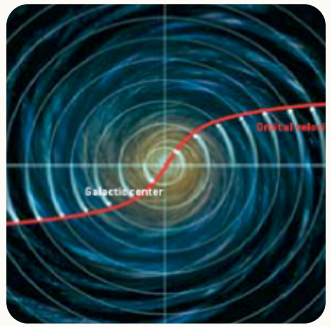
SEARCHING FOR HIDDEN SECTORS WITH THE NA64 EXPERIMENT AT THE CERN SPS - LTP/PSI Kolloquium 5.11.2020

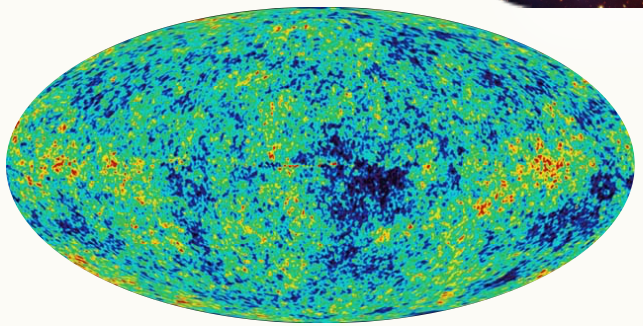
Paolo Crivelli, ETH Zurich, Institute for Particle Physics and Astrophysics

Dark Matter: Astro + Cosmology through Gravitational effects



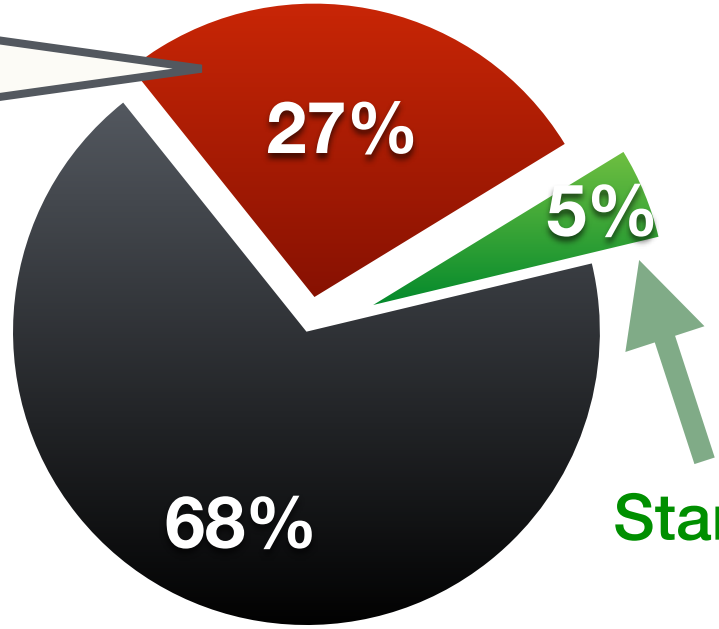
GALACTIC
ROTATION CURVES

GRAVITATIONAL
LENSING



COSMIC MICROWAVE BACKGROUND

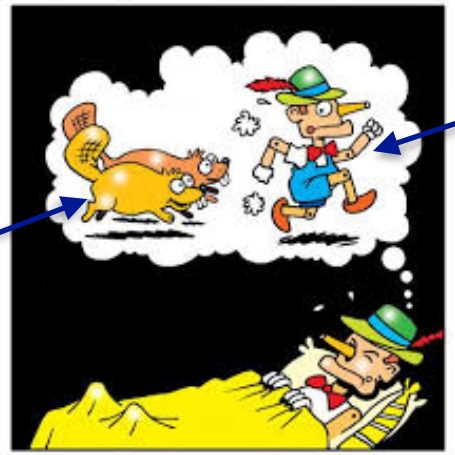
ΛCDM (Lambda Cold Dark Matter)



Some slides were adapted from F. Tanedo's talk @ APS 2018, thanks Flip for sharing them!

Does DM interact only gravitationally?

particle physicist



Dark matter interacting only gravitationally

Nightmare scenario

Is there an interaction between DM-SM other than gravity?

$$\Omega_{DM} \sim 5\Omega_{SM}$$

Relic densities of Standard Matter (SM) and Dark Matter (DM) are "similar"

SUGGESTS COMMON ORIGIN BETWEEN SM and DM.

Can those be related with **A SINGLE THEORY?**

ADDITIONAL DM-SM interaction? If it exists it should be very weak...

Weakly Interacting Massive Particles (WIMPs)

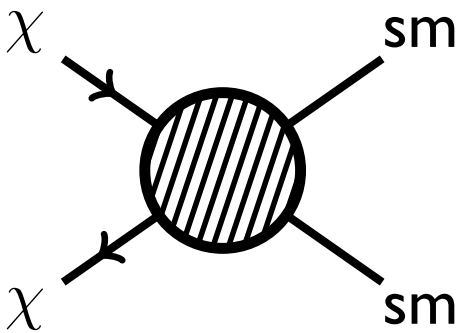
INTERACTS VIA WEAK FORCE (**W** and **Z** BOSONS)

Dark Matter — WEAK FORCE? — **Standard Model**

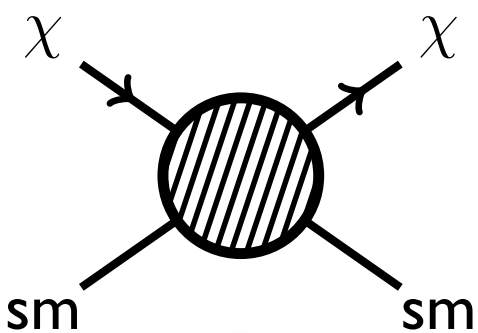
$$\sigma \sim G_F^2 m_X^2$$

Dark matter searches related by crossing symmetry:

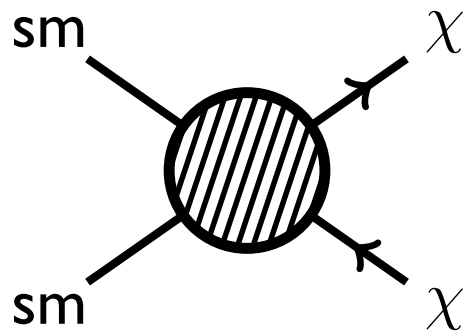
INDIRECT

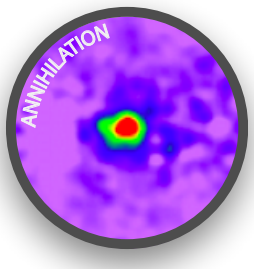


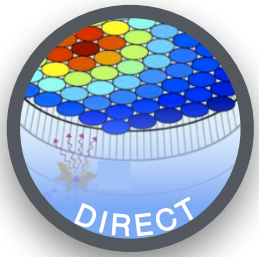
DIRECT

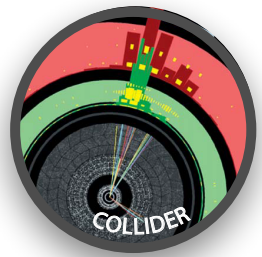


COLLIDER

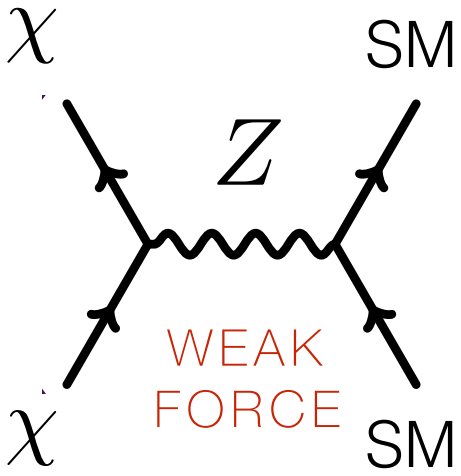








The WIMP miracle



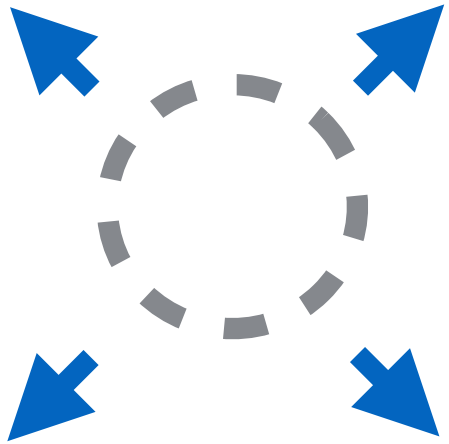
annihilation

OBSERVED **AMOUNT OF DARK MATTER** TODAY

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

Thermal averaged **ANNIHILATION** RATE

vs.



expansion of universe

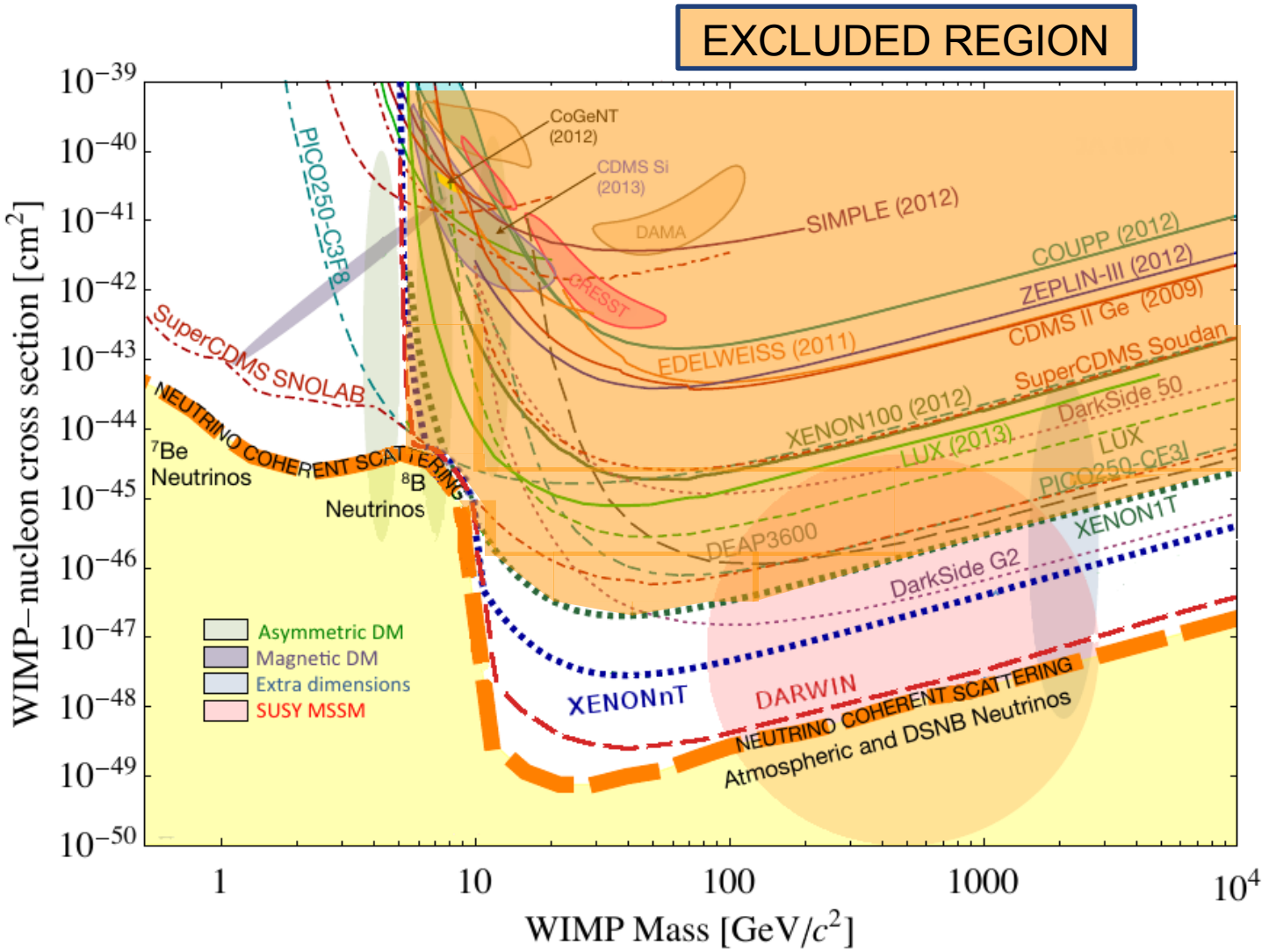
"WEAK SCALE" MASS

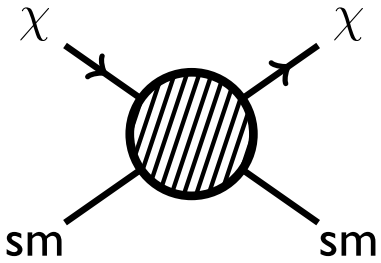
$m_X \sim 100$ GeV,

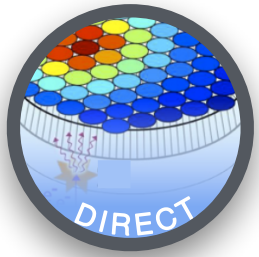
$g_X = g_{WEAK}$

IDEAL CANDIDATE:
Lightest Super-symmetrical Particle

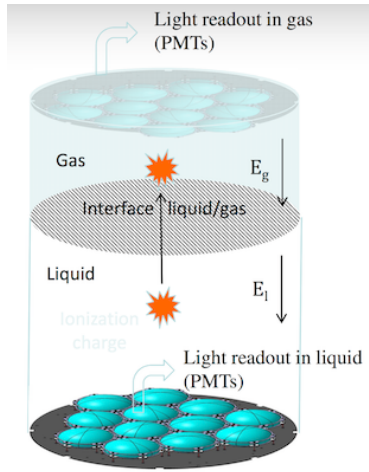
Status of direct Searches







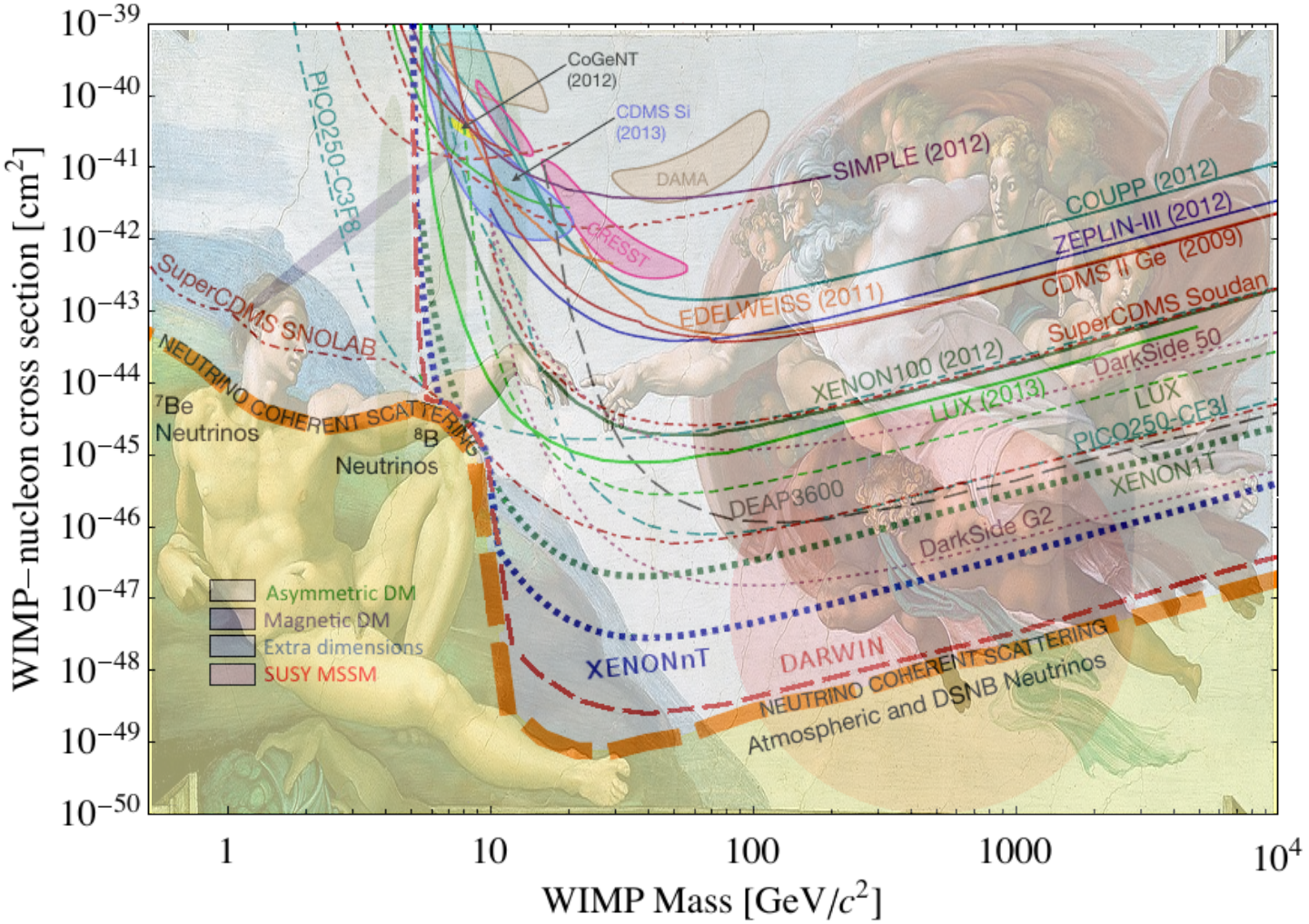
MEASURE NUCLEAR RECOIL
e.g. in liquid Argon or Xenon

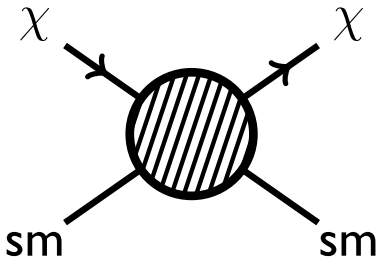


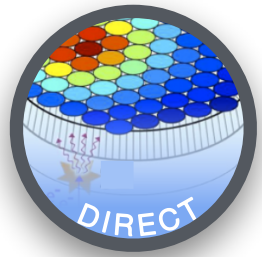
ionisation charge

M. Klasen et al. et al. Prog.Part.Nucl.Phys. 85 (2015) 1-32

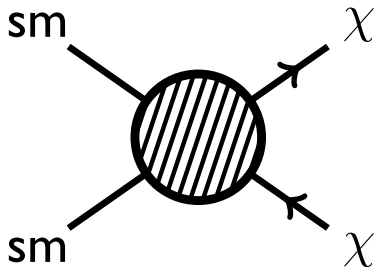
Tough times for the WIMP miracle?

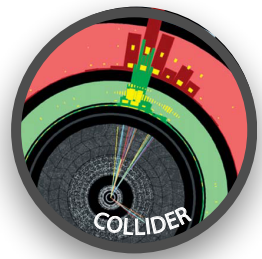






+





So far no WIMP/SUSY

M. Klasen et al. et al. Prog.Part.Nucl.Phys. 85 (2015) 1-32 & MICHELANGELO

Light Mediators searches complementary to WIMPs

For a review see e.g. https://arxiv.org/abs/2011.02157

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

OBSERVED **AMOUNT OF DARK MATTER** TODAY

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

The WIMP miracle

$$(m_X, g_X) \sim (m_{\text{weak}}, g_{\text{weak}})$$

The WIMPless MIRACLE

$$\frac{m_X}{g_X^2} \sim \frac{m_{\text{weak}}}{g_{\text{weak}}^2}$$

J. Feng and J. Kumar Phys.Rev.Lett.101:231301,2008

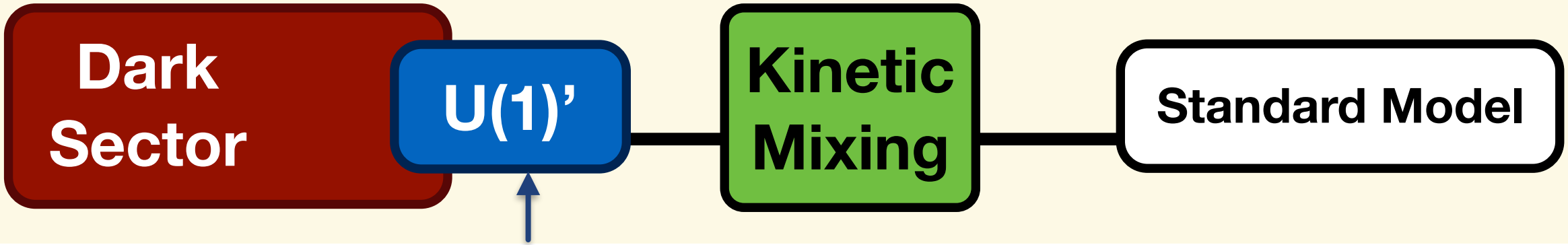
Large range for g_X and m_X

Renormalizable Portals

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

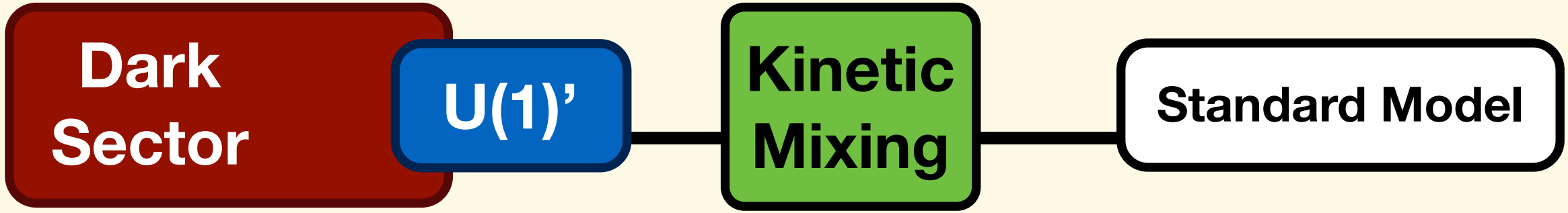
- "Axion" $\frac{1}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu} a$ axions & axion-like particles (ALPs)
- "Higgs" $\lambda H^2 S^2 + \mu H^2 S$ exotic Higgs decays?
- "Vector" $\epsilon F^{Y,\mu\nu} F'_{\mu\nu}$ dark photon A′
- "Neutrino" $\kappa (HL) N$ sterile neutrinos?

MAIN FOCUS OF THIS TALK



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

DARK SECTORS - THE VECTOR PORTAL

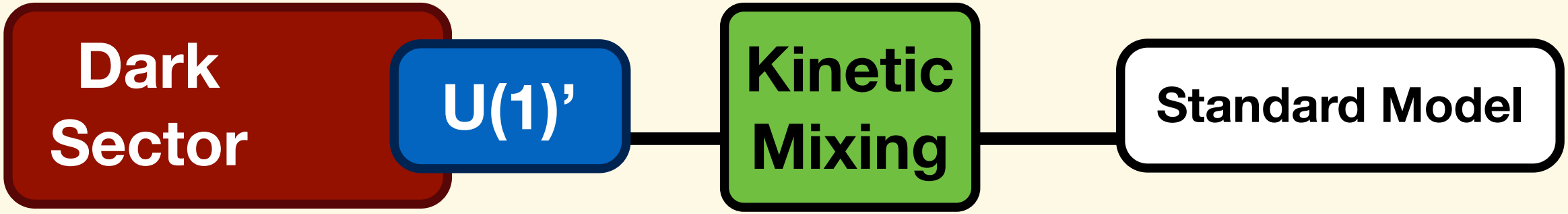


DARK SECTOR (DS) charged under a new U(1)' gauge symmetry and interacts with SM through kinetic mixing (ε) of a MASSIVE VECTOR MEDIATOR (A') with our photon.
Dark matter with mass (m_χ), part of DS.

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu} + \frac{m^2_{A'}}{2} A'_\mu A'^\mu + i\bar{\chi}\gamma^\mu \partial_\mu \chi - m_\chi \bar{\chi}\chi - e_D \bar{\chi}\gamma^\mu A'_\mu \chi,$$

Four parameters: $m_{A'}$, m_χ, $\alpha_D = e_D^2/4\pi$, ε

DARK SECTORS - THE VECTOR PORTAL



In this framework DM can be produced thermally in the early Universe

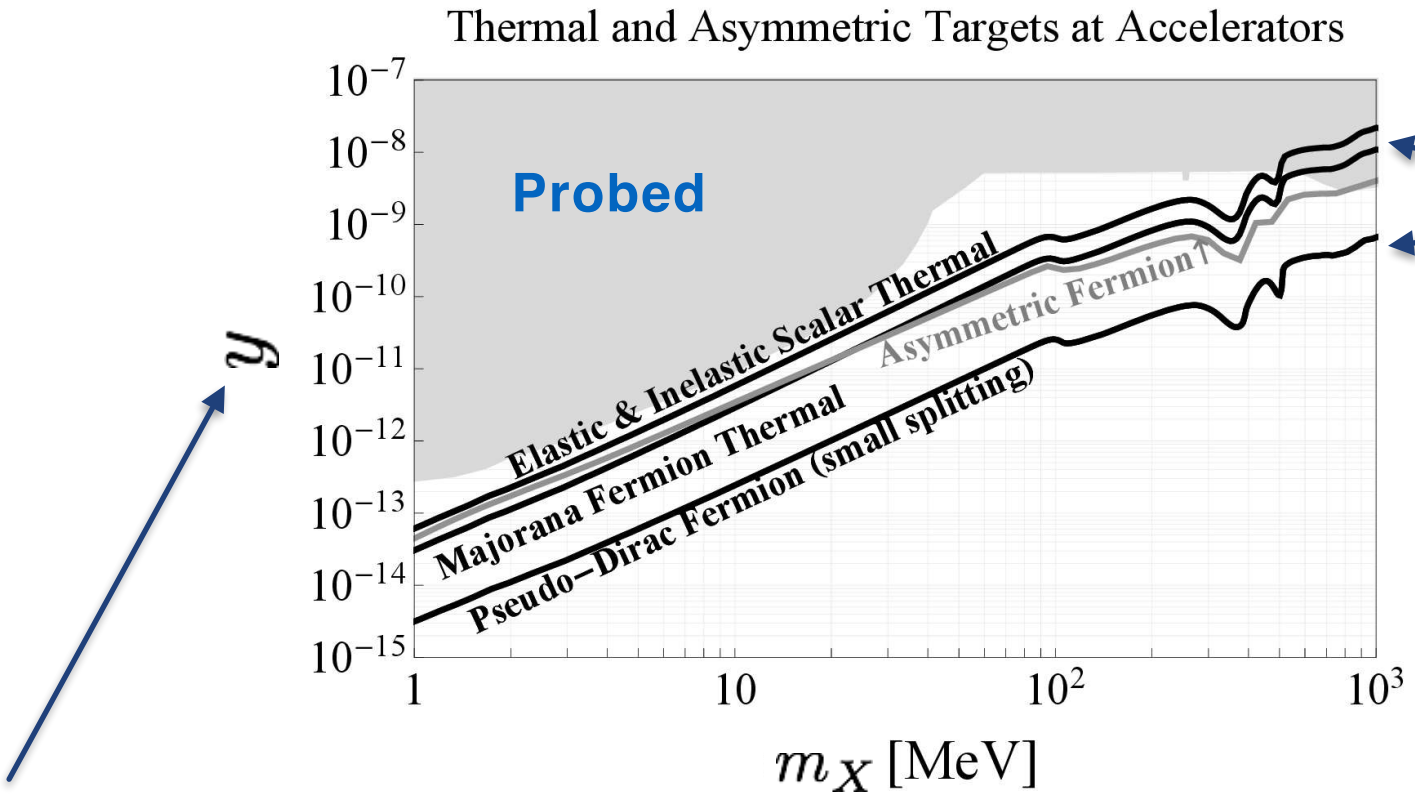
OBSERVED **AMOUNT OF DARK MATTER** TODAY

$$\Omega_X \propto \frac{1}{< v\sigma >} \sim \frac{m_X^2}{y}$$

WHERE $y = \epsilon^2 \alpha_D \left(\frac{m_X}{m_{A'}}\right)^4$

The (y,m_X) DM PARAMETER SPACE

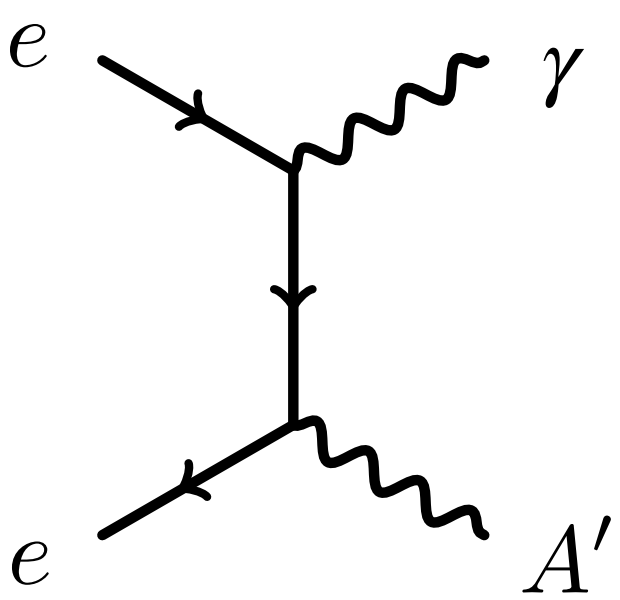
For a review see e.g https://arxiv.org/pdf/1707.04591.pdf



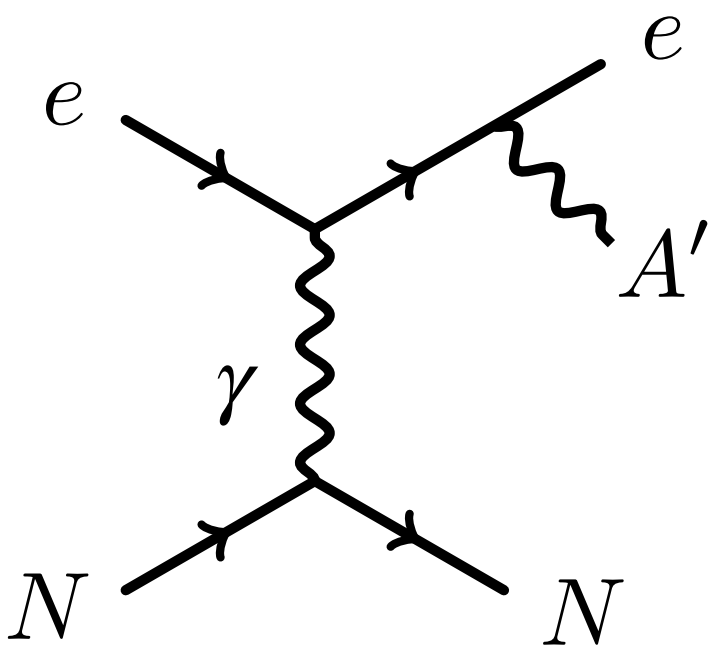
Solid lines predictions from DM relic abundance

DM -> SM annihilation rate is ~ y,
useful variable to compare exp. sensitivities

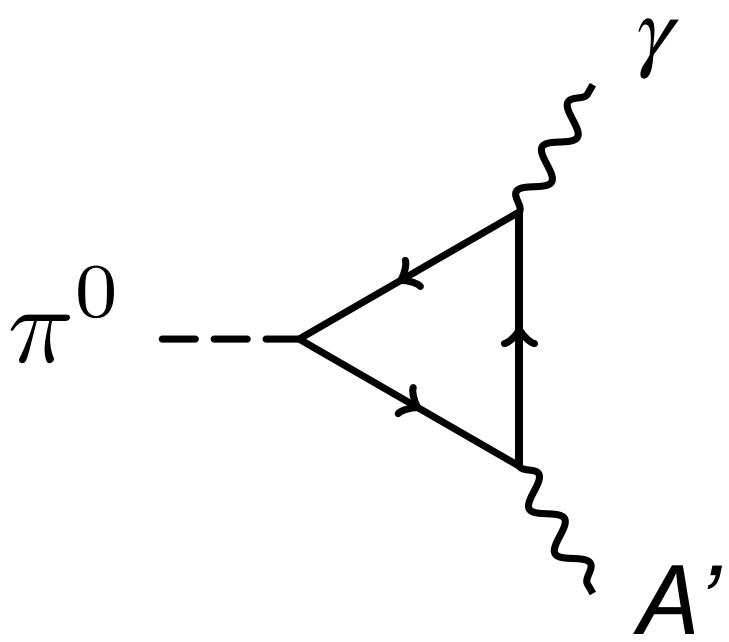
Some production mechanisms for Dark Photons



annihilation



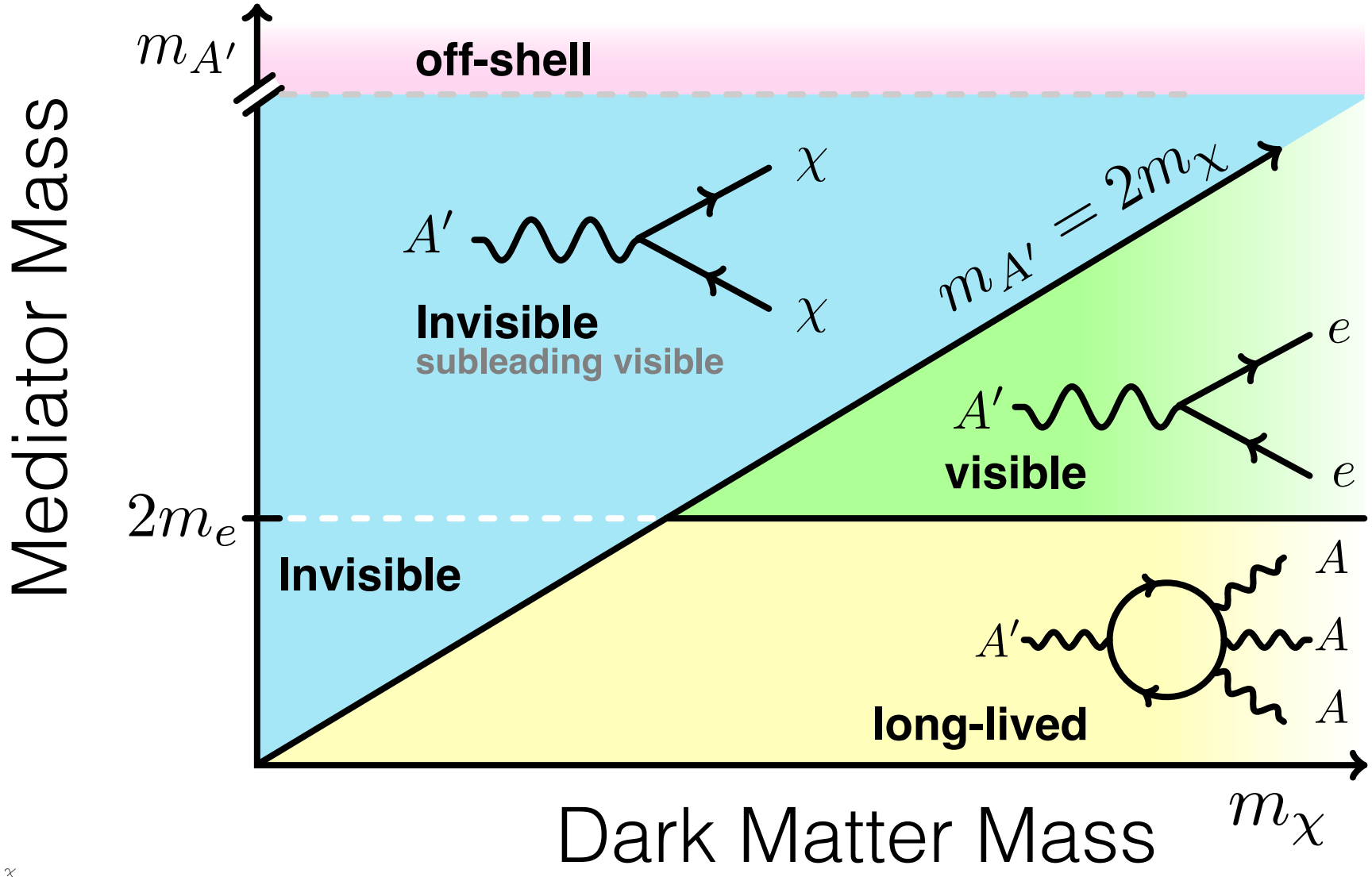
bremsstrahlung



meson decay

Decays of Dark Photons

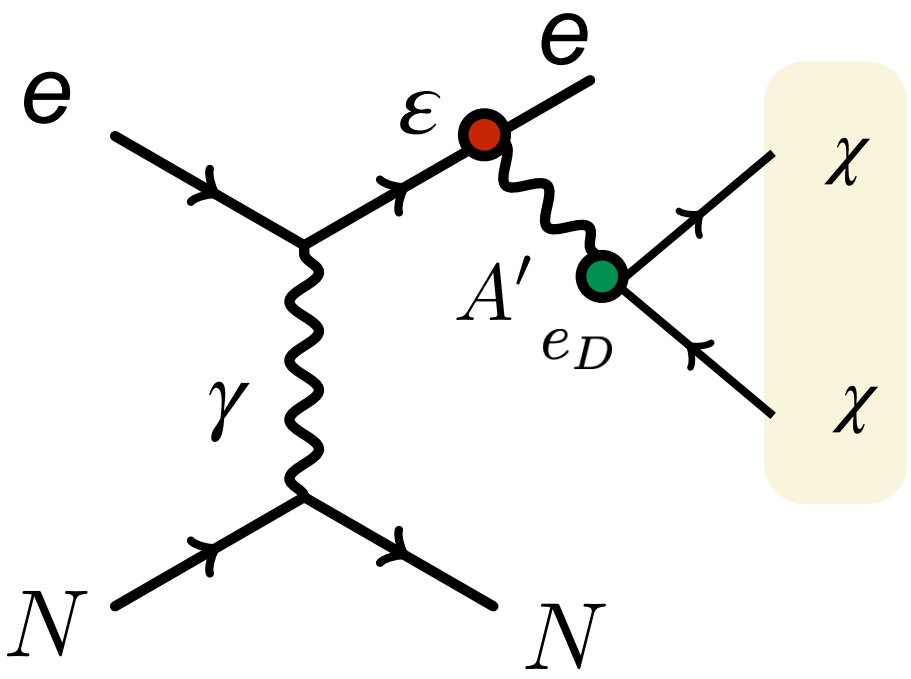
Adapted from Natalia Toro, Dark Sectors 2017 (1608.03591)



SEARCHES FOR DARK SECTORS AT ACCELERATORS

INVISIBLE DECAY MODE $m'_A > 2m_X$

1) BEAM DUMP APPROACH (MiniBooNE, LSND, NA62...)



Flux of X generated by decays of A's produced in the dump.

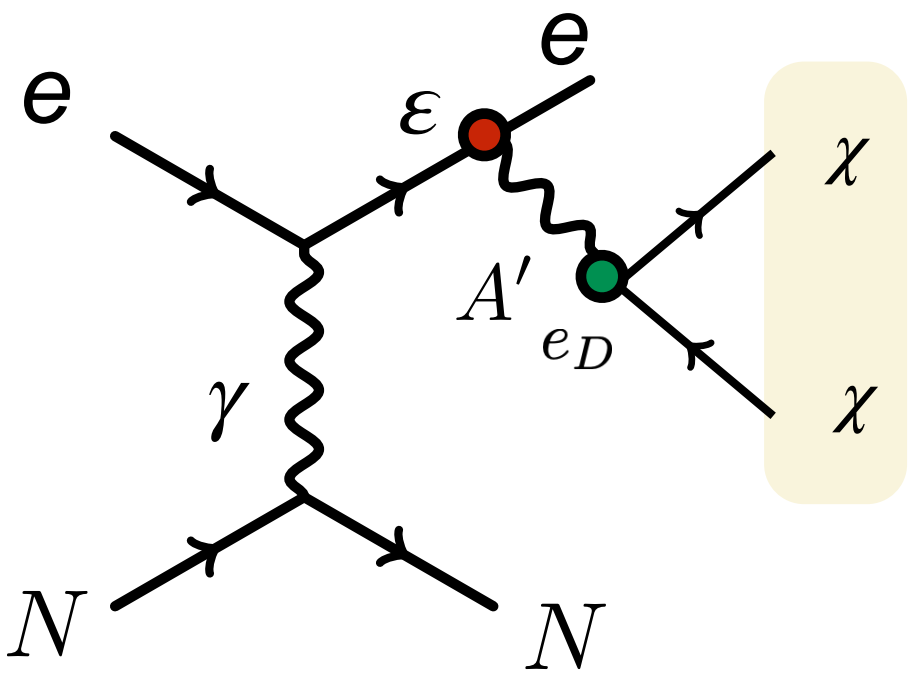
Signal: X scattering in far detector

$$\sigma \propto \epsilon^4 \alpha_D$$

SEARCHES FOR DARK SECTORS AT ACCELERATORS

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

2) NA64/LDMX APPROACH

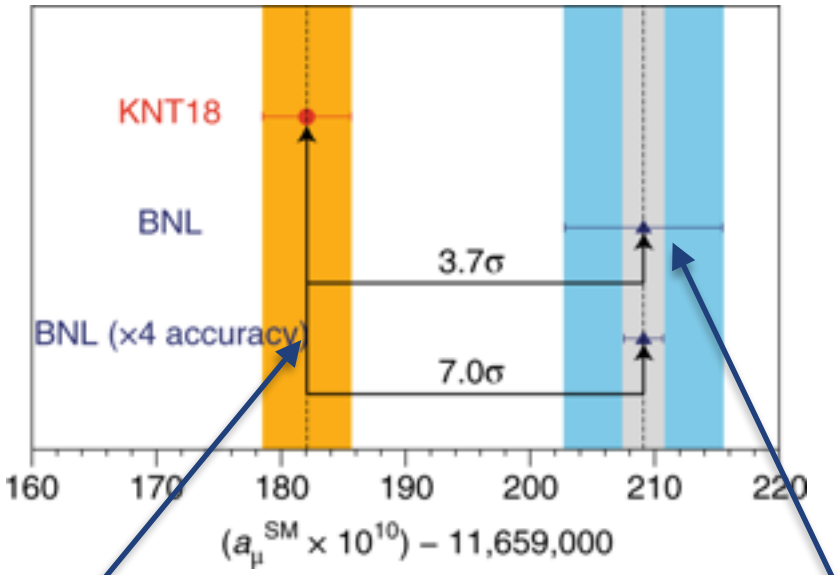


NA64 **missing energy**: produced A's carry away energy form the active dump used to measure recoil e- energy

$$\sigma \propto \epsilon^2$$

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

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

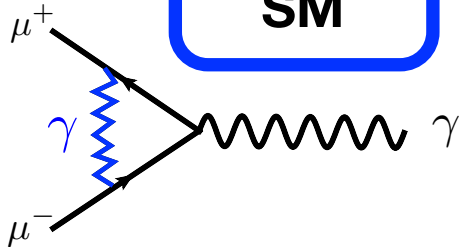


THEORY

BNL EXPERIMENT

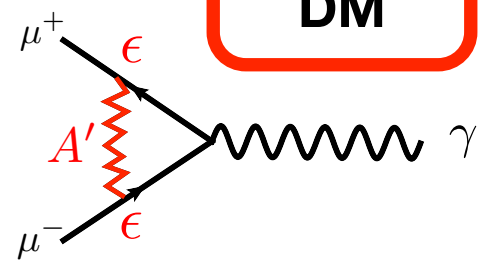
NEW EXP. ongoing@Fermilab

SM



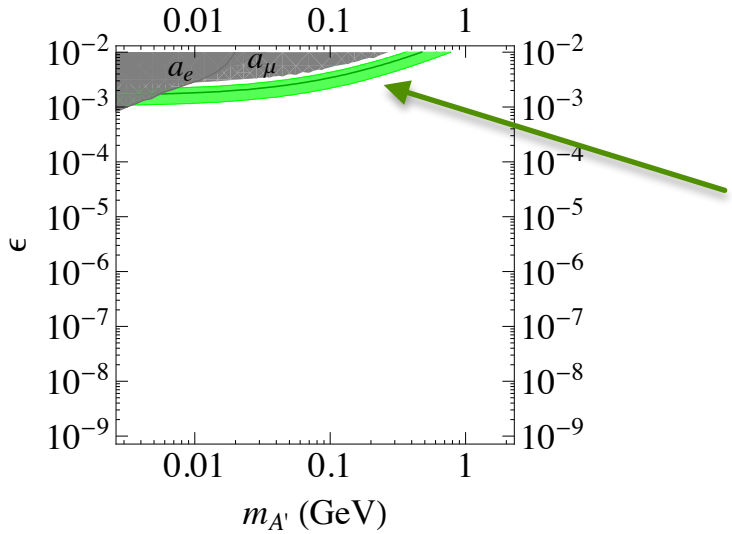
$$(g_s - 2)_\mu^\gamma \simeq \frac{\alpha}{2\pi} \simeq 10^{-3}$$

DM



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

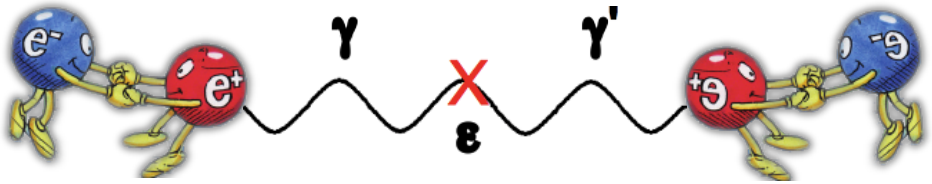
M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662, 53 (2008)

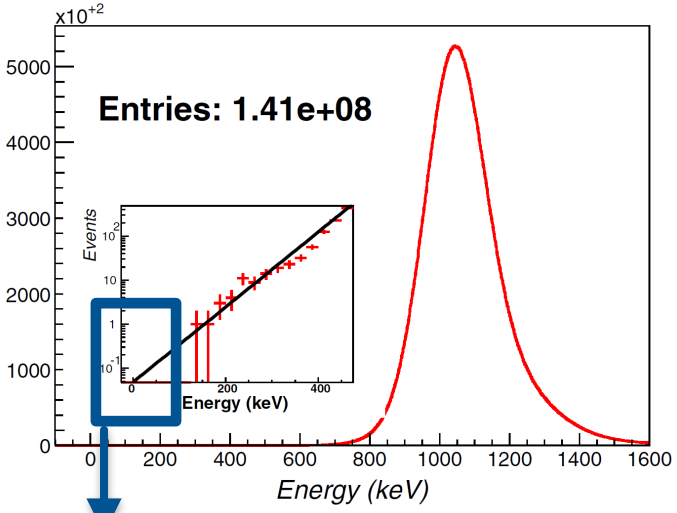


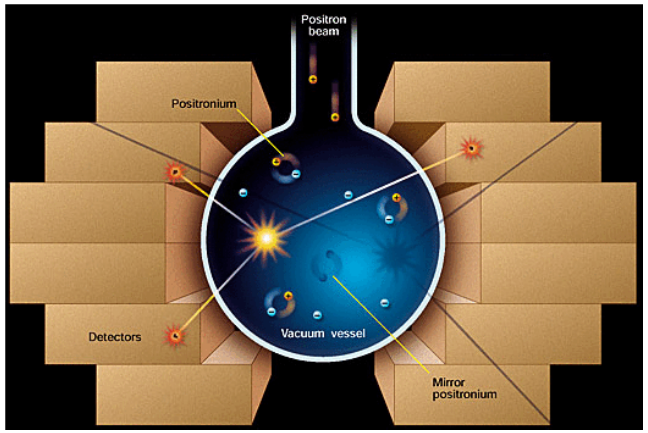
A' may explain observed anomaly

From positronium (search for massless dark photon) → NA64

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







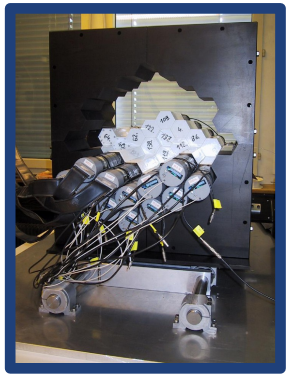


Table top

IPA ETH zürich

At rest → 100 GeV

Signature: disappearance of 1 MeV energy

A. Badertscher, P. Crivelli et al., Phys. Rev. D. 75, 032004 (2007)
Latest results 2020 C. Vigo, L. Gerchow, B. Radics, A. Rubbia, P. Crivelli, PRL124,101803

The NA64 collaboration (~50 researchers from 13 Institutes)

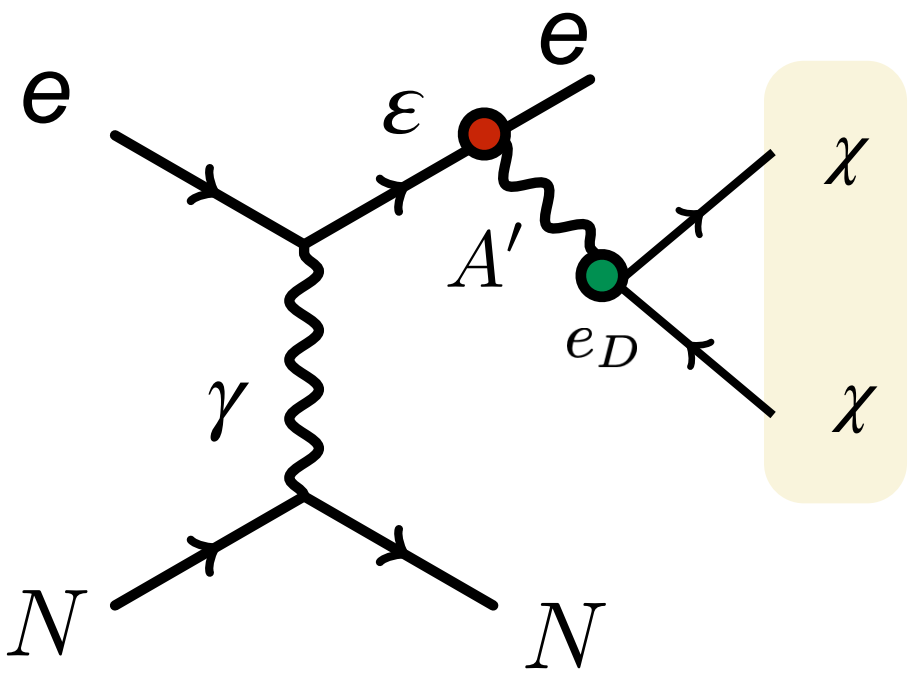
D. Banerjee[k], J. Bernhard[d], V.E. Burtsev[j], A.G. Chumakov[j], P. Crivelli[m], E. Depero[m], A. Dermenev[e], S.V. Donskov[i], R. Dusaev[j], T. Enik[b], V. Frolov[b], A. Gardikiotis[h], S.Gerassimov[c,f], S.N. Gninenko[e], M. Hösgen[a], A. Karneyeu[e], G. Kekelidze[b], B. Ketzer[a], D. Kirpichnikov[e], 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]

[a] *Universität Bonn, Helmholtz-Institut für Strahlen-und Kernphysik, 53115 Bonn, Germany*
[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' → $\chi\bar{\chi}$

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



DS Lagrangian

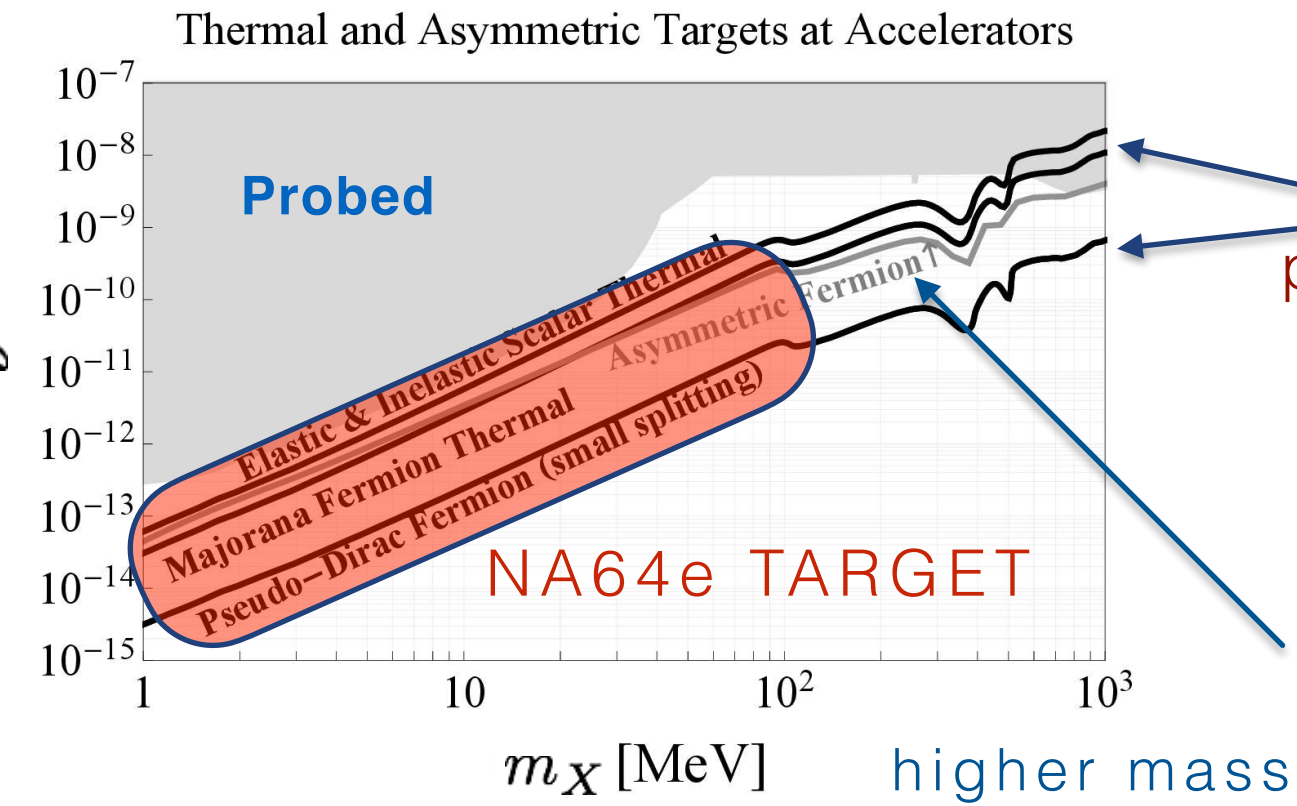
$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu} + \frac{m^2_{A'}}{2}A'_\mu A'^\mu + i\bar{\chi}\gamma^\mu\partial_\mu\chi - m_\chi\bar{\chi}\chi - e_D\bar{\chi}\gamma^\mu A'_\mu\chi,$$

Missing Energy/momentum

EXPLICIT TARGET FOR NA64 (y,m_X) DM PARAMETER SPACE

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

$$y = \epsilon^2 \alpha_D (m_X/m_{A'})^4$$



Solid lines predictions from DM relic abundance

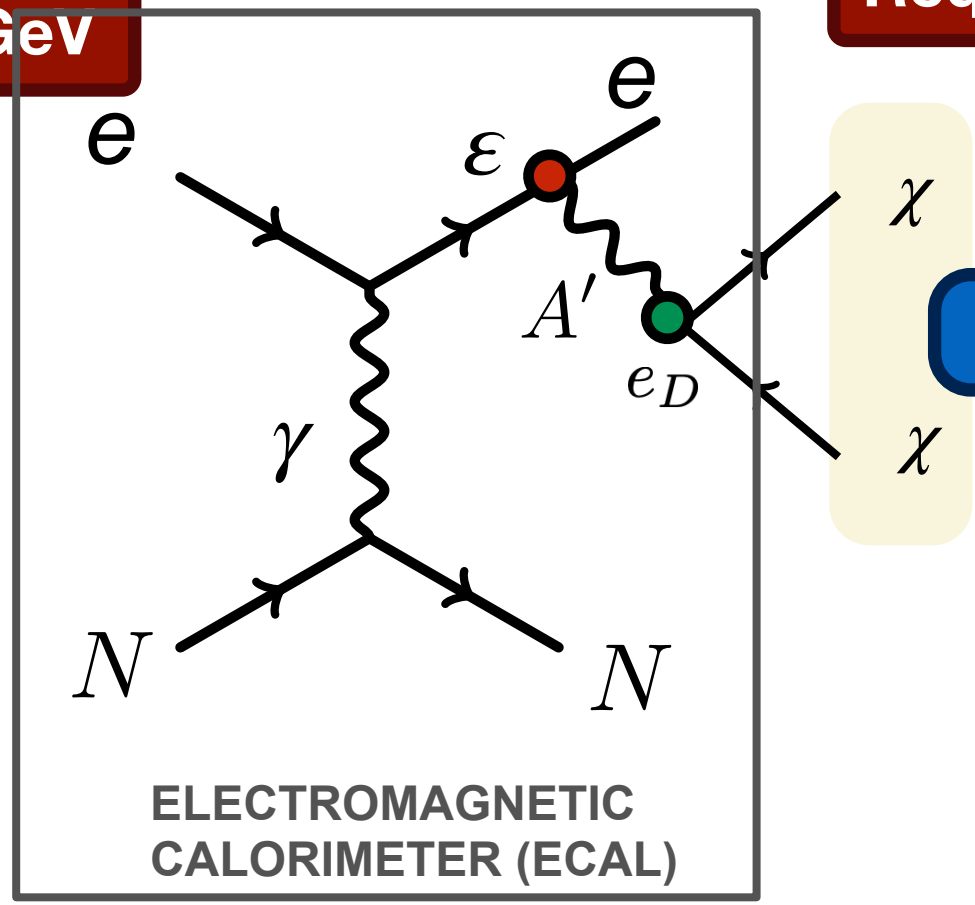
higher mass region could be covered by NA64 in muon mode

PLB796, 117 (2019)

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

TAGGED 100 GeV

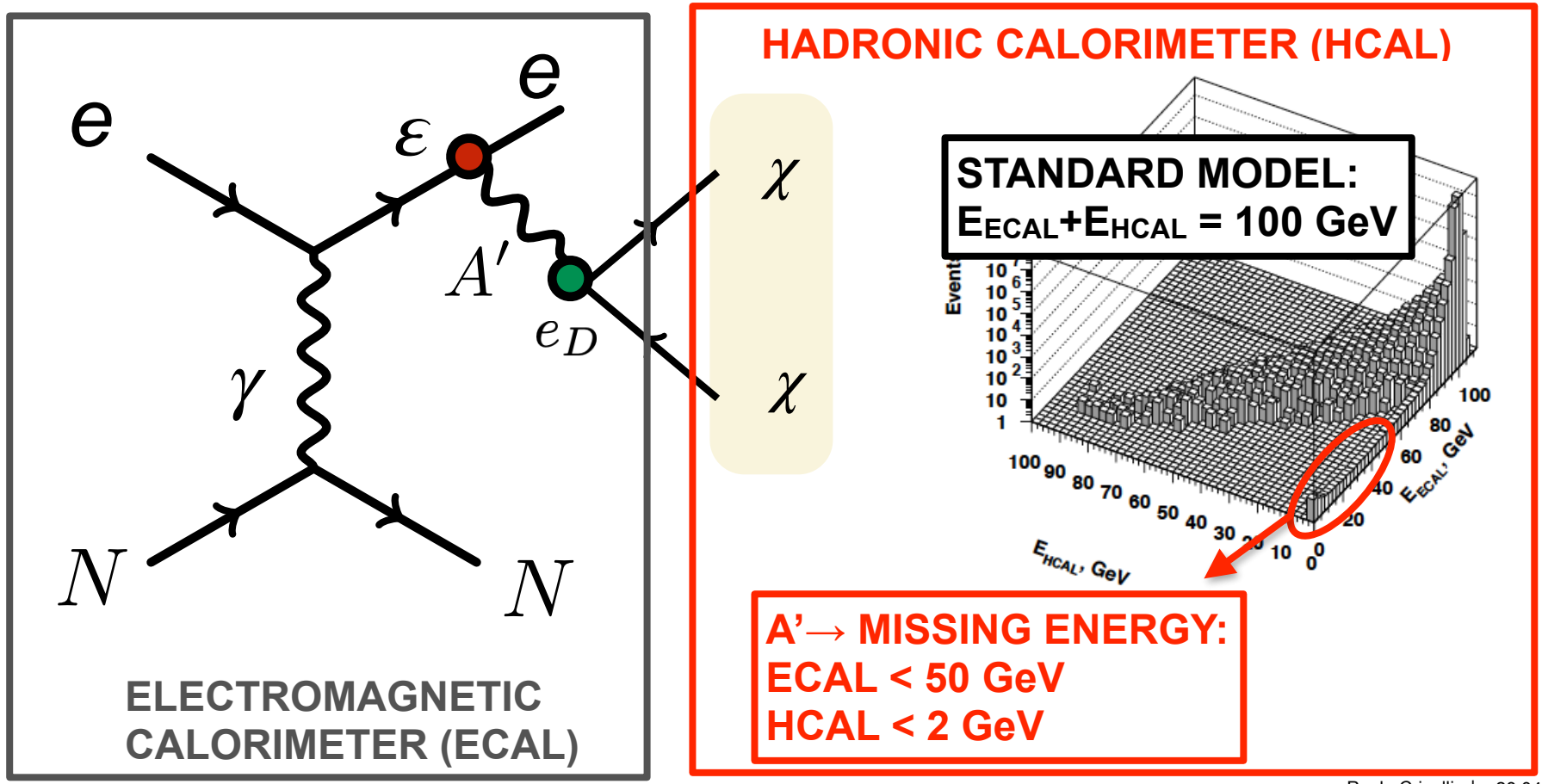
Requested ECAL ENERGY < 50 GeV



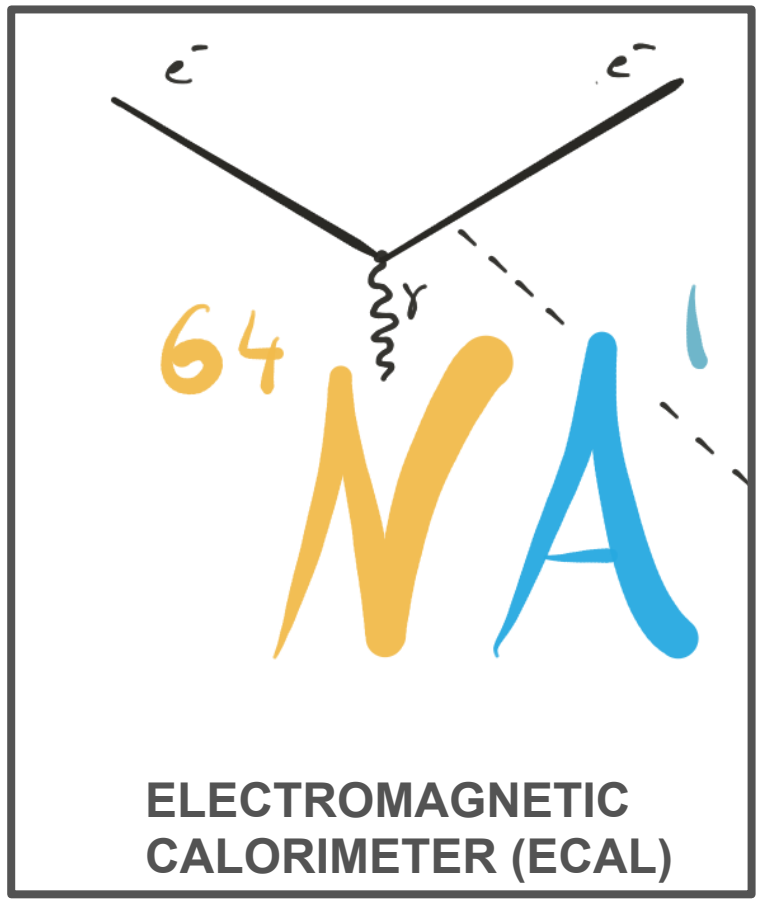
"BREMSSTRAHLUNG" OF A'

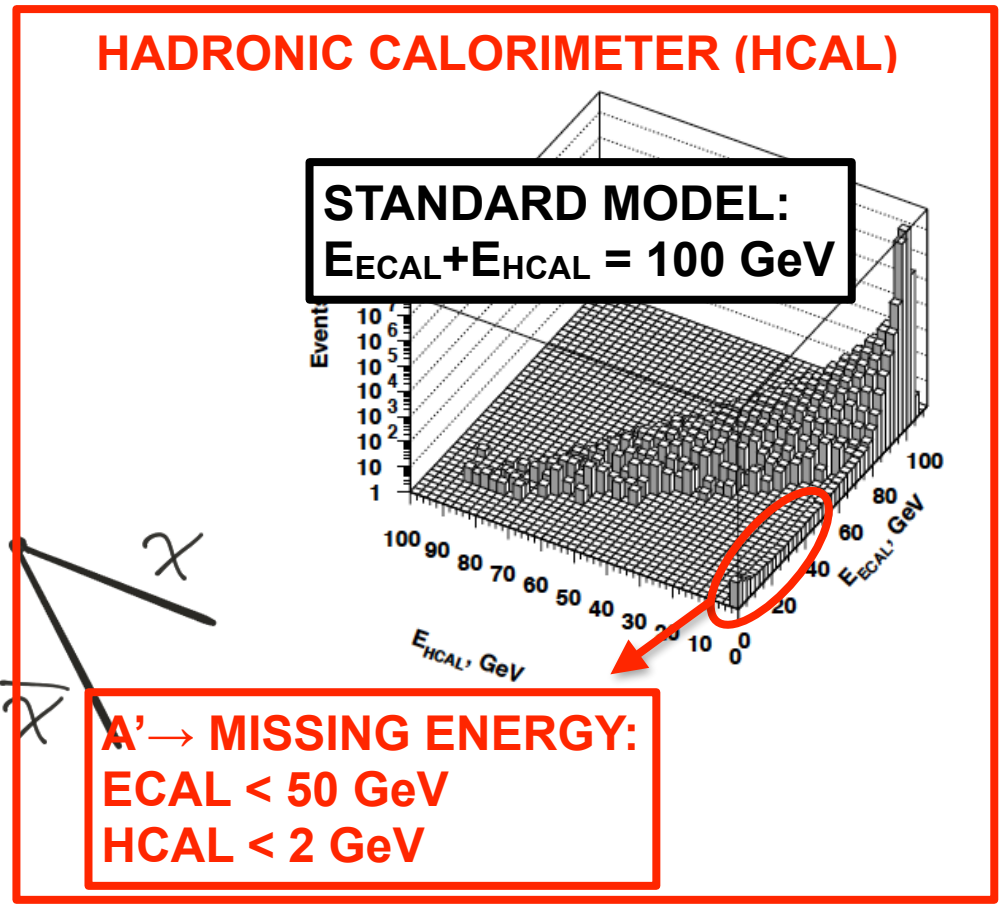
Active Dump

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

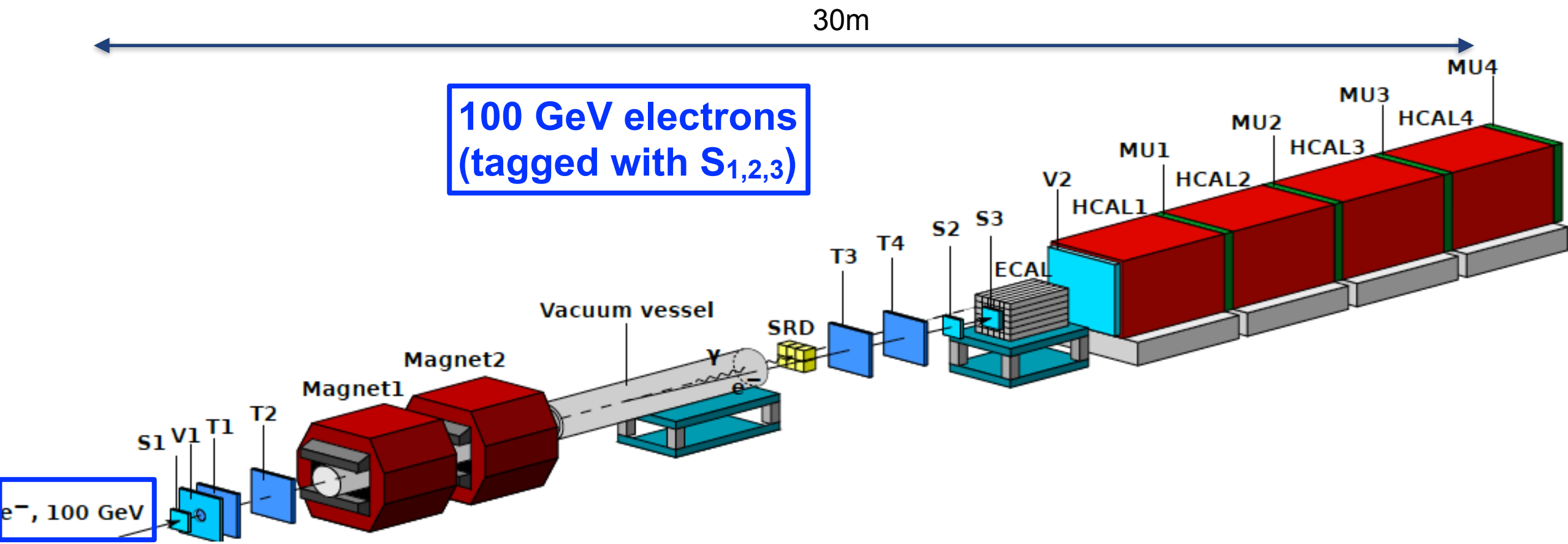


The NA64 method to search for A' → $\chi\bar{\chi}$





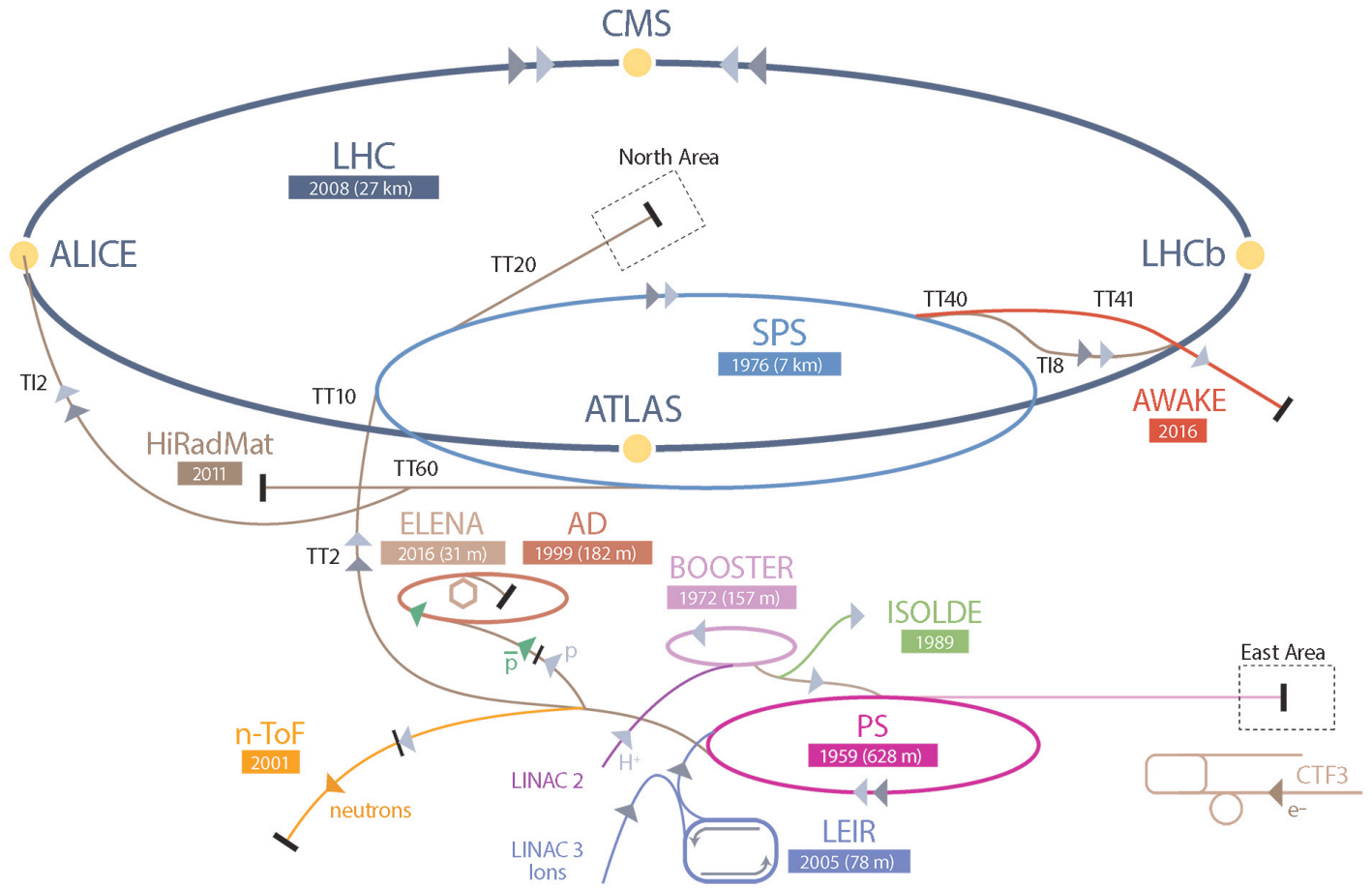
The CERN SPS H4 electron beam



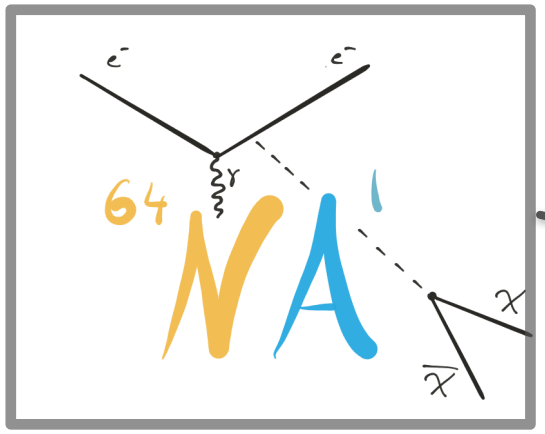
- Up to 7x10^6 e$^-$/spill, 2-4 spill/min, spill duration 5s
- Low contamination: π (<1%), μ/K (0.1%)
- Low energy tails (<1%)
- Beam spot of 1.5 cm (FWHM)

The CERN SPS H4 electron beam

https://home.cern/science/accelerators

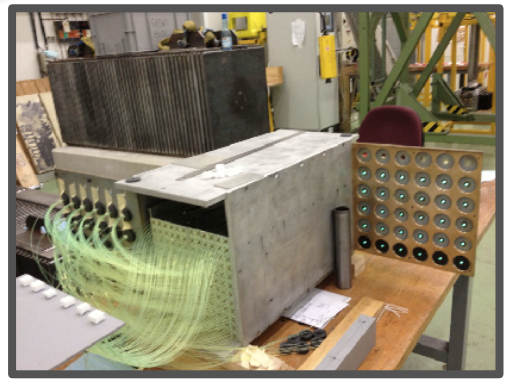


The Electromagnetic Calorimeter (ECAL)



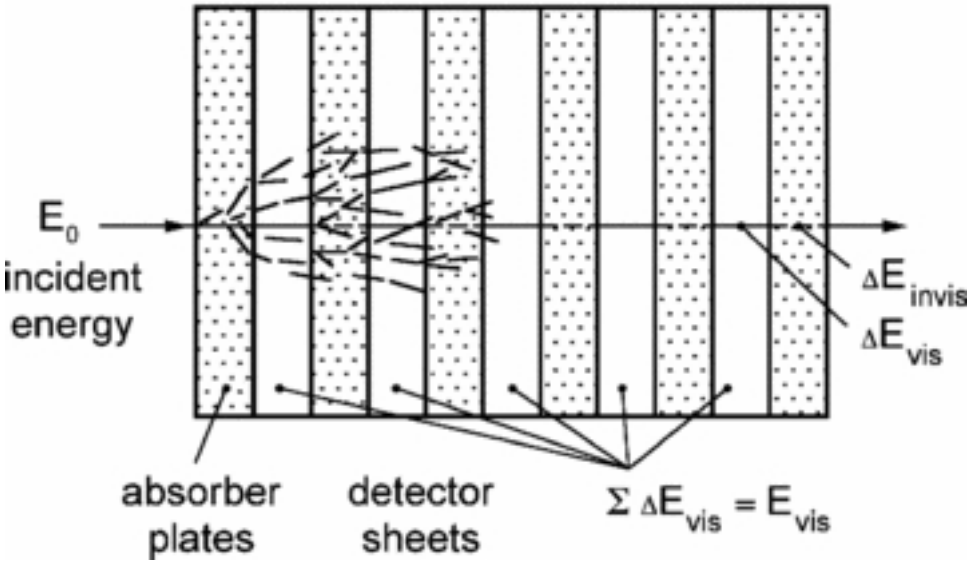
Active target

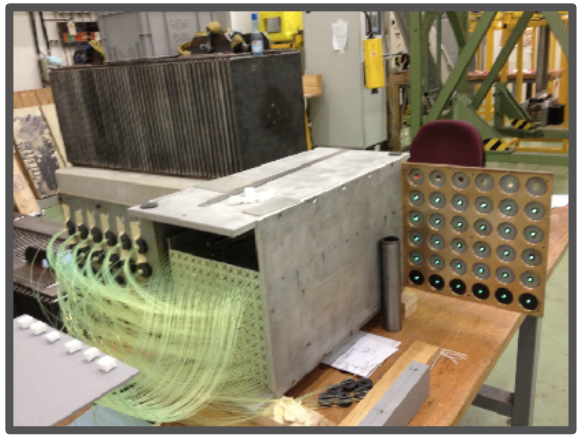
MU4
MU3
HCAL4
MU2
HCAL3
MU1
HCAL2
V2
HCAL1
S2
S3
T4
T3
ECAL
Vacuum vessel
SRD
γ
e⁻
Magnet2
Magnet1
S1
V1
T1
T2
e⁻, 100 GeV

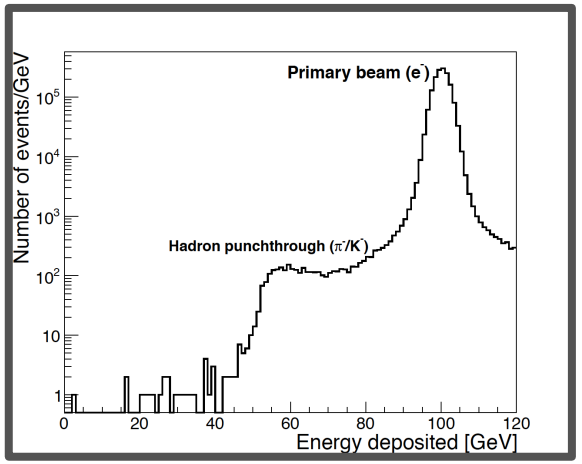


The Electromagnetic Calorimeter (ECAL)

$$\Sigma \Delta E_{invis} + \Sigma \Delta E_{vis} = E_{invis} + E_{vis} = E_{absorbed}$$



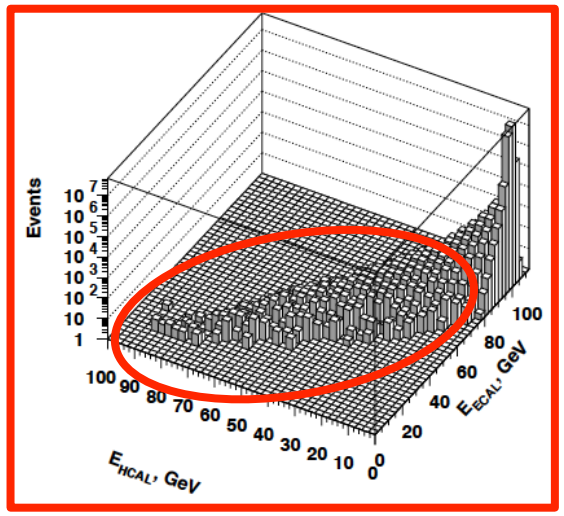




- High hermeticity (~40 X_0)
- PbSc sandwich, 6x6 matrix, cells 38x38x490 mm3
- WLS fibers in spiral→ suppress energy leaks
- Energy resolution ~ 9%/√(E[GeV])
- Longitudinal (Pre-shower) and lateral segmentation

→ shower profiles (hadron rejection)

The Hadronic Calorimeter (HCAL)



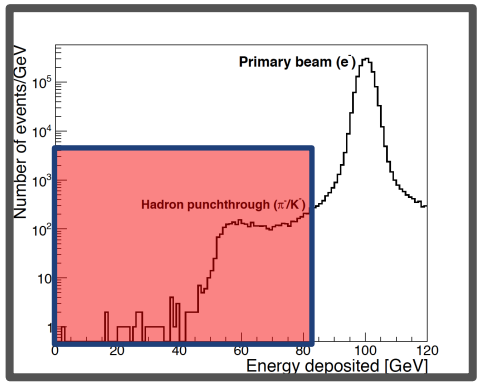
High hermeticity

- 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

IPA ETH zürich

D. Banerjee, P. Crivelli and A. Rubbia, Advances in HEP, 105730 (2015) and
D. Banerjee, PhD Thesis, ETH Zurich (2017)



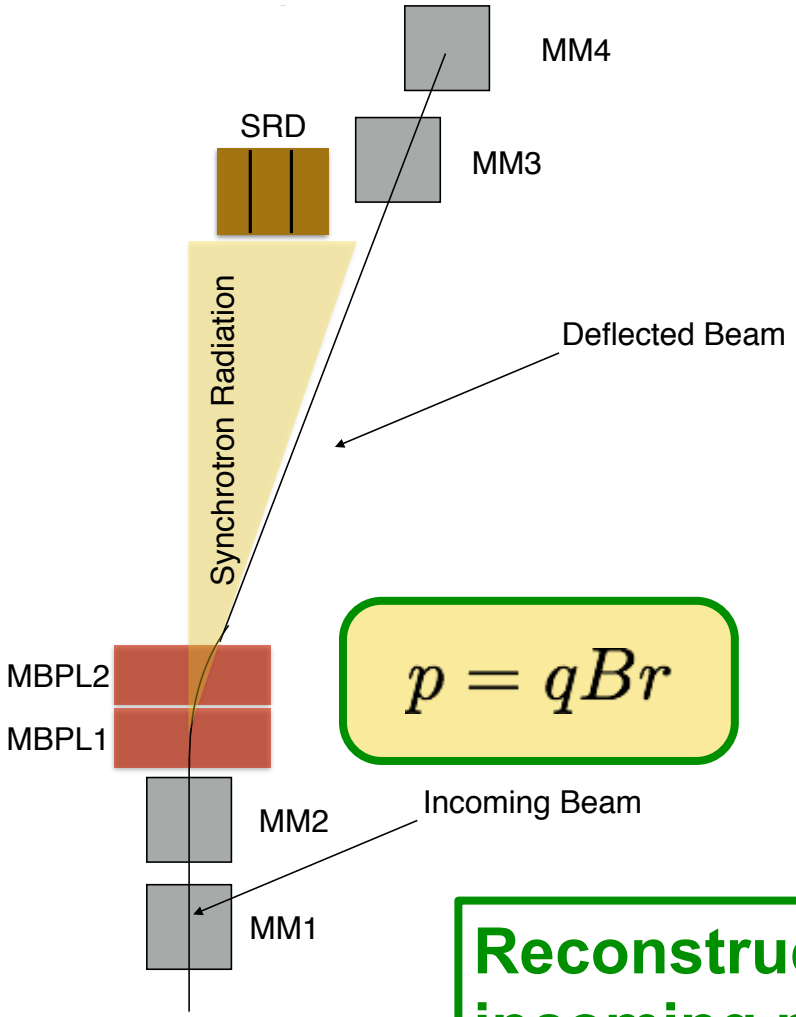
Reconstruction of e⁻ incoming momentum

Tracking system:
8 XY multiplexed resistive micromegas

Two bending magnets in series → 7 T.m field

The magnetic spectrometer

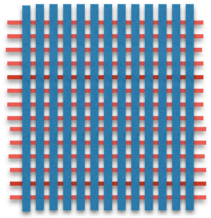
D. Banerjee et al., NIMA881 (2018) 72-81 and
D. Banerjee, PhD Thesis, ETH Zurich (2017)



$$p = qBr$$

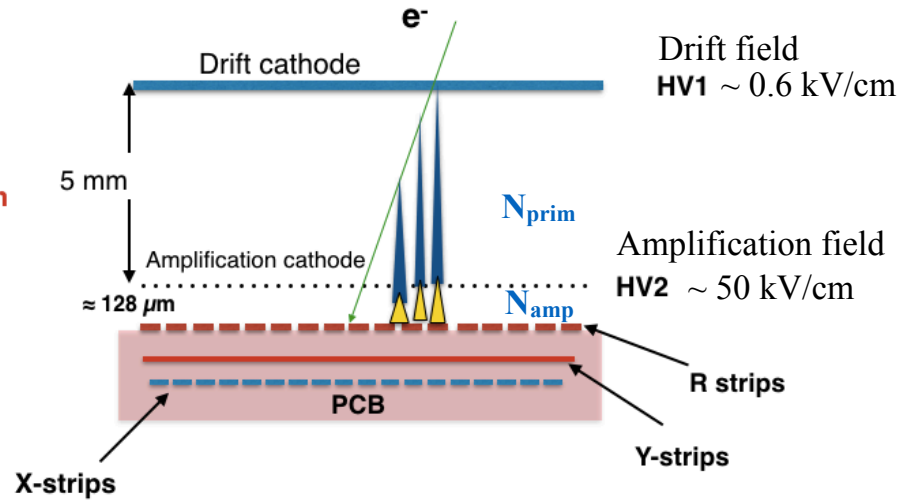
Tracking system MM1-MM4: multiplexed resistive micromegas

320 strips/layer

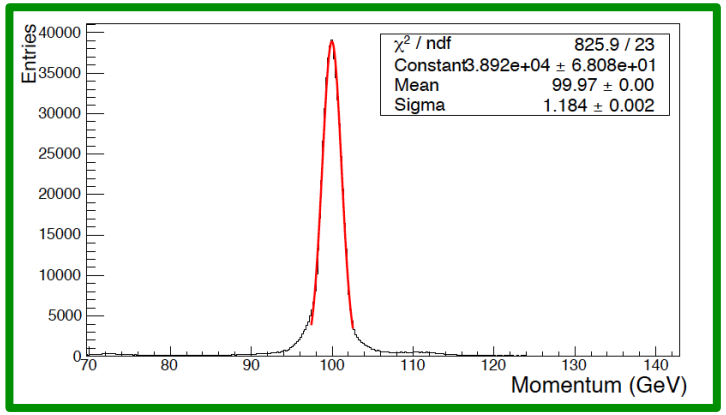


Y: 250/50 μm

X : 250/200 μm
R : 250/200 μm

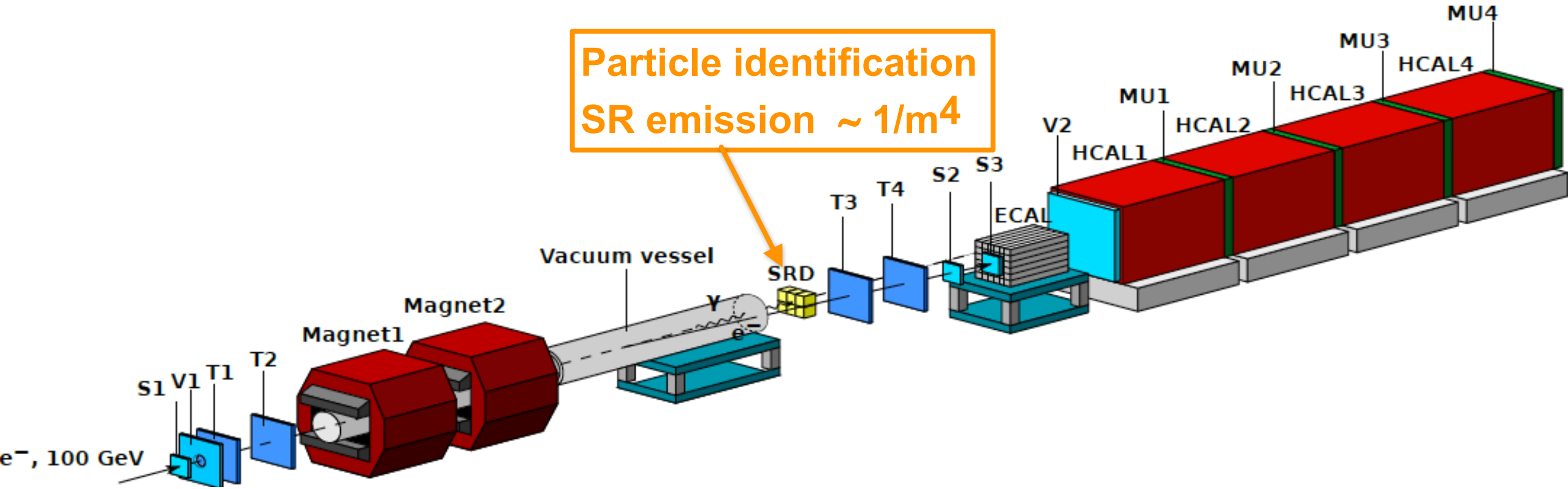


Reconstruction of e- incoming momentum



The Synchrotron Radiation (SR) detector

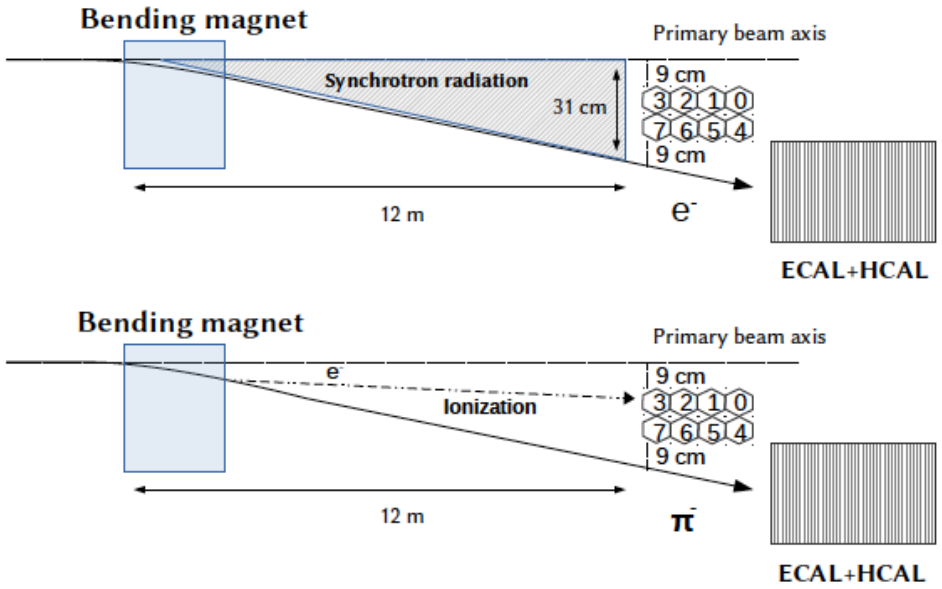
IPA ETH zürich

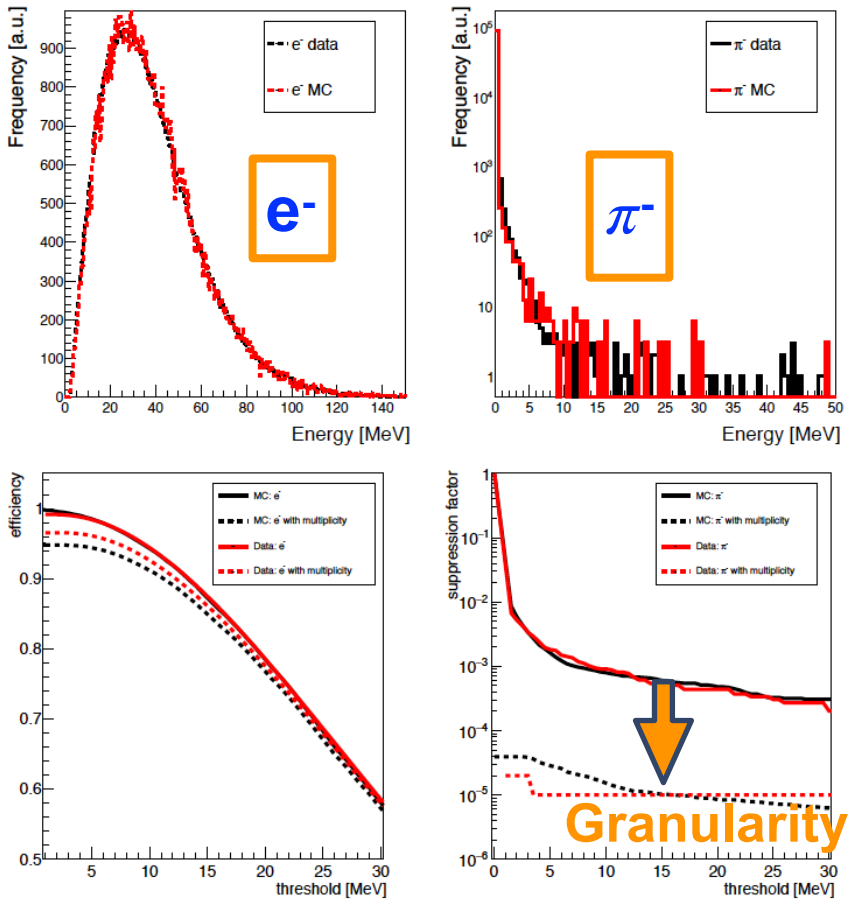


The Synchrotron Radiation (SR) detector

IPA ETH zürich

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

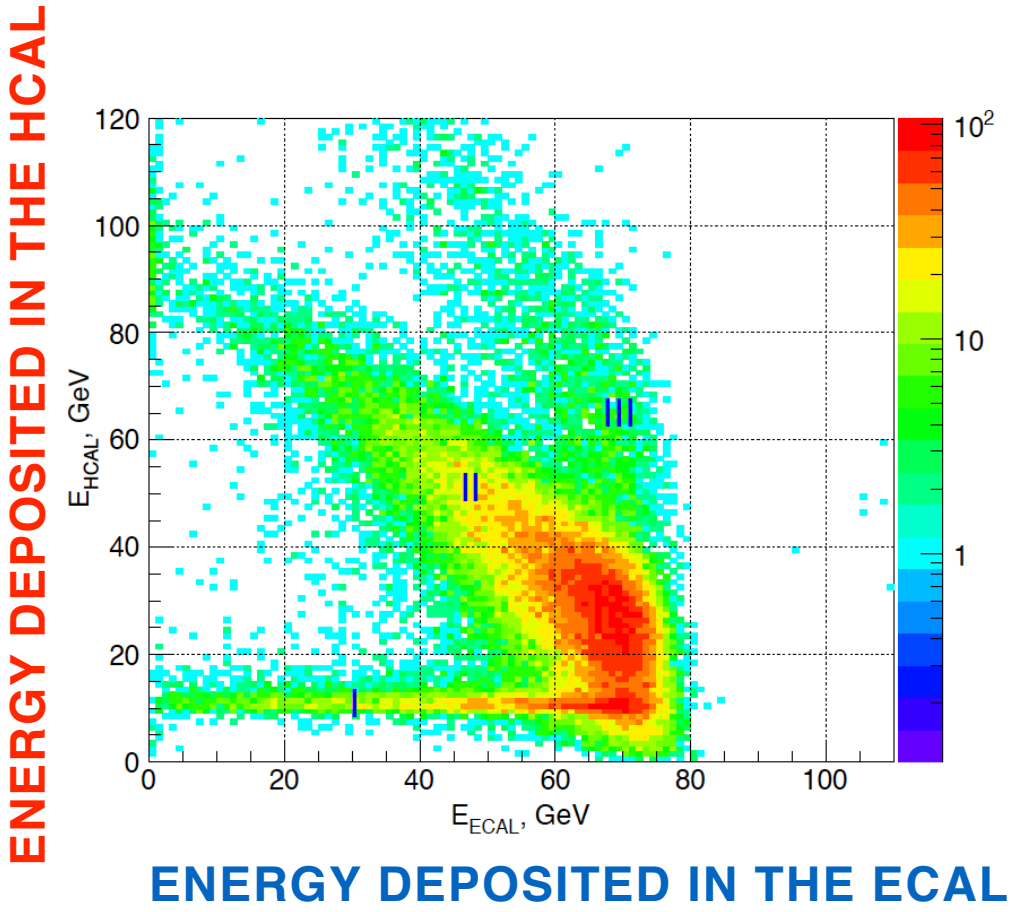




Efficiency > 95%
Suppression >10^{-5}

E. Depero et al., NIMA 866 (2017) 196-201 and
E. Depero, PhD thesis (defence 27.11.2020)

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

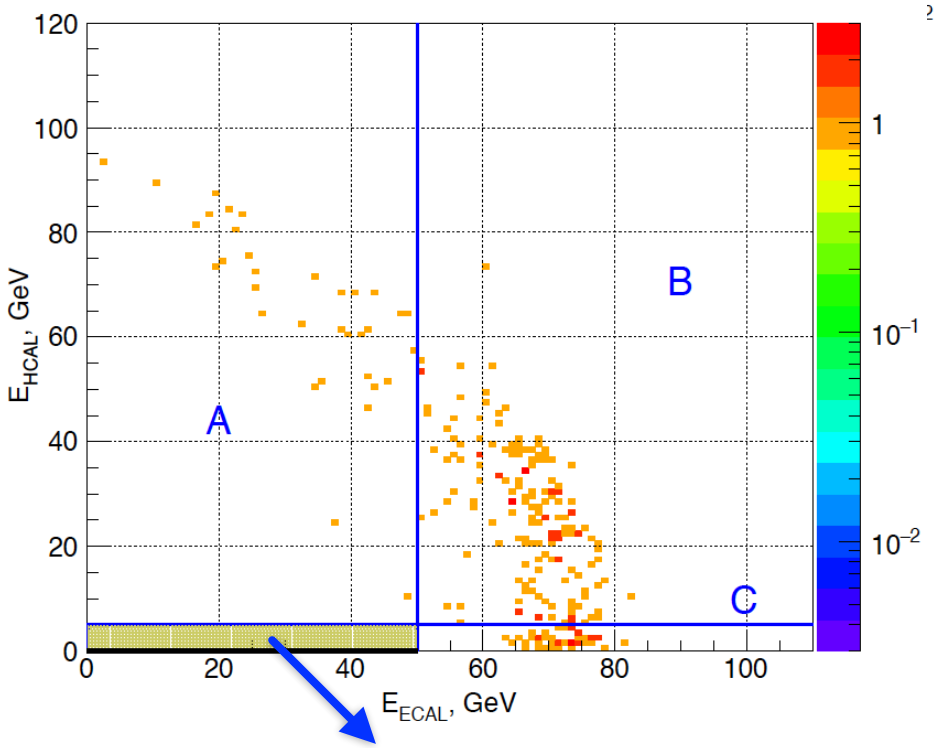


★ **Region I:** e- Z → e-Zγ; γ → μ+μ-
→ benchmark for MC

★**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)



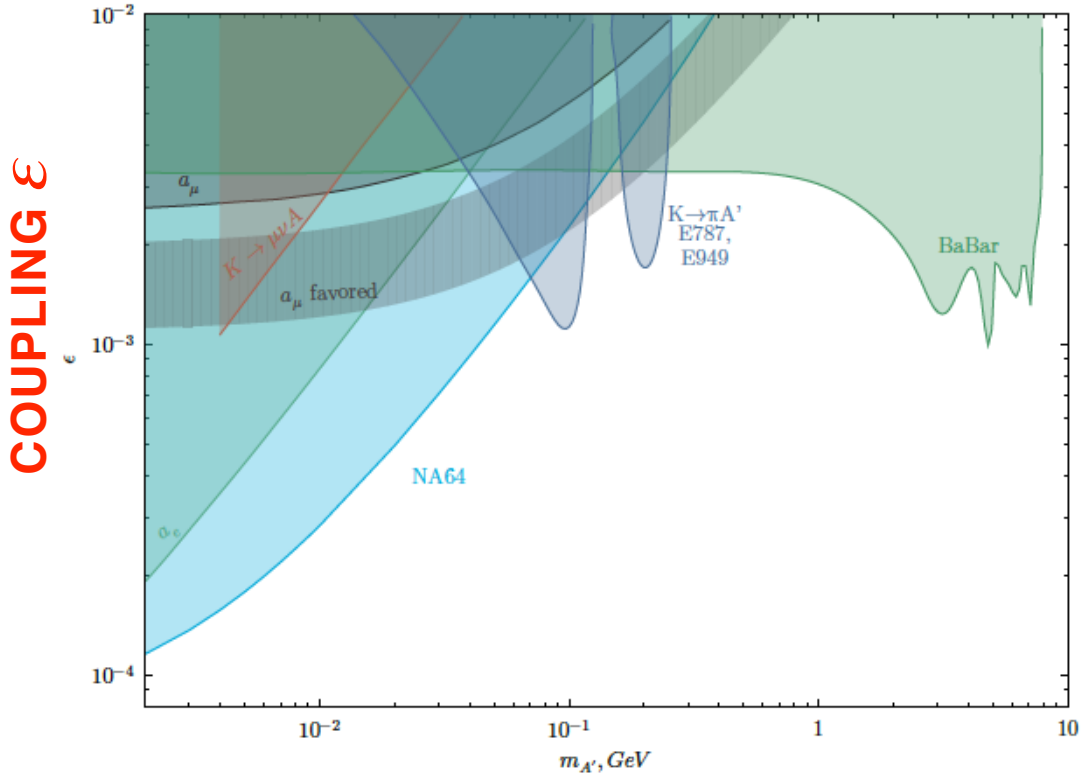
Event Selection Criteria:

- 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 counters.

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



MASS OF THE DARK PHOTON

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

→ exclusion of most of g-2 muon favored region

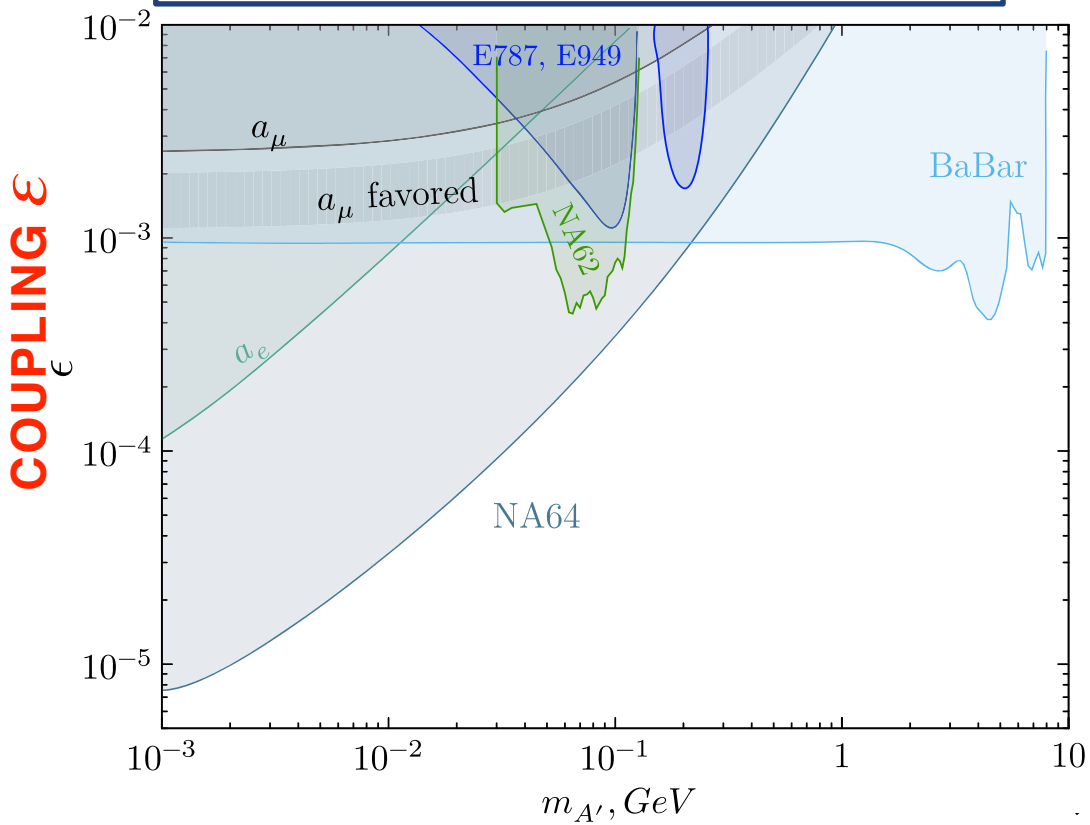
M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662, 53 (2008)

g-2 closed completely by BABAR results

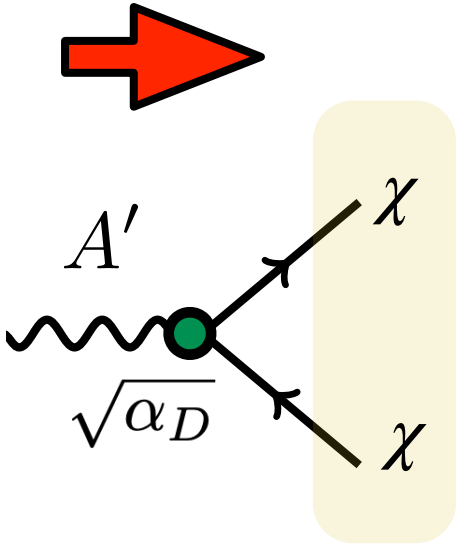
BABAR collaboration, Phys. Rev. Lett. 119, 131804 (2017)

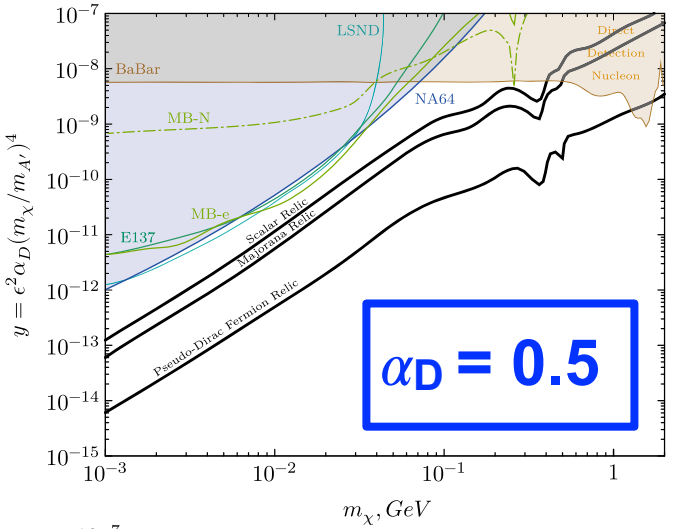
The NA64 search for A' → $\chi\bar{\chi}$ - *results combined analysis 2016-2018*

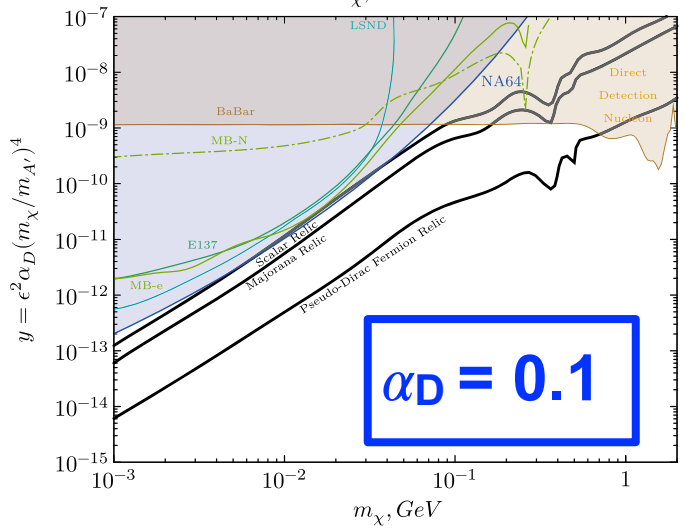
2.8 x 10^{11} electrons on target



NA64 sensitivity on light thermal DM start exceeding constraints of beam dump exp. (suppressed by $\epsilon^2\alpha_D$)

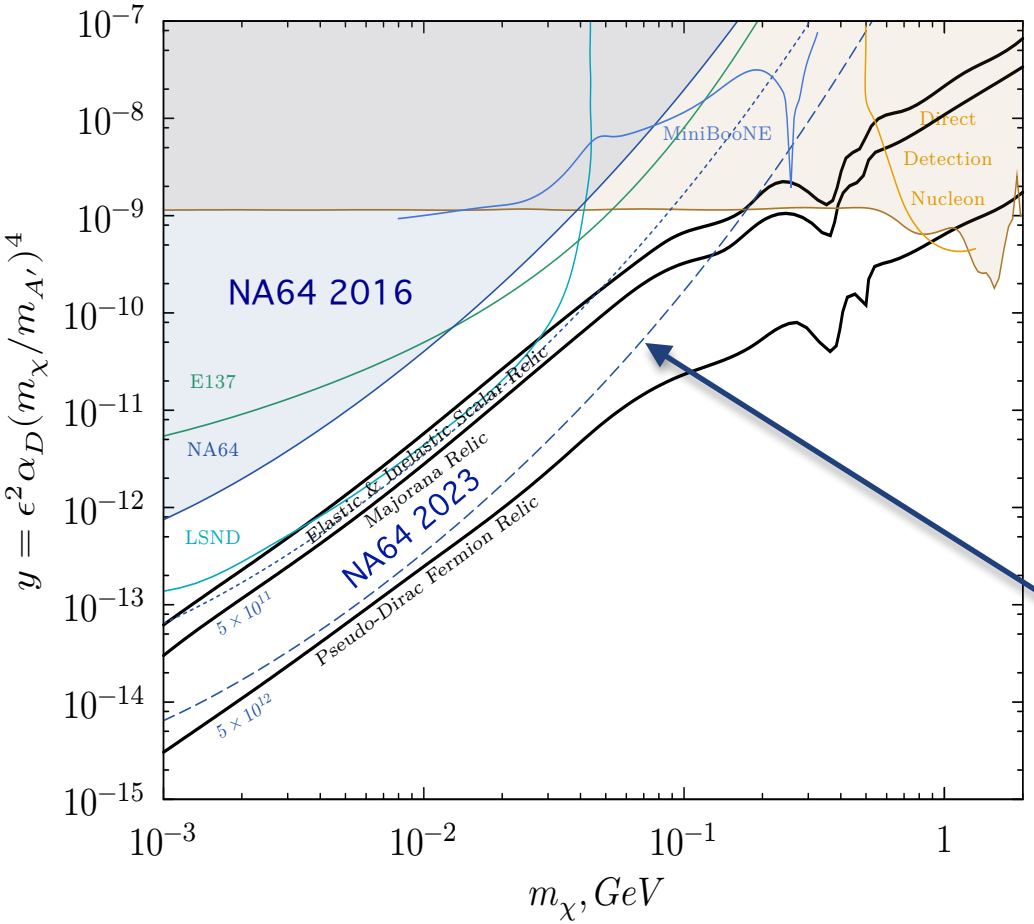






NA64 collaboration, Phys. Rev. Lett. 123, 121801 (2019)

The NA64 search for A' → $\chi\bar{\chi}$ - *Future prospects 2021-2023*



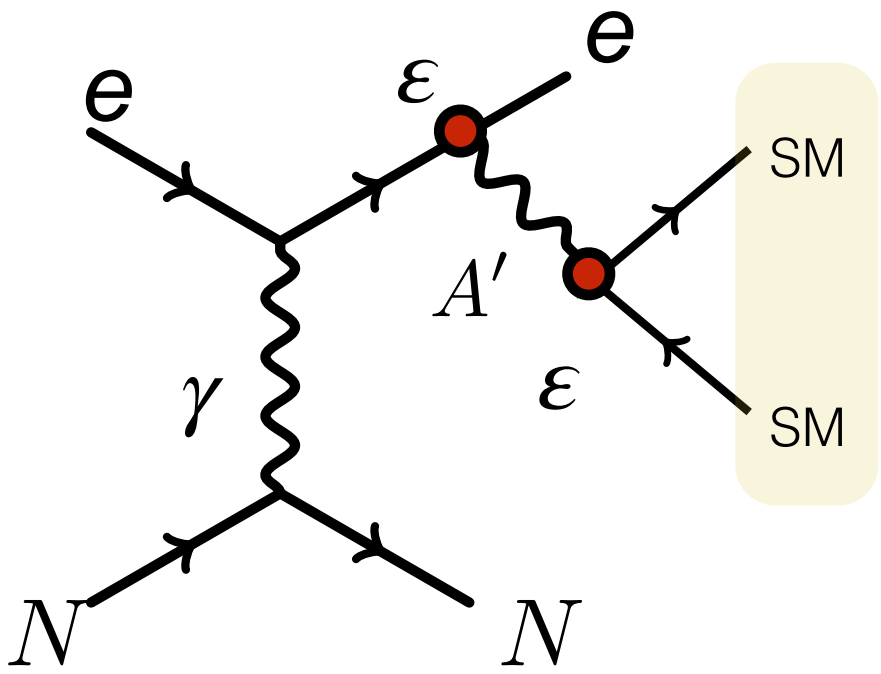
MASS OF THE DARK PHOTON

$\alpha_D = 0.1$ and $m_{A'} = 3m_\chi$

Setup upgrade/ optimisation required (ongoing)

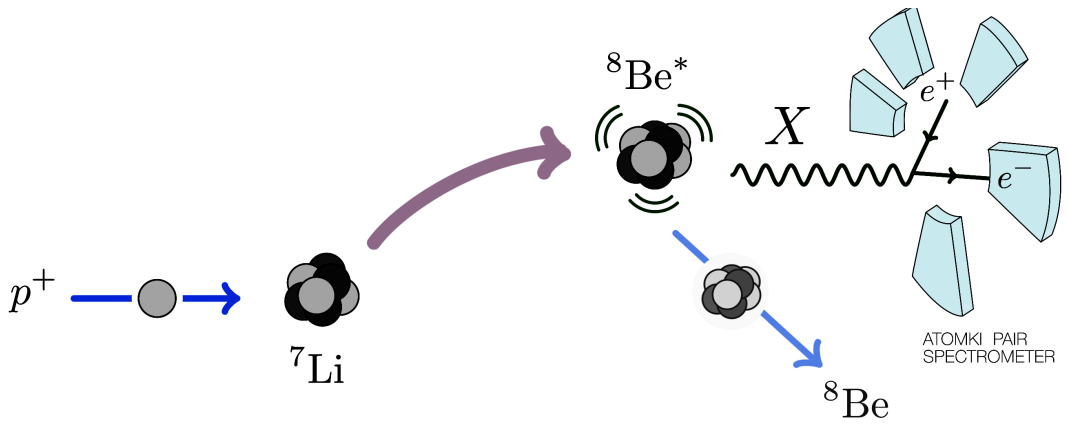
2) The NA64 search for A' → e^+e^-

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

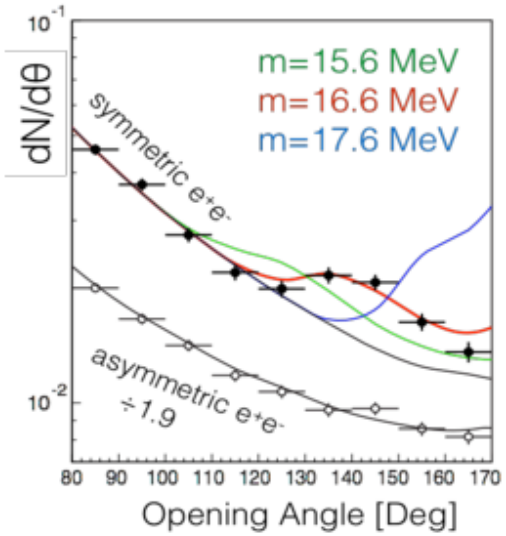


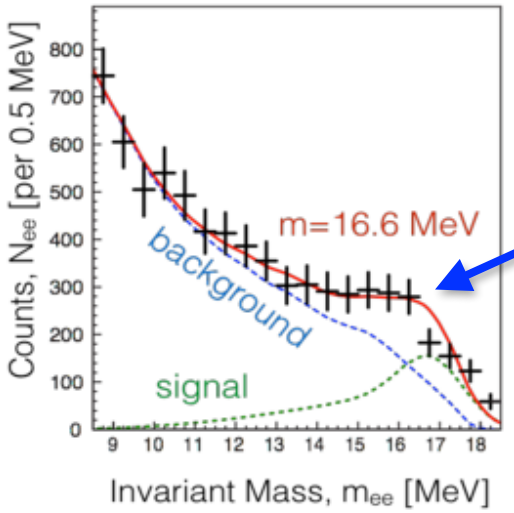
Pair production of SM particles

^{8}Be anomaly and X boson



A. J. Krasznahorkay et al. Phys. Rev. Lett.116, 042501 (2015) and recent results for 4He arXiv:1910.10459

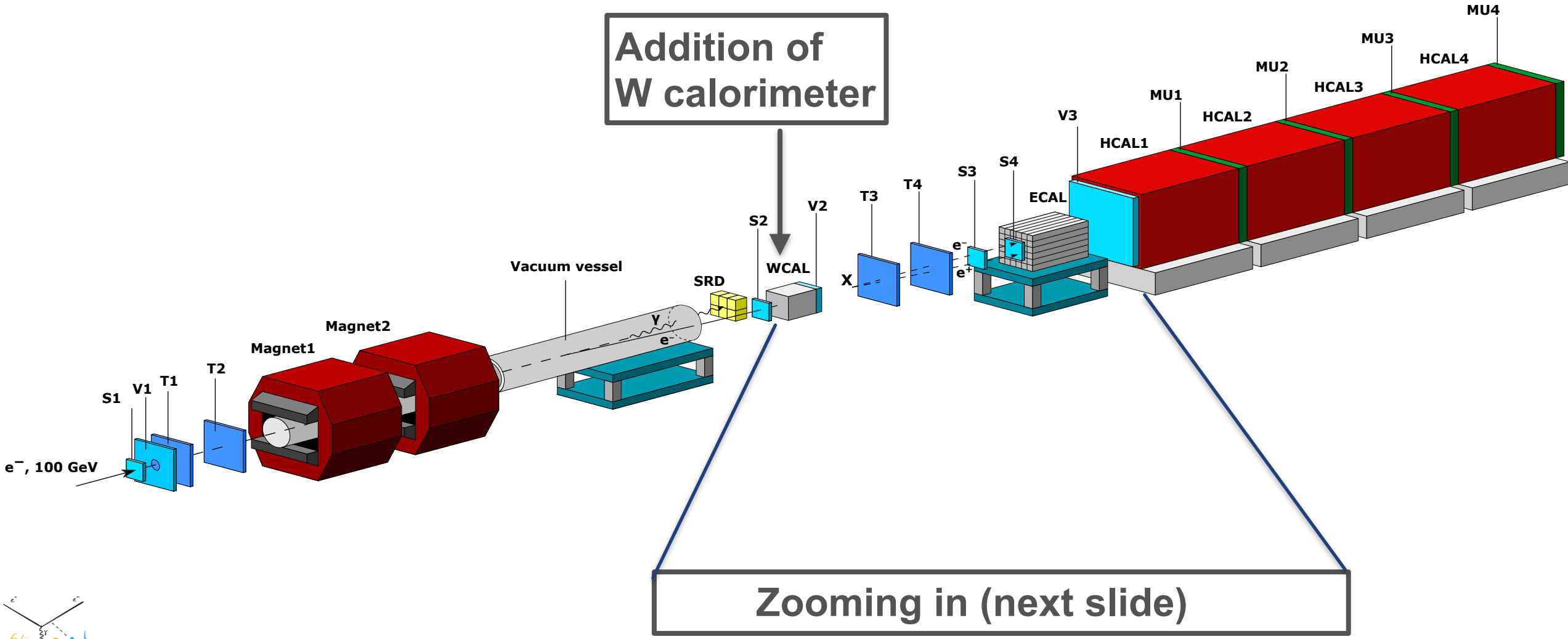




Could be explained by new 'protophobic' gauge boson X with mass around 17 MeV

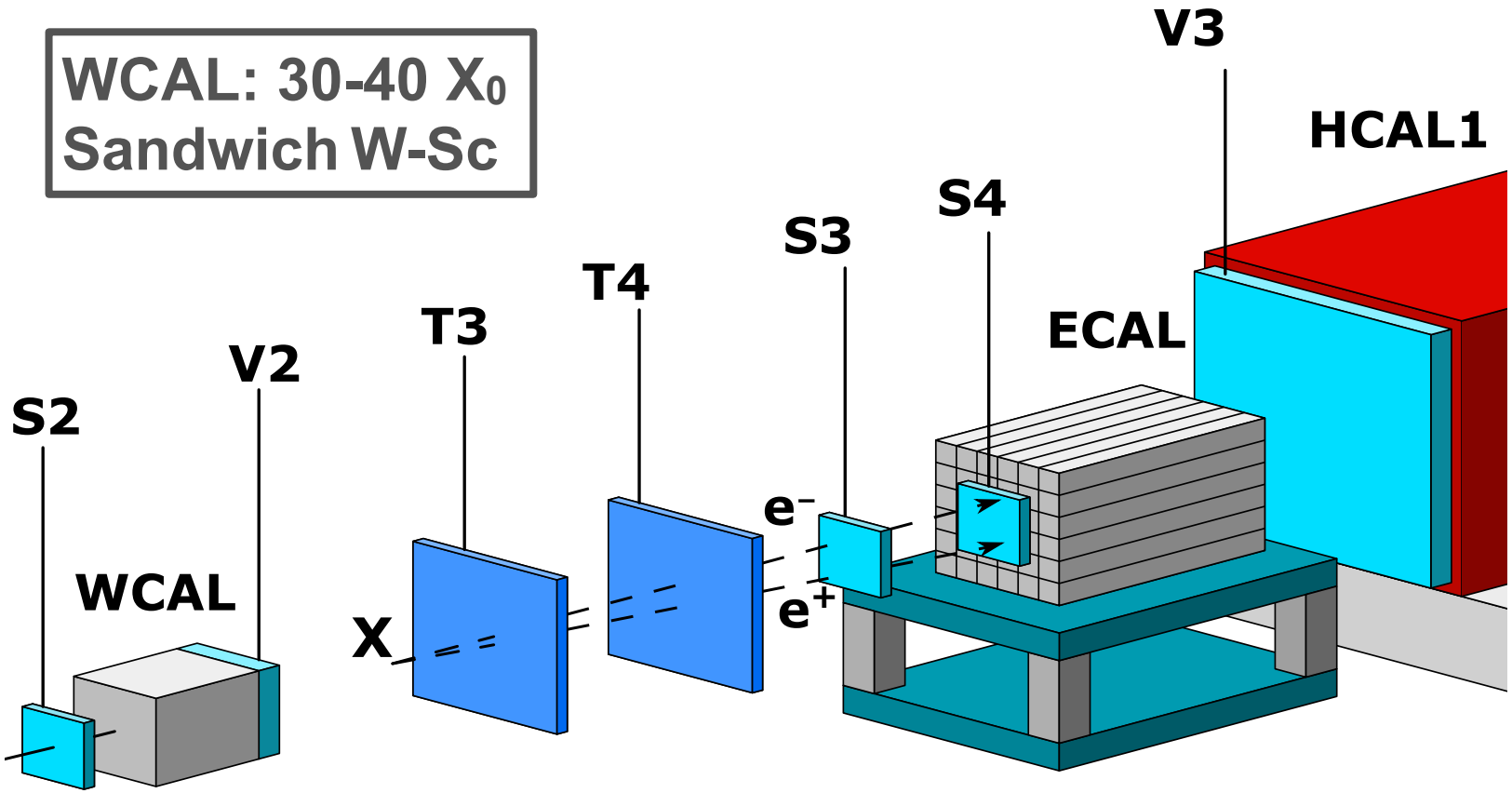
J. L. Feng et al. Phys. Rev. D95, 035017 (2017)

The NA64 search for A'/*X17*→ e^+e^- - *experimental setup*



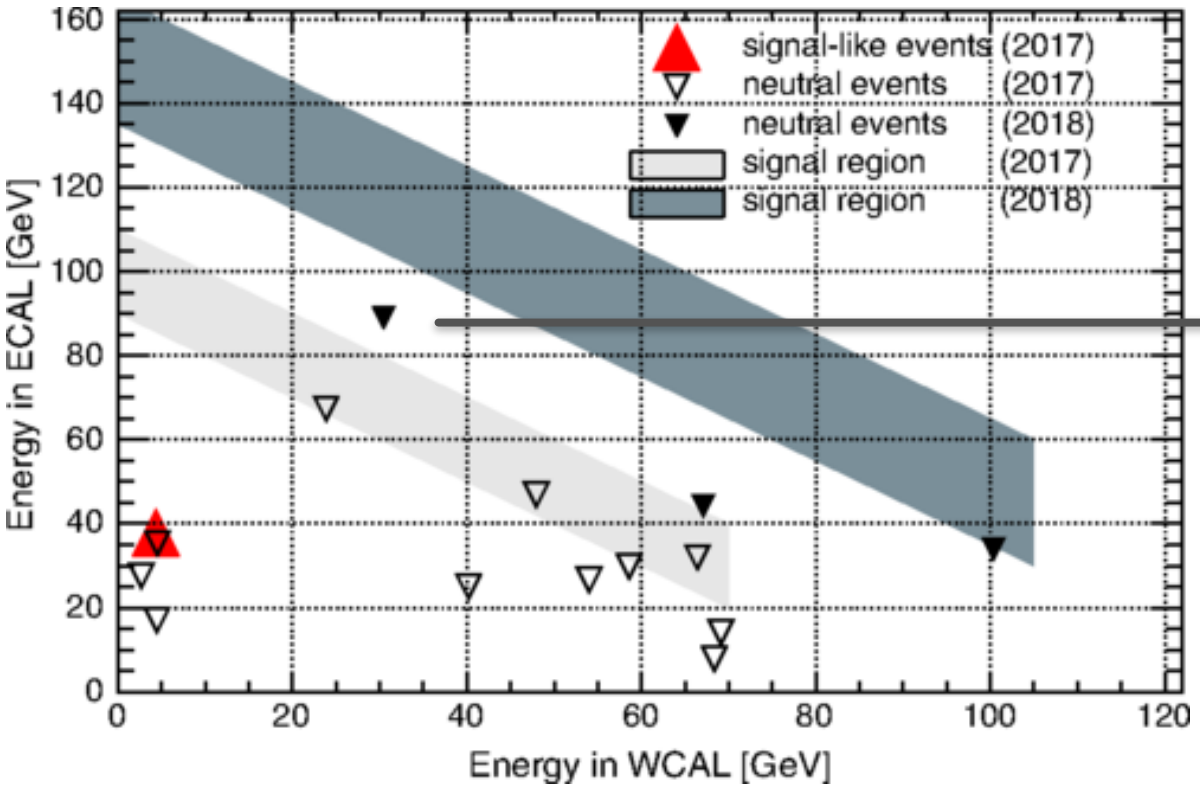
The NA64 search for A'/*X17*→ e^+e^- - *experimental signature*

WCAL: 30-40 X_0
Sandwich W-Sc



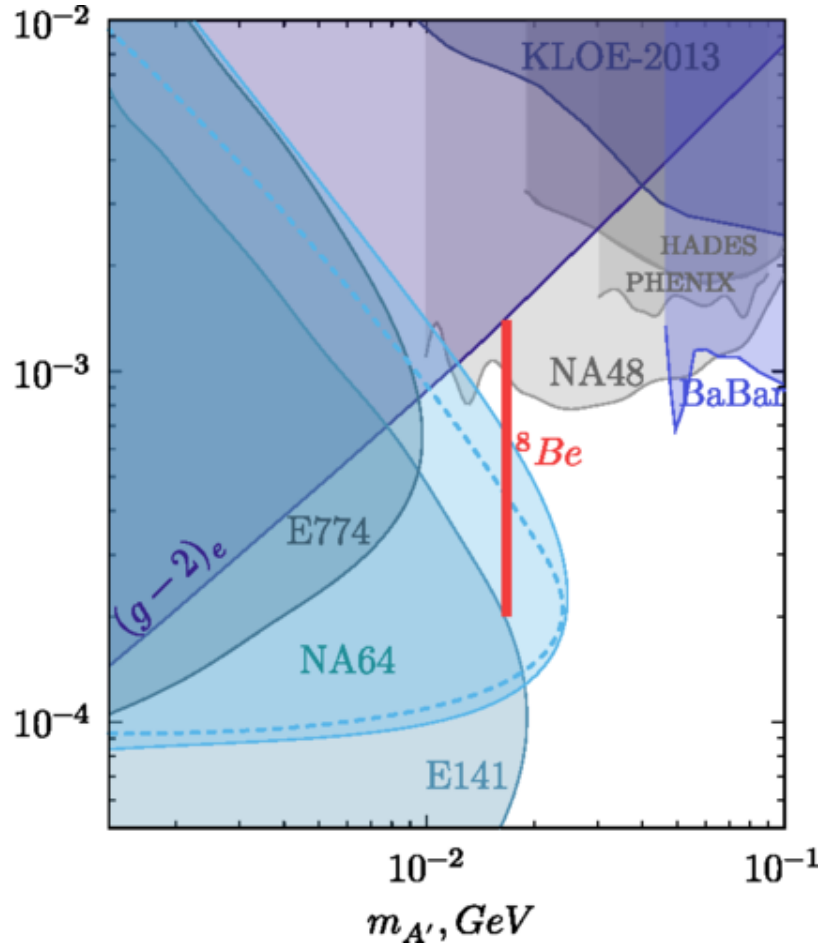
Signature:
1) $E_{WCAL}+E_{ECAL}$ = 100 GeV
2) No activity in $V_{2,3}$ and HCAL
3) Signal in S3, S4
4) e-m shower in ECAL

The NA64 search for A'/*X17*→ e^+e^- - *results (2017-2018)*



No signal-like event in signal box

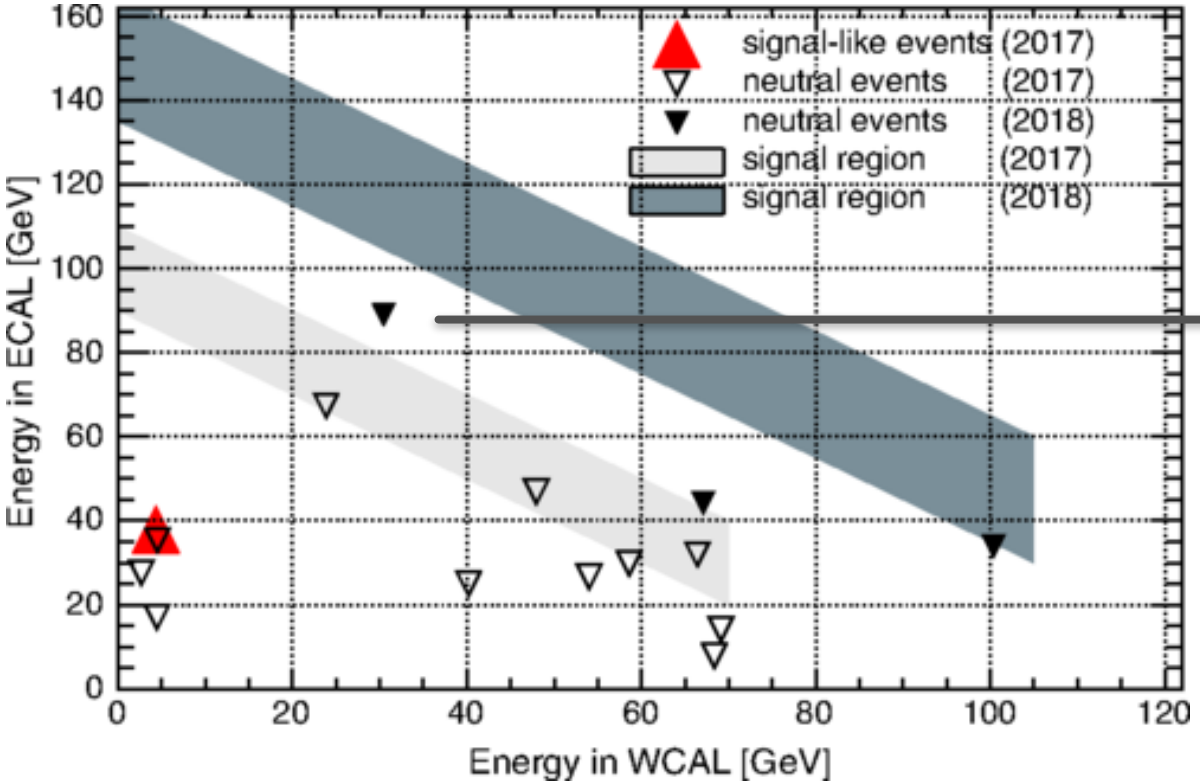
~ 8×10^{10} EOT

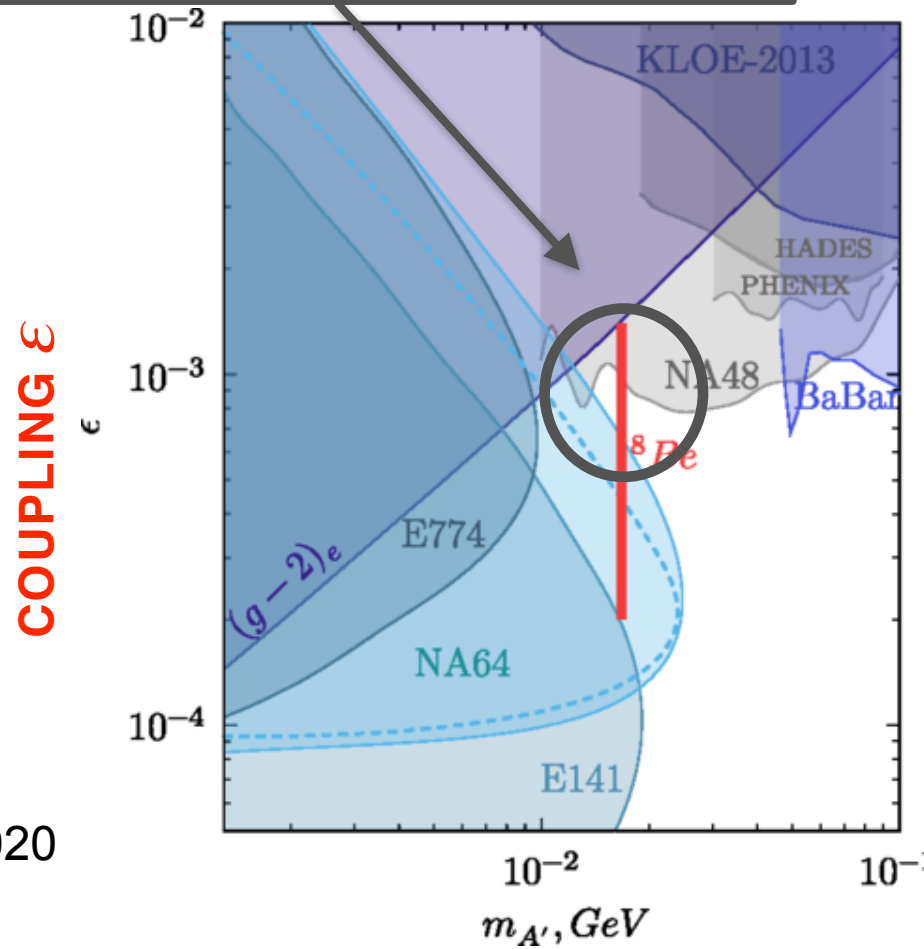


NA64 collaboration, PRL 120, 231802 (2018), PRD 107, 071101 (R) 2020

The NA64 search for A'/*X17*→ e^+e^- - *results (2017-2018)*

X17 very short lived <10^{-13} s

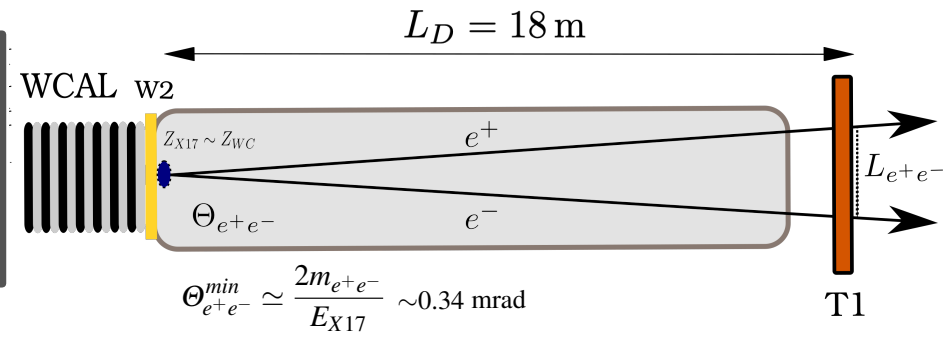


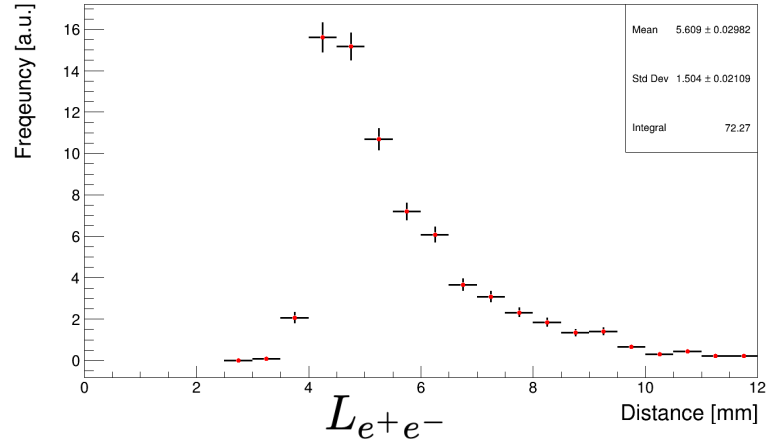


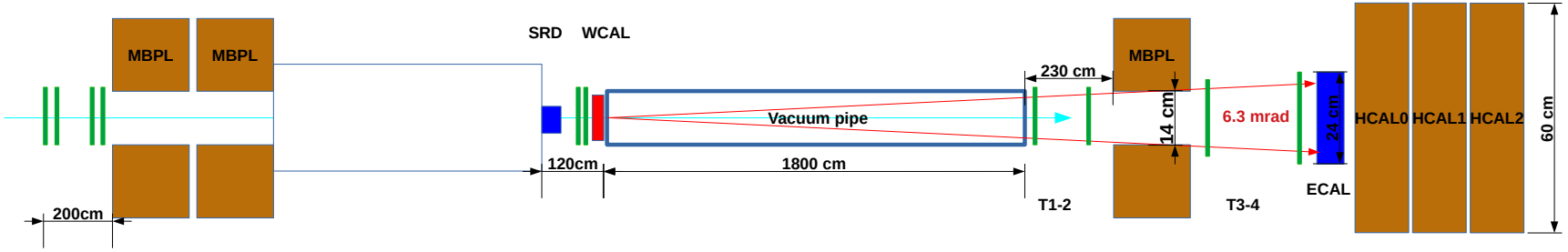
NA64 collaboration, PRL 120, 231802 (2018), PRD 107, 071101 (R) 2020

The NA64 search for *X17→ e⁺e⁻ - prospects (2021-2023)*

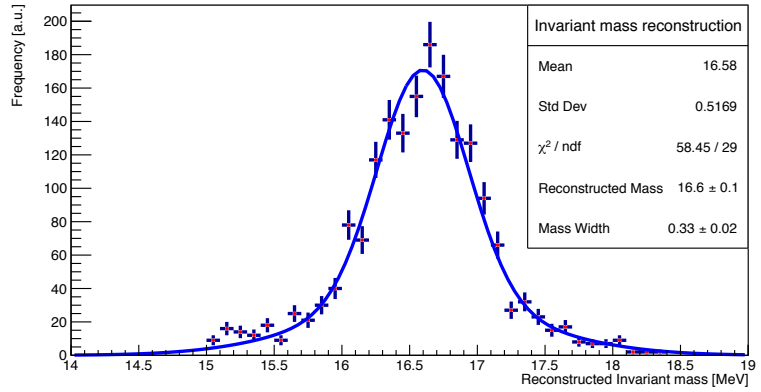
Optimization of WCAL: 20% shorter keeping 30X₀







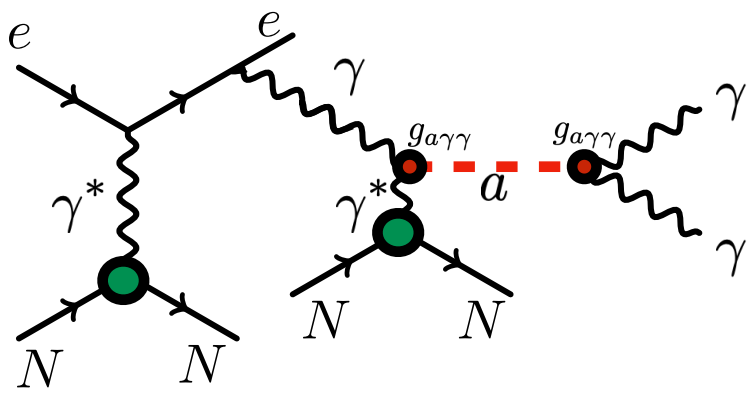
$$m_{X17} = [E_{e^+}E_{e^-}]^{1/2}\Theta_{e^+e^-}$$



Invariant mass reconstruction: Spectrometer + angle measurement

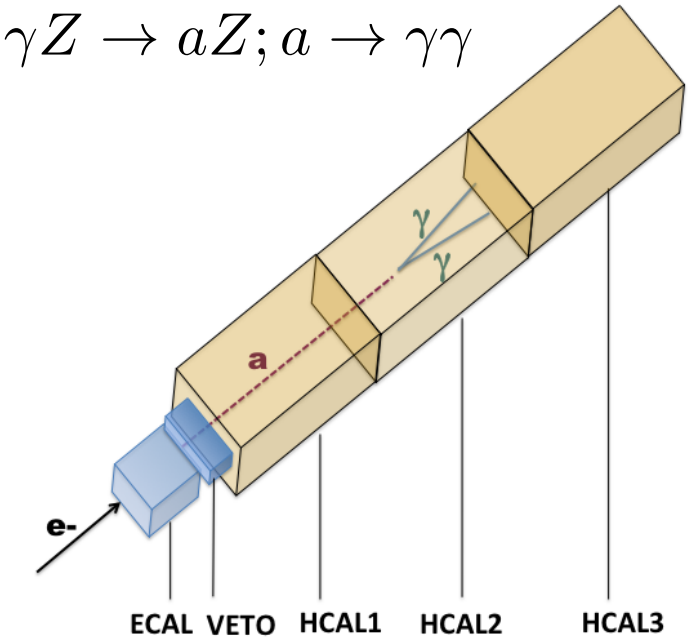
~ 10^{11} EOT (20 days) required to cover remaining X17 phase space

The NA64 ALP search - *results*

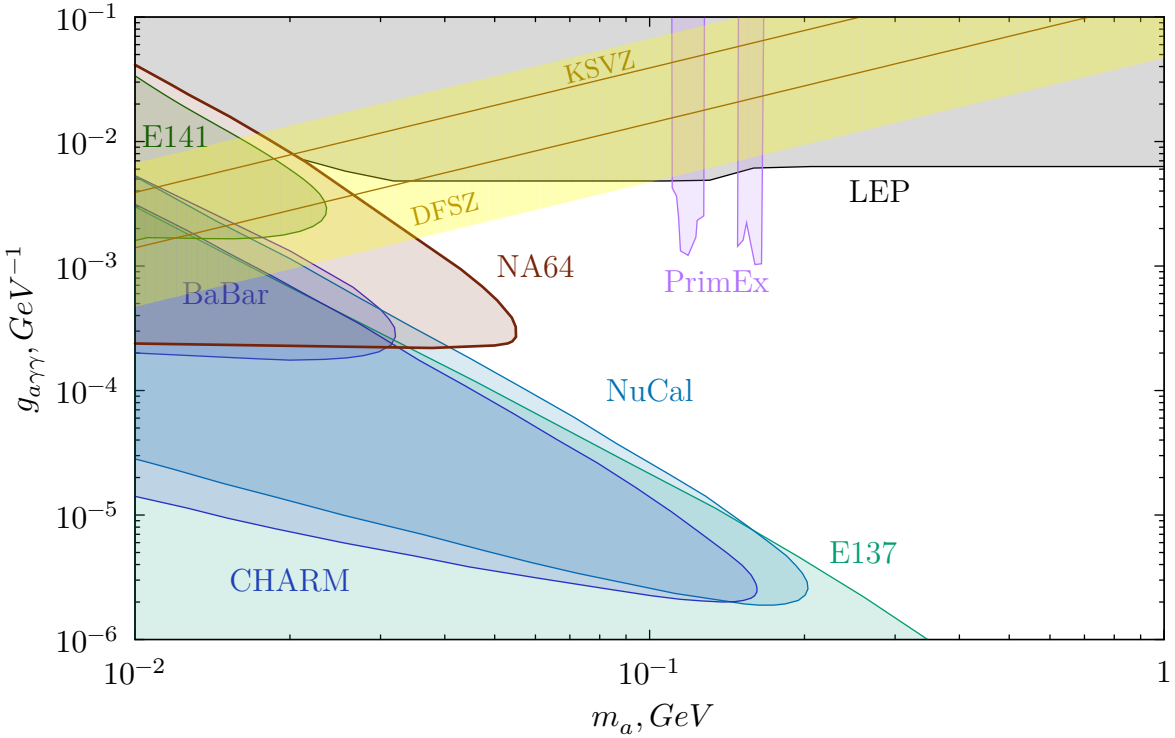


Production via Primakoff effect

$$e^- Z \to e^- Z\gamma; \gamma Z \to aZ; a \to \gamma\gamma$$



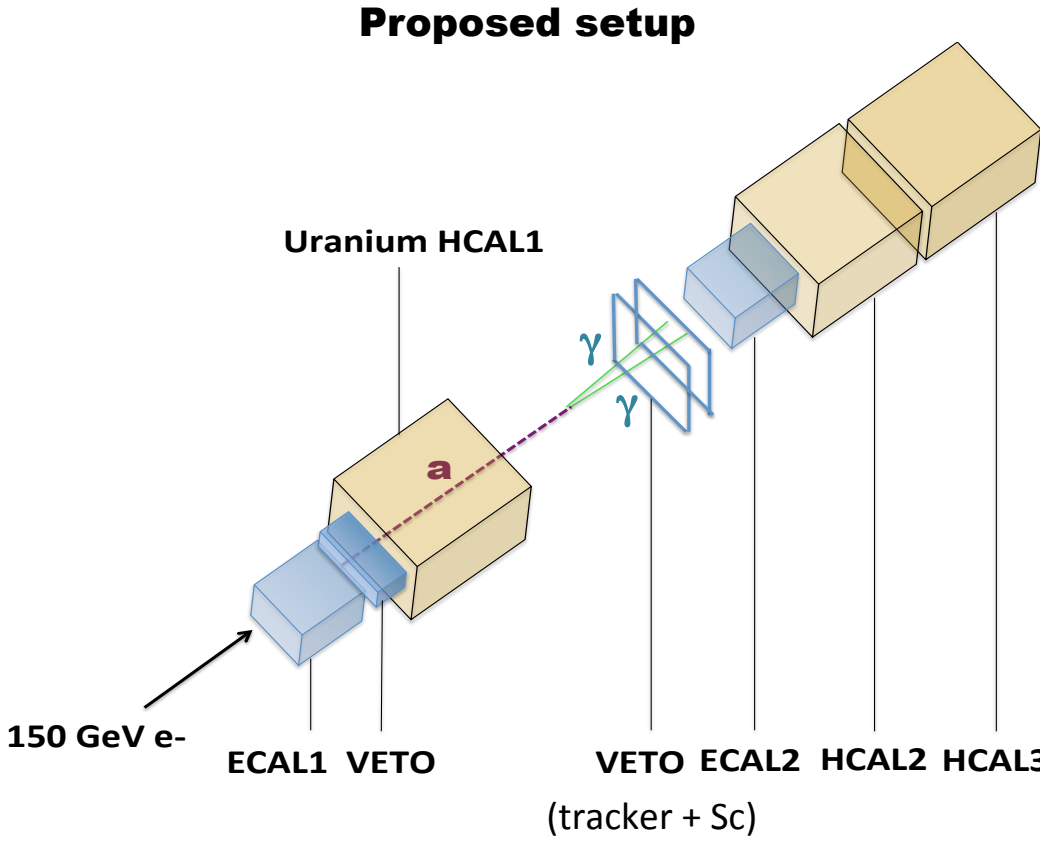
Closing the gap between beam dump and colliders

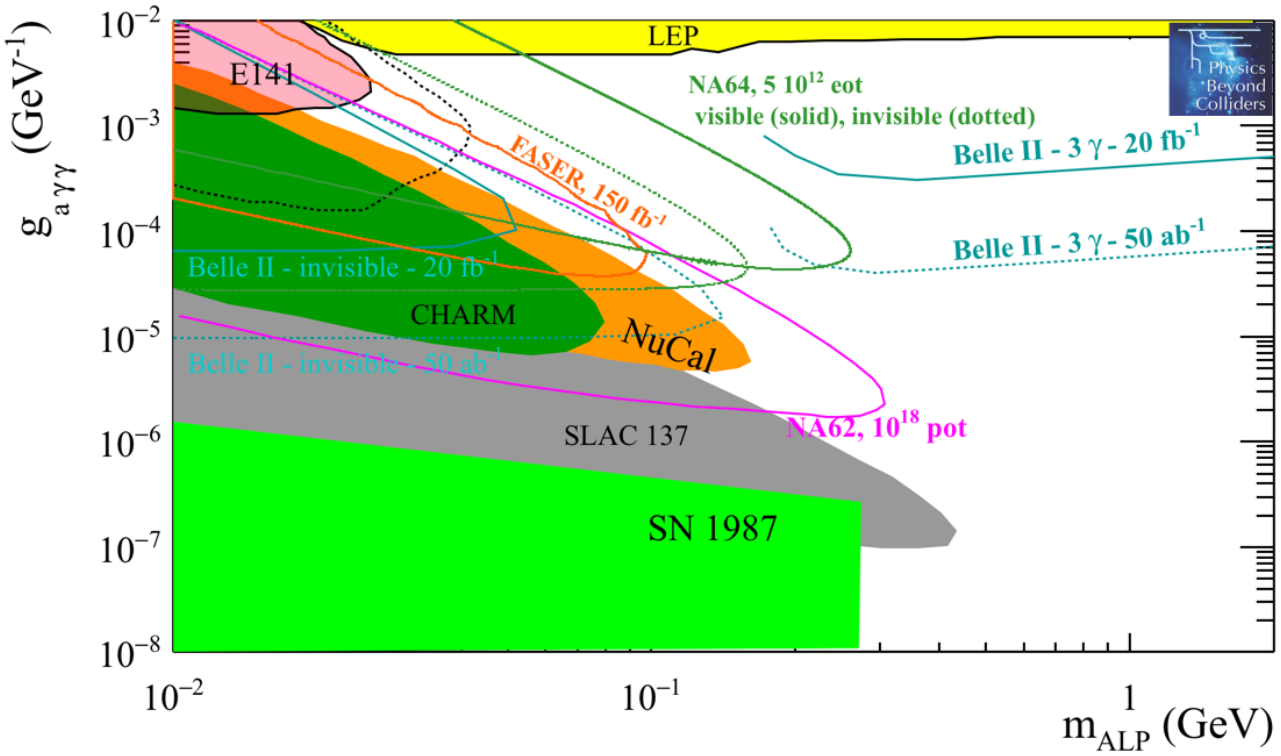


NA64 collaboration PRL 125, 081801 (2020)

The NA64 ALP search - *future prospects*

Feasibility of combining ALPs with A' → $\chi\bar{\chi}$ search under study





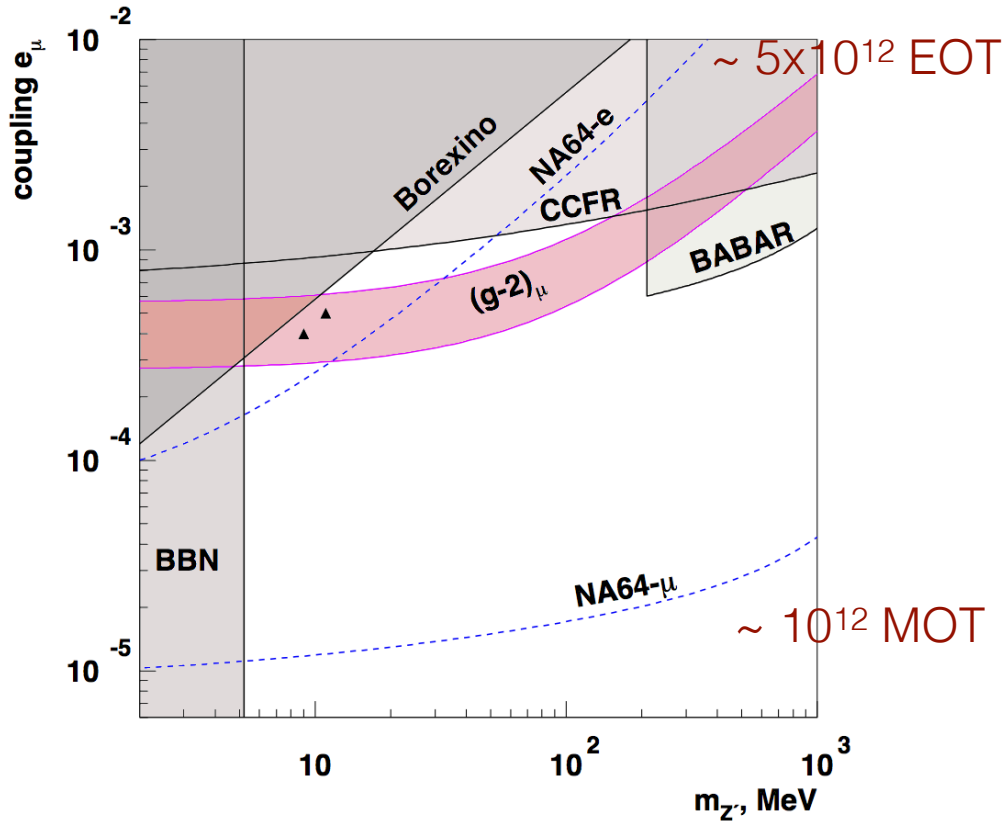
J. Beacham et al., J.Phys. G 47, 010501 (2020).

NA64 in muon mode- NA64$_\mu$

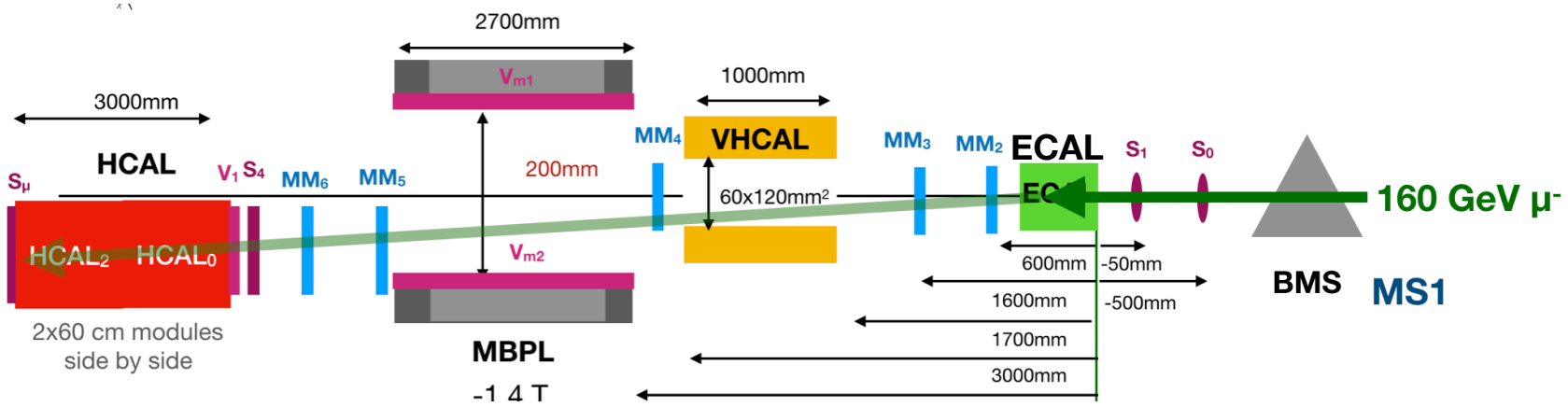
CERN SPS **M2 160 GeV muon beam** offers unique opportunities to further **searches for DS** of particles predominantly weakly-coupled to 2nd second and possibly 3rd generations of the SM.

$$\mu + Z \to \mu + Z + Z_\mu,\ Z_\mu \to \nu\bar{\nu}$$

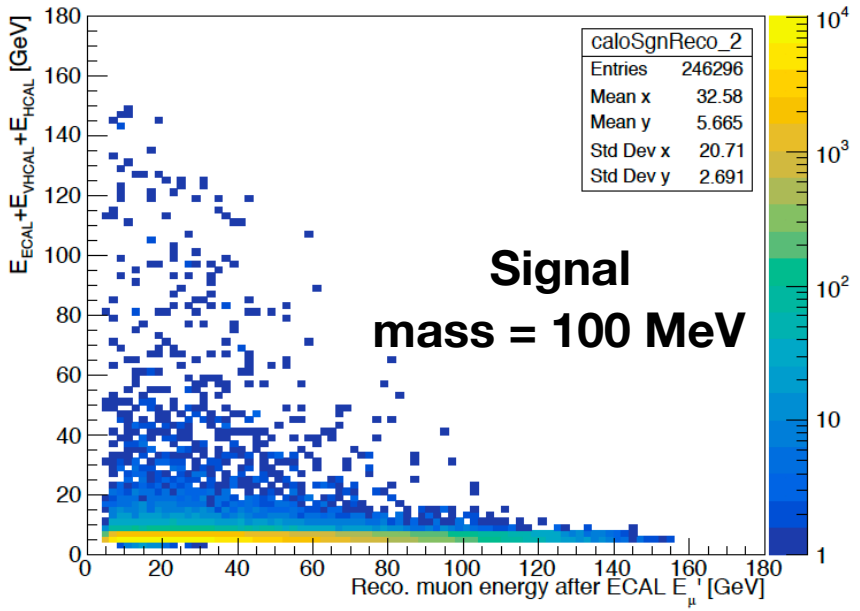
L_μ-L_τ models Z could explain (g-2)$_\mu$

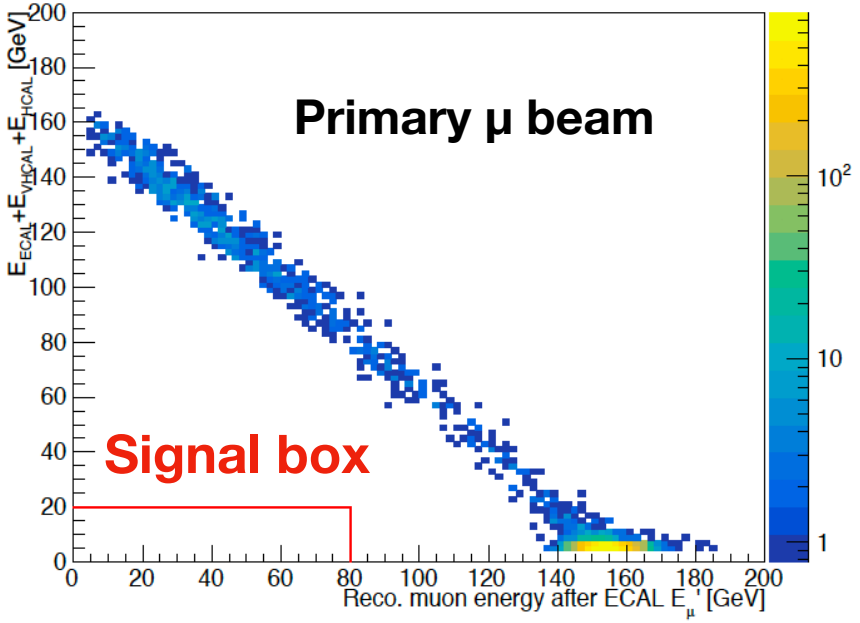


NA64 in muon mode- experimental setup (pilot run 2021, 2 weeks)



Signature:
1) Tagged 160 GeV incoming muon
2) Scattered muon with <80 GeV
3) No activity in HCAL

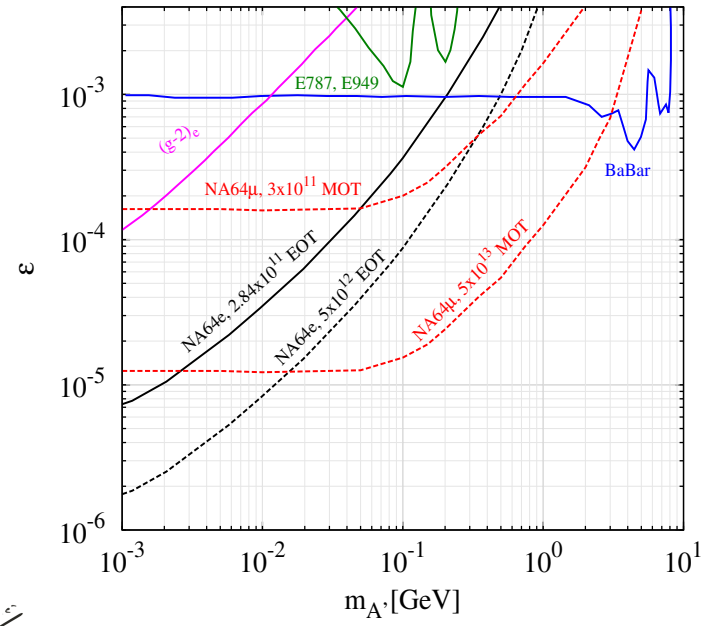




NA64 in muon mode - Search for LDM

Search for **Dark photons** complementary to NA64e in mass region $m_{A'} > 0.1$ GeV

$$\mu + Z \to \mu + Z + A', A' \to \chi\bar{\chi}$$



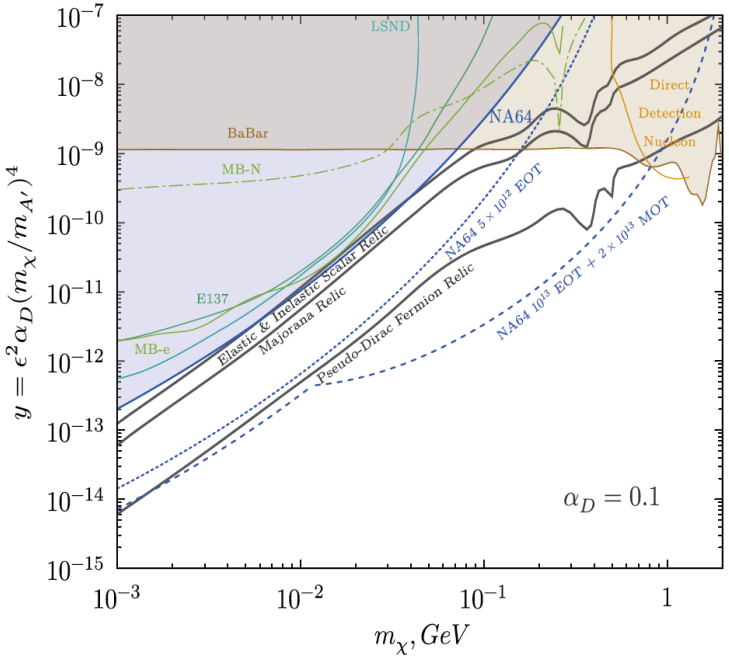
NA64$_e$

$$N^e_{A'} \sim L^e \sigma^e_{A'}$$
$$L^e \simeq X_0$$
$$\sigma^e_{A'} \sim \epsilon_e^2 / m^2_{A'}$$

NA64$_\mu$

$$N^\mu_{A'} \sim L^\mu \sigma^\mu_{A'}$$
$$L^\mu \simeq 40 X_0$$
$$\sigma^\mu_{A'} \sim \epsilon_\mu^2 / m^2_\mu \qquad m_{A'} \lesssim m_\mu$$

Combined LDM sensitivity of NA64$_e$ -NA64$_\mu$



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

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' → $\chi\bar{\chi}$:** 3x10^{11} EOT collected PRL 123, 121801 (2019)

- *X*→ e^+e^- : 5x10^{10}EOT@100 GeV PRL120, 231802 (2018), 3x10^{10} EOT@150 GeV PRD (2020)

AFTER CERN LONGSHUDOWN (July 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^-), Pilot run in 2021 at M2 (muon mode)

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

Acknowledgments

NA64 collaboration and in particular S: Gninenko

CERN & PBC

ETH Zurich group
L. Molina-Bueno, B. Radics, A. Rubbia,
Graduate Students: Emilio Depero, H Sieber
Former members of the ETH group: D. Banerjee, D. Cooke
Undergraduate Students: C. Cazzaniga, P. Odagiu, L. Pedrelli, R. Schwarz and all the past students.

IPA

ETH zürich

Funding: ETH Zurich and SNSF Grant No. 169133 and 186158 (Switzerland)

FNSNF
Swiss National Science Foundation