The A′ Experiment (APEX)

Searching for New Gauge Bosons in the A' Experiment at Jefferson Laboratory

Philip Schuster (Perimeter Institute)

for the APEX Collaboration

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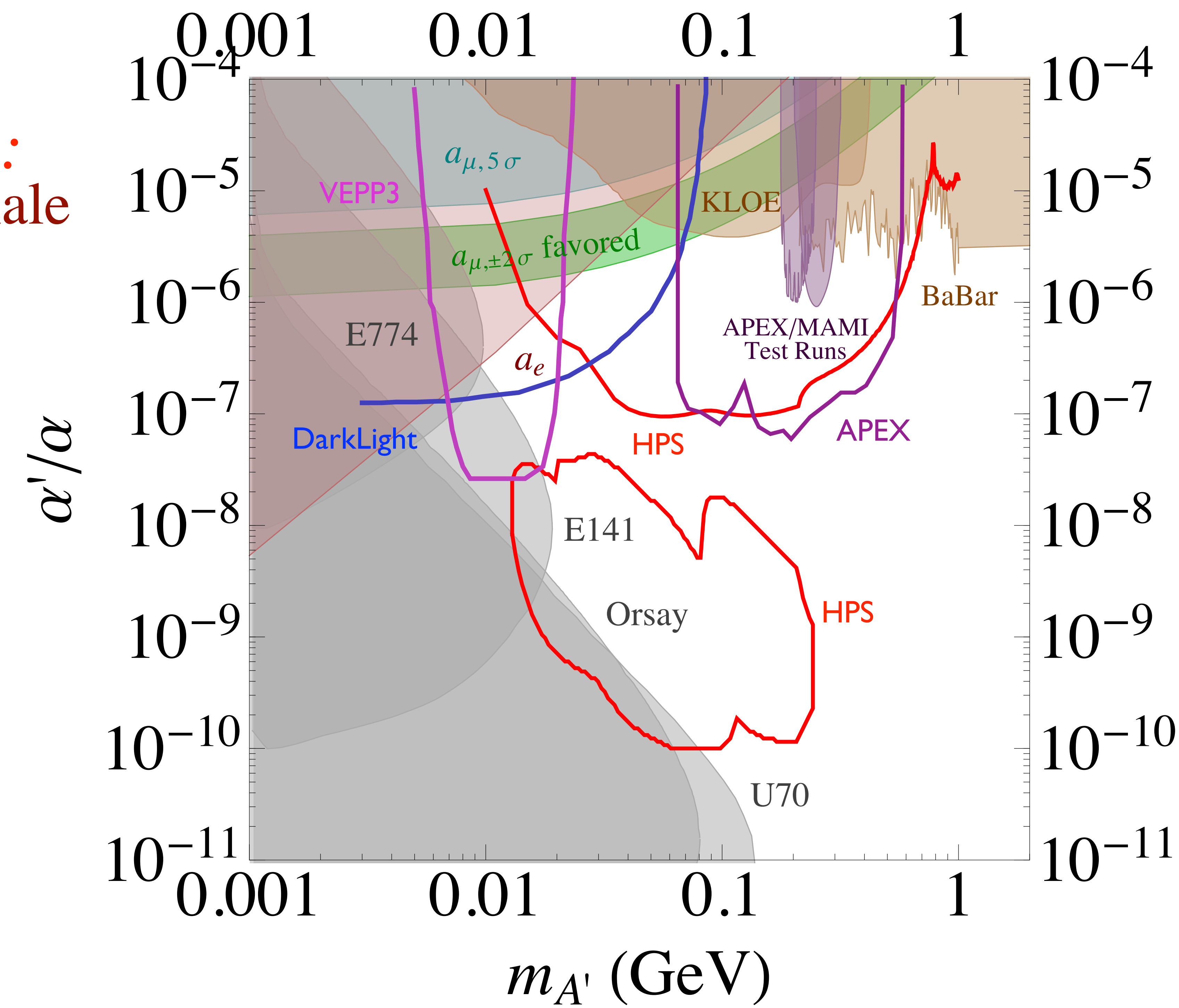
In brief: *APEX is a spectrometer-based search, at JLab Hall A, for 50-500 MeV hidden-sector photons decaying* ***promptly*** *to e^+e^-.*

1) The APEX experiment:
general setup and rationale
a few important details
JHEP 1102:009,2011, arxiv:1001.2557

2) Test run (July 2010)
results
PRL 107:191804,2011, arxiv:1108.2750

3) Full APEX
extended target and improvements to mass resolution

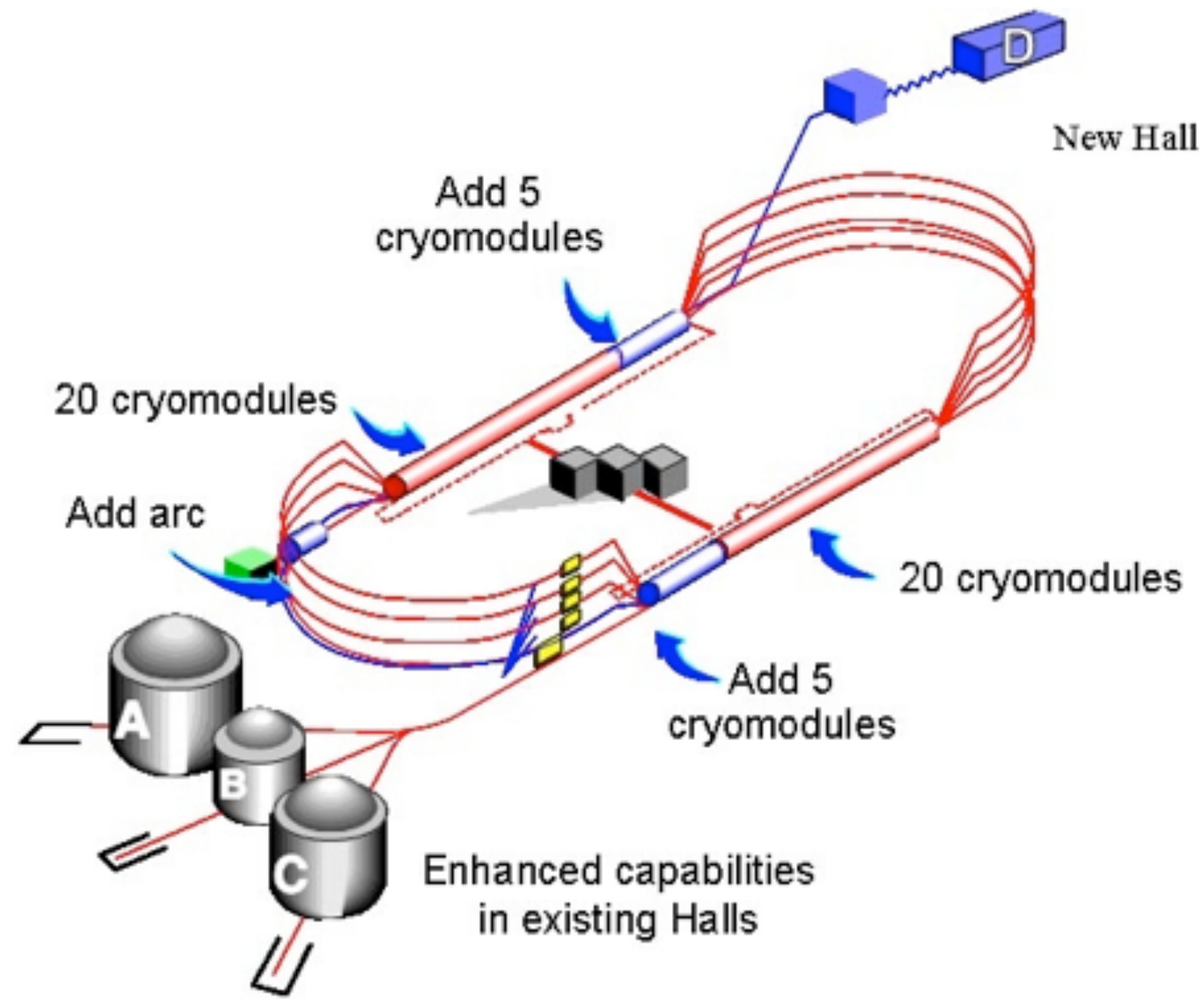


Continuous Electron Beam Accelerator Facility

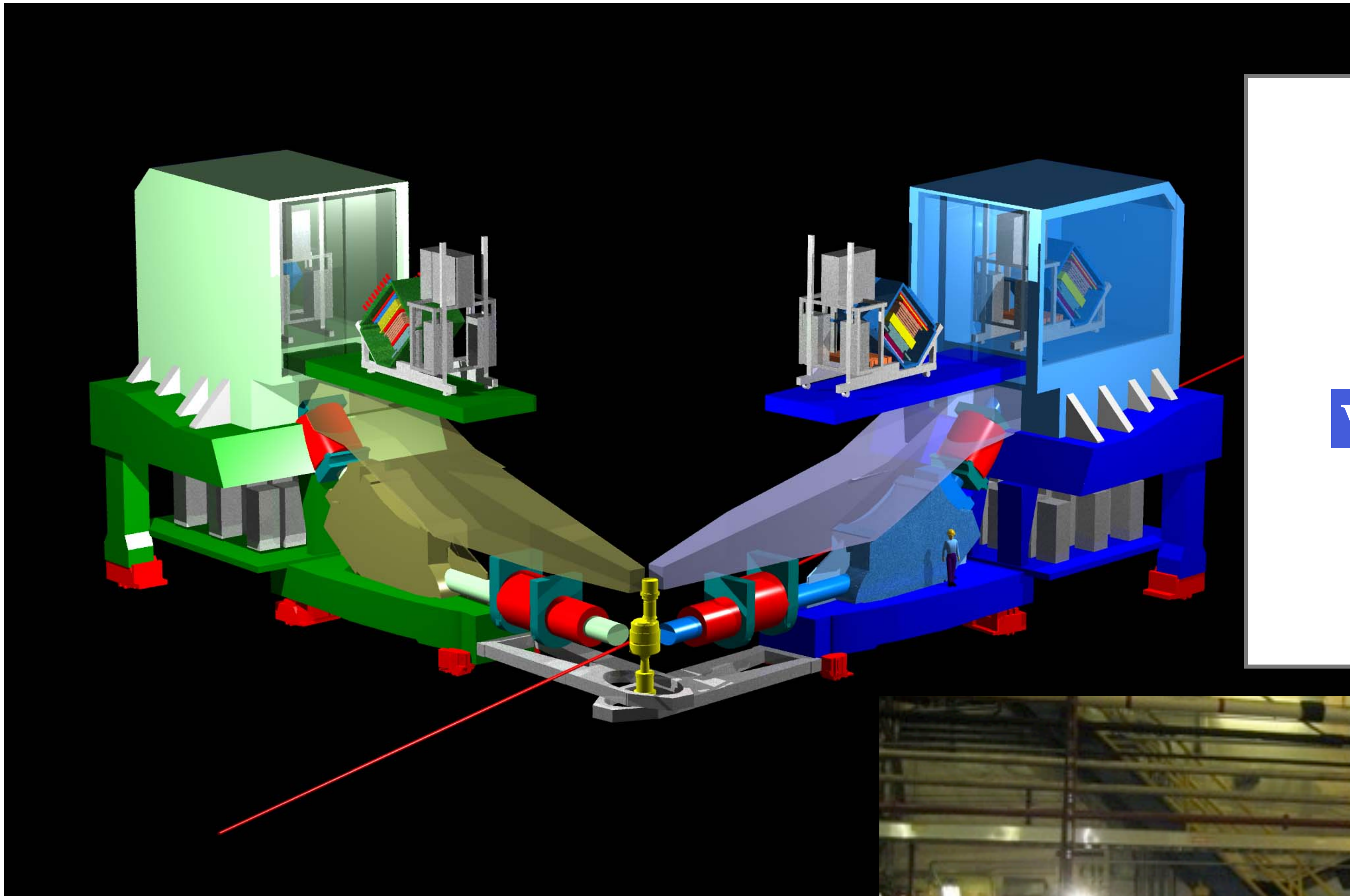
- Delivers beam up to 6 GeV to 3 experimental halls

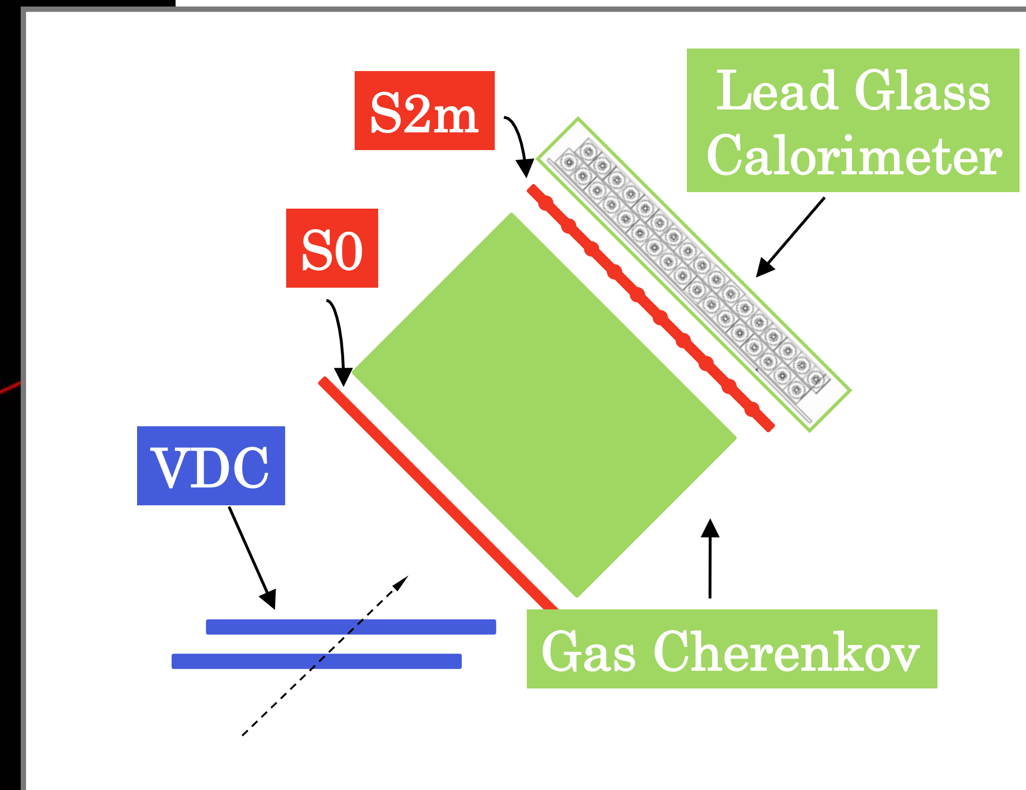
Halls A,C up to 100 μA
Hall B: 1 μA

- 1.5 GHz RF ⇒ each hall gets bunch every 2ns
- 12 GeV upgrade by 2014

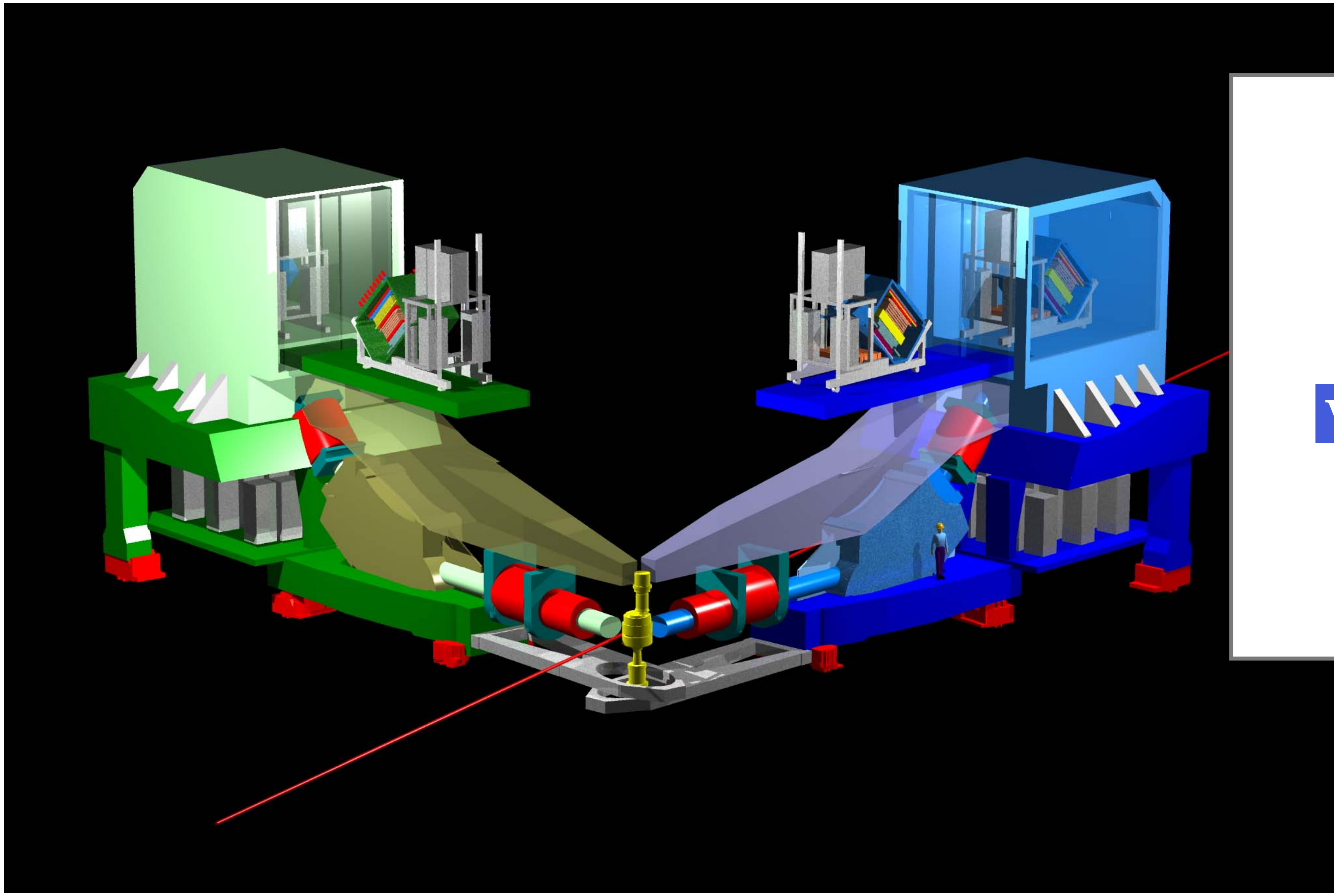


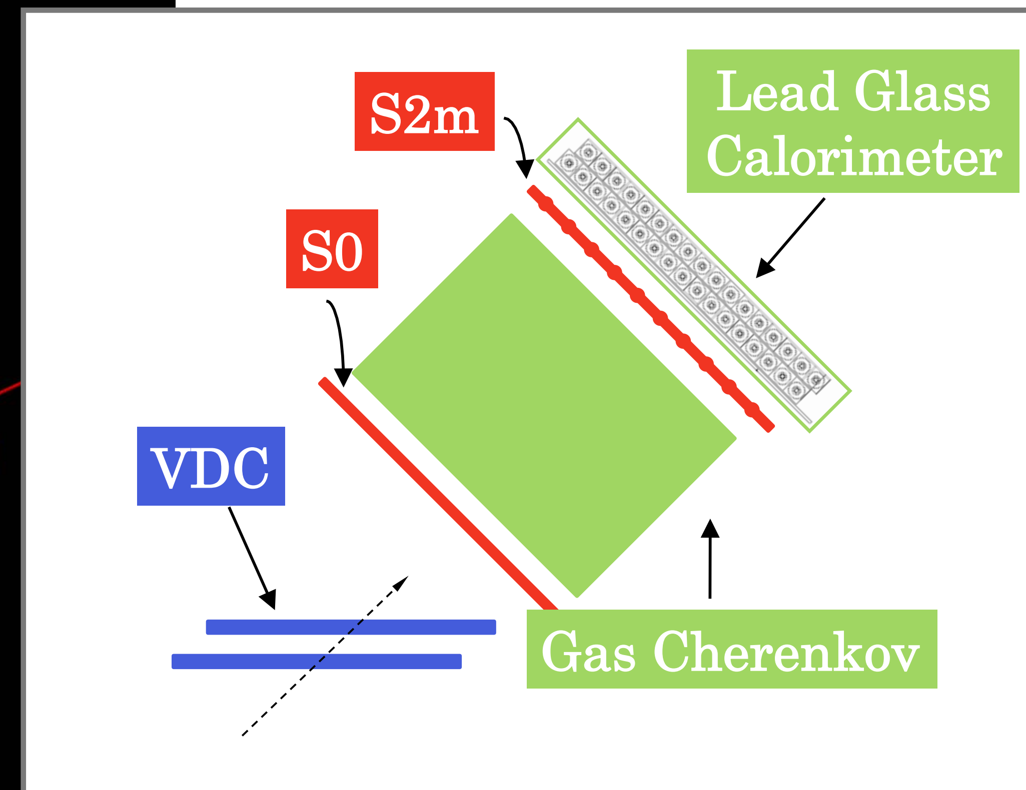
The High Resolution Spectrometers





The High Resolution Spectrometers

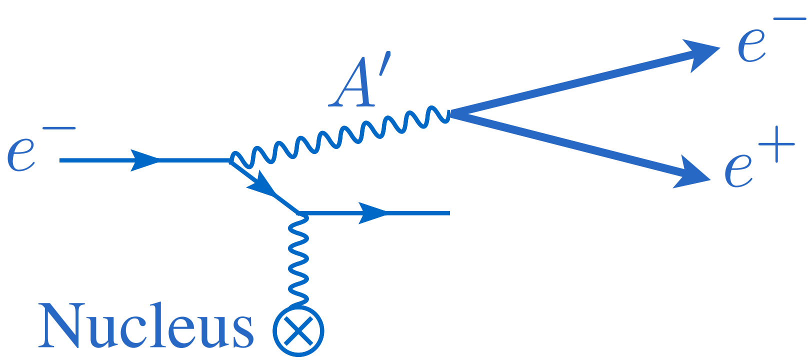


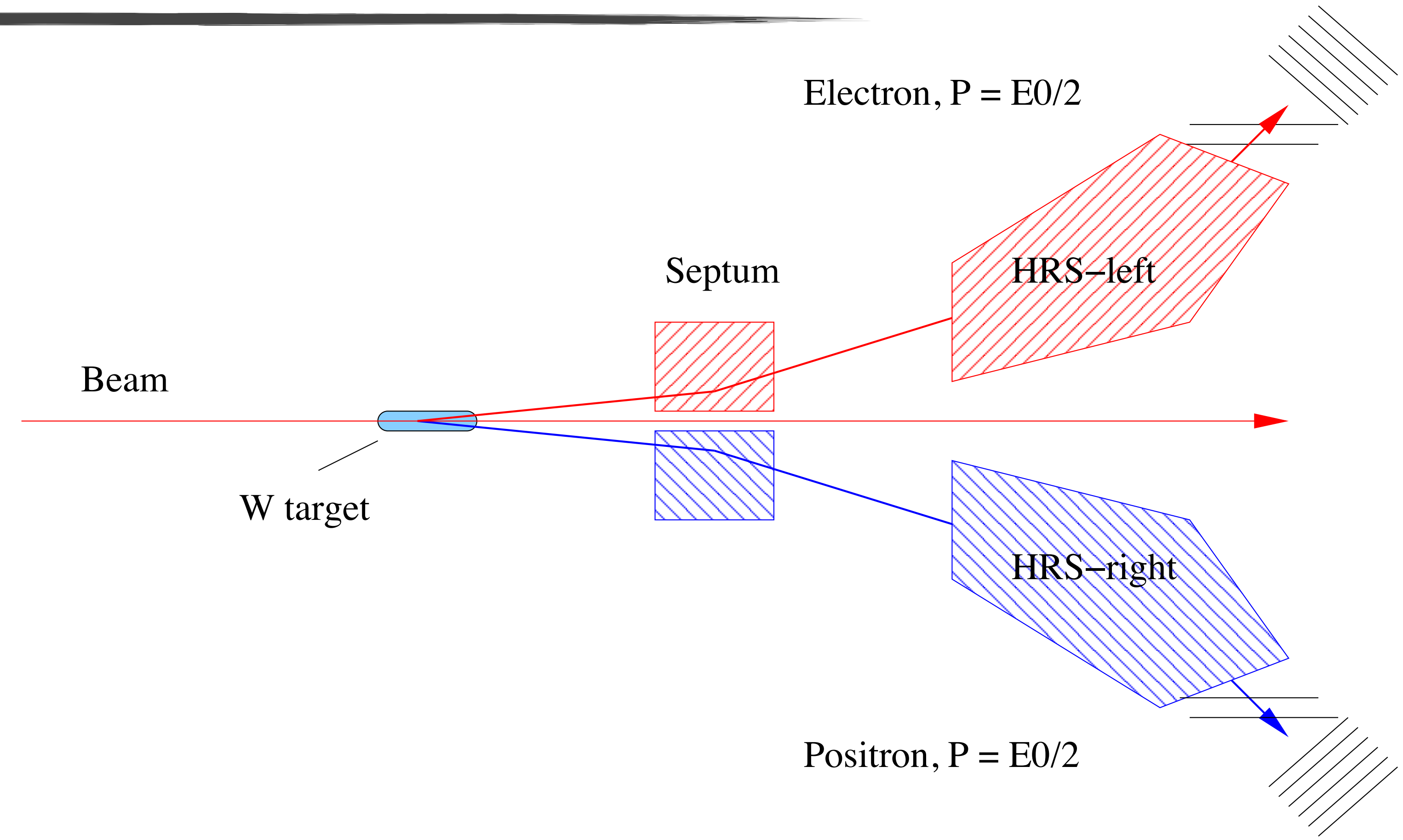


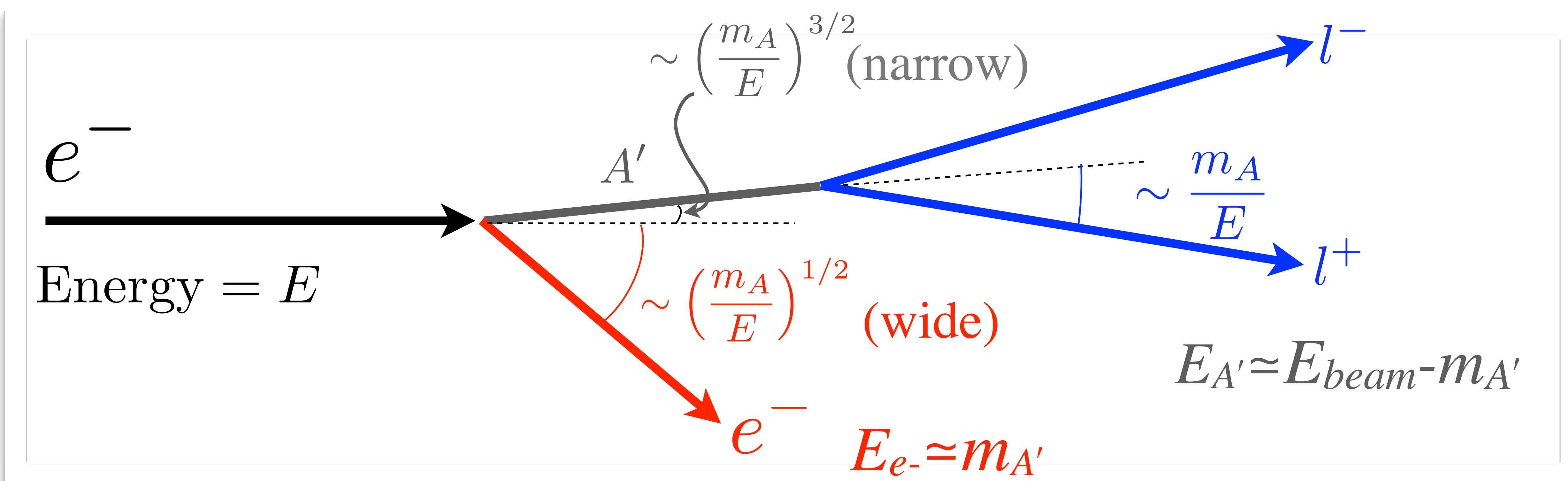
Range	Acceptance	Resolution
$0.3<p<4.0$ GeV/c	$-4.5\%<\Delta p/p<4.5\%$	$\delta p/p \leq 2\ 10^{-4}$
$12.5^{o}<\theta_0<150^{o}$	6msr	$\delta\phi=0.5$ mrad (H)
		$\delta\theta=1$ mrad (V)

(4.5 msr at $\theta_0=6^{o}$ with septum)

A′ Production Kinematics



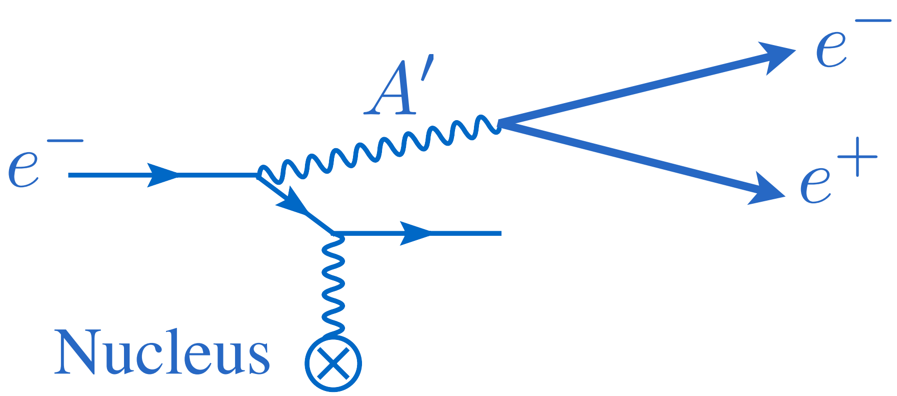




Note $m_{A'}/E \leftrightarrow \theta$: 0.5 *(DarkLight)*, 0.3 *(MAMI)*, 0.1 *(APEX)*, 0.03 *(HPS)*

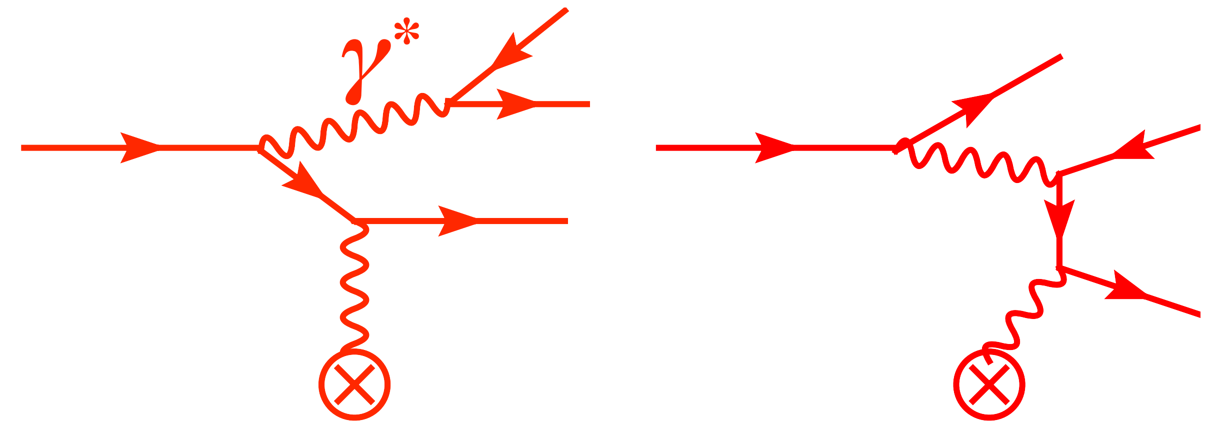
A′ Production and Background Kinematics ($m_{A'} \ll E_{beam}$)

A′ Production



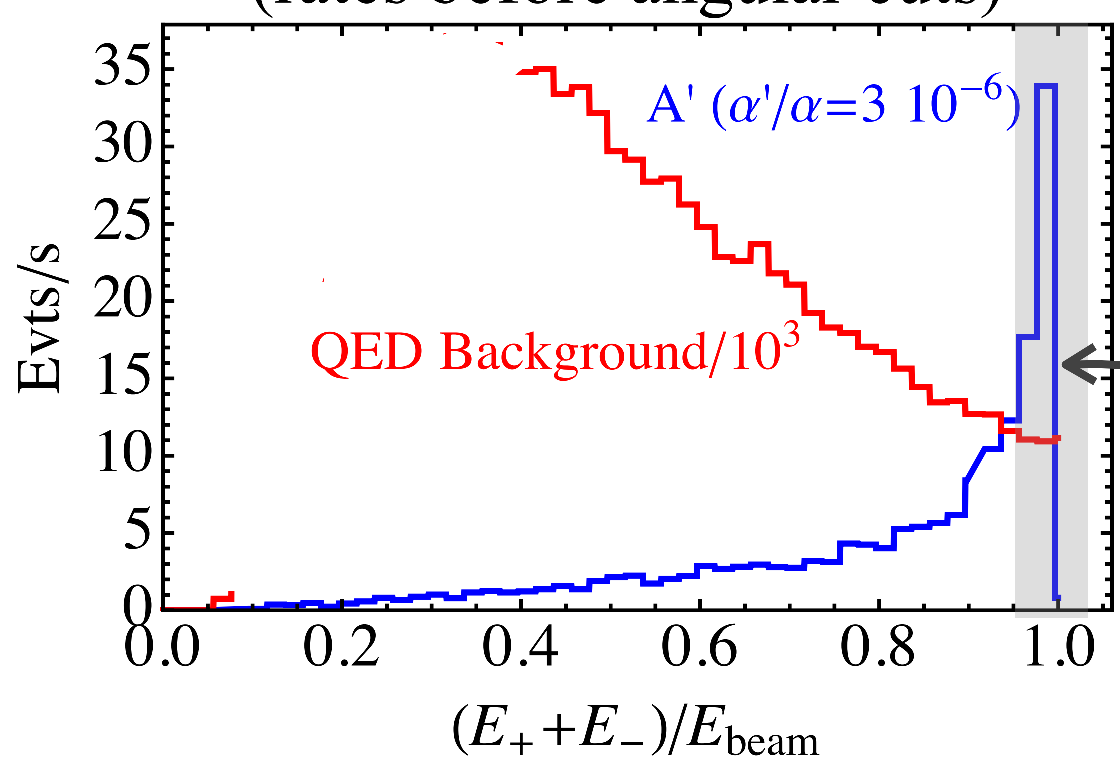
$$\sigma \sim \alpha'/m^2 = \varepsilon^2\alpha/m^2$$

QED Backgrounds



$$d\sigma \sim \alpha^2/m^3\, dm$$

(rates before angular cuts)



– Distinctive kinematics:

A′ products carry (almost) full beam energy!

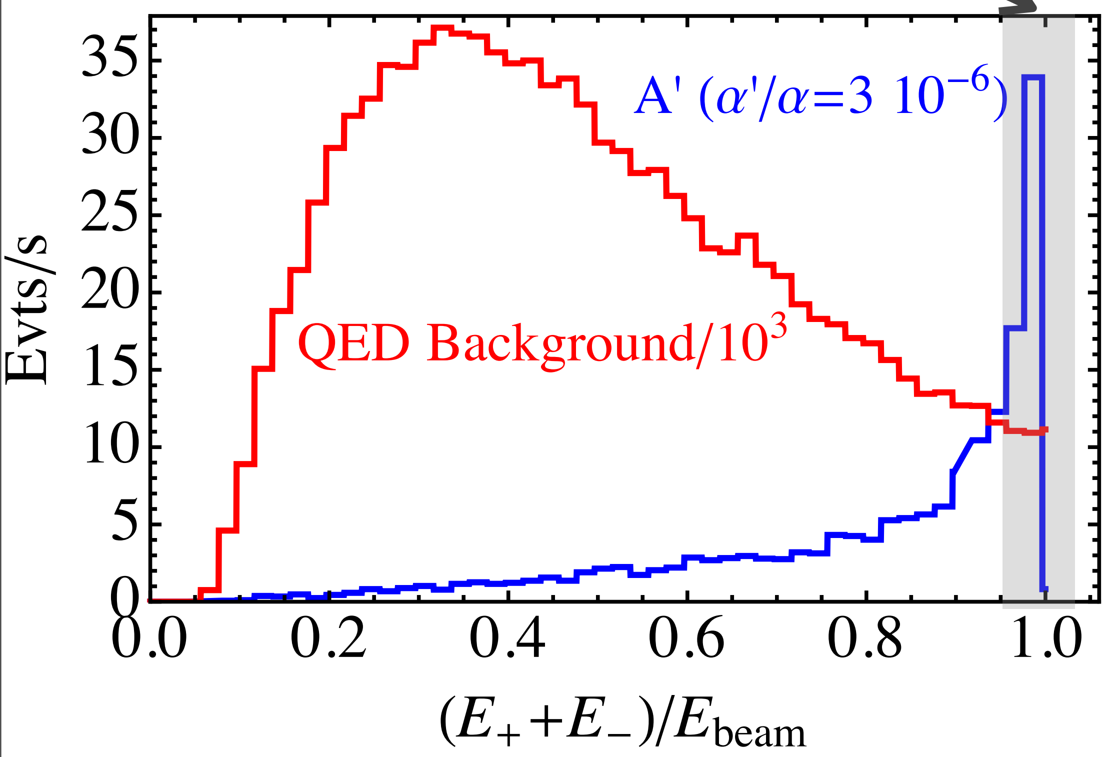
Symmetric energy, angles in two arms optimize A′ acceptance

$$E^+ \approx E^- \approx E_{beam}/2$$

Advantages of narrow momentum aceptance

Small acceptance allows excellent mass resolution; also greatly suppresses singles and non-QED coincidence backgrounds

Events outside this window never reach spectrometer



Singles:

- Elastic scattered e^- (above acceptance)
- Moller e^-

Coincidence:

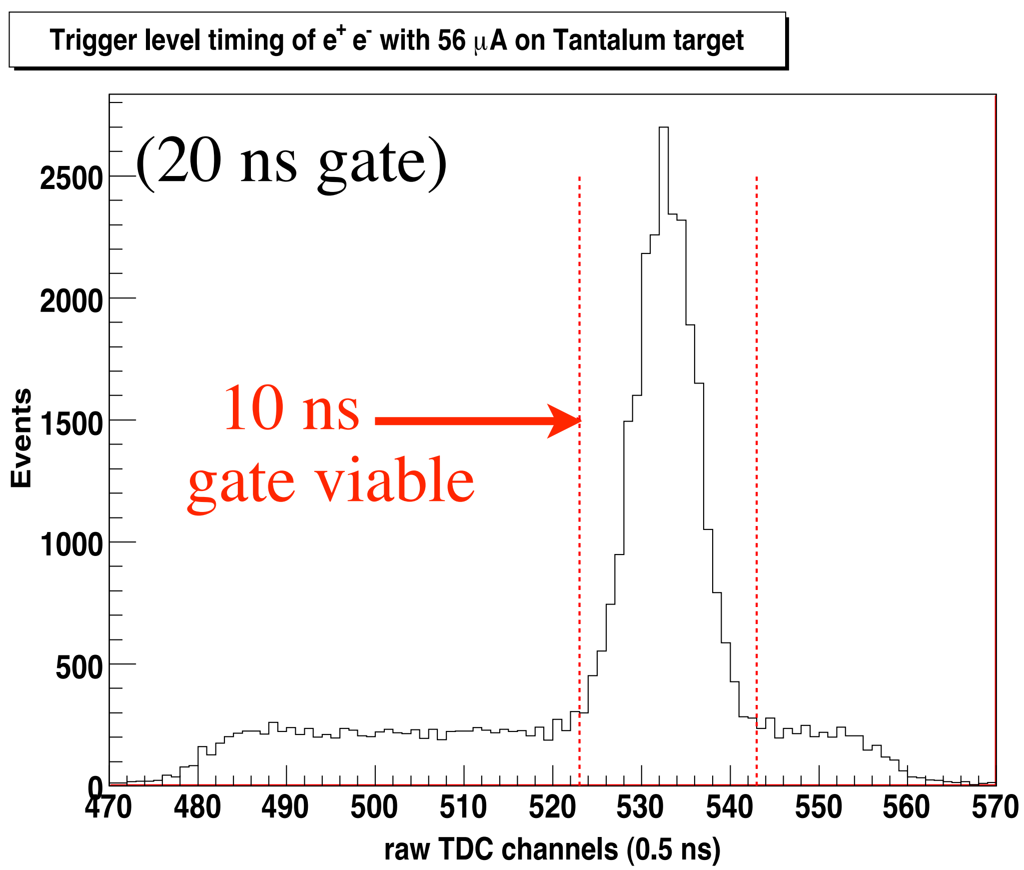
- $\pi^0 \rightarrow \gamma\, e^+e^-$
- Radiated $\gamma \rightarrow e^+e^-$

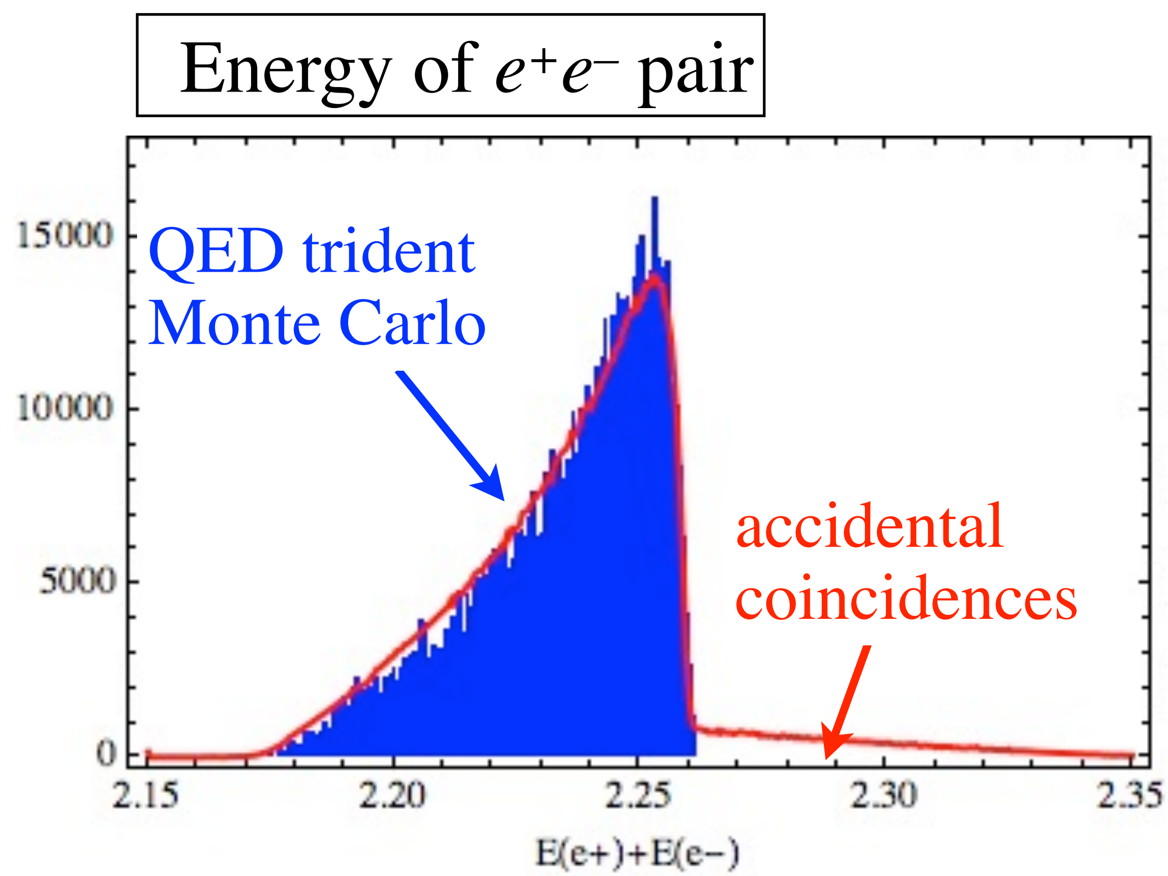
(below acceptance)

Dominant coincidence background (accidental $e^-\pi^+$) can be rejected by using Gas Cherenkov detector in coincidence trigger.

APEX test run

- Test run performed in Hall A, July 2010
  Many thanks to JLab & Hall A staff for tremendous support!
- Demonstrated many key elements for full experiment
  - accurate & efficient VDC reconstruction at high e^- track rate
  - coincidence trigger on S2 scintillators and Gas Cherenkov (e^+ arm)
  - tested understanding of background processes
  - spectrometer optics & mass resolution
  - resonance search on 700K good trident events





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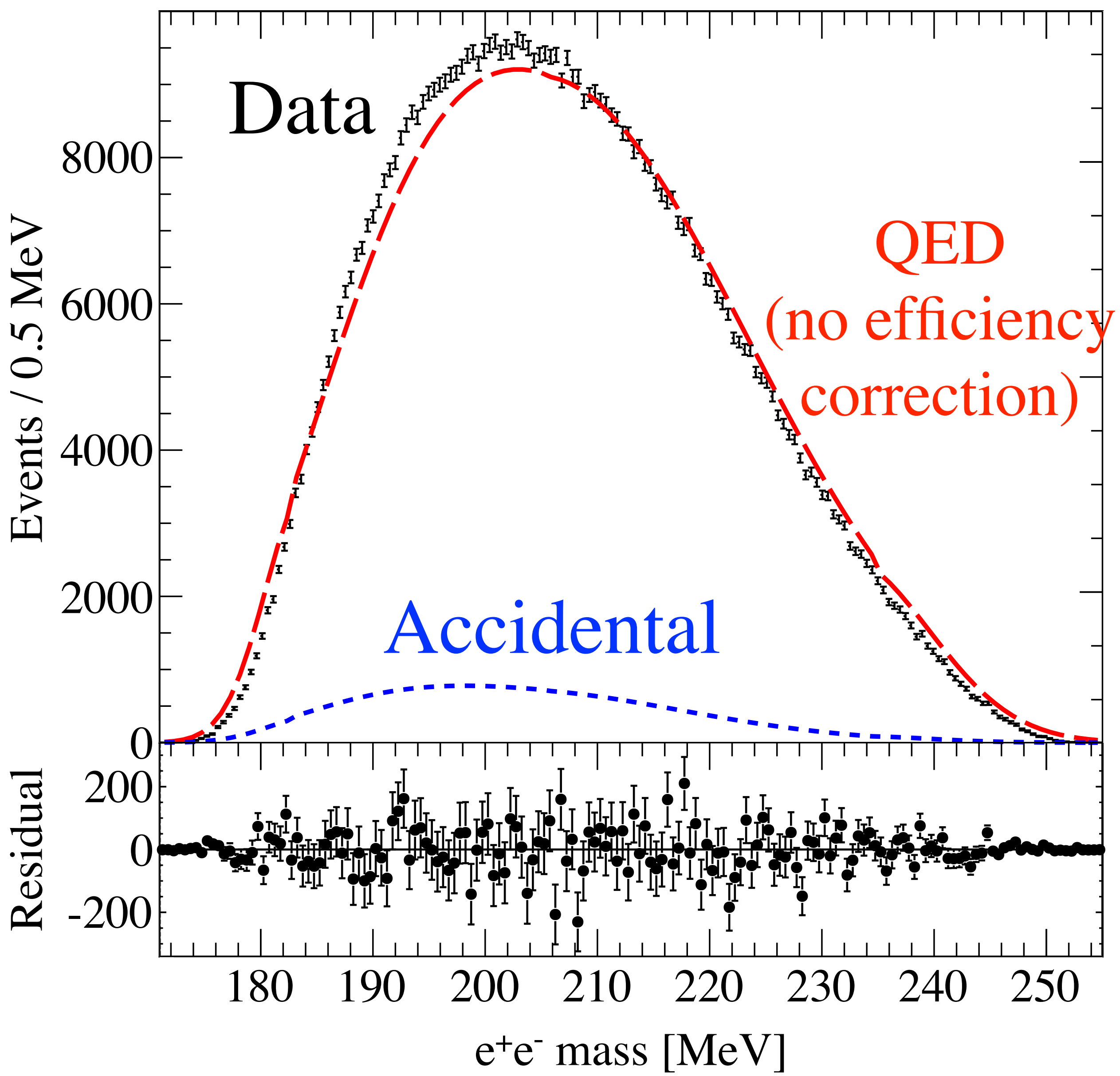
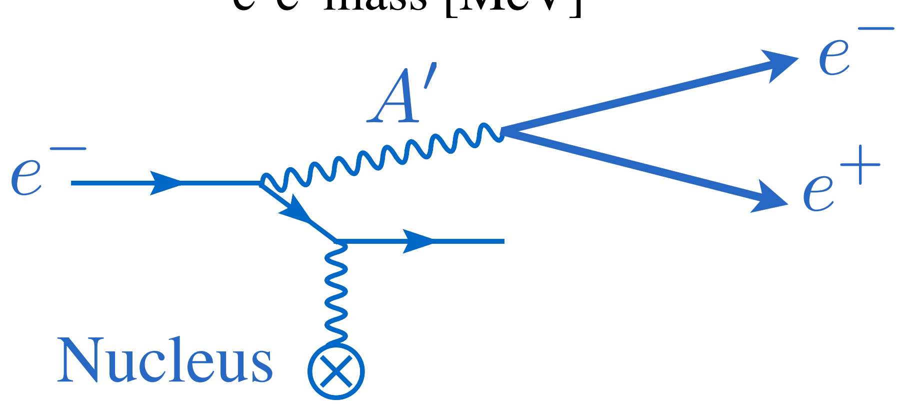
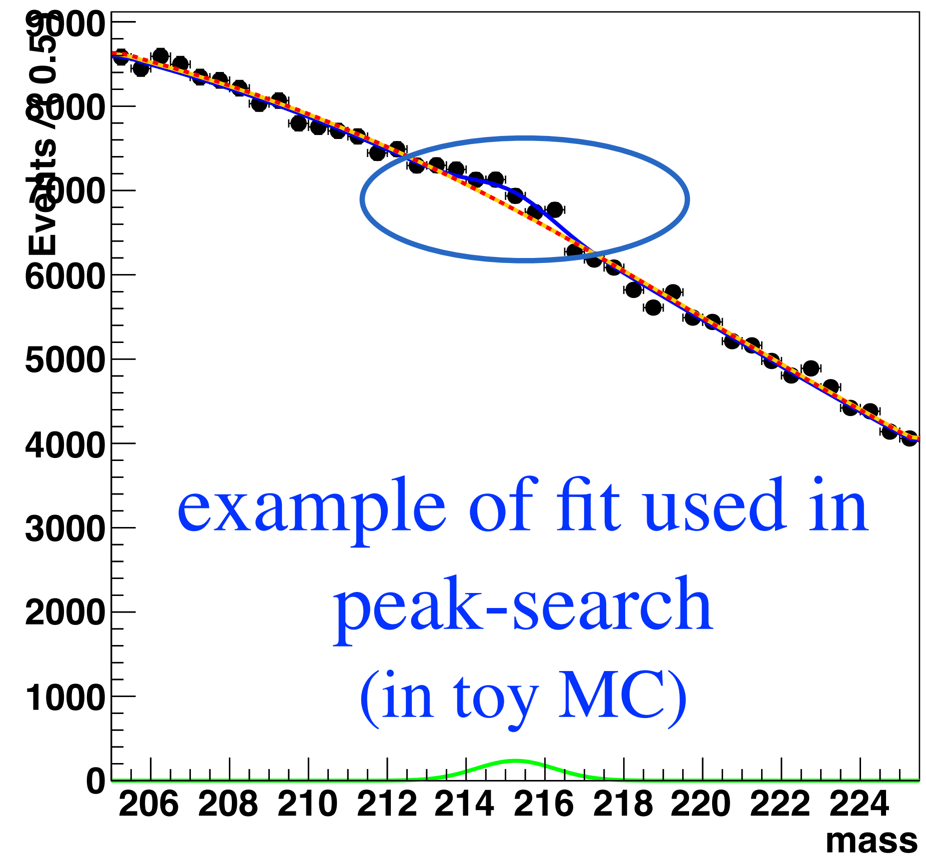
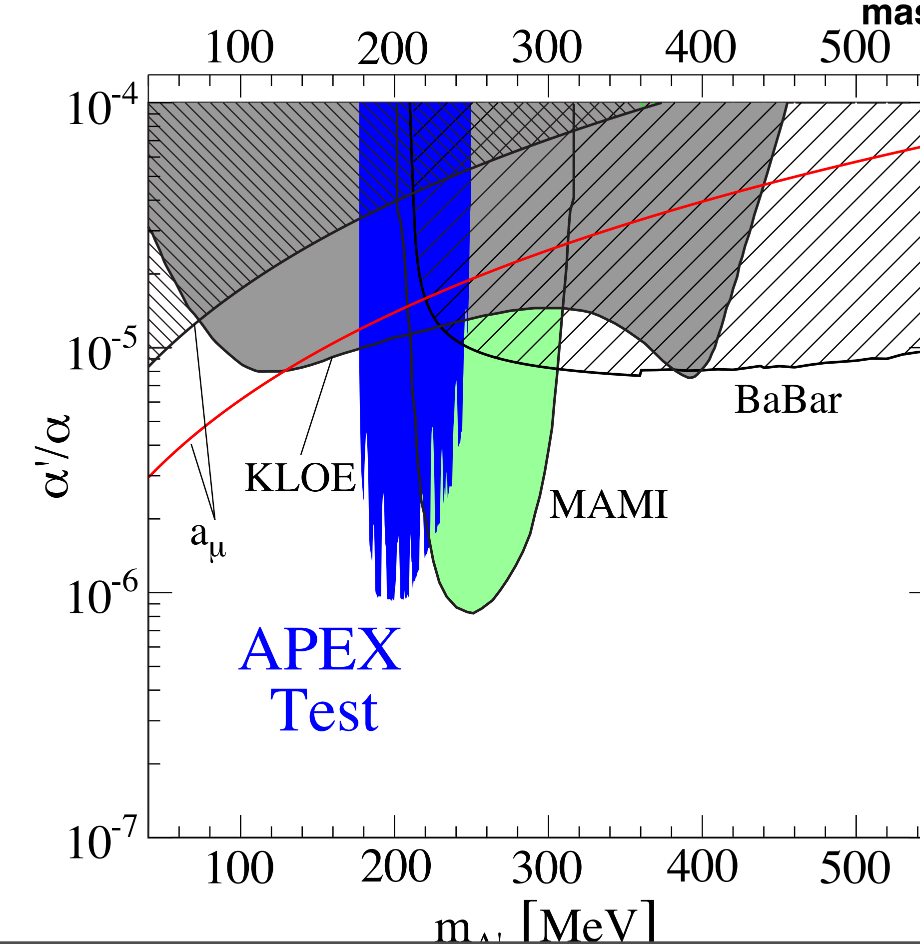
Test-Run Science Data and Resonance Search









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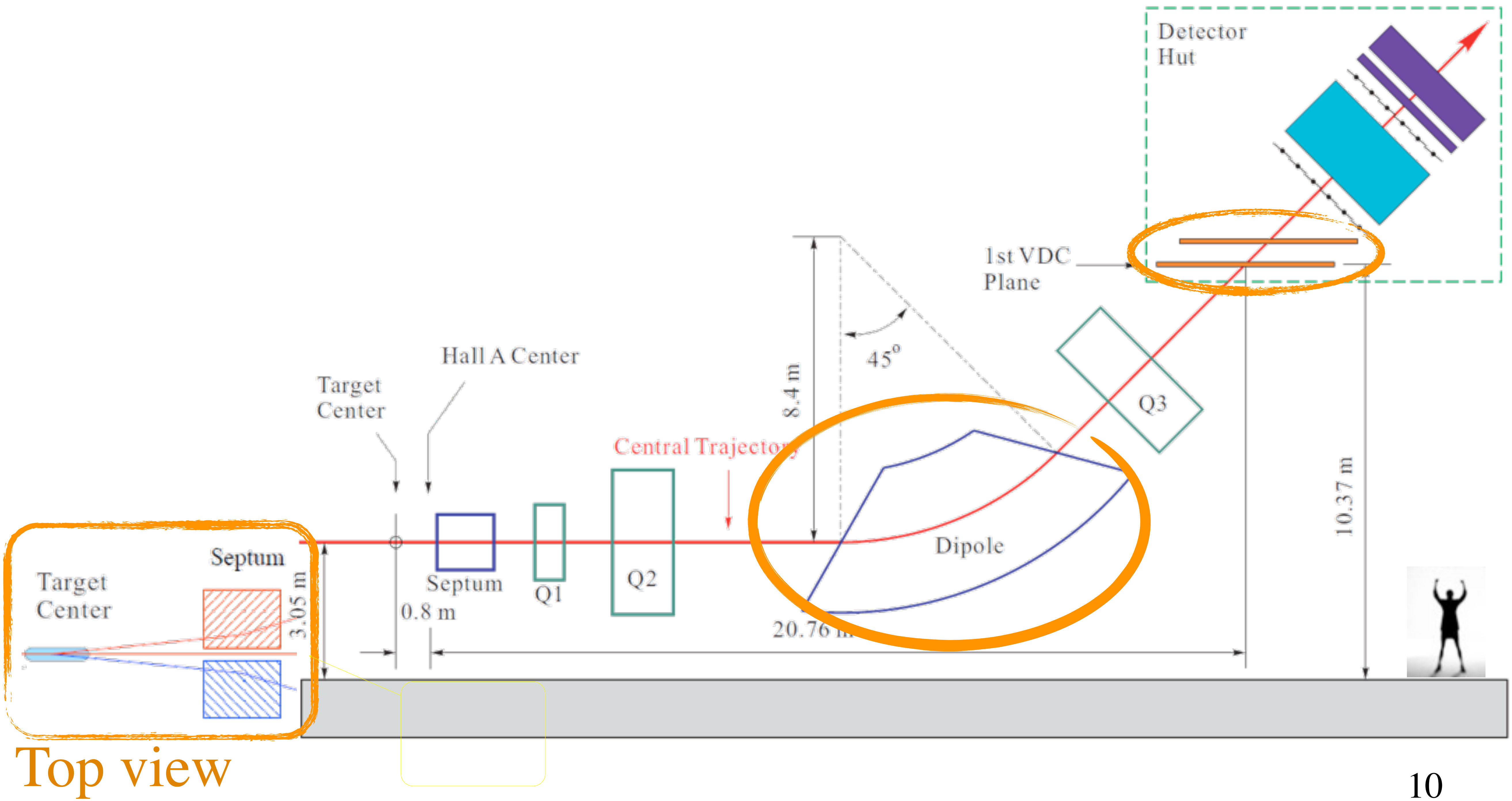
Magnetic Spectrometer Optics

Measuring Contributions to the Mass Resolution
(dominant: **angular resolution** + mult. scatter)



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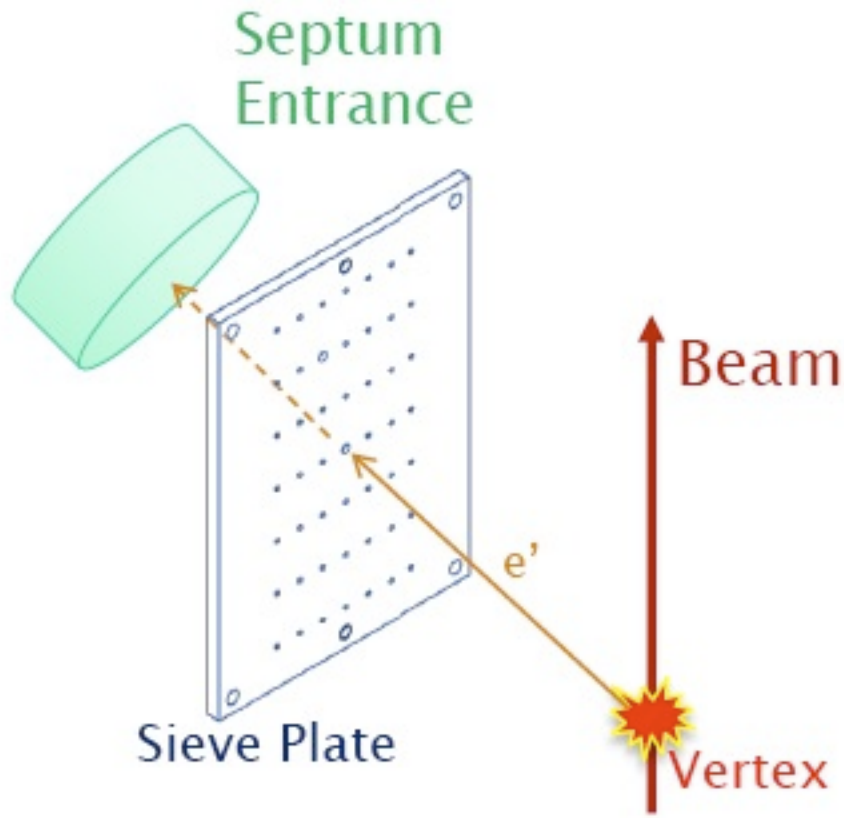
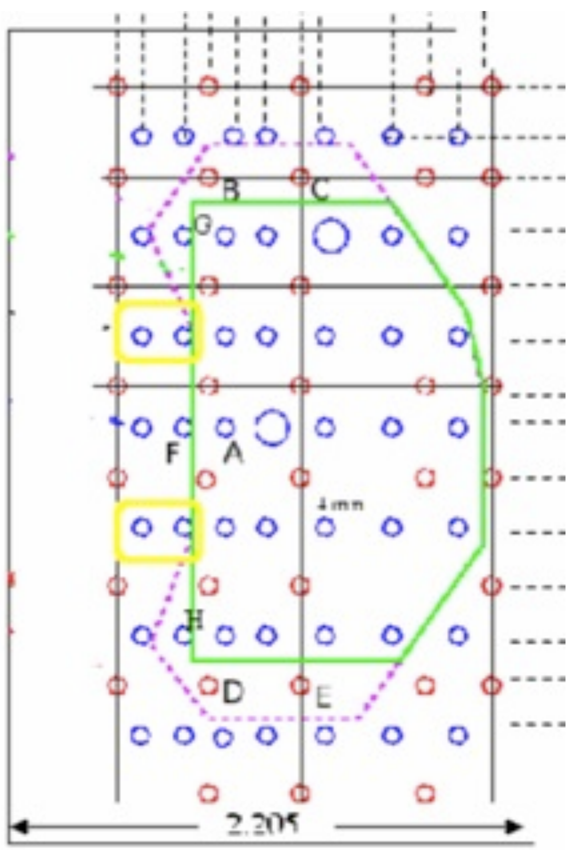
Optics Calibration





Removable sieve plate is inserted upstream of septum.

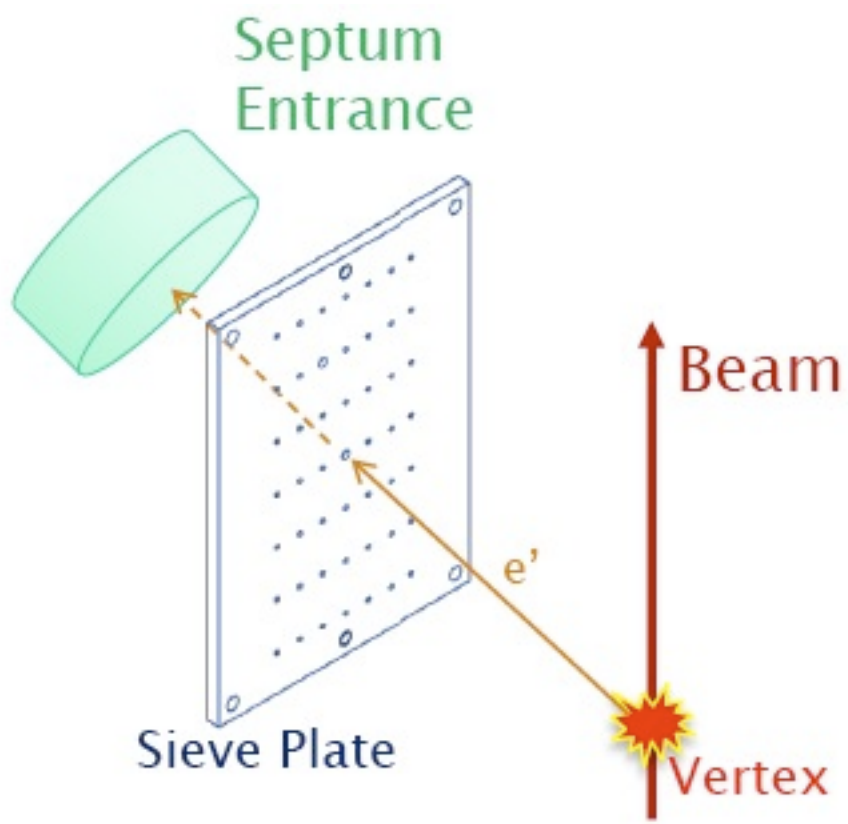
Use surveyed locations of sieve holes to calibrate magnetic optics.

Use reconstructed hole sizes to measure resolution.

...this method only works for negative polarity, and requires running at different beam energy.

Mass resolution≈1 MeV ~0.5%

Optics Calibration



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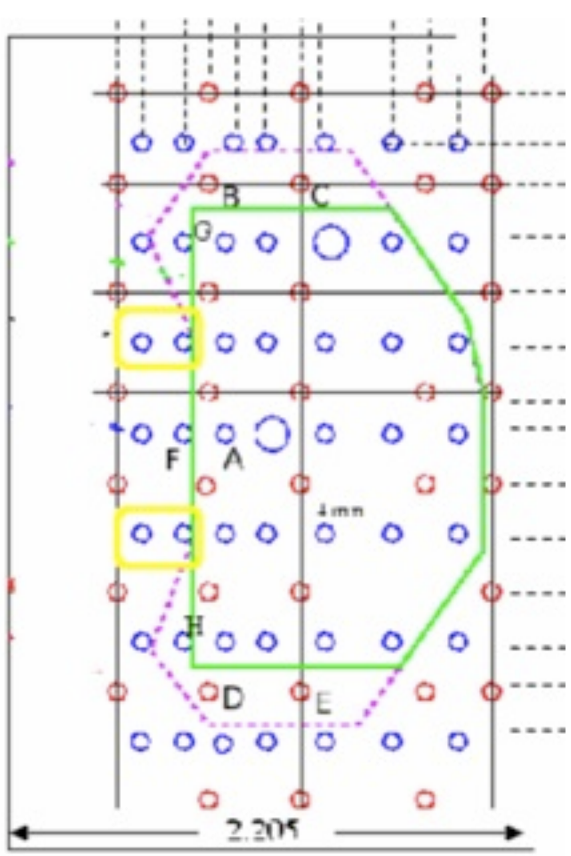

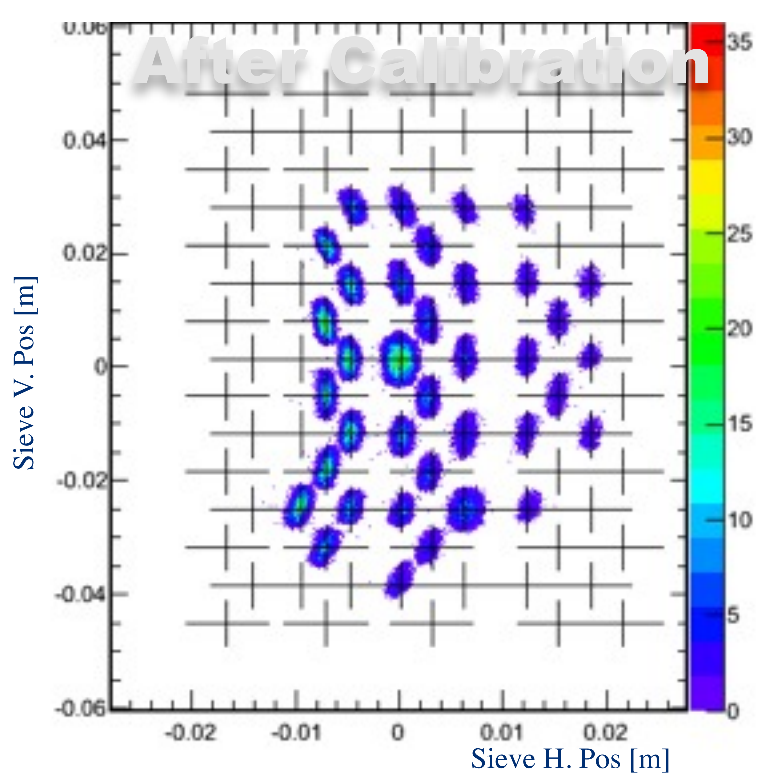

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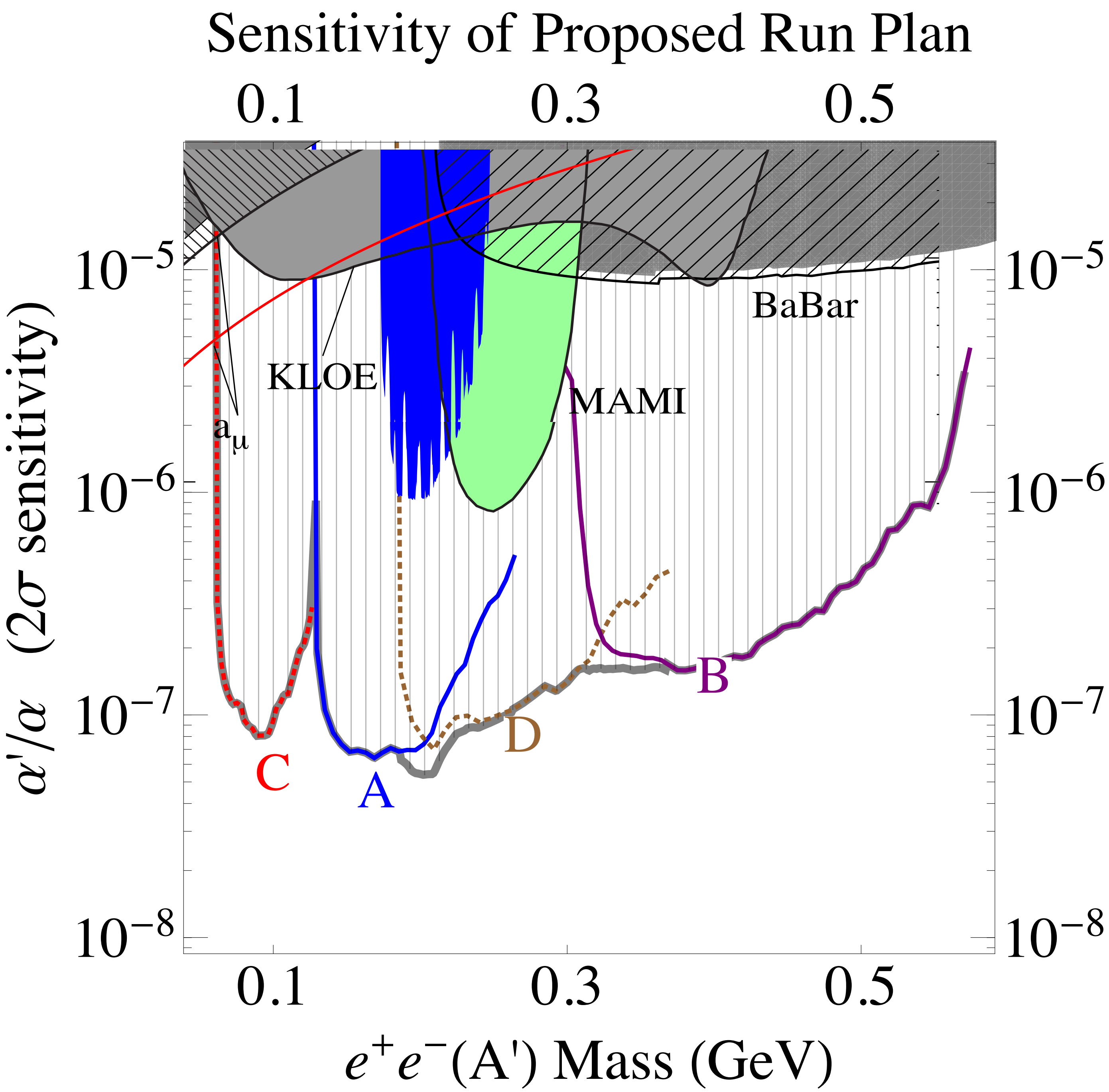
Full APEX run plan and sensitivity



1 Month Beam Time
- 6 days at 1,2,3 GeV
- 12 days at 4.5 GeV)

Approved by JLab PAC 37;
Planning underway for full run – will greatly extend sensitivity to dark forces.

Target Design: Minimizing Multiple Scattering

Target designed and built by SLAC APEX group for the test run (but not installed), currently at JLab.

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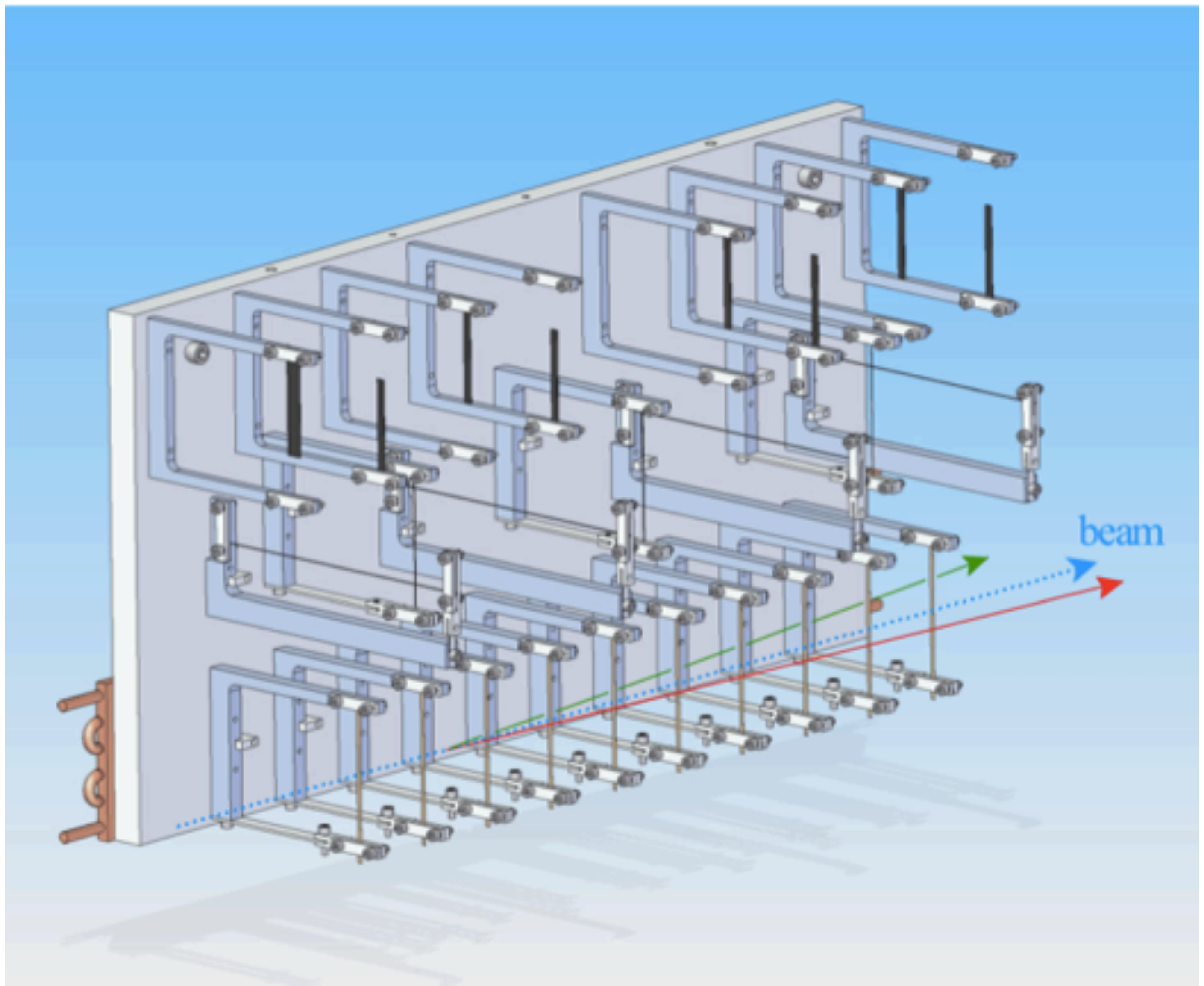
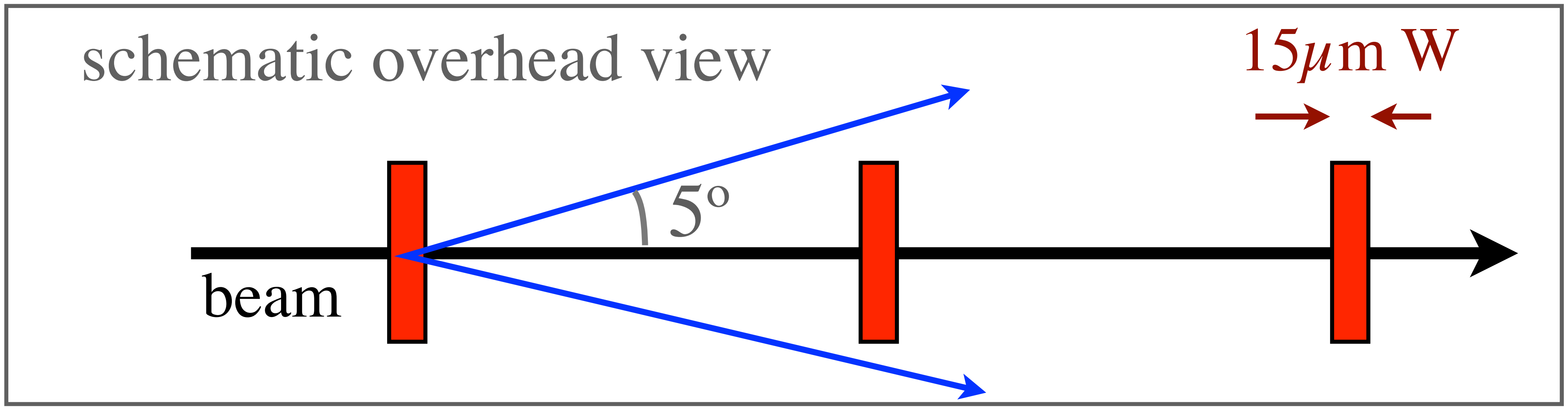


Target Design: Minimizing Multiple Scattering

Target designed and built by SLAC APEX group for the test run (but not installed), currently at JLab.

Goals:

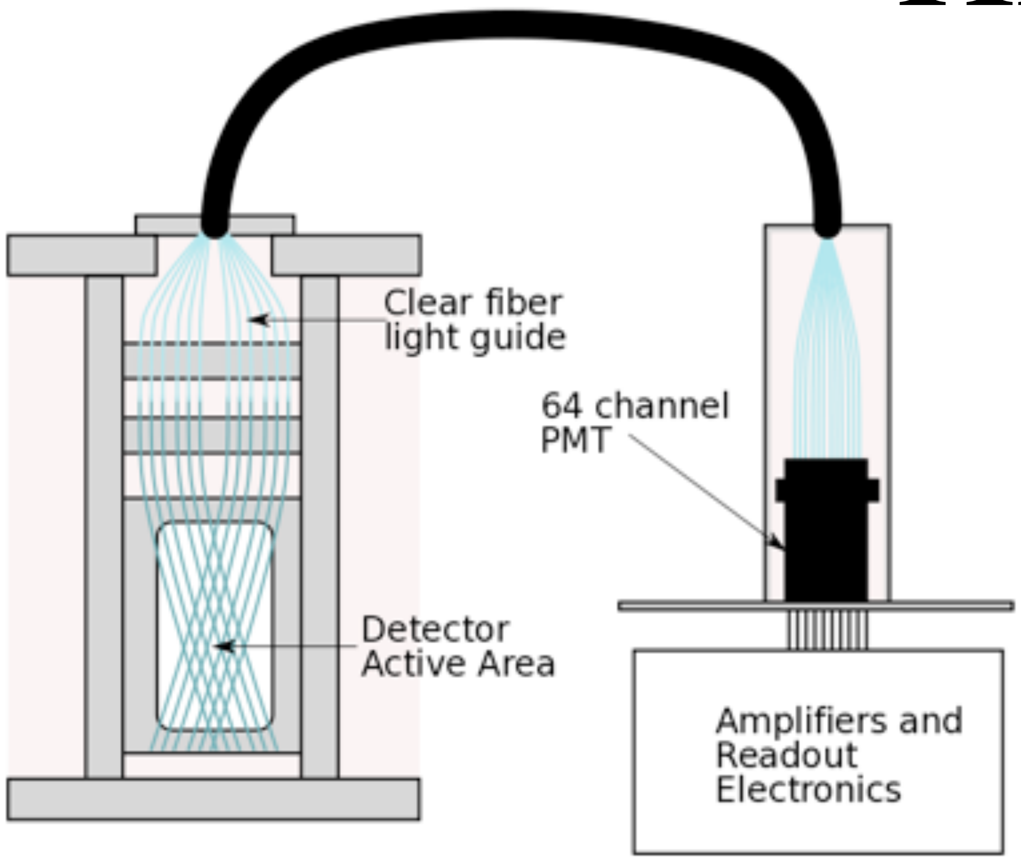
- $\sigma(\theta)_{\text{mult scat}} \leq 0.5$ mrad
  $\Rightarrow$ typical e^+e^- pair must only go through 0.3% X_0 (2-pass)
- Target thickness 0.7–8% X_0 (depending on E_{beam})



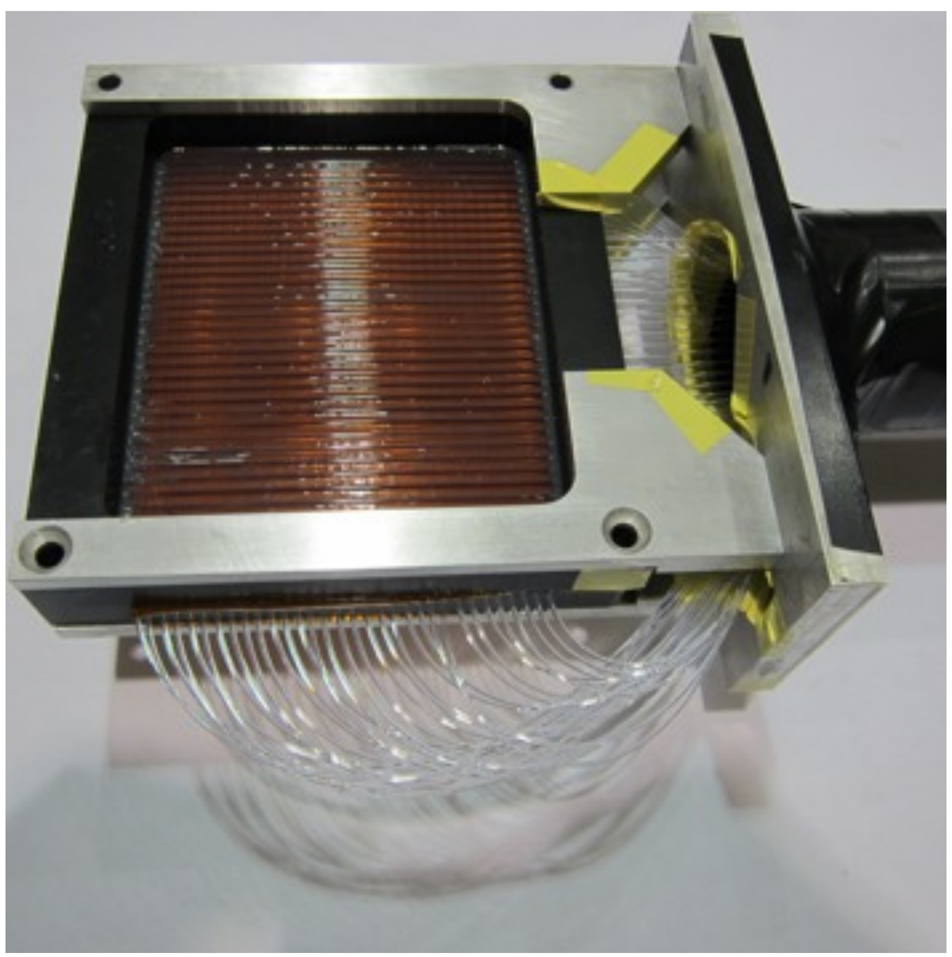
- High-Z target (reduce π yield for given QED rates)
- Stable under currents up to ~100 μA

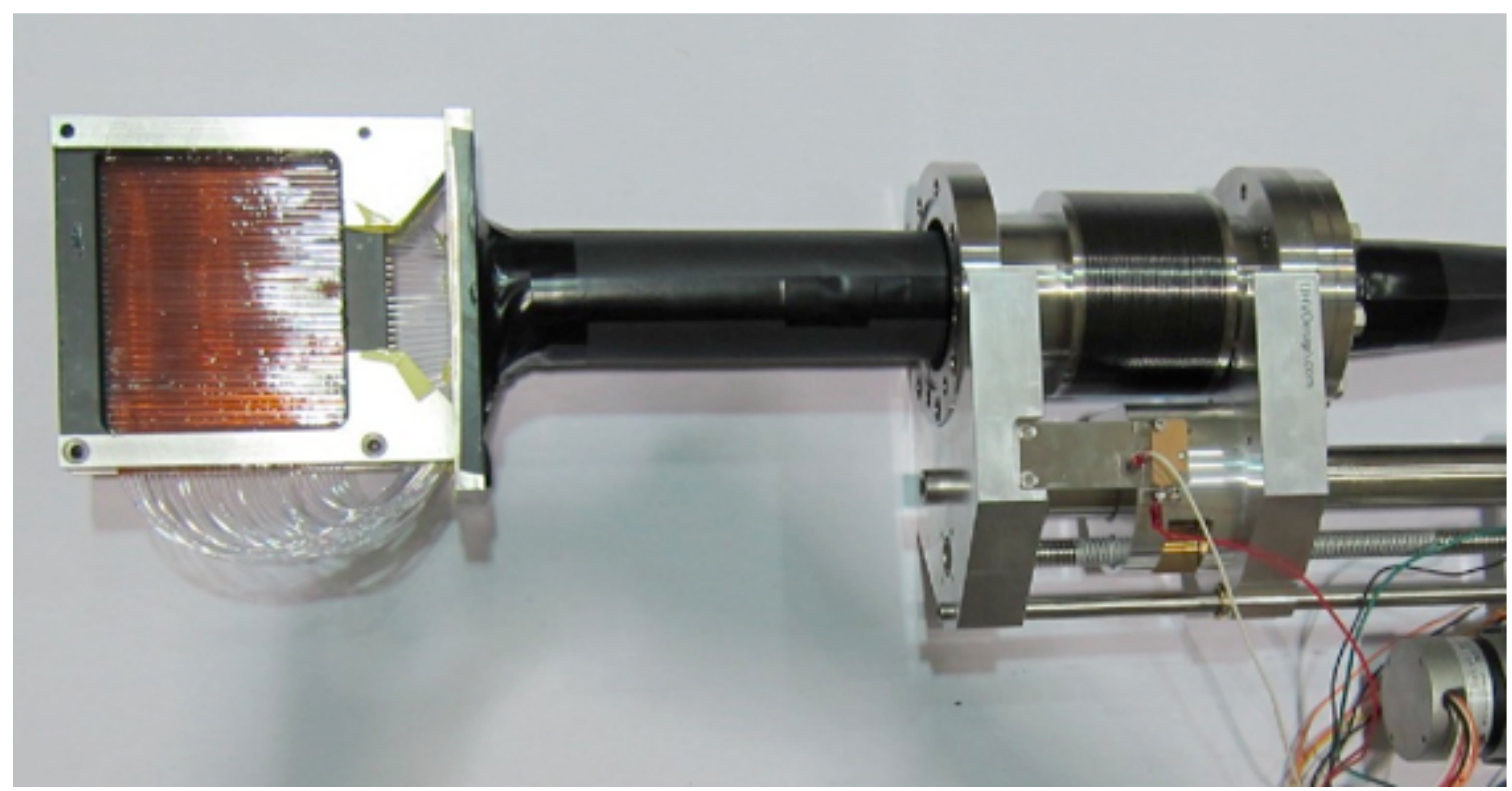
long target $\Rightarrow$ wider single-run mass coverage

HRS optics



- Active "sieve slit": tagging by a Sci Fiber detector
- 1 mm fibers with 1/16" pitch connected to a maPMT
- Readout via 1877s TDC
  1-3 MHz rate per fiber
- Off-line time window of < 5 ns
- Nearing completion





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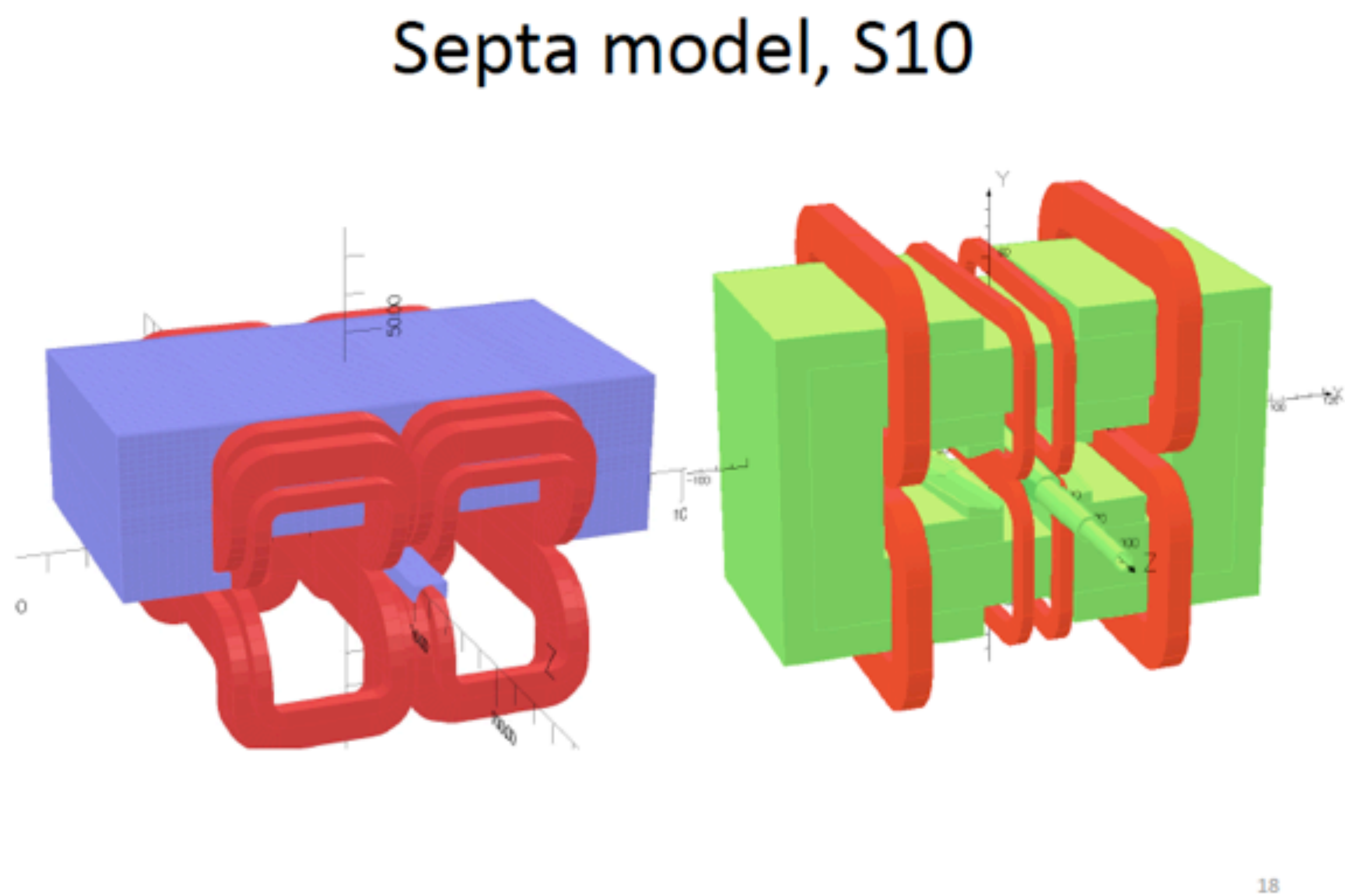
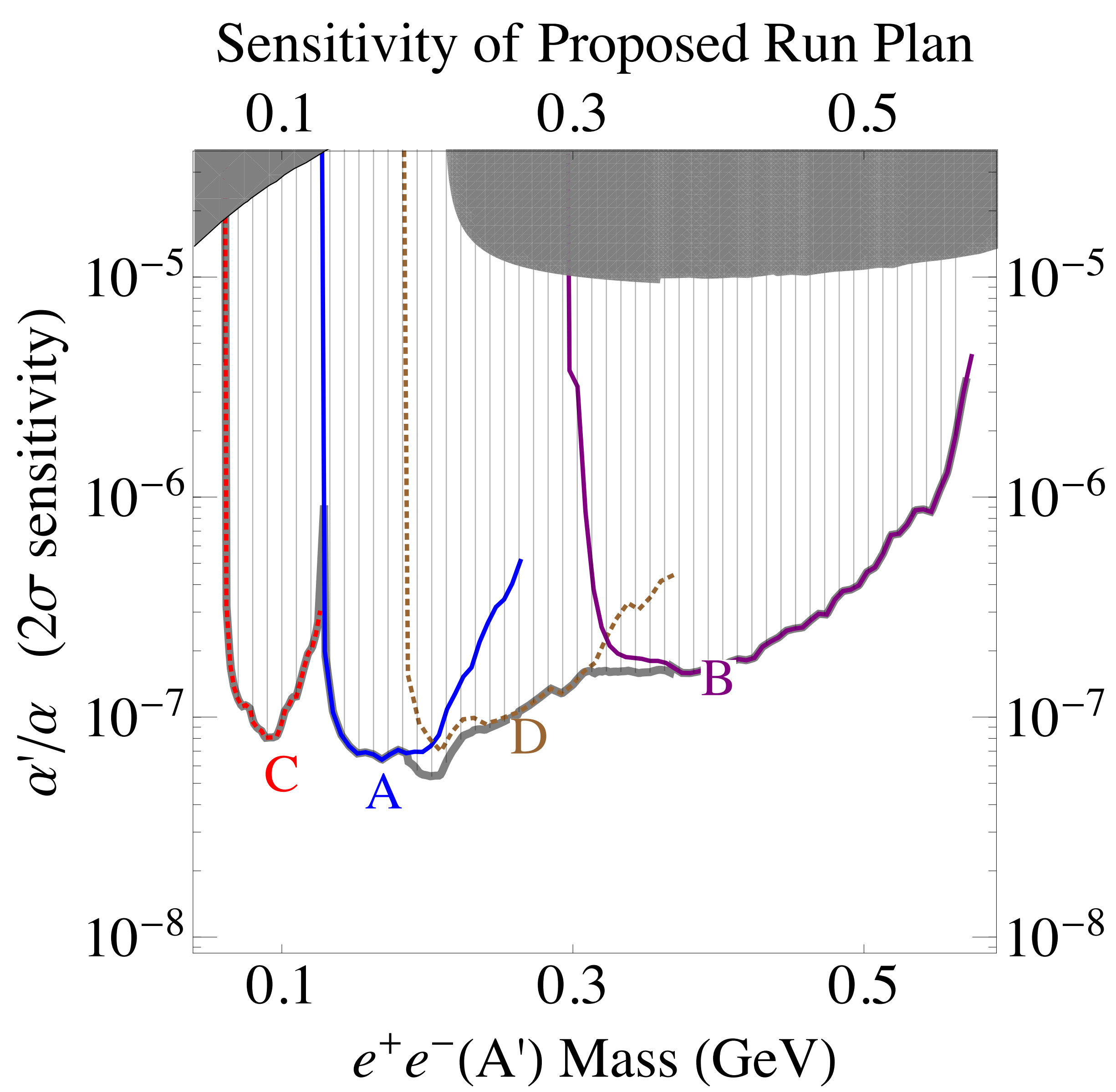
New HRS Septum Magnet

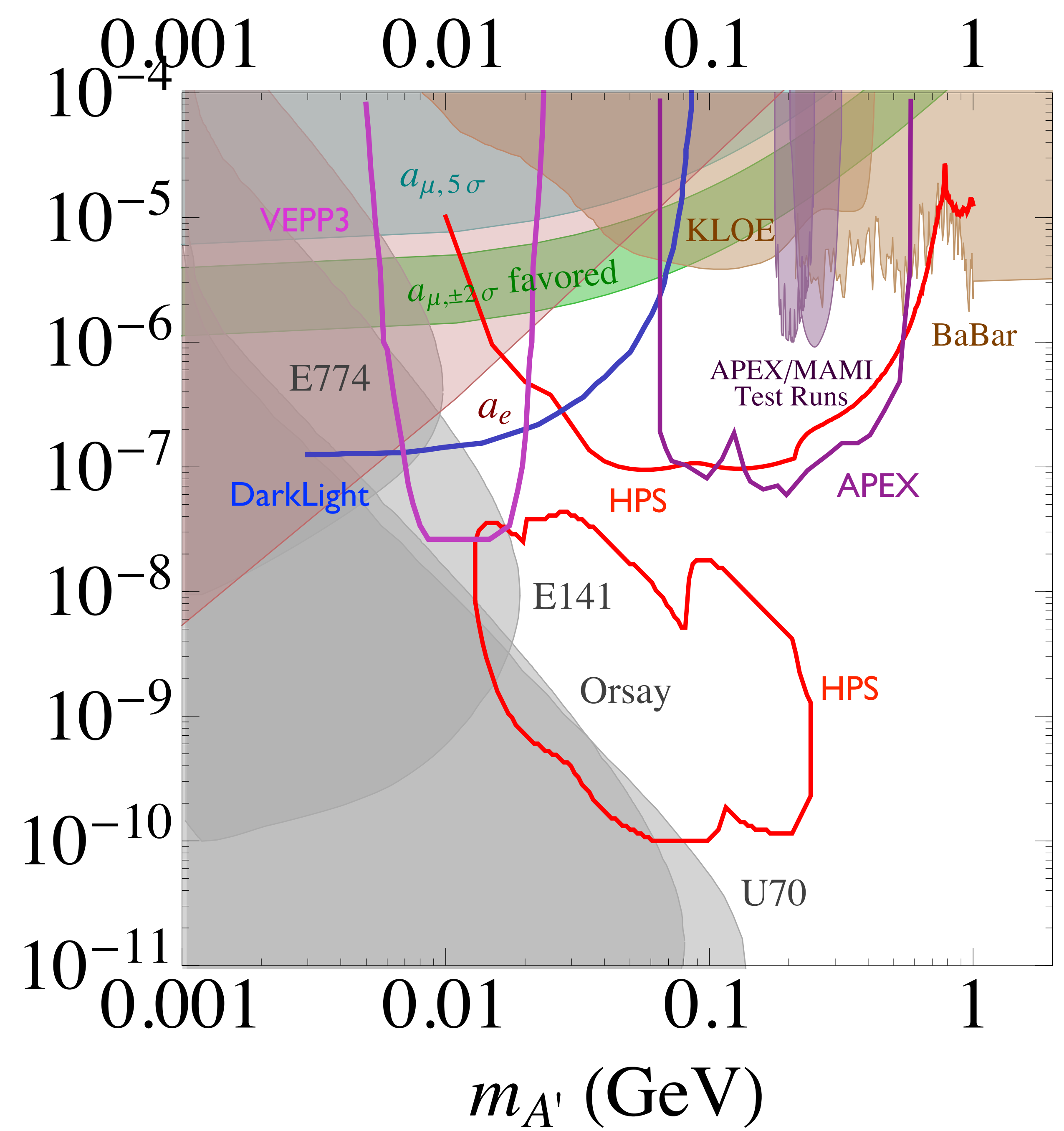


- Designed for parallel field configuration
- Optimized for full angular acceptance
- High density coils used to enable high energy use
- Use of NSERC DAS for partial funding

Summary

APEX has demonstrated feasibility and power of spectrometer searches for hidden-sector photons





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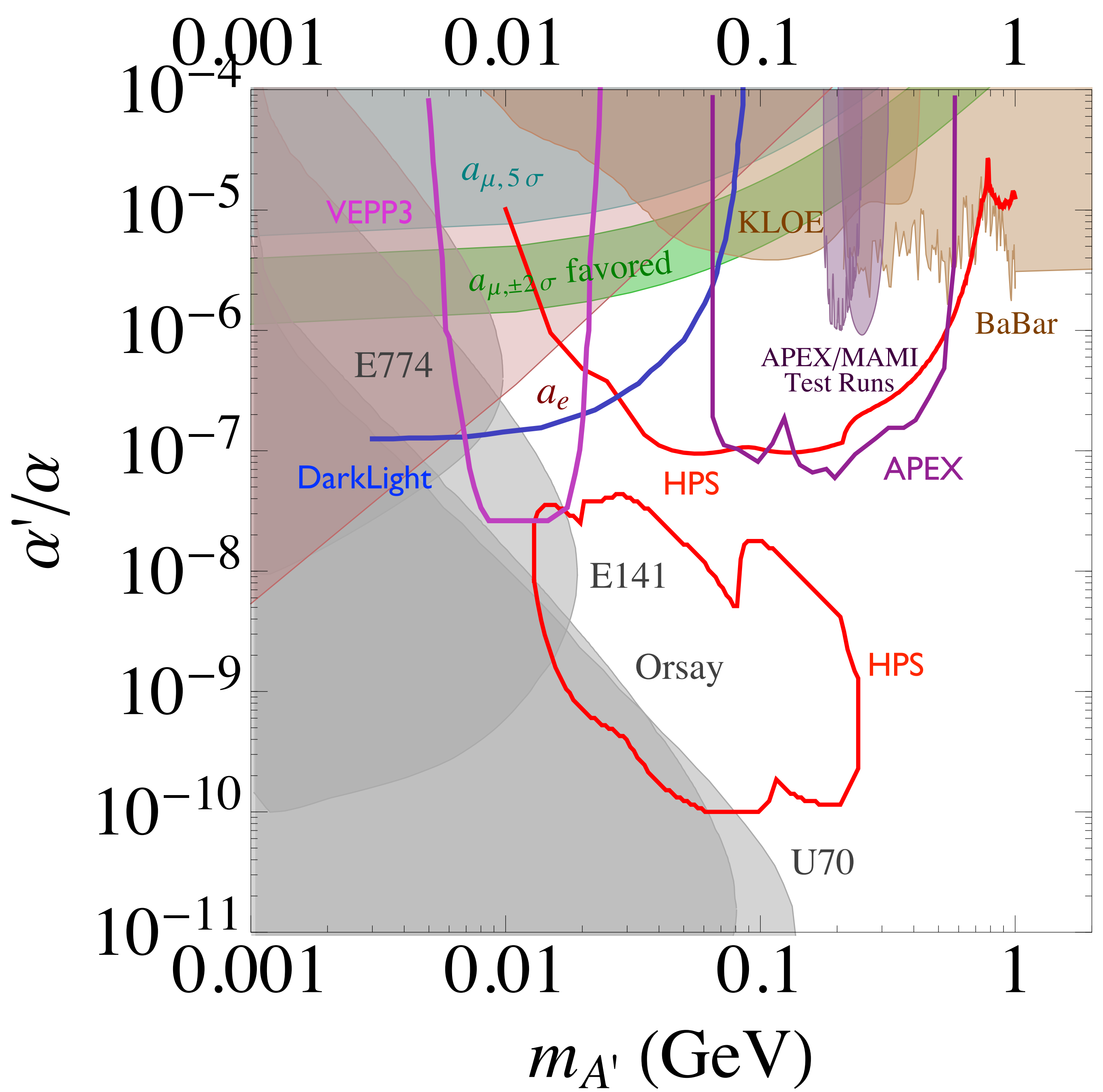
Summary

APEX has demonstrated feasibility and power of spectrometer searches for hidden-sector photons

Improvements planned for full run

Important range of mass and coupling will be explored



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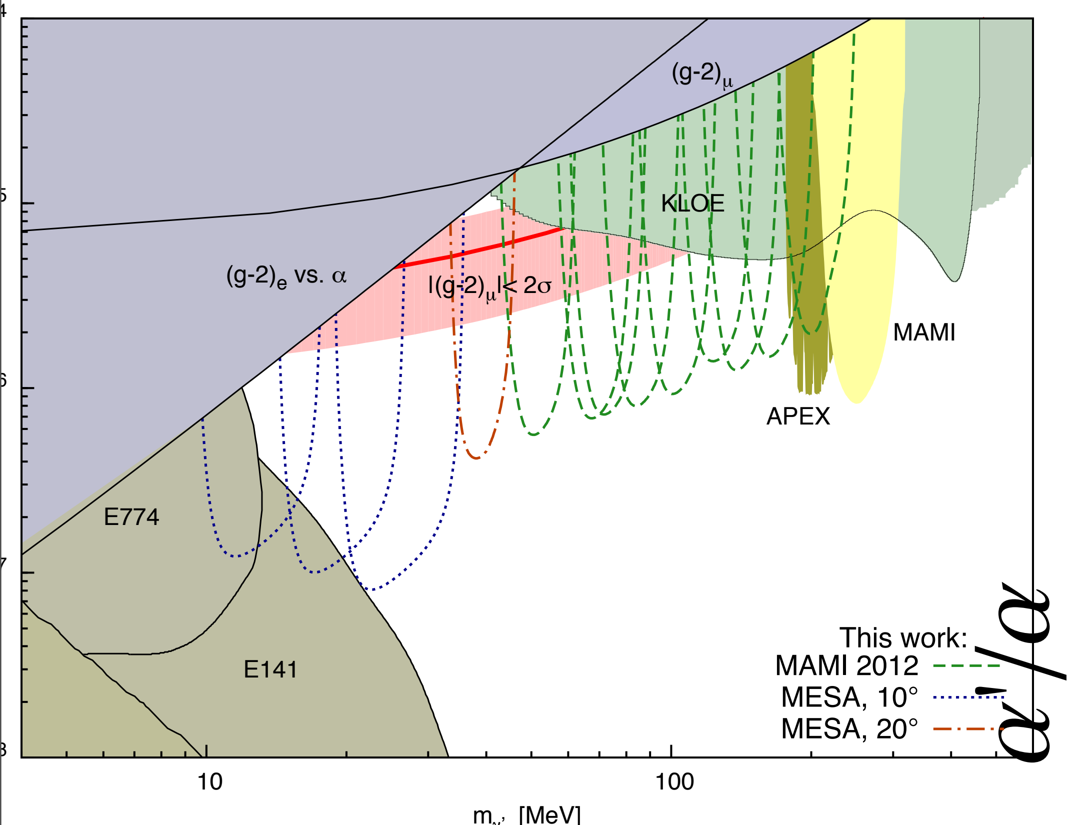
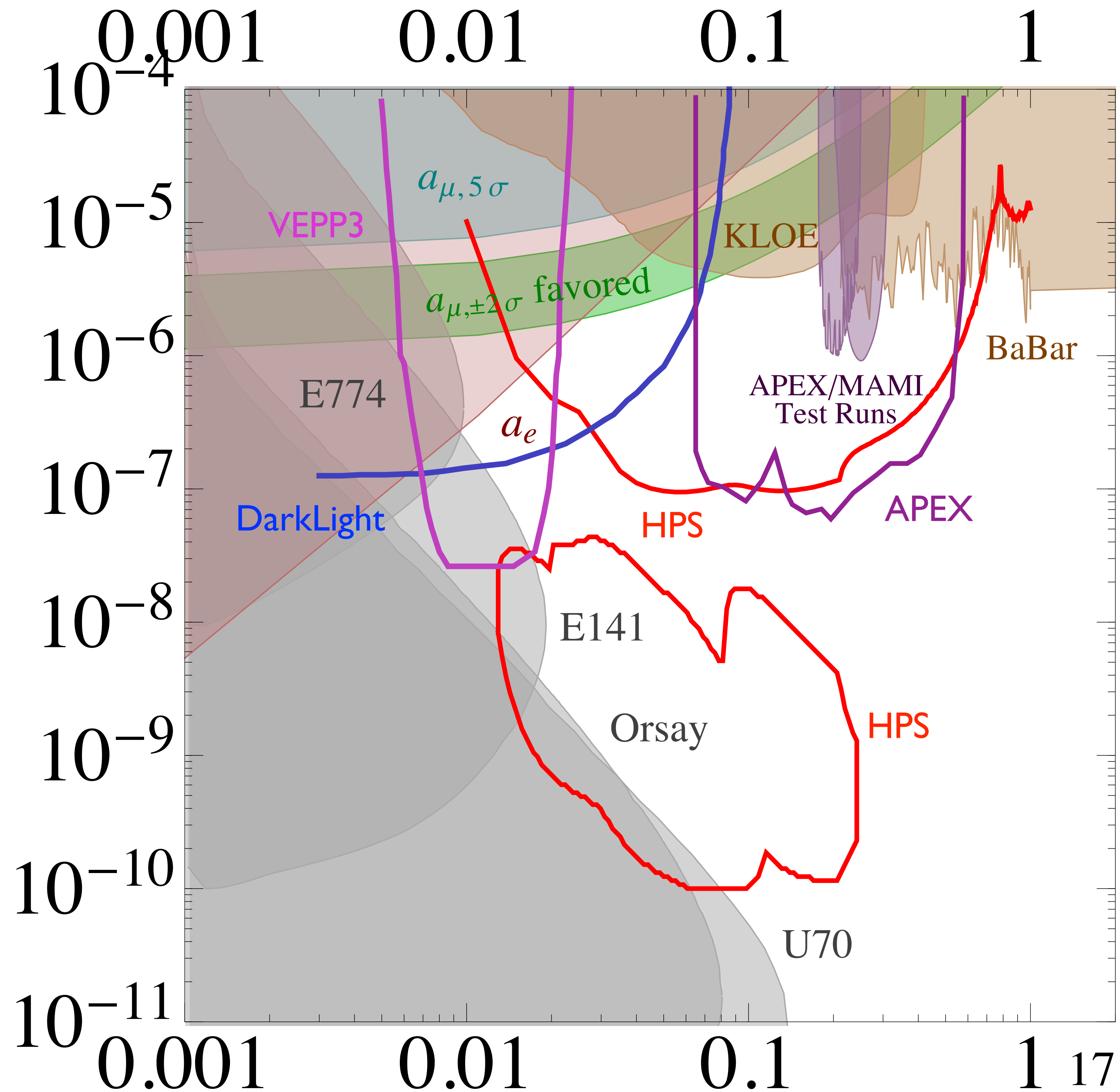
Summary

APEX search region complements and extends region being explored by Mainz



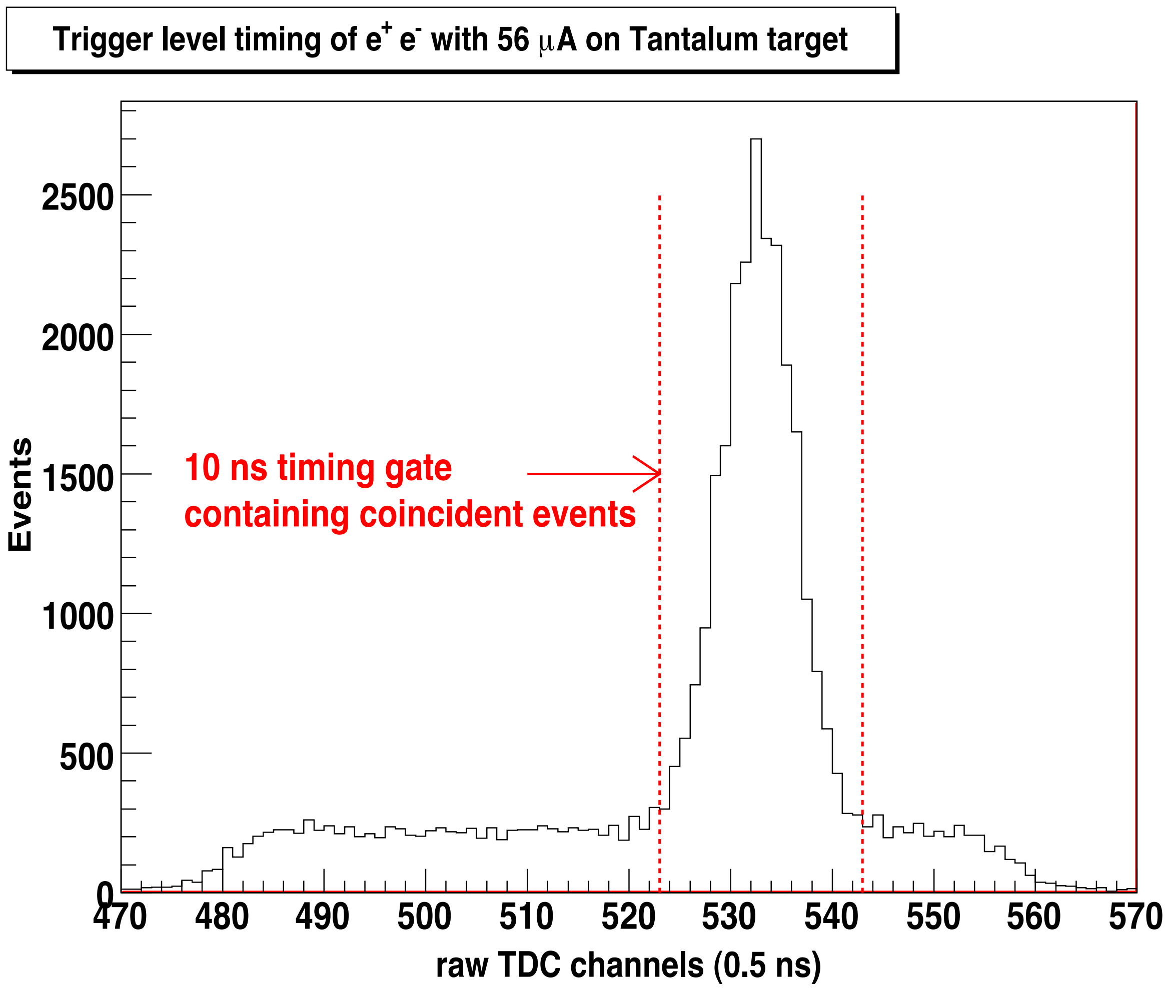
arXiv:1303.2540

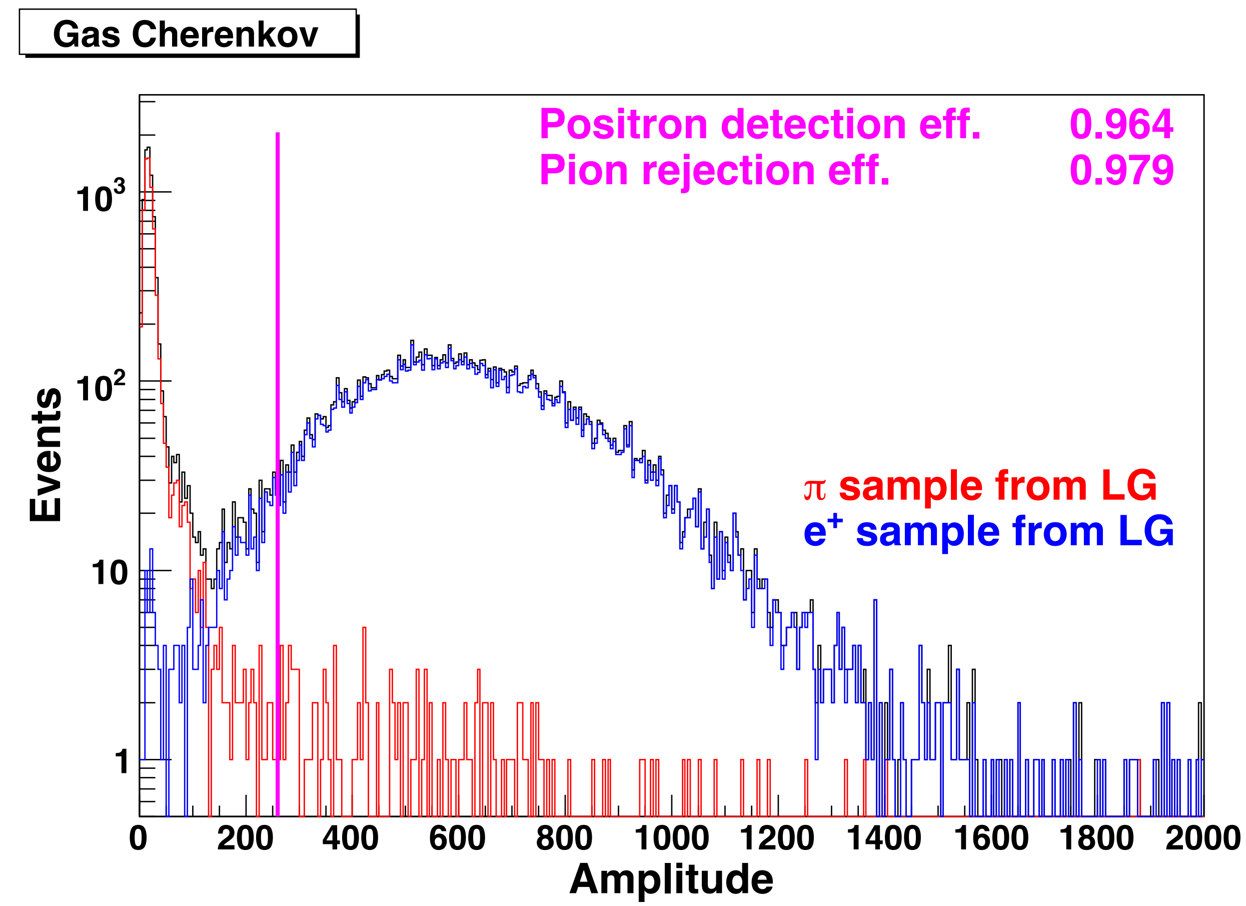


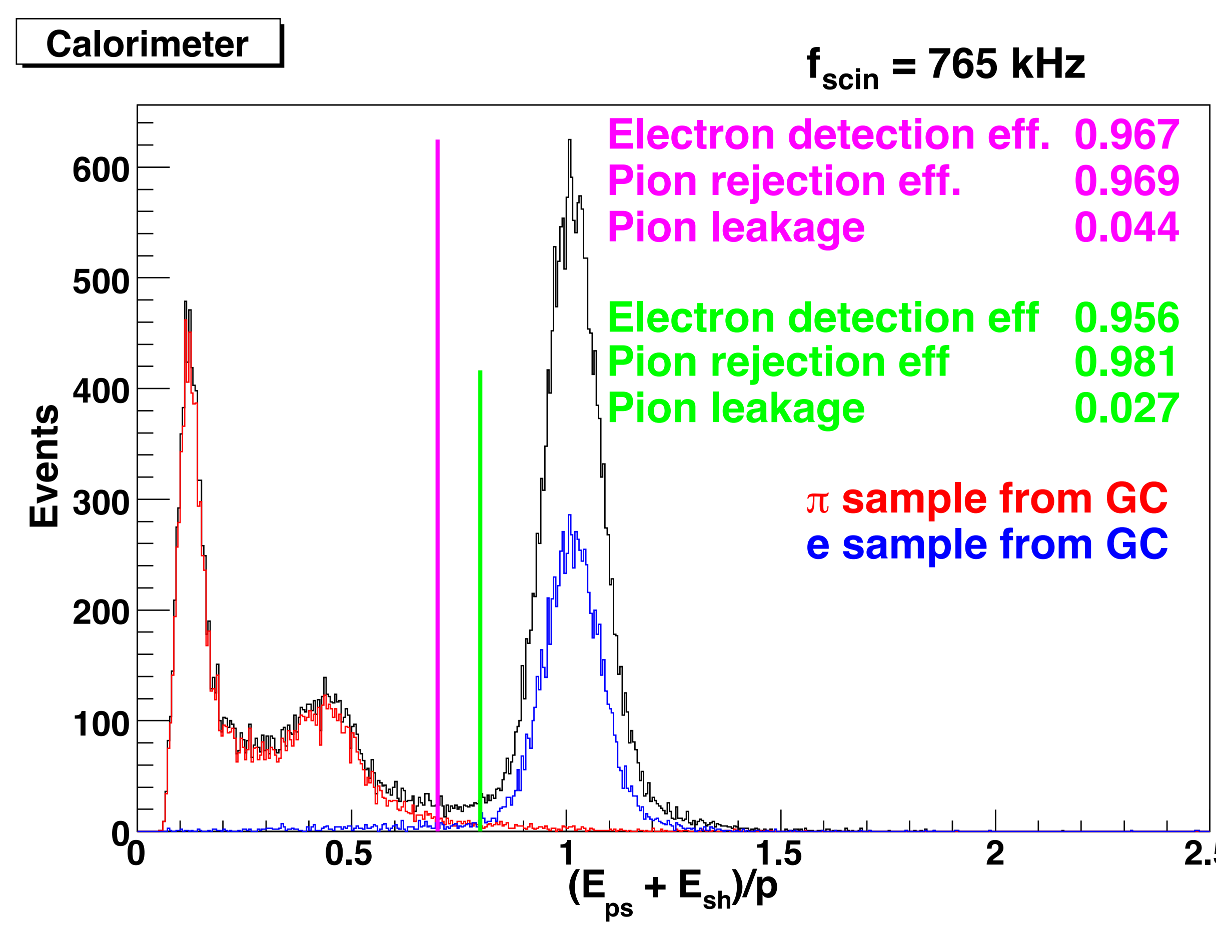
Thanks!

BACKUP SLIDES

Coincidence trigger and particle ID performance







coincidence peak for two-arm $X^{-}e^{+}$ trigger (requires coincident GC signal in positive-polarity arm)

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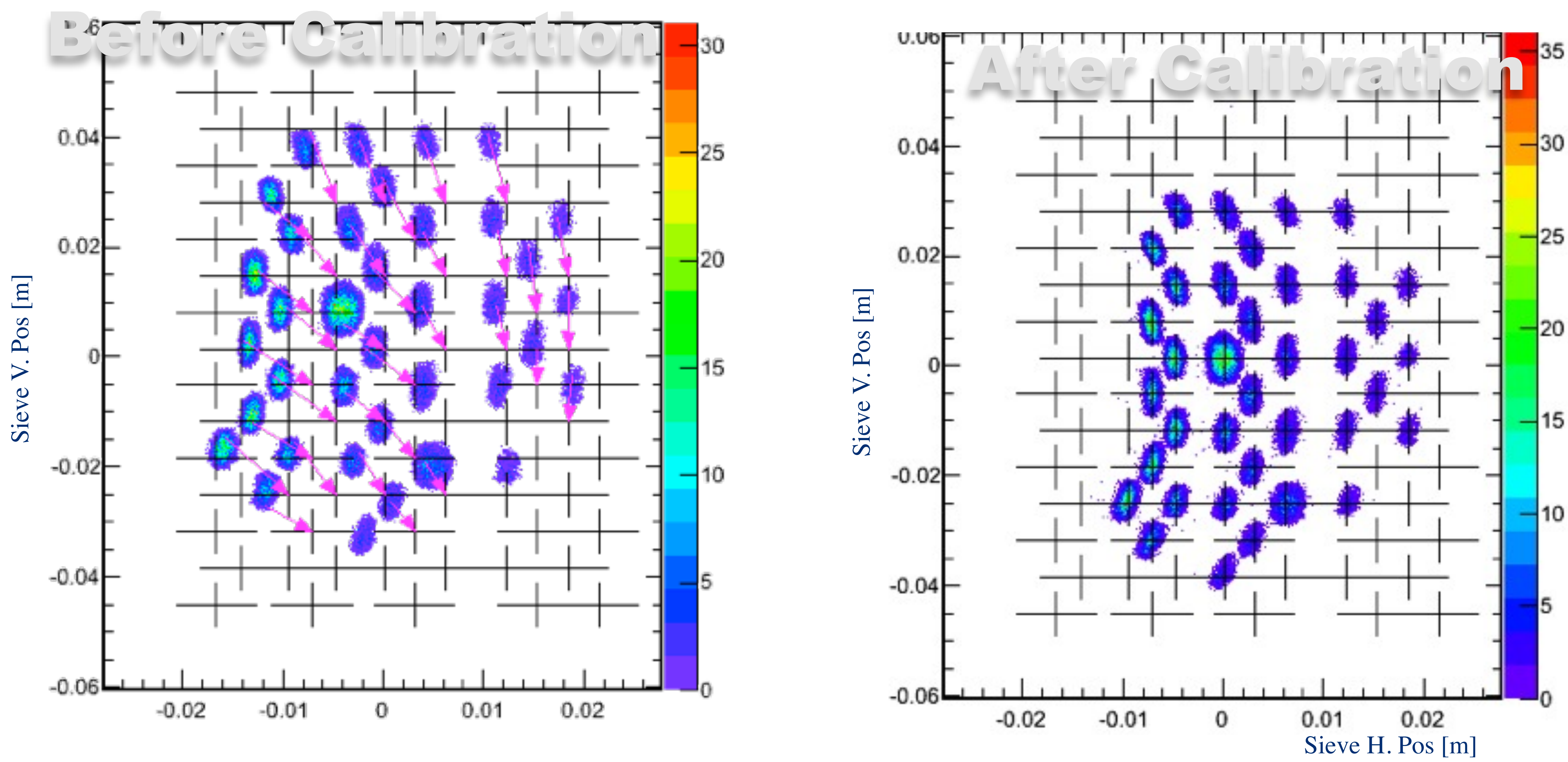
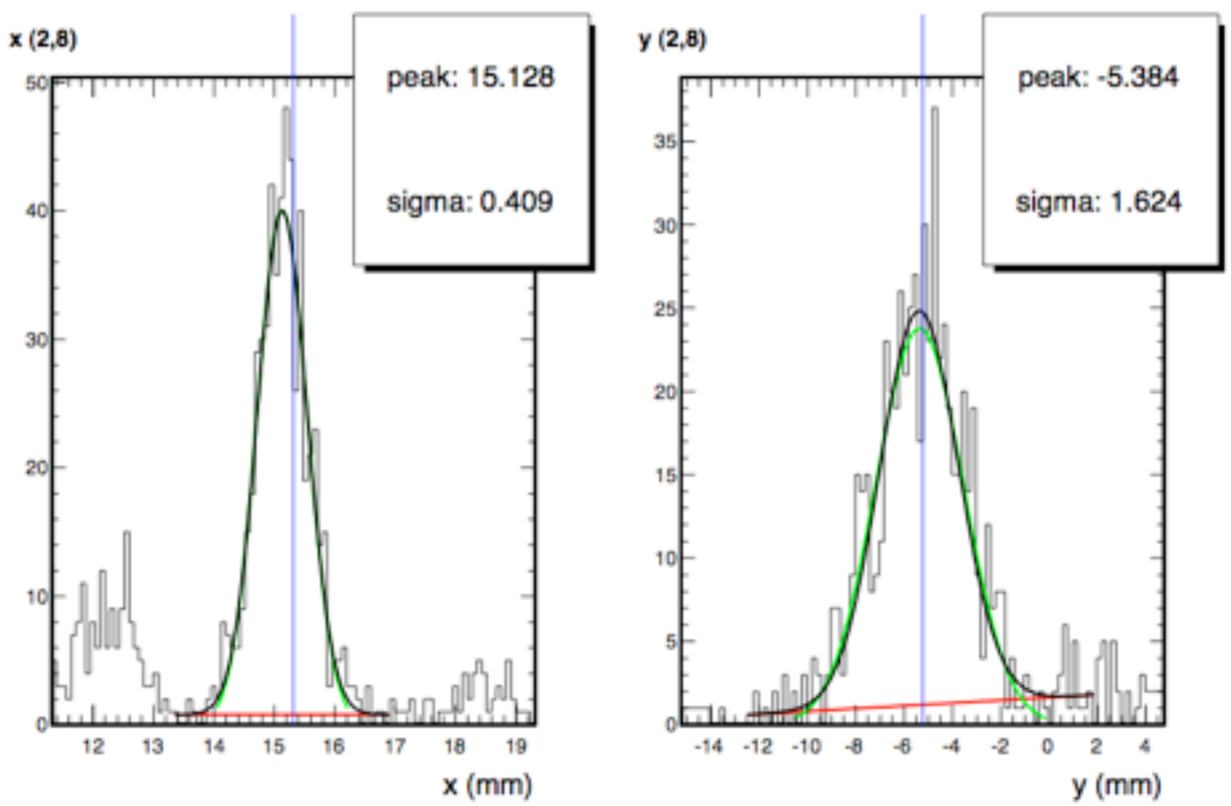
Sieve Slit Method

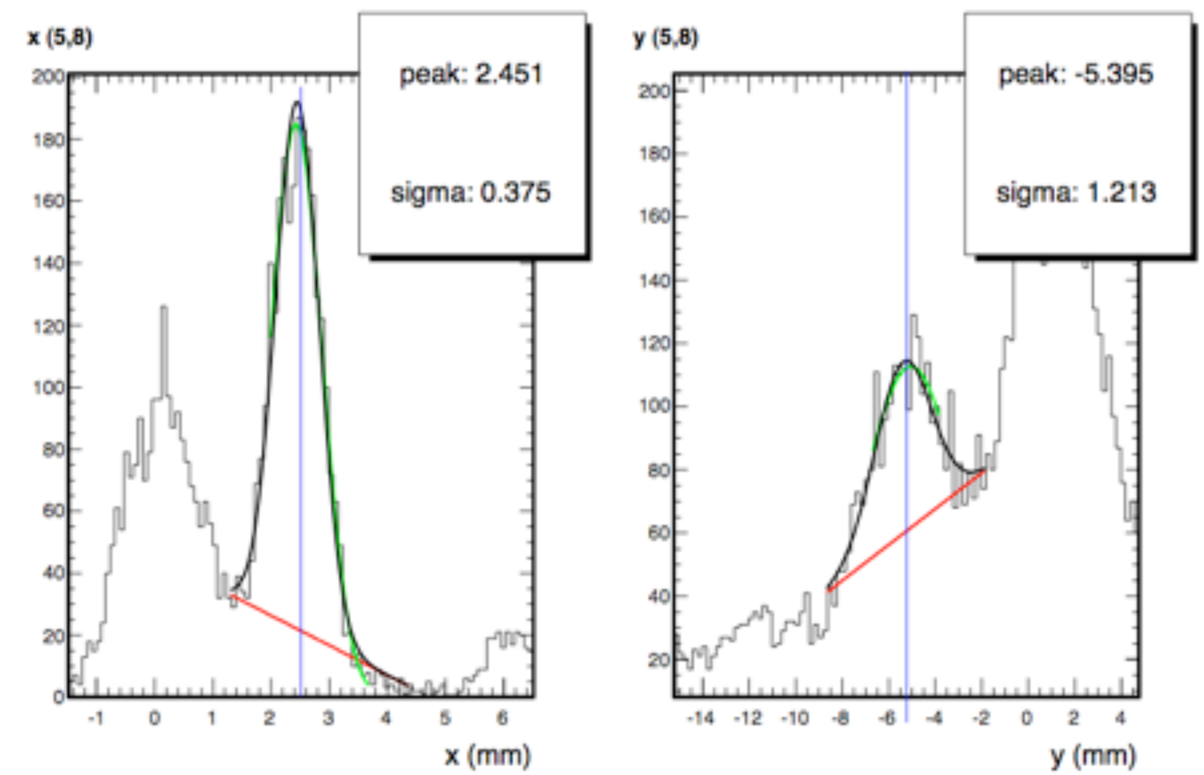


Left HRS calibration used 35 holes, Right HRS calibration used 38 holes

HRS optics for APEX



Left Sieve Run 1898-1899



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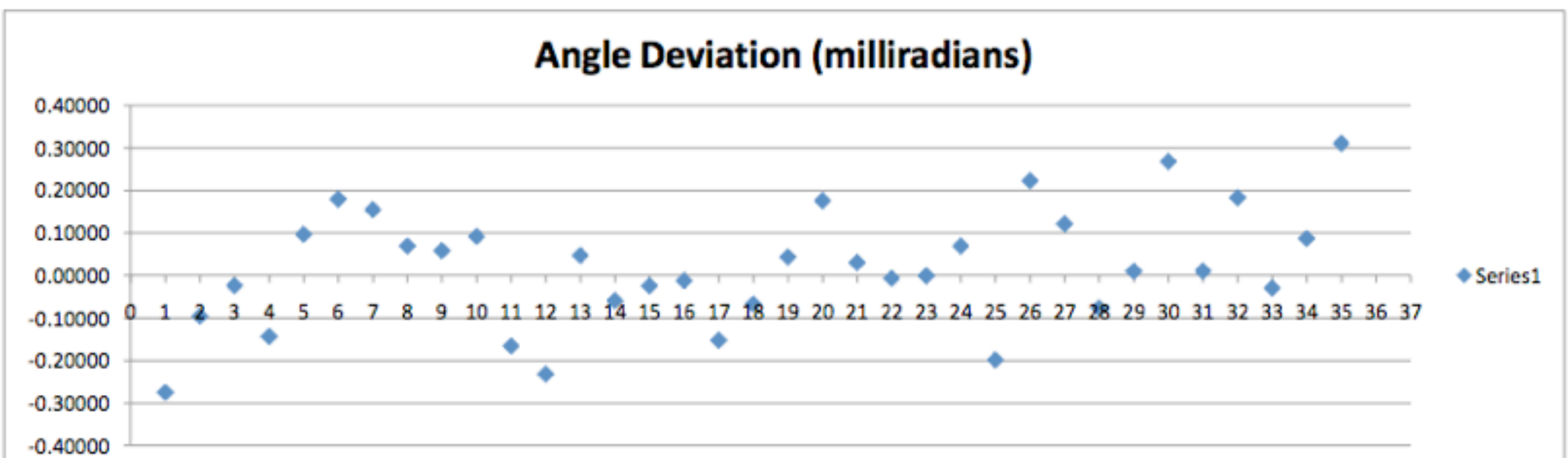

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Angular Resolutions

Averages weighted according to statistics

	LHRS (mrad)		RHRS (mrad)	
Optics calibration precision	Δ_φ	0.10	Δ_φ	0.10
	Δ_θ	0.24	Δ_θ	0.20
Tracking precision	σ_{φ_width}	0.26	σ_{φ_width}	0.43
	σ_{θ_width}	1.81	σ_{θ_width}	1.75
Final resolutions	σ_φ	0.29	σ_φ	0.44
	σ_θ	1.86	σ_θ	1.77

φ/θ – hor / vert angles

Mass Resolution

Angular resolution averages (mrad) determined for different masses

Mass (MeV)	180	195	210	225	240	Average
Left theta (mrad)	1.95	1.87	1.89	1.93	1.88	1.86
Left phi (mrad)	0.26	0.3	0.32	0.33	0.33	0.29
Right theta (mrad)	1.69	1.74	1.81	1.85	1.85	1.77
Right phi (mrad)	0.38	0.43	0.46	0.5	0.53	0.44

Mass resolutions (MeV) determined for different masses using 3 different methods

Mass (MeV)	180	195	210	225	240	Average
Using different angular resolutions for each event	0.833	0.965	1.026	1.061	1.037	1.005
Using angular resolutions listed in above table for all events	0.822	0.962	1.023	1.054	1.043	-
Using angular resolutions from "Total" column in above table for all events	0.869	0.965	0.995	0.994	0.966	0.977