Future facilities: SPS

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HP2024
NAGASAKI

Future facilities: SPS

focus on hard and em probes

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The Super Proton Synchrotron @ CERN

- First proton beams in 1976

CERN/1236
Original: English
1 September 1976

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

FIFTY-SEVENTH SESSION OF THE COUNCIL

Geneva - 17 June 1976

4. PROGRESS REPORTS PRESENTED TO COUNCIL BY THE DIRECTORS-GENERAL (Item 4 of the Agenda) (CERN/1225, CERN/1225/Corr.)

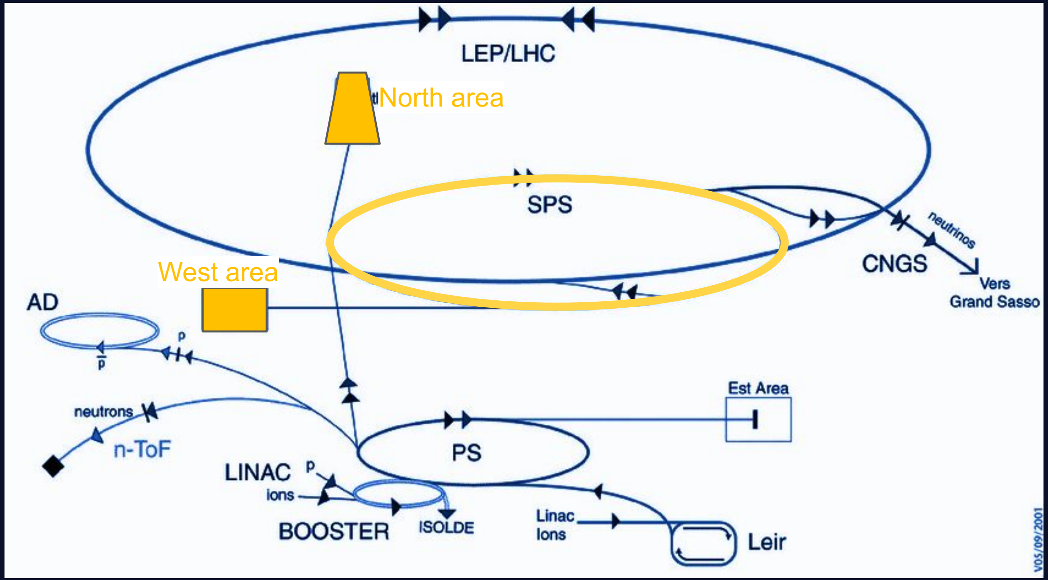
- Oral Presentation by Dr Adams

The Council agreed that the SPS could now proceed to energies above 300 GeV.**

** The SPS reached 400 GeV energy with an intensity of 10^{12} pp at 15.35 hours.

The Super Proton Synchrotron @ CERN

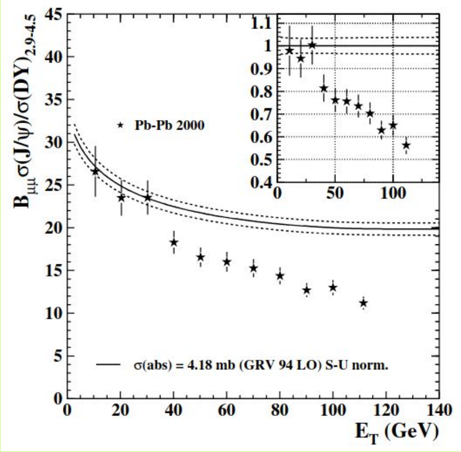
- First proton beams in 1976
- First CERN cross-border accelerator
- Multi-purpose accelerator:
  - proton and antiprotons (also as a collider)
  - electrons and positrons as injector for LEP
  - LHC injector (p from 26 to 450 GeV)
  - heavy-ions (since 1986)



- wide energy range for fixed-target experiments: $6 < \sqrt{s_{NN}} < 17$ GeV
- high luminosity ion beams, up to 10^{6}-10^{7} s^{-1}
- numerous beam lines and experimental areas

First SPS results on hard/em probes

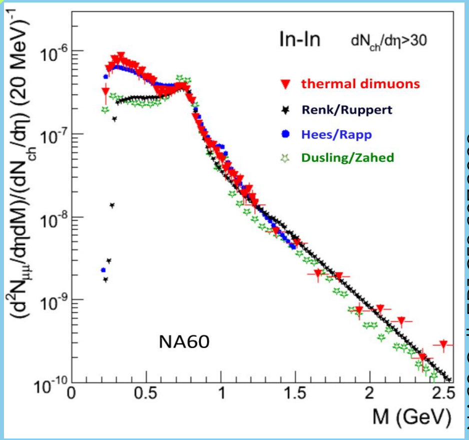
NA50



NA50 Coll, EPJ.C39:335,2005

Discovery of the anomalous J/ψ suppression

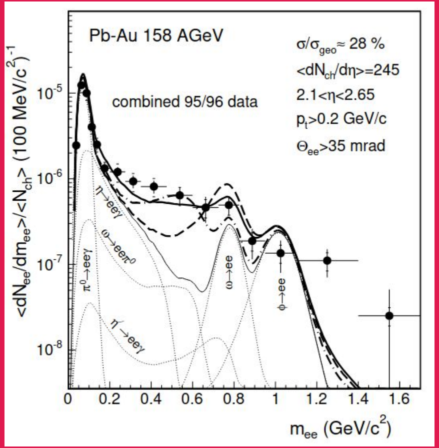
NA60



NA60 Coll, EPJ.C59:607,2009

First evidence of $T > T_c$ via thermal dimuons

CERES



CERES Coll, EPJ.C41:475,2005

Observation of the ρ spectral function modification

...towards the SPS future

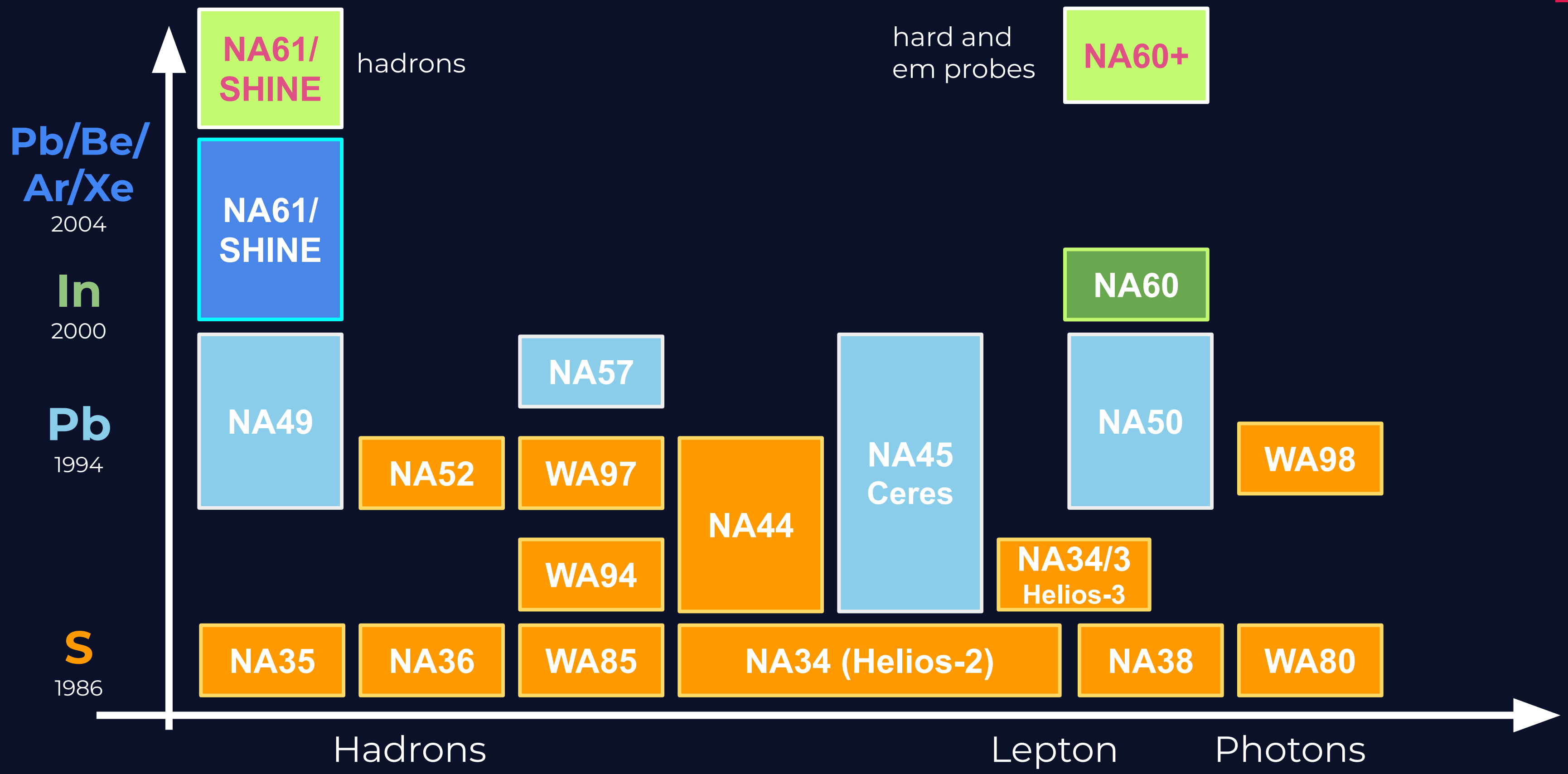
Very rich “past” SPS program

- most of the hard/em results obtained only at top SPS energy
- high accuracy not yet surpassed in many observables

A systematic study of hard/em probes with a beam energy scan at SPS will

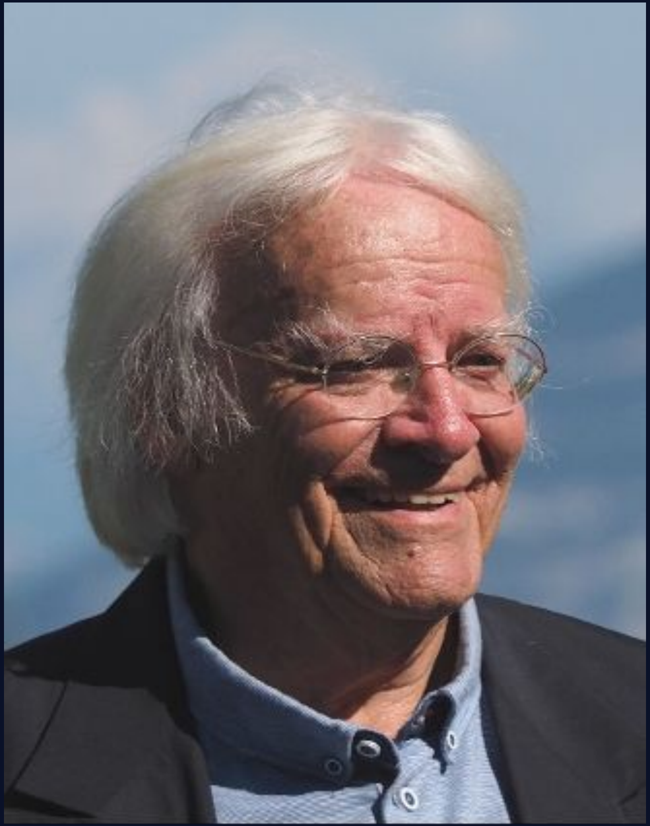
- allow the exploration of the high μ_B region
- provide results complementary to RHIC and LHC measurements

Future HI experiments at SPS



(E. Scomparin. HP2023)

Prof. Hans Specht



1936 - 2024

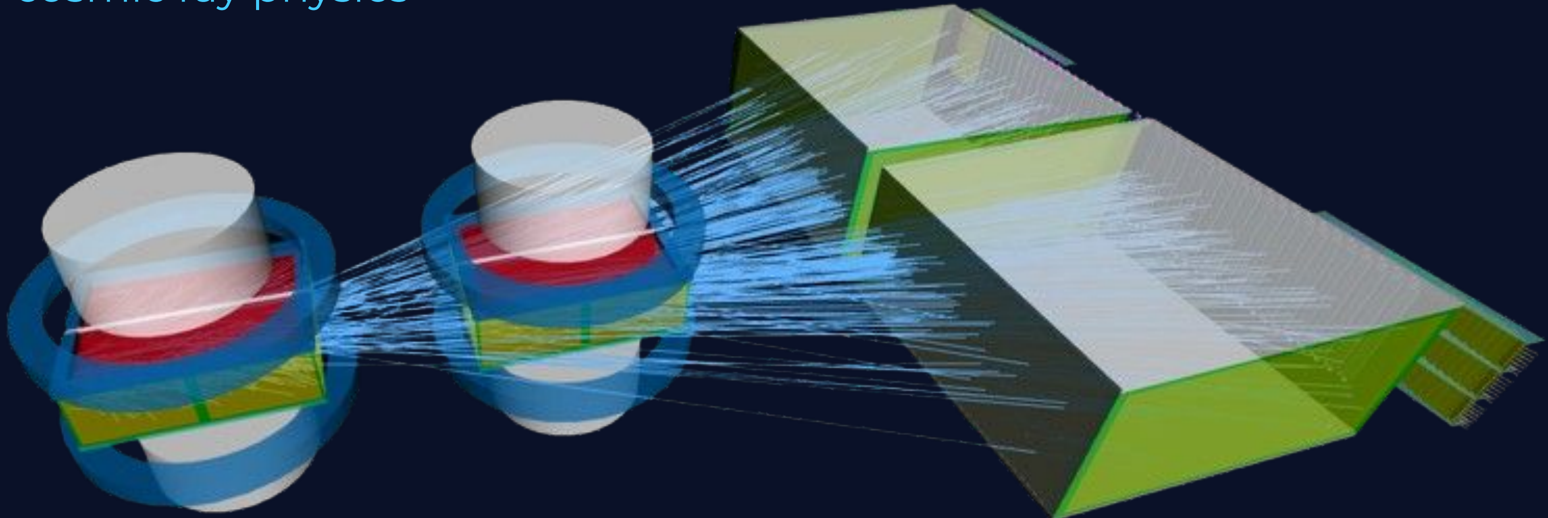
NA61/SHINE

Multi-purpose experiment exploring hadron production since 2009

- study the properties of the onset of deconfinement and fireball
- search for critical point
- measurement of open charm
- neutrino and cosmic ray physics

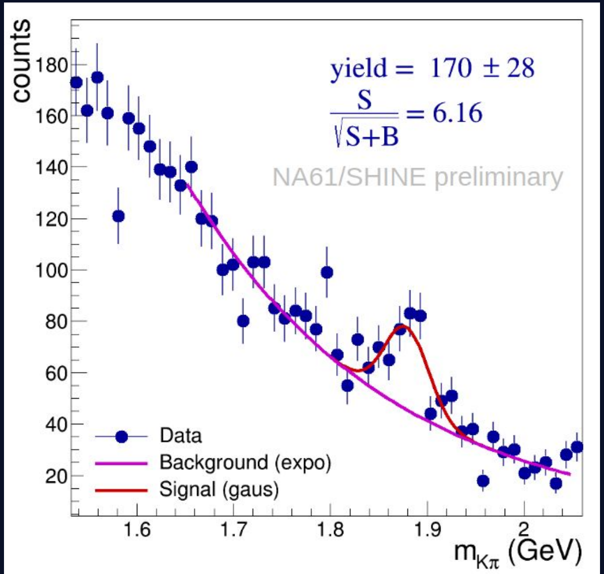
➡

- energy scan with light ions for phase diagram studies
- large statistics PbPb interactions for charm studies



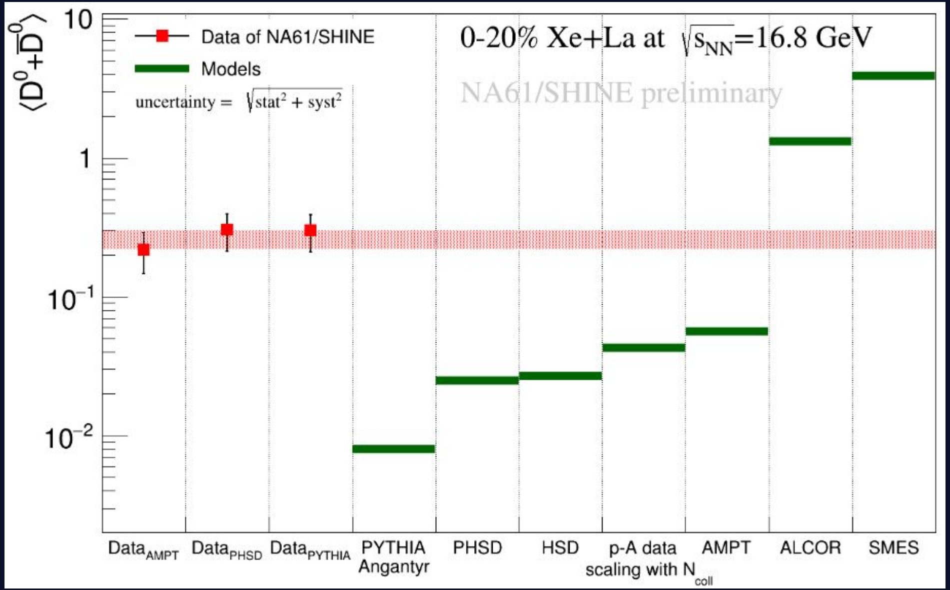
First direct charm measurement

D reconstructed in the Kπ decay channel in 0-20% Xe-La @ 150AGeV
(1.9M events, 2017 data)



First direct open charm observation at SPS, significance better than 5

Anastasia Merzlaya, Mon Parallel 2

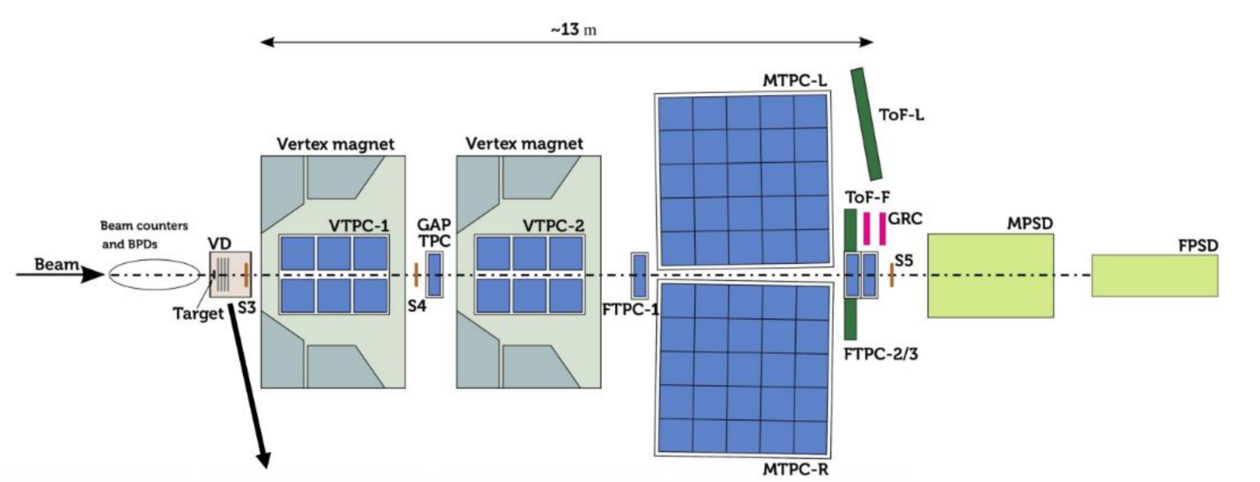


- data precision is sufficient to discriminate between extreme model predictions
- results are above pA extrapolation by 2-3 σ

NA61/SHINE - today

Detector significantly upgraded in LS2, already in data taking since 2022

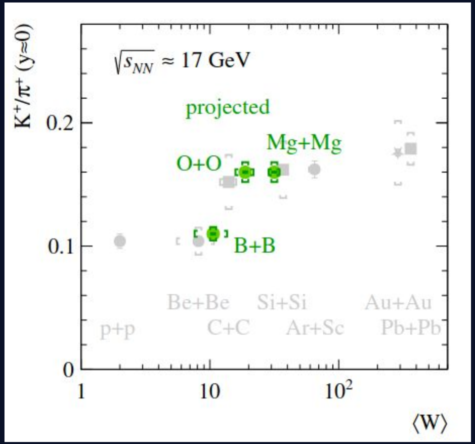
- new VT detector, with ALPIDE pixel sensors
- upgrade of the TPC readout electronics and DAQ
- data taking ~1 kHz rate

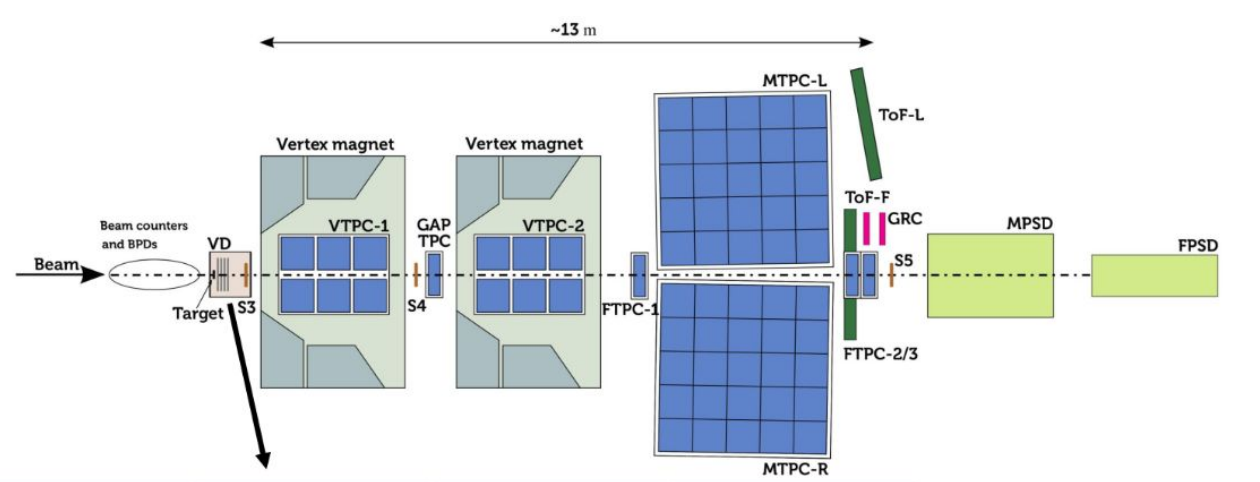


➡ open charm will be studied in PbPb @ 150 GeV/c
~180M PbPb events collected in 2022+23

NA61/SHINE - future

No further upgrade needed for post-LS3

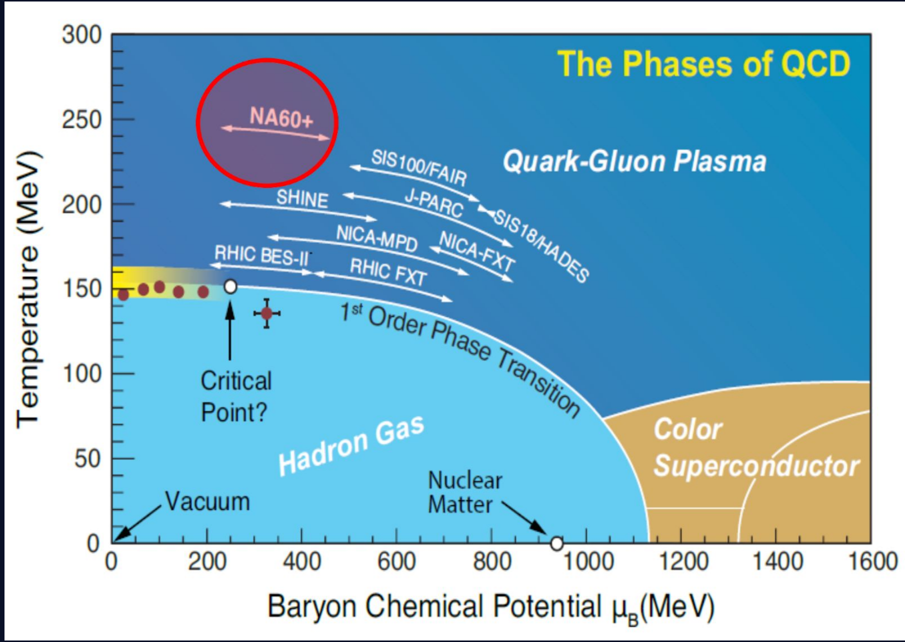




- Light beam energy scan: ^{4}Mg, ^{16}O, ^{10}B beams at 13, 30, 150A GeV/c, to investigate signals of the onset of deconfinement (addendum submitted to SPSC SPSC-P-330-ADD-14)
- Future upgrade beyond : replace a VTPCs with a fast Si tracker
  - at least a 10-fold increase of the readout speed
  - charm-correlation studies might be feasible

NA60+

aims to explore the QCD phase diagram at high baryon chemical potential (μ_B)

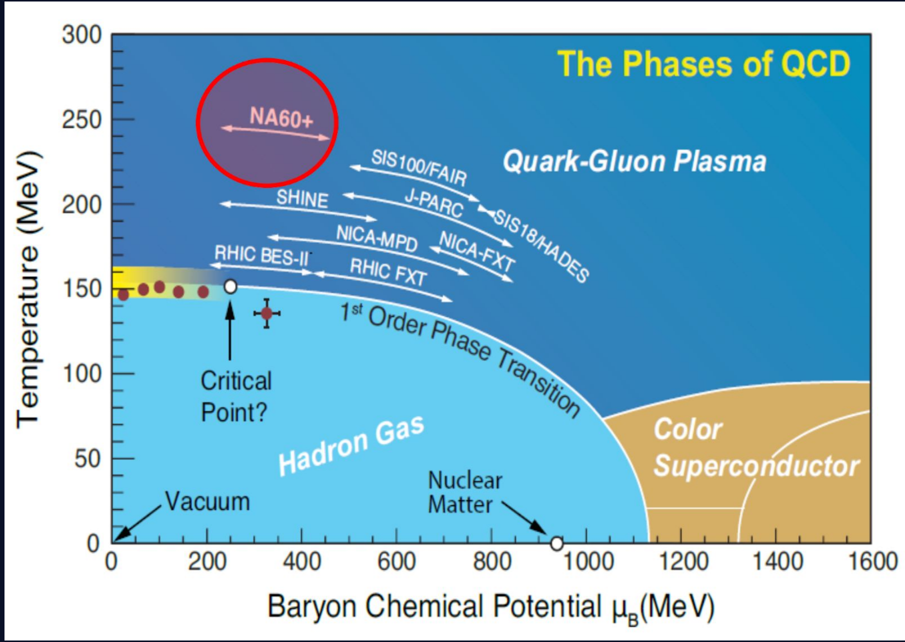


NA60+ will perform precision studies of hard and electromagnetic processes

- accessing muon pair production from threshold up to $m_{\mu\mu}$ ~ 4 GeV/c^2:
  - dilepton continuum
  - low mass resonances
  - quarkonia
- measuring hadronic decays of strange and charm hadrons and hypernuclei

NA60+

aims to explore the QCD phase diagram at high baryon chemical potential (μ_B)



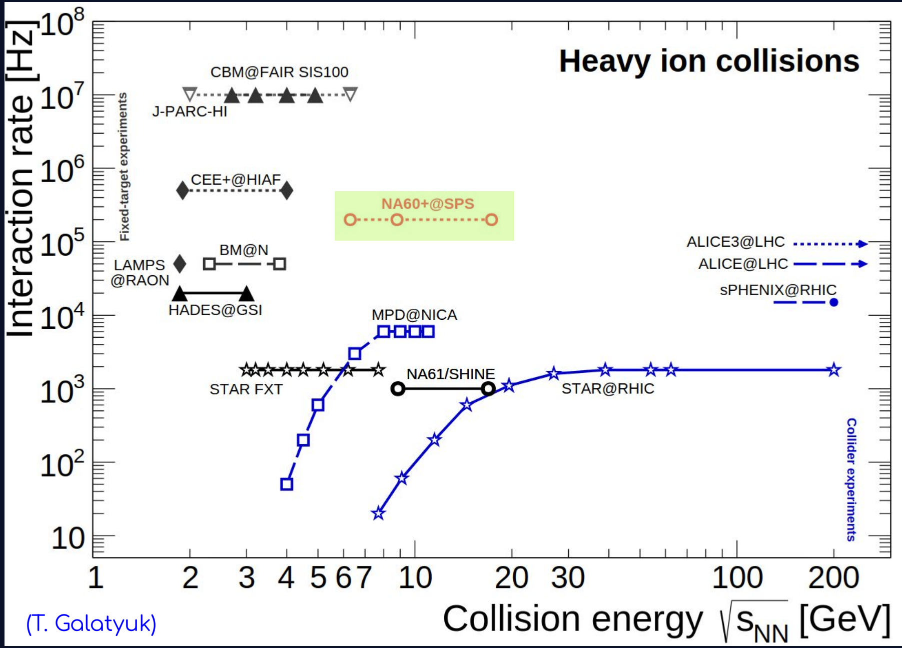
NA60+ will perform precision studies of hard and electromagnetic processes

- via a beam energy scan between $\sqrt{s_{NN}}$ ~ 6 - 17 GeV, to access the μ_B region ~220 - 550 MeV
- exploiting large luminosities, needed for rare QGP probes studies
  - PbPb interactions rates > 10^5 Hz, reachable with 10^6 Pb/s in a fixed target environment

Uniqueness of NA60+

- NA60+ is unique, for energy coverage AND interaction rate, in the heavy-ion landscape

- NA60+ is complementary to experiments accessing:
  - different (hadronic) observables in the same energy range (STAR BES, NICA, NA61)
  - similar observables in a lower energy range (CBM)



The NA60+ setup

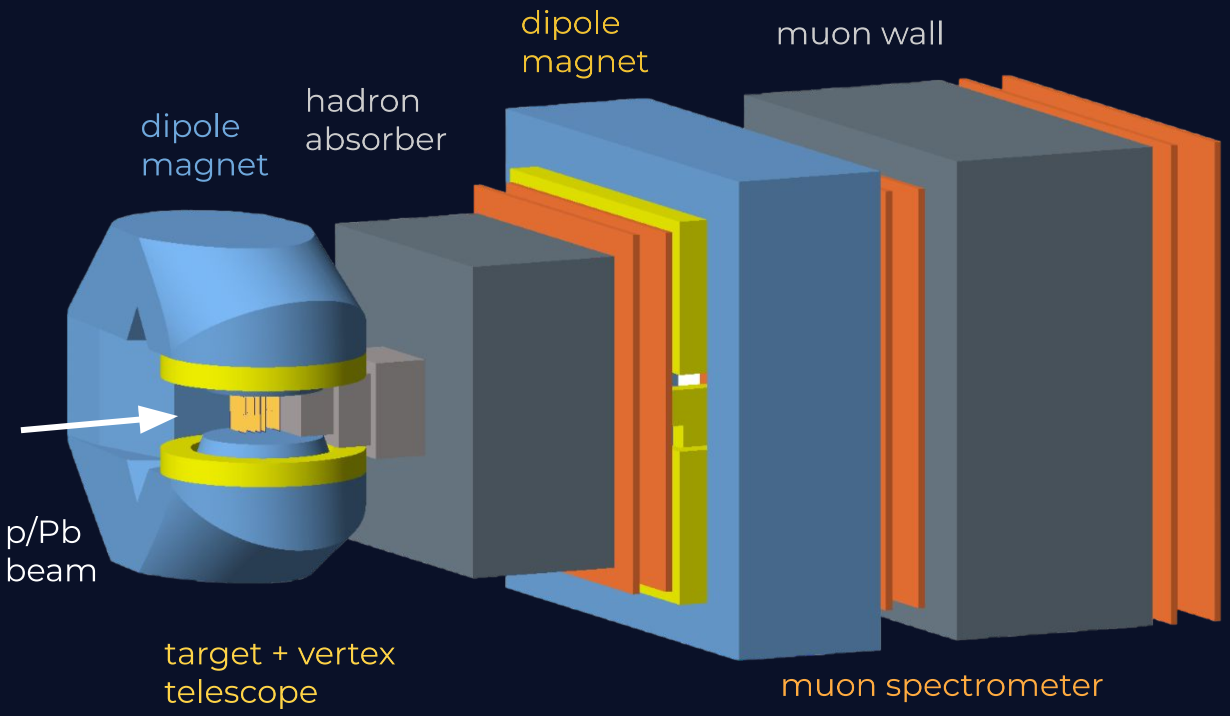
Setup inspired by the former NA60 detector:

- muon spectrometer
- vertex spectrometer

To be installed in the H8 beam line at SPS

Energy/systems:

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



Sasha Milov, Tue Parallel 20 Enrico Scomparin, poster Gianluca Usai, poster

What's new?

MS magnet
- toroidal magnet
- MNP33 magnet

Reconstruction framework

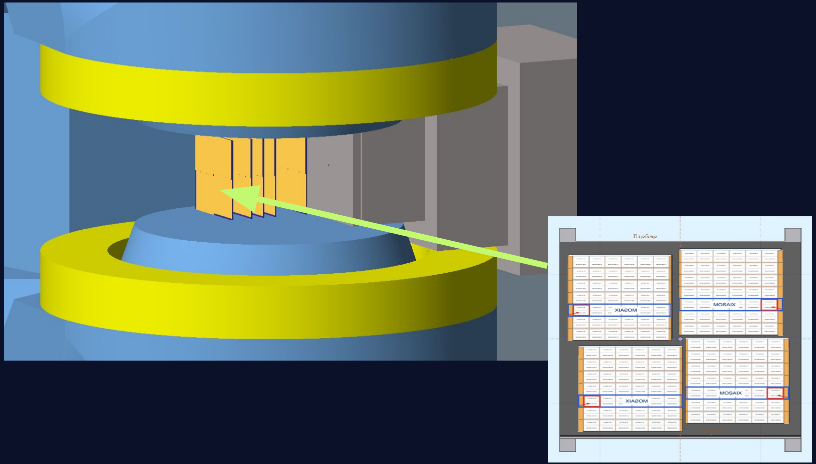
MS chambers
- beam test of first prototype
- second prototype

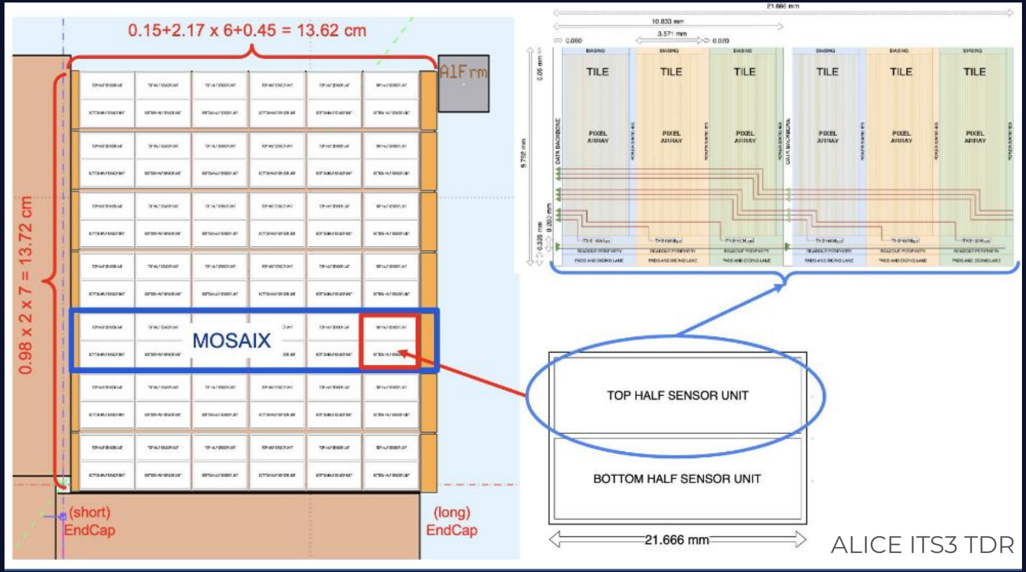
Beam studies
- planning HI and p beams
- test beams

Vertex Telescope
- design of the sensor
- mechanics and cooling

The vertex telescope

5 planes of MAPS detectors inside the VT dipole (MEP48)





realistic sensor floorplan available (13.6 x 13.7 cm^2)

synergy with ALICE ITS3
→ first large area stitched sensor (MOSS) tested

Sasha Milov, Tue Parallel 20

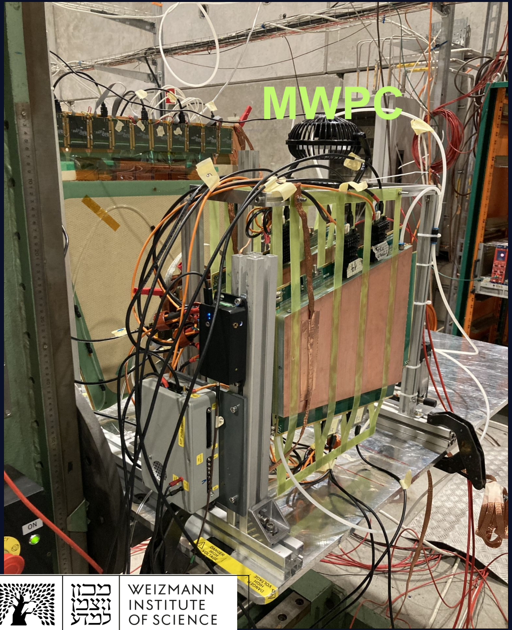
- MOSAIX with 6 stitched RSU (25 mm long units)
- 7 MOSAIX replicated vertically

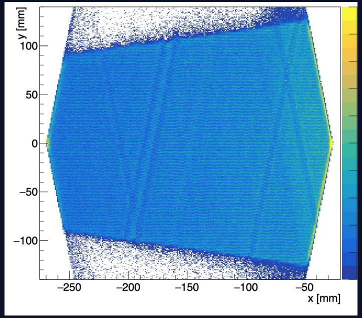
(almost) final sensor prototype expected in 2025

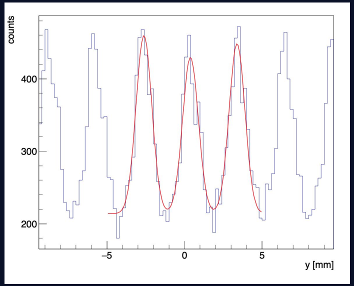
The Muon Spectrometer chambers

GEM or MWPC ➡ can match the expected rates of charged particles (2 kHz/cm^2)

Prototype 1 characterised in a Pb test beam at CERN (Fall 23)

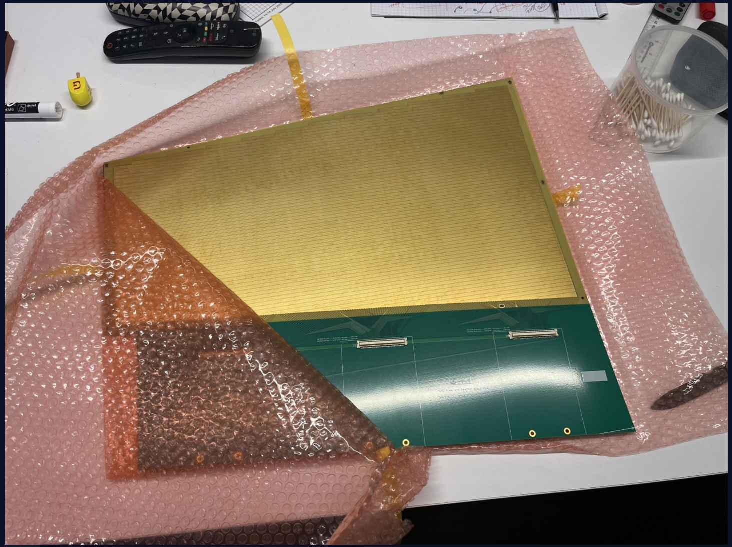






MWPC: σ_x < 0.1 mm, σ_y = 0.5 mm

Prototype 2 to be used in the Pb test beam at CERN (Fall 24)



- New optimized design
- Real electronics (USTC)

The dipole magnet MNP33

A new opportunity: the NA62 dipole **MNP33** will become available in LS3

- Iron yokes: 2.40 m x 3.20 m
- Integrated field: 0.864 T m, similar to that of the toroid

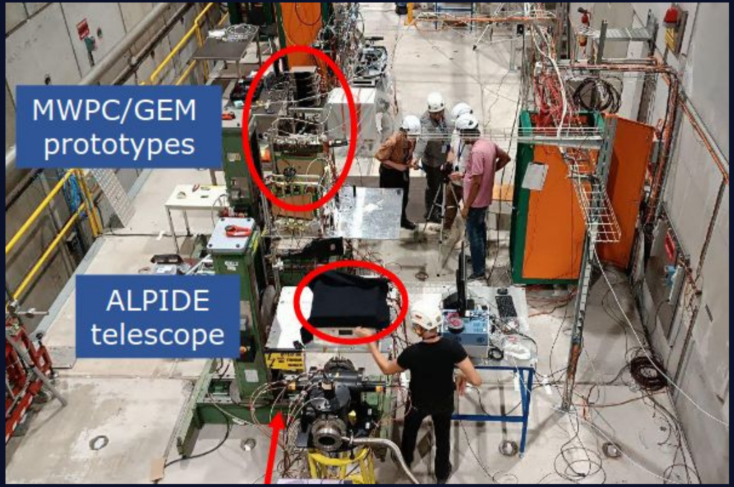
MNP33 looks very promising

- Potential significant simplification of integration of NA60+ in H8
  - more compact setup
- Cost reduction of NA60+ project by ~3 M€
- Detailed simulations to assess the physics performances on-going

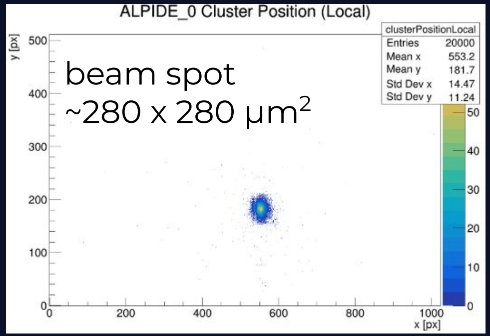
The beam

Planning of HI and p beams quickly converging ➡
- to achieve 10^{12} Pb on target, in 1 month at all energies
- to collect pA at the same energy (~5-6 x 10^{8} p/spill)

Very stringent beam requests at all energies ➡
- high-intensity (10^{7} Pb/spill)
- very focussed sub-mm beam (vertex spectrometer has 6 mm hole)



Beam optics studies ongoing:
up to 2.4 10^{5} Pb/s at 150 GeV (25% of expected NA60+ intensity)

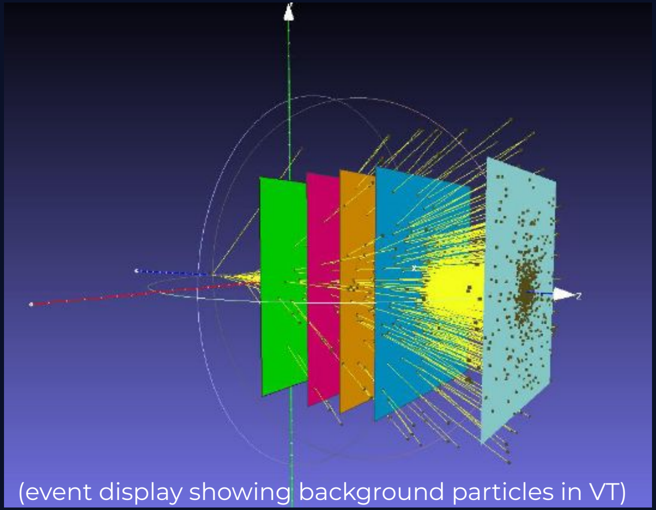


Second high intensity test
in Fall 2024:
- reach 10^{6} Pb/s
- low energy (15 AGeV) Pb beam, with larger emittance

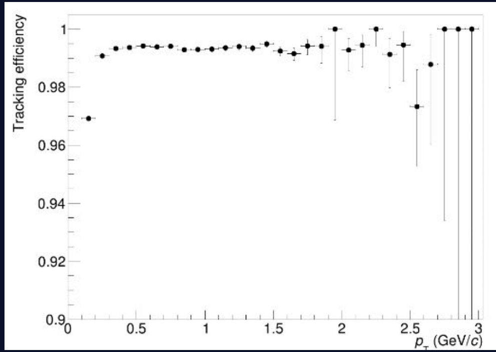
Track reconstruction

Based on ACTS, an experiment-independent toolkit for (charged) particle track reconstruction in (high energy) physics

➡ Currently developing track reconstruction in the vertex telescope and muon spectrometer


(event display showing background particles in VT)

- realistic multiplicities and particle distributions (from NA49 measurements)
- ACTS resolutions in agreement with fast simulation studies (used for LOI)
- two step reconstruction: primary particles followed by reconstruction of secondaries → large tracking efficiencies in both cases



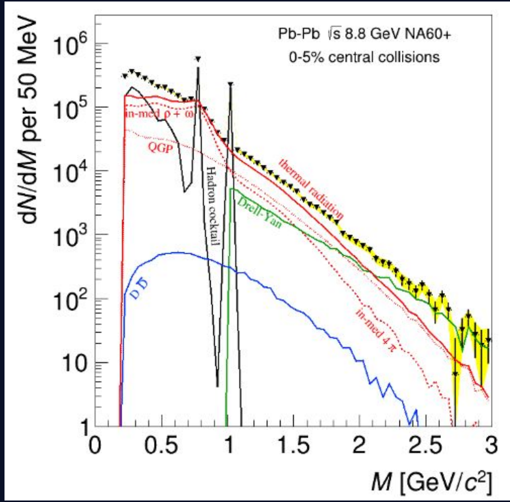
Performances: thermal dimuons

Thermal radiation yield

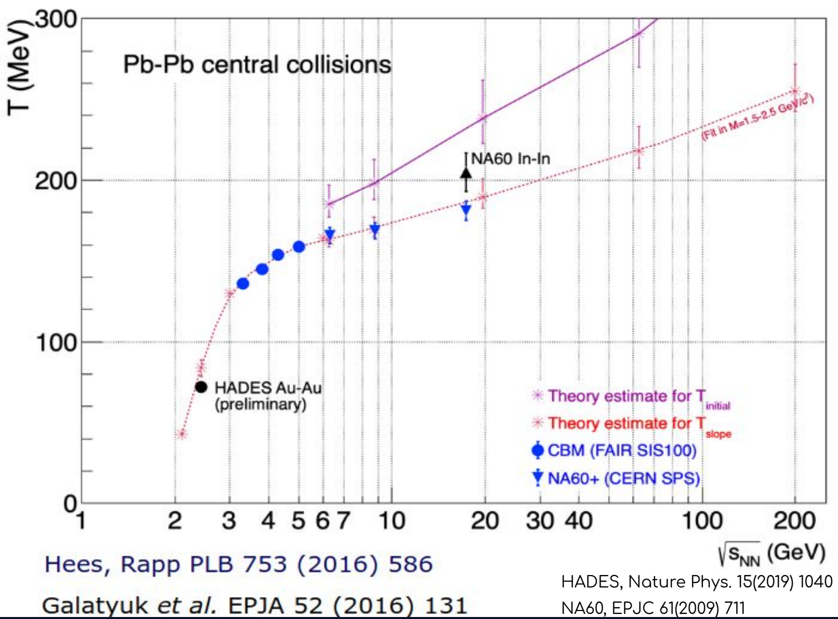
- accessible up to M= 2.5-3 GeV/c^2
- dominated by ρ contribution at low mass

Drell-Yan to be estimated via pA measurements

Open charm negligible dimuon source



→ T_{slope} from fit to 1.5 < M < 2.5 GeV/c^2



~1-3% uncertainty on T_{slope} →

- accurate mapping of T_{slope} √s-dependence
- strong sensitivity to possible flattening of the caloric curve due to 1st order transition

Gianluca Usai, poster

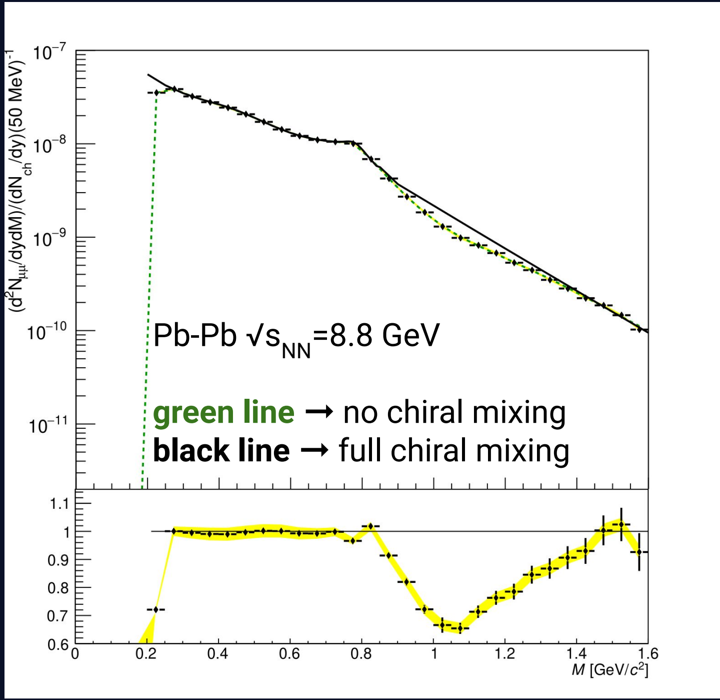
Performances: ρ-a_1 mixing

Chiral symmetry restoration investigated with the measurement of the ρ-a_1 mixing

Full ρ-a_1 chiral mixing detected studying the modification of the dimuon continuum

➞ a 20-30% enhancement is expected in the region $0.8 < M < 1.5$ GeV/c^2 w.r.t. no mixing

NA60+ could clearly detect a signal of chiral symmetry restoration



Gianluca Usai, poster

Performances: charmonium

Quarkonium never studied below top SPS energies

SPS

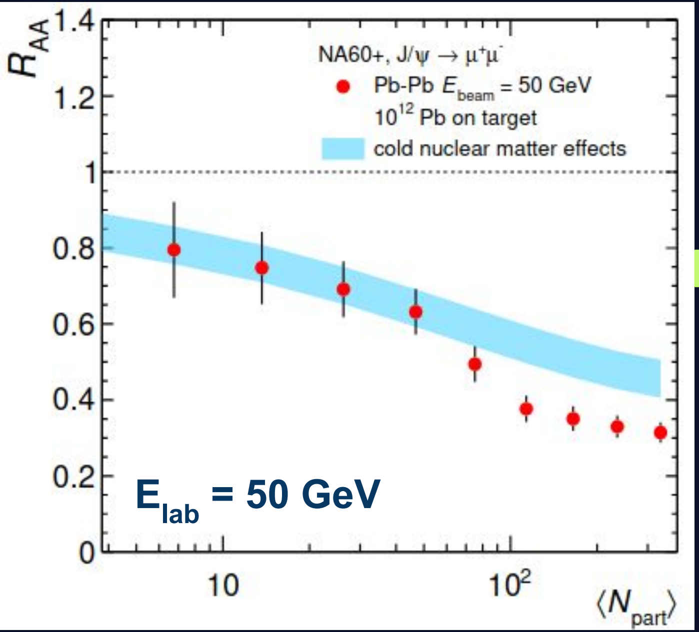
hot matter effects
suppression

→ **AA**

initial state effects
(anti)shadowing
$x_{BJ} \sim 10^{-1}$ for y~0

final CNM effects
sizable breakup in
nuclear matter
τ~0.5 fm/c for y~0

→ **pA**



→ Precise evaluation of anomalous suppression within reach even at low energy

~O(10^4-10^5) J/ψ at 50-158 GeV

Intrinsic charm in p-A collisions will also be investigated

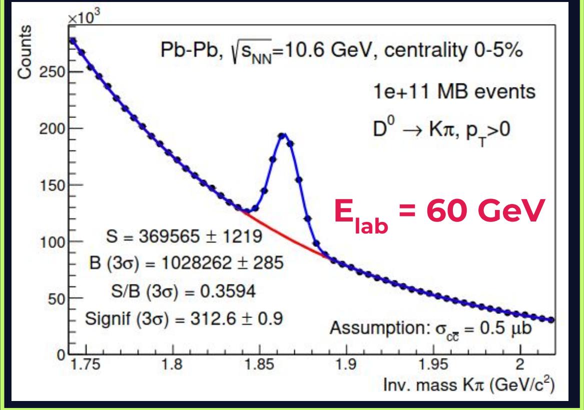
Enrico Scomparin, poster

Performances: open charm

Hadronic decays reconstructed in the vertex telescope, with topological cuts

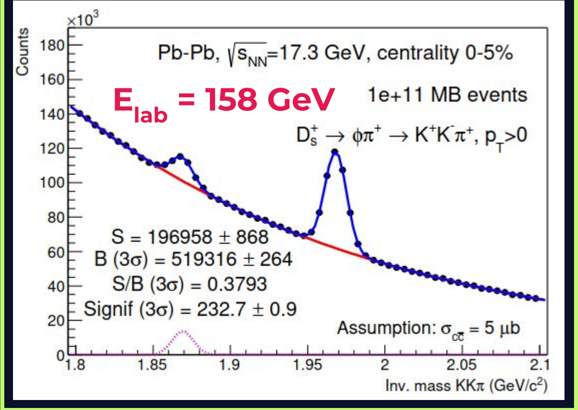
$D^0 \rightarrow K\pi$

accessible also at low $\sqrt{s_{NN}}$, ~1% statistical precision



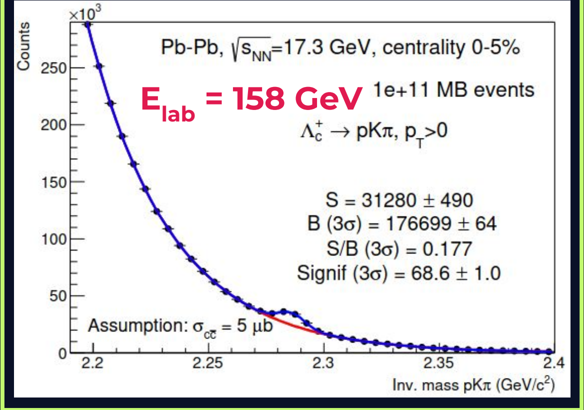
$D_s \rightarrow \phi\pi \rightarrow KK\pi$

yields measurement, few percent statistical precision



$\Lambda_c \rightarrow pK\pi$

feasible, improvement with timing layers under study



with 10^{11} MB Pb-Pb collisions (1 month of data taking)

First studies at SPS energies of ➡

- QGP transport properties
- charm thermalization
- hadronization mechanisms
- total charm cross section

Enrico Scomparin, poster

The NA60+ timeline

2023 LOI → **2025** Proposal → **2026-2028/29** Construction → **2029/30-2036/7** Data taking

- Project is part of CERN Physics Beyond Collider Initiative
- LOI (arXiv:2212.14452) discussed with SPSC in February 2023
- Expect proposal to SPSC in Spring 2025
- Aim is taking data in 2029/30, after LHC LS3
  - 7-years running with Pb beam (one beam energy per year)
  - proton beams for reference and dedicated p-A studies

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

The NA60+ Collaboration

C. Ahdida[1], G. Alocco[2,3], F. Antinori[4], M. Arba[3], M. Aresti[2,3], R. Arnaldi[5], A. Baratto Roldan[1], S. Beolè[6,5], A. Beraudo[5], J. Bernhard[1], L. Bianchi[6,5], M. Borysova[7,8], S. Bressler[7], S. Bufalino[9,5], E. Casula[2,3], C. Cicalò[3], S. Coli[5], P. Cortese[10,5], A. Dainese[4], H. Danielsson[1], A. De Falco[2,3], K. Dehmelt[11], A. Drees[11], A. Ferretti[6,5], F. Fionda[2,3], M. Gagliardi[6,5], A. Gerbershagen[12], F. Geurts[13], V. Greco[14,15], W. Li[13], M.P. Lombardo[16], D. Marras[3], M. Masera[6,5], A. Masoni[3], L. Micheletti[1], L. Mirasola[2,3], F. Mazzaschi[1,6], M. Mentink[1], P. Mereu[5], A. Milov[7], A. Mulliri[2,3], L. Musa[1], C. Oppedisano[5], B. Paul[2,3], M. Pennisi[6,5], S. Plumari[14], F. Prino[5], M. Puccio[1], C. Puggioni[3], R. Rapp[17], I. Ravinovich[7], A. Rossi[4], V. Sarritzu[2,3], B. Schmidt[1], E. Scomparin[5], S. Siddhanta[3], R. Shahoyan[1], M. Tuveri[3], A. Uras[18], G. Usai[2,3], H. Vincke[1], I. Vorobyev[1]

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17 .Cyclotron Institute and Department of Physics and Astronomy, Texas A&M University, College Station, Texas, USA
18 .Institut de Physique des 2 Infinis de Lyon, Université de Lyon, CNRS/IN2P3, Lyon, France

- the LoI was signed by 62 physicists, engineers, technicians
- support also from members of the QGP theory community

- funding for the R&D phase since 2020
- still ample space for contributions on many items, more Collaborators welcome!

Conclusions

Significant progresses made so far, towards a bright SPS future!

- support of experimental and theoretical heavy-ion community is crucial

Two projects followed by CERN Physics Beyond Collider initiative:

- NA61/SHINE, breaking the ground with first measurements of open charm cross section
- NA60+, proposed for high precision measurements of thermal dileptons, charmonium, open-heavy flavors from 2029/30

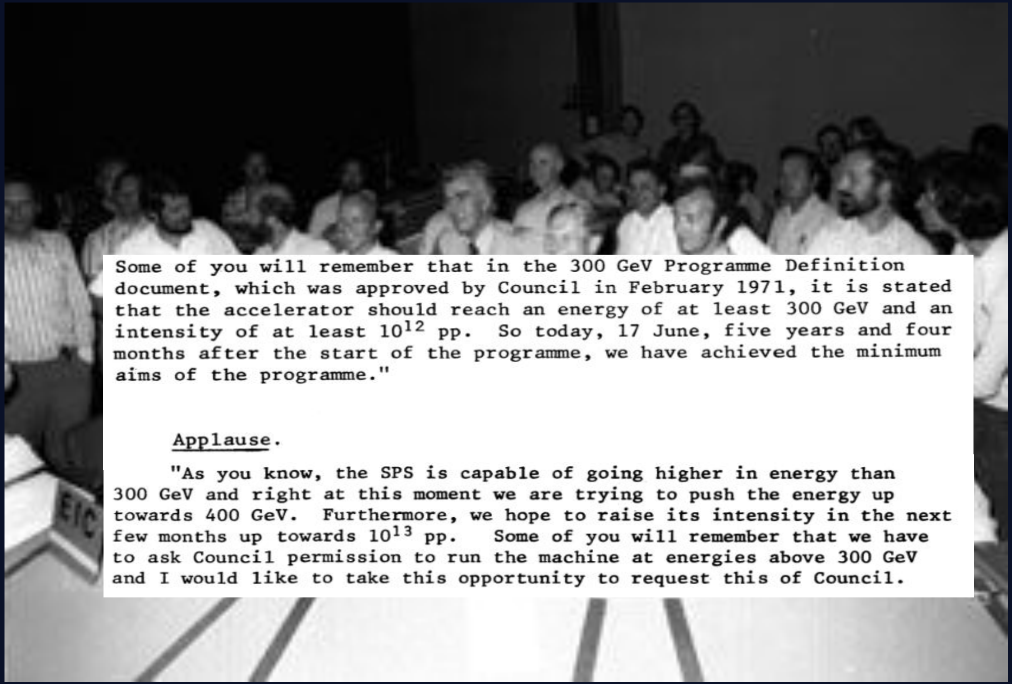
Precision studies of em and hard probes in $6 < \sqrt{s_{NN}} < 17$ GeV are currently lacking
big interest in dusting off the glories of the first generation of SPS experiments

Thank you!

Backup

The Super Proton Synchrotron @ CERN

- First proton beams in 1976



Some of you will remember that in the 300 GeV Programme Definition document, which was approved by Council in February 1971, it is stated that the accelerator should reach an energy of at least 300 GeV and an intensity of at least 10^{12} pp. So today, 17 June, five years and four months after the start of the programme, we have achieved the minimum aims of the programme."

Applause.

"As you know, the SPS is capable of going higher in energy than 300 GeV and right at this moment we are trying to push the energy up towards 400 GeV. Furthermore, we hope to raise its intensity in the next few months up towards 10^{13} pp. Some of you will remember that we have to ask Council permission to run the machine at energies above 300 GeV and I would like to take this opportunity to request this of Council.

CERN/1236
Original: English
1 September 1976

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CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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- Oral Presentation by Dr Adams

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** The SPS reached 400 GeV energy with an intensity of 10^{12} pp at 15.35 hours.

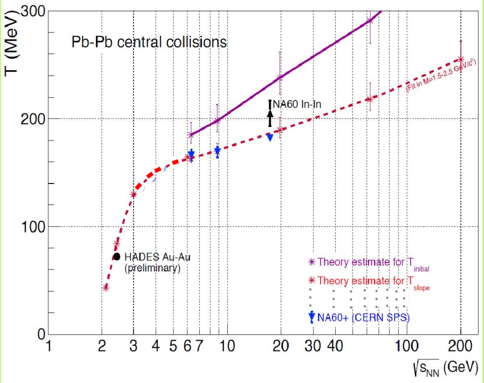
The NA60+ physics program

Several new and unique measurements

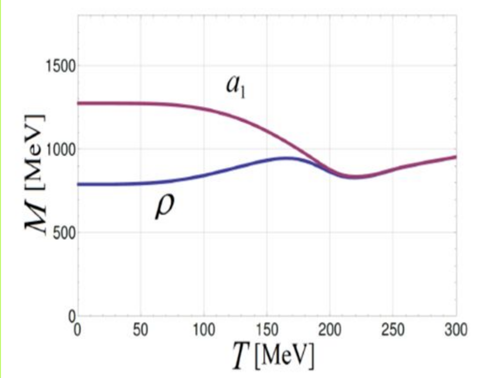
1) caloric curve of QGP

measurement of thermal dimuons temperature vs $\sqrt{s_{NN}}$

Rapp and v.Hees, PLB753(2016) 586
T. Galatyuk et al., EPJA52(2016) 131



2) chiral symmetry restoration



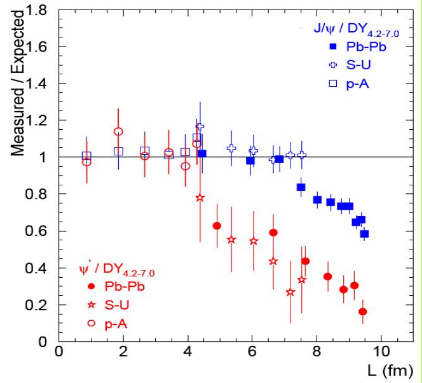
ρ-a_1 mixing in the dimuon channel

C. Jung et al., PRD 95 (2017) 036020

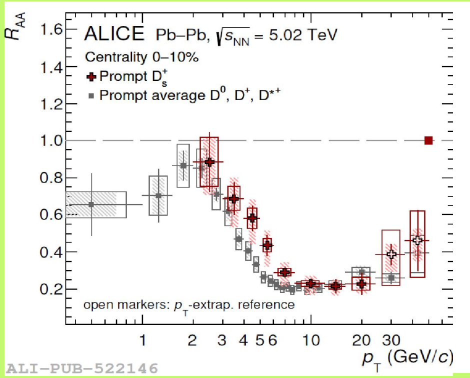
3) charmonium melting in the QGP

suppression of charmonium vs $\sqrt{s_{NN}}$ (dimuon decay channel)

NA50, PLB 477 (2000) 28
NA50, EPJC49 (2007) 559



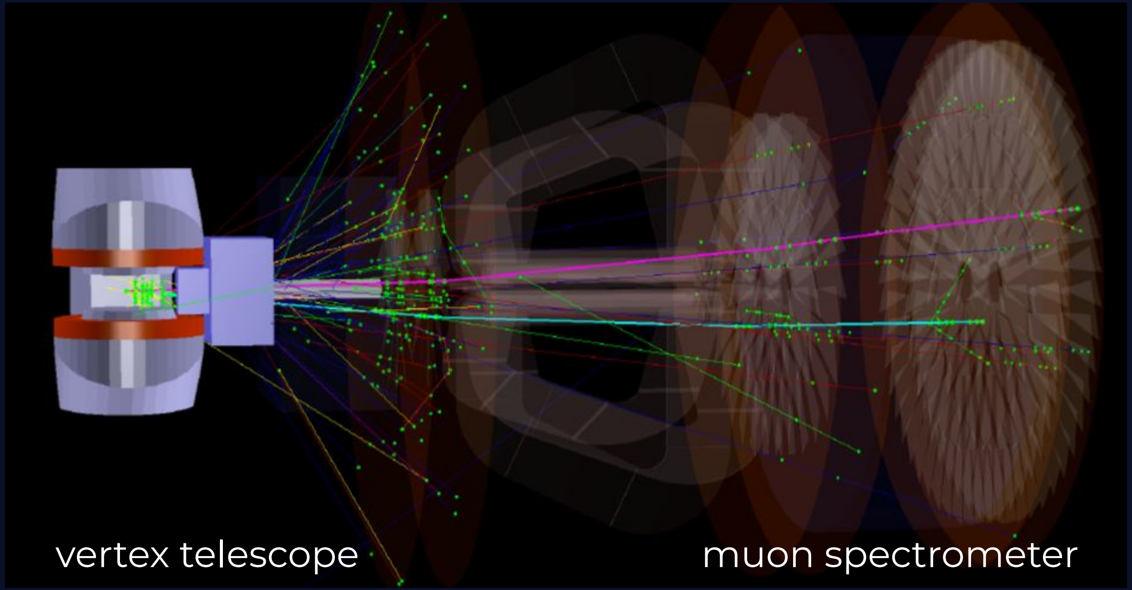
4) QGP transport coeff and charm hadronization



hadronic decays of open HF mesons and baryons

ALICE, PLB 827 (2022) 136986

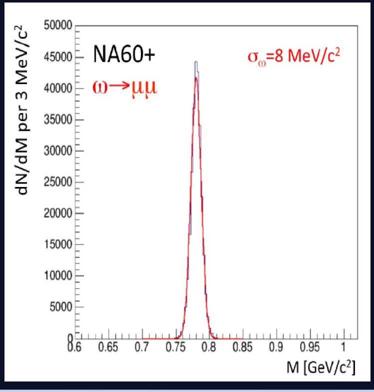
Dimuons in NA60+

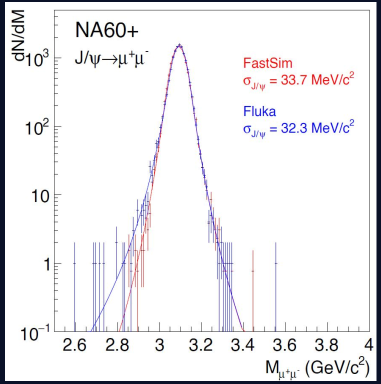


Muon tracks

- matching (in coordinates and momentum space) of tracks in vertex and muon spectrometer
- measure muon kinematics before multiple scattering and energy loss

very good mass resolution





Charmonium in NA60+

Quarkonium never studied below top SPS energies

1

AA: onset of charmonium suppression

accessible via energy scan

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

2

pA: cold nuclear matter effects

CNM effects increase at low $\sqrt{s}$

- mandatory (at the same $\sqrt{s}$ as AA) for a correct evaluation of hot matter effects
- disentangle the various contributions (shadowing, nuclear breakup...)

3

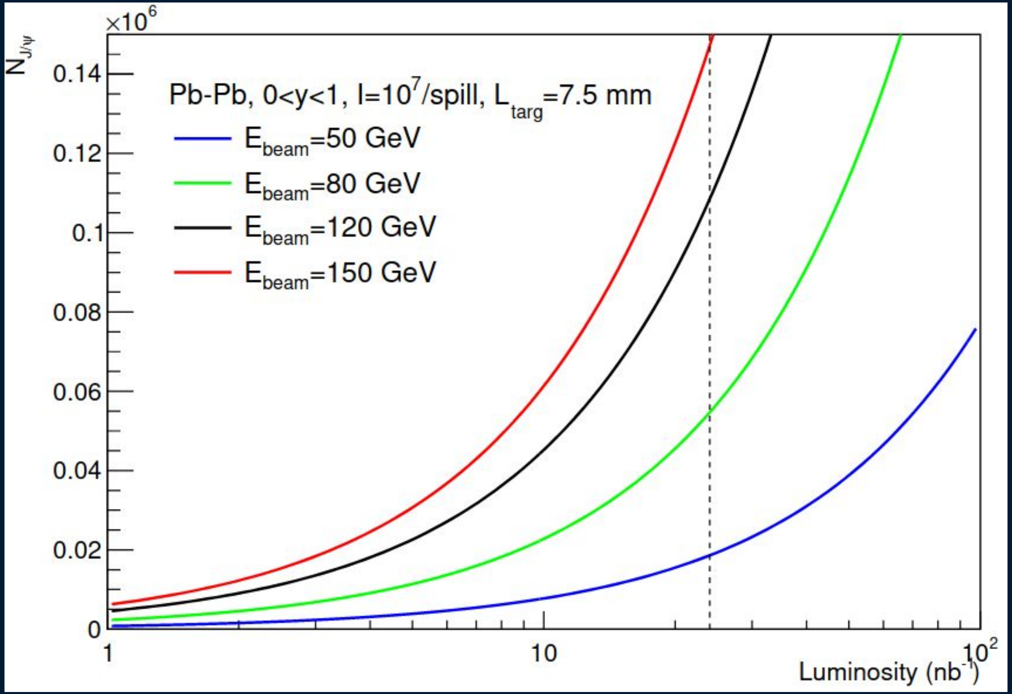
pA: intrinsic charm

expected enhanced charm production at large x_F

- fixed target is the ideal configuration → enhancement is expected 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)

Charmonium in AA

High luminosity is needed to cope with the low production cross sections at low √s



Assuming:

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

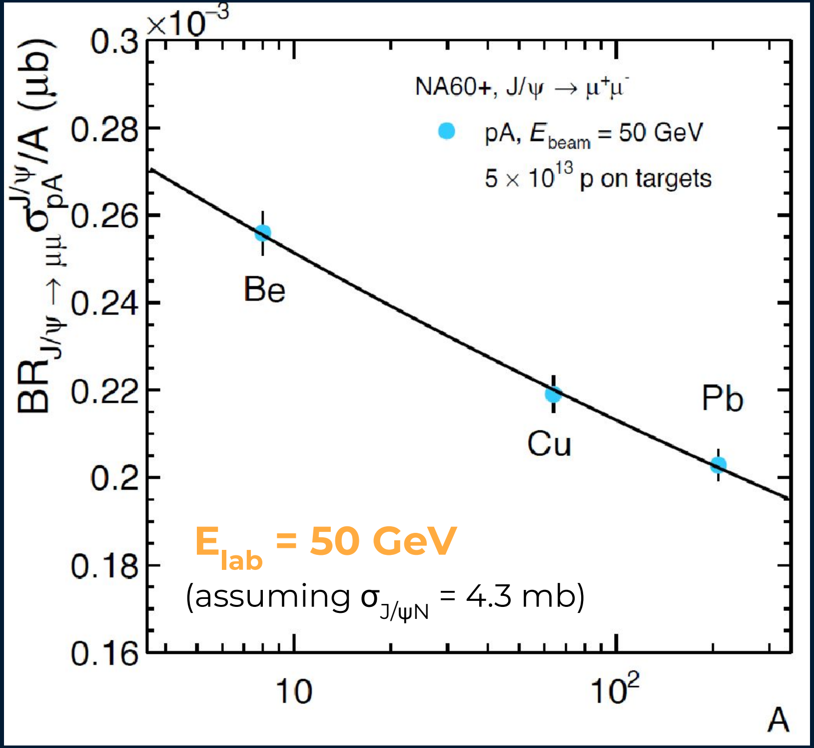
⇩

NA60+ can aim at

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

Charmonium in pA

p-A data taking mandatory to calibrate CNM effects



Assuming:

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

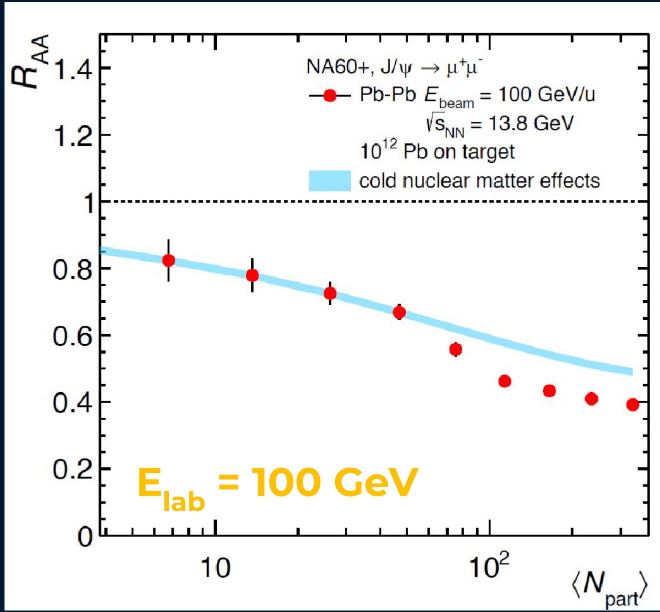
⇓

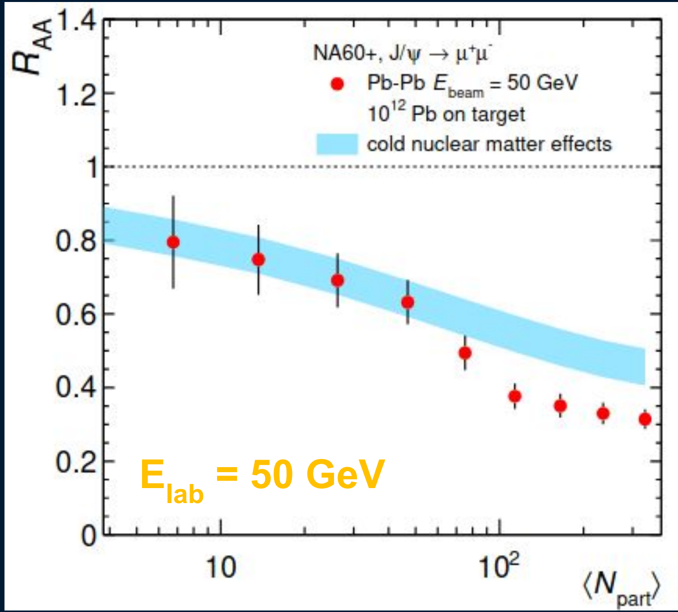
- NA60+ can aim at

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

- pA data will provide an estimate of CNM effects
- extrapolating the pA measurements down to A = 1, we can estimate σ_{pp}, to be used in the R_{AA} evaluation

Charmonium R_{AA}





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

Assume
- CNM effects for N_{part}<50
- CNM effects + 20% QGP suppression for N_{part}>50

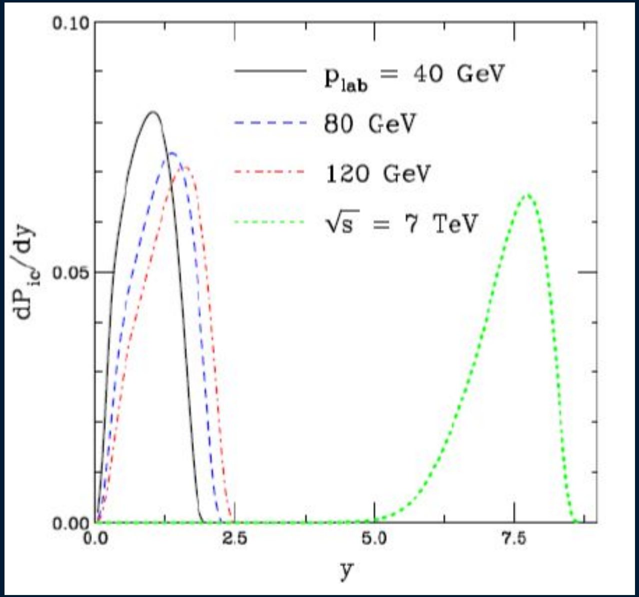
Precise evaluation of anomalous suppression within reach even at low energy

Uncertainties on CNM (σ_{abs}) are ~6 - 15% at 158 and 50 GeV, respectively

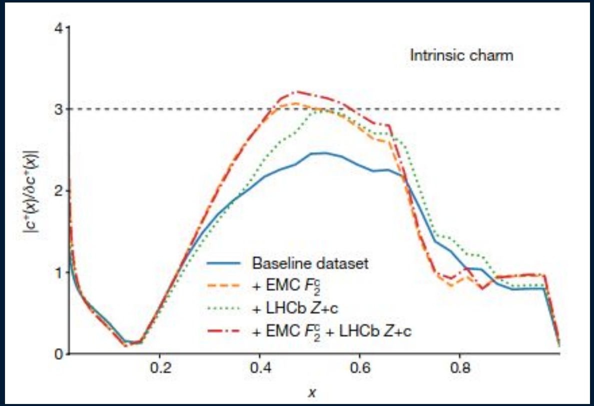
Intrinsic charm

Intrinsic charm component of the hadron wave function |uudccbar>

enhanced charm production in the forward region



- at collider energies, the region where the IC effects can be observed is at very large y
- for fixed-target, low √s, the enhancement is closer to mid-y
- first evidence recently claimed by NNPDF group based on LHCb data (Nature 608,483(2022))



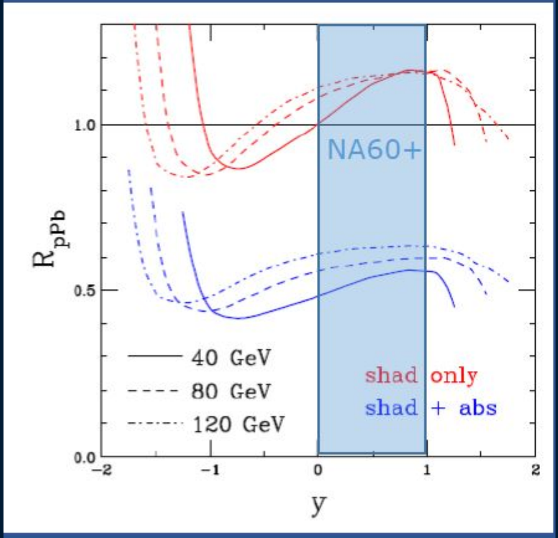
R. Vogt PRC 103, 035204 (2021)
R. Vogt arXiv:2207.04347

Intrinsic charm

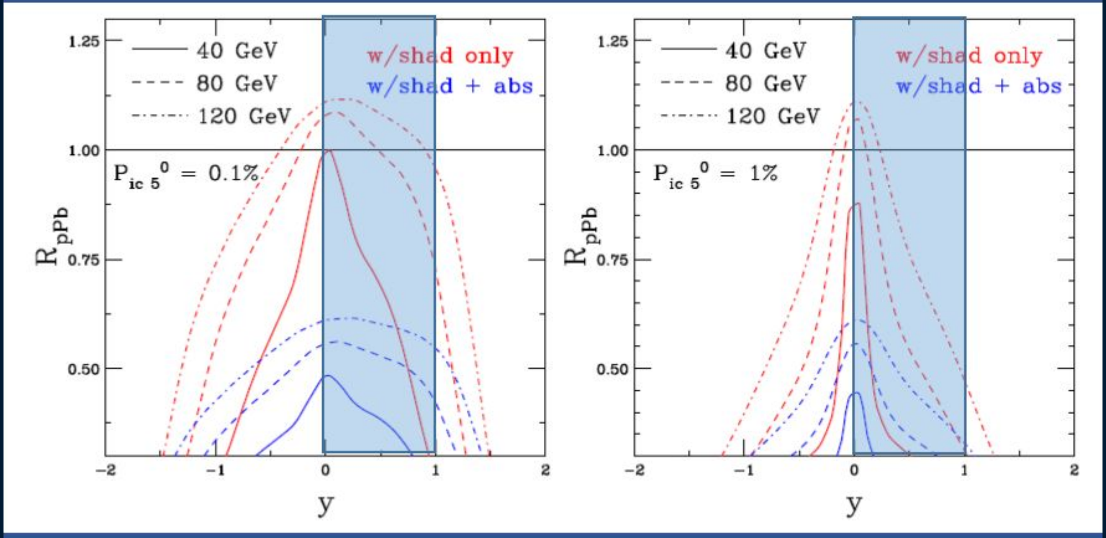
p-Pb collisions:

- EPPS16 shadowing
- σ_{abs} = 9, 10, 11 mb, E_{lab} = 120, 80, 40 GeV
- Intrinsic charm content P_{ic} varied between 0.1 and 1%

without intrinsic charm



with P_{IC} = 0.1% | with P_{IC} = 1%



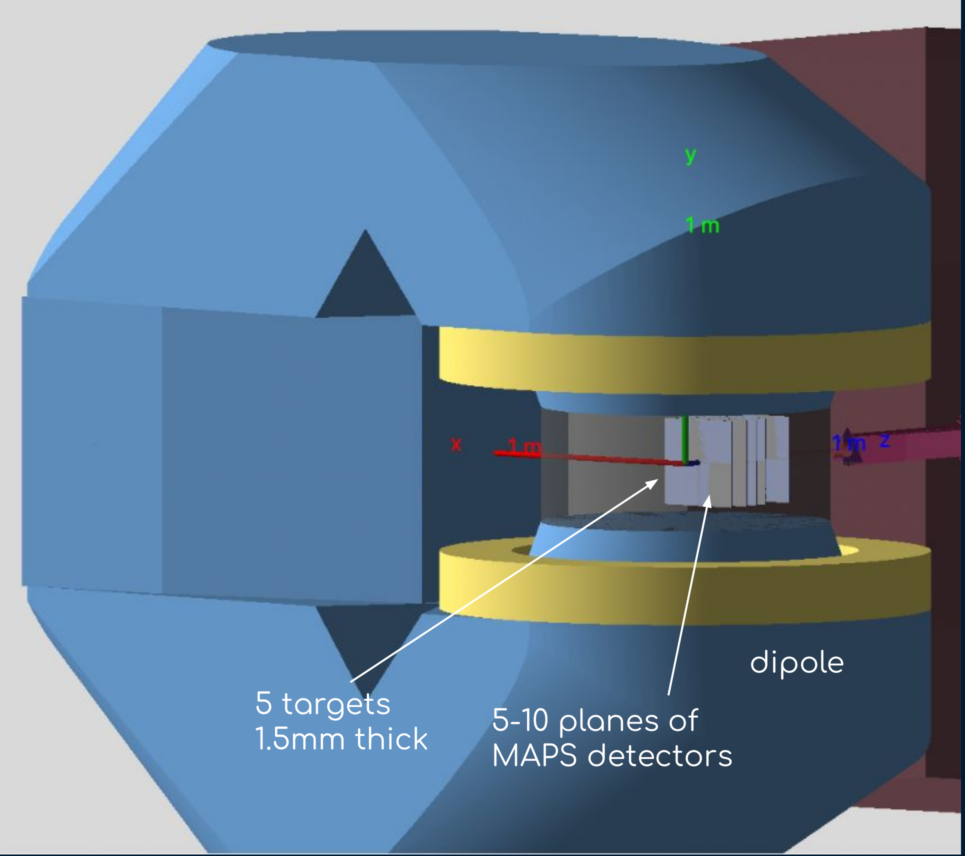
R_{pPb} shape is dominated by intrinsic charm already with P_{ic} = 0.1%

open charm in NA60+

Measurement performed through hadronic decays reconstructed in the vertex telescope

	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%

Combinatorial background reduced via geometrical selection on the displaced decay-vertex topology



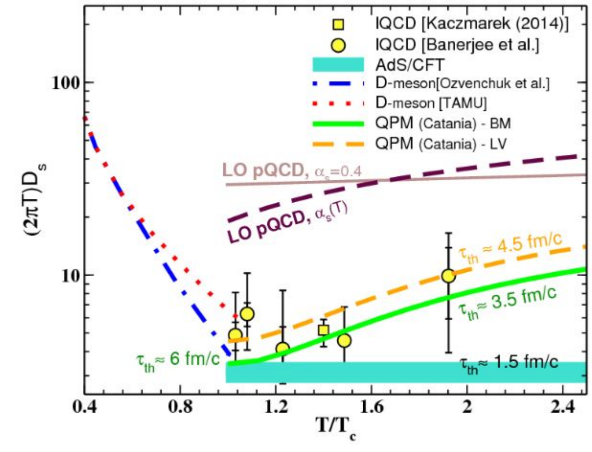
open charm in AA at low √s

1 QGP transport properties

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

At SPS

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

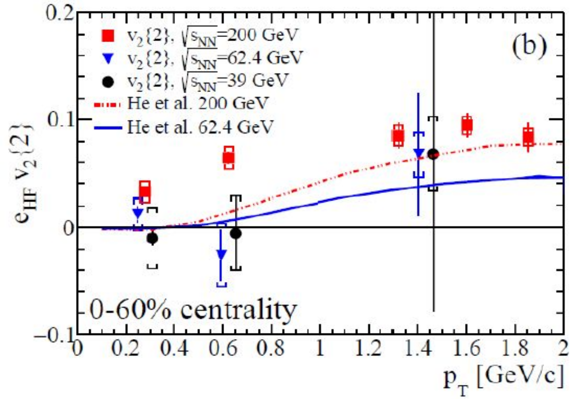


F. Scardina et al. PRC96, 2017 (044905)

2 charm thermalization

Impact on charm of a shorter-lived medium can be explored

- 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



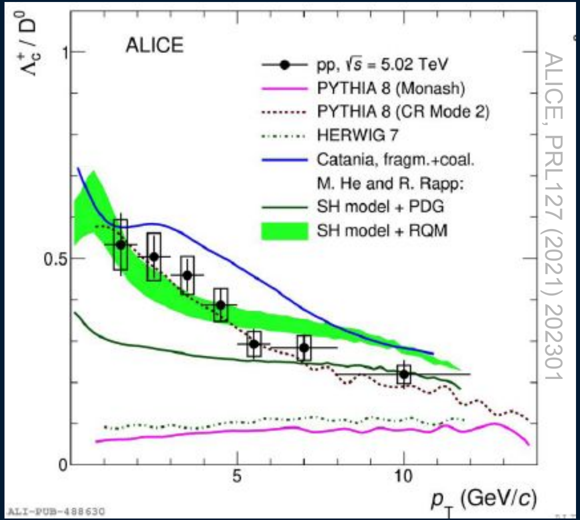
STAR, PRC95 (2017) 034907

open charm in AA at low √s

3 hadronisation mechanisms

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

- 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
  - interesting also in pp and pA, as observed at LHC



ALICE, PRL127 (2021) 202301

4 total charm cross section

Limited measurements so far (NA60,NA49) because of low yields

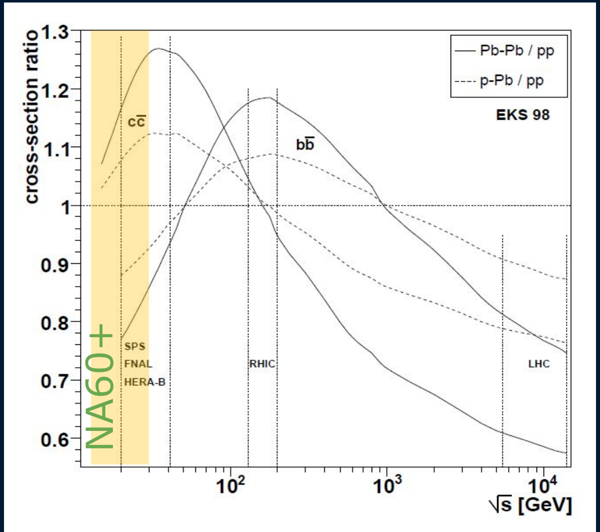
- precise measurement requires to reconstructs mesons and baryons ground states
- ideal reference for charmonia

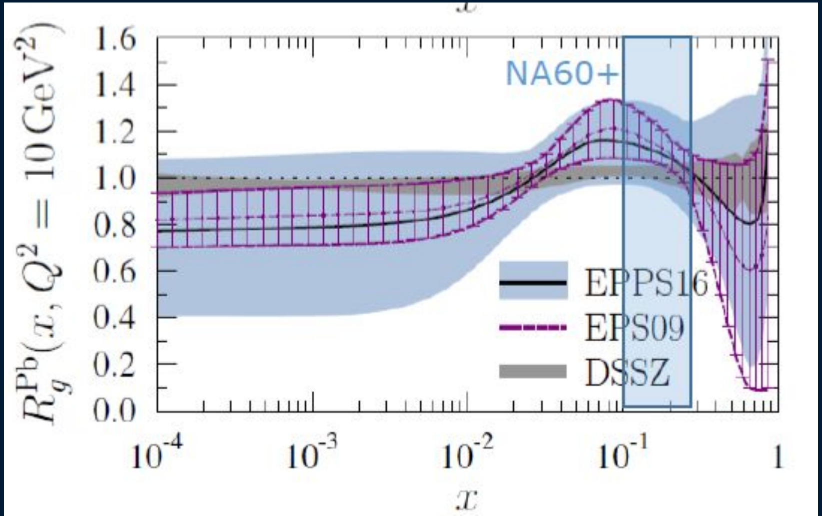
open charm in pA at low √s

5 nuclear PDFs via D meson production in pA

NA60+ will cover the range $0.1 < x_{Bj} < 0.3$ at Q^2~10-40 GeV^2

- EMC and anti-shadowing regions accessible,
- PDFs poorly constrained by existing data



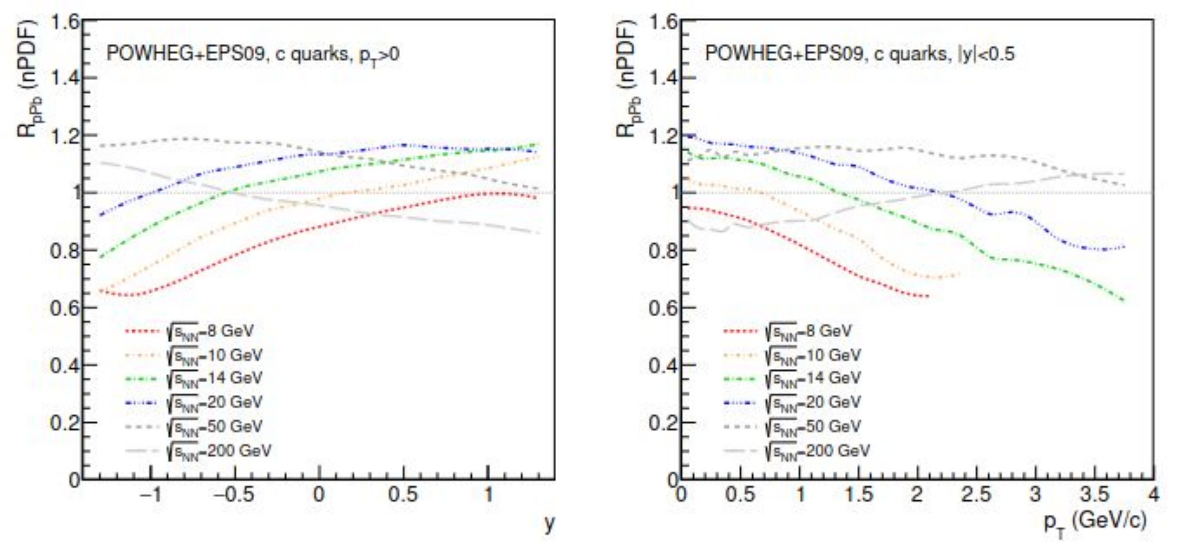


open charm in pA in NA60+

5 nuclear PDFs via D meson production in pA

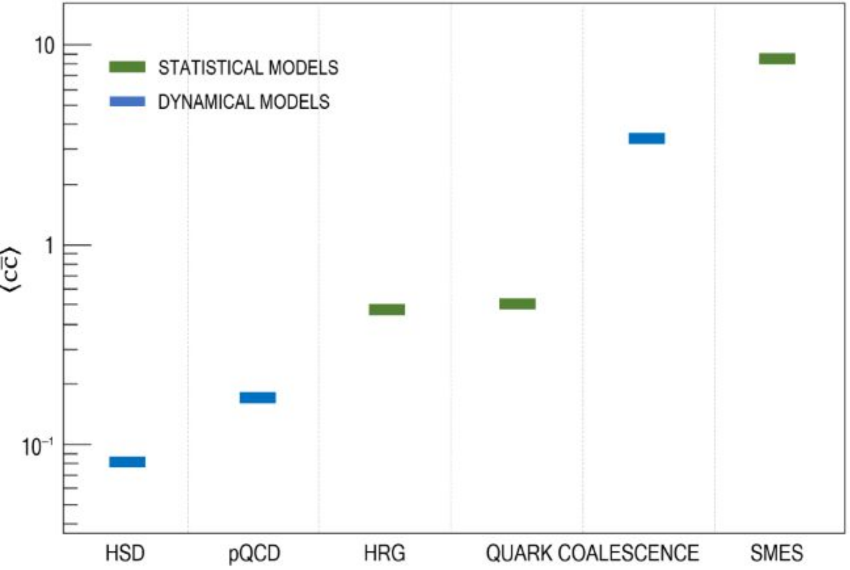
NA60+ will use several nuclear targets, from Be to Pb

- access to the A-dependence of nPDF
- precise inputs to nPDF from D production ratios pA/pBe at different √s, vs y and p_T



Models of charm production

- Predictions of charm yield differ by up to two orders of magnitude for central heavy-ion collisions at the top SPS energy (beam momentum 150*A* GeV/*c*, $\sqrt{s_{NN}}$ = 16.8 GeV);



- Obtaining precise data on $D^0+\bar{D}^0$ is expected to narrow the spectrum of viable theoretical models and thus learn about the charm quark and hadron production mechanisms.

- **HSD:** Hadron-String Dynamics
  O. Linnyk et al. Int. J. Mod. Phys. E 17 (2008), 1367-1439
- **pQCD**: the scaled PYTHIA calculations
  P. Braun-Munzinger et al. Phys. Lett. B 490 (2000), 196-202
- **HRG**: Hadron Resonance Gas Model
  M. I. Gorenstein et al. J.Phys.G 27 (2001) L47-L52
- **Statistical Quark Coalescence**:
  M. I. Gorenstein et al. Phys.Lett.B 509 (2001) 277-282
- **Dynamical Quark Coalescence**: ALCOR and MICOR models extended to charm formation.
  P. Levai et al. J.Phys.G 27 (2001) 703-706
- **SMES**: A statistical model of the early stage
  M. Gazdzicki et al., Acta Phys. Polon. B 30 (1999), 2705

Visible yield of $D^0 + \overline{D}^0$ in 0-20% Xe+La at 150A GeV/c

correction with:	$N_{visible}(D^0 + \overline{D}^0)$
AMPT	0.184±0.032 (stat)
PHSD	0.204±0.036 (stat)
PYTHIA/Angantyr	0.201±0.035 (stat)

$N_{visible}(D^0 + \overline{D}^0)$
0.196 ± 0.035 (stat) **± 0.051** (syst)

-0.5 < y < 1.0
0.2 < p_T< 2.0 GeV/c

Systematic uncertainties include:

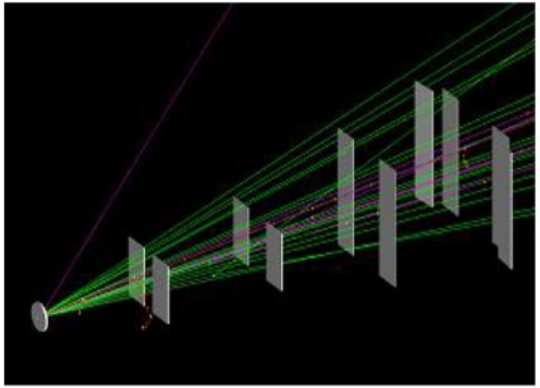
- Model-dependent phase space;
- Track quality cut selection;
- Spatial cuts selection;
- Signal extraction procedure;
- Background fitting procedure.

$\langle D^0 + \bar{D}^0 \rangle$ and dN/dy in 0-20% Xe+La at 150A GeV/c

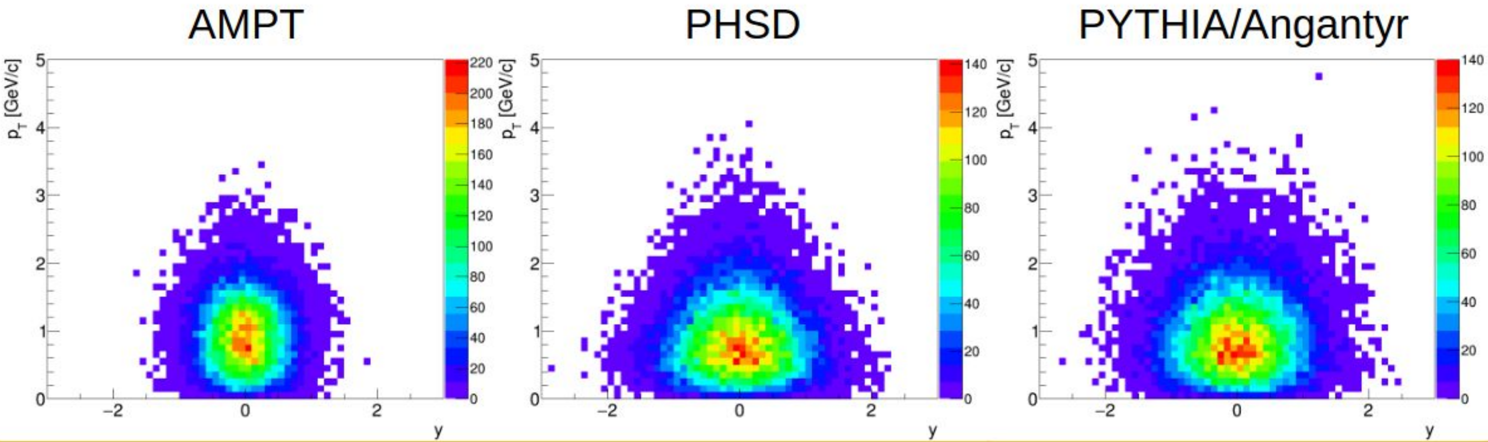
correction with:	$\frac{dN\,(D^0+\bar{D}^0)}{dy}$ for **-0.5 < y < 1.0**	**Yield in 4π** $\langle D^0 + \bar{D}^0 \rangle$
AMPT	**0.129**±0.023(stat) ± 0.035(syst)	**0.218**±0.039(stat) ± 0.060(syst)
PHSD	**0.148**±0.026(stat) ± 0.036(syst)	**0.303**±0.054(stat) ± 0.074(syst)
PYTHIA/Angantyr	**0.147**±0.026(stat) ± 0.037(syst)	**0.300**±0.052(stat) ± 0.075(syst)

- Extrapolation factors for AMPT significantly differ from PHSD and PYTHIA/Angantyr due to different phase space distribution of $D^0+\bar{D}^0$:
  AMPT: 84.1% of all $D^0+\bar{D}^0$ are in the selected $y - p_T$ bin
  PHSD: 67.4%
  PYTHIA/Angantyr: 66.9%

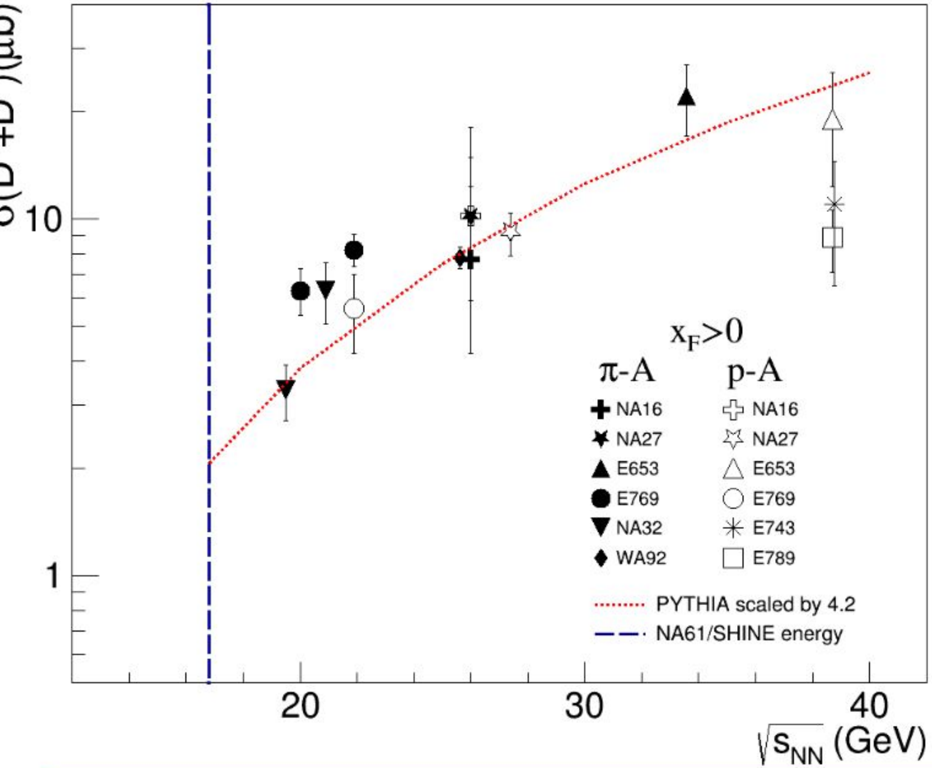
Simulations in GEANT4



- For obtaining the corrections the simulation in GEANT4 was performed:
  - The background was described using the EPOS model;
  - The signal phase space was parametrized using 3 models;
  - The yield of $D^0+\overline{D}^0$ from the models not used;
  - Parametrized signal is used to enrich background event.



Estimation of $\langle D^0 + \bar{D}^0 \rangle$ for Xe+La from p+A data



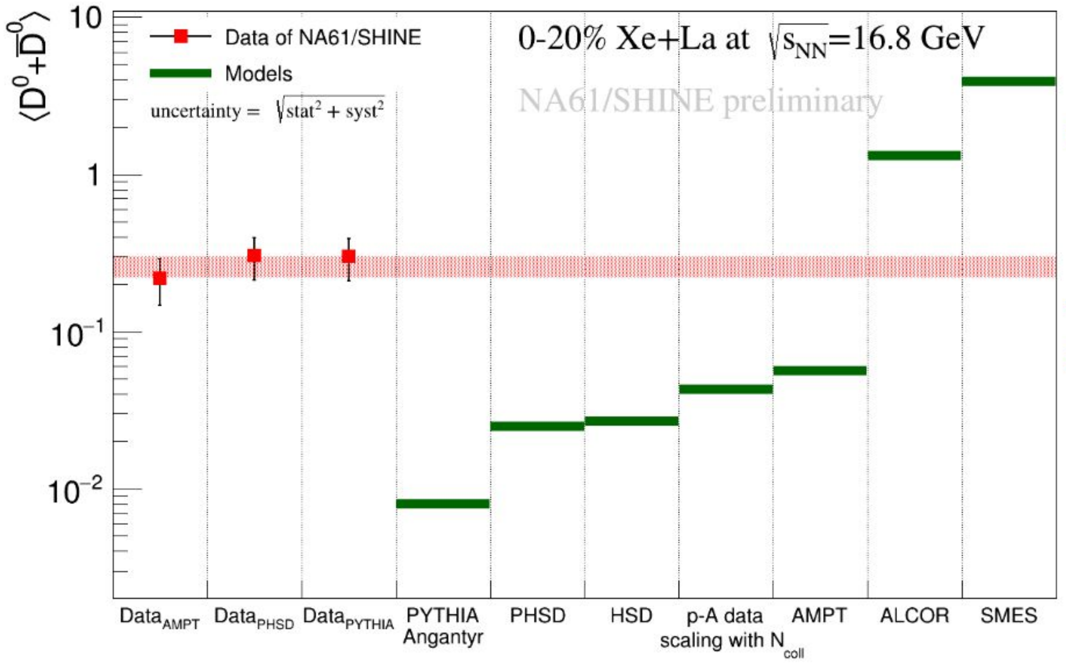
- Fit *p*+A data with PYTHIA:
  - PYTHIA reasonably describes energy dependence;
  - PYTHIA underestimates the $D^0+\bar{D}^0$ production cross-section by the factor 4.2.

- One can estimate $D^0+\bar{D}^0$ yield for Xe+La at $\sqrt{s_{NN}}$= 16.8 GeV from the extrapolation of *π*+A and *p*+A data:

$$\langle D^0 + \bar{D}^0 \rangle = 2 \times \frac{\sigma_{D^0+\bar{D}^0}}{\sigma_{inelastic\ for\ p+p}=32\text{mb}} \times N_{coll} = 0.043$$

Xe+La 0-20% N_{coll} = 331.1

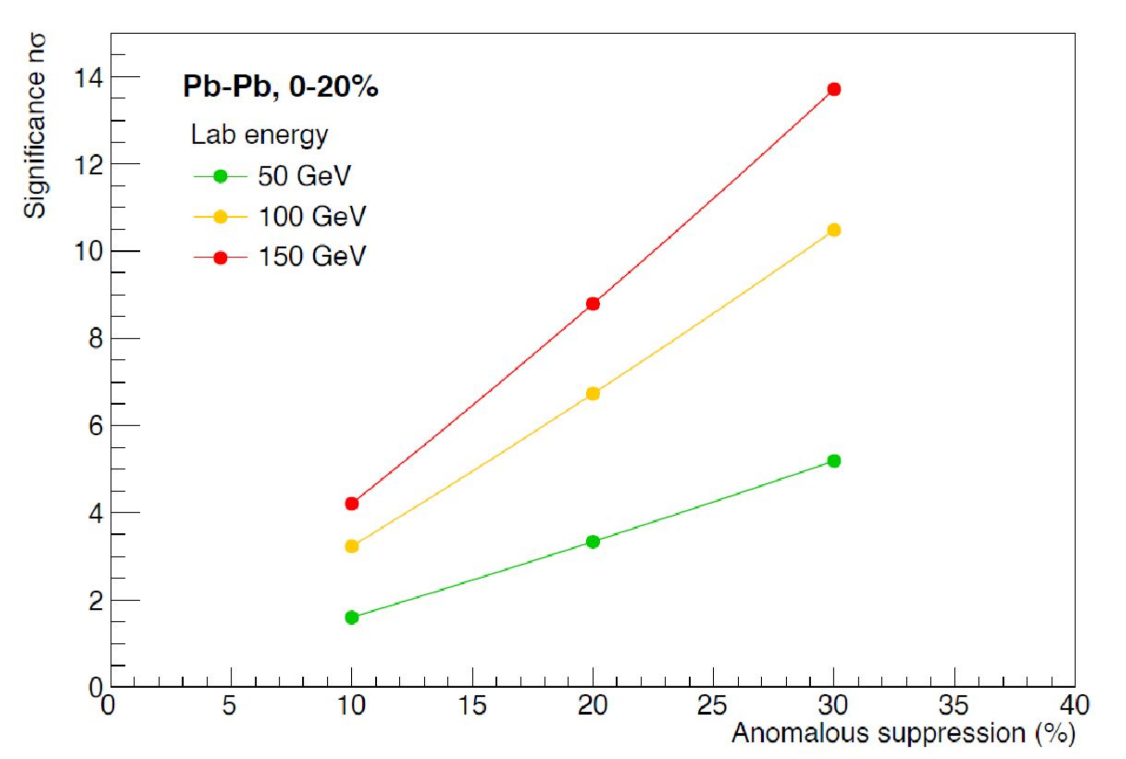
Comparison of $\langle D^0 + \bar{D}^0 \rangle$ with models



Red band indicates theoretical uncertainty of the obtained result.

- Precision of the data is sufficient to discriminate between extreme model predictions;
- The dynamical microscopic models (Pythia, PHSD, HSD) significantly underestimate $\langle D^0 + \bar{D}^0 \rangle$ while ALCOR and SMES overestimate it;
- AMPT predicts value slightly (~2σ) lower;
- The obtained results are above *p*+A extrapolation at the level of ~2-3σ:
  - Imprecision of the extrapolated *p*+A cross-section;
  - Imprecision of the obtained result due to unknown phase space;
  - Hadronisation in A+A vs *p*+A?
  - Fermi-motion?
  - N_{coll} or N_{part} scaling?

SMES: scaled from 0-20% Pb+Pb using N_{part} = 173.7/272.5
ALCOR (Dynamical Quark Coalescence): scaled from *J.Phys.G 27 (2001) 703-706* using N_{coll} = 331.1/598.8



Pb-Pb, 0-20%
Lab energy
50 GeV
100 GeV
150 GeV
Significance nσ
Anomalous suppression (%)
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30
35
40

Open charm

SPS

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
- new NA61 result (Xe-La, $\sqrt{s_{NN}} = 16.8$ GeV)

NA60+:

measurement performed through hadronic decays reconstructed in the vertex telescope
(combinatorial background reduced via topological cuts)

1 QGP transport properties

charm diffusion coefficient depends on the medium T, being larger in the hadronic than in QGP phases

2 charm thermalization

impact on charm of a shorter-lived medium can be explored

3 hadronization mechanisms

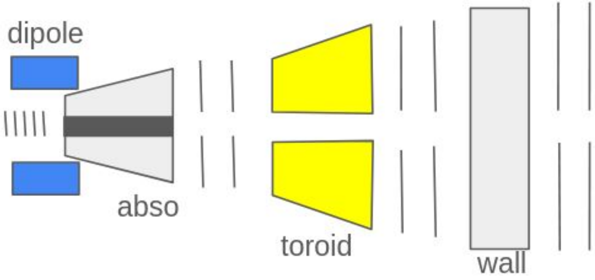
measure the relative abundances of charm-hadrons (D^0, D^+, D^+_s mesons and Λ_c baryons) in a high μ_B environment

4 total charm cross section

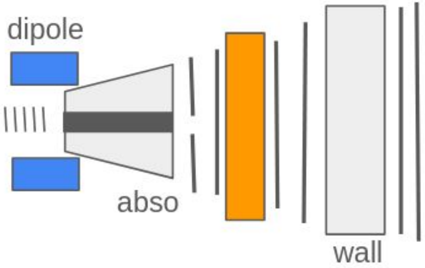
limited measurements so far because of low yields

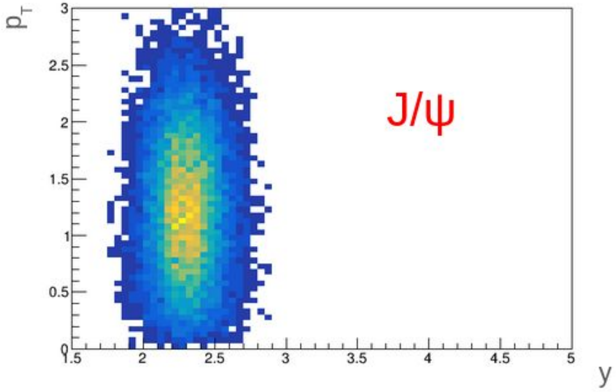
Preliminary physics performance studies: $J/\psi \rightarrow \mu^+\mu^-$

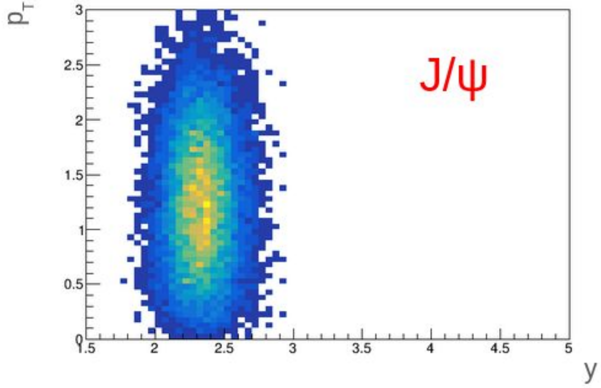
- Toroidal magnets have a significant dead-zone at small angle, that affects the measurement of relatively soft particles (in our case, dimuon and Dalitz-decays of hadronic resonances)
- This limitation is removed with the use of a dipole



Acceptance for high-mass hadrons does not change significantly, harder muons less affected by the toroid dead zone







Preliminary physics performance studies: $\omega \to \mu^+\mu^-$

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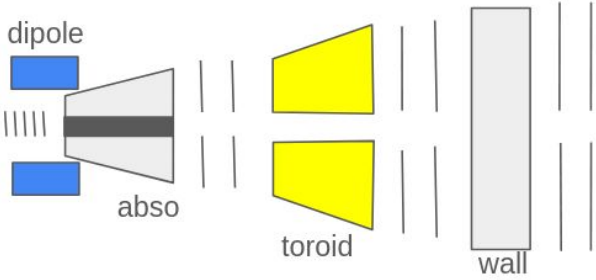
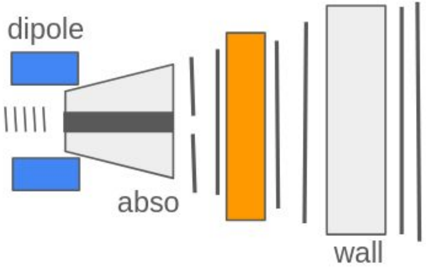
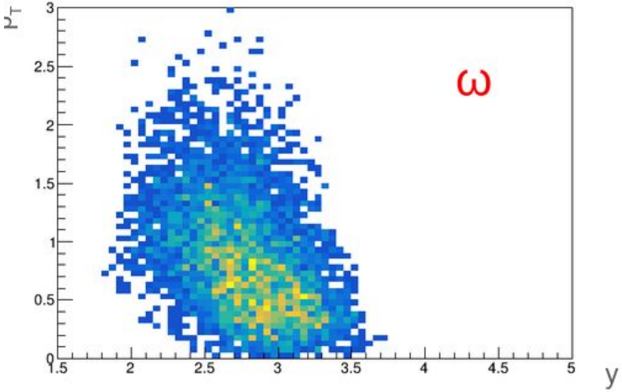
- This limitation is removed with the use of a dipole

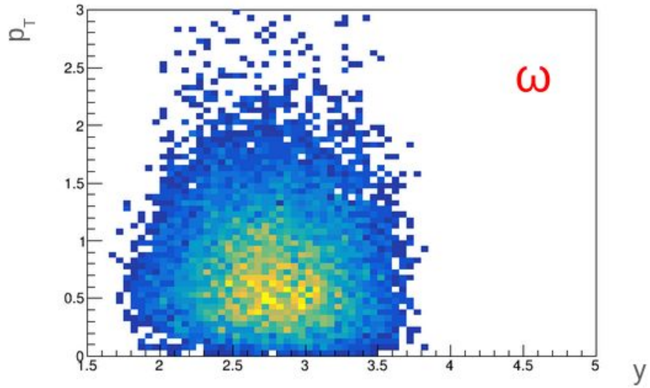


Very significant increase of the acceptance in particular at low mass/low pT



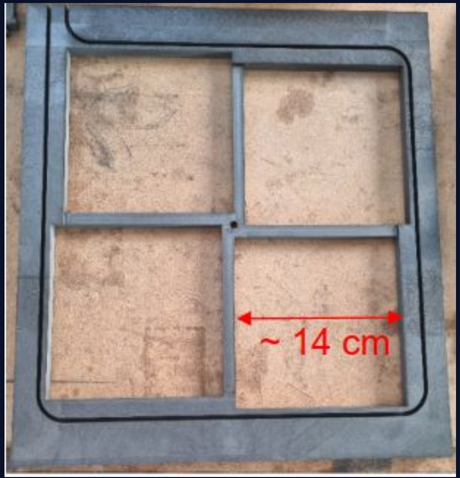


factor ~3 increase

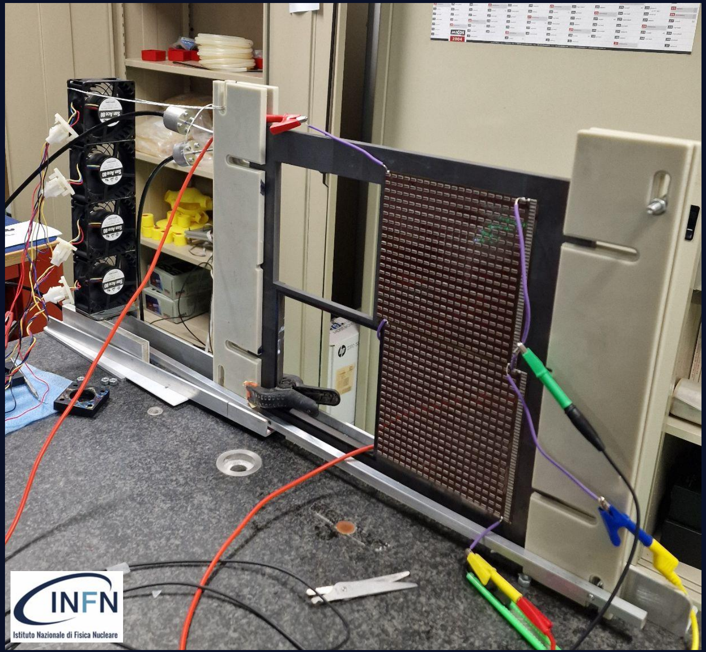


The vertex telescope

Each plane is composed by 4 sensors, to be glued on a graphite frame



Air and water cooling is foreseen



Lab measurements using PCB with resistor array to mimics MOSAIX power dissipation

The toroidal magnet

Warm toroid

- 8 sectors with 36 turns per coil
- light design → low material budget in the acceptance area

Prototype (1:5 scale)
built and tested to check calculations and investigate mechanical solutions

→

Design of the full-scale magnet (including mechanics) ongoing, CERN/TE-MSC