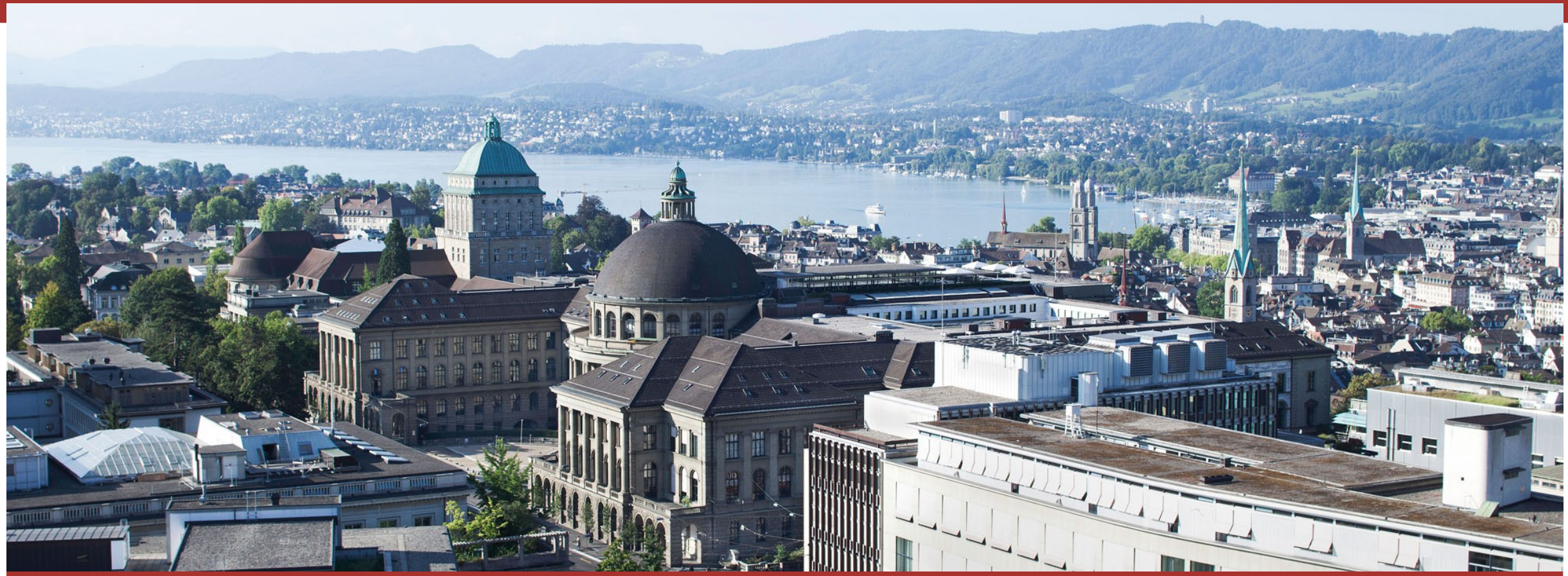

NA64 SEARCHING FOR HIDDEN SECTORS AT THE CERN SPS

Emilio Depero, ETH Zurich, Institute for Particle Physics and Astrophysics on behalf of the NA64 collaboration

The NA64 collaboration (47 researchers from 12 Institutes)

D. Banerjee,[12] V. E. Burtsev,[10] A. G. Chumakov,[10] D. Cooke,[12] P. Crivelli,[12] E. Depero,[12] A. V. Dermenev,[4] S. V. Donskov,[9] F. Dubinin,[5] R. R. Dusaev,[10] S. Emmenegger,[12] A. Fabich,[3] V. N. Frolov,[2] A. Gardikiotis,[8] S. G. Gerassimov,[5,7] S. N. Gninenko,[4,*] M. Hösgen,[1] A. E. Karneyeu,[4] B. Ketzer,[1] D. V. Kirpichnikov,[4] M. M. Kirsanov,[4] I. V. Konorov,[5,7] S. G. Kovalenko,[11] V. A. Kramarenko,[2,6] L. V. Kravchuk,[4] N. V. Krasnikov,[4] S. V. Kuleshov,[11] V. E. Lyubovitskij,[10,11] V. Lysan,[2] V. A. Matveev,[2] Yu. V. Mikhailov,[9] D. V. Peshekhonov,[2] V. A. Polyakov,[9] B. Radics,[12] R. Rojas,[11] A. Rubbia,[12] V. D. Samoylenko,[9] V. O. Tikhomirov,[5] D. A. Tlisov,[4] A. N. Toropin,[4] A. Yu. Trifonov,[10] B. I. Vasilishin,[10] G. Vasquez Arenas,[11] and P. Ulloa[11]

(The NA64 Collaboration)

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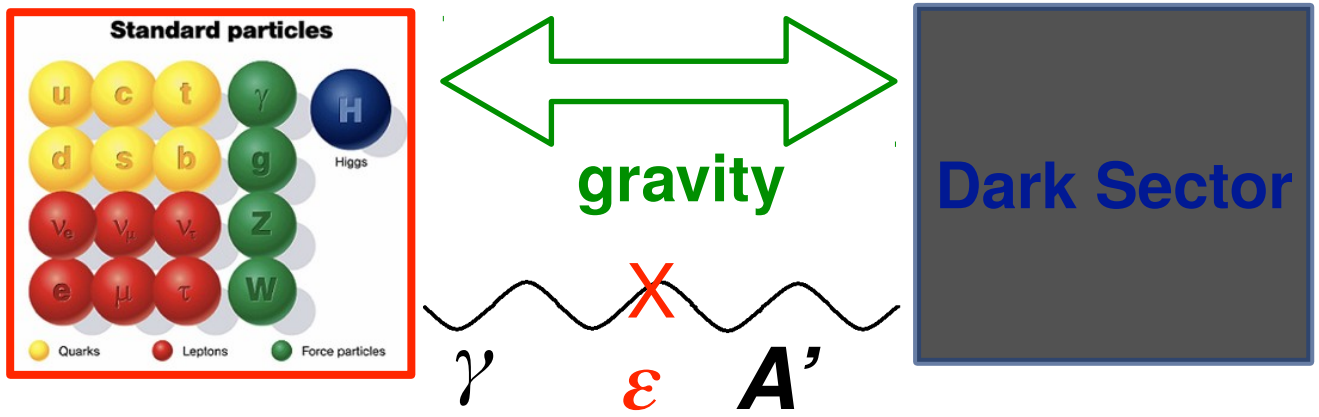
[9]*State Scientific Center of the Russian Federation Institute for High Energy Physics of National Research Center 'Kurchatov Institute' (IHEP), 142281 Protvino, Russia*
[10]*Tomsk Polytechnic University, 634050 Tomsk, Russia*
[11]*Universidad Técnica Federico Santa María, 2390123 Valparaíso, Chile*
[12]*ETH Zürich, Institute for Particle Physics, CH-8093 Zürich, Switzerland*

- Proposed (P348) in 2014, first test beam in 2015 (2 weeks),
- Approved by CERN SPSC in March 2016 → NA64.
- 2016: 5 weeks, 2017: 5 weeks, 2018: 6 weeks (starting in May).

Sergei Gninenko
NA64 spokesperson

Dark Sectors

In several models (e.g. string theory, super-gravity, ...) **Dark Sectors** of particles arise naturally → interesting candidate for Dark Matter.



For a recent review of DS activities see e.g. M. Battaglieri et al., arXiv:1707.04591.

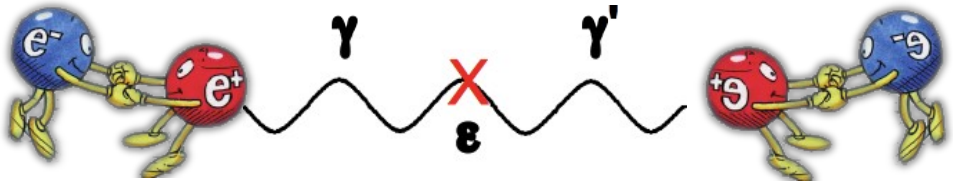
Kinetic mixing? If YES → New massive boson A' (so called Dark Photon)

A' decay modes:

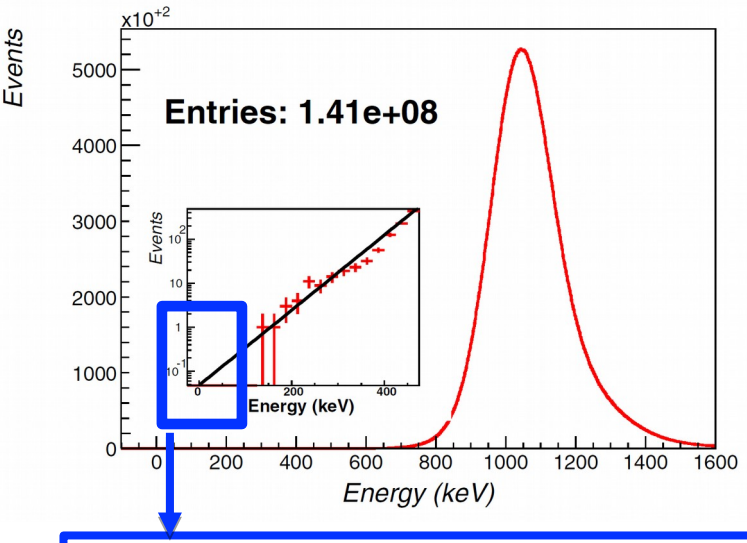
1) Invisible: $A' \rightarrow \chi\bar{\chi}$
2) Visible: $A' \rightarrow e^+e^-, \mu^+\mu^-$

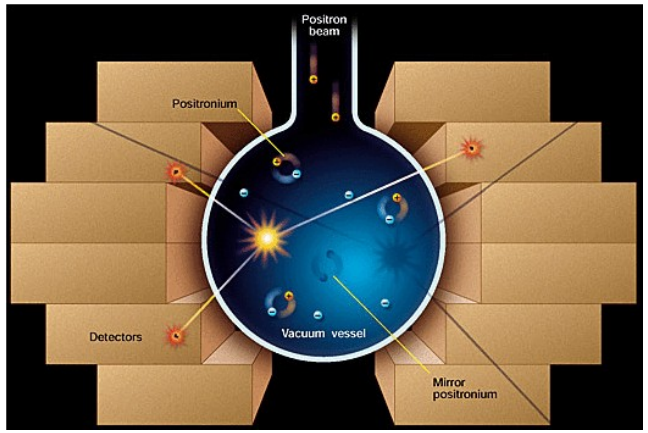
From positronium (search for massless dark photon) → NA64

Presented at **Patras** conference 2011:
https://bib-pubdb1.desy.de/record/295124



S. L. Glashow, Phys. Lett. B167, 35 (1986)





Signature: disappearance of 1 MeV energy

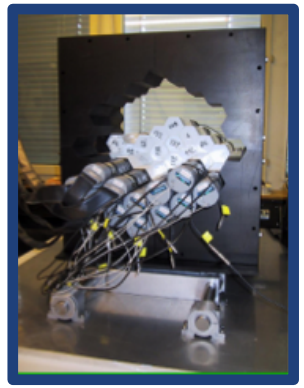


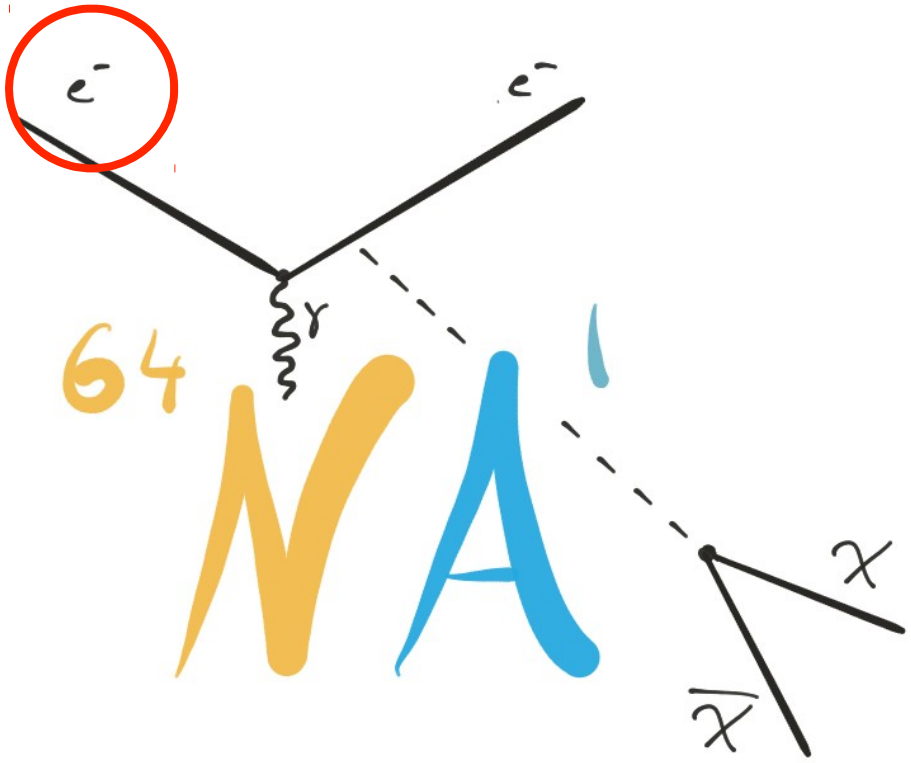
Table top

At rest → 100 GeV

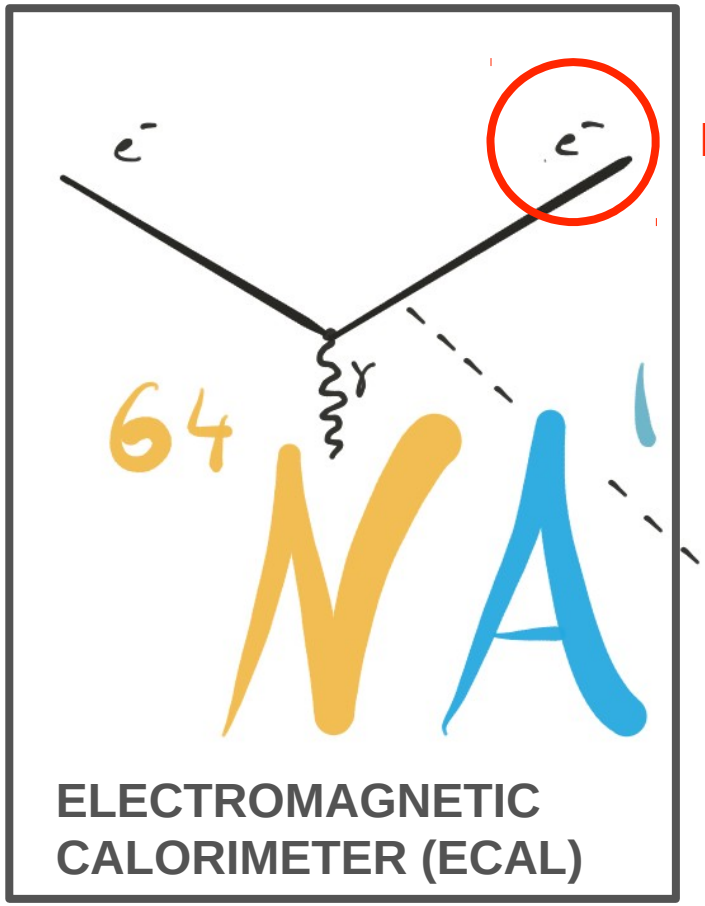
A. Badertscher, P. Crivelli et al., Phys. Rev. D. 75, 032004 (2007)
NEW results C. Vigo, L. Gerchow, L. Liszkay, A. Rubbia, P. Crivelli, PRD 97, 092008 (2018)

The NA64 working principle to search for A’ → $\chi\bar{\chi}$

TAGGED 100 GeV



The NA64 working principle to search for A' → $\chi\bar{\chi}$

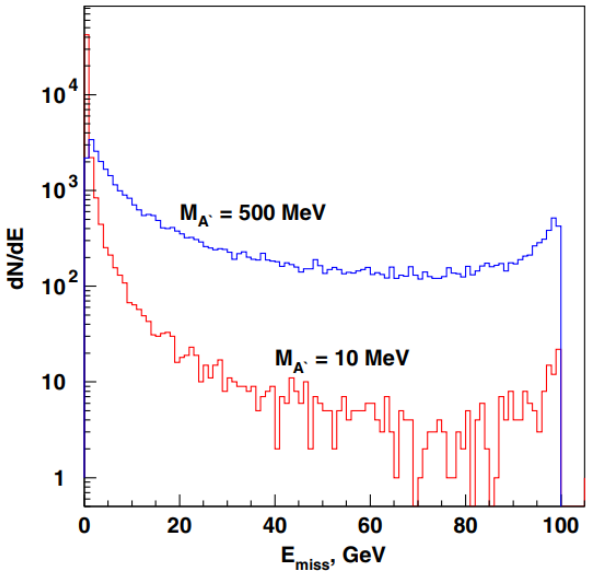


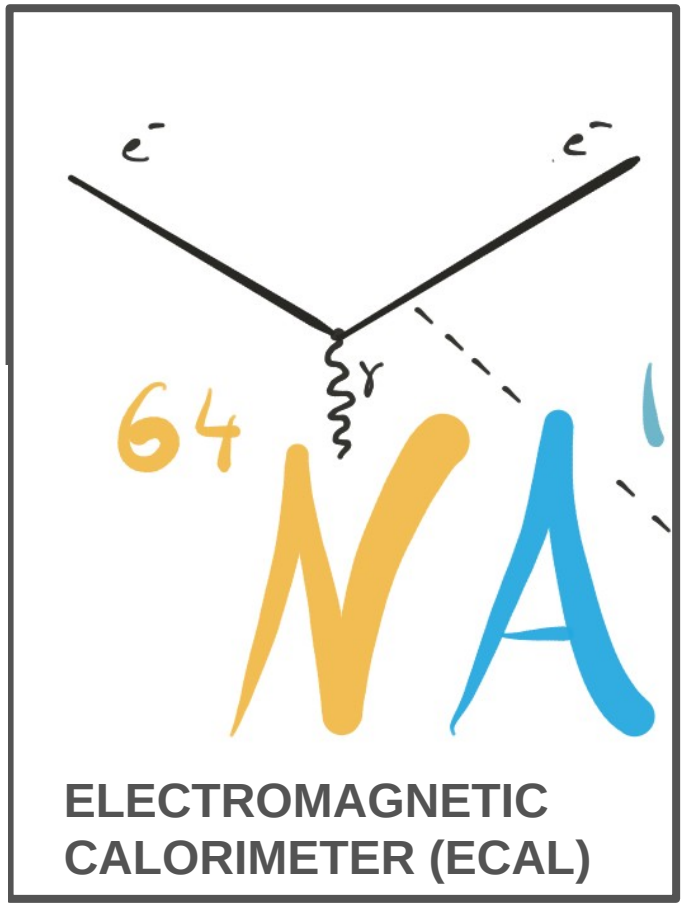
DETECTED ENERGY < 50 GeV

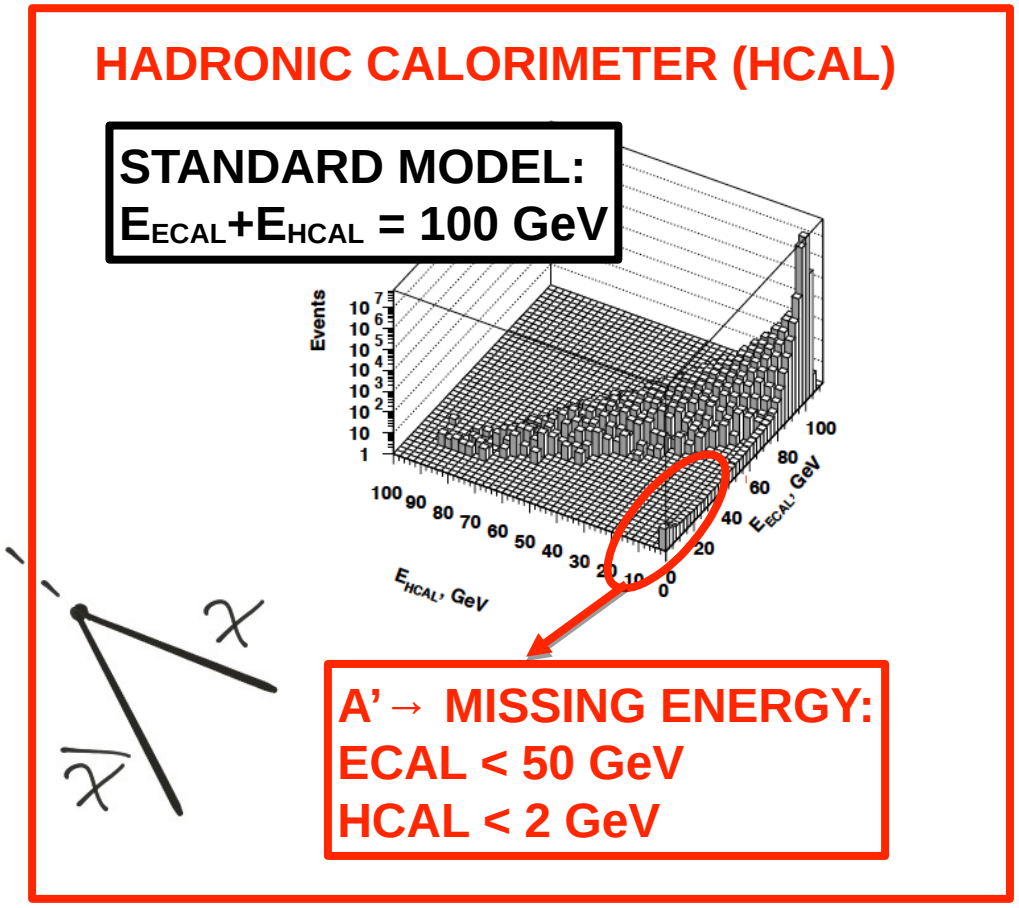
"BREMSSTRAHLUNG" OF A'

The NA64 working principle to search for A' → $\chi\bar{\chi}$

Simulated A' emission spectrum

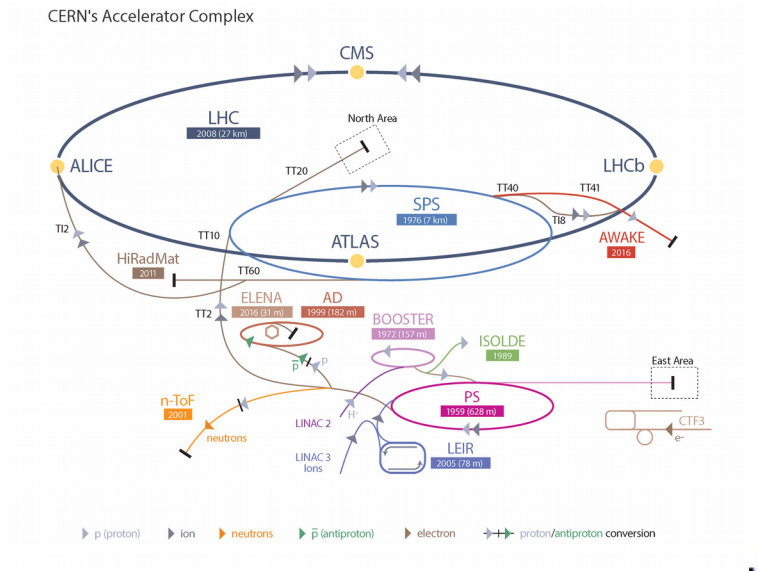






S. Gninenko et al.,Phys. Rev. D 94, 095025 (2016)

The CERN SPS H4 electron beam dumped over active target



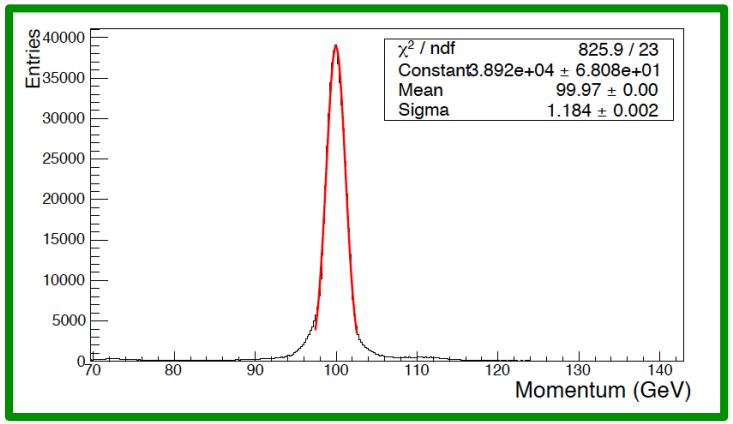
- Up to 7x10^6 e$^-$/spill, 2-4 spill/m
- Low contamination: π (<1%), μ/K (0.1%)
- Low energy tails (<1%)
- Beam spot of 1.5 cm (FWHM)

High hermeticity

- High hermeticity (~40 X_0)
- PbSc sandwich, 6x6 matrix, cells 38x38x490 mm3
- WLS fibers in spiral → suppress energy leaks
- Energy resolution ~ 9%/√(E[GeV])
- Longitudinal (Pre-shower) and lateral segmentation

→ shower profiles (hadron rejection)

The magnetic spectrometer



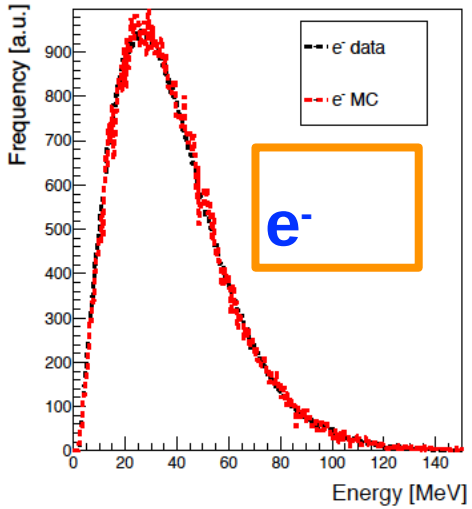
Reconstruction of e⁻ incoming momentum

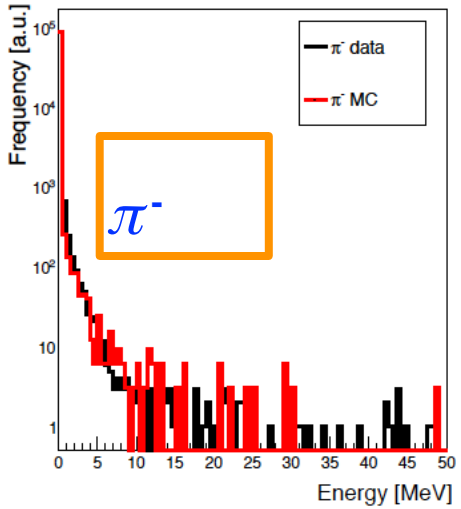
D. Banerjee et al., NIMA881 (2018) 72-81

Two bending magnets in series → 7 T.m field

Tracking system:
8 XY multiplexed resistive micromegas modules and 2 GEM detectors

The Synchrotron radiation detector

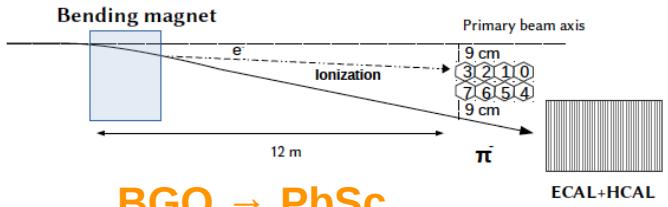




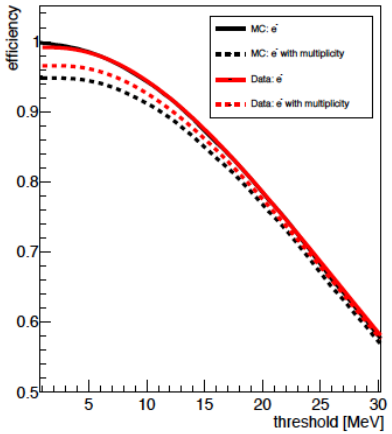
Particle identification

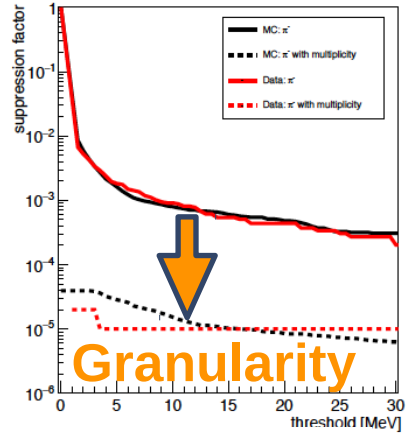
SR emission ~ 1/m⁴

E. Depero et al., NIMA 866 (2017) 196-201.



BGO → PbSc

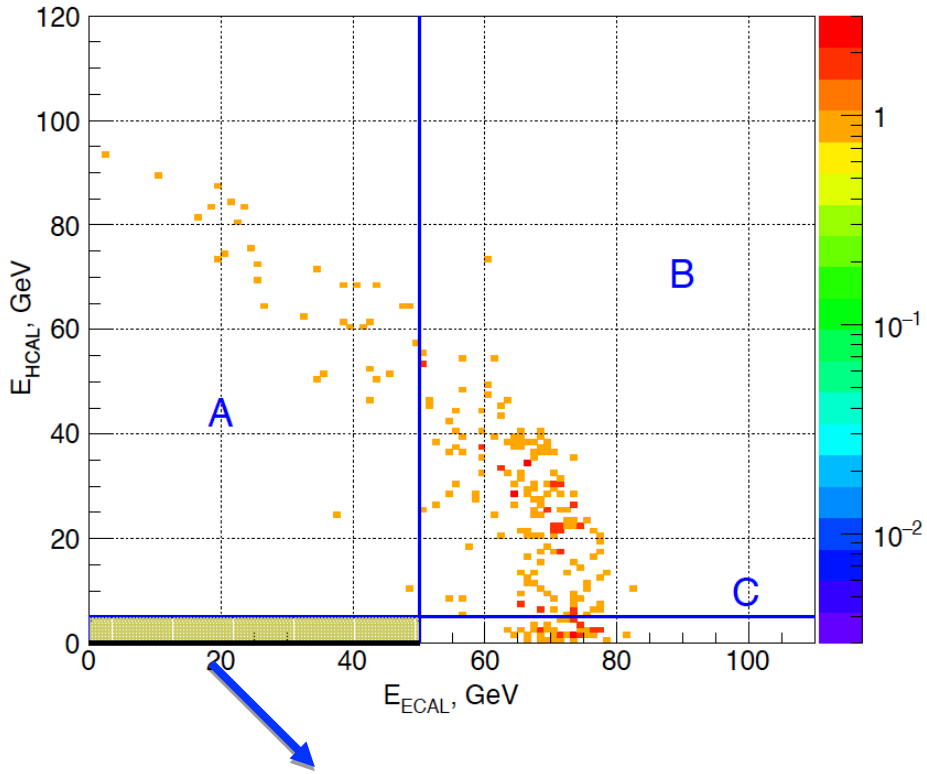




Efficiency > 95%

Suppression >10^{-5}

The NA64 search for A' → $\chi\bar{\chi}$ - results (July 2016, 2 weeks)



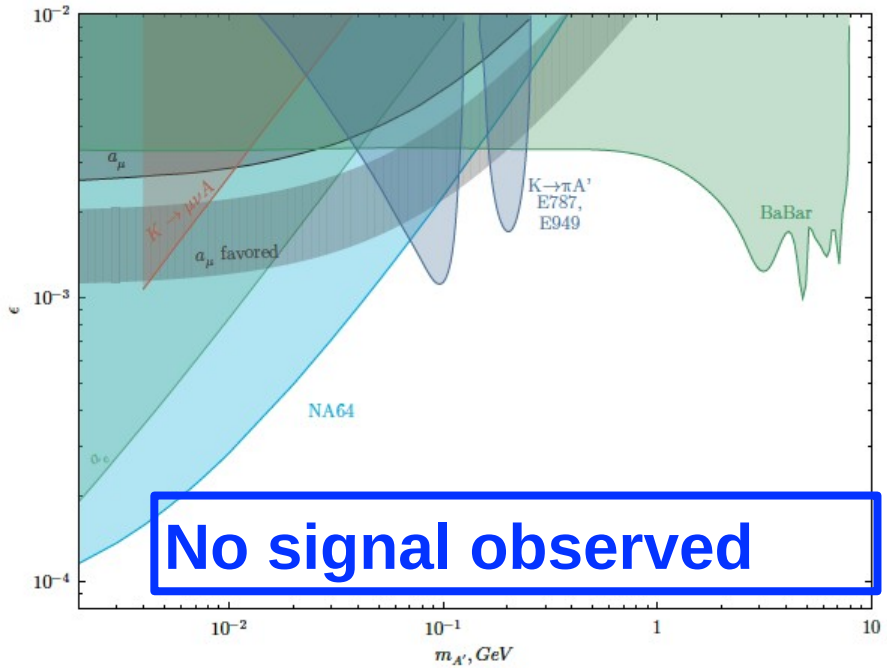
Event Selection Criteria:

- Timing information → Pile up suppression.
- Clean incoming track: angle + single hit in all trackers, correct momentum.
- Synchrotron radiation → Hadron suppression
- Shower profile compatible with e^-
- No activity in Veto.

All selection cuts applied → no event in signal region

The NA64 search for A' → $\chi\bar{\chi}$ - results (July 2016, 2 weeks)

2.75 x 10^9 electrons on target



No signal observed

→ exclusion of most of g-2 muon favored region

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

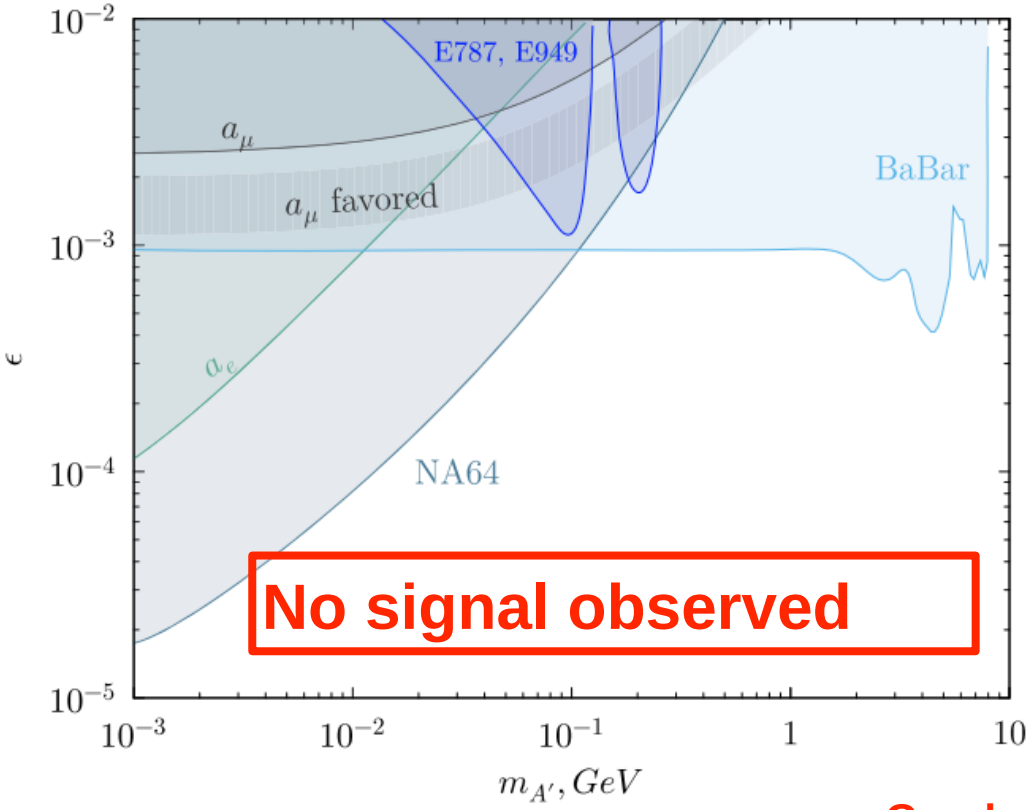
g-2 closed completely by BABAR results

BABAR collaboration, Phys. Rev. Lett. 119, 131804 (2017)

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

The NA64 search for A' → $\chi\bar{\chi}$ - results (October 2016, 3 weeks)

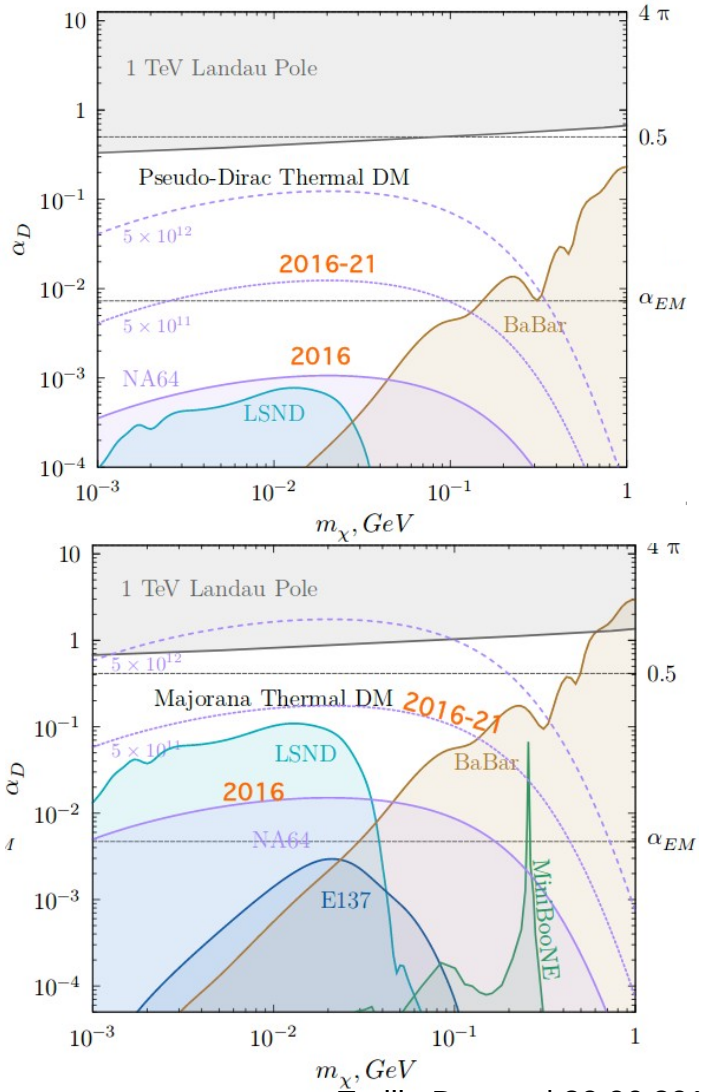
4 x 10^{10} electrons on target



No signal observed

NOTE: NA64 limits obtained with exact tree level cross section calculation, S. Gninenko et al. arXiv 1712.05076

Constraints on sub-GeV thermal DM

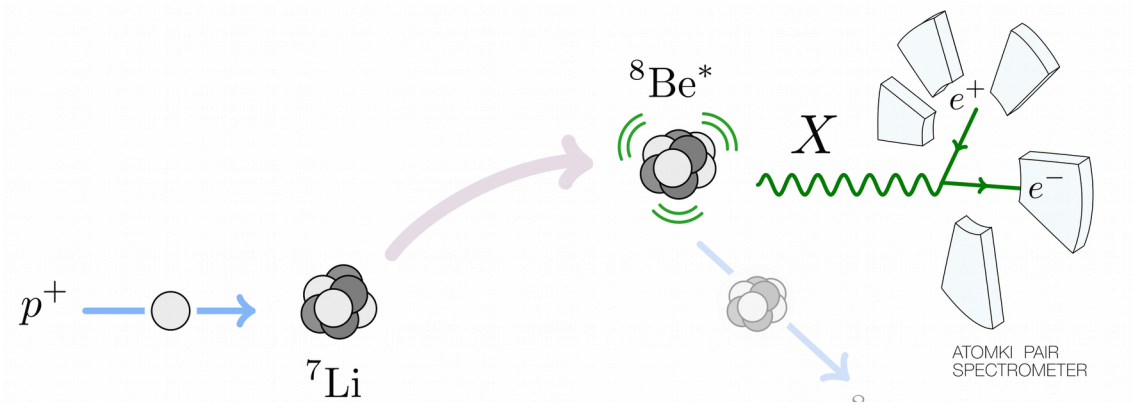


NA64 collaboration,
Phys. Rev. D 97, 072002 (2018)

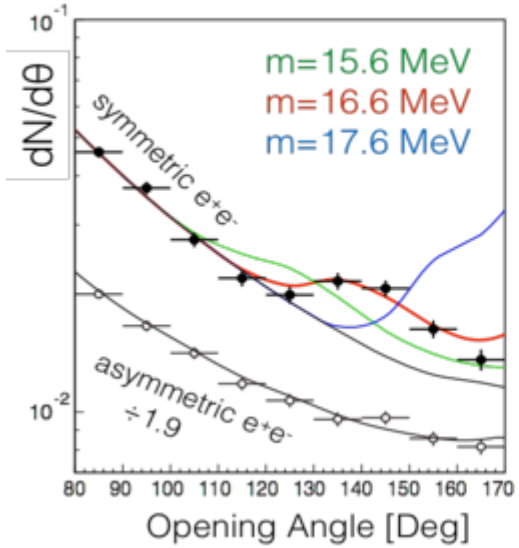
Good scaling for small couplings

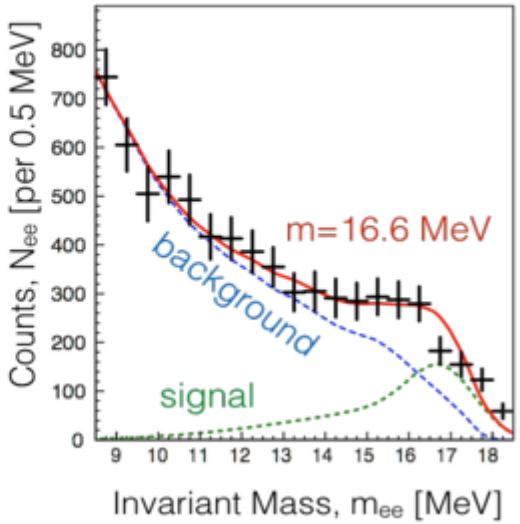
(~ϵ^2 Instead of ~$\epsilon^4\alpha_D$)

^{8}Be anomaly and X boson



ATOMKI Experiment





Could be explained by new 'protophobic' gauge boson X with mass around 17 MeV

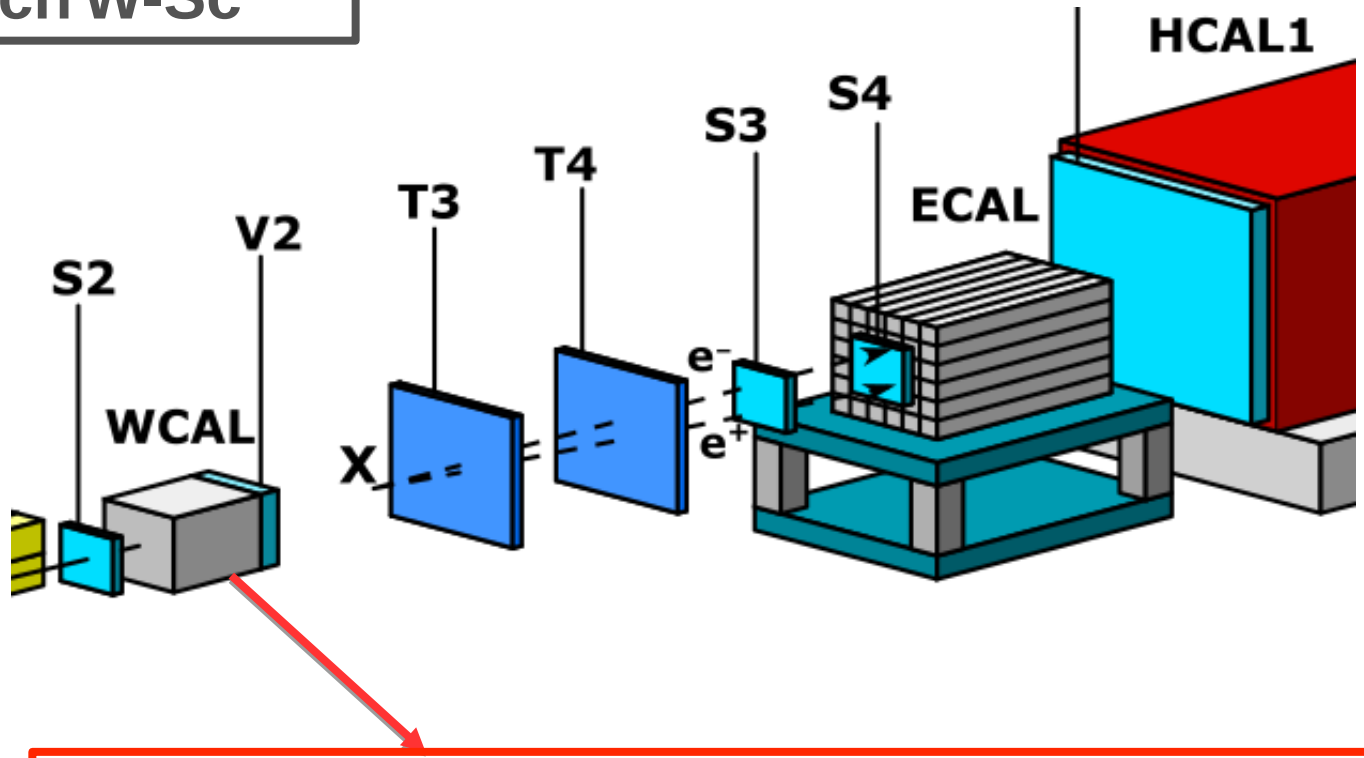
J. L. Feng et al. Phys. Rev. D95, 035017 (2017)

A. J. Krasznahorkay et al. Phys. Rev. Lett.116, 042501 (2015)

The NA64 search for $X \rightarrow e^+e^-$ - *experimental signature*

WCAL: 30-40 X_0

Sandwich W-Sc

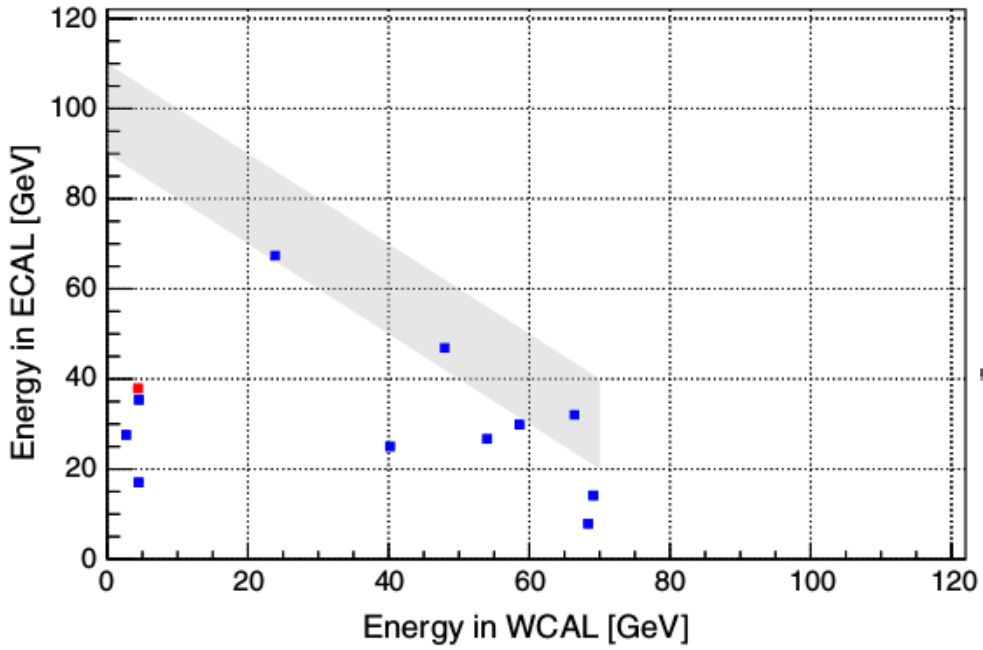


Signature:

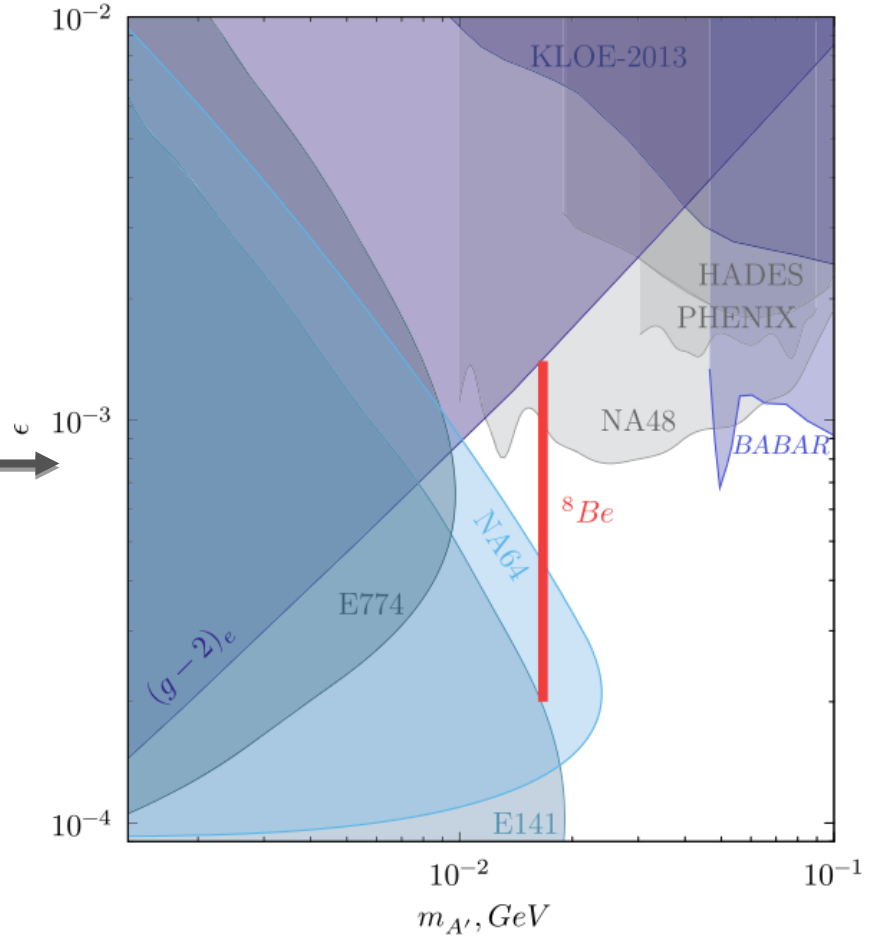
1) $E_{WCAL}+E_{ECAL}$ = 100 GeV
2) No activity in $V_{2,3}$ and HCAL
3) Signal in S3, S4
4) e-m shower in ECAL

New compat Tungsten ECAL for conversion

The NA64 search for $X \rightarrow e^+e^-$ - *results (2017)*



No signal-like event in signal box

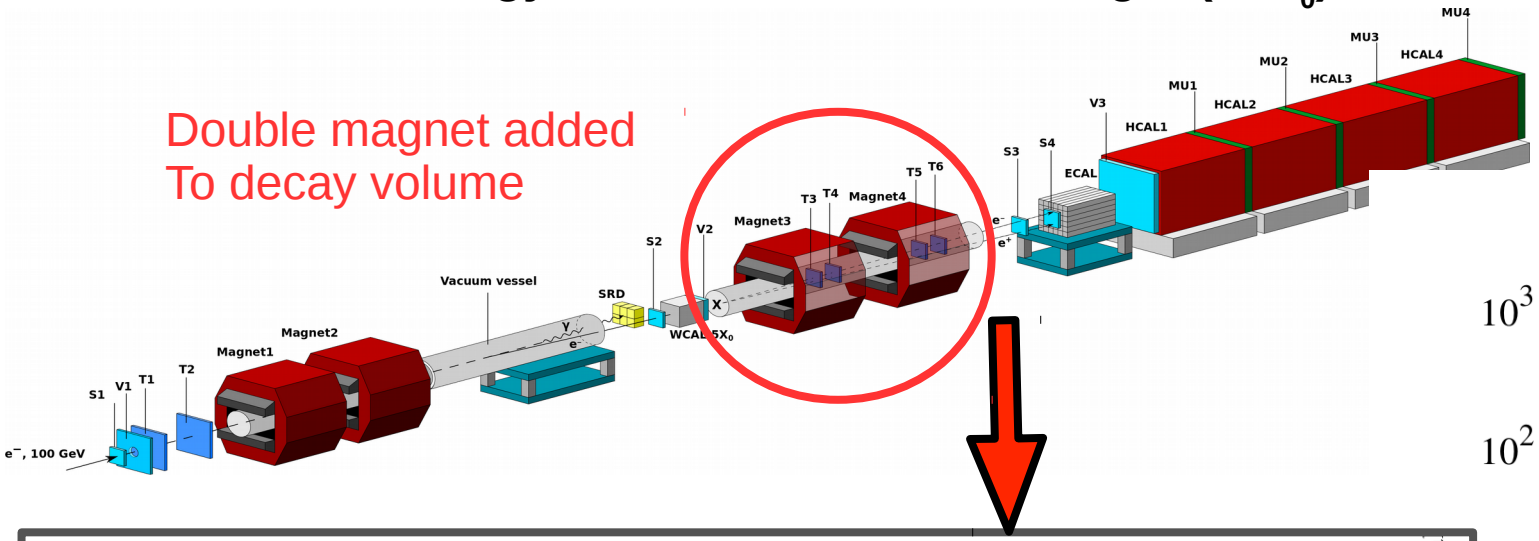


- **Neutral events**
- **Signal like**

NA64 collaboration, Phys. Rev. Letter 120, 231802(2018)

The NA64 physics prospects – cover X-boson anomaly

→ **Increase the energy and decrease WCAL length (~5X$_0$) to cover short lived X-boson**



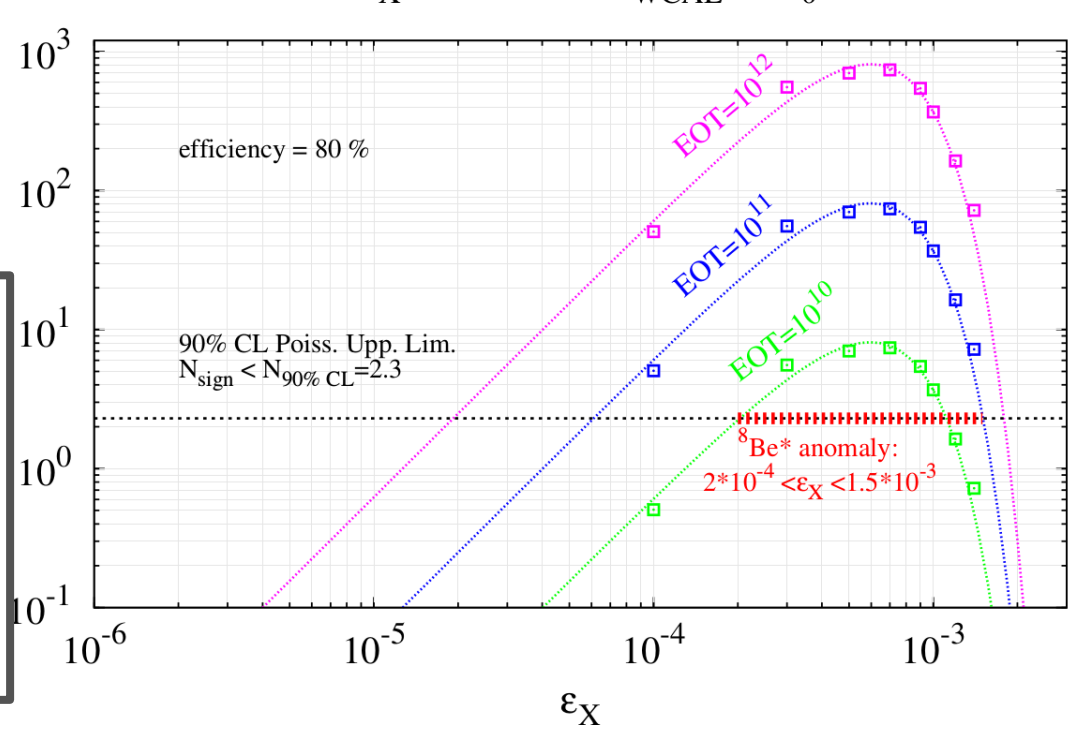
Signature:

1) Reconstructed vertex outside WCAL

2) Reconstructed Invariant mass ~ 16.7 MeV

3) Double e.m. shower in ECAL

→ **10^{11} EOTS could cover the anomaly completely**



ALPS detection in NA64

→ **NA64 setup is capable to search for axion-like particles created through Primankov effect using decay channels a → γγ and a → e + e −**

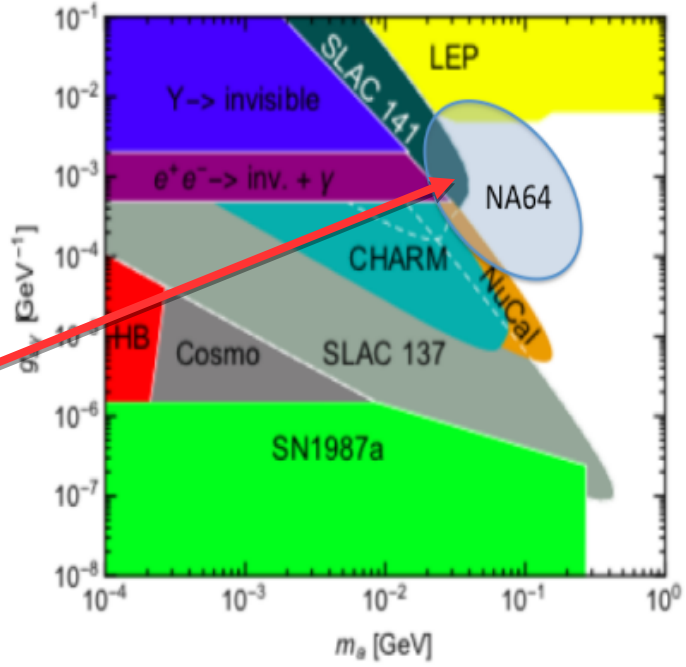
- Two possible **decay channels** to detect:

- **Visible:**
  - ECAL + WCAL = 100 GeV
  - Pure neutral shower in ECAL
  - High collinearity
- **Invisible:**
  - Missing energy in ECAL

- **Combining the two channels allow us to cover a new region of parameter space!**

$10^{-4} < g_{ayy} < 10^{-2}$

$10 < m_a < 500$ MeV



And many others!

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. π (K)p $\to M^0 n + E_{miss}$		
✧ $K_L \to$ invisible ✧ $K_S \to$ invisible ✧ π^0, η, $\eta' \to$ 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}

Full NA64 program: in preparation for PBC

→ input for the European Strategy Group

S.N. Gninenko and N.V. Krasnikov

arXiv 1801.10448

S.N. Gninenko and N.V. Krasnikov

Phys. Rev. D92 (2015)

S.N. Gninenko,

Phys. Rev. D91 (2015) 015004

Summary and Outlook

2016: A' → $\chi\bar{\chi}$

- July run: 2.75x10^{9} EOT: no signal → most of g-2 muon favored region excluded (PRL118, 011802 (2017)) .
- October run : 4x10^{10} EOT: no signal → new constraints on TLDM (PRD97, 072002 (2018)).

→ active beam dump + missing-energy: very powerful tool to search for dark sector physics.

2017-2018:

- **A' → $\chi\bar{\chi}$**: goal ~3X10^{11} EOT (analysis 2017 ongoing)
- ***X* → e^+e^-** : 5x10^{10} EOT at 100 GeV (2017) arXiv 1803.07748, expected 5x10^{10} EOT at 150 GeV (2018)

>2021 (after LS2)

- goal 5x10^{12} EOT for *A'* → $\chi\bar{\chi}$ and explore remaining parameter space *X* → e^+e^-
- resonant production of A' with positrons (L.Marsicano et al. arXiv 1802.03794)
- Search for *Z*' coupled to muons with M2 beamline at CERN (160 GeV/c muon), proposal in preparation
- Searches for h,h', p0, KL, KS → invisible

→ Proposed searches of dark sectors in NA64 with leptonic and hadronic beams: unique sensitivities: highly complementary to similar projects.

- Contribution to the CERN PBC program after LS2
- Input to the European Strategy for Particle Physics

Acknowledgments

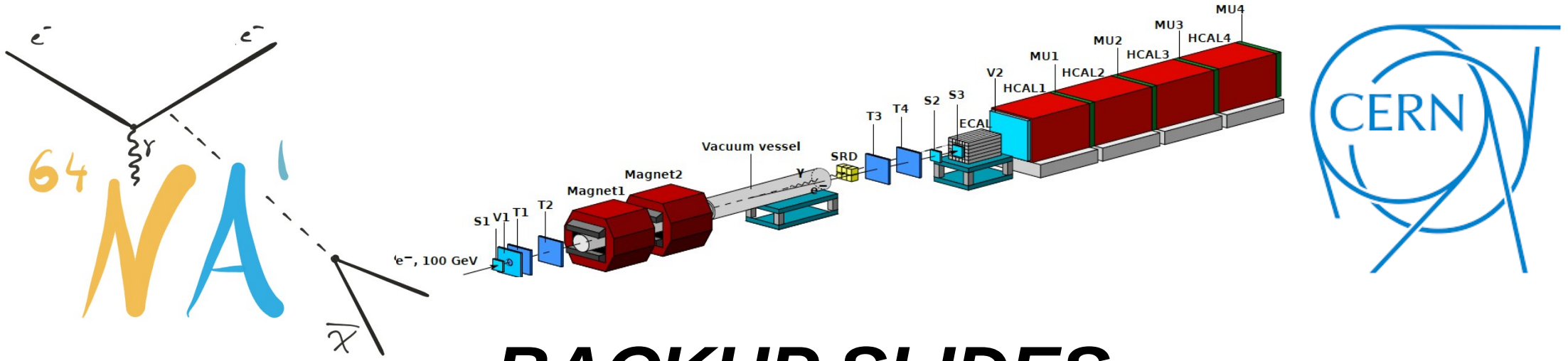
NA64 collaboration and in particular P.Crivelli and S. Gninenko

CERN

ETH Zurich group:
Prof. André Rubbia
Post docs: D. Cooke, B. Radics
Graduate Students: Dipanwita Banerjee and Emilio Depero
Undergraduate Students: Y. Chen, J. Riebatsch S. Emmenegger, M. Bachmayer, U. Molinatti

Funding: ETH Zurich and SNSF Grant No. 169133 (Switzerland),
PI: **P. Crivelli**

FNSNF
Swiss National Science Foundation



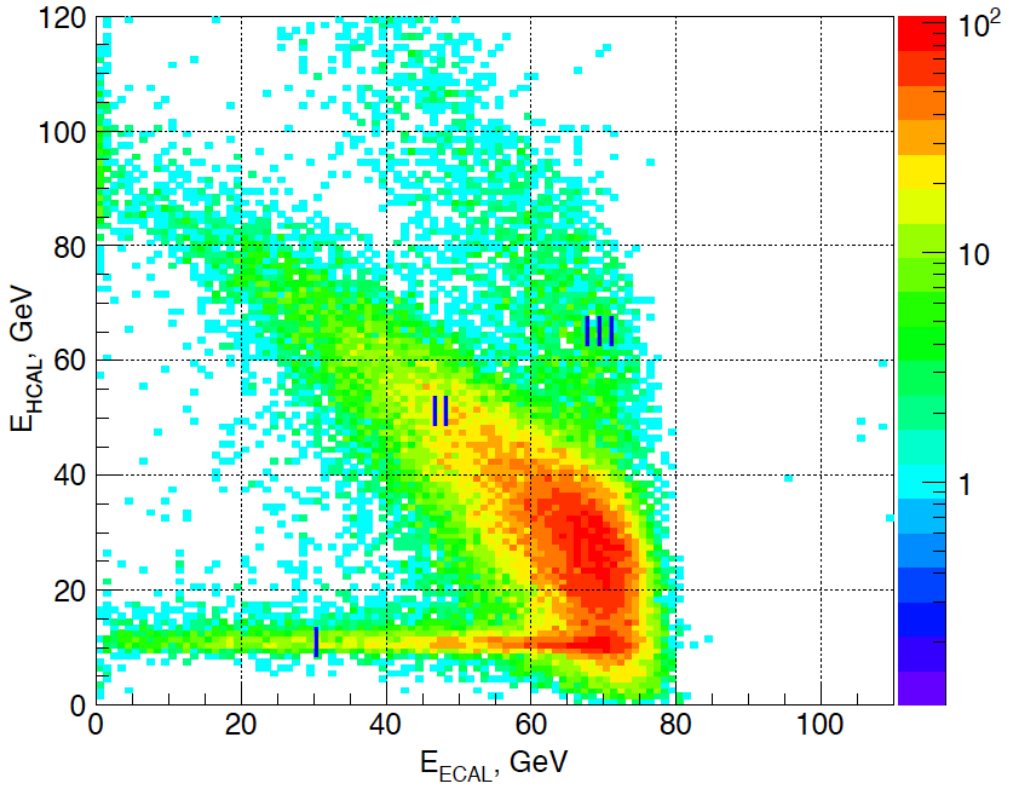
CERN

BACKUP SLIDES

IPA

ETH zürich

The NA64 search for A' → $\chi\bar{\chi}$ - results (July 2016, 2 weeks)

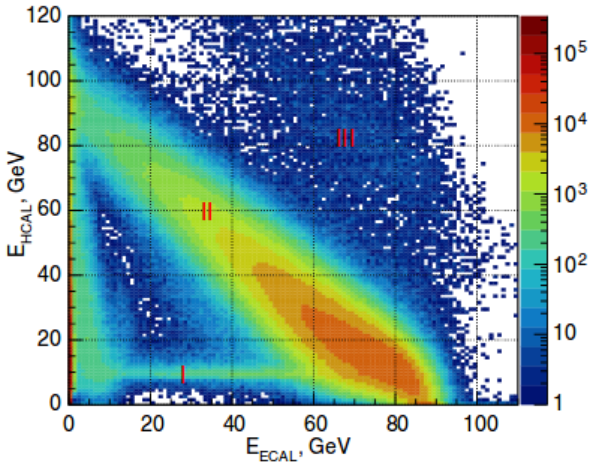


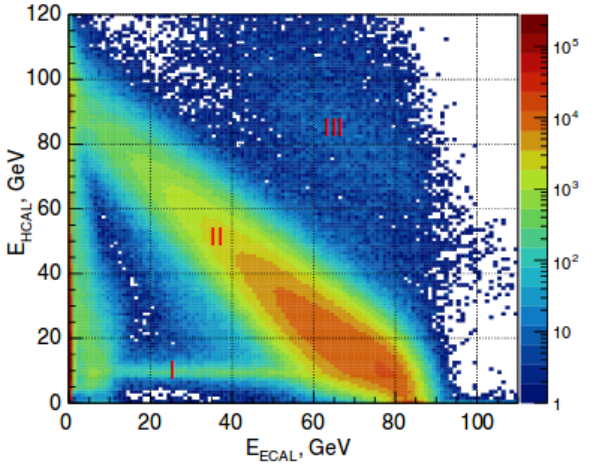
Electron selection with SRD

- **Region I:** e- Z → e-Zγ; γ → μ+μ- → benchmark for MC
- **Region II:** SM events $E_{ECAL} + E_{HCAL} \simeq 100$ GeV
- **Region III** —> pile-up events

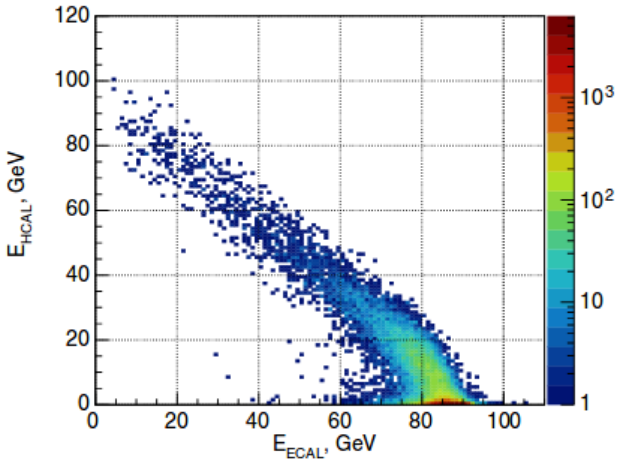
Effects of the cuts

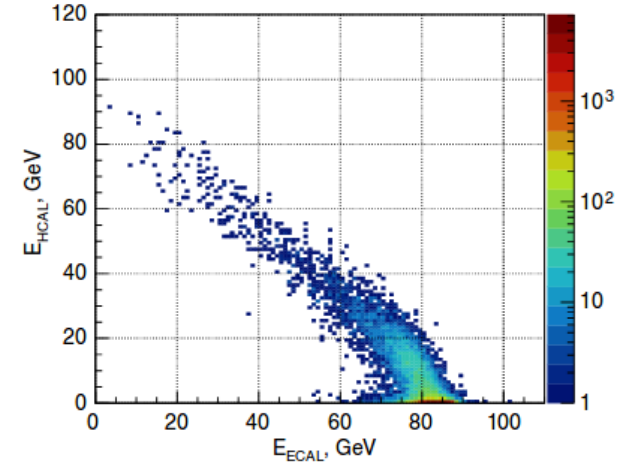
Trigger event



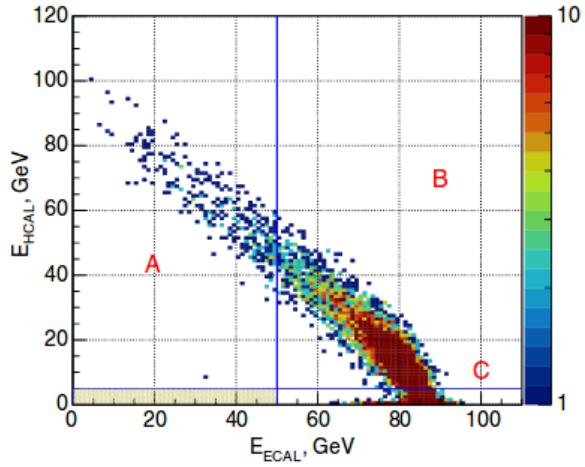


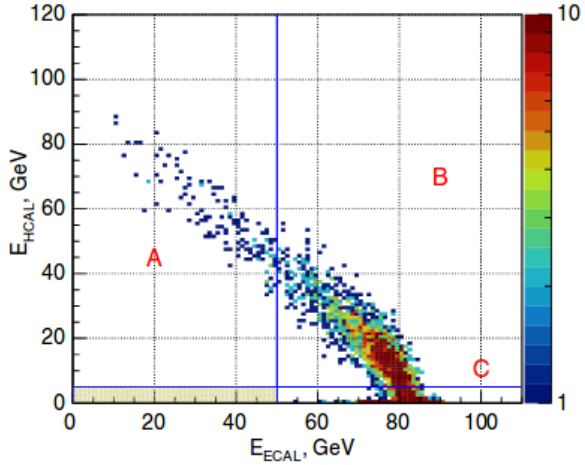
SRD,Momentum,Veto Pileup rejection



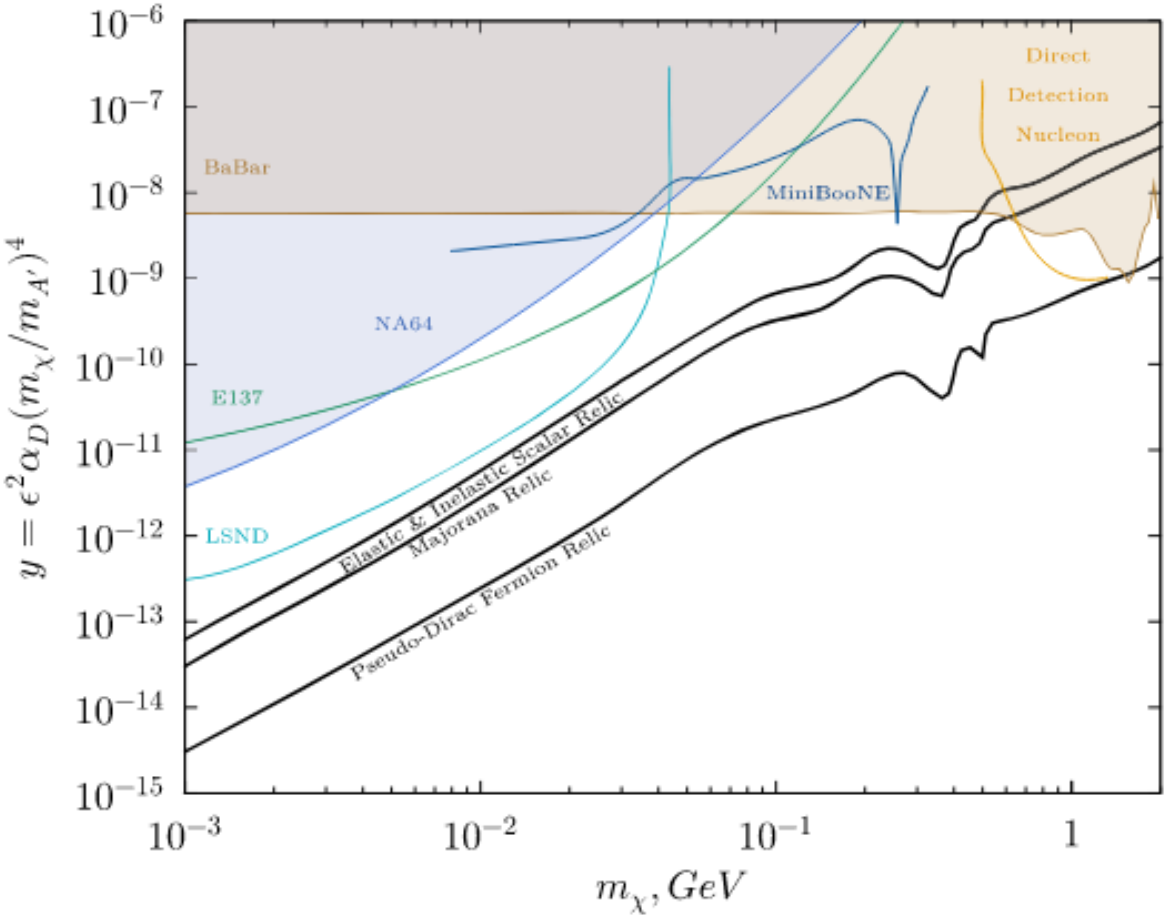


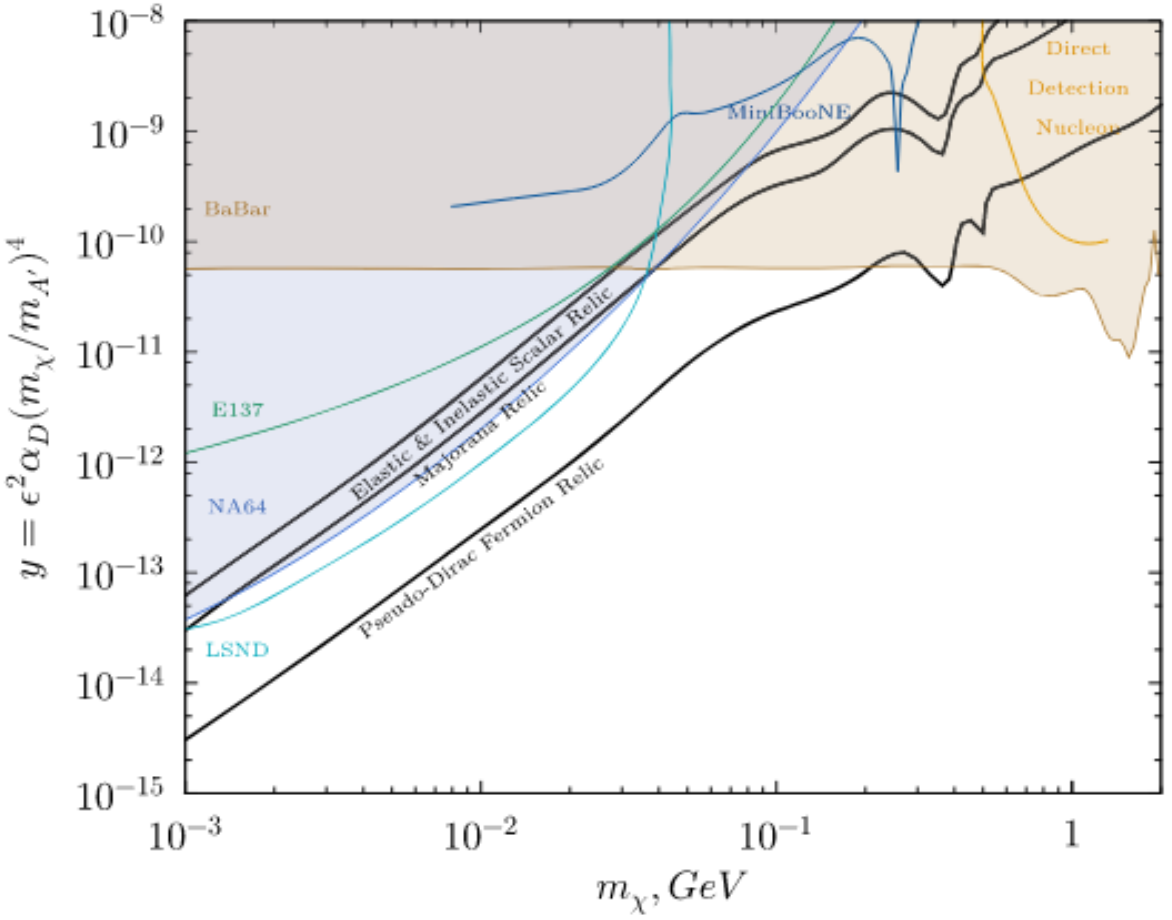
ALL cuts applied



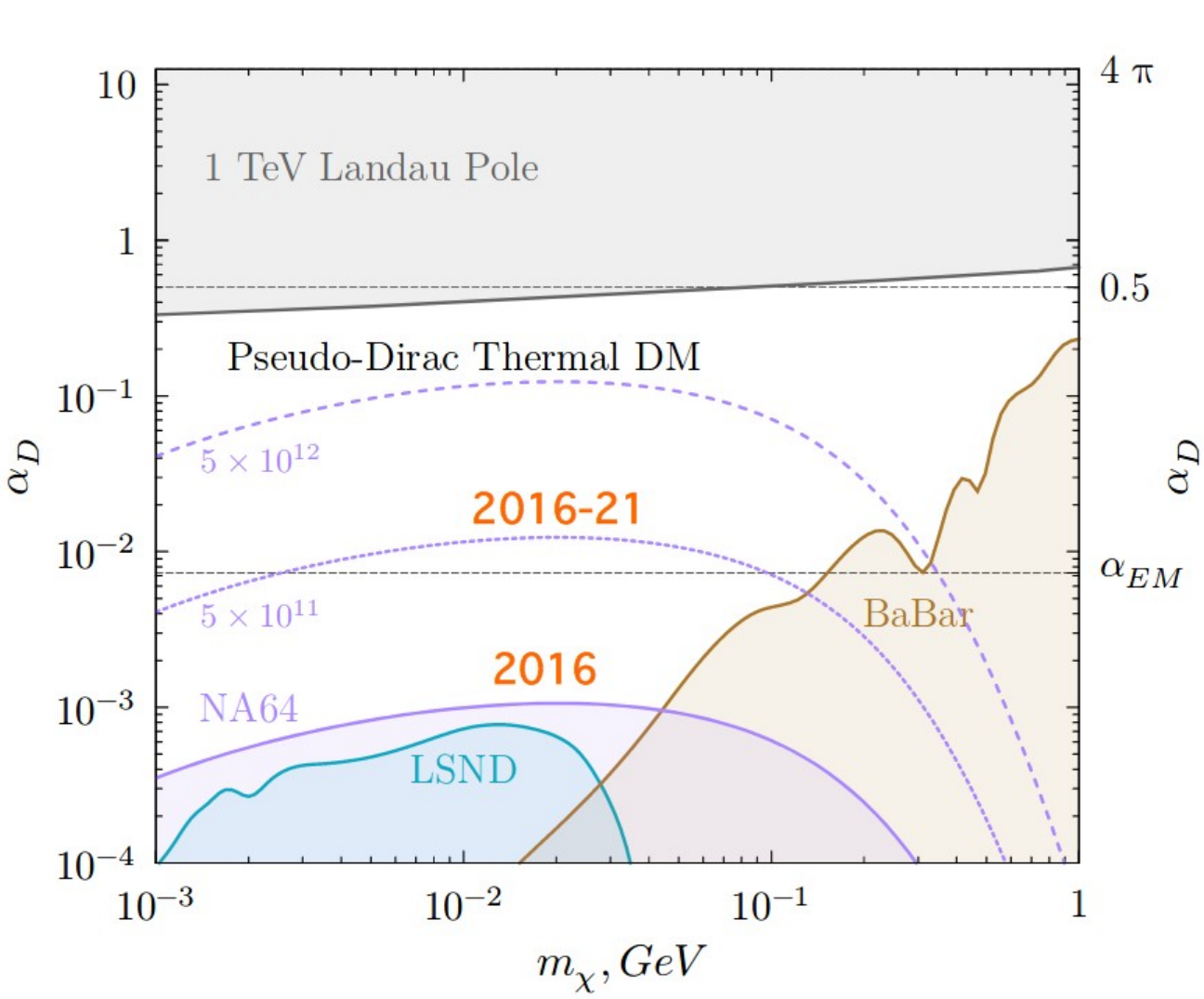


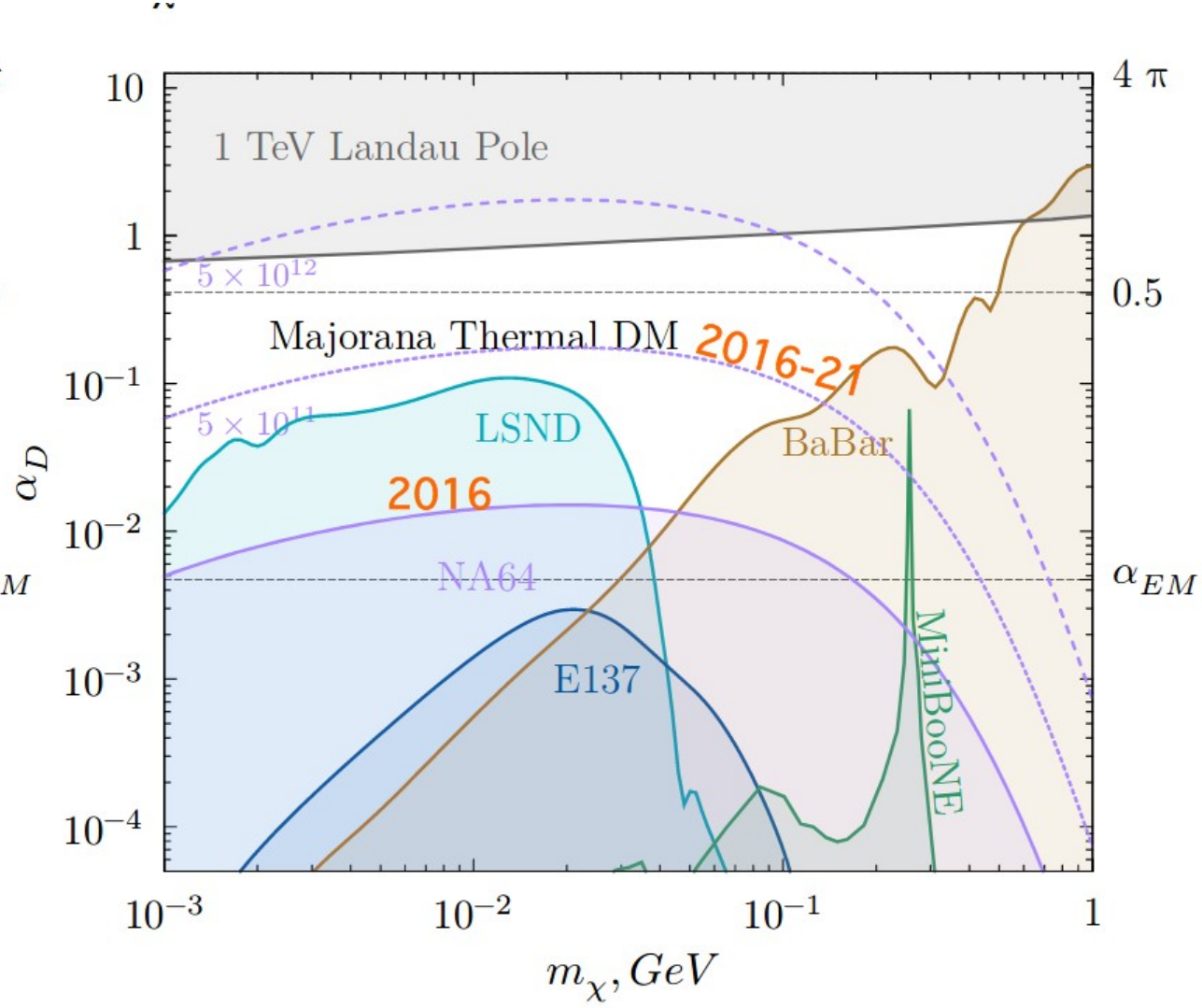
Constraint on light thermal Dark matter





Constraint on light thermal Dark matter

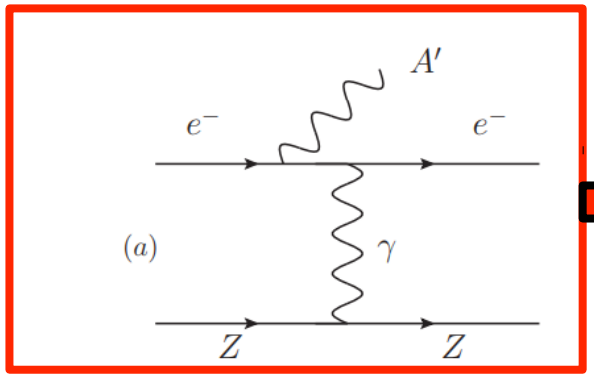




The NA64 physics prospects – further correction of sensitivity?

→ **Possible other corrections for the interaction** $e^- \rightarrow A' \rightarrow \chi\bar{\chi}$

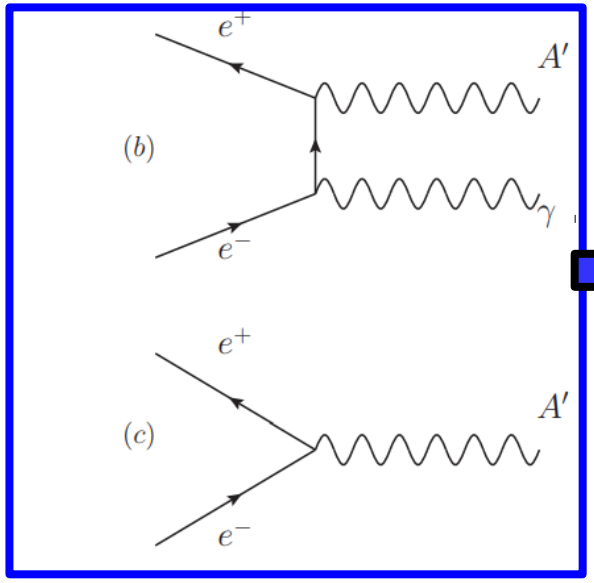
A' strahlung



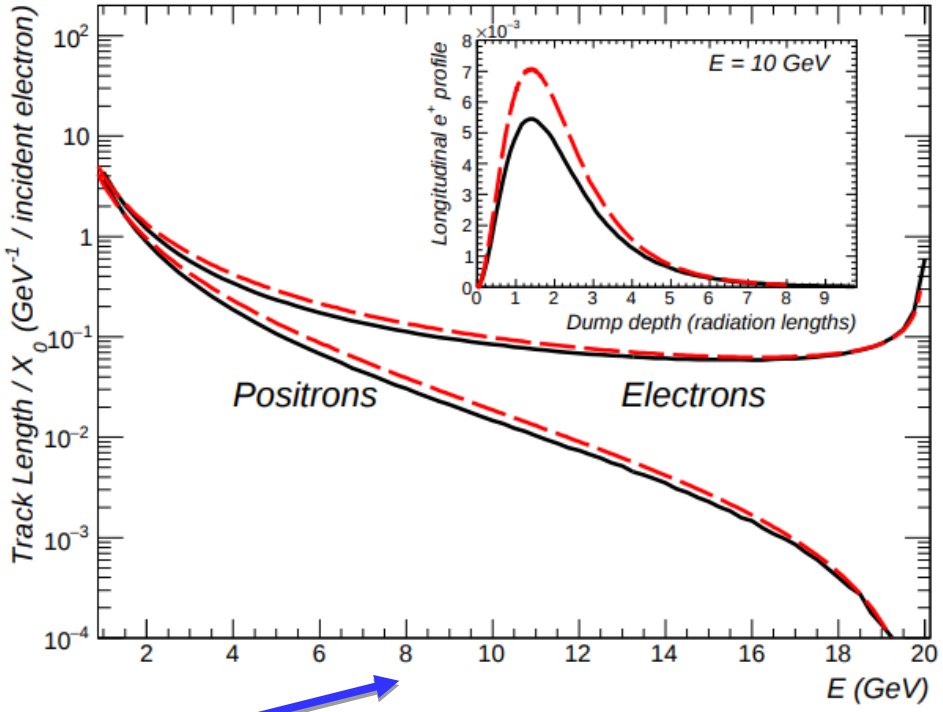
already accounted at tree level

Aresonant production

Resonant production



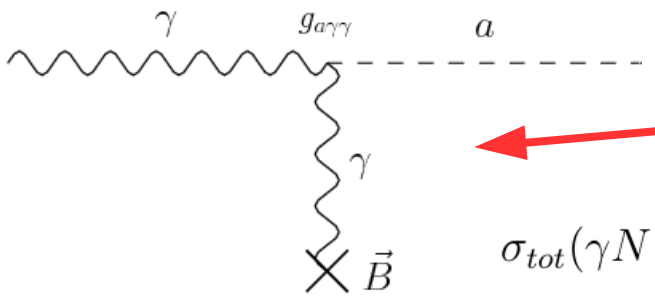
Could be significant due to positron rich environment



L.Marsicano et al. arXiv 1802.03794

ALPS detection in NA64

→ **NA64 setup is capable to search for axion-like particles created through Primankov effect using decay channels a → γγ and a → e + e −**



$$\mathcal{L}_{int} \supset -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{1}{2}(\partial_\mu a)^2 - \frac{1}{2} m_a^2 a^2$$

$$\sigma_{tot}(\gamma N \to aN) = \frac{16\pi\alpha}{m_a^3} \cdot \Gamma_{a\to\gamma\gamma} \cdot \left[Z^2 \ln(184 Z^{-1/3}) + Z \ln(1194 Z^{-2/3})\right]$$

- **Decay length:**

$$l_a = 40\text{m} \cdot \frac{E_a}{10\,\text{GeV}} \cdot \left(\frac{g_{a\gamma\gamma}}{10^{-5}\,\text{GeV}^{-1}}\right)^{-2} \cdot \left(\frac{m_a}{100\,\text{MeV}}\right)^{-4}$$

- **Decay width:**

$$\Gamma_{a\to\gamma\gamma} = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$

- **Signal:**

$$N_{sign} = N_{eff}^{\gamma} \cdot \Delta X_{eff}^{\gamma} \cdot \frac{\rho N_A}{A} \cdot \sigma_{tot}(\gamma N \to aN) \exp\left(-\frac{L_{dec}}{l_a}\right)\left[1 - \exp\left(-\frac{L_{fid}}{l_a}\right)\right]$$

Constraint on ALPS

$10^{-4} < g_{ayy} < 10^{-2}$

$10 < m_a < 500$ MeV