ator Facility

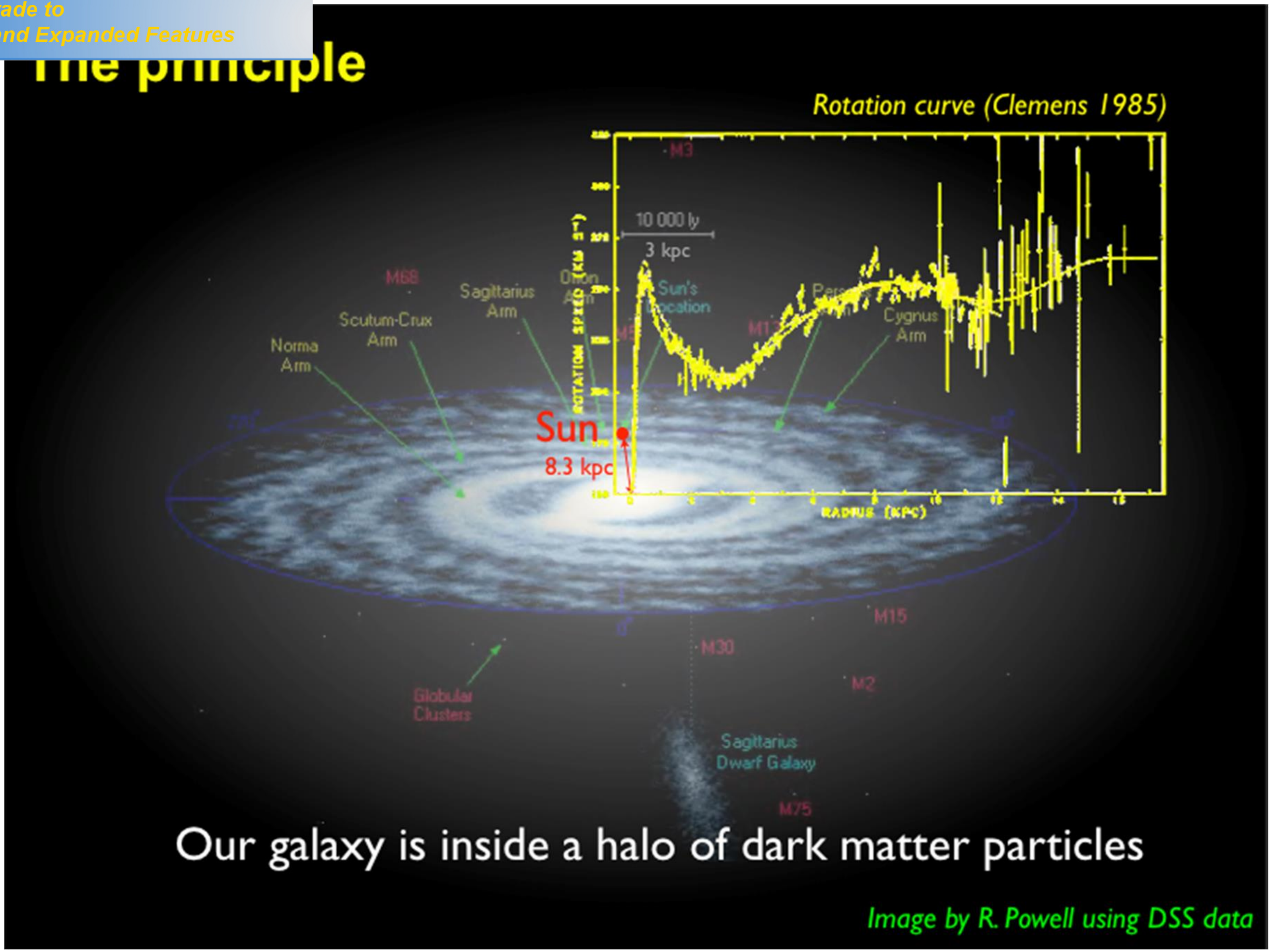
A Prime EXperiment:
Sensitive search for a heavy photon

Bogdan Wojtsekhowski, Jefferson Lab

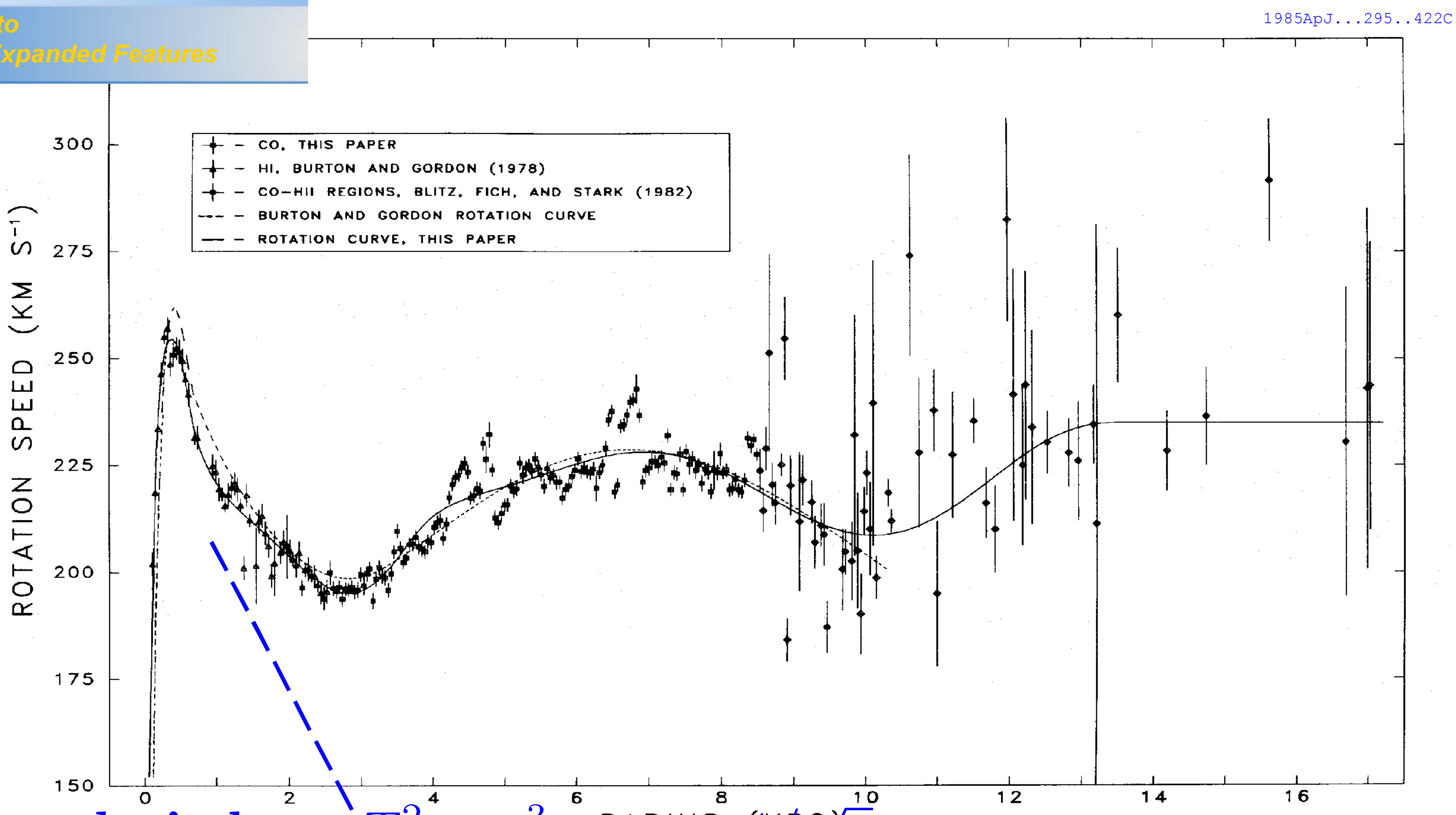
ÅMotivation
- ÅPhysics beyond SM
- ÅDark matter astronomical observations
- ÅHeavy photon as a DM force mediator

ÅAPEX-2019 data quality and sensitivity
ÅNew configuration for a e+e- machine: VAC

New physics indication



New physics indication



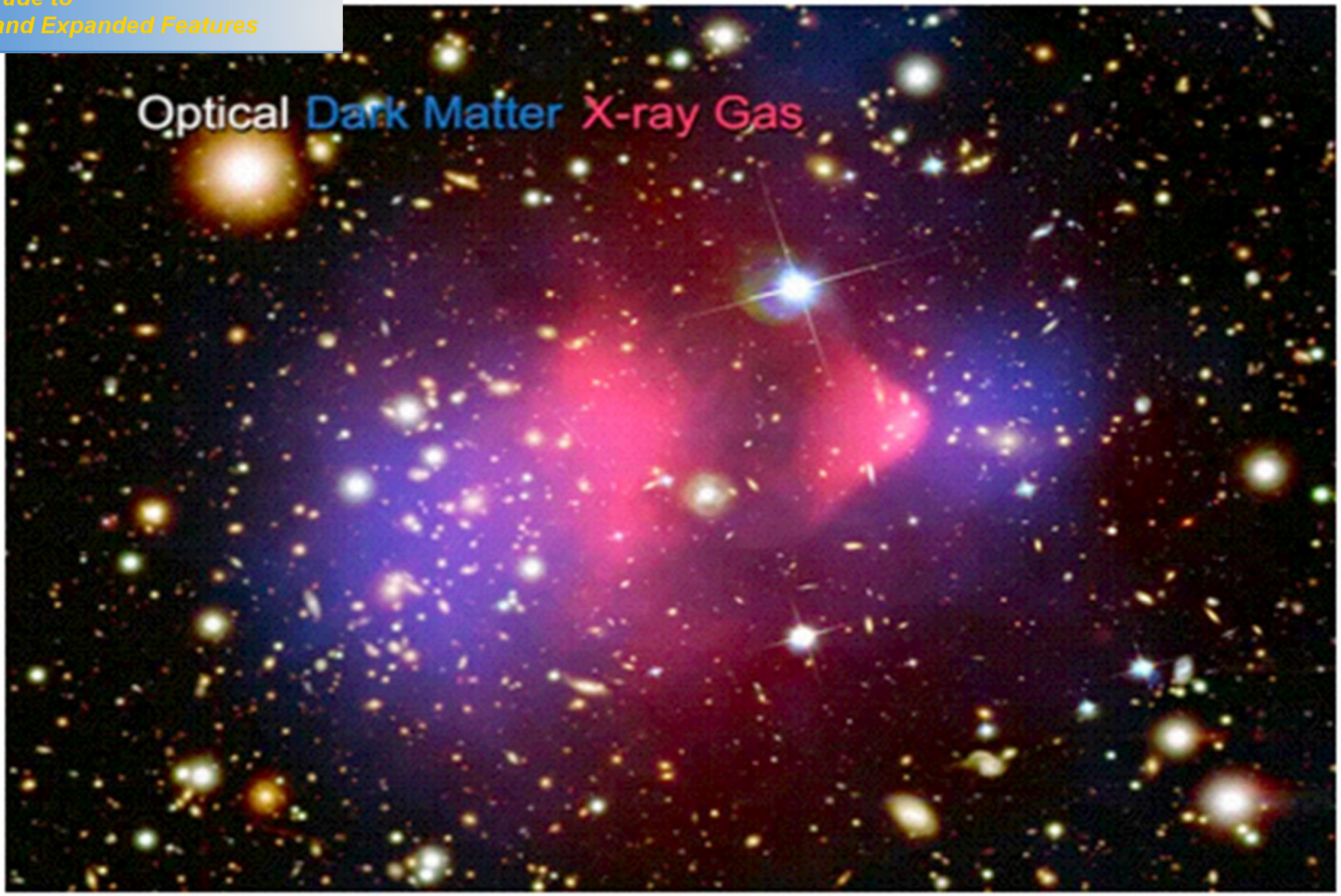
Keppler's law: $T^2 \propto a^3$ or $v \sim 1/\sqrt{a}$

FIG. 3.—Plots of the rotation speed versus galactocentric radius. The solid lines correspond to the polynomials, and the dashed lines are the BG rotation curve. (*upper panel*)(R_0, θ_0) = (10 kpc, 220 km s^{-1}); (*lower panel*) (8.5 kpc, 220 km s^{-1}).

1619

DM in 1933 by F. Zwicky. The plot from D. Clemens, 1985

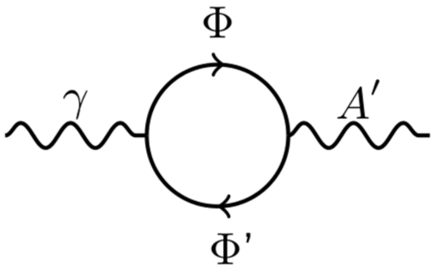
New physics observed

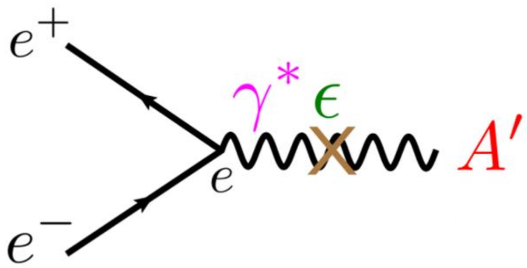


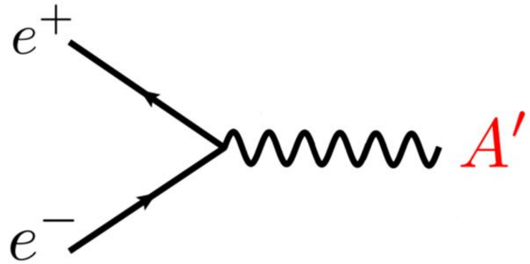
D. Clowe et al., òA direct empirical proof of the existence of dark matterò, Astrophys. J., Vol.648, L109 (2006). doi:10.1086/508162

ection of the dark matter to SM

$$\mathcal{L} = \mathcal{L}_{\mathsf{SM}} + \frac{\varepsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu}$$







rch for the DM particles

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544

(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

gnal of the DM particle

PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. J. Krasznahorkay,* M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár,
T. G. Tornyi, ar
Institute for Nuclear Research, Hungarian Academy of Sciences

T. J. Ke
Nikhef National Institute for Subatomic Physics, Scien

A. Kraszna
CERN, CH-1211 Geneva 23, Switzerland and Institute for Nuclea
P.O. Box 51, H-4001 L
(Received 7 April 2015; pub

Electron-positron angular correlations were measur
($J^\pi = 1^+$, $T = 1$) state → ground state ($J^\pi = 0^+$, $T =$
($J^\pi = 1^+$, $T = 0$) state → ground state transitions in ^{8}E
pair creation was observed at large angles in the angu
confidence level of > 5σ. This observation could possib
might indicate that, in an intermediate step, a
$16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV/c^2 and $J^\pi = 1^+$ v

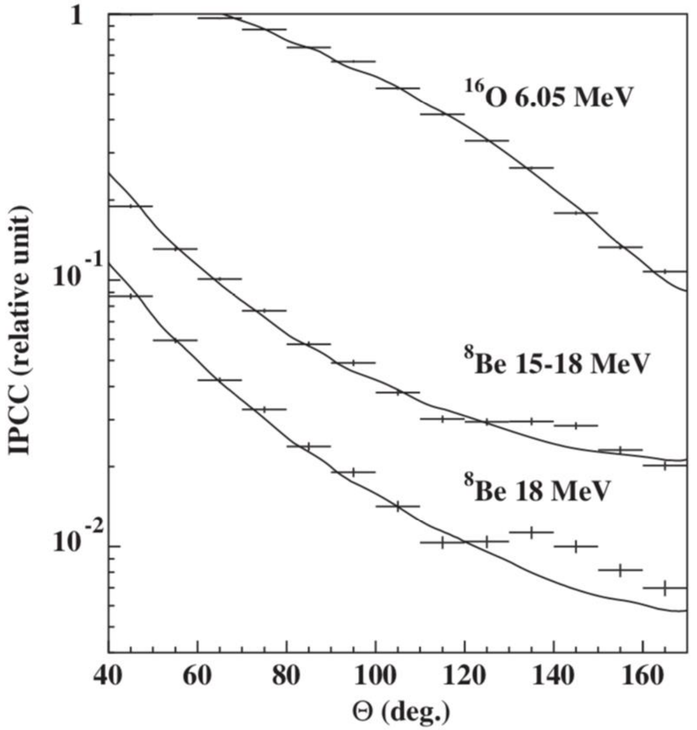
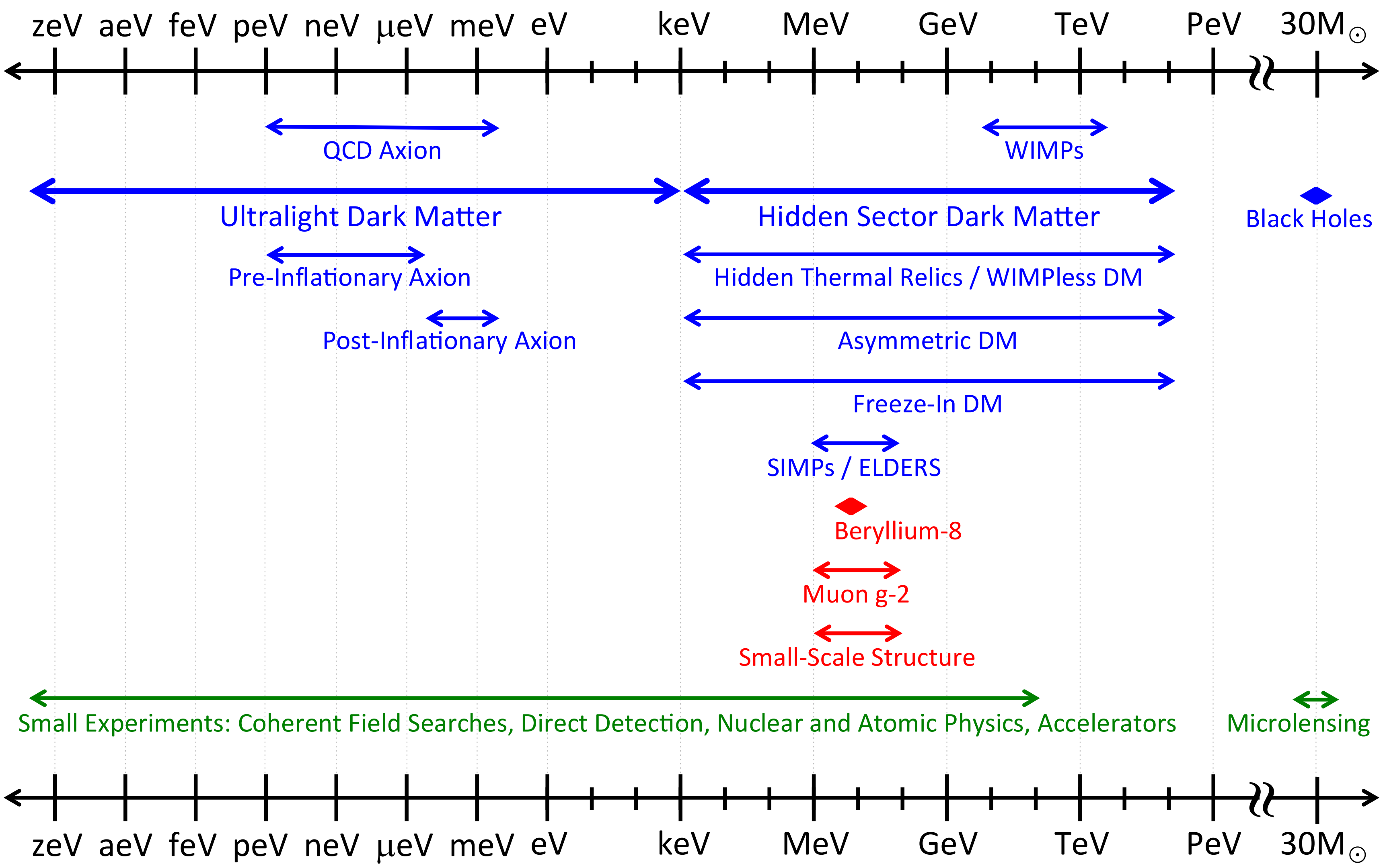


FIG. 2. Measured angular correlations ($E_P = 1.10$ MeV) of the e^+e^- pairs created in the different transitions labeled in the figure, compared with the simulated angular correlations assuming $E0$ and $M1 + E1$ mixed transitions.

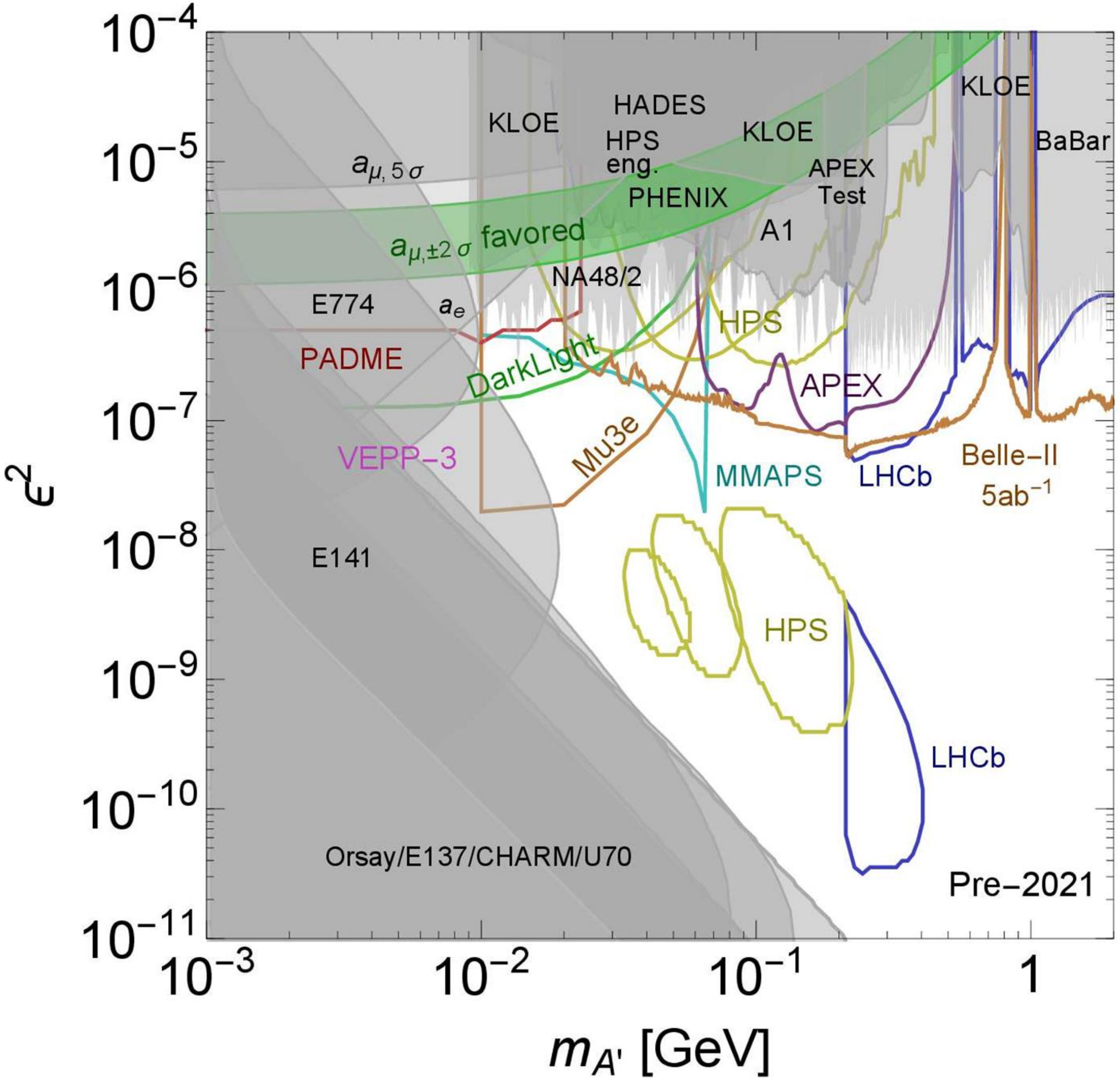
^{7}Li+p -> ^{8}Be*-> ^{8}Be + e+e-

The DM overview

Dark Sector Candidates, Anomalies, and Search Techniques



mediator parameter space



to search for a new particle

$$e^+e^- \leftrightarrow \gamma^* \text{ and } e^+e^- \leftrightarrow A'$$

- Search for a bump in the mass spectra

  as it was done - Vector Mesons, Z/W, H

- Impact of ñinvisibleò modes in decay products

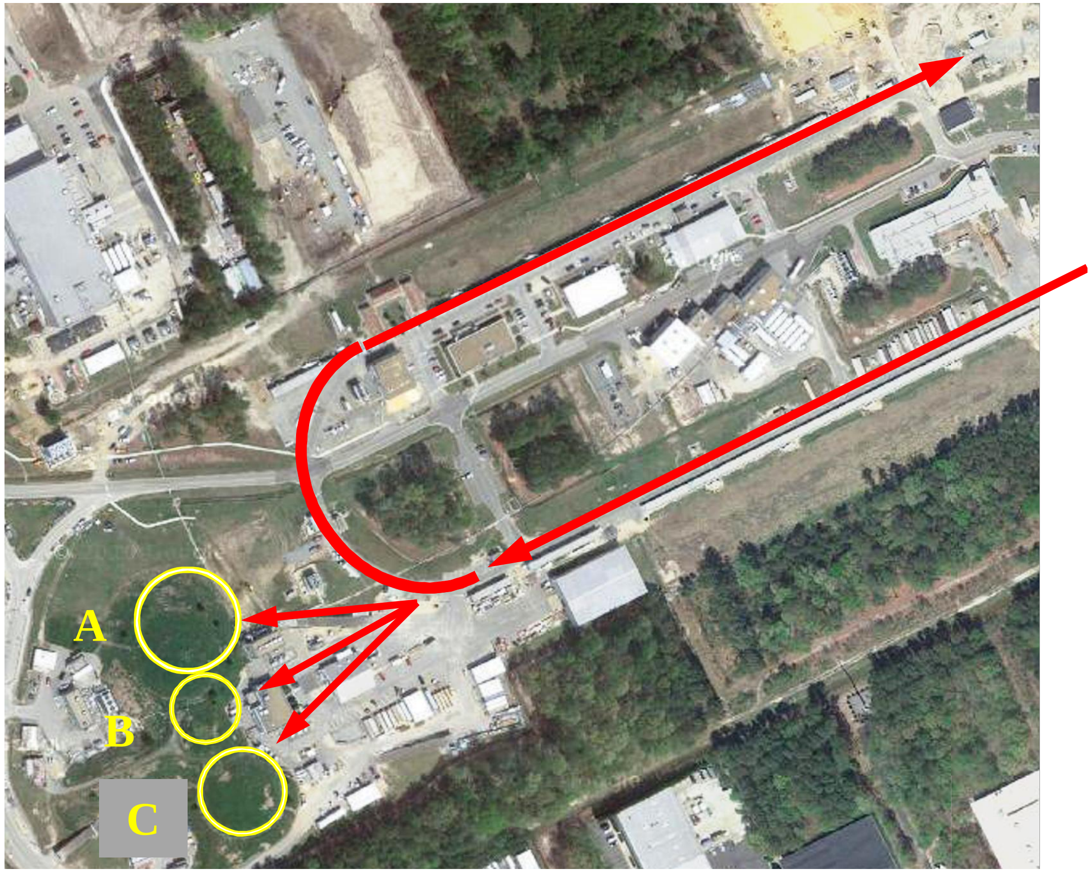
  How large is the e+e- decay branching fraction?

efferson Laboratory

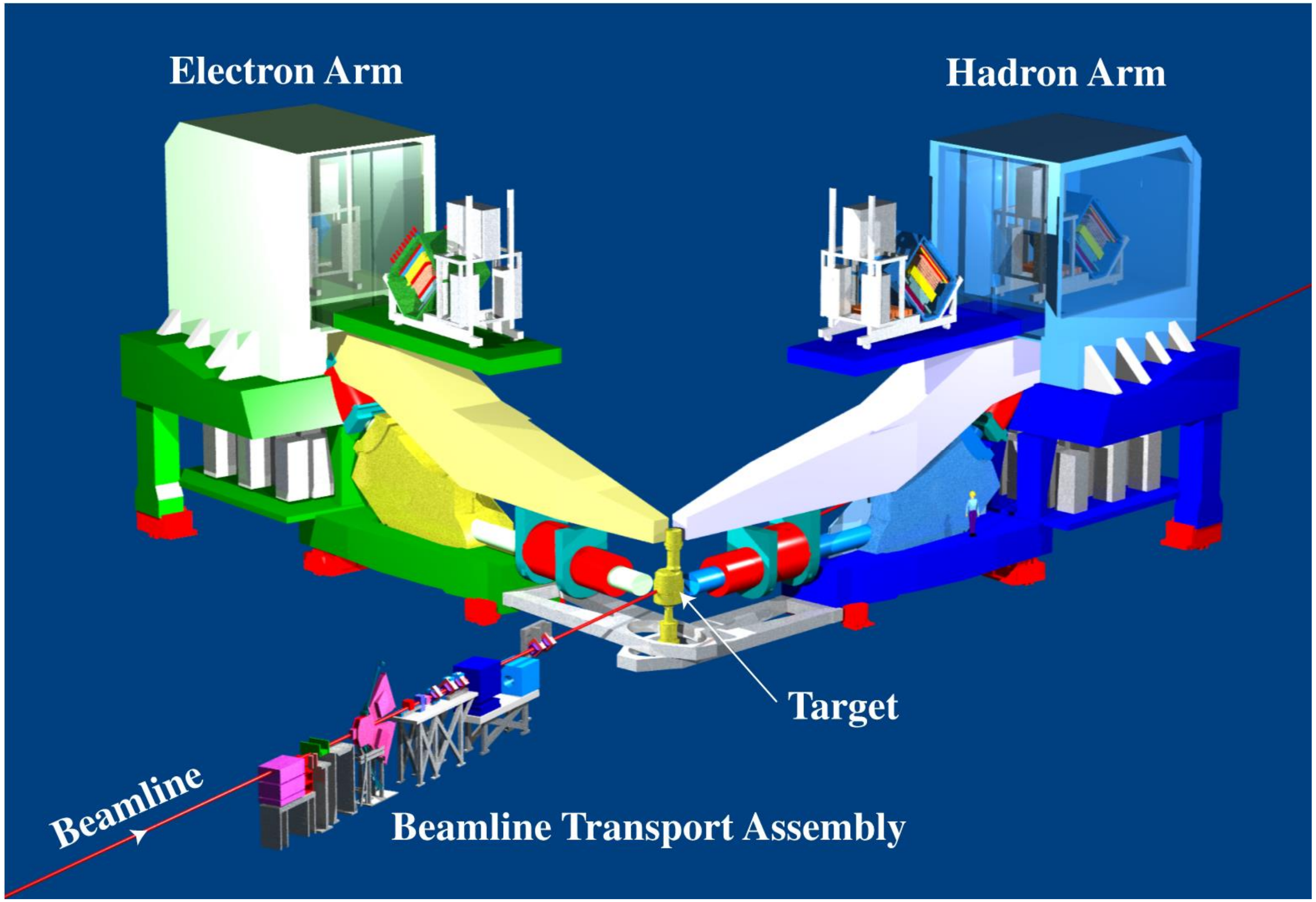
The laboratory, founded in 1984 in Newport News, Virginia, operates a 12 GeV continuous electron beam accelerator.

Three experimental halls (A, B, C) are equipped to study electron and photon induced reactions.

A new hall D constructed for searches of the exotic states produced in γp interactions.



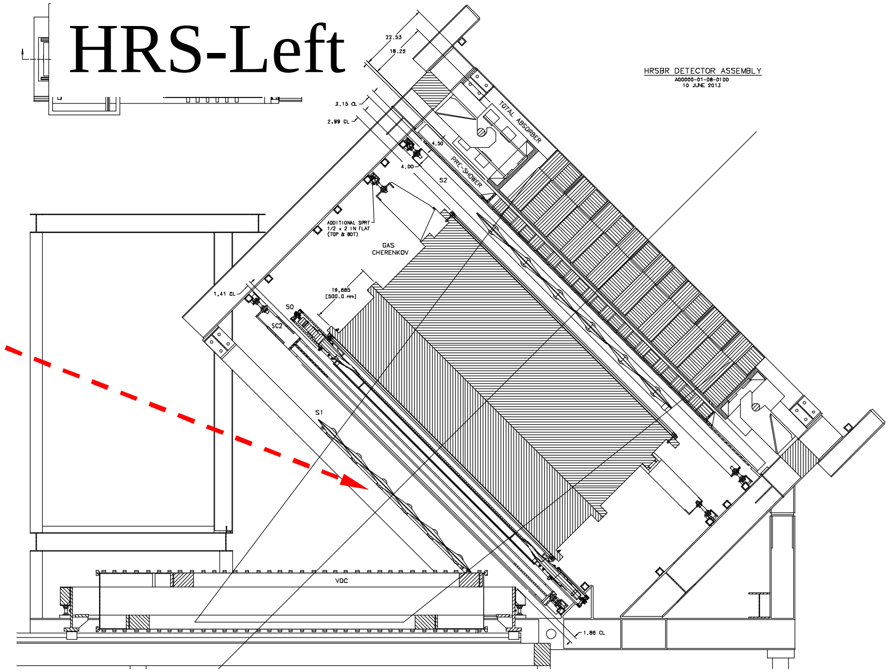
Hall A at JLab



Hall A is equipped with two high resolution magnetic spectrometers.

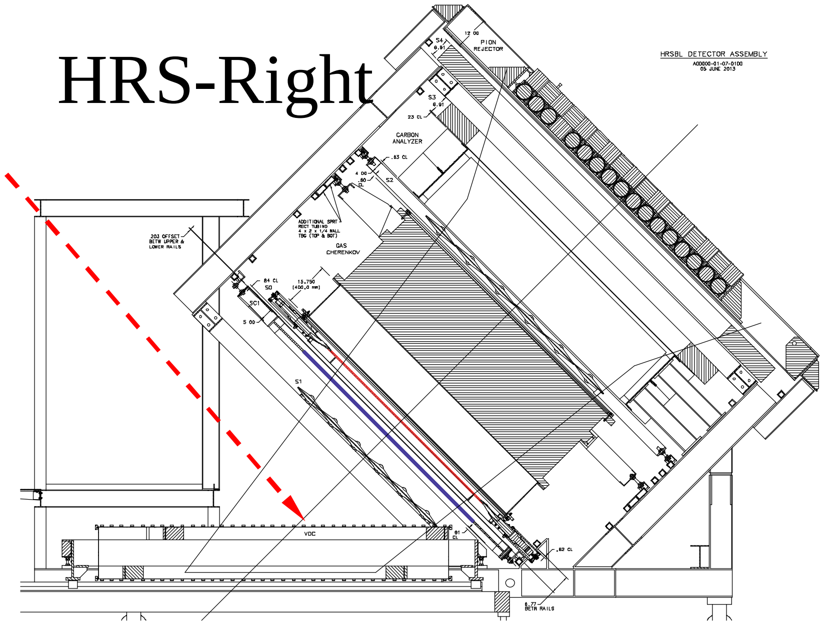
Detectors of the HRS spectrometers

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



DAQ has fADCs for:

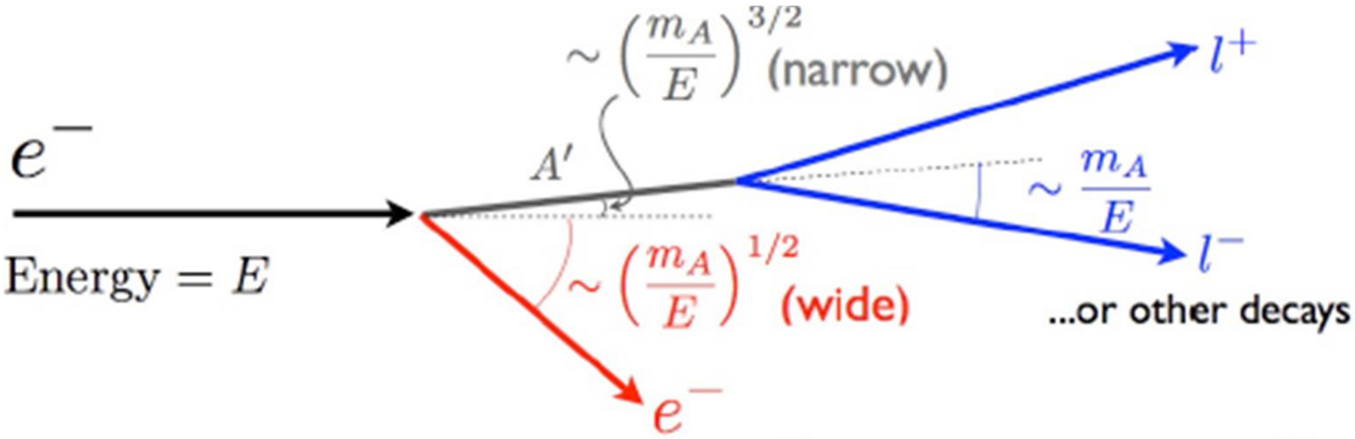
1. S0 plane, 2
2. S2 hodoscope, 32
3. Gas Cherenkov, 10
4. Lead-glass on L-arm (a negative charged particle arm), 64
5. BPM, 8
6. SciFi, 64



ô radiation and decay

Å Like photon Bremstrahlung, production is enhanced by high Z target, but suppressed by ~ $(Ům_e/m_{Aô})^2$

Å Emitted mostly at beam energy ($E_{Aô}$å E) and at small angle

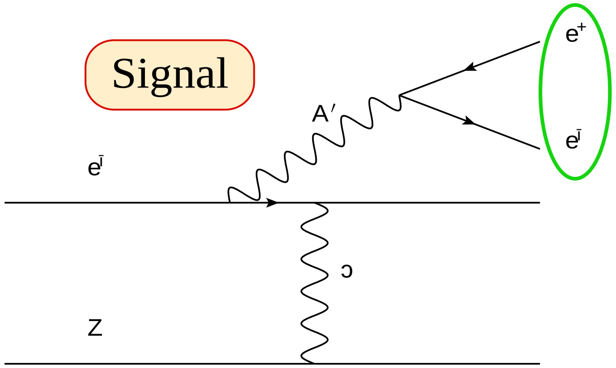


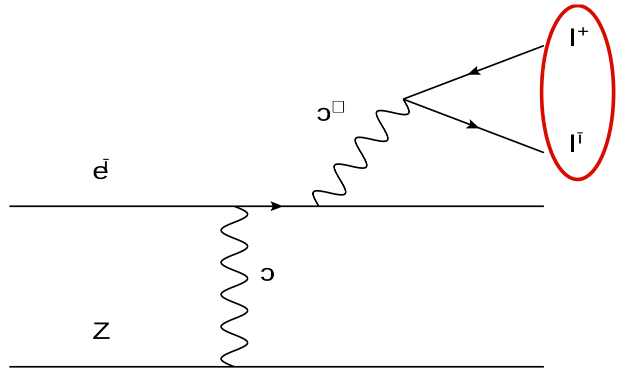
Å Huge QED background

Bjorken et al., PRD 80 (2009) 075018

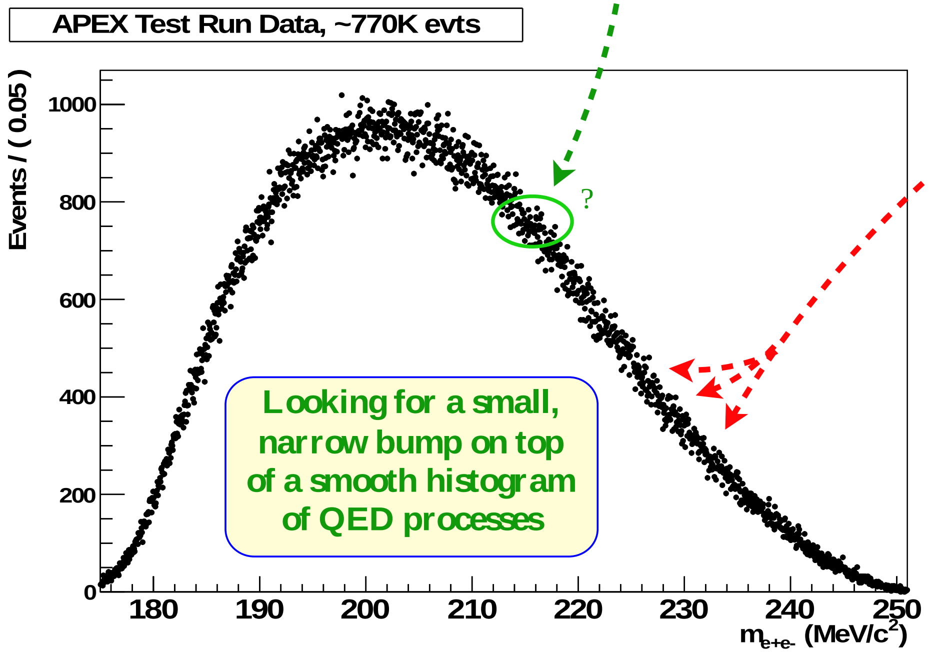
…on and decay => bump search

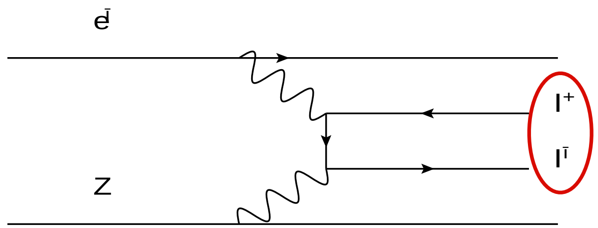
Signal





QED backgrounds



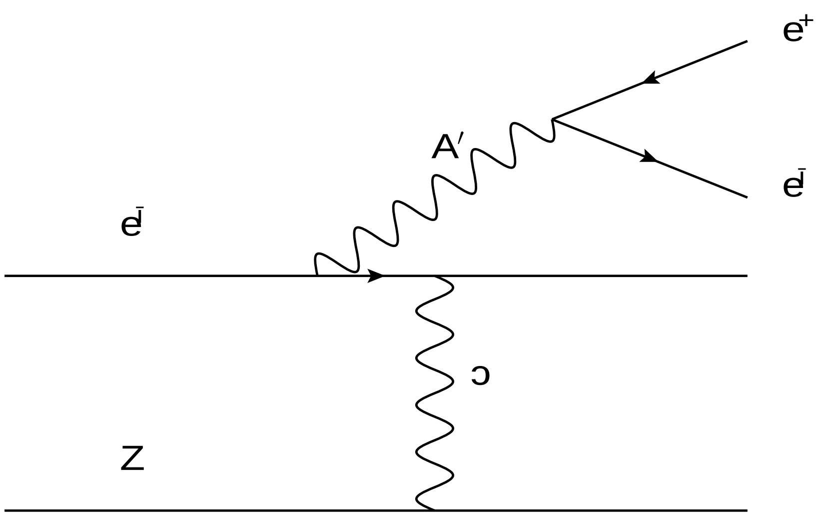


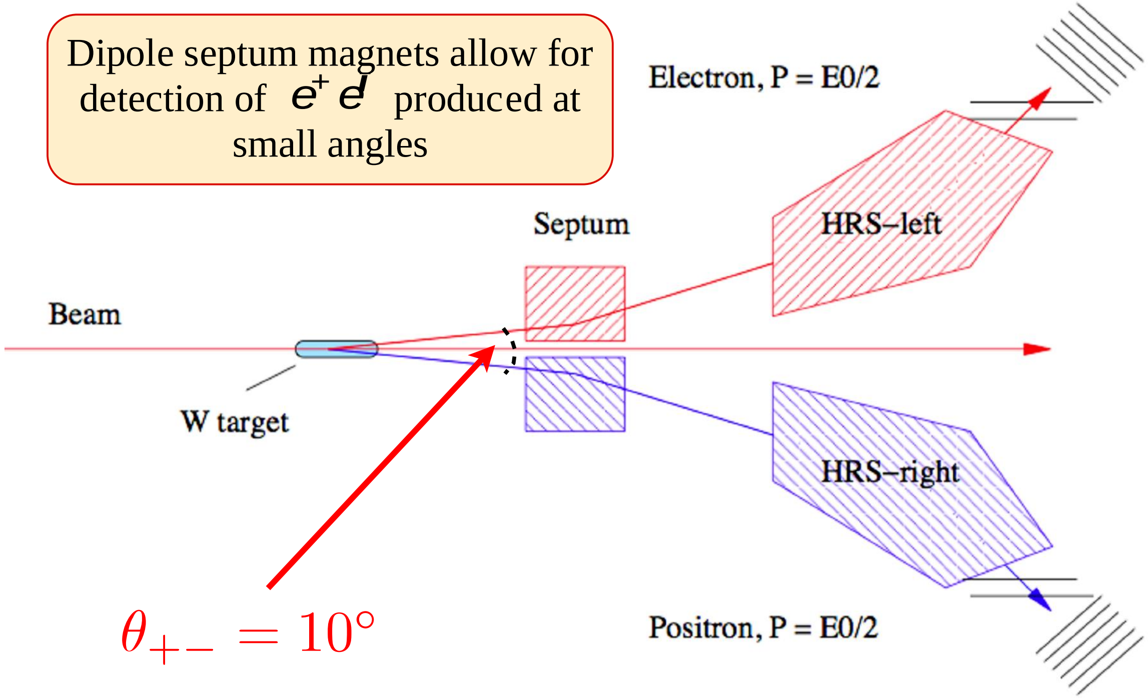
Excellent mass resolution required

S… for a gauge boson A′ in Hall A

Direct production at JLab

- Produce low mass hidden gauge bosons with weak coupling to SM via high energy electron beam incident on fixed high-Z (Ta) target
- A' decays to e^+e^- pair with opening angle $\sim m_{A'}/E_b$

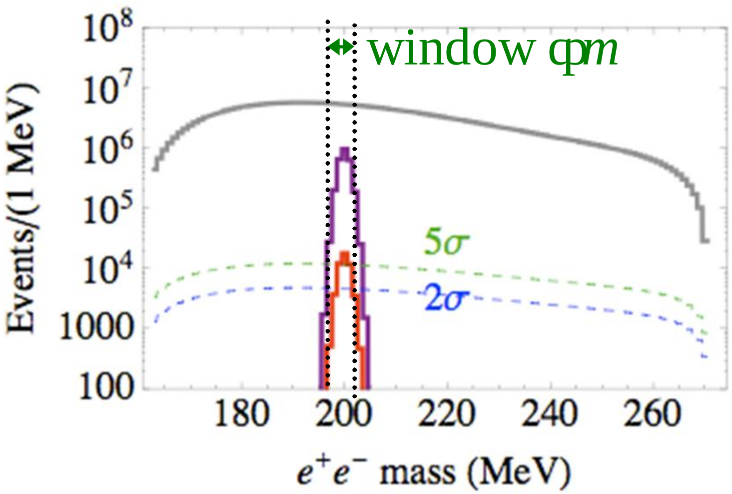


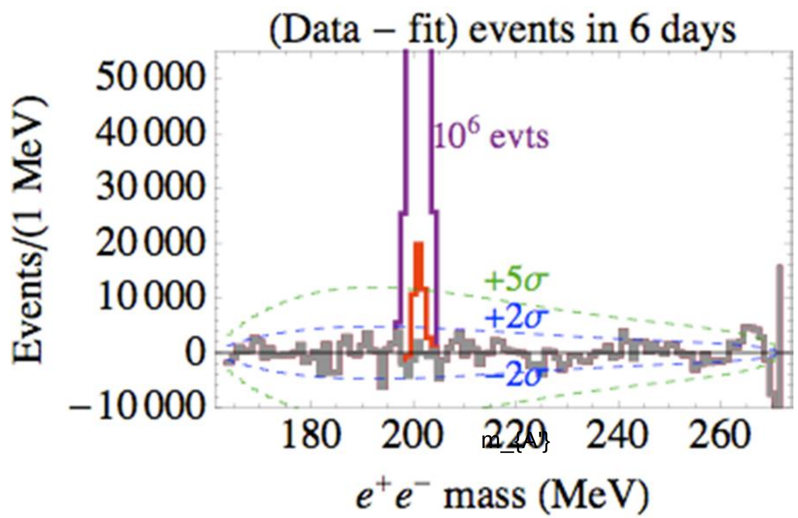


Aôradiation and decay => bump search

…nal, must study invariant mass distribution

$$m_{A'} \approx \sqrt{E_+ E_- (\theta_+ + \theta_-)}$$



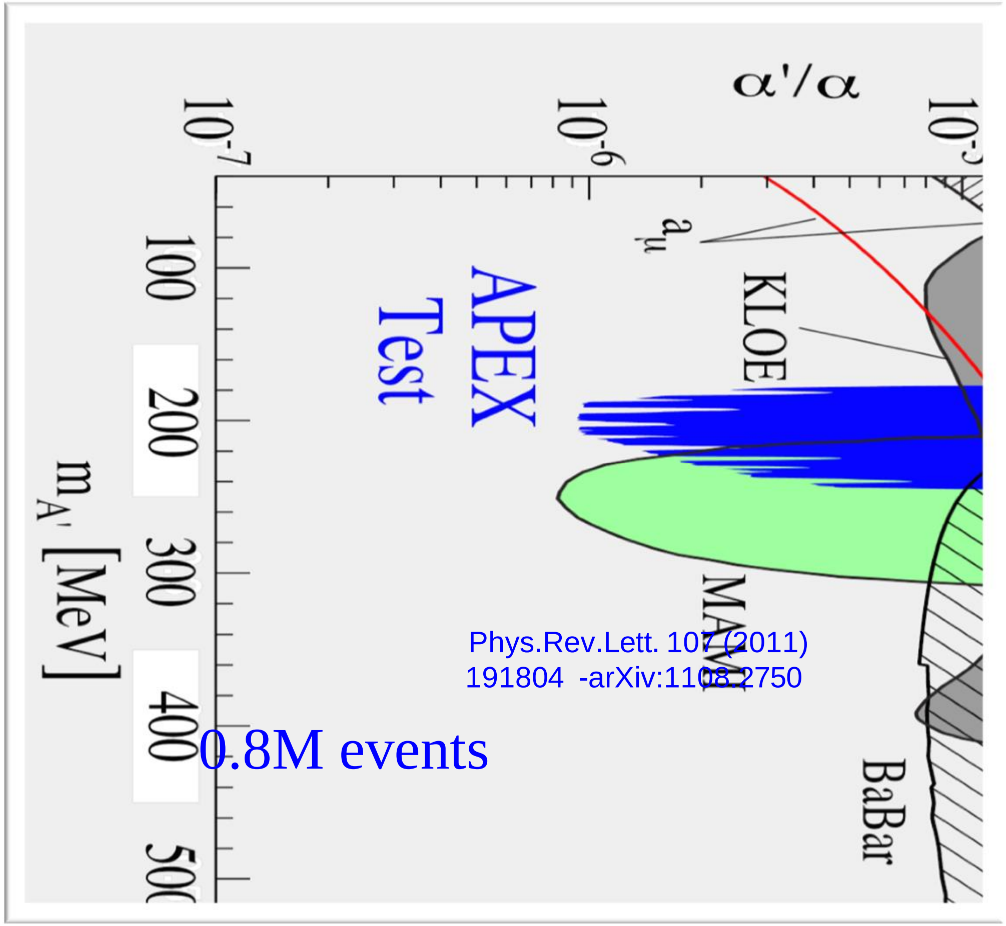


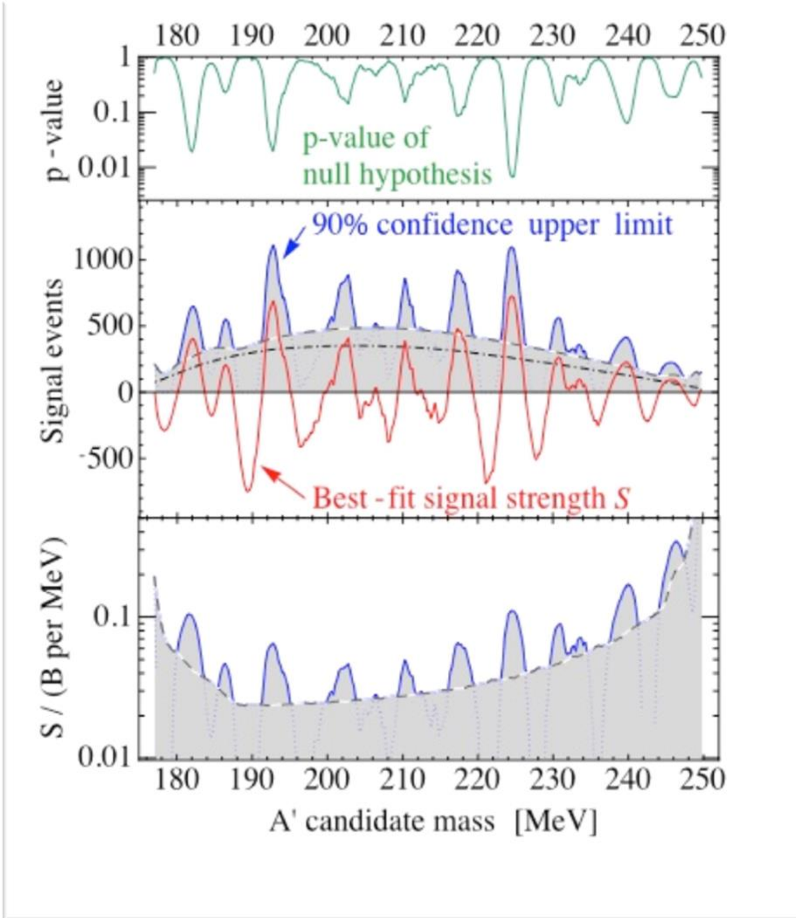
In mass window ɸm: $\frac{S}{\sqrt{B}} \sim \frac{\alpha'}{\alpha^2}\sqrt{N_{QED}\left(\frac{m_{A'}}{\Delta m}\right)}$

To search at small Ŭɋ need:

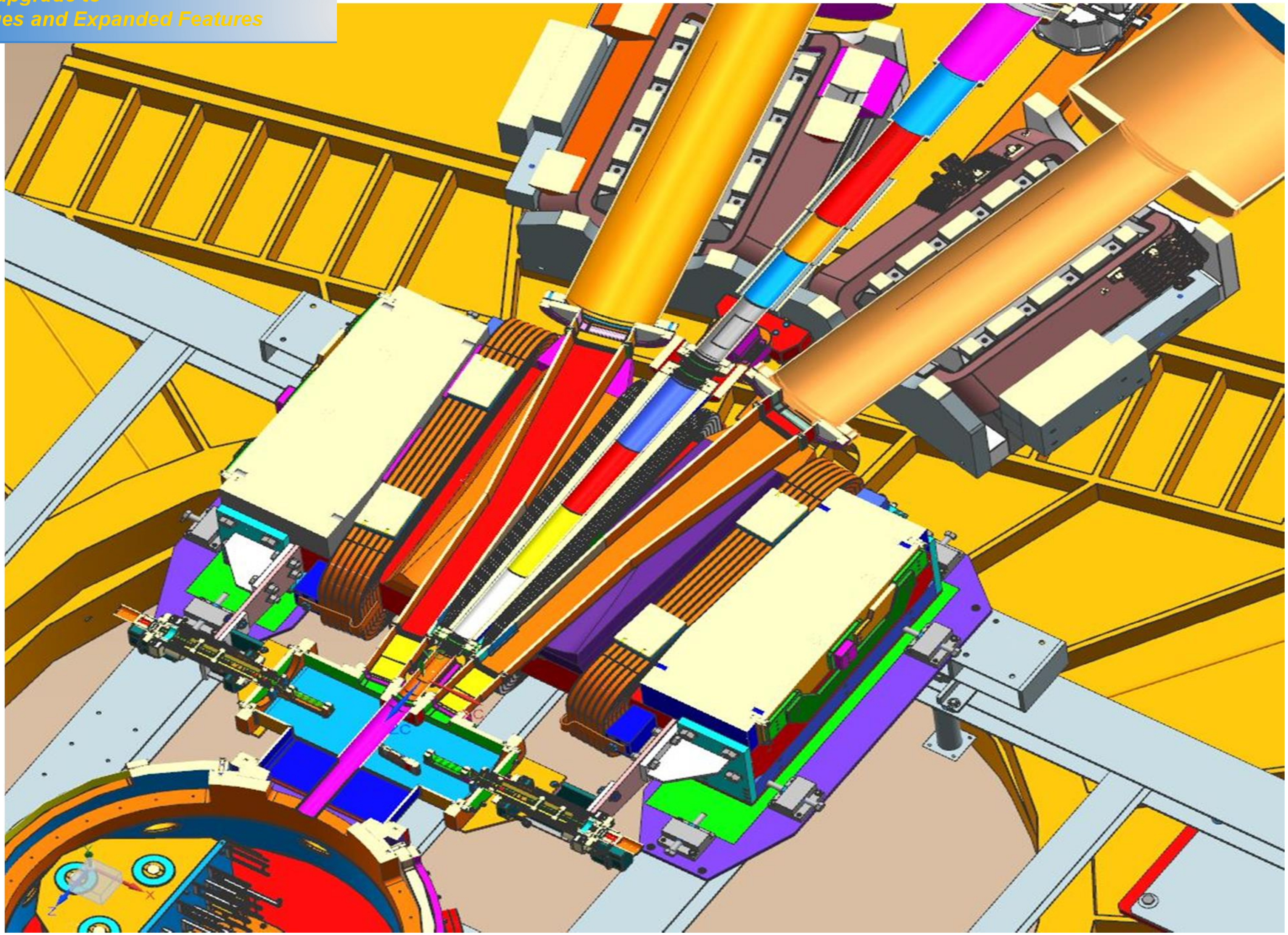
- High e^+eï statistics
- Best possible mass resolution

…le from the APEX-2010 analysis

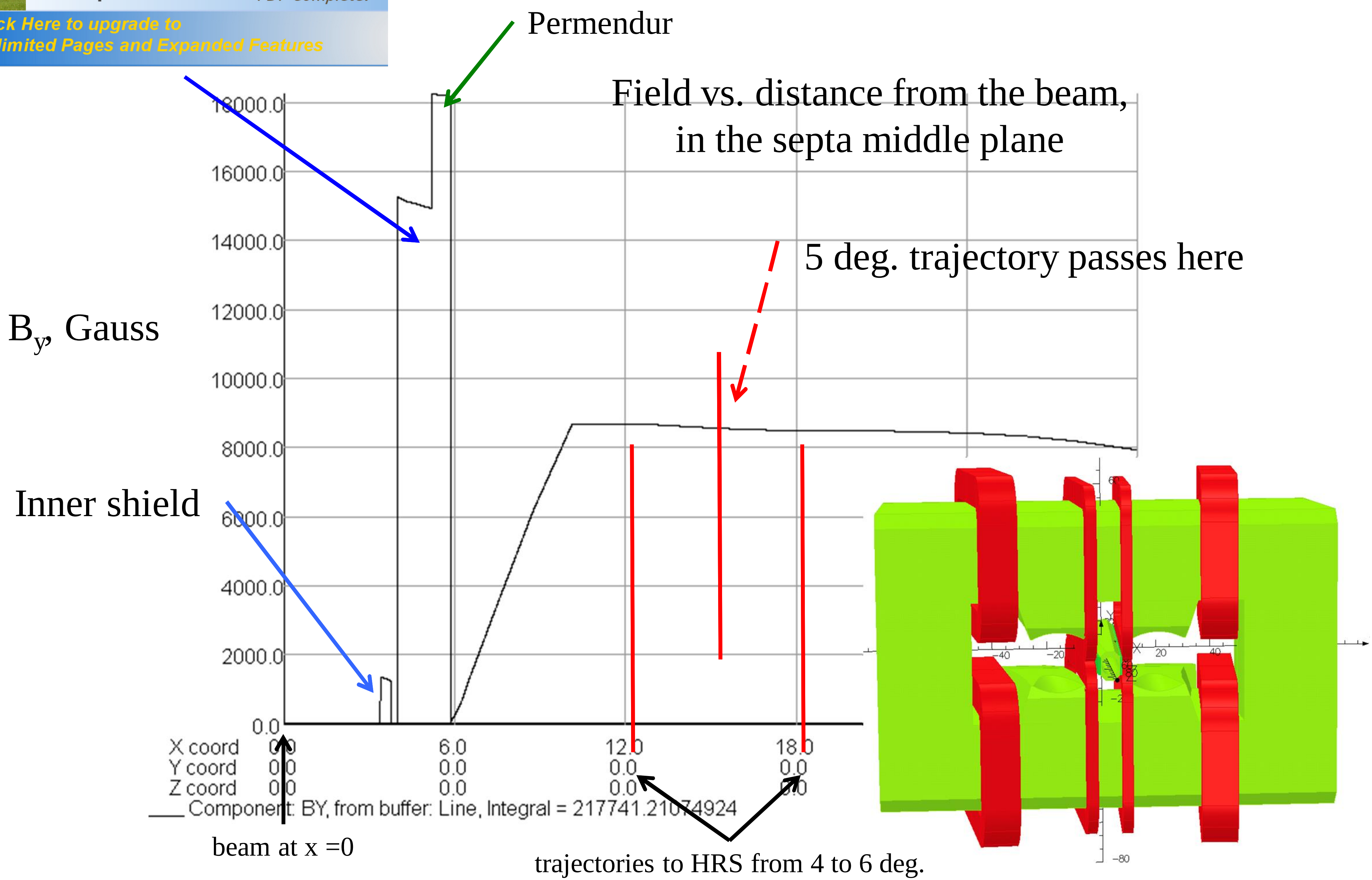




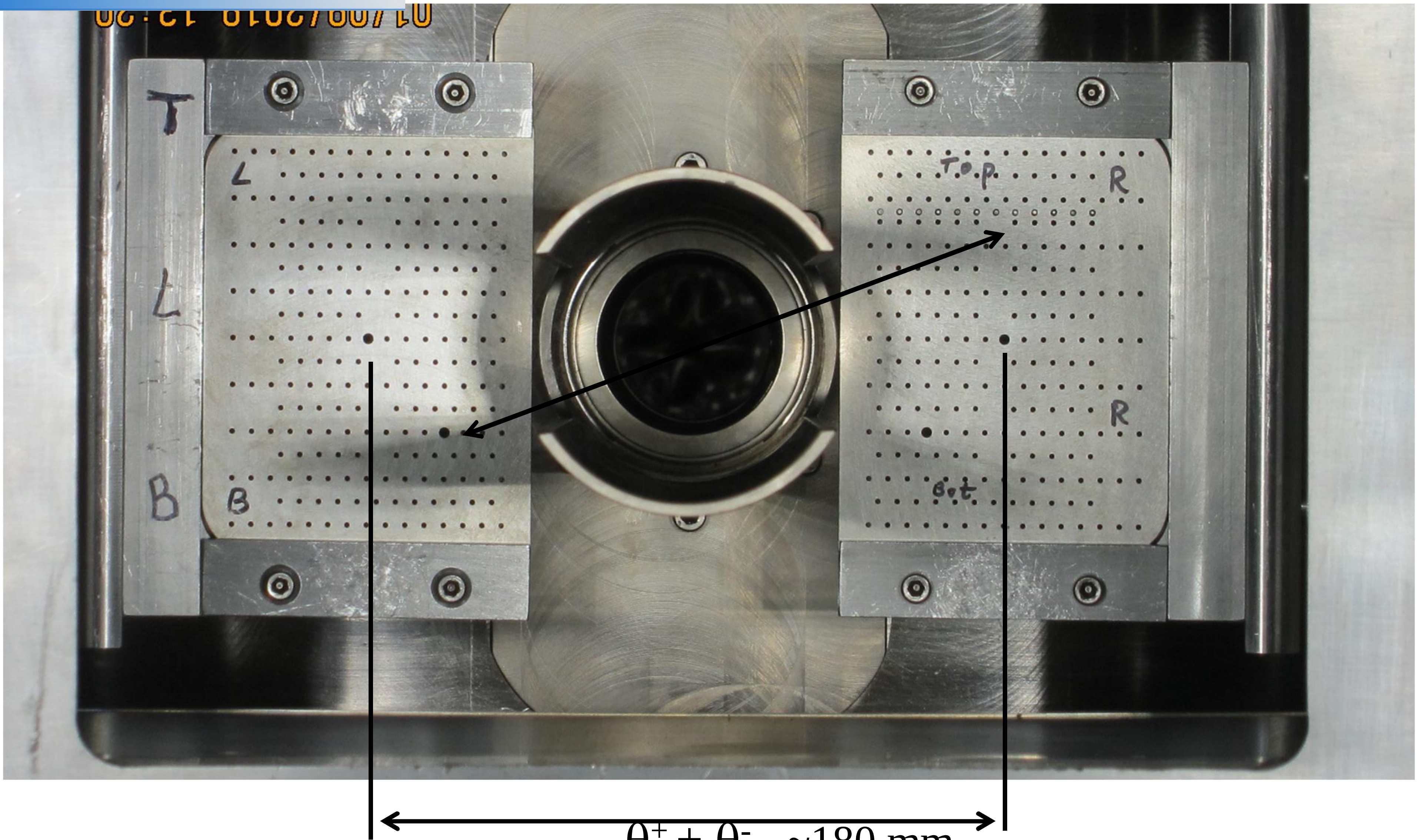
f the APEX-2019 experiment



APEX hardware: Septa magnet

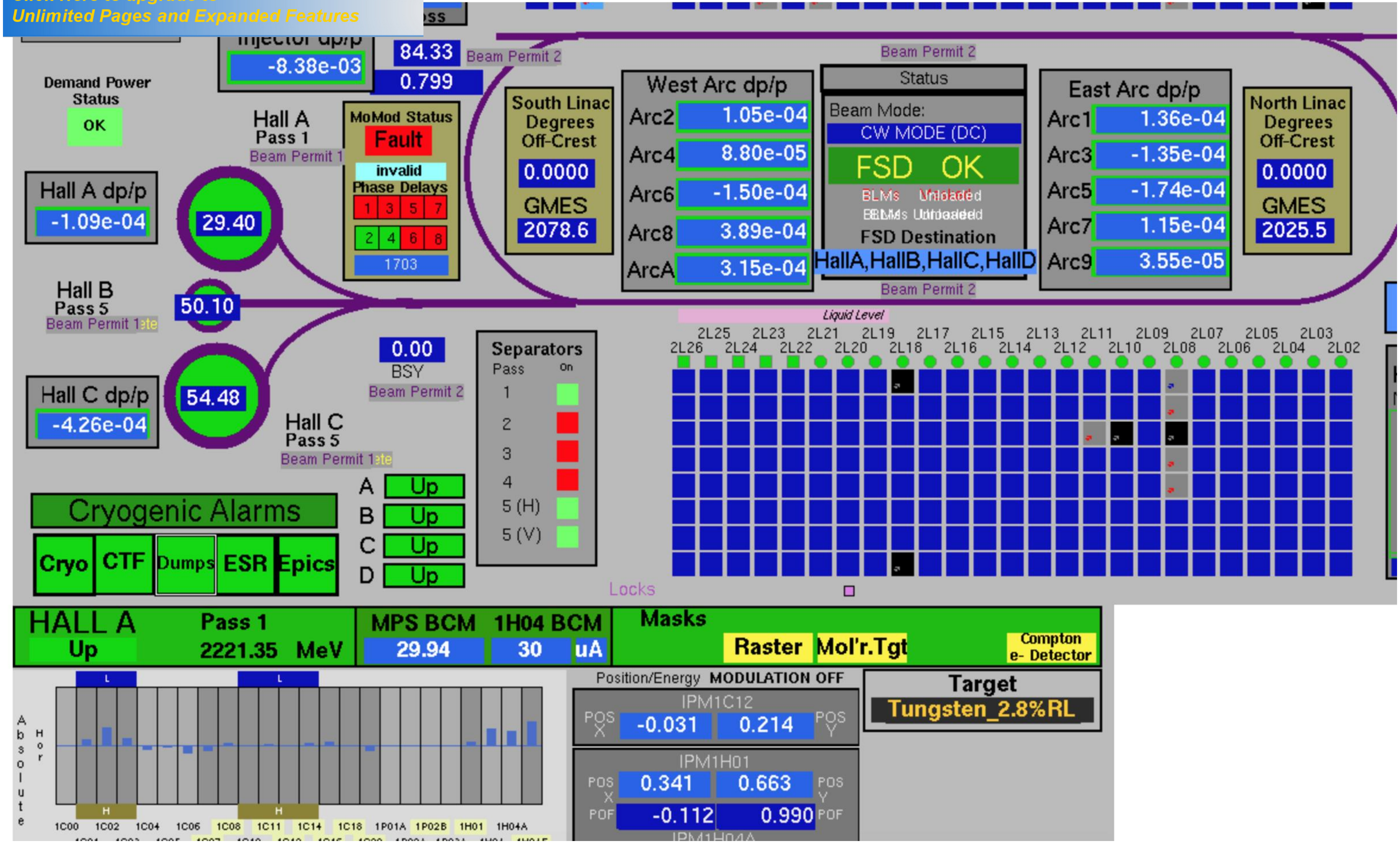


slits for optics calibration

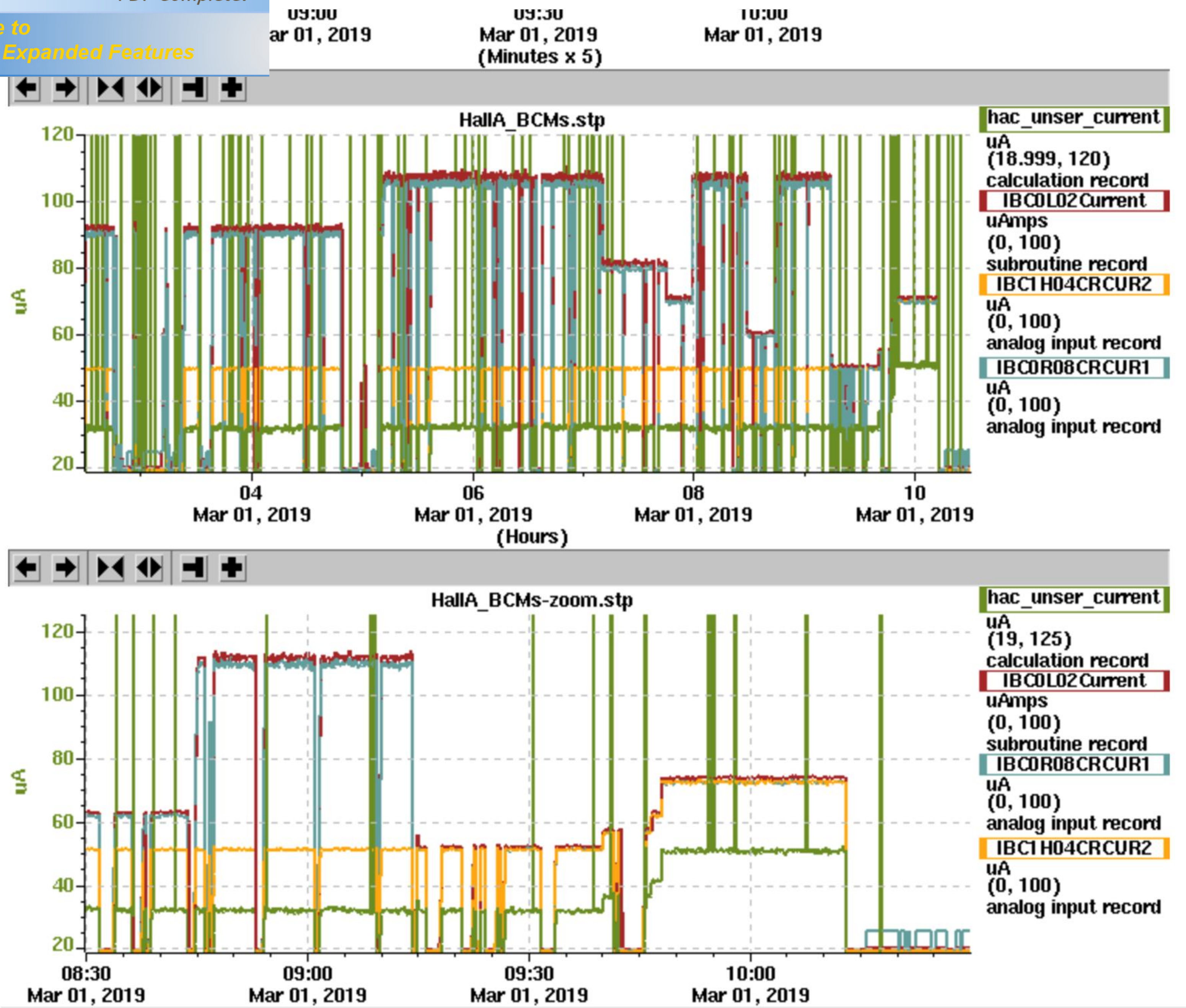


$\theta^{+} + \theta^{-}$ ~180 mm

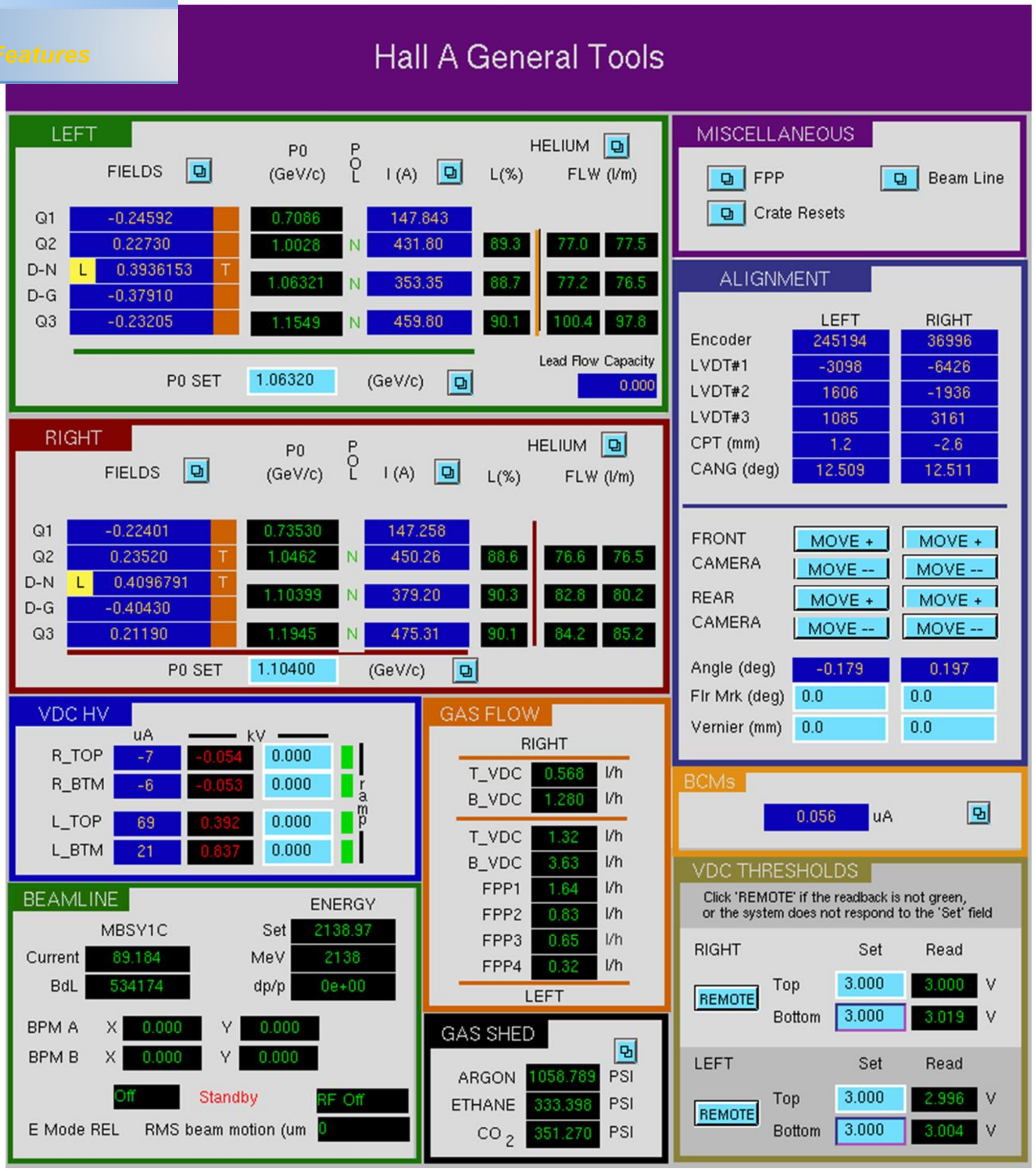
Data taking four-hall operation



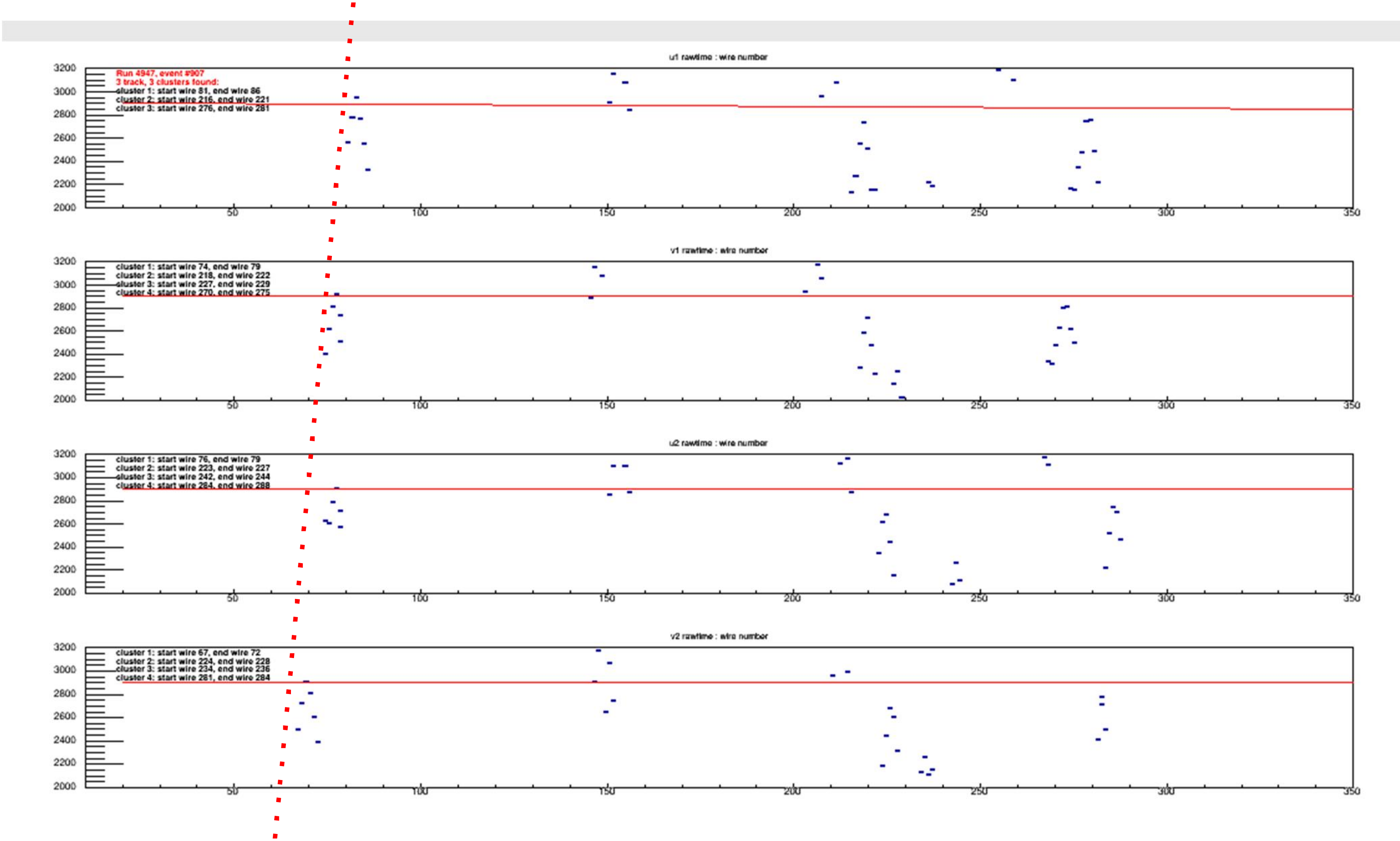
Data taking


09:00
Mar 01, 2019
09:30
Mar 01, 2019
(Minutes x 5)
10:00
Mar 01, 2019
HallA_BCMs.stp
uA
120
100
80
60
40
20
04
Mar 01, 2019
06
Mar 01, 2019
(Hours)
08
Mar 01, 2019
10
Mar 01, 2019
hac_unser_current
uA
(18.999, 120)
calculation record
IBC0L02Current
uAmps
(0, 100)
subroutine record
IBC1H04CRCUR2
uA
(0, 100)
analog input record
IBC0R08CRCUR1
uA
(0, 100)
analog input record
HallA_BCMs-zoom.stp
uA
08:30
Mar 01, 2019
09:00
Mar 01, 2019
09:30
Mar 01, 2019
10:00
Mar 01, 2019
hac_unser_current
uA
(19, 125)
calculation record
IBC0L02Current
uAmps
(0, 100)
subroutine record
IBC0R08CRCUR1
uA
(0, 100)
analog input record
IBC1H04CRCUR2
uA
(0, 100)
analog input record

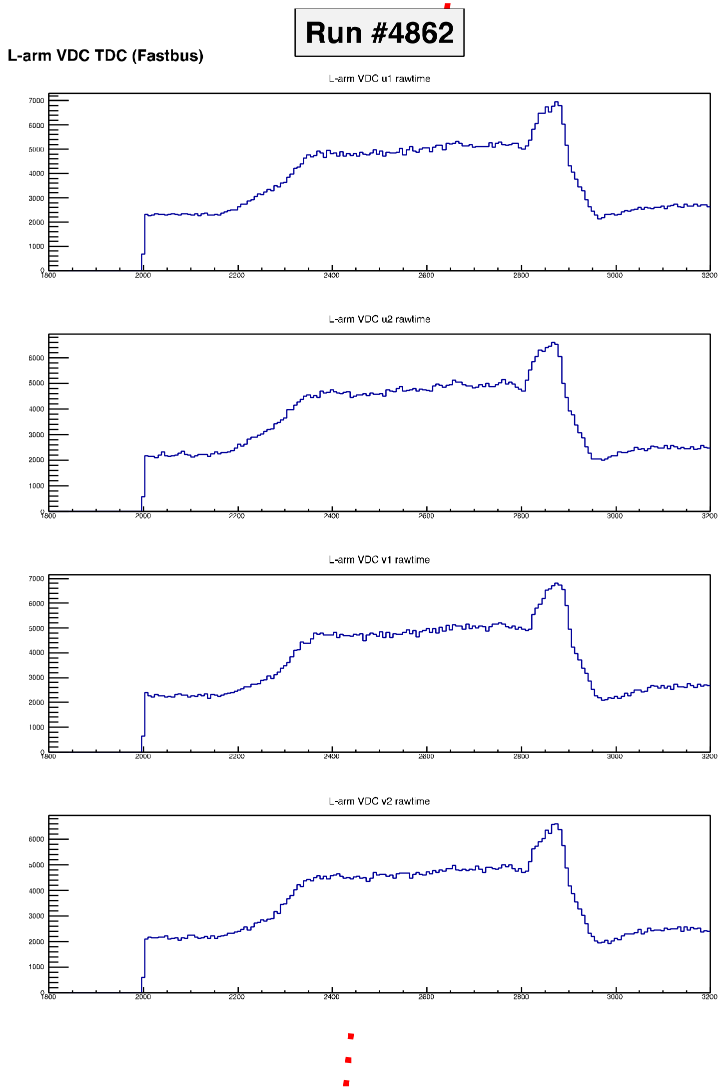
Data taking

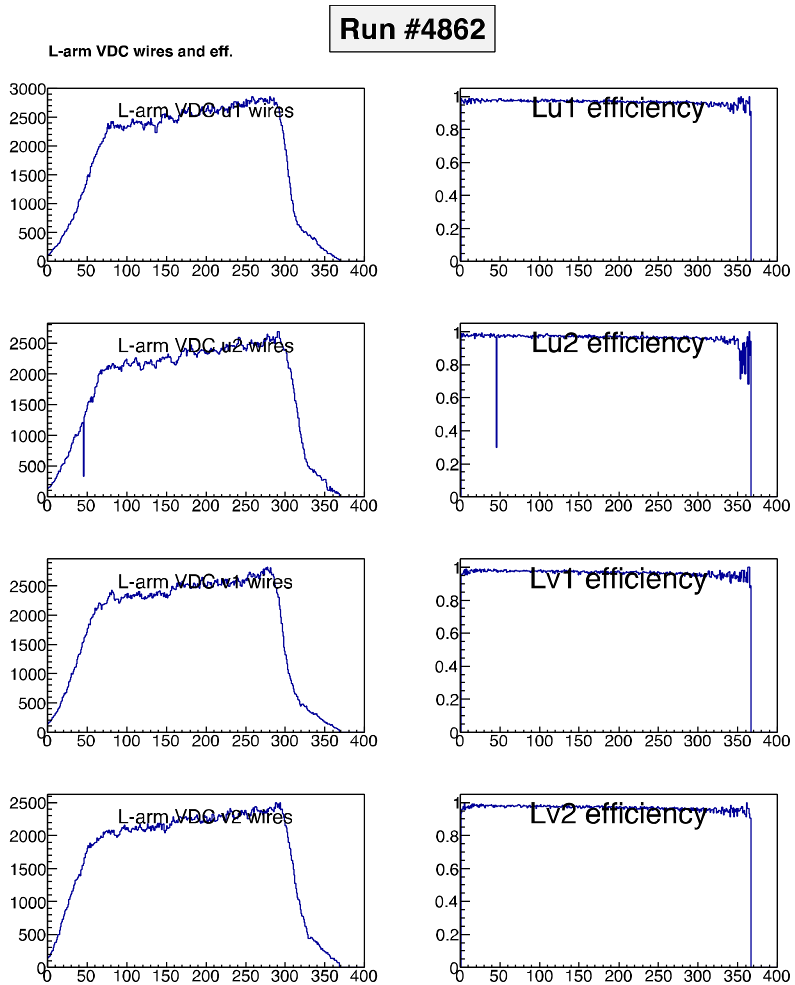

Hall A General Tools
LEFT
FIELDS
P0 (GeV/c)
POL
I (A)
HELIUM
L(%)
FLW (l/m)
Q1
Q2
D-N
D-G
Q3
Lead Flow Capacity
P0 SET
1.06320
RIGHT
1.10400
MISCELLANEOUS
FPP
Beam Line
Crate Resets
ALIGNMENT
Encoder
LVDT#1
LVDT#2
LVDT#3
CPT (mm)
CANG (deg)
FRONT CAMERA
REAR CAMERA
MOVE +
MOVE --
Angle (deg)
Flr Mrk (deg)
Vernier (mm)
VDC HV
R_TOP
R_BTM
L_TOP
L_BTM
GAS FLOW
T_VDC
B_VDC
FPP1
FPP2
FPP3
FPP4
BCMs
VDC THRESHOLDS
Click 'REMOTE' if the readback is not green, or the system does not respond to the 'Set' field
REMOTE
Top
Bottom
Set
Read
BEAMLINE
ENERGY
MBSY1C
Current
BdL
MeV
dp/p
BPM A
BPM B
Standby
RF Off
E Mode REL
RMS beam motion (um
GAS SHED
ARGON
ETHANE
CO 2
PSI

Data taking, tracking in HRS

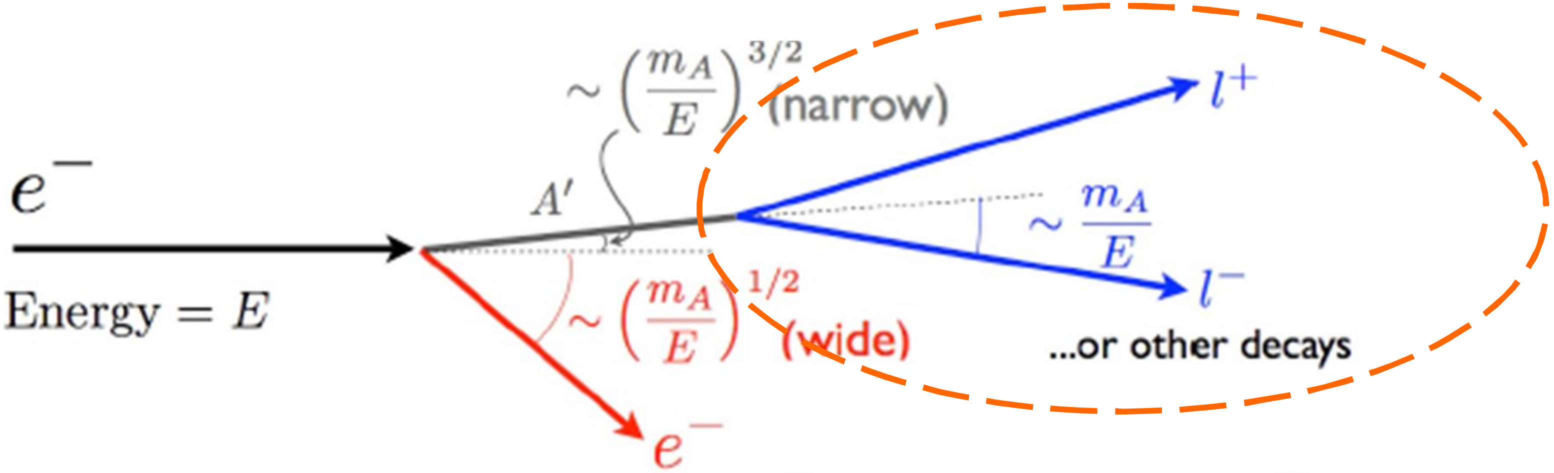


D[illegible]taking, detector occupancy





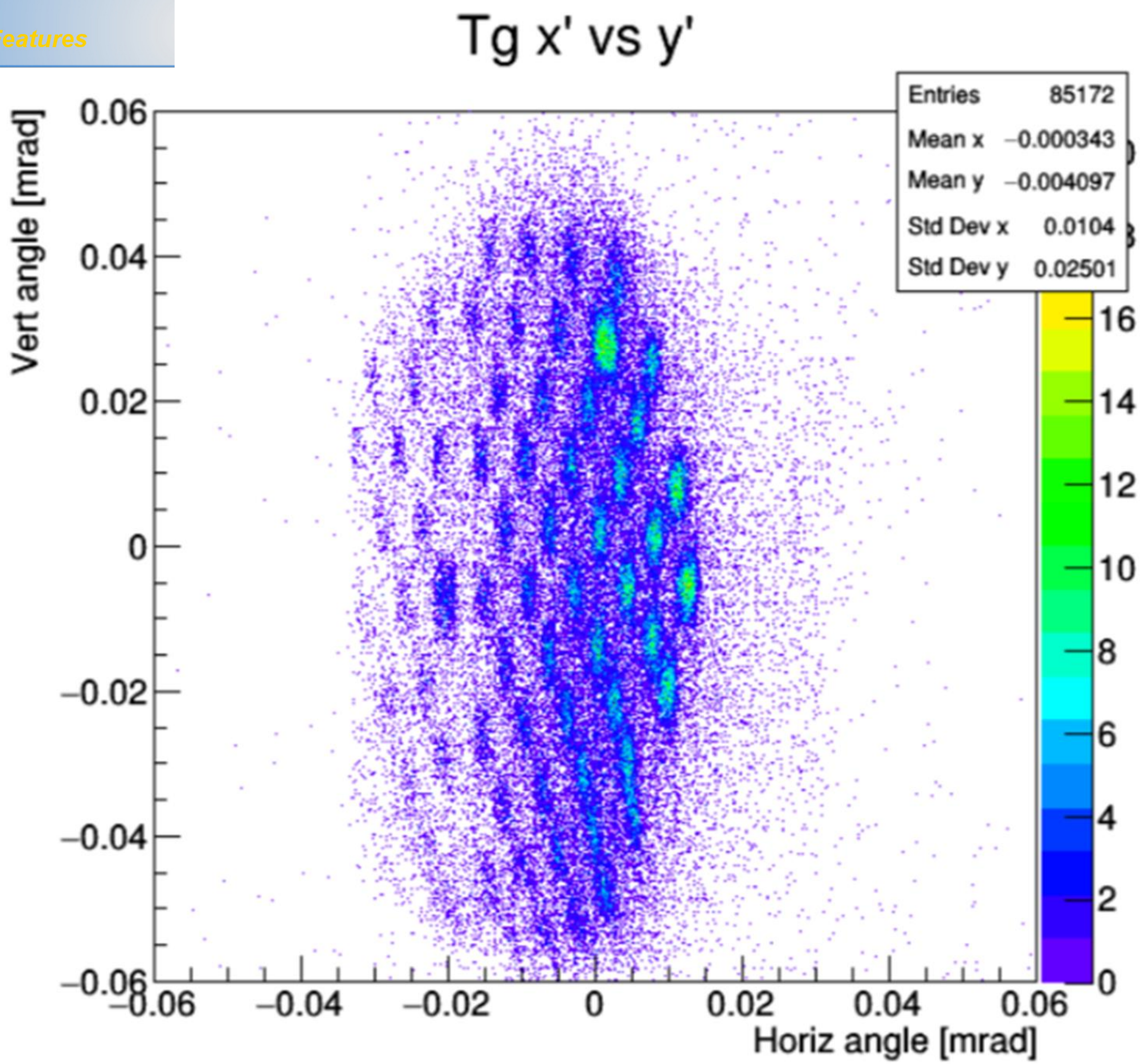
pair mass reconstruction



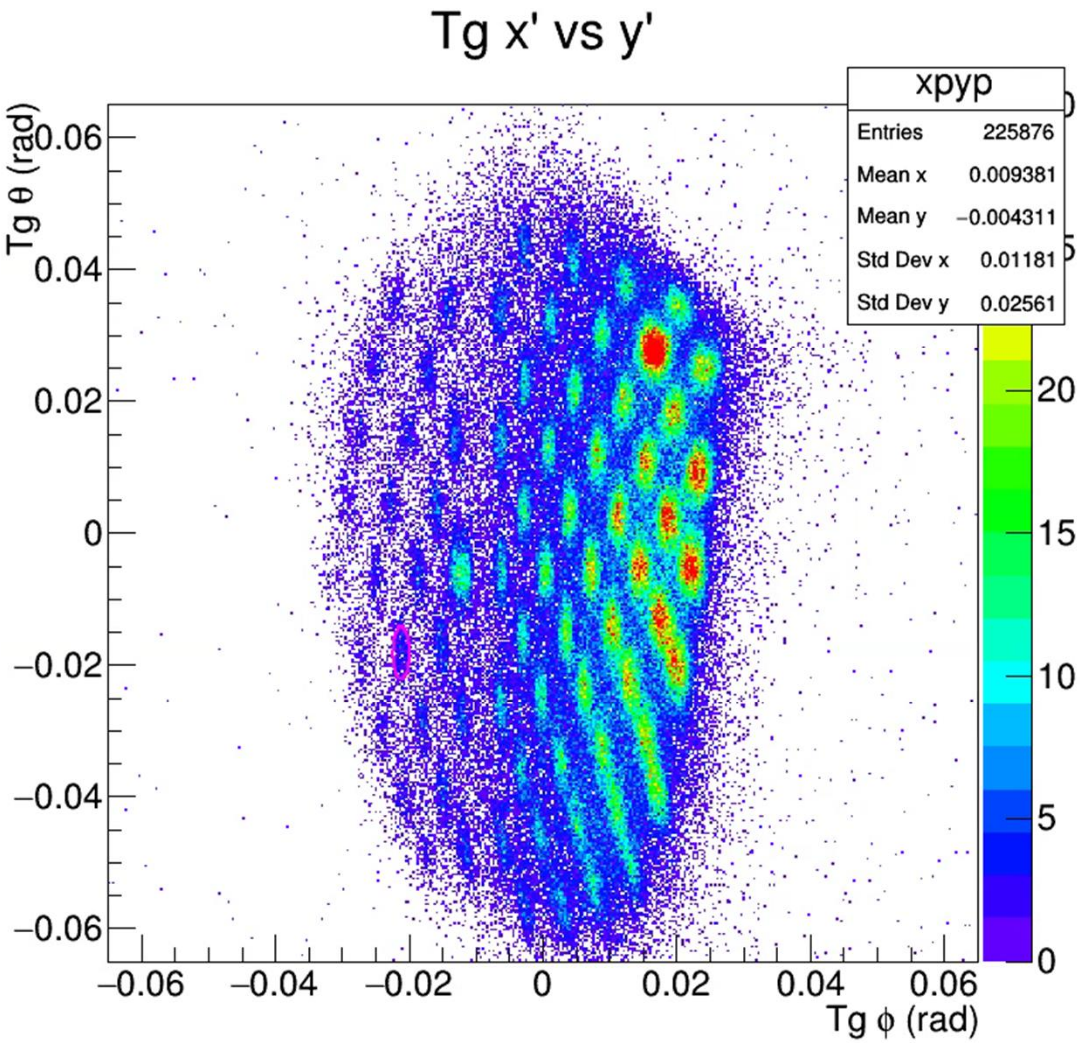
$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta E_+}{E_+}\right)^2 + \left(\frac{\delta E_-}{E_-}\right)^2 + \left(\frac{\delta\theta_+}{\theta_+ + \theta_-}\right)^2 + \left(\frac{\delta\theta_-}{\theta_- + \theta_+}\right)^2$$

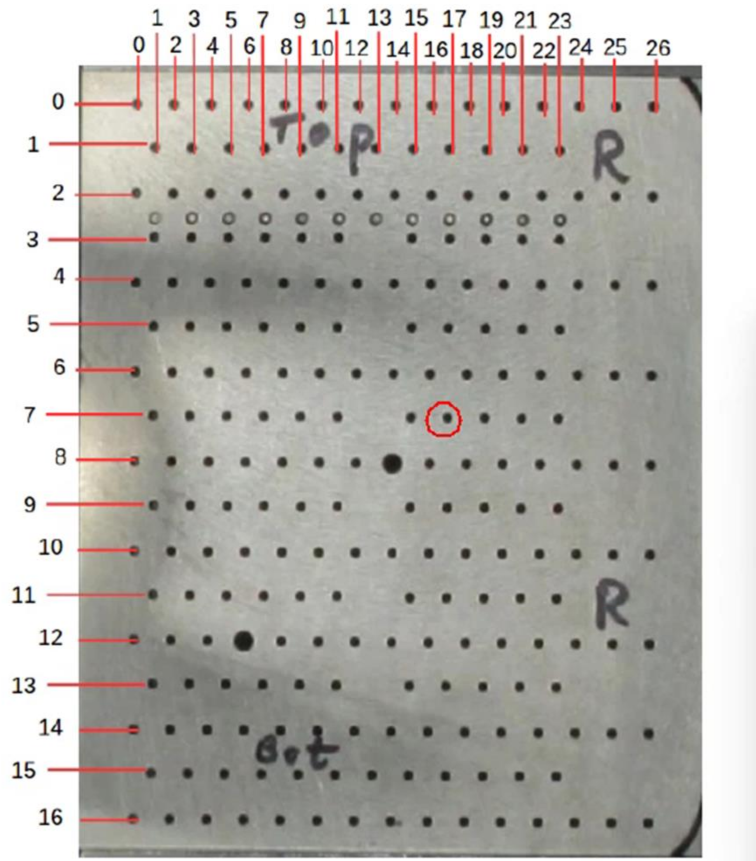
$\sim 10^{-6}$ $\sim 10^{-4}$

cs calibration first look

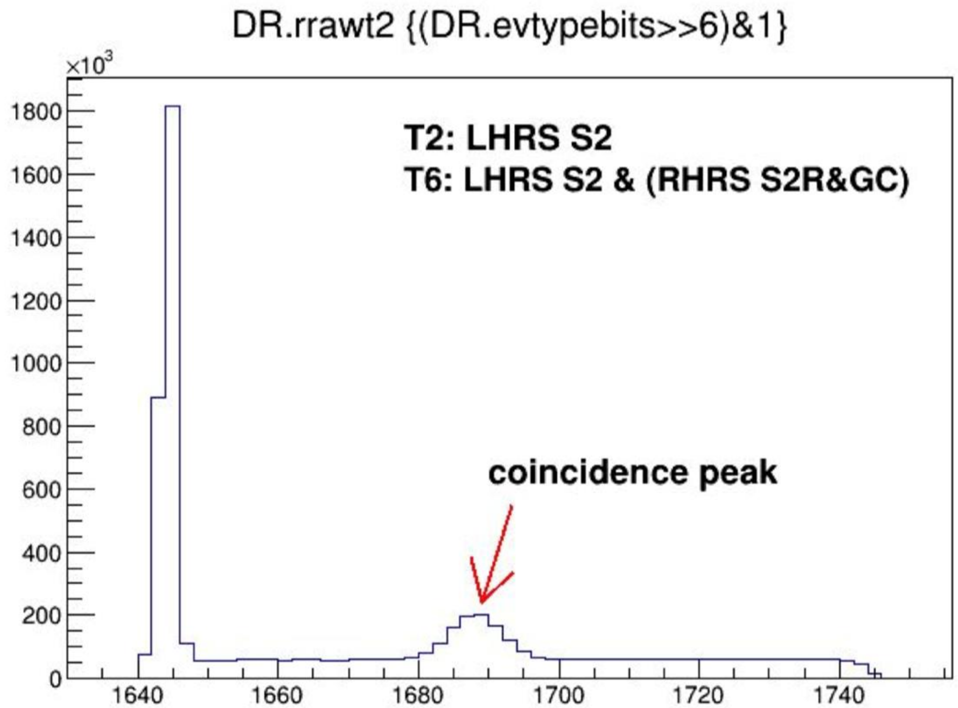


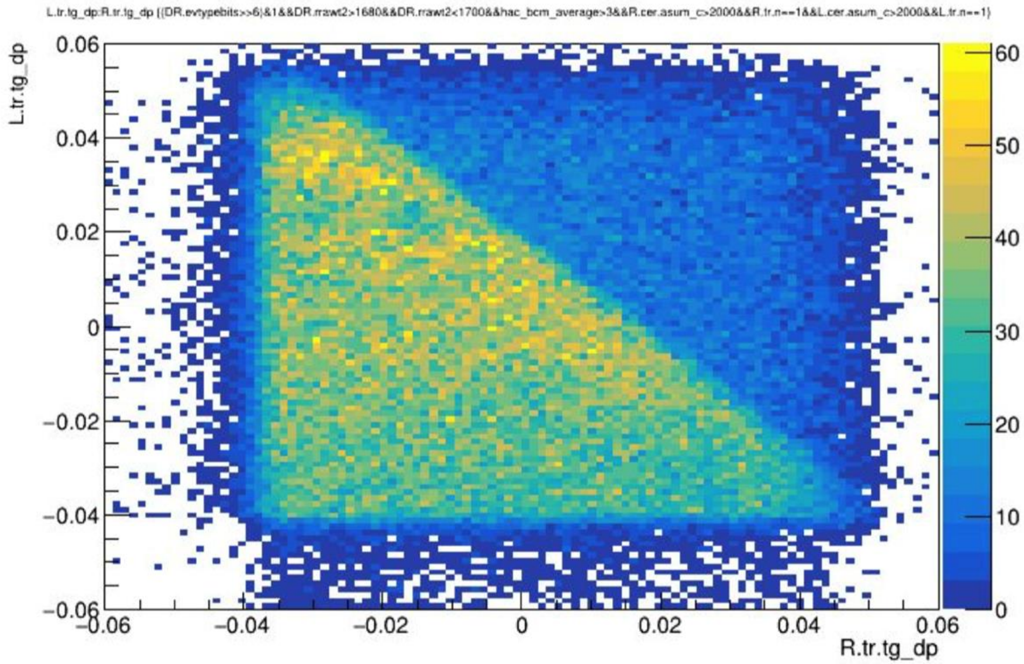
calibration and the sieve





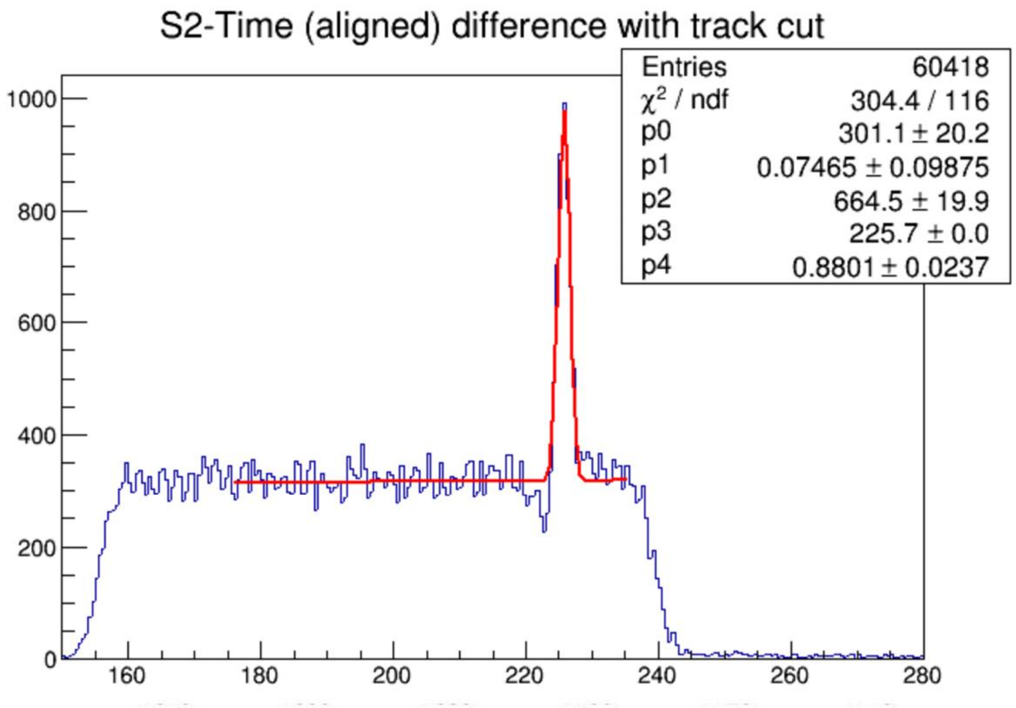
Online data analysis plots

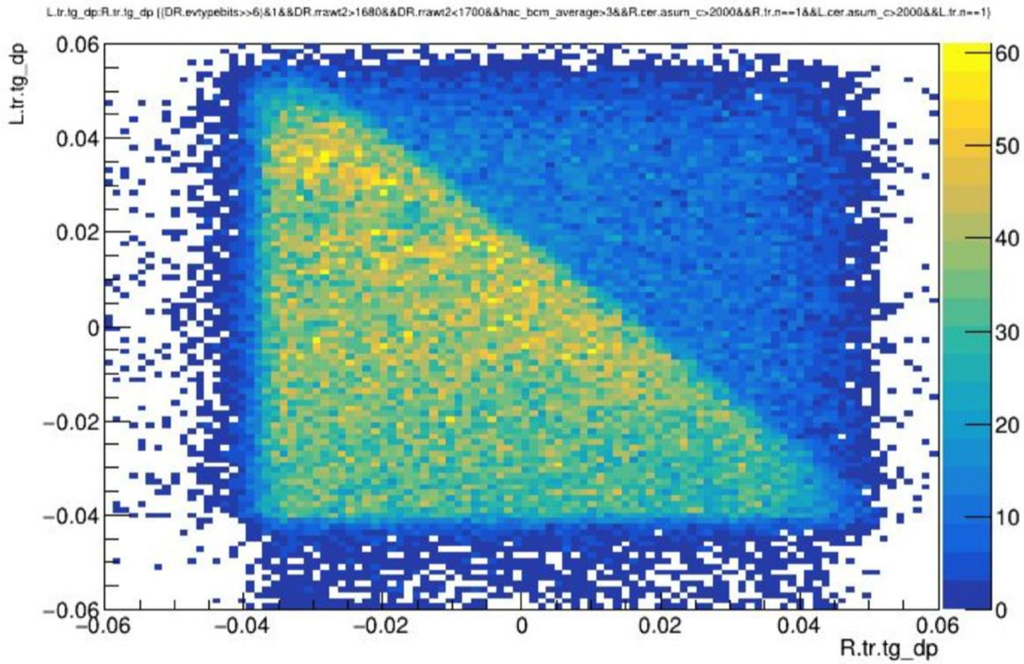




Online data analysis plots

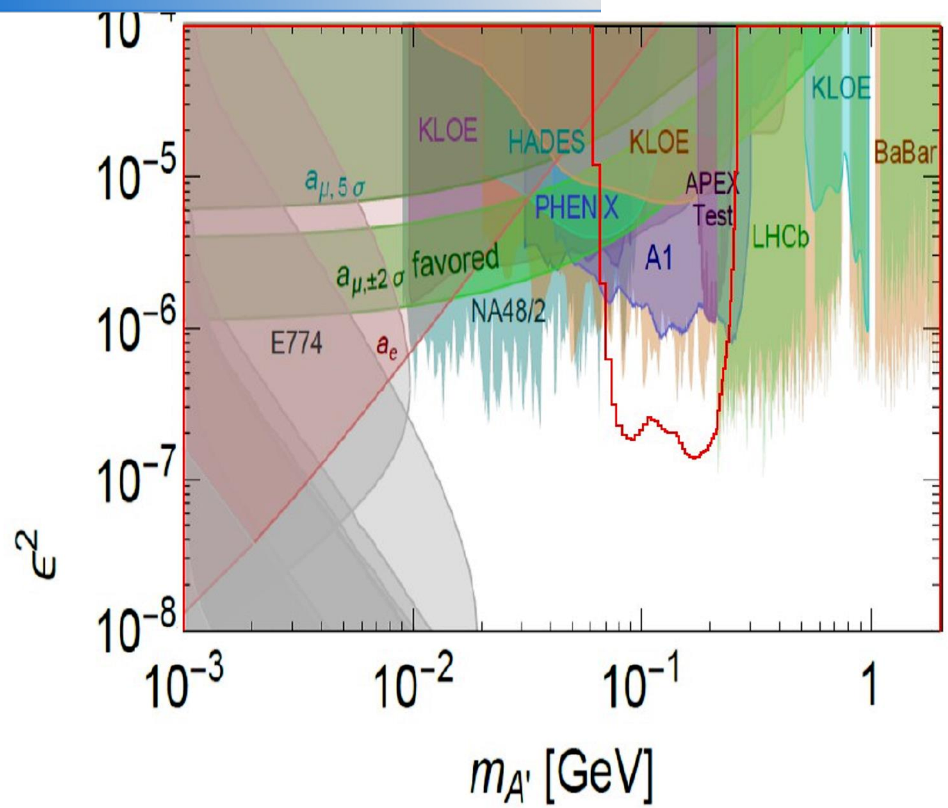
S2m time alignment



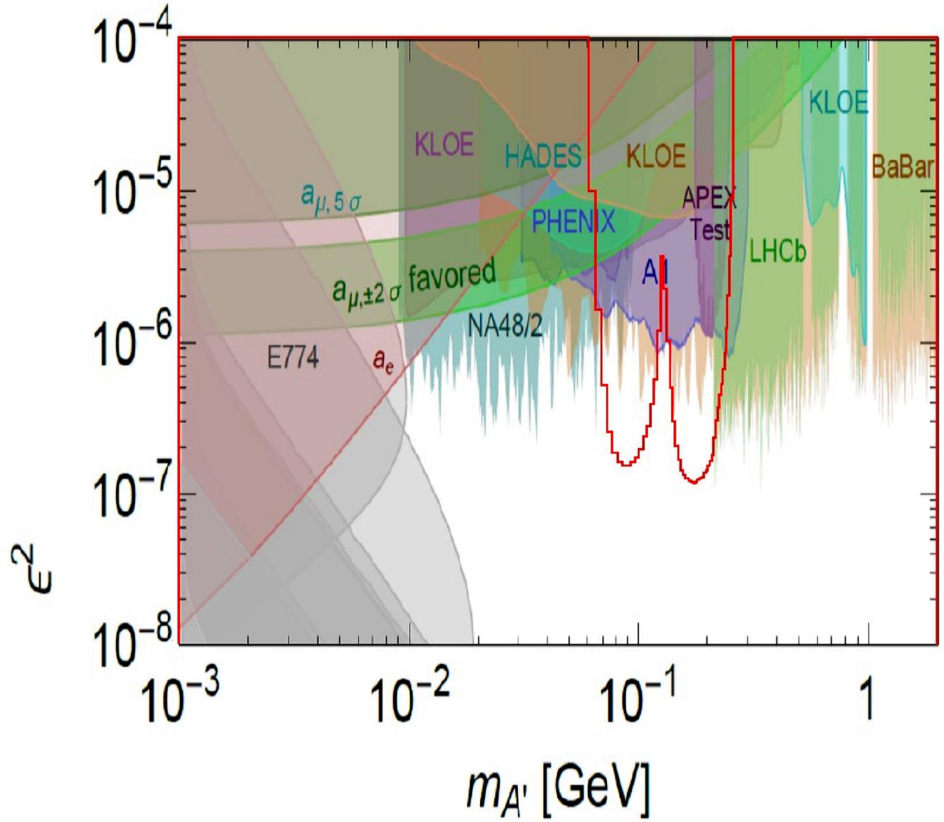


Resolution 1.4 ns => 0.9 ns

APEX plan

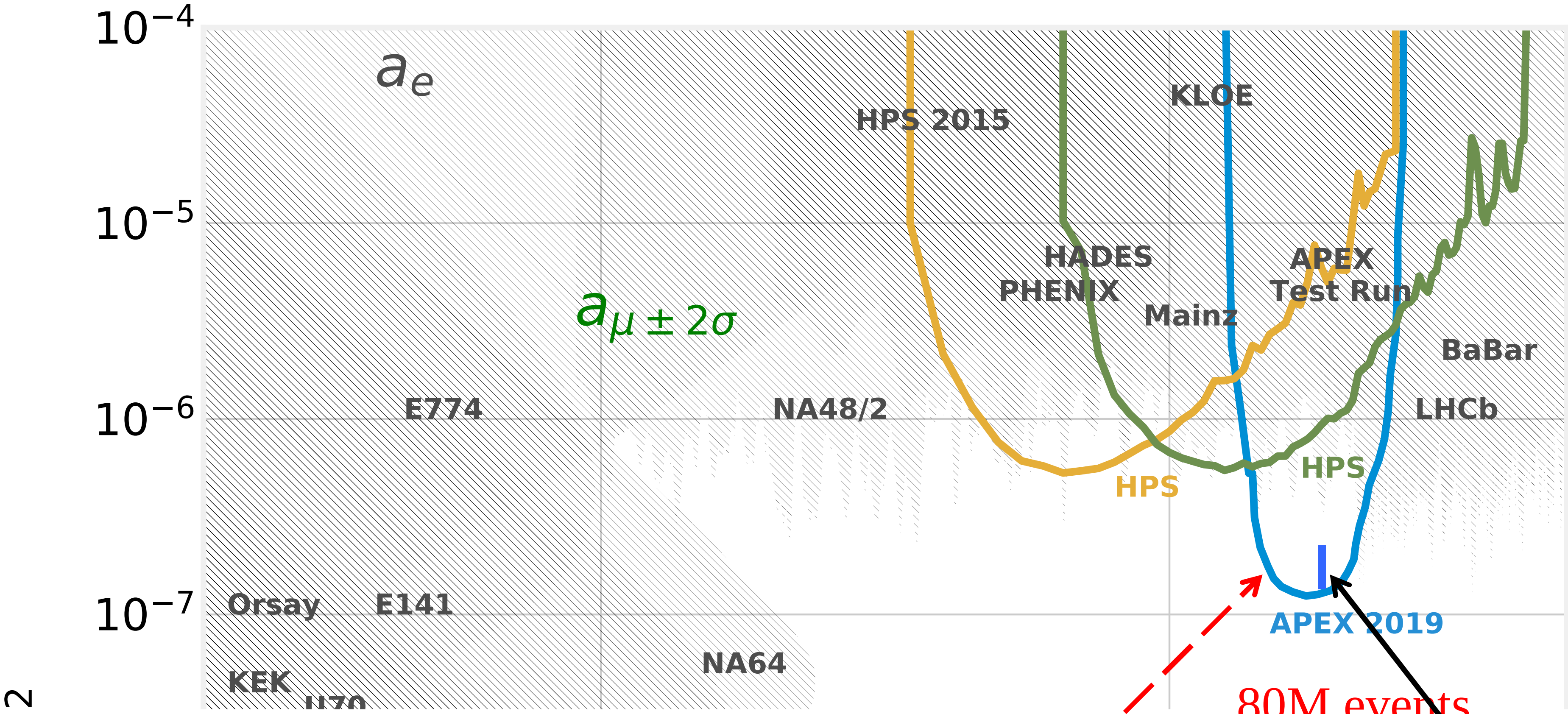


10 days at 1.1 GeV beam
10 days at 1.65 GeV beam
10 days at 2.2 GeV beam



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

APEX-2019



80M events

collected

Analysis is going.
The signal of this size
is not excluded.

for e^+e^- experiment at low s

$$m \sim \sqrt{4 \cdot E_+ \cdot E_-}$$

1. 10 MeV x 10 MeV collider of e+e- => very low luminosity

2. Sliding beams of e+e- (250 MeV x 250 MeV)=>
 need specialized accelerator with two rings

3. Positron beam and atomic electrons, m < 20 MeV: PADME

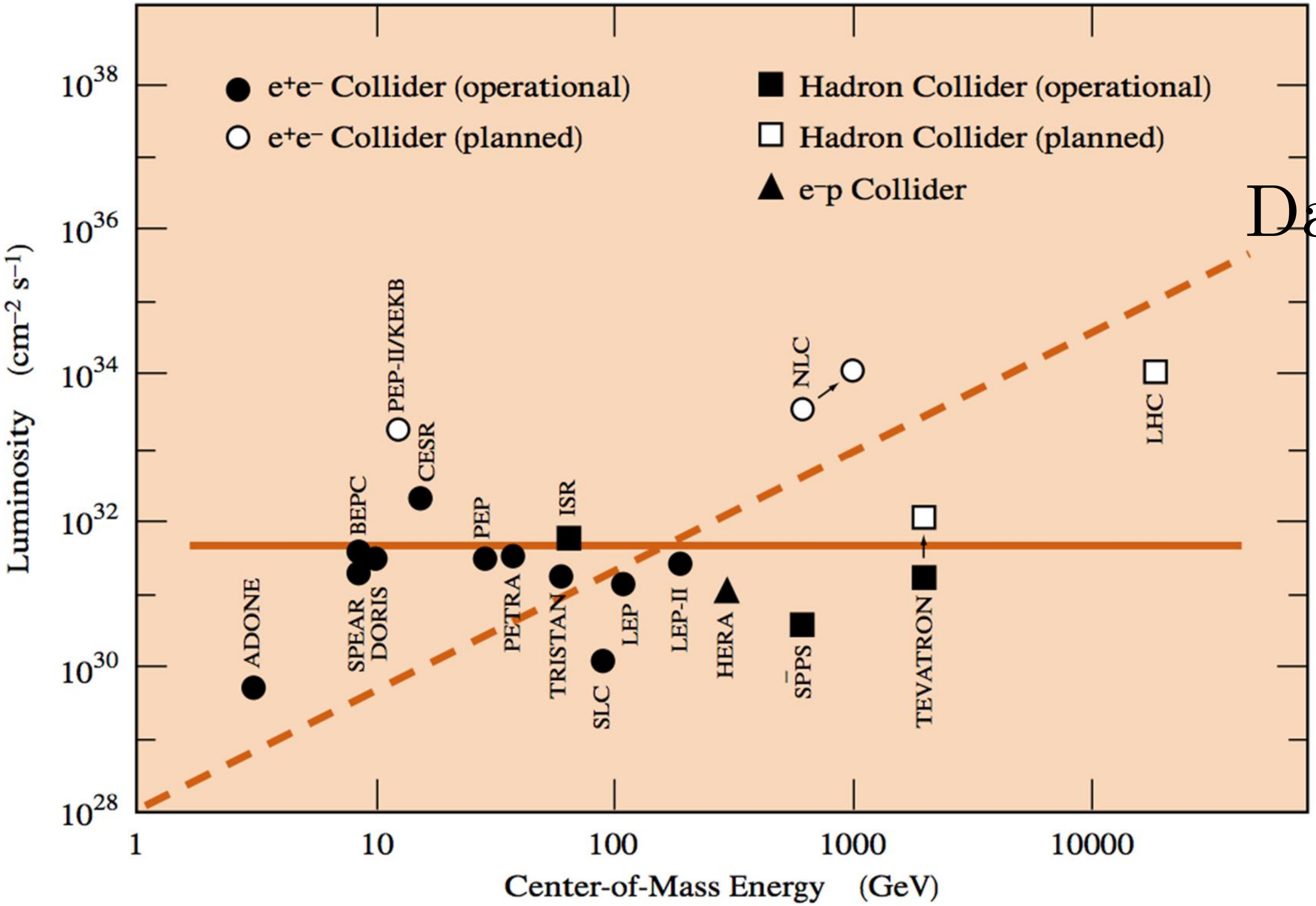
3. A head-head collider for the mass range 100-200 MeV

Very Asymmetric Collider

in collaboration with
V.S. Morozov, Y.S. Derbenev
see also arXiv:1705.00051

uminosity of the colliders

in BEAM LINE



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

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

or a e^+e^- experiment at ñlowò s

a) 10 MeV x 10 MeV head-head circular collider
The problem is a very low luminosity $\mathcal{L} \sim 10^{29}$ cm^{-2}/s

b) Sliding beams of e+e- (250 MeV x 250 MeV)=>
Project needs a specialized accelerator setup with two rings
(it was recently proposed in BINP)

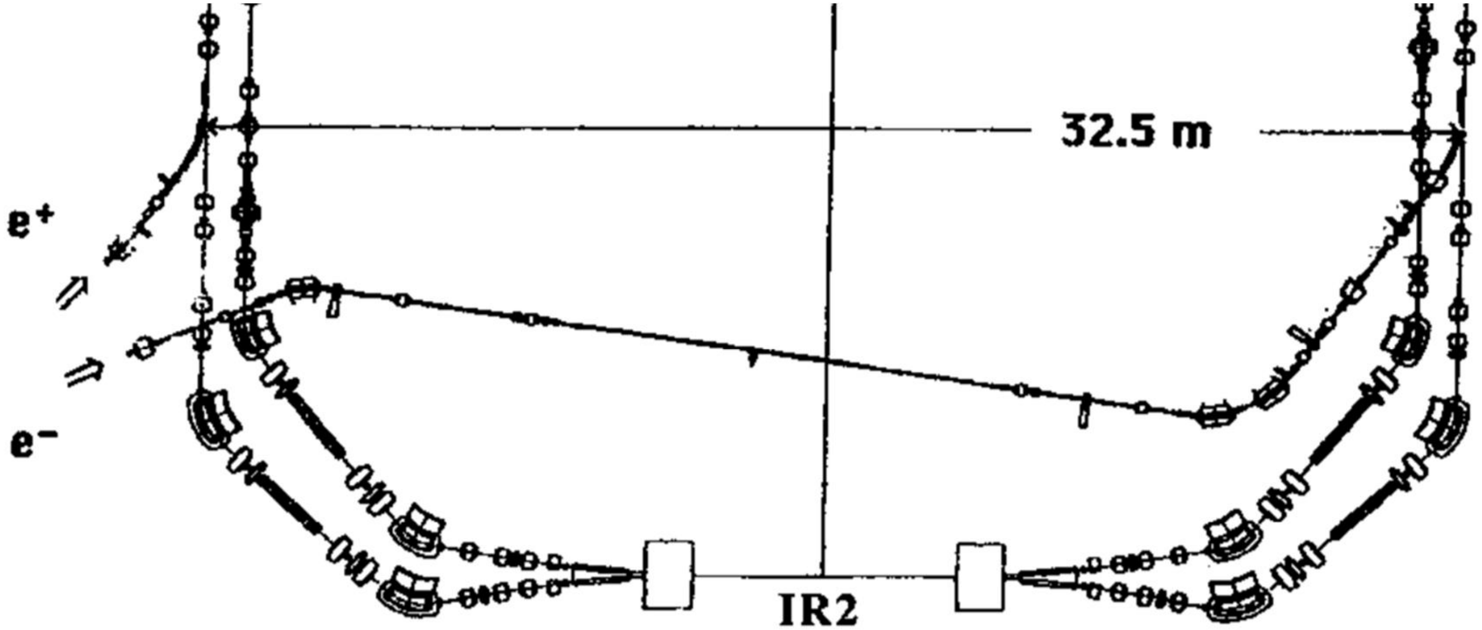
c) DAΦNEôs 500 MeV positron beam and a 10-100 MeV (ERL?)
looks like an ideal combination for a new device:
a Very Asymmetric Collider

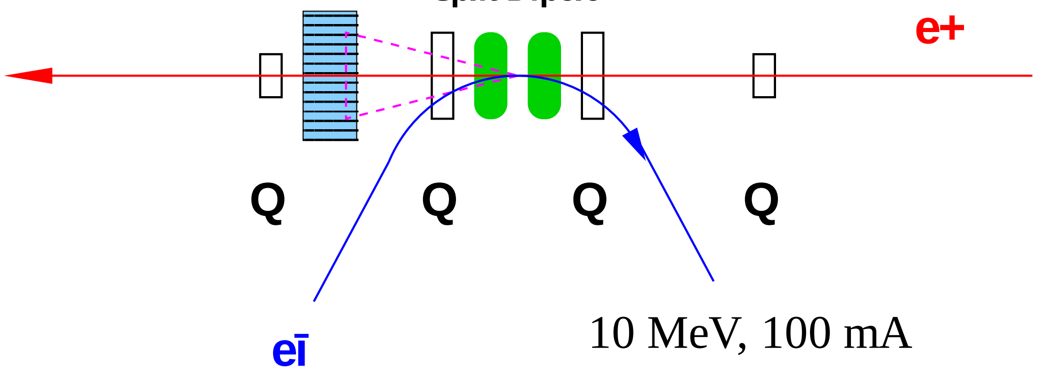
Can we reach the luminosity close to 10^{32} cm^{-2}/s?

Luminosity

- Luminosity comes from charge (particles/bunch N_{e+}, N_{e-}), current (collision frequency f_c), and beam size (σ_x, σ_y)
- If beam-beam interaction is strong enough and bunch charges asymmetric, the ñweakò bunch can be disrupted and dumped.
- An estimate of luminosity by using: $$\mathcal{L} = \frac{N_e N_p f_c}{4\pi\sigma_x\sigma_y} H_D$$
- We evaluated luminosity, for a few system concepts:
  - Cornell-BNL Cβ + CESR e^+
  - DAΦNE e^+ + JLab-style ERL at 100 MeV
  - DAΦNE e^+ + warm cw linac **at 10 MeV** for 1 MW power

The VAC at LNF





The VAC at LNF

Using DAΦNE parameters for a positron beam of 1.4 Amp, 325 ns period, 111 bunches, for $\sigma_x = 0.2$ mm and $\sigma_y = 10$ μm and a focused bunched 100 mA electron beam, the luminosity could be estimated from the classical formula as 8×10^{31} cm^{-2}/s.

The full calculation with the beam-beam effects taken into account by using a BeamBeam3D code for a 0.8 Amp positron beam current and a 100 mA electron beam current with $\sigma_x = 0.26$ mm and $\sigma_y = 4.8$ μm resulted in 4.5×10^{31} cm^{-2}/s.

ditional application(s)

Slow positrons produced with the proposed high intensity electron beam for:

1. Applied material research and industry
2. Plasma physics experiments
3. Positronium decay ï new physics search

...d and fundamental use of ...ow positrons in the world

TABLE 1. Summary of a few slow positron beams and applications

Name and place	Contact persons	Positron source	Beam Energy	Beam Intensity e^+/s	Applications
EPOS, Halle, Dresden	Prof. Kraus-Rehberg	40 MeV e^-Linac	0.2 – 100 keV	Moderated: 10^9 and Pulse: 10^6	Defects, AMOC, CDBS, PACS etc.
LLNL, Livermore	Dr. R. H. Howell	Pelletron, 3 MeV	1 – 50 keV	300, 20 MHz	Defects, CDBS, PACS etc.
KEK-B Factory, Tsukuba	Dr. T. Kurihara	2.5 GeV e^- Linac	10 – 100 keV	10^8	2D-ACAR, TOF, Spin polarization
TU-Delft reactor, Amsterdam	Prof. P. J. Schultz	Reactor based	1 eV – 40 keV	10^8	2D-ACAR, 2D-Doppler, Depth profile
MRR-FRM-II, Munich	Prof. G. Kogel	Reactor based	100 eV	$10^7 – 10^9$	Positron microprobe, defect concentration
TOPS, Tokyo M. University	Dr. N. N. Mondal/ Dr. T. Kumita	^{22}Na (150 mCi) source	1 eV – 250 keV	10^6	BEC, Laser cooling, defects, polarization etc.
GU, Tokyo	Dr. I. Kanazawa	^{22}Na (3 mCi)	30 eV	10^3	Vacancy-type defects
Bonn University	Dr. K. Maier	^{22}Na (10 mCi)	150 eV	10^3	Surface and dislocation of materials
TUS, Tokyo	Dr. Y. Nagashima	^{22}Na (740 MBq)	100 eV	10^5	Ps^-, moderator, defects of materials.
SHI, Tokyo	Dr. M. Hirose	Compact Cyclotron	10 – 150 keV	10^6	Commercial purpose, surface, interface, polarization.
NCSU	Dr. Ayman Hawari	Reactor based	variable	6×10^8	Defect studies of various materials
Jefferson	Joe Grames	LINAC	---	---	Fundamental research

N.Mondal, AIP Conference Proceedings 1970, 040005 (2018)

...nt and past conferences ...e slow positrons topics

ICPA-18 will be organized in Orlando / Florida in Summer 2018: 19.-24.8.2018, Contact, Website

POSITRON-2018 will be organized by Prof. P. Pujari in Mumbai, India: The third Trombay Positron 22.-24. March 2018. Contact & Website

JPos17 Intern. Workshop on Physics with Positrons at Jefferson Lab, September 12-15, 2017 (Websit

PSD-17 Positron Studies of Defects, Dresden-Rossendorf, 3.-8. September 2017 (Website; Contact)

PPC-12 "12. Intern. Workshop on Positron and Positronium Chemistry", 28.8.-1.9.2017, Lublin, Pola

Treffen deutscher Positronengruppen 2017, 27. and 28. March 2017 in Würzburg (start of meeting

SLOPOS-14 International Workshop on Slow Positron Beam Techniques; Matsue City (Link), Japa

Treffen Deutscher Positronengruppen 2015, Universität der Bundeswehr, München, 12.-13. Noven

Methods of Porosimetry and Applications, Workshop, HZDR Dresden-Rossendorf, 21.-23. Octobe

ICPA-17 17. Intern. Conference on Positron Annihilation; 2015 Wuhan (20.-25. September 2015),

ed and fundamental uses

Prague

September 2 – 6, 2019

15th International Workshop on Slow Positron Beam Techniques & Applications (SLOPOS-15)

- About
- Circulars
- Venue
- Registration
- Payment
- Book of abstracts
- Invited speakers
- Program
- Presentation
- Excursions
- Social events
- Proceedings
- Travel
- Visa
- Accommodation
- Committees
- Contact

SLOPOS is a well established international workshop dedicated to variable energy positron beams, related techniques and all aspects of surface science and defect studies using positron beams. The workshop has long term tradition and is being organized with period of three years at various places. The 15th SLOPOS workshop will be held in Prague, Czech Republic.
On behalf of the SLOPOS-15 organizing team I sincerely invite all scientists interested in positron annihilation to come to Prague and attend the workshop.

Jakub Cizek

Main topics of the workshop

- positron and positroinum beams and related technologies
- pulsed beams and positron traps
- thin films and layered structures
- nano structures
- porous materials
- defect depth profiling in bulk and layered structures
- surfaces and interfaces
- positronium formation and emission
- positron interaction with atoms and molecules
- many positrons and anti-hydrogen
- theoretical calculations of positron parameters
- digital processing of positron annihilation data
- improvement of experimental techniques

important dates:

Abstract submission deadline **May 15, 2019**

Notification about abstract acceptance **May 15, 2019**

Early bird registation fee deadline **May 31, 2019**

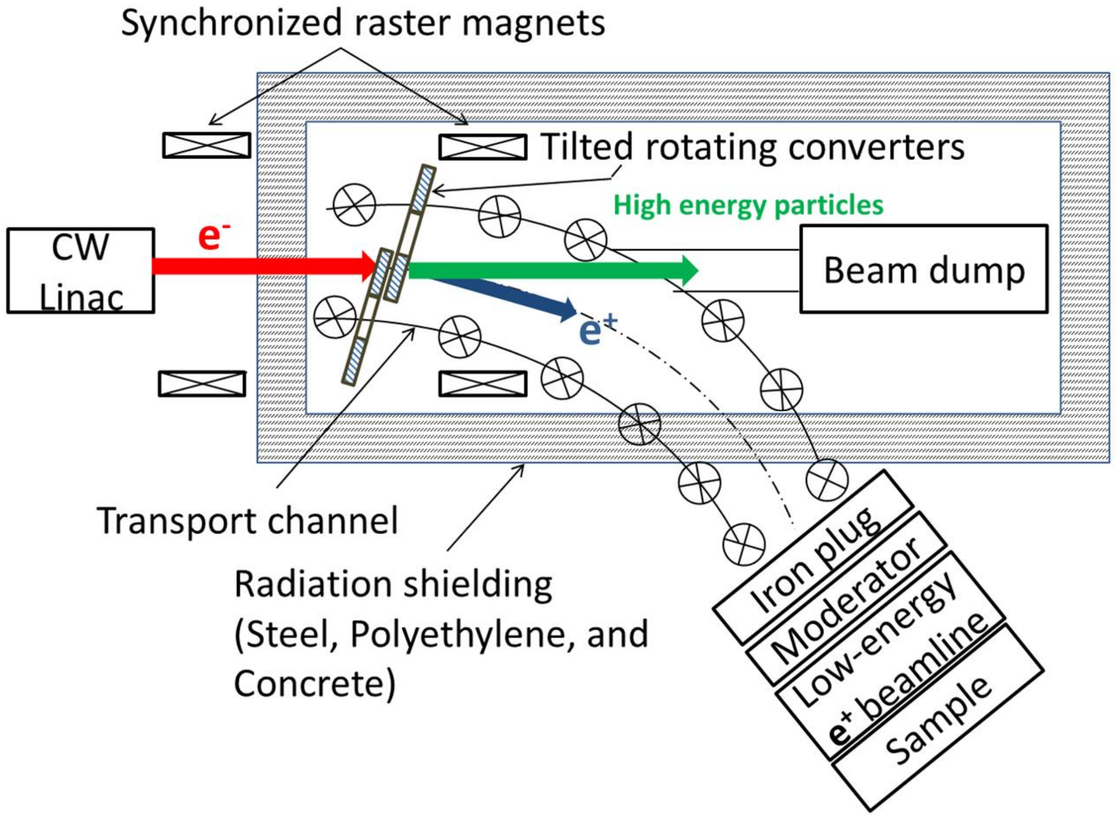
SLOPOS-15 conference **September 2-6, 2019**

Full paper submission deadline **September 20, 2019**

number of registered participants: 135

Applied use of the low energy linac

A huge applied physics field is positron-based material research



Our MC studies see in J.Appl.Phys. 115 (2014) 234907
arXiv:1404.1534

Summary

- APEX took a very good data sample. Projected search sensitivity for α_D is of 0.1 ppm of the α_{EM} coupling (assuming 100% decay to the SM particles).

- The e+e- initial state has many advantages (as in PADME) which could be extended to much high masses by means of a Very Asymmetric Collider.
  We propose to use the beam of 500 MeV positrons in DAΦNE and 10 MeV electrons from a new low energy machine (cw linac). With 25 MeV electron beam energy VAC will be able also produce the μμ-atoms.

- Best low energy positron beam for applied research with a proposed 10 MeV accelerator is an important bonus.

Comment on the recent NA64 result

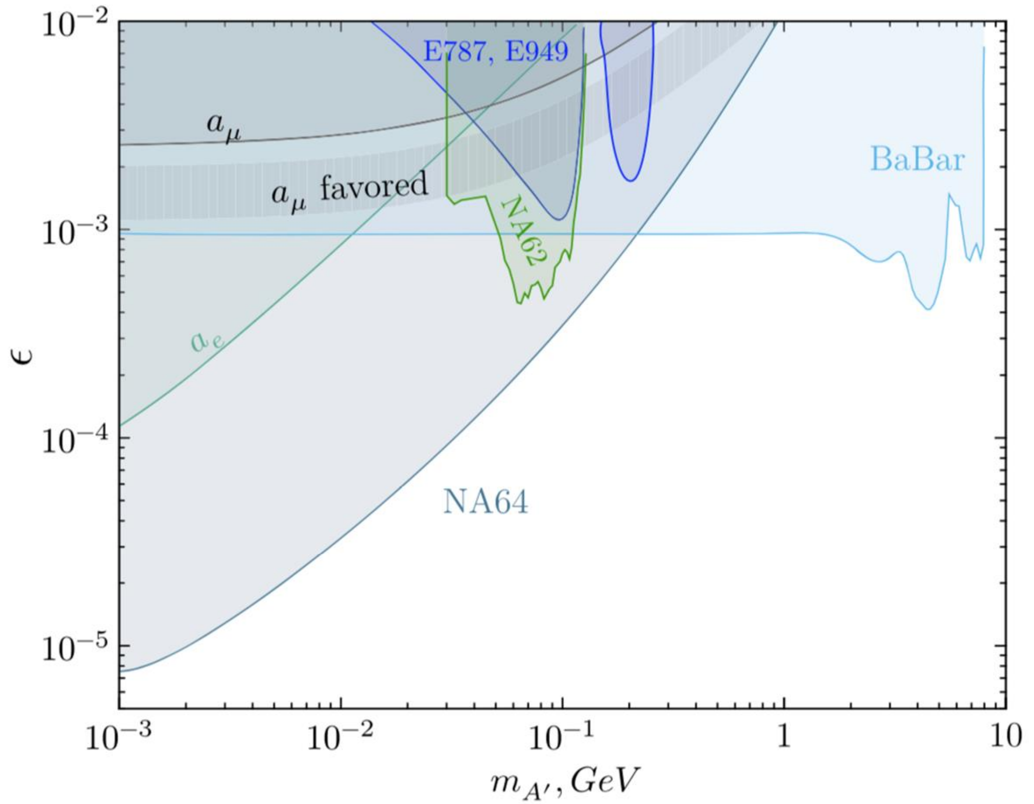


FIG. 3. The NA64 90% C.L. exclusion region in the ($m_{A'}$, ϵ) plane. Constraints from the E787 and E949 [32,33], *BABAR* [39], and recent NA62 [40] experiments, as well as the muon α_μ favored area are also shown. For more limits from indirect searches and planned measurements see, e.g., Refs. [12–14].

Options for the Aôdecay modes:

Search method

1. large SM ï > APEX
2. large DM ï > NA64
3. omni ï > PADME

The Aôdecay mode is not known. It could be 100% semi-DM for such a case the most reliable bump search method is PADME.