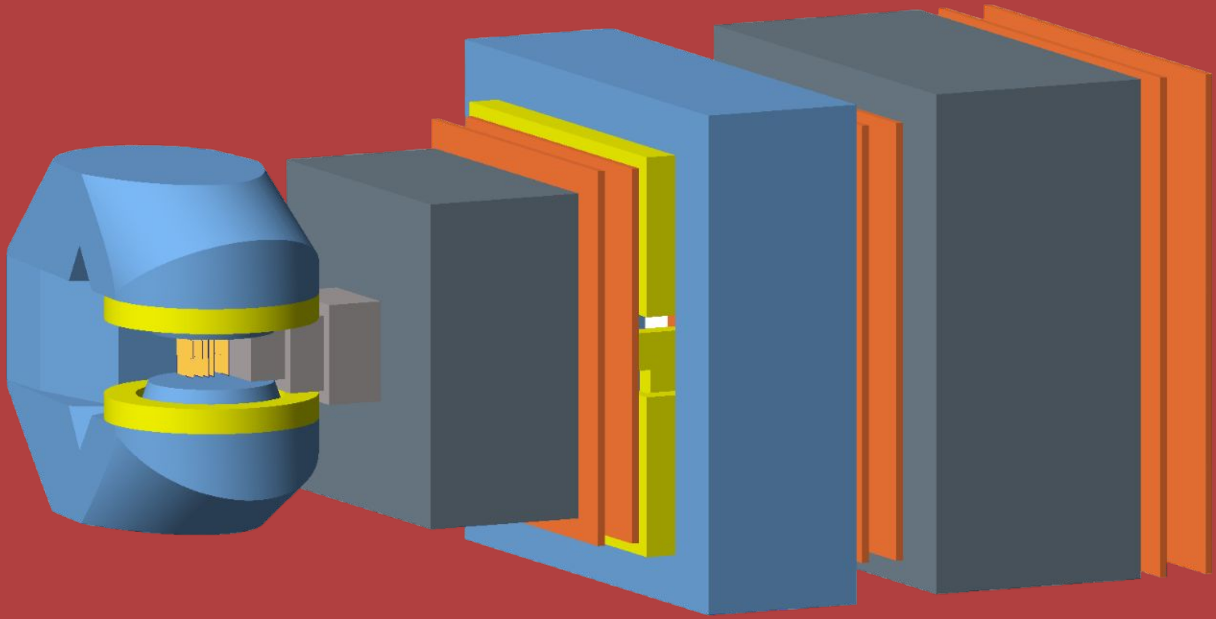

ACTS and NA60+

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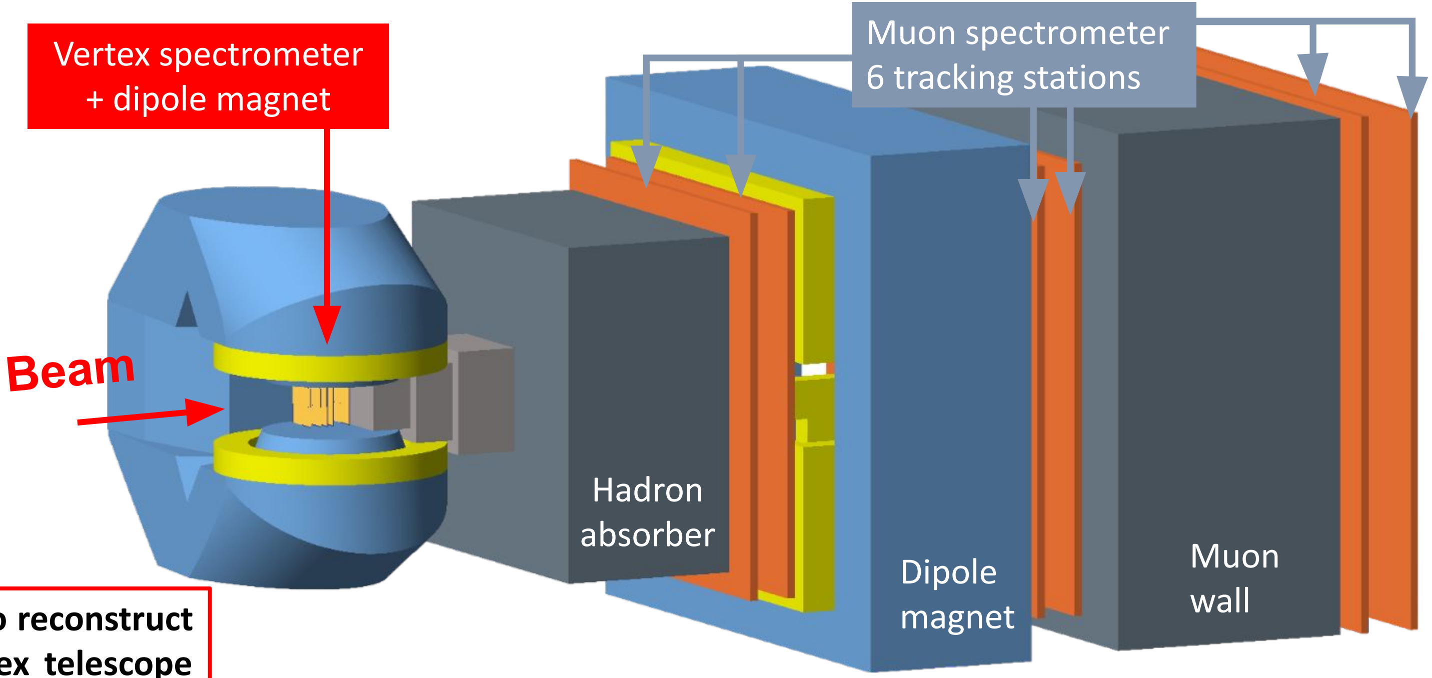
ACTS workshop - 18th November 2024

NA60+: experimental setup

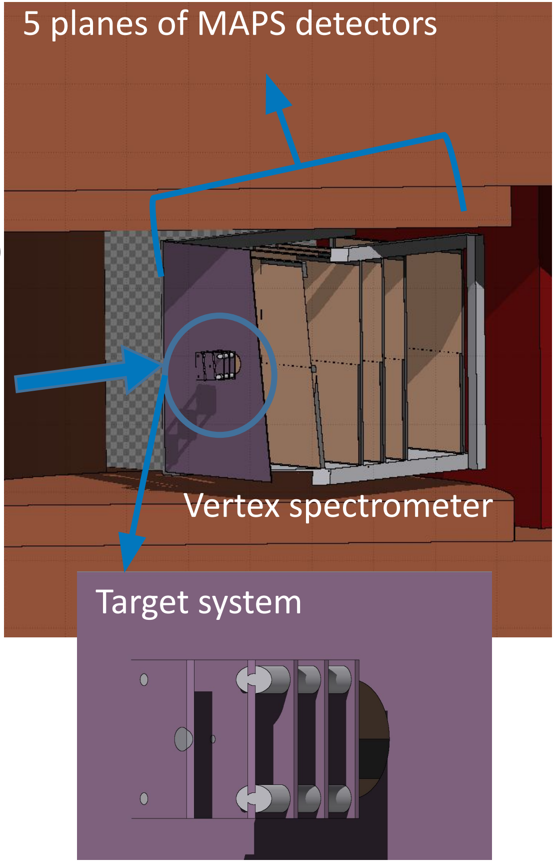
- NA60+ is a heavy ion fixed target experiment proposed at CERN SPS after LS3 (LOI arXiv:2212.14452)
- Vertex Telescope: 5 Si layers
- Muon Spectrometer: 6 stations of WMPC or GEM placed after thick absorbers
- We aim to study Pb–Pb collision in the energy range $\sqrt{s_{NN}}$ = 6 - 17 GeV ➞ high multiplicity environment:
    - Up to 1200 tracks in the vertex telescope and 100 in the muon spectrometer



GOAL: use ACTS to reconstruct tracks in the vertex telescope and muon spectrometers

Vertex region

- NA60+ target system will comprise 5 Pb sub-targets:
    - 1.5 mm thick
    - 1 mm diameter
    - 12 mm spacing between targets
- "Large" Pb beam (σ_{Pb} = 500 µm) ➞ we cannot always assume that $x_{PV} = y_{PV} = 0$
- Vertex telescope (VT) composed of 5 layers:
    - Large area: 30 x 30 cm^2 sensors
    - Excellent spatial resolution $\sigma_{x(y)}$ = 5 µm
    - 6mm diameter central hole for the non interacting ions
    - Low material budget: 0.01% X_0 per station
- VT is used to:
    - **Provide precise measurement all particles produced in the collision**
    - Reconstruct the primary vertex
    - Study open charm and strange particle production ➞ **need to reconstruct also secondary vertices**



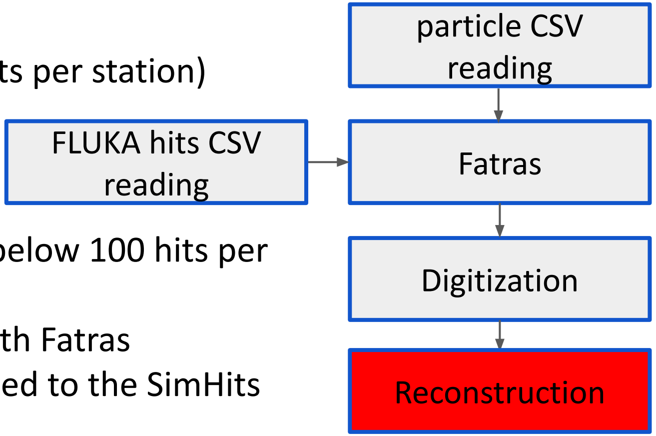
Muon spectrometer

- A thick BeO + graphite hadron absorber is positioned upstream of the muon spectrometer
- Six large area stations with a spatial resolution of σ_x= 100 µm, σ_y = 500 µm
- Two chambers before and two after the dipole magnet
- A second thick graphite wall is place before the last two chambers
- MS is used to track the particles that survive the absorber ➞ crucial for the measurement of muon from quarkonia (J/ψ, ω, …) or thermal dileptons

Station	z (cm)	side length (cm)	η_{min}	η_{max}
0	300	162	1.37	4
1	360	240	1.19	∞
2	530	240	1.53	∞
3	590	318	1.38	∞
4	810	437	1.38	∞
5	850	458	1.38	∞

Simulation and reconstruction chain

- Simulation of Pb–Pb collision at $\sqrt{s_{NN}}$ = 8.7 GeV:
  - Vertex telescope:
    - p, $K^{\pm}$, $\pi^{\pm}$, J/ψ ➞μμ, K^0_S➞ππ, and Λ^0 ➞pπ generated from parametrization (up to 1000 particles per event)
    - Hits from δ electrons simulated with FLUKA (100-200 hits per station)
  - Muon spectrometer:
    - J/ψ ➞μμ generated from parametrization
    - Hits from δ electrons, μ, $K^{\pm}$, $\pi^{\pm}$ simulated with FLUKA (below 100 hits per station)
- The particles are saved in csv files ➞ read by ACTS and propagate with Fatras
- The FLUKA hits are saved in csv files ➞ read by ACTS and concatenated to the SimHits from Fatras
- **Reconstruction based on full_chain_odd.py:**
  - Standard Seeding with SP rotation (x,y,z) ➞ (x,z,-y)
  - CKF
  - Greedy Ambiguity Resolution
  - Iterative Vertex Finder
- Separate reconstruction of VT and MS
- New algorithms have been added to the chain to face the NA60+ specific challenges: they can be find in our fork: https://github.com/NA60plus/acts

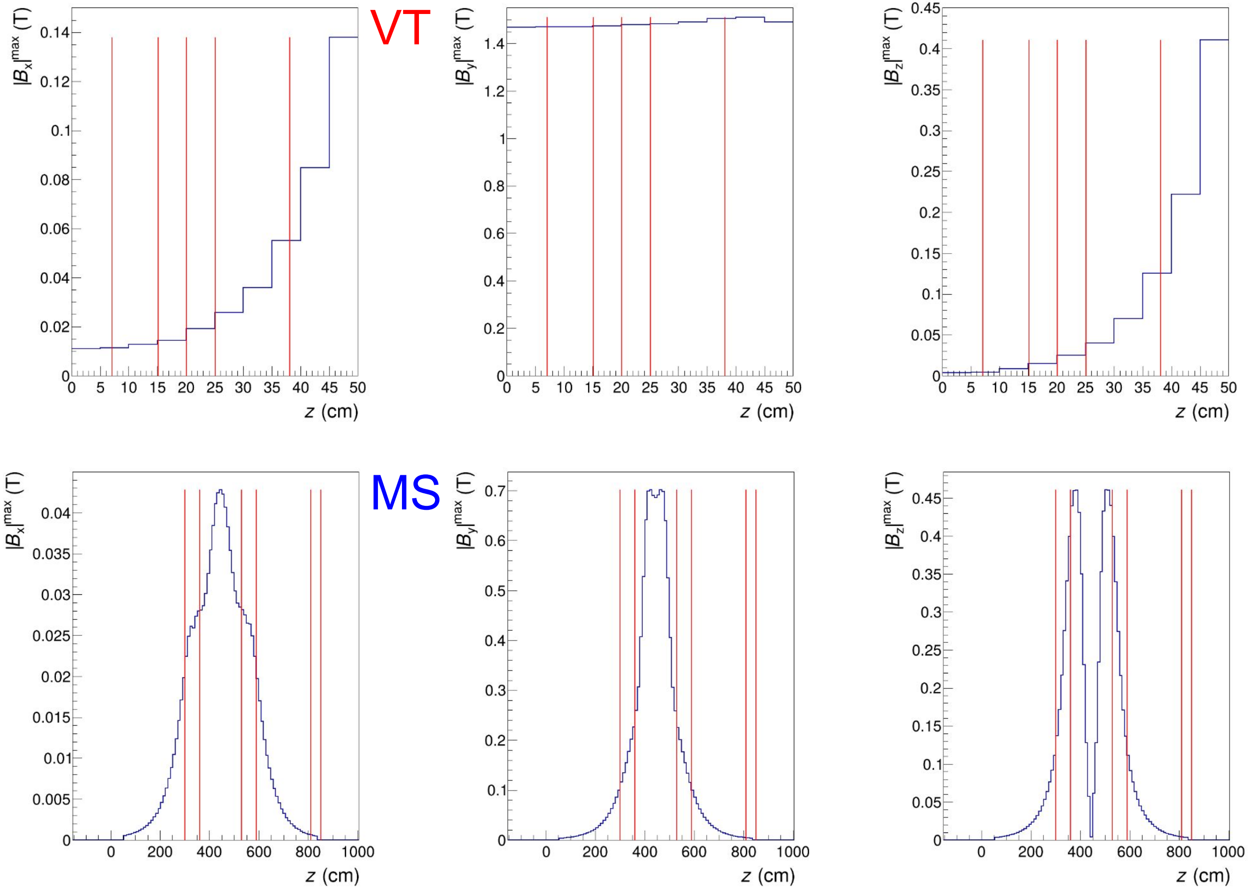


NA60+: magnetic field

- The maps have been converted into the ACTS csv standard
  - Maps expanded to cover a region larger than our experiment to avoid propagation errors

- EstimateTrackParamsFromSeed assumes constant magnetic field along z ➞ **not our case:**
  - **B_y changes in our MS magnet**
  - **B_z is not negligible**

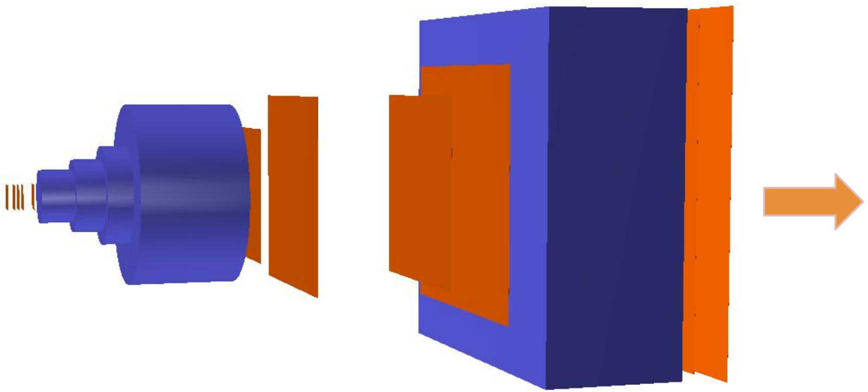
- In EstimateTrackParamsFromSeed we provide the average field ➞ **but we may lose efficiency in the MS**



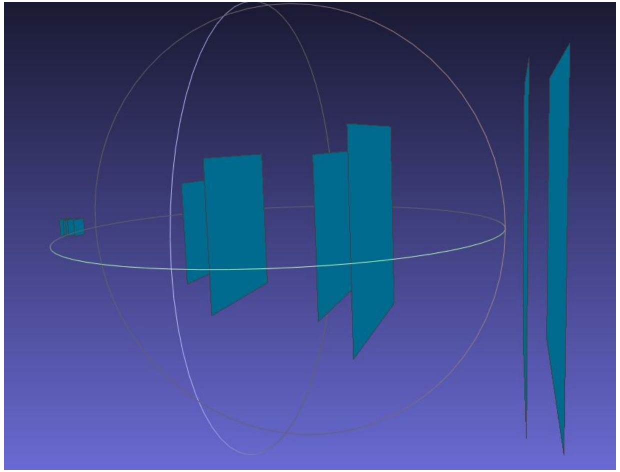
Geometry

- Geometry is built via TGeo: few changes to deal with rectangle shapes in ACTS (GeoLayerBuilder.hpp, DiscLayer.cpp, Layer.cpp, TGeoDetector.hpp)

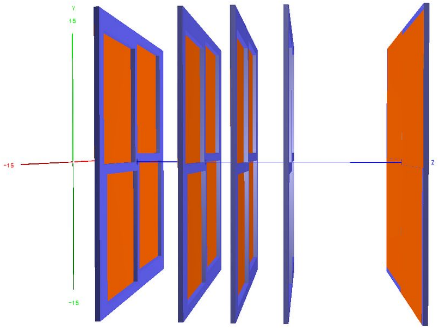
TGeo geometry



ACTS geometry



- Work in progress to create the ACTS geometry starting from a gdml using the new geometry framework
- Open issues on the mapping under discussion with Andreas



Primary vertex identification using tracklets

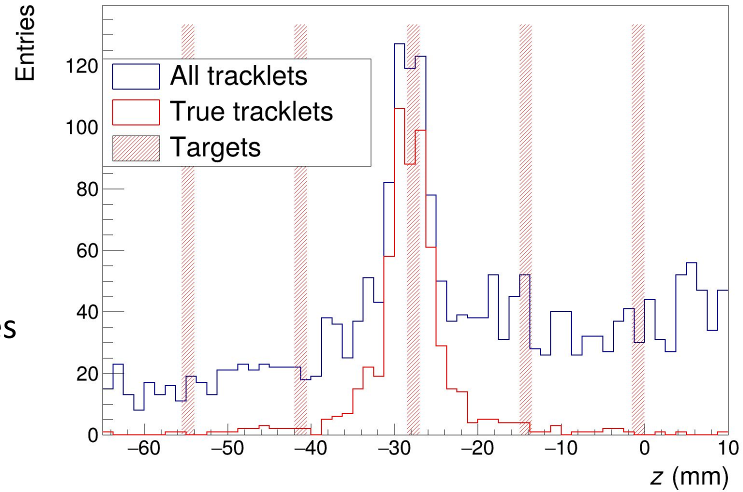
- **We need to have a first guess of PV position to apply d_0 selection in the seeding**
- We wrote a ACTS algorithm to perform the PV identification by building tracklets in the first two VT planes
- In the (almost) non-bending plane y-z the trajectories are straight lines

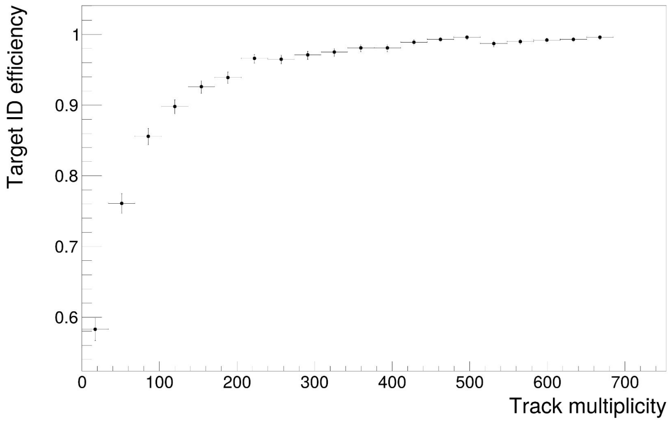
$$y(t) = v_y z + p_y$$

$$v_y = \frac{y_{L2} - y_{L1}}{z_{L2} - z_{L1}} \quad \rightarrow \quad z_{PV} = \frac{y_{PV} - p_y}{v_y} \sim -\frac{p_y}{v_y}$$

$$p_y = y_{L1} - v_y z_{L1}$$

Example of an event





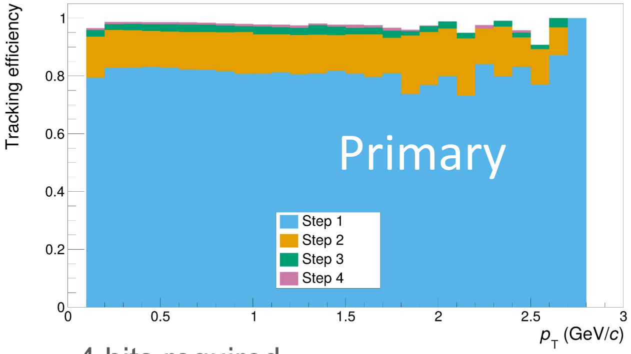
- Tracklet selection to reduce the background:
  $|\Delta\varphi| < 0.1$, $-0.15 < \Delta\theta_{z=0} < 0.04$
- In the seeding the collision is assumed to be at the z of the closest target to the maximum of the z_{PV} distribution
- **High Target ID efficiency at high track multiplicities**
- **The SP are shifted for a correct d_0 estimation: $(x,y,z) \rightarrow (x,y,z-z_{PV})$**

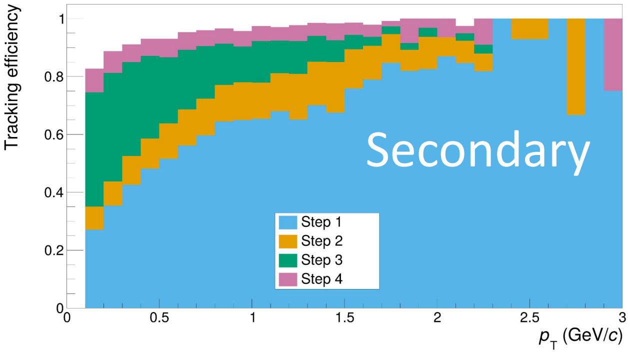
Vertex telescope reconstruction

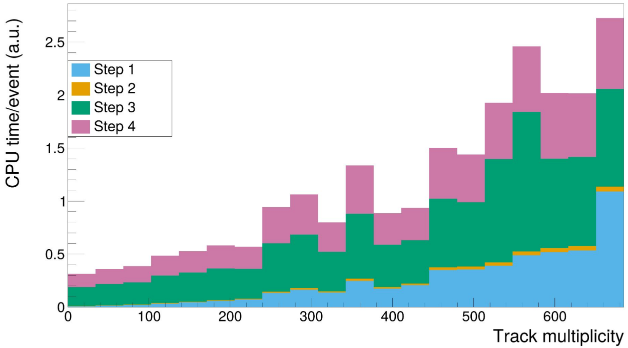
- We are interested in reconstructing decay daughters from long lived particles (cτ ~ few cm)
- The secondaries complicate the reconstruction:
  - The seed cannot be selected with d_0 (or other) selections ➞ we need to try many triplets of SPs (large MaxSeedsPerMSP)

- **Reconstruction chain in steps**: we reconstruct first the "easy" particles (primary) to remove their hits and reduce the combinatorics in steps for the secondaries

- Each step comprise Seeding + CKF + Ambiguity resolution + new algorithm to remove used hits. The steps are:
  1. Quasi-primary: seed with d_0 < 1 mm, layer 1-2-3, MaxSeedsPerSpMP = 1
  2. Quasi-primary: seed with d_0 < 1 mm, layer 2-3-4, MaxSeedsPerSpMP = 1
  3. Secondary: seed with layer 1-2-3, MaxSeedsPerSpMP = 20
  4. Secondary: seed with layer 2-3-4, MaxSeedsPerSpMP = 20





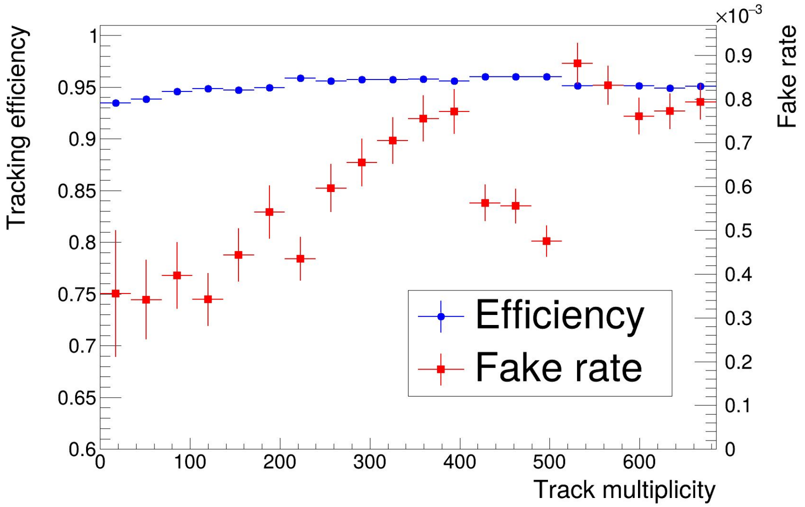


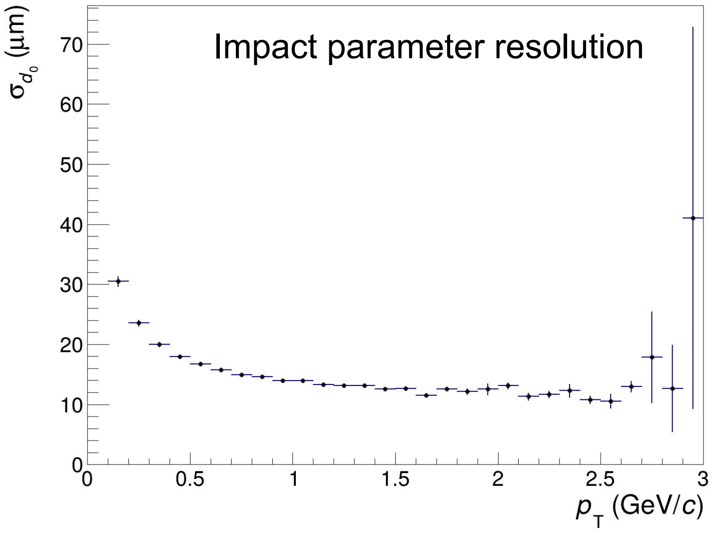
4 hits required

Vertex telescope reconstruction

- The VT faces high multiplicity events (up to 1000 particles) of which up 800 are reconstructable (4 or more hits)

- We are interested in studying all multiplicities

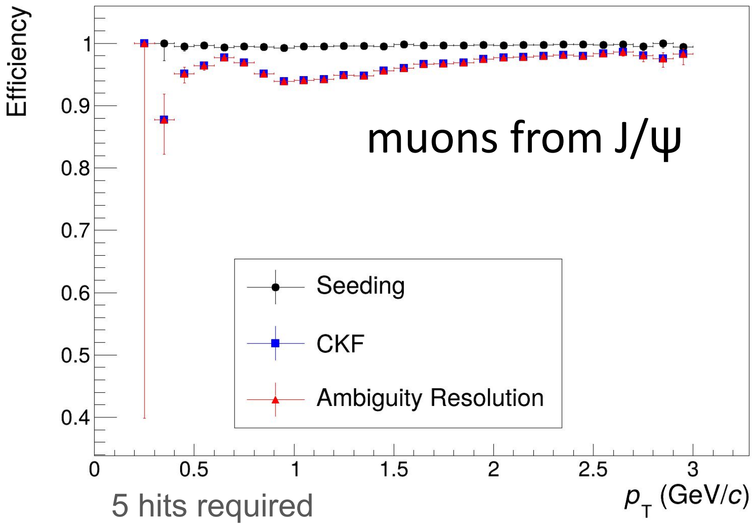


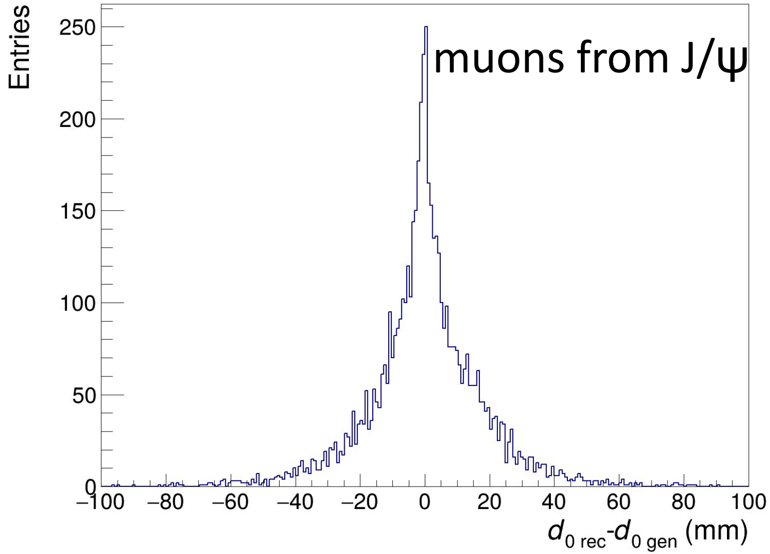


- **Good resolution on the d_0 (few tens of μm)** ➞ crucial to select non prompt particles
- Ambiguity resolution ➞ no shared hits allowed:
  - **Still high tracking efficiency**
  - **Low Fake rate**

Muon spectrometer reconstruction

- Low multiplicities + worse d_0 resolution ➞ no need (or benefit) for multi-step reconstruction
- Seeding with station 1-2-3 and we require the tracks to have hits in all stations

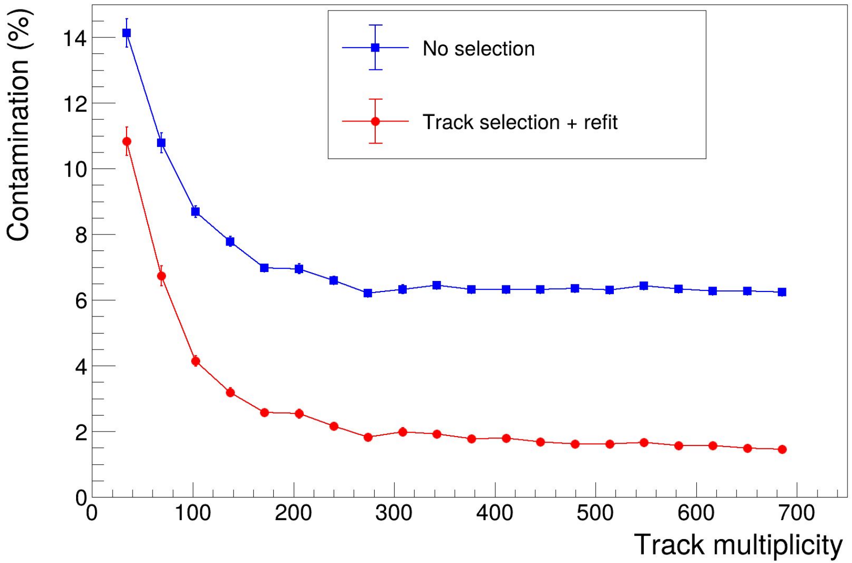


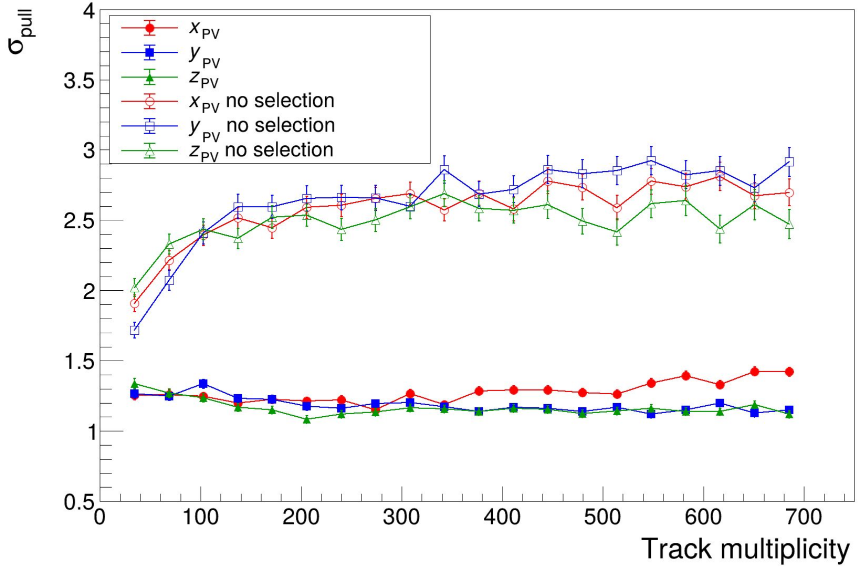


- Efficiency drop from the seeding to CKF likely due to bad track parameter estimation
- Studies performed with μ from J/ψ ➞ studies ongoing with other particles ω➞μμ, ϕ➞μμ, ρ➞μμ
- **Are there attempt to generalize EstimateTrackParamsFromSeed?**

Primary vertex identification

- Interaction rate of 10^5 Hz in Pb–Pb ➞ pile-up is negligible (1 collision per event in our simulation)
- In NA60+ $\boldsymbol{\sigma_{beam} >> \sigma_{d0}}$:
  - Gaussian track density seeder with loose d_0 selections (d_0 < 500 µm)
  - Secondary particles cannot be removed in the seeding ➞ strong bias in the PV reconstruction
- **Custom version of the Iterative Vertex Finder: seeding** ➞ vertexing fitting ➞ track selection ➞ vertexing fitting

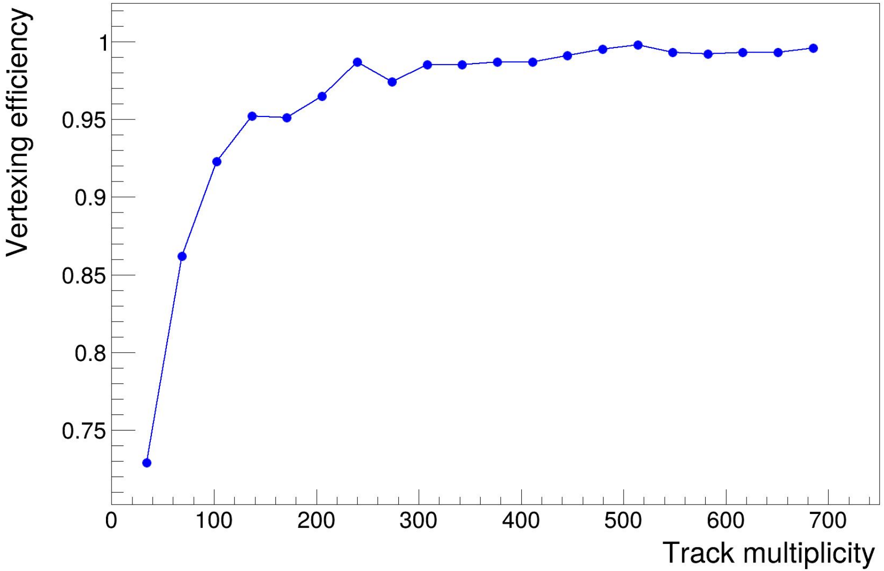


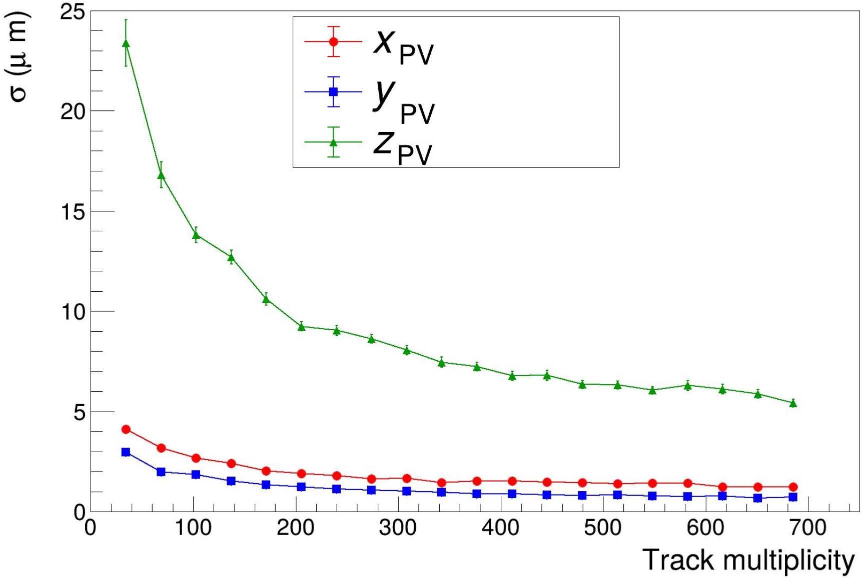


- Next step: try to iterate more times to further reduce the contamination

Primary vertex identification

- **Very good resolution on the PV position:**
  Caveat: the multiple scattering inside the targets is not yet implemented

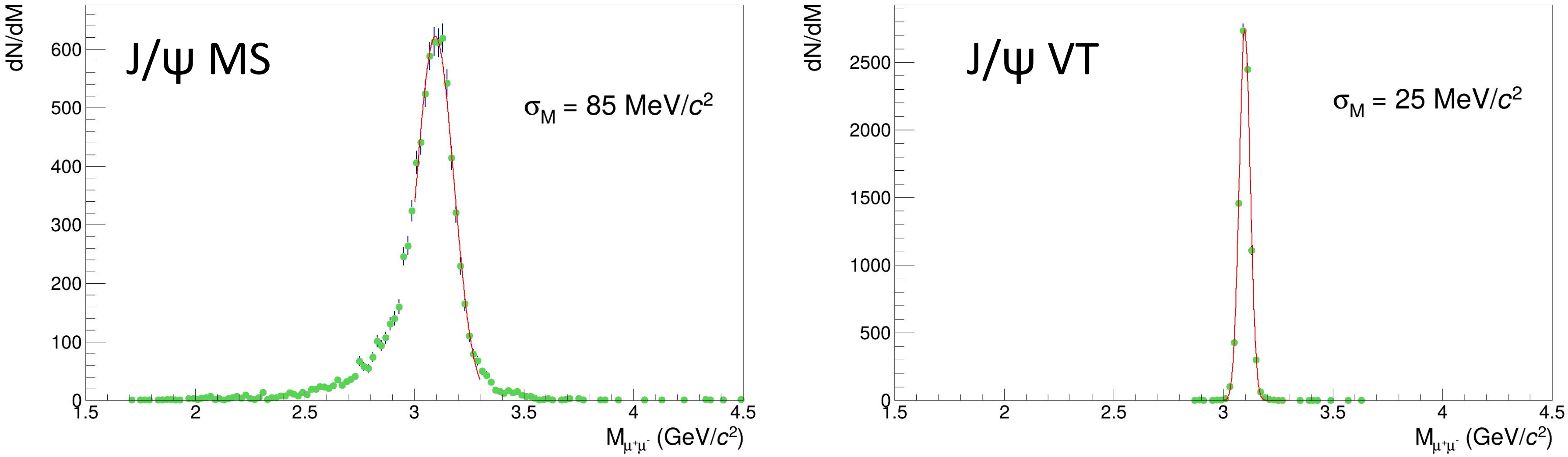




- The vertexing efficiency decrease going to lower multiplicities ➞ likely linked to the tracklet vertexing inefficiencies

Matching

- We aim to measure dimuon to reconstruct particles such as J/ψ, ω, …
- Low background in the MS thanks to the absorber
- VT provides a precise measurement ➞ 4x better resolution on the J/ψ mass w.r.t. the MS



- Matching MS tracks to the VT tracks can reduce the background and exploit the VT resolution
- **New ACTS algorithm added to perform the VT MS matching by comparing the track parameters**
- MS track matched to the VT track with the lowest χ^2 ➞ **high matching purity = 96%**
- **The next step is to perform the VT+MS refit to further improve the resolutions**

track parameter

$$\chi^2 = \sum_i \frac{(q_{iVT} - q_{iMS})^2}{\sigma_{iVT}^2 + \sigma_{iMS}^2}$$

Conclusions

- In May 2025 we will submit the Technical Proposal to the SPS committee ➞ our goal is to show that we can use ACTS to perform the event reconstruction

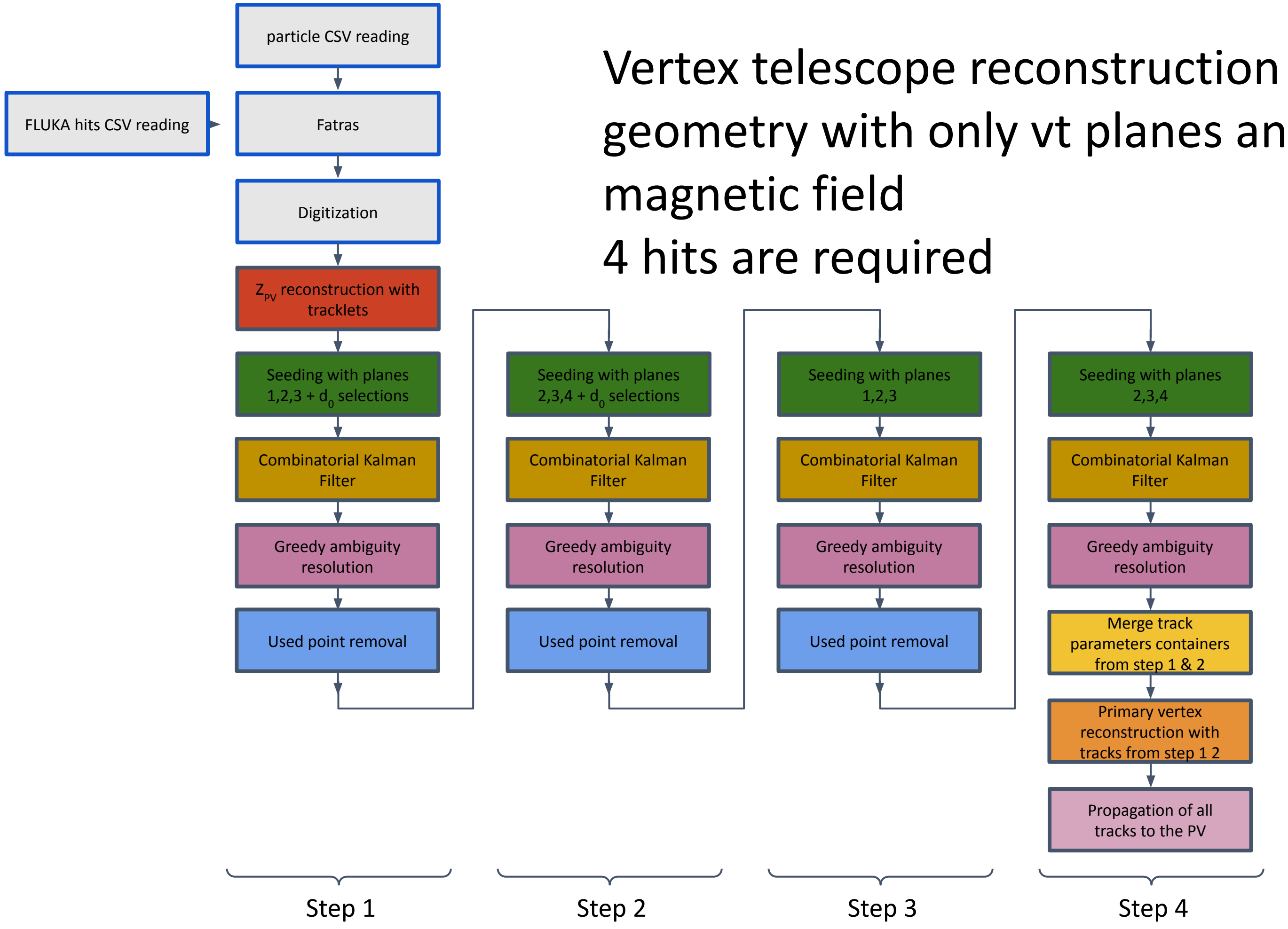
- **Achievements:**
  - We are able to reconstruct the tracks both in the VT and in MS with good efficiency and resolutions
  - We can reconstruct the primary vertex
  - We are ready to start the physics performance analysis

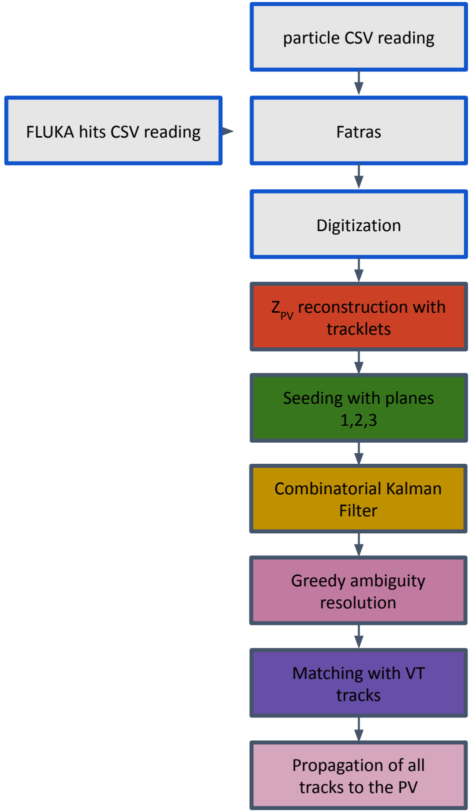
- **Next steps:**
  - Implement the new geometry
  - Perform the particle propagation with Geant4
  - Optimize the reconstruction parameters
  - Improve the track parameter estimation
  - Implement the VT+MS refit for matched tracks
  - Estimate the CPU time

Many thanks for your help and suggestions!

Backup

Vertex telescope reconstruction chain geometry with only vt planes and magnetic field
4 hits are required

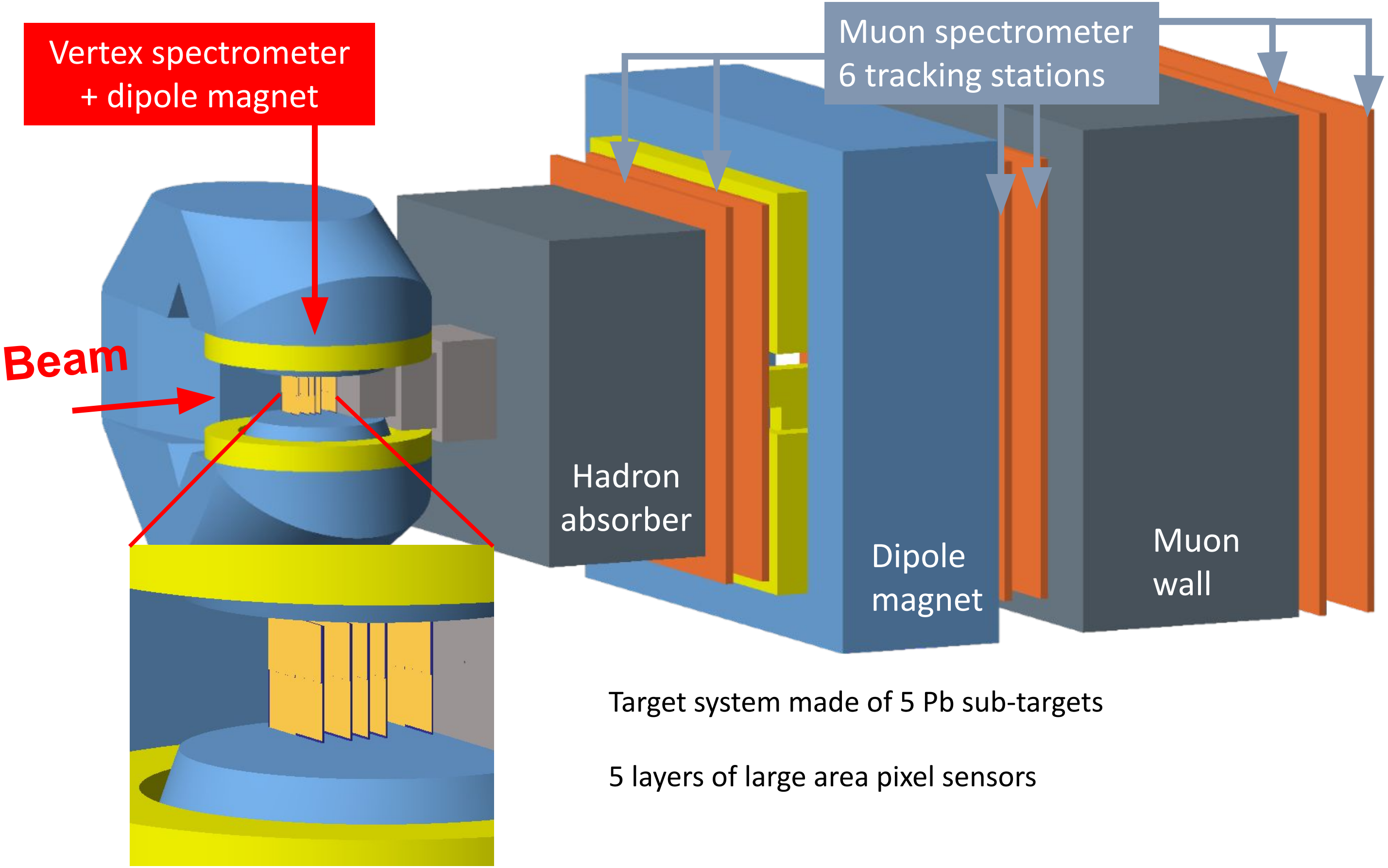




Magnetic field both from MEP43 and NA62 dipole

5 hits are required

NA60+: experimental setup



Target system made of 5 Pb sub-targets

5 layers of large area pixel sensors