Поиск Новой Физики в Ускорительных Экспериментах

С.Н. Гниненко

ИЯИ РАН

Содержание

1. Проверка SM и поиски BSM в экспериментах ИСТРА, ИСТРА+, ОКА

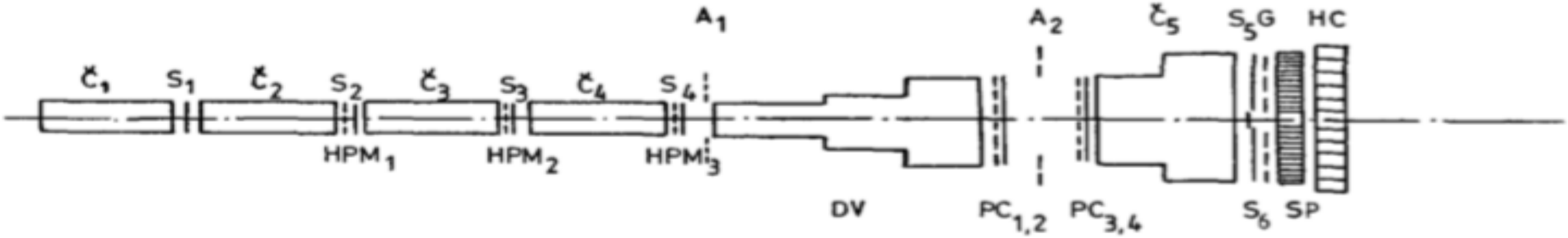
2. Сотрудничество с BNL, KEK, GSI (E865, E949, E246, E470, HADES)

3. Сотрудничество с CERN (NOMAD, CMS, ALICE, LHCb, AEGIS, NA50, NA61, NA62, NA64e,μ) и ETHZ (e+ beam)

(I) Rare decays: ИСТРА

В.М. Лобашев
В.Н. Болотов
В.В. Исаков

First INR experiment on rare π, K decays at IHEP using 15-25 GeV beam from U-70 PS (НКС, 1976–1990)



π, K decays	Physics
$\pi \rightarrow e\nu\gamma$	Br~10^{-7}, Str.Rad., TI? Poblaguev, Voloshin PLB'90
$\pi^0 \rightarrow 4\gamma$	first observation
$K \rightarrow \pi\pi\gamma$	direct γ radiation
$K \rightarrow 3\pi(\gamma)$	Dalitz plot
$K \rightarrow \pi e\nu\gamma$	form-factors
$K \rightarrow \pi\pi e\nu$	

Volume 243, number 3 PHYSICS LETTERS B 28 June 1990

The experimental study of the $\pi^- \to e^- \bar{\nu}\gamma$ decay in flight

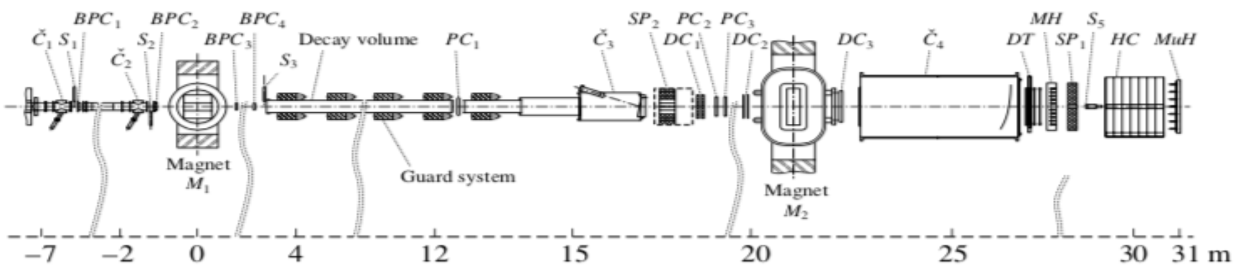
V.N. Bolotov, S.N. Gninenko, R.M. Djilkibaev, V.V. Isakov, Yu.M. Klubakov, V.D. Laptev, V.M. Lobashev, V.N. Marin, A.A. Poblaguev, V.E. Postoev and A.N. Toropin
Institute for Nuclear Research of the Academy of Sciences of the USSR, SU-117 312 Moscow, USSR

Received 22 December 1989

An experiment studying the radiative pion decay, $\pi^- \to e^- \bar{\nu}\gamma$, has been performed with a secondary 17 GeV negative pion beam on the IHEP machine with the ISTRA facility of the Institute for Nuclear Research. The high energy beam has enabled us to investigate this decay in a wide range of kinematic variables: $E_\gamma > 21$ MeV, $E_e > 70 - 0.8E_\gamma$ MeV, which included events with $\theta_{e\gamma} > 60°$. The axial-to-vector form factor ratio has been determined unambiguously: $\gamma = 0.41 \pm 0.023$. The vector form factor has been determined in a model independent way: $|F_V| = 0.014 \pm 0.009$. The probability of the $\pi^- \to e^- \bar{\nu}\gamma$ decay was found to be $BR = (1.61 \pm 0.23) \times 10^{-7}$ for the region under consideration. The contributions of the inner bremsstrahlung and of the structure dependent radiation were investigated. A possible interpretation is discussed.

(II) Rare decay: ИСТРА+

IHEP- INR experiment on rare K decays at IHEP using ~ 20 GeV from U-70 PS (2000 – 2010)



K decays	Physics
K –> $\pi e \nu \gamma$	Tests of Chiral Perturbation Theory high accuracy form-factors
K –> $e(\mu)\nu\gamma$	F_V-F_A differs 2σ ChPT, TI ~0
K –> $\mu\nu_h$ (ν_h–> $\nu\gamma$)	MiniBooNE anomaly, SG PRL’09; PRD’11
K –> $\mu\nu\pi\gamma$	first observation, agrees SM
K –>$\pi\pi\gamma$	direct γ radiation
K –>$\pi\pi$P	Light P-sgoldstino, Gorbunov, Rubakov PRD’01

(III) Rare decays: OKA

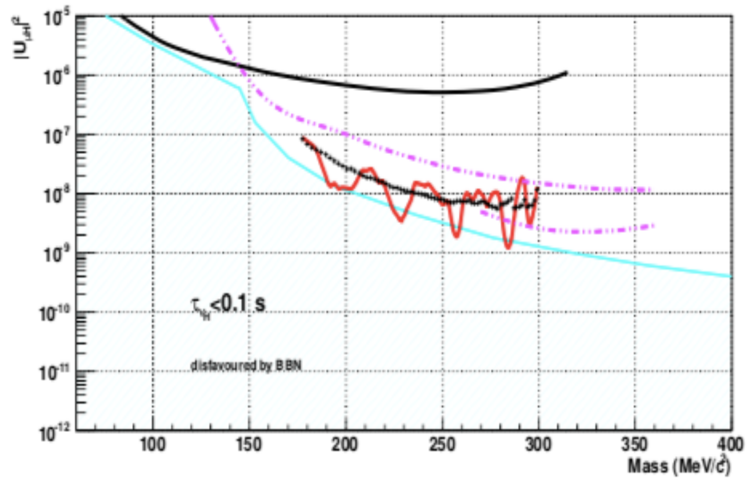
IHEP- INR-JINR experiment on rare K^+ decays at IHEP using ~20 GeV RF-separated secondary beam from U-70 PS (2010➔)
RF uses two SC deflectors, IHEP cryogenic. ~ 10^6 K+/spill

K^+ decays	OKA Physics
$K \to \pi e \nu \gamma$	Tests of Chiral Perturbation Theory
$K \to \mu \nu \gamma$	F_V-F_A 1.6σ ChPT, high accuracy form-factors
$K \to \mu \nu_h$	Limits on $\|U\mu h\|^2$
$K \to e \nu \gamma$	form-factors study, agrees SM, S, T~0
$K^+ \to \pi \pi \pi \gamma$	~450 ev, In agreement with ChPT

(IV) Rare decays: BNL, KEK, CERN

INR participation ~1995➔

K decays	PDG'20
BNL E949: K –> $\mu\nu_h$	Best limits on $\|U\mu h\|^2$
BNL E949: K–>$\mu\nu\nu\nu$	Br < 2.4 x10^{-6}
BNL E865: K–>$\pi\mu e$ K–> e$\nu\mu\mu$, $\mu\nu ee$	Br ~10^{-11} LVF Br ~10^{-8} observation
KEK E246: K–>$\pi\mu\nu$	Search for T violation
KEK E470: K–>$\pi\pi\gamma$	direct γ radiation
CERN NA62: K–>$\pi\nu\nu$ many interst. results	observation ~17 ev In agreement with SM



E949: K –> $\mu\nu_h$
(Yu. Kudenko et al.)

Shashlik ECAL–уникальная разработка ИЯИ-ИФВЭ

- Идея светосбора из слоистого калориметра спомощью WLS волокон, H. Fessler et al., NIM (1985)
- Первый годоскопический ECAL типа Shashlik создан в ИЯИ 1991–1992 Pr. INR-736/91, Atojan et al NIM (1992)
- ECAL в E865 (BNL)
- Основной вариант ECAL для H->γγ в CMS, и также LHCb, COMPASS, NA64
- Дальнейшее развитие – В. Поляков(ИФВЭ), Е. Гущин (ИЯИ)

Nuclear Instruments and Methods in Physics Research A320 (1992) 144–154
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

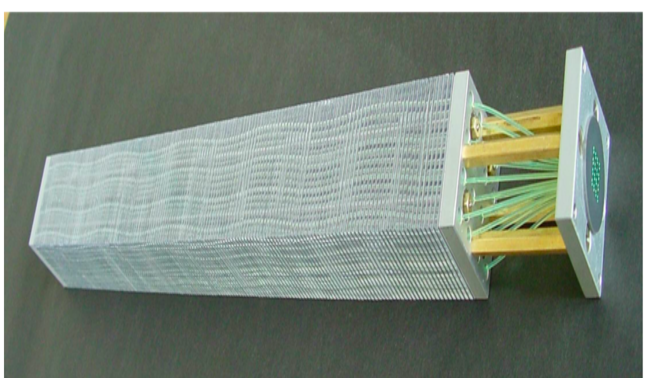
Lead–scintillator electromagnetic calorimeter with wavelength shifting fiber readout

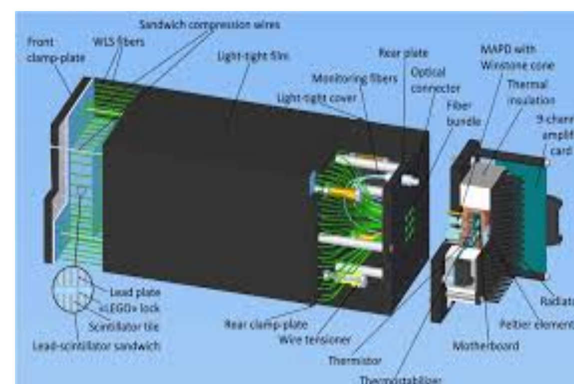
G.S. Atoyan, V.A. Gladyshev, S.N. Gninenko, V.V. Isakov, A.V. Kovzelev, E.A. Monich, A.A. Poblaguev, A.L. Proskuryakov and I.N. Semenyuk
Institute for Nuclear Research of the Russian Academy of Sciences, 117312 Moscow, Russia

V.G. Lapshin, Yu.V. Protopopov, V.I. Rykalin and V.K. Semenov
Institute for High Energy Physics, Protvino, Russia

Received 11 September 1991 and in revised form 21 February 1992

A study has been made of the characteristics of electromagnetic calorimeter modules with the structure (1.4 mm Pb+4 mm Sc)×60 layers using 72 wavelength shifting fibers for readout. These modules were made according to a specially developed technology and were tested with a beam of electrons, pions and muons with energies between 0.5 and 5 GeV. It was found that their energy resolution is $\delta E/E = 0.014 + 0.067/\sqrt{E[\mathrm{GeV}]}$, response nonuniformity < 2%, and π/e rejection at the level 10^{-2} to 10^{-3}.



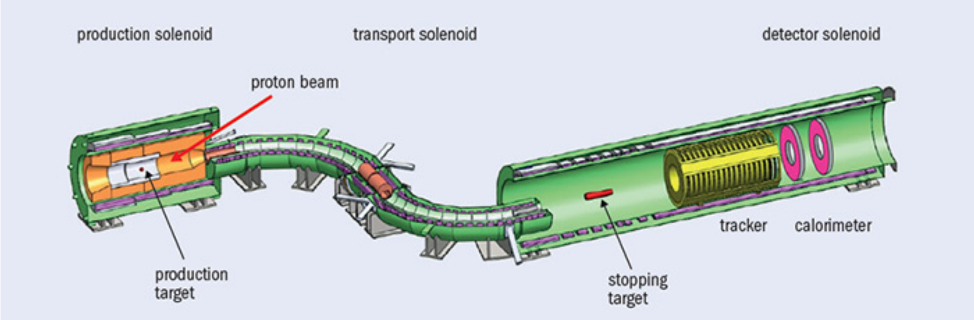


Участие в разработке программы ММФ ИЯИ

R.M. Dzhilkibaev, V.M. Lobashev ➔ **Fundamental Idea !**

On the Search for μ –> e Conversion on Nuclei (in Russian)(1989)

Published in: *Sov.J.Nucl.Phys.* 49 (1989) 384–385, *Yad.Fiz.* 49 (1989) 622–624



SES: $\mu^- N \rightarrow e^- N \sim 2.5\times10^{-17}$

5σ: $\mu^- N \rightarrow e^- N > 2\times10^{-16}$

$\mu^- N \rightarrow \nu_\mu N$

"…Using a concept first proposed some 25 years ago (Dzhilkibaev and Lobashev 1989), Mu2e at FNAL will place the primary production target in a solenoidal magnetic field. " Mu2e Proposal FNAL (2015)

S.N. Gninenko "The Experimental Setup for searching for the process π^0 –> *nothing* ~ 10^{-10} at MMF"Материалы V выпуска "Программа фундаментальных исследований на ММФ ИЯИ РАН СССР" (1987).
Motivated by M.I. Dobroliubov, A.Yu. Ignatiev, V.A. Matveev "A Search for Light Photino in Neutral Pion Decay" *Phys.Lett.B* 192 (1987)

- Concept for How to measure "Nothing In –> Nothing Out?" Null isn't "nothing" !
- Collaboration with TH is important!

Начало сотрудничества ИЯИ в ЦЕРН

1993 ➔ Визит В.А. Матвеева в ЦЕРН – “Прорыв в обороне” Договоренность о сотрудничестве.

1993 ➔ Подписание первого MoU с ЦЕРН по экперименту NOMAD. Ответственность за разработку и создание ~1000 канального Lead-Glass ECAL в сотрудничестве с CERN и INFN.

1993 ➔ Соглашение CERN-CNRS-INR по участию в разработке электромагнитного калориметра типа Shashlik для поиска H–> $\gamma\gamma$ в эксперимента CMS на LHC, CERN-R&D-36. Большой цикл работ.

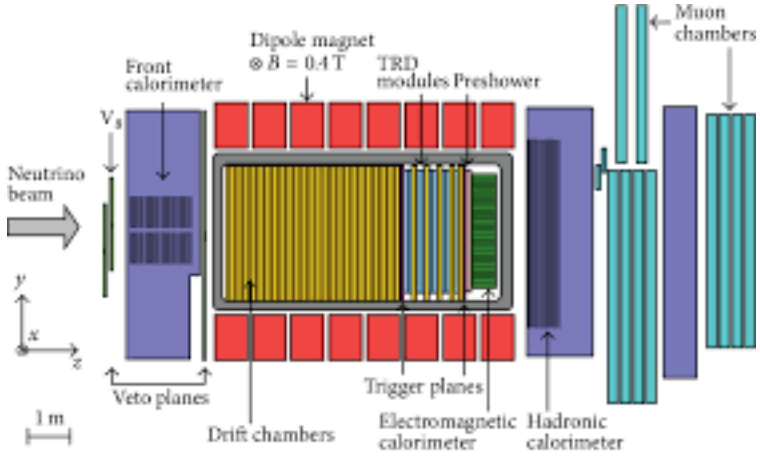
1995 ➔ Подписание MoU по созданию детектора CMS, огранизация коллаборации RDMS CMS (ОИЯИ – Российские институты, ~ 300 участников). Участие ИЯИ в руководящих структурах RDMS.

1996 ➔ Вклад в формирование программы исследований на CMS N.V. Krasnikov, V.A. Matveev “Physics at LHC”, hep-ph/9703204; Участие в разработке и создании компактного PWO ECAL CMS – радиационные измерения в ОИЯИ и ИВФЭ, тестовые измерения на пучках CERN SPS. Большой цикл работ.

~2000 ➔ Широкое участие ИЯИ в ALICE, LHCb, CAST, AEGIS, ICARUS, NA50, NA61, NA62, NA64 и ускорительной программе ЦЕРН.

WA96 (NOMAD) 1993-2000

Neutrino Experiment at the CERN SPS, 450 GeV proton beam.
$\nu_\mu - \nu_\tau$ oscillations at ~600 m. Massive ν_τ as main component of DM.



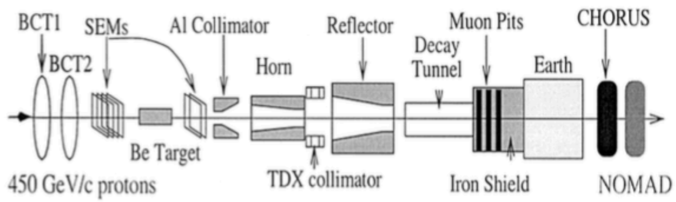
Close collaboration with TH INR.

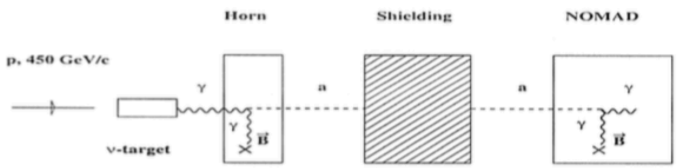
INR group	NOMAD Physics, PDG'20
$\pi^0, \eta, \eta' \to \gamma + X$	a new gauge boson X
$\nu_\tau - \nu_h$ mixing	first limits on $\lvert U_{\tau h}\rvert^2$
ν_h magnetic moment	BSM searches
KARMEN anomaly	excluded
Sub-eV scale axions	Light shining through the wall
$\rho^0(770), f_0(980) f_2(1270)$	First $f_0(980)$ observation

Some NOMAD results

~sub-eV scale axions

P. Astier et al. / Physics Letters B 479 (2000) 371–380





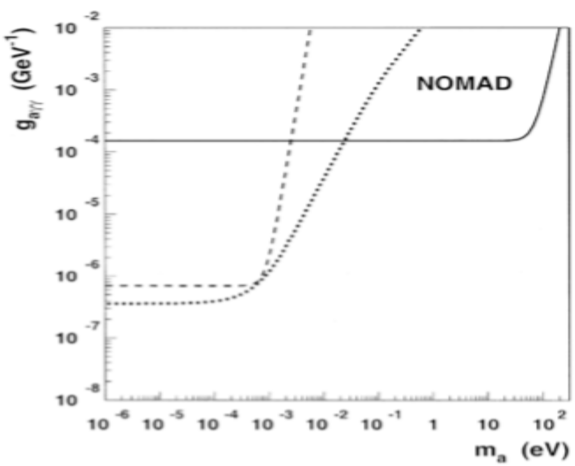
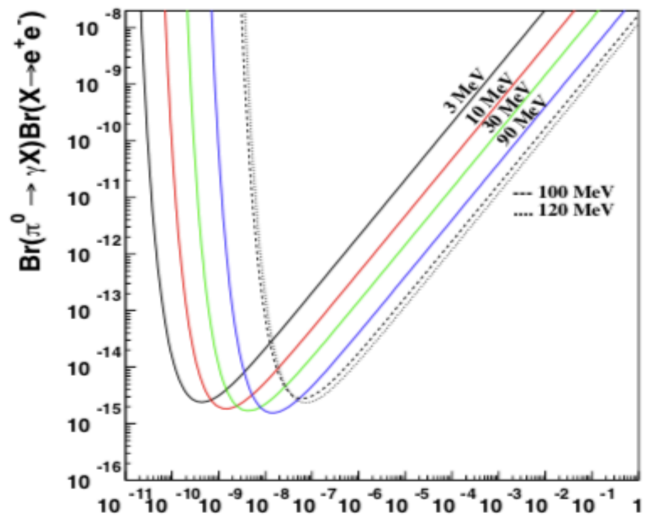


Fig. 5. Upper limit on the coupling $g_{a\gamma\gamma}$ as a function of the (pseudo)scalar mass m_a derived from the present analysis and from the direct searches of light (pseudo)scalars performed by using the polarisation rotation of a laser beam in a magnetic field [10] (dotted line) and using the laser photon regeneration method [9,10] (dashed line).

$\pi^0, \eta, \eta' \to \gamma + X$



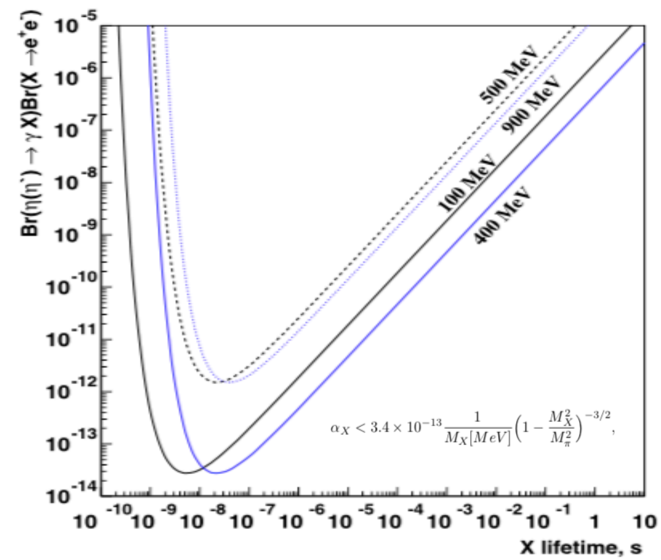
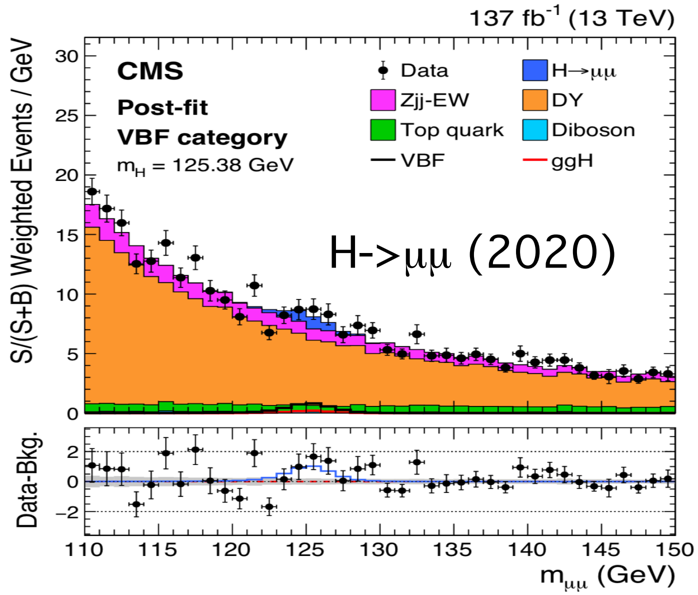
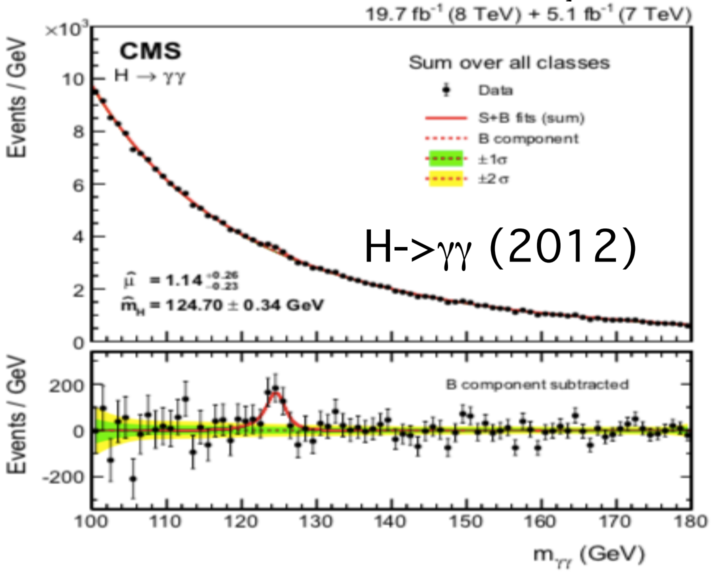


Fig. 5. The 90% C.L. upper limits on the branching ratio $Br(\eta(\eta') \to \gamma X)Br(X \to e^+e^-)$ versus τ_X obtained from the CHARM experiment for η (solid curves) and η' (dashed curves) decays. The numbers near the curves indicate the corresponding values of M_X.

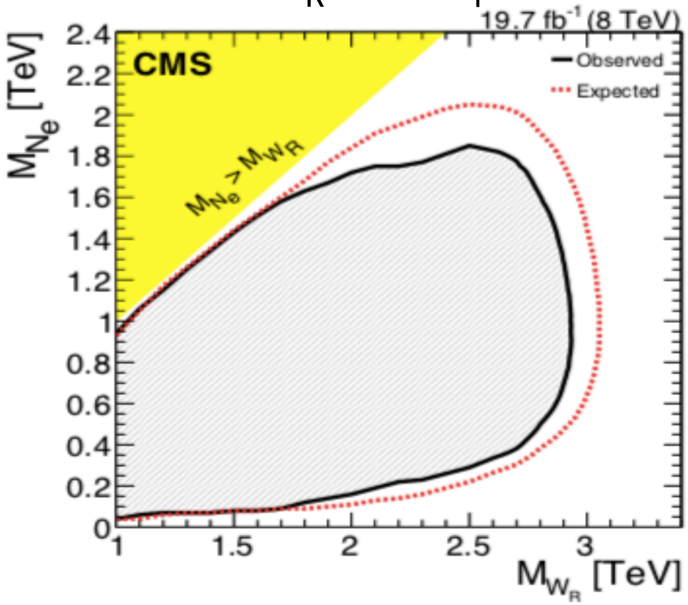
CMS results (> 1000 papers!)

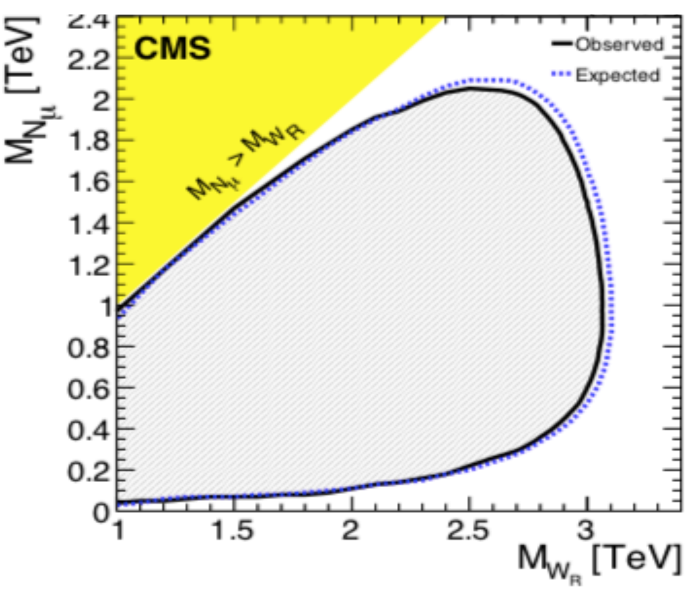




Search for W_R and N_l from LRSM

$$W_R \to \ell_1 N_\ell \to \ell_1 \ell_2 W_R^* \to \ell_1 \ell_2 q\bar{q}.$$





Physics Beyond Colliders at CERN 2016→

BSM WG

- Dark Sector physics (DM, DE, BAU)
- New particles and new interactions
- Symmetry Violation: CLFV, n,pEDM
- Experimental Anomalies: (g-2)e,μ, Be, MiniB, KOTO, XENON1T,

Preparation for Update of the European Strategy for Particle Physics 2020

OPEN ACCESS
IOP Publishing
Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. 47 (2020) 010501 (114pp)
https://doi.org/10.1088/1361-6471/ab4cd2

Major Report

Physics beyond colliders at CERN: beyond the Standard Model working group report

J Beacham[1], C Burrage[2,30], D Curtin[3], A De Roeck[4], J Evans[5], J L Feng[6], C Gatto[7,8], S Gninenko[9], A Hartin[10], I Irastorza[11], J Jaeckel[12], K Jungmann[13,30], K Kirch[14,30], F Kling[6], S Knapen[15], M Lamont[4], G Lanfranchi[4,16,30,31], C Lazzeroni[17], A Lindner[18], F Martinez-Vidal[19], M Moulson[16], N Neri[20], M Papucci[4,21], I Pedraza[22], K Petridis[23], M Pospelov[24,30], A Rozanov[25,30], G Ruoso[26,30], P Schuster[27], Y Semertzidis[28], T Spadaro[16], C Vallée[25] and G Wilkinson[29]

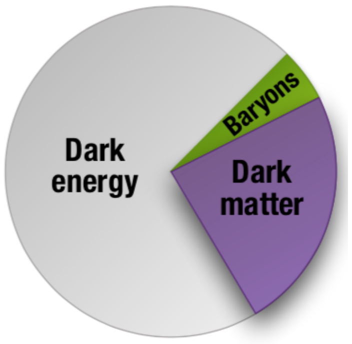
Prepared for submission as input to the European Particle Physics Strategy

Prospects for exploring the Dark Sector physics and rare processes with NA64 at the CERN SPS

The NA64 Collaboration[1]

Abstract:
The CERN SPS offers a unique opportunity for exploring new physics due to the availability of high-quality and high-intensity secondary beams. In the 2016-18 runs, the NA64 experiment has successfully performed sensitive searches for Dark Sector and other rare processes in missing energy

Dark Sector



Massive WIMPs are still not seen at LHC and in direct searches

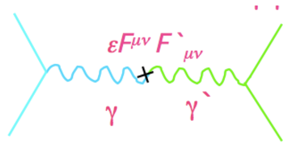
Why Dark Matter should be a single particle extension of SM?

Dark Matter (DM) from a Dark Sector (DS)

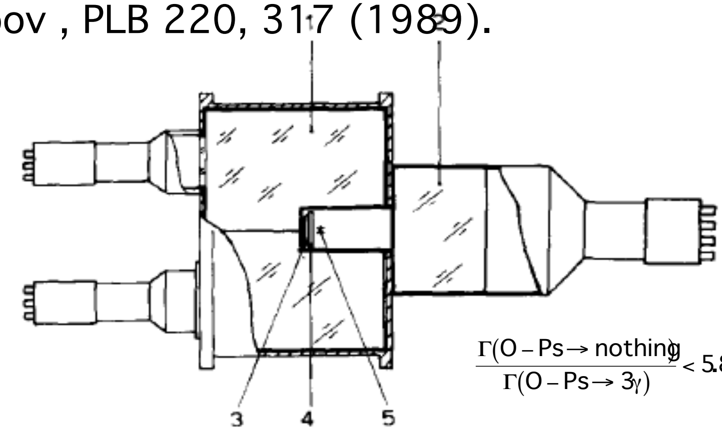
- ✧ DM is a part of DS,
- ✧ DS consists of particles and fields which are singlet with respect to the SM gauge group (but could be charged e.g. under a new U(1)´ gauge symmetry)
- ✧ interacts with the SM via gravity
- ✧ a new interactions transmitted via vector, Higgs, neutrino portals are possible

Mirror Dark Sector: search for oPs´-oPs oscillations

"Positronium vs Mirror Univers"
Glashow PLB 167, 35 (1986).



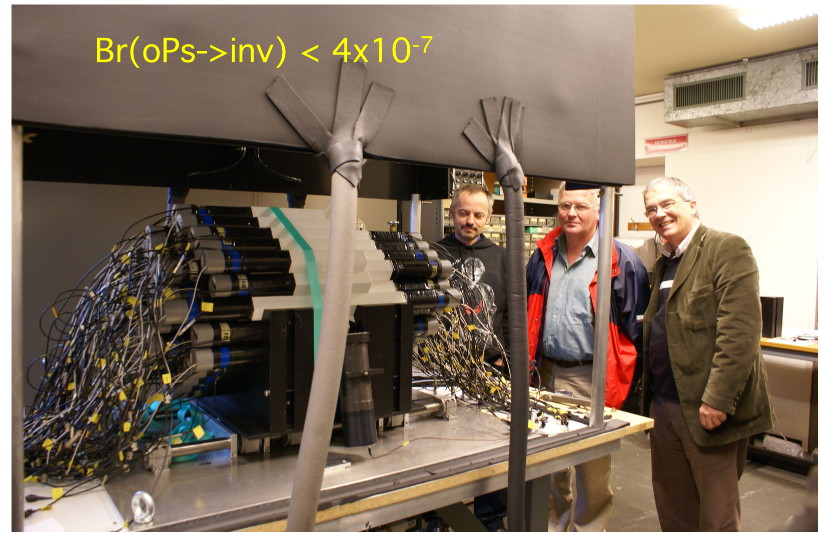
A search for photonless annihilation of orthopositronium," Atoyan, Gninenko, Razin, Ryabov , PLB 220, 317 (1989).



$$\frac{\Gamma(O-Ps \to nothing)}{\Gamma(O-Ps \to 3\gamma)} < 5.8\times 10^{-4}$$

Fig. 1. Schematic view of the set-up: (1): NaI calorimeter; (2): NaI counter (3): target; (4): proportional counter; (5): the positron source ^{22}Na.

ETHZ-INR-LAPP experiment at CERN
"Improved limits on oPs->invisible"
Badertscher et al, PRD (2006).



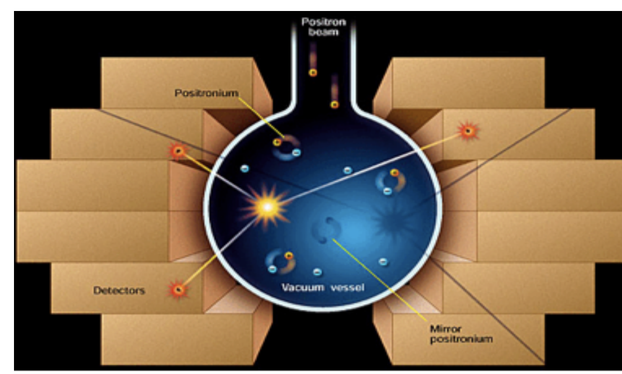
Vacuum oPs experiment required!

Vacuum is required to avoid wave function quenching
Branchnig ratio in vacuum:

$$Br(oPs \to invisible) = \frac{2(2\pi\varepsilon f)^2}{\Gamma^2_{SM} + 4(2\pi\varepsilon f)^2};\ t >> \frac{1}{\Gamma_{SM}}$$

Branchnig ratio in vacuum + collisions:

$$Br(oPs \to invisible) \simeq \frac{2(2\pi\varepsilon f)^2}{\Gamma_{SM} + \Gamma_{COLL}};\ t >> \frac{1}{\Gamma_{COLL}}$$



SG'95, Foot and SG '00

ETHZ-INR pulse e+ beam for Ps experiments and applications

Available online at www.sciencedirect.com

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Nuclear Instruments and Methods in Physics Research A 560 (2006) 224–232

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

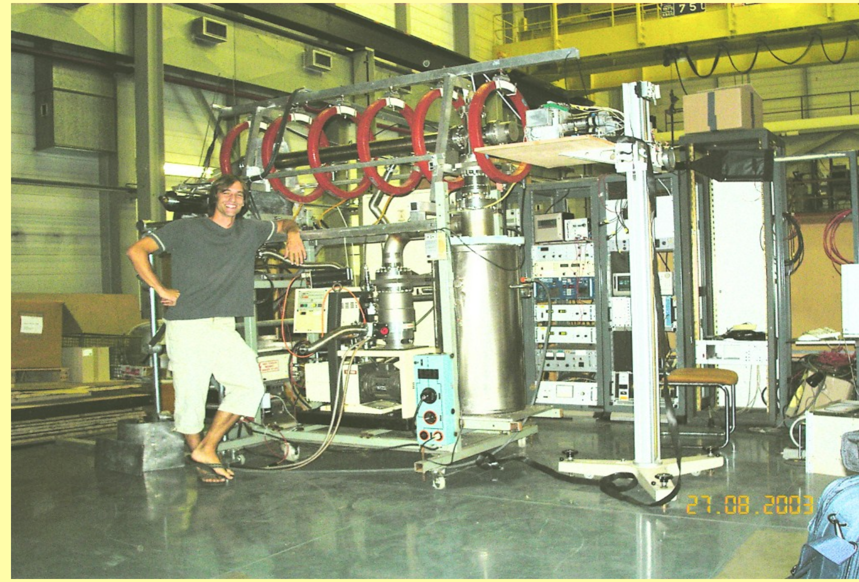
www.elsevier.com/locate/nima

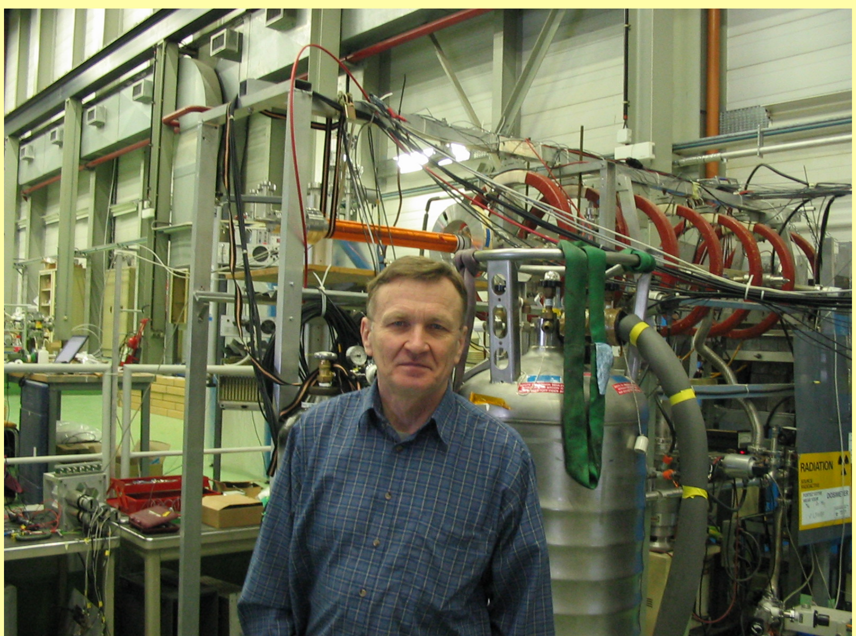
Development of a high-efficiency pulsed slow positron beam for measurements with orthopositronium in vacuum

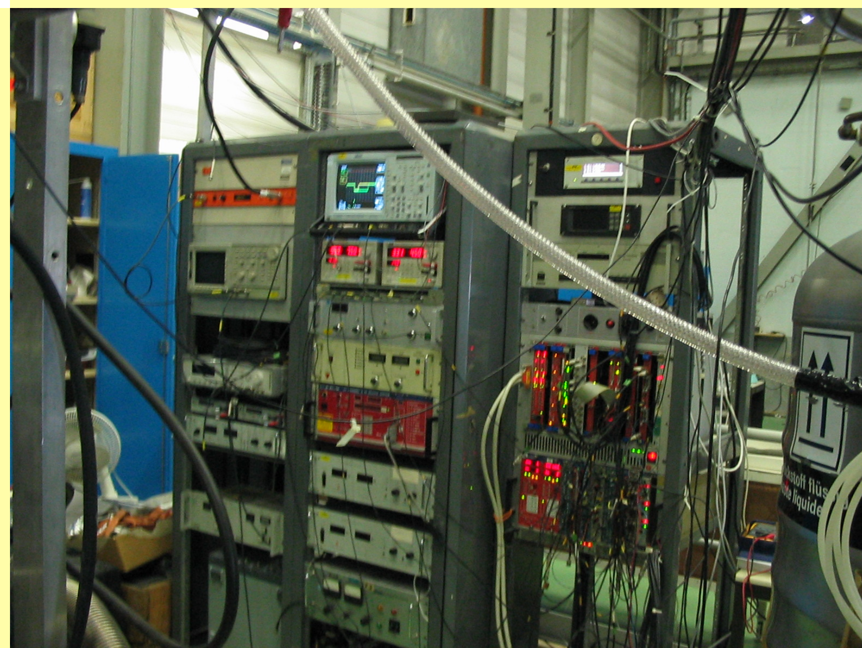
N. Alberola[a], T. Anthonioz[b], A. Badertscher[c], C. Bas[a], A.S. Belov[d], P. Crivelli[c], S.N. Gninenko[d,*], N.A. Golubev[d], M.M. Kirsanov[d], A. Rubbia[c], D. Sillou[b]

[a] *LMOPS, Le Bourget du Lac, CNRS, France*
[b] *LAPP, Annecy le Vieux, CNRS-IN2P3, France*
[c] *Institut für Teilchenphysik, ETHZ, CH-8093 Zürich, Switzerland*
[d] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow 117312, Russia*

Received 9 November 2005; received in revised form 6 January 2006; accepted 13 January 2006
Available online 9 February 2006





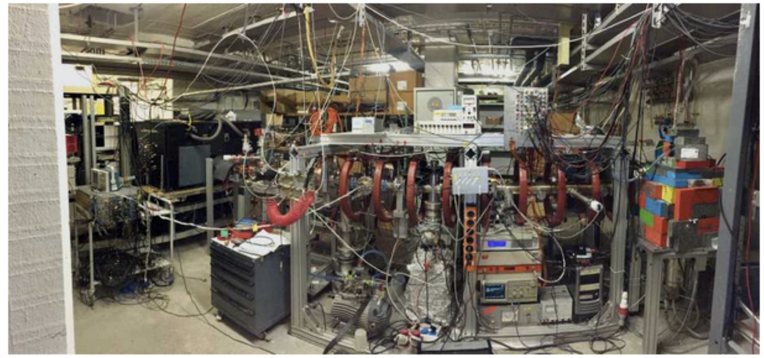


Further applications of ETHZ-INR e+ Beam

ETHZ e+ Lab: Particle Physics, Nano-materials, Industrial applications

"New bound on oPs->invisible"
P. Crivelli et al, PRL (2020).

"New light on nano-Si structures with PAS"
Advanced Functional Materials (2019)



The older low energy positron beamline of the lab operating in the 0-20 keV energy range. It is a continuous beam with a secondary electron tagging system and time buncher and is equipped with a positron annihilation lifetime spectrometer, high purity Ge detector for Doppler broadening spectroscopy, and fast sample changeover capabilities for material science studies →. In addition, this beamline is also used to supply tagged positrons for the EPIC experiment →, searching for invisible decays of positronium, and was used in recent positronium laser spectroscopy measurements →

LPPP

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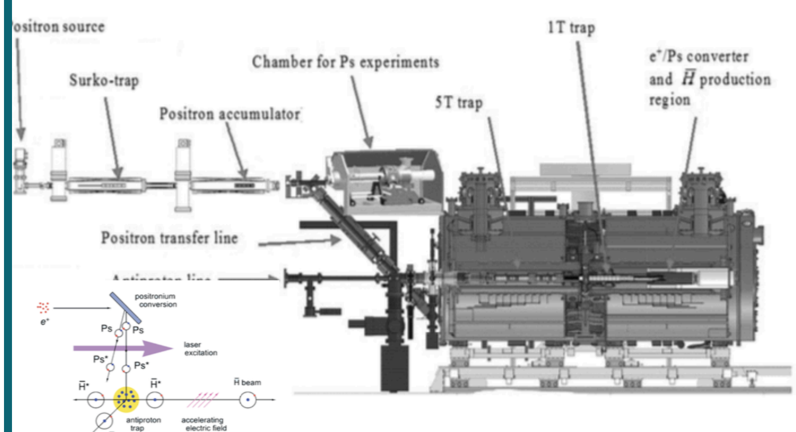
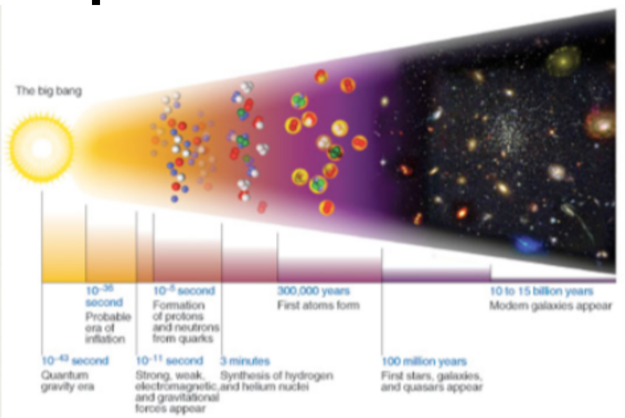
+41 44 633 11 04 →
E-mail →
V-Card (vcf, 1kb) ↓

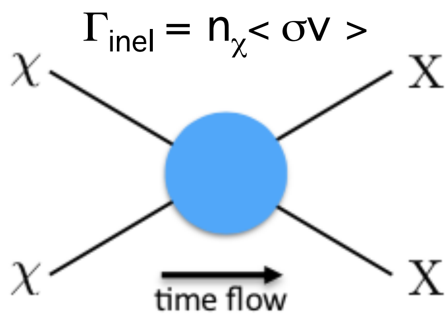
AEGIS at CERN: Gravity fall of Hbar

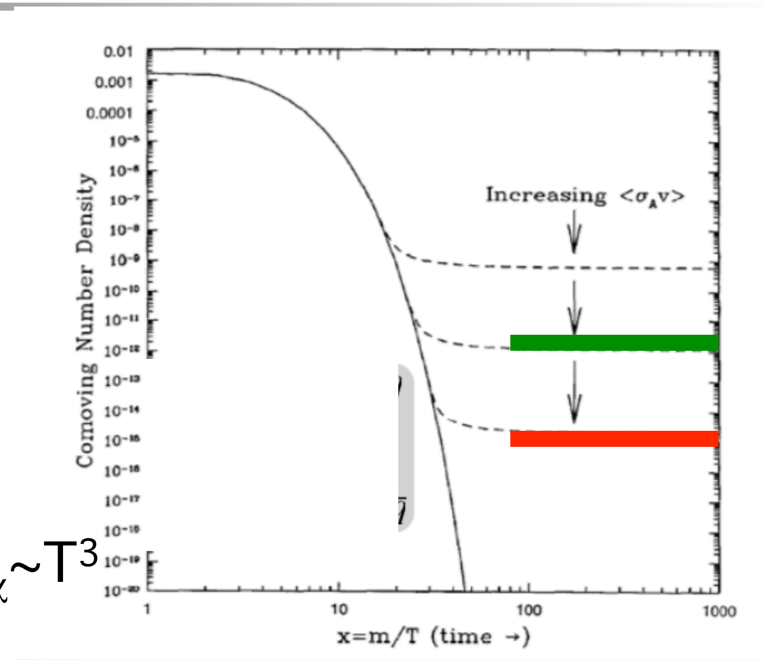


INR

Light Thermal Dark Matter (m_χ << 100 GeV)







- For T>>m_χ, χχ-SM ann. is in equilibrium,n_χ~T^3
- Hubble expansion, T & n_χ decrease
- For T < m_χ χχ-SM annihilation gets suppressed, $n_\chi \sim T^{3/2}e^{-m_\chi/T}$
- Finally χχ-SM annihilation stops, n_χ~ frozen in time $\Gamma_{inel} = n_\chi < \sigma v > \sim H$
- $< \sigma v > \cong 3\times10^{-26}\ cm^3/s \cong (1/20\ TeV)^2$
- If DM is in sub-GeV range it must be SM neutral
- Thermal freeze-out motivate new interaction to mediate DM-SM annihilation. **New force in addition to gravity is required! (Boehm,Fayet)**
- new interaction can be transmitted via vector, Higgs, neutrino portals

Vector portal to Dark Sector

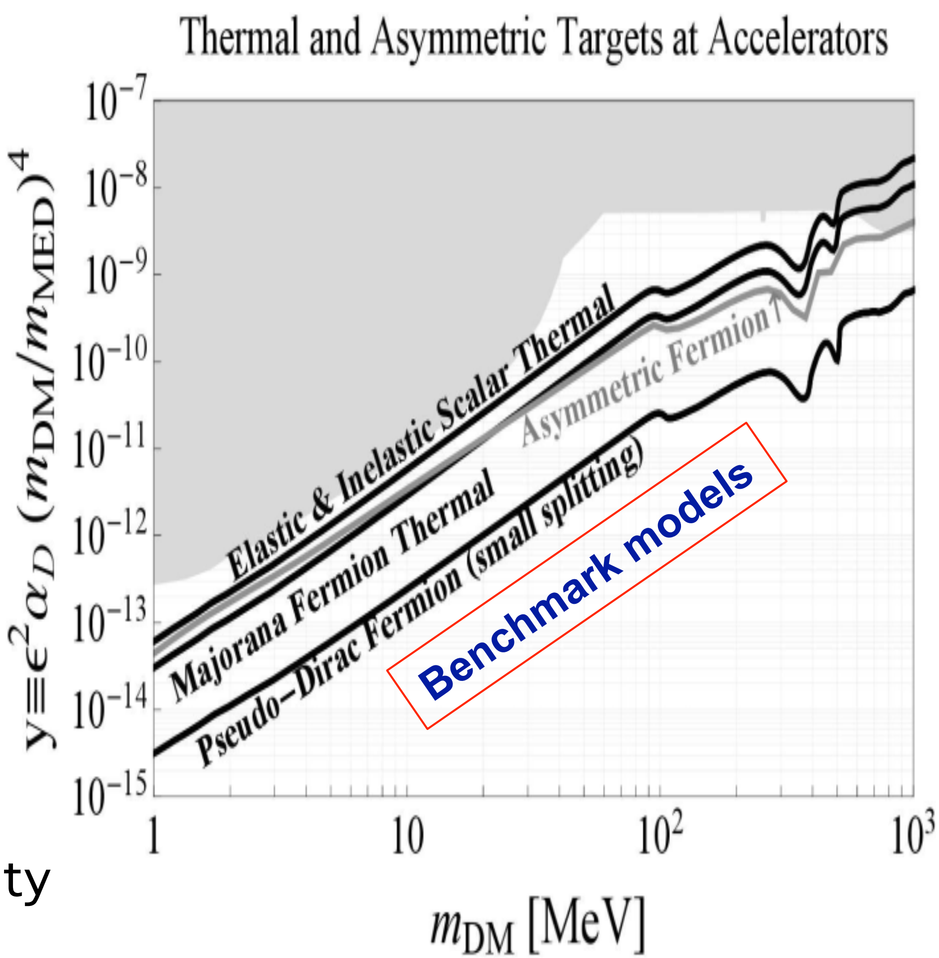
- massive dark photon (A´)
- γ–A´ kinetic mixing: $\Delta L = \varepsilon/2\, F^{\mu\nu} A'_{\mu\nu}$
- coupling strength ~ εe
- $\varepsilon \sim 10^{-5} - 10^{-2}$, $m_{A'} \sim \varepsilon^{1/2} M_Z$

- A´ decay modes:
  $m_{A'} < 2m_\chi$, $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$
  $m_{A'} > 2m_\chi$, $A' \rightarrow \chi\chi$

- popular DM candidates χ :
  S, Majorana, p-Dirac fermions

- TDM ($\varepsilon, \alpha_D, m_\chi, m_A$) parameters can be probed at accelerators

- Useful variable to compare sensitivity χ–SM annihilation:
  $n_\chi < \sigma v > \approx [\alpha_D\, \varepsilon^2 (m_\chi/m_{A'})^4]\alpha/m_\chi^2 = y\, \alpha/m_\chi^2$



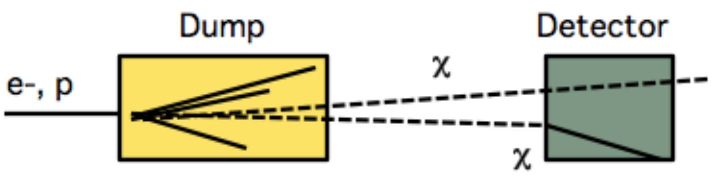
Two approaches to probe LDM in fixed-target exp.

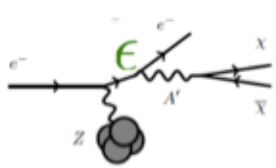
LDM(χ) Production

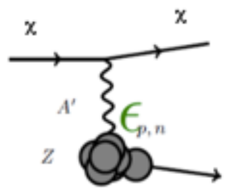
- Bremsstrahlung $e^- Z \rightarrow e^- Z A'$; cross section $\sigma \sim Z^2 \varepsilon^2 / m_{A'}^2$
- $\pi^0, \eta, \eta' \ldots \rightarrow \gamma A'$, $A' \rightarrow \chi\chi$

LDM Detection

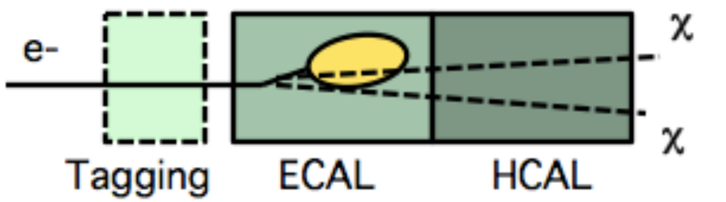
Beam-dump: BDX, SHIP, NA62D, SeaQuest,...

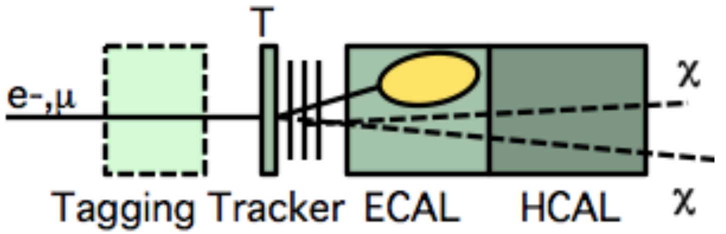


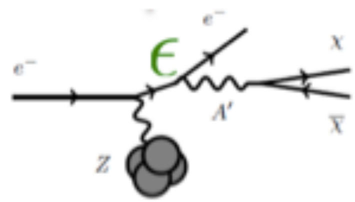




Active beam-dump+E_{ms}/P_{ms}: NA64,LDMX







Sensitivity of beam-dump exp.

$n_S \sim \alpha_D \varepsilon^4 N_{pot}$

Sensitivity of NA64

$n_S \sim \varepsilon^2 N_{pot}$

Great advantage of NA64!

NA64 at the CERN SPS

Univ. Bonn, JINR , CERN, INR RAS, IHEP, LPI, SINP MSU, TPU Tomsk, UTFSM Chile, ETH Zurich

NA64 is designed to search for BSM, in particular Dark Sector physics in missing energy events. Broad research program with e-, m, p, K, and p beams at the CERN SPS (PBC’16-19).

History:

- **December 2013:** proposal P348 to SPSC
- **April 2014:** recommended for feasibility test
- **April 2014 - March 2015:** design, production, delivery at CERN.
- **October 2015:** feasibility test run+upgrade, recommended by SPSC
- **March 2016:** approved as NA64 experiment by the CERN RB (the first since NA62 approval in 2007)

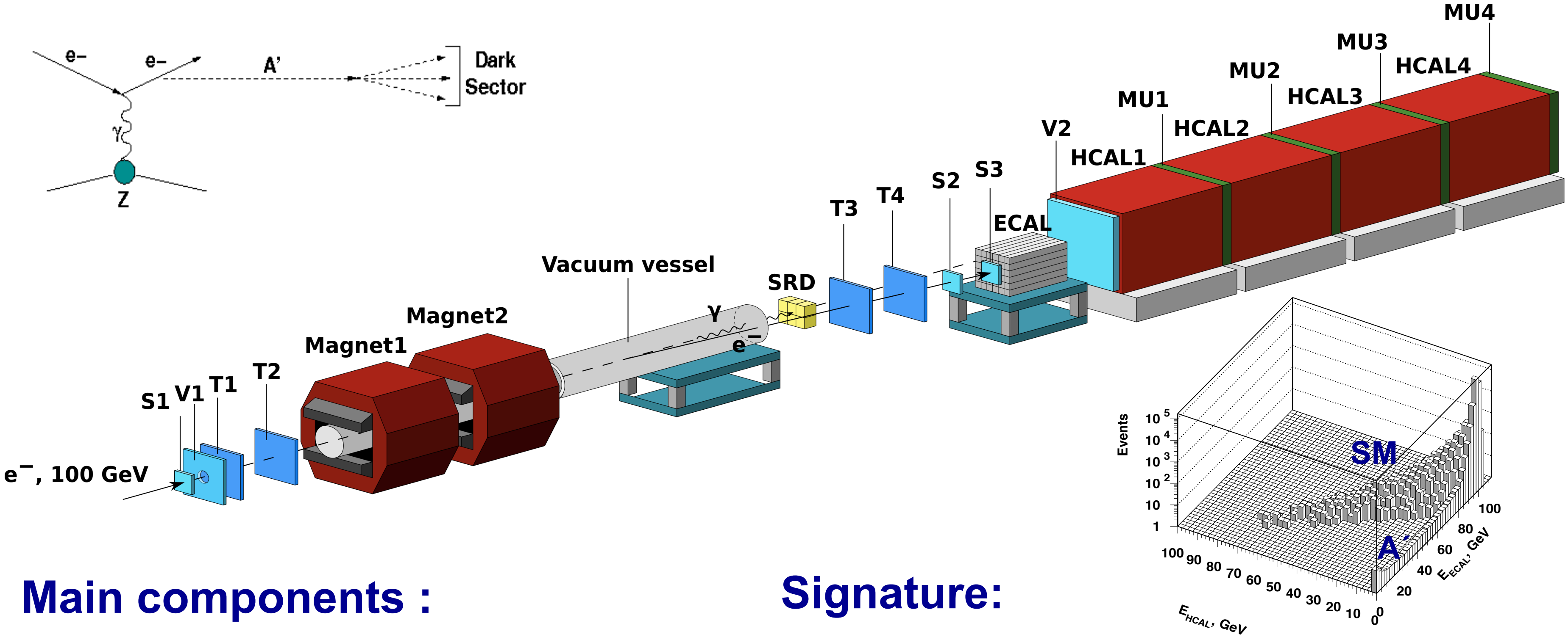
2016 - 2018 runs aimed at:

- Invisible A´ as an explanation of $(g-2)_\mu$
- LDM production in A´ invisible decay mode
- New X(17) boson from the ^{8}Be anomaly, A´->e+e- decays

В.И. Саврин
В.А. Матвеев
Л.В. Кравчук
Минобрнауки
CERN

NA64: Search for LDM in missing energy events

LDM produced in invisible decays of A´s



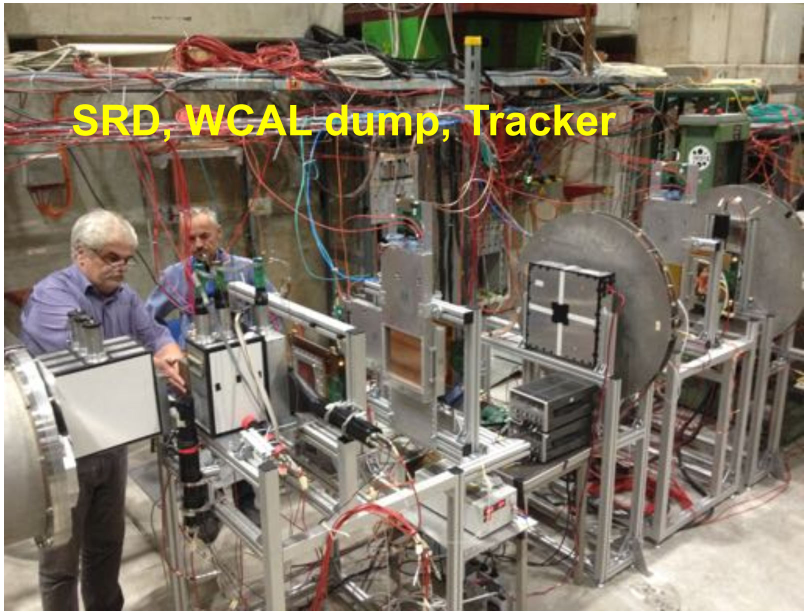
Main components :

- clean 100 GeV e- beam
- e- tagging: tracker+SRD
- fully hermetic ECAL+HCAL

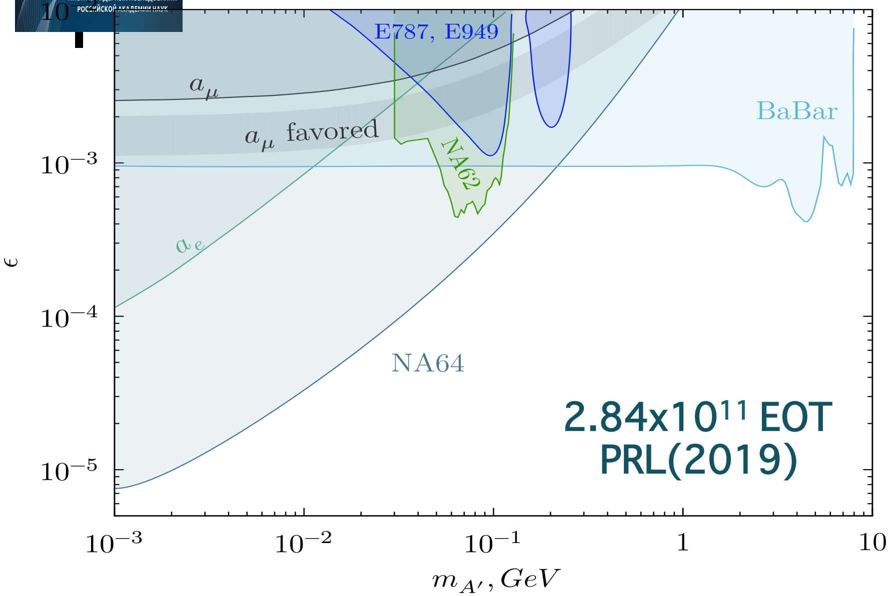
Signature:

- in: 100 GeV e- track
- out: $E_{ECAL} < E_0$ shower in ECAL
- no energy in Veto and HCAL

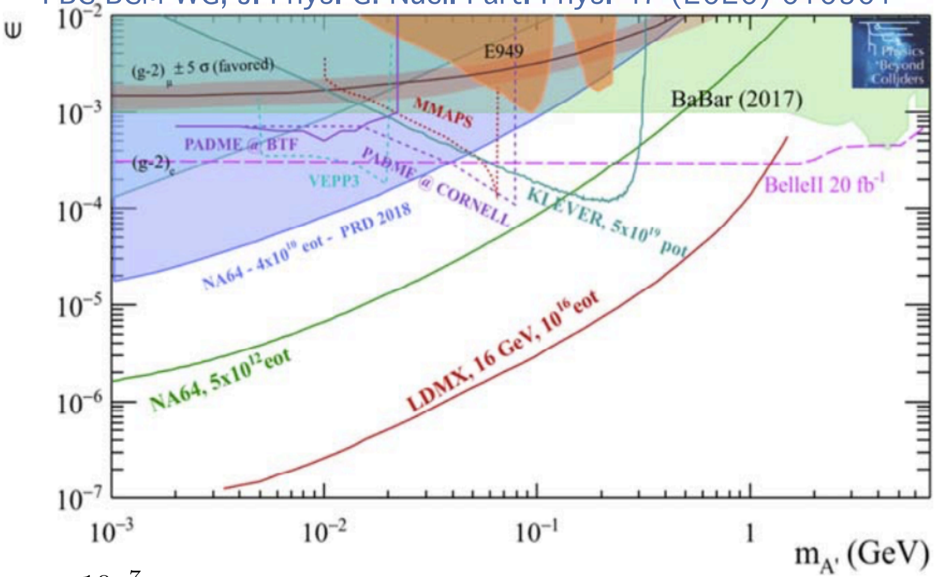
NA64: Search for LDM in missing energy events

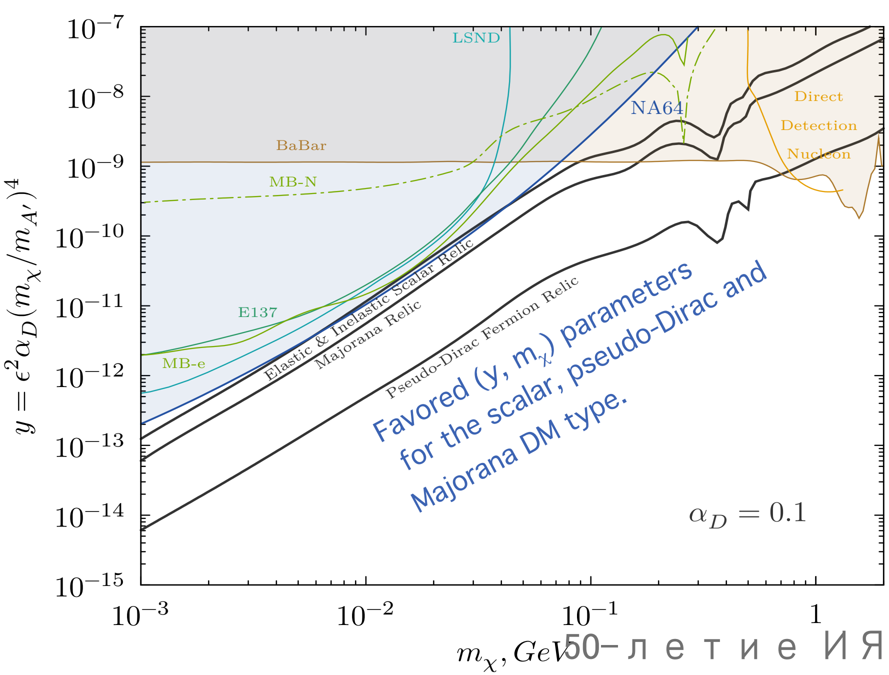


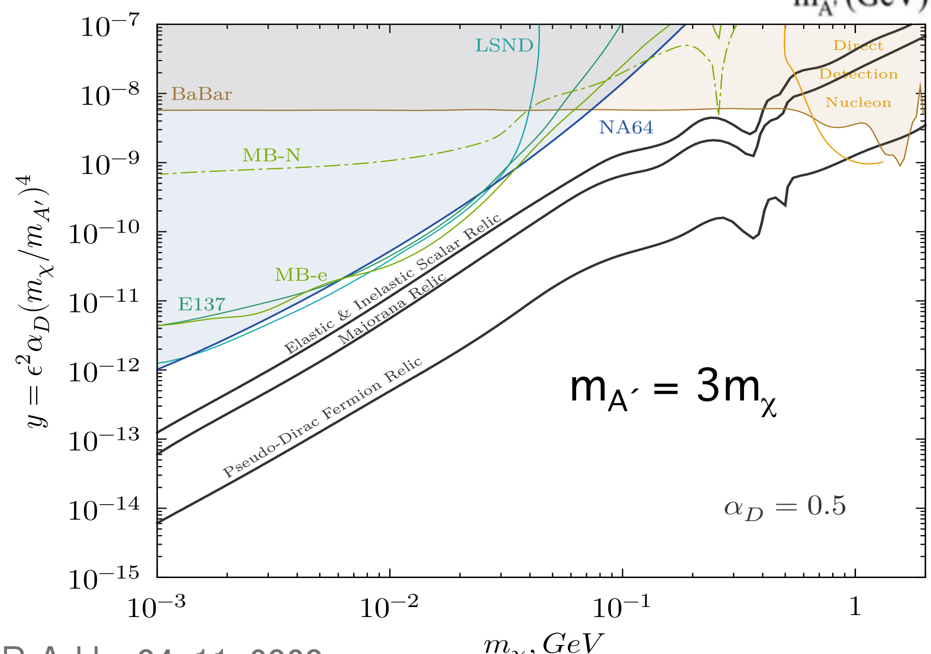
2016-18 limits and projections for mixing and LDM



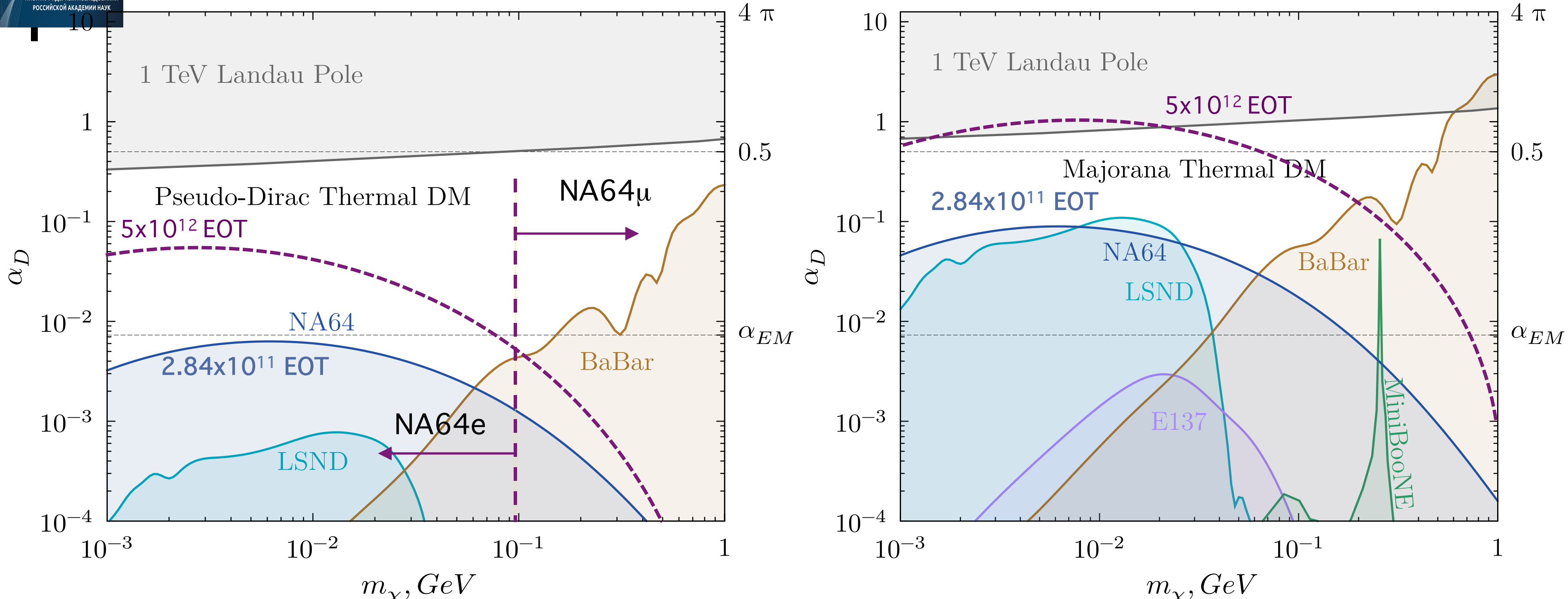
PBC BCM WG, J. Phys. G: Nucl. Part. Phys. 47 (2020) 010501







2016–18 Limits and projections for α_D



- NA64 bounds are more stringent than present experimental limits from LSND, MiniBooNE, E137 obtained with $\sim 10^{22}$, 10^{20} POT, 10^{19} EOT
  Advantage of NA64 approach: the rate $\sim \varepsilon^2$, while for beam-dump exp. $\sim \varepsilon^4 \alpha_D$
- Region $m_{A'} \leq m_\mu$ can probe with $\sim (5\text{–}10)\times10^{12}$ EOT, ~3–6 m run after LS2 at a new H4 location with improved e- beam quality.
- The region $m_{A'} \geq m_\mu$ can be probed by NA64μ with $\sim 2\times10^{13}$ MOT, ~ 6 m run at M2 line. Pilot run in 2021 with a new μ-beam design.

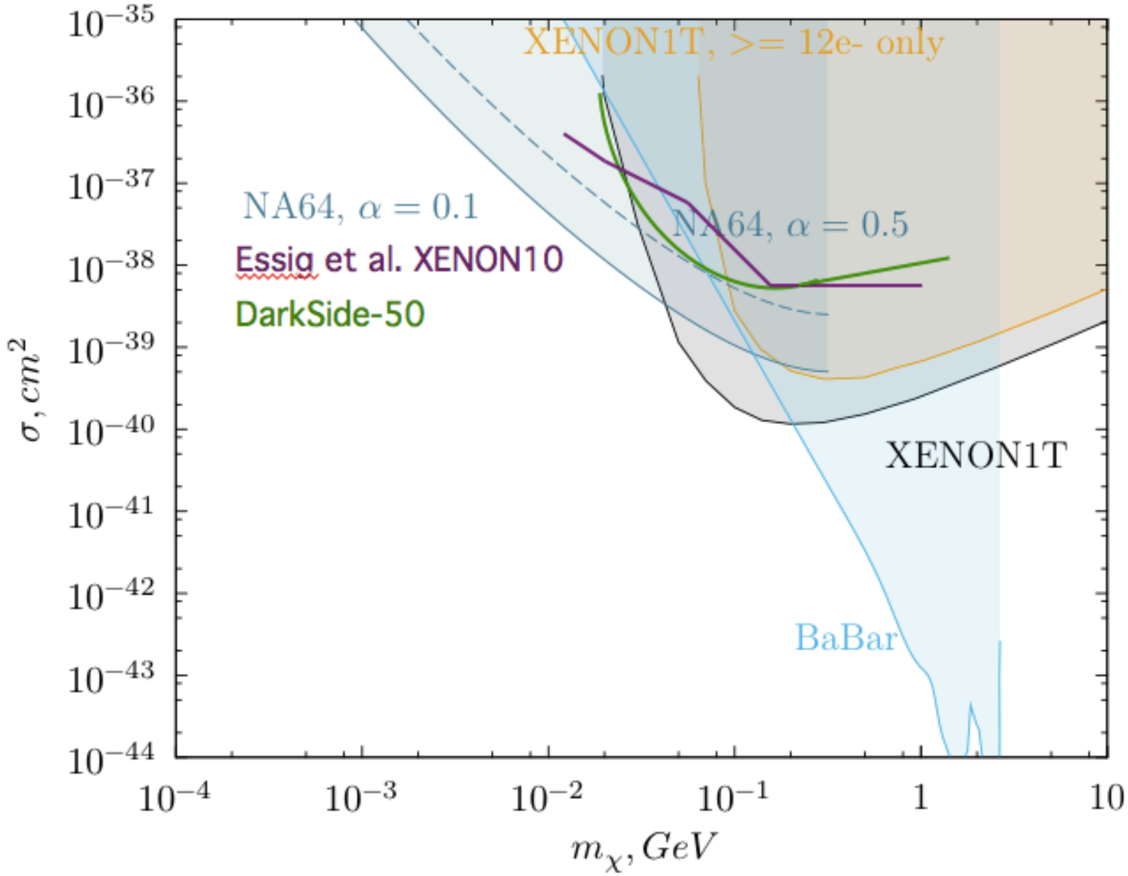
Thanks to EN-EA-LE

(see next slide)

arXiv:1903.07899

Constraints on DM-electon cross-sections

Complementarity of NA64 and direct DM searches (XENON1T)

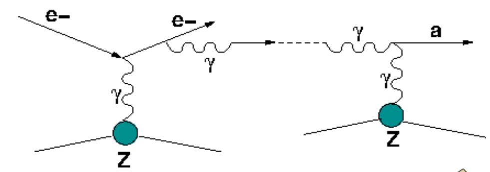


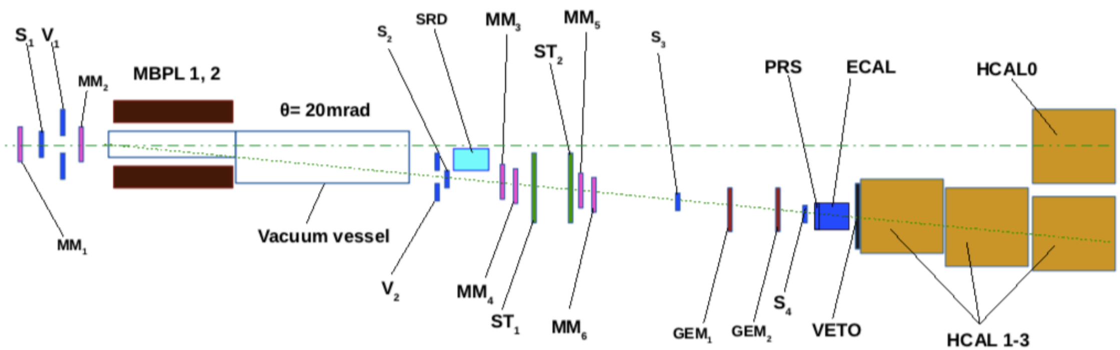
XENON Coll. arXiv:1907.11485
SG,Krasnikov,Matveev arXiv:2003.07257

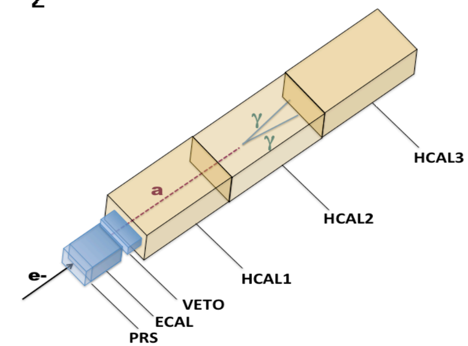
The 90% C.L. upper limits on DM-electron scattering cross-sections
NA64: no assumptions on DM number density and velocity distribution

Search for the *ALP*, *S* → $\gamma\gamma$ decays

- Dominant *a*-γ coupling, $L = -\, g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}/4$
- Primakoff production in the ECAL dump :







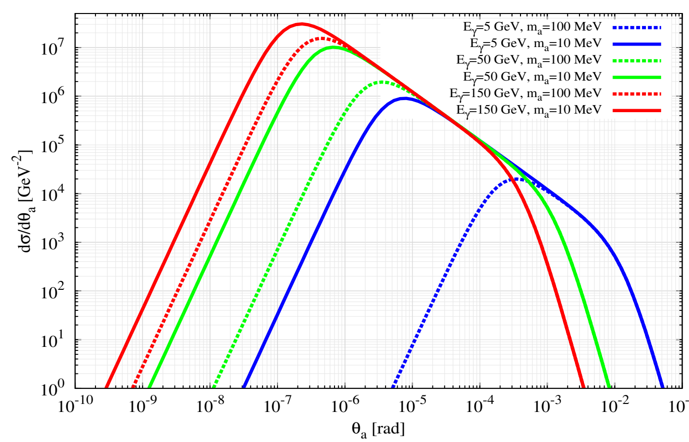
Signature:

- 100 GeV e- track
- $E_{ECAL} < E_0$ shower in ECAL
- no activity in Veto and HCAL1
- Then, either

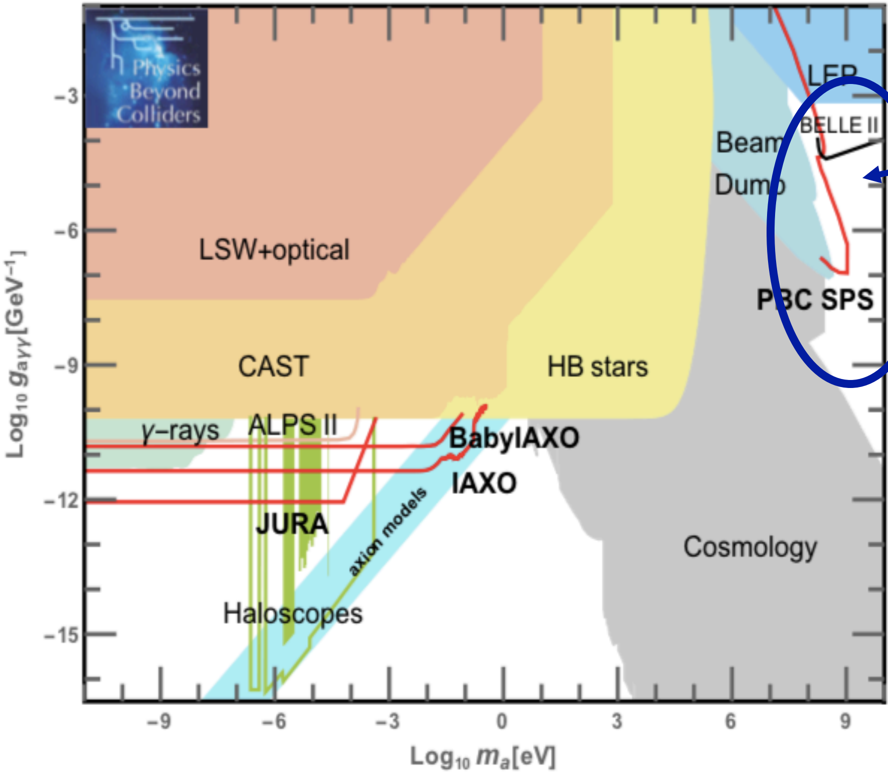
a) no activity in HCAL2 and HCAL3:
a decays outside HCAL, or

b) e-m like energy in HCAL2+HCAL3
a decays inside HCAL

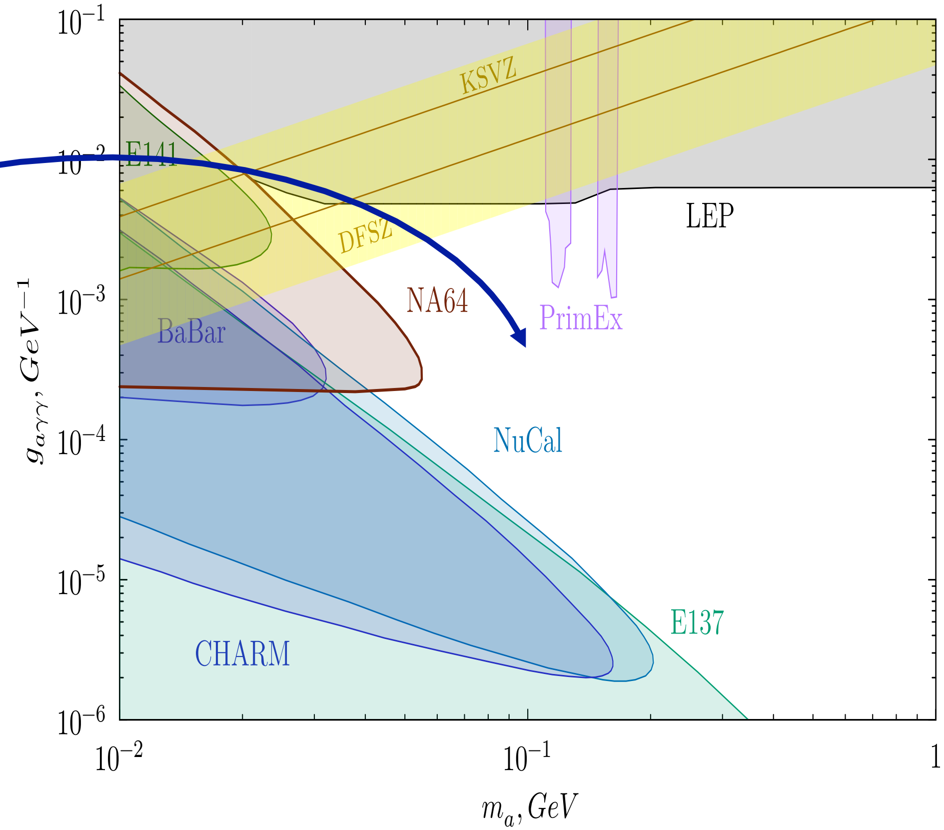
Production cross-section:
ETL full calculations,
e.g. the *a* emission angle



Bounds on the coupling $g_{a\gamma\gamma}$



Phys. Rev. Lett. 124, 211803 (2020)

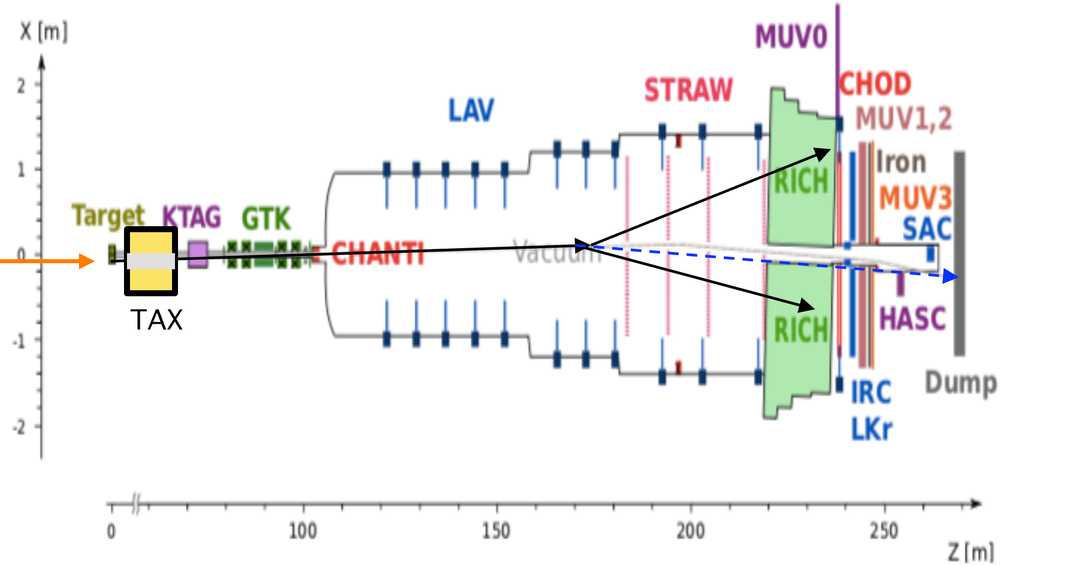


The results on the $a \to \gamma\gamma$ decay are also applicable to the A´→e^+e^- decay search. Plan to improve limits on γ–A´ mixing and ε_e around ~10^{-4} (^{8}Be region).

Probing Dark Sector with NA62 and NA62-dump

✧ NA62 kaon mode 75 GeV

- A´, ALP, ..production in target pA→X+A´, ALP or in π, K,..decays
- Searching for long-lived A´→ee, μμ; a→γγ decays

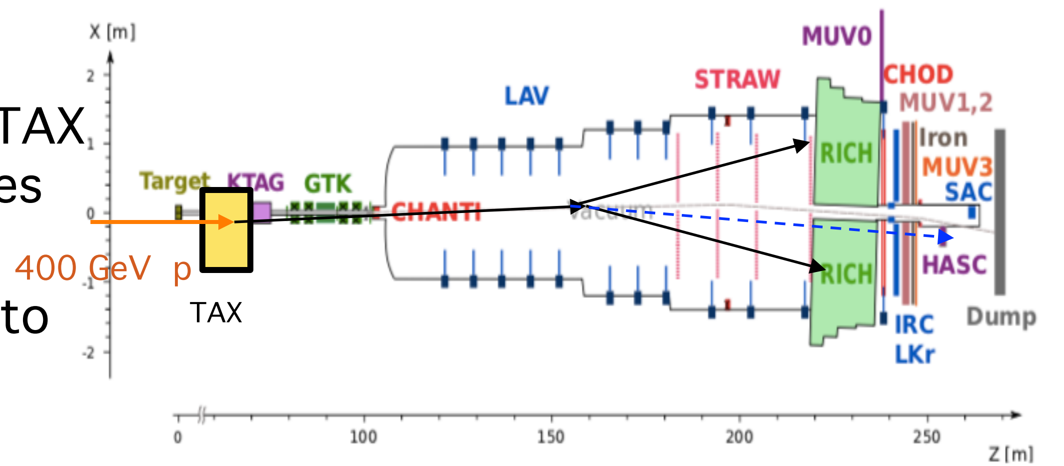


✧ NA62++ beam dump mode

10^{18} pot dumped onto Cu collimator (TAX), ~21λ

CERN-SPSC-2019-039; SPSC-P-326-ADD-1

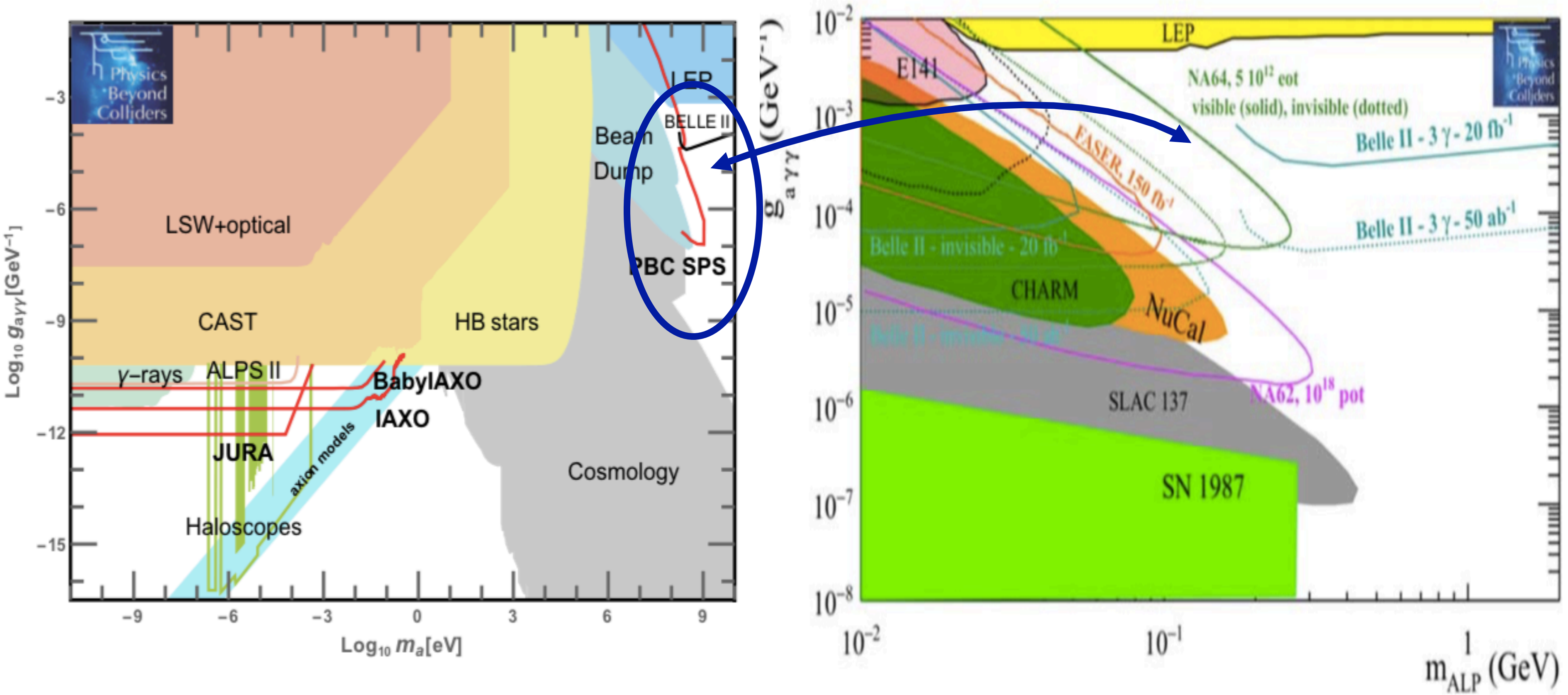
- Flux of A´,ALP,NHL produced in TAX directly, or via decays of secondaries
- Downstream part acts as a high-resolution tracker, PID, hermetic veto
- Rich program actively studied in the framework of PBC BSM WG



PBC BCM WG, J. Phys. G: Nucl. Part. Phys. 47 (2020) 010501

NA64, NA62-dump: Projections for ALP → γγ decay

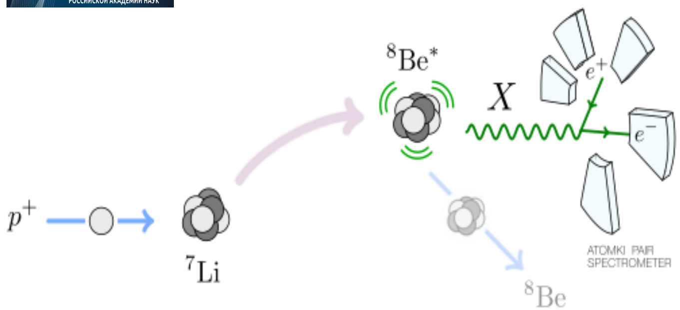
PBC BCM WG, J. Phys. G: Nucl. Part. Phys. 47 (2020) 010501



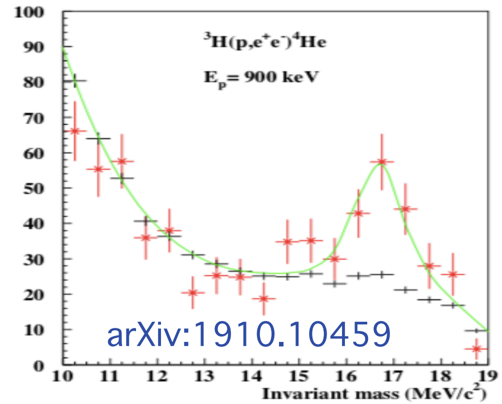
- ALP Primakoff production JHEP 1602 (2016) 018
- ALPs decay in NA62 FV (~60 m long), sensitivity ~ $g_{a\gamma\gamma}^{4}$
- 400 GeV, 10^{18} POT, zero-background assumed

Searching for BSM physics: Experimental anomalies

^{8}Be-^{4}He anomaly (ATOMKI): a new X17 boson ?



Feng et al, 2016



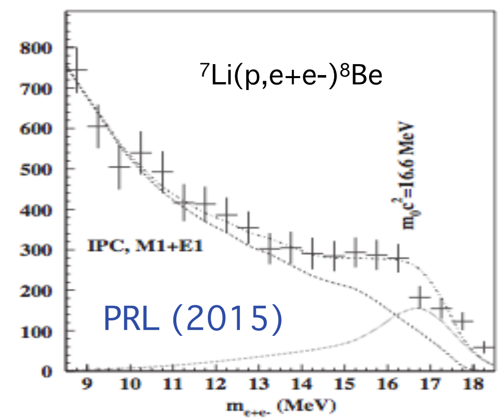
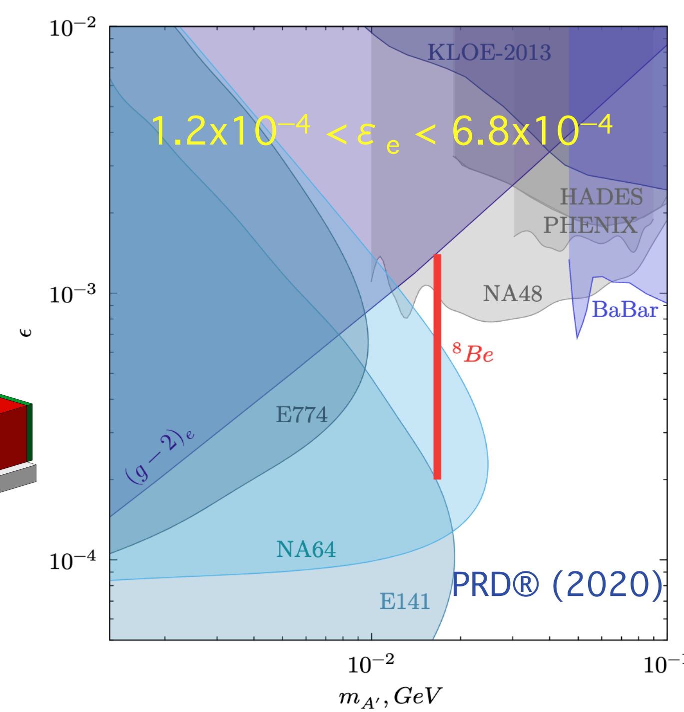
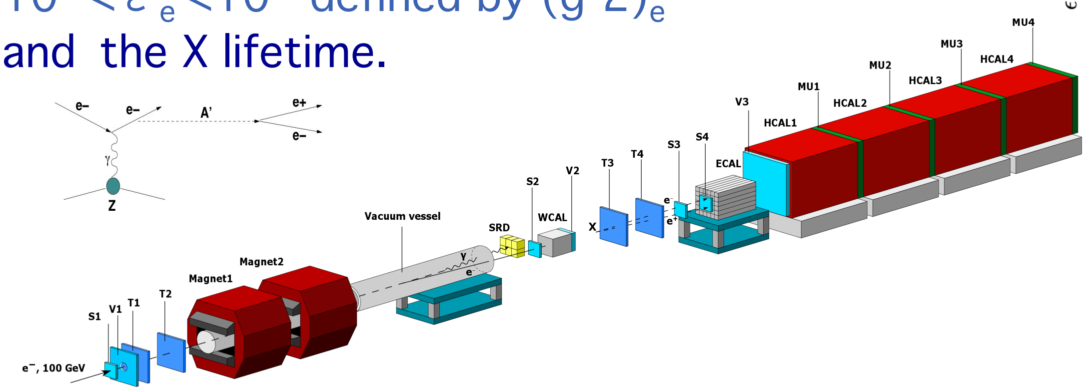


FIG. 5. Invariant mass distribution derived for the 18.15 MeV transition in ^{8}Be.

- The emission rates look similar:
  $\Gamma_X(^{8}Be) = 1.2 \times 10^{-5}$ eV
  $\Gamma_X(^{4}He) = 3.9 \times 10^{-5}$ eV
- Many models: X= *S, PS, V, AV*
  X≠ A´ (π^0->Xγ)
- NA64 model-independent view:

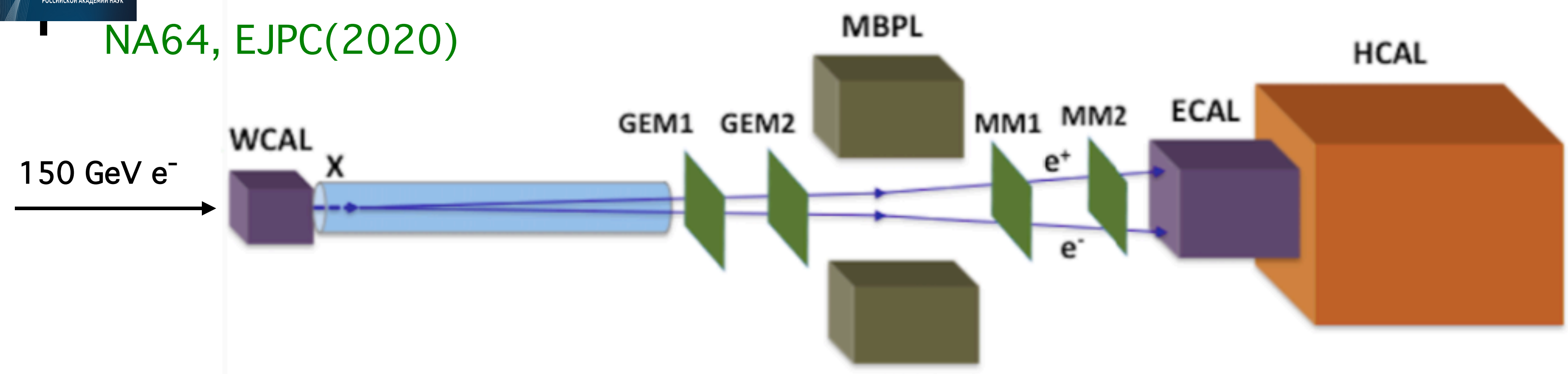
- no assumptions on ε_q, just $\varepsilon_e \neq 0$
- search for X->ee in the region
  $10^{-5} < \varepsilon_e < 10^{-3}$ defined by $(g-2)_e$ and the X lifetime.





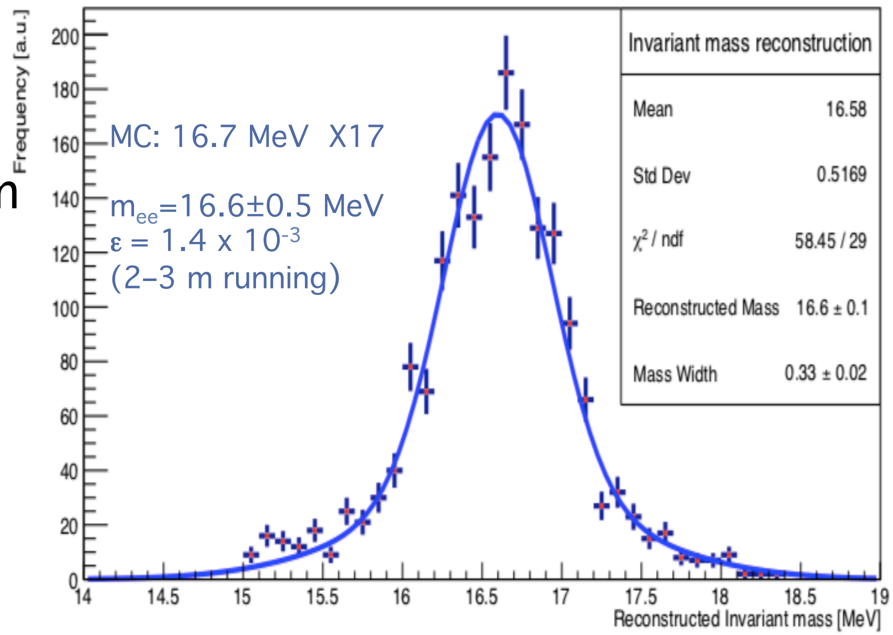
Hunting the short-lived X17 with NA64 in 2021 run

NA64, EJPC(2020)



Visible mode setup update

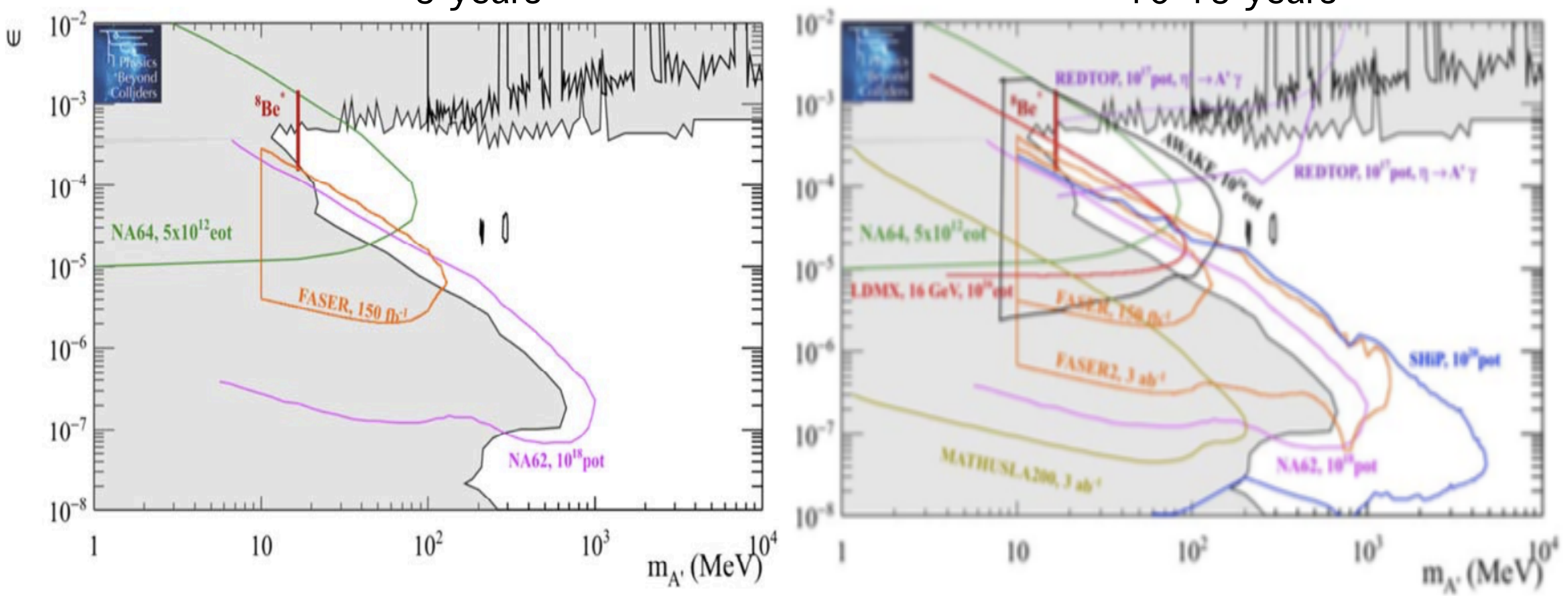
- WCAL dump length is optimized not for the beam energy, but for the energy of "signal" shower! L_{WC} ~200 mm => 142 mm
- Reconstruction of inv. mass m_{ee};
  Challenge: Θ_{ee} ~ 0.3 mrad!
  Measure $\Theta_{ee} \sim \Delta_{ee} / L_{ee}$; Δ_{ee}- gap between tracks in GEM1
  L_{ee}–decay length is constant, ~18 m



Перспективы A´→ee, μμ, ππ

PBC BCM WG, J. Phys. G: Nucl. Part. Phys. 47 (2020) 010501

~ 5 years ~ 10-15 years



- short-lived A´, $\varepsilon > \sim 10^{-5}$ - Complementarity and competition between NA64, AWAKE, LHCb Upgrade, HPS(Jlab), LDMX(SLAC)
- long-lived A´, $\varepsilon < \sim 10^{-5}$ - Complementarity and competition between NA62-dump, SHIP, FASER, SeaQuest

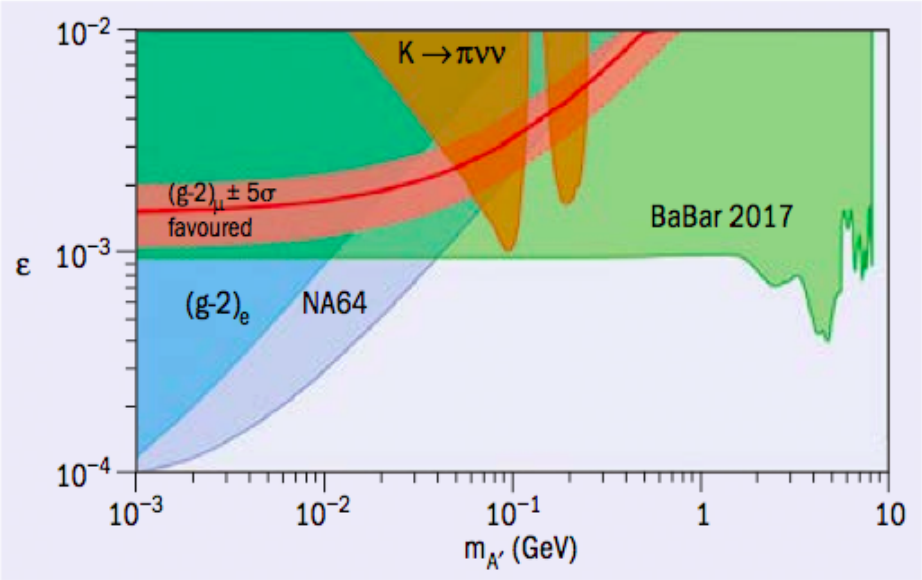
INR participation in NA64(AWAKE), NA62-dump, SHIP is foreseen.

$(g\text{-}2)_\mu$ anomaly: Z´ with universal coupling is ruled out

CERN Courier April 2017

$(g\text{-}2)_\mu$: ~ 3.6 σ discrepancy between TH and EXP, BNL E821 (2004)

News



Regions of the dark-photon parameter space (mixing strength versus mass) excluded by BaBar (green) compared with the previous constraints. The new analysis rules out dark-photon coupling as the explanation for the muon (g-2) anomaly and places stringent constraints on dark-sector models.

of Caltech, who has worked on dark-photon models. "In contrast to massless dark photons, which are analogous to ordinary photons, this experiment constrains a slightly different idea of dark force-carrying particles that are associated with a broken symmetry, which therefore get a mass and then can decay. They are more like 'dark Z bosons' than dark photons."

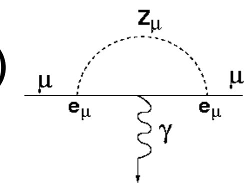
- **Further reading**

BaBar Collaboration 2017 arXiv:1702.03327.
NA64 Collaboration 2017 *Phys. Rev. Lett.* **118** 011802.

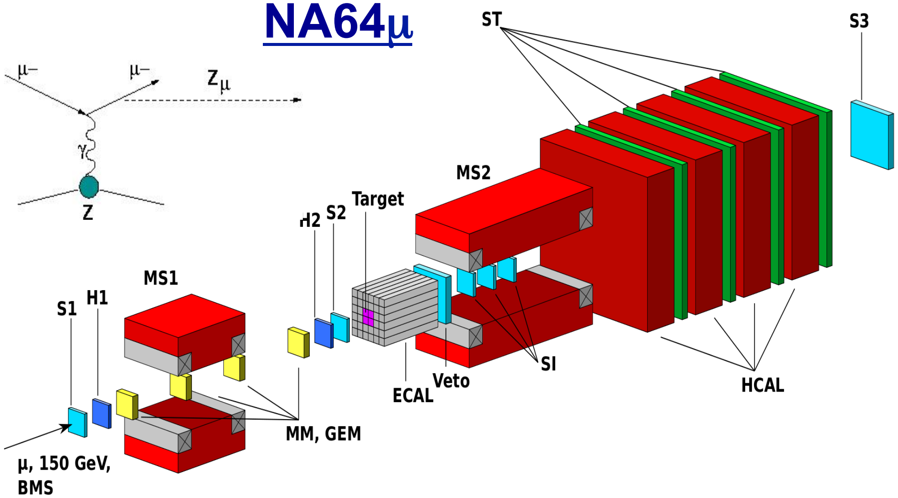
$(g-2)_\mu$ anomaly, L_μ-L_τ Z′ and LFV $\mu N \to \tau N'$

E989 on $(g-2)\mu$ at FNAL: will result in ~**5** σ if confirmed (2020?)

Explanation: **new sub-GeV L_μ-L_τ Z′coupled predominantly to muon**



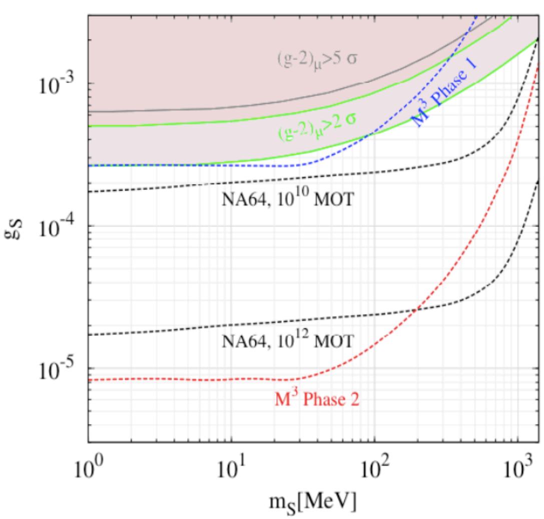
NA64μ

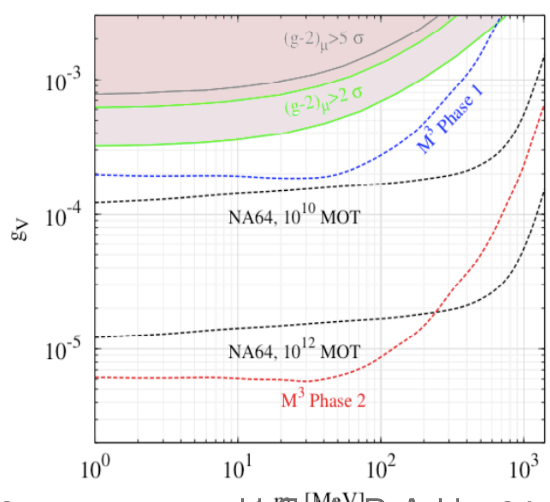


SG, Krasnikov, Matveev PRD(2014)

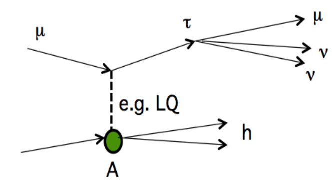
New ideas for a'la NA64μ experiment

- L_μ-L_τ Z_μ M^3@FNAL,arXiv:1804.03144
- Leptophilic TDM, arXiv:1807.03790
- Light scalars of DS, arXiv:1701.07437





$\mu N - \tau N'$



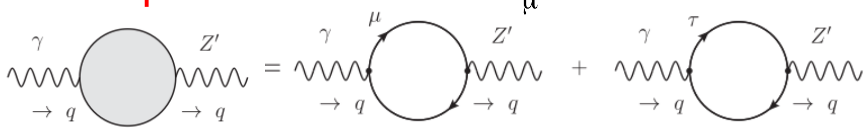
$R_{\mu\tau} = \sigma(\mu N \to \tau N') / \sigma(\mu N \to \mu N') < \sim 10^{-12}$

H1, ZEUS e-τ vs NA64 μ−τ bounds:

- *S* operators: $\Lambda^{e\tau} \geq 0.2$ TeV; $\Lambda^{\mu\tau} \geq 1.3$ TeV
- *V* operators: $\Lambda^{e\tau} \geq 0.3$ TeV; $\Lambda^{\mu\tau} \geq 2.4$ TeV
- *T* operators: $\Lambda^{e\tau} \geq 0.3$ TeV; $\Lambda^{\mu\tau} \geq 2.6$ TeV

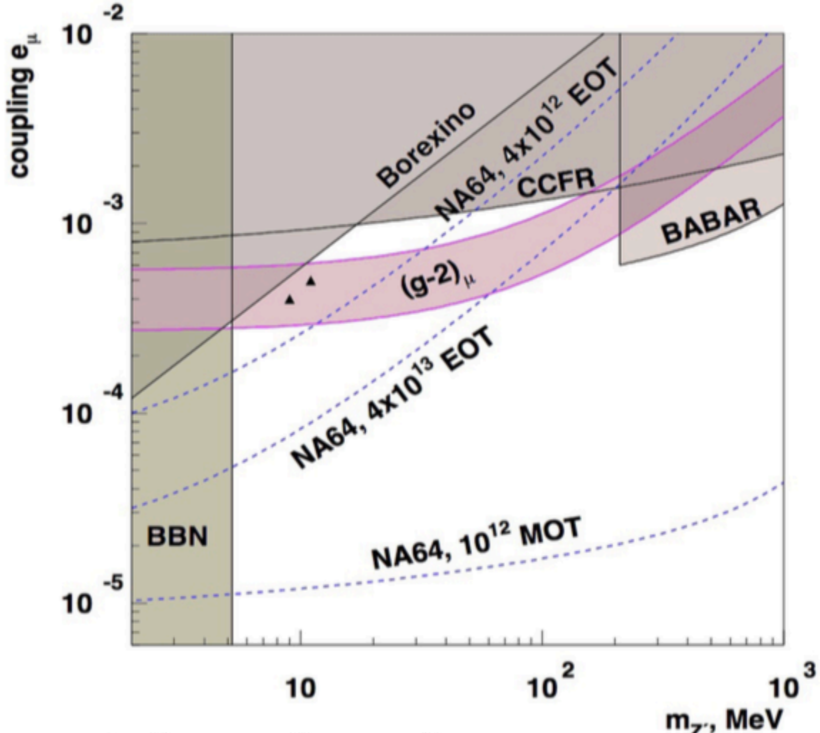
Complementarity of e and μ searches: γ –Z_μ mixing

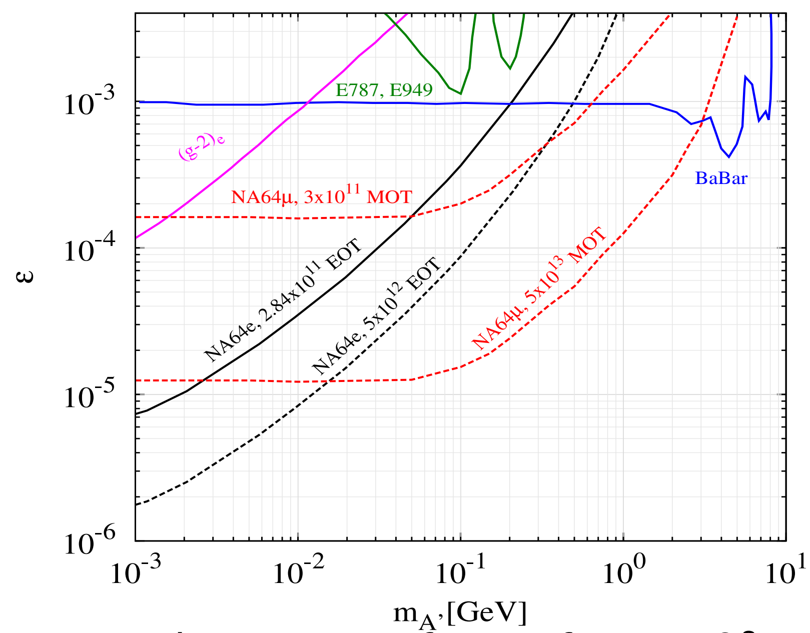
Loophole: search for Z_μ with e- beams



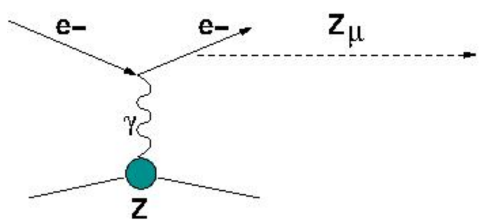
$N_{A'} \sim N_e\, \varepsilon^2\, m_e^2/m_{A'}^2 \quad m_{A'} > \sim m_\mu$

γ –Z_μ mixing $\varepsilon \sim 3eg_\mu/16\pi^2 \ln(m_\tau/m_\mu)$

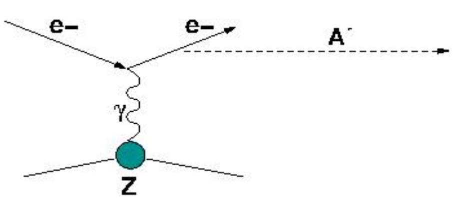




- An enhancement factor for $\mu \sim 10^2$ came from the ratio of the effective e- and muon target length t_μ/t_e



μ , Z_μ ⟺ e, A´

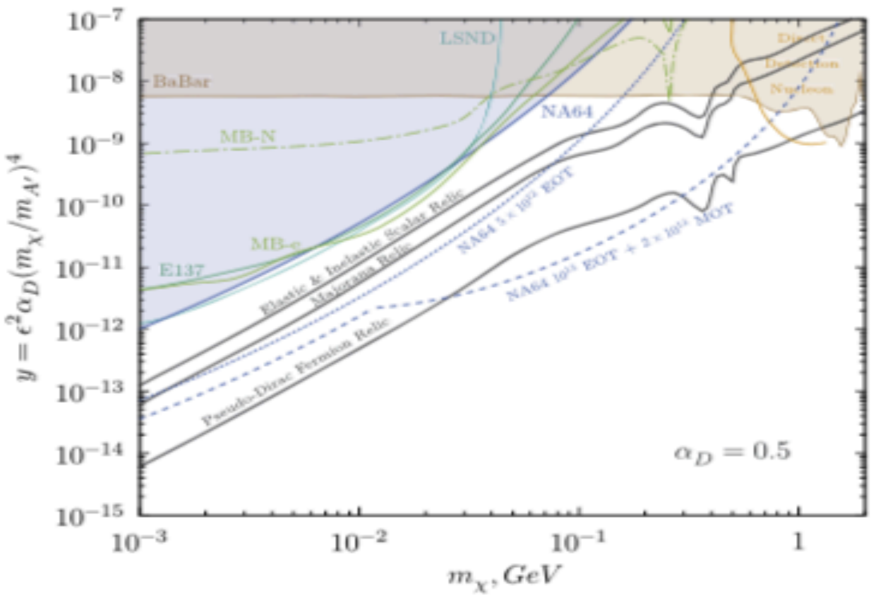


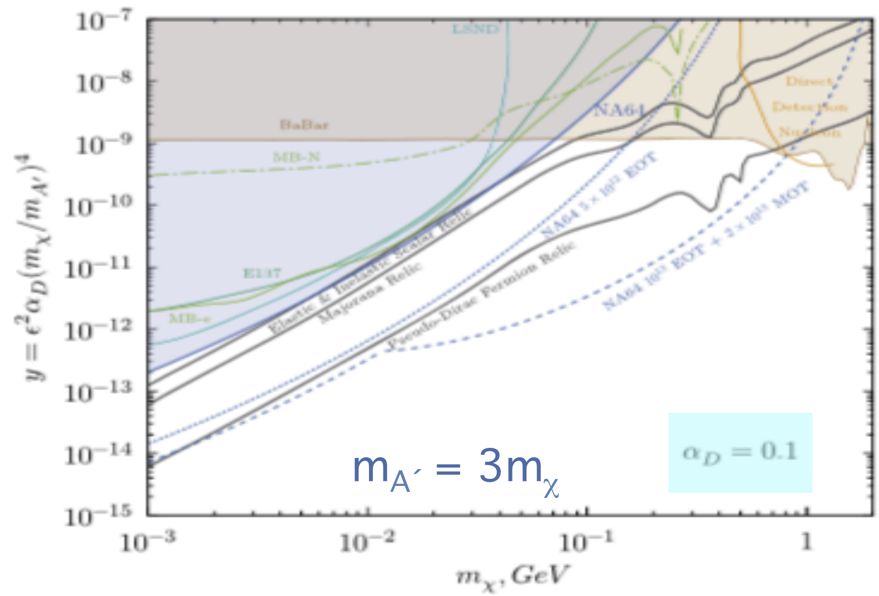
1801.10448

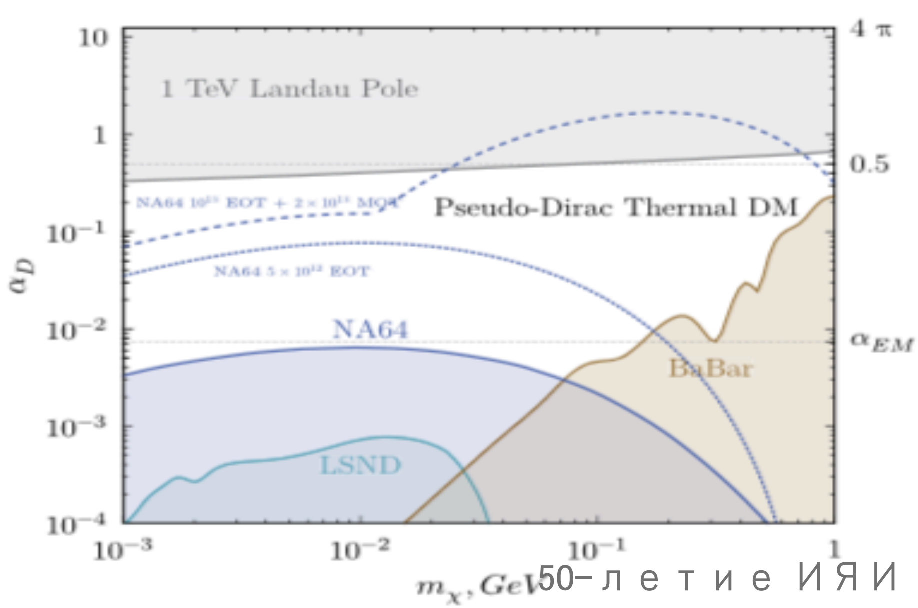
arXiv:1903.07899, ETL

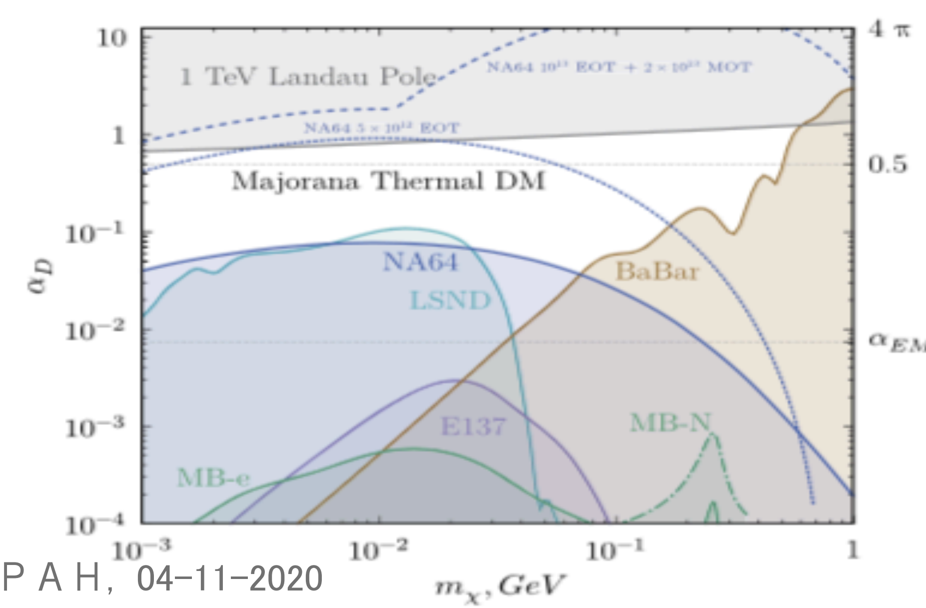
Combined NA64e - NA64μ LDM search (Projections)

Full coverage with 10^{13} EOT+$2\text{x}10^{13}$ MOT









NA64 Physics in Collabioration with TH INR

Process	New Physics	Comments, Projections for limits
e^- **beam**		Required number of EOT: 5×10^{12}
$A' \to e^+e^-$, and	Dark photon	$10^{-5} < \epsilon < 10^{-2}$, $1 \lesssim m_{A'} \lesssim 100$ MeV
$A' \to invisible$		$2 \times 10^{-6} < \epsilon < 10^{-3}$, $10^{-3} \lesssim m_{A'} \lesssim 1$ GeV
$A' \to \chi\overline{\chi}$	sub-GeV Dark Matter (χ)	Scalar, Majorana, pseudo-Dirac DM
		$\alpha_D^{S,M} \lesssim 1$, $\alpha_D^{p-D} \lesssim 0.1$, for $m_\chi \lesssim 100$ MeV
$X \to e^+e^-$	new gauge X- boson	^{8}Be* anomaly, $\epsilon_e^{up} < 10^{-5}$; $\epsilon_e^{low} > 2 \times 10^{-3}$
milliQ particles	Dark Sector, charge quantisation	$10^{-4} < mQ < 0.1$ e, $10^{-3} < m_{mQ} < 1$ GeV
$a \to \gamma\gamma, invisible$	Axion-like particles	$g_{a\gamma\gamma}^{inv} \lesssim 2 \times 10^{-5}$, $m_a \lesssim 200$ MeV
μ^- **beam**		Required number of MOT: 10^{11} – 5×10^{13}
$Z_\mu \to \nu\nu$	gauge Z_μ-boson of $L_\mu - L_\tau$, $< 2m_\mu$	(g-2)$_\mu$ anomaly; $g_\mu^V \lesssim 10^{-4}$, with $\lesssim 10^{11}$ MOT
$Z_\mu \to \chi\overline{\chi}$	$L_\mu - L_\tau$ charged Dark Matter (χ)	$y \lesssim 10^{-12}$ for $m_\chi \lesssim 300$ MeV with $\simeq 10^{12}$ MOT
milliQ	Dark Sector, charge quantisation	$10^{-4} < mQ < 0.1$ e, $10^{-3} < m_{mQ} < 2.5$ GeV
$a_\mu \to invisible$	non-universal ALP coupling	$g_Y \lesssim 10^{-2}$, $m_{a_\mu} \lesssim 1$ GeV
$\mu - \tau$ conversion	Lepton Flavour Violation	$\sigma(\mu - \tau)/\sigma(\mu \to all) \lesssim 10^{-11}$
π^-, K^- **beams**	Current limits, PDG'2018	Required number of POT(KOT):$5 \times 10^{12}(5 \times 10^{11})$
$\pi^0 \to invisible$	$Br(\pi^0 \to invisible) < 2.7 \times 10^{-7}$	$Br(\pi^0 \to invisible) \lesssim 10^{-9}$
$\eta \to invisible$	$Br(\eta \to invisible) < 1.0 \times 10^{-4}$	$Br(\eta \to invisible) \lesssim 10^{-8}$
$\eta' \to invisible$	$Br(\eta' \to invisible) < 5 \times 10^{-4}$	$Br(\eta \to invisible) \lesssim 10^{-7}$
$K_S^0 \to invisible$	no limits	$Br(K_S^0 \to invisible) \lesssim 10^{-9}$
$K_L^0 \to invisible$	no limits	$Br(K_L^0 \to invisible) \lesssim 10^{-7}$
		complementary to $K^- \to \pi\nu\nu$

Заключение

1. Эксперименты ИСТРА, ИСТРА+, ОКА, SM и BSM в распадах π, K:

- Измерение форм-факторов
- Проверка V-A и ChPT
- Обнаружение новых распадов π^0, K
- Поиски CP нарушения в $K^{\pm}$
- Поиски S, T взаимодействий
- Поиски новых частиц (ν_h , P, ..)

2. Разработка и создание пульсирующего пучка позитронов ETHZ-INR для проведение фундаментальных (и прикладных) исследований с Ps

- Лучшие ограничения на осцилляции oPs, поиски новых легких частиц

3. Сотрудничество с BNL, FNAL, КЕК, GSI (E865, E949, E246 E470, HADES)

- Разработал концепцию поиска μ2e
- Поиски LFV в распадах K
- Обнаружение новых распадов K
- Поиски тяжелых нейтрино
- Поиски S, T взаимодействий
- Поиски новых частиц (ν_h , P, A´..)

5. Цикл работ по программе поисков BSM на LHC. Поиски LRSM W_R, N_l CMS

6. Physics Beyond Colliders at CERN, NA62, NA64, SHIP

- Определяющий вклад в создание NA64
- Широкая Программа поисков на e-, μ, h пучках: LDM, ALPs, S, Z´, milliQ, Be, g-2, XENON1T, KOTO anomalies
- Измерение $K\to\pi\nu\nu$ NA62
- LFV, новые част. в распадах K
- Участие в NA64-dump, SHIP
- Широкая программа поиска BSM