The NA64 multiplexed micromegas tracker

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Introduction

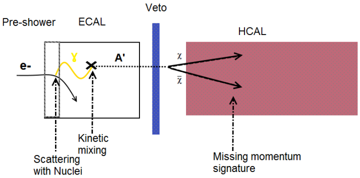
- NA64 introduction—2016 set up
- Micromegas detector-based tracker
- NA64 introduction—2017 set up
- Micromegas multi-hit reconstruction and vertexing/dimuon test data
- Future prospects

NA64 search for invisible decays of dark photons

Initial experimental setup used to search for reaction:

$$e^- Z \to \gamma \to A' \to \chi\bar{\chi}$$

where A' is produced through kinetic mixing with ordinary photon, and decay products $\chi\bar{\chi}$ are not detected.

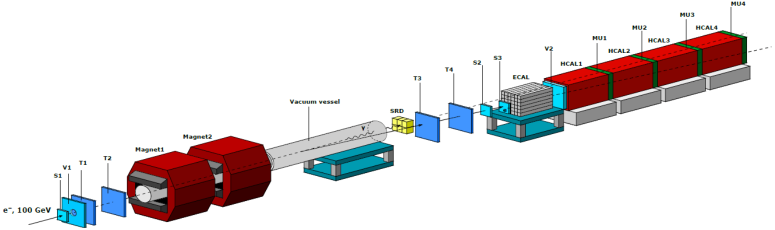


One class of dark matter models implies the existence of a dark sector coupled to ordinary matter by gravity, and possibly other very weak forces. These models admit a massive boson A' through an extra broken $U(1)'$ symmetry—Dark Photon.

- $\Delta L = \varepsilon F^{\mu\nu} A'_{\mu\nu}$ kinetic mixing γ–A', ε coupling strength
- Natural coupling $\varepsilon \sim 10^{-3}$–10^{-4}; $M_{A'} \sim \varepsilon^{\frac{1}{2}} M_Z$
- Decay modes:
  - invisible ($A' \to \chi\bar{\chi}$);
  - visible ($A' \to e^+e^-$ or $\mu^-\mu^+$)

NA64 initial experimental setup—2016/2017 runs

Active beam dump with missing energy setup at CERN SPS:



Beam requirements:

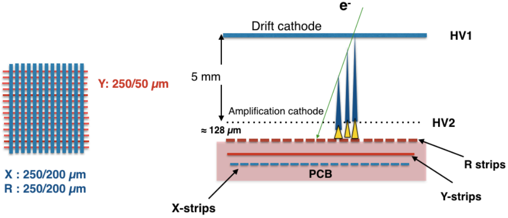
- High enough particle energy to produce A'
  - 100 GeV e^- from SPS
- High purity e^- beam
  - $\pi^- \sim 1\%$; μ^-, $K^- < 0.1\%$

Key features:

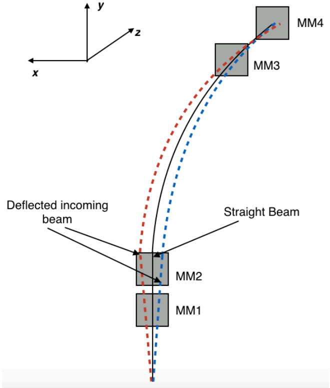
- High hermiticity calorimetry
- Single particle tagging
- Good momentum resolution from tracker
- Effective rejection of hadronic beam contamination

NA64 tracker

Tracker based on four XY multiplexed resistive micromegas modules (main responsibility of ETH) and two MBPL magnets (7 Tm) for momentum analysis (and synchrotron radiation tagging).[1]

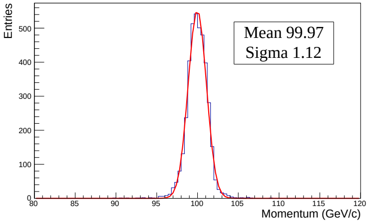


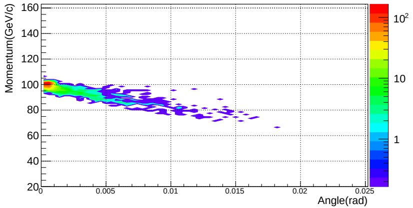
Principle of micromegas operation.

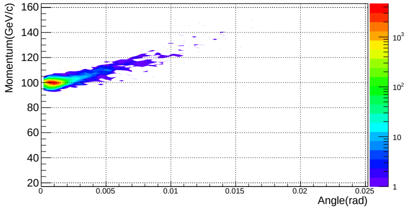


[1] E. Depero et al. Nucl. Instr. Meth. A **866**, 196 (2017)

Tracker performance



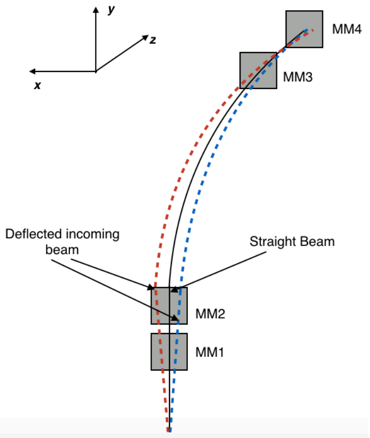


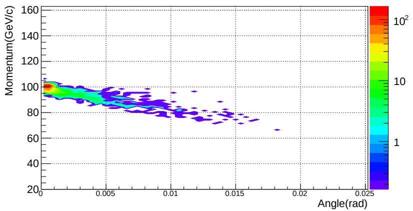


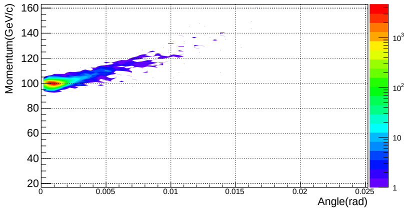
Left: reconstructed momentum. Right: reconstructed momentum as a function of incoming angle. Good perfomance ($\sim$ 96% efficiency) up to intensities of 3.3×10^5 e^- s^{-1} cm^{-2}.[2]

[2] D. Banerjee et al. Nucl. Instr. Meth. A **881**, 72 (2018)

Tracker performance

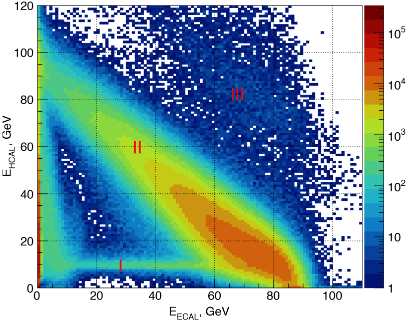






Input angle selection cut allows the rejection of the low energy tail, which are only in the acceptance cone of the detector if they are incident at large angles with respect to the axis.

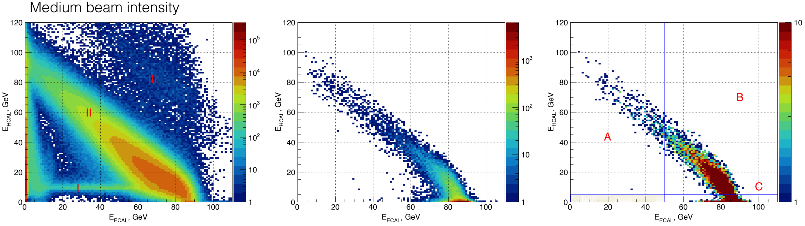
Invisible mode results—2016 run



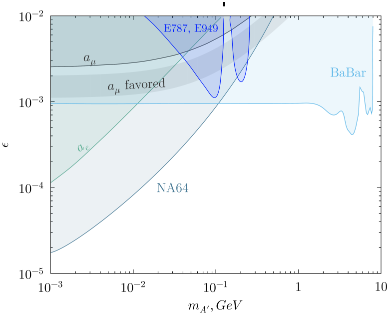
- Region I: dimuon events (more on these later).
- Region II: $E_{ECAL} + E_{HCAL} =$ 100 GeV.
- Region III: Pile-up (e^- + beam hadron)

Shown with only synchrotron radiation cut (for selecting e^- events—beam hadrons supressed by factor $\sim 10^{-5}$)

Invisible mode results—2016/2017 runs[3,4]



Apply additional selection cuts to reject pile-up, upstream interactions; and then finally other event selection cuts.



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[3] D. Banerjee et al. Phys. Rev. Lett. **118**, 011802 (2017)

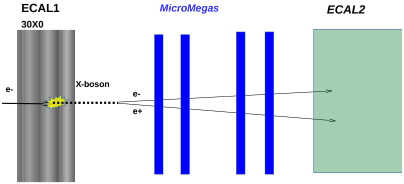
[4] `https://arxiv.org/abs/1710.00971`

NA64 search for visible decays/X-boson[5,6]

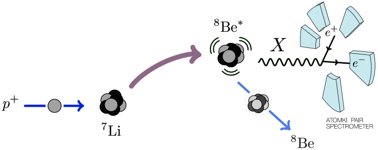
New experiment geometry to search for reaction:

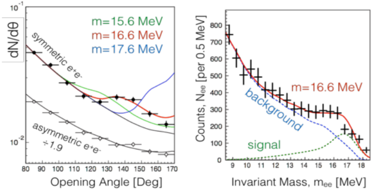
$$e^- Z \to \gamma \to A' \to e^- e^+$$

but actually, maybe more sensitive to X-boson decays into $e^- e^+$



An anomaly in angular spectrum of ^{8}Be nuclear decays observed by group at ATOMKI in Hungary led to the proposal of a new 'protophobic' gauge boson (X) with mass $\sim$ 17 MeV

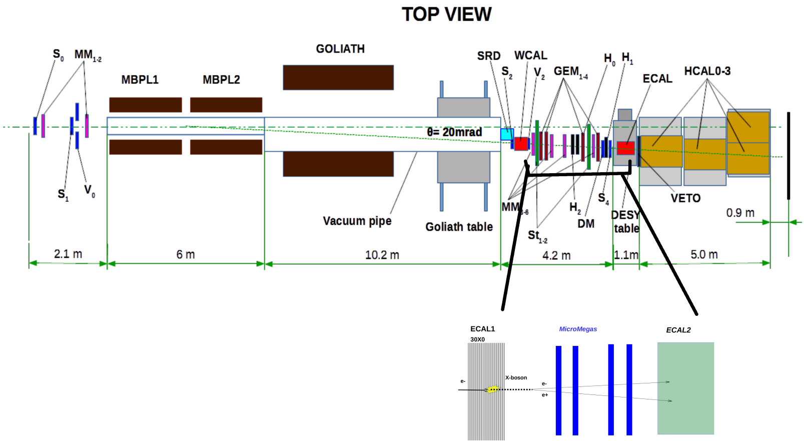




[5] A. J. Krasznahorkay et al. Phys. Rev. Lett. **116**, 042501 (2015)
[6] J. L. Feng et al. Phys. Rev. D **95**, 035017 (2017)

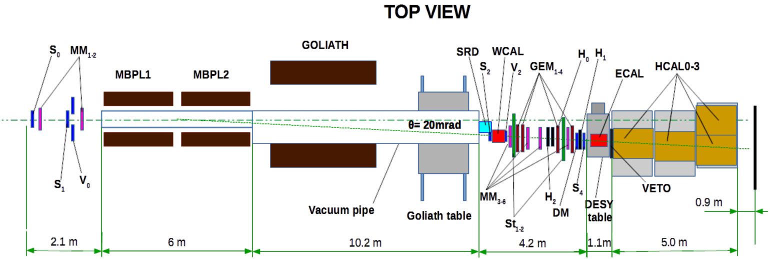
NA64 visible mode experimental setup

Place additional tracker modules after active target (WCAL) for search for $A' \to e^+e^-$ and X-boson



Visible decay signature

- Energy is not missing anymore (decay products carry energy from WCAL to ECAL)
- Decay pair detected by downstream tracker and reconstructed vertex should be outside any detector (e.g. WCAL)



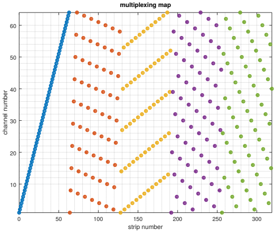
Downstream tracker performance—MM demultiplexing

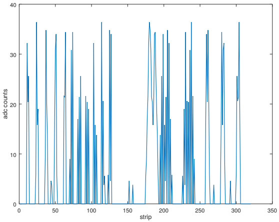
MM Multiplexing is done in hardware (on PCB) following 'genetic multiplexing' method:[7]

Naive reconstruction maps signal from readout channels to every strip it is connected to, this is equivalent to least square solution to $Ms = c$ (M is multiplexing matrix):

$$\implies s = \left(M^T M\right)^{-1} M^T c$$

Fine for single hit (can select largest cluster) but complicated for multiple hit reconstruction (as required).





[7] S. Procureur, R. Dupré, S. Aune, Nucl. Instr. Meth. A **729**, 21 (2013)

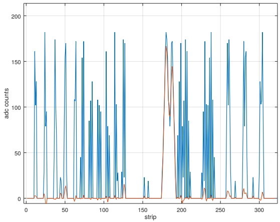
MM demultiplexing with ridge regression

Introduce a Tikhonov regularization term into minimization target, now seek:

$$\min\left\{||Ms - c||^2 + ||Rs||^2\right\}$$
$$\implies s = \left(M^T M + R^T R\right)^{-1} M^T c$$

where R is some matrix which helps to discriminate between solutions. Using centered 2nd derivative matrix, try to smooth the solution (k is small):

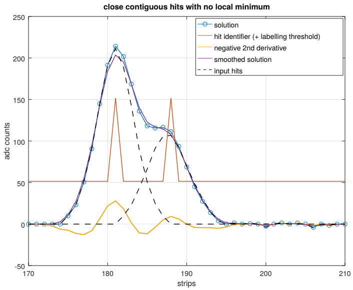
$$R = k \begin{pmatrix} -2 & 1 & 0 & 0 & 0 & \dots & 0 \\ 1 & -2 & 1 & 0 & 0 & \dots & 0 \\ 0 & 1 & -2 & 1 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \dots & 0 \\ 0 & 0 & \dots & 0 & 1 & -2 & 1 \\ 0 & 0 & \dots & 0 & 0 & 1 & -2 \end{pmatrix}$$



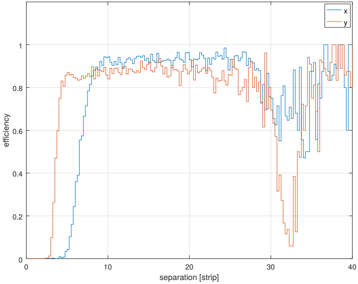
‘Ghost’ clusters are nearly eliminated

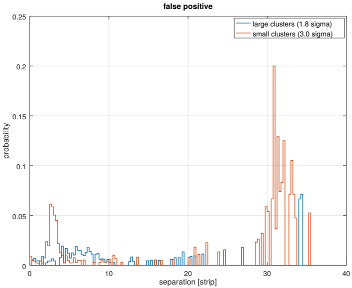
MM cluster location algorithm

Use threshold + analysis of 2nd derivative of strip signal w.r.t. strip number to label clusters:



High efficiency to reconstruct two hits with correct separation (tested with simulated events synthesized from two single-hit events).



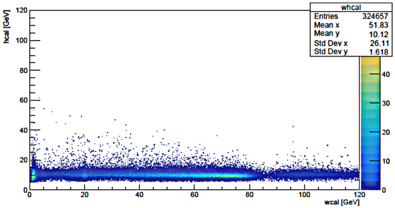


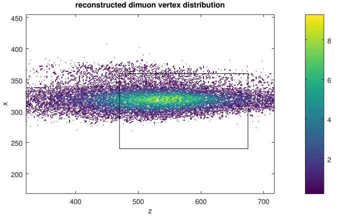
Track pair and vertex reconstruction strategy

- Tracks constructed assuming straight line propagation (fitted in 3D if more than two detectors are used).
- Combinatoric problem since we have to test all (x, y) values from each detector with all the others to find best vertex.
- Since (x, y) are independent in micromegas detector, an additional level of combinations is introduced.
- Currently, just a brute force method (test all combinations) is employed. If greater than ~ 10 hits on a detector, method is very slow (though maybe still ok if the number of events to analyse is small).
- Vertex is chosen as midpoint on the shortest line connecting the two tracks for which this distance is smallest in the collection (vertices between the detectors are rejected).

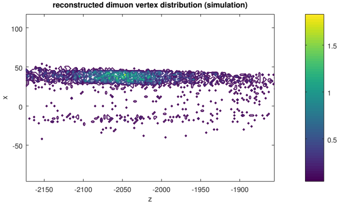
Downstream tracker performance—dimuon test

Dimuon event set extracted from data by selection cuts on other detectors:

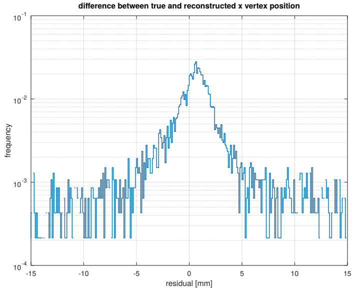


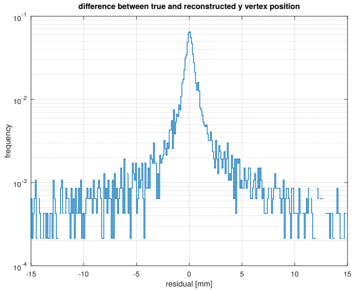


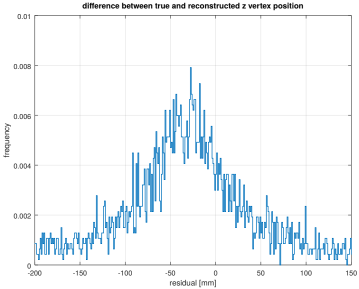
Comparison between data and simulation showing distribution of dimuon vertices. Micromegas response also simulated in order to test complete algorithm.



Vertex reconstruction precision (dimuons—simulation)



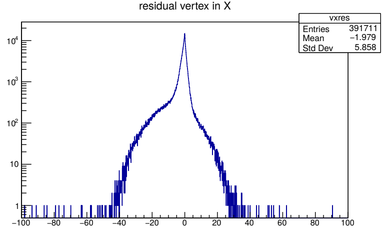


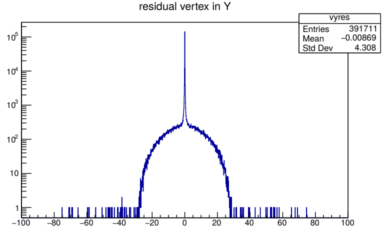


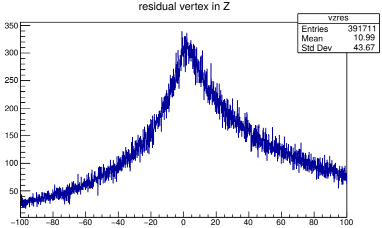
Poor resolution in z (propagation direction), but there is a large amount of dense material in the way (WCAL is large fraction tungsten), so scattering causes problems.

Vertex reconstruction of *X*-boson decays

Simulation:





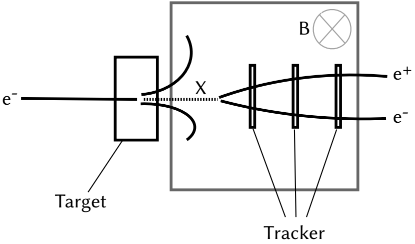


Now the only limitation on the resolution is the material in the micromegas modules themselves!

Future prospects

- For NA64, multiplexed micromegas is very useful for upstream tracker, and (in invisible mode) downstream as well (magnetic spectrometer):
  - Low cost
  - Multiplexing reduces complexity of electronics, reduces data storage requirements
- But in multihit environment, such as for vertex reconstruction:
  - Increases complexity of analysis
  - Introduces ambiguities (especially with *this* multiplexing map)
- However, continued search for X-boson will need upgrade of vertex tracker

Future prospects



- Reduced target thickness to allow X to escape before decay
- Magnet to reject additional particles and to allow reconstruction of reaction kinematics.

Micromegas lose precision in magnetic field due to $\mathbf{E}\times\mathbf{B}$ drift effects, also would be better to reduce material budget—use alternative detector technology (e.g silicon).

Thanks

Thanks for listening