NA64 at Cern

Michael Hösgen
on behalf of the NA64 collaboration,

Helmholtz-Institut für Strahlen und Kernphysik, University Bonn

The NA64 Collaboration

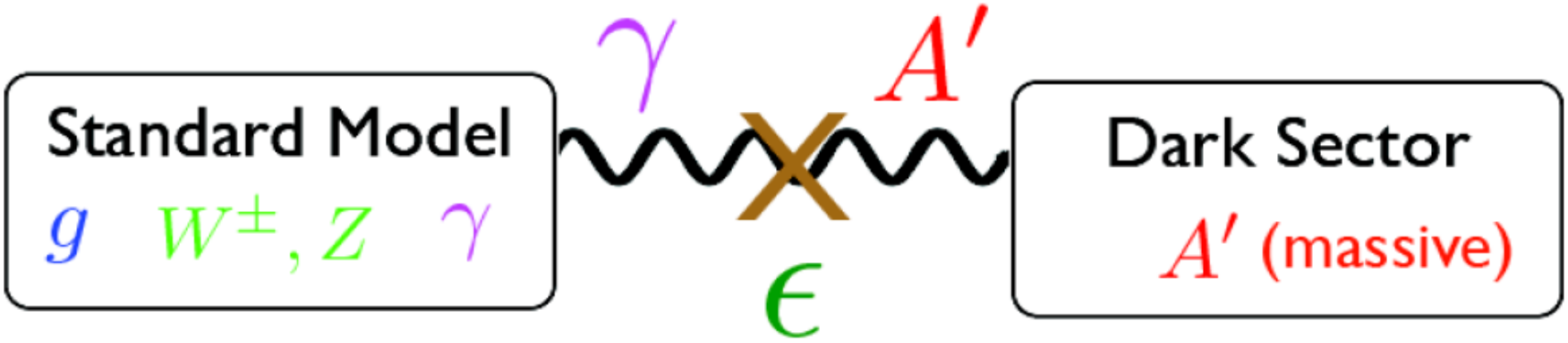
D. Banerjee,[11] V. Burtsev,[9] D. Cooke,[11] P. Crivelli,[11] E. Depero,[11] A. V. Dermenev,[4] S. V. Donskov,[8] F. Dubinin,[5] R. R. Dusaev,[9] S. Emmenegger,[11] A. Fabich,[3] V. N. Frolov,[2] A. Gardikiotis,[7] S. N. Gninenko*,[4] M. Hösgen,[1] V. A. Kachanov,[8] A. E. Karneyeu,[4] B. Ketzer,[1] D. V. Kirpichnikov,[4] M. M. Kirsanov,[4] I. V. Konorov,[5] S. G. Kovalenko,[10] V. A. Kramarenko,[6] L. V. Kravchuk,[4] N. V. Krasnikov,[4] S. V. Kuleshov,[10] V. E. Lyubovitskij,[9] V. Lysan,[2] V. A. Matveev,[2] Yu. V. Mikhailov,[8] V. V. Myalkovskiy,[2] V. D. Peshekhonov†,[2] D. V. Peshekhonov,[2] O. Petuhov,[4] V. A. Polyakov,[8] B. Radics,[11] A. Rubbia,[11] V. D. Samoylenko,[8] V. O. Tikhomirov,[5] D. A. Tlisov,[4] A. N. Toropin,[4] A. Yu. Trifonov,[9] B. Vasilishin,[9] G. Vasquez Arenas,[10] P. Ulloa,[10] K. Zhukov,[5] and K. Zioutas[7]

(The NA64 Collaboration‡)

[1] *Universität Bonn, Helmholtz-Institut für Strahlen-und Kernphysik, 53115 Bonn, Germany*
[2] *Joint Institute for Nuclear Research, 141980 Dubna, Russia*
[3] *CERN, European Organization for Nuclear Research, CH-1211 Geneva, Switzerland*
[4] *Institute for Nuclear Research, 117312 Moscow, Russia*
[5] *P.N. Lebedev Physics Institute, Moscow, Russia, 119 991 Moscow, Russia*
[6] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
[7] *Physics Department, University of Patras, Patras, Greece*
[8] *State Scientific Center of the Russian Federation Institute for High Energy Physics of National Research Center 'Kurchatov Institute' (IHEP), 142281 Protvino, Russia*
[9] *Tomsk Polytechnic University, 634050 Tomsk, Russia*
[10] *Universidad Técnica Federico Santa María, 2390123 Valparaíso, Chile*
[11] *ETH Zürich, Institute for Particle Physics, CH-8093 Zürich, Switzerland*

47 researchers from 12 institutes

Hidden/Dark sectors



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

"Kinetic Mixing"

Holdom

Galison, Manohar

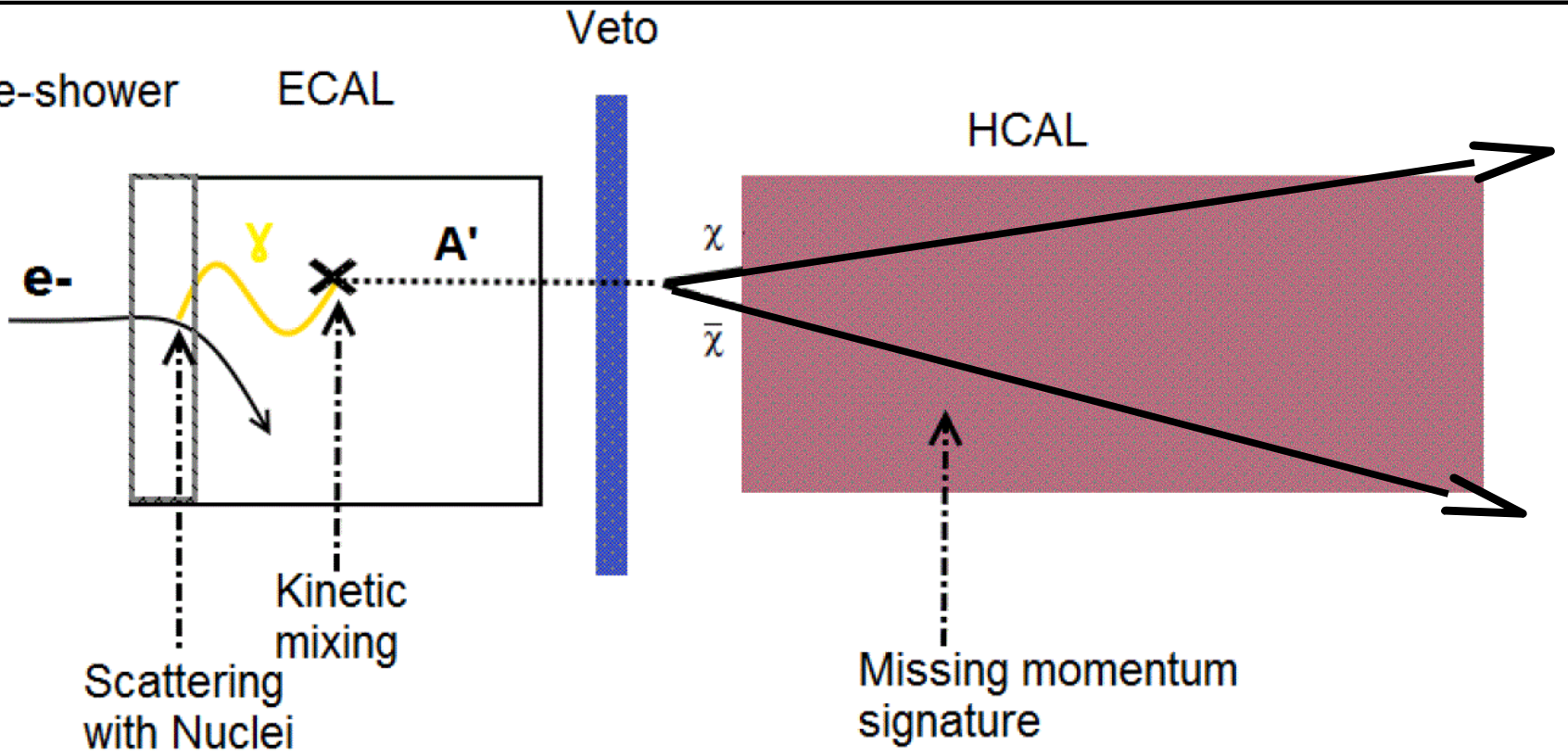
- Extra (broken) U(1)' symmetry → new massive boson A'

$$10^{-6} \leq \epsilon \leq 10^{-3} \qquad M_{A'} \leq 1\,\mathrm{GeV}$$

- Explanation for muon g-2 anomaly?

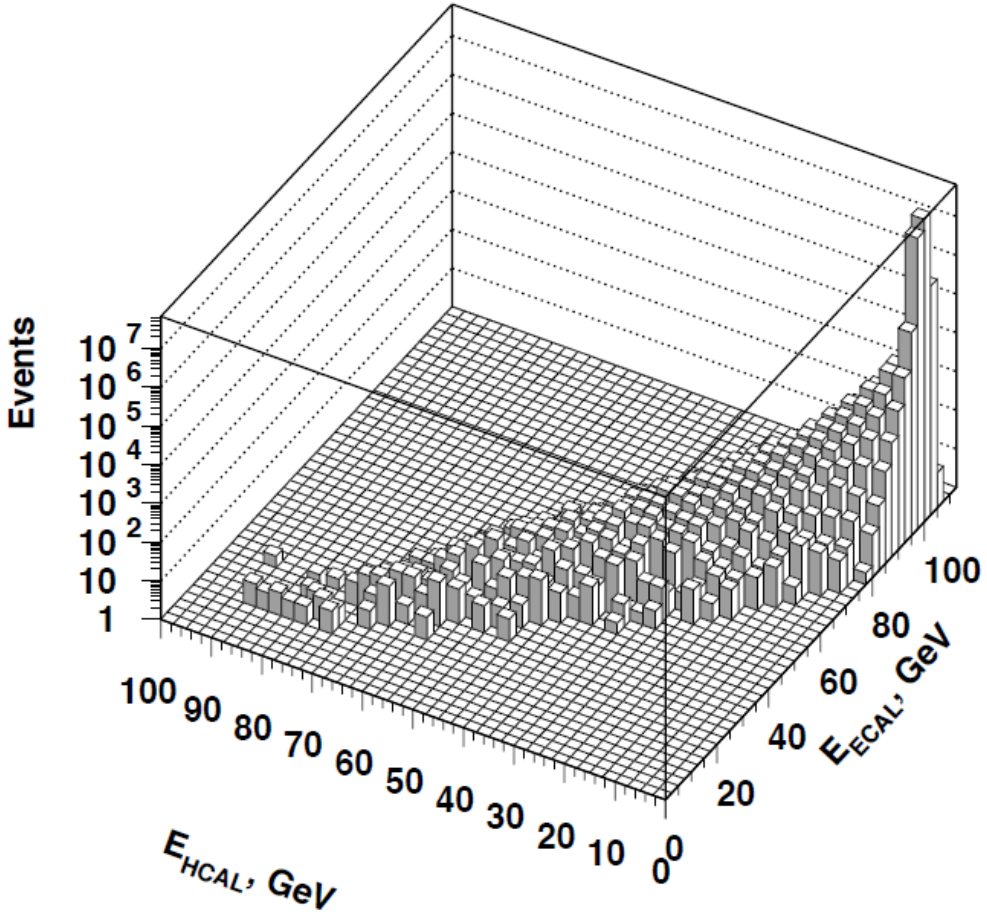
- A' decay modes:
  - Visible: A' → e^+e^-, $\mu^+\mu^-$
  - Invisible: A' → $\chi\bar{\chi}$, current focus of NA64

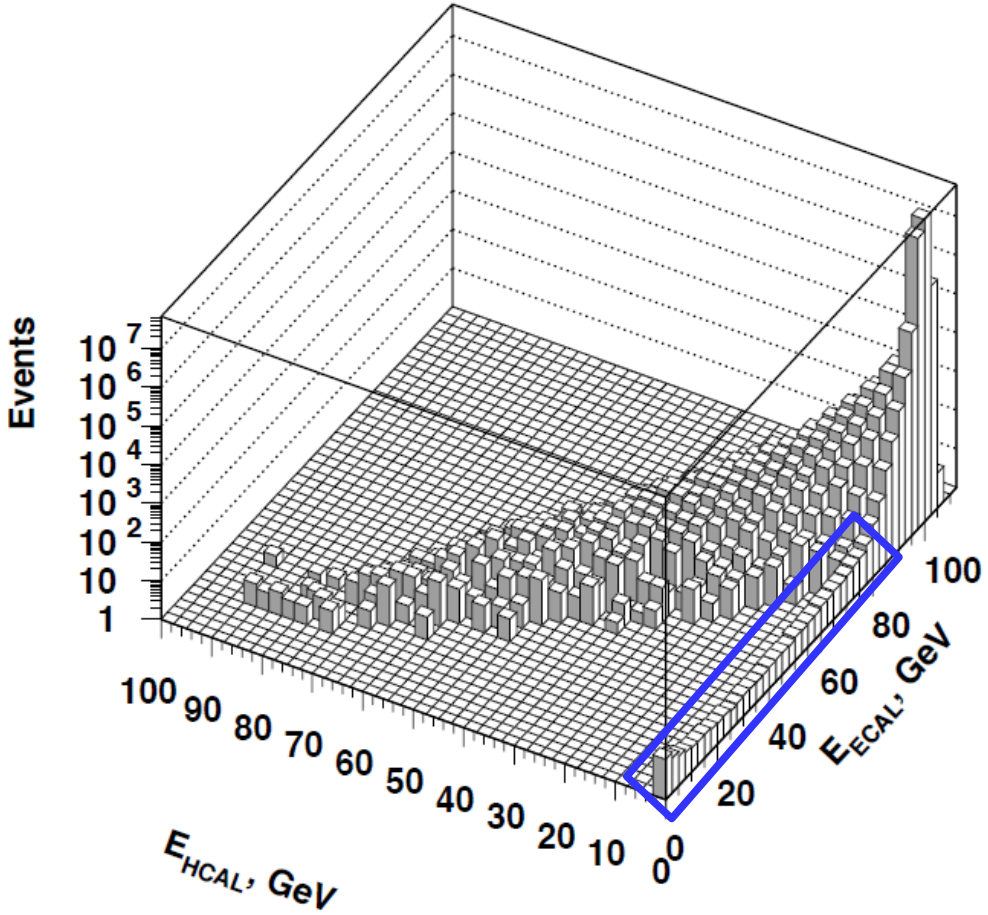
Active target beam dump concept



- Dark photon production by kinetic mixing in the ECAL
  - 4 + 36 radiation length shashlik Pb + Sc with fibre read-out
- Hermetic HCAL with ~ 30 nuclear interaction length (FeSc Sandwich)
- Veto counter for charged hadron events (Scintillator ~40 mm)

Active target beam dump concept

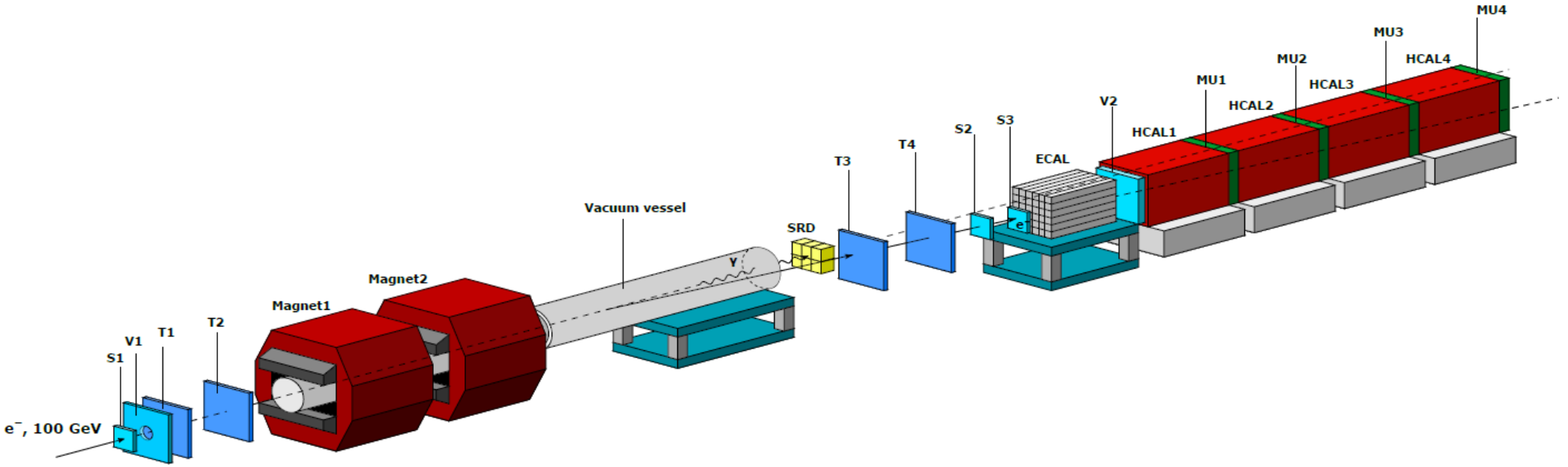




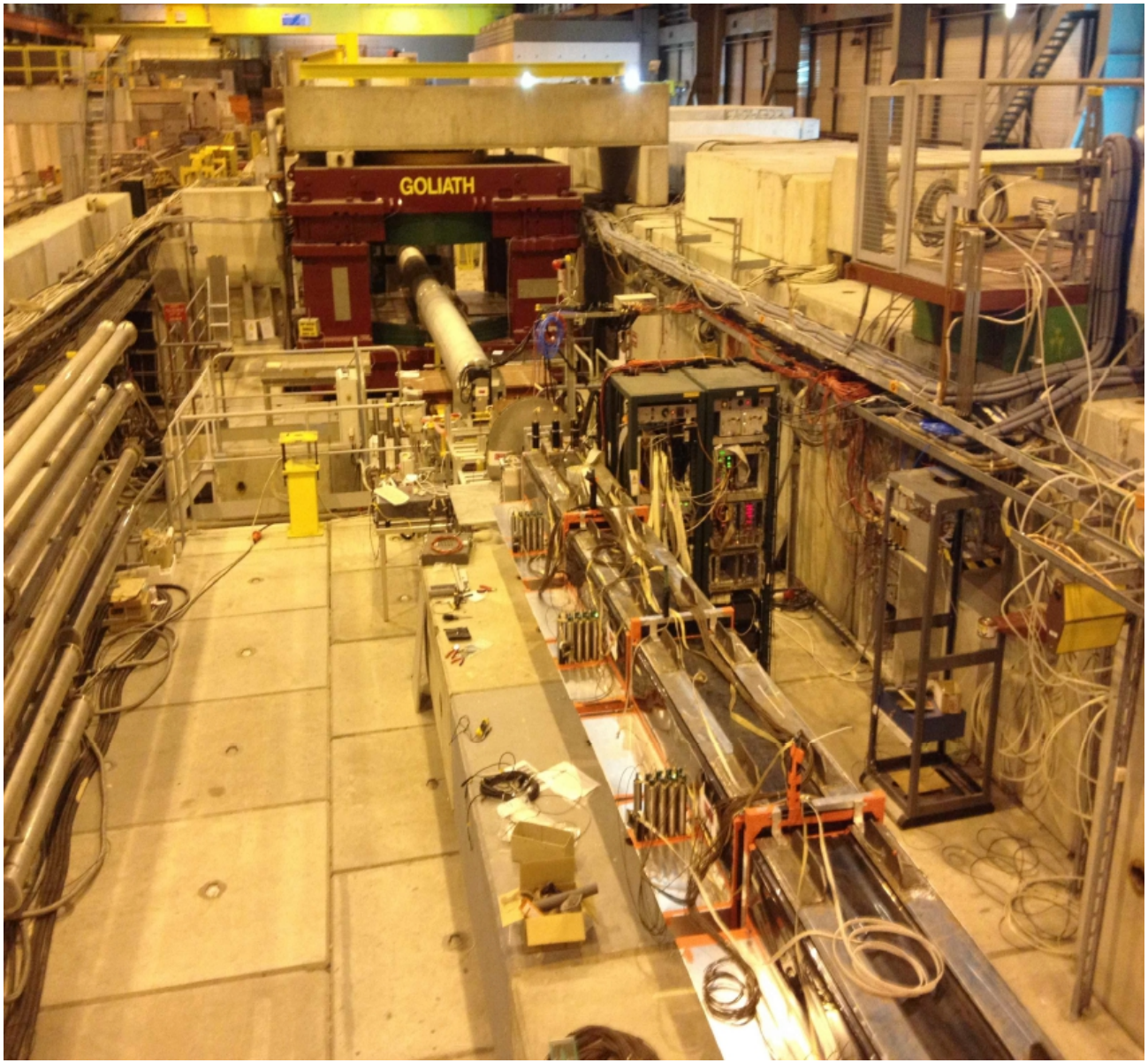
Dark Photon Signature for 100 GeV electron beam:

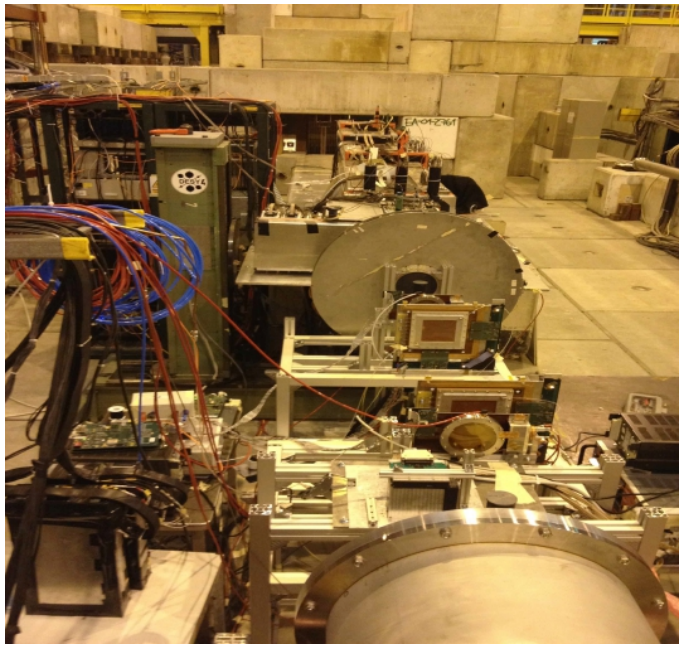
- Missing energy in ECAL (ECAL threshold < 50 GeV)
- No activity in Veto and HCAL

The NA64 detector

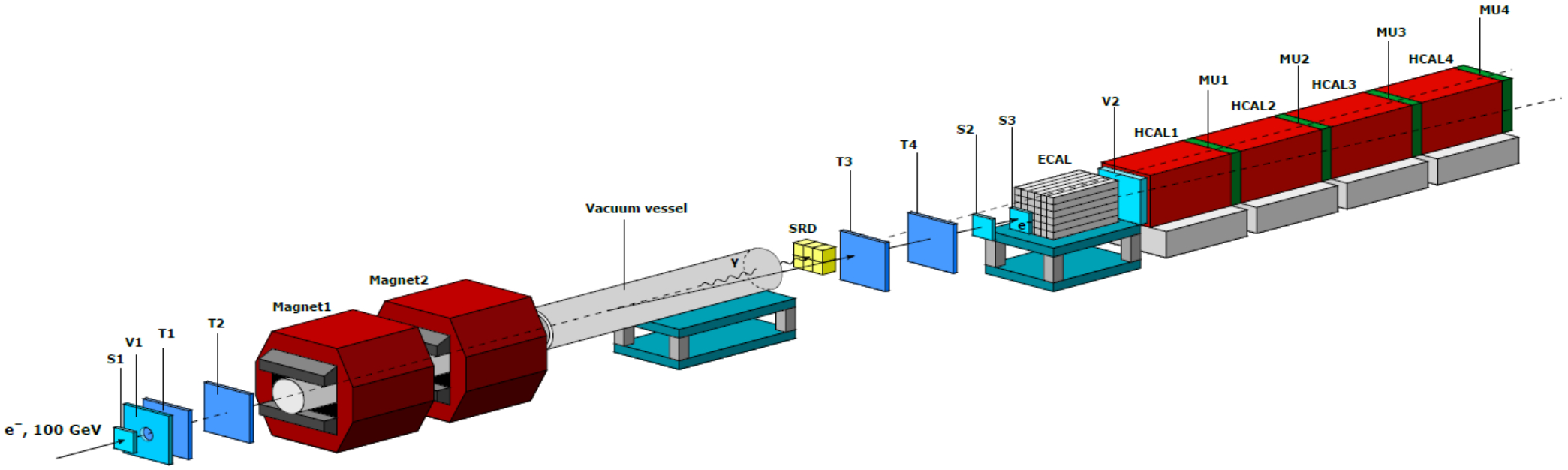


The NA64 detector





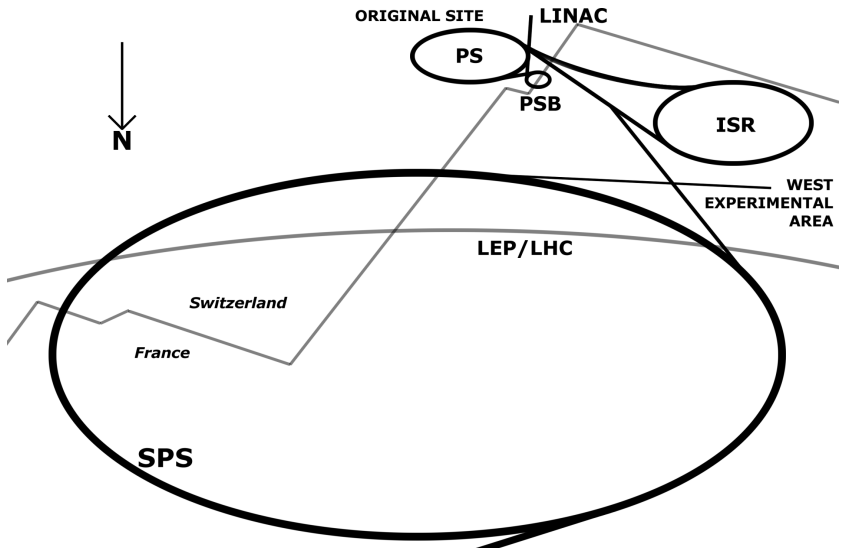
The NA64 detector



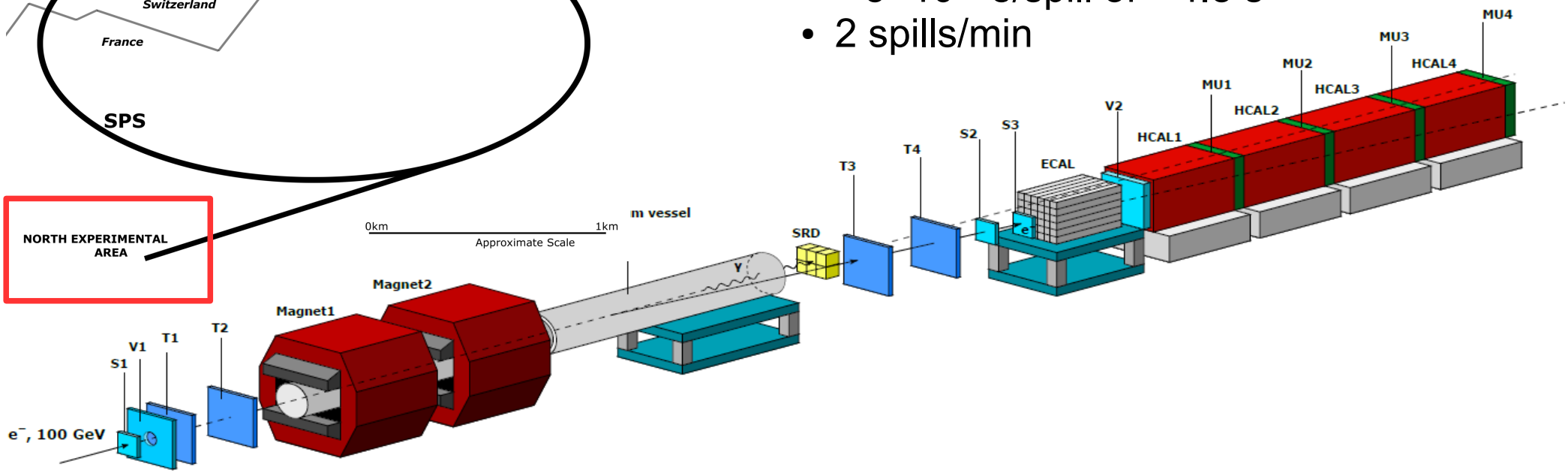
Requirements to the beam:

- Highest possible intensity (~5×10^6 e/spill of ~4.8 s)
- Lowest possible hadron/muon contamination
- Smallest possible low energy tails

The NA64 detector



- CERN SPS H4 Beam in NA
- 450 GeV proton + beryllium target
- 100 GeV electron beam
- ~5×10⁶ e/spill of ~4.8 s
- 2 spills/min



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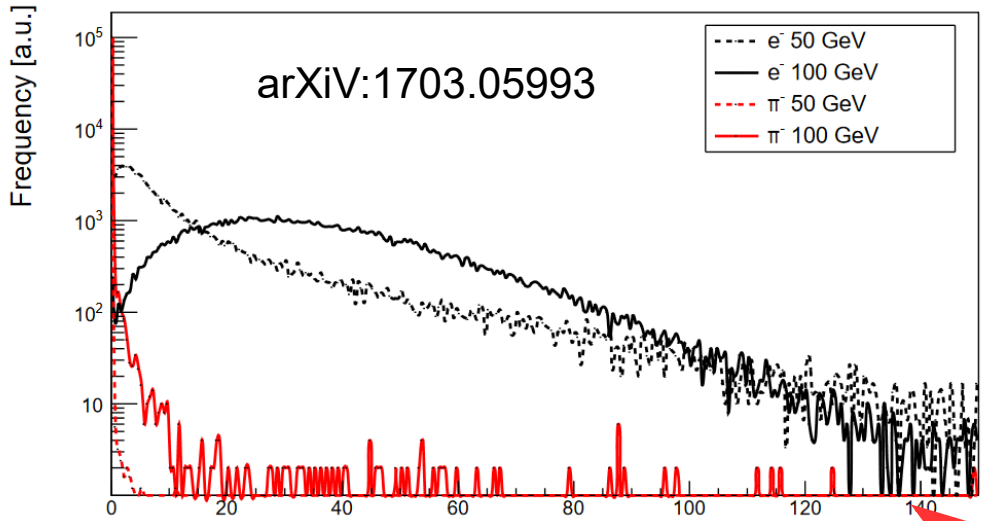
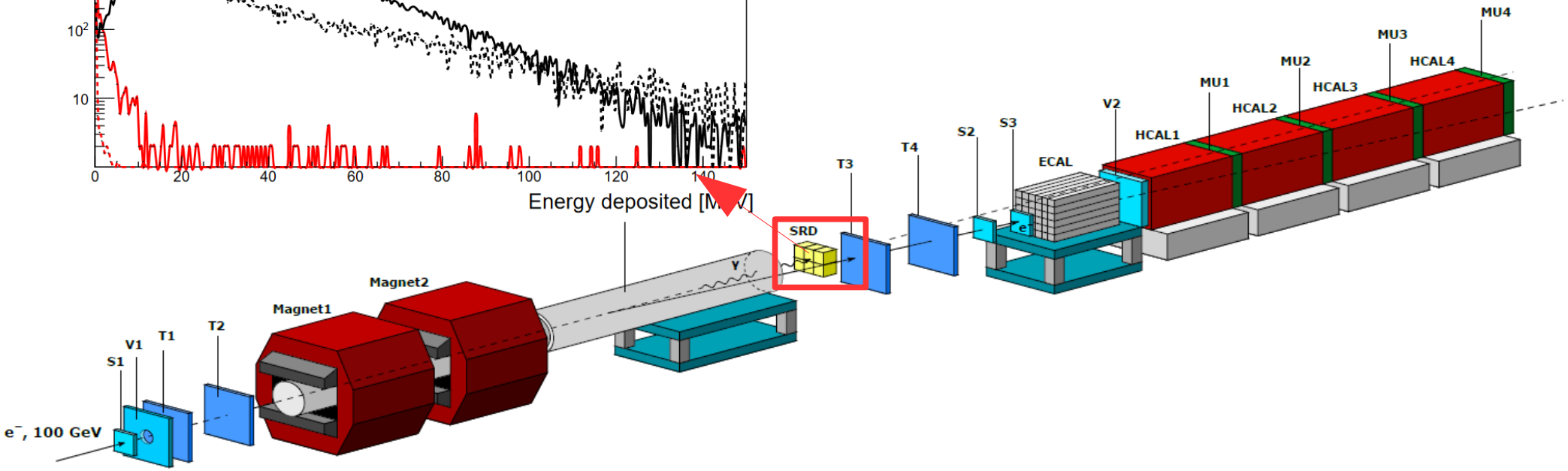
Background suppression



SRD: (BGO crystals or PbSc Sandwich)

- Contamination: ~1% π, <0.1% K, μ
- ~ factor 10^4 hadron suppression



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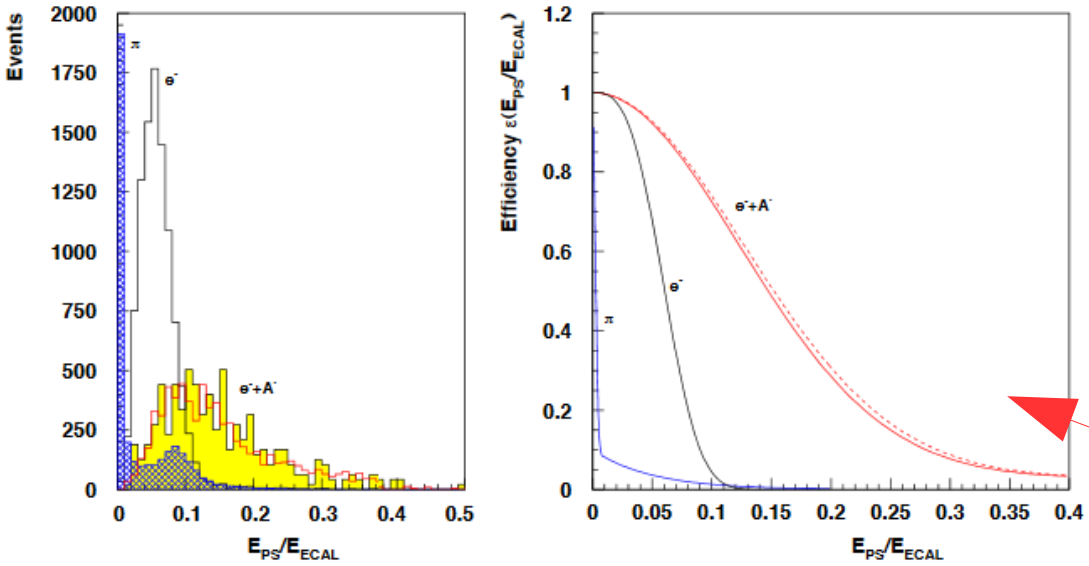
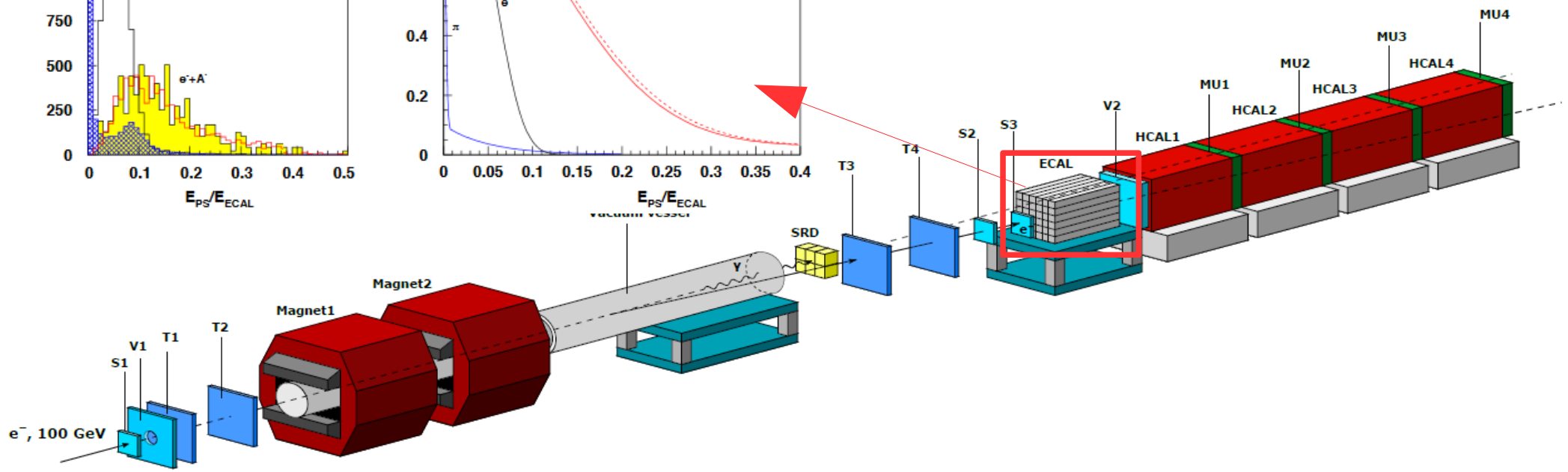


Pre-shower vs. ECAL (4 + 36 X_0)

- Hadrons deposit small fraction on Pre-shower

~ factor 10 hadron suppression



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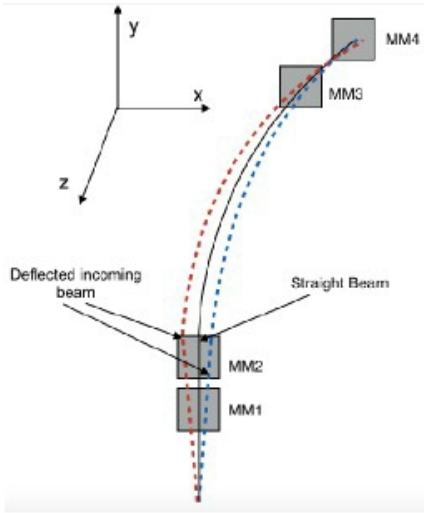
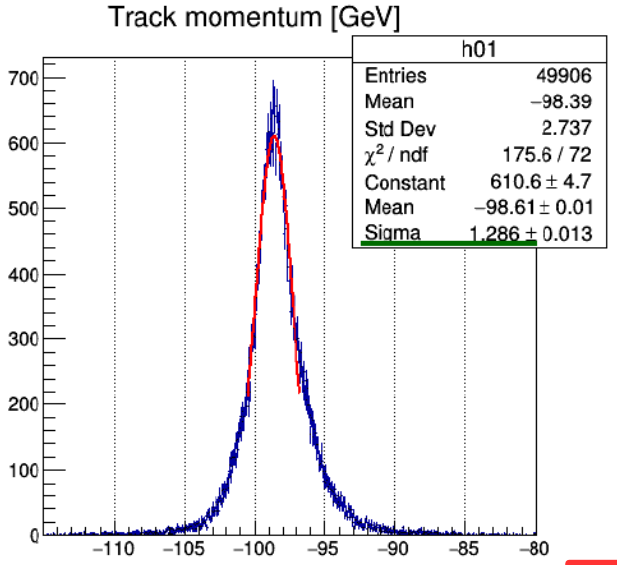
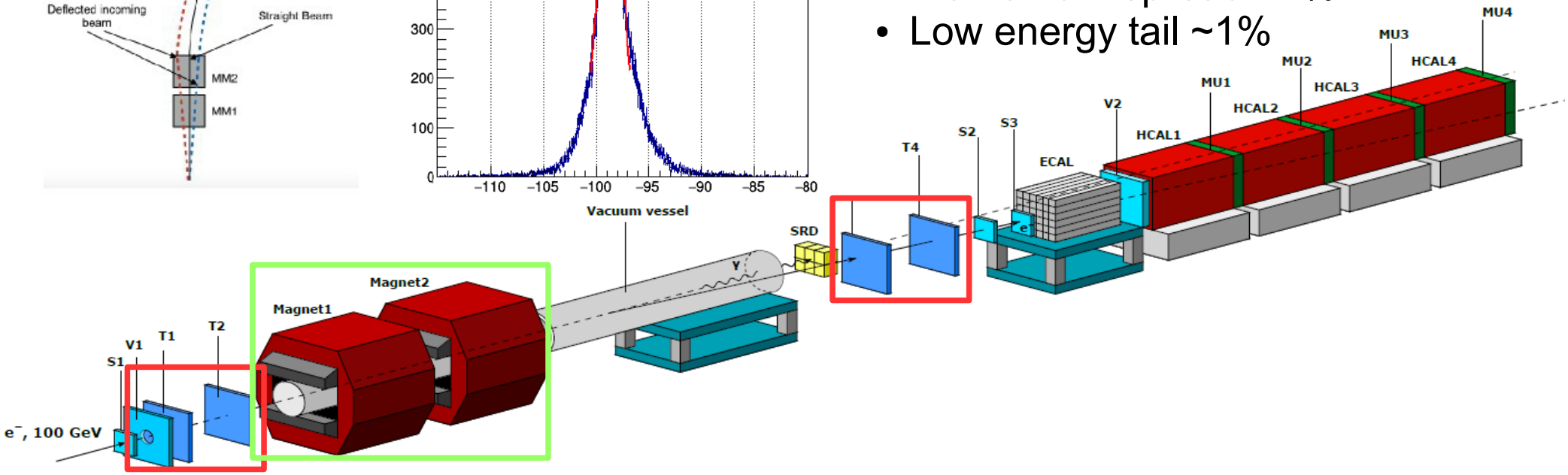
Background suppression





Tracking System
- 4 Micromegas + 2 GEMs
- 2 Magnets (~7 Tm)
- Momentum spread ~1%
- Low energy tail ~1%



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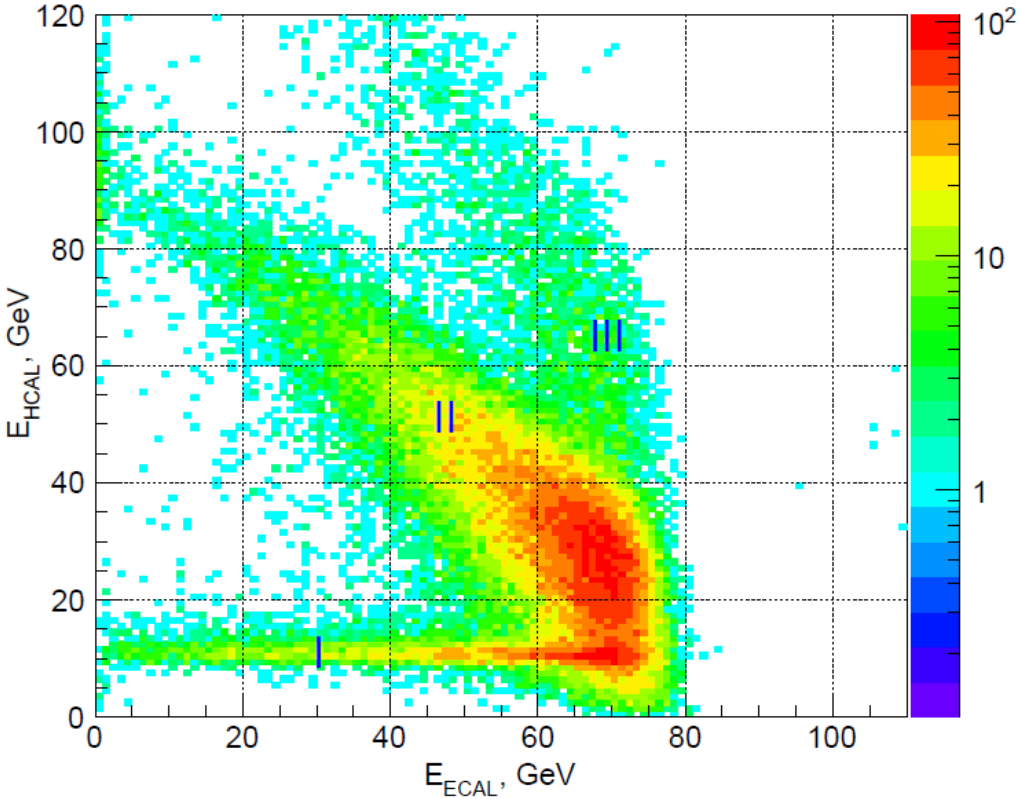
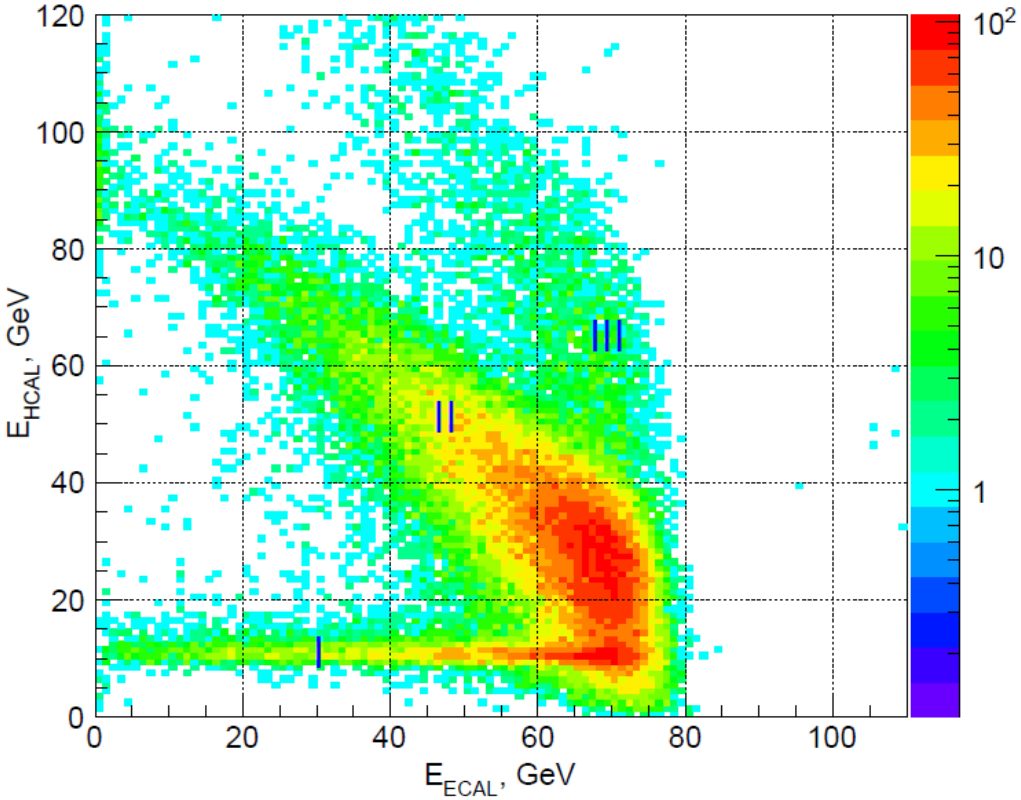
Data from July 2016

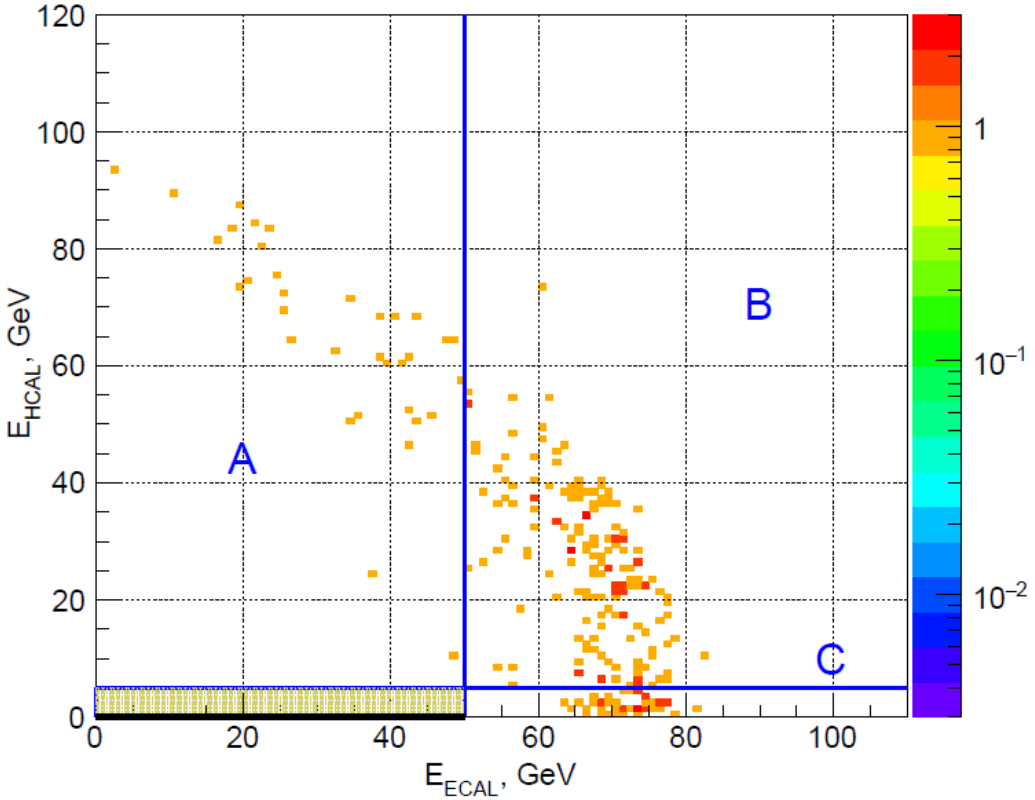


Summer 2016, 2×10^9 *eot.*

Sector I : eZ → eZγ; γ → μμ (benchmark channel for background/MC)
Sector II : ECAL + HCAL = 100 GeV
Sector III: pile-up and beam hadrons

Data from July 2016

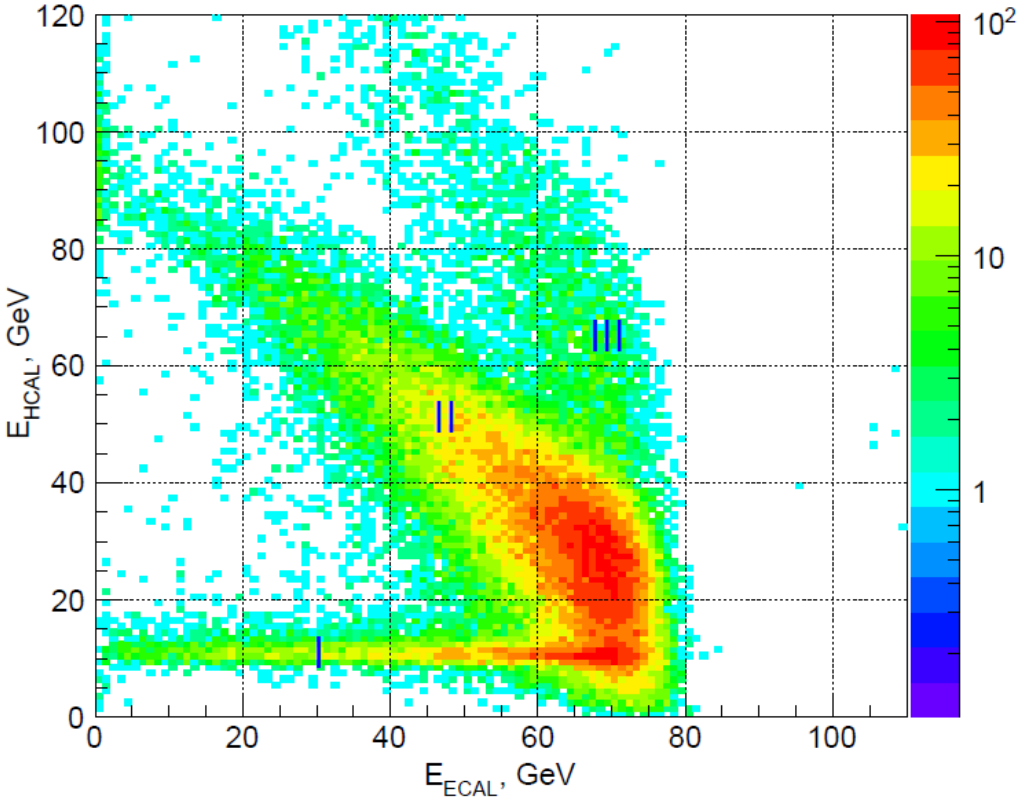


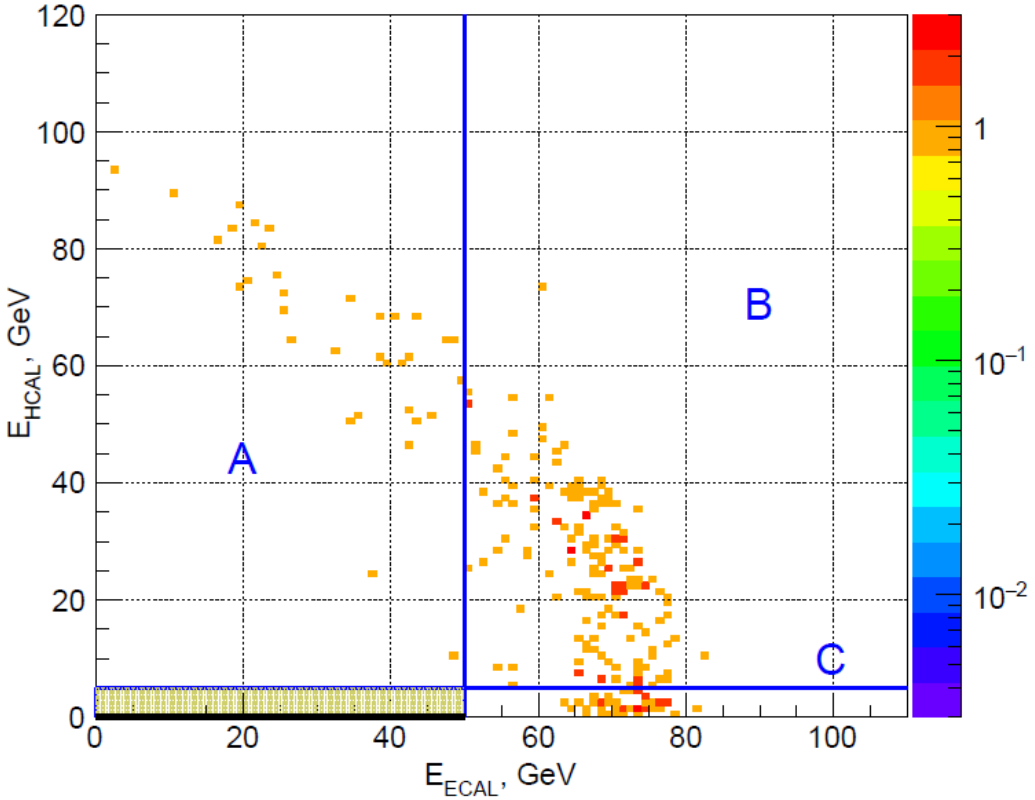


Maximize signal acceptance and minimize background:

- Particle track with small incoming angle wrt. beam axis
- SRD signal hinting to an electron
- Consistent lateral and longitudinal shower profile in ECAL
- No activity in Veto

Data from July 2016





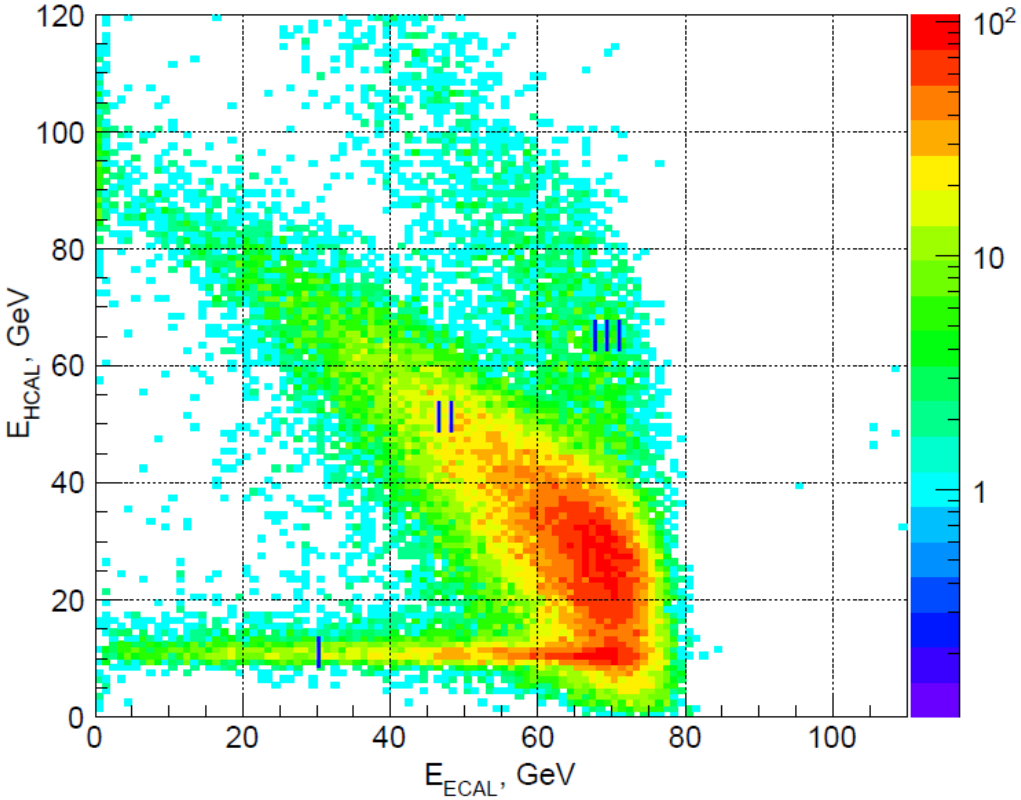
What is background, what is signal?:

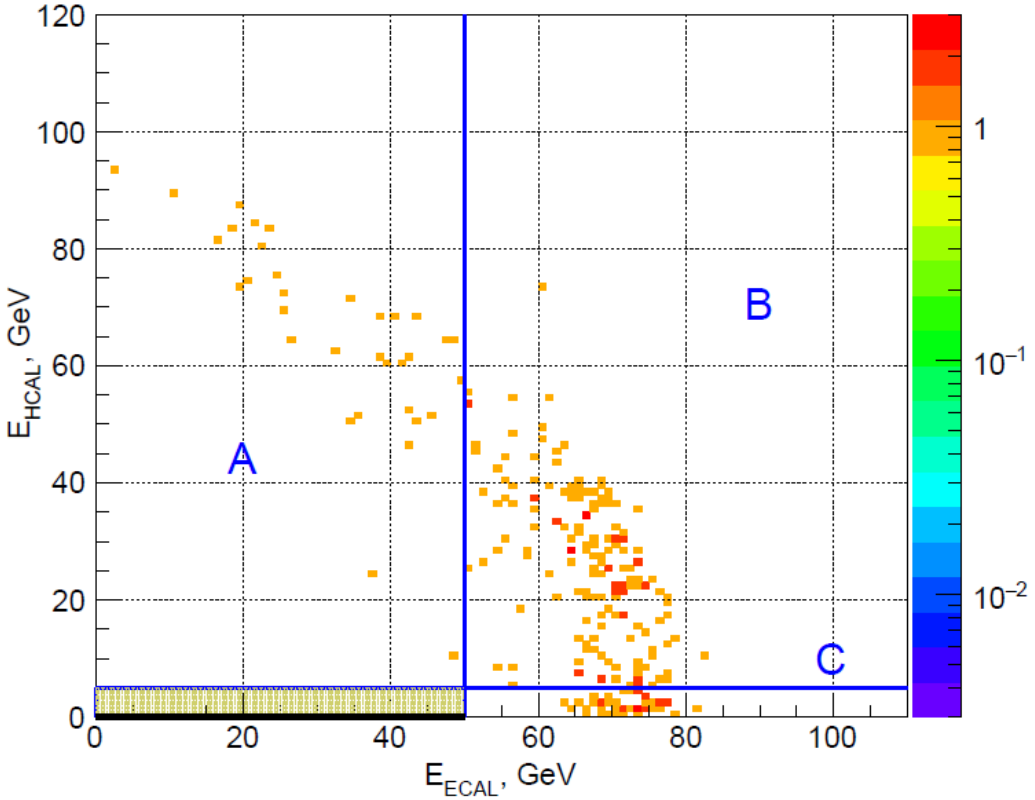
- Two methods to estimate the background surviving cuts
- First: GEANT4 MC for muon/hadron impurities and dimuon events
- Second: Background estimate based on data in A and C
  (A is mainly pure neutrals from ECAL shower,
  C likely from interactions outside the vacuum vessel)

Background estimates

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, transverse hermeticity, holes, dead material, cracks...	<10^{-13}	Full upstream coverage
Physical		
- hadron electroproduction, e.g. $e^-A \to e^-A^* + n,\pi,\rho,J/\psi-$ - n punchthrough, μ inefficiency - WI process: $e^- Z \to e^- Z\nu\nu$	< 10^{-13} < 10^{-13}	HERA ep-data (H1 Collaboration) WI σ estimated.
Total	< 10^{-12}	

Data from July 2016





No event in Signal region (enlarged by factor 5):

- Observation consistent with expected background

- What are the achieved limits for A' mass and mixing ϵ?

Limits on A' parameters

Average number of A' from Poisson distribution:

$$N_{A'} = n_{eot} \cdot n_{A'}(\epsilon, m_{A'}, \Delta E_{A'}) \cdot \varepsilon_{A'}(m_{A'}, \Delta E_{A'})$$

- A' yield depends on coupling, mass and missing energy
- Signal selection efficiency slightly depends on mass and Energy

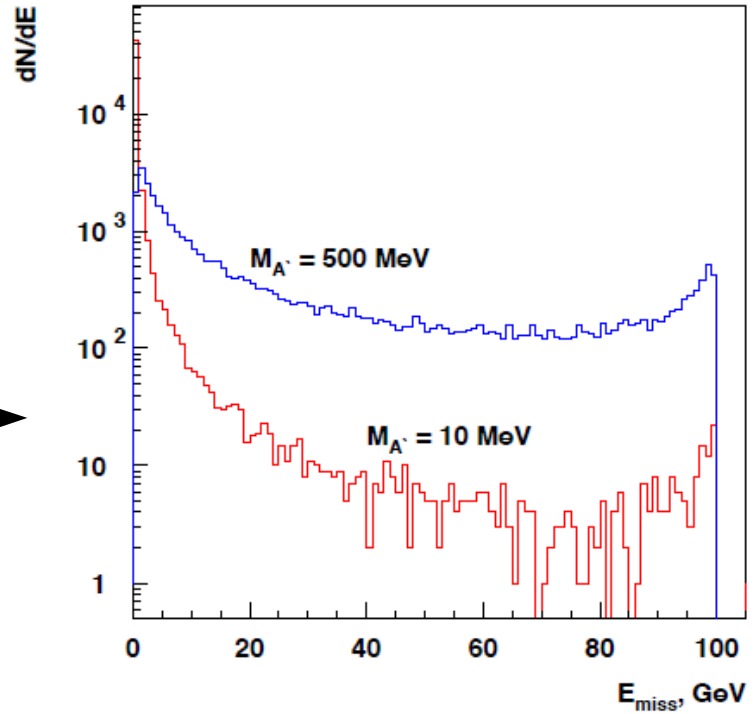
$$N_{A'} = n_{eot} \cdot \frac{\rho N_A}{A_{Pb}} \cdot \varepsilon_{A'} \cdot \int \frac{\mathrm{d}n}{\mathrm{d}E_{A'}} \mathrm{d}E_{A'}$$

With signal selection efficiency:

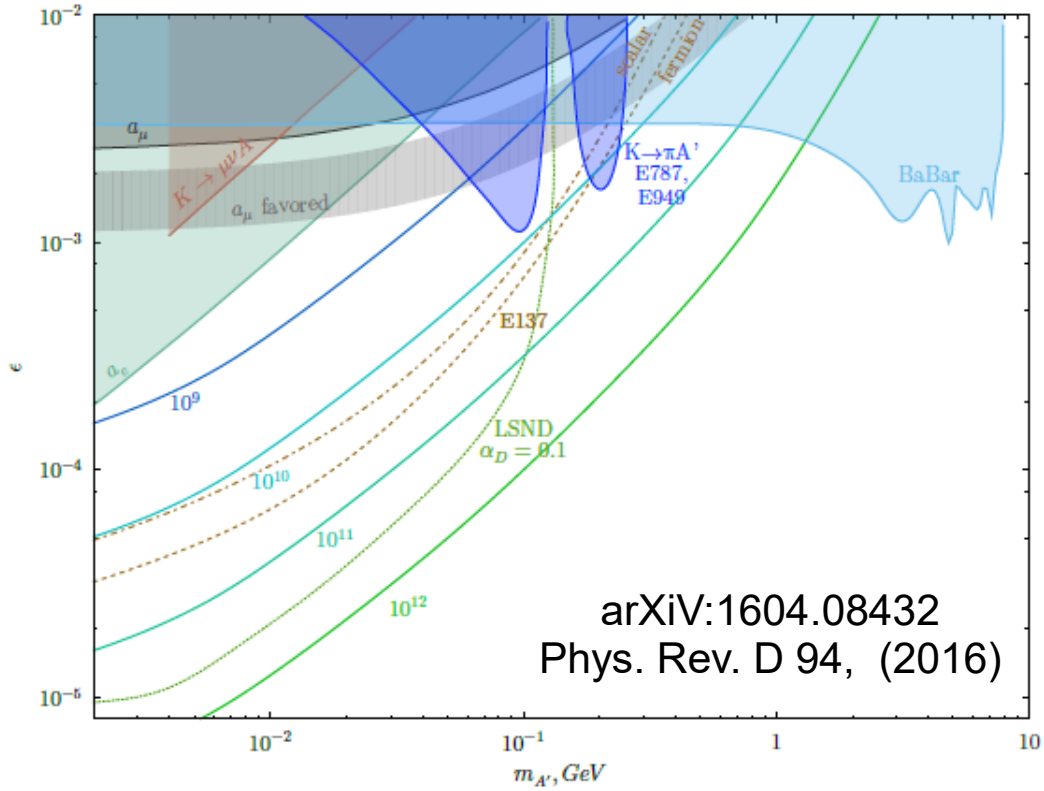
$$(0.69 \pm 0.09) \leq \varepsilon_{A'} \leq (0.55 \pm 0.07)$$

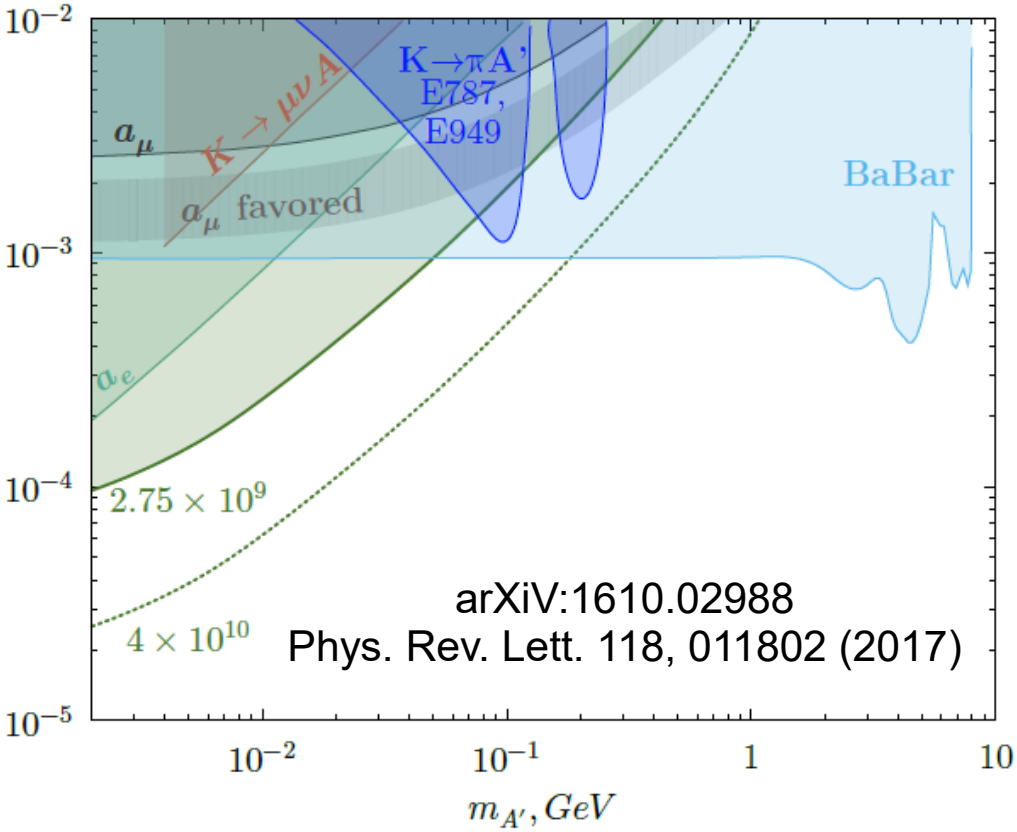
And yield predictions from MC

$$N_{A'} = \frac{k \cdot n_{eot}}{10^{12}} \left(\frac{\epsilon}{10^{-5}}\right)^2 \left(\frac{10\,\mathrm{MeV}}{M_{A'}}\right)^2$$



Limits on A' parameters





Excluded almost all muon (g-2) favoured region with 2 weeks data

- NA64 can reach new limits rather quick
  - 4 weeks of data taken in Oktober 2016 (3−4×10¹⁰ *eot.*)
  - Analysis in progress

Summary

Active target beam dump concept:

- Can probe large range of A' parameter space
- Can collect data in short time
- Has low background level in signal region

Results from 2016:

- 2×10^{9} *eot.* in Summer → No A' signal observed
- Most of muon (g-2) favoured region excluded

- $3-4\times10^{10}$ *eot.* in Autumn → Analysis in progress

2017 outlook

2017 beamtime granted for 5 weeks:

- Improved tracking with additional Micromegas and GEMs
- Better e^- identification at higher intensities

- Primary goal to collect 10^{11} *eot.* for invisible mode (~2−3 weeks)

- If primary goal achieved,
  → switch to visible mode for $\chi \rightarrow e^+e^-$ decay
  → with extra WCAL for production and gap for decay
  → light Boson could explain e^+e^- excess in excited ^{8}Be transition

- Maybe use high intensity muon beam for search of new massive Z'
  - $\mu\, Z \rightarrow \mu\, Z\, Z'$; $Z' \rightarrow$ μμ or νν (leptonic dark photon)

Possible projects 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 Sectors: Dark Photons and DM $(g-2)_\mu$ new particles, Charge Quantization	$10^{-3} < \varepsilon < 10^{-6}$ $M_{A'} \sim$ sub-GeV $e' < 10^{-5}$-10^{-7}
2. $\mu^- Z \to \mu^- Z + E_{miss}$		
✧ $Z_\mu \to \nu\nu$, $\mu^+\mu^-$ ✧ $\mu \to \tau$ conversion	New gauged symmetry L_μ-L_τ and leptonic forces LFV	$\alpha_\mu < 10^{-11}$-10^{-9} $\sigma < 10^{-9}$-$10^{-8}/\mu$
3. π (K)p-> $M^0 n + E_{miss}$		
✧ $K_L \to$ invisible ✧ $K_S \to$ invisible ✧ $\pi^0, \eta, \eta \to$ invisible	CP, CPT symmetry B-S Unitarity, new particles: NHL, $\phi\phi$, VV	Br $< 10^{-8}$-10^{-6}, comple-mentary to $K \to \pi\nu\nu$ Br$< 10^{-8}$-10^{-7}
4. pA -> X+ E_{miss}		
✧ leptophobic X	~ GeV DM	$\sigma < 10^{-7}$-10^{-8} /p

Search for dark sectors in missing energy events

Thank You for your attention!

Search for dark sectors in missing energy events

[1] S.N. Gninenko, N.V. Krasnikov, M.M. Kirsanov, D.V. Kirpichnikov, Missing energy signature from invisible decays of dark photons at the CERN SPS, Phys. Rev. D 94, 095025 (2016), arXiV:1604.08432 [hep-ph]

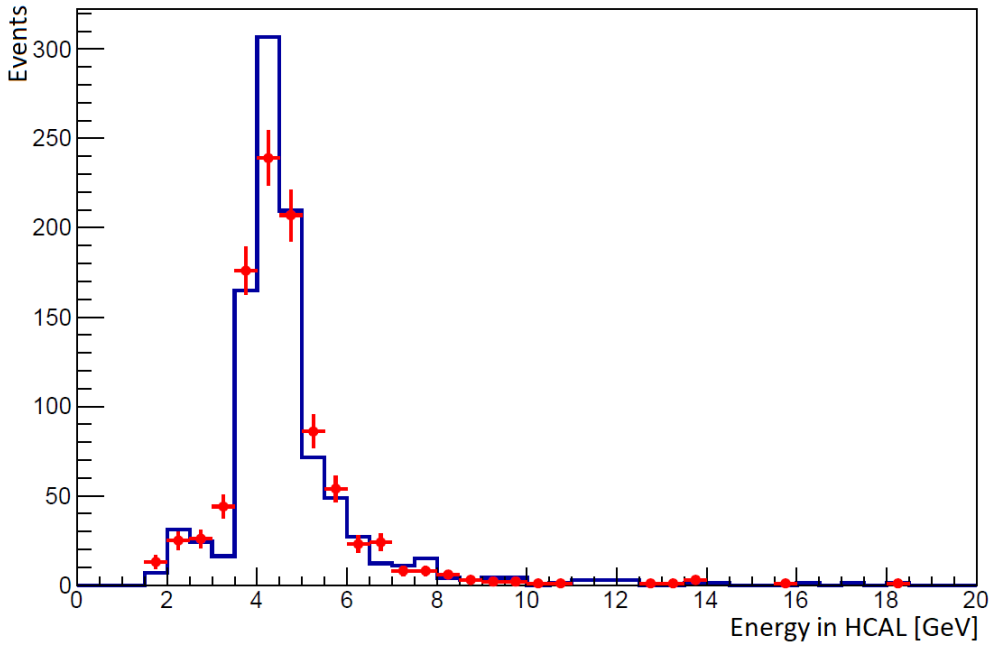
[2] NA64 Collaboration, High purity 100 GeV electron identification with synchrotron radiation, arXiV:1703.05993 [hep-ex]

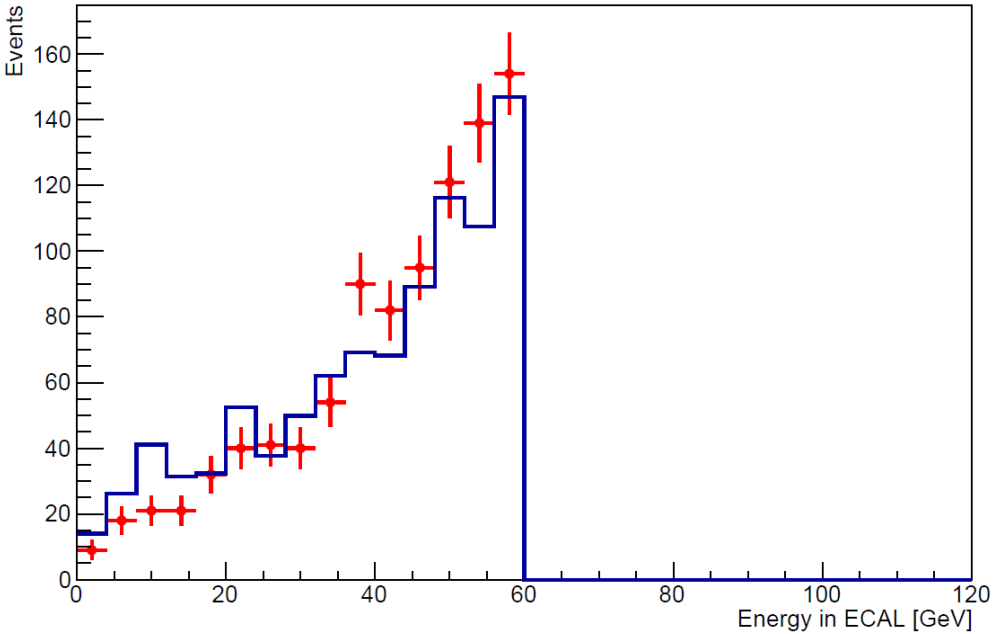
[3] NA64 Collaboration, Search for invisible decays of sub-GeV dark photons in missing-energy events at the CERN SPS, Phys. Rev. Lett. 118, 011802 (2017), arXiV:1610.02988 [hep-ph]

Search for dark sectors in missing energy events

BACKUP

Dimuon benchmark



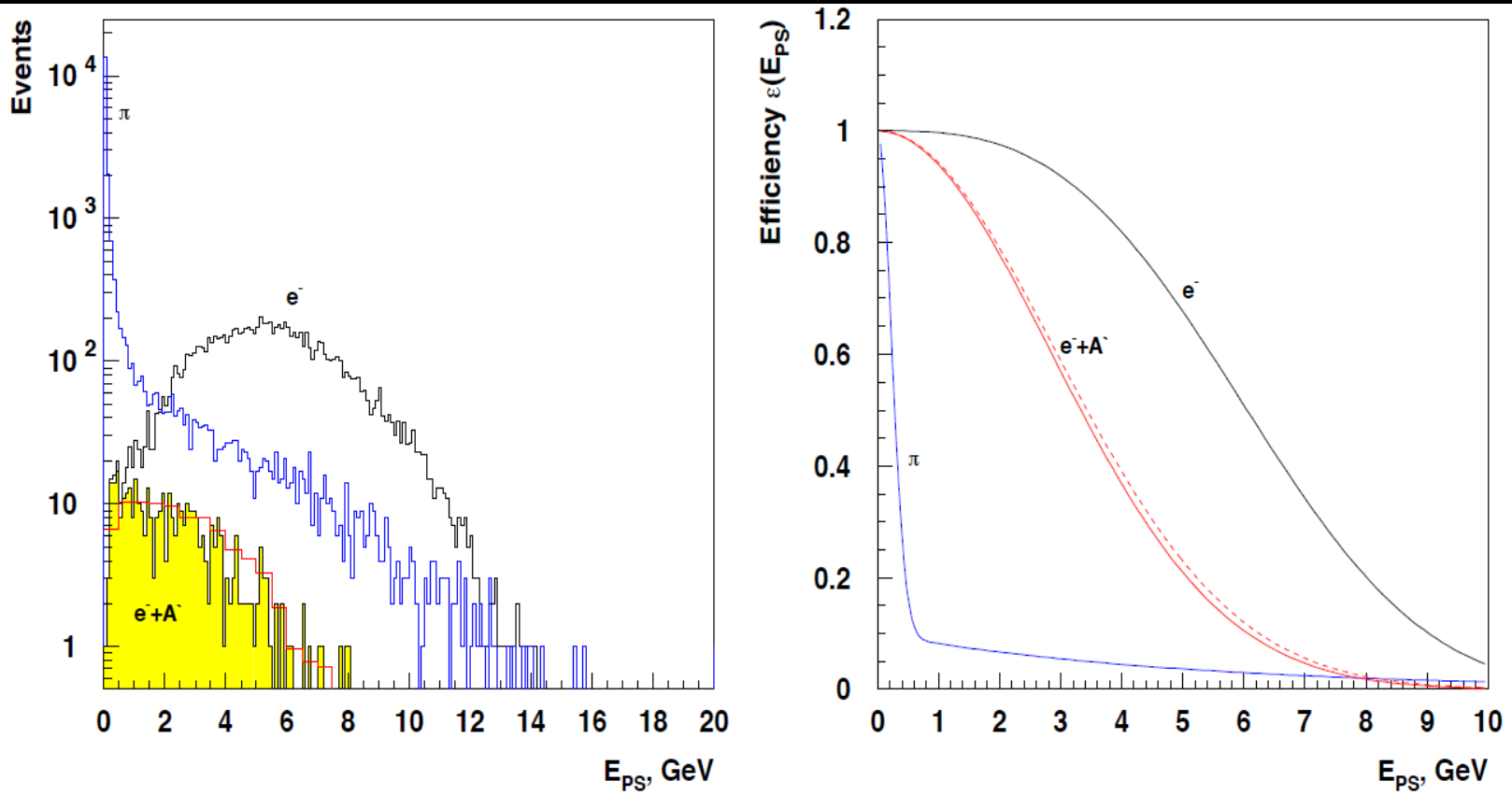


Rare Dimuon production in em-shower as benchmark channel:

- Used as a cross-check for background estimation

- Used to estimate the signal selection efficiency
  - Compare observed number of muons in HCAL to MC
  - Over all good agreement
  - Showed dependency on beam intensity (ECAL pile-up)

Preshower trigger

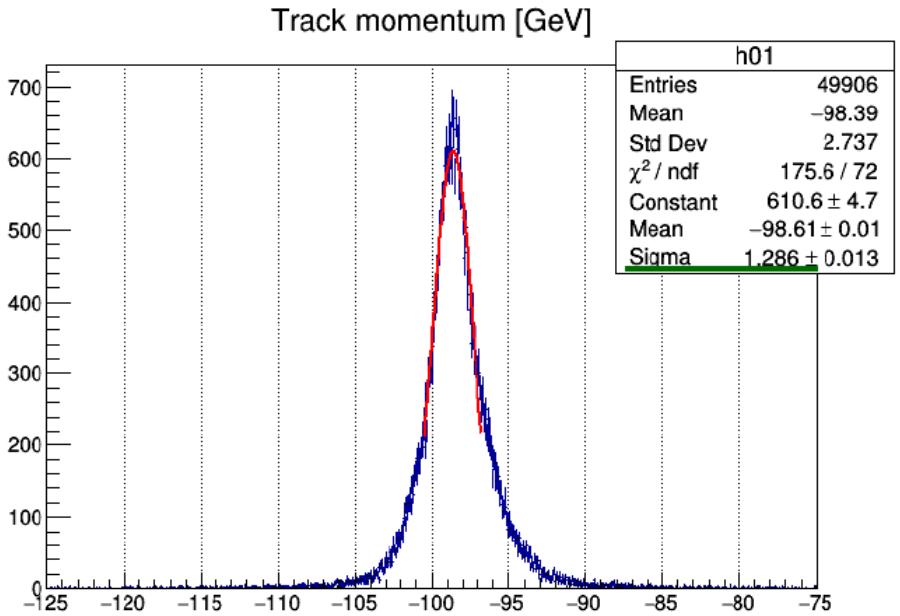


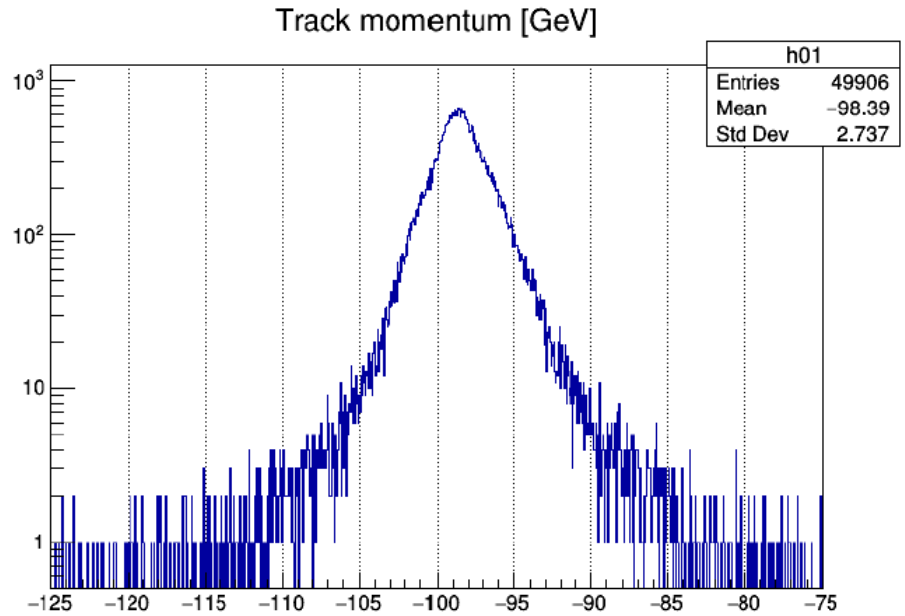
- e + A' events very seldom deposit much energy in preshower
- Electrons and pions can deposit higher amounts of energy
- Veto on high preshower energies reduces the trigger rate

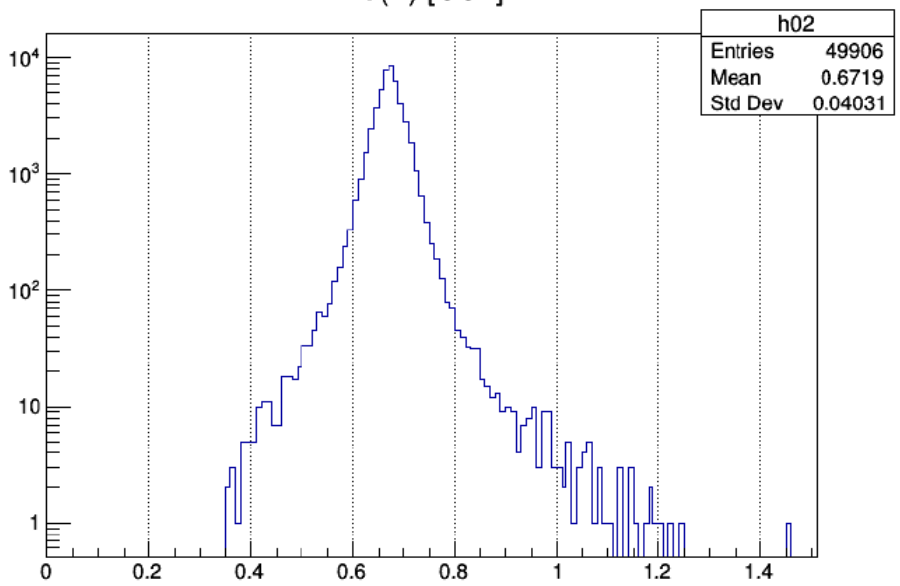
Signal selection efficiency

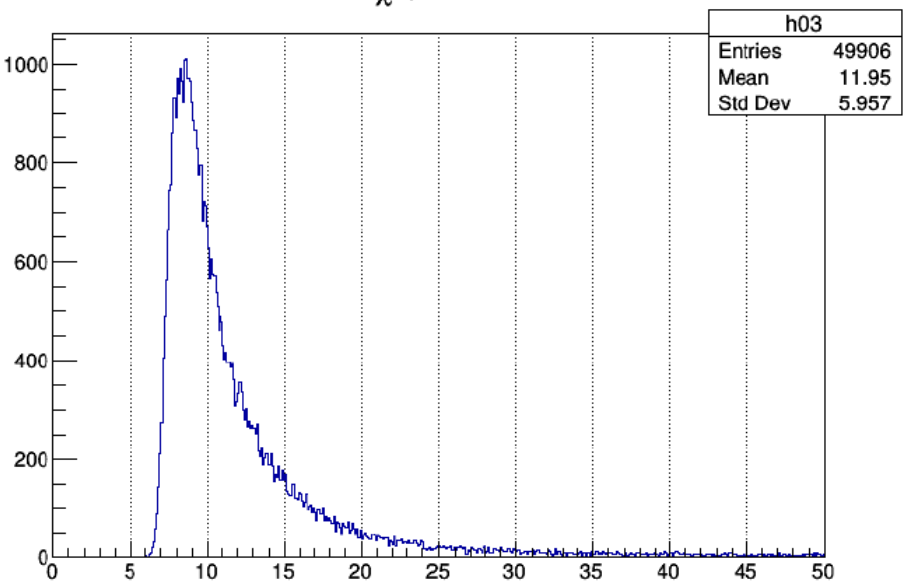
Geometrical acceptance	0.97
Veto 2 efficiency	0.96
HCAL efficiency	0.94
SRD efficiency	0.97
Trigger efficiency	0.95
BGO (PbSc) pileup	0.92 (0.93)
Trigger deadtime	0.93
Total efficiency	~0.69

Tracking and Momentum Reconstruction

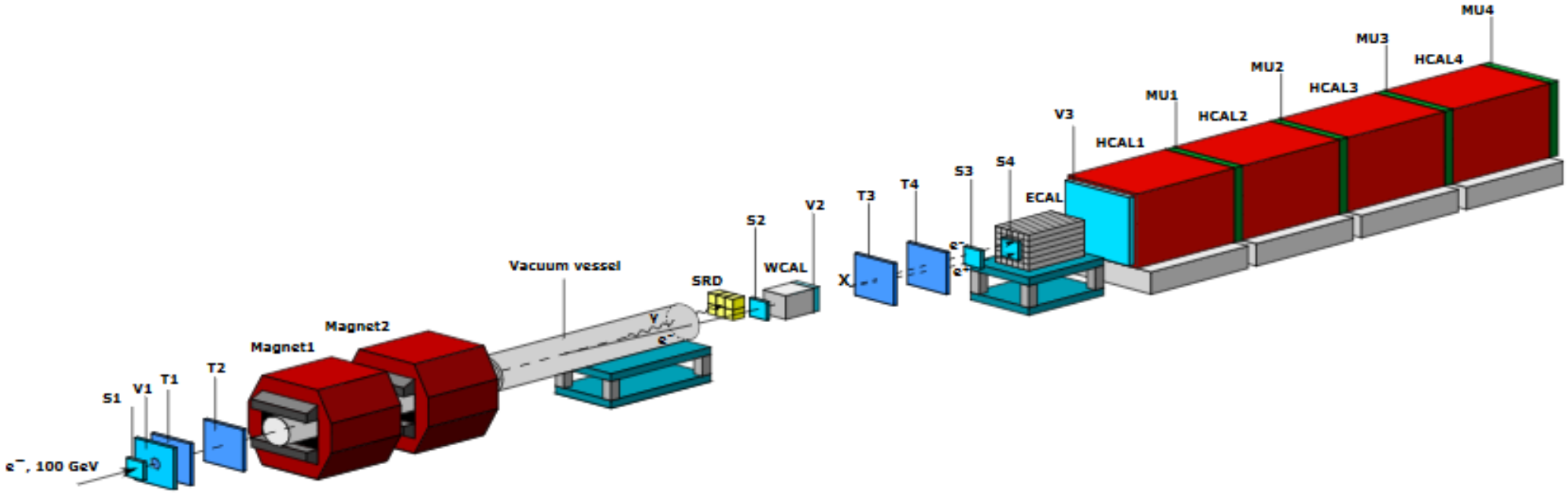








Visible search



- Tungsten Scintillator electromagnetic calorimeter (WCAL) as target
- A' → e^+e^-, search for two track events
- Proposal and first results: CERN-SPSC-2017-016 ; SPSC-SR-211