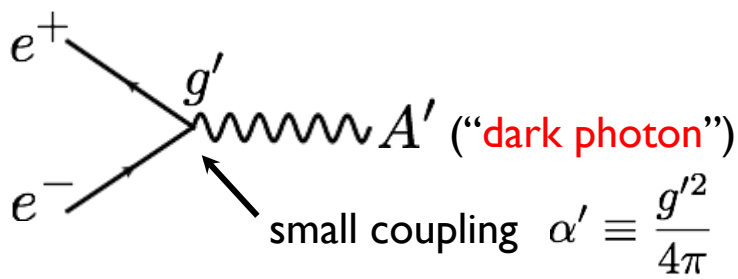
APEX: A Search for Dark Photons in Hall A

R. Essig (SUNY), P. Schuster (SLAC), N. Toro (SLAC), B. Wojtsekhowski (JLab)

Goal: Search for a new ~100 MeV gauge boson (A′) with very weak coupling to electrons

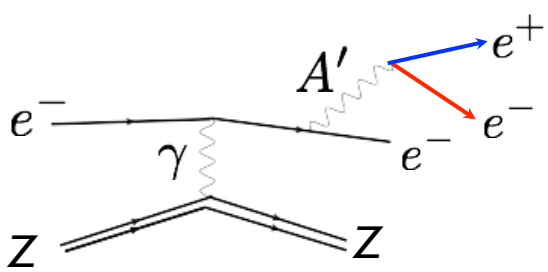


- Large interest in A′ search
- Number of considerations *naturally* give A′ mass ~ 100s MeV

A′ is motivated from theory and anomalies related to dark matter

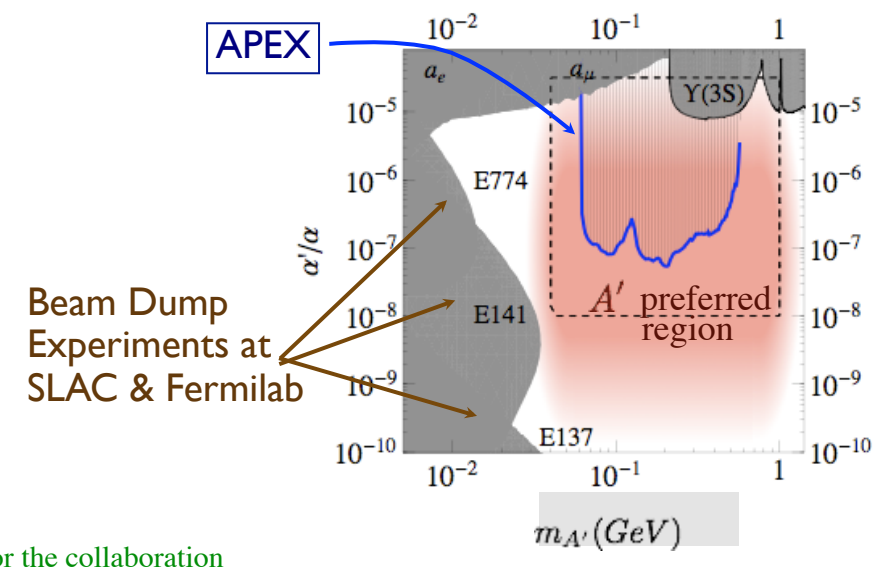
- A' can be a force carrier of new Abelian force (*ubiquitous* in extensions of Standard Model)
- New high-energy physics *generically* mixes A′ with the photon giving $\alpha'/\alpha \sim 10^{-6}$–$10^{-8}$
- Dark Matter charged under A′ may explain *famous* data "anomalies" (PAMELA, Fermi, DAMA)

Discovery potential in Hall A:



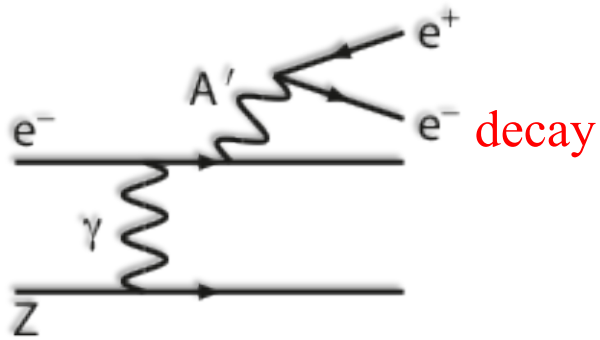
★ APEX will achieve unprecedented statistics
~10^9 e^+e^- trident events ~10,000-fold gain

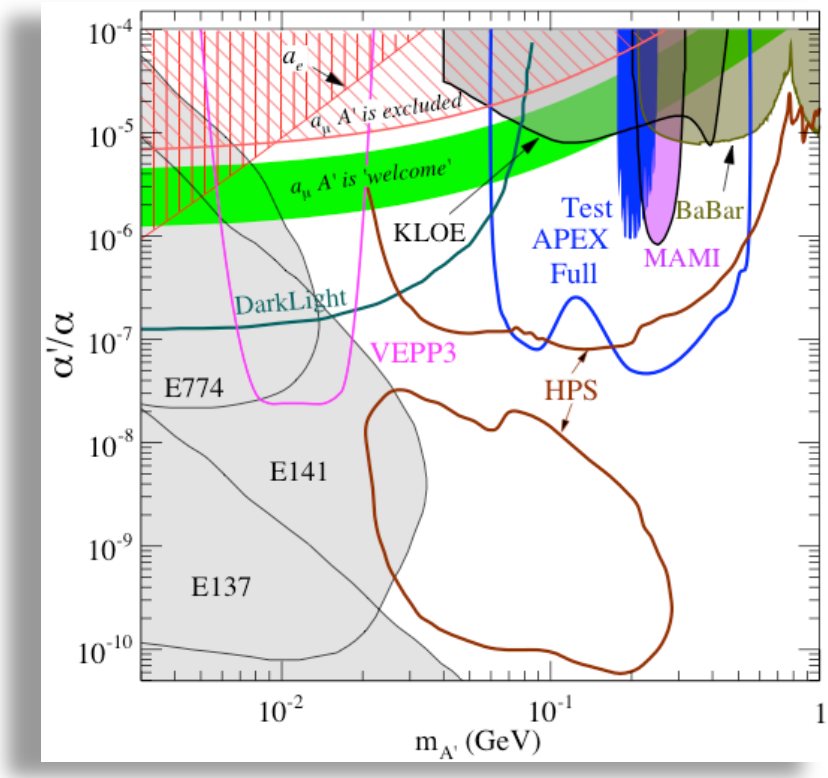
★ All equipment is ready for measurements



Searches for a gauge boson A' – APEX Test Run Result

Electroproduction of A'





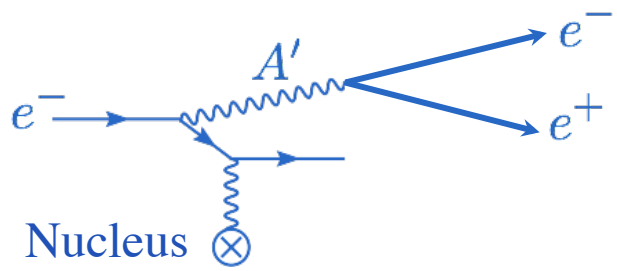
Published results :
- Beam dump searches: SLAC:E137, 141; FNAL: E774
- electron and muon (g-2), limits
- BaBar, Υ(3s)-> γ and μ+μ- (inferred limit)
- KLOE, mass of e+e- pair (bump search)
- **APEX test run, mass of e+e- pair – in publication**
- MAMI – APEX type scheme

Future searches for a new force carrier:
- APEX – electron-nucleus fixed-target, a e+e- pair in two focusing spectrometers
- HPS – same, the e+e-, μ+μ- pairs in a custom Si-tracker magnetic spectrometer
- DarkLight – an internal target with an electron beam in Jefferson Lab ERL, detect a e+e- pair and e'p
- VEPP3 – a positron beam incident on an internal H_2 target, missing mass in (e+e-, γ X)
- MAMI – APEX type scheme with lower beam energy

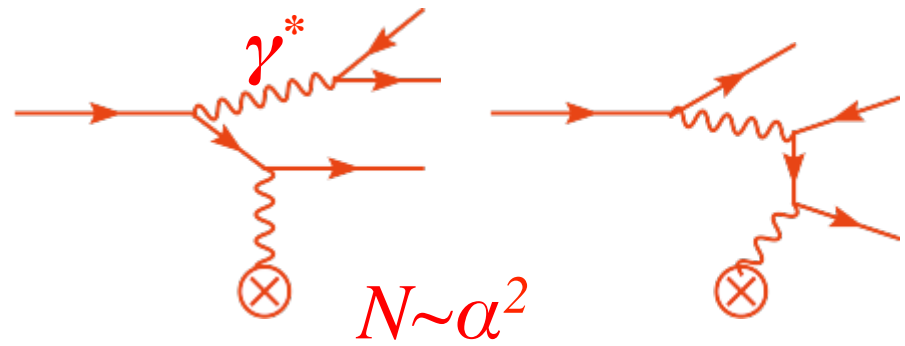
Mont's slide in 2011

A′ Production and Background Kinematics

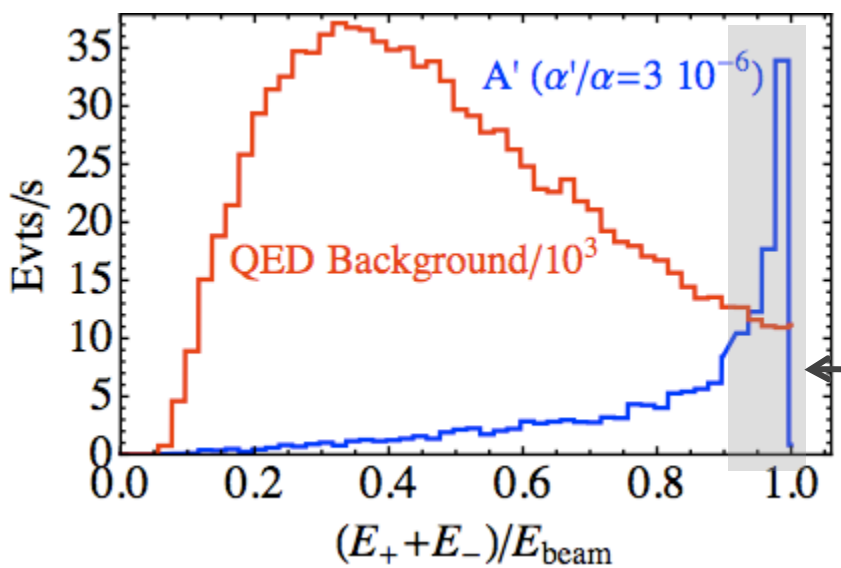
J.Bjorken, R.Essig, P.Schuster, N.Toro, PRD 80 (2009)



$N \sim \alpha'$ x Branching → O(1)



(rates before angular cuts)

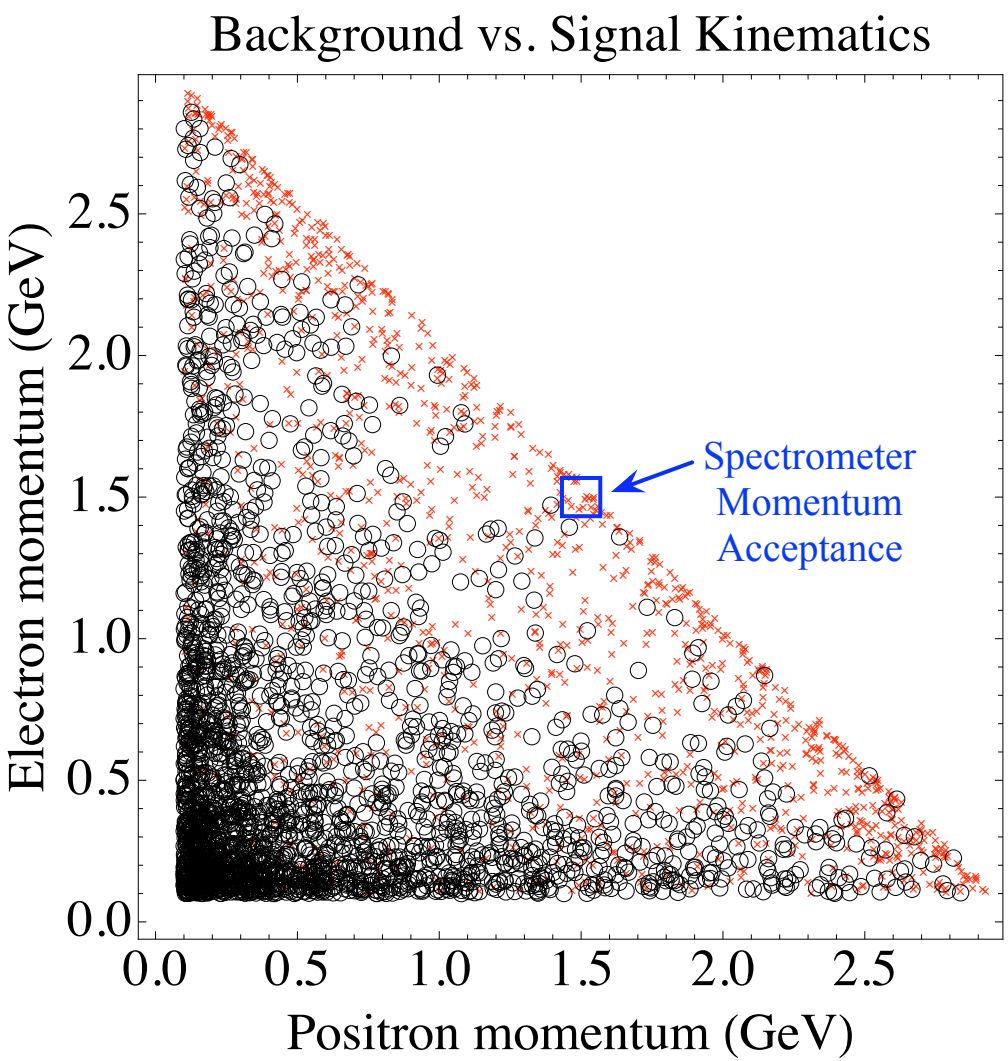


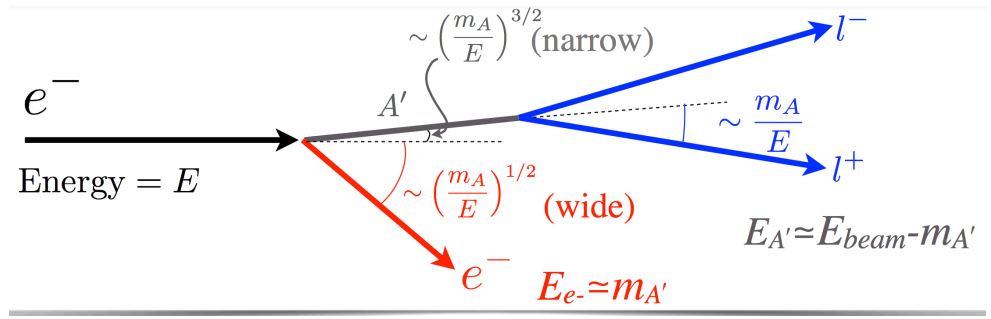
A′ products carry full beam energy!

– Distinctive kinematics
– Δp/p assists in background suppression

Best kinematics to select events for A′ search

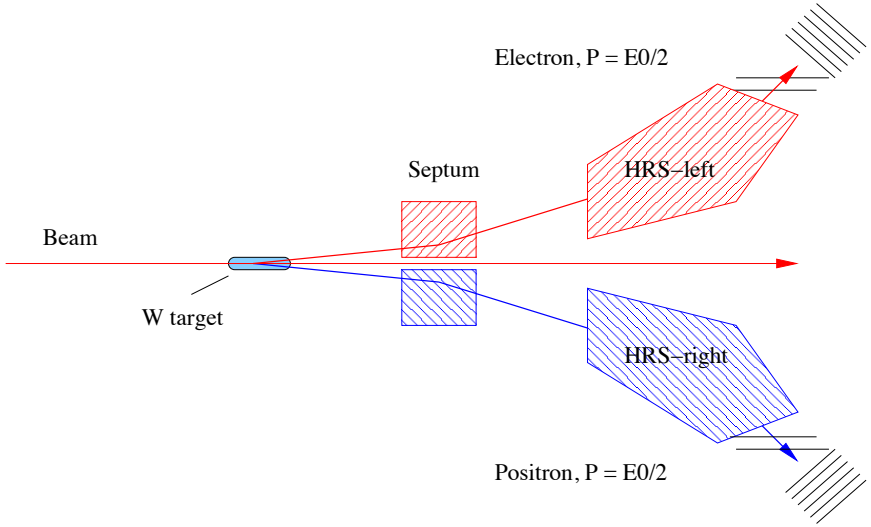
Spectrometer Acceptance and S/N Ratio

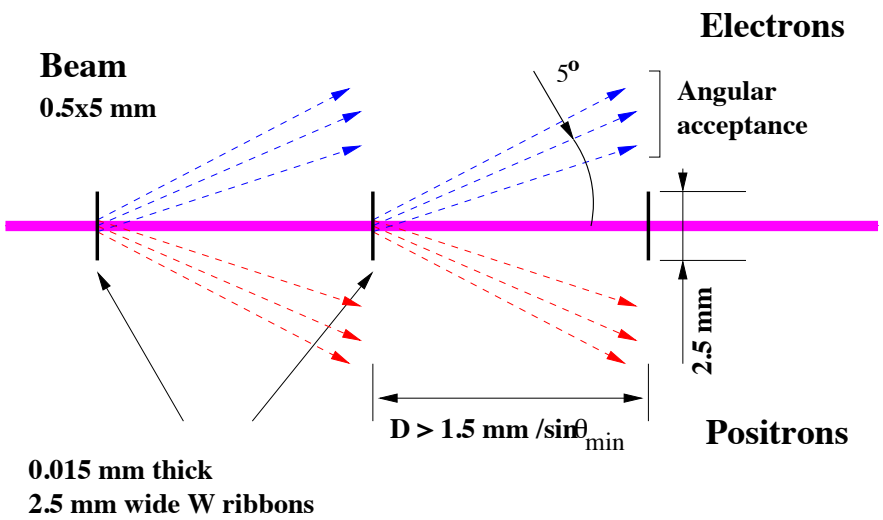


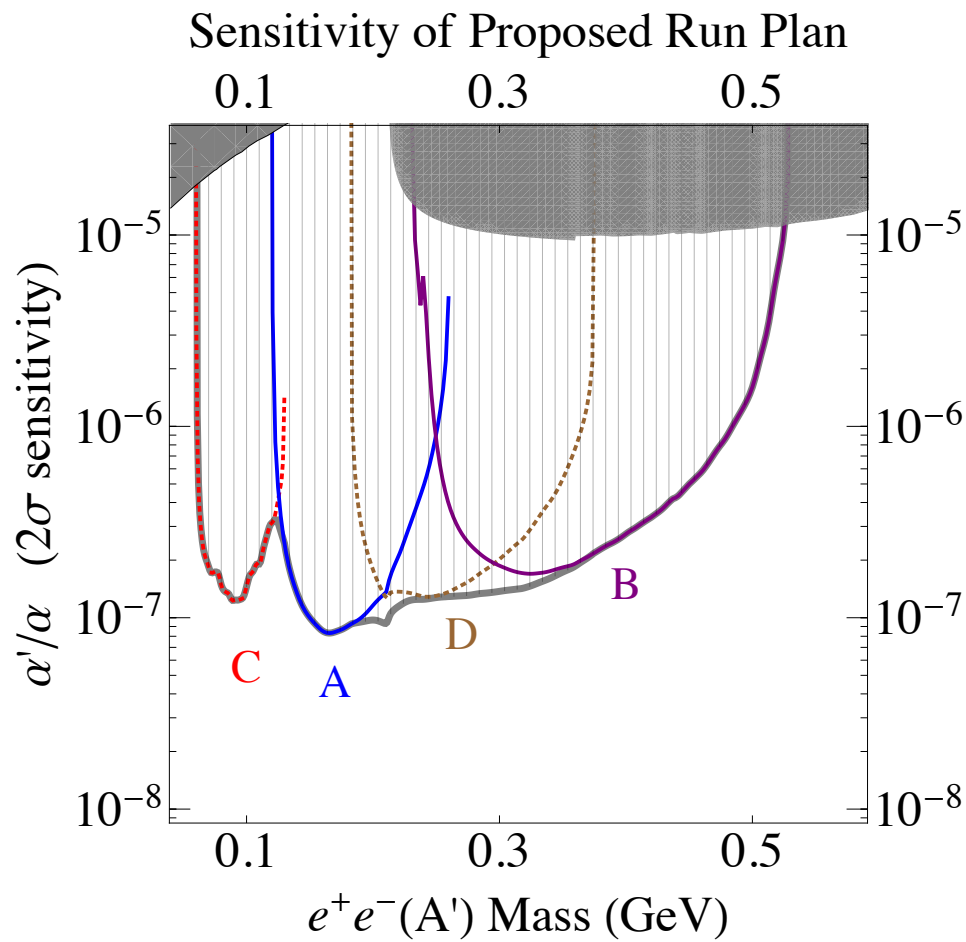


When the productivity reaches the limit of the detector/DAQ capabilities, a modest momentum range is better!

Angular Range and Smooth Mass Acceptance







Readiness Review Process – Flow Chart

PROPOSAL PHASE

- Submitting Proposals
- TAC & PAC Process
- Director's Decision

↓

PRELIM. PLANNING PHASE

- Exp. Description and Requirements
- Exp. Readiness Review Calendar

↓

DESIGN PHASE

- PESAD, specific equipment reviews
- Complete Conceptual Designs & "1st" Readiness Review

↓

CONSTRUCTION PHASE

- Fabrication of the equipment
- Test of the individual elements of the equipment (OSP/TOSP)

↓

SCHEDULING OF EXPERIMENT by JLab

- Construction near-completed, designs frozen
- "2nd" Readiness Review before scheduling request submission

↓

EQUIPMENT INSTALLATION

↓

RUN THE EXPERIMENT

"Final" readiness review

http://www.jlab.org/user_resources/PFX/NP-PFX/

Readiness Review Process – Flow Chart

PROPOSAL PHASE

APEX test run 6/2010

- Submitting Proposals
- TAC & PAC Process
- Director's Decision

PRELIM. PLANNING PHASE

- Exp. Description and Requirements
- Exp. Readiness Review Calendar

DESIGN PHASE

- PESAD, specific equipment reviews
- Complete Conceptual Designs & "1st" Readiness Review

CONSTRUCTION PHASE

- Fabrication of the equipment
- Test of the individual elements of the equipment (OSP/TOSP)

SCHEDULING OF EXPERIMENT by JLab

APEX 4/2016

- Construction near-completed, designs frozen
- "2nd" Readiness Review before scheduling request submission

EQUIPMENT INSTALLATION

APEX 2018!

"Final" readiness review

RUN THE EXPERIMENT

http://www.jlab.org/user_resources/PFX/NP-PFX/

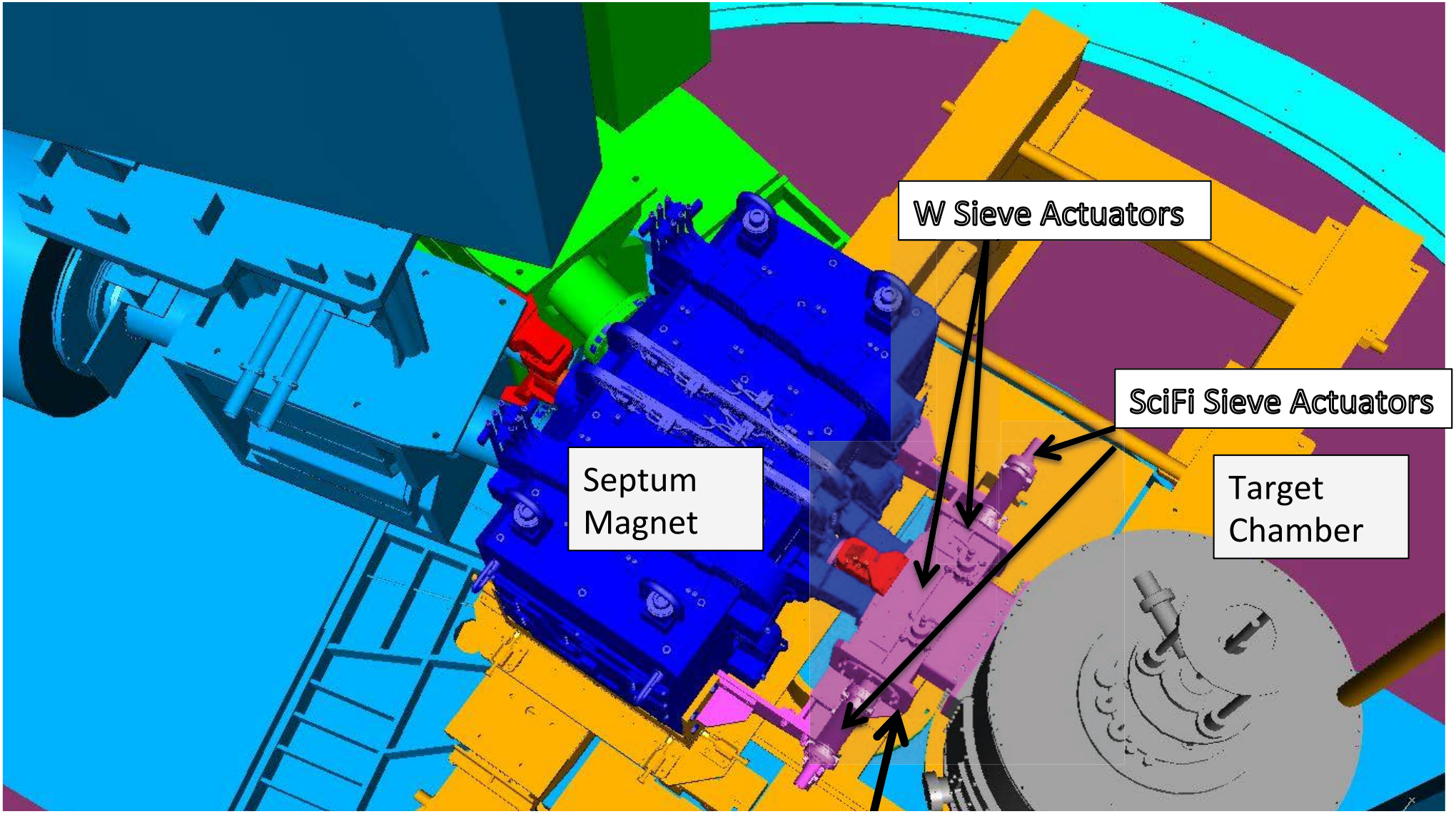
Nominal Dates for Scheduling Requests

- Please see the information for the requirements before scheduling can be requested at http://www.jlab.org/user_resources/PFX/NP-PFX/text.html.

You can only request scheduling when construction of all major components of the experiment are completed, as at this stage the experiment layout and components are considered frozen, and any design modifications will require a change control, approved by the Division Management.

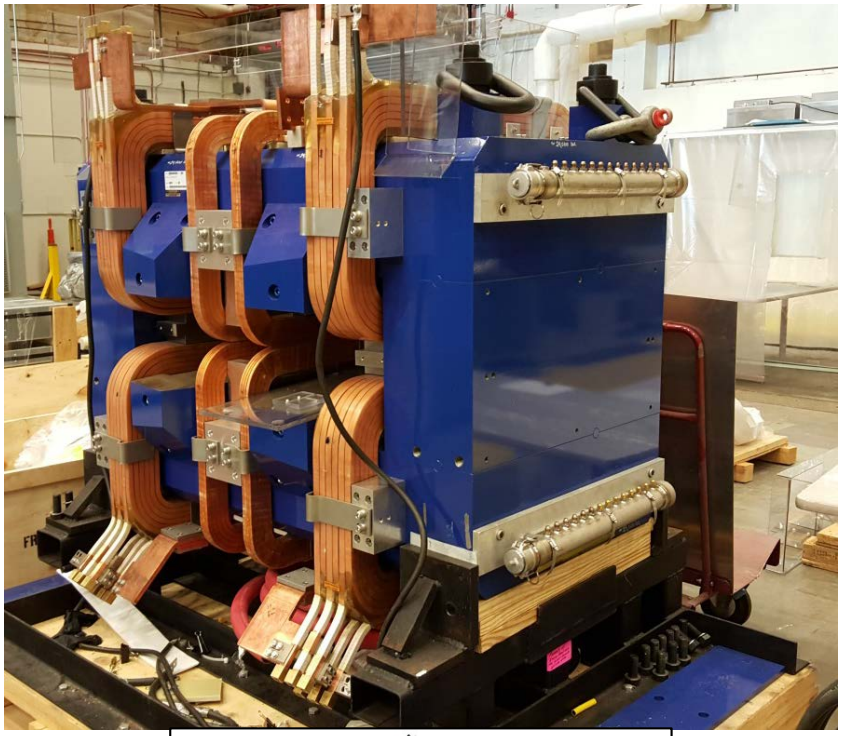
June 1	**Call for Scheduling (Beam Time) Request**		
June 30	Deadline for Scheduling Request Submissions		
September 1	Draft 18-Month Schedule Released		
September 15	Deadline for Input of User Community on Draft Schedule		
October 1	18-Month Schedule Released		
	Year 1	January - June	Schedule Reaffirmed
	Year 1	July - December	Firm Schedule
	Year 2	January - June	Tentative Schedule
March 1	Draft 18-Month Schedule Released		
March 15	Deadline for Input of User Community on Draft Schedule		
April 1	18-Month Schedule Released		
	Year 1	July – December	Schedule Reaffirmed
	Year 2	January - June	Firm Schedule
	Year 2	July - December	Tentative Schedule

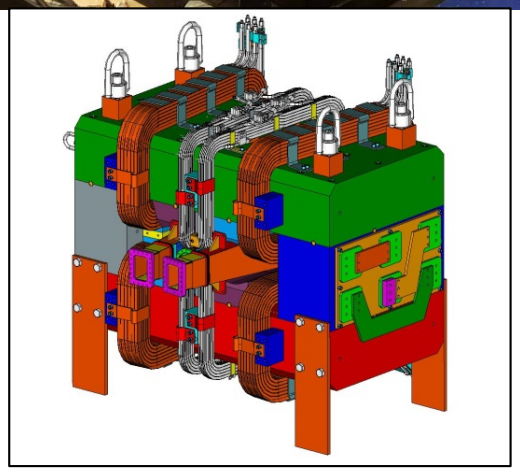
APEX specialized equipment



New Septum Magnet

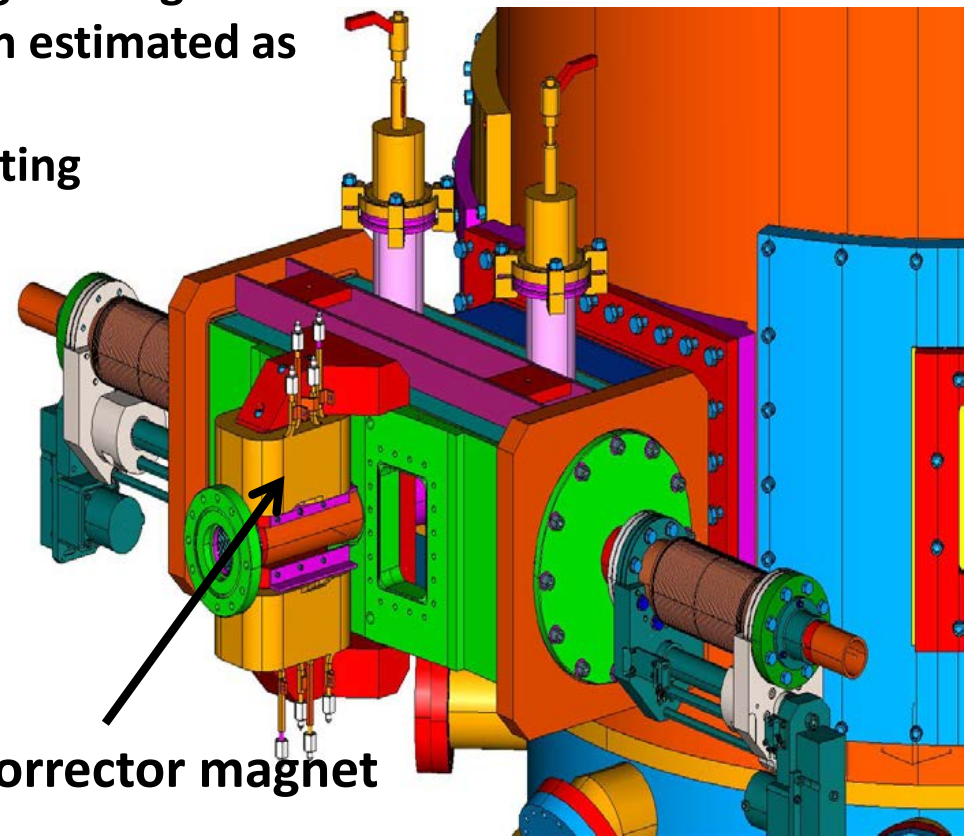
- New Septum magnet required. Magnet procured by Collaboration; StoneyBrook U. Septum Magnet has been fabricated and delivered to Jlab.
- In process of implementing test plan for magnet in the TestLab at 10-20% operating limit.
- Magnet is a water-cooled iron septum. Magnet operates at 2100 A, 120V, 250 KW for integral of 0.95 T-m. Experiment will utilize SBS power supply to operate the septum magnet.
- At dP=100 psi, dT =25 C. Preliminary analysis indicates sufficient water flow in Hall A for cooling magnet with other LCW dependencies.
- Fringe fields determined to be 100 G at target and 80 G at 1.5 meters from center of septum. Field range above 5 G to be indicated, ~ 5 meters out from magnet.





Corrector magnets

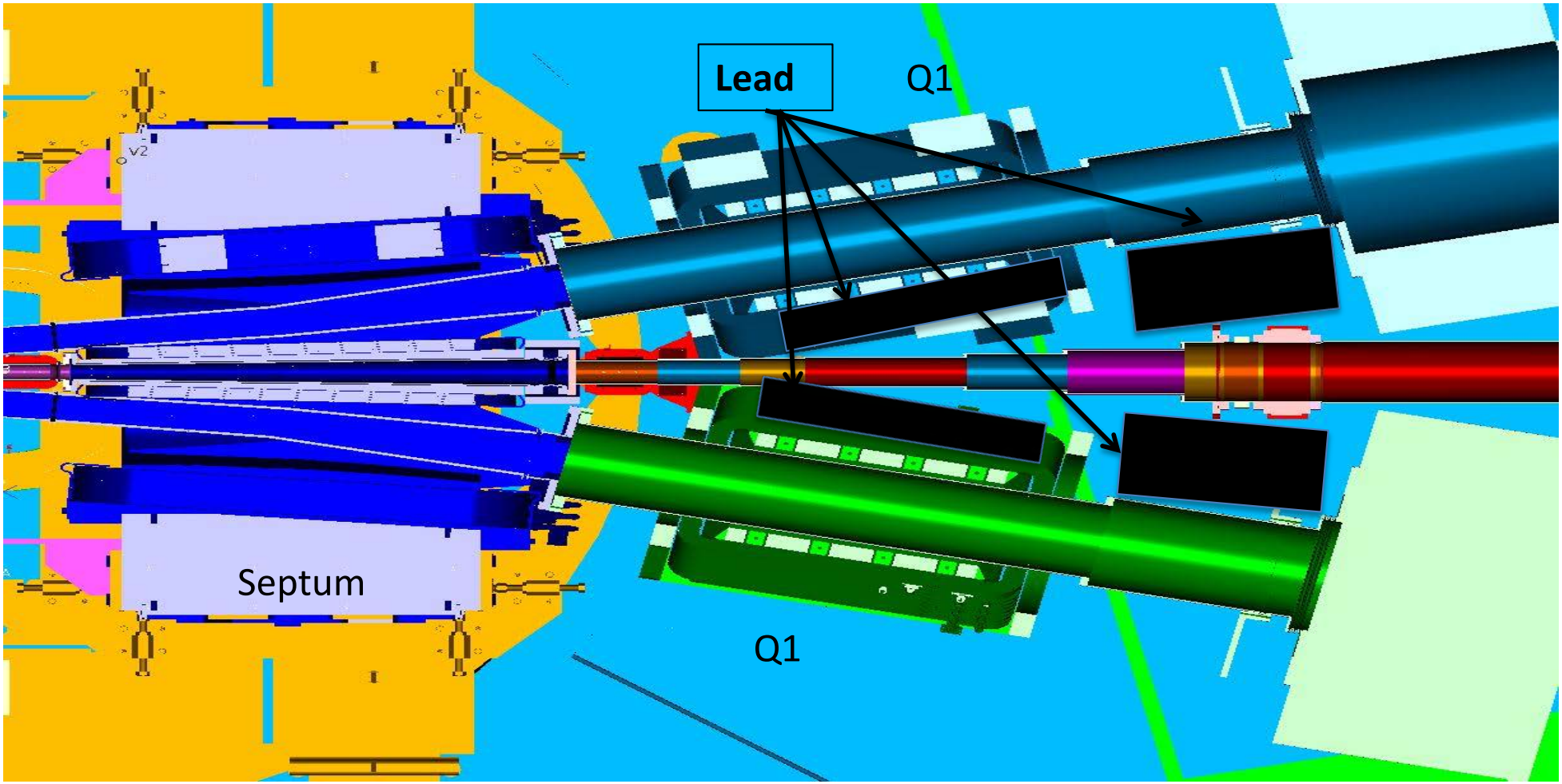
- Corrector magnets are required upstream and downstream of the septum magnet to reduce field effects on the beam line.
- Upstream corrector design is complete and ready for procurement. Water-cooled coils, 122A, dP=100 psi gives dT=14C. Sufficient LCW available in Hall A for cooling.
- Downstream corrector to be re-evaluated with use of SOS Q1 magnets. Conceptual design exists. Require 4 MW engineering and 8 MW design to complete design. Fabrication estimated as 12 weeks.
- Corrector magnets can be powered with existing Hall A power supplies.



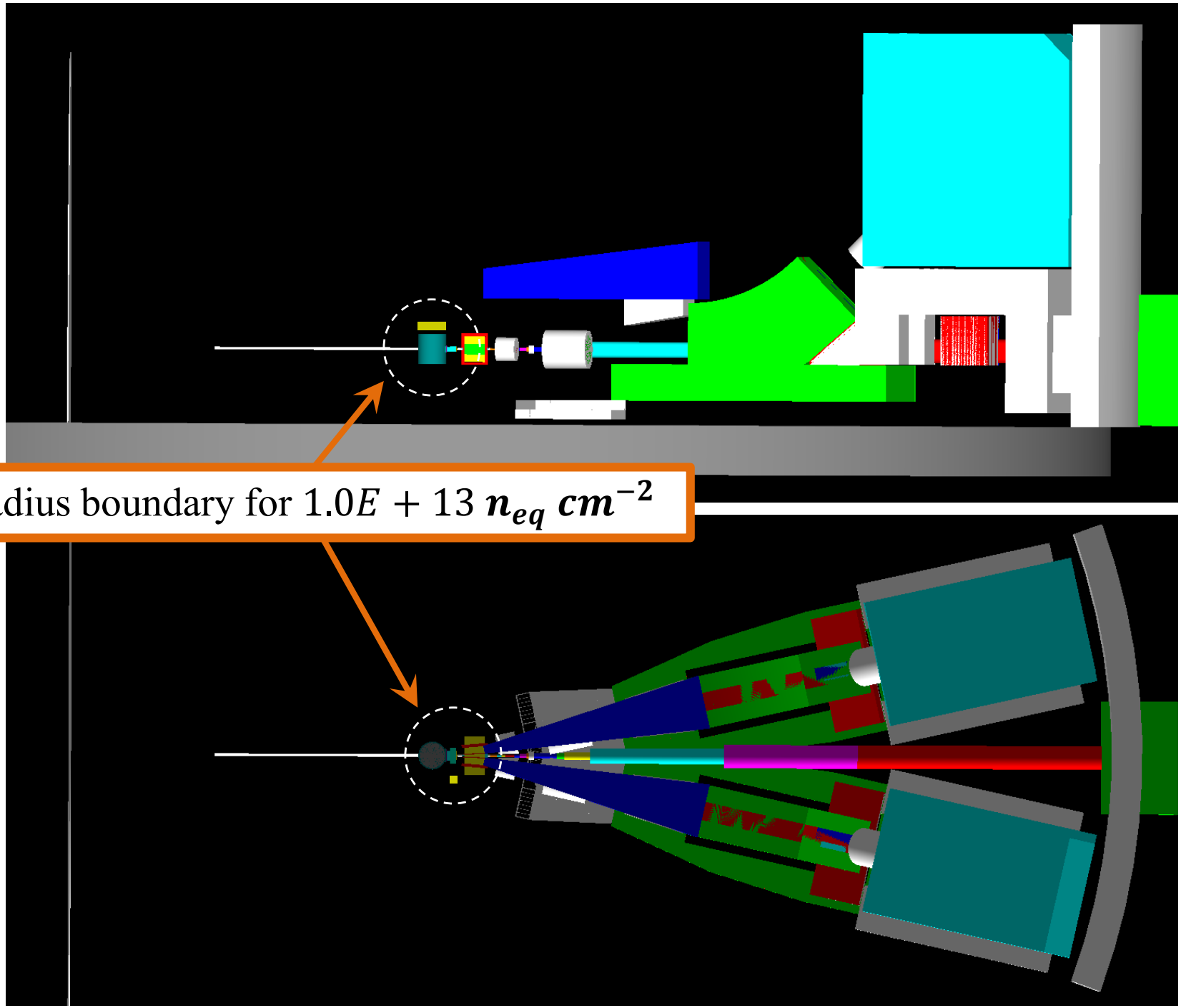
Upstream corrector magnet

Shielding

- Lead shielding is planned to be placed in open area of SOS Q1 magnets facing beam line and downstream of SOS Q1 magnets where diameter of pipe changes.
- Analysis indicates no additional radiation shielding is required.
- Requires 2 MW design to complete lead layout and support.



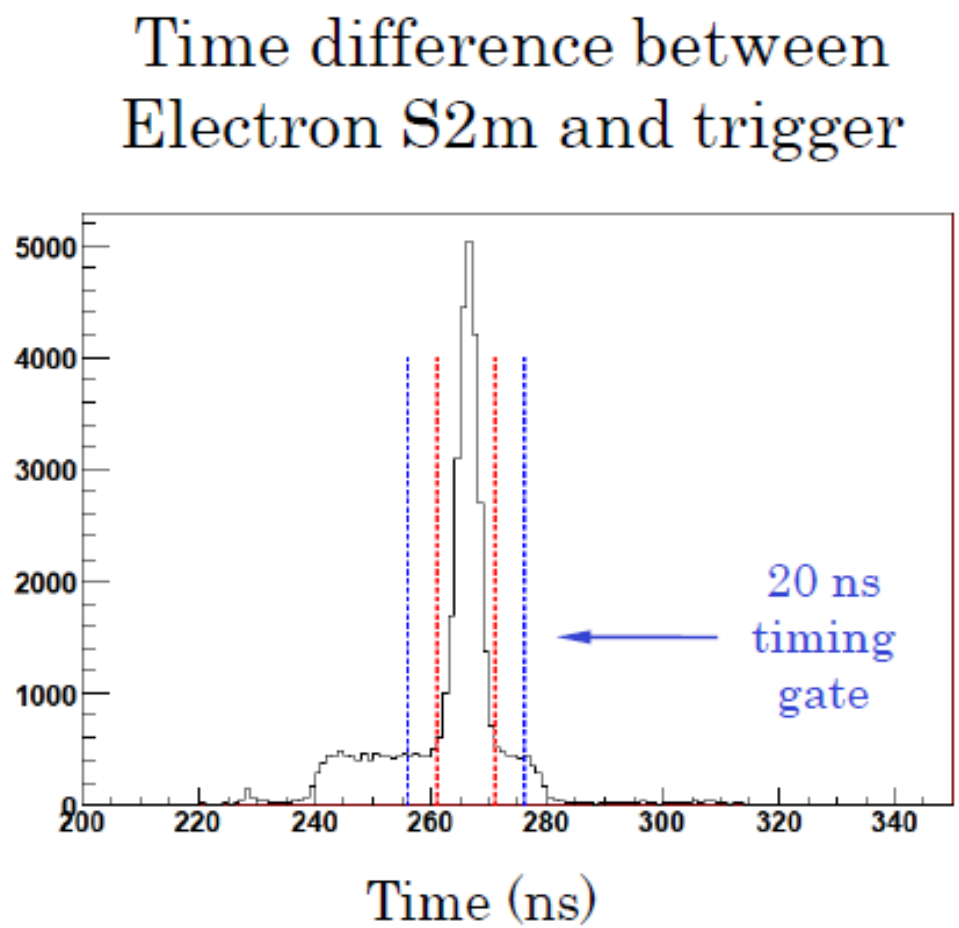
Radiation damage to electronics



2 m radius boundary for $1.0E + 13\ \boldsymbol{n_{eq}\ cm^{-2}}$

DAQ rates and dead time
2.2 GeV full luminosity

- A 20 ns coincidence gate would acquire a rate of 3.1 kHz
- DAQ dead time is 10% for 4 kHz
- Full rate capability has been demonstrated in the APEX test run



20 ns coincidence time easily achievable

Ideally 10ns could be used

Mass Resolution: $$\left(\frac{\sigma_M}{M}\right)^2 = \frac{1}{2}\left(\frac{\sigma_p}{p}\right)^2 + \left(\frac{\sigma_\theta}{\theta}\right)^2$$

Mass Resolution Goal: $$\frac{\sigma_M}{M} \leq 0.5\%$$

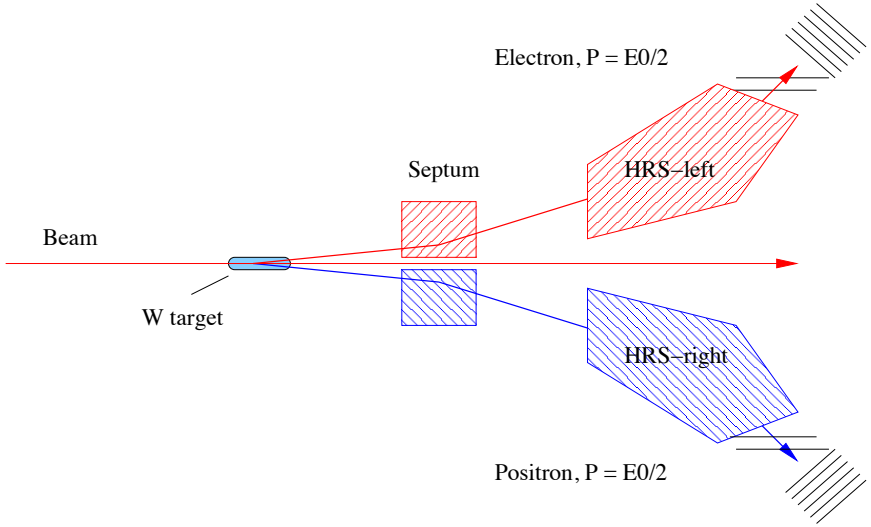
HRS Resolution: $$\frac{\sigma_P}{P} < 10^{-3}$$ (Not a problem)

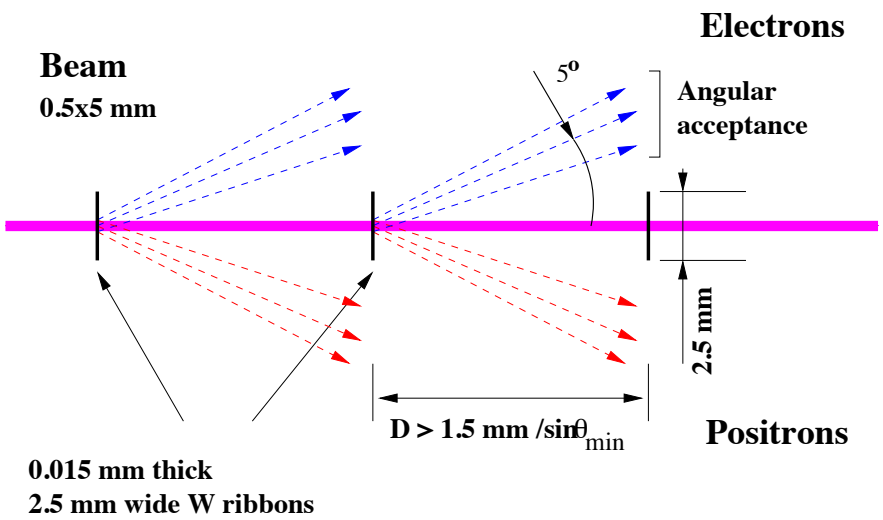
Thus goal requires: $$\frac{\sigma_\theta}{\theta} \leq 0.5\%$$

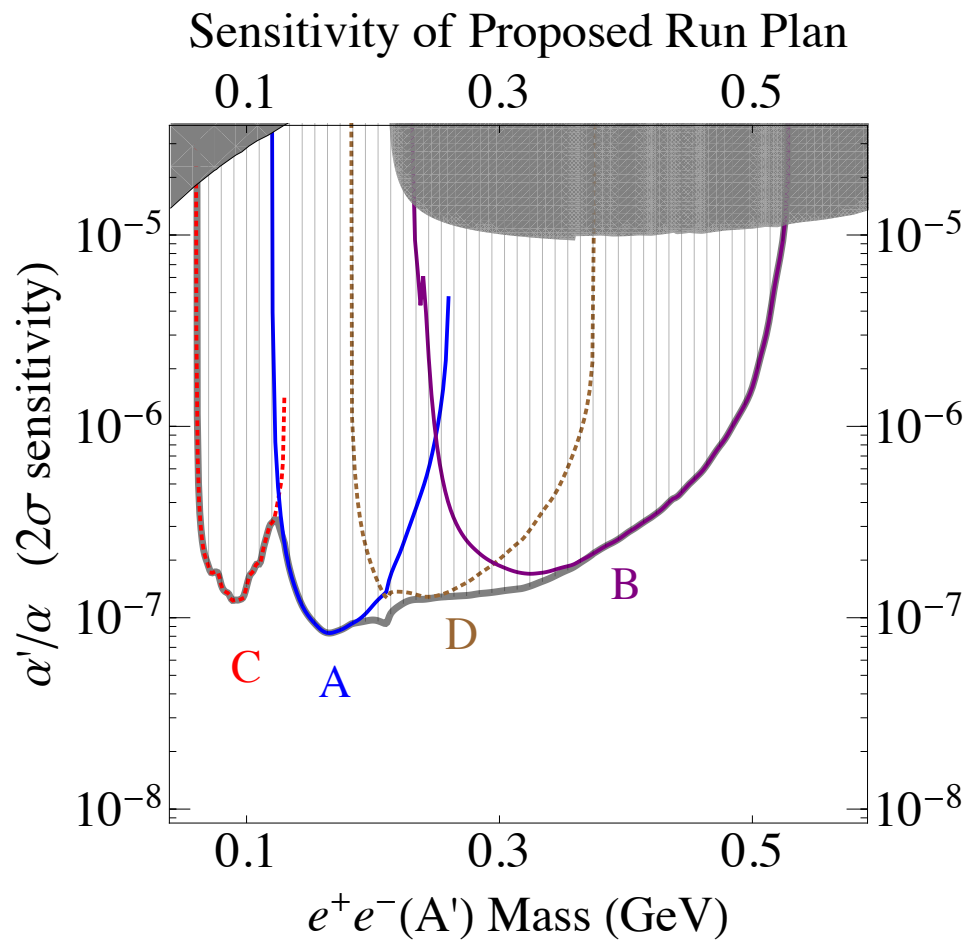
For $\theta = 10^0$, requires: $\sigma_\theta < 0.9$ mrad

Target multiple scattering: $\sigma_{\theta-\text{targ}} \approx 0.5$ mrad (p_{beam}=2.2 GeV)

Angular Range and Smooth Mass Acceptance







Summary

- The APEX equipment is designed and construction is under way. All equipment is delivered or ordered.
- The APEX experiment is ready to run on 6 months' notice.
- The data taking run will likely be in spring 2018.

A high luminosity electron-positron collider for the search for (or study of) a Dark Force Mediator (including invisible decay)

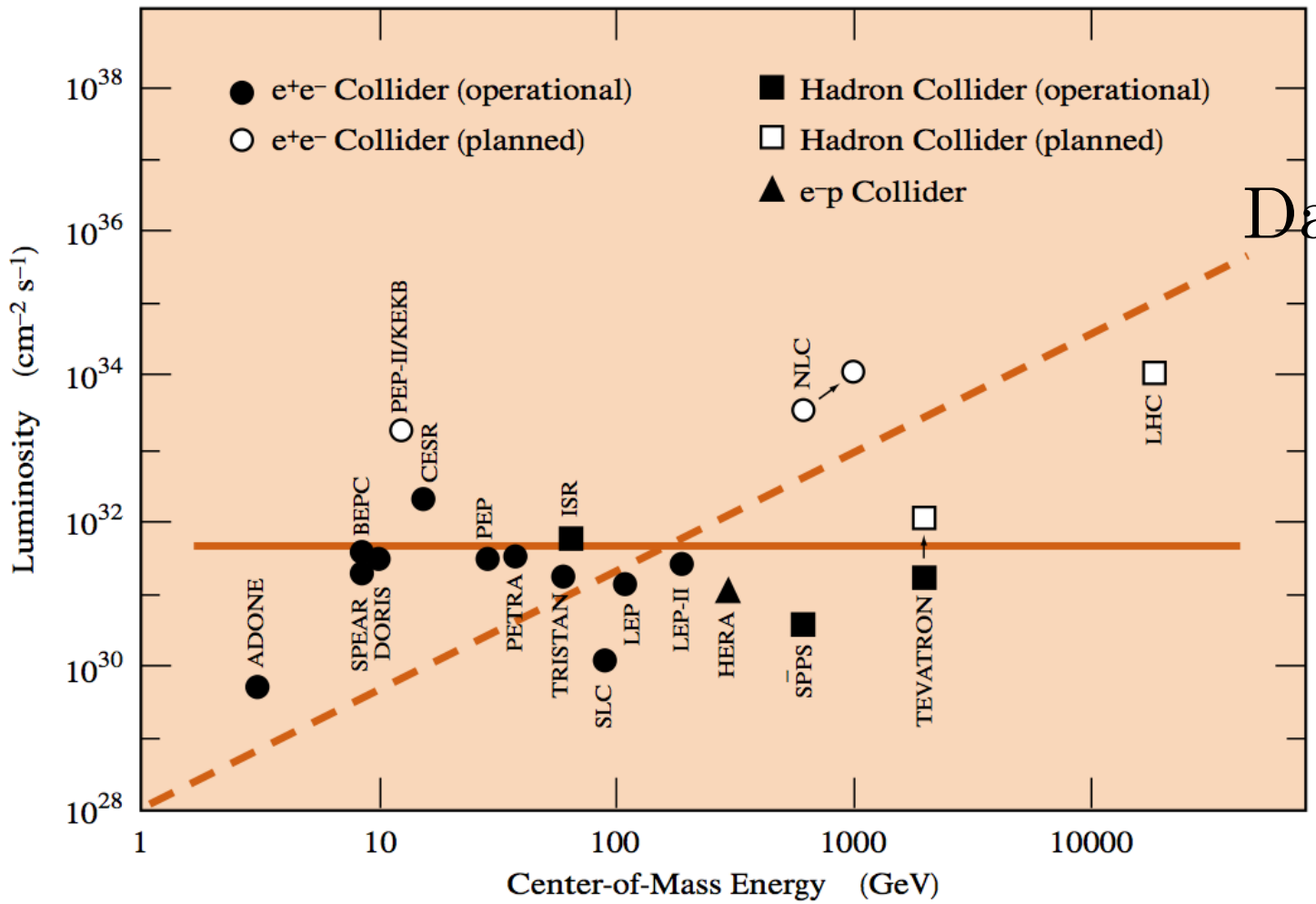
Bogdan Wojtsekhowski, Jefferson Lab

presented at

Intense Electron Beams workshop, Cornell, June 2015

Luminosity of the colliders

from W. Panovsky's article in BEAM LINE



Dashed line is $\mathcal{L} \propto E_{cm}^2$

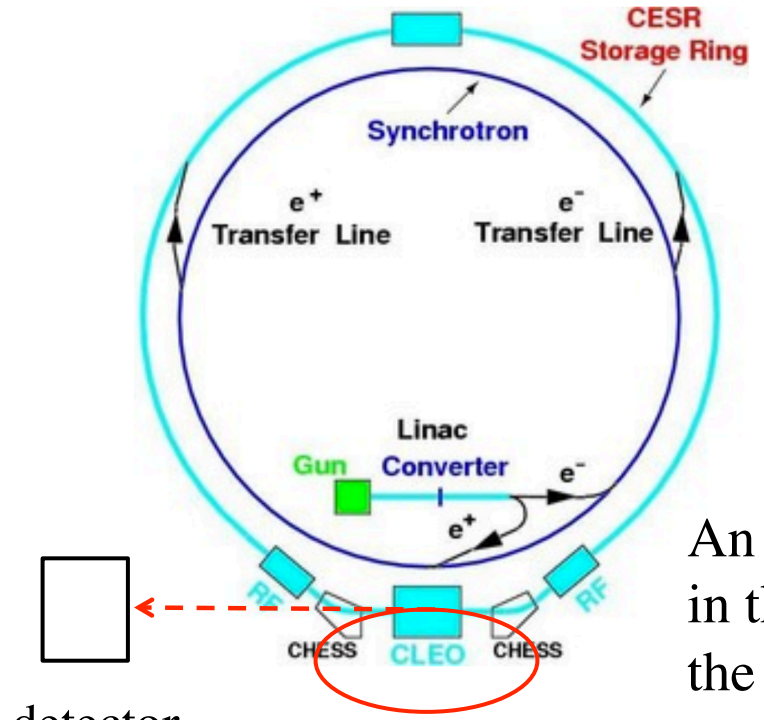
For E_{cm}=100 MeV $\mathcal{L} \sim 10^{26} - 10^{29} cm^{-2}/s$

Options for e^+e^- experiment at low s

A "very" low energy s ~ 10-30 MeV

a) Search in existing data from good detector => problem with resolution at low s
b) 5 MeV x 5 MeV collider of e+e- => very low luminosity
c) Sliding beams of e+e- (200 MeV x 200 MeV)=> need specialized accelerator with two rings
d) Positron beam and atomic electrons

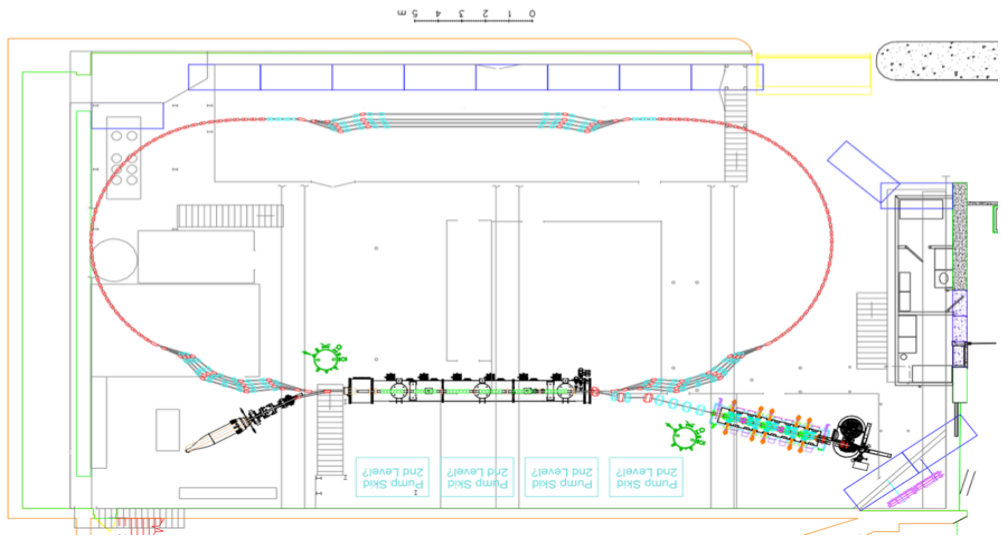
A new concept: Very Asymmetric Collider CESR and ERL



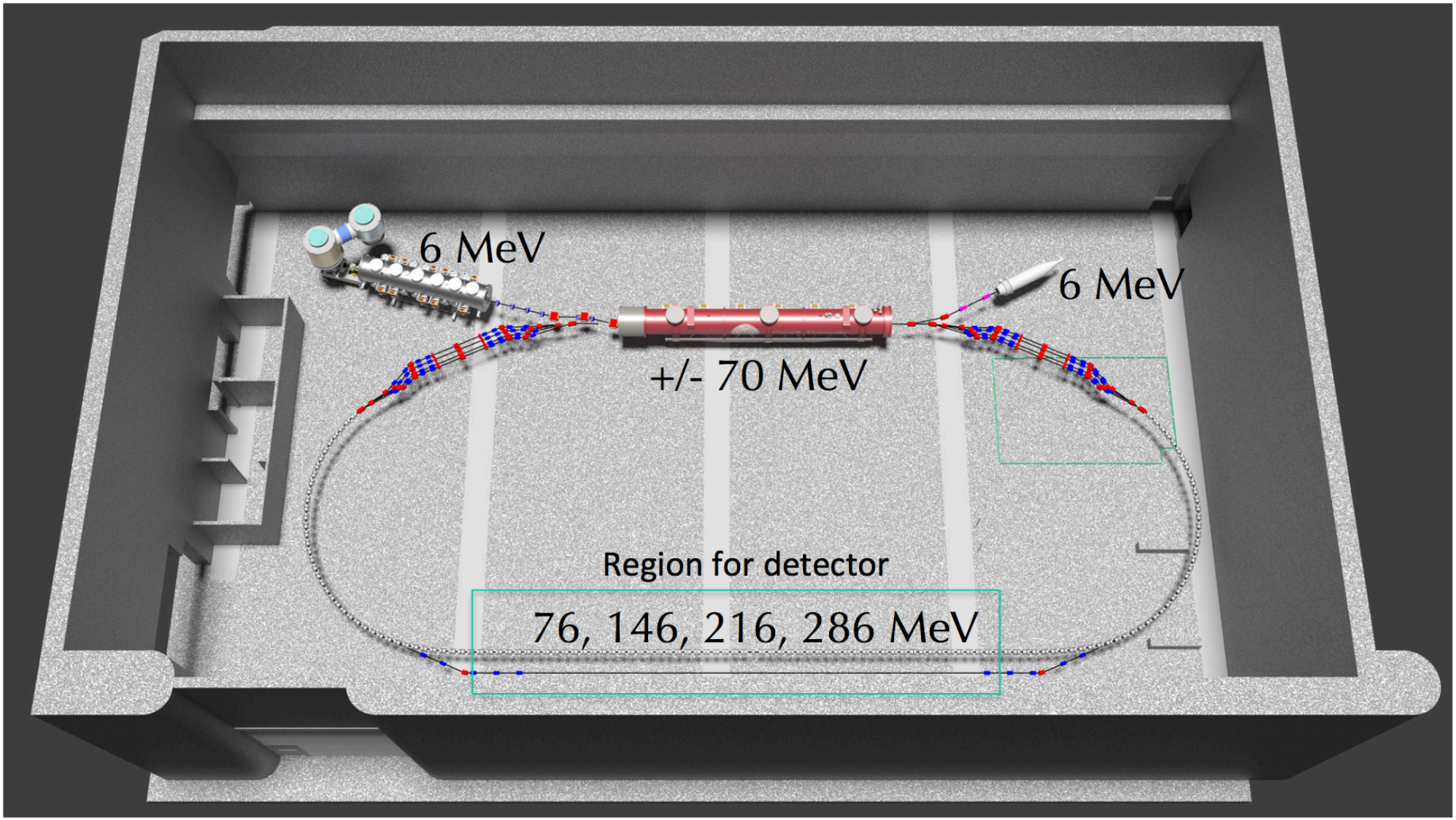
detector

up to 5 GeV x 0.3 GeV

An electron beam of 100 mA in the ERL is focused to match the e^+ CESR beam



Goal: 4-turn FFAG ERL at 16MV/m



Options for a e^+e^- experiment at low s

A "very" low energy $s^{1/2} \sim$ 30-300 MeV

a) 15 MeV x 15 MeV head-to-head collider
The problem is a very low luminosity $\mathcal{L} \sim 10^{26}$

b) Sliding beams of e+e- (250 MeV x 250 MeV)=>
Project needs a small specialized accelerator with two rings

c) CESR's 2-5 GeV positron beam and a 60-300 MeV ERL
looks like an ideal combination for a new device:
a Very Asymmetric Collider @ Cornell

$\mathcal{L} \sim 10^{34}$?

at least to keep L ~ 10^{33} - the level of
5 GeV x 5 GeV regime

VAC for precision physics

A Very Asymmetric Collider @ Cornell with a positron beam of the CESR ring and an electron beam of ERL could be the ultimate device for study of the Dark Photons in the mass range up to 1-2 GeV.

Very Asymmetric Collider using e^+ storage ring & e^-ERL

David Douglas, 4/22/2016

next 6 slides

Notional System Configuration

- e^+e^- colliders now run with high e+ currents
  - e.g. CESR (365 mA in 36 bunches)
- e^- ERLs are poised for significant increase in beam power
  - e.g. Cβ (Cornell-BNL FFAG test ERL): 250 MeV x 25 mA
- What luminosity might be achieved with a Very Asymmetric Collider made from a Cβ class ERL and a CESR-like e+ ring?

Confession: this is a genetically modified clone of the collider discussed by Bisognano et al. *at LINAC'88*

Luminosity: Comes from Charge, Frequency, and Beam Size…

- Cβ parameters:
  - E=250 MeV
  - $Q_{e\text{- bunch}}$ = 77 pC (N_{e-}~5x10^8); f=325 MHz => I_{e-}=25 mA,
  - $\varepsilon_H=\varepsilon_V$< 1 mm-mrad
- CESR parameters (http://www.lepp.cornell.edu/Research/CESR/OperatingParameters.html)
  - E ~ 5 GeV
  - I_{e+} ~ 365 mA (in up to 45 bunches: 9 trains of 5 bunches)
  - ε_V<<ε_H ~ 0.3 mm-mrad, β_H^*=0.019 m => σ_x~75μm

Miracles

- Note that all successful experiments have a Benson Index of unity
  - The "Benson Index" is the number of miracles required for the experiment to work…
- Here we invoke 2 miracles
  1. We assume CESR e+ bunch charge and timing can be reworked to give 365 mA at 325 MHz
     a. Change of ring frequency needed to match Cβ RF frequency (1.3 GHz/4) – not impossible, but incurs cost
     b. With change to 325 MHz, $Q_{e+\ bunch}$ = 0.365 A / 325 MHz ~ 1.1 nC => N_{e+}= 7 x 10^9
  2. ERL beam is ~round, so invoke flat beam transform (FBT) at IR to "round up" the ring beam
     a. Then $\varepsilon_V=\varepsilon_H$ ~ 0.15 mm-mrad; $\beta_x^*=\beta_y^*$=1.9 cm (yes, a third miracle) => $\sigma_x=\sigma_y$=50 μm
     b. spot sizes readily matched with e- beam in Cβ (as in DarkLight test runs at JLab)

Luminosity

- Bisognano *et al.* LINAC-88 (http://accelconf.web.cern.ch/AccelConf/l88/papers/th3-23.pdf) describe linac/ring collider, noting

- Here

  $N_{e+}=7x10^9$ $N_{e-}=5x10^8$ $f=3.25x10^8$ *Hz*

  $\sigma_x=\sigma_y=50\ \mu m$

  H_D = *disruption factor ~ 1 (no enhancement)*

- With these values **~ 3.6 x 10^{34} $cm^{-2}sec^{-1}$ ~ 100 times of DAΦNE**

Machine Issues

- e^+ single bunch effects less dramatic than at lower frequency/higher charge
- Shallow-angle crossing (few mrad) provides notional avenue for higher collision frequency/ closer bunch spacing
- Can use electostatic separation on low energy e^- beam to greater effect than at high energy
- Positron tune shift mitigated by low electron bunch charge; electron tune shift tolerable due to ERL architecture

Conclusions

- High energy e^+ on low energy e^- provides avenue to high luminosity at low *s*
- CESR e^+ on Cβ a promising possibility for realization of novel system configuration