HPS Update

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For the HPS Collaboration

JLab User Group Meeting June 2, 2015

University of
New Hampshire

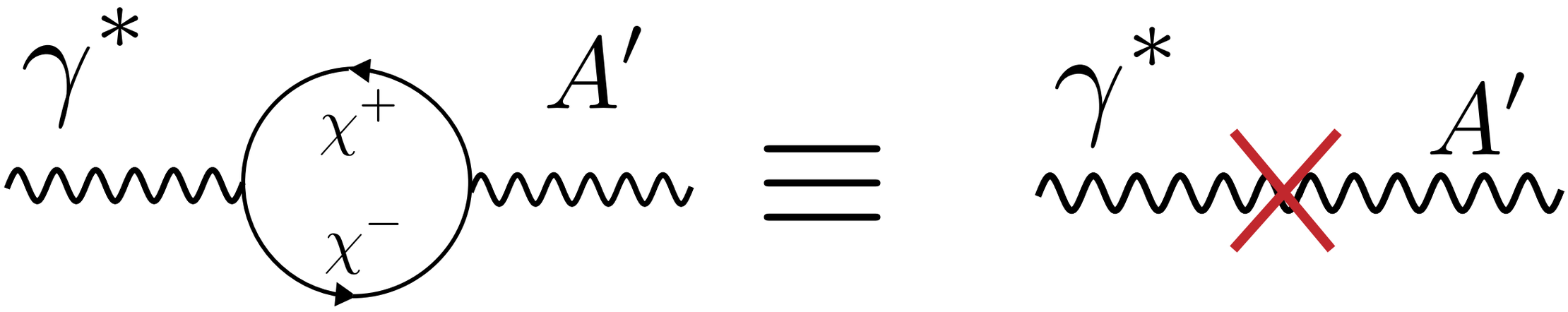
Heavy Photons?

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

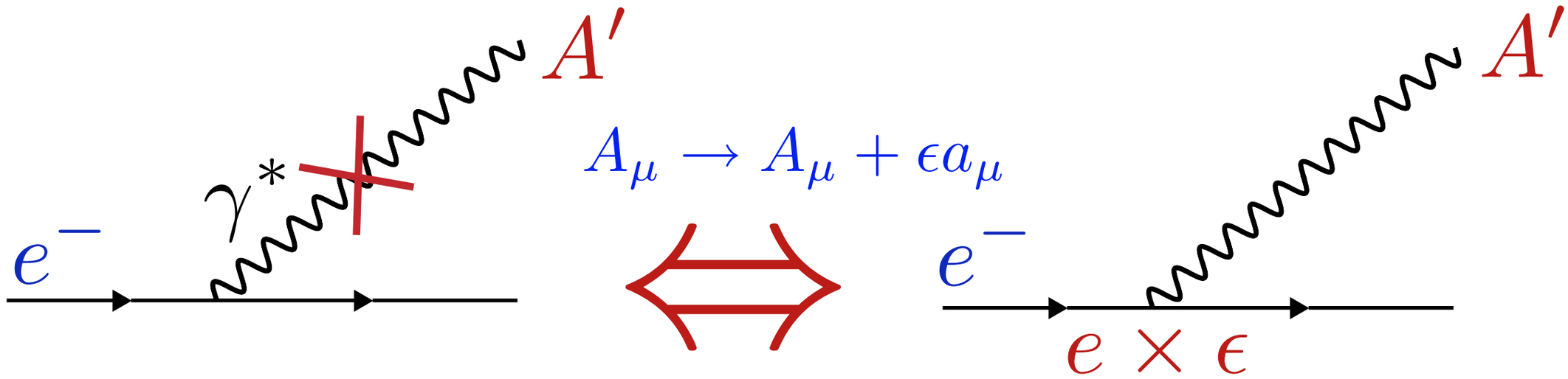
$$\mathcal{L}_{U(1)'} = -\frac{1}{4}V_{\mu\nu}^2 - \boxed{\frac{\epsilon}{2}V_{\mu\nu}F^{\mu\nu}} + |D_\mu\phi|^2 - V(\phi)$$

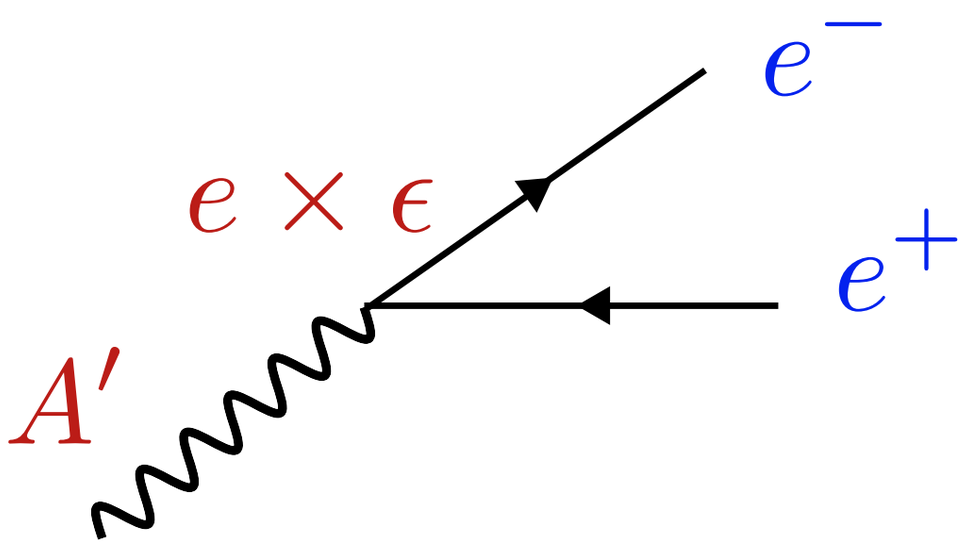
Kinetic Mixing term.



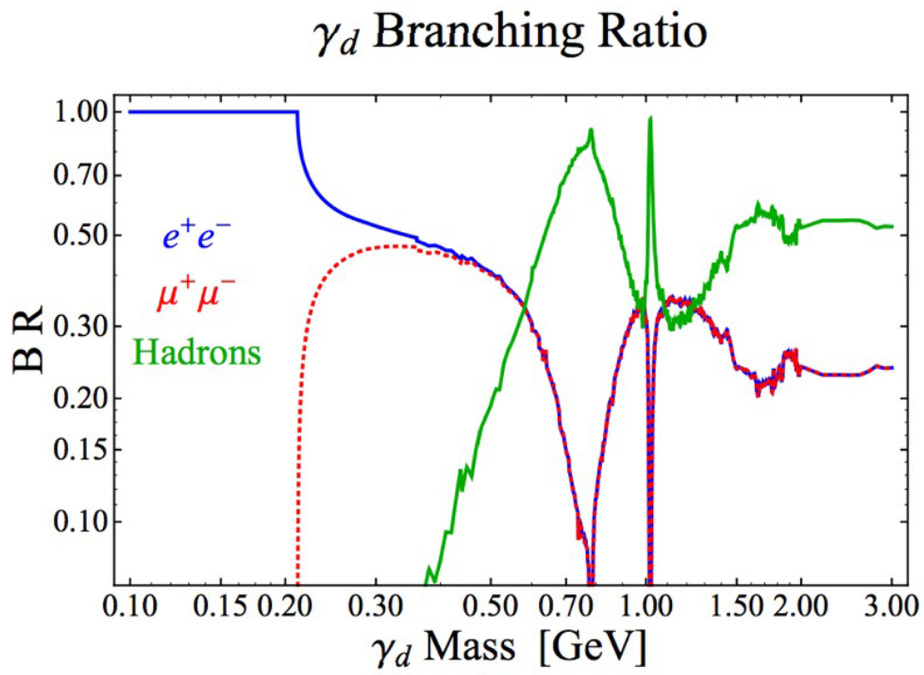
Mixing

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





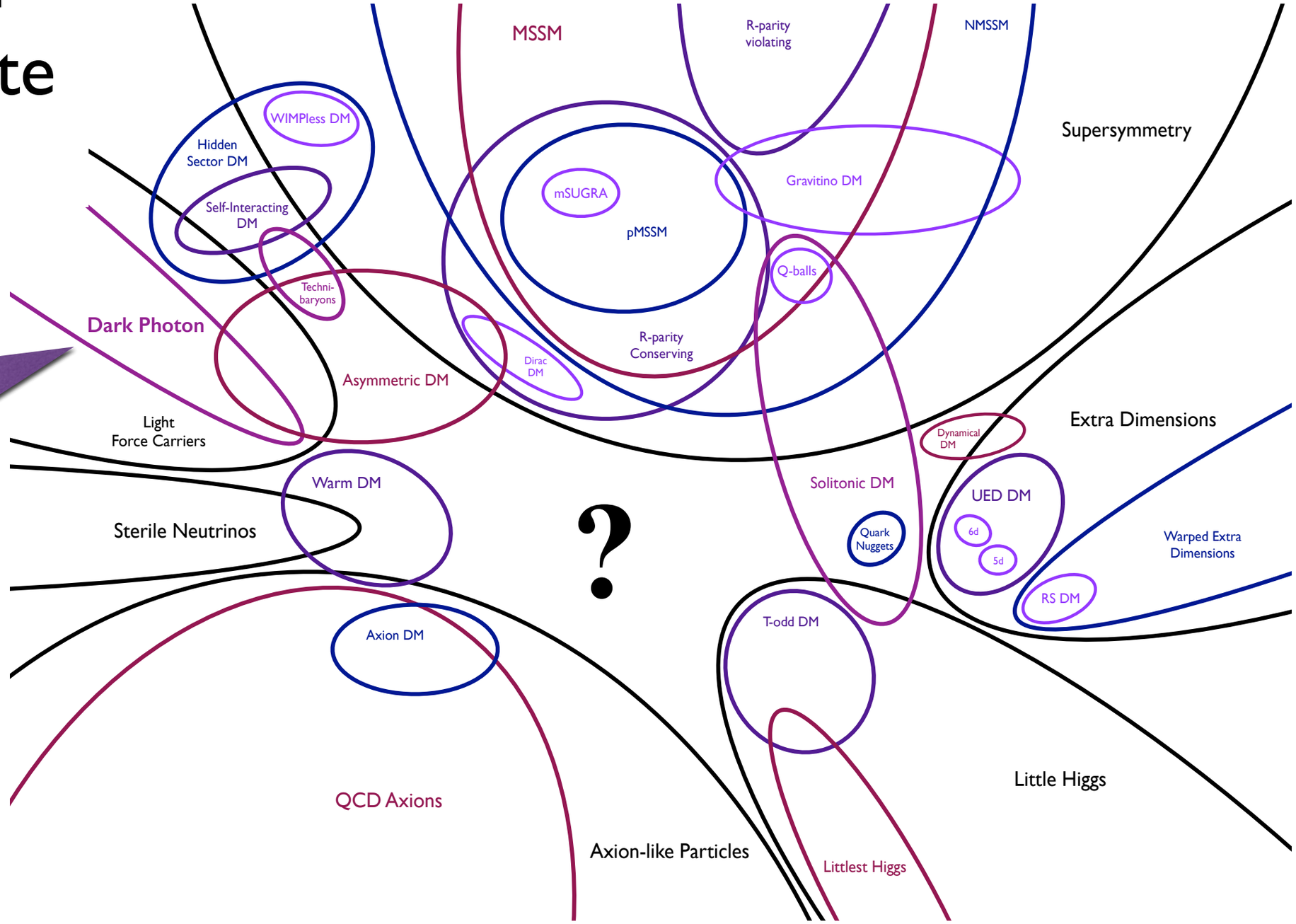
A' will pair produce:
e^+e^-,
$\mu^+\mu^-$,
$\pi^+\pi^-$, ...



Putting this in perspective

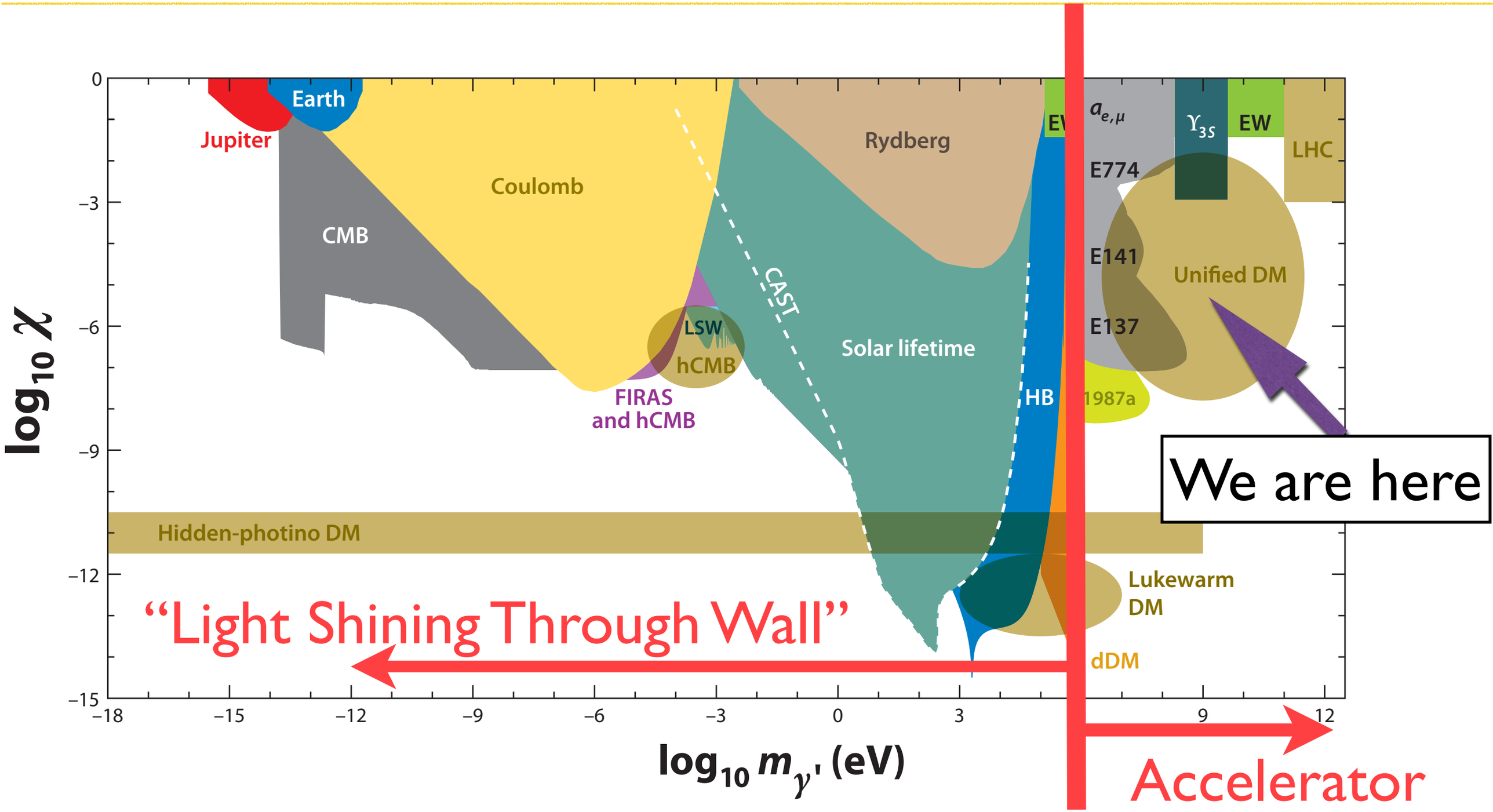
Venn Diagram "DM Candidate Landscape"

We are here



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

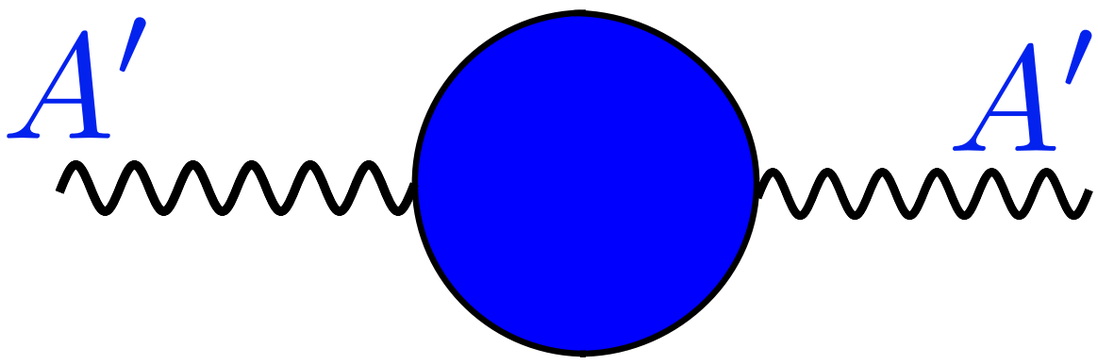
Putting this in perspective



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

"Natural*" Coupling and Mass

- Depends on the model



Mass inherited from "electro-weak" scale

$$m^2_{A'} \sim \epsilon M^2_W$$

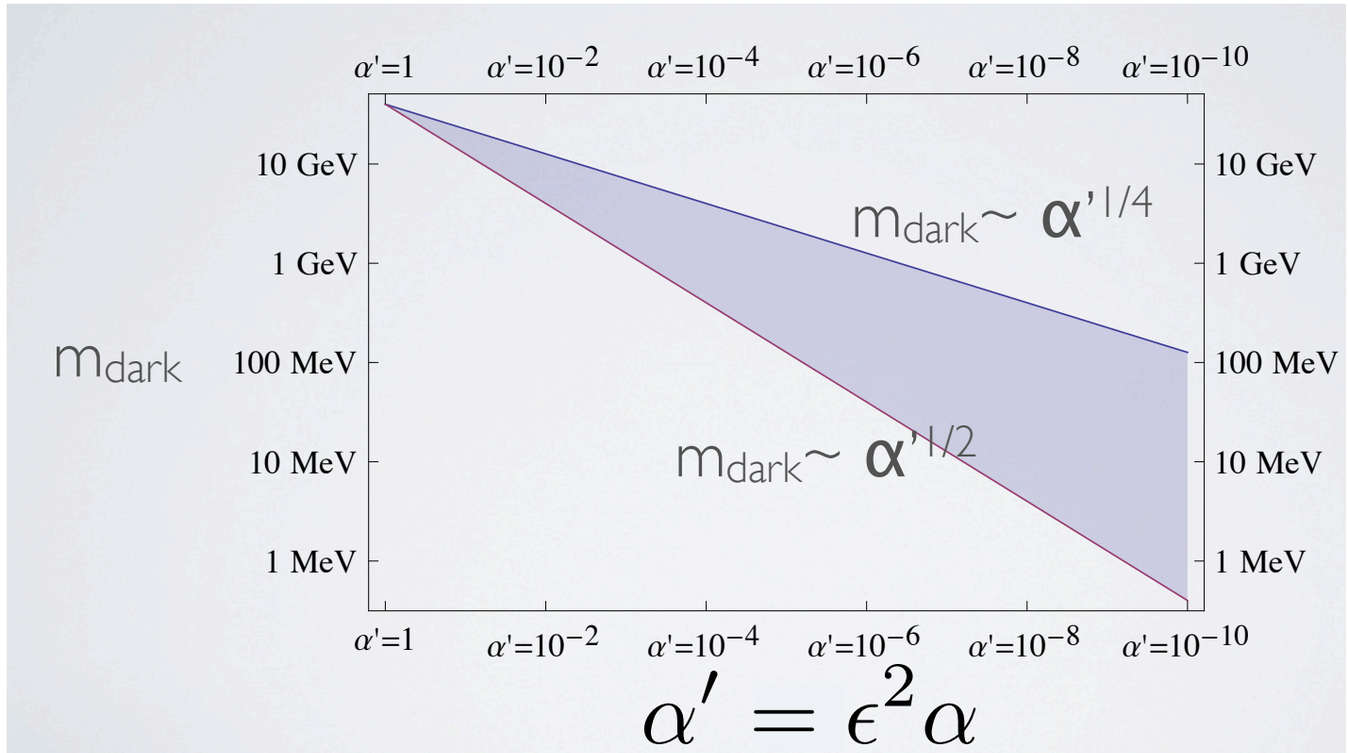
or

$$m^2_{A'} \sim \frac{e g_D}{16\pi^2} M^2_W$$

or

Stückelberg mechanism:

$m_{A'}$ ~ meV



Neil Weiner, Intensity Frontier WS '11

Natural ε could be ~ 1 (tree level)

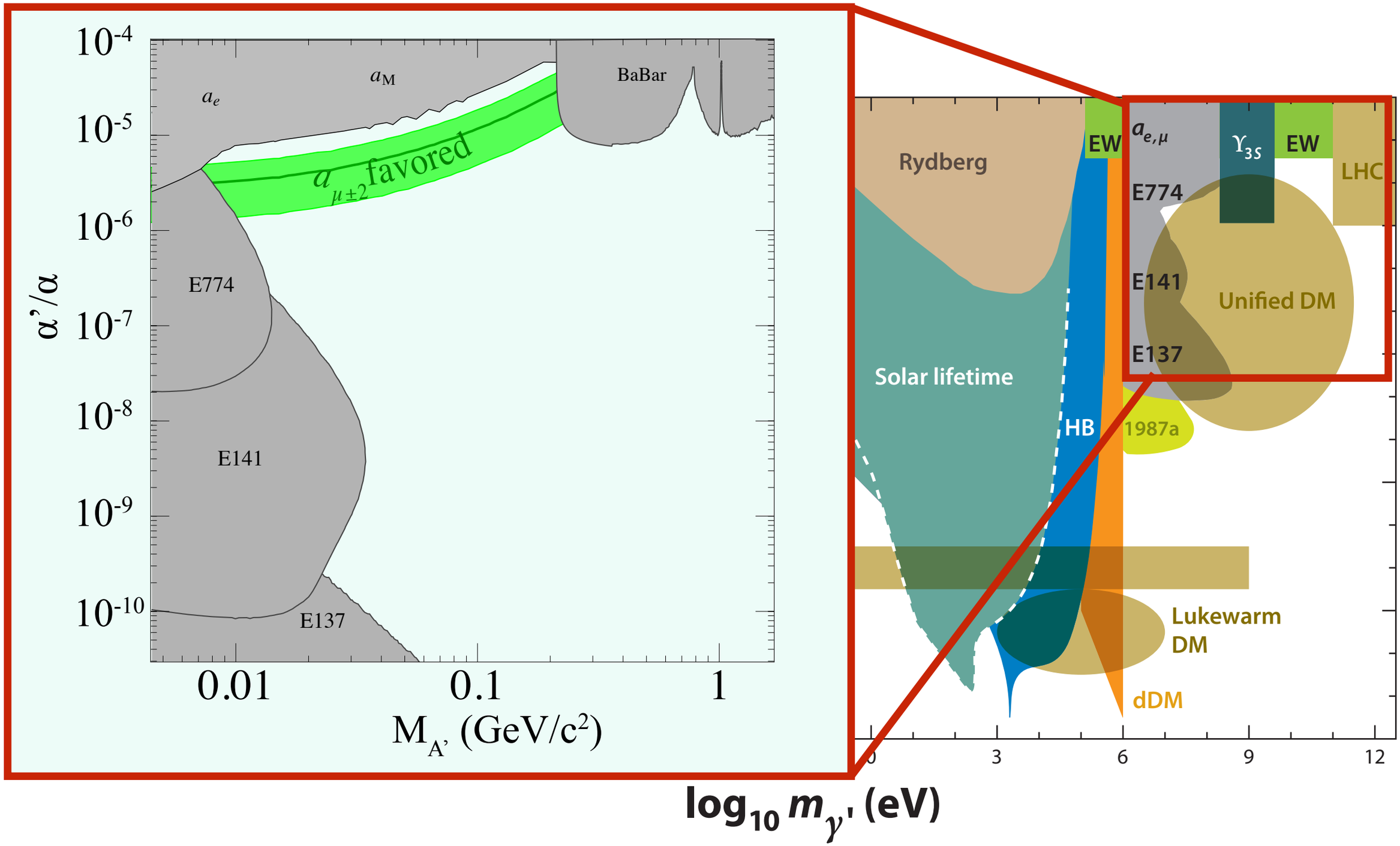
Or 1 < ε < 10^{-8} (loops)

or "anything" ...

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

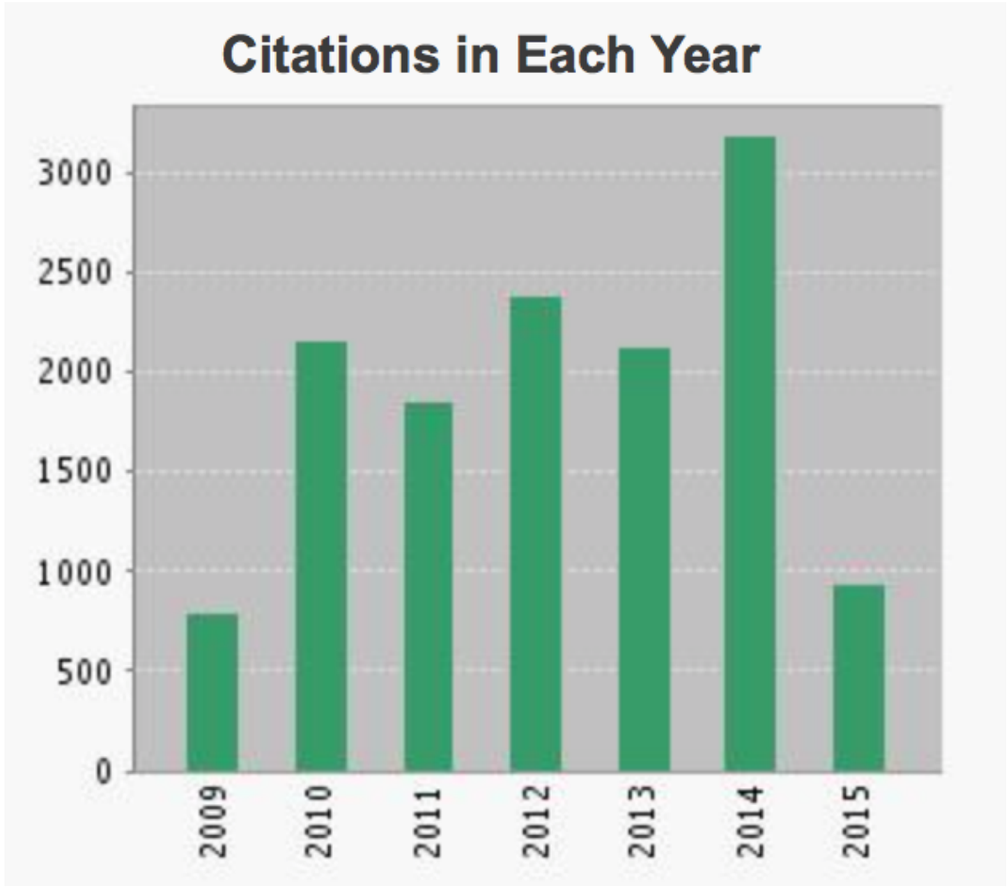
See: R. Essig et al, Intensity Frontier WS '11 summary paper.

Search area of choice

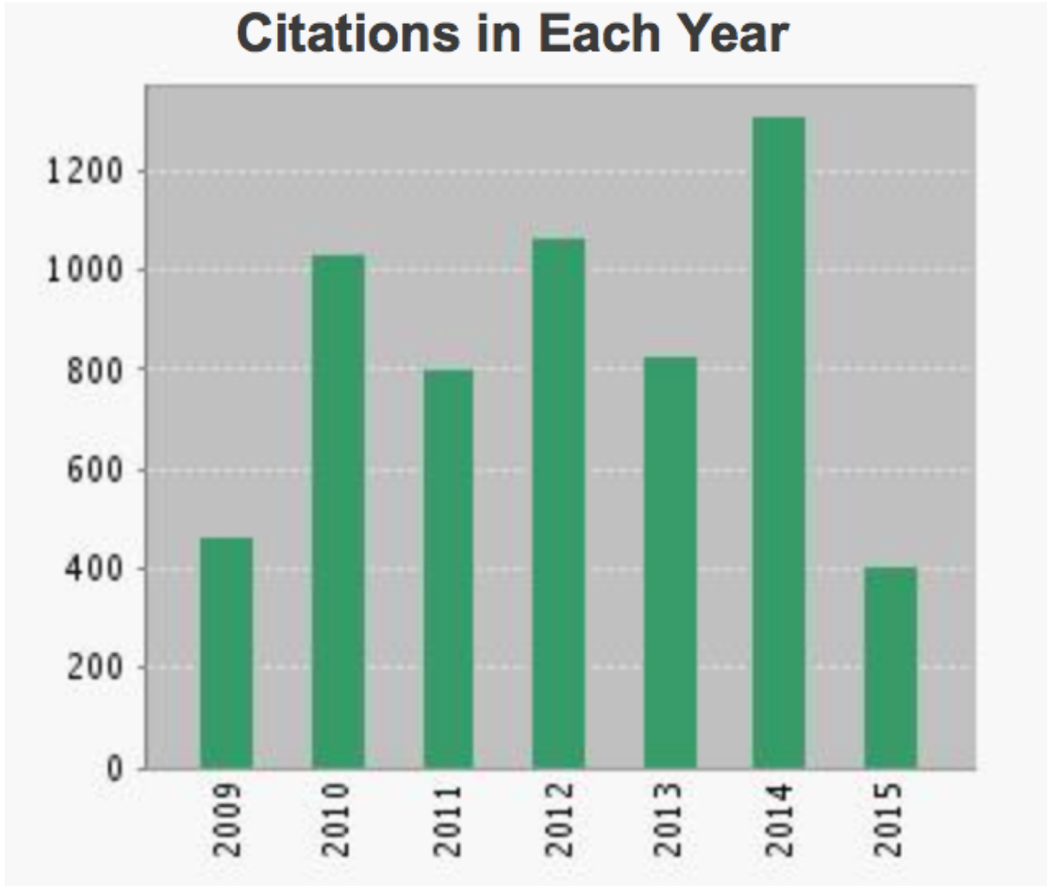


A lot of interest!

Since 2010, a lot of interest in this field.



Arkani-Hamed et al.
PRD **79** 015014 (2009)



Pospelov, Ritz
Phys. Let. B**671**, 391 (2009)

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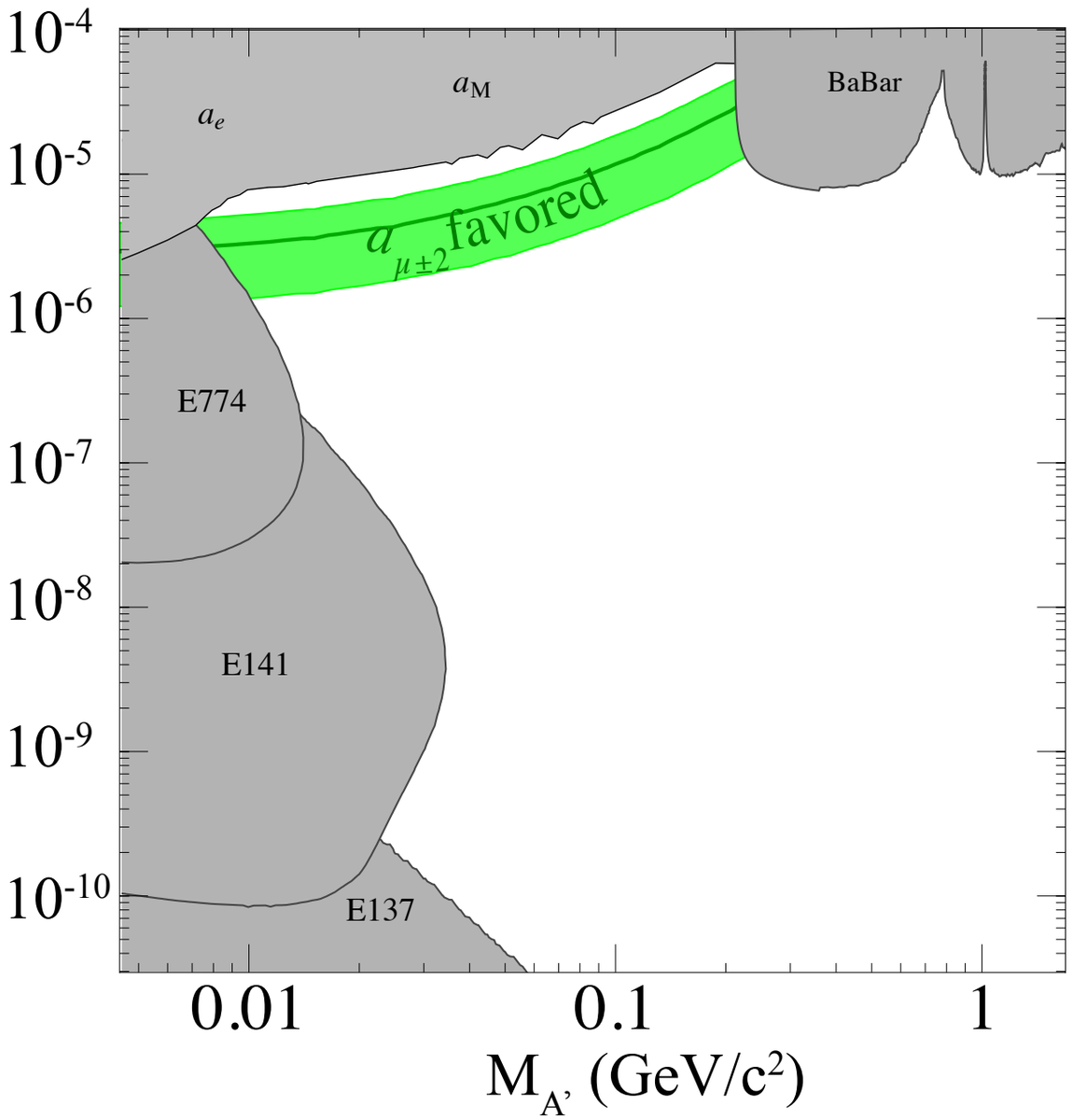
Exclusion areas in 2010



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

A lot of interest!

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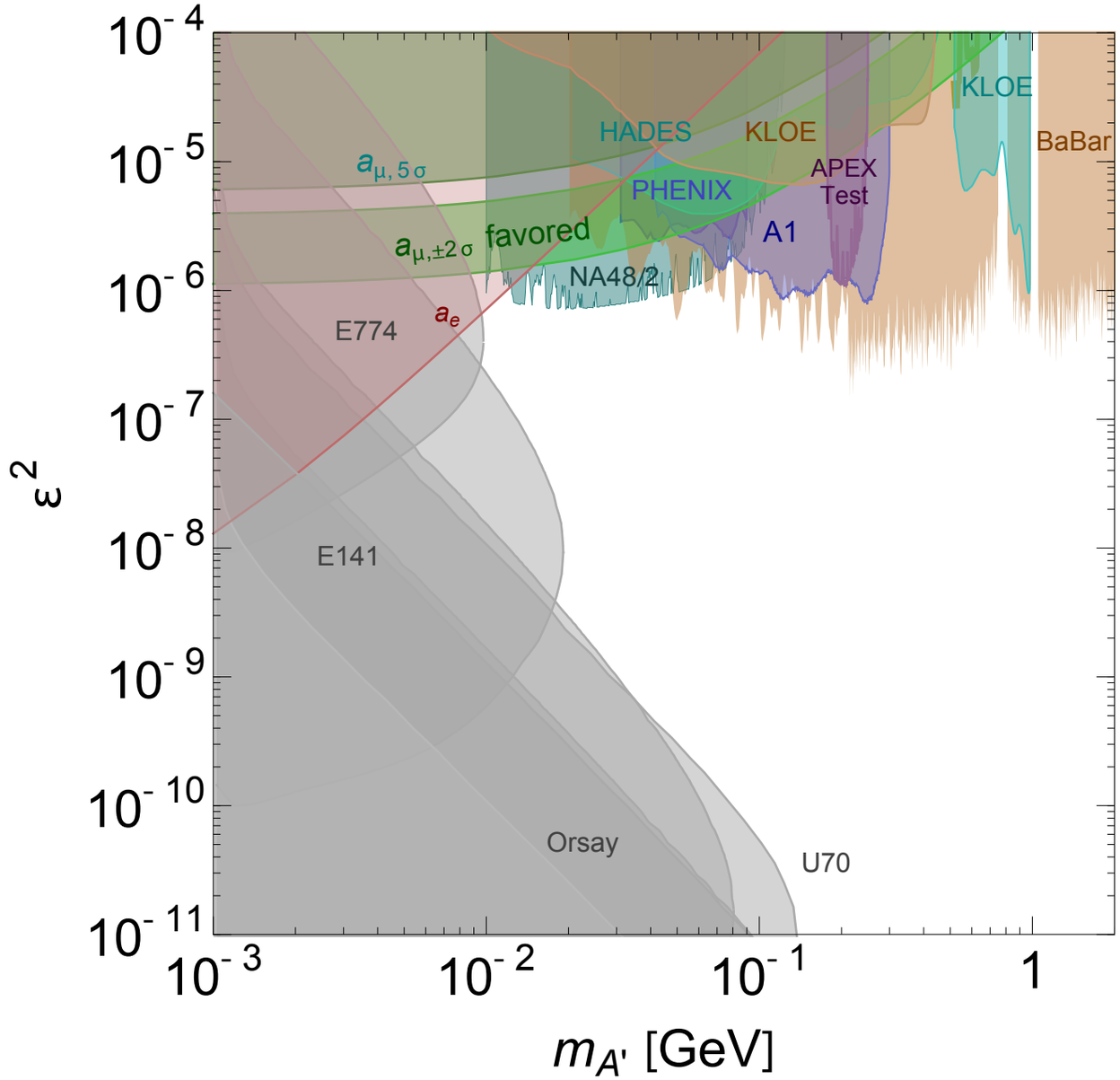
Exclusion areas in 2015



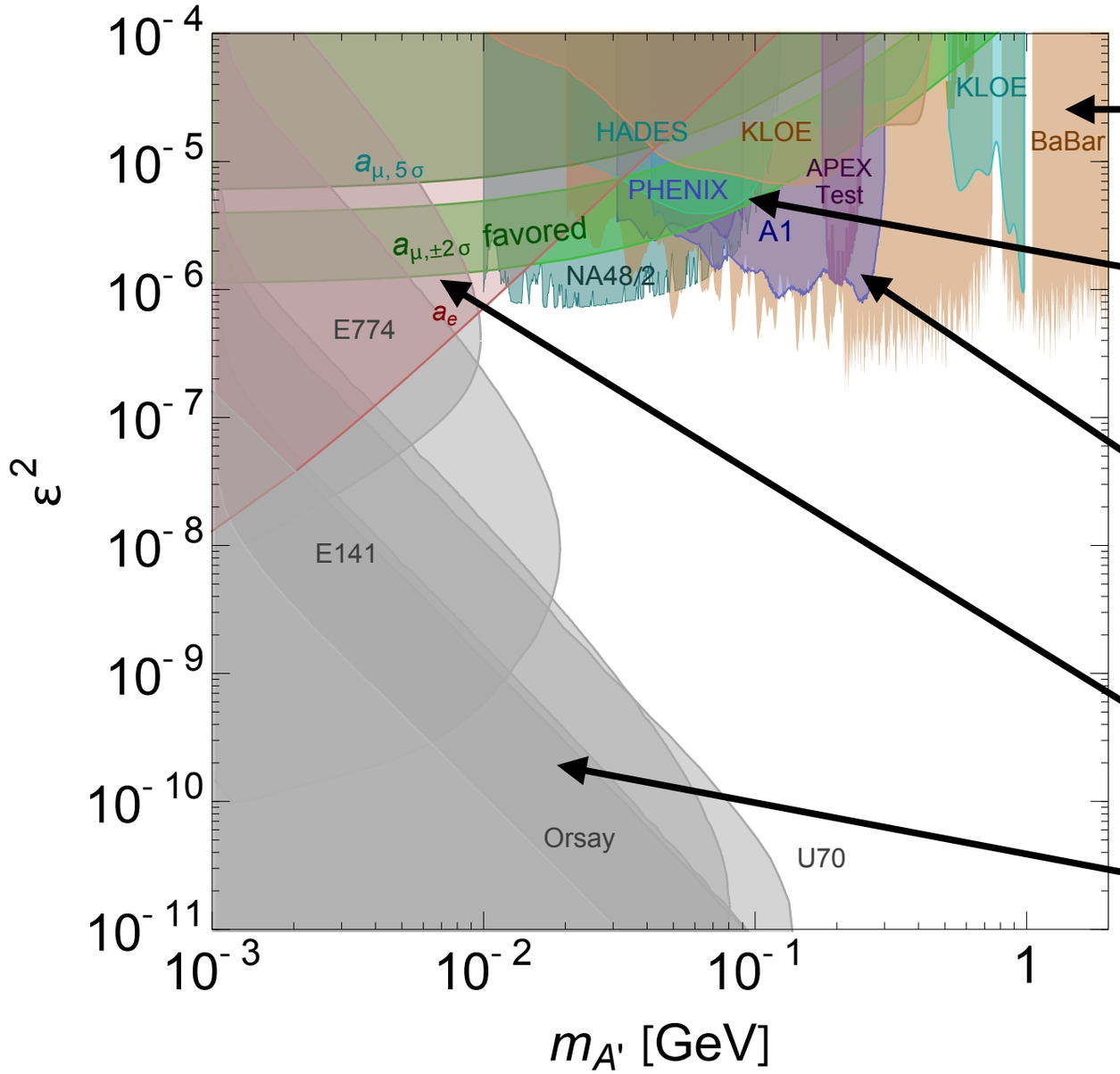
At the time of the HPS proposal, exclusion areas were mostly due to beam dump searches.

Since then, a lot of existing data has been re-analyzed to set improved limits.

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

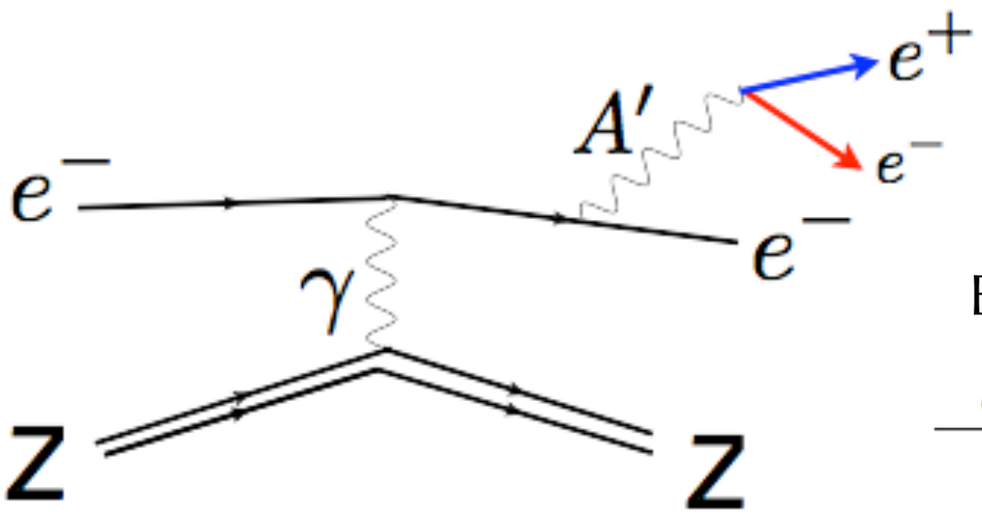
Fixed target experiments.

Precision Measurements

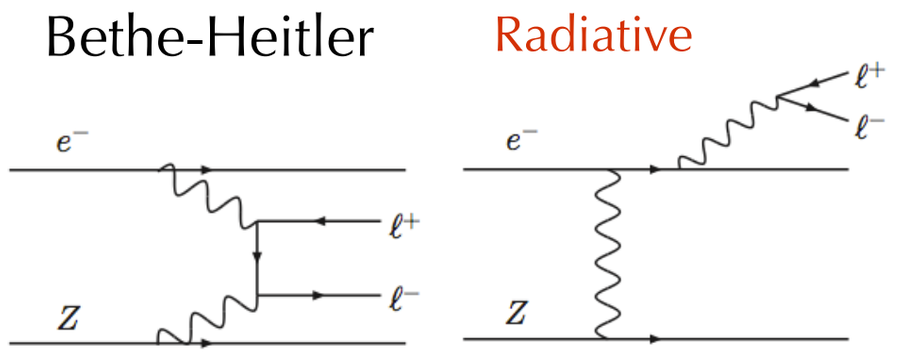
Beam dump experiments.

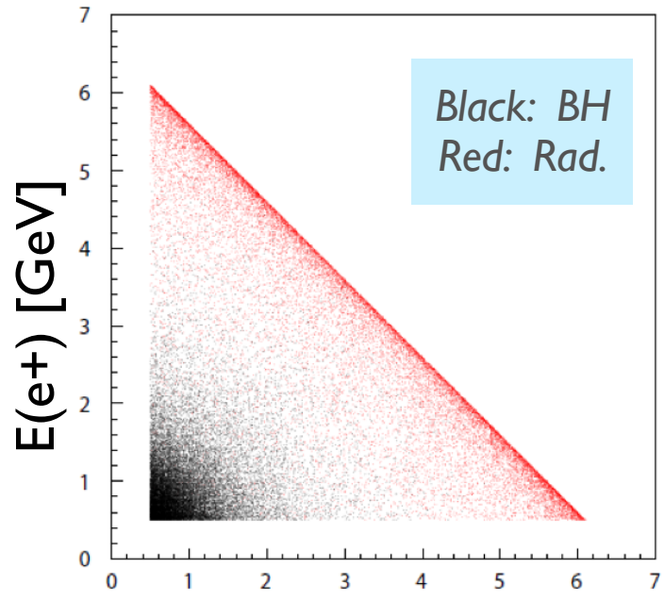
Fixed Target Searches

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



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





Very high luminosities: Intensity Frontier Physics.

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

Bump Hunt:
Look for signal over background.

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

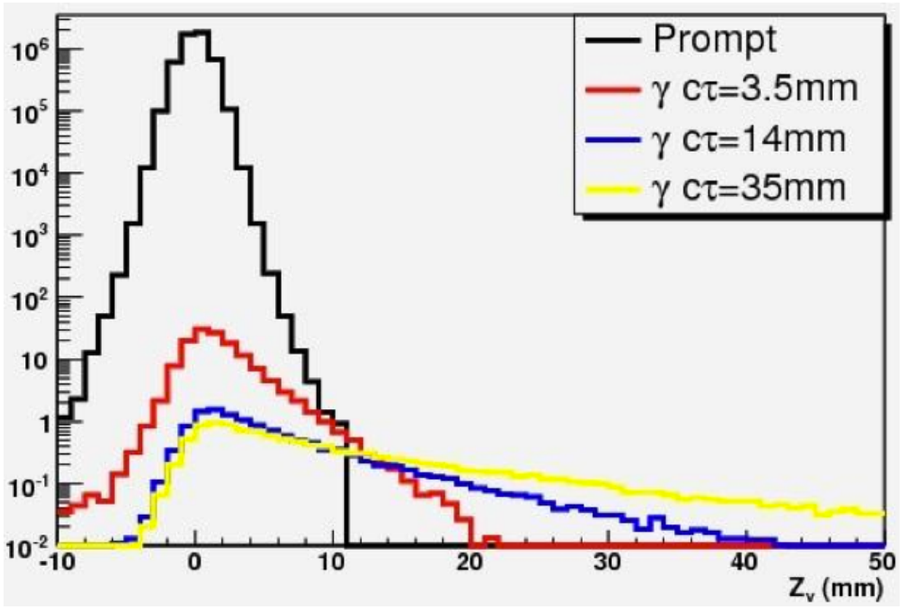
BEST: *Bjorken, Essig, Schuster, Toro, Phys.Rev. D80 (2009) 075018*

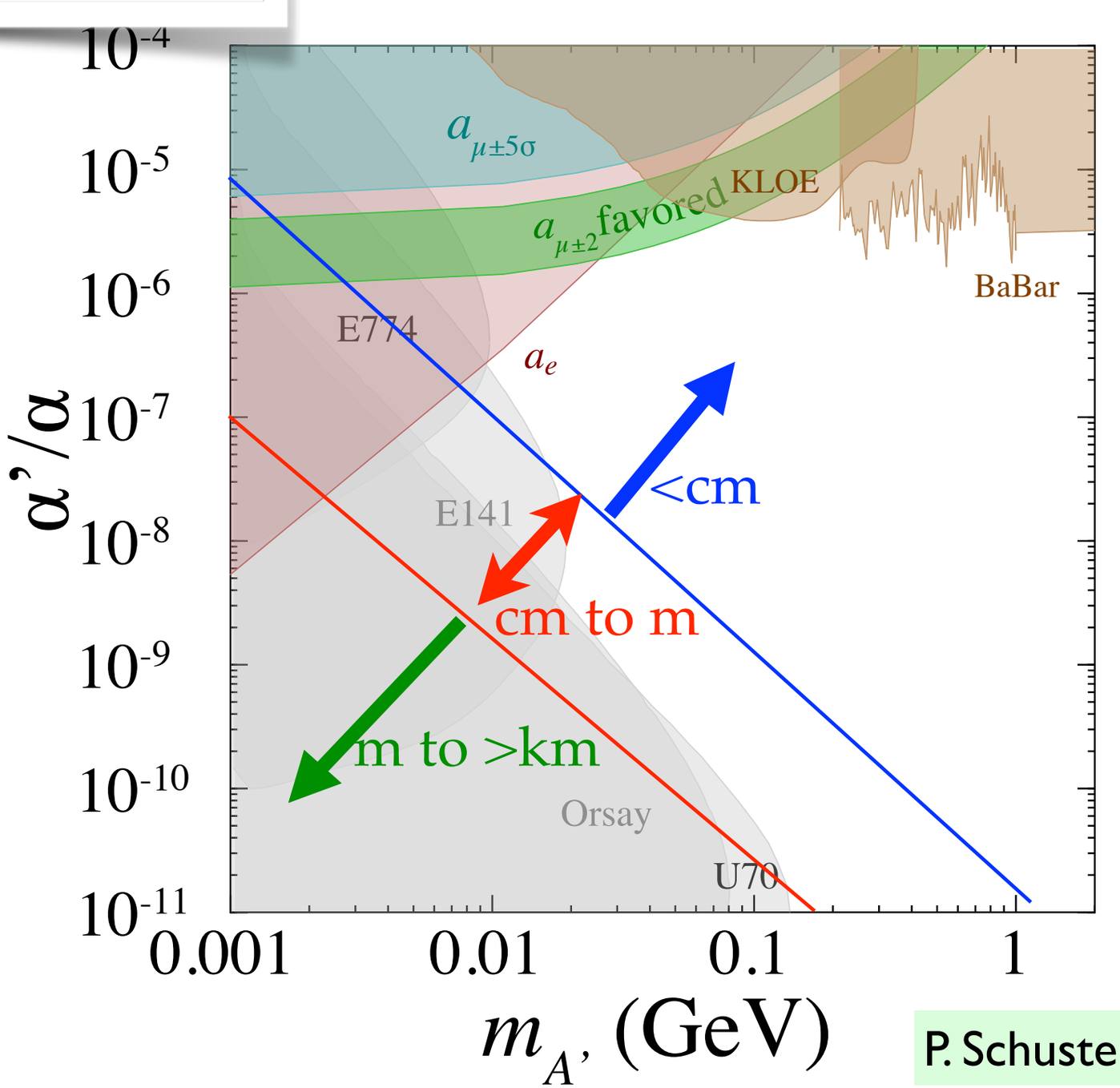
A´ lifetime

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

Lower α′, lower mass
→longer lifetime

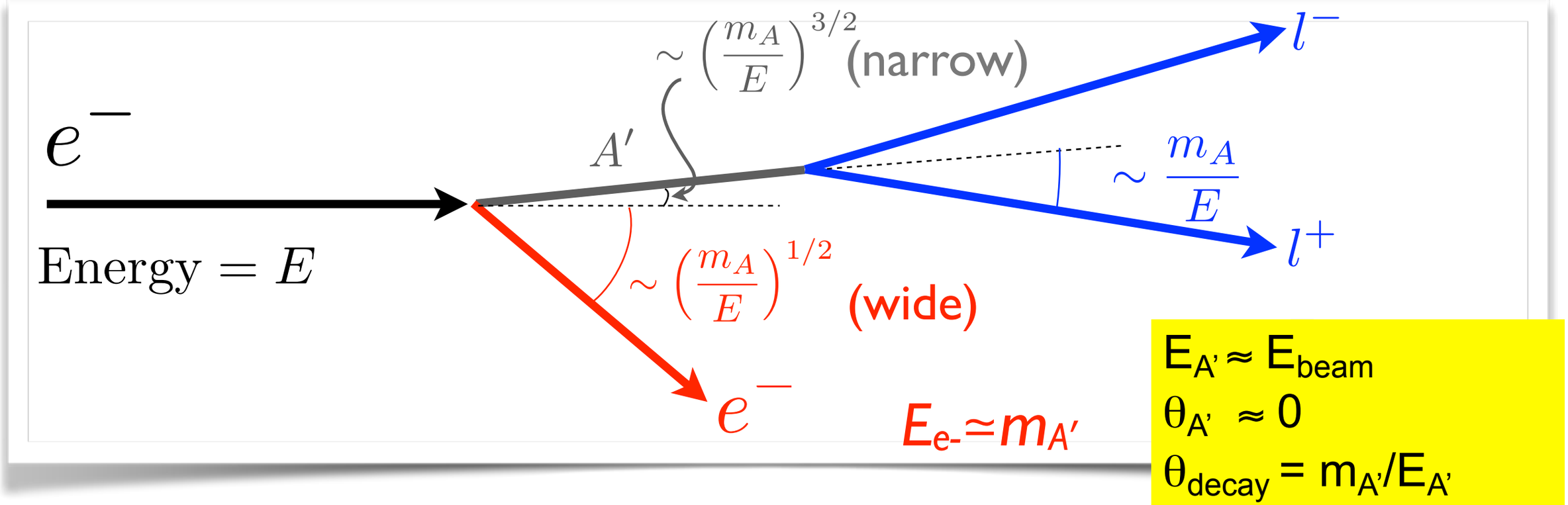
Background is all prompt
➜ Lower coupling can be reached using vertexing.

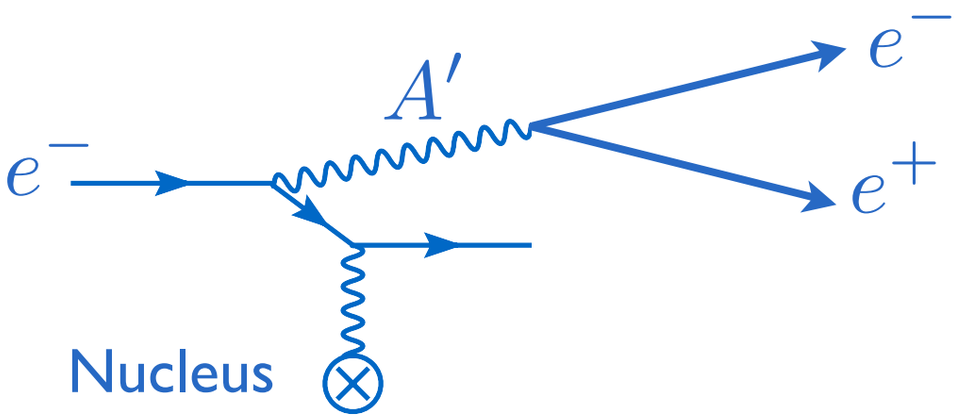




P. Schuster

Detecting A' decays

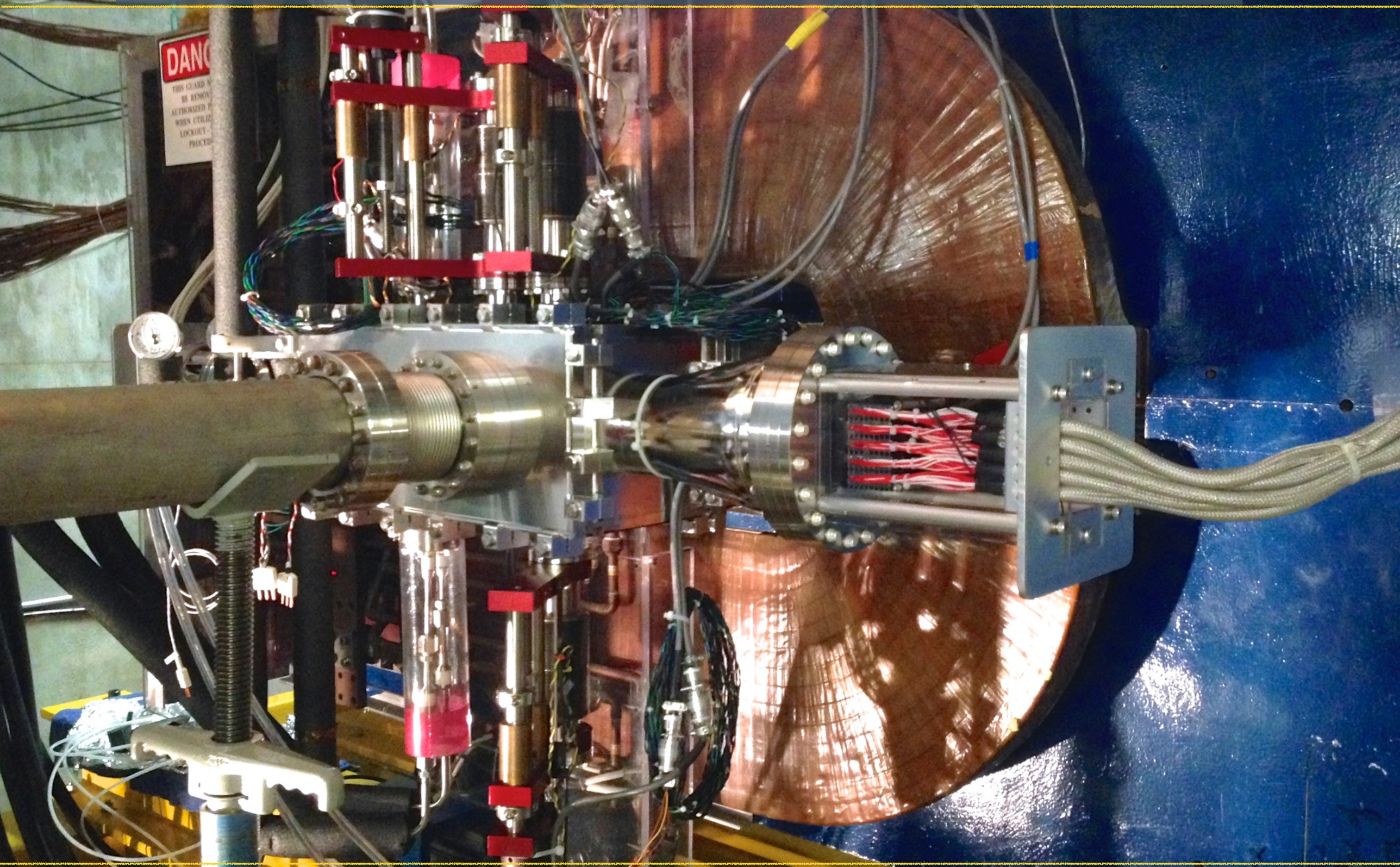




Need:

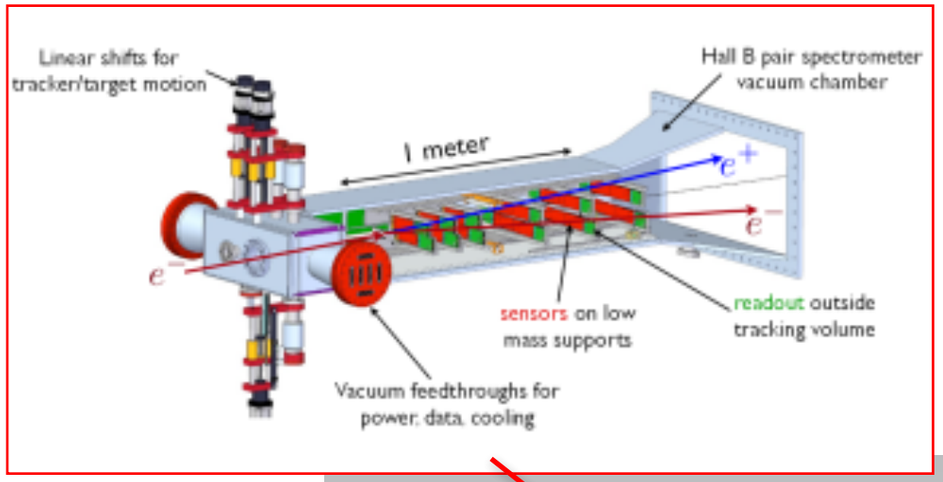
- Small angle detection of e+ e-
- Very high luminosity
- Good invariant mass resolution

The HPS Experiment

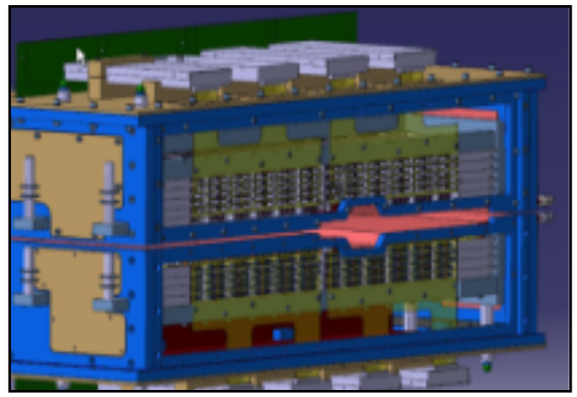


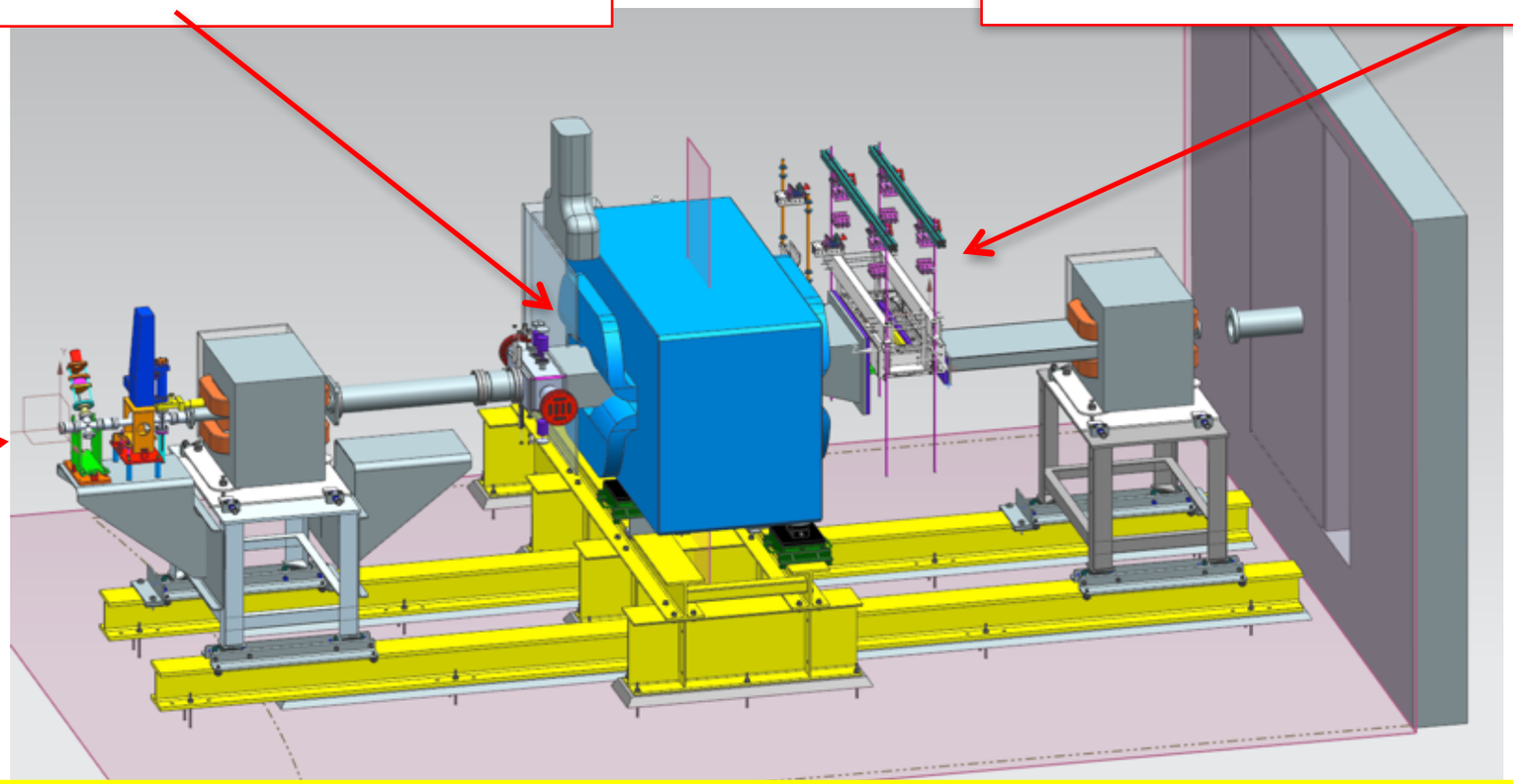
HPS Setup in Hall B Alcove

Si Vertex Tracker Installed Feb 23, 2015



$PbWO_4$ Ecal Installed September, 2014



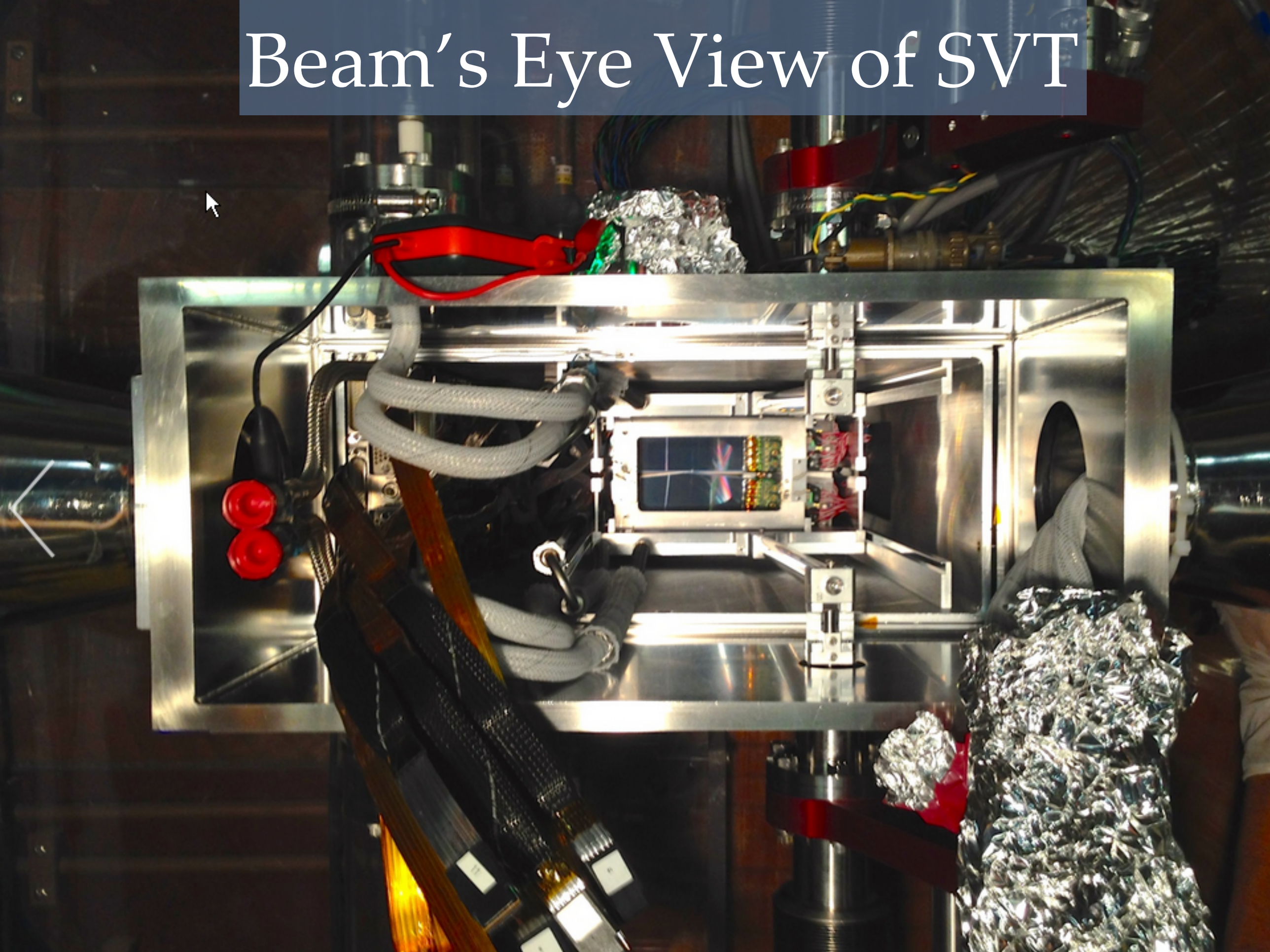


e^-

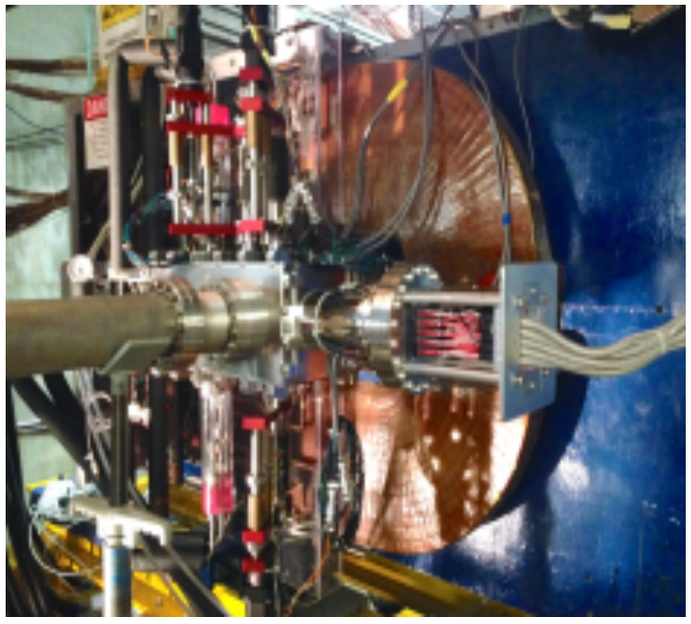
A magnet chicane directs the CEBAF 12 electron beam onto a W foil, producing heavy photons. They decay to e^+e^- pairs, which are measured by the Si vertex tracker inside an analyzing magnet. A $PbWO_4$ ECal provides a fast trigger.

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

Beam's Eye View of SVT



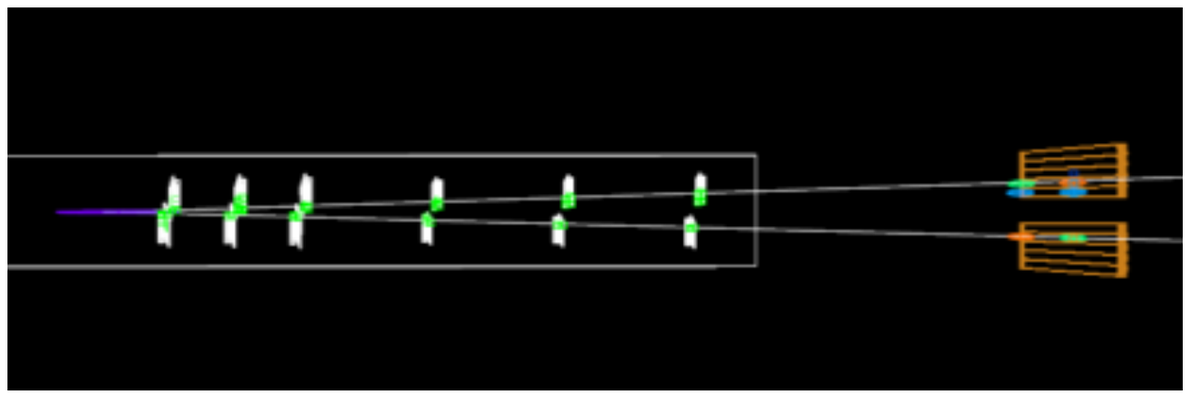
Spring Engineering Run



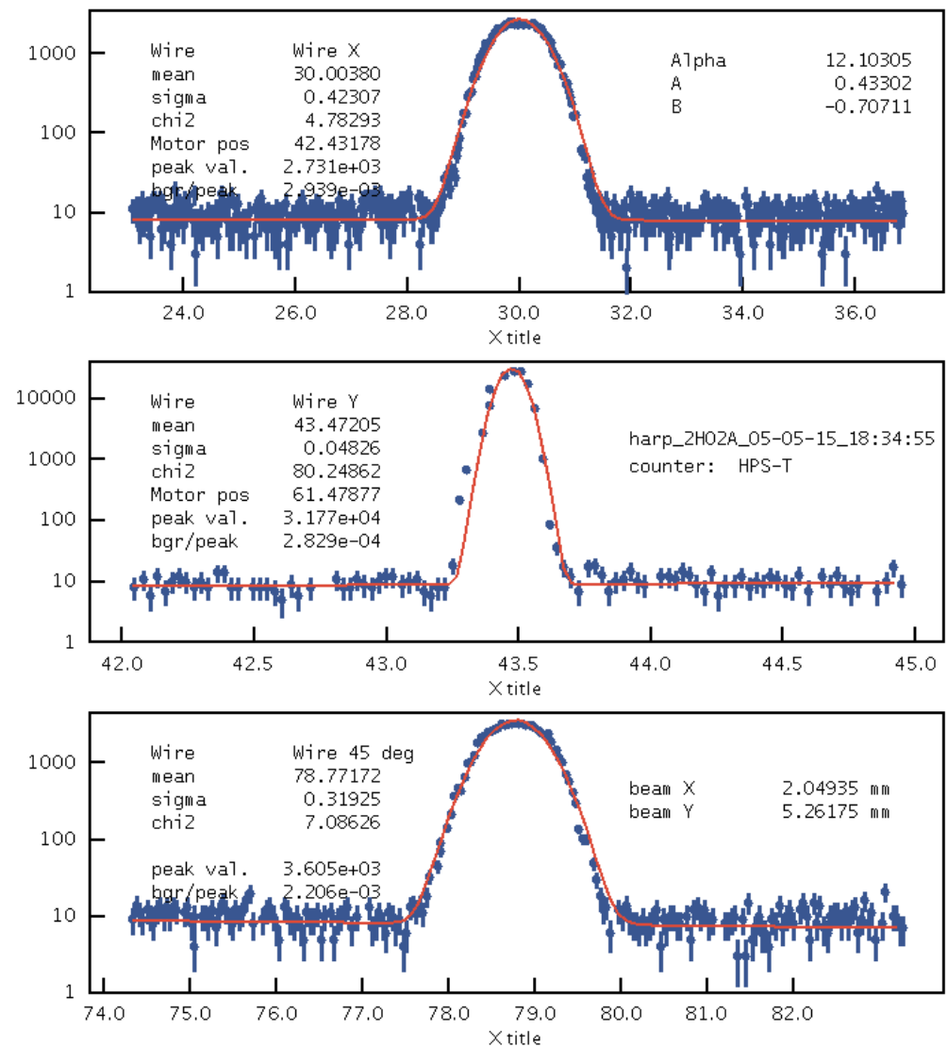
- Installed SVT end of February
- Commissioned Hall B beamline March-April
  * Calibrated bpms & established orbit locks
  * Set up SVT Protection Collimator
  * Checked beam position stability
- CEBAF down after power outage
- Commissioned Trigger and Integrated SVT DAQ late April
- Explored SVT backgrounds 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 ends May 18th.

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



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

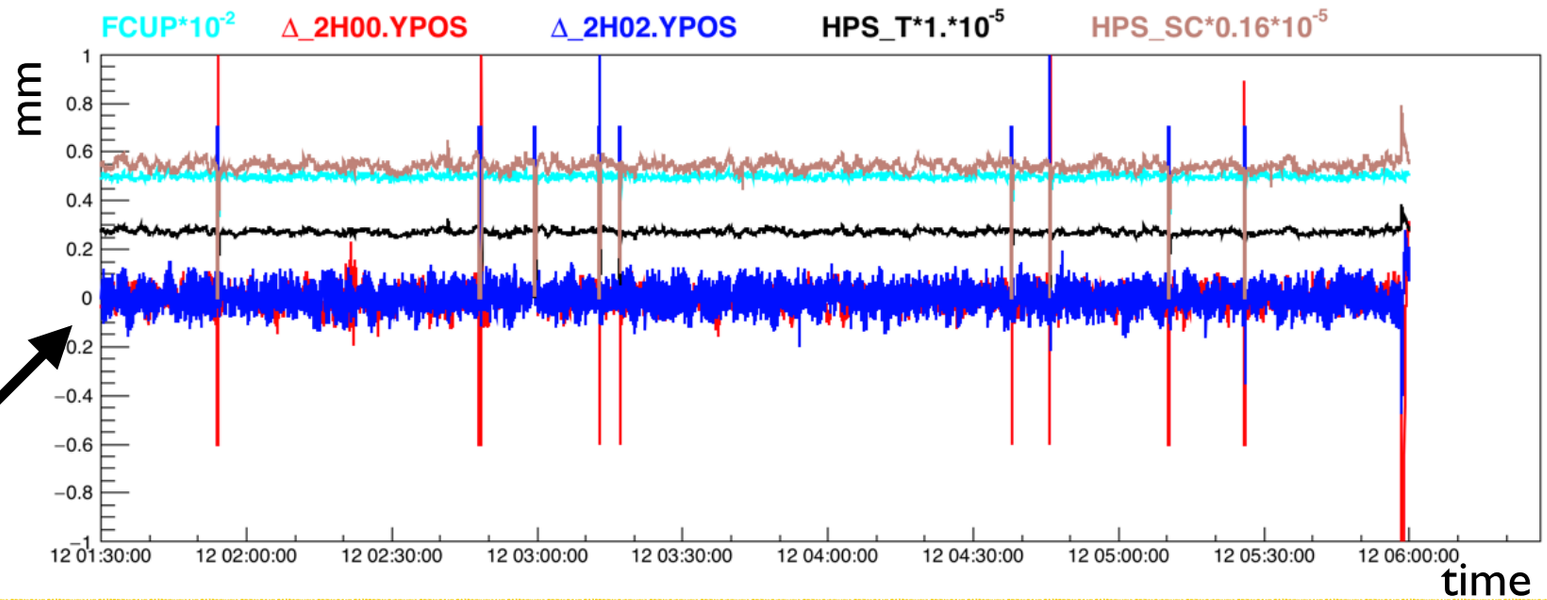
Very stable beam on May 12th.

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

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

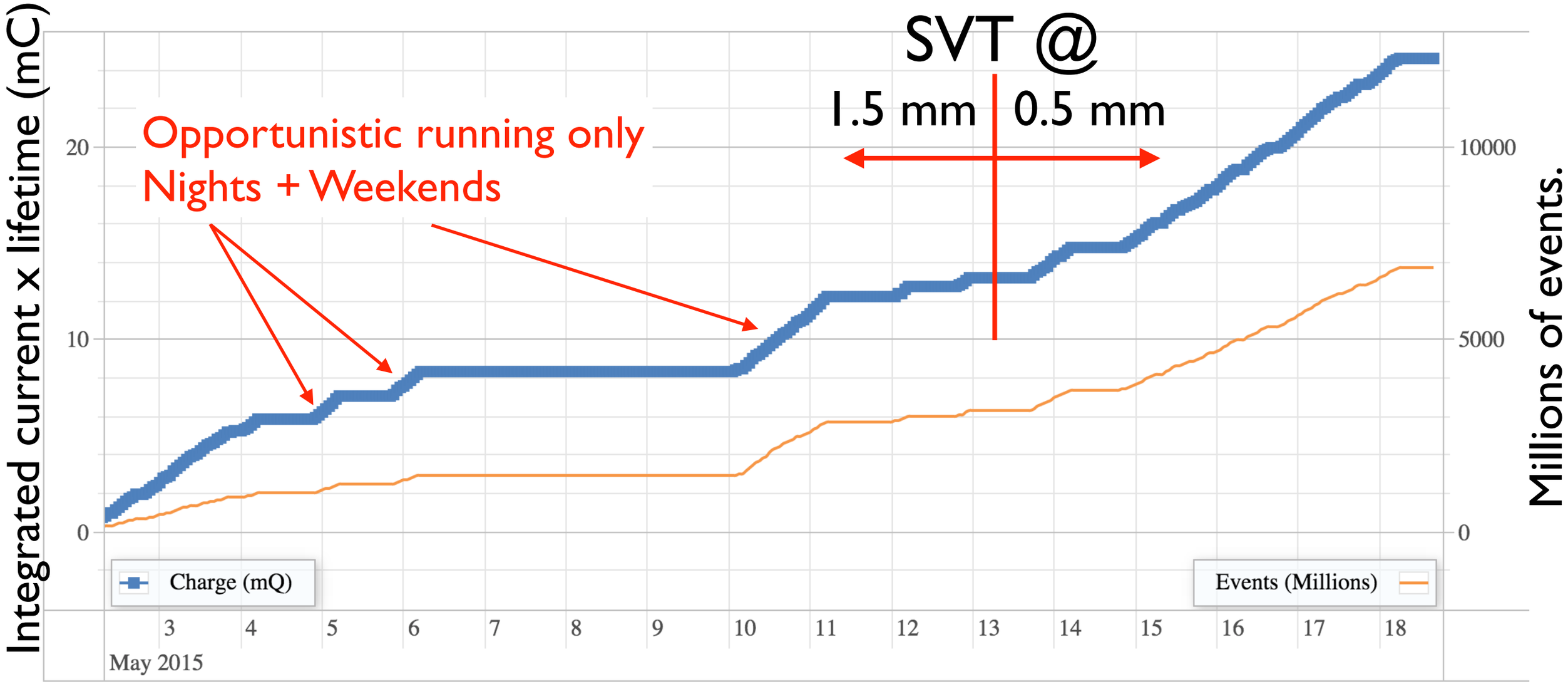
σ_Y ~ 15 - 50 μm - To help vertexting & tracking.

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.

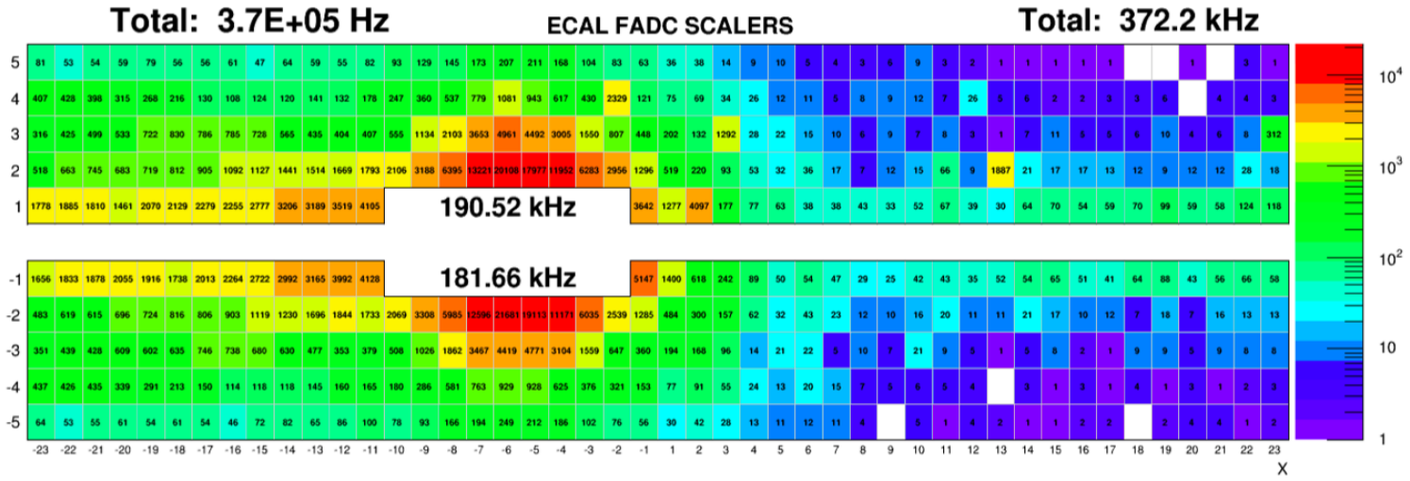


1 GeV Run, Charge on target.

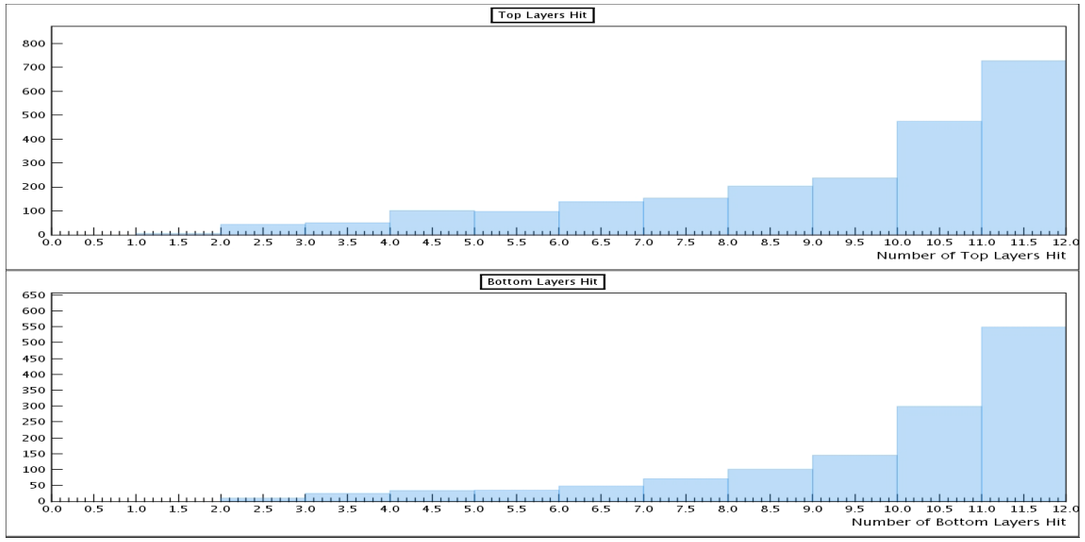
Proposal: 1 full week of 50 nA beam on target, 30mC
Achieved: ~10 mC with SVT at 1.5mm, 10 mC at 0.5 mm

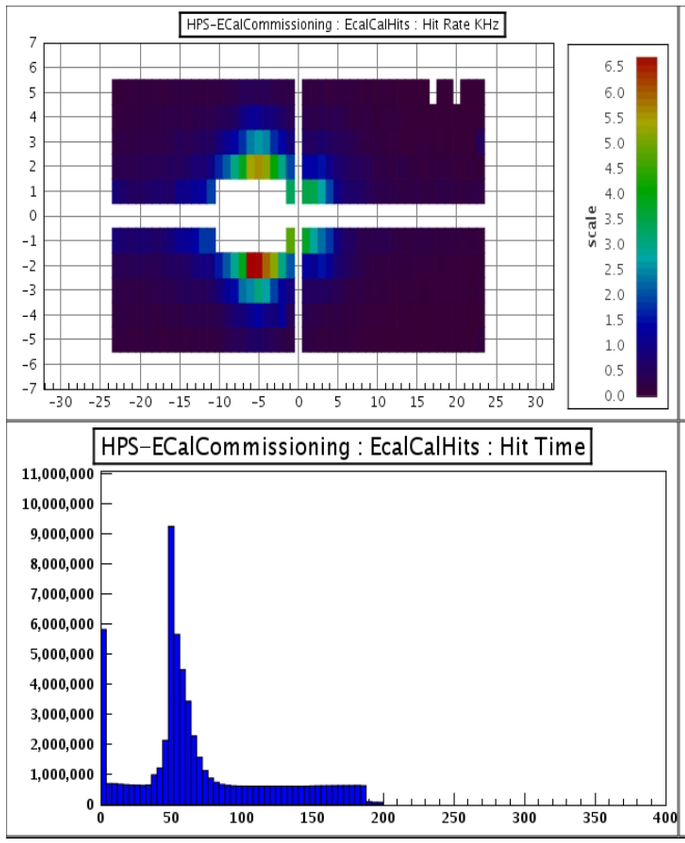


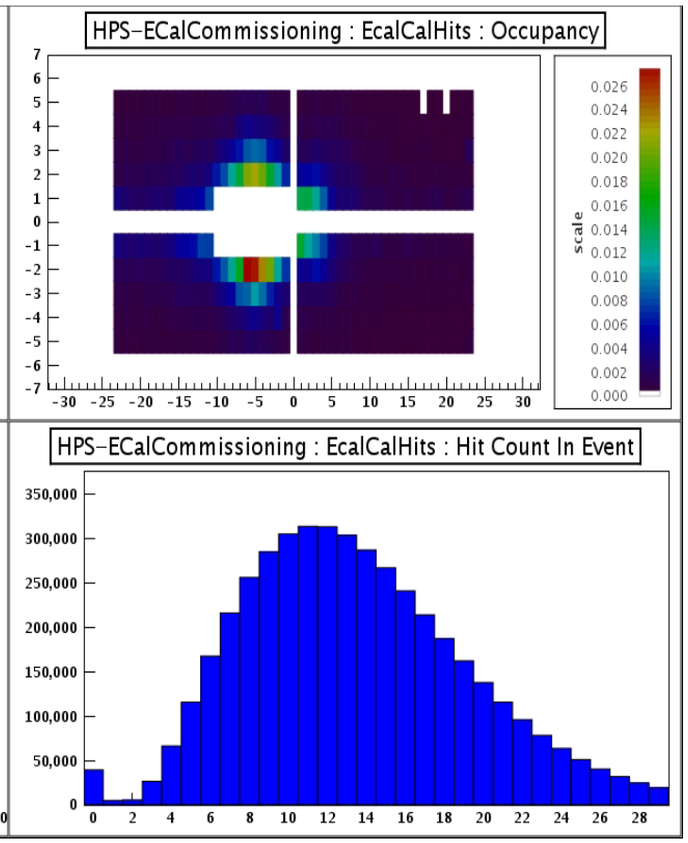
Online data quality



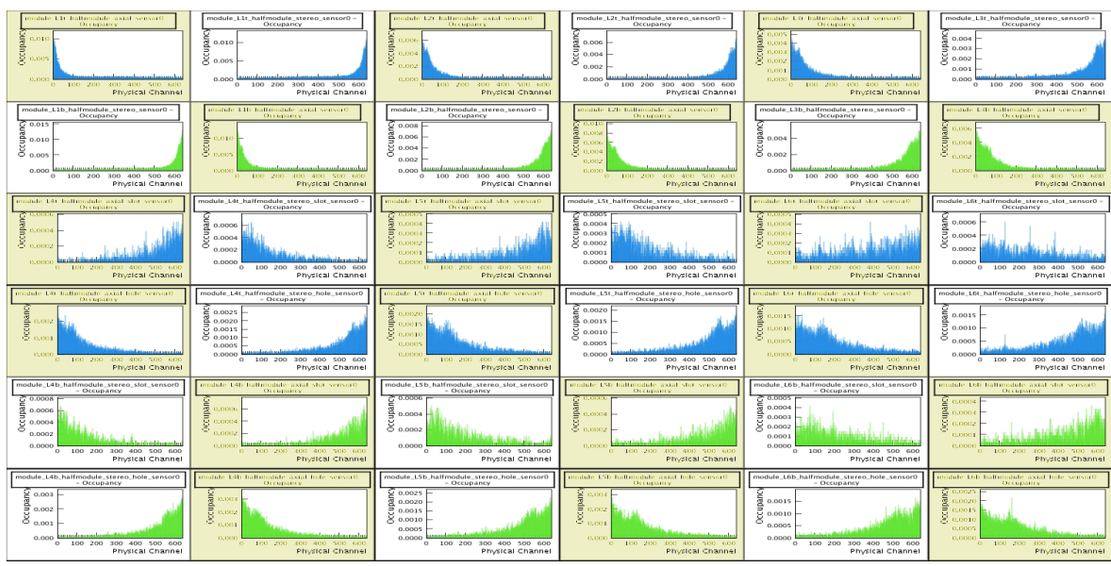
SVT Number of layers hit







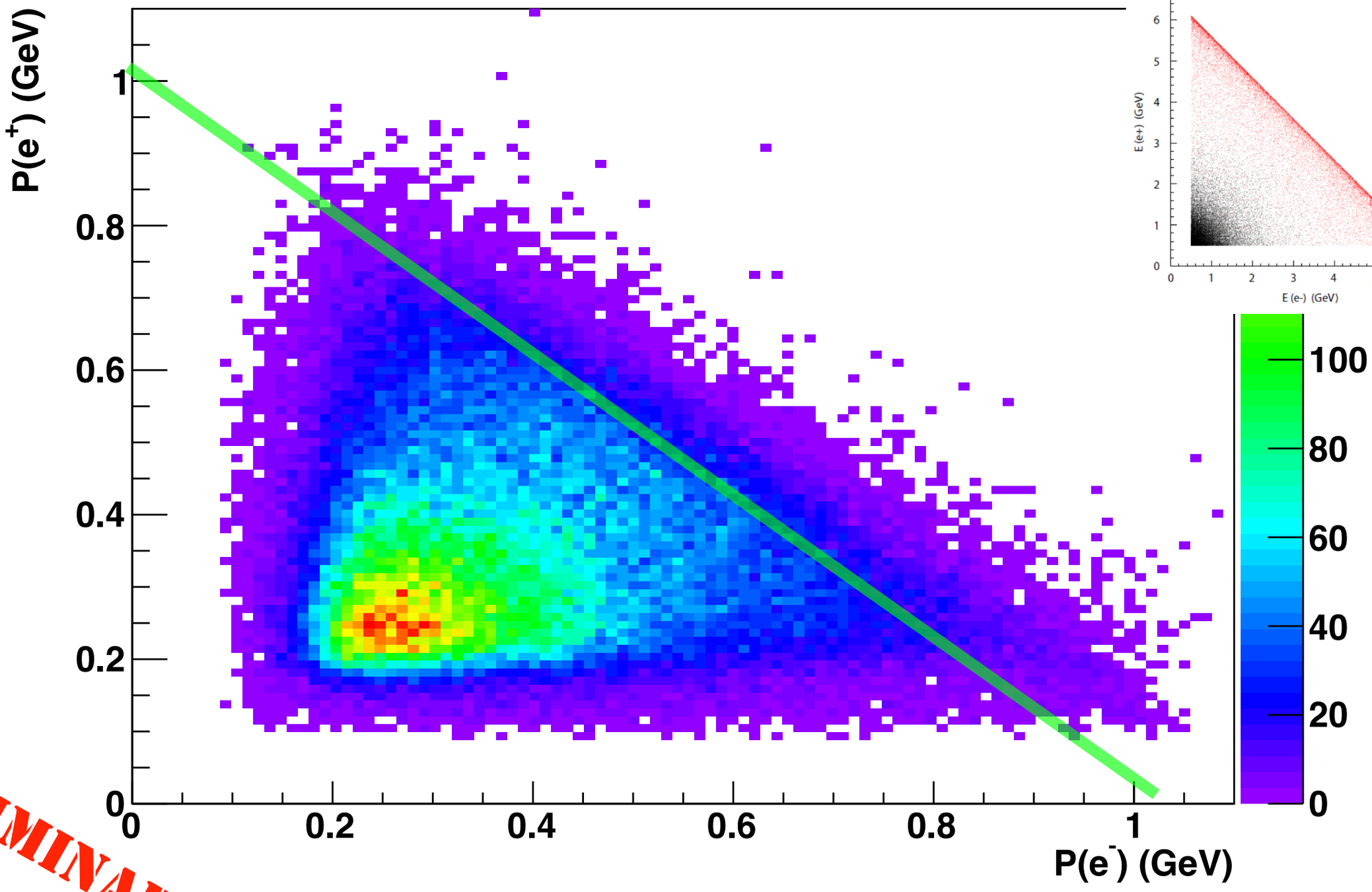
Occupancy



Tracked Pairs at 1.5 mm

Plots from M. Graham

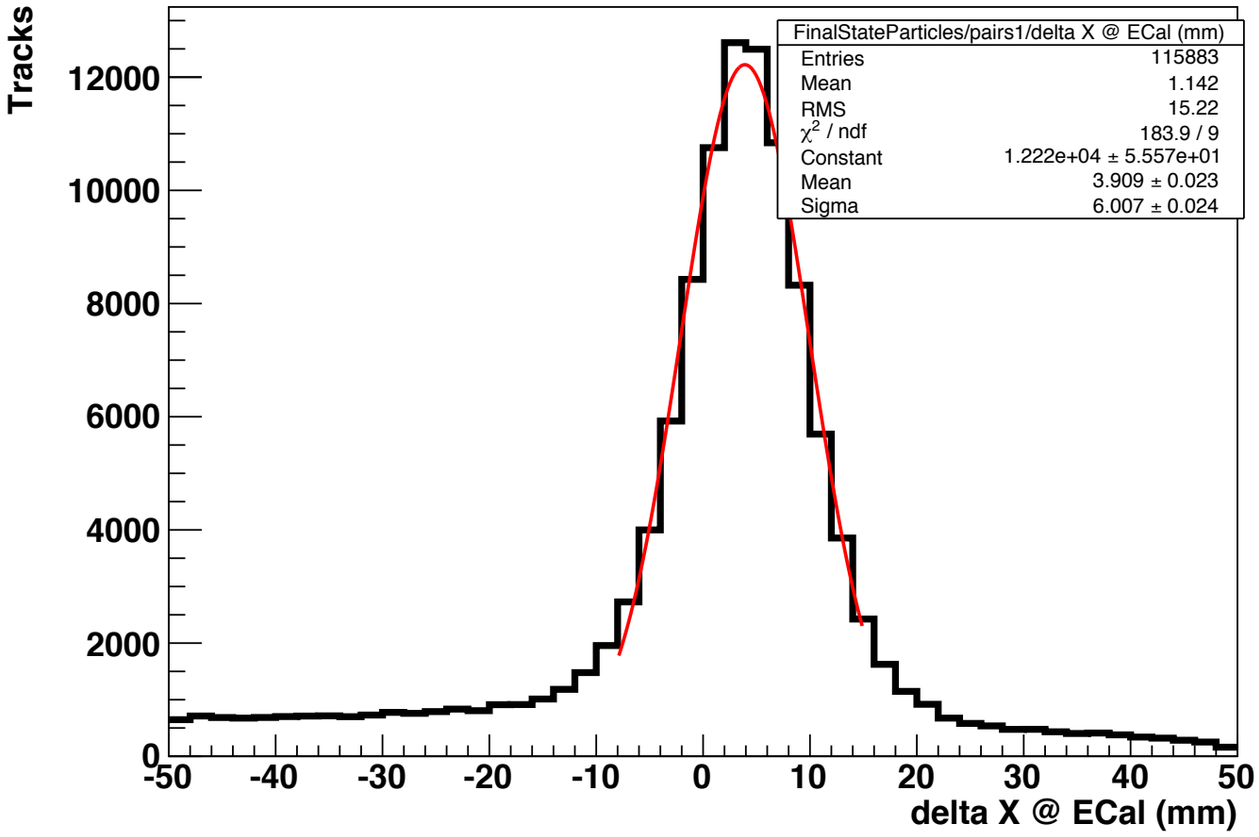
A′ candidates have $P_{e+} + P_{e-} \approx P_{beam} = 1.05$ GeV

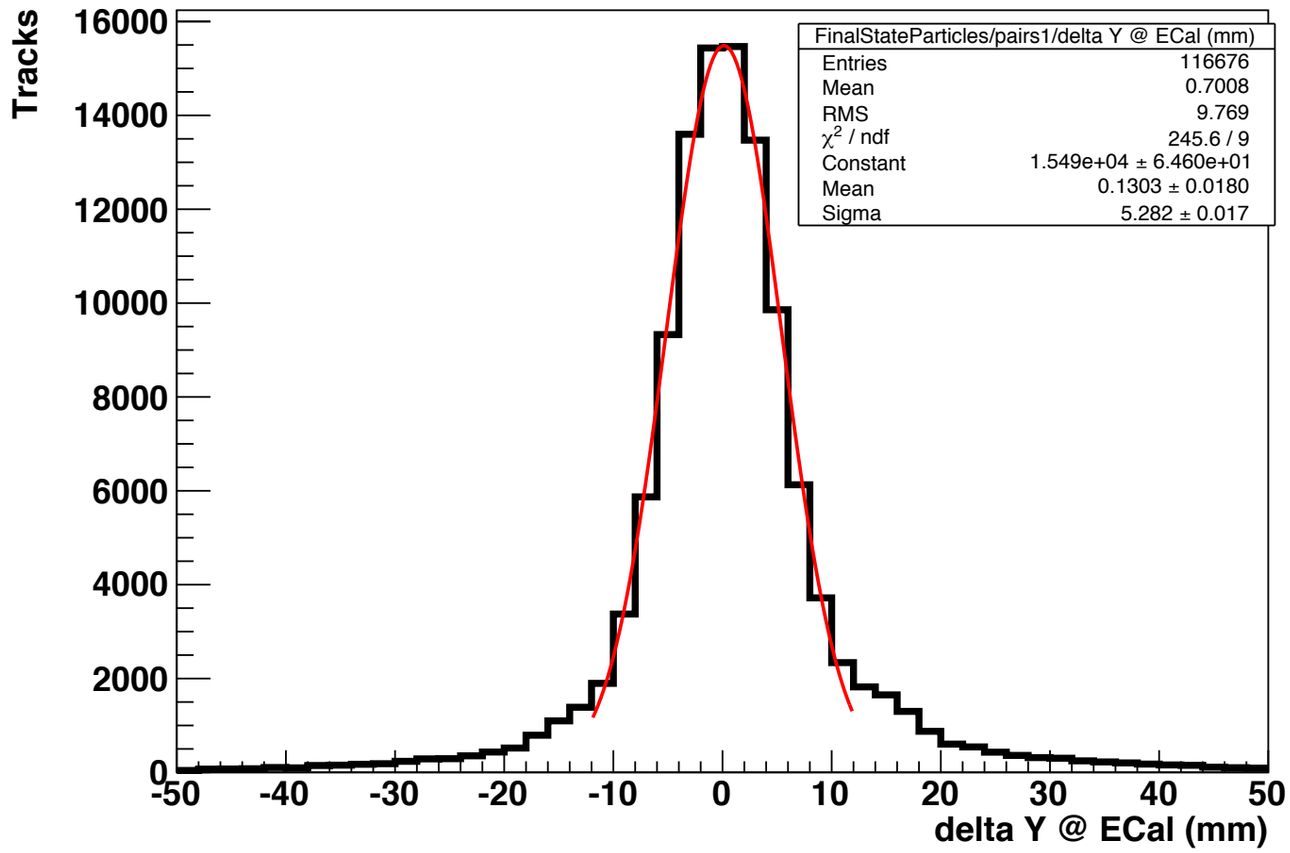


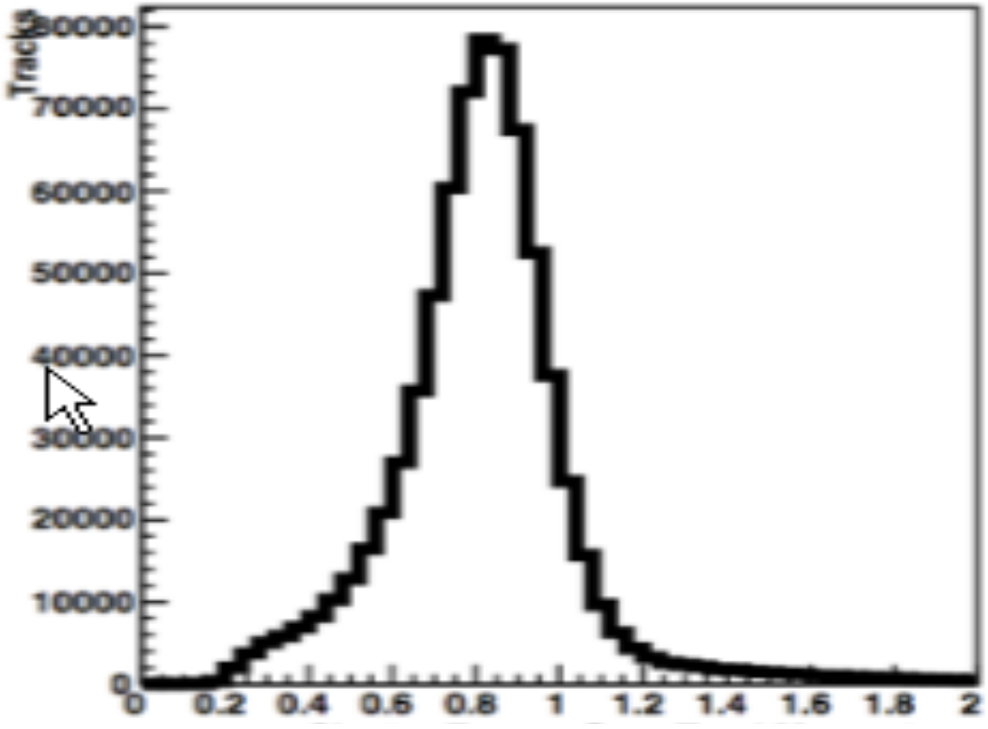
Simulation (for 6GeV)

PRELIMINARY

Track Matching at ECal





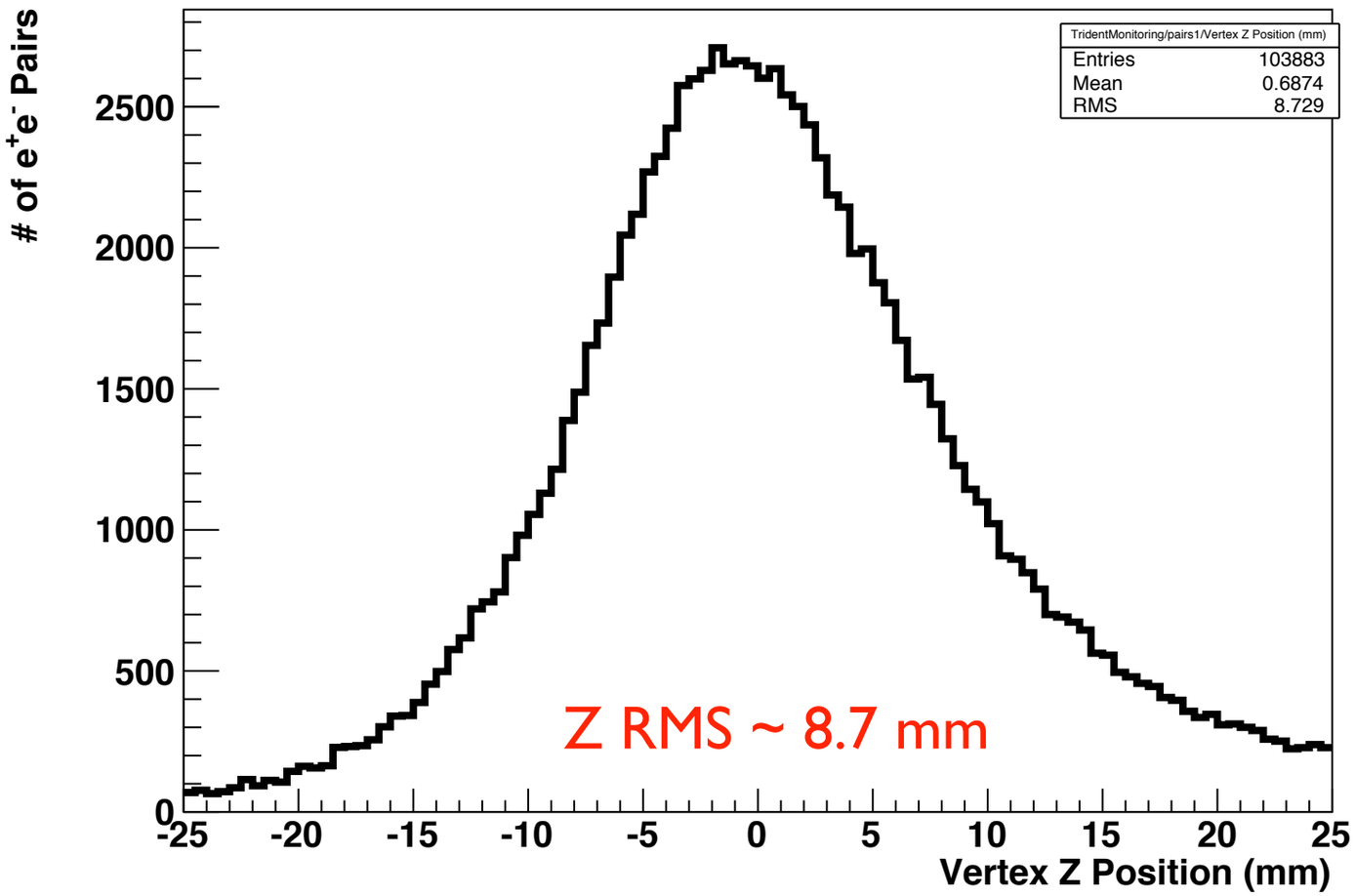


Cluster energy/track momentum

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

PRELIMINARY

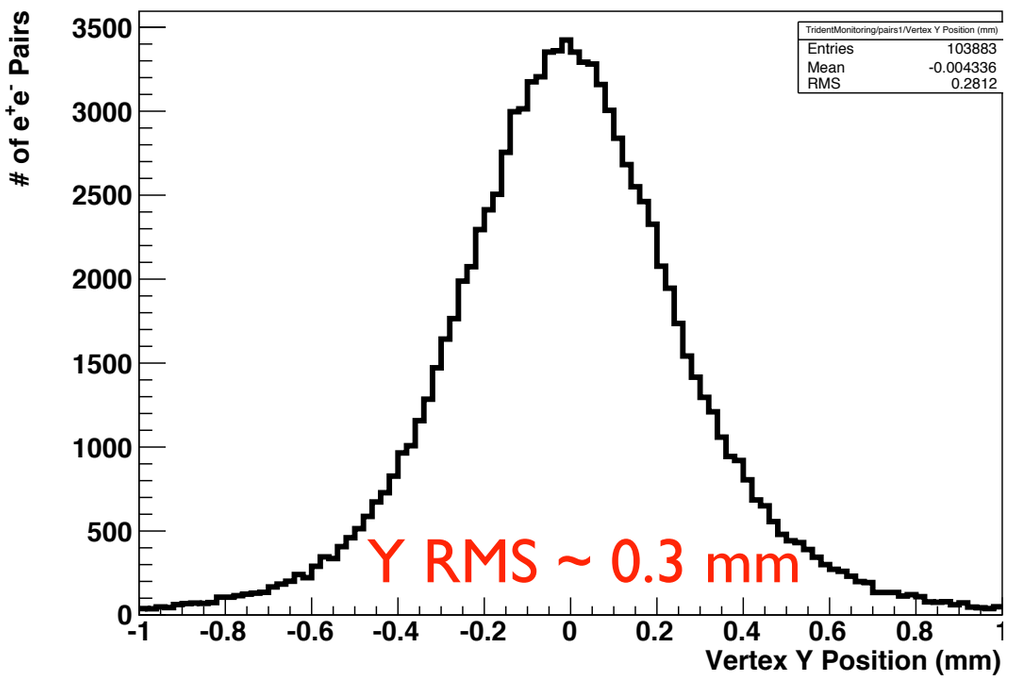
Pairs Vertex at the Target

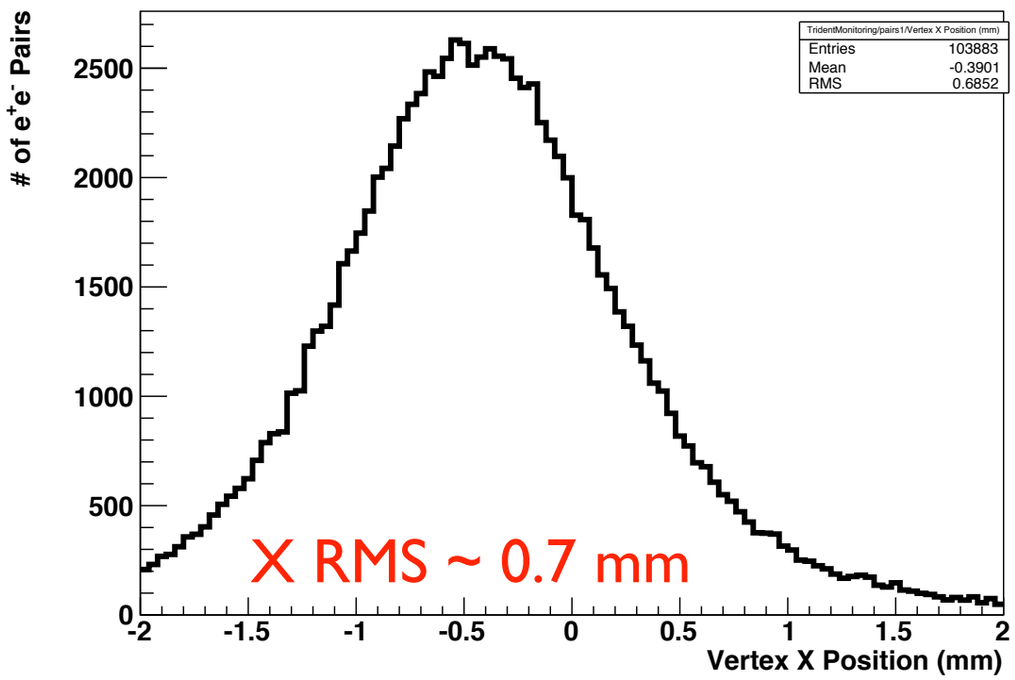


Z-vertex is critical for the experiment.

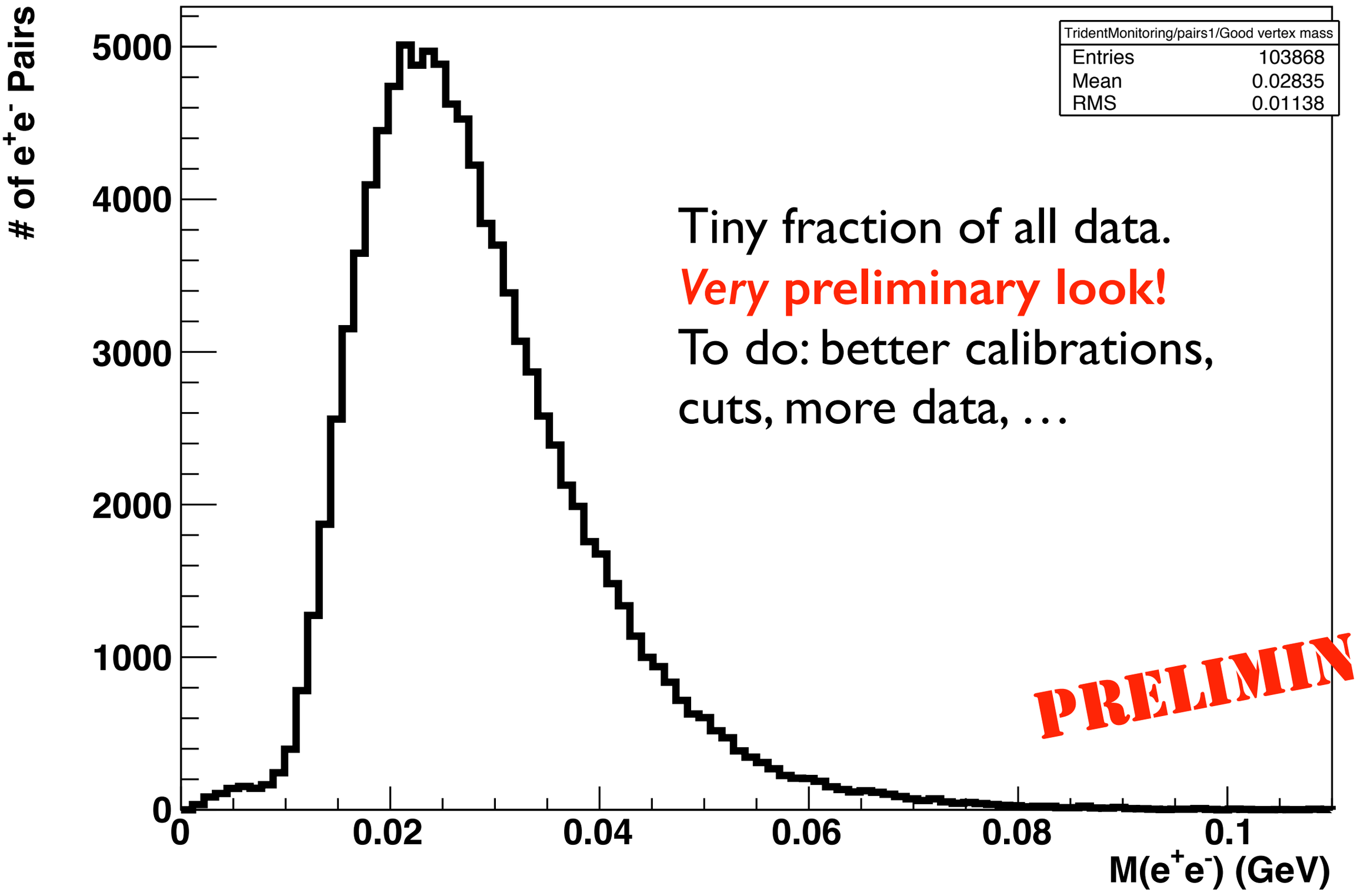
- Also the hardest @ 15 mrad.
- Requires very good SVT alignment (not yet done!)

PRELIMINARY

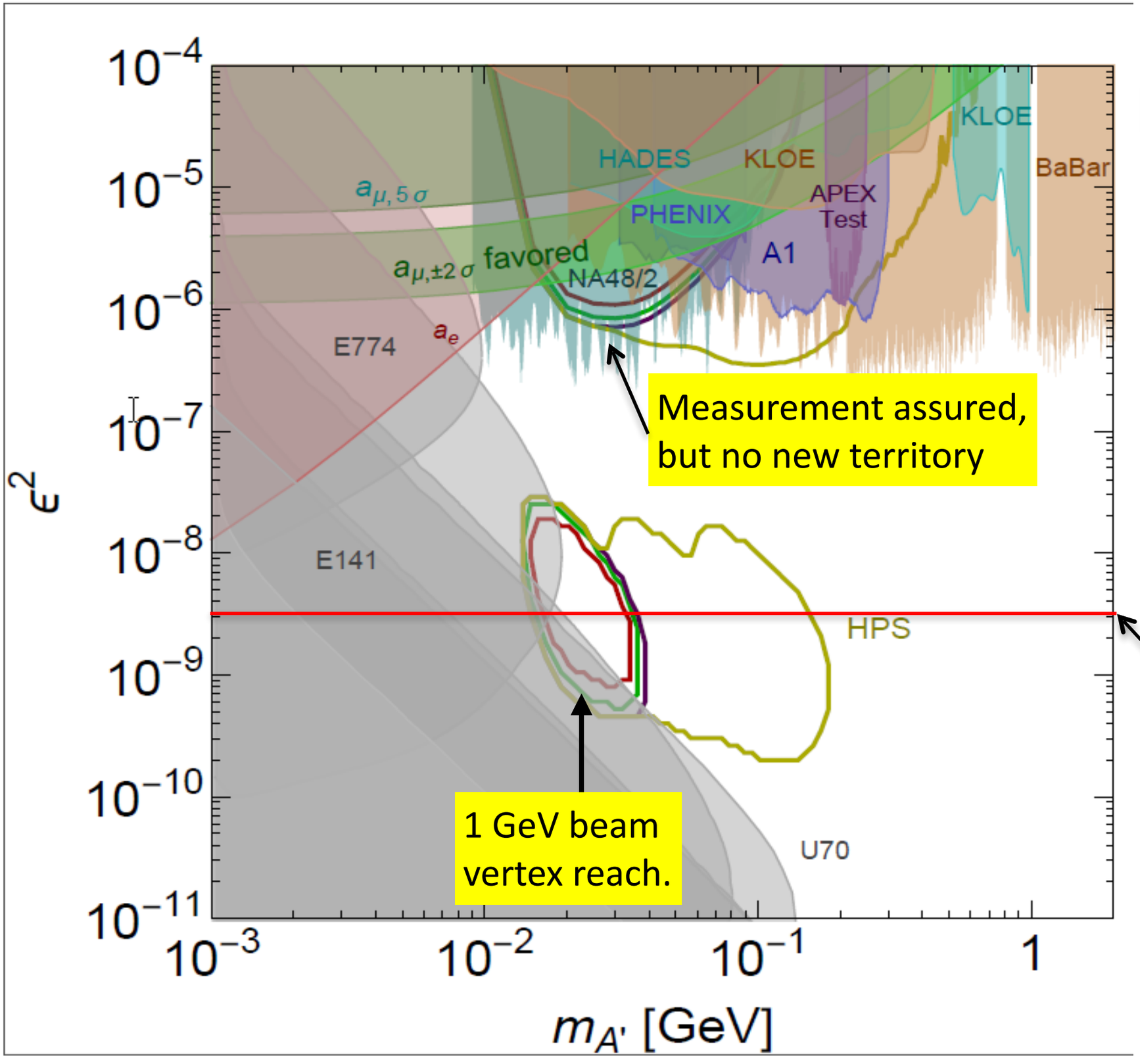




Pairs Mass Distribution



Reach vs Runtime



For 1 GeV beam

Assumes coverage to 15 mrad

Contours:

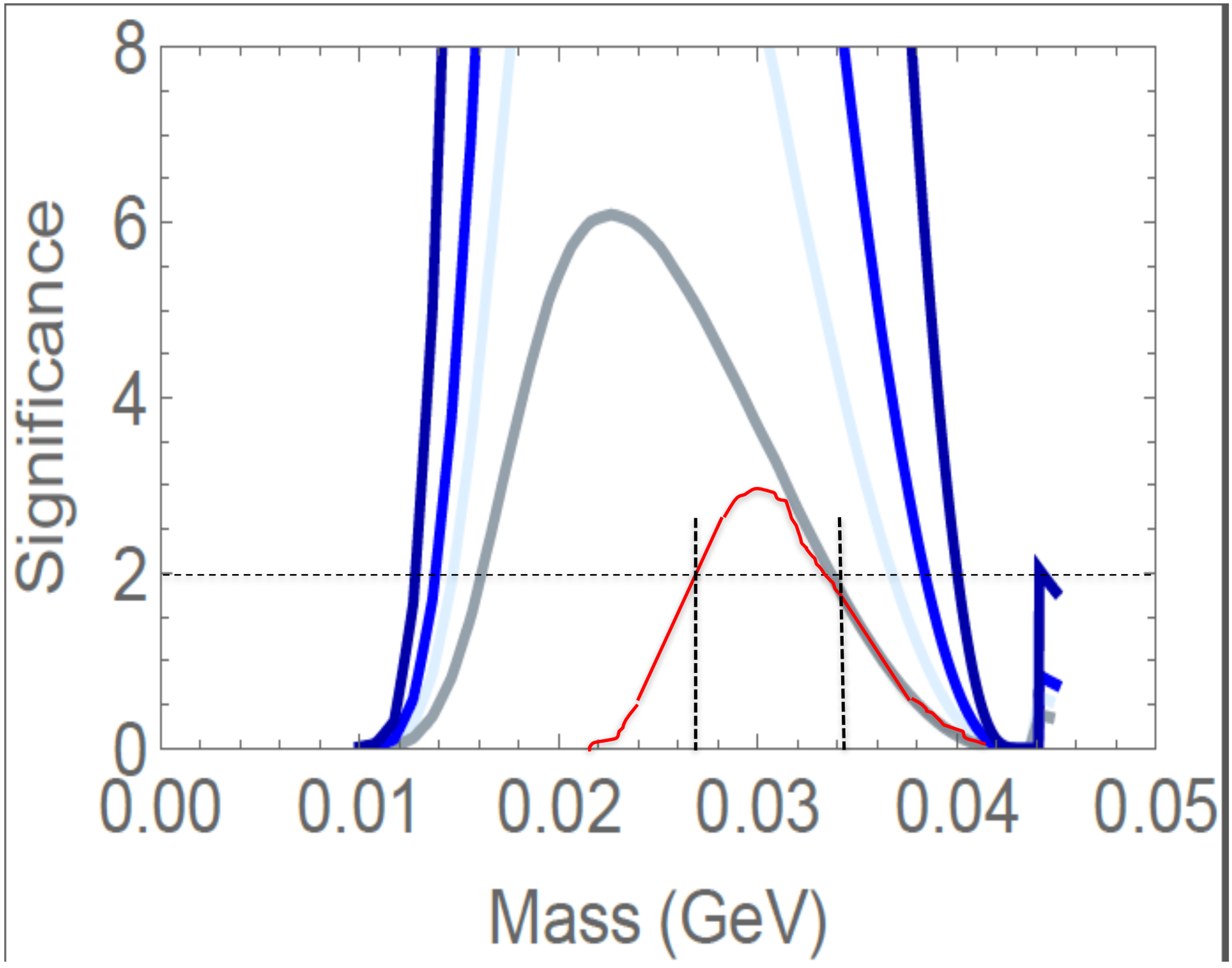
1 **PAC week**

5/7 PAC week

3/7 PAC week

Significance vs Mass (1.1 GeV; ε=3x10-9)

Plot from Matt Graham



PAC Days

3 days 15 mrad

3 days 25 mrad

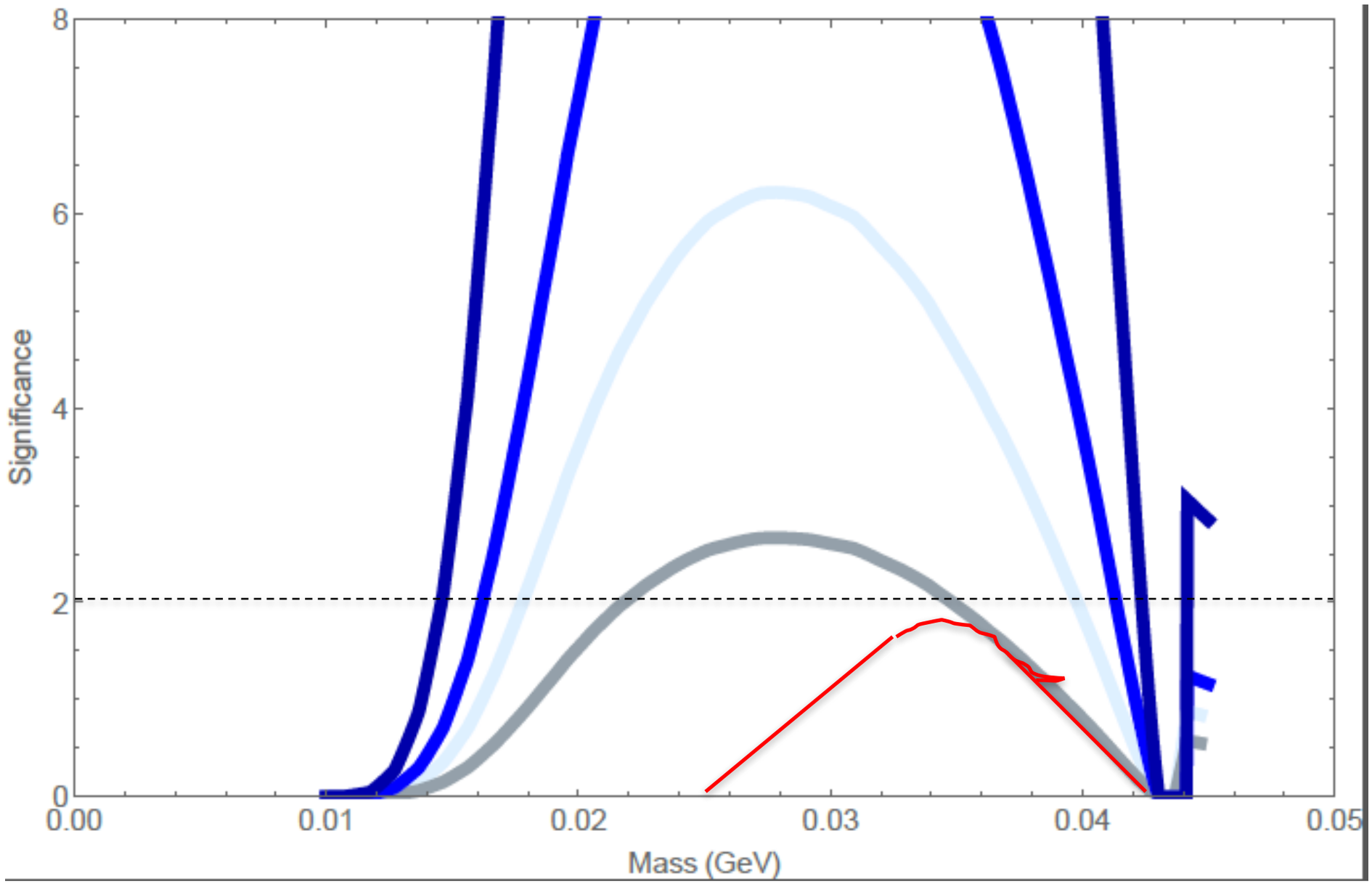
7 days 15 mrad

14 days 15 mrad

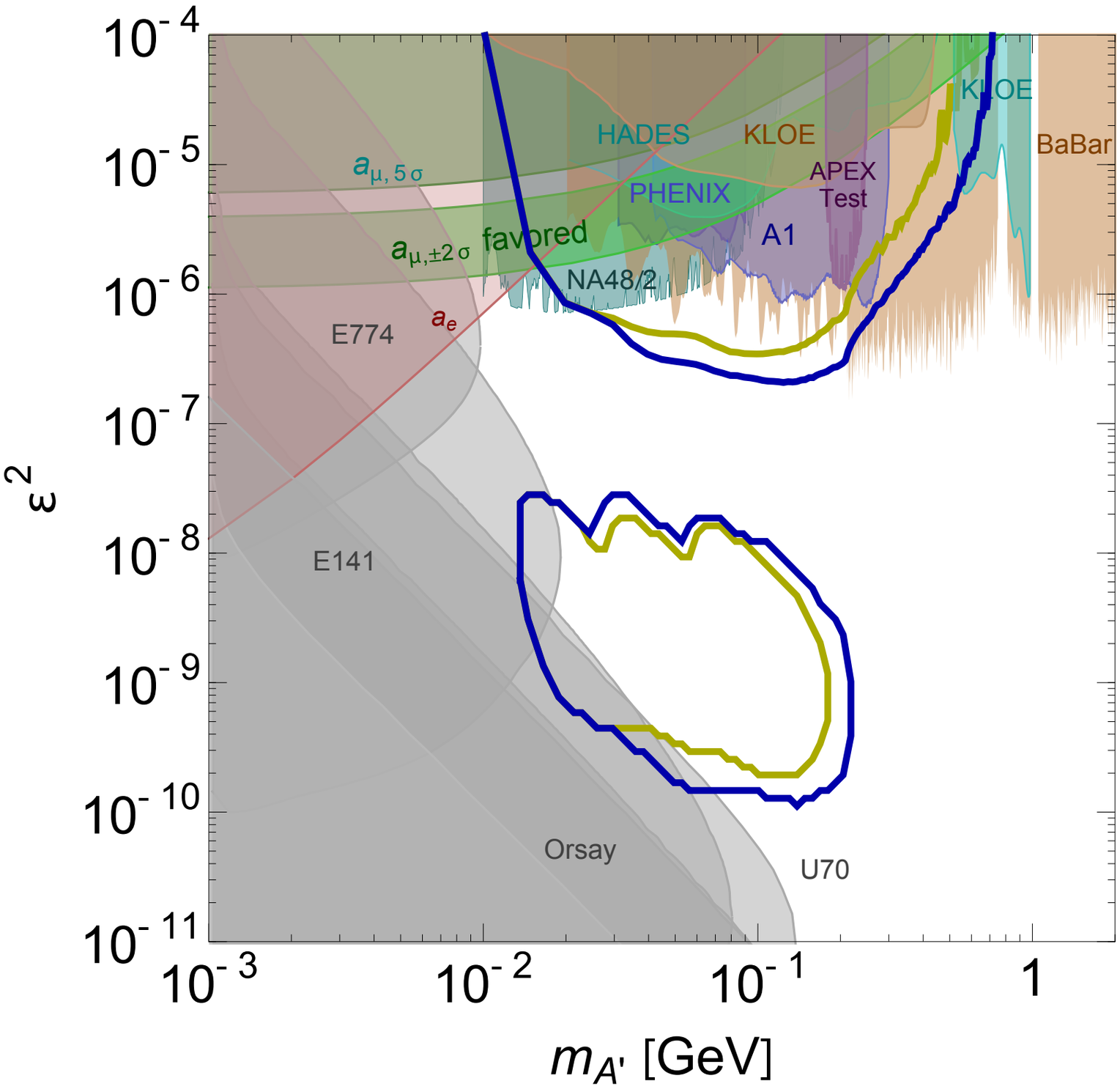
Note:
Signif ∝ Time

HPS could cover
25 – 34 MeV
in 3 PAC days

Much Worse at $\varepsilon = 10^{-9}$



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

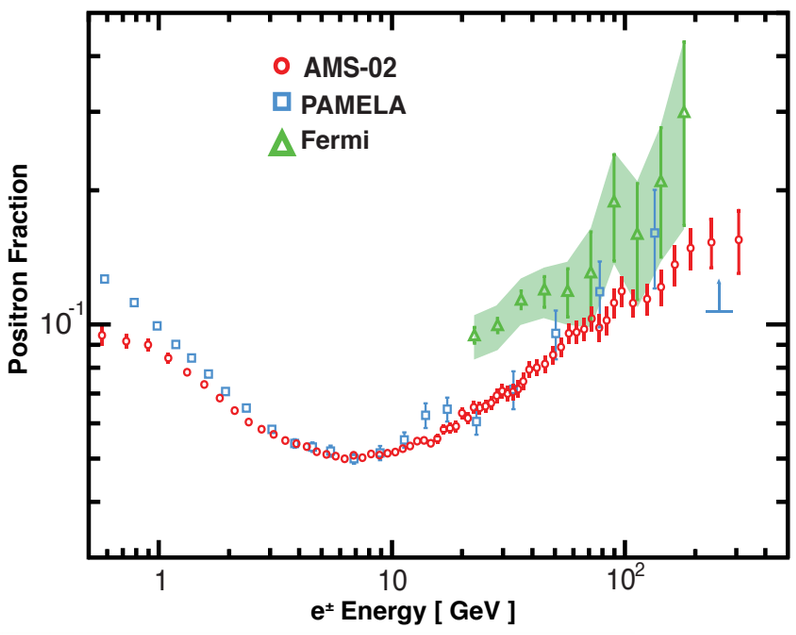
- The HPS experiment has successfully completed its first physics data taking during the 2015 "Engineering Run".
- Roughly 1/3 "PAC week" of data was gathered with the SVT at 0.5 mm from the beam. Enough data for several PhD theses.
- Initial look at the data looks very promising.
- Opportunistic running,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

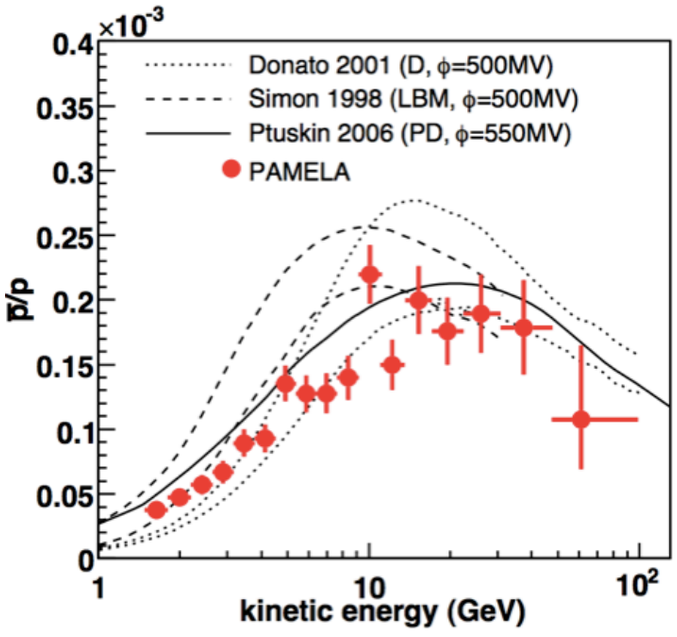
Some Extras

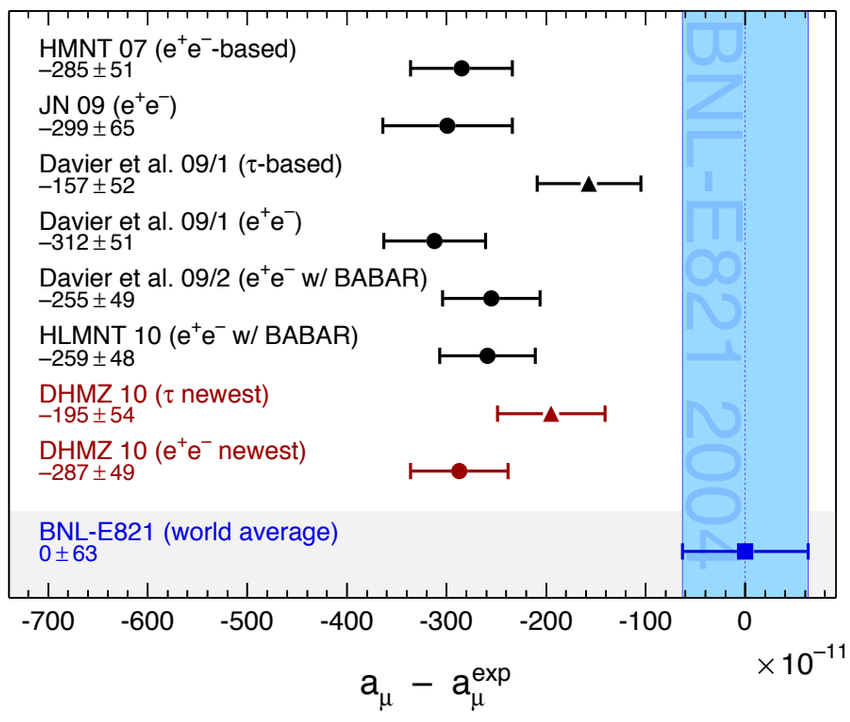
Hints from astrophysics?

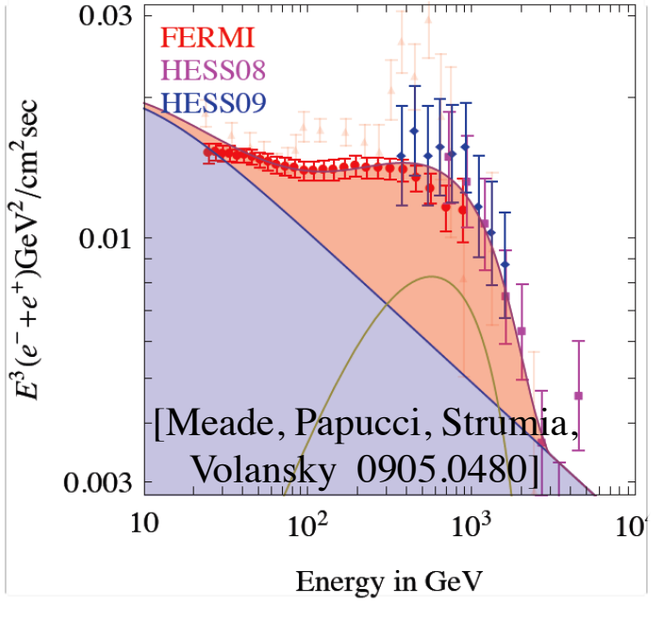
PAMELA, FERMI, AMS
Energetic e+/e- cosmic rays from DM annihilation through *A′* ?

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")

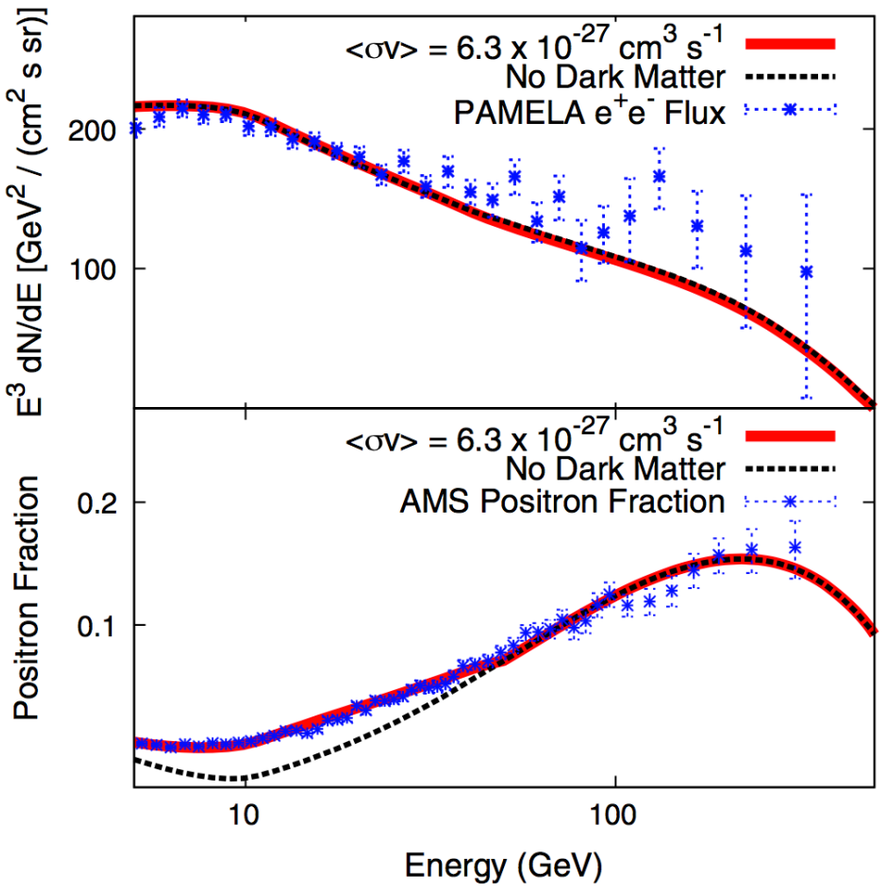


FIG. 3 (color online). The e^+e^- spectrum (top) and positron fraction (bottom) for the SIDM model, compared to observations from PAMELA and AMS-02, respectively. Note that excellent fits with no dark matter can be found by varying the diffusion and solar modulation parameters away from what has been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

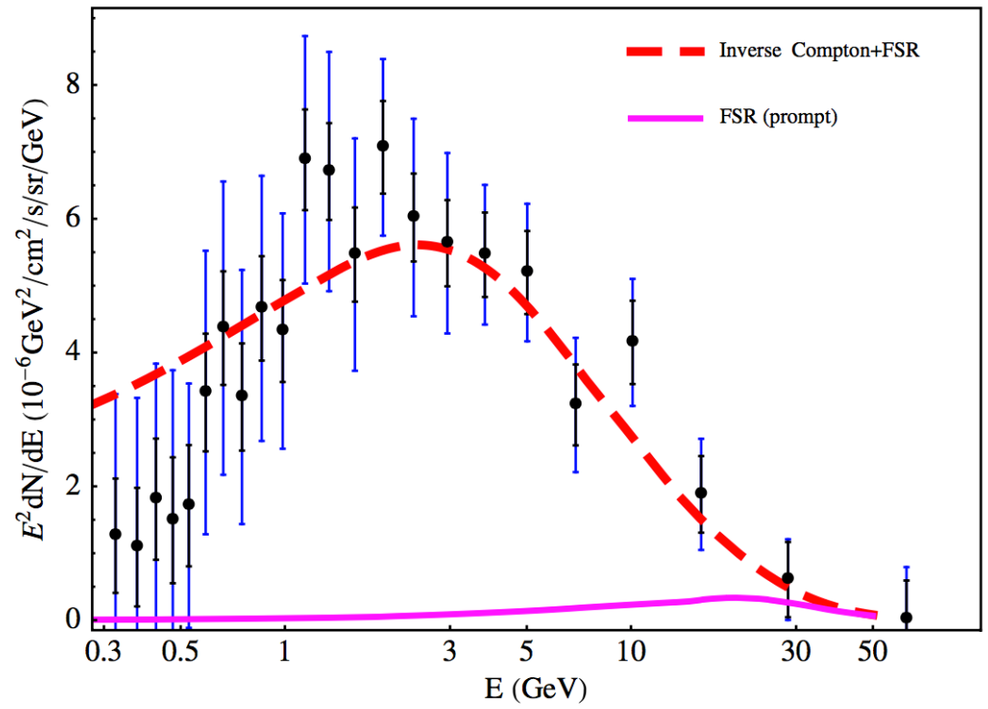


FIG. 1 (color online). γ-ray spectrum from Inverse Compton emission and final-state radiation produced by annihilation of a 50-GeV dark matter particle through a light mediator into e^+e^- final state. The spectrum is compared to the Galactic center excess [10].

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

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