New Experiments at the Intensity Frontier

Andreas Ringwald
• **Axions- and axion-like particles** ⇒ laser-light shining through a wall experiment **ALPS II** (Any Light Particle Search)

• **Hidden or dark photons** ⇒ beam dump experiment **HIPS** (Hidden Particle Search)

• **Non-linear QED** ⇒ non-perturbative $e^+e^-$ pair production in collision of (multi-)GeV electron beam with petawatt laser beam
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, ...)
- light shining through a wall searches (e.g. ALPS, GammeV, ...)

=> two photon coupling $g$
• LSW (helioscopes) probe currently $g \sim 10^{-7} \text{ GeV}^{-1}$ ($g \sim 10^{-10} \text{ GeV}^{-1}$):

![Graph showing regions for various experiments and astronomical sources.]

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

A. Ringwald (DESY)
- **LSW experiments**

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

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\omega$</th>
<th>$P_{\text{prim}}$</th>
<th>$\beta_g$</th>
<th>Magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPS (DESY)</td>
<td>2.33 eV</td>
<td>4 W</td>
<td>300</td>
<td>$B_g = B_r = 5$ t</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$L_g = L_r = 4.21$ m</td>
</tr>
<tr>
<td>BFRT (Brookhaven)</td>
<td>2.47 eV</td>
<td>3 W</td>
<td>100</td>
<td>$B_g = B_r = 3.7$ t</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$L_g = L_r = 4.4$ m</td>
</tr>
<tr>
<td>BMV (LULI)</td>
<td>1.17 eV</td>
<td>$8 \times 10^{21}$ $\gamma$/pulse</td>
<td>14 pulses</td>
<td>$B_g = B_r = 12.3$ T</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$L_g = L_r = 0.4$ m</td>
</tr>
<tr>
<td>GammeV (Fermilab)</td>
<td>2.33 eV</td>
<td>$4 \times 10^{17}$ $\gamma$/pulse</td>
<td>3600 pulses</td>
<td>$B_g = B_r = 5$ t</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>$L_g = L_r = 3$ m</td>
</tr>
<tr>
<td>LIPSS (JLab)</td>
<td>1.03 eV</td>
<td>180 W</td>
<td>1</td>
<td>$B_g = B_r = 1.7$ t</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$L_g = L_r = 1$ m</td>
</tr>
<tr>
<td>OSQAR (CERN)</td>
<td>2.5 eV</td>
<td>15 W</td>
<td>1</td>
<td>$B_g = B_r = 9$ t</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$L_g = L_r = 7$ m</td>
</tr>
</tbody>
</table>

- **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

⇒ “**Not a WISP of evidence**”


• **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:**

<table>
<thead>
<tr>
<th>6 + 6 HERA magnets ($\ell = 8.8$ m)</th>
<th>$L = 52.8$ m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field</td>
<td>$B = 5.5$ T</td>
</tr>
<tr>
<td>Primary laser power</td>
<td>$P_{\text{prim}} = 3$ W</td>
</tr>
<tr>
<td>Power build-up</td>
<td>$\beta_g = \beta_r = 10^5$</td>
</tr>
<tr>
<td>Laser frequency</td>
<td>$\omega = 1.17$ eV</td>
</tr>
<tr>
<td>Overlap between ALP mode and electric field mode</td>
<td>$\eta = 0.95$</td>
</tr>
<tr>
<td>Detection time</td>
<td>$\tau = 100$ h</td>
</tr>
<tr>
<td>Dark count rate</td>
<td>$n_b = 10^{-4}$ Hz</td>
</tr>
</tbody>
</table>
• **Upgrade plans** at DESY (similar at Fermilab)
  - exploit more HERA (Tevatron) magnets
  - exploit resonant regeneration cavity [Hoogeveen,Ziegenhagen ’91; Sikivie, Tanner, van Bibber ’07]

⇒ **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 $\gamma'$:**
  - 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)
  - 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 $\gamma - \gamma'$ mixing angle $\chi$ 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:

![Graph showing sensitivity vs. mass](image)

[Andreas, AR '10]

• **APEX** at JLab's CEBAF (80 $\mu$A; 2 ÷ 6 GeV) and A1 collaboration at MAMI (100 $\mu$A; 800 MeV ÷ 1.6 GeV) made already test runs

A. Ringwald (DESY)

Dortmund, October 2010
Proposals: **JLab:** HPS at CEBAF; **DarkLight** at FEL (10 mA; $E_{\text{max}} = 140$ MeV); **Mainz** internal gas experiment at proposed **MESA** facility

[Andreas, AR '10]
Parasitic beam dump experiment exploiting FLASH-like $e$-beam (30 $\mu$A; 1.2 GeV) would enlarge discovery potential
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. \( \eta = \frac{eE_L}{\omega_L m_e} \)

– **Non-linear Compton**
  \( e + n \gamma_L \rightarrow e + \gamma \)
  Electron yield,
  \( Y_e \propto \eta^{2(n-1)} \propto I^{n-1} \)

– **Pair production:**
  * Stimulated process \((\eta \ll 1)\)
    \( \gamma + n \gamma_L \rightarrow e^+ e^- \)
    Positron rate,
    \( R_{e^+} \propto \eta^{2n} \propto I^n \)
  * Spontaneous tunneling process \((\eta \gg 1)\)
    \( R_{e^+} \propto \exp(-8/3\kappa) \) where
    \( \kappa = 2\frac{E_\gamma E_L}{m_e \varepsilon_{\text{crit}}} \)

● **SLAC E144**
  \( \eta \ll 1, \kappa \ll 1 \)

A. Ringwald (DESY)
• 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:

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

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

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

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?)