The APEX Experiment and Test Run

Natalia Toro (Perimeter Institute)

for the APEX Collaboration

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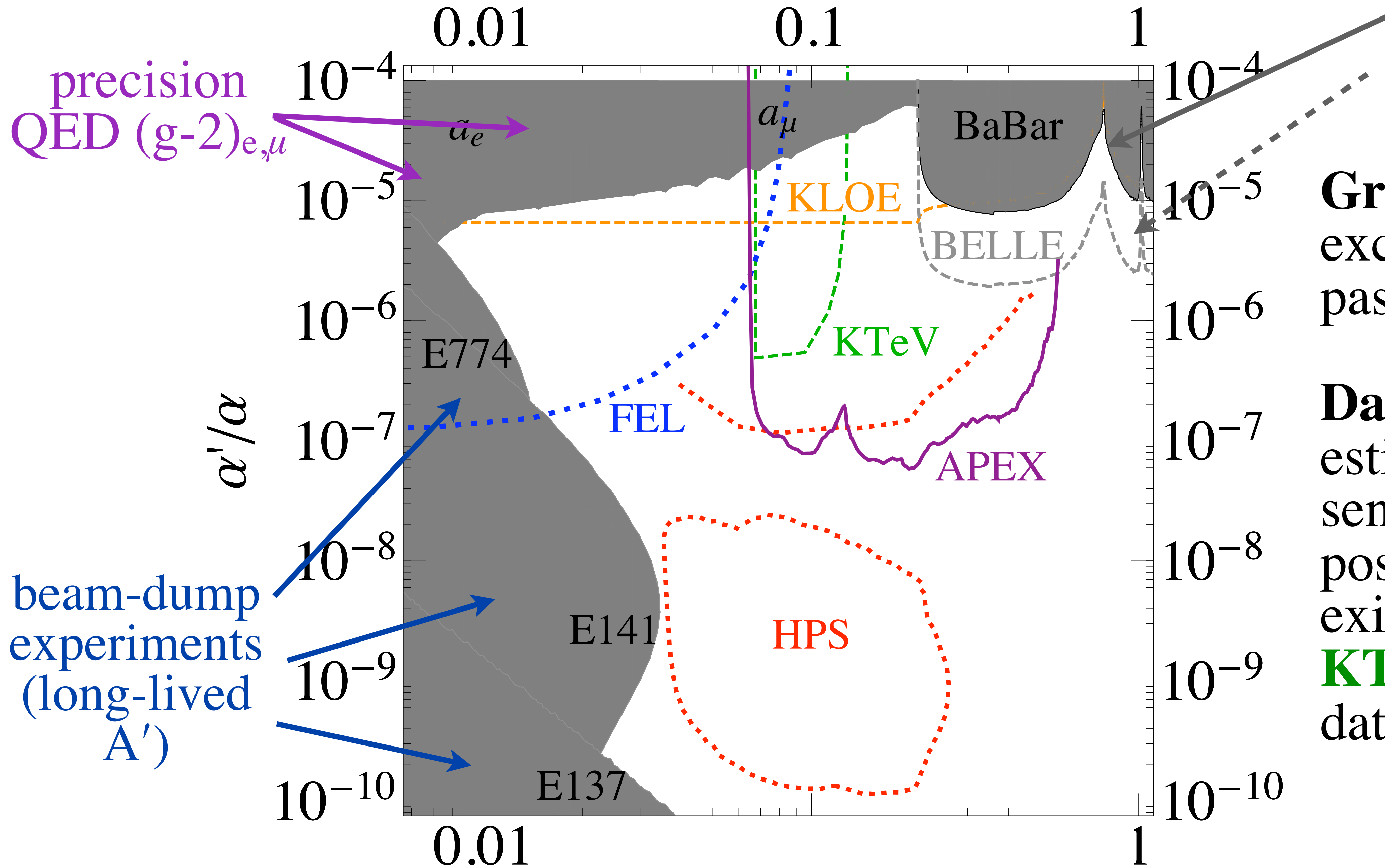
Searching for a New Gauge Boson at JLab

September 20-21, 2010

Outline

- Role of APEX in A' search program
- APEX concept (presented to PAC 35, conditionally approved)
- Technical challenges
- Test Run Summary (3 weeks June 2010)
- Conclusion & APEX Talks

Existing limits and APEX Sensitivity



Gray regions: excluded (2σ) by past experiments

Dashed lines: estimated 2σ sensitivity of other possible searches in existing **KLOE**, **KTeV**, and **Belle** data.

✦$(g\text{-}2)_\mu$ ✦dark matter motivation ✦GUT region of α'/α

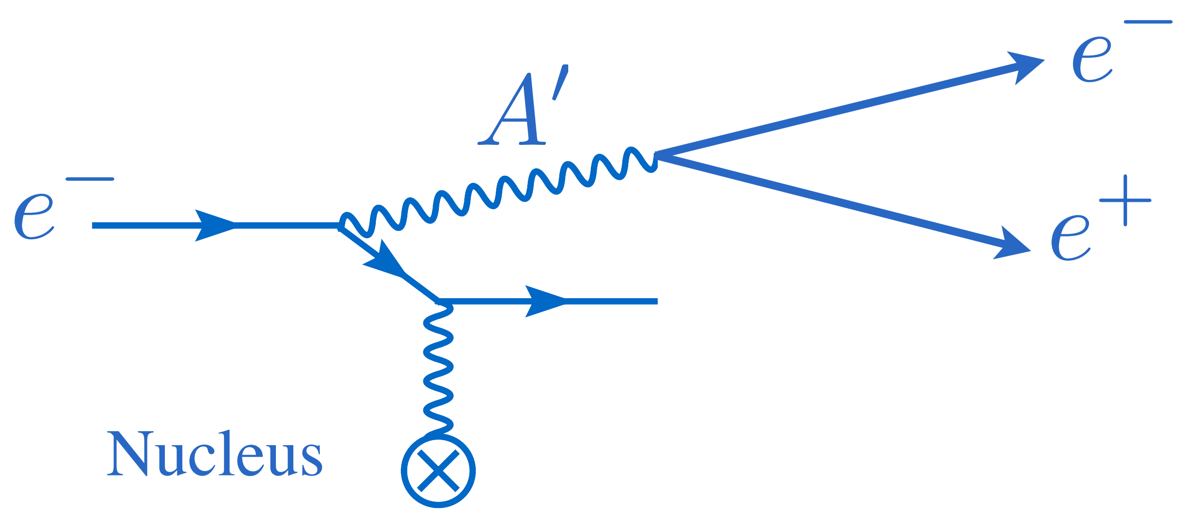
Wide open range of couplings to explore

Timely measurement, ready equipment

Could be ready with 1-month notice

A′ Properties in APEX Search Region ($\alpha'/\alpha > 10^{-7}$)

- Produced abundantly through bremsstrahlung
  (e.g. >1/second for 75 μA beam, 0.1 X_0)

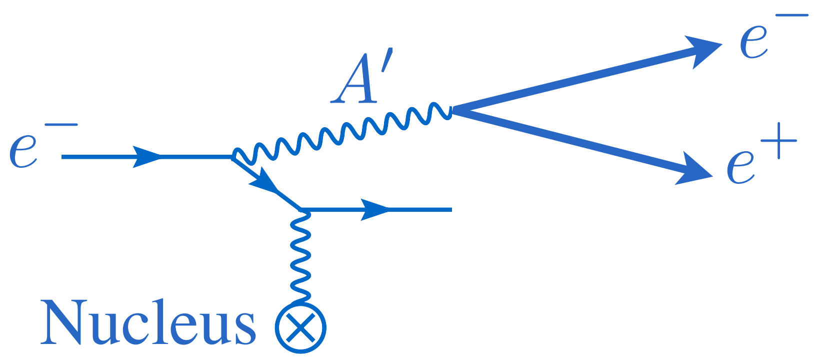


- A′ decays promptly to e^+e^-, $\mu^+\mu^-$, or $\pi^+\pi^-$
  ⇒ large QED background

Strategy: measure e^+e^- mass spectrum **precisely**, search for **small** peak ⇒ maximize rate & resolution

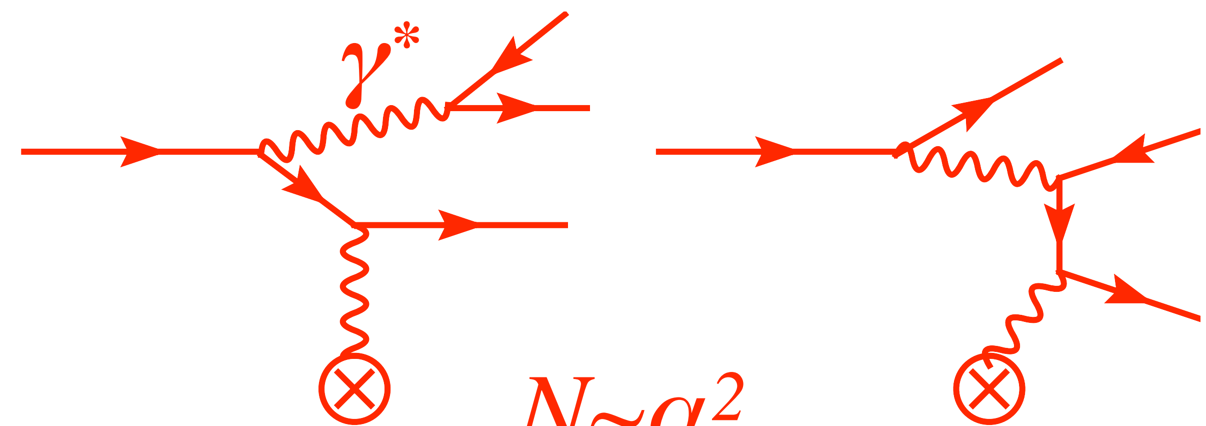
A′ Production and Background Kinematics ($m_{A'} \ll E_{beam}$)

Production diagrams analogous to photon bremsstrahlung



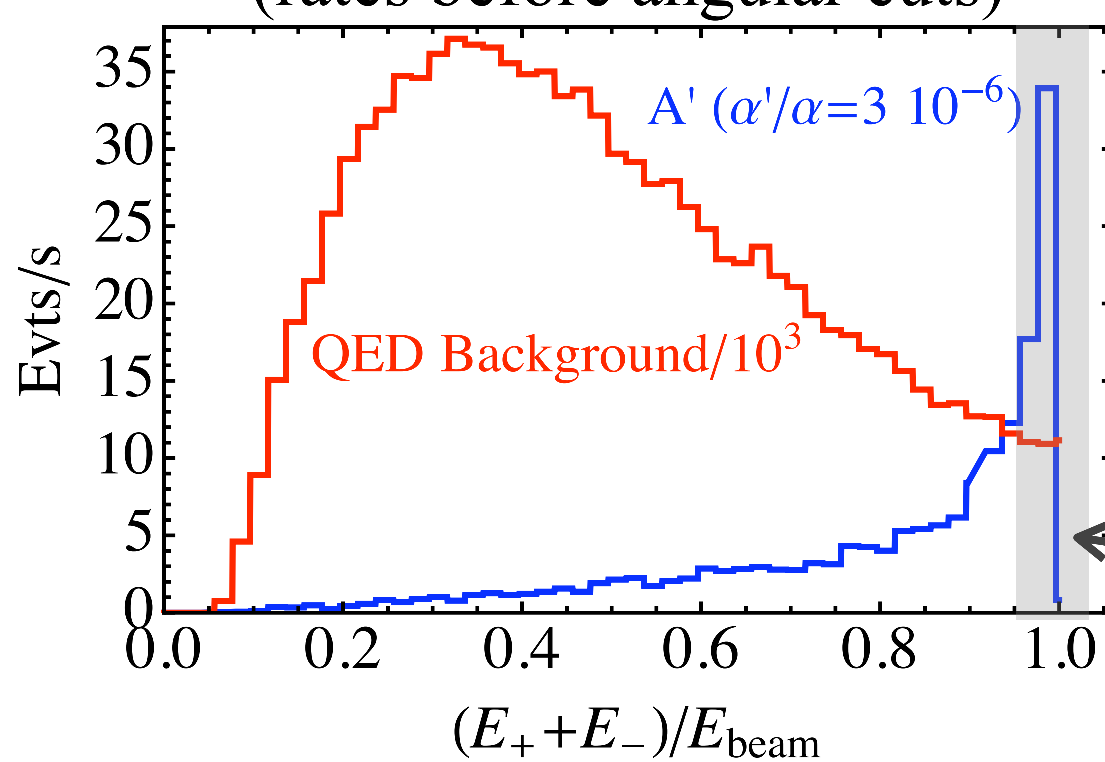
$N \sim \alpha'$ x Branching → O(1)

QED Backgrounds



$N \sim \alpha^2$

(rates before angular cuts)



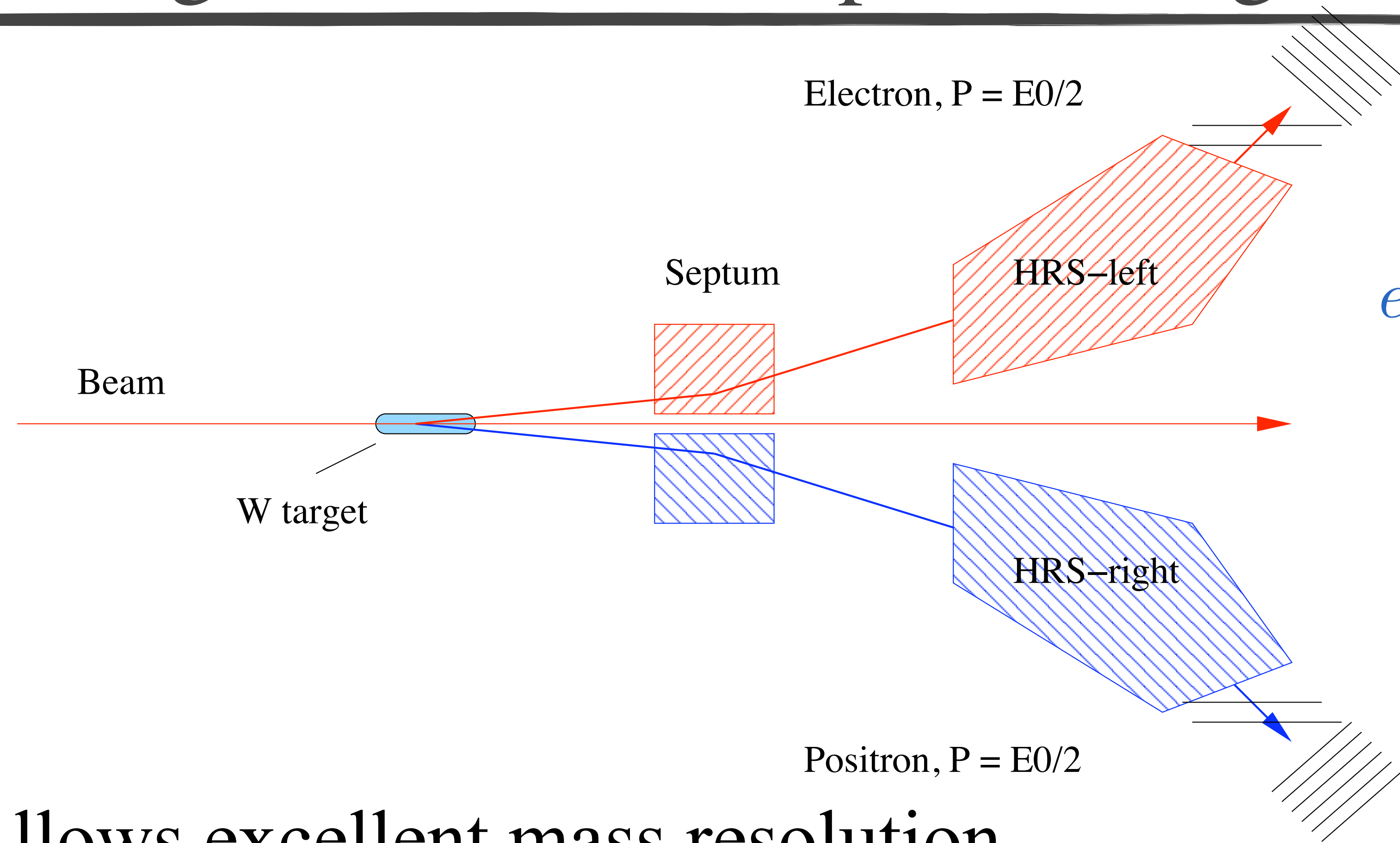
– Distinctive kinematics:

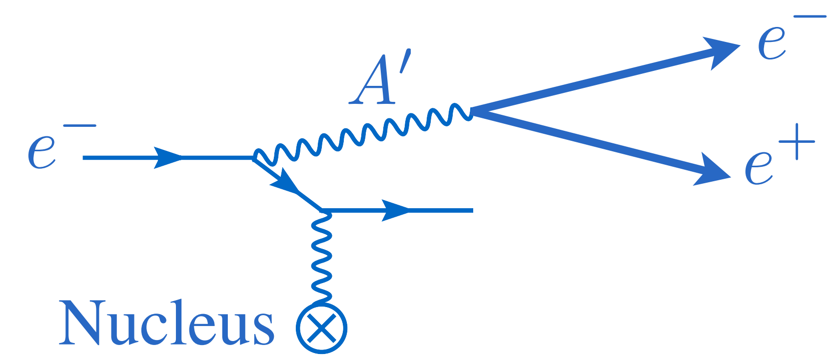
A′ products carry (almost) full beam energy!

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

Optimal kinematic selection for A′ search

Advantages of small-acceptance magnetic spectrometer





Events outside this window never reach spectrometer

– Allows excellent mass resolution

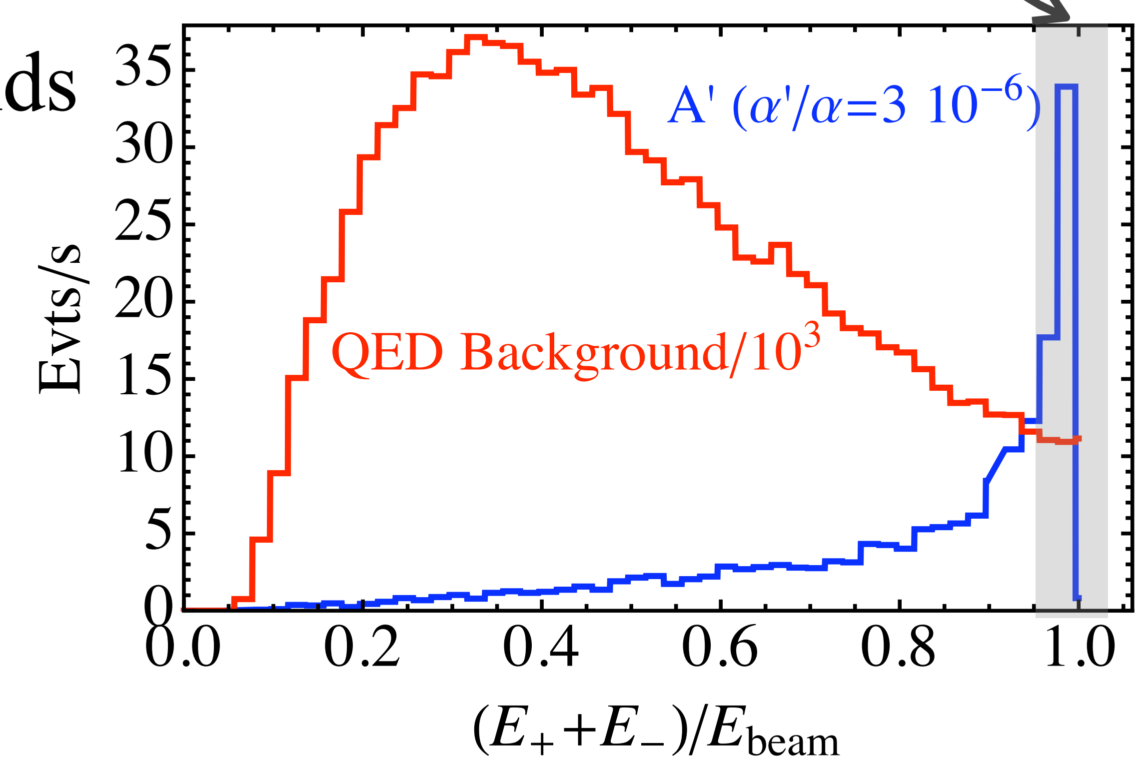
– Dramatic suppression of large backgrounds

Singles:

- Elastic scattered e^-
- Moller e^-

Coincidence:

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



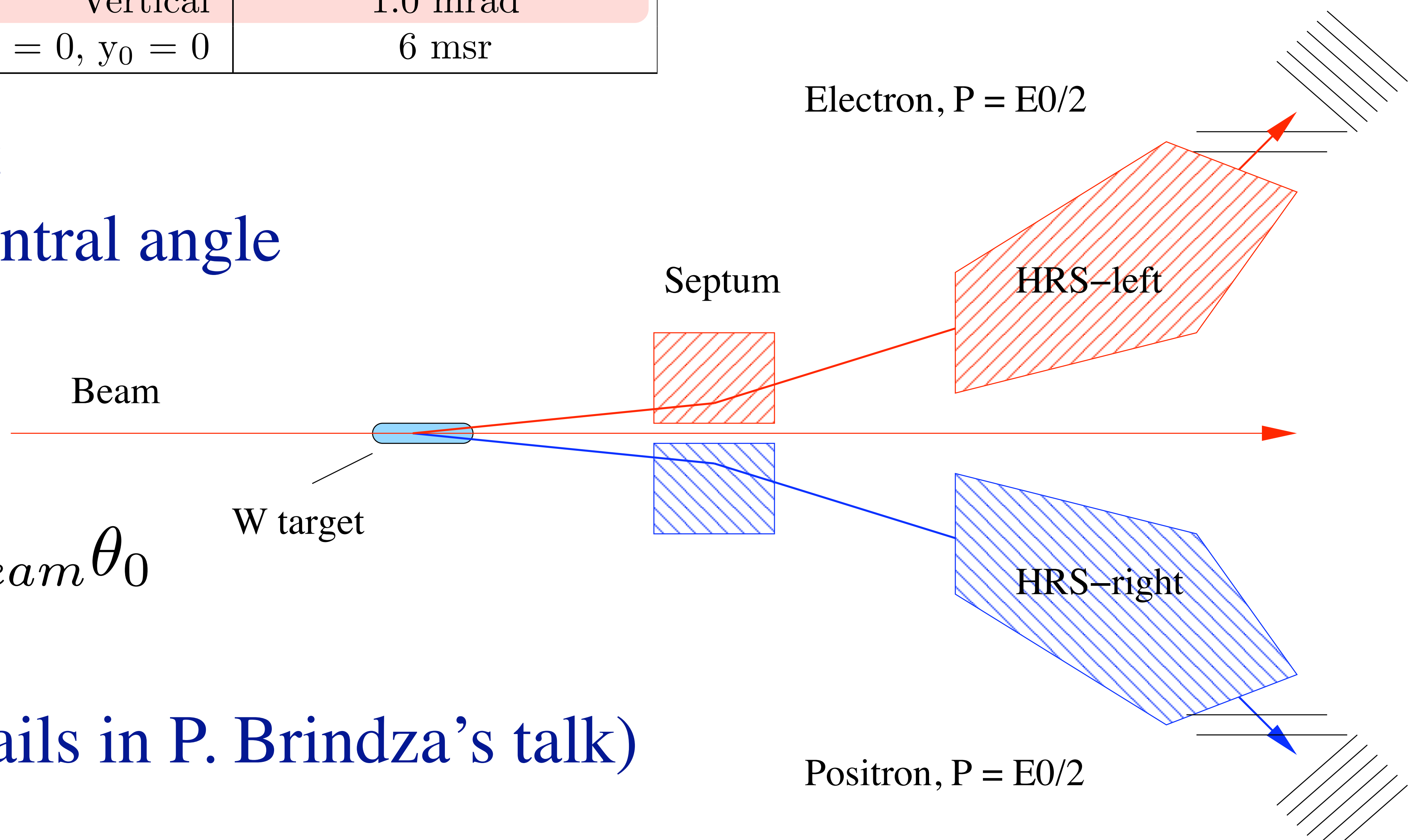
To maximize **angular acceptance**, operate at narrow angles

Hall A High Resolution Spectrometers (HRS)

Configuration	QQD_nQ Vertical bend
Bending angle	45°
Optical length	23.4 m
Momentum range	0.3 - 4.0 GeV/c
Momentum acceptance	-4.5% < δp/p <+4.5%
Momentum resolution	1×10^{-4}
Angular range HRS-L	12.5° - 150°
HRS-R	12.5° - 130°
Angular acceptance: Horizontal	±30 mrad
Vertical	±60 mrad
Angular resolution : Horizontal	0.5 mrad
Vertical	1.0 mrad
Solid angle at $\delta p/p = 0$, $y_0 = 0$	6 msr

With septa:
5–5.5° central angle

$$m \sim E_{beam}\theta_0$$



(Septa details in P. Brindza's talk)

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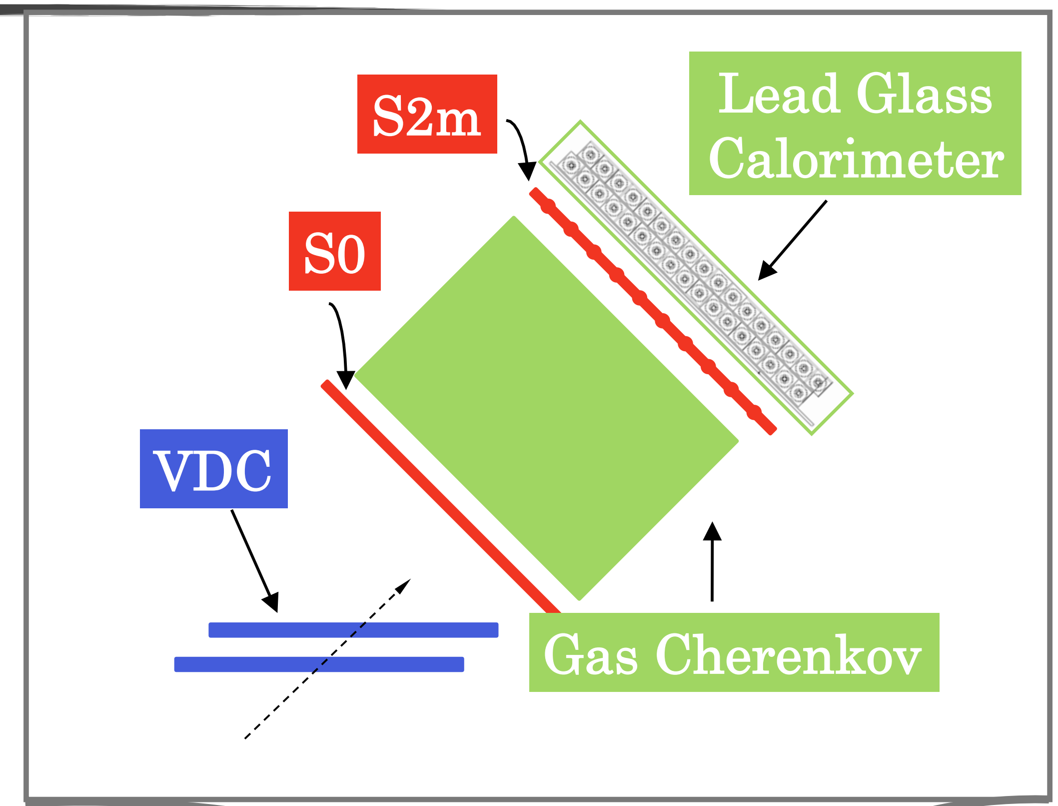

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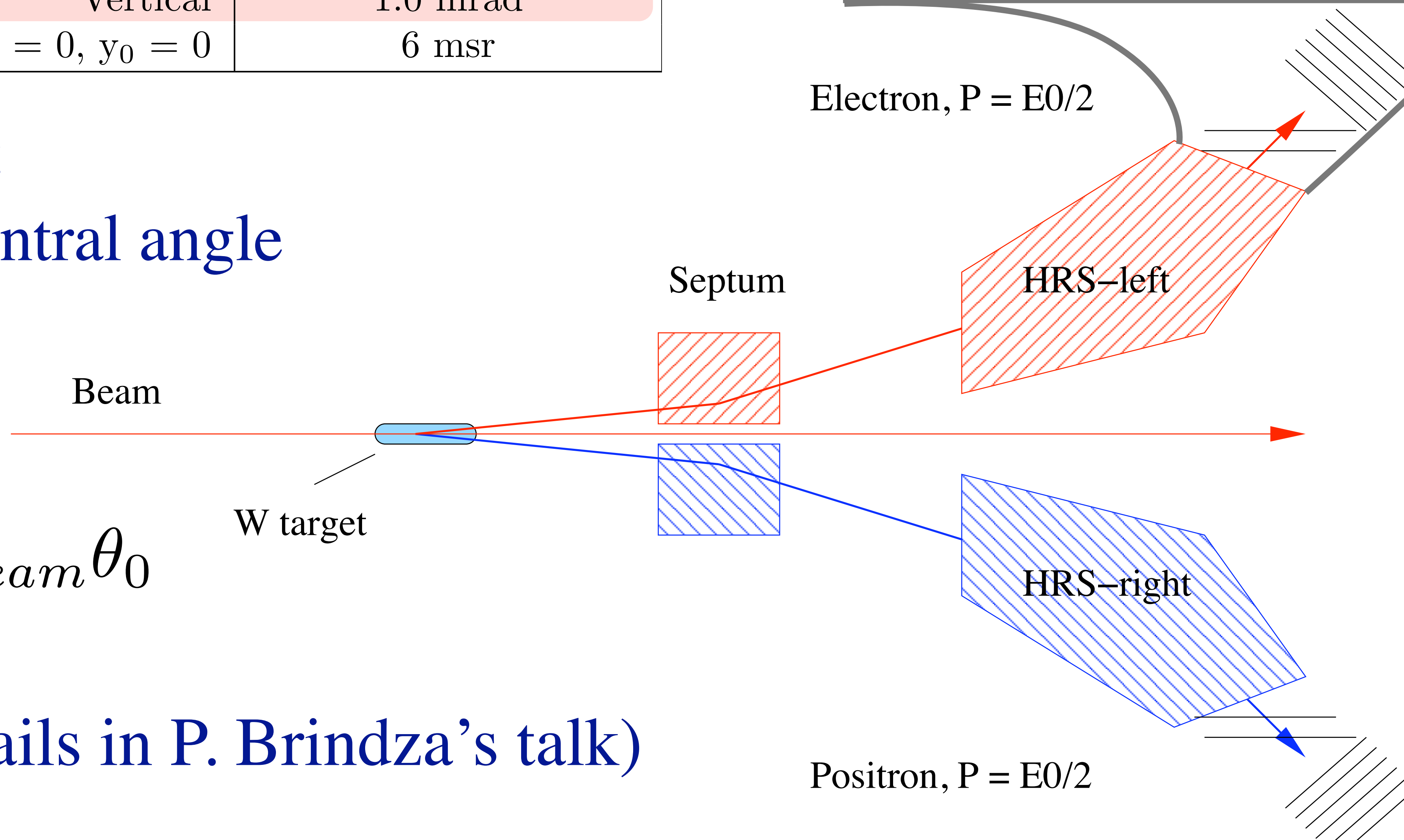
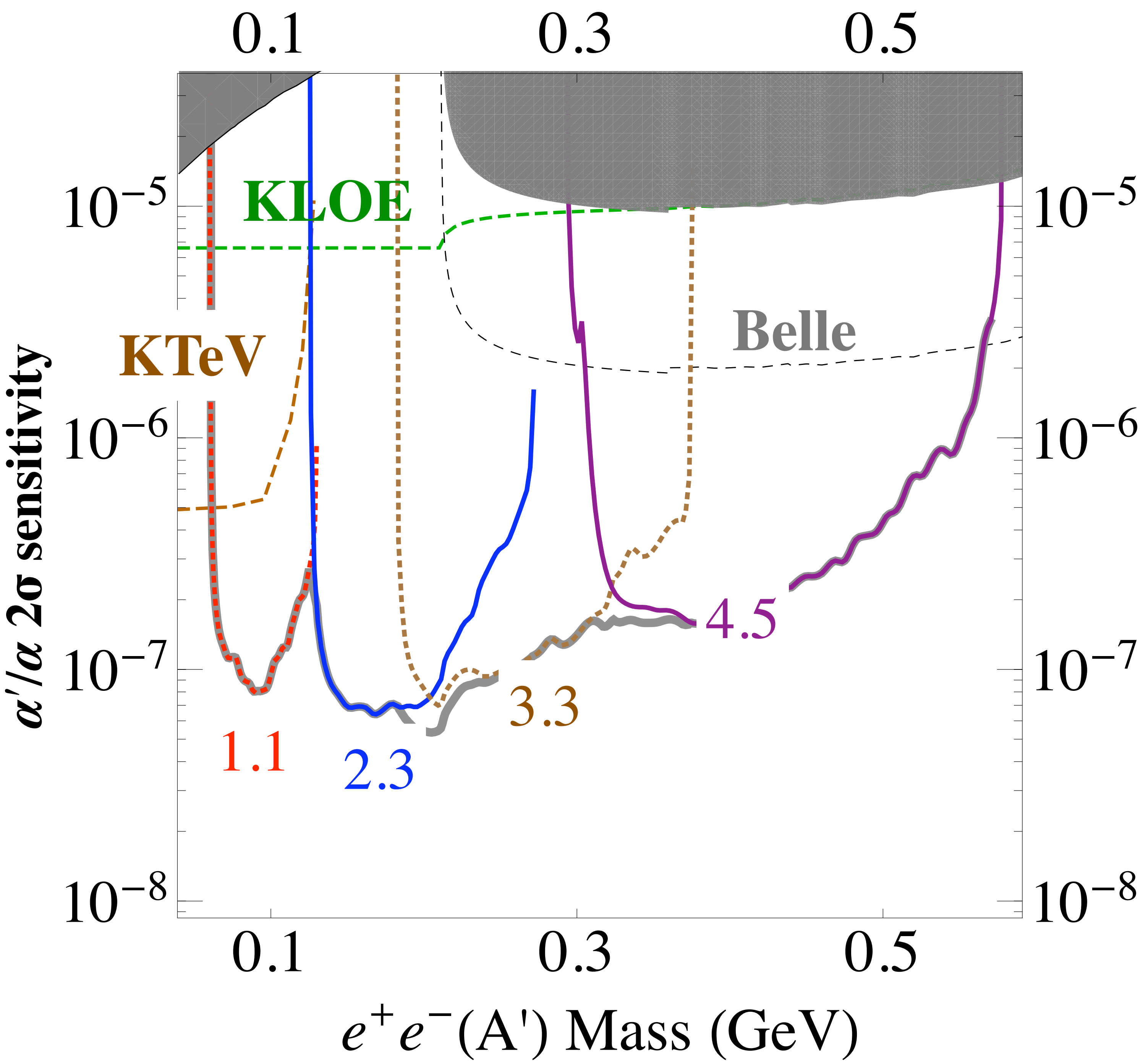


$$m \sim E_{beam}\theta_0$$

(Septa details in P. Brindza's talk)

Narrow acceptance ⇒ cover mass range from 60 to 600 MeV with separate 6–12 day runs at 4 beam energies



Factors Controlling Sensitivity

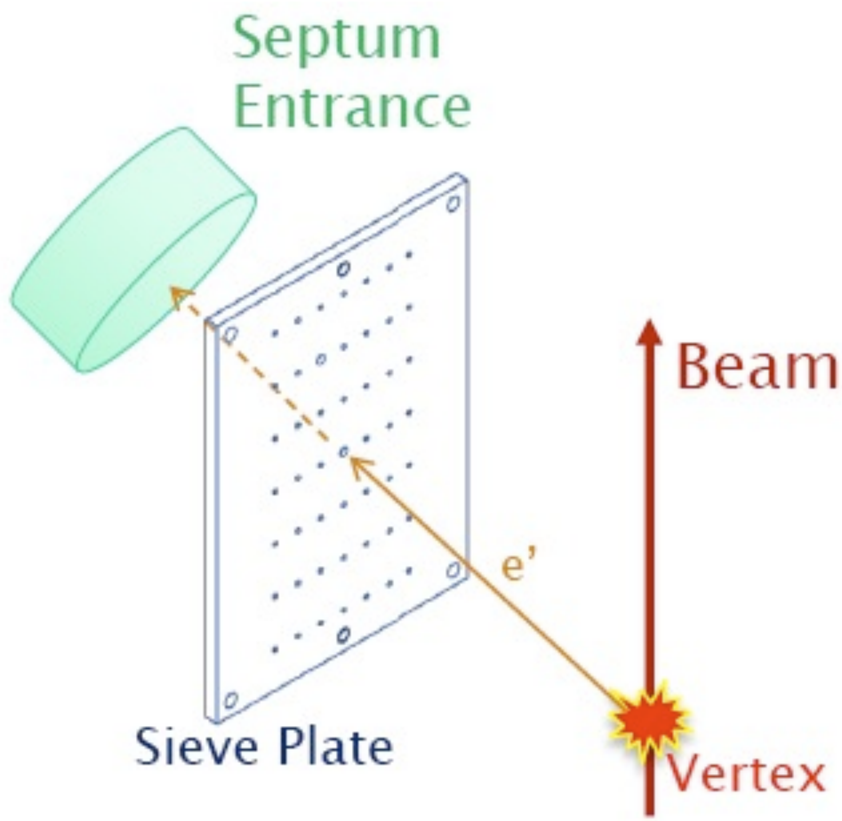
- Minimize mass Resolution (limited by angular resolution)
  - Intrinsic detector resolution (0.5 mrad)
  - Calibration of spectrometer optics
  - Multiple scattering in target

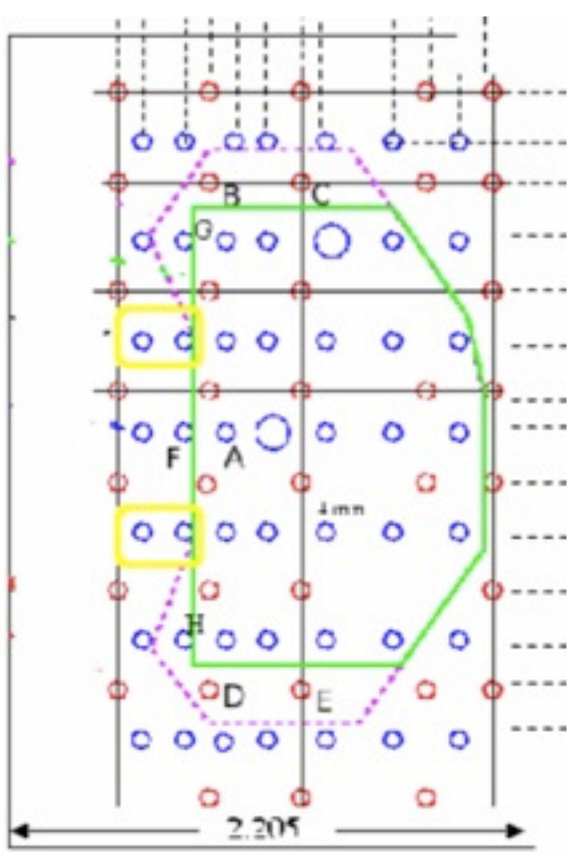
    Goal: Sub-mrad resolution from each source $\Rightarrow$

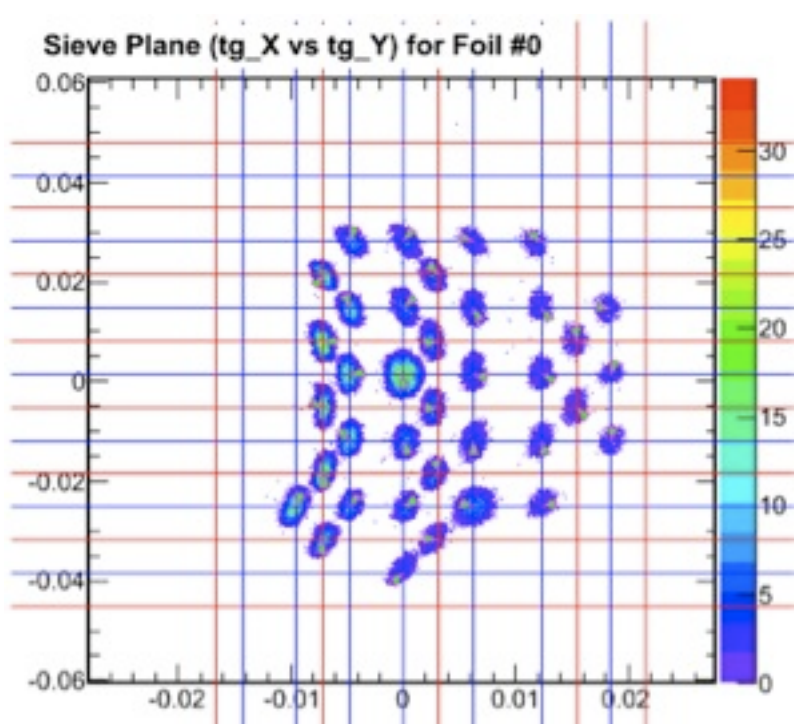
    $\lesssim$1% mass resolution

- Maximize rate of e^+e^- coincidences recorded

Mass Resolution from Optics [J. Huang]







Removable "Sieve plate" with holes at definite positions used to fine-tune reconstruction of target kinematics from hit position & angle in VDC

Non-linear polynomial ⇒ account for non-uniformity of magnetic optics

Test run: 0.2 mrad achieved in 1st iteration, single foil. precision in horizontal angle

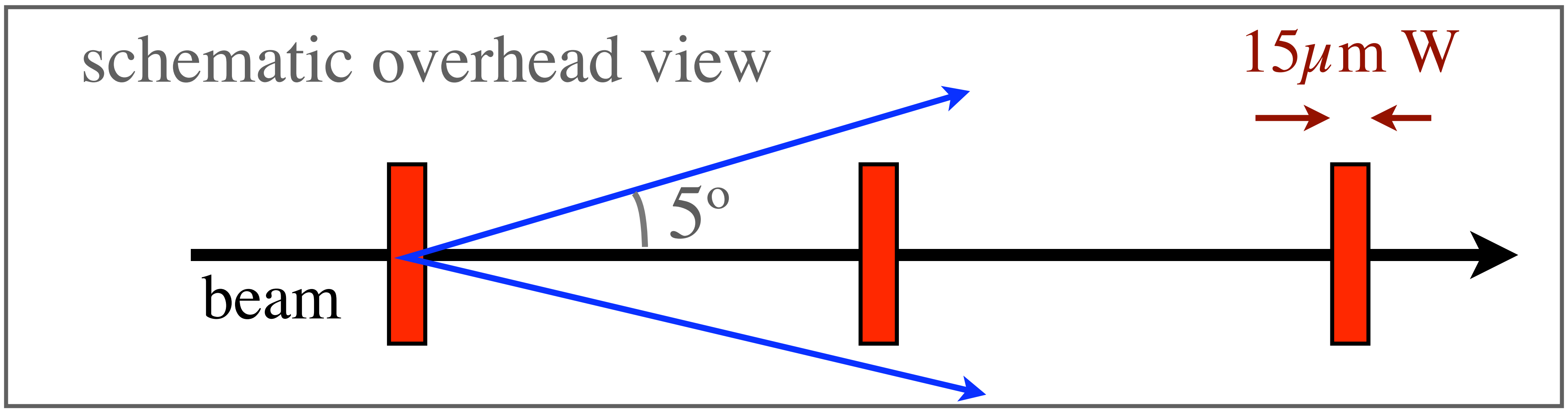
- Improvable w/ more analysis
- May be degraded for long target

Target Design: Minimizing Multiple Scattering [P. Schuster]

Target assembled for 2.2 GeV test run (1.1 GeV central momentum)

Goals:

- 4.5% X_0 target, $\sigma(\theta)_{\text{mult scat}} \leq 0.5$ mrad
  $\Rightarrow$ typical e^+e^- pair must only go through 0.3% X_0



- High-Z target (reduce π yield for given QED rates)
- Performance under 50–100 uA current

Designed and built by SLAC APEX group

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  - Other contributions below intrinsic detector resolution (0.5 mrad)

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- Maximize rate of e^+e^- coincidences recorded
  - Thick target
  - Detector performance @ high singles rate
  - Efficient coincidence trigger (4 kHz DAQ limit)

    Reject accidentals (narrow timing gate)

    Reject π^+ background (Gas Cherenkov in coinc. trigger)

Background: Singles [S. Riordan]

Cluster-finding and tracking in VDC become more challenging at high rates.

Largest singles rates:

- ✦ e^- (radiative elastic & inelastic) – about 10^4 x coincidence rate
- ✦ $\pi^\pm$ – 3 x larger than e^- for highest-energy setting

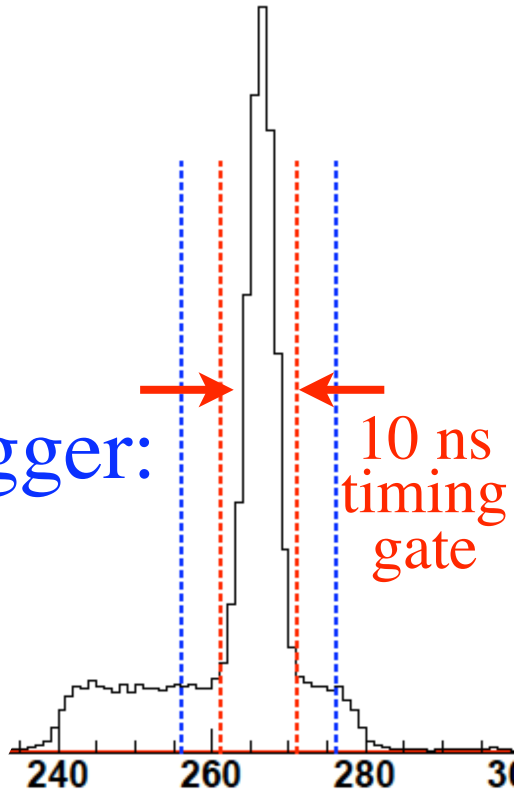
Test run: installed new electronics in VDC, studied performance up to ~5 MHz (used 6 MHz in proposal)

⇒ Obtained **60%** track reconstruction efficiency, may be improvable to 75%

Good news for full run!

Background: Coincidence [E. Jensen]

Largest coincidence rates between L and R-HRS are accidentals:



- 10 ns online timing achieved in test run for "golden" trigger:
  Electron S2m + Positron S2m + Positron Gas Cherenkov
- Rates estimated for proposal [kHz]:

	1.1 GeV	2.3 GeV	3.3 GeV	4.5 GeV
$\mathbf{e}^-$:	**6000**	**4500**	**2900**	700
π^-:	36	640	**2500**	**2200**
π^+:	36	640	**2500**	**2200**
$\mathbf{e}^+$:	24	31	23	3.6 + 9 [π^0]
20 ns coinc:	**7**	**68**	**270**	**130**
1/30 π^+:	3	**5**	**11**	**5**
1/60 π^+:	3	4	7	3
QED $\mathbf{e}^+ e^-$:	0.35	0.6	0.5	0.07

?

π rates extrapolated from higher-energy data; **observed rates lower**

DAQ limit: ~4 kHz

1/30 π+ rejection allows 5x current ⇒ **2.2x α′/α sensitivity**.

Offline: further π± rejection possible with Lead Glass, but don't rely on it: (1/30 π+) + (2ns timing) + (vertex along target) sufficient to reduce accidentals to ¼ of true coincidence

Factors Controlling Sensitivity

- Minimize Mass Resolution (limited by angular resolution)
  - Intrinsic detector resolution [0.5 mrad]
  - Calibration of spectrometer optics [≲ 0.2 mrad – J. Huang]
  - Multiple scattering in target [0.45 mrad – P. Schuster]

  Goal: Sub-mrad resolution from each source ⇒

  ≲1% mass resolution

- Maximize rate of e^+e^- coincidences recorded
  - Thick target
  - Detector performance @ high singles rate [≲ 5 MHz – S. Riordan]
  - Efficient coincidence trigger (4 kHz DAQ limit) [E. Jensen]

  Reject accidentals (short timing gate) [10 ns demonstrated]

  Reject π^+ background (Gas Cherenkov in coinc. trigger) [1/30–1/60 achieved in test run]

  Allows 300–500 Hz true coincidence (most settings)

Thanks!

- JLab management
- Hall A Technical & Scientific Staff
- APEX Collaborators
- MCC

3-week test run (with extension) immediately after PREX: June 21 – July 12

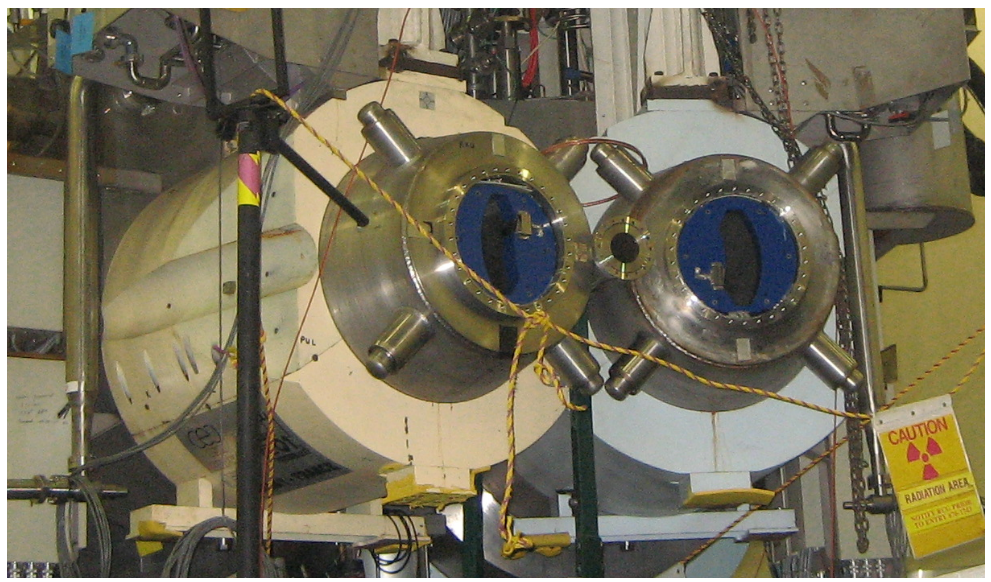
Primary goal: validate high-rate VDC, trigger, PID performance to address PAC 35 concerns

Also: Test target performance, alignment…

Target was delivered to JLab but not installed (high radiation, manpower & time limitations)

Test Run: Differences from Full Run

- Used PREX target ladder (10% Pb target, thin Ta) and shorter optics target
- PREX collimators ⇒ reduced Q1 acceptance



- PREX septum configuration (removed coils, power supply limit) ⇒ max. spectrometer momentum = 1.16 GeV
- Improvised beamline with corrector magnets for running with parallel field in two sides of septum.

Test Run Timeline

Week 1: Installation of L-HRS detector components,
High-rate VDC tests

Week 2: Installation of R-HRS detector components,
Coincidence trigger electronics, DAQ testing
Commissioning of modified beamline

Week 3: High-rate tests of VDC (L-HRS) and particle ID
High-quality optics data for both left & right HRS
1.44 M true coincidence events for physics analysis
[J. Beacham's talk]

Conclusions

- APEX is ready to be first A$'$ search experiment at JLab

- Well-optimized design probes cross-sections 30-100 times smaller than currently explored

- Test run demonstrated equipment performance

Outline of APEX Talks

- Septum & Radiation – *P. Brindza*
- Target – *P. Schuster*
- HRS parameters and optics – *J. Huang*

Coffee break

- HRS trigger and PID – *E. Jensen*
- HRS wire chamber tracking – *S. Riordan*

- Strategy for peak search, test-run sensitivity – *J. Beacham*

- Summary and plan of APEX – *P. Schuster*