bar{c}$

violation of isospin symmetry

$D^0 \approx 2.6\ D^+$

31% 12%

$\bar{D}^0 \approx 2.6\ D^-$

31% 12%

⩔ *higher mass states* ⩔

D_s^+ Λ_c

5% 3%

D_s^- $\bar{\Lambda}_c$

5% 2%

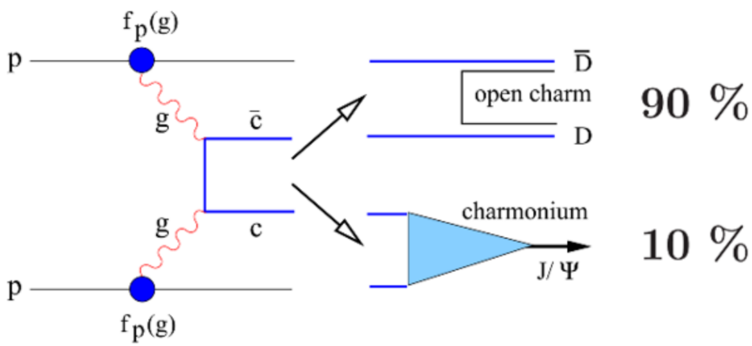
PHSD, Elena Bratkovskaya & Taesoo Song, private communication

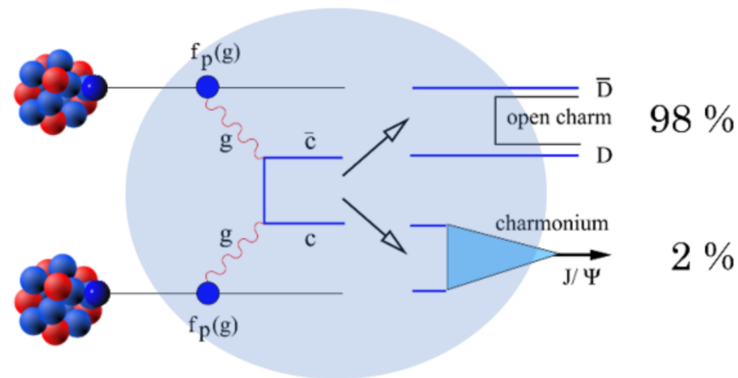
Hadrons containing charm considered for measurements in NA61/SHINE

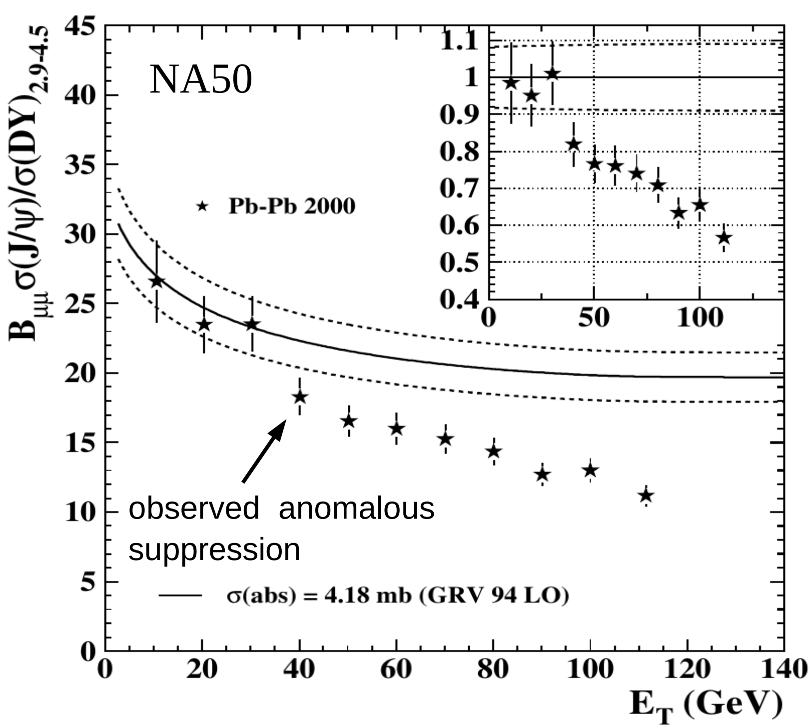
Hadron	Decay channel	$c\bar{\tau}$ [μm]	BR
D^0	$\pi^+ + K^-$	123	3.89%
D^+	$\pi^+ + \pi^+ + K^-$	312	9.22%
D_S^+	$\pi^+ + K^- + K^+$	150	5.50%
Λ_c	$p + \pi^+ + K^-$	60	5.00%

Measuring $\mathbf{D^0}$, $\mathbf{\bar{D}^0}$, $\mathbf{D^+}$, $\mathbf{D^-}$ provides good $\langle \boldsymbol{c\bar{c}} \rangle$ estimate

J/ψ suppression as signal of deconfinement







Medium reduces probability of J/ψ production
(H. Satz, Adv. High En. Phys. (2013) 2429)

J/ψ normalized to DY measured by NA50 (Eur. Phys. J. C39, 335, 2005)

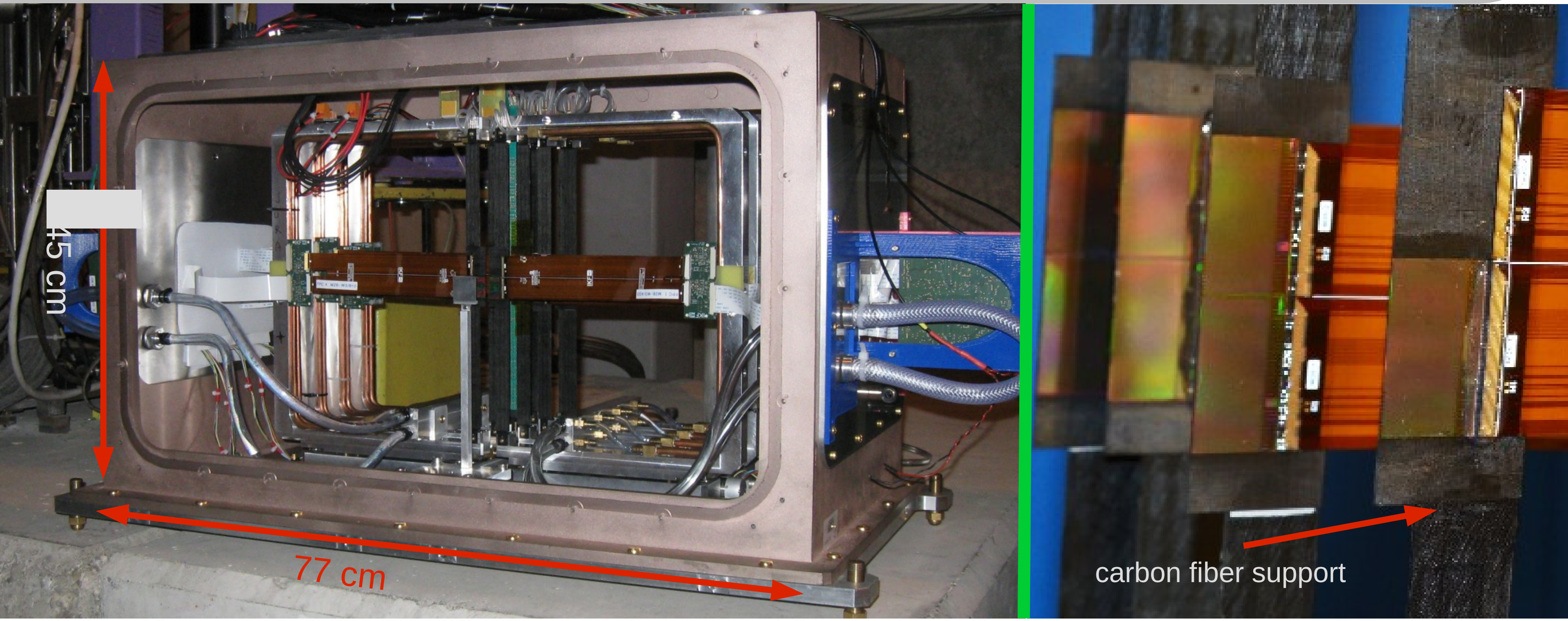
Data was interpreted in terms of final state interaction in the deconfined medium created in nucleus-nucleus collisions.

To validate this interpretation we need to control experimentally $\langle c\bar{c}\rangle$

→ **measurements of Open Charm!!!**

Performance of **S**mall **A**cceptance **V**ertex **D**etector (SAVD)

Vertex Detector tests with Pb+Pb at 150*A* GeV/*c*



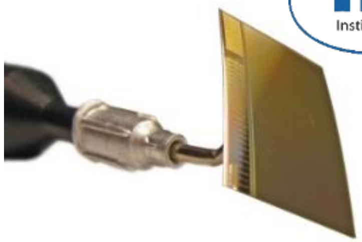
SAVD:

- 16 MIMOSA-26 sensors located on 2 horizontally movable arms.
- Target holder integrated with SAVD base plate

Achieved goals:

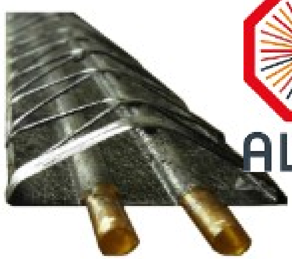
- tracking in the large track multiplicity environment
- precise Primary Vertex reconstruction
- TPC and SAVD track matching
- first search for D^0 signal

Main project components



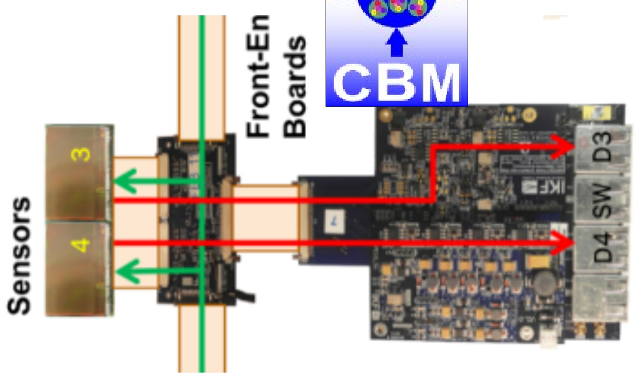
MIMOSA-26AHR
- 1152x576 pixels of $18.4 \times 18.4 \mu m^2$
- 3.5 µm resolution, 0.05% X_0
- Readout time: 115.2 µs, 50µm thin

PICSEL Group, IPHC Strasbourg



ALICE ITS ladder
- Ultra light carbon fibre
- < 0.3% X_0 including water cooling

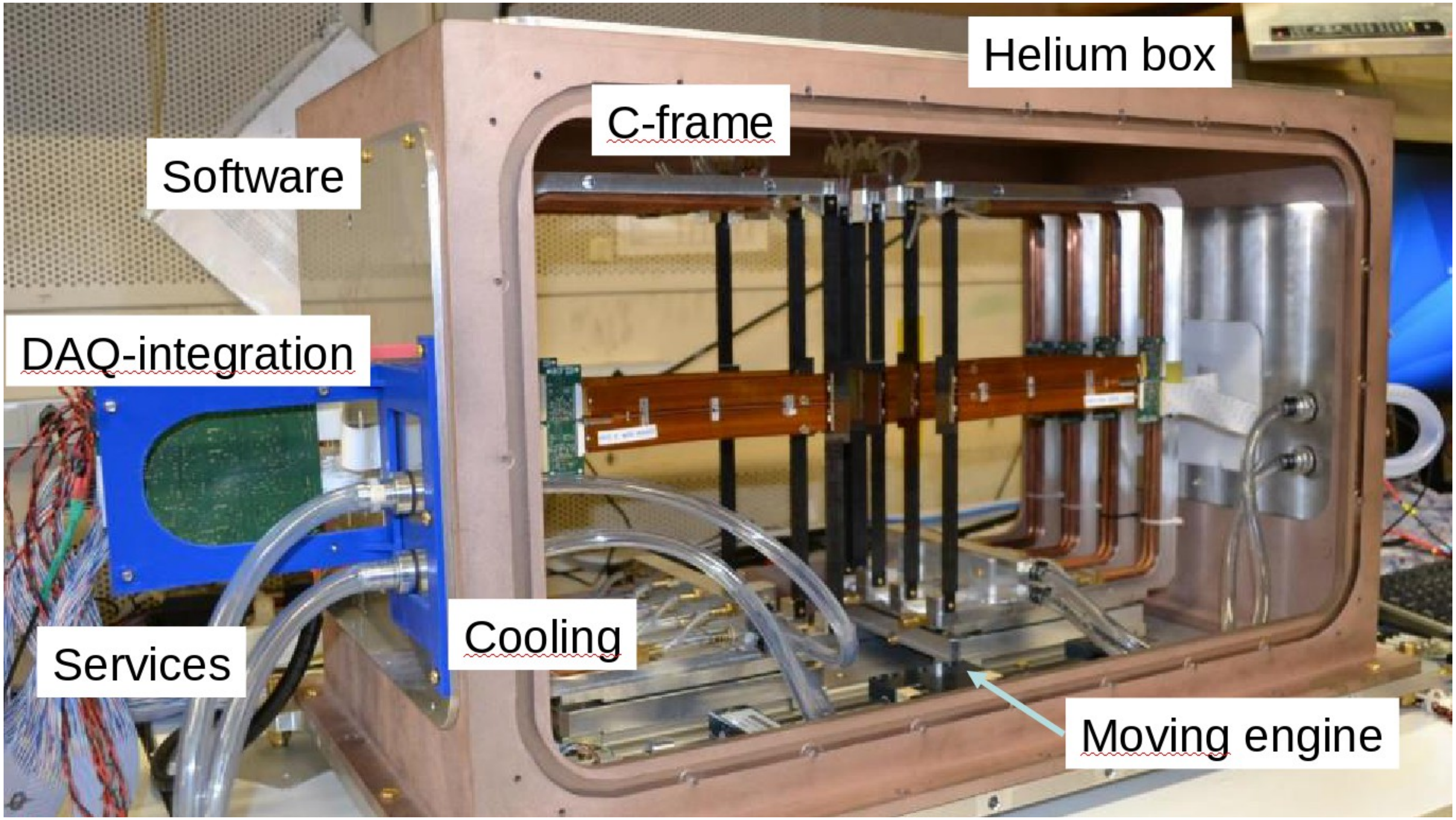
St. Petersburg, CERN



CBM Micro Vertex Detector Prototype
- Sensor integration
- Flex print cables, Front-end boards
- Read-out based on TRB3 FPGA Board

Goethe Universitet Frankfurt am Main

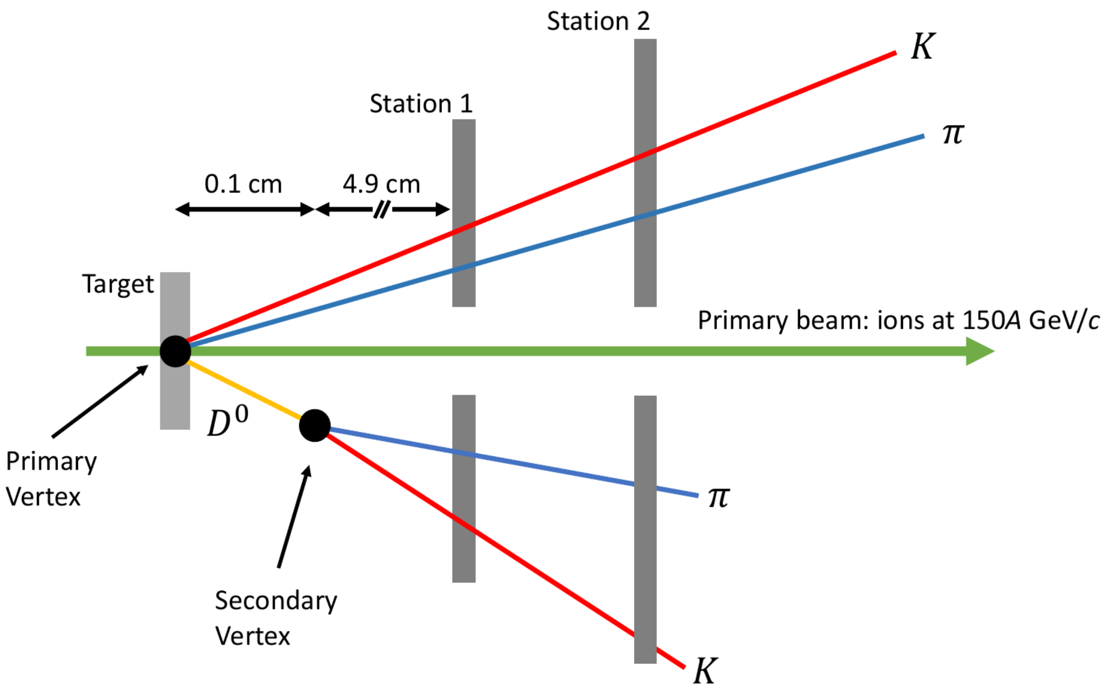
Main project components (c.d.)



System integration and project leadership:
Jagiellonian University Krakow,
supported by AGH Krakow, WUT Warsaw

Why Vertex Detector is needed to measure open charm?

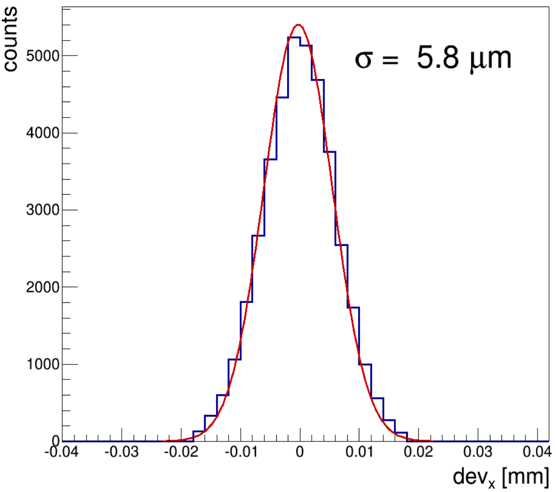
$$D^0 \rightarrow \pi^+ + K^-$$

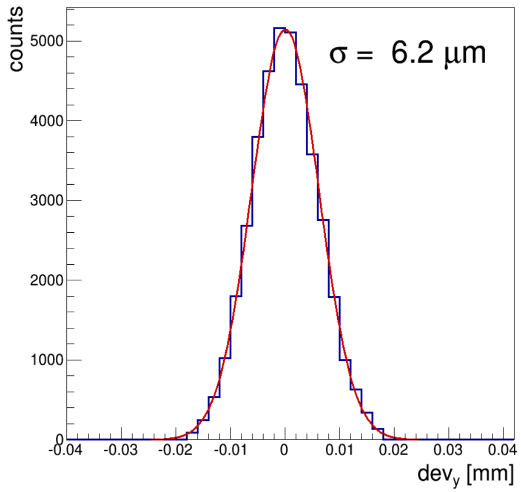


- Daughters of D^0 (π and K) are recognized as a pair forming a secondary vertex displaced form the primary vertex
- $c\tau(D^0) \simeq 122$ μm, however, due to Lorentz boost ($\beta\gamma \approx 10$) the displacement is on the level of 1 mm.
- This holds also for other charm mesons like D^+, D^-, D^+_s
- The Lorentz Boost makes the measurements significantly easier than in case of collider experiments

Vertex detector is needed to reconstruct **primary vertex** and **secondary vertexes** with high precision.

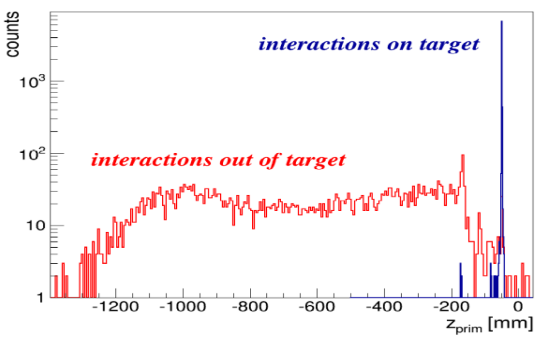
Vertex Detector performance

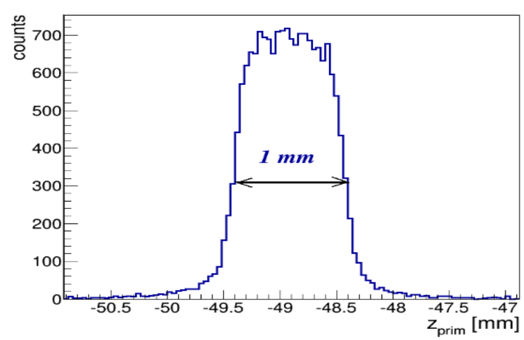




Spacial resolution of the sensor < 5μm as expected

$$\sigma_{x/y} = \sqrt{\frac{2}{3}}\,\sigma_{dev_{x/y}}$$





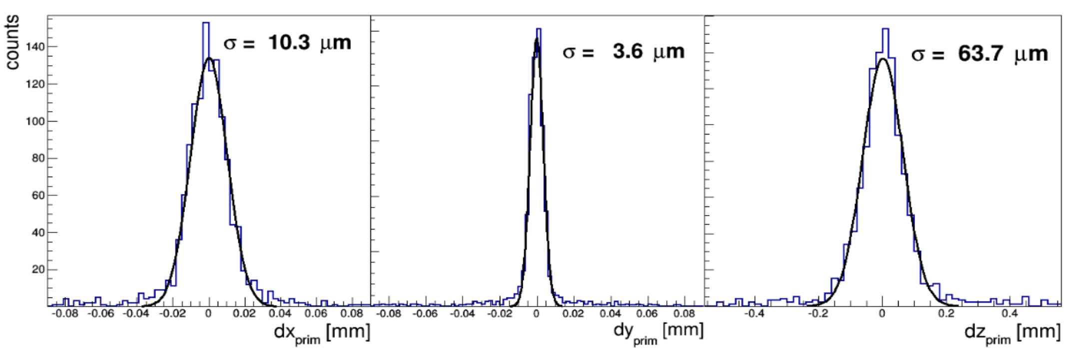
Reconstruction of primary vertex allows to separate **in-** and **out-target** interactions

Spacial primary vertex resolution:

σ_x = 5 μm

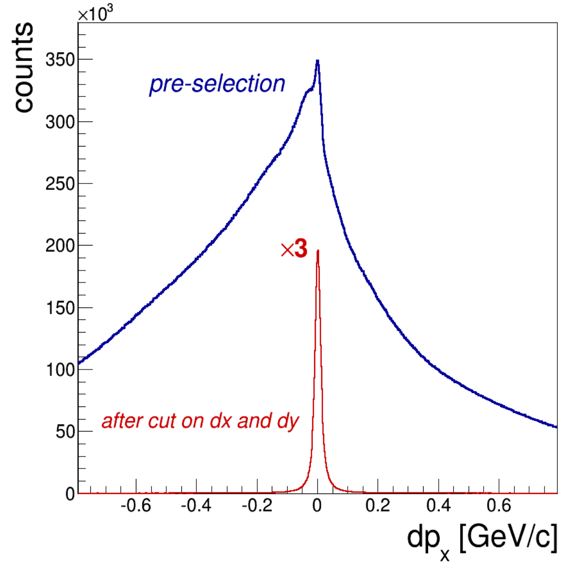
σ_y = 1.8 μm

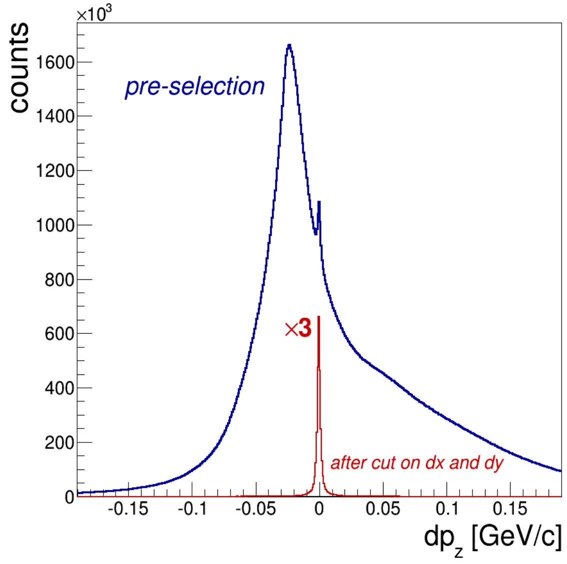
σ_z = 30 μm



Worse resolution in x due to presence of magnetic field (B_y)

VD – TPC track matching

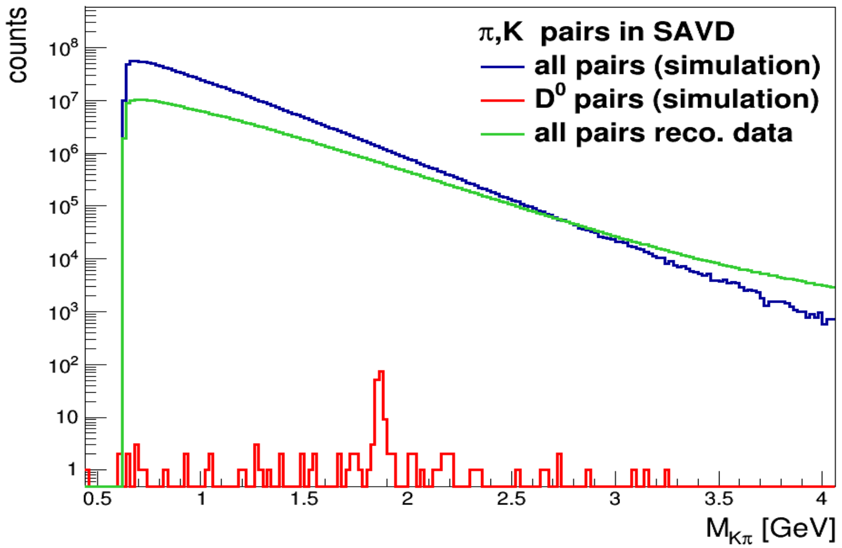




Extrapolate SAVD tracks to TPC volume.

Pre-selection: cut on y-slopes of tracks.

After cuts on dx and dy clear correlation peaks are seen in dp_x and dp_z



Matching with TPC provides:

momenta and PID to VD tracks

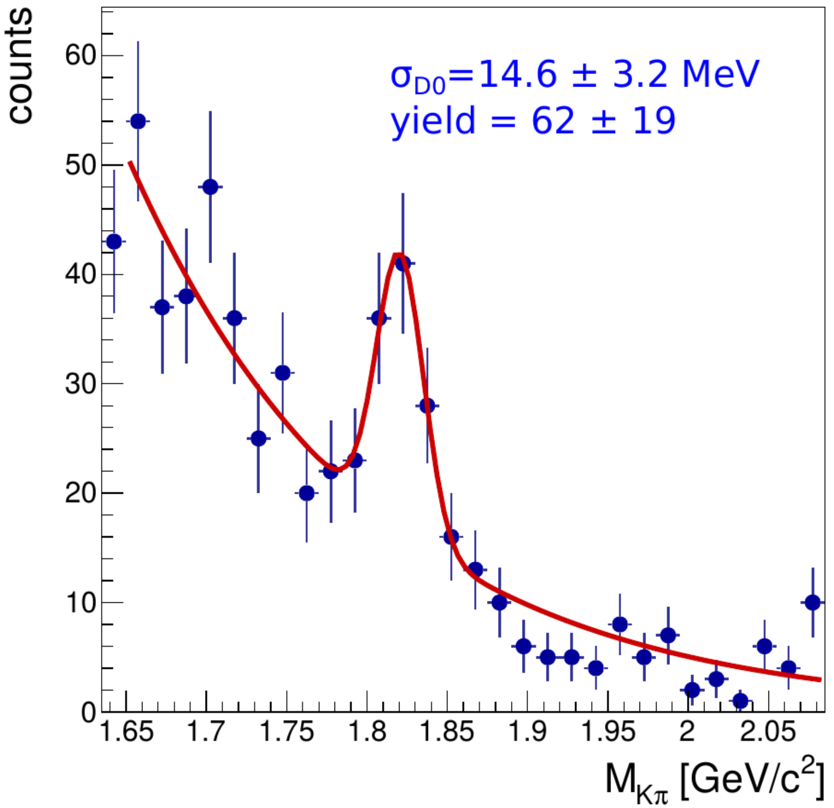
→ invariant mass distribution

VD: search for D^0

First results for 140k (trigger set for detector test → not precise centrality measurement)

Background suppression → cuts on:

1. track p_T
2. track impact parameter d
3. longitudinal distance V_z (pair vertex to primary vertex)
4. parent impact parameter d_P



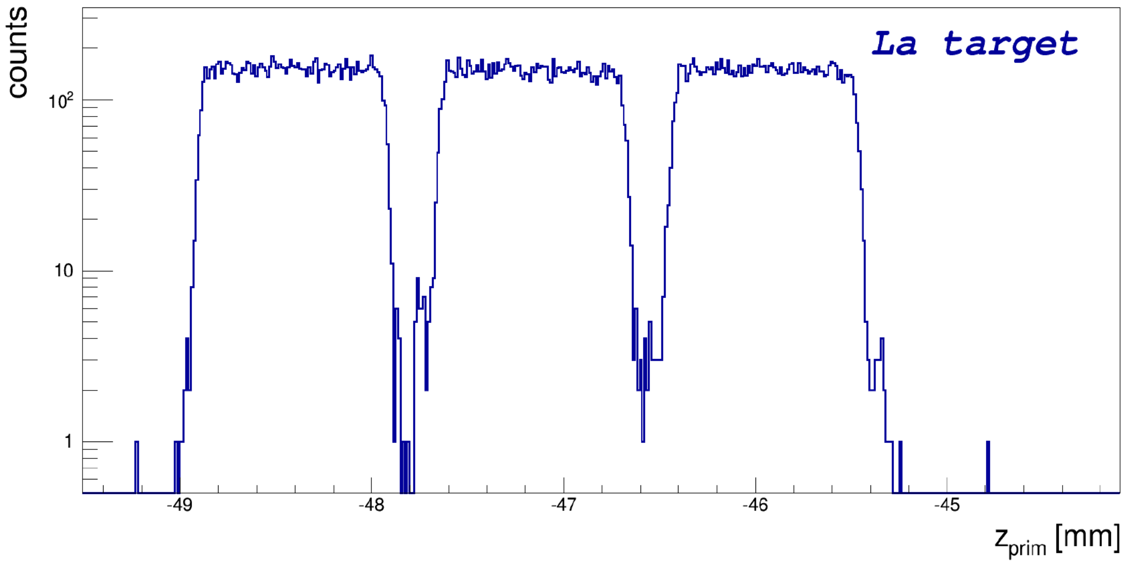
Analysis details:

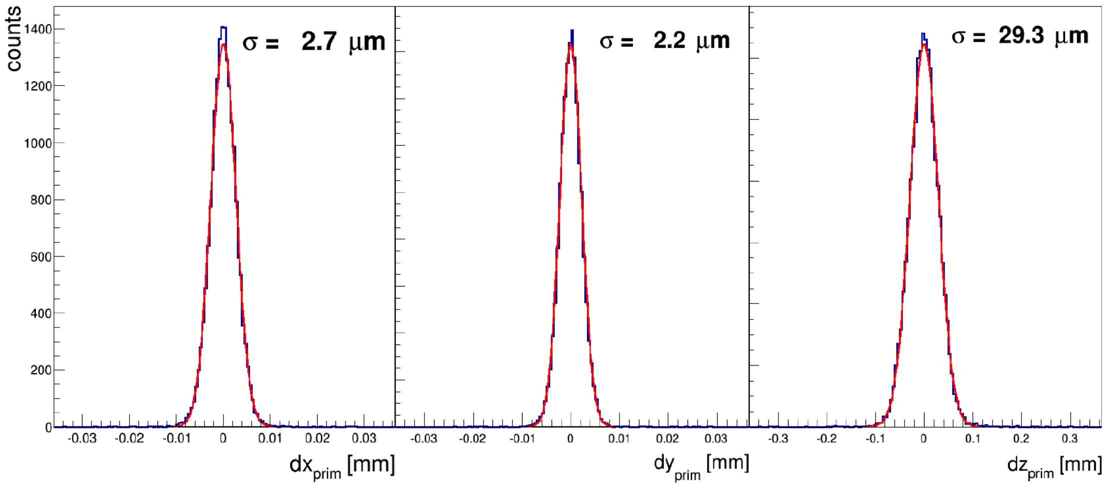
1. Global fit (VD+TPCs) using Kalman Filter
2. PID not used yet (should reduce background by factor of 5)

Allocated beam time in 2018: 10M 0-20% central Pb+Pb

→ 2.5k $D^0 + \bar{D}^0$

Performance for Xe+La at 150A GeV/c





- Large statistic Xe+La data taken in late 2017 at 150A and 75A GeV/c for minimum bias and 0-20% central events.
- Segmented target was used (tree 1mm thick La blocks squeezed together). The structure of the target can be well seen in the z_{prim} distribution plot.
- Obtained primary vertex resolution: 1.3, 1.0 and 15 μm in *x*, *y* and *z* coordinate, respectively. Significant improvement as compare to test measurement due to better setup of sensor thresholds.
- Xe+La data should allow for reinterpretation of J/ψ yields measured by NA60 for medium size systems.

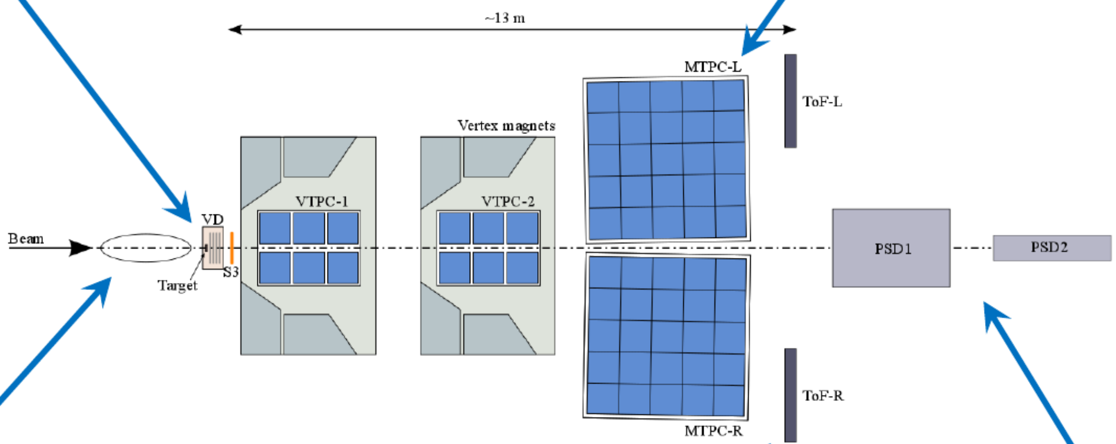
Proposed measurements beyond LS2

LS2 upgrades of NA61/SHINE setup

For details of upgrade of VD see poster of A. Merzlaya

Construction of Vertex Detector (VD) for D^0, $\overline{D^0}$ decay reconstruction

Replacement of the TPC read-out electronics to increase data rate to 1 kHz



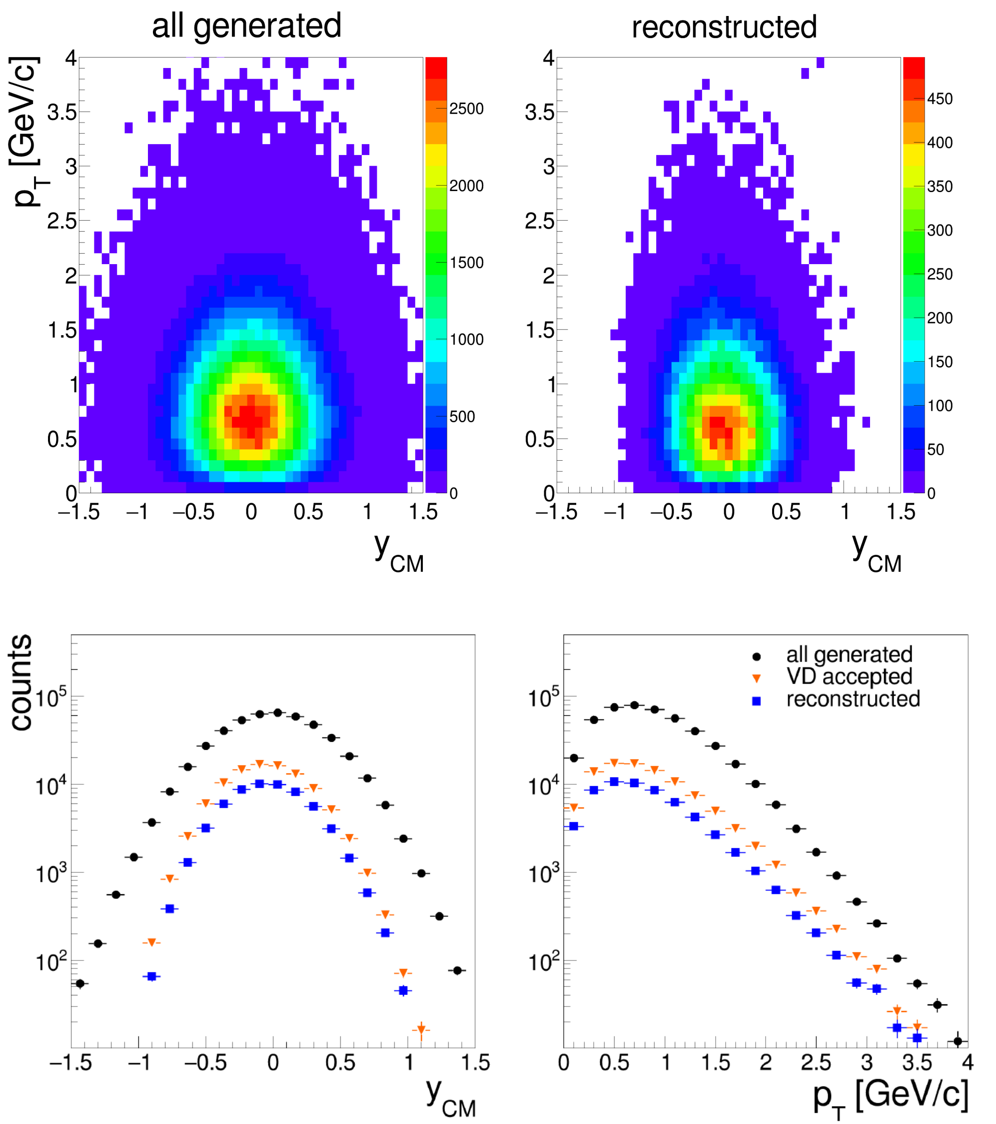
New trigger and data acquisition system

New Time-of-Flight detectors

Upgrade of Projectile Spectator Detector

Upgrades are needed to increase rate capability of NA61/SHINE by one order of magnitude to 1 kHz

Anticipated results



- Precise measurements of charm hadron production by NA61/SHINE are expected to be performed in 2022-2014 (see tables in A. Merzlaya poster).

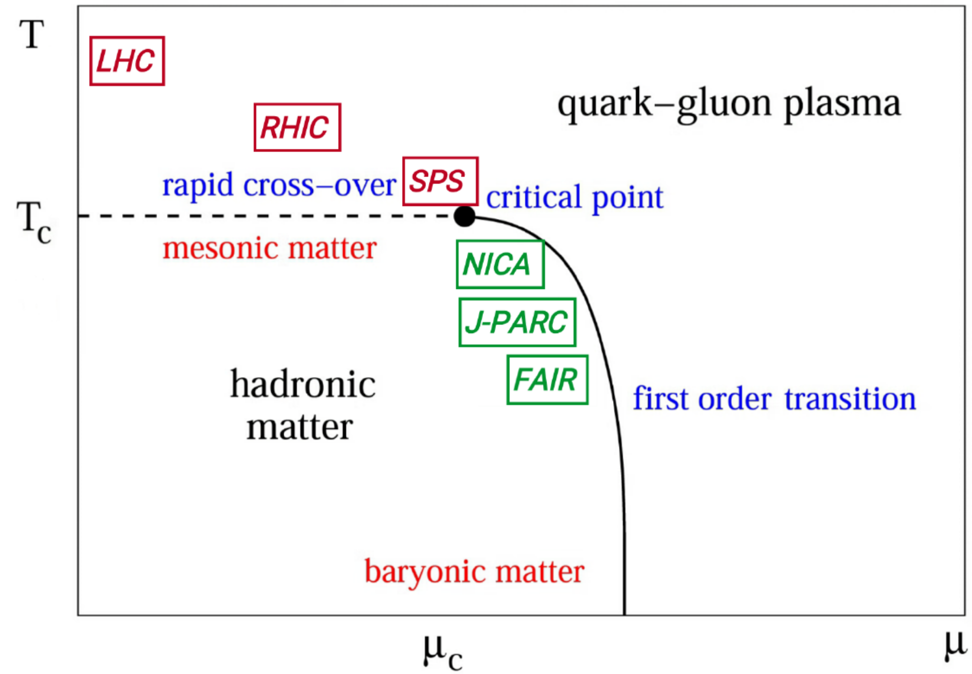
- The Lorentz boost makes the measurements significantly easier than in case of collider experiments.

- Unlike in a typical collider experiment the acceptance extends down to p_T=0 → accurate measurements of total charm meson yields.

The proposed program will allow to perform systematic study of D^0, $\bar{D}^0$, D^+, D^-, (D^+_s) production versus collision energy and centrality

Uniqueness of NA61/SHINE program

- **LHC** and **RHIC** at high energies ($\sqrt{s_{NN}} \geq$ 200 GeV): significantly limited acceptance due to collider kinematics and related detector geometry
- **RHIC BES** collider and fixed-target ($\sqrt{s_{NN}}$ = 3−39 GeV): measurement not considered in the current program
- **NICA** ($\sqrt{s_{NN}}$ < 11 GeV): measurements during stage 2 (after 2023) are under consideration (overlap in energy with NA61/SHINE)
- **J-PARC-HI** ($\sqrt{s_{NN}} \leq$ 6 GeV): under consideration, may be possible after 2025.
- **FAIR SIS-100** ($\sqrt{s_{NN}}$ < 5 GeV): sub-threshold charm production measurements are considered. Systematic charm measurements are planed with SIS-300



→ **only NA61/SHINE is able to measure open charm in heavy ion collisions in full phase space in the near future**

Summary

NA61/SHINE open charm production measurements started in 2017 with SAVD
→ expected first physics results soon

After LS2 high statistic Pb+Pb data taking with upgraded detector is proposed

The results from high statistic runs are expected to:

- distinguish between many existing models of charm production in Pb+Pb collisions
- initiate a measurement of collision energy dependence of open charm yield
- verify signal of the QGP formation by measurements of centrality dependence of charm production

Backup slides

Measurement program with SAVD

2016: Pb+Pb at 150*A* GeV/*c*

- Detector commissioning
- Good detector performance
- D^0 likely seen

2017: Xe+La at 75 and 150*A* GeV/*c*

- Improved sensor efficiency
- Improved primary vertex resolution (dx=1.3µm, dy=1.0µm, dz=15µm)
- Large statistics collected:
  5.1 MEvents@150*A*GeV/*c*
  4.0 MEvents @75*A* GeV/*c*
- Analysis ongoing, expected good data quality
- Expected open charm data suited for comparison with NA61/SHINE

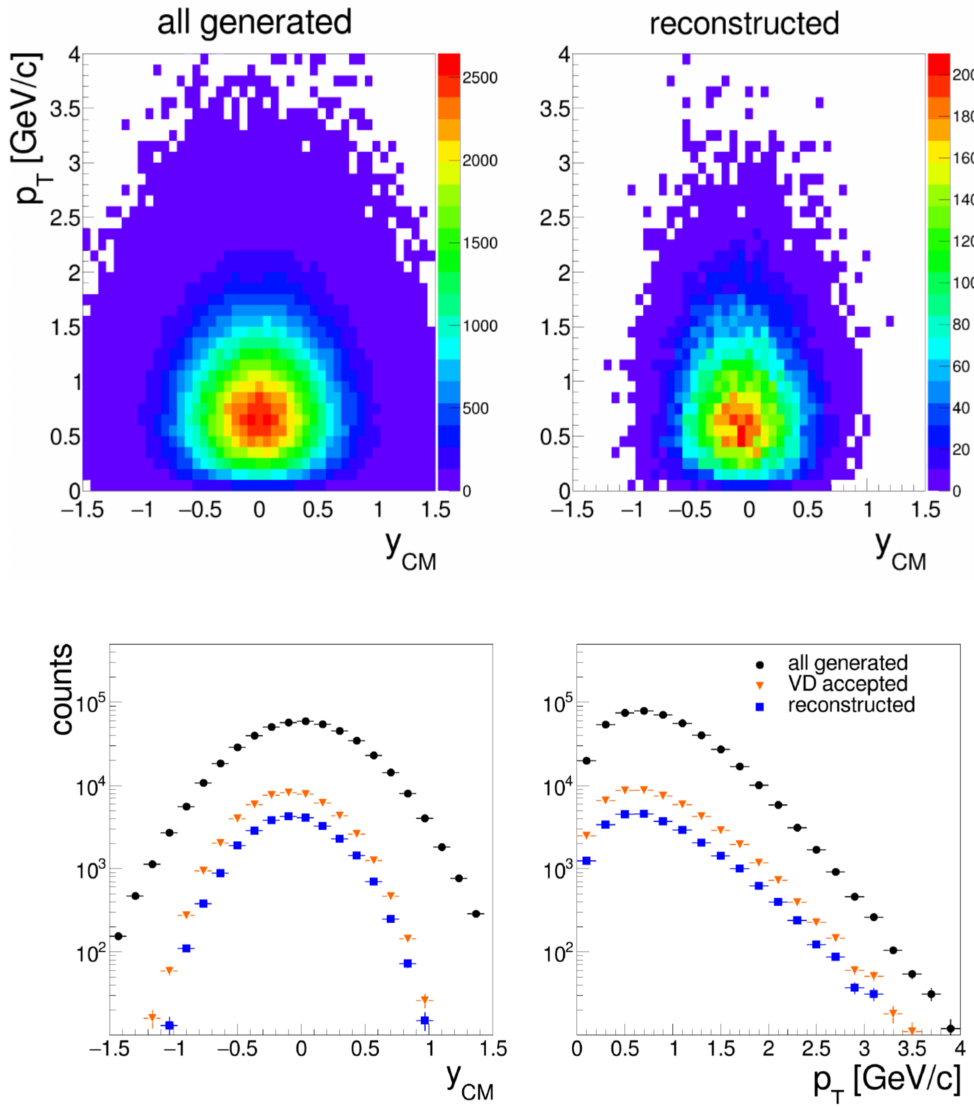
2018: Pb+Pb at 150*A* GeV/*c* run scheduled

Request for Open Charm measurements

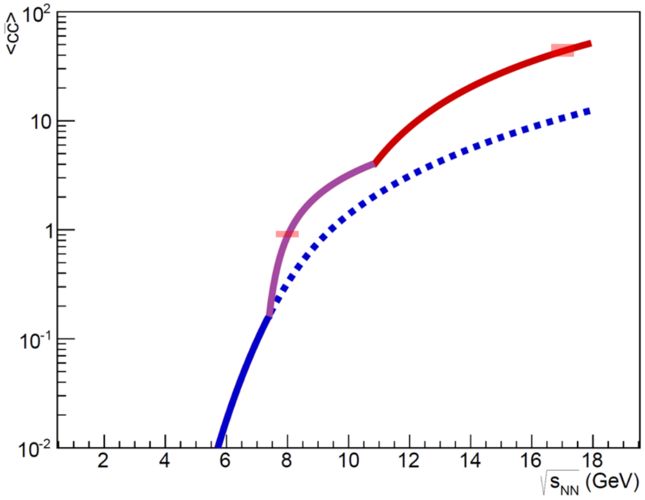
Year	Beam	#days	#events	$\#(D^0 + \overline{D^0})$	$\#(D^+ + D^-)$
2022	Pb at 150A GeV/c	42	250M	38k	23k
2023	Pb at 150A GeV/c	42	250M	38k	23k
2024	Pb at 40A GeV/c	42	250M	3.6k	2.1k

	0–10%	10–20%	20–30%	30–60%	60–90%	0–90%
$\#(D^0 + \overline{D^0})$	31k	20k	11k	13k	1.3k	76k
$\#(D^+ + D^-)$	19k	12k	7k	8k	0.8k	46k
$\langle W \rangle$	327	226	156	70	11	105

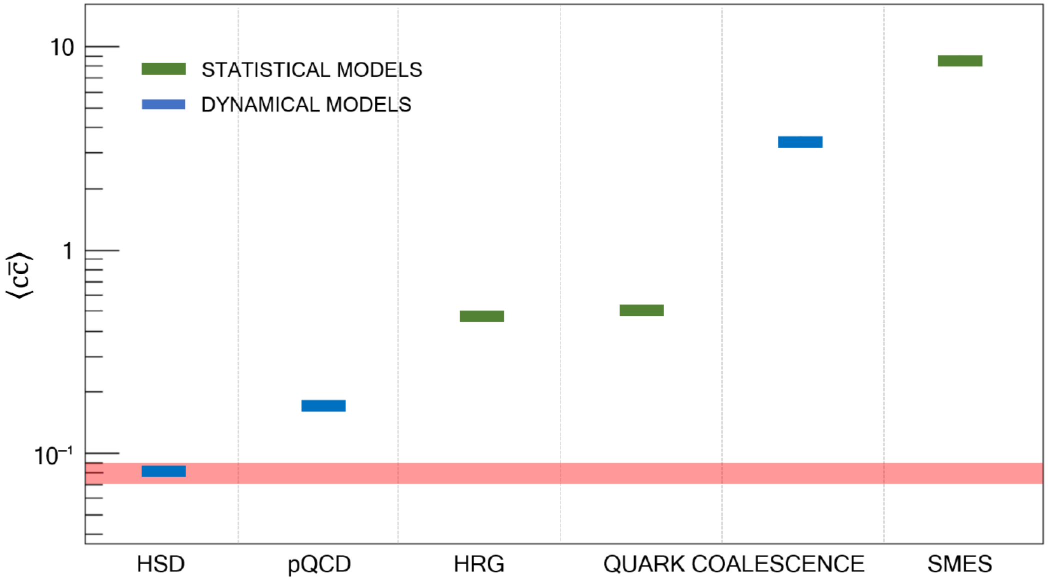
Simulated results on $D^+ + D^-$



Anticipated results

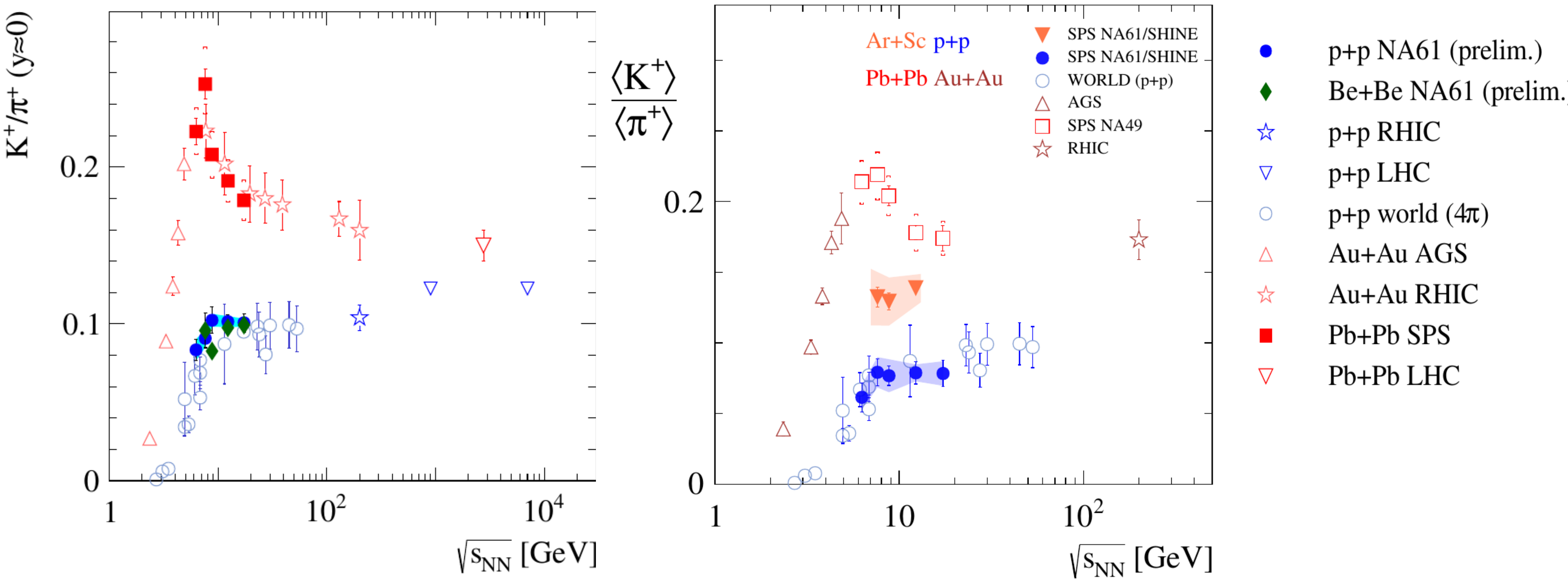


SMES predictions



Particle ratios and fluctuations (2)

Rapid changes in **K⁺/π⁺** (HORN) were observed in Pb+Pb collisions. It was predicted within SMES as a signature of onset of deconfinement

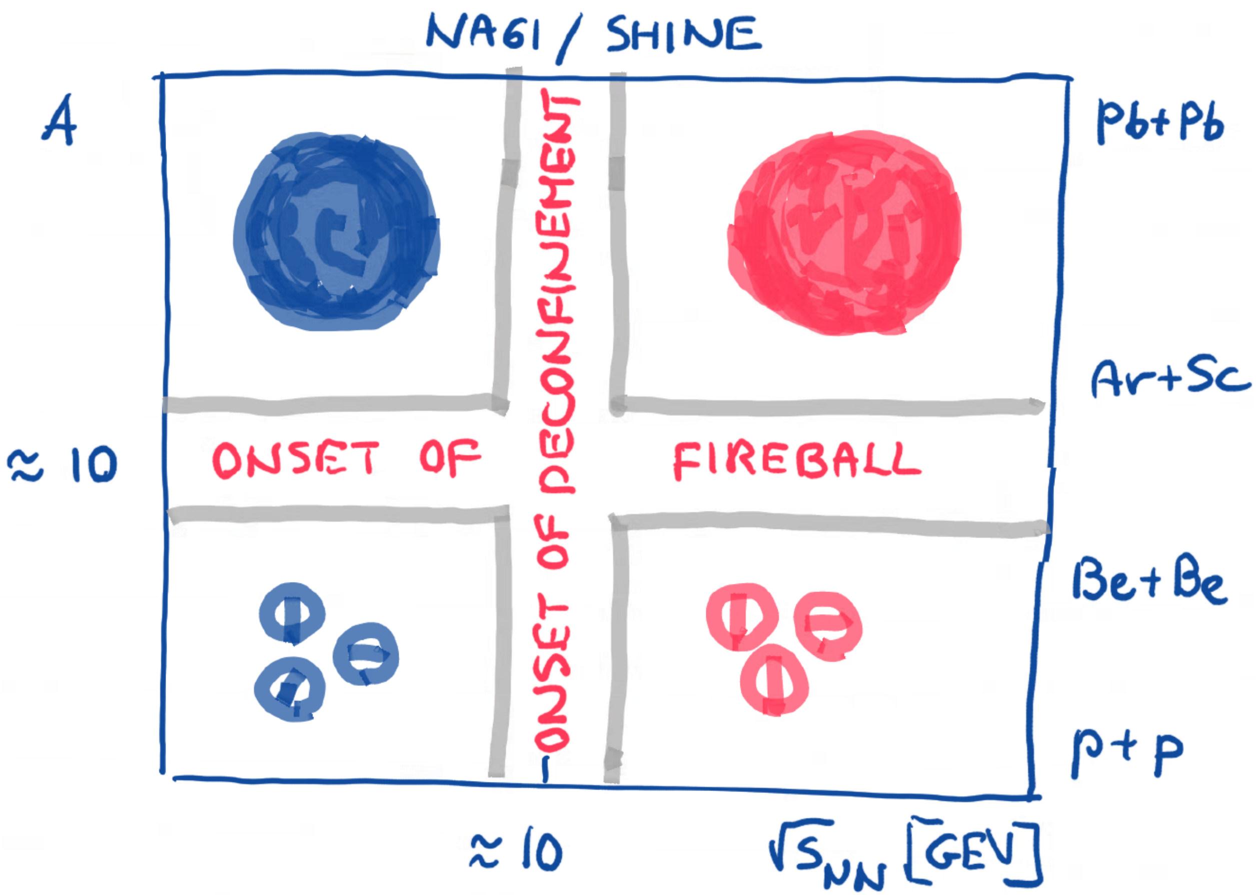


NEW RESULTS:

- plateau like structure visible in p+p
- Be+Be consistent with p+p

- <K⁺>/<π⁺> in Ar+Sc in between p+p, Be+Be and Pb+Pb

Tentative conclusions from 2D scan



Data on particle ratios and fluctuations indicate four domains of hadron production separated by two thresholds:

onset of deconfinement

and

onset of fireball

Completion of Ar+Sc analysis and new data for Xe+La awaited to verify this picture

NA61/SHINE

We would like to thank the CERN EP, BE, EN and IT Departments for the strong support of NA61/SHINE

The NA61/SHINE Collaboration

A. Aduszkiewicz[16], Y. Ali[13], E.V. Andronov[22], T. Antićić[3], B. Baatar[20], M. Baszczyk[14], S. Bhosale[11], A. Blondel[25], M. Bogomilov[2], A. Brandin[21], A. Bravar[25], W. Bryliński[18], J. Brzychczyk[13], S.A. Bunyatov[20], O. Busygina[19], A. Bzdak[14], H. Cherif[7], M. Ćirković[23], T. Czopowicz[18], A. Damyanova[25], N. Davis[11], M. Deveaux[7], P. von Doetinchem[30], W. Dominik[16], P. Dorosz[14], J. Dumarchez[4], A. Datta[30], R. Engel[5], A. Ereditato[24], G.A. Feofilov[22], Z. Fodor[8,17], C. Francois[24], A. Garibov[1], M. Gaździcki[7,10], M. Golubeva[19], K. Grebieszkow[18], F. Guber[19], A. Haesler[25], A.E. Hervé[5], J. Hylen[26], S.N. Igolkin[22], A. Ivashkin[19], S.R. Johnson[28], K. Kadija[3], E. Kaptur[15], M. Kiełbowicz[11], V.A. Kireyeu[20], V. Klochkov[7], V.I. Kolesnikov[20], D. Kolev[2], A. Korzenev[25], V.N. Kovalenko[22], K. Kowalik[12], S. Kowalski[15], M. Koziel[7], A. Krasnoperov[20], W. Kucewicz[14], M. Kuich[16], A. Kurepin[19], D. Larsen[13], A. László[8], T.V. Lazareva[22], M. Lewicki[17], B. Lundberg[26], B. Łysakowski[15], V.V. Lyubushkin[20], M. Maćkowiak-Pawłowska[18], B. Maksiak[18], A.I. Malakhov[20], D. Manić[23], A. Marchionni[26], A. Marcinek[11], A.D. Marino[28], K. Marton[8], H.-J. Mathes[5], T. Matulewicz[16], V. Matveev[20], G.L. Melkumov[20], A.O. Merzlaya[22], B. Messerly[29], Ł. Mik[14], G.B. Mills[27], S. Morozov[19,21], S. Mrówczyński[10], Y. Nagai[28], M. Naskręt[17], V. Ozvenchuk[11], V. Paolone[29], M. Pavin[4,3], O. Petukhov[19,21], C. Pistillo[24], R. Płaneta[13], P. Podlaski[16], B.A. Popov[20,4], M. Posiadała[16], R.R. Prado[5], S. Puławski[15], J. Puzović[23], R. Rameika[26], W. Rauch[6], M. Ravonel[25], R. Renfordt[7], E. Richter-Wąs[13], D. Röhrich[9], E. Rondio[12], M. Roth[5], B.T. Rumberger[28], A. Rustamov[1,7], M. Rybczynski[10], A. Rybicki[11], A. Sadovsky[19], K. Schmidt[15], I. Selyuzhenkov[21], A.Yu. Seryakov[22], P. Seyboth[10], M. Słodkowski[18], A. Snoch[7], P. Staszel[13], G. Stefanek[10], J. Stepaniak[12], M. Strikhanov[21], H. Ströbele[7], A. Shukla[30], T. Šuša[3], A. Taranenko[21], A. Tefelska[18], D. Tefelski[18], V. Tereshchenko[20], A. Toia[7], R. Tsenov[2], L. Turko[17], R. Ulrich[5], M. Unger[5], F.F. Valiev[22], D. Veberič[5], V.V. Vechernin[22], M. Walewski[16], A. Wickremasinghe[29], C. Wilkinson[24], Z. Włodarczyk[10], A. Wojtaszek-Szwarc[10], O. Wyszyński[13], L. Zambelli[4], E.D. Zimmerman[28], and R. Zwaska[26]