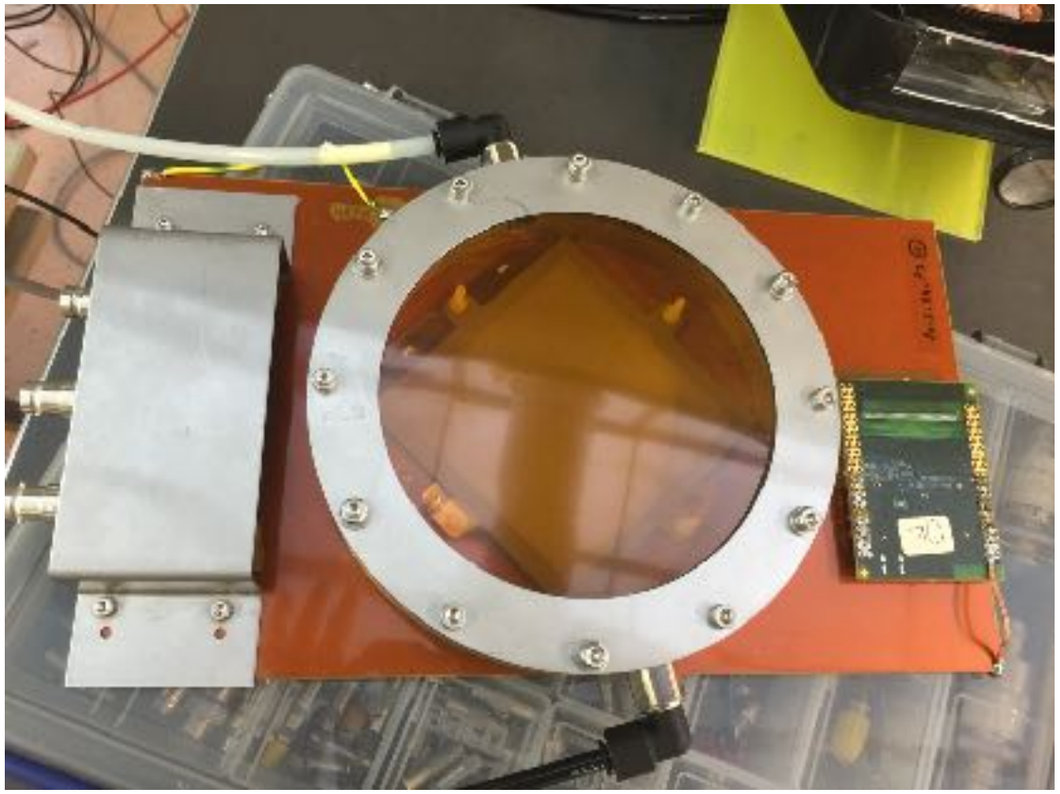
Performance of Multiplexed XY Resistive Micromegas detectors in a high intensity beam

D. Banerjee et al., NA64 Collaboration

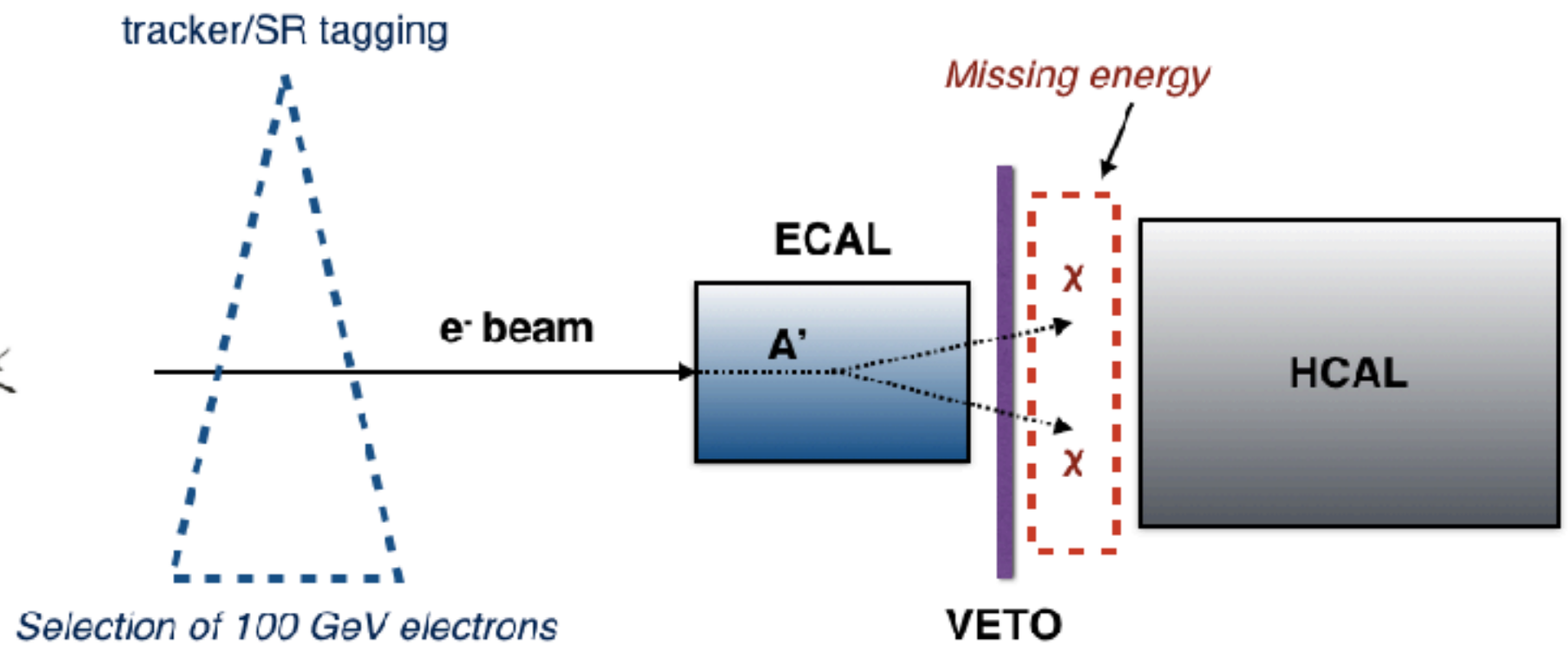
arXiv:1708.04087

ETH Zurich, Institute for Particle Physics
Group of Prof. Andre Rubbia

This work is funded by: SNSF grant 162794 PI A. Rubbia, Co-PI P. Crivelli



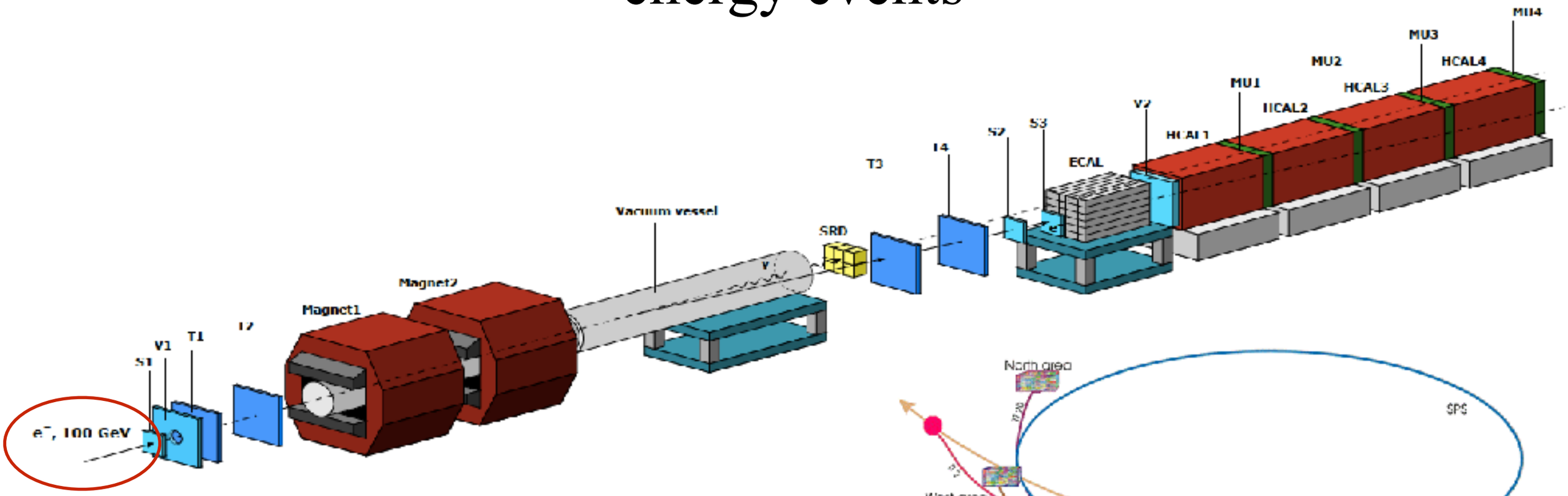
NA64 Goal and Experimental Signature

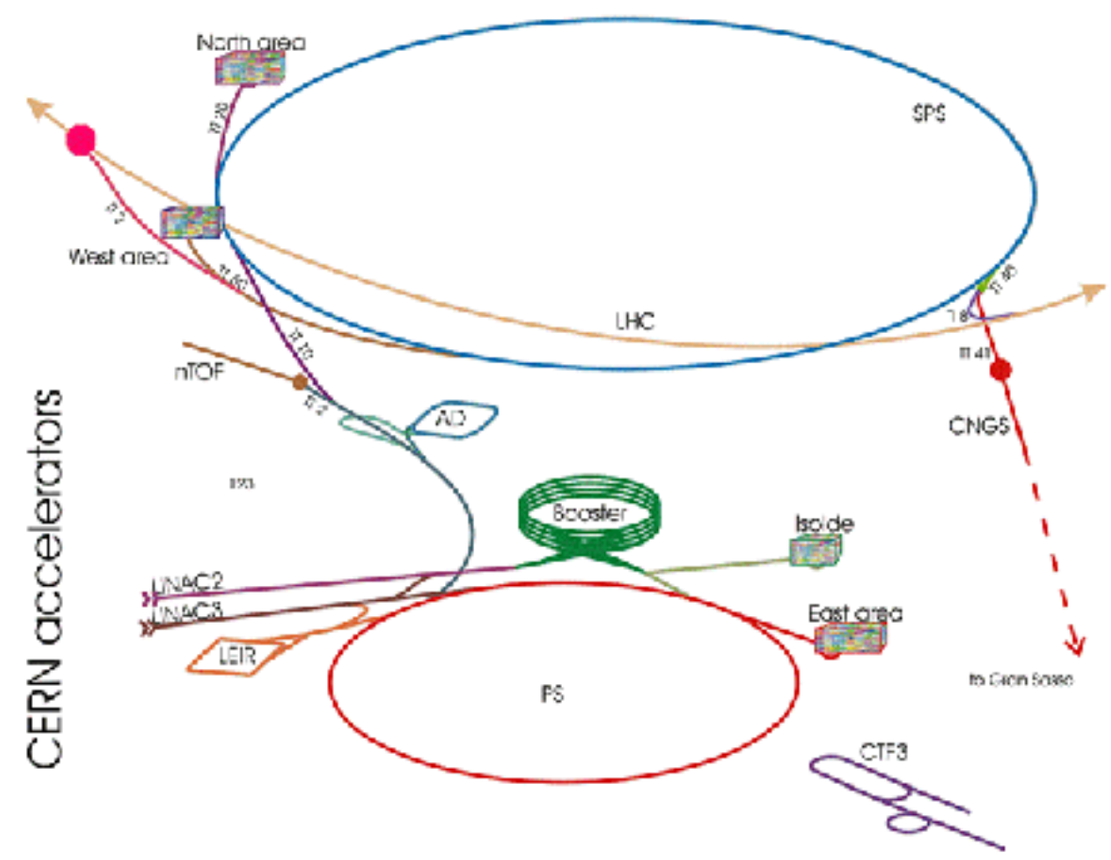


- NA64 is searching for Dark Photons, a promising candidate for Dark Matter.
- Fixed target experiment combining the active beam dump technique with missing energy measurement.
- Searching for invisible decays of massive A' produced with mixing strength $10^{-6} < \varepsilon < 10^{-3}$ and masses $M_{A'} < 100$ MeV in the reaction eZ—> eZA', of 100 GeV electrons dumped against an ECAL, a sandwich of lead and scintillators (34 X_0), through scattering with the heavy nuclei. *http://na64.web.cern.ch*

Experimental Signature:
In : 100 GeV electrons, tagged with Trackers (momentum) and Synchrotron Radiation (particle identification)
Out: $E_{ECAL} < 50$ GeV, No interaction in Veto and HCAL (missing energy)
Background: Hadrons, muons, low energy electrons with incoming energy < 50 GeV.
arXiv:1312.3309 [hep-ex]

NA64: Search for dark sector physics in missing energy events

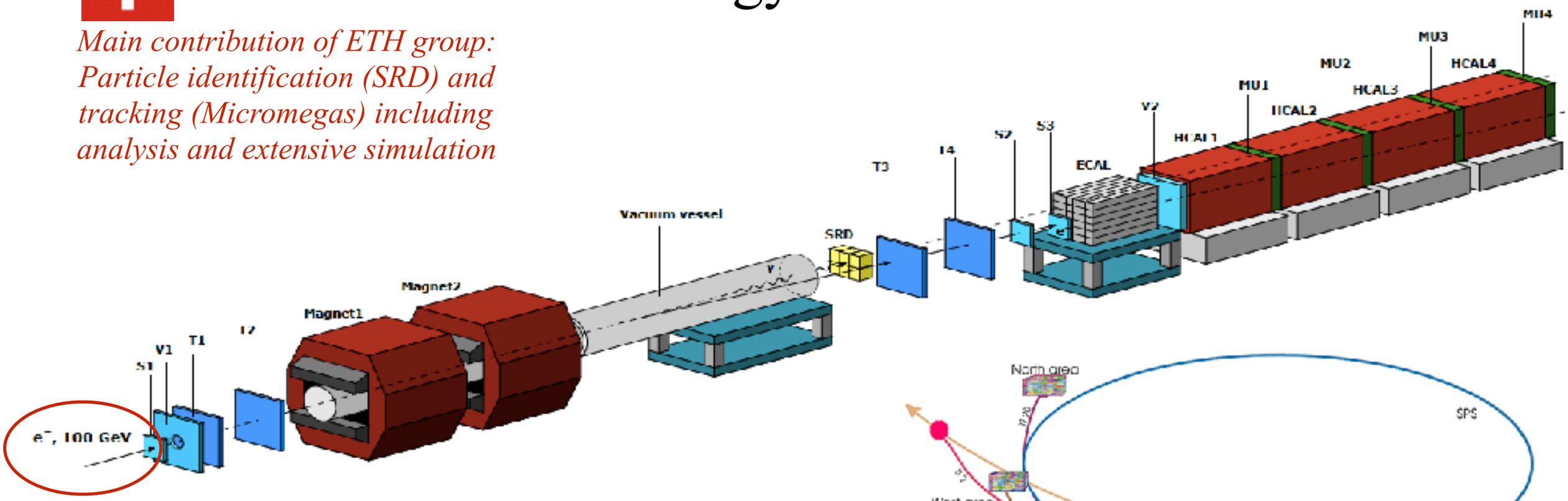


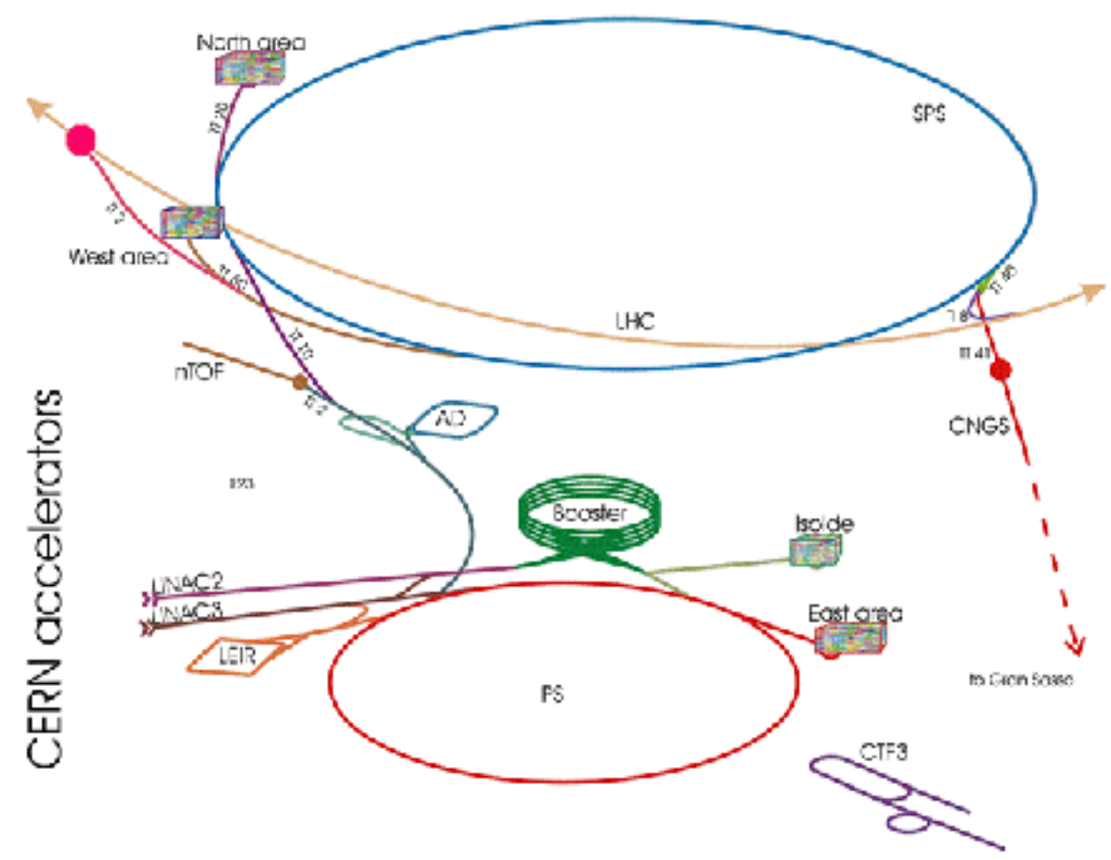


- High energy beam to trigger the reaction: 100 GeV e- beam from the CERN SPS H4 beamline.
- High intensity beam > 10^5 e^-/sec/cm^2
- Main impurities of H4 beam: π–, low energy e– (~1%) μ– and K– (≤0.1%)

NA64: Search for dark sector physics in missing energy events

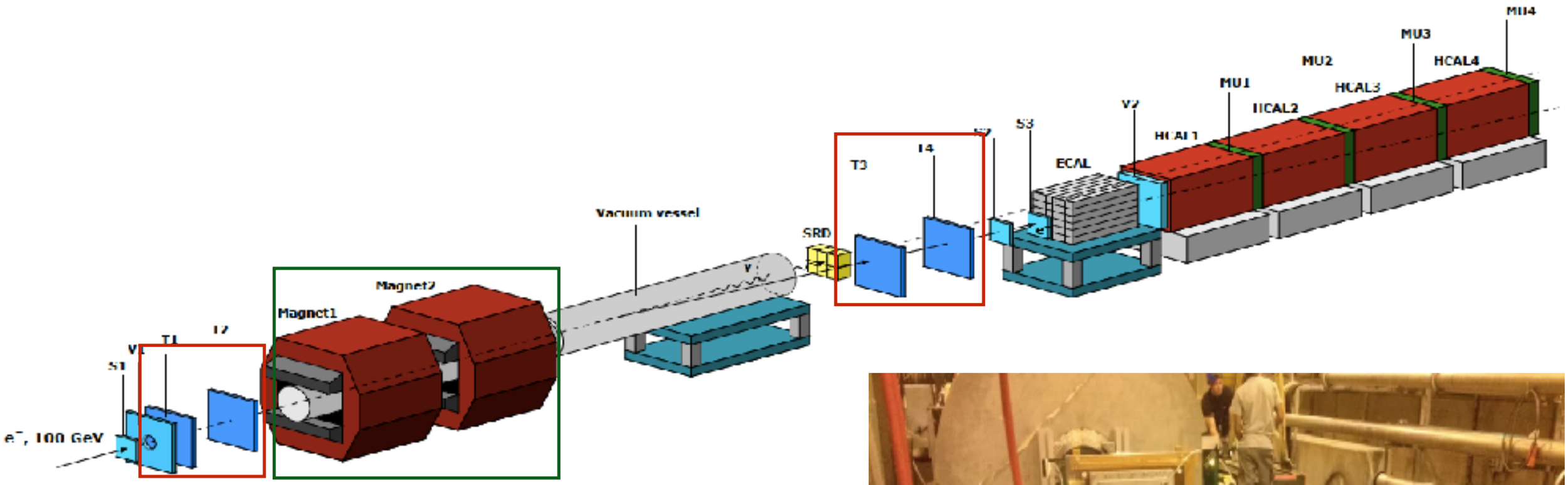
Main contribution of ETH group: Particle identification (SRD) and tracking (Micromegas) including analysis and extensive simulation



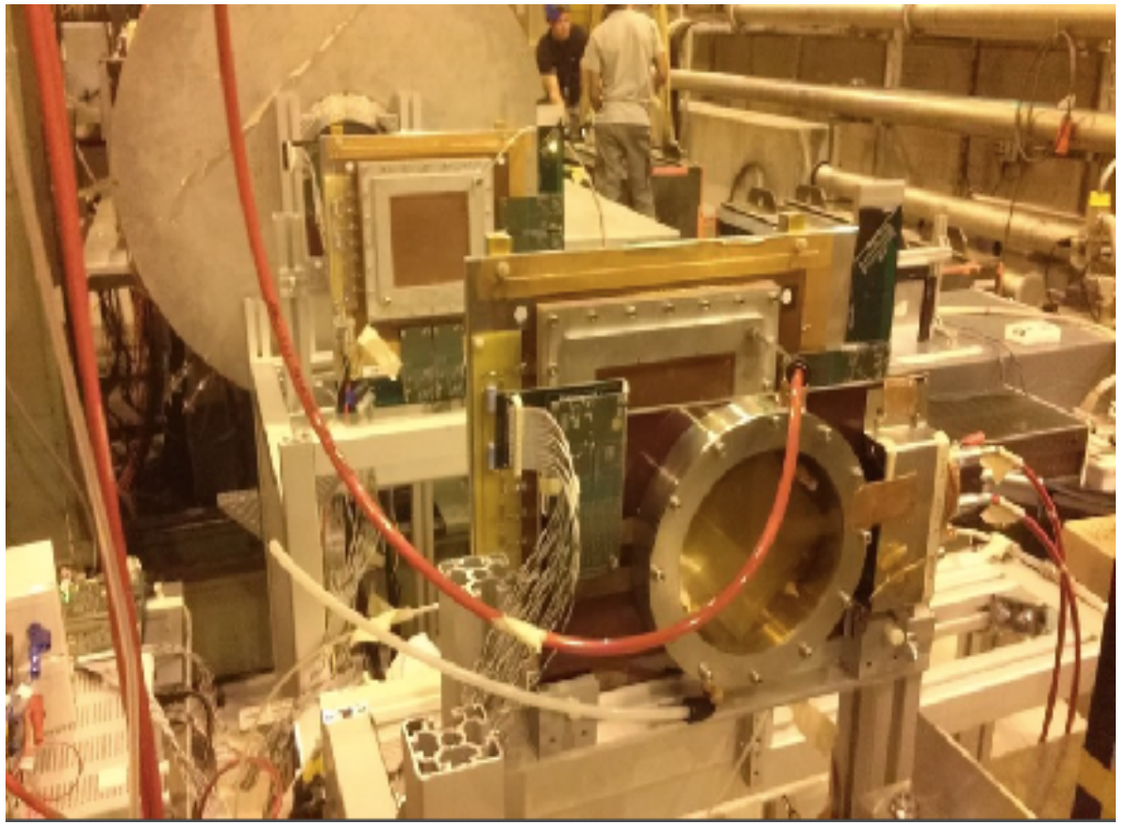


- Synchrotron radiation detection to reject beam hadron and muon background (see E.Depero's talk 25.08.2017)
- Tracker to reject background from low energy beam tail. (Focus of this talk)

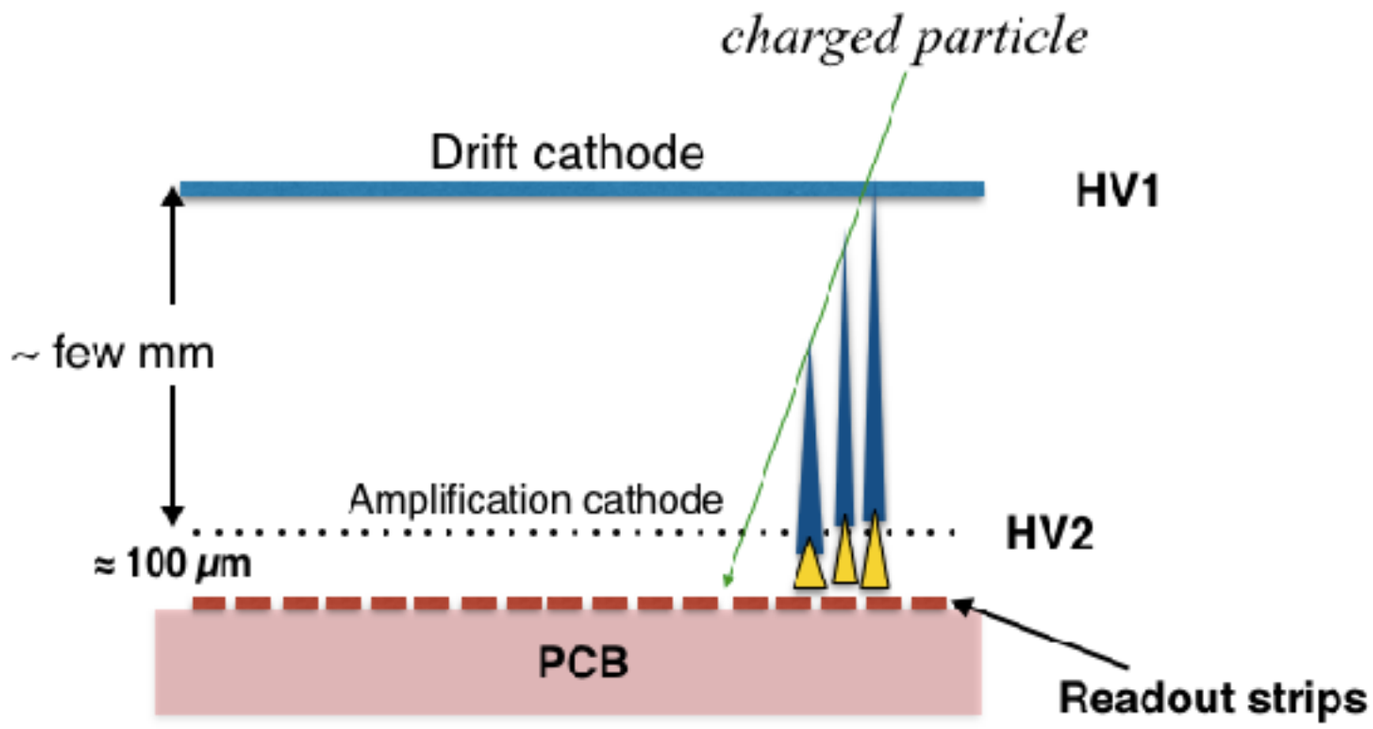
Resistive Multiplexed Micromegas for NA64



- Measure momentum to reject background from low energy beam tail
- Tracking system made of 4 MicroMegas modules together with 2 MPBL magnet ~7 T· m to measure momentum of incoming particles.

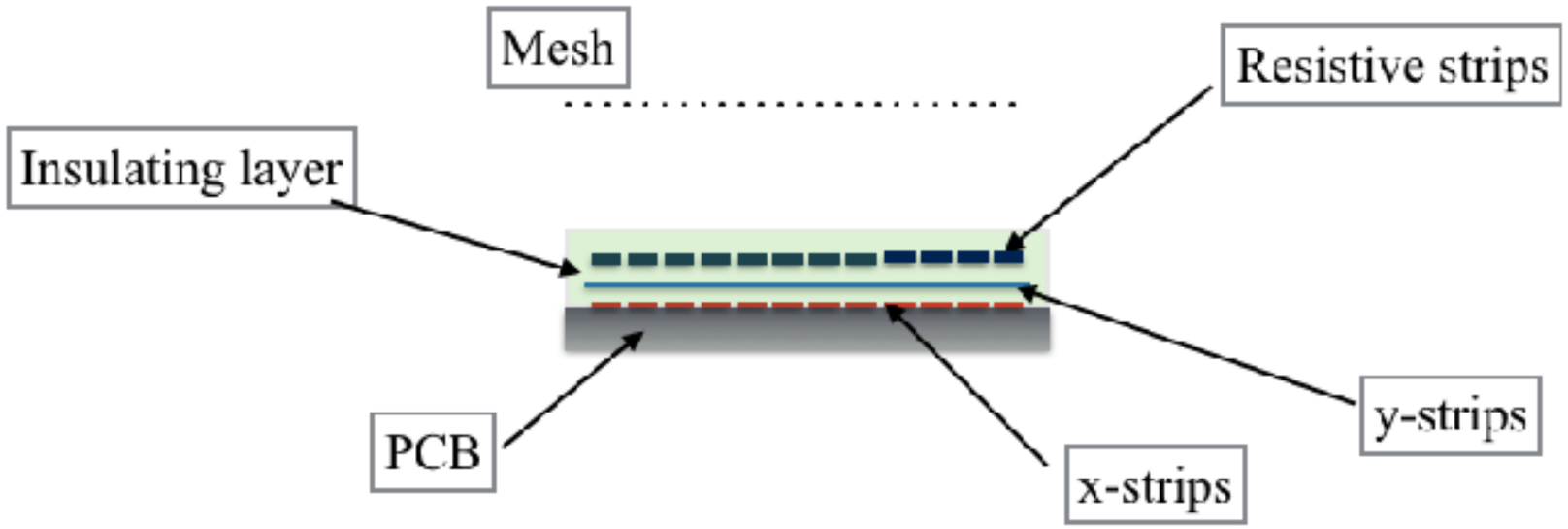


Micromegas Tracker



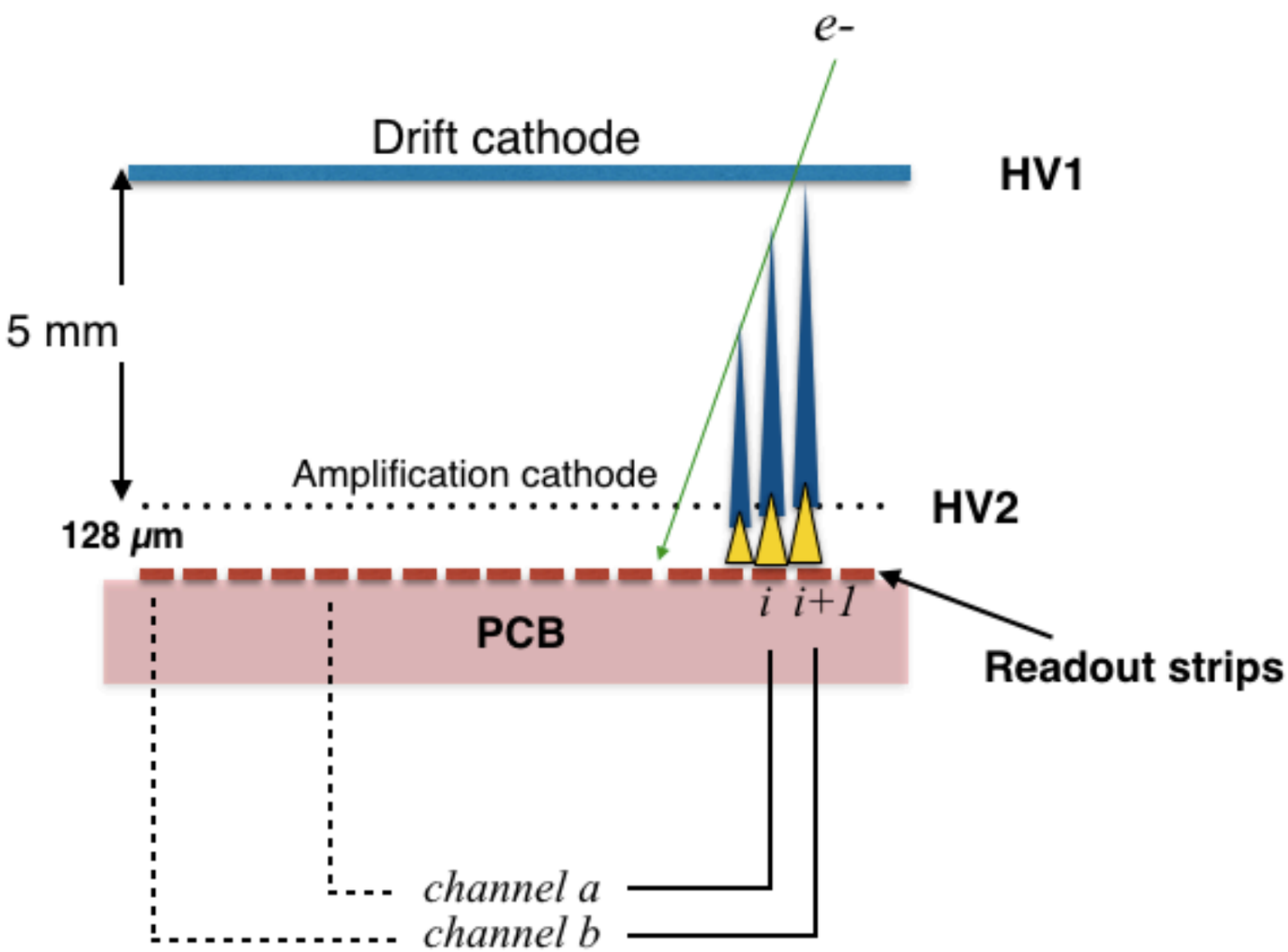
- Micromegas detectors are two stage parallel plate avalanche chambers.
- Narrow amplification gap ~ few 100 μm
- Wider drift gap ~ few mm.
- Charged particle drift towards the micro-mesh under an E-field ~ 0.6 kV/cm (HV1).
- Produces avalanche of secondary electrons under high amplification field ~ 50 kV/cm (HV2).

Resistive Modules



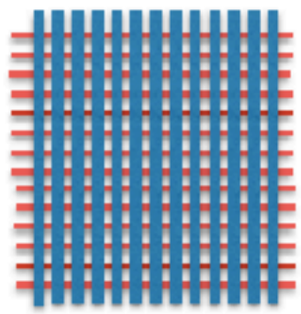
- High efficiency requires high gas gain.
- Prone to sparks at high flux environment leading to dead times.
- Introduction of Resistive layer leads to spreading of charge —> slows down spark development
  Nucl. Instrum. Meth. A566 (2006) 281
- Signal generated via capacitive coupling between resistive and readout strips.
- Similar width X and R strips with thinner Y strips to compensate for weaker capacitive coupling to X strips found optimal. *JINST 7 C02060, 2012*

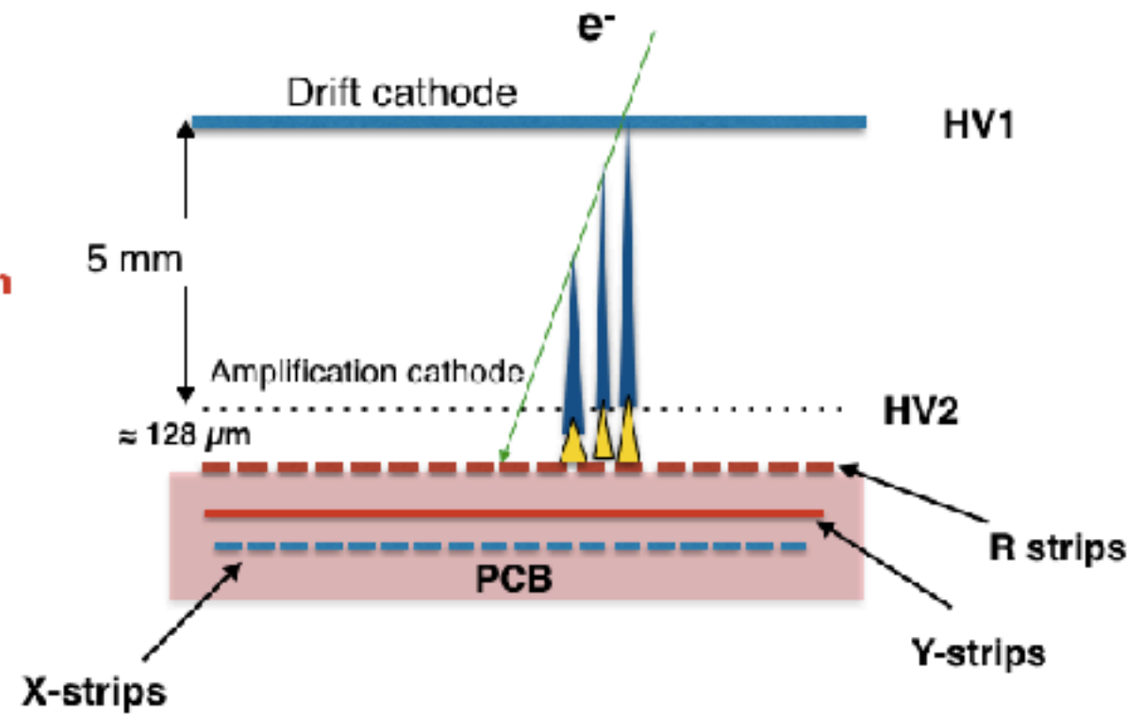
Readout Multiplexing



- Connect multiple strips to one readout channel to save electronics cost for large systems.
- Exploits the feature that a signal is collected on several neighbouring strips.
- For our specific prototype multiplexing factor of 5 chosen for first tests in a high flux environment.
- APV25 chip with 128 channels used for readout.
- Multiplexing done such that clusters <= 6 strip size does not cause repetition of two consecutive strip connections.

NA64 Modules

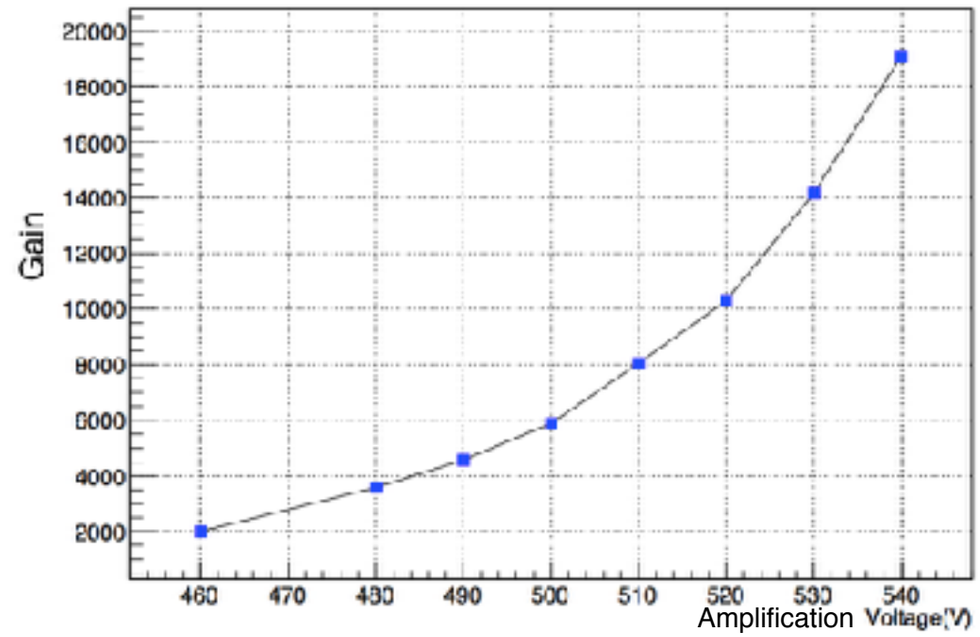


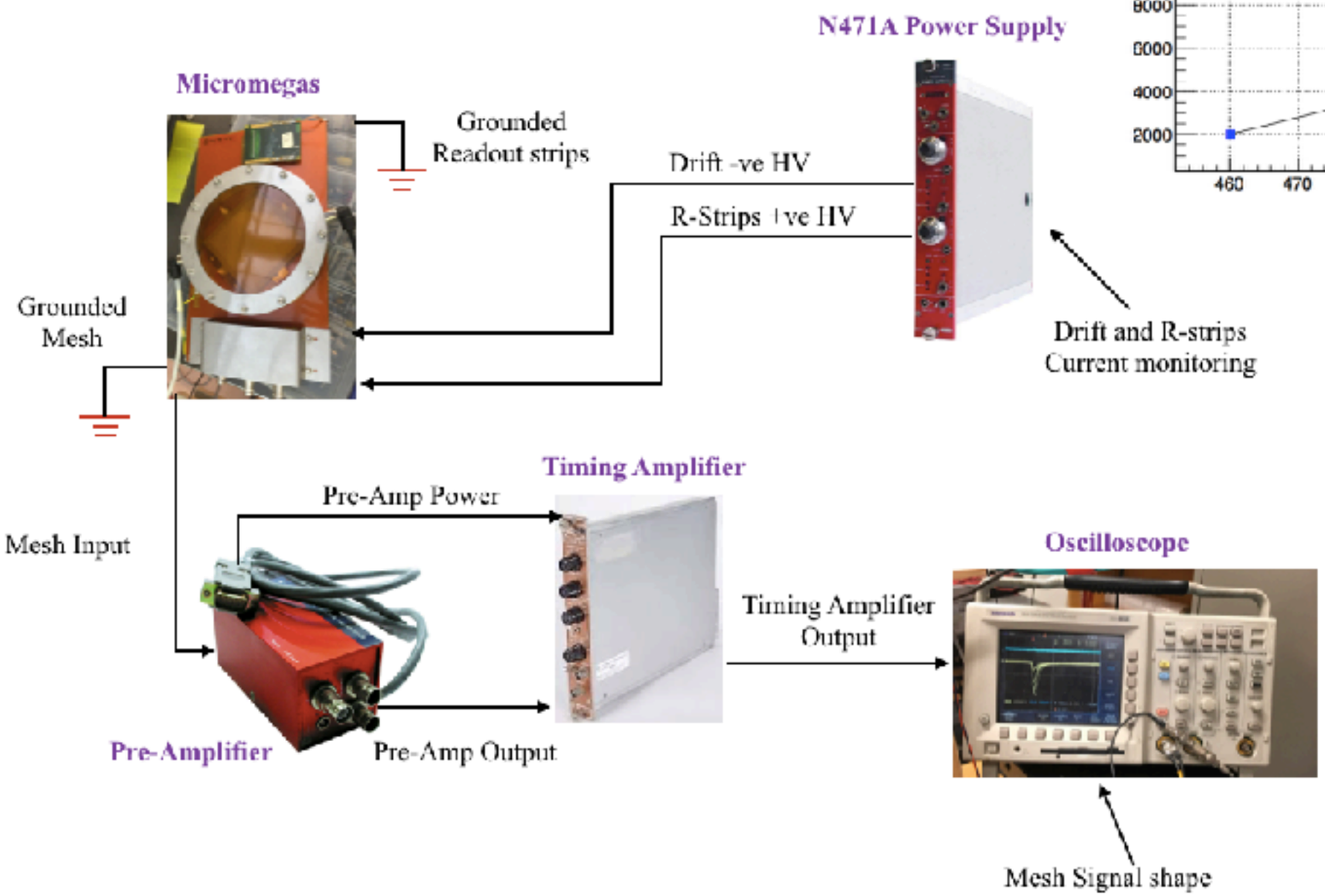


- 8 cm x 8 cm micromegas modules with 5 mm drift gap, 128 μm amplification gap produced.
- Resistive XY modules with 250 μm pitch for all layers.
- Width of X = R = 200 μm; Width of Y = 50 μm.
- Multiplexed technology used to multiplex 320 strips/layer to be read by 64 electronic channels.
- One 128 channel APV chip used per module.

Gain Calibration

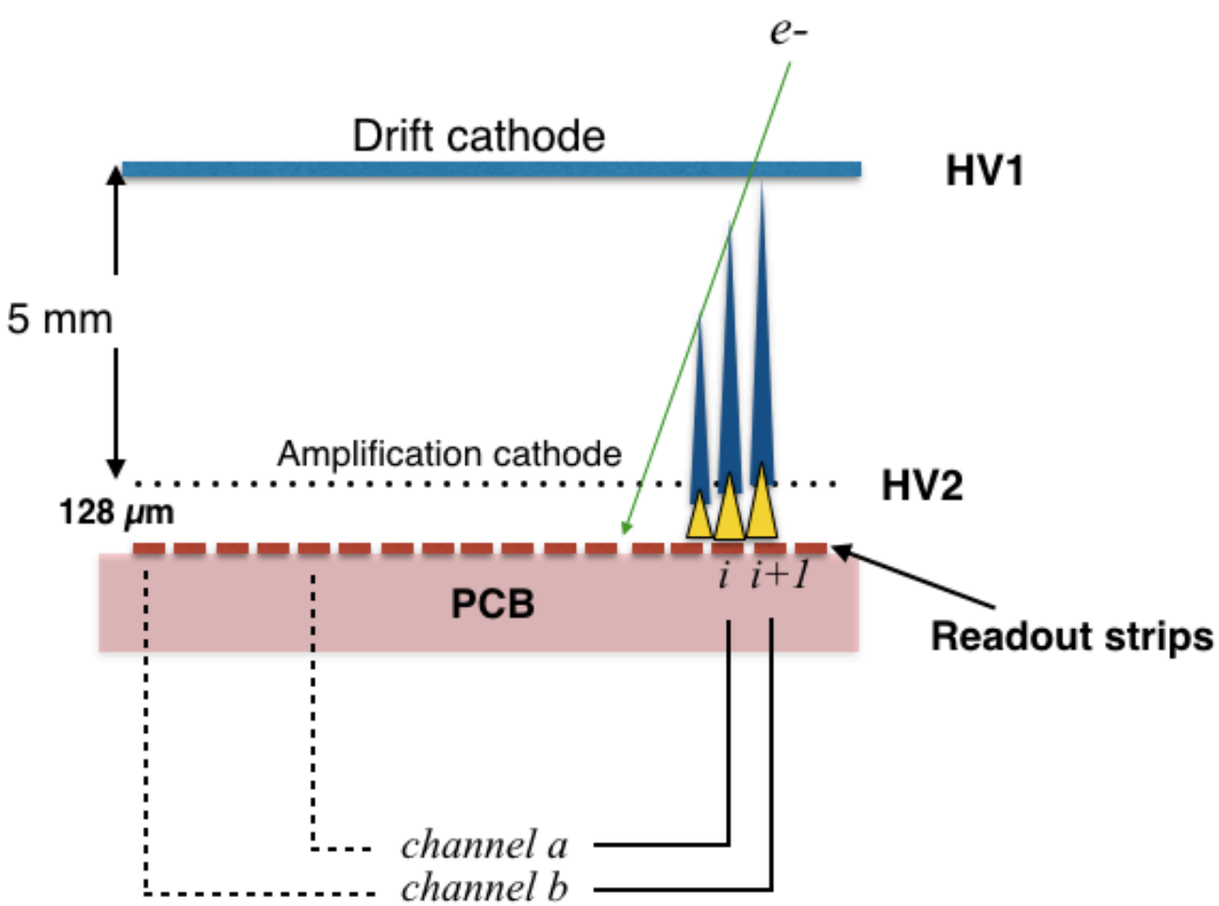
Gain calibration with Fe55 source
Gas used —> Ar/CO2 (93-7%)





Gain ~ 2 x 10^4 achieved

Multiplexing ambiguity



- Ambiguities expected due to loss of information from multiplexing
- E.g particle pile up may lead to fake combinations of clusters
- Also larger charge spread may lead to fake consecutive strip combinations
  - e.g in our case clusters > 6 strip size can lead to repetition of consecutive strip connection.
- Ambiguity can be controlled decreasing the multiplexing factor.
- On the other hand using additional information of cluster size and integrated charge is also an efficient way to limit ambiguities as done in the presented study.

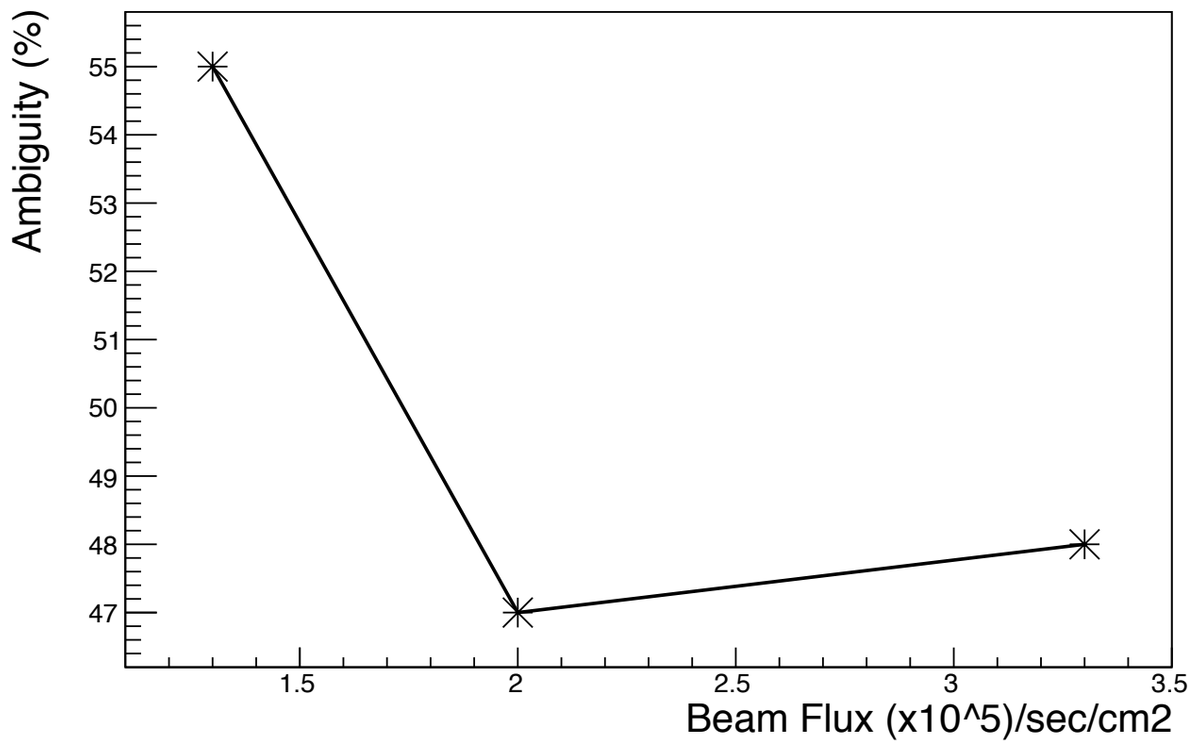
Signal and Ambiguity correction

- Accepted signal size for the test was at least two strip wide.
- All signal clusters per plane (X and Y) sharing same readout channel was compared and clusters with smaller integrated charge and size in terms of # of strips was suppressed from that group.
- Real signal clusters expected to have the largest size and integrated charge.
- Level of ambiguity checked after this correction for different beam fluxes for single and double particle events.
- Level of ambiguity defined as No. of events giving >1 clusters for a single particle event or >2 clusters for a double particle event.
- Position of hit calculated from weighted mean of the signal cluster charge.
- Efficiency, spatial resolution, timing and tracking performance of the modules was also checked.

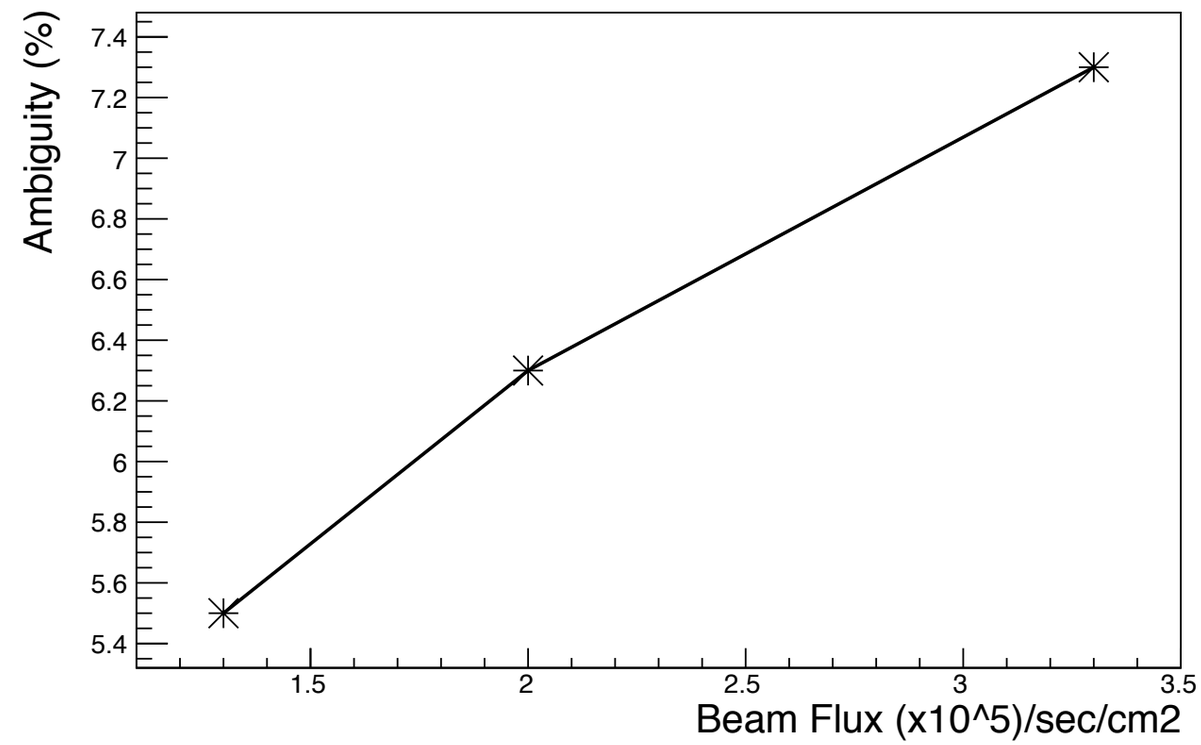
Beam Time Micromegas Performance

Level of Ambiguity

Level of ambiguity for single particle event



Level of ambiguity for double particle event



Level of ambiguity checked before the correction for single and double particle events and different beam fluxes.

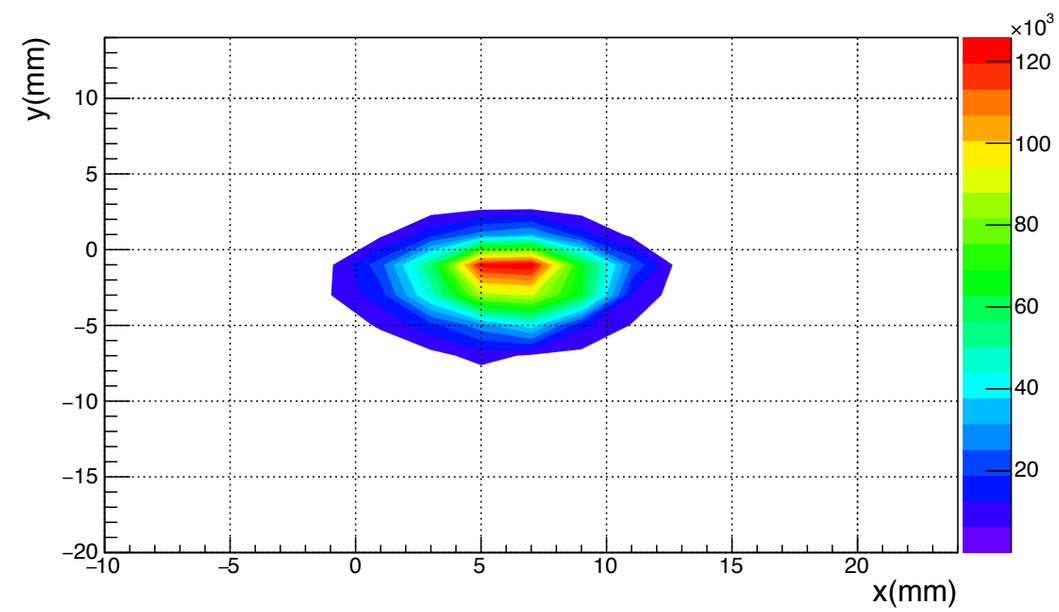
Level of Ambiguity in single particle events mainly due to signal spread (cluster size) —> Not dependent on beam flux.

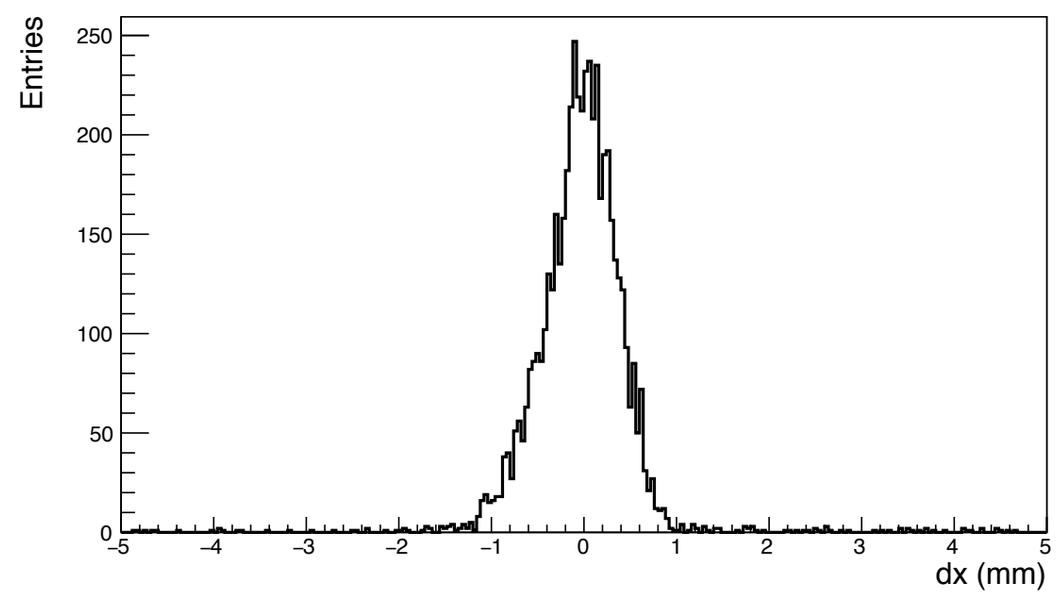
Level of Ambiguity in double particle events is a function of particle pile up (7-9 % double particle pile up/run) —> Dependent on beam flux.

Level of Ambiguity

To check the level at which a fake cluster was selected after the correction:

Position of the signal clusters on MM 3 and MM 4 compared (dx) after selecting a parallel incoming track within the beam spot using the position information from MM 1 and 2, having energy in the range 100 GeV/c ± σ_{ECAL} (σ_{ECAL} is the energy resolution of the ECAL ~ 2 GeV/c).

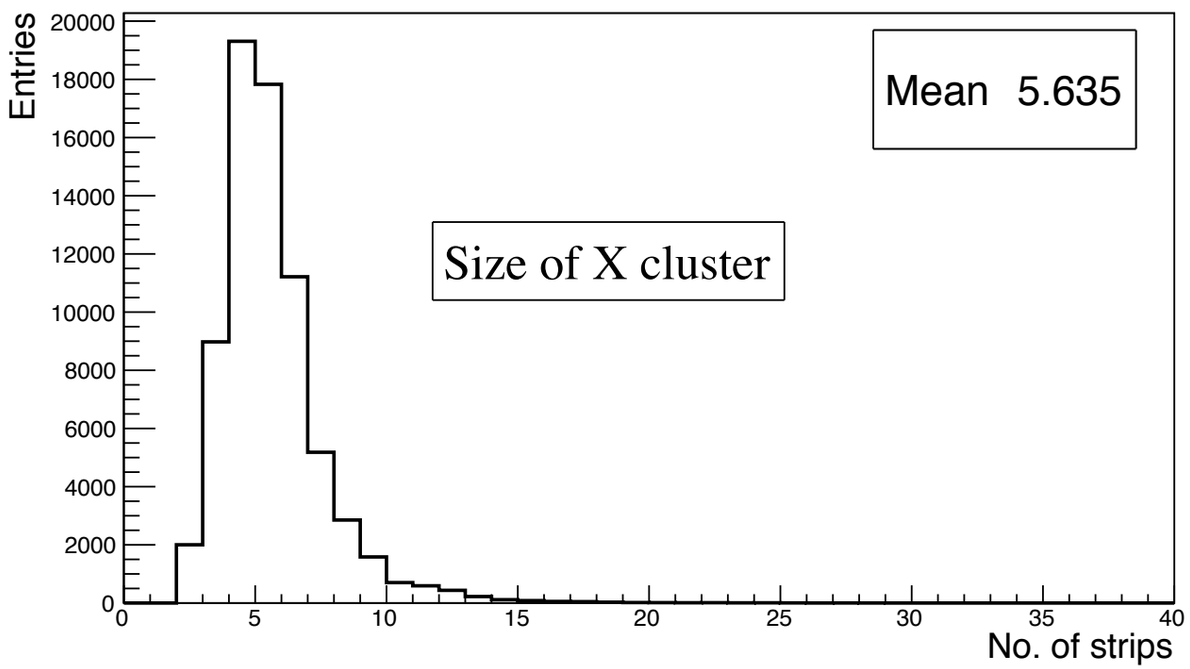


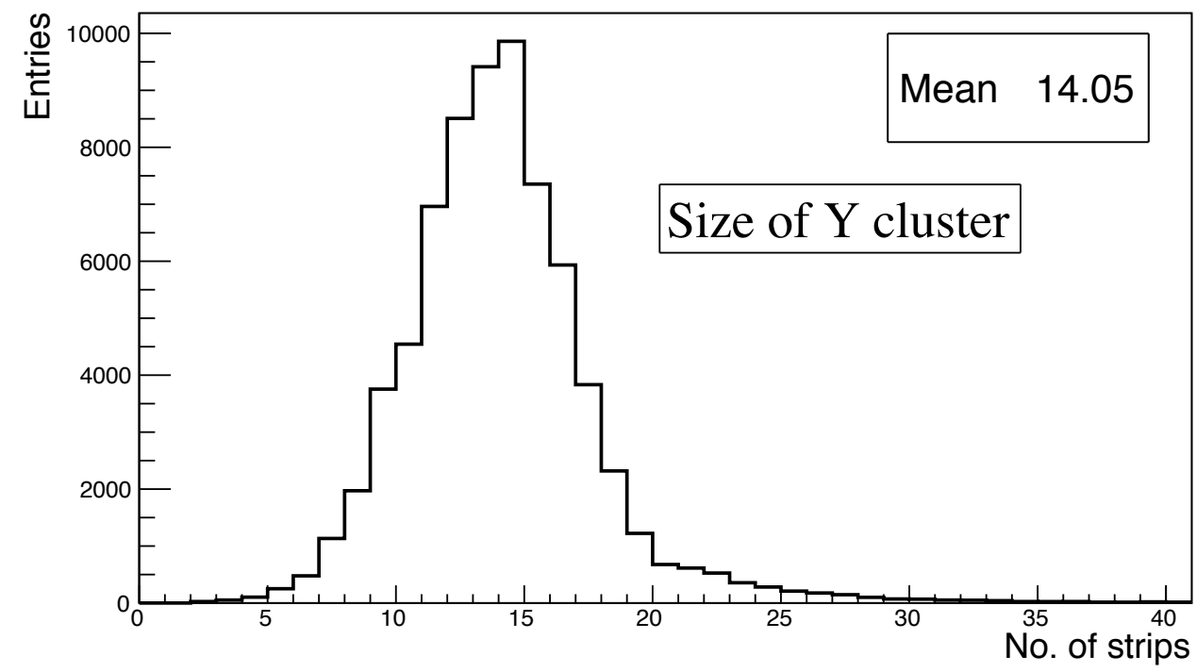


The distribution has a flat background with < 2 % of the events with a difference > 4 σ_{MM}(where σ_{MM} is the the Micromegas hit resolution)

Efficient way to limit ambiguities using signal cluster information from ~ 50 % to < 2 % chance of wrong cluster identification.

Cluster Size

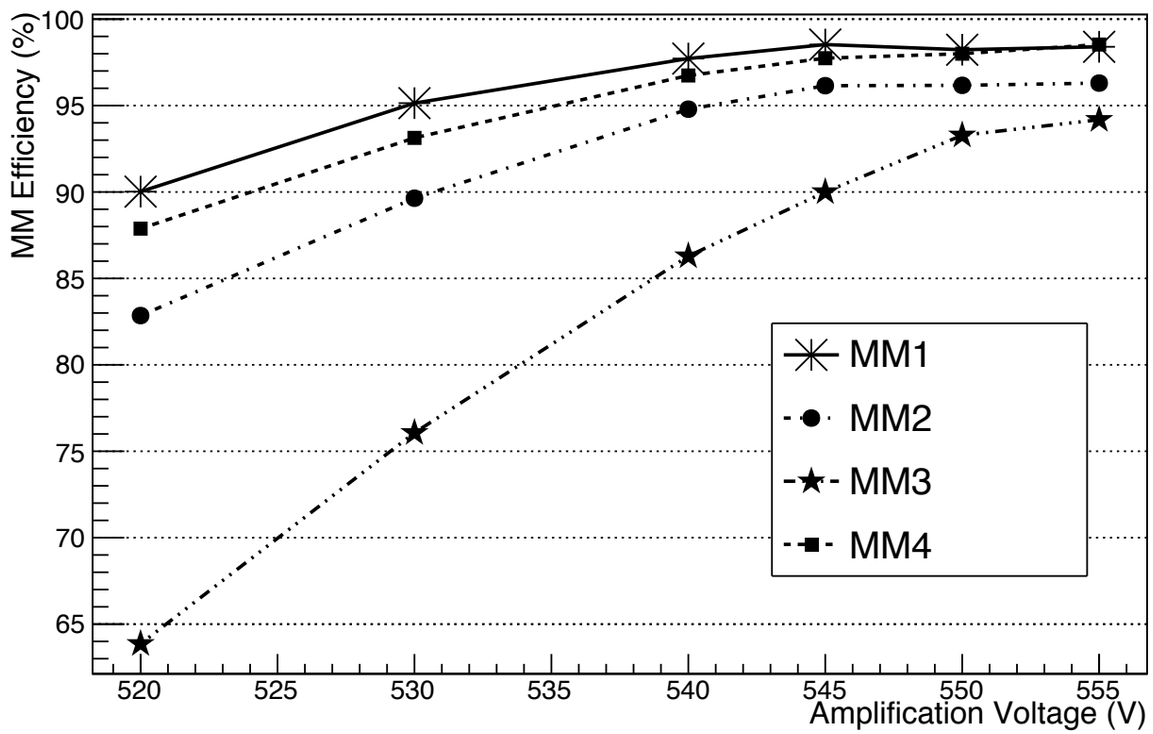




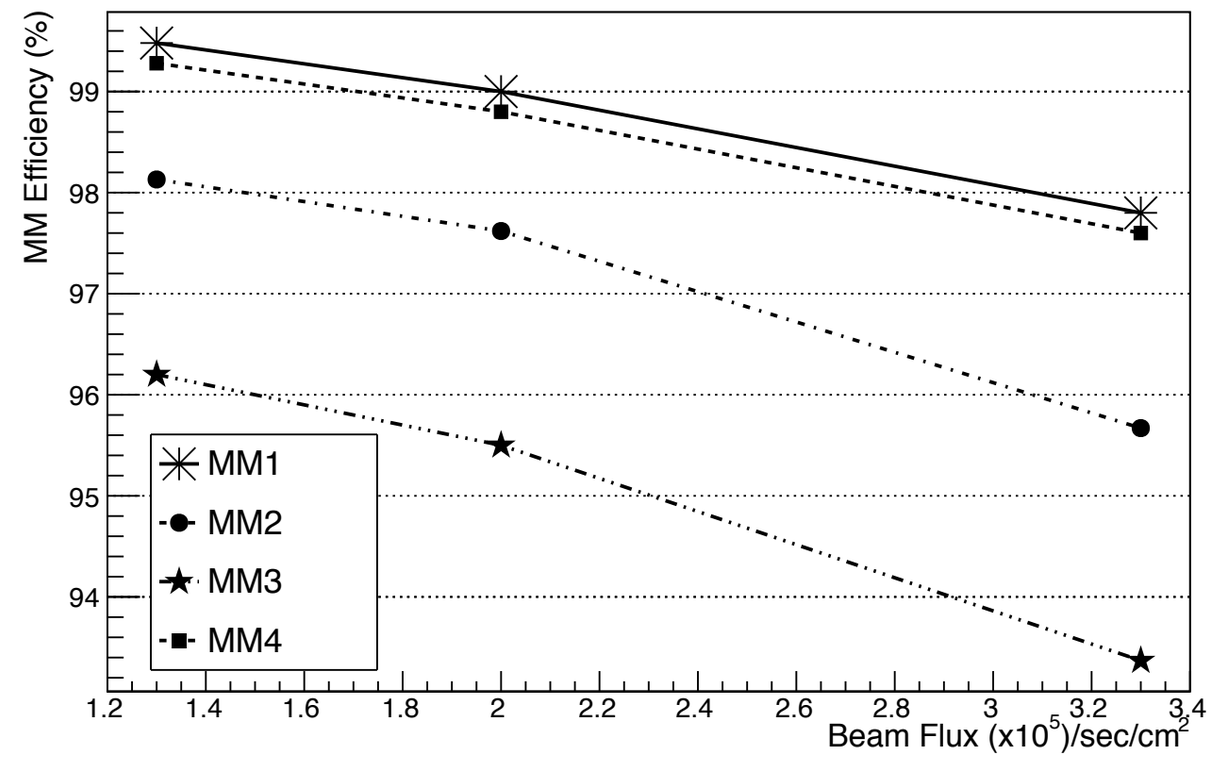
Size of X cluster < Size of Y cluster

Expected due to higher capacitive coupling to the Y plane than the X

XY Hit Efficiency



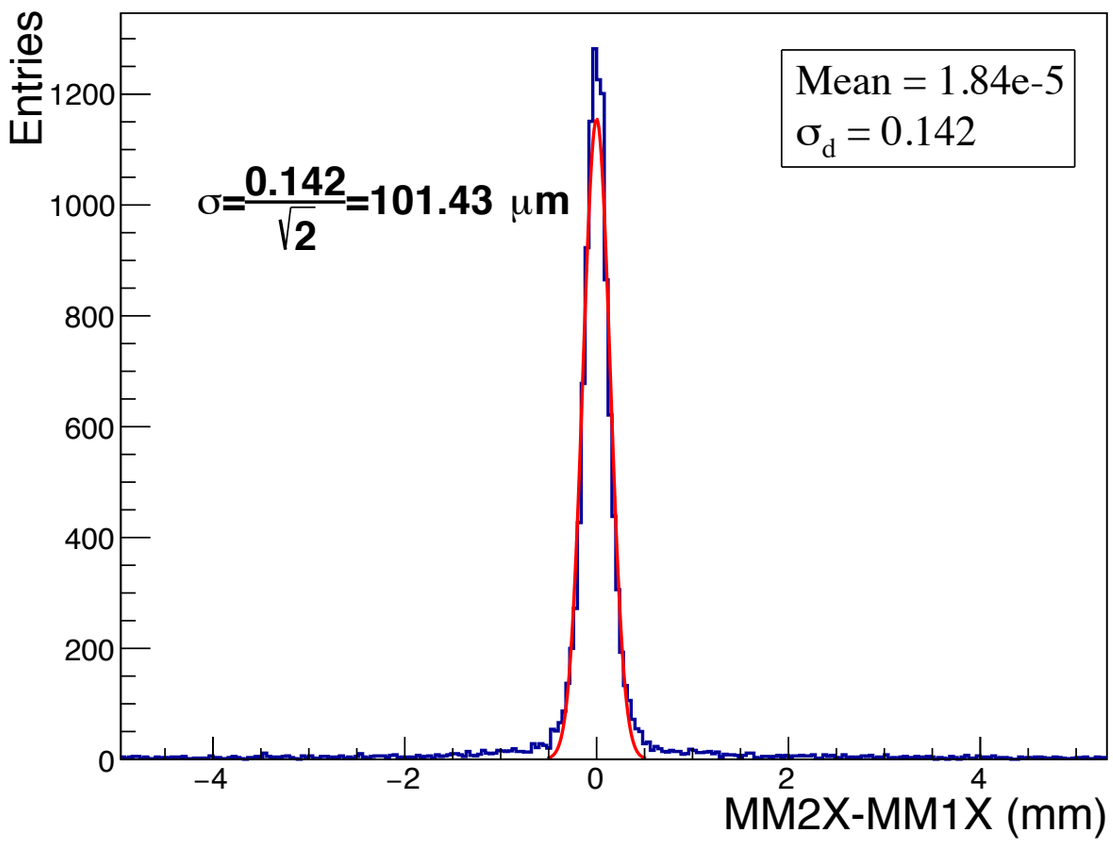
XY hit efficiency of modules checked for different amplification voltages for beam flux ~ 3.3 x 10^5 e^-/sec/cm^2

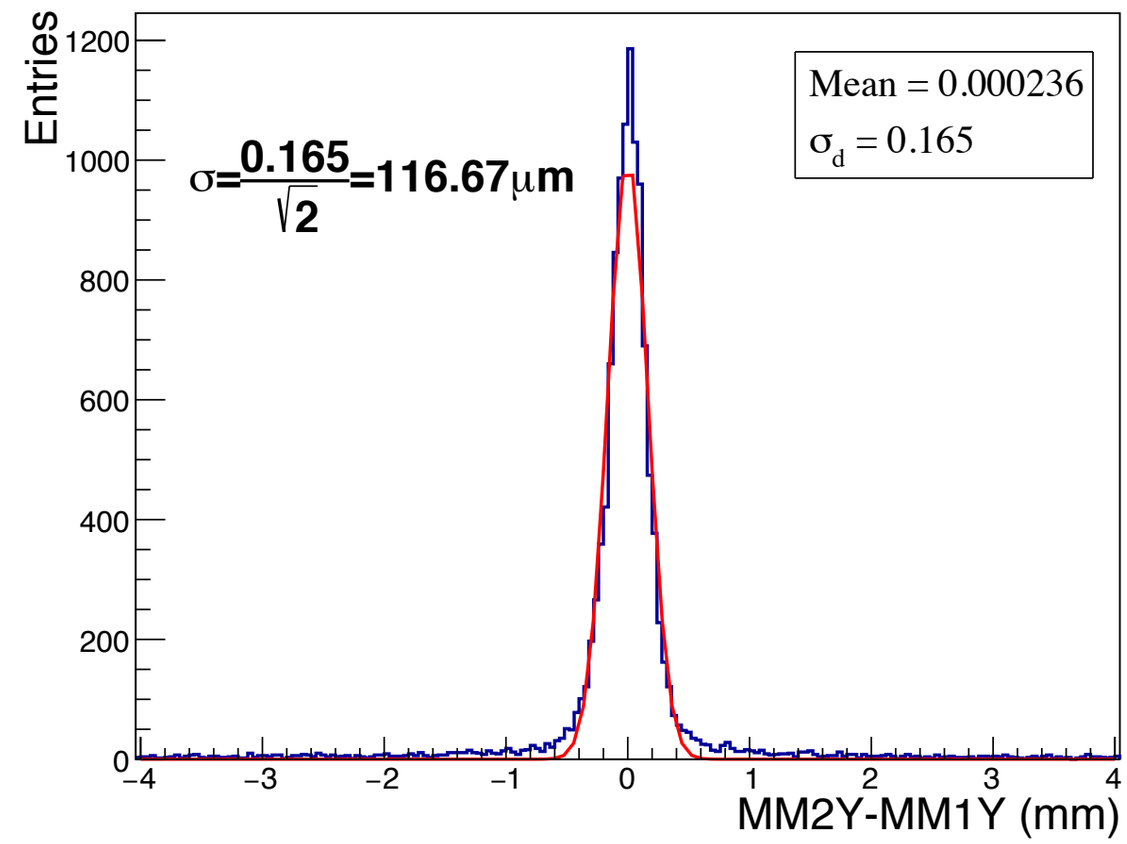


XY hit efficiency of modules checked for different beam fluxes at a fixed amplification voltage ~ 555 V. Efficiency drop with higher beam flux

Average hit **efficiency ~ 96 %** at beam flux **~ 3.3 x 10^5 e^-/sec/cm^2**

Spatial Resolution



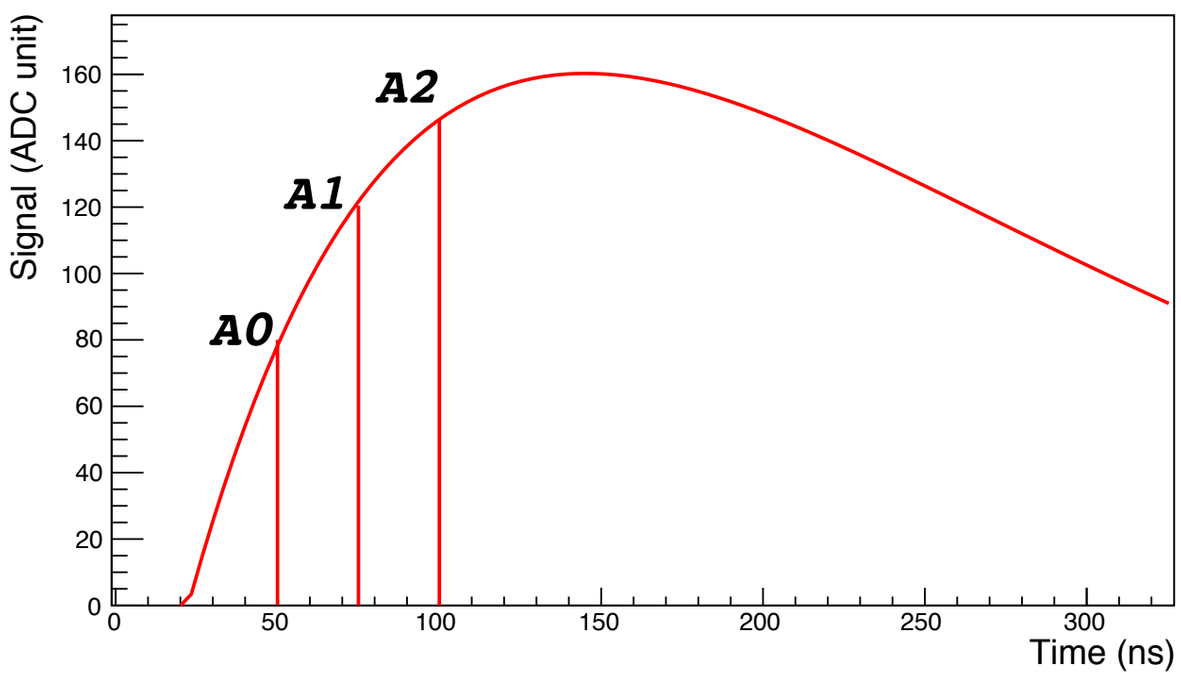


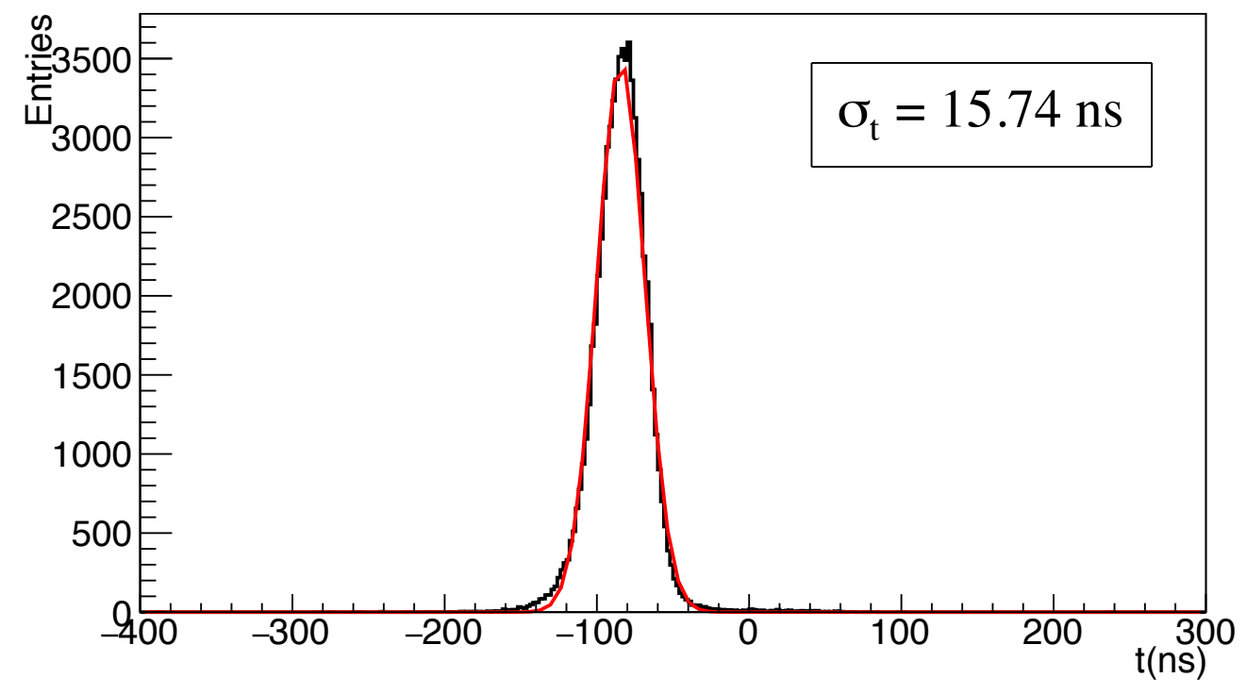
Spatial Resolution checked from the distribution of the hit position difference of an undeflected beam on the modules.

Uncertainties due to beam divergence and detector misalignment not taken into account.

Spatial Resolution ~ 100 µm achieved

Timing Resolution





r_{02} = A0/A2

r_{12} = A1/A2

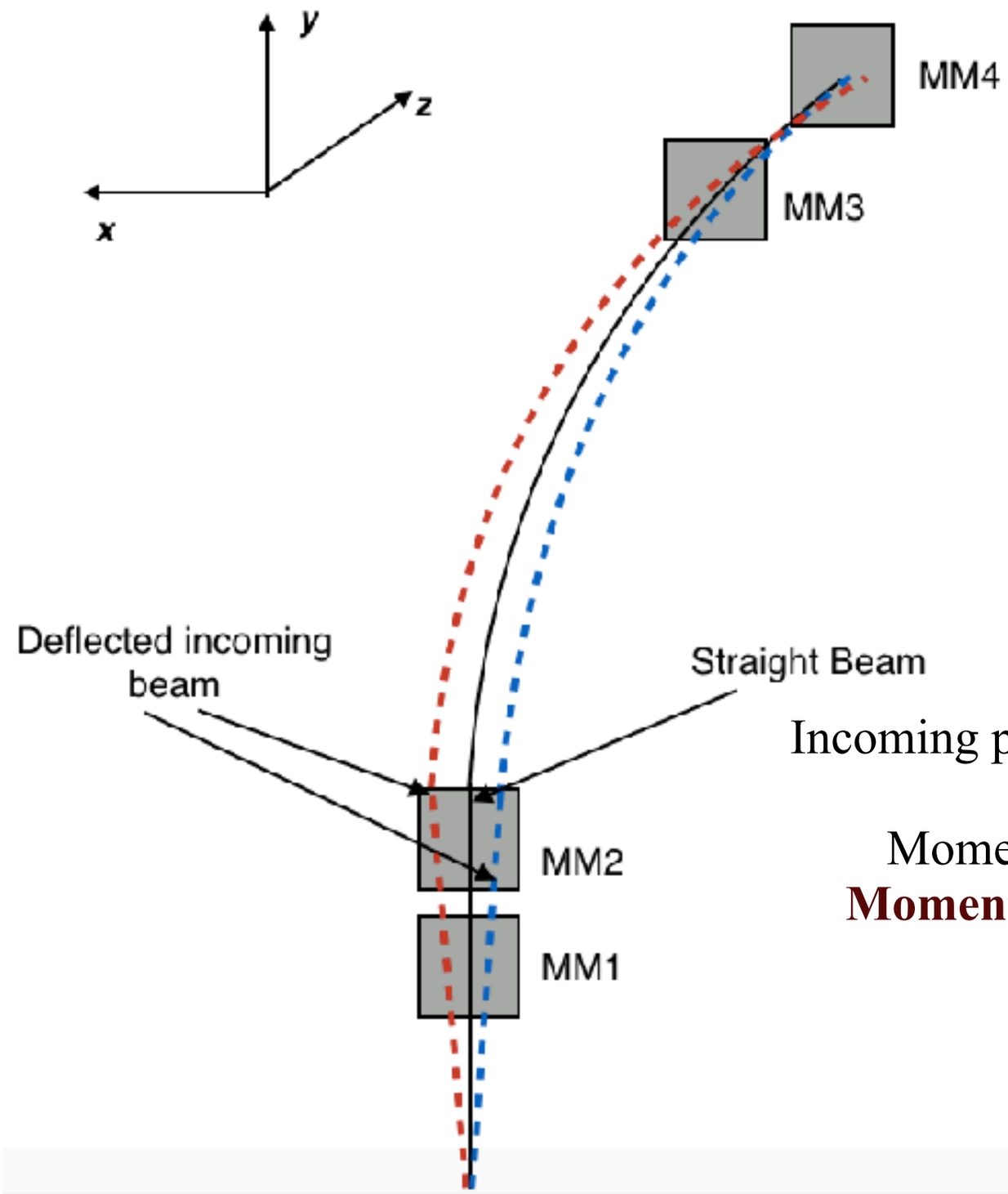
$$r(t) = \frac{r_0}{1 + \exp\left(\frac{t - t_0}{a_0}\right)}$$

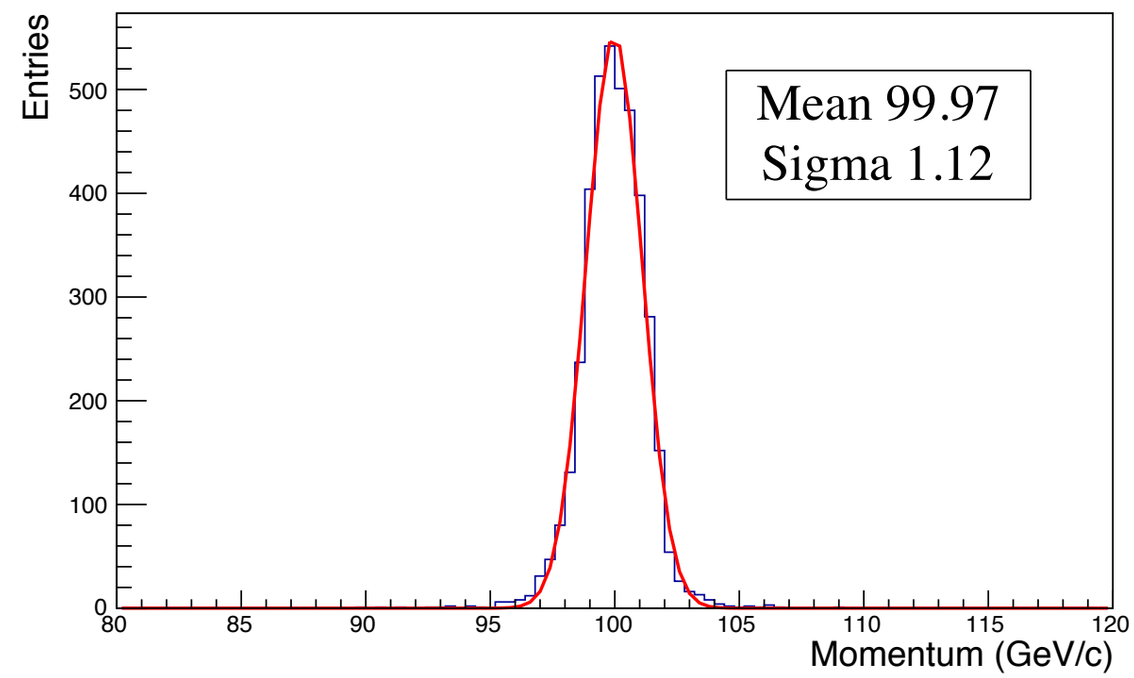
$$t(r) = \left(t_0 + a_0 \cdot \ln\left(\frac{r_0}{r} - 1\right)\right)$$

Fit parameters r_0, t_0 and a_0 obtained from calibration runs of latency scan

Timing Resolution checked sampling the signal with the APV chip.
Three time sample 25 ns apart recorded per channel.
Timing Resolution ~ 15 ns achieved

Tracking





Incoming particle tracked with four modules under a B field ~ 7 T.m

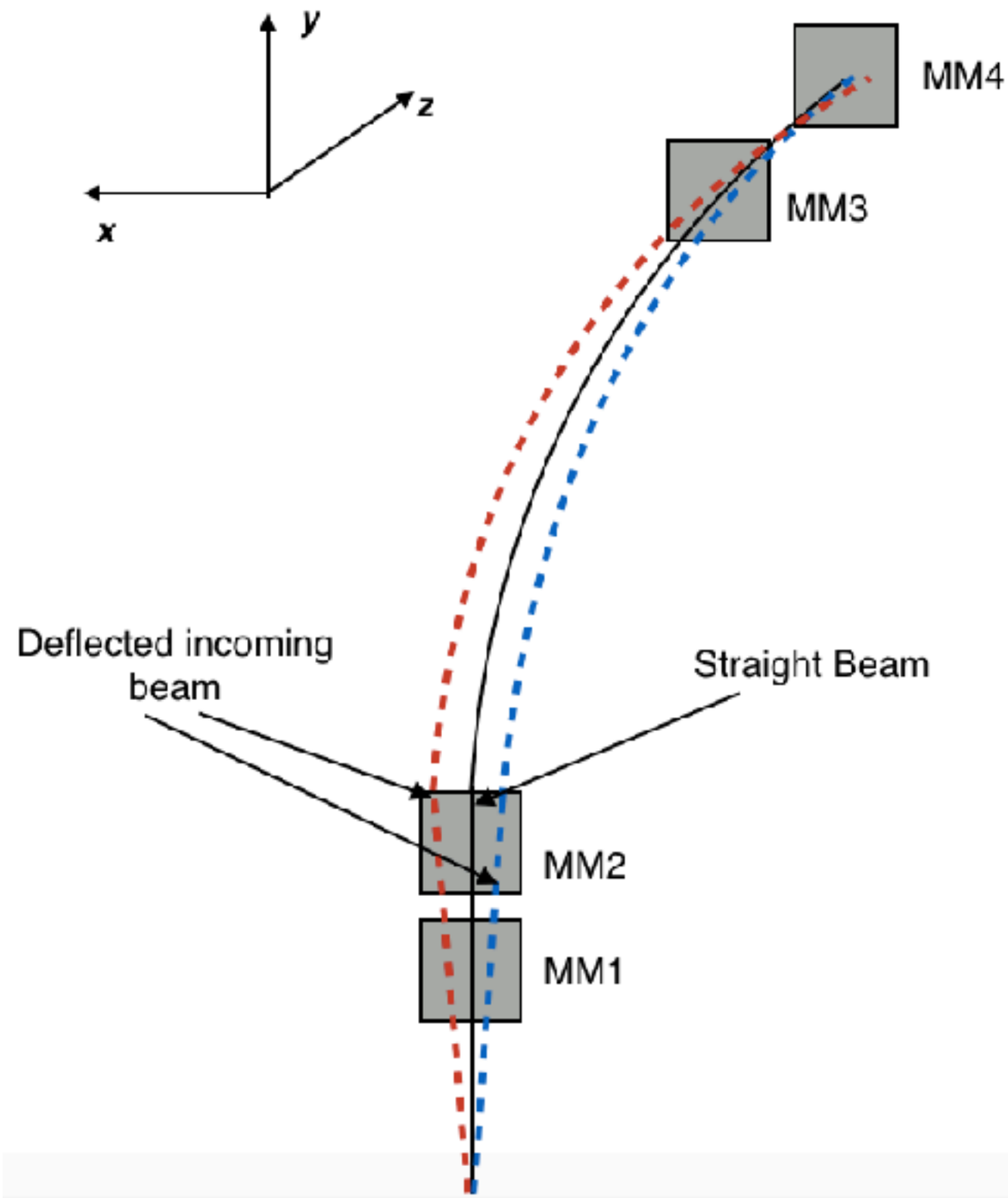
Momentum reconstruction performed with Genfit.

Momentum resolution ~ 1 % for a 100 GeV/c beam

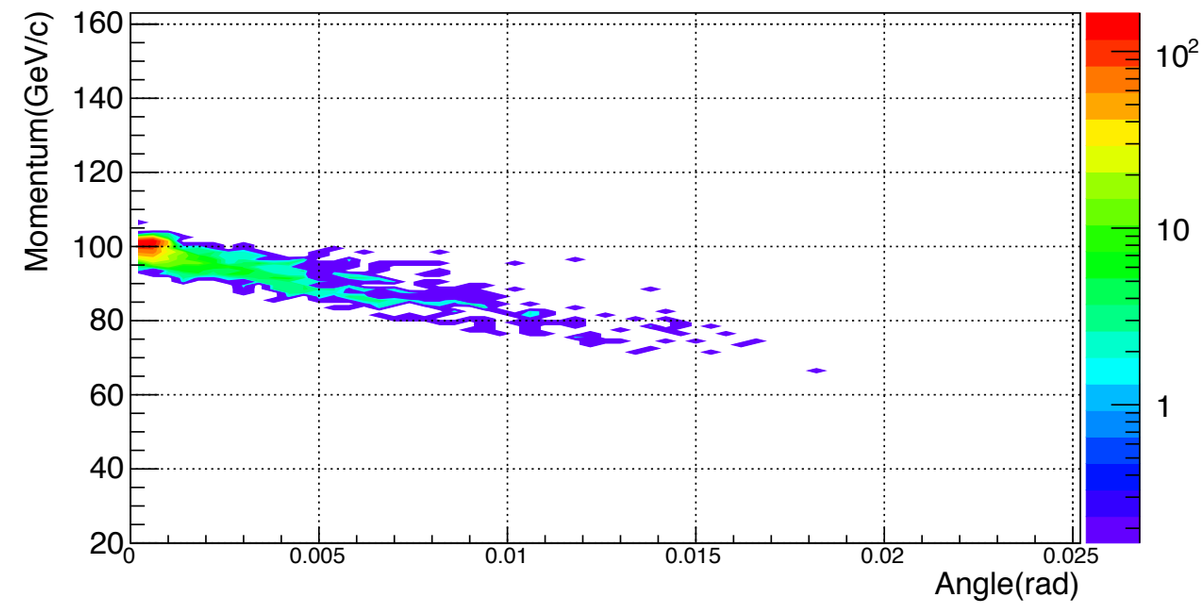
85 % tracking efficiency

Tracking

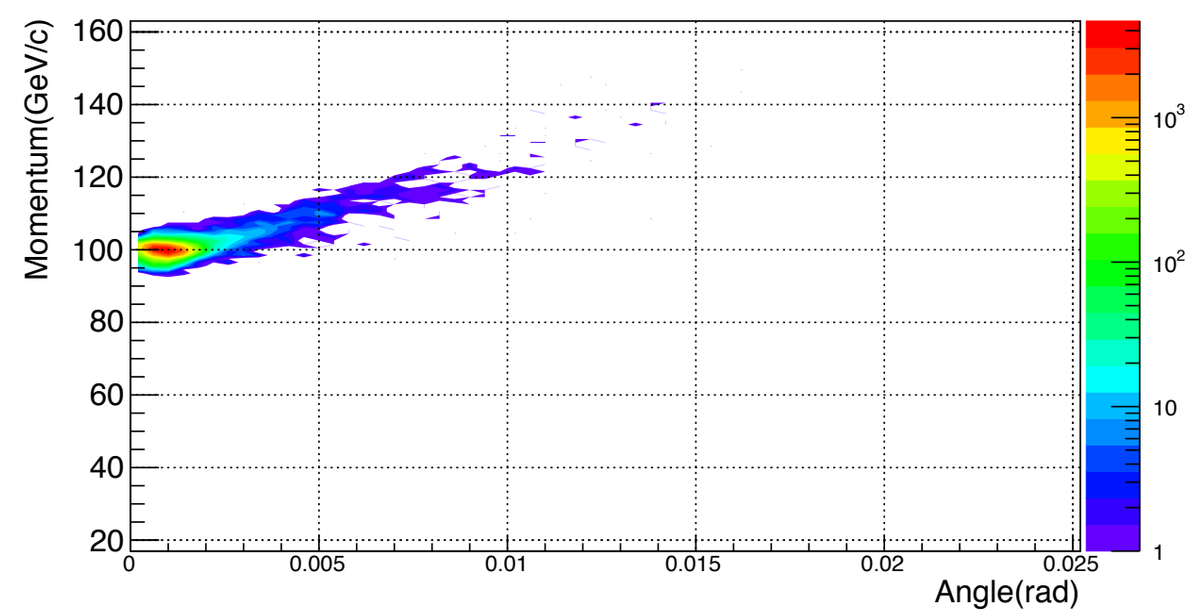
Collinearity of beam crucial for NA64



Reconstructed momentum vs Incoming Angle



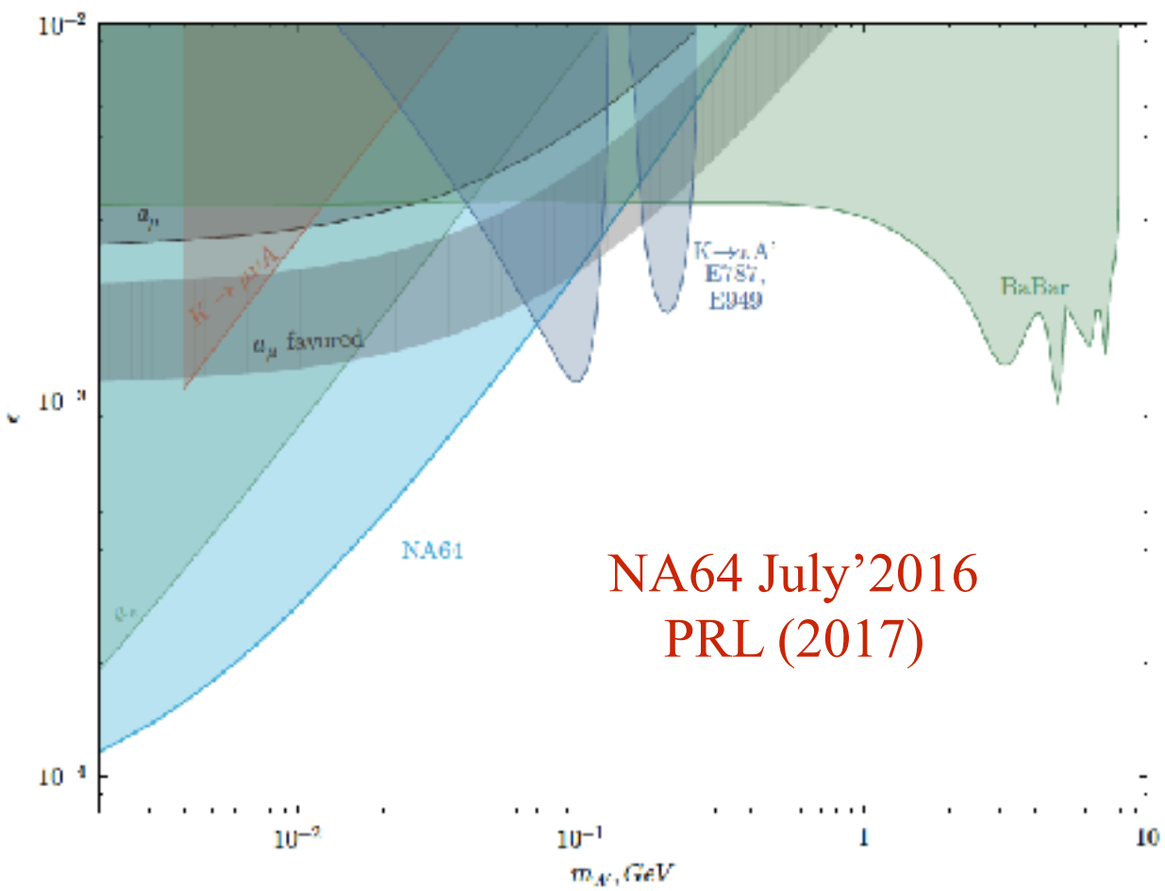
Initial deflection towards +x axis



Initial deflection towards -x axis

Beam Time Results

NA64 July 2016 results



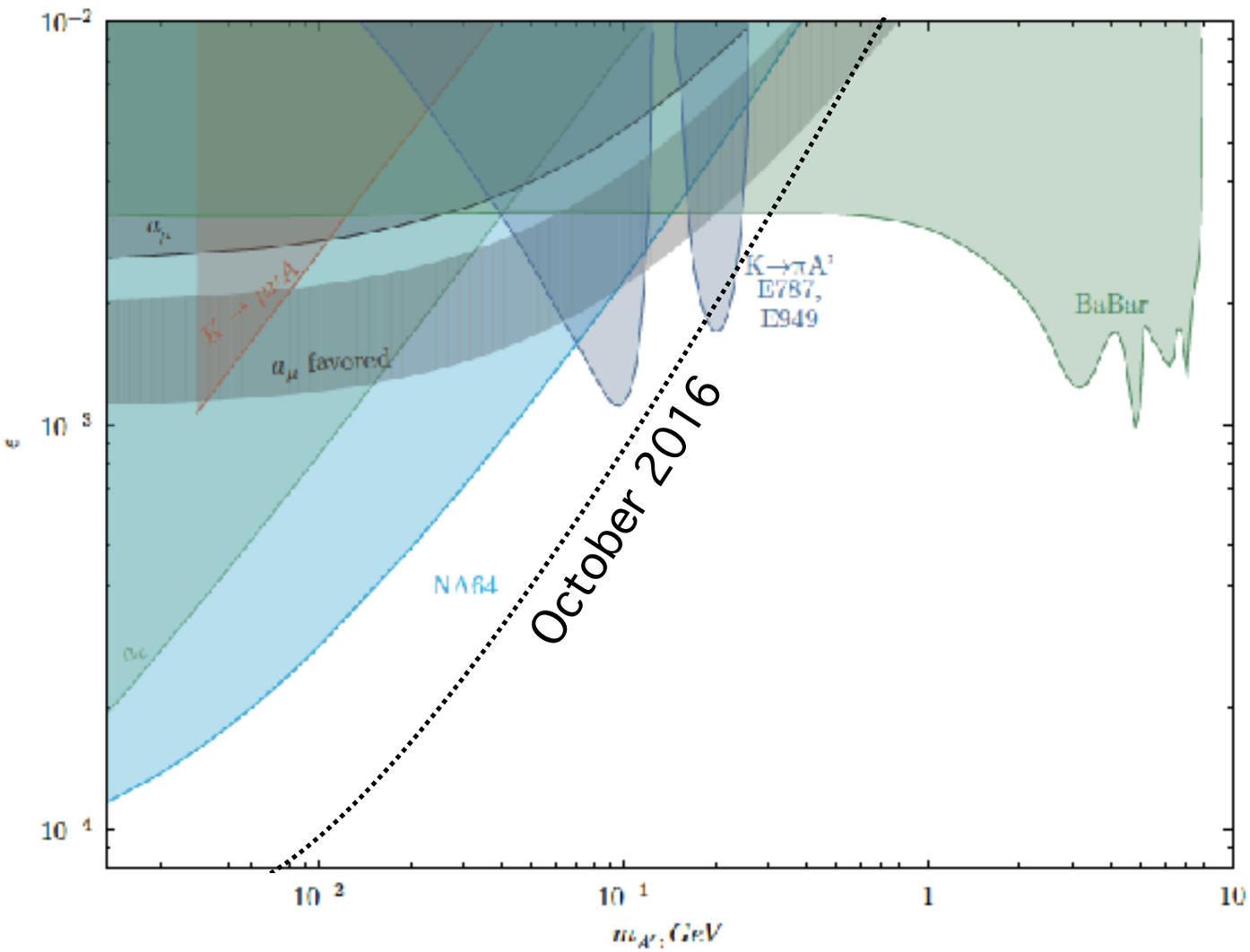
NA64 July'2016
PRL (2017)

Explanation of (g-2)$_\mu$ with invisible A′ is excluded.

2.75 x 10^9 electrons on target with beam intensity of 1.4 x 10^6 e^-/ 4.8 s spill for a 2 cm diameter beam:

- No event observed in the signal box from the July'2016 data.
- New limits set on the γ-A' mixing strength.
- In the meanwhile BABAR also completely excluded the A' favoured parameter space for (g-2)$_\mu$ anomaly. *arXiv:1702.03327*

October 2016 run and immediate plans



Expected sensitivity

- October 2016 run
  - Good performance at 5×10^6 e-/spill
  - 4×10^{10} eot collected.
  - Data analysis in progress.

- 2017 run
  - Improved e- tagging: 8 Micromegas trackers (instead of 4) + SRD
  - Tests at intensity $(7–8) \times 10^6$ e-/spill
  - Goal $(2–3) \times 10^{11}$ eot.
  - Test visible decay mode arXiv:1308.6521

ETH Zürich ETH Institute for Particle Physics

Future Prospects of NA64

Process	New Physics	Sensitivity
1. $e^- Z \to e^- Z + E_{miss}$		
✧ $A' \to e^+e^-$ ✧ $A' \to$ *invisible* ✧ *alps* ✧ *mQ*	Dark photons, Hidden sectors, $(g-2)_\mu$ new particles, milli-q	$10^{-4} < \varepsilon < 10^{-5}$ $M_{A'} \sim$ sub-GeV $e' < 10^{-5}$-10^{-7}
2. $\mu^- Z \to \mu^- Z + E_{miss}$		
✧ $Z_\mu \to \nu\nu,\ \mu^+\mu^-$ ✧ $\mu \to \tau$	$(g-2)_\mu$, gauged L_μ-L_τ, L-phobic boson Z_μ, LFV	$\alpha_\mu < 10^{-11}$-10^{-9} $< 10^{-9}$-$10^{-8}/\mu$
3. $\pi(K)p \to M^0 n \to E_{miss}$		
✧ $K_L \to$ *invisible* ✧ $K_S \to$ *invisible* ✧ $\pi^0, \eta, \eta' \to$ *invisible*	Bell-Steinberger Unitarity, CP, CPT , NHL, 2HDM,	$\sim 10^{-5}$ $Br < 10^{-8}$ $< 10^{-8}$-10^{-7}
4. $pA \to X + E_{miss}$		
✧ *leptophobic X +h*	~ GeV DM	$<10^{-7}$-10^{-8} /p

1. **On detection of narrow angle e+e- pairs from dark photon decays**
   A.V. Dermenev, S.V. Donskov, S.N. Gninenko et al;
   IEEE Trans.Nucl.Sc. 62 (2015) 3283;
   arXiv:1503.05687[physics.ins-det]
2. **The K_L invisible decays as a probe of new physics**
   S.N. Gninenko and N.V. Krasnikov;
   Phys. Rev. D92 (2015) 034009;
   arXiv:1503.01595 [hep-ph]
3. **Search for invisible decays of π0, η, η', K_S and K_L: A probe of new physics and test using the Bell-Steinberger relation**
   S.N. Gninenko;
   Phys. Rev. D91 (2015) 015004;
   arXiv:1409.2288 [hep-ph]
4. **Muon g-2 and searches for a new leptophobic sub-GeV dark boson in a missing-energy experiment at CERN**
   S.N. Gninenko, N.V. Krasnikov, V.A. Matveev;
   Phys. Rev. D91 (2015) 095015;
   arXiV:1412.1400 [hep-ph]

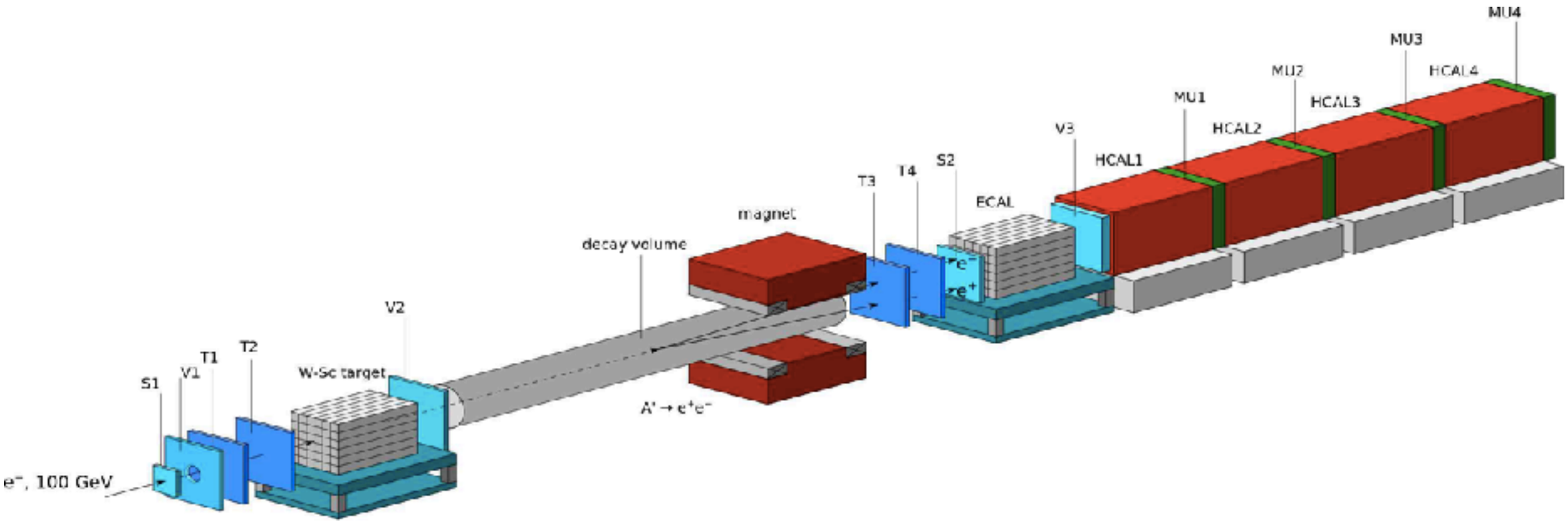
Summary

- First test of multiplexed micromegas modules in a high flux beam.
- Level of ambiguity reduced from ~ 50 % to < 2 % chance of wrong cluster identification using signal spread information.
- Hit efficiency checked for different beam fluxes with ~ 96% efficiency for a beam flux of 3.3×10^5 e^-/sec/cm^2.
- Spatial resolution ~ 100 μm for 250 μm strip pitch achieved.
- Timing resolution ~ 15 ns with three time samples 25 ns apart achieved.
- Tracking of incoming particle done with four modules and 7 T.m B-field with 1 % momentum resolution for 100 GeV/c beam.
- Tracking was a key contribution to reject background from the low energy beam tail, and select collinear beam to achieve the results published from the 2016 beam time.
- The 2016 beam results set new limits on the γ-A' mixing strength and excluded A' as an explanation for the $(g\text{-}2)_\mu$ anomaly.
- Four more modules planned to be used for the next NA64 beam time in September'2017 to improve efficiency of tracking to ~ 92 % as opposed to present case of 85 %.
- The efficient and excellent performance of the trackers which is a requirement for all prospective NA64 measurements present an optimistic step for the future.

Thank You !!

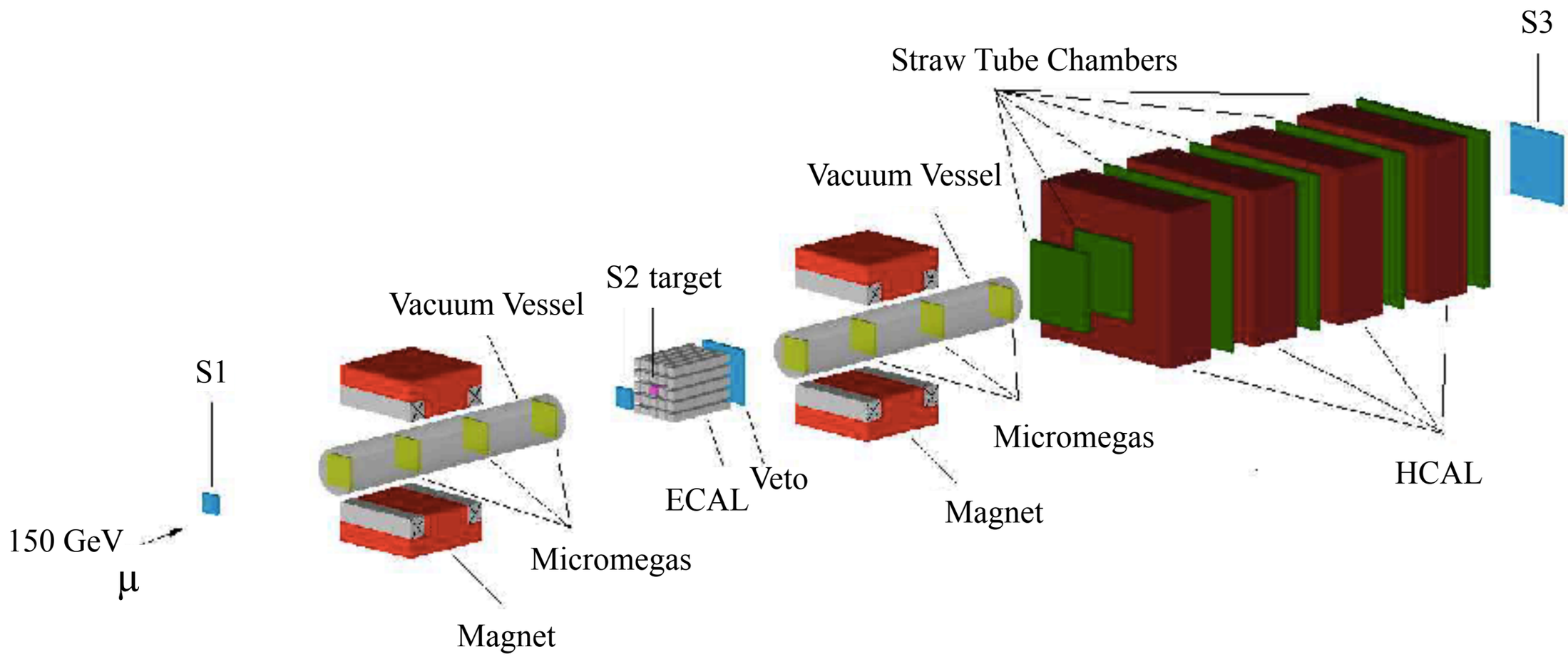
Backup

Future Prospects of NA64 and requirement of tracker



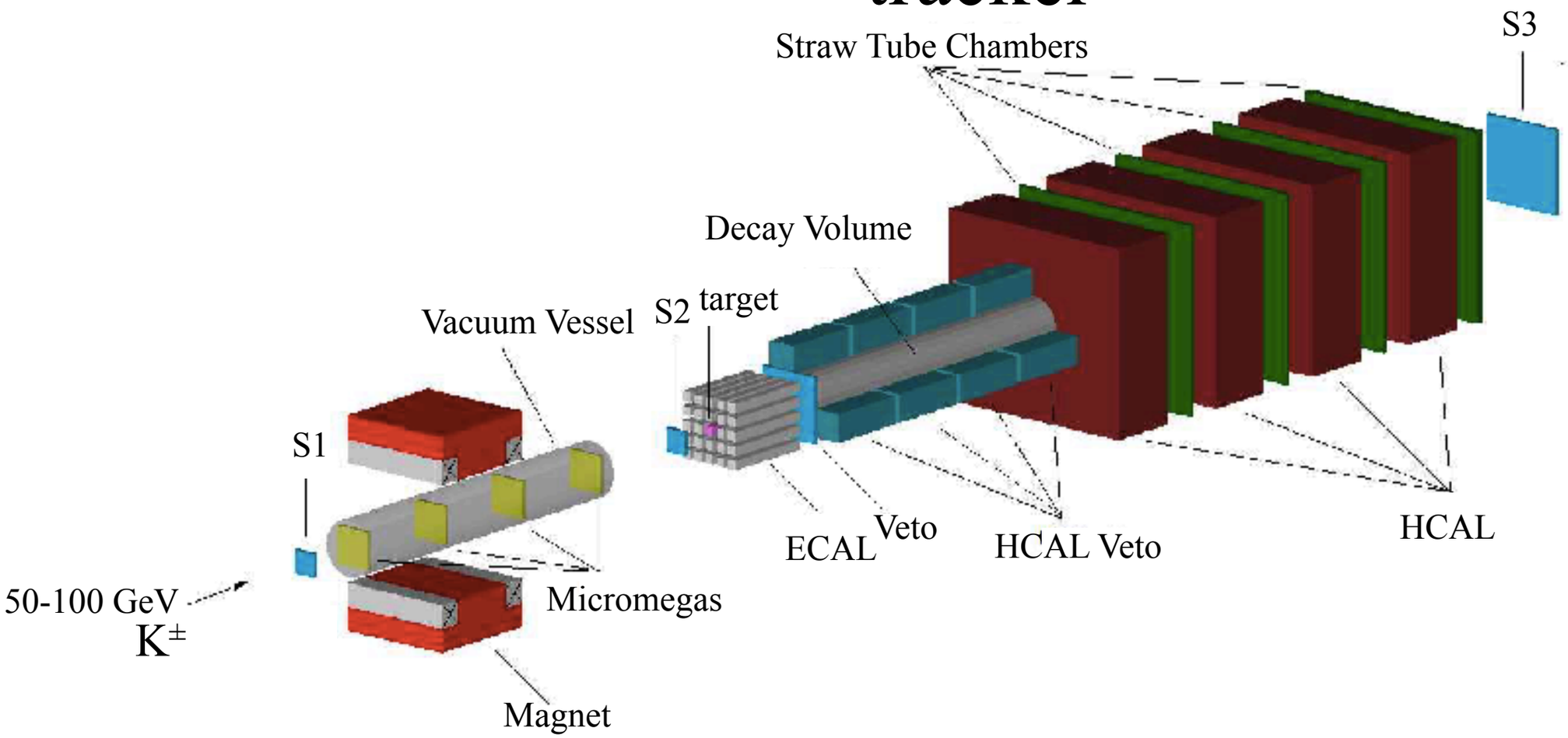
- A' Visible search : $e^- Z \longrightarrow e^- Z + A'$, $A' \longrightarrow e^- e^+$
  - Signal signature = S1 x Target x S2 x ECAL x $\overline{\text{V2xV3xHCAL}}$
  - two separated showers in ECAL and tracked with the trackers.
  - beam energy $E0 = E_{target} + E_{ECAL}$

Future Prospects of NA64 and requirement of tracker



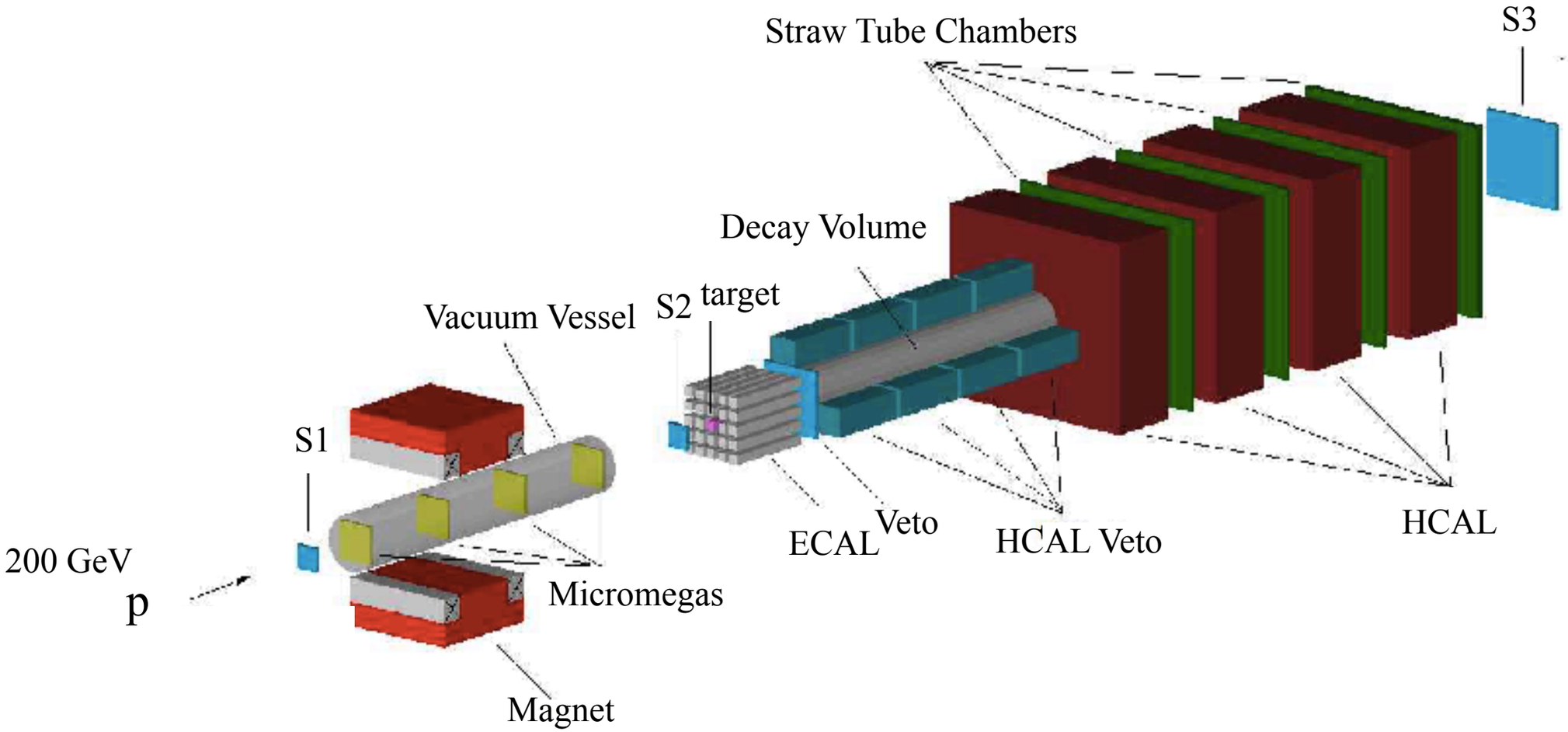
- New gauge boson, Z_μ, search : $\mu Z \longrightarrow \mu Z + Z_\mu$, $Z_\mu \longrightarrow \nu\nu, \mu\mu$
  - Signal signature
    - Incoming 150 GeV μ beam, tagged with trackers
    - Outgoing < 100 GeV μ beam, tagged with trackers
    - No energy in ECAL, Veto and HCAL

Future Prospects of NA64 and requirement of tracker



- K_L —> invisible search, $K^{\pm} + p$ —> $M^0 + n$, $M^0 = K_L, K_S$
  - Signal signature
    - Incoming ~ 50 GeV $K^{\pm}$, tagged with trackers
    - No energy in ECAL, Veto and HCAL
      Complete disappearance of beam energy.

Future Prospects of NA64 and requirement of tracker



- GeV Dark Matter Search, pA —> X+ Z', Z' —> $\chi\,\chi$
  - Signal signature
    - Incoming ~ 200 GeV p, tagged with trackers
    - Missing energy downstream of the target.