SEARCHING FOR HIDDEN SECTORS WITH THE NA64 EXPERIMENT AT THE CERN SPS

Paolo Crivelli, ETH Zurich, Institute for Particle Physics and Astrophysics

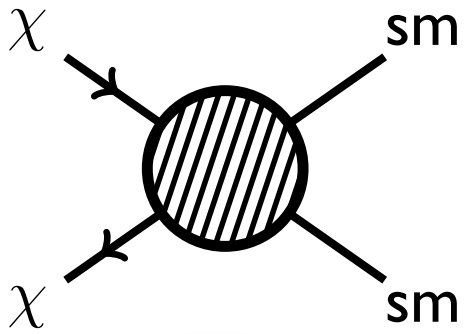
Complementary approaches for DM searches

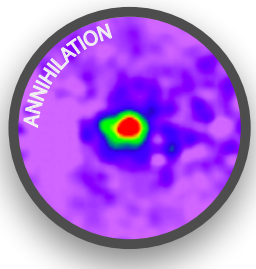
recent review https://arxiv.org/pdf/1707.04591.pdf

Dark Matter — **Mediator** — **Standard Model**

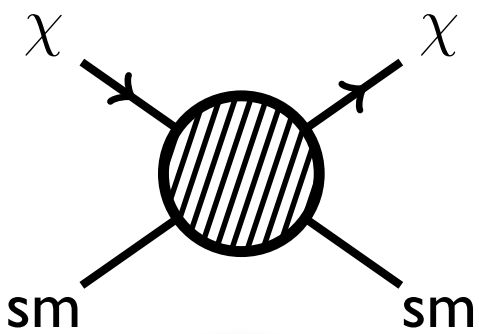
Dark matter searches related by crossing symmetry:

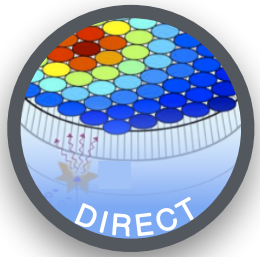
INDIRECT



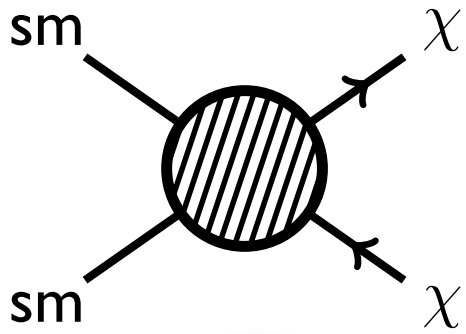


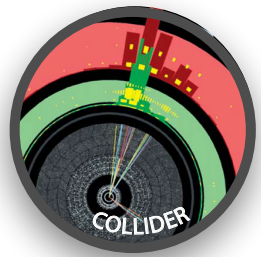
DIRECT





ACCELERATORS



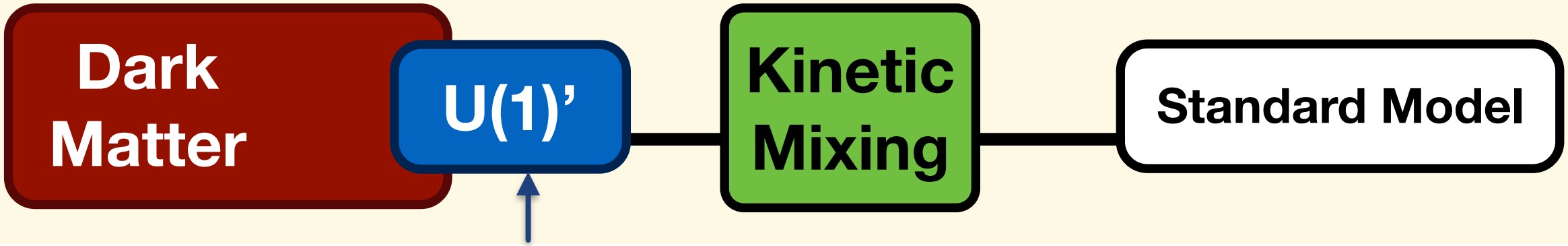


Renormalizable Portals

B. Batell, M. Pospelov and A. Ritz, Phys. Rev. D80 (2009) 095024.

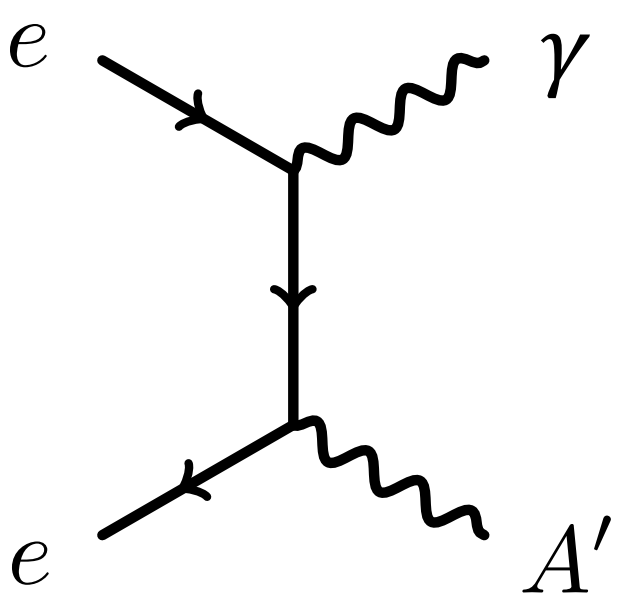
- "Axion" $\frac{1}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu} a$ axions & axion-like particles (ALPs)
- "Higgs" $\lambda H^2 S^2 + \mu H^2 S$ exotic Higgs decays?
- "Vector" $\epsilon F^{Y,\mu\nu} F'_{\mu\nu}$ dark photon A′
- "Neutrino" $\kappa (HL) N$ sterile neutrinos?

FOCUS OF THIS TALK

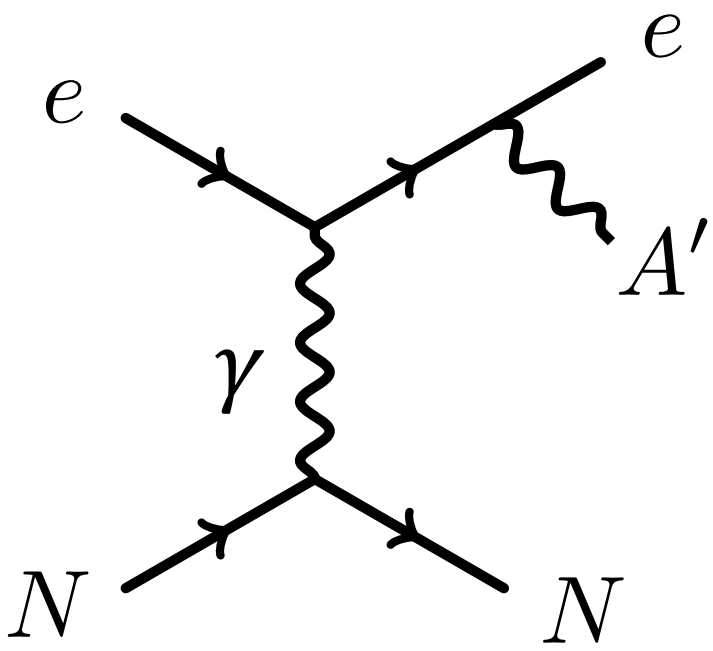


NEW FORCE CARRIED BY MASSIVE **VECTOR** BOSON: **DARK PHOTON**

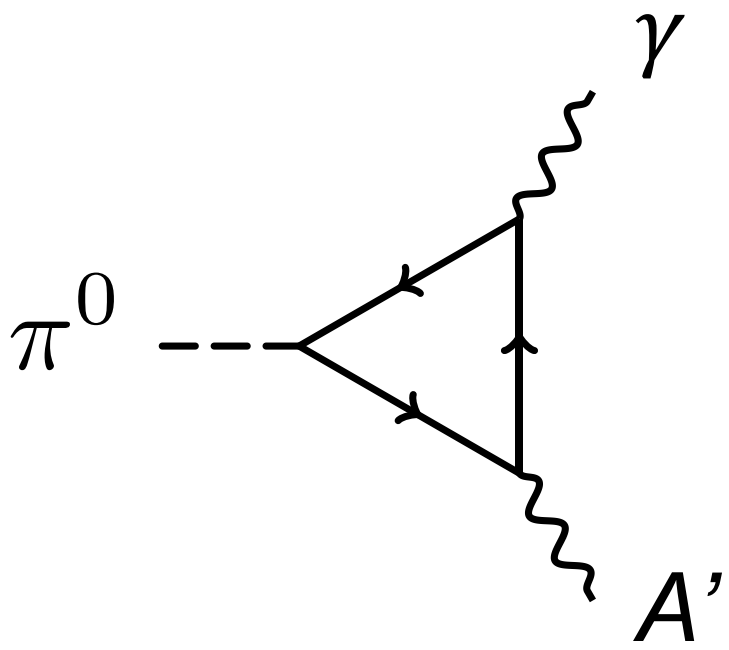
Production of Dark Photons



annihilation



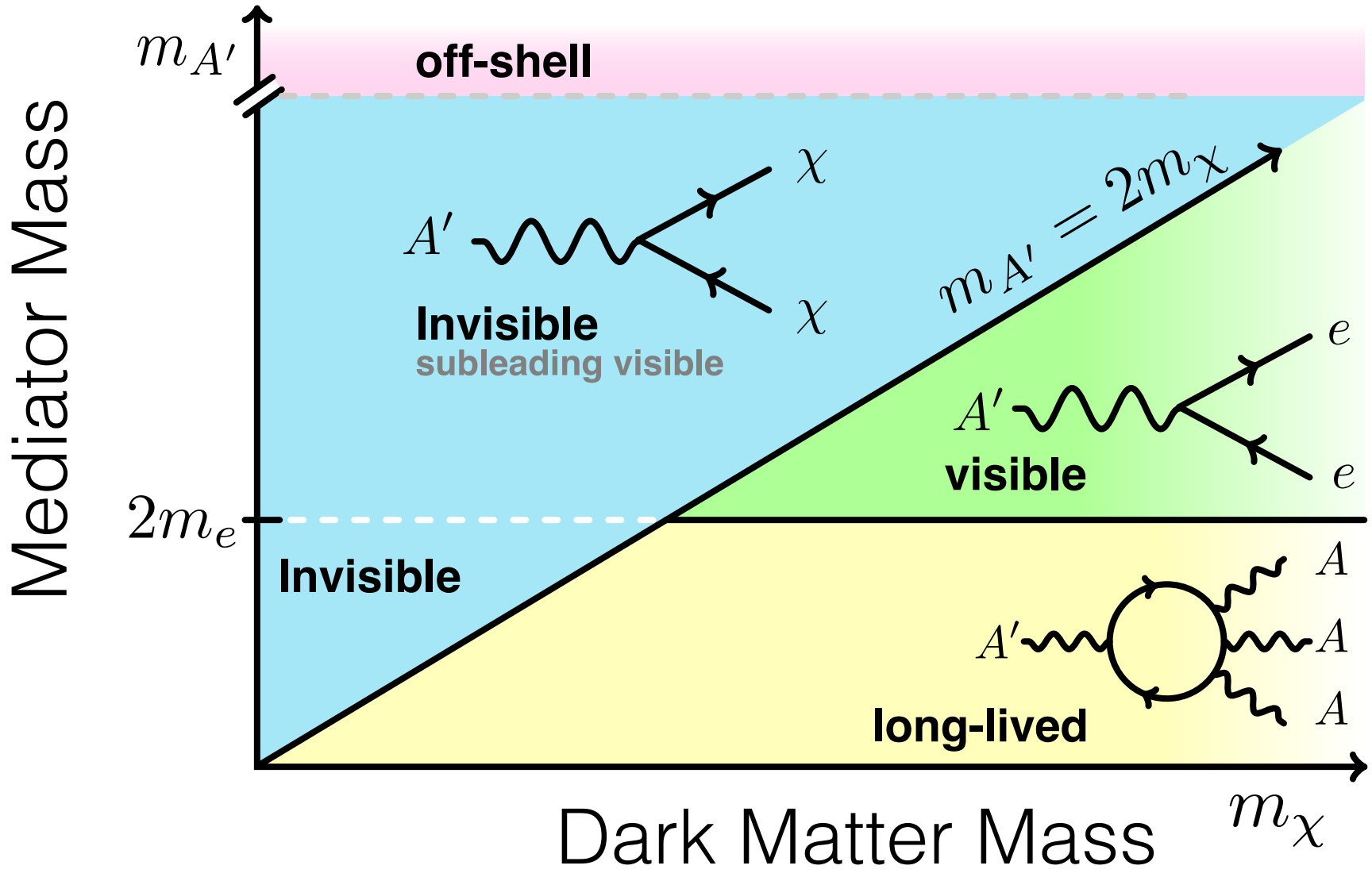
bremsstrahlung



meson decay

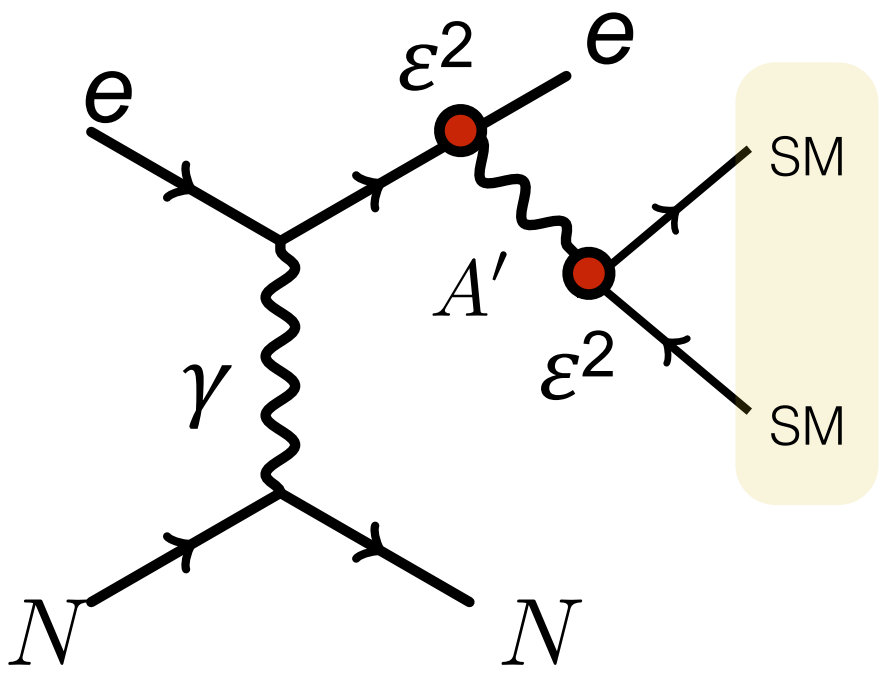
Decays of Dark Photons

Adapted from Natalia Toro, Dark Sectors 2017 (1608.03591)



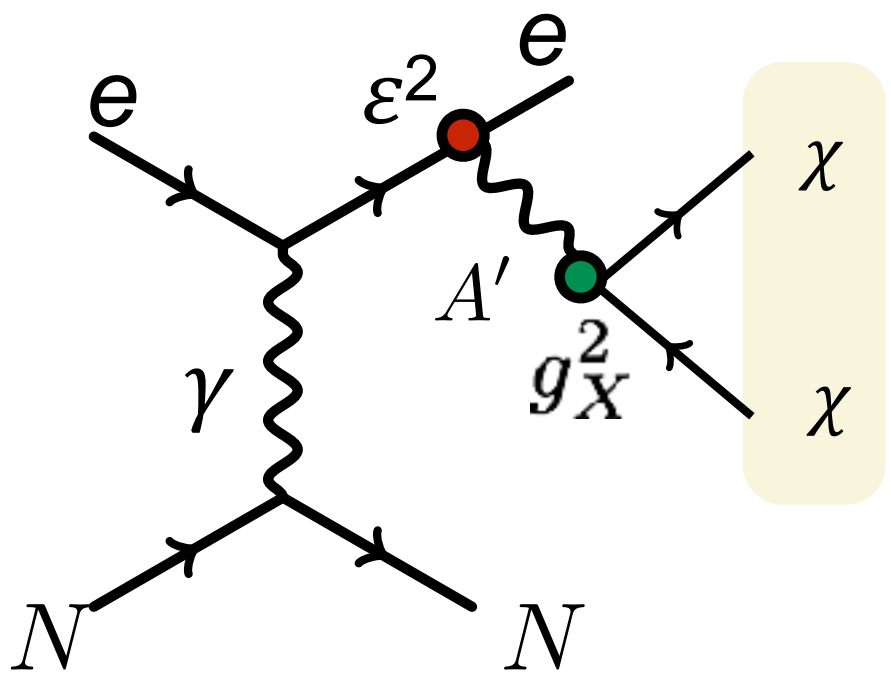
Signatures for Dark Photons production at Fixed target exp.

VISIBLE DECAY MODE $m'_A < 2m_\chi$



Pair production of SM particles

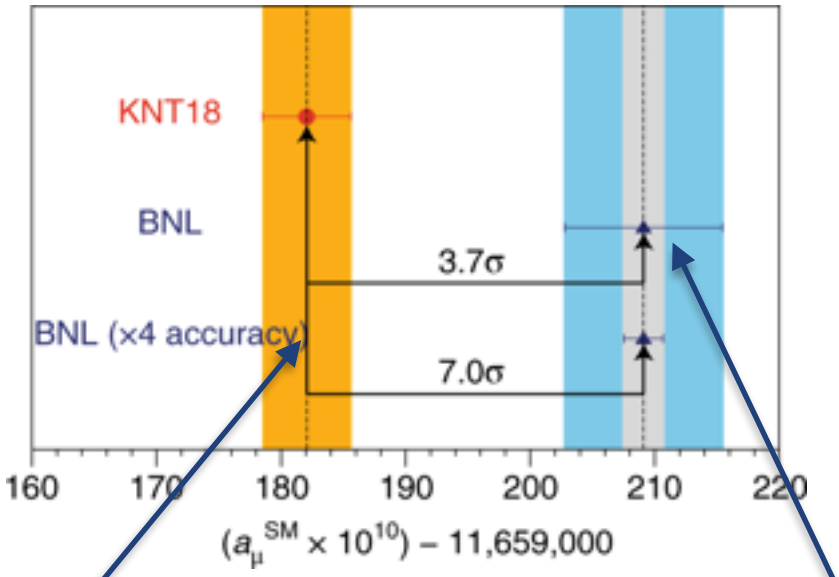
INVISIBLE DECAY MODE $m'_A > 2m_\chi$



Missing Energy/momentum

The muon (g-2): an additional motivation to search for dark photons

https://www.nature.com/articles/s41567-018-0341-3

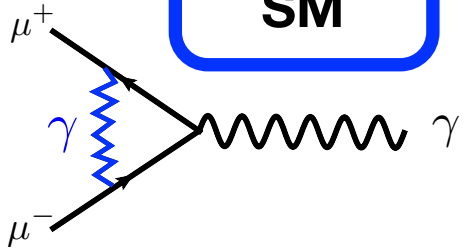


THEORY

BNL EXPERIMENT

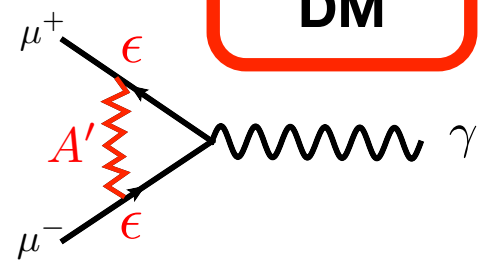
NEW EXP. ongoing@Fermilab

SM



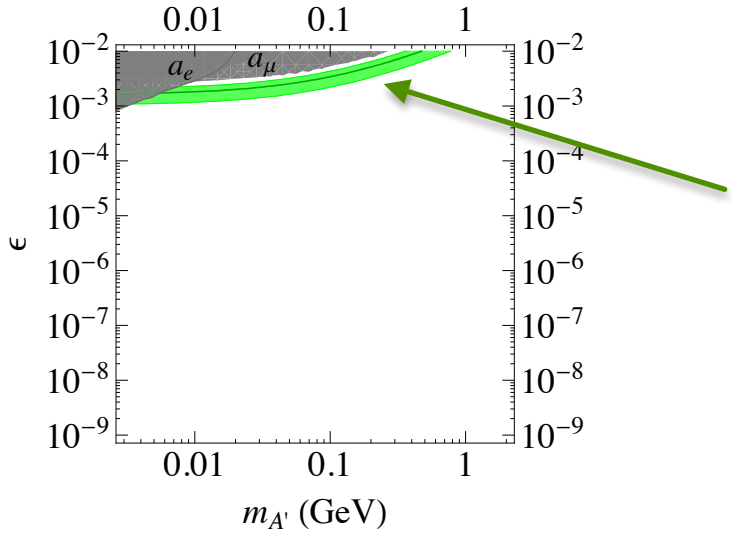
$$(g_s - 2)_\mu^\gamma \simeq \frac{\alpha}{2\pi} \simeq 10^{-3}$$

DM



$$(g_s - 2)_\mu^{A'} \simeq \frac{\alpha}{2\pi} \times \epsilon^2 \simeq 10^{-3} \times \epsilon^2 \qquad (m_{A'} \ll m_\mu)$$

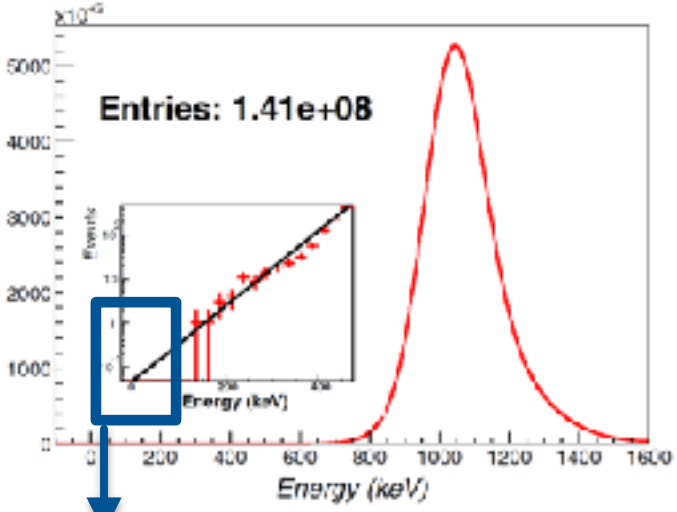
M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662, 53 (2008)

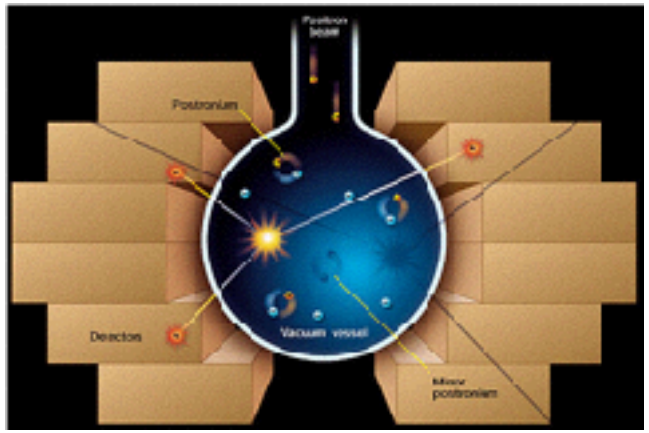


A' may explain observed anomaly

From positronium (search for massless dark photon) → NA64

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





Signature: disappearance of 1 MeV energy

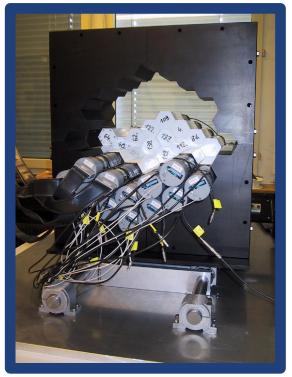


Table top

IPA ETH zürich

At rest → 100 GeV

A. Badertscher, P. Crivelli et al., Phys. Rev. D. 75, 032004 (2007)
NEW results 2018 C. Vigo, L. Gerchow, L. Liszkay, A. Rubbia, P. Crivelli,PRD97,092008

The NA64 collaboration (46 researchers from 13 Institutes)

D. Banerjee[k], J. Bernhard[d], V.E. Burtsev[j], A.G. Chumakov[j], P. Crivelli[m], E. Depero[m], A. Dermenev[e], S.V. Donskov[i], R. Dusaev[j], T. Enik[b], V. Frolov[b], A. Gardikiotis[h], S.Gerassimov[c,f], S.N. Gninenko[e], M. Hösgen[a], A. Karneyeu[e], G. Kekelidze[b], B. Ketzer[a], D. Kirpichnikov[e], M.M. Kirsanov[e], I.V. Konorov[c,f] S.G. Kovalenko[l], V.A. Kramarenko[b,g], L.V. Kravchuk[e], N.V. Krasnikov[e], S.V. Kuleshov[l], V.E. Lyubovitskij[j,l], V.M. Lysan[b], V.A. Matveev[b], Yu.V. Mikhailov[i], L. Molina-Bueno[m], D.V. Peshekhonov[b], V.A. Polyakov[i], B. Radics[m], A. Rubbia[m], V.D. Samoylenko[i], D. Shchukin[f], V.O. Tikhomirov[f], D.A. Tlisov[e], A.N. Toropin[e], A.Yu. Trifonov[j], P. Ulloa[l], B.I. Vasilishin[j], B.M. Veit[d], P.V. Volkov[b,g], and V.Yu. Volkov[g]

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NA64 spokesperson

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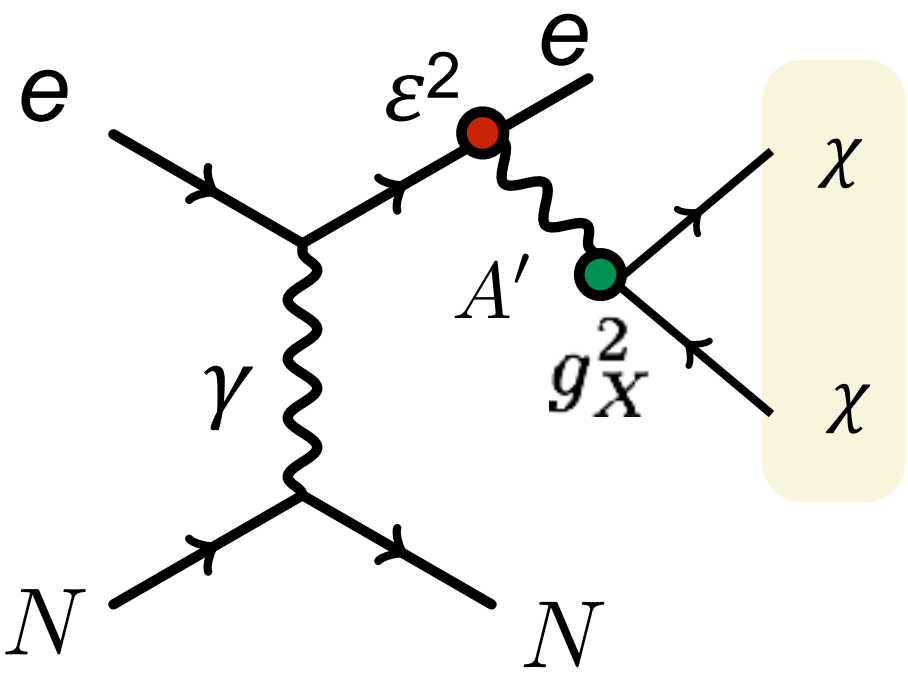
[b] *Joint Institute for Nuclear Research, 141980 Dubna, Russia*
[c] *Technische Universität München, Physik Dept., 85748 Garching, Germany*
[d] *CERN, European Organization for Nuclear Research, CH-1211 Geneva, Switzerland*
[e] *Institute for Nuclear Research, 117312 Moscow, Russia*
[f] *P.N. Lebedev Physics Institute, Moscow, Russia, 119 991 Moscow, Russia*
[g] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
[h] *Physics Department, University of Patras, Patras, Greece*
[i] *State Scientific Center of the Russian Federation Institute for High Energy Physics of National Research Center 'Kurchatov Institute' (IHEP), 142281 Protvino, Russia*
[j] *Tomsk State Pedagogical University, 634061 Tomsk, Russia*
[k] *University of Illinois, Urbana Champaign, Illinois, USA*
[l] *Universidad Técnica Federico Santa María, 2390123 Valparaíso, Chile*
[m] *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.

1) The NA64 search for A' → χχ̄

INVISIBLE DECAY MODE $m'_A > 2m_\chi$



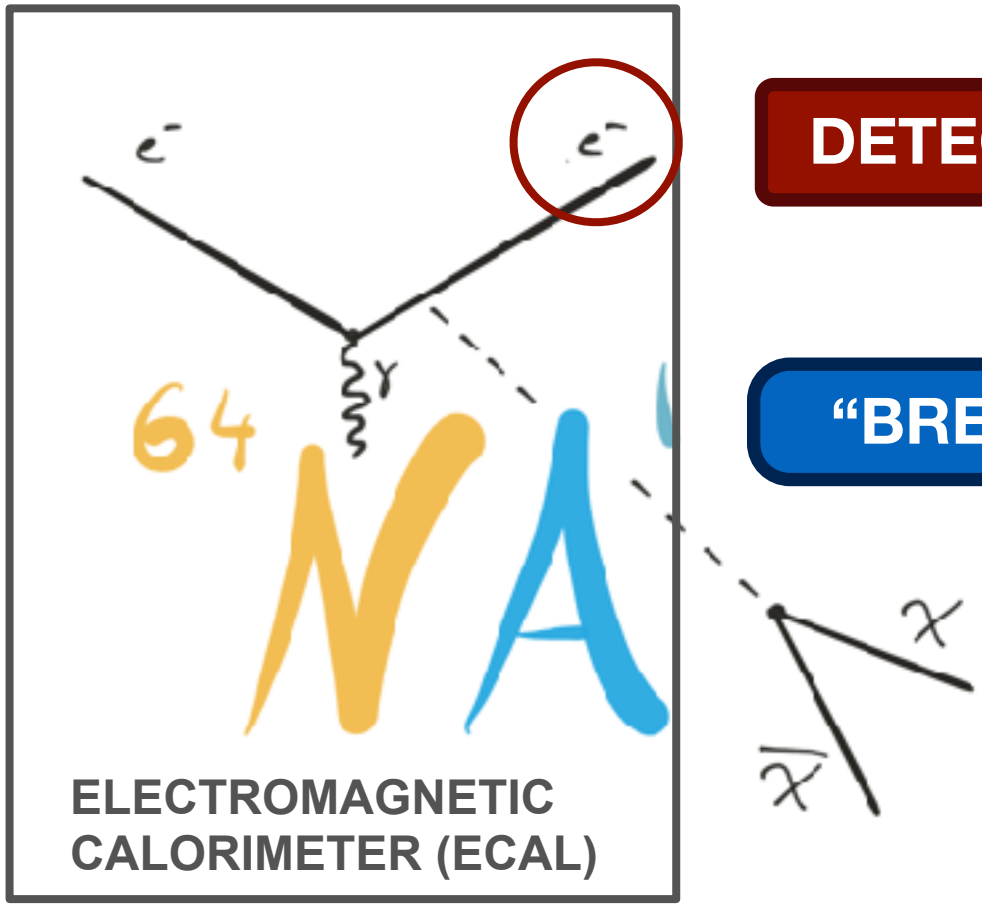
Missing Energy/momentum

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

TAGGED 100 GeV

Special thanks to Lars Gerchow
for helping with our official LOGO

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

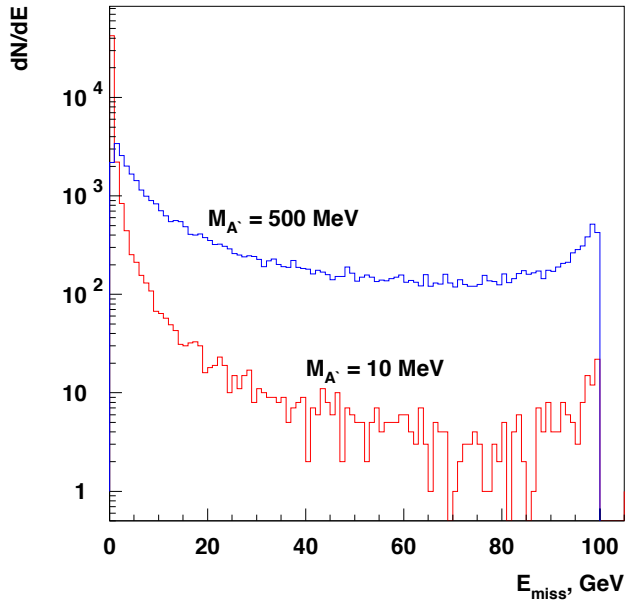


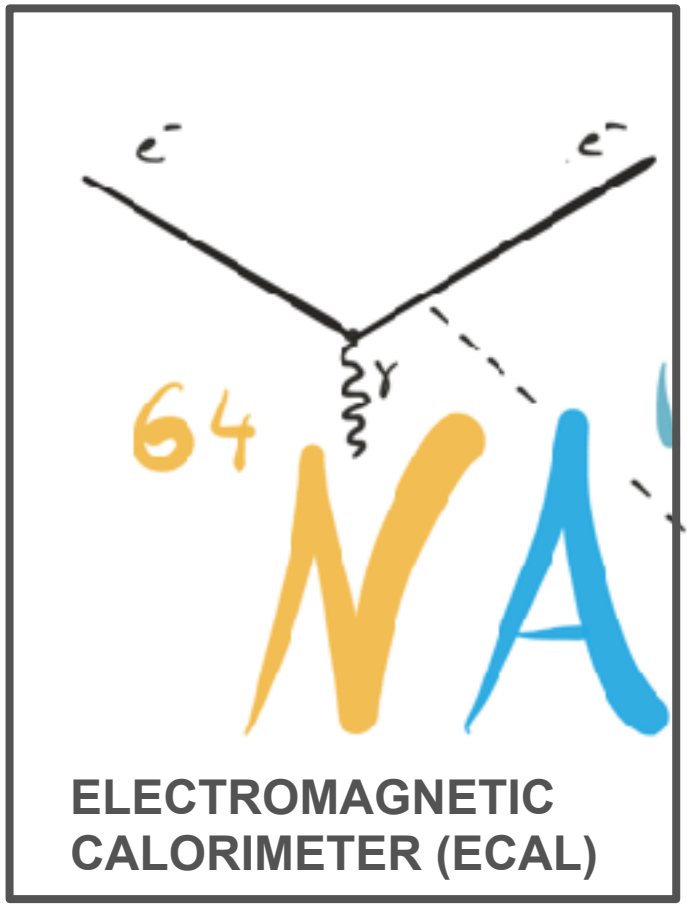
DETECTED ENERGY < 50 GeV

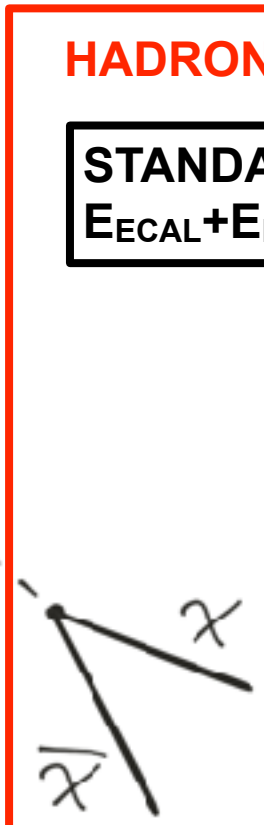
"BREMSSTRAHLUNG" OF A'

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

Simulated A' emission spectrum

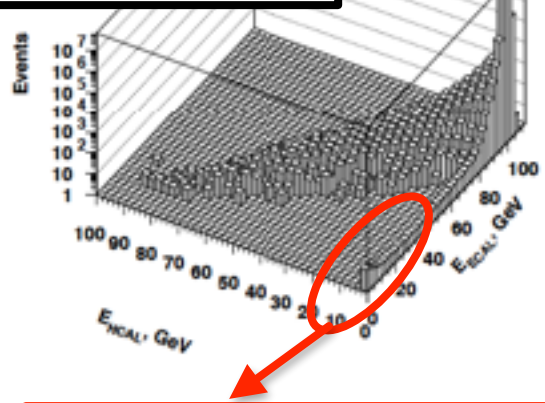






HADRONIC CALORIMETER (HCAL)

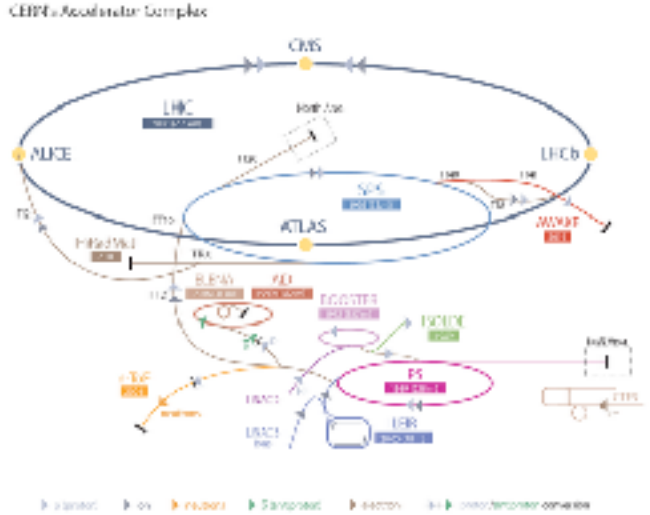
STANDARD MODEL:
$E_{ECAL}+E_{HCAL}$ = 100 GeV



A'→ MISSING ENERGY:
ECAL < 50 GeV
HCAL < 2 GeV

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

The CERN SPS H4 electron beam

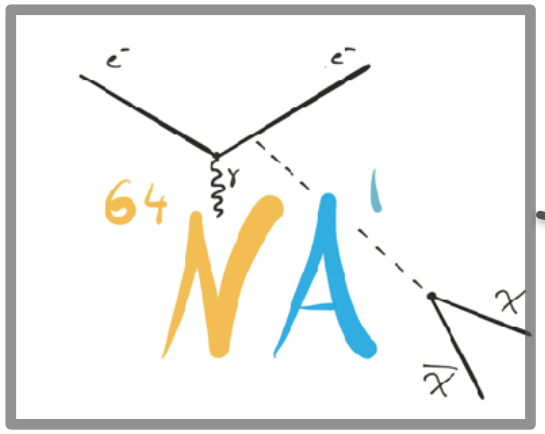


100 GeV electrons (tagged with $S_{1,2,3}$)

- Up to 7x10^6 e$^-$/spill, 2-4 spill/min, spill duration 5s
- Low contamination: π (<1%), μ/K (0.1%)
- Low energy tails (<1%)
- Beam spot of 1.5 cm (FWHM)

30m

The Electromagnetic Calorimeter (ECAL)

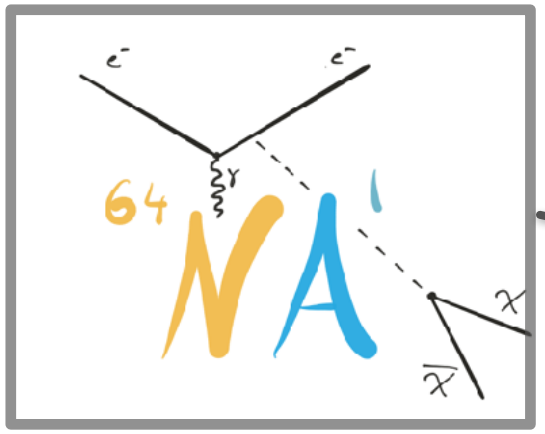


Active target

- 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 Electromagnetic Calorimeter (ECAL)



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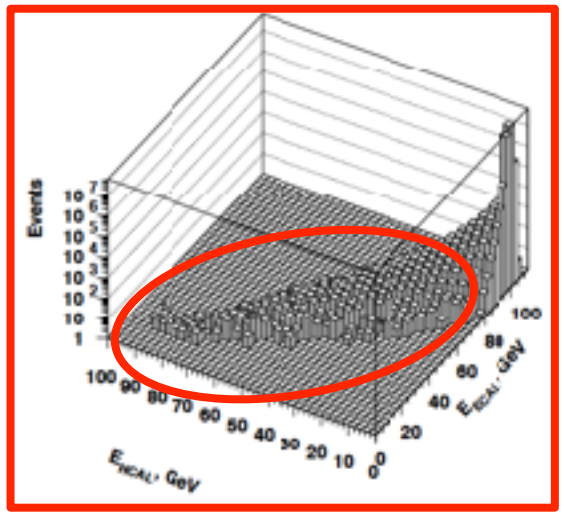
The Hadronic Calorimeter (HCAL)



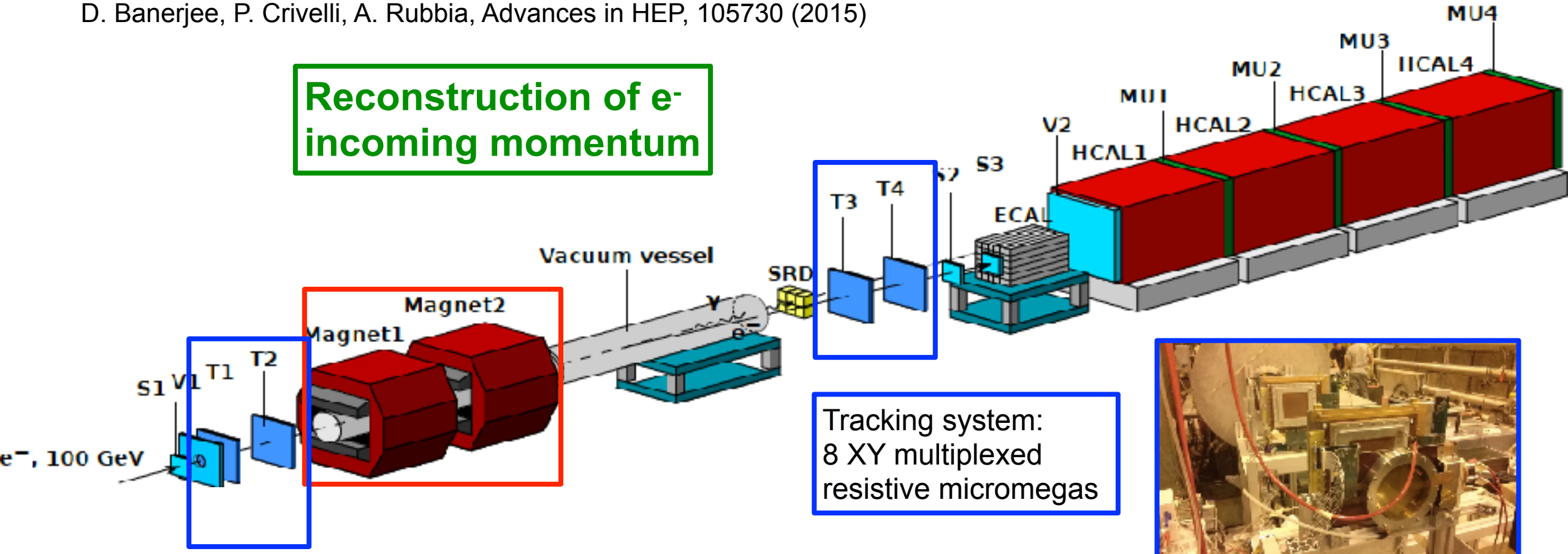
High hermeticity

- High hermeticity : 4 HCAL (~7 λ/module)
- FeSc sandwich 3x3 matrix, cells 19.4x19.2x150 cm^3
- WLS fibers in spiral→ suppress energy leaks
- Energy resolution ~ 60%/√(E[GeV])

The magnetic spectrometer

D. Banerjee, P. Crivelli, A. Rubbia, Advances in HEP, 105730 (2015)

Reconstruction of e⁻ incoming momentum



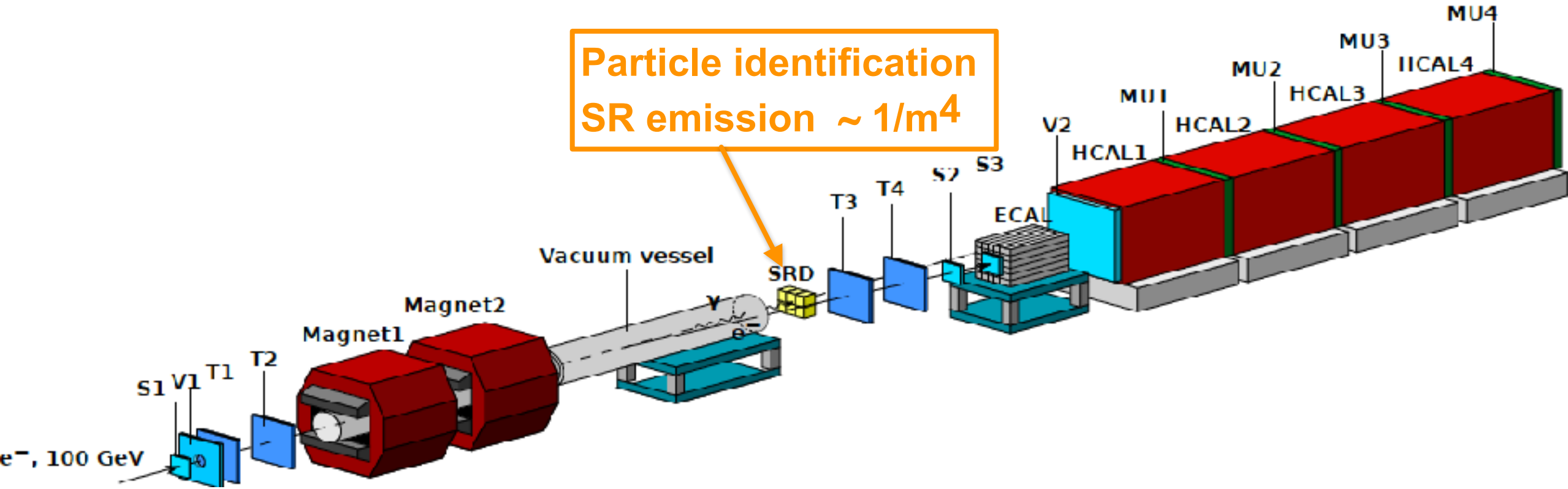
Tracking system:
8 XY multiplexed resistive micromegas

Two bending magnets in series → 7 T.m field

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

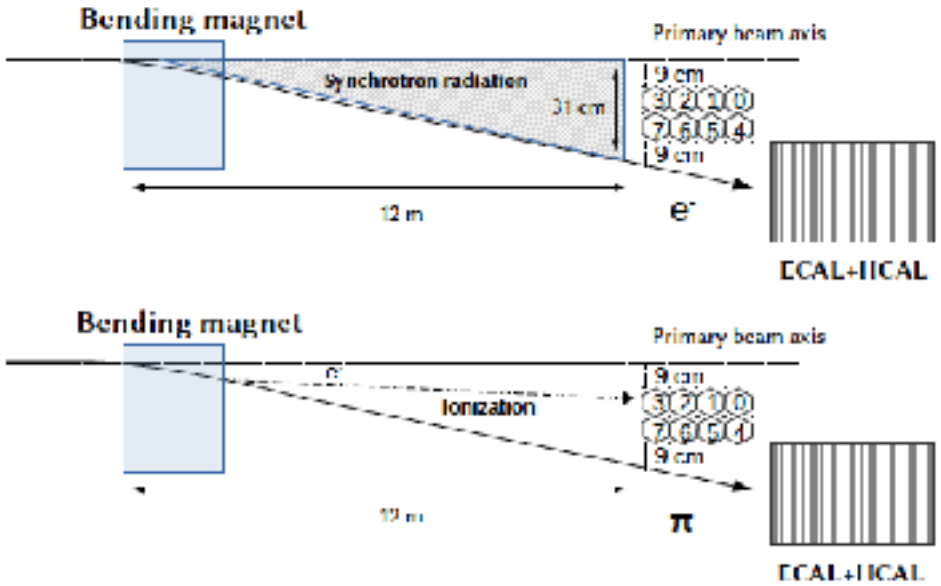
The Synchrotron Radiation (SR) detector

IPA ETH zürich

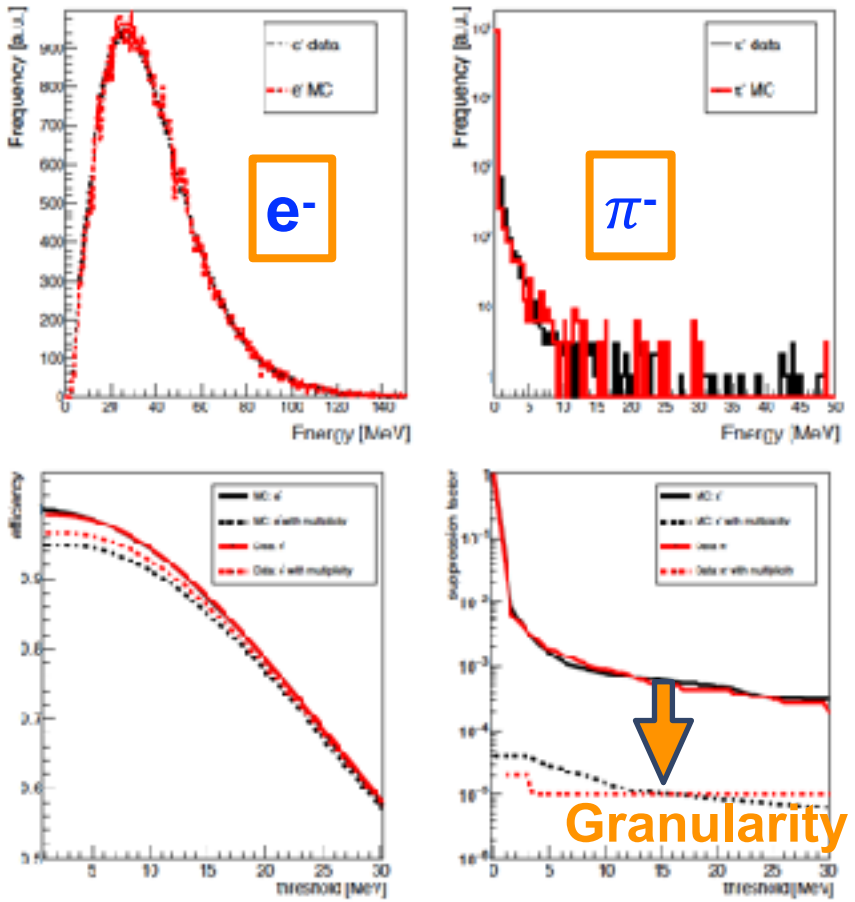


The Synchrotron Radiation (SR) detector

Particle identification
SR emission ~ $1/m^4$

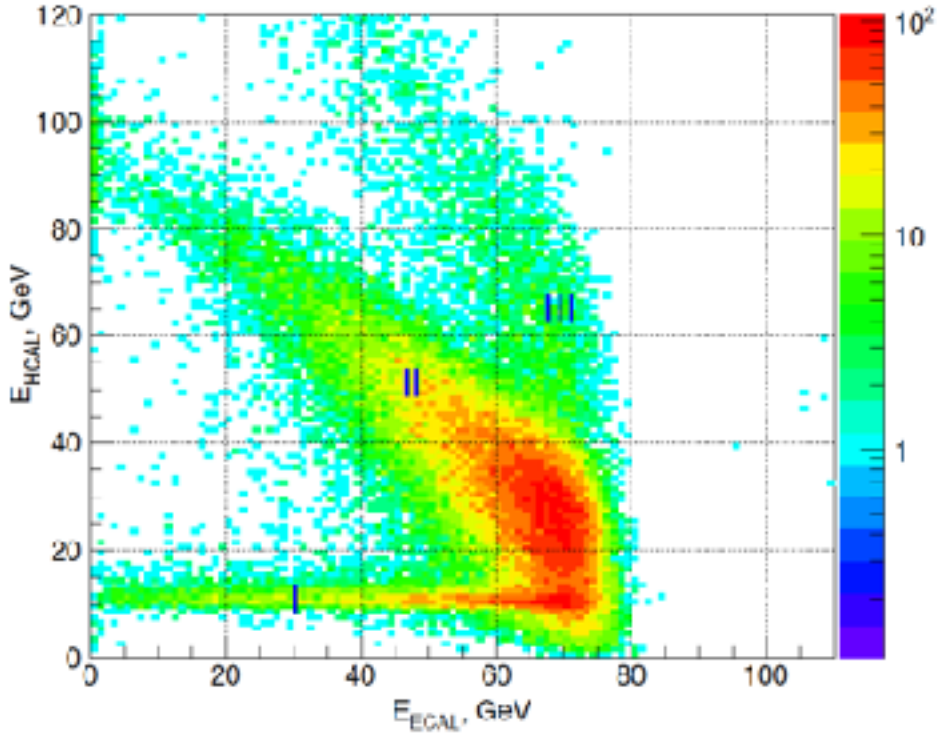


Efficiency > 95%
Suppression >10^{-5}



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

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

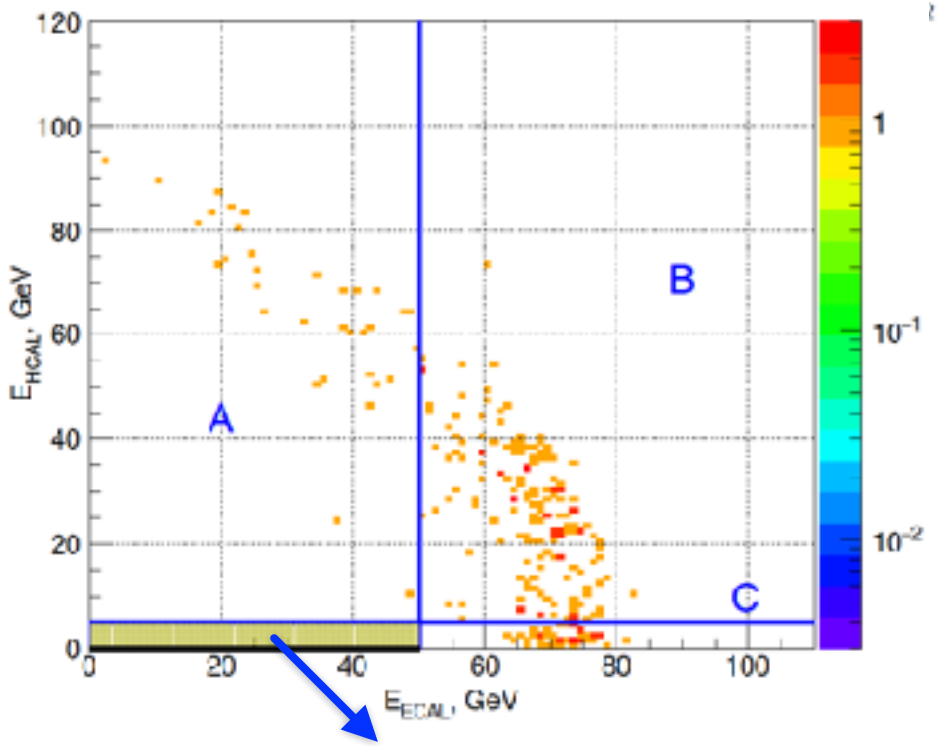


★ **Region I:** e- Z → e-Zγ; γ → μ+μ-
→ benchmark for MC

★**Region II:** SM events
$E_{ECAL} + E_{HCAL} \simeq 100$ GeV

★**Region III** —> pile-up events

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



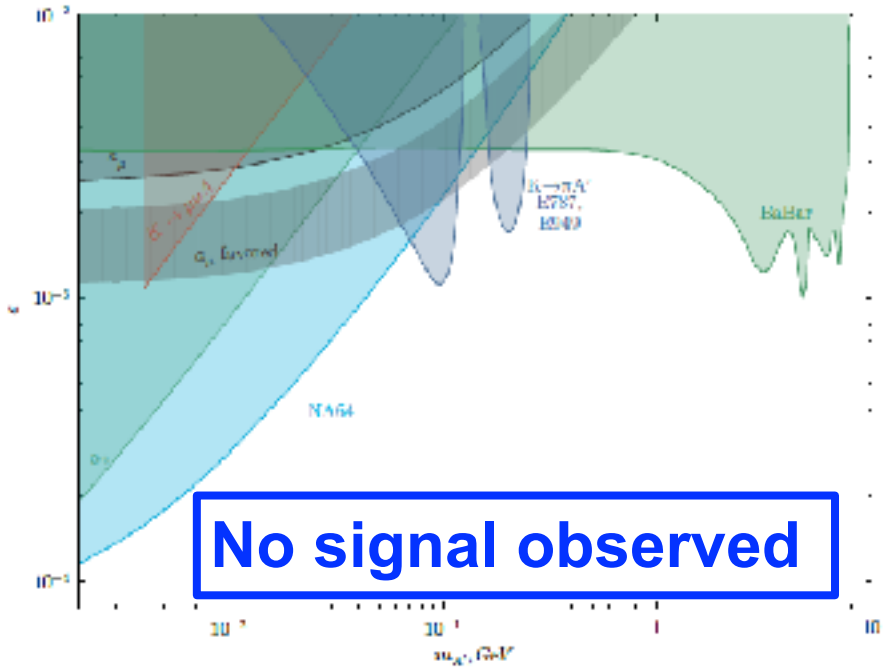
Event Selection Criteria:

- 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



→ exclusion of most of g-2 muon favored region

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

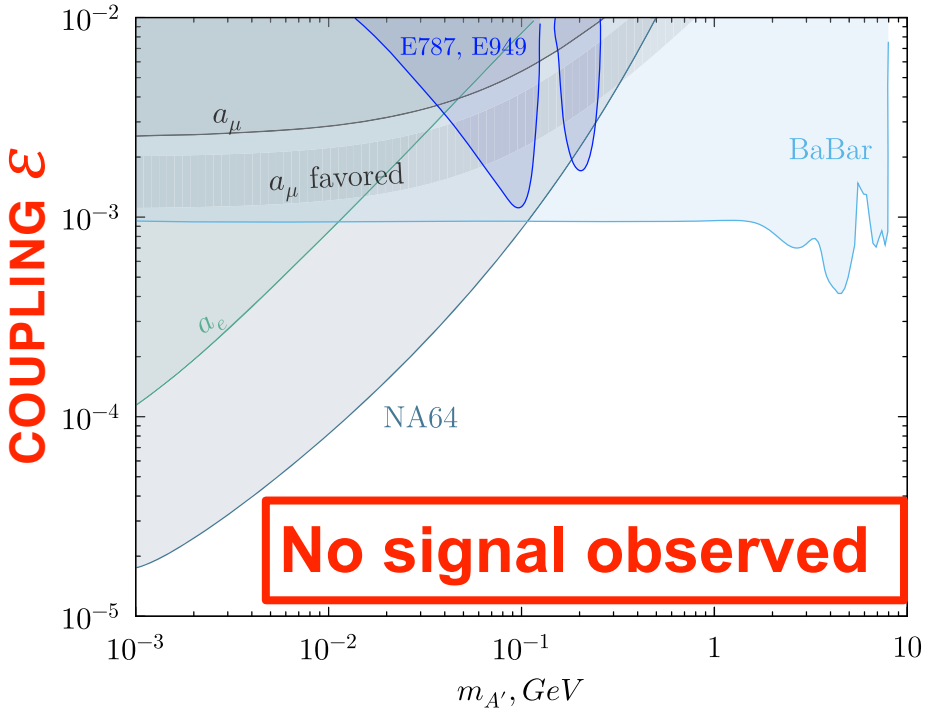
g-2 closed completely by BABAR results

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

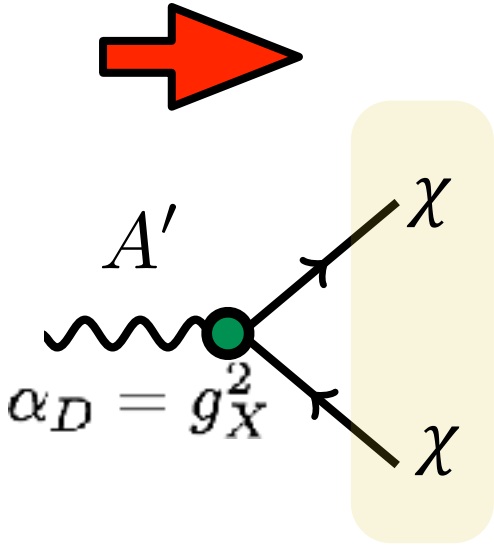
NA64 collaboration, Phys. Rev. Lett. 118, 011802 (2017)

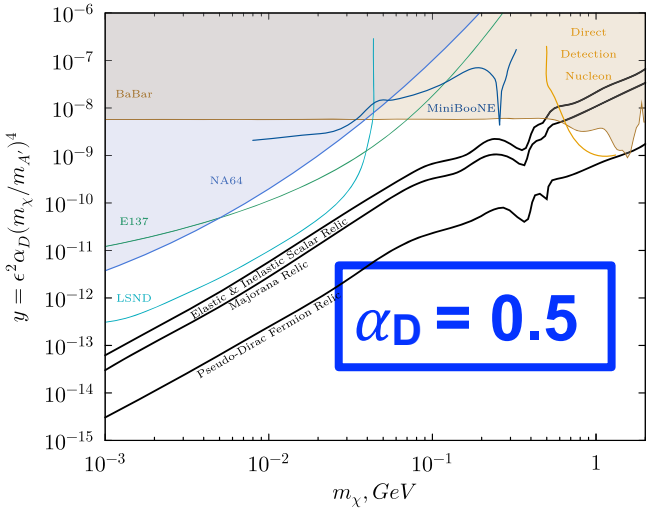
The NA64 search for A' → $\chi\bar{\chi}$ - results (October 2016, 3 weeks)

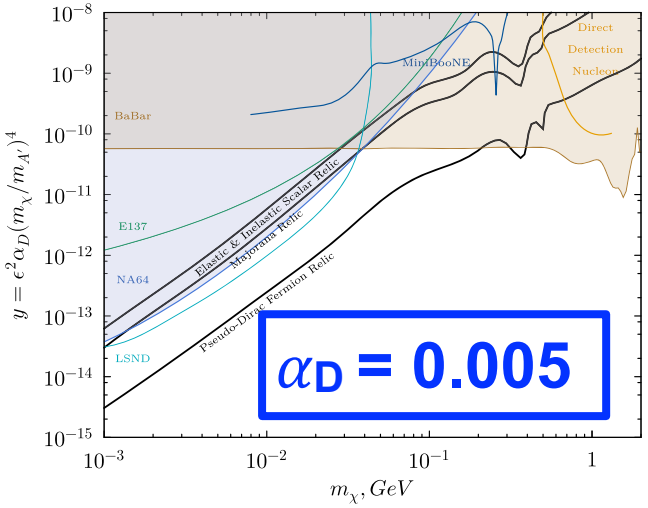
4 x 10^{10} electrons on target



Constraints on light thermal DM



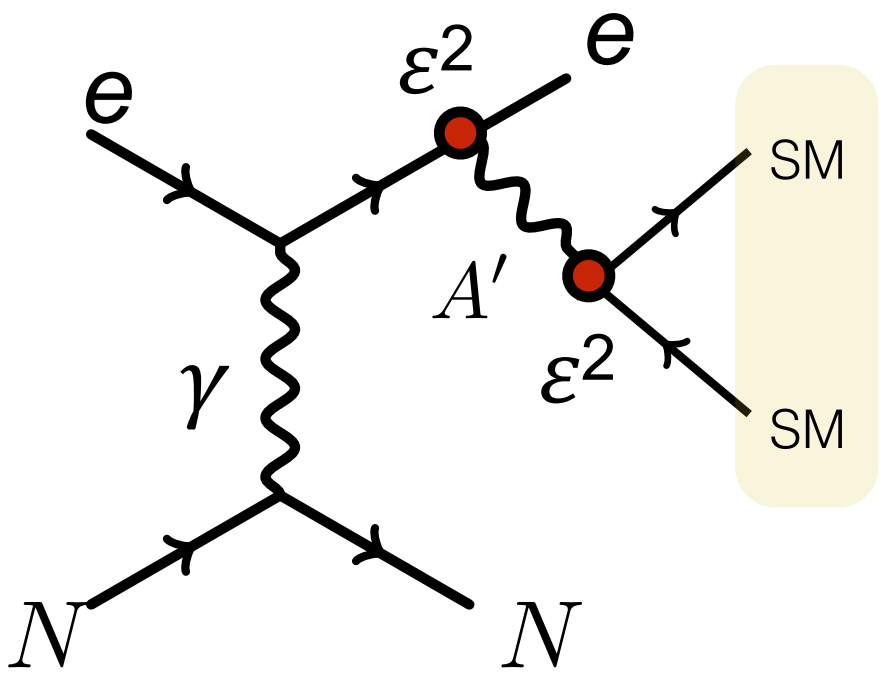




NA64 collaboration, Phys. Rev. D 97, 072002 (2018)

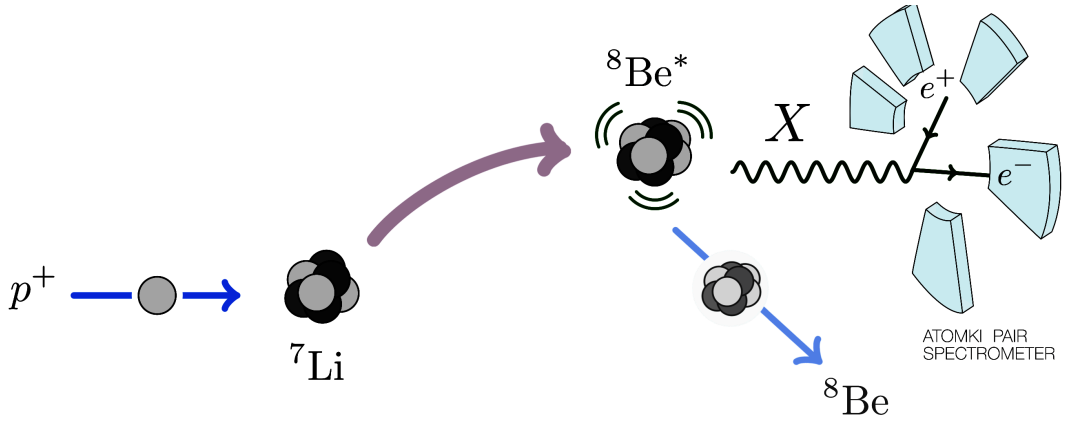
2) The NA64 search for A' → e^+e^-

VISIBLE DECAY MODE $m'_A < 2m_\chi$

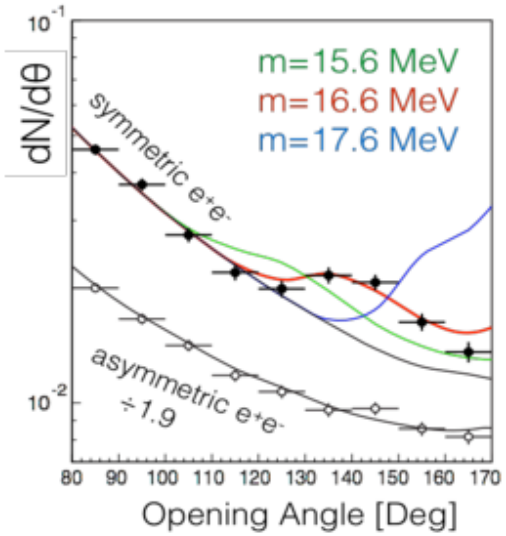


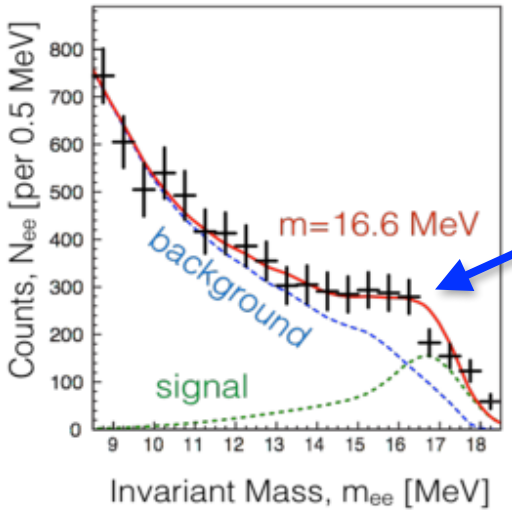
Pair production of SM particles

^{8}Be anomaly and X boson



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

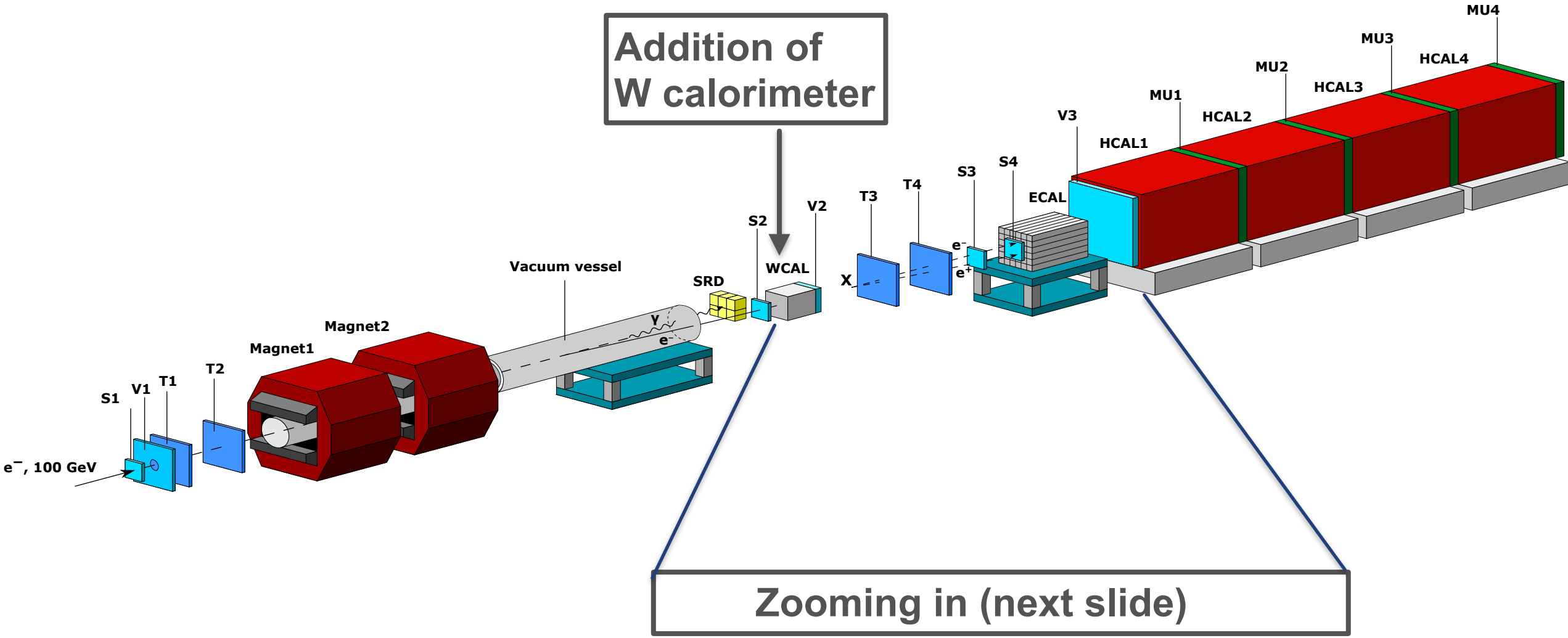




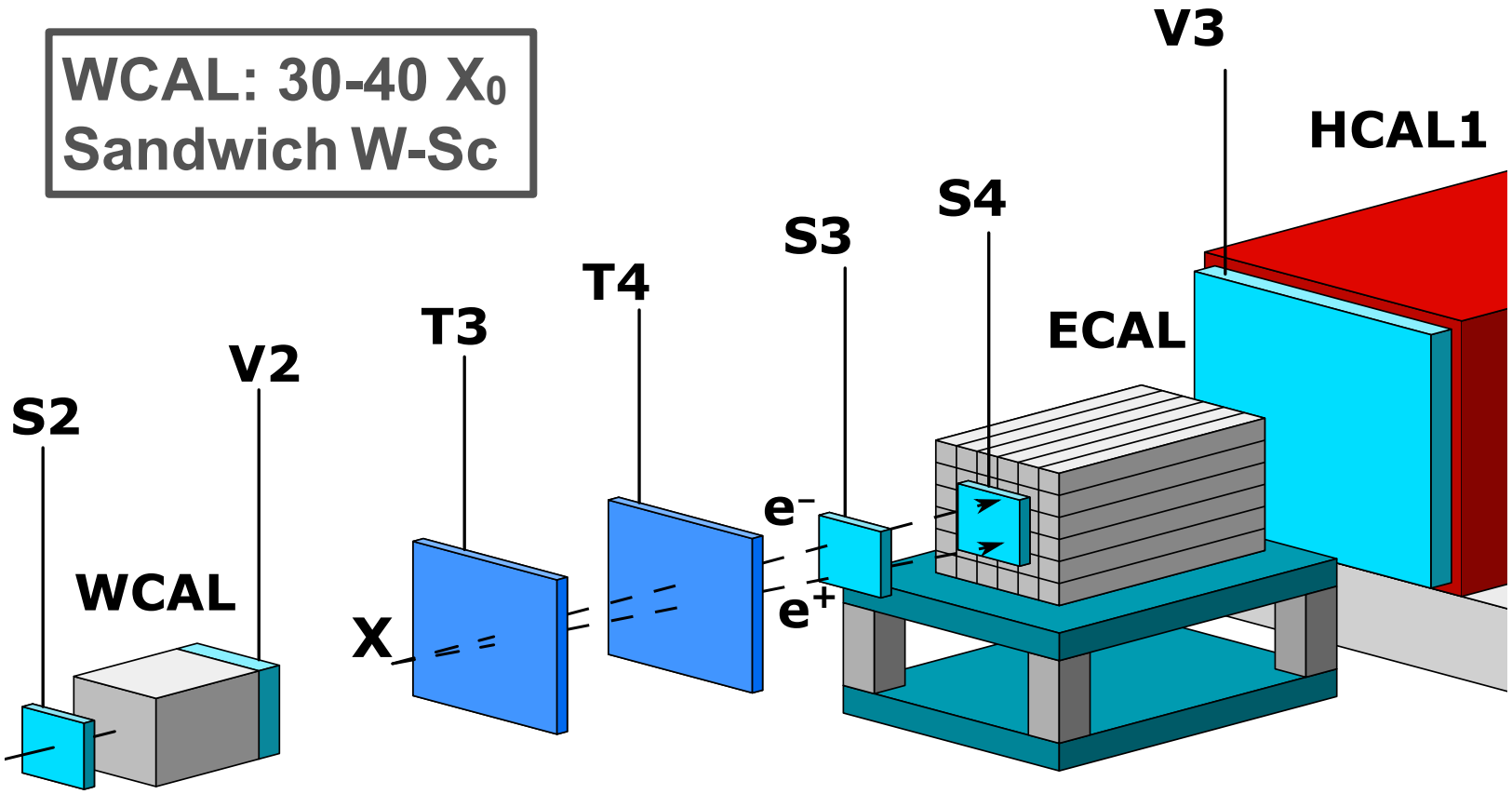
Could be explained by new 'protophobic' gauge boson X with mass around 17 MeV

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

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



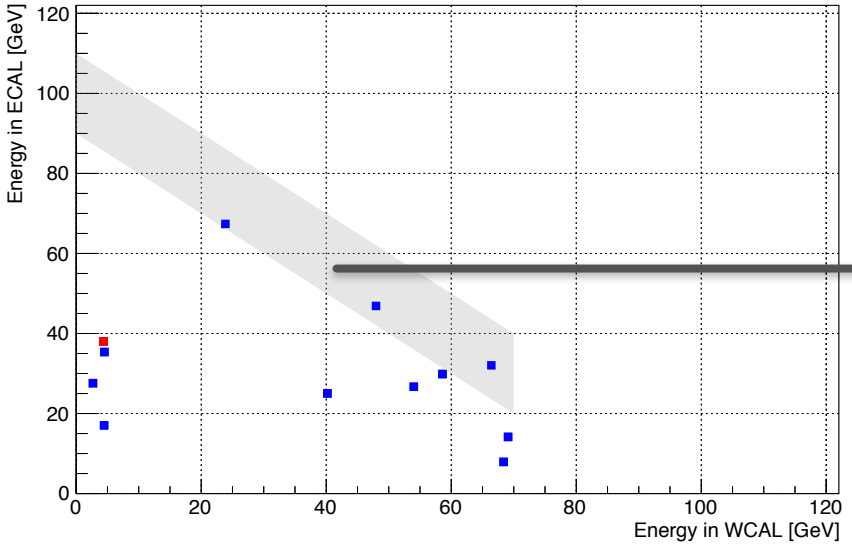
The NA64 search for $X \rightarrow e^+e^-$ - *experimental signature*



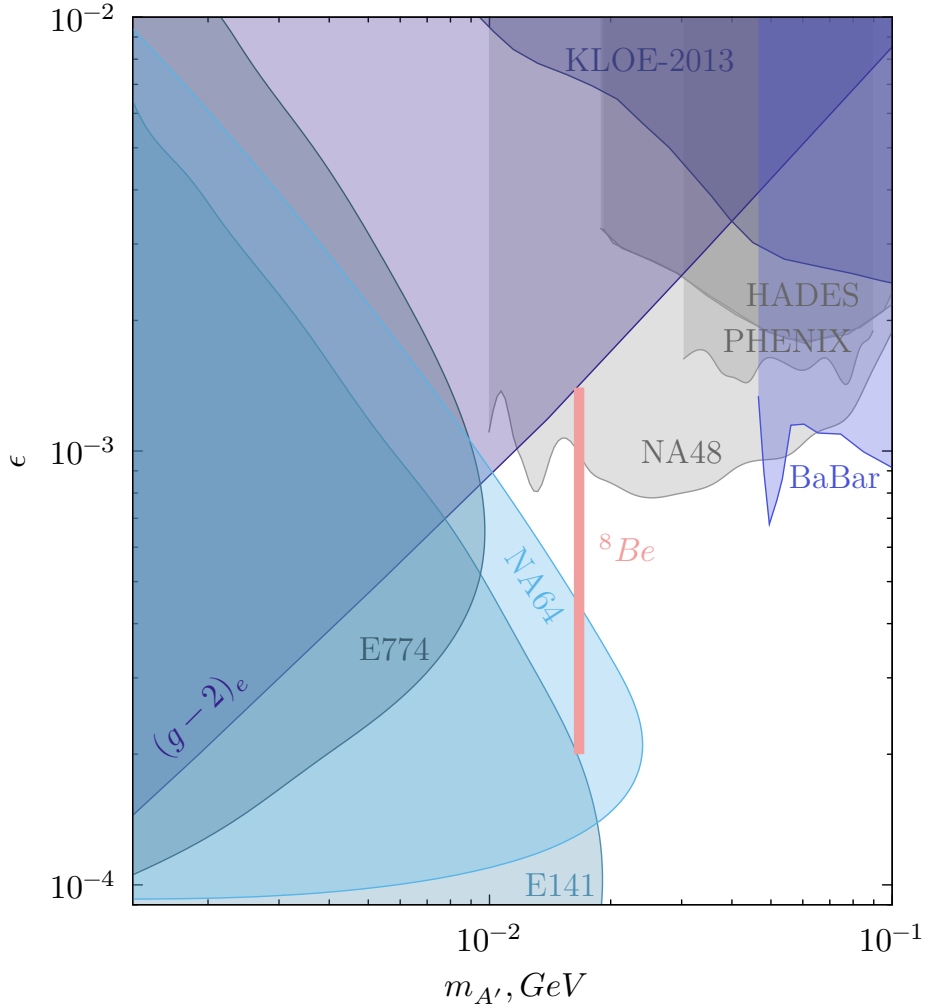
Signature:

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

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



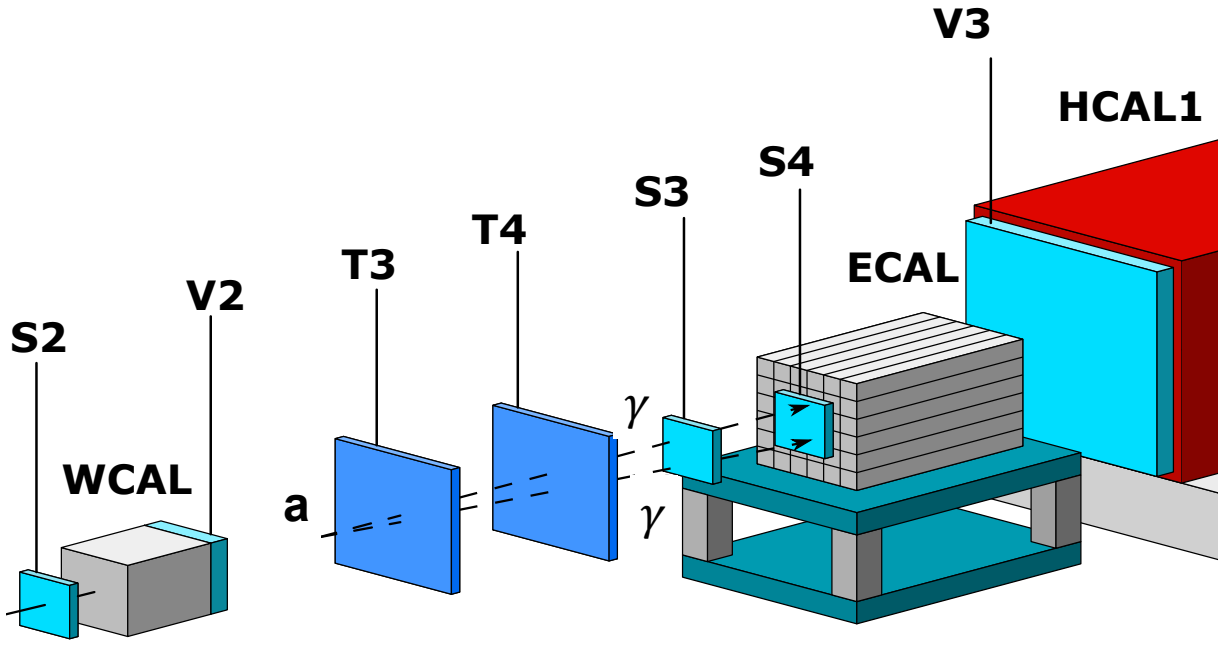
No signal-like event in signal box



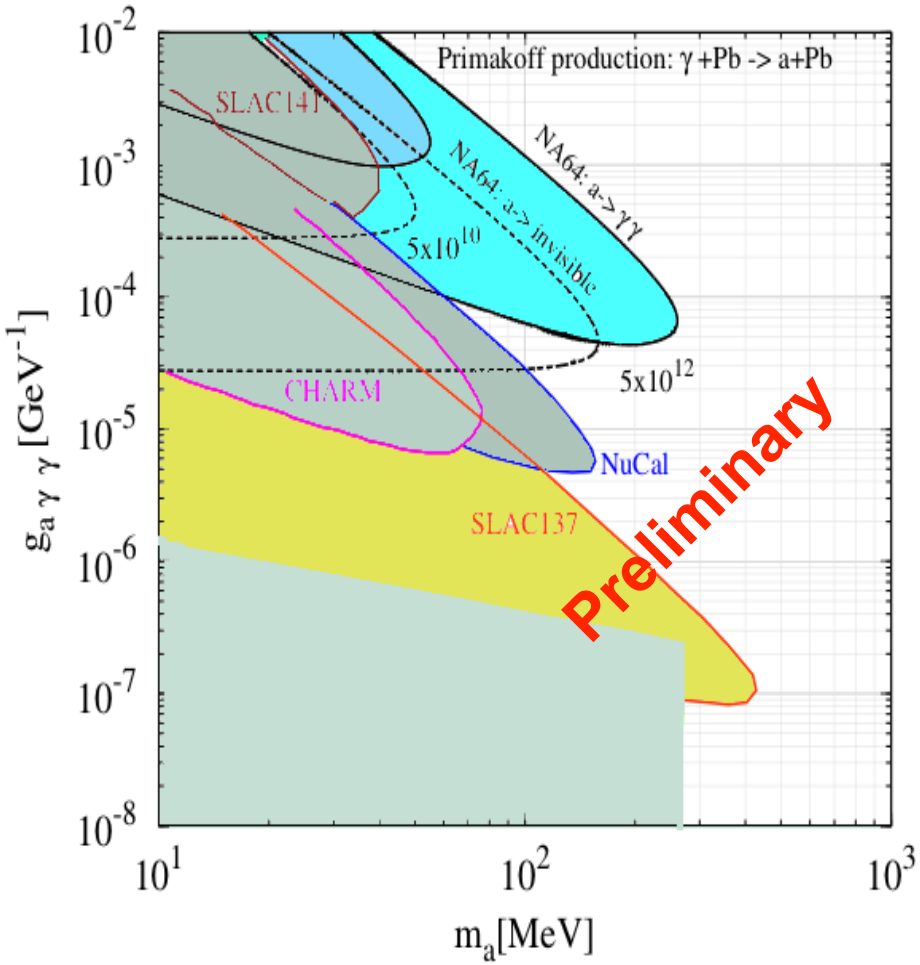
- **Neutral events**
- **Signal like**

NA64 collaboration, PRL 120, 231802 (2018), editor suggestion

Searches for ALPs in NA64 (preliminary)



Signature a→γγ
pure e-m shower in ECAL



The NA64 physics prospects

Process	New Physics
e^- **beam**	
$A' \to e^+e^-$, and	Dark photon
$A' \to invisible$	
$A' \to \chi\overline{\chi}$	sub-GeV Dark Matter (χ)
$X \to e^+e^-$	new gauge X- boson
milliQ particles	Dark Sector, charge quantisation
$a \to \gamma\gamma, invisible$	Axion-like particles
μ^- **beam**	
$Z_\mu \to \nu\nu$	gauge Z_μ-boson of $L_\mu - L_\tau$, $< 2m_\mu$
$Z_\mu \to \chi\overline{\chi}$	$L_\mu - L_\tau$ charged Dark Matter (χ)
milliQ	Dark Sector, charge quantisation
$a_\mu \to invisible$	non-universal ALP coupling
$\mu - \tau$ conversion	Lepton Flavour Violation
π^-, K^- **beams**	Current limits, PDG'2018
$\pi^0 \to invisible$	$Br(\pi^0 \to invisible) < 2.7 \times 10^{-7}$
$\eta \to invisible$	$Br(\eta \to invisible) < 1.0 \times 10^{-4}$
$\eta' \to invisible$	$Br(\eta' \to invisible) < 5 \times 10^{-4}$
$K_S^0 \to invisible$	no limits
$K_L^0 \to invisible$	no limits

NA64 program: submitted as input to the European Strategy Group in the context of the PBC

CERN-PBC-REPORT-2018-007

See next talk of Gaia Lanfranchi

Summary and Outlook

DARK SECTORS: very interesting candidate for DM

NA64: Active beam dump + missing-energy approach is very powerful

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)).

2017-2018: - **A' → $\chi\bar{\chi}$:** >10^{11} EOT collected (analysis 2017/2018 ongoing)
- ***X*→ e^+e^-** : 5x10^{10} EOT @ 100 GeV PRL120, 231802 (2018), 5x10^{10} EOT @ 150 GeV (2018)

AFTER CERN LONGSHUDOWN (May 2021) resume data taking (upgrade)
GOAL to fully exploit potential to reach LTDM (5x10^{12} EOT for *A'* → $\chi\bar{\chi}$ and explore remaining parameter space *X*→ e^+e^-)
→ Proposed searches in NA64 with leptonic and hadronic beams: unique sensitivities highly complementary to similar projects.

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