Open heavy-flavour and quarkonium measurements with the forthcoming NA60+ experiment at the CERN SPS

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https://na60plus.ca.infn.it

Abstract

❑ The NA60+ experiment, proposed for data taking from 2029/2030, aims at studying the high μ_B region of the QCD phase space diagram. It will make use of the high intensity of CERN SPS beams and detect rare probes via a beam-energy scan with Pb-Pb and p-A collisions in the interval $6.3<\sqrt{s_{NN}}<17.3$ GeV.

❑ Here, we focus on the prospects for measurements of hidden and open charm. Open charm hadrons will be detected through their hadronic decays, reconstructing tracks in the silicon detectors of the vertex telescope. High-precision measurements of the yield of D^0, D^+, and D_s mesons, and of Λ_c baryons, will allow us to constrain the transport properties of the QGP and the features of heavy-quark hadronisation.

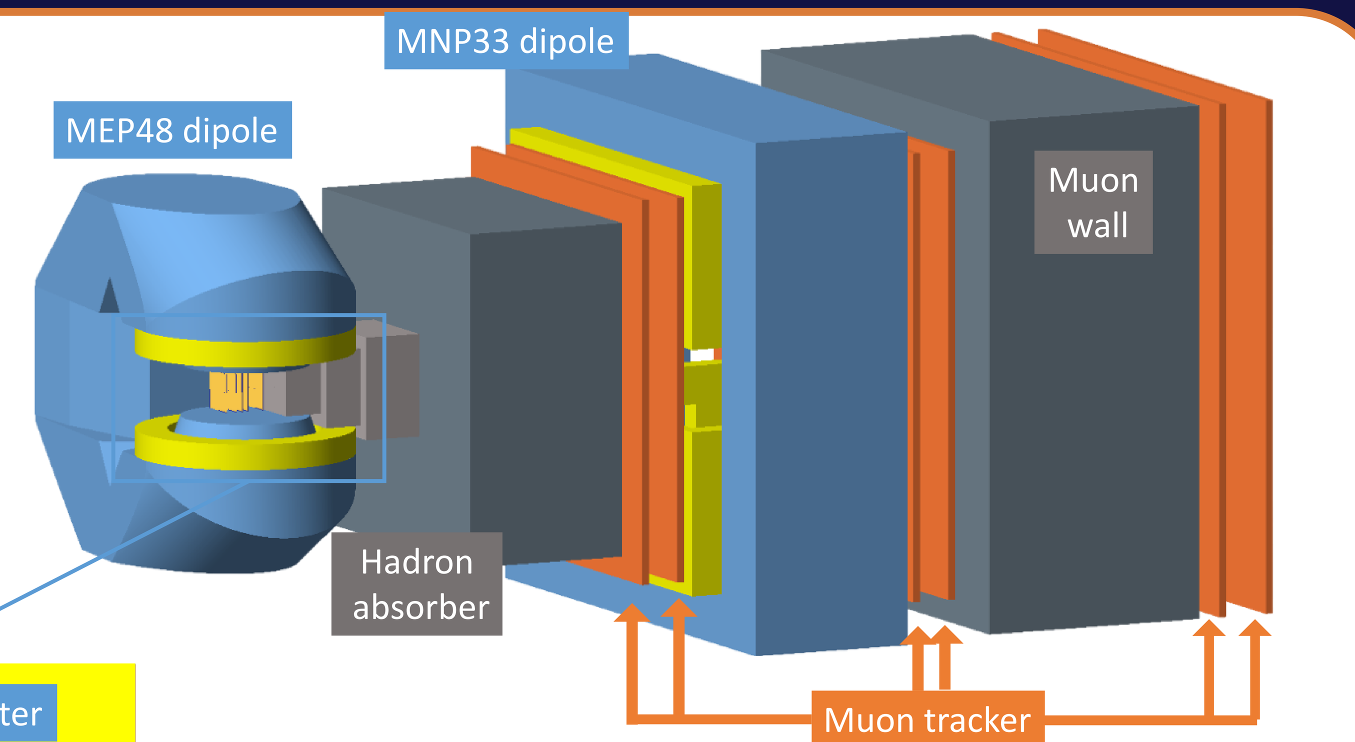
❑ Charmonium states will be accessed through their dimuon decay, matching muon tracks reconstructed in the vertex telescope and in the muon spectrometer. The J/ψ and ψ(2S) measurements at various collision energies will allow us to identify the onset of charmonium suppression in a deconfined medium, correlating this observation with the temperature of the system, measured in the same experiment via thermal dimuons.

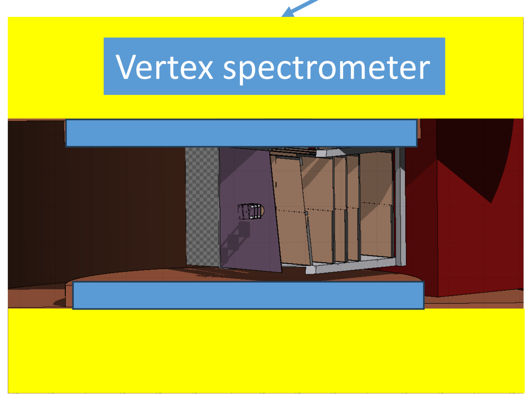
❑ Finally, we briefly mention the competitiveness and complementarity of NA60+ in the landscape of the experiments foreseen at other facilities in the next decade.

Experimental apparatus

- a muon spectrometer (dipole magnetic field, MWPC/GEM tracking detectors)
- a vertex spectrometer (dipole magnetic field, large area MAPS sensors, stitching technology)

N.B. MNP33 dipole from NA62 to replace the foreseen toroid (under study)





❑ The apparatus will be adapted to the varying beam energy by scaling the absorber thickness and moving the tracking stations

❑ Very high beam intensity! → Pb-Pb interaction rate ~ 150 kHz

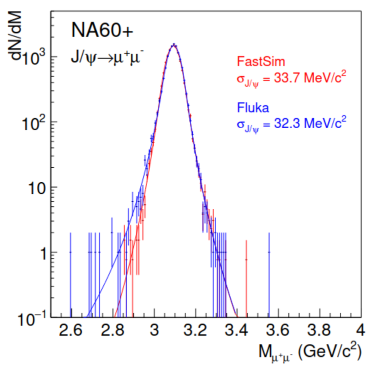
❑ Minimum bias trigger (open charm hadronic decays) or triggerless readout under study

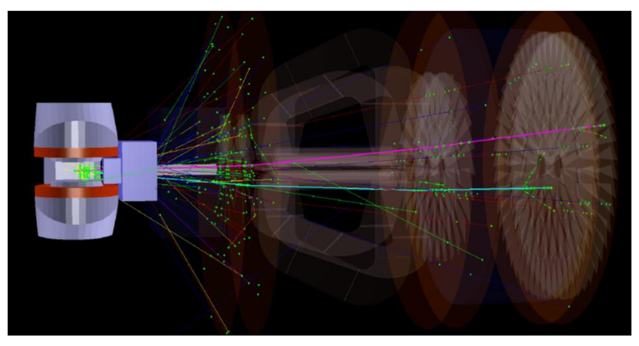
Quarkonium: performance studies

Measured via:

❑ J/ψ and ψ(2S) in the $\mu^+\mu^-$ decay channel

❑ $\chi_c \to J/\psi\ \gamma$, with γ measured via conversion in a lepton pair in the vertex telescope (studies in progress)

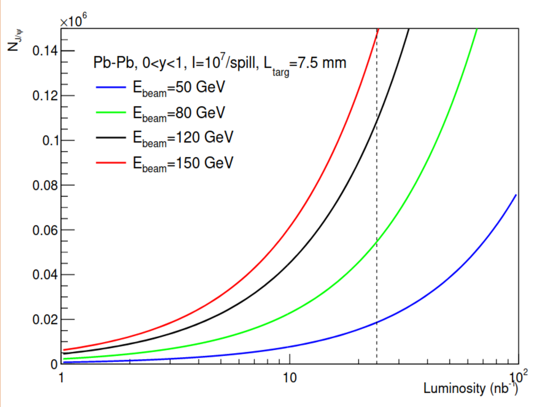




❑ Muon tracks reconstructed matching tracks in vertex and muon spectrometer

→ very good mass resolution, ~30 MeV for the J/ψ

J/ψ statistics



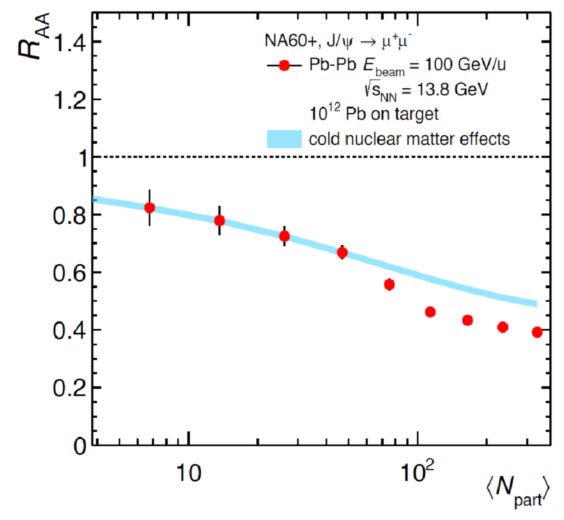
Pb-Pb:

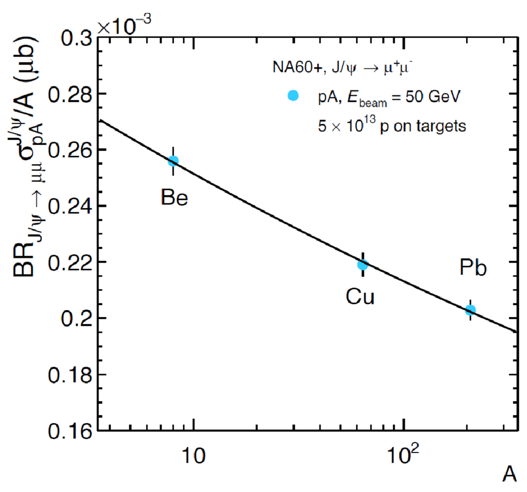
❑ I_{beam}~10^7 Pb/spill, 7.5 mm target (8.5 g cm^{-2}), 1 month data taking→ L_{int}~24 nb^{-1}

❑ a factor 3 overall suppression (CNM+ QGP)

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

J/ψ R_{AA} and anomalous suppression

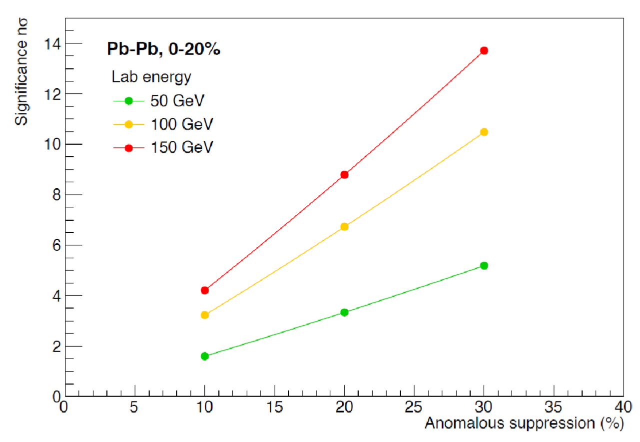




p-A:

❑ I_{beam}~5 10^{13} p on target, total target thickness 8.3 g/cm²

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



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

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

Final considerations, next steps

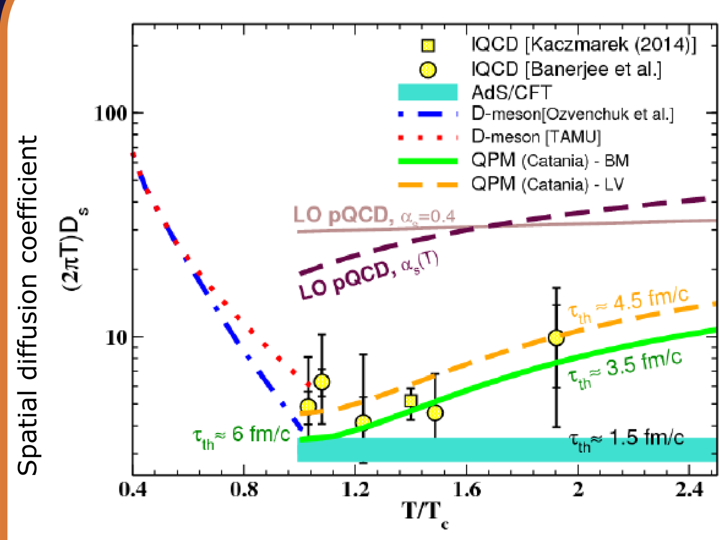
NA60+ → energy scan at SPS energy ($\sqrt{s_{NN}}$~5-17 GeV)
→ accurate measurement of open/hidden charm in p-A and A-A collisions

❑ Higher interaction rates with respect to other facilities/experiments working in the same energy range (RHIC, NICA, ...)

❑ Complementarity with corresponding measurements to be carried out at CBM/FAIR (lower energy)

❑ Start data taking after CERN Long Shutdown 3, ~7 years of data taking performing an energy scan

Open charm at low √s



1. QGP transport properties

Charm diffusion coefficient depends on T, it is 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 $\sqrt{s_{NN}}$= 54.4 GeV/c show significant v_2 wrt 200 GeV, what happens at lower $\sqrt{s_{NN}}$?

4. Total charm cross section

Measurements so far (NA49/60) limited by low yields
- Precise measurement requires to reconstruct mesons and baryons ground states
- Ideal reference for charmonia

Quarkonia at low √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-state 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 √s dependence

❑ CNM effects increase at low √s → they have to be studied at the same √s as AA, for a correct evaluation of hot matter effects

❑ Possibility to disentangle the various contributions (shadowing, nuclear breakup...)

3. 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% probability of intrinsic charm contribution in the proton (R. Vogt, arXiv:2207.04347)

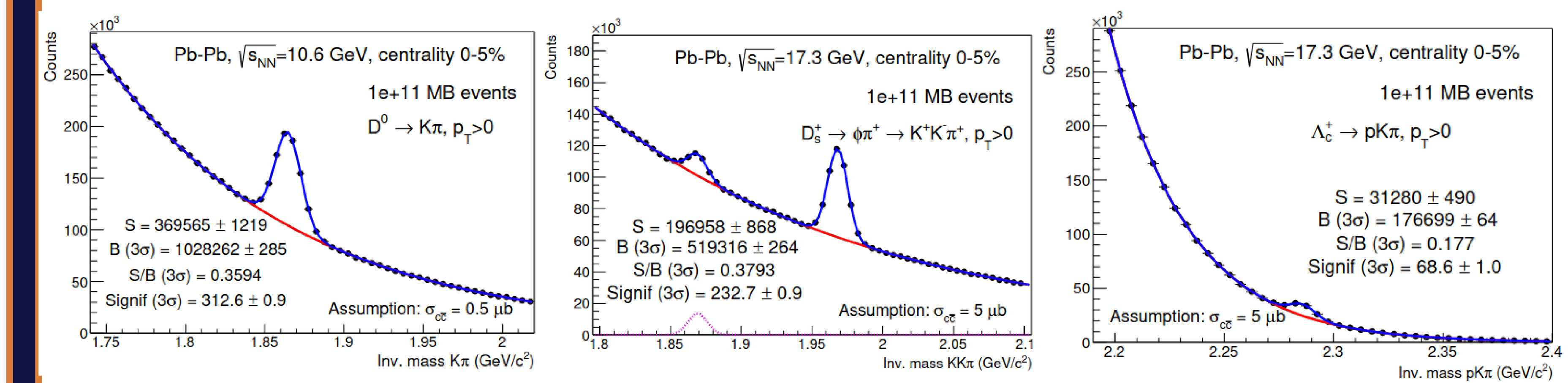
❑ First evidence claimed by NNPDF group based on LHCb data (Nature 608, 483 (2022))

Open heavy flavour: performance studies

❑ Measure 2- and 3-prong decays of charmed mesons and baryon in the vertex telescope, combining particles with proper charge signs (no PID)

❑ Huge background reduced via geometrical selections on the displaced decay vertex topology (60 < cτ < 310 μm)

$D^0 \to K\pi$	$D_s \to \phi\pi \to KK\pi$	$\Lambda_c \to pK\pi$
3 10^6 D^0 in Pb-Pb 0-5% at $\sqrt{s_{NN}}$=17.3 GeV, factor 10 smaller at $\sqrt{s_{NN}}$=10.6 GeV	Measurement of yields feasible, statistical precision of few percent	Accessible, possible improvement with timing layers under study



Top SPS energy → D^0 R_{AA} and v_2 vs p_T, y and centrality

Useful documents

❑ Project developed in the frame of the CERN Physics Beyond Collider Initiative, https://pbc.web.cern.ch

❑ Expression of Interest submitted to SPSC in May 2019, http://cds.cern.ch/record/2673280

❑ Letter of Intent submitted to SPSC in December 2022, https://arxiv.org/abs/2212.14452

❑ Submission of experiment proposal foreseen in spring 2025

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