APEX experiment

B. Wojtsekhowski, Jefferson Laboratory

for the collaboration

Search for a Short-Lived Neutral Particle Produced in Nuclear Decay

M. J. Savage, R. D. McKeown, and B. W. Filippone
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and

L. W. Mitchell
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(Received 28 February 1986)

We report on a search for a short-lived neutral particle ϕ produced in the decay of the 9.17-MeV $J^{\pi}=2^{+}$ state in ^{14}N. The experiment is sensitive to decays into an $e^{+}e^{-}$ pair with $\tau_{\phi}\lesssim 10^{-11}$ s. For $m_{\phi}=1.7$ MeV we place a limit on the branching ratio of $\Gamma_{\phi}/\Gamma_{\gamma}\leqslant 4\times 10^{-4}$ at the 90% confidence level.

PACS numbers: 14.80.Gt, 23.90.+w

Anomalous narrow peaks have been observed in the spectra of positrons emitted in heavy-ion collisions in several recent experiments at Gesellschaft für Schwerionenforschung Darmstadt (GSI).[1–3] In addition, a new experiment[4] has revealed that the positrons associated with these peaks are correlated with electrons whose energy spectrum also contains a narrow peak at the same energy as the positron peaks. One explanation[4–6] for these peaks is the production and subsequent decay of a previously unobserved neutral particle ϕ of mass ~ 1.7 MeV. Monte Carlo simulations[4] of such a particle decay, assuming the particle to be produced at rest in the center-of-mass system iments, if attributed to this new neutral particle, indicate a large branching ratio for decay to $e^{+}e^{-}$. To observe these pairs emitted from a particle produced in nuclear decay we must separate them from the ordinary internal pairs produced in the electromagnetic decay of the nuclear state (a virtual photon converts internally to $e^{+}e^{-}$). It has been suggested previously[16] that pairs produced from the decay of a pseudoscalar particle can be distinguished from internal pairs by their angular correlation. Previous detailed studies[17] of the angular correlation of nuclear pairs, which were used to extract transition multipolarities, indicate that $\Gamma_{\phi}/\Gamma_{\gamma}$ is likely to be small, although estimates are

PHYSICAL REVIEW D VOLUME 34, NUMBER 5 1 SEPTEMBER 1986

Axion bremsstrahlung by an electron beam

Yung Su Tsai
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(Received 5 May 1986)

Compact expressions for energy-angle distribution and energy distribution for axion from electron scattering on an atomic target are derived using the generalized Weizsacker-Williams method. The axion flux from an electron beam dump is estimated. It is also shown that even in a proton beam dump, the mechanism of producing axions is still predominantly due to electrons in the dump.

I. INTRODUCTION

A 1.7-MeV object[1] witnessed in the heavy-ion collisions at GSI has stimulated searches for an axion[2] of this mass range. This calculation deals with the production cross section and flux of axions produced by an electron beam on atomic targets in order to see whether such an object can be produced in the beam-dump experiment. Previous calculation by Donnelly *et al.*[3] assumed an axion mass negligible compared with the electron mass. Hence it is inapplicable for the present purpose.

We first calculate the energy-angle distribution $d\sigma/d\Omega_a dE_a$ of axions produced in the process $e^- +$atomic target$\rightarrow e^- + a +$anything using the generalized Weizsacker-Williams method.[4] Atomic screening as well as production from atomic electrons are important in the energy range of interest ($E_a = 1-100$ GeV). The angle is then integrated out and an expression for $d\sigma/dE_a$ derived. In a beam-dump experiment, the energies of the incident electrons as well as $e^\pm$ from the decay of axions are degraded due to emission of bremsstrahlung as these particles go through a thick target. These effects are also considered. Axion production in a proton beam dump is also discussed.

II. GENERALIZED WEIZSACKER-WILLIAMS METHOD

The energy-angle distribution of axions from the process $e + P_i \rightarrow e + a + P_f$, shown in Fig. 1(a), can be obtained from the Compton-type process $\gamma + e \rightarrow e + a$, shown in Fig. 1(b), using the formula[4]

$$\left[d\sigma(P_1 + P_i \rightarrow P_2 + k + P_f) \right] \qquad \left[d\sigma(q + P_1 \rightarrow P_2 + k) \right] \quad \alpha \quad \chi$$

Search for Short-Lived Axions in an Electron-Beam-Dump Experiment

E. M. Riordan, M. W. Krasny, K. Lang, P. de Barbaro, A. Bodek, S. Dasu, N. Varelas, and X. Wang
University of Rochester, Rochester, New York 14627

R. Arnold, D. Benton, P. Bosted, L. Clogher, A. Lung, S. Rock, and Z. Szalata
The American University, Washington, D.C. 20016

B. W. Filippone and R. C. Walker
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J. Button-Shafer, B. Debebe, M. Frodyma, R. S. Hicks, and G. A. Peterson
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(Received 4 May 1987)

We report results of an electron-beam-dump search for neutral particles with masses in the range 1 to 15 MeV and lifetimes τ between 10^{-14} and 10^{-10} s. No evidence was found for such an object. We rule out the existence of any 1.8-MeV pseudoscalar boson with $\tau > 8.2 \times 10^{-15}$ s and an absorption cross section in matter less than 1 mb per nucleon, and exclude $\tau > 1 \times 10^{-14}$ s were its cross section to equal 50 mb per nucleon. In conjunction with measurements of the electron's anomalous magnetic moment, this experiment shows that the narrow positron peaks observed in heavy-ion collisions at the Gessellschaft für Schwerionenforschung are not due to an elementary pseudoscalar.

The BEST paper

PHYSICAL REVIEW D **80,** 075018 (2009)

New fixed-target experiments to search for dark gauge forces

James D. Bjorken,[1] Rouven Essig,[1] Philip Schuster,[1] and Natalia Toro[2]

[1]*Theory Group, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*

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(Received 20 July 2009; published 28 October 2009)

Fixed-target experiments are ideally suited for discovering new MeV–GeV mass $U(1)$ gauge bosons through their kinetic mixing with the photon. In this paper, we identify the production and decay properties of new light gauge bosons that dictate fixed-target search strategies. We summarize existing limits and suggest five new experimental approaches that we anticipate can cover most of the natural parameter space, using currently operating GeV-energy beams and well-established detection methods. Such experiments are particularly timely in light of recent terrestrial and astrophysical anomalies (PAMELA, Fermi, DAMA/LIBRA, etc.) consistent with dark matter charged under a new gauge force.

DOI: 10.1103/PhysRevD.80.075018 PACS numbers: 14.70.Pw, 95.35.+d

I. NEW GAUGE FORCES

The interactions of ordinary matter establish that three gauge forces survive to low energies. Two striking features of these forces—electroweak symmetry breaking at a scale far below the Planck scale and apparent unification assuming low-energy supersymmetry—have driven model building for a quarter century. But the strong and electroweak forces need not be the only ones propagating at long distances. Additional forces, under which ordinary matter vary by 10 orders of magnitude for the ϵ's and masses $m_{A'}$ we consider. This wide range calls for multiple experimental approaches, with different strategies for confronting backgrounds. Beam-dump searches from the 1980s exclude the low-mass and small-ϵ parameter range, and other data constrain large ϵ. In this paper we suggest five scenarios for fixed-target experiments sensitive to distinct but overlapping regions of parameter space (see Fig. 1). Together they can probe six decades in A' coupling and three decades in A' mass with existing beam energies and

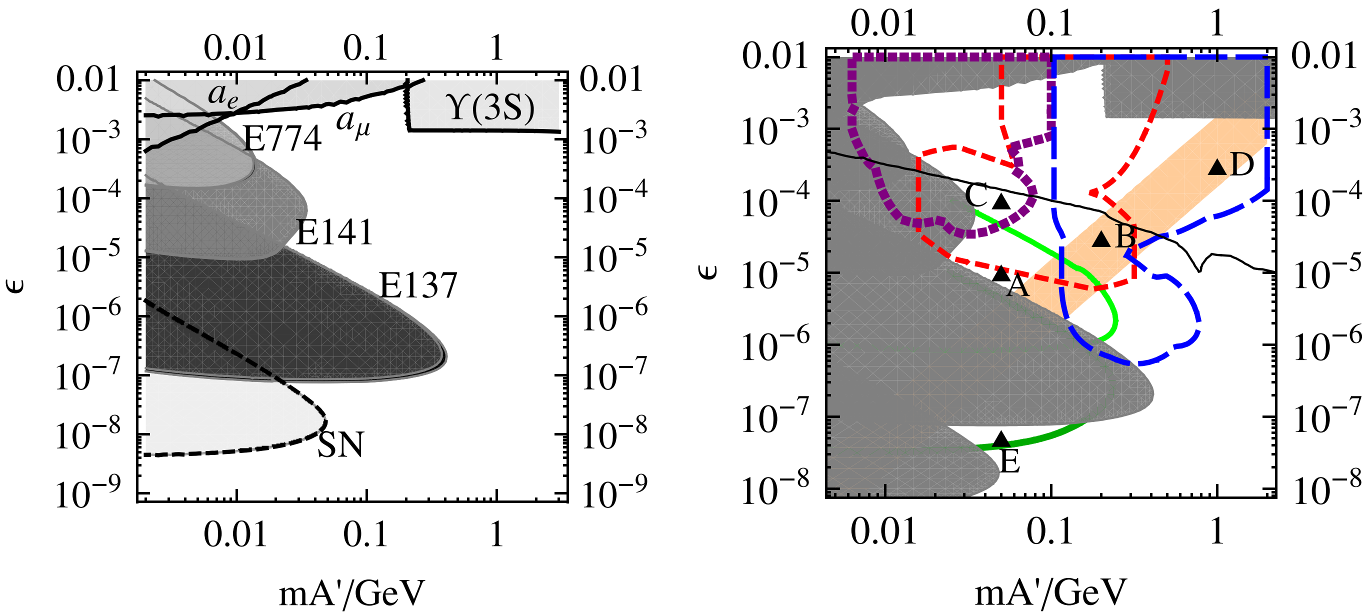
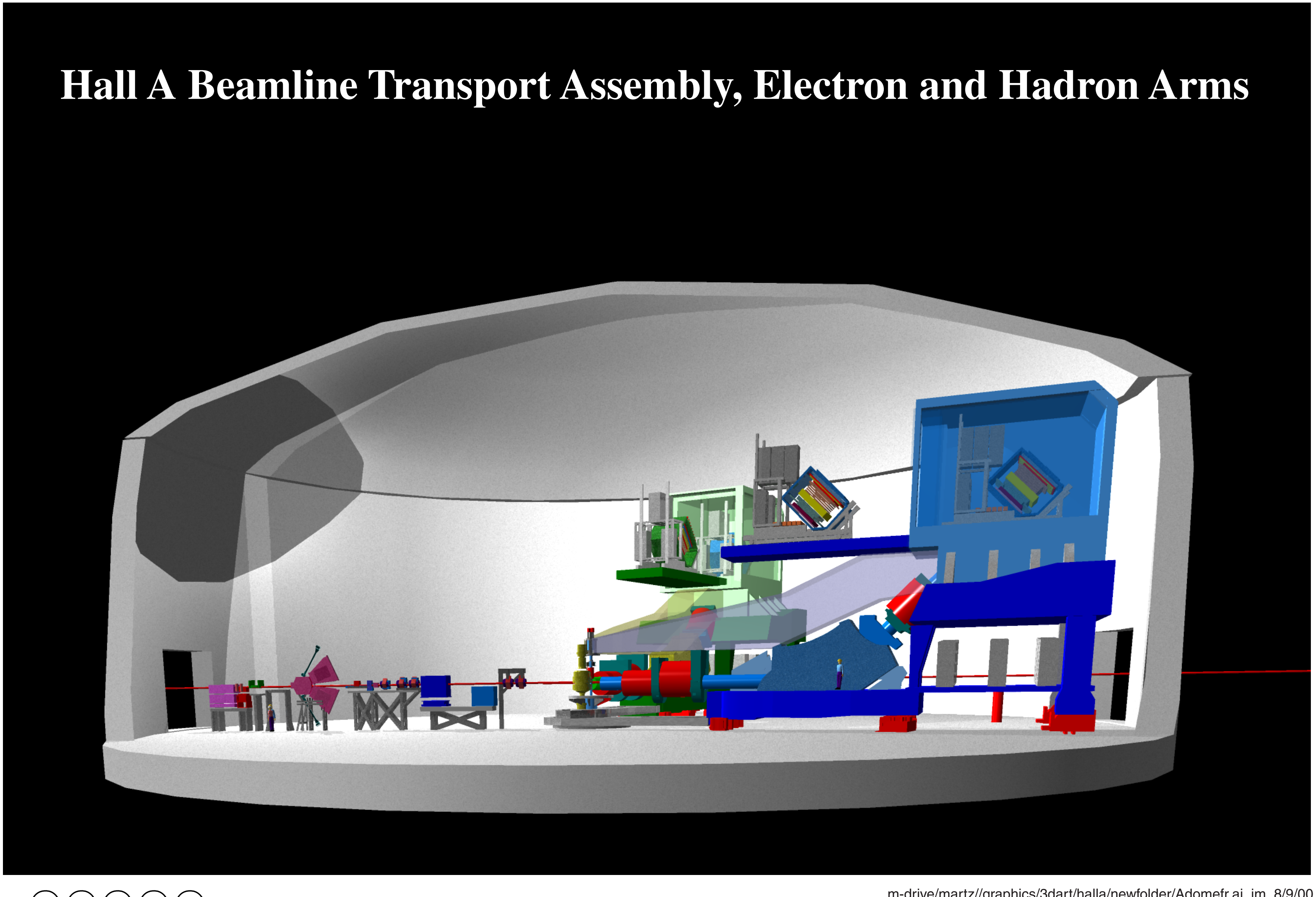


FIG. 1 (color online). *Left:* Existing constraints on an A'. Shown are constraints from electron and muon anomalous magnetic moment measurements, a_e and a_μ, the *BABAR* search for $\Upsilon(3S) \to \gamma\mu^+\mu^-$, three beam-dump experiments, E137, E141, and E774, and supernova cooling (SN). These constraints are discussed further in Sec. III. *Right:* Existing constraints are shown in gray, while the various lines—light green (upper) solid, red short-dashed, purple dotted, blue long-dashed, and dark green (lower) solid—show estimates of the regions that can be explored with the experimental scenarios discussed in Secs. IV A, IV B, IV C, IV D, and IV E, respectively. The discussion in Sec. IV focuses on the five points labeled "A" through "E." The orange stripe denotes the "*D*-term" region introduced in Sec. II A, in which simple models of dark matter interacting with the A' can explain the annual modulation signal reported by DAMA/LIBRA. Along the thin black line, the A' proper lifetime $c\tau = 80\ \mu$m, which is approximately the τ proper lifetime—see Eq. (11).

A' with $\epsilon \gtrsim 10^{-4}$ and mass above $\sim$200 MeV, particularly in sectors with multiple light states [41–45]. Their reach in ϵ is limited by luminosity and irreducible backgrounds. However, an A' can also be produced through bremsstrahlung off an electron beam incident on a fixed target [43]. This approach has several virtues over colliding-beam searches: much larger luminosities, of $\mathcal{O}(1\ \mathrm{ab}^{-1}/\mathrm{day})$,

The scenarios for points A and E use 100 MeV–1 GeV electron beam dumps, with more complete event reconstruction or higher-current beams than previous dump experiments. Low-mass, high-ϵ regions (e.g. B and C) produce boosted A' and forward decay products with mm–cm displaced vertices. Our approaches exploit very forward silicon-strip tracking to identify these vertices.

Hall A


Hall A Beamline Transport Assembly, Electron and Hadron Arms
m-drive/martz//graphics/3dart/halla/newfolder/Adomefr.ai jm 8/9/00

Hall A

Beam parameters:

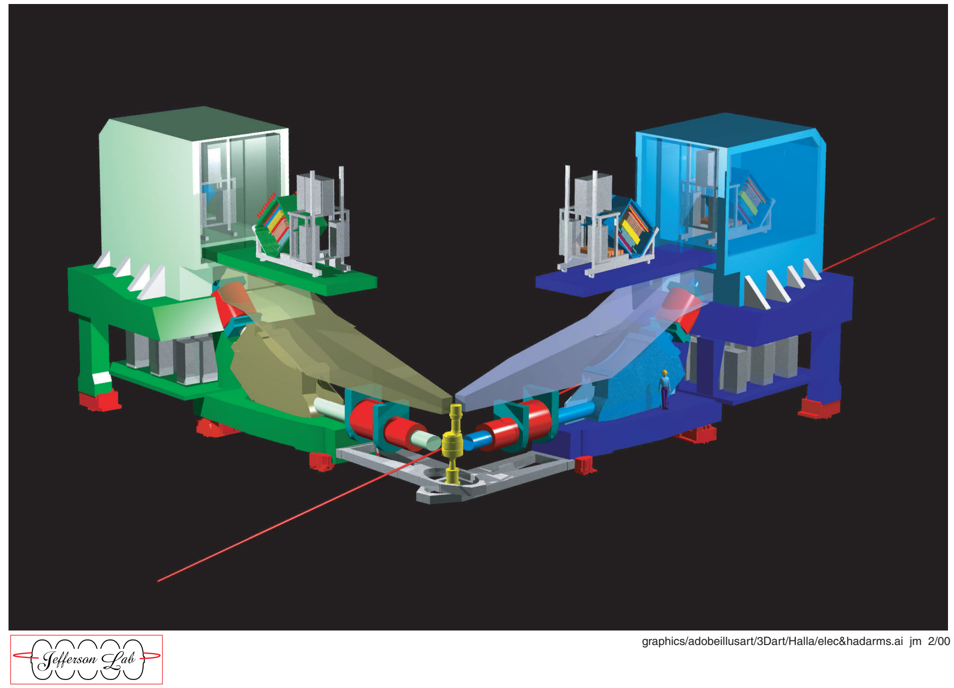
energy up to 11 GeV
intensity up to 180 μA
polarization 85%
pol. flip systematic 10^{-9}
time structure 2(4) ns

Luminosity: 10^{39} cm^{-2}/s

Detector systems: **HRSs**, SBS

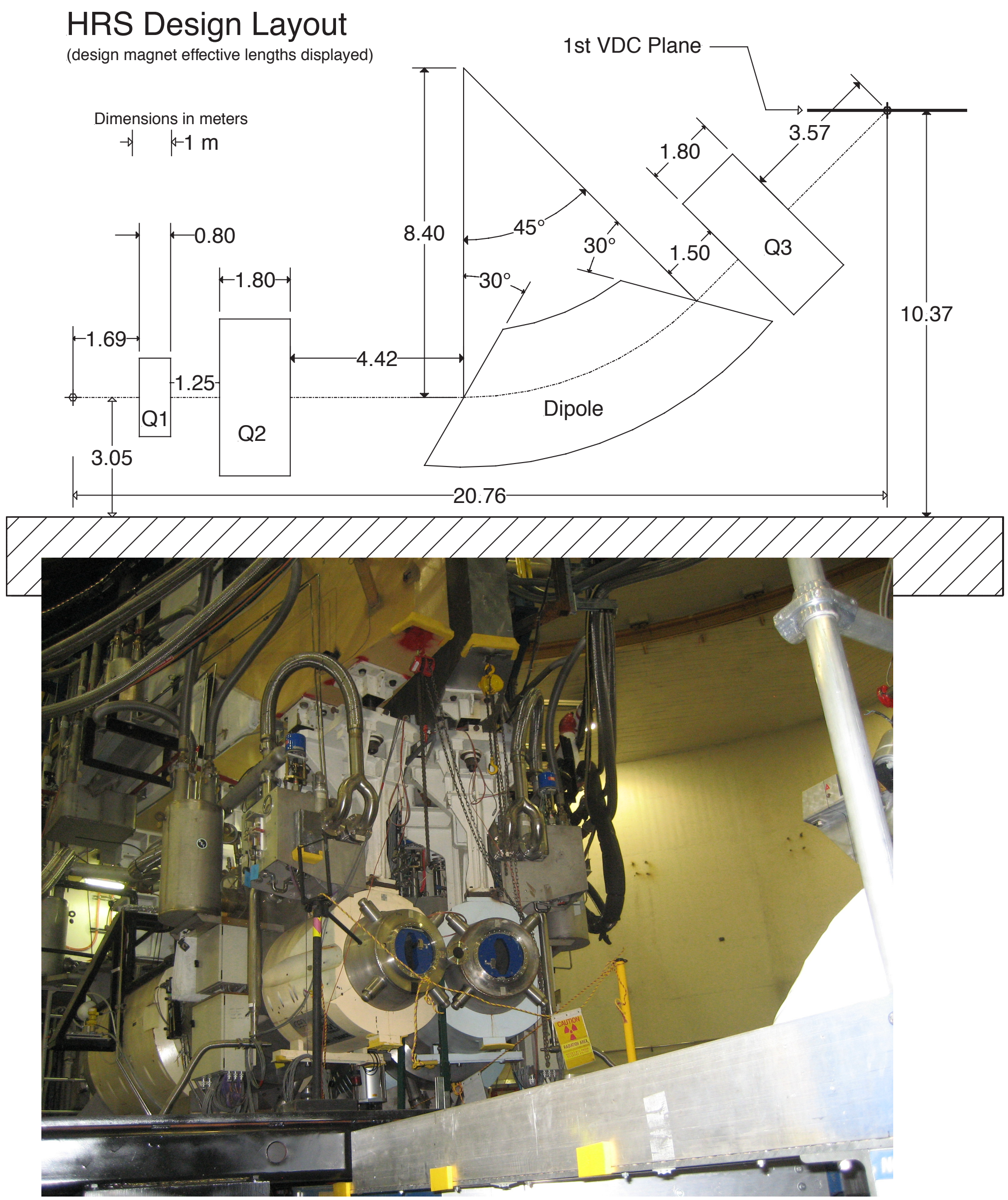
Polarized targets:
^{3}He: L ~10^{36} cm^{-2}/s
NH_3/ND_3: L ~10^{35} cm^{-2}/s

Hall A Eletron and Hadron Arms



momentum up to 4.3 and 3.2 GeV/c

The HRS spectrometers

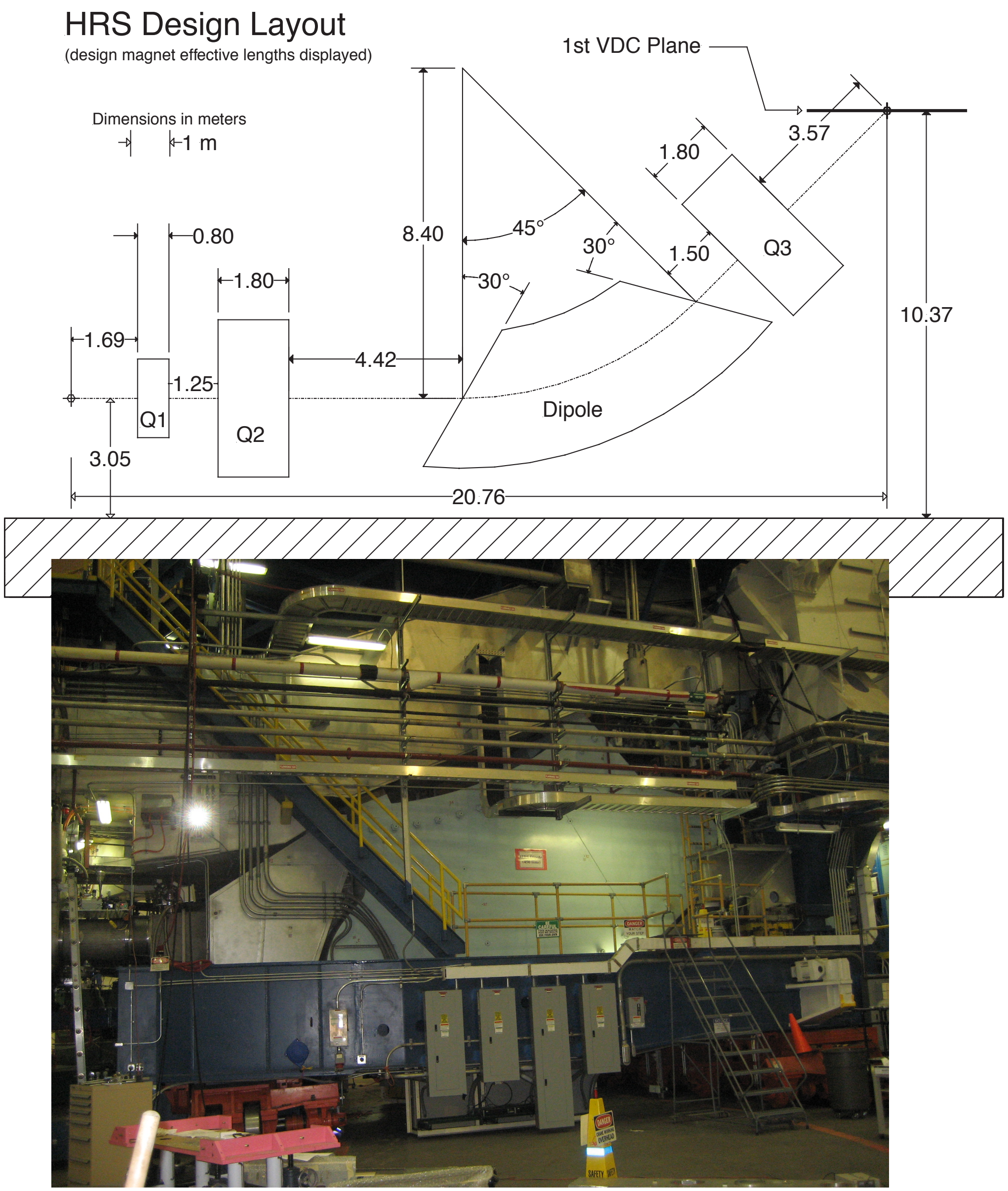


Two HRS Spectrometers
- $0.3 < p < 4.0$ GeV/c
- $-4.5\% < \Delta p/p < 4.5\%$
- 6 msr at $12.5° < \theta < 150°$
- 4.5 msr at $\theta = 6°$ with septum
- $-5\text{cm} < \Delta y < 5\text{cm}$

Optics: (FWHM)
- $\delta p/p \leq 2 \cdot 10^{-4}$ (achieved)
- **$\delta\vartheta = 0.5$ mrad, $\delta\varphi = 1$ mrad**
- $\delta y = 1\text{mm}$

Luminosity ~ 10^{39} cm^{-2}s^{-1}

The HRS spectrometers



Two HRS Spectrometers

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$\delta\vartheta = 0.5$ mrad, $\delta\varphi = 1$ mrad

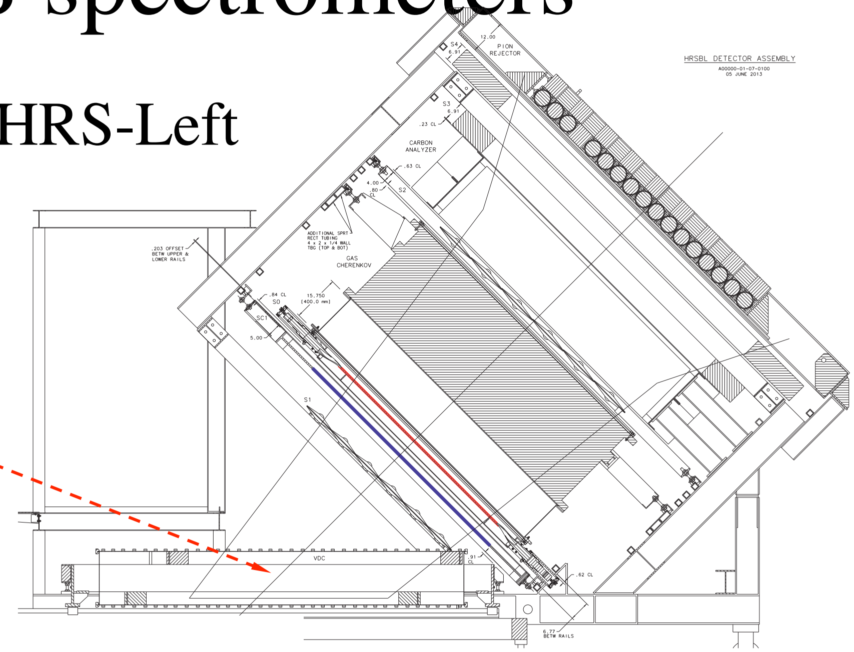
$\delta y = 1$mm

Luminosity ~ 10^{39} cm^{-2}s^{-1}

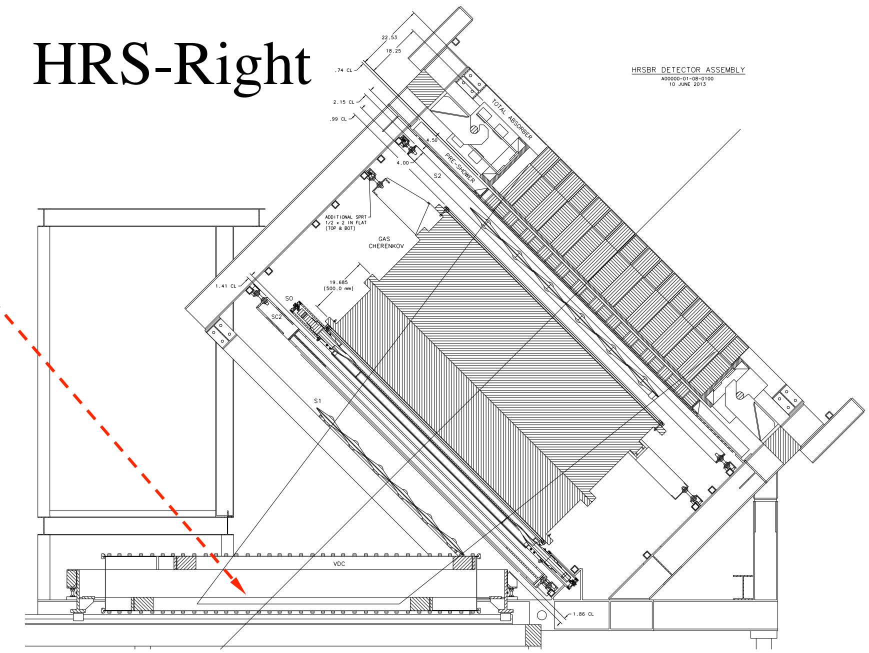
Detectors of the HRS spectrometers

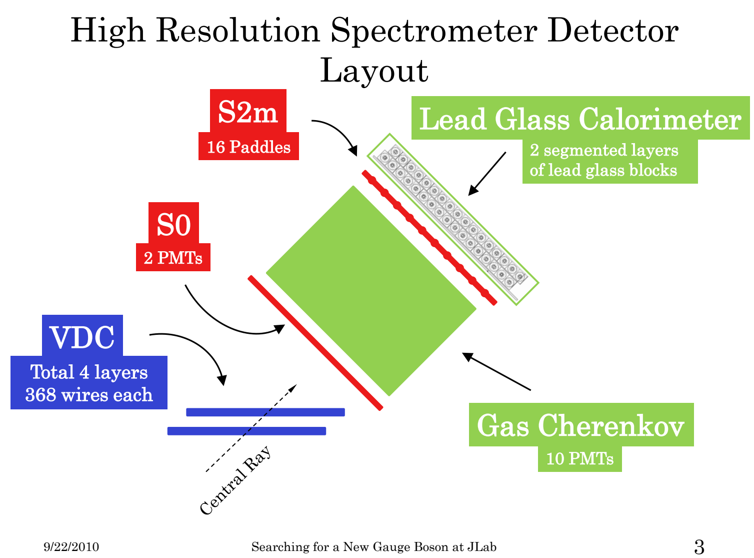
VDC tracker
S0 plane
S2 hodoscope
Gas Cherenkov
Lead-glass calorimeter

HRS-Left

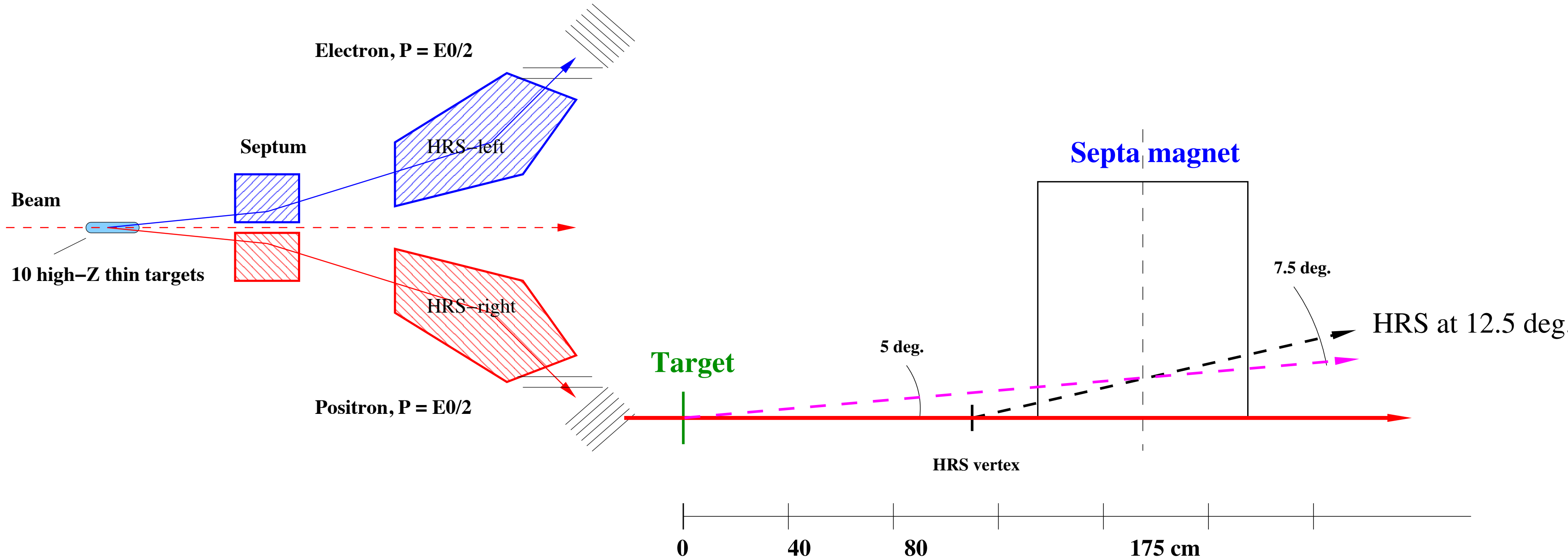


HRS-Right





Specialized APEX hardware: Septa magnet

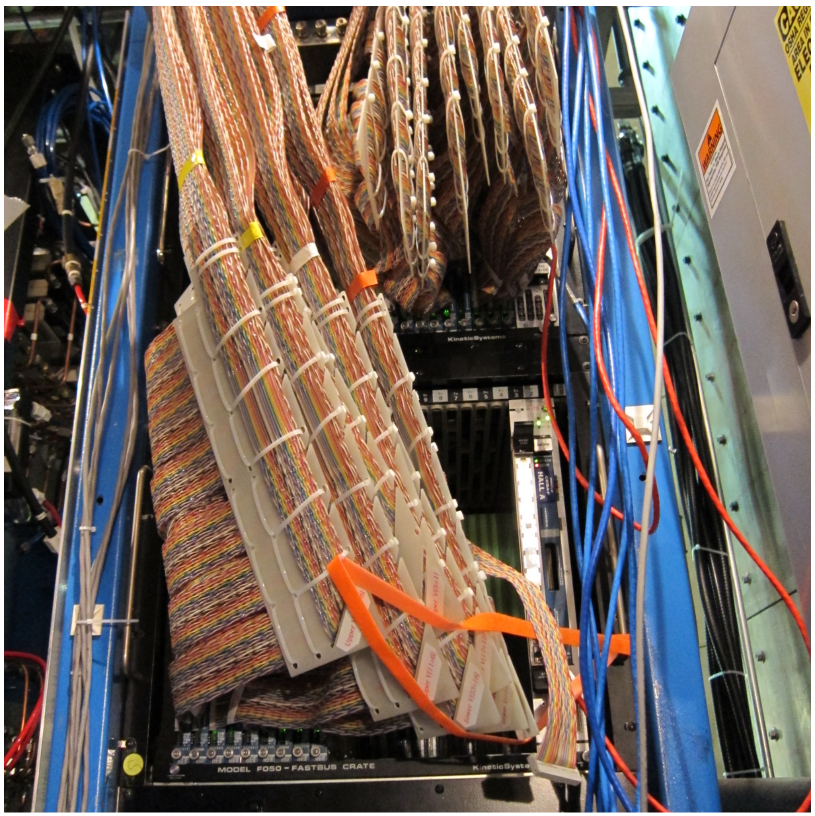


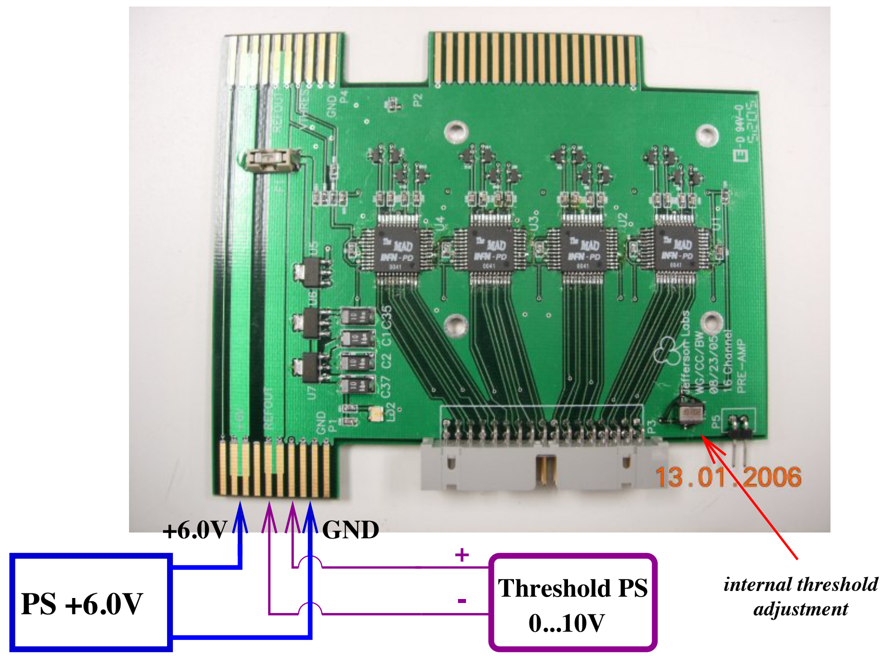
Septa works well for Δp/p << 1. In HRS Δp/p is of 0.09
Required field integral is 0.44 Tesla-m per 1 GeV/c
APEX is approved to run with 1.1, 2.2, 3.3, and 4.4 GeV beam energies, which requires 0.55, 1.1, 1.65, and 2.2 GeV in HRS

This concept was used in two previous septa magnets and well tested

Detectors of the HRS spectrometers

Vertical Drift Chambers – four planes in each HRS, 368 sense wires per plane
Upgrade of the front-end electronics - completed
Very good stability against oscillation





Detectors of the HRS spectrometers

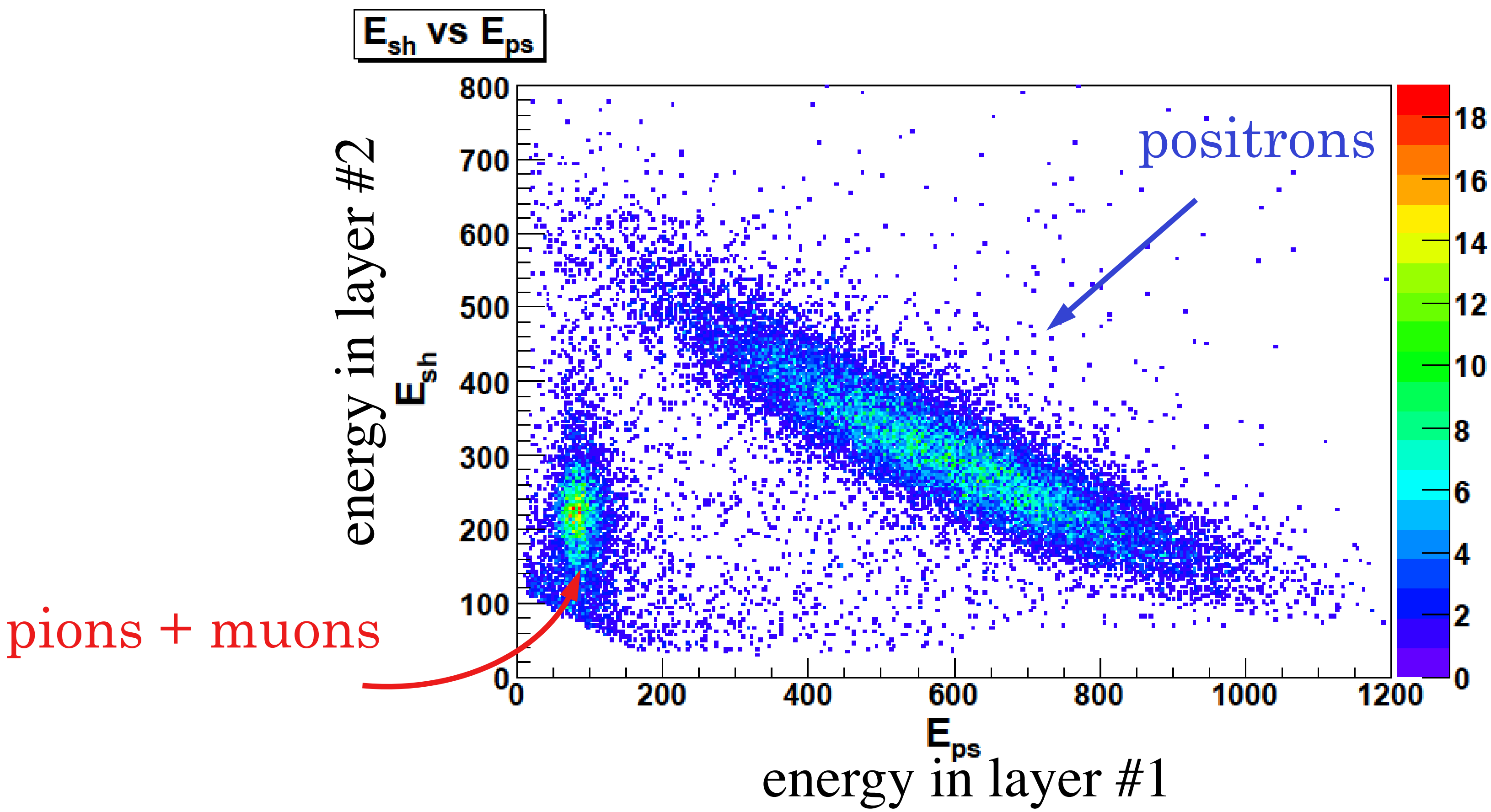
Vertical Drift Chambers – four planes in each HRS, 368 sense wires per plane
Upgrade of the front-end electronics - completed
Very good stability against oscillation
Rate capability of 8 MHz (in the whole chamber) was demonstrated

Detectors of the HRS spectrometers

Two-layer Calorimeters – total ~ 100 elements per HRS

Energy resolution of 5.5%/$E^{0.5}$

30 μA on Pb Target
Positron arm rate – 765 kHz



Detectors of the HRS spectrometers

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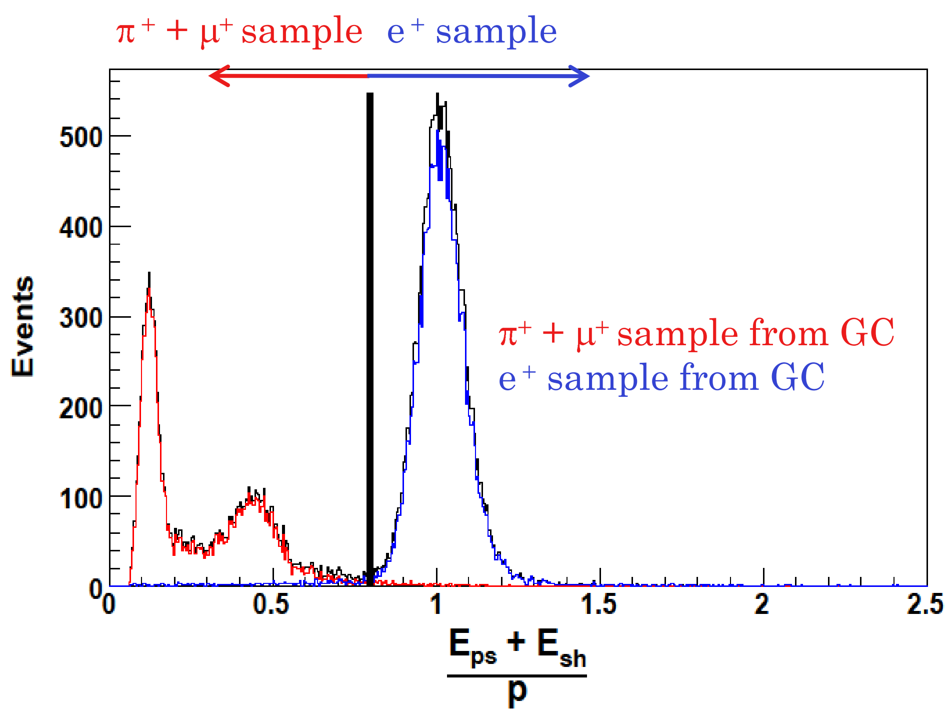


Electron detection eff.	0.977
Pion rejection eff.	0.985

Meson background rejected by a factor of 60

This analysis didn't use coordinate information

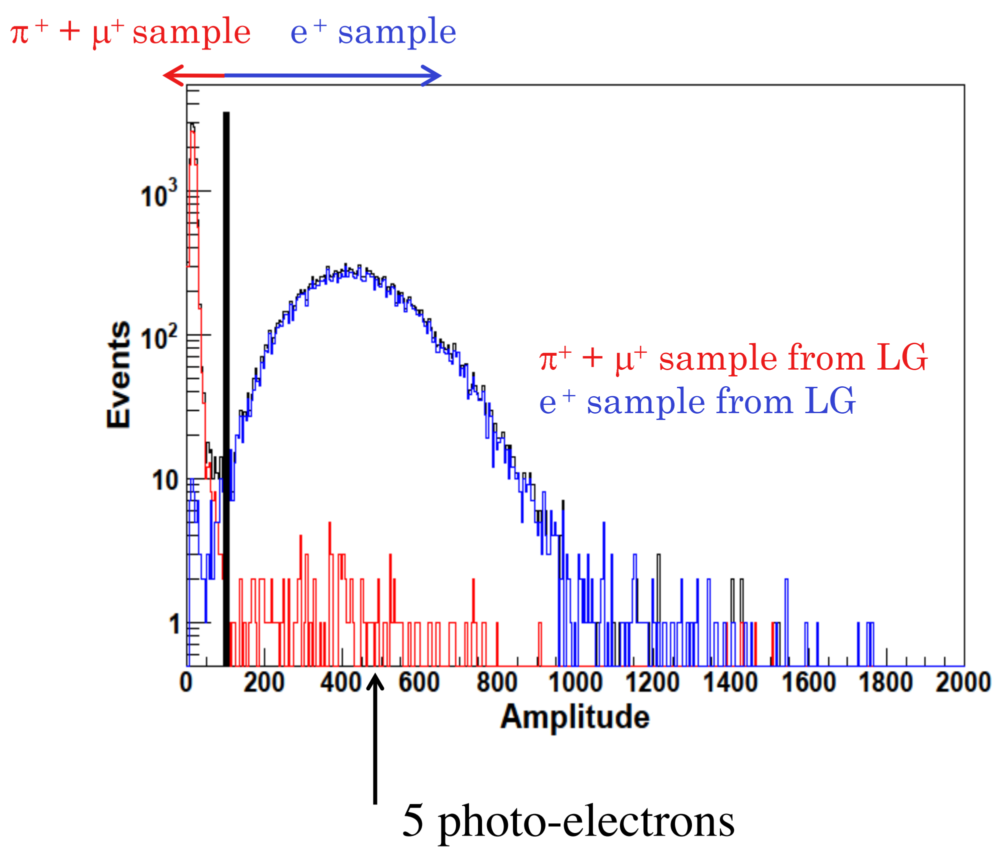
- E_{PS} – Energy deposition in 1st layer
- E_{SH} – Energy deposition in 2nd layer
- p – Particle momentum

Detectors of the HRS spectrometers

Gas Cherenkov counters – 10 PMTs in each HRS

In recent beam test (April 2014): 15 photo-electrons per e+/- track

From the test run (2010) analysis



Electron detection eff.	0.995
Pion rejection eff.	0.987

Meson background rejected by a factor of 75

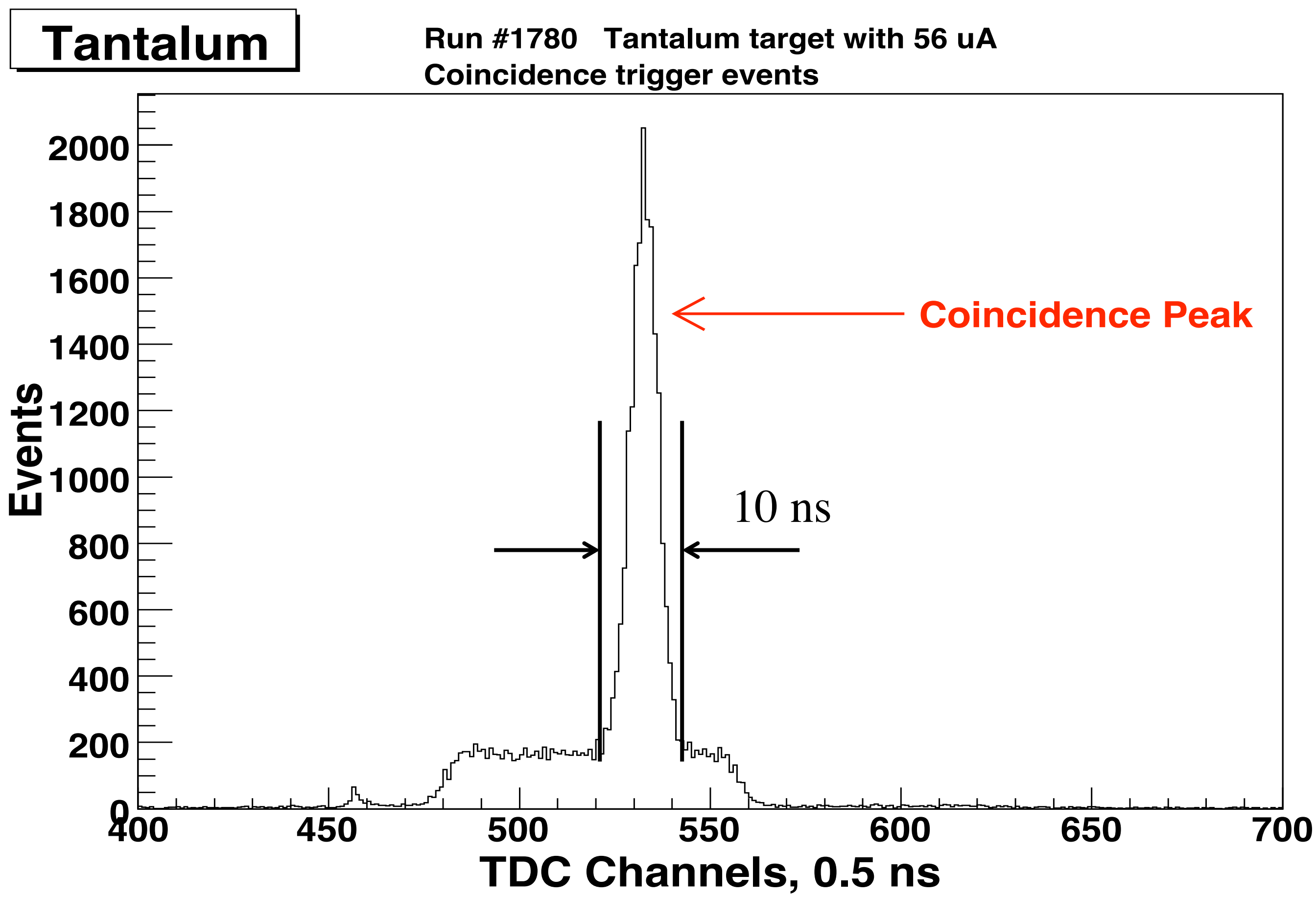
Detectors of the HRS spectrometers

Trigger hodoscopes – 16 counters in each HRS

Online time gate width of 10 ns

off-line time resolution ~ 0.25 ns

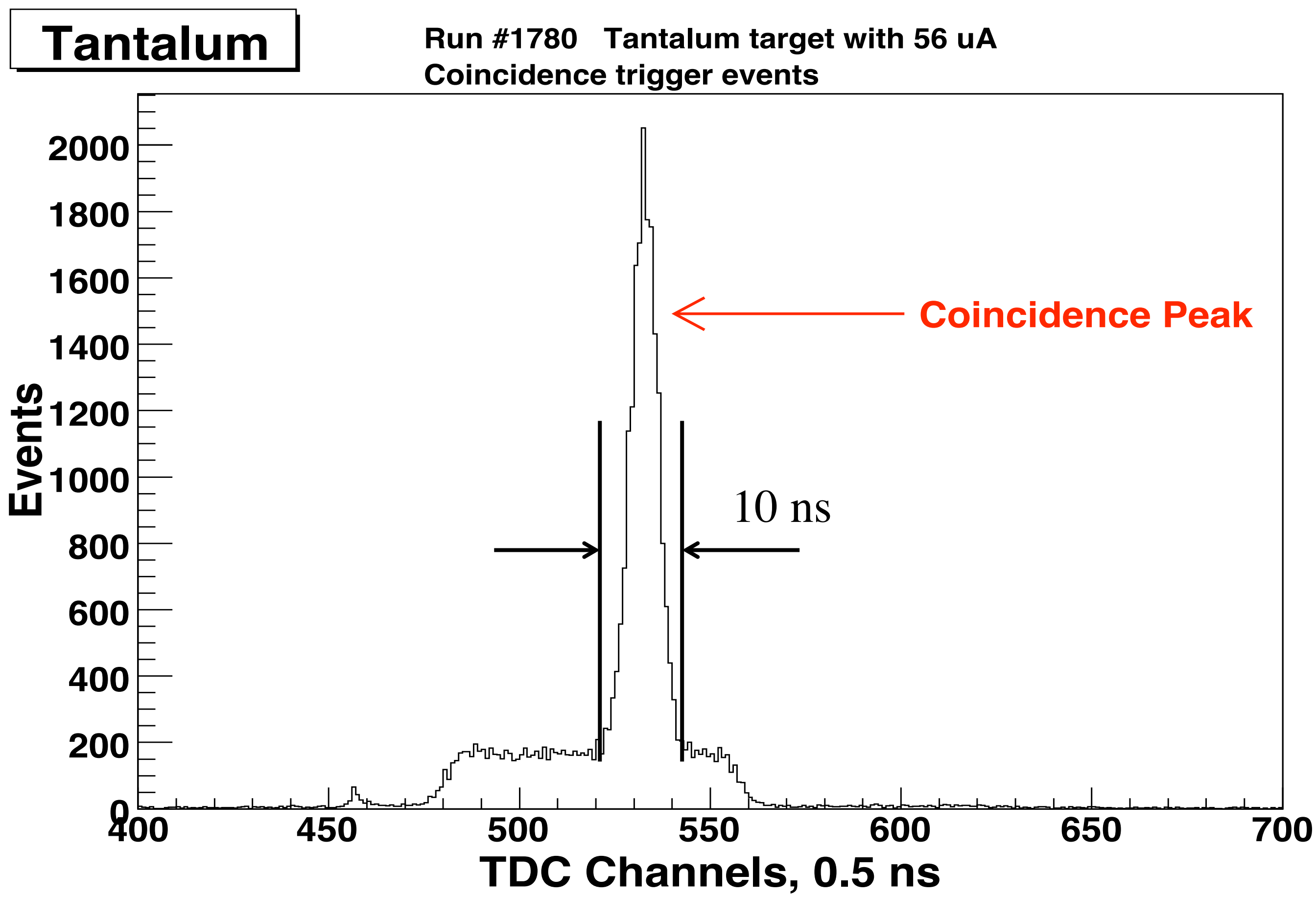
From the test run (2010) analysis



Detectors of the HRS spectrometers

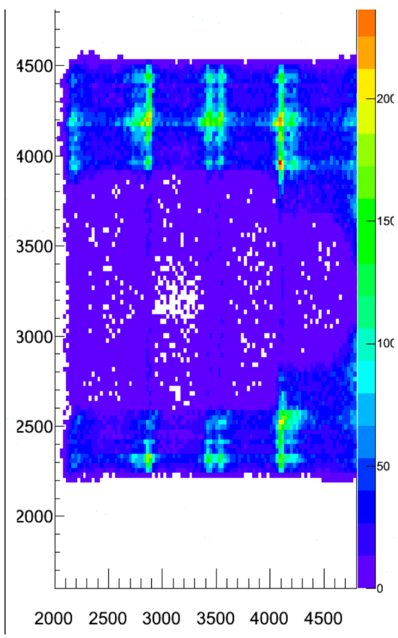
DAQ trigger is a triple coincidence of the Gas Cherenkov (e+ arm) and Scintillator hodoscopes of two arms

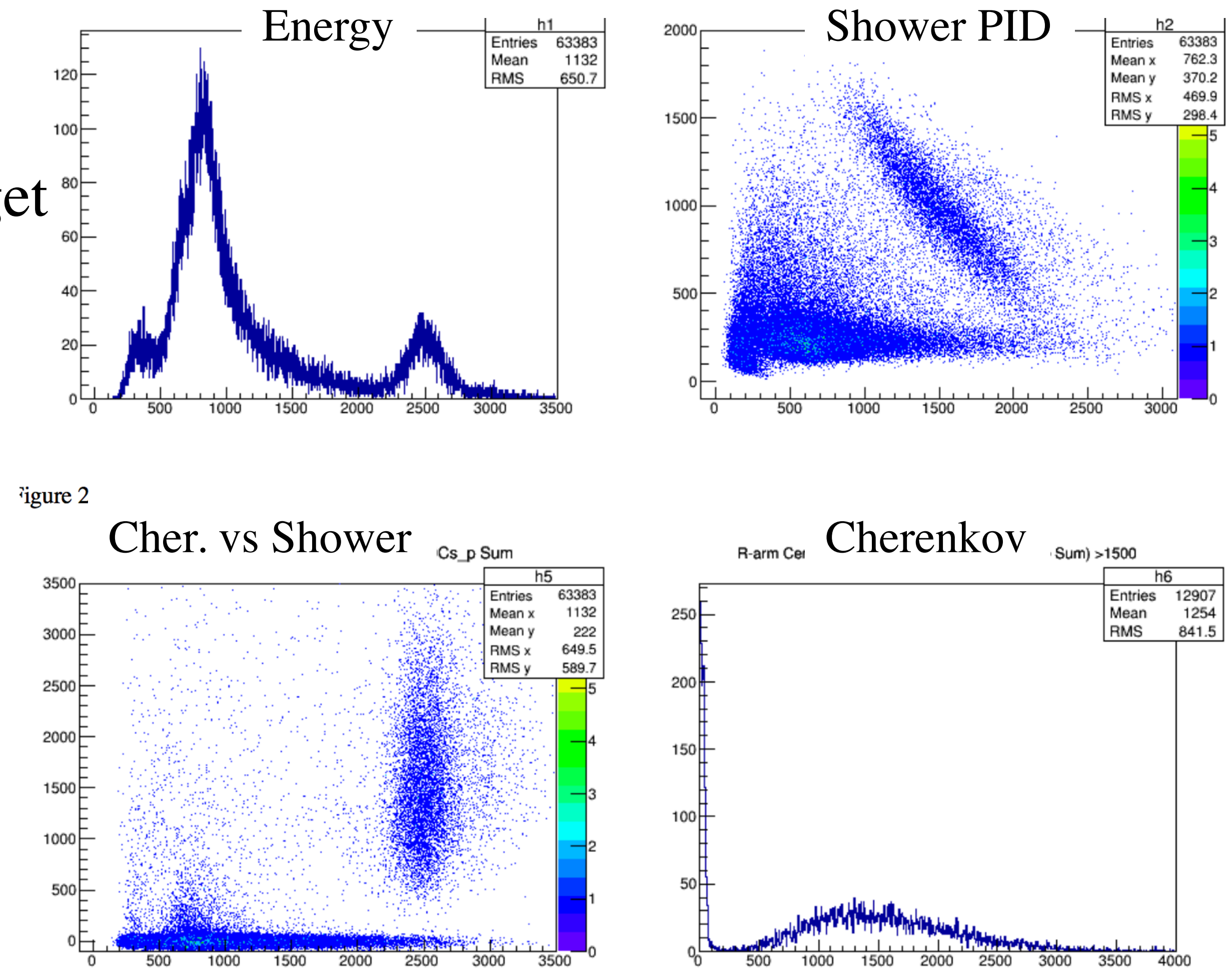
From the test run (2010) analysis



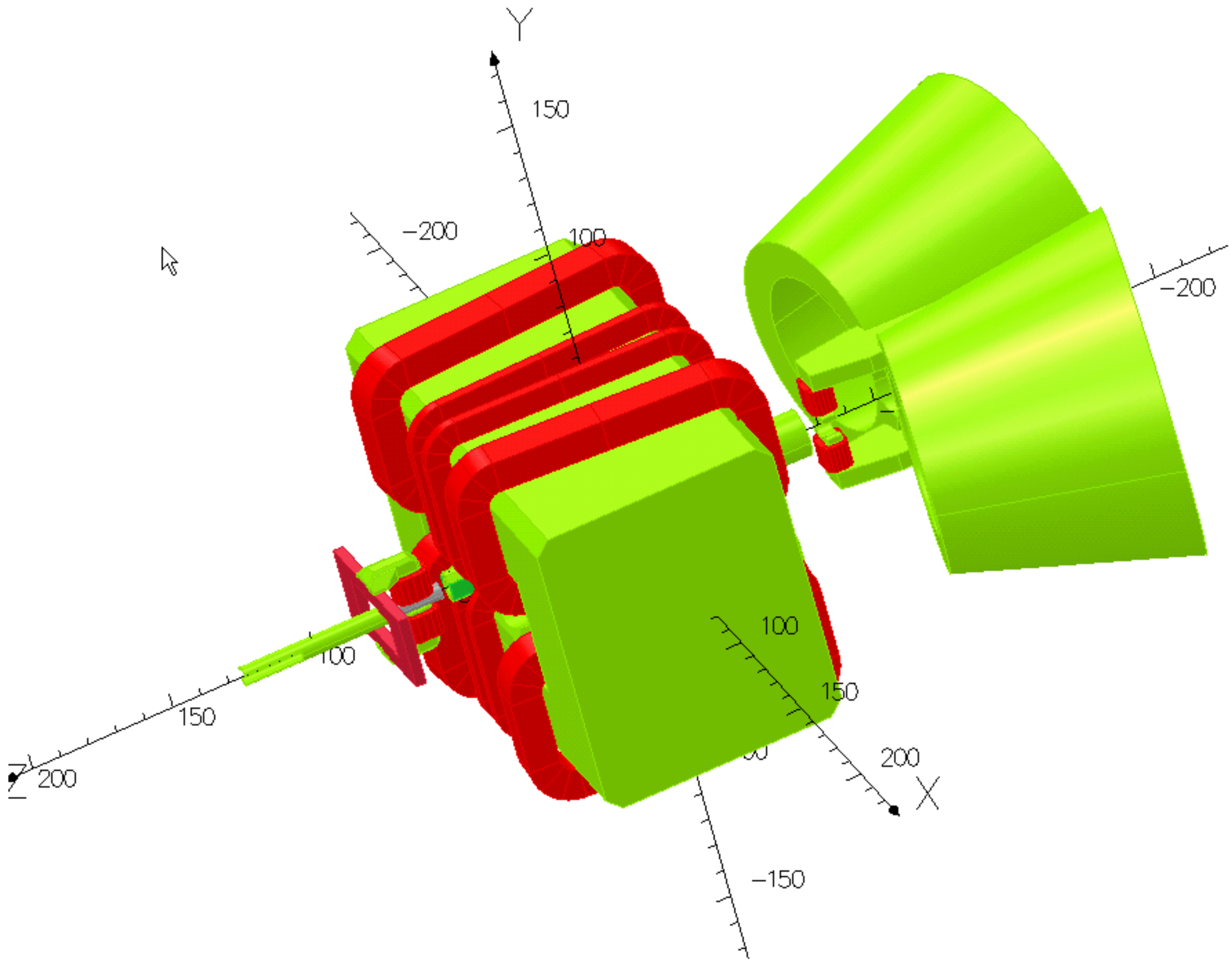
Beam from the upgraded accelerator in Hall A, 4/1/2014

Rate vs. raster current
Beam on the holey target

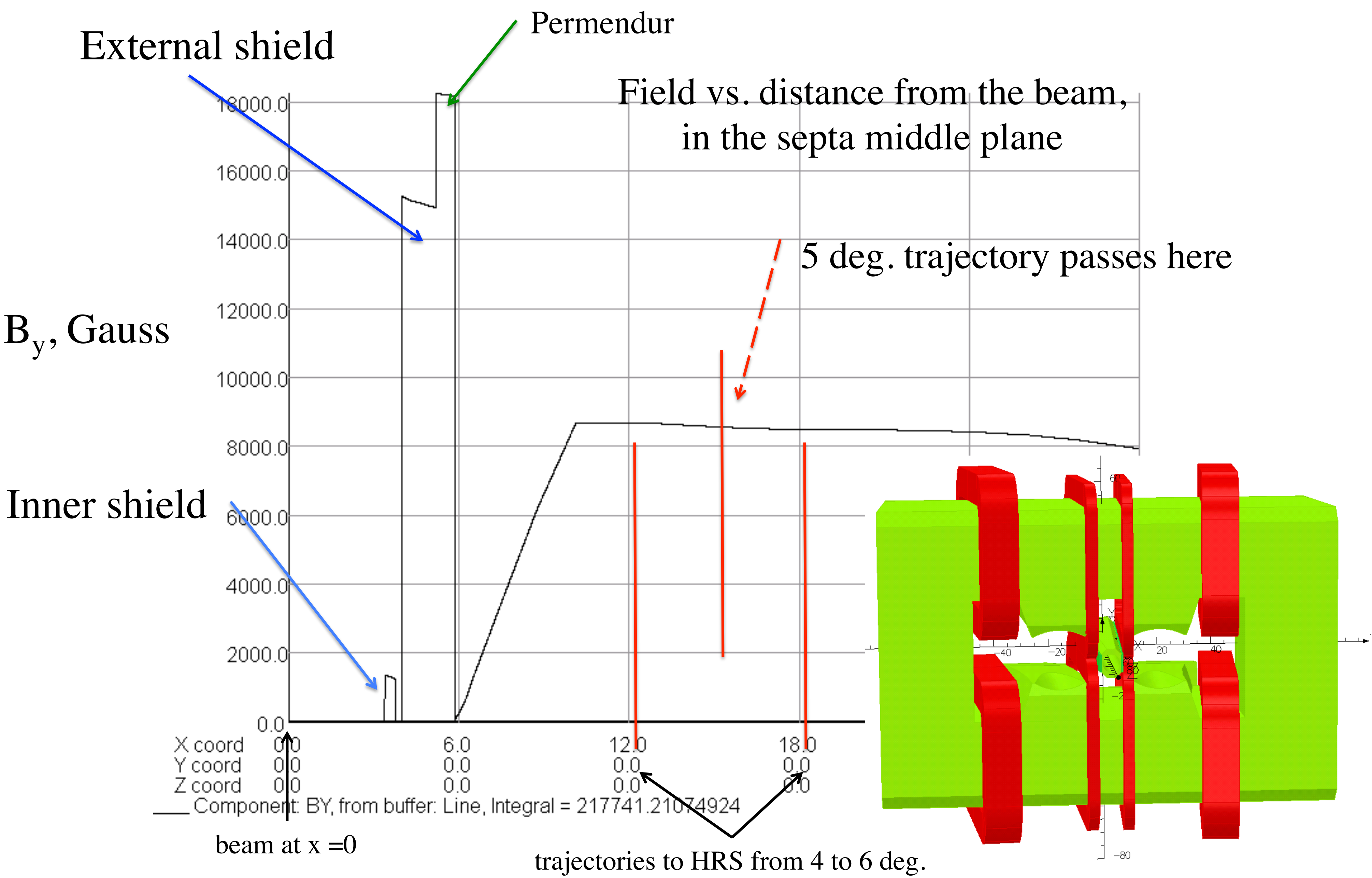




Septa magnet view and correctors

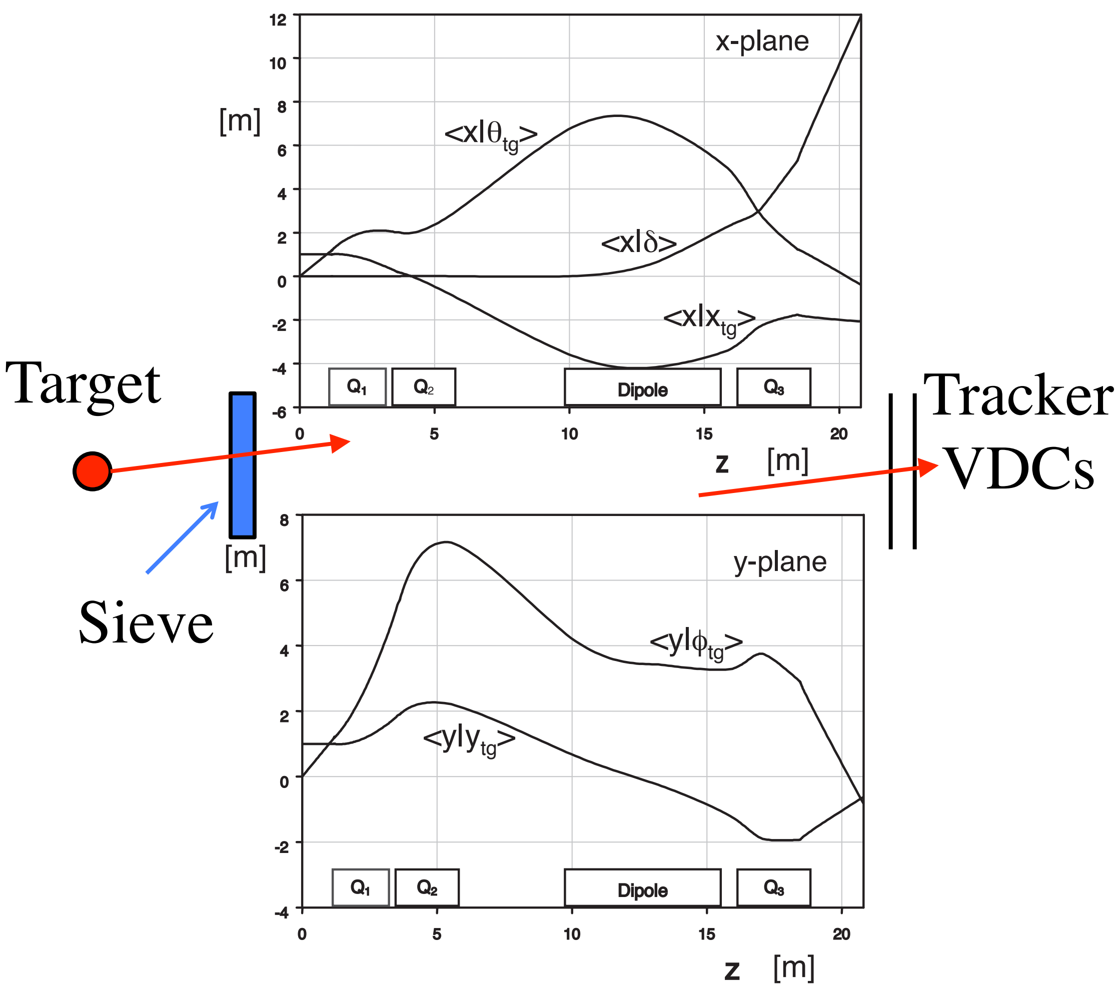


Specialized APEX hardware: Septa magnet

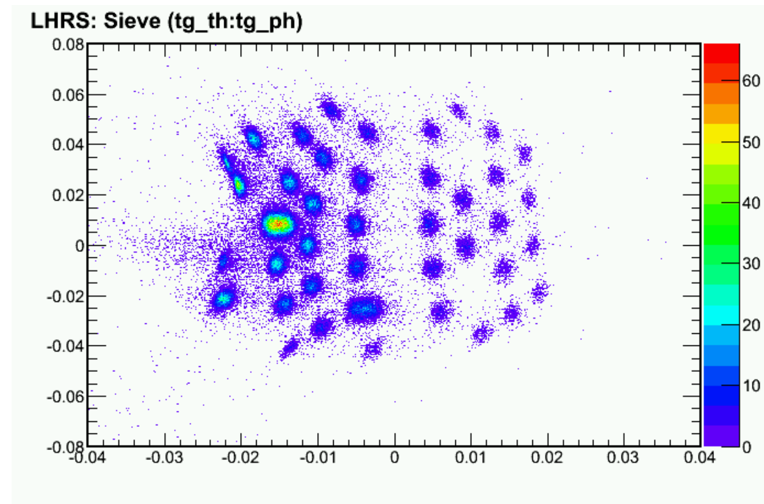


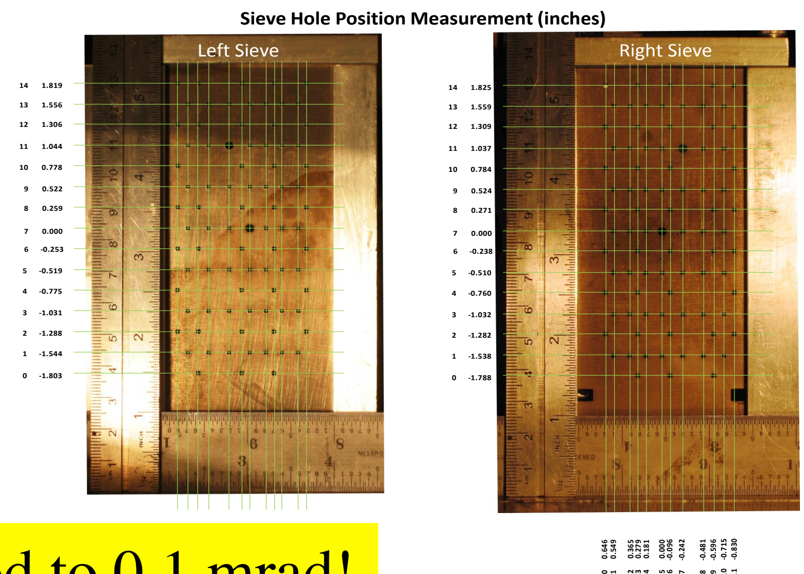
Specialized APEX detector: SciFi detector

Spectrometer optics



Traditional sieve pattern

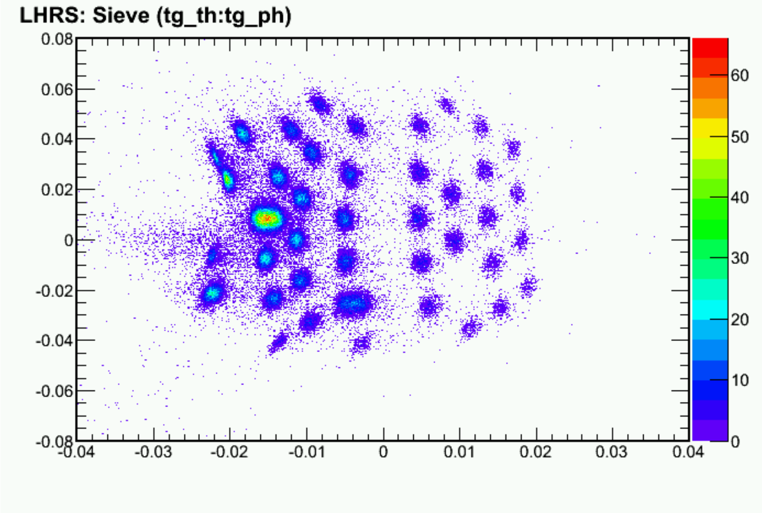




Calibrated optics is good to 0.1 mrad!

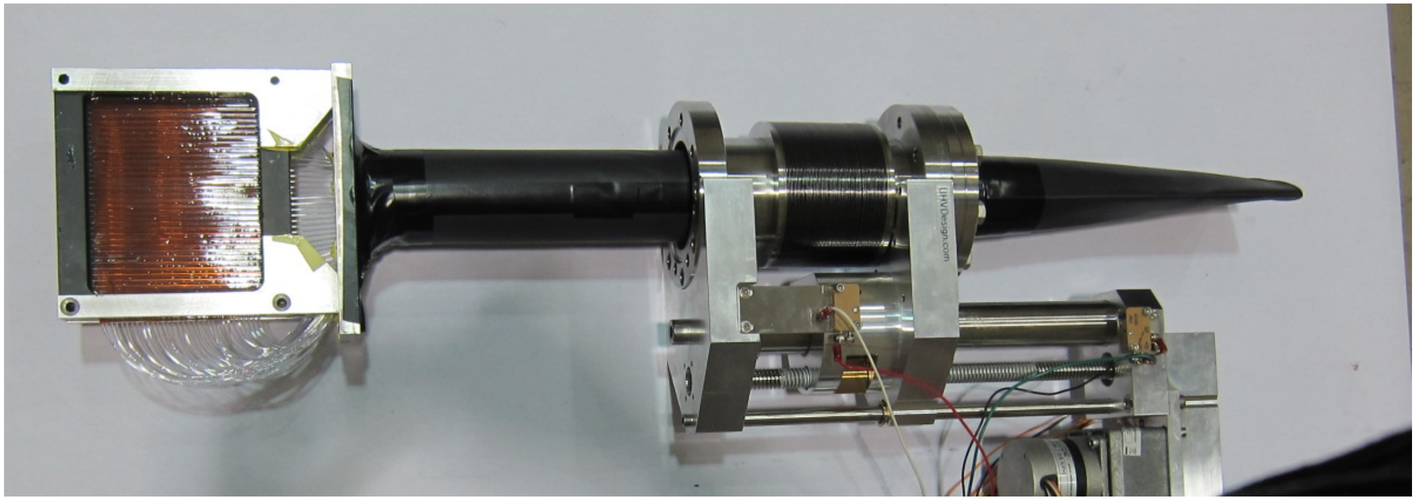
Specialized APEX detector: SciFi detector

Traditional sieve pattern



Positively charged particle optics needs a better method: the SciFi

Active "sieve slit": a Sci Fiber detector with 1 mm fibers with 1/4" pitch connected via a bundle of 1.5 mm clear fibers to a 64-channel PMT.



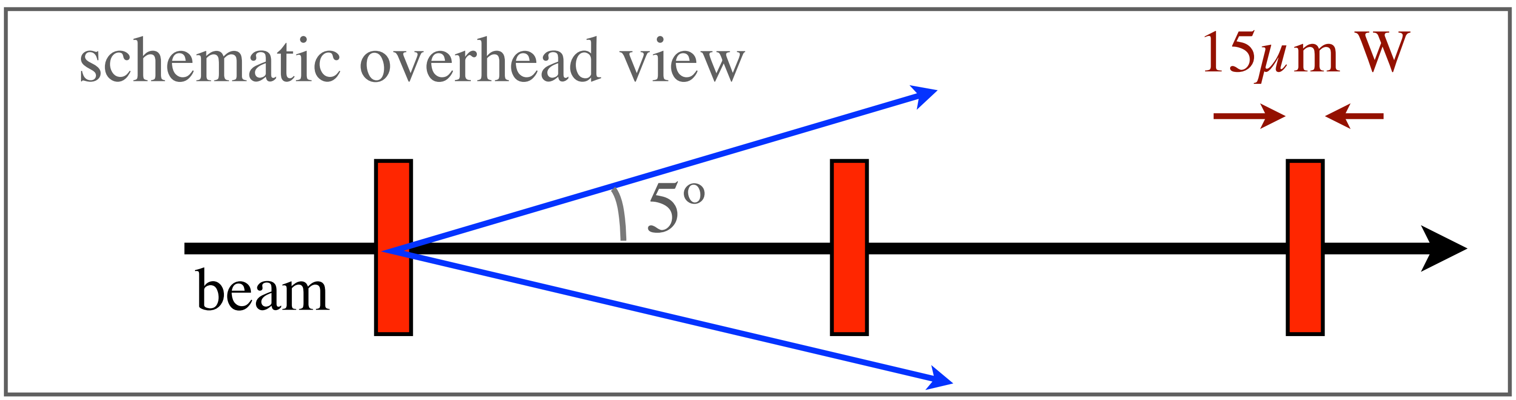
SciFI will be used during the optics calibration run with 1 μA beam intensity.
Readout via 1877S TDC; 1-3 MHz rate per fiber; off-line time window of < 5 ns

Specialized APEX target

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

APEX: A Search for Dark Photons in Hall A

Proposal: PR12-10-009

Scientific Rating: A
Recommendation: Approval

The PAC approves the proposal contingent on a successful solution of the radiation issue. The PAC feels that the experiment should be carried out as early as possible (ideally before the 6 GeV shut down in 2012).

Title: "Search for new Vector Boson *A'* Decaying to e^+e^-"

Spokespersons: R. Essig, P. Schuster, N. Toro, B. Wojtsekhowski

Motivation: The proposal is to search for a vector boson *A'* with weak coupling of about 10^{-3} e or smaller to electrons in the mass region 65-525 MeV. The proposed search is motivated by recent developments of models trying to explain inconsistencies observed in astrophysical data and dark matter search experiments. Such a vector boson would couple to charged leptons as it will mix with photon. If *A'* is produced by radiation off an electron beam, it would decay producing very narrow resonance in the invariant mass e^+e^- spectrum.

The proposal is very interesting and has the potential to make an important discovery. There are not many places where such measurement can be done, as it requires very high integrated luminosity and good control of the electromagnetic background. Part of the plane of coupling constant *versus* mass of the boson has already been excluded, but the region available for the proposed experiment coincides with the domain of greatest theoretical interest, for example explaining the deviation from SM expectations observed in the latest *g-2* experiment.

APEX: A Search for Dark Photons in Hall A

From: Bob McKeown

To: Philip Schuster, Rouven Essig, Natalia Toro, Bogdan Wojtsekhowski

Cc: Cynthia Keppel, Hugh Montgomery, Rolf Ent, Susan Brown

Dear Philip, Natalia, Rouven, and Bogdan,

As you have requested, I have reviewed the history and technical issues related to the disposition of APEX as a conditionally approved experiment. The justification for conditional approval was the PAC concern that the issue of radiation damage in Hall A be addressed. Subsequently, the Experimental Physics Division has implemented a policy that radiation damage assessment be part of the Experiment Readiness Review process. Following the implementation of this policy the conditional approval for APEX is redundant and unnecessary. In particular, I note that PREX (at a later PAC) had similar concerns from the PAC but received full approval. (In fact, the radiation damage issues for APEX and PREX are very similar as the beam current, target thickness, and running time are comparable.)

So at this point we have decided that APEX should be considered as a fully approved proposal. We will update the lab website in the near future (Susan is away on medical leave for a few weeks).

I look forward to working with you to make APEX successful in the future.

Best regards,
Bob

Organization of experiments

1. Spokespeople write a proposal
2. Spokespeople recruit collaborators
3. PAC considers the proposal
4. Spokespeople organize experiment preparation
5. Collaboration provides students and postdocs
6. Physics division schedules the beam time
7. Collaboration organizes the data taking run
8. Core group organizes the data analysis
9. Collaboration circulates the results
10. Core group writes a paper

Organization of experiments

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2. Spokespeople recruit collaborators
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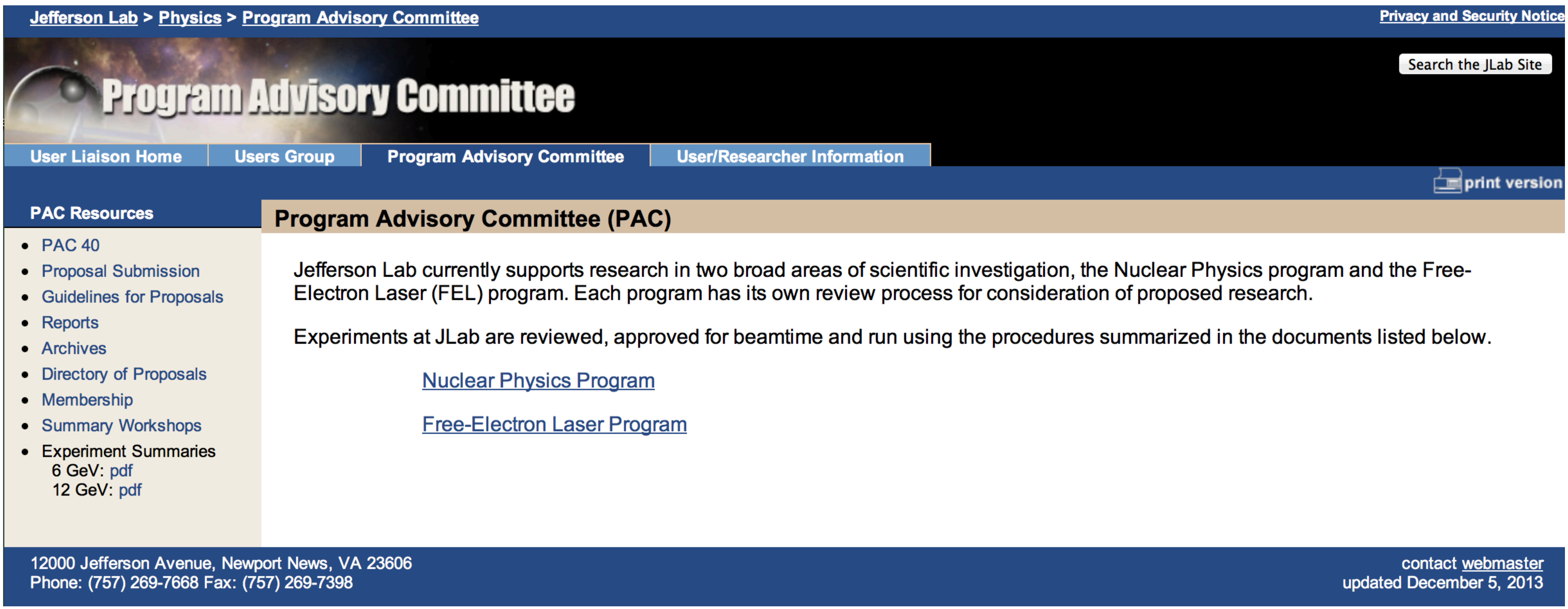
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print version

PAC Resources

- PAC 40
- Proposal Submission
- Guidelines for Proposals
- Reports
- Archives
- Directory of Proposals
- Membership
- Summary Workshops
- Experiment Summaries
  6 GeV: pdf
  12 GeV: pdf

Program Advisory Committee (PAC)

Jefferson Lab currently supports research in two broad areas of scientific investigation, the Nuclear Physics program and the Free-Electron Laser (FEL) program. Each program has its own review process for consideration of proposed research.

Experiments at JLab are reviewed, approved for beamtime and run using the procedures summarized in the documents listed below.

Nuclear Physics Program

Free-Electron Laser Program

12000 Jefferson Avenue, Newport News, VA 23606
Phone: (757) 269-7668 Fax: (757) 269-7398

contact webmaster
updated December 5, 2013

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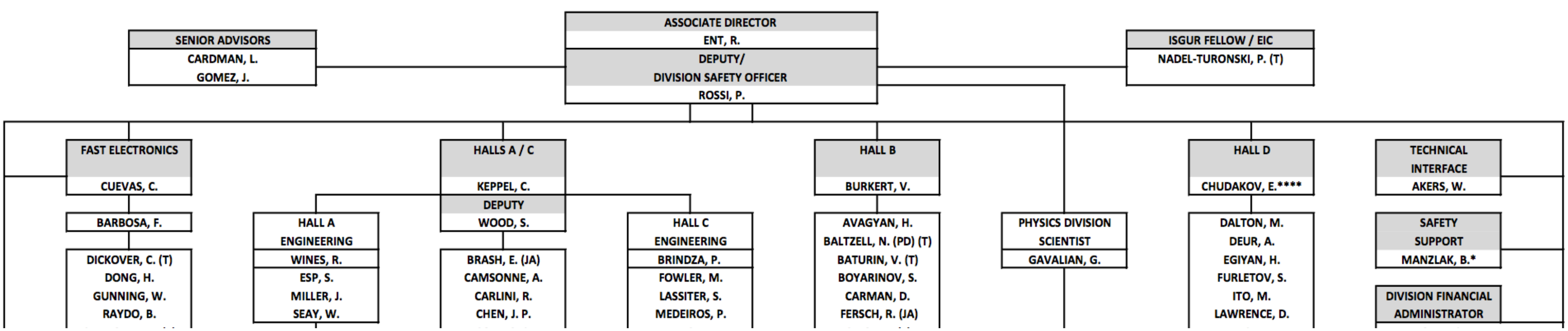
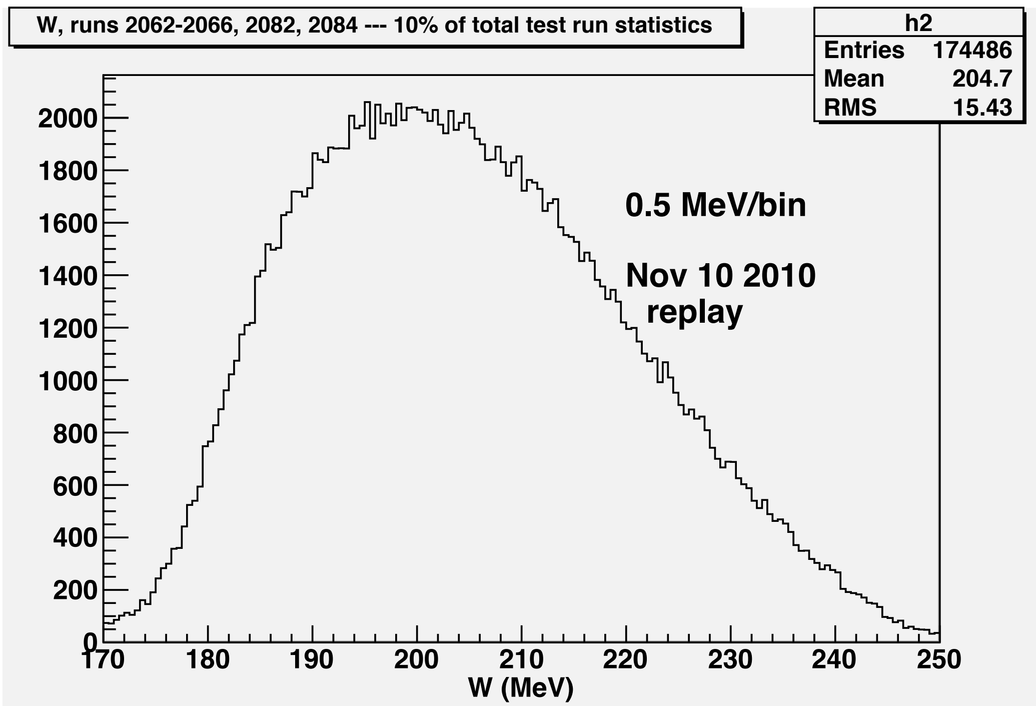
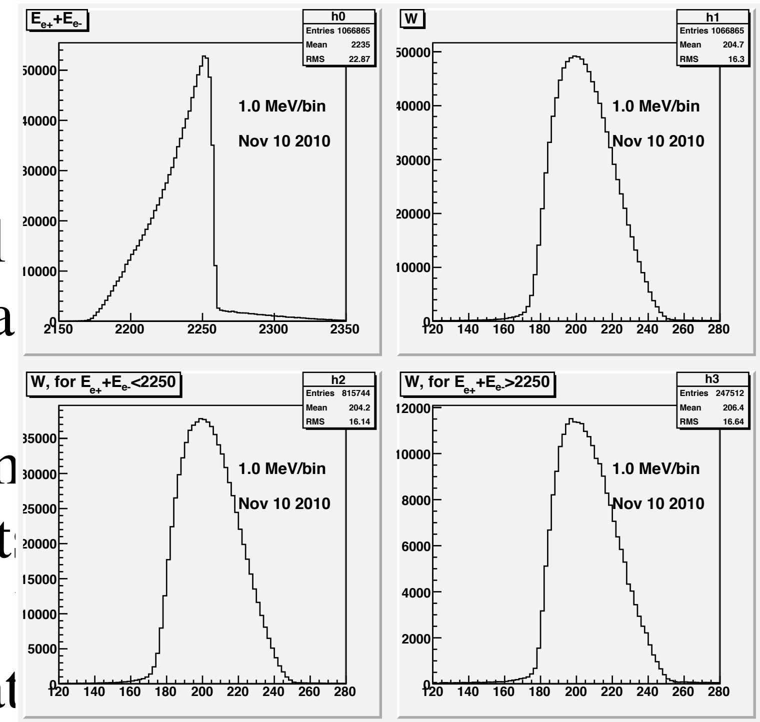
5. Collaboration provides students and postdocs
6. Physics division schedules the beam time



Organization of experiments





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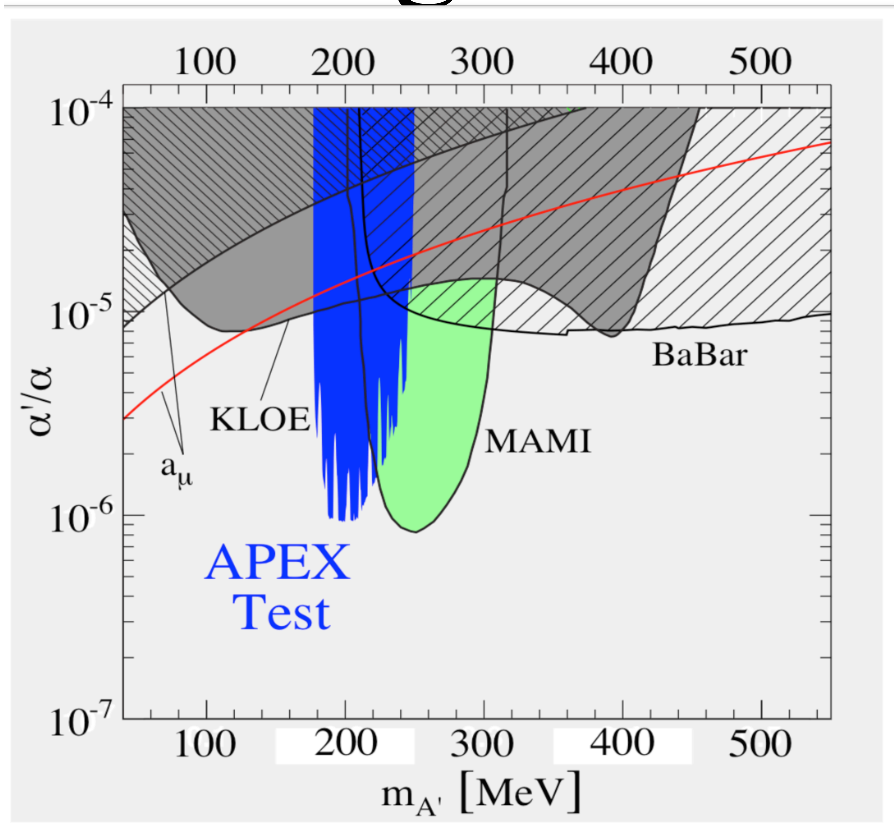
8. Core group organizes the data analysis
9. Collaboration circulates the results
10. Core group writes a paper

Organization of experiments



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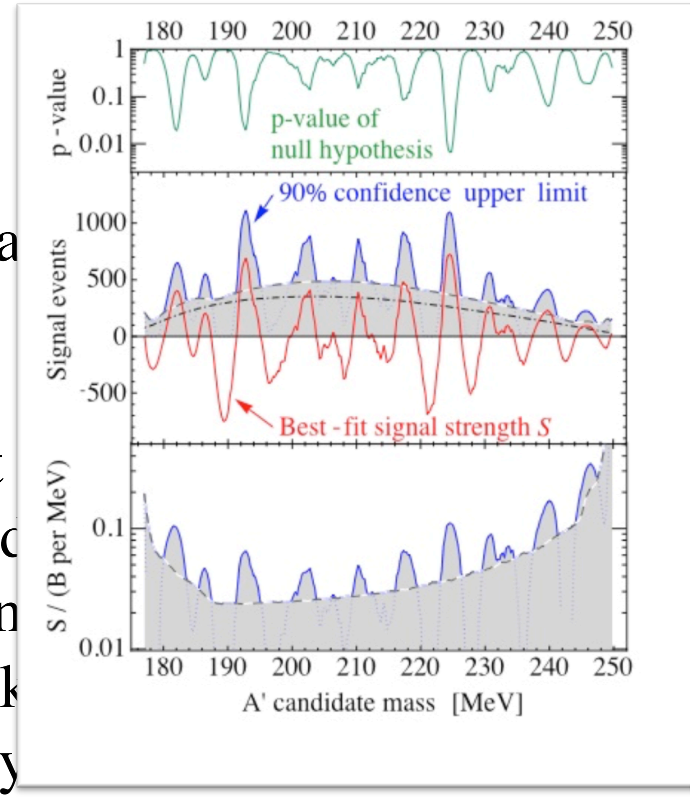


Organization of experiments

PRL **107,** 191804 (2011) PHYSICAL REVIEW LETTERS week ending 4 NOVEMBER 2011

Search for a New Gauge Boson in Electron-Nucleus Fixed-Target Scattering by the APEX Experiment

S. Abrahamyan,[1] Z. Ahmed,[2] K. Allada,[3] D. Anez,[4] T. Averett,[5] A. Barbieri,[6] K. Bartlett,[7] J. Beacham,[8] J. Bono,[9] J. R. Boyce,[10] P. Brindza,[10] A. Camsonne,[10] K. Cranmer,[8] M. M. Dalton,[6] C. W. de Jager,[10,6] J. Donaghy,[7] R. Essig,[11,*] C. Field,[11] E. Folts,[10] A. Gasparian,[12] N. Goeckner-Wald,[13] J. Gomez,[10] M. Graham,[11] J.-O. Hansen,[10] D. W. Higinbotham,[10] T. Holmstrom,[14] J. Huang,[15] S. Iqbal,[16] J. Jaros,[11] E. Jensen,[5] A. Kelleher,[15] M. Khandaker,[17,10] J. J. LeRose,[10] R. Lindgren,[6] N. Liyanage,[6] E. Long,[18] J. Mammei,[19] P. Markowitz,[9] T. Maruyama,[11] V. Maxwell,[9] S. Mayilyan,[1] J. McDonald,[11] R. Michaels,[10] K. Moffeit,[11] V. Nelyubin,[6] A. Odian,[11] M. Oriunno,[11] R. Partridge,[11] M. Paolone,[20] E. Piasetzky,[21] I. Pomerantz,[21] Y. Qiang,[10] S. Riordan,[19] Y. Roblin,[10] B. Sawatzky,[10] P. Schuster,[11,22,†] J. Segal,[10] L. Selvy,[18] A. Shahinyan,[1] R. Subedi,[23] V. Sulkosky,[15] S. Stepanyan,[10] N. Toro,[24,22,‡] D. Walz,[11] B. Wojtsekhowski,[10,§] and J. Zhang[10]

[1]*Yerevan Physics Institute, Yerevan 375036, Armenia*
[2]*Syracuse University, Syracuse, New York 13244, USA*
[3]*University of Kentucky, Lexington, Kentucky 40506, USA*
[4]*Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada*
[5]*College of William and Mary, Williamsburg, Virginia 23187, USA*
[6]*University of Virginia, Charlottesville, Virginia 22903, USA*

10.Core group writes a paper

Why HRSs can do the search?

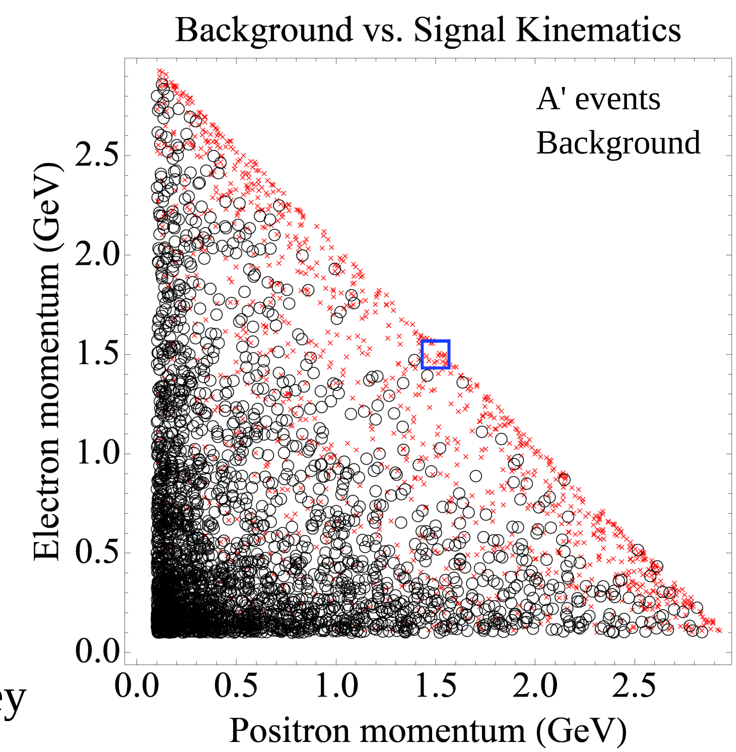
Symmetric energy, angles in two arms optimize A′ acceptance.

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

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'.

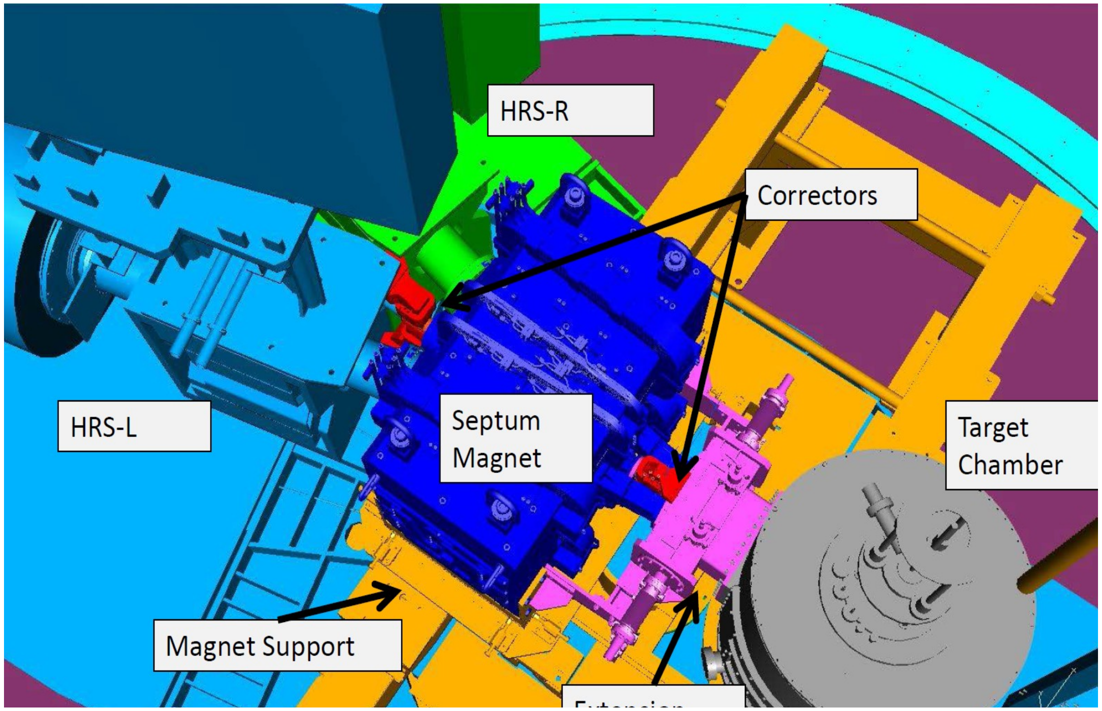


HRS acceptance takes about 5% of signal events (A') while the background rate is reduced dramatically (by several orders of magnitude).

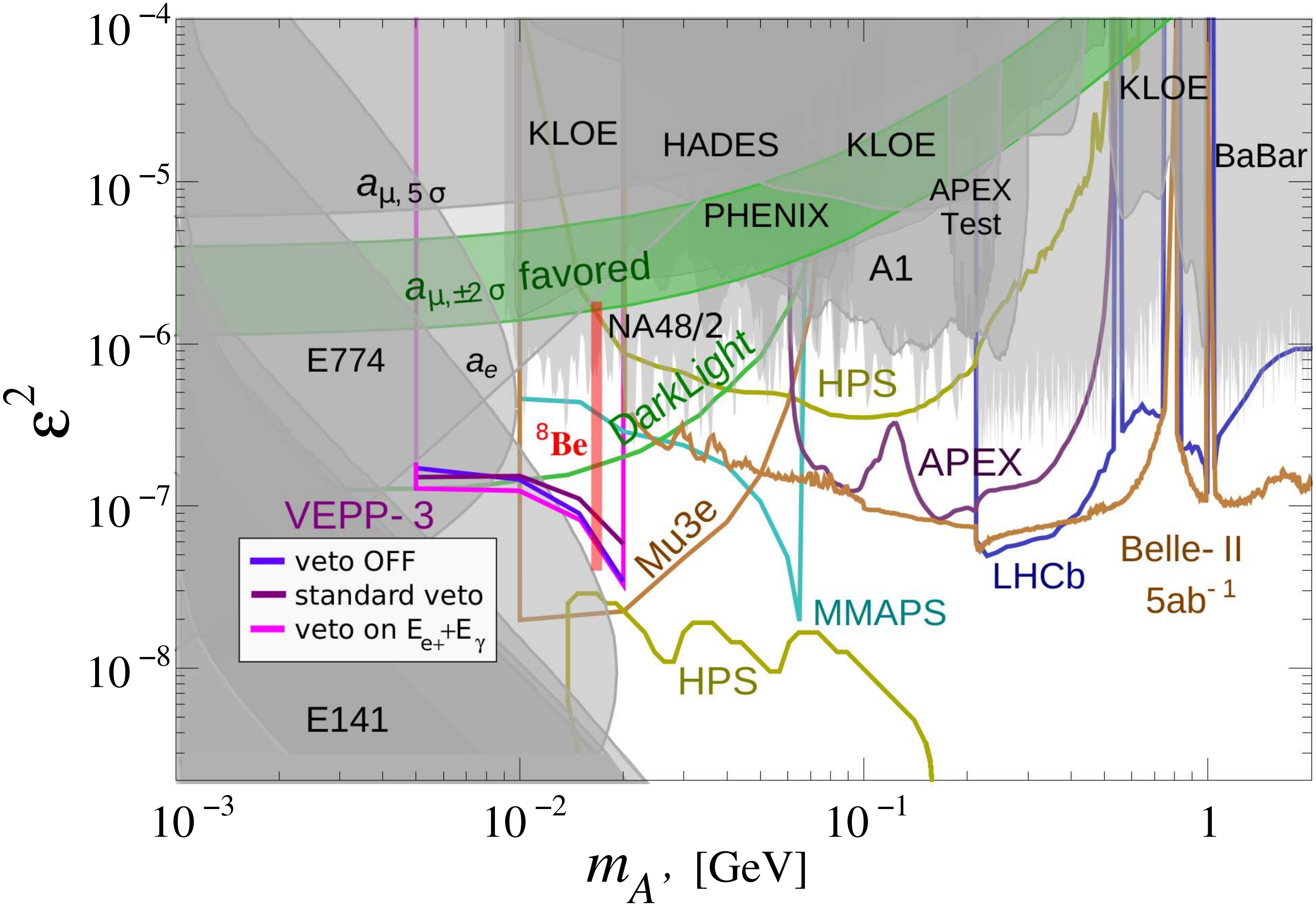
New equipment for APEX

New septum:

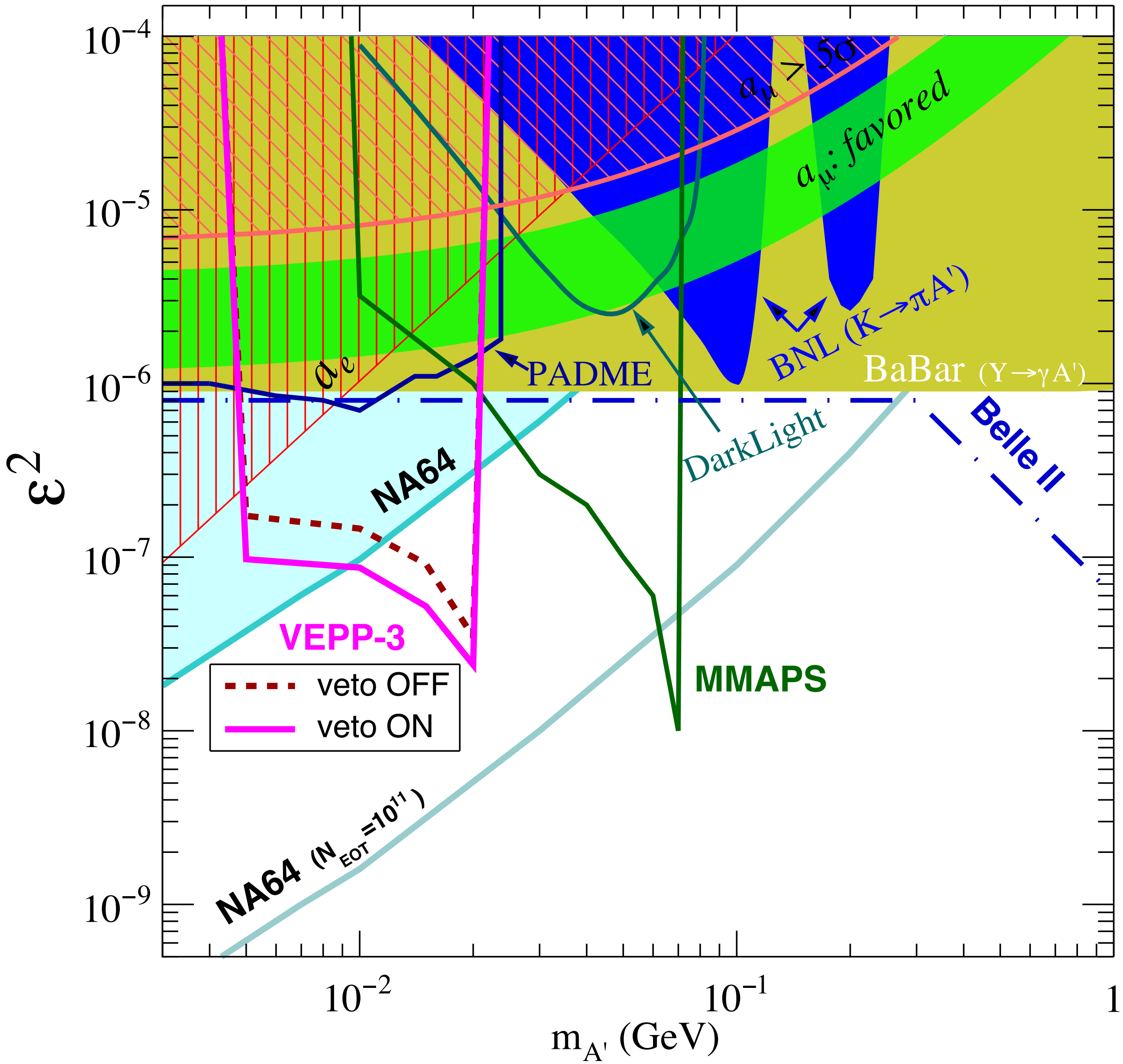
- allows registration of small-angle e^+e^- pairs in HRS;
- provides operation for full momentum range of the experiment (up to 2.2 GeV);
- has a good magnetic shielding of the beam line.



Phase space for all A' searches



Phase space for invisible decay A'



Beam time schedule in Hall A

	Spring	Fall	Spring	Fall	Spring	Fall	Spring
2014	Hall checkout (DVCS –I/ GMp)	DVCS - I/ GMp checkout					
2015			DVCS - I/ GMp	^{3}H/^{3}He			
2016					*A_1^n* *APEX*	*PREX* *CREX*	
2017							*A_1^n* *APEX* *PREX* *CREX* *DVCS-II*

SBS

MOLLER,
SOLID…?….

Experiments in italics, being further out in time, have less scheduling certainty and could be rescheduled amongst the 2016,2017 run periods. The 2017 period shown indicates a potential time for any not yet run.

available at: hallaweb.jlab.org/wiki/index.php/Main_Page#12_GeV_Era_Run_Schedule

Hall A Projected Experiment Schedule as of 1/18 (also see https://www.jlab.org/exp_prog/experiment_schedule/2018/20180108.2a.pdf *through 12/18*)

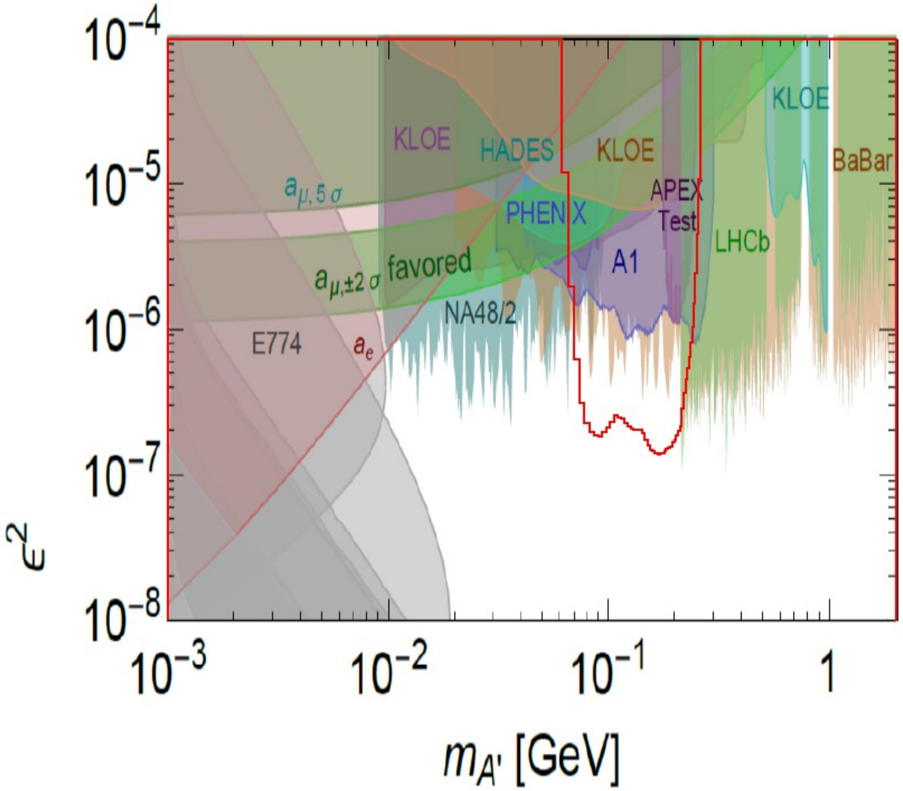
	Spring	**Fall**	**Spring**	**Fall**	**Spring**	**Summer !!!!**	**Fall**
CY 2017	Ar(e,e'p)	^{3}H/^{3}He group*					
CY 2018			^{3}H/^{3}He group	^{3}H/^{3}He group			
CY 2019					*APEX*	*PREX2*	*CREX*

New and exciting news!
This is the plan…
…BUT…there are caveats….

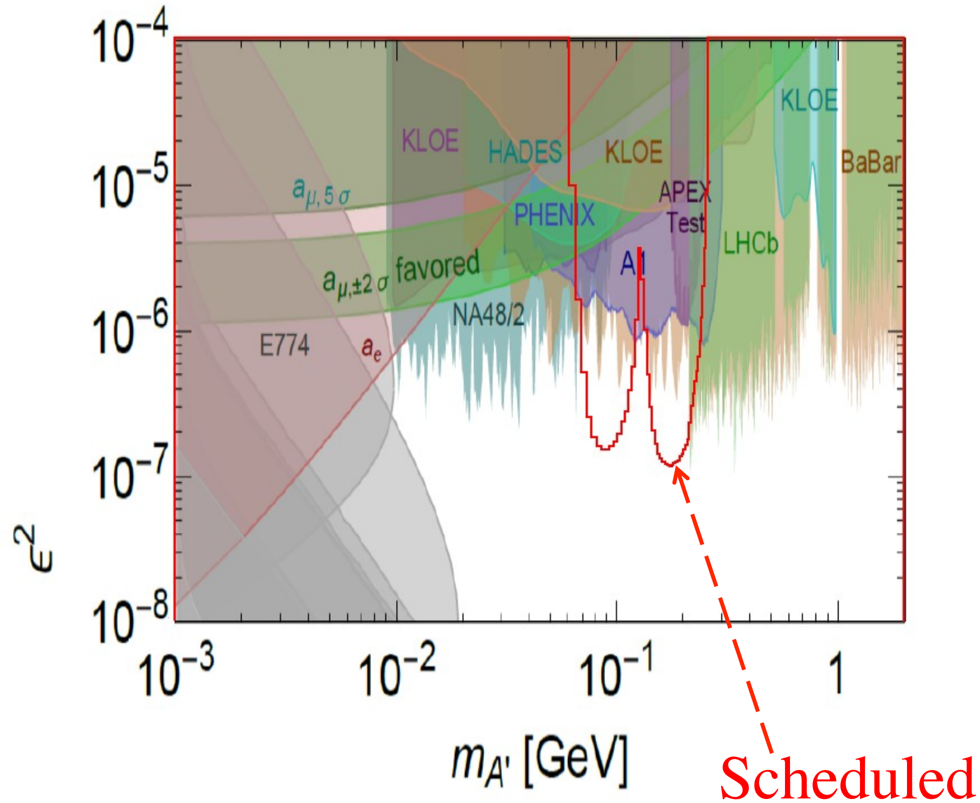
SBS 2020
MOLLER?, SoLID? →

Experiments in red represent PAC "high impact" experiments

Updated plan (all energies)



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