New Experiments at the Intensity Frontier

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Outline

- **Axions- and axion-like particles** $\Rightarrow$ laser-light shining through a wall experiment **ALPS II** (Any Light Particle Search)

- **Hidden or dark photons** $\Rightarrow$ beam dump experiment **HIPS** (Hidden Particle Search)

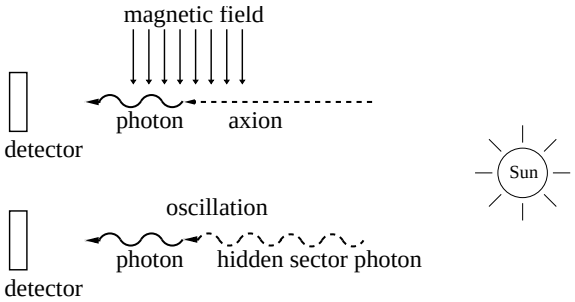
- **Non-linear QED** $\Rightarrow$ non-perturbative e^+e^- pair production in collision of (multi-)GeV electron beam with petawatt laser beam

Axions and axion-like particles

[Peccei,Quinn '77; Weinberg '78; Wilczek '78]

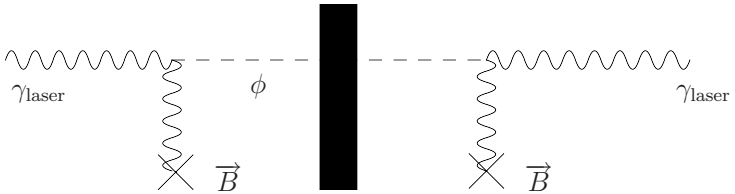
- Axions and axion-like particles (ALPs) occur in many extensions of the standard model and are viable dark matter candidates
- Most sensitive probes of light ALPs based on photon-ALP conversion:
  - helioscope searches (e.g. CAST, SUMICO, SHIPS, ...)

[Sikivie '83;...;Redondo '08;...]



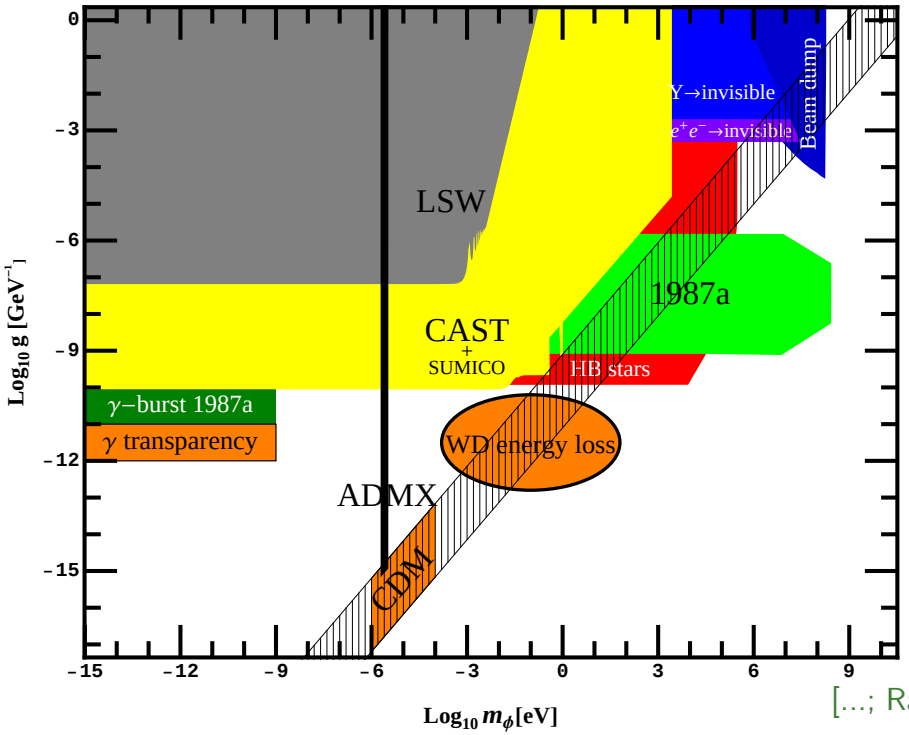
  - light shining through a wall searches (e.g. ALPS, GammeV, ...)

[Okun '83;Anselm ; van Bibber]



$\Rightarrow$ two photon coupling g

- LSW (helioscopes) probe currently $g \sim 10^{-7}$ GeV^{-1} ($g \sim 10^{-10}$ GeV^{-1}):



[...; Raffelt '86;...; Jaeckel,AR '10]

- Astrophysical hints (TeV γ transparency puzzle (H.E.S.S., MAGIC); anomalous energy loss of white dwarfs) point at $g \sim 10^{-12} \div 10^{-11}$ GeV^{-1}

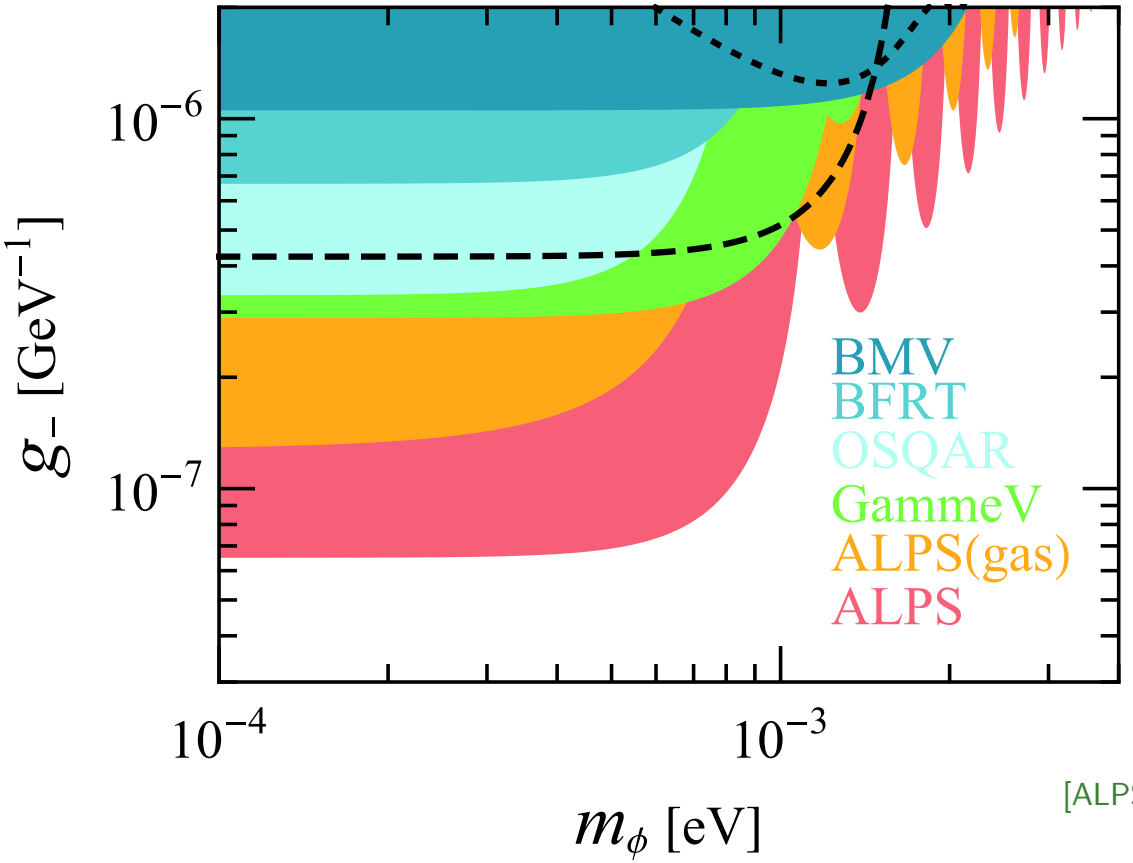
- **LSW experiments**
  - worldwide activity at accelerator labs recycling existing dipole magnets

Experiment	ω	$\mathcal{P}_{\rm prim}$	β_g	Magnets
ALPS (DESY)	2.33 eV	4 W	300	$\mathsf{B}_g = \mathsf{B}_r = 5$ T $L_g = L_r =$ 4.21 m
BFRT (Brookhaven)	2.47 eV	3 W	100	$\mathsf{B}_g = \mathsf{B}_r = 3.7$ T $L_g = L_r =$ 4.4 m
BMV (LULI)	1.17 eV	8×10^{21} γs/pulse	14 pulses	$\mathsf{B}_g = \mathsf{B}_r =$ 12.3 T $L_g = L_r =$ 0.4 m
GammeV (Fermilab)	2.33 eV	4×10^{17} γs/pulse	3600 pulses	$\mathsf{B}_g = \mathsf{B}_r = 5$ T $L_g = L_r = 3$ m
LIPSS (JLab)	1.03 eV	180 W	1	$\mathsf{B}_g = \mathsf{B}_r = 1.7$ T $L_g = L_r = 1$ m
OSQAR (CERN)	2.5 eV	15 W	1	$\mathsf{B}_g = \mathsf{B}_r = 9$ T $L_g = L_r = 7$ m

  - **ALPS** at forefront in sensitivity (highest integrated photon flux)
  - have to increase efforts in order to stay competitive ⇒ **ALPS II**

- Last **ALPS** run end of 2009 [Phys. Lett. B 689 (2010) 149-155]

$\Rightarrow$ *"Not a WISP of evidence"* [Nature 465 (2010) 271]



[ALPS Collaboration '10]

- **Upgrade plans** at DESY (similar at Fermilab)
  - exploit more HERA (Tevatron) magnets
  - exploit resonant regeneration cavity [Hoogeveen,Ziegenhagen '91;Sikivie,Tanner,van Bibber '07]

- Benchmark parameters:

$6+6$ HERA magnets ($\ell = 8.8$ m)	$L = 52.8$ m
Magnetic field	$B = 5.5$ T
Primary laser power	$\mathcal{P}_{\rm prim} = 3$ W
Power build-up	$\beta_g = \beta_r = 10^5$
Laser frequency	$\omega = 1.17$ eV
Overlap between ALP mode and electric field mode	$\eta = 0.95$
Detection time	$\tau = 100$ h
Dark count rate	$n_b = 10^{-4}$ Hz

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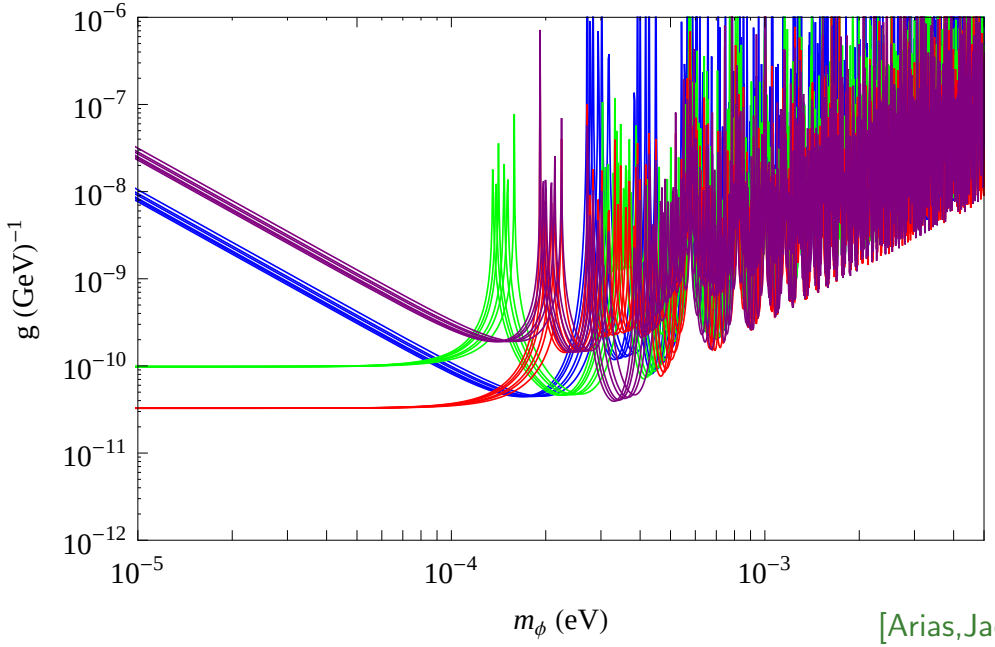


[Arias,Jaeckel,Redondo,AR '10]

$\Rightarrow$ ALPS II will exceed sensitivity of CAST and probe astro hints

- DESY supports planning and first steps towards ALPS II; TDR in 2011

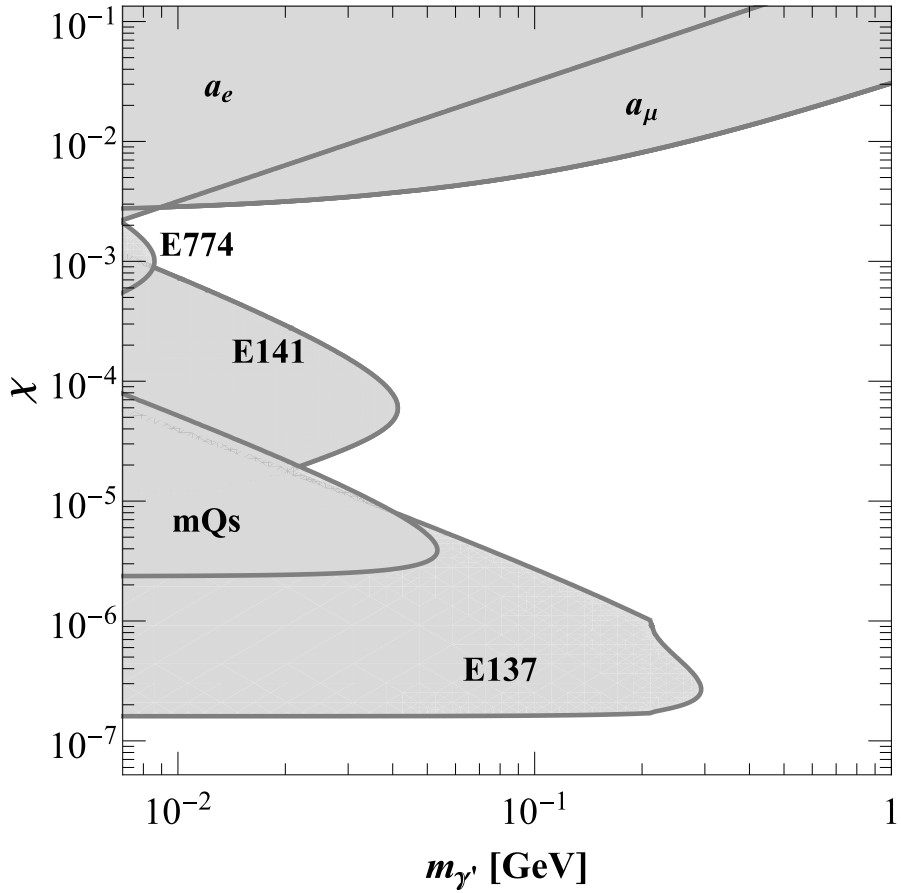
Hidden or dark photons

- MeV-GeV scale hidden or dark photon γ':
  - may explain $(g-2)_\mu$ anomaly [Pospelov '08]
  - may explain [Arkani-Hamed *et al.* '08; Pospelov,Ritz '08;...]
    - terrestrial (DAMA, CoGeNT vs. CDMS, XENON) and
    - cosmic ray (PAMELA, FERMI)

    DM anomalies if DM charged under hidden U(1)
  - can be checked in beam dump and other fixed-target experiments with intense electron beams [Reece,Wang '09; Bjorken,Essig,Schuster,Toro '09]

$\Rightarrow$ New experiments commissioned/funded/proposed/designed at DESY (HIPS), MAMI (A1 Collaboration), and JLab (APEX, DarkLight, HPS)

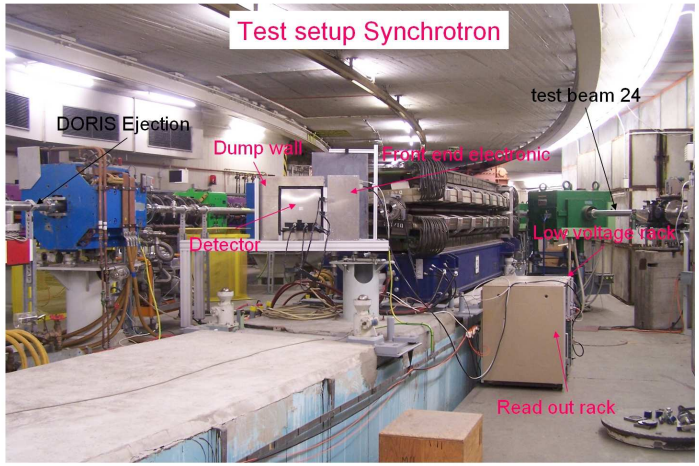
- Current limits on γ-γ' mixing angle χ from past beam dumps and $g-2$:

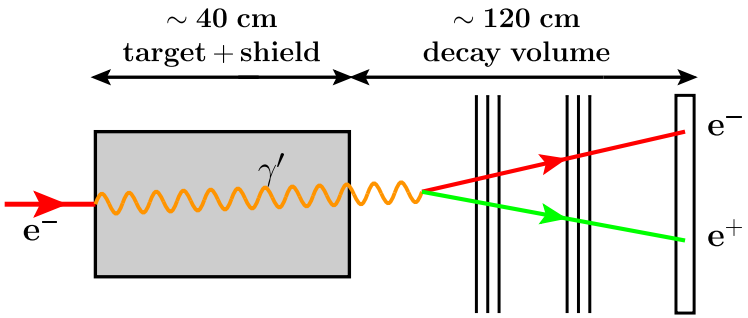


[Andreas,AR '10]

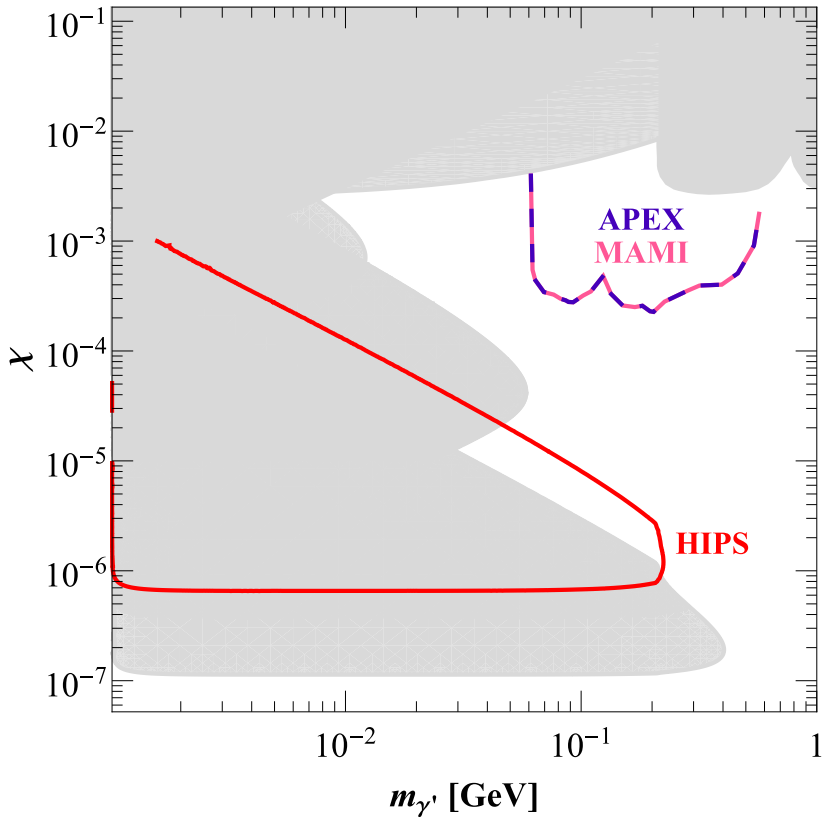
- HIdden Particle Search HIPS: a (parasitic) beam dump experiment at DESY II (10 nA; 450 MeV ÷ 6 GeV); funded by SFB 676; run in 2011

  [Andreas, Bechtle, Ehrlichmann, Garutti, Lindner, Niebuhr, AR]





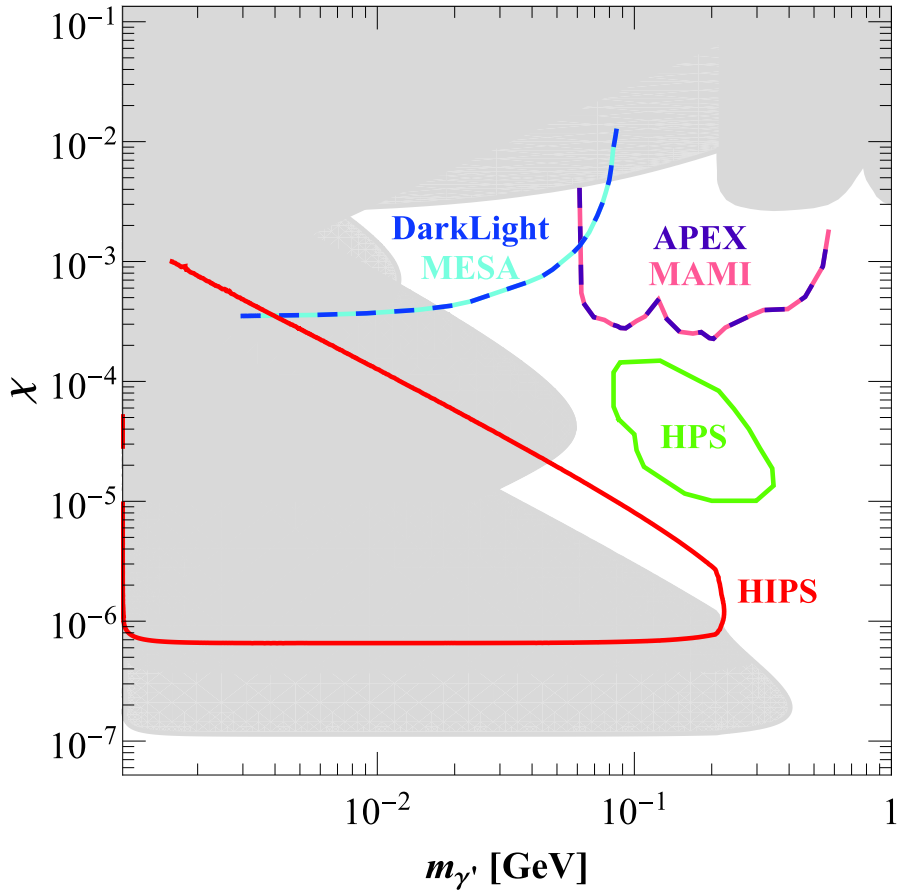
- Projected sensitivity of HIPS complementary to the one of competitors:



[Andreas,AR '10]

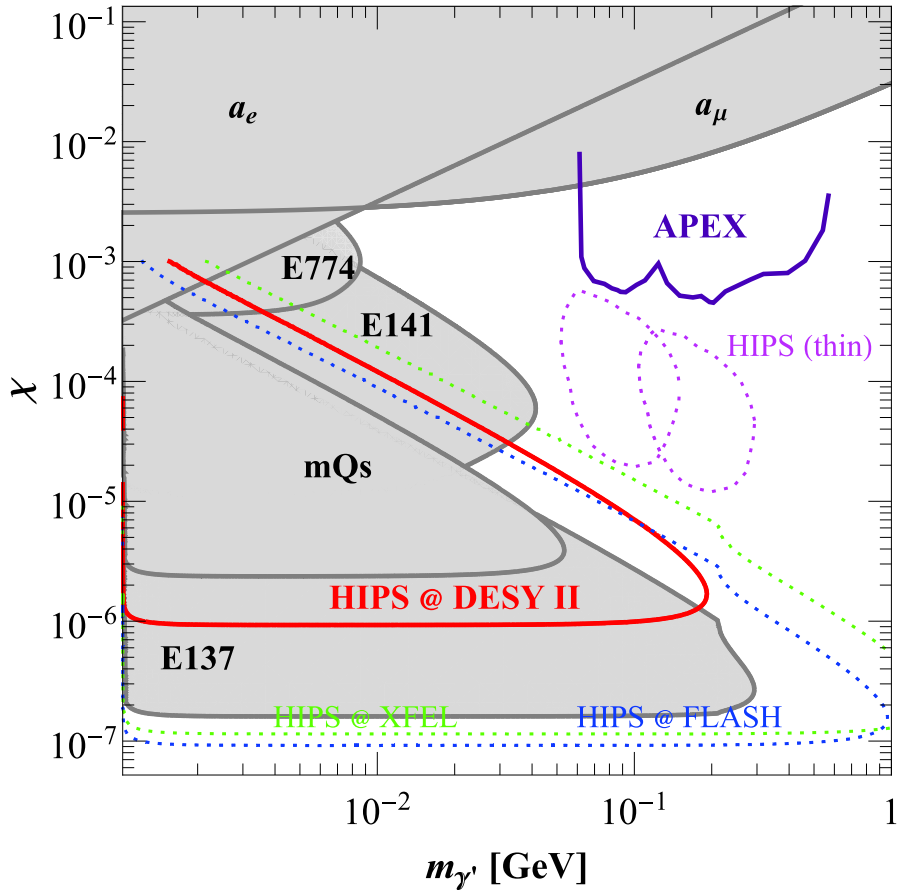
- APEX at JLab's CEBAF (80 μA; 2 $\div$ 6 GeV) and A1 collaboration at MAMI (100 μA; 800 MeV $\div$ 1.6 GeV) made already test runs

- Proposals: JLab: HPS at CEBAF; DarkLight at FEL (10 mA; $E_{\max} = 140$ MeV); Mainz internal gas experiment at proposed MESA facility



[Andreas,AR '10]

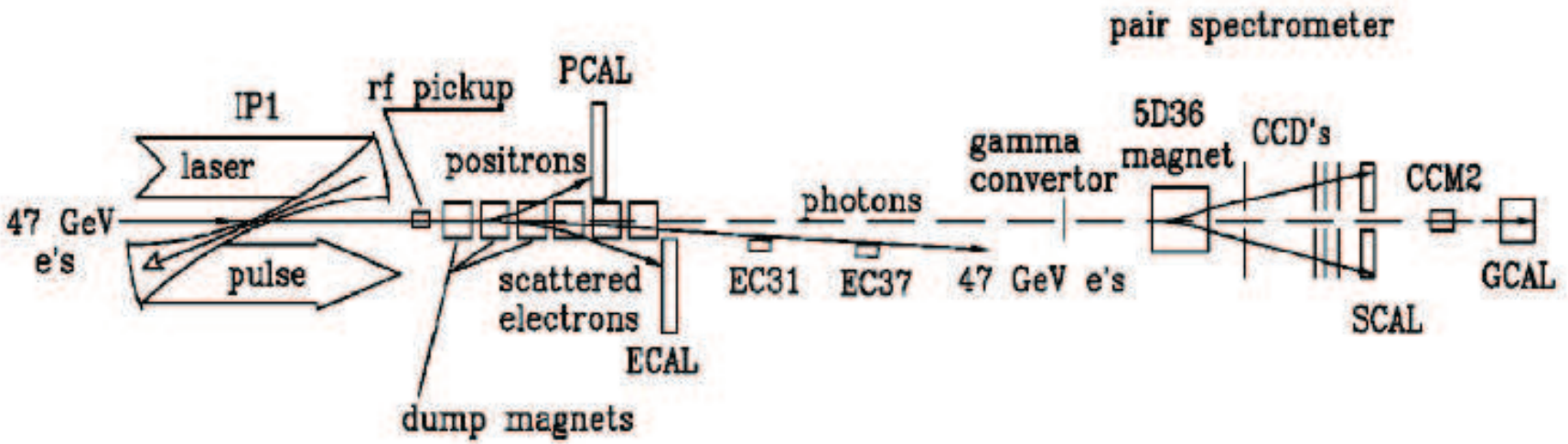
- Parasitic beam dump experiment exploiting FLASH-like e-beam (30 μA; 1.2 GeV) would enlarge discovery potential



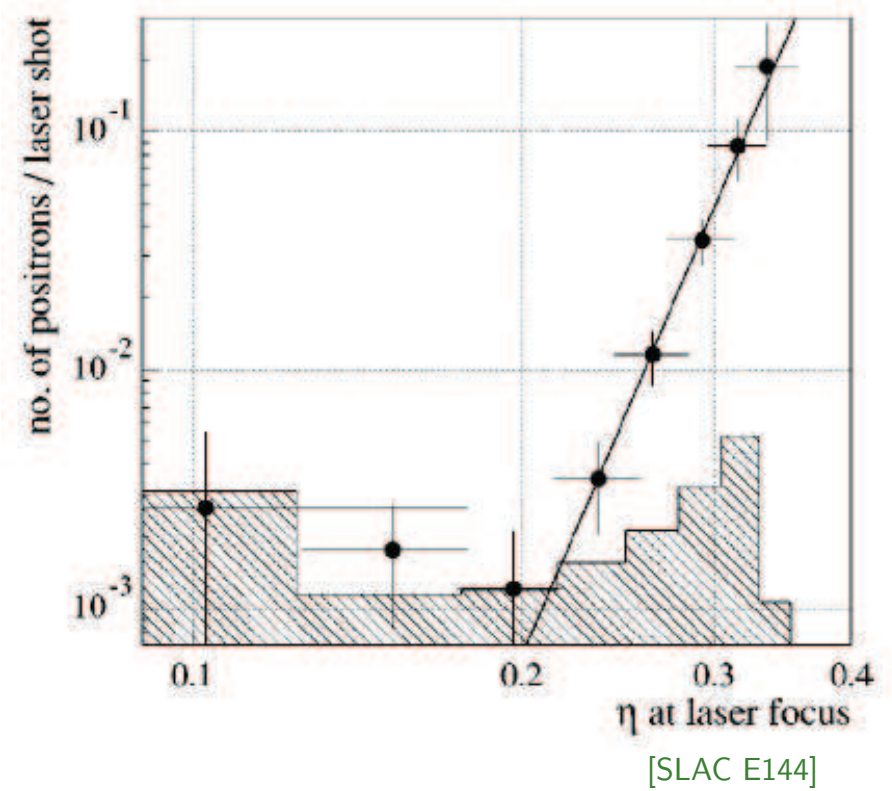
[Andreas,AR '10]

Non-linear QED in collision of e^- beam with intense laser beam

- SLAC E144 studied non-linear QED in the collision of a 46.6 GeV electron beam (the Final Focus Test Beam) with Terawatt pulses from a Nd:glass laser [Bula et al., PRL 76 (1996) 3116; Burke et al., PRL 79 (1997) 1626; Bamber et al., PRD 60 (1999) 092004]



- **Non-linear QED**
  multi-photon param. $\eta = \frac{e\mathcal{E}_{\rm L}}{\omega_{\rm L} m_e}$
  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$
    Electron yield,
    $Y_e \propto \eta^{2(n-1)} \propto I^{n-1}$
  - **Pair production:**
    * Stimulated process ($\eta \ll 1$)
      $\gamma + n\,\gamma_{\rm L} \to e^+e^-$
      Positron rate,
      $R_{e+} \propto \eta^{2n} \propto I^n$
    * Spontaneous tunneling process ($\eta \gg 1$)
      $R_{e+} \propto \exp(-8/3\kappa)$ where
      $\kappa = 2\frac{E_\gamma}{m_e}\frac{\mathcal{E}_{\rm L}}{\mathcal{E}_{\rm crit}}$



[SLAC E144]

- SLAC E144: $\eta \ll 1$, $\kappa \ll 1$

- Petawatt laser plus electron beam such as in FLASH or in XFEL will allow to probe the non-perturbative tunneling regime,

$$\eta \gg 1,$$

for the first time in the laboratory:

– laser at SLAC E144:

$$I \approx 0.5 \times 10^{18}\ \mathrm{W/cm^2}\ \text{at}\ 1035(527)\ \mathrm{nm}$$

– laser such as POLARIS currently set up in Jena reach easily

$$I \sim 10^{21}\ \mathrm{W/cm^2}\ \text{at}\ 1035(527)\ \mathrm{nm}$$

and thus more than one order of magnitude larger values of $\eta \propto I^{1/2}$

Conclusions

- There are experiments around the globe, notably at accelerator labs (CERN, DESY, FNAL, JLab, ...), exploiting/recycling existing equipment and intense particle beams,

New intensity frontier, complementary to energy frontier

- **DESY** has excellent opportunities at this new frontier:
  - **ALPS II:** stay at the forefront of laboratory searches for axions and axion-like particles with recycled superconducting HERA magnets
  - **HIPS:** (parasitic) electron beam dump experiment at DESY II (and later at FLASH?)
  - **Laser-e-beam collisions:** study of non-perturbative pair production at FLASH (and later XFEL?)