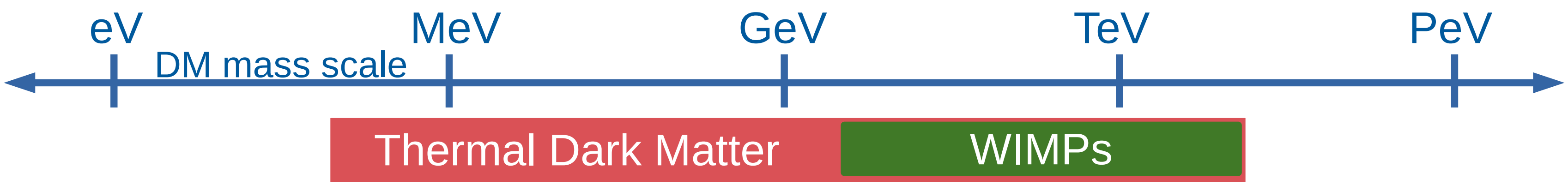
UCLA Dark Matter 2023

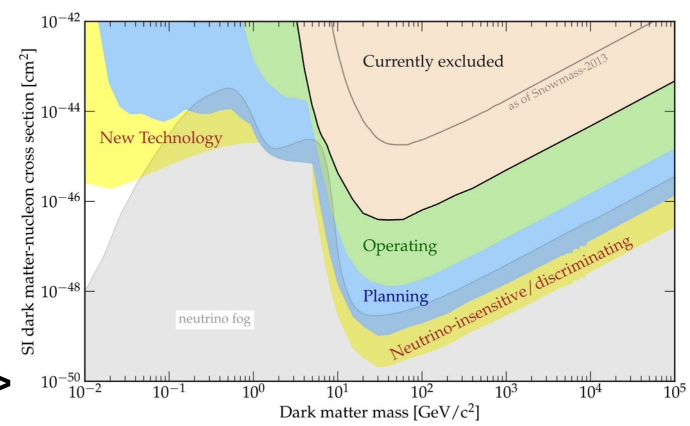
New Results from the Heavy Photon Search Experiment

Cameron Bravo (SLAC)

WIMPs Space is Getting Tight

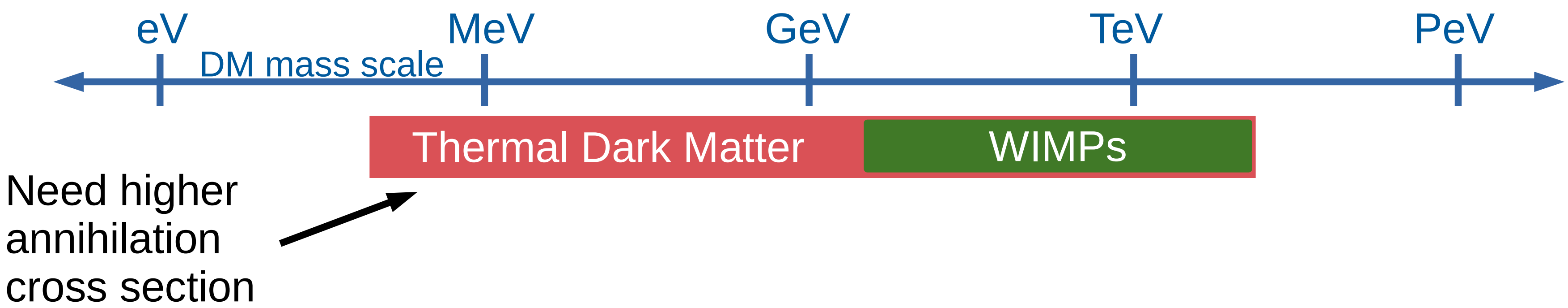


- Dark matter annihilation cross section sets scale, Weak scale mediators can give correct relic abundance in a thermal freeze-out scenario
- Available WIMP parameter space shrinking and mass can't be too low -----> too high of a relic abundance ($\sigma \sim m^2/M_Z^4$)
- Higher masses would result in relic abundance lower than observed



arxiv:2209.07426

A New Place to Look: Dark Sectors

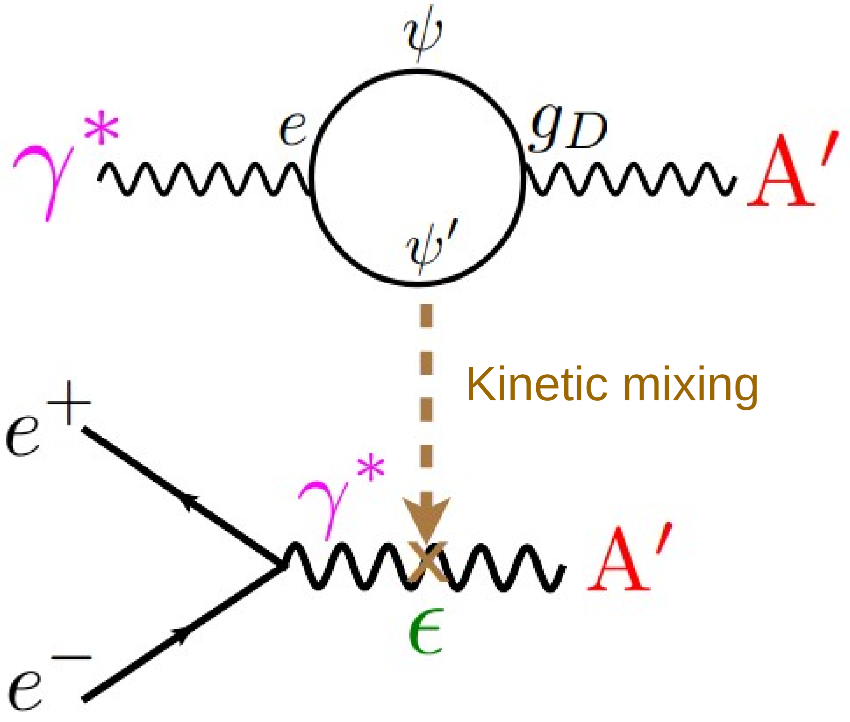


- Weak interactions can't give high enough annihilation cross sections below ~ 2 GeV (Lee-Weinberg bound)
- Introducing a Dark Sector with a new gauge boson will result in relatively larger annihilation cross section
  - Coupling to SM becomes a level deeper (need a loop)
  - Relatively low mass makes production a viable option

A Minimal Dark Sector

SLAC

- Simplest case is a new U(1)'
  - New "photon" called A' or dark photon or heavy photon
  - Can have non-zero mass
- Kinetic mixing to SM photon
  - Tiny coupling to SM
  - Annihilation cross section of DM is increased in early universe ($\sigma \sim m^2/M_{A'}^4$)
- A dark sector with standard model scale masses is a natural expectation



Mass Hierarchy Determines Search Strategy

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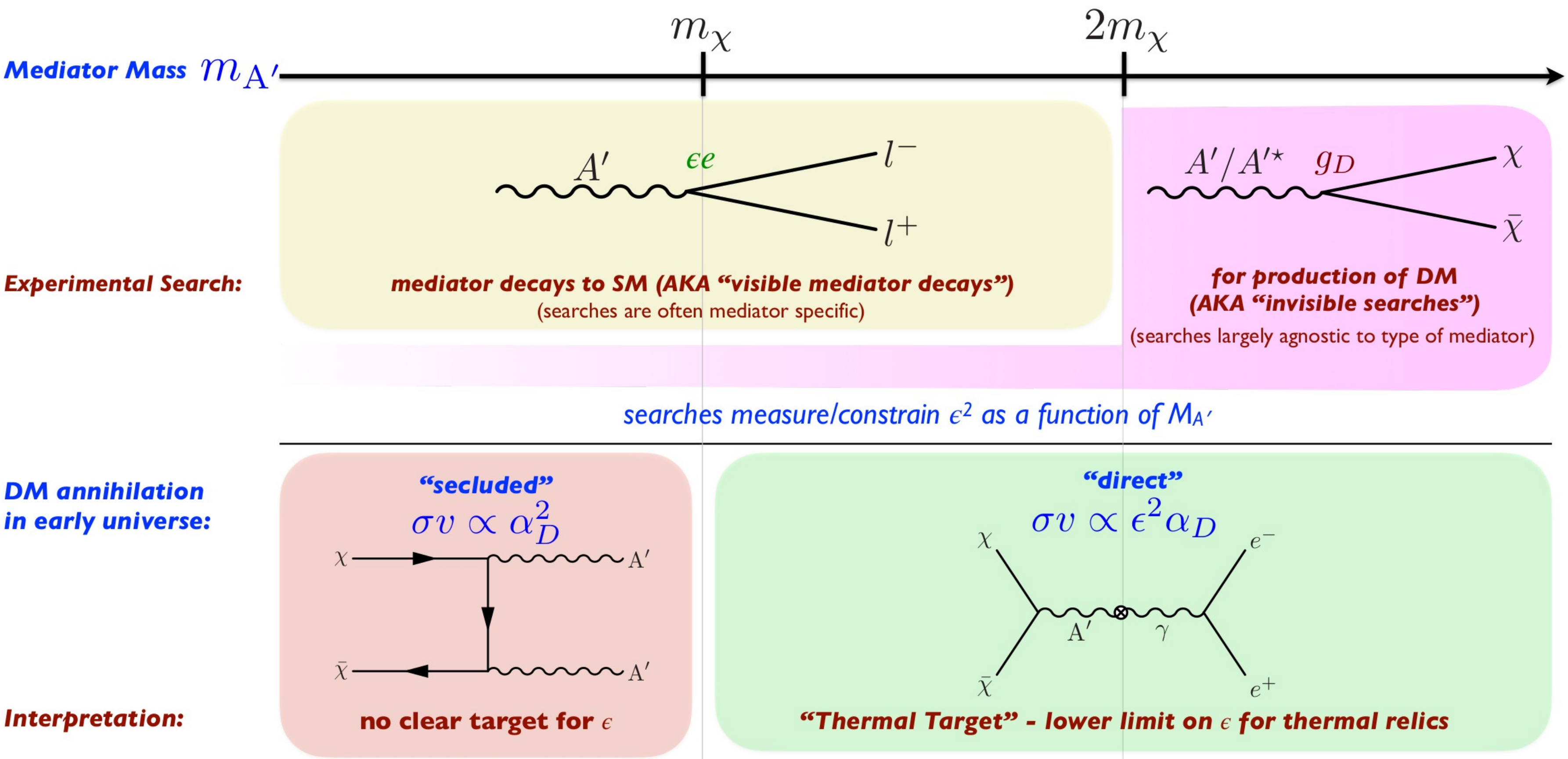
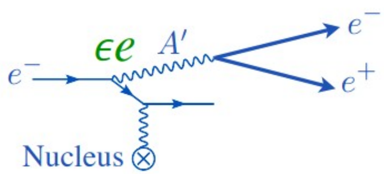


Hunting for a “Visible” Dark Sector

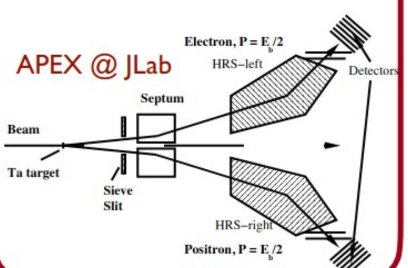
Where there are photons, there are dark photons!

e^- fixed target

$N \propto \epsilon^2$

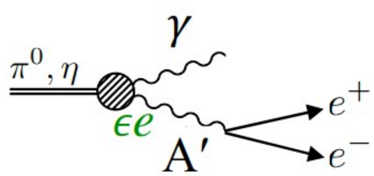


dark bremsstrahlung

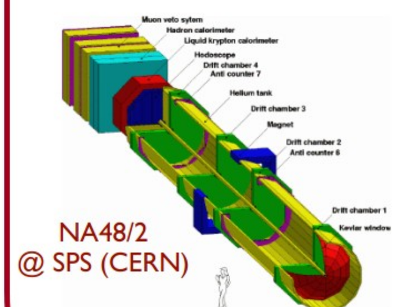


p fixed target

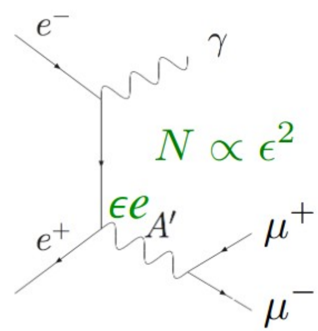
$N \propto \epsilon^2$



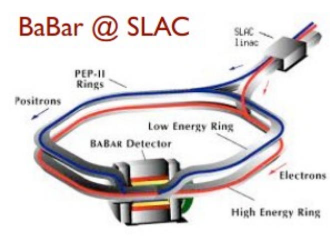
meson decays



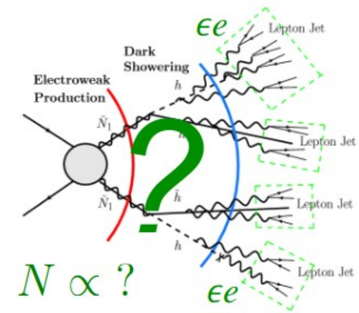
e^+e^- colliders



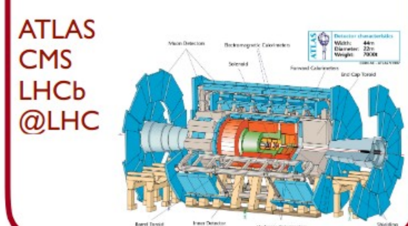
+ meson decays



pp collider



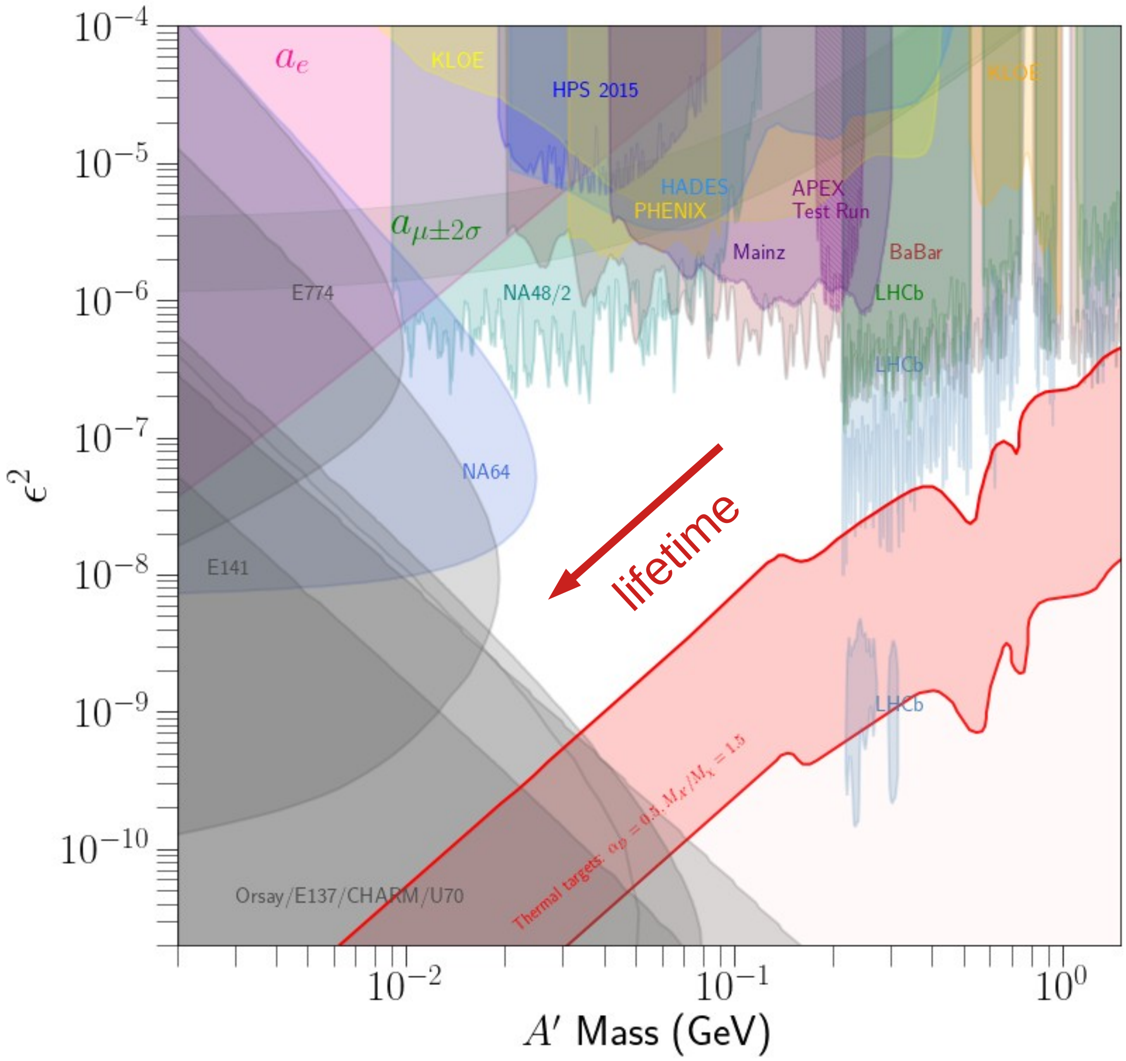
“lepton jets”
+ meson decays



Different production mechanisms sensitive to different mass-coupling ranges

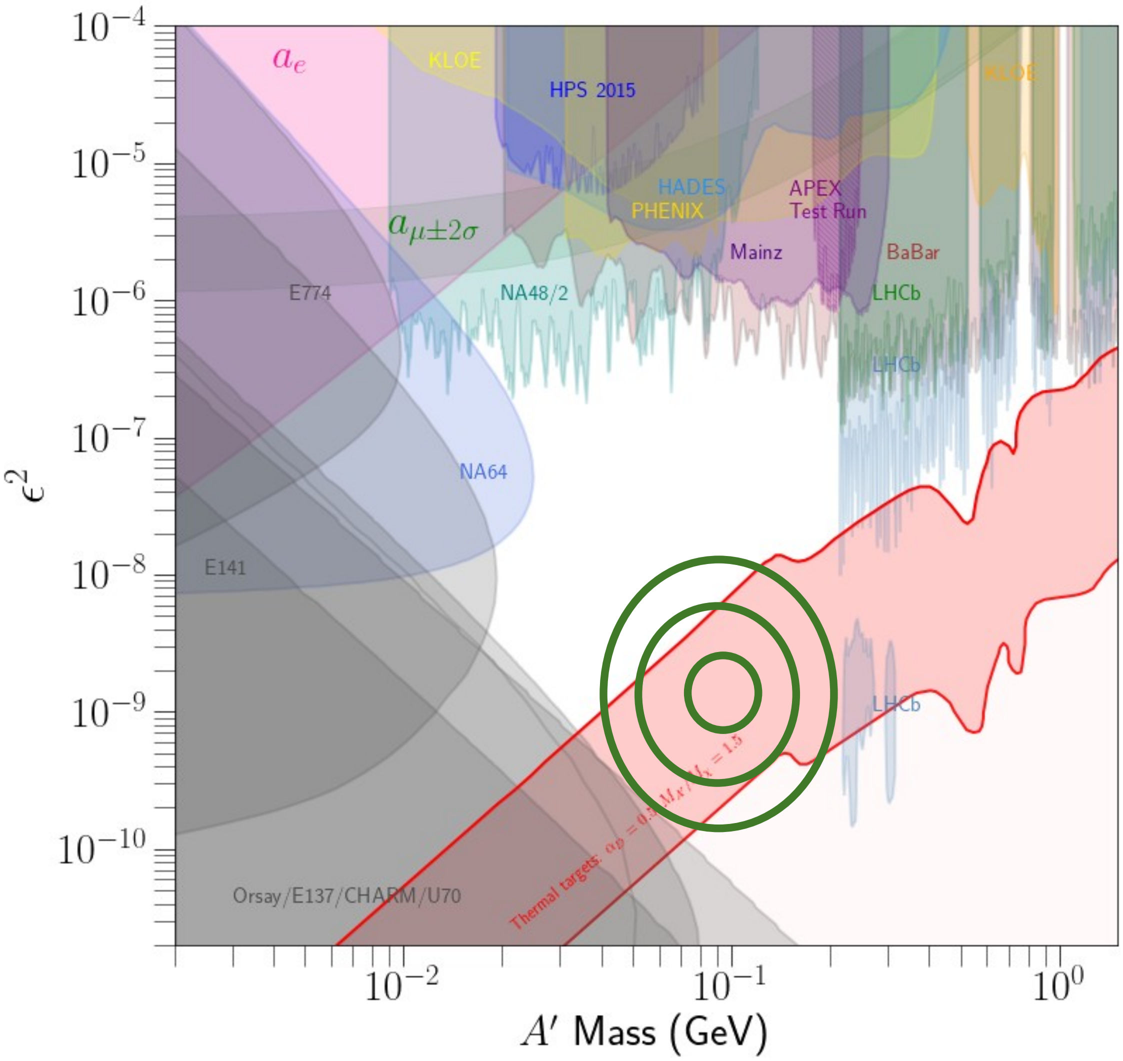
Searching for Visibly Decaying Dark Photons

- Current constraints are still missing for longer lived dark photons decaying to e^+e^-
- Red "band" shows the thermal targets
  - $m_\chi < m_{A'} < 2m_\chi$
- HPS is designed to be sensitive to "shorter" long lived thermal targets



Searching for Visibly Decaying Dark Photons

- Large region of untested thermal targets
  - Decay lengths in this region for a few GeV of kinetic energy are ~ mm-cm
  - Small mixing parameter means huge number of electrons on target required

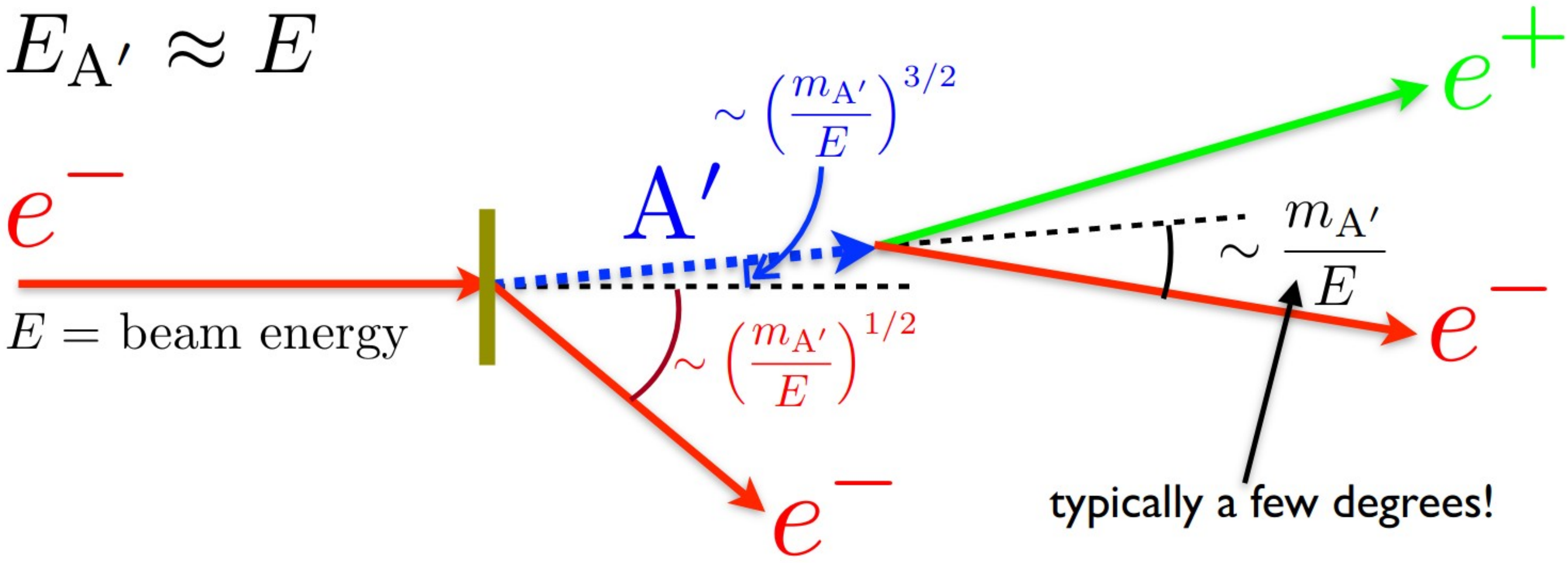


Dark Bremsstrahlung

- Short decay lengths, small angles of deflection from beam, and large number of electrons on target makes thermal target "band" a challenging region to test

$$\text{rate} \propto \frac{Z^2 \epsilon^2}{m_{A'}^2}$$

$$E_{A'} \approx E$$



The HPS Collaboration

- HPS is a small diverse collaboration
- ECAL made possible via major contributions from France and Italy

SLAC (15)
JLab (12)
ODU (1)
UNH (3)
UCSC (3)
Stanford (4)
Stony Brook (1)

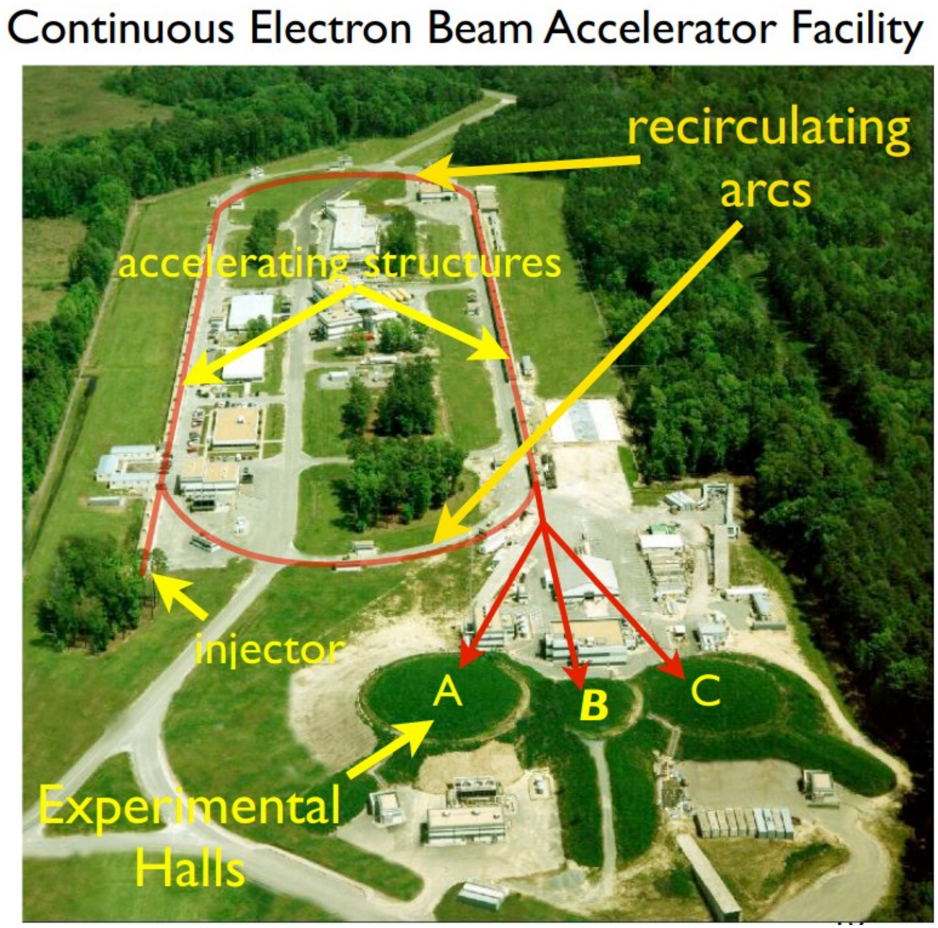
INFN Catania (2)
INFN Genova (4)
INFN Rome (1)
INFN Sassari (3)
INFN Torino (1)
INFN Padova (1)

Orsay (6)

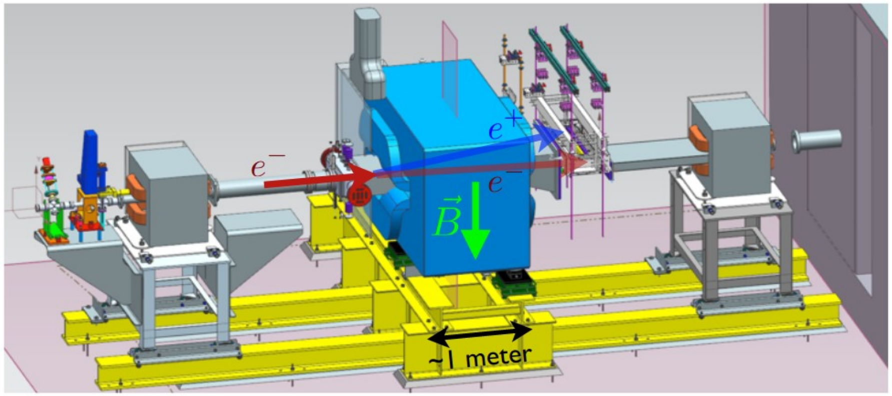
Yerevan (3)

Glasgow (1)

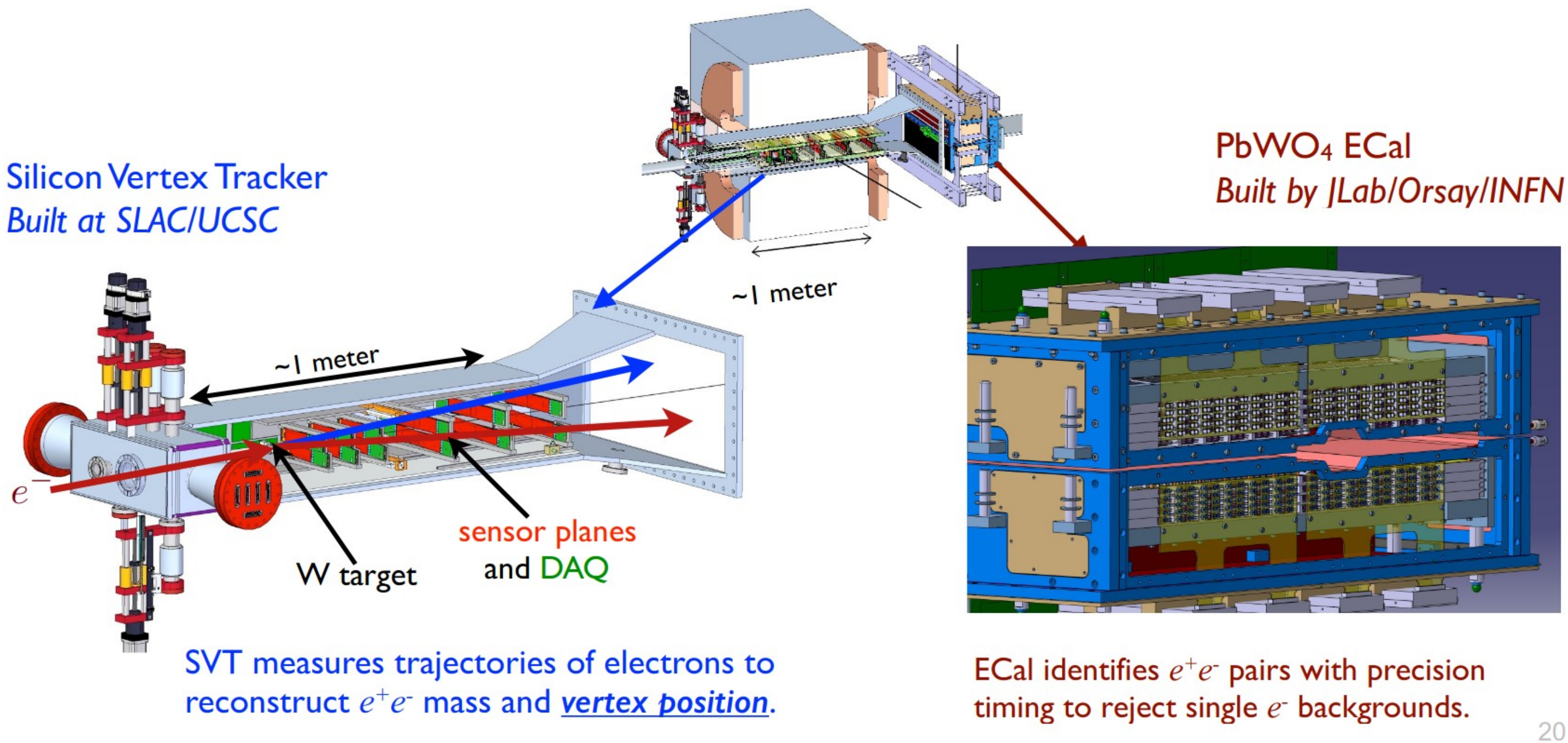
The HPS Experiment at JLab



- Search for visible dark photon final states using ~ 10^{19} electrons, energies 1-6 GeV, on a thin W foil
- Dipole enables momentum measurement of e^+e^-
- Trigger on e^+e^- pair



The HPS Detector

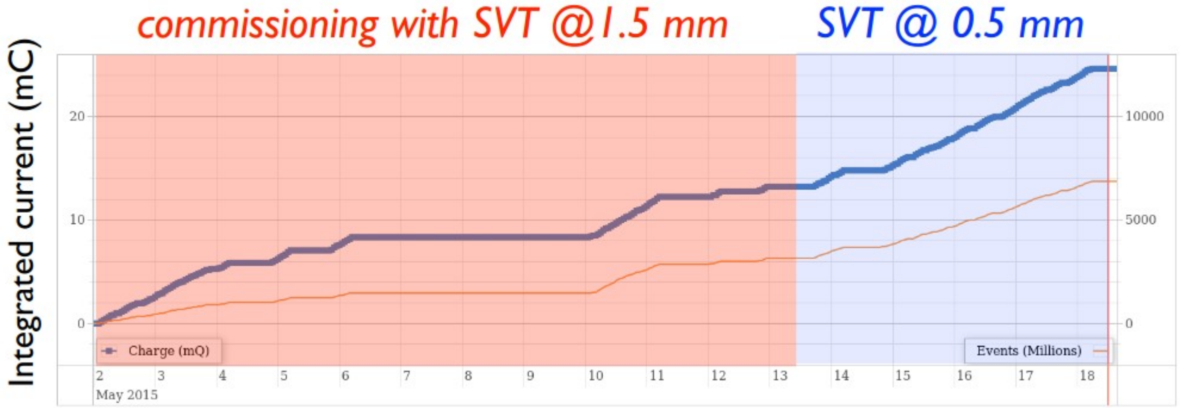


HPS Engineering Runs

2015 Engineering Run

50 nA @ 1.06 GeV

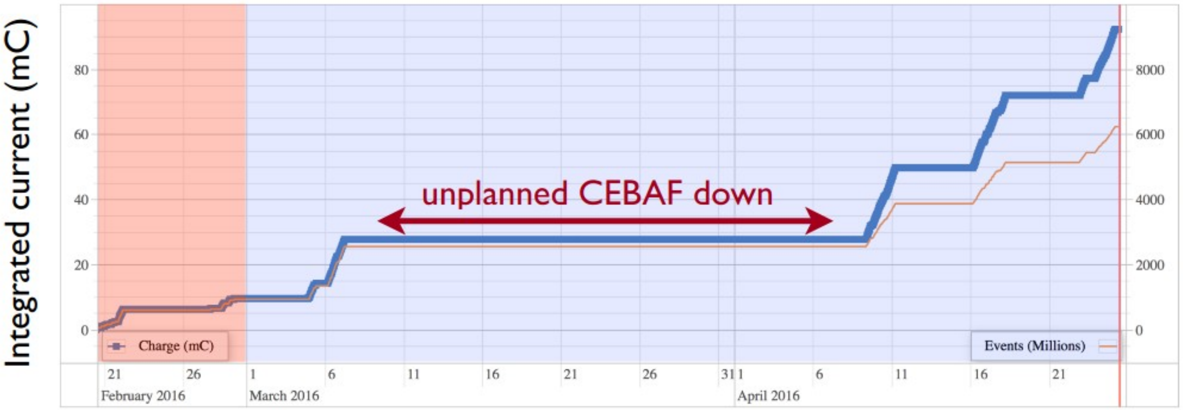
1.7 days (10 mC) of physics data



2016 Engineering Run

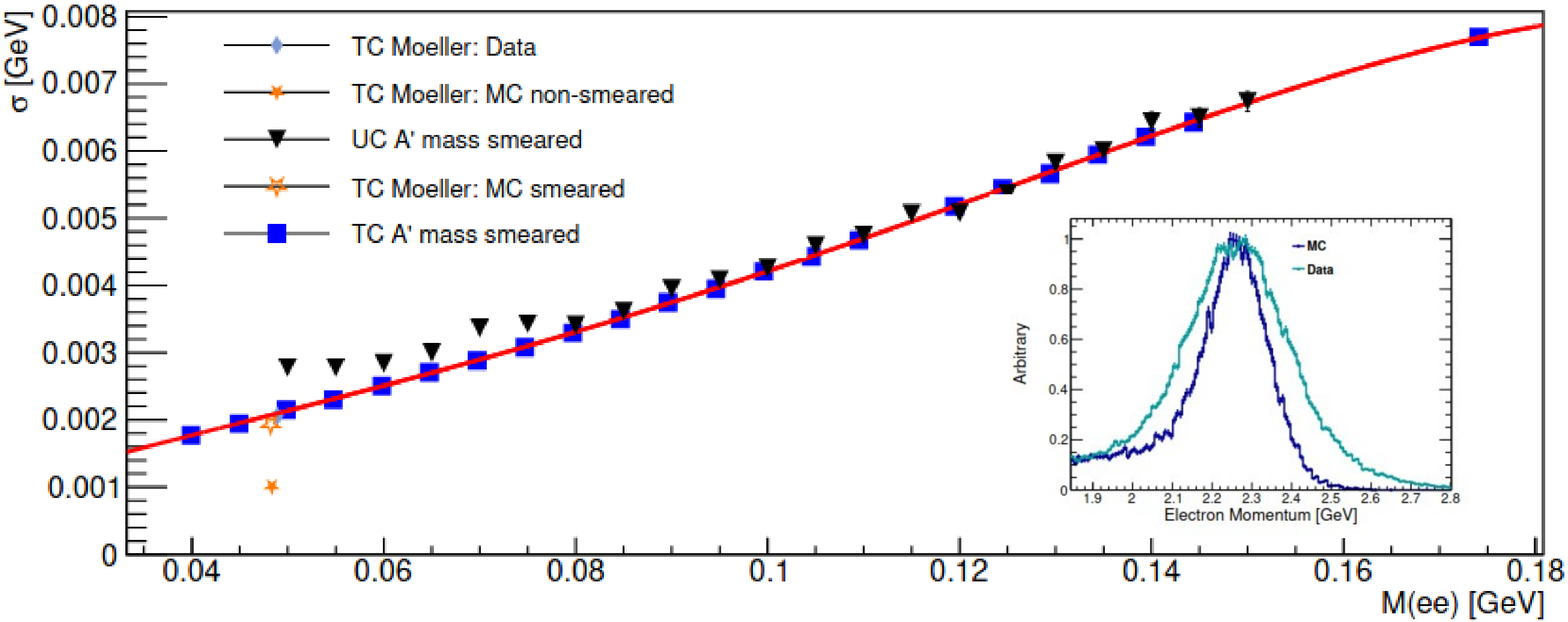
200 nA @ 2.3 GeV

5.4 days (92.5 mC) of physics data



HPS 2016 Mass Resolution

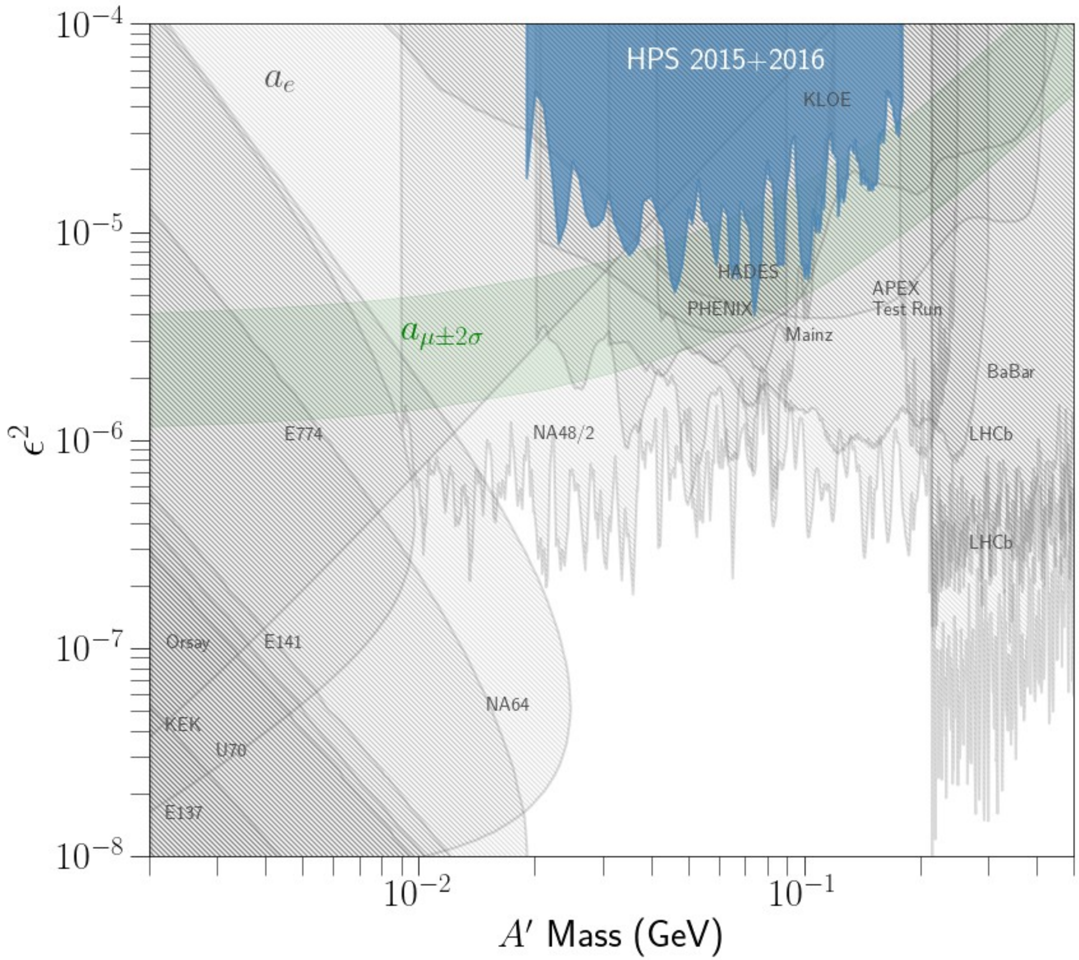
SLAC



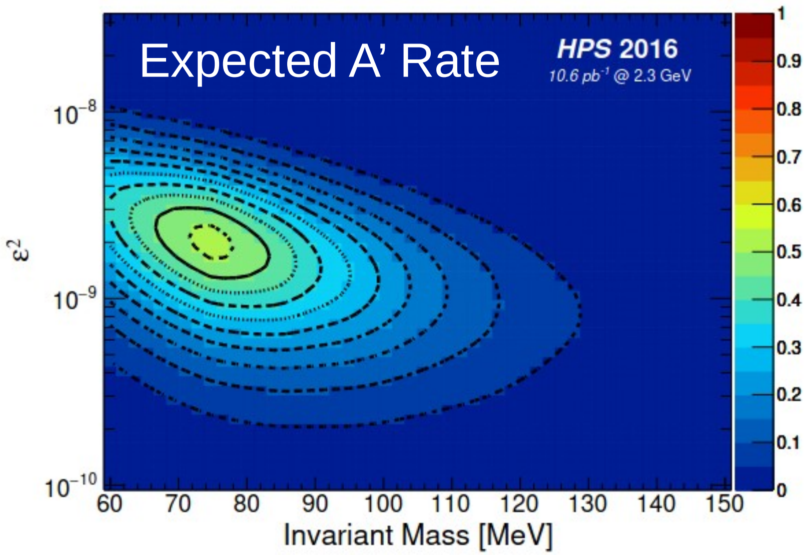
- Smearing MC momenta by ratio of resolution in data over MC
  - Møller scattering used as crosscheck that MC mass resolution is in agreement with data after momentum smearing

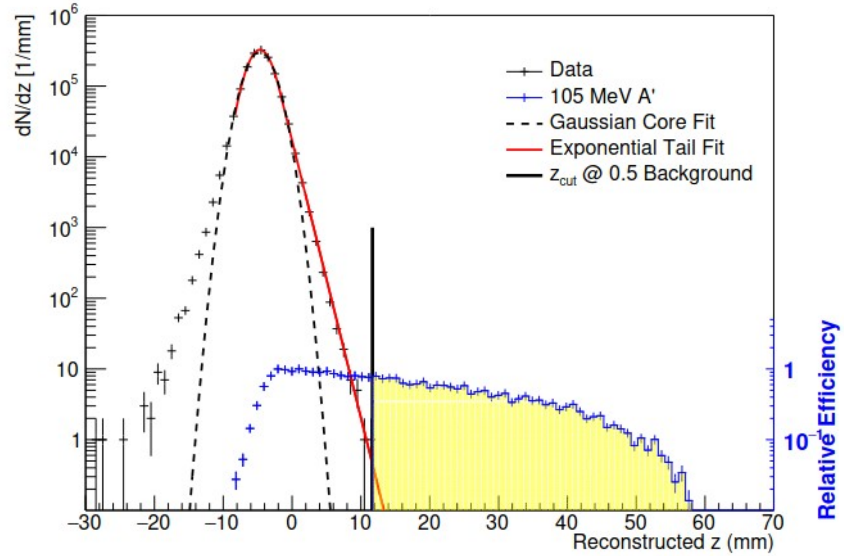
Bump Hunt Results from Engineering Runs

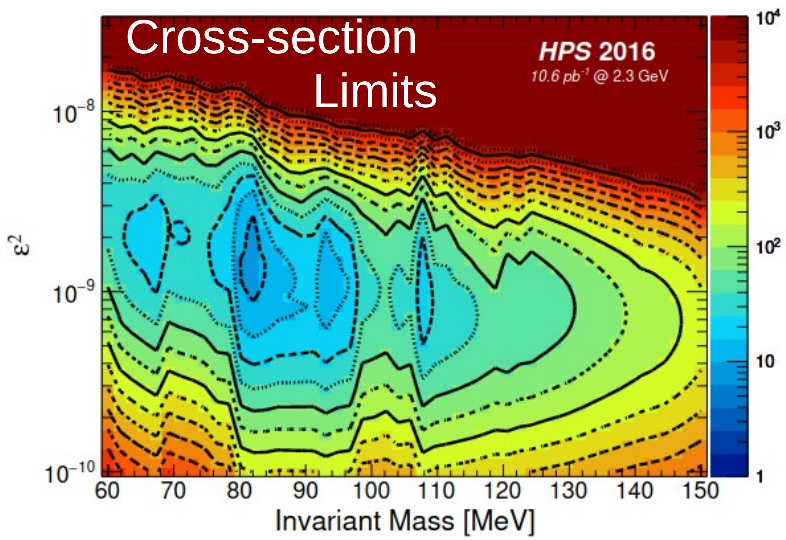
- New bump hunt statistical procedure developed with respect to first paper on 2015 engineering data alone
  - Now using 95% CL_s limit
- Looking into new ideas to improve sensitivity of this analysis
- Paper recently submitted to PRD
  - arxiv:2212.10629



HPS 2016 Displaced Vertex

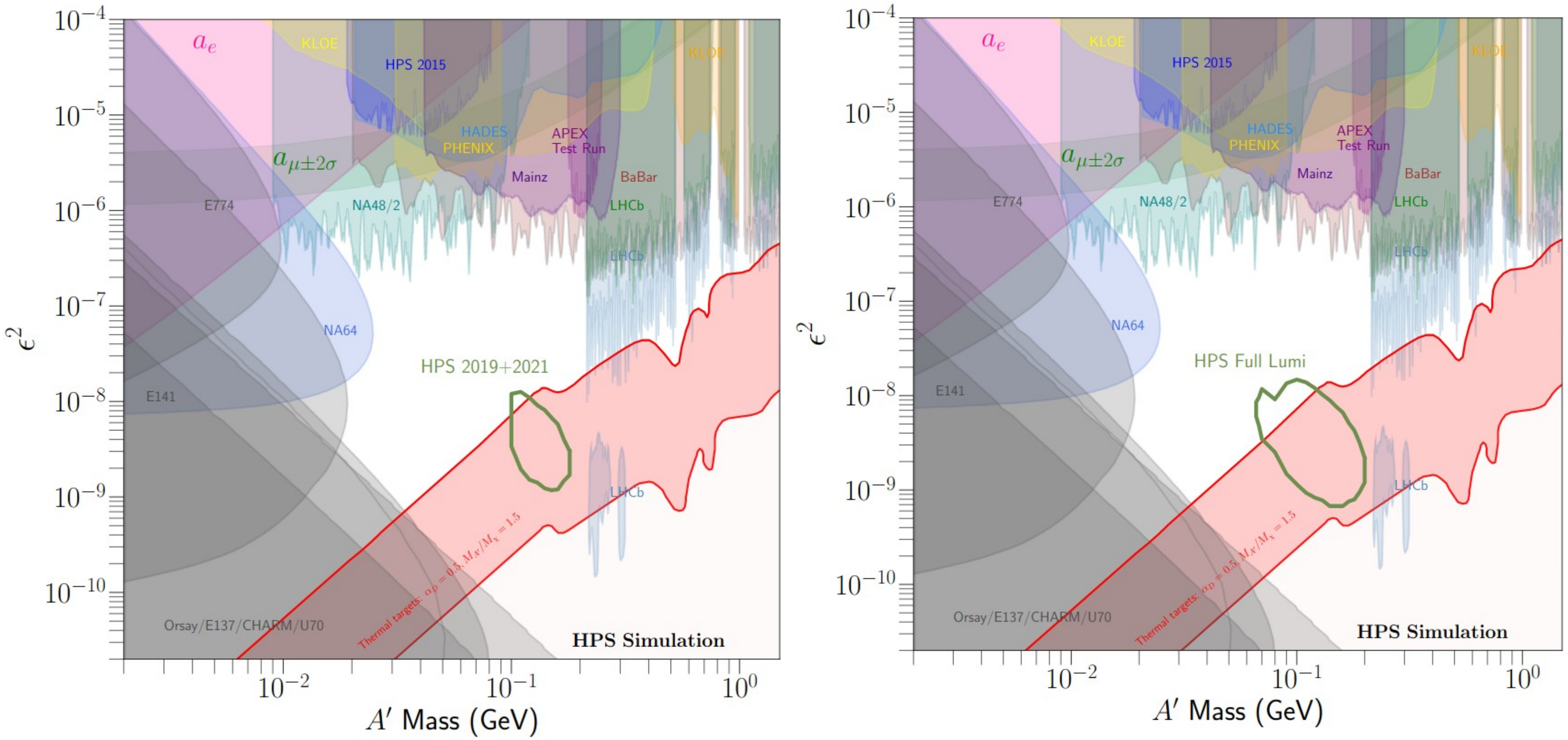






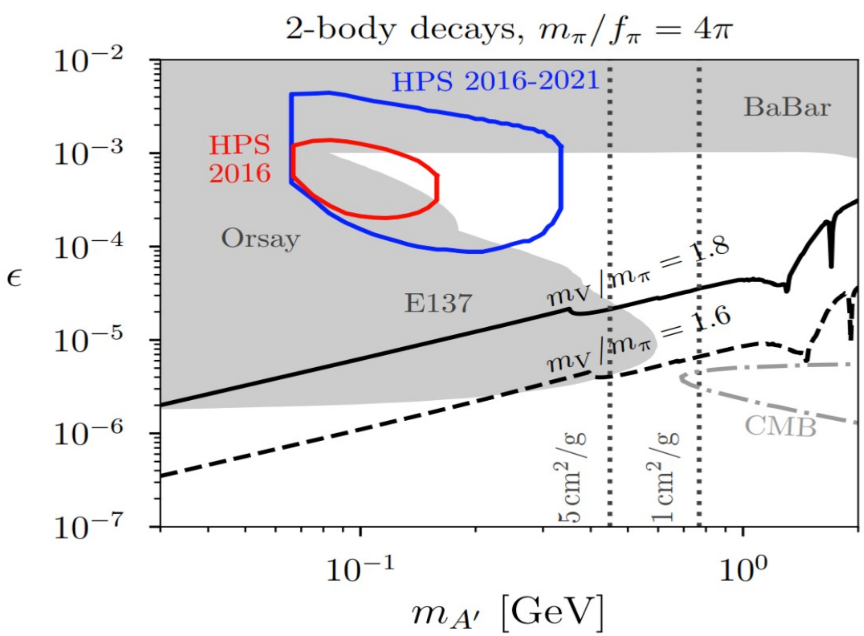
- No sensitivity to canonical A' yet, however sensitive to unique phase space
- Cross-section limits are relative to canonical A' model
  - Smallest relative cross-section limit is 7.9 times higher than canonical model

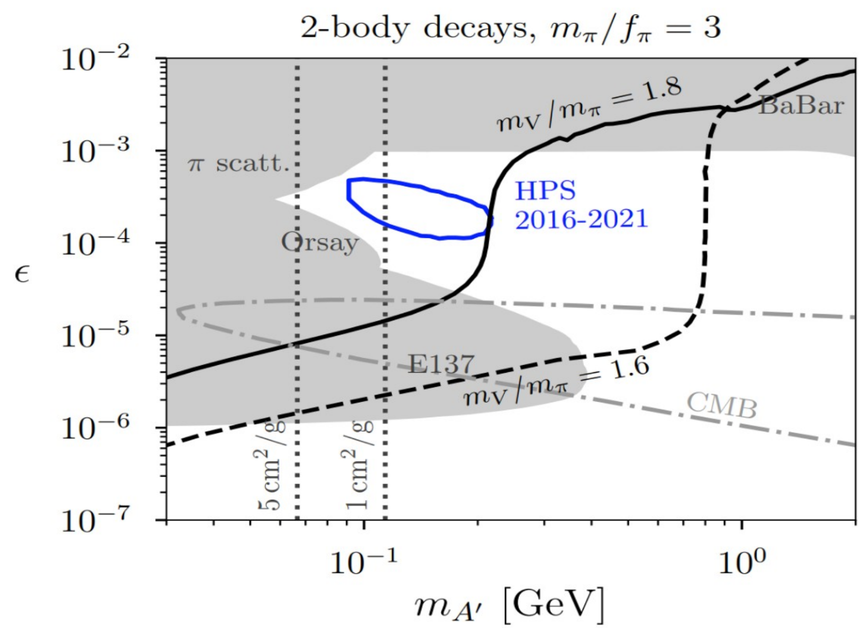
HPS Reach Estimates



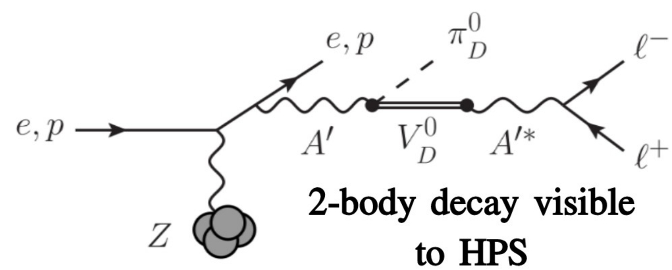
- New reach estimates using full detector Geant4 simulation and taking into account lessons learned while analyzing engineering run data
- Full Luminosity beam time is already granted to HPS by JLab PAC
- The Dark Sector details can make things more complicated though...

HPS SIMP Reach Estimates





- Dark Sector could also have an SU(3) gauge symmetry
  - A' might not directly decay to SM leptons
- Analysis team will start looking at 10% data sample soon



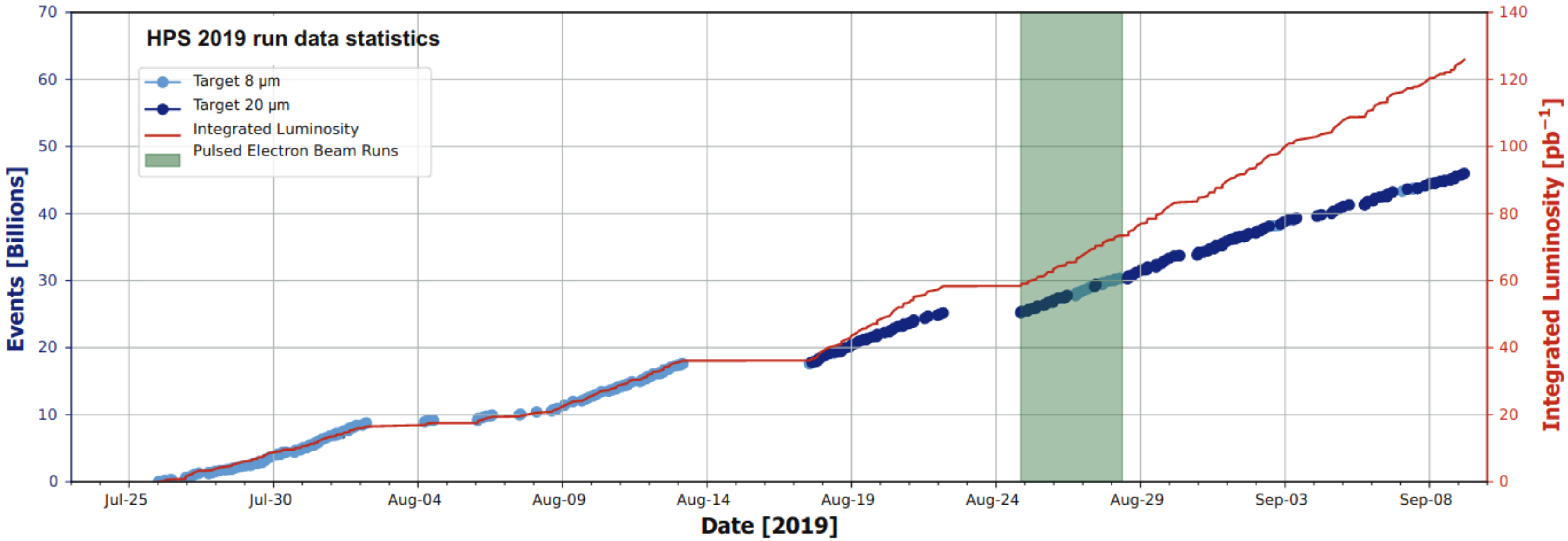
Thank You!

- Getting close to publishing HPS engineering run results for A'
- Upgraded HPS Si Vertex Tracker before 2019 run
- HPS physics data taken recently with reach estimates showing sensitivity to visibly decaying A' thermal targets
- Starting to study models beyond canonical A'

- Thank you for your attention, questions?

Thank You!

HPS 2019 Physics Run



- Ran HPS with 4.55 GeV electron beam in 2019
- Overcame several operational challenges along the way
  - Ungrounded target sparking and crashing DAQ
  - Power outage caused magnet to quench and move SVT
- Focusing on calibration of this data and moving on to the physics analysis

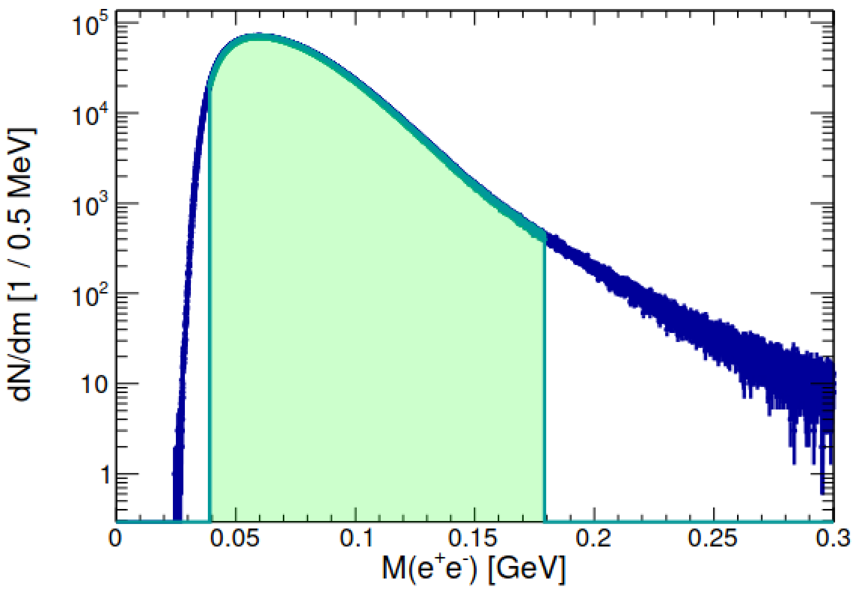
HPS Run 2021

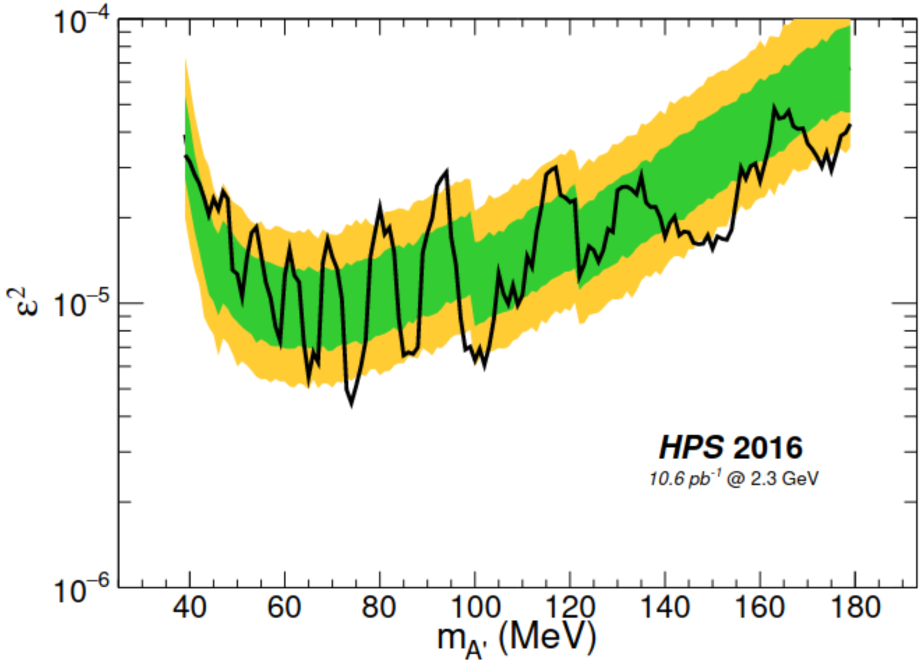
Beam Energy = 3.74 GeV

- Collected 84% of luminosity we had hoped to get
- Biggest data set collected by HPS so far!
- Mostly focused on alignment of tracker at this point

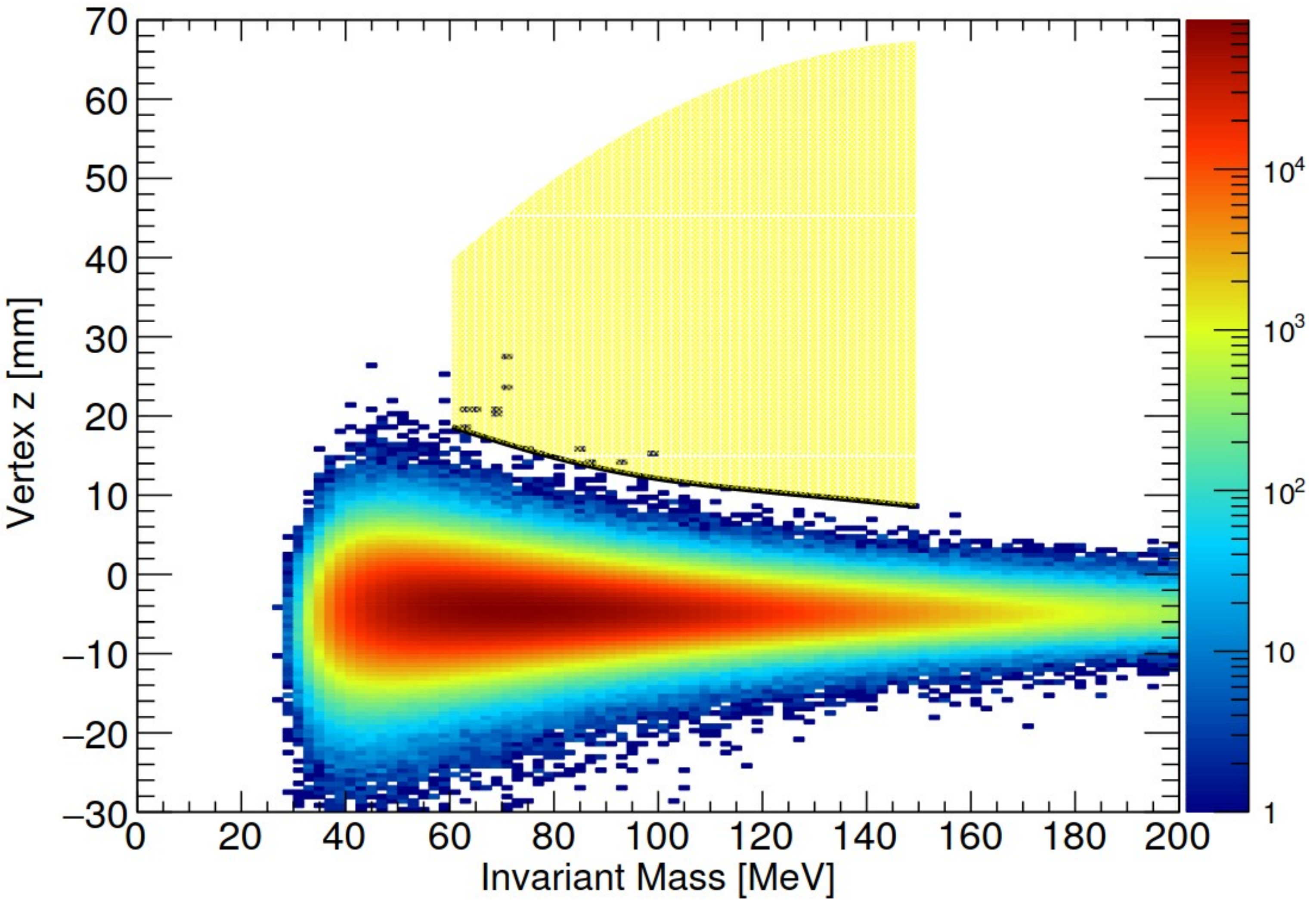
HPS 2016 Bumphunt

$$\left.\frac{d\sigma_{A'}}{dm}\right|_{m=m_{A'}} = \frac{3\pi m_{A'}\epsilon^2}{2N_{\text{eff}}\alpha}\left.\frac{d\sigma_{\gamma^*}}{dm}\right|_{m=m_{A'}}$$





HPS 2016 Displaced Vertex (L1L1)



HPS 2016 Displaced Vertex (L1L2)