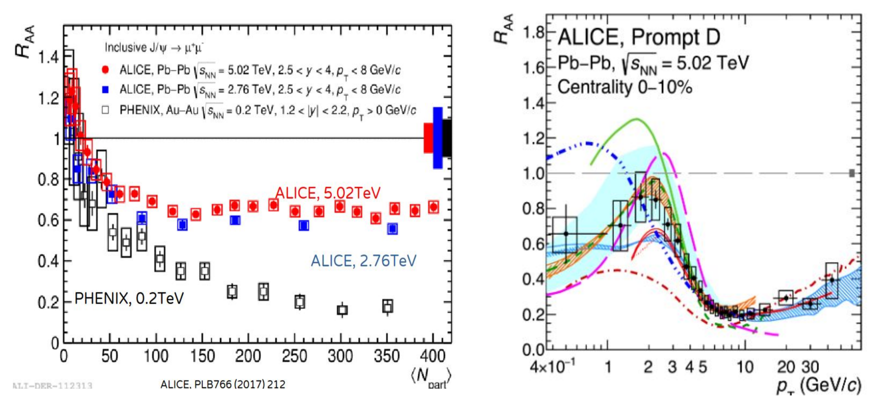
OPEN HEAVY-FLAVOUR AND QUARKONIUM MEASUREMENTS WITH NA60+

Heavy ions at high energy: RHIC and LHC



Extensively measured → unprecedented insight on QGP properties at low μ_B

Open heavy flavour and quarkonium as probes of the quark gluon plasma

Heavy ions at low energy: fixed target experiments

open charm

very few results

- indirect open charm measurement by NA60 with 20% uncertainty ($1 < M_{\mu\mu} < 2.5$ GeV/c^2)
- upper limit on D^0 by NA49

quarkonium

many results for J/ψ, ψ(2S) by NA50/60, but only at top SPS energy

NEW high precision open and hidden charm measurements would allow to

- probe the medium at lower T wrt collider experiments
- explore a non-zero μ_B region

new experiment proposed at CERN SPS: NA60+

Goals in the heavy quarks sector

high precision measurements of

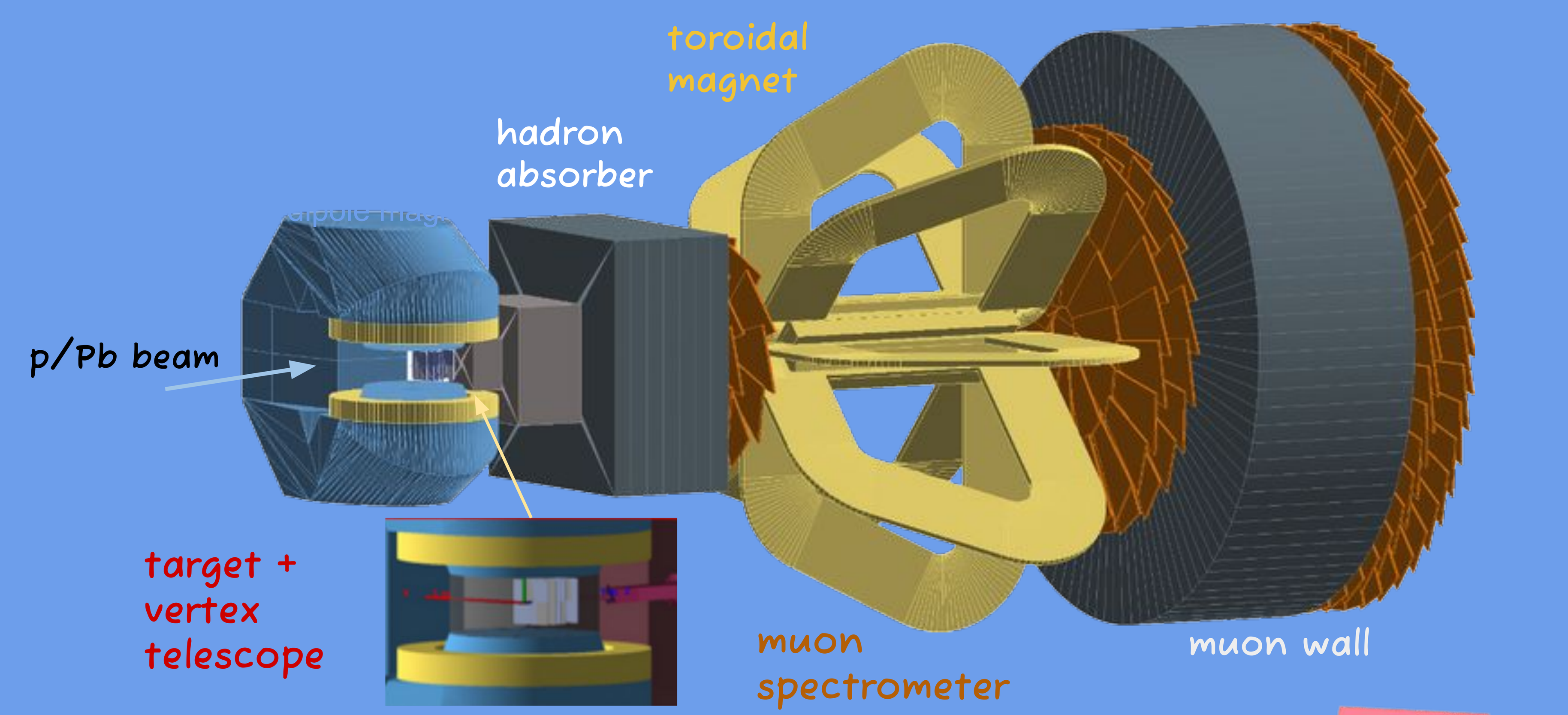
- dimuon spectrum from threshold to the charmonium mass region
- hadronic decays of charm and strange hadrons

Setup

- Muon spectrometer
- Vertex spectrometer

Energy/systems

- Pb-Pb and p-A collisions
- energy scan $6 < \sqrt{s} < 17$ GeV/c ($20 < E_{lab} < 158$ GeV/c)
- high luminosity ~10^6 Pb/s



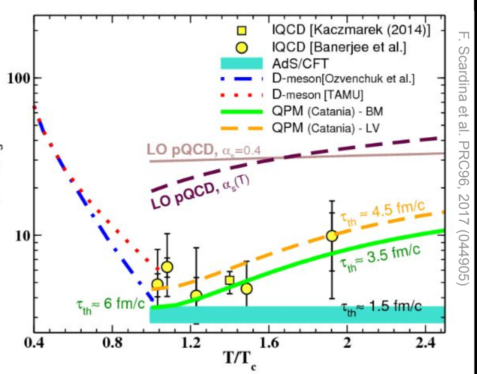
Open charm at low $\sqrt{s}$

1. QGP transport properties

Charm diffusion coefficient depends on T, being larger in the hadronic than in QGP phase

At SPS

- temperatures closer to T_{PC} can be explored
- hadronic phase is a large part of the collision evolution → sensitivity to hadronic interactions



2. hadronisation mechanisms

Measure the relative abundances of charm-hadrons (D^0, D^+, D^+_s mesons and Λ_c baryons) at high μ_B

- Strange/non-strange meson ratio (D_s/D^0) → enhanced in AA due to recombination in the strangeness rich QGP
- Baryon/meson ratio (Λ_c/D) → enhanced in AA in case of hadronisation via coalescence

3. charm thermalization

Impact on charm of a shorter-lived medium

- current measurements on HF-decay electron v_2 at RHIC $\sqrt{s_{NN}}$ = 39 and 62 GeV/c show small v_2 wrt 200 GeV, not conclusive on v_2>0

4. total charm cross section

Measurements so far (NA60,NA49) limited by low yields

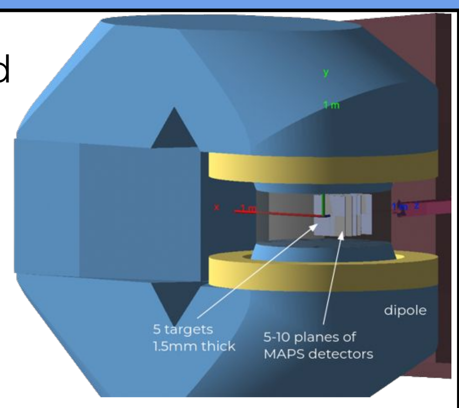
- precise measurement requires to reconstructs mesons and baryons ground states
- ideal reference for charmonia

How to measure open charm in NA60+

Measured through hadronic decays reconstructed in the vertex telescope

Fast simulation:

1) D-meson signal: simulated with p_T and y distributions from POWHEG-BOX + PYTHIA
Combinatorial background: π, K, p with NA49, p_T, y, multiplicity shapes
2) Particle transport: carried out in the VT, with parametrized simulation of its resolution
Track reconstruction: Kalman filter
3) D-meson vertex reconstructed from decay tracks
Combinatorial background reduced via geometric selection on displaced decay vertex topology



	Mass (MeV)	cτ (μm)	decay	BR
D^0	1865	123	$K^-\pi^+$	3.95%
D^+	1869	312	$K^-\pi^+\pi^+$	9.38%
D^+_s	1968	147	$\phi\pi^+$	2.24%
Λ_c	2285	60	$pK^-\pi^+$ pK^0_s $\Lambda\pi^+$	6.28% 1.59% 1.30%

D^0 in central PbPb:
initial S/B ~10^{-7} → after selections S/B ~0.5

Open charm performance studies

$D^0 \to K\pi$

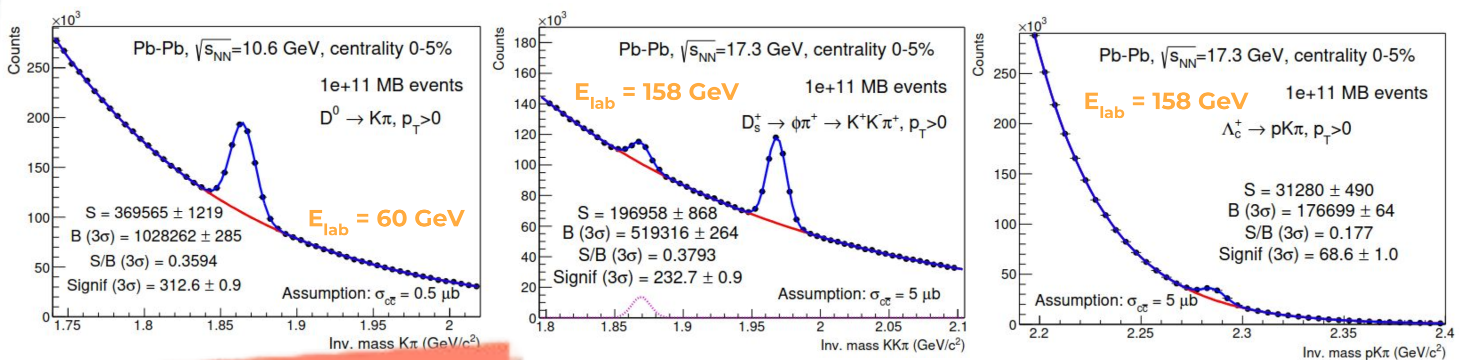
3 10^6 D^0 in Pb-Pb 0-5%, $\sqrt{s_{NN}}$=17.3 GeV
→ R_{AA} and v_2 vs p_T, y and centrality accessible also at lower $\sqrt{s_{NN}}$ with ~1% statistical precision

$D_s \to \phi\pi \to KK\pi$

measurement of yields feasible, statistical precision of few percent

$\Lambda_c \to pK\pi$

accessible, possible improvement with timing layers under study



NA60+: new experiment proposed at CERN SPS

https://na60plus.ca.infn.it/

- Complete coverage of em and hard probes
- Project is part of CERN Physics Beyond Collider Initiative
- LOI in 2022 → arXiv:2212.14452
- Expect proposal in 2024
- Aim is taking data in 2029, after LHC long shutdown 3

Quarkonium at low $\sqrt{s}$

Cold and hot matter effects

LHC/RHIC		SPS
Hot matter effects		
suppression and regeneration	→	suppression
Initial state effects		
mainly shadowing $10^{-5} < x_{BJ} < 10^{-2}$ for $-3 < y < 3$	→	(anti)shadowing x_{BJ} ~ 10^{-1} for y~0
Final CNM effects		
negligible → short crossing time τ=L/($\beta_z\gamma$)~ 7 10^{-5} (y~3) - 4 10^{-2} (y~-3) fm/c	→	sizable breakup in nuclear matter τ~0.5 fm/c for y~0

1. AA: hot matter effects

Onset of charmonium suppression, accessible via energy scan

- evaluate the charmonium melting threshold T correlating the onset with temperature measured via thermal dimuons

2. pA: cold nuclear matter effects

Role of initial and final CNM effects and their $\sqrt{s}$ dependence

- CNM effects increase at low $\sqrt{s}$ → they have to be studied at the same $\sqrt{s}$ as AA, for a correct evaluation of hot matter effects
- Possibility to disentangle the various contributions (shadowing, nuclear breakup...)

3. pA: intrinsic charm

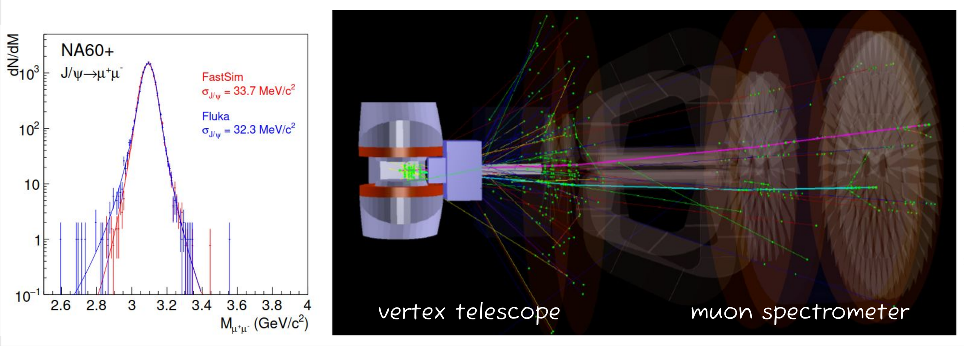
Role of intrinsic charm

- enhanced charm production expected at large x_F
- fixed target is the ideal configuration → enhancement closer to mid-y
- dominant effect even with 0.1% probab. of intrinsic charm contribution in the proton (R. Vogt. PRC 103 (2021)3, 035204)
- first evidence recently claimed by NNPDF group based on LHCb data (Nature 608, 483 (2022))

How to measure charmonium in NA60+

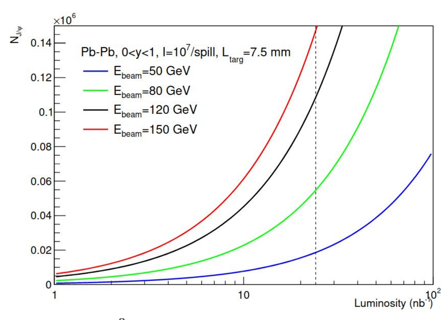
Measured via:

- J/ψ and ψ(2S) in the $\mu^+\mu^-$ decay channel
- $\chi_c \to$ J/ψ γ, with γ measured via conversion in a lepton pair in the vertex telescope



- Muon tracks reconstructed matching tracks in vertex and muon spectrometer → very good mass resolution, ~30 MeV for the J/ψ
- High luminosity is needed to cope with the low production cross sections at low $\sqrt{s}$

Quarkonium performance studies



J/ψ statistics

Pb-Pb:

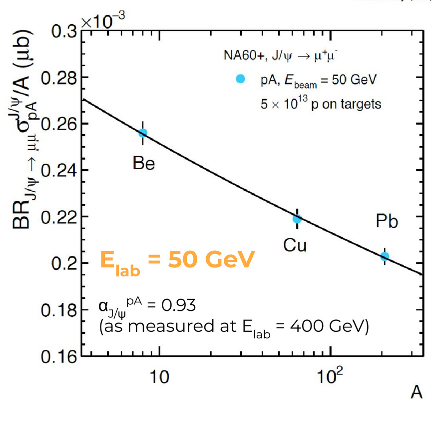
- I_{beam}~10^7 Pb/spill, 7.5 mm target (8.5 g cm^{-2}), 1 month data taking→ L_{int}~24 nb^{-1}
- a factor 3 overall suppression (CNM+ QGP)

→ ~O(10^4) J/ψ at 50 GeV, ~O(10^5) J/ψ at 158 GeV

p-A:

- I_{beam}~5 10^{13} p on target, total target thickness 8.3 gr/cm^2

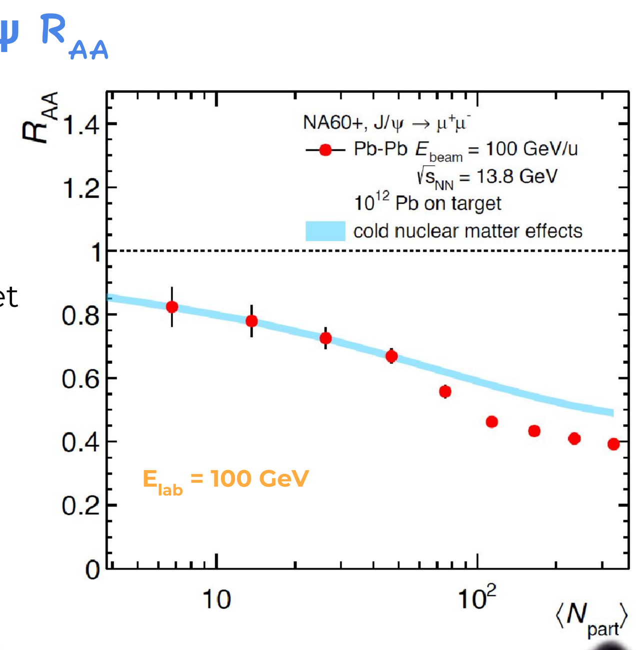
→ ~8000 J/ψ at 50 GeV, ~60000 J/ψ at 158 GeV



Based on

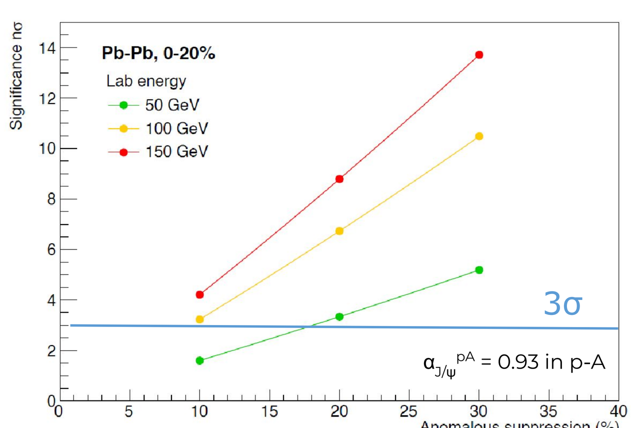
- 10^{12} Pb ions, 8.5 g cm^{-2} target
- 5 x 10^{13} protons, 8.3 g cm^{-2} target

J/ψ R_{AA}



Assume only CNM effects for N_{part}<50 and 20% extra suppression in Pb-Pb for N_{part}>50

Precise evaluation of anomalous suppression within reach even at low energy



- 10% anomalous suppression signal detectable at 3σ for E_{lab}>100 AGeV
- 20% anomalous suppression signal detectable at 3σ for E_{lab}>50 GeV

ROBERTA ARNALDI (INFN TORINO, ITALY) FOR THE NA60+ COLLABORATION - QM2023