Search for light vector boson and light dark matter. NA64 experiment

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1.Introduction

Outline

1. Introduction
2. Light dark matter
3. Experimental bounds
4. NA64 experiment and other experiments
5. Conclusion

1.Introduction

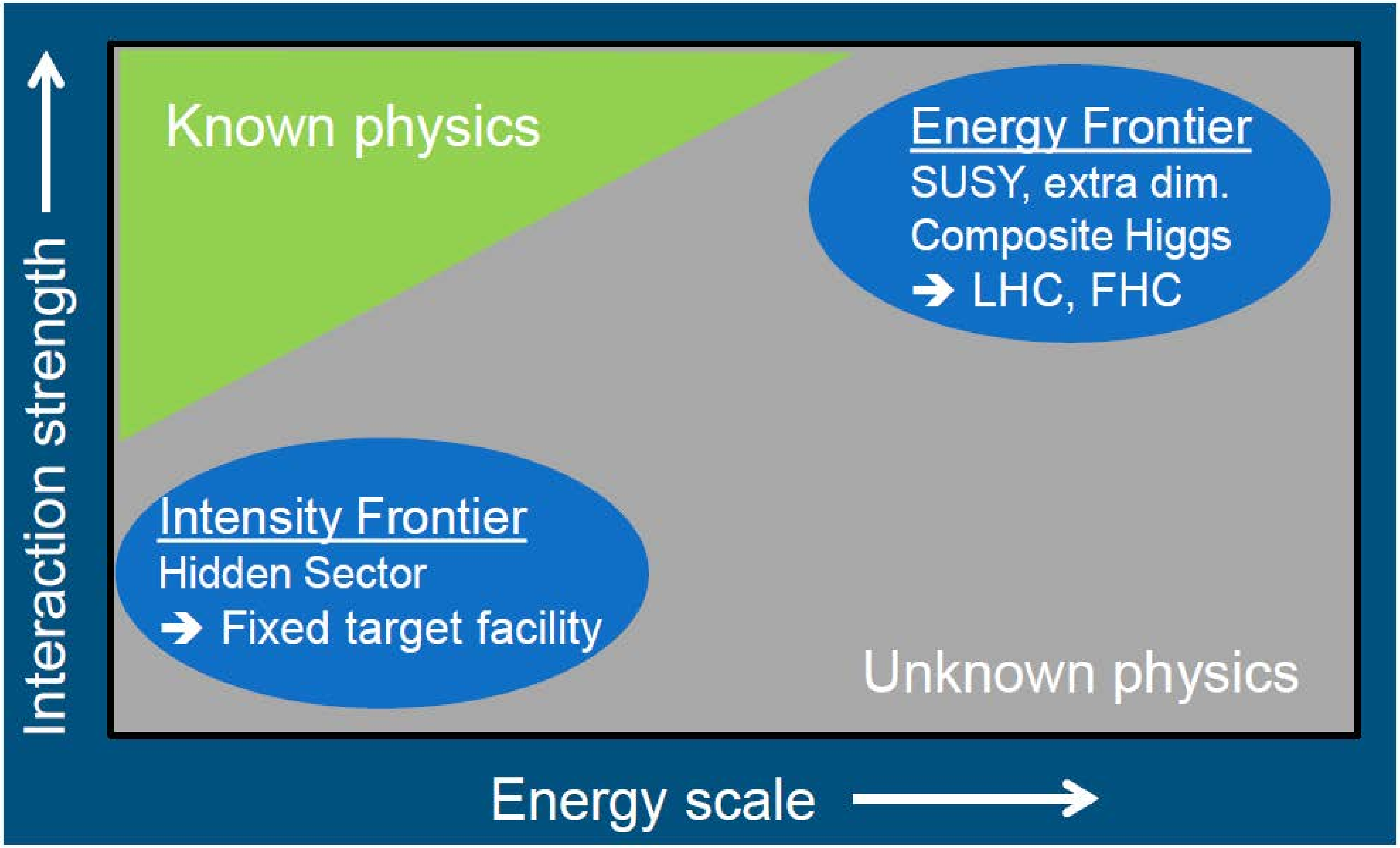
A lot of references can be found in recent workshop on light dark matter SLAC 28 – 30 april 2016

1.Introduction

Two lines of research in experimental elementary particle physics:

1. High energies → search for new massive particles (CMS and ATLAS mainly)
2. Relatively low energies → search for new relatively light O(10) GeV or less new particles with very small coupling constants

1.Introduction



1.Introduction

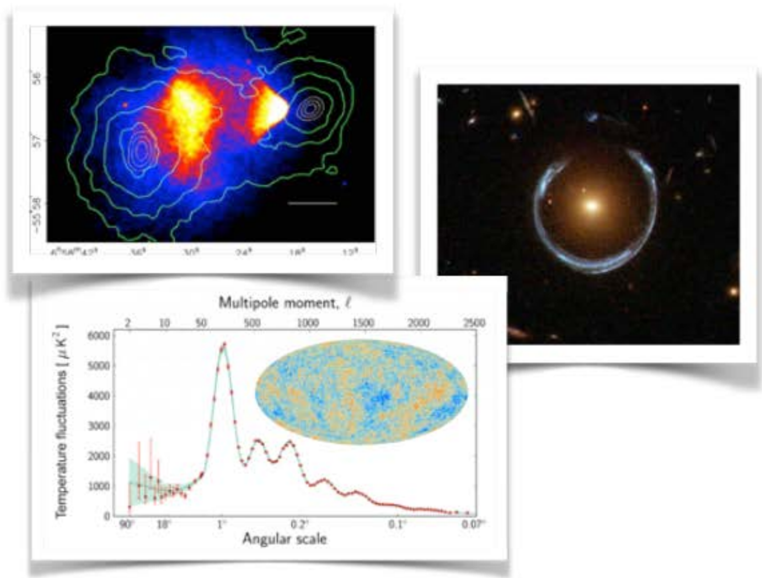
Search for new light particles:

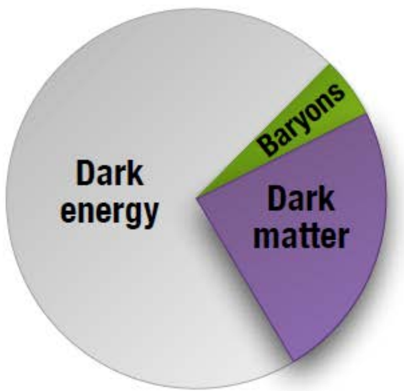
1. S = 0 - scalar portal – axions, inflantons, flavons, ...
2. S = ½ - neutrino portal - neutral leptons (sterile neutrino)
3. S =1 - vector portal – light dark vector boson
4. S = 3/2 - gravitino

As a review: arXiv:1504.04855 ; arXiv:1402.4817

Dark matter exists. It is the main motivation to search for new particles at accelerators

There is a dark sector!





- What is it?
- Where did it come from?

Other hints in favor of BSM

1. Gauge hierarchy problem
2. Muon (g-2) anomaly
3. Strong CP problem
4. …

A lot of questions about dark matter particles

If dark matter is relevant…

3. How is it produced?
   - Thermally (through annihilation to SM)?
   - Asymmetric?
   - Other?

   May imply constraints/relations among dark-sector couplings

4. Fermion or scalar?

5. Elastic (mass-diagonal) or inelastic (mass-off-diagonal) interactions?

   Affect signals in various experiments and the comparisons among them

At the largest scales the Universe is spatially FLAT

In cosmology this means that the energy density has a critical value ρ_c, $\rho = \rho_c$

$$\text{or } \Omega \equiv \rho/\rho_c = 1$$

$$\rho_c = 3H_0^2/(8\pi G) = 1.9 \times 10^{-29}\ h^2\ \frac{\mathrm{g}}{\mathrm{cm}^3} = 10.5\ h^2\ \frac{\mathrm{keV}}{\mathrm{cm}^3} \simeq 5\ \frac{\mathrm{keV}}{\mathrm{cm}^3}$$

(where $h = 0.7$ is the reduced Hubble constant, $H = 100\ h$ km/(Mpc s))

WMAP 7 (Jan 2010)

$$\Omega_{total} = \frac{\rho}{\rho_c} = 1.003 \pm 0.010$$

At the largest scales: concordance cosmology

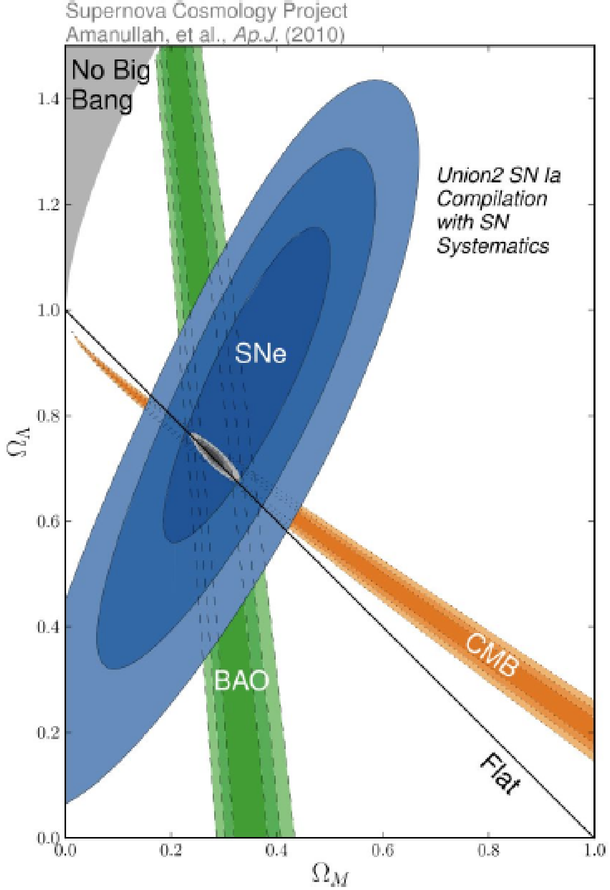


Fig: Amanullah et al 2010 (The Supernova Cosmology Project)

$\Omega = \rho/\rho_c \qquad \rho_c \simeq 5\ \mathrm{keV/cm^3}$

68.3%, 95.4%, 99.7%CL constraints on Ω_Λ vs. Ω_M obtained from Cosmic Background Radiation Anisotropy CMB (orange), Baryon Acoustic Oscillations BAO (green), and the Union Compilation of 413 Type Ia supernovae (SNe Ia) (blue); Ω_m =0.285$^{+0.020}_{-0.019}$(stat)$^{+0.011}_{-0.011}$(sys) assuming DE is a cosmological constant

WMAP7, BAO, SN1a: E. Komatsu, et al., 2010

$\Omega_\Lambda = 72.2 \pm 1.5\%$ $\Omega_M = 27.8 \pm 1.5\%$

where Ω_M is:

$\Omega_b = 4.61 \pm 0.15\%$

$\Omega_{DM} = 23.2 \pm 1.3\%$

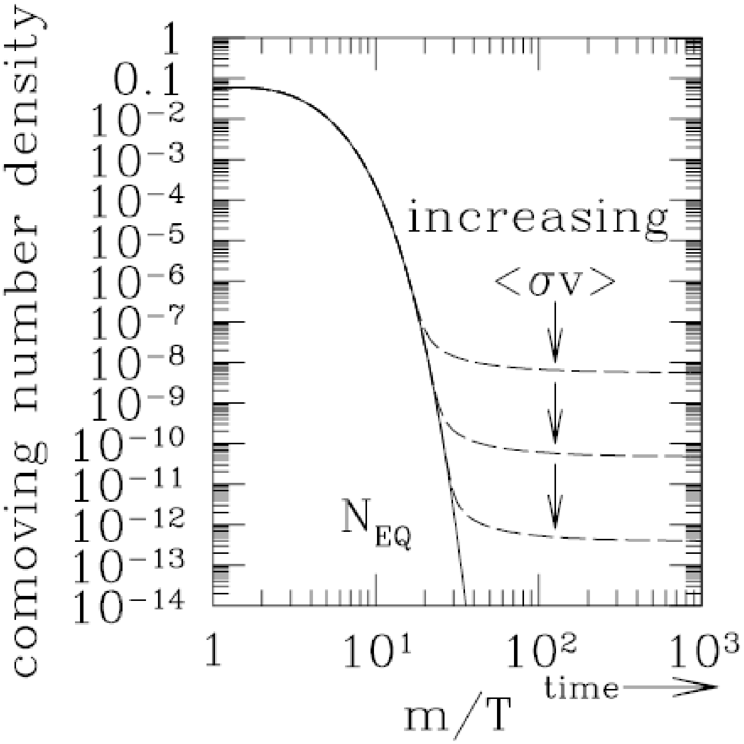
Thermal WIMPs as Dark Matter

Standard calculations: start at $T > T_{f.o.} \simeq m_\chi/20$ and assume that

- WIMPs reach equilibrium while Universe is radiation dominated
- No particle asymmetry
- Chemical decoupling (freeze-out) when $\Gamma_{\rm ann} = \langle \sigma v \rangle\, n \leq H$,
- No entropy change in matter+radiation

$$\Omega_{\rm std} h^2 \approx \frac{0.2 \times 10^{-9} {\rm GeV}^{-2}}{\langle \sigma v \rangle}$$

Weak annihilation cross section $\sigma_{\rm annih} \simeq G_F^2 T^2 \simeq 10^{-9} {\rm GeV}^{-2}$ is enough to get $\Omega = \Omega_{DM} \simeq 0.2$! "WIMP Miracle"!

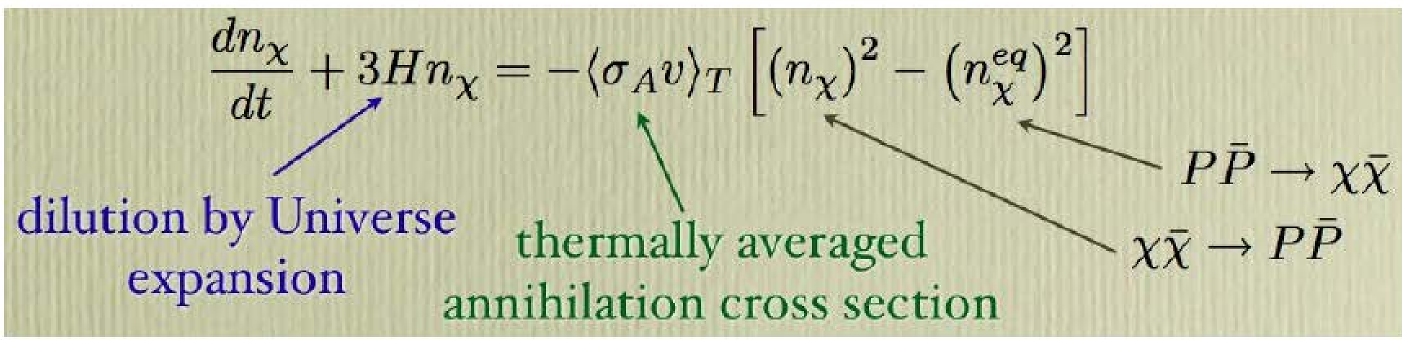


Decoupling of Non-relativistic particles $m > T$

At $T > m$: Annihilation $\chi\chi \to PP$ = Creation $PP \to \chi\chi$ Creation= Annihilation
At $m > T$: Creation $PP \to \chi\chi$ is suppressed: Boltzmann factor $e^{m/T}$

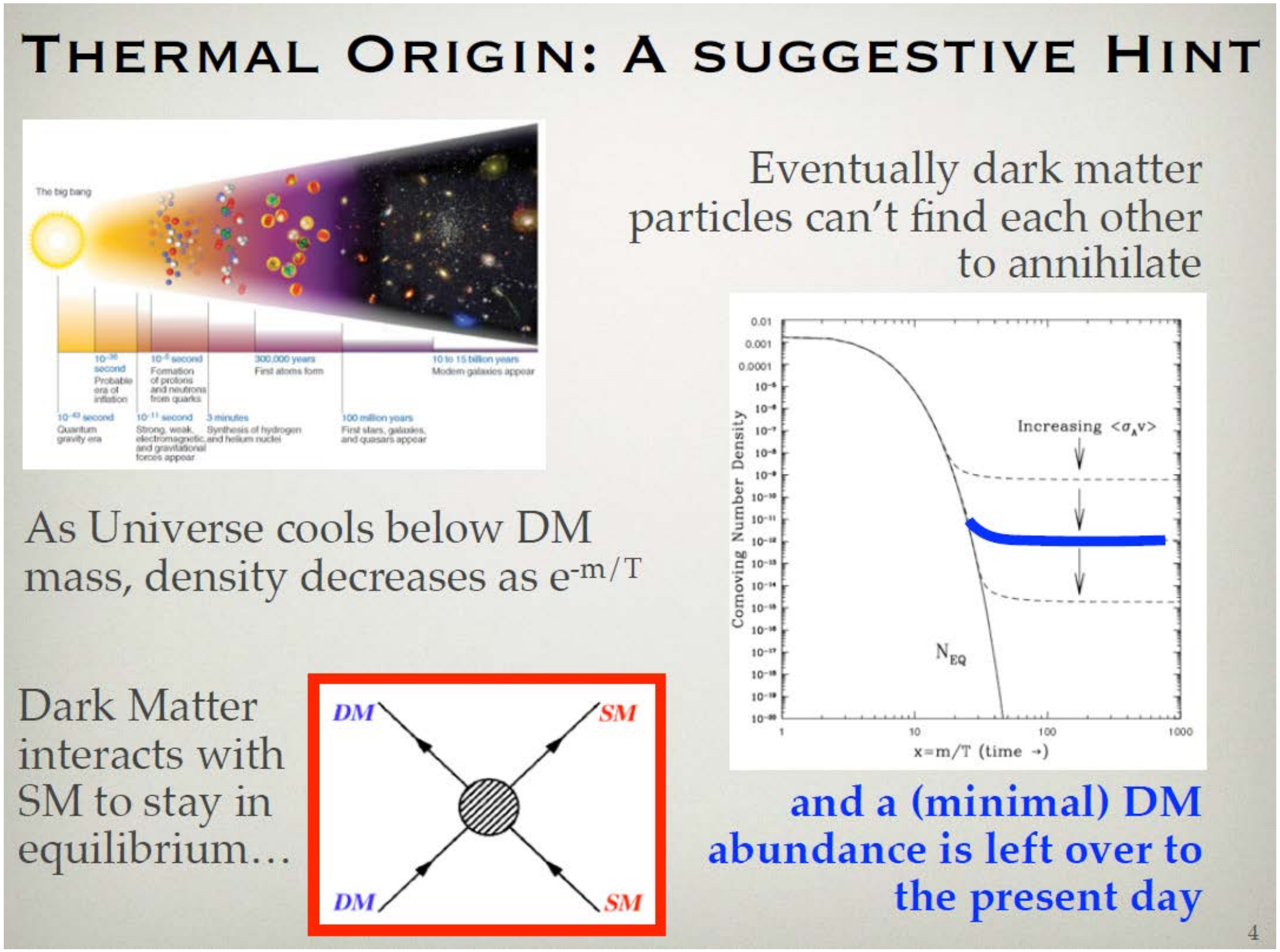
Bolzmann Transport Equation: Lee-Weinberg, 1977; Wolfram 1979(numerical solution)

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle\sigma_A v\rangle_T \left[(n_\chi)^2 - \left(n_\chi^{eq}\right)^2\right]$$



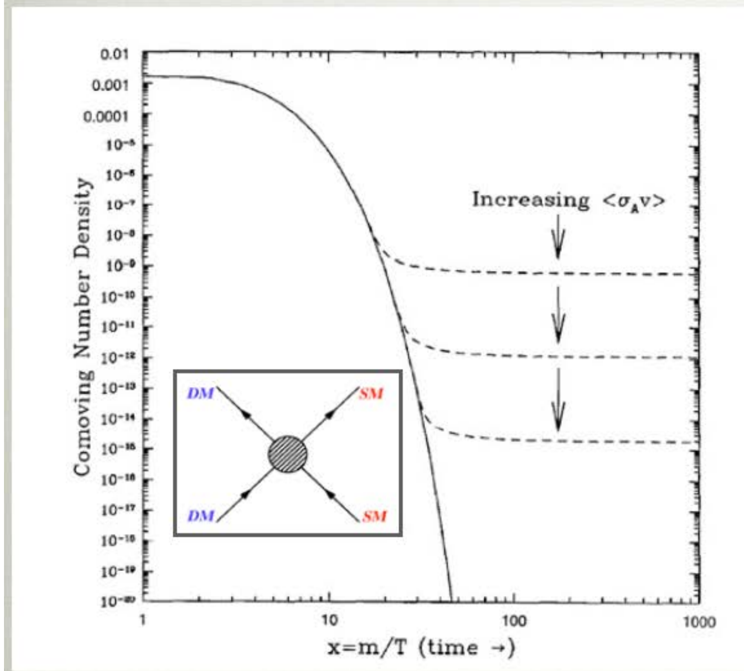
expansion: $n \sim a^{-3} \to \frac{dn}{dt} = -3\frac{\dot{a}}{a}n = -3Hn$
annihilation: $n \sim e^{t/t_A}$ thus $\frac{dn}{dt} = -n/t_A$, $t_A \simeq \lambda_{M.F.P}/v = 1/\sigma_A n v$
creation: stop expansion at T, wait for equilibrium so $\frac{dn}{dt} = 0$
χ freeze-out approx. $\langle\sigma_A v\rangle_{T=T_{f.o.}} n^{eq}(T_{f.o.}) \simeq H$

What about thermal origin?



Message from thermal origin

THERMAL ORIGIN



DM density today tells us about annihilation cross-section

Smaller cross-section
$\Rightarrow$ earlier freeze-out
$\Rightarrow$ higher density

Correct DM density for:

$$\langle \sigma v \rangle \simeq 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$

$$\simeq \frac{1}{(20\ \mathrm{TeV})^2}$$

Thermal origin suggests DM interactions and mass in the vicinity of the weak-scale

What about mass and spin

We know that dark matter exists

But we don't know:

1. Spin of dark matter particles
2. Mass of dark matter particles

In SUSY with R-parity LSP is gaugino with $s = 1/2$ and $m = O(100\ GeV)$ (as a rule)

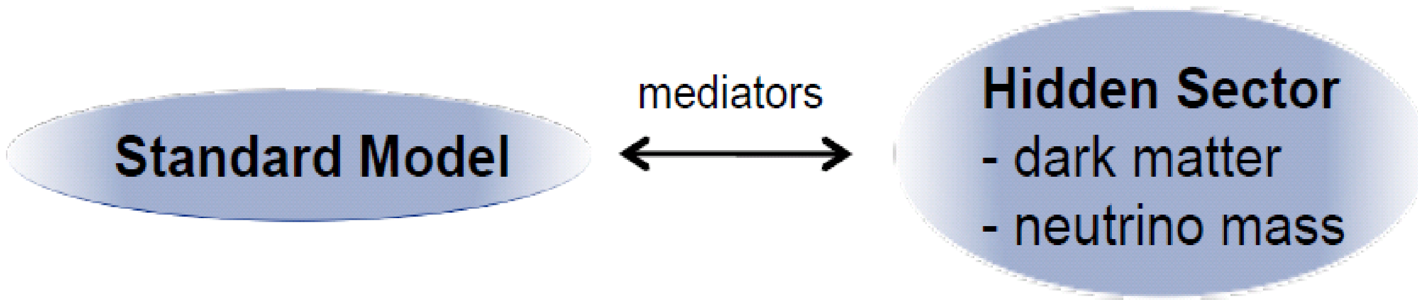
3. ….

Light dark matter

It is possible that dark matter particles are relatively light with masses O(5 GeV) or less. In this case very popular scenario with additional weak interaction that connects our world and dark particles world and responsible for existing dark matter density

The most popular is the vector portal

Arguably, most *empirical* evidence for new physics (e.g. neutrino mass, dark matter) doesn't point a priori to a specific mass scale, but rather to a hidden (or dark) sector.



- Vector portal: $\mathcal{L} = -\frac{\kappa}{2} B^{\mu\nu} V_{\mu\nu}$ [Okun; Holdom; Foot et al]
- Higgs portal: $\mathcal{L} = -H^\dagger H (AS + \lambda S^2)$ [Patt & Wilczek]
- Neutrino portal: $\mathcal{L} = -Y_N^{ij} \bar{L}_i H N_j$

General idea

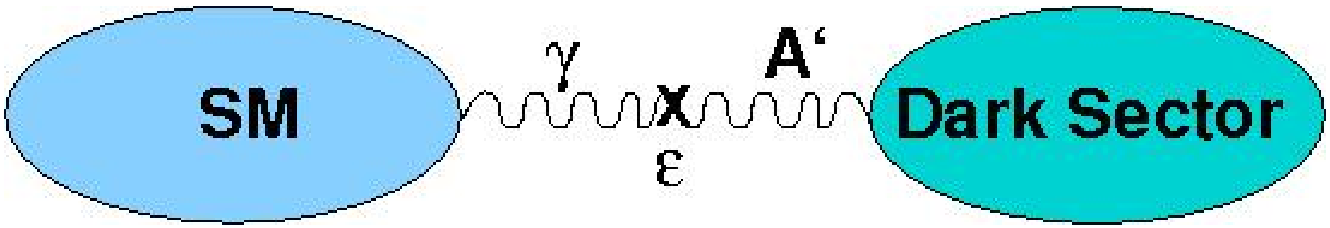
Besides SM we have some hidden sector and this sector interacts with our world due some dark force exchange. The most popular mediator is massive vector boson (dark photon)

L.Okun(1982), B.Holdom(1986), …

For a recent review: P.Hansson et al., arXiv:1311.0029(2013)

An example of dark mediator A`

Holdom'86, earlier work by Okun, ..



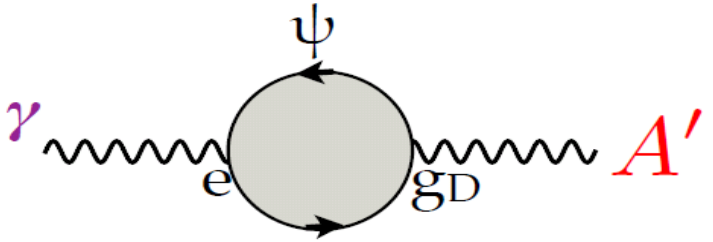
- extra U`(1), new gauge boson A`(dark or hidden photon,…)
- $2\Delta L = \varepsilon F^{\mu\nu} A`_{\mu\nu}$ - kinetic mixing
- γ-A` mixing, ε - strength of coupling to SM
- A` could be light: e.g. $M_{A`} \sim \varepsilon^{1/2} M_Z$
- new phenomena: γ-A`oscillations, LSW effect, A`decays,..
- A`decay modes: e+e-, μ+μ-, hadrons,.. or A`-> DM particles, i.e. A`-> invisible decays

Large literature, >100 papers /few last years, many new theoretical and experimental results

The origin of A, A` mixing

Sources and Sizes of Kinetic Mixing $\frac{1}{2}\epsilon_Y F^Y_{\mu\nu} F'^{\mu\nu}$

- If absent from fundamental theory, can still be generated by **perturbative** (or non-perturbative) quantum effects
  - Simplest case: one heavy particle ψ with both EM charge & dark charge



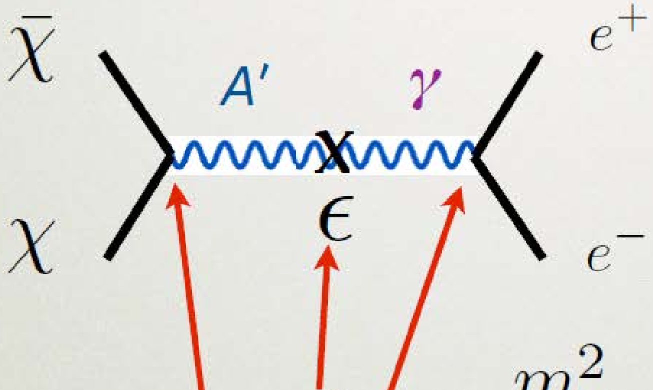
generates $\epsilon \sim \frac{e\, g_D}{16\pi^2} \log \frac{m_\psi}{M_*} \sim 10^{-2} - 10^{-4}$

The relation of mixing and dark matter abundance

VECTOR PORTAL SCENARIO

and the Thermal Origin Target

Small interaction between dark sector and Standard Model:



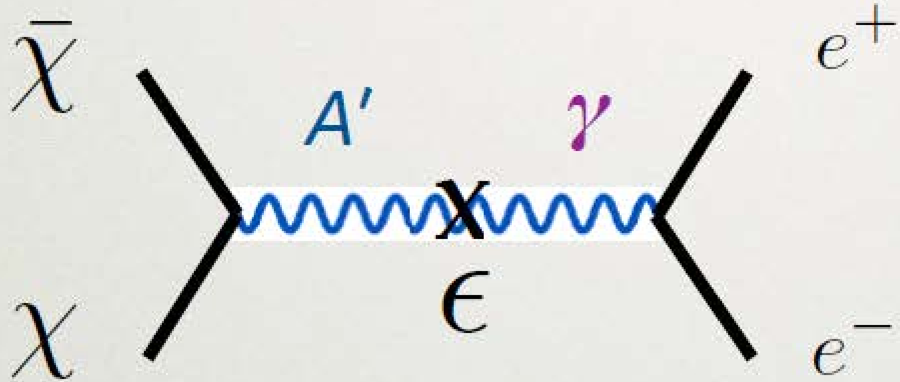
+ other modes

$$\sigma v \sim \alpha_D \epsilon^2 \alpha \times \frac{m_\chi^2}{m_{A'}^4}$$

Vector Portal Scenario

and the Thermal Origin Target

Small interaction between dark sector and Standard Model:



+ other modes

$$\sigma v \sim \alpha_D \epsilon^2 \alpha \times \frac{m_\chi^2}{m_{A'}^4} \times m_\chi^2 \times \frac{1}{m_\chi^2}$$

WIMP miracle

$$\Omega_{\rm DM} h^2 \approx \frac{10^{-26}\,{\rm cm}^3/{\rm s}}{\langle \sigma v_{\rm rel}\rangle} \approx 0.1 \left(\frac{0.01}{\alpha_{\rm DM}}\right)^2 \left(\frac{m_{\rm DM}}{100\,{\rm GeV}}\right)^2 ,$$

Possible realizations of the vector portal scenario

Vector Portal Scenario

Simple example scenarios: "massive" dark QED

$$\mathcal{L}_{DM} = g_D A'_\mu \bar{\chi}\gamma^\mu \chi + m_\chi \bar{\chi}\chi + \frac{1}{2} m_{A'}^2 A'^2 + \ldots$$

(kinetic terms)

$$+\Delta\, \chi\chi$$

Mass Eigenstates: small mass splitting by Δ

$$\begin{pmatrix} \chi \\ \bar{\chi} \end{pmatrix} \rightarrow \chi_h \propto \chi + \bar{\chi} \qquad m_{\chi_h} = m_\chi + \frac{1}{2}\Delta$$

$$\begin{pmatrix} \chi \\ \bar{\chi} \end{pmatrix} \rightarrow \chi_l \propto \chi - \bar{\chi} \qquad m_{\chi_l} = m_\chi - \frac{1}{2}\Delta$$

(Dirac fermion: pair of 2-component spinors)

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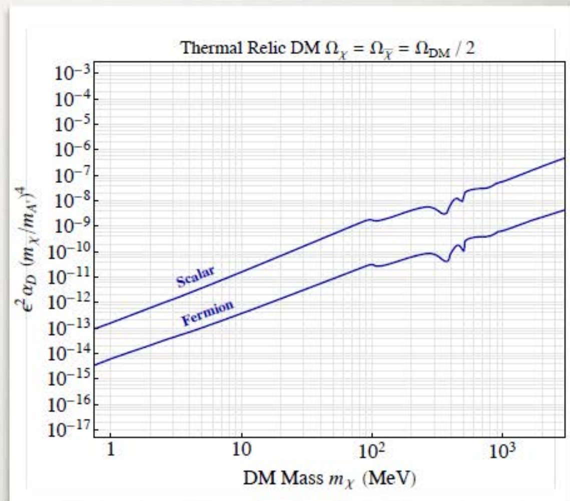
Basic scenarios

Landscape of Scenarios

Four "minimal" LDM scenarios:

– Dirac fermion
– (Elastic) Complex Scalar

– Majorana (Inelastic) fermion
– (Inelastic) Complex Scalar



The four minimal models all have a thermal DM parameter range of interest!

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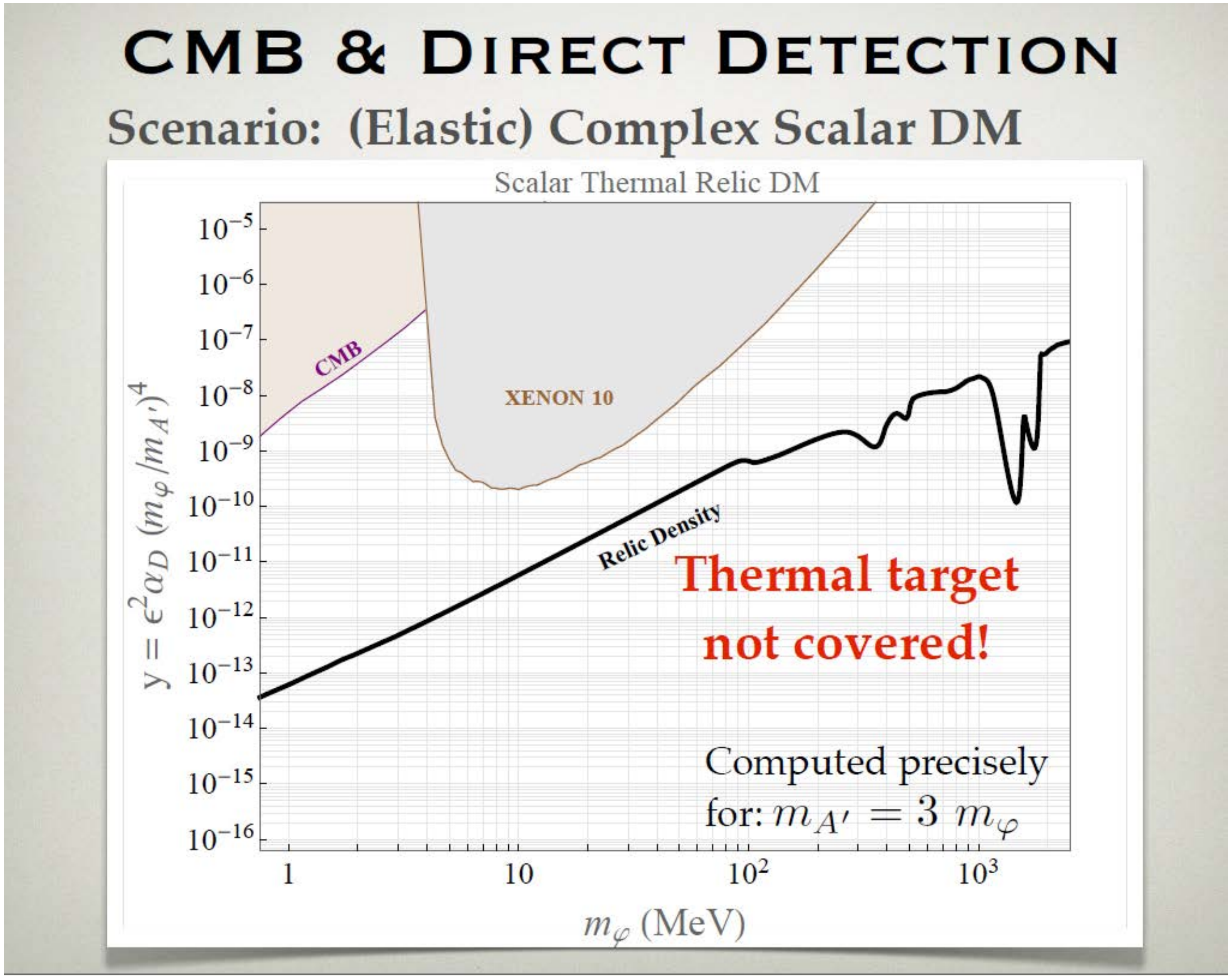
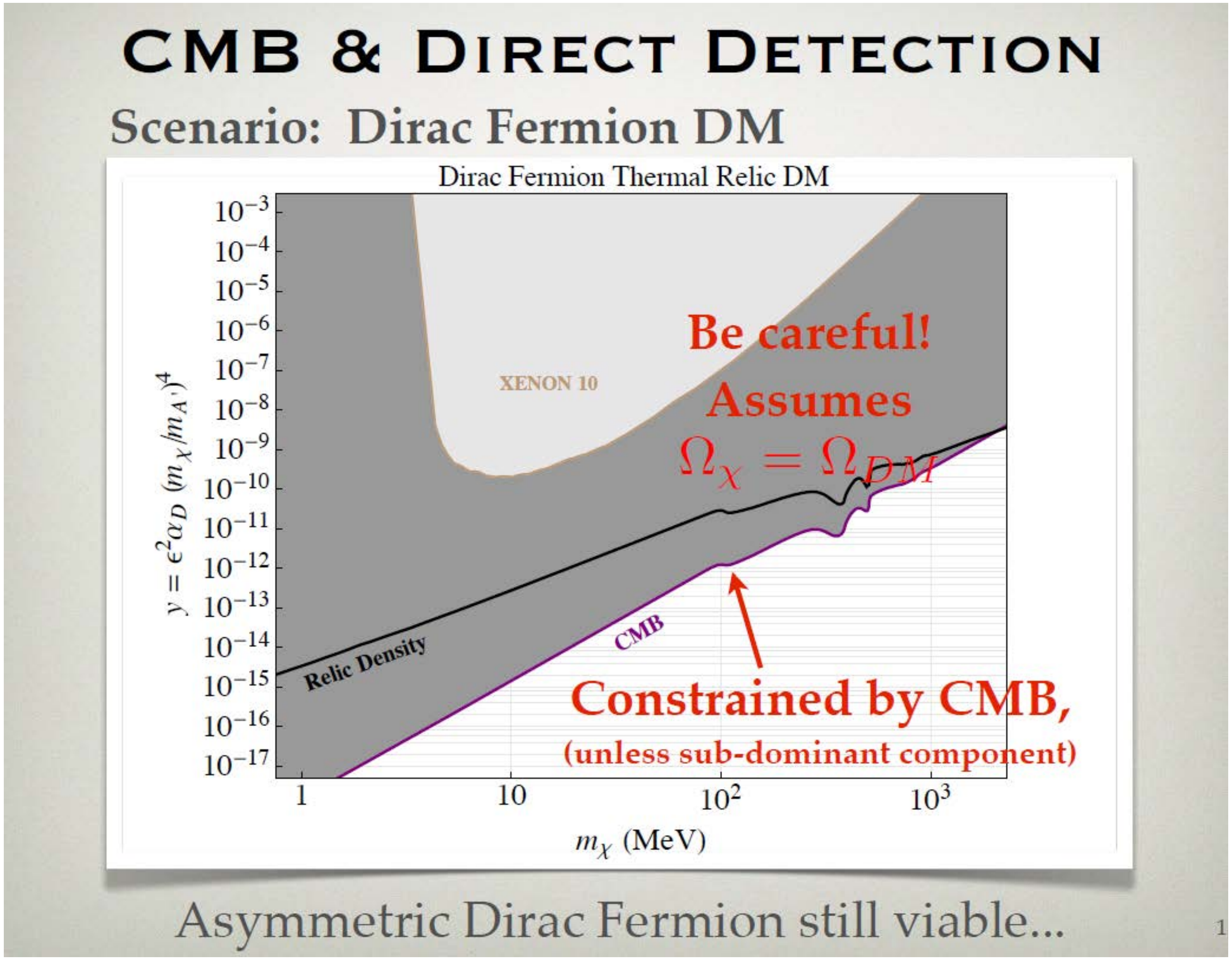
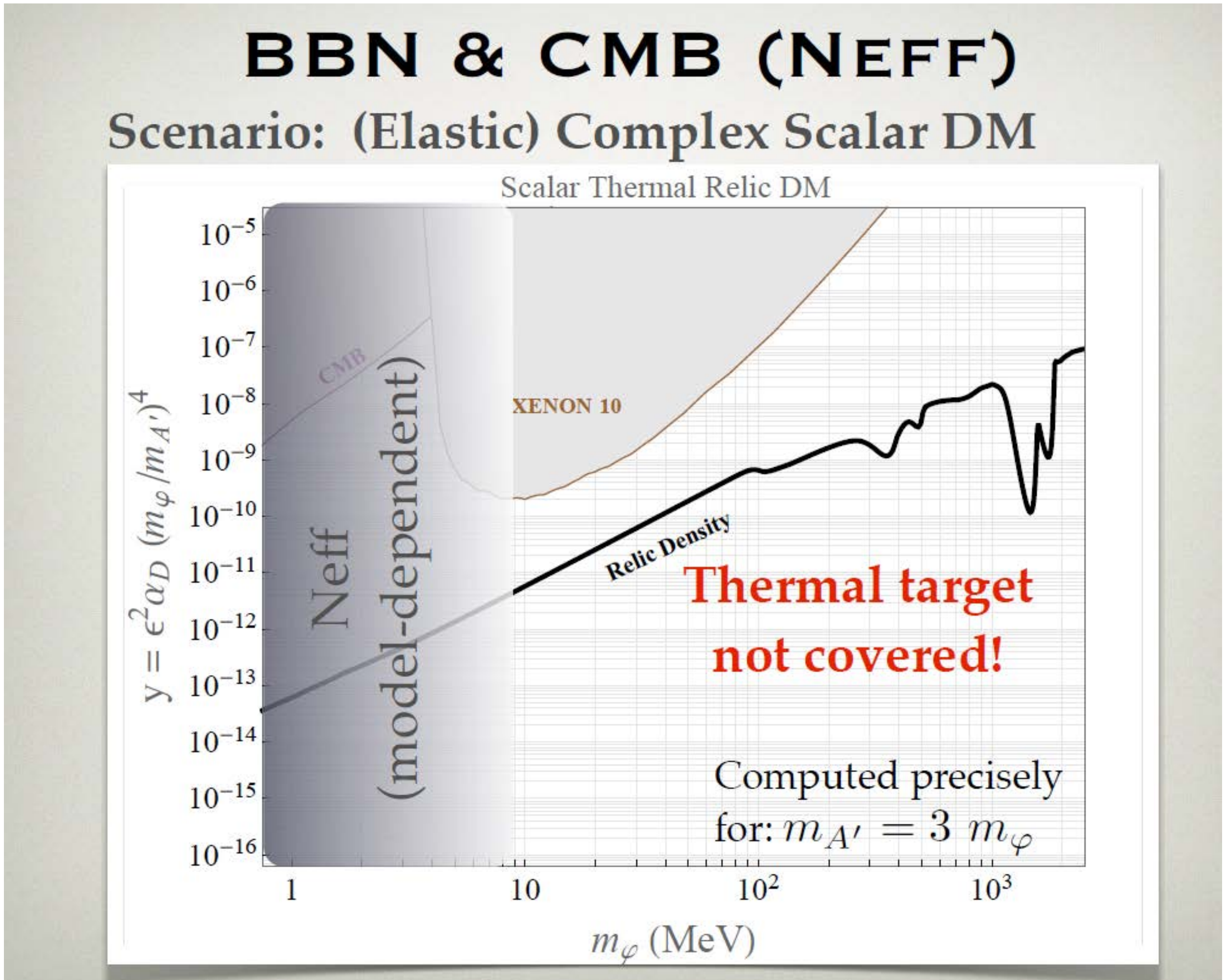
Elastic Complex DM



Dirac Fermion DM is excluded

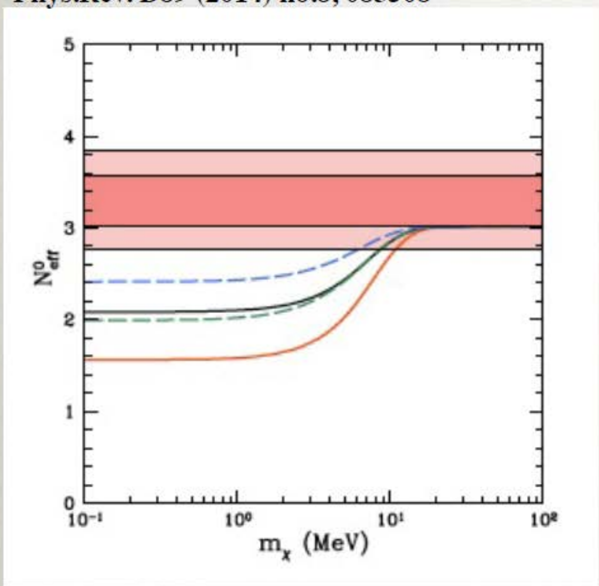



BBN & CMB (NEFF)
Scenario: (Elastic) Complex Scalar DM
Scalar Thermal Relic DM
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
$y = \epsilon^2 \alpha_D (m_\varphi / m_{A'})^4$
CMB
Neff
(model-dependent)
XENON 10
Relic Density
Thermal target
not covered!
Computed precisely
for: $m_{A'} = 3\ m_\varphi$
1
10
10^2
10^3
m_φ (MeV)

LDM and Neff

Late time annihilation of dark matter can also alter Neff

Phys.Rev. D89 (2014) no.8, 083508



Constraints	$100\,\Omega_B h^2$	N_{eff}	ΔN_ν	m_χ(MeV)
		Real scalar WIMP		
BBN only, $\Delta N_\nu = 0$	$1.97 \pm 0.10(0.19)$	2.41	$\cdots$	$0.26^{+0.09(0.30)}_{-0.07(0.12)}$
BBN only, $\Delta N_\nu \geq 0$, 68%	(1.87,2.34)	(2.41,3.78)	(0.0, 1.00)	> 0.15
95%	(1.78,2.42)	(2.41,4.02)	(0.0, 1.27)	> 0.15
BBN + CMB+BAO (η)	$2.23 \pm 0.03(0.06)$	$3.31^{+0.39(0.62)}_{-0.50(0.76)}$	$0.66^{+0.34(0.60)}_{-0.18(0.48)}$	> 0.39 (5.4)
BBN + CMB+BAO (N_{eff})	$2.23 \pm 0.08(^{+0.16}_{-0.15})$	$3.30 \pm 0.27(^{+0.47}_{-0.54})$	$0.67^{+0.33(0.56)}_{-0.26(0.56)}$	> 0.43 (5.2)
BBN + CMB+BAO (η, N_{eff})	$2.23 \pm 0.03(0.06)$	$3.30 \pm 0.26(^{+0.46}_{-0.51})$	$0.67^{+0.33(0.55)}_{-0.33(0.55)}$	> 0.48 (5.2)
BBN + CMB+BAO (η, N_{eff}, Y_P)	$2.23 \pm 0.03(0.06)$	$3.28^{+0.33(0.54)}_{-0.35(0.61)}$	$0.69^{+0.31(0.54)}_{-0.38(0.58)}$	> 0.42 (4.7)

Global fits to CMB & BBN favor ~5-10 MeV with a sterile neutrino component

If sterile neutrino (or dark radiation) component is set to zero, then there is tension with Neff below ~5-10 MeV

~MeV dark matter → non-minimal dark sector

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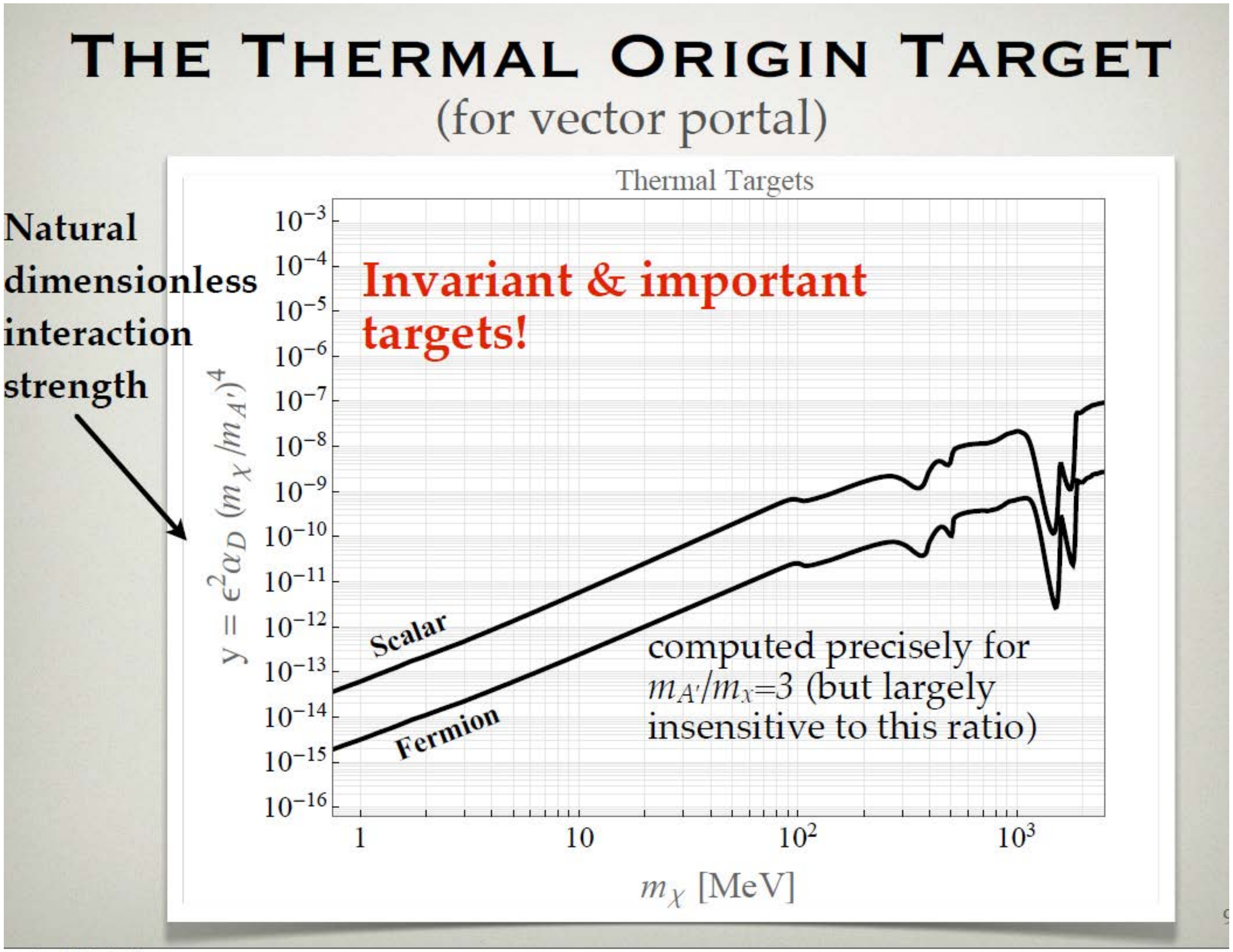

THE THERMAL ORIGIN TARGET
(for vector portal)
Natural dimensionless interaction strength
Thermal Targets
Invariant & important targets!
Scalar
Fermion
computed precisely for $m_{A'}/m_\chi$=3 (but largely insensitive to this ratio)
$y = \epsilon^2 \alpha_D (m_\chi/m_{A'})^4$
m_χ [MeV]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
1
10
10^2
10^3

Other scenarios are possible

CMB disfavors the Dirac Fermion scenario

Complex Scalar scenario has p-wave annihilation in early Universe, so is wide open...

(~MeV range compatible with sterile neutrinos...etc)

What about inelastic fermion or scalar scenarios?

Essentially no robust constraint from CMB or Direct Detection.

Neff constraints in ~MeV region not known.

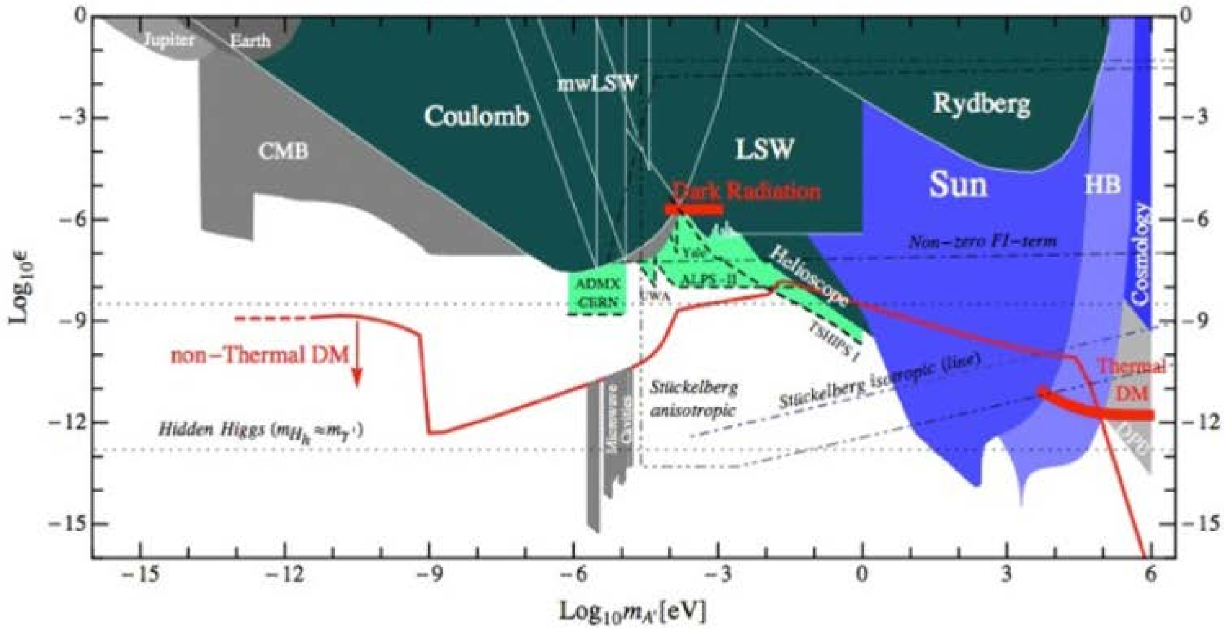
Dark photon bounds

For Sub-MeV dark photons the main bounds are from astrophysics(sun , supernovae…)

and cosmology.

Non accelerator bounds

Sub-MeV Dark Photons



[Figure from 2013 Intensity Frontier report – Javier Redondo]

Accelerator dark photon searches

Dark Photon Searches

Production Modes

- Electron-positron annihilation
- Meson Decays
- Drell-Yan (collider or fixed target)
- Bremsstrahlung

Detection Signatures

- Pair resonance
- Beam-dump late decay
- Inclusive missing mass
- Reconstructed displaced vertex

A` decays – visible and invisible

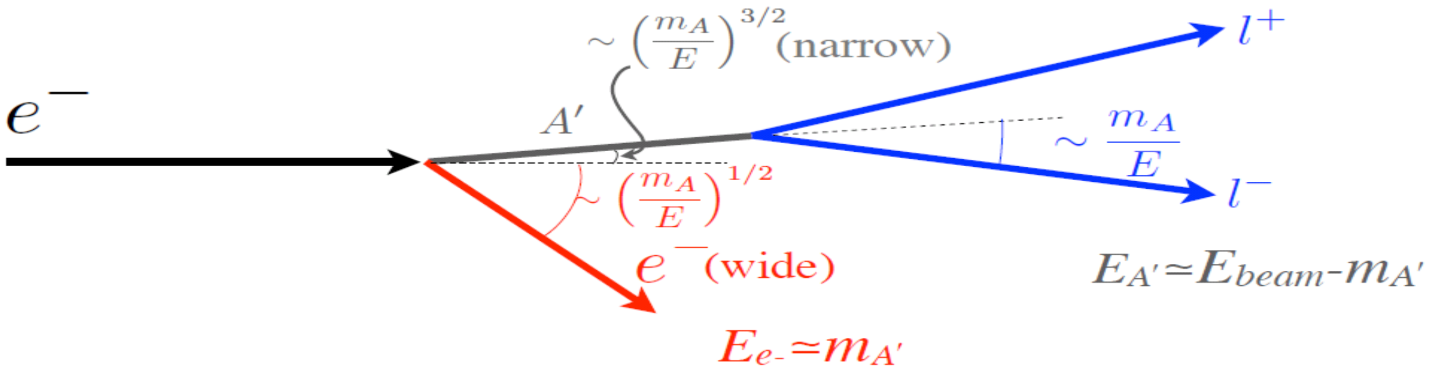
$$\Gamma(A' \to \bar{\chi}\chi) = \frac{\alpha_D}{3} m_{A'} \left(1 + \frac{2m_\chi^2}{M_{A'}^2}\right) \sqrt{1 - \frac{4m_\chi^2}{M_{A'}^2}},$$

$$\Gamma(A' \to e^- e^+) = \frac{\alpha_{QED}\epsilon^2}{3} m_{A'} \left(1 + \frac{2m_e^2}{M_{A'}^2}\right) \sqrt{1 - \frac{4m_e^2}{M_{A'}^2}}$$

The most interesting A` production mechanism

Production: e⁻ bremsstrahlung

Distinctive kinematics: for $m_e \ll m_{A'} \ll E_{beam}$, A′ carries most of beam energy & very forward-peaked



Cross section

The details of cross section calculations are contained in:

J.D.Bjorken, R.Essig, P.Scuster and N.Toro, Phys.Rev.D80 (2009) 075018

Cross section

$$e^- Z \to e^- Z A', \; A' \to invisible \quad (4)$$

The A'-production cross section in this process was calculated [6] in the Weizsäcker-Williams (WW) approximation [21], namely

$$\frac{d\sigma}{dx\, d\cos\theta_{A'}} = \frac{8 Z^2 \alpha_{QED}^3 \epsilon^2 E_0^2\, x}{U^2} \frac{\chi}{Z^2} \left[(1 - x + x^2/2) - \frac{x\,(1-x) m_{A'}^2 E_0^2\, x\, \theta_{A'}^2}{U^2} \right], \quad (5)$$

where E_0 is the energy of incoming electron, $E_{A'}$ is the energy of A', $E_{A'} = xE_0$, $\theta_{A'}$ is the angle in the lab frame between the emitted A' and the incoming electron, Z is the atomic number of nucleus ($Z = 82$ for lead). The function $U = U(m_{A'}, E_0, Z, A)$ which determines the virtuality of intermediate electron has the following form:

$$U = E_0^2\, x\, \theta_{A'}^2 + m_{A'}^2 \frac{1-x}{x} + m_e^2\, x. \quad (6)$$

Cross section

The effective flux of photons, $\zeta = \zeta(m_{A'}, E_0, Z, A)$ is defined as follows:

$$\zeta = \int_{t_{min}}^{t_{max}} dt \, \frac{t - t_{min}}{t^2} \, G_2(t), \qquad (7)$$

where $t = -q^2$, $|\vec{q}| = U/(2E_0(1-x))$, $t_{min} \simeq |\vec{q}|^2$, $t_{max} = m_{A'}^2$, and $G_2(t) = G_{2,el}(t) + G_{2,in}(t)$ is the sum of elastic and inelastic electric form factor (for details see

Cross section

e.g. Ref. [6] and references therein). In the numerical integration (7) we neglect x- and $\theta_{A'}$-dependences of t_{min}.

Several additional remarks should be made. First, the approximation of collinear A' emission is justified for the benchmark points, $m_{A'} \lesssim 1$ GeV and $E_0 \lesssim 100$ GeV, when $m_{A'}/E_0 \ll 1$ (see Ref. [6] for details). Second, one can perform the cross-section (5) integrated over x and $\theta_{A'}$,

$$\sigma_{tot} \simeq \frac{4}{3} \frac{\alpha^3 \epsilon^2 \zeta}{m_{A'}^2} \log(\delta^{-1}), \qquad (8)$$

where $\delta = \max(m_{A'}^2/E_0^2, m_e^2/m_{A'}^2)$ is the infrared (IR) cut-off of the cross-section, which regulates either soft intermediate electron singularity or validation of WW approximation [6].

Numerically for Pb we have

$$\sigma_{A'} \sim 100\,\mathrm{pb}\,(\epsilon/10^{-4})^2\,(100\,\mathrm{MeV}/m_{A'})^2 \quad (1)$$

$$\gamma c\tau \sim 1\ \mathrm{mm}\,(\gamma/10)\,(10^{-4}/\epsilon)^2\,(100\,\mathrm{MeV}/m_{A'}) \quad (2)$$

The number of signal events

For the case of a signal observation with a limited statistics of 10 - 100 events it would be possible to determine a band of allowed ϵ values in the two-dimensional plot (ϵ, $M_{A'}$). This could be done as follows. The observed number of signal events $n_{A'}$ passing the selection cuts is distributed according to Poisson statistics

$$P(n_{A'}, \lambda) = \frac{\lambda^{n_{A'}}}{n_{A'}!} e^{-\lambda} \quad (13)$$

where $\lambda =< n_{A'} >$ is the average number of signal events. The λ depends in particular on ϵ, $M_{A'}$, E_e, n_{eot} - the total number of electrons on target, and other parameters related to the target. It can by expressed in the form

$$\lambda = \frac{n_{eot}\lambda_0}{10^{12}} (\frac{\epsilon}{10^{-5}})^2 (\frac{10 \text{ MeV}}{M_{A'}})^2 \quad (14)$$

where parameter λ_0 depends rather weakly (logarithmically) on $M_{A'}$ and E_0 and is $\lambda_0 = 1.52$ for $M_{A'} \simeq 10$ MeV and E_0 =100 GeV.

If $\lambda \gg 1$ the Poisson distribution is approximated by the Normal distribution. Hence, for given (ϵ, $M_{A'}$), the number of signal events at "one-sigma" confidence level is given by

The A` emission spectrum

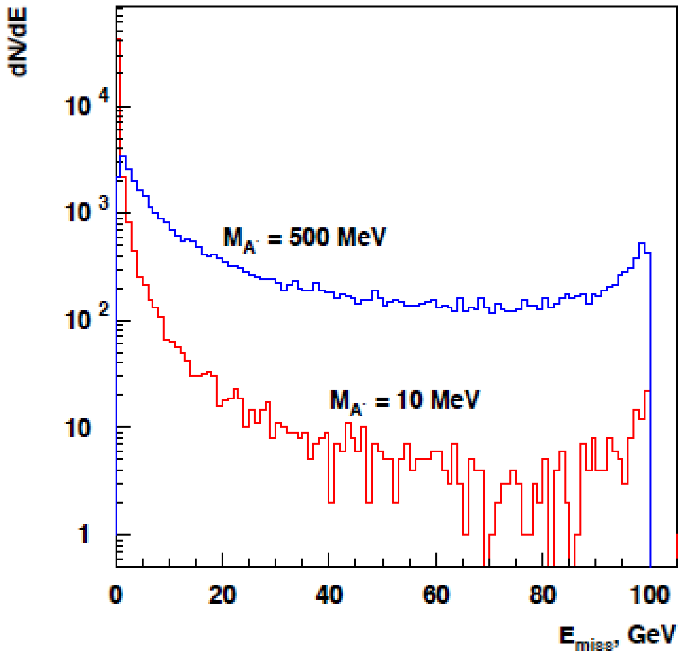
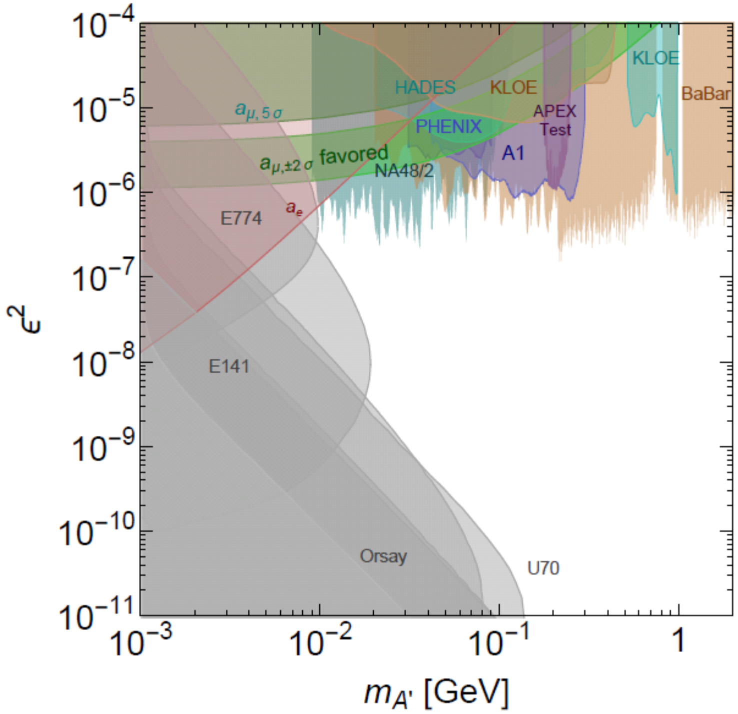


FIG. 2: The A' emission spectrum from 100 GeV electron beam interactions in the Pb target calculated for $m_{A'}$ = 10 MeV and $m_{A'}$ = 500 MeV. The spectra are normalized to about the same number of events.

Dark Photon Search: Current Constraints



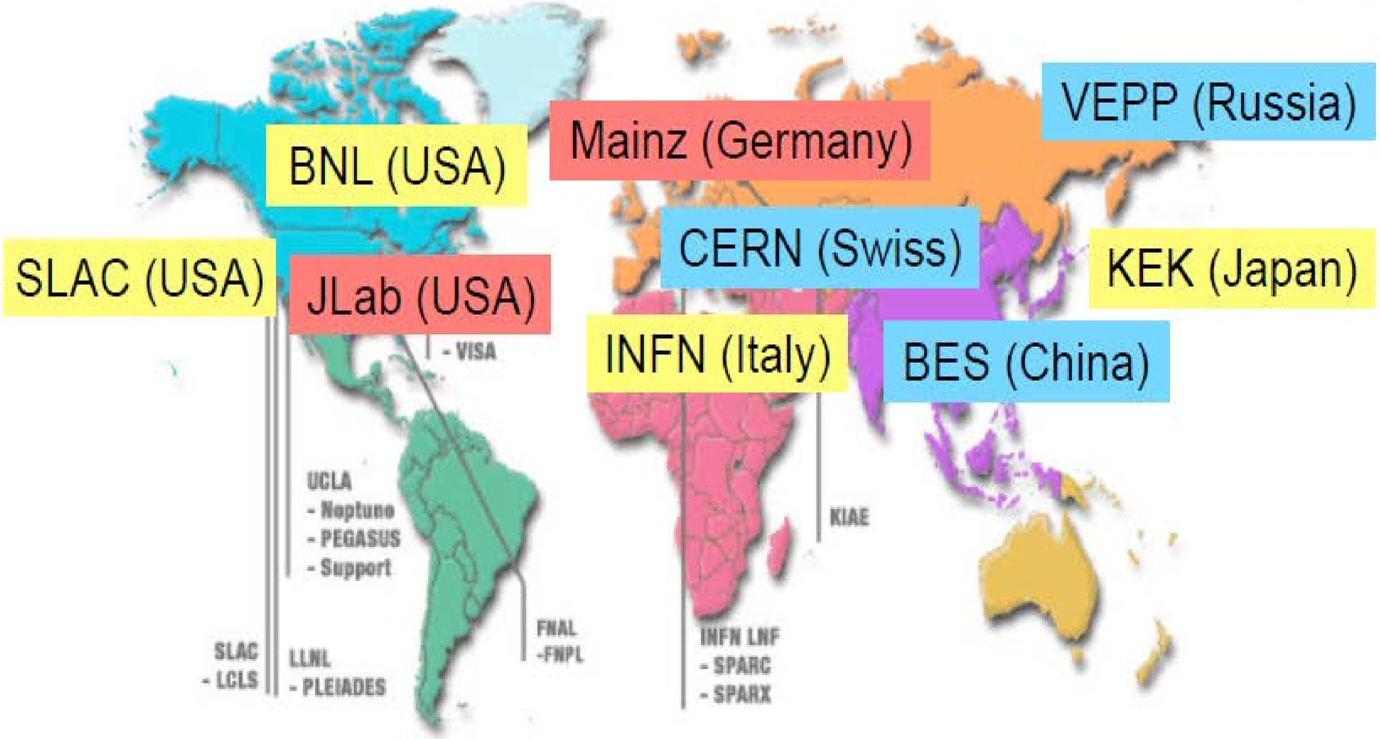
Red/green: e,μ anomalous dipole moments

All other colors: Pair resonance searches

Gray: Beam Dump

Dark Force searches in the Labs

Many searches for Dark Force in the Labs around the world (ongoing/proposed).



Other possible experimental hints in favor of light vector boson

1. Muon (g-2) anomaly.

The muon g-2 anomaly discovered at BNL AGS experiment 821

$$a_\mu^{\exp} - a_\mu^{SM} = 288(80) \times 10^{-11}$$

gives 3.6 σ difference with the SM prediction

A lot of explanations exist:

Supersymmetry, leptoquarks, additional vector boson (dark photon)

2. Experimental evidence in favor of new A´ vector boson

- (g-2 M $_{A´}$ < ~100 MeV
- ^{7}Li(p, M $_{A´}$ =16.7 MeV
- astrophysical observations

PRL **116**, 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

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(Received 7 April 2015; published 26 January 2016)

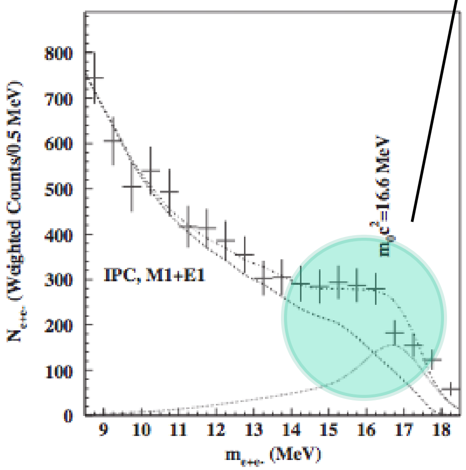

FIG. 5. Invariant mass distribution derived for the 18.15 MeV transition in ^{8}Be.

Br(A´→ e^+e^-)=1, ε^2~ 10^{-7}

Br(A´→ inv)=0.9, ε^2~10^{-6}
Br(A´→ e^+e^-)=0.1

$m_0c^2 = 16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV. The branching ratio of the e^+e^- decay of such a boson to the γ decay of the 18.15 MeV level of ^{8}Be is found to be 5.8×10^{-6} for the best fit.

Such a boson might be a good candidate for the relatively light $U(1)_d$ gauge boson [4], or the light mediator of the secluded WIMP dark matter scenario [5] or the dark Z (Z_d) suggested for explaining the muon anomalous magnetic moment [7].

Very recently dark photon (DP) signals were searched for in the $\pi^0 \to \gamma e^+e^-$ decay [2]. No signal was observed, and the obtained upper limits ruled out the DP as an explanation for the muon (g-2) measurement under the assumption that the DP couples to quarks and decays predominantly to standard model fermions. However, in the case of the dark Z, the predominant decay to e^+e^- is not assumed [42].

Our observed branching ratio can also be related to the mixing parameter ε^2 [2]. A somewhat similar calculation was performed by Donnelly *et al.* [43] for nuclear deexcitations via axions. When we use Eq. 22a of that article, our experimental branching ratio gives an ϵ^2 in the 10^{-7} range, which is already below the best upper limit published recently [2]. If we consider a vector or axial vector dark Z particle, which decays only with 10% branching to e^+e^- pairs, than our ϵ^2 is consistent with the description of the g-2 anomaly [7].

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Muon (g-2) anomaly

- An explanation of g-2 with additional light vector boson assumes vector like interaction

of new light boson A`(Z`) with muons with coupling constant $\alpha_{\mu} \approx O(10^{-8})$

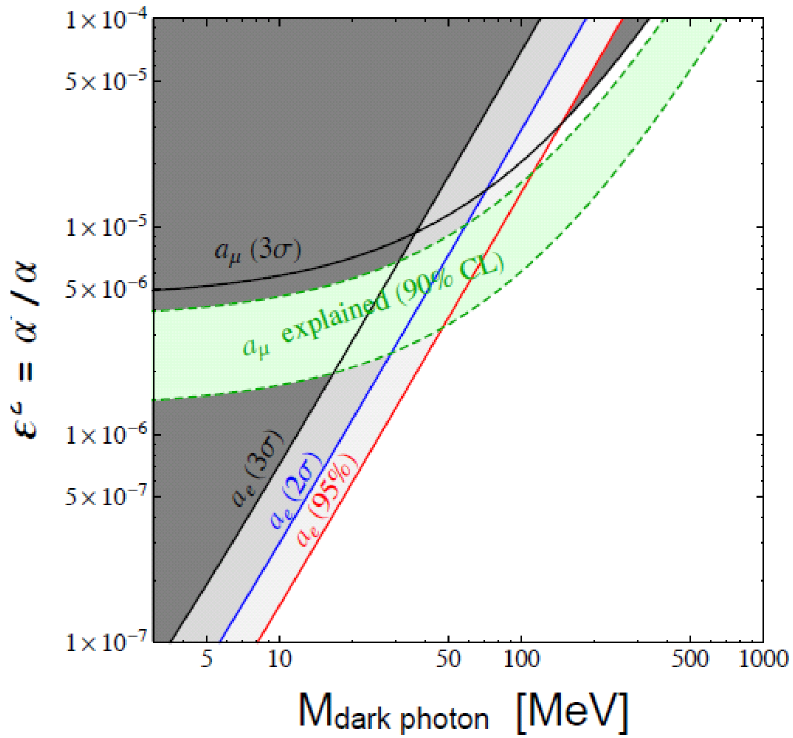
For instance for, very light (much lighter than μ-meson) vector boson

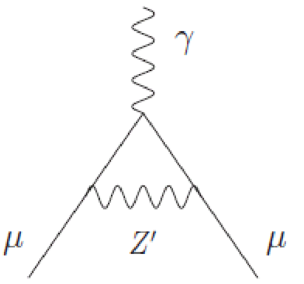
$$\alpha_{\mu} = (1.8 \pm 0.8) \times 10^{-8}$$

For opposite case of heavy A`

$$\alpha_{\mu} \frac{m_{\mu}^{2}}{M_{Z_{\mu}}^{2}} = (2.7 \pm 0.8) \times 10^{-8}$$

Anomalous Magnetic Moment





$$(\text{magnetic moment}) = -\frac{g\mu_B S}{\hbar}$$

Green band: explains the 3.6σ deviation in a_μ

(possibly early hint of Dark Force)

[Gninenko, Krasnikov (2001); Pospelov (2008)]

a_μ **= (g_μ - 2) / 2** : Always an important motivation/constraint for New Physics.

- One of the major motivations for the light Dark gauge boson (Z’).
- Unlike other motivations, it is independent of the unknown Dark Matter properties.
- It is independent of the Z’ decay branching ratios.

But the postulation of the interaction of dark boson with muon is not the end of the story. What about the interaction of the new boson with other quarks an leptons? Very popular scenario in which new vector boson interact with electromagnetic current of leptons and hadrons

$$L_{\text{int}} = e_{\mu} J^{\nu}_{em} A^{'}_{\nu}$$

Decay modes and signatures

Unfortunately theory can't predict the mass of A`(Z`) and its coupling constants with our world and hidden sector. We shall be interested in the region when the A' mass is between 1 MeV and O(1) TeV. For A` mass lighter than 210 MeV A` boson decays mainly into electron-positron pairs

2. Experimental bounds

For the scenario when dark photon decays mainly into visible modes (electron-positron, ..) there are several bounds which exclude possible g-2 muon anomaly explanation

1. Bound from electron magnetic moment

excludes masses below 30 MeV

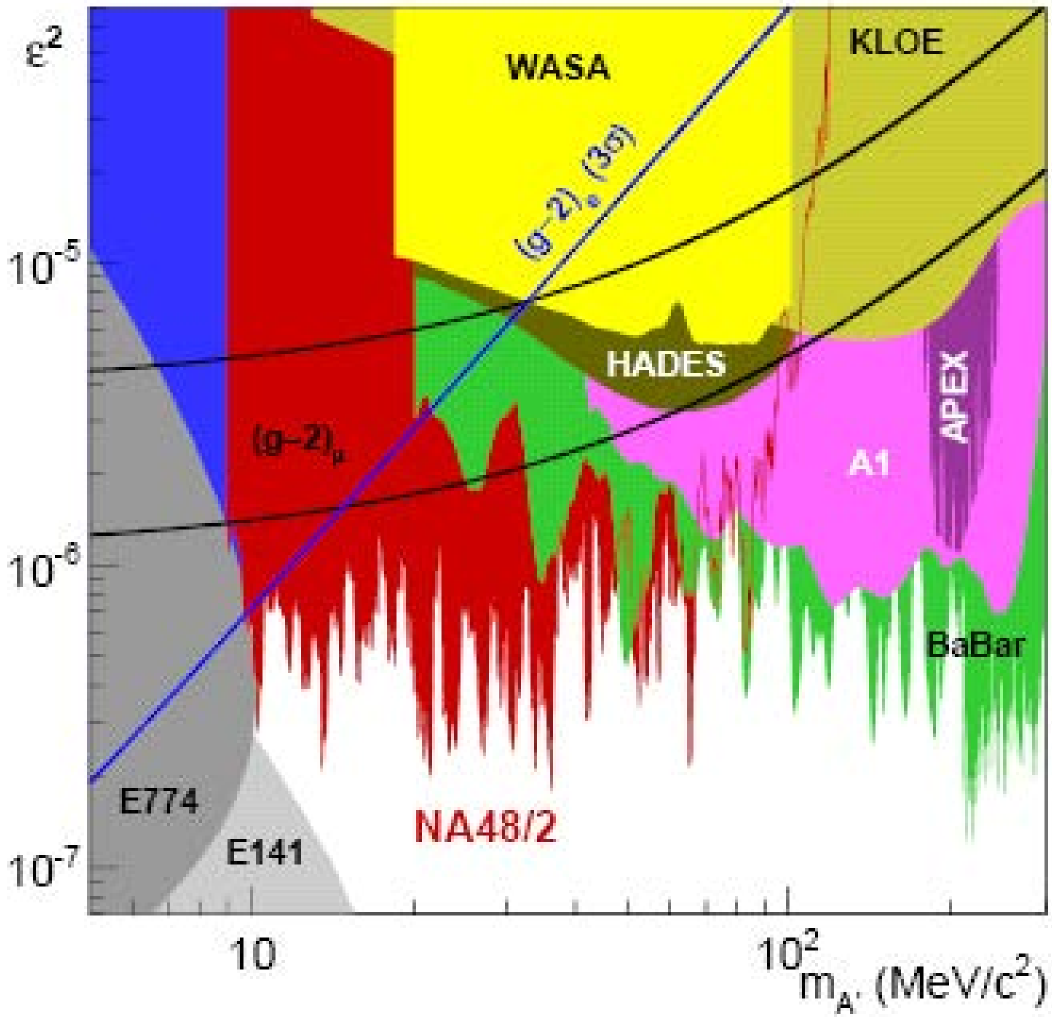
2. Experimental bounds

2. The A1 and NA48 collaborations excluded masses between 30 MeV and 300 MeV.

3. BaBar collaboration excluded masses between 32 MeV and 10.2 GeV.

So the possibility of g-2 anomaly explanation in the model with visible A` decays is excluded.

Exclusion plot



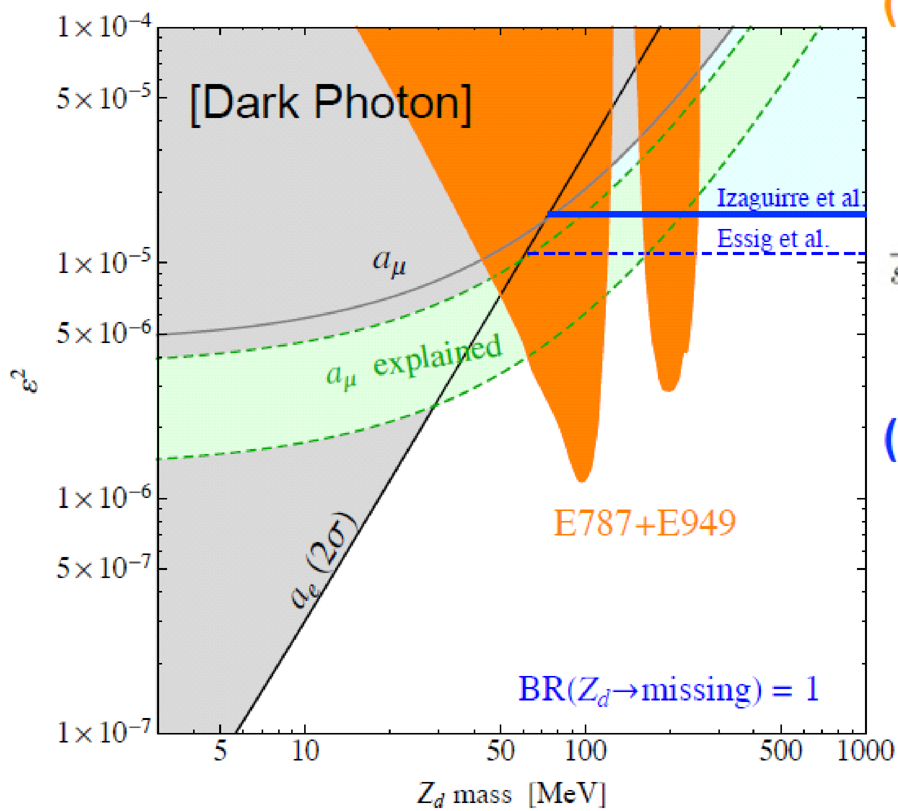
2. Experimental bounds

There is also possibility that new boson Z`
decays mainly into invisible modes,
new light particles χ. For such scenario
bound from $K^+ \to \pi^+ + nothing$ decay and the off
resonance Ba Bar result exclude masses
except 30 MeV and 50 and around 140 MeV

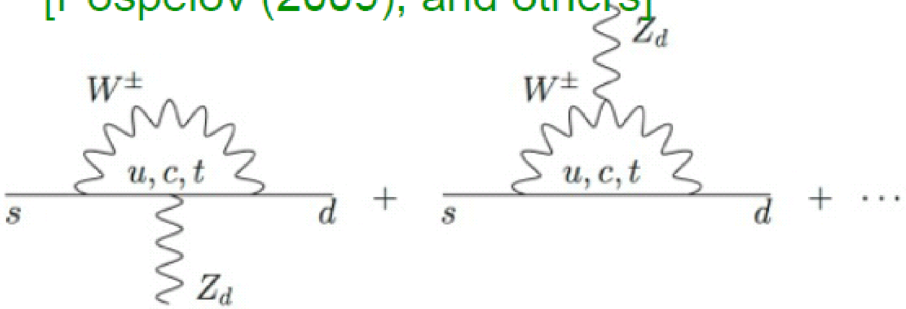
2. Experimental bounds

Invisibly decaying Dark gauge boson

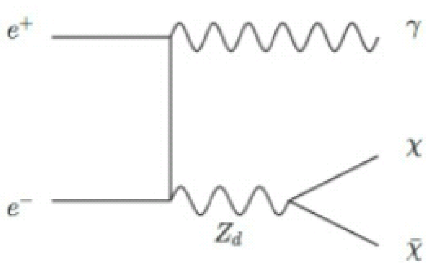
(ii) Missing Energy (Z' $\to \chi\chi$) searches



(i) $K^+ \to \pi^+$ + nothing (BNL E787+E949)
[Pospelov (2009); and others]



(ii) $e^+e^- \to \gamma$ + nothing (BABAR)
[Izaguirre *et al* (2013); Essig *et al* (2013)]



2. Experimental bounds

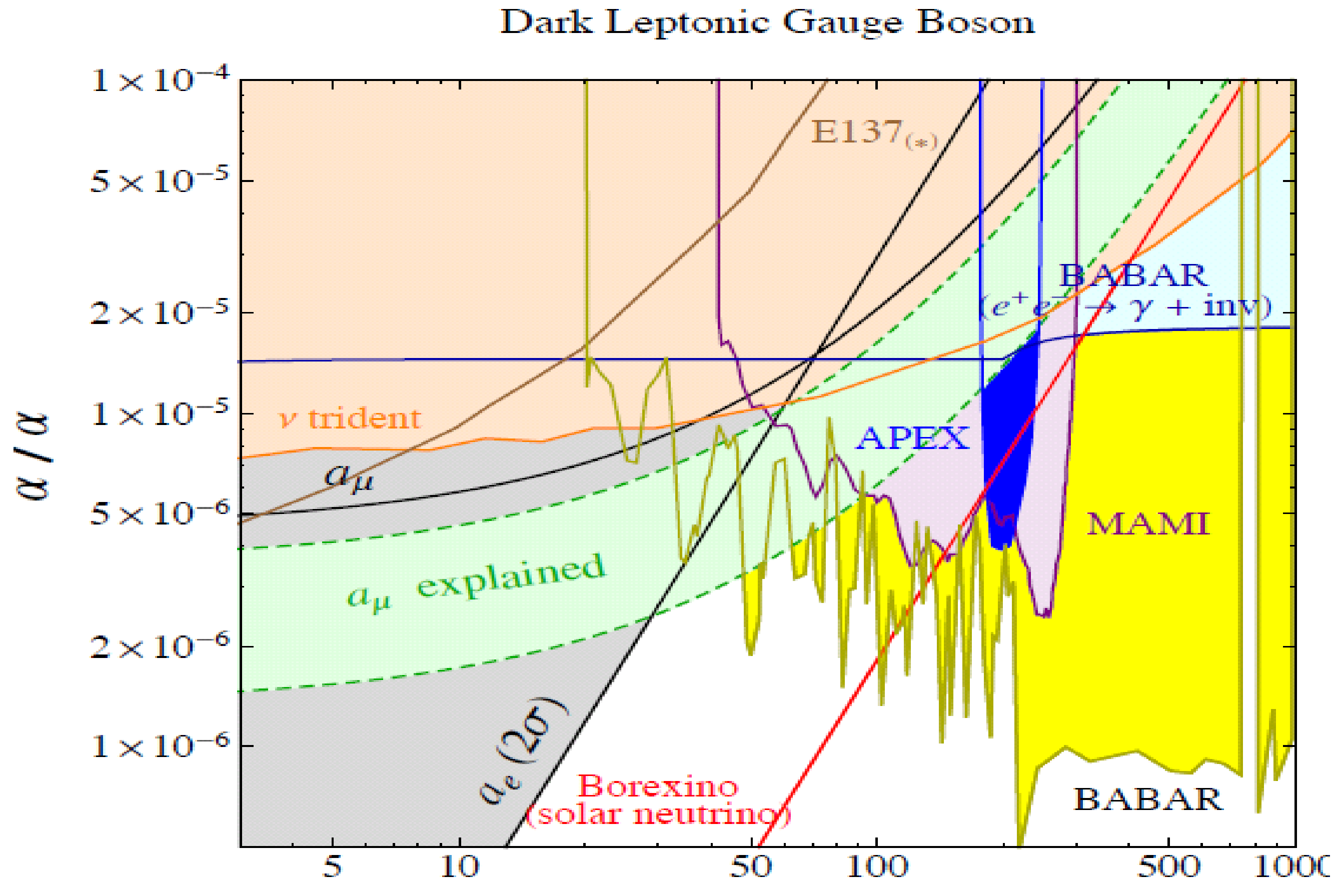
Other possibility is that new boson Z` interacts only with leptonic current

$$L_{Z_\mu} = e_\mu[\bar{e}\gamma_\nu e + \bar{\nu}_{eL}\gamma_\nu\nu_{eL} + \bar{\nu}\gamma_\mu\mu + \bar{\nu}_{\mu L}\gamma_\nu\nu_{\mu L} + \bar{\tau}\gamma_\nu\tau + \bar{\nu}_{\tau L}\gamma_\nu\nu_{\tau L}]Z^\nu_\mu$$

The bound from Borexino $862\ KeV\ ^7Be$ experiment excludes the possibility of g-2 explanation

2. Experimental bounds

[LEE (2014)]



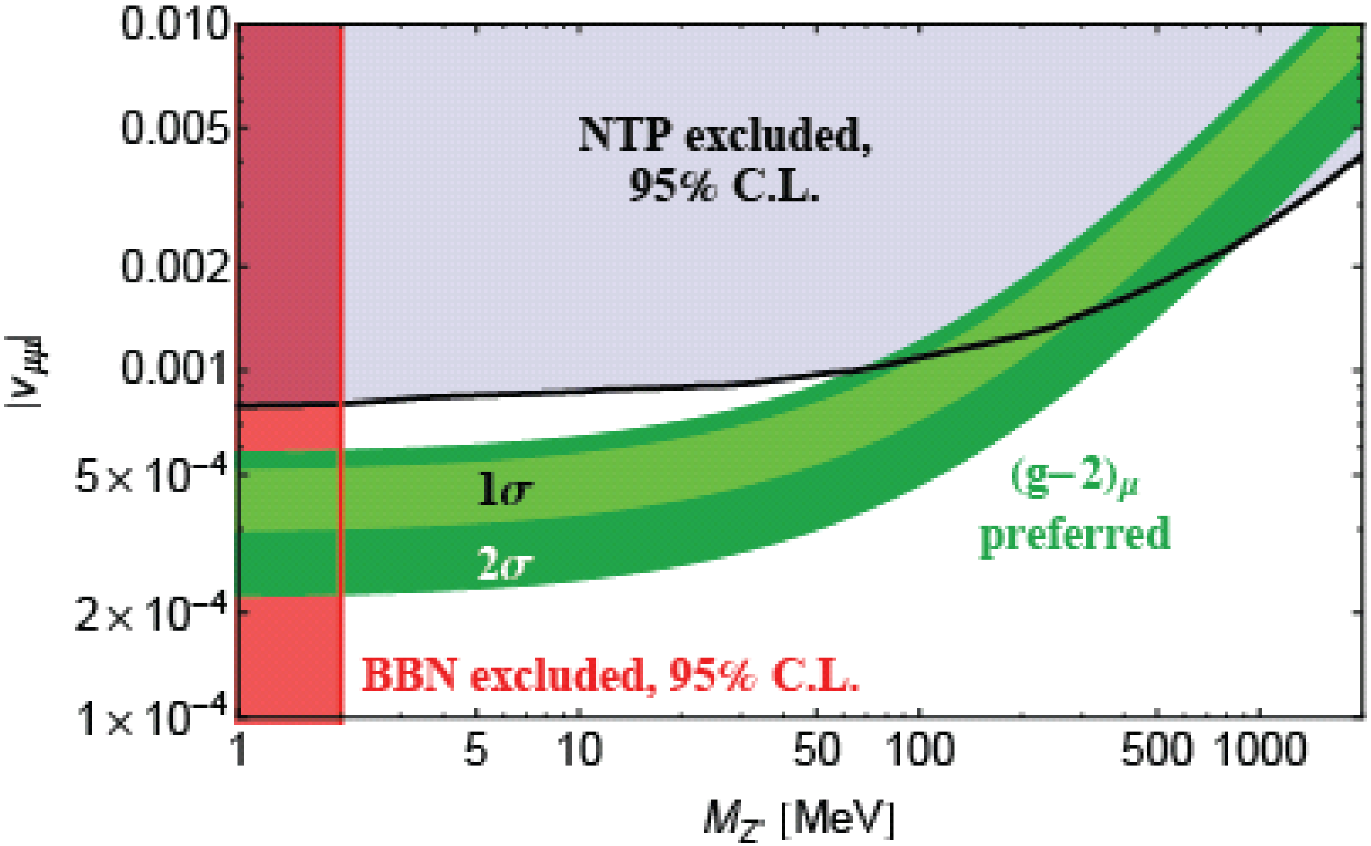
Experimental bounds

There is possibility that new boson Z` interacts only with $L_\mu - L_\tau$ current

$$L_{Z_\mu} = e_\mu [\bar{\mu}\gamma_\nu \mu + \bar{\nu}_{\mu L}\gamma_\nu \nu_{\mu L} - \bar{\tau}\gamma_\nu \tau - \bar{\nu}_{\tau L}\gamma_\nu \nu_{\tau L}] Z^\nu_\mu$$

For this model the most nontrivial bound (W.Almannsofer et. al) comes from CCFR data on neutrino trident $\nu_\mu N \to \nu_\mu N + \mu^+ \mu^-$ production. Masses $m_{Z_\mu} \geq 400\ MeV$ excluded

2.Experimental bounds



New BaBar bound(arXiv:1606.03501)

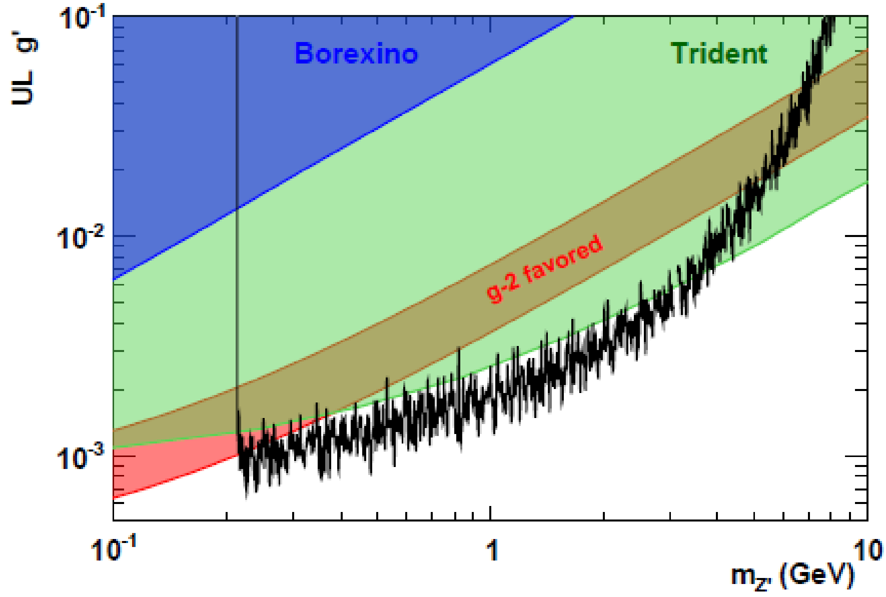


FIG. 5: The 90% CL upper limits on the new gauge coupling g' as a function of the Z' mass, together with the constraints derived from the production of a $\mu^+\mu^-$pair in ν_μ scattering ("Trident" production) [29, 30]. The region consistent with the discrepancy between the calculated and measured anomalous magnetic moment of the muon within 2σ is shaded in red.

The main conclusion

Light vector boson explanation of g-2 muon anomaly is strongly restricted but not excluded

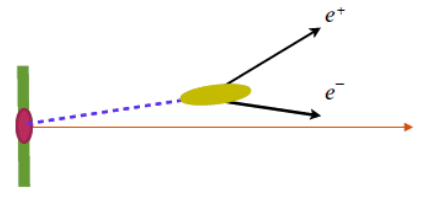
3. NA64 experiment and other experiments

NA64 - Searches

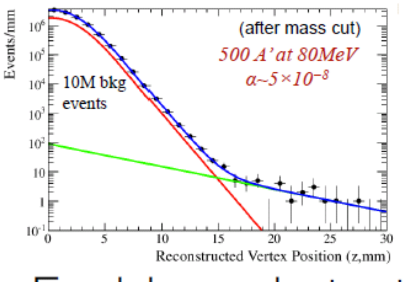
A´-> invisible A´-> e^+e^-

at SPS CERN

New Dark Photon Searches:
Visible Vertex Searches



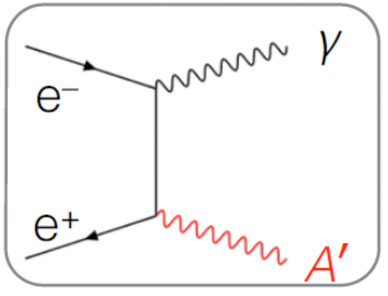
Look for A′ decay displaced from target by reconstructing final-state tracks



Enables substantial background reduction → sensitivity to lower ϵ (assuming no other decays that broaden A′ resonance)

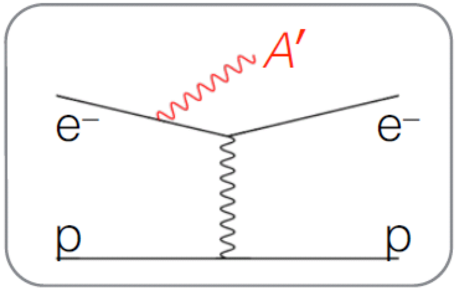
New Dark Photon Searches:
Fixed Target Missing Mass Searches

New technique, being pursued by several proposed experiments:



"Easier" missing mass: e^+ beam on atomic e^-: measure γ [e.g. MMAPS, VEPP-3]

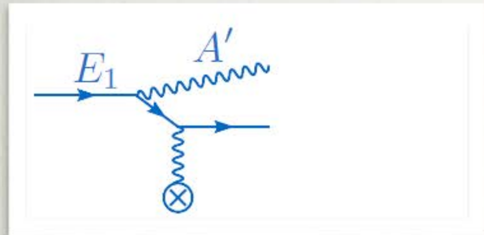
"Harder" missing mass: e^- beam on H, reconstruct e– & [e.g. DarkLight, in conjunction with visible resonance or veto to reject background]



Quantifying Direct Mediator Searches

For fixed-target on-shell mediator production:

Recall: $y \equiv \alpha_D \epsilon^2 \left(\frac{m_\chi}{m_{A'}}\right)^4$



$$\sigma \sim \epsilon^2 \frac{1}{m_{A'}^2}$$

$$\sim y \times \underbrace{\frac{1}{\alpha_D}\left(\frac{m_{A'}}{m_\chi}\right)^2}$$

For $m_\chi \leq m_{A'} \leq 2 \times m_\chi$
be conservative and fix combination:

$$\alpha_D \left(\frac{m_\chi}{m_{A'}}\right)^2 \sim 1$$

Cross sections

$$\sigma_{A'} \sim 100\ \mathrm{pb}\,\left(\epsilon/10^{-4}\right)^2 \left(100\,\mathrm{MeV}/m_{A'}\right)^2 \qquad (1)$$

$$\gamma c\tau \sim 1\ \mathrm{mm}\,(\gamma/10)\left(10^{-4}/\epsilon\right)^2 \left(100\,\mathrm{MeV}/m_{A'}\right) \qquad (2)$$

A lot of experiments current and future

Ongoing Efforts

Broad worldwide effort to search for dark forces!
(this is the list of **ongoing** searches for **visible** dark photons)

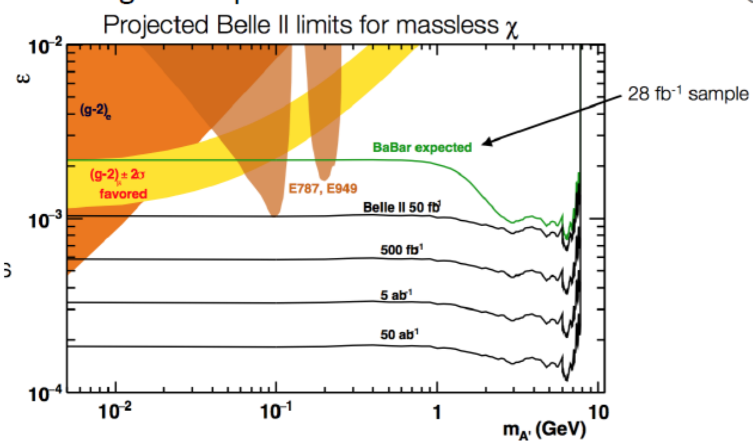
- DarkLight
- APEX
- HPS
- CMS & ATLAS lepton jets & exotic Higgs decays
- LHCb
- Belle II
- MMAPS
- VEPP-3
- MESA
- Future MAMI-A1
- SHiP
- SeaQuest
- KLOE-II
- NA64
- **????**

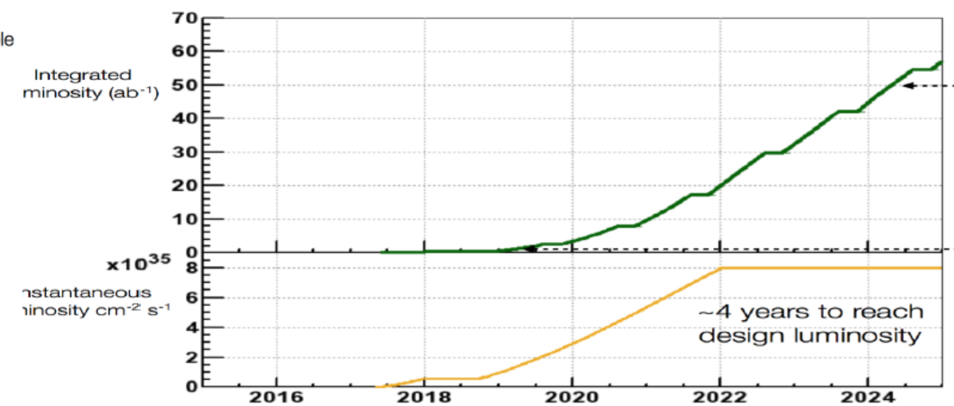
Invisible A' Searches at Belle II

Summary

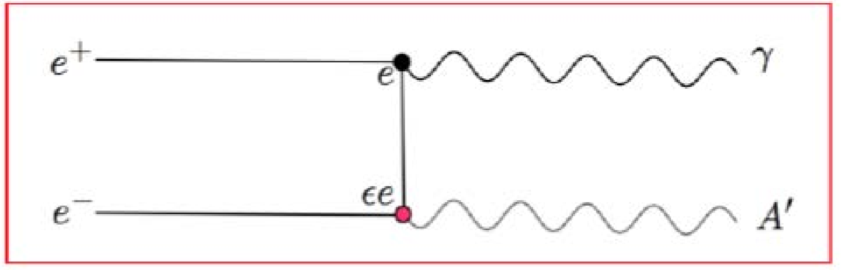
- Goal is that the search for dark photon decaying invisibly will be one of the earliest Belle II measurements, possibly even during Phase 2 running starting in late 2017.
- The Belle II calorimeter and tracking are improvements over BaBar.
- Wider range of event generators (wrt BaBar) helps with projections.
- Our current focus is on developing the triggers to enable hese measurements.

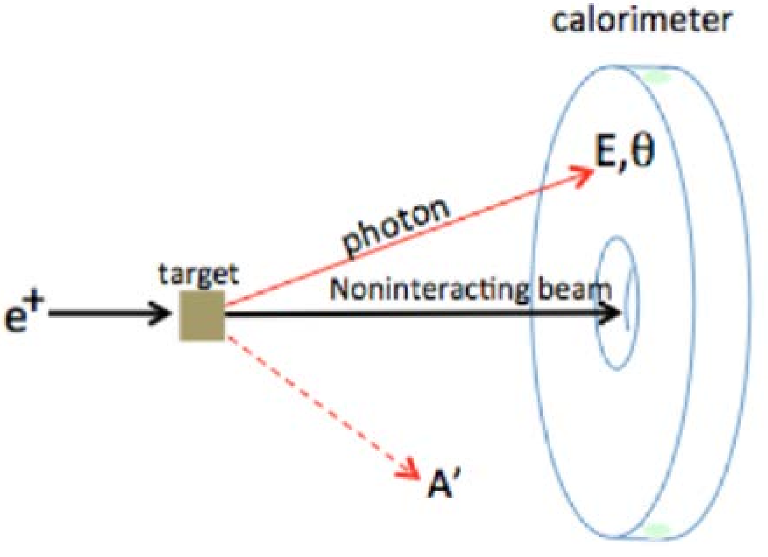
Rough extrapolation from Babar results



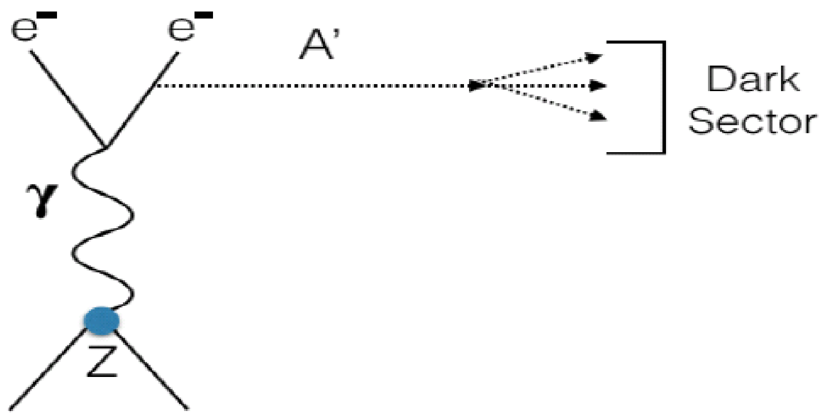


Invisible dark photon decay search at Frascati PADME experiment



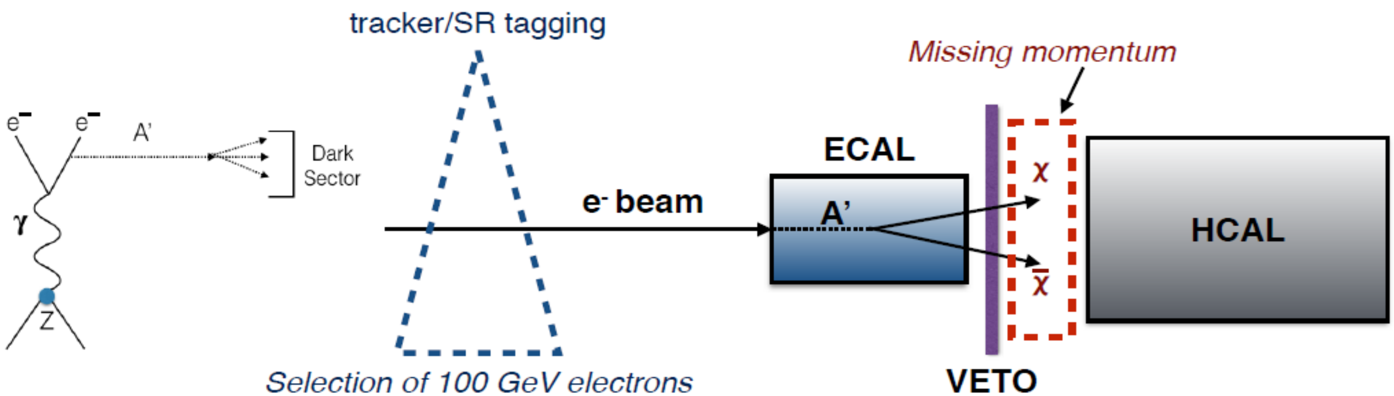


NA64 Experiment



NA64 is a fixed target experiment combining the active beam dump technique with missing energy measurement searching for invisible decays of massive A' produced in the reaction eZ—> eZA' of electrons scattering off a nuclei (A,Z), with a mixing strength $10^{-5} < \varepsilon < 10^{-3}$ and masses $M_{A'} < 100$ MeV.

NA64 Experiment



*For NA64 a beam of **100 GeV electrons** will be dumped against an ECAL, a sandwich of lead and scintillators (34 X_0), to produce massive A' through scattering with the heavy nuclei.*

*A typical signature for a signal will be **missing energy in the ECAL** and no activity in the the VETO and HCAL.*

Background from hadrons, muons and low energy electrons must be rejected upstream.

Proposal for an Experiment to Search for Light Dark Matter at the SPS

(Search for A´->e+e- and A´-> invisible Decays of Dark Photons)

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CERN-SPSC-2013-034 / SPSC-P-348
06/12/2013

December 6, 2013

Brief history of NA64

Dec' 13 – proposal to SPSC

Apr' 14 – SPSC recommendation for tests in 2015.
Обращение в Рабочую Группу. Протокол №02/14, 30.05.2014

Apr.' 14 - design, production, delivery at CERN, assembly,
Sept' 15 commisioning. Обмен письмами ЦЕРН, РГ, МОН.

Oct' 15 – two weeks run. Two reports: *CERN-SPSC-2015-037 / SPSC-SR-172;*
CERN-SPSC-2015-042 / SPSC-P-348-ADD-1

Jan' 16 – SPSC recommendation to the Reasearch Board to approve
as a SPS experiment with the focus on the A´ invisible mode.

March' 16 **– CERN Research Board approved NA64,**
as a part of the CERN Research Programme.

Collaboration NA64 (2015)

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S. Andreas, A. Ringwald

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ETH Zurich, Institute for Particle Physics, CH-8093 Zurich, Switzerland
D. Banerjee, E. Depero, P. Crivelli, H-S. Cheng, A. Rubbia

2016: ~ 35 участника, MoU в процессе подготовки
Chile, Greece, Germany, South Korea, Switzerland, and JINR.
РФ: ИФВЭ, ИЯИ, ФИАН, ТПУ, ~ 20 физик + 5 аспир. + 4 магистр-студента.
Вклад РФ Институтов: ~ 370 kCHF / 520 kCHF ≈ 70 %.

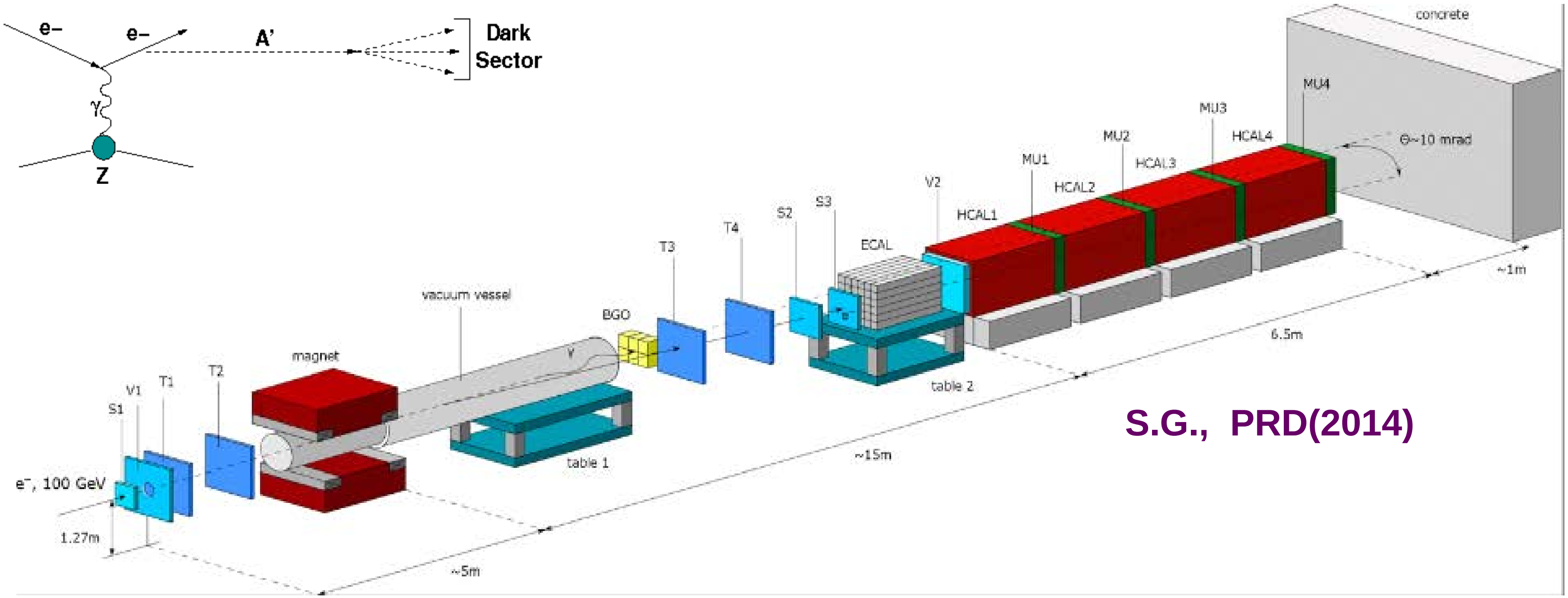
NA64 Research program

Reasearch program: Searches for sub-GeV Z`boson, NHL,… coupled to e, μ, q' s.
New method: Active beam dump combined with missing-energy technique

1. **Beam Purity for Light Dark Matter Search in Beam Dump Experiment**
   D. Banerjee, P. Crivelli, and A. Rubbia (Zurich, ETH) Adv.High Energy Phys. 2015(2015)105730
2. **On detection of narrow angle e+e- pairs from dark photon decays**
   A.V. Dermenev, S.V. Donskov, S.N. Gninenko, S.B. Kuleshov, V.A. Matveev, V.V. Myalkovskiy, V.D. Peshekhonov, V.A. Poliakov, A.A. Savenkov, V.O. Tikhomirov, I.A.Zhukov
   IEEE Trans.Nucl.Sc. 62 (2015) 3283;
3. **The K_L invisible decays as a probe of new physics**
   S.N. Gninenko and N.V. Krasnikov
   Phys. Rev. D92 (2015) 034009;
4. **Search for invisible decays of π0, η, η', K_S and K_L: A probe of new physics and test using the Bell-Steinberger relation**
   S.N. Gninenko,
   Phys. Rev. D91 (2015) 015004;
5. **Muon g-2 and searches for a new leptophobic sub-GeV dark**
   S.N. Gninenko, N.V. Krasnikov, V.A. Matveev,
   Phys. Rev. D91 (2015) 095015;
6. **Search for MeV dark photons in a light-shining-through-walls experiment at CERN**
   S.N. Gninenko,
   Phys. Rev. D89 (2014) 075008
7. **The Muon anomalous magnetic moment and a new light gauge boson,**
   S.N. Gninenko and N.V. Krasnikov,
   Phys. Lett. B420 (2000) 9;
8. **Proposal for an Experiment to Search for Light Dark Matter at the SPS**
   S. Andreas, D. Banerjee, S.V. Donskov, P. Crivelli, A. Gardikiotis, S.N. Gninenko, F. Guber et al.,
   arXiv:1312.3309[hep-ex]

search for *A´->invisible* at CERN SPS

Invisible decay of Invisible State!



S.G., PRD(2014)

3 main components :

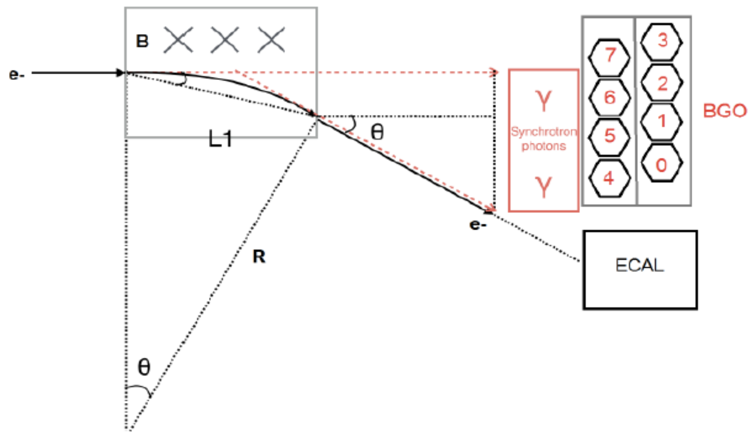
- clean, mono-energ. 100 GeV e- beam
- e- tagging system: MM tracker + SR
- 4π fully hermetic ECAL+ HCAL

Signature:

- in: 100 GeV e- track
- out: < 50 GeV e-m shower in ECAL
- no energy in the Veto and HCAL
- Sensitivity ~ ε^2

The use of e tagging to get rid of beam related background

e^- tagging with SR photons



$$\Delta E = \frac{e^2}{3\epsilon_0 (mc^2)^4}\frac{E^4}{R}$$

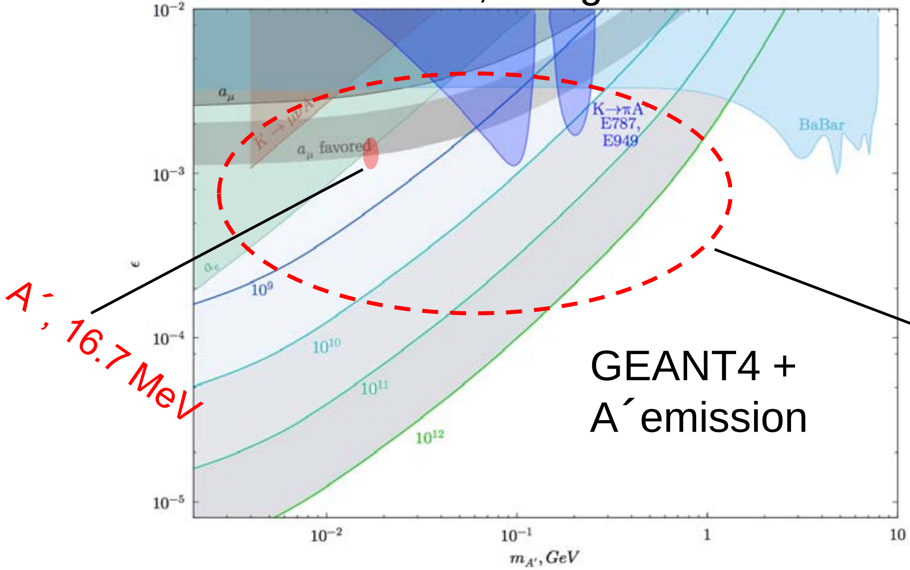
- *Charged particles when accelerated radially (a⊥v, as in a magnetic field) emit electromagnetic radiation.*
- *The energy emitted* ***ΔE*** *∝* ***m***$^{-4}$ *.*
- *Hadrons and muons emit almost no photons compared to electrons and can be suppressed.*
- *BGO crystals are used to select events with such radiation.*
- B-field 1.4 T (max 1.8 T) for a 2 m magnet -100 GeV electrons —>
  - Suppression factor ~ 10^{-5} for 4 m magnet of 1.8 T field.
  - <ΔE> ~ 30 MeV
  - E_γ^{min} ~ 1 MeV ; n_γ = 10
  - $(h\omega)_\gamma^c$ ~ 10 MeV

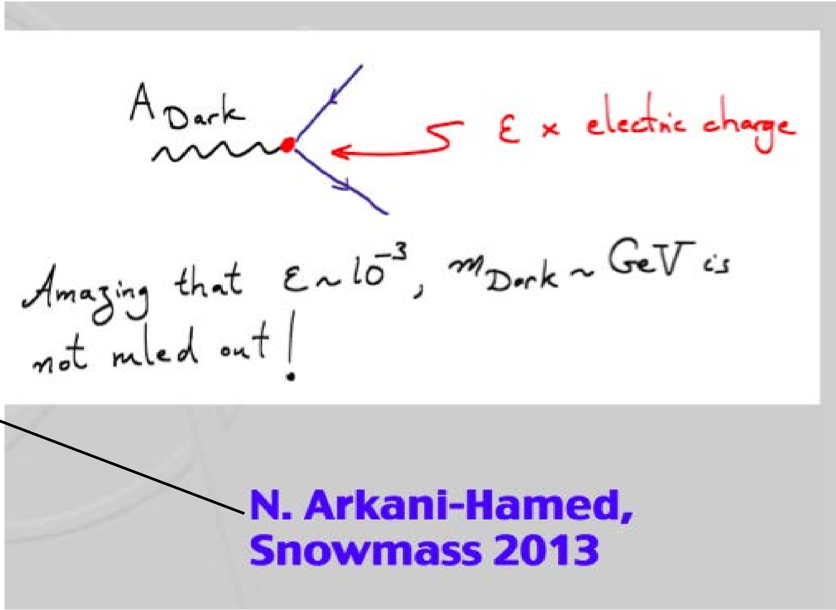
Summary of background sources for A`-> invisible

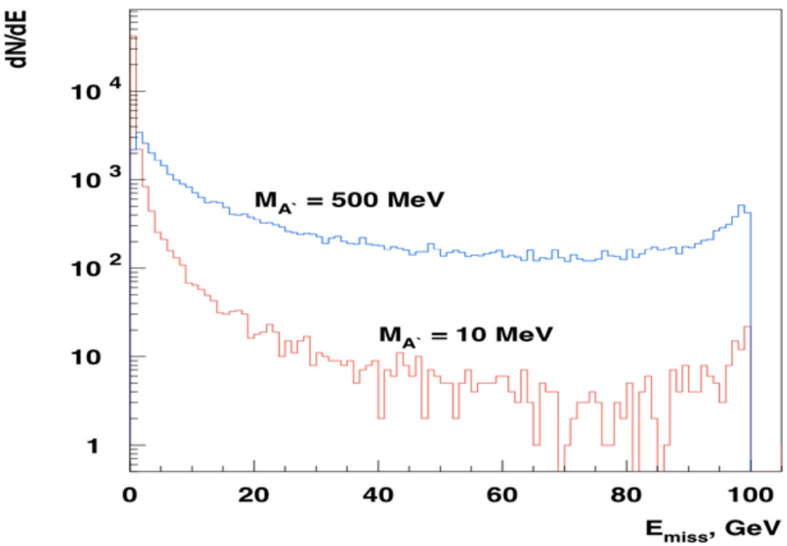
Source	Expected leve	Comment
Beam contamination		
-π, *p*, μ reactions and punchthroughs,… - e- low energy tail due to bremss., π,μdecays in flight,..	$< 10^{-13}$-10^{-12} ?	Impurity < 1% SR photon tag
Detector		
ECAL+HCAL energy resolution, hermeticity: holes, dead materials, cracks…	$< 10^{-13}$	Full upstream coverage
Physical		
-hadron electroproduction, e.g. eA->neA*, n punchthrough; - WI process: e Z->e Zvv	$< 10^{-13}$ $< 10^{-13}$	~10 mb x nonherm. WI σ estimated. textbook process, first observation?
Total	$< 10^{-12}$ + ?	

Exclusion plots

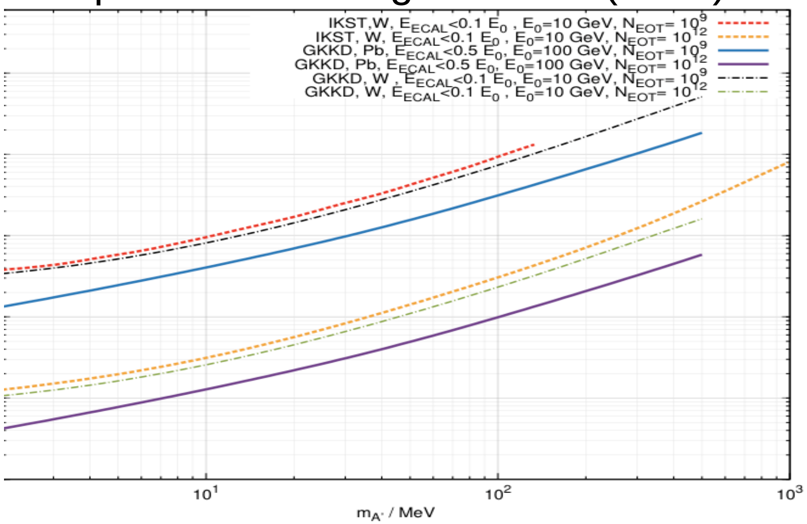
The reach of P348, A´signal detec. eff. ~0.5







Comparison with Izaguirre et al.(2015)



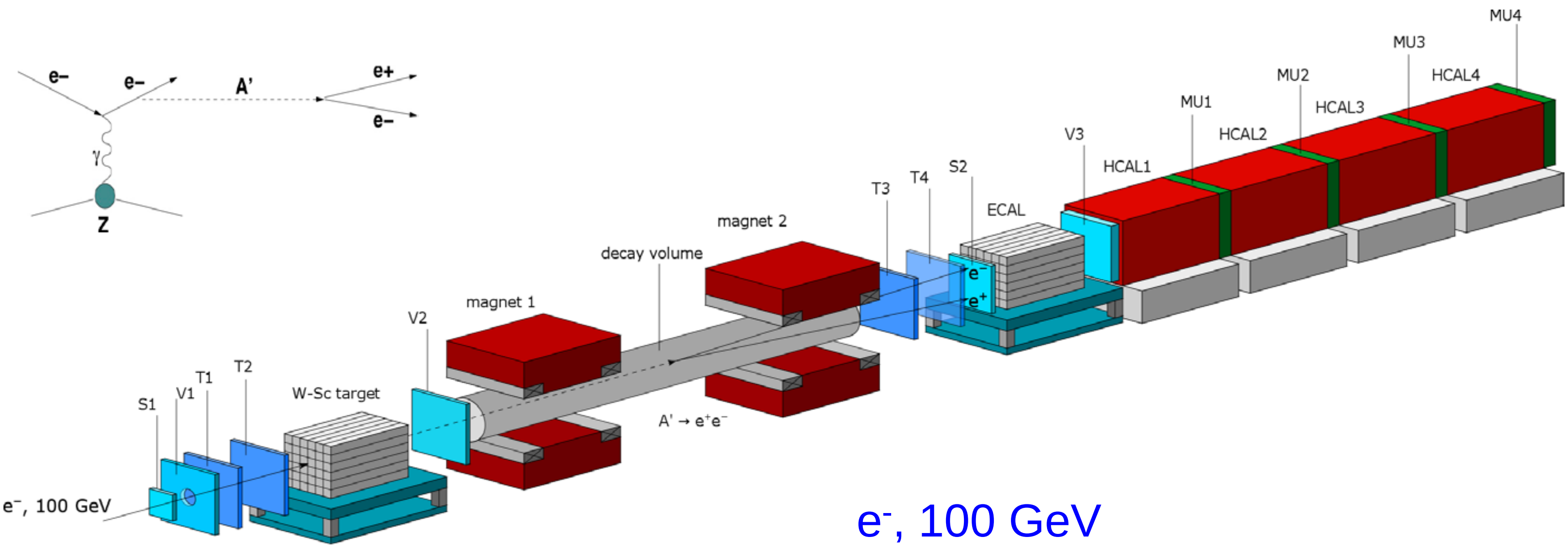
Upper bounds on A` mixing

11

$m_{A'}$, MeV	(A)		(B)		(C)	
	$N_{eot} = 10^9$	$N_{eot} = 10^{12}$	$N_{eot} = 10^9$	$N_{eot} = 10^{12}$	$N_{eot} = 10^9$	$N_{eot} = 10^{12}$
2	$1.33 \cdot 10^{-4}$	$4.20 \cdot 10^{-6}$	$3.40 \cdot 10^{-4}$	$1.07 \cdot 10^{-5}$	$3.61 \cdot 10^{-4}$	$1.20 \cdot 10^{-5}$
10	$3.91 \cdot 10^{-4}$	$1.23 \cdot 10^{-5}$	$8.14 \cdot 10^{-4}$	$2.57 \cdot 10^{-5}$	$8.98 \cdot 10^{-4}$	$2.73 \cdot 10^{-5}$
50	$1.44 \cdot 10^{-3}$	$4.57 \cdot 10^{-5}$	$3.48 \cdot 10^{-3}$	$1.10 \cdot 10^{-4}$	$4.26 \cdot 10^{-3}$	$1.29 \cdot 10^{-4}$
500	$1.84 \cdot 10^{-2}$	$5.83 \cdot 10^{-4}$	$5.12 \cdot 10^{-2}$	$1.61 \cdot 10^{-3}$	–	$2.77 \cdot 10^{-3}$

TABLE II: Upper bounds on mixing ϵ at 90 % CL for the following cases: (**A**): this work, Pb-Sc dump, $E_{miss} > 0.5E_0$, $E_0 = 100$ GeV; (**B**): this work, W-Sc dump, $E_{miss} > 0.9E_0$, $\mathbf{E_0 = 10}$ GeV; (**C**): IKST, W-dump, $E_{miss} > 0.9E_0$, $\mathbf{E_0 = 10}$ GeV.

Search for A'->e^+e^-



e^-, 100 GeV

- A´ decay outside W-Sc ECAL1
-
- Signature: two separated e-m showers from a single e^-

$S = ECAL1 x S1 x S2 x ECAL2\ x\overline{V1 x V2 x HCAL}$

- $E_1 < E_0$, and $E_0 = E_1 + E_2$
- θ_{e+e-} is small to be resolved

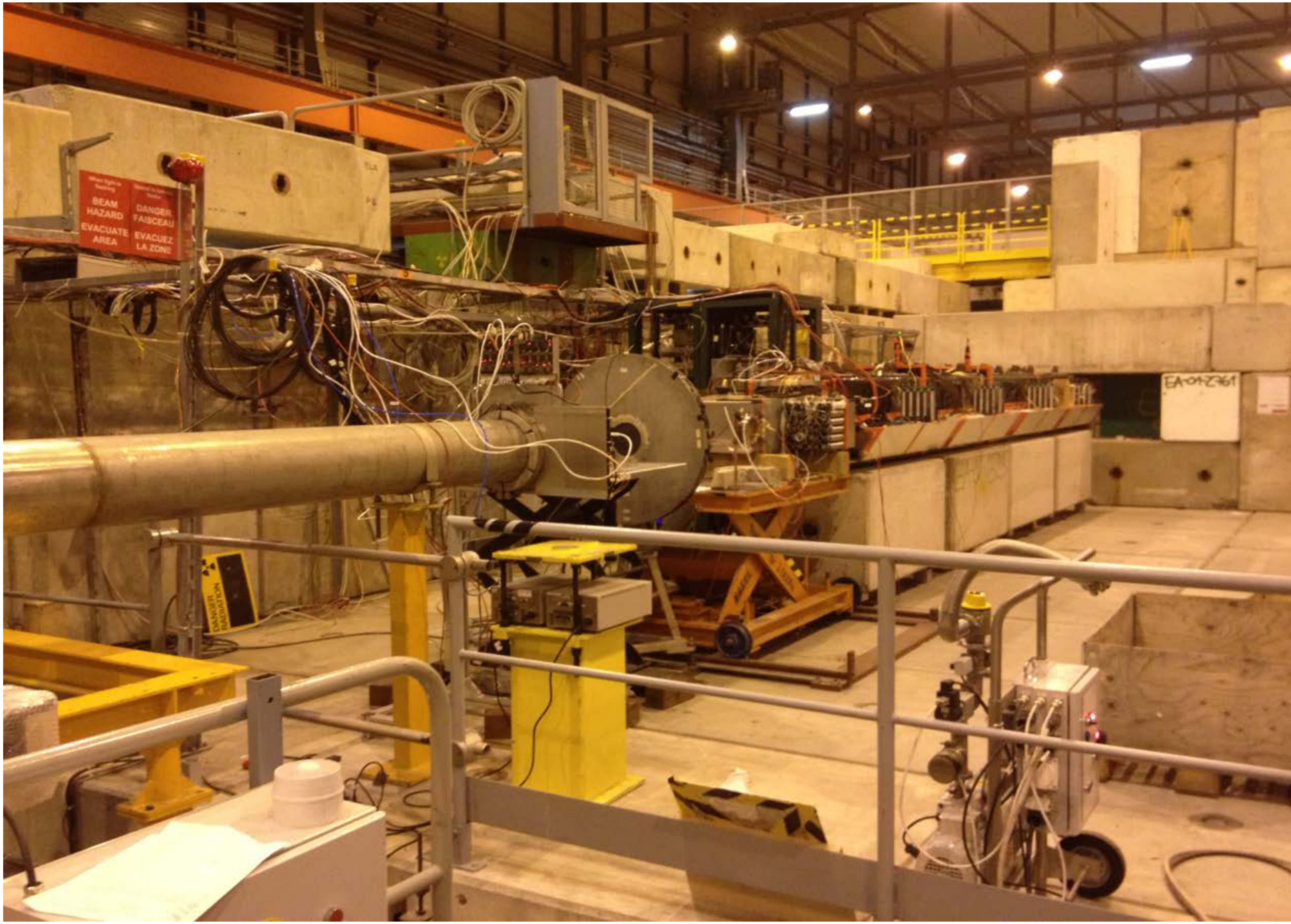
Summary of background sources for A`-> e+e-

Source	Expected leve	Comment
Beam contamination		
-π,μ reactions, e.g. πA->π^0n+X, … -accidentals: ππ,μμ, ... decays, e-n pairs, …	$< 10^{-12}$ $< 10^{-13}$	Impurity < 1% Leading n cross sect. ISR data
Detector		
- e,γ punchthrough, - ECAL thickness, dead zones, leaks	$< 10^{-13}$	Full upstream coverage
Physical		
hadron electroproduction: - eA->neA*, n -> ECAL2, - eA-> e+π+X, π->eν	$< 10^{-13}$	
Total	$< 10^{-12}$	

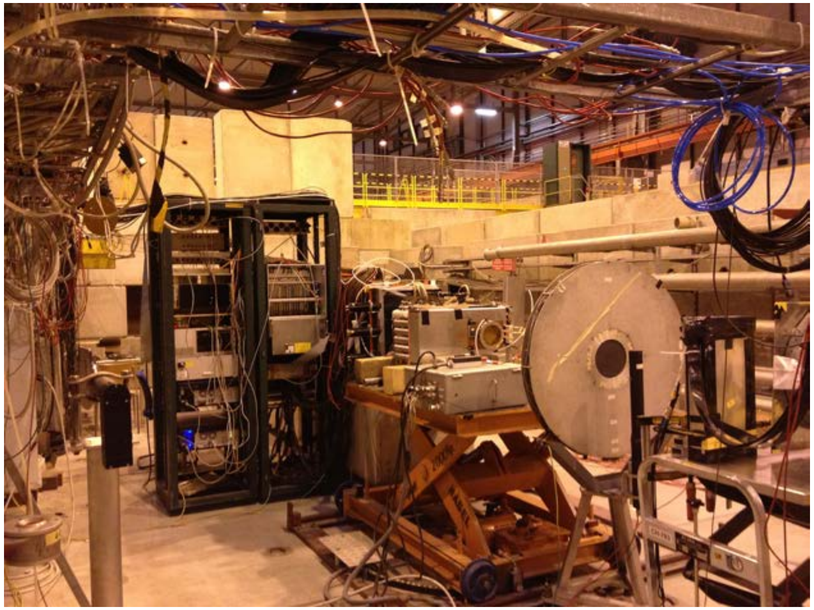
Test beams 2015 and 2016

NA64 detector(2015)

NA64 detector(2015)

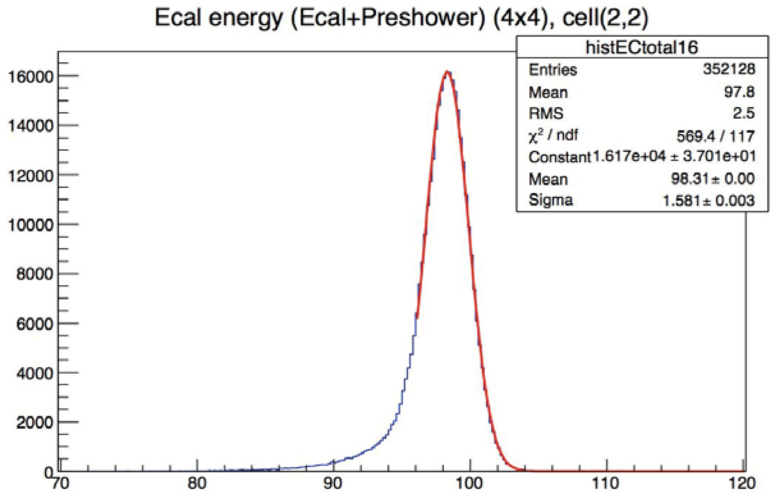


BGOs, Micromegas, straws, hodoscopes, …

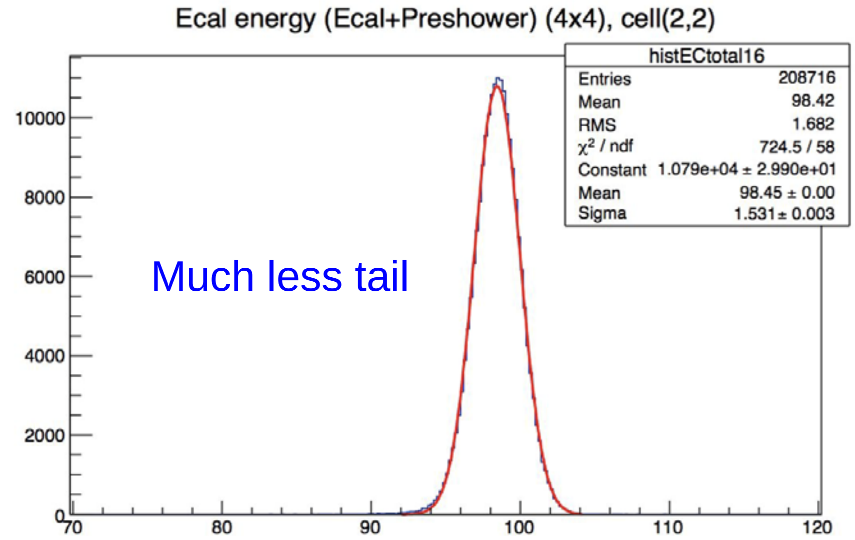


Performance of the SR tagging system

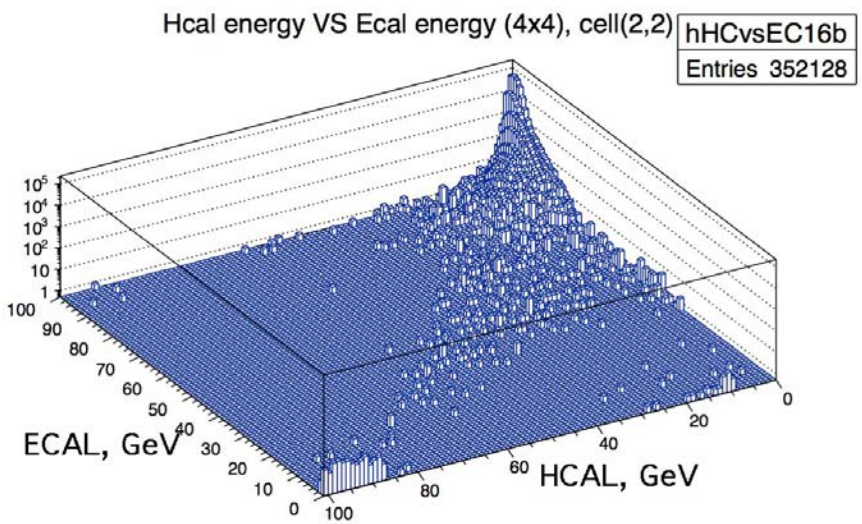
No SR tagging of e$^-$'s



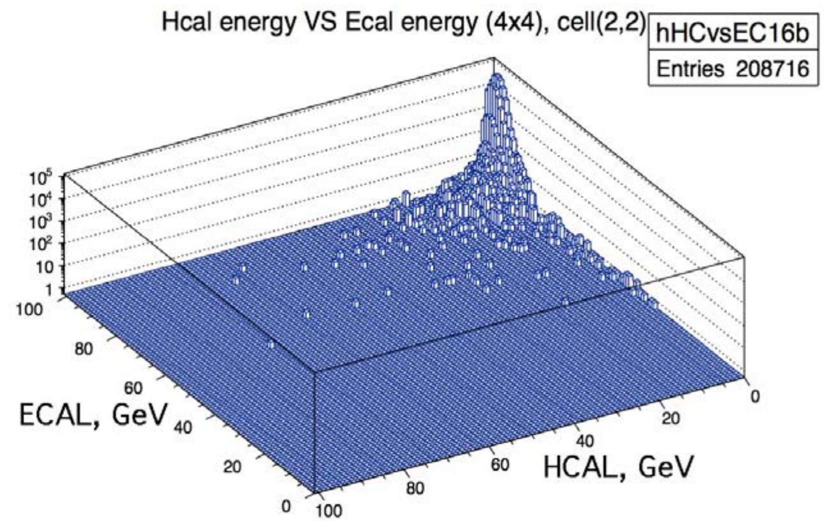
With SR tagging of e$^-$'s



Much less tail



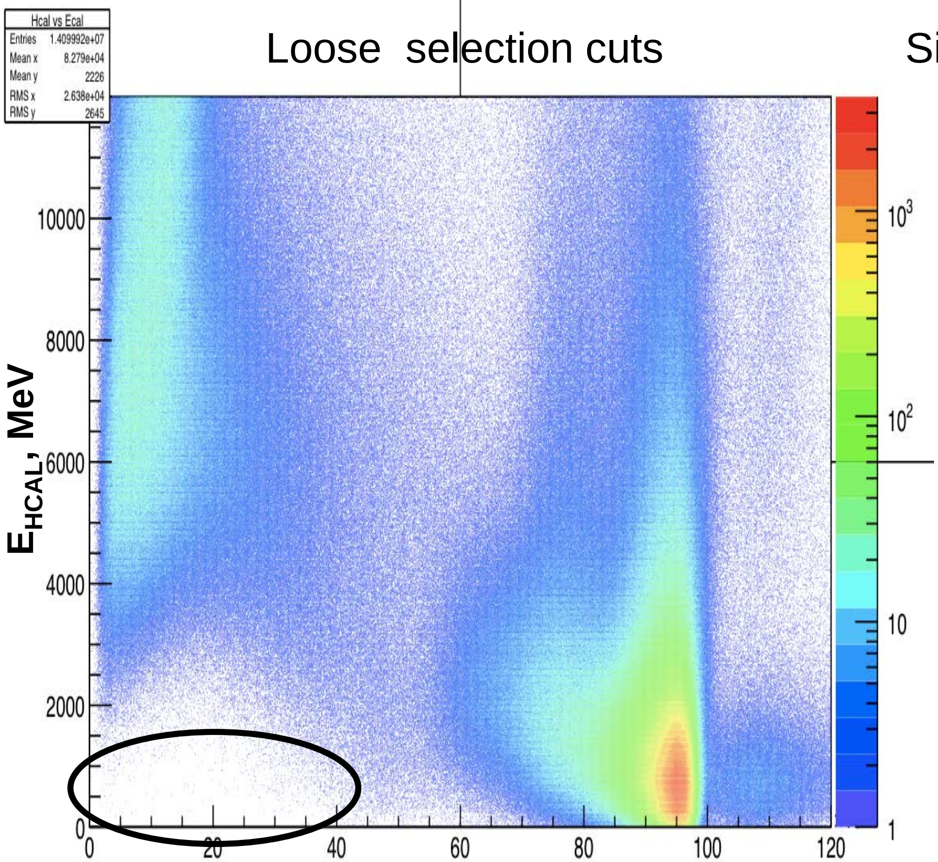
μ,π,.. rejection > 100



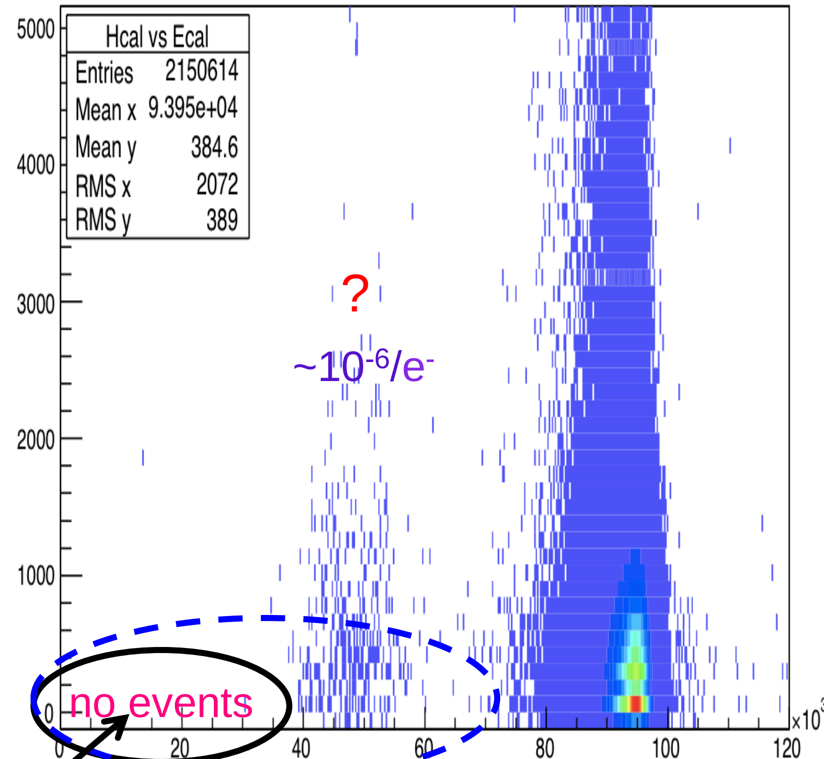
A´ signal in (E_{HCAL}; E_{ECAL}) plaine

Tr = S0 x S1x PS(>2 GeV) x ECAL(< 95 GeV)

Loose selection cuts



Single hit in X-Y Hodoscope plane + SR tag



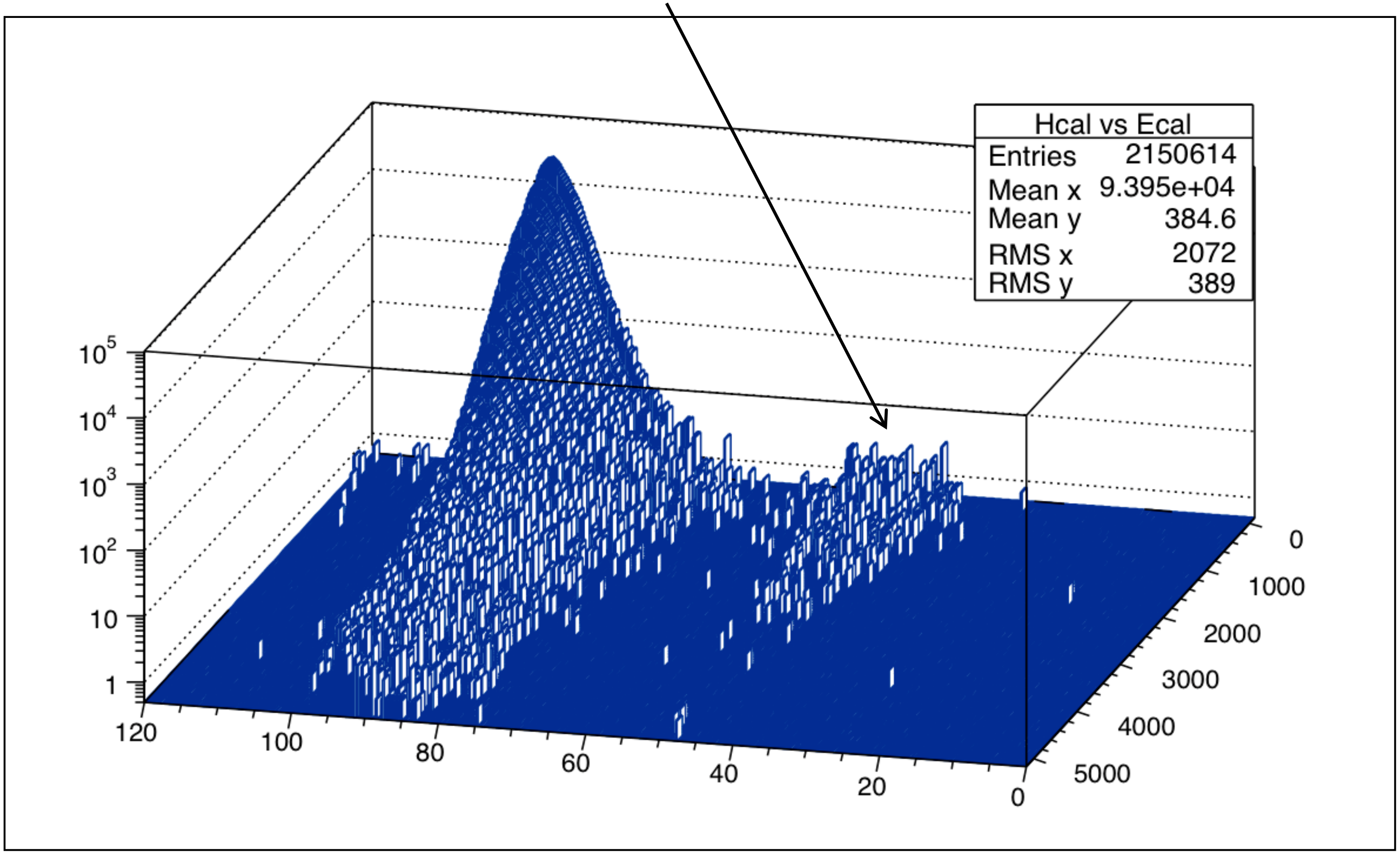
SIGNAL REGION

Background < 10^{-8} /e^-

Possible extension of signal region

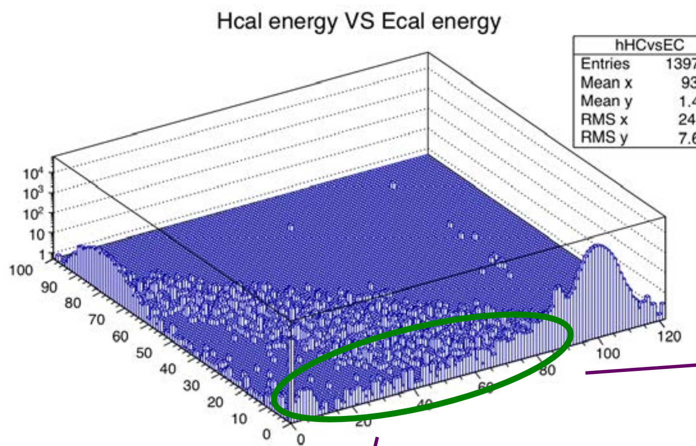
A´ signal in (E_{HCAL}; E_{ECAL}) plaine

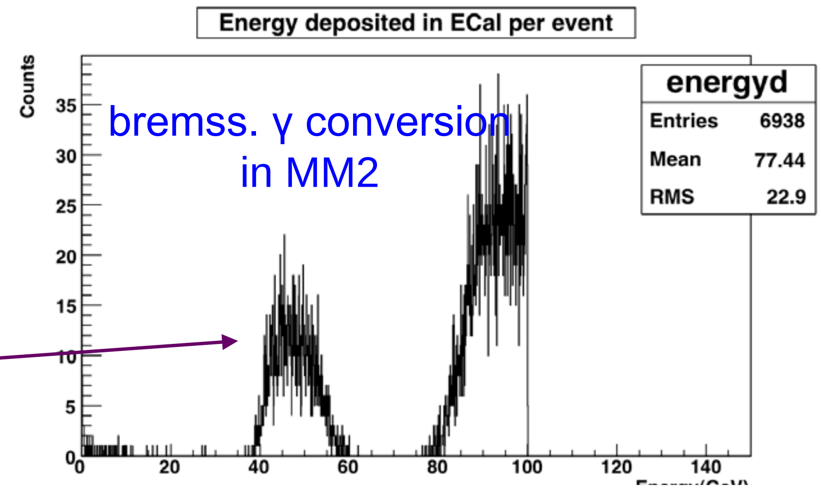
Conversion of bremss. γ ->e^+e^- in ~200 μm MM2 inside the magnet



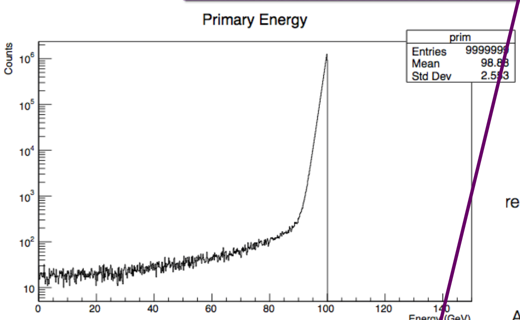
SR tag is triggered by either SR γ from 50 GeV , or
by low energy bremss. γ/knock-on .

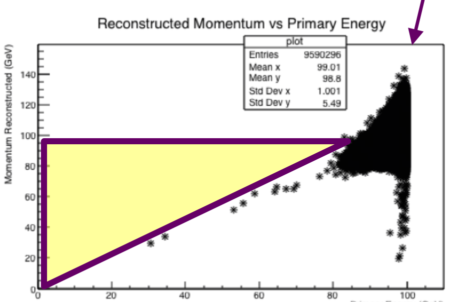
MM tracker: tail background rejection





MM Tracker Simulation Summary

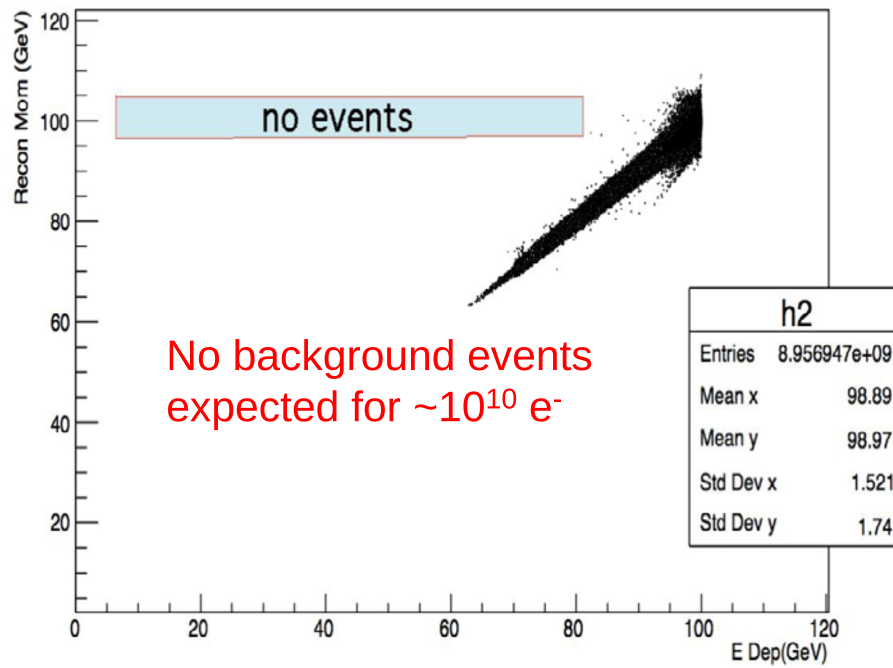


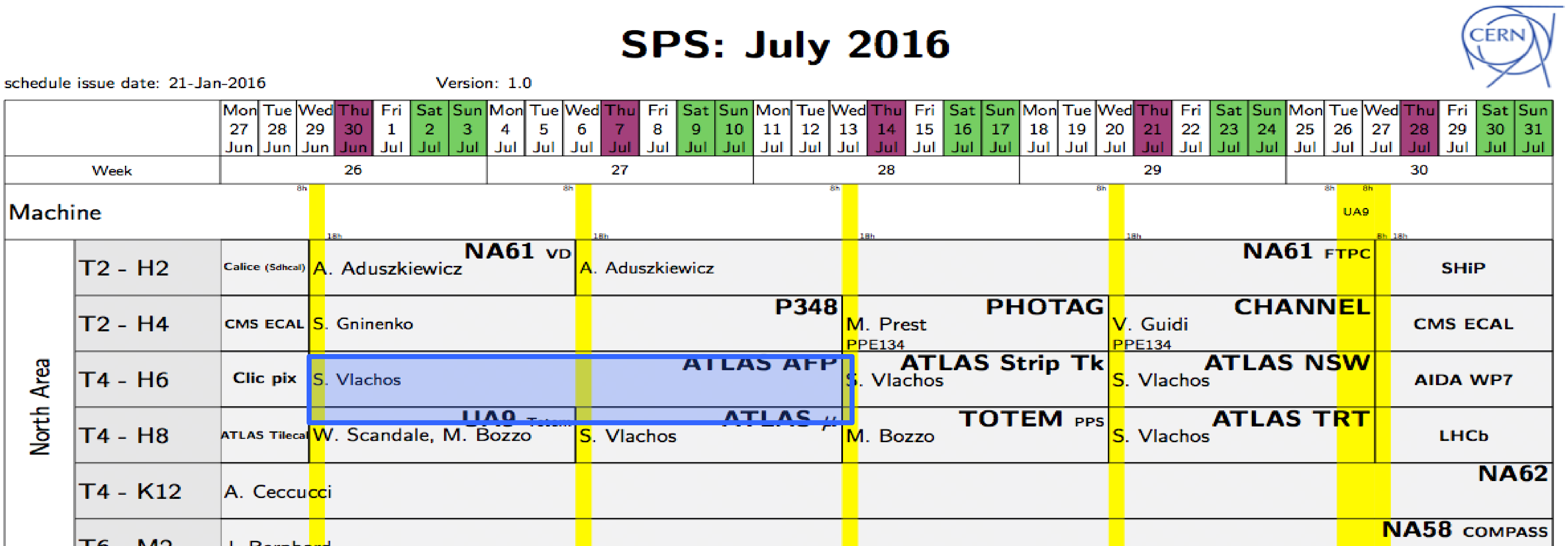


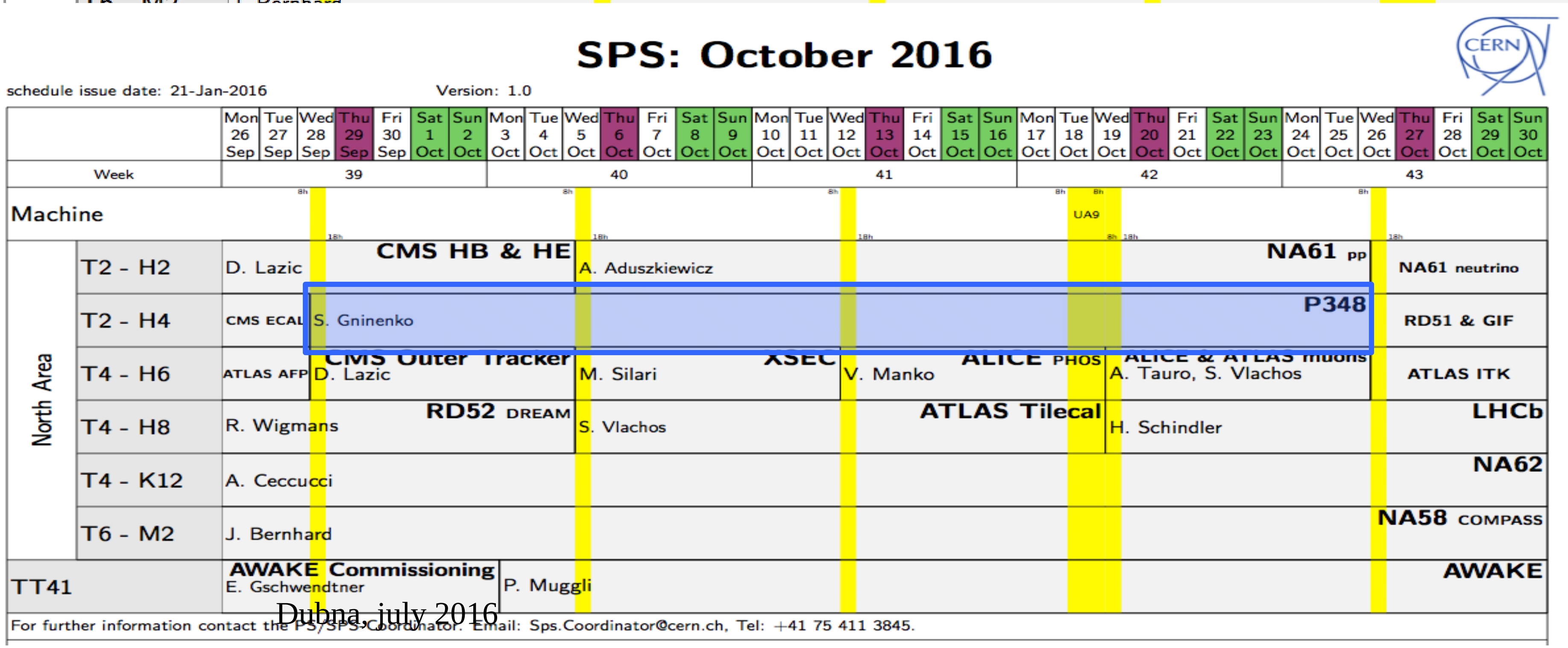
A spread of energy as shown in the plot was given to the primaries and the reconstructed momentum (when there is a hit in the ECA compared with the actual primary energy.

As seen in the second plot the reconstructed momentu compares well with the actual primary energy of the particles hitting the ECAL. Most low energy primaries miss the ECAL due to the field.

Level of rejection of events when energy deposited in ECAL< 50 GeV and momentum reconstructed with tracker > 50 GeV …. **< 10^{-10}** for 100 GeV primaries.




SPS: July 2016
schedule issue date: 21-Jan-2016
Version: 1.0
Mon 27 Jun Tue 28 Jun Wed 29 Jun Thu 30 Jun Fri 1 Jul Sat 2 Jul Sun 3 Jul Mon 4 Jul Tue 5 Jul Wed 6 Jul Thu 7 Jul Fri 8 Jul Sat 9 Jul Sun 10 Jul Mon 11 Jul Tue 12 Jul Wed 13 Jul Thu 14 Jul Fri 15 Jul Sat 16 Jul Sun 17 Jul Mon 18 Jul Tue 19 Jul Wed 20 Jul Thu 21 Jul Fri 22 Jul Sat 23 Jul Sun 24 Jul Mon 25 Jul Tue 26 Jul Wed 27 Jul Thu 28 Jul Fri 29 Jul Sat 30 Jul Sun 31 Jul
Week 26 27 28 29 30
Machine
UA9
North Area
T2 - H2
Calice (Sdhcal)
NA61 VD
A. Aduszkiewicz
A. Aduszkiewicz
NA61 FTPC
SHiP
T2 - H4
CMS ECAL
S. Gninenko
P348
M. Prest
PPE134
PHOTAG
V. Guidi
PPE134
CHANNEL
CMS ECAL
T4 - H6
Clic pix
S. Vlachos
ATLAS AFP
S. Vlachos
ATLAS Strip Tk
S. Vlachos
ATLAS NSW
AIDA WP7
T4 - H8
ATLAS Tilecal
W. Scandale, M. Bozzo
UA9
S. Vlachos
ATLAS μ
M. Bozzo
TOTEM PPS
S. Vlachos
ATLAS TRT
LHCb
T4 - K12
A. Ceccucci
NA62
NA58 COMPASS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schedule issue date: 21-Jan-2016
Version: 1.0
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Week 39 40 41 42 43
Machine
UA9
North Area
T2 - H2
D. Lazic
CMS HB & HE
A. Aduszkiewicz
NA61 pp
NA61 neutrino
T2 - H4
CMS ECAL
S. Gninenko
P348
RD51 & GIF
T4 - H6
ATLAS AFP
CMS Outer Tracker
D. Lazic
XSEC
M. Silari
ALICE PHOS
V. Manko
ALICE & ATLAS muons
A. Tauro, S. Vlachos
ATLAS ITK
T4 - H8
R. Wigmans
RD52 DREAM
S. Vlachos
ATLAS Tilecal
H. Schindler
LHCb
T4 - K12
A. Ceccucci
NA62
T6 - M2
J. Bernhard
NA58 COMPASS
TT41
AWAKE Commissioning
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For further information contact the PS/SPS Coordinator. Email: Sps.Coordinator@cern.ch, Tel: +41 75 411 3845.

NA64 in the Grey Book !

The CERN Experimental Programme

Grey Book database

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- SPS
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- Neutrino Platform
- CTF3
- R&D
- Non-accelerator experiments

RESEARCH ACTIVITIES

- Experiments and Projects under Study
- Recognized Experiments
- Completed Experiments

RELATED LINKS

- PH Department
- Users' Office
- Scientific Committees
- Conditions for experiments

NA64

Search for dark sectors in missing energy events

SYNONYM:

RESEARCH PROGRAMME: SPS

APPROVED: 09-03-2016

BEAM:

STATUS: Preparation

Overview | Institutes | Participants

SPOKESPERSON:

Sergei GNINENKO

DEPUTY SPOKEPERSON(S):

CONTACT PERSON:

Sergei GNINENKO

TECHNICAL COORDINATOR:

Vladimir POLIAKOV

RESOURCES COORDINATOR:

GROUP LEADER IN MATTERS OF SAFETY (GLIMOS):

DEPUTY GLIMOS:

DEPARTMENTAL FLAMMABLE GAS

NUMBER OF INSTITUTES: 0

NUMBER OF AUTHORS: 0

NUMBER OF PARTICIPANTS: 0

NUMBER OF COUNTRIES: 0

Status history

Status	Start date	End date
Preparation	15-03-2016	

http://cern.ch/na64
http://na64.web.cern.ch

Next goal – October 2016 physical run.

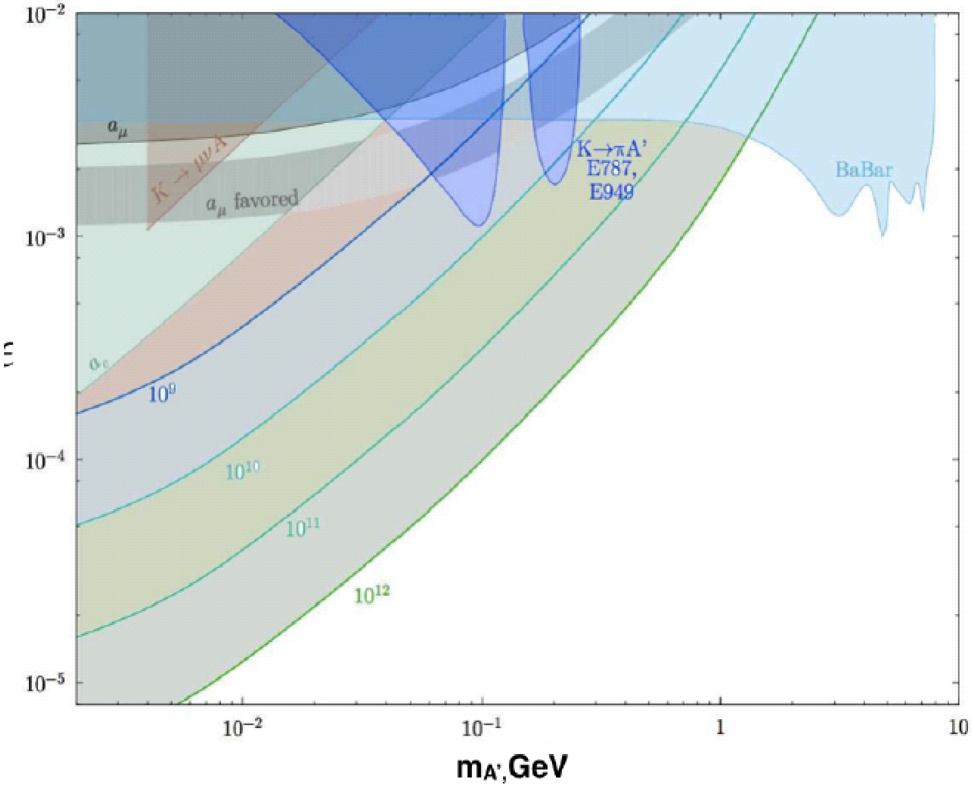
Our goal to have statistics with at least

10^10 electrons and to close (or discover)

(g-2) muon anomaly explanation with

A` invisible decays.

Projected Sensitivity



The discrepancy between the predicted and experimental values for the anomalous magnetic moment $(g\text{-}2)_\mu$ of the muon could be explained by the presence of an additional boson.

With 10^{10} accumulated events (possible to accumulate 5×10^{10} electrons in a month's run time) NA64 may completely exclude the still favoured parameter space by $(g\text{-}2)_\mu$.

Potentially can cover a much bigger region with enough accumulated statistic

Conclusions

Dark matter definitely exists but we don’t know the mass of dark matter particles , spin and the interaction of dark matter with the SM matter. LHC looks for O(100 GeV) dark matter particles mainly. Low energy accelerators with high intensity probably

Conclusions

the best way to discover light dark matter. A lot of experiments in preparation. In particular, NA64 experiment at CERN SPS will obtain the first nontrivial results at the end of 2016.

Conclusions

(g-2) anomaly explanation due to existence of hypothetical light vector boson is severely restricted (but not excluded by current experiments).

NA64 experiment at CERN SPS will allow to discover A` $\rightarrow$ invisible decay mode or reject this explanation of (g-2) anomaly at the end of 2016.

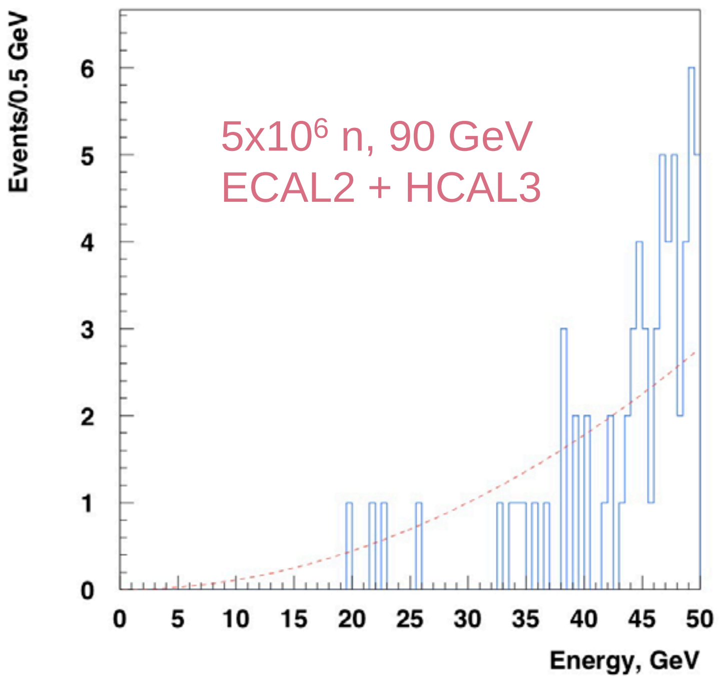
NA64 also plan to *use in future (> 2018) secondary muon beam to search for Z` boson in a model with* $L_\mu - L_\tau$ interaction and secondary hadron beams.

BACKUP

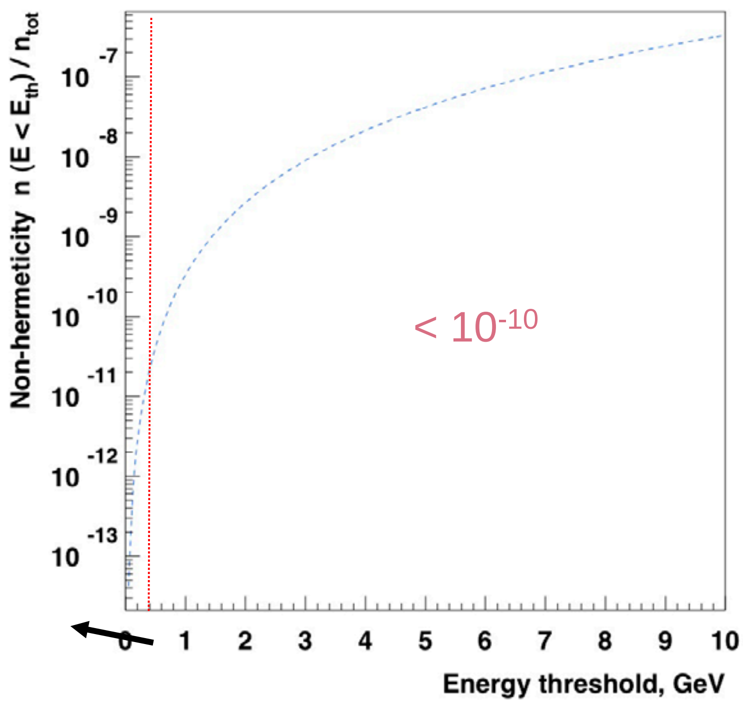
The natural y scale

The natural scale of y is between 10^{-15} and 10^{-8}

Estimated ECAL2+ HCAL3 nonhermeticity



Fit of the low energy tail with a smooth function f(E)

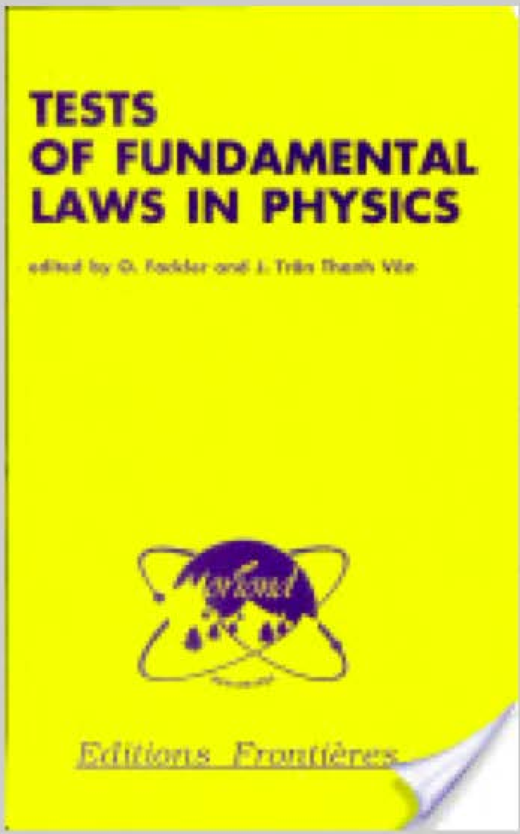


ECAL2+HCAL3 nonhermeticity as a funcion of the energy threshold

Experimental bounds

- Astrophysical bounds
- Photon Regeneration Experiments
- K-meson decays
- Upsilon decays
- Electron Beam Dump experiments
- Electron Fixed-Target Experiments
- Proton Beam Dump Experiments

New U'(1) is not new for INR TH



RARE DECAYS, NEW U(1) BOSONS AND THE FIFTH FORCE

T.M.ALIEV, M.I.DOBROLIUBOV, A.Yu.IGNATIEV, V.A.MATVEEV
Institute for Nuclear Research of the Academy of Sciences of the USSR, 60th October Anniversary pr.,7a, 117312 Moscow, U S S R

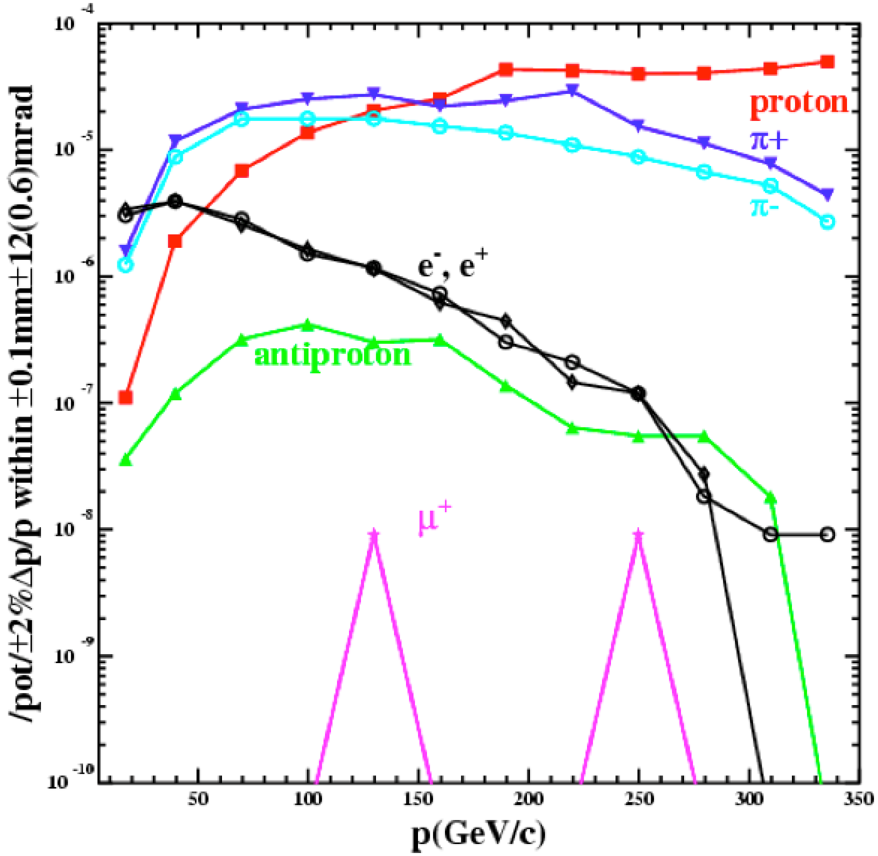
ABSTRACT

We present a brief review of a number of works discovering new perspectives of looking for new light particles in rare meson decays. Among them are the production of light photinos in the decay $\pi^0 \to$ "nothing" and production of new U(1) gauge bosons in the decays $\pi^0 \to \gamma +$ "nothing" and $K^+ \to \pi^+ +$ "nothing". We also discuss the problem of kaon decay constraints on the carrier of the fifth force.

January 21–28, 1989

Н.В.Красников (ИЯИ РАН) Марковские чтения 14 мая 2014 11/33

SPS e- beams

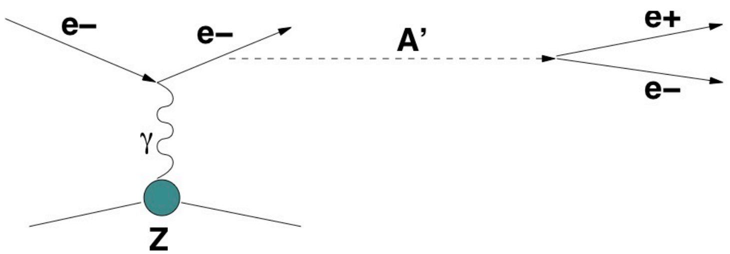


- H4, I_{max}~ 50 GeV e-
- 10^{12} pot per SPS spill,
- ~ $5x10^{6}$ e- per spill
- duty cycle is 0.25
- ~10^{12} e- / month

  additional tunning by

  a factor 2-3 ?
- beam spot ~ cm^2
- beam purity < 1 %

MeV A` production and decay



bremsstrahlung A`

- e Z->e Z A`cross section $\sigma_{A`} \sim \varepsilon^2 (m_e/M_{A`})^2 \sigma_\gamma$; Bjorken'09, Andreas'12
- decay rate $\Gamma(A` \to e^+e^-) \sim \alpha\varepsilon^2 M_{A`}/3$ is dominant for $M_{A`} < 2\, m_\mu$
- sensitivity $\sim\varepsilon^4$ for long-lived A`, typical for beam dump searches

For $10^{-5} < \varepsilon < 10^{-3}$, $M_{A`} < \sim 100$ MeV

- very short-lived A`: $10^{-14} < \tau_{A`} < 10^{-10}$ s
- very rare events: $\sigma_{A`}/\sigma_\gamma < 10^{-13}\text{-}10^{-9}$
- A`energy boost to displace decay vertex,

  $\varepsilon \sim 10^{-4}$, $M_{A`} \sim 50$ MeV, $E_{A`} \sim 100$ GeV, $L_d \sim 1$ m
- background suppression

1.Introduction

The aim of this talk is the review of new light vector boson(dark photon) and light dark matter experimental searches including new experiment NA64 at CERN SPS

$$L_{Z_\mu} = e_\mu \bar{\mu} \gamma_\nu \mu Z^\nu_\mu \,. \tag{2}$$

The interaction (2) gives additional contribution to the muon anomalous magnetic moment $a_\mu \equiv \frac{g_\mu - 2}{2}$

$$a_l^{Z_\mu} = \frac{\alpha_\mu}{\pi} \int_0^1 \frac{x^2(1-x)}{x^2 + (1-x)M^2_{Z_\mu}/m_l^2} \,, \tag{3}$$

where $\alpha_\mu = (e_\mu)^2/4\pi$ and M_{Z_μ} is the mass of the Z_μ-boson. Equation (3) allows to determine the α_μ which explains $g_\mu - 2$ anomaly. For $M_{Z_\mu} \ll m_\mu$ we find from Eq.(1) that

$$\alpha_\mu = (1.8 \pm 0.5) \times 10^{-8} \tag{4}$$

For another limiting case $M_{Z_\mu} \gg m_\mu$ Eq.(1) leads to

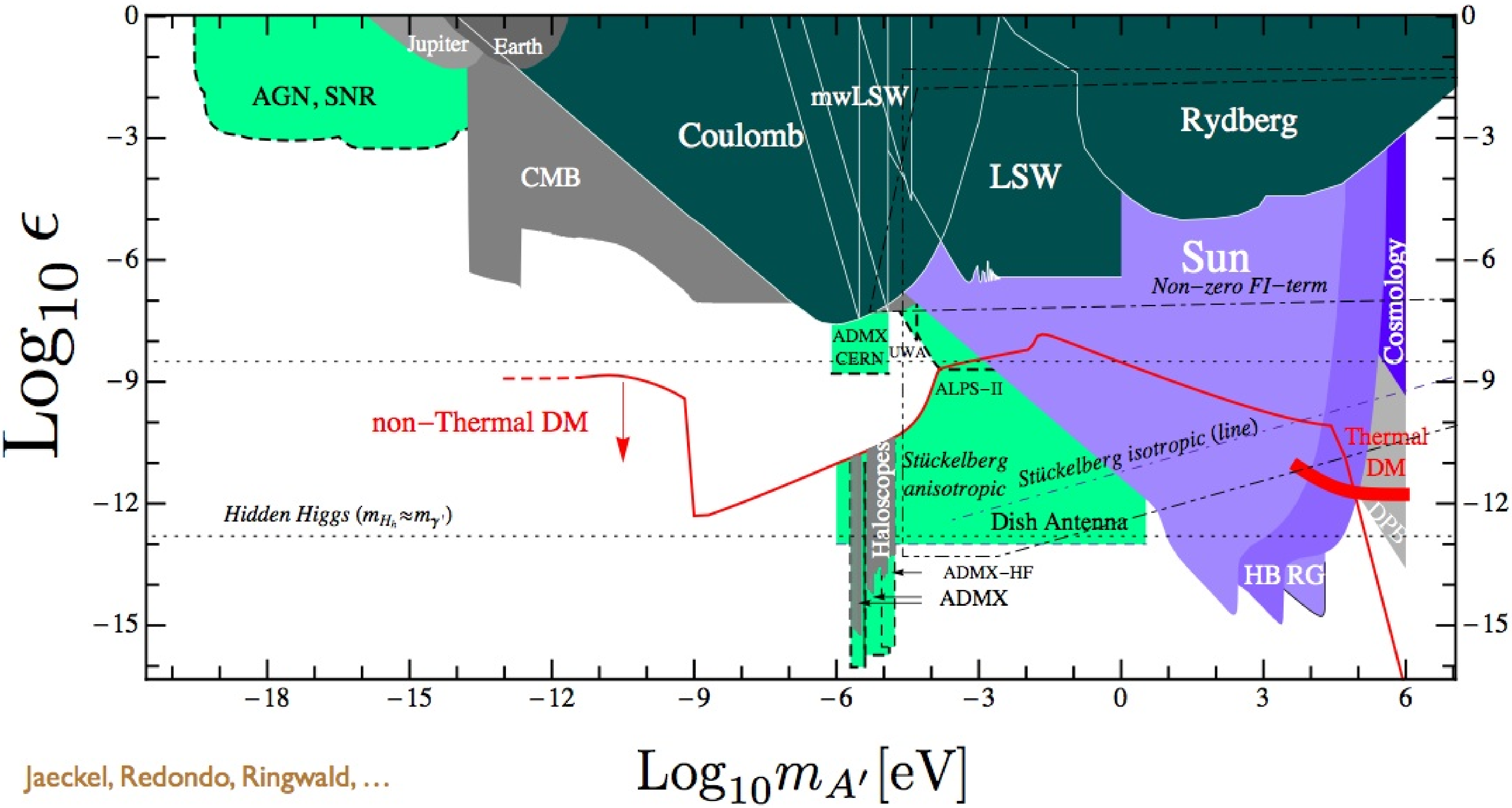
$$\alpha_\mu \frac{m_\mu^2}{M^2_{Z_\mu}} = (2.7 \pm 0.8) \times 10^{-8} \tag{5}$$

5. Conclusion

(g-2) anomaly explanation due to existence of hypothetical light vector boson is severely restricted (but not excluded by current experiments).

NA64 experiment at CERN SPS and(or) experiment with muon beams will allow to discover new light vector boson or reject this explanation of (g-2) anomaly.

low-mass (< MeV) A′ parameter space

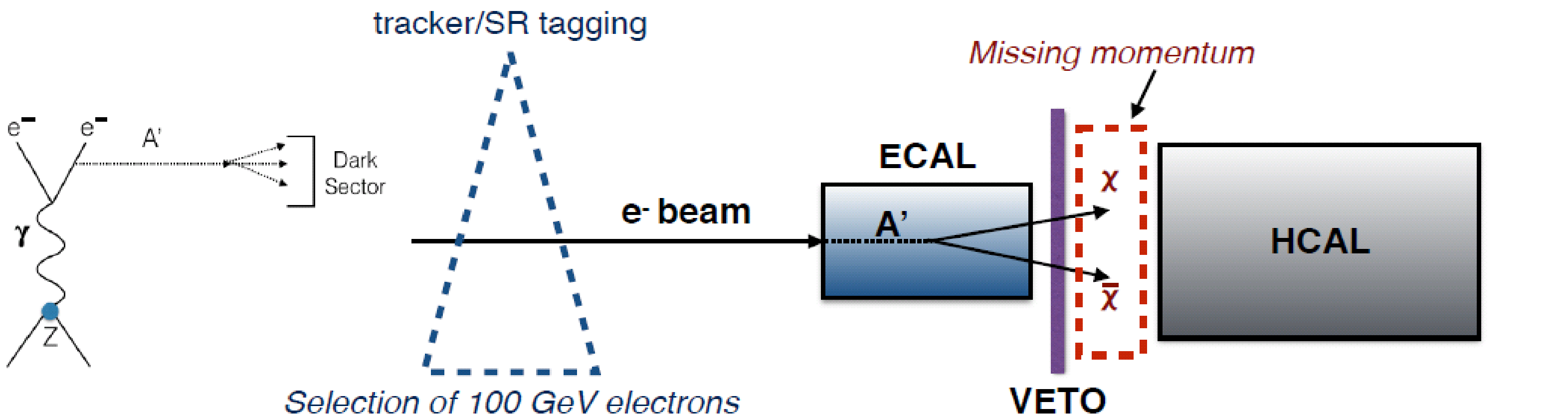


Jaeckel, Redondo, Ringwald, …

2. Experimental bounds

It should be noted that in the considered model for A`(Z`) boson lighter than 210 MeV the A`(Z`) boson decays mainly into electron-positron pair

NA64 Experiment



For NA64 a beam of ***100 GeV electrons*** *will be dumped against an ECAL, a sandwich of lead and scintillators (34 X_0), to produce massive A' through scattering with the heavy nuclei.*

A typical signature for a signal will be ***missing energy in the ECAL*** *and no activity in the the VETO and HCAL.*

Background from hadrons, muons and low energy electrons must be rejected upstream.