Charming future of SHINE

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for NA61/SHINE
Goethe University

Tsukuba Workshop
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Outline

- Why open charm is important?
- First measurements in NA61/SHINE 2017-2018
- Precise open charm studies in 2021-2024

Why open charm is important?

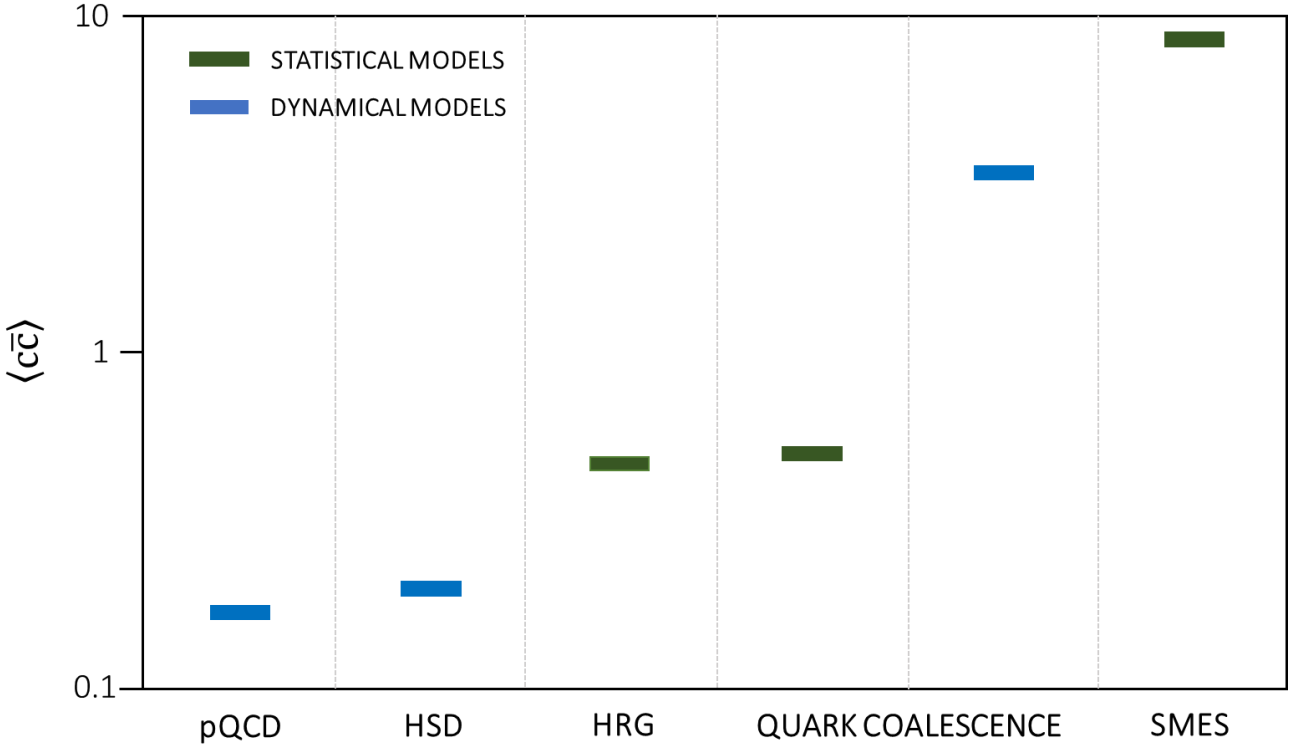
Questions that motivate open charm measurements at the CERN SPS:

- What is the mechanism of open charm production?
- How does the onset of deconfinement impact open charm production?
- How does the formation of quark gluon plasma impact J/ψ production?

To answer these questions **mean number of charm quark pairs, $\langle c\bar{c} \rangle$**, produced in the full phase space in A+A collisions has to be known. Up to now corresponding experimental **data does not exist**.

Models of open charm production

Predictions for $\langle c\bar{c} \rangle$ in central Pb+Pb at 158A GeV/c differ by a factor of about **50**.



pQCD
Gavai *et al.* IJMP A 10 2999.
Braun-Munzinger, J. Stachel, PL B 490, 196.
HSD
Linnyk, Bratkovskaya, Cassing, IJMP E17 1367
HRG, Quark Coalesc. Stat.
Gorenstein, Kostyuk, Stoecker, Greiner, PL B 509, 277.
Quark Coalesc. Dyn.
Levai, Biro, Csizmadia, Csorgo, Zimanyi, JP G 27, 703
SMES
Gazdzicki, Gorenstein, APP B30, 2705.

Charm yield as the signal of deconfinement

$$\textbf{confined matter} \xrightarrow{T_c \approx 150\text{MeV}} \textbf{deconfined matter}$$

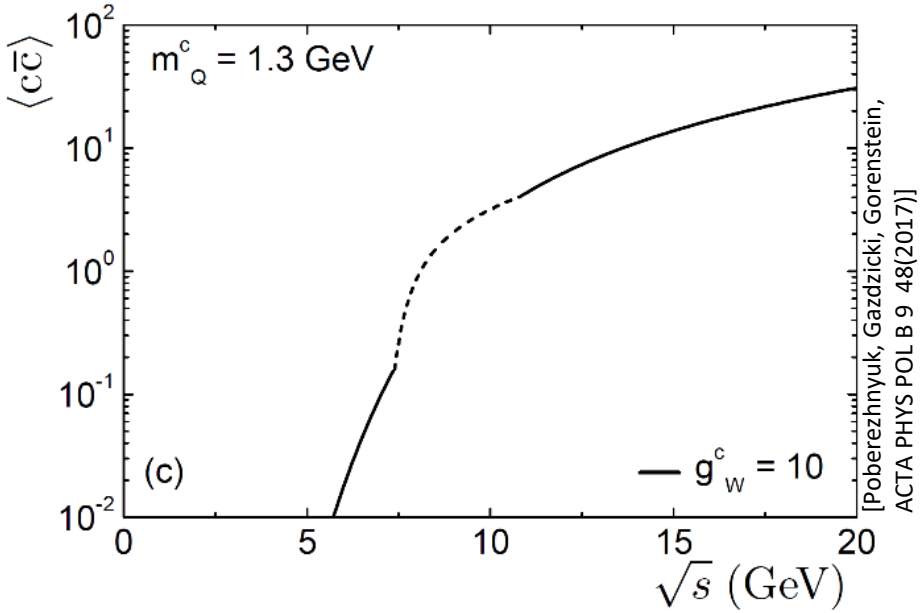
$$\mathrm{D\bar{D}}\ \text{mesons} \rightarrow \text{charm quarks}$$

$$2m_{\mathrm{D}} = 3.7\ \mathrm{GeV} \rightarrow 2m_{\mathrm{c}} = 2.6\ \mathrm{GeV}$$

$$g_{\mathrm{D}} = 4 \rightarrow g_{\mathrm{c}} = 12$$

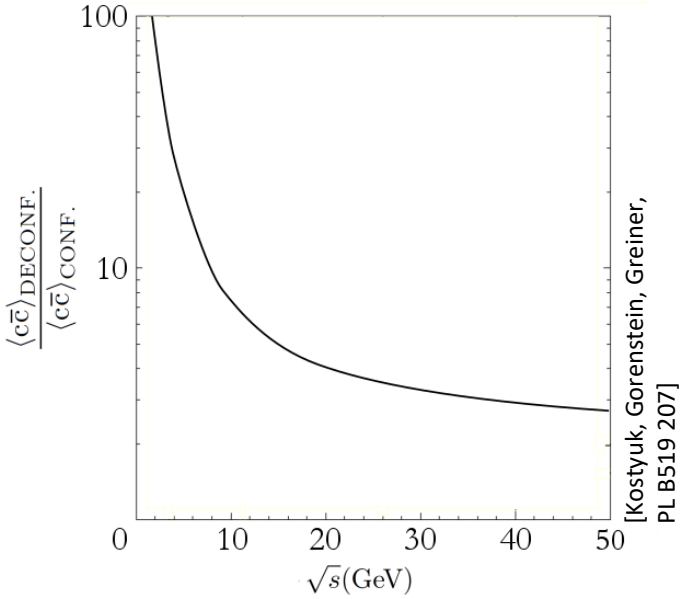
central Pb+Pb collisions

Statistical Model of the Early Stage



[Poberezhnyuk, Gazdzicki, Gorenstein, ACTA PHYS POL B 9 48(2017)]

QCD-inspired calculations

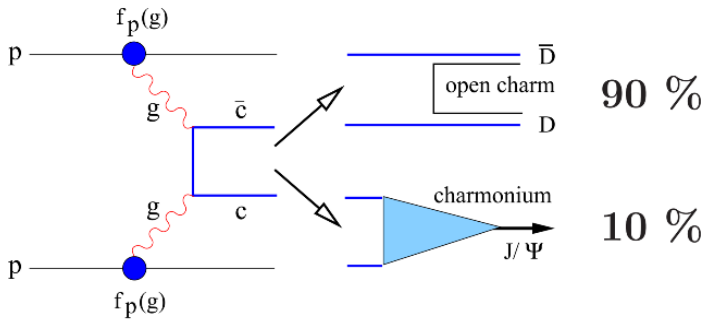


[Kostyuk, Gorenstein, Greiner, PL B519 207]

J/ψ production as the signal of deconfinement

Open charm and J/ψ production within Matsui-Satz model
[PL B178 416]

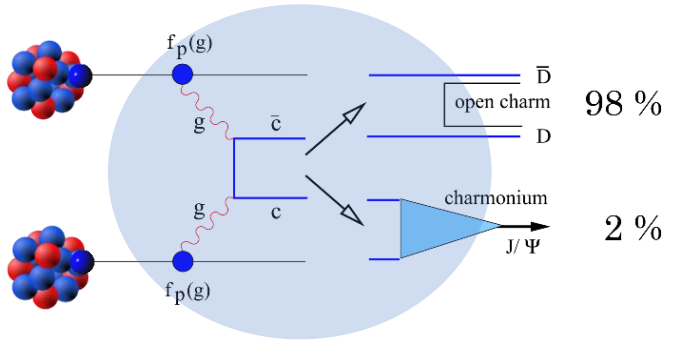
vacuum



90 %

10 %

medium



98 %

2 %

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

$$P_{\text{vacuum}}(c\bar{c} \to J/\psi) \quad > \quad P_{\text{medium}}(c\bar{c} \to J/\psi)$$

Medium reduces probability of J/ψ production

[Satz, Adv. High Energy Phys. 2013 (2013) 242918]

J/ψ production as the signal of deconfinement

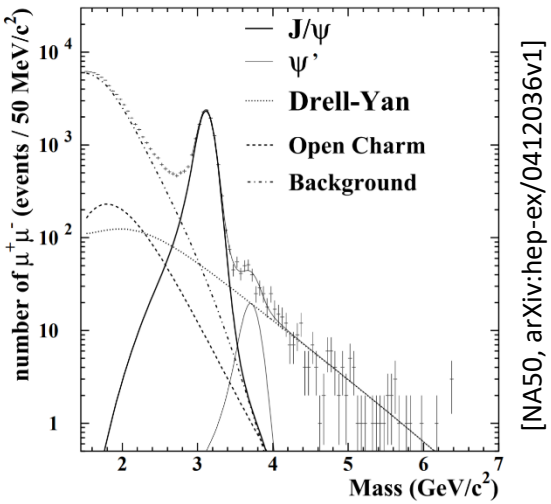
Calculation of $P(c\bar{c} \to J/\psi)$ requires data on:

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

- $\langle J/\psi \rangle$ – precise data at SPS by NA38, NA50, NA60
- $\langle c\bar{c} \rangle$ – not available up to now, NA61 has just started the corresponding measurements

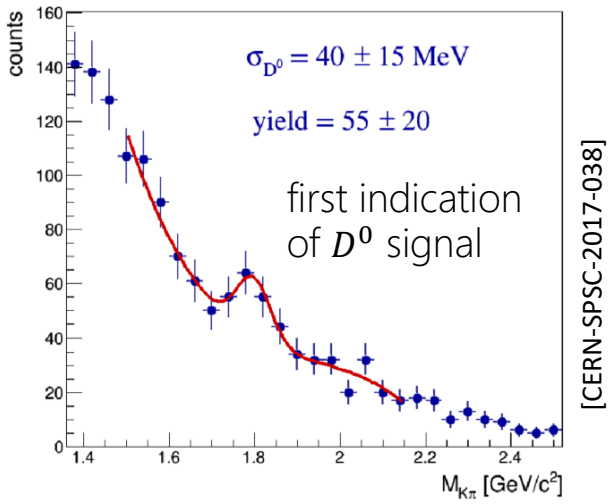
central Pb+Pb at 150-158A GeV/c

NA50



[NA50, arXiv:hep-ex/0412036v1]

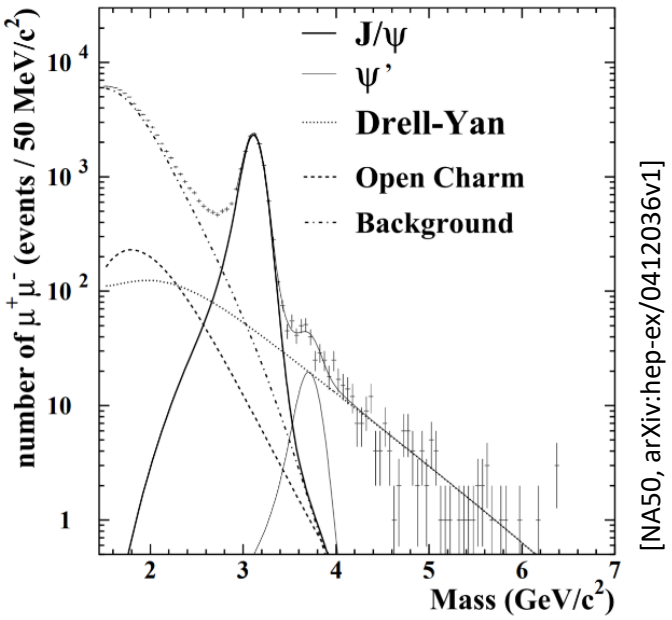
NA61



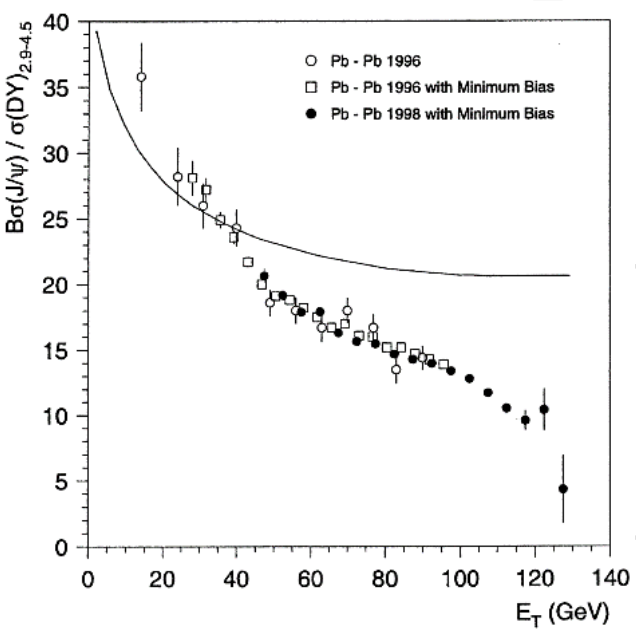
[CERN-SPSC-2017-038]

J/ψ production at the CERN SPS

Data on J/ψ production has been normalized by the Drell-Yan yield



[NA50, arXiv:hep-ex/0412036v1]



[NA50, PL B 477 28–36]

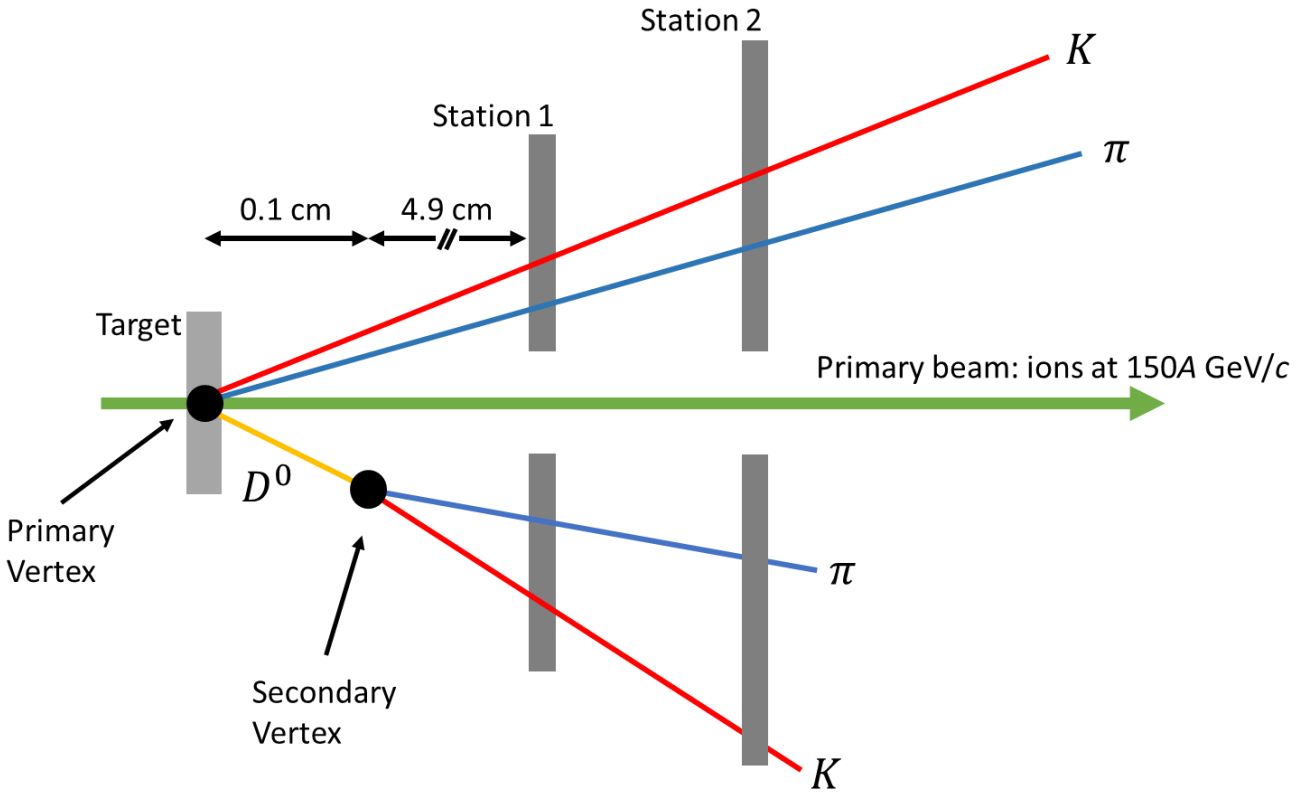
Interpreting these results one frequently assumes:

$\langle c\bar{c} \rangle \sim \langle \mathrm{DY} \rangle$

This assumptions may be incorrect due to many effects:
shadowing, parton energy losses, etc.

First measurements in NA61/SHINE 2017-2018

Open charm measurement concept



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

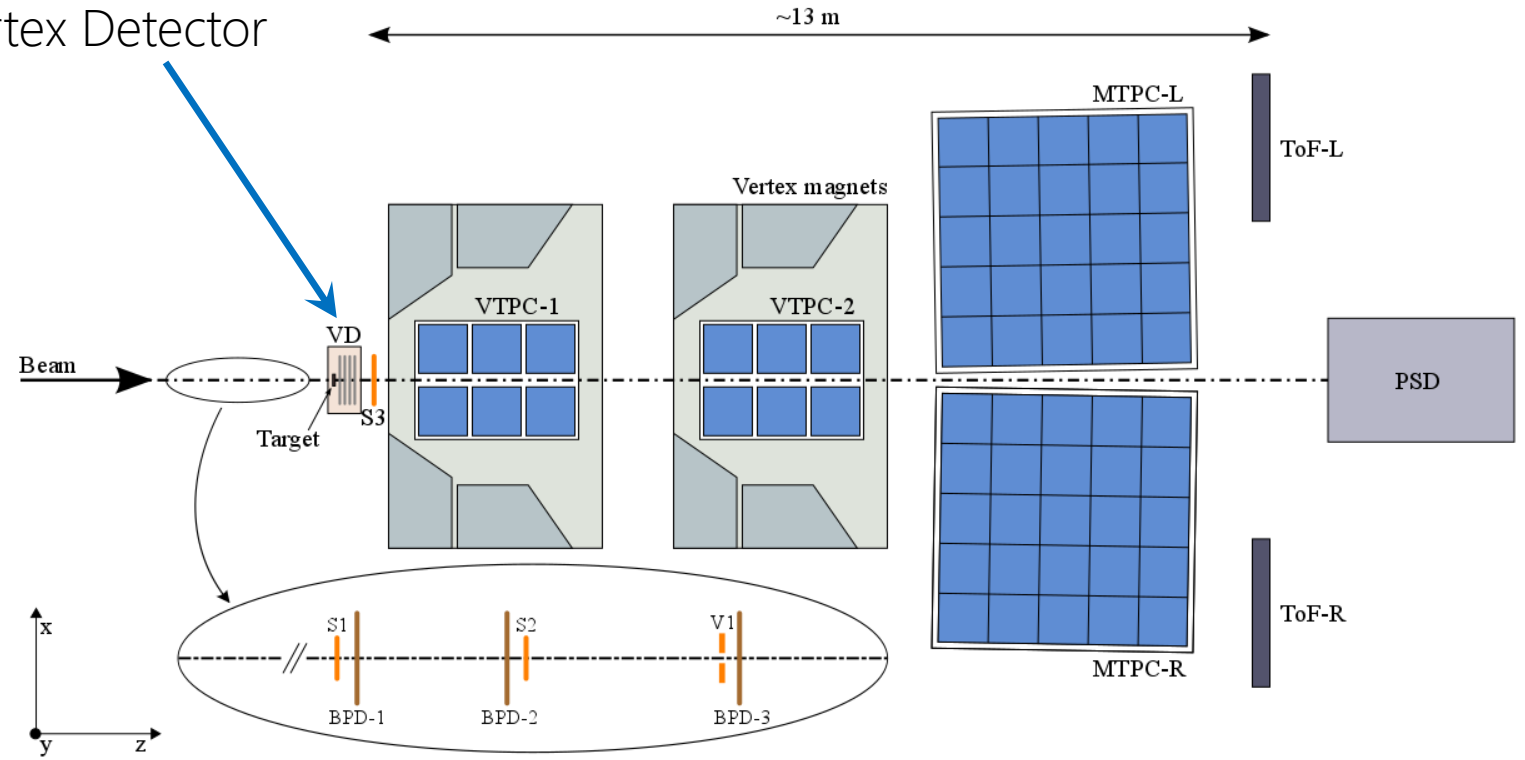
$$\bar{c\tau} \approx 123\ \mu\text{m}$$

$$\text{BR} = 3.89\%$$

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

NA61/SHINE setup

Small Acceptance
Vertex Detector



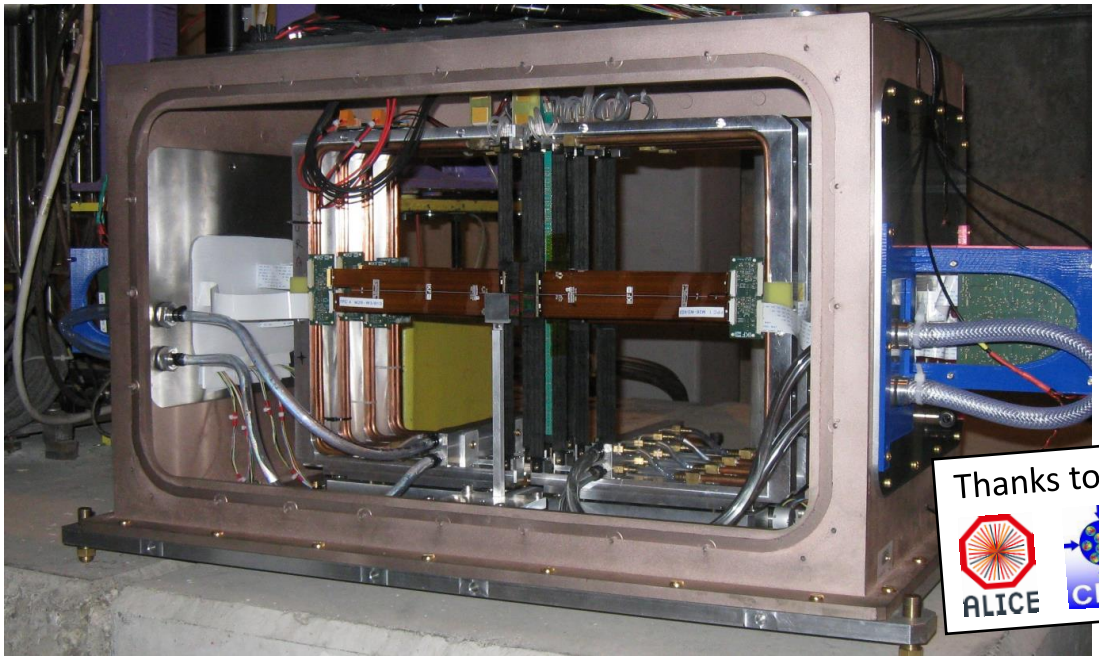
Small Acceptance Vertex Detector

Small Acceptance Vertex Detector introduced in 2016:

- 16 CMOS MIMOSA-26 sensors located on two horizontally movable arms
- target holder integrated

Achieved goals:

- tracking in the large track multiplicity environment
- precise primary vertex reconstruction
- TPC and SAVD track matching
- first search for D^0 and $\overline{D^0}$ signal



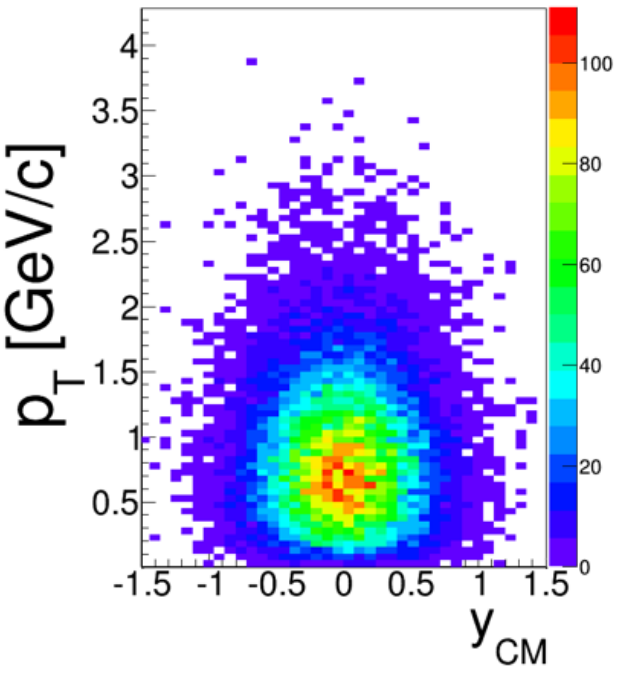
Thanks to:

ALICE CBM IPHC PICSEL Group TRB TRB - collaboration

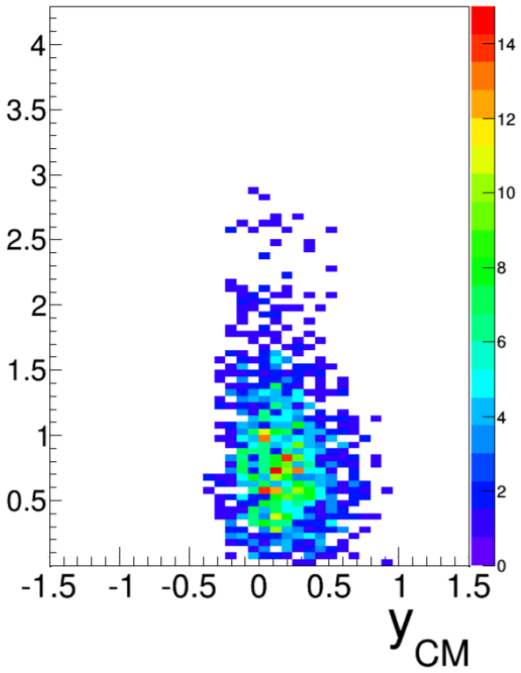
Acceptance of SAVD

AMPT simulation for central Pb+Pb collisions at 150A GeV/c.
SAVD reconstructs 4% out of all $D^0 \rightarrow \pi^+ + K^-$ decays

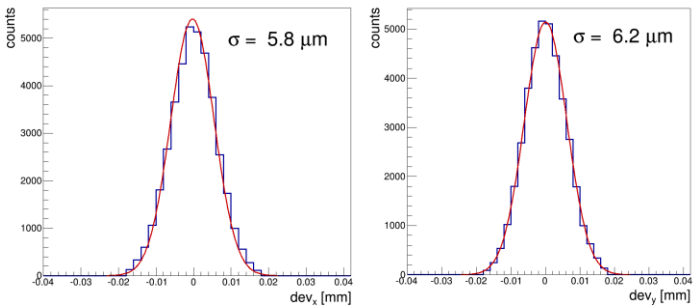
all generated

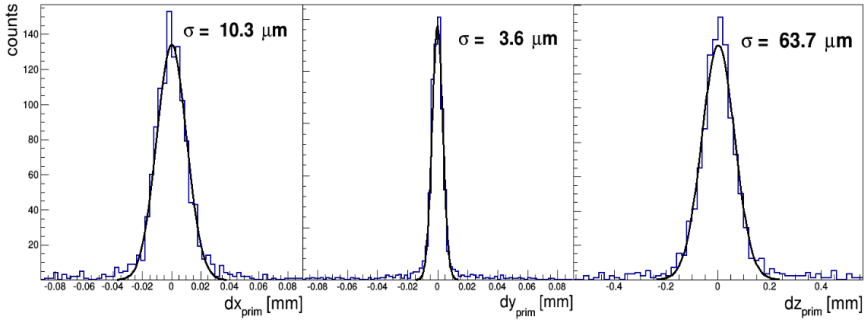


reconstructed



Vertex Detector performance from 2016 data



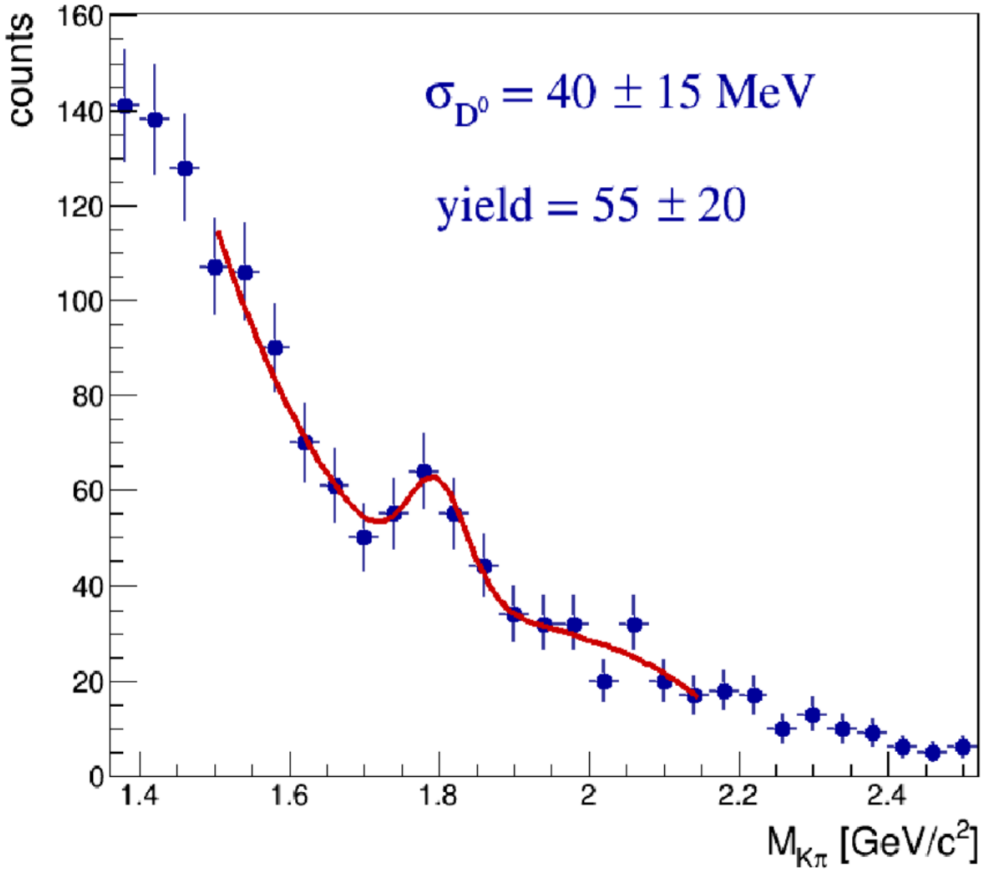


From the analysis of the recorded data one concludes that:

- Cluster position resolution is $\sigma_{x,y}(Cl) \approx 5\ \mu m$
- Primary Vertex resolution is:
  $\sigma_x(PV) \approx 5\ \mu m$,
  $\sigma_y(PV) \approx 1.8\ \mu m$,
  $\sigma_z(PV) \approx 30\ \mu m.$
  ($\sigma_x(PV) > \sigma_y(PV)$ due to $B_y > B_x \approx 0$)

Search for D^0 and $\overline{D^0}$

First indication of D^0 and $\overline{D^0}$ peak

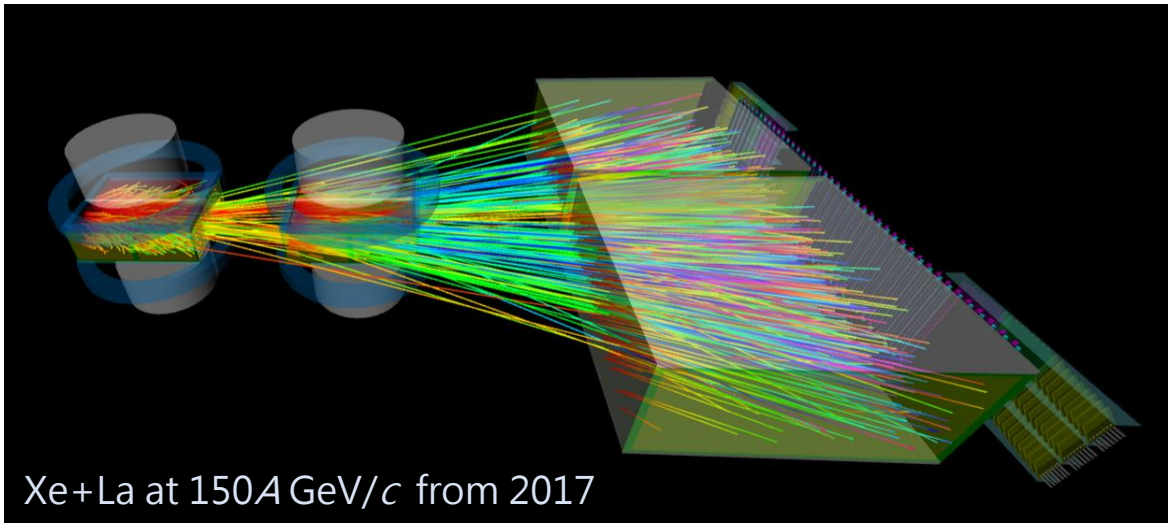


Xe+La 2017 data taking

About 5M events on central Xe+La collisions at 150A GeV/c were recorded at the beginning of November.

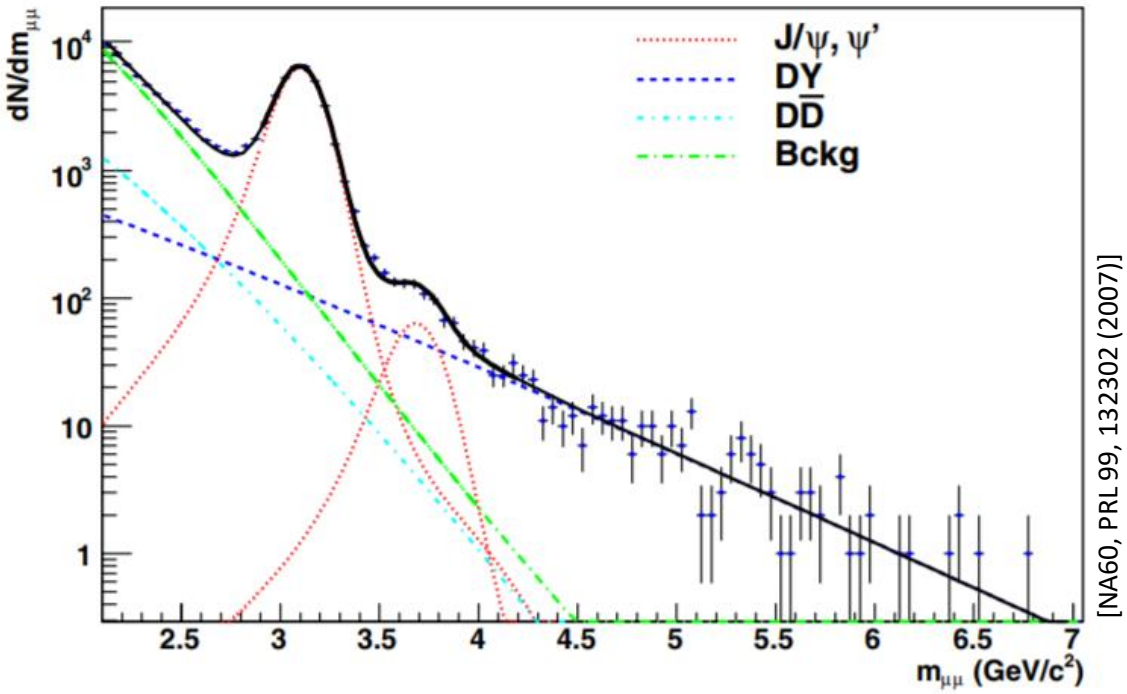
Based on simulations from Pb+Pb and p-QCD inspired system size dependence, one expects several hundred of $D^0 + \overline{D^0}$ meson decays to be reconstructed.

This should allow to obtain the first physics results on open charm production in heavy ion collisions at the CERN SPS.


Xe+La at 150A GeV/c from 2017

Impact of Xe+La data

J/ψ production in In+In ($A = 115$) collisions at 158A GeV/c was precisely measured by NA60.



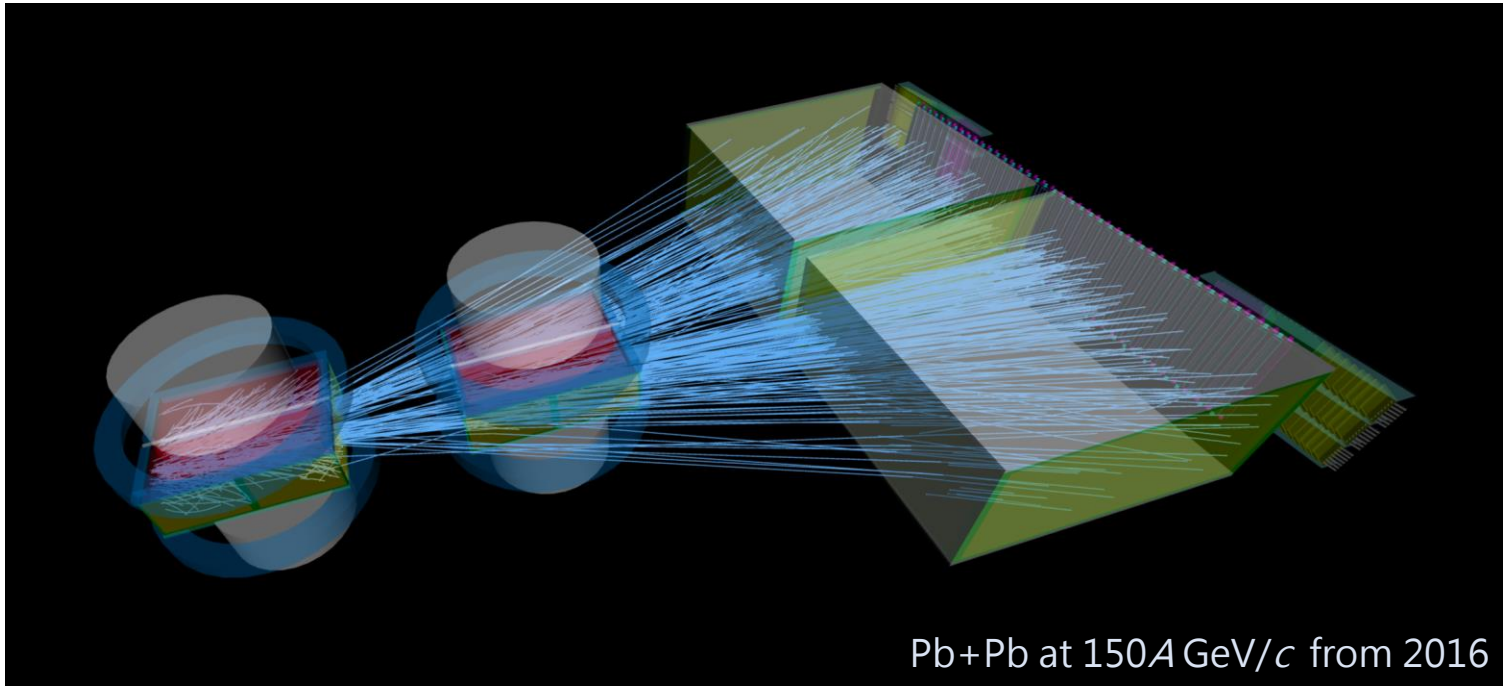
This data together with NA61 results on open charm production in Xe+La ($A = 129$, $A = 139$) collisions at 150A GeV/c will strongly challenge theoretical models.

Pilot data on Pb+Pb at 150A GeV/c in 2018

Data taking in 2018 on central Pb+Pb collisions for open charm measurement recommended by CERN SPSC in October 2017.

Three weeks of data taking:

- 10M central collisions recorded
- 4000 D^0 and $\overline{D^0}$ decays is expected to be reconstructed



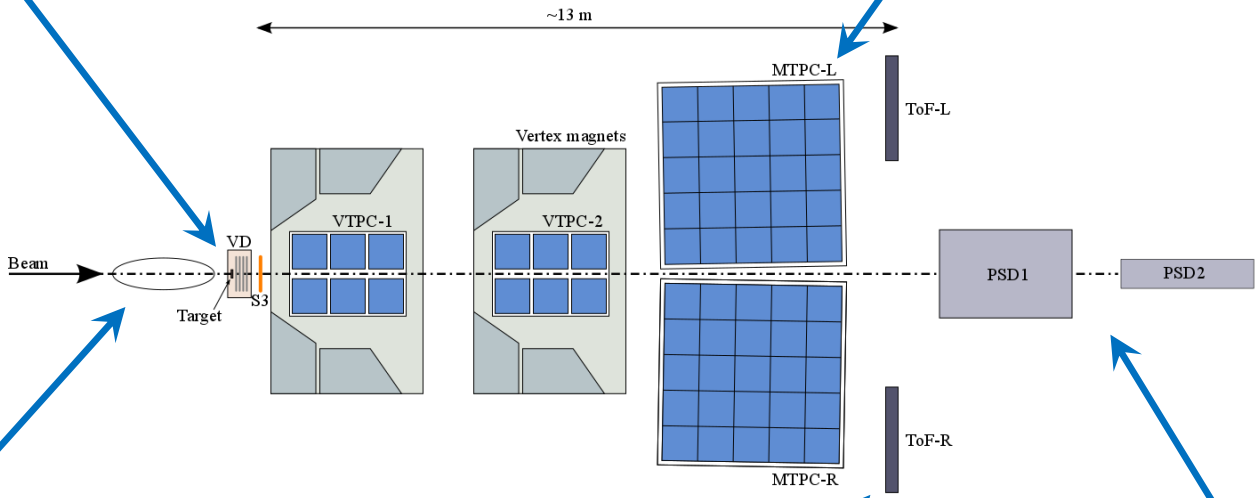
Pb+Pb at 150A GeV/c from 2016

Precise open charm studies in 2021-2024

Upgrades of NA61/SHINE setup

Construction of Large Acceptance Vertex Detector (LAVD)
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

Large Acceptance Vertex Detector

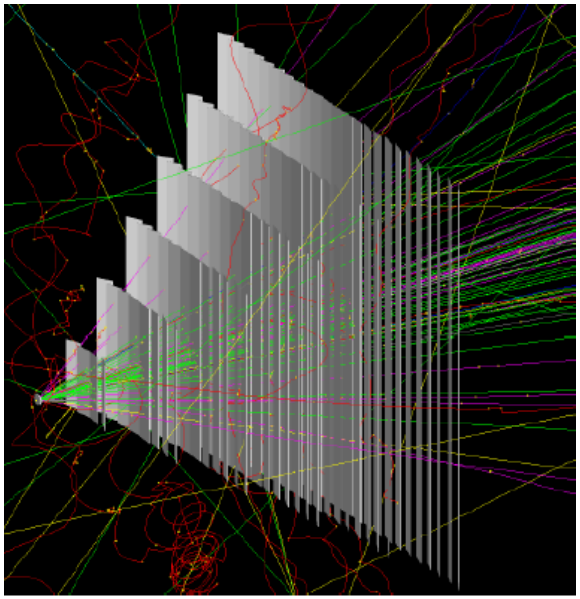
General requirements:

- Precise vertex measurement
- Fast detectors with high granularity
- The low material budget
- Large acceptance

Technology developed for ALICE ITS:

- CMOS ALPIDE pixel sensors
- Carbon fiber support structure
- Read-out electronics

6 stations with about 200 sensors



Beam request for 2021-2024

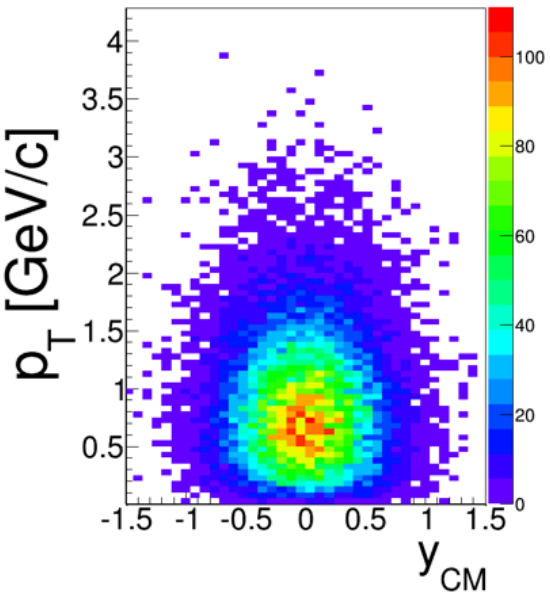
Year	Beam	Duration	Purpose	$D^0 + \overline{D^0}$ stat.
2021	p at 150 GeV/c	4 weeks	detector tests	
2022	Pb at 150A GeV/c	2 weeks	charm in central collisions	40k
2022	Pb at 150A GeV/c	4 weeks	charm in peripheral collisions	8k
2023	Pb at 150A GeV/c	2 weeks	charm in mid-central collisions	20k
2024	Pb at 40A GeV/c	4 weeks	charm in central collisions	2k

Performance for open charm measurements

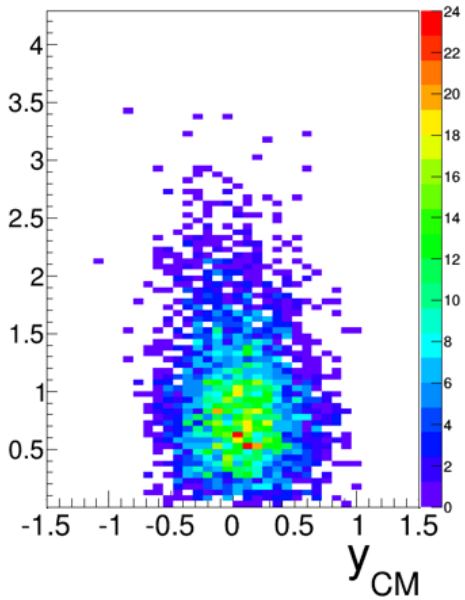
Two weeks in 2022 (1kHz + LAVD) ≈ $\mathbf{40\,000}$ $D^0 + \overline{D^0}$ decays reconstructed in 40M central Pb+Pb collisions at 150A GeV/c

LAVD reconstructs 12% out of all $D^0 \to \pi^+ + K^-$ decays.

all generated



reconstructed

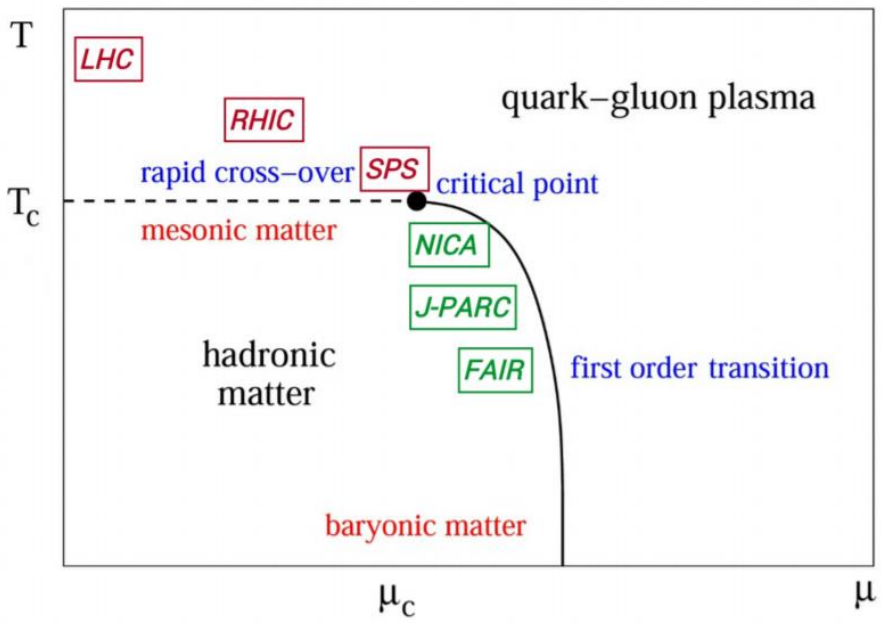


Based on AMPT one estimates that fully corrected results will cover most of the phase space.

Total systematic uncertainty of $\langle D^0 \rangle$ and $\langle \overline{D^0} \rangle$ is expected to be about 10%.

Uniqueness of NA61 open charm program

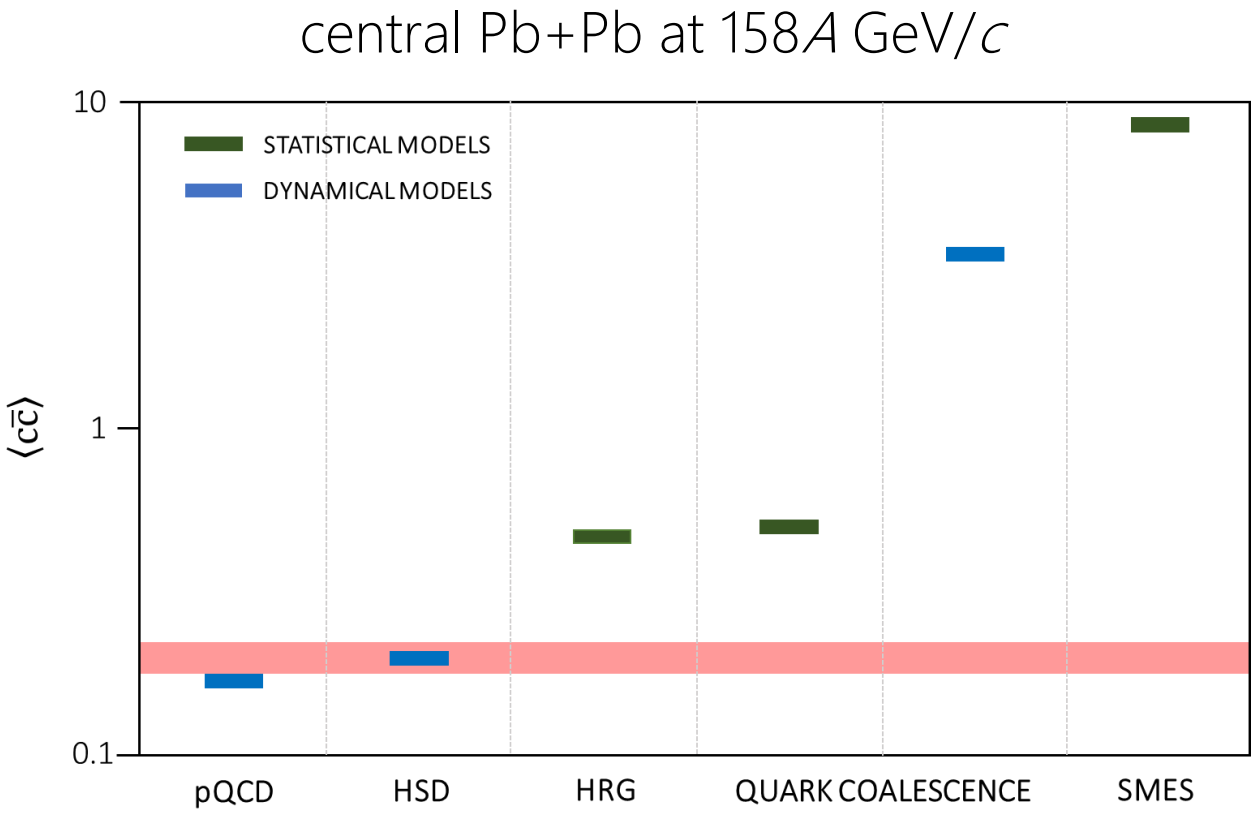
Landscape of present and future heavy ion experiments



Only NA61/SHINE is able to measure open charm production in heavy ion collisions in full phase space in the near future.

- LHC and RHIC at high energies: measurements in small phase space due to collider geometry and kinematics
- RHIC BES collider: measurement not possible due to collider geometry and kinematics
- RHIC BES fixed-target: measurement require dedicated setup, not under consideration
- NICA (< 80*A* GeV/*c*): measurement during stage 2 under consideration
- J-PARC (< 20*A* GeV/*c*): maybe possible after 2025
- FAIR (< 10*A* GeV/*c*): not possible

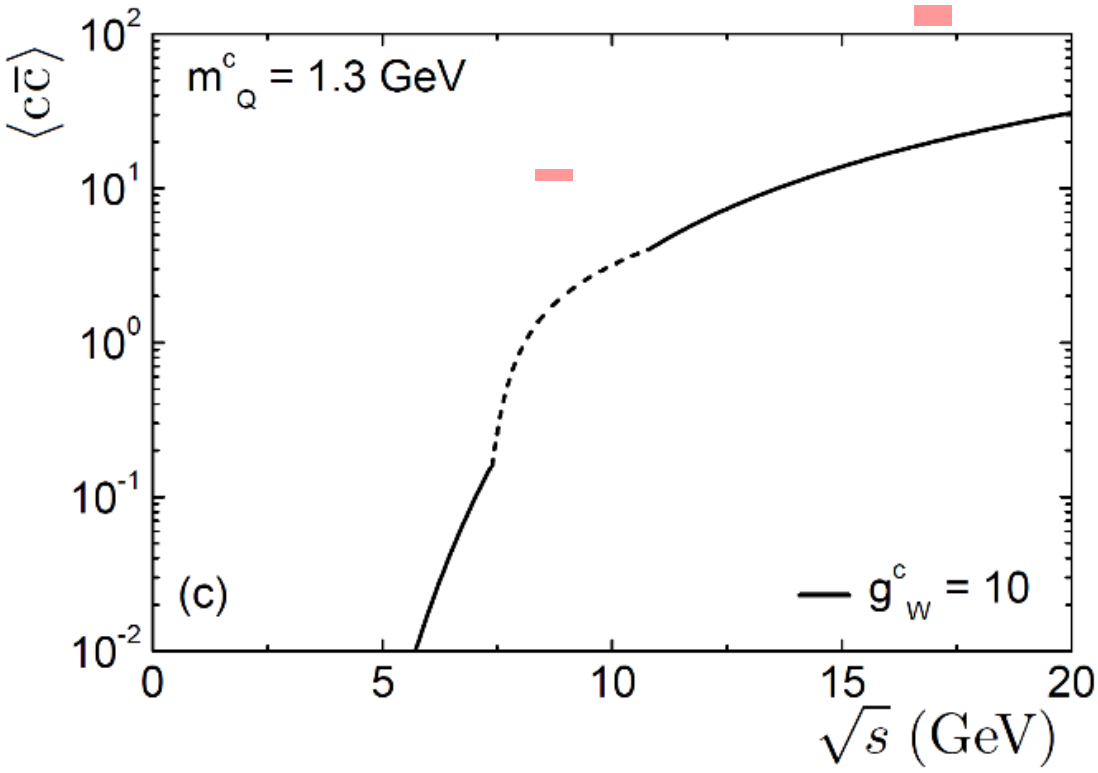
Impact of open charm measurements



accuracy of NA61 2020+ result assuming HSD yield

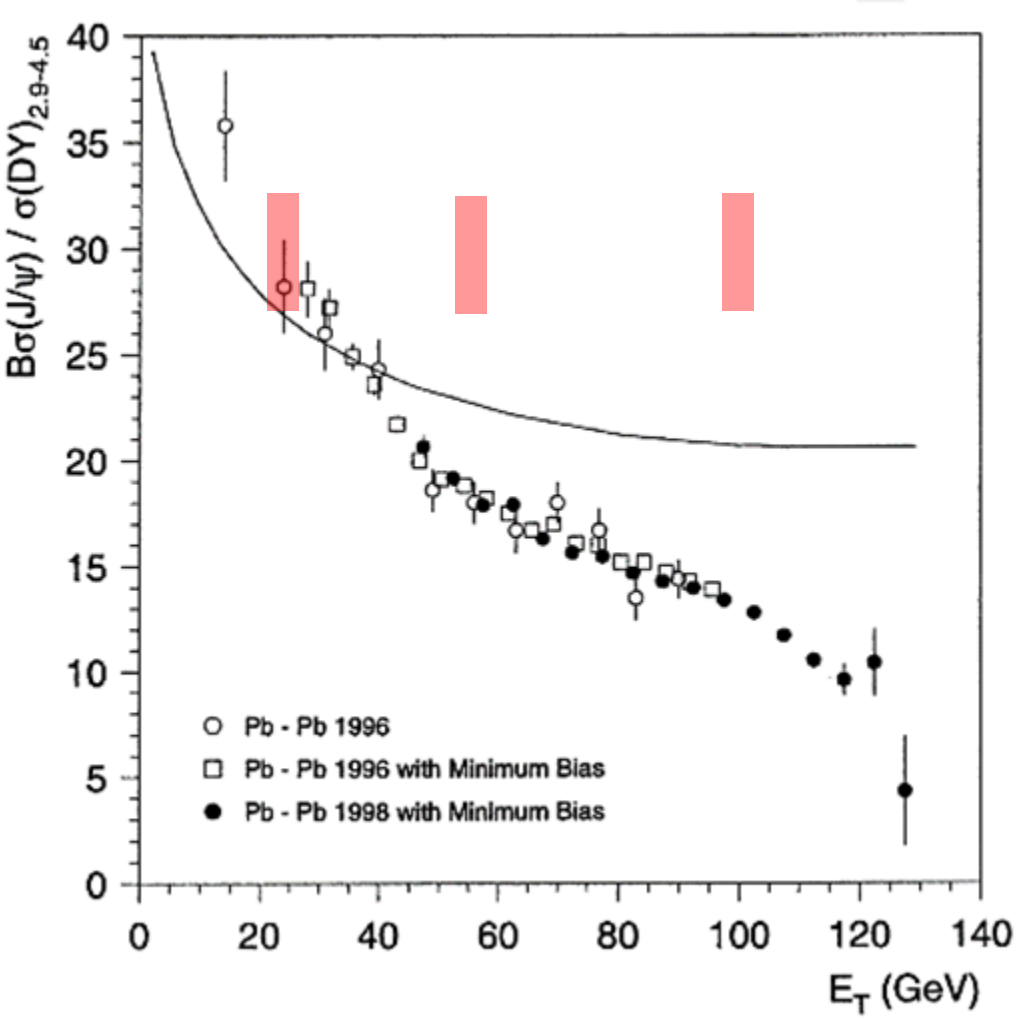
Impact of open charm measurements

central Pb+Pb at 158*A* GeV/*c*



accuracy of NA61 2020+ result assuming SMES yield

Impact of open charm measurements



Pb+Pb at 158A GeV/c

- $\langle J/\psi \rangle / \langle c\bar{c} \rangle$ accuracy of NA61 2020+ result assuming
  $\langle c\bar{c} \rangle \sim \langle \pi \rangle$
  and scaling to
  $\langle J/\psi \rangle / \langle \mathrm{DY} \rangle$
  for peripheral collisions

Summary

NA61 charm program addresses following questions:

- What is the mechanism of open charm and J/ψ production?
- How does the onset of deconfinement impact open charm production?
- How does the formation of quark gluon plasma impact J/ψ production?

To answer these questions mean number of charm quark pairs produced in heavy ion collisions will be measured in 2017-2018 and in 2021-2024.

Only NA61/SHINE can perform this measurement in the near future.

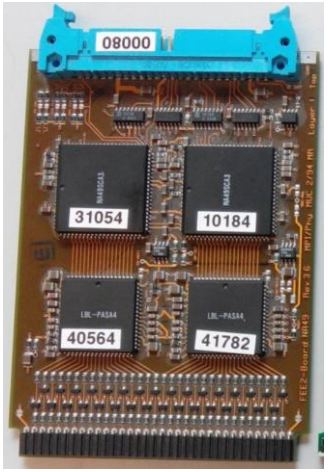
Backup slides

Replacement of the TPC electronics

Will increase the read-out rate by a factor of about 10 (up to 1 kHz)

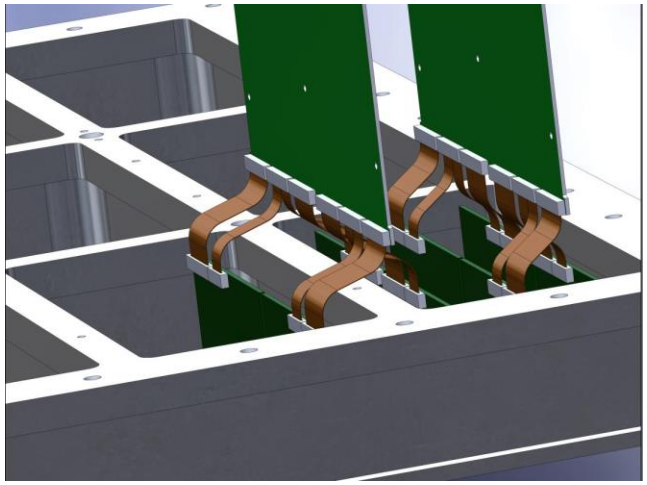
ALICE will transfer to NA61/SHINE its present TPC electronics that will be replaced during the long shutdown LS2

Present NA61
Front-End Card



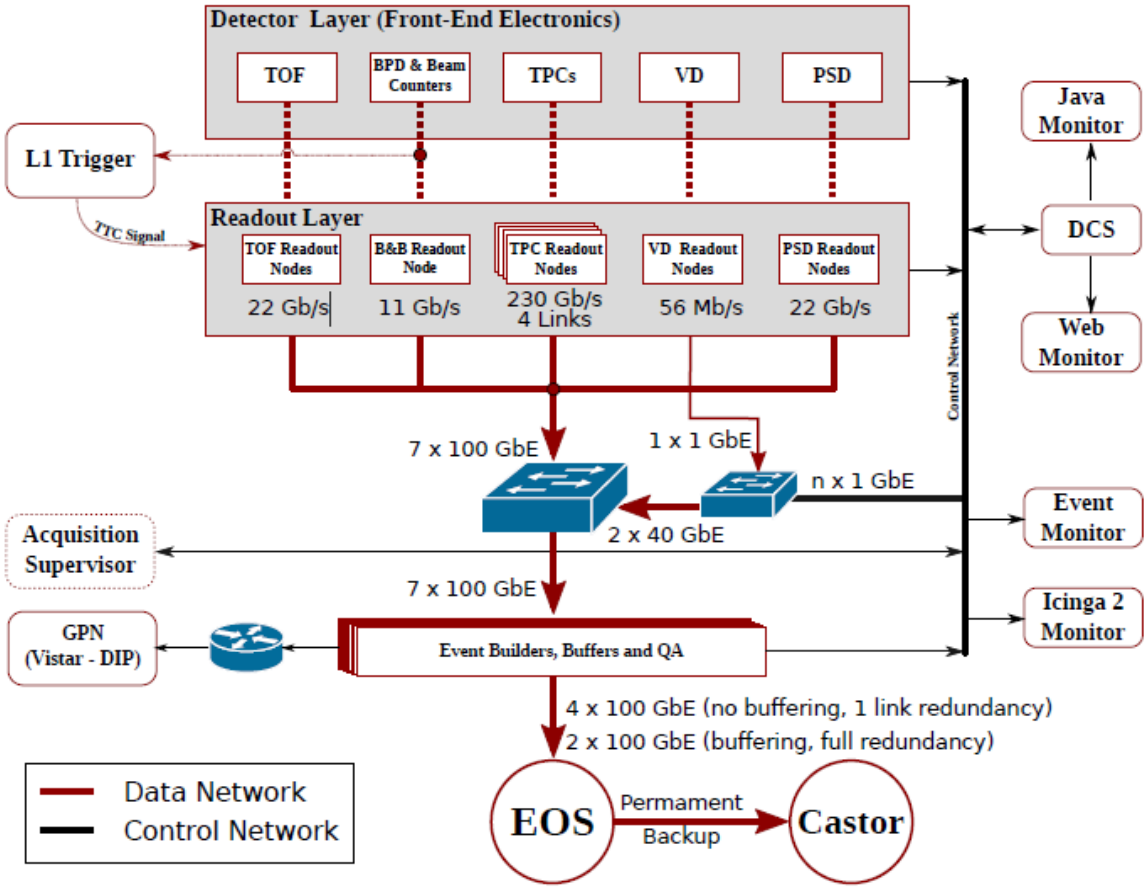
ALICE
Front-End Card

ALICE
Front-End Card
on NA61 TPC

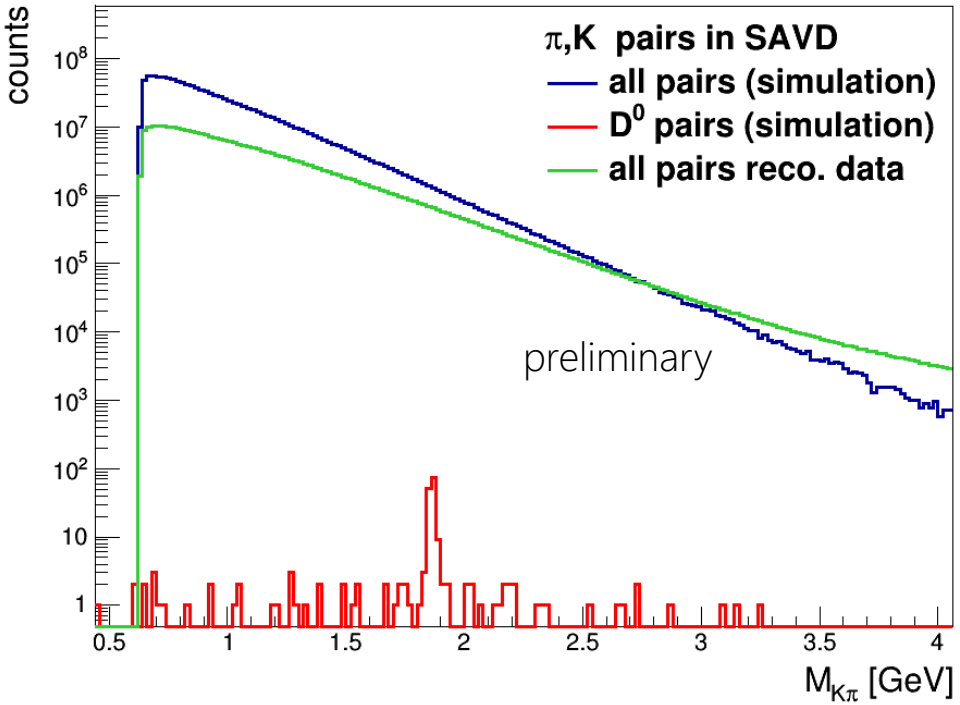


Upgrade of the trigger and data acquisition

Need for 1kHz readout frequency



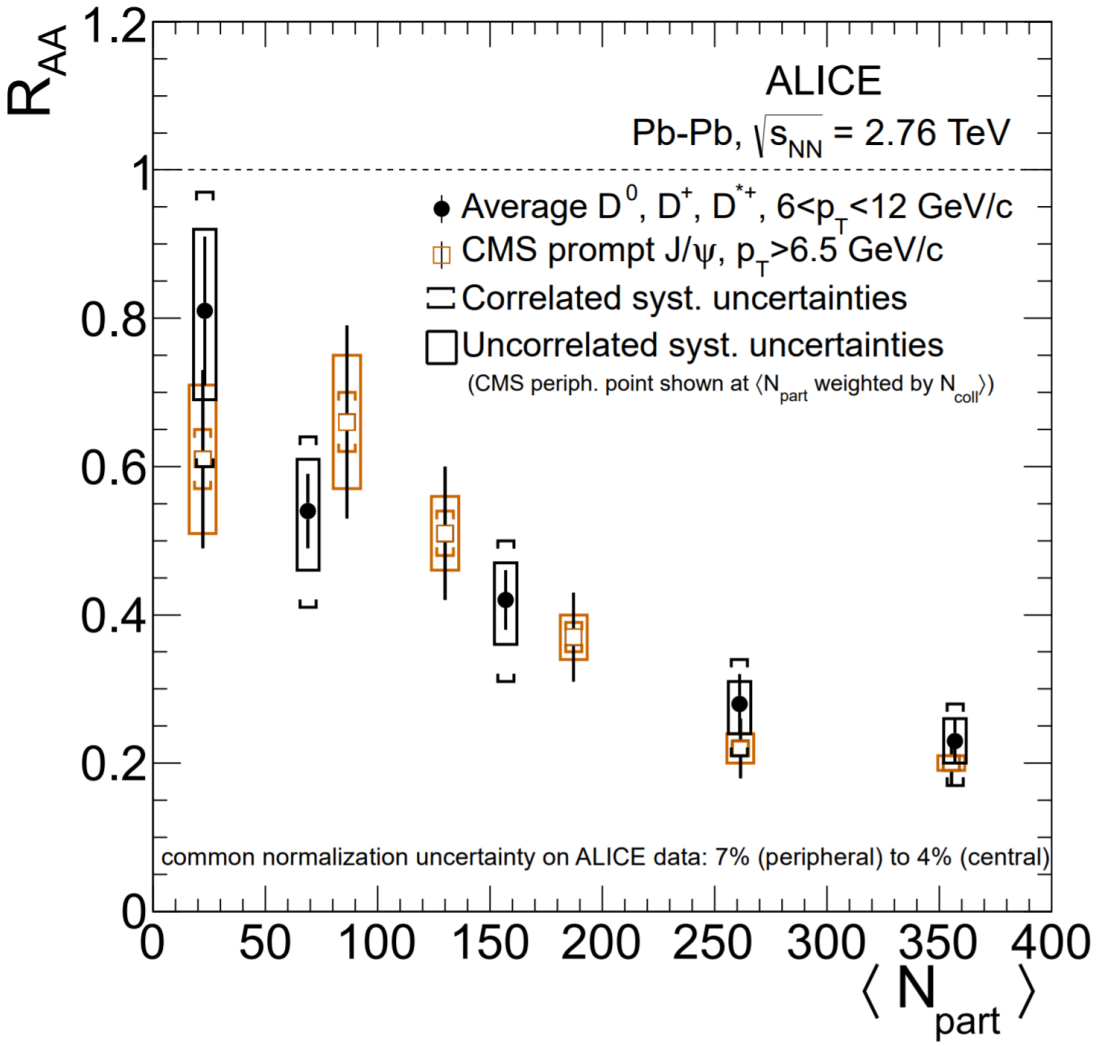
Search for D^0 and $\overline{D^0}$



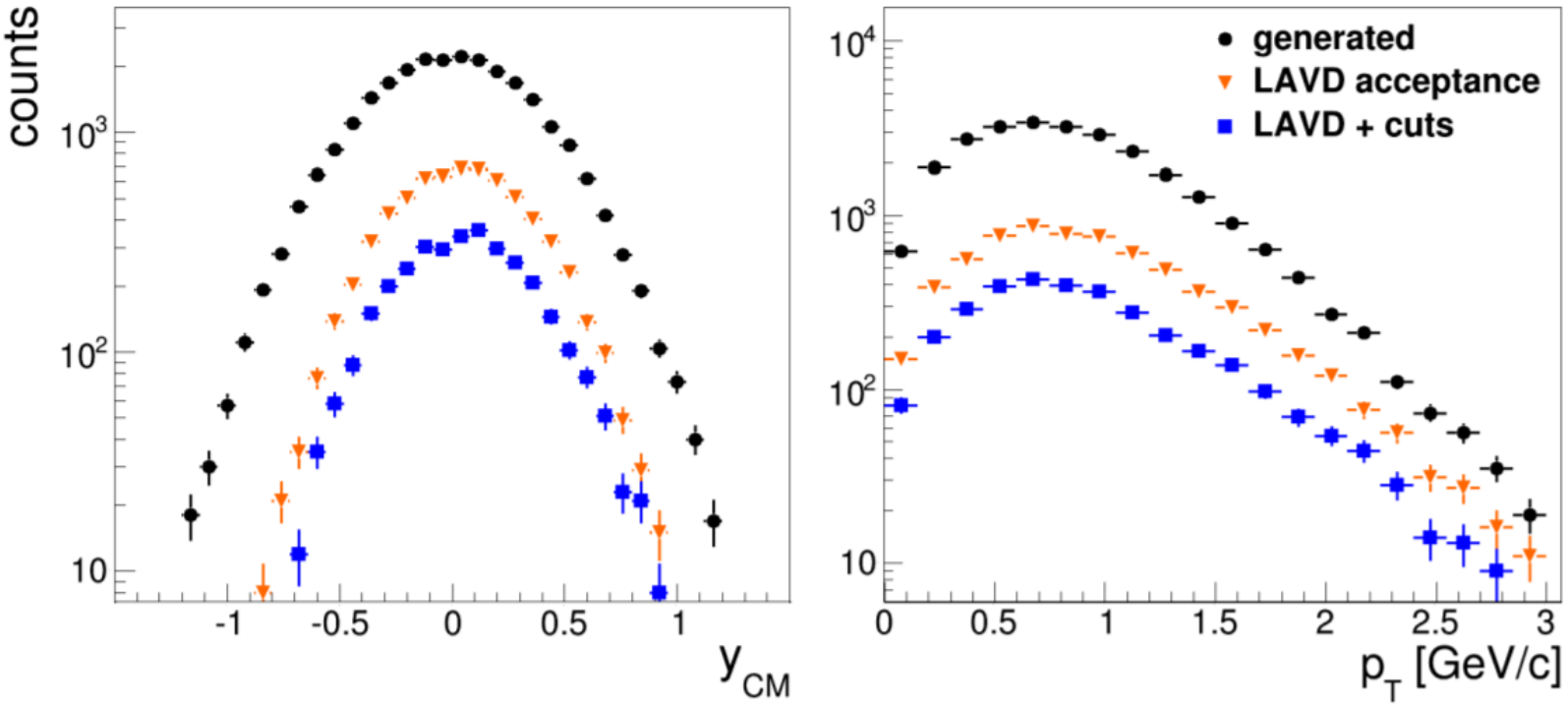
Huge combinatorial background is suppressed by cuts on:

- track transverse momentum
- track impact parameter
- longitudinal distance between secondary and primary vertices
- pair impact parameter

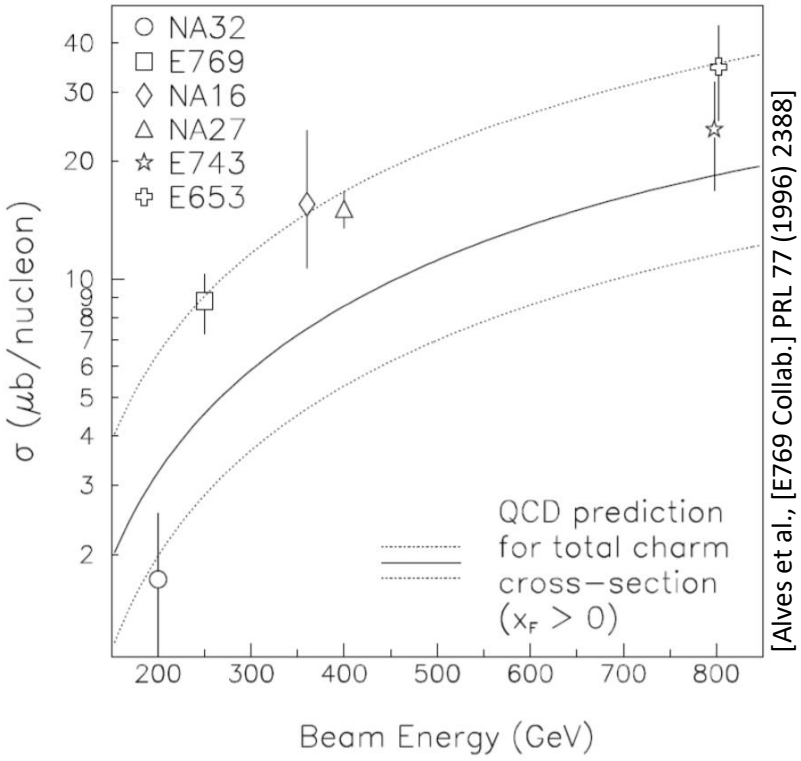
LHC open charm and J/ψ



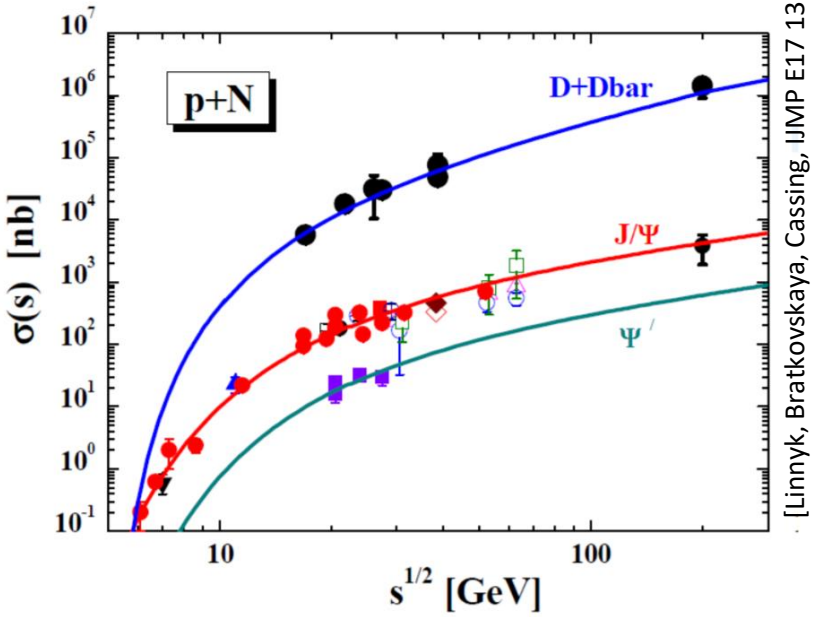
LAVD acceptance



Charm in h+A collisions

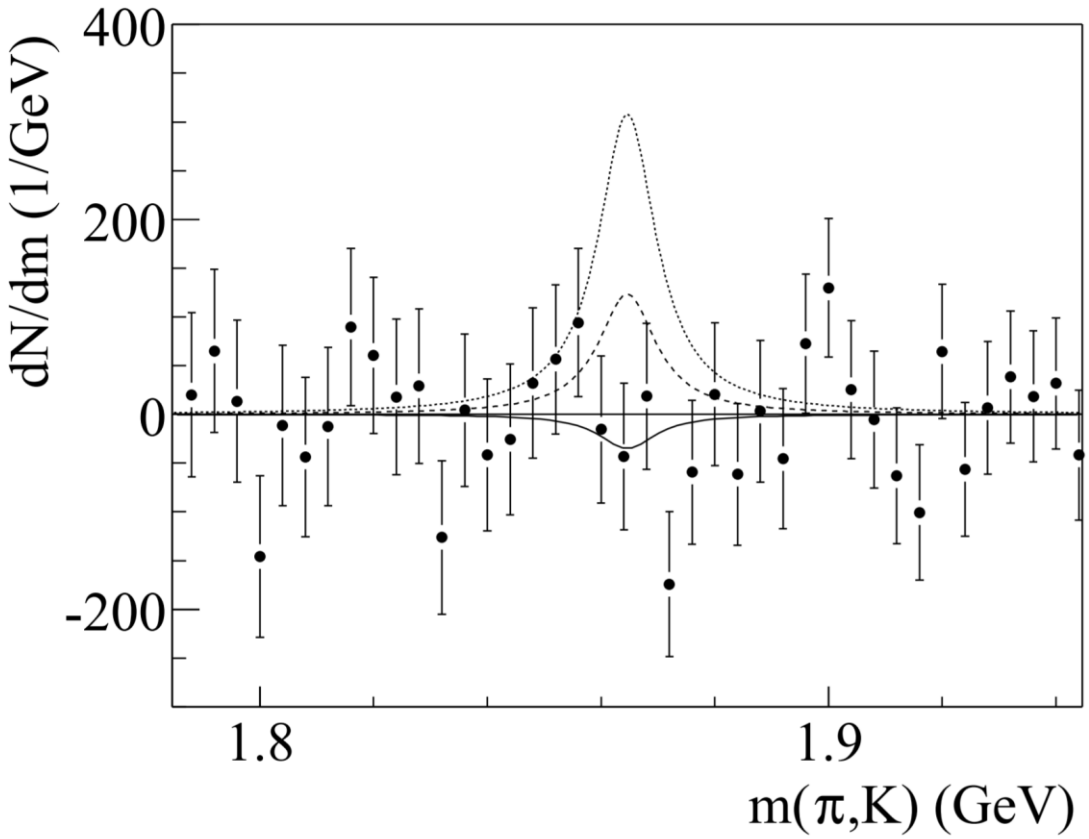


[Alves et al., [E769 Collab.] PRL 77 (1996) 2388]

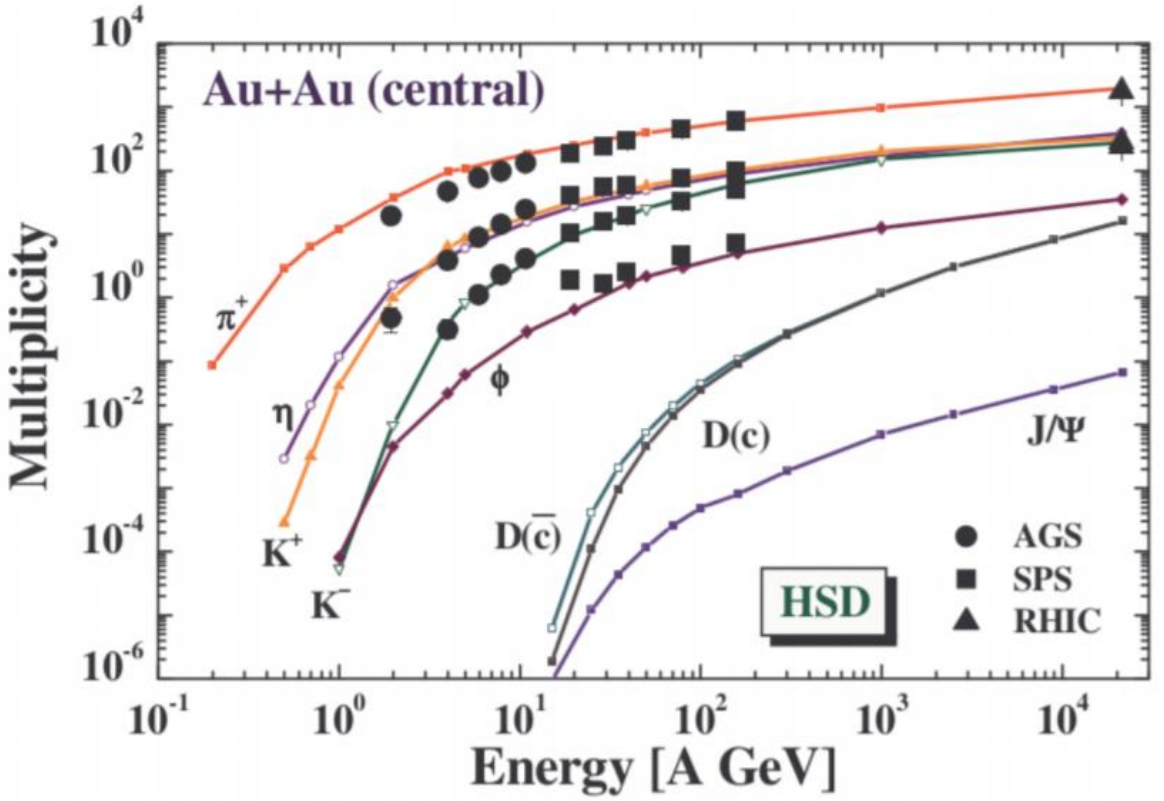


[Linnyk, Bratkovskaya, Cassing, IJMP E17 1367]

NA49 open charm upper limit



HSD predictions



[Linnyk, Bratkovskaya, Cassing, IJMP E17 1367]

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 dpx and dpz

Matching with TPC provides: momenta and PID to VD tracks
→ invariant mass distribution