HEAVY PHOTON SEARCH
AT JEFFERSON LAB

Maurik Holtrop
For the HPS Collaboration
LEPP, Mainz, April 5, 2016

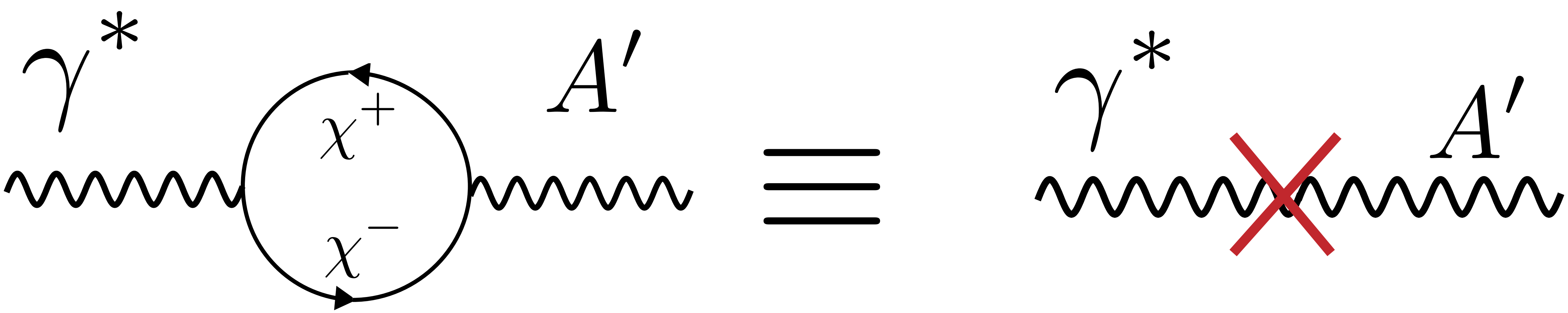
Heavy Photons?

Old idea: Nature may have an additional *U(1)* symmetry. If so there will be kinetic mixing between the photon and the new gauge boson.

Holdom, Phys. Lett B166, 1986

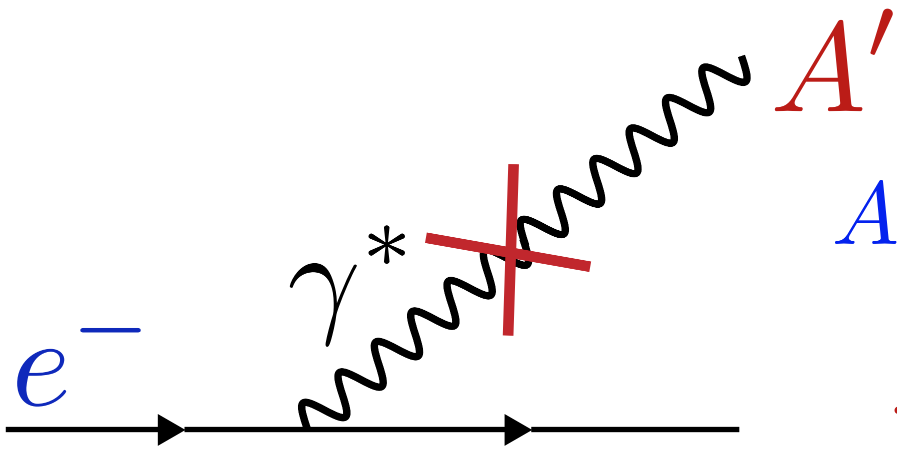
$$\mathcal{L}_{U(1)'} = -\frac{1}{4}V_{\mu\nu}^2 - \boxed{\frac{\epsilon}{2}V_{\mu\nu}F^{\mu\nu}} + |D_\mu\phi|^2 - V(\phi)$$

Kinetic Mixing term.



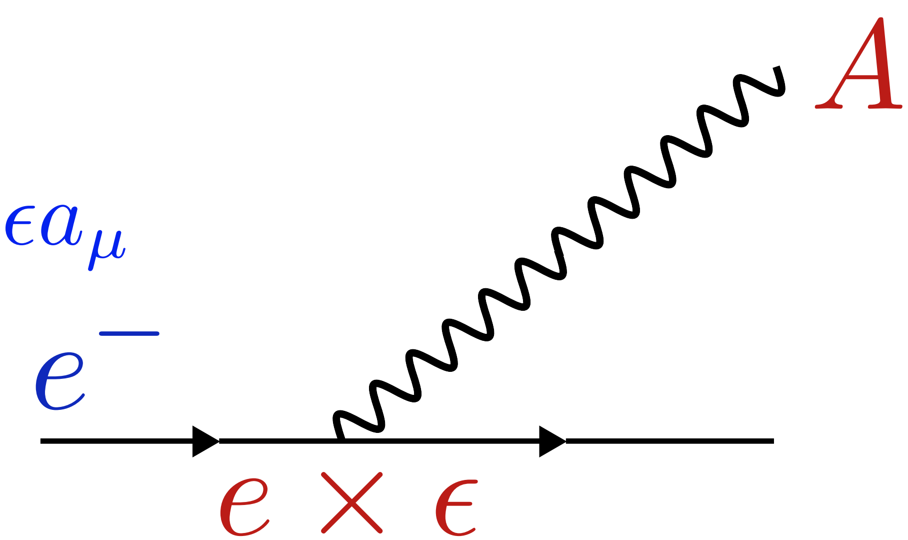
Mixing

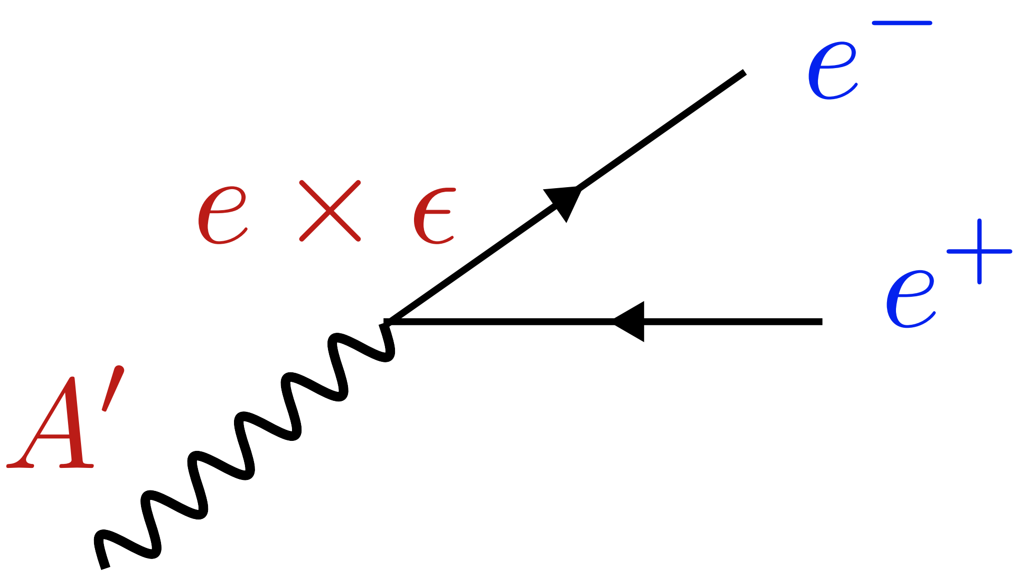
Photon mixing with A′ is equivalent to ordinary charged matter acquiring a milli-charge under the A′



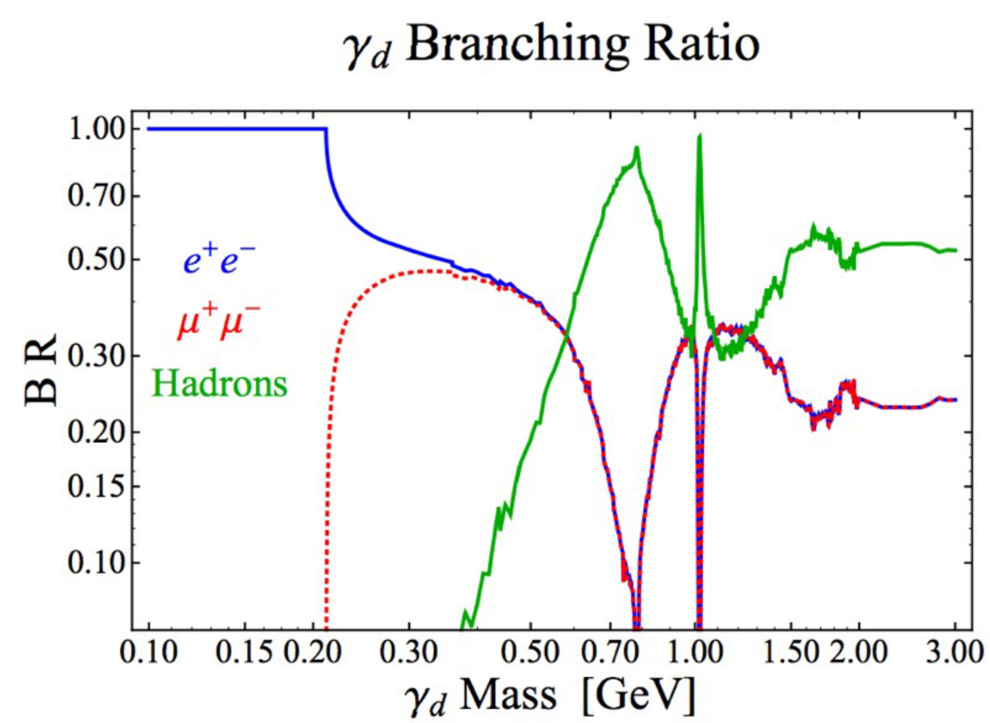
$A_\mu \to A_\mu + \epsilon a_\mu$

$\Leftrightarrow$





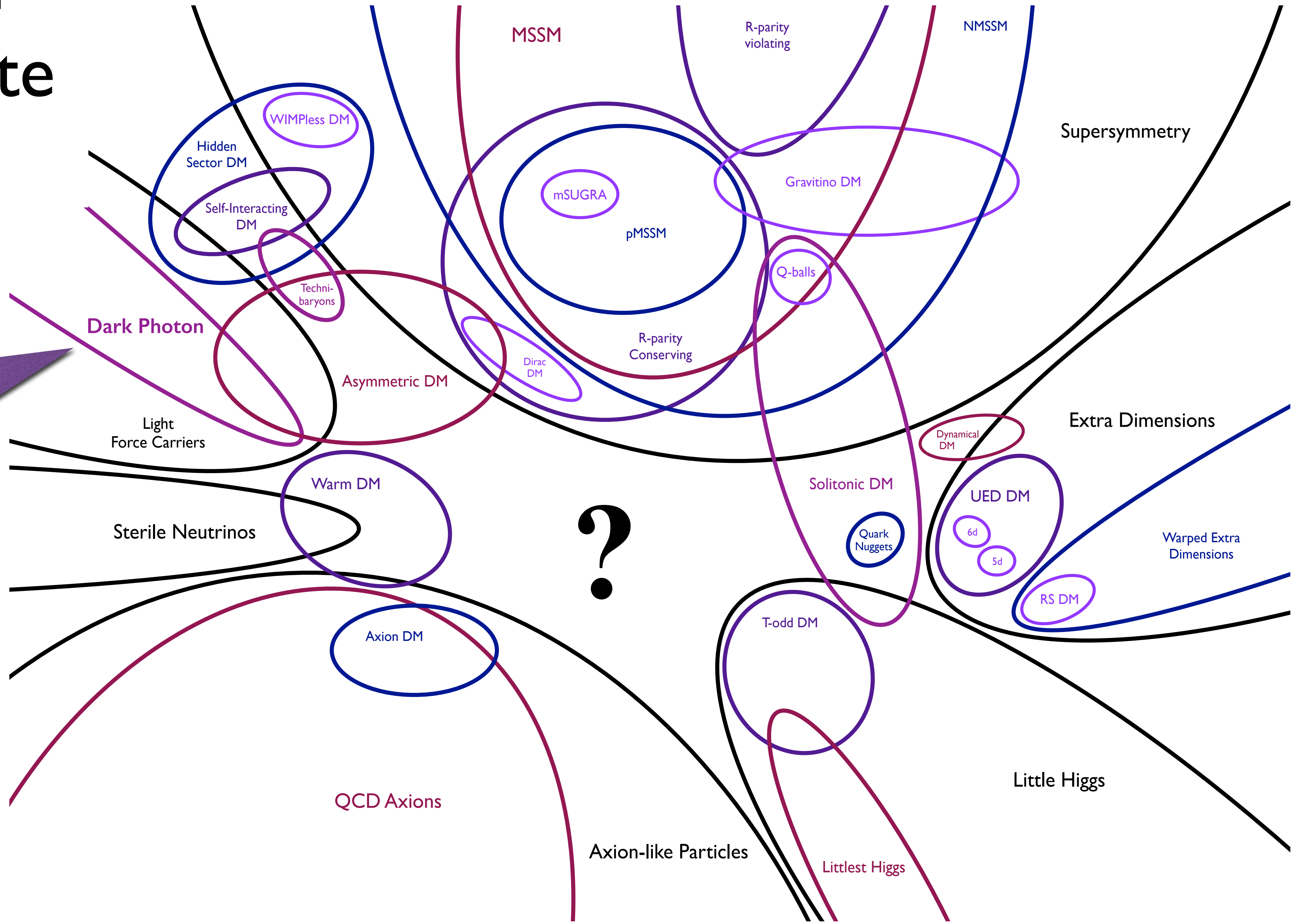
A’ will pair produce: e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, …



Putting this in perspective

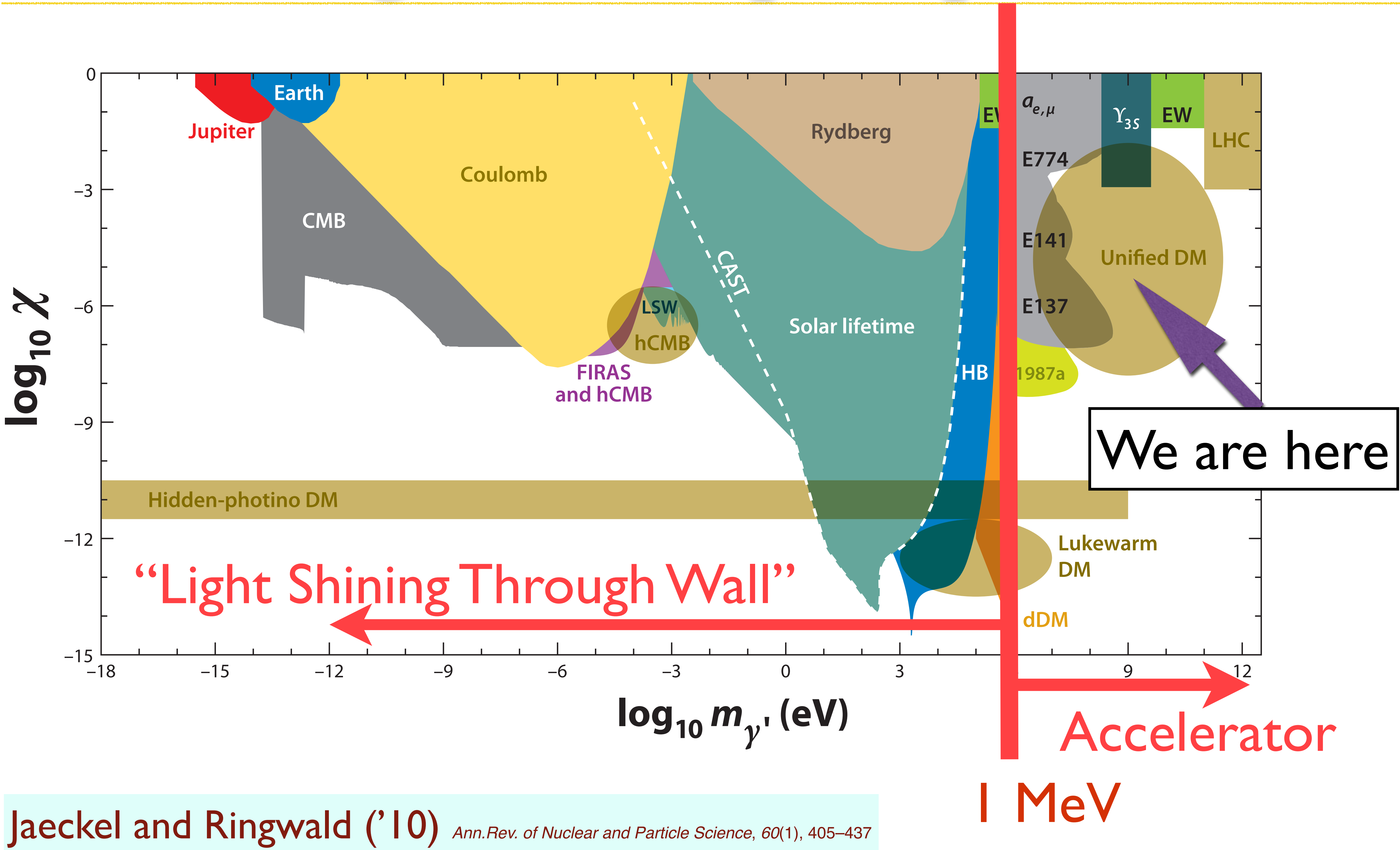
Venn Diagram
"DM Candidate Landscape"

We are here



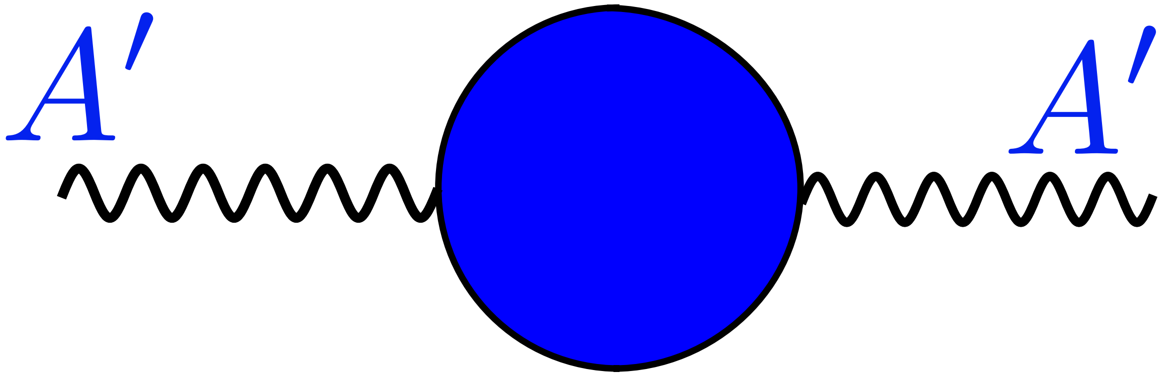
T. Tait from arXiv:1401.6085v1 [hep-ex]

Putting this in perspective



Jaeckel and Ringwald ('10) *Ann.Rev. of Nuclear and Particle Science, 60*(1), 405–437

"Natural*" Coupling and Mass



Mass inherited from "electro-weak" scale

$$m_{A'}^2 \sim \epsilon M_W^2$$

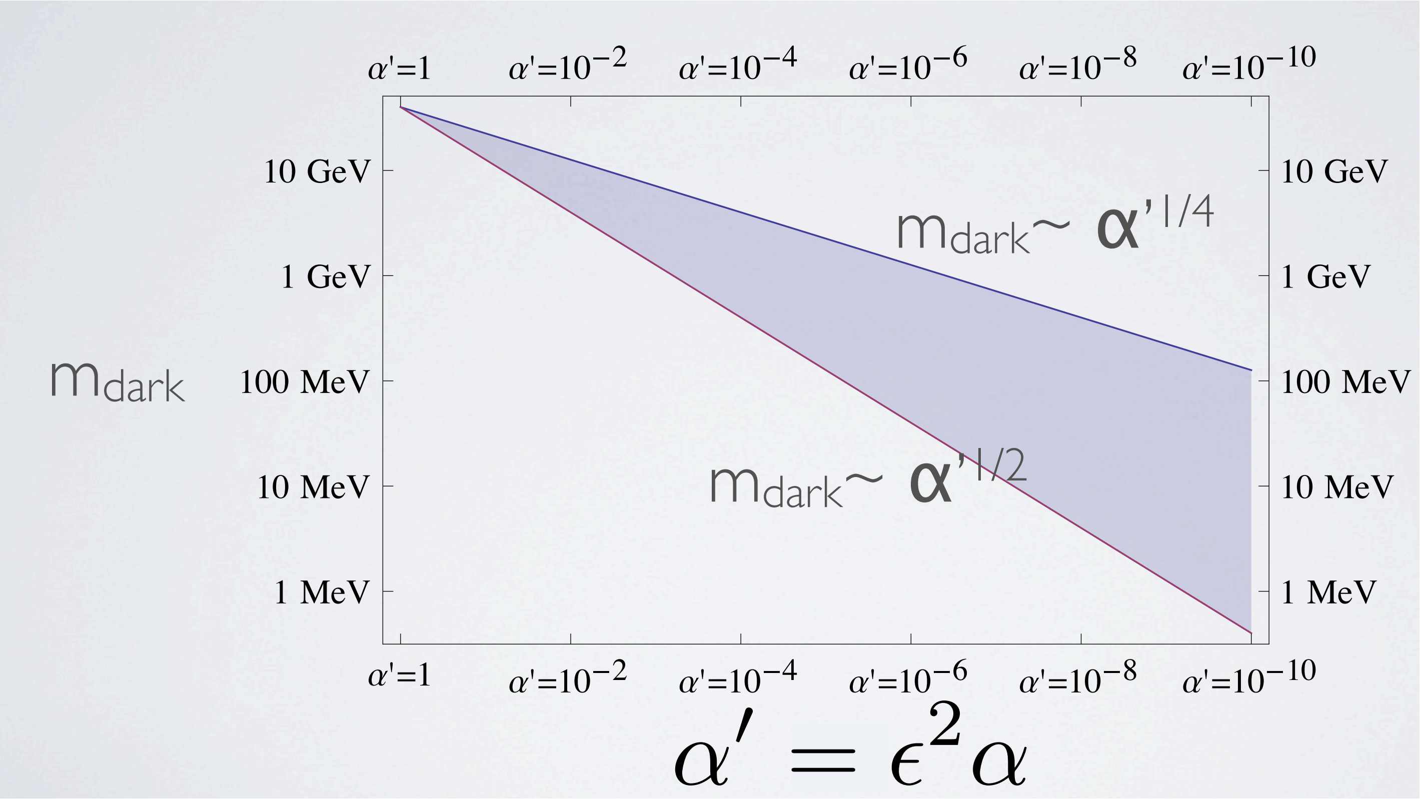
or

$$m_{A'}^2 \sim \frac{e g_D}{16\pi^2} M_W^2$$

or

Stückelberg mechanism:

$m_{A'} \sim$ meV



Neil Weiner, Intensity Frontier WS '11

Natural ε could be ~ 1 (tree level)

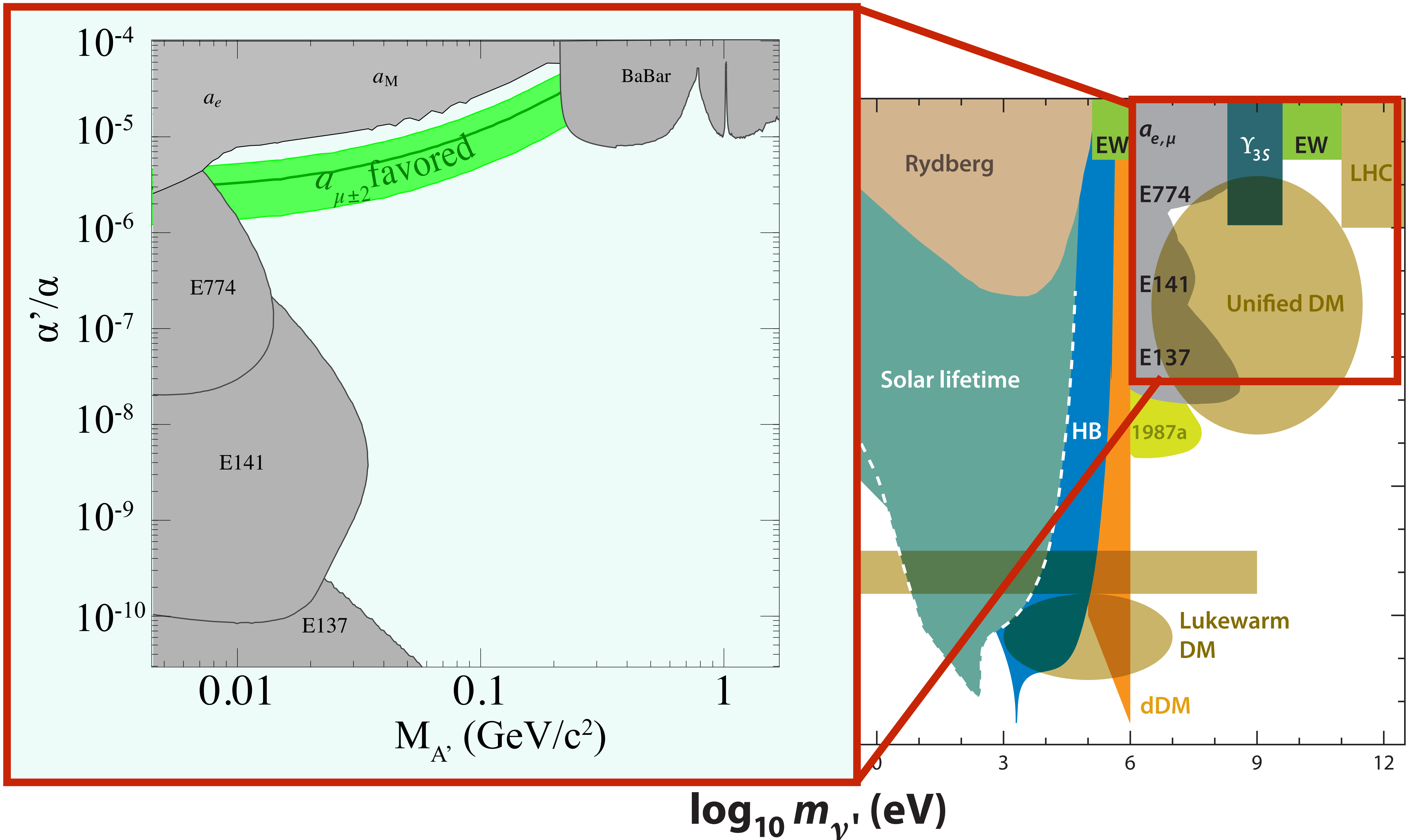
Or 1 < ε < 10^{-8} (loops)

or "anything" ...

Leading to: $M_{A'} \sim \mathrm{MeV} - \mathrm{GeV}$

See: R. Essig et al, Intensity Frontier WS '11 summary paper.

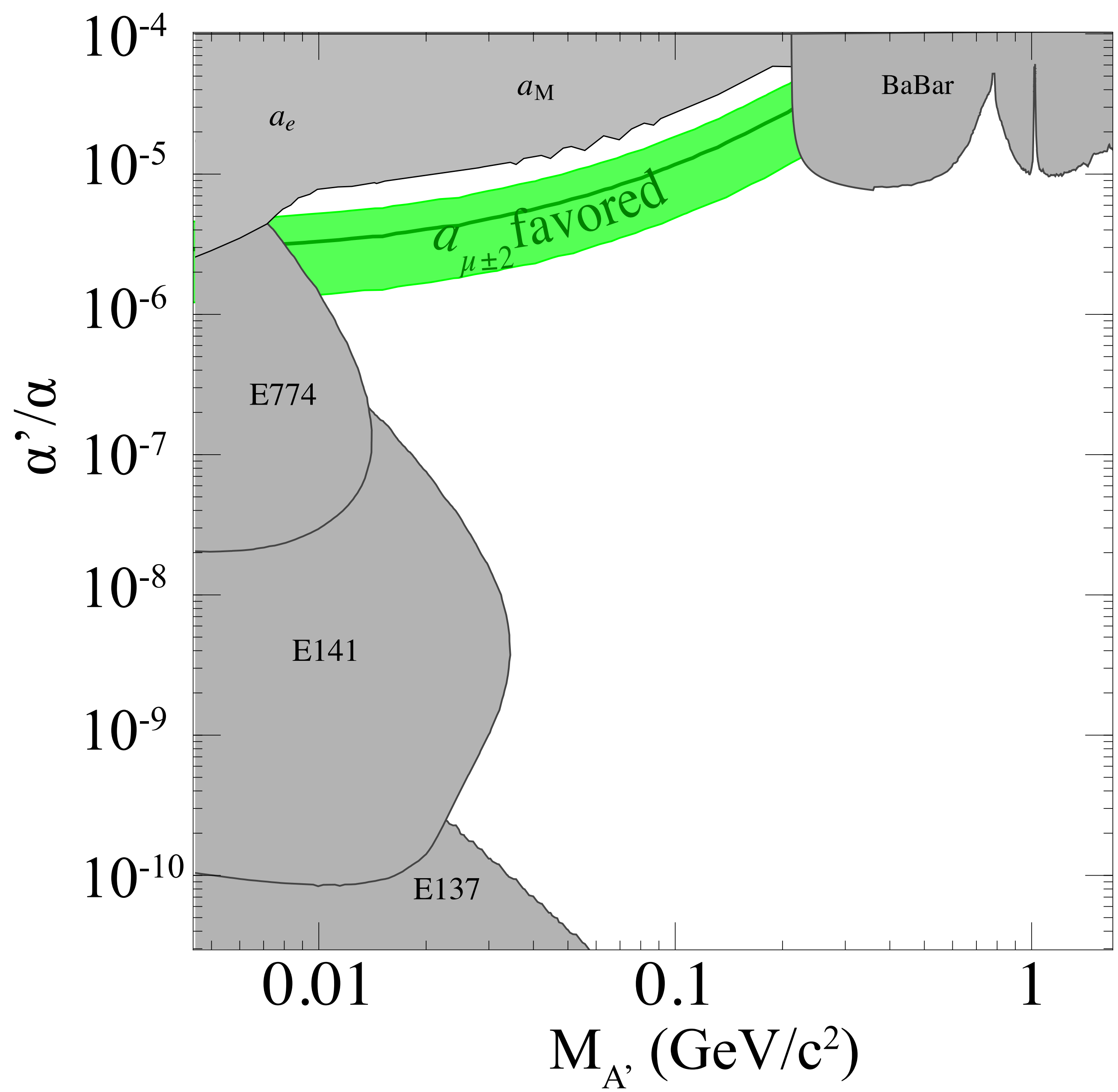
Search area of choice



A lot of interest!

Since 2010, a lot of interest in this field.

Exclusion areas in 2010

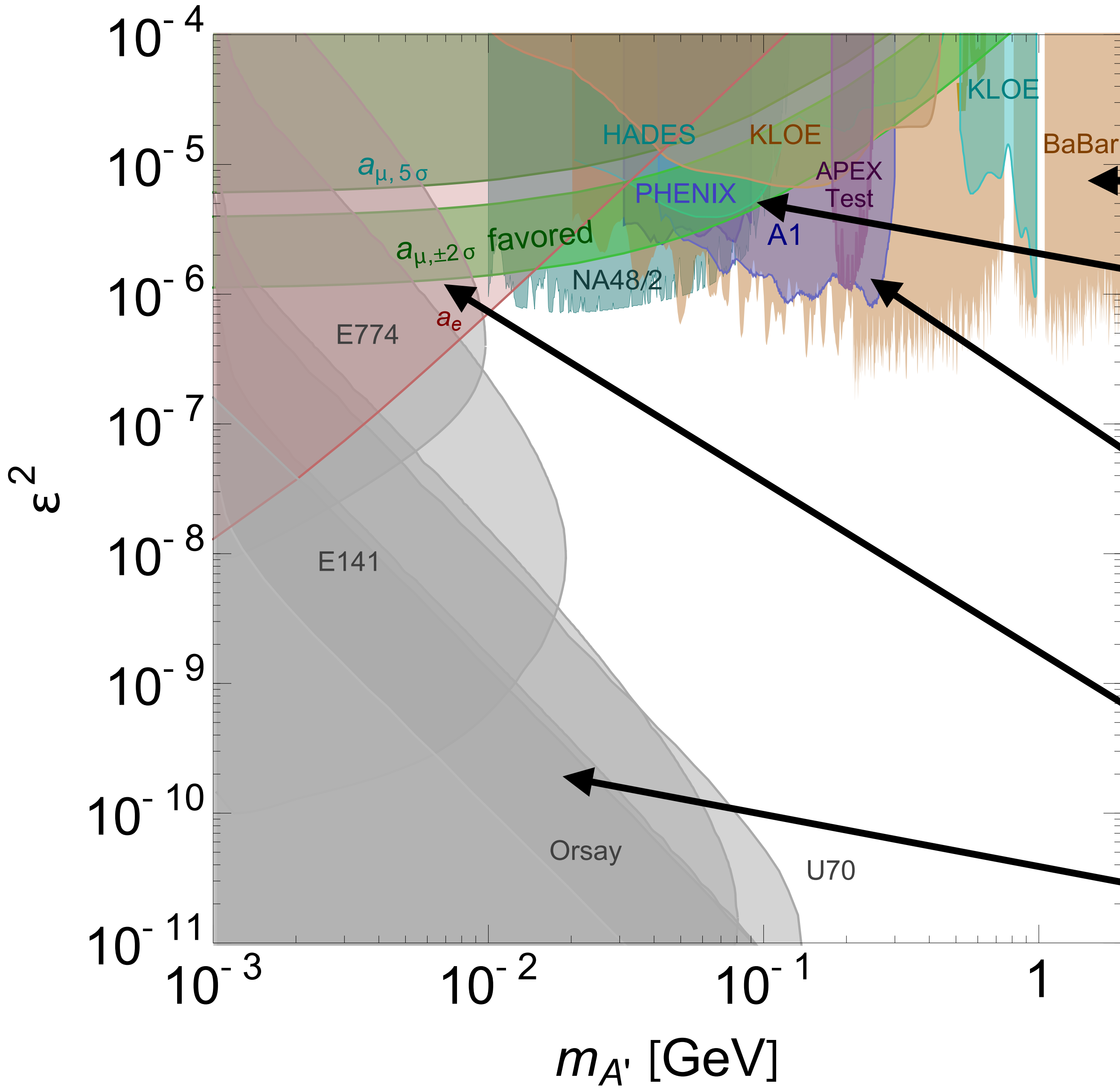


At the time of the HPS proposal, exclusion areas were mostly due to beam dump searches.

A lot of interest!

Since 2010, a lot of interest in this field.

Exclusion areas in 2015



Lots of places to look:

Flavor Factories

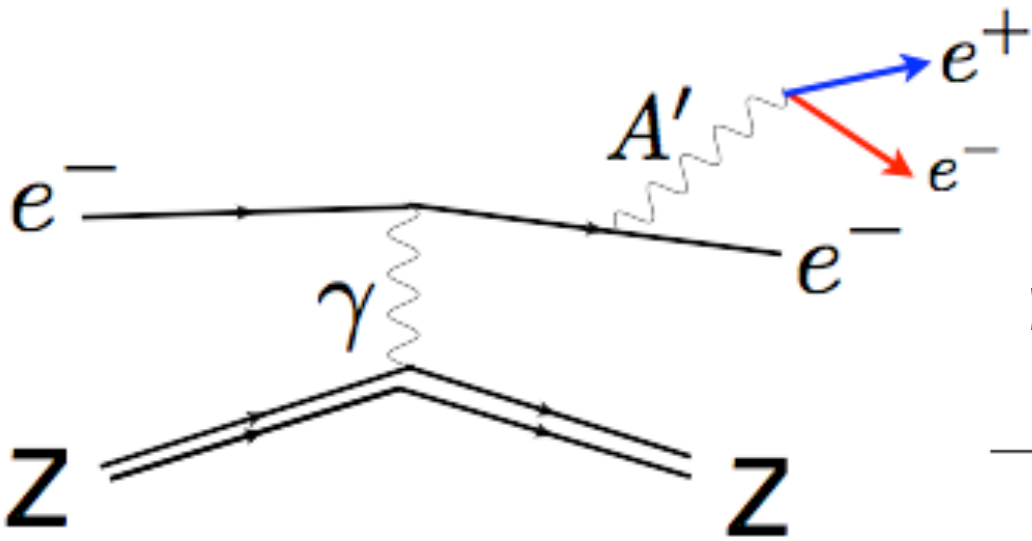
Rare Meson Decays

Fixed target experiments.

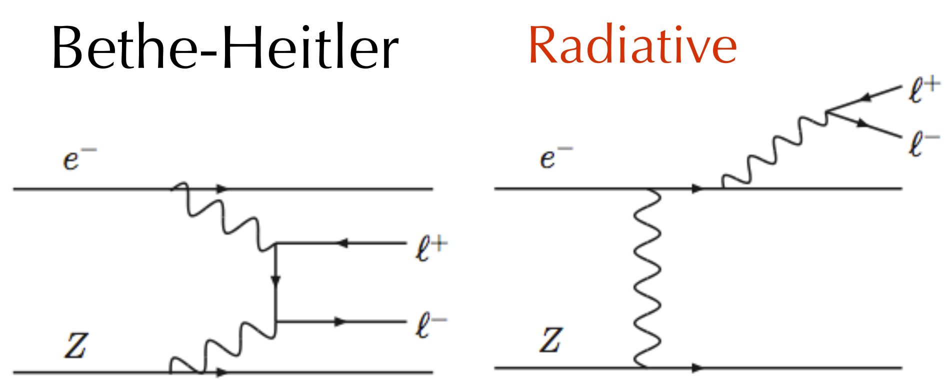
Precision Measurements

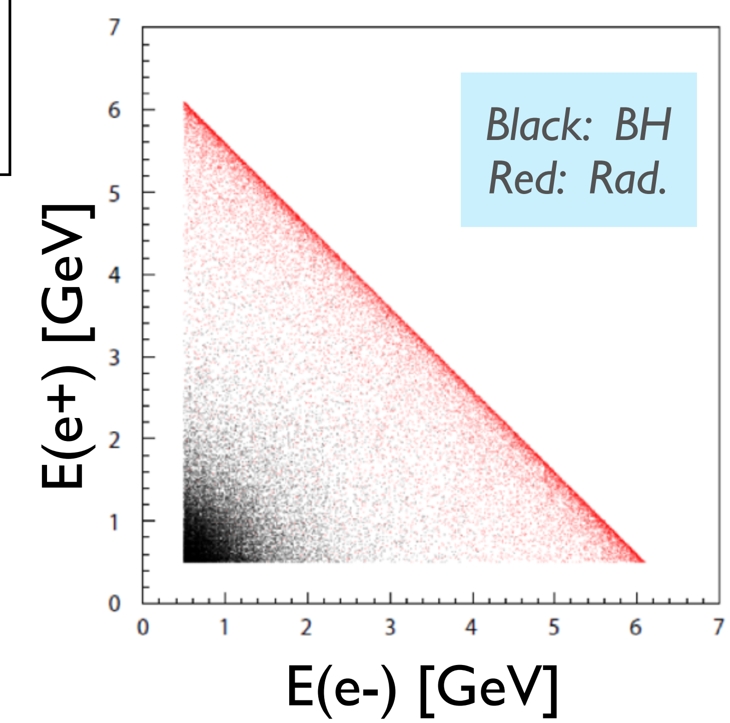
Beam dump experiments.

Fixed Target Searches



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





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*

A′ lifetime

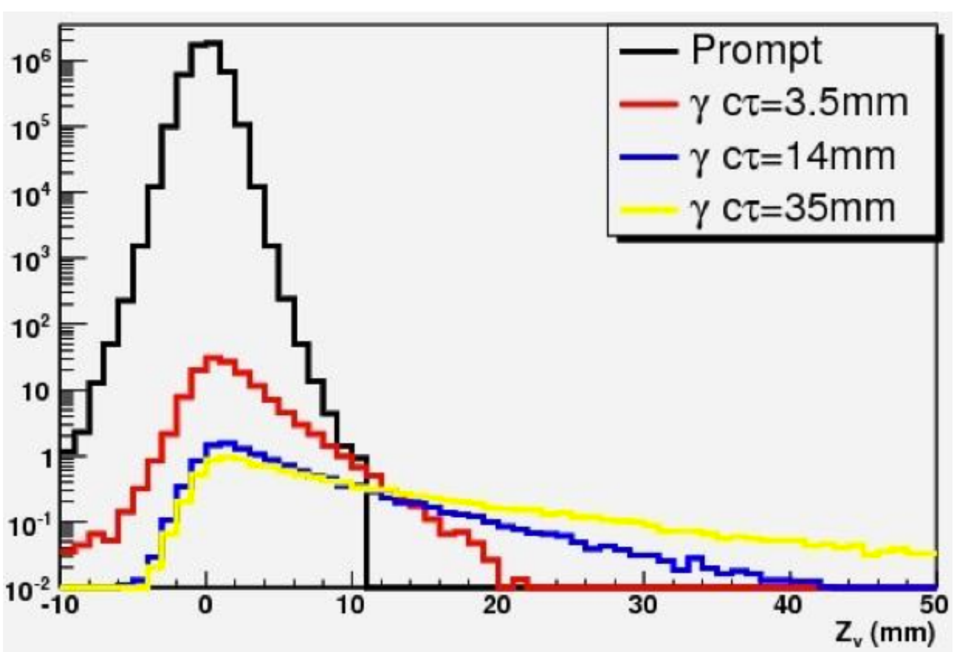
$$\gamma c\tau \approx 1\ \text{mm} \left(\frac{\gamma}{10}\right)\left(10^{-8}\frac{\alpha}{\alpha'}\right)\left(\frac{100\ \text{MeV}}{m_{A'}}\right)$$

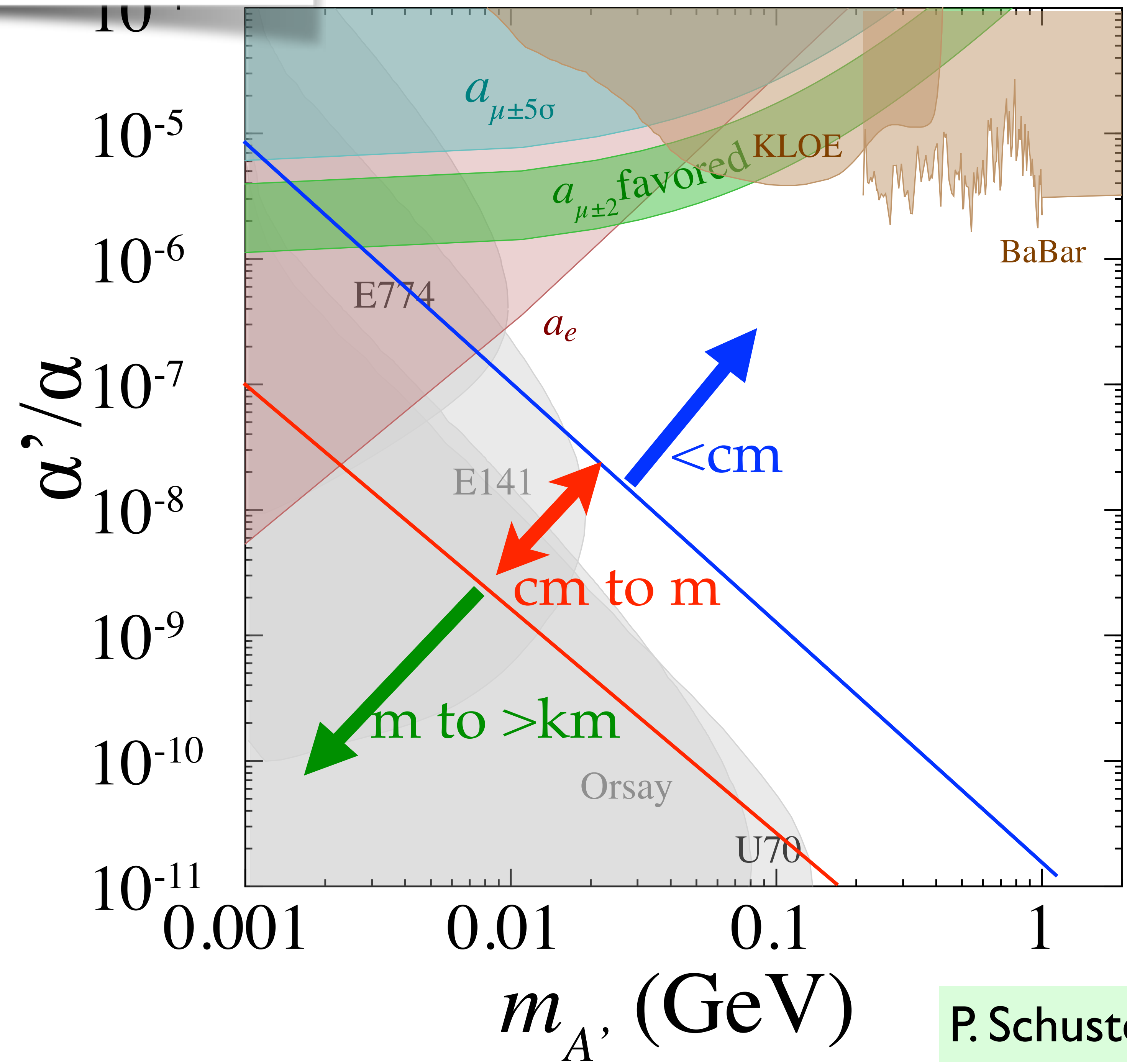
Lower α′, lower mass

→longer lifetime

Background is all prompt

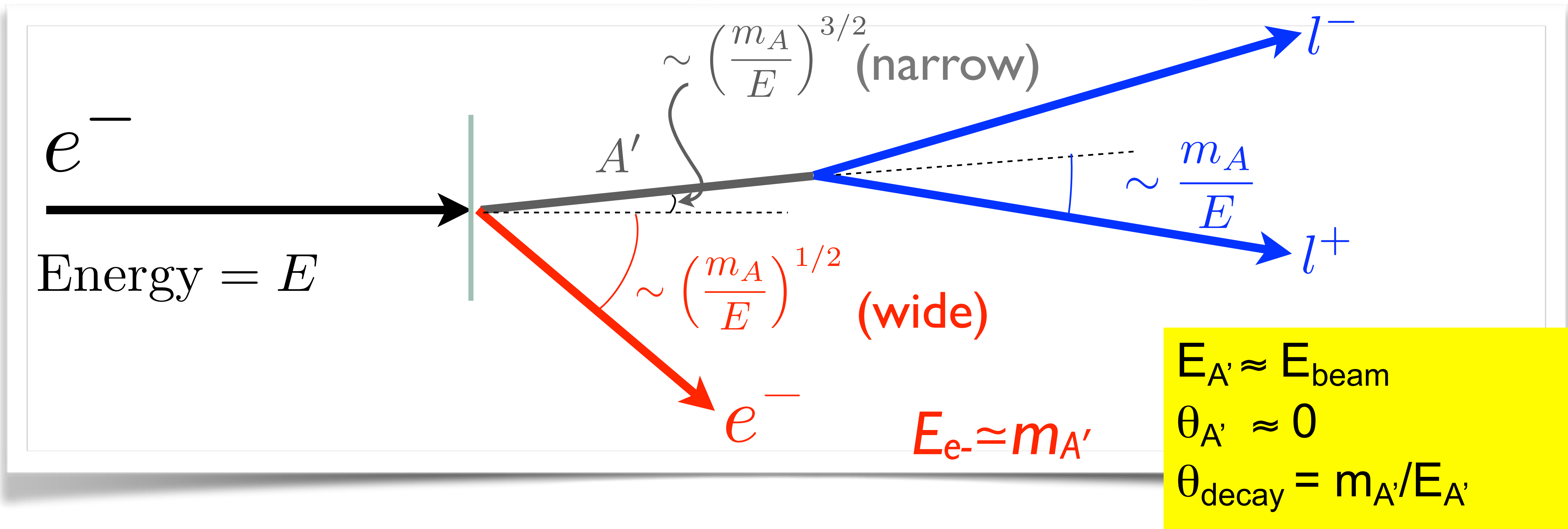
➜ Lower coupling can be reached using vertexing.

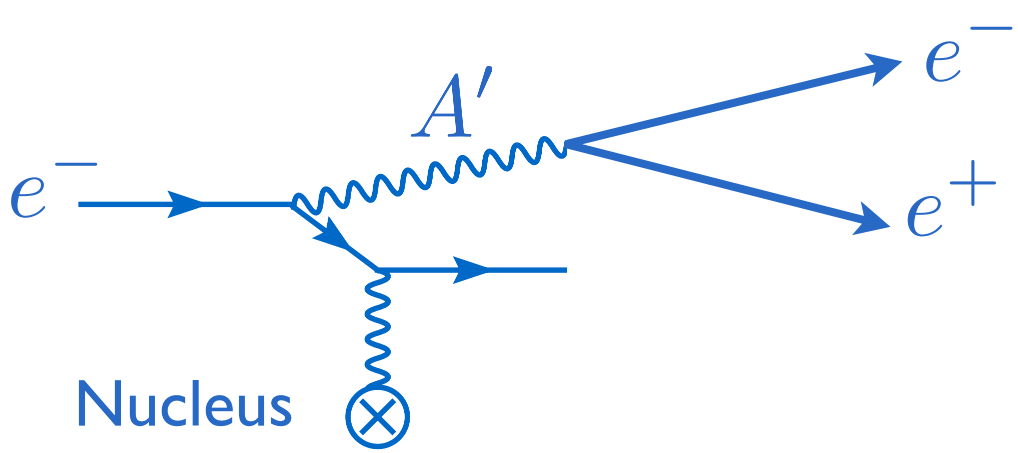




P. Schuster

Detecting A' decays

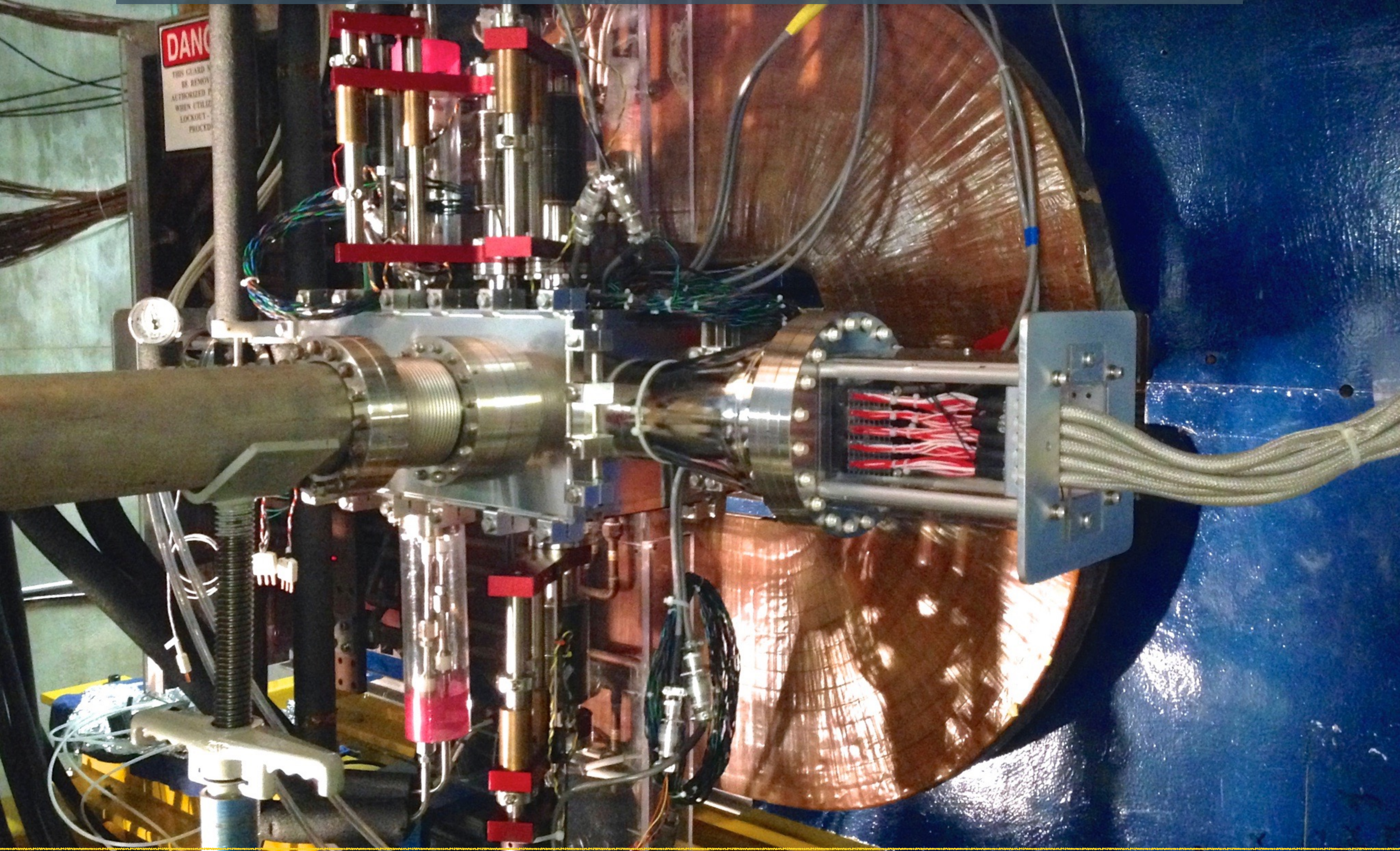




Need:

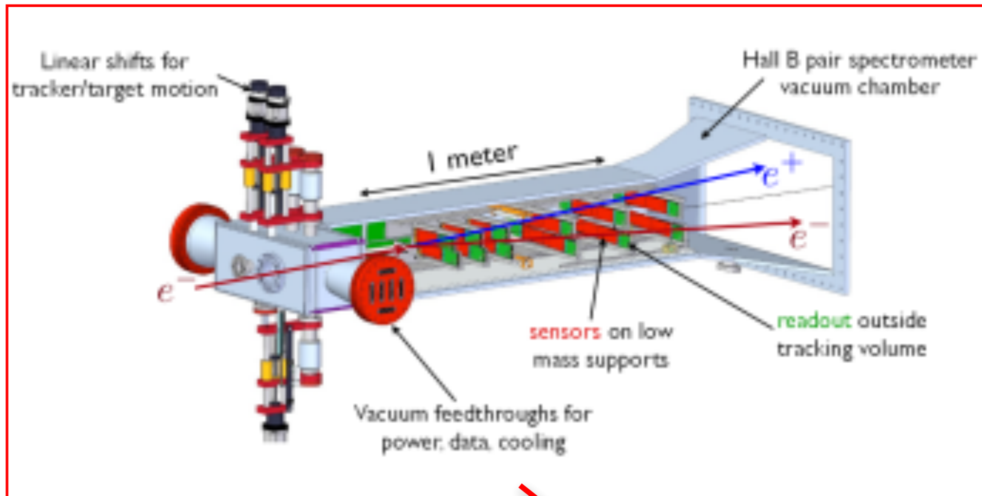
- Small angle detection of e+ e-
- Very high luminosity
- Good invariant mass resolution

The HPS Experiment

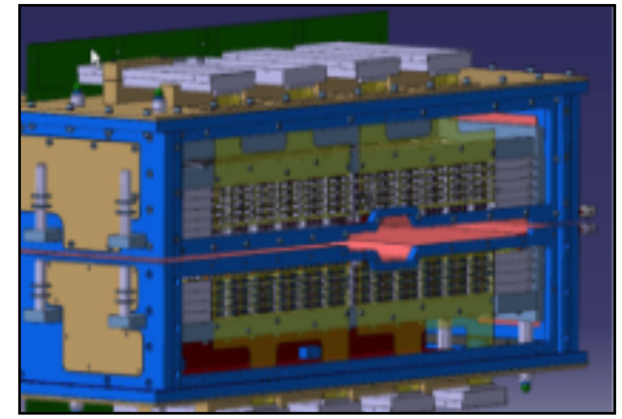


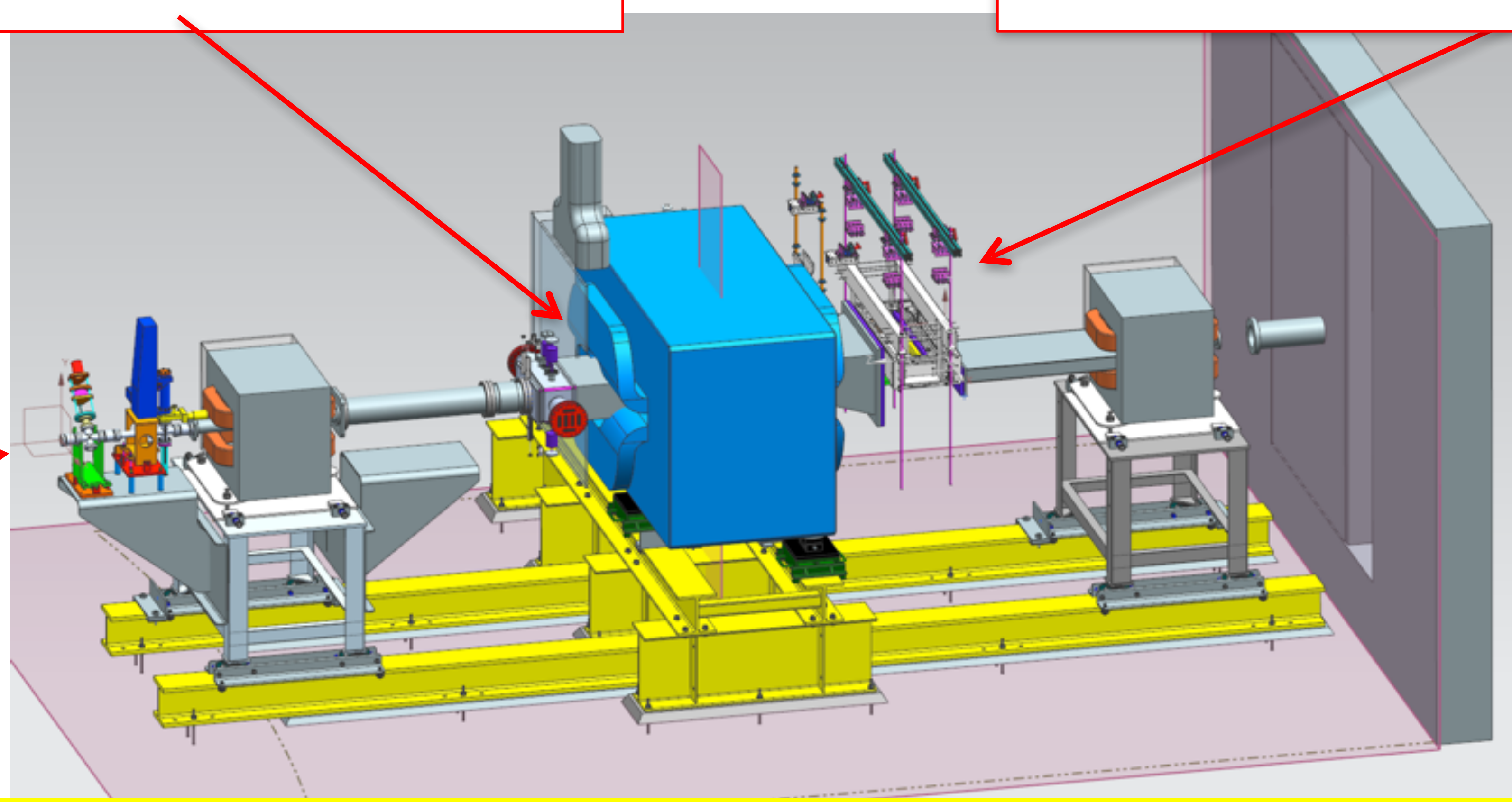
HPS Setup in Hall B Alcove

Si Vertex Tracker Installed Feb 23, 2015



$PbWO_4$ Ecal Installed September, 2014

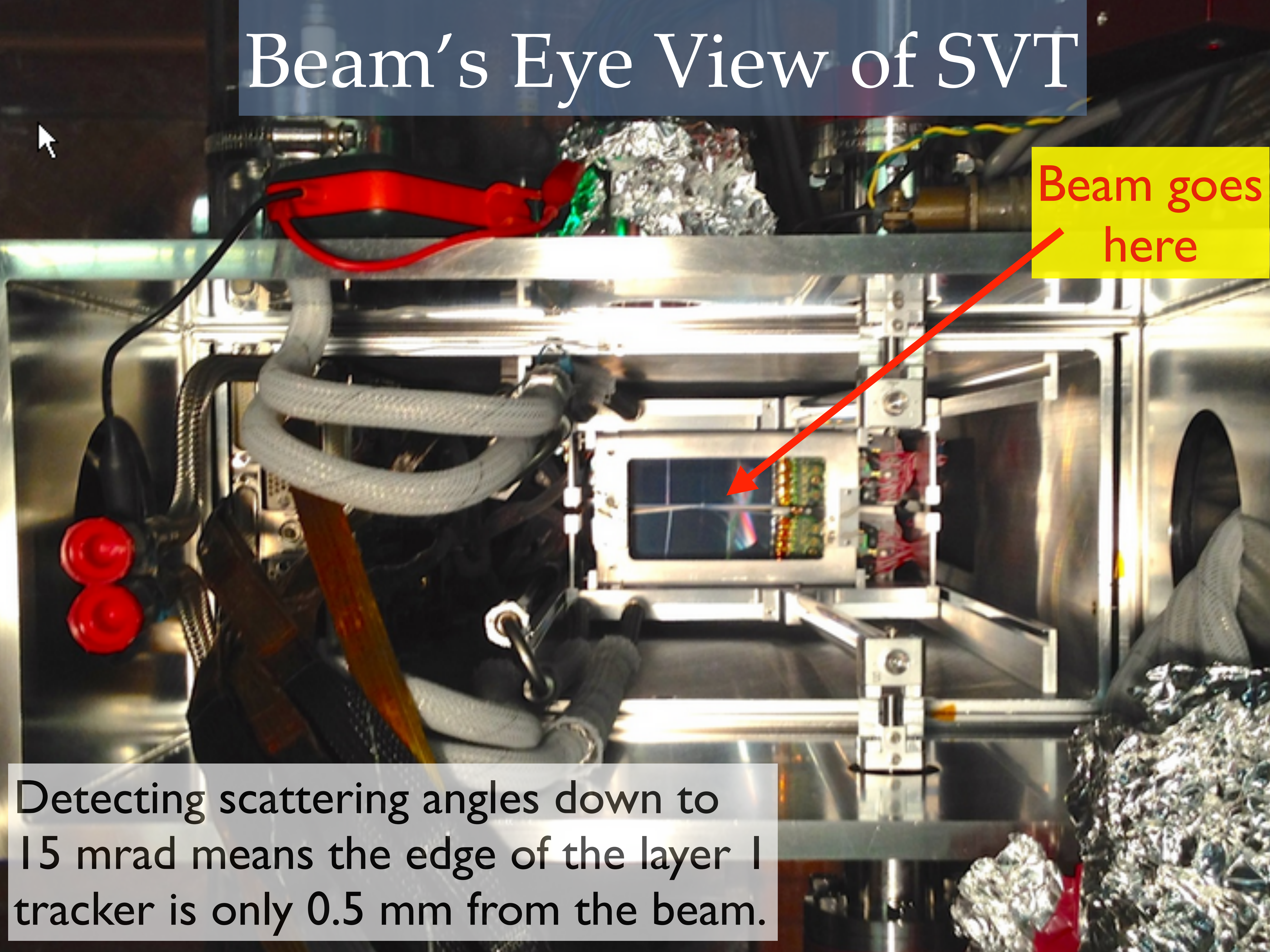




e^-

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
Beam goes here
Detecting scattering angles down to 15 mrad means the edge of the layer 1 tracker is only 0.5 mm from the beam.

The Engineering Runs '15 & '16

HPS is making use of "opportunistic" running in 2015 & 2016, while the CLAS12 detector is being build in Hall-B.

Spring 2015: Beam time during nights and weekends.

Beam: 1.05 GeV @ 50 nA on 4 μm W target

Data rate: 20 kHz, 150 MB/sec

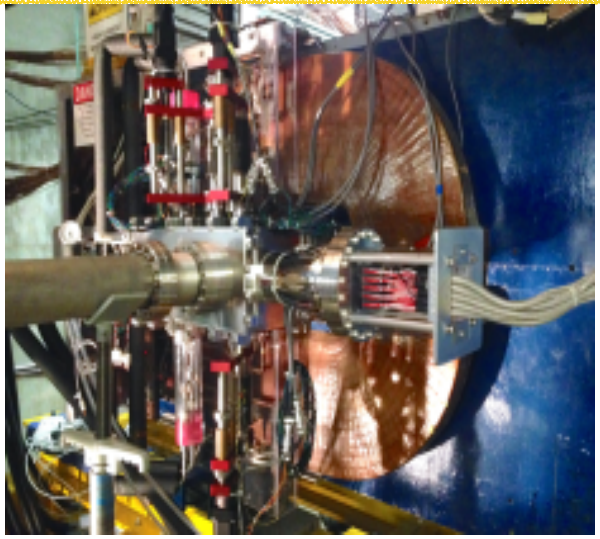
Spring 2016: Beam time during weekends only

Beam: 2.3 GeV @ 200 nA on 4 μm W target

Data rate: 25 kHz (up to 50 kHz), 200 MB/sec

- These are challenging running conditions, with a lot of time spend on beam tuning each startup.
- Excellent support from accelerator division made physics quality data possible.
- Both runs had interruptions due to issues with accelerator (CHL)
- Both runs received extensions from lab management.

The Engineering Runs '15 & '16

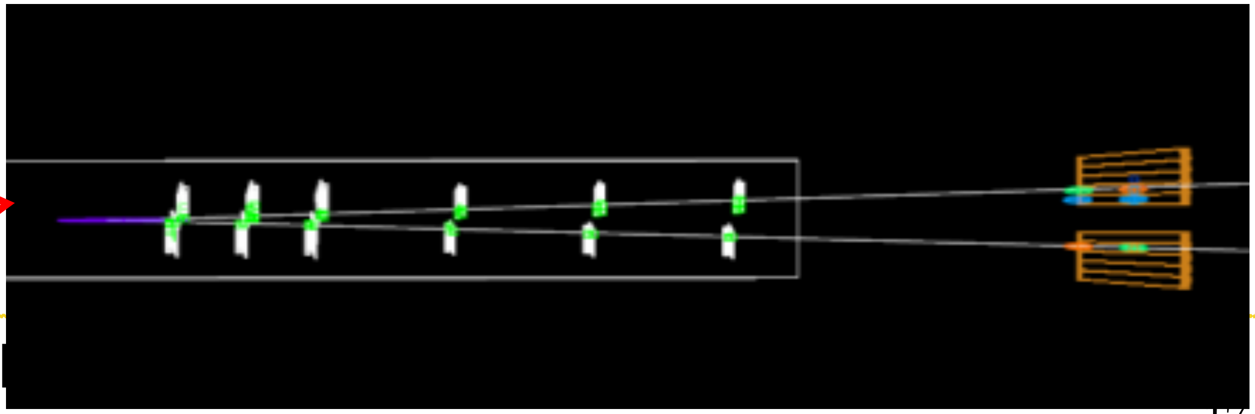


Timeline:

- February 2015: HPS fully installed.
- March- April: Commissioned Hall B beam line 1 GeV
- mid-April: CEBAF down (CHL crash)
- late April: Commissioned Trigger and SVT DAQ
- late April: Explore SVT backgrounds
  - Move SVT closer to beam
- May 1-12 : Production running, 1GeV at 1.5 mm
- May 12-18: Production running, 1 GeV at 0.5 mm
- February 2016: Commissioned Hall B beam line 2.3 GeV
- March 2016: CEBAF down (CHL problem)
- April 2016: Production running …

Run 5623
Event 62
N. Graf

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



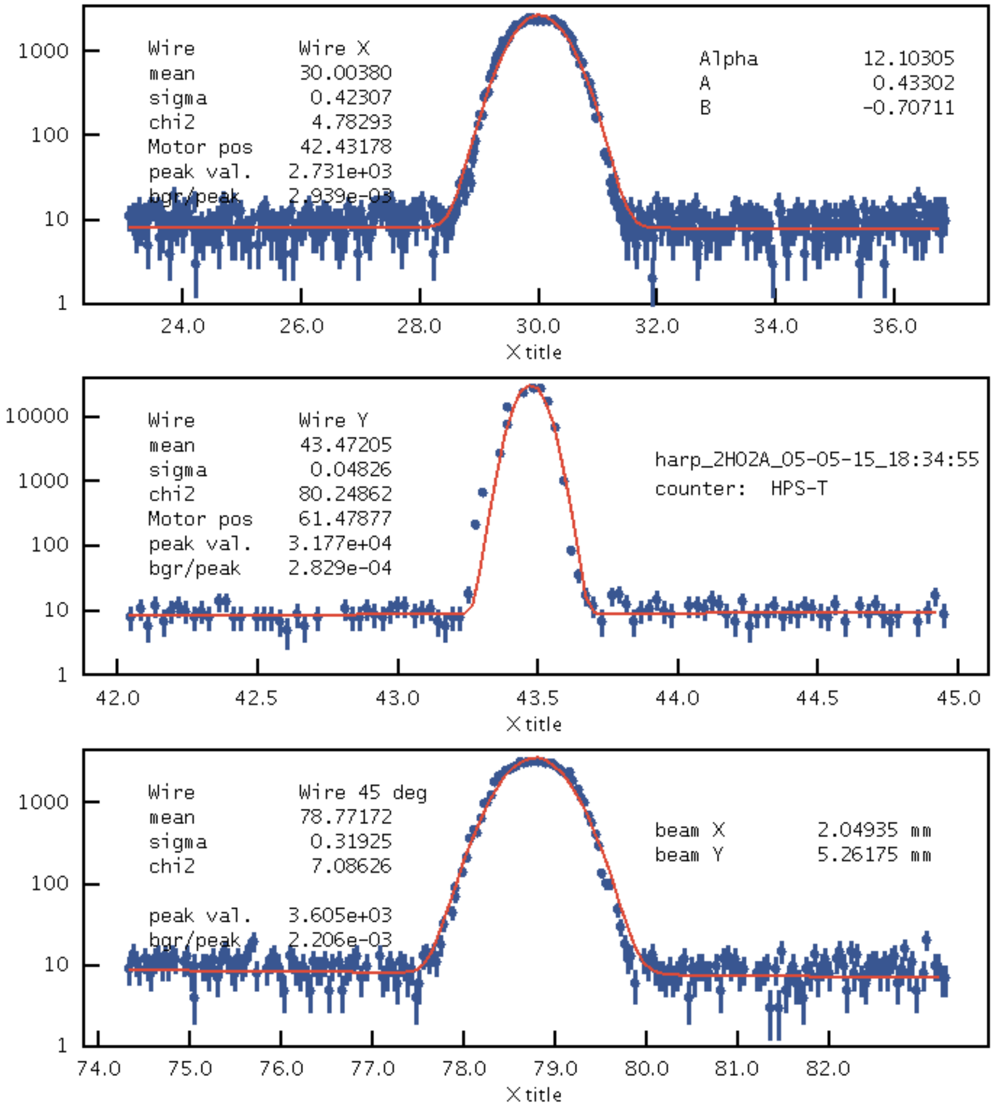
Beam Quality

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

$\sigma_X \sim$ 300 to 500 μm - To spread heat load.

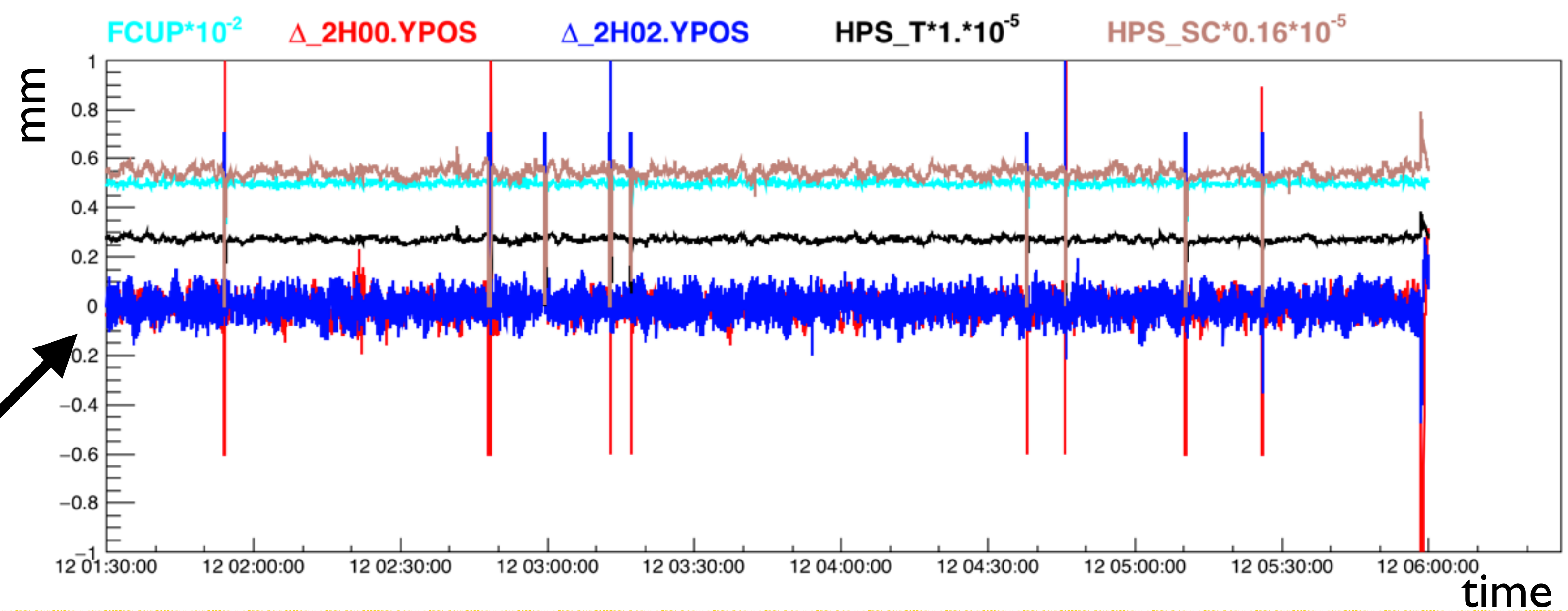
$\sigma_Y \sim$ 15 - 50 μm - To help vertexting & tracking.

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.



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

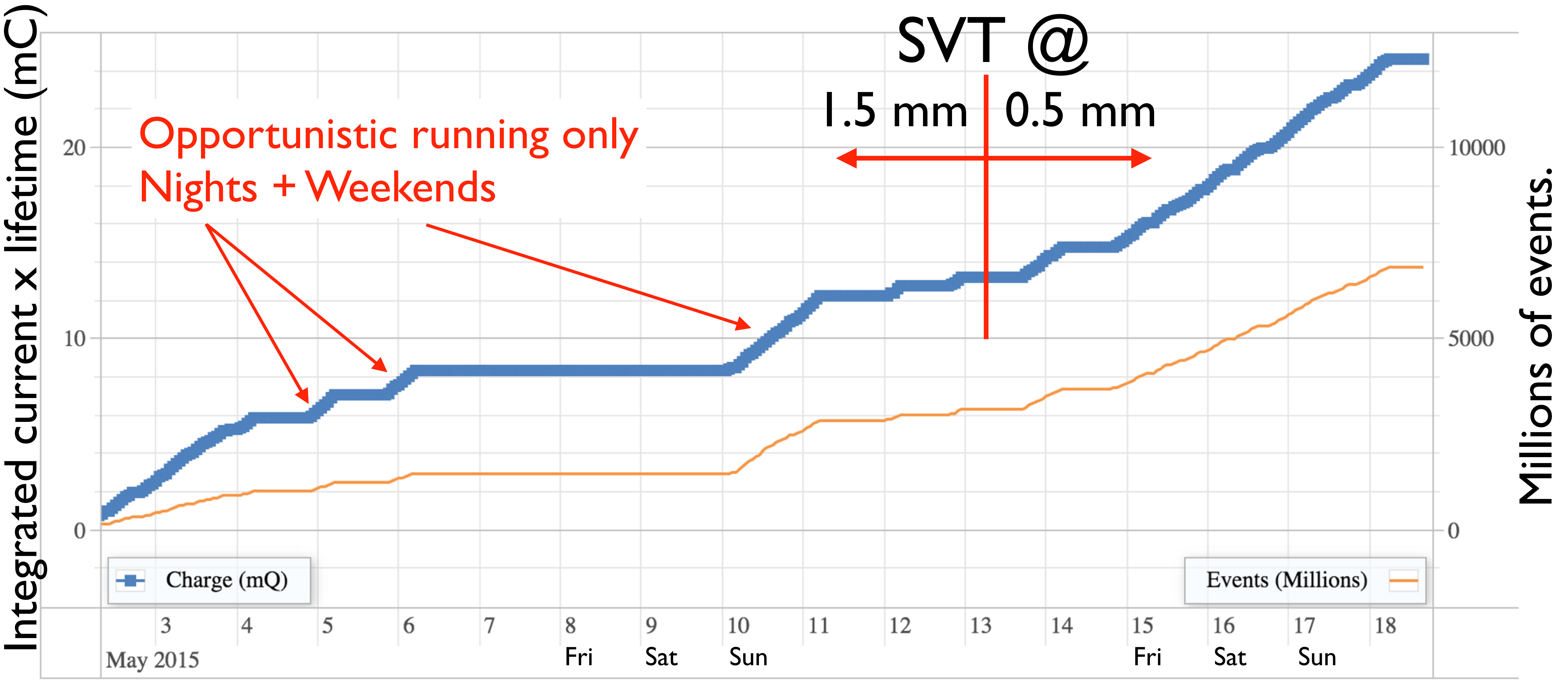
Very stable beam on May 12th.



2015: 1.05 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



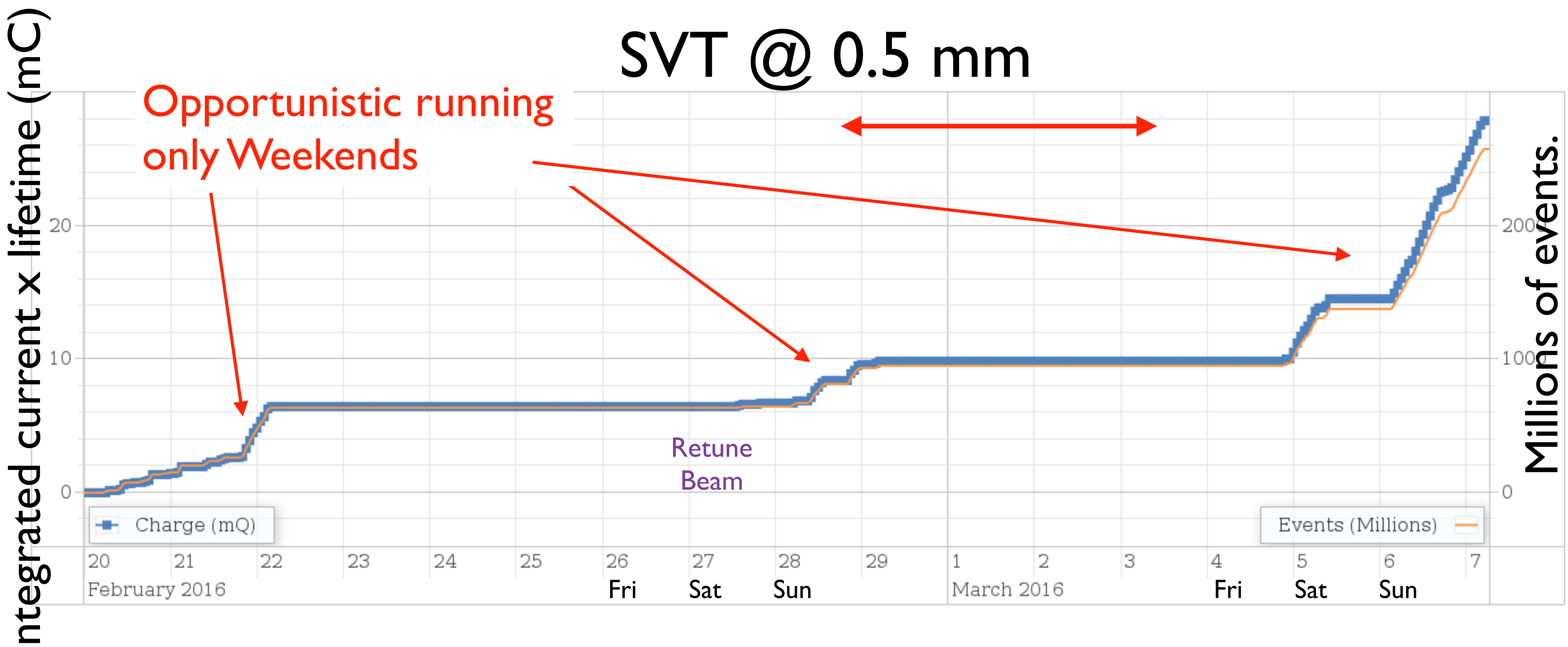
2016: 2.3 GeV Run, Charge on target.

Running 200 nA, 2.3 GeV on target

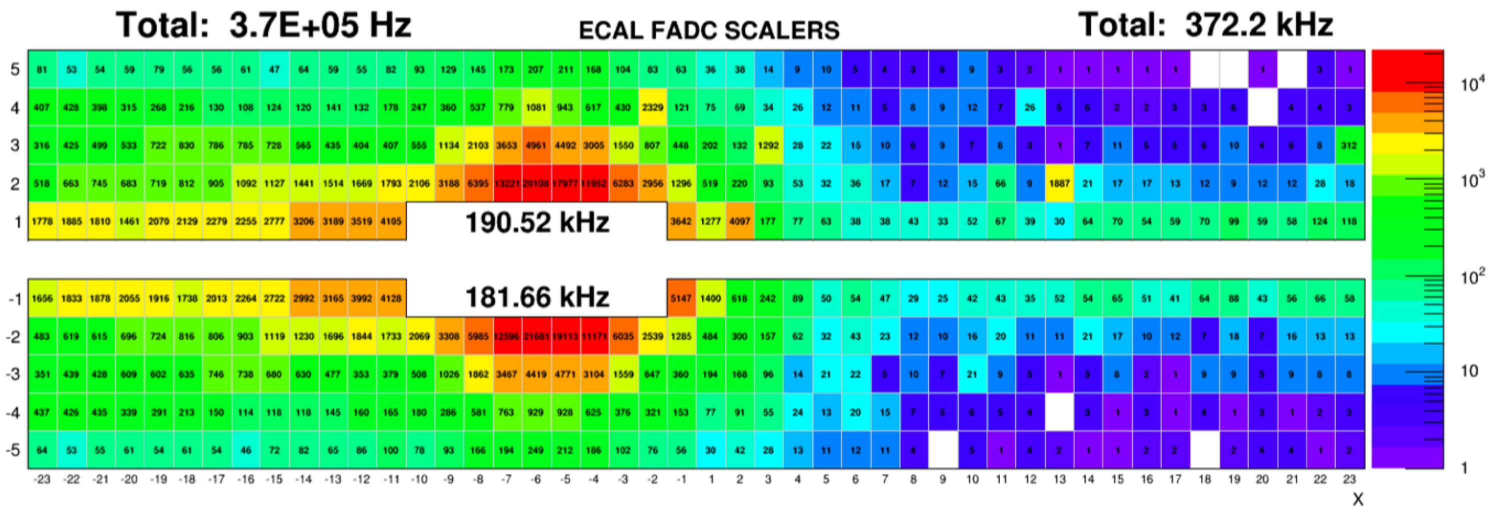
Still opportunistic running, weekends only.

CHL work stopped run from March 8 until April 1.

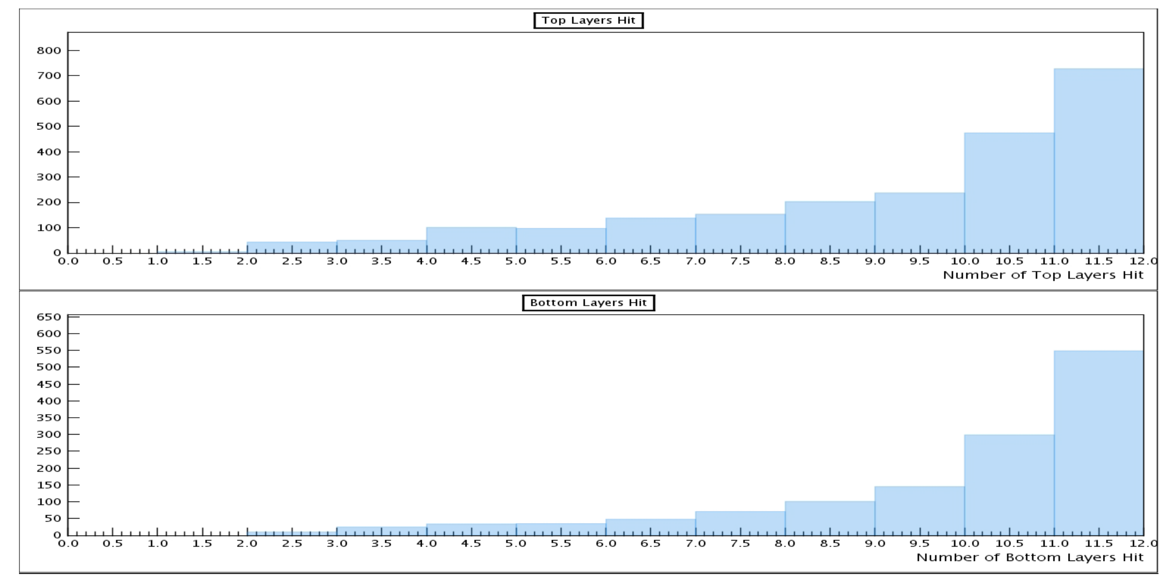
Run is still happening! Extended until end of April 2016.

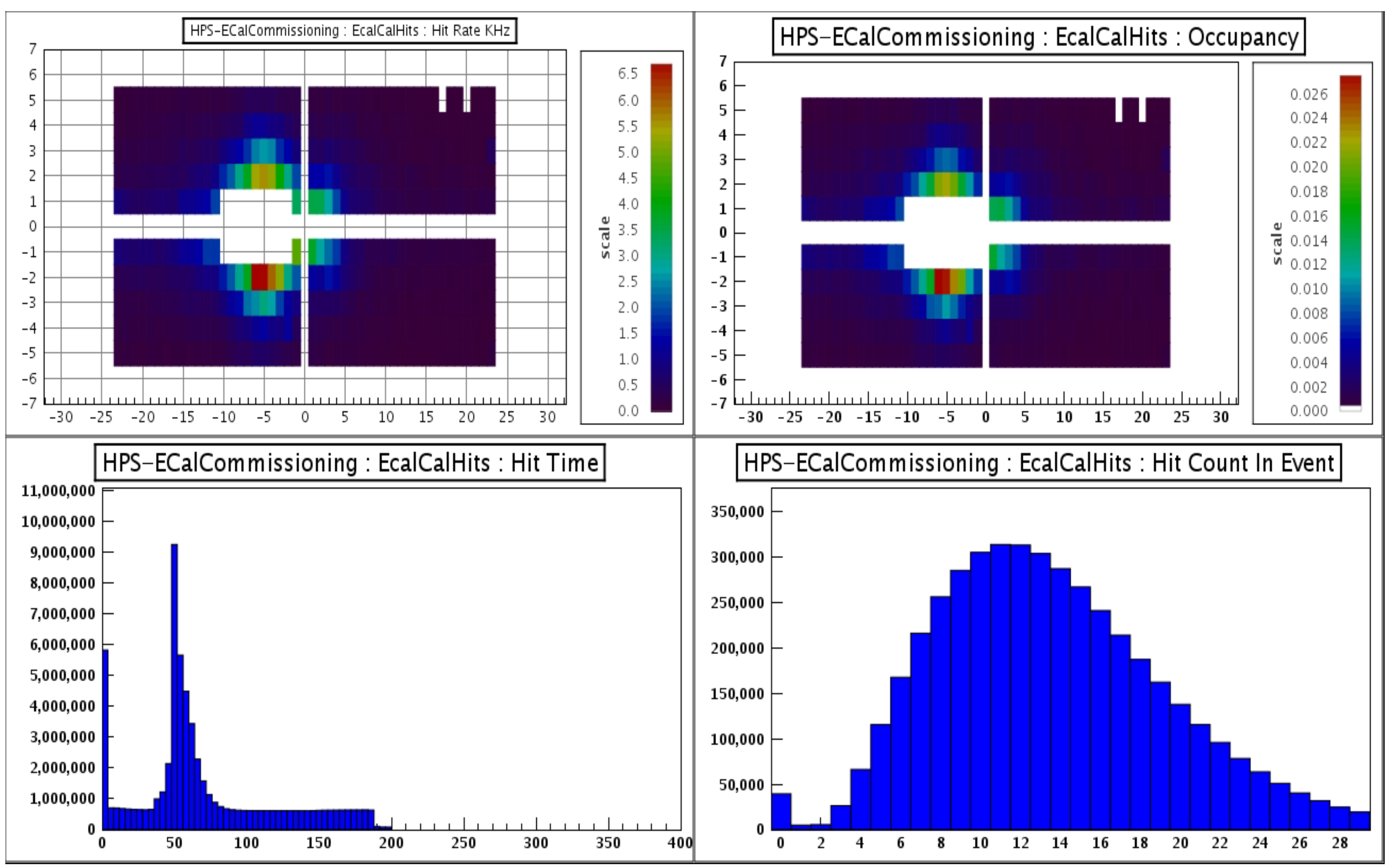


Online data quality

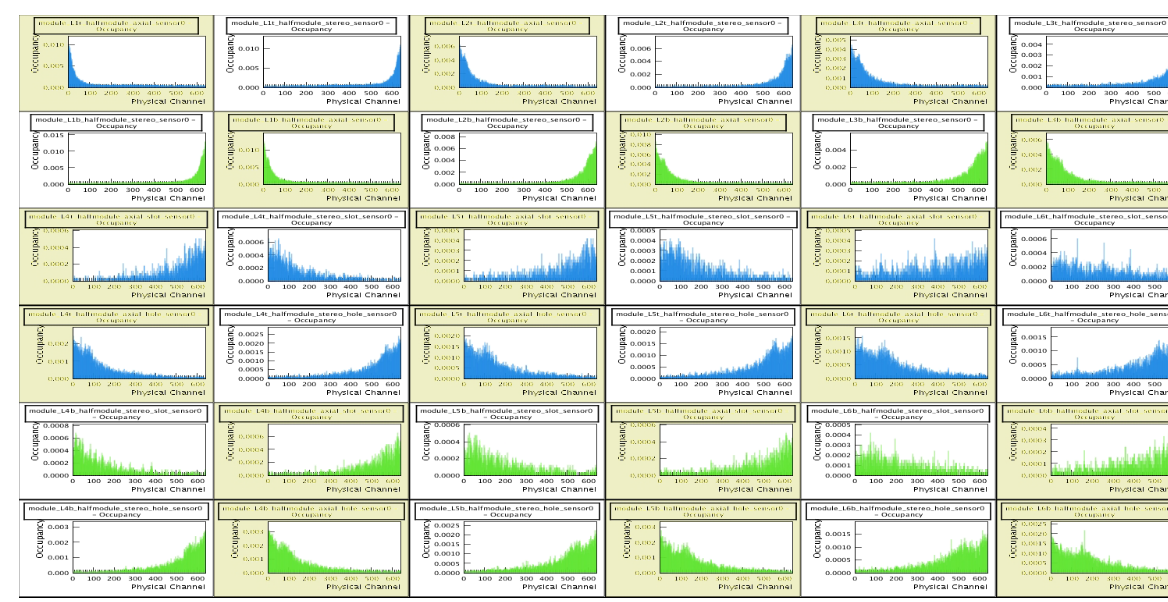


SVT Number of layers hit





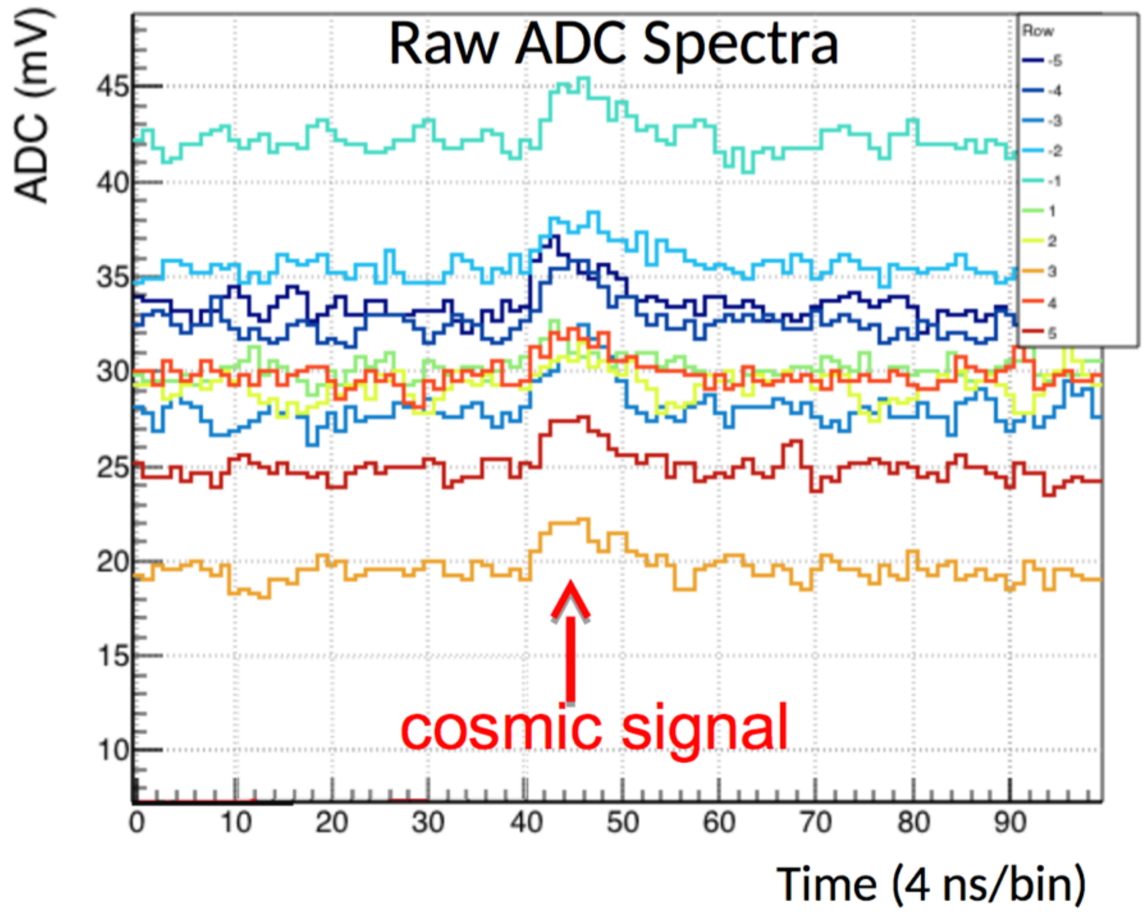
Occupancy



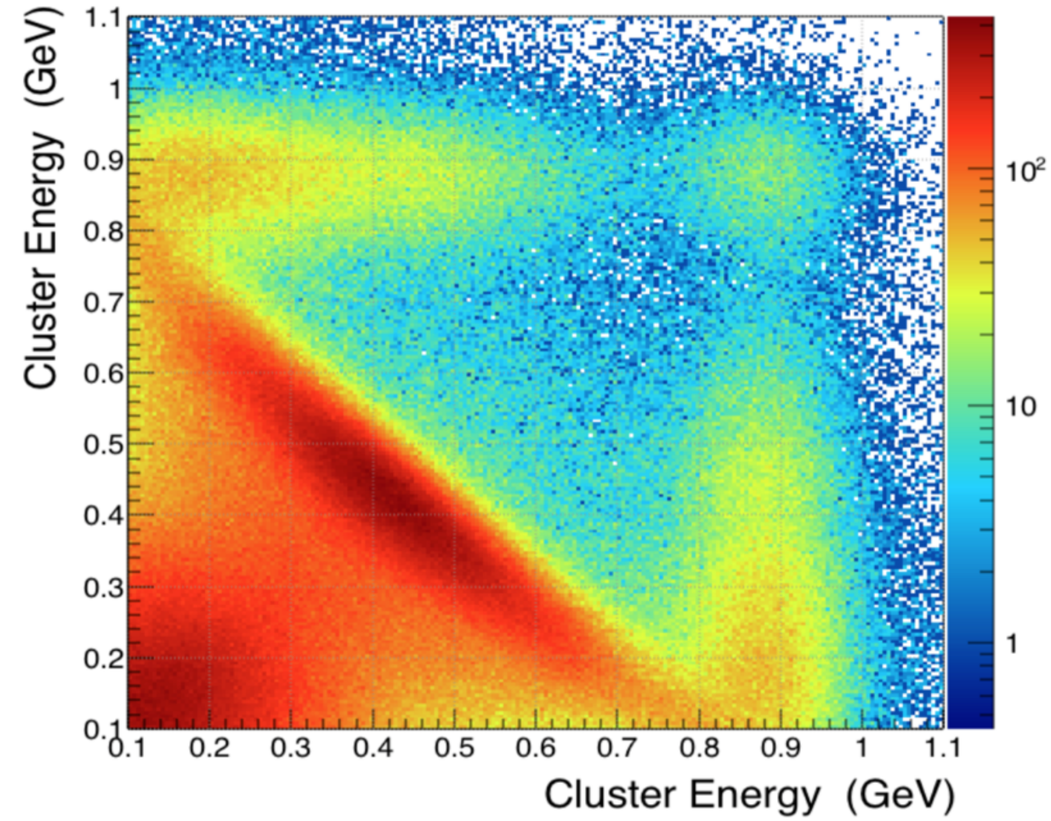
Occupancy rates agree with MC calculations

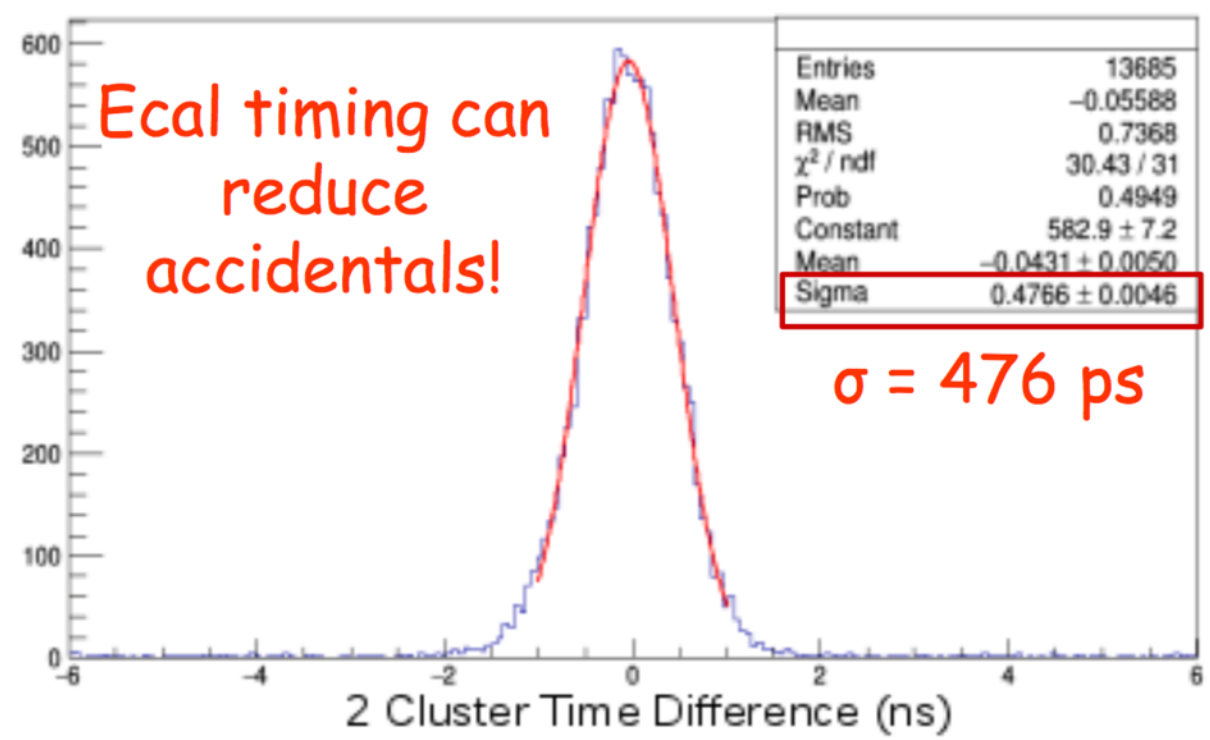
ECal Calibrations

- Ecal provides fast trigger for experiment
- At 1 GeV beam, Ecal and SVT energy resolution comparable



Cosmic ray muon passing vertically through 10 crystals in the Ecal

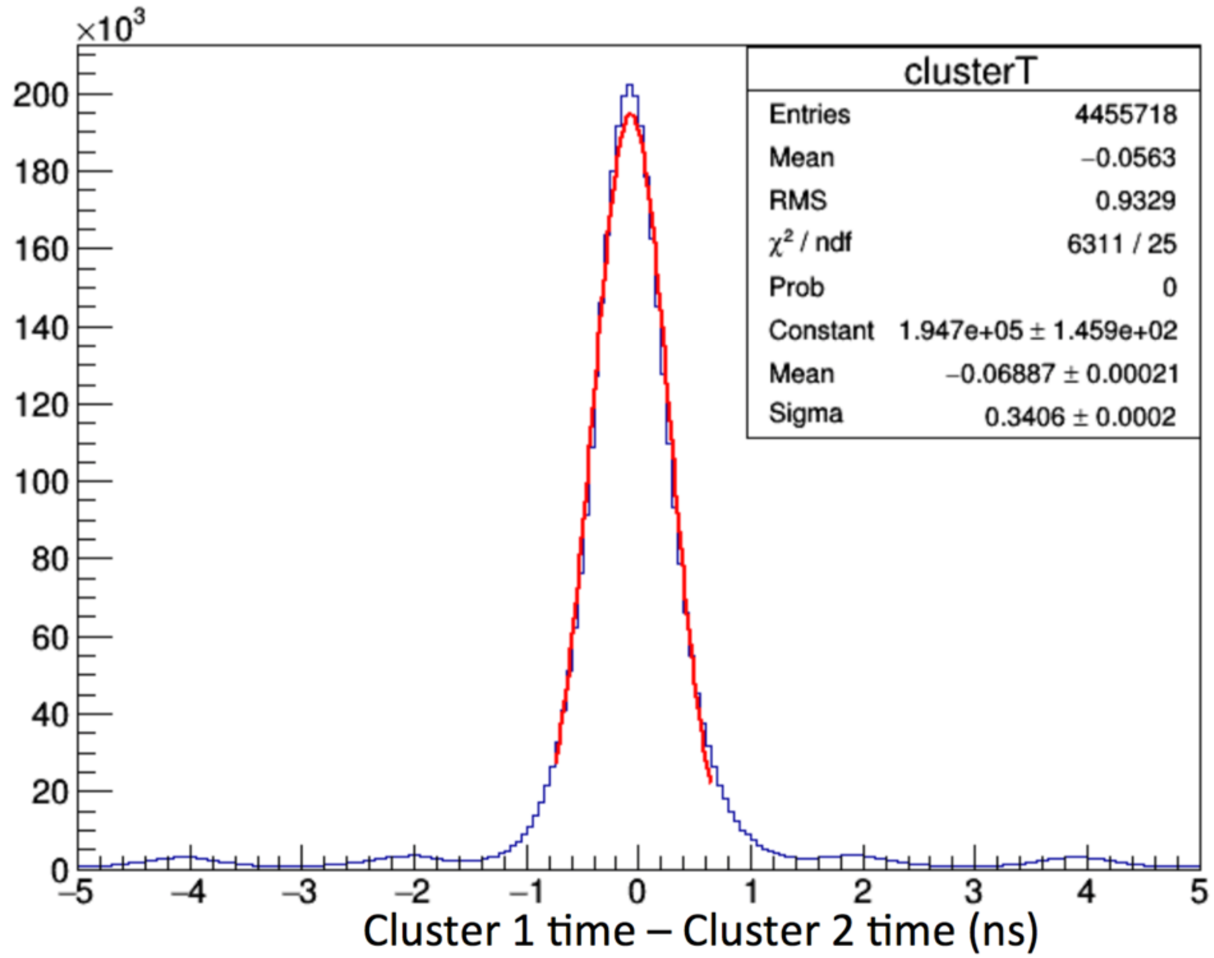




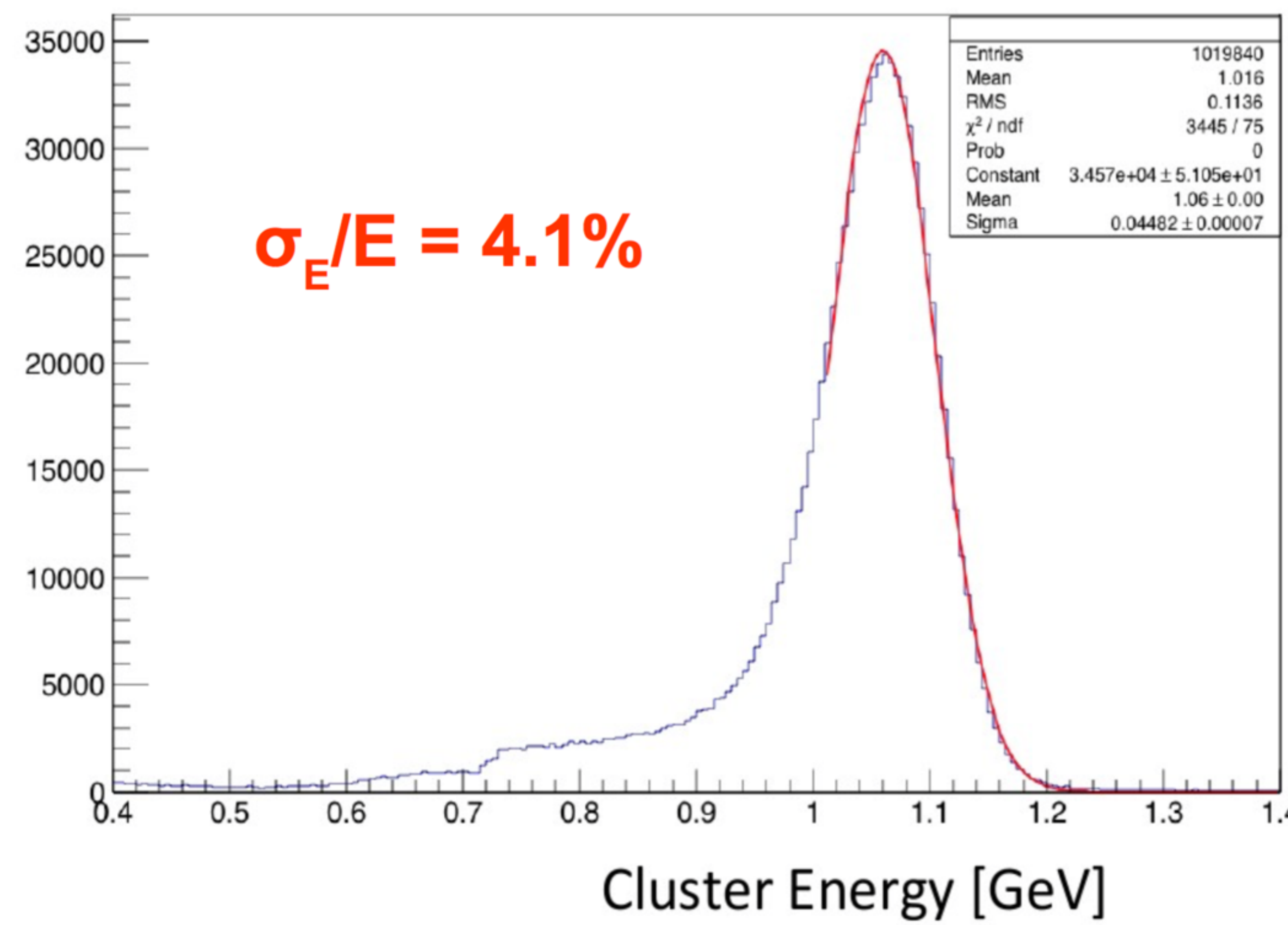
Plots from Holly Vance

ECal Resolution

Further calibration reduces
Timing resolution ~ 340 ps



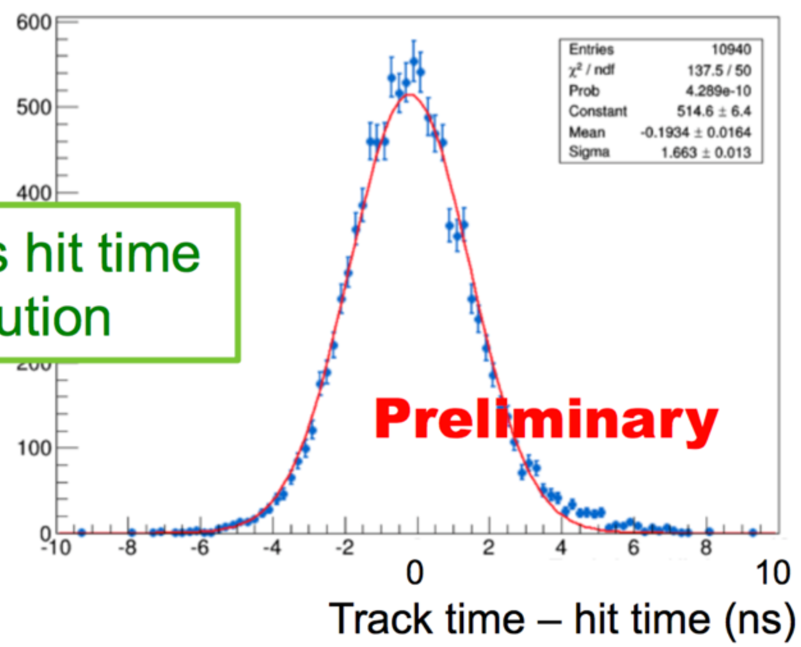
Full energy electrons
used for calibration:
Energy resolution ~ 4%



Plots from Holly Vance

Tracker Performance

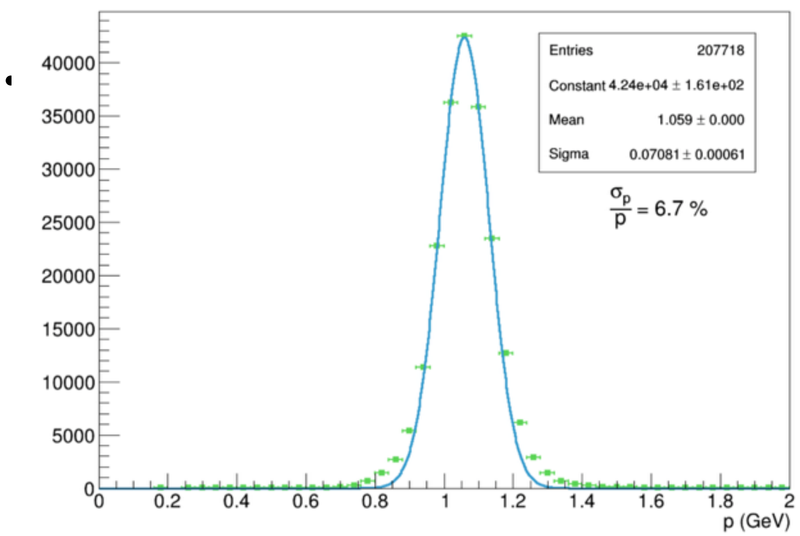
Hit time resolution



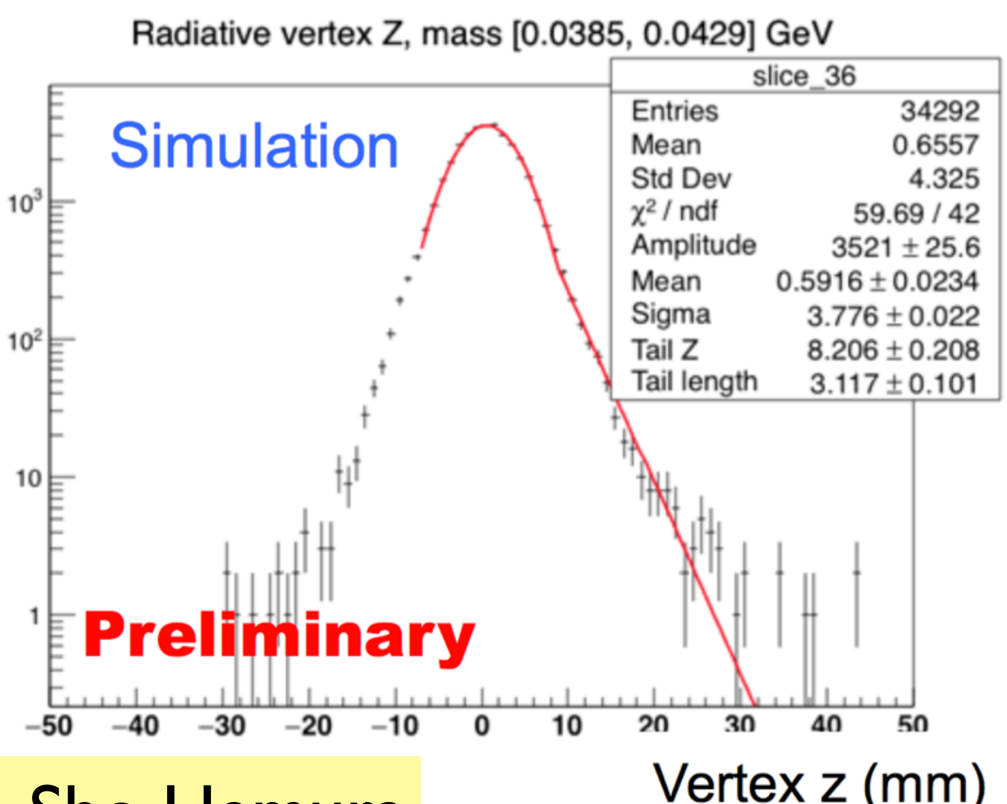
Tracker has good timing and momentum resolution.

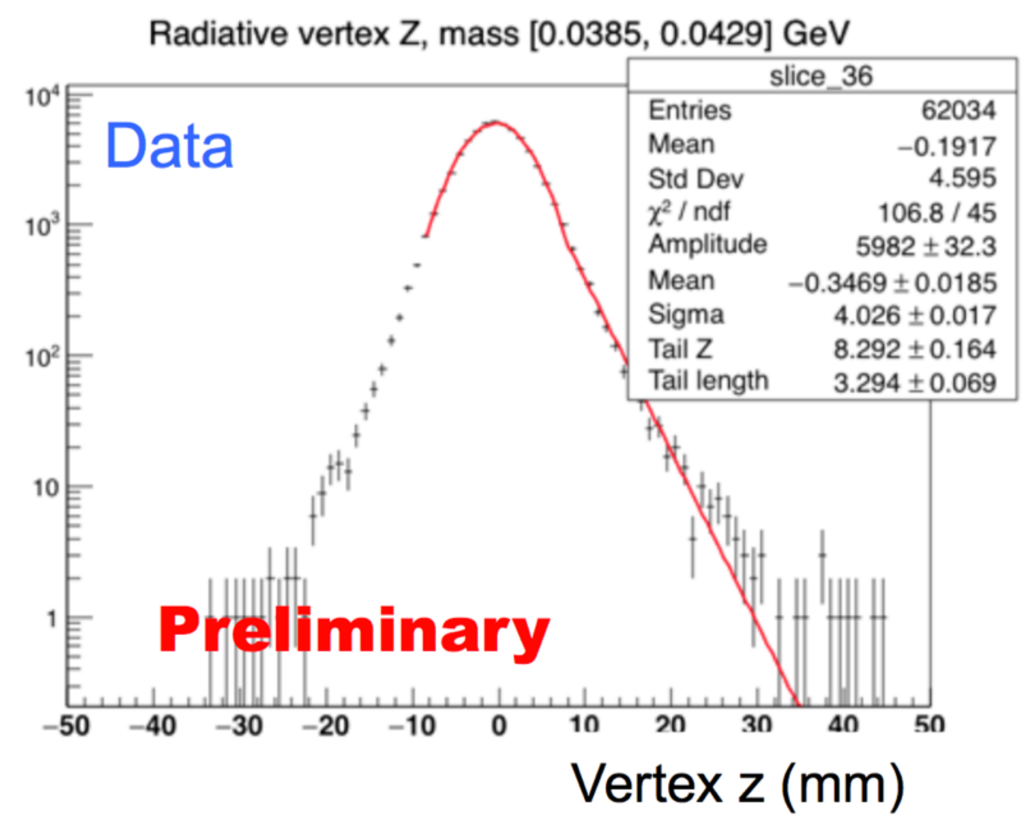
Very good vertex resolution for small angle tracks!

Full energy e^-



$\sigma_p/p \sim 6.7\%$

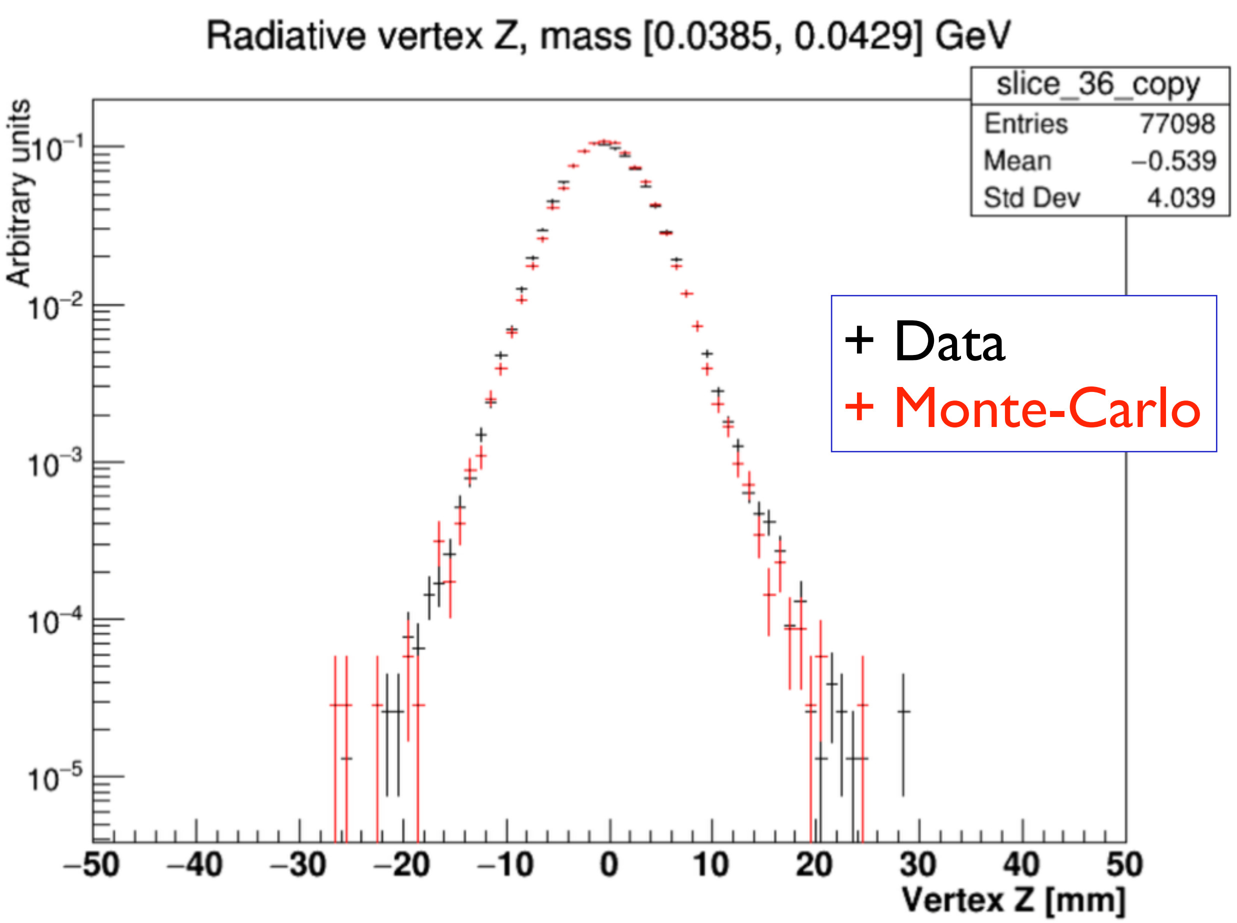


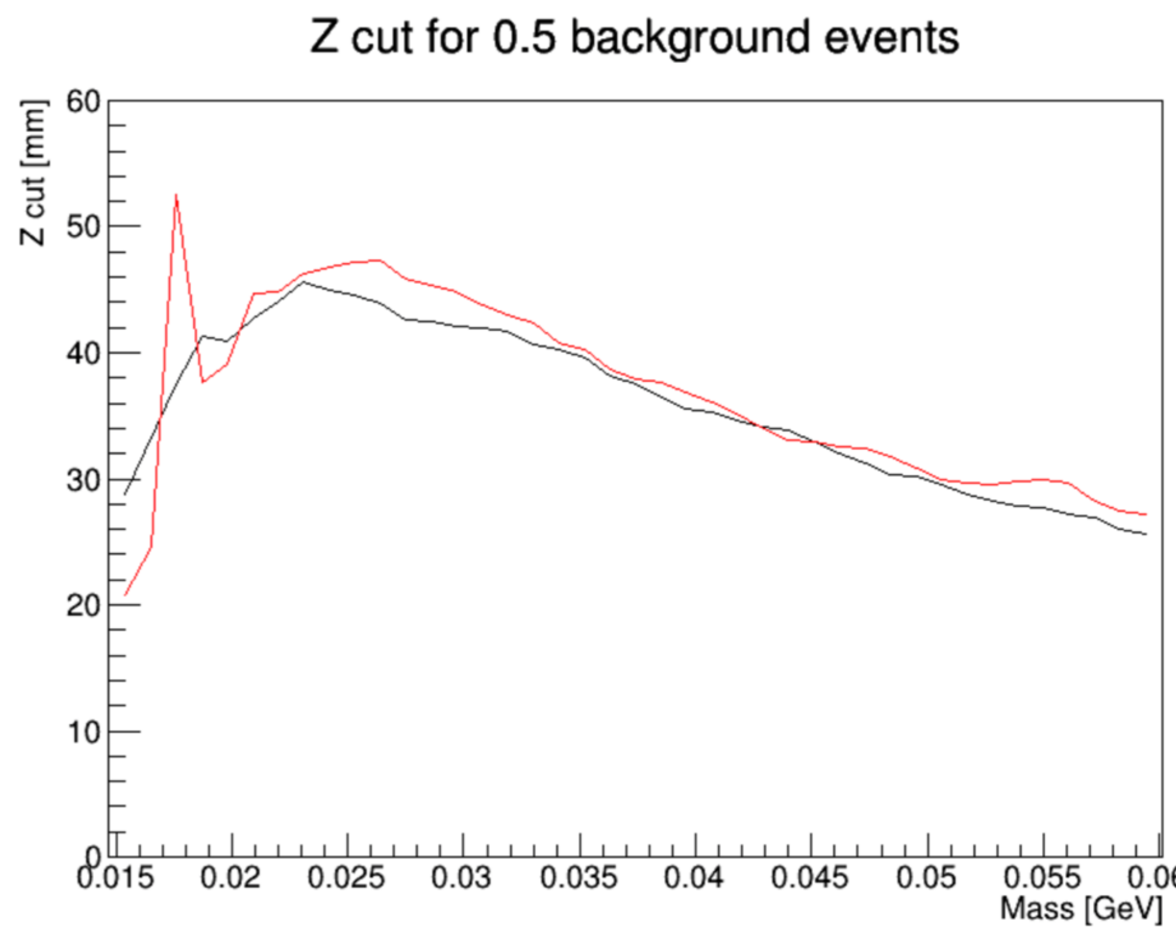


Plots from Sho Uemura

Vertexing Performance

Good vertex resolution is critical for the experiment.
Excellent agreement between Monte-Carlo & Data.
Normalized to 7 PAC days luminosity (5420 nb^{-1})
⇒ results (reach) agree with original HPS proposal.





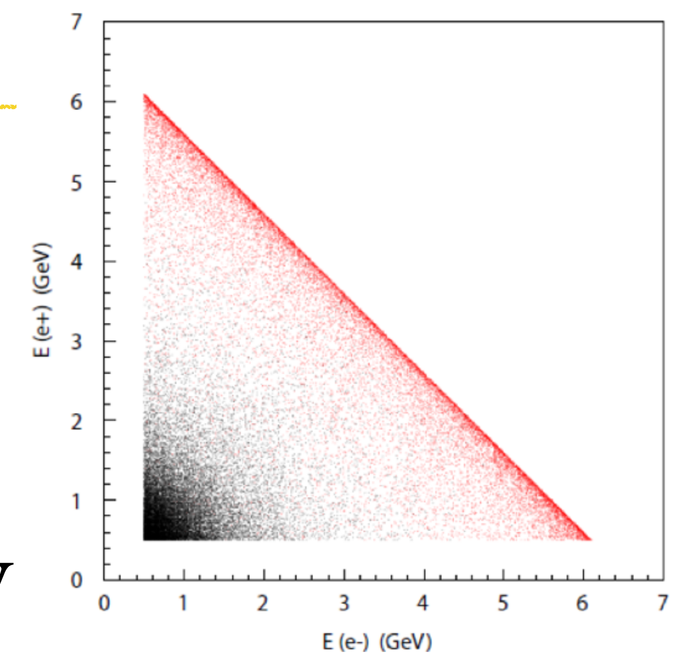
Plots from Sho Uemura

Tracked Pairs

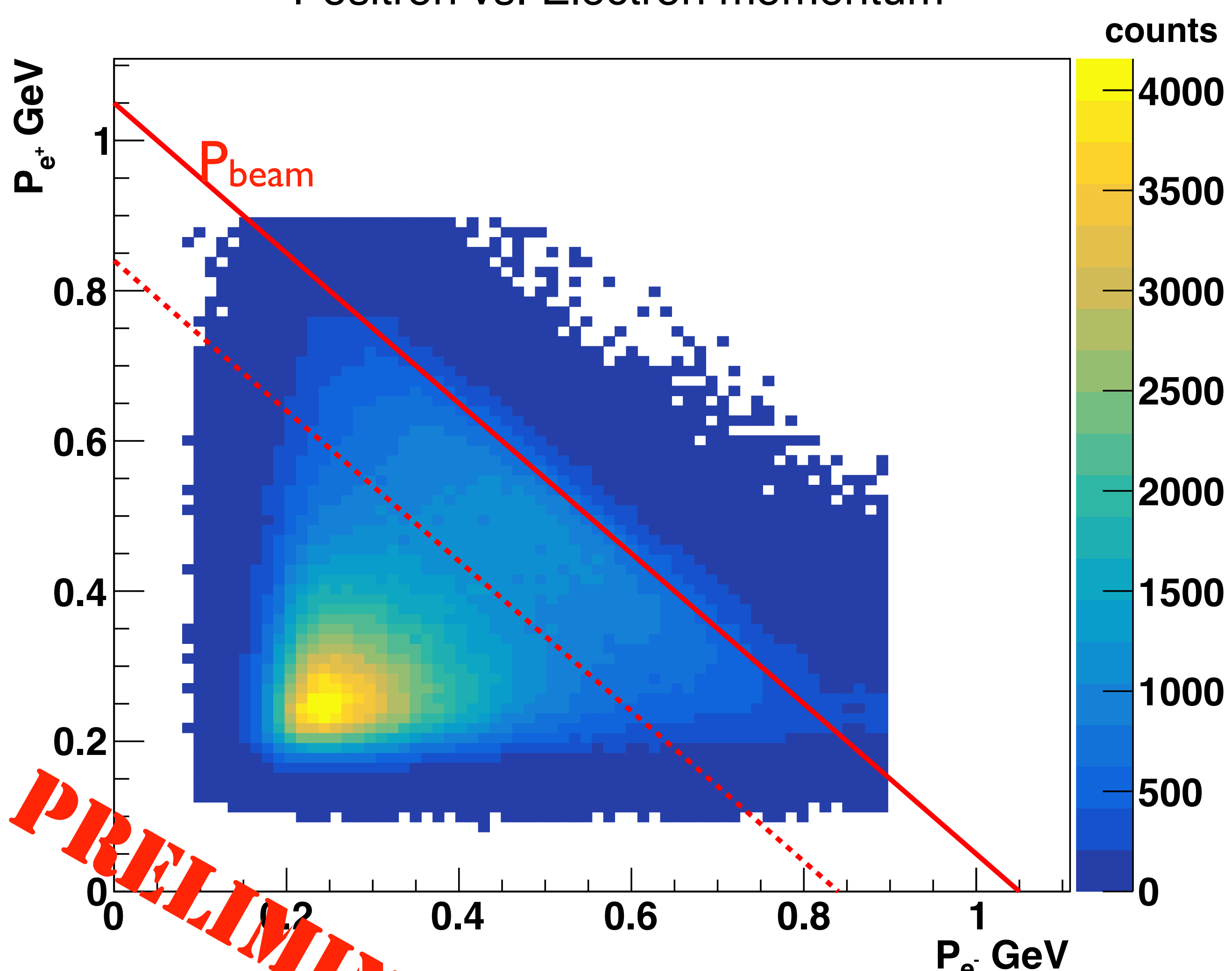
A′ candidates have $P_{e+} + P_{e-} \approx P_{beam}$

A′ selection cut at $|P_{e+} + P_{e-}| = 0.8\ P_{beam}$

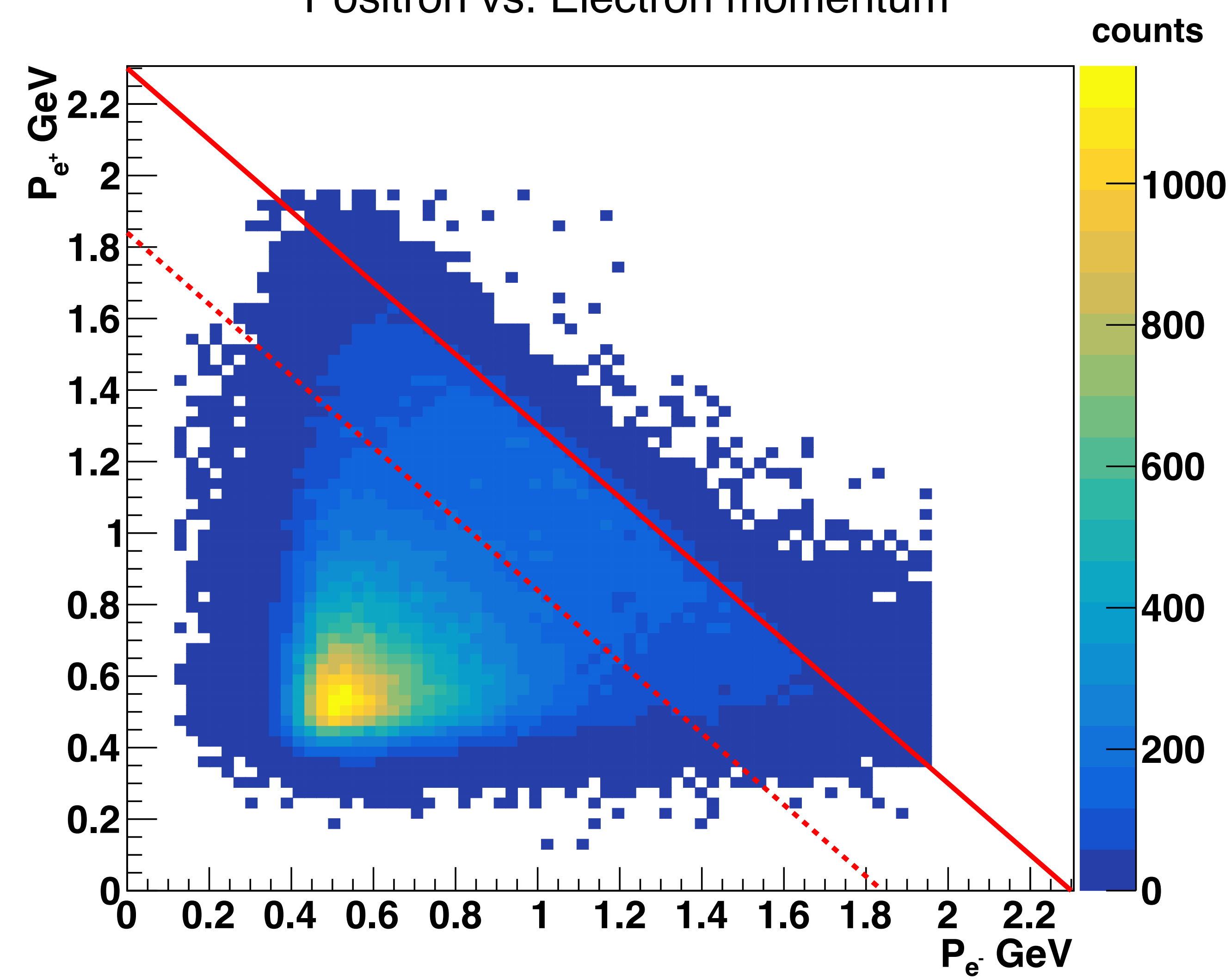
Simulation (for 6GeV)



$P_{beam} = 1.05$ GeV

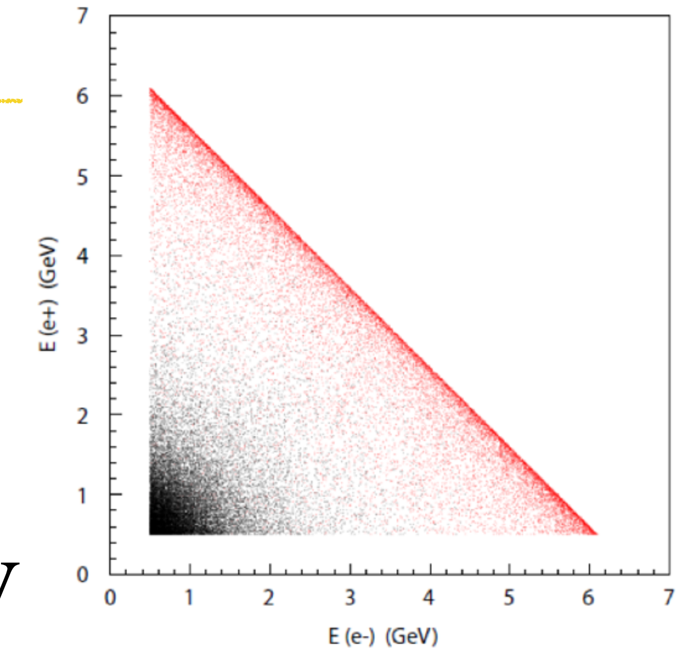


$P_{beam} = 2.3$ GeV



Selected Tracked Pairs

Simulation (for 6GeV)



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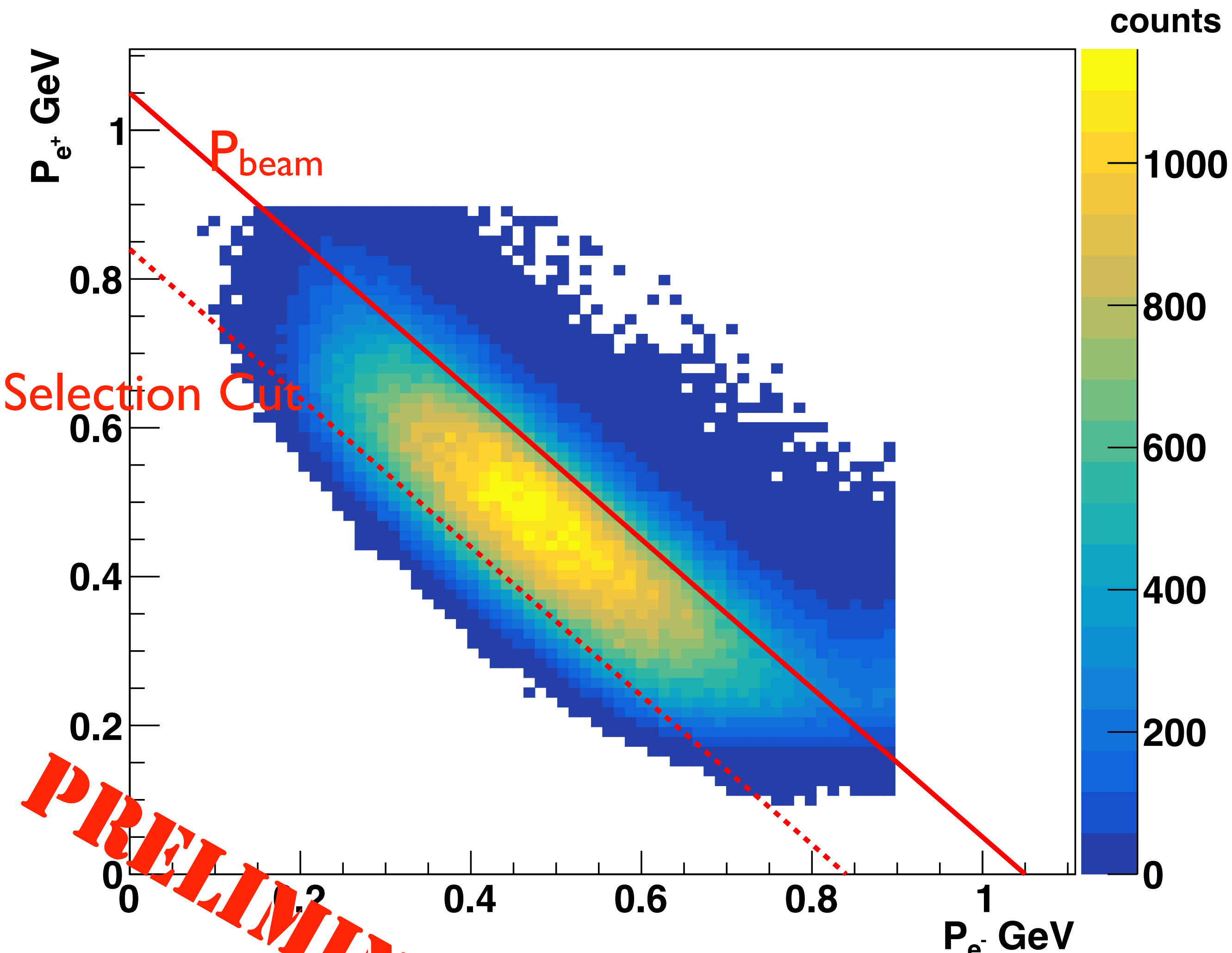
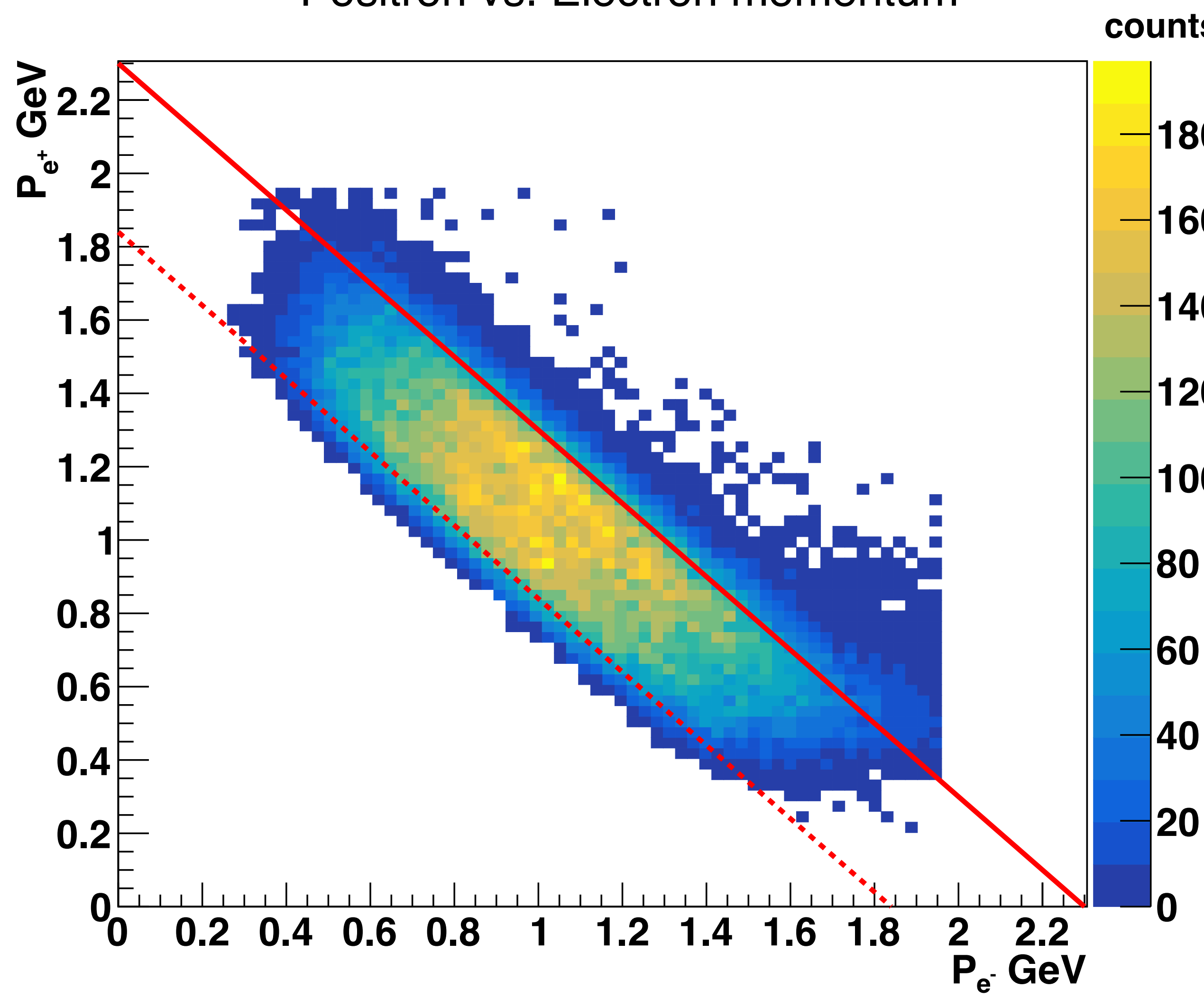


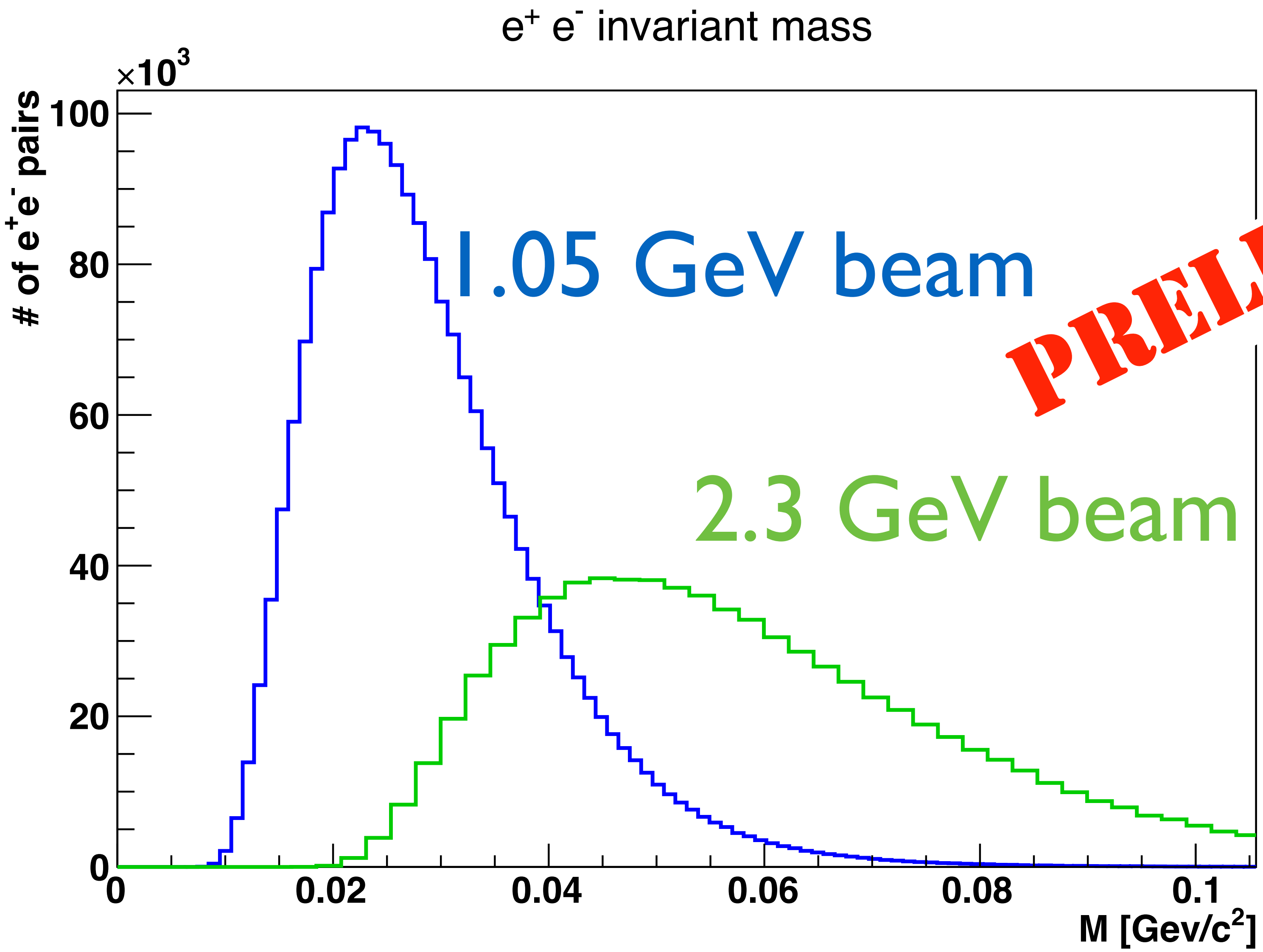
$P_{beam} = 2.3$ GeV



PRELIMINARY

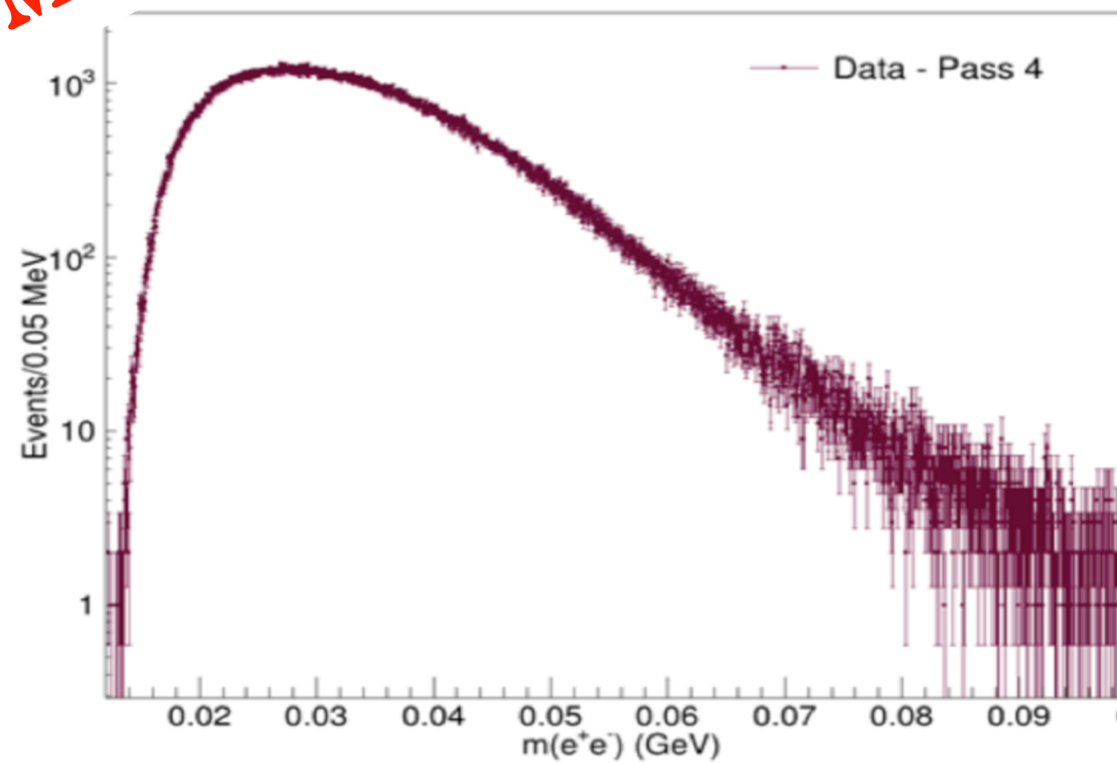
Pairs Mass Distribution

Data blinding policy: only 10% of data made available.
This plot is a small fraction of unblinded data, tiny fraction of all data.
Very preliminary look!
To do: better calibrations, study cuts, more data, …

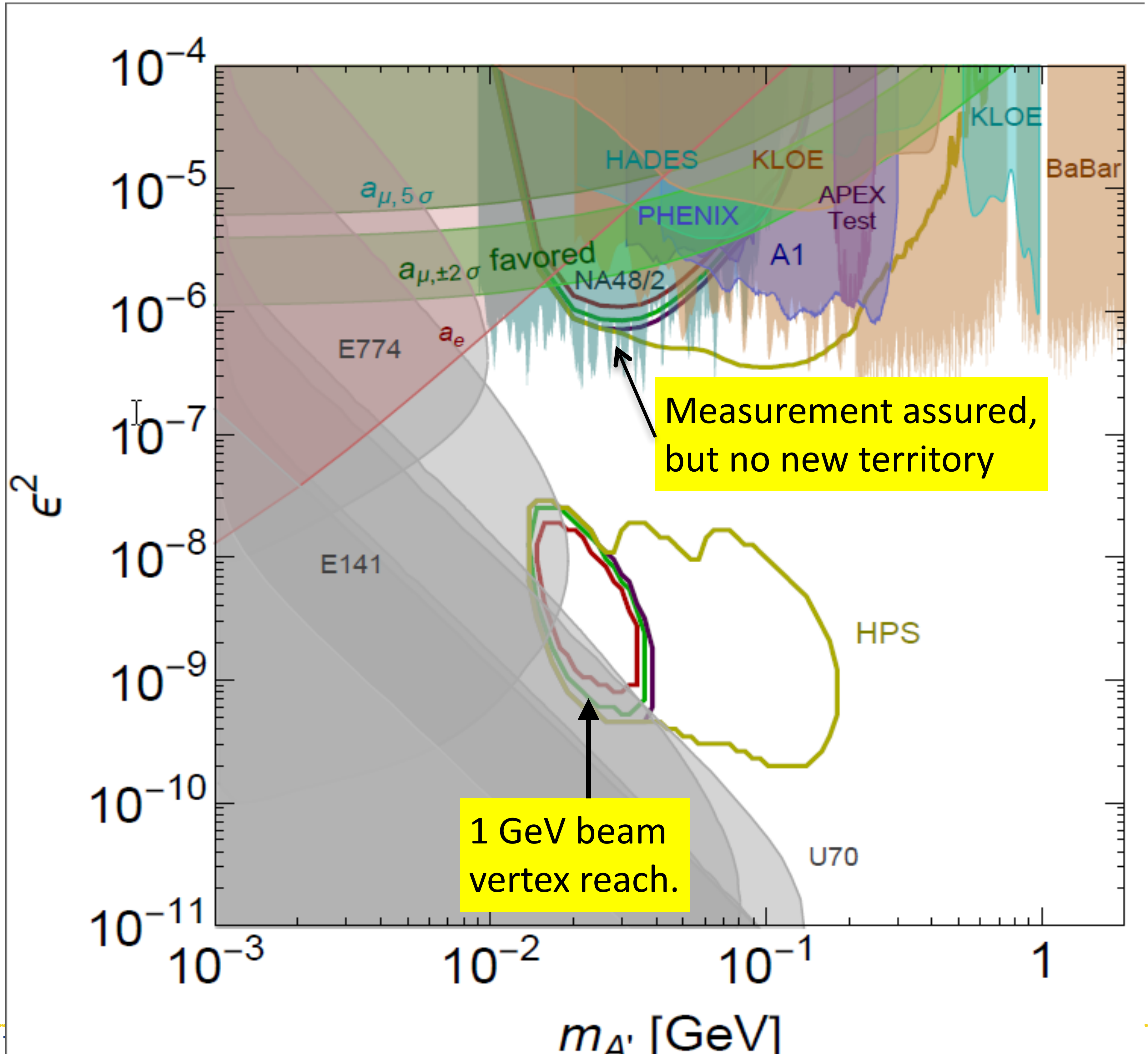


PRELIMINARY

1.05 GeV beam



Reach vs Runtime



For 1 GeV beam

Assumes coverage to 15 mrad

Contours:

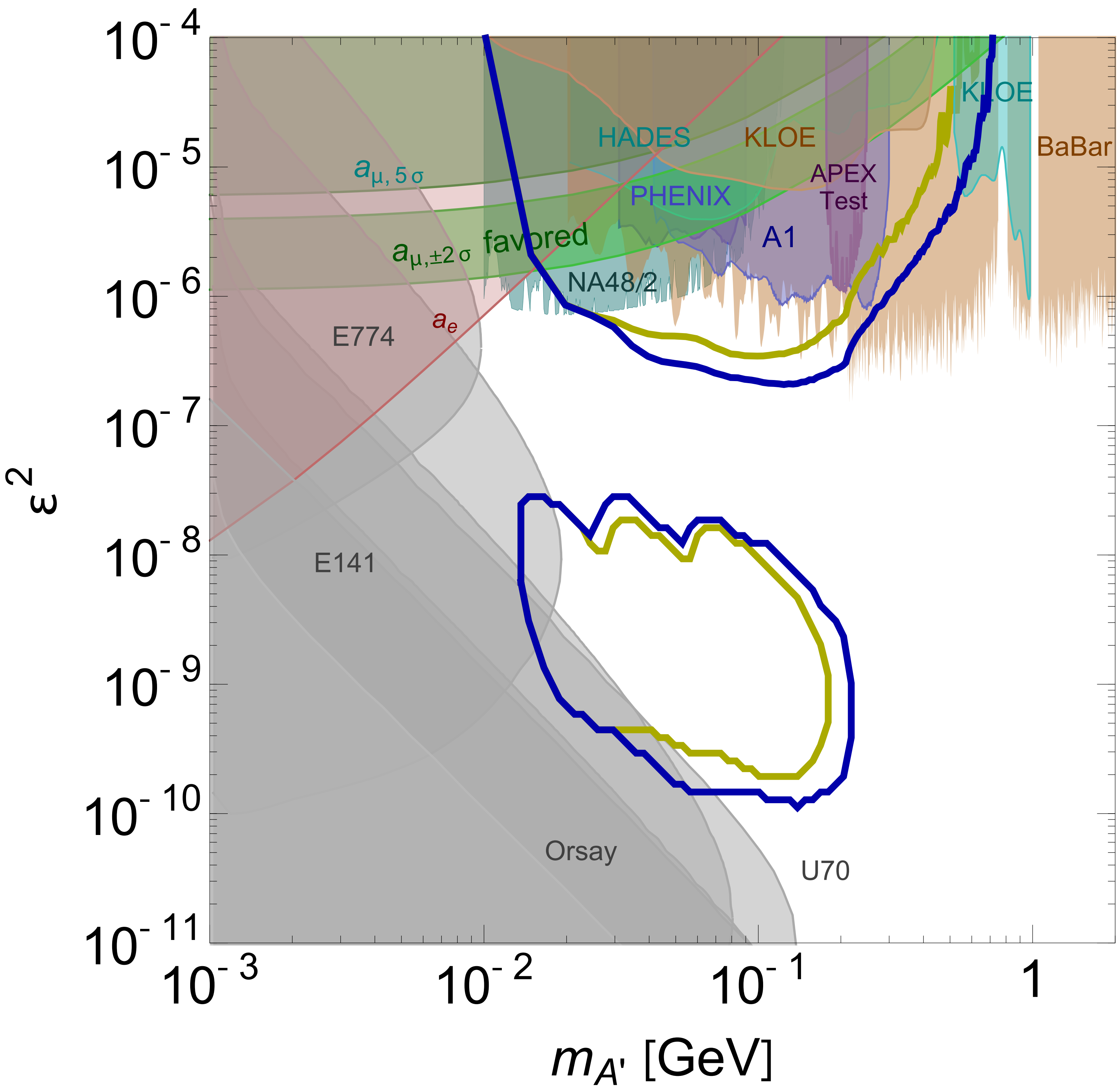
1 PAC week

5/7 PAC week

3/7 PAC week

We got about 1/3 PAC week of good data at 0.5 mm

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

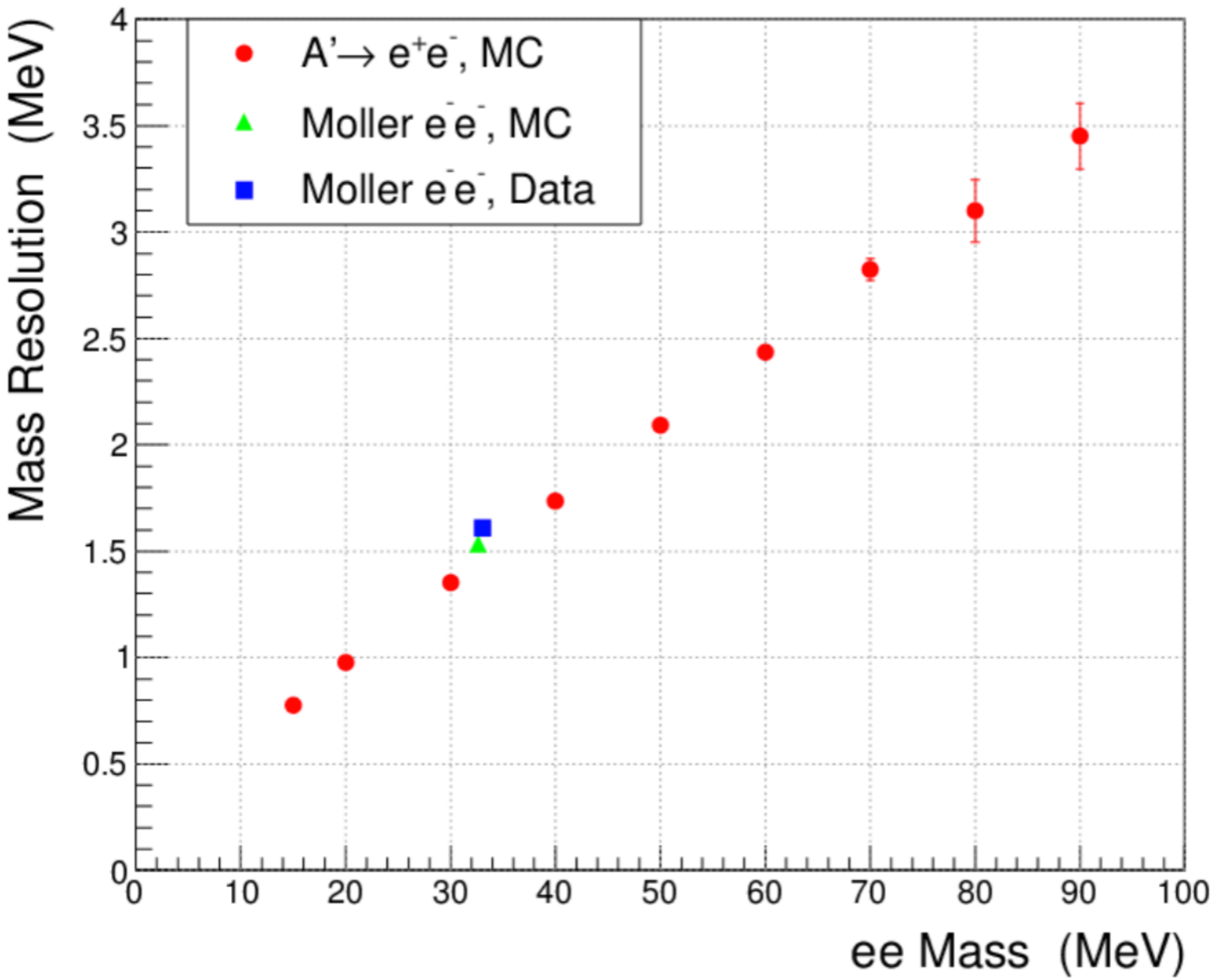
Times are "PAC" times = Calendar time/2

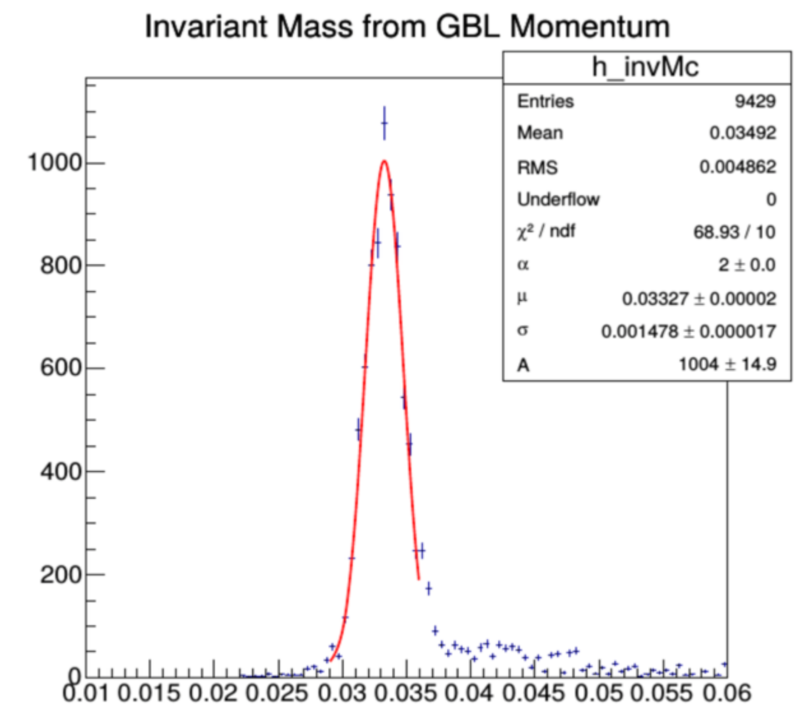
Conclusions

- The HPS experiment has successfully completed its first physics data with 1.05 GeV beam, during the 2015 "Engineering Run".
  - Roughly 1/3 "PAC week" of data was gathered for 1.05 GeV with the SVT at 0.5 mm from the beam. Enough data for several PhD theses.
- Current "Engineering Run 2" (2016) taking data at 2.3 GeV
- Initial look at the data looks very promising.
- Opportunistic running, with CLAS12 installation during the day, is a challenge, but possible.
- We hope to take a lot more data in the next few years.

Some Extras

Mass resolution vs. Mass



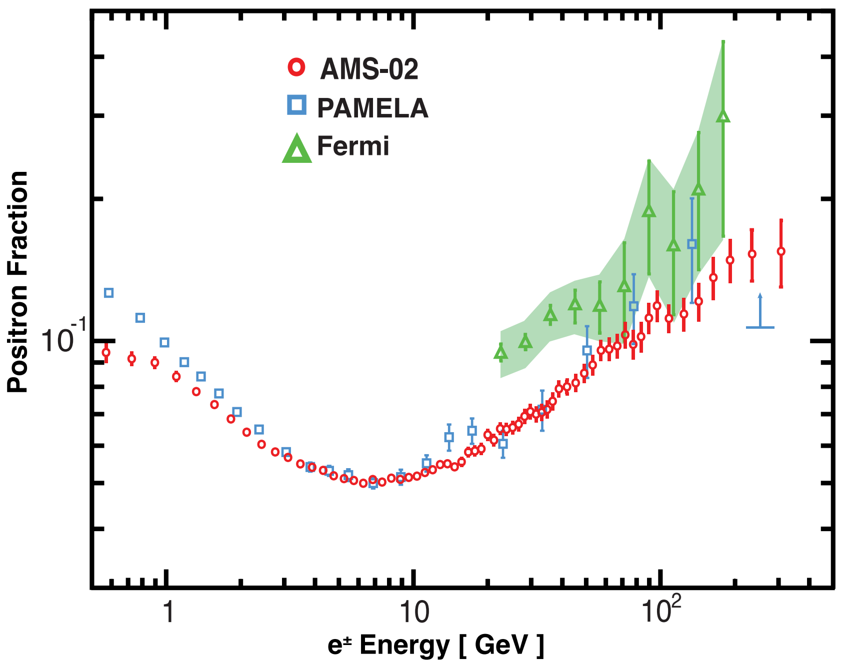


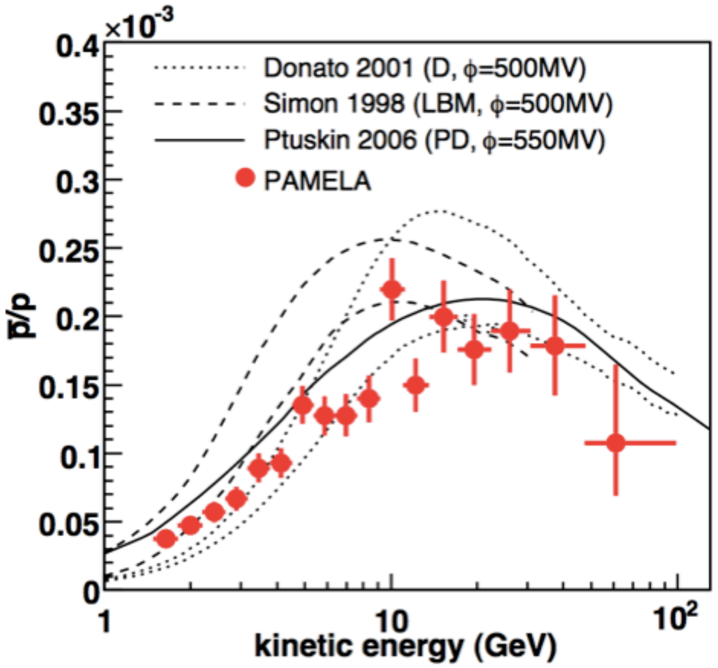
Invariant mass for Möller scattering.

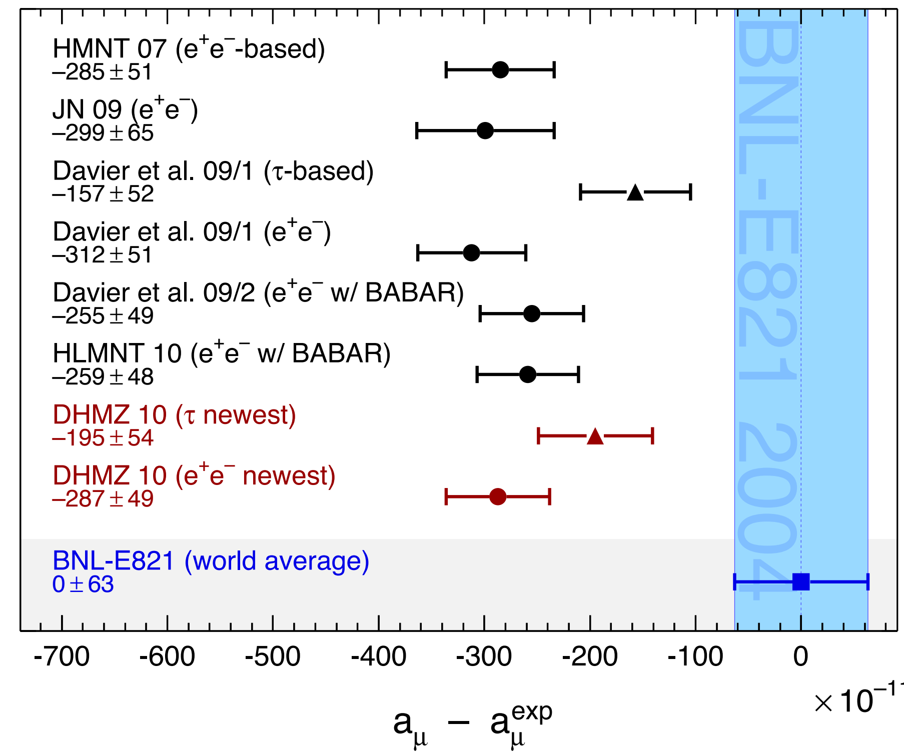
Hints from astrophysics?

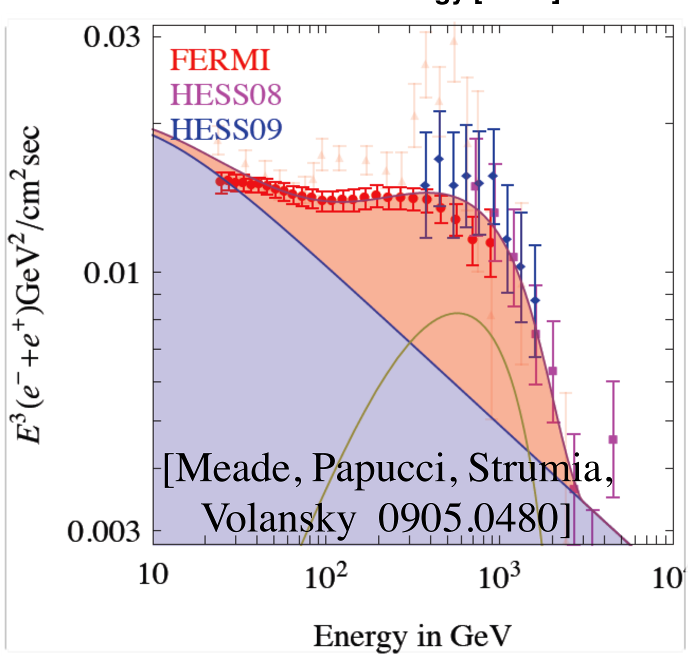
PAMELA, FERMI, AMS
Energetic e+/e- cosmic rays from DM annihilation through *A′* ?

10-100 MeV A′ could explain muon g-2 anomaly









Arkani-Hamed, Finkbeiner, Slatyer, Weiner. '09 PRD 79, 015014
Pospelov and Ritz '09 PLB, 671, 391–397
Cholis, Finkbeiner, Goodenough, Weiner '09 JCAP 0912 (2009) 007

Davier, Hoecker, Malaescu, Zhang '11, Eur. Phys. J. C (2011) 71: 1515

More recent hints?

Excess of γ-rays from the galactic center is compatible with 50 GeV DM annihilating through a dark photon ("light mediator")

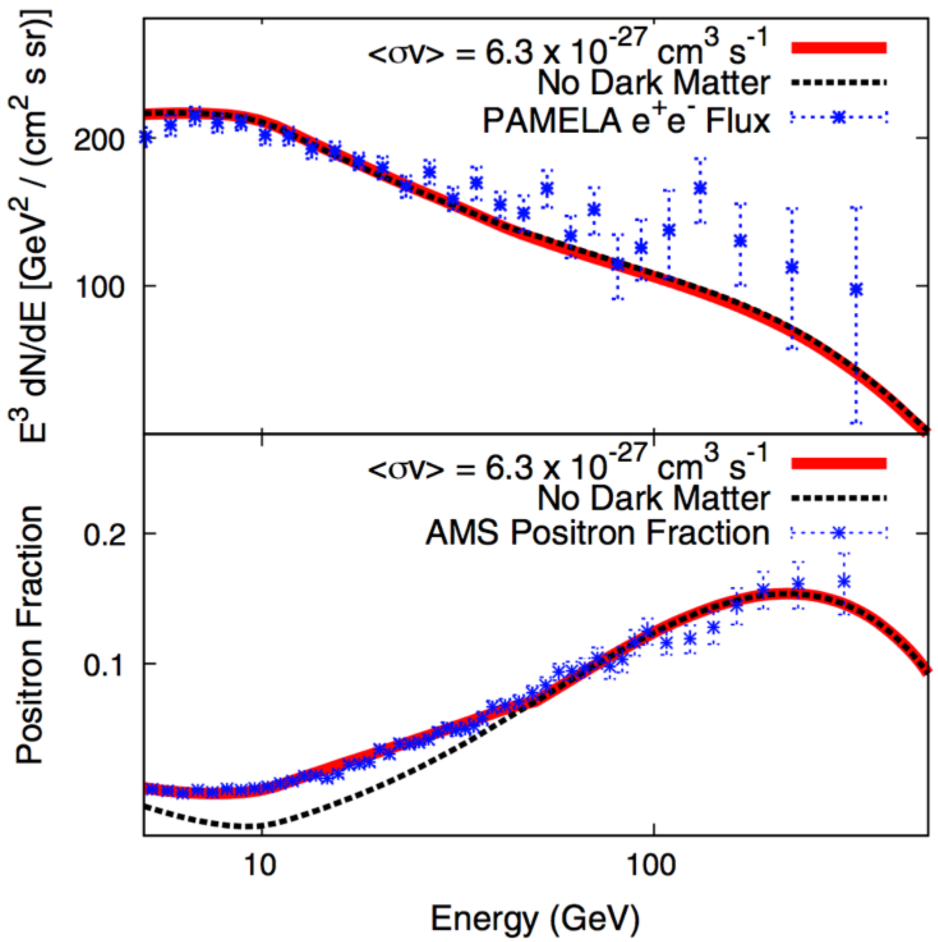


FIG. 3 (color online). The e^+e^- spectrum (top) and positron fraction (bottom) for the SIDM model, compared to observations from PAMELA and AMS-02, respectively. Note that excellent fits with no dark matter can be found by varying the diffusion and solar modulation parameters away from what has been assumed here.

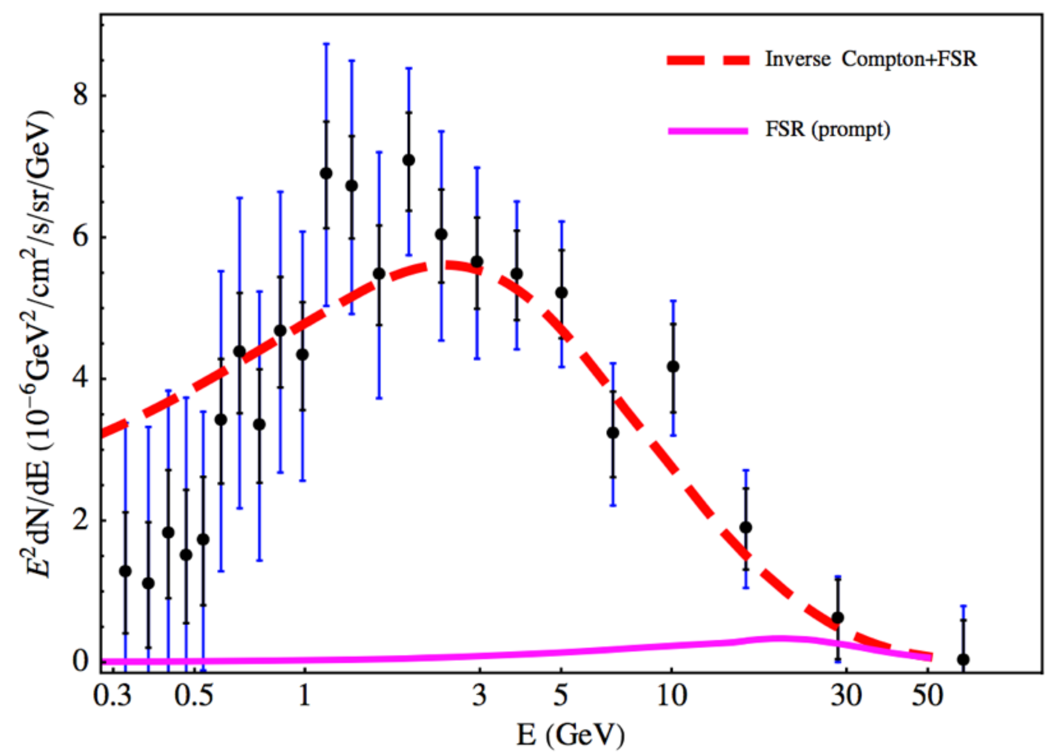


FIG. 1 (color online). γ-ray spectrum from Inverse Compton emission and final-state radiation produced by annihilation of a 50-GeV dark matter particle through a light mediator into e^+e^- final state. The spectrum is compared to the Galactic center excess [10].

Caveat: Astro-physics is complicated!
(and theorists are creative)

10.1103/PhysRevLett.114.211303 (May 2015)