The NA60+ experiment at SPS

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הפקולטה לפיסיקה

for the NA60+ Collaboration

HP2024 NAGASAKI

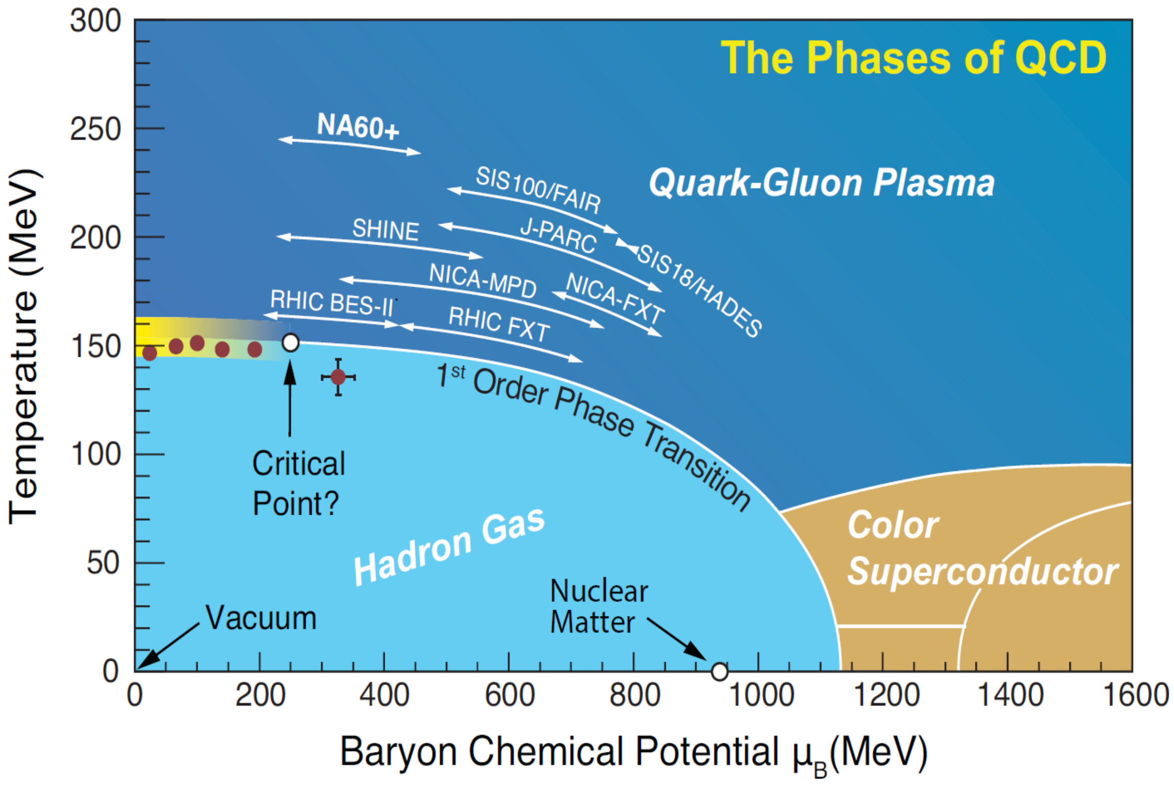
The NA60+ project

New experiment at the CERN SPS to explore the QCD phase diagram at high baryon chemical potential (μ_B)

NA60+ will perform precision studies of hard and electromagnetic processes

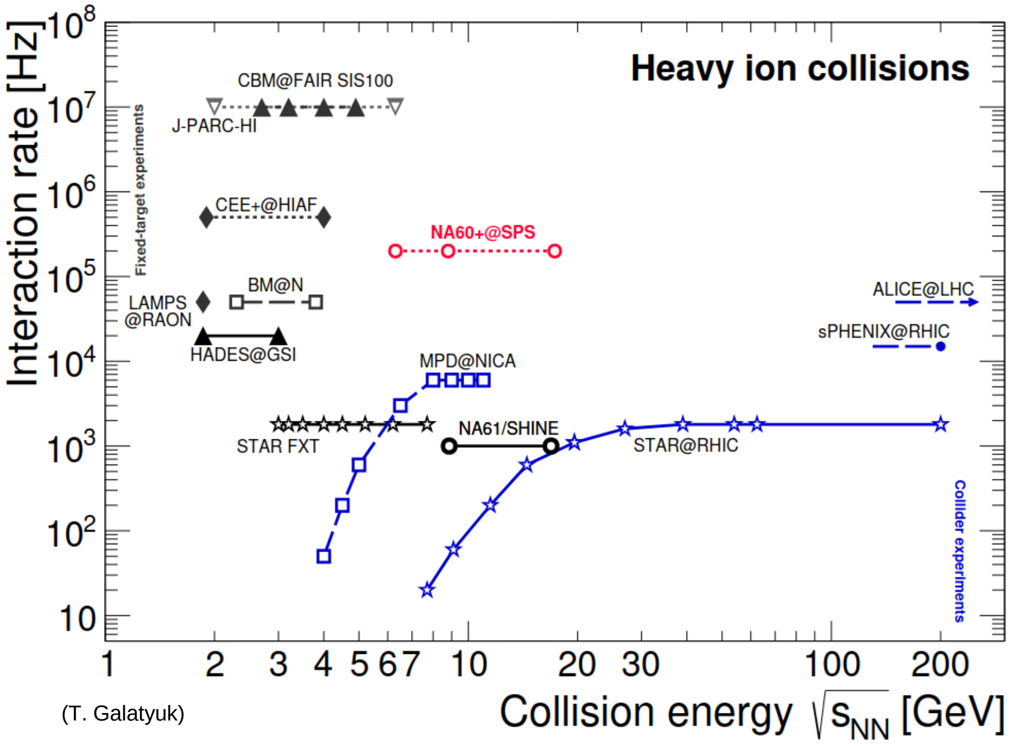
- accessing muon pair production from threshold up to $m_{\mu\mu} \sim 4$ GeV/c^2 (dilepton continuum + quarkonia)
- measuring hadronic decays of strange and charm hadrons

A beam energy scan between $\sqrt{s_{NN}} \sim 6 - 17$ GeV will allow us to access the μ_B region ~220 - 550 MeV



Uniqueness of NA60+

The NA60+ program needs a large luminosity to search for rare QGP probes



(T. Galatyuk)

This luminosity can be collected with Pb+Pb interaction rates $>10^5\ s^{-1}$, reachable with $10^6\ s^{-1}$ beam intensity in a fixed target environment

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

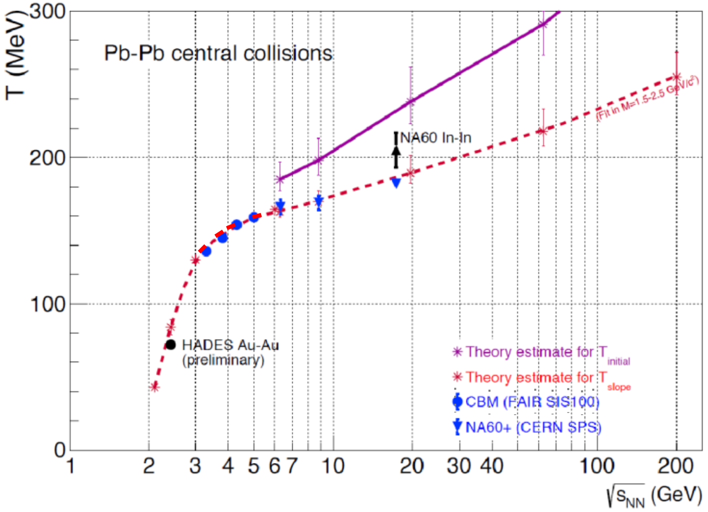
NA60+ is complementary to experiments accessing different (hadronic) observables in the same energy range (STAR BES, NICA, NA61) and similar observables in a lower energy range (CBM)

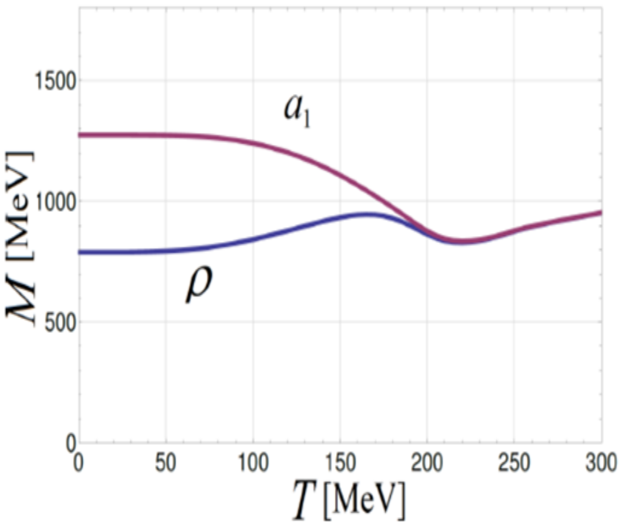
The NA60+ physics program

Caloric curve of QGP

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

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





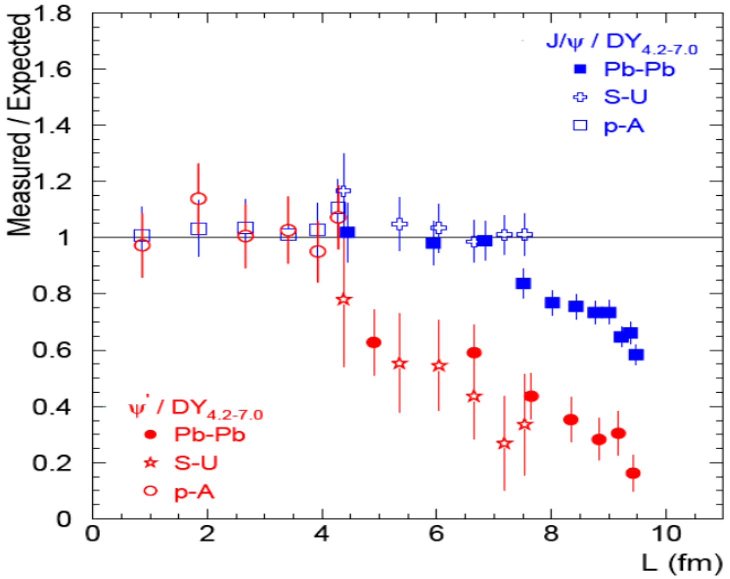
Chiral symmetry restoration via ρ-a_1 mixing in the dimuon channel

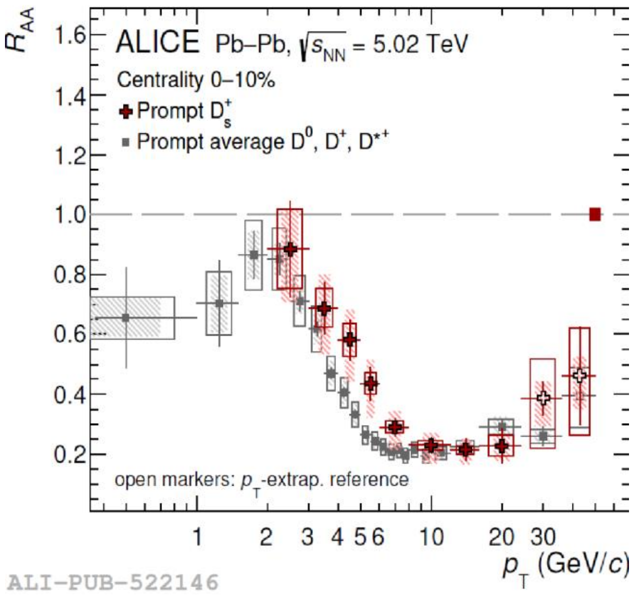
C. Jung et al., PRD 95 (2017) 036020

Suppression of charmonium vs . $\sqrt{s_{NN}}$ in dimuon decay channel

$c\bar{c}$ melting in QGP

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



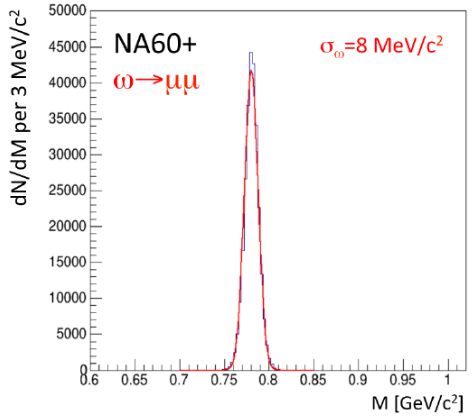


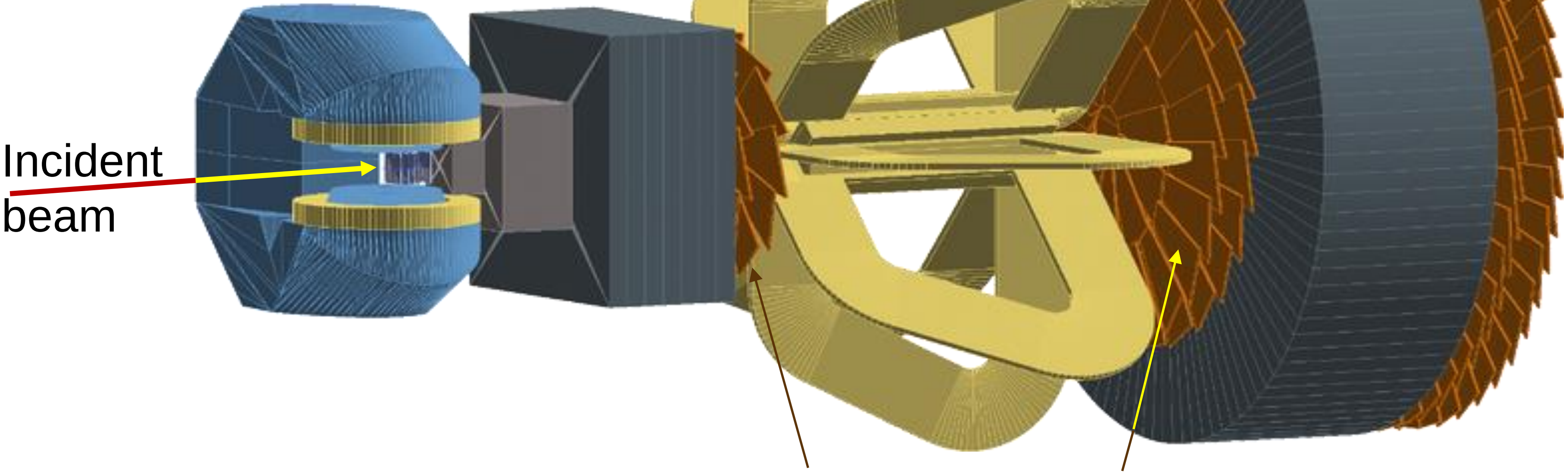
Hadronic decays of open HF to measure QGP transport coefficients and charm hadronization

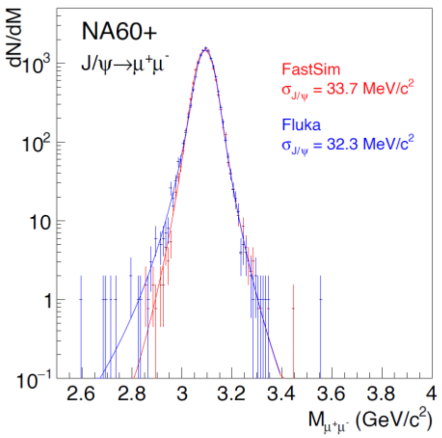
ALICE, PLB 827 (2022) 136986

The NA60+ apparatus

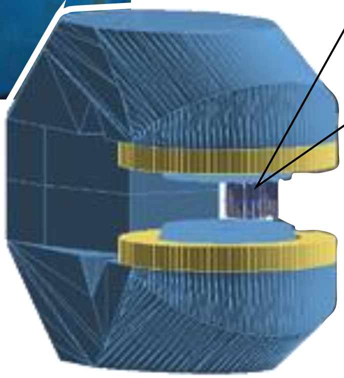
IR → Vertex telescope → Absorber → Muon spectrometer → Absorber → Muon Identifier



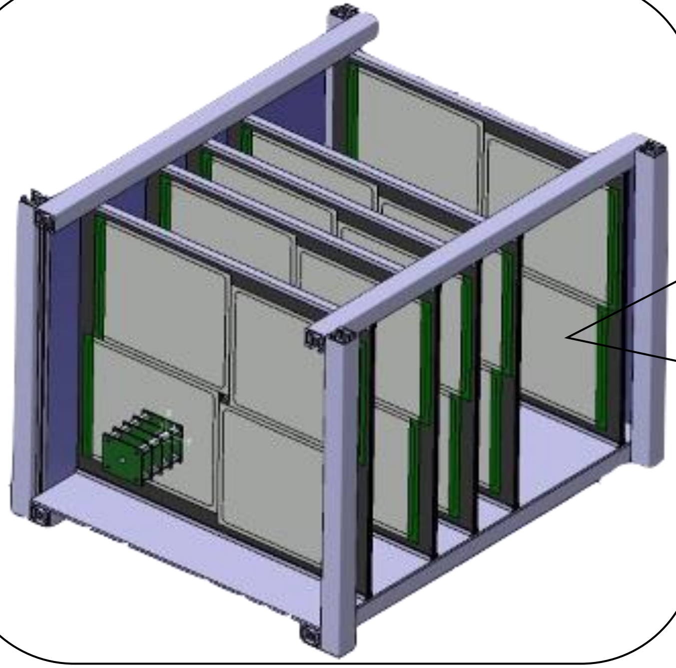


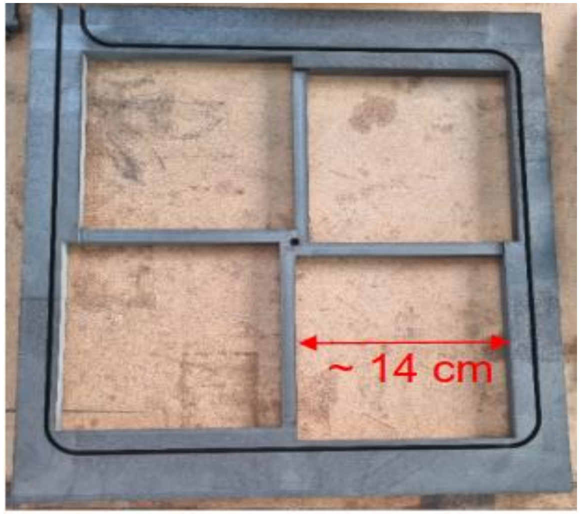


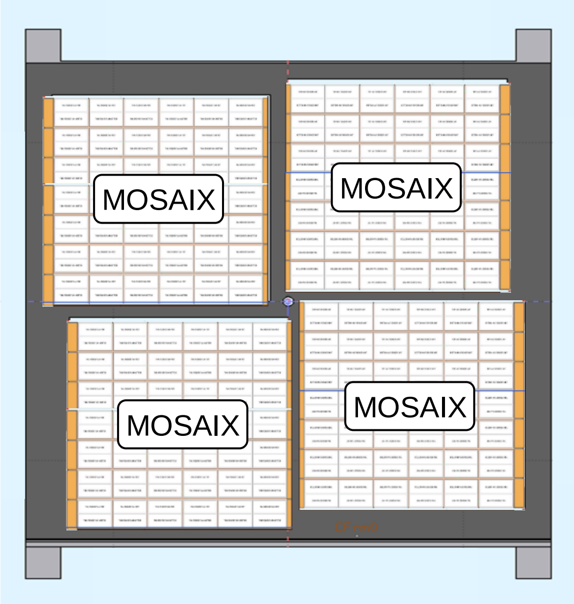
The vertex telescope



MEP48
B = 1.5 T
bore 400 mm



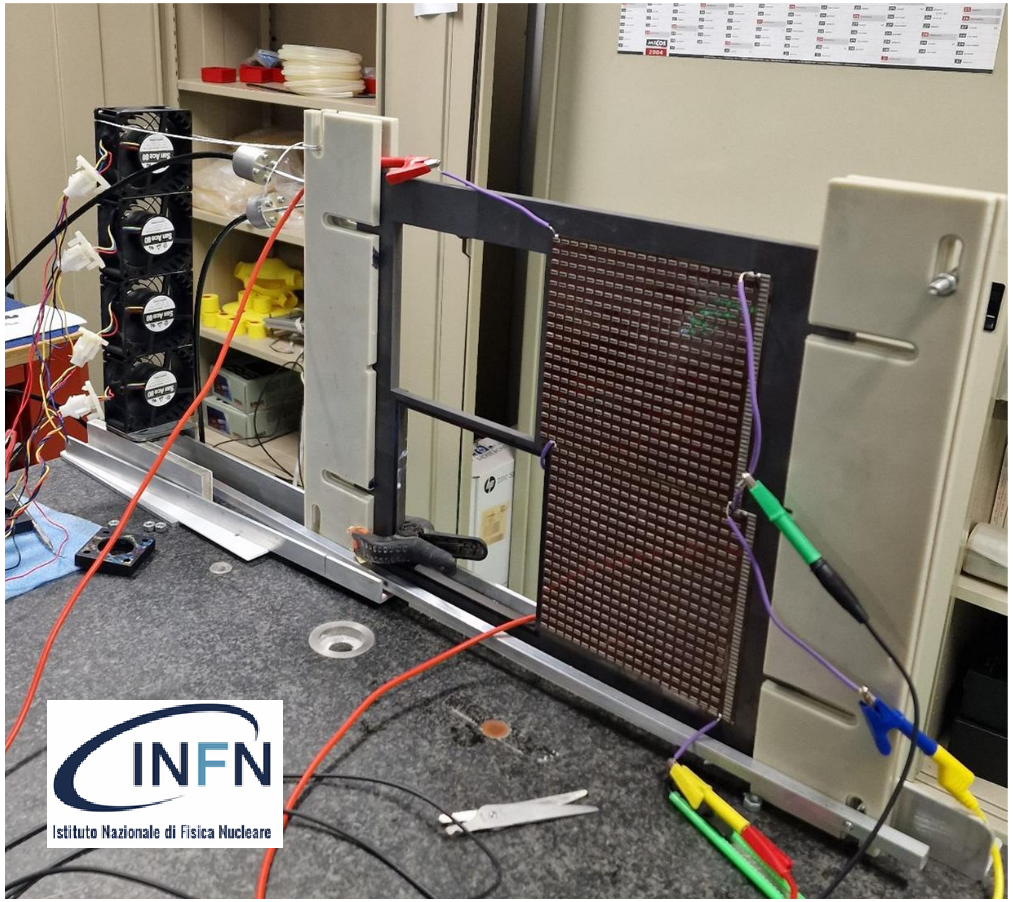


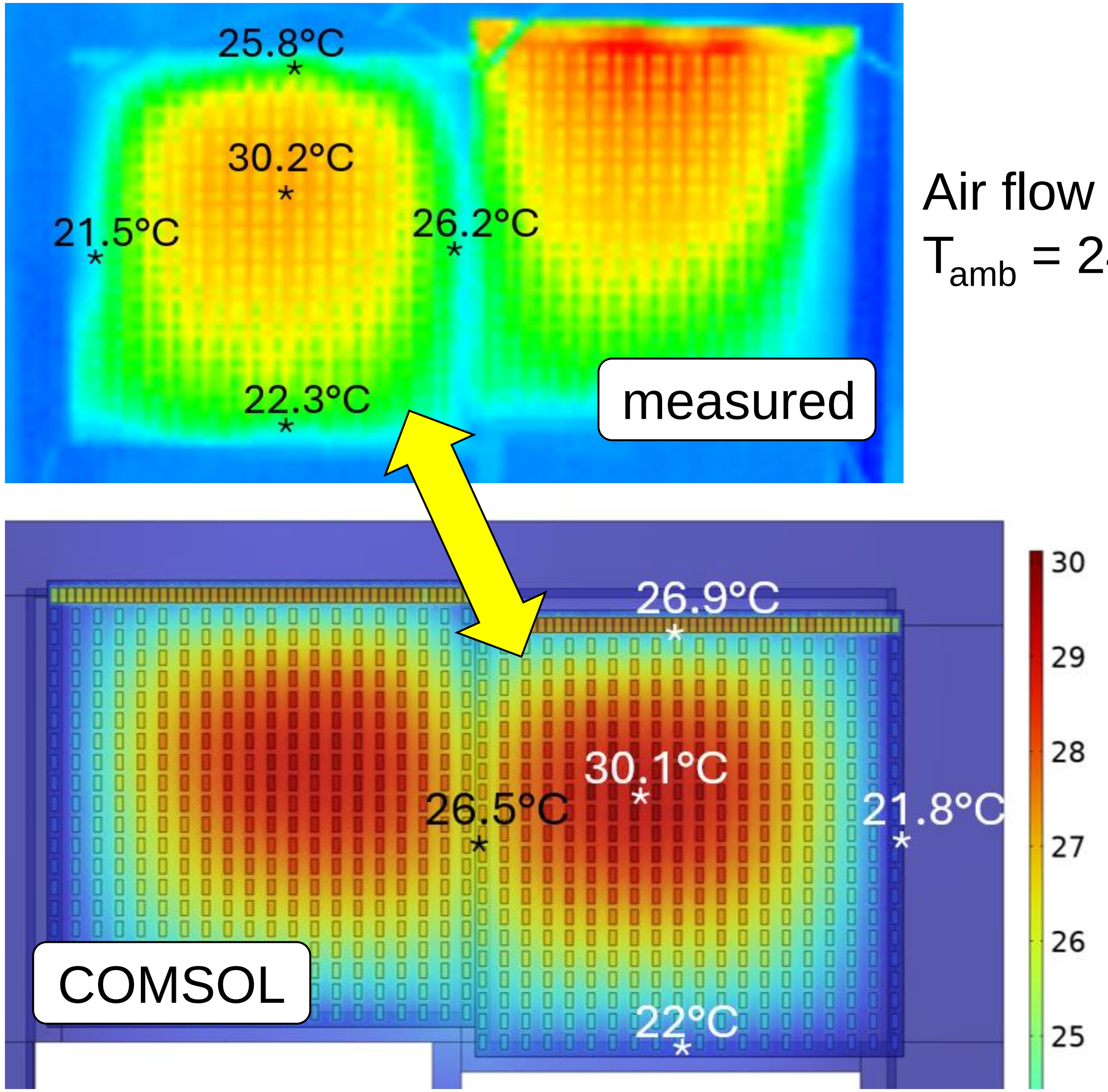


5 layers of MAPS detectors, joint development with ALICE ITS3
The sensor is based on 25 mm long units, replicated and stitched together
Sensors 15 x 15 cm^2 have a thickness of 0.1% X_0 and resolution 5 μm
Each plane is composed of 4 sensors glued on a graphite frame
The first large-area sensor (MOSAIX) is expected next year

The vertex telescope: cooling

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



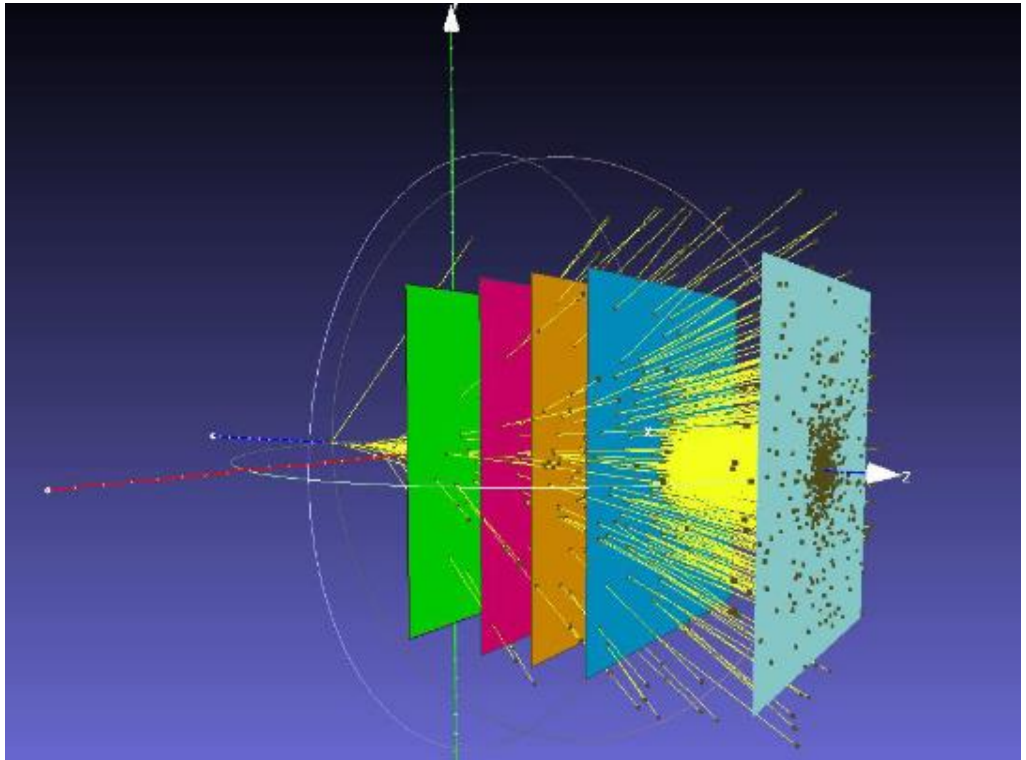


Air flow 1 m/s
T_{amb} = 24° C

Tracking with ACTS

ACTS is an experiment-independent toolkit for particle track reconstruction in HEP experiments

Currently developing track reconstruction in the vertex telescope and muon spectrometer



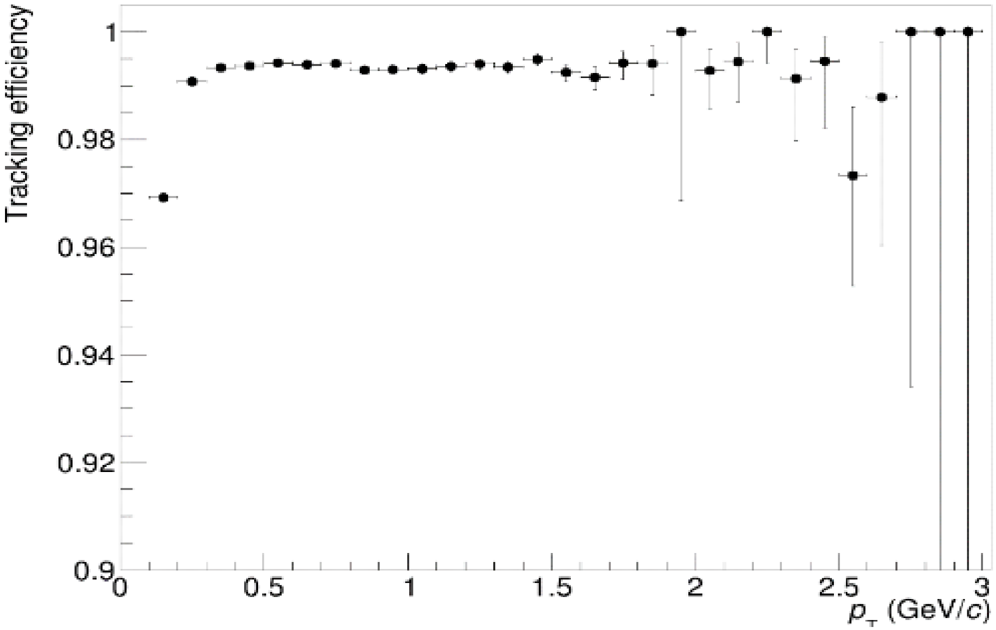
(event display showing background particles in

Realistic multiplicities and kinematics from NA49

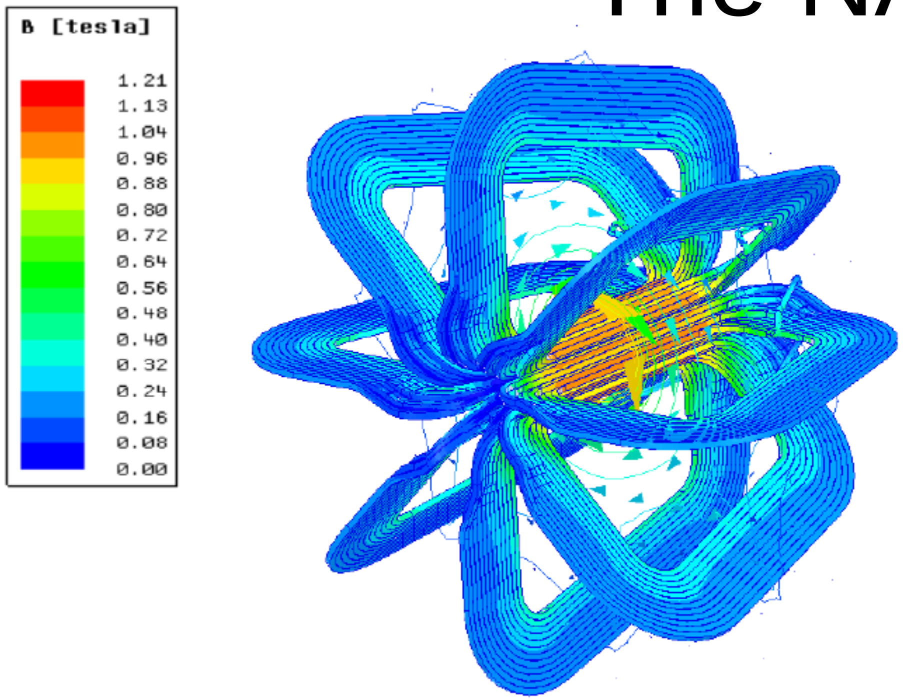
Results agree with Fast Sim studies used for LoI

Two-step reconstruction: primary particles followed by reconstruction of secondaries.

High reconstruction efficiencies for both types

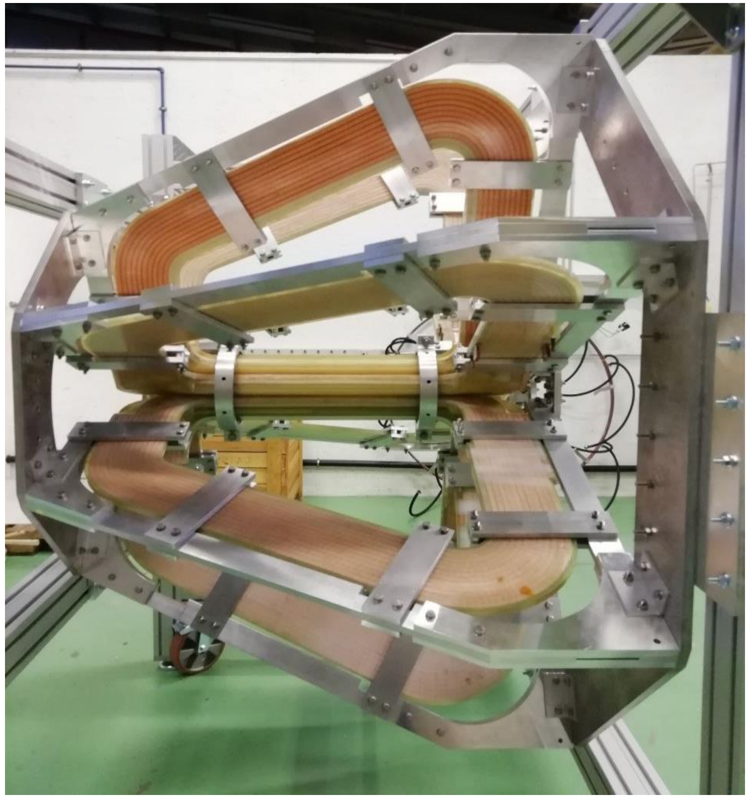


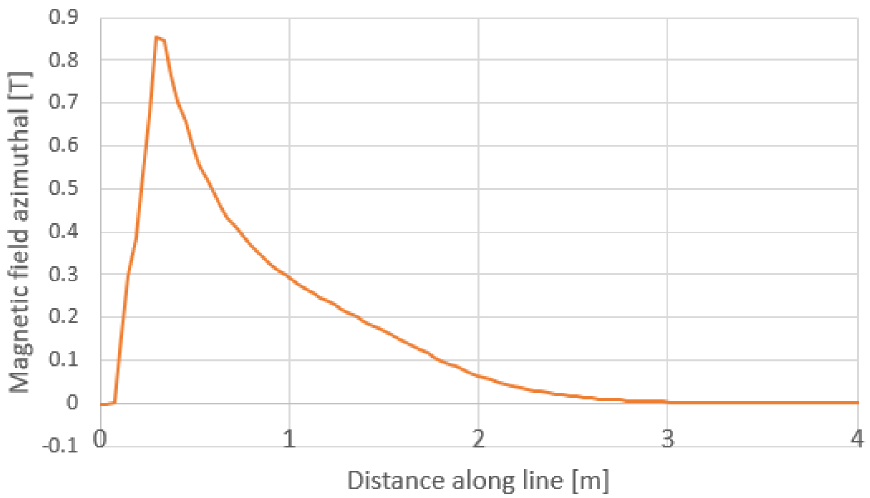
The NA60+ toroid: prototype



Warm magnet

8 coils,
12 turns per coil
16.6 kA operational current
Square copper conductor with water cooling in the center

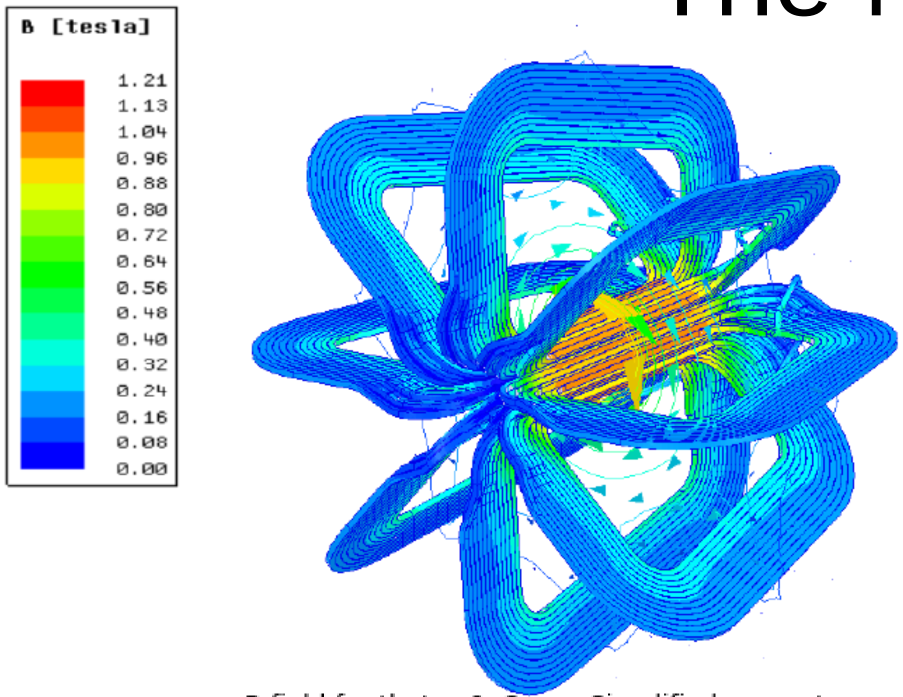


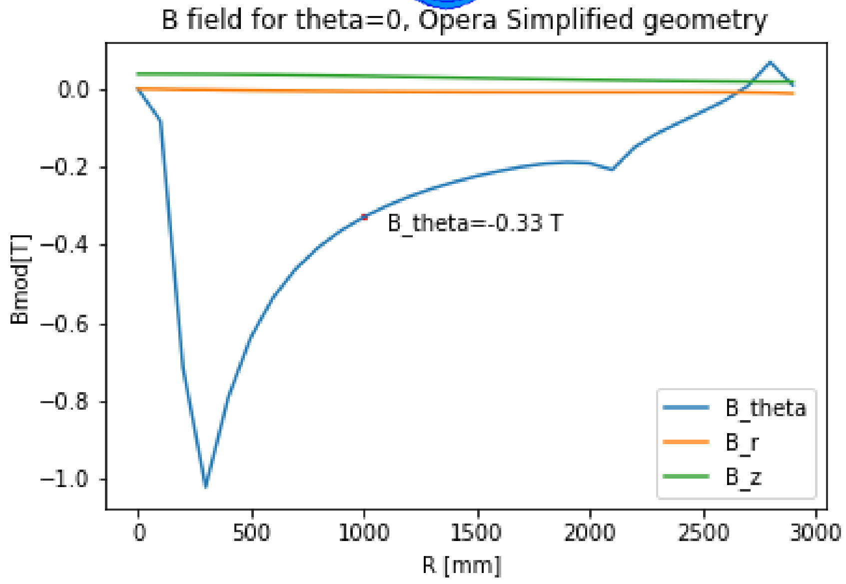


1:5 scale prototype

Measurements of resistance, inductance, cooling performance, and magnetic field were carried out
Filed measurement agreement with simulations by 3%

The NA60+ toroid: design

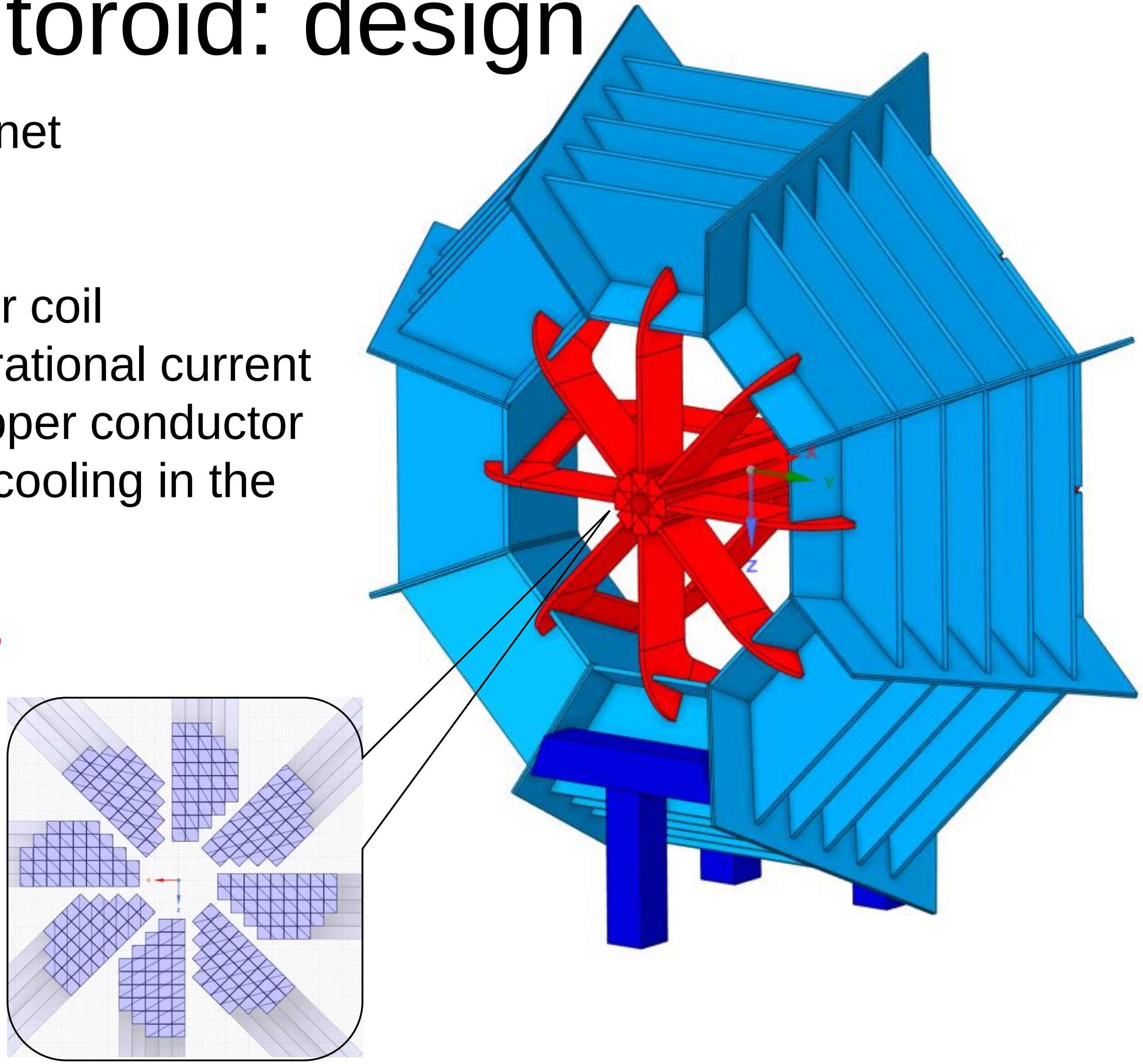




Warm magnet

8 coils,
36 turns per coil
5.5 kA operational current
Square copper conductor with water cooling in the center

~3.8 MChF



The NA62 dipole

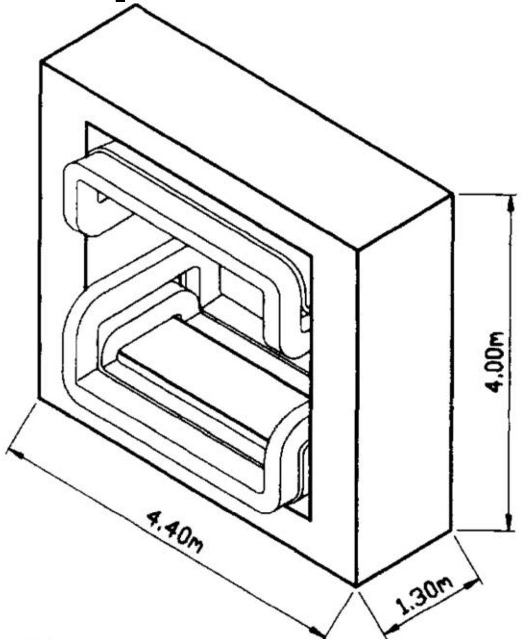
The NA62 experiment completes its experimental program in 2026

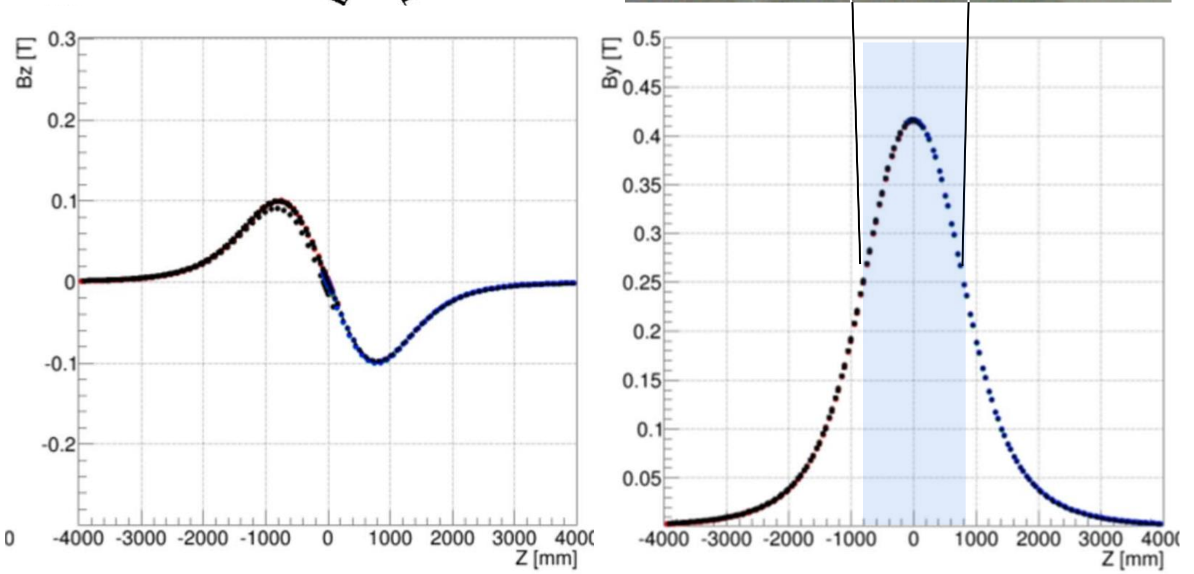
The experiment uses the MNP33 dipole magnet with additional coils

It’s a dipole with a rather extended field

Pros	Cons
Larger acceptance for soft muons	Need powering two coils
Compactness	Lower $\int Bdl$
No price tag	

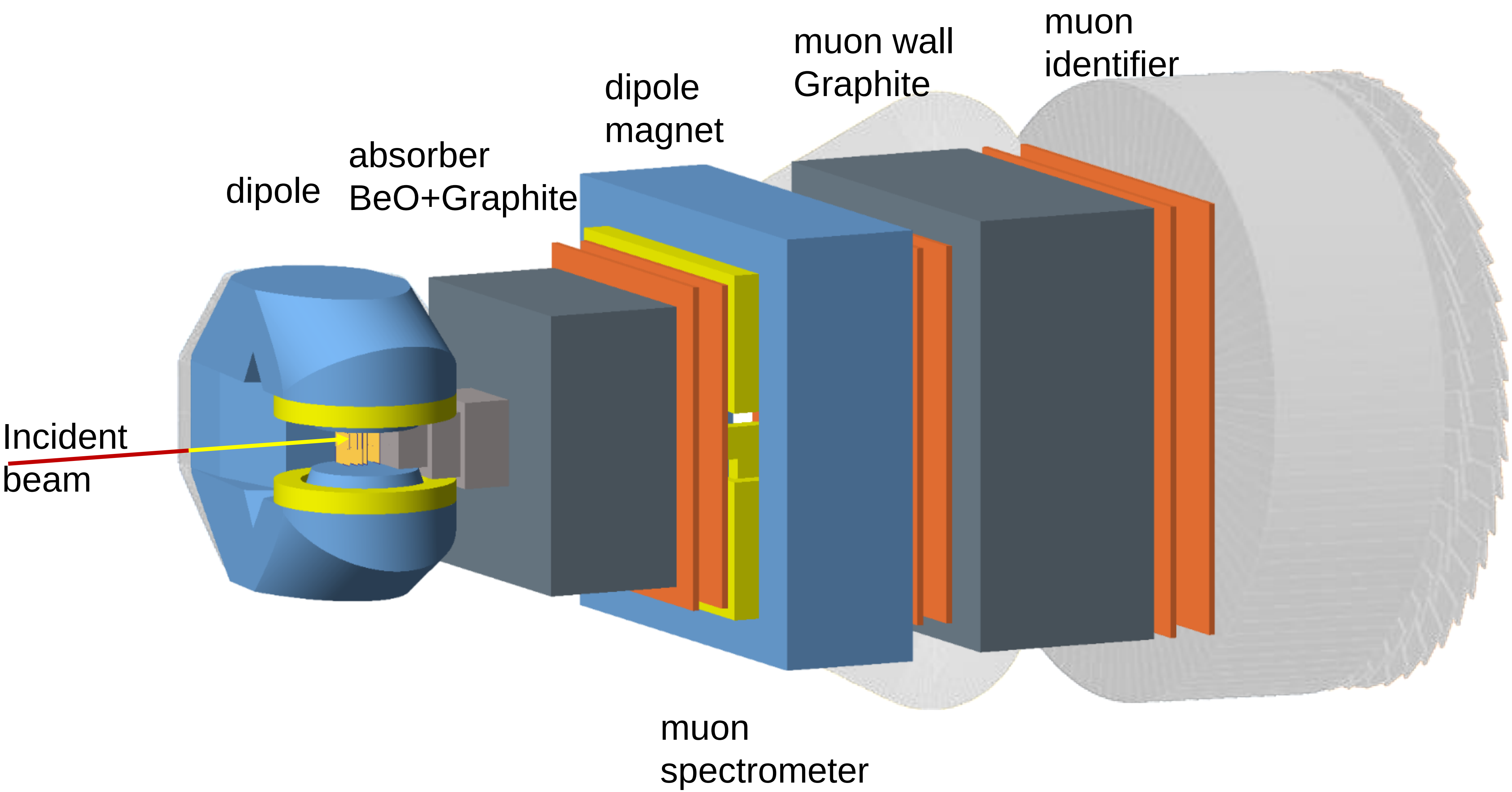
In the real world, the dipole wins 3.8:0





J. Phys. G: Nucl. Part. Phys. 43 (2016) 125004

Meet the new NA60+ setup!



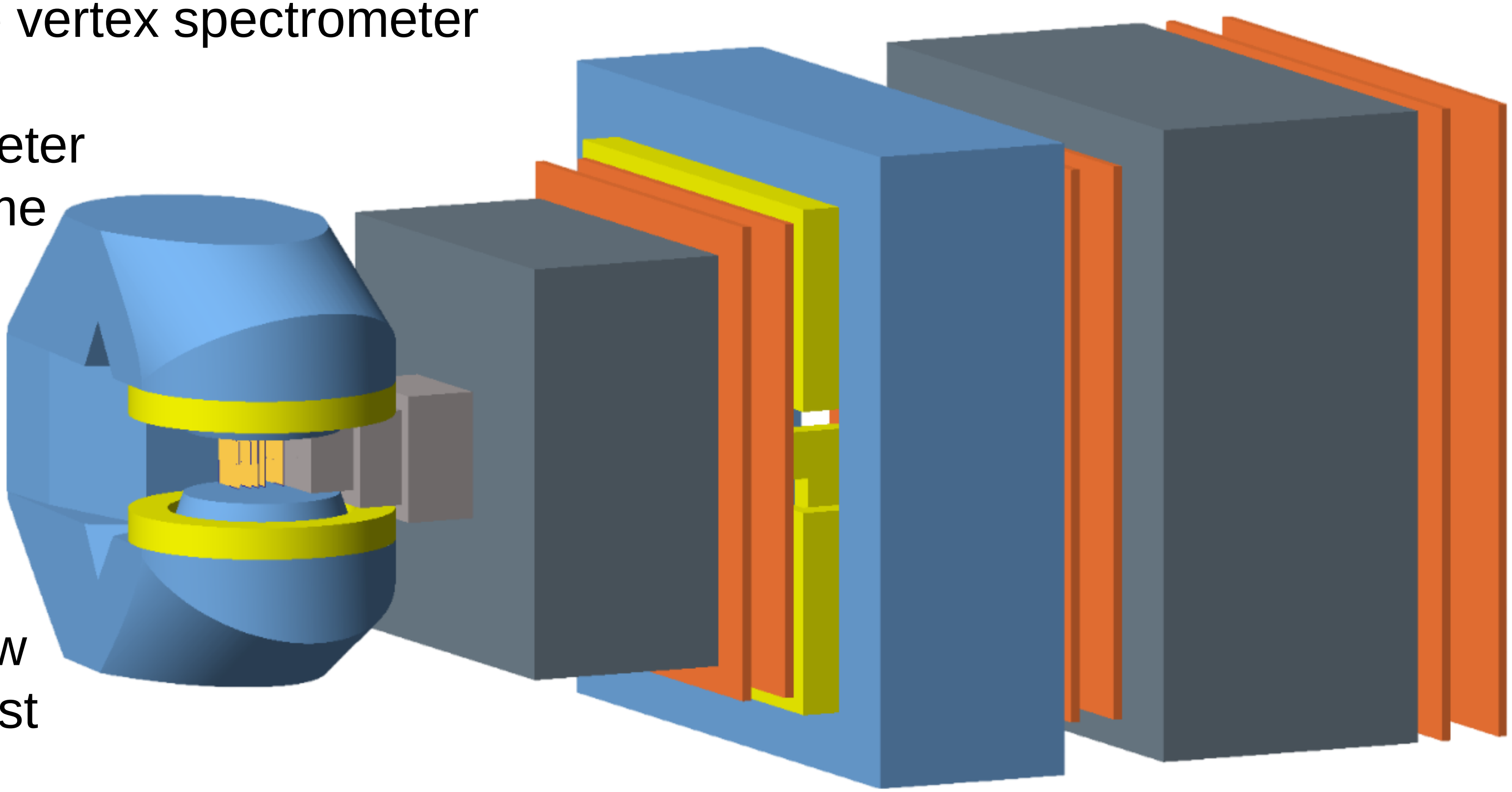
NA60+ setup

Radiation protection to be reconsidered

No effect on the vertex spectrometer

Muon spectrometer can use the same technology in a different geometry

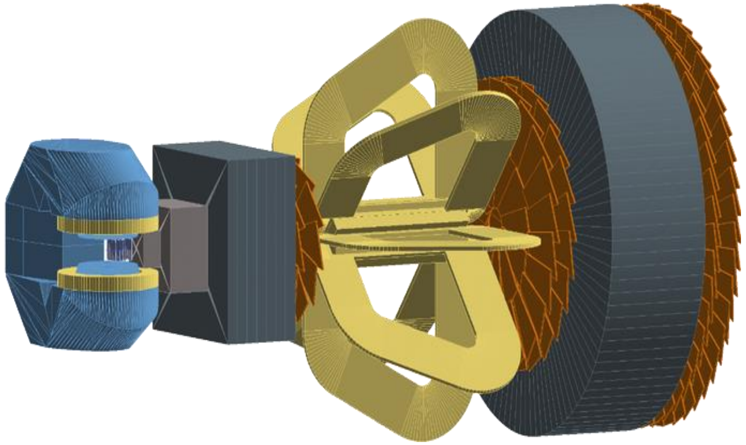
Multiple other changes to optimize the new setup for the best performance

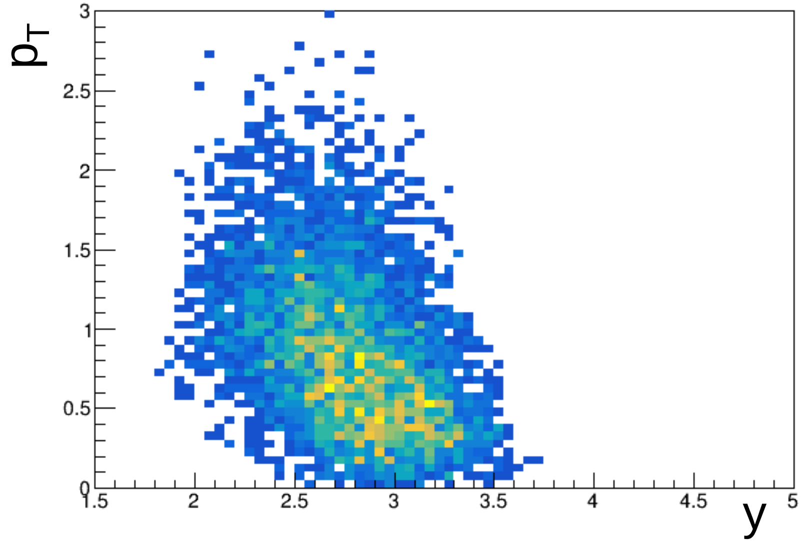


Using the MNP33 magnet resolves the most critical financial obstacle in building the NA60+ experiment

Preliminary performance for $\omega \rightarrow \mu\mu$

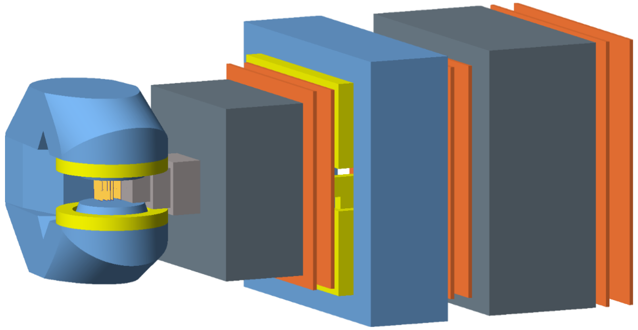
The toroidal magnet has a significant dead zone at small angles. In the previous configuration, soft muons from low- and intermediate-mass processes were affected, which is now improved. Acceptance of heavy hadrons changes less since harder muons avoid the dead zone

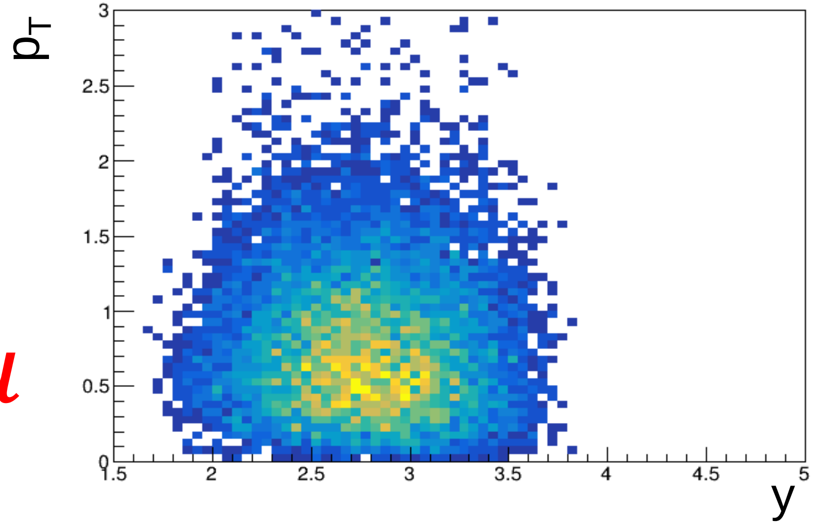




factor 3

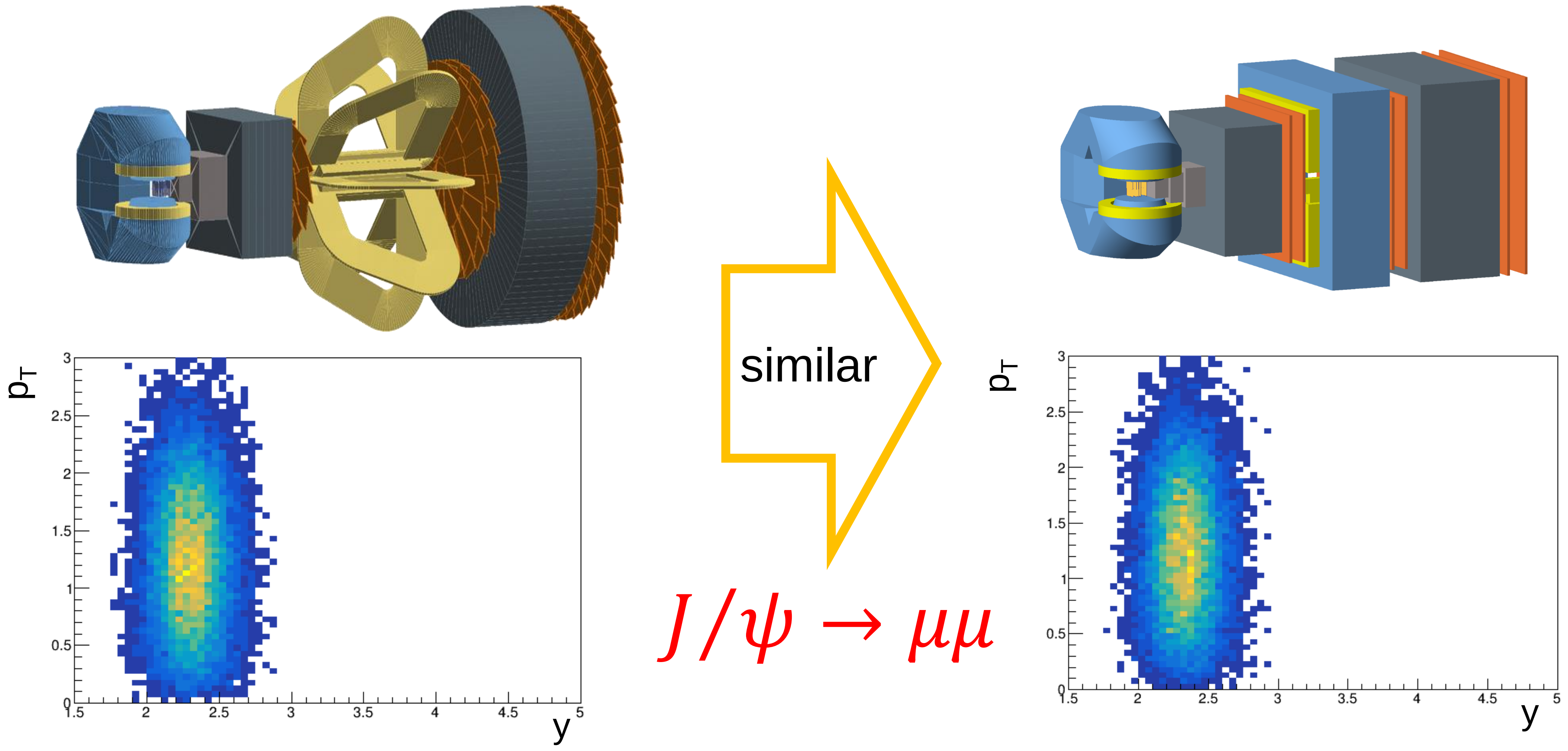
$\omega \rightarrow \mu\mu$





Preliminary performance for $J/\psi \rightarrow \mu\mu$

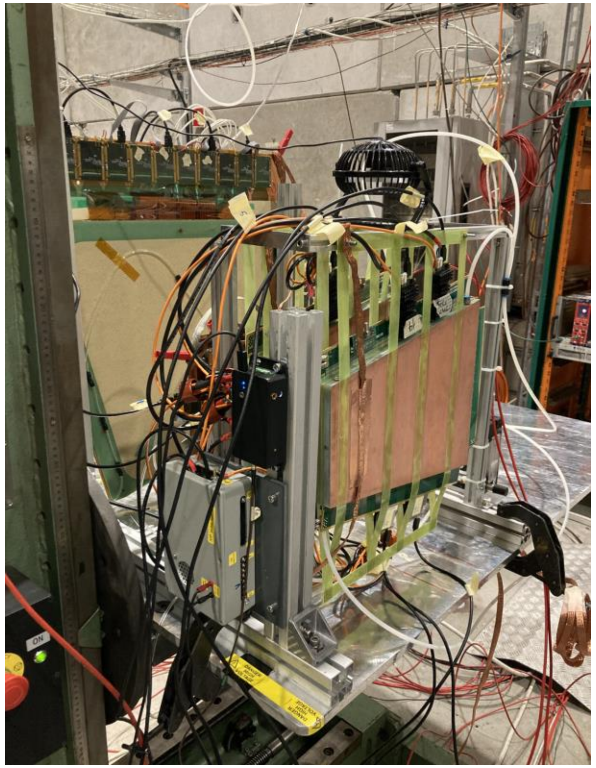
The toroidal magnet has a significant dead zone at small angles. In the previous configuration, soft muons from low- and intermediate-mass processes were affected, which is now improved. Acceptance of heavy hadrons changes less since harder muons avoid the dead zone

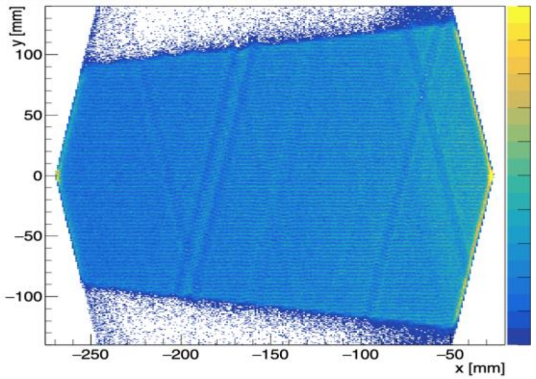


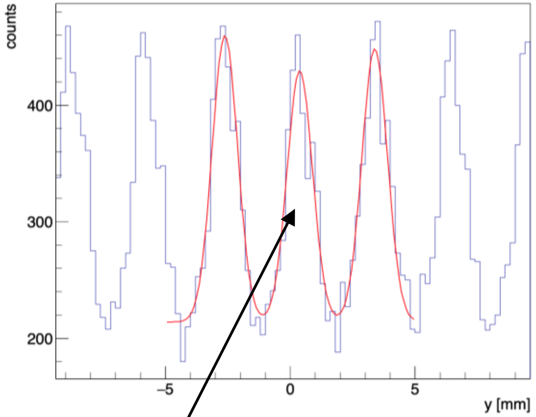
The Muon Spectrometer technology

MWPC with strip readout satisfies NA60+ requirements. The readout is based on a VMM3a chip

Prototype 1: Test beam at CERN in fall 2023



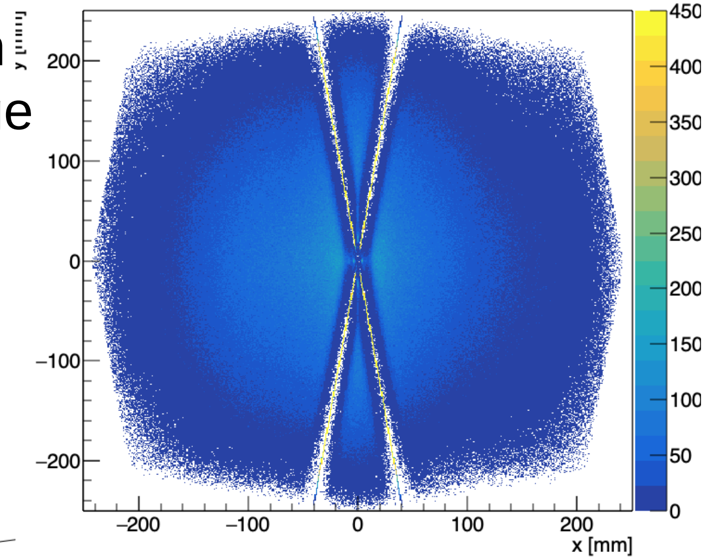




$\sigma_x < 0.1$ mm, $\sigma_y = 0.51$ mm

Uncovered problems in SRS vmm-sdat package related to DHR

Which has been fixed



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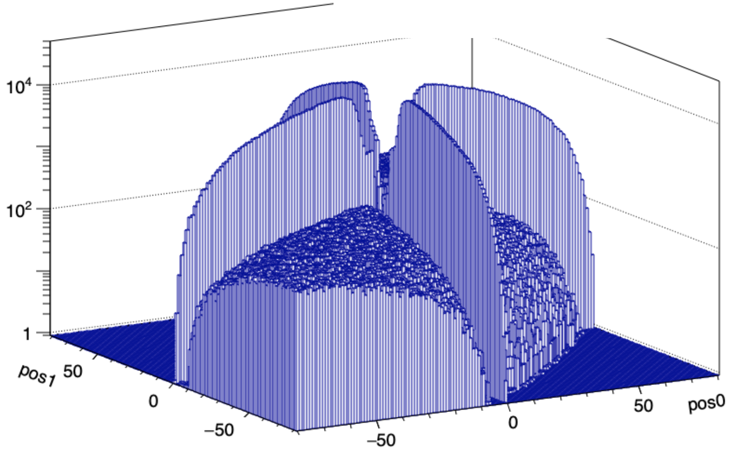
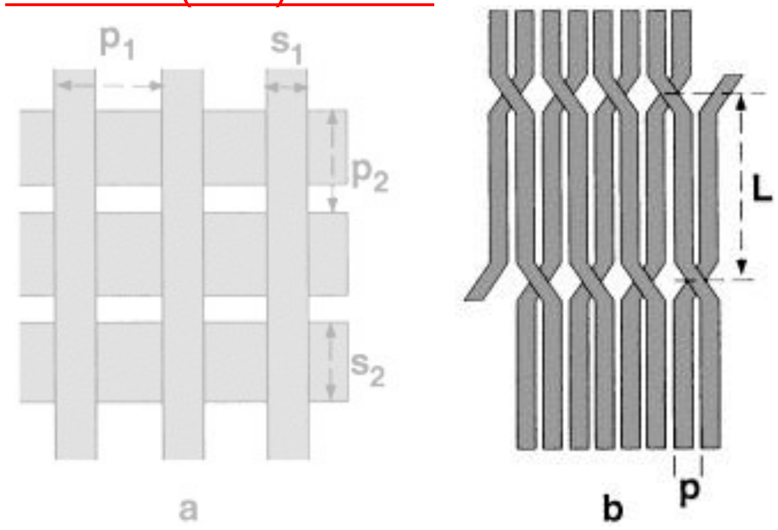
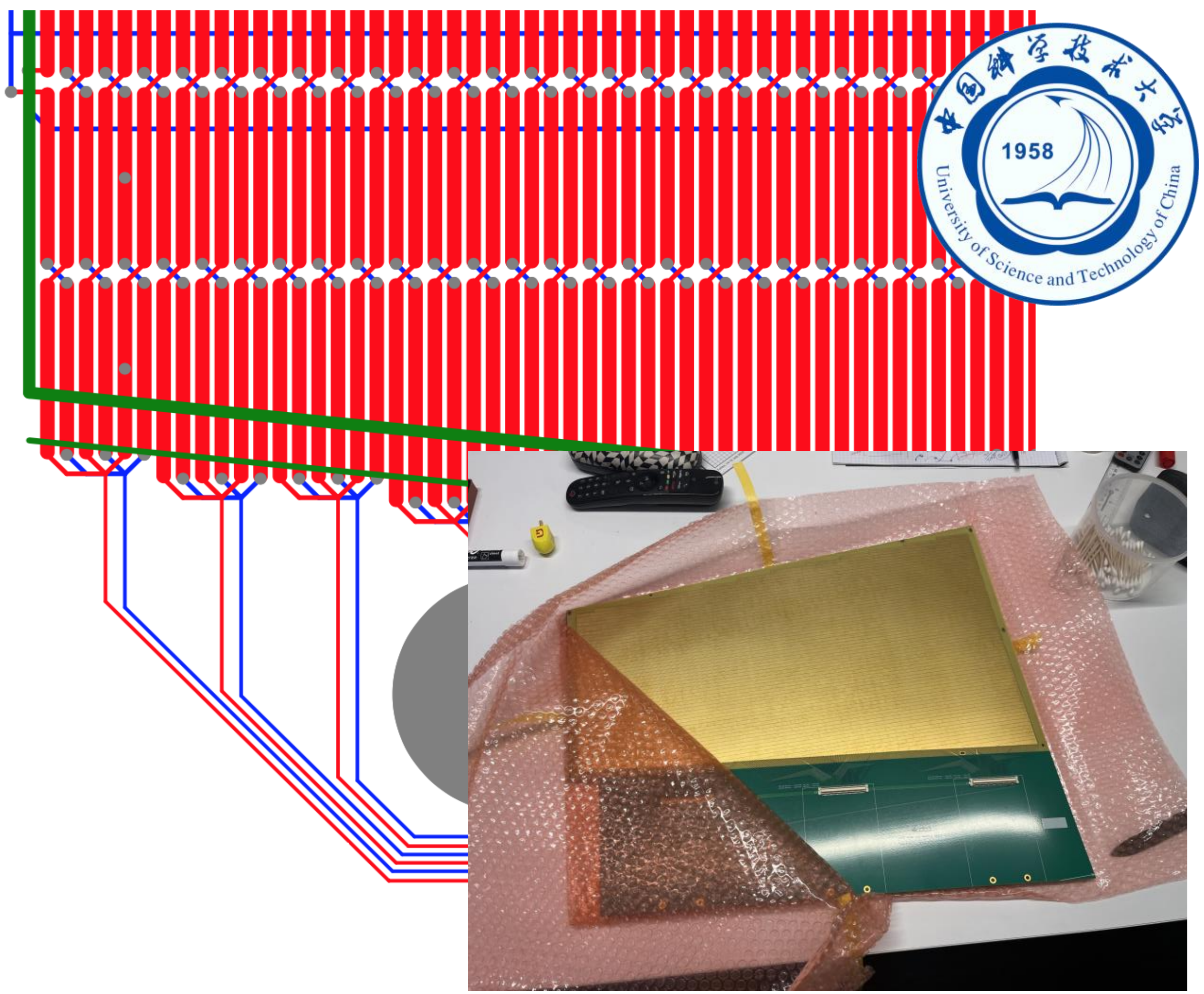


The Muon Spectrometer technology

Prototype 2: Test beam at CERN in Nov 2024

NIMA 425 (1999) 254-261





Single-sided strip readout better suited for VMM-based electronics with optimized geometry

Near-final electronics (USTS, Hefei group)

Additional test to optimize the electronic channels

The NA60+ timeline

2023
LoI

2025
Proposal

2026-2028/29
Construction

2029/30-2036/7
Data taking

The project is part of the CERN Physics Beyond Collider Initiative

LoI (arXiv:2212.14452) discussed with SPSC in February 2023

Expect a proposal in Spring 2025

The aim is to take data in 2029/30, after LHC LS3
- 7 years running with Pb beam: one beam energy per year
- proton beams for reference for dedicated p-A studies

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

Summary and plans

MNP33 magnet resolves the most critical financial obstacle in building the NA60+ experiment

Various studies are ongoing to optimize the new setup:

- Possible use of NA62 straw tracker as a part of the NA60+ muon system
- Alternative technology (SBU GEM-based tracking) was tested during the 2023 test beam
- Muon station layout is scrutinized for the best performance
- Muon identifier placement can allow more flexibility for optimizing the purity-to-efficiency ratio

The Collaboration is looking for more groups to join the experiment!

THANK YOU!

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

The NA60+ Collaboration

Appendix: NA60+ Collaboration arXiv:2212.14452

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]

- The LoI was signed by 62 authors representing institutions in
  - Italy (Cagliari, Padova, Torino)
  - Israel (Weizmann)
  - USA (StonyBrook, Rice)
  - France (Lyon)
  - CERN
- China (USTC) group joined the NA60+
- Contacts ongoing to strengthen the Collaboration on specific items and reach critical manpower level

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