The Status of the APEX experiment at JLab

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on behalf of APEX Collaboration

Hall A Winter Collaboration Meeting
January 18, 2017

Contents

APEX Collaboration

The A' Experiment (APEX) Collaboration:

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Total financial support from the selected institutions is ~ $300k

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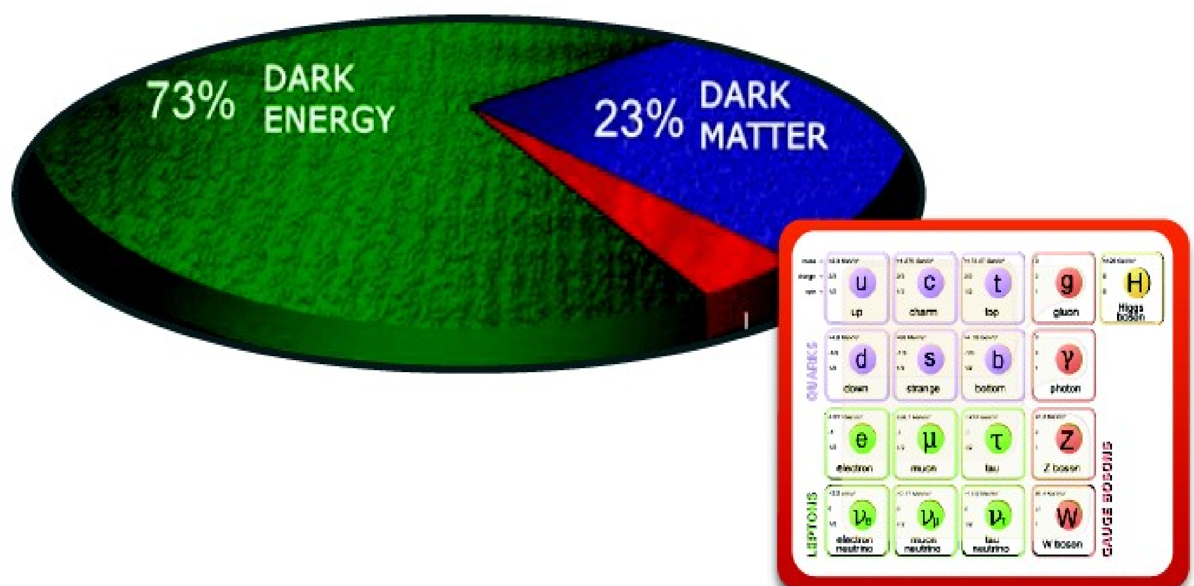
Hebrew University of Jerusalem, Jerusalem, Israel

Physics Motivation

Experimentally explore the ways in which a dark sector can interact with familiar matter

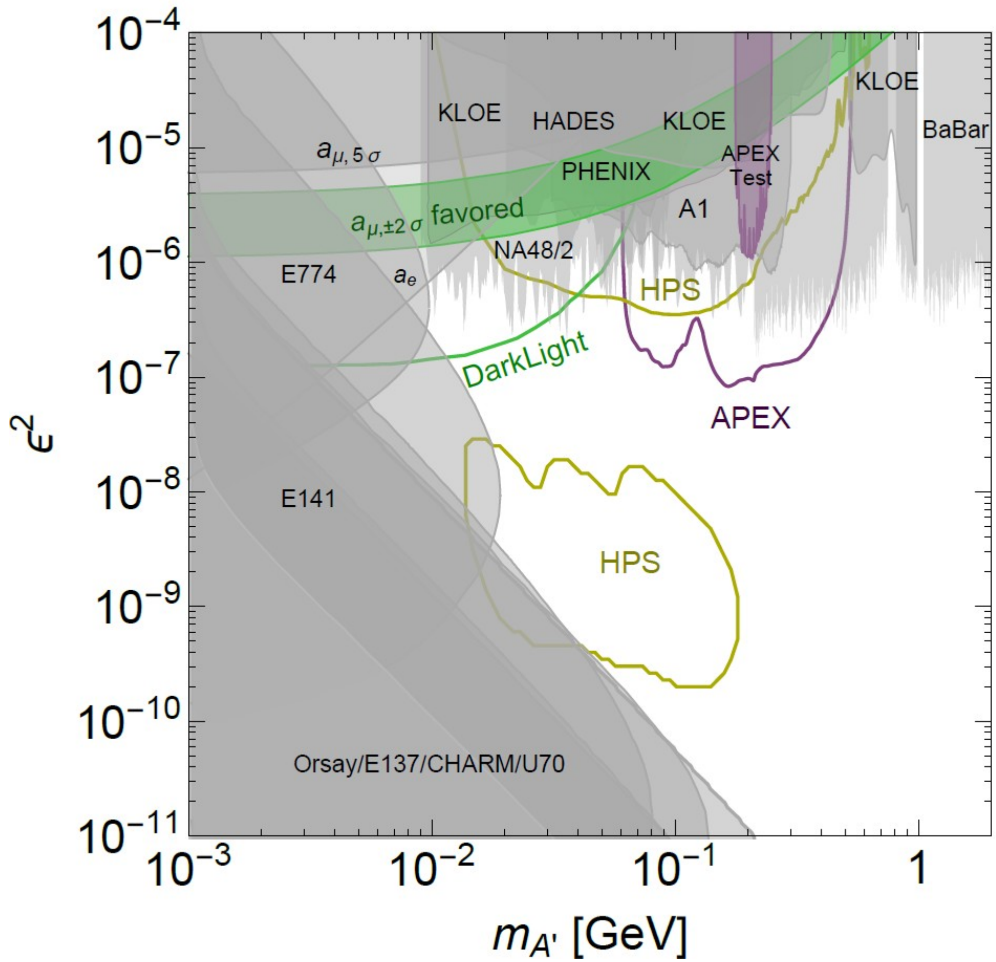
- Do so paying attention to hints that arise from new and existing data, but not to the point of distraction

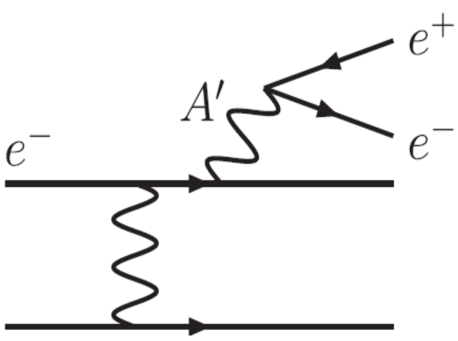
Discover the new forces and/or matter responsible for the "dark matter" that we observe all around us



A' Current Status

APEX is a spectrometer-based search, at JLab Hall A, for 65-550 MeV dark photons decaying promptly to e^+e^-.
The goal of the APEX is to measure the invariant mass spectrum of e^+e^- pairs produced by electron scattering on a high-Z target, and search for a narrow peak with width corresponding to the instrumental resolution.





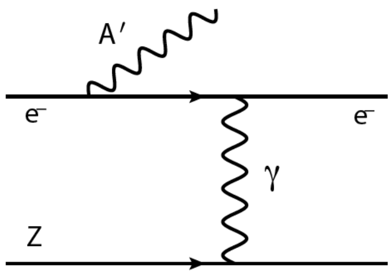
2 weeks APEX run ~ 3 months HPS (at $M_{A'}$ =200 MeV)

A' Current Status

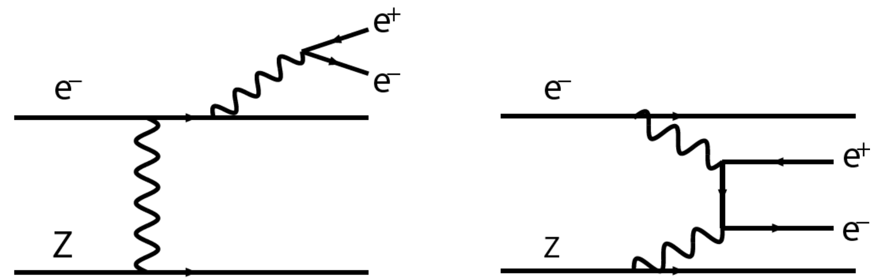
Summary of dark photon experiments. (Dark Sectors 2016 Workshop: Community Report, 1608.08632)

Experiment	Lab	Production	Detection	Vertex	Mass (MeV)	Mass Res. (MeV)	Beam	Ebeam (GeV)	Ibeam or Lumi	Machine	1st Run	Next Run
APEX	JLab	e-brem	$\ell^+\ell^-$	no	$65-600$	0.5%	e^-	1.1–4.5	150 μA	CEBAF(A)	2010	2018
A1	Mainz	e-brem	e^+e^-	no	$40-300$	?	e^-	0.2–0.9	140 μA	MAMI	2011	–
HPS	JLab	e-brem	e^+e^-	yes	$20-200$	1–2	e^-	1–6	50–500 nA	CEBAF(B)	2015	2018
DarkLight	JLab	e-brem	e^+e^-	no	< 80	?	e^-	0.1	10 mA	LERF	2016	2018
MAGIX	Mainz	e-brem	e^+e^-	no	$10-60$	?	e^-	0.155	1 mA	MESA	–	2020
NA64	CERN	e-brem	e^+e^-	no	$1-50$	?	e^-	100	2×10^{11} EOT/yr	SPS	2016	2022
Super-HPS	SLAC	e-brem	vis	yes	< 500	?	e^-	$4-8$	1 μA	DASEL	?	?
(TBD)	Cornell	e-brem	e^+e^-	?	< 100	?	e^-	0.1-0.3	100 mA	CBETA	?	?
VEPP3	Budker	annih	invis	no	$5-22$	1	e^+	0.500	10^{33} cm^{-2}s^{-1}	VEPP3	–	2019?
PADME	Frascati	annih	invis	no	$1-24$	$2-5$	e^+	0.550	$\leq 10^{14}\, e^+$OT/y	Linac	–	2018
MMAPS	Cornell	annih	invis	no	$20-78$	$1-6$	e^+	6.0	10^{34} cm^{-2}s^{-1}	Synchr	?	?
KLOE 2	Frascati	several	vis/invis	no	< 1.1 GeV	1.5	e^+e^-	0.51	2×10^{32} cm^{-2}s^{-1}	DAϕNE	2014	–
Belle II	KEK	several	vis/invis	no	$\lesssim 10$ GeV	$1-5$	e^+e^-	4×7	$1\sim10$ ab^{-1}/y	Super-KEKB	–	2018
SeaQuest	FNAL	several	$\mu^+\mu^-$	yes	$\lesssim 10$ GeV	$3-6$%	p	120	10^{18} POT/y	MI	2017	2020
SHIP	CERN	several	vis	yes	$\lesssim 10$ GeV	$1-2$	p	400	2×10^{20} POT/5y	SPS	–	2026
LHCb	CERN	several	$\ell^+\ell^-$	yes	$\lesssim 40$ GeV	~ 4	pp	6500	~ 10 fb^{-1}/y	LHC	2010	2015

Concept of the experiment

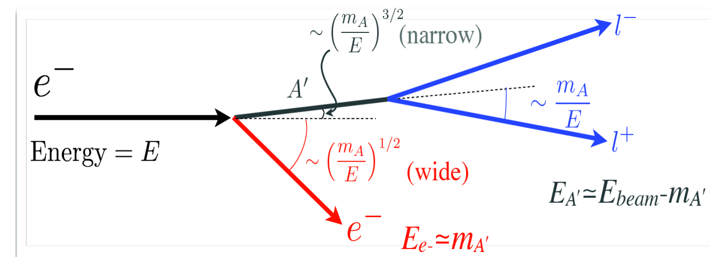


A' signal



Backgrounds

- **Assuming large decay to SM particles (e^+e^-), electroproduction rate** $\sim \epsilon^2 \left(m_e^2 / m_{A'}^2 \right) \sigma_{QED}$

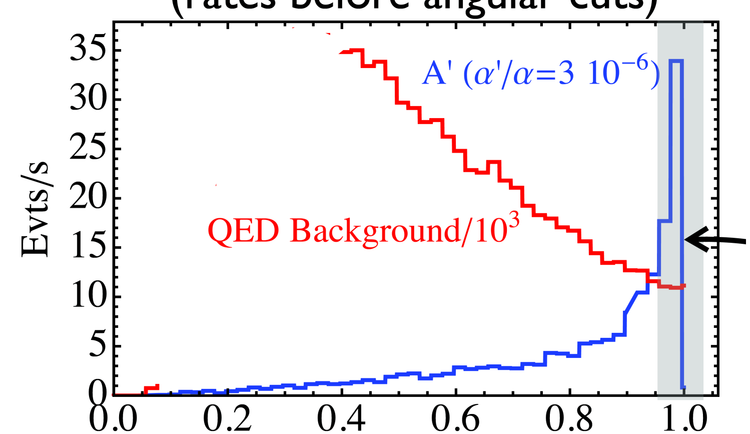


- **A' emission is dominated at angles $\theta_{A'}$**

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

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

(rates before angular cuts)

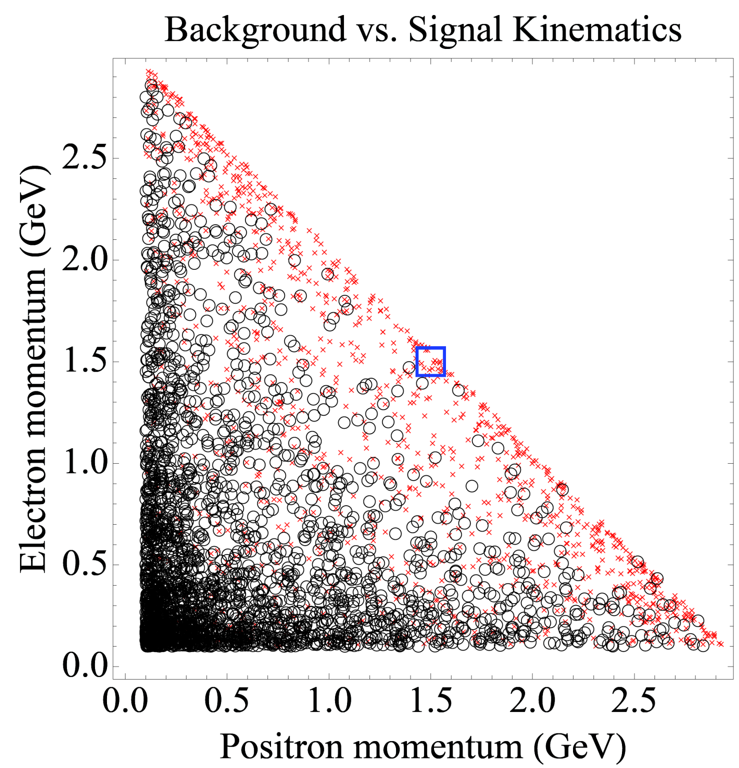


A′ products carry (almost) full beam energy

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):**

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

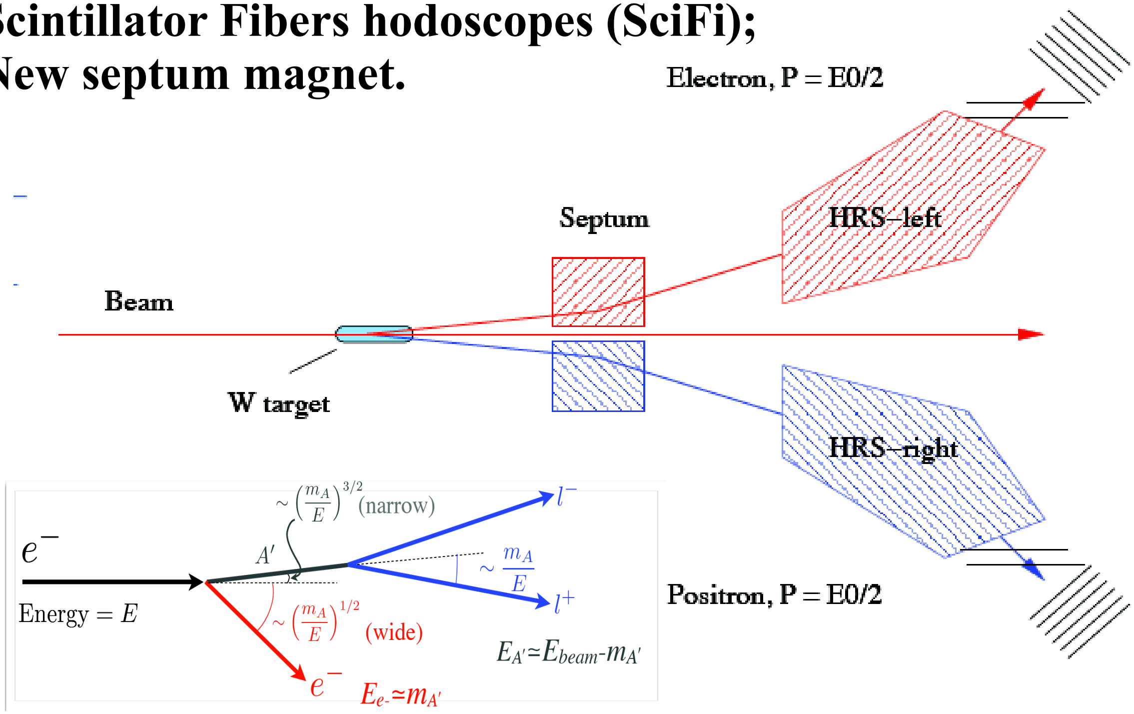
high e^+e^- statistics and excellent mass resolution are playing key roles for the searches at small α'.

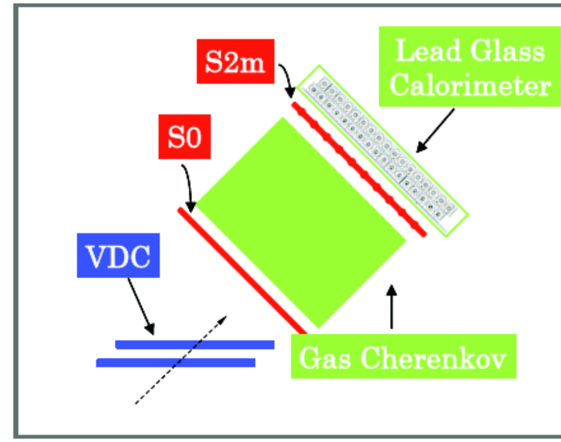
For these reasons JLab's beam and the High Resolution Spectrometers (HRS) in Hall A are suitable for the A' searches.

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.**





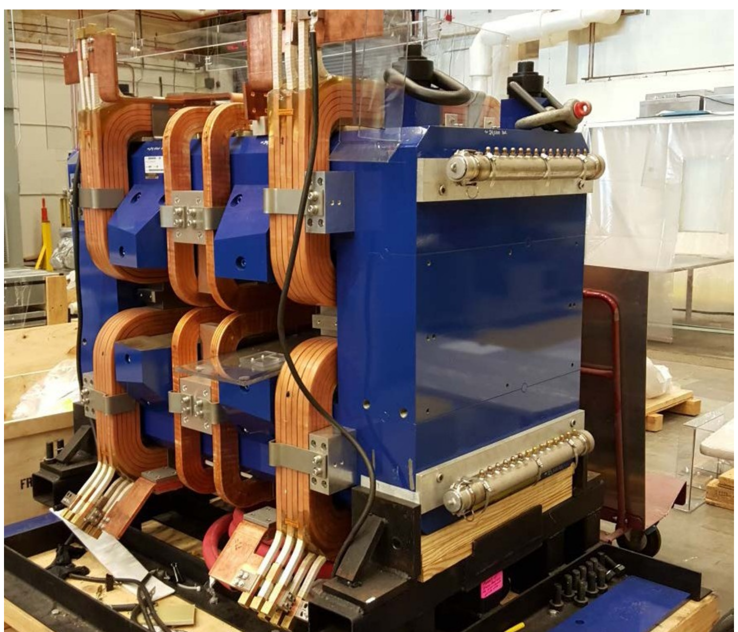
VDCs are used for tracking;
Cerenkov and calorimeter are used for particle identification;
s2m is used for trigger and timing.

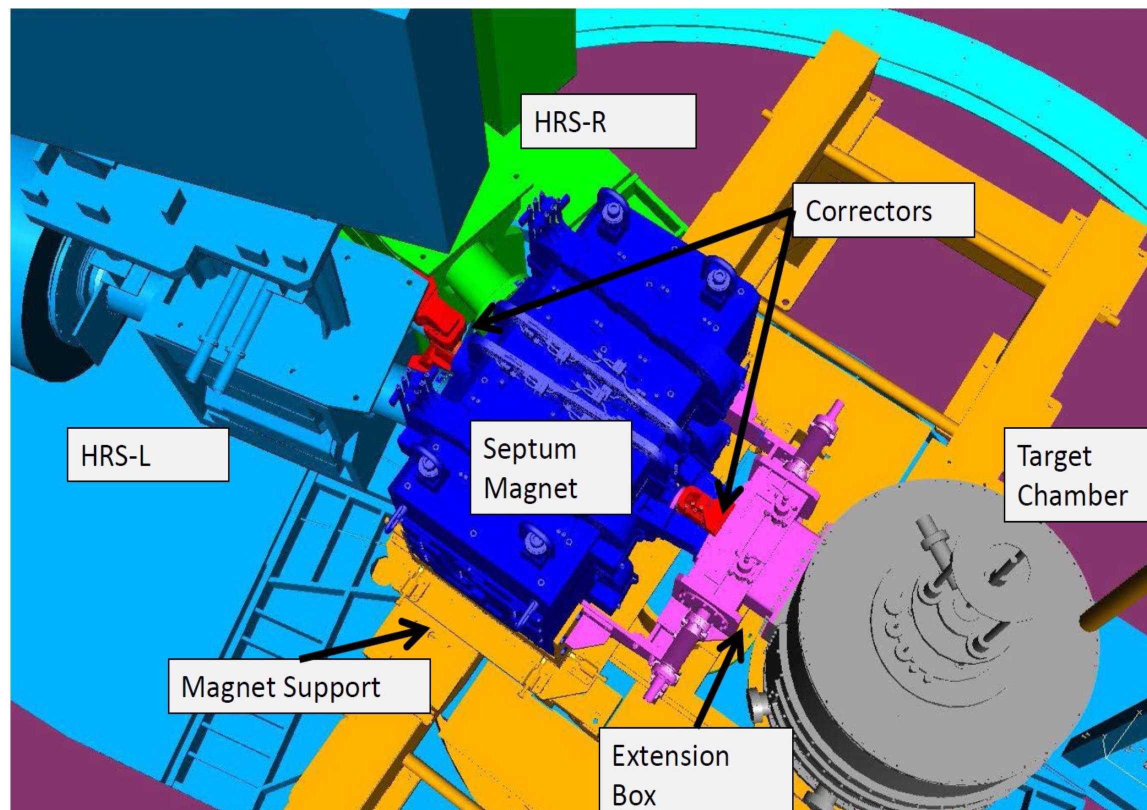
Demonstrated that HRS has up to 5 MHz Rate operation capability with on-line coincidence 20 ns.
e^+e^- invariant mass resolution is ~0.5%.

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.**

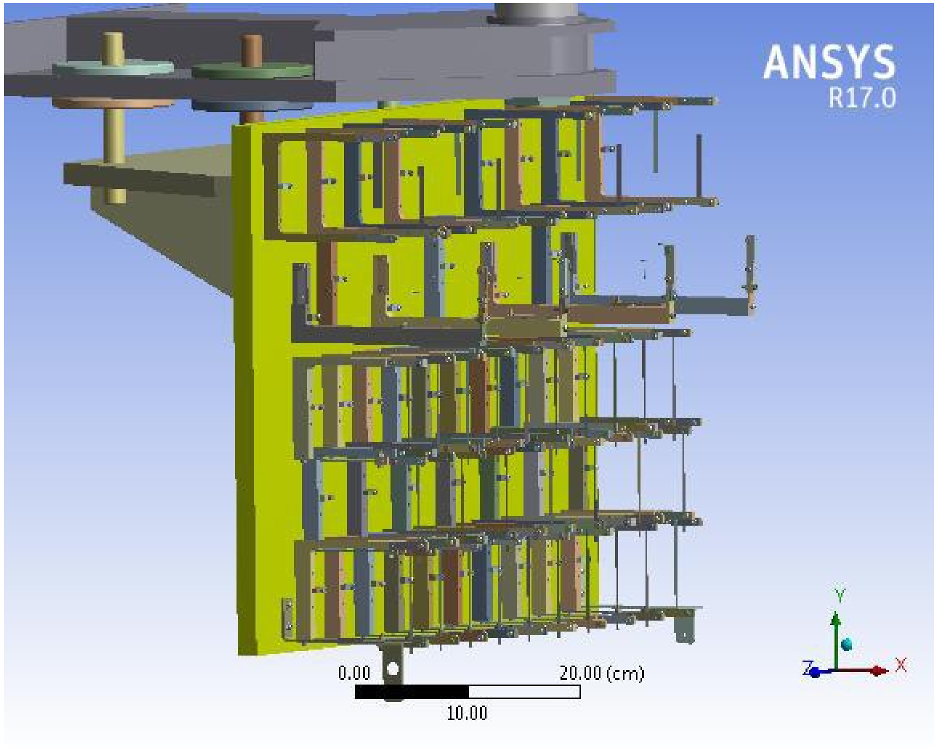


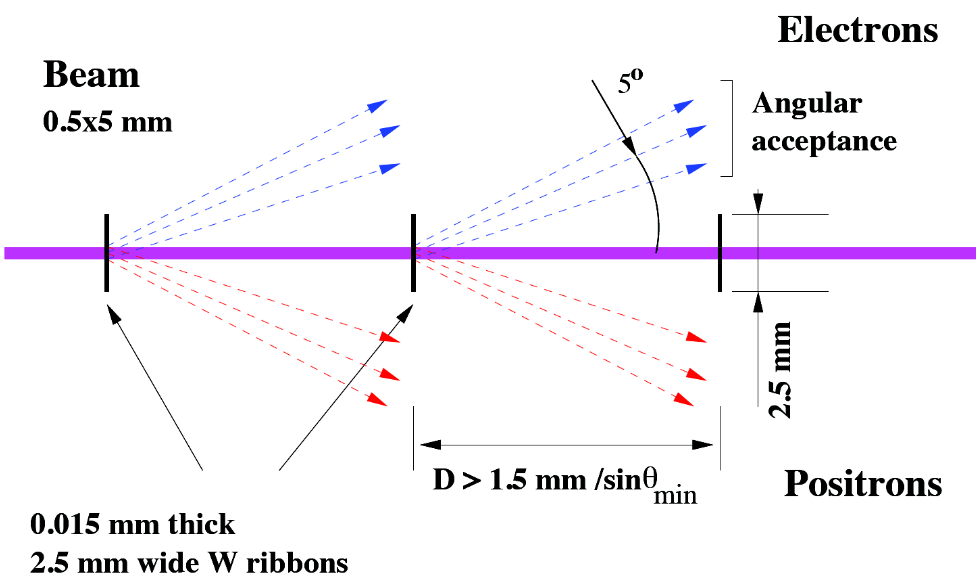


Experimental Setup

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

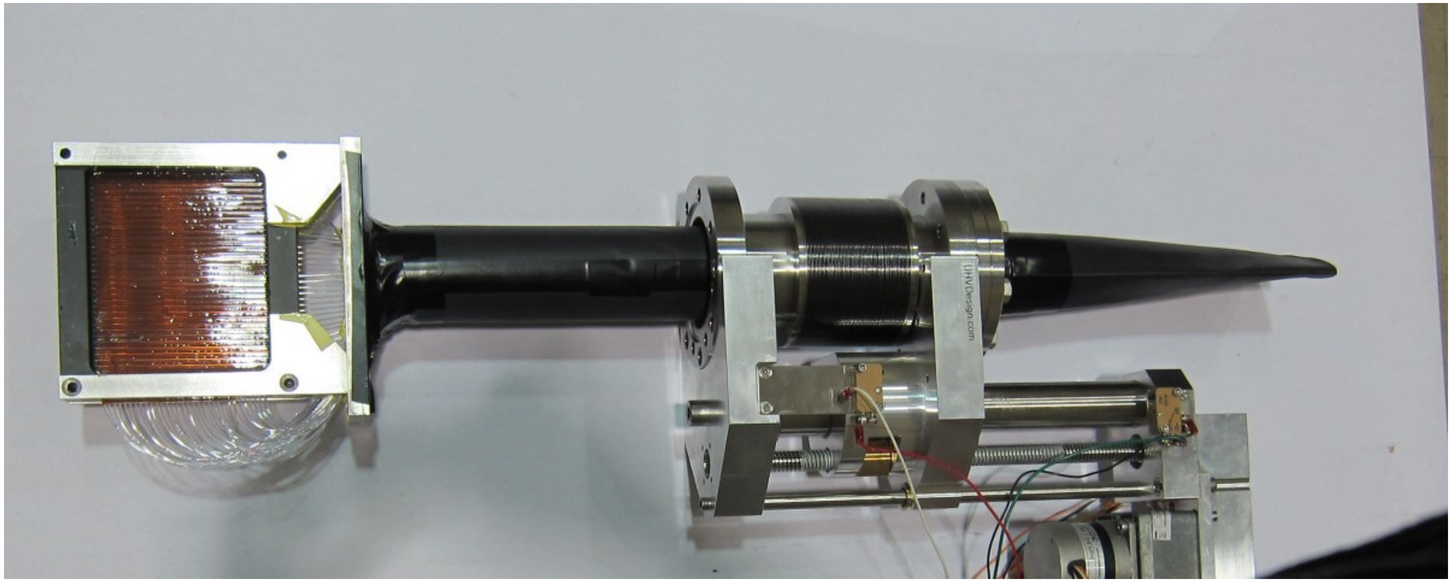
Table 1. Target characteristics.

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	170	$520
2.2	W/Ta	100	34	7/10	0.028 15/12	166	$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):

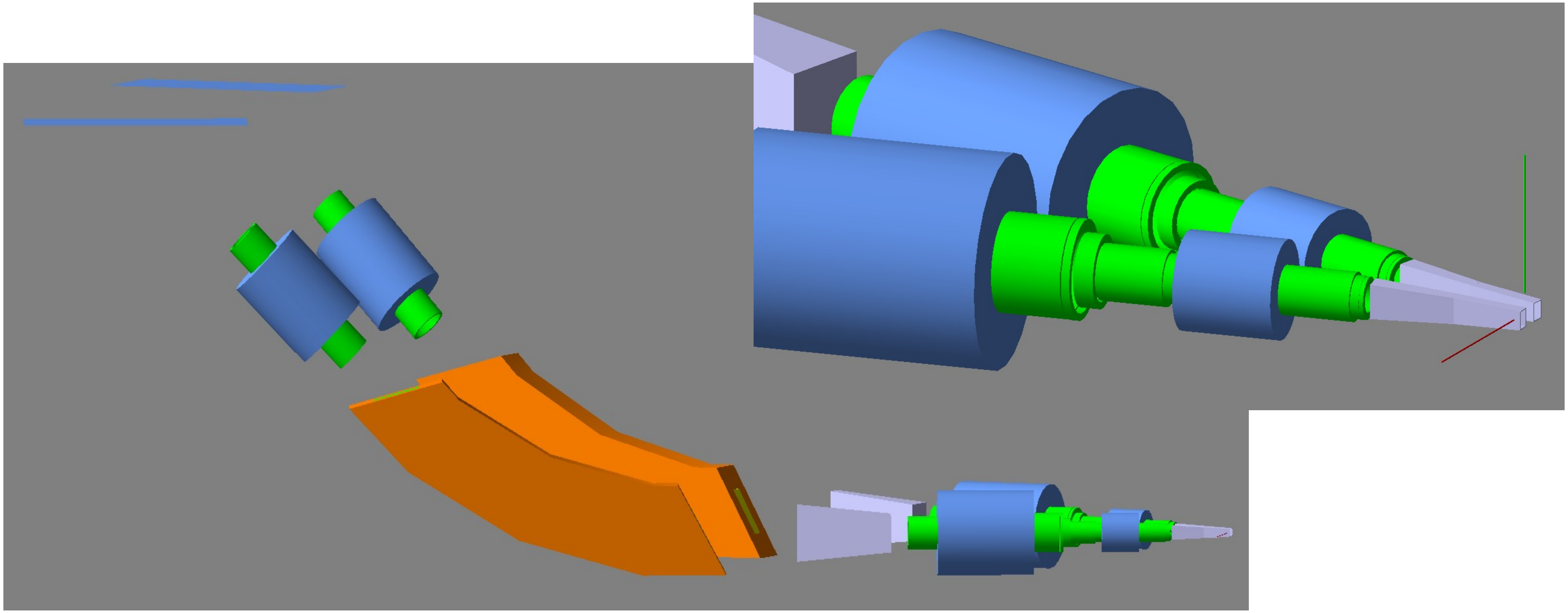
- **with 8.8 cm x 10.3 cm active area in front of Septum Magnet SciFi will allow optics calibration to 0.1 mrad precision;**
- **makes possible HRSR optics calibration without change of HRS polarity.**



Geant4 HRS Model

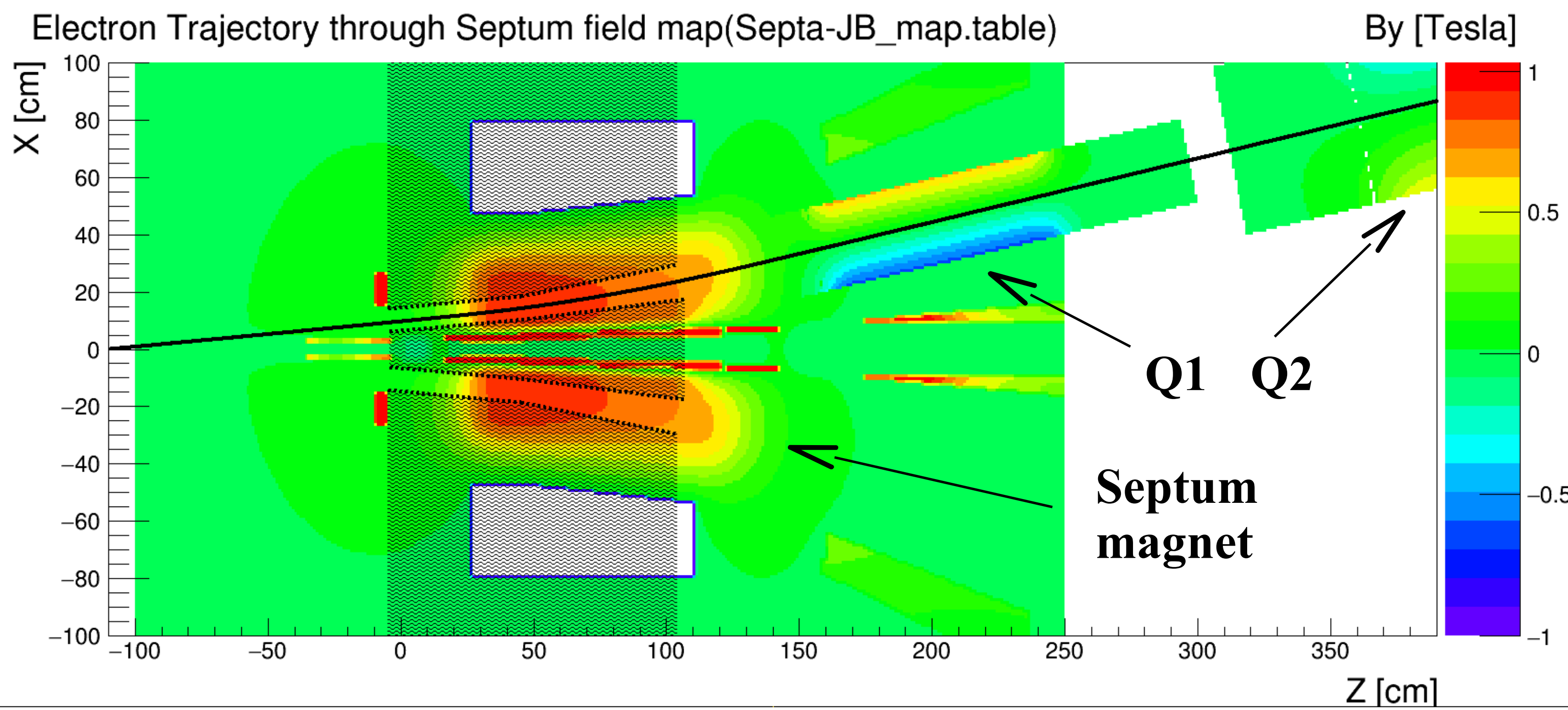
High Resolution Spectrometer in Geant4

- **Magnetic Field Components are: Quadrupoles 1, 2, 3 and Dipole**
- **The geometry is in agreement with real HRS detector**



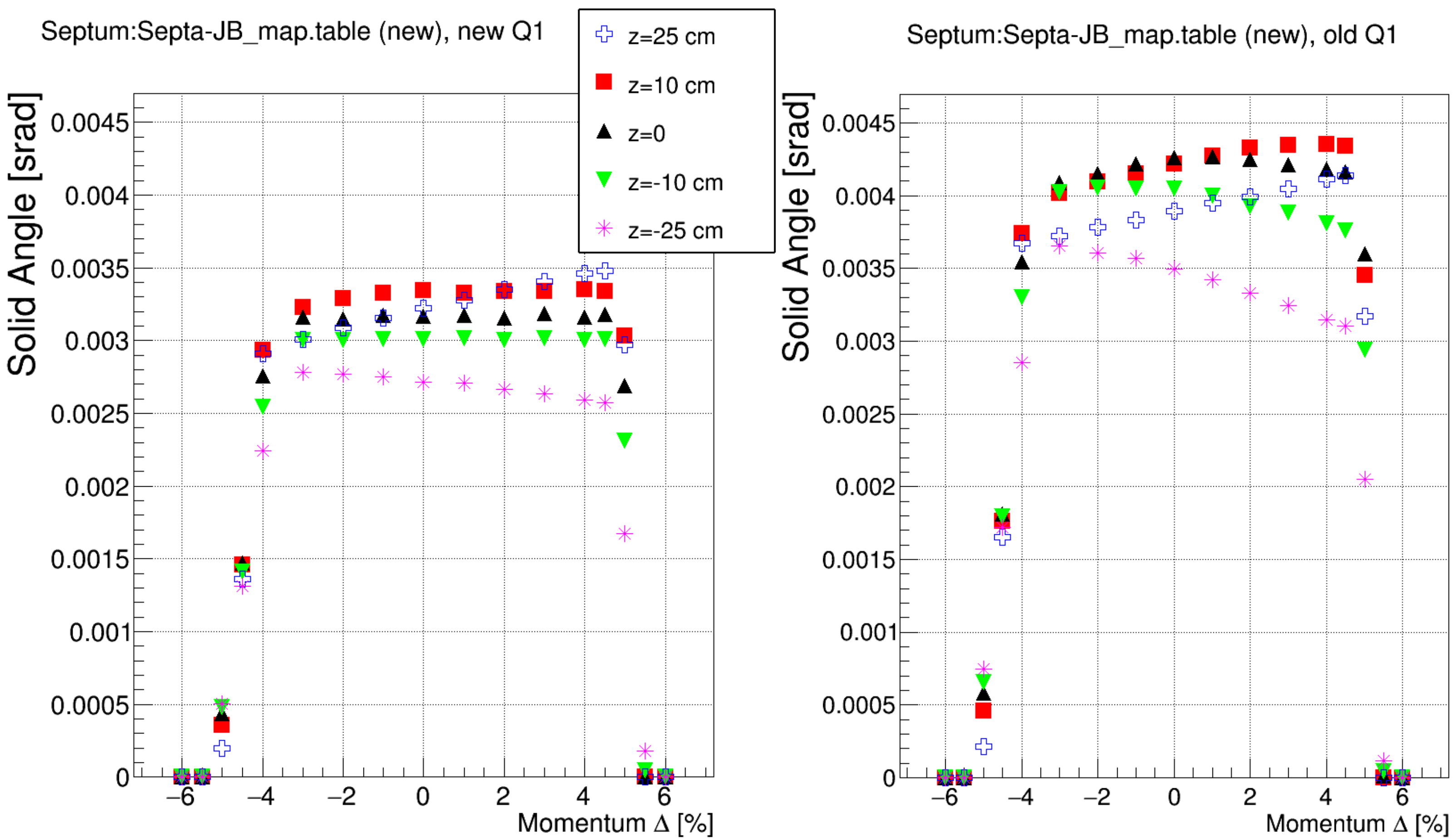
Geant4 HRS Model

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.



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) - in progress, expected to be done this spring;**
- **SciFi integration in HRS-DAQ (G. Franklin) - in progress;**
- **Septum Magnet tests (J. Butler) – expected to be done in March;**
- **Vacuum system assembly and tests (J. Butler) – delivery of vacuum system parts to HRSs are expected in February.**

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: owner Silviu Covrig/Jessie Butler;
3. Beam line optics & commissioning: owner-Yves Roblin;
4. Radiation analysis: Gordon Cates/B. Wojtsekhowski;
5. Septa + correctors preparation and tests: owner Jessie Butler;
6. Vacuum connections preparation and tests: owner Jessie Butler;
7. SciFi preparation and tests: owner Gregg Franklin;
8. Power supplies and power lines (septa, corrector): owner-Jack Segal;
9. Documentation (safety, run plan, TOSP, ...): R. Essig/Physics Liaison;
10. DAQ for full rate modification (VDC HV control): Roman Pomatsalyuk/B. Wojtsekhowski;
11. Online software (VDC, calibration, trigger time): Seamus Riordan;
12. HRS Upgrade (flash ADC integrations): Vardan Khachatryan;
13. Data taking shifts (collaboration): SBU/SLAC/JLab/UVa/CMU/CatU/NCCU/FIU/YerPhI + Hall A collaboration;
14. Experiment coordination: PIs/Physics Liaison
15. Data analysis: PIs/Postdoc (Vardan Khachatryan)/Students.

Summary

- Most of the experiment components are ready;
- Tests of subsystems are scheduled in 2017;
- Every sub-project has a responsible person/owner and plan of completion;
- According to the current JLab plans and time-line we can start the experiment in the fall of 2018.

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