

LPNHE-Biennale 2007 – hopes ...and 2014 reality

The LHC light on Dark Matter and Dark Energy

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This talk:

- The questions
- The cosmo-path
- The parti-path
- Their (possible) convergences
- The (expected) LHC verdicts
- Outlook



The LHC was supposed to discover the DM particle(s)

Evolution of the Dark Matter Density

- Heavy particle initially in thermal equilibrium
- Annihilation stops when number density drops

$$H > \Gamma_A \approx n_\chi \langle \sigma_A v \rangle$$

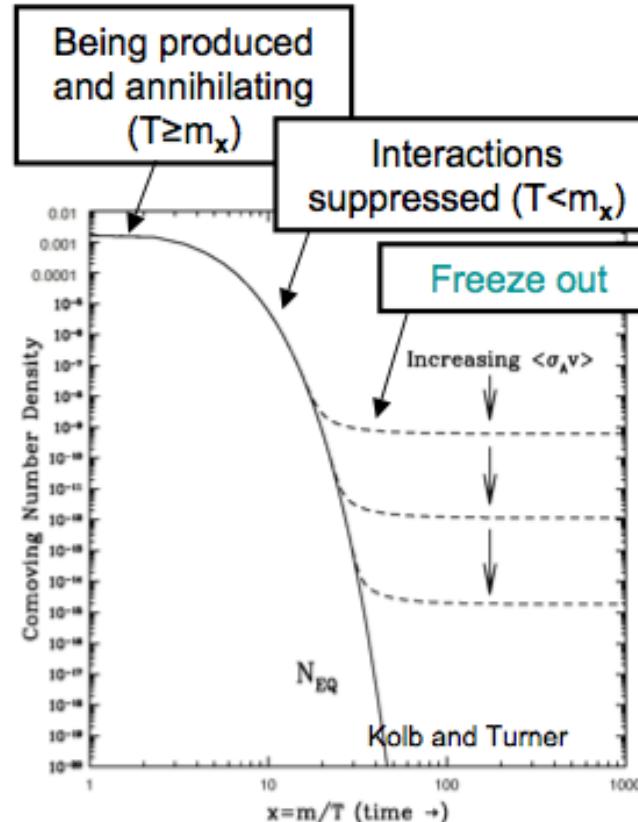
- i.e., annihilation too slow to keep up with Hubble expansion ("freeze out")
- Leaves a relic abundance:

$$\Omega_{DM} h^2 \approx \langle \sigma_A v \rangle^{-1}$$

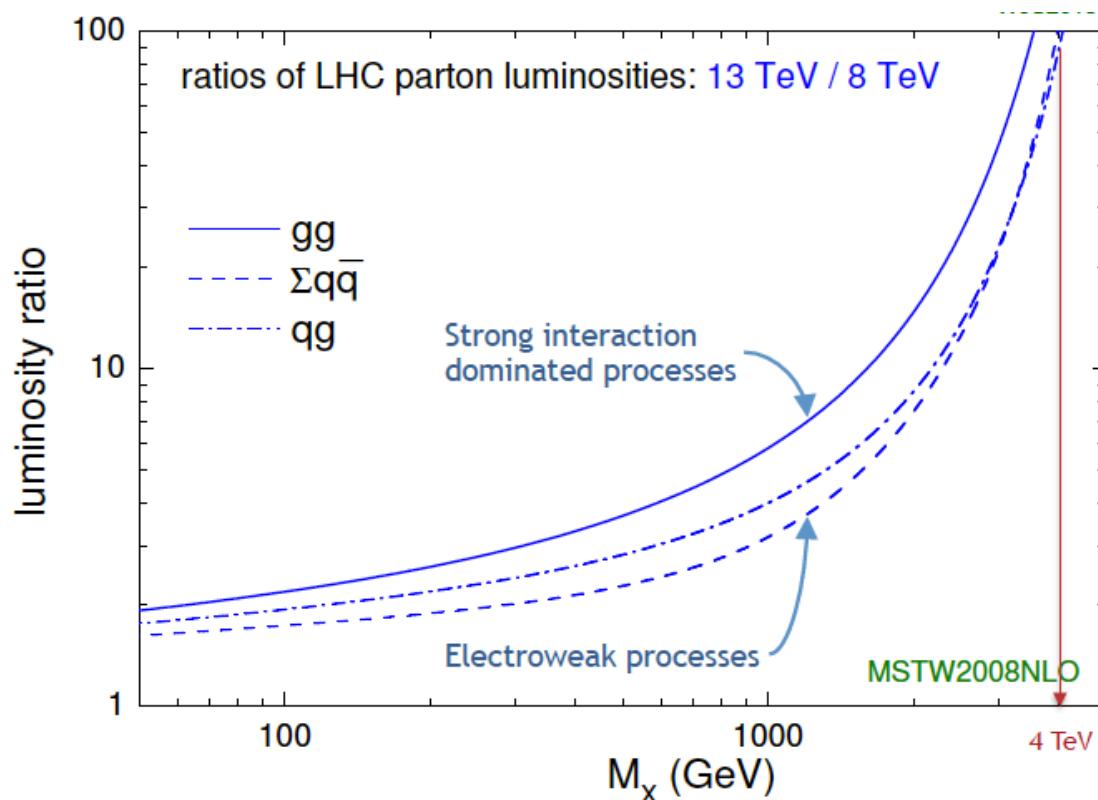
If m_χ and σ_A determined by electroweak physics,

$$\sigma_A \approx k\alpha_w^2 / m_\chi^2 \approx \text{a few pb} \quad \text{then } \Omega_{DM} \sim 0.1 \text{ for } m_\chi \sim 0.1-1 \text{ TeV}$$

Remarkable agreement with WMAP-SDSS → $\Omega_{DM} = 0.104 \pm 0.009$



A.D. 2014 ...remaining hopes



A.D. 2017 ...forlorn hopes?
new methods (ideas) of DM searches badly needed

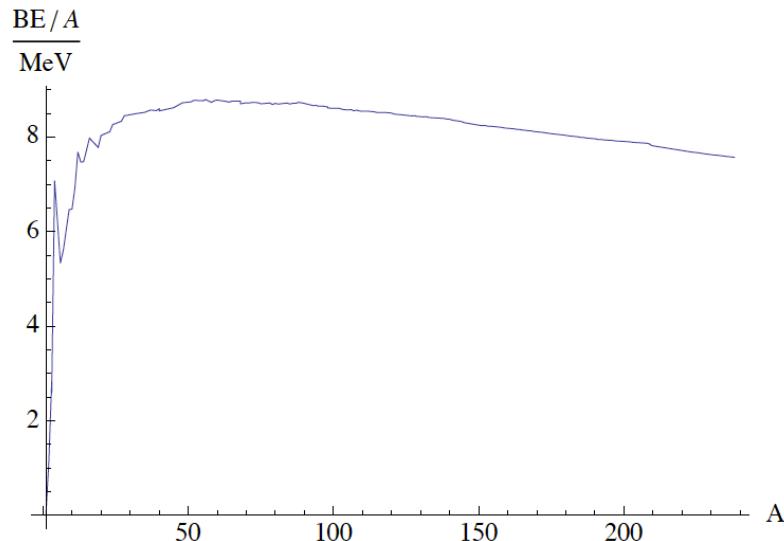
The guiding puzzle for new ideas

- Why the dark energy, dark matter and visible matter are “almost” equally abundant?
- Does it tell us that the dark matter has similar properties as the normal matter (dark atoms, dark molecules, dark nuclei...) but “refuses” to communicate with normal matter?

The example of dark nuclei

(last week seminar of Robert Lasenby at CERN)

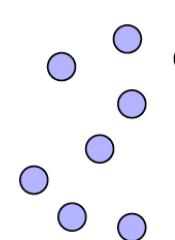
SM nuclei



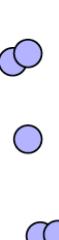
Dark nucleosynthesis

Free energy $F = E - TS$:
large $T \Rightarrow$ everything dissociated
small $T \Rightarrow$ large states favoured

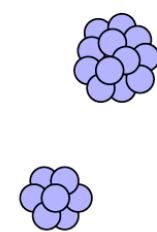
$T \gg BE$



$T \sim BE$

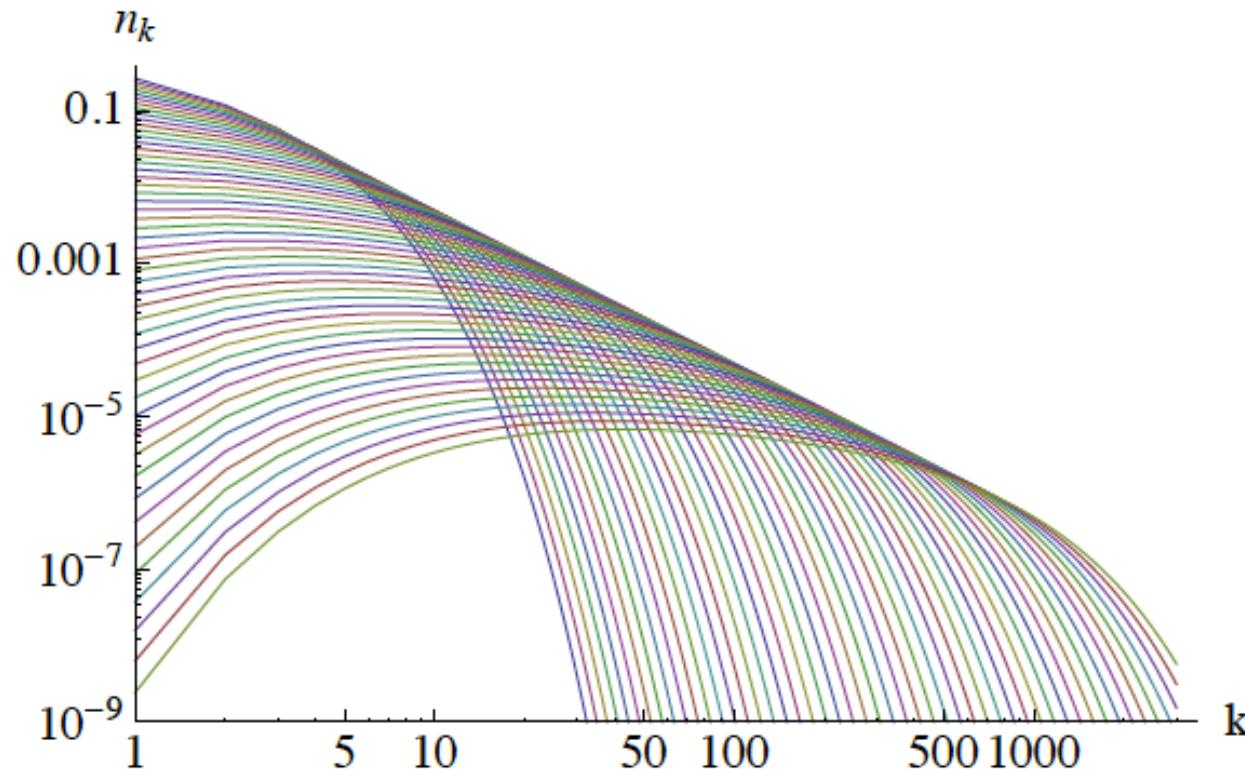


$T \ll BE$



The example of dark nuclei

R.Lasenby



The distribution of k (number of dark nucleons in dark nuclei) evolves with the age of the universe up to a certain limit - further evolution possible only in dark stars

The dark matter messengers

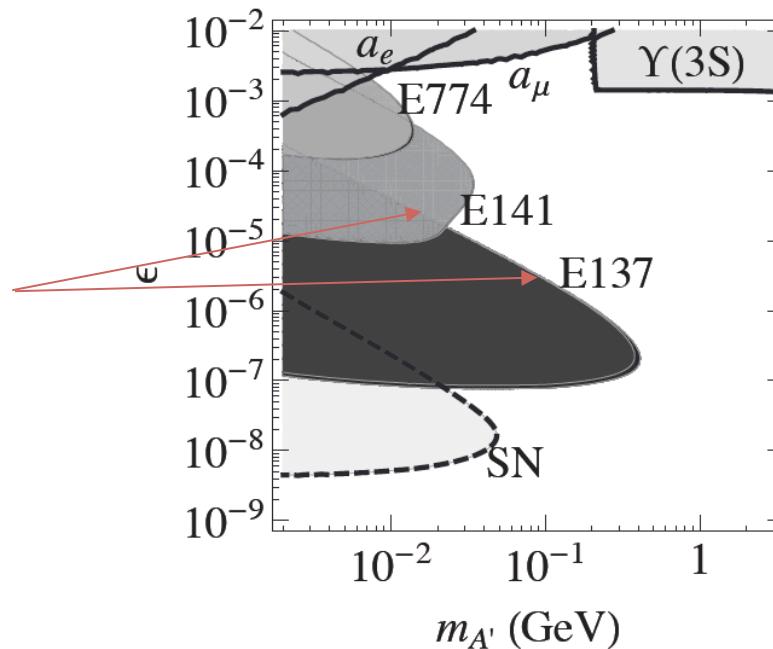
- “Higgs” portal messenger(s) (to be elucidated at the LHC?)
(superconducting and dark matter media)
- Neutrino portal (Jacques)
- Dark photon messenger (discussed below)
(Z/γ mixing in the SM and photon/dark photon mixing)

Dark Gauge Forces

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \epsilon_Y F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m_{A'}^2 A'^\mu A'_\mu, \quad (3)$$

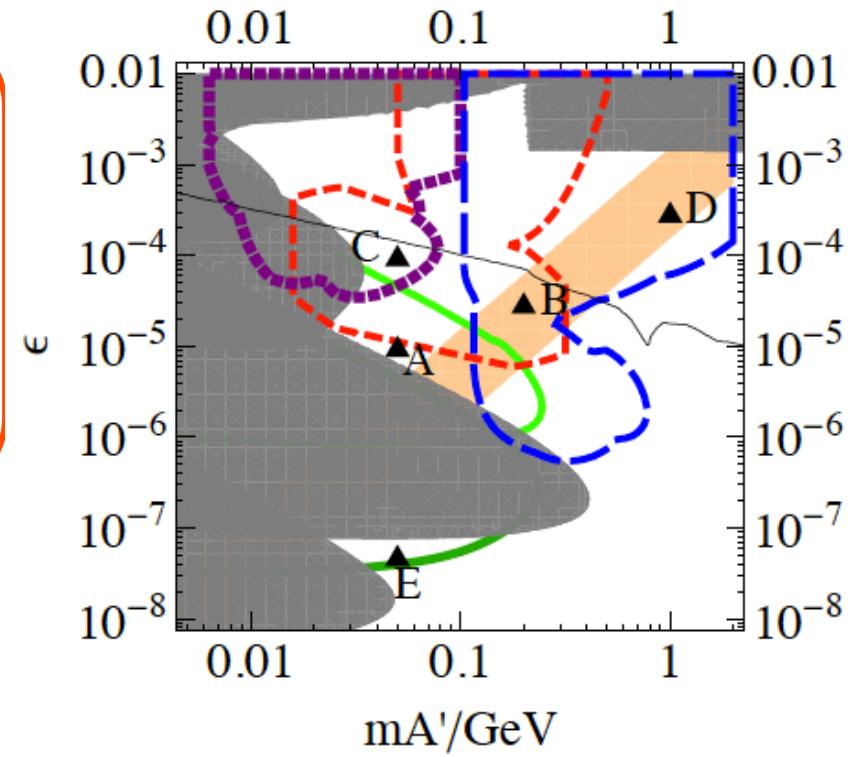
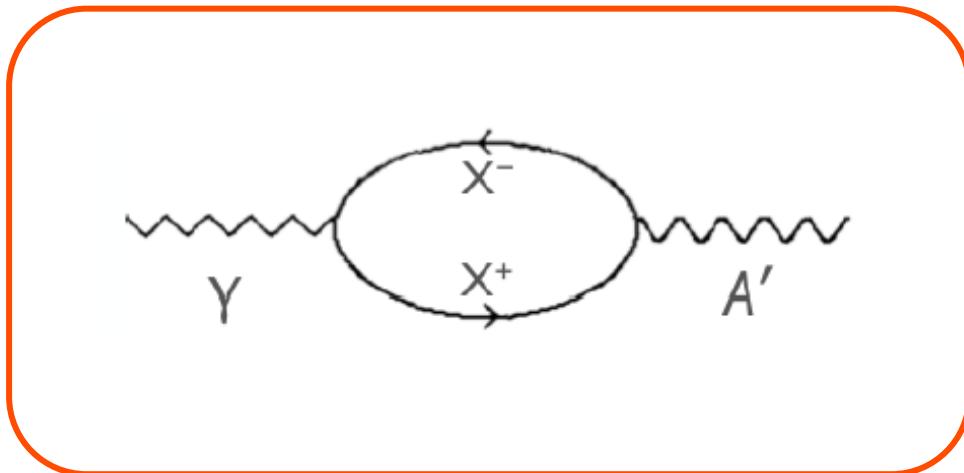
where \mathcal{L}_{SM} is the Standard Model Lagrangian, $F'_{\mu\nu} = \partial_{[\mu} A'_{\nu]}$, and A' is the gauge field of a massive dark $U(1)'$ gauge group [1]. The second term in (3) is the kinetic

Rejection regions of SLAC Experiments in the 80-ties



SLAC-PUB-13650
SU-ITP-09/22

Dark Gauge Forces



$1/m_Z^2$. Equivalently, one can redefine the photon field $A^\mu \rightarrow A^\mu + \epsilon A'^\mu$ as in [37], which removes the kinetic mixing term and generates a coupling $e A_\mu J_{\text{EM}}^\mu \supset \epsilon e A'_\mu J_{\text{EM}}^\mu$ of the new gauge boson to electrically charged particles

The yellow region is the DAMA/LIBRA signal region

How to extend the rejection region?

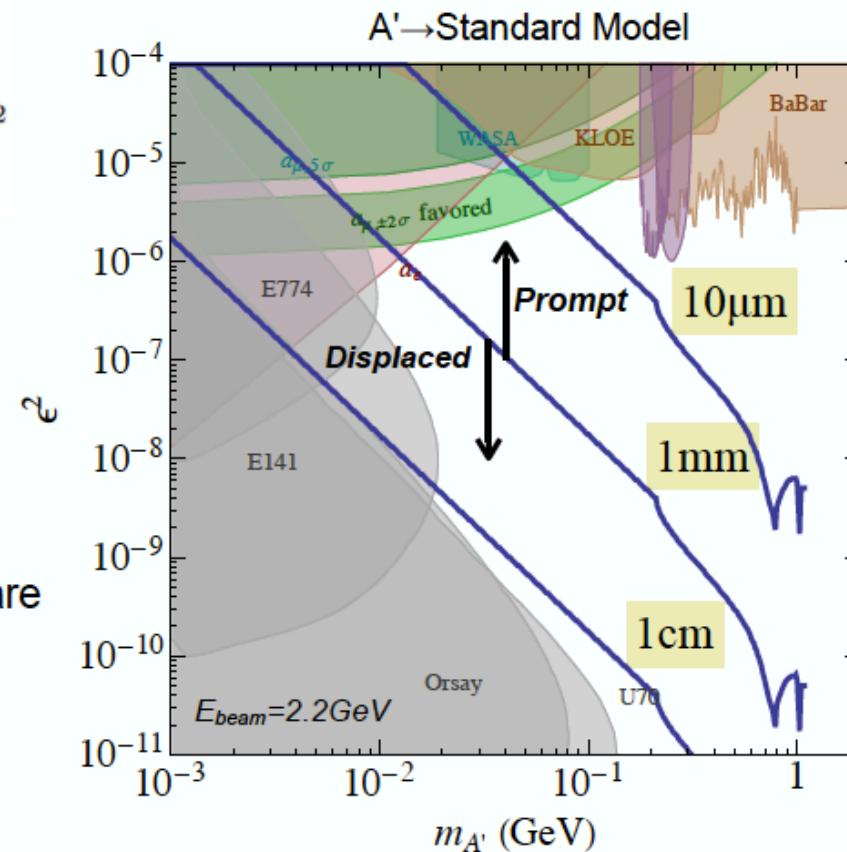
$$\ell_0 \equiv \gamma c \tau \simeq \frac{3E_1}{N_{\text{eff}} m_{A'}^2 \alpha \epsilon^2}$$

$$\simeq \frac{0.8 \text{cm}}{N_{\text{eff}}} \left(\frac{E_0}{10 \text{GeV}} \right) \left(\frac{10^{-4}}{\epsilon} \right)^2 \left(\frac{100 \text{MeV}}{m_{A'}} \right)^2$$

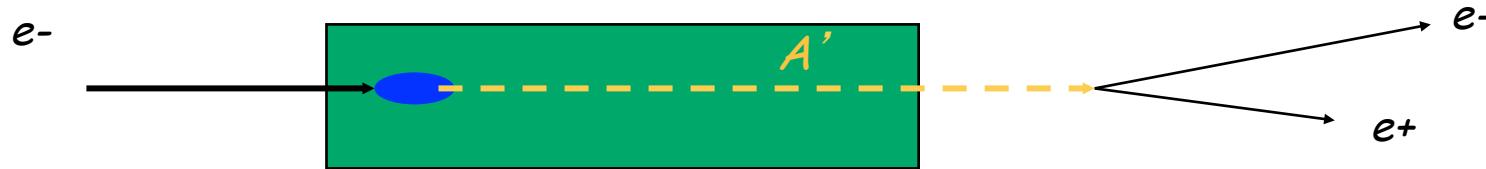
lower ϵ , lower mass
 → longer lifetime

...this is why beam dump experiments are so effective at low mass/coupling.

Hard to get the 10μm-1cm regime...



Experimental search for A'



Canonical procedure:

Measure $N_{e^+e^-}$ at angle 0° (low mass), calculate (Monte Carlo) N_{back} ,
If $N_{e^+e^-} > N_{\text{back}}$ discovery, otherwise rejection limits...

Need to generate 10^{19} cascades ... Monte-Carlo methods useless
Approximate calculation methods fail in reaching the requisite precision

...dedicated precision measurement method obligatory

Dedicated, precision searches



Run 1: dump thickness $d=d_1$, length $l=l_1$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$

Dedicated, precision searches



Run 1: dump thickness $d=d_1$, length $l=l_1$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$



Run 2: dump thickness $d=d_1$, length $l=l_2 +$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$

Dedicated, precision searches



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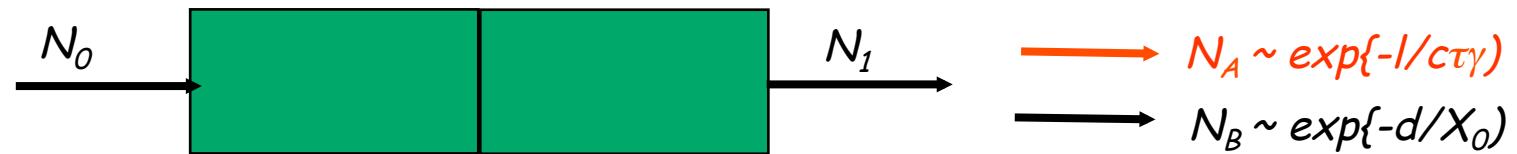


Run 2: dump thickness $d=d_1$, length $l=l_2 +$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$



Run 3: dump thickness $d=d_2$, length $l=l_2 +$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$

Dedicated, precision searches



Run 1: dump thickness $d=d_1$, length $l=l_1$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$



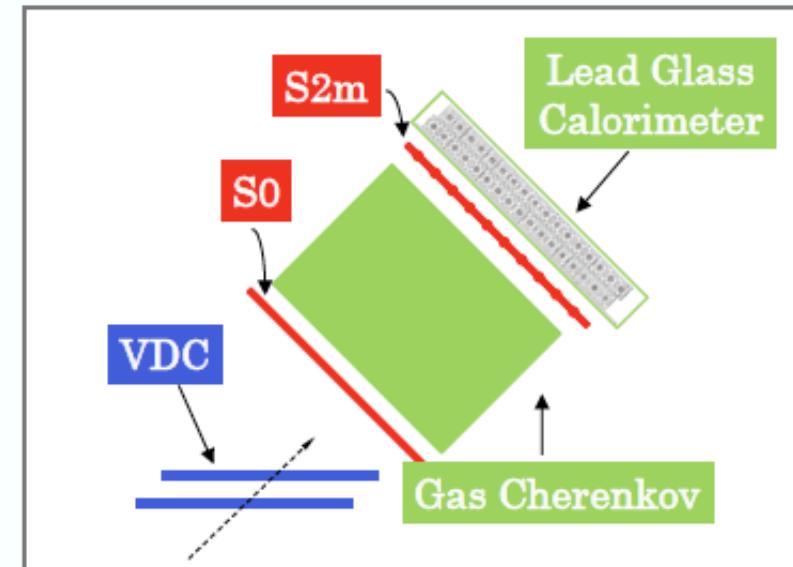
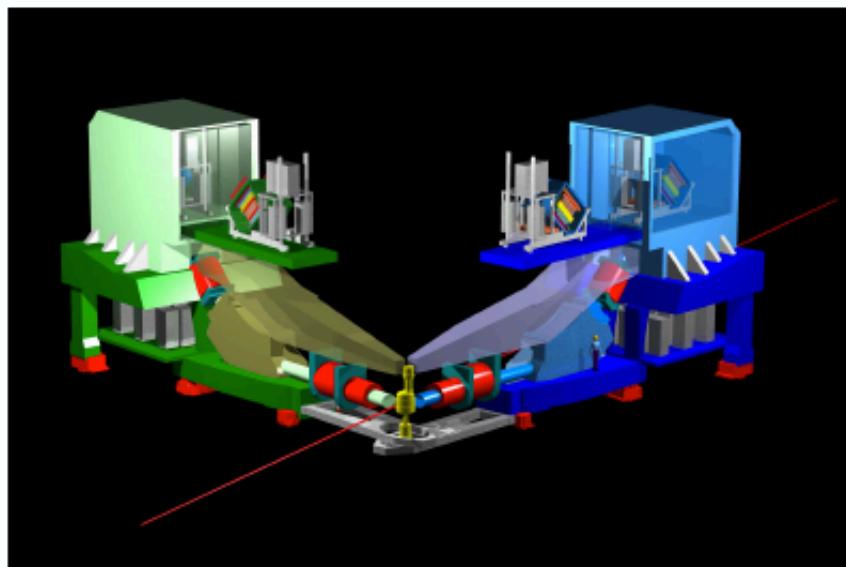
Run 2: dump thickness $d=d_1$, length $l=l_2 +$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$



Run 3: dump thickness $d=d_2$, length $l=l_2 +$, $\gamma_{beam} = \gamma_0$, $B_{spectr} = B$

Repeat Run 1-3: for $B \rightarrow -B$ and $\gamma_{beam} = 2\gamma_0$
to verify the hypothesis of a decay of a neutral particle

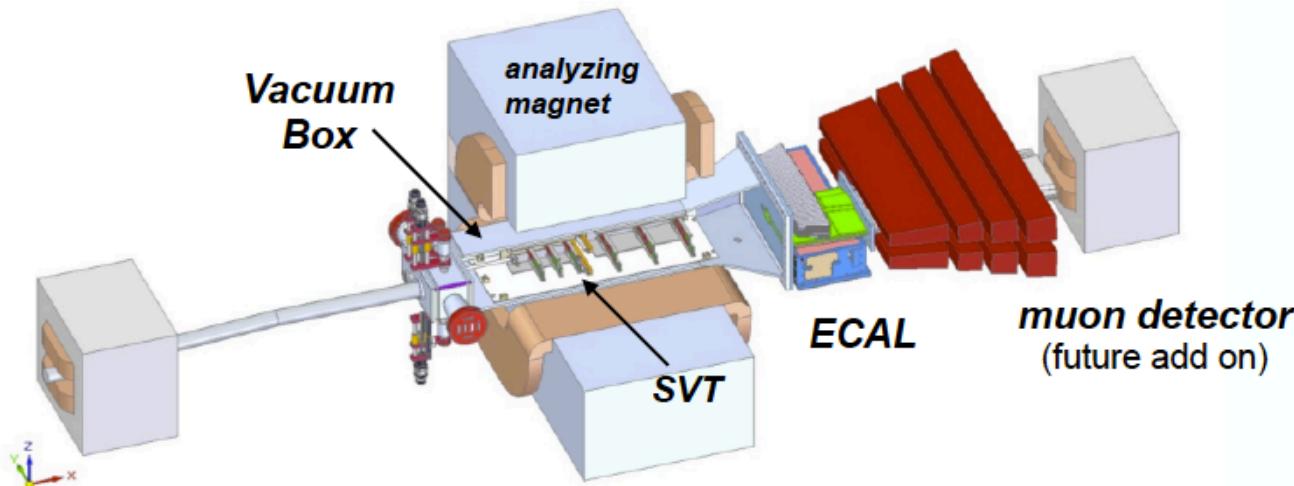
The APEX experiment at JLAB



The HPS experiment at JLAB

The Heavy Photon Search uses the lower current beam on a thin target with a high precision vertexing & tracking detector to search for displaced vertices

- ➡ HALL B beam: <700 nA with 2 ns bunch spacing; $\sigma_{x,y} < 50\text{um}$
- ➡ 12-layer Si microstrip detector inside 0.5T magnet measures momentum & decay vertex
- ➡ PbW crystal calorimeter w/APD readout used for triggering
- ➡ decent mass resolution (~2-10%), decent acceptance (up to ~20%)
- ➡ vertex resolution ~few mm; 10^{-6} rejection of prompt decays
- ➡ mass resolution dominated by MS in tracker



New CERN experiment being considered

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

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V.A. Matveev^{f,g}, Yu.V. Mikhailov^e, Yu.V. Musienko^f, V.A. Polyakov^c, A. Ringwald^a,
A. Rubbia^d, V.D. Samoylenko^c, Y.K. Semertzidis^h, K. Zioutas^e

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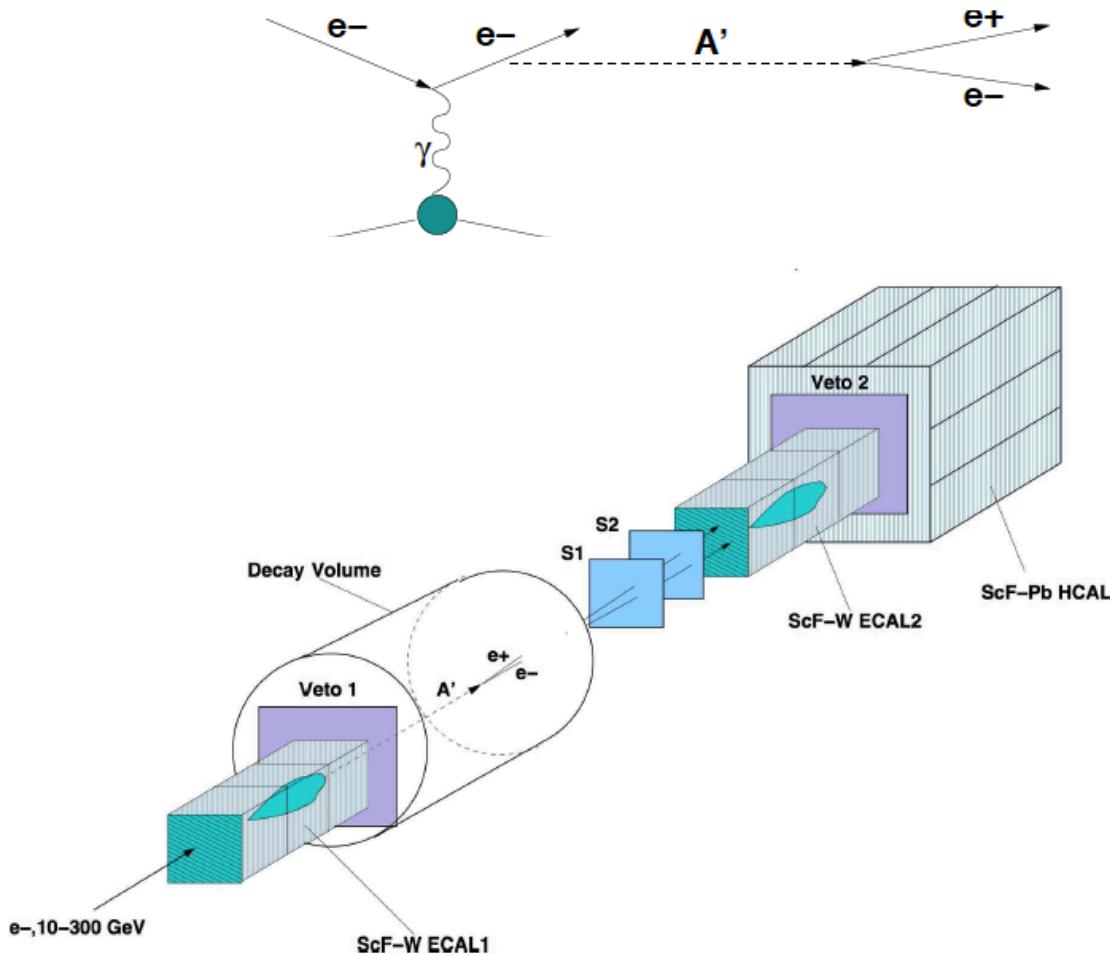
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^g*Joint Institute for Nuclear Research, 141980 Dubna, Russia*

^h*Center for Axion and Precision Physics, IBS, Physics Dept., KAIST, Daejeon, Republic
of Korea*

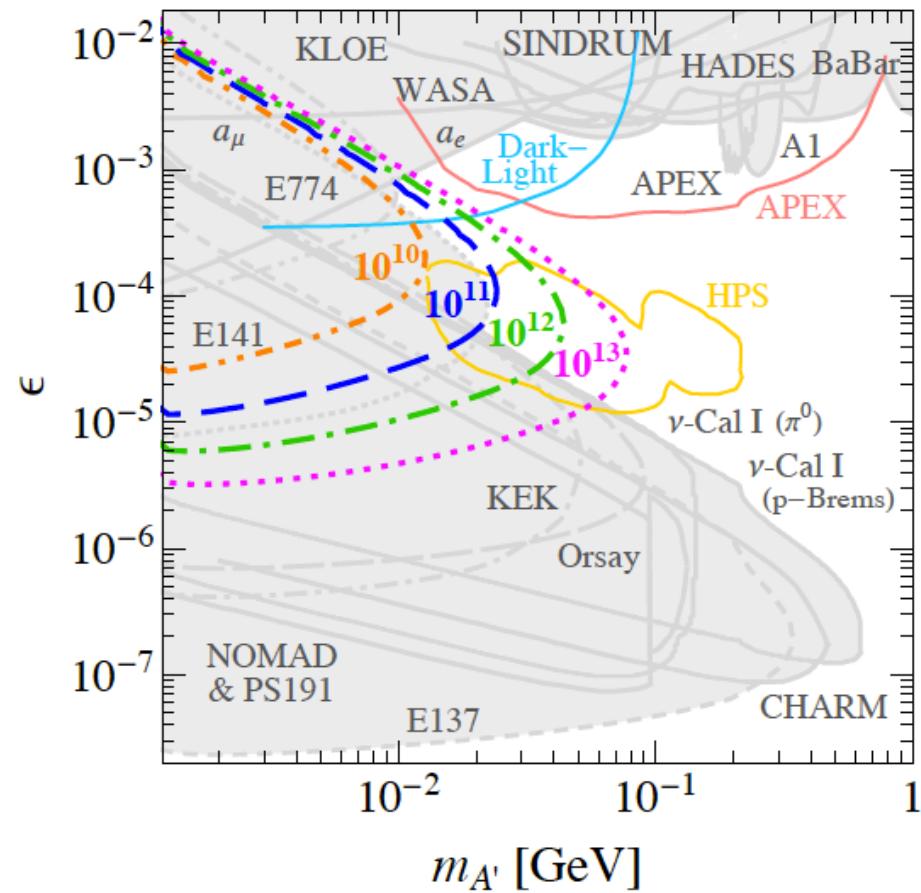
New CERN experiment being considered



Main points in my evaluation of the CERN proposal

- Pion and Kaon admixture of the CERN electron beam (secondary K0s) – required purity of the beam below 10^{-4} - 10^{-5} h/e
- The integrated charge deposited (present CERN beam – $N_e \sim 2 \times 10^{12}$ e/month)
- photoproduction of rho mesons in electromagnetic cascades (Veto efficiency must be higher than 0.999)

Prospects



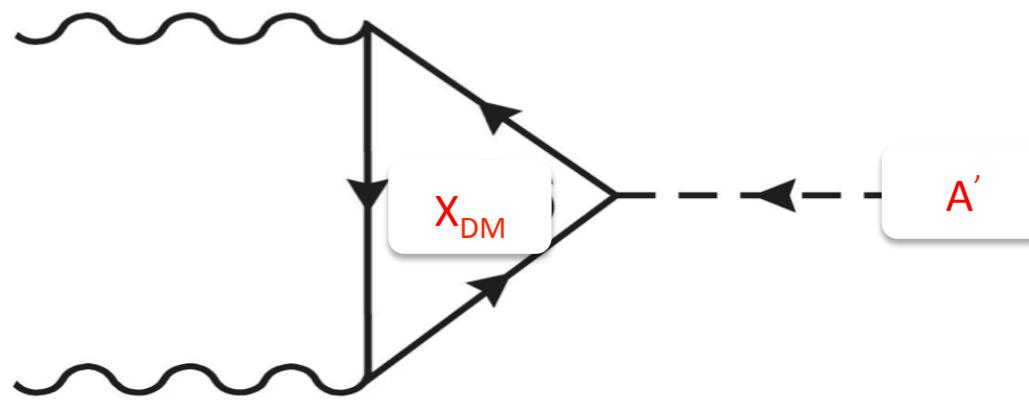
... new ideas:

Acceleration, storage and **physics**
opportunities of partially
stripped ions in CERN's LHC
(MWK – ...in preparation)

Section on:

Dark Matter messengers searches

Direct production of dark photons via Primakoff process



Profit from a factor 10^6 - 10^8 increase of
the gamma beam intensity in the range
with respect to all previous sources

EXAMPLE:

interaction of the extracted gamma beam with the photons stocked in the cavity

Direct production of dark photons in the large span of the masses $\sim(0.1\text{--}130\,000)$ MeV.

Interaction of gamma beam with (1) laser photons, (2) another gamma beam ... or (3) the energy boosted gamma beam formed by the inverse Compton process

