The Status of the APEX experiment at JLab

Vardan Khachatryan (Stony Brook University)
on behalf of APEX Collaboration

Hall A Winter Collaboration Meeting
January 25, 2018

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APEX - The search for new fundamental forces
  Collaboration institutions

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Update on Monte-Carlo studies
- rate calculations (with new background processes, new MadGraph)
- reach calculations

Update on preparation
- Septum magnet
- Target system
- HRS DAQ (FADCs, VDC electronics, VDC HV)
- SciFi
- ERR

Summary

APEX Collaboration

The A' Experiment (APEX) Collaboration:

APEX Spokespeople:
Rouven Essig
Philip Schuster
Natalia Toro
Bogdan Wojtsekhowski

APEX Executive Committee
Gordon Cates
Silviu Covrig
Greg Franklin
PIs

APEX postdoc
Vardan Khachatryan

Previous Ph.D. students
Eric Jensen
Maduka Kaluarachch

APEX will provide theses for three additional Ph.D. students

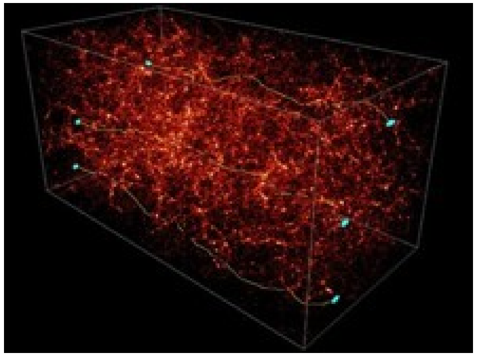
Total financial contribution from the collaboration institutions >$300k

Yerevan Physics Institute, Yerevan 0036, Armenia
Syracuse University, Syracuse, New York 13244, USA
University of Kentucky, Lexington, Kentucky 40506, USA
Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada
College of William and Mary, Williamsburg, Virginia 23187, USA
University of Virginia, Charlottesville, Virginia 22903, USA
University of New Hampshire, Durham, New Hampshire 03824, USA
New York University, New York, New York 10012, USA
Florida International University, Miami, Florida 33199, USA
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
C. N. Yang Institute for Theoretical Physics, Stony Brook University, Stony Brook, NY 11794-3840
Theory Group, SLAC National Accelerator Laboratory, Menlo Park, CA 94025
North Carolina Agricultural and Technical State University, Greensboro, North Carolina 27411, USA
Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
Longwood University, Farmville, Virginia 23909, USA
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
California State University at Los Angeles, Los Angeles, California 90032, USA
Norfolk State University, Norfolk, Virginia 23504, USA
Kent State University, Kent, Ohio 44242, USA
University of Massachusetts, Amherst, Massachusetts 01003, USA
University of South Carolina, Columbia, South Carolina 29225, USA
Tel Aviv University, Tel Aviv, 69978 Israel
Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada
George Washington University, Washington D.C. 20052, USA
Theory Group, Stanford University, Stanford, CA 94305
Old Dominion University, Norfolk, VA 23529
INFN Sezione di Catania, Italy

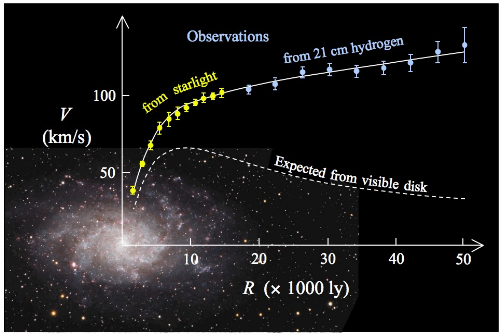
Hall A Collaboration

Dark Photon Search Motivation

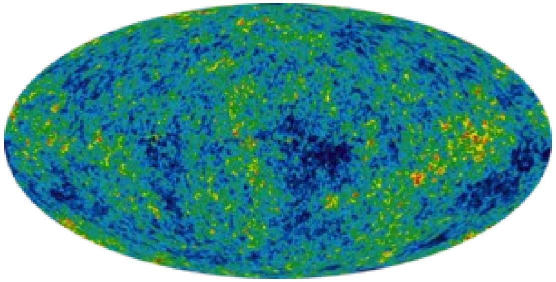
Large scale structures



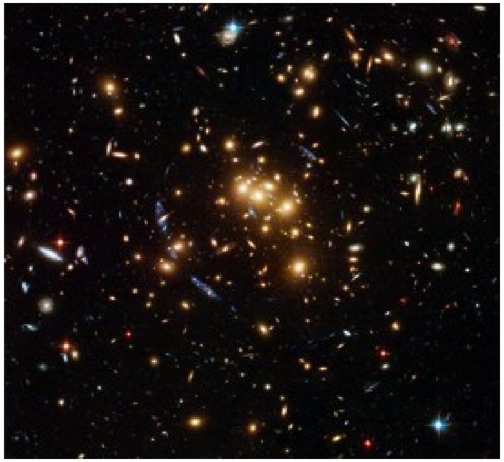
Rotation curves



Cosmic Microwave Background



Lensing

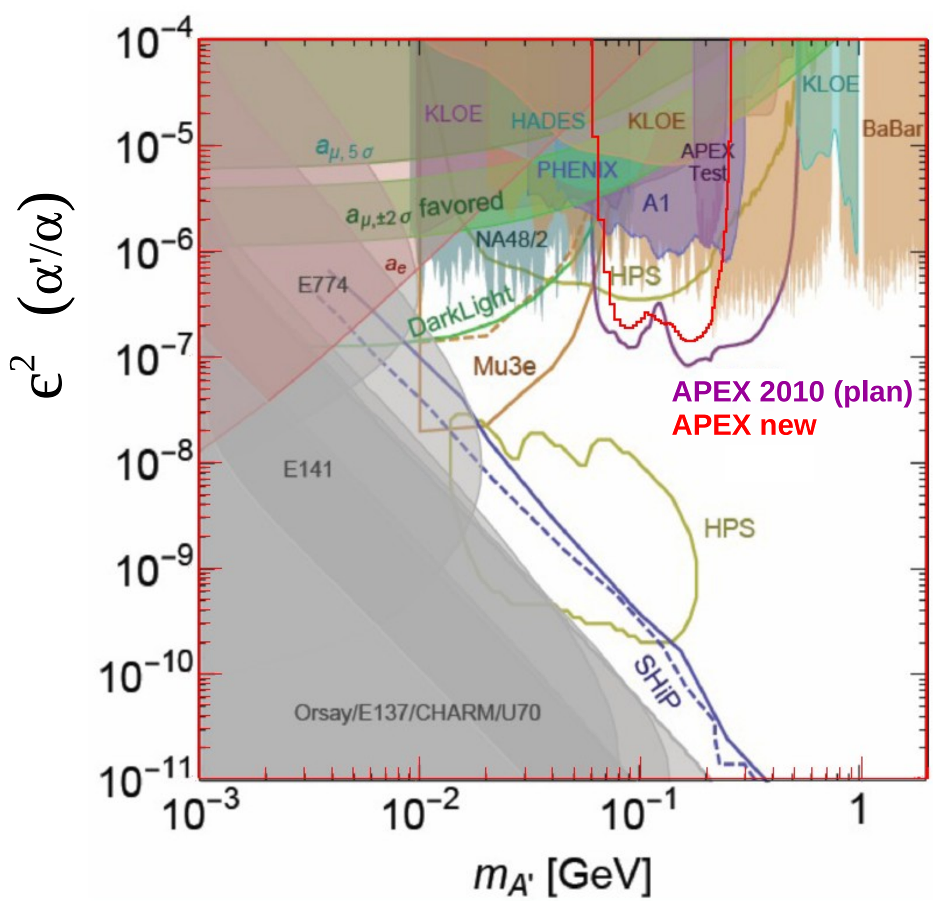


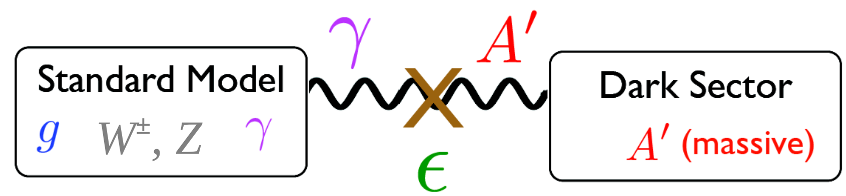
Colliding clusters (Chandra)

A' (Dark Photon) Current Status

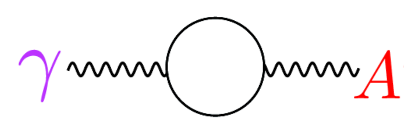
APEX is a spectrometer-based search, at JLab Hall A, for 65-550 MeV new boson (dark force mediator) decaying promptly to e^+e^-.

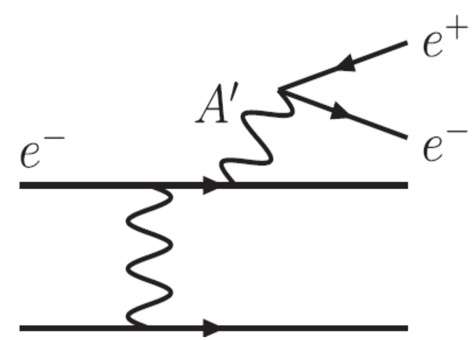
The goal of APEX is to measure the invariant mass spectrum of e^+e^- pairs produced by electron scattering on a high-Z target, and to search for a narrow peak with width corresponding to the instrumental resolution.



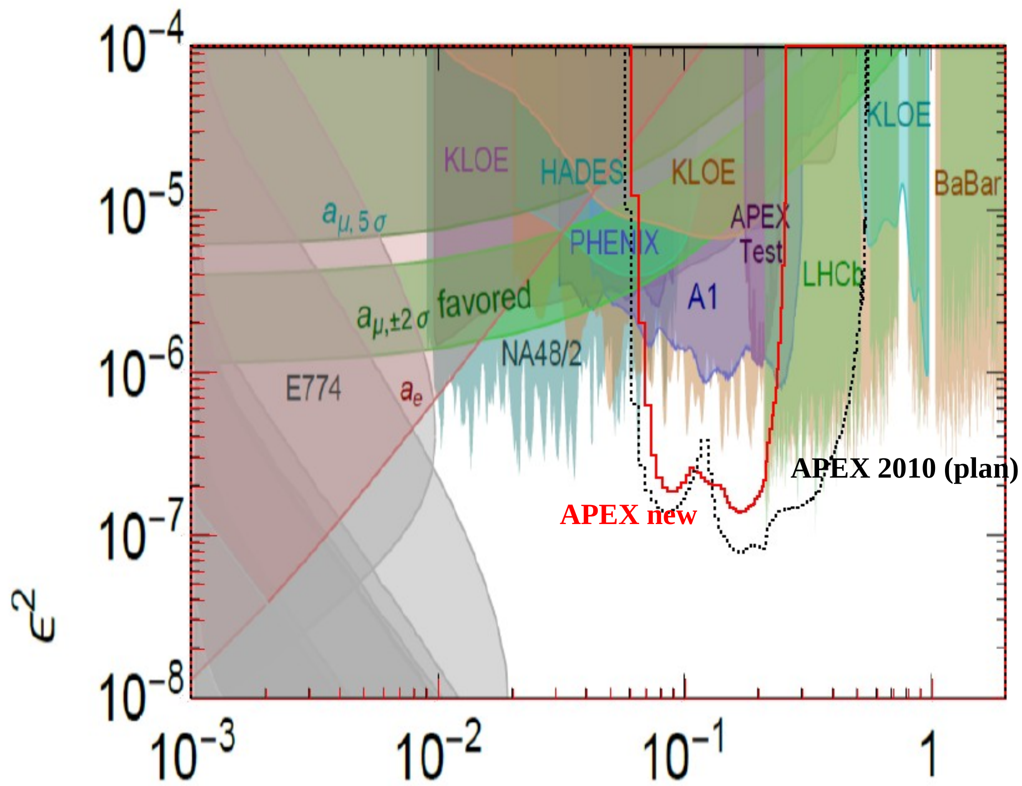


$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$ ($\epsilon^2 = \alpha'/\alpha$)





Modified run plan

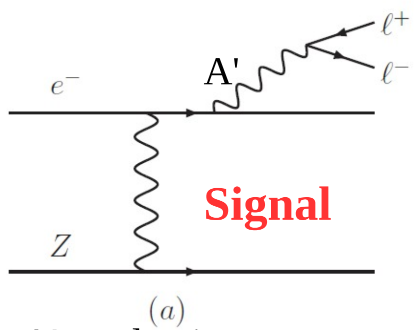


10 days at 1.1 GeV beam
10 days at 1.65 GeV beam
10 days at 2.2 GeV beam

The reasons for the run plan modification:

1. Growing competitions from other experiments (LHCB, Belle)
2. HRS Q1-quadrupole change reduced the acceptance
3. MadGraph Monte-Carlo generator update

Concept of the experiment

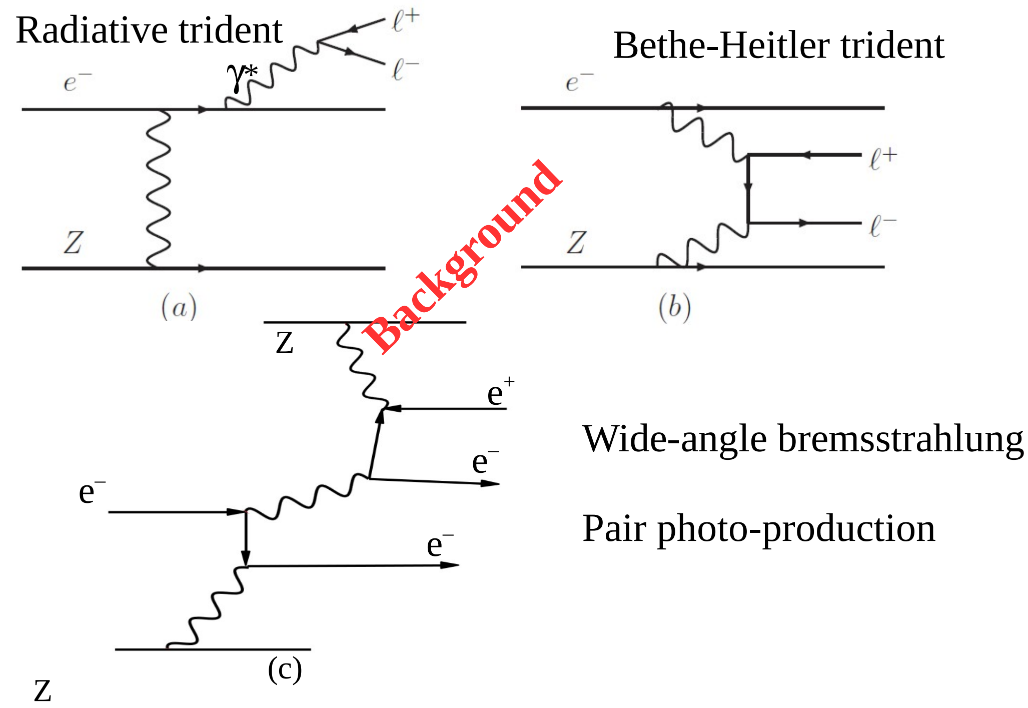


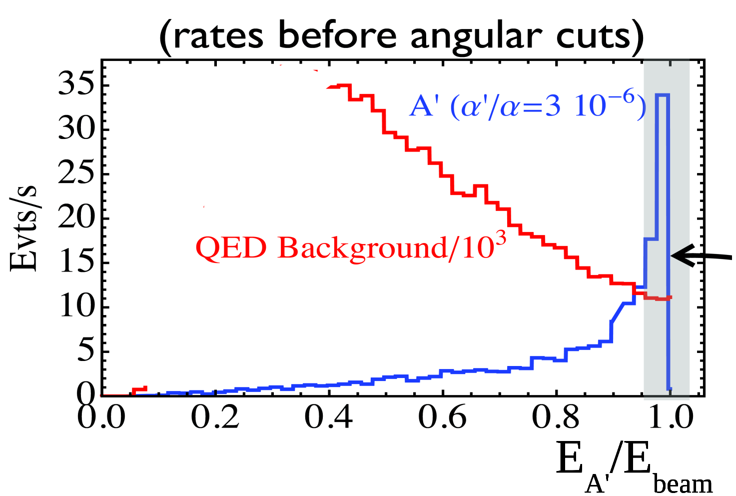
A' production

$$\frac{d\sigma(e^- Z \to e^- Z(A' \to \ell^+\ell^-))}{d\sigma(e^- Z \to e^- Z(\gamma^* \to \ell^+\ell^-))} = \left(\frac{3\pi\epsilon^2}{2N_{\text{eff}}\alpha}\right)\left(\frac{m_{A'}}{\delta m}\right)$$

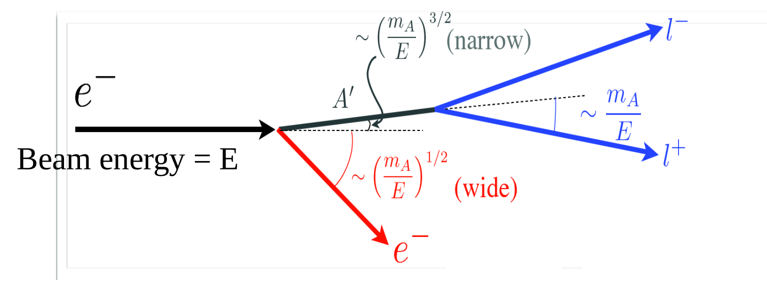
Assuming large decay to SM particles (e^+e^-),

electro-production rate $\sim \epsilon^2 \left(m_e^2 / m_{A'}^2\right)$





A′ products carry (almost) full beam energy



$$\theta_{A',\,max} \sim max\left(\frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}}\right),$$

$\theta_{A'}$ is parametrically smaller than the opening angle of the A' decay products ($m_{A'}/E_0$)

Concept of the experiment

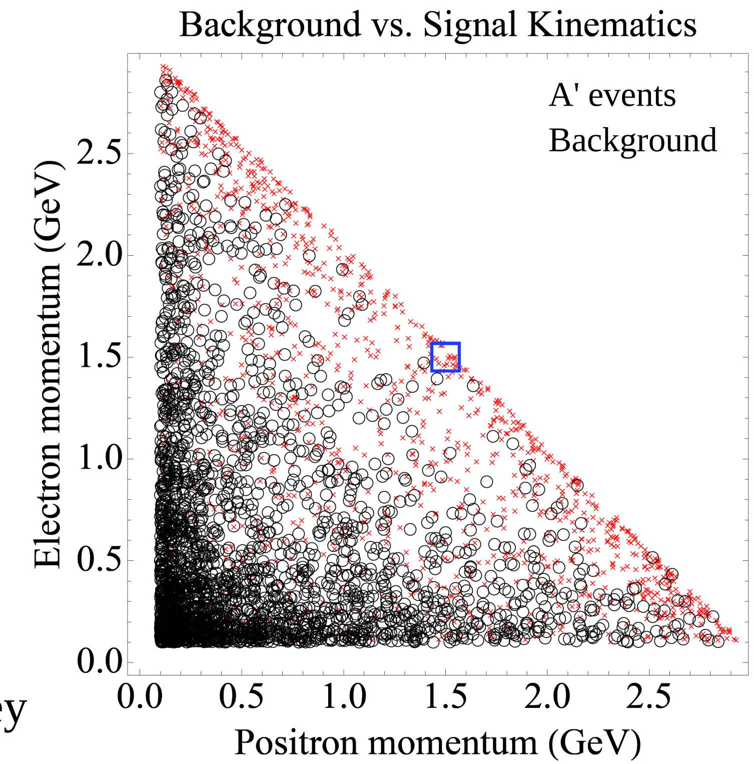
Symmetric energy, angles in two arms optimize A′ acceptance.

$$E_{e+} \approx E_{e-} \approx E_{beam}/2$$

Experiment sensitivity (in mass window Δm):

$$\frac{s}{\sqrt{B}} \sim \frac{\alpha'}{\alpha^2}\sqrt{\frac{m_{A'}}{\Delta m} N_{QED}}$$

high e^+e^- statistics and excellent mass resolution play key roles in the searches at small α'.



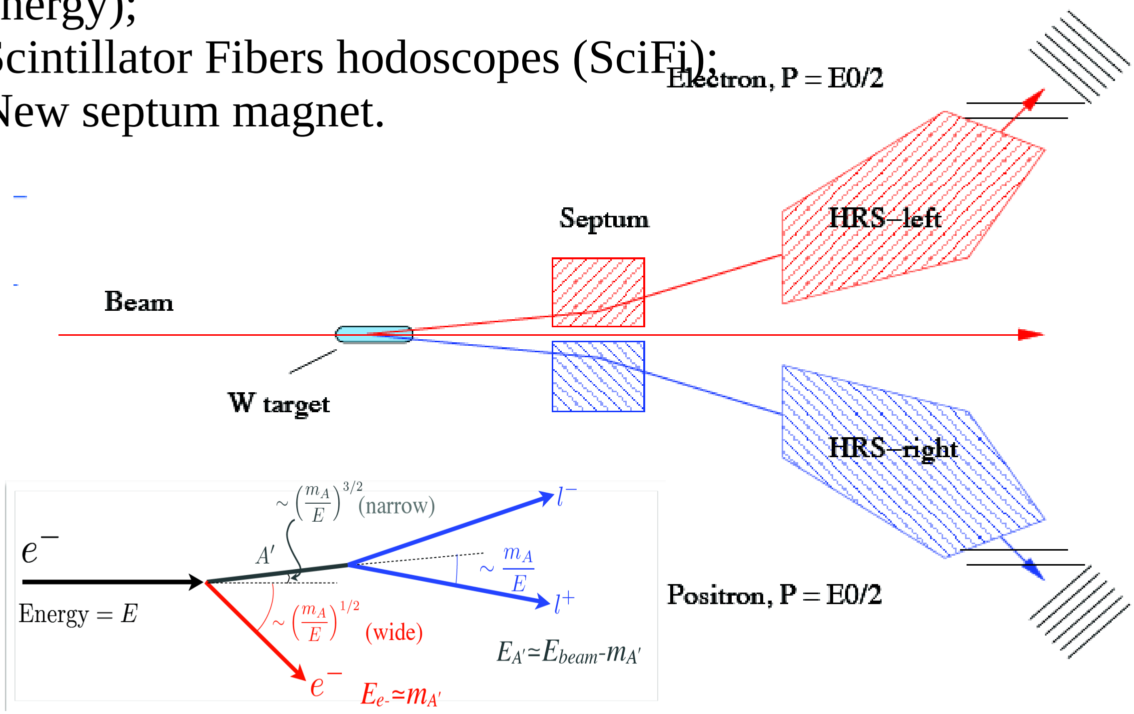
HRS acceptance takes about 5% of signal events (A') while the background rate is reduced dramatically (by several orders of magnitude).

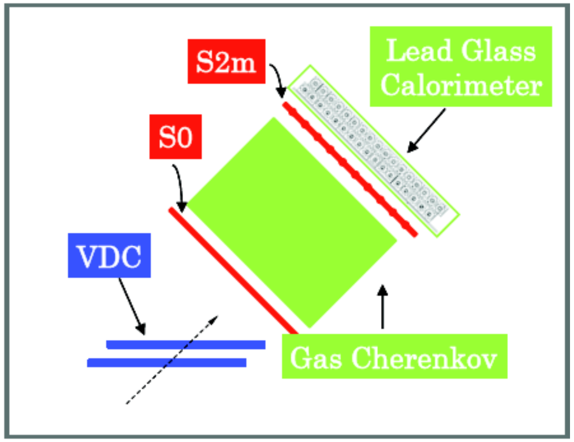
Presented in my talk at Hall A Winter Collaboration Meeting, Jan 19, 2017

Experimental Setup

Experimental equipment consists on:

- High Resolution Spectrometer (HRS);
- Multi-foil target (C, Ta, W – depends on beam energy);
- Scintillator Fibers hodoscopes (SciFi);
- New septum magnet.





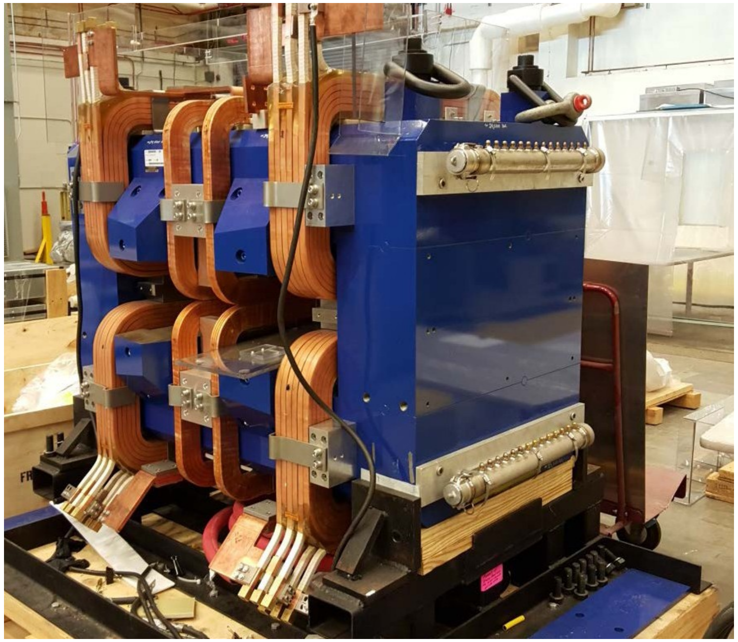
VDCs are used for tracking;
Cerenkov and calorimeter are used for particle identification;
s2m is used for trigger and timing.

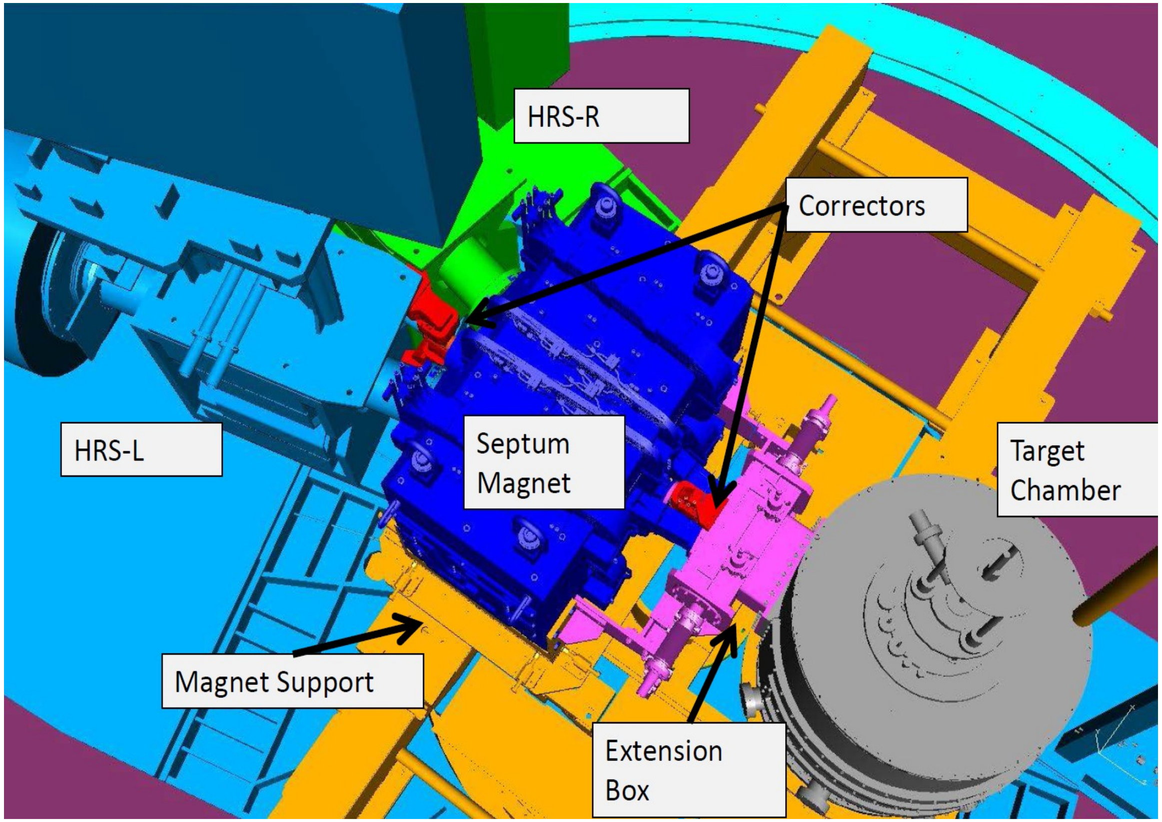
Demonstrated that HRS has up to 5 MHz Rate operation capability with on-line coincidence 20 ns.
e^+e^- invariant mass resolution is ~0.5%.

Experimental Setup

New septum:

- allows registration of small-angle e^+e^- pairs in HRS;
- provides operation for full momentum range of the experiment (up to 2.2 GeV);
- has a good magnetic shielding of the beam line.

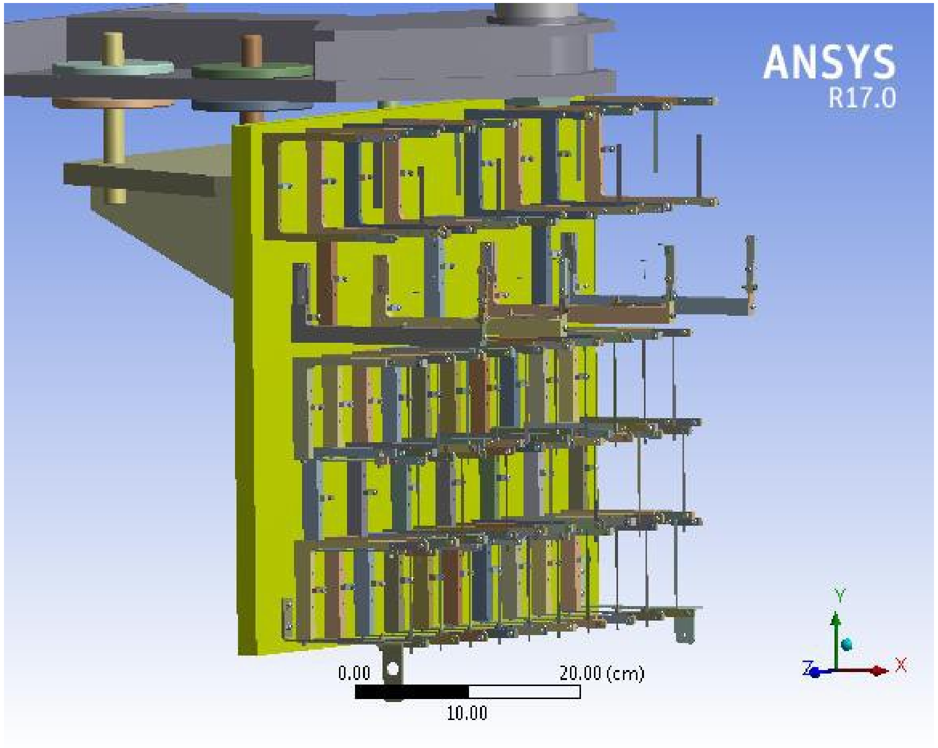


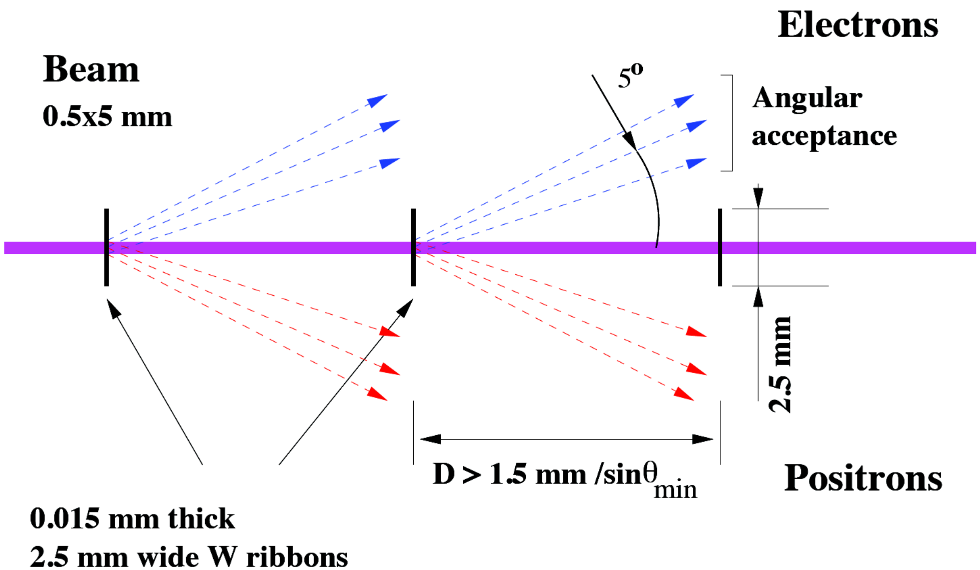


Experimental Setup

Target:

- multiple foil target allows to achieve high rate and good (A') mass resolution while keeping multiple scattering to a minimum;
- such design of the target provides wide A' mass range for each fixed beam energy;
- by using high-Z targets (tungsten and tantalum) we maximize the production rate of electron/positron pairs as compared to pions.





Experimental Setup

Target design completed (see the table 1).
Current estimated price of the complete target system (foils and other parts) is ~$16k

Table 1. Target characteristics.

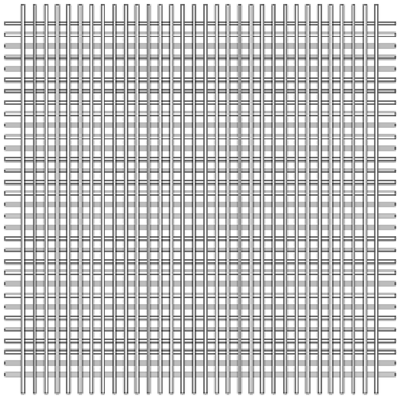
Energy (GeV)	Target	Beam Current (μA)	Beam Heating (W)	Number of foils	Total Thickness (RL) Single foil (μm)	Time (h)	Estimated Price
1.1	C	50	33	7/10	0.007 200/135	240	$520
1.65	C	100	66	7/10	0.007 200/135	240	$520
2.2	W/Ta	100	34	7/10	0.028 15/12	240	$2600
3.3	W	120	75	10	0.053 18.5	170	$2200
4.4	W	90	57	10	0.053 18.5	314	

Experimental Setup

SciFi (Scintillator Fibers hodoscopes):

- with 8.8 cm x 10.3 cm active area in front of Septum Magnet SciFi will allow optics calibration to 0.1 mrad precision;
- makes possible HRSR optics calibration without change of HRS polarity.

64 scintillation fibers:
32(V) and 32(H) directions
Size: 8.8(H) × 10.3 (V) cm^2
Fiber Ø – 1 mm

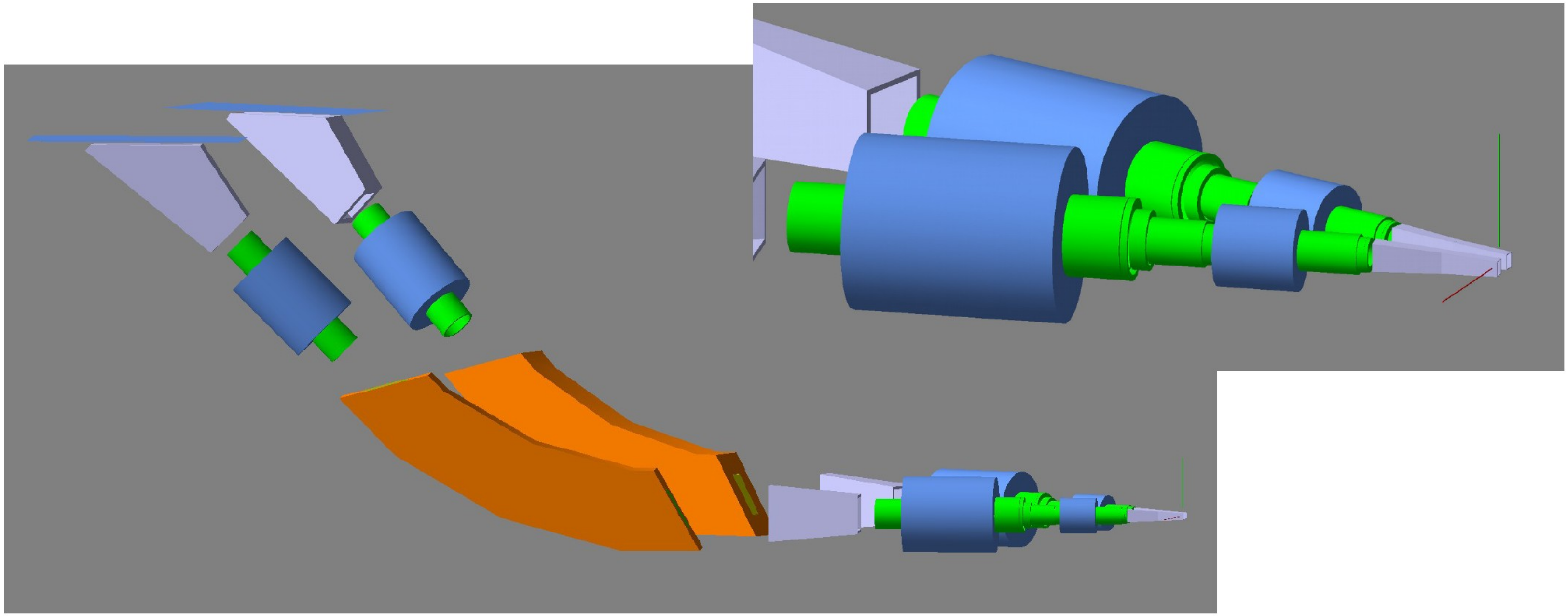


The pictures are taken from Toshiyuki Gogami, Hall A weekly meeting

Geant4 HRS Model

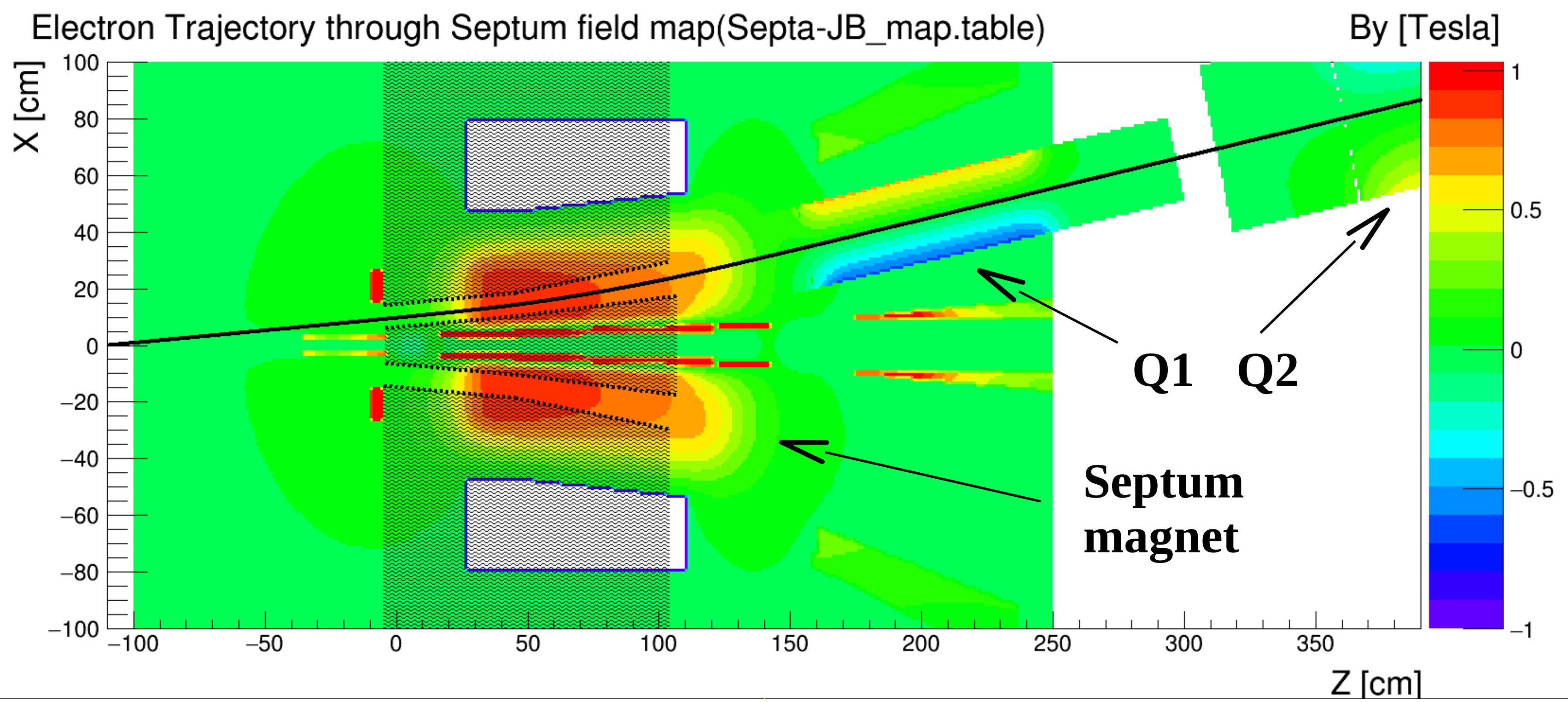
High Resolution Spectrometer in Geant4

- Magnetic Field Components are: Quadrupoles Q1, Q2, Q3, Dipole and the new septum magnet
- Detector geometry is fully described and corresponds to actual HRS
- Acceptance apertures are in agreement with SIMC



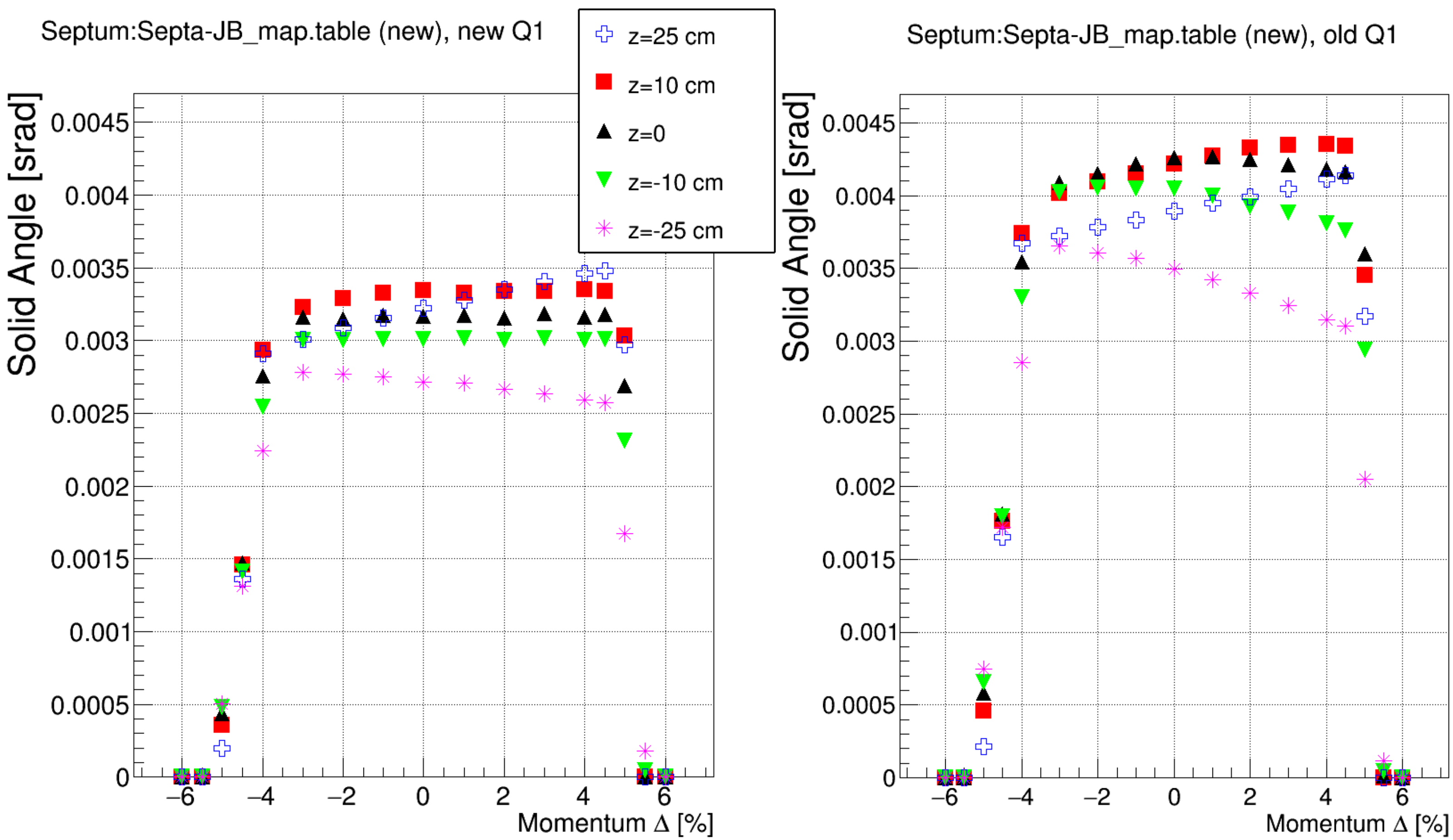
Geant4 HRS Model

Septum magnetic field and geometry are given according to realistic magnetic field map and drawings.



Geant4 HRS Model

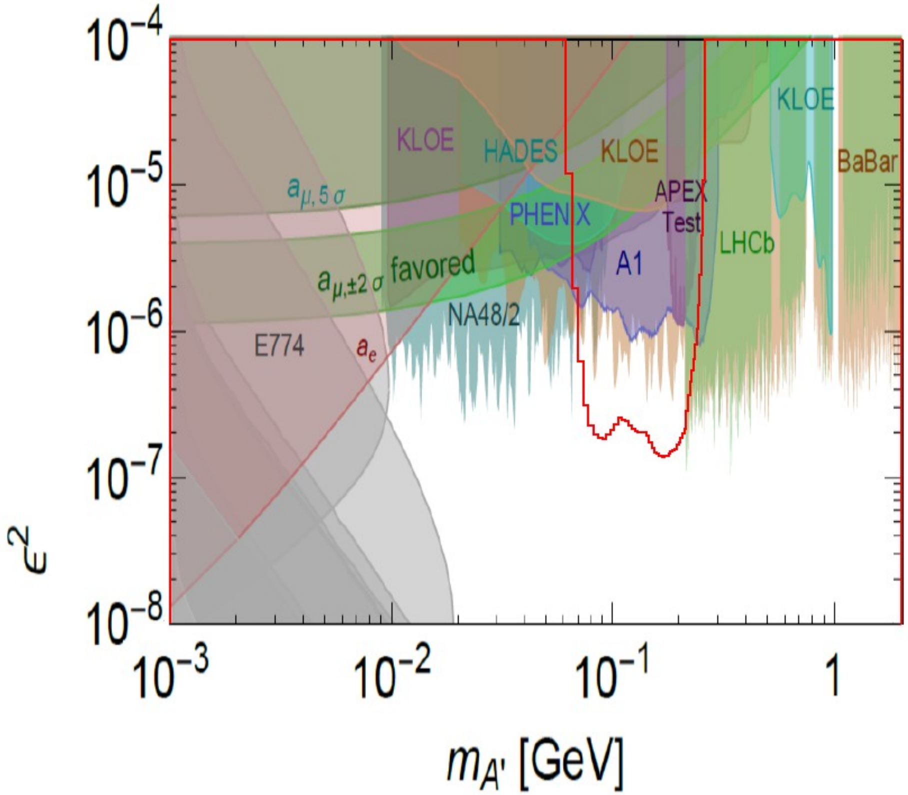
Solid angle distributions for different Z_{target} vs momentum Δ with old and new Quad1.



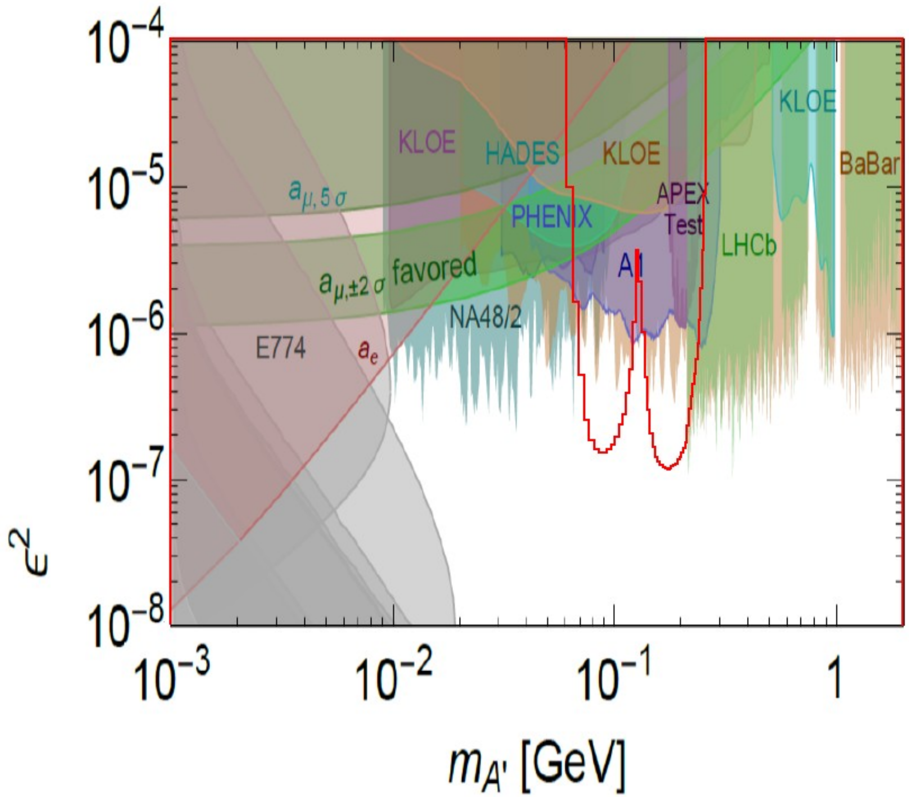
Expected Rates

E_{beam} [GeV]	1.1	1.65	2.2	3.3	4.4
Target material	C	C	W	W	W
Target Thickness	0.7% X_0	0.7% X_0	2.8% X_0	5.3% X_0	5.3% X_0
Beam current [μA]	50	100	100	120	90
L/RHRS Central momentum [GeV/c]	0.545	0.818	1.095	1.634	2.189
ee pair photoproduction Rate [Hz]	**16.2**	**15**	**207**	**270**	**105**
Trident rate [Hz]	**235**	**190**	**560**	**520**	**160**

APEX reach



10 days at 1.1 GeV beam
10 days at 1.65 GeV beam
10 days at 2.2 GeV beam



15 days at 1.1 GeV beam
15 days at 2.2 GeV beam

Documentation

APEX Home page:
http://hallaweb.jlab.org/experiment/APEX/index.html

Test Run results:
S. Abrahamyan et al (APEX Collaboration), “Search for a New Gauge Boson in Electron-Nucleus Fixed-Target Scattering by the APEX Experiment”.
Phys. Rev. Letters 107 (2011) 191804

Last news: Readiness Review has been passed in Apr 2016
(agenda: https://hallaweb.jlab.org/wiki/index.php/APEX)

APEX Experimental Readiness Review
April 7, 2016

Review Committee: V. Burkert (chair), P. Degtiarenko, E. Folts, C. Keith, B. Manzlak, Q. Sun, K. Welch.

The committee reviewed the APEX experiment and experimental equipment as proposed by the APEX collaboration according to the documentation available and based on the presentations given to the committee. The committee commends the collaboration for the excellent presentations and the preparatory work that entered into them. The presented material was reviewed to address the **nine charge items** given to the committee and the presenters prior to the review. The answers to the charges are presented below and separated into **Answer, Findings, Comments, and Recommendations.**

Recommendations by the ERR Committee:

- Design and install lockable radiation barrier around target for 1 R/hr field.

- W-ribbon thermal cycle test using a high power (10 W) laser or DC electric current.
  The collaboration should implement a program to address concerns about the viability of the tungsten ribbons due to repeated thermal cycling. The option of using a high power (10 W) laser to locally heat the ribbon was mentioned by the collaboration. Another and potentially simpler option, would be to use a DC electric current to heat the ribbon, suitably shaped to localize the heat into a 1.5 x 5 mm^2 area.
  The collaboration should develop estimates of who, when, and how often personnel will require access to the target area. This information is to be passed on to the Jefferson Lab Radiation Control Group for ALARA planning and development of a suitable Radiation Work Permit.

- Assign responsibility for placement of the beam line protection Ion Chambers at the strategic locations around the beam line.

Status of the preparation

- Beam-time request – submitted in July 2016;
- Target design is completed. W-ribbon thermal cycle test (S. Covrig) – the work is in progress, some of the target foils were tested in 2017 and the results are reported at Hall A weekly meeting (Nov-7, 2017). For 2.2 GeV beam energy the target regime is relaxed;
- SciFi integration in HRS-DAQ (Tohoku Univ and CNU) - in progress, the status was reported at Hall A weekly meeting (Dec-5, 2017);
- Septum Magnet tests (J. Butler) – the first test of the magnet was done in Aug-2017. Support frame needs design;
- Corrector magnets – design is completed, need to be ordered;
- Vacuum system (J. Butler) – all the parts are delivered. The system needs to be assembled and tested;
- VDC electronics and HV system – upgraded in spring of 2017, ready to run for APEX rates.

List of Jobs

The list of jobs and responsible persons

1. Design of the septa support + power lines: Robin Wines;
2. Target preparation and tests: Silviu Covrig/Jessie Butler;
3. Beam line optics & commissioning: Yves Roblin;
4. Radiation analysis: Juan Carlos Cornejo;
5. Septa + correctors preparation and tests: Jessie Butler;
6. Vacuum connections preparation and tests: Jessie Butler;
7. SciFi preparation and tests: Gregg Franklin/Toshiyuki Gogami;
8. Power supplies and power lines (septa, corrector): Jack Segal;
9. Documentation (safety, run plan, TOSP, ...): R. Essig;
10. DAQ for HRS: Vardan Khachatryan
11. Online software (VDC, calibration, trigger time): Seamus Riordan;
12. Data taking shifts (collaboration): SBU/SLAC/JLab/UVa/CMU/CatU/NCCU/FIU/YerPhI + Hall A collaboration;
13. Data analysis: PIs/Postdoc (Vardan Khachatryan)/Students.

Summary

- Most of the experiment components are ready;
- Tests of subsystems are in progress;
- Every sub-project has a responsible person/owner and will be completed by Dec-2018.

APEX run schedule still needs to be approved. We are looking forward to finalizing our preparation (including installation) works by the end of 2018 and proceed with APEX data taking.