Neutral Particle Spectrometer Project in Hall C at JLab

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ANSL EPD seminar, May 2, 2019

Outline

- Overview Scientific Program
- Neutral Particle Spectrometer
- $PbWO_4$ calorimeter, prototype, beam test

Overview Scientific Program

- Approved experiments to date

- E12-13-007: Measurement of Semi-inclusive π^0 production as Validation of Factorization
- E12-13-010 –Exclusive Deeply Virtual Compton and π^0 Cross Section Measurements in Hall C
- E12-14-003 –Wide-angle Compton Scattering at 8 and 10 GeV Photon Energies
- E12-14-005 –Wide Angle Exclusive Photoproduction of π^0 Mesons
- E12-17-008 –Polarization Observables in Wide-Angle Compton Scattering

- Conditionally approved experiments

- TCS with transverse target

E12-13-007: Measurement of Semi-inclusive π^0 production as Validation of Factorization

Kinematics	E (GeV)	E' (GeV)	θ_e (deg)	W^2 (GeV^2)	θ_γ (deg)	q_γ (GeV)	x	Q^2 (GeV^2)	z
A	11.0	5.67	10.27	8.88	10.57	5.513	0.20	2.0	0.4–0.8
B	11.0	6.56	11.70	6.21	16.20	4.767	0.36	3.0	0.5–0.8
C	11.0	5.08	15.38	7.99	12.44	6.250	0.36	4.0	0.4–0.8
D	11.0	2.86	24.15	10.66	7.93	8.472	0.36	5.5	0.3–0.8
E	11.0	5.88	15.65	5.68	16.57	5.565	0.50	4.8	0.4–0.8
F	11.0	5.67	17.84	4.88	17.23	5.865	0.60	6.0	0.4–0.8

Kinematic settings, with HMS providing the electron spectrometer and NPS the neutral-pion spectrometer.

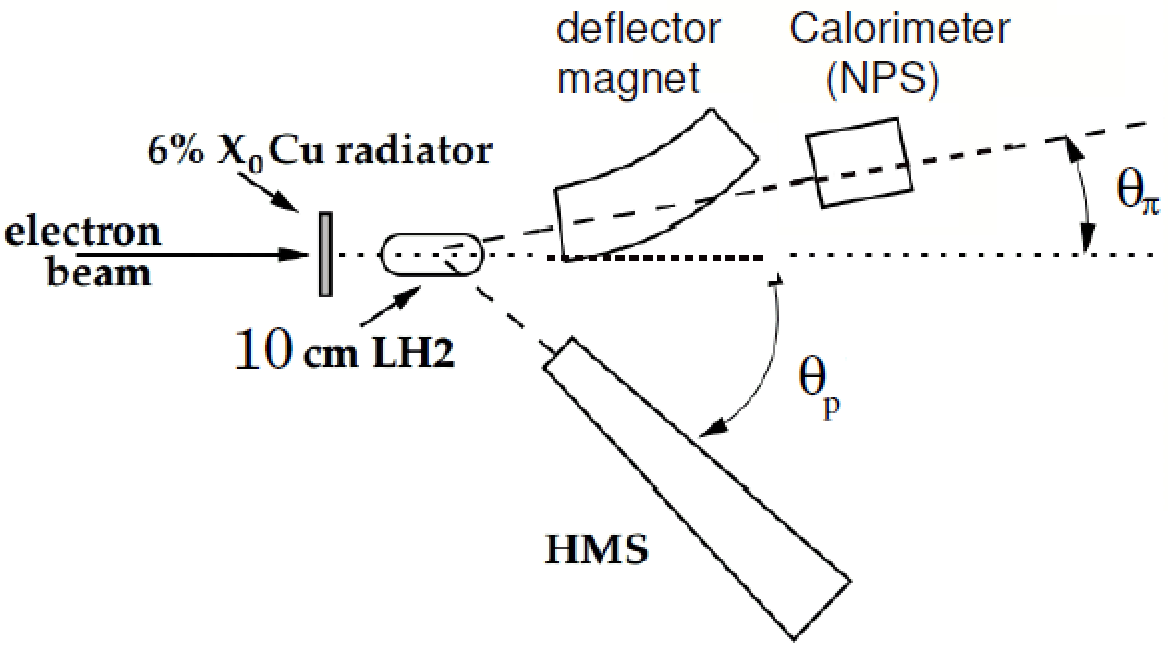
E12-13-010 –Exclusive Deeply Virtual Compton and π^0 Cross Section Measurements in Hall C

	Energy Dependence at fixed (Q^2, x_B)												Low-x_B				High-Q^2		
x_B	0.36					0.50			0.60				0.2				0.36	0.50	0.60
Q^2 (GeV)^2	3.0			4.0		3.4		4.8	5.1			6.0	2.0			3.0	5.5	8.1	10
k (GeV)	6.6*	8.8	11	8.8*	11	8.8	11	11	6.6	8.8*	11	11	6.6	8.8	11	11	11		
k' (GeV)	2.2	4.4	6.6	2.9	5.1	5.2	7.4	5.9	2.1	4.3	6.5	5.7	1.3	3.5	5.7	3.0	2.9	2.4	2.1
θ_{Calo} (deg)	11.7	14.7	16.2	10.3	12.4	20.2	21.7	16.6	13.8	17.8	19.8	17.2	6.3	9.2	10.6	6.3	7.9	8.0	8.0
D_{Calo} (m)	3	3	3	4	3	3	3	3	3	3	3	3	6	4	4	6	4	4	4
I_{beam} (μA)	28	28	28	50	28	28	28	28	28	28	28	28	11	5	50	11	50	50	50
N_{evt} (10^5)	1.5	8.8	8.2	2.1	7.9	7.3	11	5.1	0.2	0.2	2.7	2.6	3.5	3.6	64	3.4	6.1	0.8	0.4
$\sigma_{M_X^2}$ (GeV^2)	0.13	0.13	0.12	0.15	0.15	0.09	0.09	0.11	0.09	0.09	0.09	0.09	0.17	0.17	0.17	0.22	0.19	0.15	0.13
Days	1	2	1	1	3	3	2	5	5	1	5	10	1	1	1	1	5	5	12

DVCS and π^0 kinematics for Hall C. The incident and scattered beam energies are k and k', respectively. The calorimeter is centered at the angle Θ_{Calo}, which is set equal to the nominal virtual-photon direction. The front face of the calorimeter is at a distance D_{Calo} from the center of the target, and it is adjusted to optimize multiple parameters: First to maximize acceptance, second to ensure sufficient separation of the two clusters from symmetric $\pi^0 \rightarrow \gamma\gamma$ decays, and third to ensure that the edge of the calorimeter is never at an angle less than 3.2◦ from the beam line. The row I_{beam} shows the beam current and Nevt is the number of DVCS counts expected integrated over $\phi\gamma\gamma$ in a bin in t of width 0.1 GeV^2.

E12-14-003 –Wide-angle Compton Scattering at 8 and 10 GeV Photon Energies

WACS H(γ,γ′p)



Kin	θ^{cm} [°]	s [GeV^2]	$-t$ [GeV^2]	$-u$ [GeV^2]
4A	55.8	15.89	3.10	11.03
4B	67.6	15.89	4.39	9.75
4C	80.4	15.89	5.91	8.22
4D	90.9	15.89	7.20	6.93
4E	104.8	15.89	8.90	5.23
5A	48.9	19.65	3.07	14.81
5B	59.5	19.65	4.41	13.47
5C	70.1	19.65	5.91	11.97
5D	78.7	19.65	7.21	10.68
5E	103.2	19.65	11.01	6.88

Kinematics variables for WACS in five settings with a 4-pass, 8.8 GeV electron beam (4A-4E) and five settings with a 5-pass, 11 GeV electron beam (5A-5E).

E12-14-005 –Wide Angle Exclusive Photoproduction of π^0 Mesons

	E_γ	θ_{cm}^{π}	$\sqrt{s}$	$\|t\|$	θ_p (lab)	θ_{π^0} (lab)	P_p	P_{π^0}
3A	6.0	70	3.48	3.44	35.6	21.2	2.602	4.170
3B	6.0	90	3.48	5.21	26.7	30.1	3.595	3.218
3C	6.0	105	3.48	6.98	21.1	38.5	4.334	2.50
3D	5.0	70	3.20	3.14	37.6	23.1	2.251	3.497
3E	5.0	90	3.20	4.81	28.3	32.5	3.079	2.716
3F	5.0	105	3.20	5.32	22.5	41.6	3.691	2.125
5F	10.0	90	4.43	8.01	22.1	23.9	5.632	5.227

Table of kinematics for the $p(\gamma,\pi^0 p)$ reaction at E_{beam} of 11.0GeV at pion c.m. angle of 90^0 and 6.6 GeV at pion c.m. angle of , 90^0, 90^0 and 105^0 .

E12-17-008 –Polarization Observables in Wide-Angle Compton Scattering at large s, t, and u

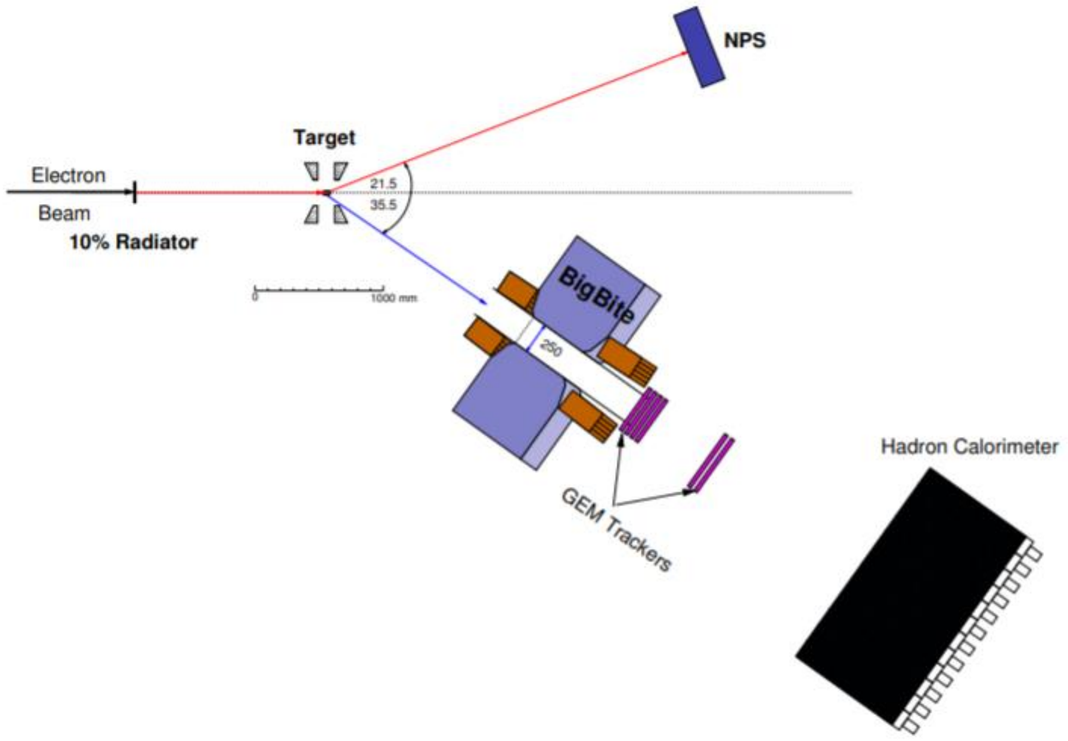


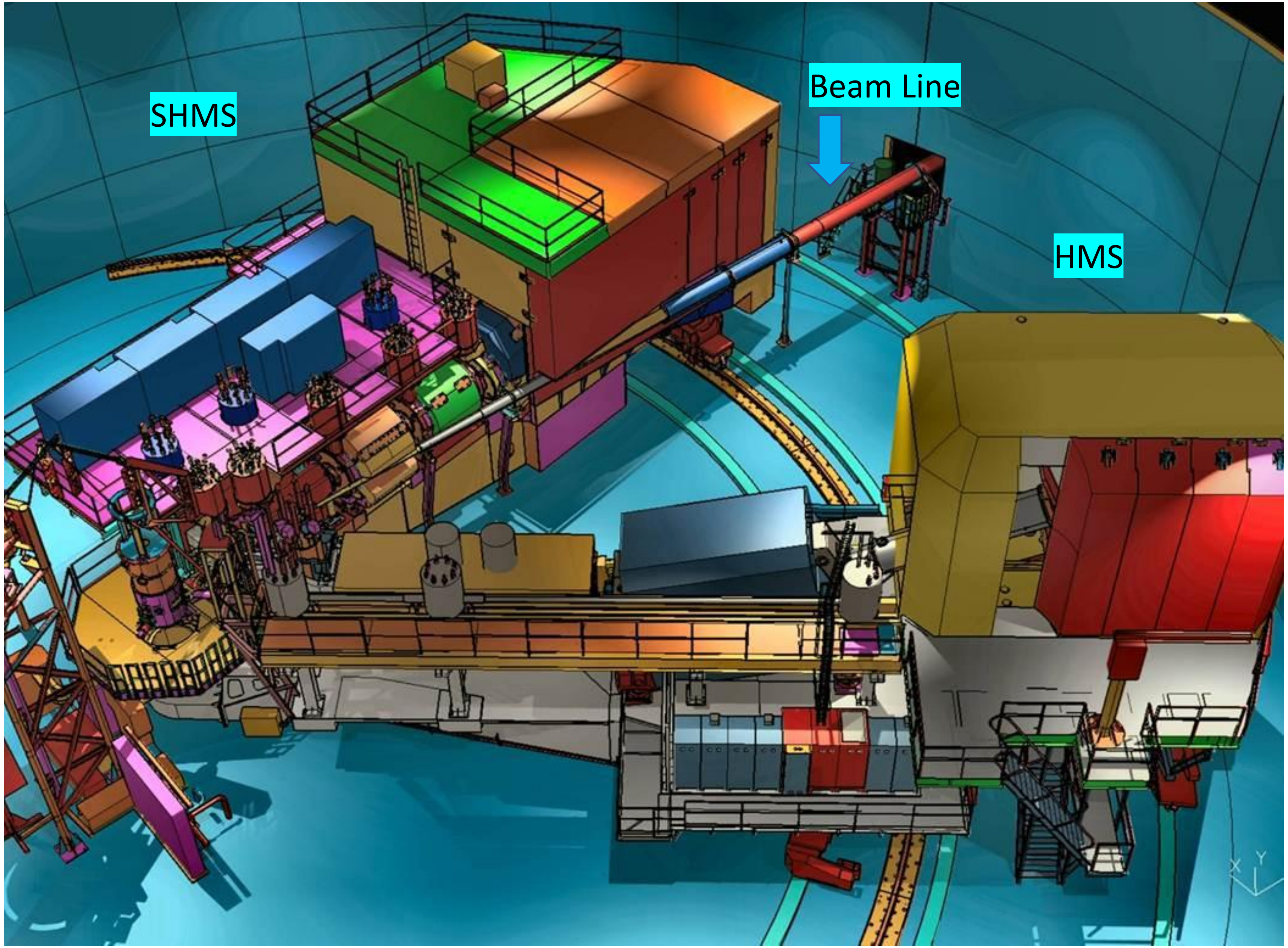
Figure 9: Schematic of the experimental setup, with the scattered photon detected by the NPS and the recoil proton detected by BigBite (kinematic setting L1).

E12-17-008 –Polarization Observables in Wide-Angle Compton Scattering at large s, t, and u

Kin	E_{Beam} [GeV]	P_{Target}	E_{in} [GeV]	θ_γ [°]	E_γ [GeV]	D_{NPS} [m]	θ_{p} [°]	p_{p} [GeV/c]	D_{BB} [m]	θ^{cm} [°]
L1	8.8	L	6.0	21.5	4.16	3.0	35.5	2.62	1.5	70.0
S1	8.8	T	6.0	21.5	4.16	3.0	35.5	2.62	1.5	70.0
L2	11.0	L	9.5	17.4	6.49	3.0	30.5	3.82	1.5	70.0
L3	8.8	L	6.0	30.2	3.22	3.0	26.5	3.63	2.5	90.0
L4	8.8	L	6.0	42.3	2.25	1.0	19.4	4.55	3.5	110.0
S4	8.8	T	6.0	42.3	2.25	1.0	19.4	4.55	3.5	110.0

Table 2: Kinematics variables for WACS in four settings with a longitudinally polarized target (L1–L4) and two settings with a transversely polarized target (S1 and S4).

Hall C at 12 GeV

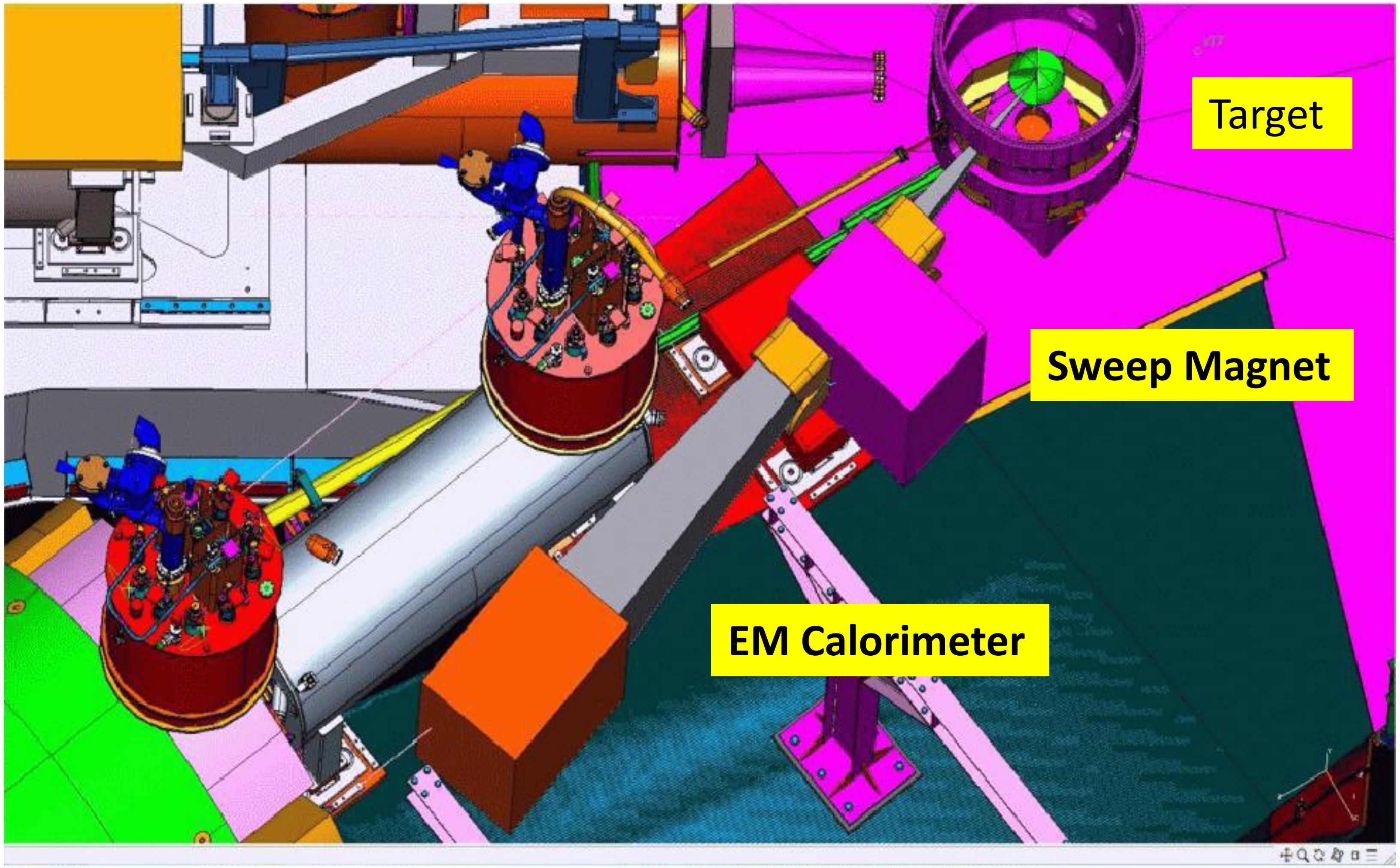


SHMS parameters:
Magnets: (HB)QQQD
P: 2 -- 11 GeV/c
ΔP: (-10% , +22%)
δP: 0.03%-0.08%
θ: 5.5 ° -- 40°
Δ Ω: 4.0 msr

HMS parameters:
Magnets: QQQD
P: 0.5 – 7.5 GeV/c
ΔP: (-10% , +10%)
δP: 0.1%
θ: 12.5 ° -- 90°
Δ Ω: 6.0 msr

Neutral Particle Spectrometer

The angular acceptance by design is well matched to the HMS acceptance. Hence will be used in pair with HMS for precision (coincidence) cross section measurements of neutral particles (γ,π^0).



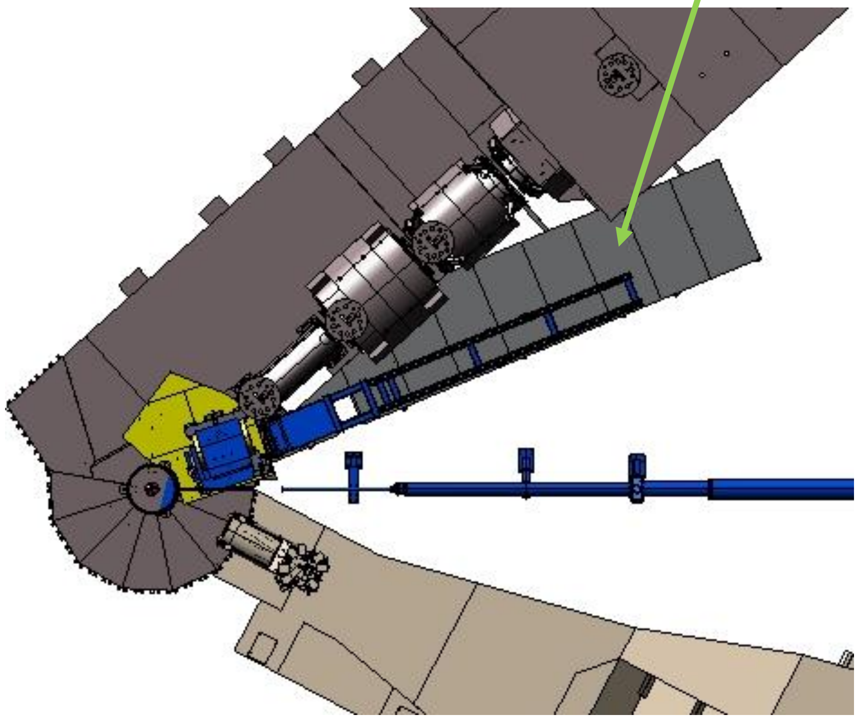
A new 0.3T sweeping magnet allowing for small-angle and large angle operation at 0.6 T. The magnet is compatible with existing JLab power supplies.

25 msr (at 4m from target) segmented electromagnetic calorimeter.

Relocation of NPS to SHMS Left Side

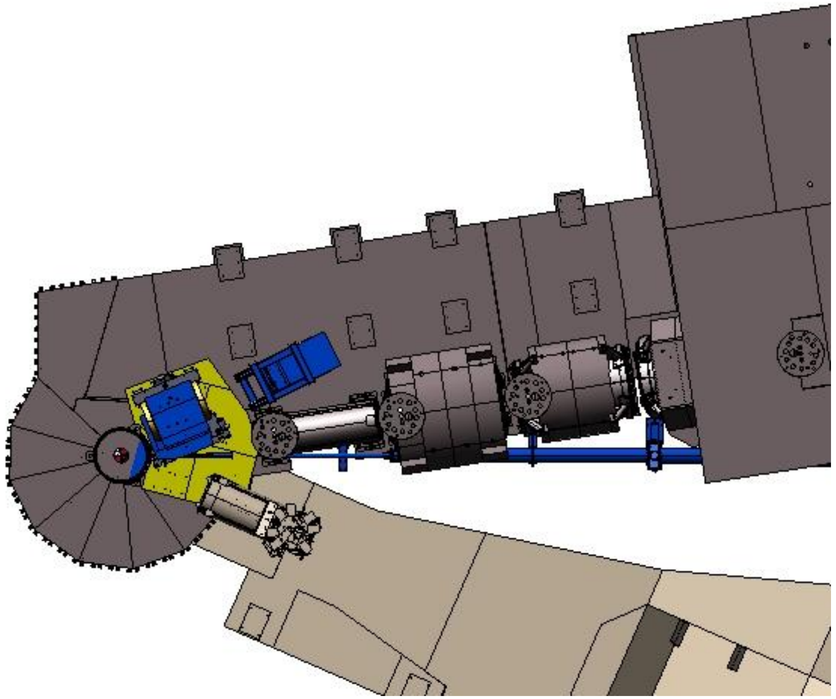
Detector Platform and Supports removed.

Experiments with ϴγ = 6° to 23° will be installed on SHMS right side.



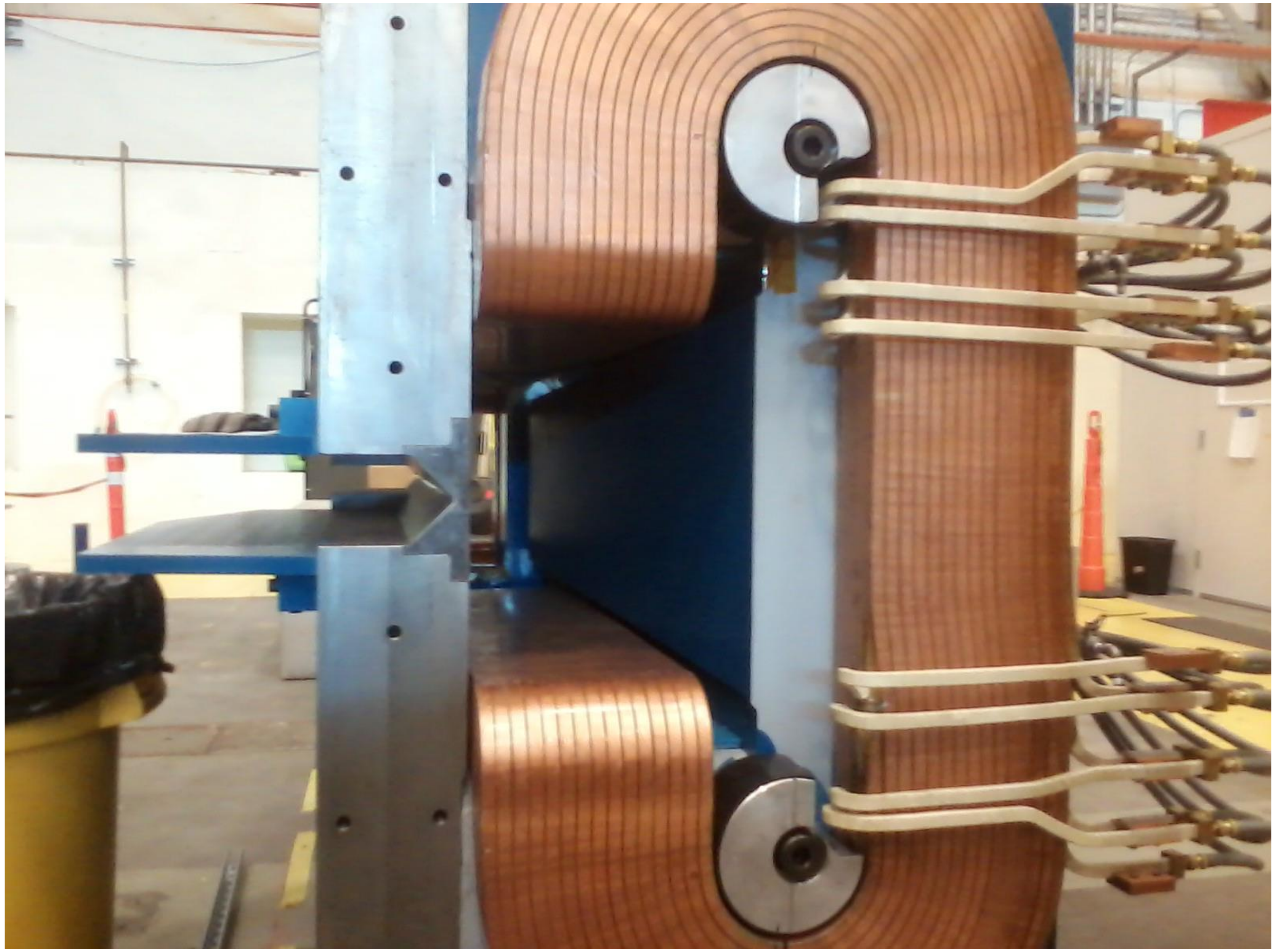
Sweeper Magnet, Detector, Patch Panel #1 and section of rails moved to left side of SHMS.

Experiments with ϴγ = 23° to 60° will be installed on SHMS left side.



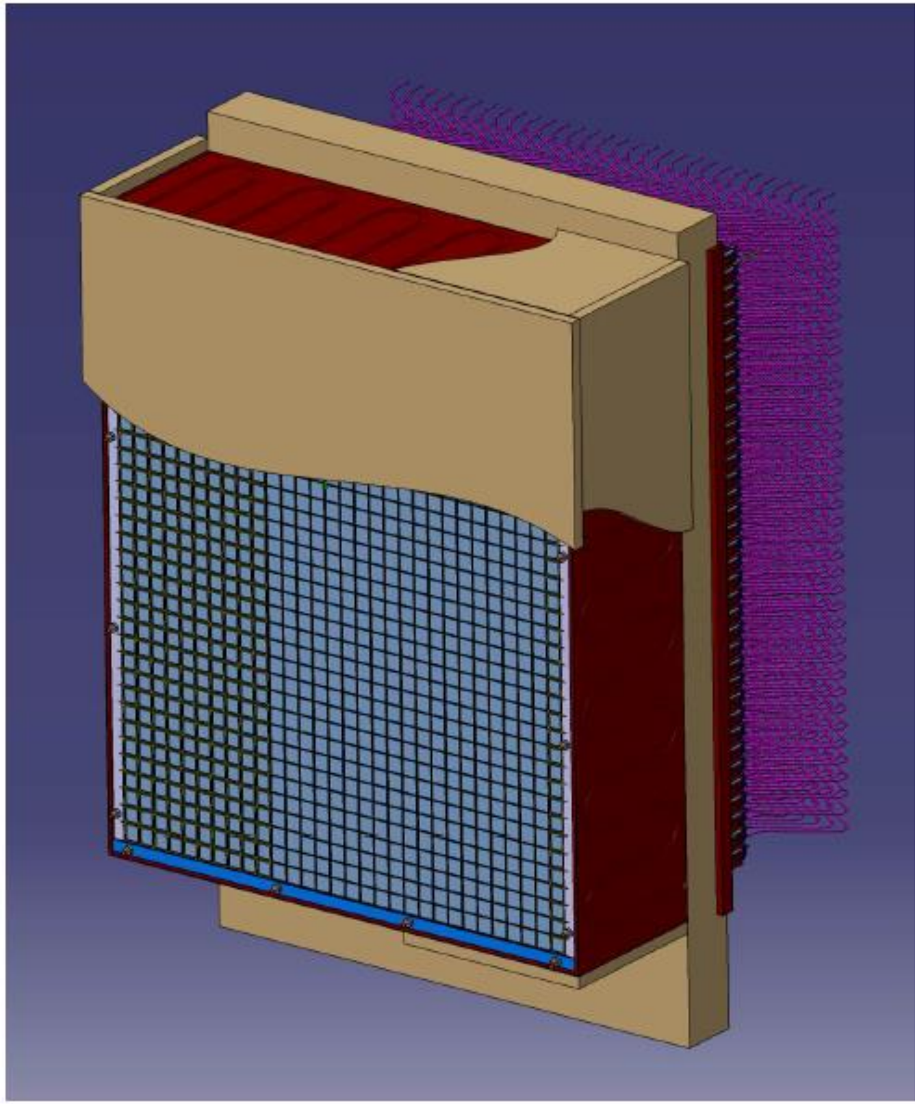
Sweeping magnet

Sweeping magnet in Test-Lab (JLab)



Water cooling in test-lab limited to 200A ~20% of full power

NPS Calorimeter



36 raws of 30 crystals =1080,crystals 20,5 x 20,5 x 200 mm

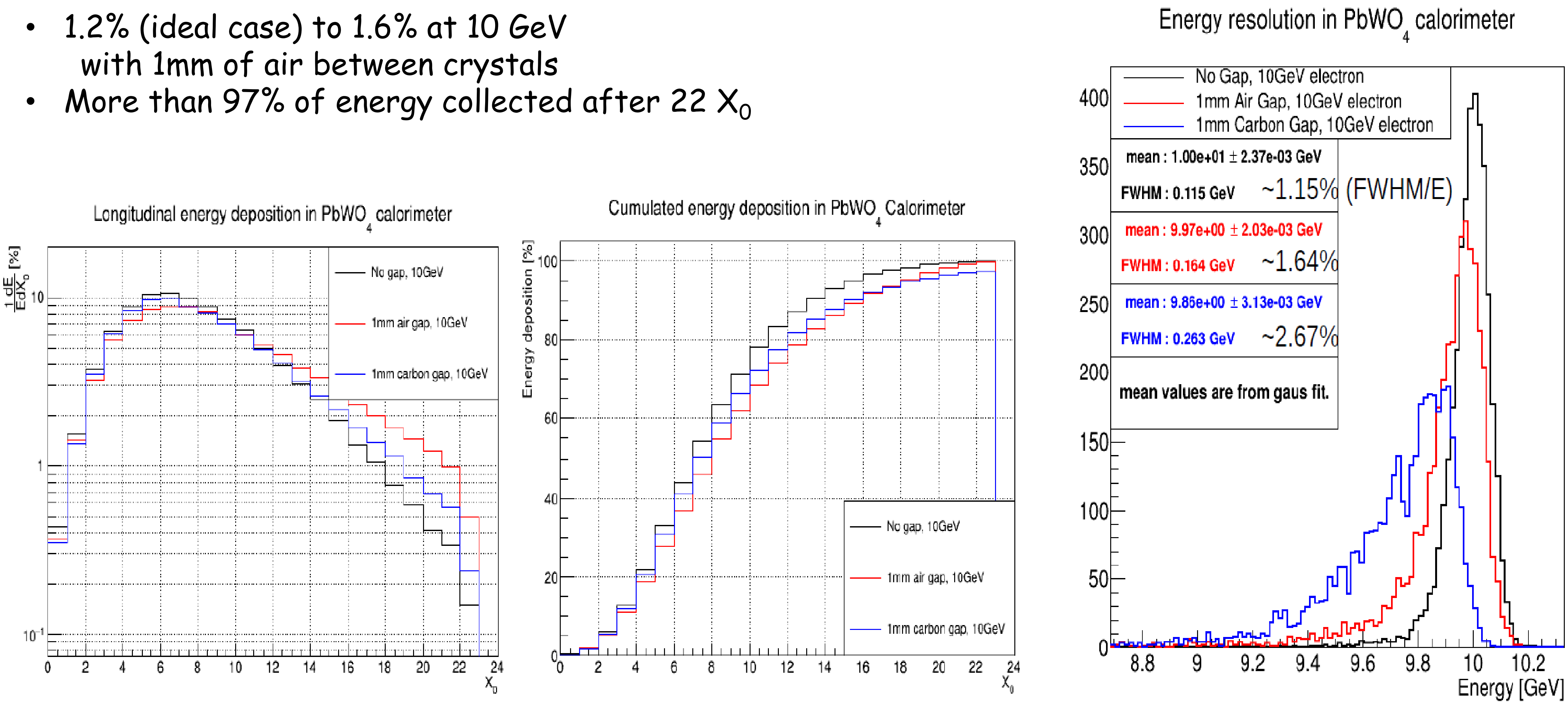
Each crystal is wrapped of 1 reflective sheet on each side except the back side toward the PMT (Reflecteurs, Enhanced Specular Reflector 3M S+ESR 65µ thickness) (Tests have been made to check light crosstalk between 2 crystals: No crosstalk so no layer tedlar added)

Pitch between 2 crystals = 21,35 mm at the moment in each direction (gap between 2 crystals = 0,85mm)
Have to be optimized in order to facilitate the introduction of all the crystals in the composite honeycomb .

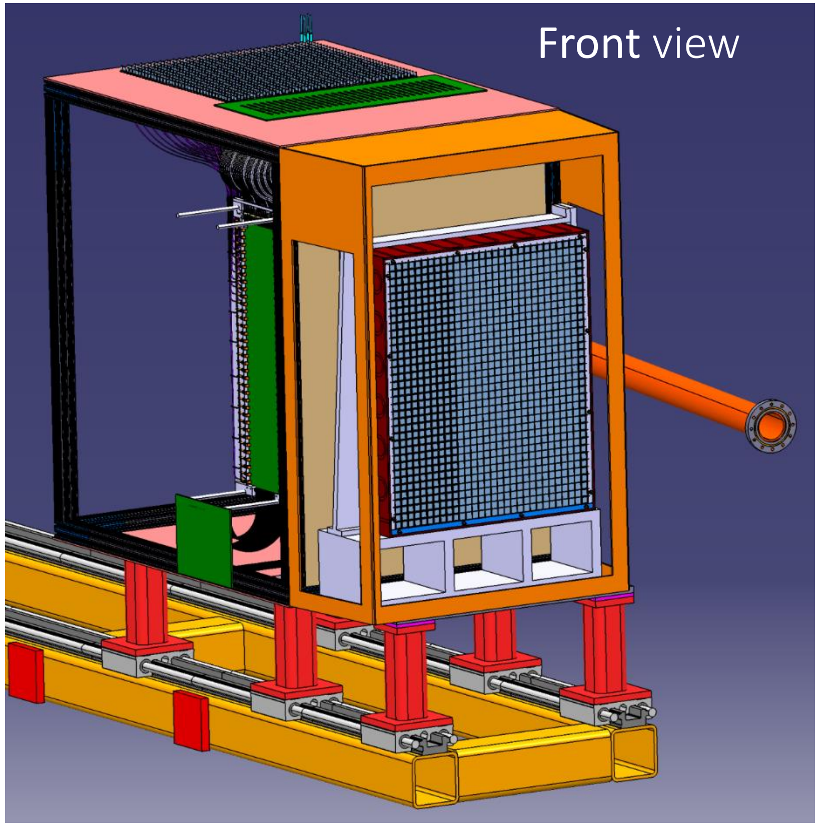
Cooling copper plates around the calorimeter + insulation with Foam in order to maintain the T° @ 18°=/- 0,1 °(Study in progress)

NPS Calorimeter

- 1.2% (ideal case) to 1.6% at 10 GeV with 1mm of air between crystals
- More than 97% of energy collected after 22 X_0

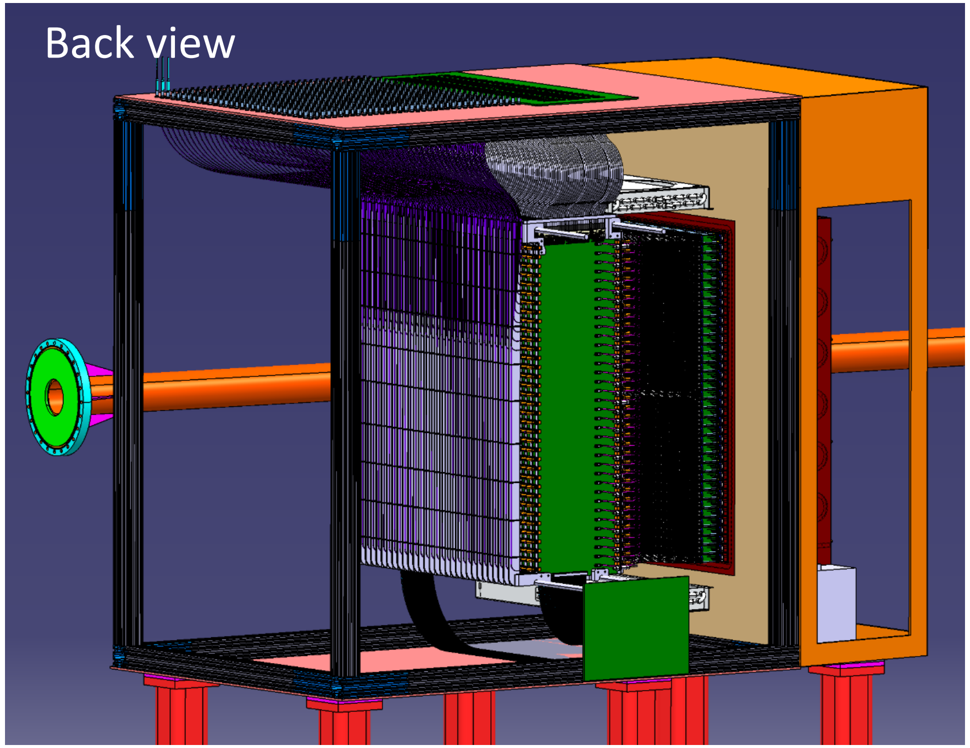


NPS Calorimeter



- 30x36 (1080) $PbWO_4$
- Hamamatsu R4125 PMTs
- Active HV bases for PMTs

- Crystals placed in a 0.5 mm-thick carbon frame to ensure good positioning
- PMTs accessible from the back side to allow maintenance
- Calibration and radiation curing with blue LED light though quartz optical fiber

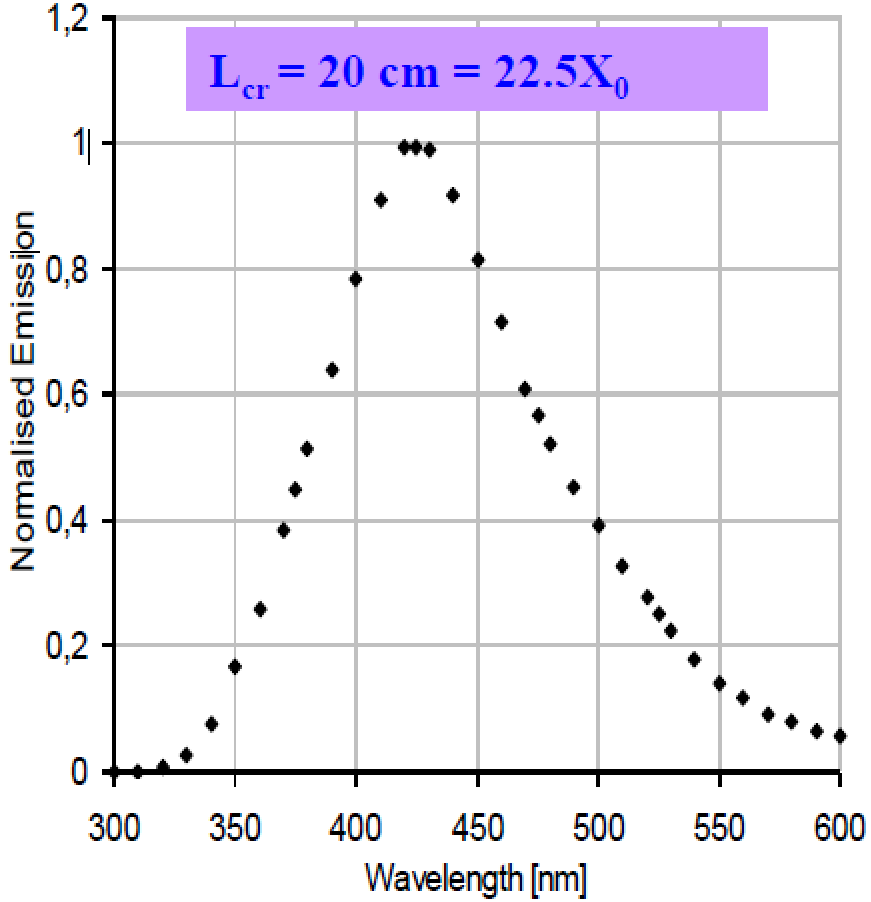


NPS Calorimeter
Selection of Inorganic Scintillators

Material/ Parameter	Density (g/cm^3)	Melt. Point (ºC)	Rad. Length (cm)	Moliere Radius (cm)	Refr. Index	Emission peak	Decay time (ns)	Light Yield (γ/MeV)	Rad. Hard. (krad)	Radiation type	Z_{Eff}
BaF_2	4.89	1280	2.03 2.06	3.10 3.40	1.50	300 220	650 0.9	16000 2000	>50	Scint.	52.7
CeF_3	6.16	1460	1.70 1.68	2.41 2.60	1.62 1.68	340 300	5 30	2800	>100	Scint.	50.8
(BGO)$Bi_4Ge_3O_{12}$	7.13	1050	1.12	2.23 2.30	2.15	480	300	8000 4000	>1000	.98 scint, .02 Č	83
(PWO)$PbWO_4$	8.30	1123	0.89 0.92	2.00	2.20	560 420	50 10	40 240	>1000	.90 scint. .10 Č	75.6
PbF_2	7.77	824	0.93	2.21	1.82	280 310	<30	2-6	50	Pure Č	77
(BSO):Ce$Bi_4Si_3O_{12}$	6.80	1030	1.85	≈5	2.06	470 505	≈100	1000 4000	>10	Scint.	75
(LSO):CeLu_2SiO_5	7.40	2050	1.14	2.07	1.82	420	40	30000	>1000	.98 sint ..02 Č	64.8
(LYSO):Ce$[LuY]_2SiO_5$	7.40	2050	1.14	2.07	1.82	420	40	30000	>1000	.98 scint. .02 Č	64.8

NPS Calorimeter
$PbWO_4$ crystals – general characteristics

Properties of $PbWO_4$	
Density	8.28 g/cm^3
Radiation length	0.89 cm
Interaction length	19.5 cm
Moliére radius	2.2 cm
Emission peak	420 nm
Light yield	120 photons /MeV
Radiation hardness	10^7 rad

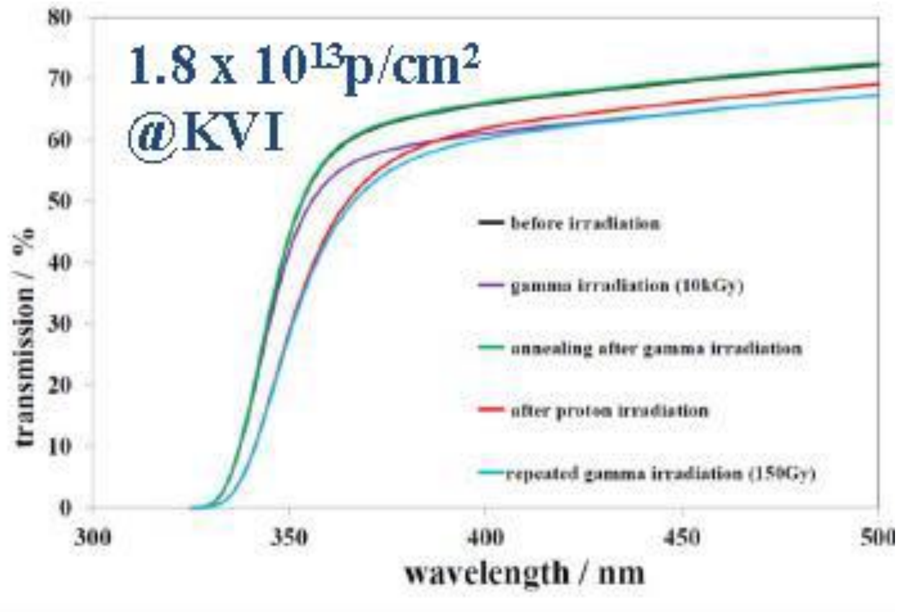


Experiments using PbWO4: CMS, Phenix, Panda, PrimEX

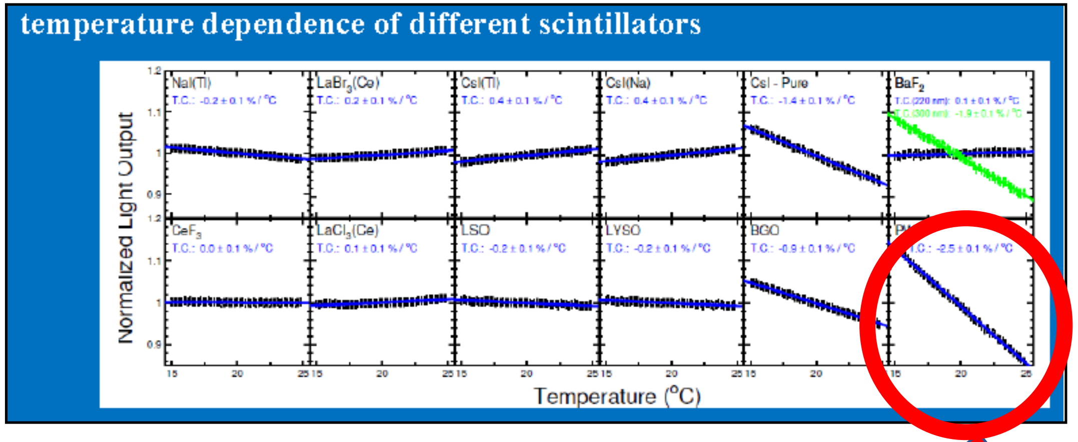
NPS Calorimeter
$PbWO_4$ crystals – general characteristics

Advantages
- Dense and Radiation hard
- Short radiation length
- Fast

Disadvantages
- Temperature dependence
- Low light yield



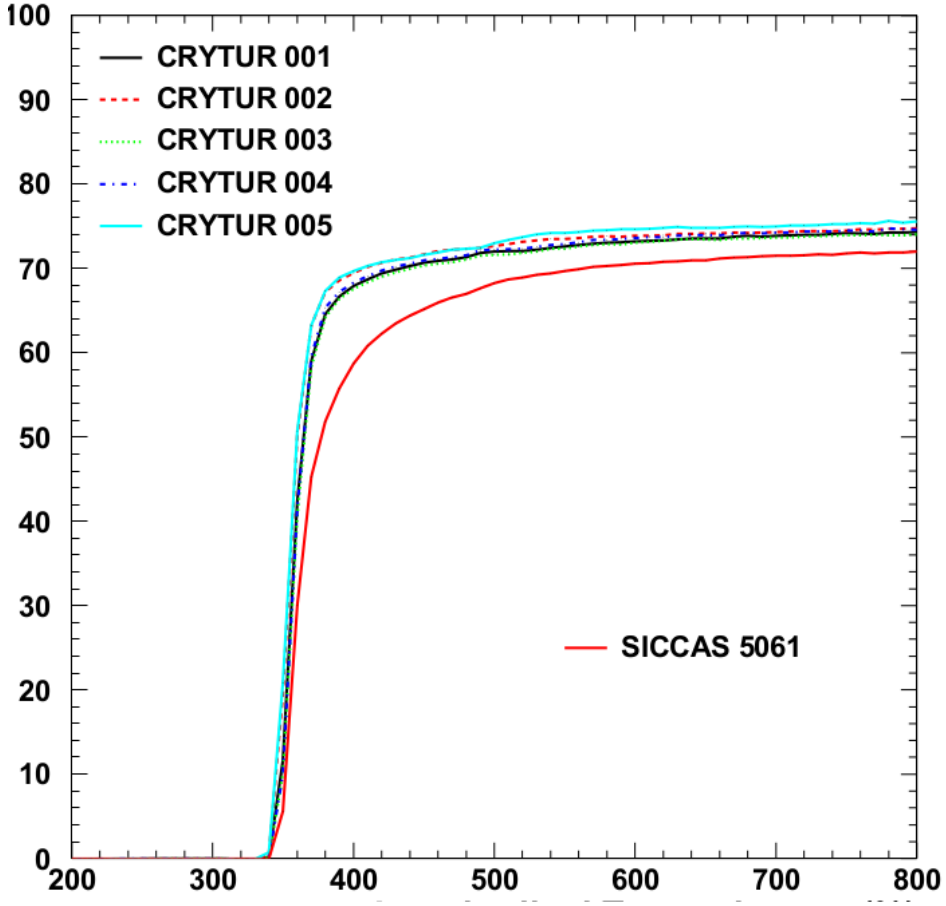
$PbWO_4$ radiation resistance



$PbWO_4$ crystal light yield depends strongly on temperature - approximately 2% per °C

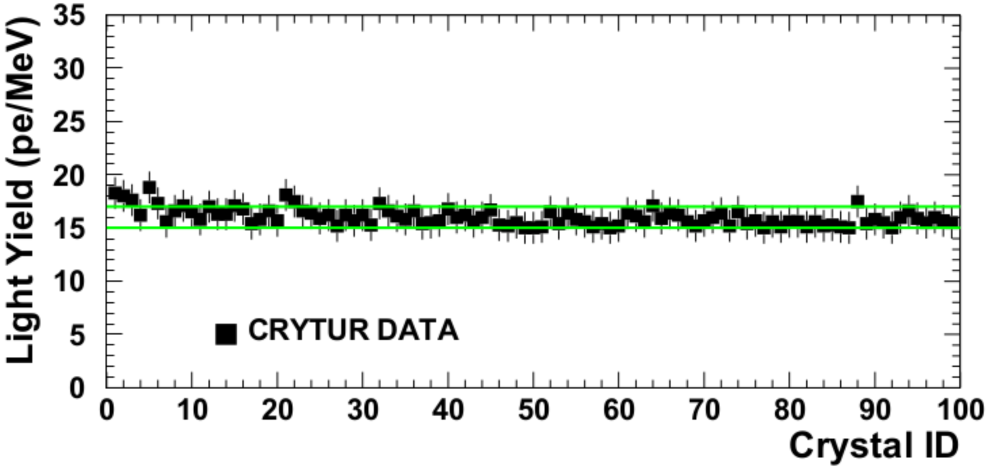
NPS Calorimeter
$PbWO_4$ crystals – general characteristics

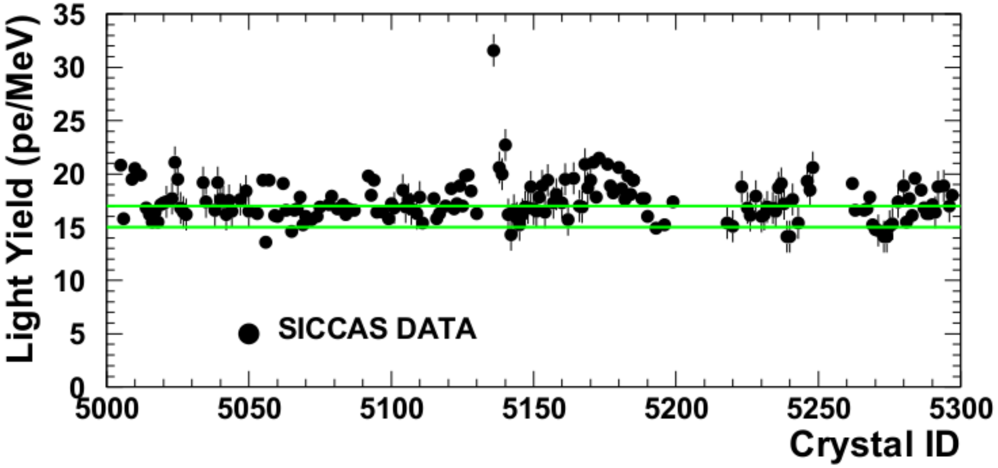
Transmittance



Wavelength (nm)

Light Yield





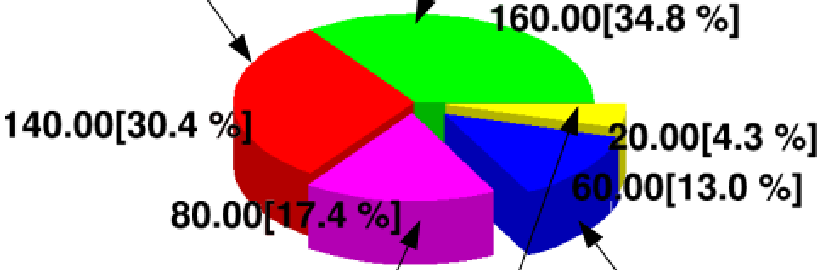
Crystals status

Vendor	Samples	Delivered
SICCAS	460	FY 2017
CRYTUR	100	FY 2018

Experimental investigation	CRYTUR	SICCAS
Visual inspections including 5mW green laser	100%	100%
Dimension measurements	100%	100%
Transmittance measurements	37%	100%
Light yield measurements	30%	70%
Radiation resistance, sample of 10 pieces	to be done	done
Beam tests (additional)	to be discussed	done; data analysis ongoing
Chemical and surface analysis few samples (optional)	done	done

SICCAS

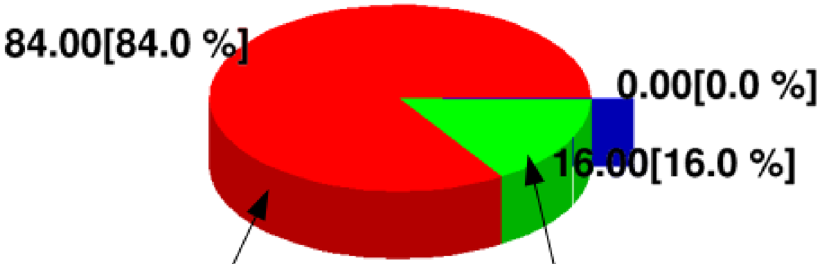
- Crystals with small defects
- Good crystals



- LY and other defects
- Milky crystals, X-mas trees, Shabby
- Bad transmittance and visual defects

160 rejected crystals

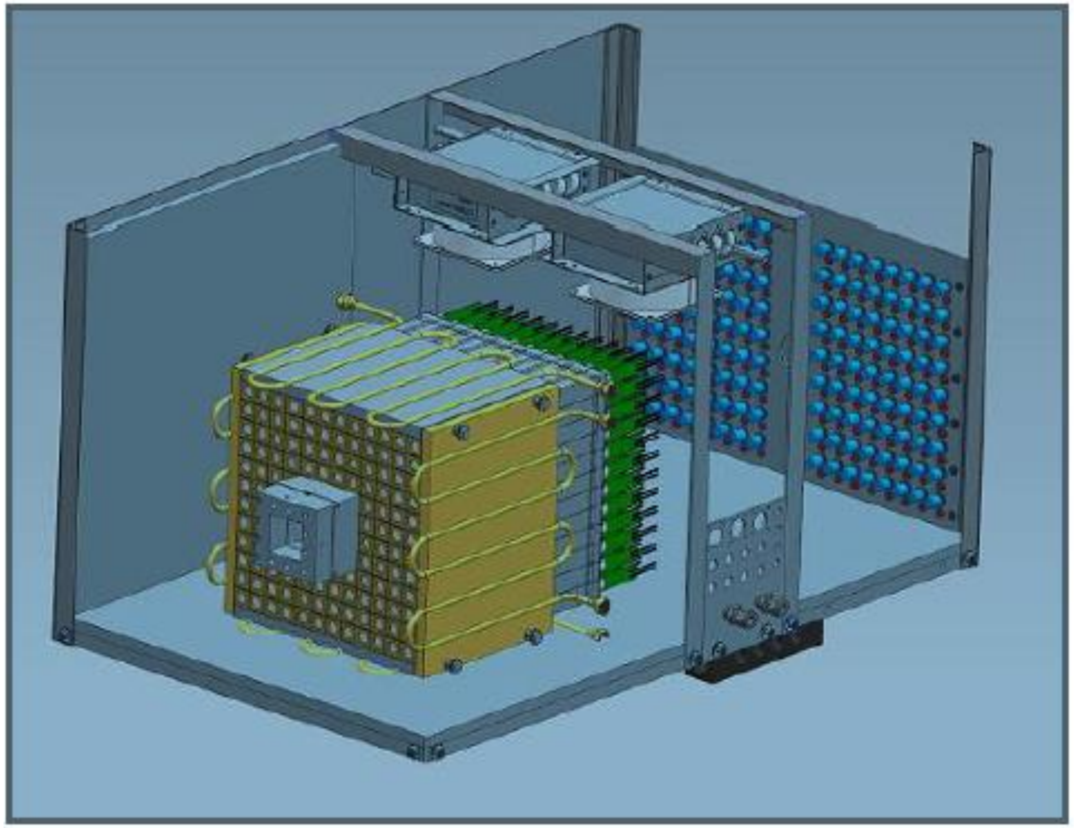
CRYTUR



- Great crystals
- Some negligible defects (chips, scratches)
- 0 rejected crystals

(Adapted from Carlos)

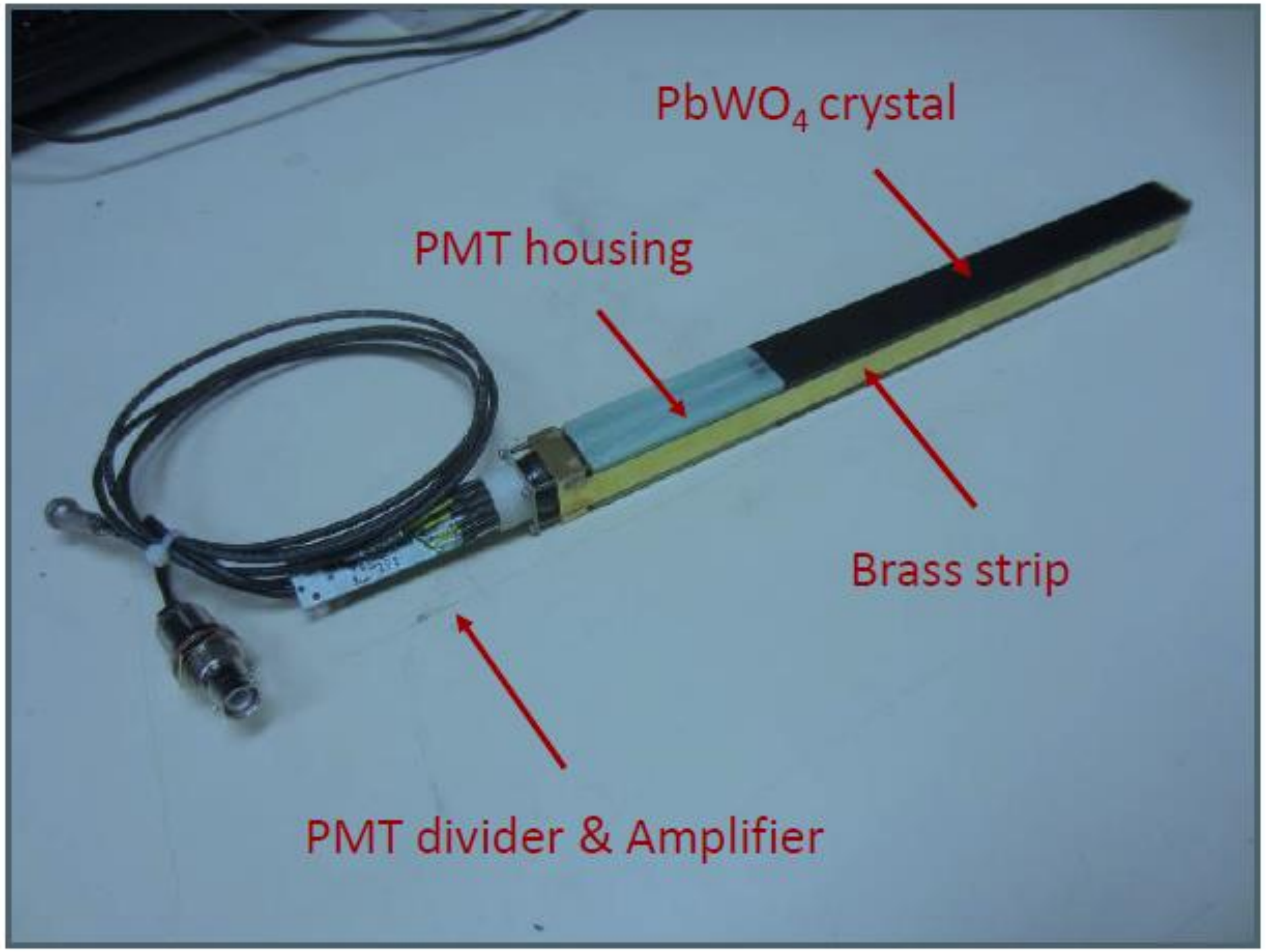
NPS prototype (Hall D Compton Calorimeter)



- Array of 12x12 $PbWO_4$ crystals
- Beam hole: 2 x 2 crystals
- Tungsten absorber covers the inner most layer (taken from HyCal)
- Water cooling, cooled to 5^o C, nitrogen purge
- LED-based gain monitoring system
- Positioned on X-Y movable platform
- Hamamatsu R4125 PMT [d=19mm, 8.7E+5 gain at 1.5 kV voltage, rise time 2.5 ns]
- HV dividers with amplifiers, designed by Vlad Popov

NPS prototype (Module Assembly)

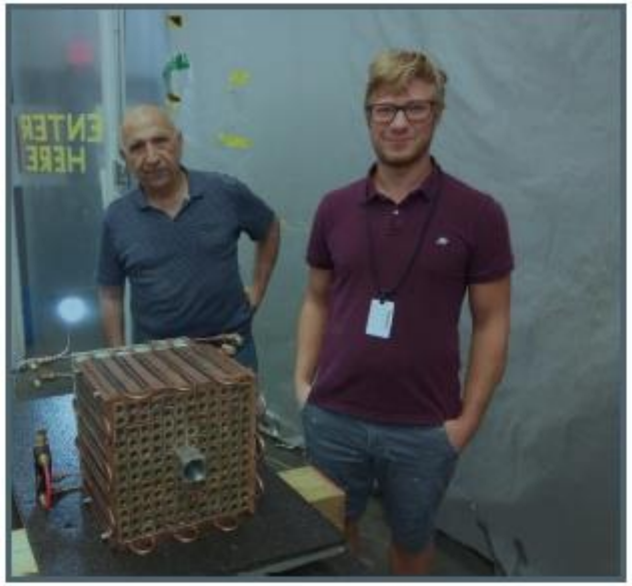
Design from HyCal (Hall B)



- PbWO4 crystal wrapped with a ESR reflective foil (60 µm) and Tedlar (35 µm)
- Brass tension strips (25 µm) are brazed to flanges and hold pieces together
- PMT is placed inside G-10 housing with mu-metal

NPS prototype (Fabrication)

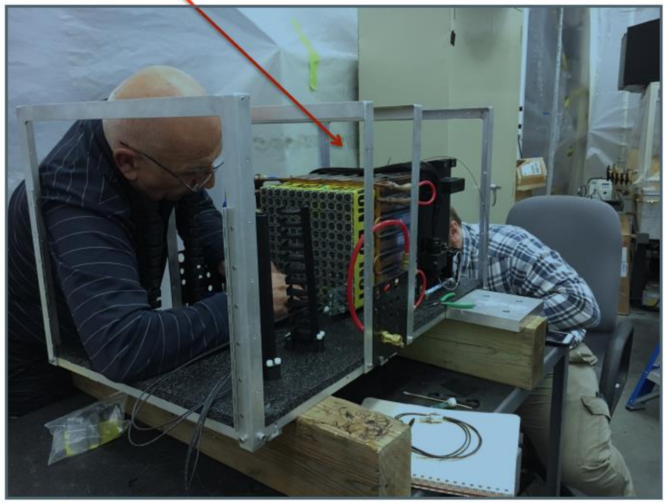
Crystals QA



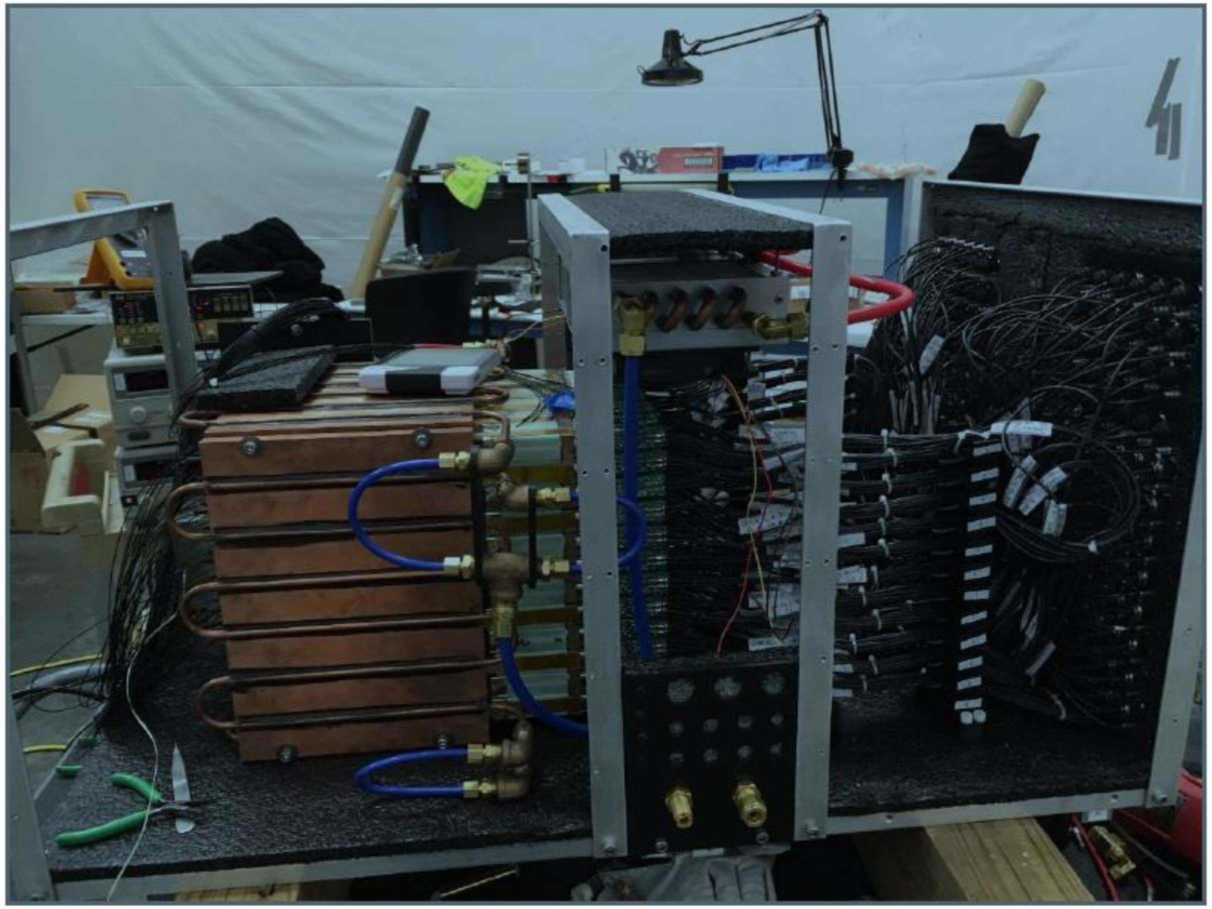
140 modules assembled and stacked

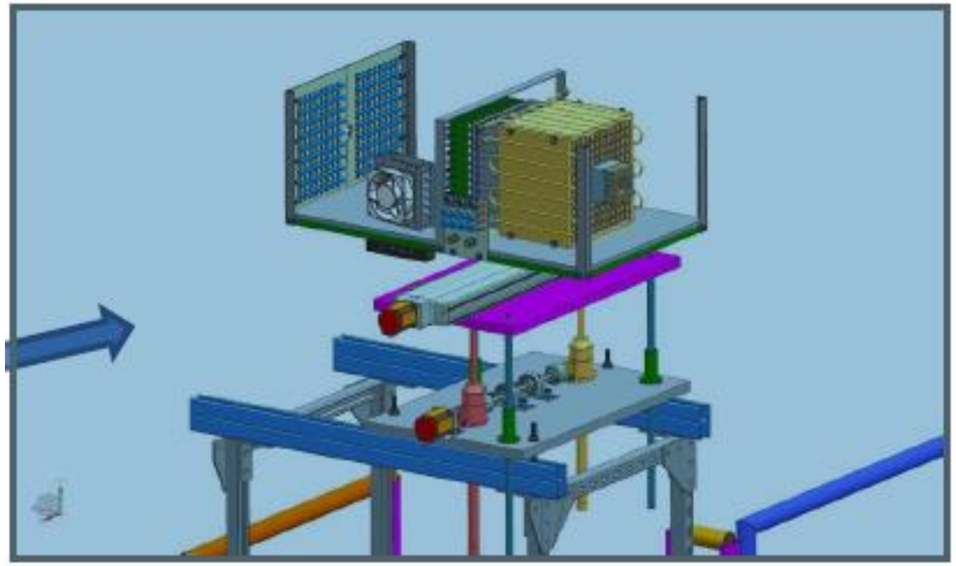
Shaping ESR reflective foil

RTD-5



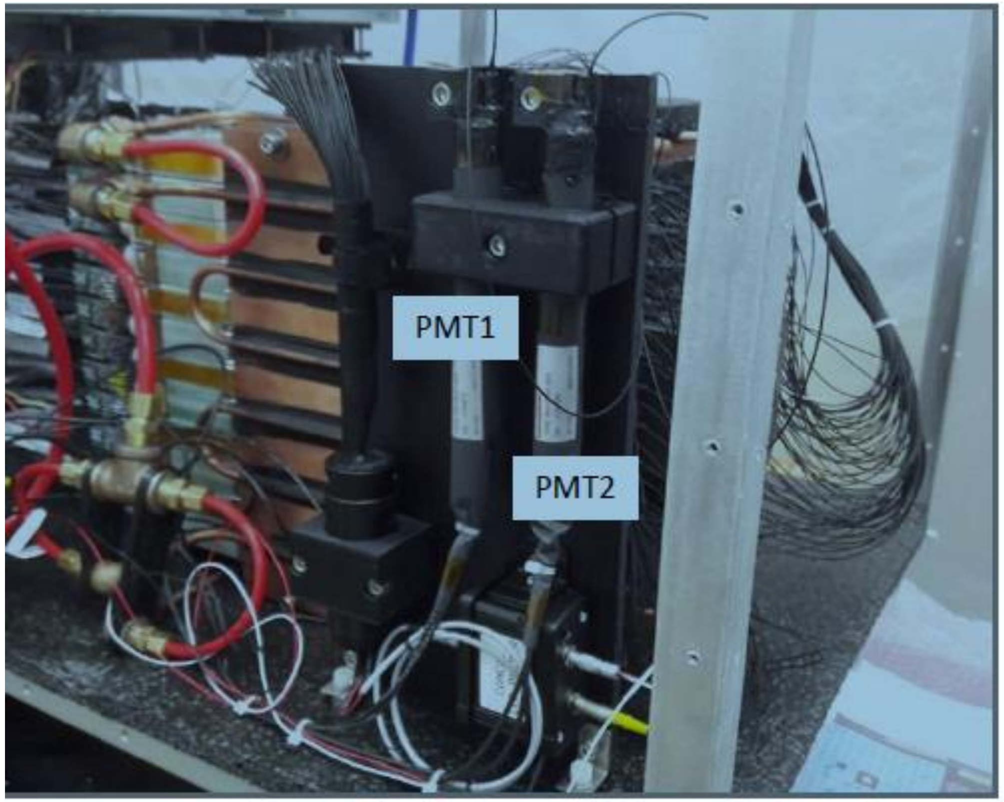
NPS prototype (Fabrication)



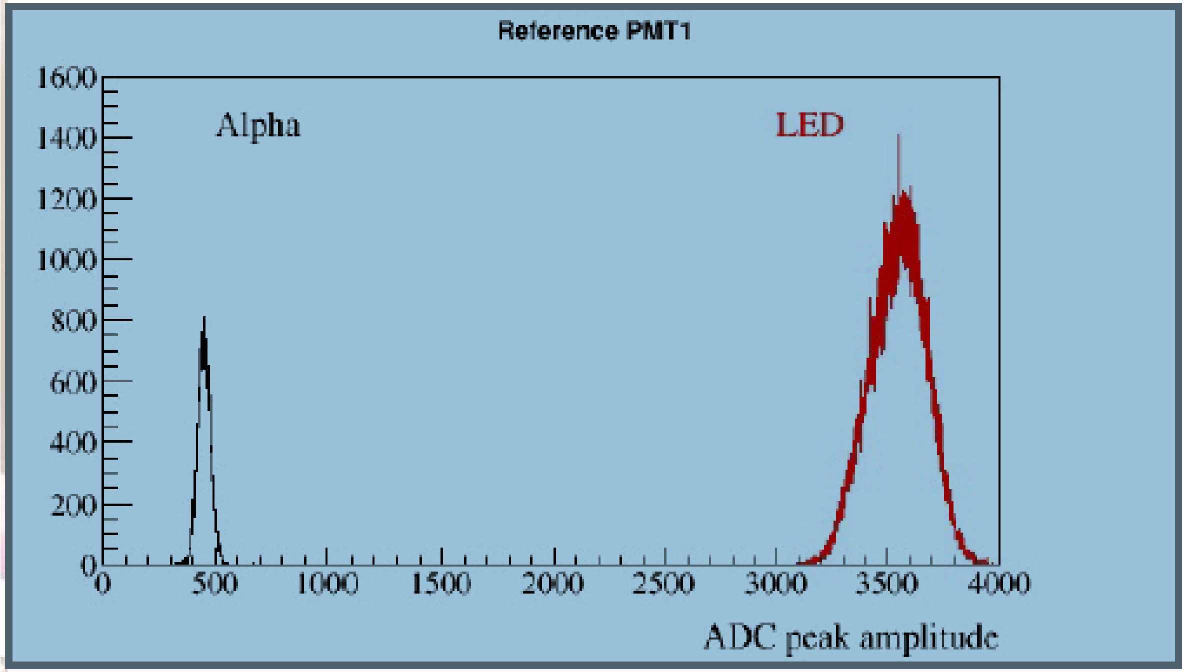


Calorimeter on the movable platform in Hall D

NPS prototype (Light Monitoring System)



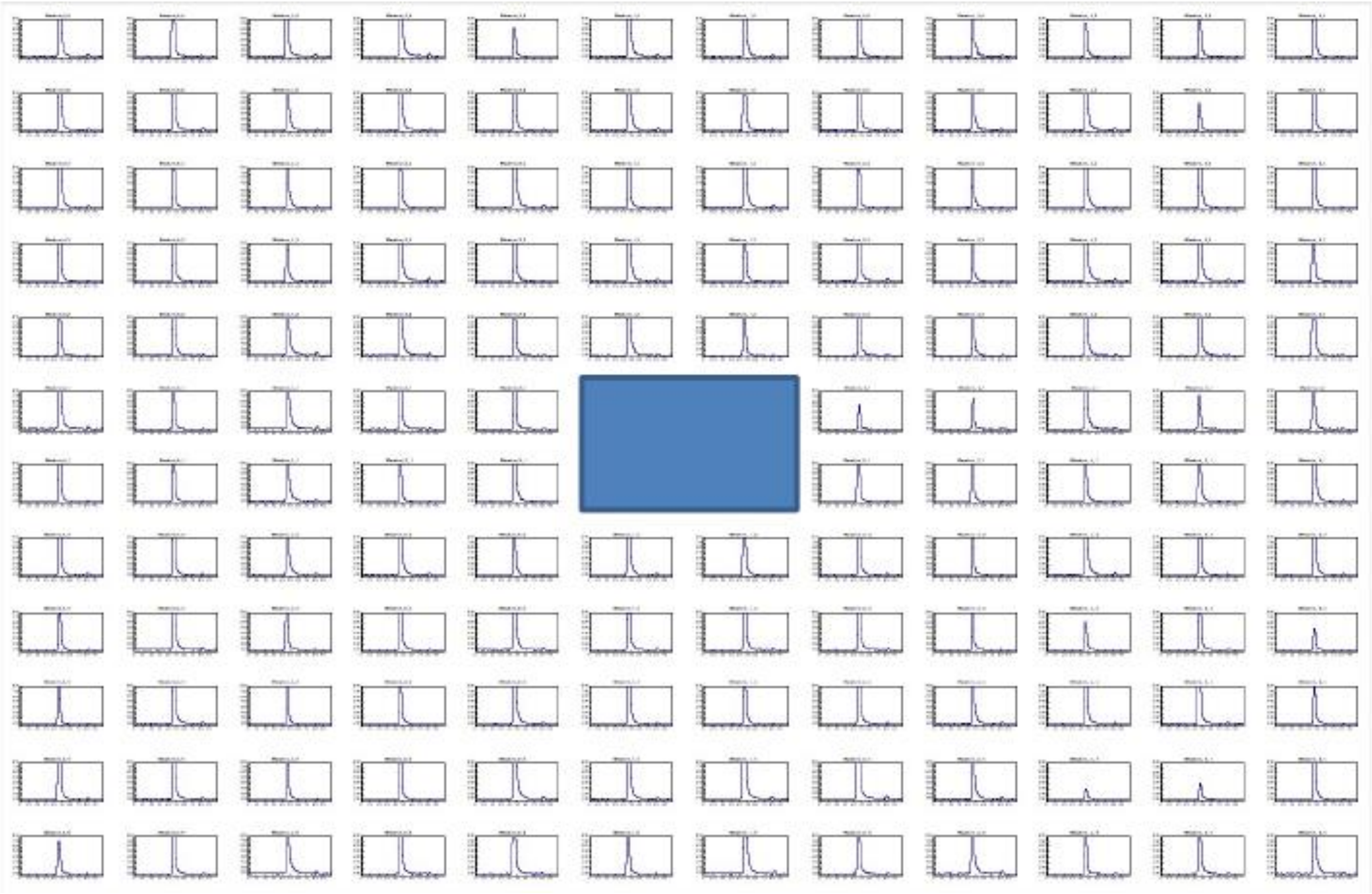
Reference PMT FADC amplitudes



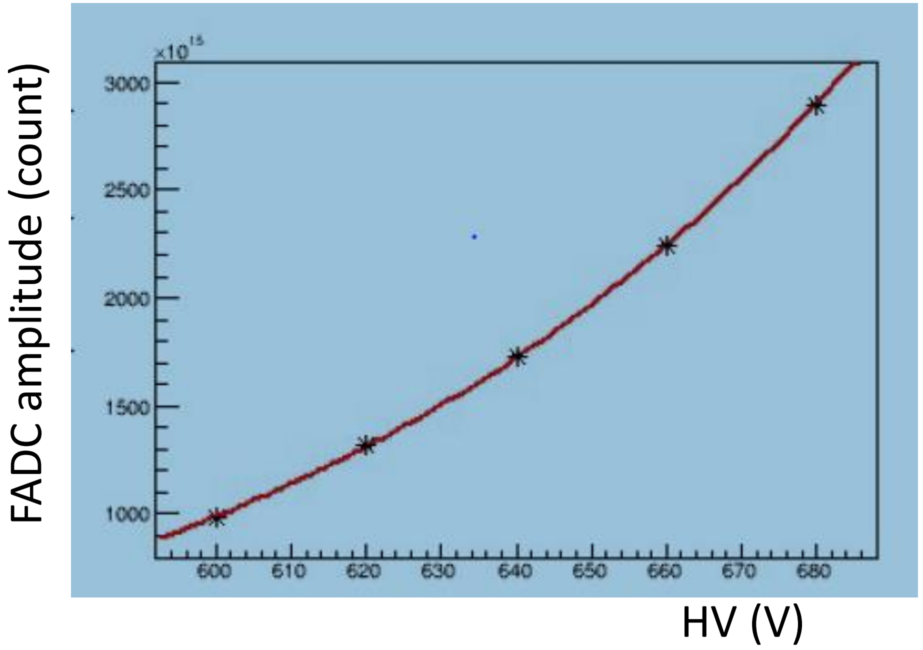
- Two reference PMTs are installed to monitor LED stability
- Each PMT receives light from the LED fiber and YAP:CE Am light source
- LED and Alpha-source triggers are used during data taking (special trigger types)

NPS prototype (Light Monitoring System)

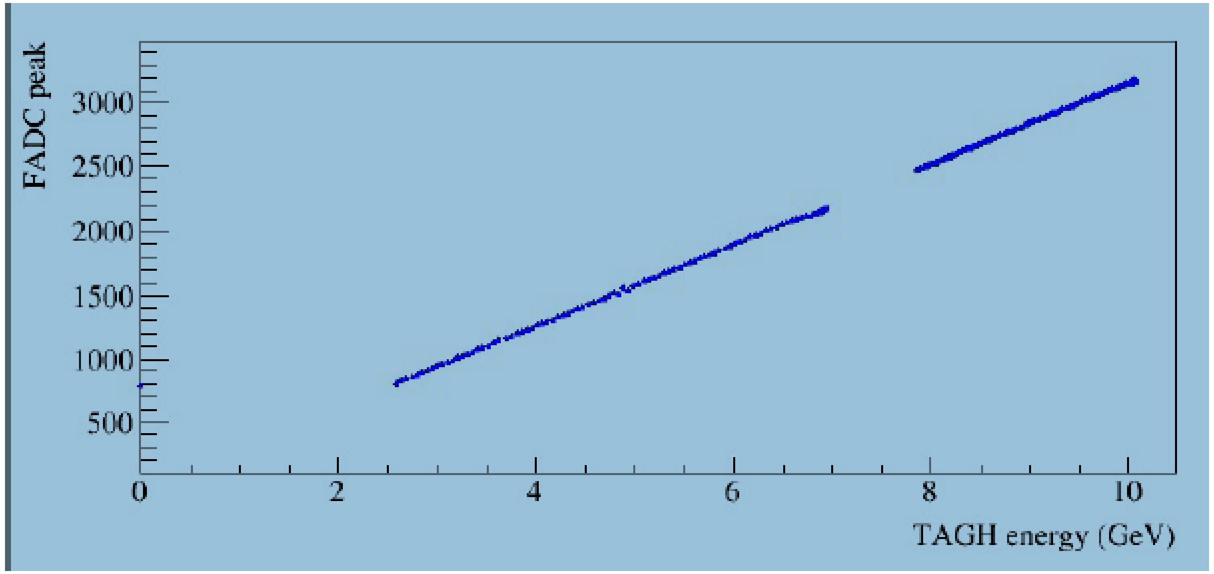
Light from an LED is distributed to the face of each crystal using optical fibers



NPS prototype (Calibration)

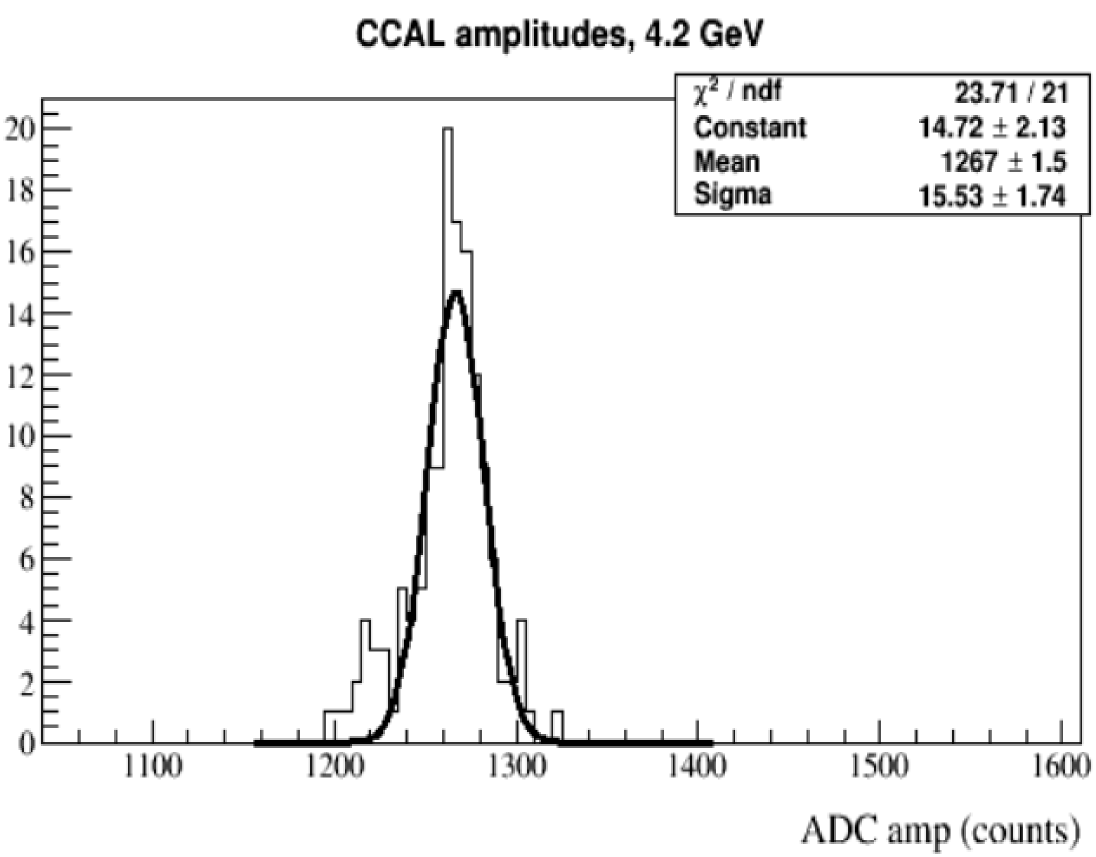


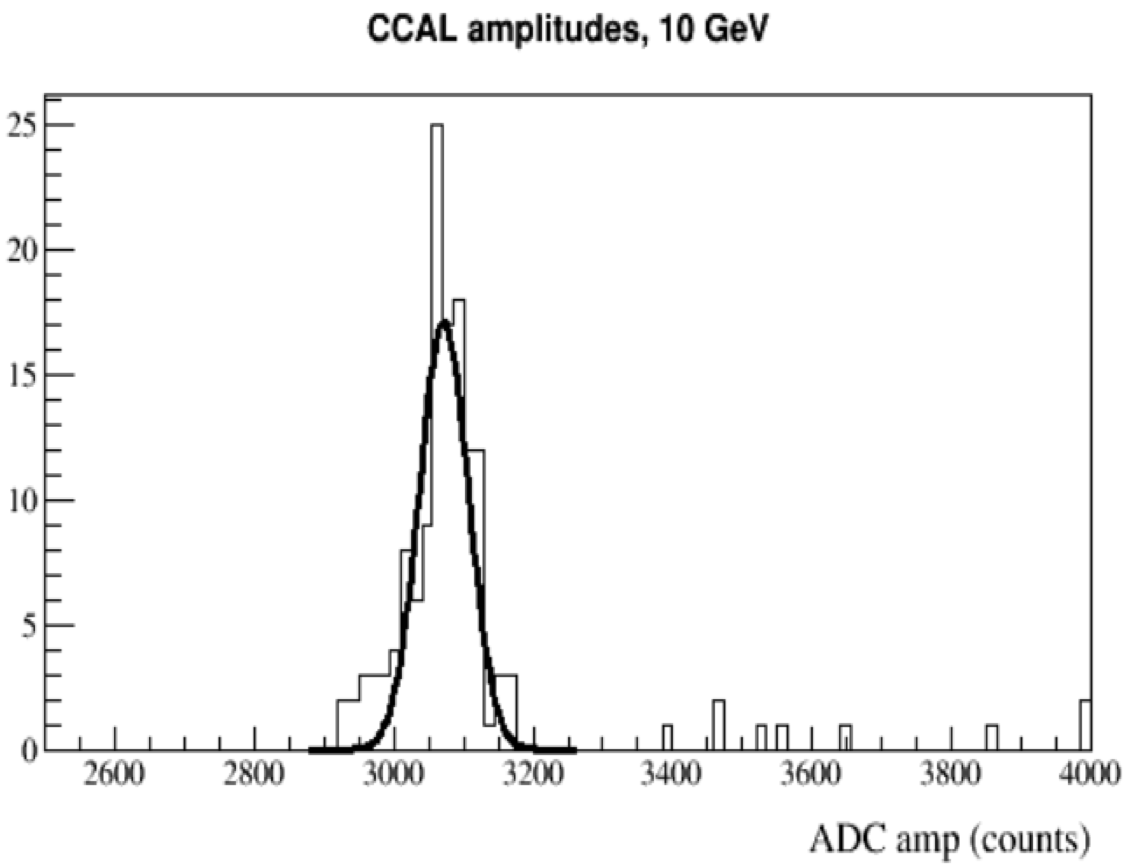
- Move each calorimeter cell to the beam
- HV scan for all channels (automatic procedure)
- Use beam energy provided by the Tagger hodoscope to equalize gains



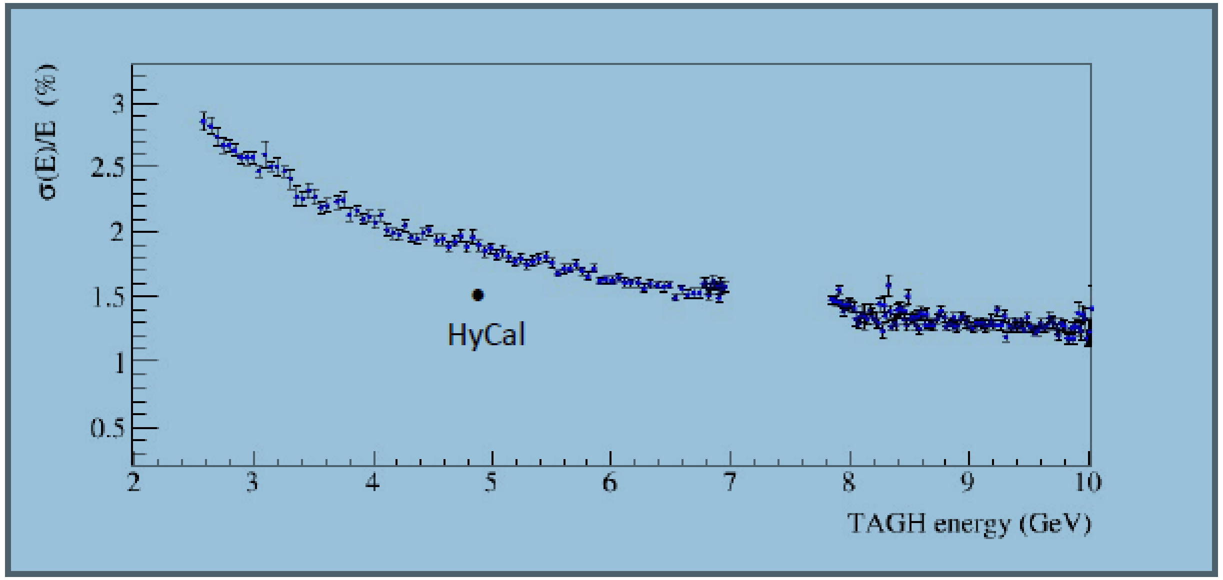
10 GeV – 3200 fadc channel

NPS prototype (Calibration)

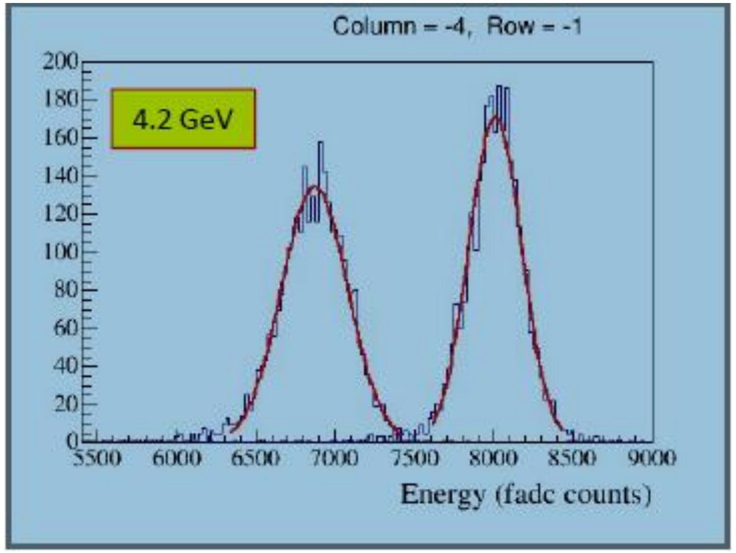


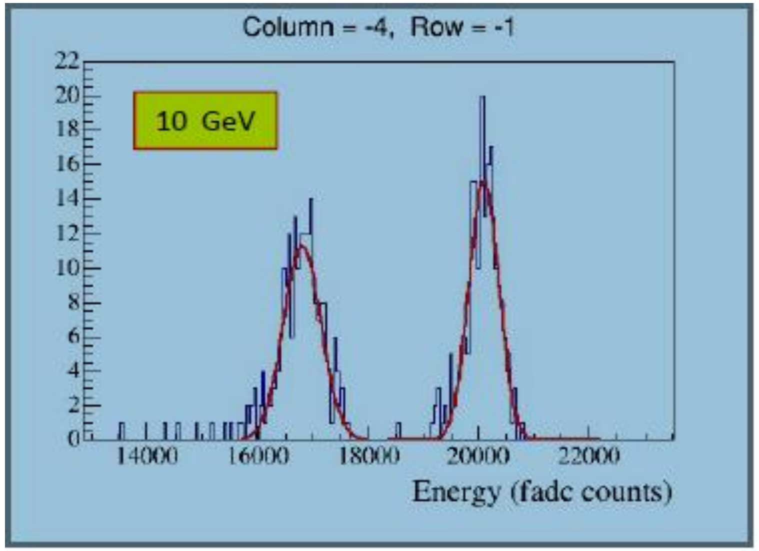


NPS prototype (Energy Resolution)



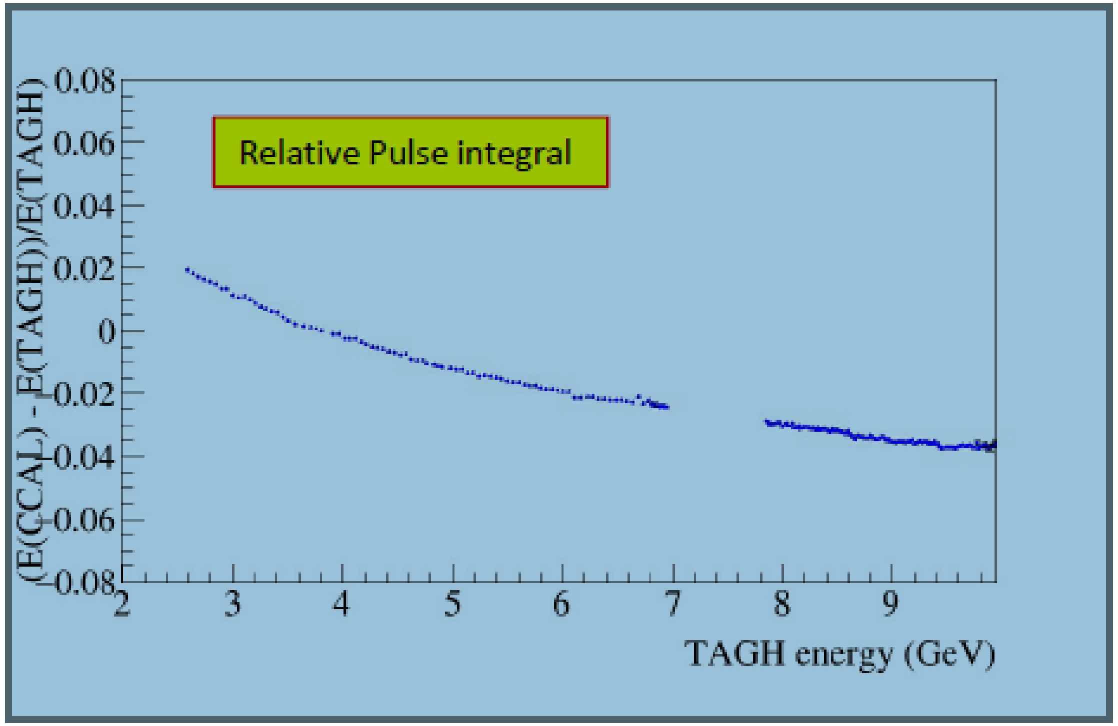
Slightly worse resolution than expected
- amplifier performance (?)
  (operating as small voltages,
   non linearities)





- Energy deposition in the central cell:
- 85 % of the total energy in the cluster (expect ~ 80%)

NPS prototype (Energy Resolution)



- Non linearity of the fadc peak amplitude between 2 GeV and 10 GeV ~2 %

(note, the energy scale of the tagger is slightly non-liner

Thank you for your attention!