

14th Workshop on European Collaboration in Higher Education on Radiological and Nuclear Engineering and Radiation Protection

Tuesday 29 May 2018 - Friday 01 June 2018
Macugnaga (VB), Italy

HCAL-J: Hadron Calorimeter for the study of nucleon Form Factors at Jefferson Lab

Catia Petta

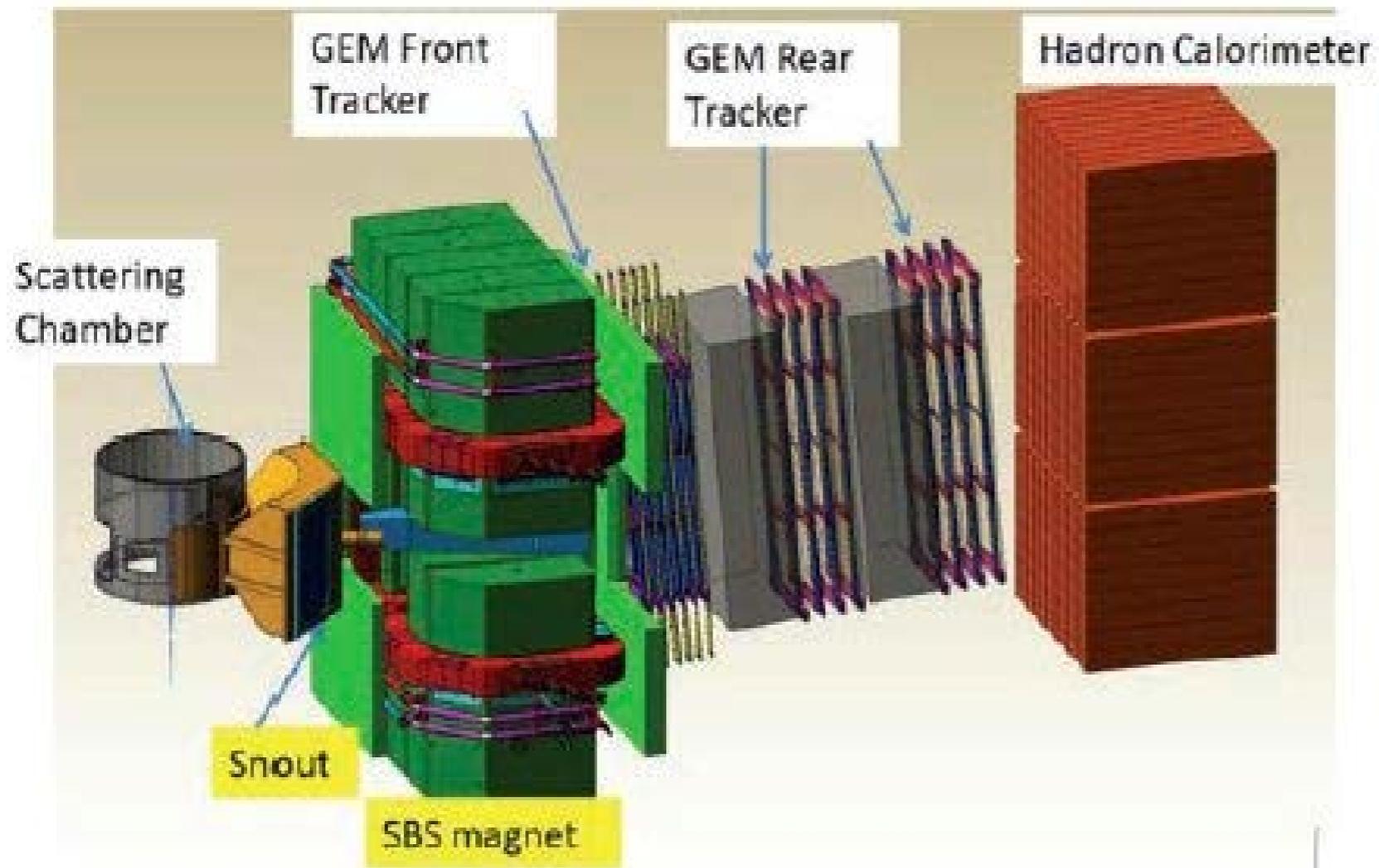
Dipartimento di Fisica e Astronomia

Università di Catania



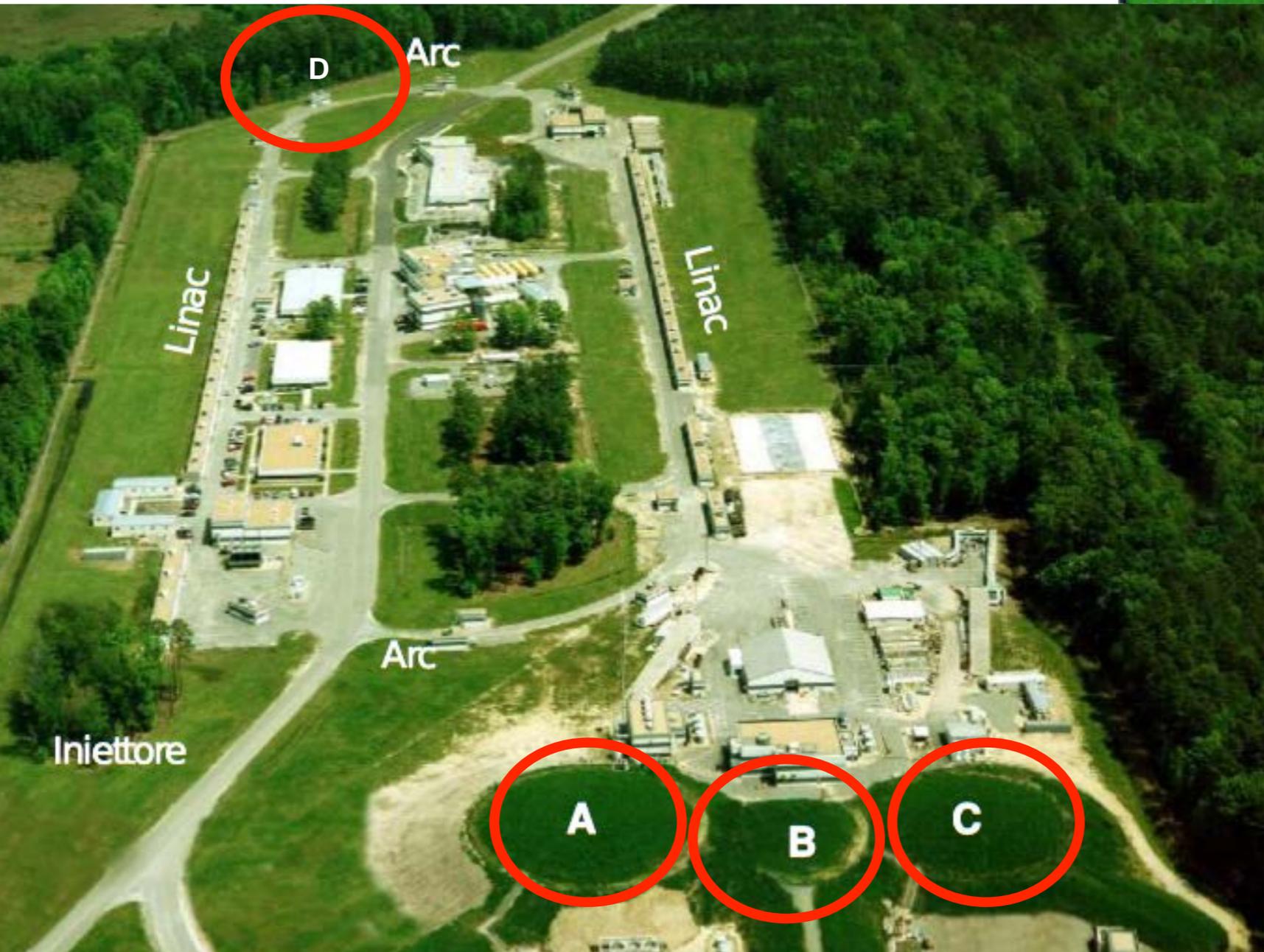
outline

- Nucleon Form Factors studies at JLAB
- SuperBigBite Spectrometer in Hall A
- The Hadron Calorimeter HCAL-J



Jefferson lab

International Research Center
in Nuclear and Hadronic Physics



HALL A

HALL B

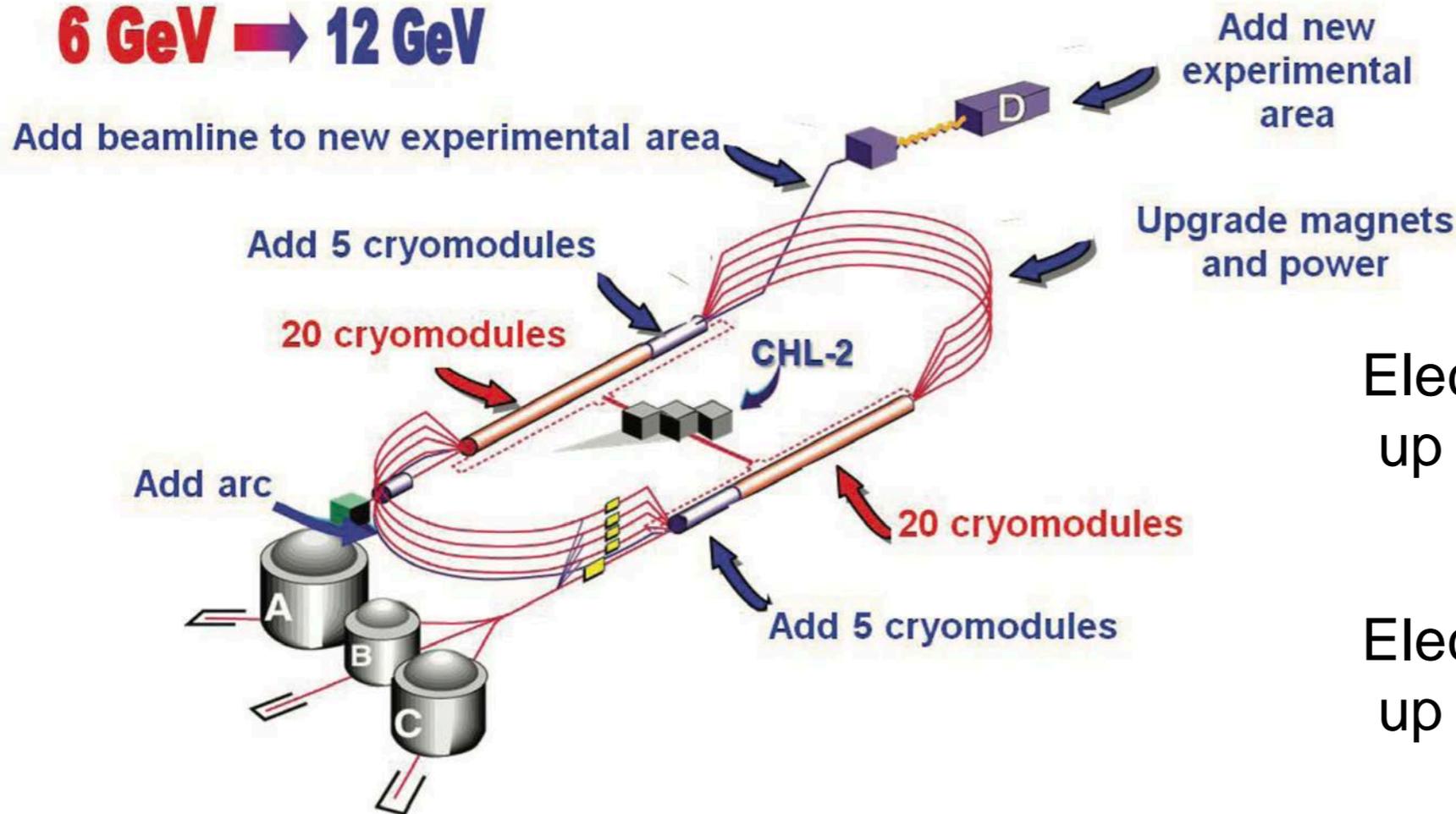
HALL C

HALL D

CEBAF

Continuous Electron Beam Accelerator Facility

6 GeV → 12 GeV



12 GeV Upgrade

Electron beam up to 12 GeV → Hall D

Electron beam up to 11 GeV → Halls A, B, and C

Max Current : 100 μ A

Longitudinal Polarization : \sim 85%

The main purpose is to investigate the fundamental nature of nuclear matter

Nucleon Form Factors

The electromagnetic structure of the nucleon, in the elastic scattering with an electron, can be described with

SACHS FORM FACTORS

$$G_E(Q^2) = \int d^3\vec{r} \rho_E(\vec{r}) e^{\frac{i\vec{q}\cdot\vec{r}}{\hbar}}$$

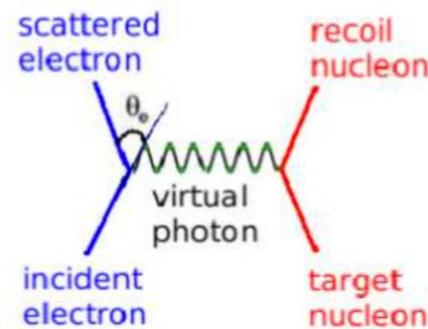
charge distribution

$$G_M(Q^2) = \int d^3\vec{r} \rho_M(\vec{r}) e^{\frac{i\vec{q}\cdot\vec{r}}{\hbar}}$$

current distribution

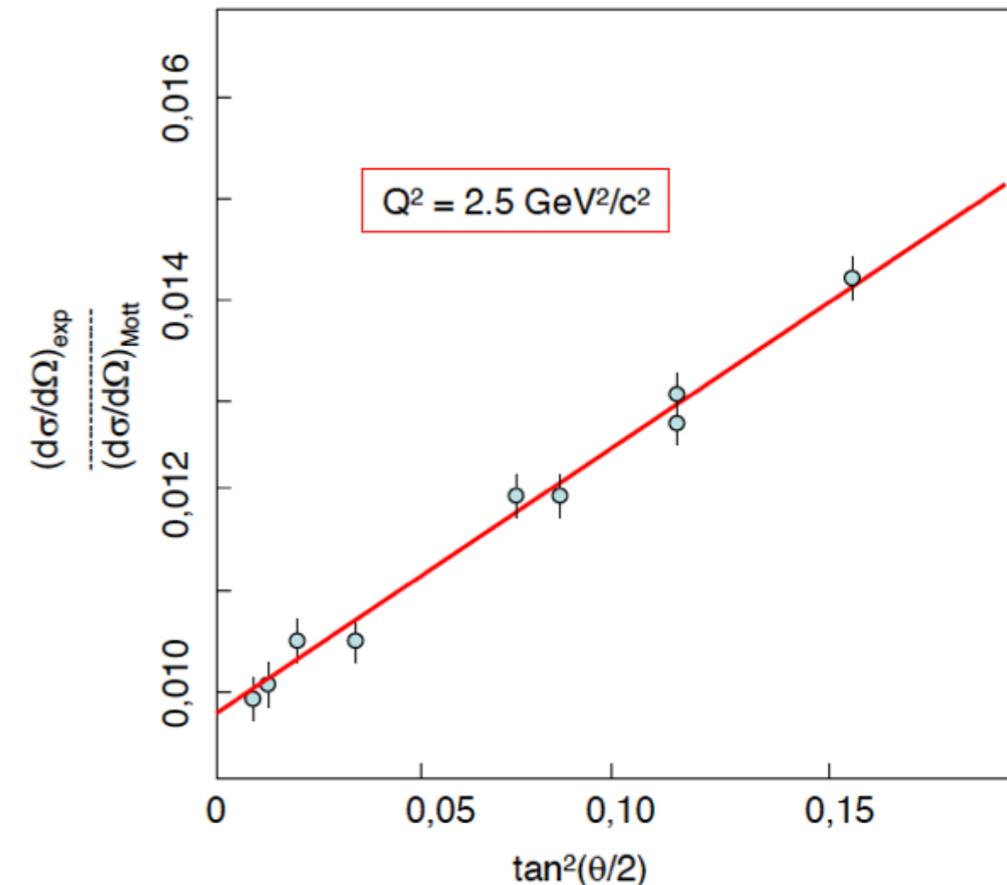
The Form Factors of the nucleons can be considered as the 3D Fourier Transforms of charge and current distributions

ROSENBLUTH formula

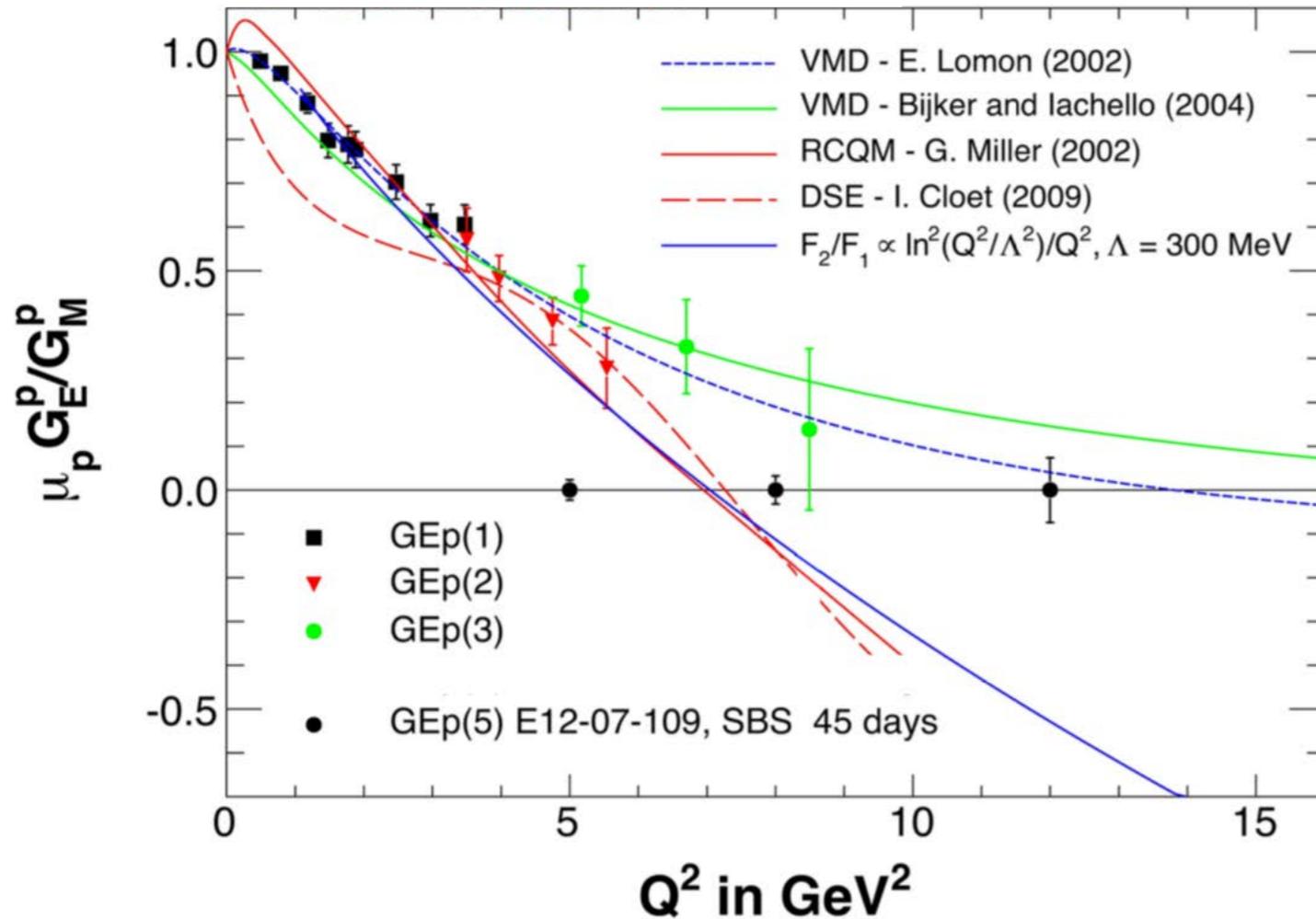


$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1 + \tau} + 2\tau G_M^2(Q^2) \tan^2 \frac{\theta}{2} \right]$$

$$\tau = \frac{Q^2}{4M^2c^2} \quad \left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \frac{Z^2 \left(\frac{e^2}{4\pi}\right)^2 \cos^2 \frac{\theta_e}{2}}{4p_0^2 \sin^4 \frac{\theta_e}{2} \left(1 + \frac{2p_0}{M} \sin^2 \frac{\theta_e}{2}\right)}$$



Recoil polarization method



It is possible to measure, in the same time, the transverse (P_t) and the longitudinal (P_l) polarization component of the recoil proton to obtain the ratio:

$$\frac{G_E(Q^2)}{G_M(Q^2)} = \frac{P_t}{P_l} \frac{E_{\text{beam}} + E_e}{2M} \tan \frac{\theta}{2}$$

The ratio between G_E and G_M decreases with q^2

Nucleon form factor studies at jlab

HALL A EXPERIMENTAL SETUP

e^- Beam
11 GeV, 75 μ A, 85% pol.

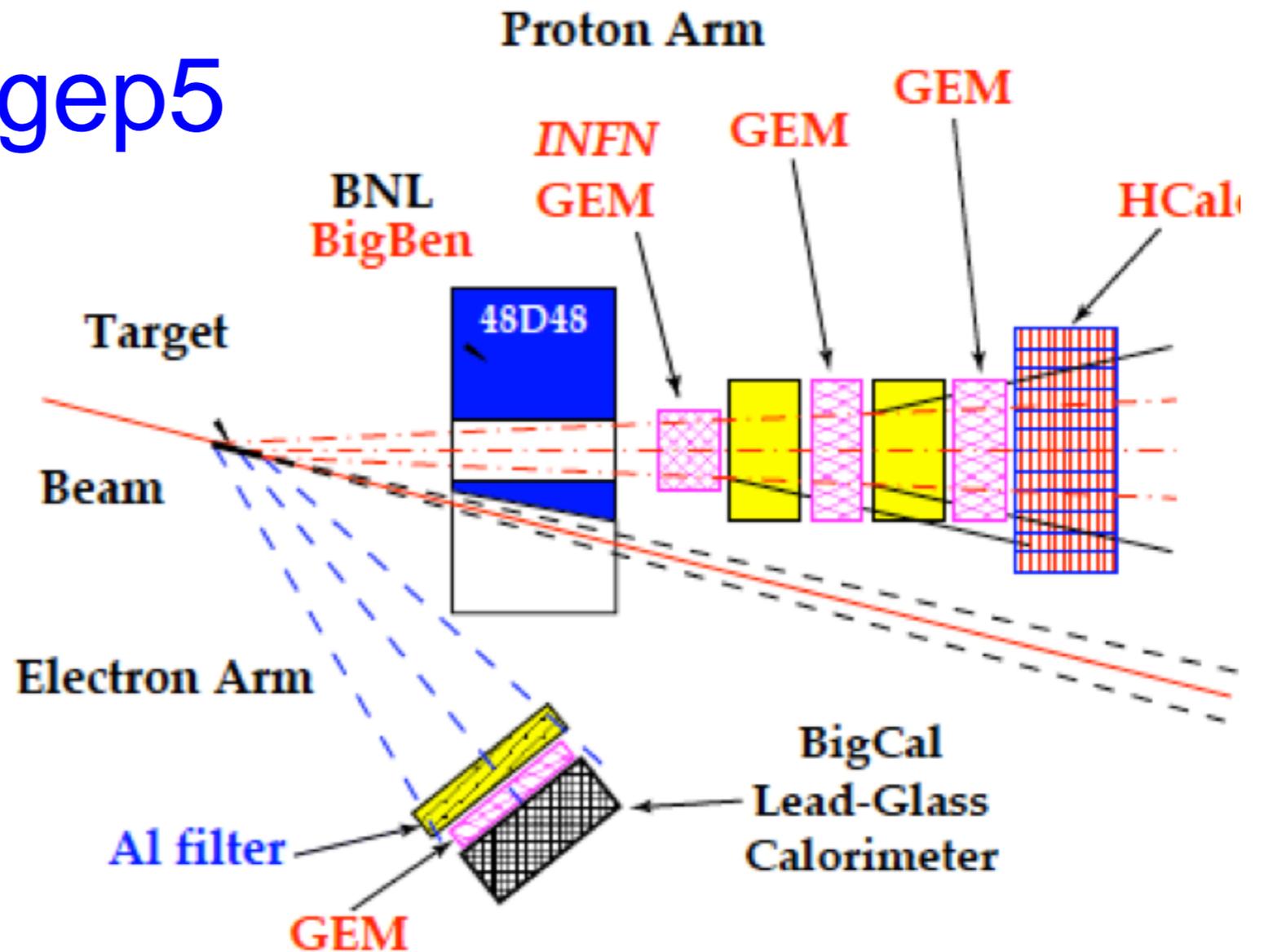
Target
Liquid H₂, 40 cm

Electron \rightarrow BigCal
 $\theta = 37^\circ, \Omega = 180$ msr

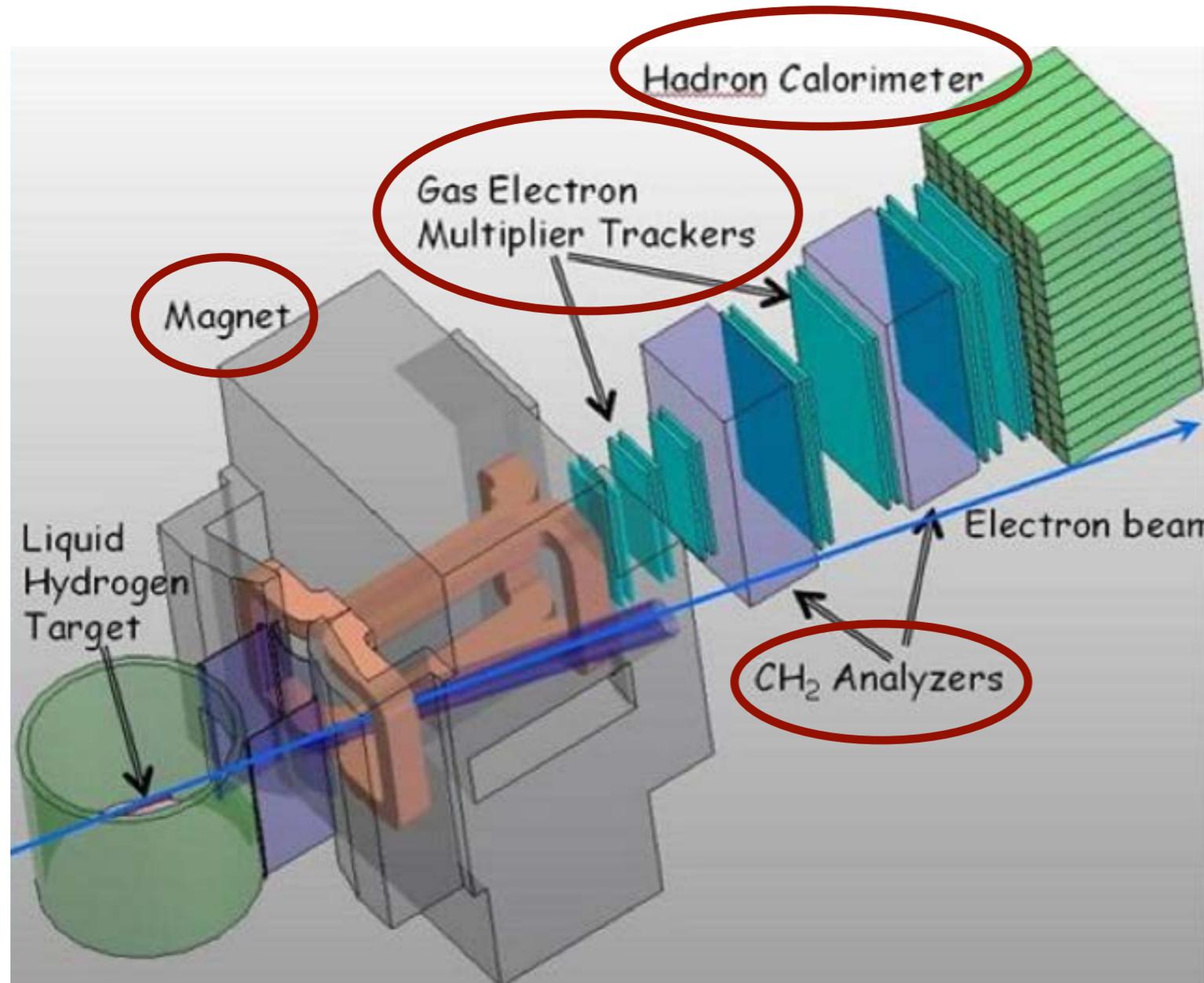
Proton \rightarrow New Spec.
 $\theta = -14^\circ, \Omega = 35$ msr

Kinematic Region
 $Q^2 = 6, 12.5, 15$ GeV²

gep5



SBS – super bigbite spectrometer



Italian Collaboration

University of Catania (Dipartimento di Fisica e Astronomia)

INFN Catania

INFN Bari

INFN Genova

INFN Roma

ISS Roma



Catania Team Contribution



**GEM Tracker
(Gas Electron
Multiplier)**



**Hadronic
Calorimeter
HCAL-J**

To deflect the reaction products and directs them towards the detection system

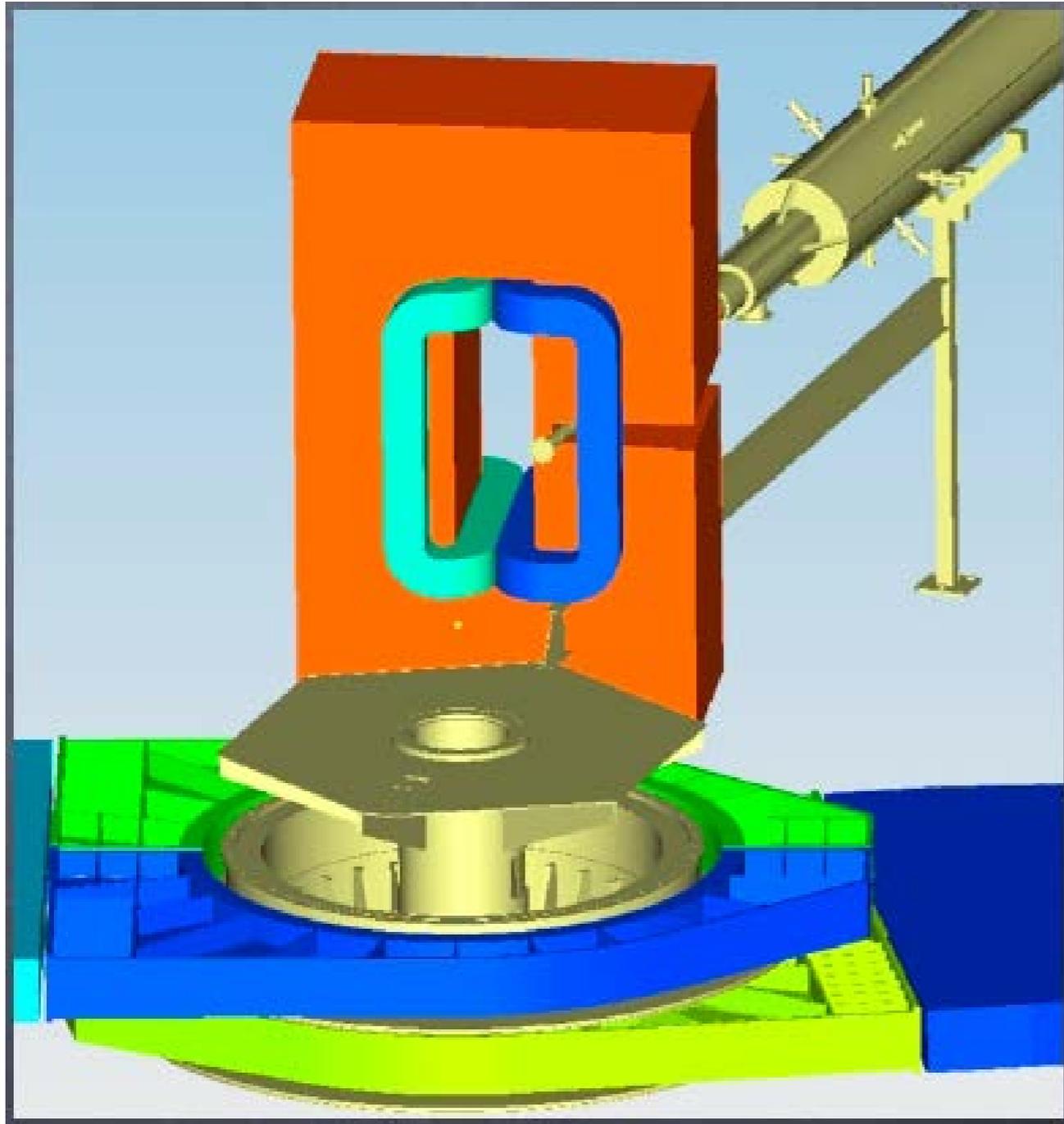
Front, second and third tracker to track the charged particles

To measure the two components of polarization

To evaluate the energy of the particles

SBS components

48D48 Dipole magnet



The Super Bigbite magnet is optimized for Form Factor measurements

- Single dipole provides adequate momentum resolution ($\sim 1\%$) and large solid angle (~ 70 msr) acceptance
- Vertical aperture well matched to electron arm while still appropriate for $\Delta Q^2/Q^2 \sim 0.1$
- Cut in yoke permits operating at small angles where the recoil is going

The magnet weights 100 tons total and consists of five iron slabs

Integral field strength ≈ 3 T·m
Excitation current ≈ 4 kA

SBS components

GEM TRACKER

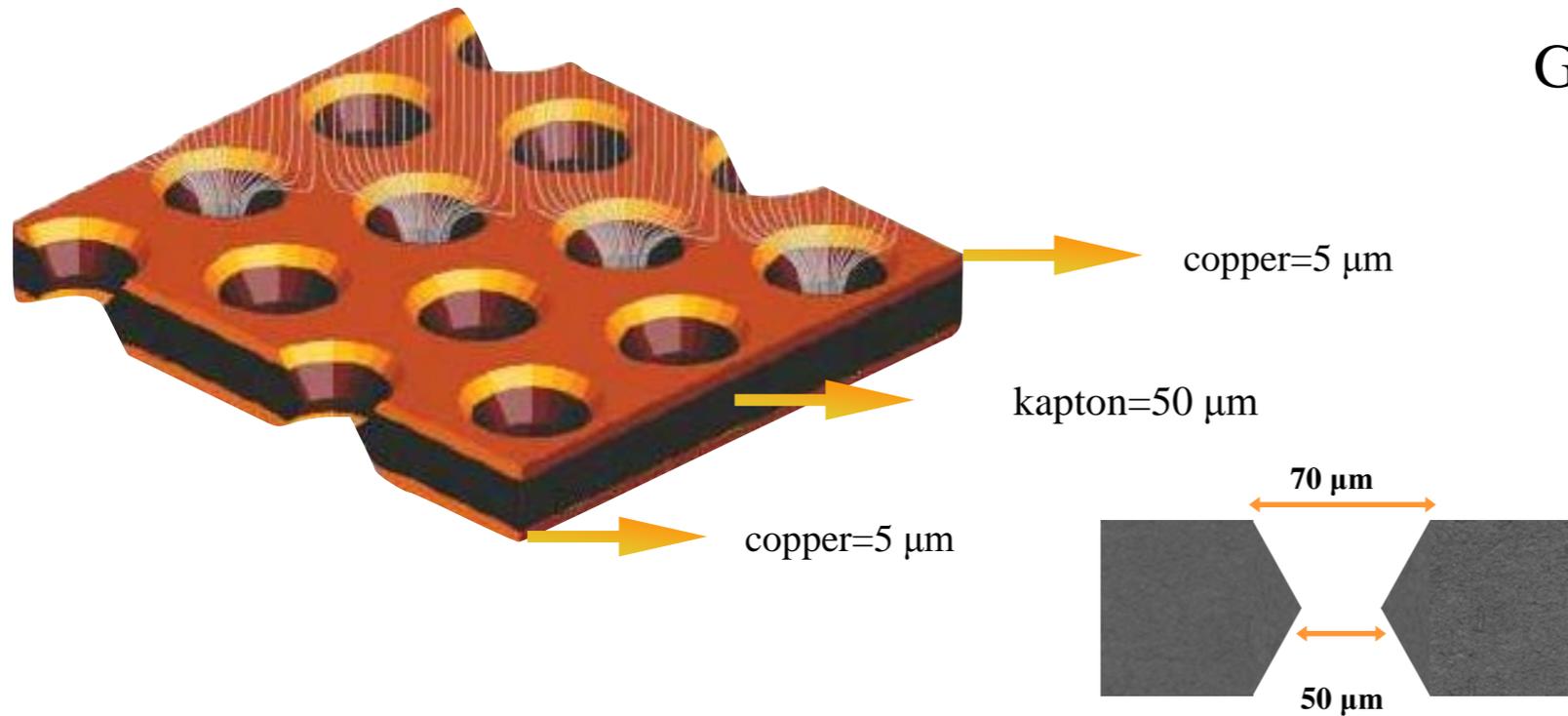
see Vincenzo Bellini's talk

Gaseous mixture: 70% Argon 30% CO₂

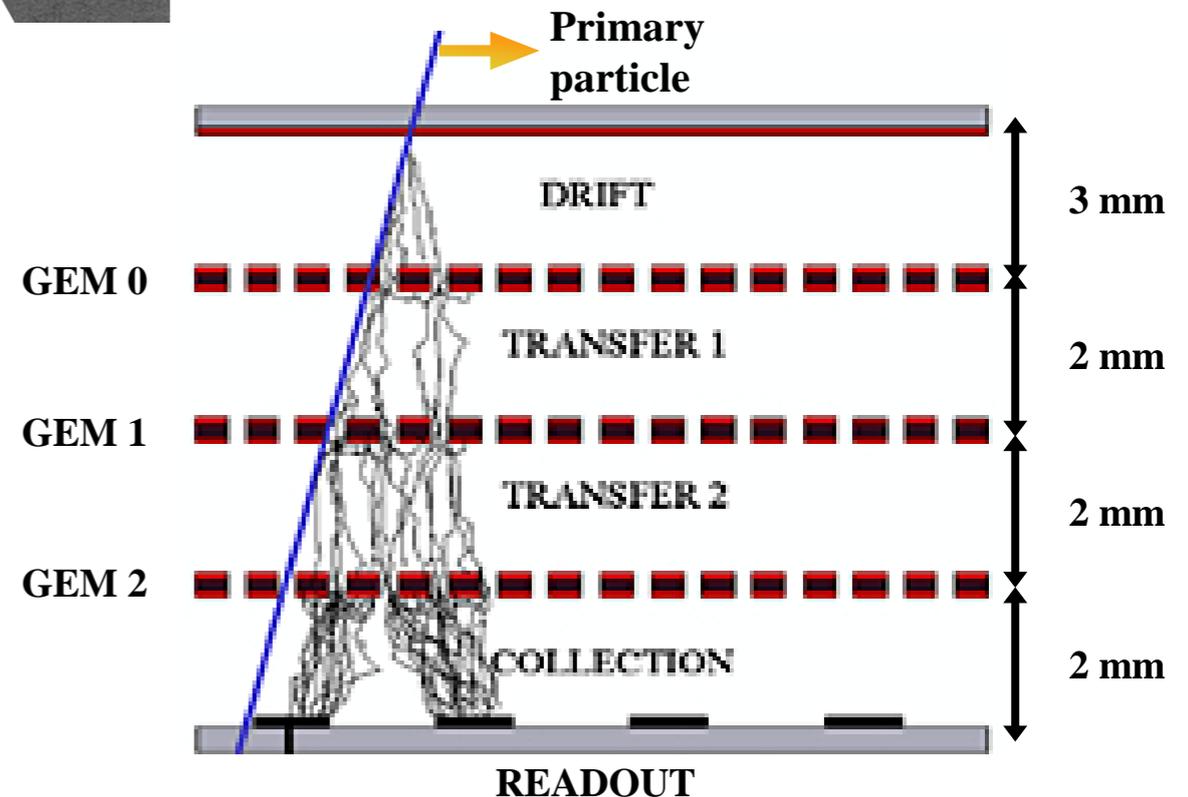
Voltage: 300-500 V

Gain: 10⁵ (triple GEM),
10³ (single GEM)

Spatial resolution: 70-100 μm

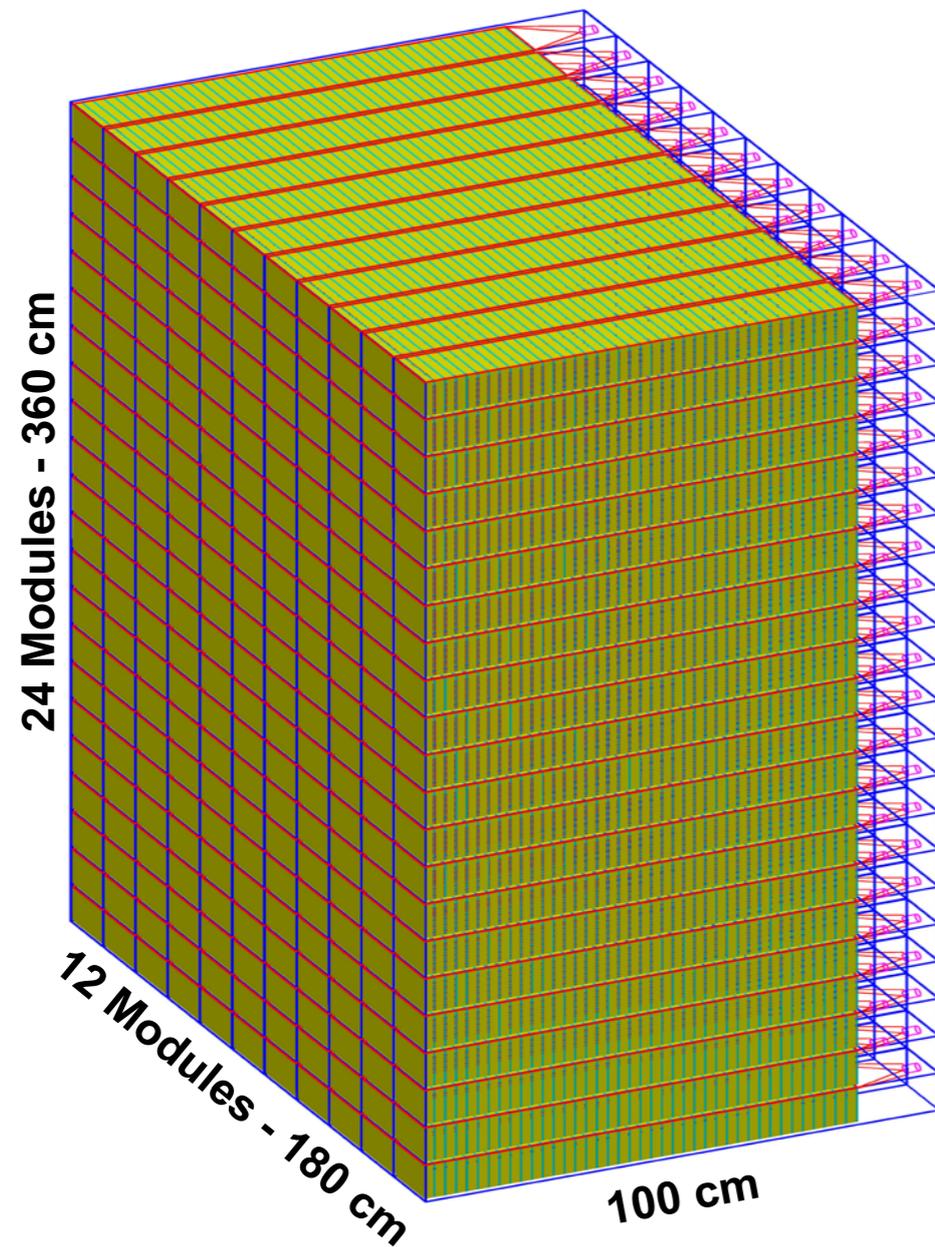


	FIRST TRACKER	BACK TRACKER
STRUCTURE	6 GEM chambers	10 GEM chambers
TOTAL AREA	40 x 150 cm ² (3 triple-GEM modules)	60 x 200 cm ² (4 triple-GEM modules)
AREA of each tracker	40 x 50 cm ²	60 x 50 cm ²



Hcal-j

It's a sampling calorimeter with a modular structure



HCAL-J Requirements

- Matching acceptance with SBS magnet/polarimeter
- Linear energy response
- Good energy resolution
- 95% efficiency with trigger threshold at 25% peak signal
- Spatial resolution ~ 5 cm rms
- Time resolution < 1.0 ns rms **Goal: 0.5 ns**
- Angular resolution 5 mrad

HCAL-J needs to be long and dense

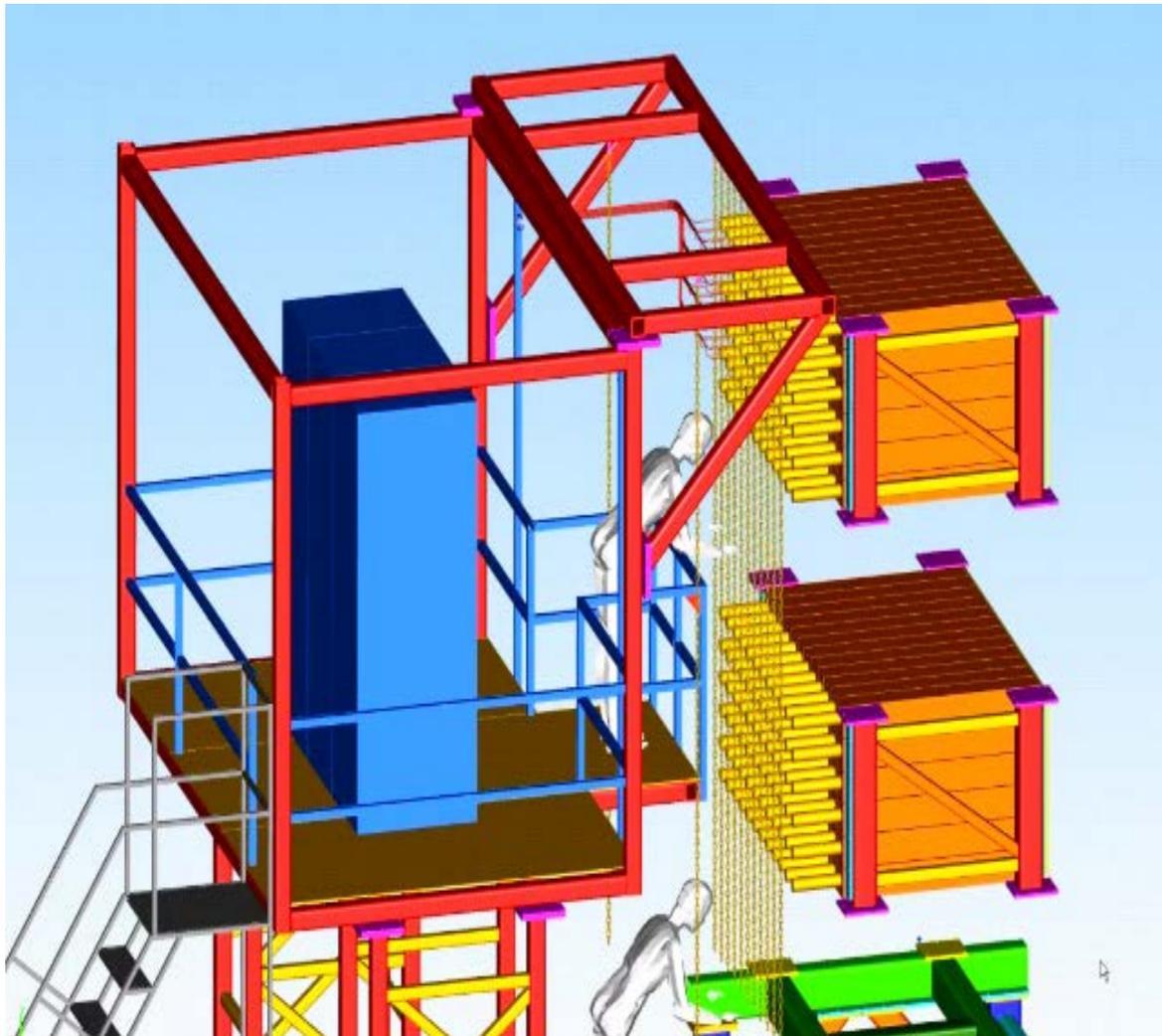
Carnegie Mellon University
INFN Catania
JLab Collaboration

Hcal-j design

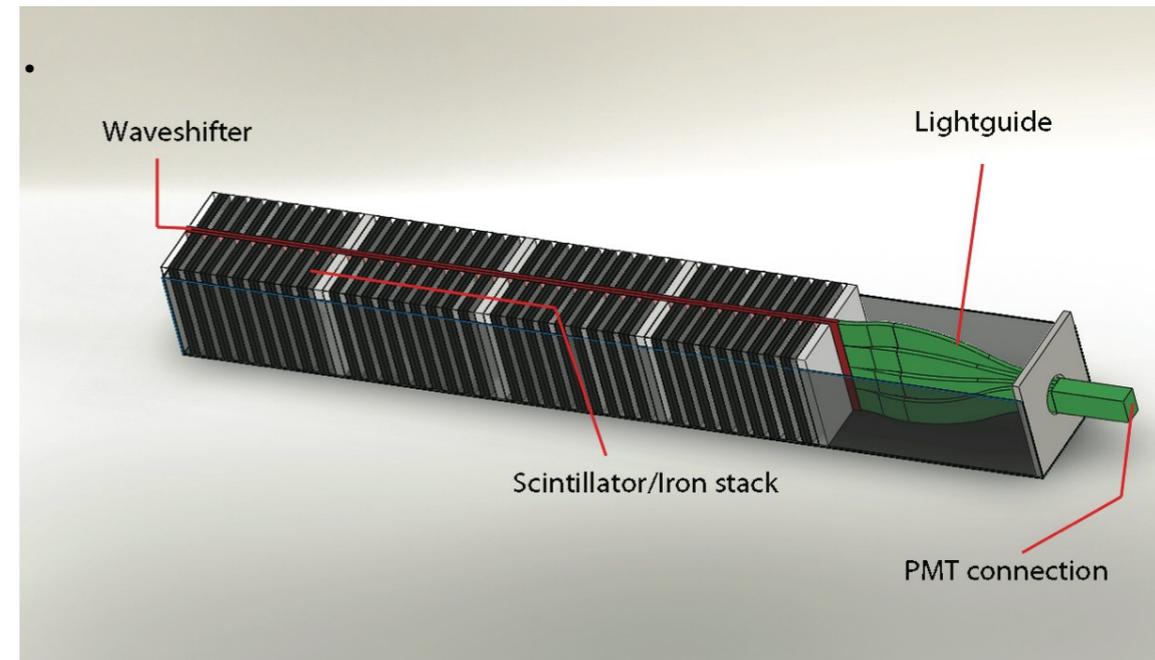
12 x 24 = 288 MODULES, about 40 tons

4 “crane-able” Sub-Assemblies

12 x 6=72 Modules/Sub-Assembly



**Optimized for 1 to 10 GeV/c
neutrons and protons detection**



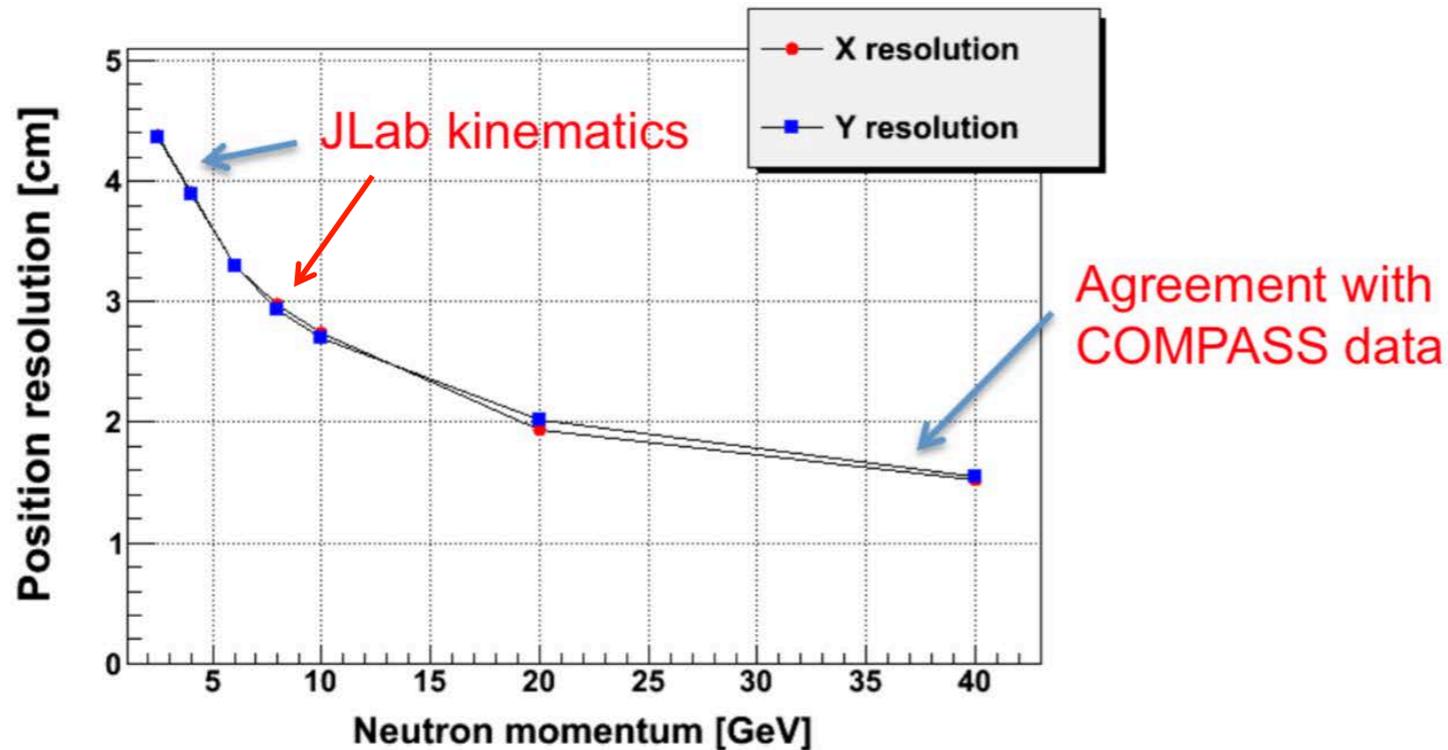
40 layers plastic scintillator and iron per Module

Each module is made up of alternating $2 \times 7.5 \times 15$ cm^2 layers of **1.5 cm thick iron** and by plastic scintillators with a thickness of **1 cm**

Wavelength shifter (WLS) readout through 2" photomultipliers (PMTs)

Hcal geant4 simulations

http://wm-jlab.physics.wm.edu/mediawiki/images/7/79/Franklin_HCAL_Oct_2012-compressed.pdf



ENERGY Resolution and Trigger efficiency

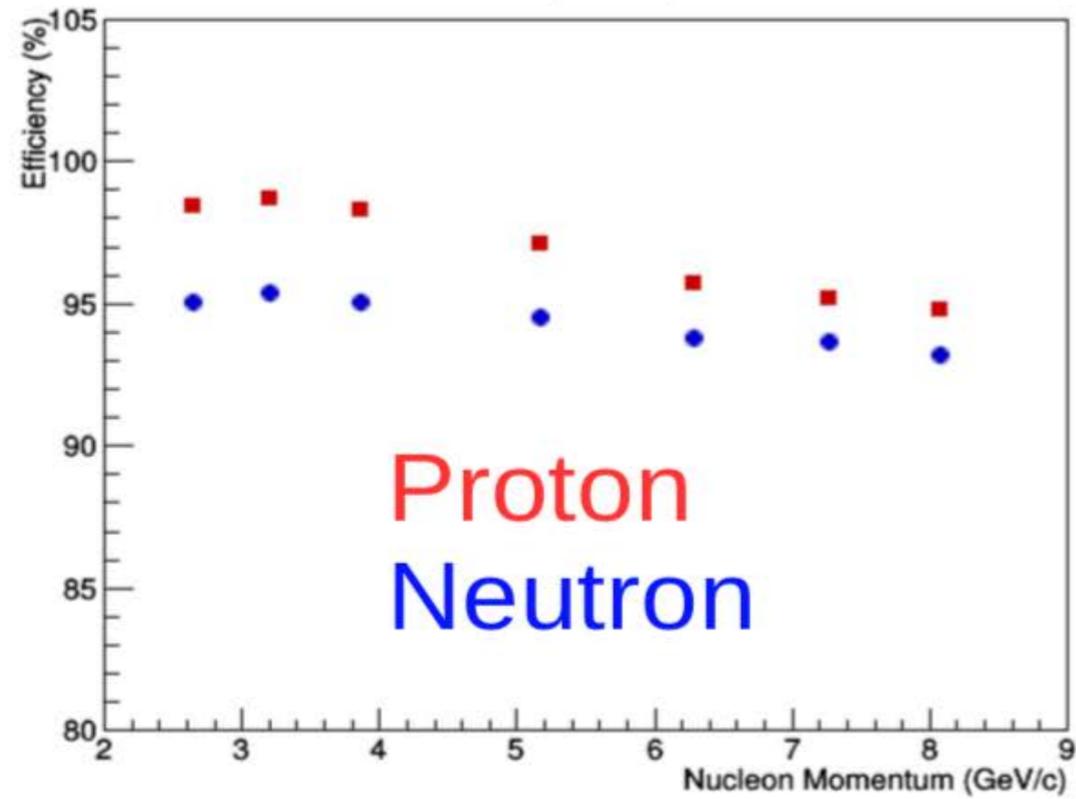
Spatial Resolution

1.5 cm at high energies
5.0 cm at Jlab energies

HCAL positioned 17 m from target:
5 cm / 17 m → 3 mrad resolution

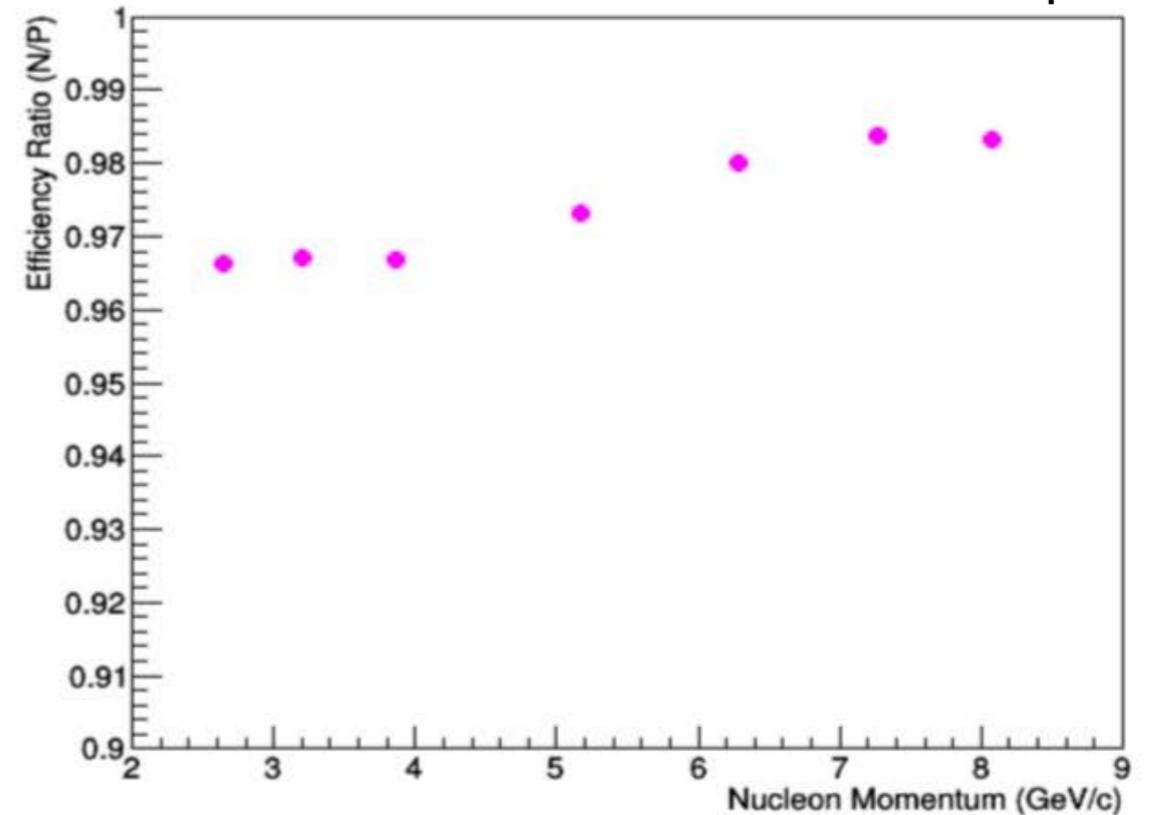
5x5 cluster	Energy	2.5 GeV	5.0 GeV	10.0 GeV
Resolution: σ/E		48%	31%	22%
Efficiency at 1/4 mean signal: Neutrons		97.3%	99.2%	99.1%
Efficiency at 1/4 mean signal: Protons		98.8%	99.6%	99.0%

HCAL Efficiency ($E_T=1/4 E_{peak}$) (3x3 cluster)

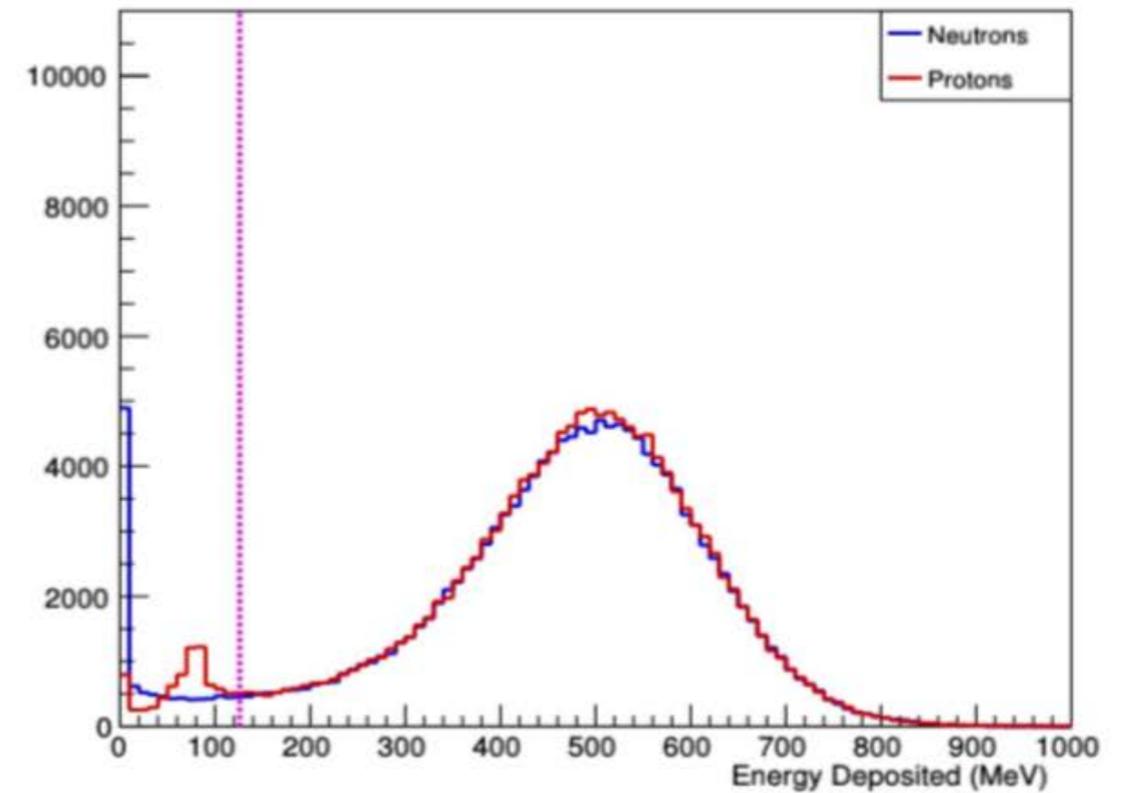
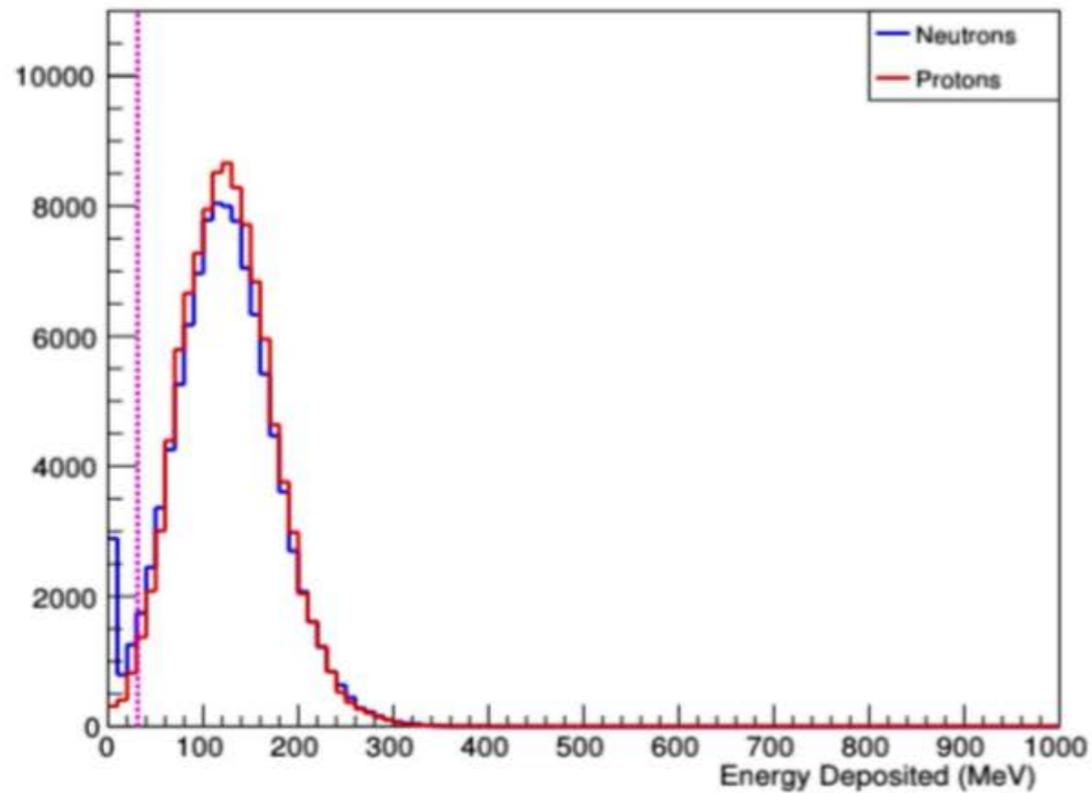


P= 2.64 GeV/c (3x3 cluster)

HCAL Efficiency Ratio (N/P) ($E_T=1/4 E_{peak}$)

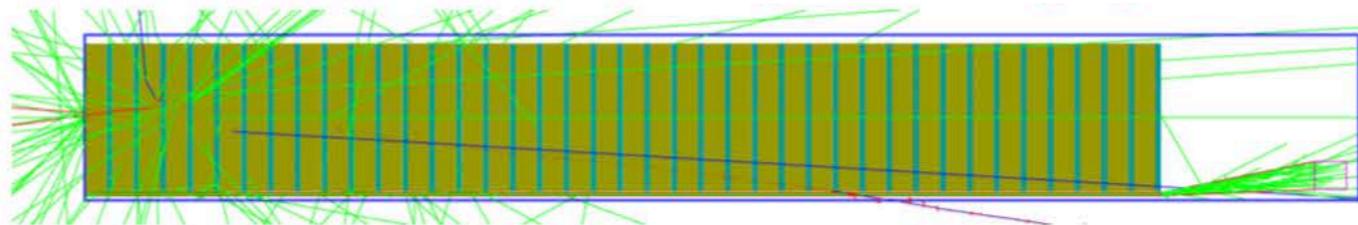


P= 8.08 GeV/c (3x3 cluster)

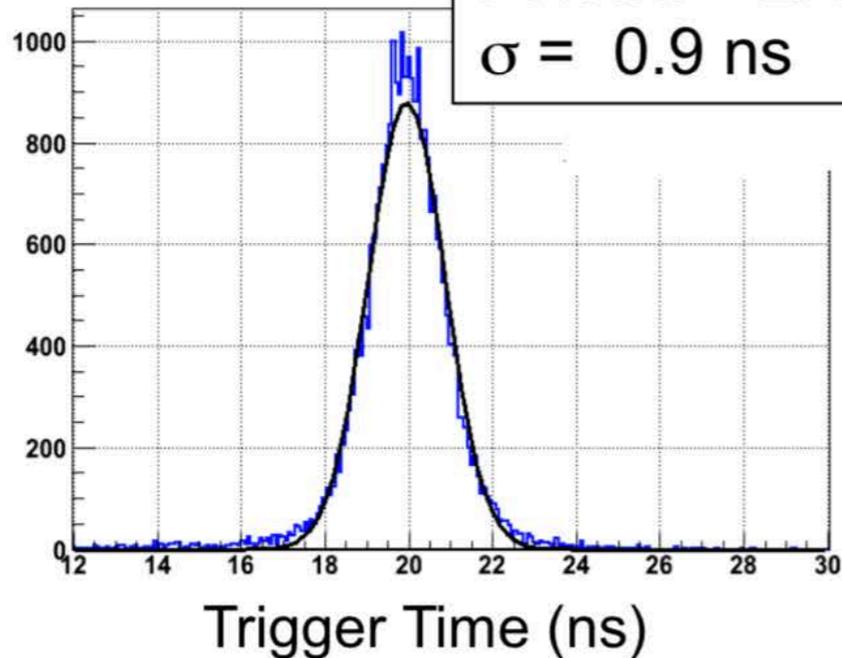


<https://www.jlab.org/indico/event/250/session/4/contribution/25/material/slides/0.pdf>

Hcal geant4 simulations

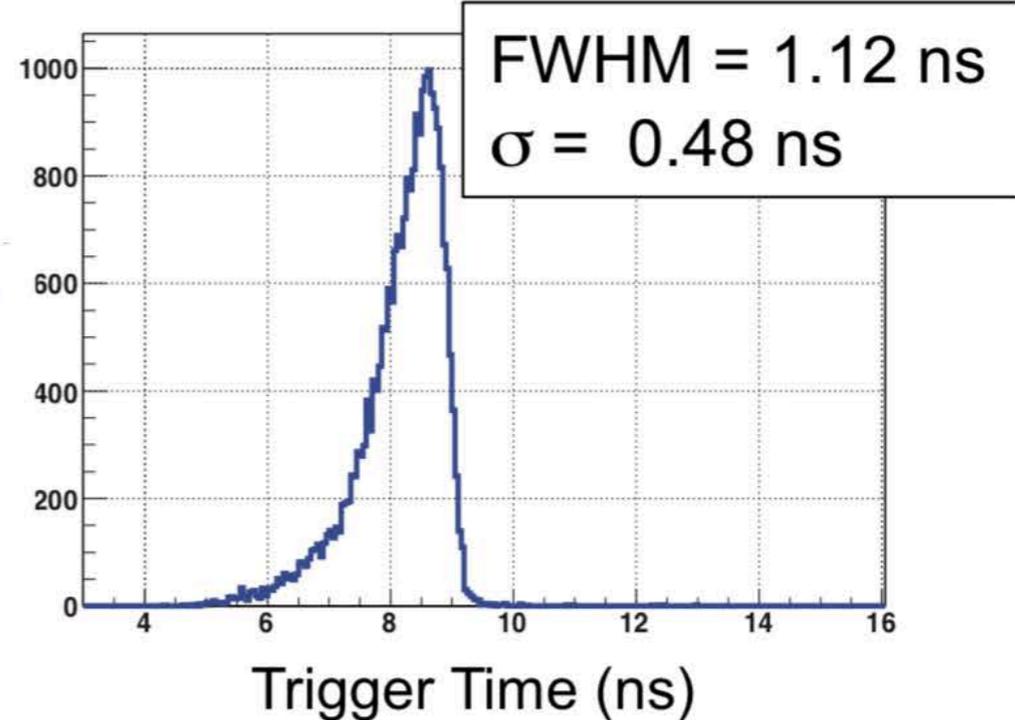


FWHM = 2.1 ns
 $\sigma = 0.9$ ns



Waveshifter decay time
8 ns --> 0.5 ns
PMT rise time
10 ns --> 2.5 ns

FWHM = 1.12 ns
 $\sigma = 0.48$ ns



**Simulation using
COMPASS
parameters**

Agreed with published
COMPASS HCAL
performance

time Resolution

http://wm-jlab.physics.wm.edu/mediawiki/images/7/79/Franklin_HCAl_Oct_2012-compressed.pdf

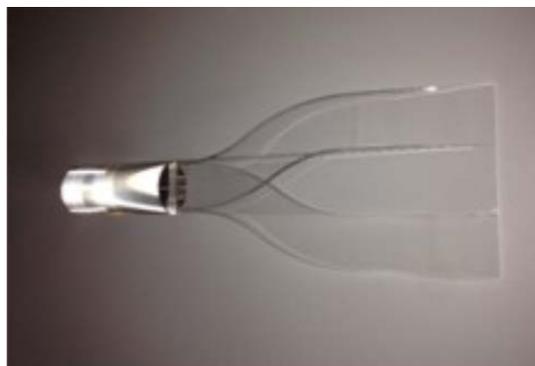
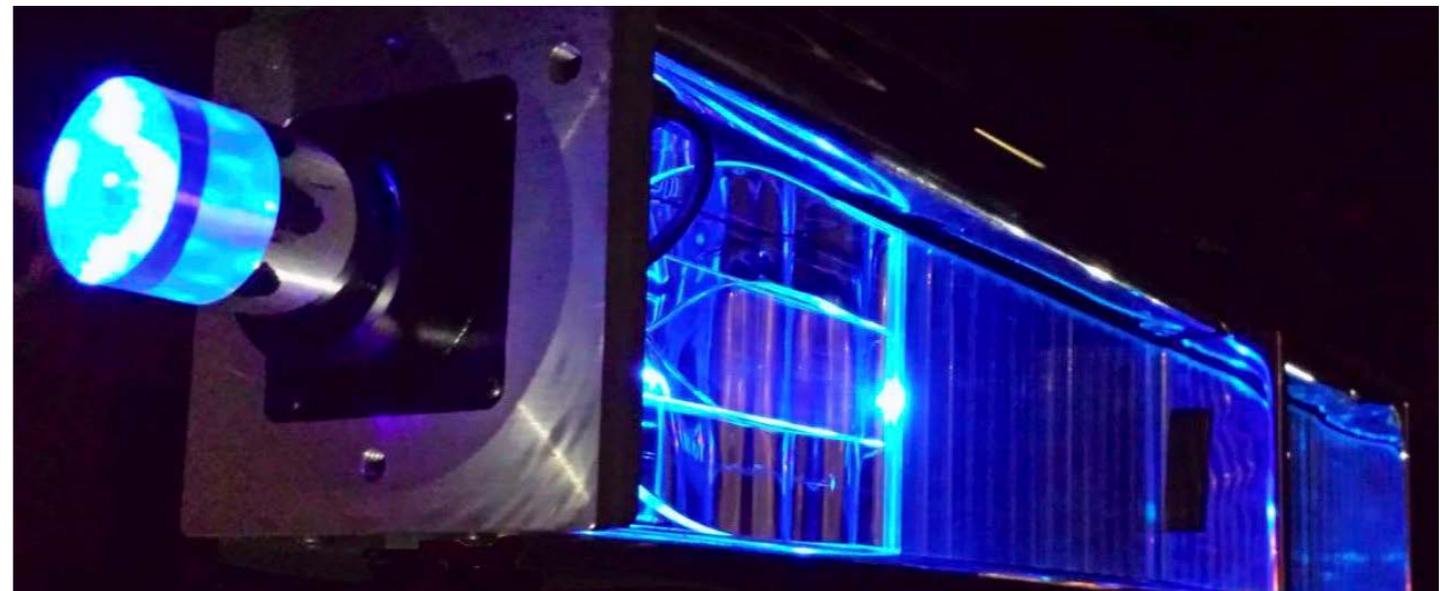
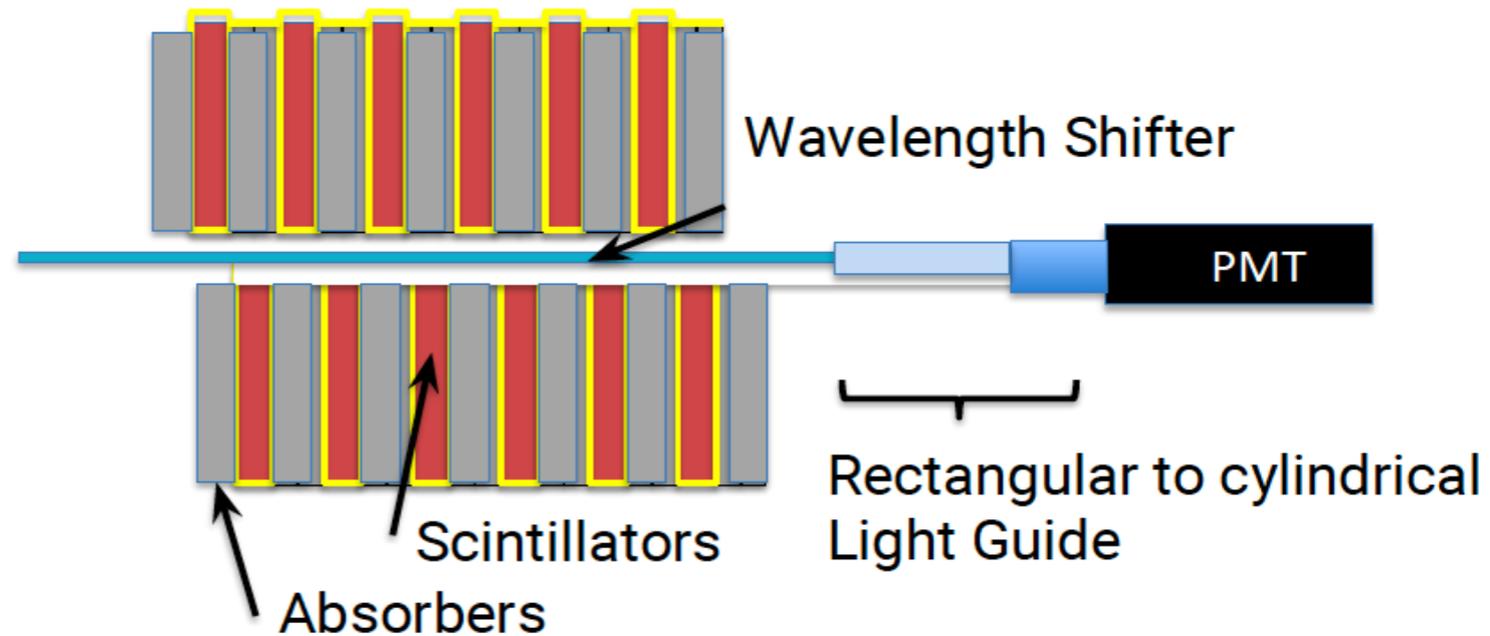
**Simulation using
faster waveshifter dye
and PMTs**

Met SBS requirements

Hcal-j MODULE

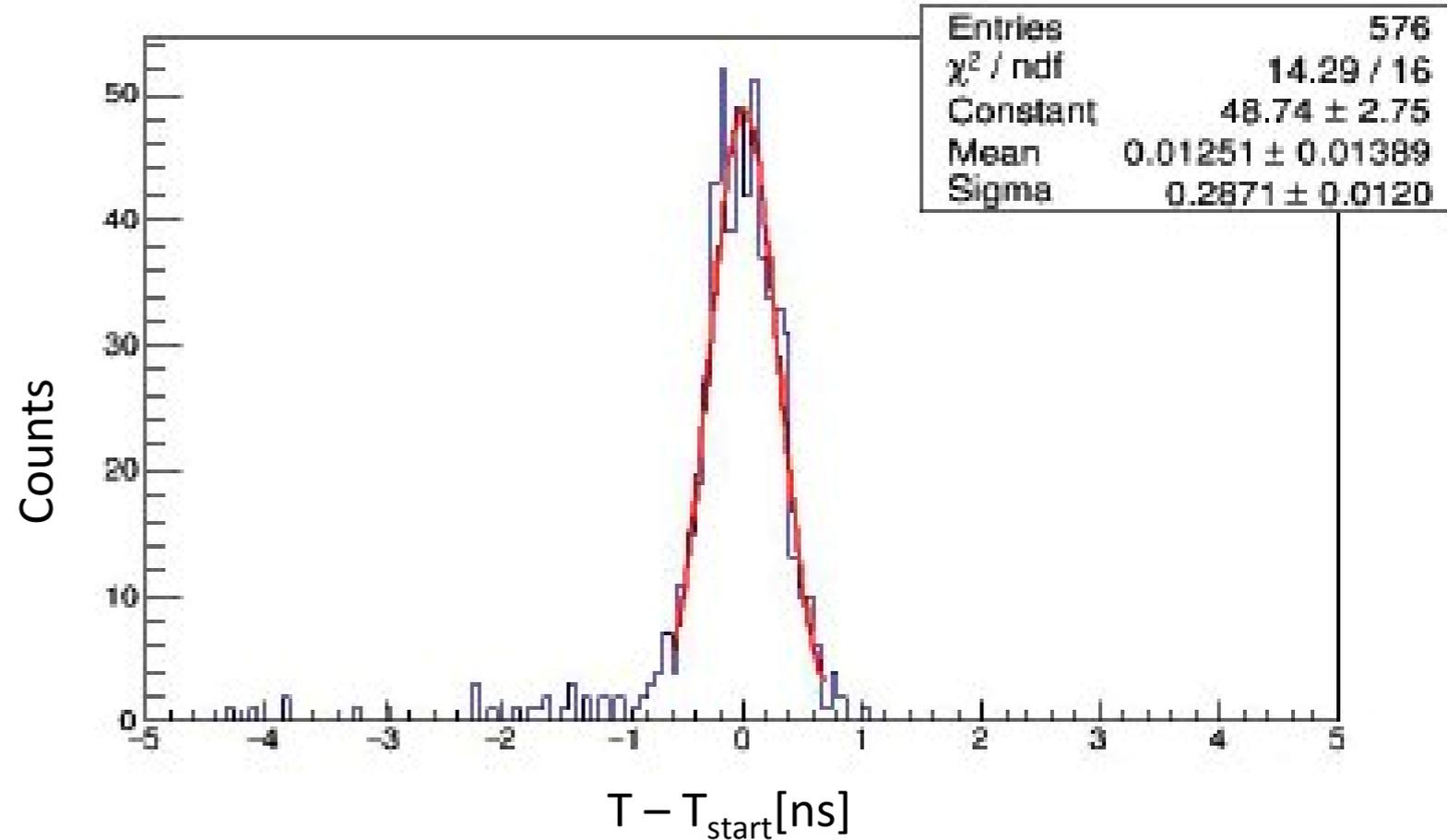
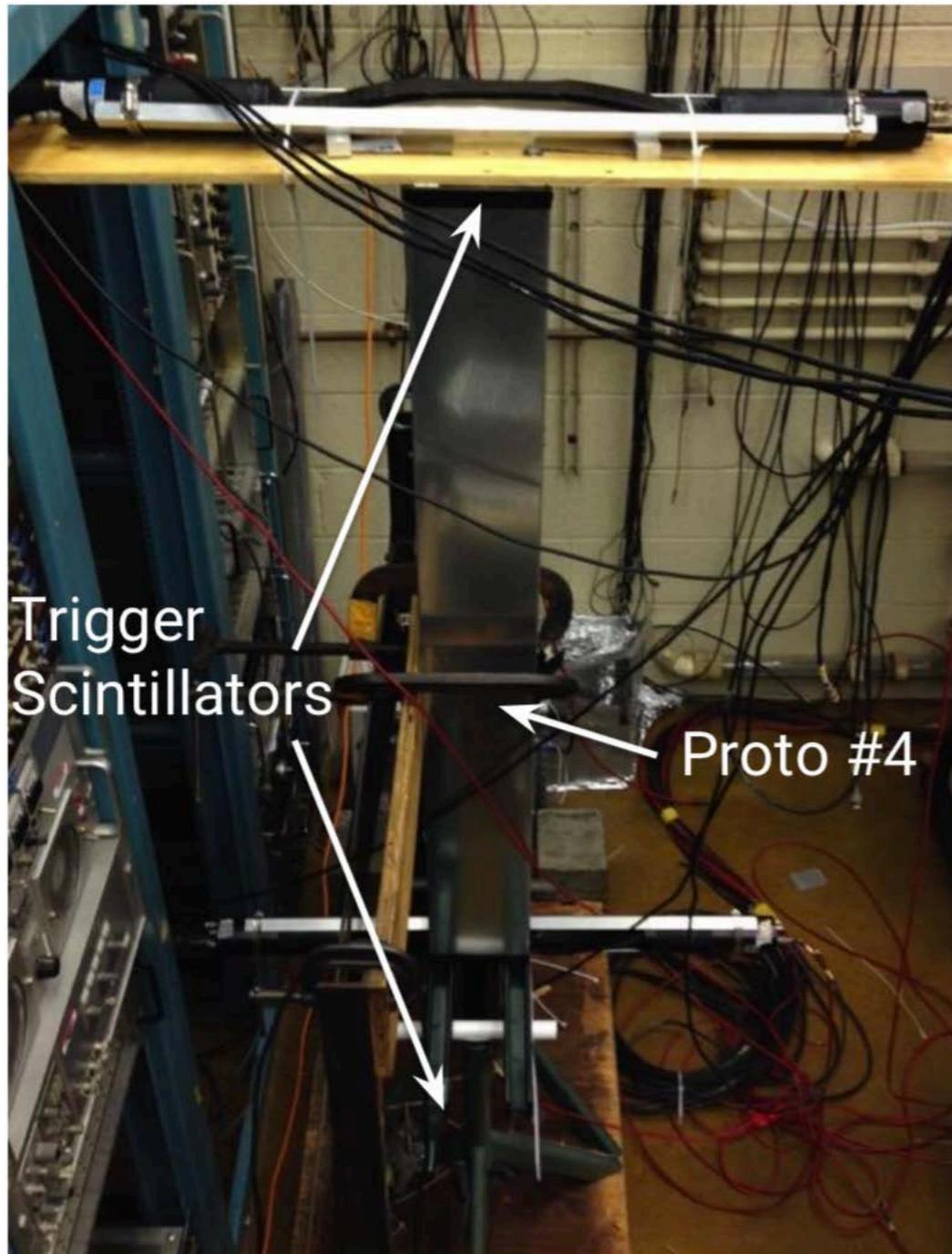
HCAL-J concept is based on HCAL1 from COMPASS, but includes:

- **very fast WLS** paired to extruded plastic PPO-only scintillators made by Fermilab
- WLS placed **at the center** of the module for better uniformity and efficiency in the light collection
- **2" fast PMTs** with better quantum efficiency
- new **light guides**



PPO = 2,5-Diphenyloxazole

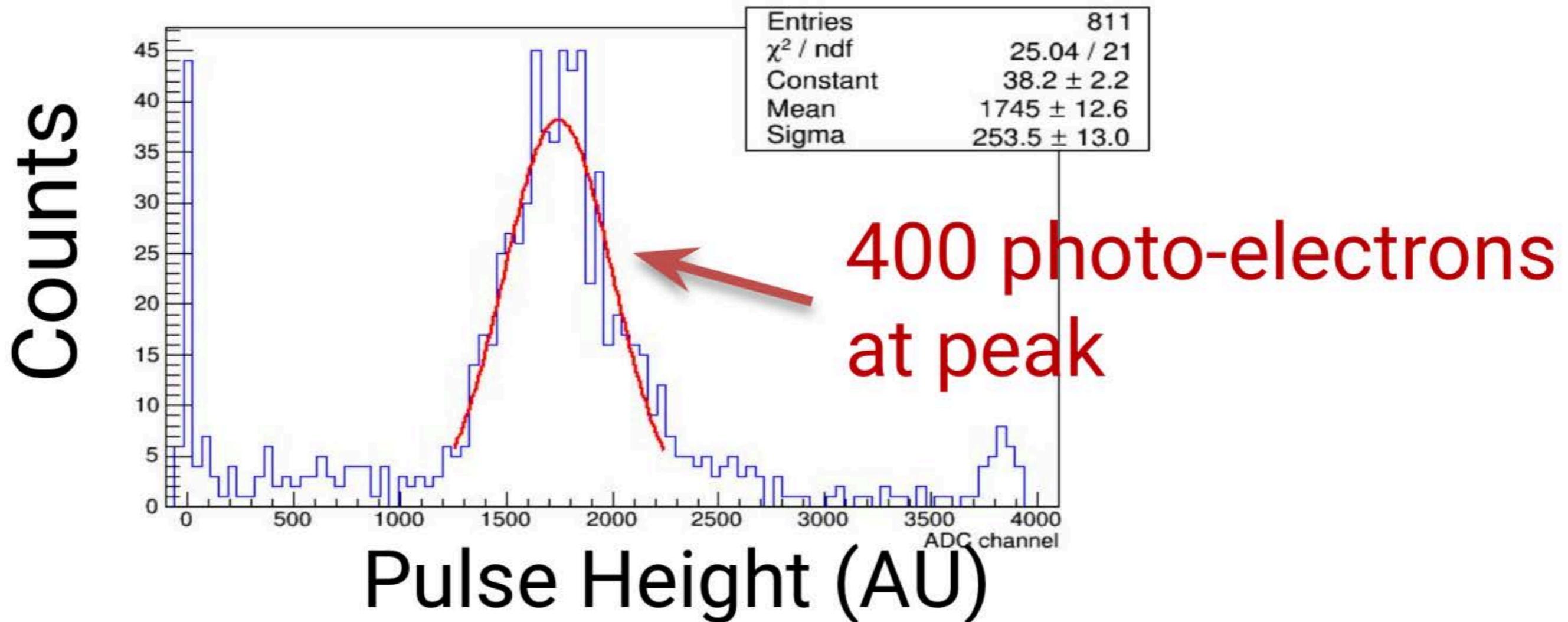
cosmic ray test



277 ps rms module time resolution for cosmic rays

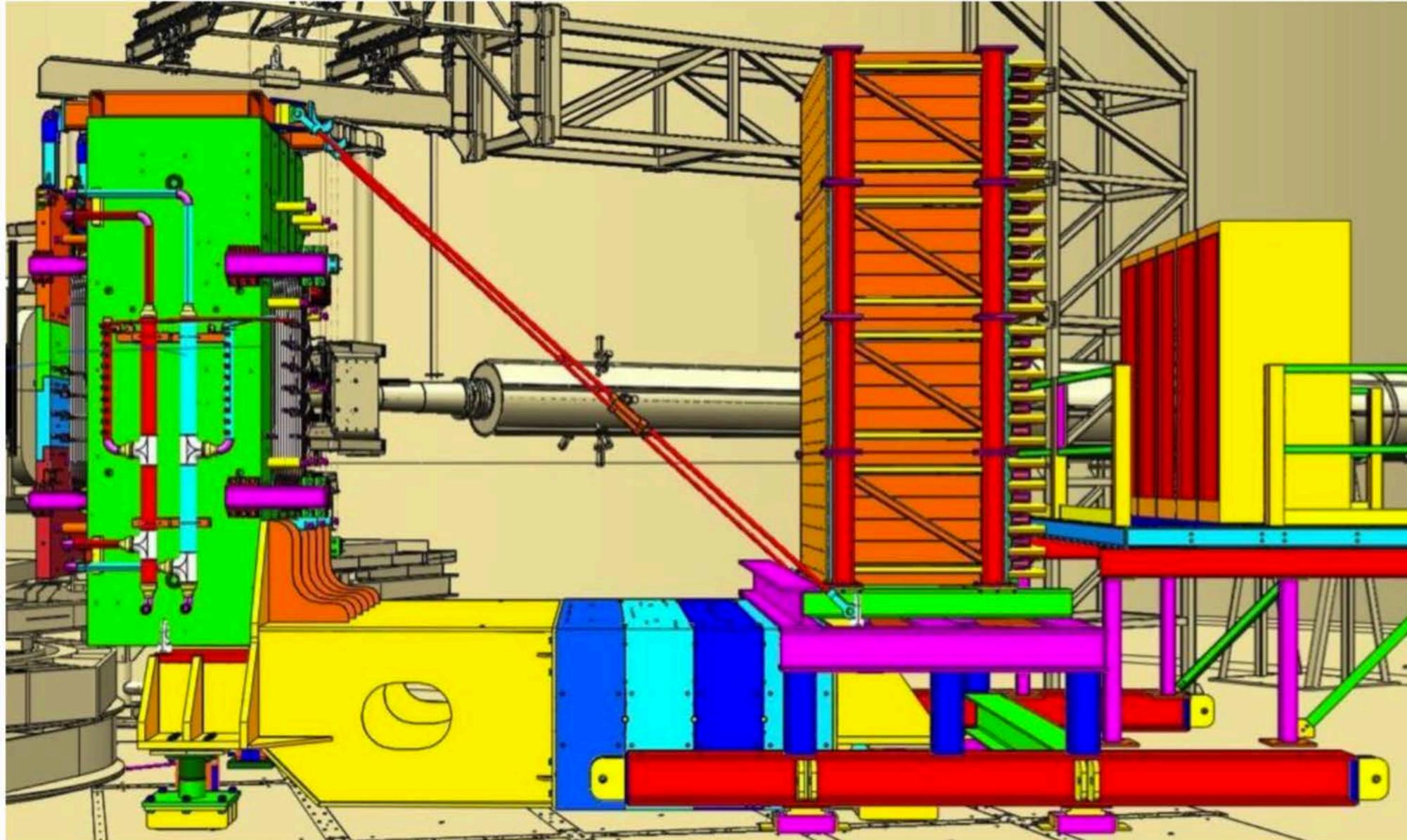
http://hallaweb.jlab.org/12GeV/SuperBigBite/meetings/col_23feb18/talks/Cornejo_HCAL_SBS_GMn_20180223.pdf

cosmic ray test



http://hallaweb.jlab.org/12GeV/SuperBigBite/meetings/col_23feb18/talks/Cornejo_HCAL_SBS_GMn_20180223.pdf

HCAL-J STAND AND CABLE GANTRY



Rollable stand to move gantry + HCAL-J together without need to disconnect cables

INFN CATANIA CONTRIBUTION TO HCAL-J

PAST ACTIVITY

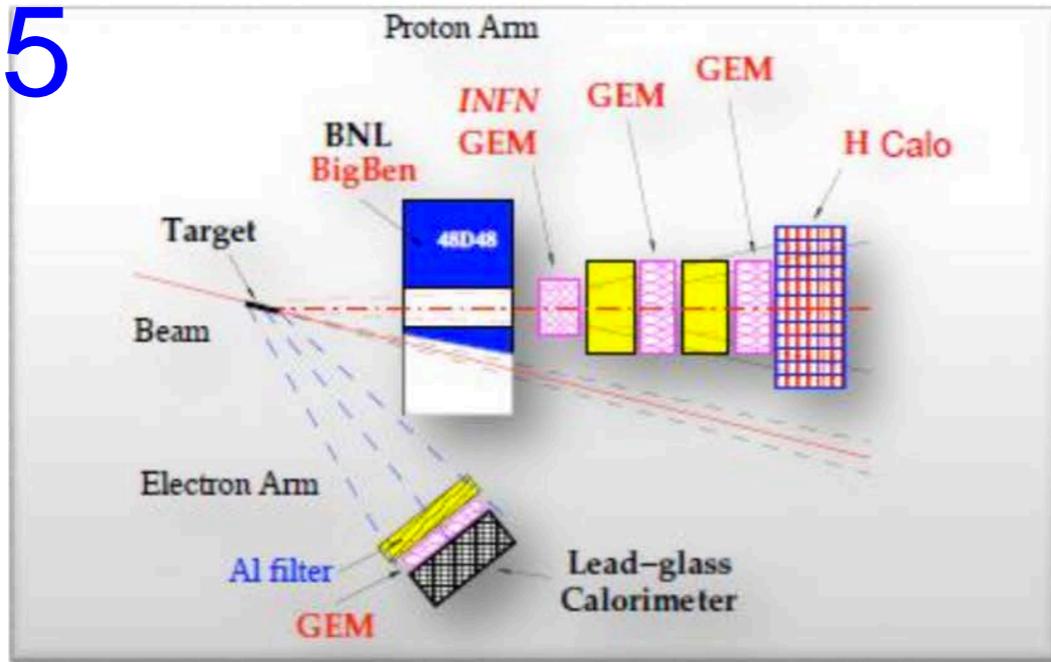
- Development of the HCAL-J concept in the framework of the Consortium CMU/INFN-CT/JLab (working group of the Hall A Collaboration)
- Organize the construction:
 - procuring of the WLS
 - procuring of the LG
 - procuring of the iron absorbers
- PMTs' test

CURRENT AND FUTURE ACTIVITY

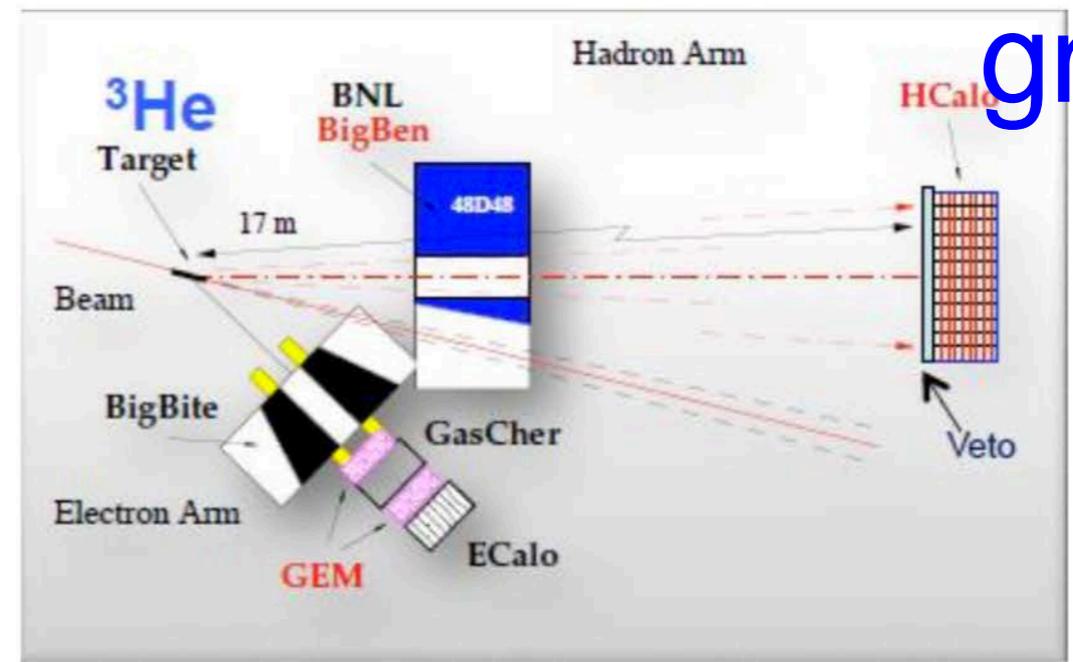
- Procuring part of the electronics module
- Contributing to electronics setup of HCAL_J
- Procuring of the mobile platform
- Complete the cable gantry and rollable stand
- Testing detector modules at JLab

JLAB experiments with sbs and HCAL-J

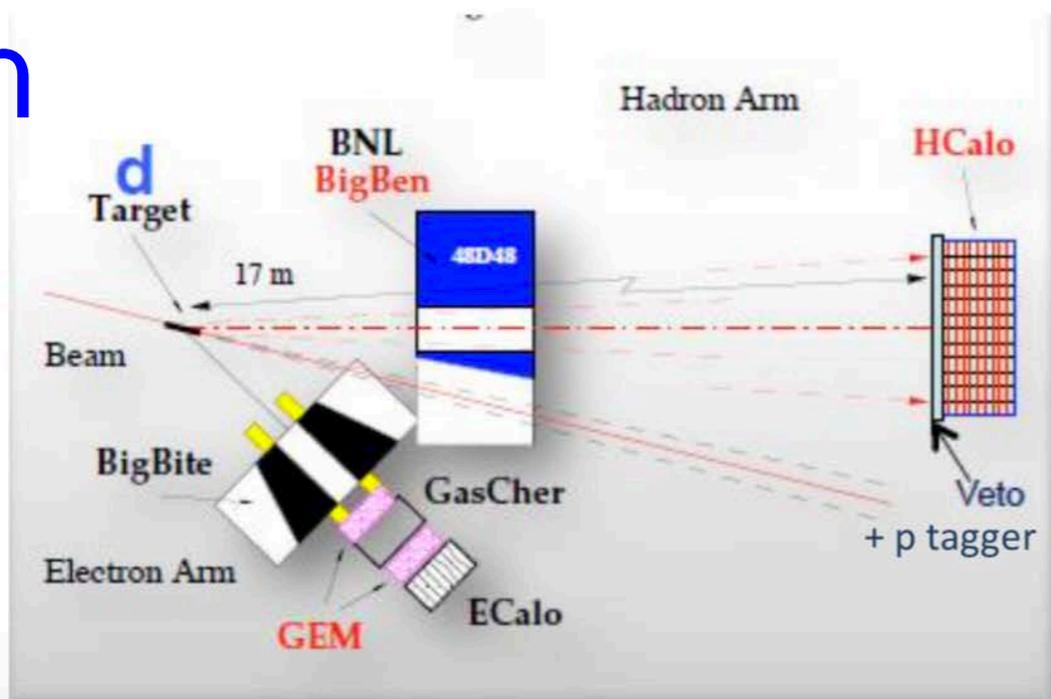
E-12-07-109: Polarization transfer



E-12-09-016: Double Polarization



E-12-09-019: Cross section ratio



«Standard» two arms setups for exclusive elastic and quasi-elastic scattering

Flexible detector configurations (sort of «LEGO detectors») optimized for the specific experimental needs

Thanks for
your attention