GlueX at Jefferson Lab: a search for exotic states of matter in photon-proton collisions

International Winter Conference on Nuclear Physics
Bormio, Italy

January 27, 2014

Matthew Shepherd
Indiana University

Outline

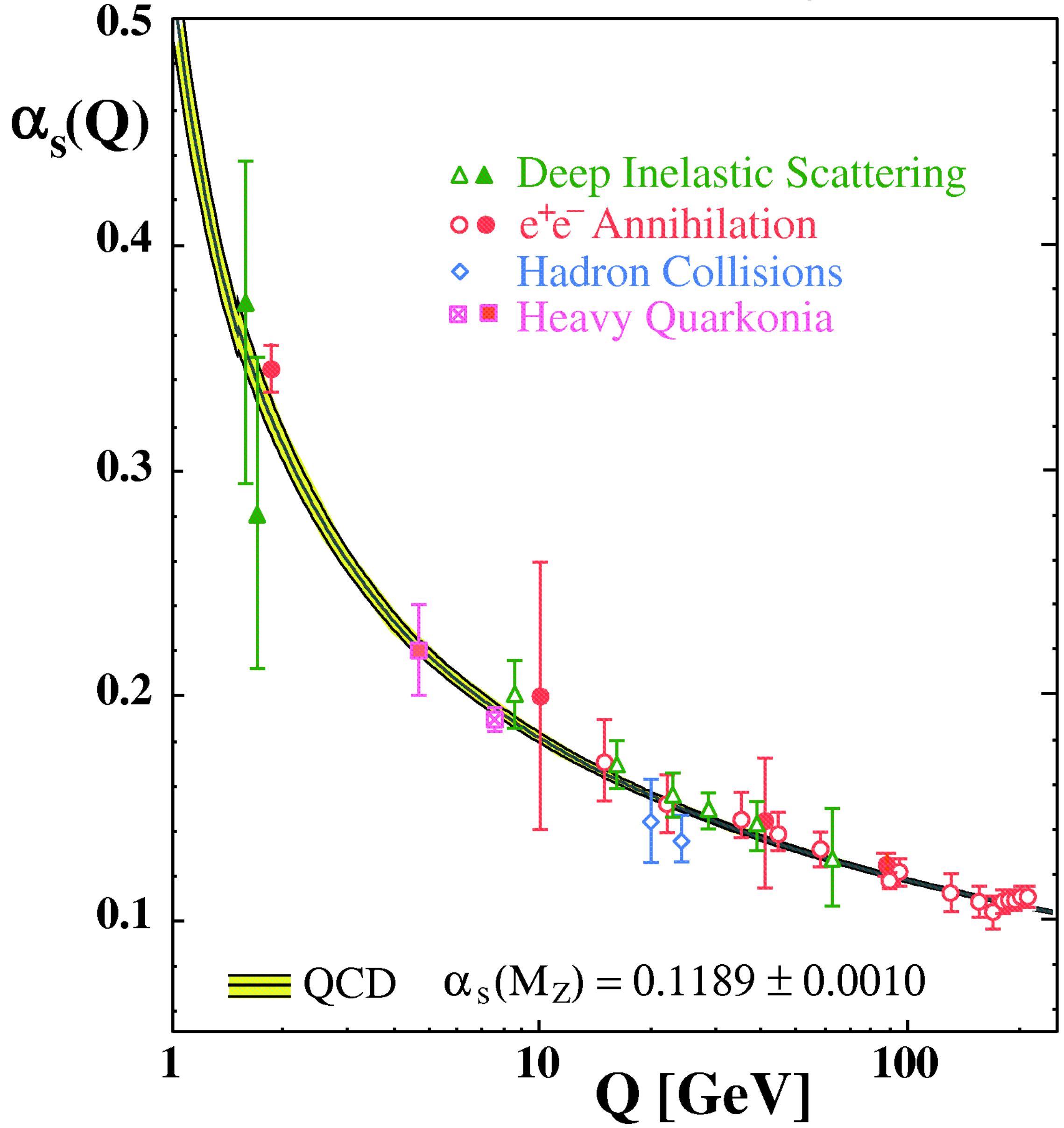
- Motivation
  - hadron spectroscopy as a tool for exploring QCD
  - expectations from Lattice QCD
  - experimental objectives
- The GlueX detector and beamline
  - subsystem design
  - status of construction and installation
- Analysis
  - expected sensitivity in key meson search channels

Gluon Interactions in QCD

- QCD has interesting properties
  - gluon-gluon interactions
  - confinement

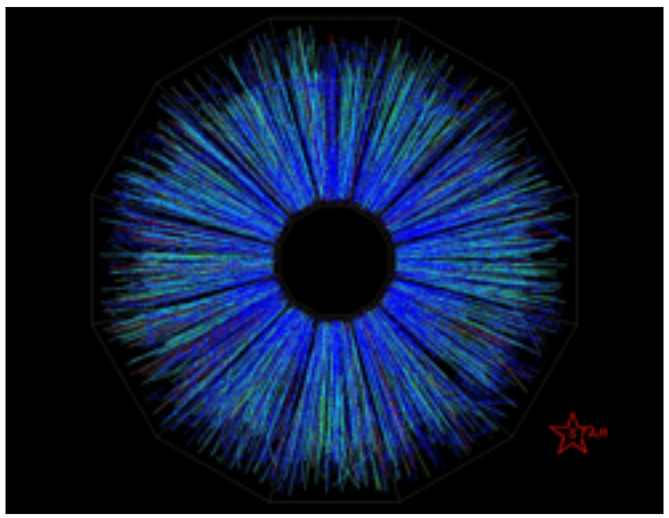
- *How do we experimentally explore the strong coupling regime of QCD?*

S. Bethke
hep-ex/0606035

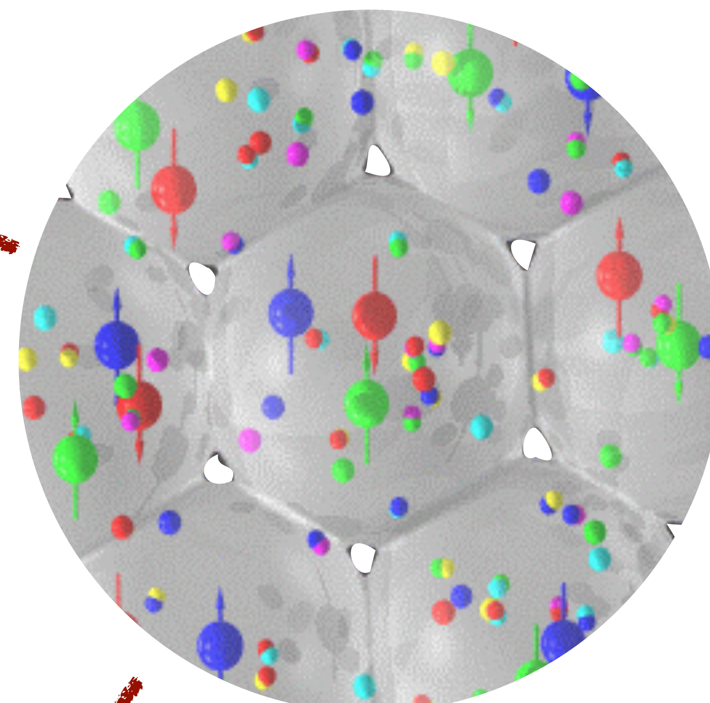


Probing Strong Interactions

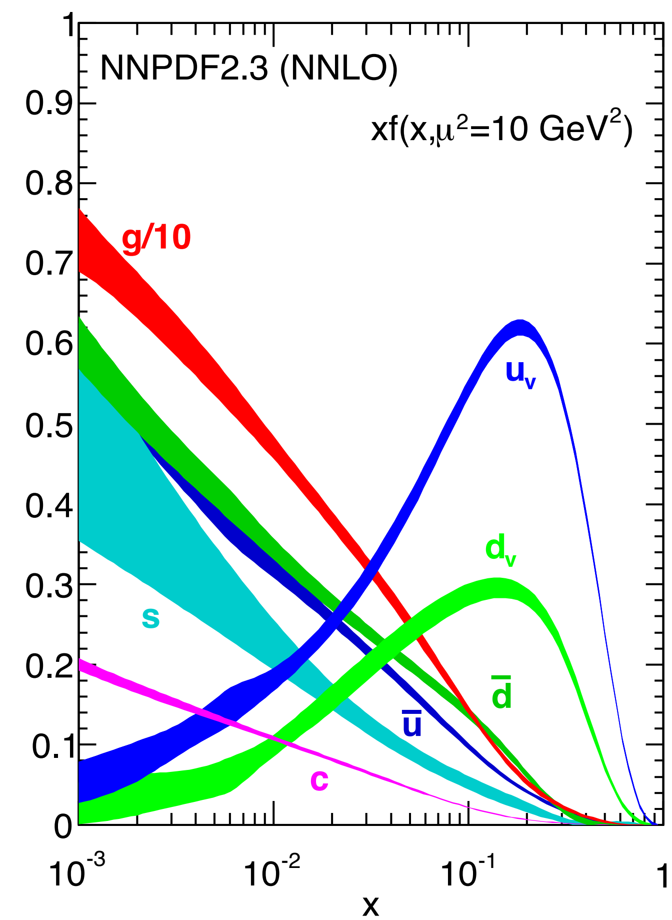
melt it



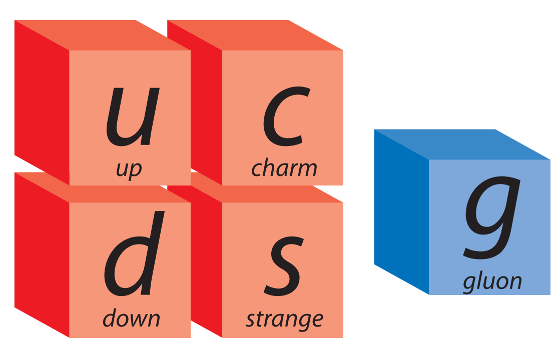
nuclear matter



put it under a microscope



take it apart and reassemble it in different ways



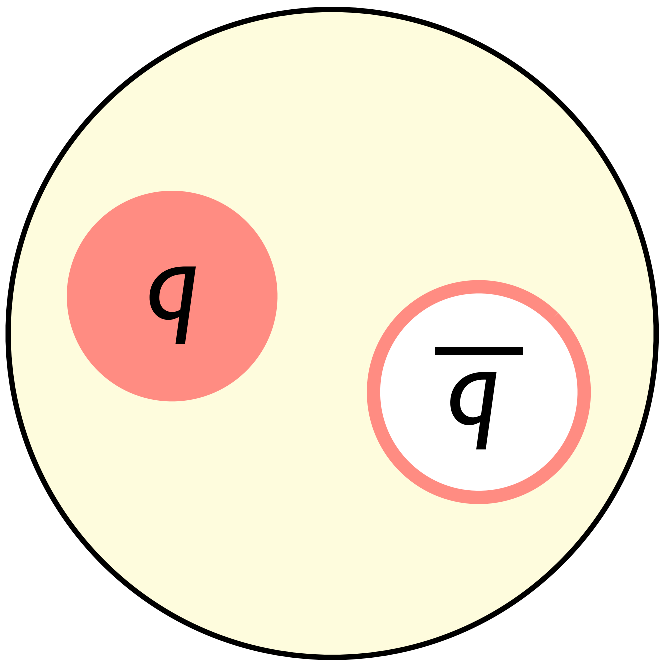
DEPARTMENT OF PHYSICS
INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

Questions for Hadron Spectroscopy

- What role do gluons play in the structure of matter?
- What are the fundamental degrees of freedom that make up hadrons?
- Does QCD predict *experimentally observable* gluonic excitations?
- Can we observe evidence for gluonic degrees of freedom in the spectrum of meson states?

Conventional and Hybrid Mesons

color singlet
quark anti-quark



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

Allowed J^{PC}: $0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, \ldots$

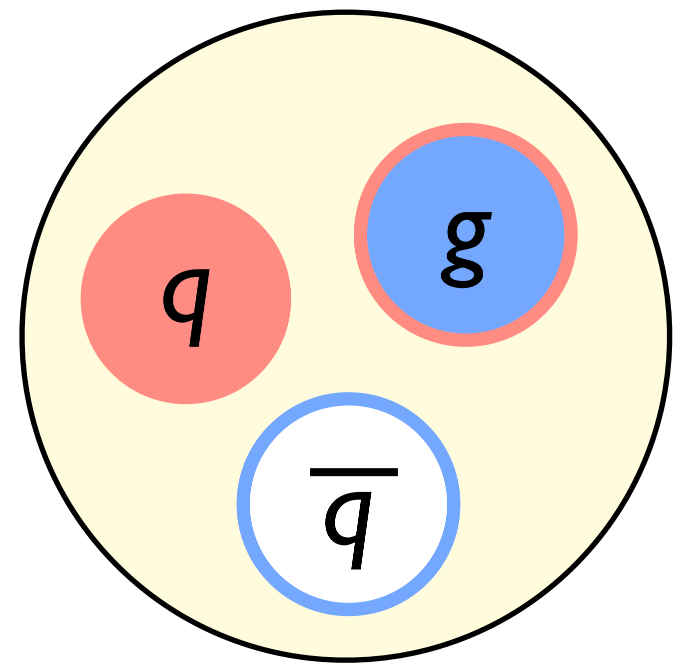
Forbidden J^{PC}: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

"constituent gluon"

$(J^{PC})_g = 1^{+-}$

mass ≈ 1.0-1.5 GeV

color-octet
$q\bar{q}$ pair



Lightest Hybrids

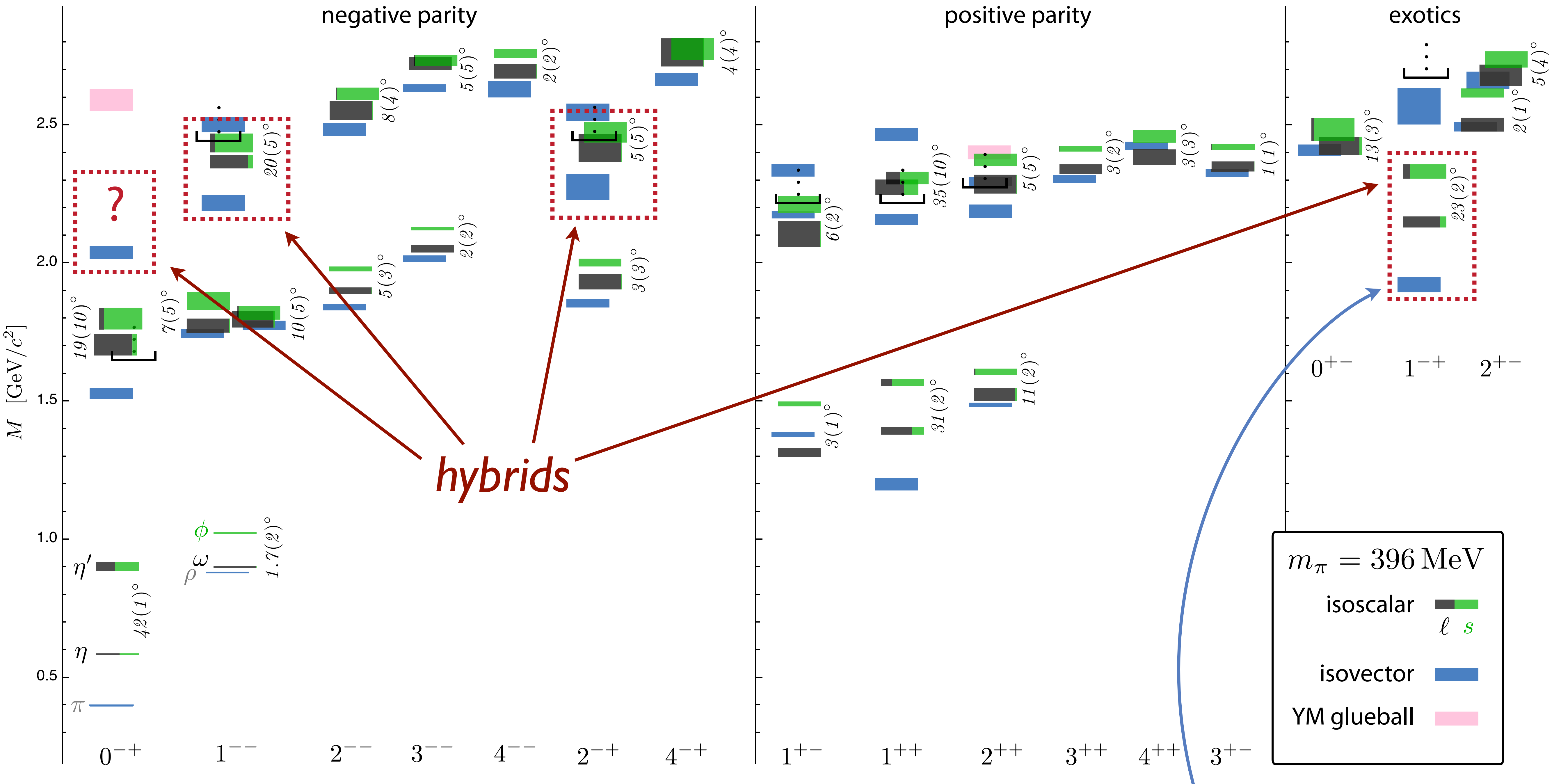
	$S_{q\bar{q}} = 1$	$S_{q\bar{q}} = 0$
J^{PC}:	$0^{-+}, 1^{-+}, 2^{-+}$	1^{--}

↑ "exotic hybrid" (1^{-+})

DEPARTMENT OF PHYSICS
INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

Lattice QCD Predictions

J. Dudek
PRD 84, 074023 (2011)



Majority of experimental data to date is related to one state, the π_1.

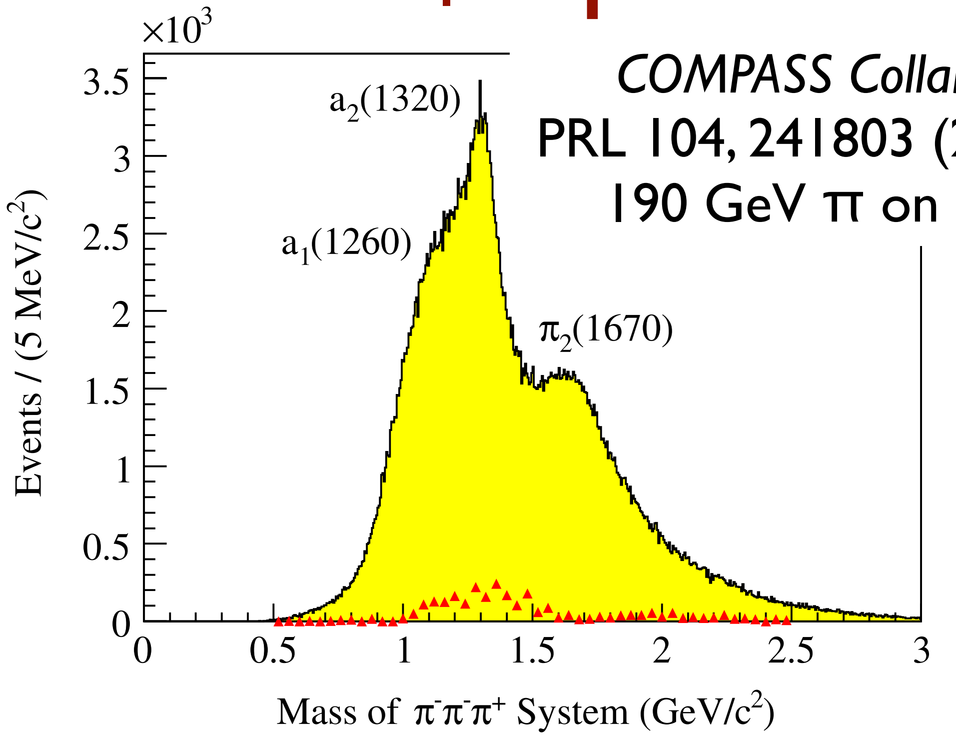
DEPARTMENT OF PHYSICS
INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

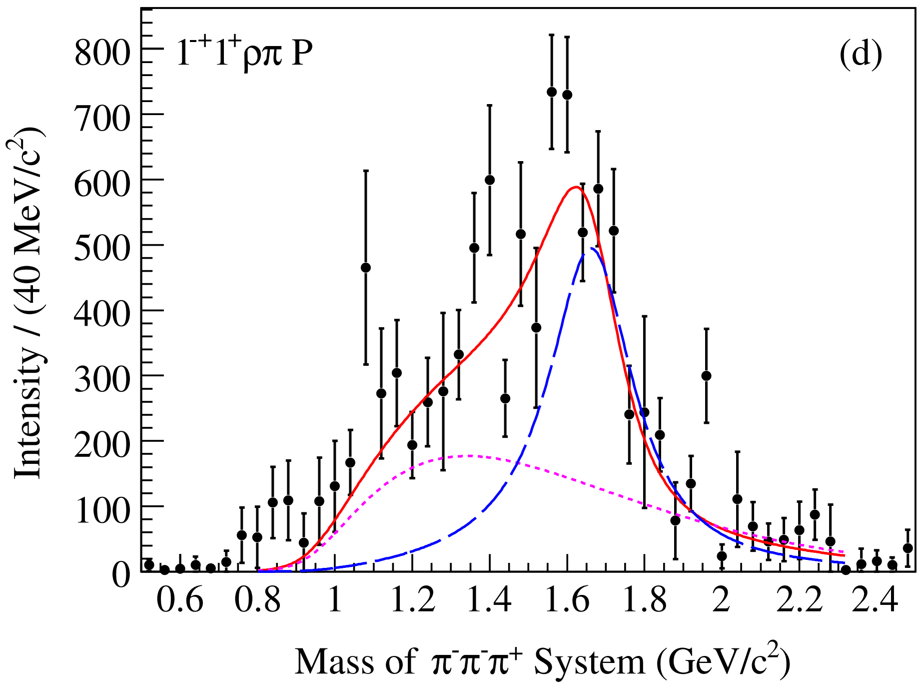
M. R. Shepherd
Intl. Mtg. on Nuclear Physics, Bormio
January 27, 2014

Searches for the π_1

$\pi_1 \to \rho\pi$

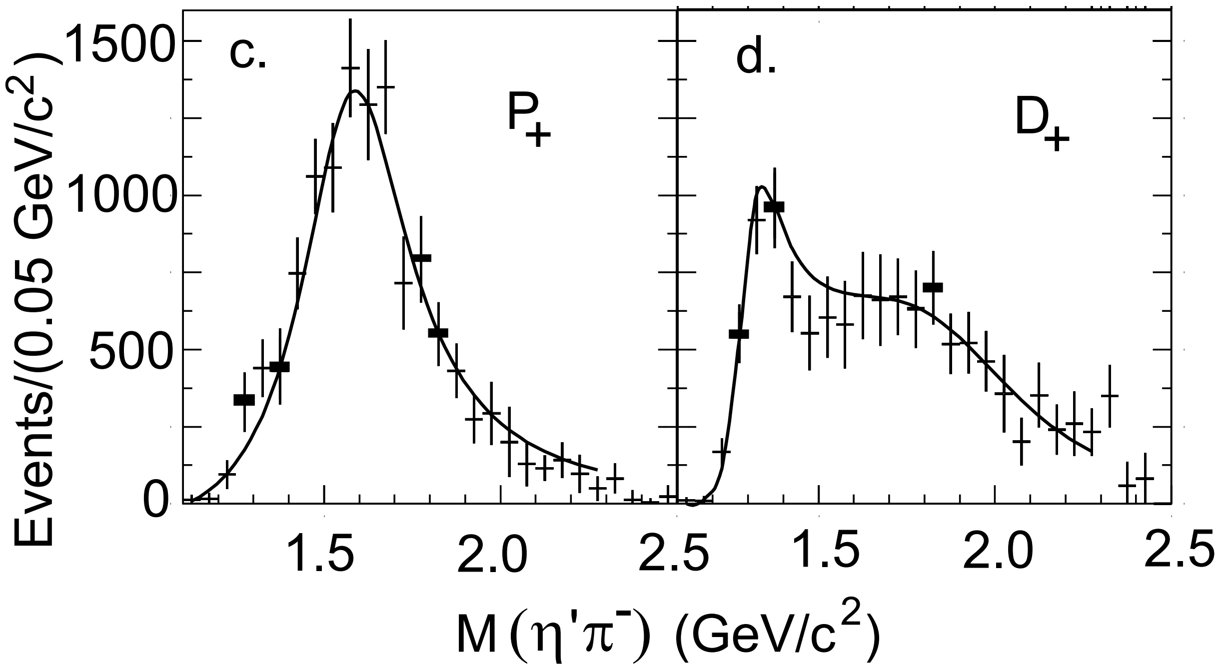
COMPASS Collab.,
PRL 104, 241803 (2010)
190 GeV π on Pb





$\pi_1 \to \eta'\pi$

E852 $\pi^- p \to \eta' \pi^- p$ [PRL 86, 3977 (2001)]
18 GeV π on p



Isoscalar Exotic Hybrids

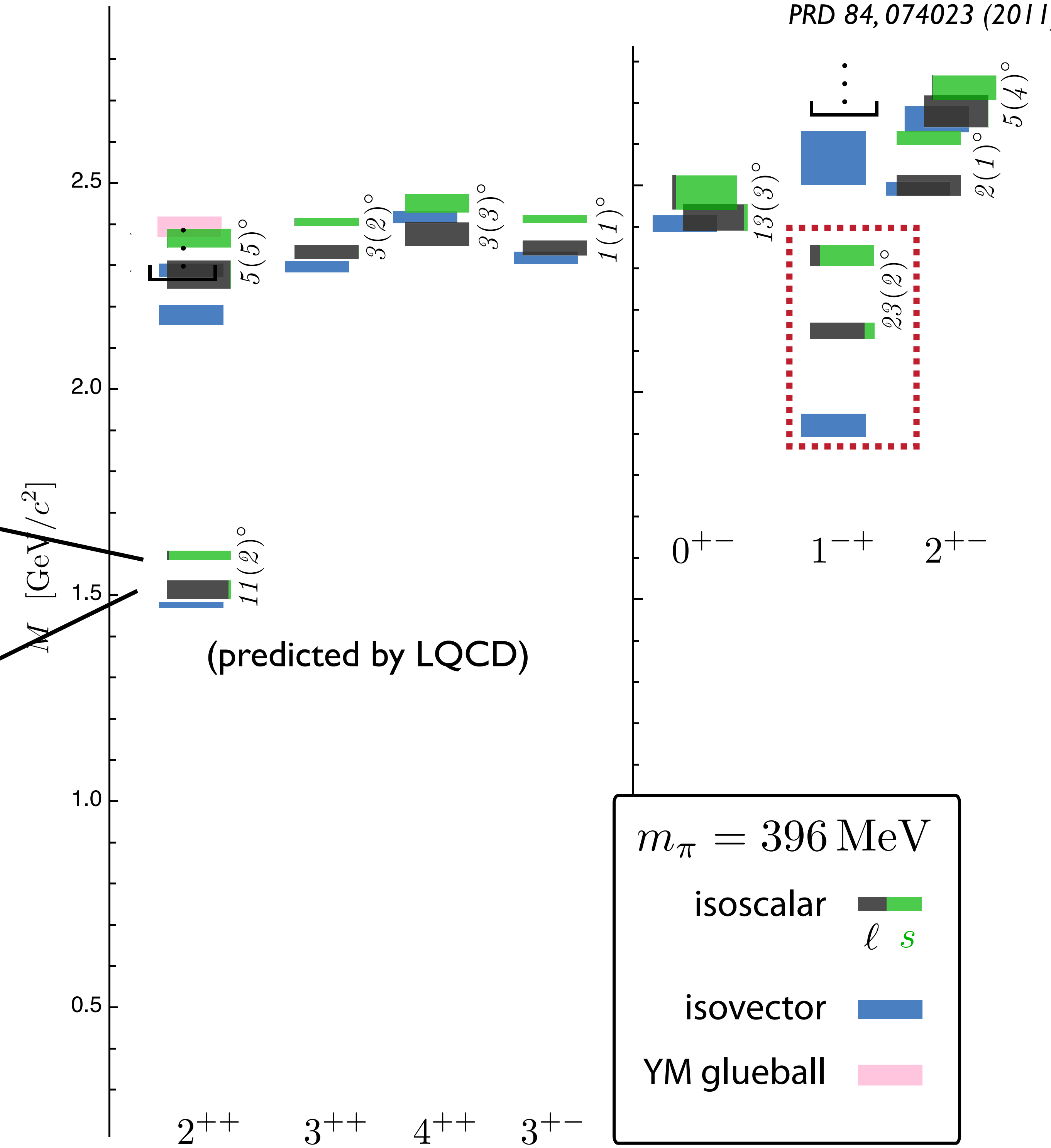
- OZI-rule and decay modes help one infer quark flavor

$$\frac{\mathcal{B}(f_2'(1525) \to \pi\pi)}{\mathcal{B}(f_2'(1525) \to KK)} \approx 0.009$$

$$\frac{\mathcal{B}(f_2(1270) \to \pi\pi)}{\mathcal{B}(f_2(1270) \to KK)} \approx 20$$

(measured by experiment)

J. Dudek
PRD 84, 074023 (2011)

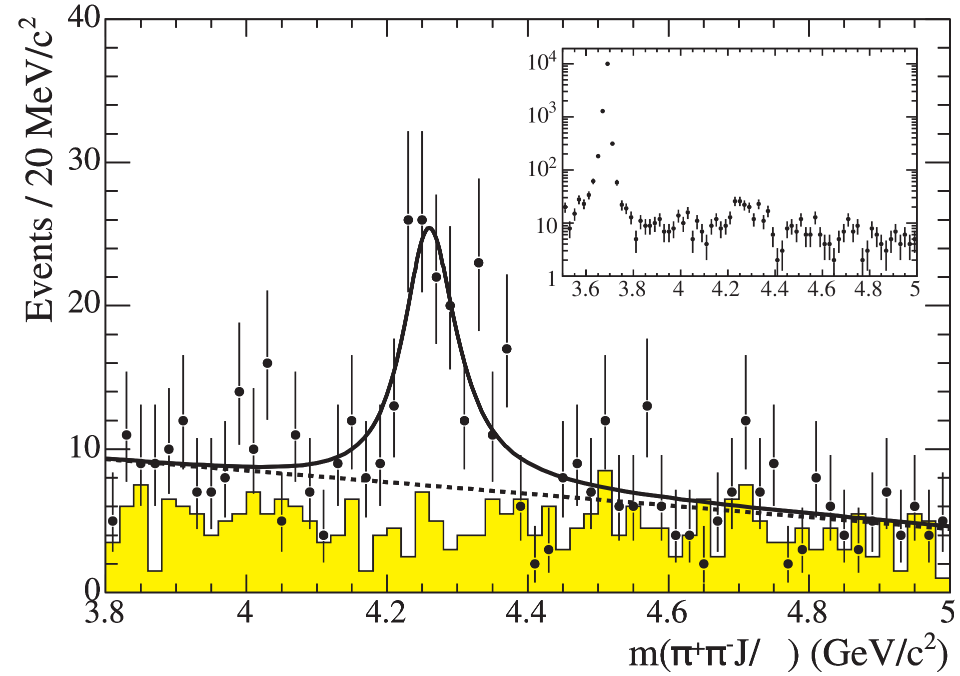


DEPARTMENT OF PHYSICS
INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

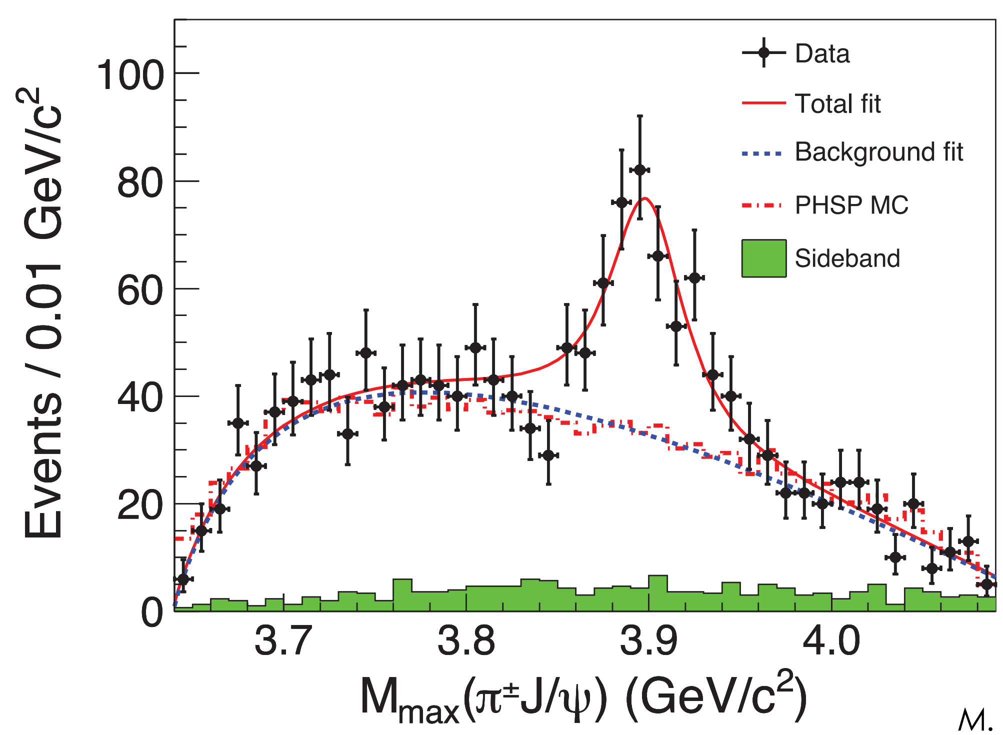
The Heavy Quarkonium Context

- Many new *XYZ* states in charmonium and bottomonium
  - see Ryan Mitchell's talk on Friday morning
- Interpretation?
  - hybrids with conventional meson quantum numbers?
  - *DD* or *BB* interactions?
  - tetraquarks?
- Can we establish a correspondence between light and heavy meson spectra?

The BaBar Collaboration [PRL 95, 142001 (2005)]

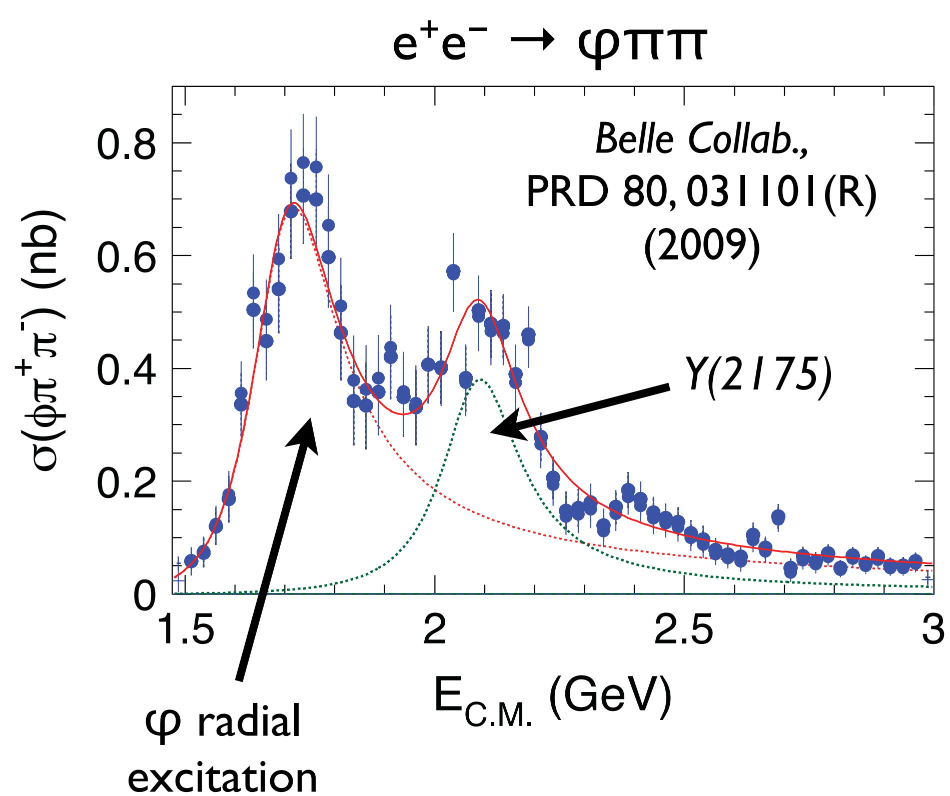


The BESIII Collaboration [PRL 110, 252001 (2013)]

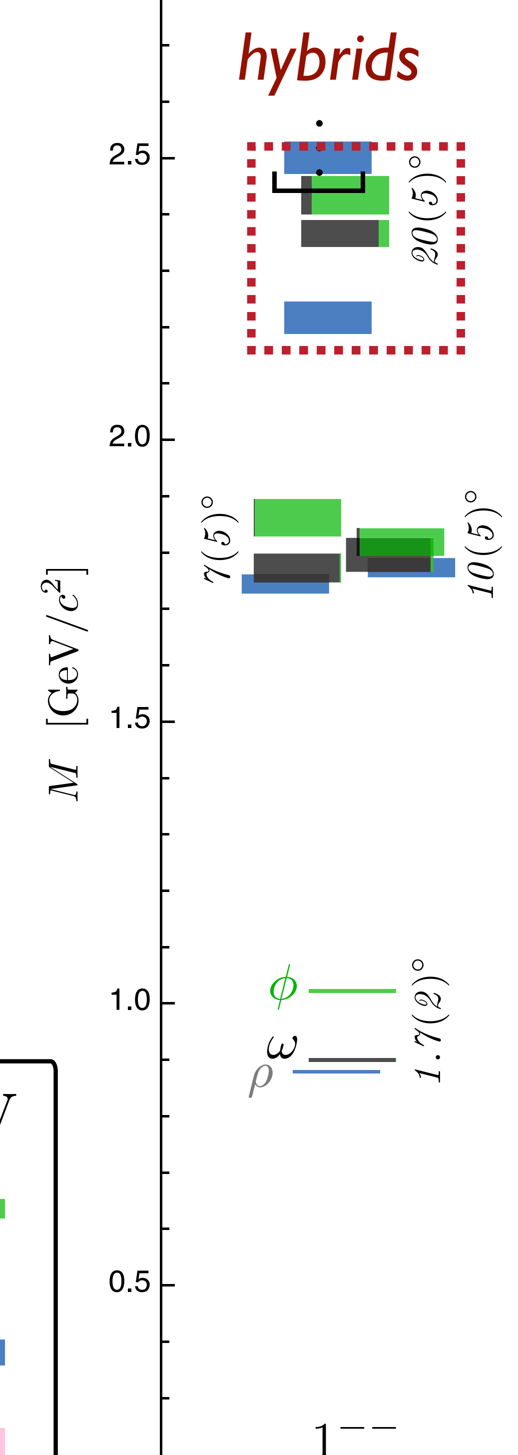


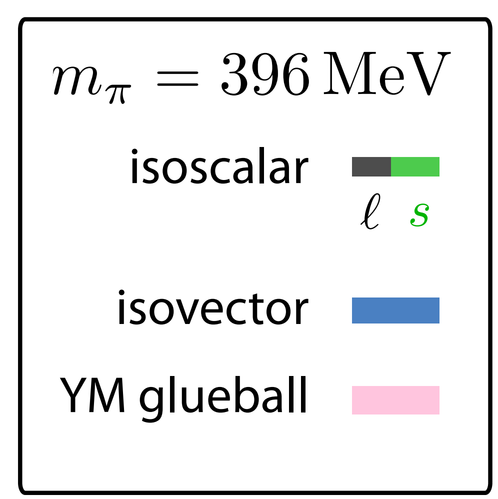
Y(2175): peculiar strangeonium?

- BaBar: $e^+e^- \to \varphi\pi\pi$ reports 1^{--} state *Y*(2175)
  - Belle, BES (in J/ψ decay) confirm
  - decay mode similar to *Y*(4260) → J/ψππ
- Questions
  - is *Y*(2175) supernumerary?
  - does *Y*(2175) behave like *Y*(4260)?
    - what does it mean?



J. Dudek
PRD 84, 074023 (2011)



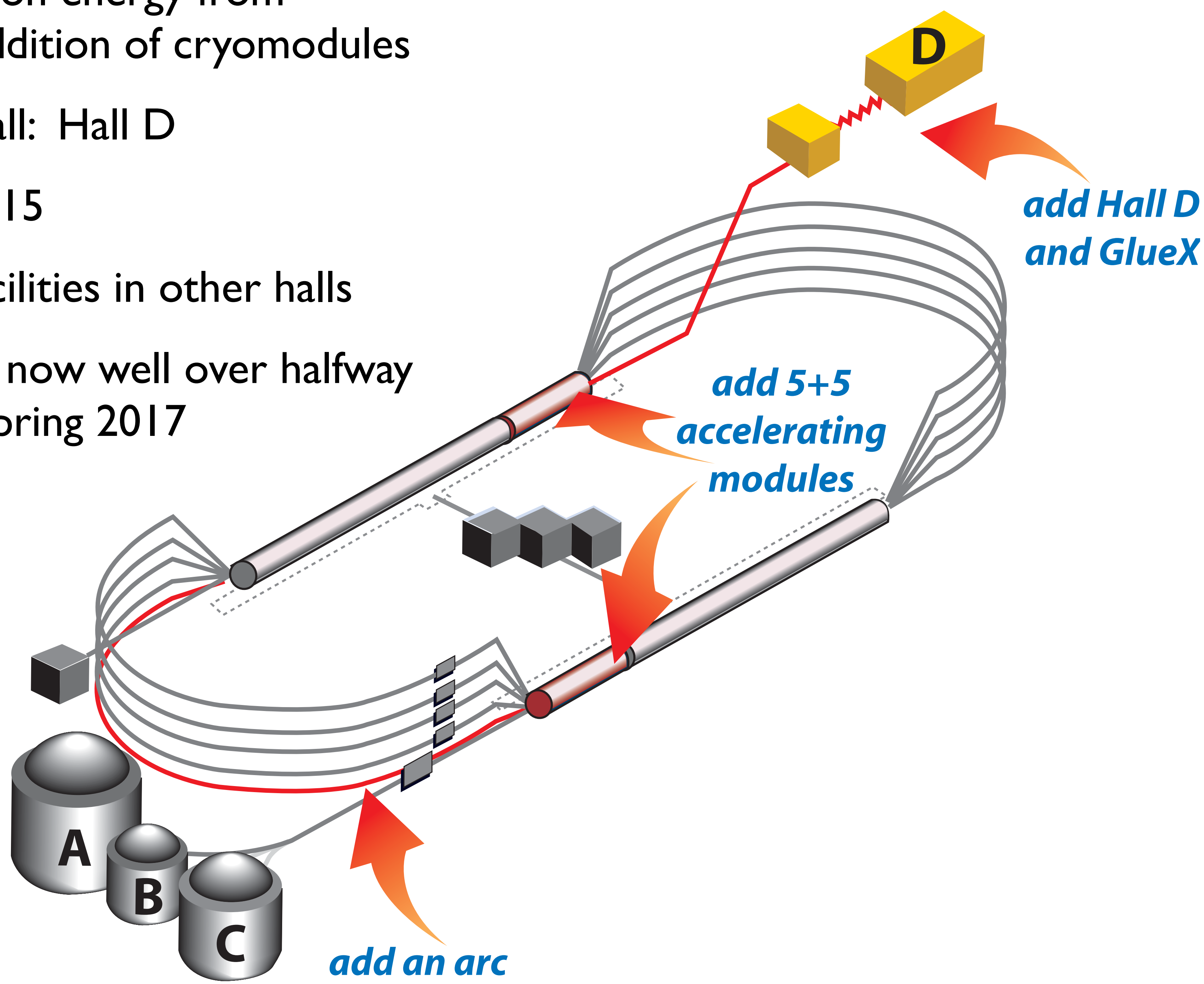


Recap

- QCD at low energy is strong: gluon-gluon interactions
- Recent advances in first-principles QCD calculations
- Experimental goals
  - search for light quark hybrids
  - study how they decay
  - compare with heavy quarks
  - ...?

12 GeV Upgrade to JLab

- Upgrade maximum electron energy from 6 GeV to 12 GeV with addition of cryomodules
- Add new experimental hall: Hall D
  - starts operation in 2015
- Upgrade experimental facilities in other halls
- $339M total project cost now well over halfway complete: CD-4B now Spring 2017

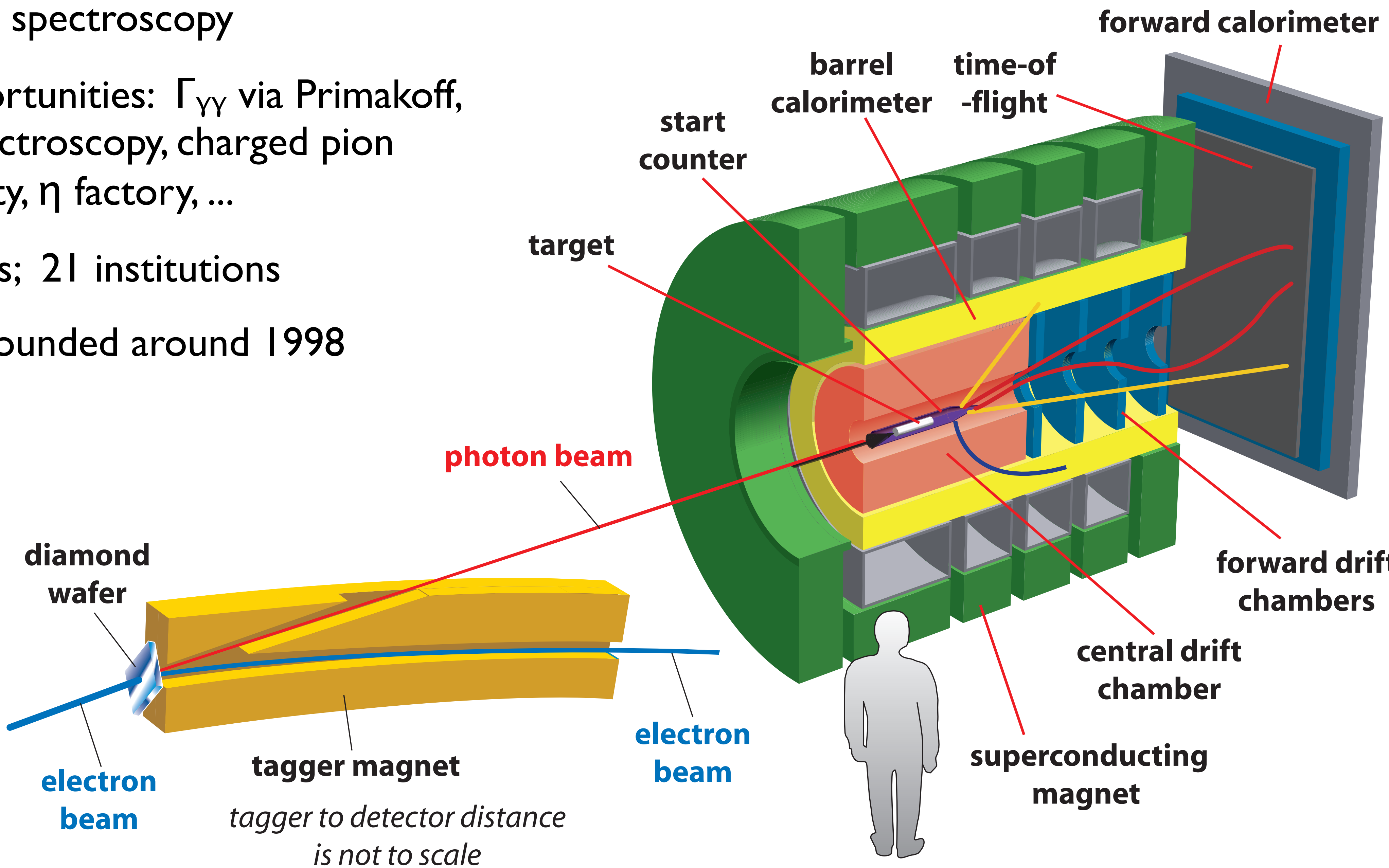


DEPARTMENT OF PHYSICS
INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

M. R. Shepherd
Intl. Mtg. on Nuclear Physics, Bormio
January 27, 2014

GlueX in Hall D

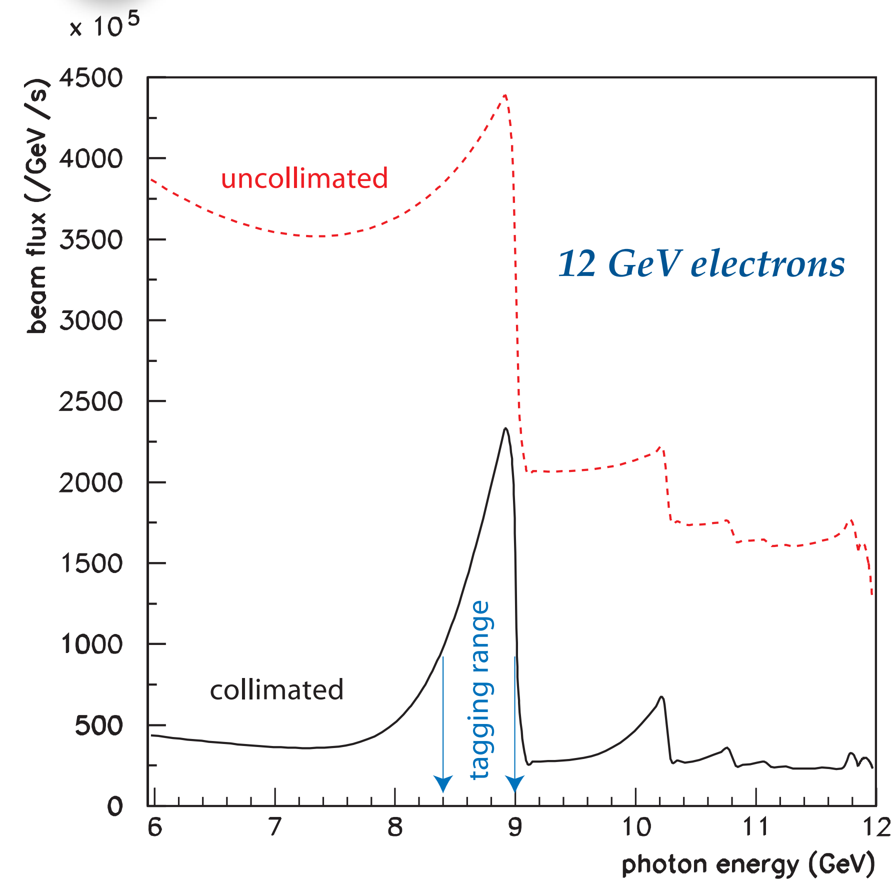
- core physics motivation:
  - light hybrid spectroscopy
  - other opportunities: $\Gamma_{\gamma\gamma}$ via Primakoff, baryon spectroscopy, charged pion polarizability, η factory, ...
- ≈115 physicists; 21 institutions
- collaboration founded around 1998

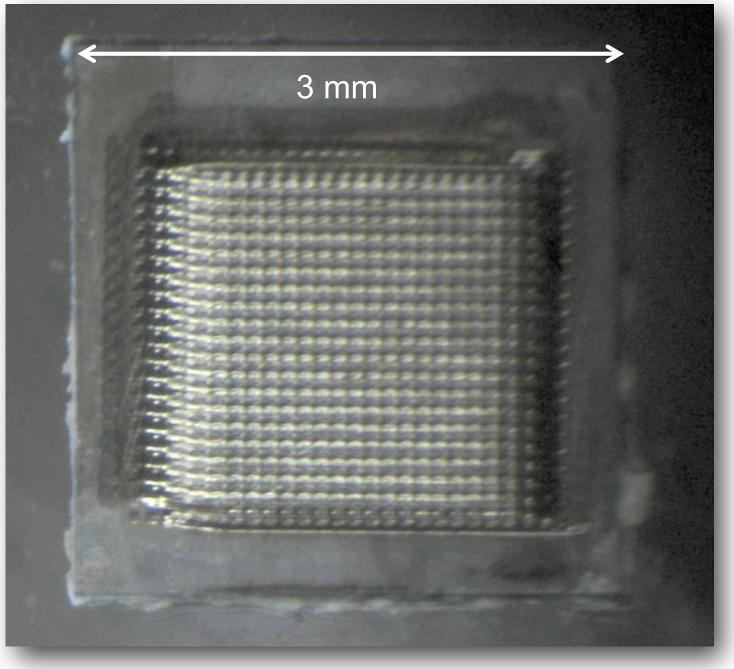



Hall D Experimental Complex
April 2012

Beamline Design

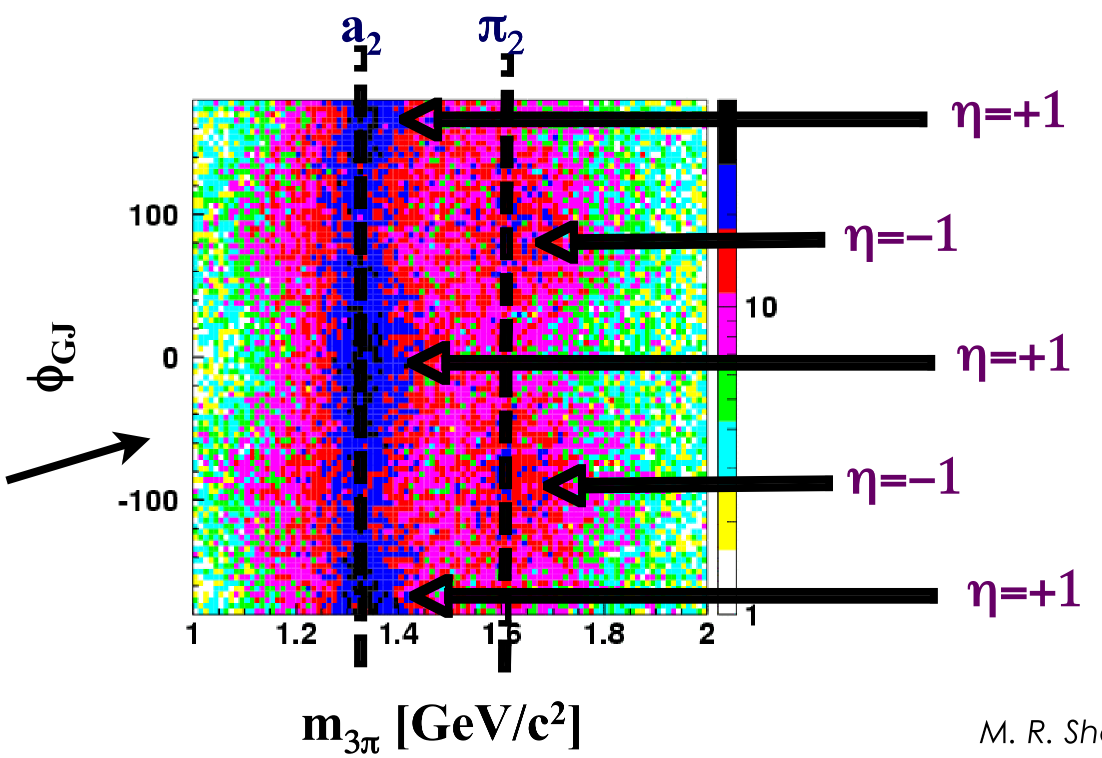
- some models predict enhanced hybrid photoproduction
- no restrictions on produced J^{PC}
- need 9 GeV tagged linearly polarized photons
  - coherent bremsstrahlung scattering of 12 GeV e^- off of a 20 μm thick diamond wafer





Simulated GlueX Analysis

$$\gamma p \to 3\pi n$$



The Tagger Area

Instrumentation

Broadband Hodoscope (3.0 - 11.8 GeV) 1-2% typical resolution on E_γ (sampling)

Tagger Microscope (8.4 - 9.0 GeV) 0.1% resolution on E_γ

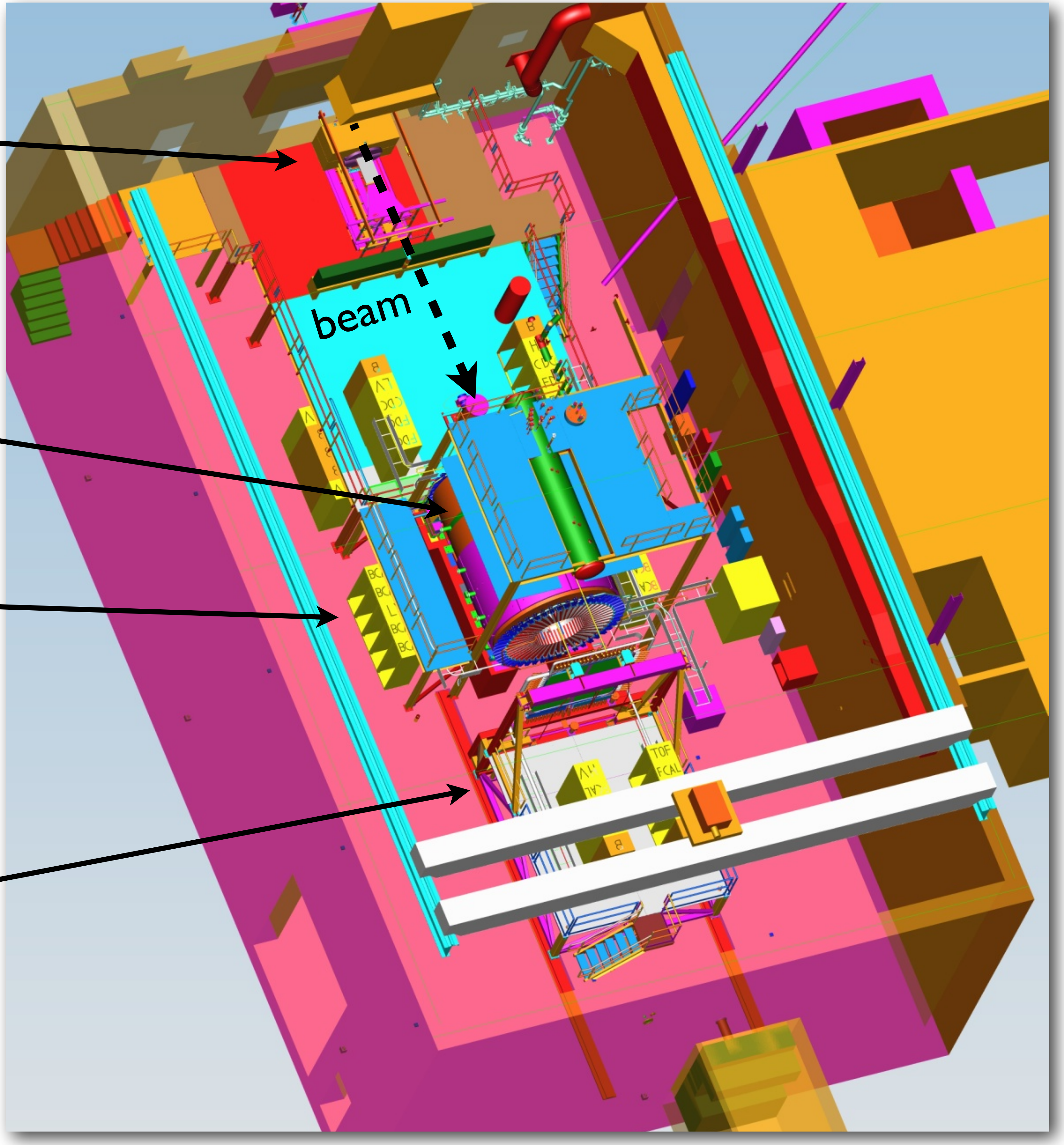
DEPARTMENT OF PHYSICS
INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

Pair Spectrometer

GlueX Solenoid (LASS Magnet)

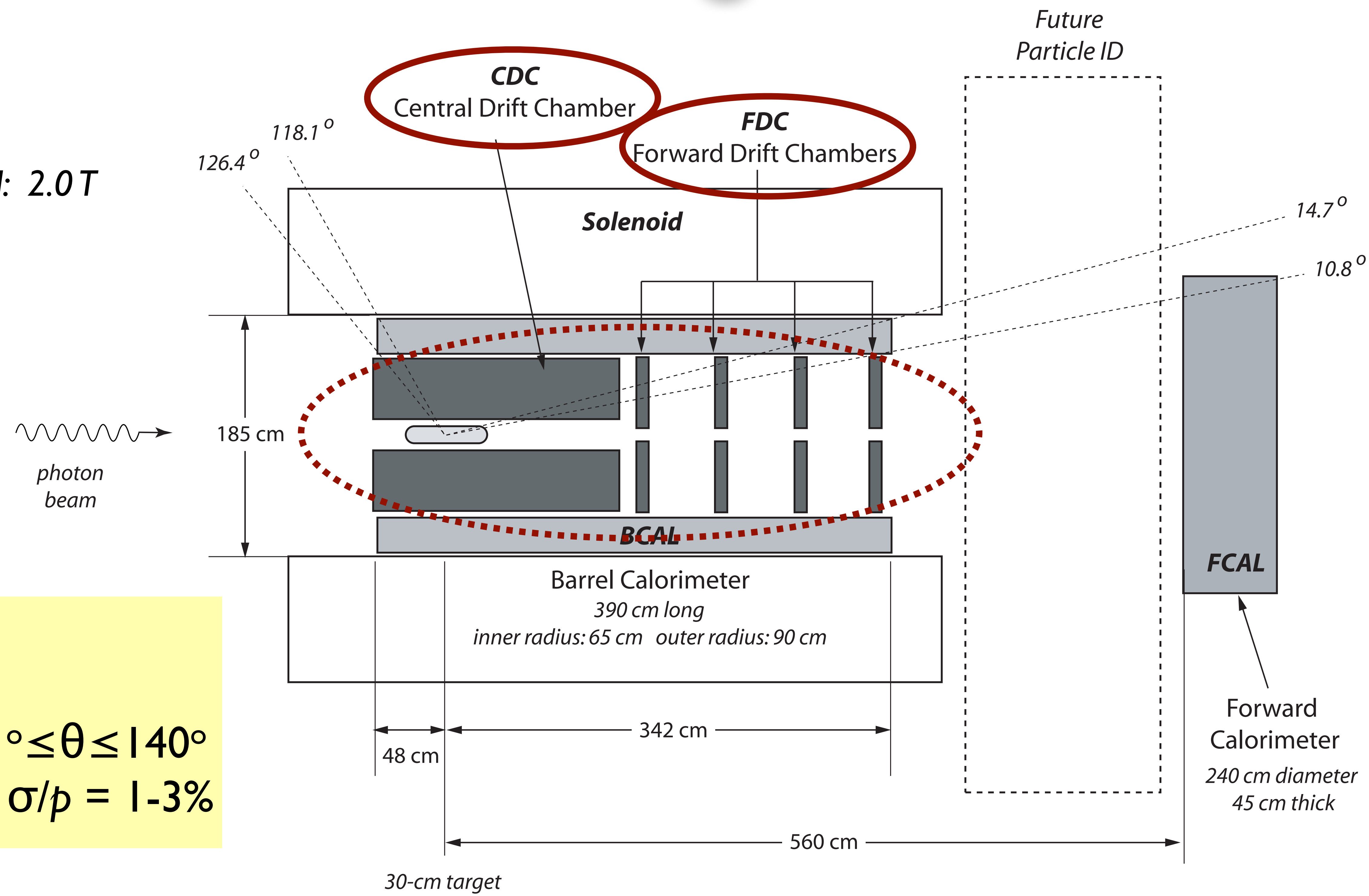
<u>Central Region</u>
Start Counter
Drift Chambers
Barrel Calorimeter

<u>Forward Platform</u>
Time of Flight
Forward Calorimeter



Tracking

Axial B-Field: 2.0 T

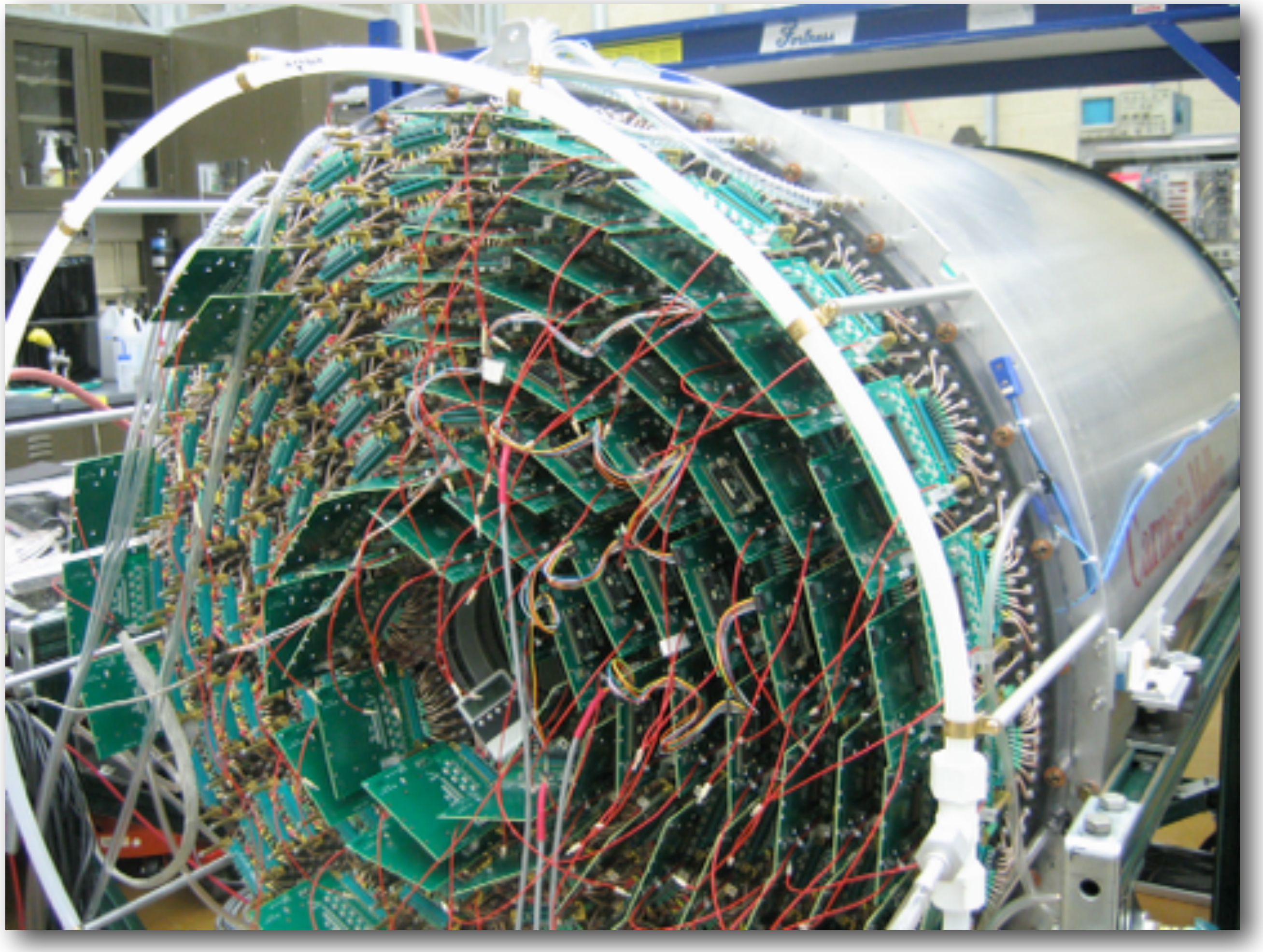


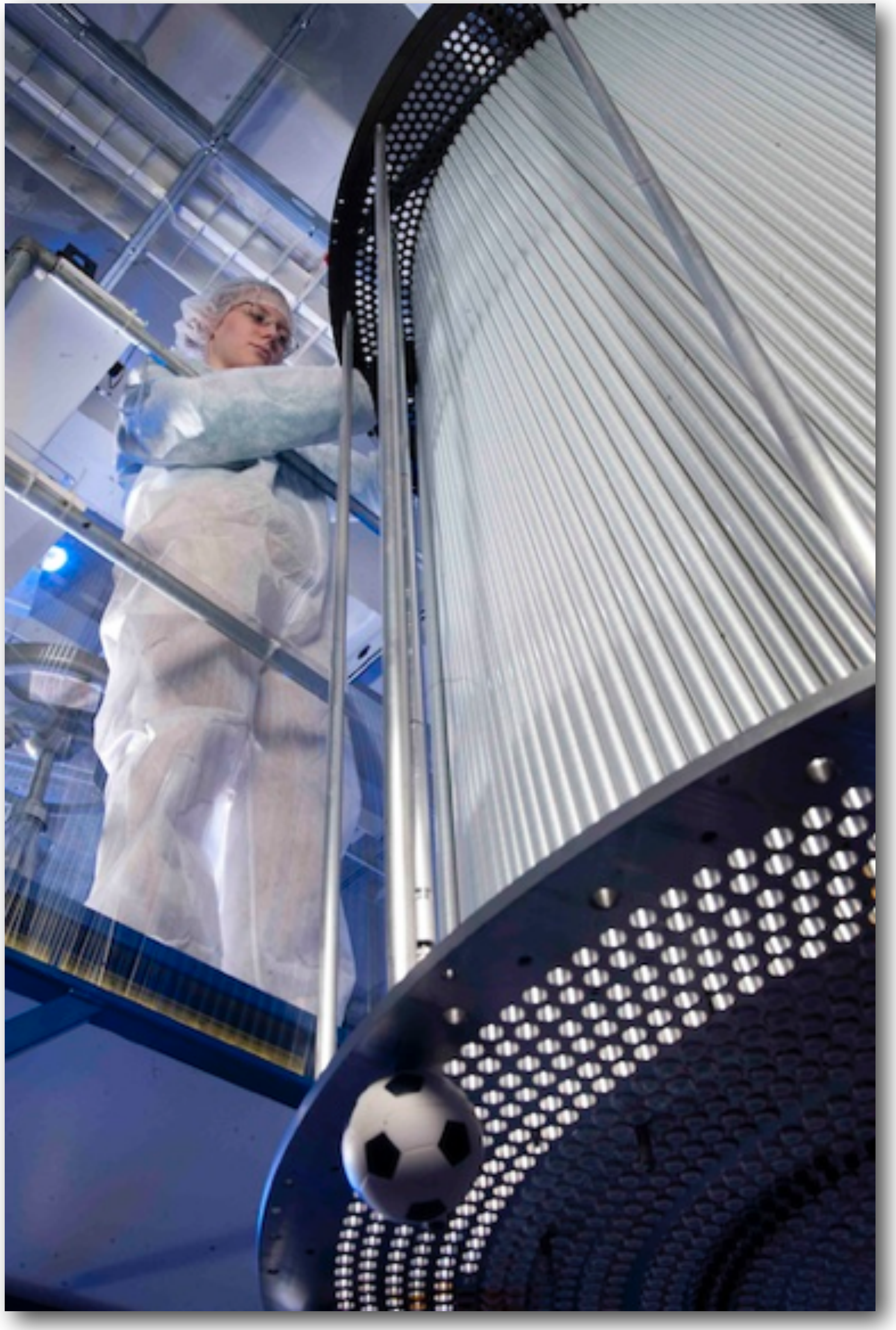
Goals

coverage: $1° \leq \theta \leq 140°$
resolution: σ/p = 1-3%

Central Drift Chamber

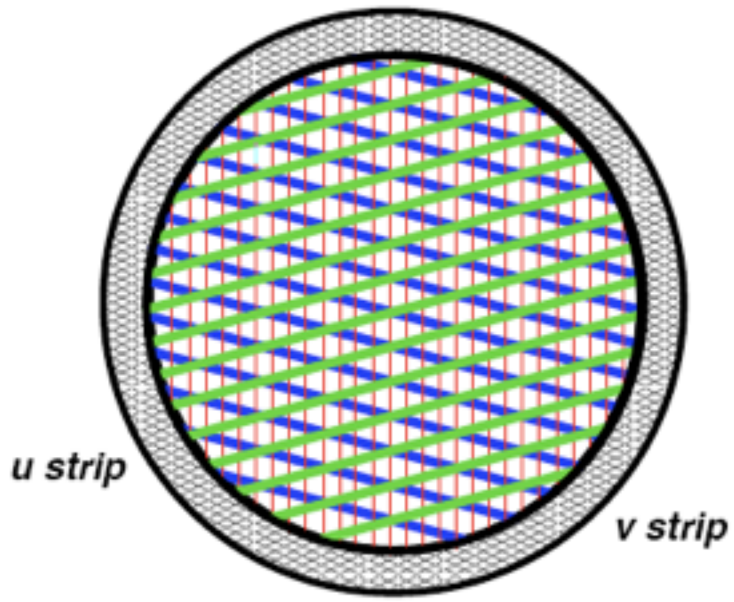
- 28 layers: 16 stereo (±6°), 12 axial
- design position resolution: 150 μm r/Φ, 2 mm z

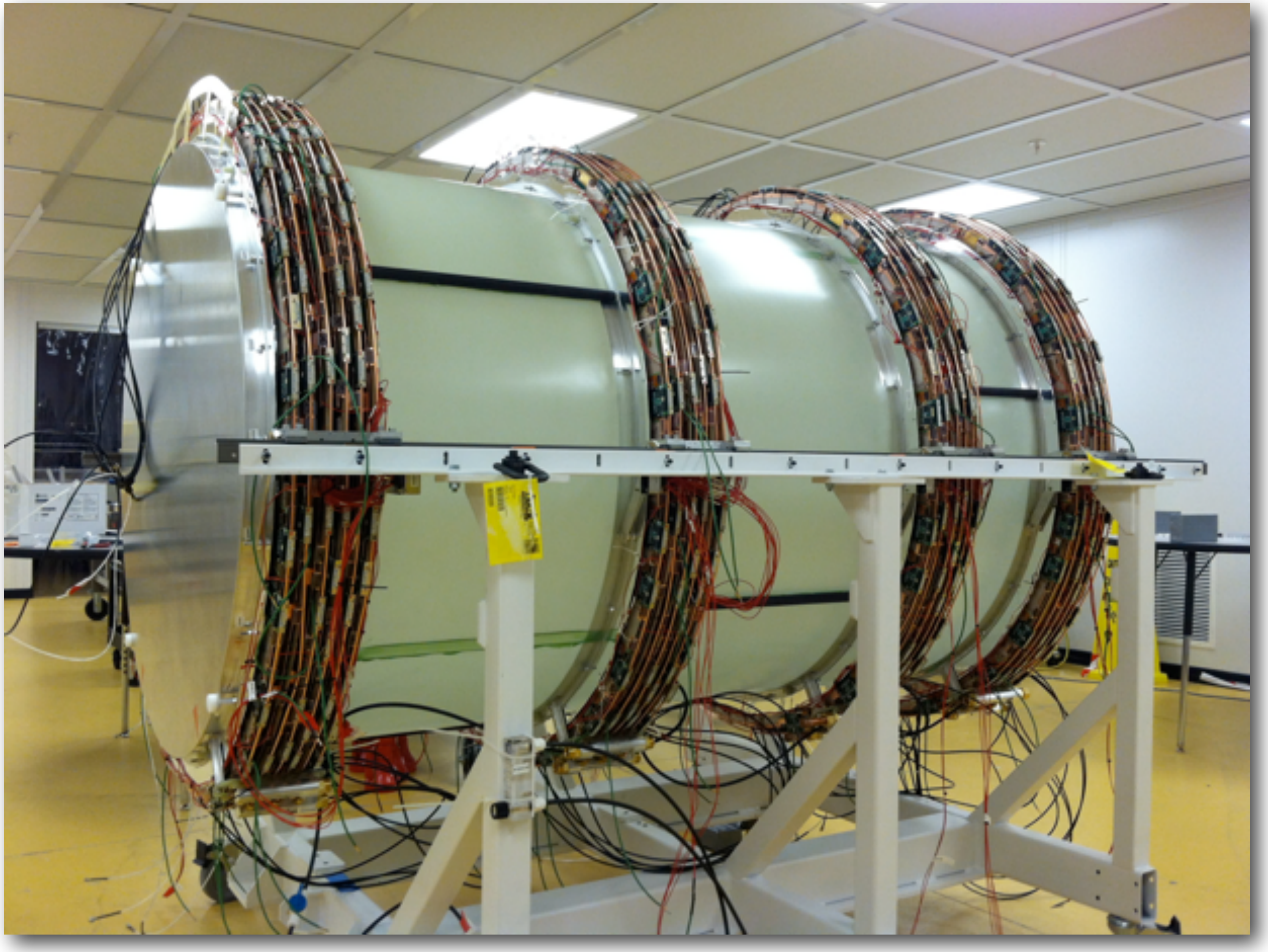




Forward Drift Chamber

- *u*/*v* cathode strip readout on each side of anode wires
- 200 μm resolution
- 4 x 6-layer packages; 60° rotation for each subsequent layer





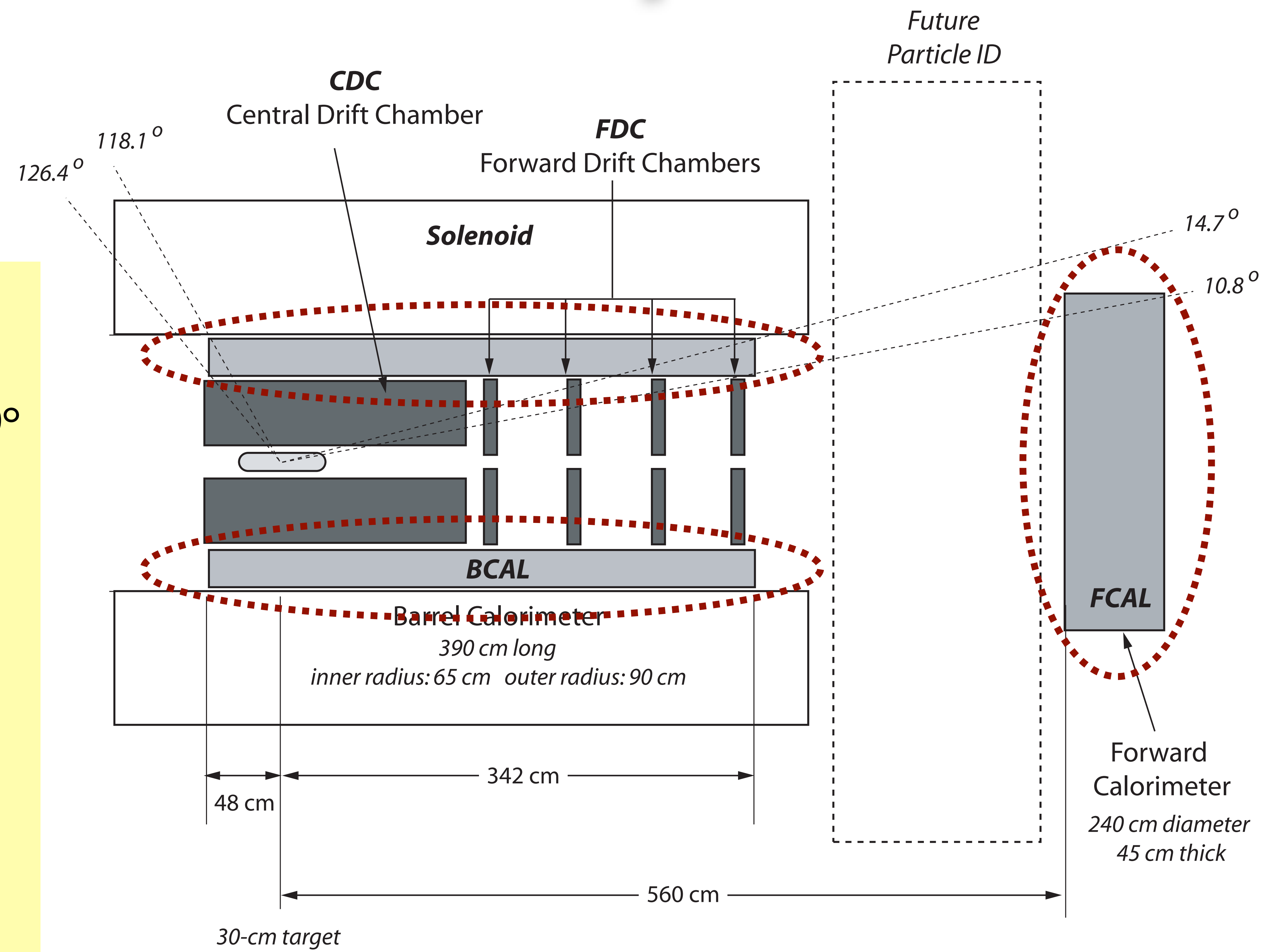
Calorimetry

Goals

coverage: $2° \leq \theta \leq 120°$

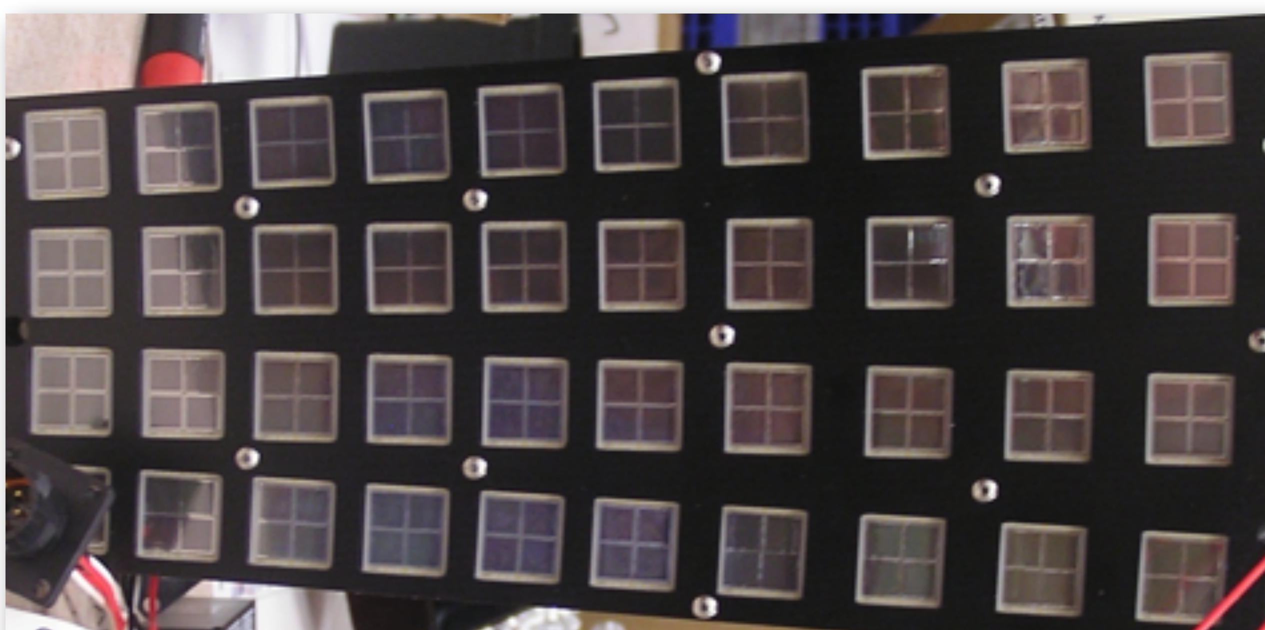
average approximate resolution:
$\sigma/E = 6\%/\sqrt{E} + 2\%$

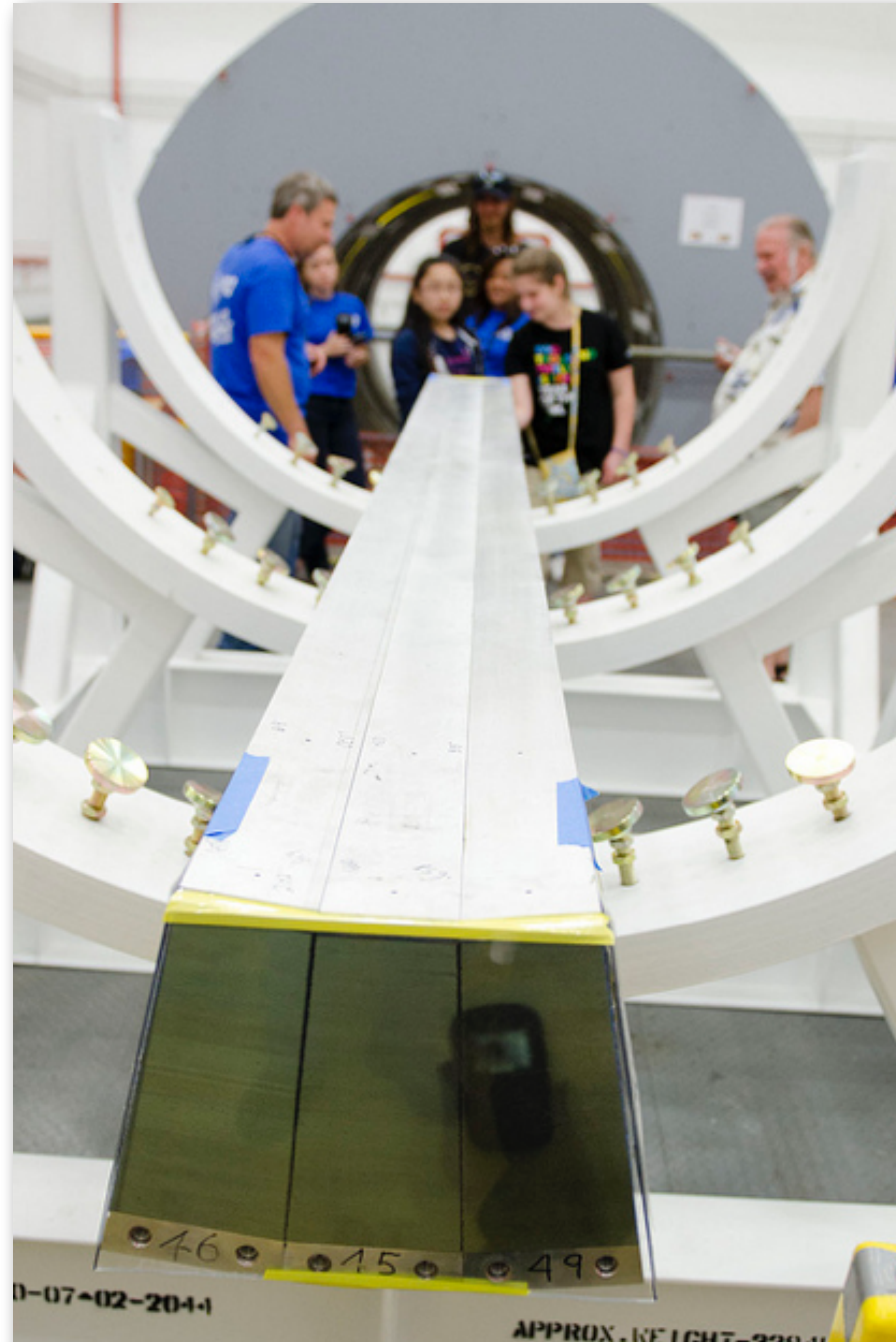
low energy threshold:
forward: 50 MeV
barrel: 60 MeV



Barrel Calorimeter

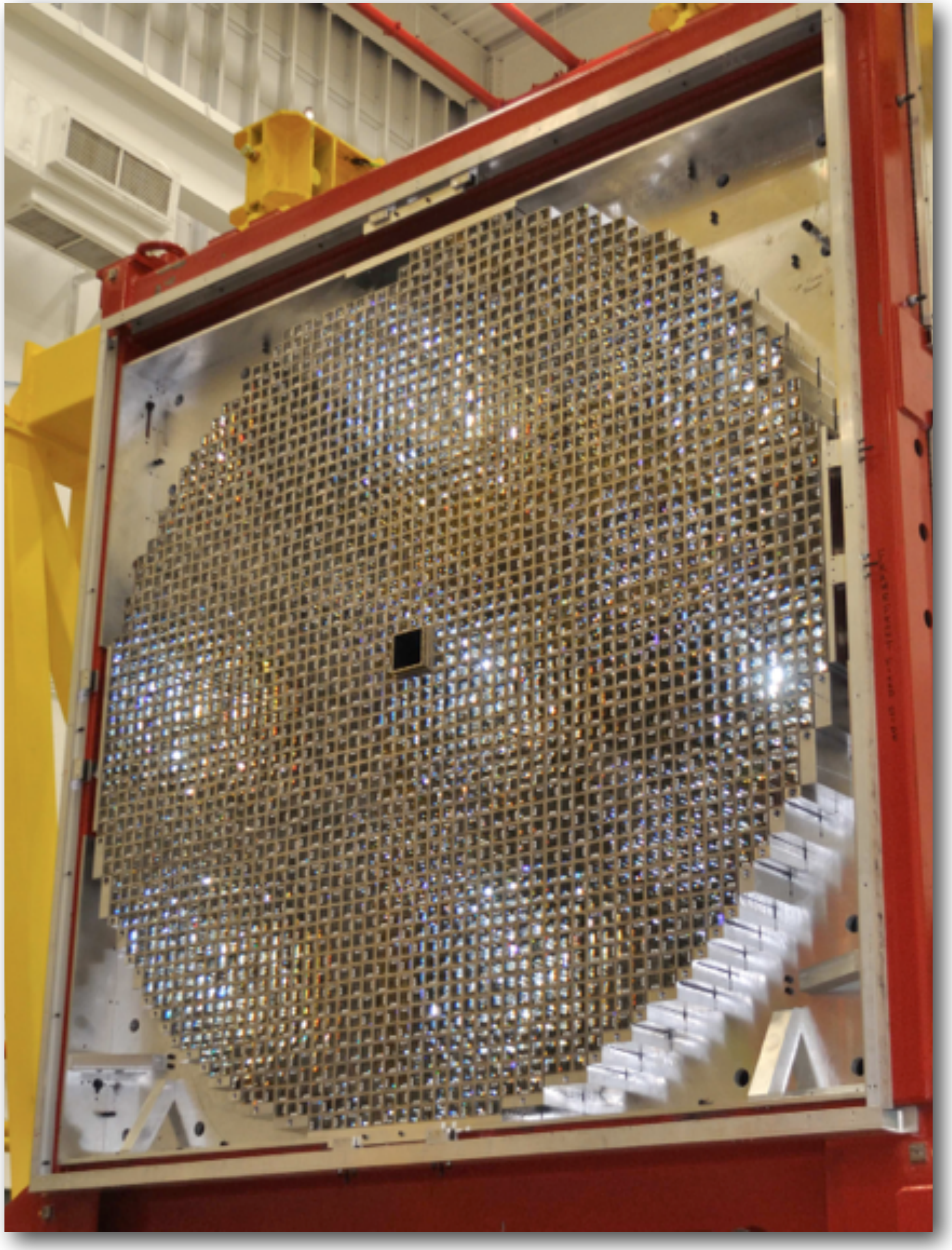
- Pb-SciFi calorimeter based on KLOE design; 48 4-m long modules
- large area (1.2 cm x 1.2 cm) Silicon photomultiplier readout (Hamamatsu)
- resolution: $\sigma/E = 5\%/\sqrt{E} + 1\%$





Forward Calorimeter

- 2800 4 cm x 4 cm x 45 cm lead glass blocks; (glass from the E852 experiment at BNL)
- readout: 1” FEU 84-3 PMTs
- $\sigma/E = 6\%/\sqrt{E} + 2\%$:

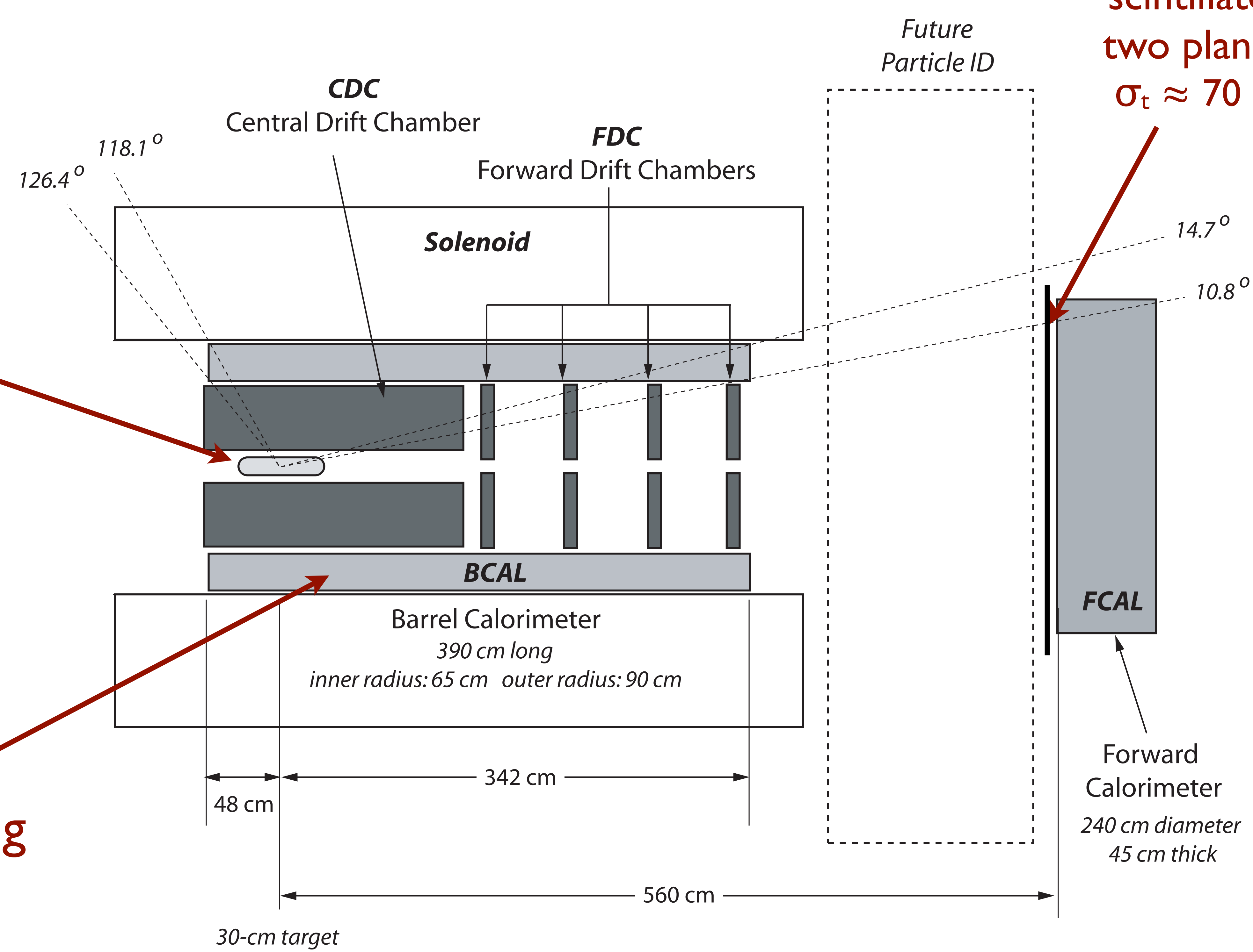


Particle ID/Timing

TOF Wall
scintillator, two planes, $\sigma_t \approx 70$ ps

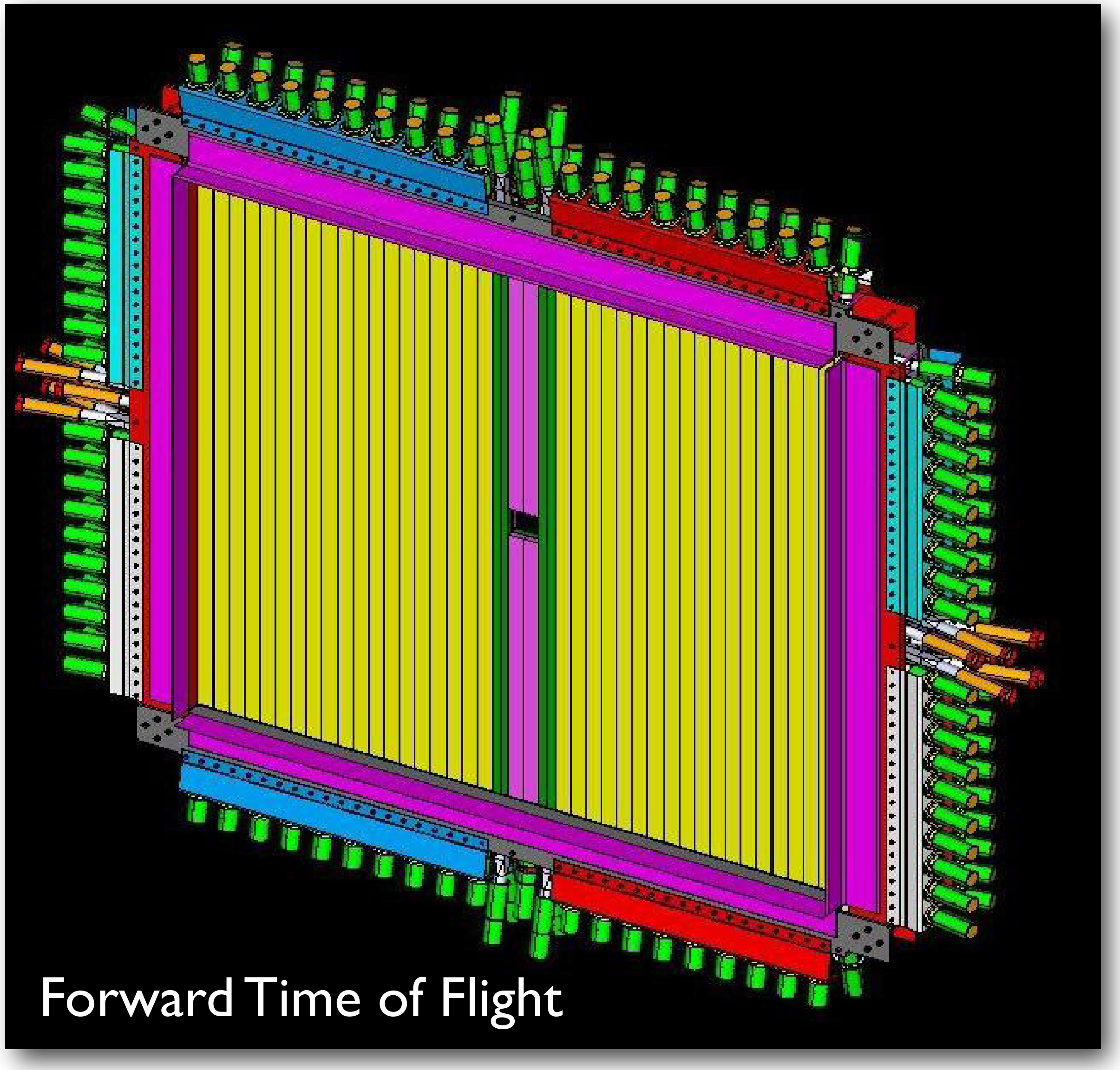
Start Counter
segmented scintillator around target
$\sigma_t \approx 300$ ps

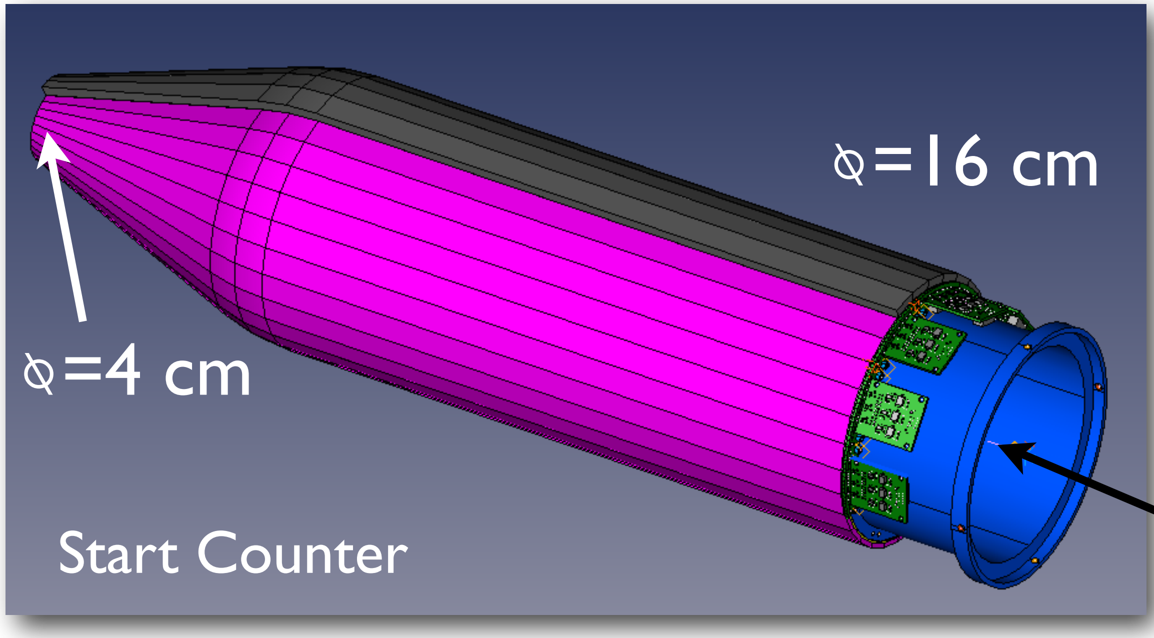
BCAL Timing



Particle ID and Timing

- Start counter: thin scintillator with approximately 300 ps resolution (strong position dependence)
  - SiPM readout
- Forward TOF: two-scintillator planes; 70 ps resolution; 4σ K/π up to 2 GeV/*c*
  - conventional PMT readout



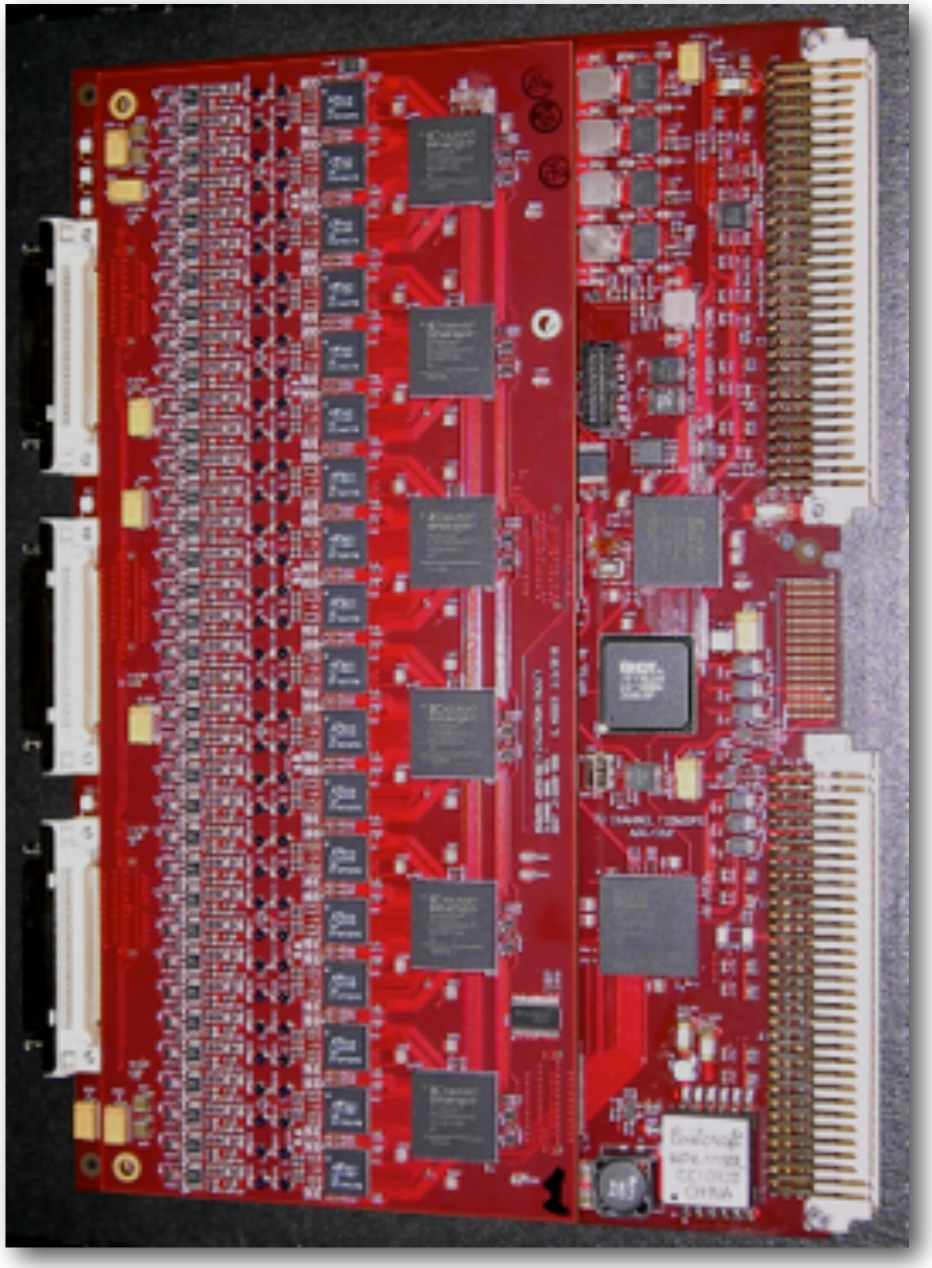


beam on
LH_2 target

M. R. Shepherd
Intl. Mtg. on Nuclear Physics, Bormio
January 27, 2014

Data Rates

- Design rate: 10^8 γ/s tagged photons on target in the polarization peak; initial running at 10^7 γ/s
- Fully pipelined, zero-deadtime readout electronics
  - level one trigger: 200 kHz
  - level three output: 300 MB/s
    (20 kHz of "interesting physics" selected with software trigger)
- Expected statistics in initial, low intensity run:
  - 1×10^8 events: $\gamma p \rightarrow \pi^+\pi^-\pi^+ n$
  - 5×10^6 events: $\gamma p \rightarrow \omega\pi^-\pi^+ p$
  - 10^5 - 10^6 events: $\gamma p \rightarrow \eta'\pi^+ n$
- *an order of magnitude more data later*

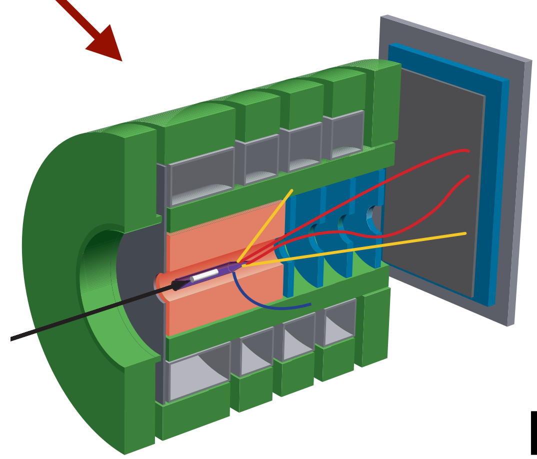


72 Channel
125 MHz 12-bit Flash ADC

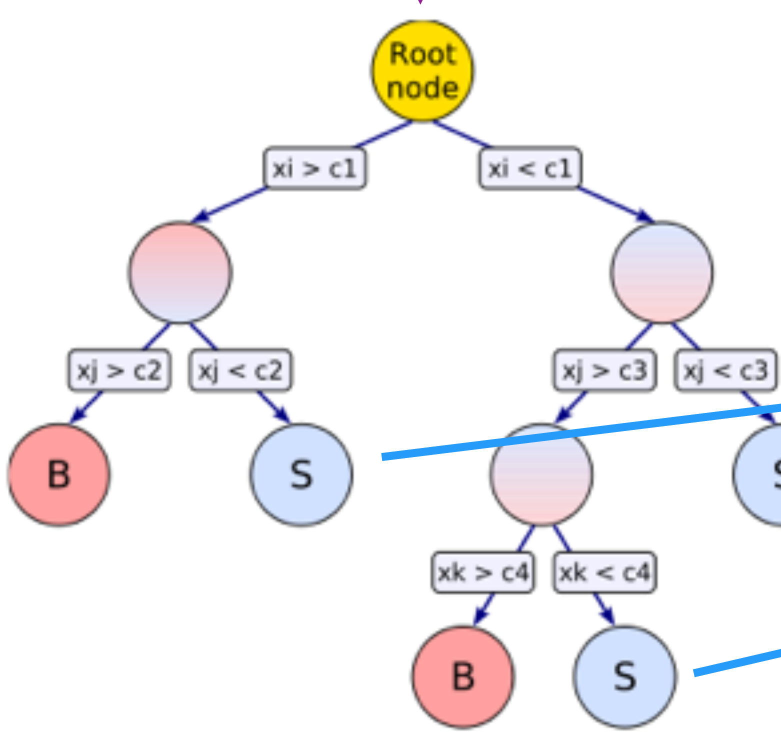
Analysis Procedure

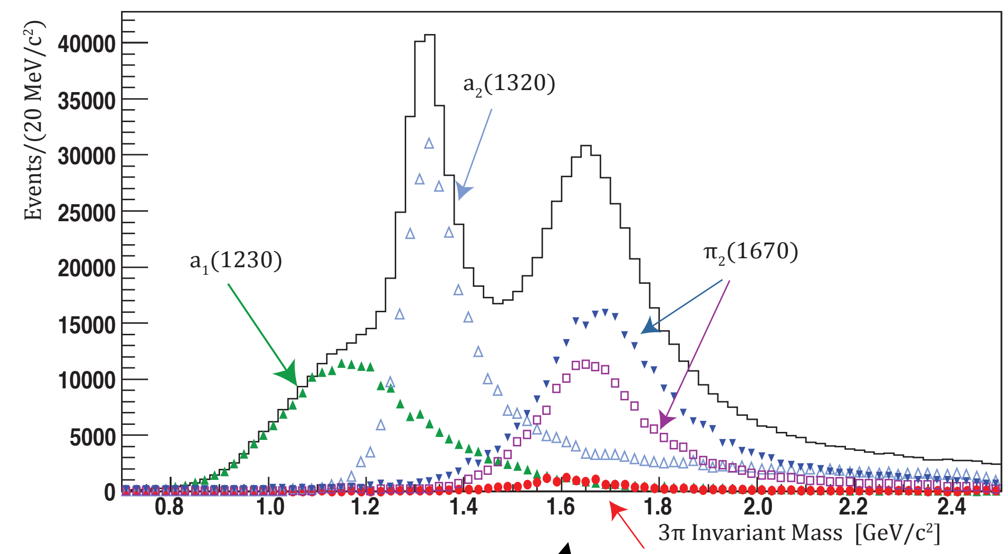
$\gamma p \to X$
(from PYTHIA)

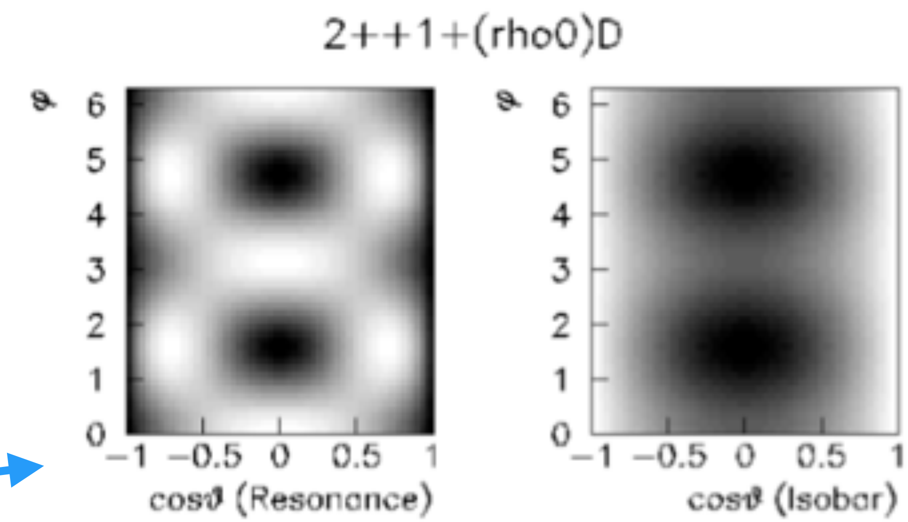
$\gamma p \to \pi^+\pi^-\pi^+ n$



GEANT +
Reconstruction





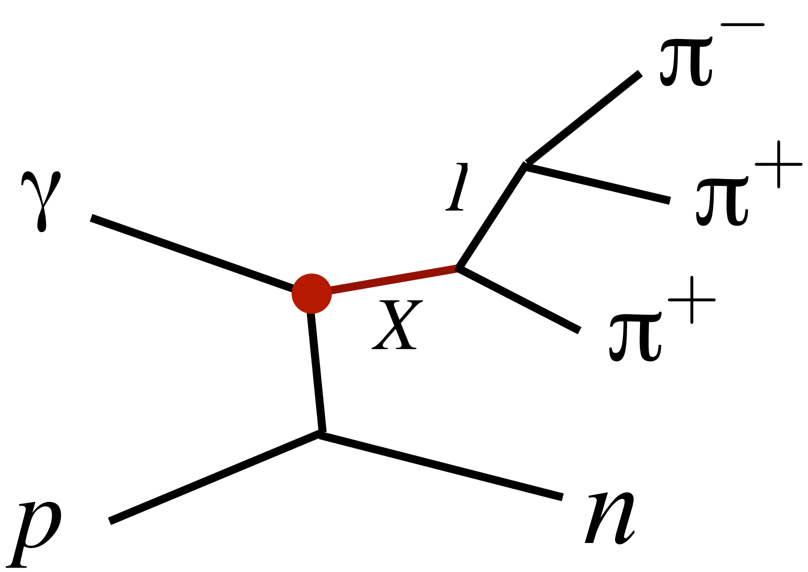


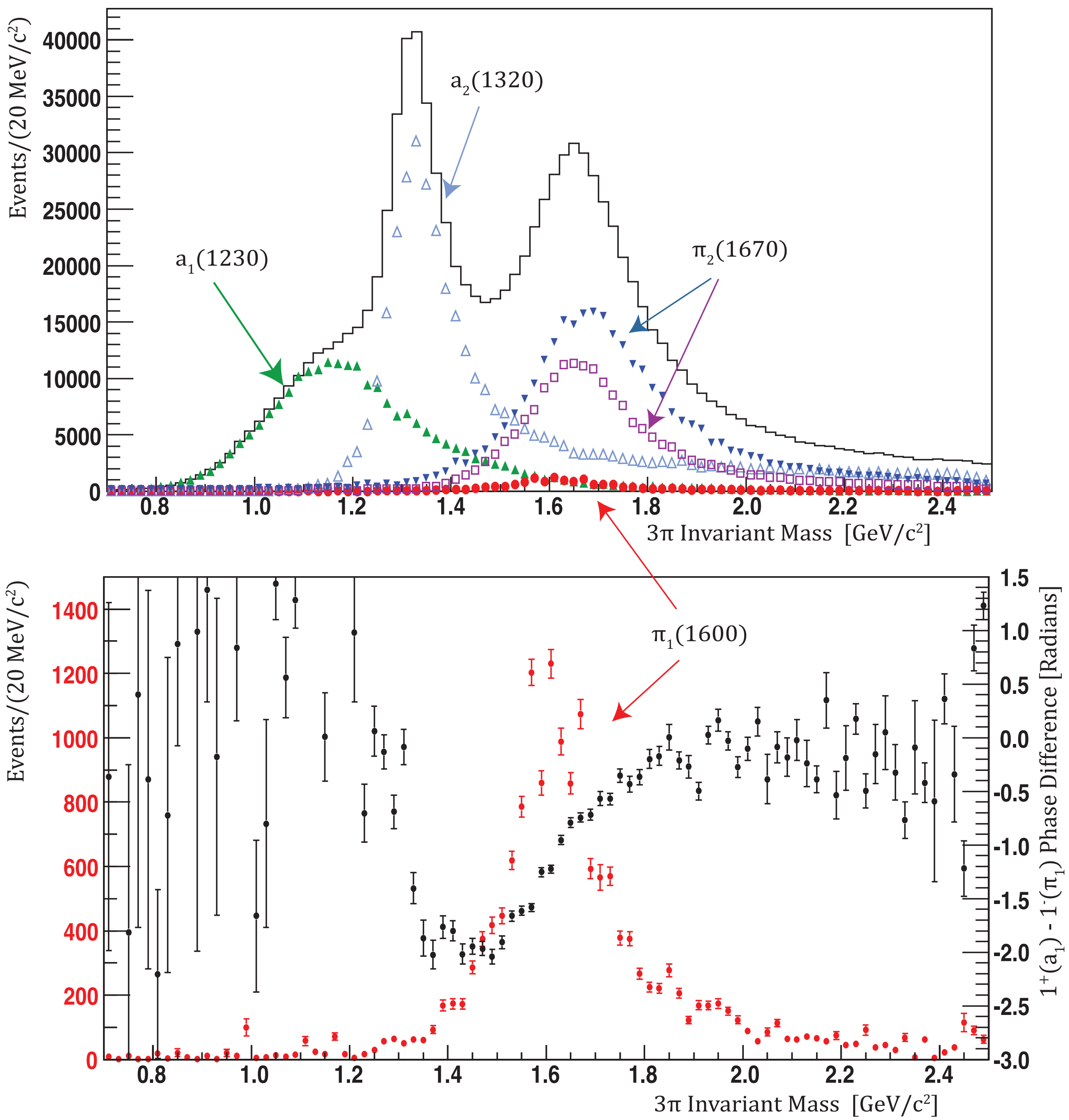
AmpTools

NVIDIA

Typical Channel: $\gamma p \rightarrow \pi^+\pi^-\pi^+ n$

- $\pi^+\pi^-\pi^+ n$ topology
  - neutron undetected
  - 2% of total hadronic cross section
  - overall 28% efficiency at 95% purity
- Use as a test of detector sensitivity to small amplitudes





Other Reactions of Interest

Meson of Interest (X)	Reaction Topology	Mass Range [MeV/c^2] $M_X^{\min}$	$M_X^{\max}$	Signal Yield [10^6]	Events per 10 MeV/c^2 [10^4]
$h_2'(2600)$	$\gamma p \to (K_1(1400)K)_X p$	2415	2785	1.5	4.0
	$K_1 \to K^*\pi$				
	$K^* \to K\pi$				
$\eta_1'(2300)$	$\gamma p \to (K^* K_S)_X p$	2000	2600	0.46	1.5
	$K^* \to K^\pm \pi^\mp$				
	$K_S \to \pi^+\pi^-$				
$\phi_3(1850)$	$\gamma p \to (K^+K^-)_X p$	1720	1980	5.3	21
$Y(2175)$	$\gamma p \to (\phi f_0(980))_X p$	2060	2290	0.12	0.52
	$\phi \to K^+K^-$				
	$f_0(980) \to K^+K^-$				

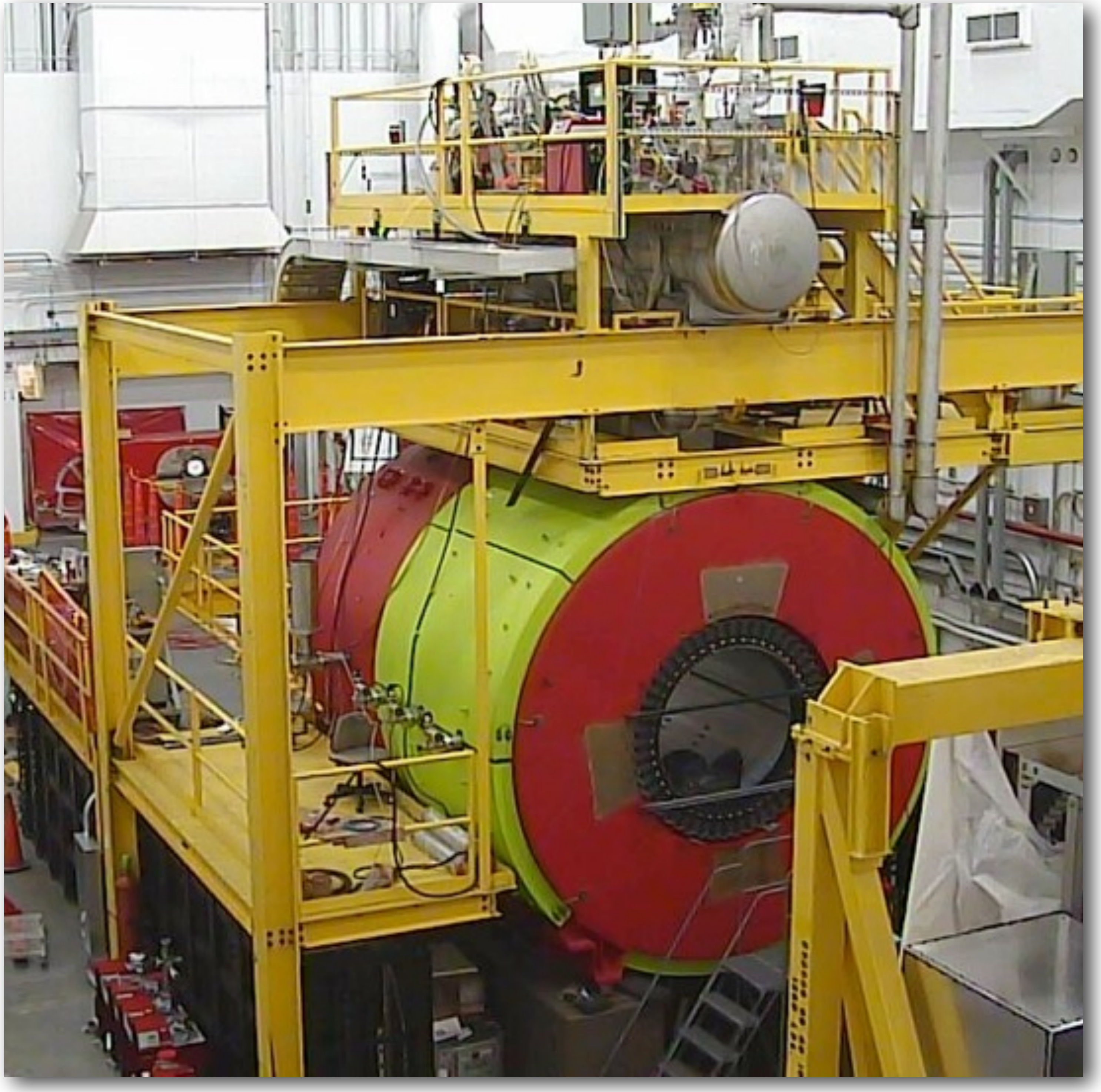
complementary to non-strange topology (h_2): $b_1\pi$

complementary to non-strange topology (η_1): $f_1\eta$

- Pythia-based *non-resonant* cross section predictions
- PAC-approved full intensity physics run (~2017)
- 90% signal purity

Upcoming Milestones

- Installation mostly complete by Spring 2014
- Fall 2014: first commissioning beam in Hall D (“readiness milestone”)
- 2015-2017: initial “low intensity” physics running
- Spring 2017: 12 GeV upgrade officially complete
- 2017-?: high intensity running and possible particle identification upgrades



Summary

- Many exciting developments in meson spectroscopy
  - "understanding" requires theory + experiment
  - studying a *spectrum* of states is essential
  - extraordinary recent results in bottomonium and charmonium
    - may provide insight for light quark studies
- The GlueX experiment
  - is in advanced stages of construction and installation
  - is poised to explore light meson photoproduction with unprecedented statistical precision in the next few years