The Heavy Photon Search Experiment at Jefferson Lab

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For the HPS Collaboration
Intense Electron Beams Workshop
Cornell University, June 17-19, 2015

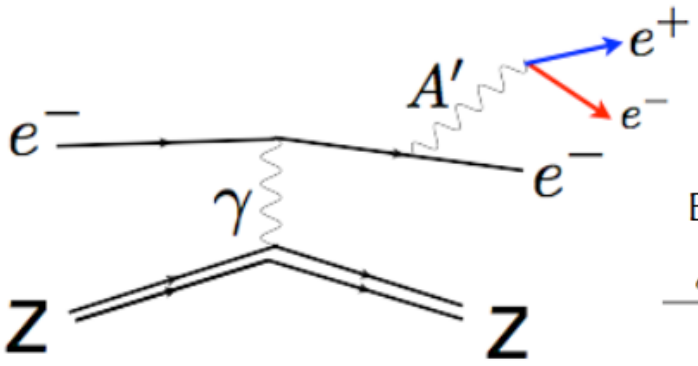
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Fixed Target Searches

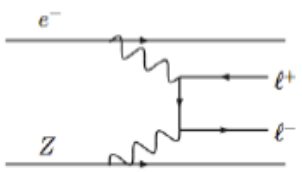
SLAC

Look for radiated A' decay to e^+e^-, ($\mu^+\mu^-$)

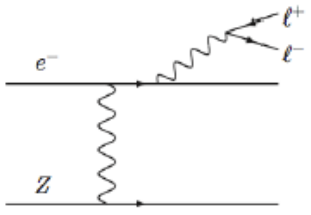


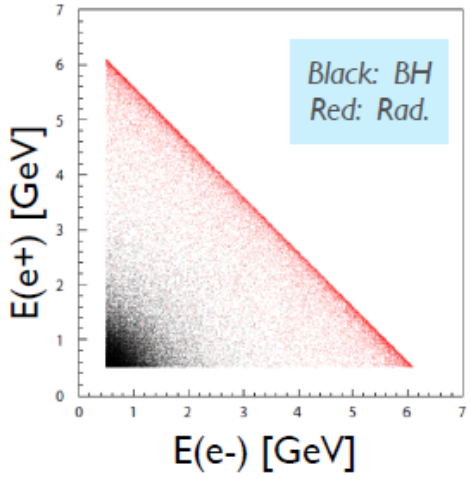
$\sigma_{B\text{-}H}$ very large » $\sigma_{Rad.}$
But kinematically distinct →
Use clever trigger to separate.

Bethe-Heitler



Radiative





Bump Hunt:
Look for signal over background.

Bump Hunt + Vertexing:
Look for signal over background, reduce background with vertexing.

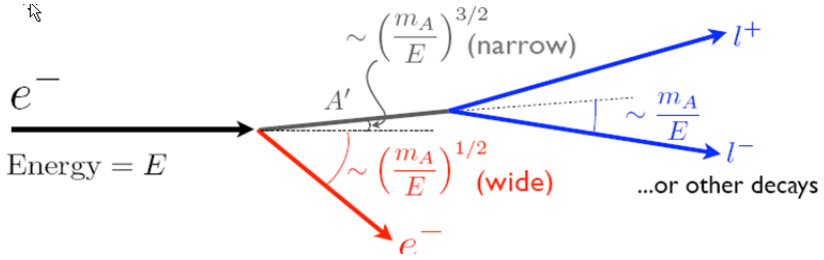
Very high luminosities: Intensity Frontier Physics.

P. Schuster, R. Essig et al, Intensity Frontier WS '11 summary paper.

BEST: *Bjorken, Essig, Schuster, Toro, Phys.Rev. D80 (2009) 075018*

HPS Design Choices

- **A' kinematics ⇒ very forward production**

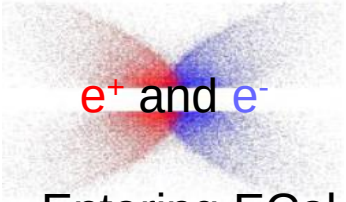


$E_{A'} \approx E_{beam}$
$\theta_{A'} \approx 0$
$\theta_{decay} = m_{A'}/E_{A'}$

- **Vertexing A' decays requires detectors close to the target**. Invariant mass is an essential signature, so good momentum/mass resolution is also required. Vertexing and bump hunting need tracking and a magnet.

Want $\Delta m/m \sim 1\%$ for bump hunt
Want $\Delta z \sim 1mm$

Beam's Eye View



Entering ECal

- **Trigger with a high rate, rad hard EM Calorimeter**
  Placed downstream of the magnet, it can ID e^+ and e^-.

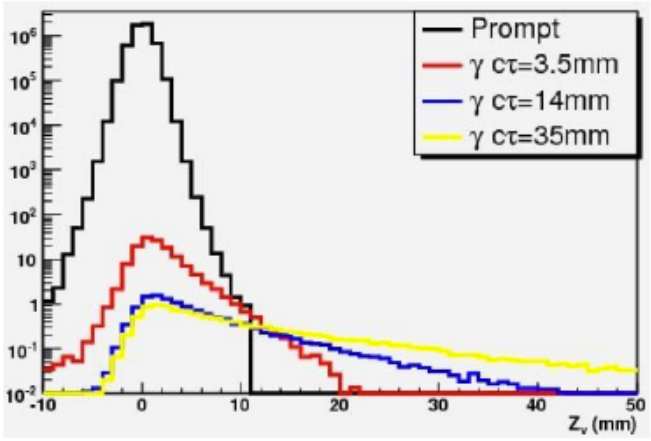
- **HPS opts for large forward acceptance/moderate currents. This requires placing sensors as close as possible to the beam.**

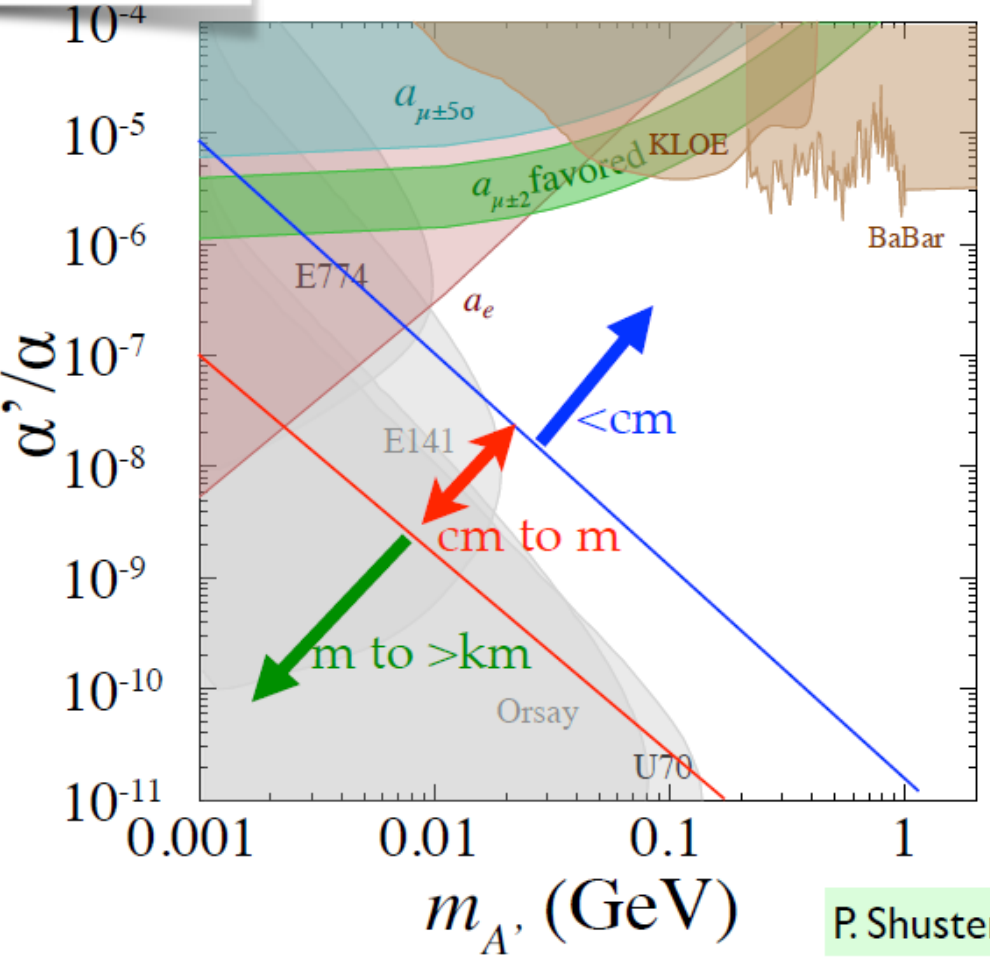
A' lifetime

$$\gamma c\tau \approx 1\ \mathrm{mm}\left(\frac{\gamma}{10}\right)\left(10^{-8}\frac{\alpha}{\alpha'}\right)\left(\frac{100\ \mathrm{MeV}}{m_{A'}}\right)$$

Lower α′, lower mass
→ longer lifetime

Background is all prompt
➜ Lower coupling can be reached using vertexing.





P. Shuster

Controlling Beam Backgrounds

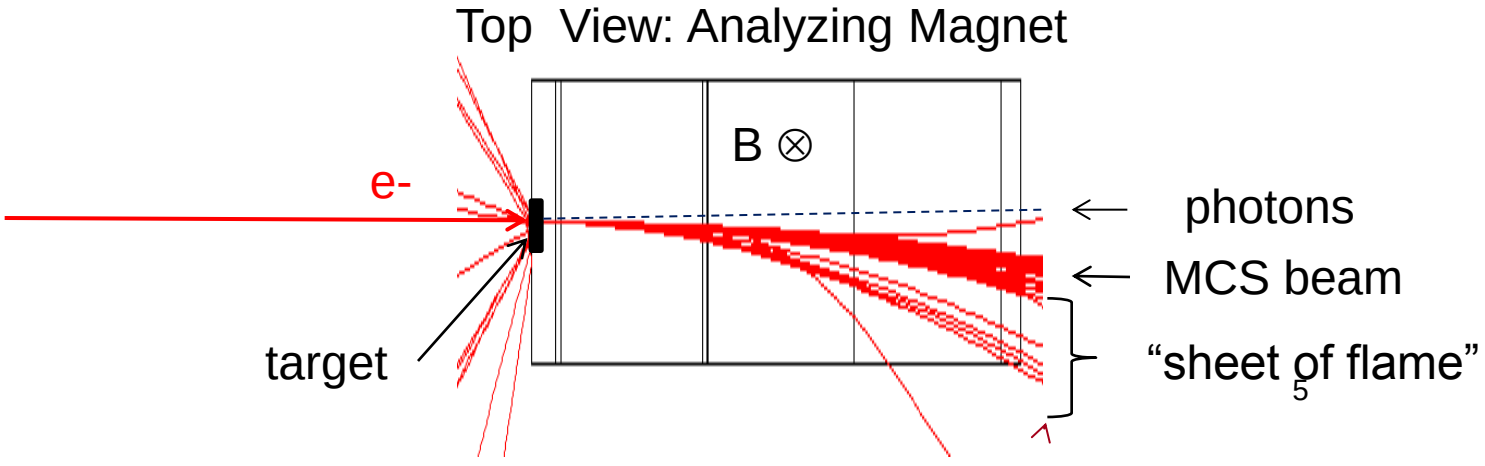
With sensors close to the beam (just ½ mm for the first Si sensor), background control, radiation damage, and beam stability become critical.

Constraints

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

Design Solutions

* Split the detectors top-bottom to avoid the beam and the “sheet of flame”
* Run the tracker in vacuum to eliminate beam gas interactions
* Tightly collimate the incident beam.



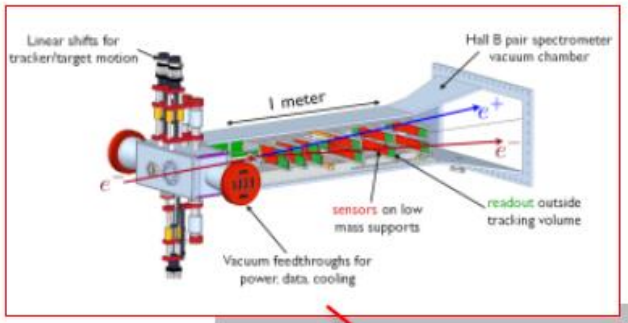
Particle Production in the Target

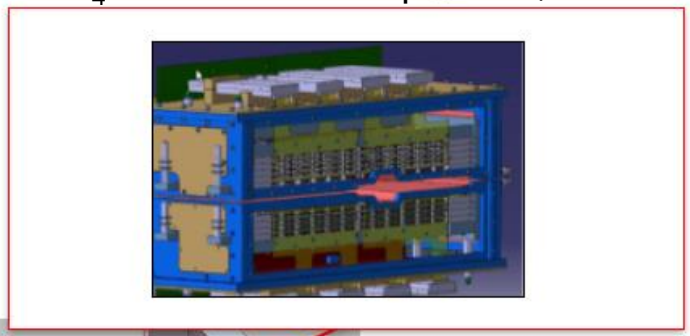
Souce	Effect on Detector	Simulation/Estimation
Multiple Coulomb Scattering	SVT occupancy SVT radiation Ecal occupancy Ecal trigger	EGS5/Geant4
Bremsstrahlung photons $\gamma \rightarrow$ e+e- (two-step tridents) energy degraded electrons Large angle bremsstrahlung	Ecal occupancy Ecal trigger Neutrons on FPGA	EGS5/Fluka/Geant4 MadGraph
Moller scattering (δ-rays)	SVT occupancy	EGS5
Hadron production	SVT occupancy Ecal trigger	Geant4/Fluka
X-ray generation Inner shell ionization followed by x-ray transition	SVT occupancy	EGS5/Geant4 NIST x-ray database
Physics background		
Tridents e-Z $\rightarrow$e-Zγ*, γ*$\rightarrow$ e+e-	SVT occupancy Ecal trigger	MadGraph

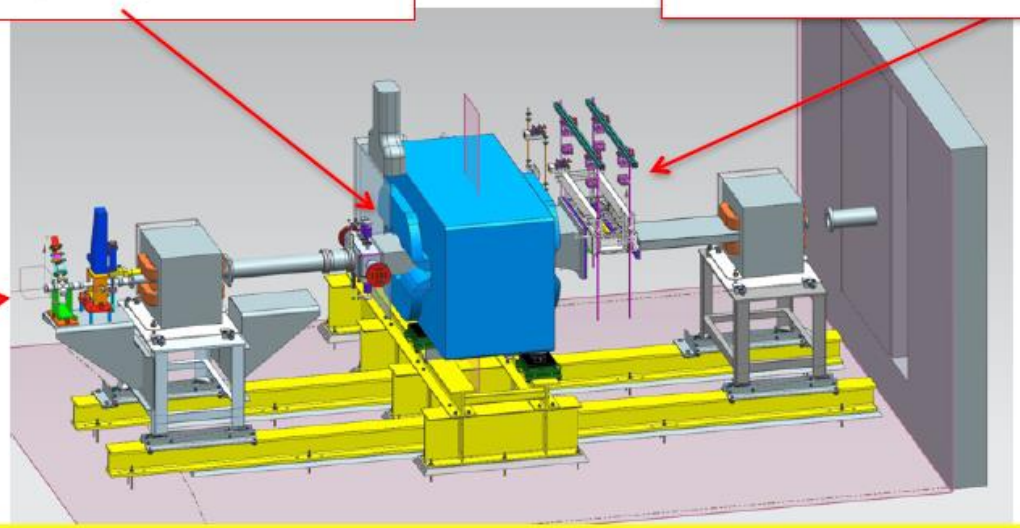
HPS Setup in Hall B Alcove

Si Vertex Tracker Installed Feb 23, 2015

$PbWO_4$ ECal Installed September, 2014



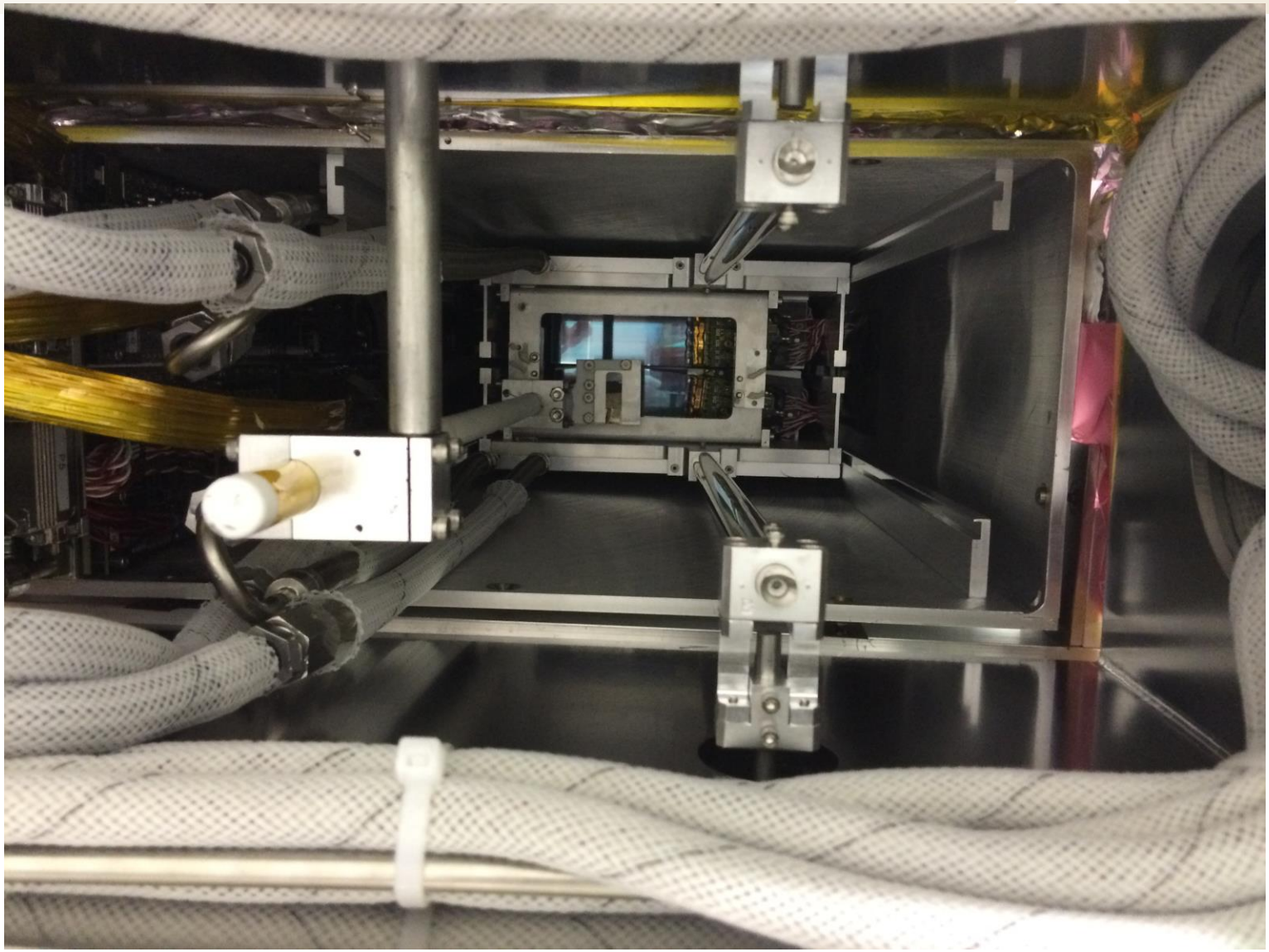




A magnet chicane directs the CEBAF 12 electron beam onto a W foil, producing heavy photons. They decay to e^+e^- pairs, which are measured by the Si vertex tracker inside an analyzing magnet. A $PbWO_4$ ECal provides a fast trigger.

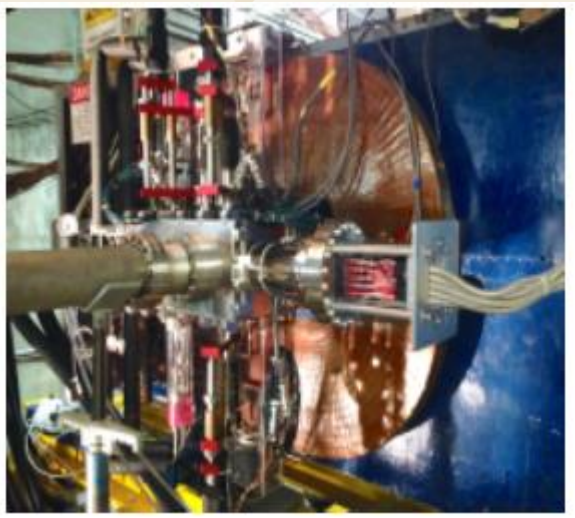
https://confluence.slac.stanford.edu/display/hpsg/Heavy+Photon+Search+Experiment

Beam's Eye View of SVT



Spring Engineering Run

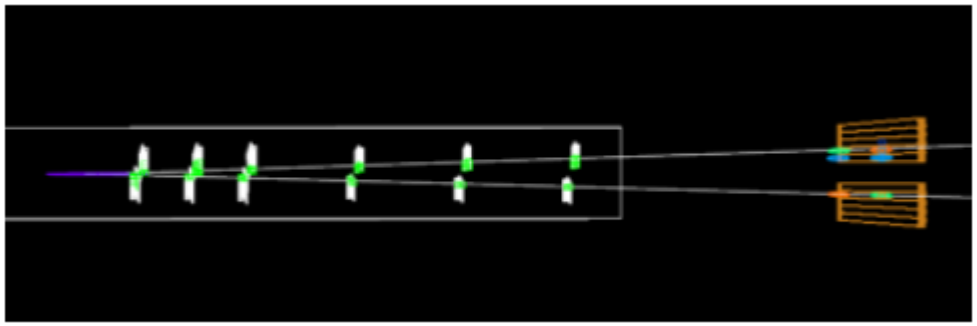
Opportunistic run: other Halls had a priority and the 12 GeV work was carried out during week-day day shift.



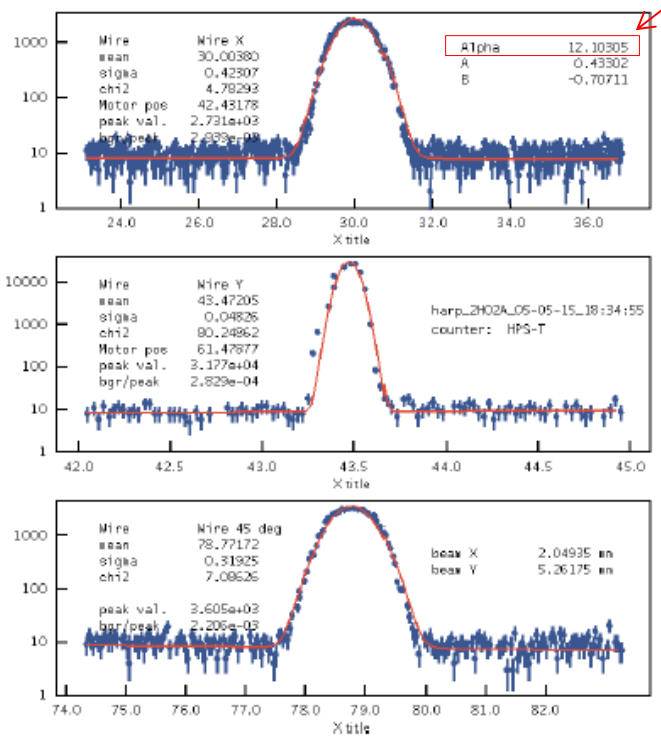
- Installed SVT end of February
- Commissioned Hall B beamline March-April
  - Calibrated bpms & established orbit locks
  - Set up SVT Protection Collimator
  - Checked beam position stability
- CEBAF down for two weeks after power outage
- Commissioned Trigger and Integrated SVT DAQ late April
- Explore SVT backgrounds as moved SVT closer to beam
- Production running at 1.5 mm started May 1
- Production running at 0.5 mm started May 12
- Run ended May 18th.

Layer 1 silicon sensors are just 0.5 mm above and below beam. Min. opening angle is θy = 15 mrad.

Run 5623
Event 62



Beam Quality



X,Y and 45 degree beam profiles. May 5th, 2015

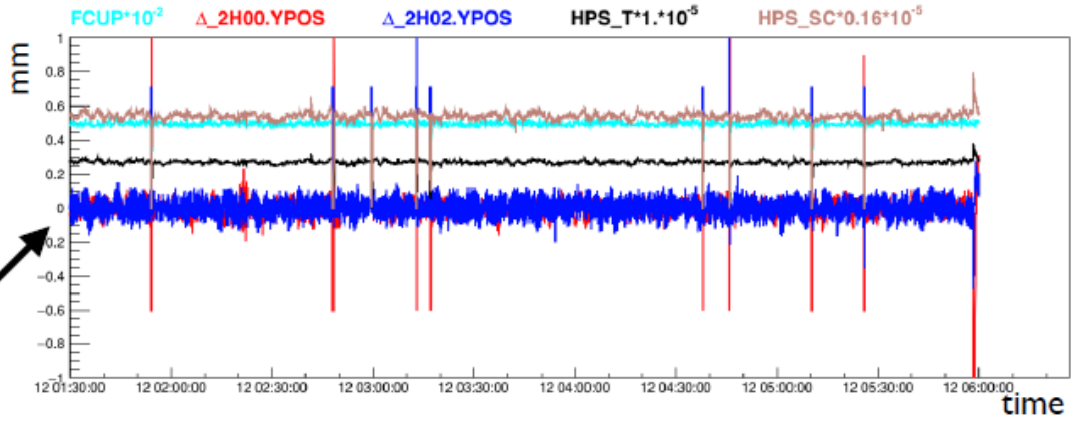
Small skewness

HPS requires a very high quality beam, with very low halo.

σ_X ~ 300 to 500 μm - To spread heat load.

σ_Y ~ 15 - 50 μm - To help vertexting & tracking.

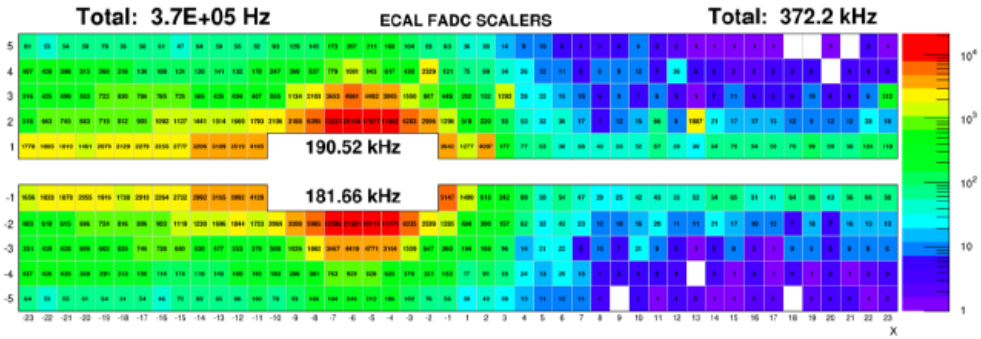
The beam also needs to be very stable over time. A Fast Shut-Down stops the beam in <10 ms, if halo counters register above threshold counts.



Very stable beam on May 12th.

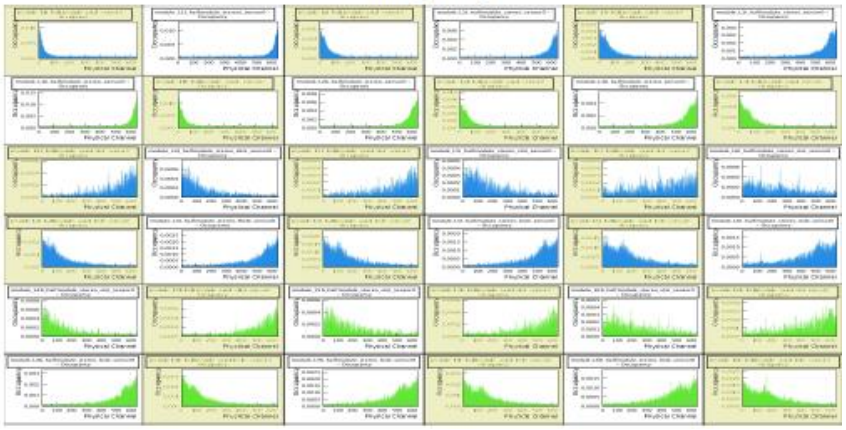
Online data quality

ECal single rates



Trigger rates

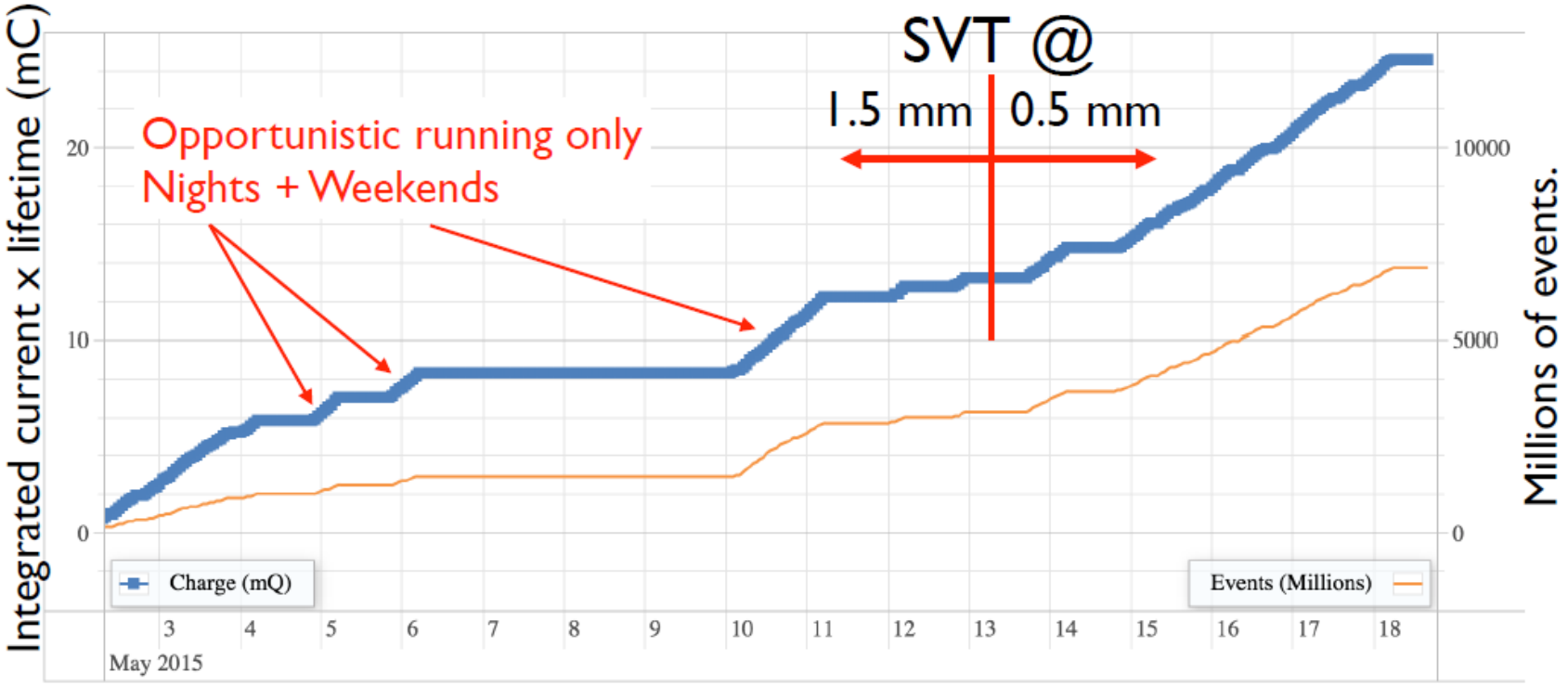
SVT Occupancy



In good agreement with simulations.

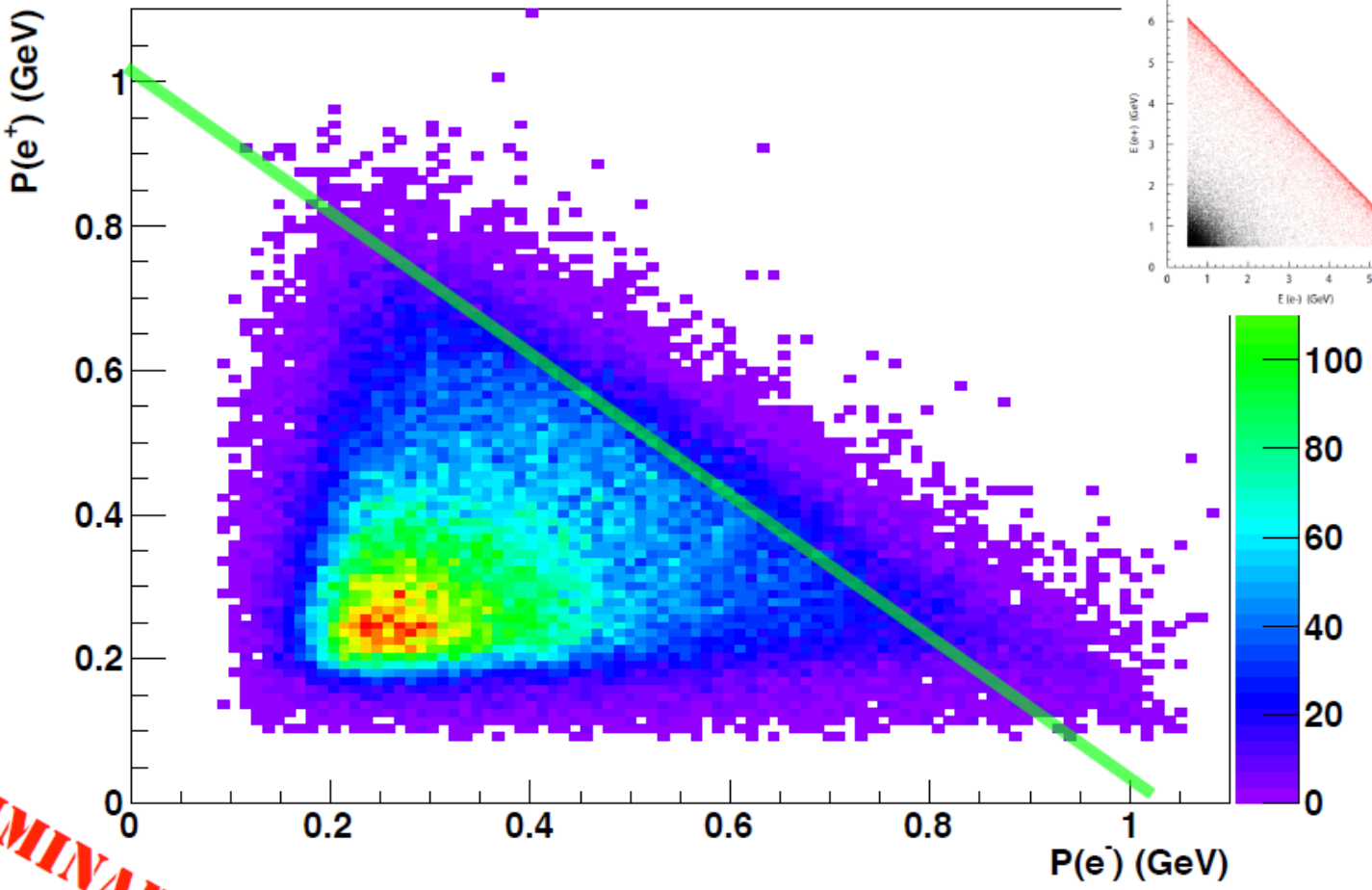
1 GeV Run, Charge on Target

Proposal: 1 full week of 50 nA beam on target, 30mC
Achieved: ~10 mC with SVT at 1.5mm, 10 mC at 0.5 mm



Tracked Pairs at 1.5 mm

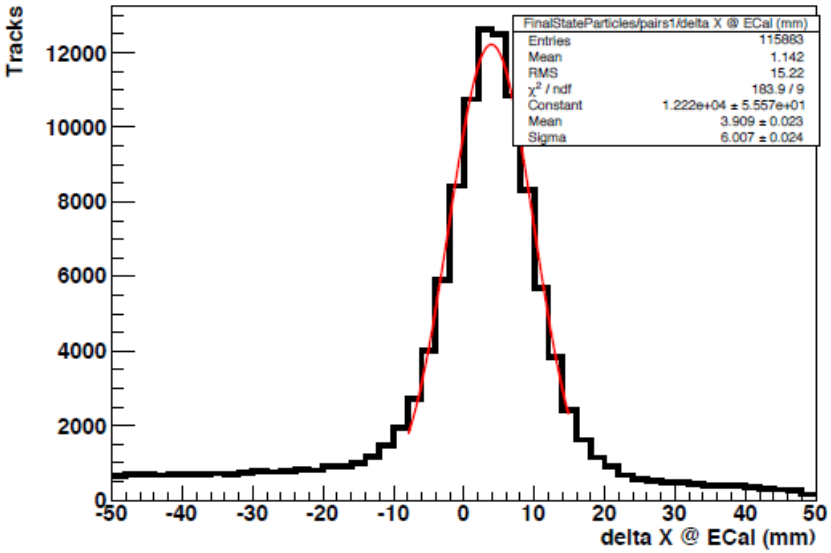
A' candidates have Pe+ + Pe- ~ Pbeam = 1.05 GeV

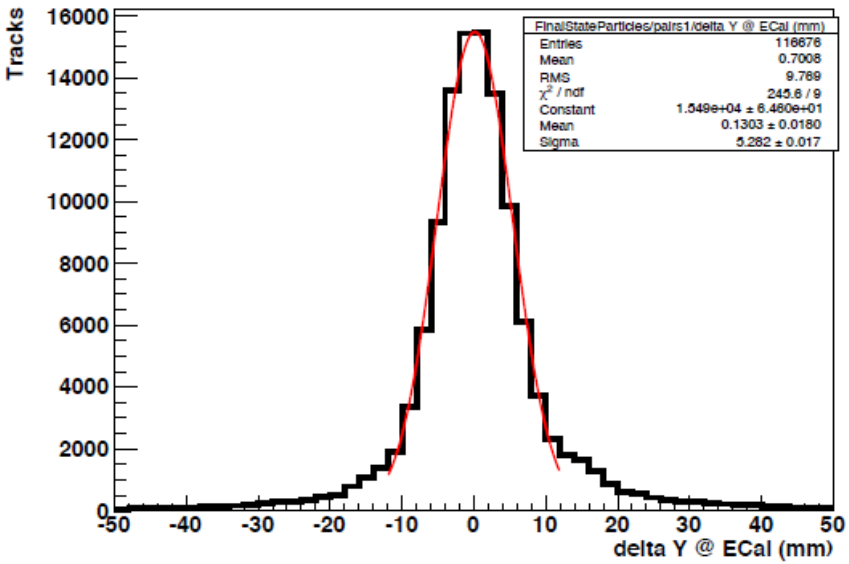


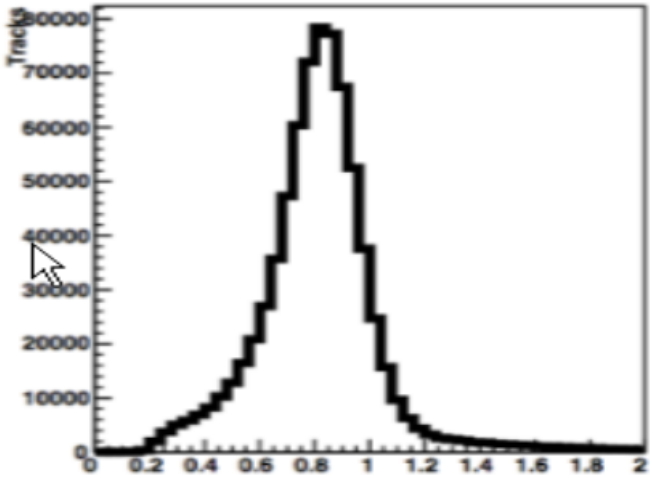
Simulation (6 GeV)

PRELIMINARY

Track Matching at ECal



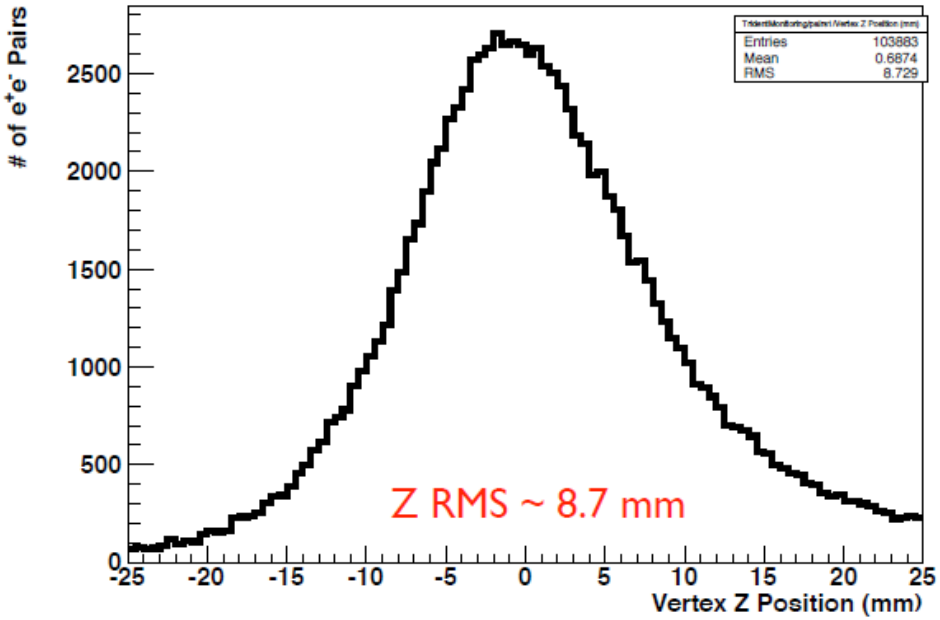




Detector is not yet fully calibrated!
Alignment fine tuning needed, but close.
Gain calibrations need improvement.

PRELIMINARY

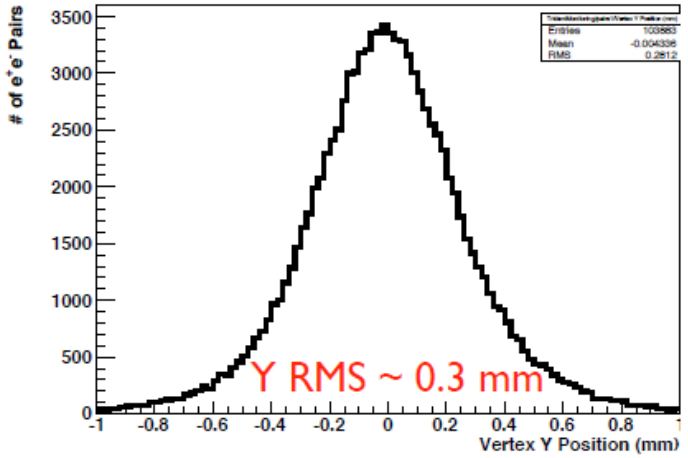
Pairs Vertex at the Target

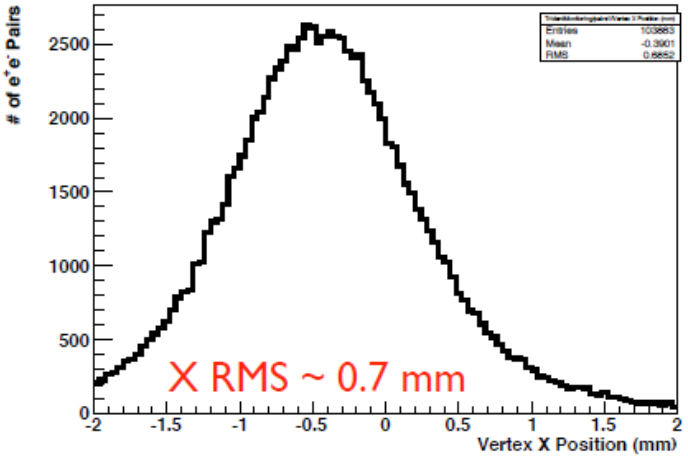


Z-vertex is critical for the experiment.

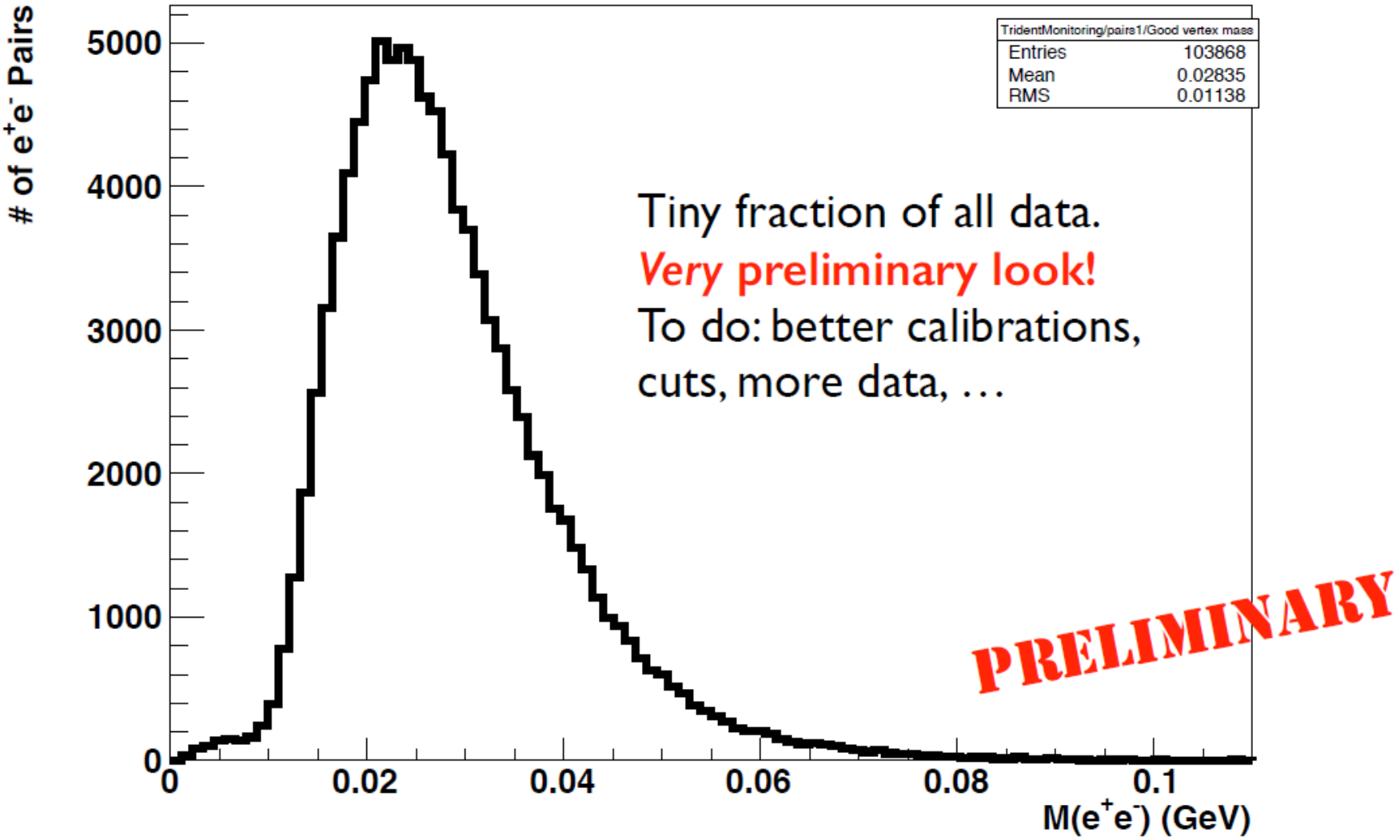
- Also the hardest @ 15 mrad.
- Requires very good SVT alignment (not yet done!)

PRELIMINARY

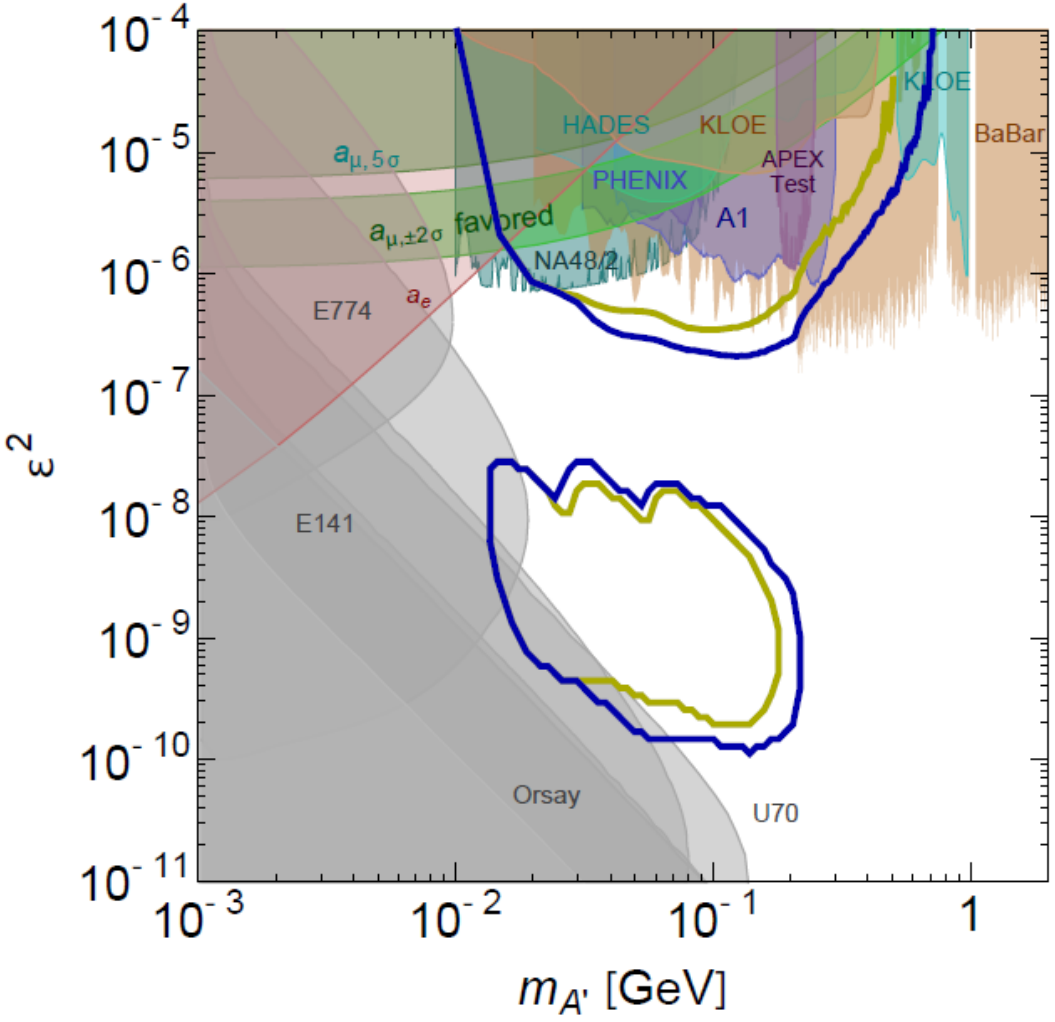




Pairs Mass Distribution



Full HPS Reach



Near term Running (Yellow)

1 week with 50nA @ 1.1 GeV
1 week with 200nA @ 2.2 GeV
2 weeks with 300nA @ 4.4 GeV

Additional Running (Blue):

2 weeks with 200nA @ 2.2 GeV
2 weeks with 300nA @ 4.4 GeV
3 weeks with 450nA @ 6.6 GeV

Times are "PAC" times = Calendar time/2

Opportunistic run Fall 2015
TBD Spring 2016

Summary

- We have roughly 1/3 PAC week with Si at 0.5 mm
  - 15 mrad acceptance
- Beamline, ECal, Trigger and SVT all worked well
  - Beam background and trigger rates are consistent with simulations.
- Lots of work to do ..
  - Check Trident Yield in the data
  - ECal energy calibration
  - SVT alignment
  - Understanding the vertex tails
- But a physics result may be in reach

HPS Collaboration
JLAB + SLAC + FNAL + IPNO Orsay + INFN Genova + Universities
(+ New Collaborators at Glasgow and INFN Catania, Torino, Sassari, Roma)

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