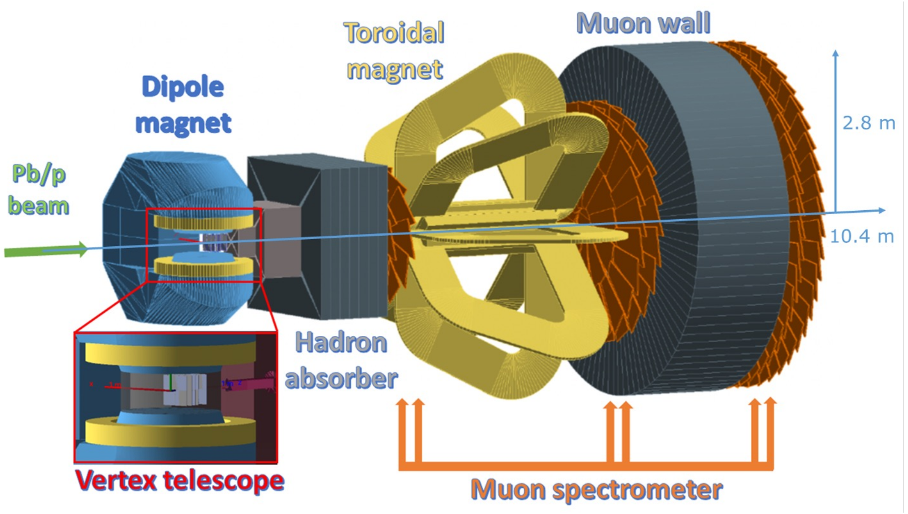
NA60+: study of dileptons and heavy quark production in Pb-Pb collisions at the CERN SPS

G. Usai – University of Cagliari and INFN

Main physics topics

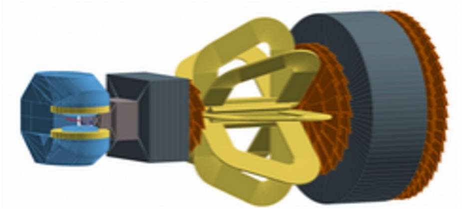
Topic		Measurement
Caloric curve of QGP	⇨	Measurement of temperature of thermal dimuons vs $\sqrt{s_{NN}}$
Chiral symmetry restoration	⇨	ρ-a_1 mixing in the dimuon channel
Charmonium melting in the QGP	⇨	Charmonium suppression vs $\sqrt{s_{NN}}$ (dimuon decay channel)
QGP transport coefficients and charm hadronization	⇨	Hadronic decays of open HF mesons/baryons

Experimental set-up



Muon spectrometer coupled to a vertex spectrometer
→ perform an energy scan in the √s region covered by the SPS (~6-17 GeV)

NA60+: recent news

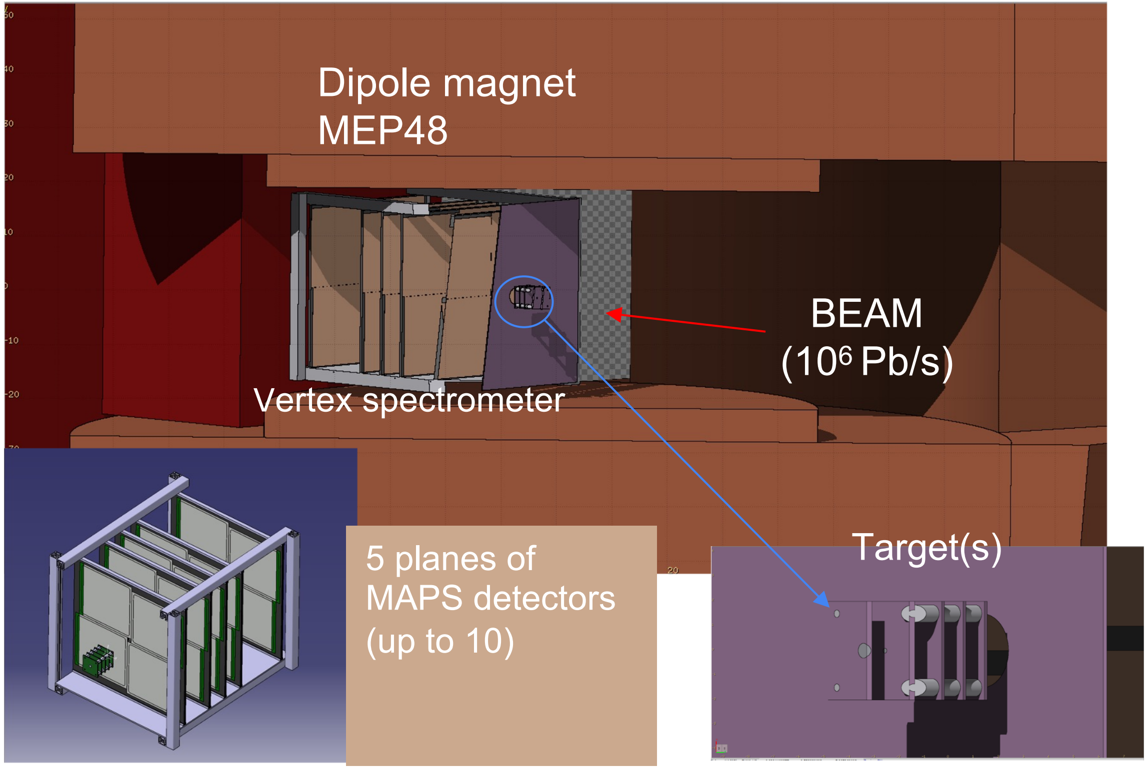


- LoI submitted in Dec 2022 →https://arxiv.org/abs/2212.14452
- Discussed at the SPSC in Feb 2023 →https://indico.cern.ch/event/1242068/contributions/5223273/attachments/2579025/4467314/SPSC_Feb23_v6.pdf
- From the minutes:

  The SPSC **recognizes** the fundamental interest of the measurements proposed by the NA60+ collaboration, which are focused on electromagnetic and hard probes of the quark gluo plasma at high baryochemical potential. In order for the project to proceed with the suggested roadmap (starting construction in 2026 and data taking in 2029), the SPSC **would expect to start examining** a proposal by 2024

- Project mentioned in US 2023 Long Range Plan for Nuclear Science and in the forthoming NUPECC Long Range Plan 2024
- In the last year, significant progress on various items towards the proposal:
  - **R&D on detectors**
  - **Toroidal magnet project**
  - **Studies of the beam optics**
  - **Availability of ion and proton beams from 2029 onwards**

The vertex spectrometer

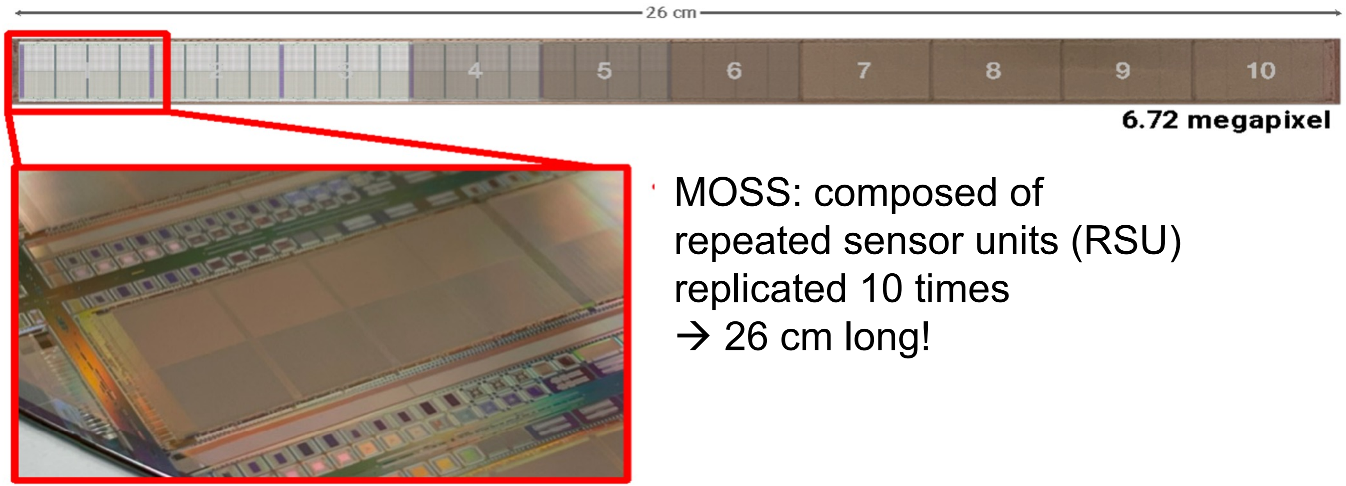


- ➢ Progress on sensor design, mechanics, cooling and cabling aspects for the vertex spectrometer

Large area monolithic sensor

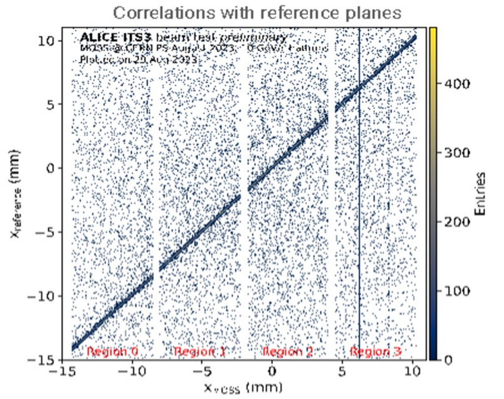
Strong synergy with ALICE ITS3

→ MOSS (Monolithic Stitched Sensor): first large area sensor prototype produced in 2023



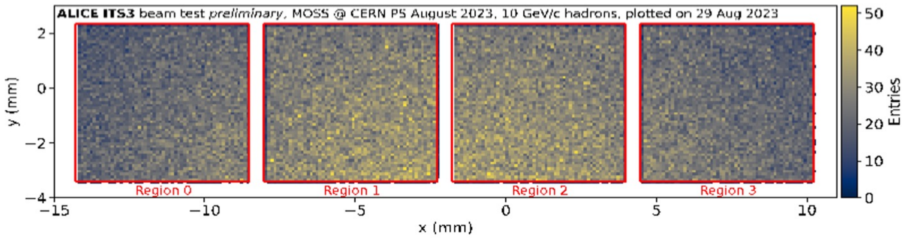
MOSS: composed of repeated sensor units (RSU) replicated 10 times

→ 26 cm long!



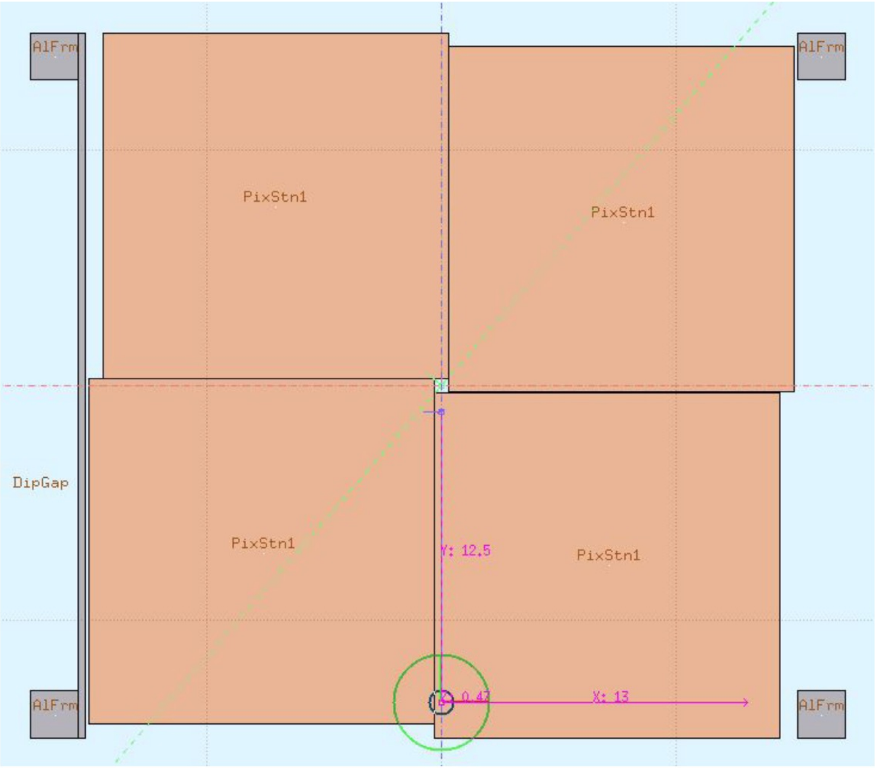
Basic goal of MOSS: **yield**

- 16 MOSS successfully wire-bonded
- No failures so far
- First correlations from beam test in Jul/Aug/Sep!



MOSAIX: (almost)-final sensor prototype expected beginning 2025

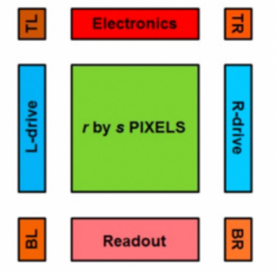
NA60+ silicon sensor

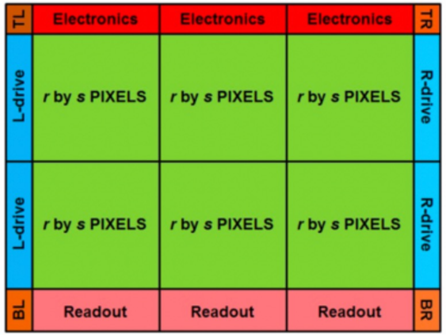


In the LoI, each vertex telescope station is made up of 4 sensors, 15x15 cm^2 each

February 2024: first meeting with ALICE ITS3 designers (G. Aglieri Rinella, W. Snoeys) to discuss the **NA60+ sensor with MOSAIX**

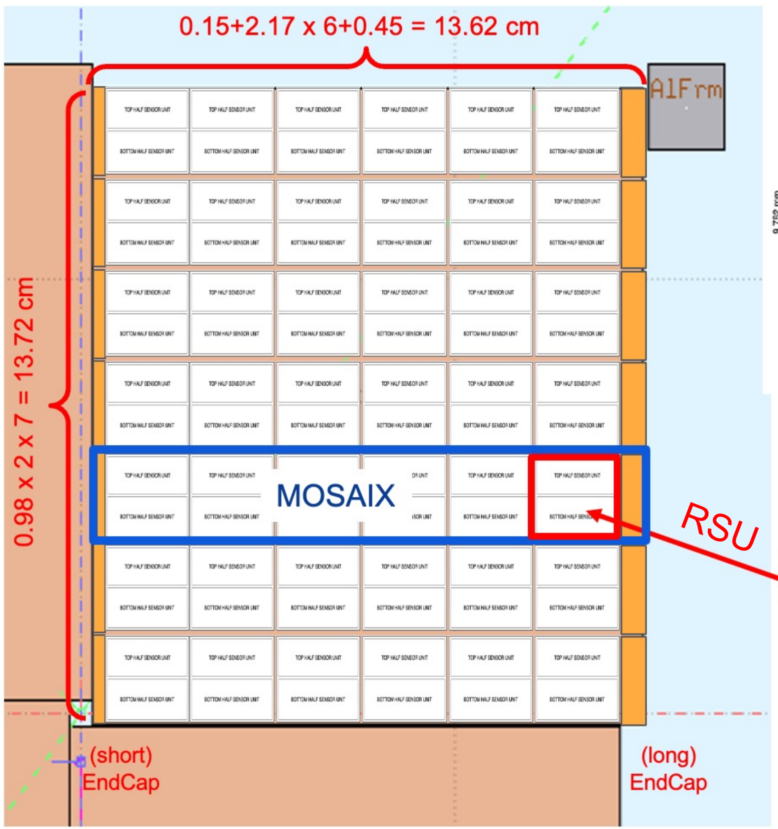
Why does it works for NA60+?
→ Stitching!

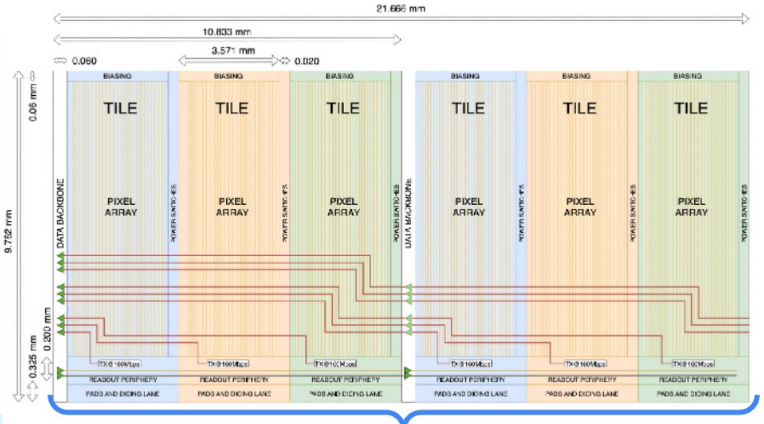


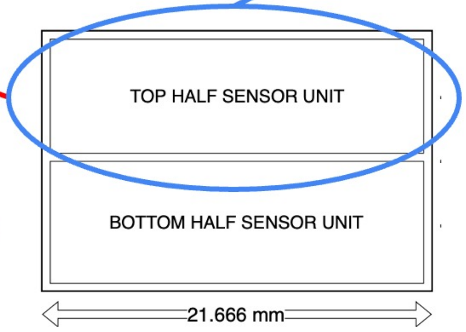


NA60+ silicon sensor: MOSAIX

Realistic NA60+ sensor floorplan now available





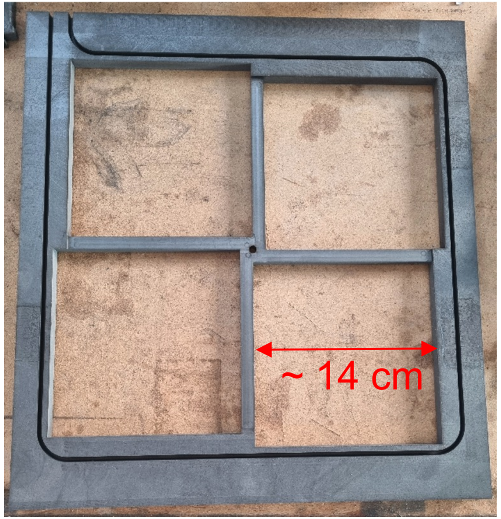


- MOSAIX with 6 stitched RSU
- 7 MOSAIX replicated vertically
- ~ 13.5 x 13.5 cm^2 total surface
- Powering and data transmission from right side
- Maximum rate: 6 MHz/cm^2 →ok for 1-1.5x10^6 Pb/s

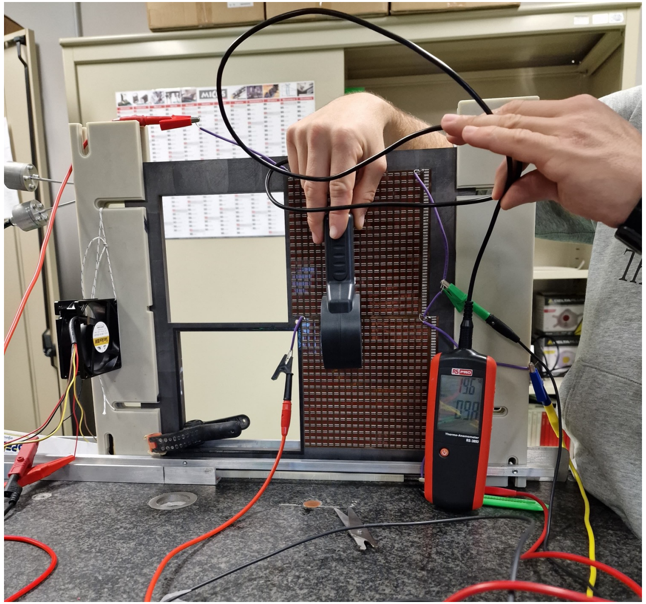
Mechanics and cooling

Sensors will be glued on a graphite frame
→ very good heat conductor

Water cooling circuit



~34 cm



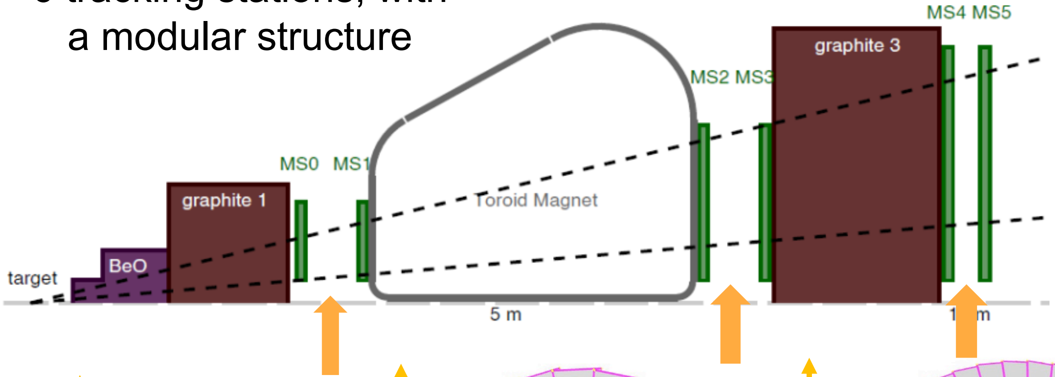
Power consumption based on specifications for the MOSAIX sensor

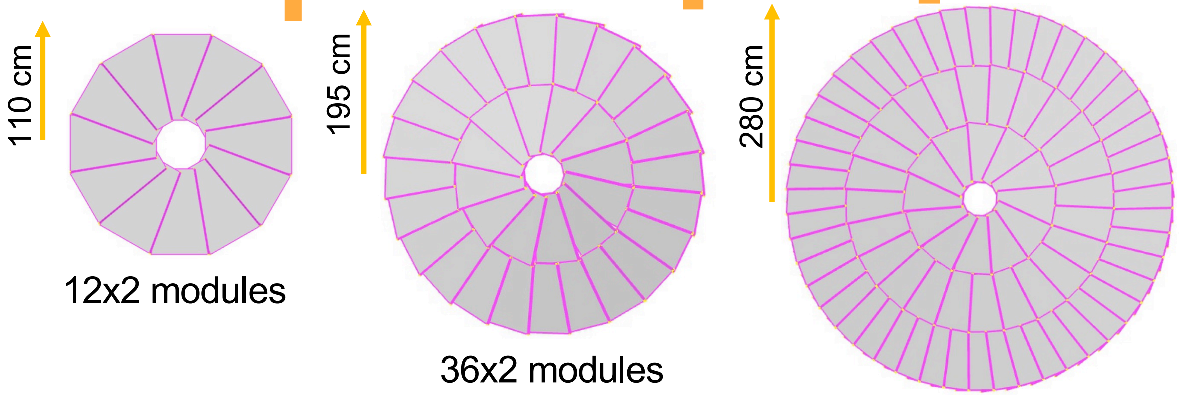
Air/water cooling studied with ANSYS/COMSOL simulations

Experimental measurements using PCB with resistor array that mimics MOSAIX power dissipation

The muon spectrometer

6 tracking stations, with
a modular structure

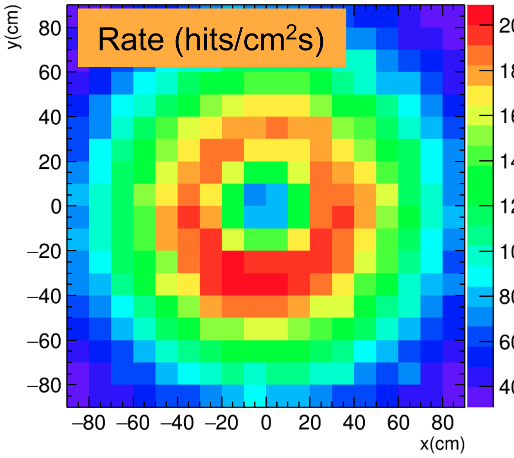




12x2 modules

36x2 modules

84x2 modules



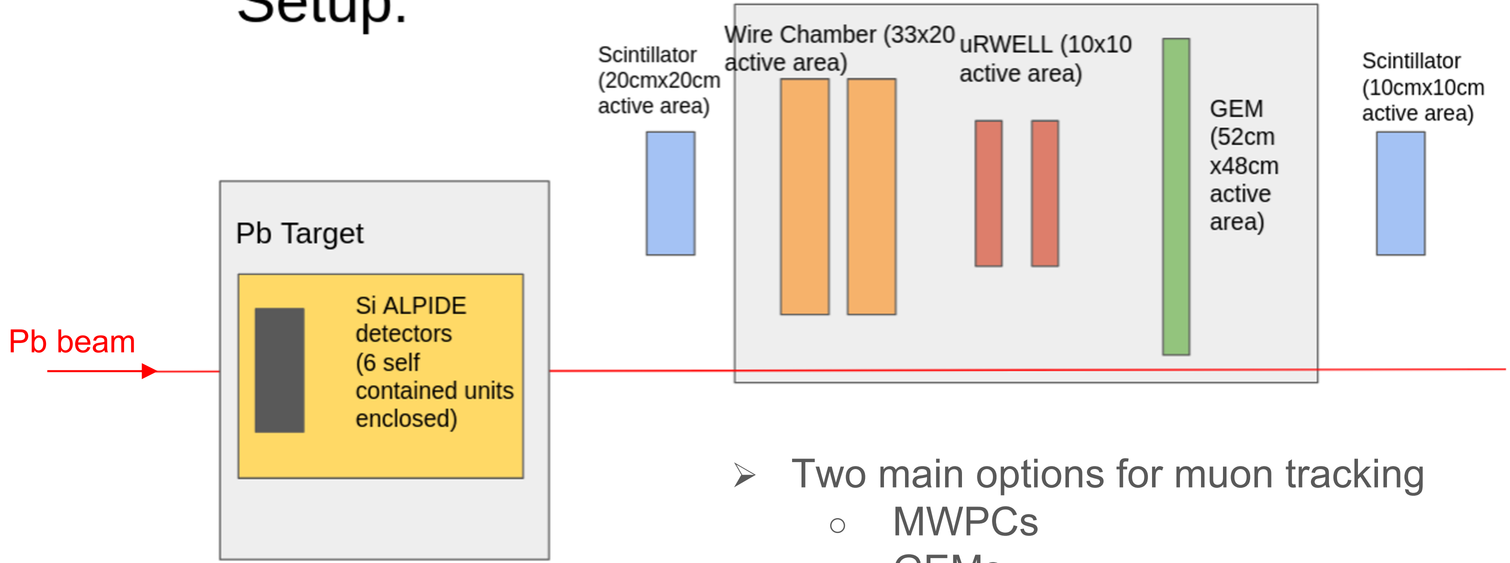
Modest rates (FLUKA) already in the upstream stations, thanks to the thick absorber (235 cm BeO +C)

For a 10^6 s^{-1} beam → charged particle rate ~2kHz/cm^2

Can be matched by **GEM or MWPC** detectors

Muon detectors R&D: test with Pb beam (oct 2023)

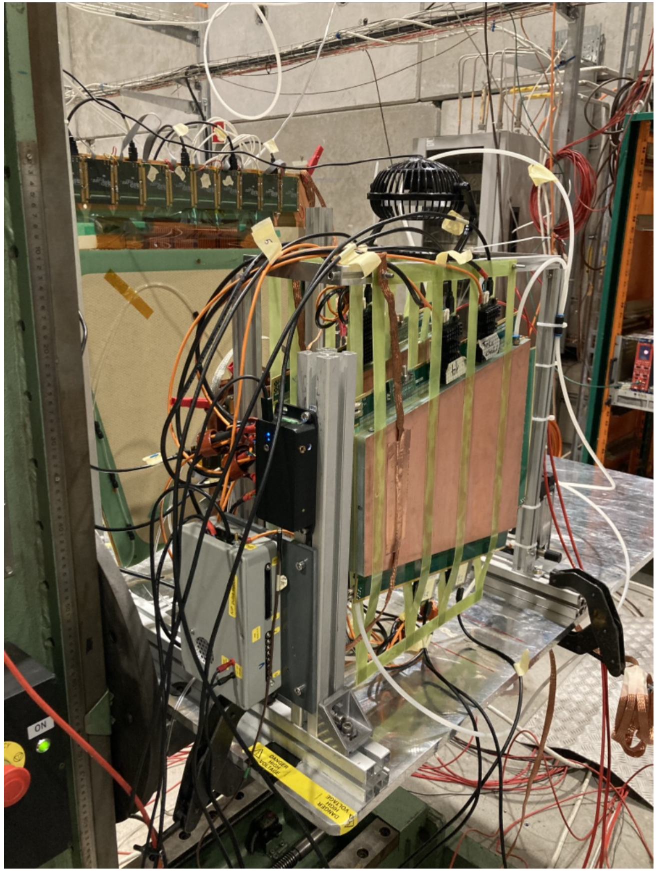
Setup:



- Two main options for muon tracking
  - MWPCs
  - GEMs
- Test of first prototypes

Detect secondaries from Pb-Pb collisions

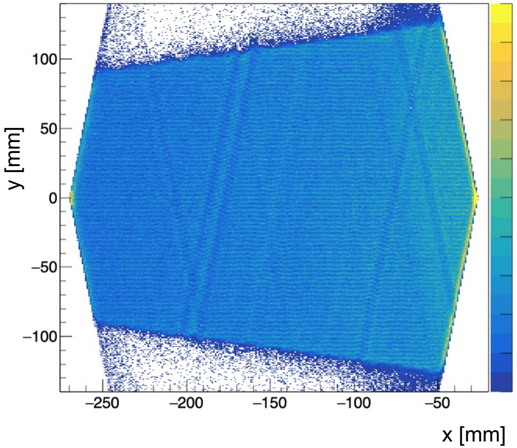
Testing MWPC for the muon spectrometer



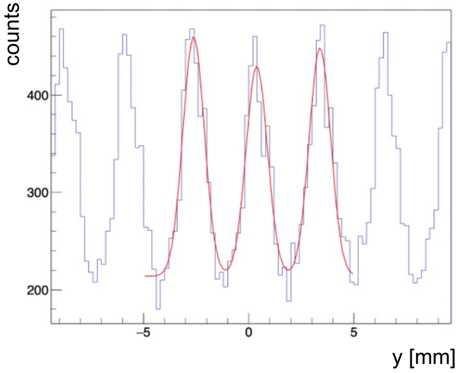
- 2 MWPC chambers (1 mm readout strips)
- ~60 cm off the beam line to reduce event multiplicity
- Continuous readout
  - Coincidence of scintillators signals to tag the events

GOAL: characterise the detectors (cluster size, resolution, efficiency, electronics based on VMM3 chip)

Good performances of the detectors:

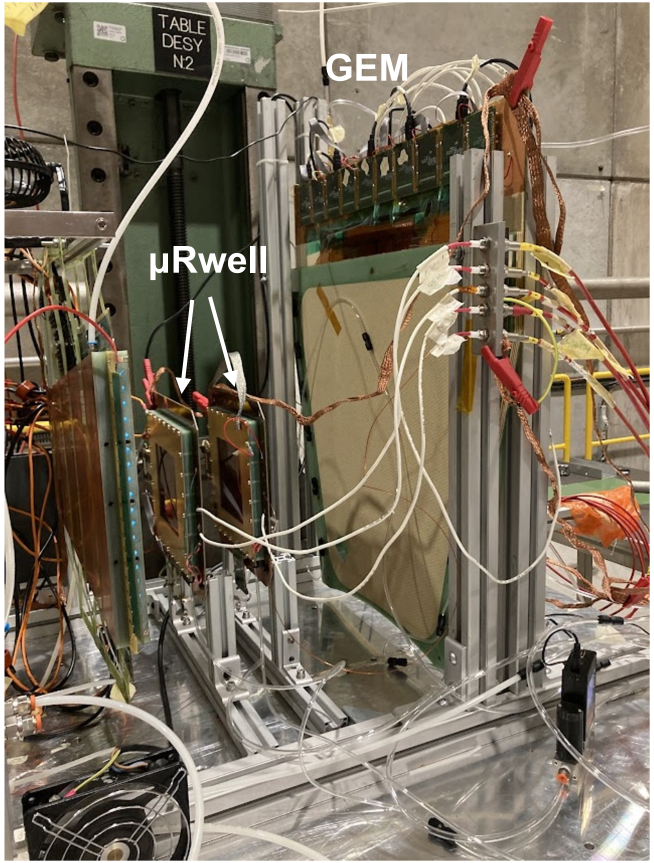


Reconstructed hits in the detector



Rough evaluation of **chamber resolution ~100 μm**

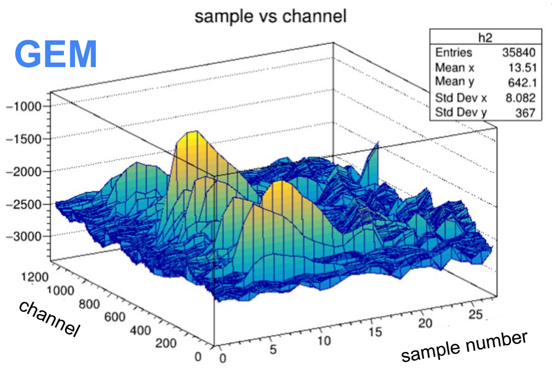
Testing GEMs for the muon spectrometer

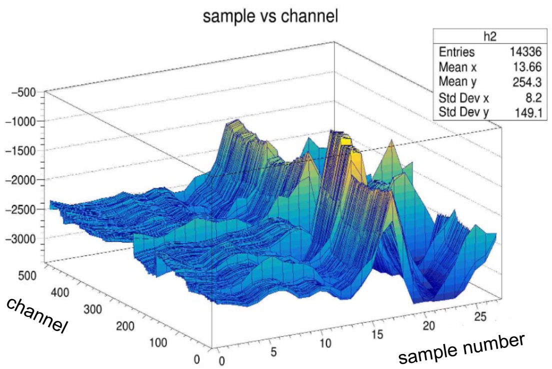


- ~60 cm off the beam line to reduce event multiplicity
- Triggered with the coincidence of scintillators
- First time tested with tens of incoming particles

GOAL: tracking efficiency + cluster size, spatial resolution,...

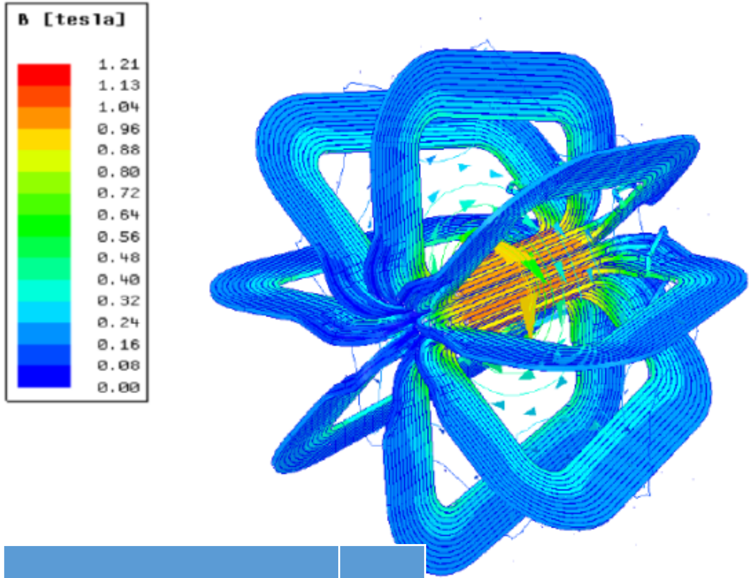
Analysis ongoing - good performances of the detectors:





1 single event (channel corresponds to readout strips, sample number to 25 ns time samples, z axis is ADC)

Toroidal magnet



Operating Current [kA]	16.6
Amp-turns [kA]	199
Combined inductance [mH]	9.5
Resistivity Al 1100 @RT [μΩ.cm]	2.67
Length Conductor [m]	800
Total resistance [mΩ]	10.4
Dissipated power [MW]	2.8

Original design done by CERN EP-DT (1:5 scale prototype built and tested):

- 8 coils
- 12 turns per coil

Design in view of technical proposal in progress under supervision of S. Izquierdo Bermudez (TE-MSC-LMF – A. Milanese involved in the starting phase)

- Regular meetings since September 2023

The project is now advancing within the expected timeline of the experiment proposal (end 2024)

Toroidal magnet

Finalisation of 3D CAD design of magnet and mechanical structures. Design driven by:

Copper for conductor:

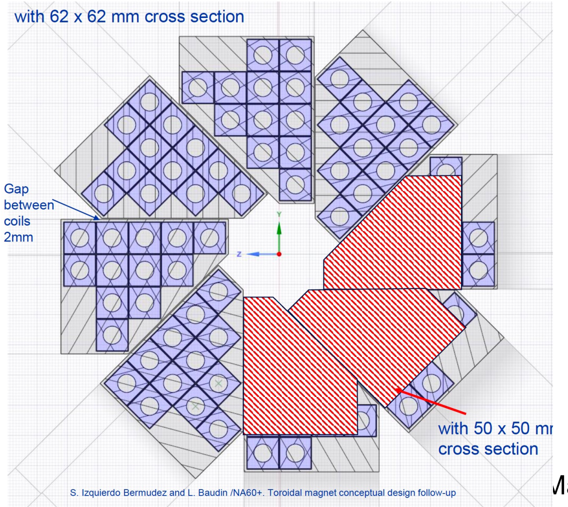
- ➢ significantly lower power consumption
- ➢ reduced size of dead central zone with smaller conductor size

	Al		Cu	
Conductor cross section, mm x mm	50 x 50			
Cooling channels d, mm	36			
Number of turns	12			
Number of coils	8			
I, kA	16.25			
I^*_{rms}, kA	16.25	9.75	16.25	9.75
$(I^*_{rms}/I)^2$	1	0.36	1	0.36
∆T, K	30			
Total voltage**, V	200		308	
Dissipated power, MW	5	1.8	3.2	1.2
Conductor weight (total), kg	4017		13280	
Conductor cost*** (total), kEUR	71		888	

Magnet operated in pulsed mode to reduce power consumption

Power convertor/current:

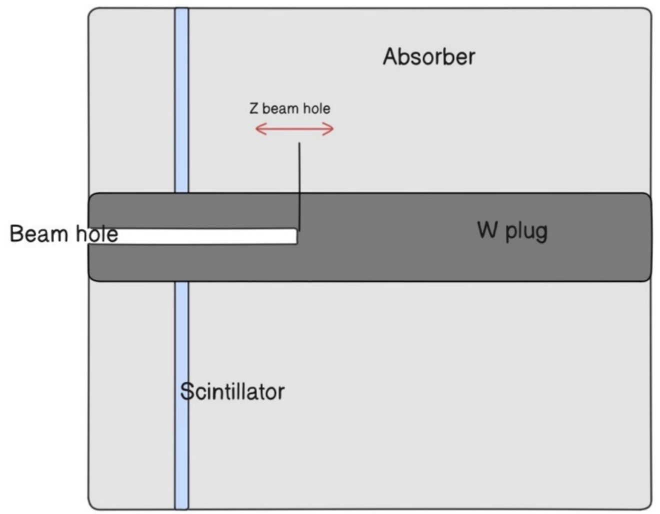
- ➢ original design with 16.25 kA (12 turns): cost exceeds 1 M€
- ➢ Conventional 5.5 kA power supplies in NA area:
  - ○ cost 300-400 k€
  - ○ Requires 36 turns → Overall geometry and winding schema have to be studied in CAD; central region may be more bulky

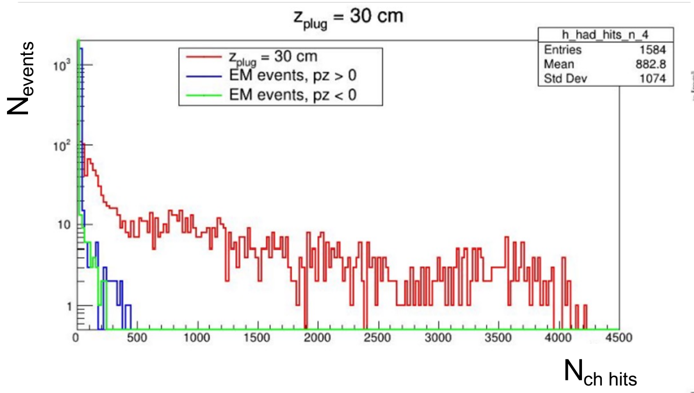


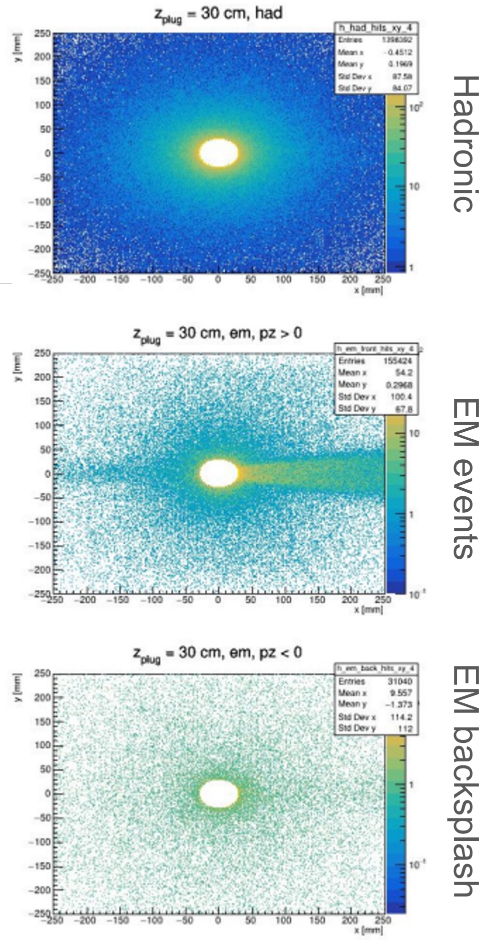
larch 2024

Studies on trigger detector

- Started after LoI submission
- Current idea: scintillator(s) embedded in the hadron absorber
- Detailed GEANT4 simulations with the NA60+ geometry







Low threshold on scintillator signal will efficiently reject background e.m. Pb-Pb interactions

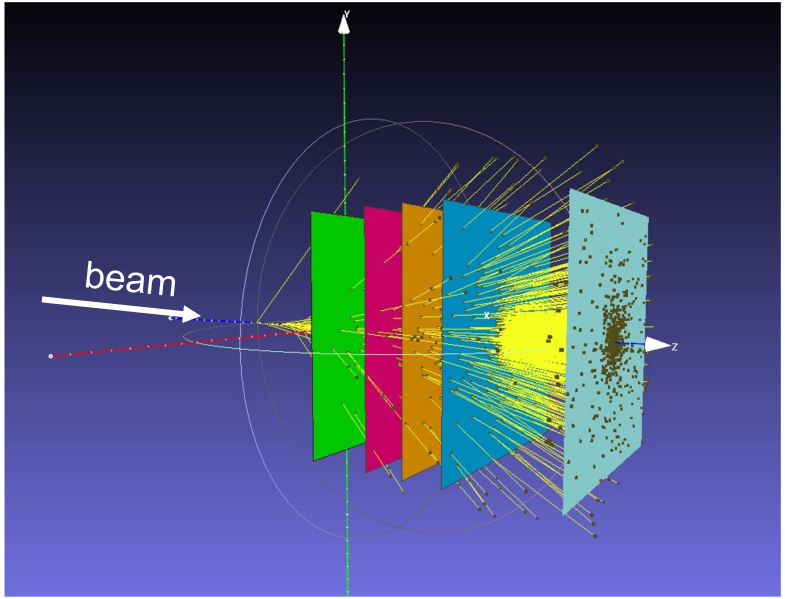
NA60+ reconstruction framework

Based on ACTS, the experiment-independent toolkit for (charged) particle track reconstruction in (high energy) physics (https://acts.readthedocs.io/en/latest/index.html)

- work carried on and followed within the ACTS Telescope Detectors group

Ongoing developments:

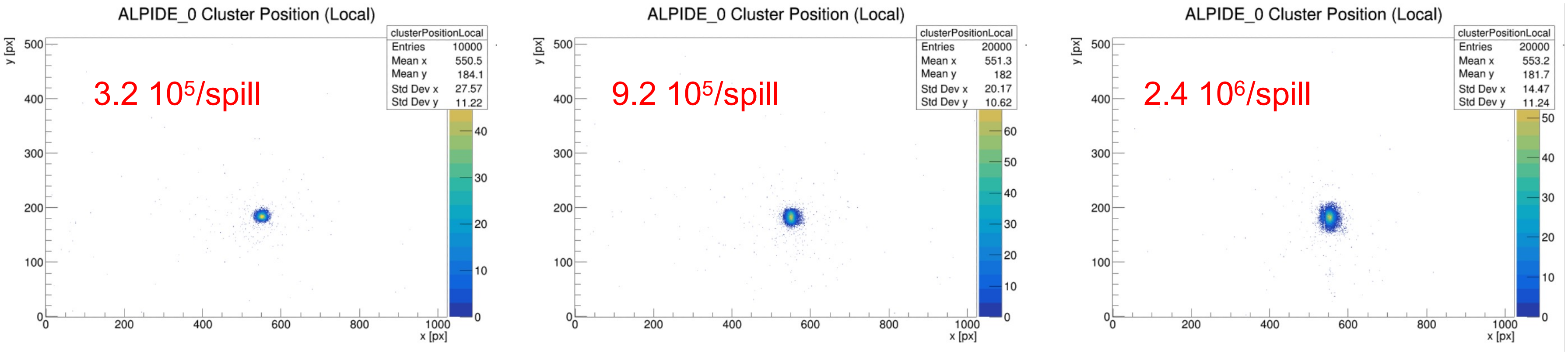
- Implementation of the NA60+ Vertex telescope geometry in ACTS
- Optimisation of the reconstruction steps for a high multiplicity fixed target configuration (presently tuned for collider setups)
  - Seeding
  - Combinatorial Kalman filter
  - Vertexing



Studies with realistic y and p_T particle distributions based on NA49 measured spectra

Towards high beam intensity in H8: test beams (2022, 23)

2023: 150 AGeV Beam with intensity increased up to 2.4 10^6/spill, with radioprotection monitoring



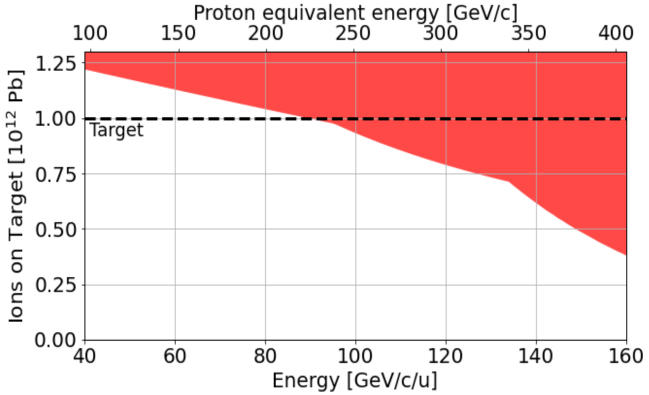
- At 2.4 10^6 /spill → **beam spot size 280 x 280 μm^2** : only a **modest increase of the beam size**

- Second high-intensity test foreseen in 2024:
  - Reach 10^7/spill
  - **low-energy primary Pb beam** (15 A GeV), where emittance will be larger

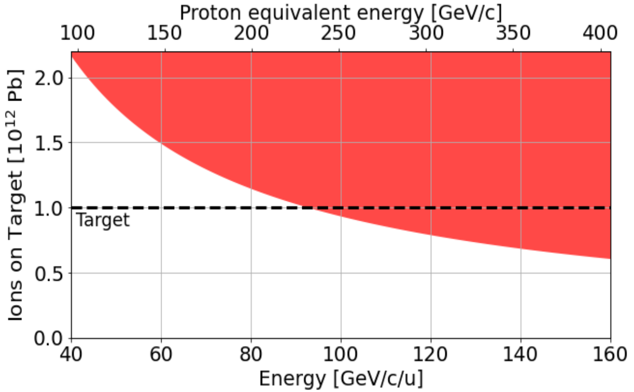
Planning heavy-ion beams from 2029 onwards

Working group organized within PBC, together with accelerator groups and experiments

- Pb beam scenario for NA60+: run in parallel with LHC (end of year)
- Estimates of ions/year on target based on RP restrictions, SPS and NA magnets, power consumption, time sharing: ~50% over 4-week run (includes other SPS users and machine availability)



- Spill rates: 1-1.5x10^6 Pb/s
- Flat-top below 90 GeV/u/c: 25 s



- Spill rates: 2-3x10^6 Pb/s
- Flat-top decreased to respect RP

T. Prebibaj

To be validated by further Fluka simulations for RP at low energies

LOI goal: **10^{12} Pb ions on target/run** – Pb instantaneous rate 10^6/s

Increasing rate allows much larger statistics at low energy

→ checking for possible inefficiencies of pixel detector

Dedicated proton beams

The LoI states the need of several control measurements with proton beams:

	Year 1	Year 2	Year 3	Year 4-5	Year 6	Year 7
Beam energy (A GeV)	160	40	120	20 (30)	80	60
Momentum per charge (GeV/c/Z)	406	101	304	50.7 (76.1)	203	152
Pb ions on target	$\sim 10^{12}$ per energy ($\sim$ 30 days)					
protons on target	$5-6 \cdot 10^{13}$ per energy ($\sim$ 22 days)					

Primary protons are only allowed to be extracted at **400 GeV/c in the SPS interlock system**

→ **solution with secondary beams being investigated**

- H8: secondary beams in a range from 20 to 380 GeV/c (both charges)
- In H8A, one can obtain about $5x10^6$ hadrons / 4.8 s spill at the moment. But with dedicated shielding, as proposed for NA60+, this rate can be significantly increased
- Beam contamination: requires particle tagging (CEDAR and XCET threshold Cherenkov detectors)

Measurements at lower momenta might take considerably longer than anticipated → rates and required running time will be estimated in incoming weeks

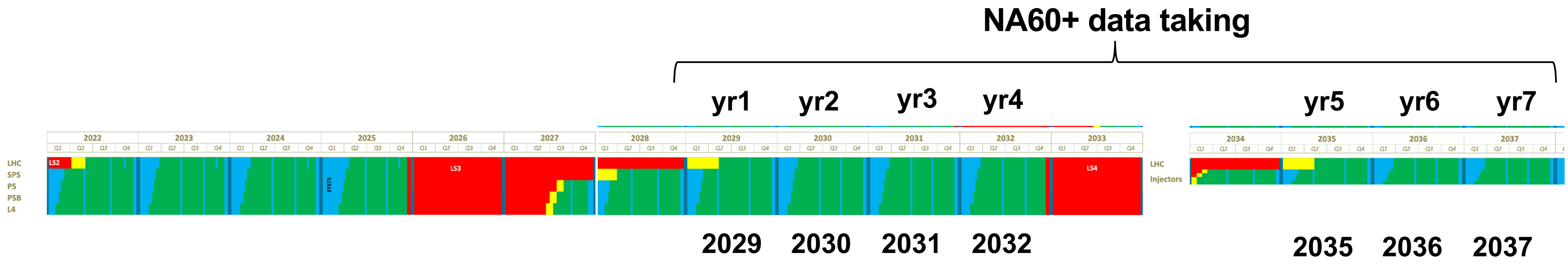
Maarten van Dijk, Johannes Bernhard (BE-EA-LE)

NA60+ timeline

The plan discussed with SPSC is to have the experiment on the floor by the end of LS3 → **2029**

Roadmap:

- Technical proposal: **2024-2025** → Good progress on fundamental technical points
- Construction and installation: **2026-2028**



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iP2i
RICE

backup

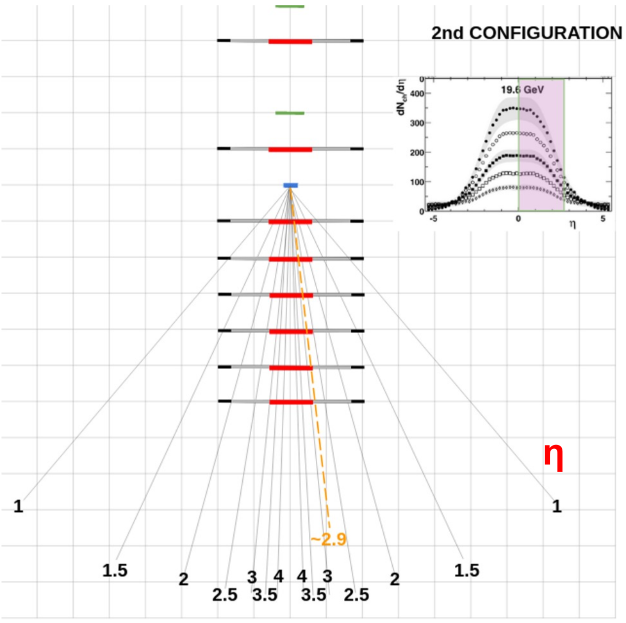
Beam requests for 2024

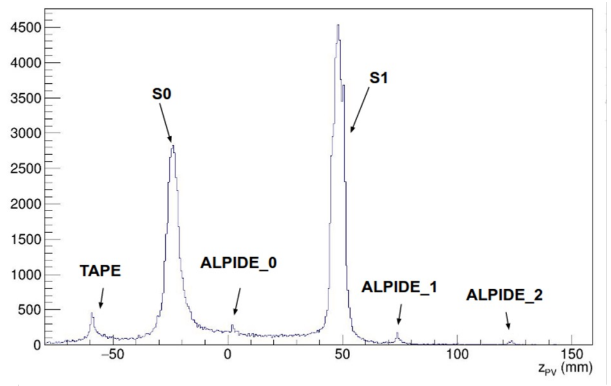
In order to continue the beam studies we have asked for 2 weeks of beam time with Pb ions in the PPE138 area on the H8 beam
→ 1 week at **13 AGeV**
→ 1 week at **150 AGeV**
(from September 30 till October 13 if low-energy Pb will be delivered first)

These two periods will be crucial to validate the possibility of a high-intensity focused beam in the experimental area
→ reach nominal beam intensity
→ check focusing is satisfactory also at low energy
→ single out RP issues along the beam line

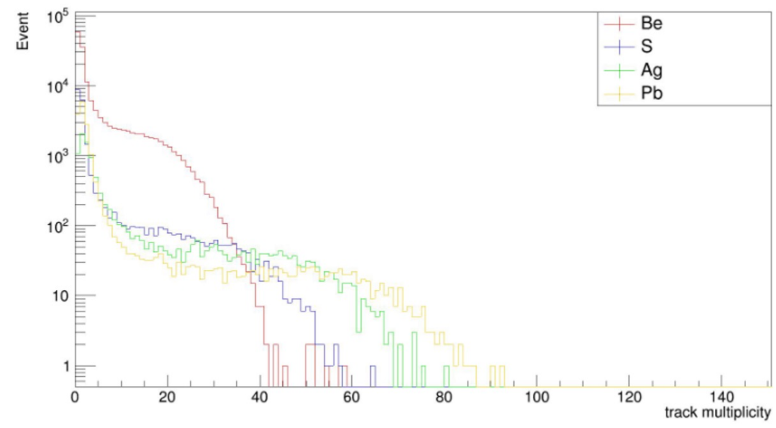
First physics publication from test beam data ?

Use ALPIDE telescope to **measure charged-particle multiplicity and dN/deta** in Pb-Pb, Pb-Ag, Pb-S and Pb-Be collisions





Primary vertex z-distribution (here for empty target run)



Preliminary track reconstruction: correct dependence of the multiplicity on A