The A′ Experiment (APEX)
Searching for New Gauge Bosons in the A' Experiment at Jefferson Laboratory

Natalia Toro (Perimeter Institute)
for the APEX Collaboration

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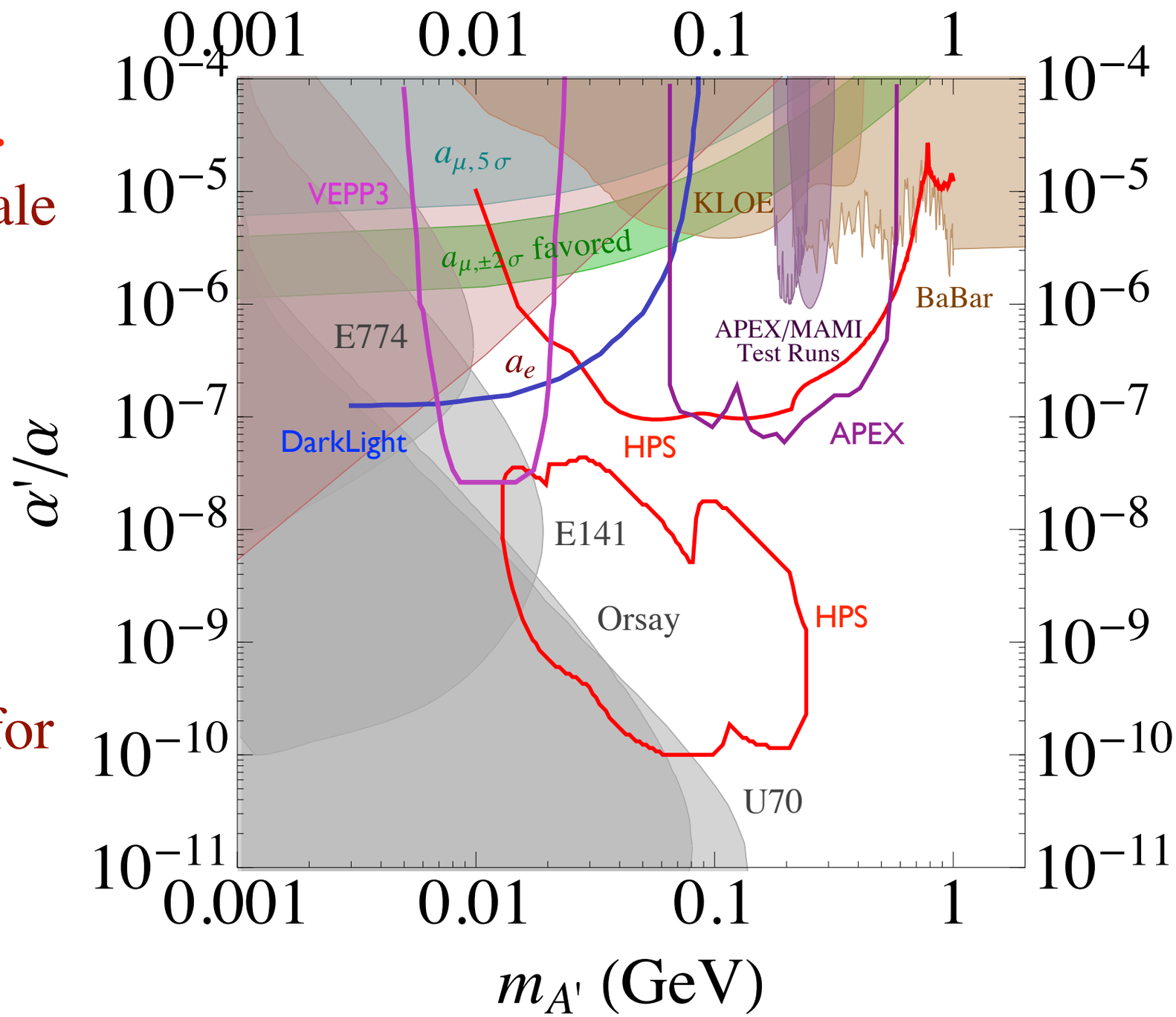
Outline

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

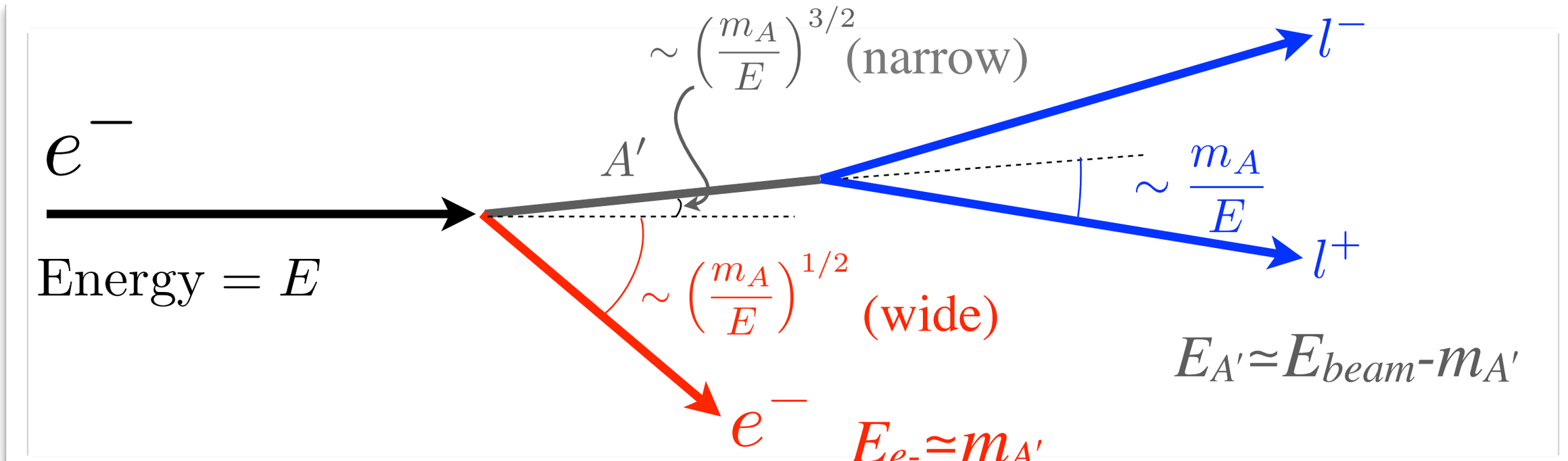
1) The APEX experiment:
general setup and rationale
a few important details
JHEP 1102:009,2011, arxiv:1001.2557

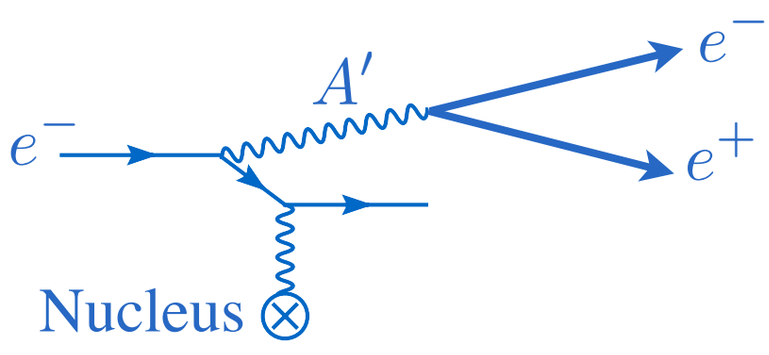
2) Test run (July 2010)
results
PRL 107:191804,2011, arxiv:1108.2750

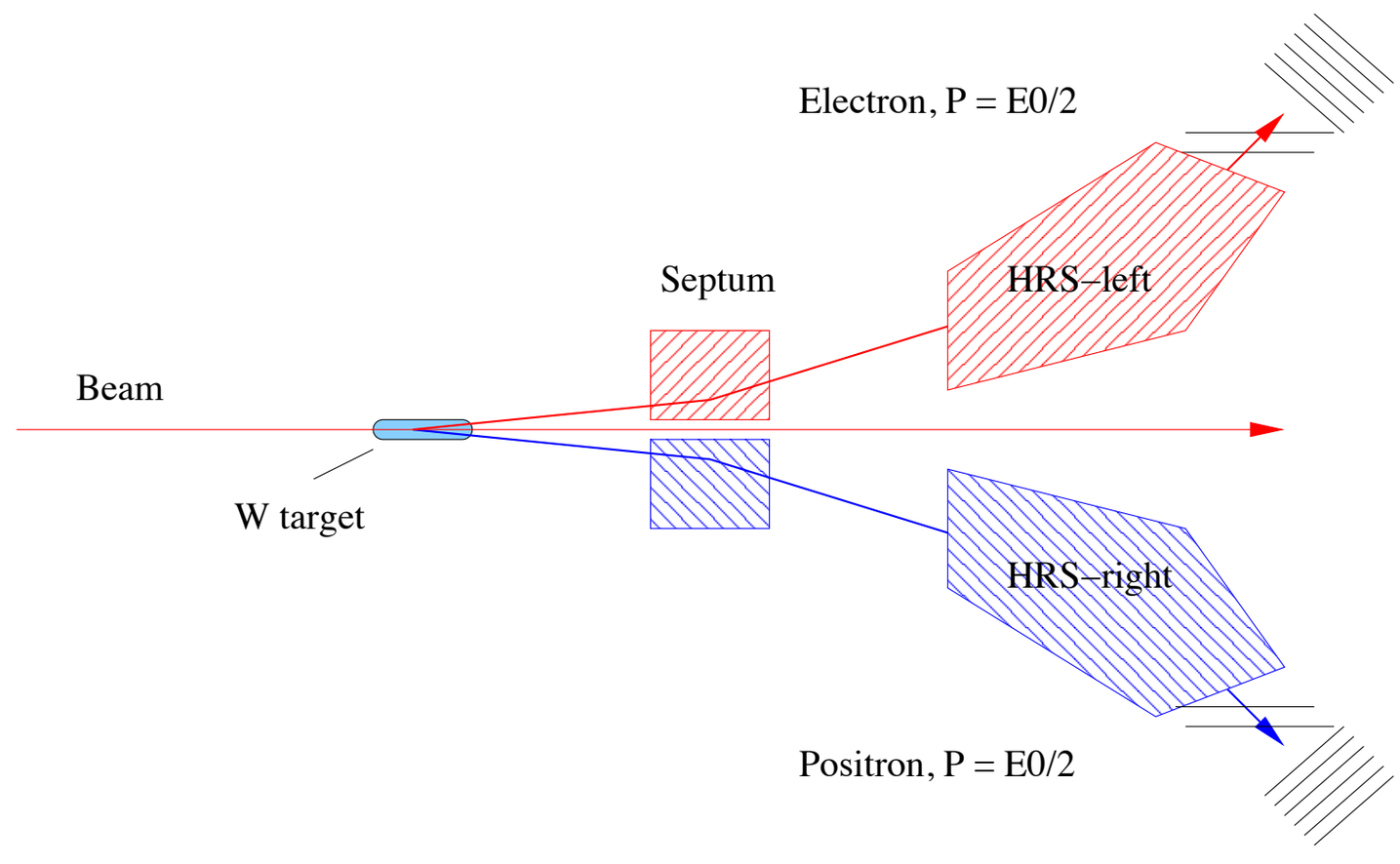
3) Full APEX
extended target
SciFi optics calibration for better mass resolution
new septum



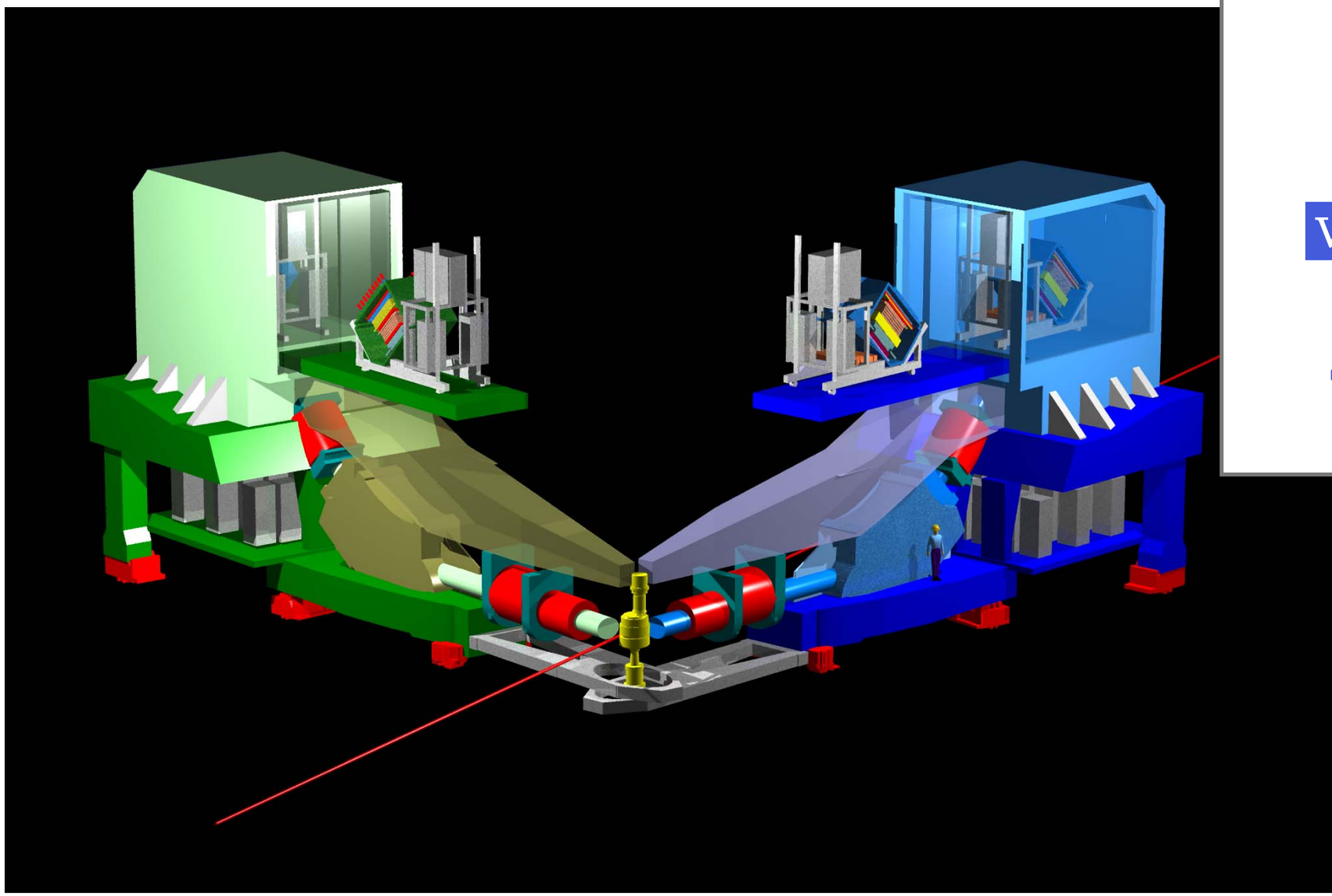
APEX Concept and Dark Photon Production

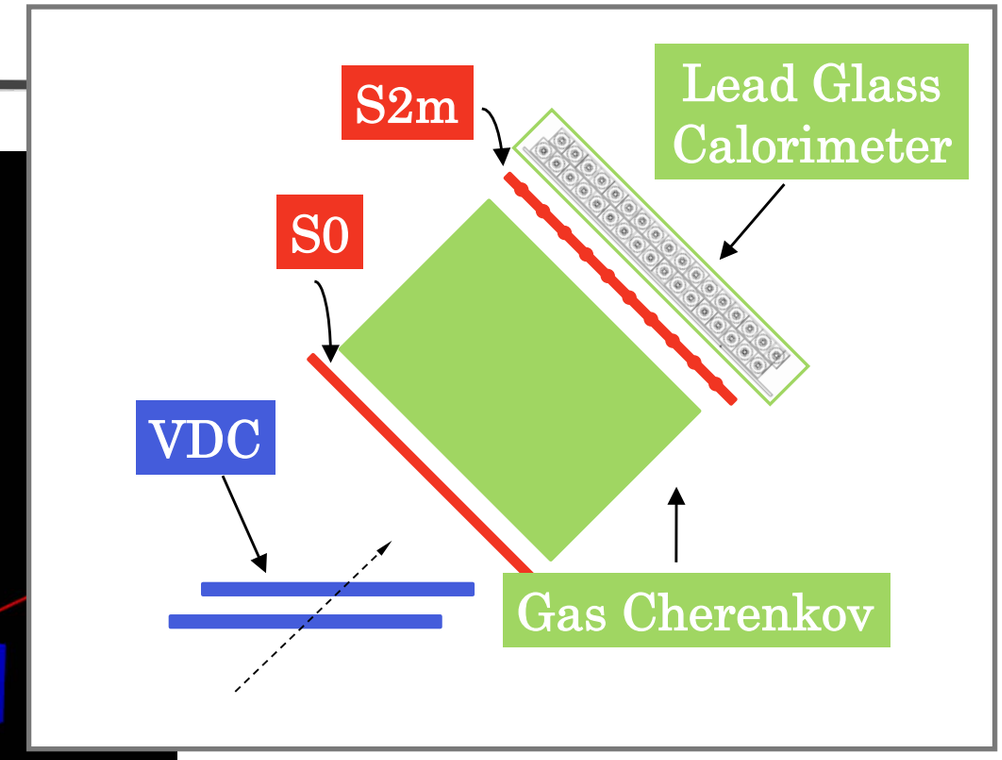






The High Resolution Spectrometers



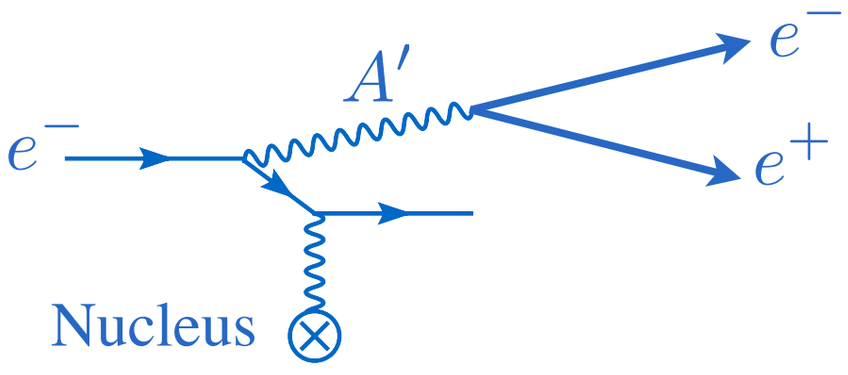


Range	Acceptance	Resolution
$0.3<p<4.0$ GeV/c	$-4.5\%<\Delta p/p<4.5\%$	$\delta p/p \leq 2\ 10^{-4}$
$12.5^{o}<\theta_0<150^{o}$	6msr	$\delta\phi$=0.5 mrad (H)
		$\delta\theta$=1 mrad (V)

(4.5 msr at $\theta_0=5^{o}$ with septum)

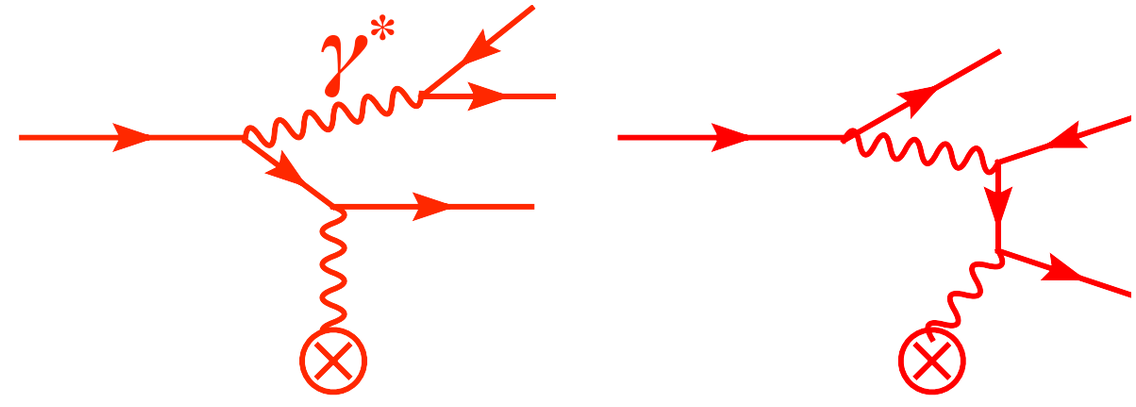
A′ Production and Background Kinematics ($m_{A'} \ll E_{beam}$)

A′ Production



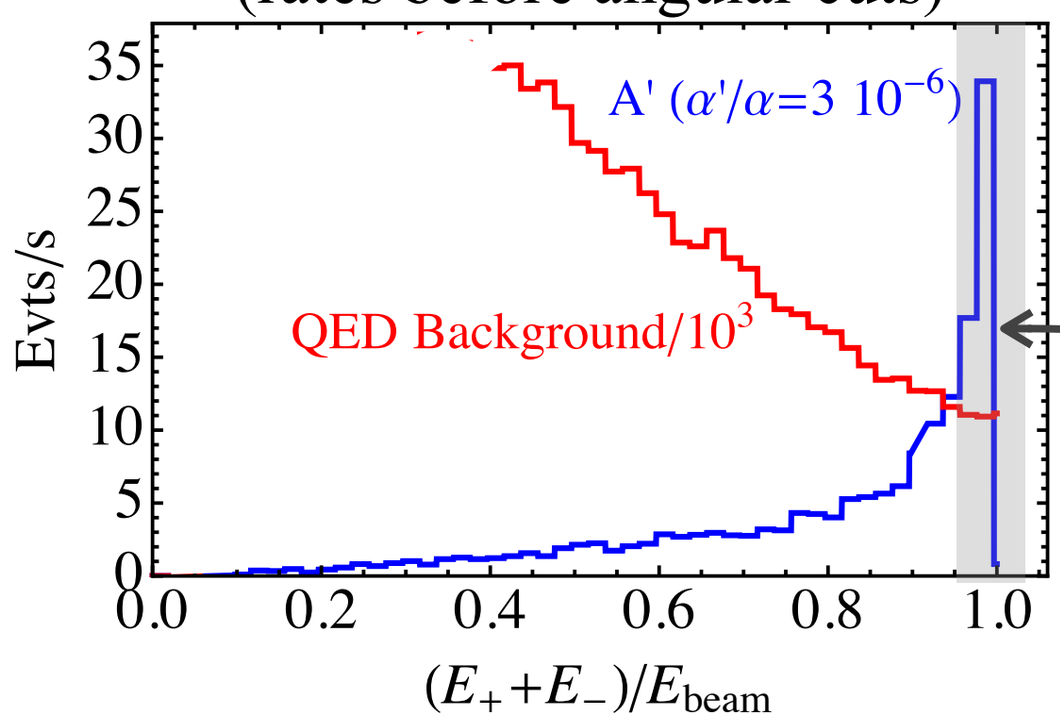
$$\sigma \sim \alpha'/m^2 = \varepsilon^2\alpha/m^2$$

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

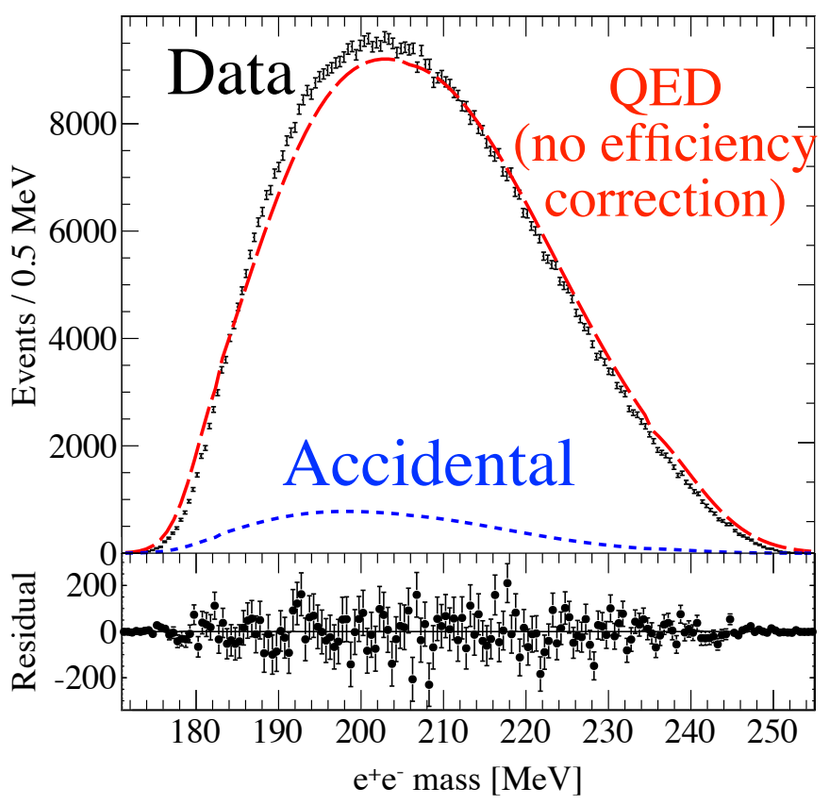
$$E^+ \approx E^- \approx E_{beam}/2$$

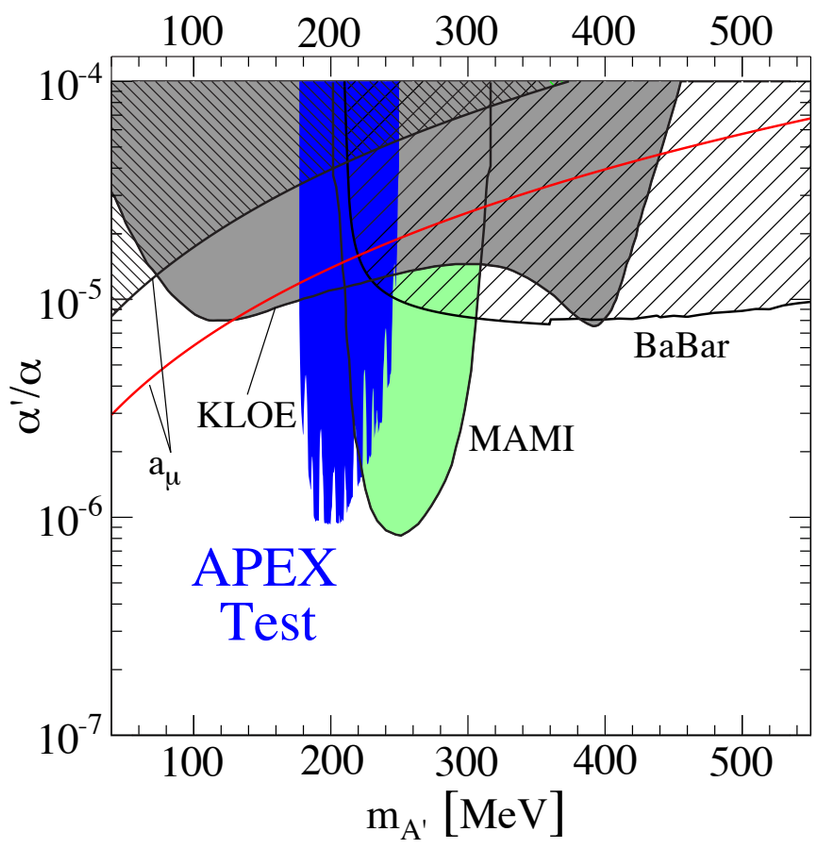
also suppresses e^- singles & other pair backgrounds

After rejecting accidental $e^-\pi^+$ (demonstrated in test run), event rate dominated by QED backgrounds above

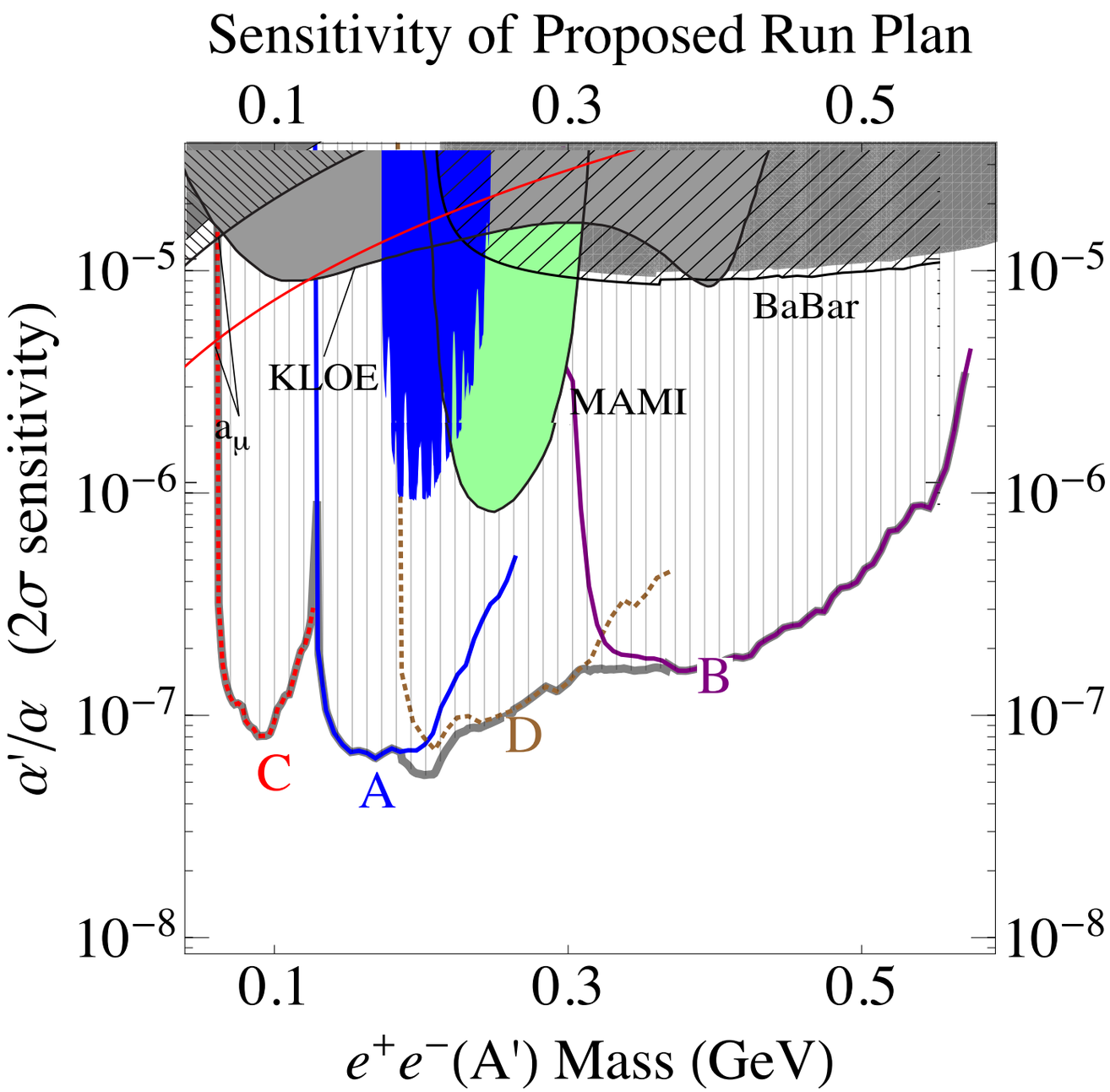
APEX test run

- Test run performed in Hall A, July 2010
  Many thanks to JLab & Hall A staff for tremendous support!
- **Verified all key aspects of apparatus performance**
  - VDC tracking performance at 4–6 MHz singles rates
  - Gas Cerenkov detector in coincidence trigger to reject π^+'s
  - spectrometer optics & mass resolution
  - measurement of physics backgrounds
- Resonance search on 700K good trident events





Full APEX run plan and sensitivity



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

>100x test-run statistics

Approved by JLab PAC 37 with recommendation to run as soon as possible

Explores parameter space with **unparalleled efficiency** (particularly above ~300 MeV)

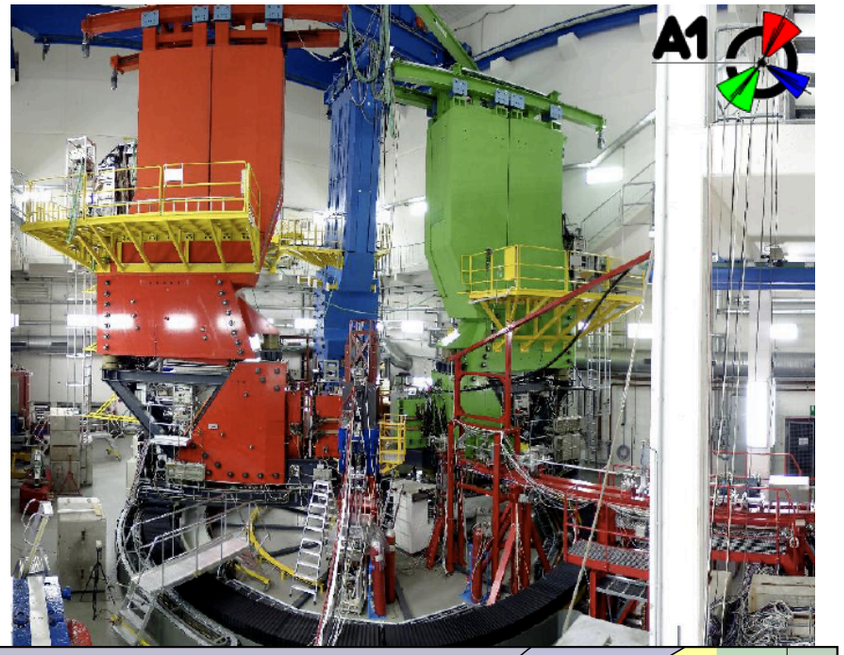
APEX in Context

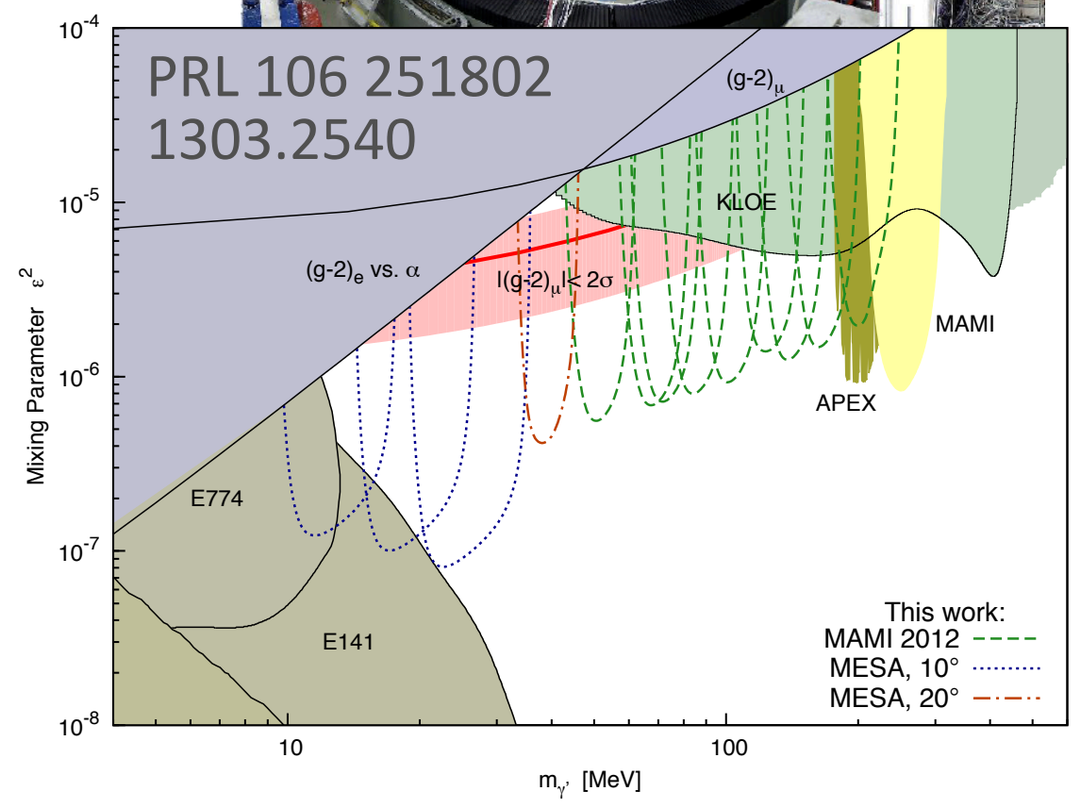
Mainz MAMI/A1 experiment

- superficially similar (spectrometer e^+e^- coincidence)
- similar test-run sensitivity

but...

- hitting <u>detector rate limits</u>
  at least 6mo run needed to match APEX below 200 MeV
- Search above ~200 MeV also hitting <u>beam current</u> and <u>radiation</u> limits





Bottom line:

APEX has unique advantage due to high-rate capability and septum magnet (small angle ⇒ higher signal acceptance)

APEX in Context

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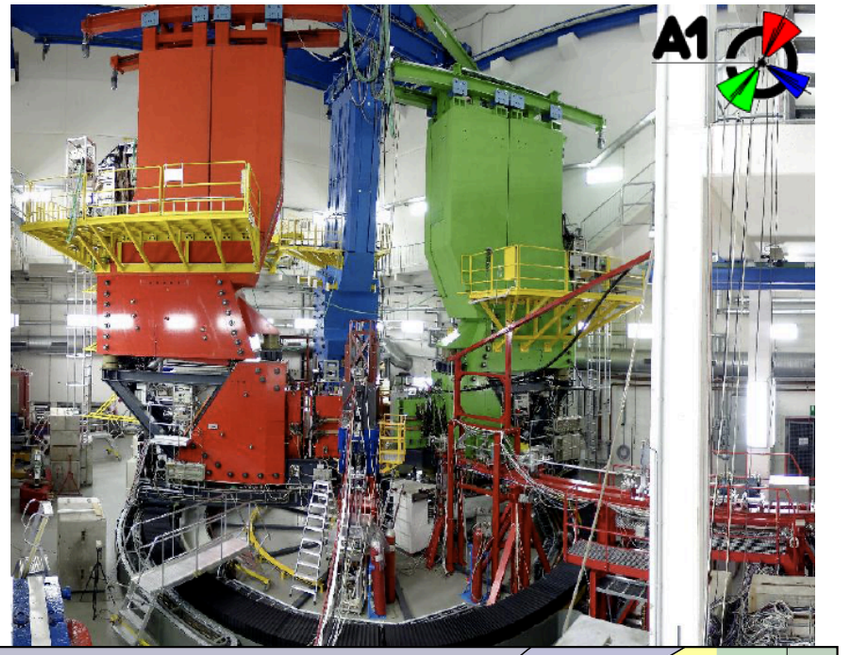
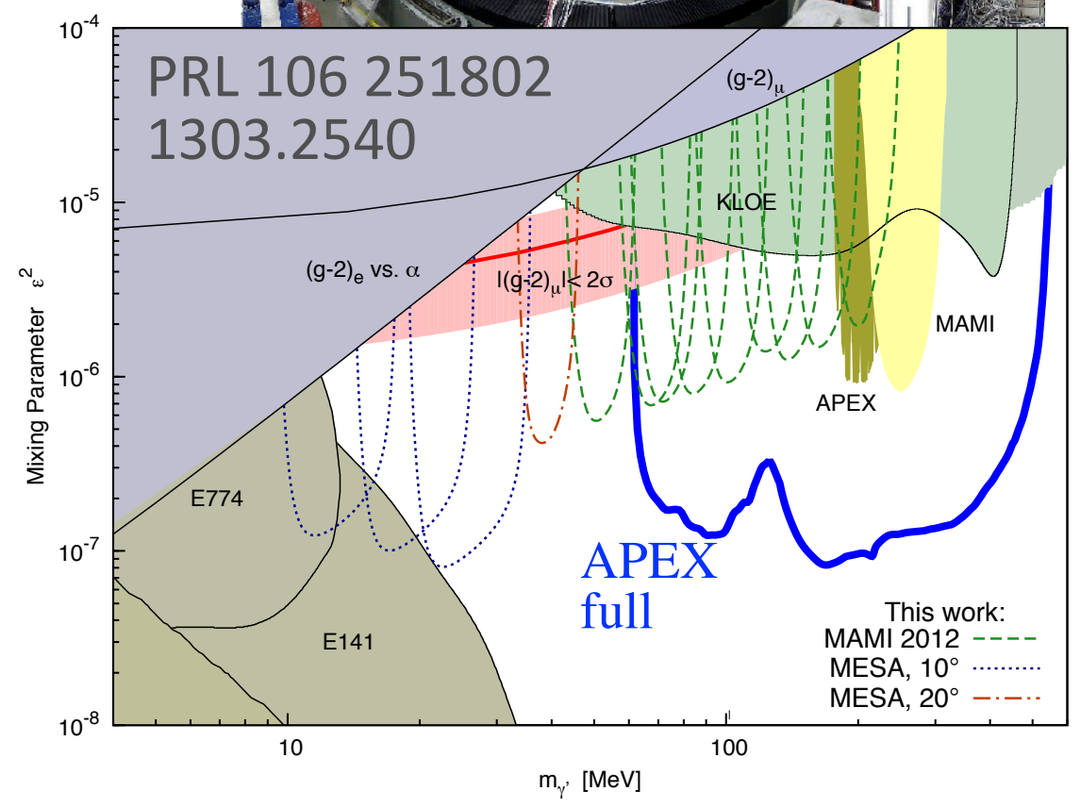




Bottom line:

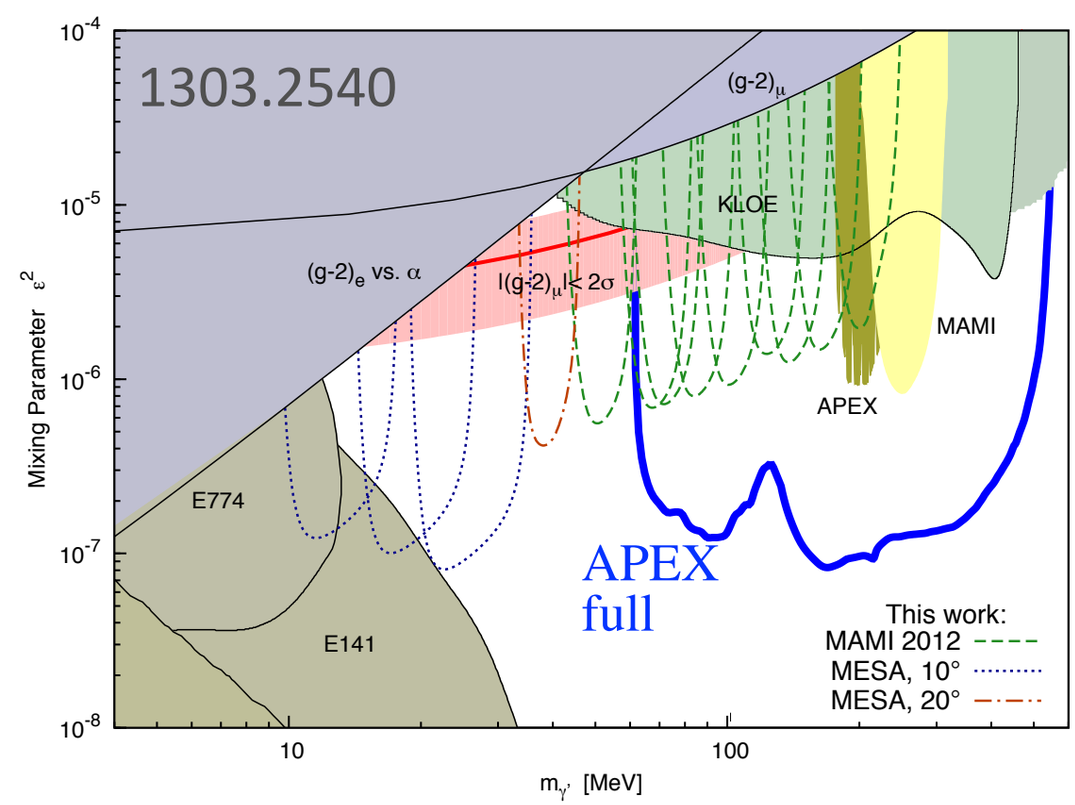
APEX has unique advantage due to high-rate capability and septum magnet (small angle ⇒ higher signal acceptance)

APEX vs. Mainz

Detector, beam, and radiation limitations ⇒ Mainz probably can only access high-coupling & low-mass portion of APEX sensitivity (without major upgrades)

Dashed green is **updated sensitivity estimate** for ~14 total beam-days (9 settings) [1303.2540 Beranek, Merkel, Vanderhaeghen]

- no publishable result expected from 2012 run
- present dark-force plans focus on lower A′ mass, including MESA



Readiness for Full Run

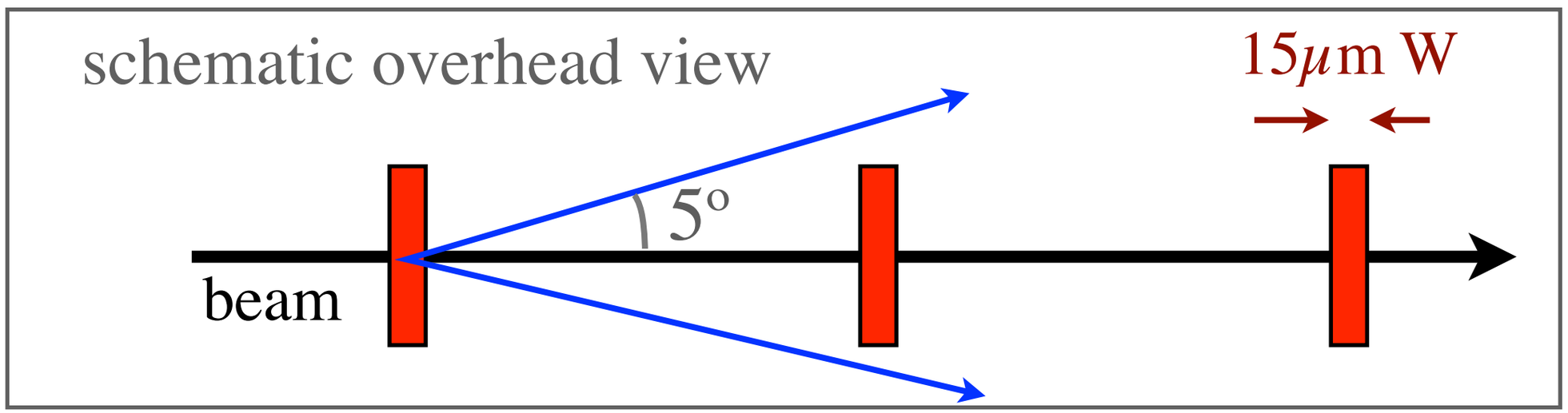
- APEX extended target
  - target built for test run is at JLab
- SciFi detector for optics calibration
  - design and production complete; first arm assembled and tested
- Septum
  - design nearly finalized & vendor quotes obtained
- HRS detector maintenance is proceeding

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

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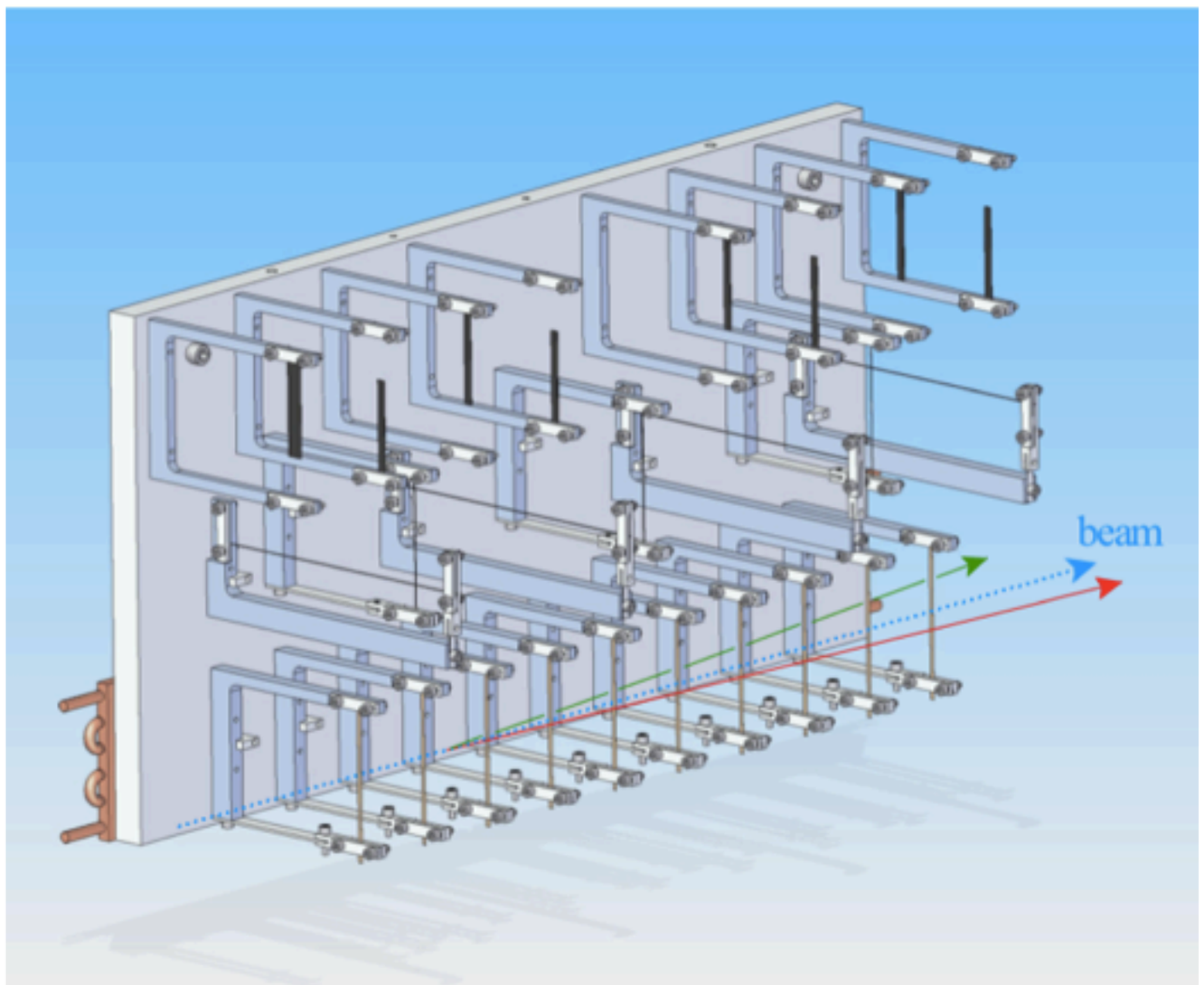
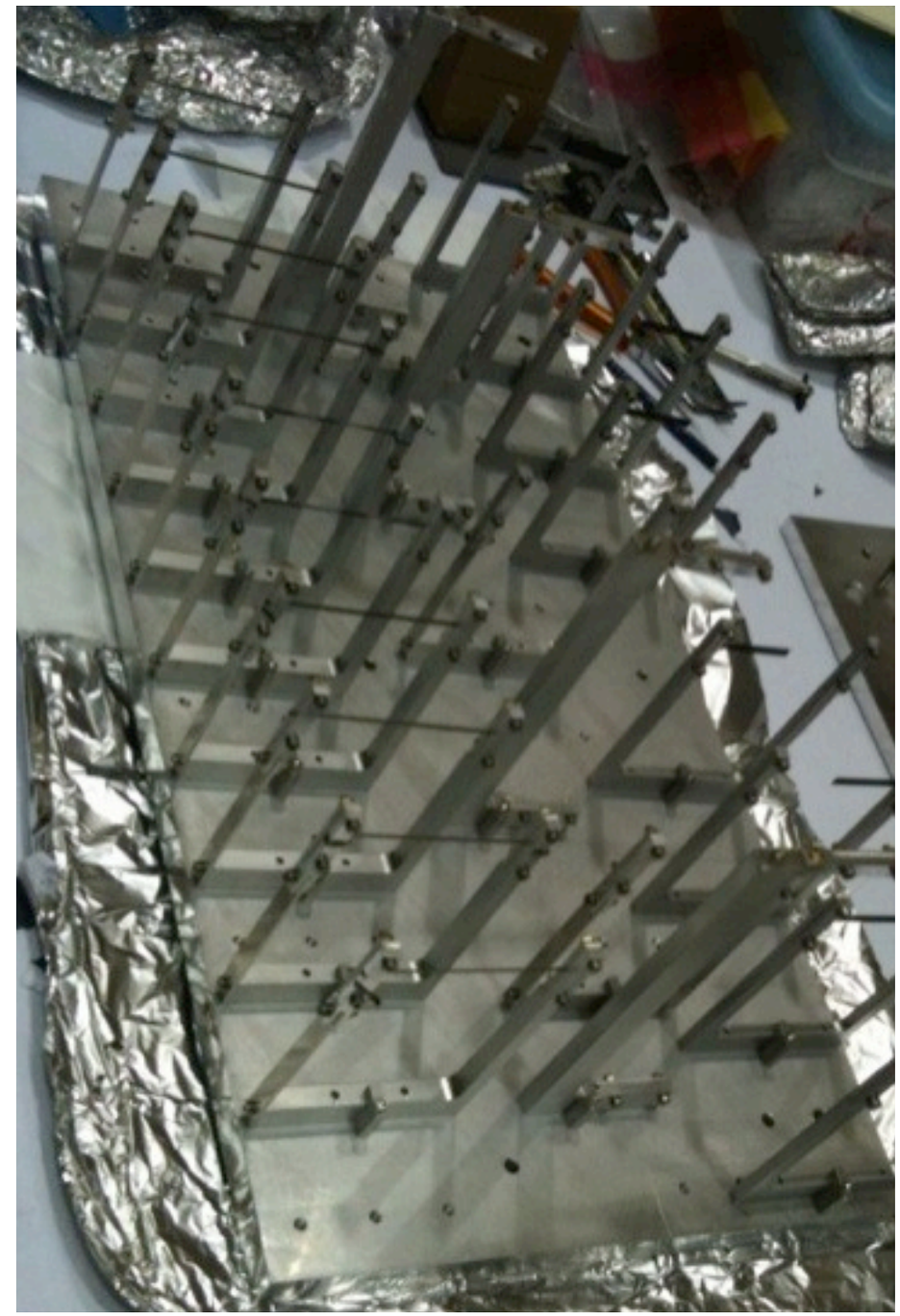
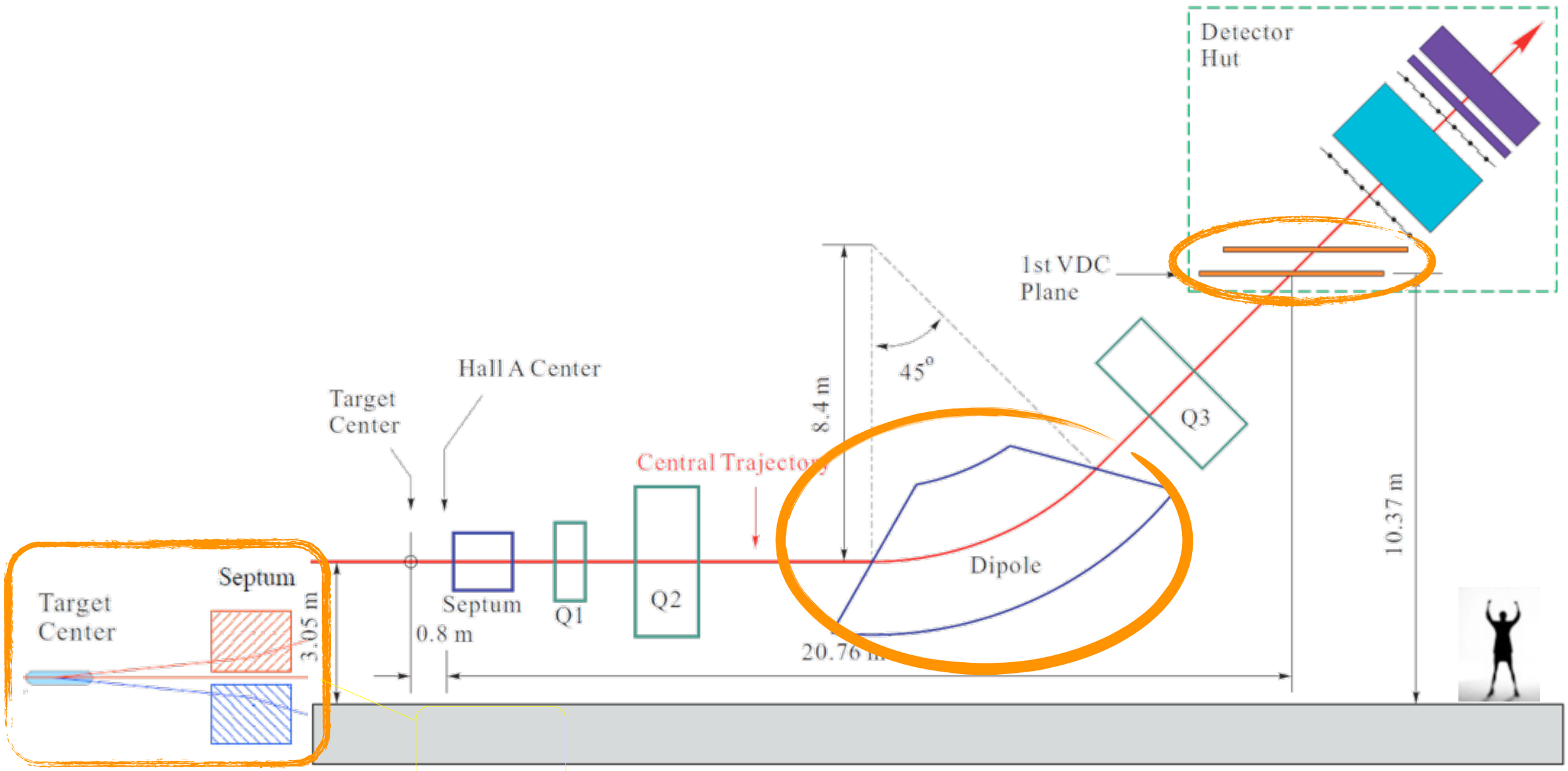




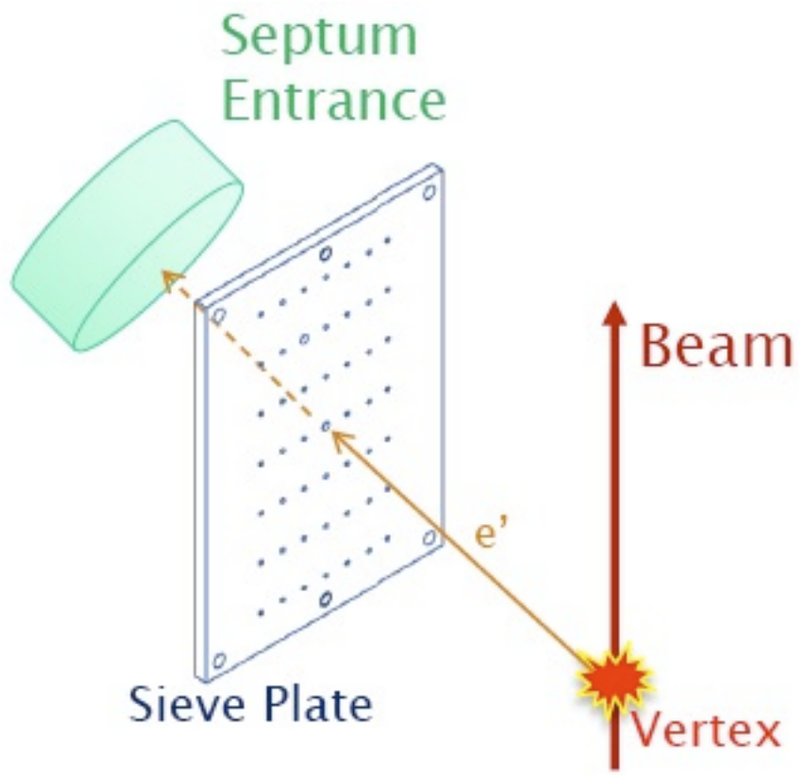
Magnetic Spectrometer Optics

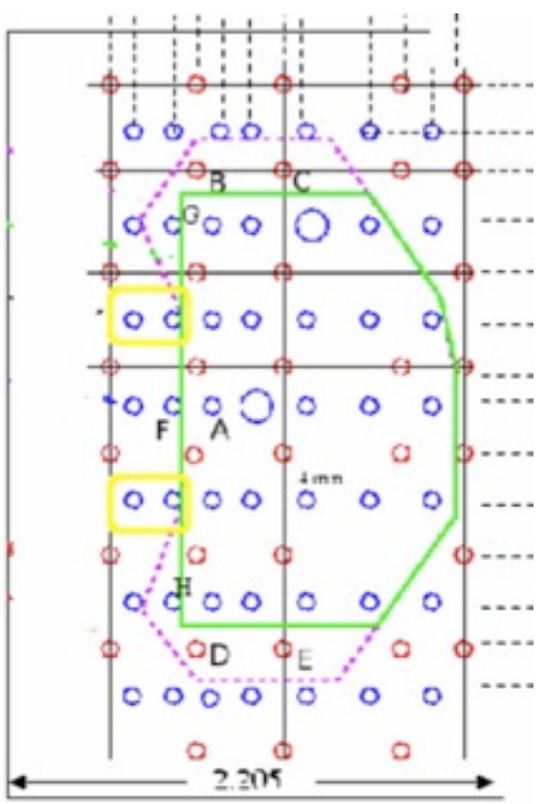
Measuring Contributions to the Mass Resolution
(dominant: **angular resolution** + mult. scatter)



Top view

Test Run Optics Calibration





Removable sieve plate is inserted upstream of septum.

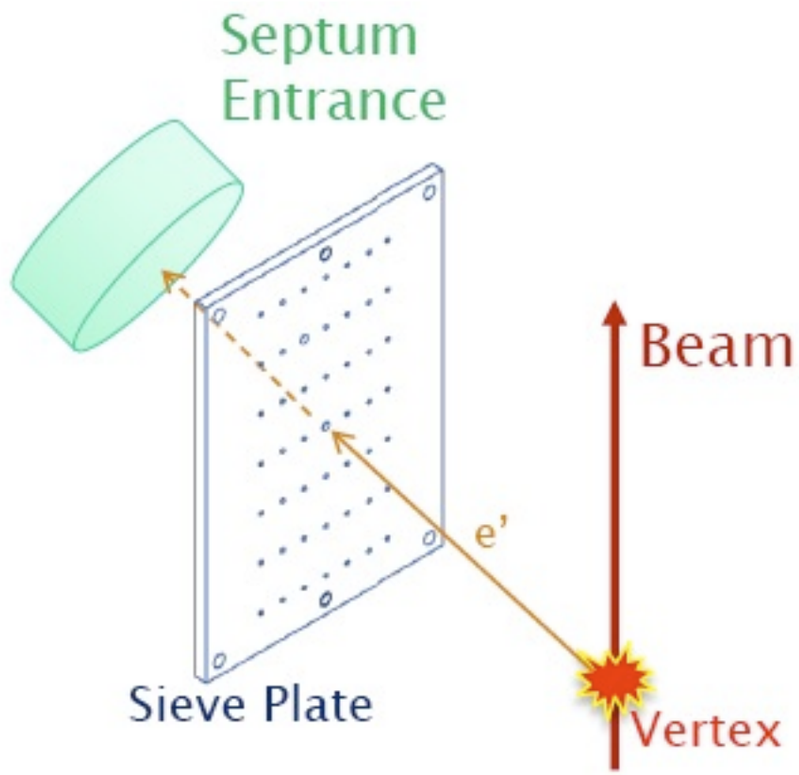
Use surveyed locations of sieve holes to calibrate magnetic optics.

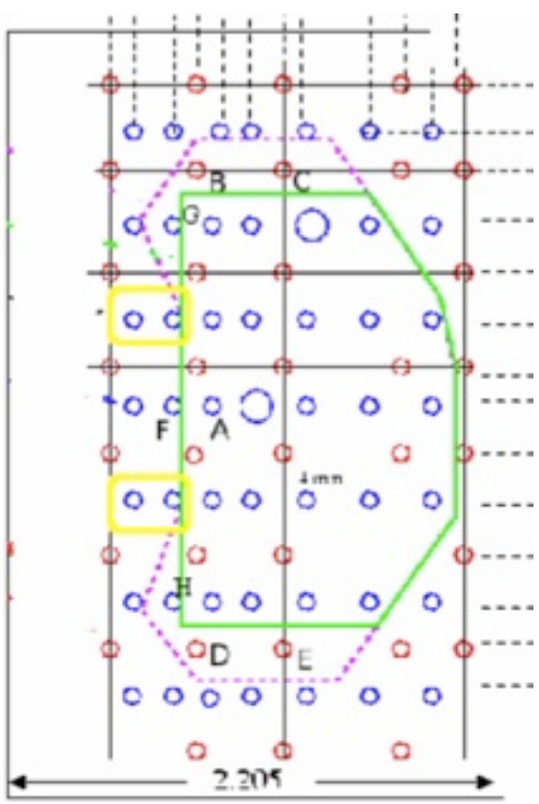
Use reconstructed hole sizes to measure resolution.

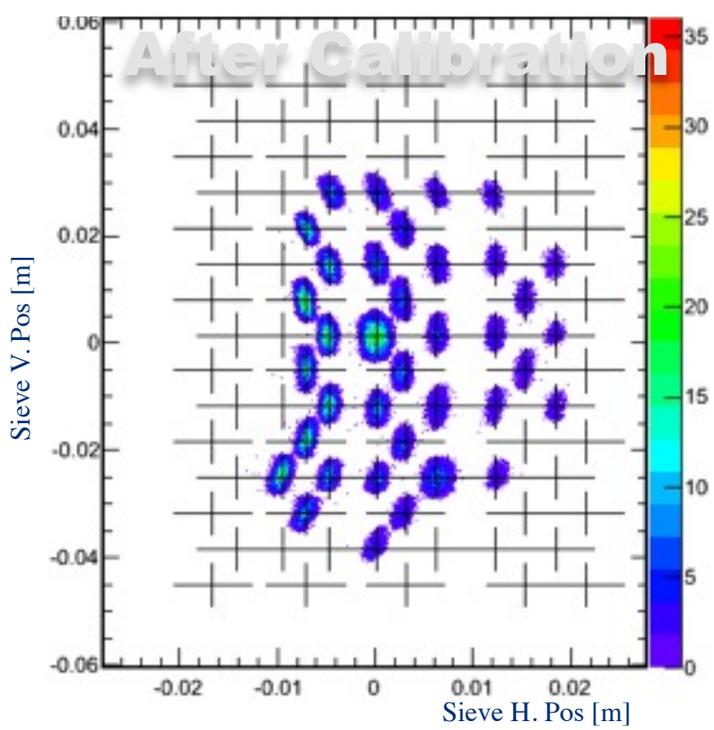
...this method only works for negative polarity, and requires running at different beam energy.

Mass resolution≈1 MeV ~0.5%

Test Run Optics Calibration







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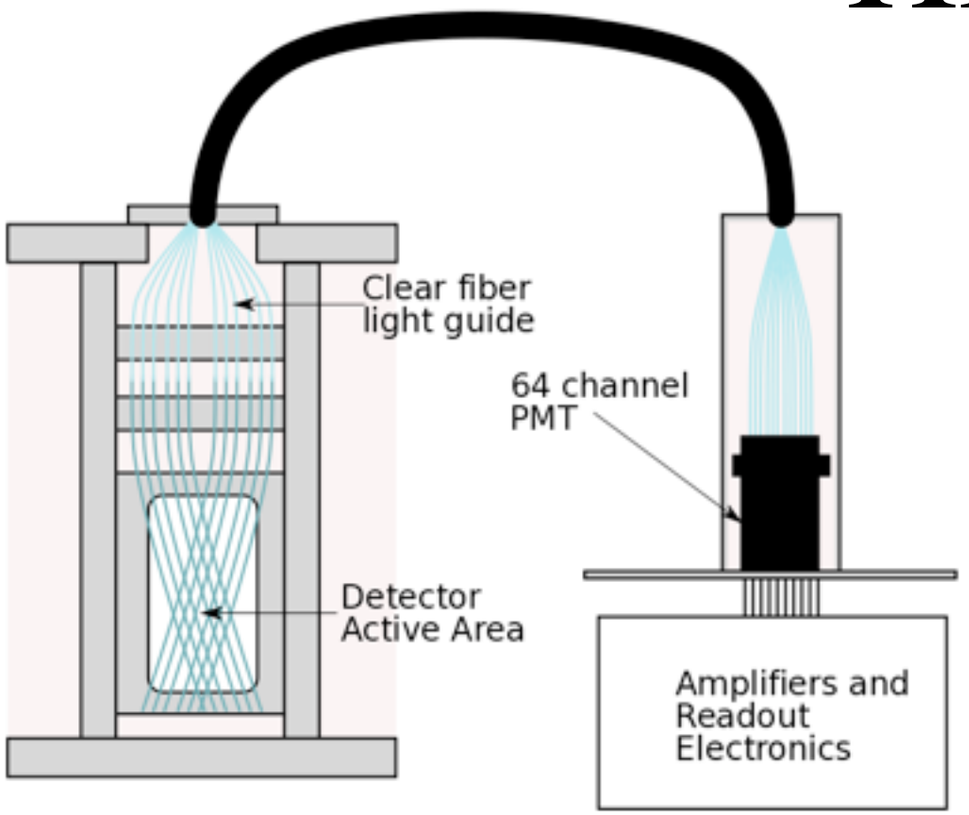
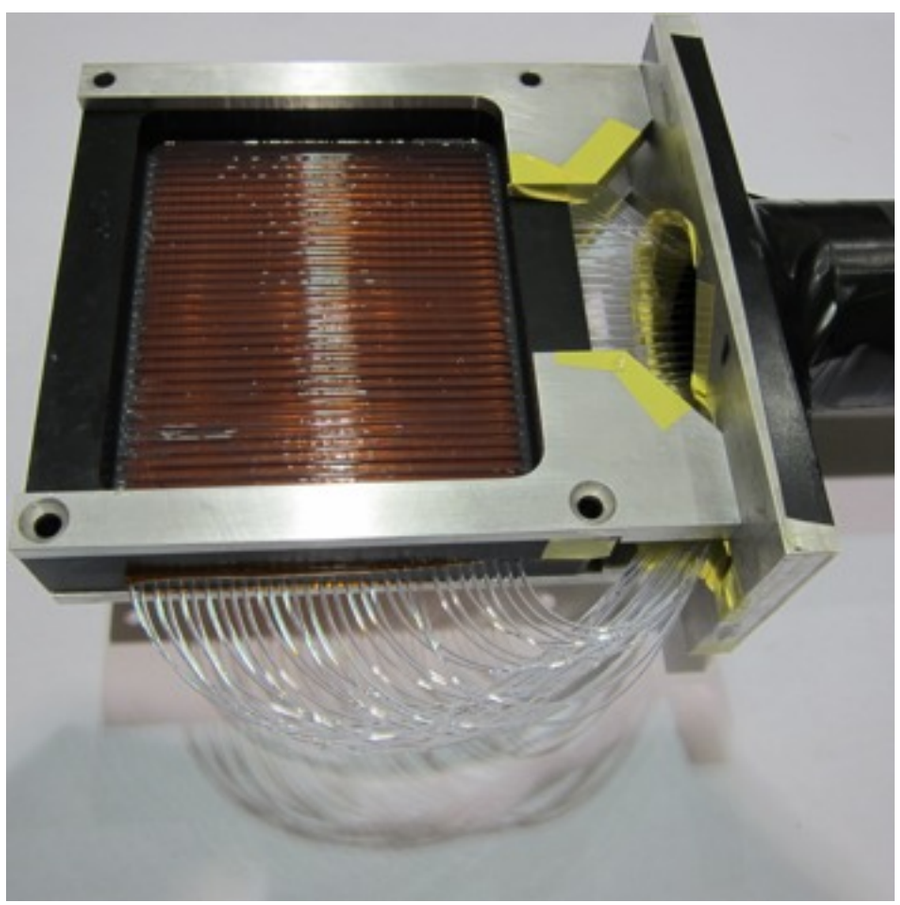
HRS optics

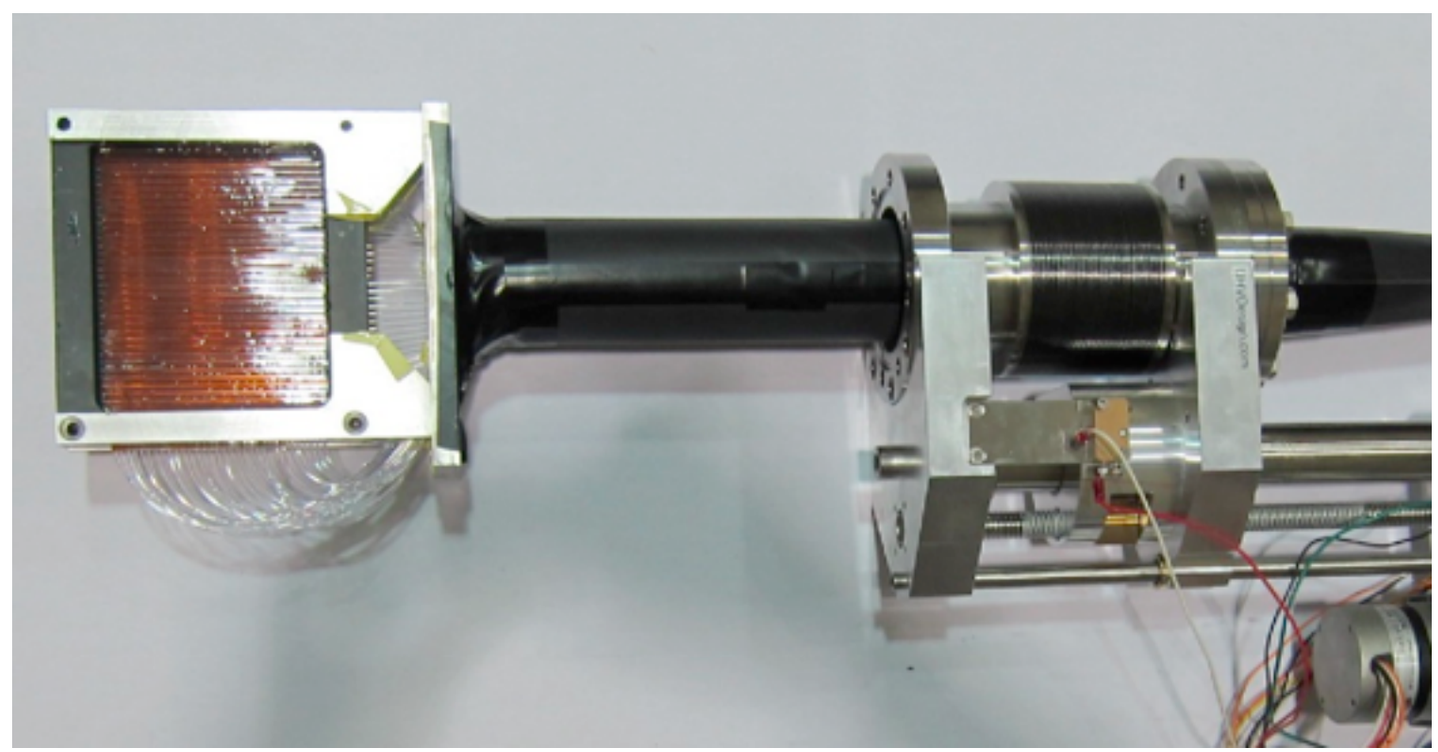


"Active sieve slit": tagging by a Sci Fiber detector

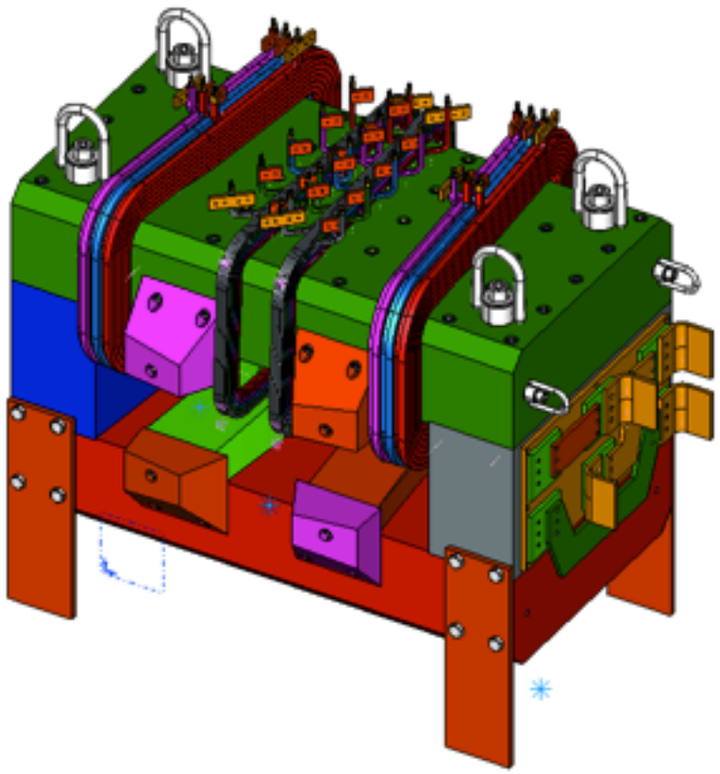
- 1 mm fibers with 1/16" pitch
- Projected rate: 1-3 MHz per fiber
- Off-line time window < 5 ns
- Nearing completion

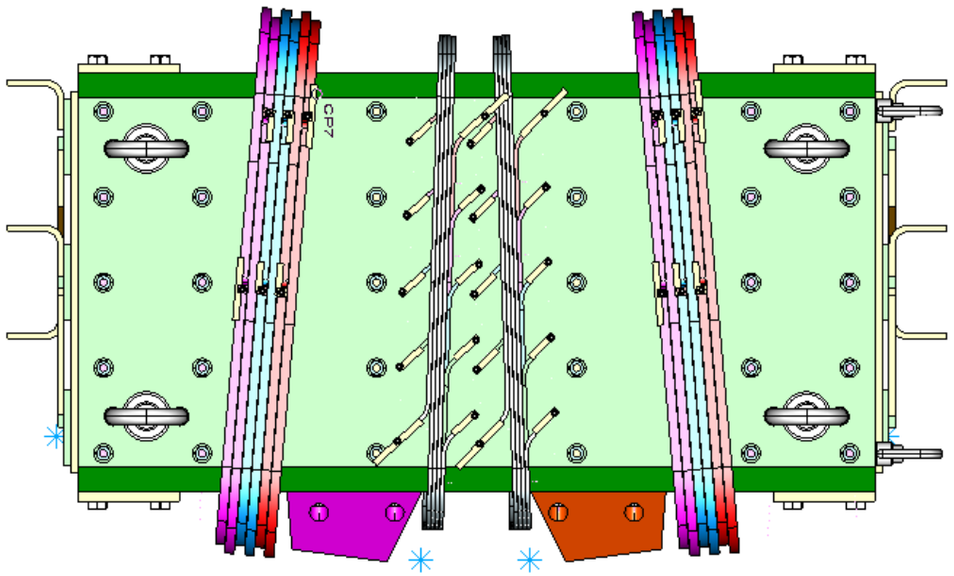
Allows optics calibration at production beam energy & for both polarities





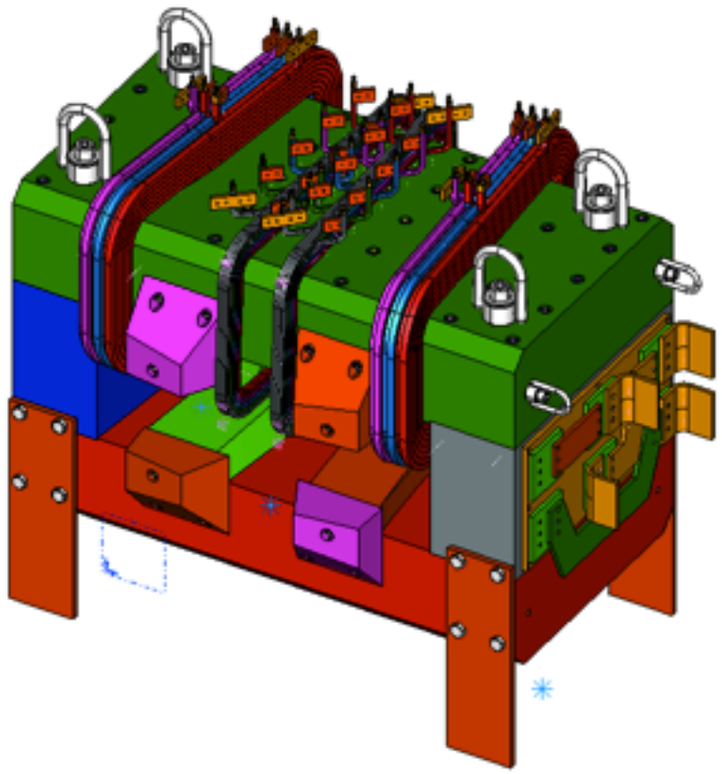
New HRS Septum Magnet

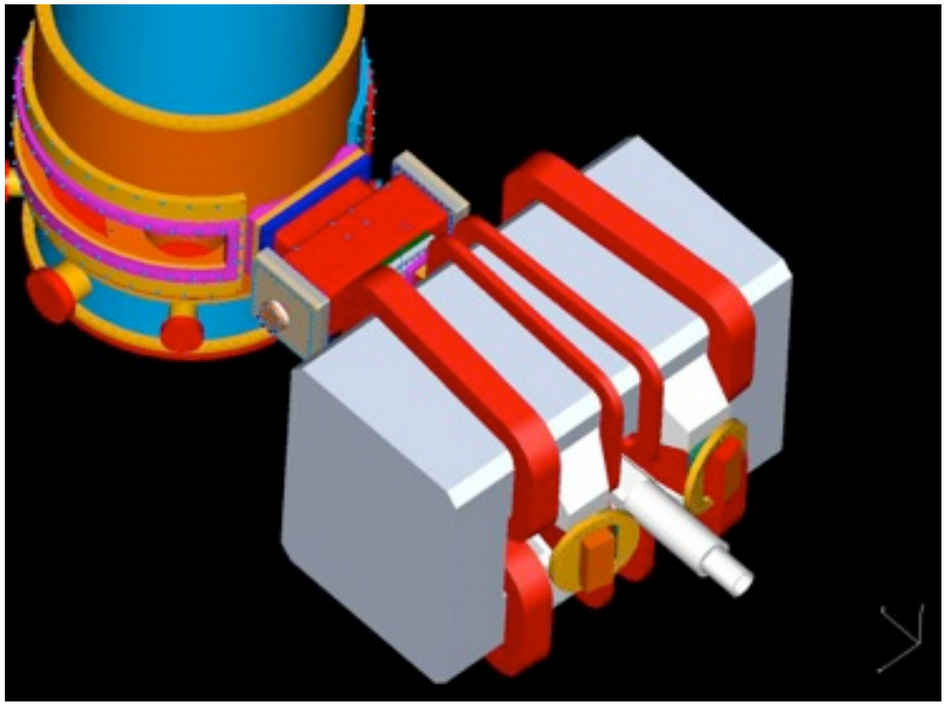




- Designed for parallel field capability
  (minimize fringe field near beamline)
- Optimized for full angular acceptance
- High density coils used to enable high-energy use

New HRS Septum Magnet





- Design to be completed in next few weeks
  - quotes obtained from vendors
  - partially funded by NSERC DAS
- New extension box (as for PREX) and vacuum connection to spectrometers needed
- Requires 2kA for high-energy settings (same as SBS magnet)

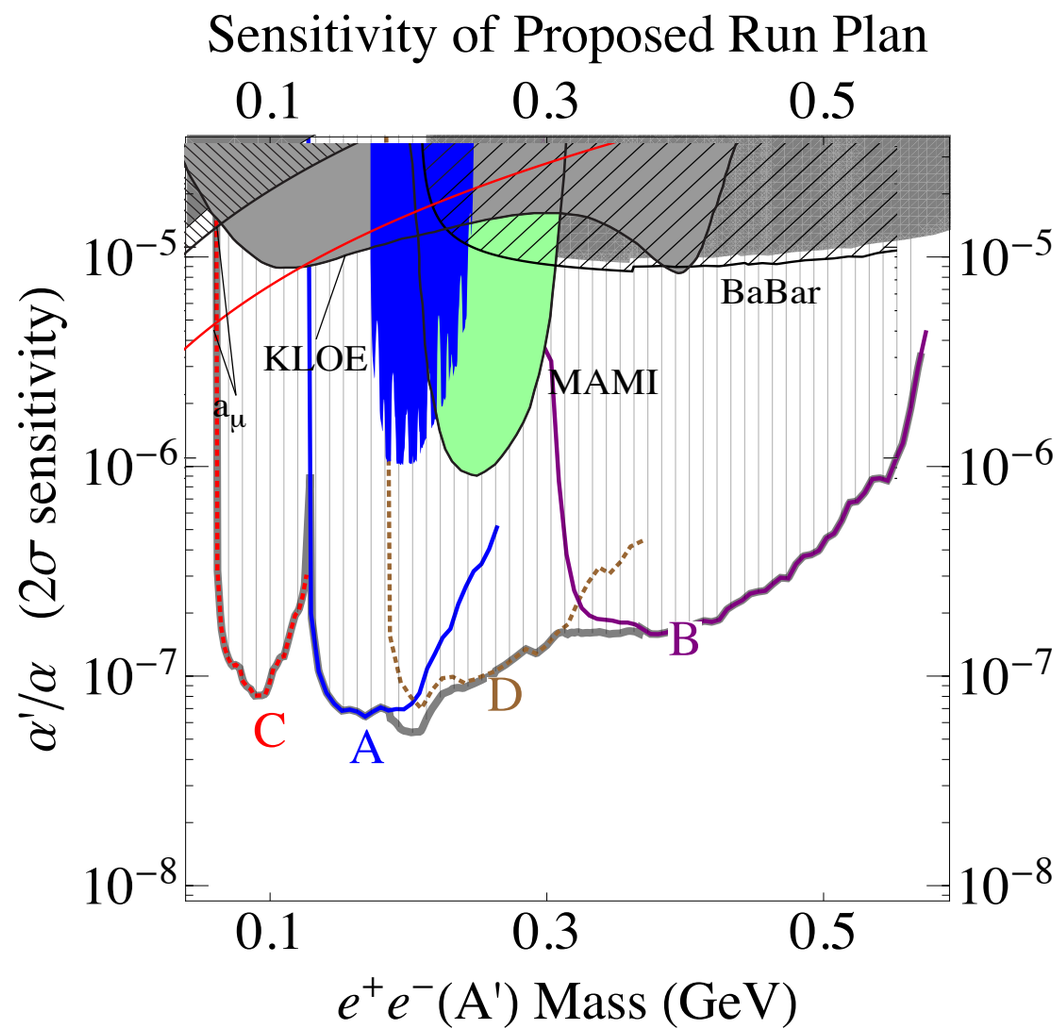
Summary

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

Strong physics impact already from test run (most cited Hall A result in last 5 years)

APEX can explore important range of mass and coupling ***most efficiently*** and ***before other experiments***

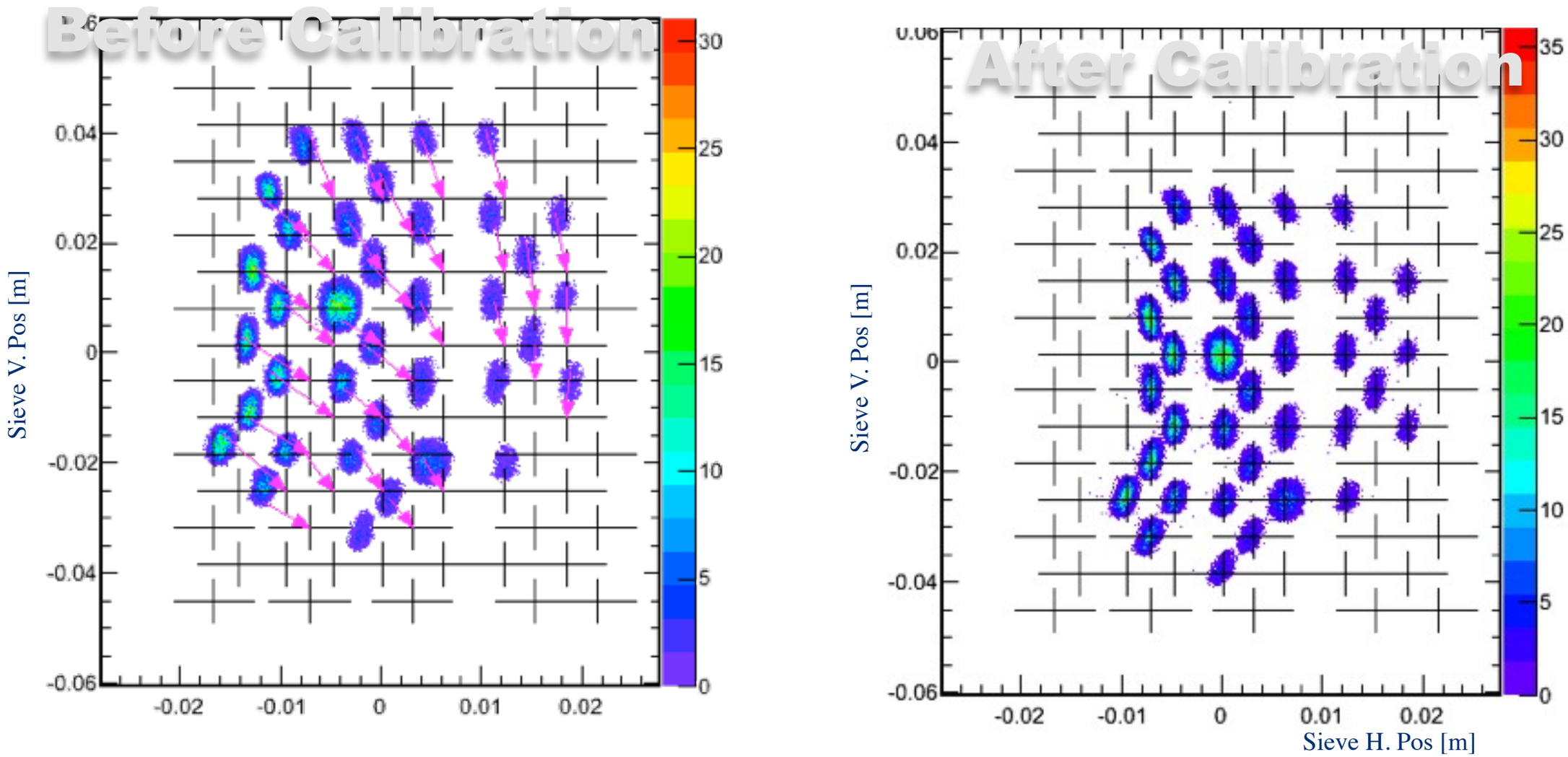
Opportunity for immediate science impact – even with commissioning-quality beam.



Thanks!

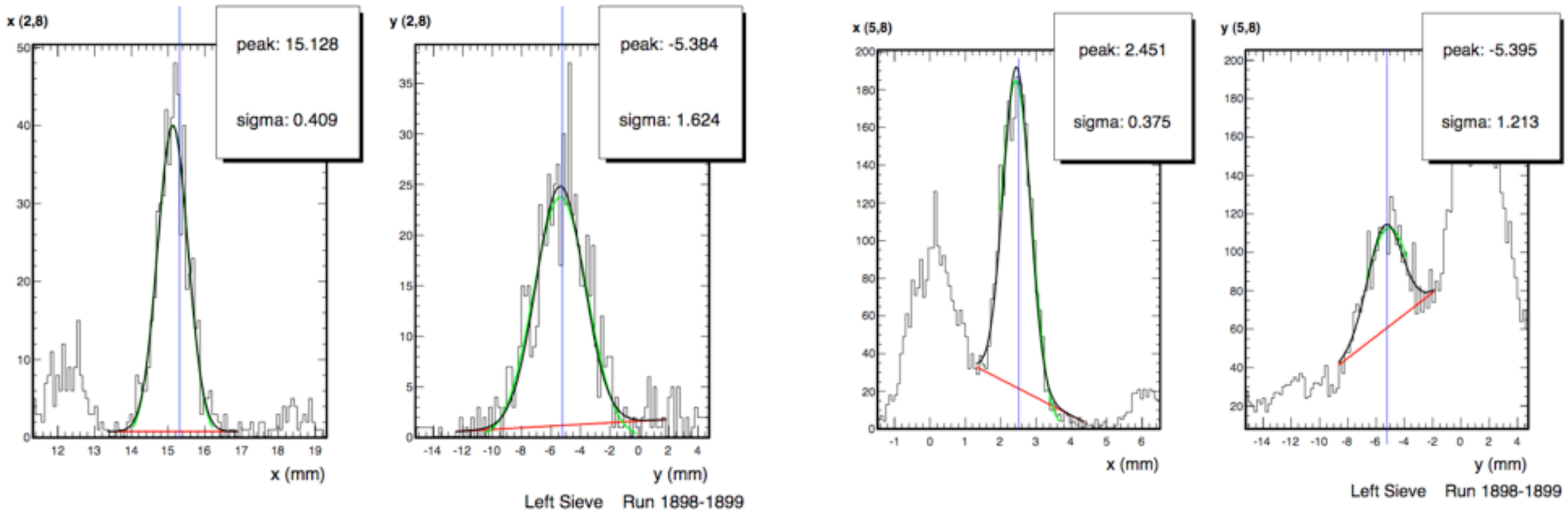
BACKUP SLIDES

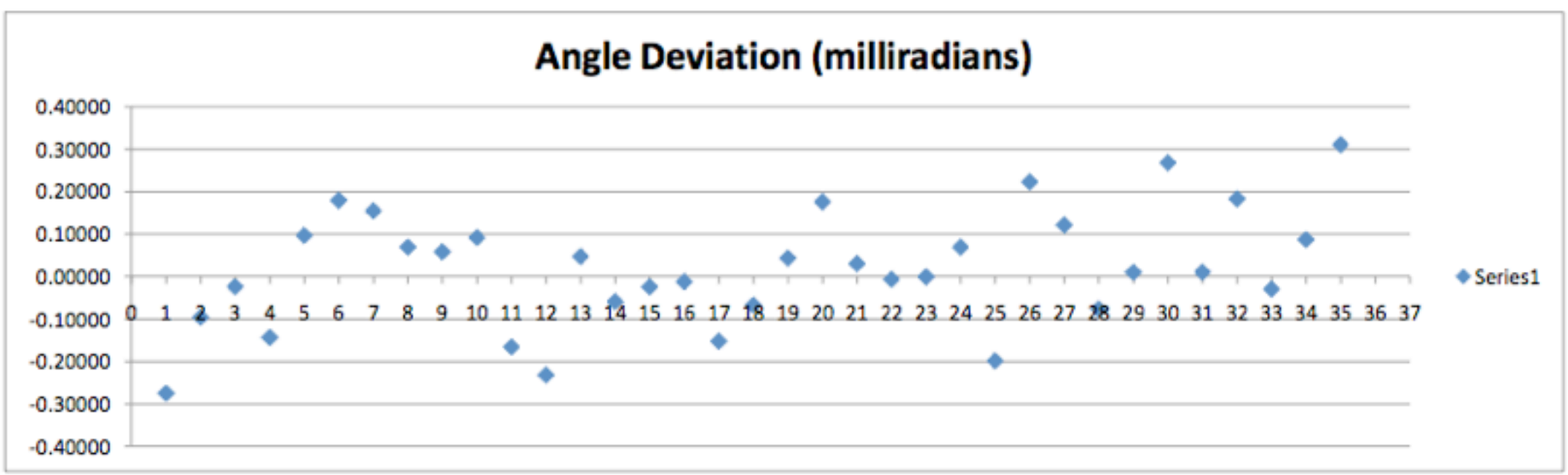
Sieve Slit Method



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

HRS optics for APEX





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

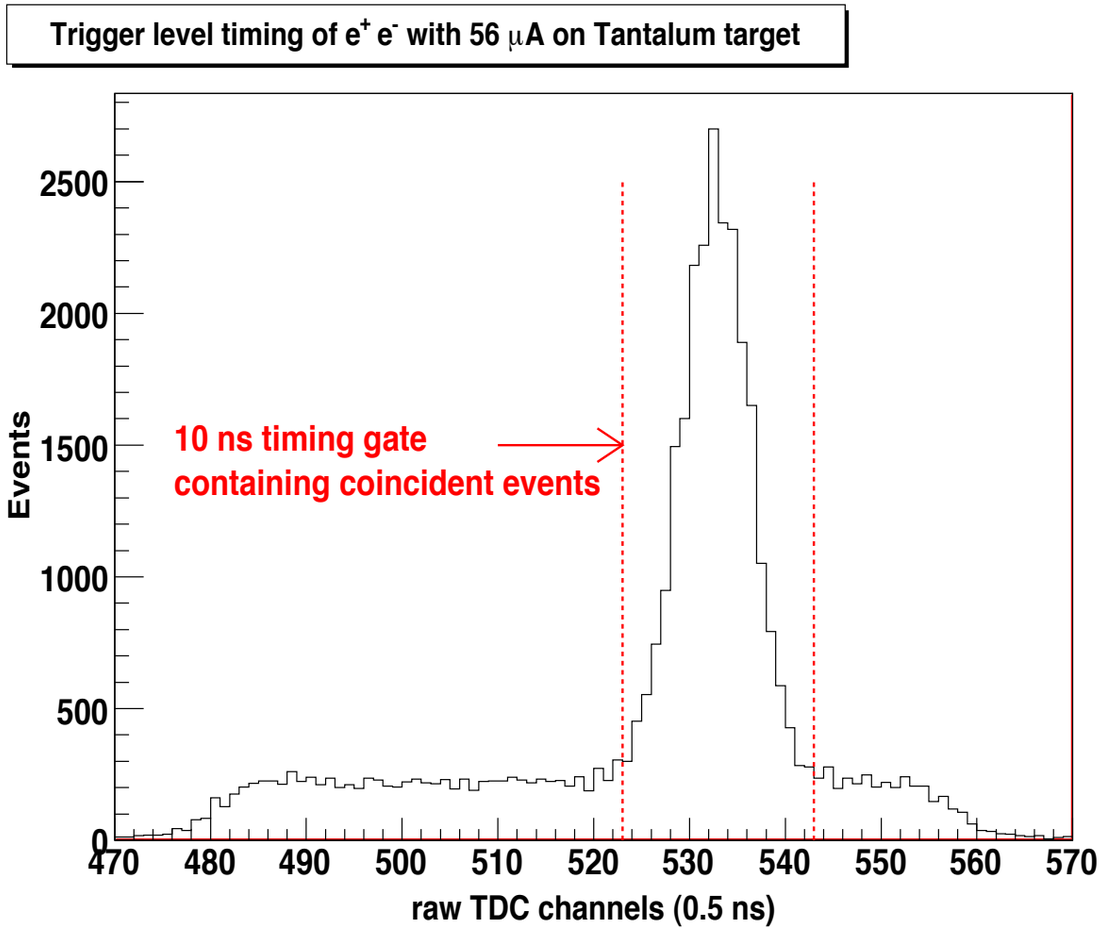
Angular resolution averages (mrad) determined for different masses

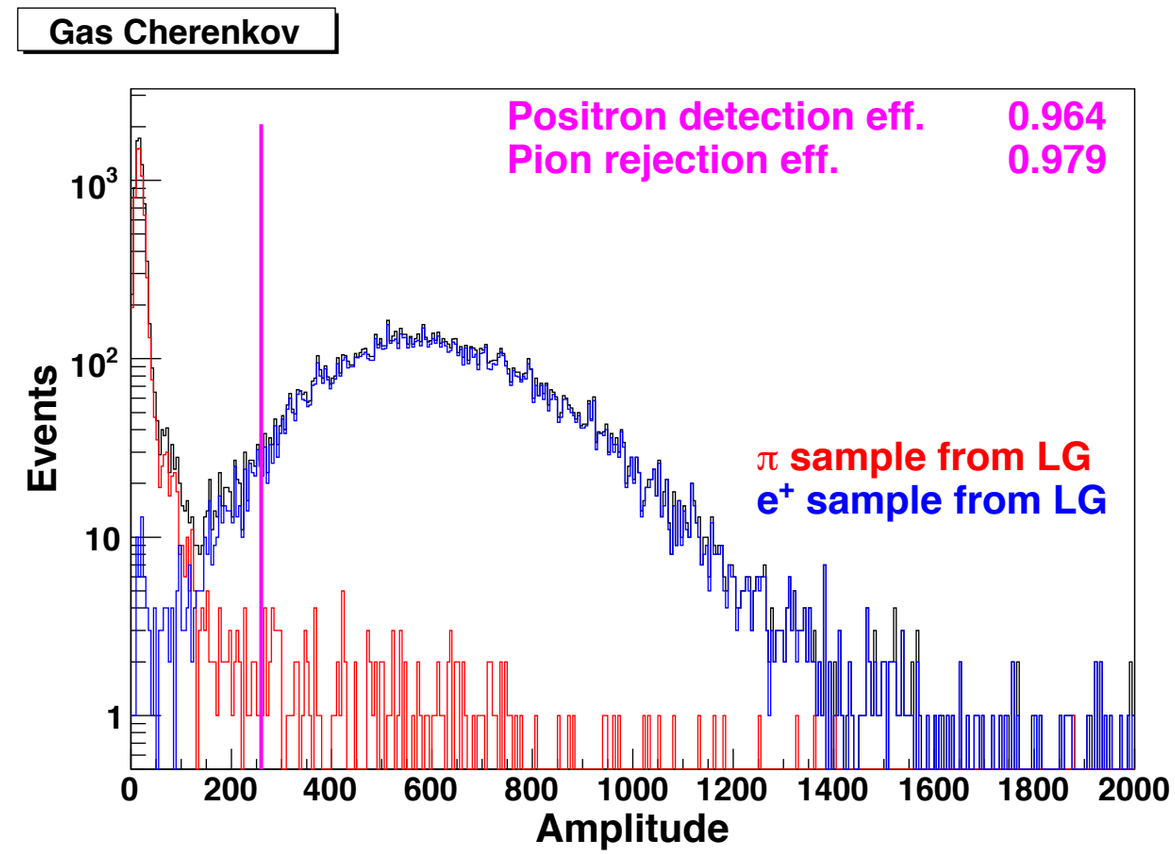
Mass (MeV)	180	195	210	225	240	Average
Left theta (mrad)	1.95	1.87	1.89	1.93	1.88	1.86
Left phi (mrad)	0.26	0.3	0.32	0.33	0.33	0.29
Right theta (mrad)	1.69	1.74	1.81	1.85	1.85	1.77
Right phi (mrad)	0.38	0.43	0.46	0.5	0.53	0.44

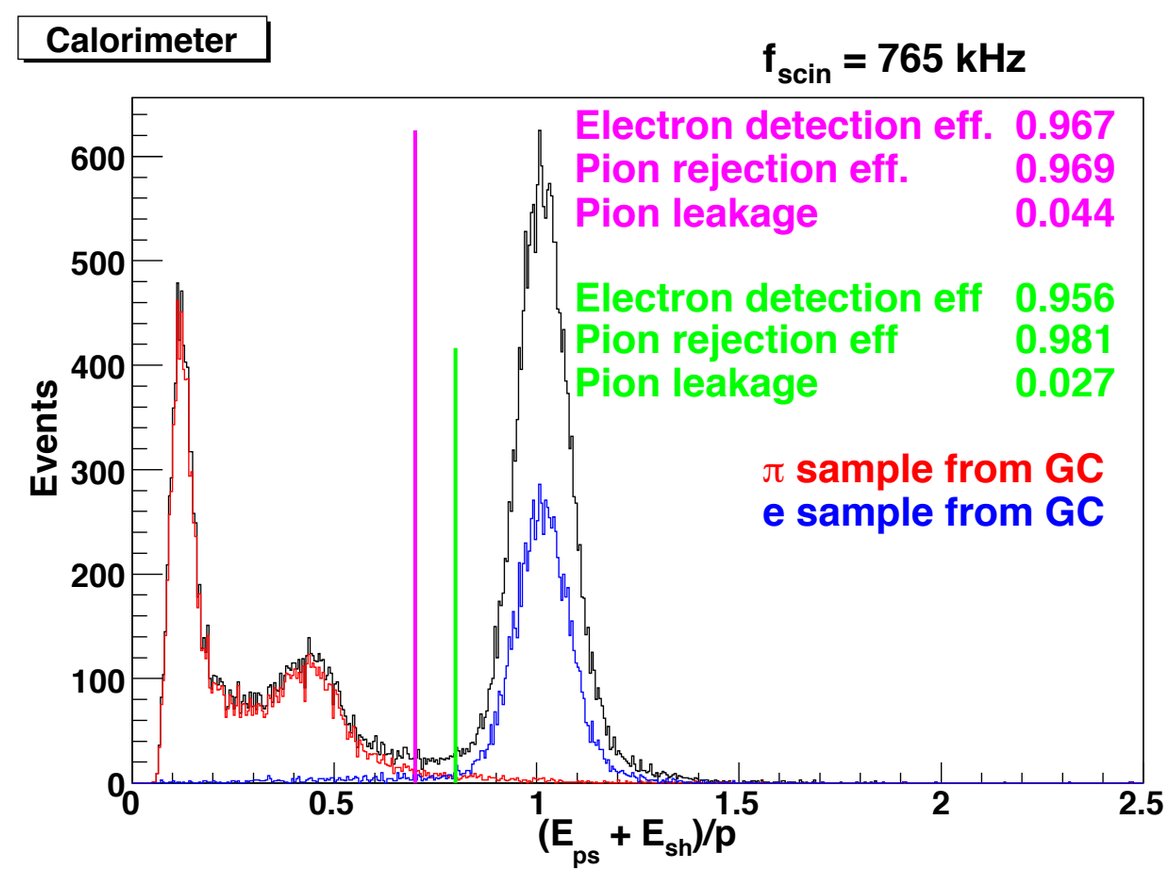
Mass resolutions (MeV) determined for different masses using 3 different methods

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

Coincidence trigger and particle ID performance







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