# The HPS experiment at JLab

**Marzio De Napoli**
**INFN - Sezione di Catania**

**for the HPS Collaboration**

International Conference
*Dark Matter, Hadron Physics and Fusion Physics*
Messina (Italy) - September 24-26, 2014

# Heavy Photon Search Collaboration

**Jefferson Lab** - N. Baltzel, S. Boryarinov, V. Burkert, C. Cuevas, A. Deur, H. Egiyan, L. Elouadrhiri, A. Freyberger, F.X. Girod, V. Kubarovsky, B. Raydo, Y. Sharabian, S. Stepanyan, M. Ungaro, B. Wojtsekhowski

**SLAC** - C. Field, N. Graf, M. Graham, P. Hansson, R. Herbst, J. Jaros, T. Maruyama, J. Mccormick, K. Moffeit, T. Nelson, A Odian, M. Oriunno, B. Reese, S. Uemura

**UCSC** V. Fadeyev, A. Grillo, O. Moreno

**INFN Genova** M. Battaglieri, A. Celentano, R. De Vita, M. Osipenko

**INFN Catania** M. De Napoli, E. Leonora, N. Randazzo

**INFN Sassari** M. Carpinelli, V. Sipala

**INFN Torino** D. Calvo, A. Filippi

**INFN U. Roma** L. Colanieri, A. D'Angelo A. Rizzo

**INFN Padova** G. Simi

**University of New Hampshire:** M. Holtrop, K. Mccarty, R. Paremuzyan

**William and Mary:** K. Griffioen, S.Paul

**Old Dominion University:** S. Bueltmann, H. Vance, L. Weinstein

**Glasgow University:** K. Livingston, B. McKinnon, D. Sokhan

**FNAL:** W. Cooper

**YerPhI:** N. Dashyan, N. Gevorgyan, H. Voskanyan

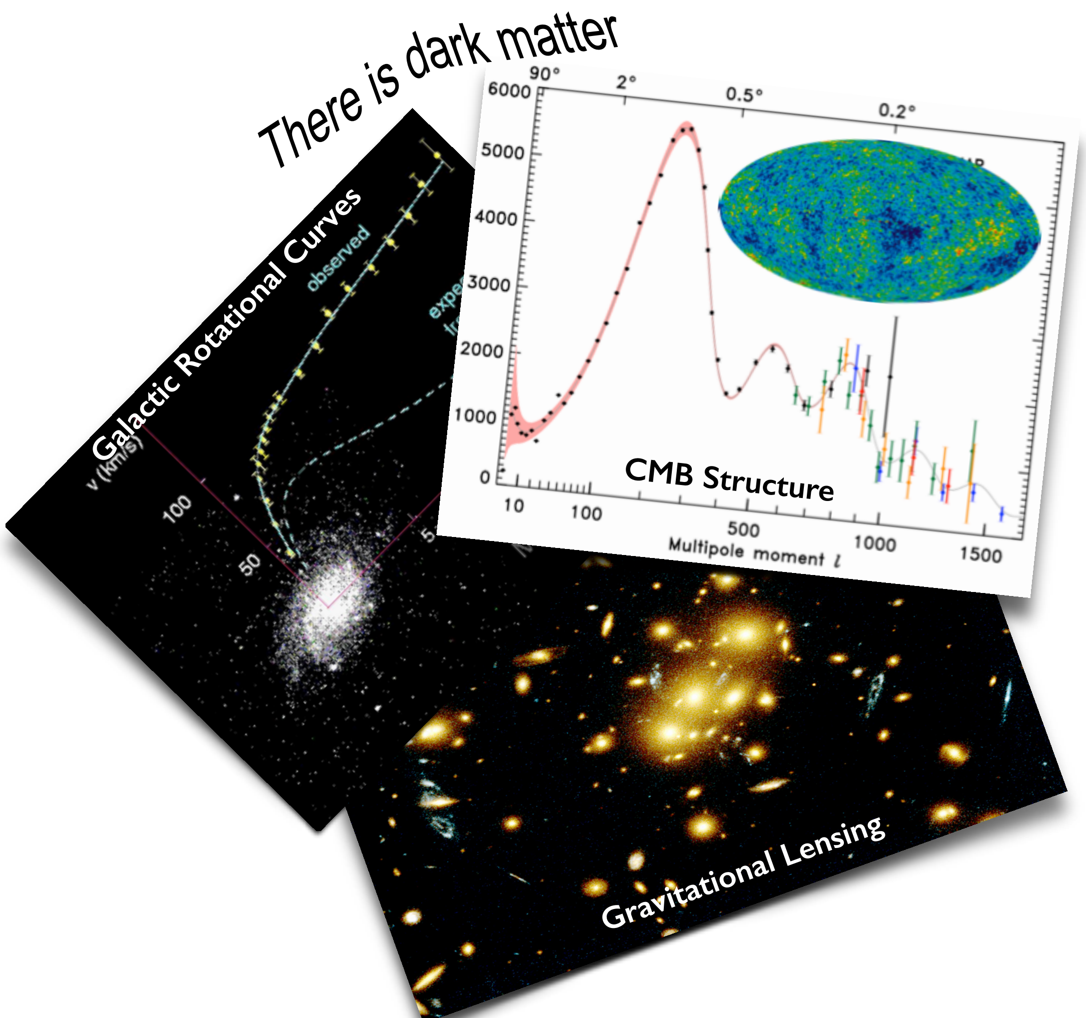
**Stony Brook University:** R. Essig

**Perimeter Institute:** P. Schuster, N. Toro

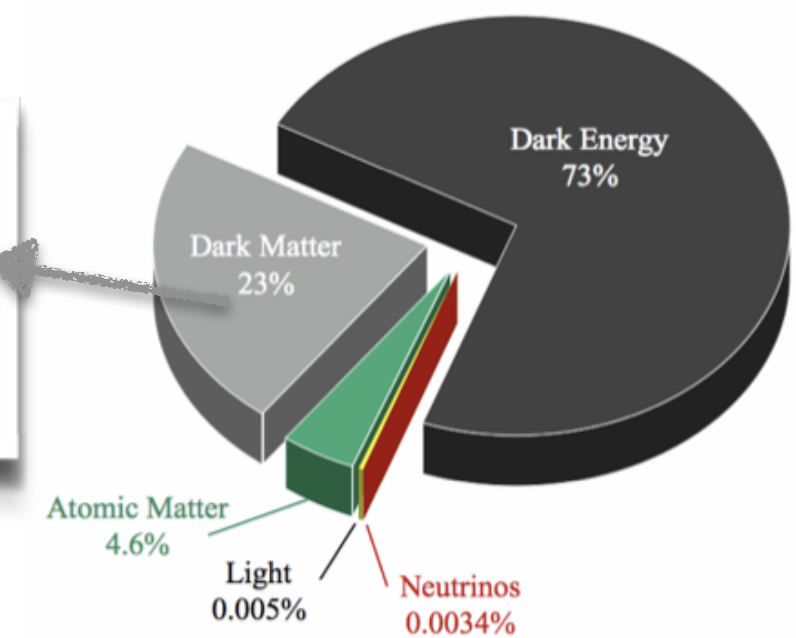
**IPN Orsay:** G. Charles, R. Dupre, M. Guidal, S. Niccolai

**Idaho University:** M. Khandaker

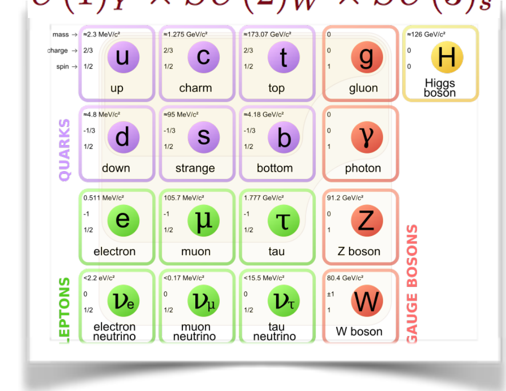
# Dark Sectors with Heavy Photons



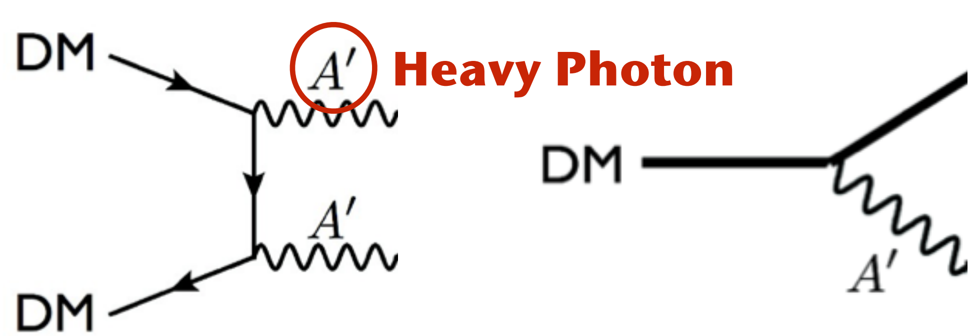

**Is it made by a "Dark Sector" of new particles and interactions?**




$U(1)_Y \times SU(2)_W \times SU(3)_s$




**AN ADDITIONAL U(1) GAUGE SYMMETRY IN NATURE IS PREDICTED IN MANY BEYOND STANDARD MODEL THEORIES**



# Kinetic Mixing

Volume 166B, number 2 PHYSICS LETTERS 9 January 1986

**An old idea: if there is an additional U(1) symmetry, the new vector boson A' kinetically mixes with the SM photon**

TWO U(1)'S AND $\epsilon$ CHARGE SHIFTS

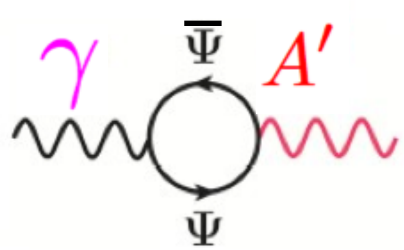
Bob HOLDOM

*Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7*

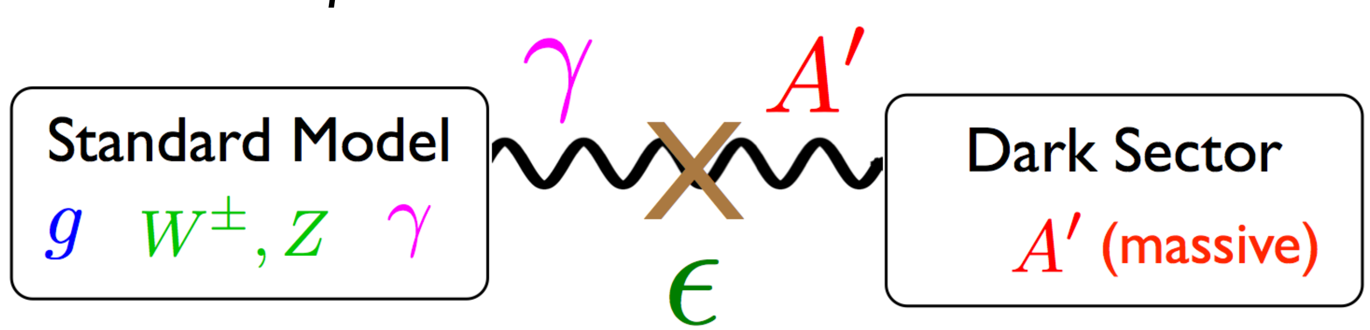
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic mixing"

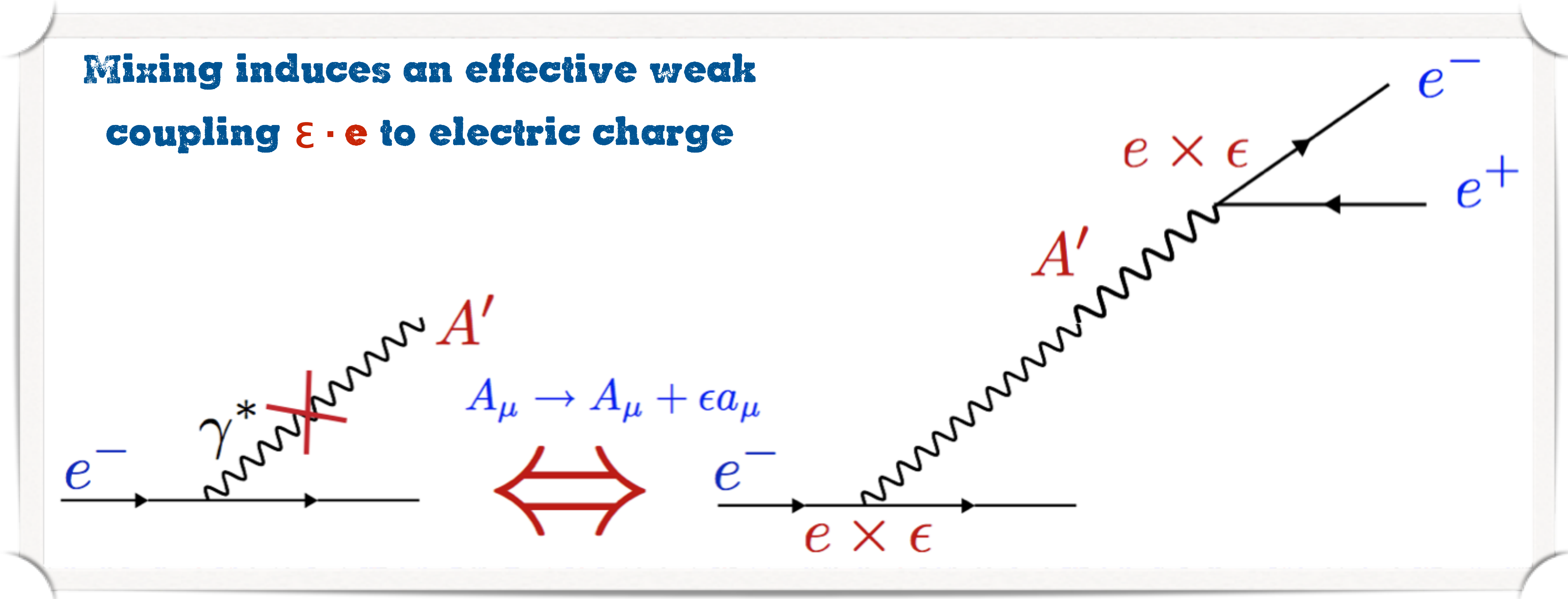
*Loops of heavy particles charged under photon and A'*




*A' acts as a "portal" between the SM and the new sector*



# Coupling to electric charge



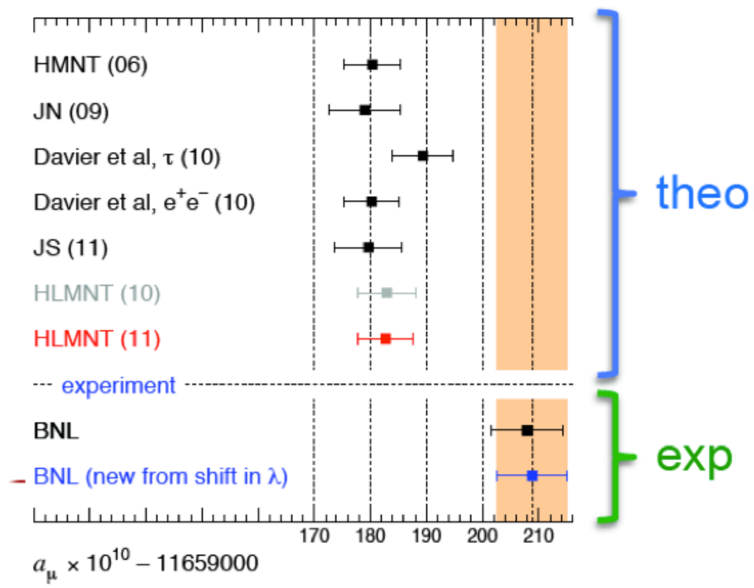
# Motivations …
## … for a light weakly coupled U(1) gauge boson

**IT IS THEORETICALLY WELL MOTIVATED AND IT CAN EXPLAIN VARIOUS PUZZLING MEASUREMENTS**

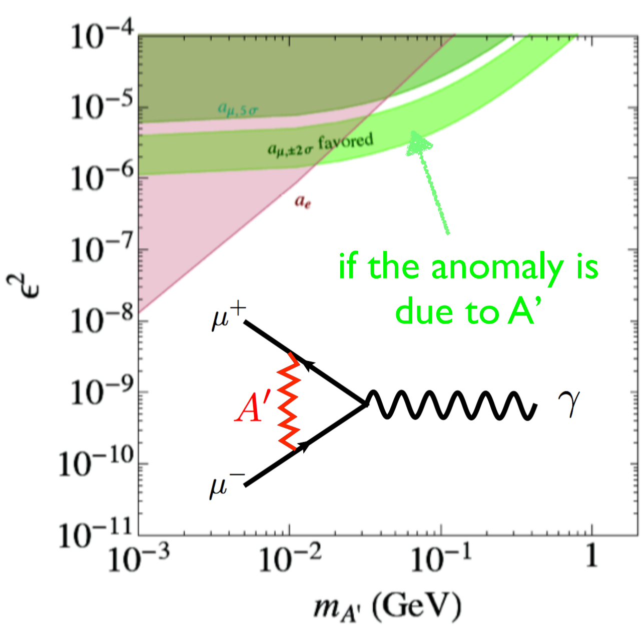
### $(g-2)_\mu$ anomaly

M. Pospelov, Phys. Rev. D80 (2009) 095002

$$a_\mu \equiv \frac{g_\mu - 2}{2}$$



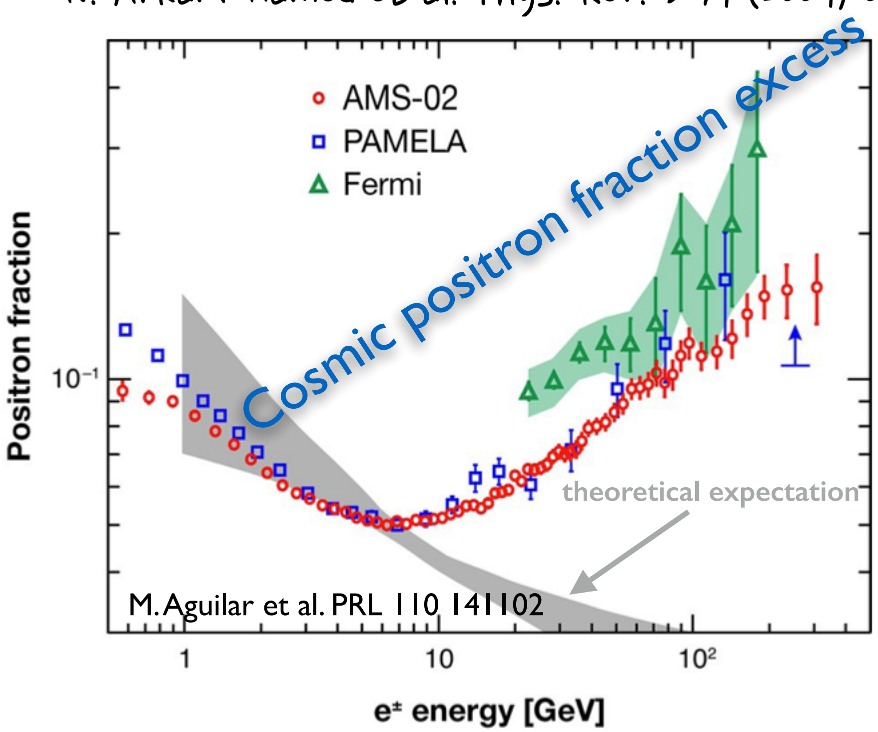

> 3 σ deviation experiment - SM prediction



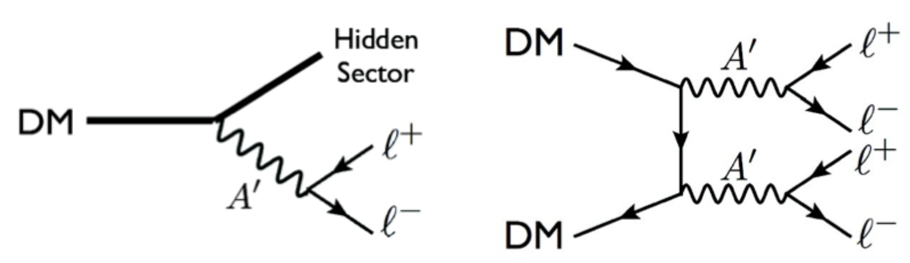

### Astrophysical anomalies

**(INTEGRAL, WMAP… PAMELA, FERMI, AMS-02…)**

N. Arkani-Hamed et al. Phys. Rev. D 79 (2009) 015014




Dark matter decaying or annihilating in a light A' which in turn decays to $e^+e^-$



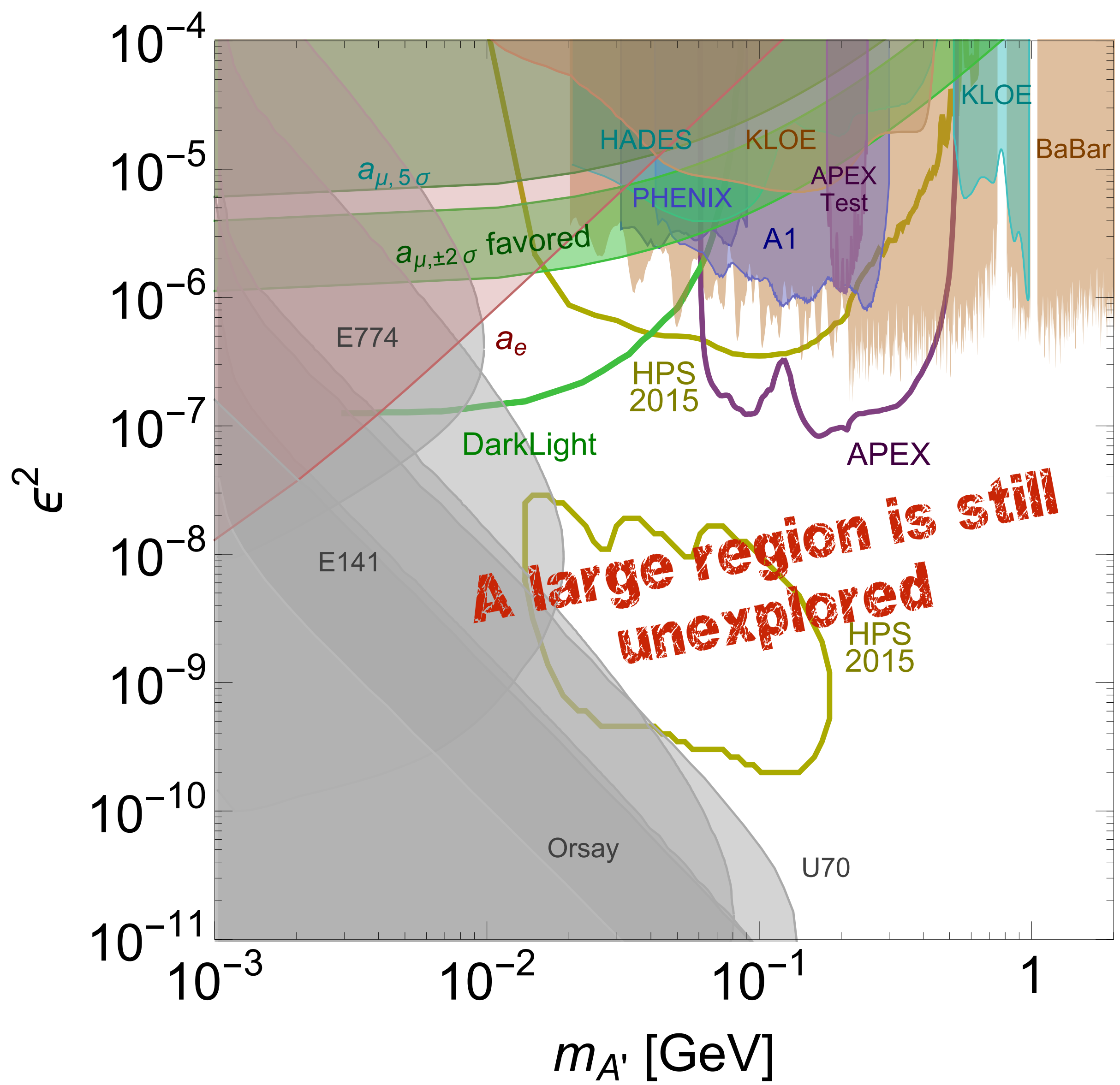

No corresponding excess in anti-protons $m_{A'} < 2m_p$

# The Hot Spot

**Both theoretical arguments and fits to astrophysical data suggest the same region in mass-coupling space**

**$\epsilon \sim 10^{-5} - 10^{-2}$**

**$M_{A'} \sim$ MeV - GeV**




**Present limits**

- Fixed target with e⁻ beam
  JLAB (APEX test), Mainz (A1)
- Fixed target with p beam
  Fermilab
- Beam dump experiments
  E774,E141,U70,Orsay
- Annihilation
  BABAR, BELLE, KLOE
- Meson decay
  KLOE, BES-3, WASA-COSY

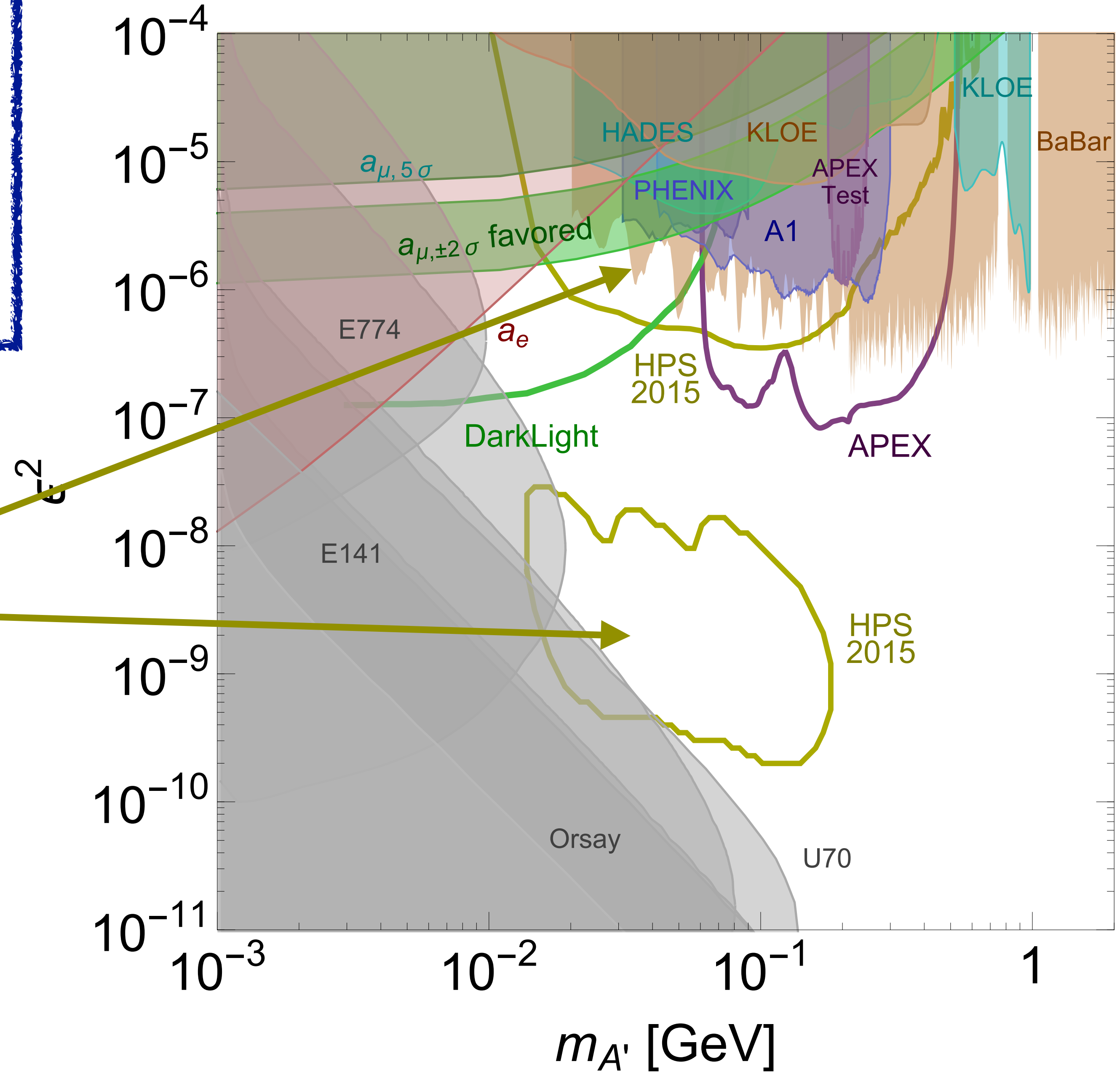
# Heavy Photon Search

**A NEW DEDICATED EXPERIMENT AT JLAB TO SEARCH FOR HEAVY PHOTONS OVER A WIDE RANGE OF MASSES AND COUPLINGS IN UNEXPLORED PARAMETER SPACE**

High intensity e⁻ beam of JLab
+
High-rate, high-acceptance and high-resolution detector

HEAVY PHOTON SEARCH

**2σ experimental reach**
**1 week @ 1.1 GeV**
**1 week @ 2.2 GeV**
**2 weeks @ 4.4 GeV**



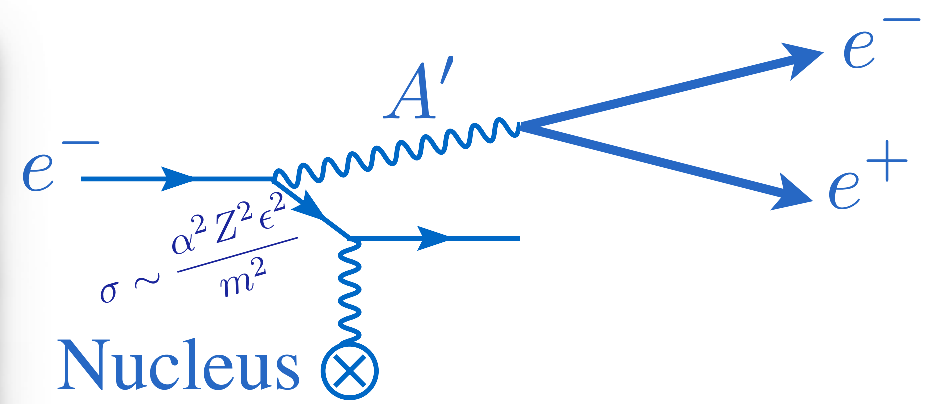
# Fixed target experiments

PHYSICAL REVIEW D **80**, 075018 (2009)

**New fixed-target experiments to search for dark gauge forces**

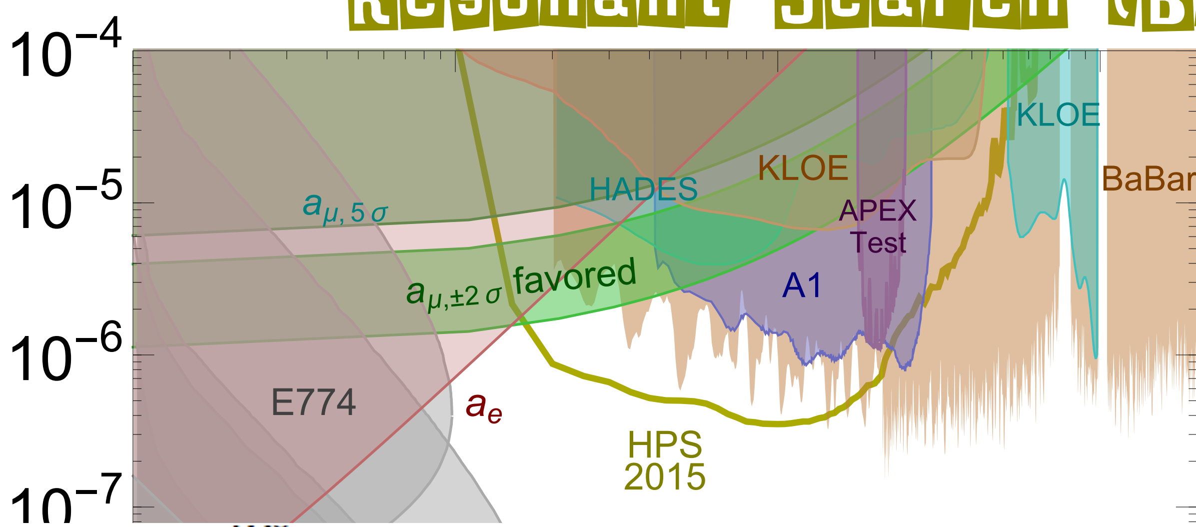
James D. Bjorken,[1] Rouven Essig,[1] Philip Schuster,[1] and Natalia Toro[2]
[1]*Theory Group, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[2]*Theory Group, Stanford University, Stanford, California 94305, USA*
(Received 20 July 2009; published 28 October 2009)

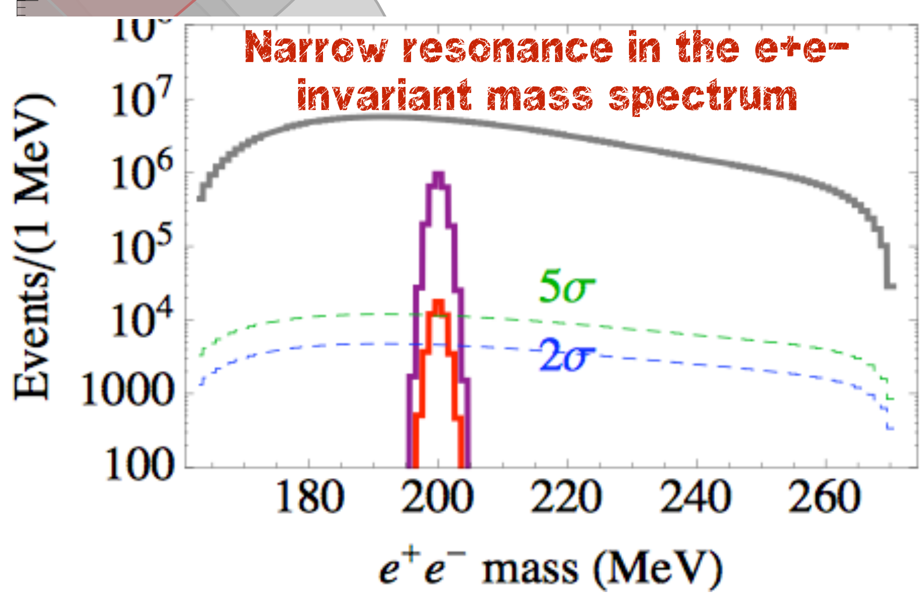
Fixed-target experiments are ideally suited for discovering new MeV–GeV mass $U(1)$ gauge bosons through their kinetic mixing with the photon. In this paper, we identify the production and decay




A' production analogous to bremsstrahlung

## Resonant Search (Bump-Hunting) approach

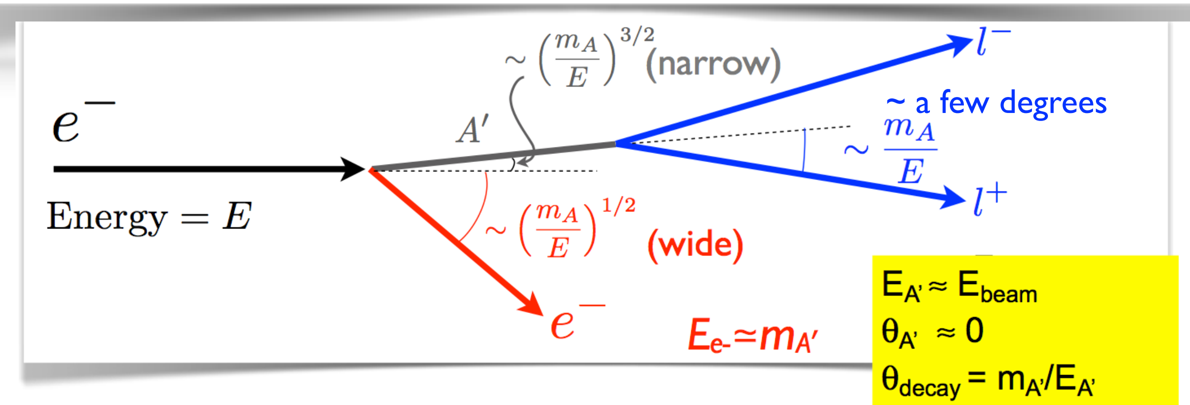



HPS needs

- ✓ High luminosity e⁻ beam
- ✓ Momentum reconstruction and good invariant mass resolution (Δm/m ~ 1%)
- ✓ Large acceptance in the forward region (detectors close to the beam) due to kinematic constrains

Fight background with high intensity and resolution

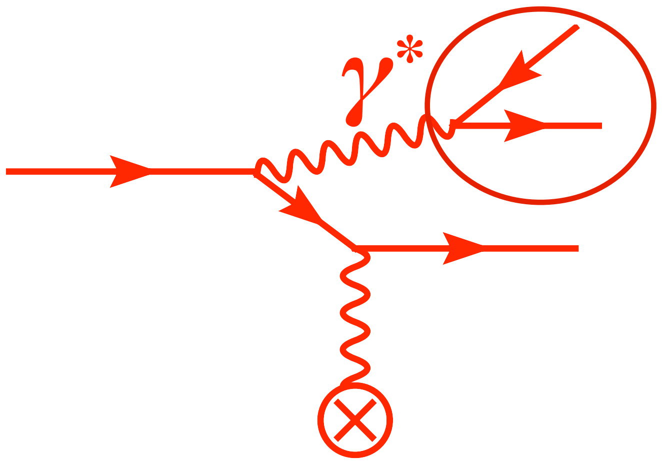


# Physics Backgrounds

**Two physics backgrounds known as "tridents"**

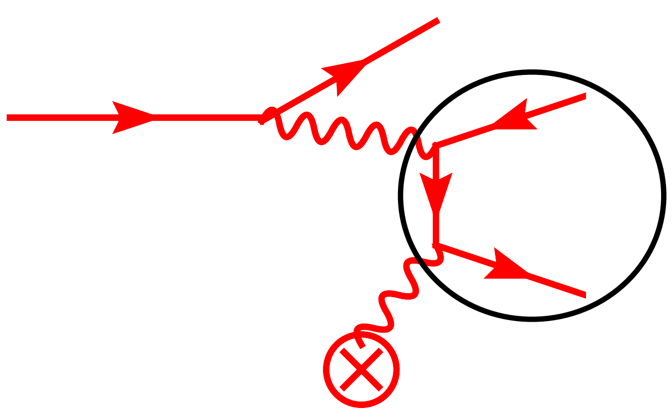
**Radiative**

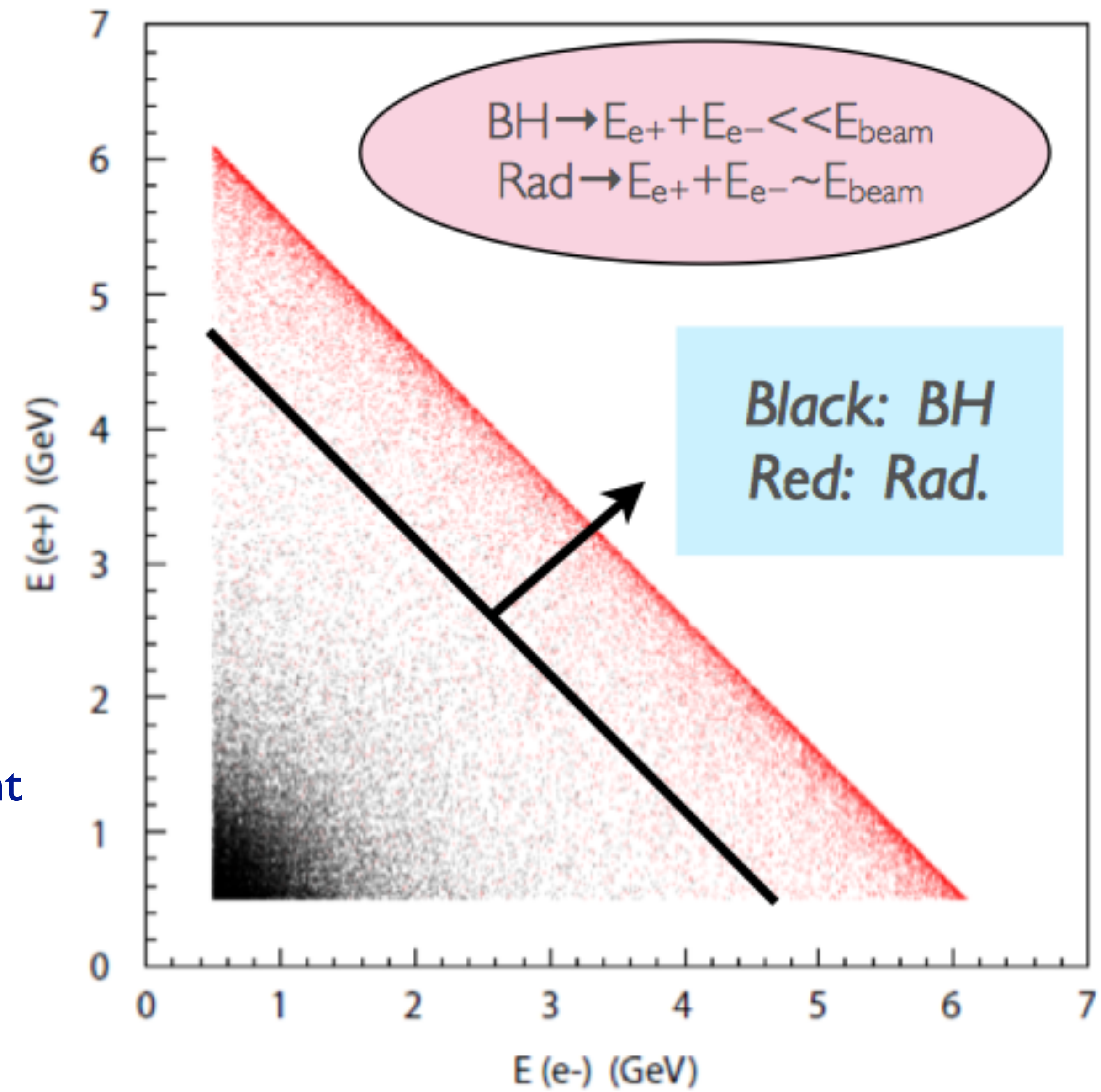
same kinematics as A' decay, irreducible




**Bethe-Heitler**

different kinematics, cross section >> radiative, dominant



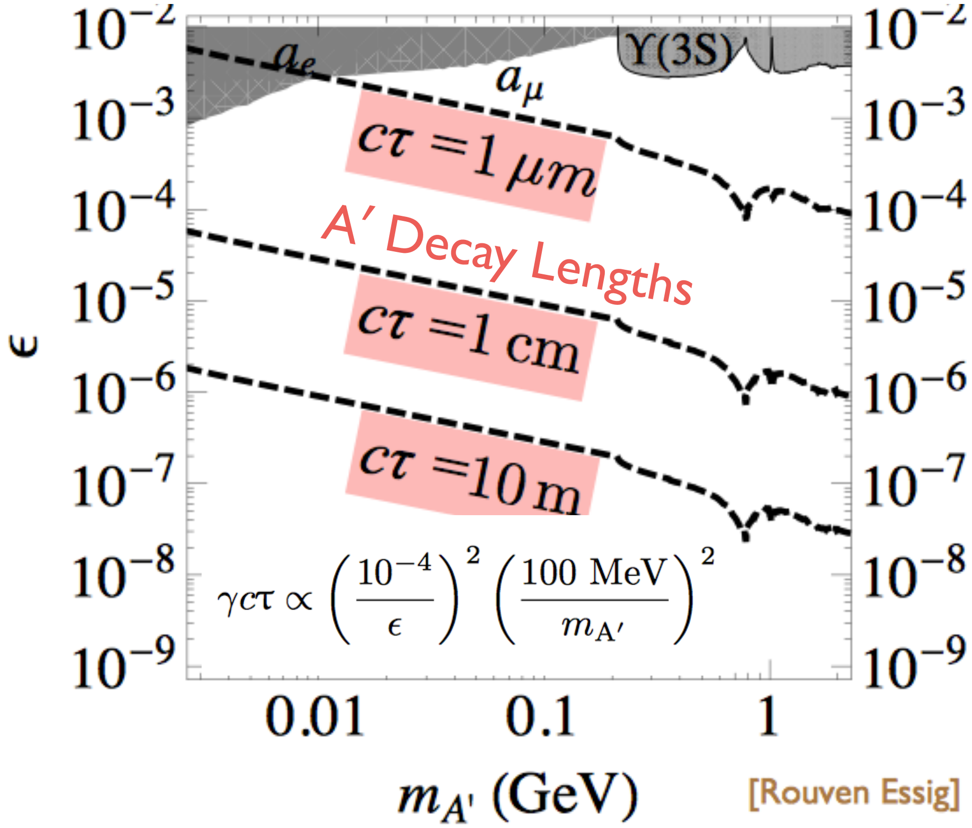


# Searching for an A' with small coupling

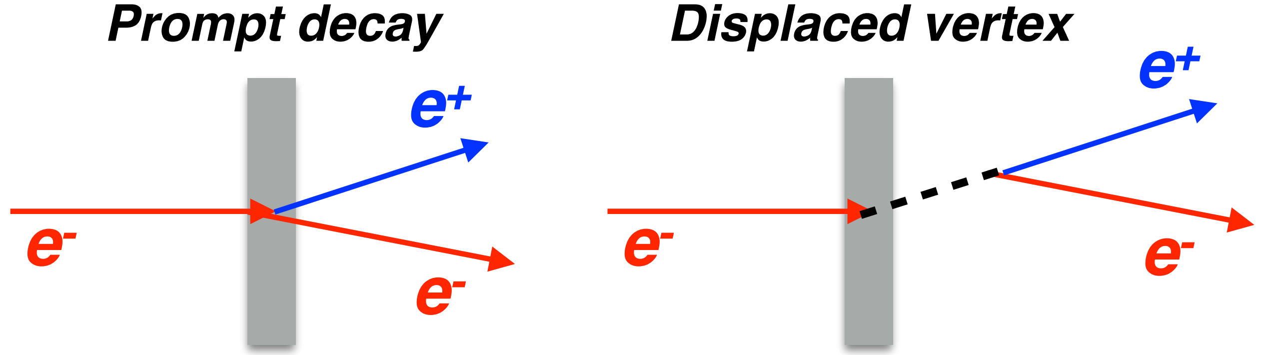
**Problem: explore small couplings ($\epsilon$ <$10^{-4}$) and intermediate mass region**

Small couplings mean very few events => Intense beam => lot of background

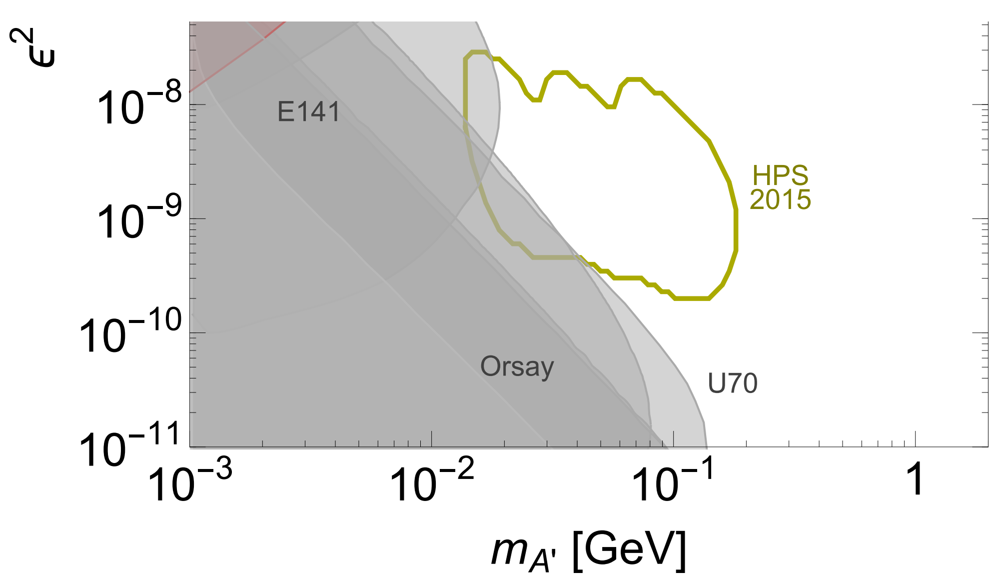
But small couplings also make A' long-lived !




**It's all about rejecting the prompt background (~ $10^{-7}$ !)**




**Bump Hunting + Vertexing**




**HPS solution: reconstruct A' decay vertex to beat down trident background**

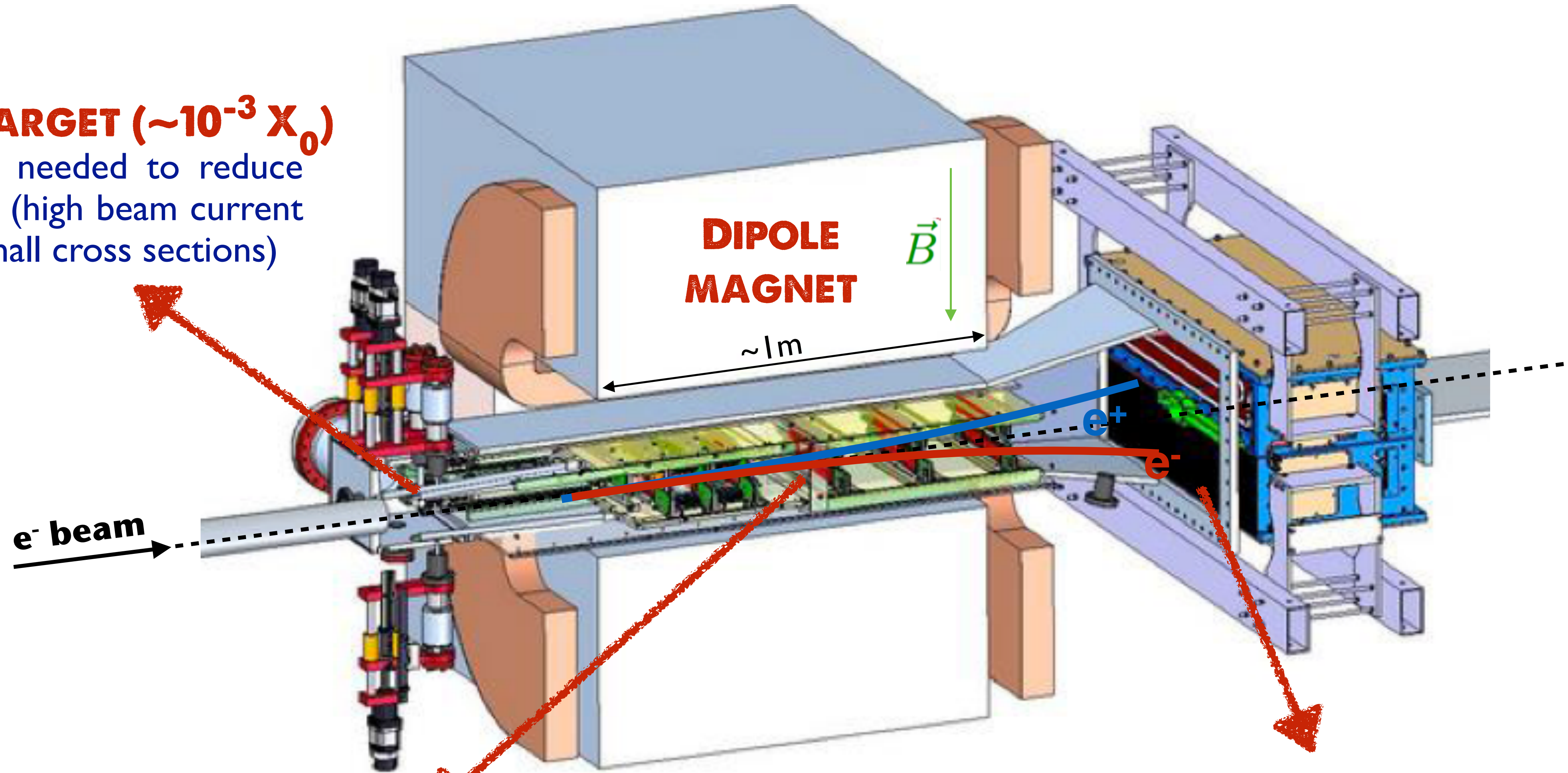
HPS needs

✓ Vertex reconstruction with good resolution
$\Delta z$ ~ 1mm (detectors close to the target)

# HPS apparatus

**THIN W TARGET ($\sim 10^{-3}\ X_0$)**

Thin target needed to reduce background (high beam current to probe small cross sections)




**COMPACT SI MICROSTIP TRACKER**

- ✓ Determine invariant mass of A′ decay products (estimate momentum vectors)
- ✓ Distinguish A′ decay vertexes as non-prompt (extrapolate tracks to their origins)

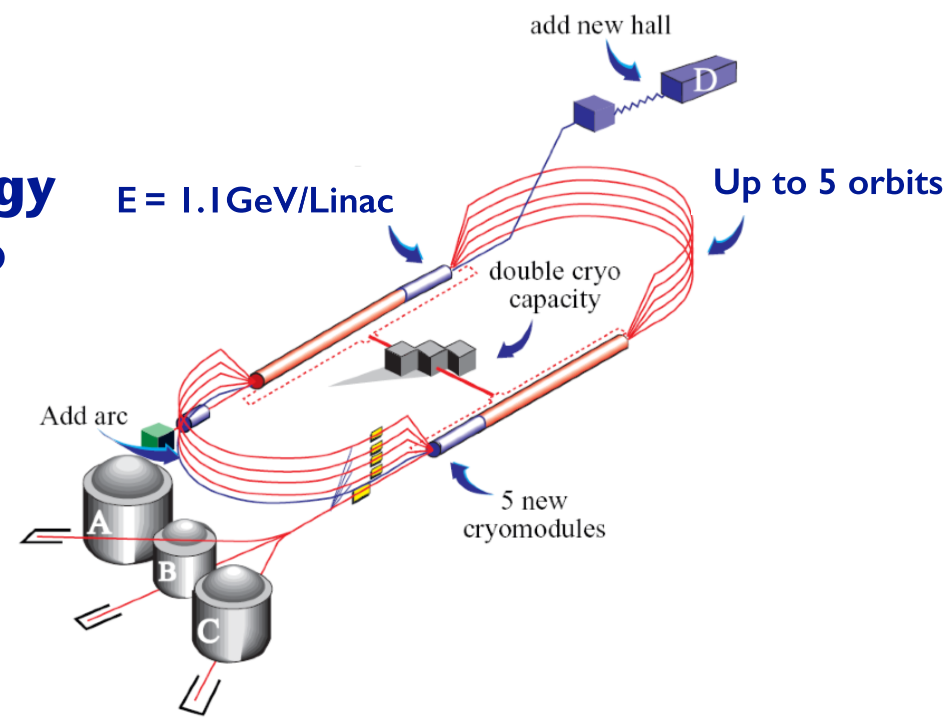
**FAST $PbWO_4$ ELECTROMAGNETIC CALORIMETER**

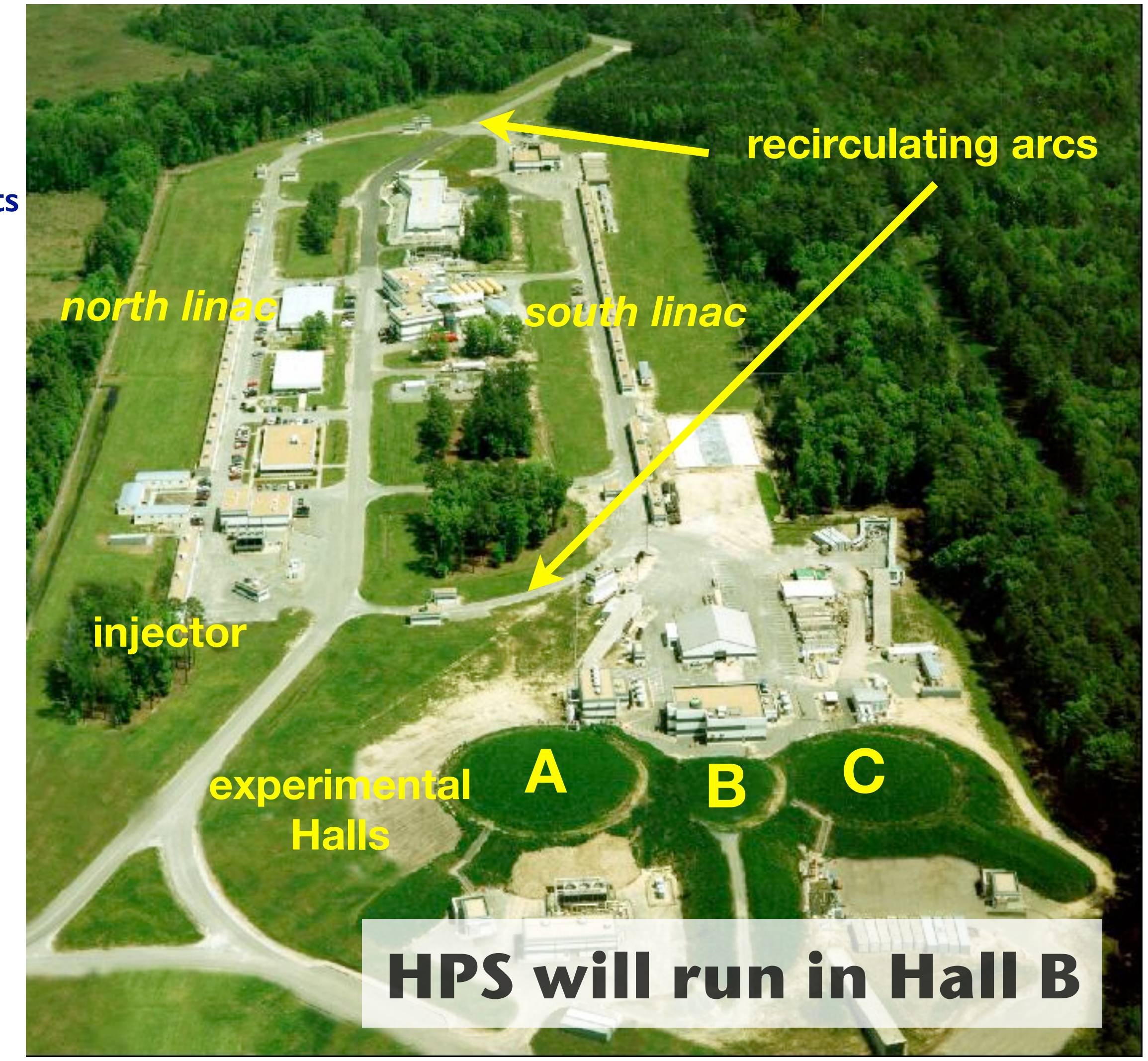
- ✓ Electrons identification
- ✓ Triggering on e+e- pairs

**FAST AND RADIATION-HARD DETECTORS AND HIGH TRIGGER RATE (UP TO 50 KHZ)**

# Continuous Electron Beam Accelerator Facility

**JLab recently completed the energy upgrade from 6 to $E_{max}$ =12 GeV**




# HIGH

## Intensity

$I_{beam}$ < 100 µA Hall A, C - < 800 nA Hall B (HPS: 200 - 400 nA)

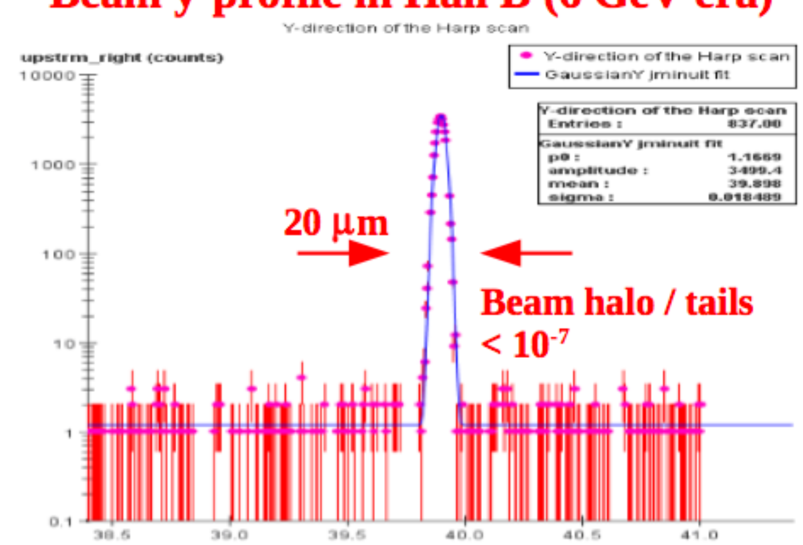
## Frequency

~ DC beam, 2 ns bunch separation (1 bunch ~ 10000 $e^-$)
Spread out beam background over time for manageable occupancies

## Quality

Tight beam spot in y helps tracking & vertexing
Very low halo = low background

**Beam y-profile in Hall B (6 GeV era)**

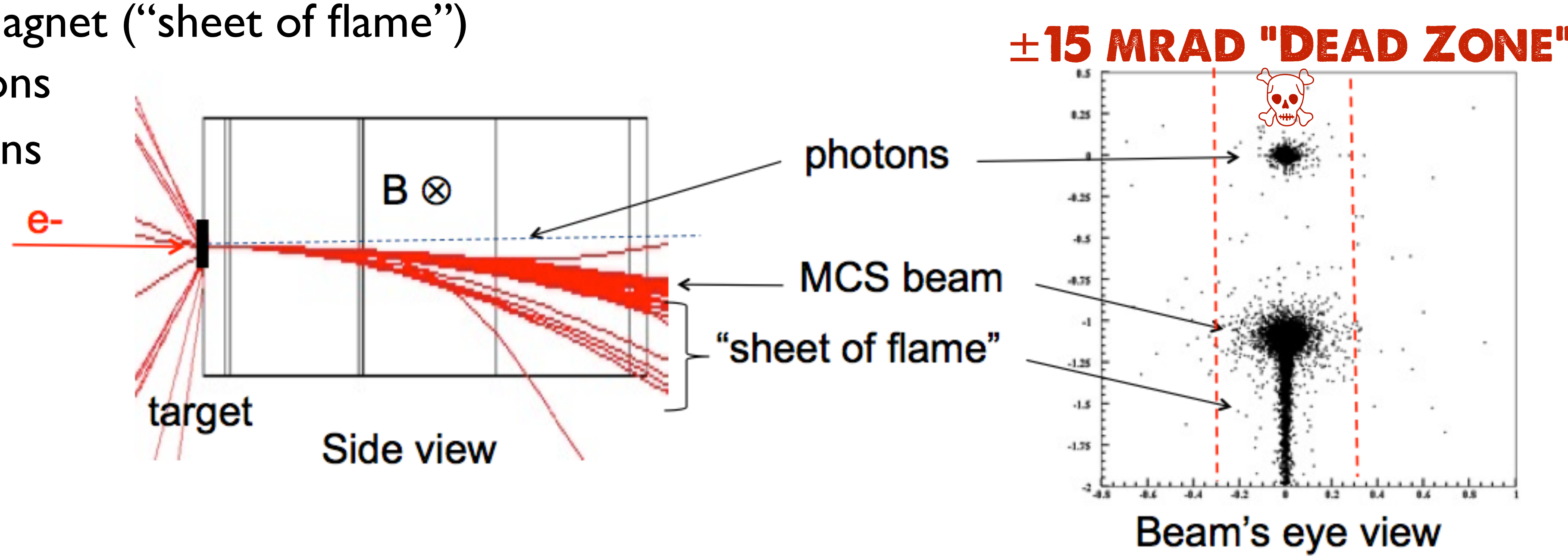


# Controlling Beam Background

**Vertexing A’ decays and maximize low mass acceptance require detectors close to the target and the beam (just 0.5 mm for the first Si sensor)**

## BACKGROUNDS MATTER !

- Avoid most of the Multiple Coulomb Scattered (**MCS**) beam (*THE* background for HPS)
- Avoid photons radiated in target
- Avoid the electrons which have radiated photons, lost energy and been deflected in the horizontal plane by the magnet (“sheet of flame”)
- Avoid beam gas interactions
- Avoid errant beam motions



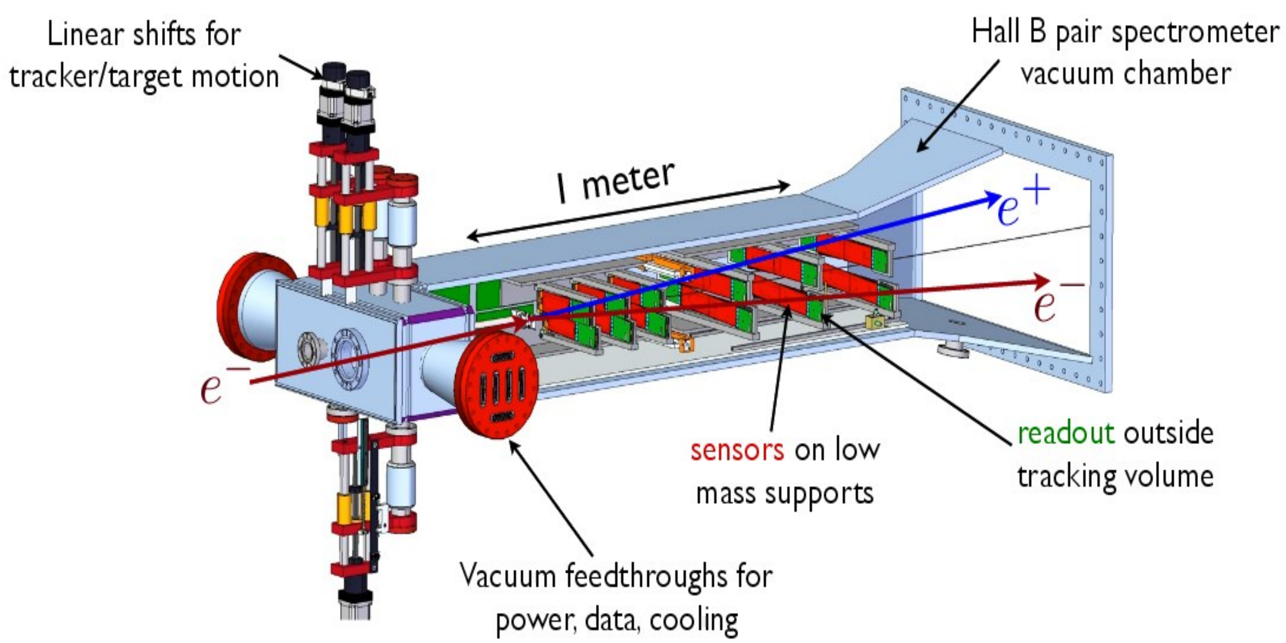

HPS design solutions

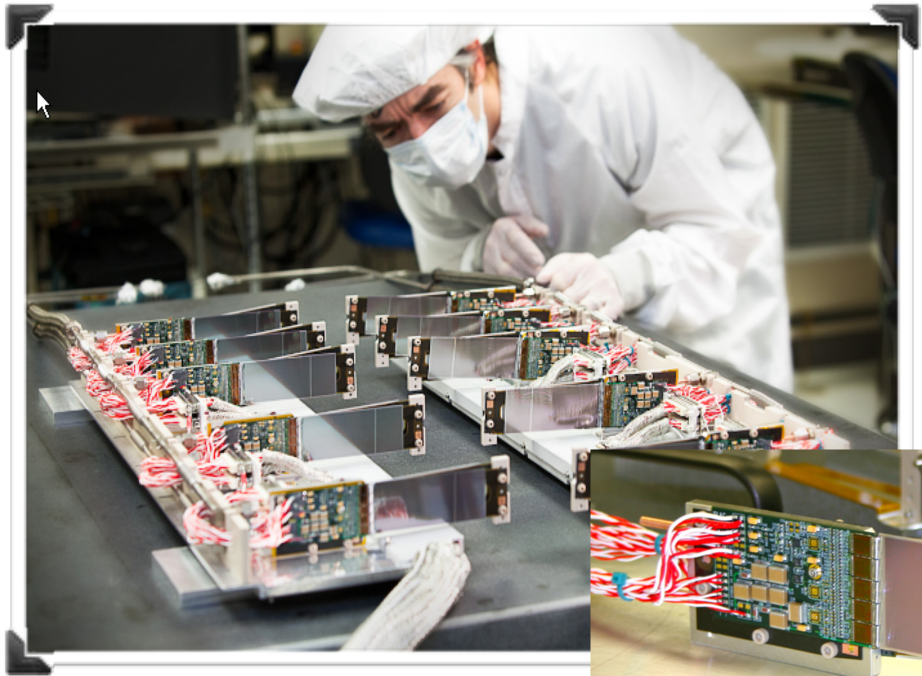
✓ Both SVT and Ecal are split vertically to avoid the "Dead Zone"

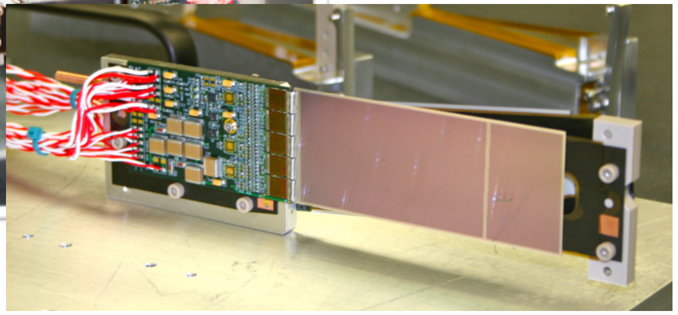
✓ SVT in vacuum to eliminate beam gas interactions

✓ Tightly collimate the incident beam

# HPS apparatus: SVT





## DESIGN

- Si microstrip detectors single-sided with 60 μm sense pitch over a 4x10 $cm^2$ surface
- 6 layers of detectors, split top-bottom, extending from 10 to 90 cm downstream of the target
- Two sensors per layer, one axial and the other at small stereo angle (100 or 50 mrad)
- <1% $X_0$ per layer to reduce MCS that dominates mass and vertexing uncertainties

## READOUT

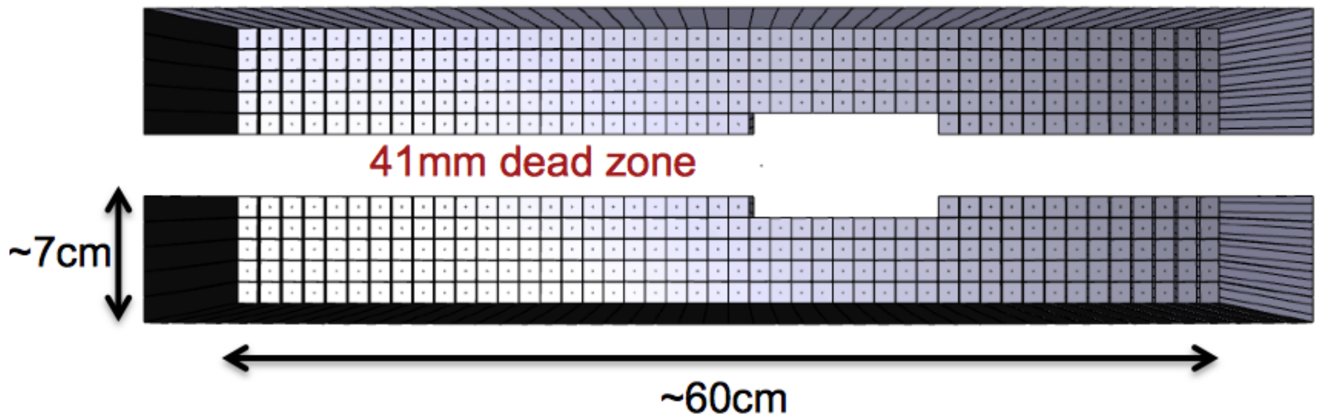
- CMS APV25 ASIC, 40 MHz continuous sampling
- Six-sample readout and the shortest possible shaping time (35 ns) to best distinguish hits that overlap in time
- Fit CR-RC shaping curve to determine the amplitude and the time of the hit
- Position and time of the cluster: amplitude-weighted mean of position and $t_0$ of individual hits

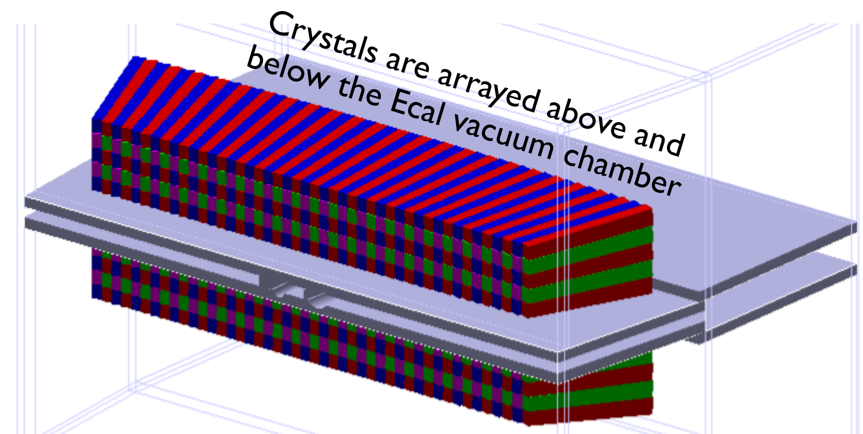
# HPS apparatus: Ecal

## DESIGN

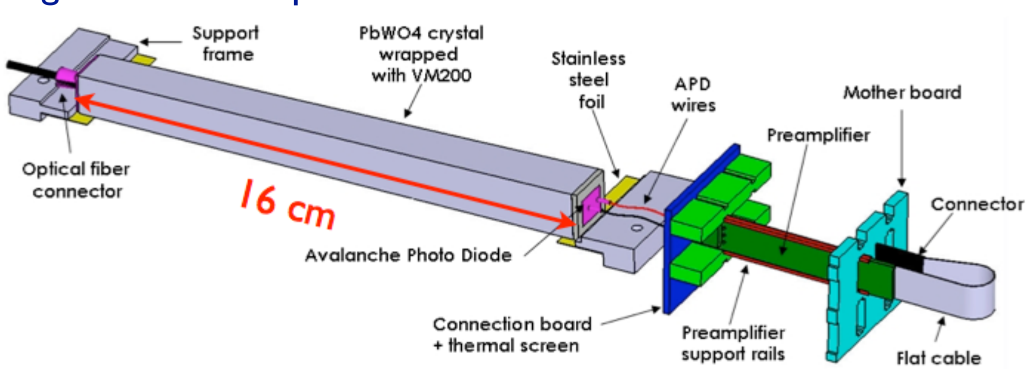
Fully absorb electrons with energies 0.5–6.5 GeV

442 $PbWO_4$ crystals: $13\times13mm^2$ ($R_M$~10mm), 160mm long ($4.5X_0$)

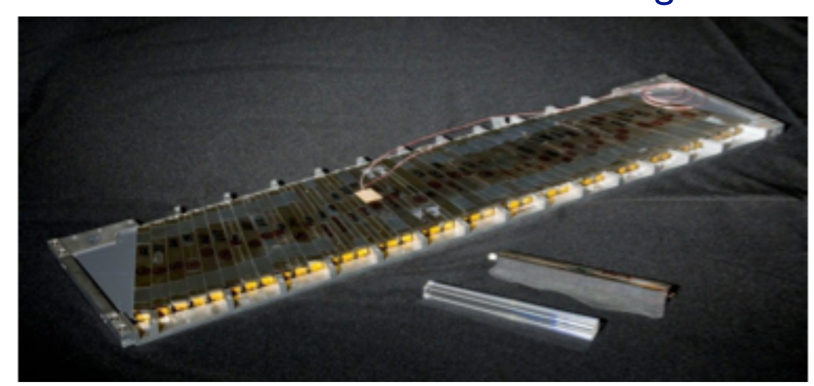



APID blue/red LED Monitoring for both radiation damage and APD response




Modules are assembled inside temperature controlled enclosure to stabilize gains



## READOUT

- Light readout by 10x10 $mm^2$ LA-APD and custom pre-amp
- Data recorded with 250 MHz 12 bit FADCs.
- Energy and time transferred every 32 ns to Trigger Processor FPGA for cluster finding
- Trigger: pair of clusters from top and bottom half in a 8 ns coincidence window

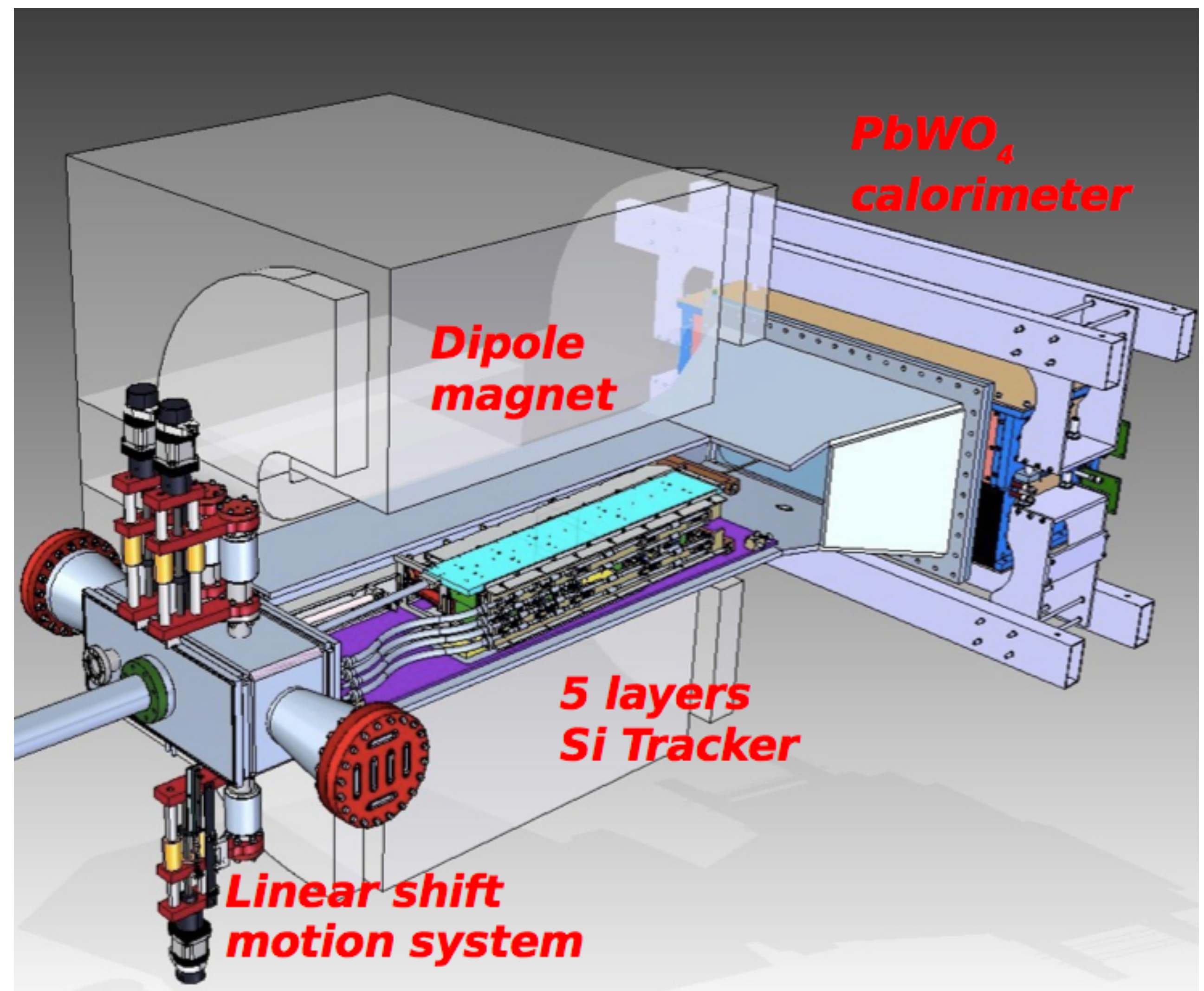
# HPS Test run 2012

description and results @ arxiv:1406.6115v1

**Test Run in Hall B with photon beam: parasitically + 8 hours dedicated time**

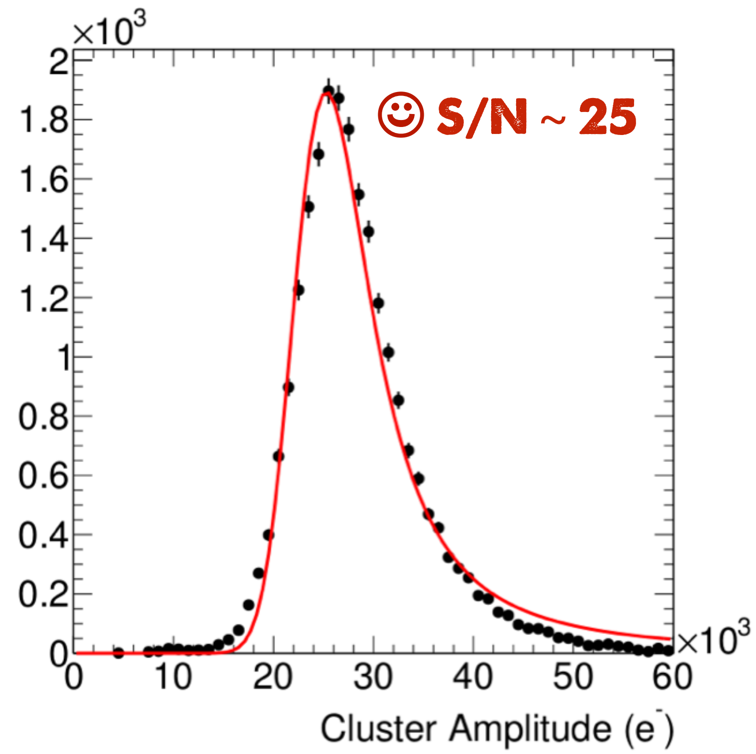
STUDY DETECTOR PERFORMANCES
&
CONFIRM TRIGGER RATES AND OCCUPANCIES

**SVT: 5 layers instead of 6**
**Ecal: before the upgrade (old 5x5 mm$^2$ APD and preamp)**

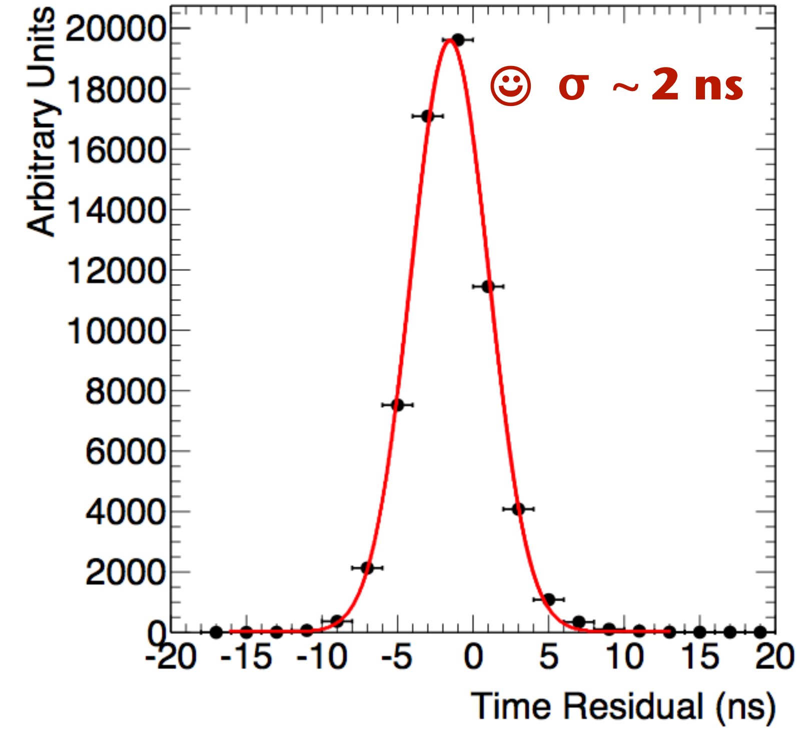


# HPS test run: SVT performances

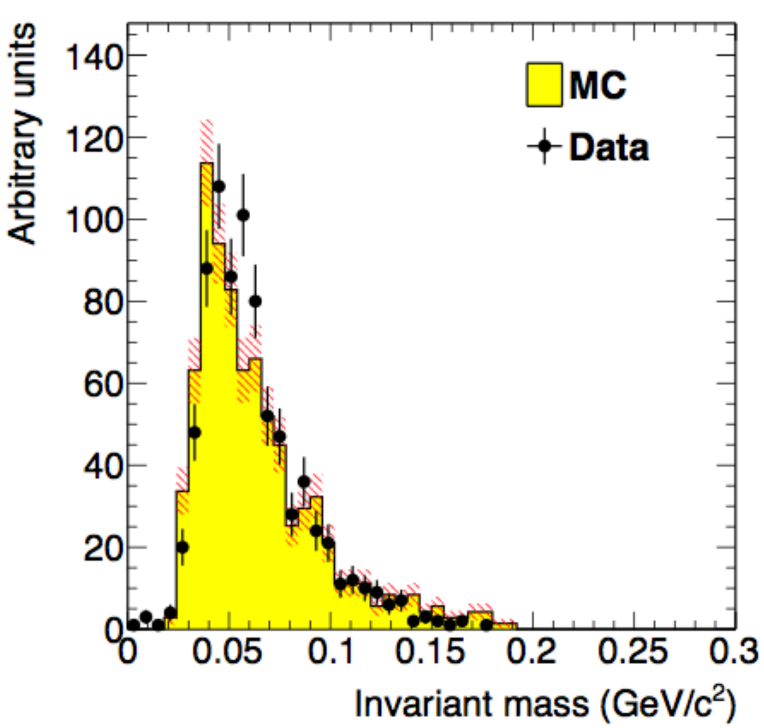
- ☺ >97% channels ok
- ☺ Hit efficiency > 98%
- ☺ Hit resolution ~ 6 μm

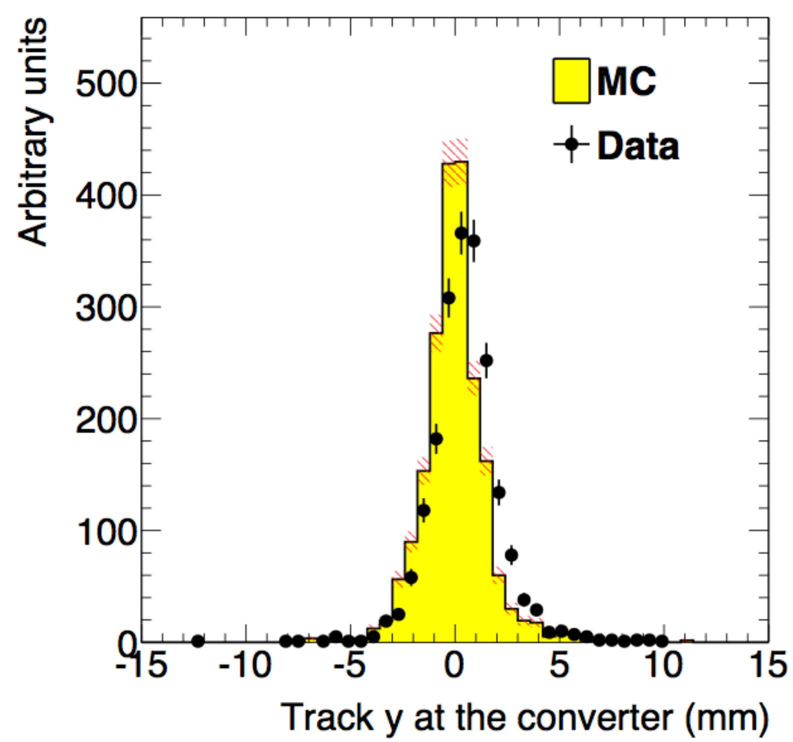



HIT TIME RESOLUTION

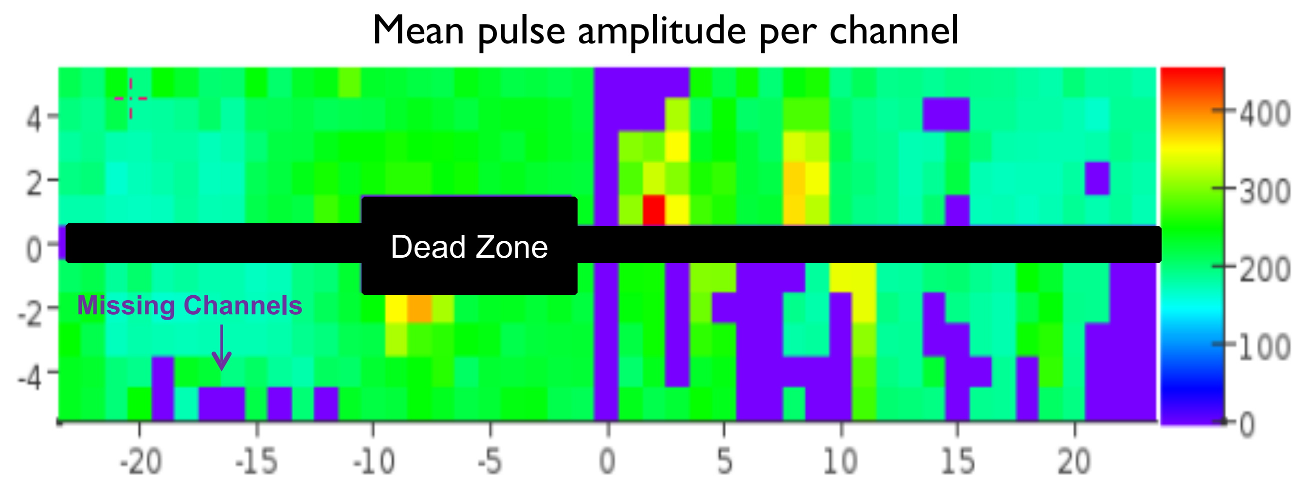



☺ Good agreement data-MC for kinematic distributions and track vertex

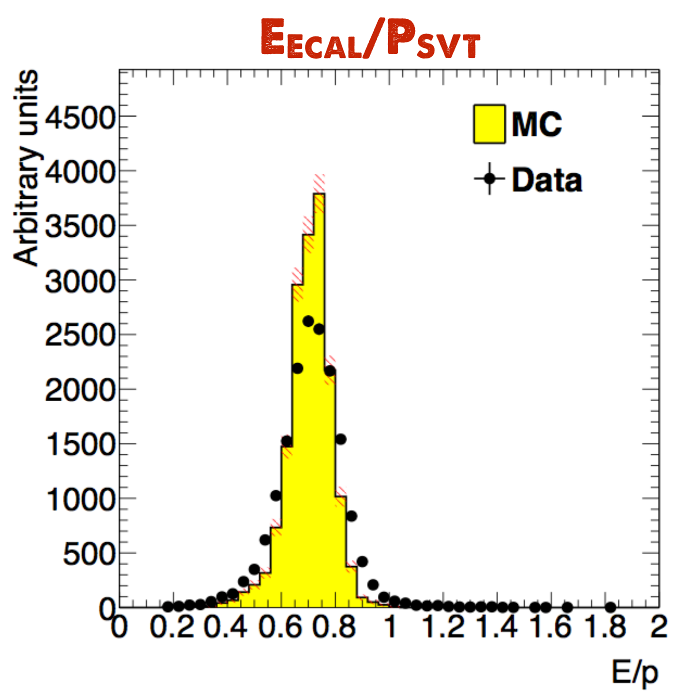


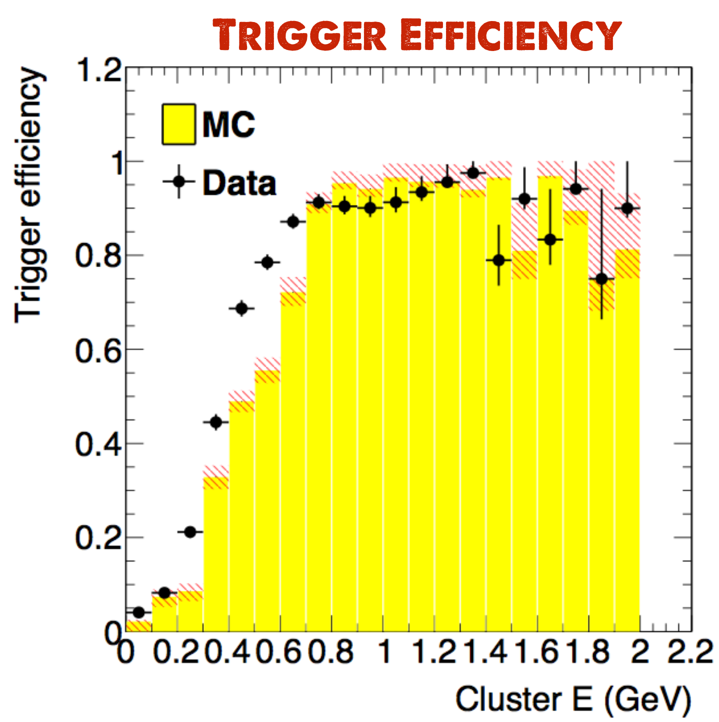



# HPS test run: Ecal performances

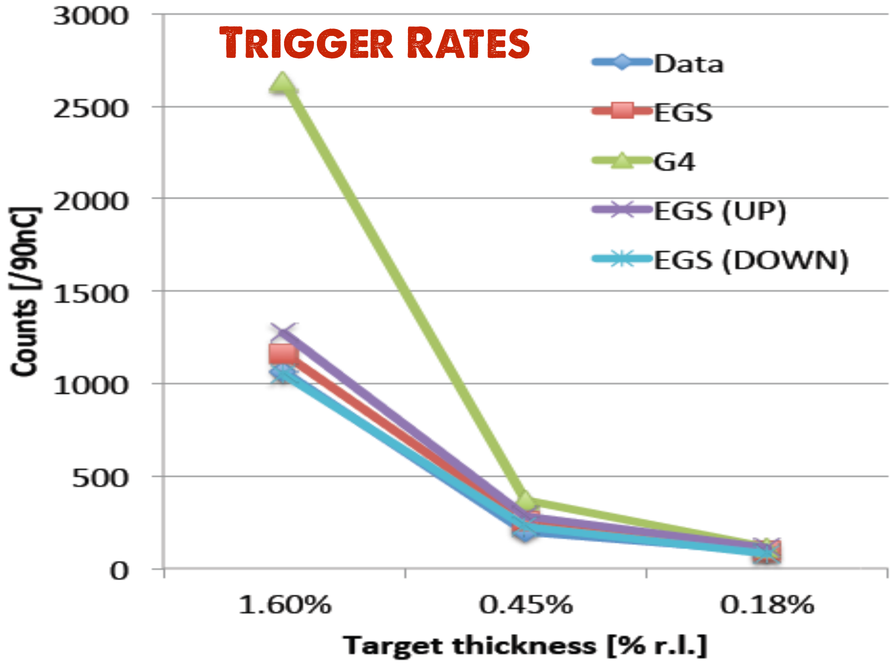



☺ **Good agreement data-MC for energy reconstruction, trigger efficiency and trigger rates.**




**BACKGROUND OCCUPANCY FOR HPS UNDER CONTROL !**



# Conclusions

HPS is a new experiment at JLab dedicated to search for heavy photons in the 10-200 MeV mass range and couplings $\epsilon=10^{-3}$ -$10^{-5}$

The HPS Test Run demonstrated the feasibility of the detector technologies proposed to conduct the full experiment successfully

HPS is now preparing for installation at JLab

NEXT WEEK - ECAL INSTALLATION IN HALL B

OCTOBER 2014 - ECAL COMMISSIONING WITH LED AND COSMIC RAYS

FALL 2014 - BEAM COMMISSIONING IN HALL B

DECEMBER 2014 - COMMISSIONING OF THE FULL HPS WITH BEAM

SPRING 2015 - START OF DATA TAKING