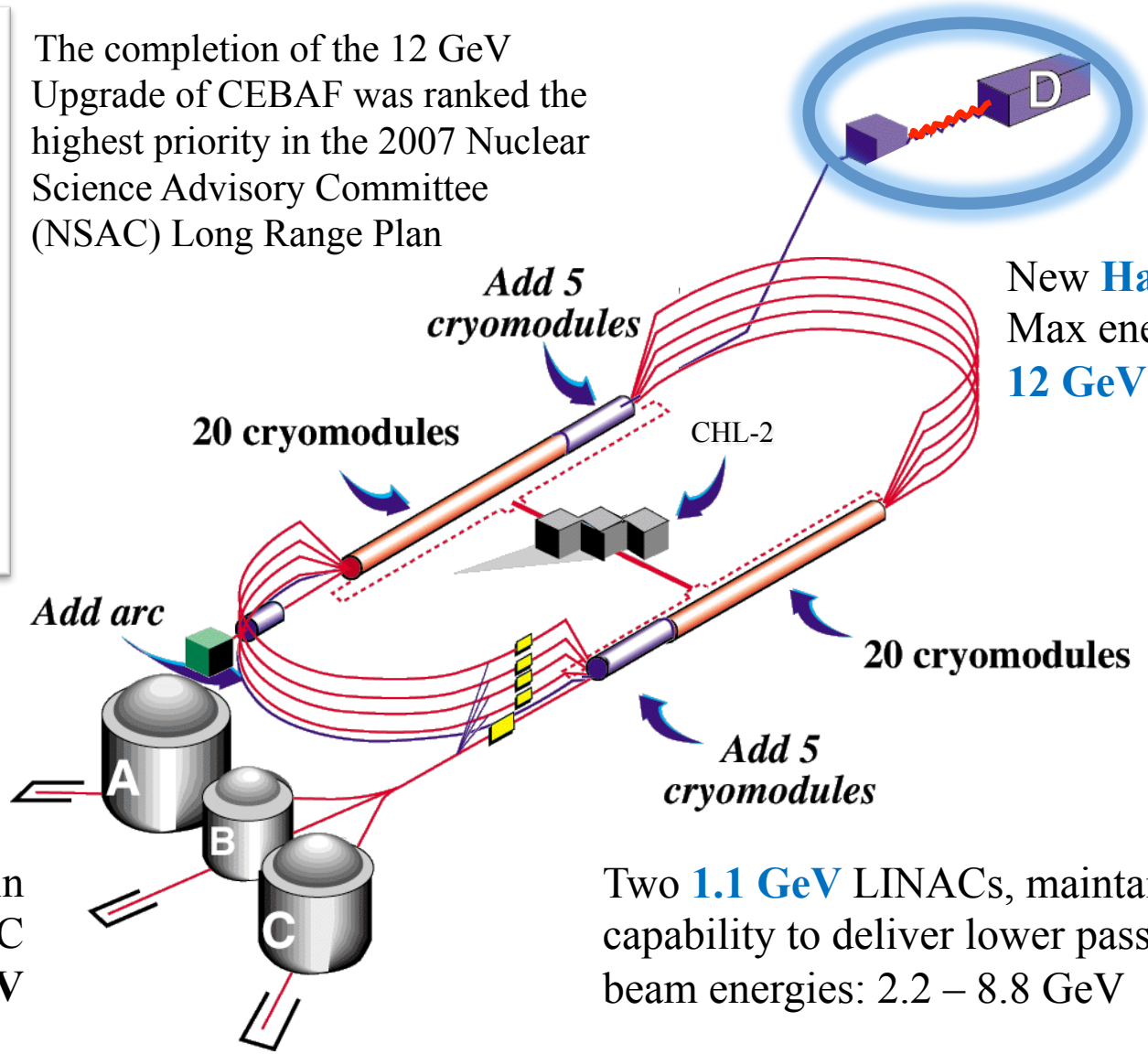
Vladimir Berdnikov

Commissioning of the Pair Spectrometer of the GlueX experiment

Jefferson Lab 12 GeV Upgrade

The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 Nuclear Science Advisory Committee (NSAC) Long Range Plan



New **Hall-D**
Max energy:
12 GeV

Enhanced capabilities in existing Halls A/B/C
Max energy: **11 GeV**

Two **1.1 GeV** LINACs, maintain capability to deliver lower pass beam energies: 2.2 – 8.8 GeV

Hall D Physics Program: Approved Experiments

Experiment	Name	Days	Condition	Target
E12-06-102	Mapping the spectrum of light quark mesons and gluonic excitations with Linearly polarized photons	120		LH_2
E12-12-002 E12-13-003	A study of meson and baryon decays to strange final states with GlueX in Hall D	220 (200)	L3 trigger PID	LH_2
E12-10-011	A precision measurement of the η radiative decay width via the Primakoff effect	79		LH_2 LHe_4
E12-13-008	Measuring the charged pion polarizability in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction	25		Sn
C12-14-004 (conditionally approved)	Eta decays with emphasis on rare neutral modes: The JLab Eta Factory experiment (JEF)	(130)	Upgrade Forward calorim.	LH_2

GlueX Collaboration in Hall D

- Arizona State
- Athens
- Carnegie Mellon
- Catholic University
- University of Connecticut
- Florida International
- Florida State
- George Washington
- Glasgow
- GSI
- Indiana University
- ITEP
- Jefferson Lab
- University Mass Amherst
- MIT
- **NRNU MEPhI**
- Norfolk State
- North Carolina A&T
- University North Carolina Wilmington
- Northwestern
- University of Regina
- Santa Maria
- Tomsk
- Yerevan Physics Institute
- College of William and Mary
- Wuhan University

International collaboration from 24 institutions

Two more groups are currently joining

Hall D Timeline

✓ First commissioning data in Fall 2014 / Spring 2015

- Beamline / detector commissioning
- Beam energy below 6 GeV
- Some liner polarization

✓ Commissioning run in Fall 2015 / Spring 2016

- 12-GeV electron beam
- Linearly polarized photon beam
- Low luminosity (5 times smaller)
- GlueX commissioning completed

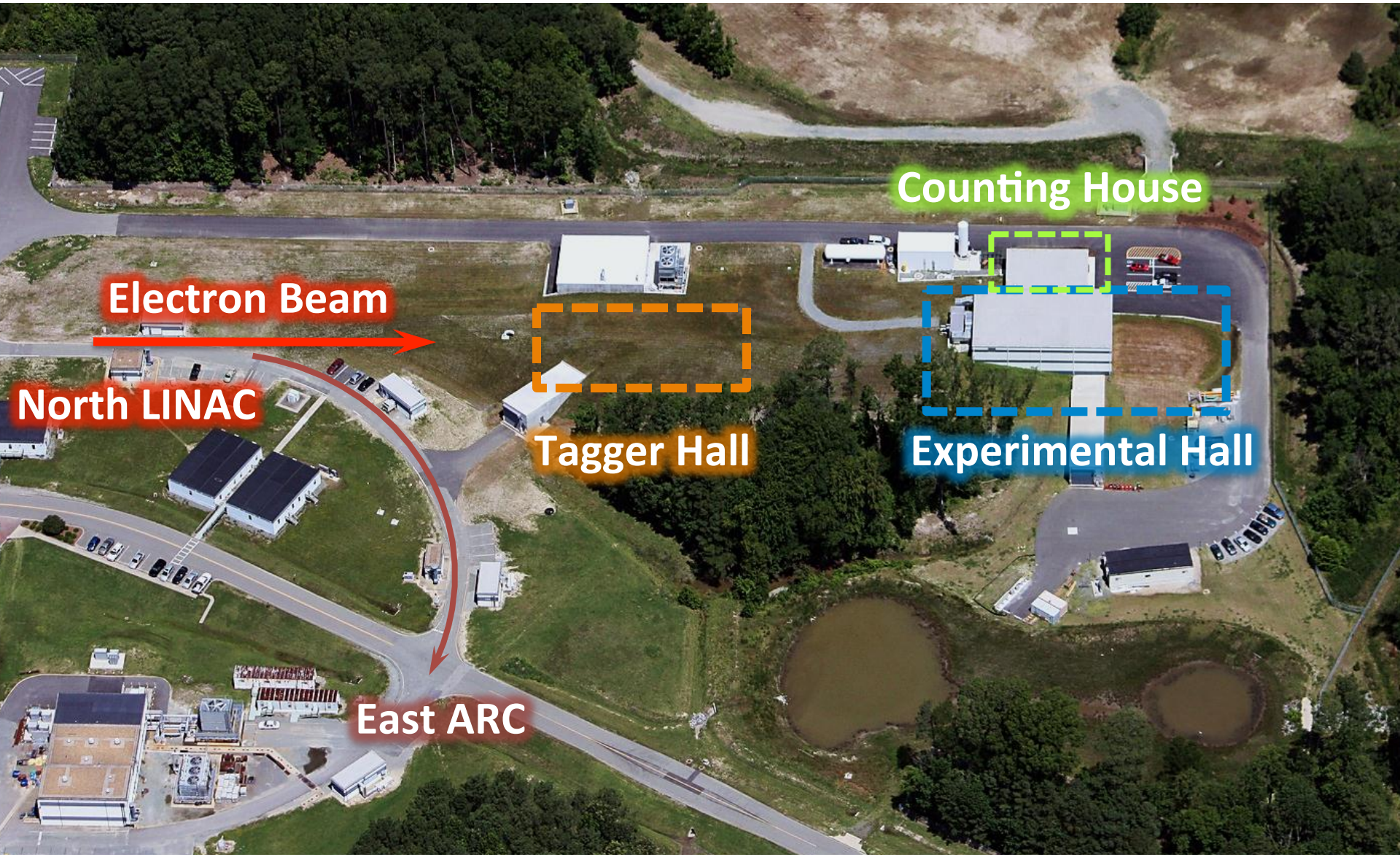
➢ Physics running: Fall 2016 - Spring 2018

➢ PrimEx D Experiment: Fall 2018 (Plan)

➢ High intensity GlueX running: Starting in spring 2019 (Plan)

- Upgrade kaon identification in 2018

Hall-D Complex



GlueX Spectrometer: Design Requirements

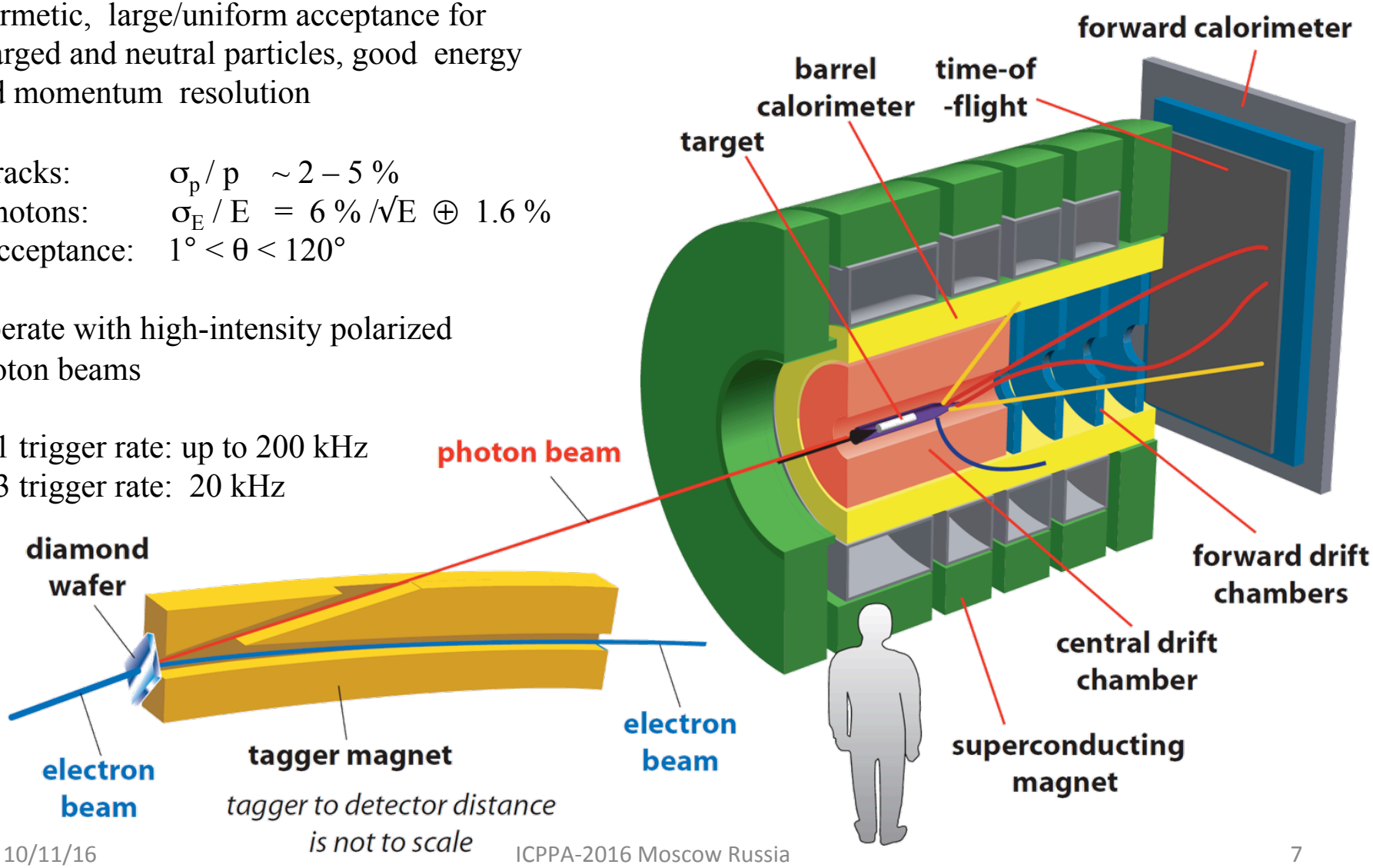
- Optimized to detect multi-particle final states

- Hermetic, large/uniform acceptance for charged and neutral particles, good energy and momentum resolution

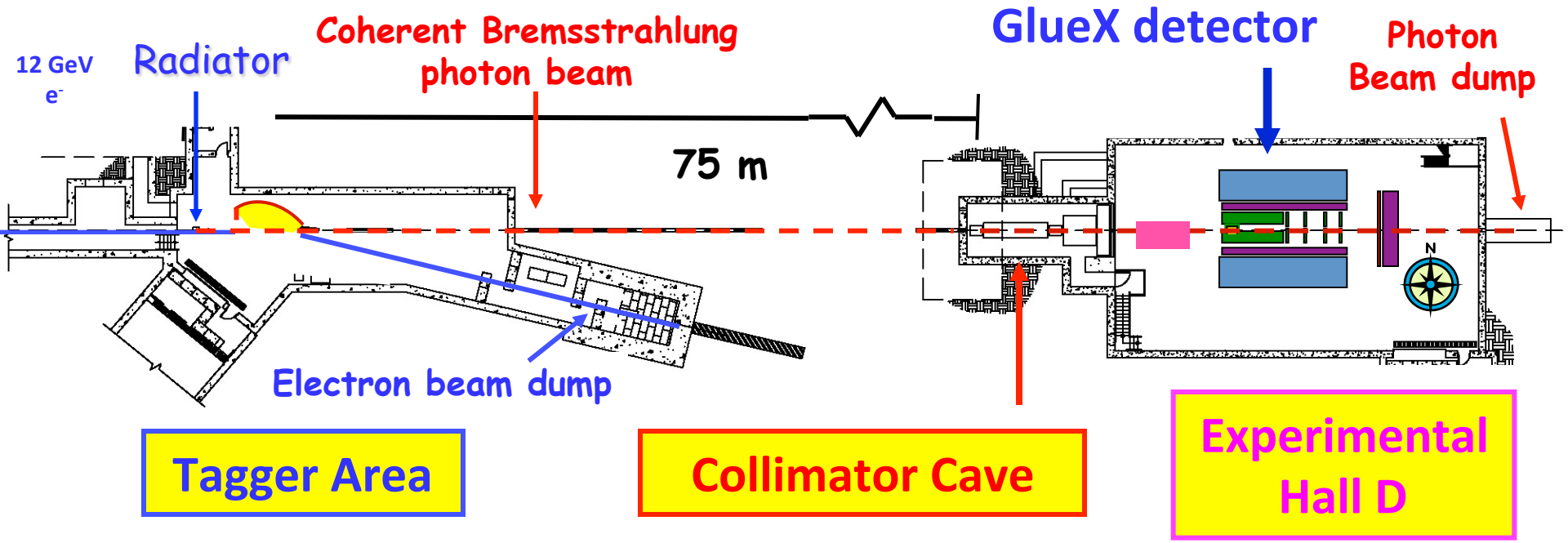
  Tracks: $\sigma_p / p \sim 2 - 5\ \%$
  Photons: $\sigma_E / E = 6\ \% / \sqrt{E} \oplus 1.6\ \%$
  Acceptance: $1° < \theta < 120°$

- Operate with high-intensity polarized photon beams

  L1 trigger rate: up to 200 kHz
  L3 trigger rate: 20 kHz



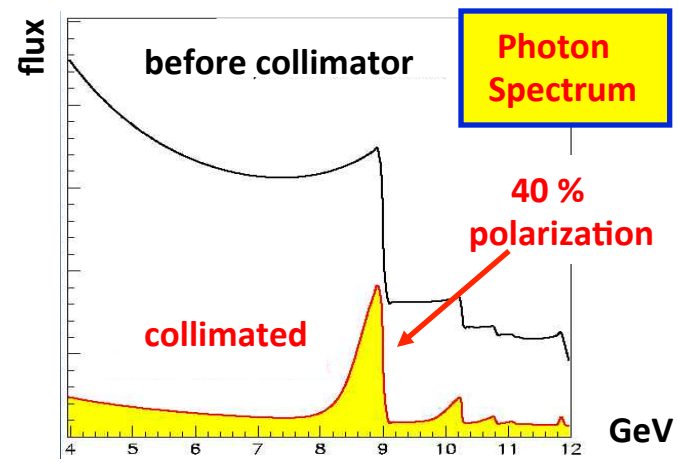
Polarized Photon Beam



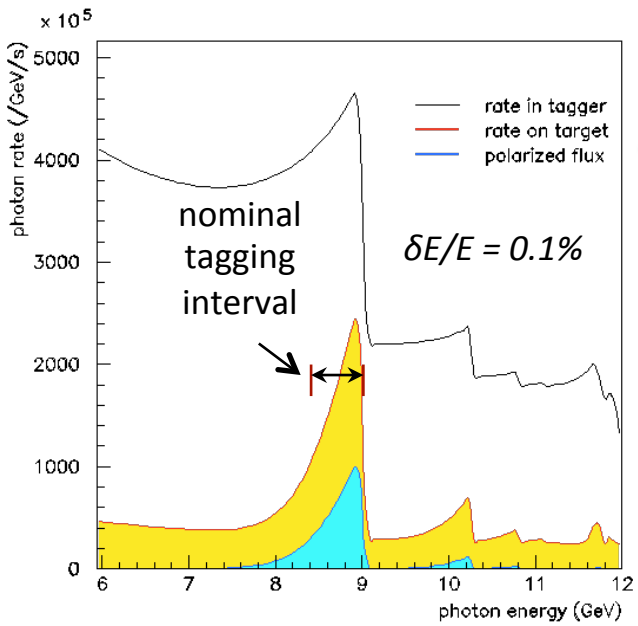
- Beam photons are produced by 12 GeV electrons (I < 1.1 μA) on a thin diamond crystal (20 – 50 μm)
- Photon energy: detect bremsstrahlung electrons

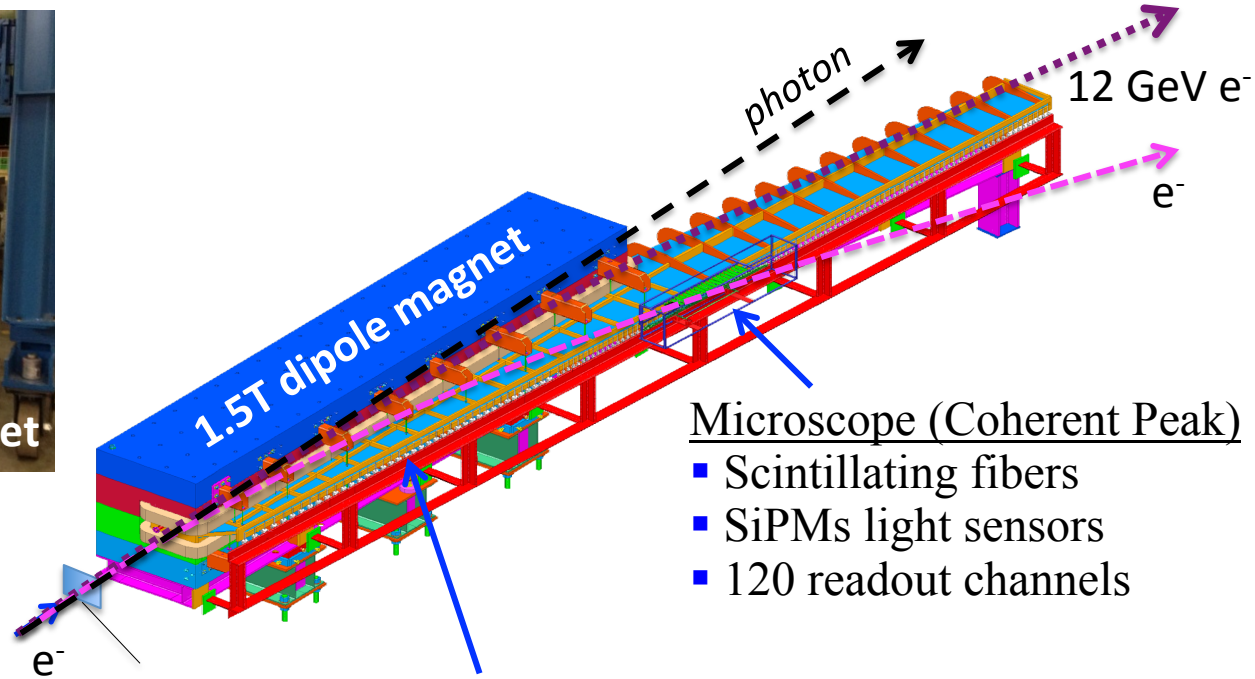
$$\Delta E / E \sim 10^{-3}$$

- Pass beam photons through the collimator
  - increase the fraction of linearly polarized photons
  - beam intensity: $5 \cdot 10^7$ γ/sec for $8.4 < E_\gamma < 9.1$ GeV



Photon Tagger



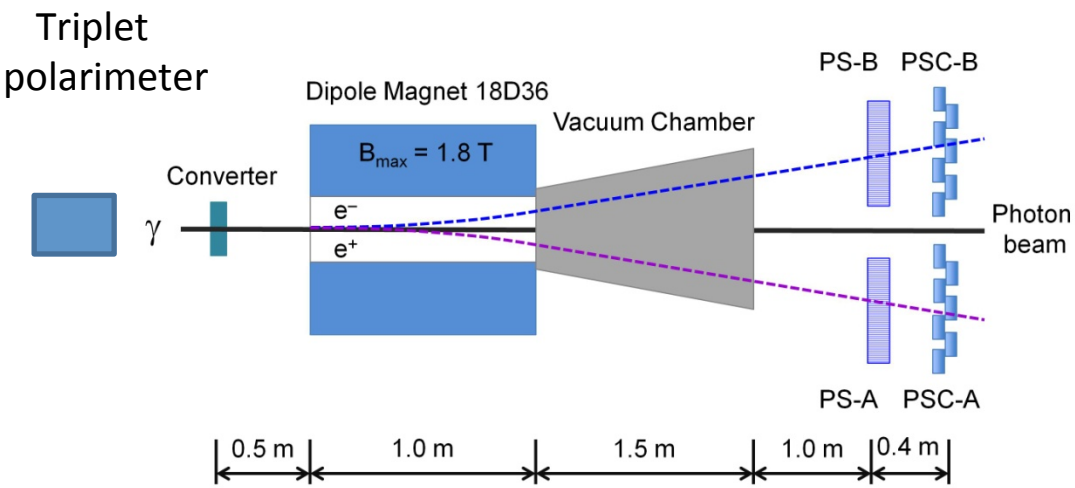


Microscope (Coherent Peak)
- Scintillating fibers
- SiPMs light sensors
- 120 readout channels

Fixed Array (Eg ~ 3-11.6 GeV)
- Small scintillators
- R9800 photomultipliers

- Initial photon flux: $10^7\gamma$/s on Target ($\Delta E\gamma$= 8.4 – 9 GeV)
- Design expandable to $10^8\gamma$/s

Photon Flux and Beam Polarization: Pair Spectrometer



Two layers of scintillator detectors:

High-granularity hodoscope (measure photon energy in the range 6 – 12 GeV)

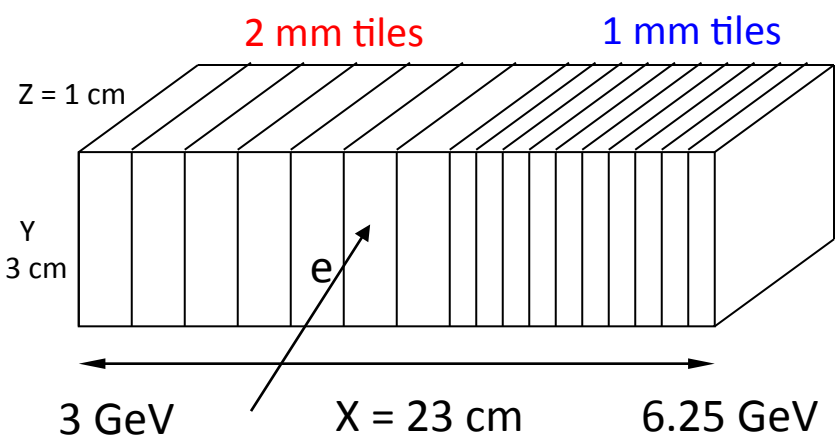
Low-granularity counters (use in the trigger)

- Reconstruct the energy of a beam photon by detecting the $e^{\pm}$ pair produced by the photon in a thin converter
  - measure the spectrum of the collimated photon beam
  - monitor the photon beam flux
  - calibrate energy of tagger detectors

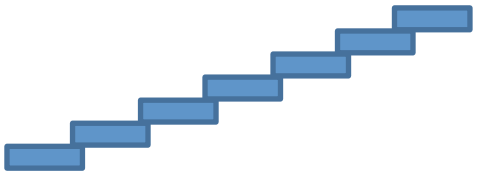
Pair Spectrometer Detectors

Hodoscope

- $e^{\pm}$ energy measurements
- $\sigma(E_{\gamma}) \sim 25 - 30$ MeV at beam end-point energy
- cover energy range for $e^{\pm}$ between 3 GeV and 6.25 GeV
- detector based on 1 mm and 2 mm wide scintillator tiles
- detector width ~23 cm
- use 3 mm x 3 mm 50μm SiPMs as photodetectors
- 128 + 128 = 256 ch read out by FADC250 (1 VXS crate)

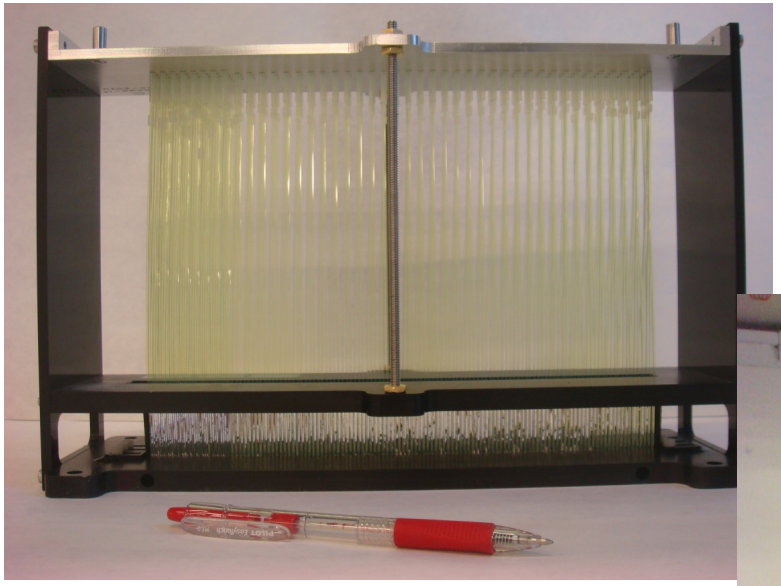


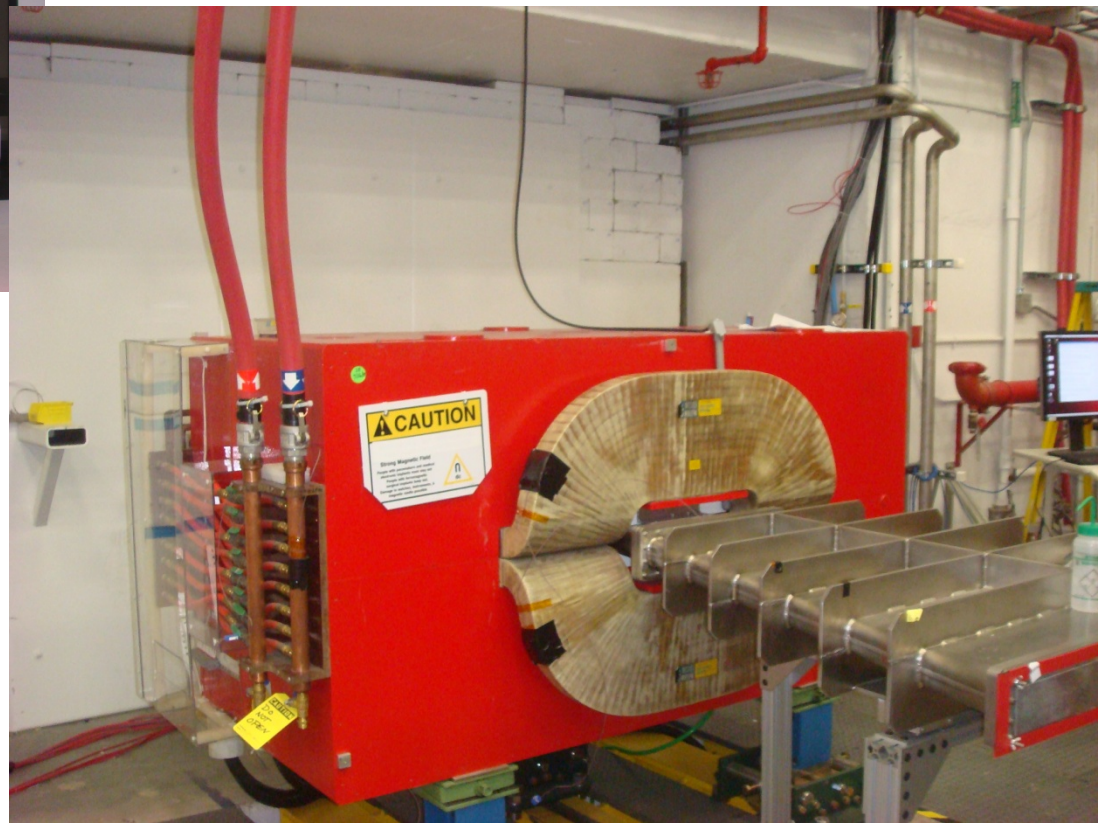
Low – Granularity Counters



- use in coincidence with hodoscope
- help to reduce BG originating in the magnet
- provide timing measurements (coincidence with tagger)
- 8 + 8 = 16 thick scintillators
- use in the trigger
- electronics:
  - FADC250
  - LE discriminator
  - F1TDC

Pair spectrometer and dipole magnet

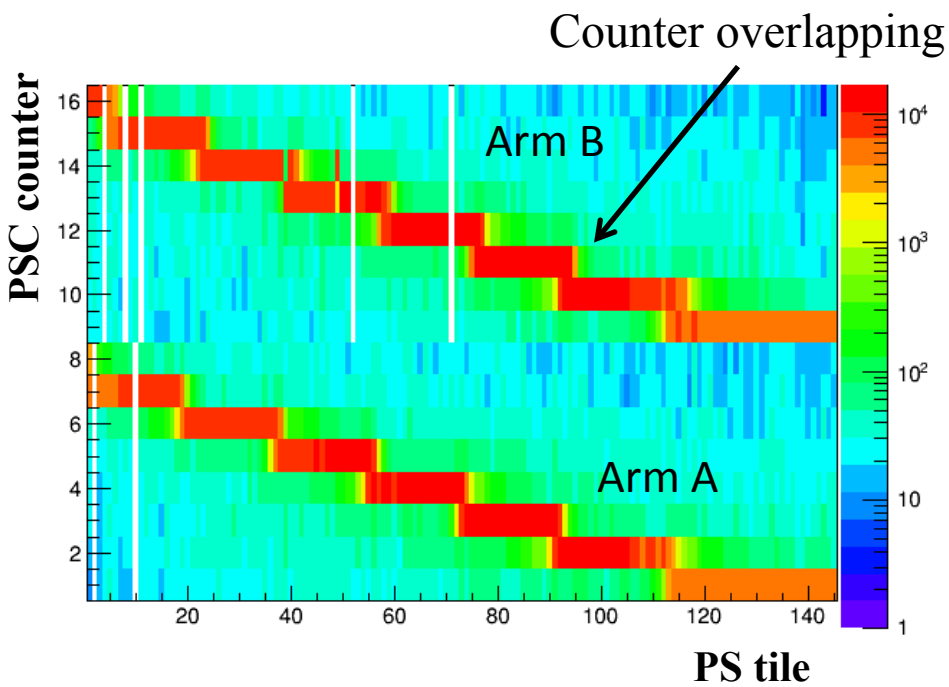


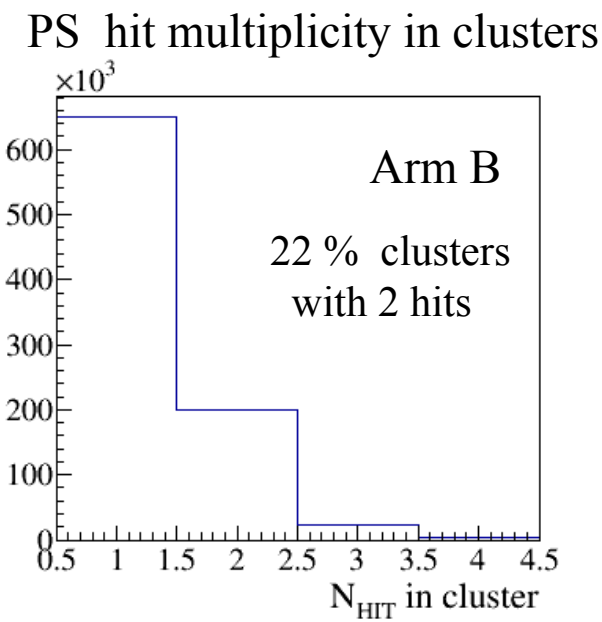


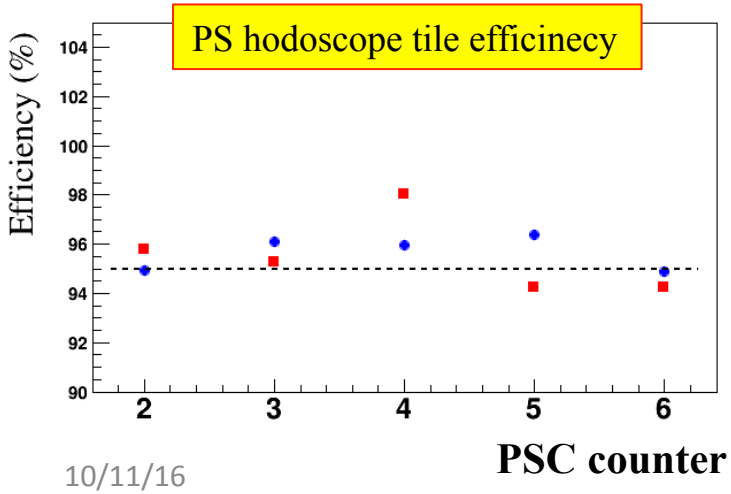
Pair Spectrometer Installed in Hall D

Coarse counters

PS Performance during First Commissioning Runs

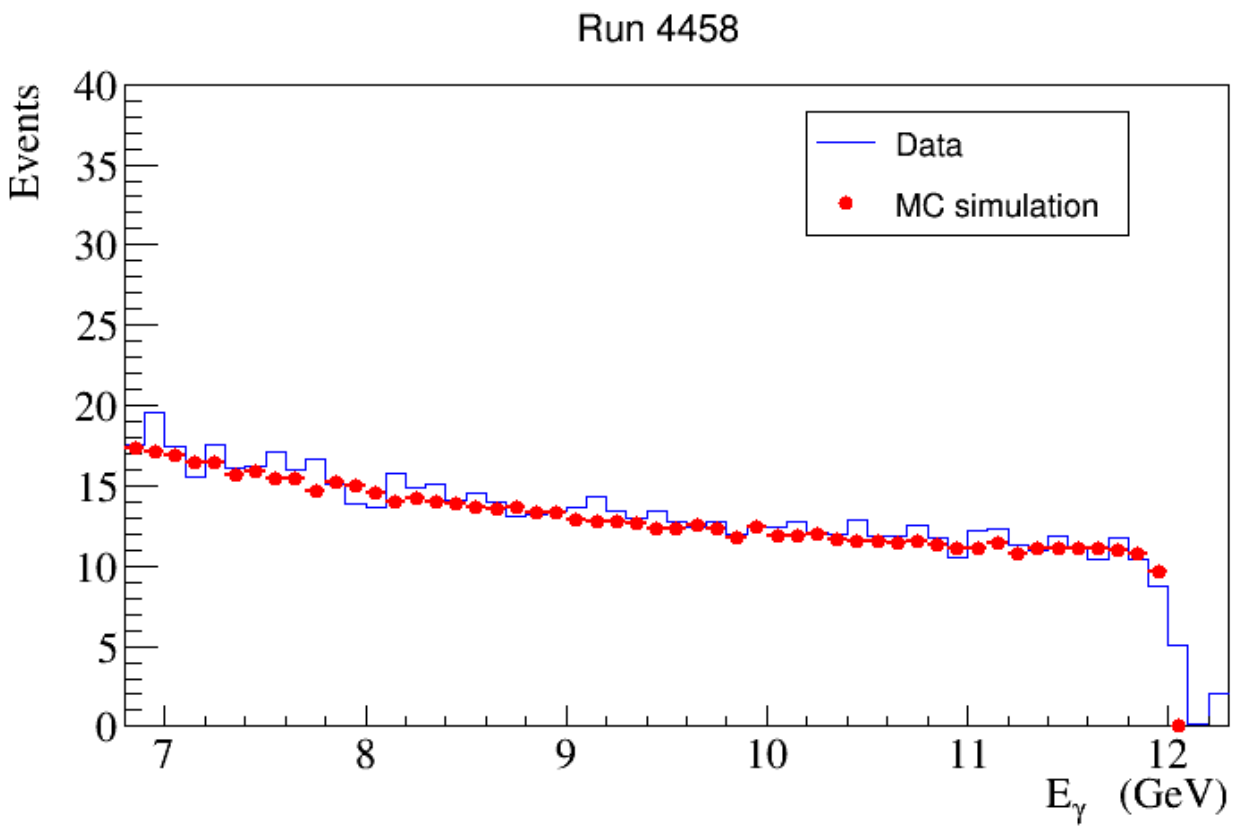






- Require coincidence of hits between PS and PSC in one detector arm
- Constrain photon beam energy using TAGH
- PS hodoscope detection efficiency > 95 %
- The coincidental background is on the level of 1 – 1.5 %

Pair Spectrometer Energy Calibration



- Energy corrected by about 4 % to match with the 12 GeV endpoint
  - implement current PS energy calibration in the PS reconstruction

- The energy spectrum is in a 'reasonable' agreement with cobrems

Pair Spectrometer Acceptance Calibration

- Data samples were acquired for three converters

  - 5.7×10^{-3} R.L. Al (508 μm foil) run 10851
  - 2.1×10^{-3} R.L. Be (750 μm foil) run 10852
  - 0.21×10^{-3} R.L. Be (75 μm foil)

- Run conditions

  - 3.4 mm collimator , $2 \cdot 10^{-5}$ radiator, 2 nA beam current

- Trigger

  - run two triggers in parallel: PS and TAC (energy sum)
  - PS rate: 10 Hz 750 μm Be
  - TAC rate: 200 – 300 kHz (trigger prescaling factor 129)

Acceptance Calibration

Compute number of triggers N_{PS} and N_{TAC} acquired for each TAGH counter

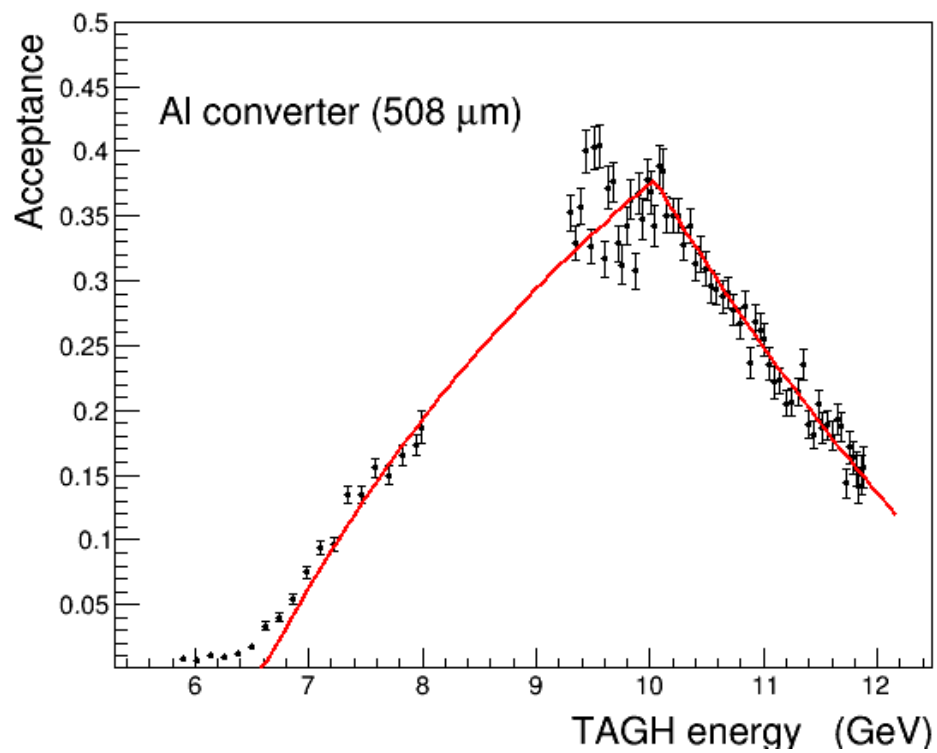
Coincidental rate < 10 %

$$A = \frac{9}{7} \cdot \frac{N_{PS}}{N_{TAC}} \cdot \frac{Eff_{TAC}}{Eff_{PS}} \cdot \frac{1}{L \cdot P}$$

L – converter thickness in R.L. (has not been measured)

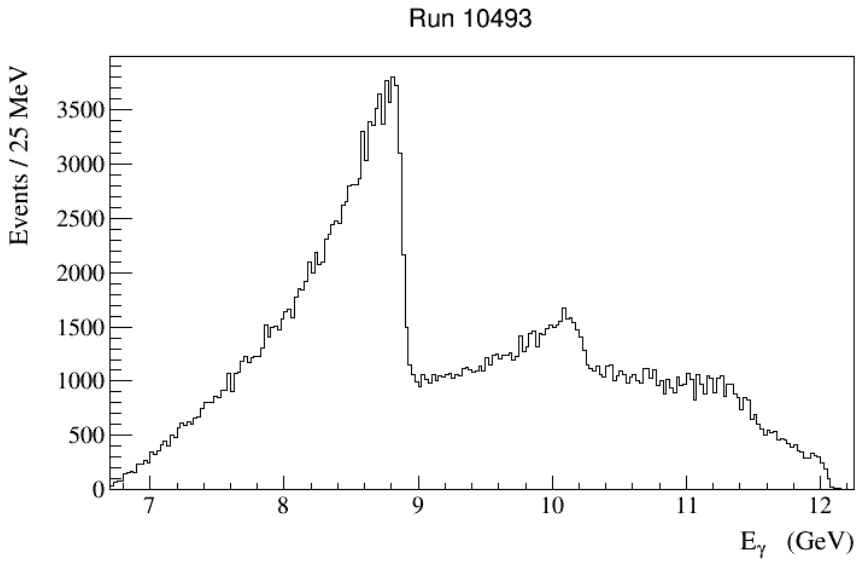
P = 129 is the prescaling factor for the TAC trigger

Assume that Eff $_{TAC,\ PS}$ = 1

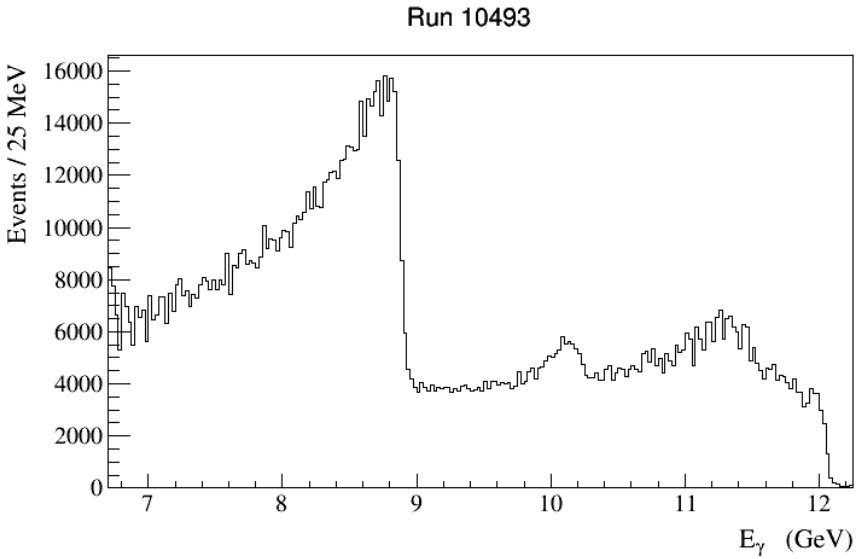


Pair Spectrometer Spectrum

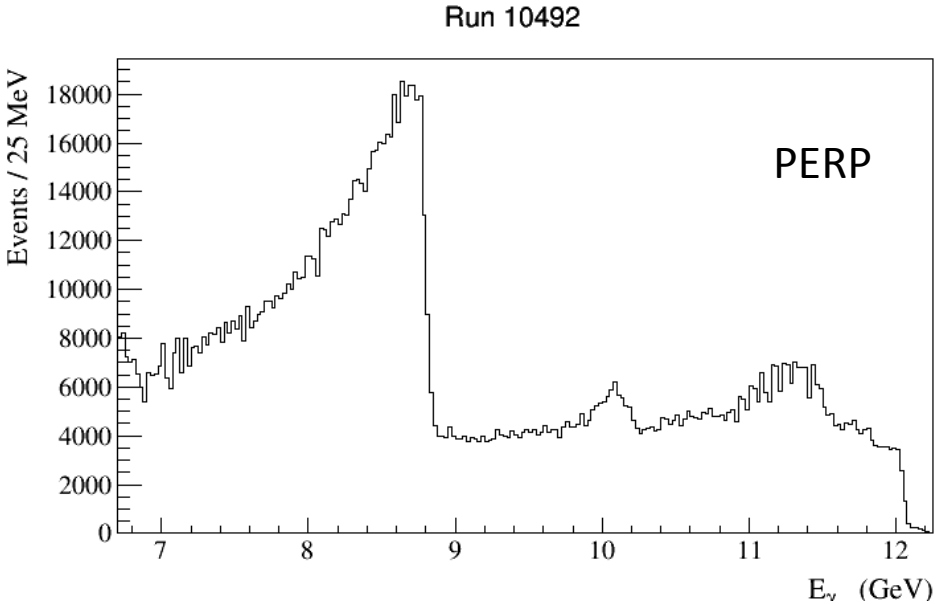
No acceptance corrections

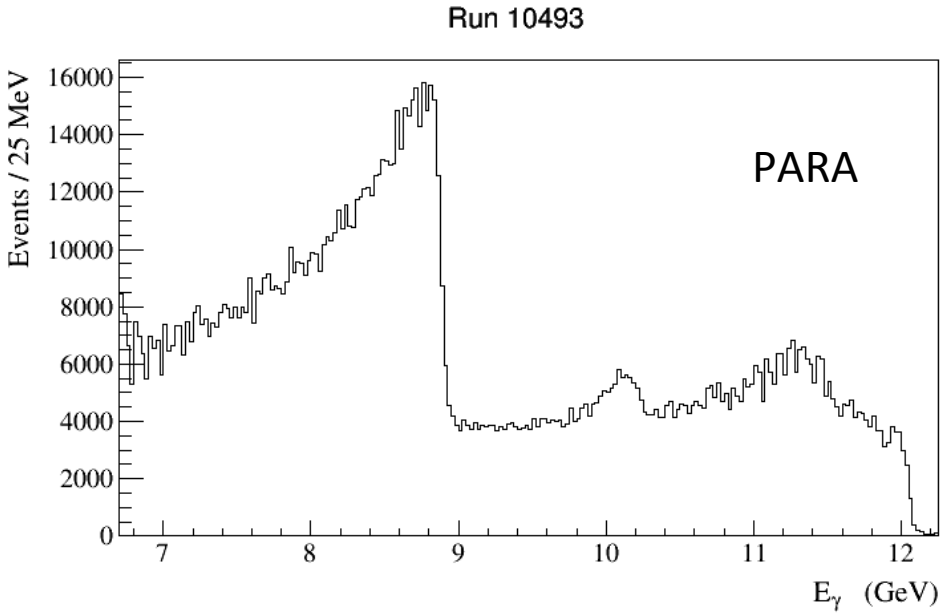


Acceptance corrected

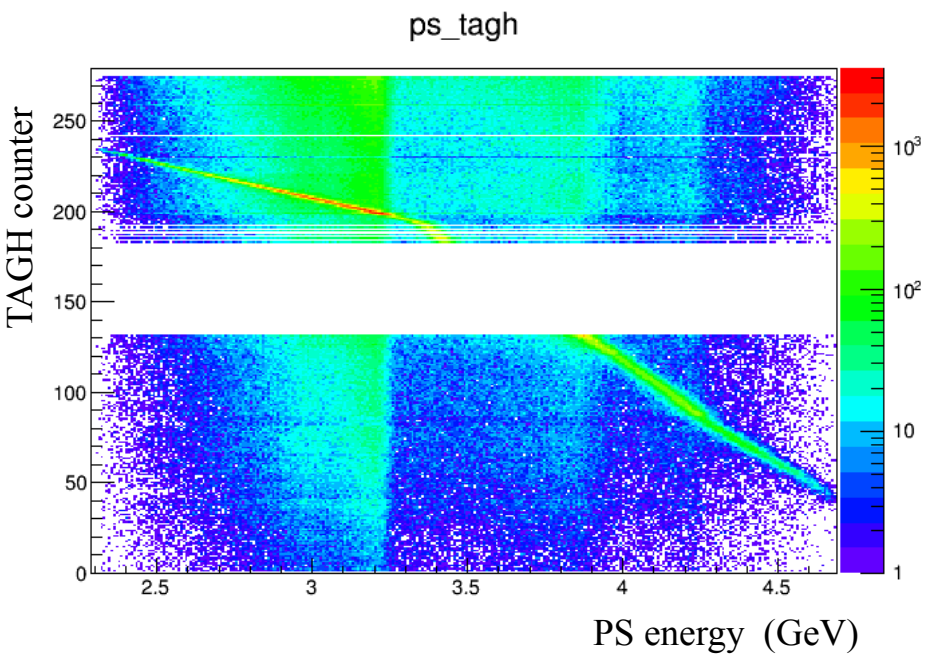


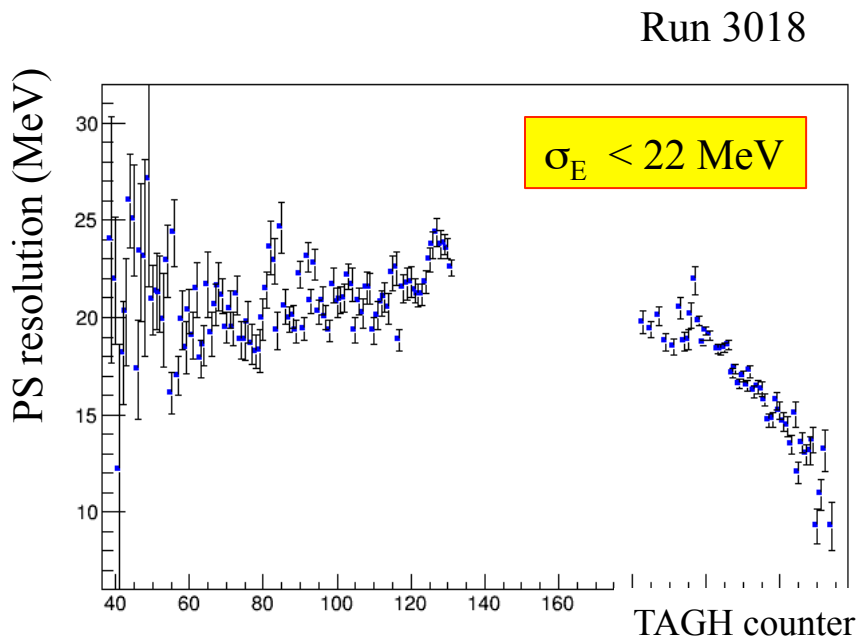
Pair Spectrometer Spectrum





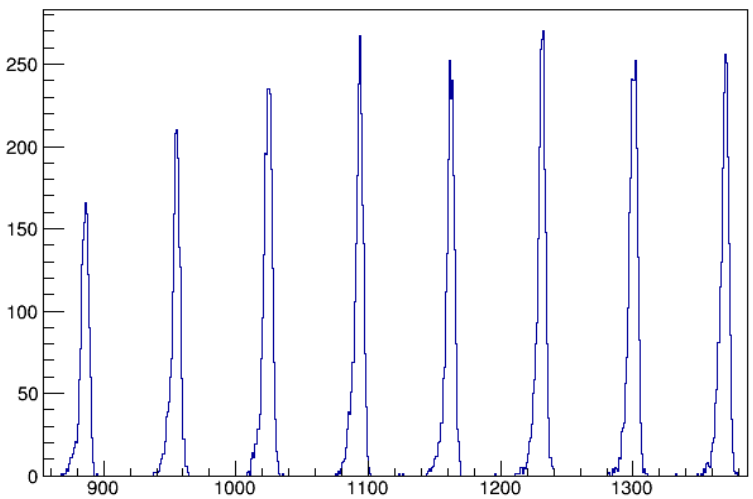
PS Energy Resolution



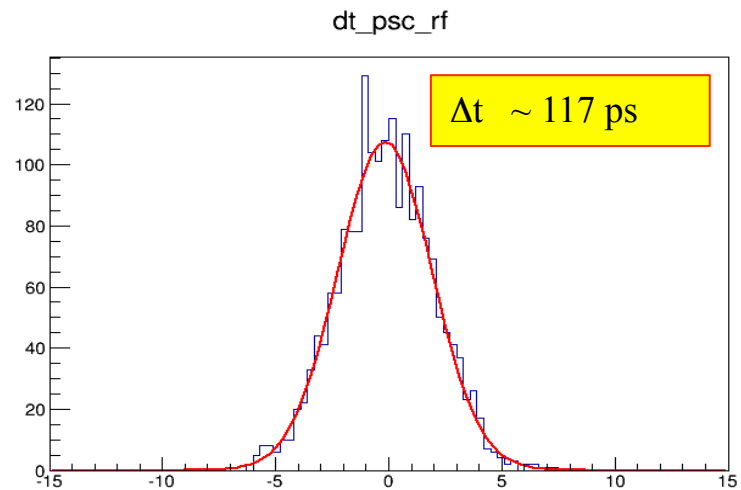


PSC Time Resolution

$RF_{time} - PSC_{time}$



Δt(PSC –RF) (counts)

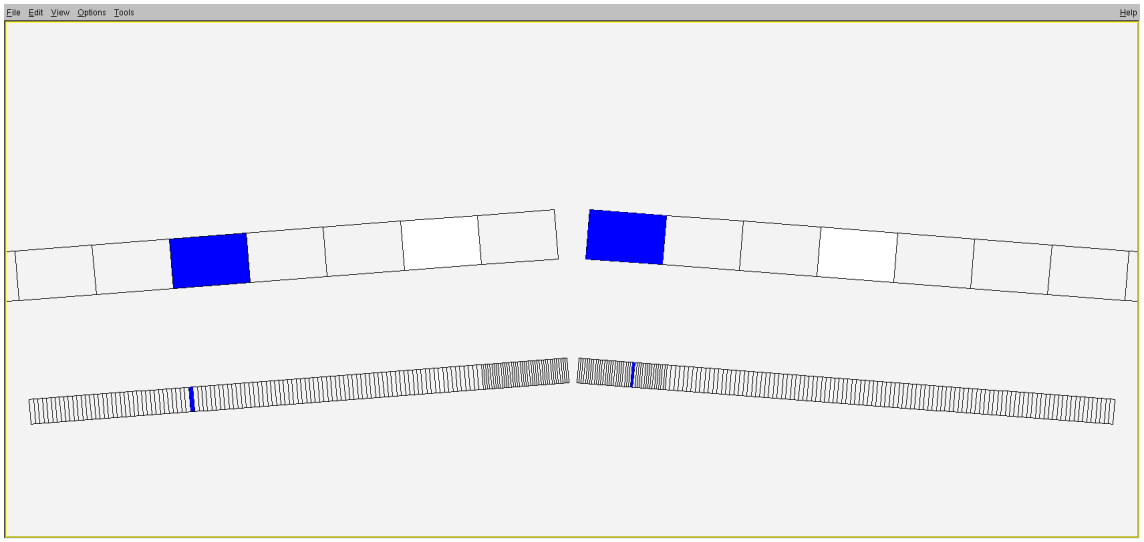


Δt (counts)

- Time resolution of PS coarse counters $\sigma_t < 150$ ps

PS Trigger and Data Sample

- Trigger based on hit coincidence between two arms of PSC



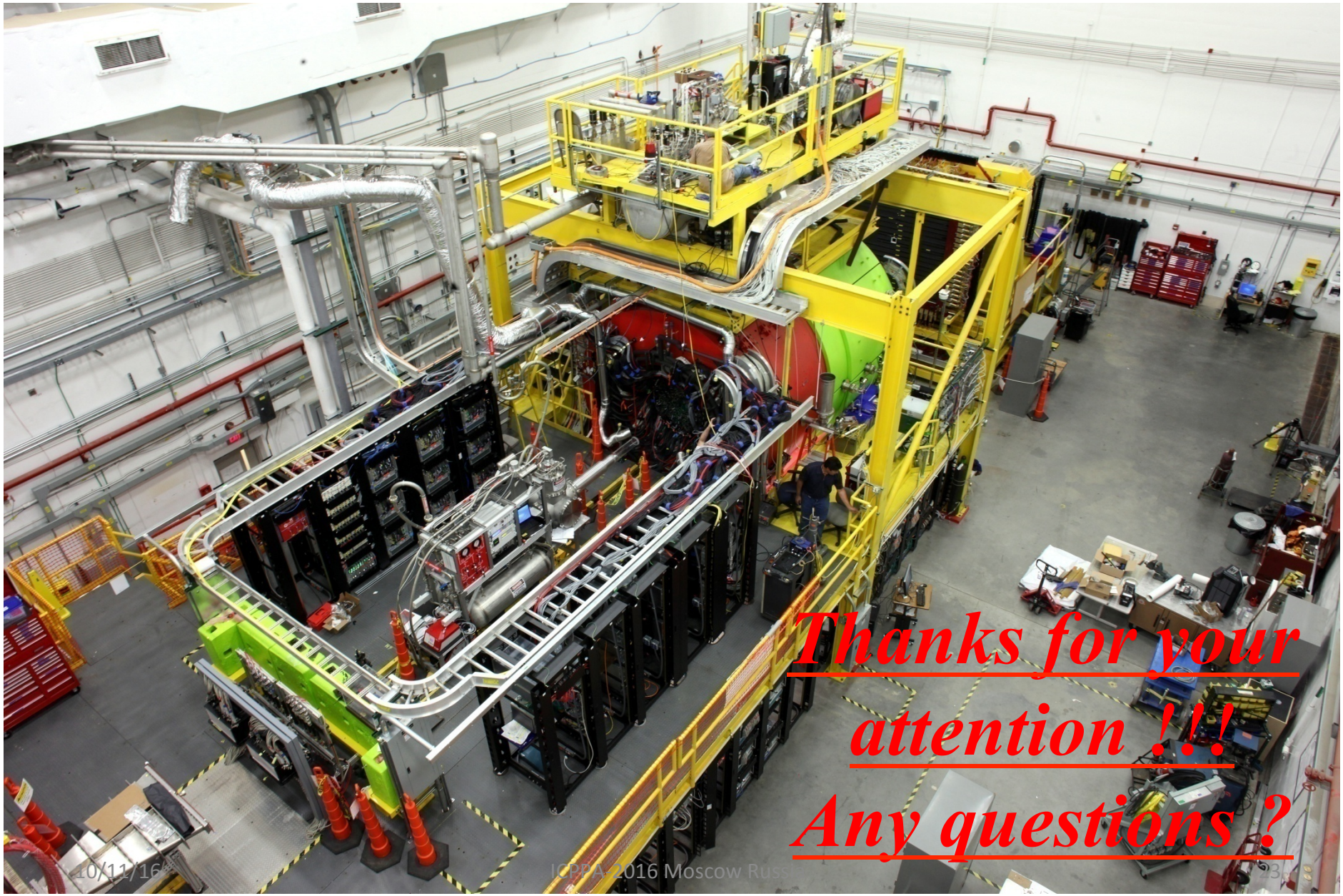
PSC used in trigger

PS hodoscope

- Took calibration data with the PS trigger
  - read out pair spectrometer and TAGM/TAGH crates.

- Operated PS trigger in parallel with other trigger types for production runs.

GlueX Detector



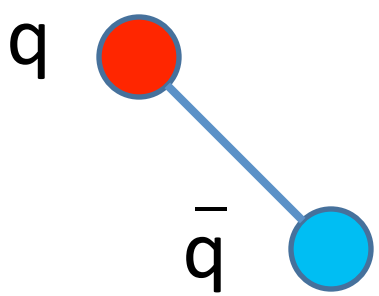
Thanks for your attention !!!

Any questions ?

BACKUP SLIDES

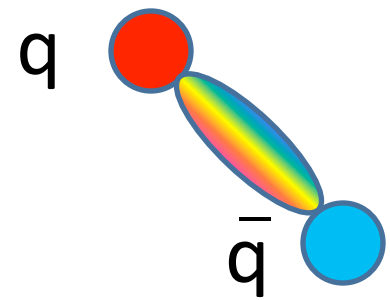
Exotic Mesons

Conventional Mesons



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

Hybrid Mesons

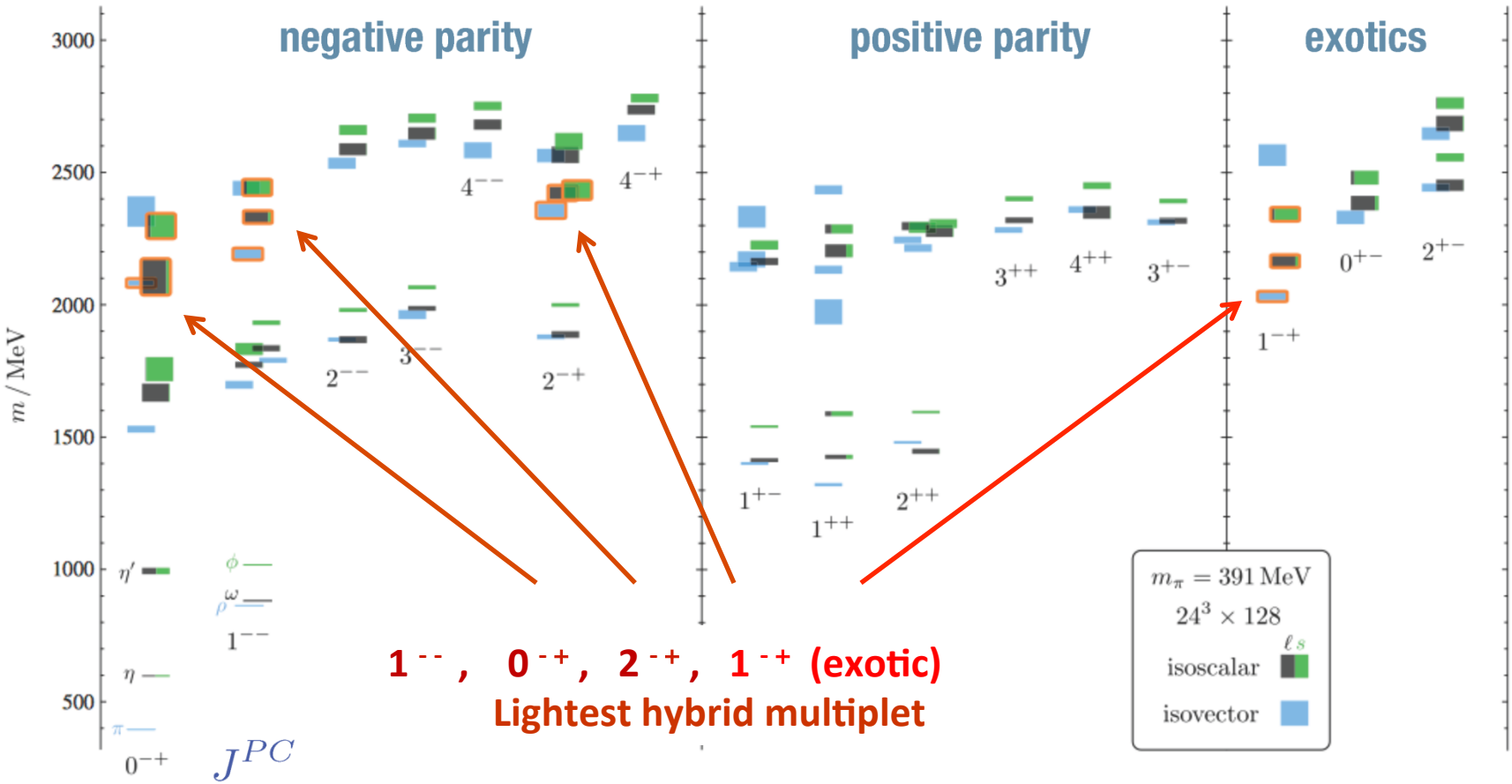


- Excited gluonic field coupled to a $q\bar{q}$ pair can result in hybrid mesons with **exotic J^{PC}**
- Predicted by several models. Recent calculations using lattice QCD - constituent gluon with $J^{PC} = 1^{+-}$ and mass 1 – 1.5 GeV

	0^{--}	0^{-+}	0^{+-}	0^{++}
J^{PC}:	1^{--}	1^{-+}	1^{+-}	1^{++}
	2^{--}	2^{-+}	2^{+-}	2^{++}

Lattice QCD Predictions

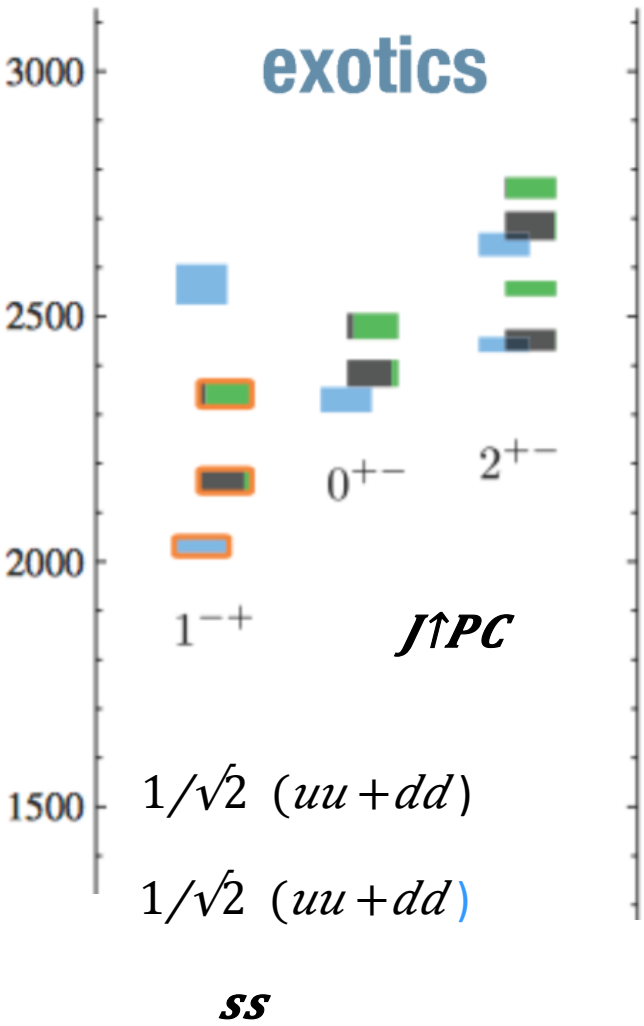
Dudek et al. PRD 88 (2013) 094505



1^{--}, 0^{-+}, 2^{-+}, 1^{-+} (exotic)

Lightest hybrid multiplet

Lattice QCD Predictions



Mass predictions:

	$1\uparrow-+$	2.0 – 2.4 GeV/c^2
$J\uparrow PC$	$0\uparrow+-$	2.3 – 2.5 GeV/c^2
	$2\uparrow+-$	2.4 – 2.8 GeV/c^2

- Lattice calculations predict light-quark hybrid mesons and with strange quark content
  - good identification of kaons required (GlueX PID upgrade)
- Search for mesons in many final states

Search Modes of Exotic Decays

J^{PC}	Exotic Meson	Possible Decays
1^{-+}	π_1 (1900)	$\pi\rho$, πb_1, πf_1, $\pi\eta'$, ηa_1
	η_1 (2100)	ηf_2, $a_2\pi$, ηf_1, $\eta\eta'$, $\pi(1300)\,\pi$
	η_1' (2300)	K^*K, $K_1(1270)\,K$, $K_1(1410)\,K$, $\eta\eta'$
2^{+-}	b_2 (2500)	$\omega\pi$, $a_2\pi$, $\rho\eta$, $f_1\rho$, $a_1\pi$, $h_1\pi$, $b_1\eta$
	h_2 (2500)	$\rho\pi$, $b_1\pi$, $\omega\eta$, $f_1\omega$
	h_2' (2600)	$K_1(1270)\,K$, $K_1(1410)\,K$, $K_2^*\,K$, $\phi\eta$
0^{+-}	b_0 (2400)	$\pi(1300)\,\pi$, $h_1\pi$, $f_1\rho$, $b_1\eta$
	h_0 (2400)	$b_1\pi$, $h_1\eta$
	h_0' (2500)	$K_1(1270)\,K$, $K_1(1460)\,K$, $h_1\eta$

Multiparticle final states:

- **(p,n) + 3π, 4π, $3\pi\eta$, $4\pi\eta$ …**
- **70% of decays involve at least one π^0**
- **50% more than two π^0**

Experimental Status

- Exotic mesons have been searched in several experiments: GAMS, VES, CBAR, E852, COMPASS, CLAS
- Exotic Meson Candidate ($J^{PC} = 1^{-+}$)

$\pi_1(1400) \rightarrow \eta\pi$

Seen by several experiments. Interpretation unclear: dynamic origin, 4-quark state. Not a hybrid (?)

$\pi_1(1600) \rightarrow \eta'\pi$
$\pi_1(1600) \rightarrow \rho\pi$
$\pi_1(1600) \rightarrow b_1\pi$
$\pi_1(1600) \rightarrow f_1\pi$

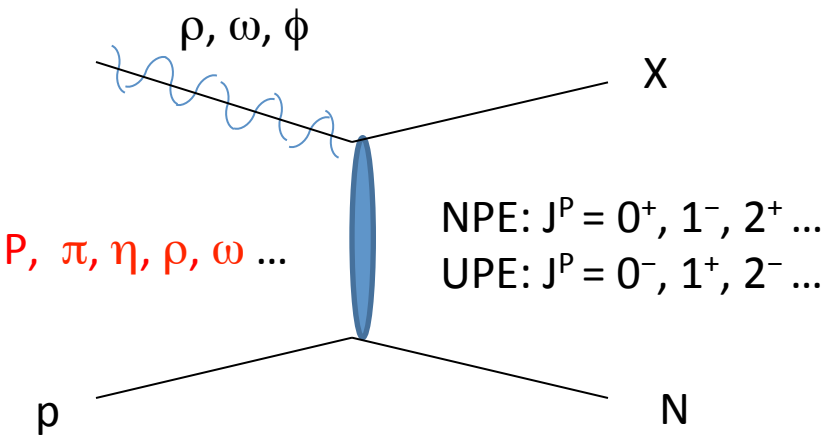
- First seen by VES, E852, COMPASS
- 3π controversial:
  - 3π not seen in photoproduction (CLAS)
- May be a hybrid
- Need more analysis and data

$\pi_1(2000) \rightarrow f_1\pi$
$\pi_1(2000) \rightarrow b_1\pi$

- Seen by E852 (but not seen by VES)
- Statistics is limited
- May be a hybrid

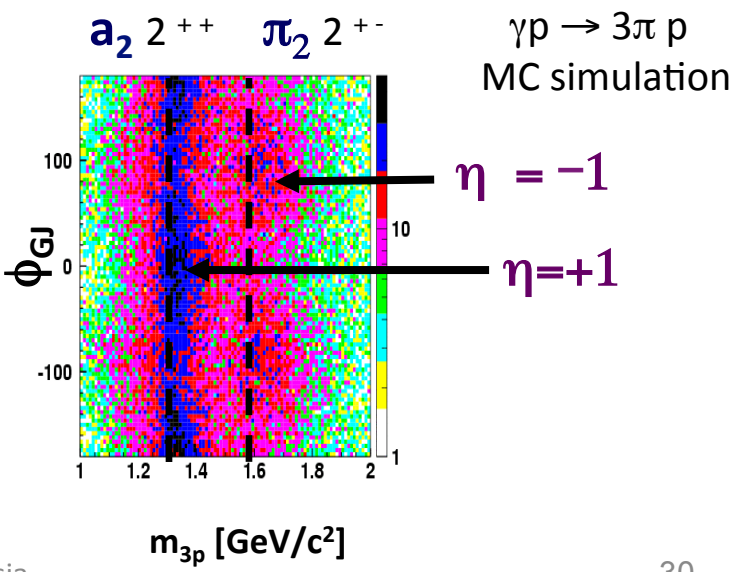
- Exotic meson candidates, but no strong evidence
- Reconstruct exotic mesons in any final state. More data are needed

Photoproduction of Exotic Mesons



Exchange particle		Final States	
P	0^{+}	$0^{+-}, 2^{+-}$	b^0, h, h′
π^0	0^{-}	2^{+-}	b_2^0, h_2, h_2'
$\pi^{\pm}$	0^{-}	1^{-+}	$\pi_1^{\pm}$
ω	1^{-}	1^{-+}	π_1, η_1, η_1'

- t-channel exchange
- couple to photoproduction (via Vector Meson Dominance)
- Polarized photon beam helps to determine production mechanism (naturality)



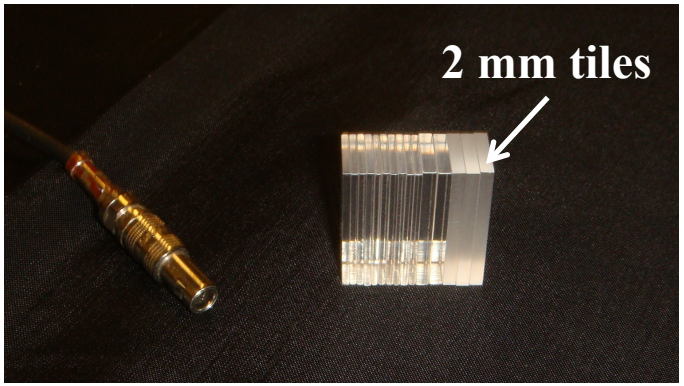
Photon Beam Requirements

Experiment	Photon Energy Range (GeV)	Polarization	Photon Flux γ/ sec
GlueX Search for gluonic excitations in the spectra of light mesons	**8.4 – 9.0**	**44 %**	**$5 \cdot 10^7$**
PrimEx A precision measurement of the $\eta \rightarrow \gamma\gamma$ decay width via the Primakoff effect	**10.5 – 11.7**	**None**	**$7.6 \cdot 10^6$**
Measuring the charged pion polarizability	**5.5 – 6.0**	**76 %**	**10^7**

Prototype Construction & Performance

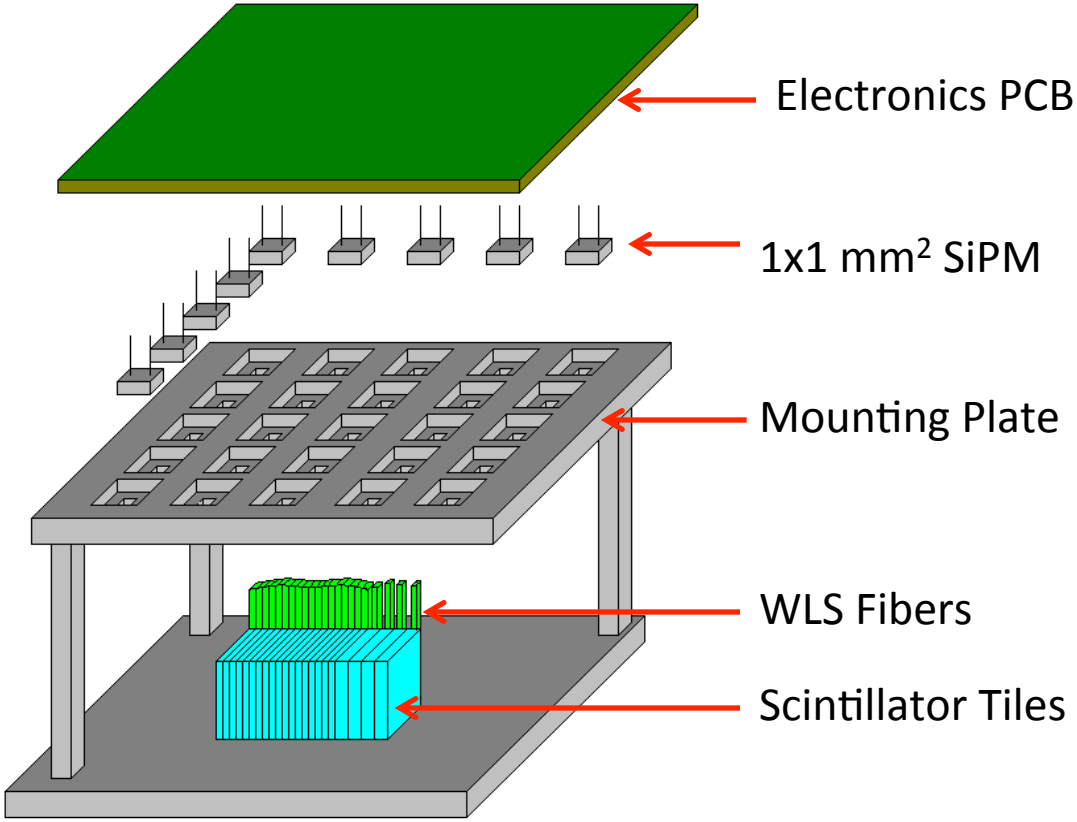
A lot of help from Chuck Hutton

- 21 scintillator tiles (EJ – 212)
  1 cm x 2 cm x 1 mm and
  1 cm x 2 cm x 2 mm



- 1 mm x 1 mm WLS square double-clad fiber (BCF-92) glued to one side of the tile:
  - checked several UV glues
  - consider to use optical cement BC-600 for the final production

- Use 50 μm (18 ch) and 25 μm (3 ch) 1x1 mm^2 SiPMs (Ceramic package)



Mounting Structure

Chuck Hutton