NA64
Search for dark sector physics in missing energy experiments

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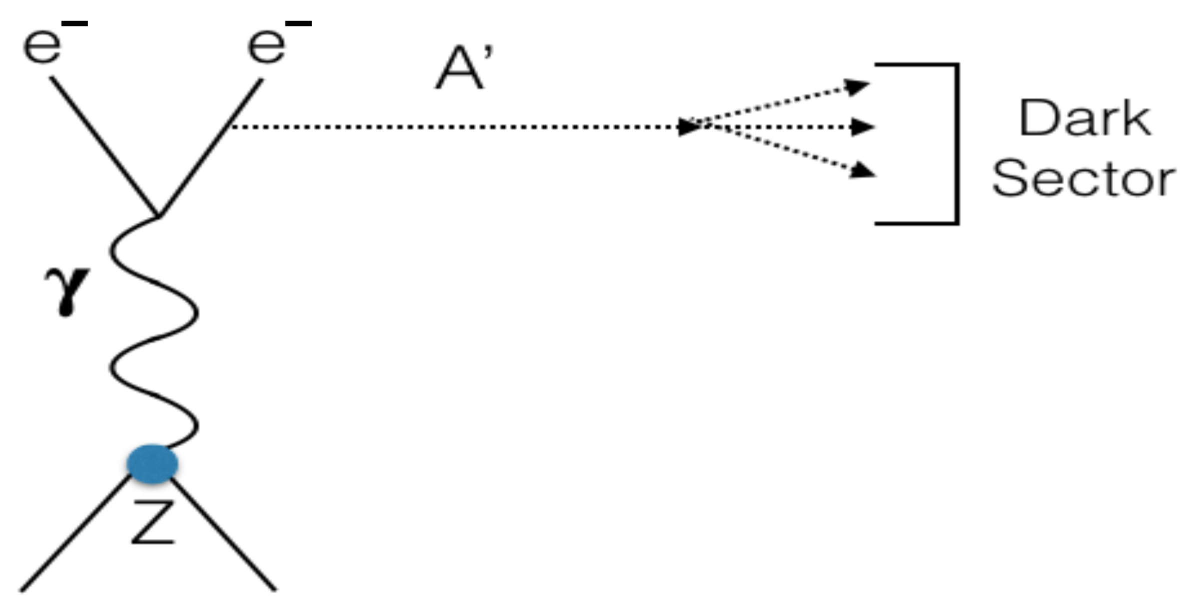
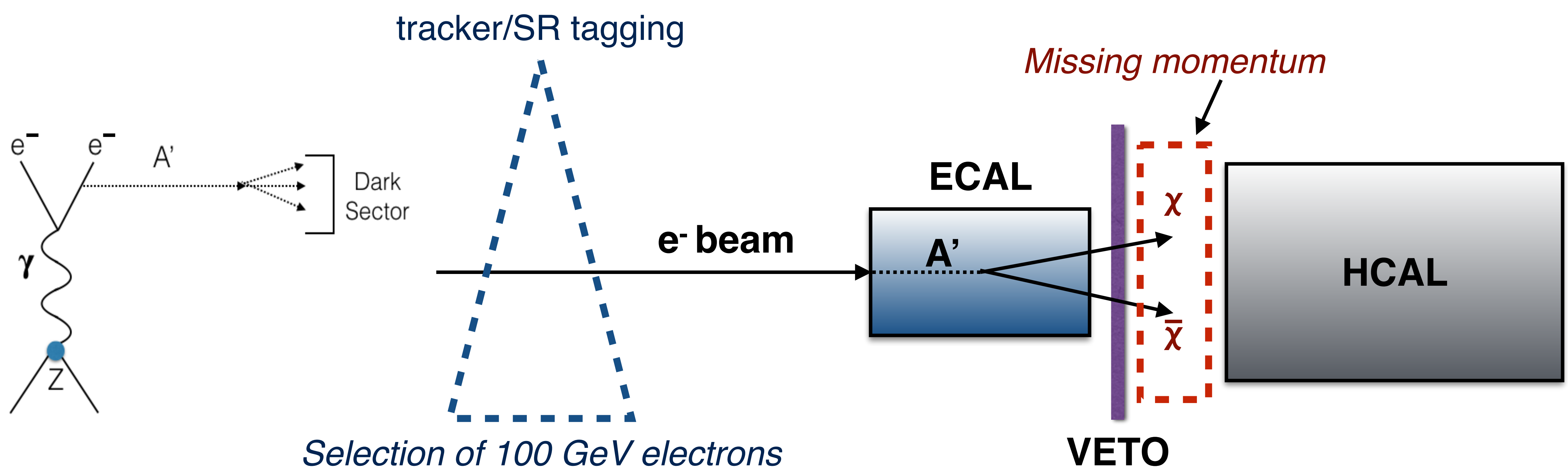
On behalf of the NA64 collaboration

NA64 Experiment



NA64 is a fixed target experiment combining the active beam dump technique with missing energy measurement searching for invisible decays of massive A' produced in the reaction eZ—> eZA' of electrons scattering off a nuclei (A,Z), with a mixing strength $10^{-5} < \varepsilon < 10^{-3}$ and masses $M_{A'} < 100$ MeV.

NA64 Experiment



*For NA64 a beam of **100 GeV electrons** will be dumped against an ECAL, a sandwich of lead and scintillators (34 X_0), to produce massive A' through scattering with the heavy nuclei.*

*A typical signature for a signal will be **missing energy in the ECAL** and no activity in the the VETO and HCAL.*

Background from hadrons, muons and low energy electrons must be rejected upstream.

NA64

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The P348 collaboration

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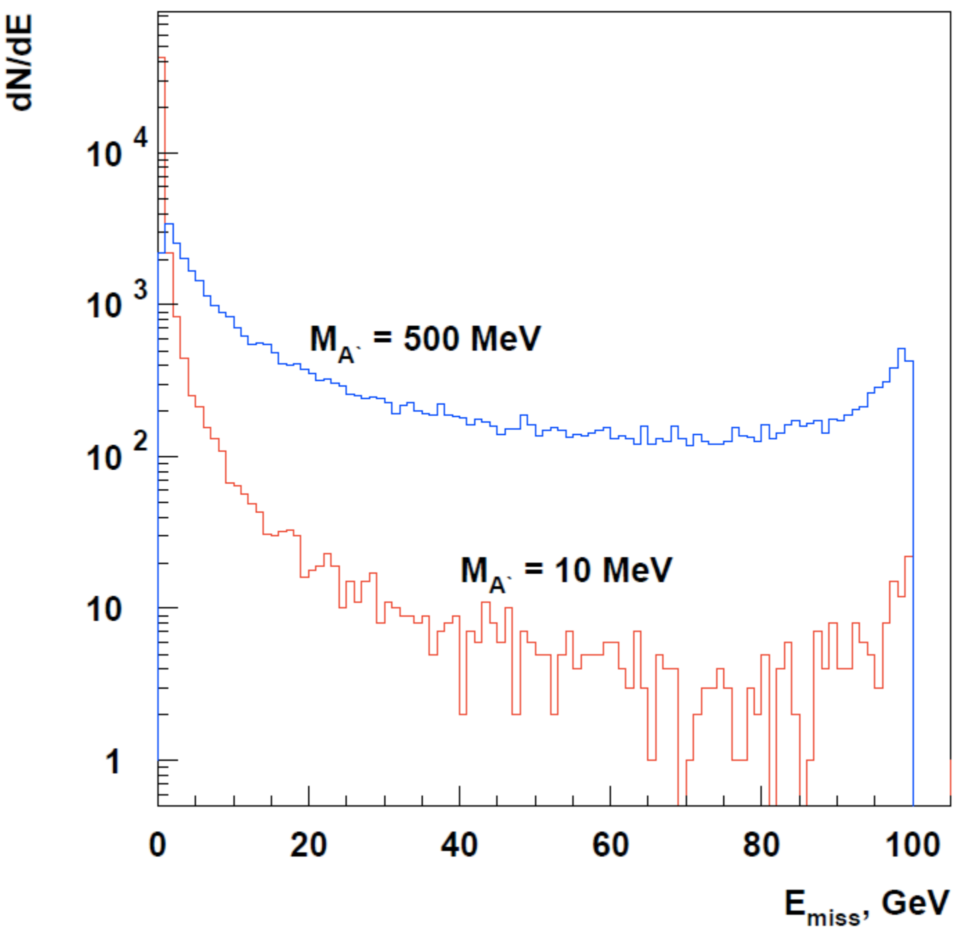
- **December 2013:** proposal to SPSC
- **April 2014:** recommended for tests
- **April 2014 - March 2015:** design production and delivery at CERN
- **October 2015:** 2 week test run
- **February 2016:** Proposal approved as a SPS experiment! P348 becomes NA64
- **July 2016 – October 2016:** next two run of data taking

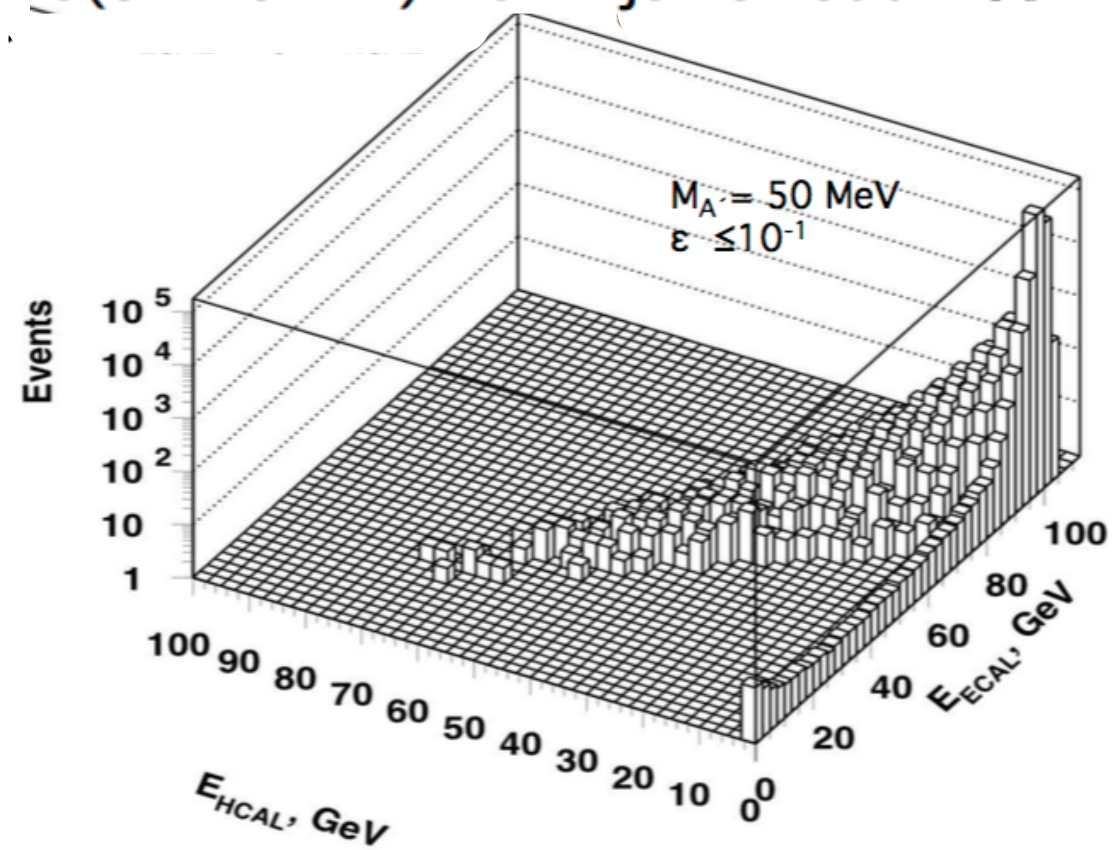
Search for A' —> invisible decay

Signature for A' production

SM events: $E_{ECAL} + E_{HCAL} = E_0$
A' events: $E_{ECAL} < E_0$; $E_{HCAL} = 0$

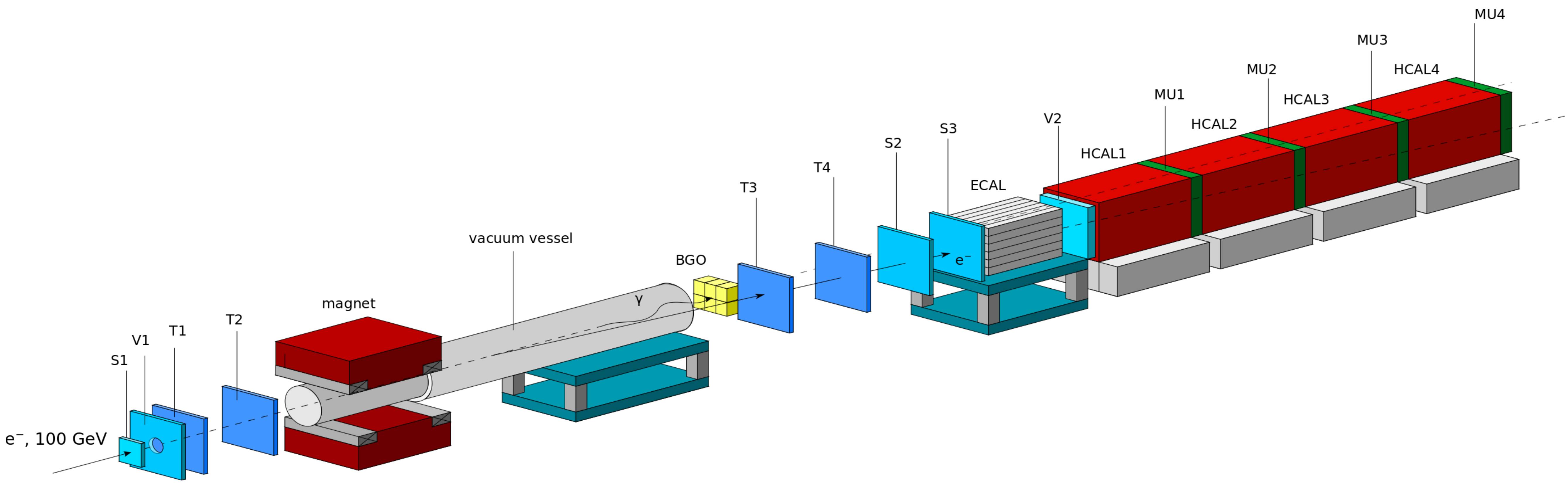


GEANT4+code for A´emission in the process of e-m shower development σ(e⁻Z->e⁻ZA´) from Bjorken et al.`09



- Background due to Muons, Pions and low energy electrons must be rejected to free the signal region.
  → SR tagging of electrons for hadron and muon rejection.
  → Micromegas tracker for low energy electron suppression.

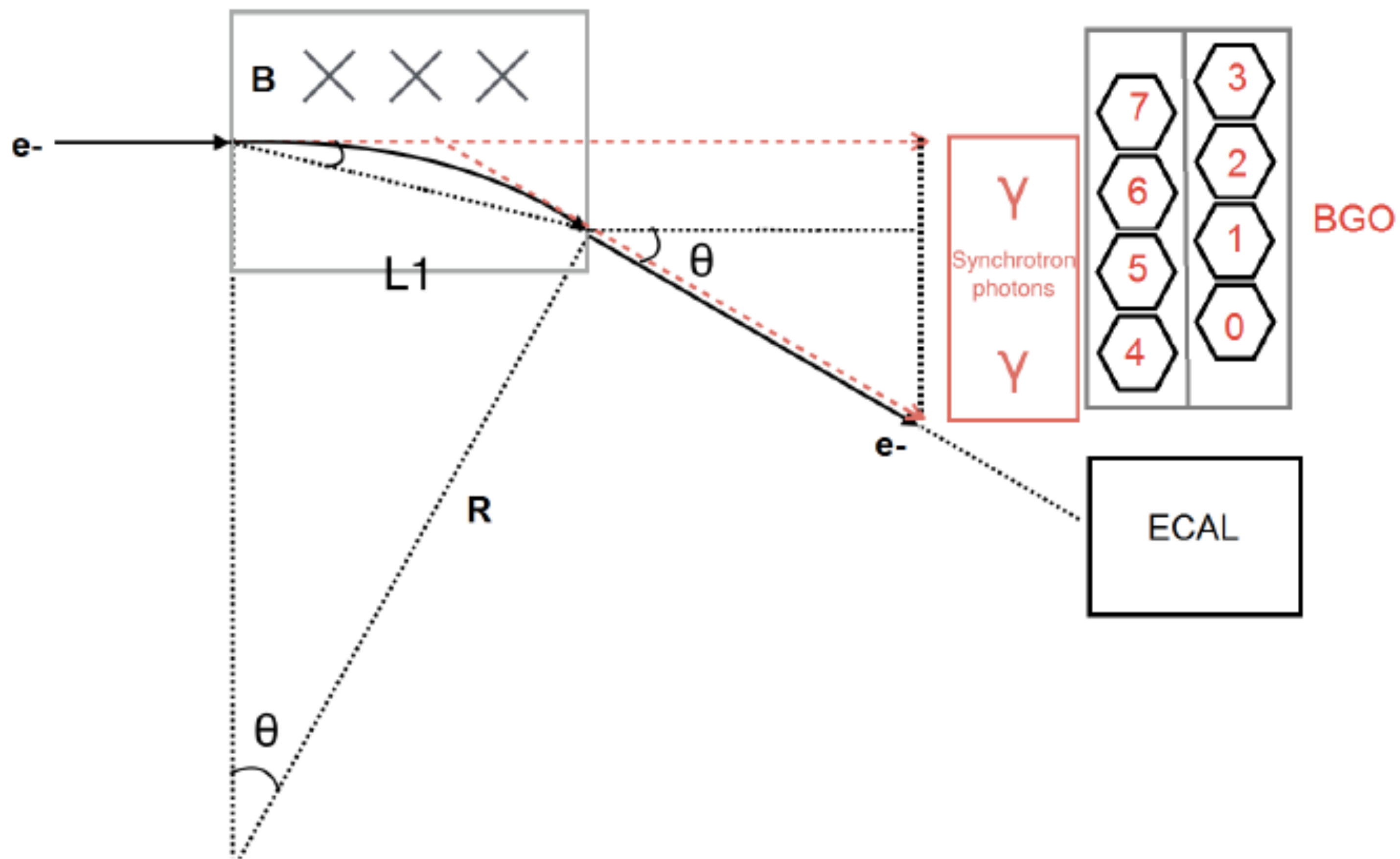
Direct search for A'—> invisible decay at CERN



- 3 main requirements:
  - clean mono-energetic electron beam of 100 GeV
  - e^- tagging with MM tracker and SR
  - 4π fully hermetic ECAL + HCAL

- Signature:
  - in: 100 GeV e^- track.
  - < 50 GeV EM shower in ECAL
  - no energy in Veto + HCAL
  - Sensitivity ~ ε^2

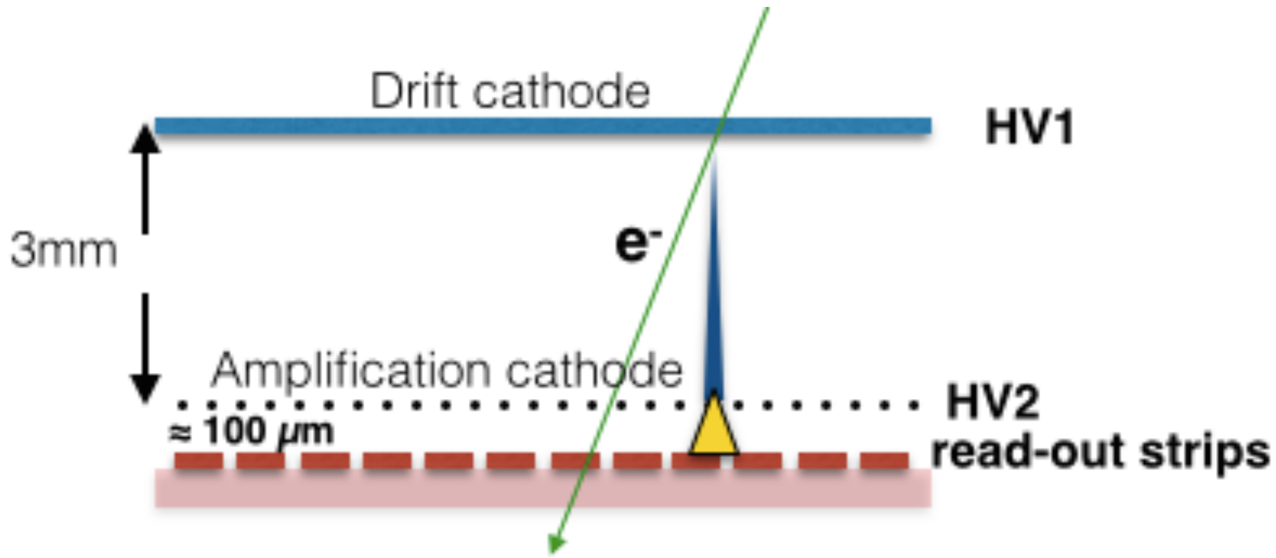
e^- tagging with SR photons

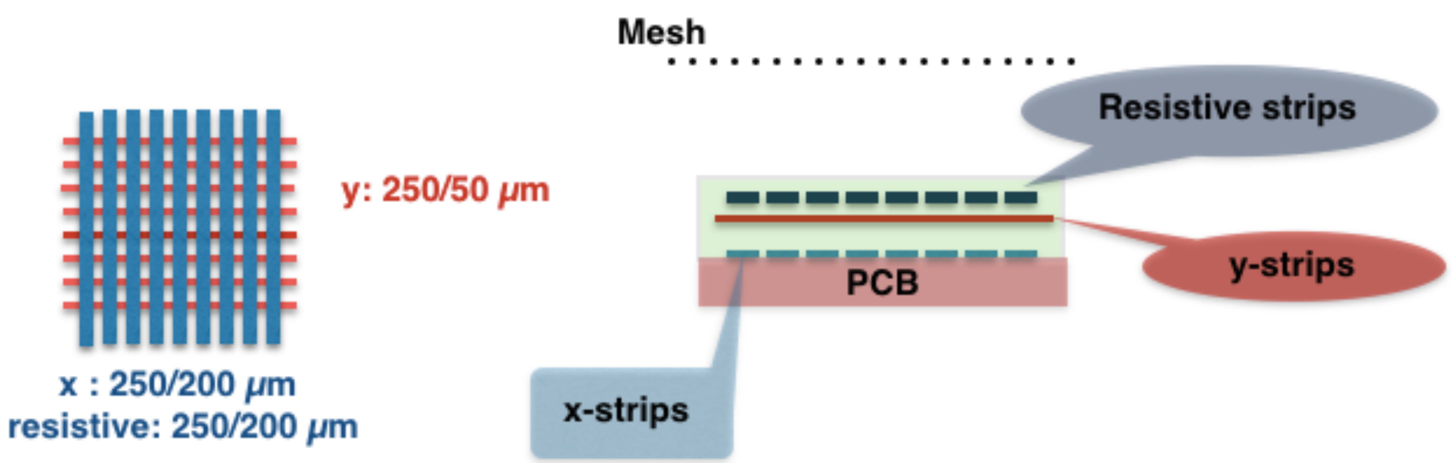


$$\Delta E = \frac{e^2}{3\epsilon_0 (mc^2)^4} \frac{E^4}{R}$$

- *Charged particles when accelerated radially (a⊥v, as in a magnetic field) emit electromagnetic radiation.*
- *The energy emitted* ***ΔE ∝ m⁻⁴*** *.*
- *Hadrons and muons emit almost no photons compared to electrons and can be suppressed.*
- *BGO crystals are used to select events with such radiation.*
- B-field 1.4 T (max 1.8 T) for a 2 m magnet -100 GeV electrons —>
  - Suppression factor ~ 10^{-5} for 4 m magnet of 1.8 T field.
  - <ΔE> ~ 30 MeV
  - E_γ^{min} ~ 1 MeV ; n_γ = 10
  - $(h\omega)_\gamma^c$ ~ 10 MeV

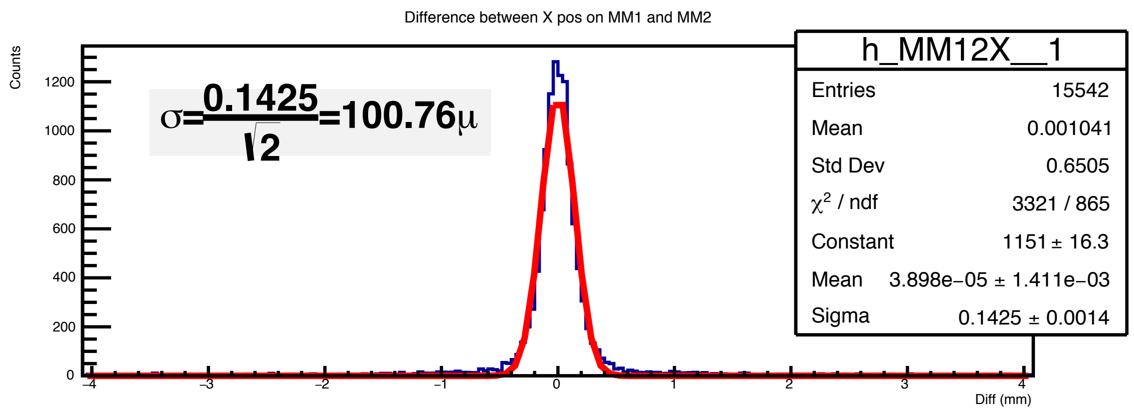
MM tracking spectrometer

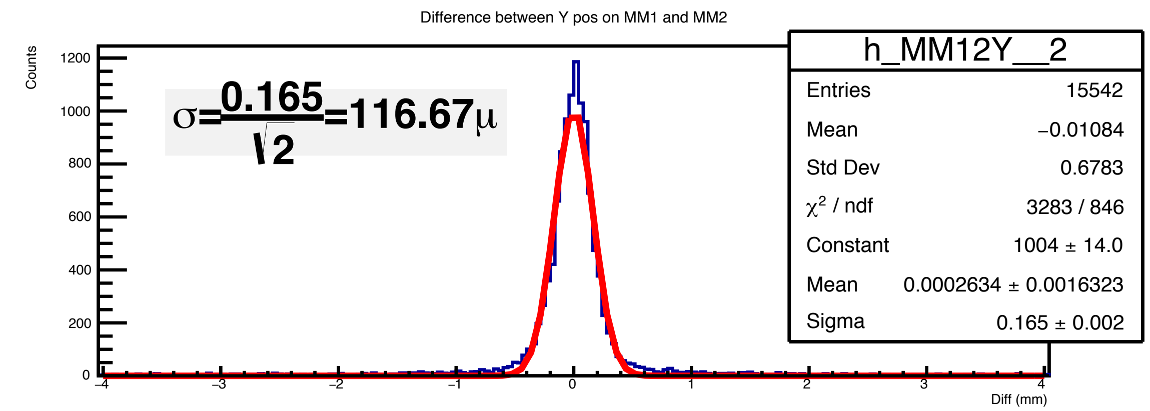


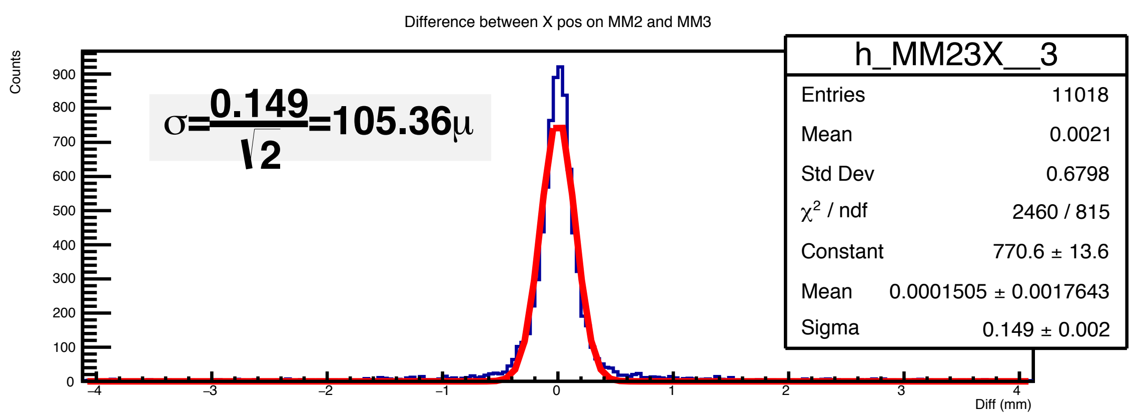


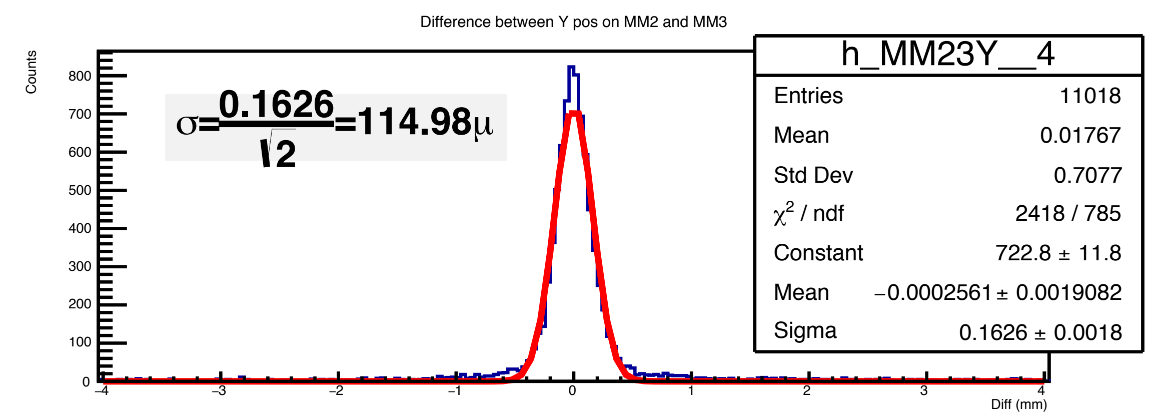
- *Micromegas detectors are two stage parallel plate avalanche chambers.*
- *Narrow amplification gap ~ 128 μm*
- *Wider drift gap ~ 3 mm.*
- *Charged particle drift towards the micro-mesh under an E-field of 0.6 kV/cm (HV1).*
- *Produces avalanche of secondary electrons under high amplification field ~ 50 kV/cm (HV2).*
- *Resistive XY modules of 250 μm pitch.*

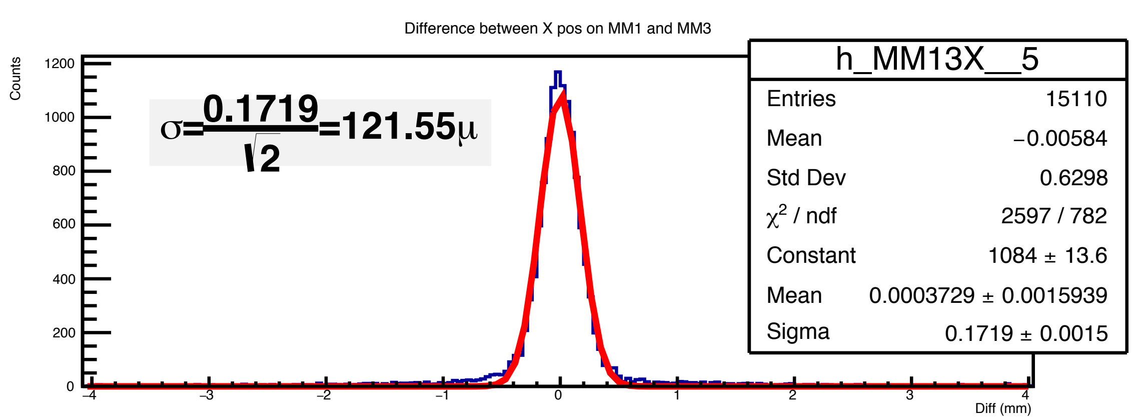
MM tracking spectrometer

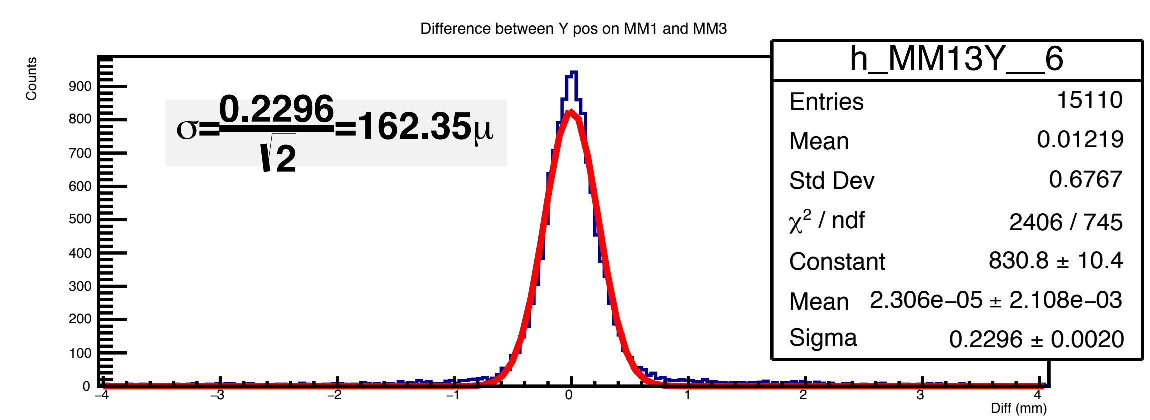










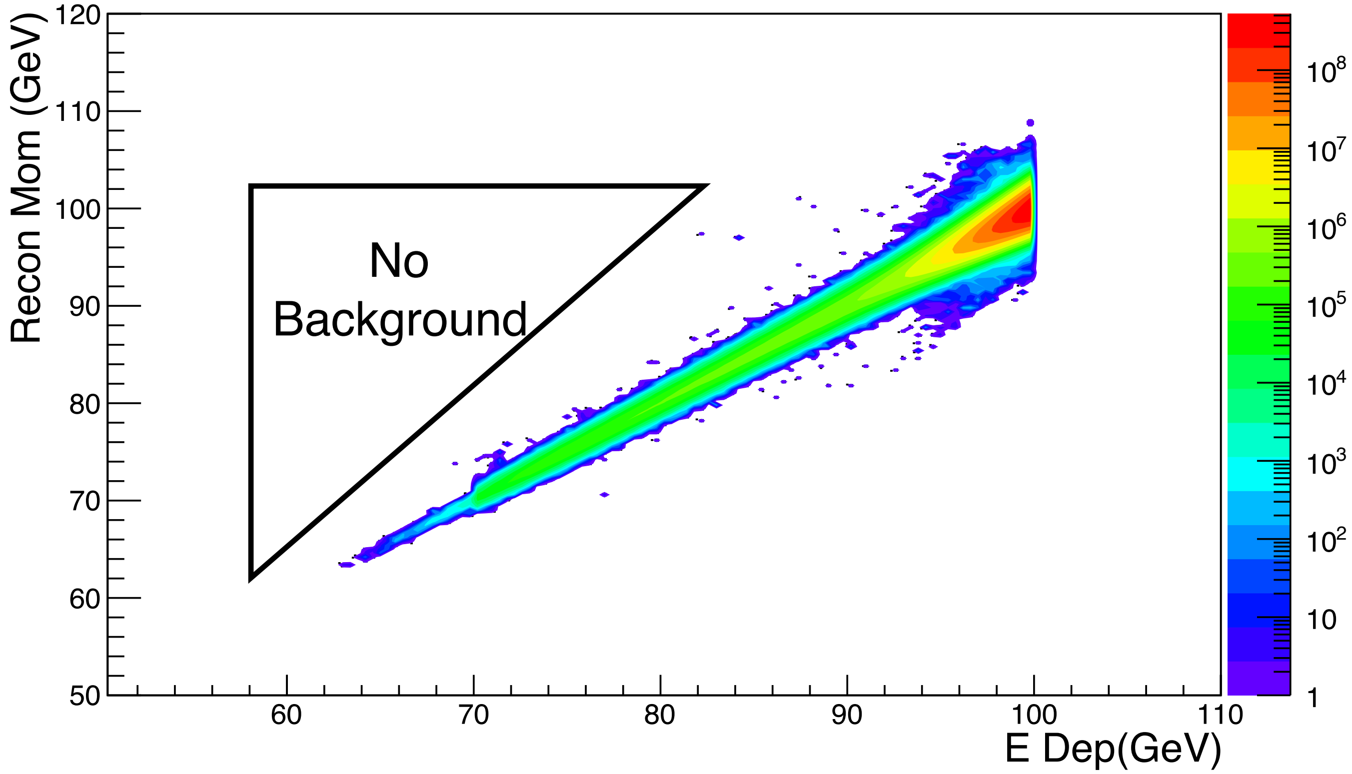


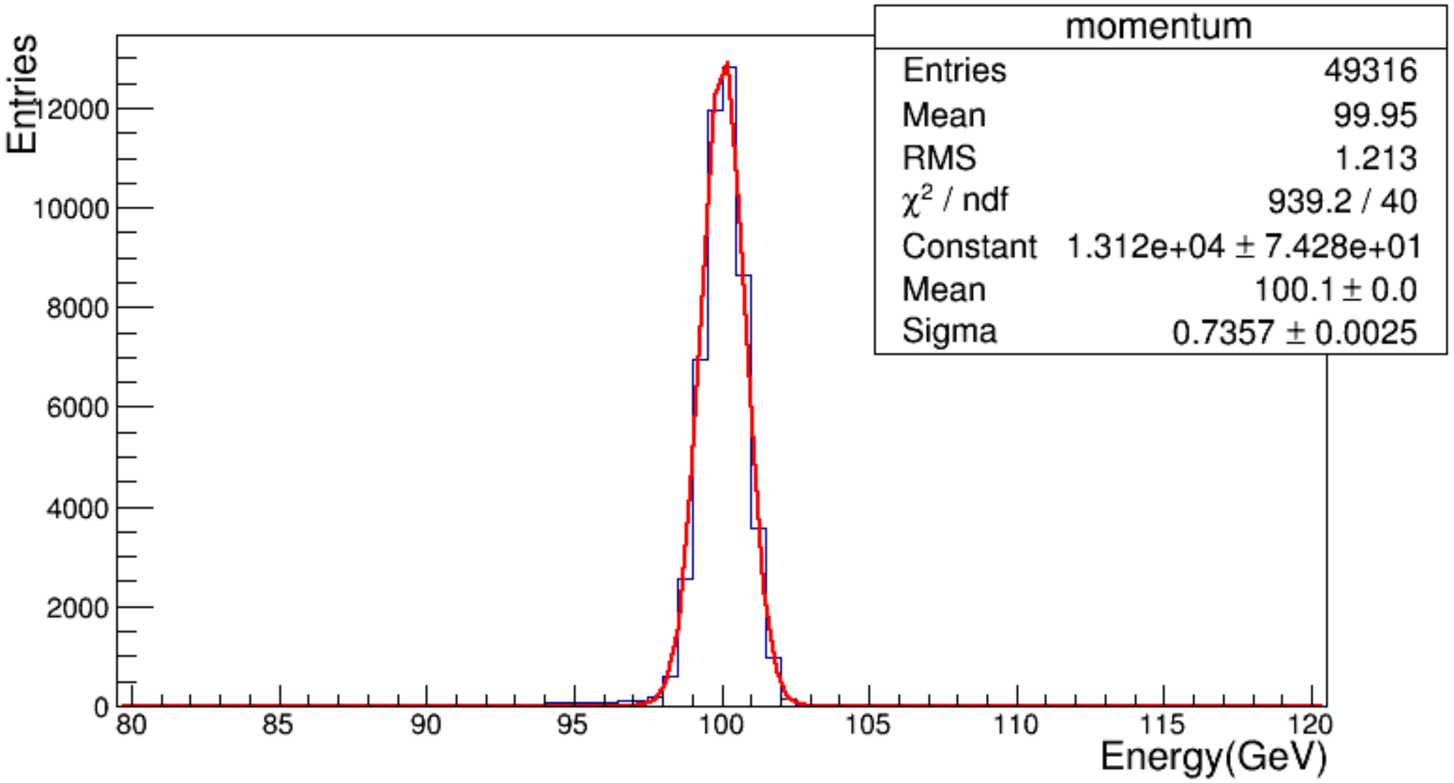
Spatial Resolution obtained with 3 MM modules of 250 μm pitch
~ 100 μm/co-ordinate for each module from data

MM tracking spectrometer

Micromegas XY modules to be used as tracker in the next beam time:

Resolution for 100 GeV electrons ~ **0.74 GeV** from simulation (Geant4)





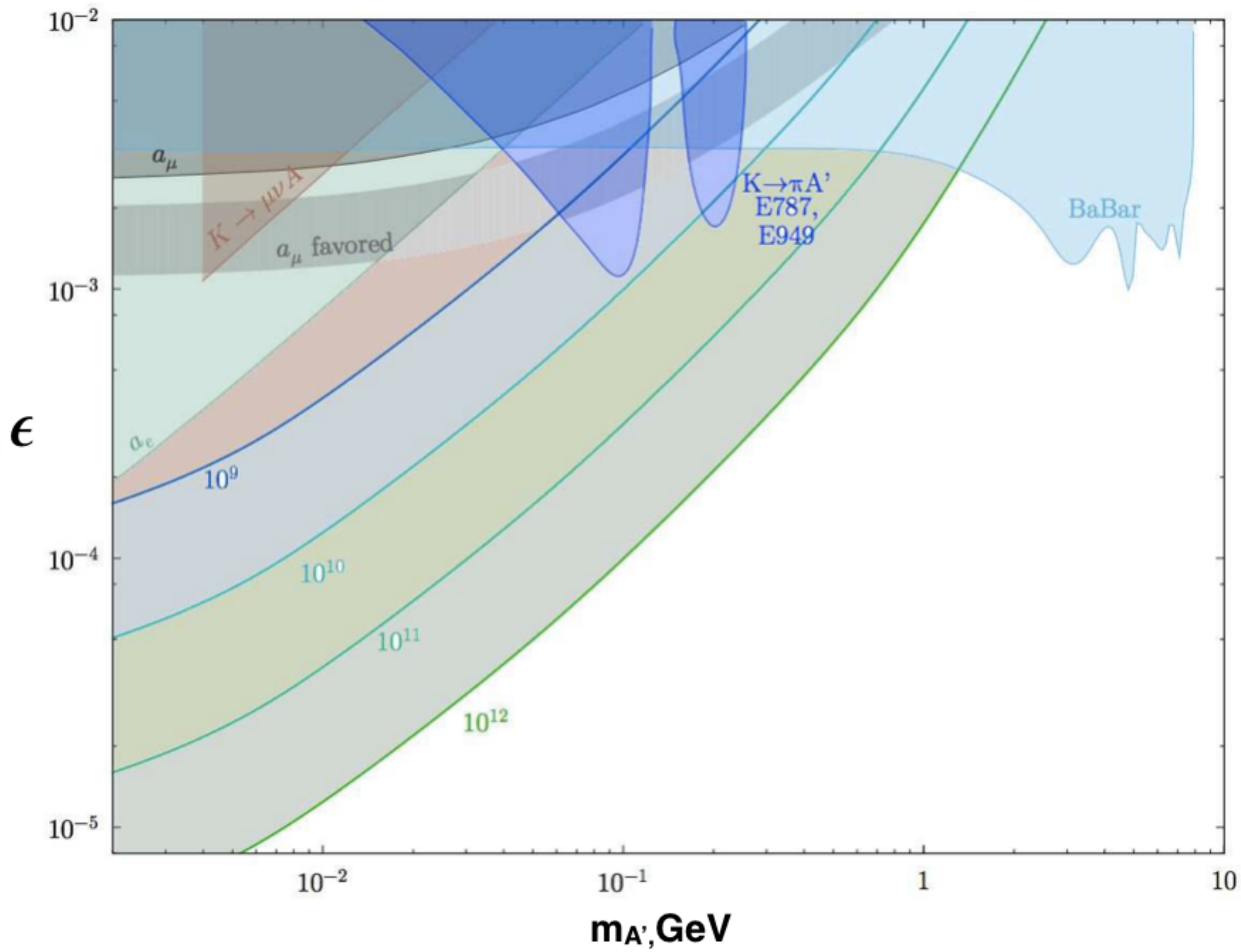
Background suppression for low energy tail (< 60 GeV for 100 GeV beam)

$< 10^{-10}$

Summary of background for A'—>invisible channel

Source	Expected level	Comment
Beam contamination		
- π , p, μ reactions and punchthroughs,... - e^- low energy tail due to bremss., π , μ decays in flight,..	$< 10^{-13}$-10^{-12} $< 10^{-12}$	Impurity < 1% high precision MM tracker + e^- SR photon tag
Detector		
ECAL+HCAL energy resolution, hermeticity: holes, dead materials, cracks...	$<10^{-13}$	Full upstream coverage
Physical		
-hadron electroproduction, e.g. $e^-A \to n e^- A^*$, n punchthrough; - WI process: $e^- Z \to e^- Z \nu \nu$	$< 10^{-13}$ $< 10^{-13}$	~10 mb x nonherm. WI σ estimated. textbook process, first observation?
Total (conservative)	$< 10^{-12}$	

Projected Sensitivity



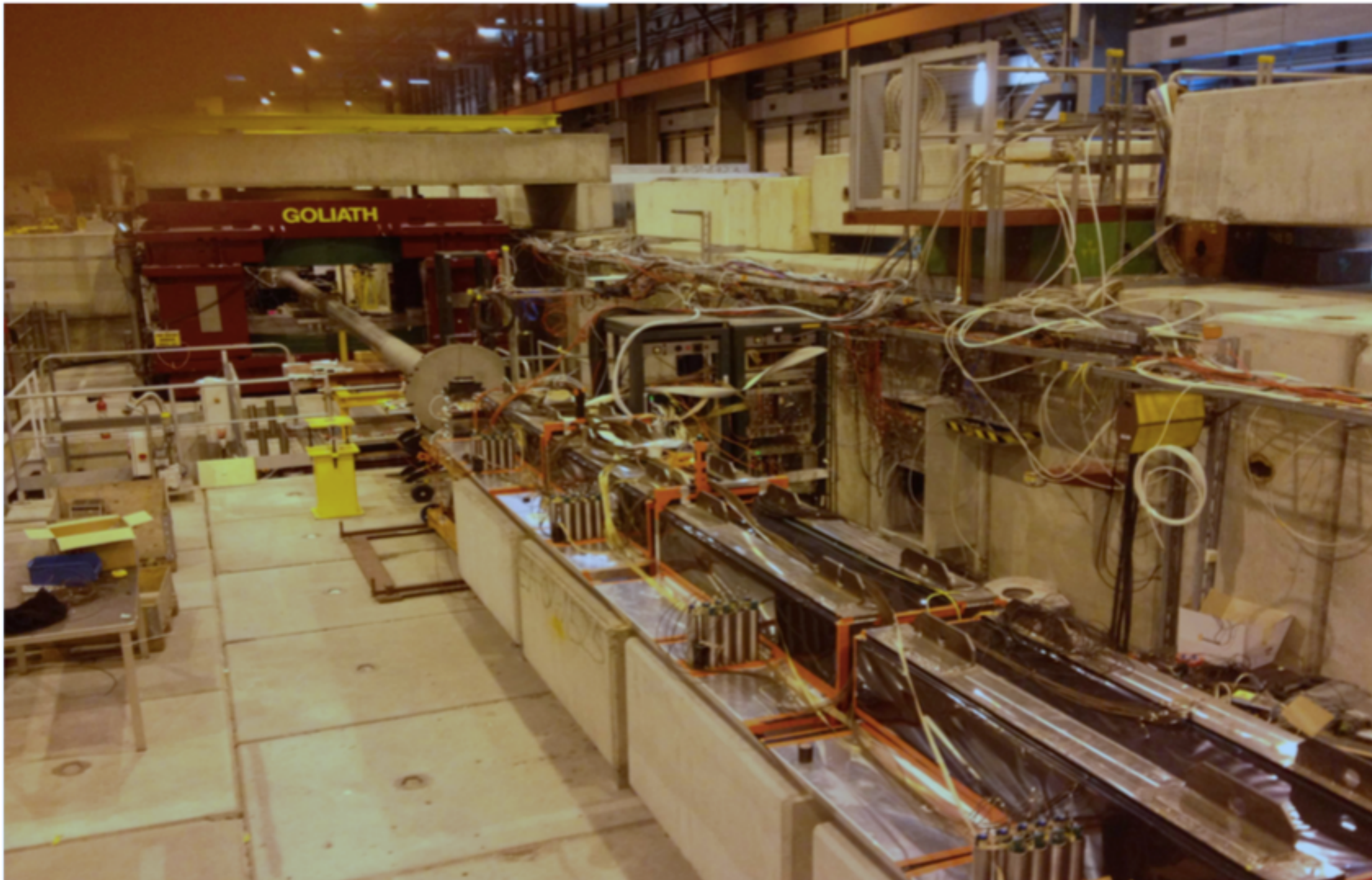
The discrepancy between the predicted and experimental values for the anomalous magnetic moment $(g\text{-}2)_\mu$ of the muon could be explained by the presence of an additional boson.

With 10^{10} accumulated events (possible to accumulate $5\text{x}10^{10}$ electrons in a month's run time) NA64 may completely exclude the still favoured parameter space by $(g\text{-}2)_\mu$.

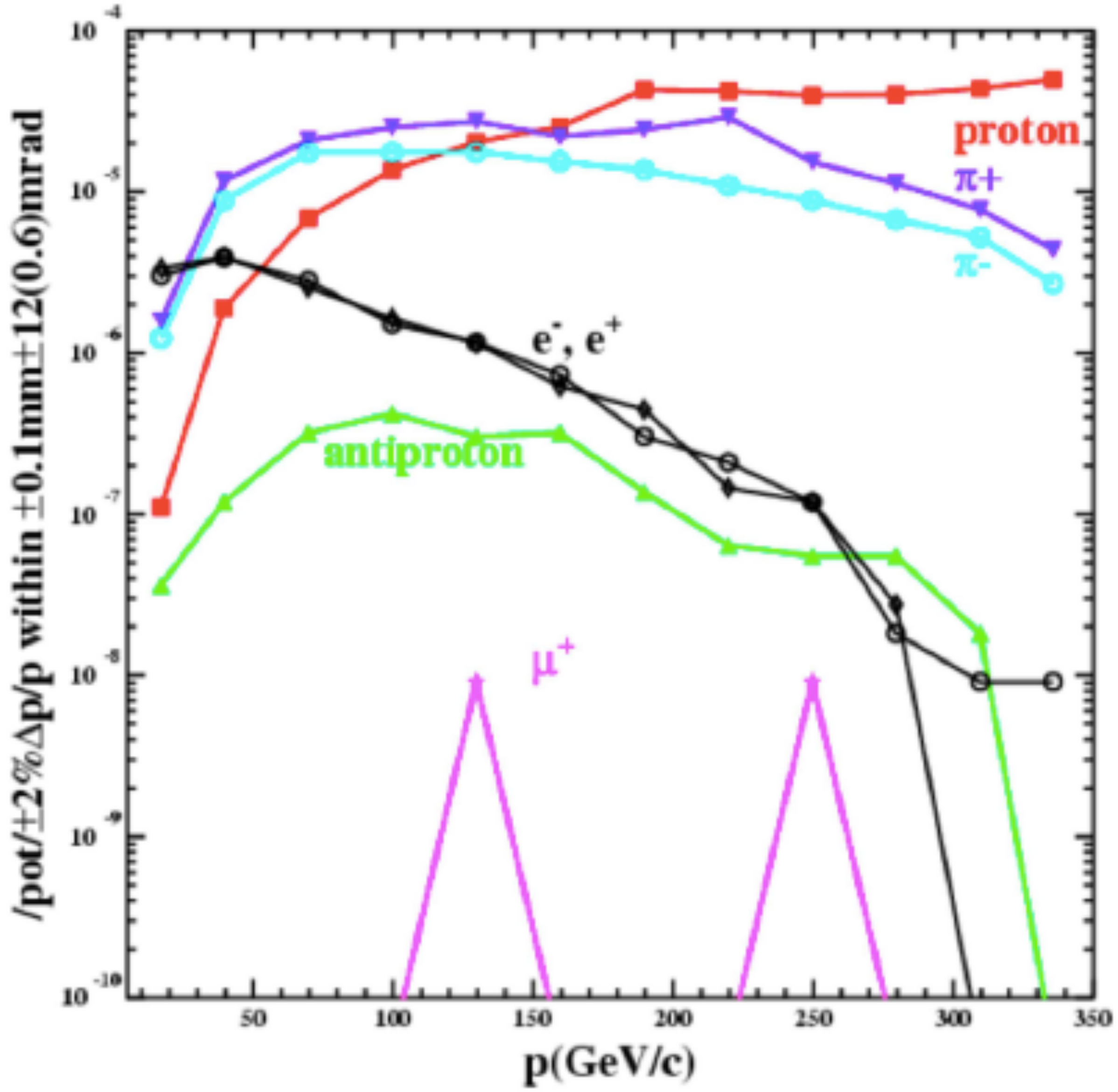
Potentially can cover a much bigger region with enough accumulated statistic

Test Run 2015

Experiment Setup

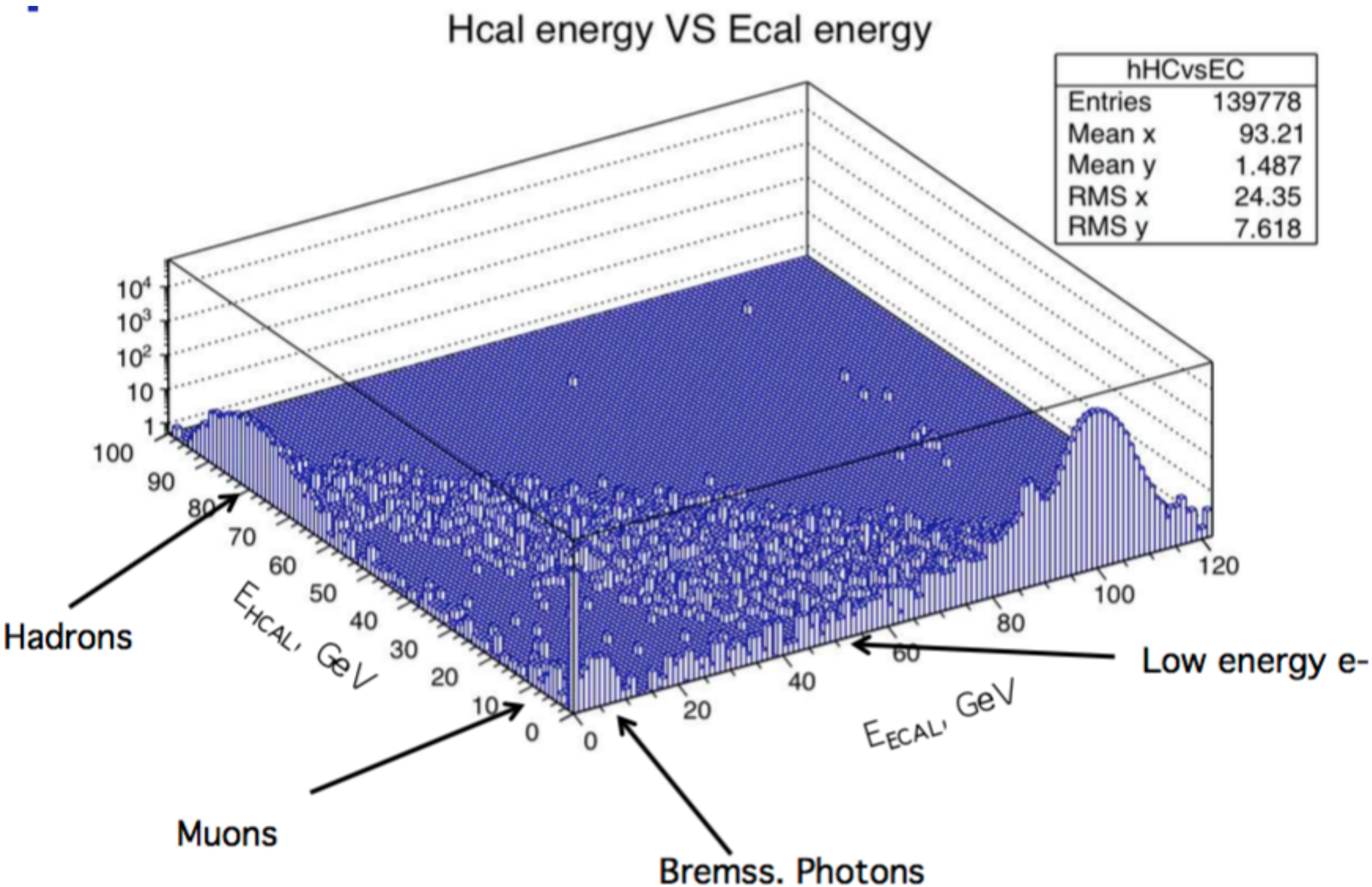


H4 Beamline



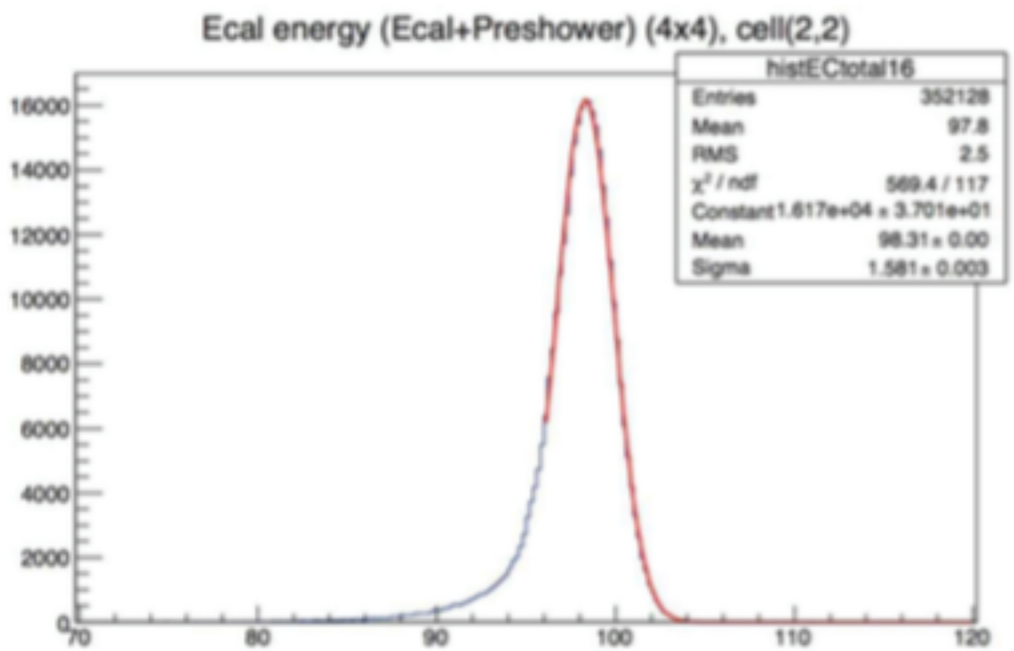
- e^-, I_{max} at 50 GeV
  In our experiment tuned to 100 GeV
- I_{max} ~ 10^6 e^-/spill.
- Spill length 4.8 sec
  - 1 spill every 14.8 sec
- ~10^{11} e^-/month.
- beam spot ~ 4 cm^2
- hadron mixture < 1%

First Look B-field off

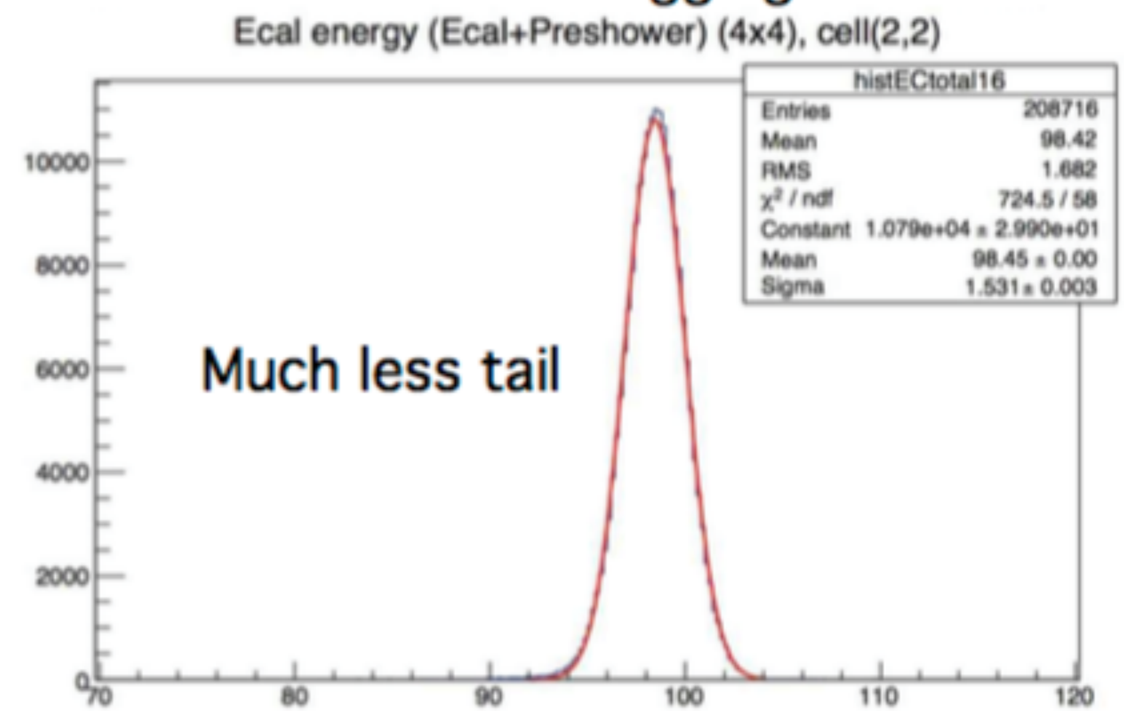


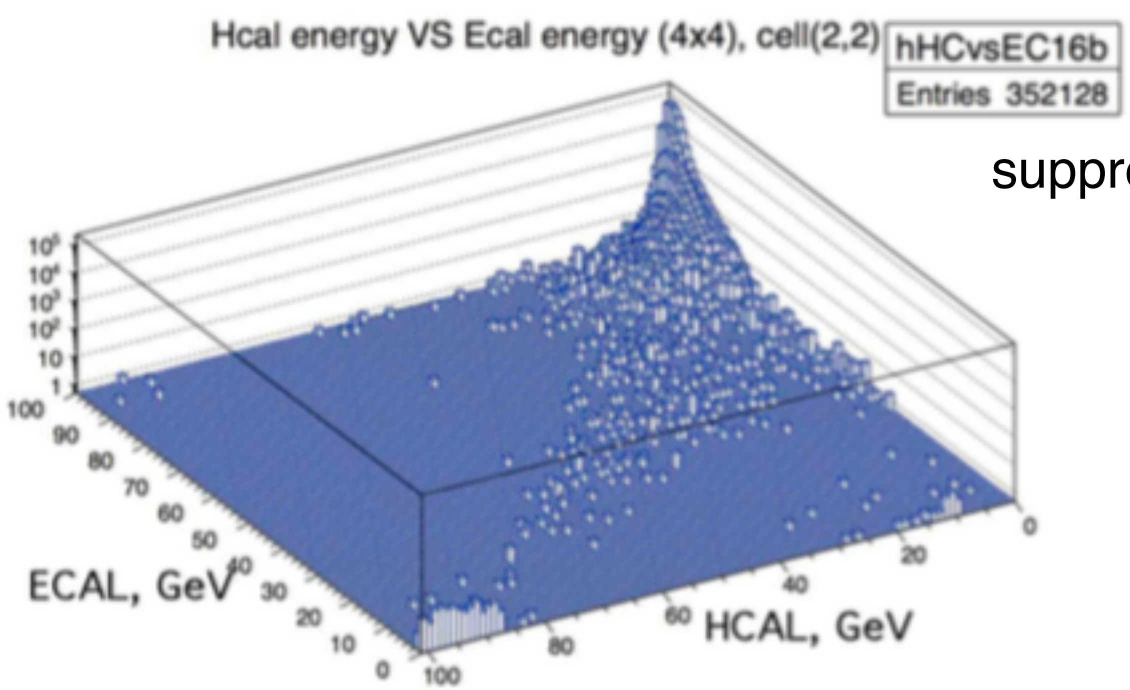
SR tagging cut

No SR tagging of e⁻'s



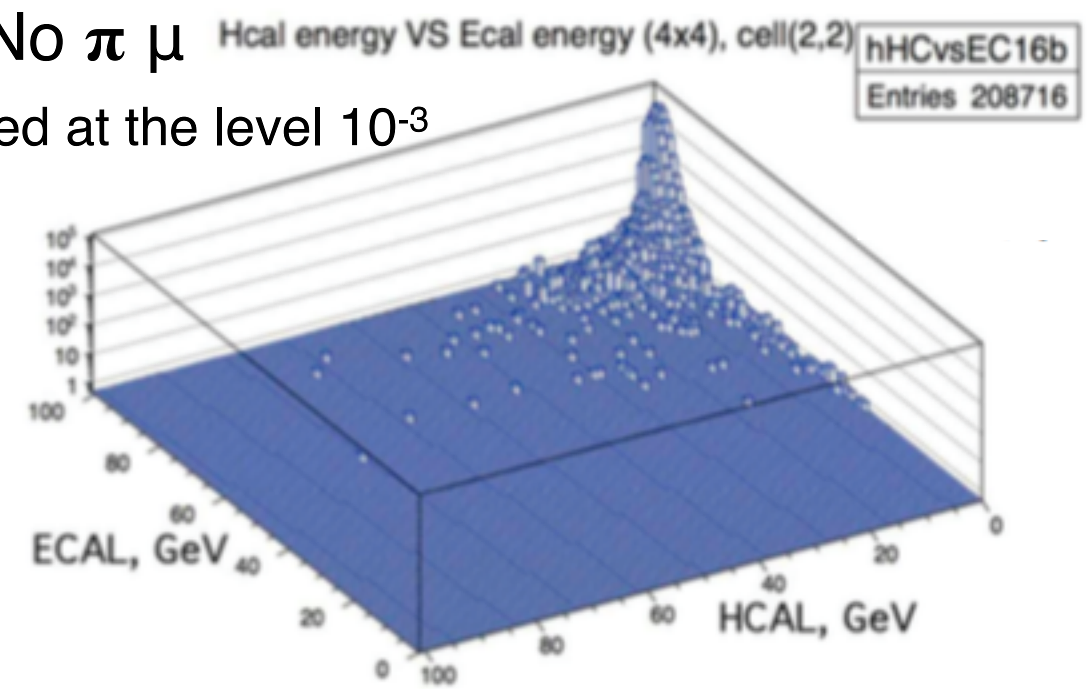
With SR tagging of e⁻'s





No π μ

suppressed at the level 10^{-3}



Summary

The conceptual idea of NA64 is to search for dark sector physics in missing-energy events with an active beam dump experiment.

The test run 2015:
The capability of such an approach and background-free operation of the NA64 detector have been demonstrated for the first time.

The run 2016:
Further increase in efficiency and sensitivity over 2015 results is expected due to
i) use of a larger magnetic field
ii) the ability of a high efficiency tagging of initial state (hadronic suppression) with SR detectors,
iii) precise measurement of the incoming electron momentum with the MM tracker,
iv) and thus, rejection of all known backgrounds.

Runs >2016 :
Further increases in efficiency and other improvements are in development, including increased beam rate.

These results expand the reach of NA64.

Physics Prospects

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]

Thank You !!