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Heavy Photon Search

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The Hidden Sectors

➔ Hidden sectors

- ➔ **The universe may include *Hidden Sectors***

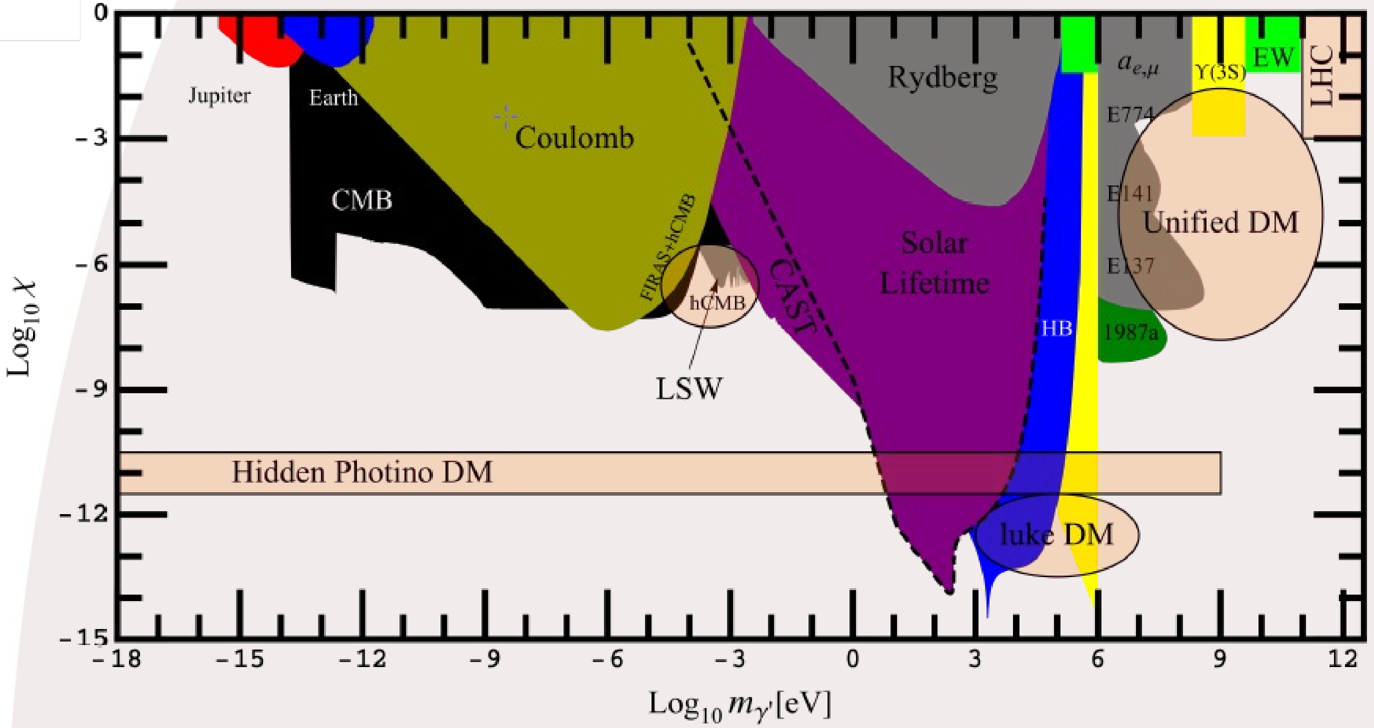
  i.e. particles and forces that don't couple directly to the Standard Model
- ➔ **Dark matter may be part of a *hidden sector***
- ➔ **Hidden sectors would be detectable through gravity and "*portals*"**

  The *photon portal* , through which the SM photon mixes with the hidden sector photon, can allow our world to interact with the hidden sector

➔ The heavy photon (A') is a conjectured new particle that can mix with SM photon

- ➔ **U(1) boson**
- ➔ **Small coupling to electrons (reduced by ε)**
- ➔ **It is massive !**

The Heavy Photon Motivations



➔ **Why assume there are more U(1)'s in Nature?**

- ➔ **String theories and other BSM theories generate hidden sectors with additional U(1)'s**
- ➔ **Given that only 4% of the universal mass-energy is well-accounted for, there is plenty of room!**
- ➔ **We will concentrate on the "unified DM" region that fits particularly well with an A' as the main force between DM particles**

The Heavy Photon Motivations

→ Impact on direct dark matter searches

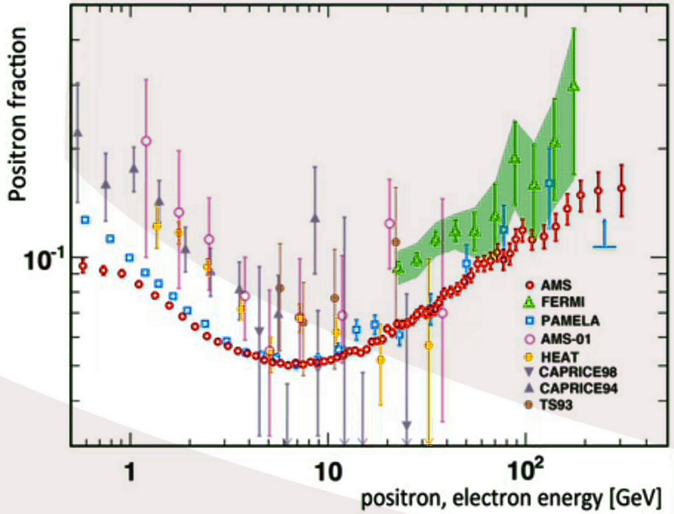
- → It is possible to explain various unexpected and apparently contradicting results using a new force in the dark sector
- → In particular discrepancies between direct dark matter searches (CDMS & XENON100 vs DAMA/LIBRA & CoGeNT)

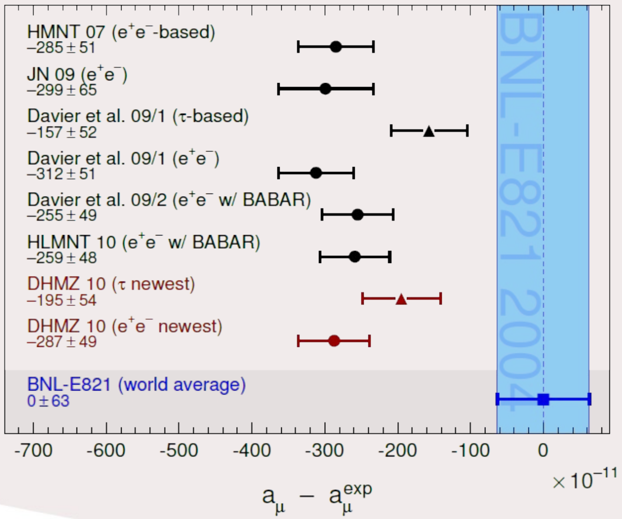
→ Observation of unexpected flux of positrons can be explained by a coupling of A' to DM

- → Mass > MeV

→ Could help solve the muonic g-2 discrepancy (3σ)

- → By adding new diagrams the presence of a new force would modify the theoretical g-2





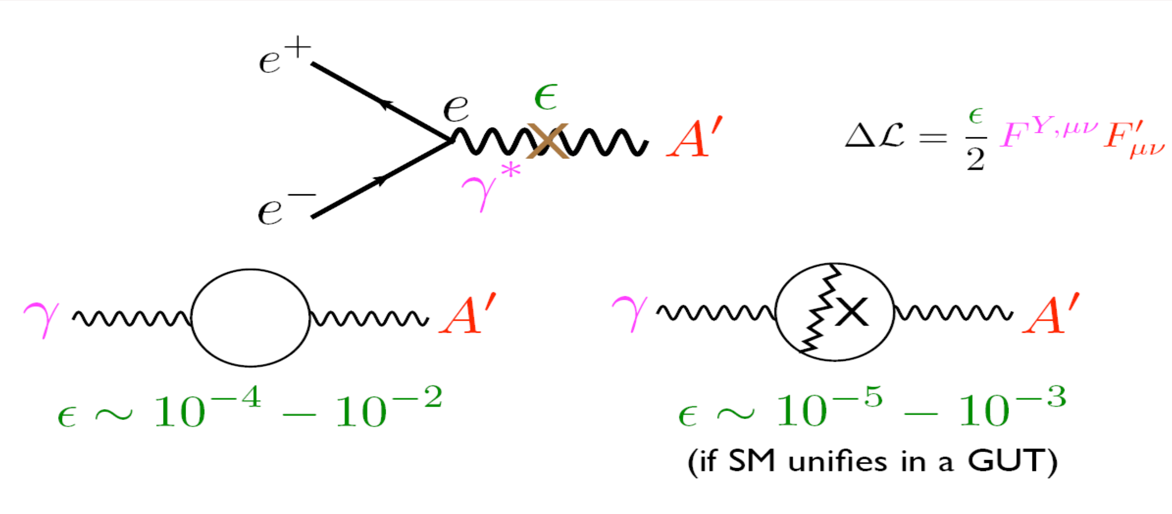
The Heavy Photon Search

➔ Where to look for heavy photon ?

- ➔ **Masses from few MeV to a GeV**
  - ➔ Lower limit set by previous measurements in the high ε region
  - ➔ Higher limit set by the absence of anti-proton excess in cosmic rays

- ➔ **Vector boson**

- ➔ **Small coupling to electrons (reduced by ε)**
  - ➔ Perturbative contributions like heavy messengers
  - ➔ Non-perturbative contributions and other effects can lead to even smaller coupling (frequent in string theories)



Production of the Heavy Photon

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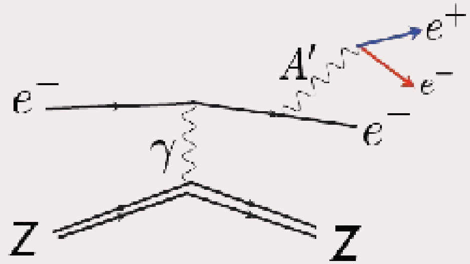
- ➔ **Production by bremsstrahlung like process**
  - ➔ **High Z target (W) to enhance production mechanism)**



- ➔ **Important QED backgrounds**

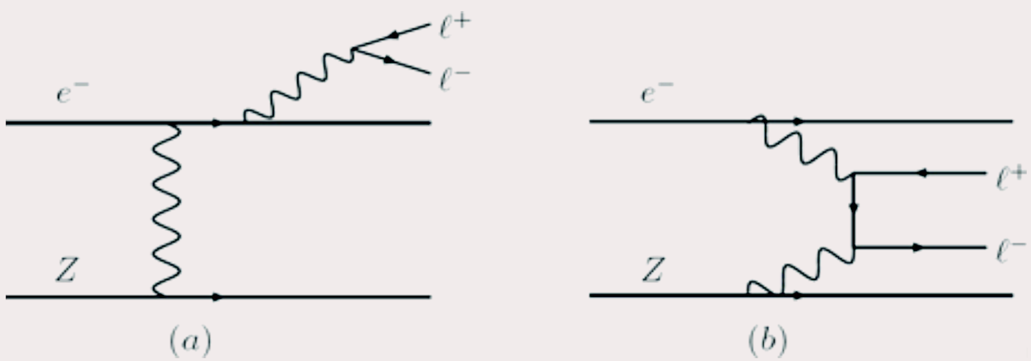
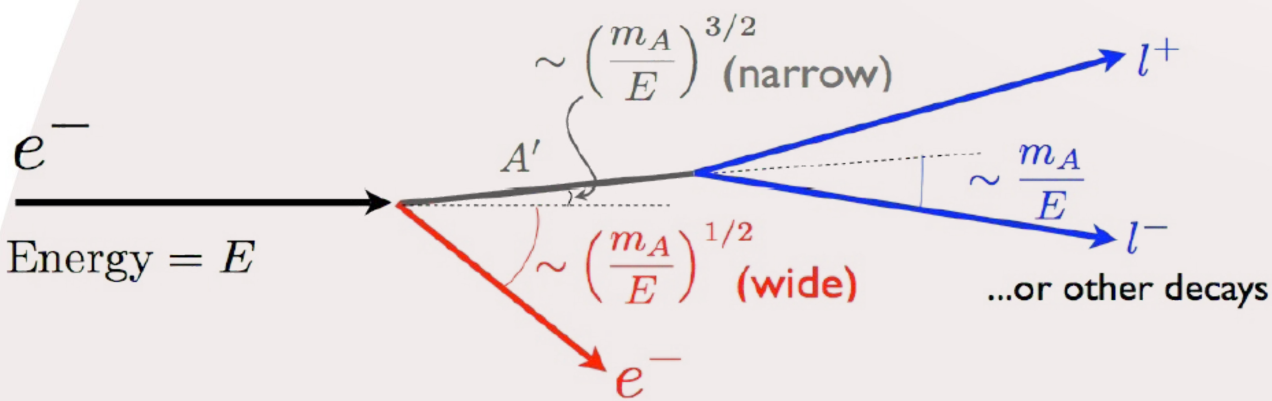


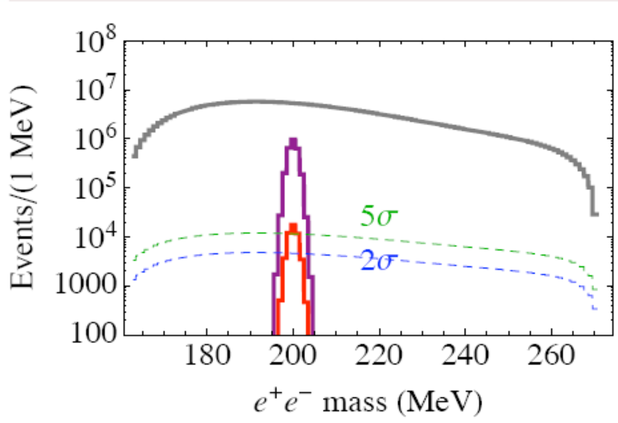
FIG. 4: Sample diagrams of (left) radiative trident (γ^*) and (right) Bethe-Heitler trident reactions that comprise the primary background to the $A' \to l^+l^-$ search.

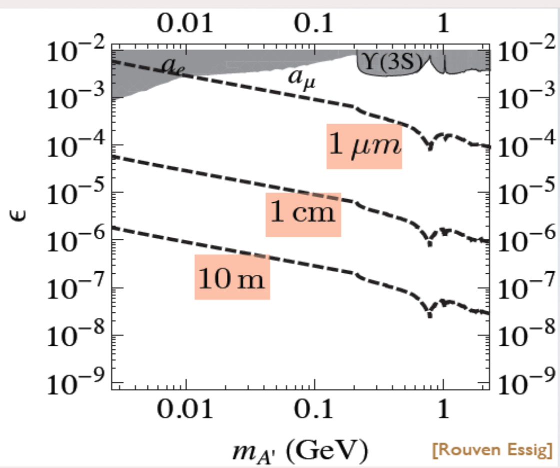
- ➔ **Use very thin target (0.00125 RL) to reduce hadronic backgrounds and multiple scattering**
  - ➔ **High beam intensity with thin target limited by heat problems**

Detection of the Heavy Photon



- ➔ **Search based on a bump hunt**
  - ➔ **Looking for a peak in the large QED background**
  - ➔ **Limited at very low coupling**
- ➔ **Supplemented by displaced vertex**
  - ➔ **Reduce drastically the QED background**
  - ➔ **Limited at high coupling because we need a long life time**



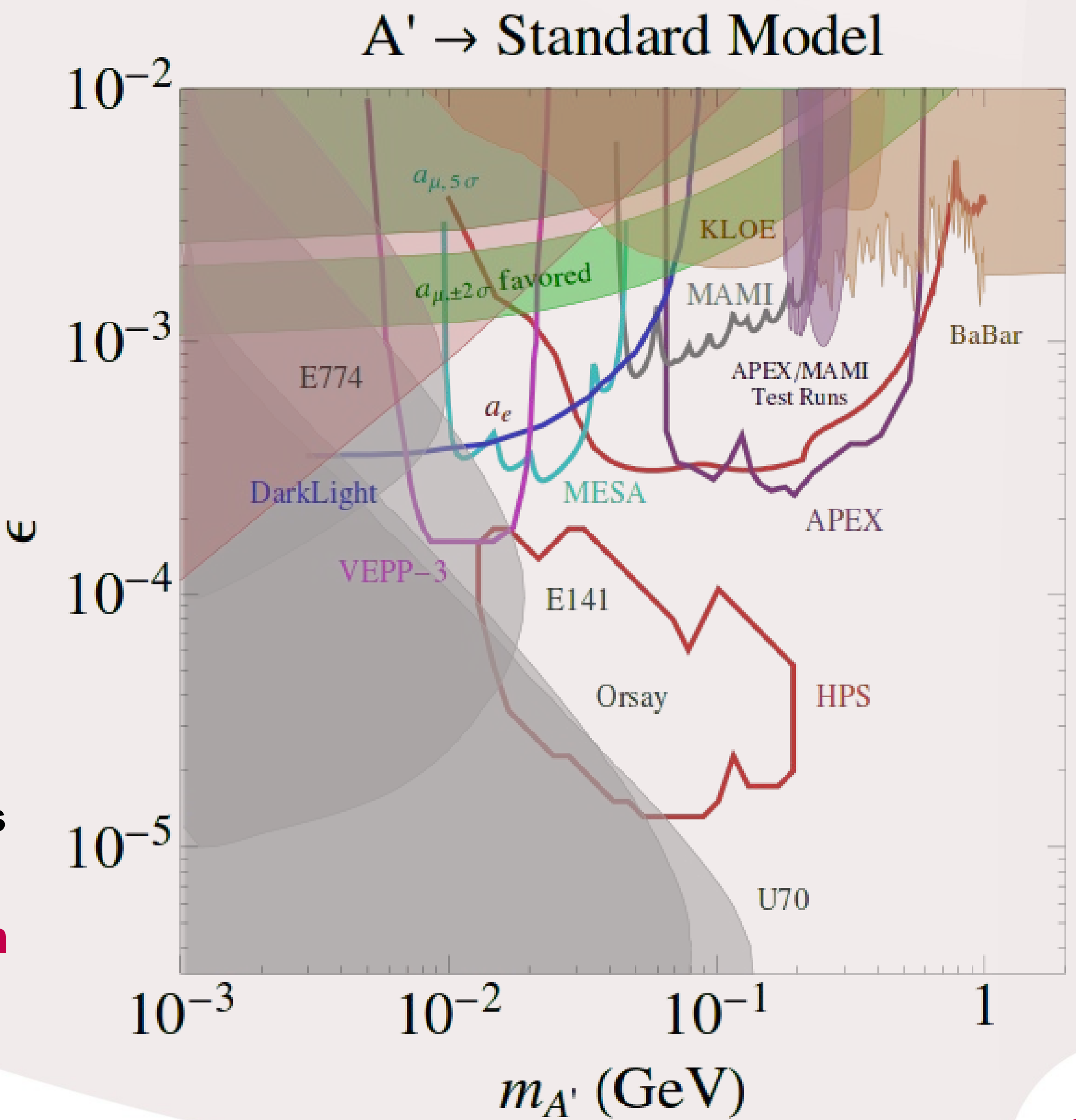


Heavy Photon Searches

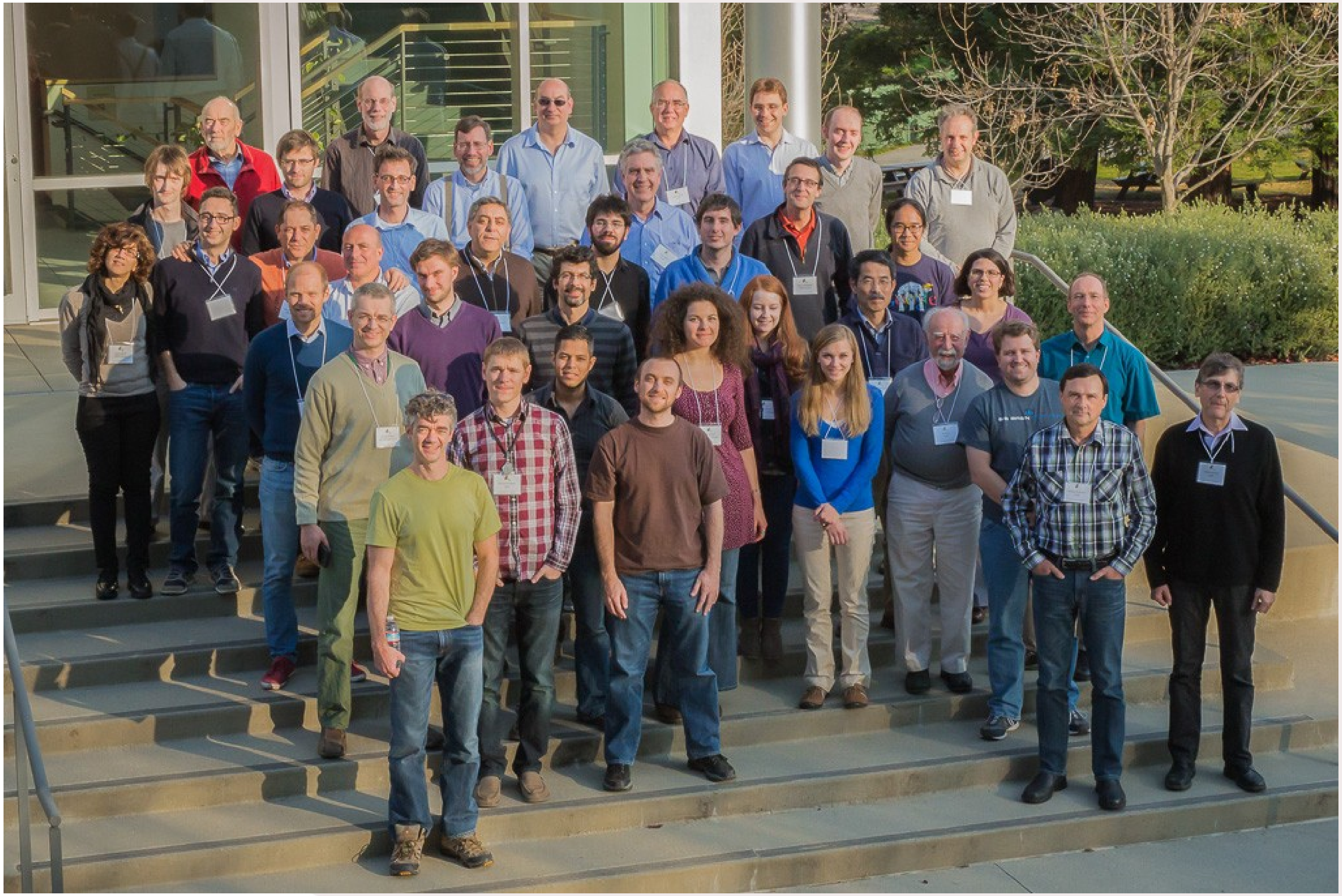
- **Former measurements are mainly:**
  - **Beam dump experiments**
  - **Lepton collider experiments**

- **Three strategies for recent fixed target experiments**
  - **Two arm spectrometers**
  - **Forward vertexing spectrometers**
  - **Full final state measurements**

- **In green the g-2 favored region**



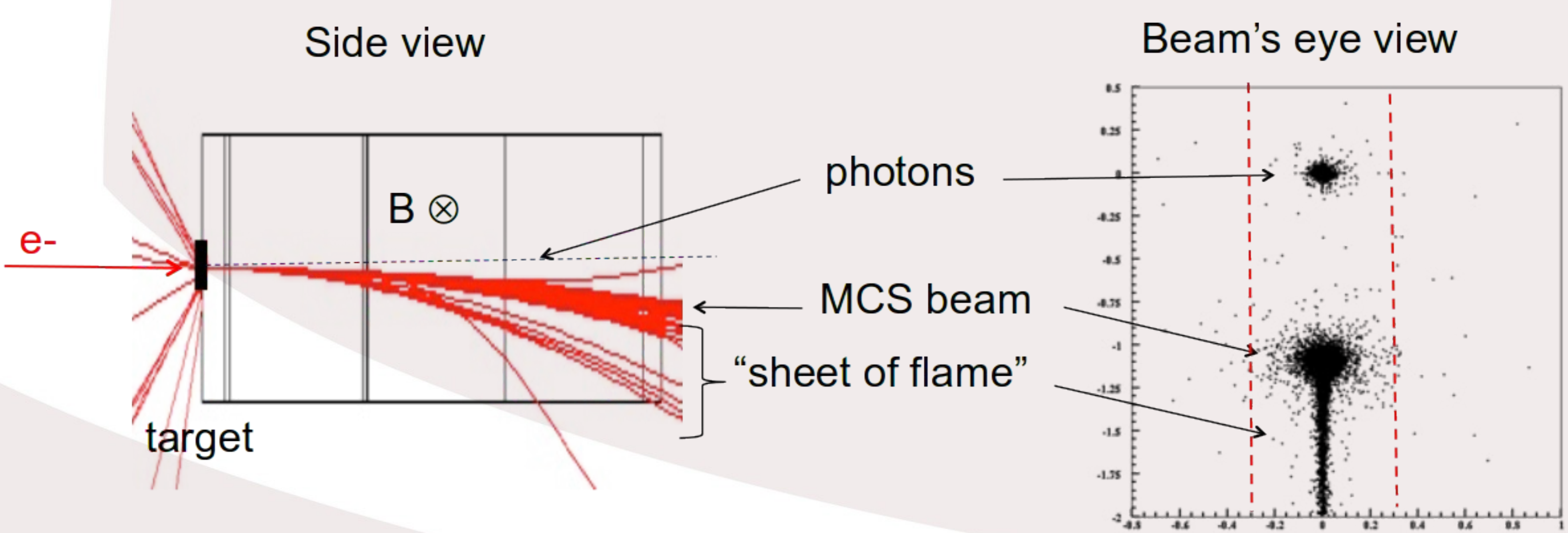
The HPS collaboration



An effort from ~ 80 members from ~ 20 institutions

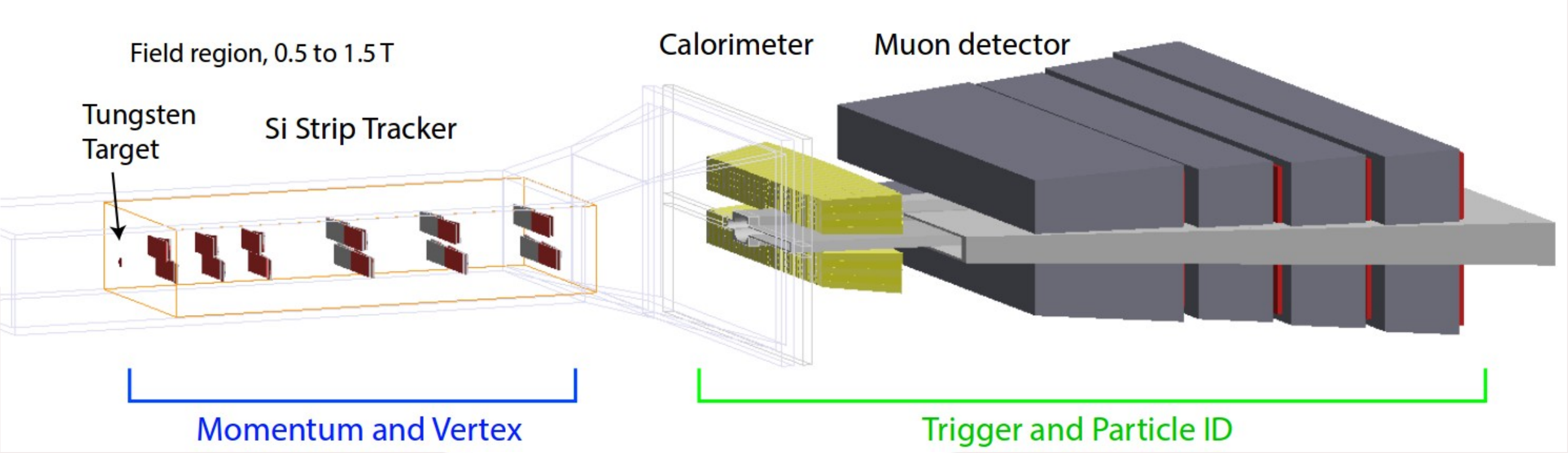
HPS Experimental Setup

- ➔ **Forward, compact spectrometer and vertex detector**
  - ➔ **Silicon detector in ~1T dipole magnet**
- ➔ **Dipole analyzing magnet spreads the degraded beam and all low angle scattered electron**
  - ➔ **All detectors are split to avoid this region**
- ➔ **The whole tracking system is kept in the beam line vacuum to limit scattering**
  - ➔ **First silicon detectors are placed only half a millimeter from the center of the beam!**

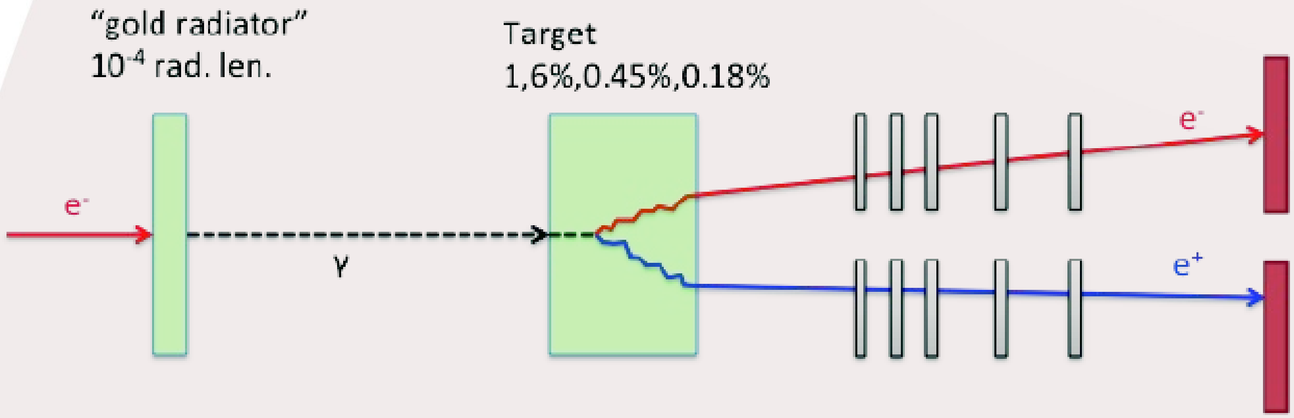


HPS Experimental Setup

- **EM Calorimeter provides the trigger signal**
  - **Allows to identify electrons and positrons**
  - **$PbWO_4$ Crystals refurbished from CLAS IC calorimeter**
  - **Main responsibility of the Orsay group**
- **Small production cross section for the A'**
  - **Need for high statistics → high luminosity**
  - **Topological selection at trigger level**
  - **High rate DAQ up to 43 kHz**
- **Muon detector for alternate trigger & muon ID is planned for the future**



HPS Test Run (1/2)



➔ **The main goal was to validate the critical assumptions made in our simulations for rates and occupancies**

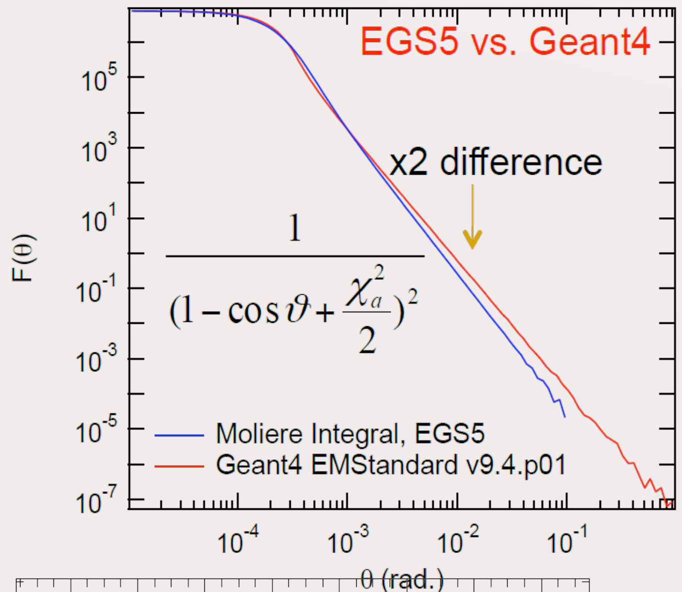
- ➔ **Most of trigger rates come from multiple Coulomb scattered electrons**
- ➔ **Correct simulation of the electromagnetic background is therefore crucial for the design of the experiment**
- ➔ **Two simulation tools, GEANT4 and EGS5 gave different results in the rate estimates**

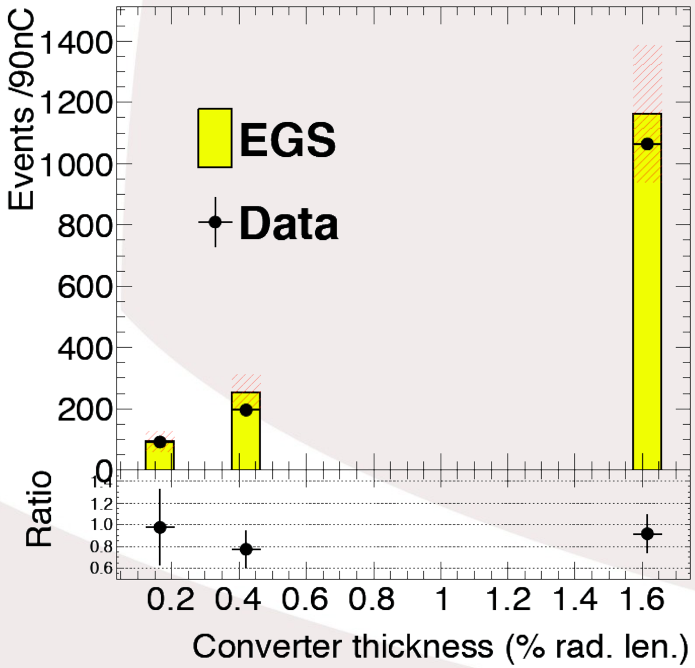
➔ **The other goal of the test run was to demonstrate the feasibility of the proposed apparatus and data acquisition**

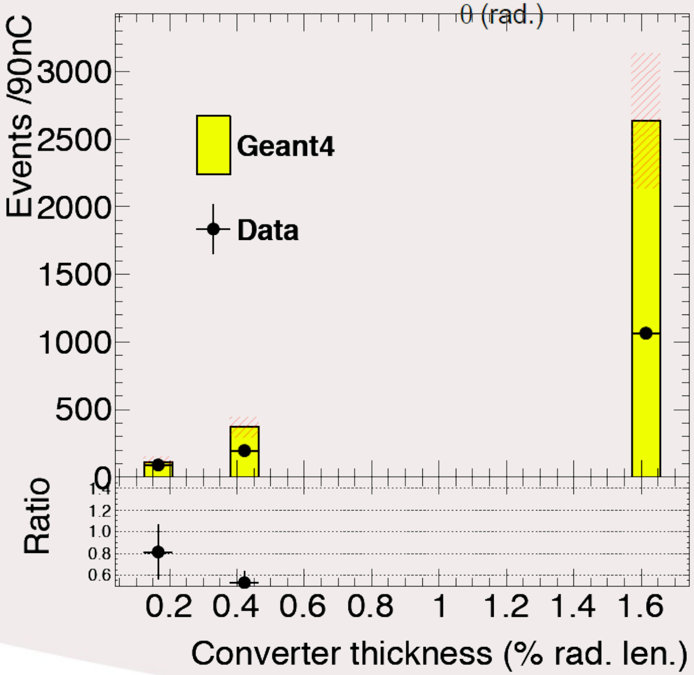
HPS Test Run (2/2)

- ➔ **The test run was successful but consist only on a very reduced data set**
  - ➔ **No new A' search limits**
  - ➔ **Validation of our detection system**

- ➔ **We found that EGS was giving the correct estimation for large angle coulomb scattering against GEANT 4**







Silicon Vertex Tracker

➔ **Will be installed in the vacuum inside the analyzing magnet**

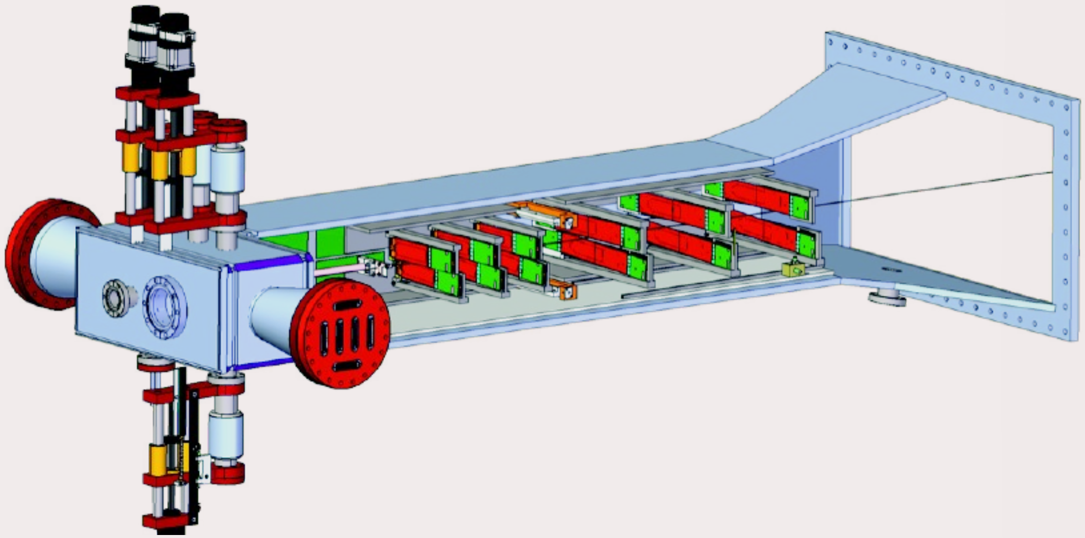
- ➔ **First layer is located at 10 cm from the target for maximum precision on vertex position**
- ➔ **the first layer of silicon sensor is only 0.5 mm from the center of the beam to detect small A' masses**

Layer number	1	2	3	4	5	6
nominal z, from target (cm)	10	20	30	50	70	90
Stereo Angle (mrad)	100	100	100	50	50	50
Bend-plane resolution (μm)	≈60	≈60	≈60	≈120	≈120	≈120
Non-bend resolution (μm)	≈6	≈6	≈6	≈6	≈6	≈6
Number of sensors	4	4	4	8	8	8
Nominal dead zone in y (mm)	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5
Module power consumption (W)	6.9	6.9	6.9	13.8	13.8	13.8

➔ **Silicon will be actively cooled to retard radiation damage**

➔ **The sensors have 60 µm readout pitch**

➔ **The sensors are read out continuously at 40 MHz**

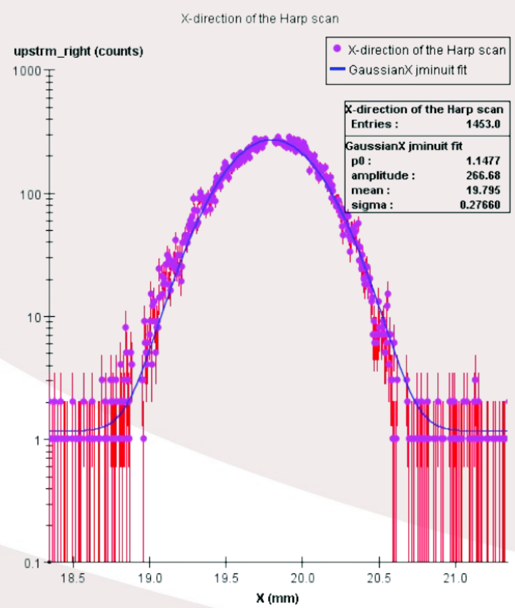


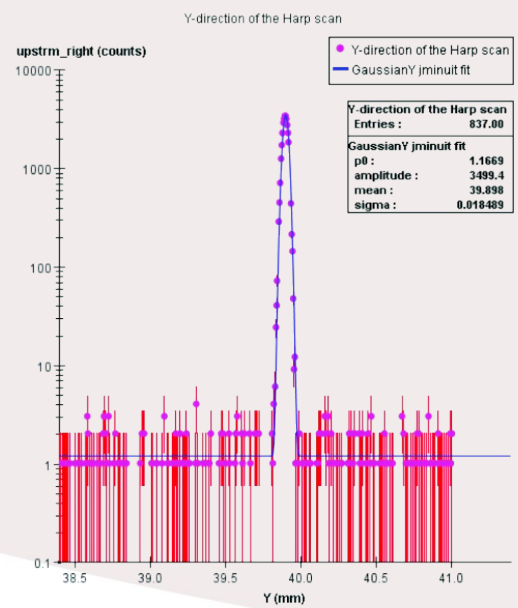
Beam Characteristics

- ➔ HPS will use up to 500 nA electron beam of 1.1, 2.2 and 6.6 GeV and a thin W target
- ➔The size of the beam is very important because of
  - ➔ The proximity of the silicon tracker (0.5 mm from the beam)
  - ➔ The heat load that can be taken by the target
  - ➔ The precise vertex reconstruction we want to measure
- ➔ Asymmetric profile will be used in order to satisfy all these criteria

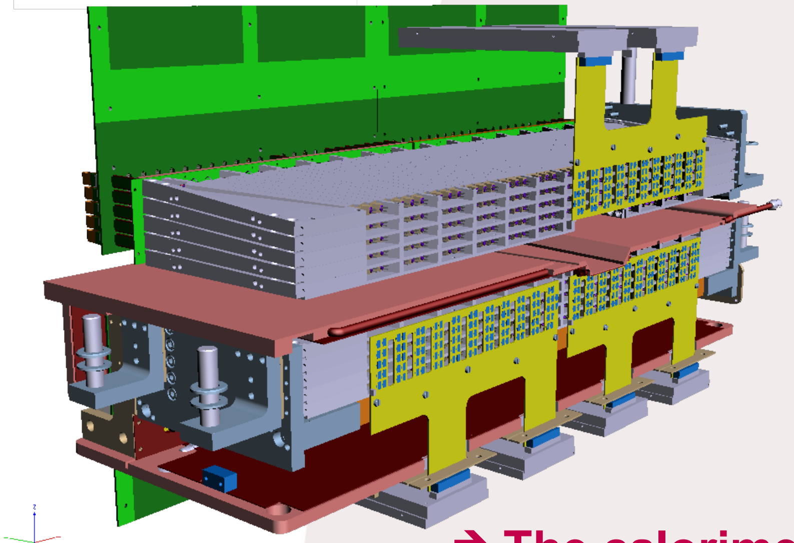
Parameter	Requirement			Unit
E	1100	2200	6600	MeV
$\delta E/E$	$< 10^{-4}$			
Current	< 200	< 400	< 500	nA
Current Instability	< 5			%
σ_x	< 300			μm
σ_y	< 50			μm
Position Stability	< 30			μm
Divergence	< 100			μrad
Beam Halo ($> 5\sigma_Y$)	$< 10^{-5}$			

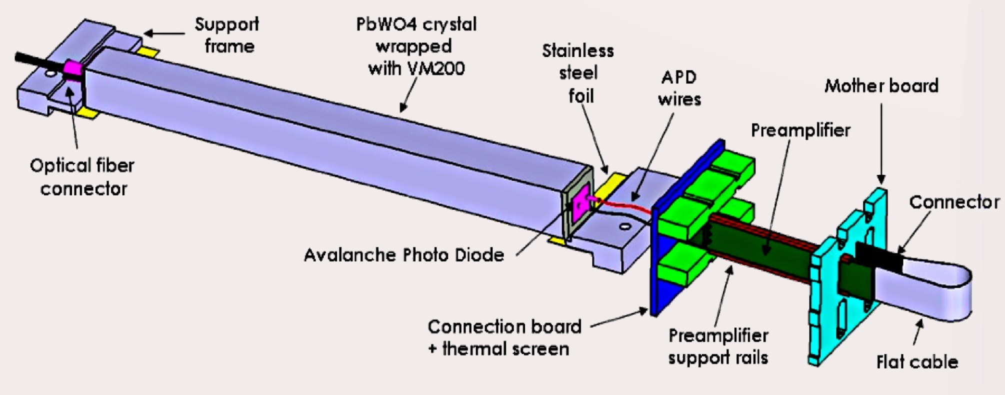
TABLE I: Required beam parameters.





Electromagnetic Calorimeter



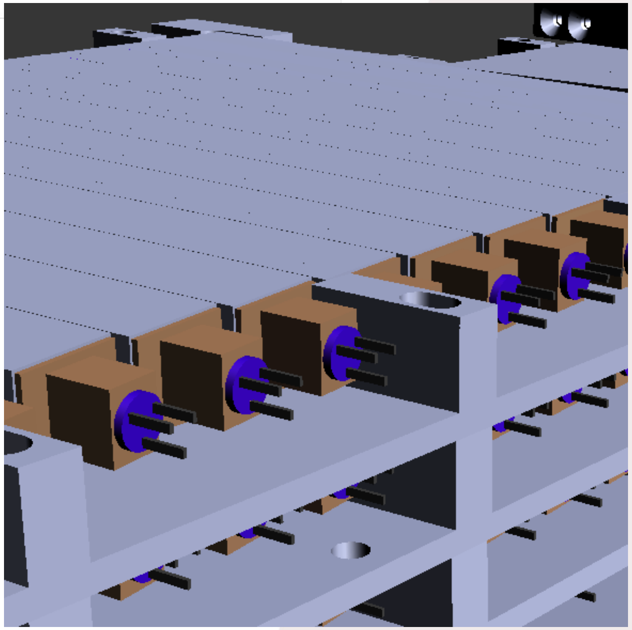


→ The calorimeter in details

- → We have 442 PbWO4 crystals (from CLAS IC)
- → Light amplified with new larger Avalanche Photo-Diodes
- → Thermal box keeps the calorimeter at 18 degree Celsius
- → All the detector electronics is updated (mother boards, preamplifiers and FADC)
- → Addition of a light monitoring system using LEDs placed in front of the crystals

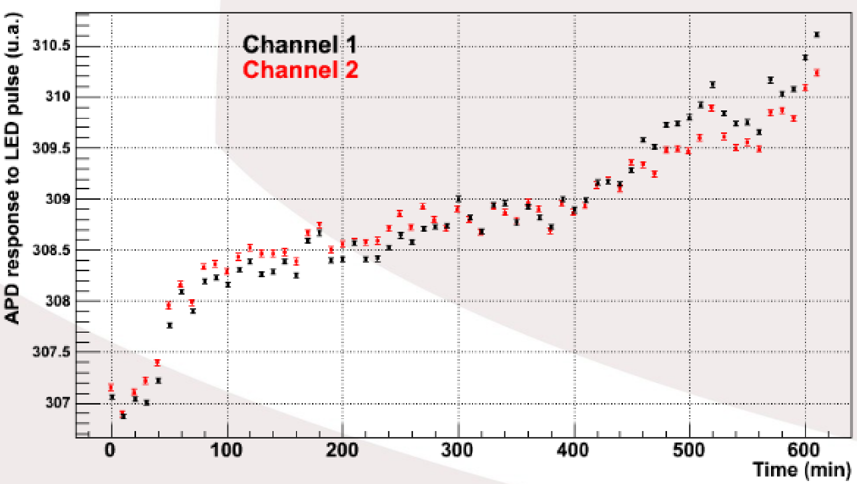
→ Lot of this work is done in IPN Orsay

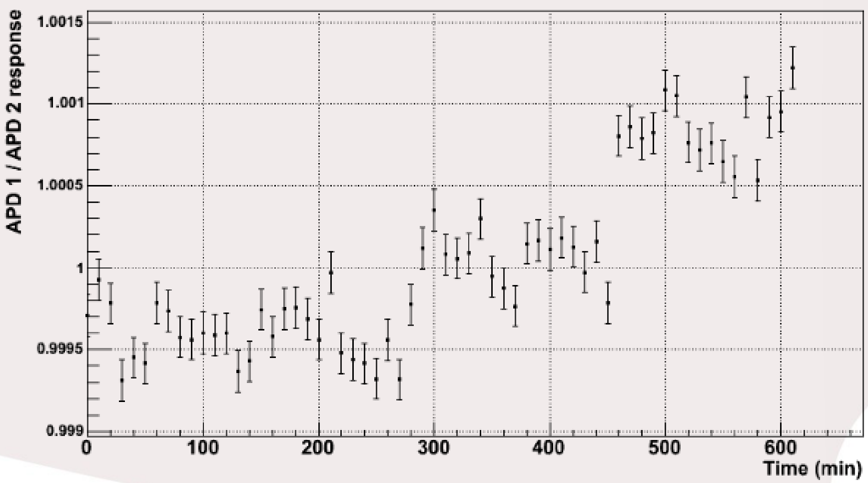
Light Monitoring System



- LED are inserted in front of crystal to send light pulse
  - system has been tested showing overall stability around 1% and 0.1% for channel to channel comparisons
- We are going to use bi-color LEDs in order to test different wave length (red and blue)
  - Radiation damage tests showed ~10% effect on blue but no effect on red
- Important tool to check variation of gains and time calibration during the run

10 hours strip-charts





Trigger Algorithm

- **Cluster finding**
  - Look at energy deposit for all 3x3 configurations of crystal
  - Need two clusters on different sides of the beam
- **Topological Selection**
  - Energy sum, time coincidence, energy difference, coplanarity and energy slope
- **The Maximum rate for electronics is 43 kHz**
- **Evaluation using Monte-Carlo Simulation**
  - Reproduce bunches of electrons
  - Simulation also helped determine trigger cuts

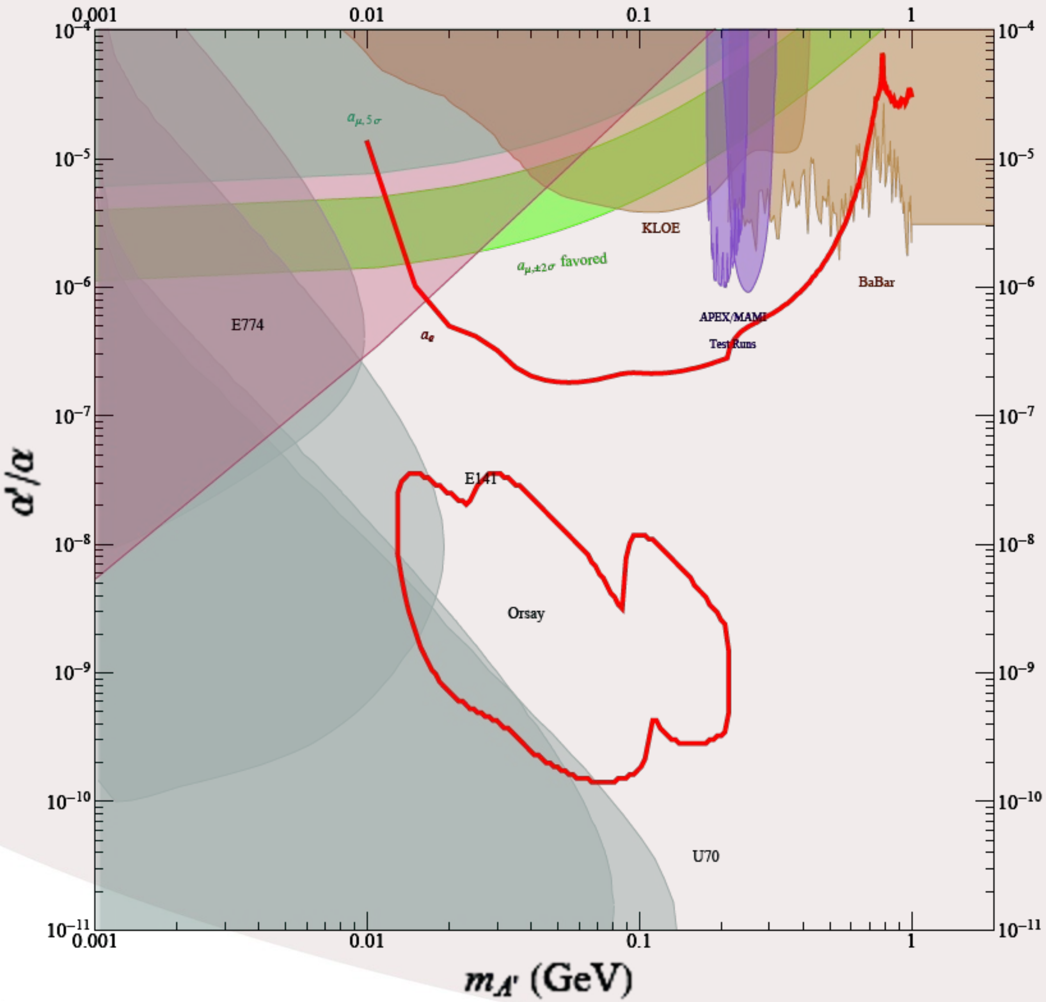
Sample	Rate (kHz)
1.1 GeV beam background	15.7 ± 0.4
1.1 GeV beam background+tridents	18.3 ± 0.4
2.2 GeV beam background	11.2 ± 0.3
2.2 GeV beam background+tridents	15.8 ± 0.4
6.6 GeV beam background	10.2 ± 0.3
6.6 GeV beam background+tridents	12.6 ± 0.4
6.6 GeV beam background+tridents+pions (FLUKA)	13.4 ± 0.4
6.6 GeV beam background+tridents+pions (G4)	13.5 ± 0.4

TABLE XVIII: Trigger rates using various background samples, with statistical uncertainties.

HPS performance

➔**Reach of the experiment for the simple bump hunt and the displaced vertex methods**

- ➔ **Combined data at 1.1, 2.2 and 6.6 GeV**



True Muonium

➔ HPS experiment has the potential to discover a new bound state of matter: the true muonium ($\mu^+\mu^-$) atom

➔ True muonium is an hydrogen like atom

- ➔ binding of E = - 1407 eV/n^2
- ➔ Much more compact than hydrogen !

➔ The production process is very similar to the one of A'

- ➔ When two muons are produced at close enough energy they can coalesce into a bound state
- ➔ Then decay into e^+e^- with a life time much shorter than free muons

➔ Search will require a vertex cut in order to suppress the QED background

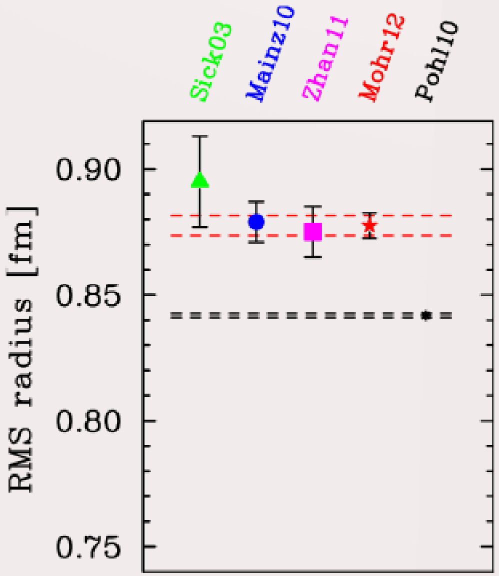
➔ Estimations indicates that we will be able to discover the 1S, 2S and 2P states of true muonium

- ➔ Obtain ~15 true muonium events with two weeks of 6.6 GeV run planned for 2015
- ➔ A. Banburski and P. Schuster, PRD 86, 093007 (2012)

Links to Nuclear Physics

➔Proton radius puzzle

- ➔ The discrepancy of atomic and electron scattering measurements with muonic ones is at 7 sigma level
- ➔ Could be explained by some extra force from the dark sector such as the one we look for in HPS
  - ➔ Like the muonic g-2 discrepancy
- ➔ Can be explained by a fundamental difference between electron and muons we missed
  - ➔ This can be uncover by the true muonium measurement



➔Hadronization

- ➔ True muonium production by coalescence of muons is very similar to coalescence theory used to describe hadronization
- ➔ Measuring the production rate of true muonium will test how well we understand this phenomena with the well understood QED interaction

Outlooks

- ➔ **Scientific program with a wide reach**
  - ➔ Search for A'
    - ➔ Linked to dark matter, cosmology and precision QED
  - ➔ Search for true muonium
    - ➔ Linked to precision QED and hadronic physics

- ➔ **Development & Constructions 2013-2014**
  - ➔ Construction of all SVT modules
  - ➔ We will improve the ECal with new APDs and preamplifier
  - ➔ Addition of a LED monitoring system

- ➔ **Data taking in the Hall B of Jefferson laboratory at the end of 2014 and during 2015**