Commissioning the TOF and the First Results from the GlueX Experiment

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Nuclear Physics Seminar

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Outline

- Motivation
- GlueX overview
- TOF overview
- Current Status
- Future Plans

Quark Model Picture

Mesons in the constituent QM = bound states of $q\bar{q}$

Mesons described by J^{PC} quantum numbers

- Quark spins can be aligned or anti-aligned, with total intrinsic spin **S=0** or **S=1**
- Quark relative orbital momentum L couples with **S** to yield total spin **J=L ⊕ S**

Example:

- L=0
  - S=0: J=0, P=-1, C=+1 → $\mathbf{0^{-+}}$
  - S=1: J=1, P=-1, C=-1 → $\mathbf{1^{--}}$
- L=1
  - S=0: J=1, P=+1, C=-1 → $\mathbf{1^{+-}}$
  - S=1:
    - J=0, P=+1, C=+1 → $\mathbf{0^{++}}$
    - J=1, P=+1, C=+1 → $\mathbf{1^{++}}$
    - J=2, P=+1, C=+1 → $\mathbf{2^{++}}$
- ...

Parity:

$P=(-1)^{L+1}$

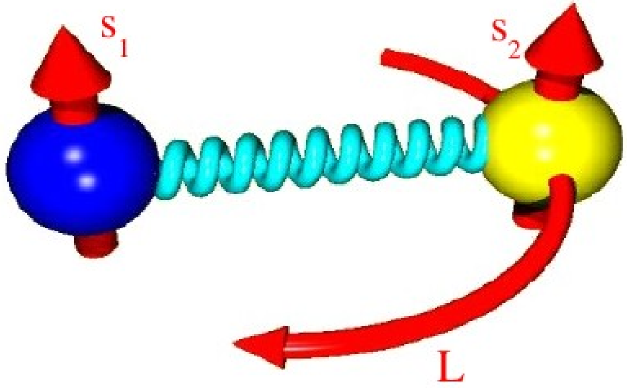
Charge conjugation (C-parity):

$C=(-1)^{L+S}$

$n^{2s+1}L_J$	J^{PC}	$I=1$ $u\bar{d}\cdots$	$I=\frac{1}{2}$ $u\bar{s}\cdots$	$I=0$ f	$I=0$ f'
1^1S_0	0^{-+}	π	K	η	η'
1^3S_1	1^{--}	ρ	K^*	ω	ϕ
1^1P_1	1^{+-}	$b_1(1235)$	K_{1B}	$h_1(1170)$	$h_1(1380)$
1^3P_0	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1370)$	$f_0(1710)$
1^3P_1	1^{++}	$a_1(1260)$	K_{1A}	$f_1(1285)$	$f_1(1420)$
1^3P_2	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2(1270)$	$f_2'(1525)$
1^1D_2	2^{-+}	$\pi_2(1670)$	$K_2(1770)$	$\eta_2(1645)$	$\eta_2(1870)$
1^3D_1	1^{--}	$\rho(1700)$	$K^*(1680)$	$\omega(1650)$	
1^3D_2	2^{--}		$K_2(1820)$		
1^3D_3	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\omega_3(1670)$	$\phi_3'(1850)$
1^1F_4	4^{++}	$a_4(2040)$	$K_4^*(2045)$	$f_4(2050)$	
1^3G_5	5^{--}	$\rho_5(2350)$			
1^3H_6	6^{++}	$a_6(2450)$		$f_6(2510)$	
2^1S_0	0^{-+}	$\pi(1300)$	$K(1460)$	$\eta(1295)$	$\eta(1475)$
2^3S_1	1^{--}	$\rho(1450)$	$K^*(1410)$	$\omega(1420)$	$\phi(1680)$

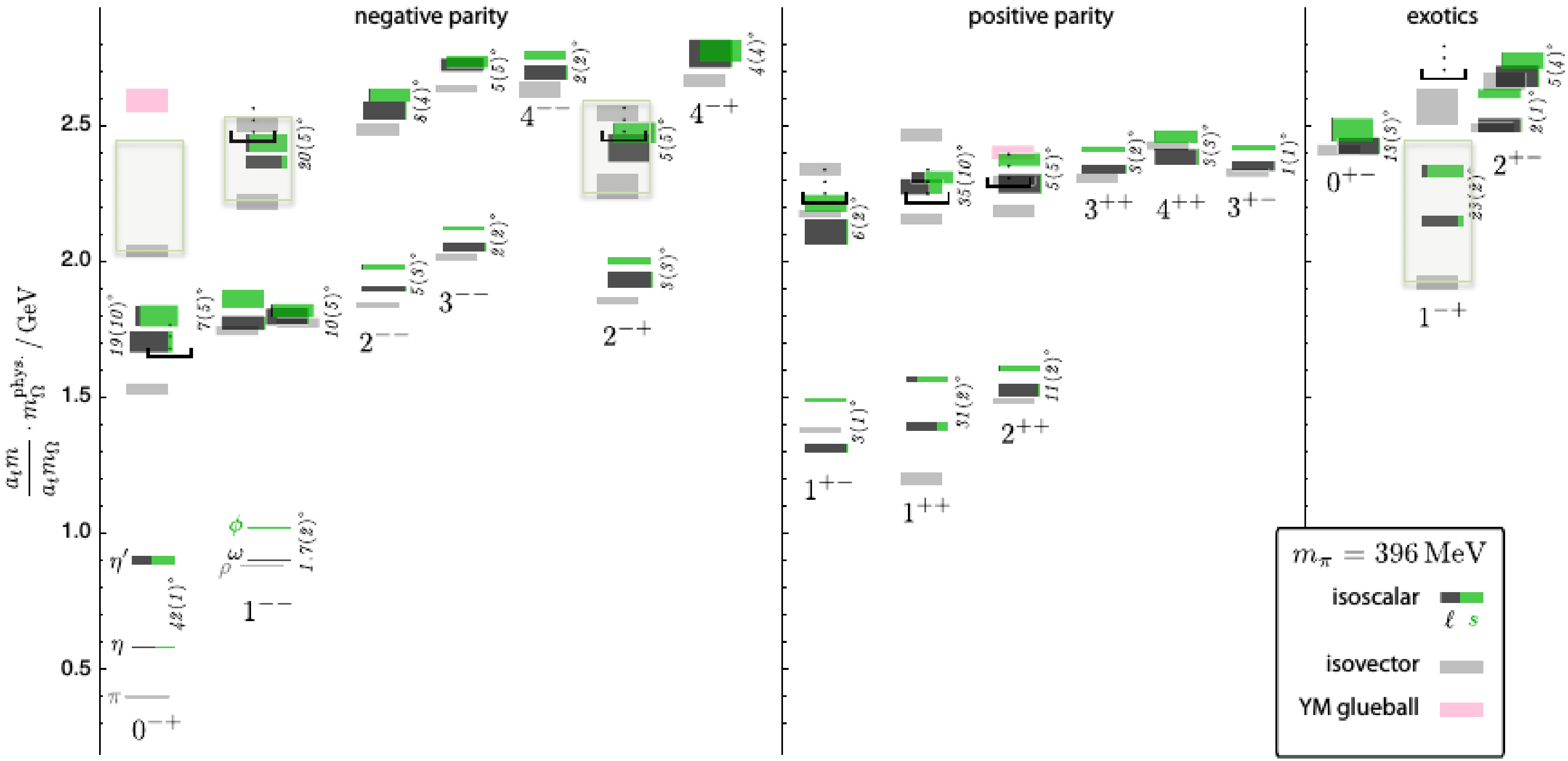
GlueX: Study Gluon Excitations

- In the constituent quark model:
  - Mesons → $q\bar{q}$ $with\ J^{PC} = 0^{-+}, 0^{++}, 1^{++}, 1^{+-}, 2^{-+}, 2^{++}$
  - Baryons → $q\,q\,q$
- QCD (much richer spectrum):
  - Hybrid states $(q\,\bar{q}\,g)$ and gluon – gluon interactions $(g\,g)$ $with\ J^{PC} = 0^{-+}, 0^{++}, \mathbf{0^{+-}}, 1^{++}, \mathbf{1^{-+}}, 1^{+-}, 2^{-+}, 2^{++}, \mathbf{2^{+-}}$



- Role of gluons in the structure of matter
- Observe evidence of gluonic degrees of freedom in the spectrum of meson states?

Lattice QCD Meson Spectrum



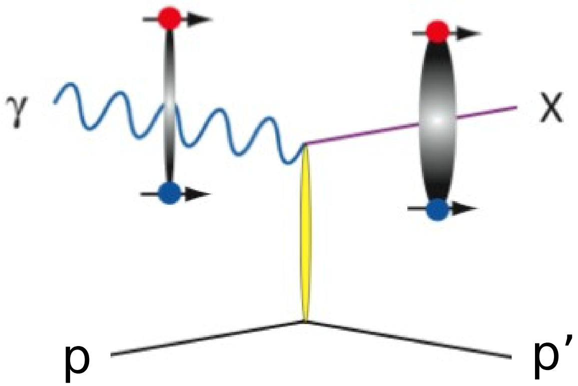
States with non-trivial gluonic fields.

$J^{PC} = 1^{--}, 0^{-+}, 1^{-+}, 2^{-+}$

Dudek J. Phys Rev. D84 074023 (2011)

Photo-production of Exotic Hybrids

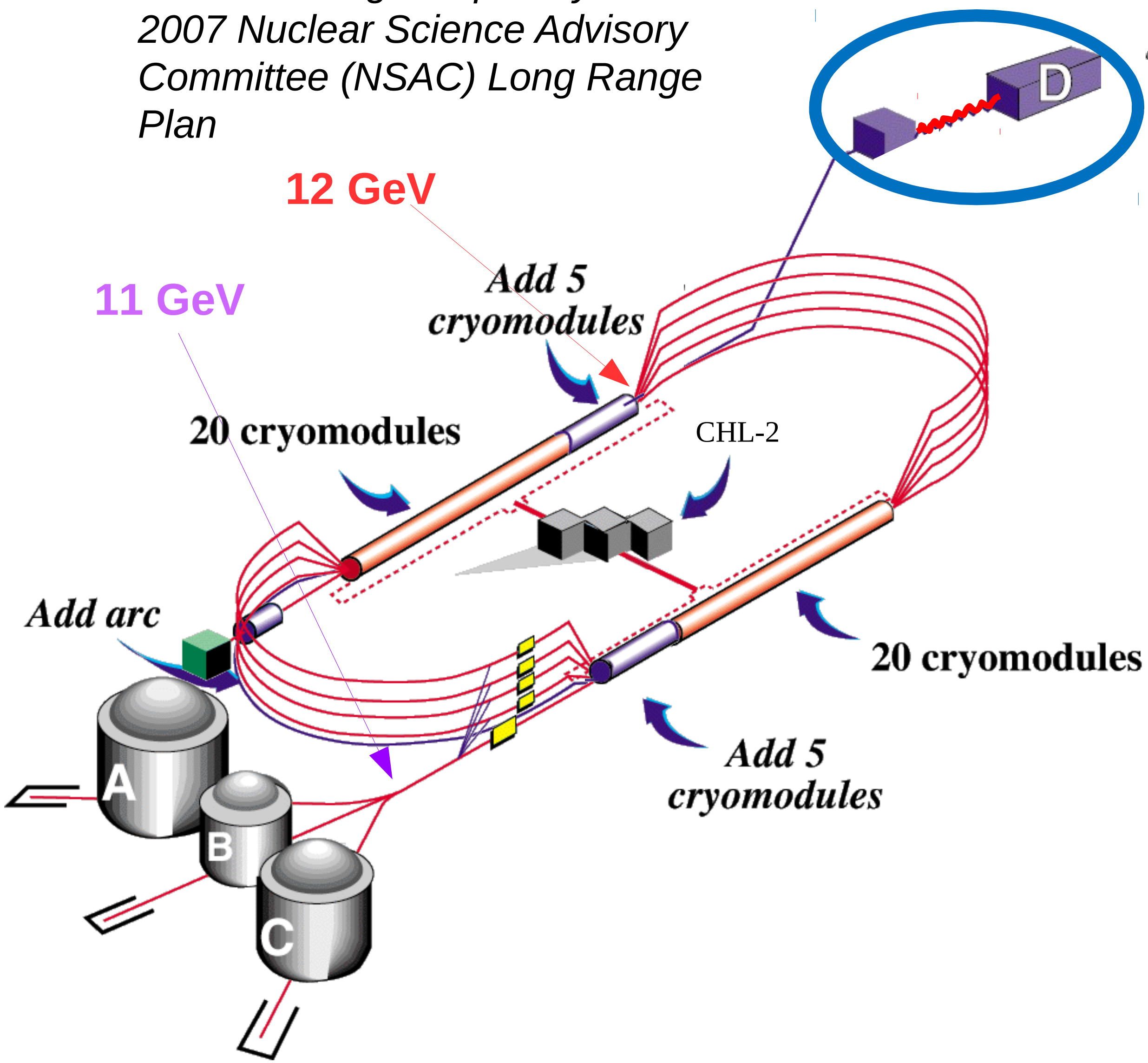
- GlueX has 9 GeV linearly polarized photon beam (12 GeV electron beam)
- LQCD calculations indicate similar radiative decay widths for hybrids and normal mesons*
  - Photons have spin-1, allow easier production of exotics compare to pion beam where a spin flip must occur
  - Small data world wide with photon beam
- Linearly polarized beam
  - Helps determine production mechanism
  - Provides additional particle quantum numbers and so it helps to break the ambiguity in the angular distributions

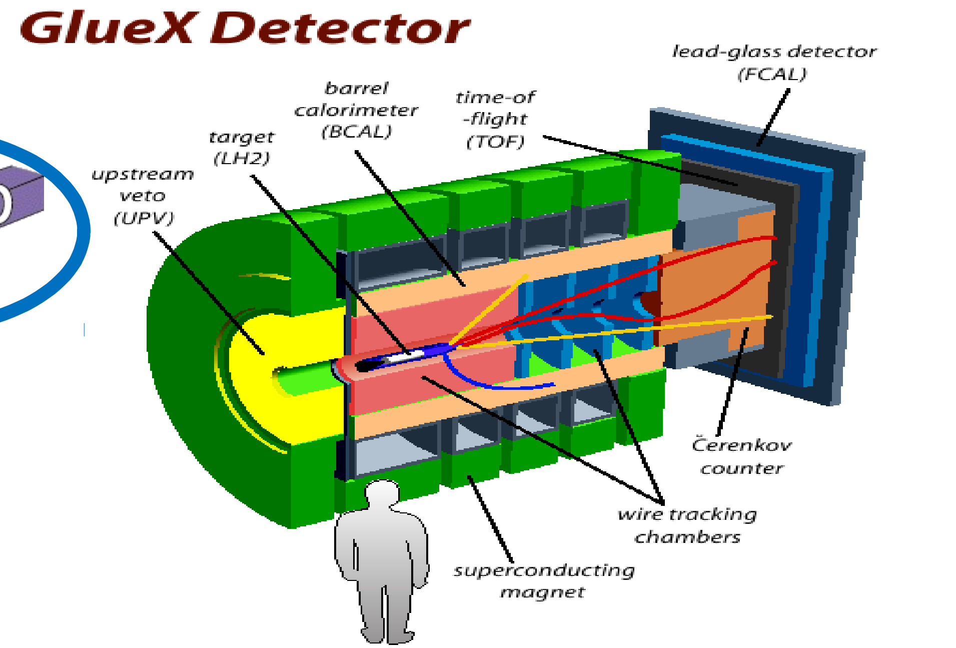


*(Dudek PRD 79 (2009) 095404)

Jefferson Lab 12 GeV Upgrade

JLab's 12 GeV Upgrade was ranked the highest priority in the 2007 Nuclear Science Advisory Committee (NSAC) Long Range Plan

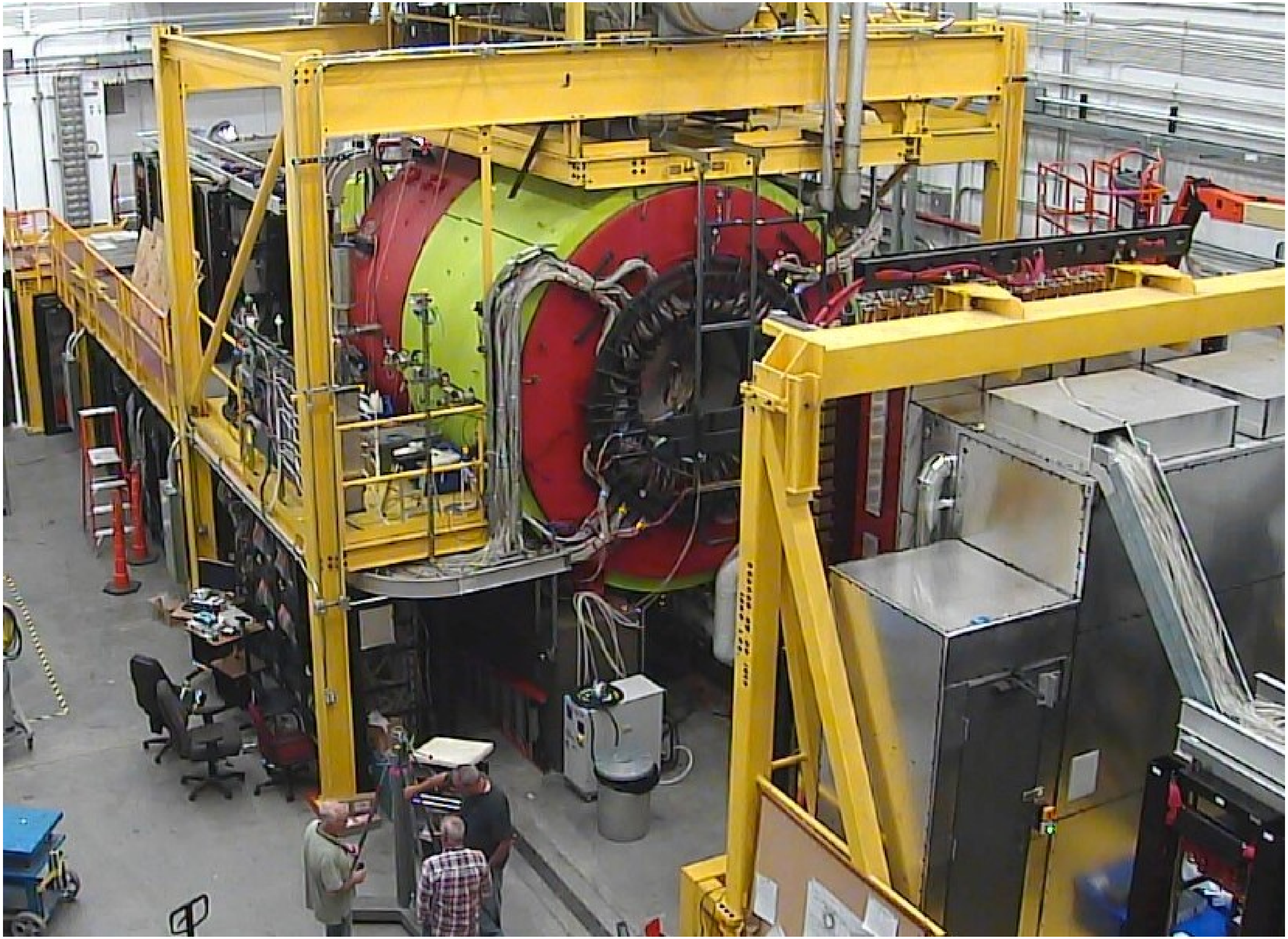




- *Electron beam cannot enter Hall-D (permanent magnet)*
- *Tagger hall is the only structure outside the accelerator that will see 12 GeV electron beam*

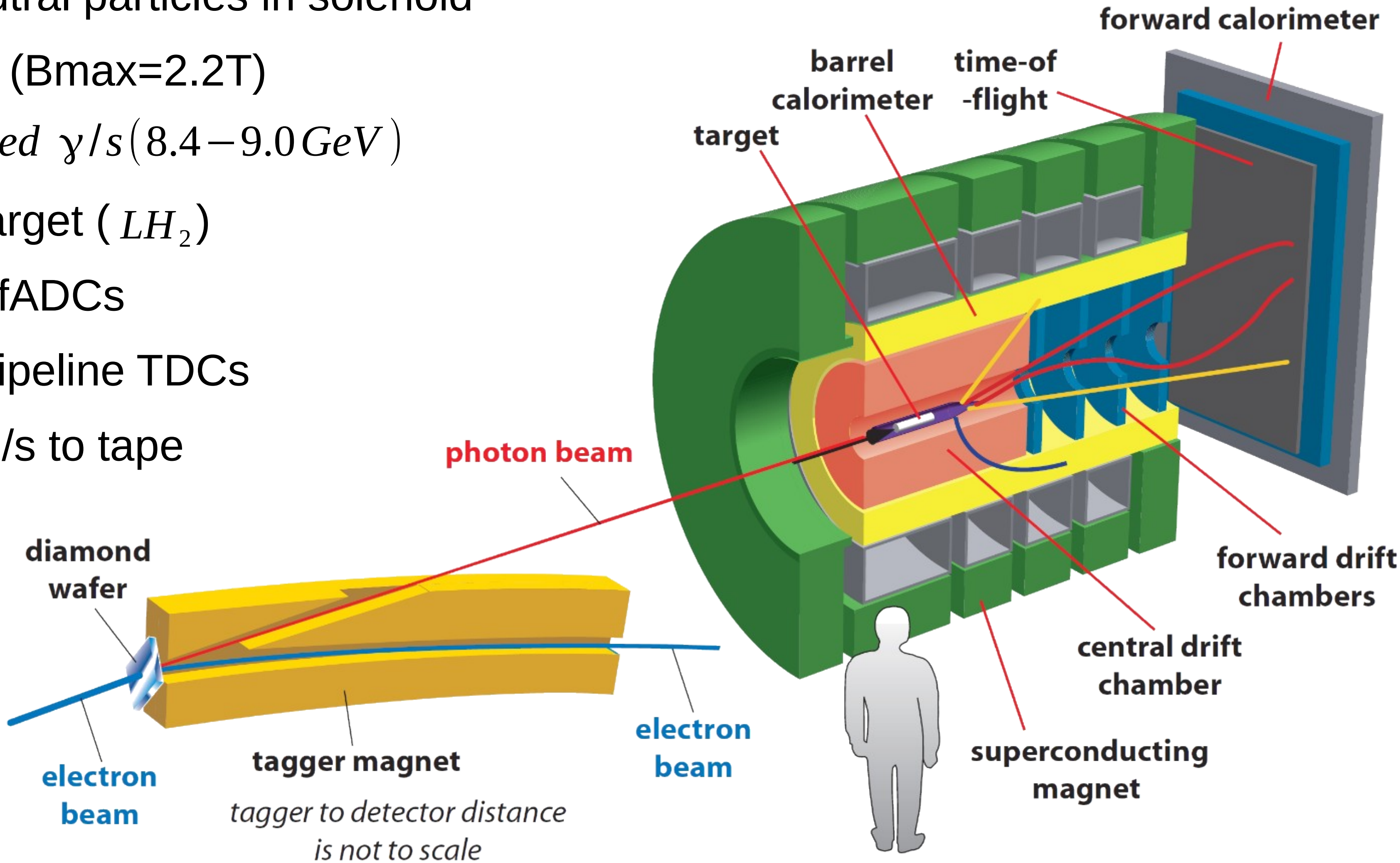
The Hall D Complex at Jefferson National Lab

GlueX Detector in Hall D

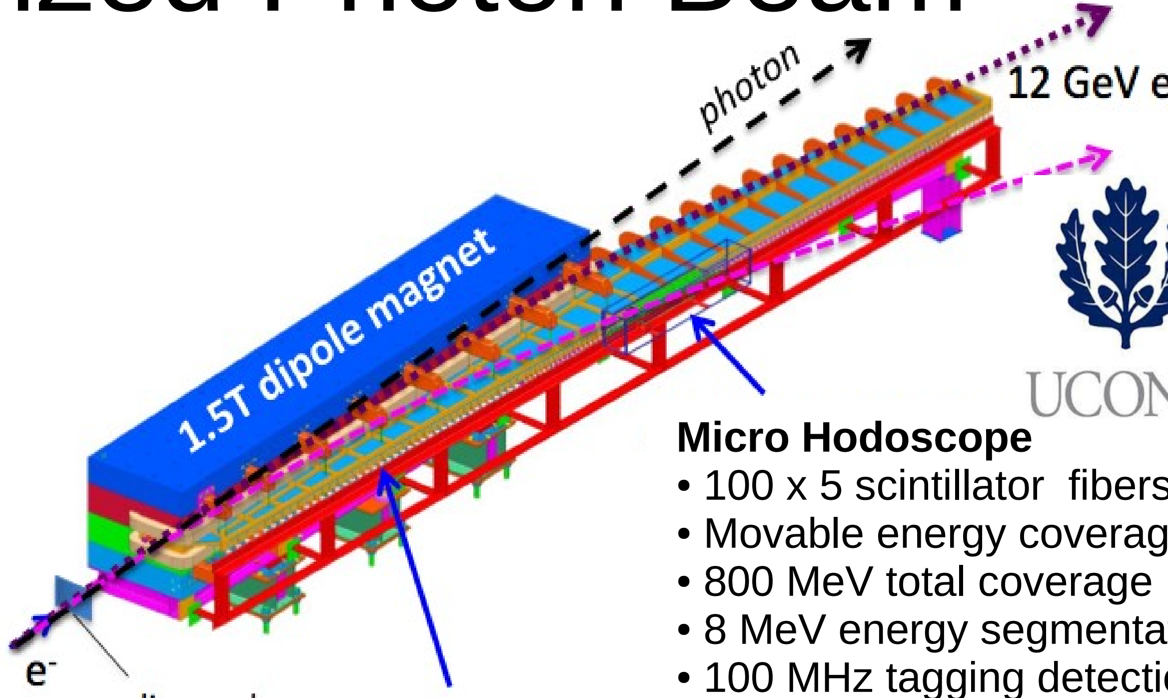


GlueX Detector

- Hermetic detection of charged and neutral particles in solenoid magnet (Bmax=2.2T)
- 10^8 $tagged\ \gamma/s(8.4-9.0\,GeV)$
- Fixed target (LH_2)
- 18,000 fADCs
- 4,000 pipeline TDCs
- 300 MB/s to tape

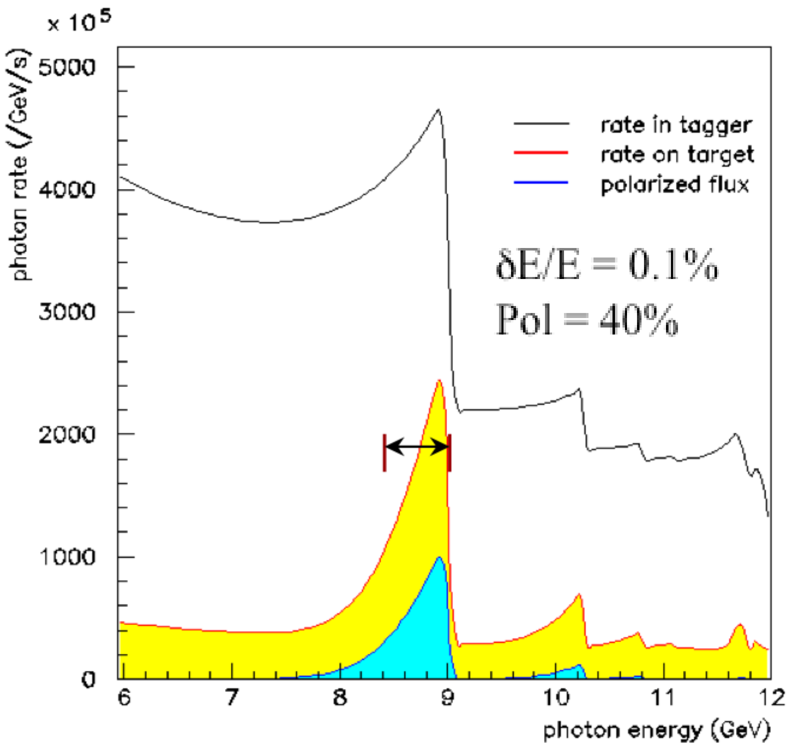


Linearly Polarized Photon Beam



Micro Hodoscope
- 100 x 5 scintillator fibers
- Movable energy coverage
- 800 MeV total coverage
- 8 MeV energy segmentation
- 100 MHz tagging detection

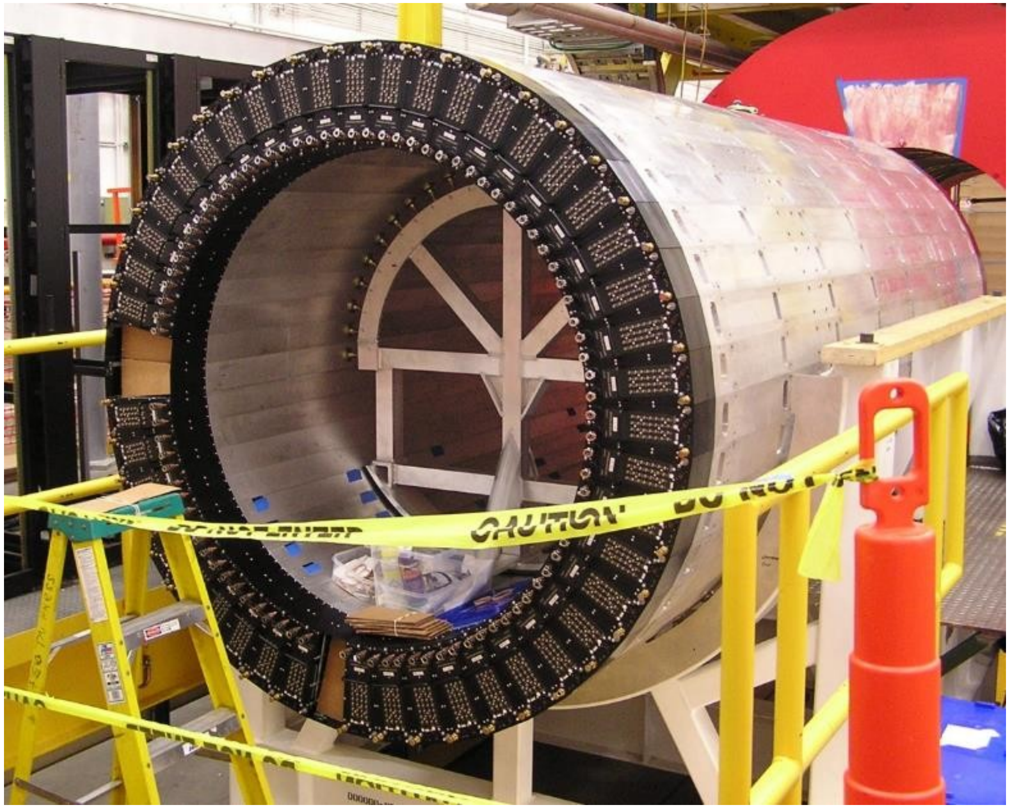
Fixed array hodoscope
- 190 scintillator counter
- Tags 3.0 – 11.7 GeV photons
- 30 MeV energy segmentation
- 17 MHz detection/counter

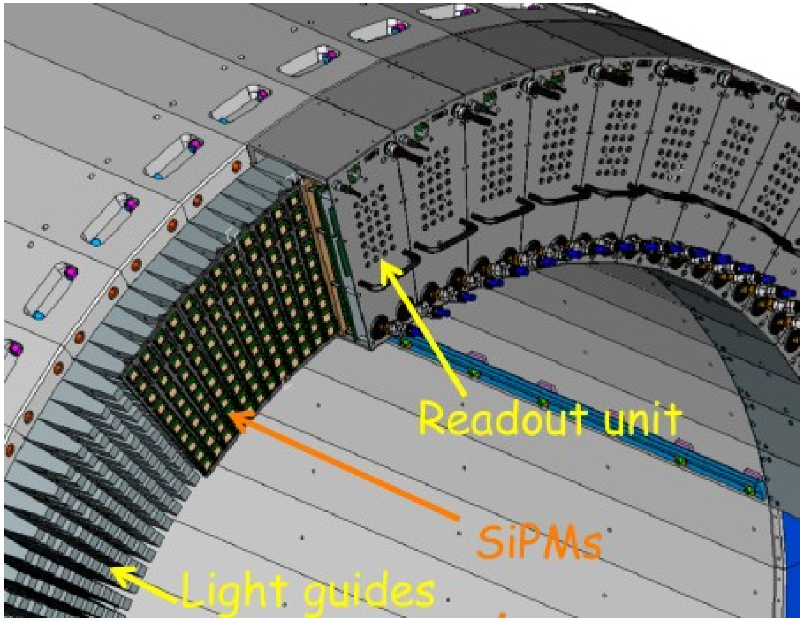


Photon Polarization
- 20 mm diamond radiator
- 40% linear polarization

Neutral Particle Detection

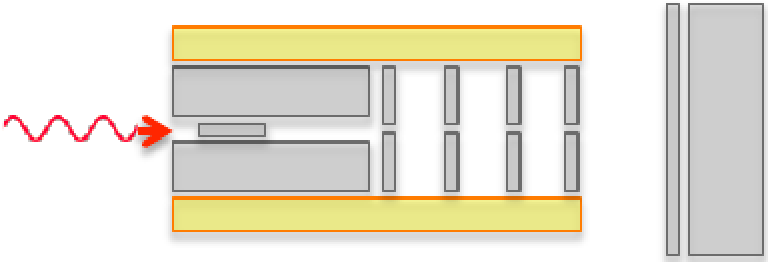
Barrel Calorimeter





Pb-scintillating fiber calorimeter

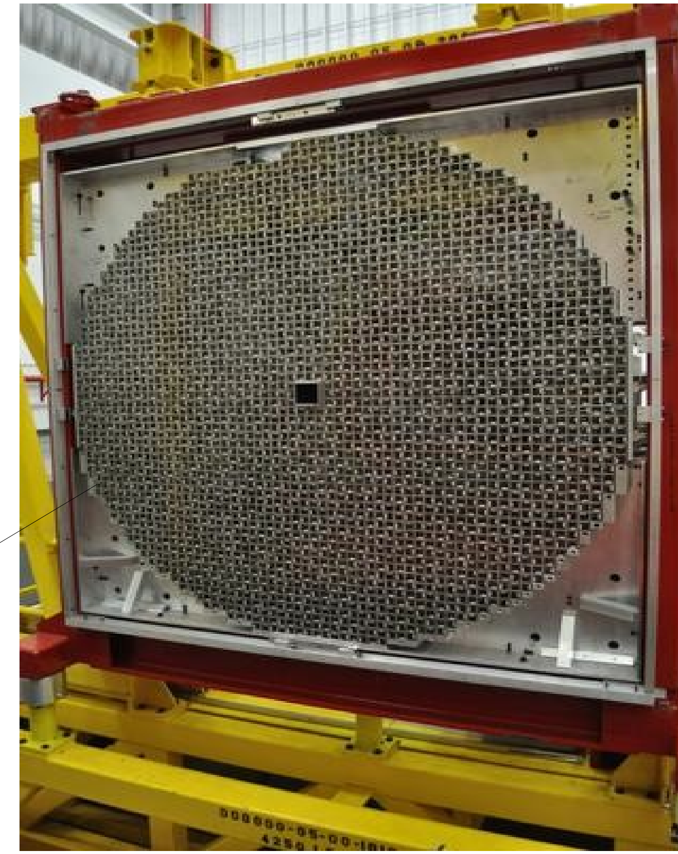
- 48 4-m long modules
- $15.5X_{o,}$ 12.5% sampling fraction
- $\sigma_E/E = 5\%/\sqrt{E} + 1\%$
- $\sigma_z = 5mm/\sqrt{E}$
- $\sigma_t = 74ps/\sqrt{E} + 33ps$
- angular coverage $11^o < \theta < 120^o$



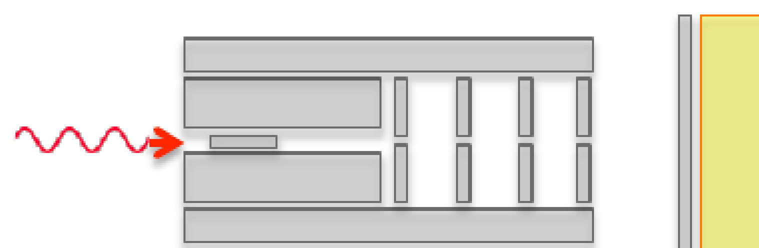
Forward Calorimeter

Lead Glass Calorimeter:

- 2800 F8-00 and F108 (center) Pb-glass blocks
- 4cm x 4cm x 45cm
- $\sigma\sigma_E/E = 6\%/\sqrt{E} + 2\%$
- $\sigma\sigma_{xy} = 6.4\text{mm}/\sqrt{E}$
- angular coverage $2^o < \theta < 11^o$



An FCAL module



Tracking of Charge Particles

Central Drift Chamber

<ins>Central Drift Chamber (CDC):</ins>

28 layers total (stereo layers: +/- 6^0)

Gas mixture: ~60/40 Ar/CO_2

Angular Coverage: 6^o-155^o

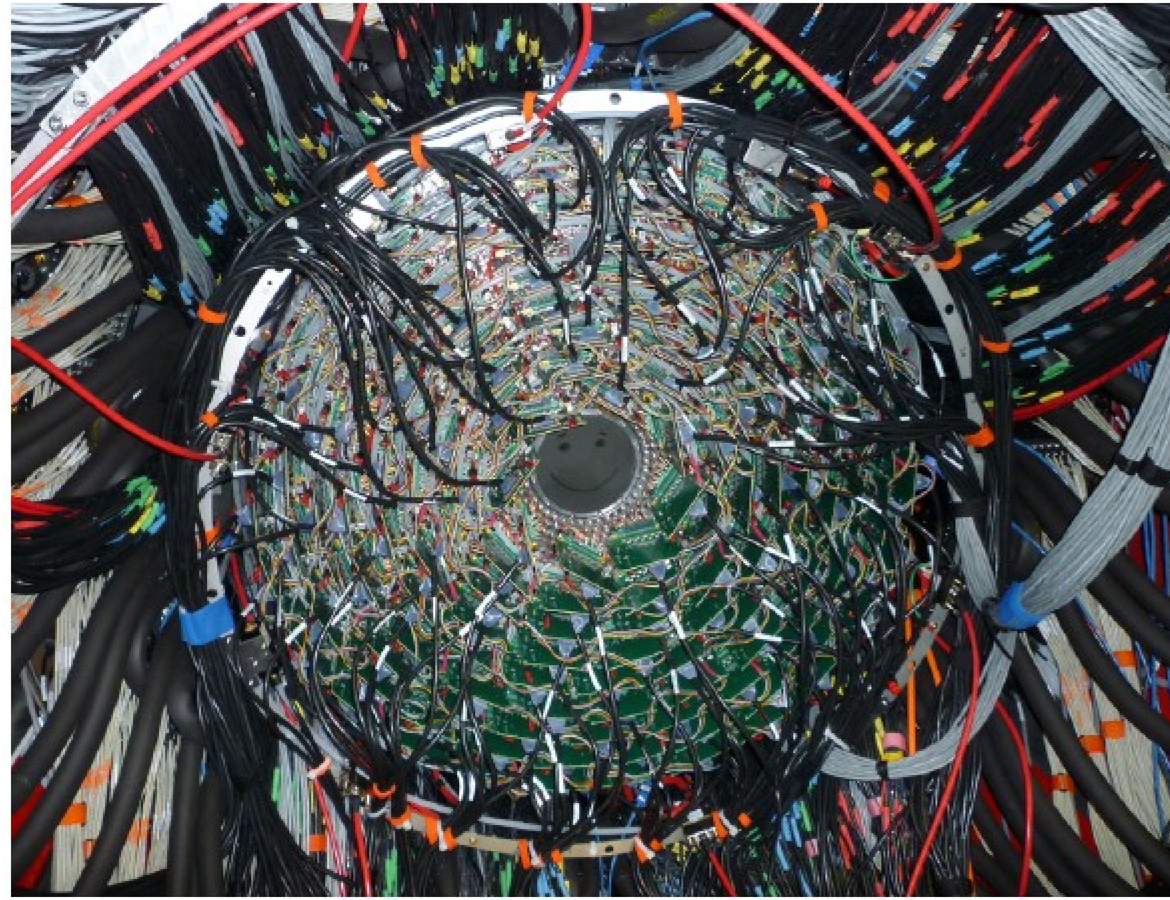
3500 straw tubes r=8mm

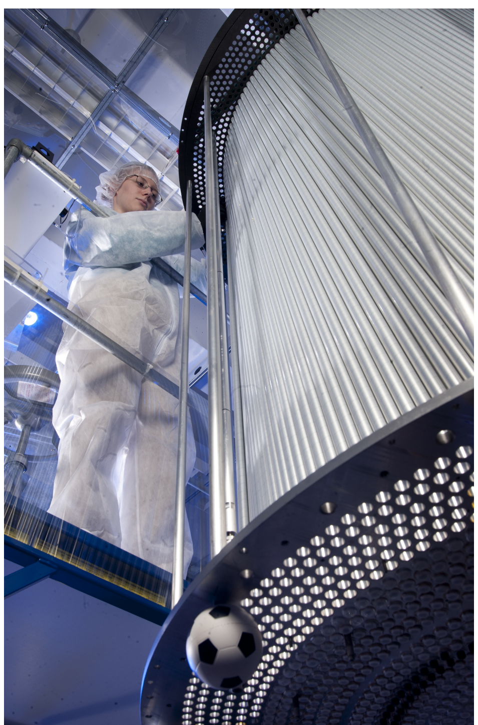
dE/dx for p < 450 MeV/c

Readout: FADC-125MHz

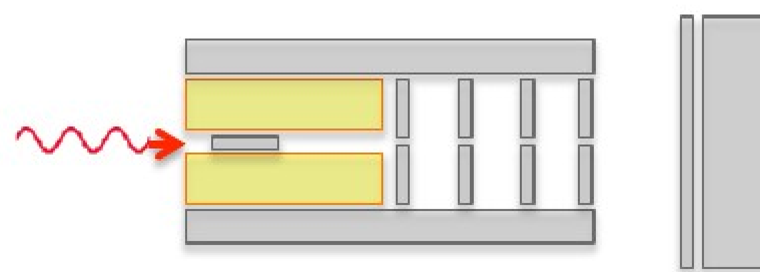
Resolution: $\sigma_{r\phi} \sim 150\ \mu m$

$\sigma_z \sim 1.5$ mm





Carnegie Mellon



Forward Drift Chamber

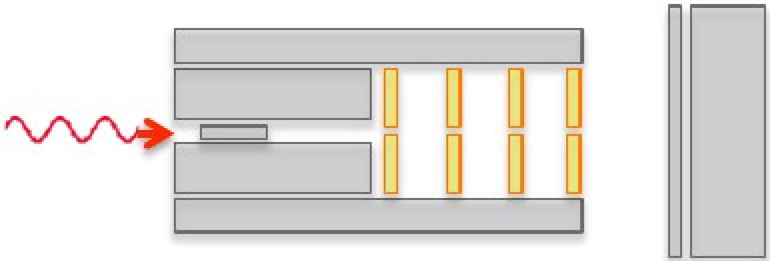
Forward Drift Chamber (FDC):
Gas Mixture: 40/60 Ar/CO_2
Angular Coverage: 1° – 30°
Readout:
- 2300 anode wires → F1TDC
- 10200 cathode strips → FADC-125
- *3 measured projections per plane*

Resolution: 200μm wires
200μm strips

Complete FDC in the lab prior to being moved to Hall-D

FDC is being installed into magnet in April 2014

Jefferson Lab

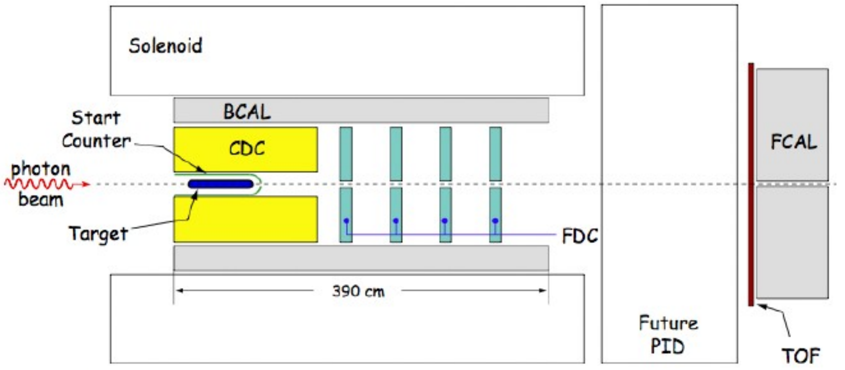


Particle Identification

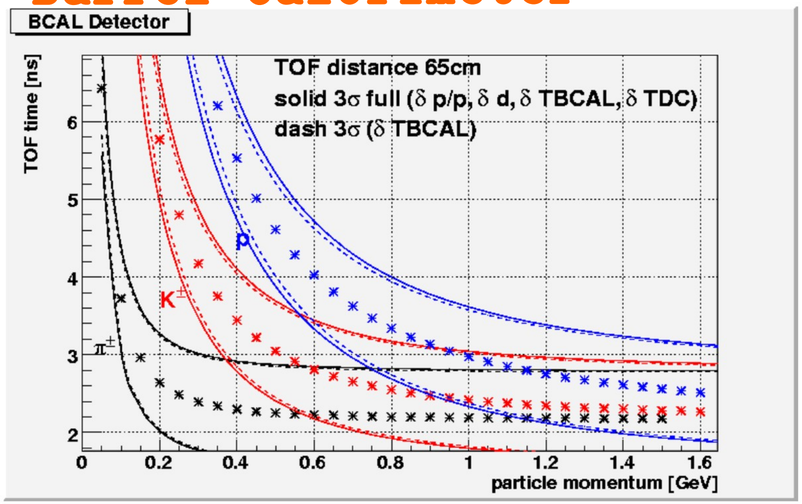
Particle ID

Identify the Mass of the particle

Expected Separation

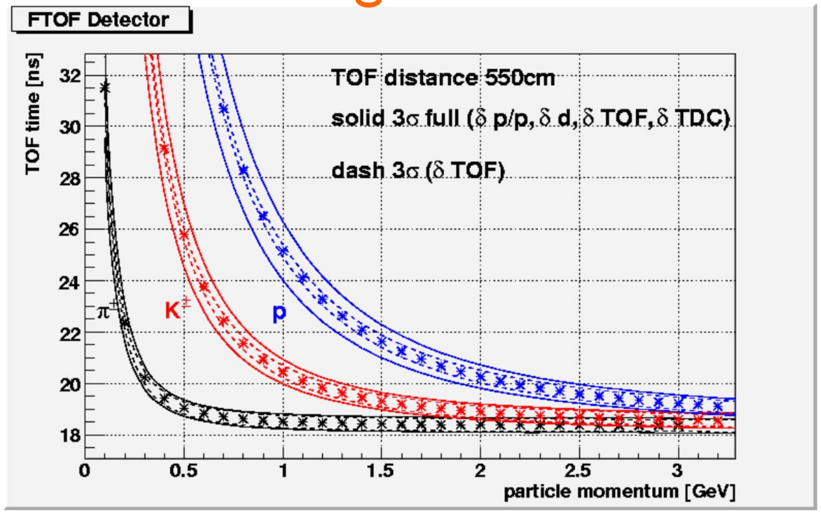


Barrel Calorimeter



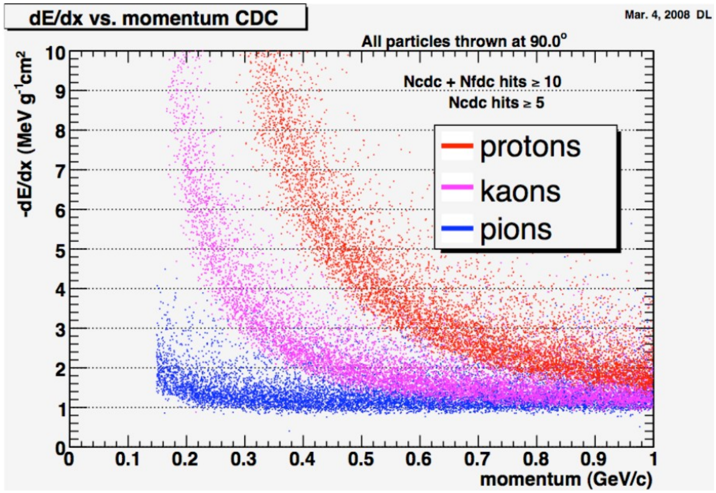
PID is done primarily through time of flight with some help from dE/dx in chambers. Space left in design for future PID detector

Time-of-Flight

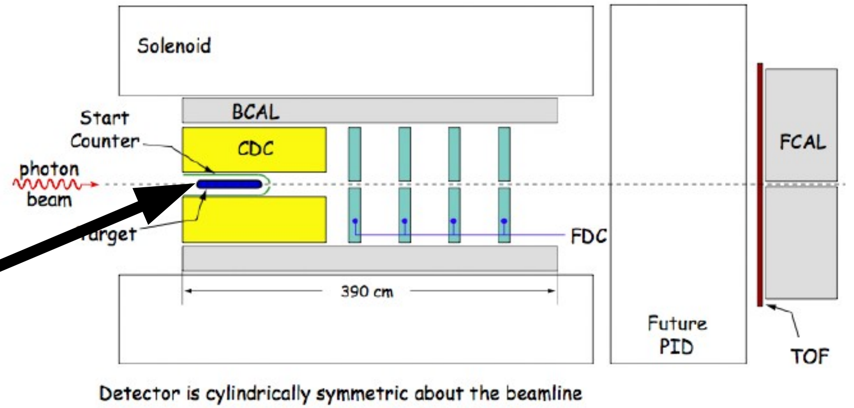


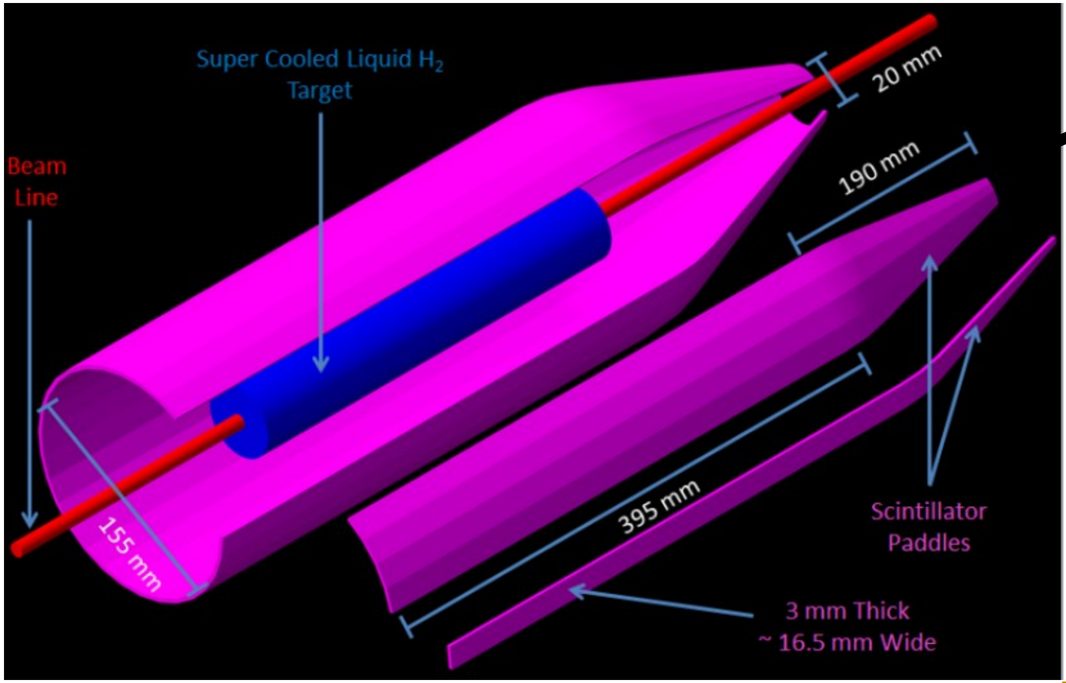
Central Drift Chamber

CDC dE/dx

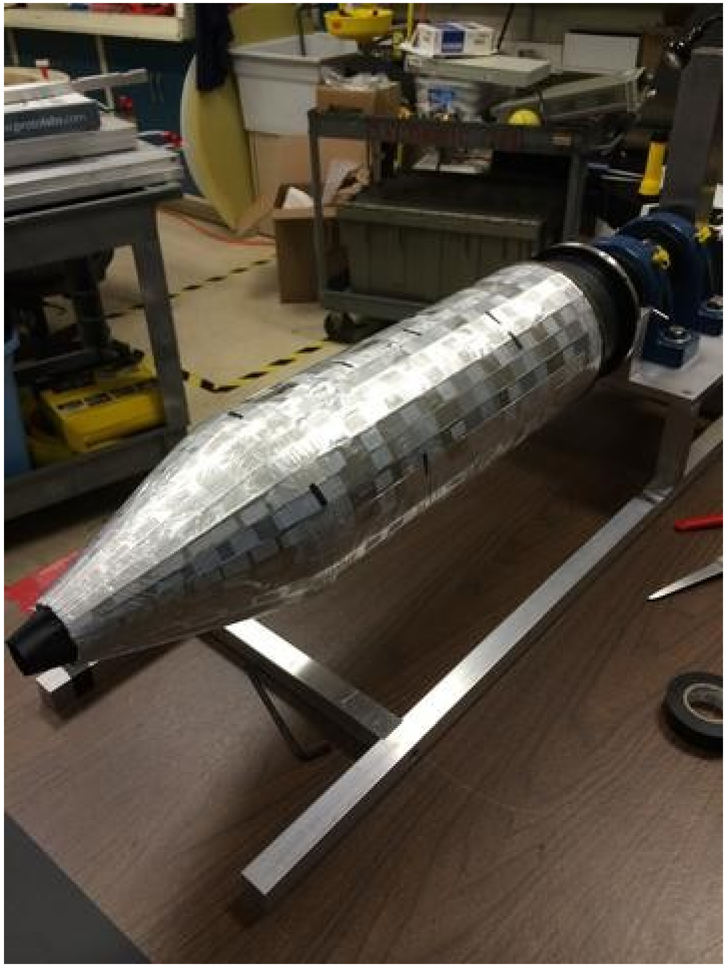


Start Counter



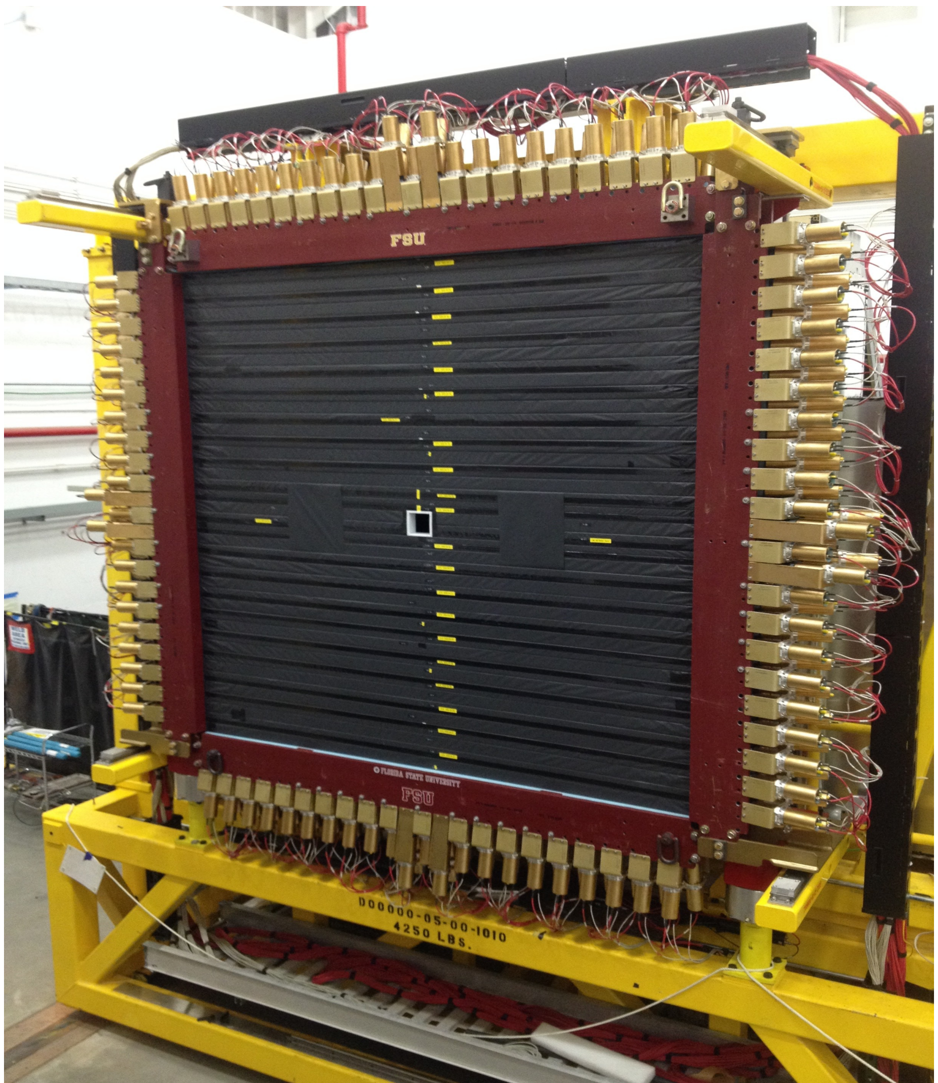


FIU
FLORIDA INTERNATIONAL UNIVERSITY



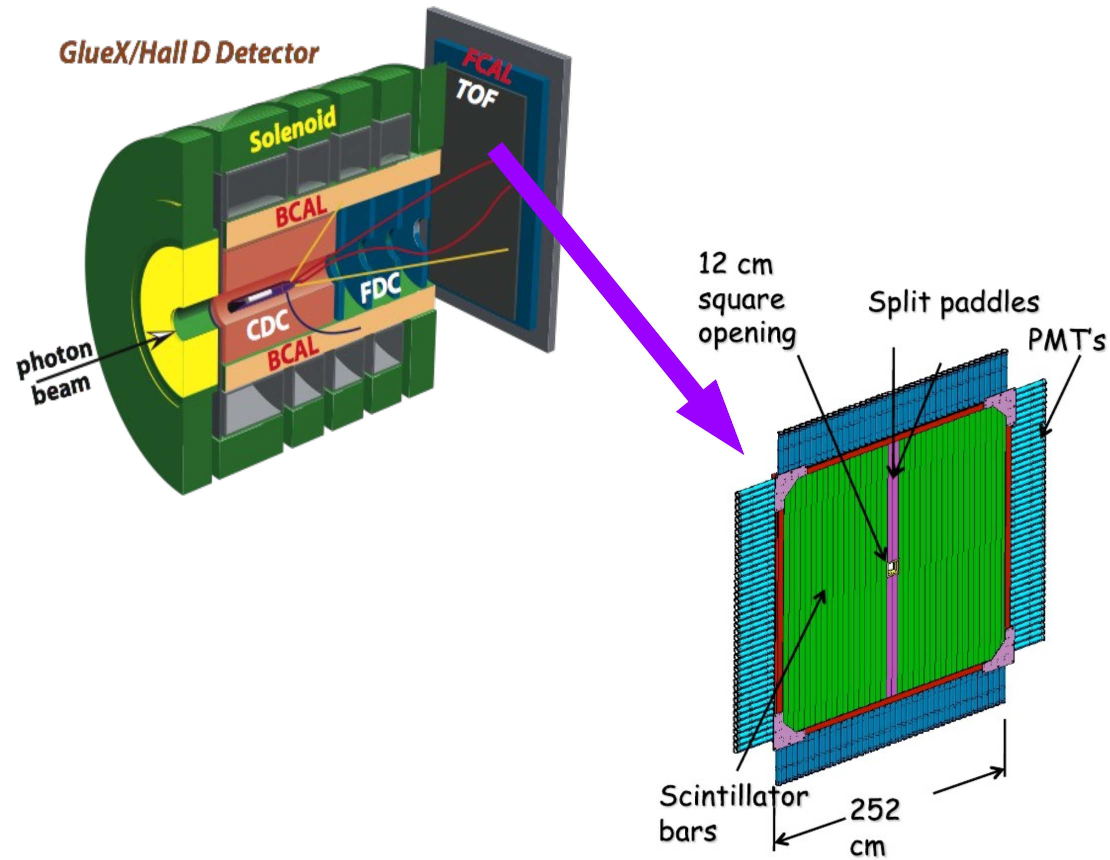
- **40 scintillators paddles to tag the accelerator beam bunch**
- **300 ps (w/tracking)**

Time-of-Flight Wall

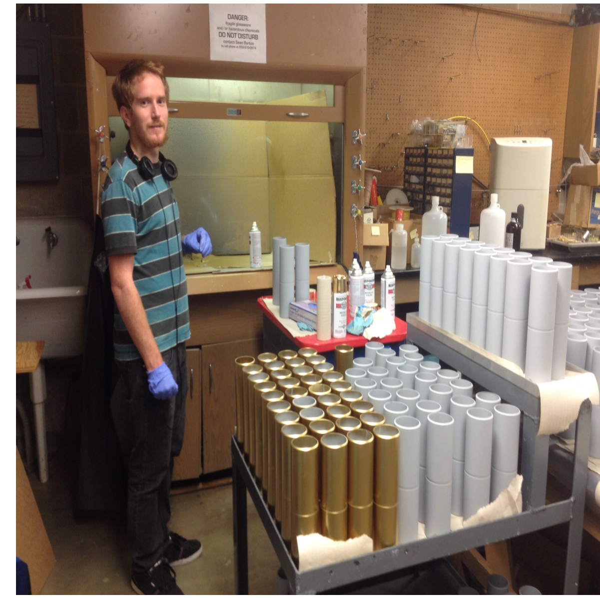


TOF Detector Overview

- Particle id (π/K/p) up to 2-3 GeV/c at 4σ
- Two independent TOF planes: horizontal and vertical (~3m x 3m)
- 92 modules with 176 H10534 Hamamatsu PMTs
- 176 fADC (250 MHz) and TDC (25 psec) readout channels
- Angular coverage $2^{o} < \theta < 11^{o}$



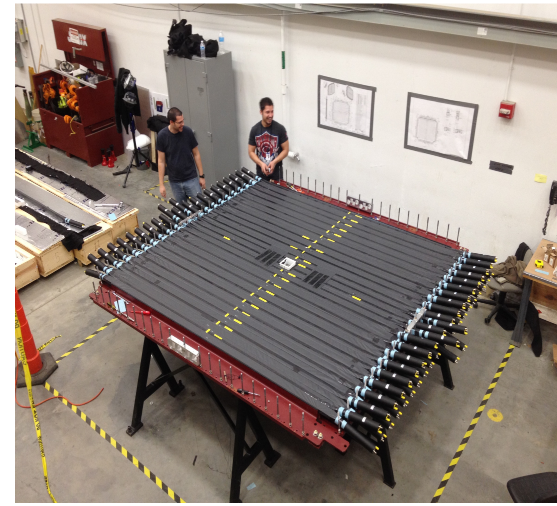
Time-of-Flight Construction at FSU



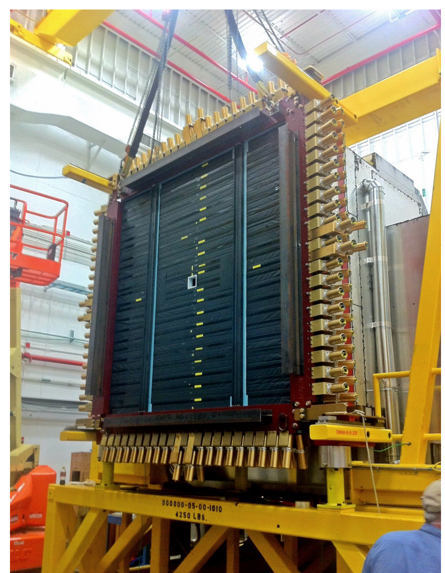
TOF construction

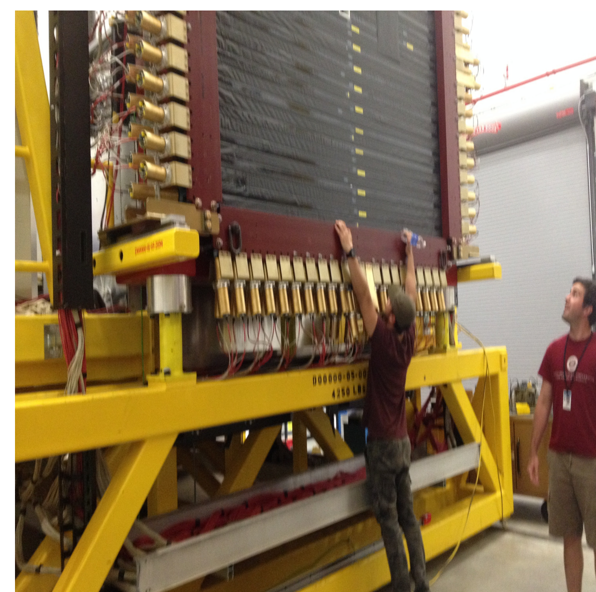
Fall 2013 completion and tested of modules

Time-of-Flight Assembly & Installation by FSU



Spring 2014 assembly & installation

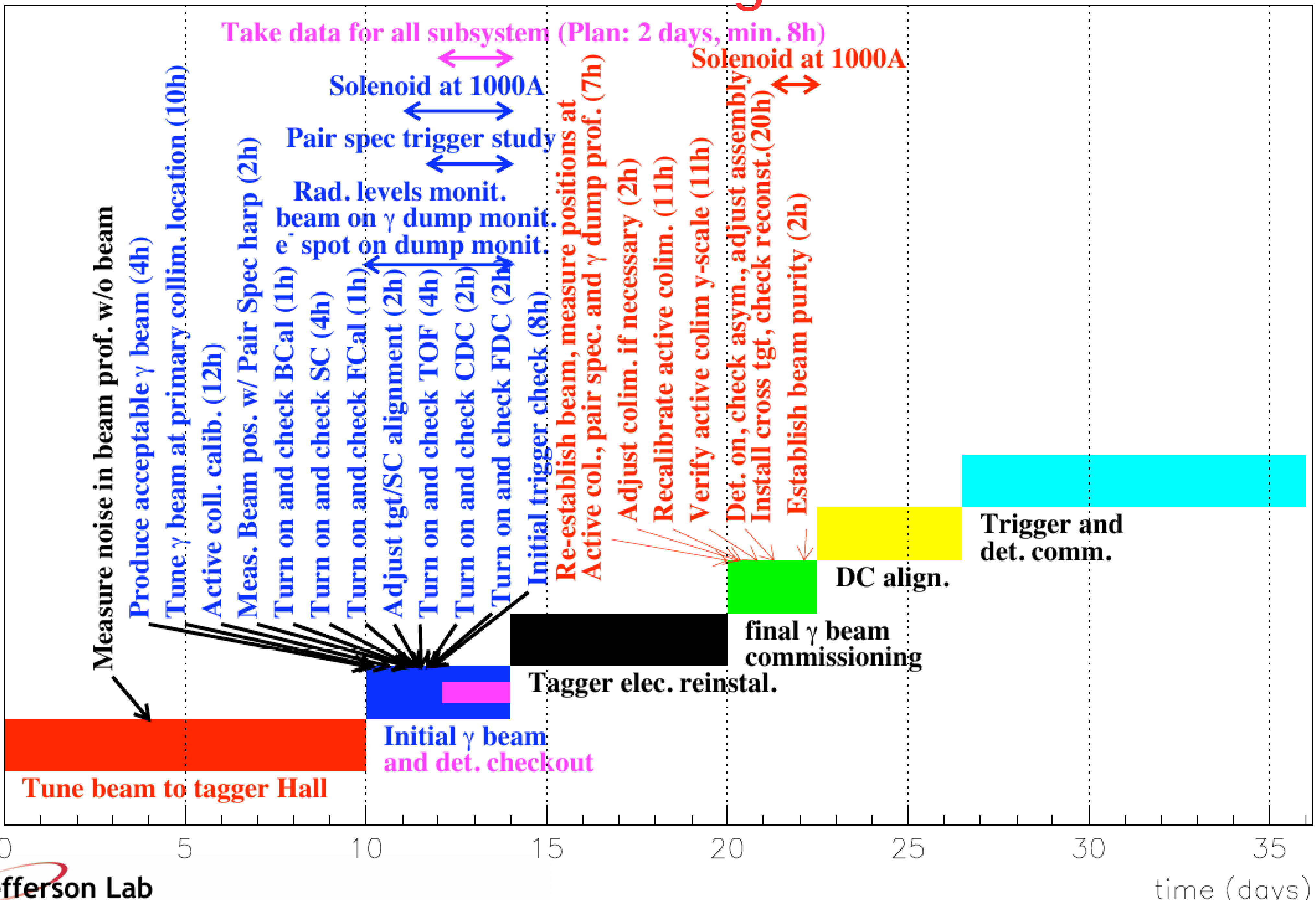




Fall 2014 Commissioning Goals

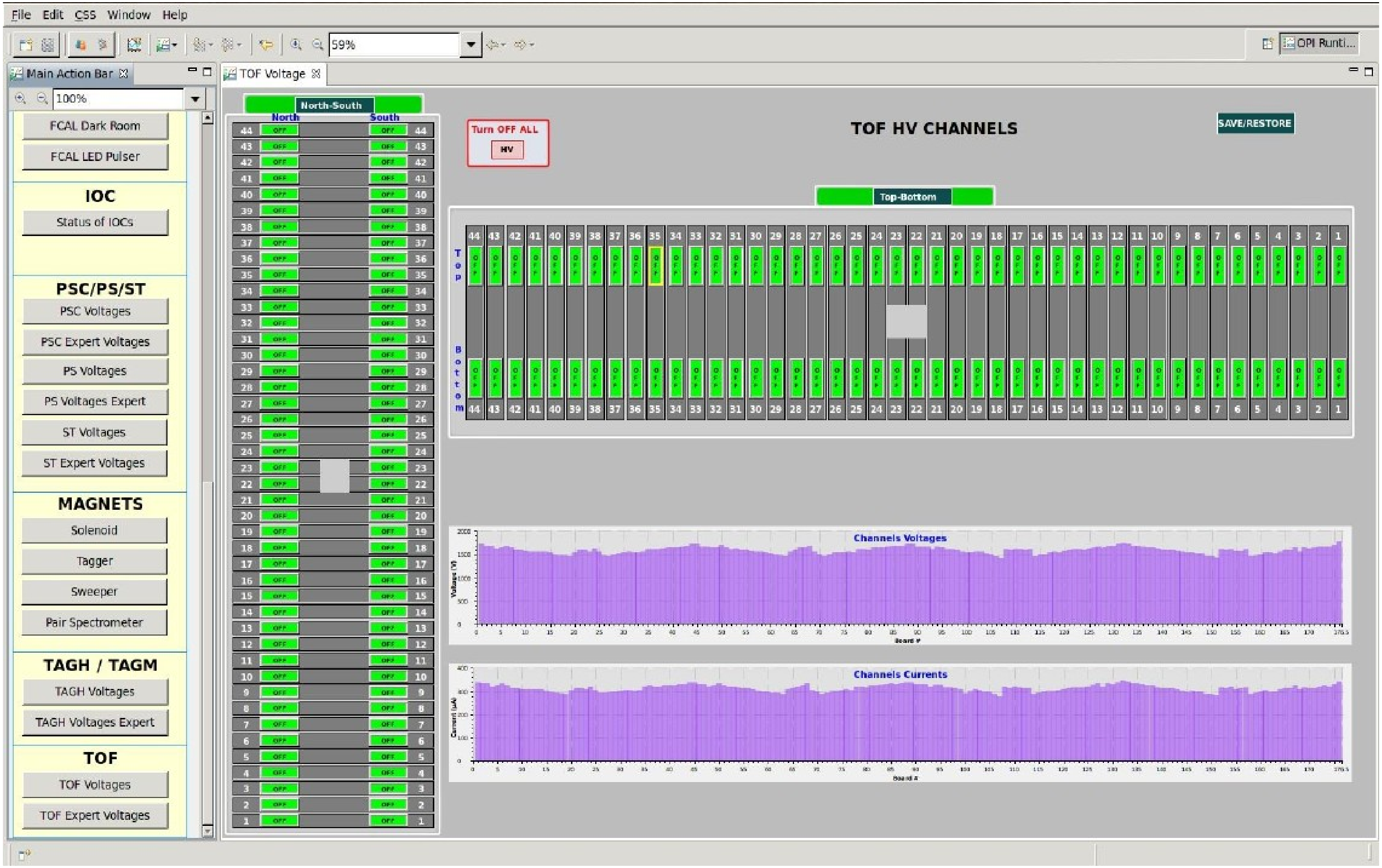
- CW electron beam to tagger with acceptable radiation levels (~10.5 GeV).
- Create unpolarized photon beam and tune it through:
  - Collimators
  - Target location
  - Photon beam dump
- Detectors and trigger check out, optimization, calibration and alignment.

Commissioning time-line

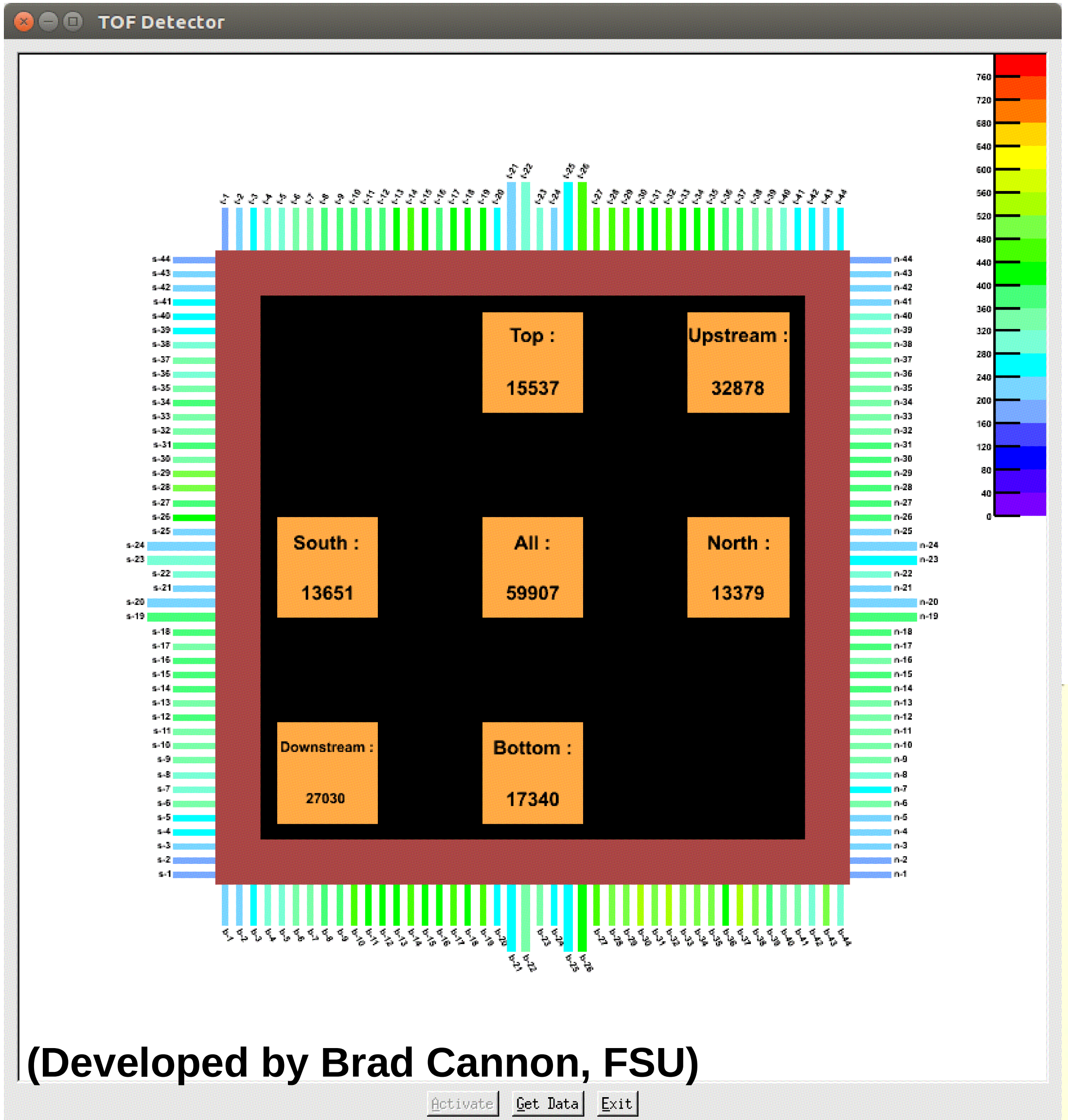


TOF Calibration and Commissioning

TOF Voltage Controls



Discriminator Scaler Read-out and Viewer



(Developed by Brad Cannon, FSU)

Discriminator Scaler Viewer

Example from Cosmic Events

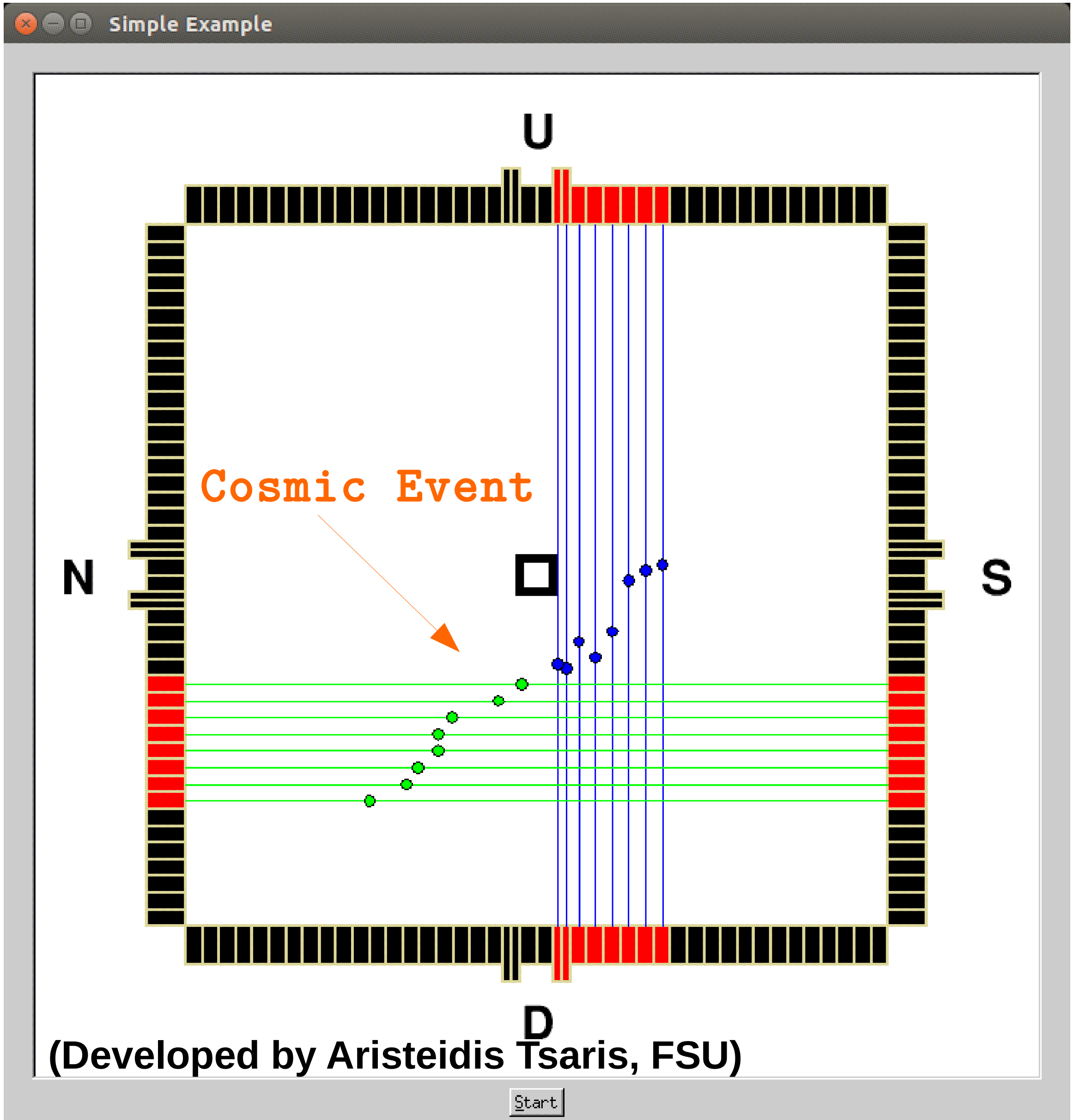
Scaler Read-out

n-6 321	n-7 278	n-8 314	n-9 334	n-10 350	n-11 322
n-17 372	n-18 370	n-19 376	n-20 214	n-21 228	n-22 285
n-28 395	n-29 378	n-30 382	n-31 374	n-32 352	n-33 341
n-39 286	n-40 282	n-41 234	n-42 227	n-43 203	n-44 182
s-6 335	s-7 292	s-8 302	s-9 342	s-10 344	s-11 328
s-17 355	s-18 377	s-19 373	s-20 215	s-21 220	s-22 308
s-28 492	s-29 494	s-30 357	s-31 360	s-32 347	s-33 332
s-39 268	s-40 262	s-41 254	s-42 216	s-43 200	s-44 164
t-6 320	t-7 355	t-8 381	t-9 381	t-10 395	t-11 387
t-17 429	t-18 431	t-19 439	t-20 245	t-21 233	t-22 307
t-28 455	t-29 451	t-30 433	t-31 434	t-32 461	t-33 426
t-39 337	t-40 292	t-41 276	t-42 245	t-43 209	t-44 252

Bottom 1-44:

b-1 213	b-2 238	b-3 267	b-4 287	b-5 319	b-6 324	b-7 357	b-8 364	b-9 374	b-10 441	b-11 429
b-12 420	b-13 438	b-14 464	b-15 427	b-16 437	b-17 460	b-18 426	b-19 453	b-20 250	b-21 252	b-22 330
b-23 321	b-24 252	b-25 262	b-26 432	b-27 471	b-28 488	b-29 509	b-30 524	b-31 483	b-32 553	b-33 483
b-34 510	b-35 486	b-36 432	b-37 545	b-38 481	b-39 376	b-40 357	b-41 328	b-42 287	b-43 506	b-44 281

TOF Stand Alone Viewer

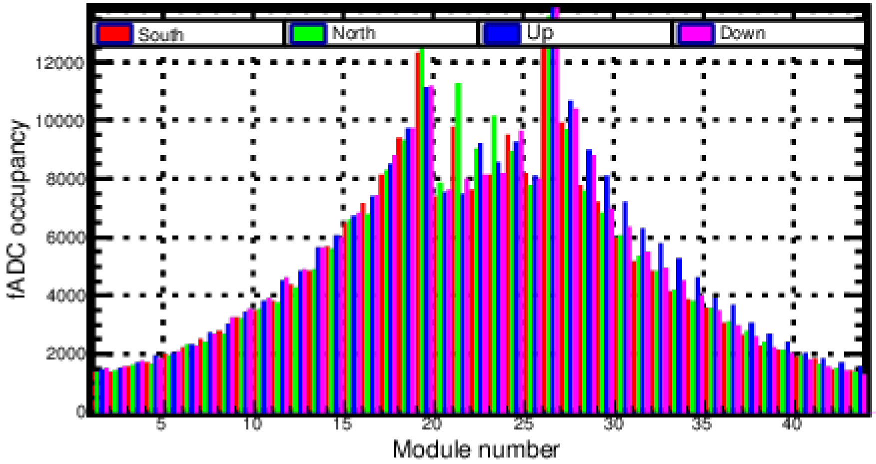


$$\Delta_t = \frac{t_{\text{TDC, Left}} - t_{\text{TDC, Right}}}{2}$$

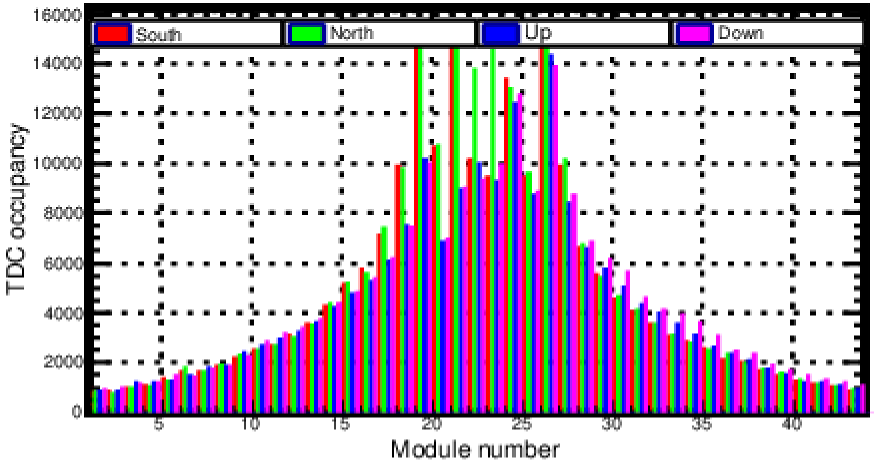
$$x = V_{effective} \Delta_t$$

TOF Monitoring

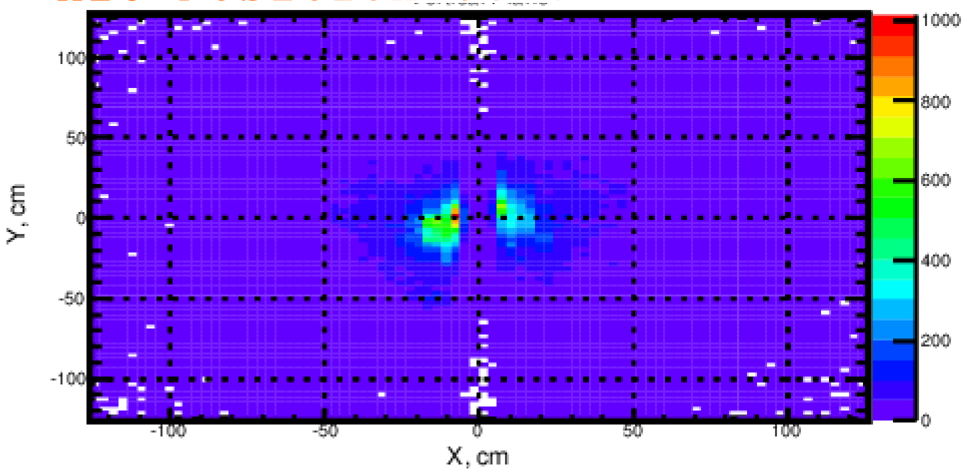
fADC Occupancy



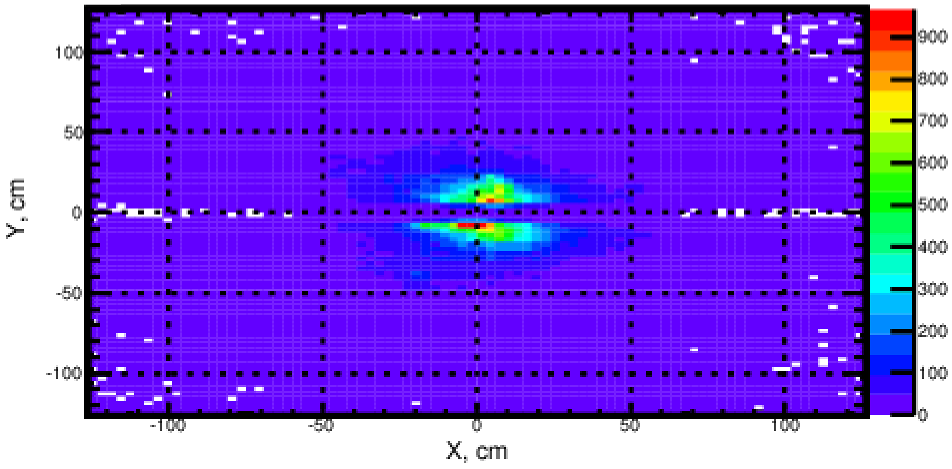
TDC Occupancy



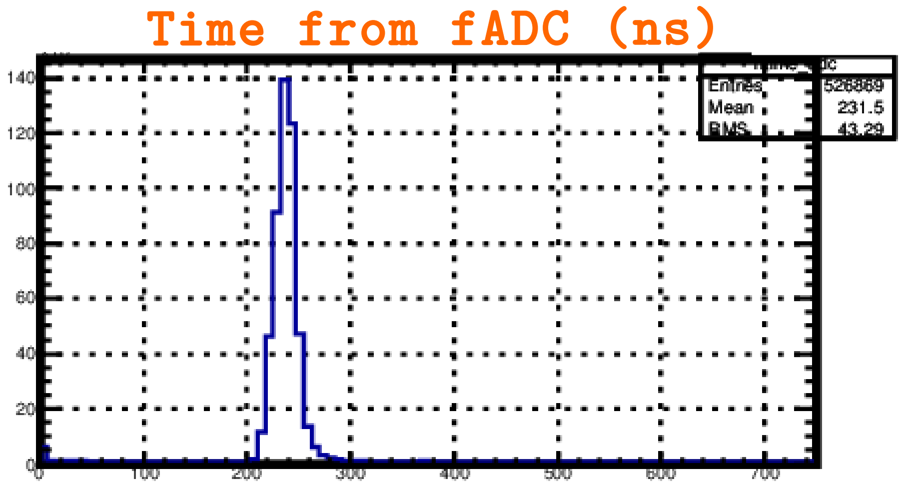
Hit Position Vertical Plane

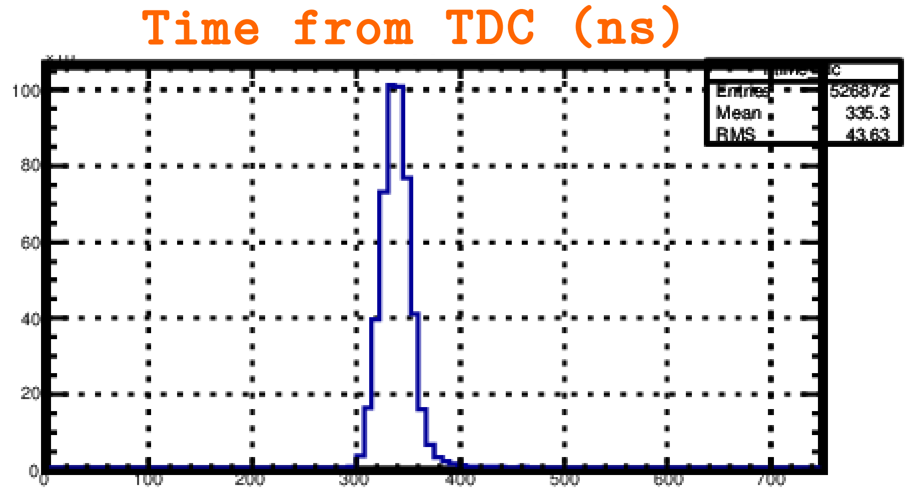


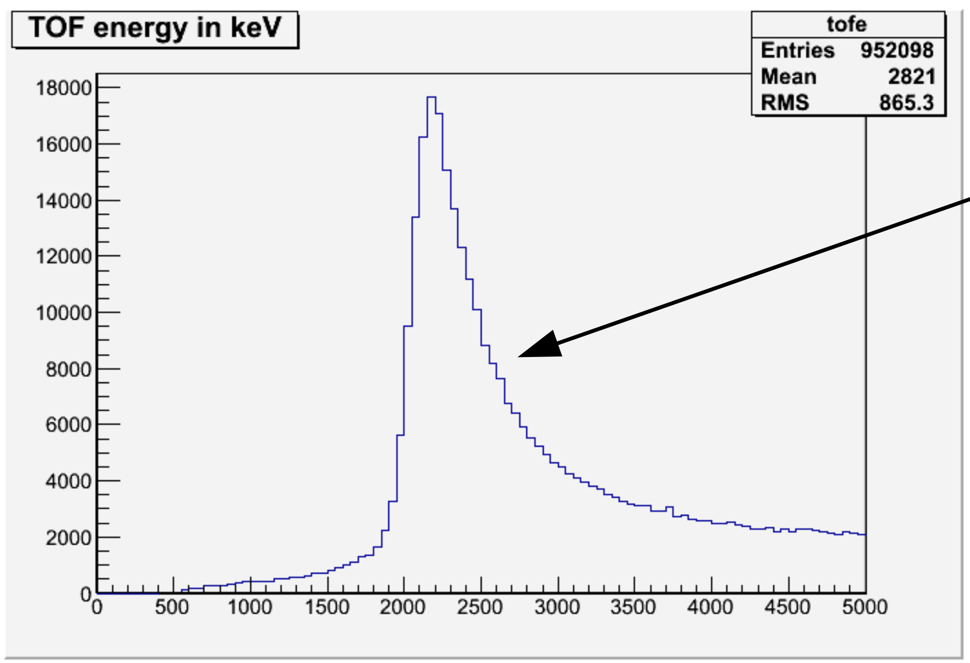
Hit Position Horizontal Plane



TOF Monitoring



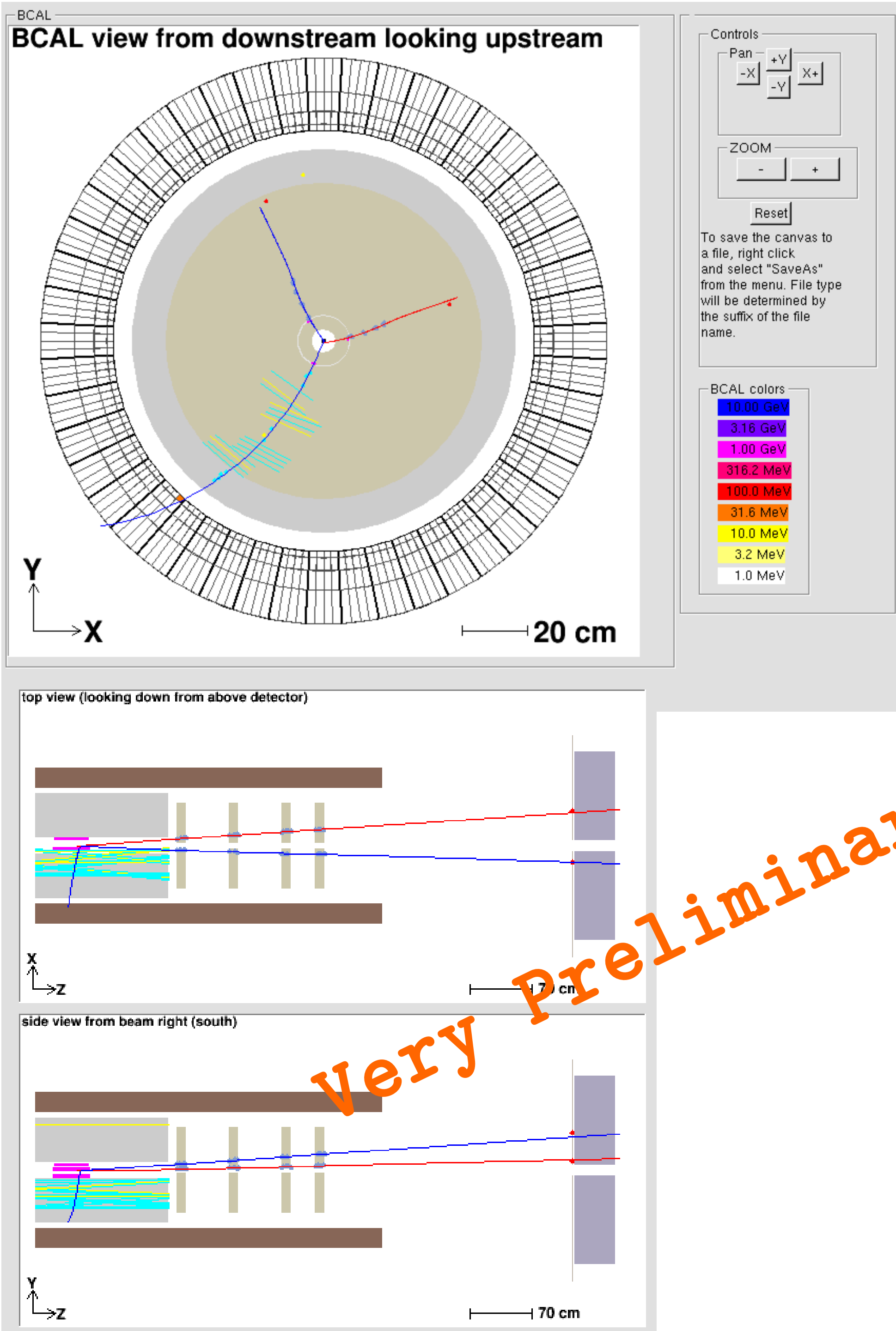


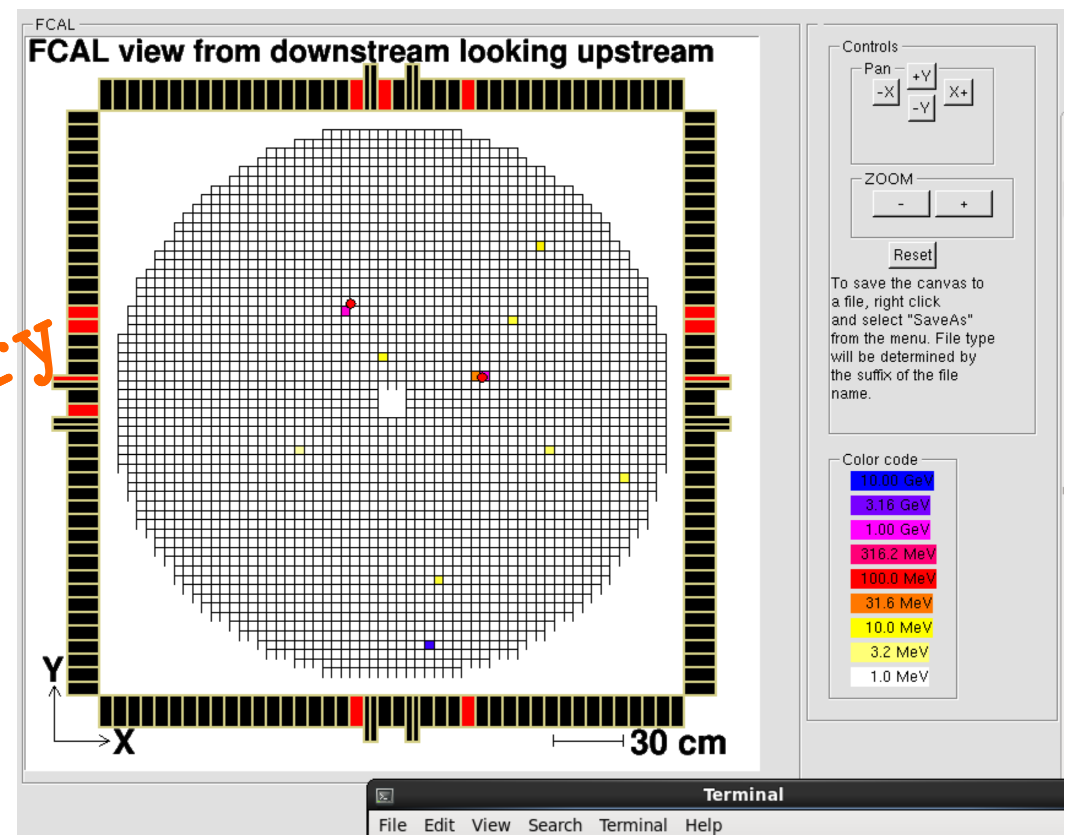


the expected Landau shape for all channels

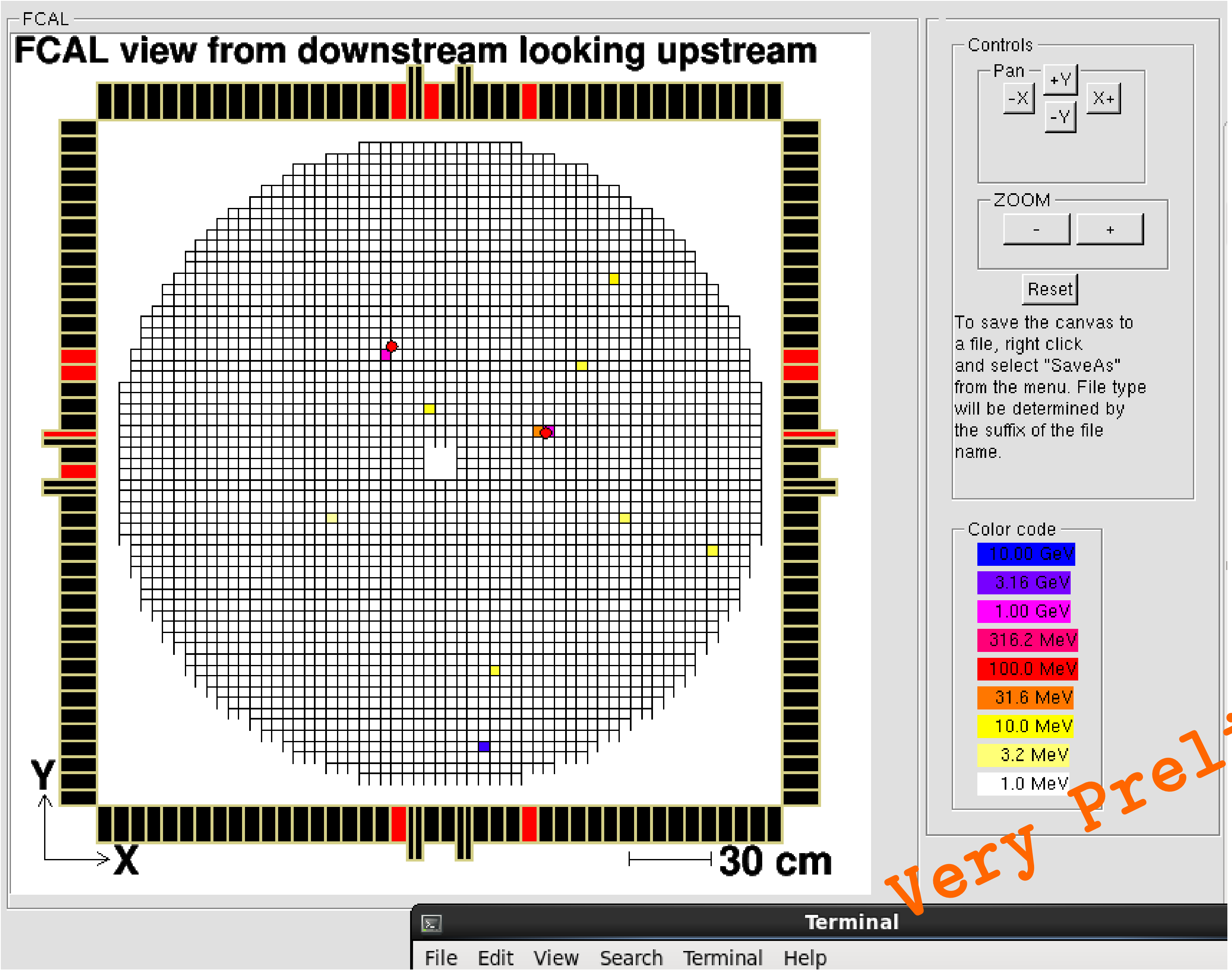
Hall-D Event Display

A week old event





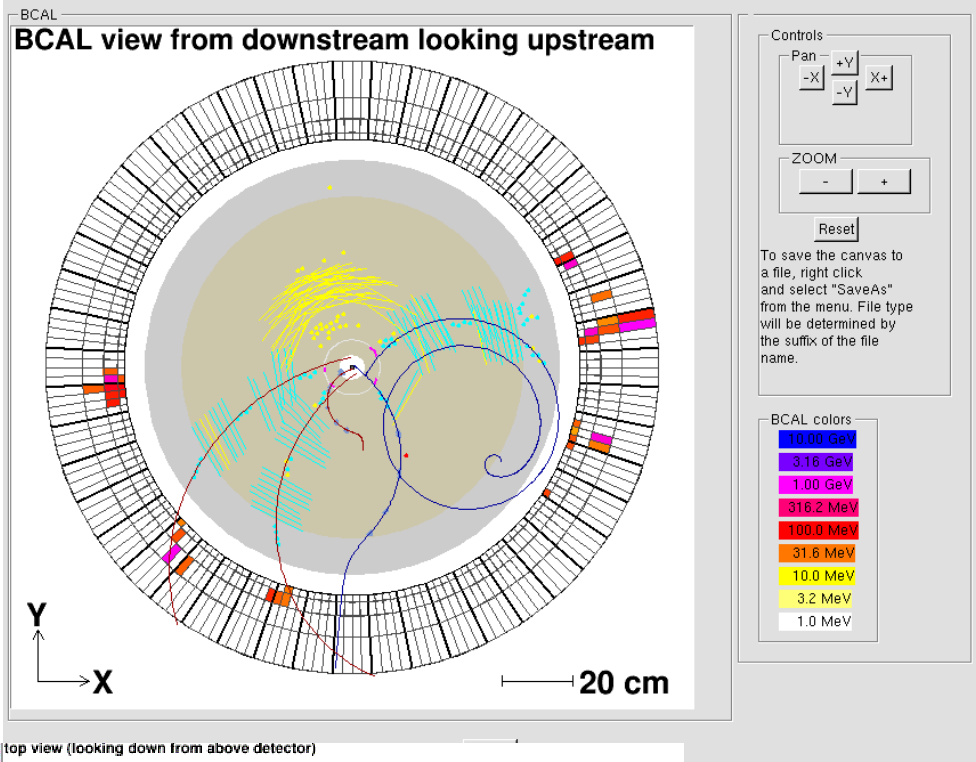
Hall-D Event Display

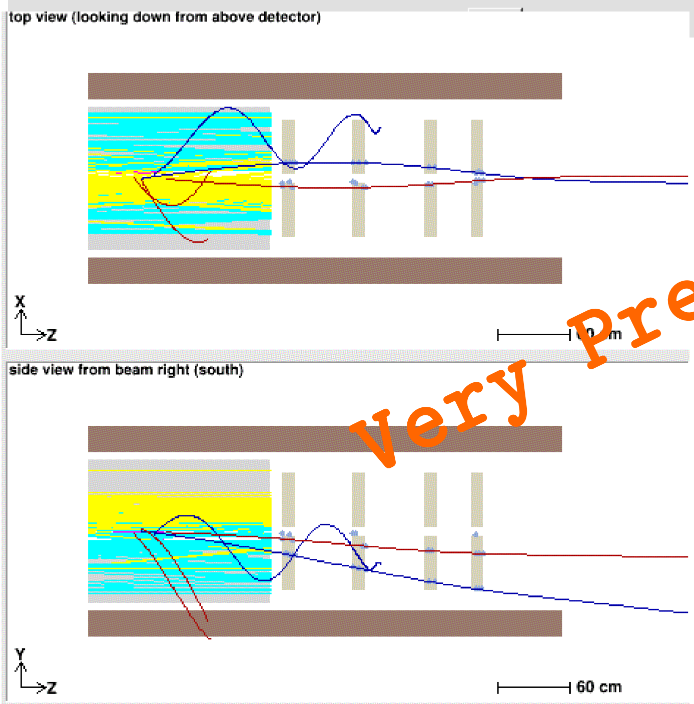


(Implemented by Aristeidis Tsaris, FSU)

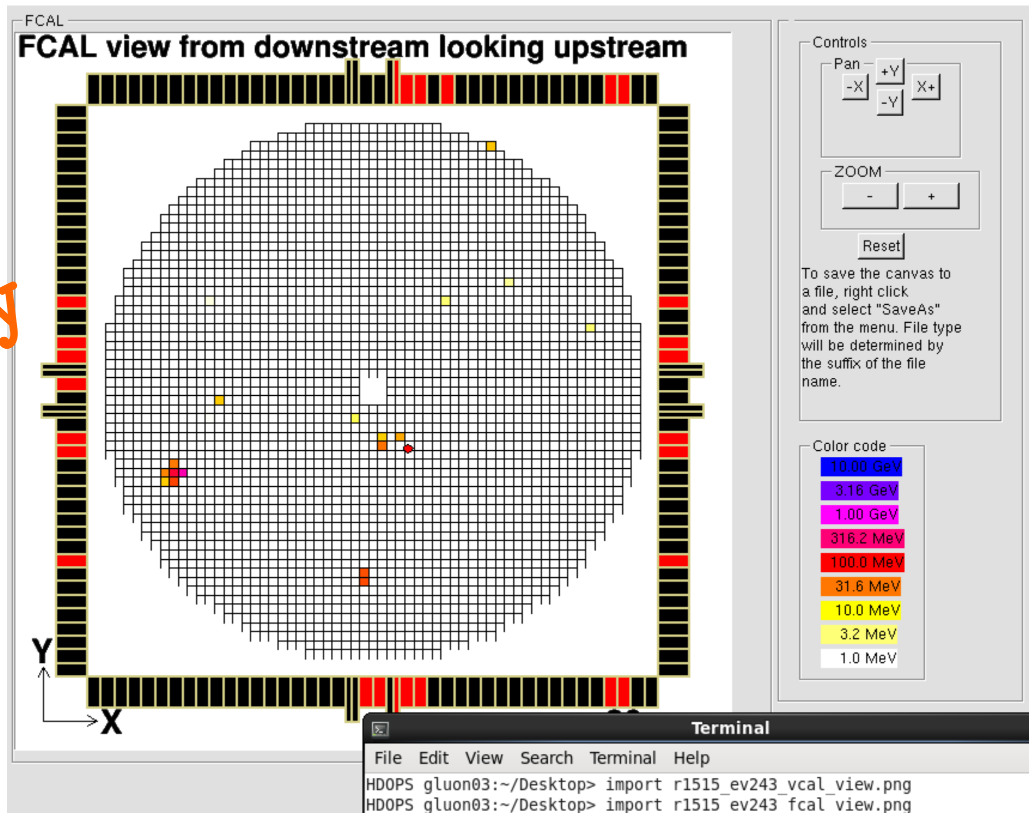
Hall-D Event Display

A week old event





Very Preliminary



Timing PID with SC-TOF coincidence

Very Preliminary

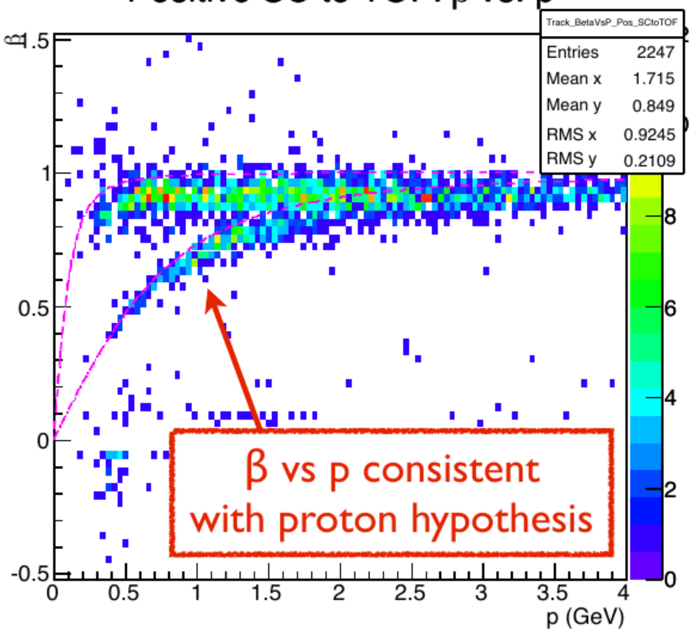
Use SC as t_0 and β is calculated with the SC and TOF times and path lengths between SC and TOF

$$\beta = \frac{pathlength(TOF - SC)}{c \cdot (t_{TOF} - t_{SC})}$$

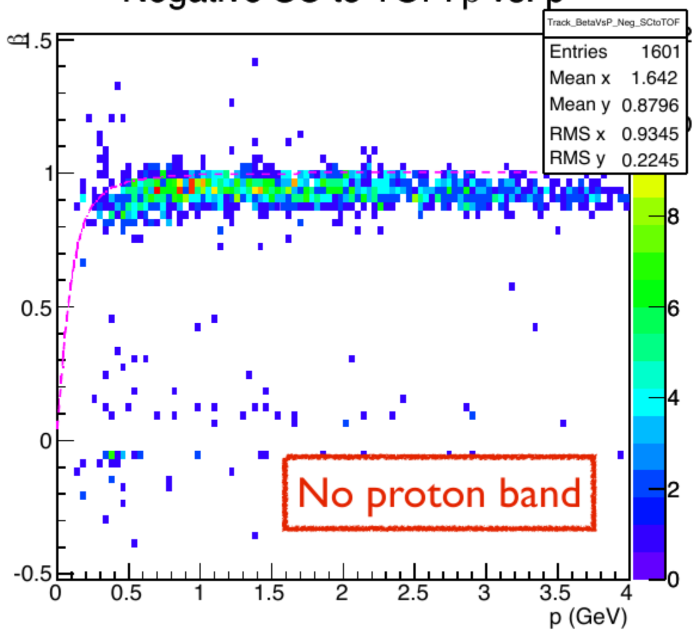
Dataset with solenoid at 1200 A:

- **BCAL trigger**
- **8.5 M events with BCAL trigger**
- **Tracking FOM >** 10^{-4}
- **POCA to beam line: 50 < Z < 80 cm**
- **Using only fADC hits**
- **Require track has matched hit in SC and TOF**

Positive SC to TOF: β vs. p



Negative SC to TOF: β vs. p



$$\beta = \frac{p}{\sqrt{p^2 + m^2}}$$

Data from 11/25/2014

Future Plans – Spring 2015 Commissioning Run

- We want to have the best calibration we can get at the start of this run.
- We would like to come into with our calibration and alignment procedures working.
- Our ultimate goal is to achieve physics quality data at some point during this run.

JEFFERSON LAB ELECTRONIC LOGBOOK

https://logbooks.jlab.org/book/halld

Experimental evidence for 1^{-+} exotic

$\pi_1(1400)$ $I^G(J^{PC}) = 1^-(1^{-+})$

Unlikely Hybrid
Dynamical origin?

See also the mini-review under non-$q\bar{q}$ candidates in PDG 06, Journal of Physics, G **33** 1 (2006).

$\pi_1(1400)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*CHG*	*COMMENT*
1354 ±25	**OUR AVERAGE**	Error includes scale factor of 1.8. See the ideogram below.			

$\pi_1(1600)$ $I^G(J^{PC})$

May be hybrid
Challenge in 3π
to separate exotic π_1 from π_2
Cleaner $\eta'\pi$ signal

$\pi_1(1600)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*
1662^{+8}_{-9} OUR AVERAGE			

$\pi_1(2015)$ $I^G(J^{PC}) = 1^-(1^{-+})$

MASS (MeV)	*WIDTH* (MeV)	*EVTS*	*DOCUMENT IL*
$2014 \pm 20 \pm 16$	$230 \pm 32 \pm 73$	145k	LU
$2001 \pm 30 \pm 92$	$333 \pm 52 \pm 49$	69k	KUHN

Listed among
"further states"
Needs confirmation

p
$\pi^- p$

GlueX Data Rates

		Front End DAQ Rate	Event Size	L1 Trigger Rate	Bandwidth to mass Storage	
JLab	GlueX	3 GB/s	15 kB	200 kHz	300 MB/s	private comm.
	CLAS12	0.1 GB/s	20 kB	10 kHz	100 MB/s	
LHC	ALICE	500 GB/s	2,500 kB	200 kHz	200 MB/s	CHEP2007 talk Sylvain Chapelin
	ATLAS	113 GB/s	1,500 kB	75 kHz	300 MB/s	
	CMS	200 GB/s	1,000 kB	100 kHz	100 MB/s	
	LHCb	40 GB/s	40 kB	1000 kHz	100 MB/s	
BNL	STAR	50 GB/s	1,000 kB	0.6 kHz	450 MB/s	*
	PHENIX	0.9 GB/s	~60 kB	~ 15 kHz	450 MB/s	**

* Jeff Landgraf Private Comm. 2/11/2010
** CHEP2006 talk Martin L. Purschke. current capability is 800MB/s peak, 500MB/s sustained (priv. comm. 2/14/2010)