The NA64 experiment at the CERN SPS

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on behalf of the NA64 collaboration

13th Patras Workshop on Axions, WIMPs and WISPs, 15th of May 2017, Thessaloniki (Greece)

The NA64 collaboration

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47 researchers from 12 Institutes
Proposed in 2014, first test beam in 2015 (2 weeks), our proposal (P348) was approved by CERN SPSC in March 2016 → NA64. In 2016 two runs of 2 and 3 weeks.

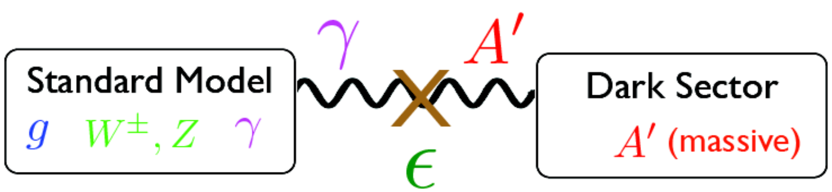
Motivations for Hidden/Dark sectors

- In several models (e.g. string theory, super-gravity, ...) dark sectors of particles arise naturally providing an interesting candidate for Dark Matter.

  For a review: J. Jaeckel and A. Ringwald, Annu. Rev. Nucl. Part. Sci. 60, 405 (2010)

- In addition to gravity, Dark Sectors could be coupled to ordinary matter by other very weak forces. An extra (broken) U(1)' symmetry would imply a new massive boson A' (so called Dark Photon)

ordinary photon & A′ can mix



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic Mixing" Holdom Galison, Manohar

simplest Dark Sector consists of just an A′

- Dark photons could provide an explanation of the muon g-2 anomaly.

  M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662, 53 (2008)

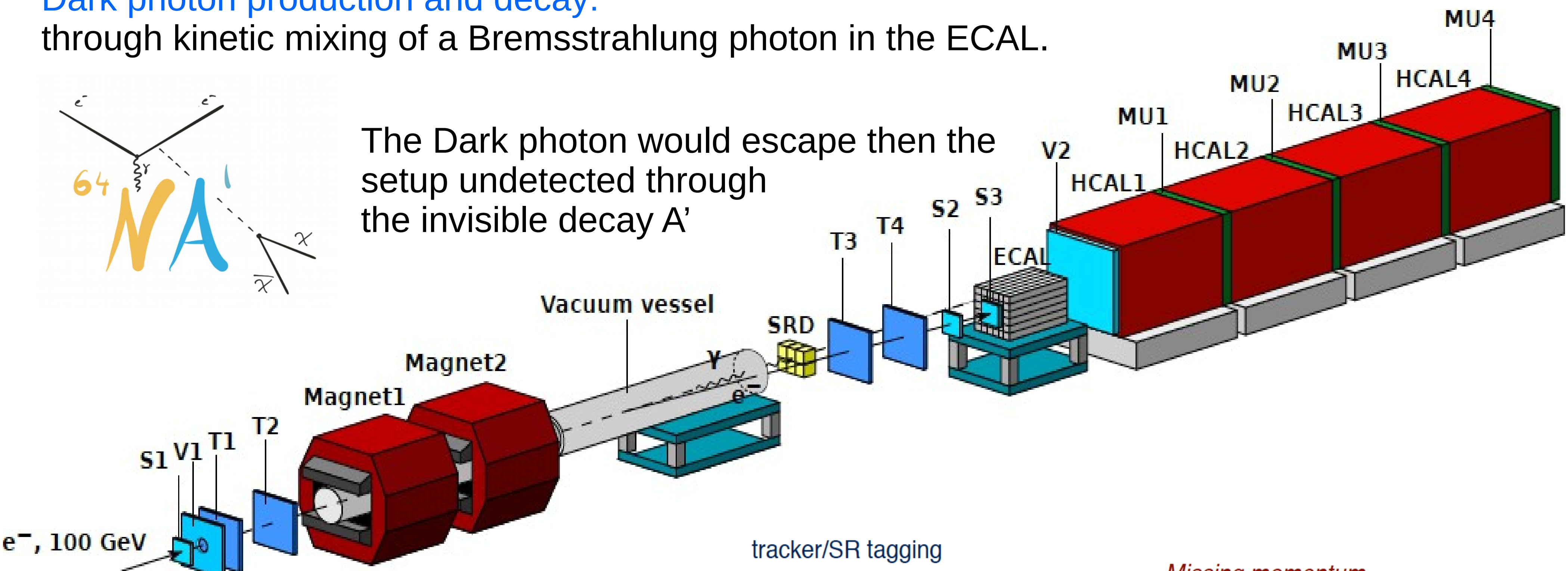
- A' decay modes:
  1) Visible: A' → e+e-, μ+μ-
  2) Invisible A' → $\chi\bar{\chi}$ current focus of NA64

For a recent review of DS activities see e.g. J. Alexander et al., arXiv:1608.08632.

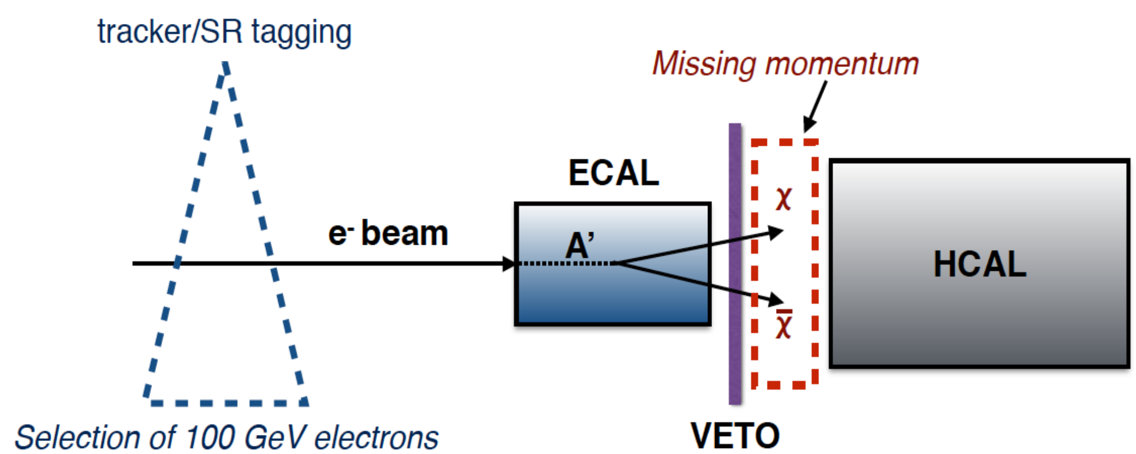
NA64 – Principle of the Experiment

Dark photon production and decay:
through kinetic mixing of a Bremsstrahlung photon in the ECAL.

The Dark photon would escape then the setup undetected through the invisible decay A'

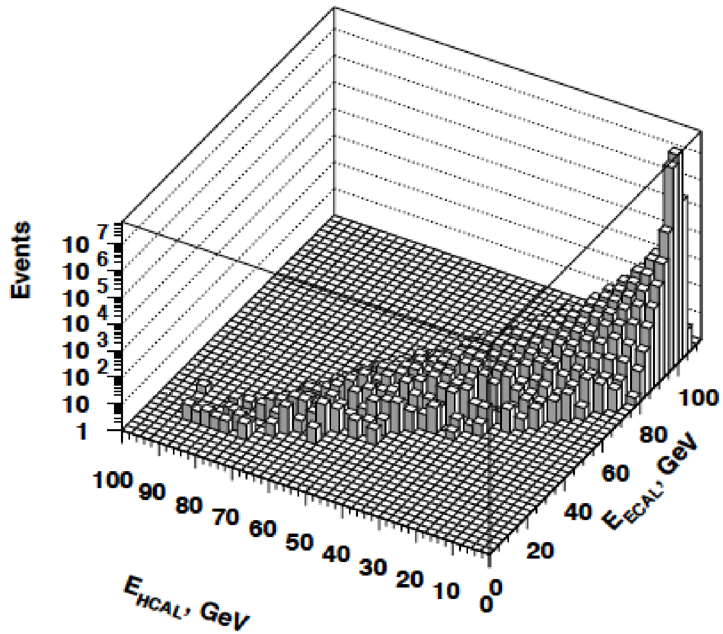


Dark Photon signature:
- Tagged 100 GeV electron
- Missing energy in the ECAL (threshold<50 GeV)
- no activity in VETO and HCAL

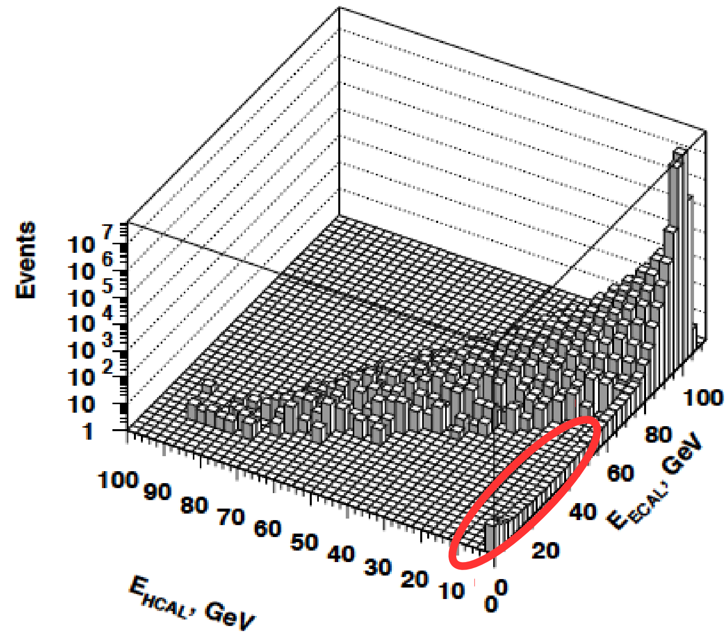


Experimental signature: $A' \rightarrow \chi\bar{\chi}$

STANDARD MODEL:
$E_{ECAL}+E_{HCAL}$ = 100 GeV



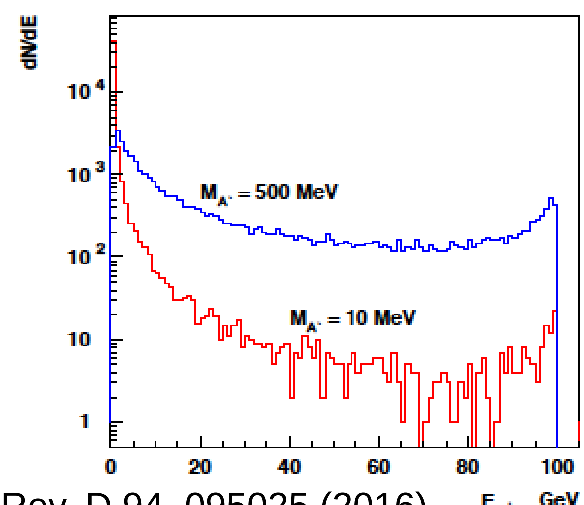
STANDARD MODEL + DARK PHOTON



SIGNAL
E_{ECAL}<50 GeV
E_{HCAL} < 2 GeV

GEANT 4 simulation:

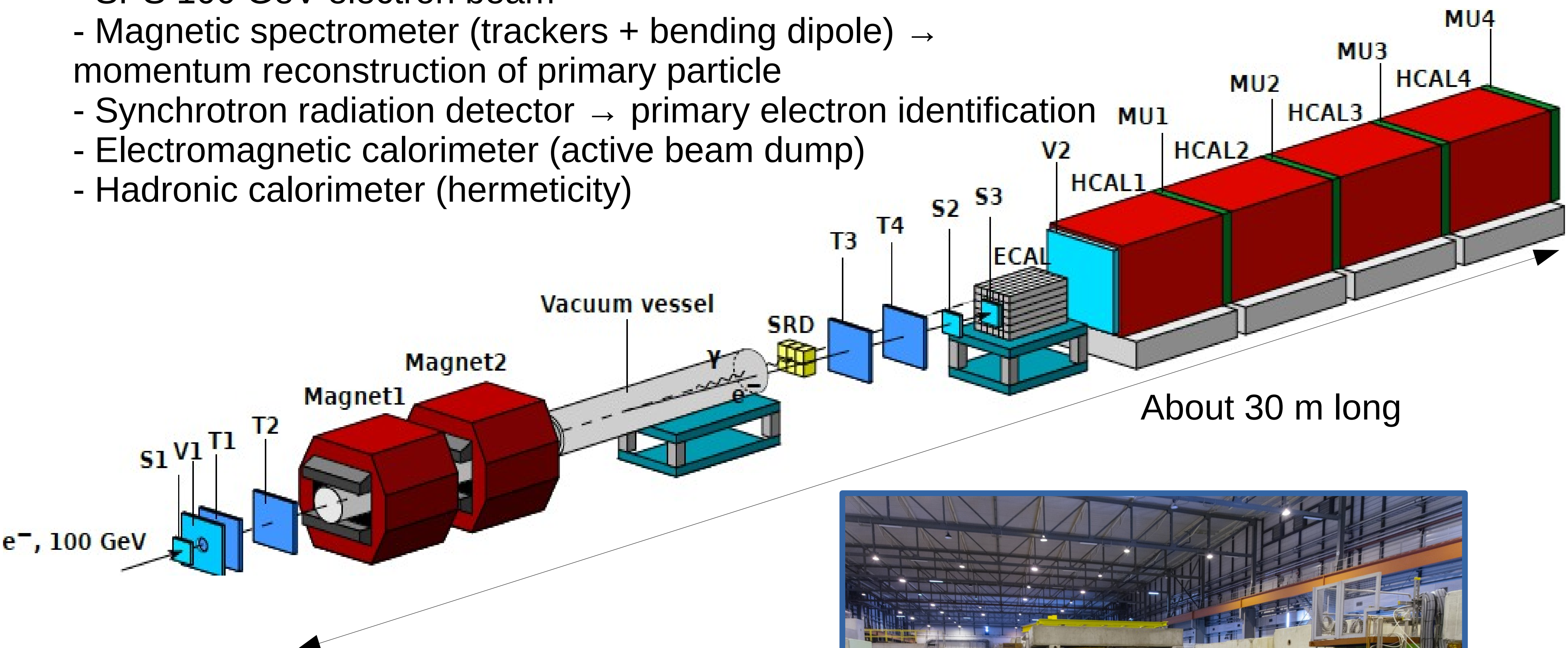
A' emission spectrum from 100 GeV electron beam interactions in the Pb target calculated for $m_{A'}$ =10 MeV and $m_{A'}$= 500 MeV.



S. Gninenko et al.,Phys. Rev. D 94, 095025 (2016)

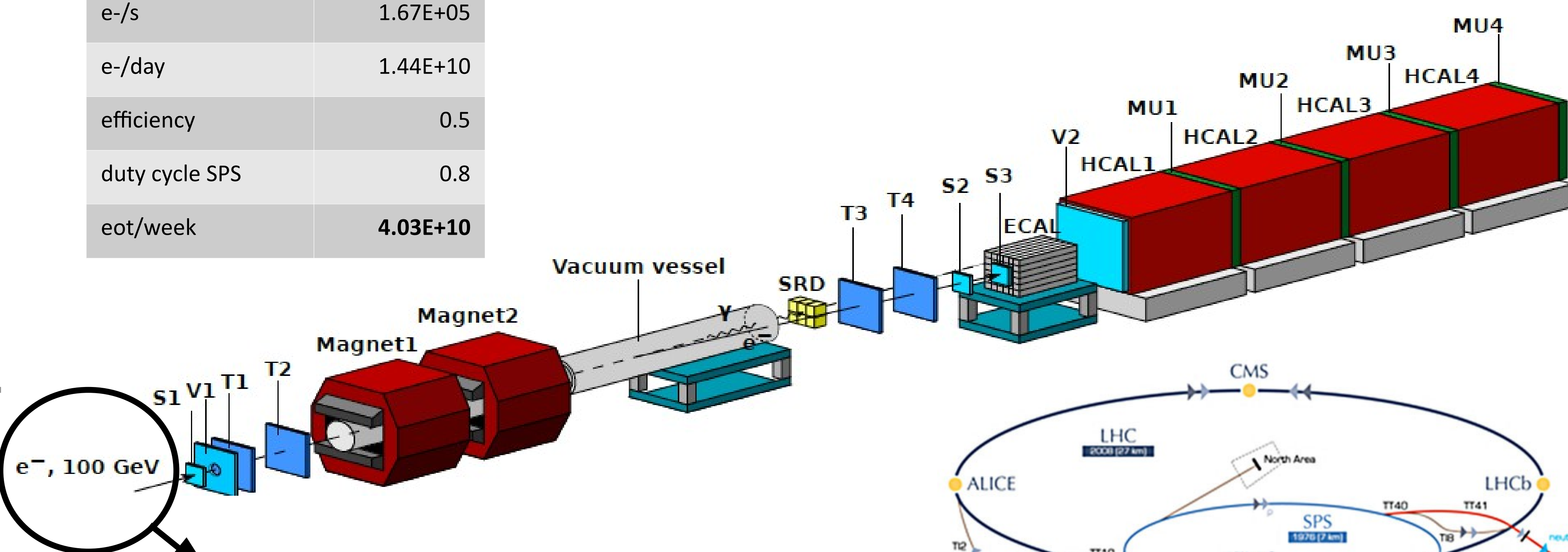
NA64 – Experimental setup

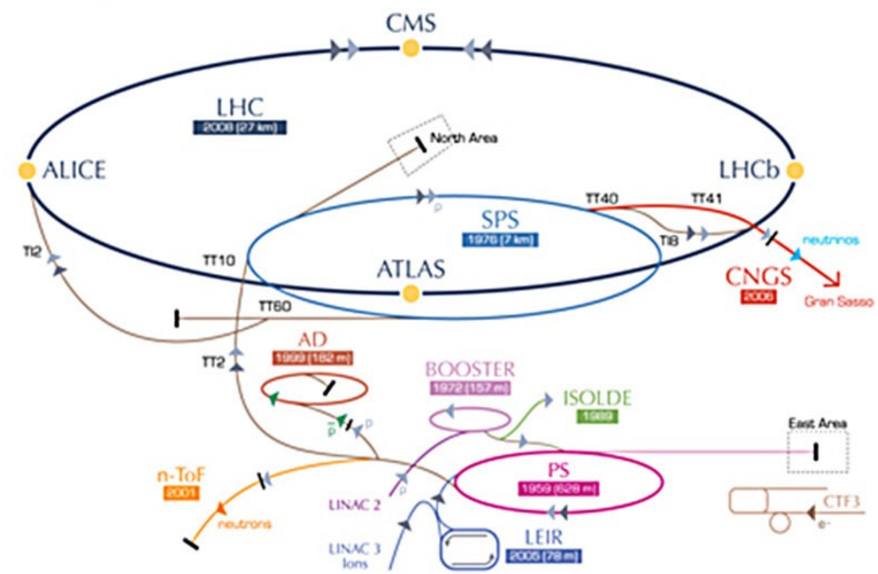
Key features
- SPS 100 GeV electron beam
- Magnetic spectrometer (trackers + bending dipole) → momentum reconstruction of primary particle
- Synchrotron radiation detector → primary electron identification
- Electromagnetic calorimeter (active beam dump)
- Hadronic calorimeter (hermeticity)



NA64 – SPS electron beam

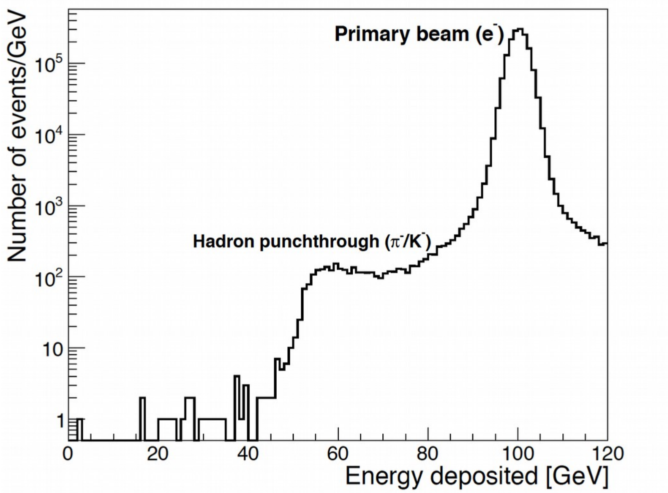
NA64 event rate	
e- per spill	5.00E+06
spill/min	2
e-/s	1.67E+05
e-/day	1.44E+10
efficiency	0.5
duty cycle SPS	0.8
eot/week	**4.03E+10**

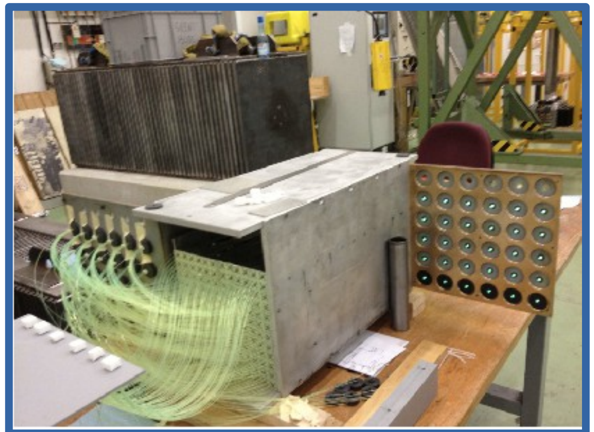


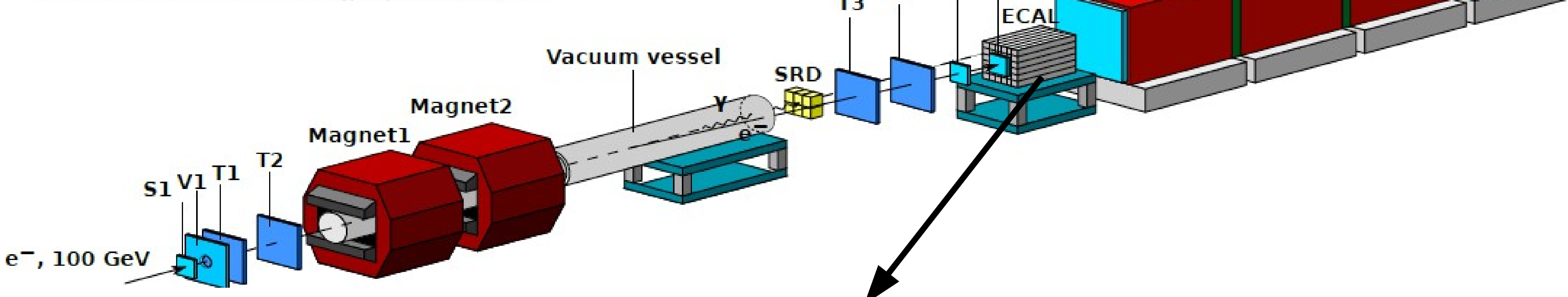


The CERN SPS H4 electron beam:
- Intensity up to $5x10^6$ e^-/spill, typically 2 spill/min
- Low contamination of pions (<1%) and muons/kaons (0.1%), low energy tails (<1%)
- Beam spot of 1.5 cm (FWHM)

NA64 – ECAL







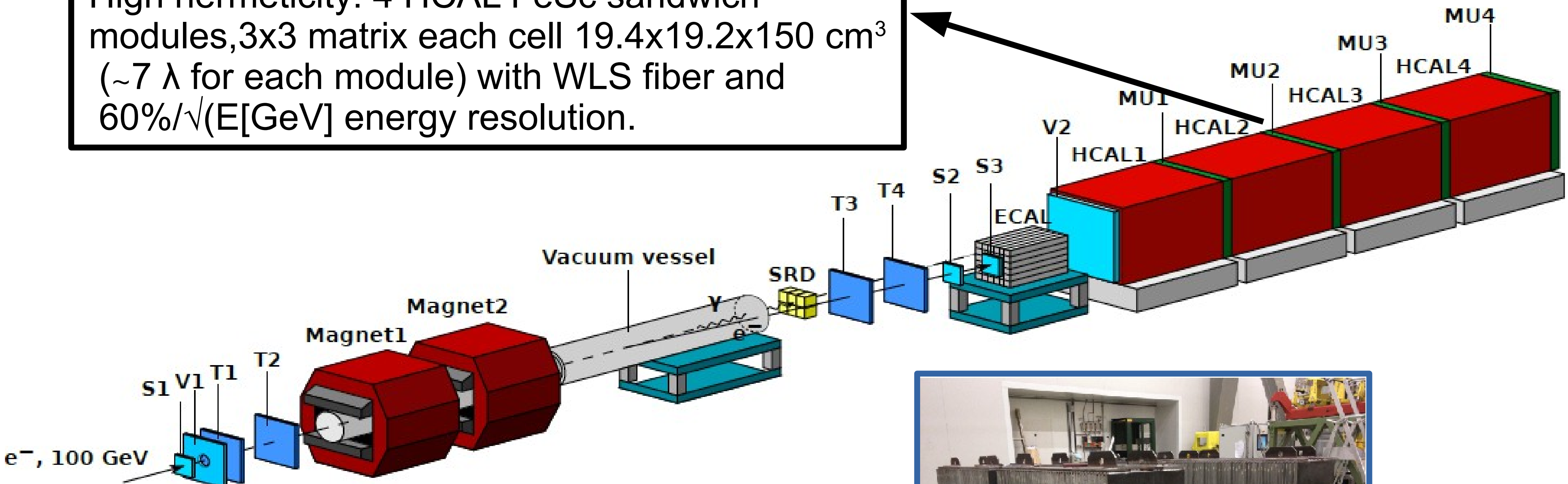
<u>The NA64 electromagnetic calorimeter (ECAL):</u>

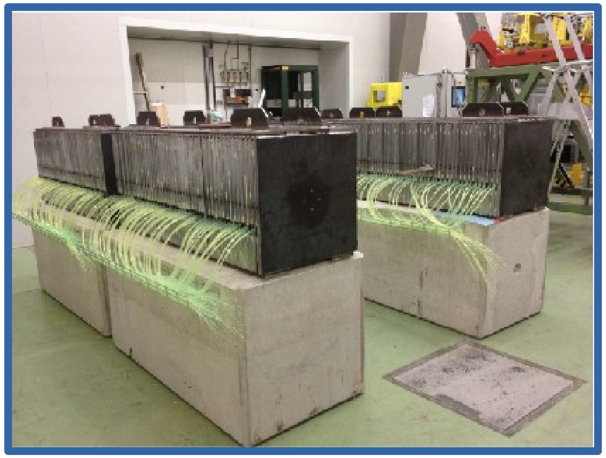
- High hermeticity: PbSc sandwich, 6x6 matrix each cell with 38x38x490 mm^3 (~40 X_0) with WLS fibers inserted in spiral to avoid energy leak through them
- ~ 9%/√(E[GeV]) energy resolution
- Longitudinal (Pre-shower) and lateral segmentation

→ measurements of shower profiles (hadron rejection)

NA64 – HCAL

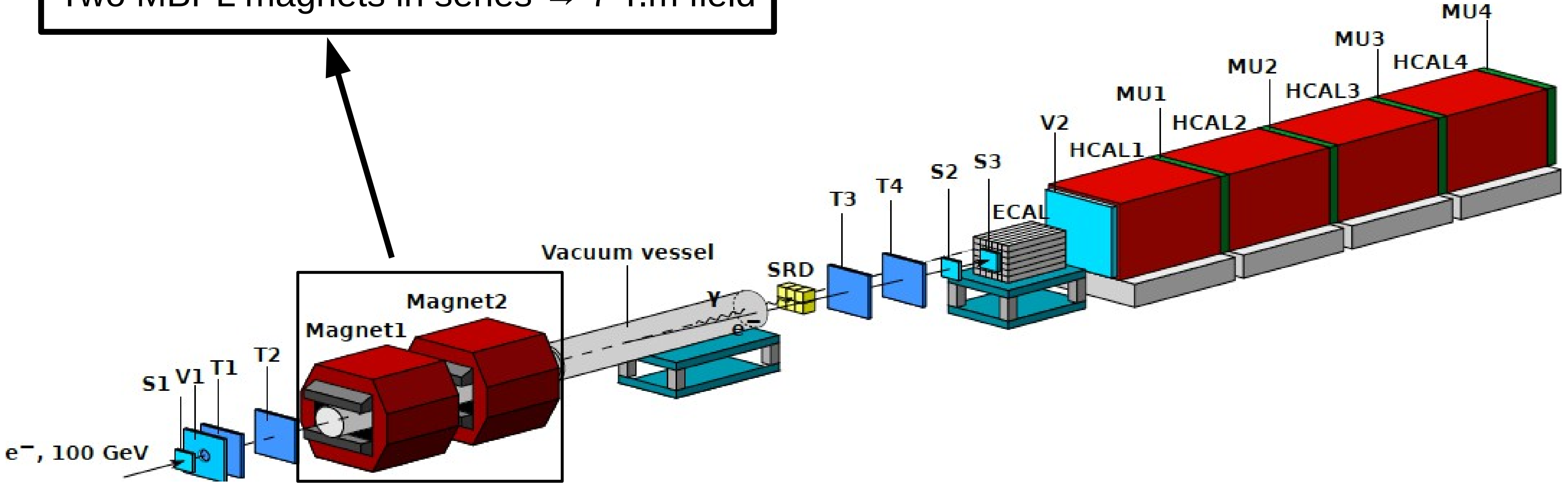
NA64 hadronic calorimeter (HCAL):
High hermeticity: 4 HCAL FeSc sandwich modules,3x3 matrix each cell 19.4x19.2x150 cm^3 (~7 λ for each module) with WLS fiber and 60%/√(E[GeV] energy resolution.





The magnetic spectrometer

Two MBPL magnets in series → 7 T.m field



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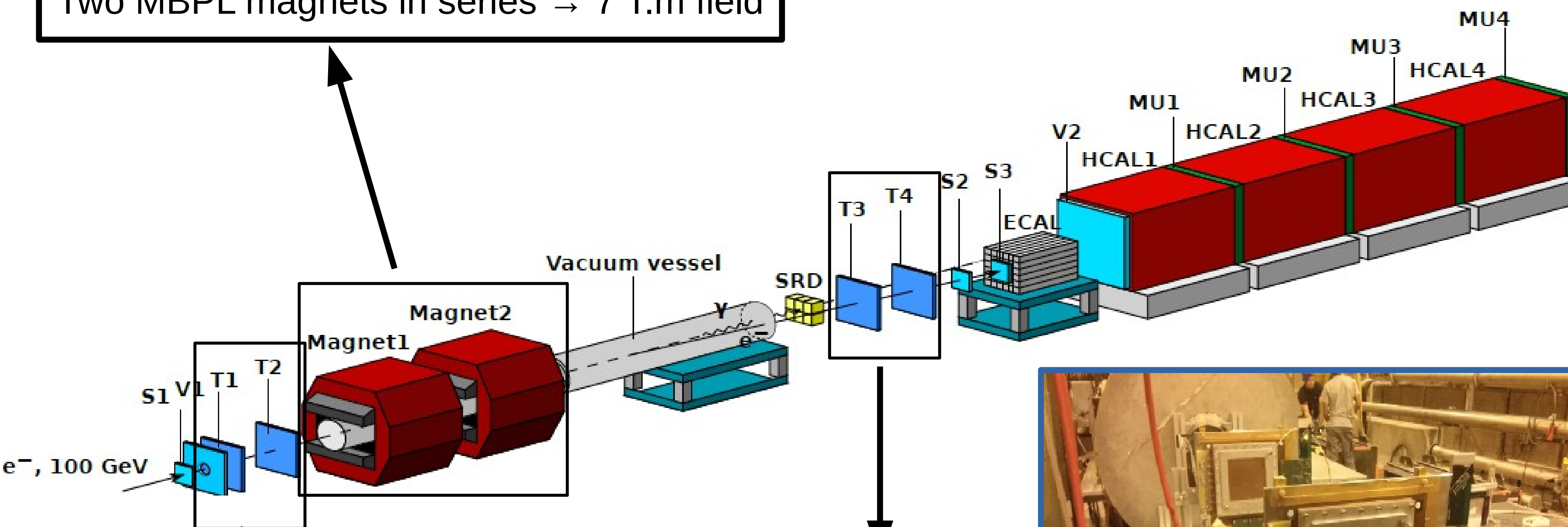
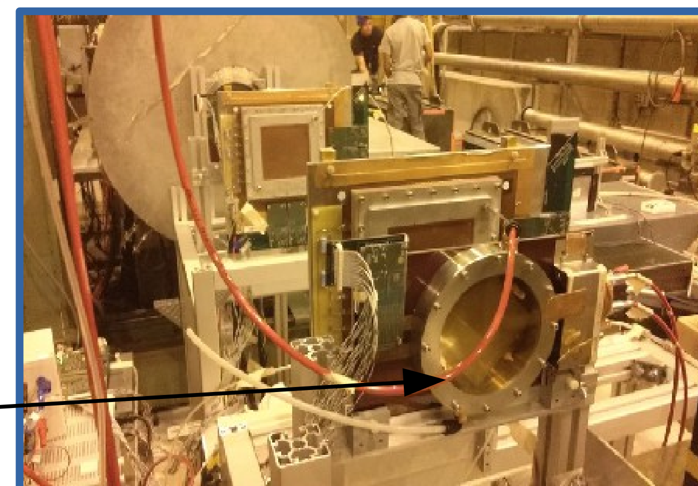


<u>The tracker</u>
Tracking system made of 4 XY multiplexed resistive micromegas modules and 2 GEM detectors



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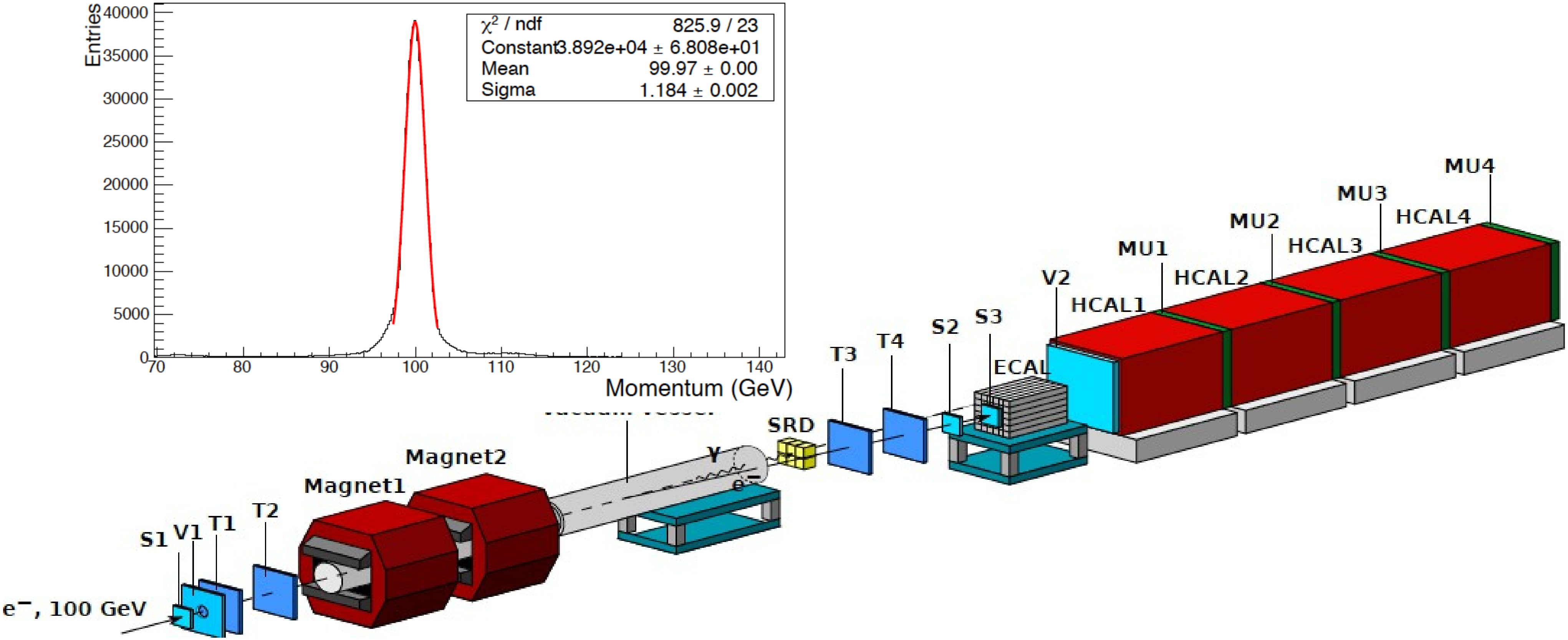
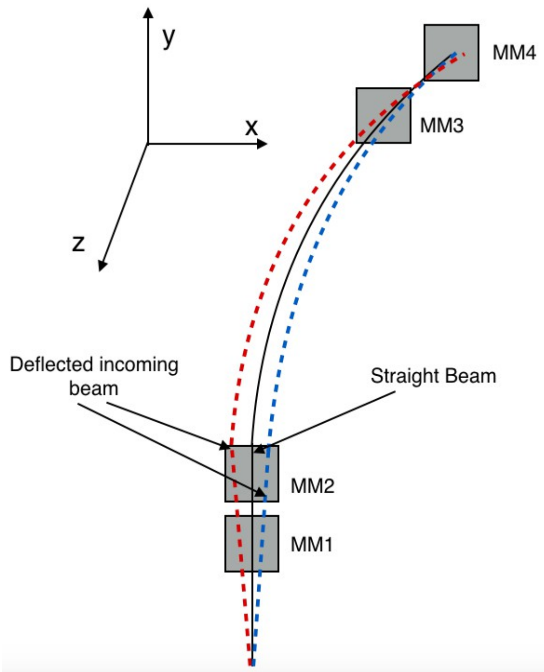
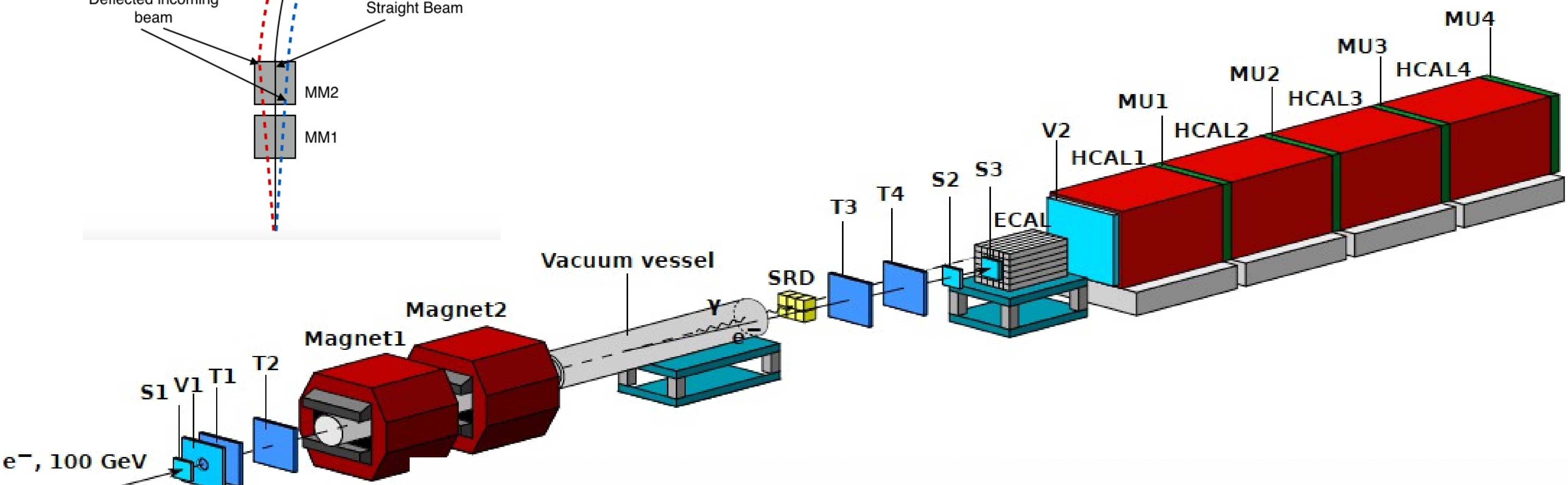


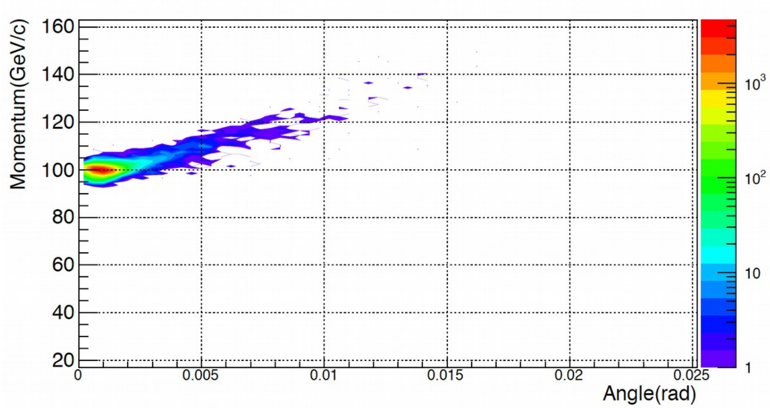
The magnetic spectrometer
→ Reconstruction of the incoming particle momentum

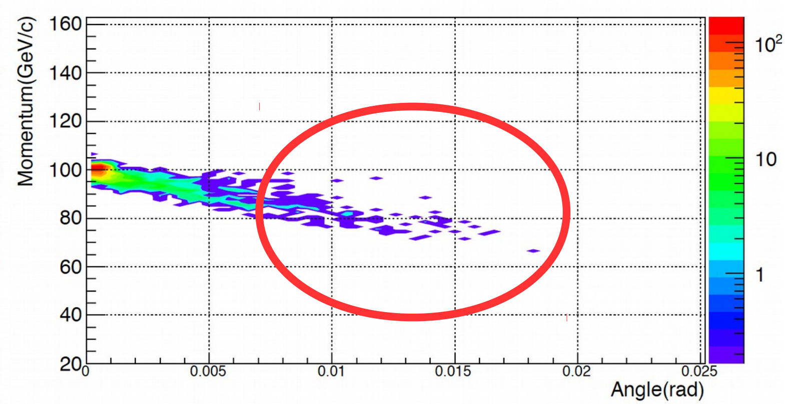
The magnetic spectrometer



→ Definition of incoming particle angle → suppression of low energy tails





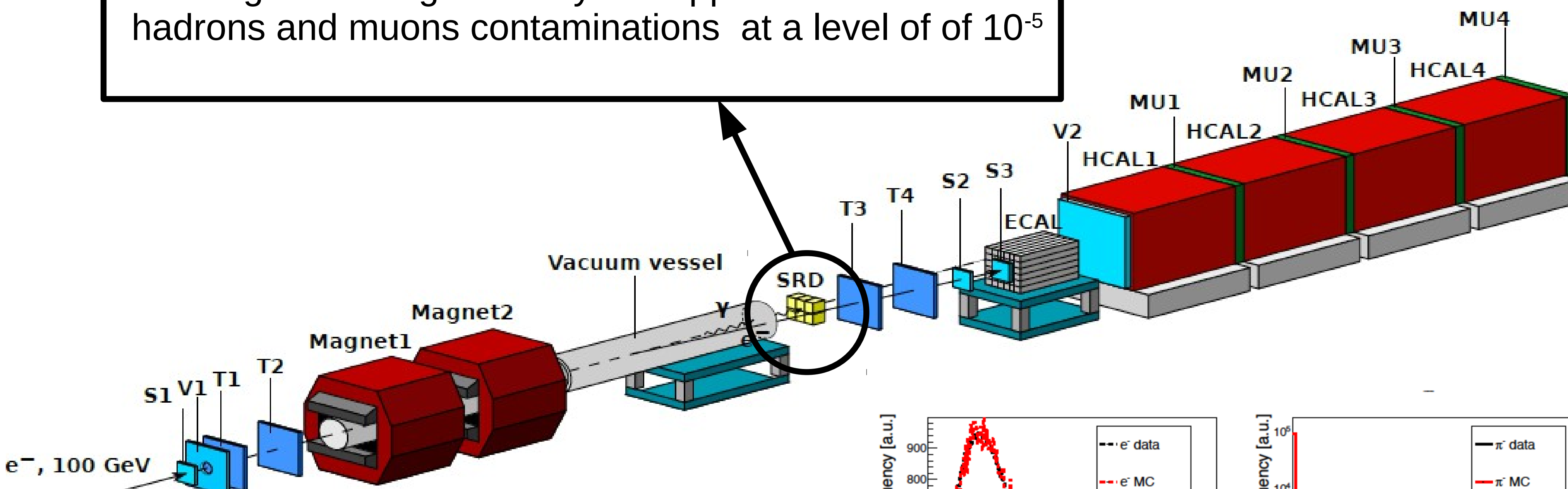


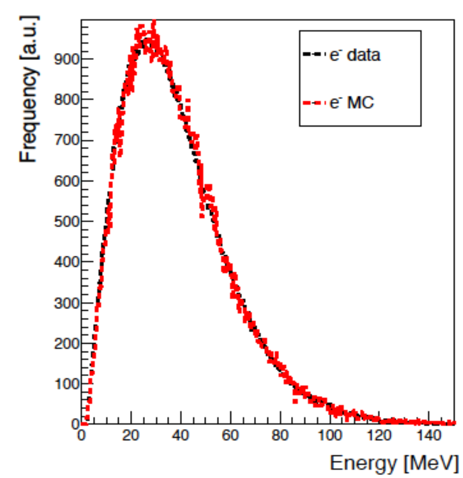
The Synchrotron Radiation Detector

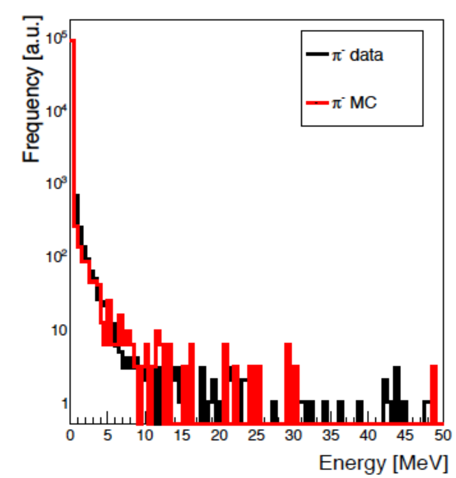
<u>Synchrotron Radiation detector (SRD): BGO and PbSc</u>

→ Exploit SR emission spectra ~ $1/m^4$

→ Using detector granularity → suppression of hadrons and muons contaminations at a level of of 10^{-5}







NA64, arXiv:1703.05993
submitted to NIMA

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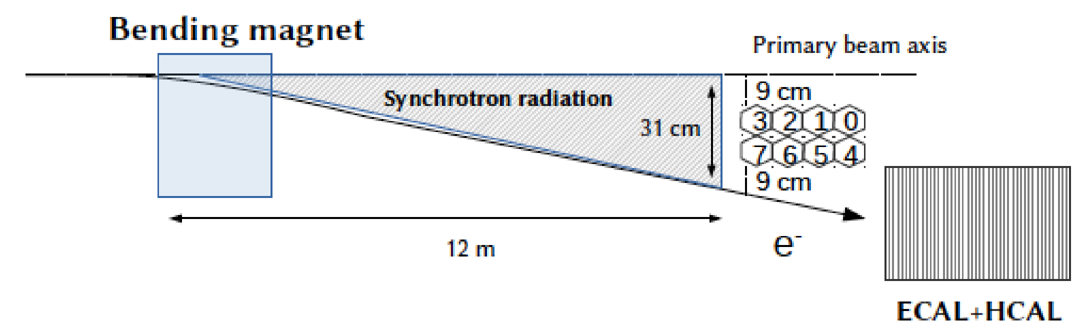

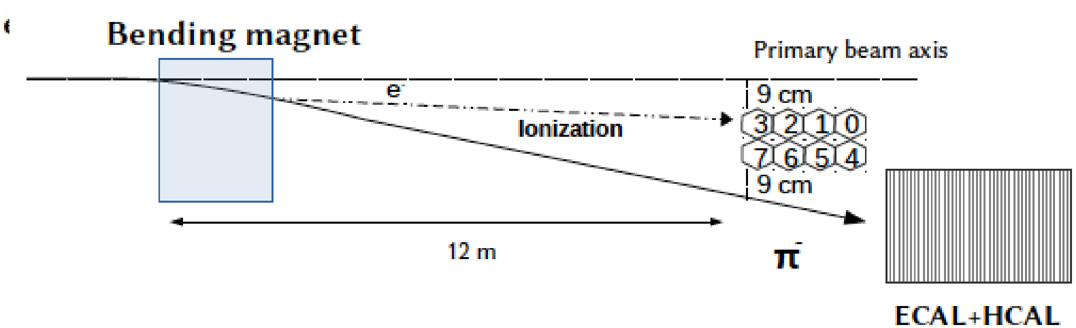

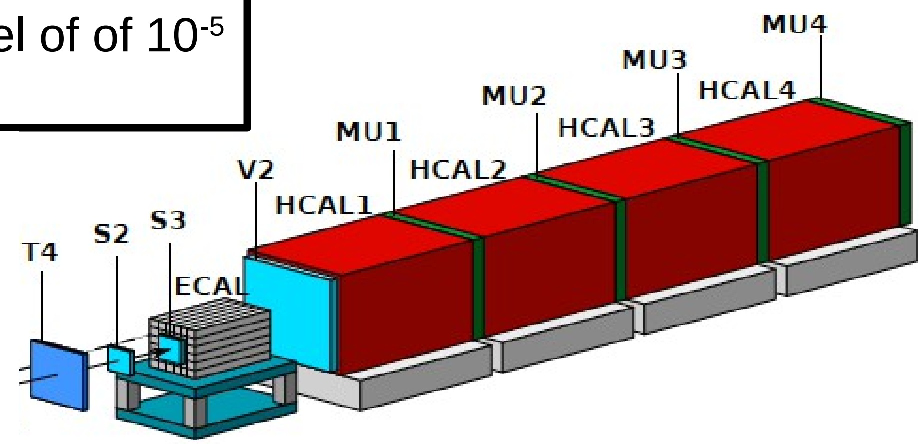

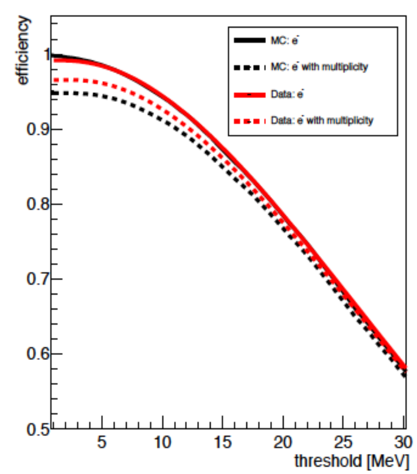

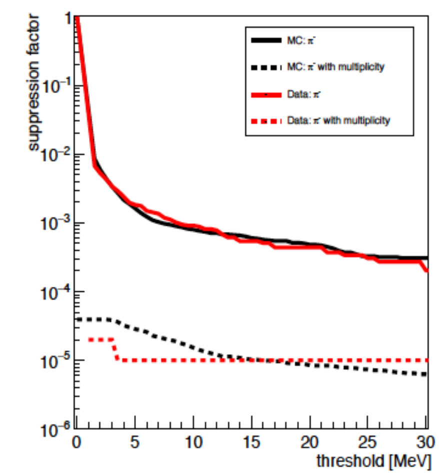

NA64, arXiv:1703.05993
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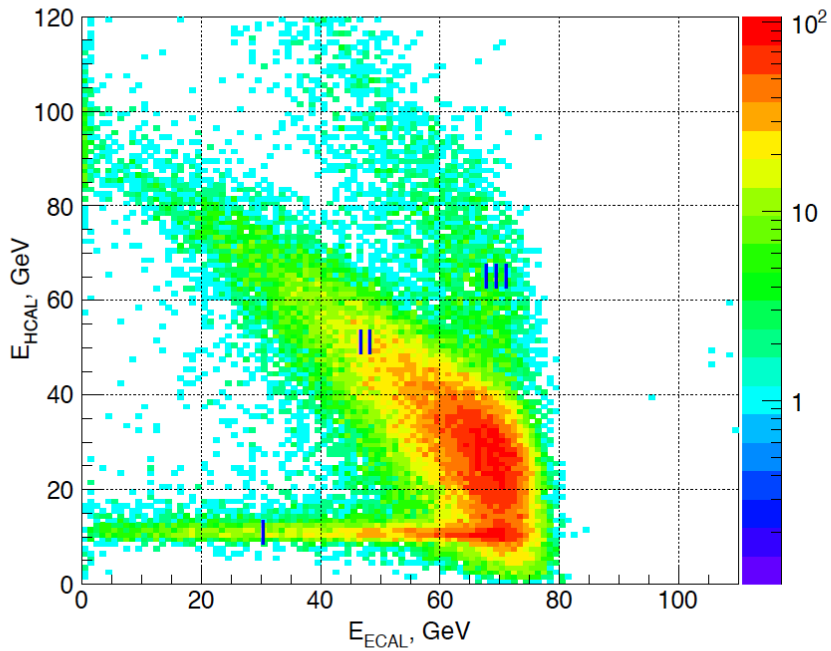
NA64 results

2016 beamtime (2 weeks in July 2016):
2.75 x 10^9 electrons on target with beam intensity of 1.4 x 10^6 e-/ 4.8 s spill with a 1.5 cm (FWHM) diameter beam.

Electron selection with SRD



Region I —> rare QED dimuon production e- Z → e- Zγ; γ → μ+μ-, characterised by the energy of ≃ 10 GeV deposited by the dimuon pair in the HCAL.
→ benchmark for the MC and estimate systematics in signal reconstruction.

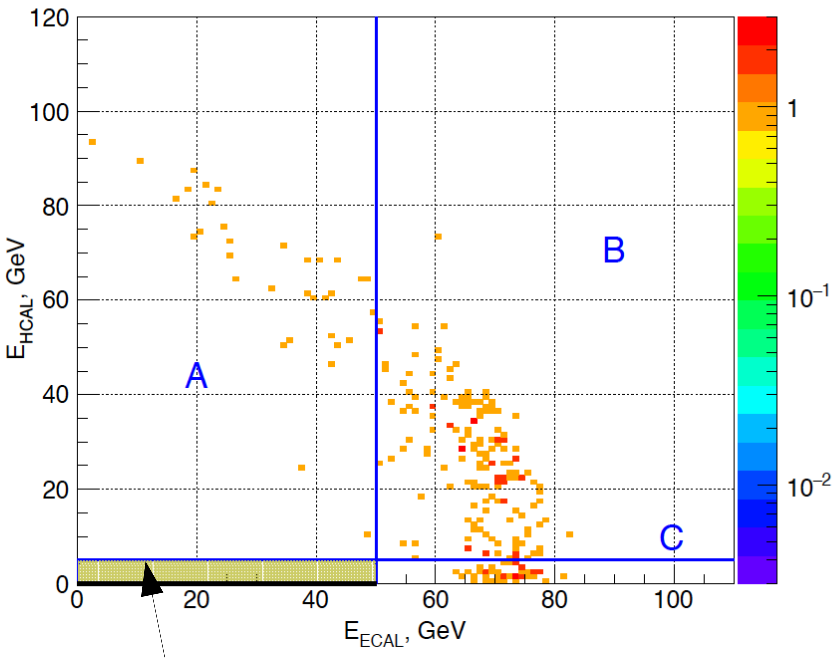
Region II —> SM events from the hadron electro-production in the target:
$E_{ECAL} + E_{HCAL} \simeq 100$ GeV.

Region III —> pile-up events of e− and beam hadrons (few %).

2016 beamtime (2 weeks in July 2016):

2.75 x 10^9 electrons on target with beam intensity of 1.4 x 10^6 e-/ 4.8 s spill with a 1.5 cm (FWHM) diameter beam.

All selection cut applied



Signal region: E_{ECAL}< 50 GeV and E_{HCAL}< 1 GeV

Event Selection Criteria:

- Pile up suppression using timing information.
- Selecting clean incoming track (angle + single hit in all 4 MMs) with correct momentum.
- Hadron suppression with synchrotron radiation.
- Events with shower profile as expected.
- No activity in Veto 2.

NA64 results

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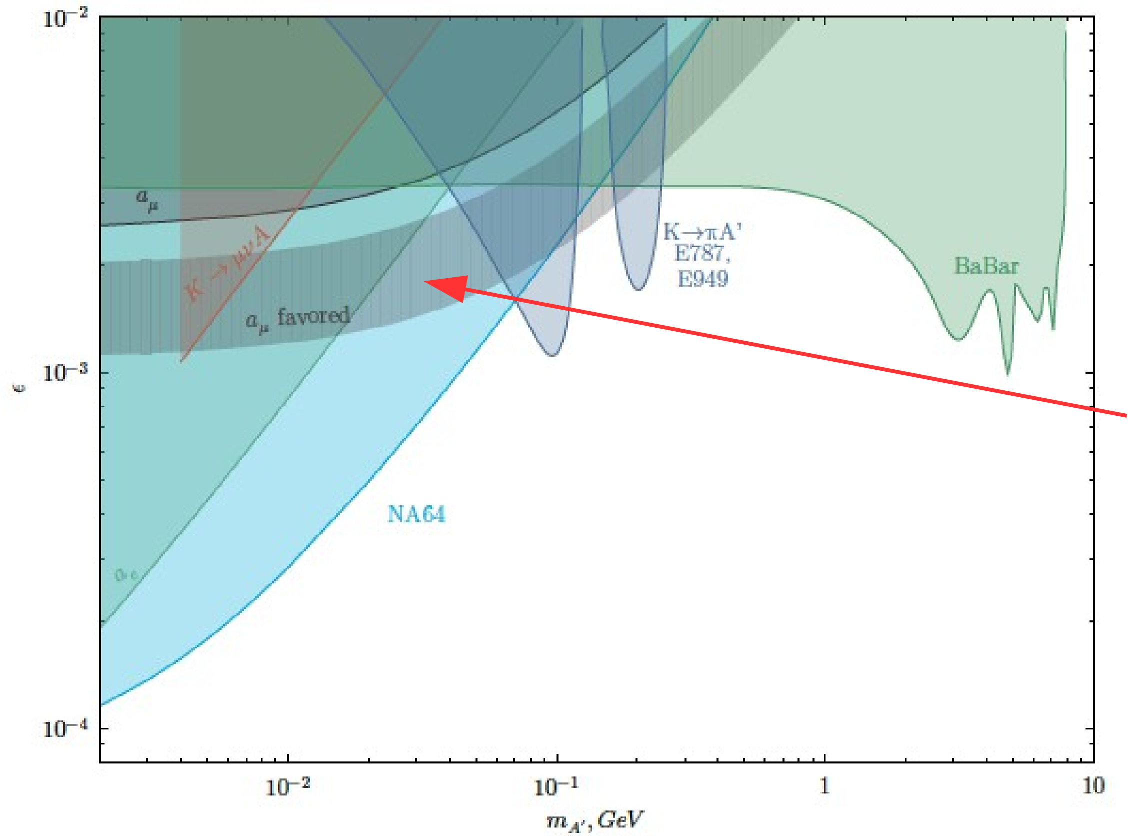
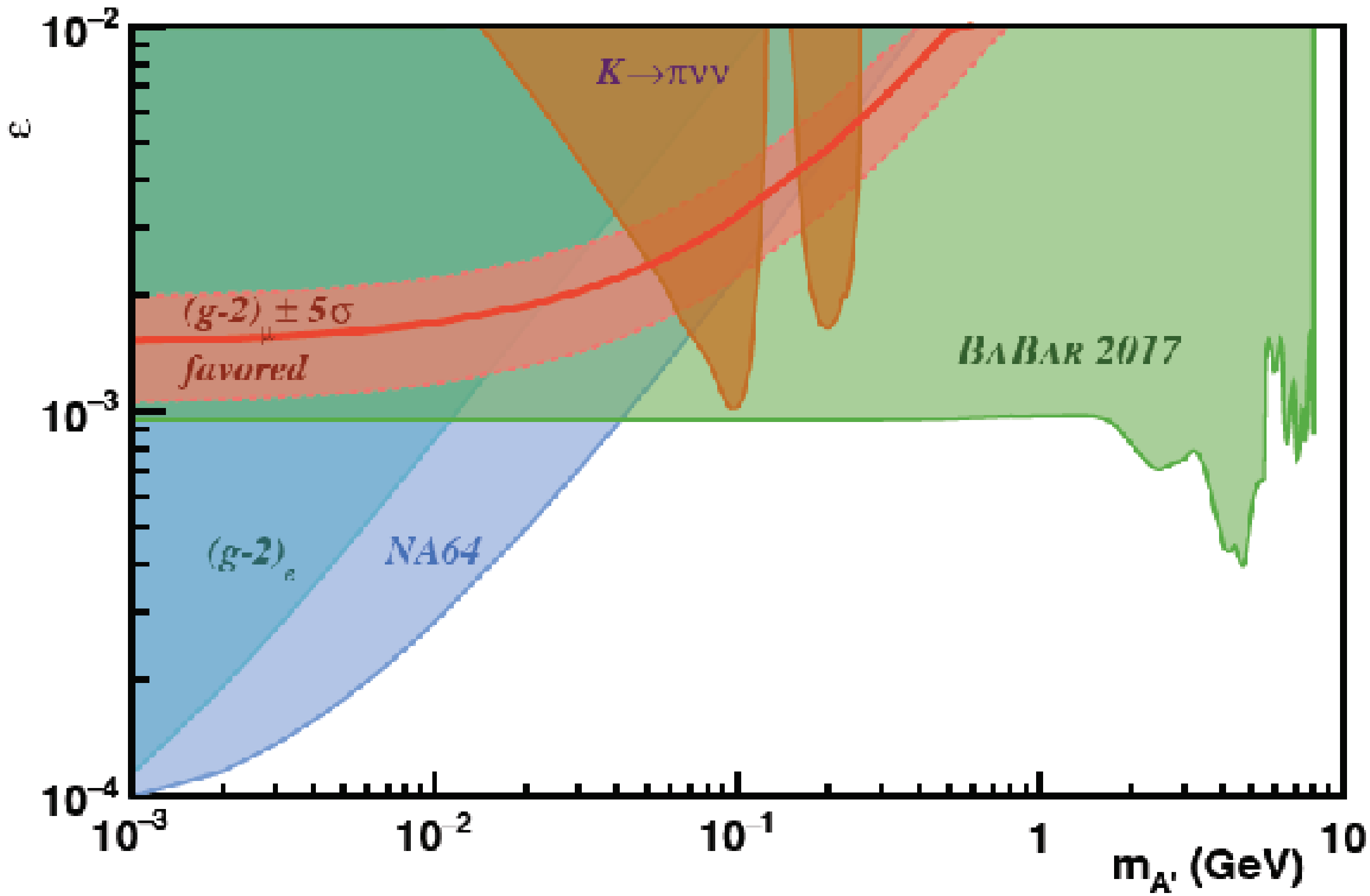


No event observed in the signal region → exclusion of most of the g-2 muon favored region

NA64 collaboration, Phys. Rev. Lett. 118, 011802 (2017)

New results from BABAR

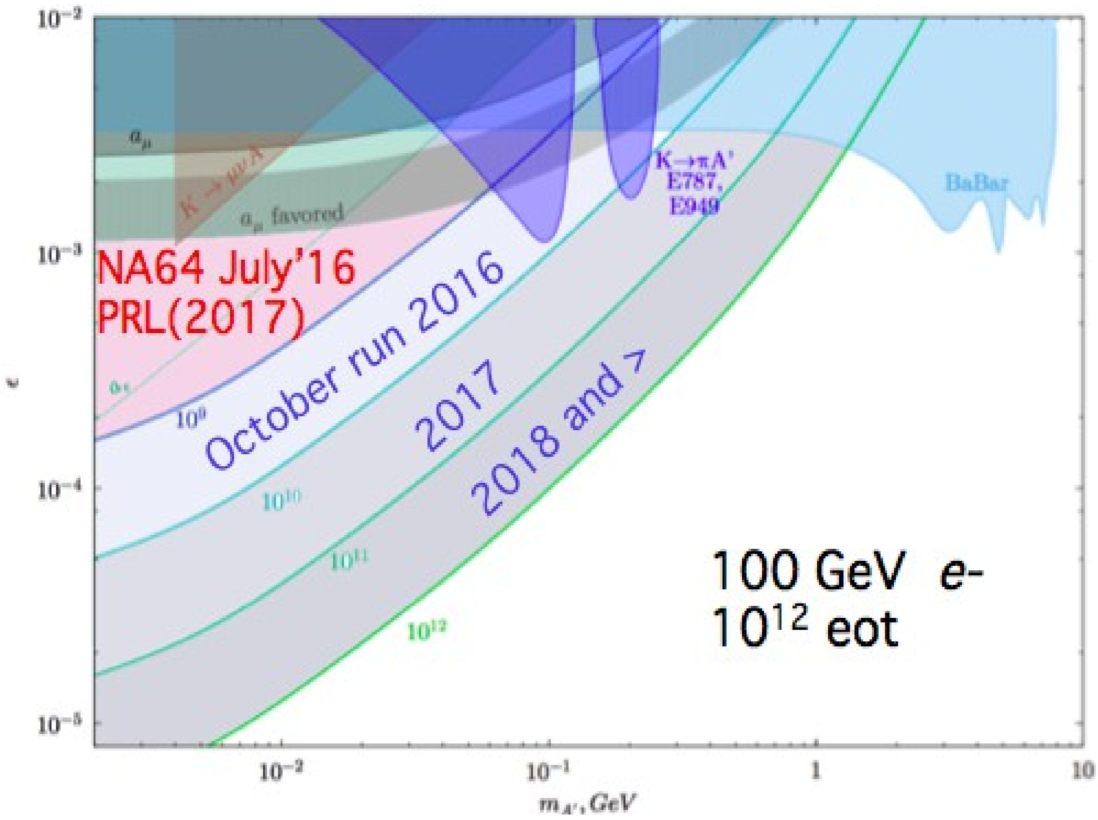
New Babar results → explanation of muon g-2 with invisible A' completely ruled out



BABAR collaboration, arXiv:1702.03327

NA64 - obtained limits and expected sensitivity

<u>2016 October Run</u> (3 weeks): Good performance at $5x10^6$ e-/spill, $4x10^{10}$ eot collected. Data analysis in progress. Short (1 day) test of visible mode.
<u>2017 September run</u> (5 weeks): Test upgrades of subdetectors for more efficient operation at high intensity, better e- ID, improved tracker.
- Goal: collect: $>10^{11}$ eot for invisible mode (3 weeks)
- Switch to visible mode to collect few 10^{10} eot (1 week) → confront ^{8}Be decay anomaly which could be explained by 17 MeV gauge boson. J. Feng et al., Phys. Rev. D 95, 035017 (2017)



Physics Prospects for NA64

Process	New Physics	Sensitivity
1. $e^- Z \to e^- Z + E_{miss}$		
✧ $A' \to e^+e^-$ ✧ $A' \to$ invisible ✧ alps ✧ milli-Q	Dark Sector: Dark Photons and DM New light states (V,S) weakly coupled to e- ^{8}Be excess	$10^{-3} < \varepsilon < 10^{-6}$ $M_{A'} \sim$ sub-GeV $mQ < 10^{-5}$-10^{-7} e $M_{mQ} \sim$ sub-GeV
2. $\mu^- Z \to \mu^- Z + E_{miss}$		
✧ $Z_\mu \to \nu\nu,\ \mu^+\mu^-$ ✧ a_μ ✧ $\mu \to \tau$ conversion	$(g-2)_\mu$ anomaly, New Z_μ from L_μ-L_τ gauged symm., scalars coupled to μ LFV	$\alpha_\mu < 10^{-11}$-10^{-9} $\sigma_{\mu\tau}/\sigma_\mu < 10^{-9}$-$10^{-8}$
3. $\pi(K)p \to M^0 n + E_{miss}$		
✧ $K_L \to$ invisible ✧ $K_S \to$ invisible ✧ $\pi^0, \eta, \eta' \to$ invisible	CP, CPT symmetry Bell-Steinberger Unitarity, new WC particles: NHL, $\phi\phi$, VV	Br $< 10^{-8}$-10^{-6}, Complementary to $K \to \pi\nu\nu$ Br $< 10^{-8}$-10^{-7}
4. $pA \to Z' + E_{miss}$		
✧ leptophobic Z'	~ GeV DM	$\sigma_{Z'} < 10^{-7}$-10^{-8} /p

Summary and Outlook

2016:
- July run: 2.75×10^9 electrons on target, no signal observed → exclusion of most of the g-2 muon anomaly favored region (PRL118, 011802 (2017)) .
- October: 4×10^{10} eot collected → analysis in progress, results expected soon.

→ **Our results show that the combination of an active beam dump and missing-energy techniques is a very powerful tool to search for dark sector physics.**

2017-2018:
- goal $>10^{11}$ eot for invisible channel
- explore visible channel and possibly confront ^{8}Be decay anomaly.

>2021 (after LS2)
- goal $>10^{12}$ eot for invisible and visible channels
- Search for $Z'\mu$ coupled to muons with the M2 beamline at CERN (160 GeV/c muon)
- Searches for $\eta,\eta', \pi^0, K_L, K_S \rightarrow$ invisible

→ **The proposed searches of dark sectors in NA64 with leptonic and hadronic beams have unique sensitivities and are highly complementary to similar project.**

Thank you for your attention!