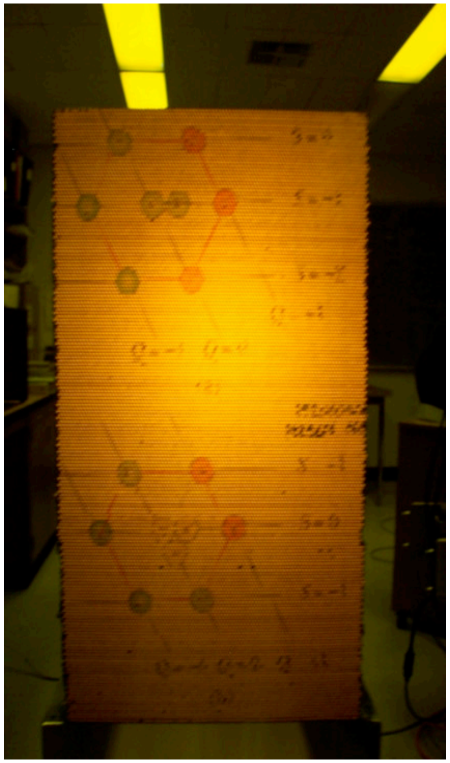
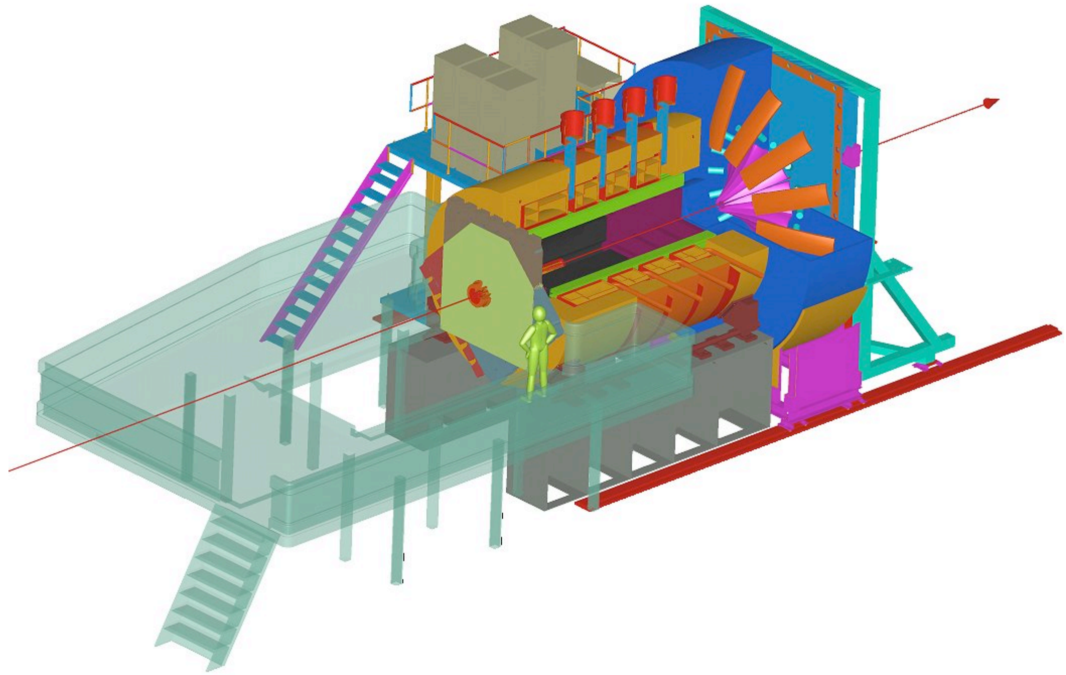
Performance of the prototype module of the GlueX electromagnetic barrel calorimeter





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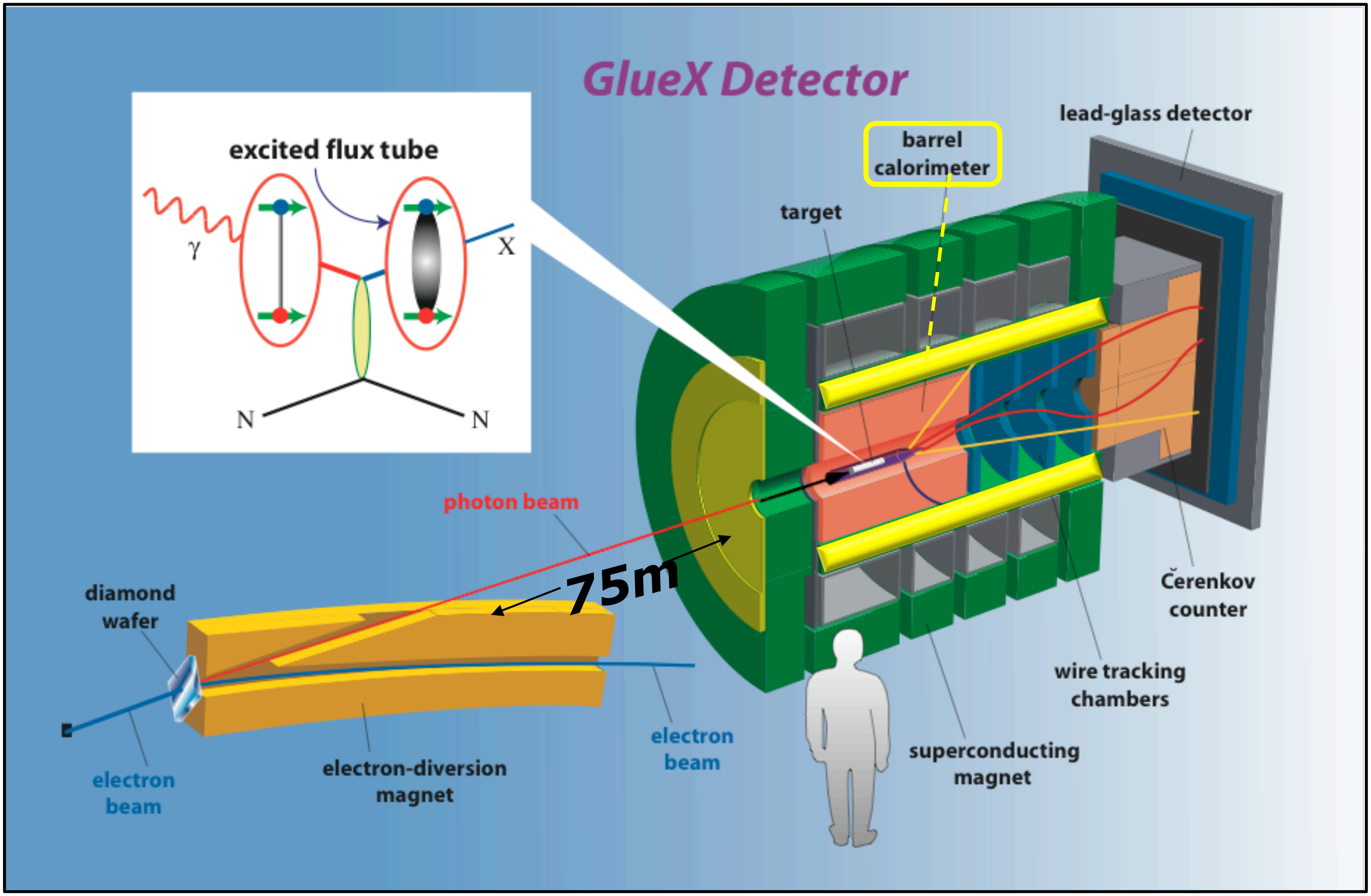
GlueX Collaboration
University of Regina, Canada

Jefferson Lab
Exploring the Nature of Matter

Scientific Goals and Means

- **GlueX Physics**
  - Elucidate the phenomenon of confinement in QCD
  - Definitive and detailed mapping of hybrid meson spectrum
  - Search for smoking gun signature of exotic J^{PC} hybrid mesons; no mixing with $q\bar{q}$
  - Test photo-couplings and phenomenology
  - $s\bar{s}$ and baryon spectroscopy, …
- **Tools for the GlueX Project**
  - 12 GeV electrons, 9 GeV tagged, linearly polarized photons with high flux
  - Detector: hermiticity, resolution, charged and neutrals
  - Spin-Amplitude Analysis of multi-particle final states
  - Computing power: Tb+/year data collection, databases, distributed computing, …
- **Key detector subsystem: BCAL**
  - Pb-Scintillating Fiber sampling calorimeter
  - 70% of decay photons are captured by BCAL
  - 50% of BCAL ones have energies < 300MeV
  - 40 MeV – 2 GeV operating range; high magnetic field, tight space

BCAL06: A beam test of the electromagnetic calorimeter in Hall B at JLab


GlueX Detector
excited flux tube
γ
X
N
N
lead-glass detector
barrel calorimeter
target
photon beam
75m
diamond wafer
electron beam
electron-diversion magnet
electron beam
superconducting magnet
wire tracking chambers
Čerenkov counter

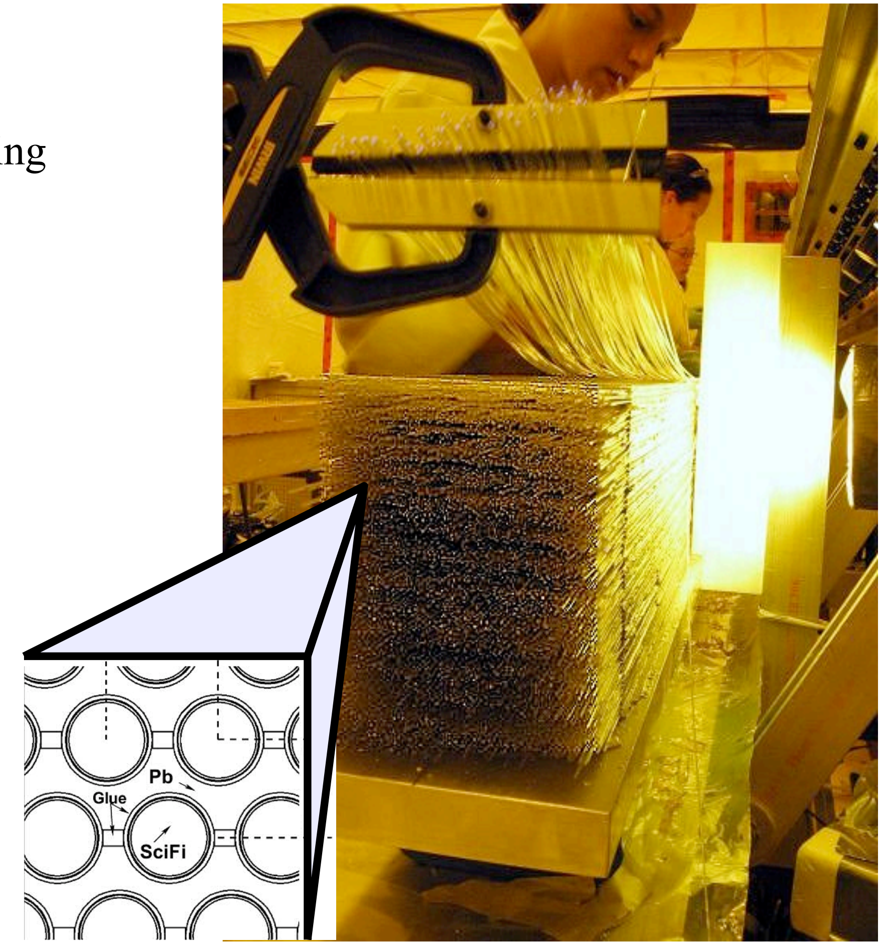
BCAL Highlights

Key component of the GlueX detector

- Crucial for reconstructing γ from π^0 and η resulting from decay mesons
- Provides timing information (neutrals/charged)
- With the CDC it provides charged particle PID
- It supplies secondary dE/dx

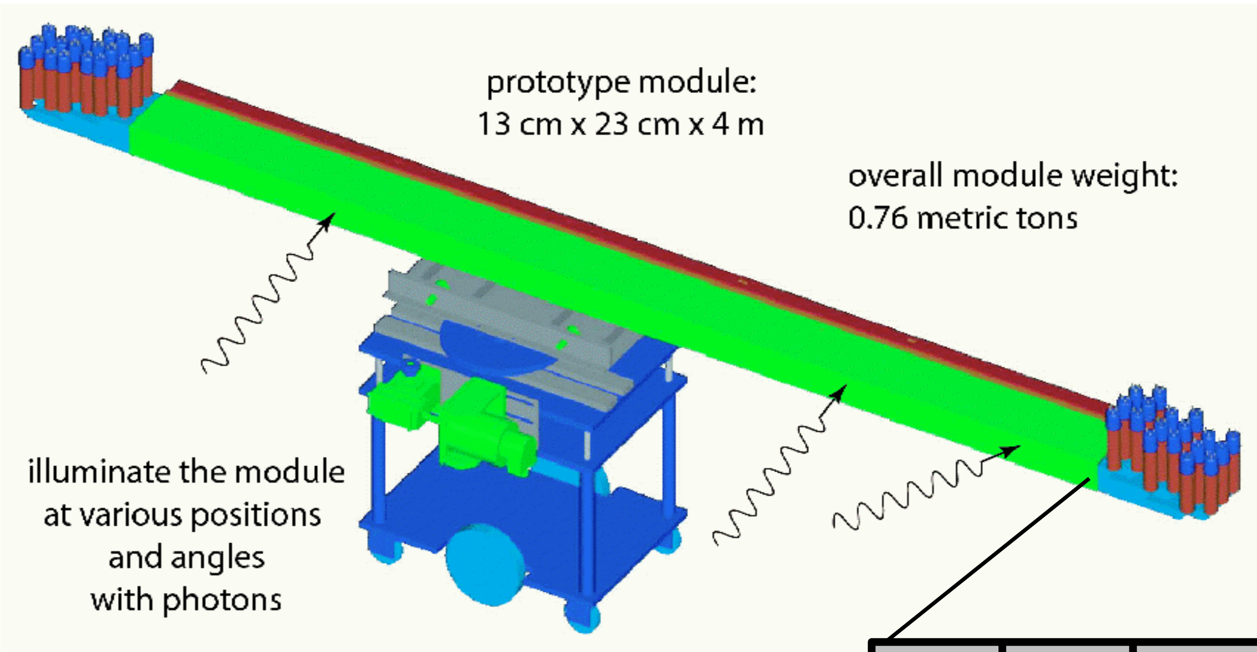
Geometry & Configuration

- Sampling calorimeter (12% sampling fraction)
- Made of alternating layers of Pb, scintillating fibres and optical epoxy (vol. 37:49:14)
- Based on KLOE design (DAΦNE)
- BCAL: 48 modules, 390cm long, in a barrel configuration with 65 cm inner radius, and $16X_0$ thick (~25 tonnes)
- The scintillating fibres have a polystyrene core which produces 8000 photons/MeV and are fast green or blue double clad (increases light captured by ~50%)



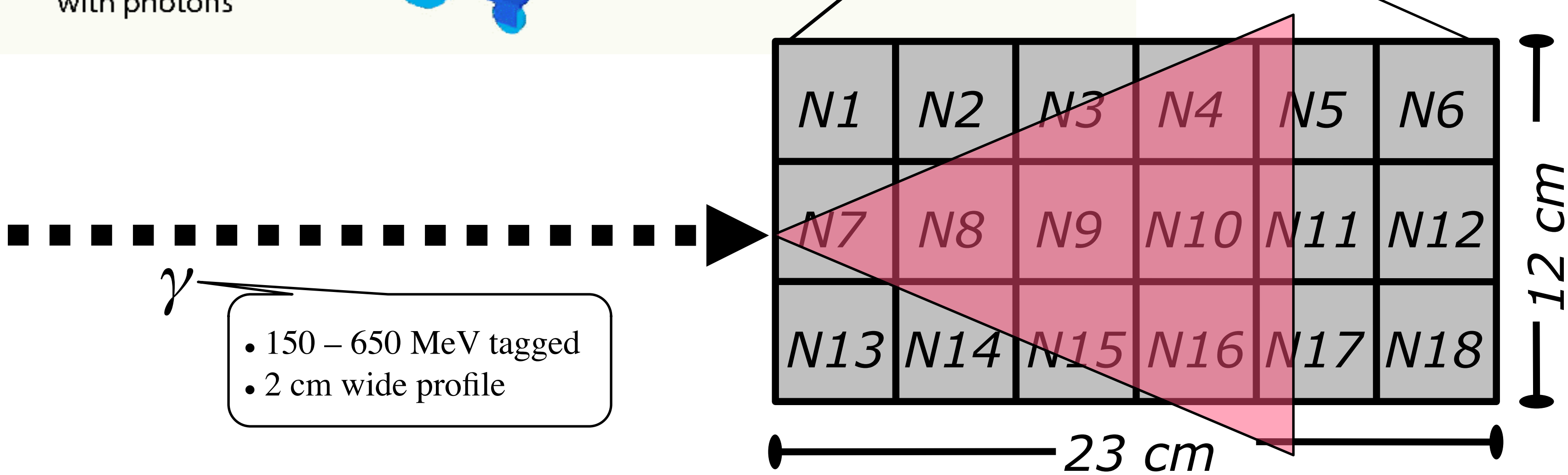
Students construct a prototype BCAL module in Edmonton, Alberta.

Beam test at Hall B (fall 2006)



Verify
- Construction
- Fiber light output

Measure
- Energy resolution
- Timing resolution
- No. of p.e.



- 150 – 650 MeV tagged
- 2 cm wide profile

BCAL Gain Balancing and Calibration

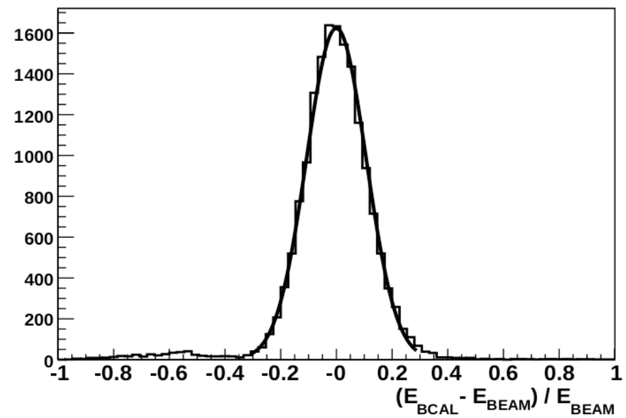
Important step: Gain balance all 36 PMTs

✓Online: the means of the cosmic ADC spectra were balanced to within 10% during setup

✓Offline:

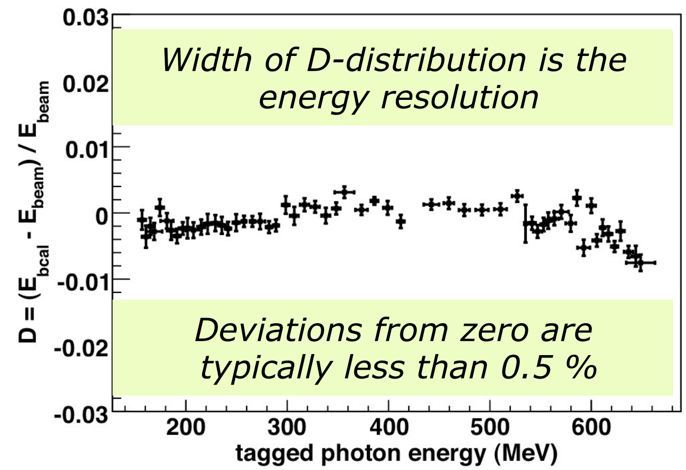
- gain balance using dedicated cosmics runs
- energy calibration
- minimize the width of the difference between the tagged beam energy, E_{beam} and the reconstructed energy in the BCAL, E_{bcal}

$$D = \frac{E_{beam} - E_{bcal}}{E_{beam}}$$

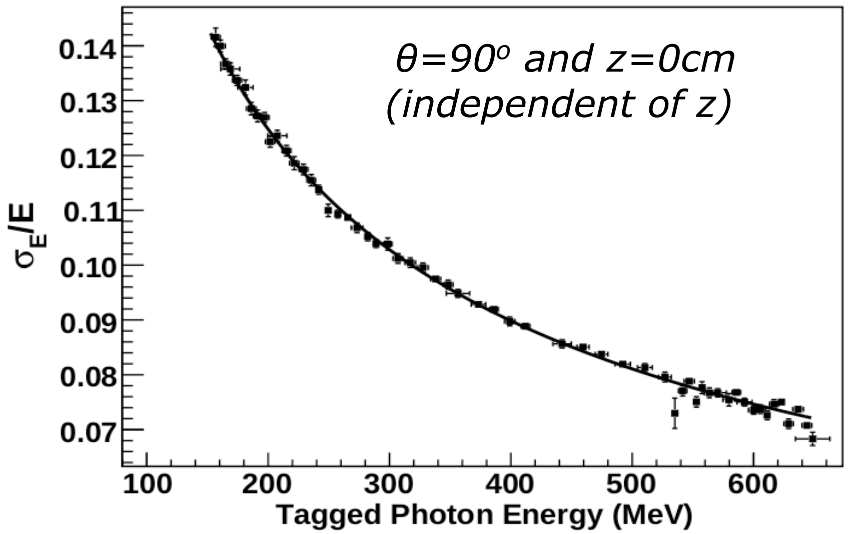


$$C_{N,i} = \frac{N_{ADC,i}}{N_{ADC,7}}$$

$$E_{BCAL} = K \cdot \sqrt{\left(\sum_{i=1}^{18} \frac{N_{ADC,i}}{C_{N,i}}\right) \cdot \left(\sum_{i=1}^{18} \frac{S_{ADC,i}}{C_{S,i}}\right)}$$



Energy Resolution



$$\frac{\sigma_E}{E} = \frac{5.5 \pm 0.1\%}{\sqrt{E}} \oplus 2.4 \pm 1\%$$

KLOE $\left(\frac{\sigma_E}{E} = \frac{5.4\%}{\sqrt{E}} \oplus 0.7\% \right)$

Contributions to Energy Resolution

- The dominant contribution to the energy resolution is the fluctuations in the energy sampling by the scintillating fibres.

- The properties of the scintillating fibres and coupling will affect the photon statistics contribution to the resolution.

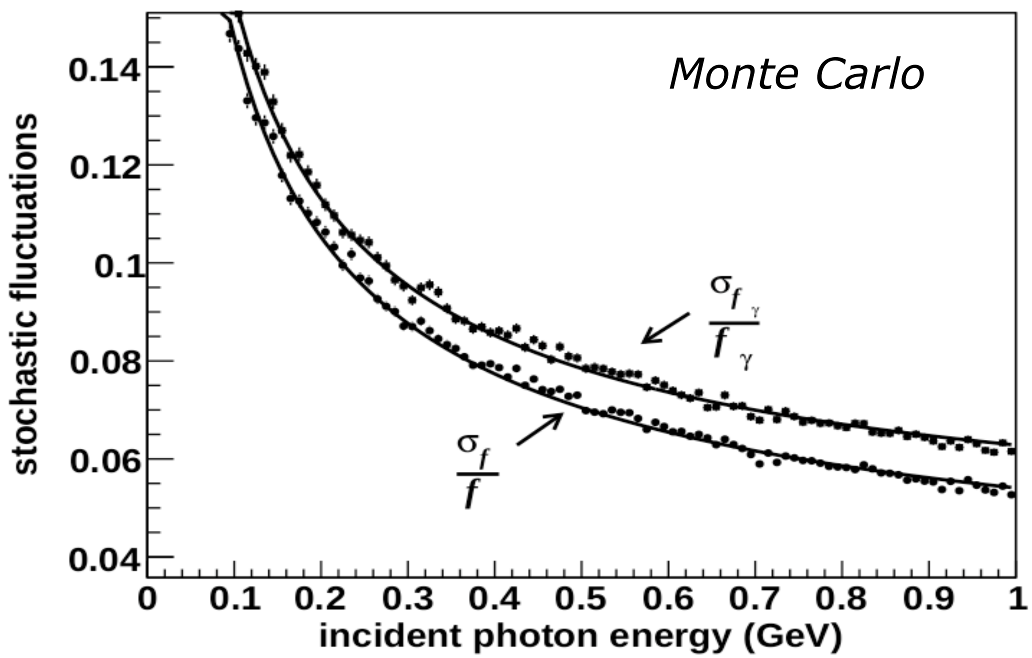
$$\frac{\sigma_E}{E} = \frac{\sigma_f}{f(E)} \oplus \frac{\sigma_{pe}}{E}$$

sampling fluctuations

$$\frac{\sigma_f}{f(E)} = \frac{4.1\%}{\sqrt{E(GeV)}} \oplus 1\%$$

photoelectron statistics

$$\frac{\sigma_{pe}}{E} = \frac{3.1\%}{\sqrt{E(GeV)}}$$

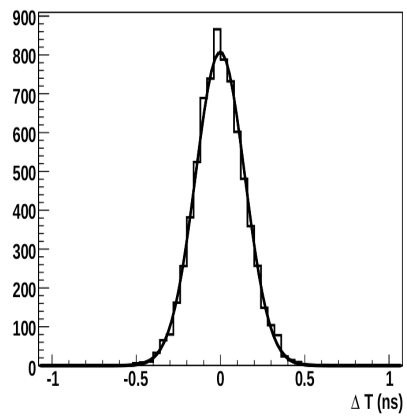


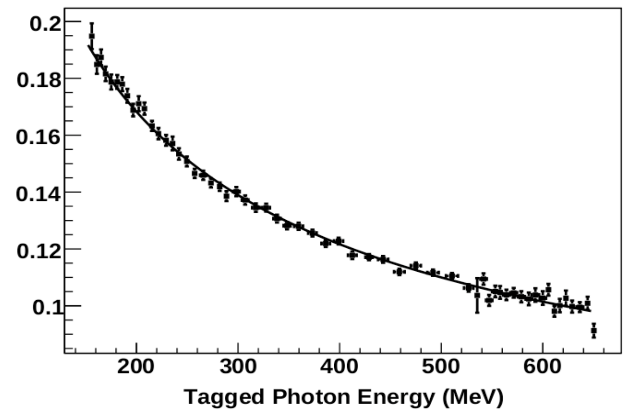
Timing Resolution

- The time difference resolution will provide position information for neutral particles.
- Good resolution is needed for reconstructing events that contain neutral final states.

time difference

$$\frac{\Delta T}{2} = \frac{1}{2}\frac{\sum_i E_i (T_{N,i} - T_{S,i})}{\sum_i E_i}$$





Walk correction was done

Beam width (1.8 cm @ BCAL) contributed to the resolution (σ/√12) = 30ps and was removed.

time difference resolution

$$\sigma_{\Delta T/2} = \frac{70\,ps}{\sqrt{E(GeV)}}$$

position resolution

$$\sigma_z = \sigma_{\Delta T/2} \cdot c_{eff} = \frac{1.1cm}{\sqrt{E(GeV)}}$$

KLOE $\left(\sigma_t = \frac{72\,ps}{\sqrt{E}}\right)$

Number of Photo-Electrons

No. of photoelectrons important:

- Low energies: threshold
- SiPM versus FM PMTs (readout)

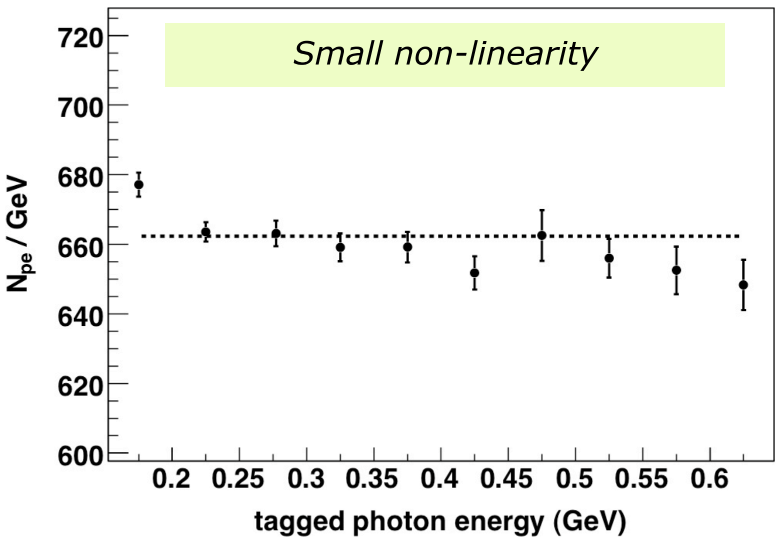
$$R(E_j) = \frac{\sum_{i=1}^{18} E_{N,i;j}}{\sum_{i=1}^{18} E_{S,i;j}}$$

Calibrated energies:
i^{th} segment, j^{th} energy bin

$$f(r) \approx \int P\left(x, N_{pe} \cdot \sqrt{R}\right) \cdot \frac{1}{r} \cdot P\left(\frac{x}{r}, \frac{N_{pe}}{\sqrt{R}}\right)\left[\frac{x}{r} dx\right]$$

Poisson-shape for amplitude spectra

z=0 cm & θ=90°



KLOE: 700 pe/GeV

- single clad fibers
- better light guides

Summary

• **The nature of confinement is an outstanding and fundamental question of quarks and gluons in QCD.**
•**The definitive experiment for this search will be GlueX at the energy -upgraded JLab. If exotic hybrids are there, we will find them!**

The GlueX BCAL

- Energy and timing resolution meet GlueX requirements
- No. of p.e. is more than adequate
- Agreement with KLOE numbers
- Final work on determining the resolution at angles and near the end of the module is being carried out
- This work is in press:
  - NIMA *http://dx.doi.org/10.1016/j.nima.2008.08.137*

Acknowledgments

Many thanks to our fellow collaborators on this work:

B.D. Leverington, G.J.Lolos[1], Z.Papandreou[1], R.Hakobyan, G.M.Huber[1], K.L.Janzen[1], A. Semenov[1], A.R.Dzierba[2], E.B.Scott[2], M.R.Shepherd[2], D.S.Carman[3], D.W.Lawrence[3], E.Smith[3], S.Taylor[3], E. Wolin[3], F.Klein[4], J.P.Santoro[4], D.I.Sober[4], C. Kourkoumeli[5]

[1]University of Regina , [2]Indiana University, [3]Thomas Jefferson National Accelerator Facility, [4]The Catholic University of America, [5]University of Athens

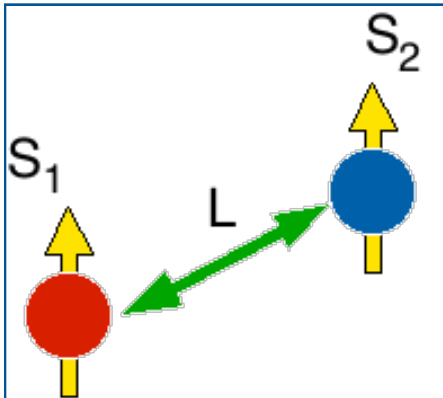
Backup Slides

“Pluck” the Flux Tube

Color Field: Gluons possess color charge: they couple to each other!

How do we look for gluonic degrees of freedom in spectroscopy?

Nonets characterized by given J^{PC}

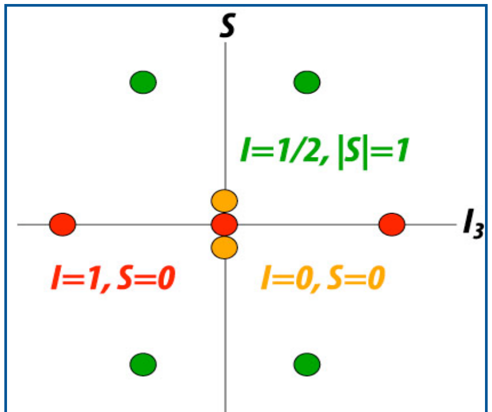


$S = S_1 + S_2$

$J = L + S$

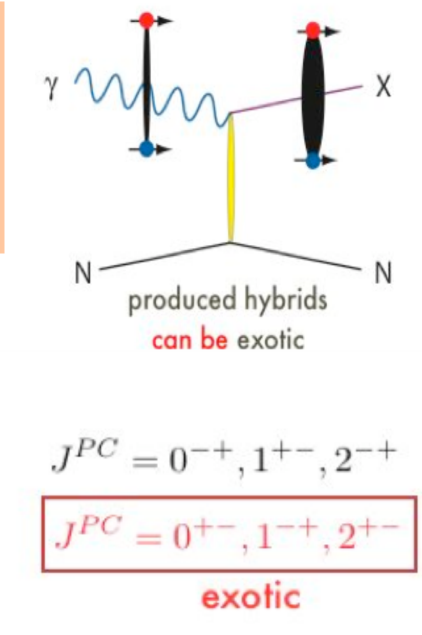
$P = (-1)^{L+1}$

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

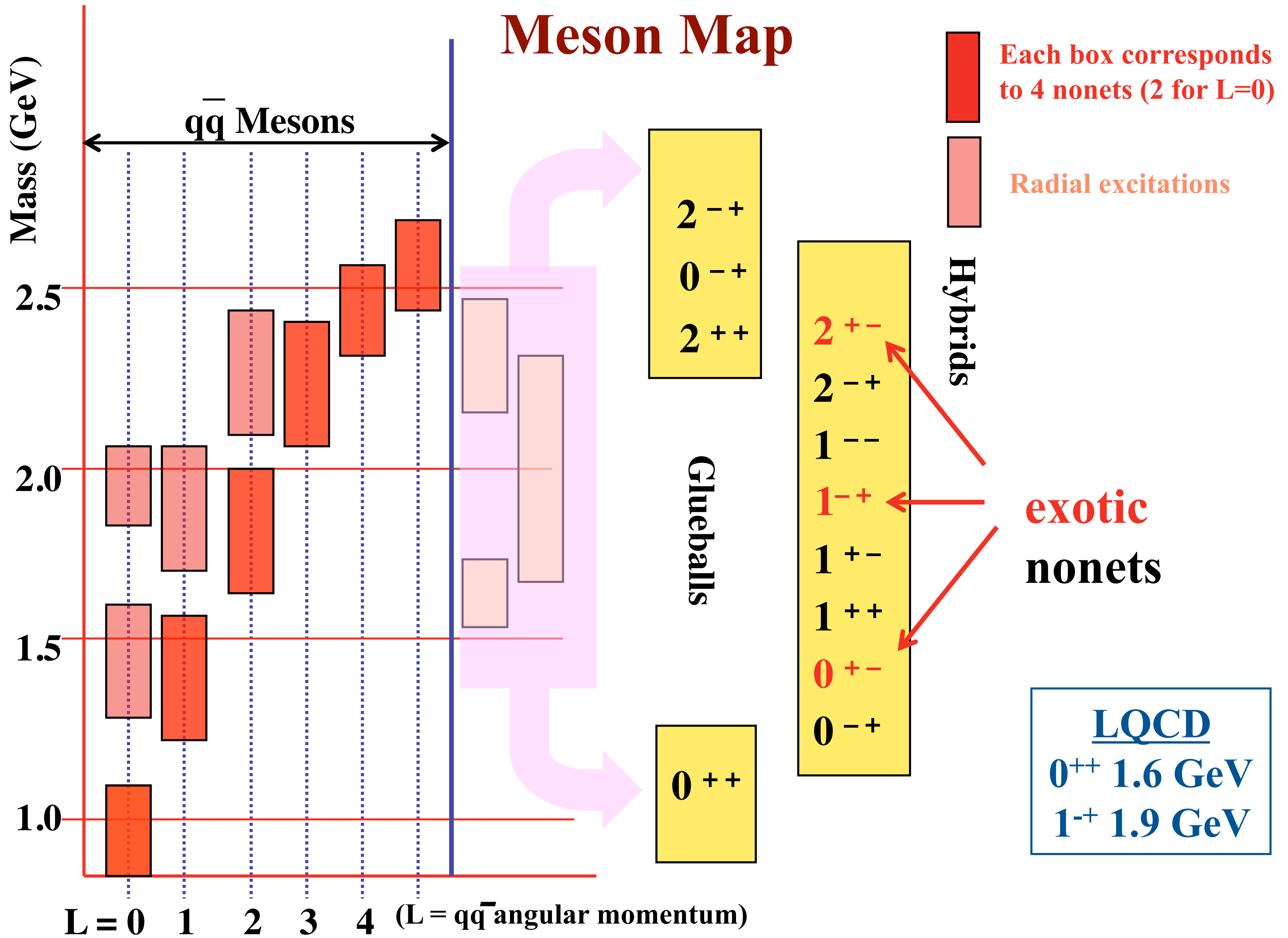


Normal meson:
flux tube in
ground state
$PC=(-1)^{S+1}$

Hybrid meson:
flux tube in
excited state
$PC=(-1)^{S}$

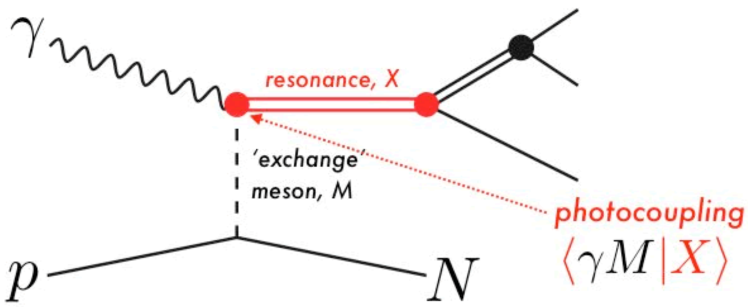


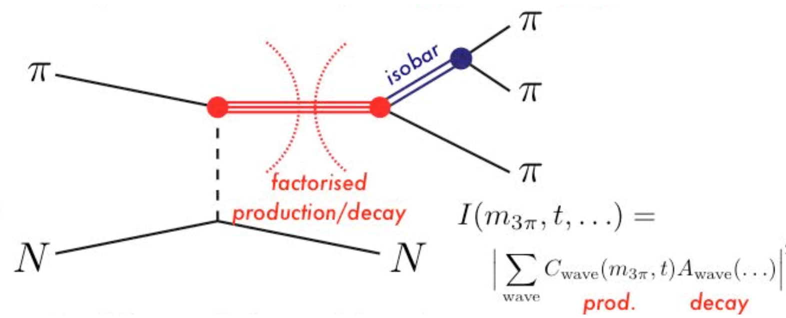
Meson Map



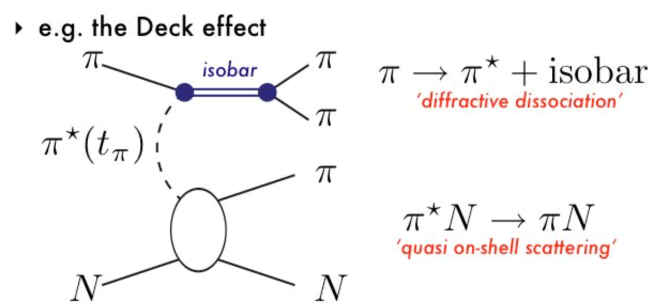
LQCD
0^{++} 1.6 GeV
1^{-+} 1.9 GeV

Photocouplings & Phenomenology



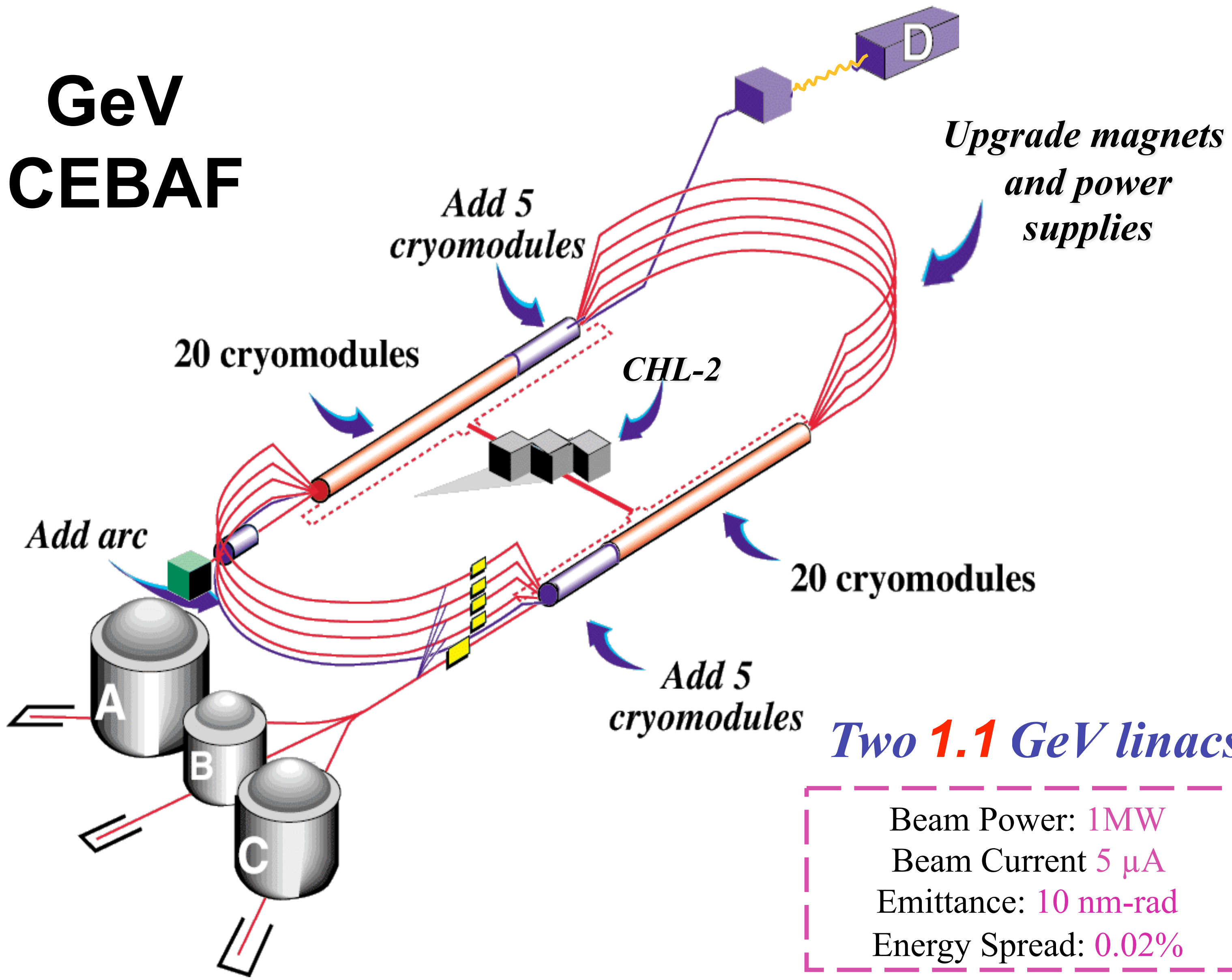


- Couplings virtually unknown even for conventional mesons
- Testbed: by the time GlueX runs expect all predictions to be tested by Lattice QCD



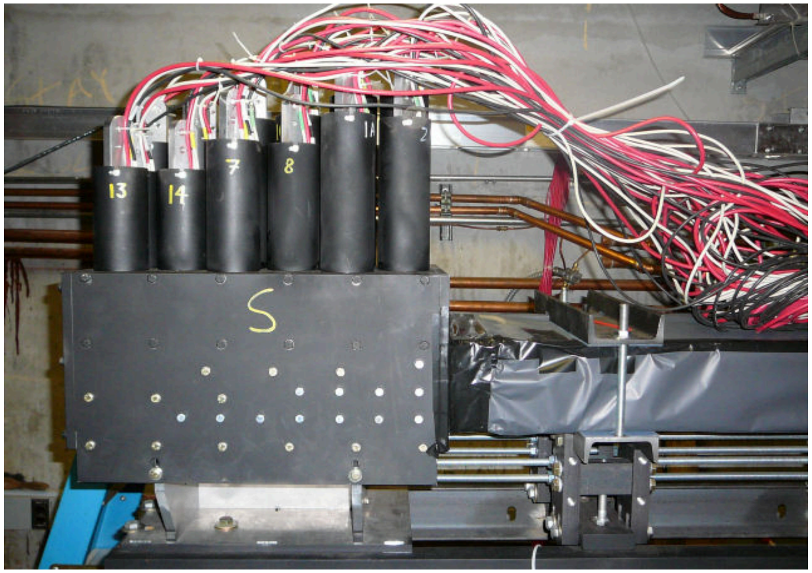
- Phenomenology:
  - isobar model widely used in multi-particle πN→ πππN states; it is not completely general
  - factorized approach has limitations: e.g. Deck effect where we get threshold peak in isobar π S-wave

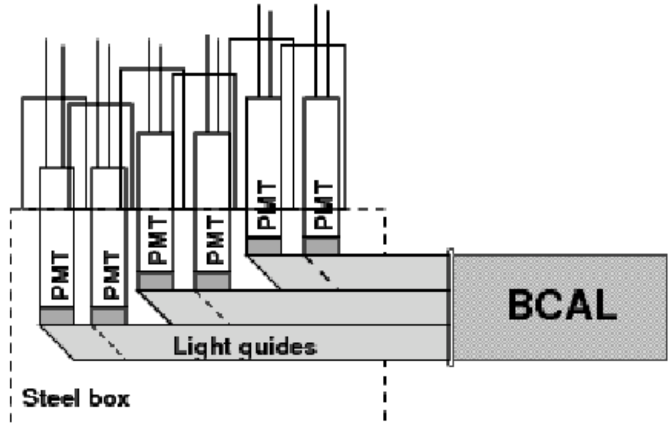
12 GeV CEBAF

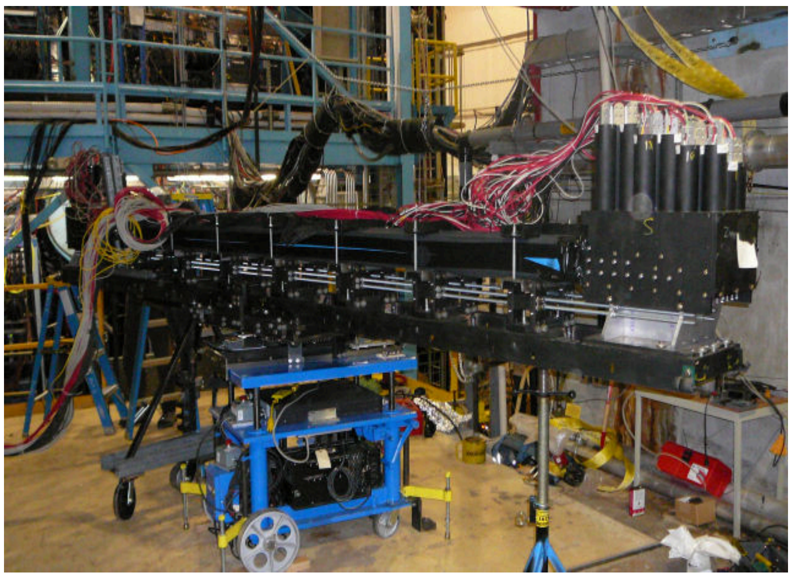


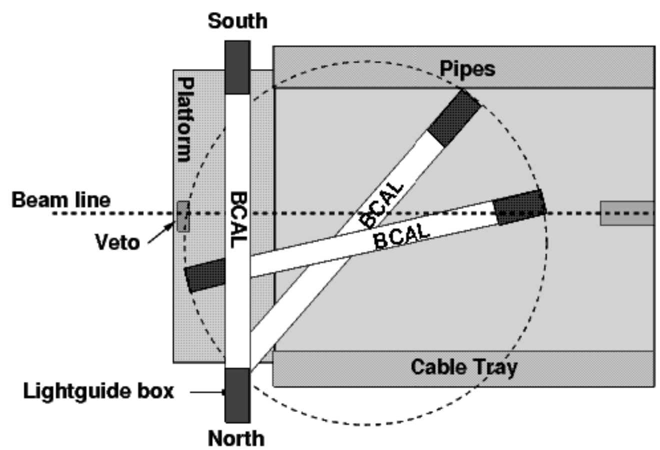
Two 1.1 GeV linacs

Beam Power: 1MW
Beam Current 5 µA
Emittance: 10 nm-rad
Energy Spread: 0.02%




PMT
PMT
PMT
PMT
PMT
PMT
BCAL
Light guides
Steel box




South
Pipes
Platform
Beam line
Veto
BCAL
BCAL
BCAL
Cable Tray
Lightguide box
North