THE CATHOLIC UNIVERSITY of AMERICA

Jefferson Lab

Crystals characterization

Vladimir V. Berdnikov
on behalf of the NPS collaboration

NPS Collaboration Meeting
Jefferson Lab; February 3 2020; Newport News; Virginia

Action items from 2019 NPS collaboration meeting

- **Specify expected number of crystals from each vendor and when will have them**
- Finalize layout with final number of CRYTUR and SICCAS crystals
- Quantify shower leakage – make photon energy spectrum for crystals next to the one hit
- Send 10 crystals to IPN for irradiation
- Characterize 400 crystal
- Further investigate glass scintillator option
- **Test divider with bypassed amplifier**

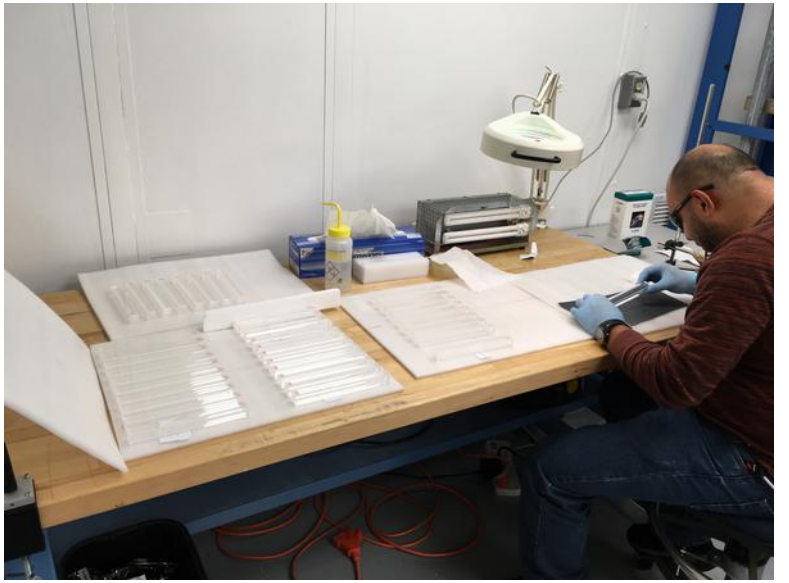
NPS requirements

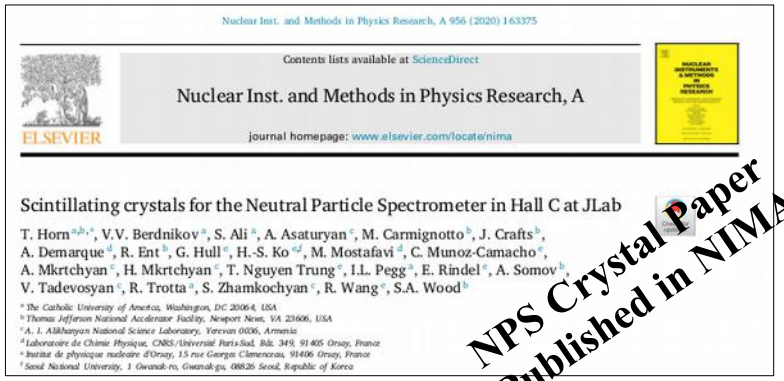
$PbWO_4$ crystal specification				
Parameter	**Unit**	**NPS Required**	**COMCAL/FCAL**	**PANDA specifications**
Light Yield at RT	phe/MeV	≥15	≥9.5	≥16
LY uniformity between the blocks (%)		<10 (<20)		
LY(100ns)/LY(1us)	%	>90	>90	>90
Longitudinal Transmission at				
λ = 360nm	%	≥35 (≥25)	≥10	≥35
λ = 420nm	%	≥60	≥55	≥60
λ = 620nm	%	≥70	≥65	≥70
Transverse Transmission and LY uniformity along the crystal	%	10		
Inhomogeneity of Transverse Transmission				
D λ at T=50%	nm≤	≤5	≤6	≤3
Induced irradiation absorption coefficient dk at λ =420nm and RT, for integral dose >10Gy	m-1	<1.1 (<1.5)	<1.5	≤1.1
Mean value of dk	m-1	≤0.75		≤0.75
Tolerance in Length	μm	≤±100	+0/, -100	≤±50
Tolerance in sides	μm	≤±50	+300, -0.	≤±50
Surface polished, roughness Ra	μm	≤0.02		
Tolerance in Rectangularity	degree	≤0.1		≤0.01
Mo contamination	ppm	<10		<1
La, Y, Nb, Lu contamination	ppm	<40ppm (≤100)		≤40

PbWO4 crystal properties and performance tests

- **Primary quality assurance of the crystals:**
  - Precise dimension measurements and visual inspections
  - Optical transmittance measurements
  - Light yield measured using a radioactive source Na-22 and 2in PMT inside of thermo-controlled darkbox

- **Crystal/glass beam test program in HallD:**
  - Installed the 3x3 prototype behind the PS (2018,2019,2020)
  - Installed 12x12 prototype/CCAL
  - Energy resolution measurement
  - Readout chain optimization
  - Glass-ceramic scintillator tests
  - Streaming readout
  - Crystal test stand 12 crystal measured at the same time (2020)
  - Studies of crystal defects, light guides, cookies and etc.





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Scintillating crystals for the Neutral Particle Spectrometer in Hall C at JLab

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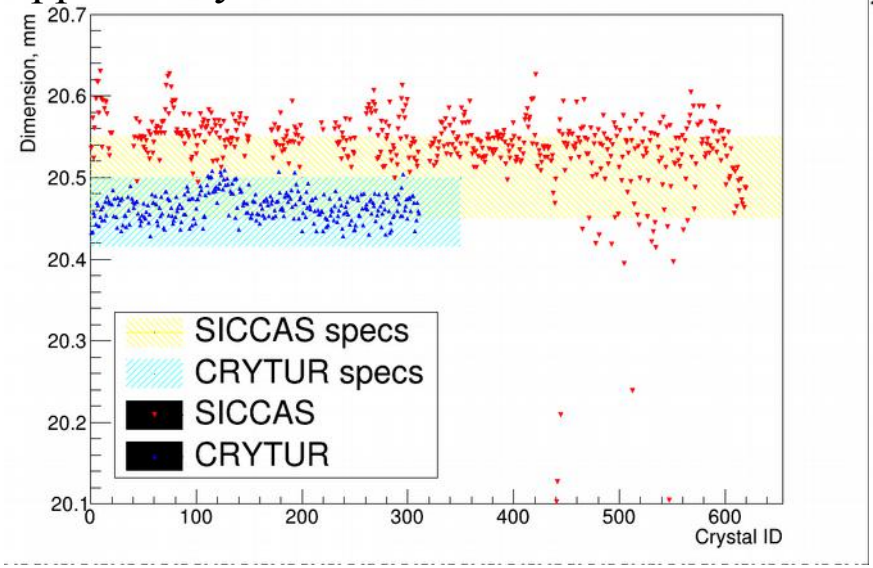
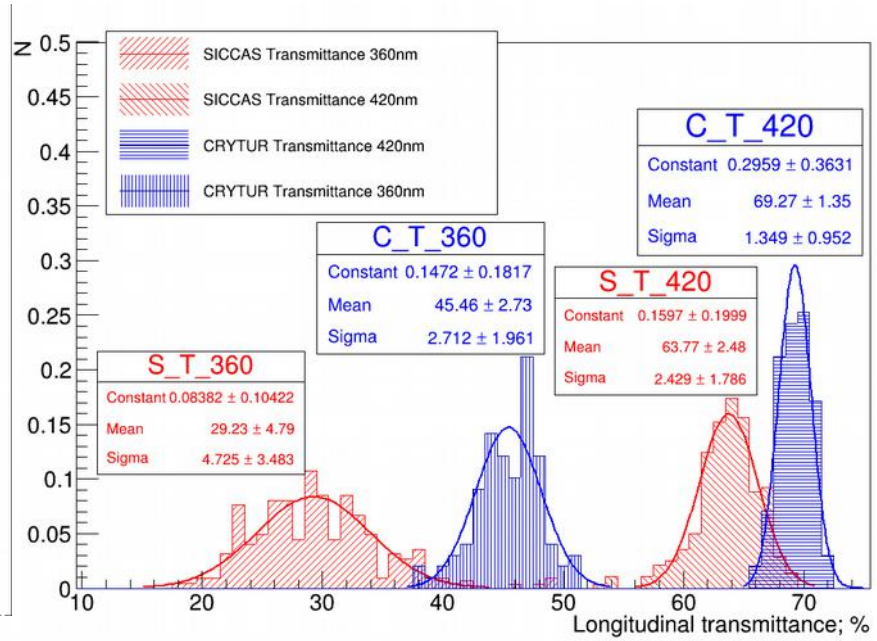
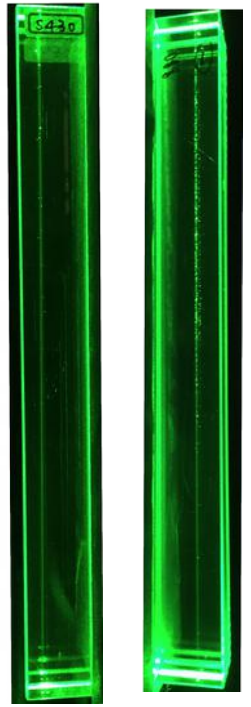
NPS Crystal Paper Published in NIMA 2020

SICCAS vs CRYTUR

Supported by NSF MRI PHY-1530874





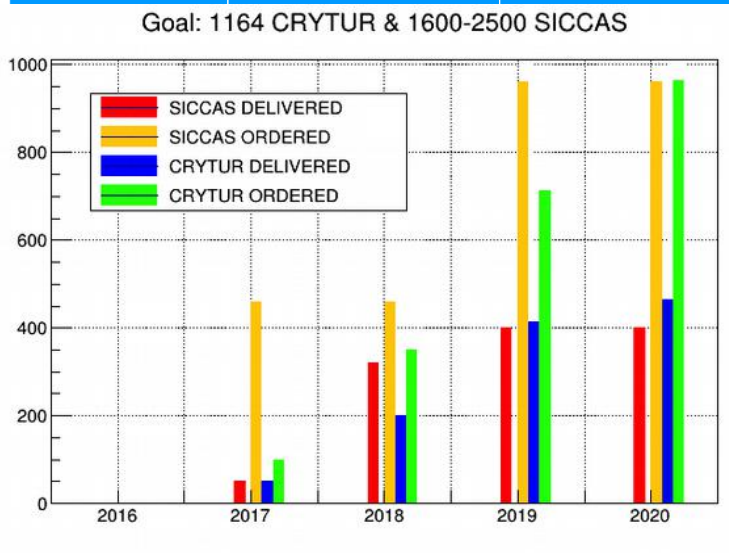


Only two $PbWO_4$ crystals vendors available worldwide

Vendor	Quantities	Growing method	Dimensions	Observed visual defects	Visual inspection with 5mW green laser	Rejection
CRYTUR (Czech)	850	Czochralski	20.46±0.01 20.46±0.01 200.00±0.01	(30% crystals) negligible • small chip(<1mm) • not deep scratches	• Some small dispersion doping in bulk much less than 25% of crystal volume	None
SICCAS (China)	460	Bridgeman	20.54±0.02 20.54±0.02 200.10±0.02	(70% crystals) • Long,deep scratches and cracks • Excessive number of small chips along edges • Large chips on corners • Pits, old Labels, chemical film	• Medium dispersion doping in bulk up to 50% of crystal volume • Excessive number of doping (>50% volume) in bulk • Chemical film on surface • Traces of old labels or markings on surface	~30%

SICCAS and CRYTUR crystals delivery/order status

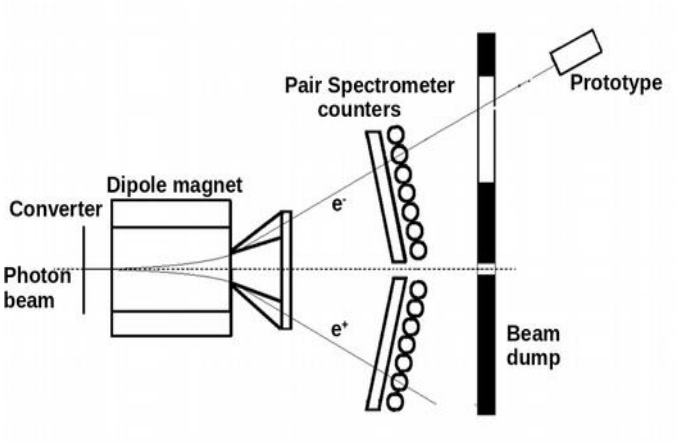
CRYTUR		
ordered	delivered	institution
100	100	Jlab HallC
150	150	Jlab HallC
55	55	CUA
45	45	Ohio
64	64	Jlab HallD
300	50	Jlab HallC
250	0	Jlab HallC

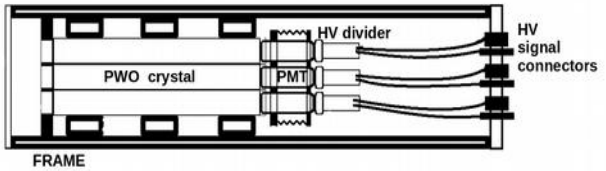


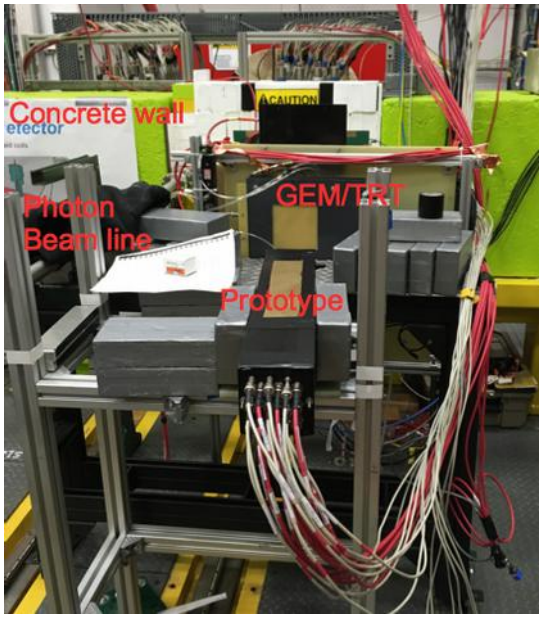
SICCAS		
ordered	delivered	status
460	all	Jlab HallC
	160	Rejected/returned
	140	12x12 prototype
	9	3x3 prototype
	5	Spare modules
	146	stored
160	all	Replacement HallC
	60	Rejected
	100	Accepted
500	none	Jlab
	60	Replacement HallC
	440	HallD

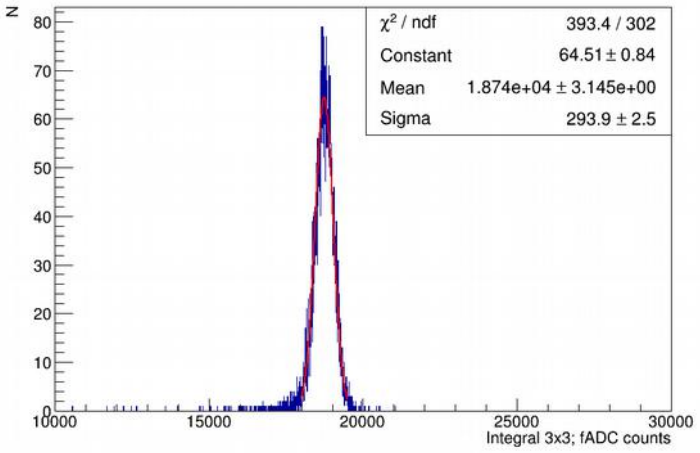
Beam tests with 3x3 prototype

- Installed a 3x3 prototype behind the PS with SICCAS and CRYTUR crystals
- Energy resolution at 4.7 GeV is about 1.5 %, bypassed bases
- Light yield of SICCAS crystals is about 6 % larger than CRYTUR

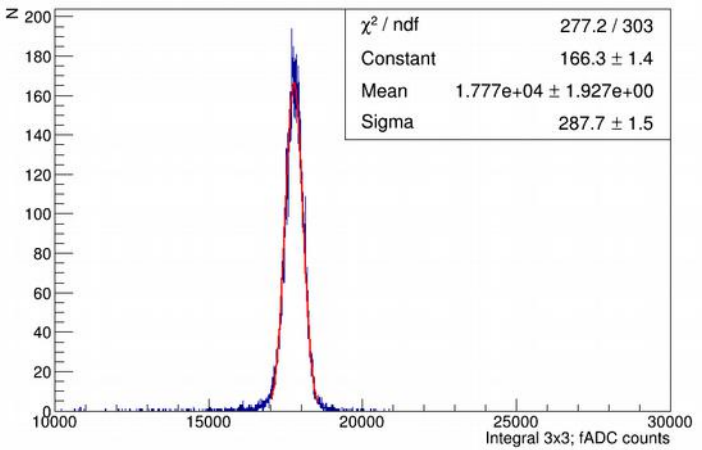








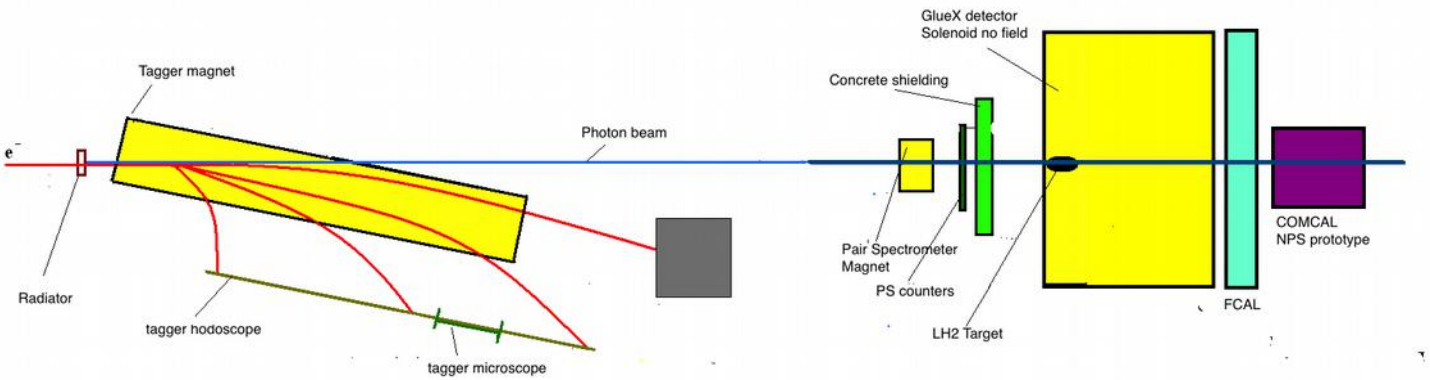
SICCAS



CRYTUR

Beam test program with 12x12 NPS prototype

12x12 prototype

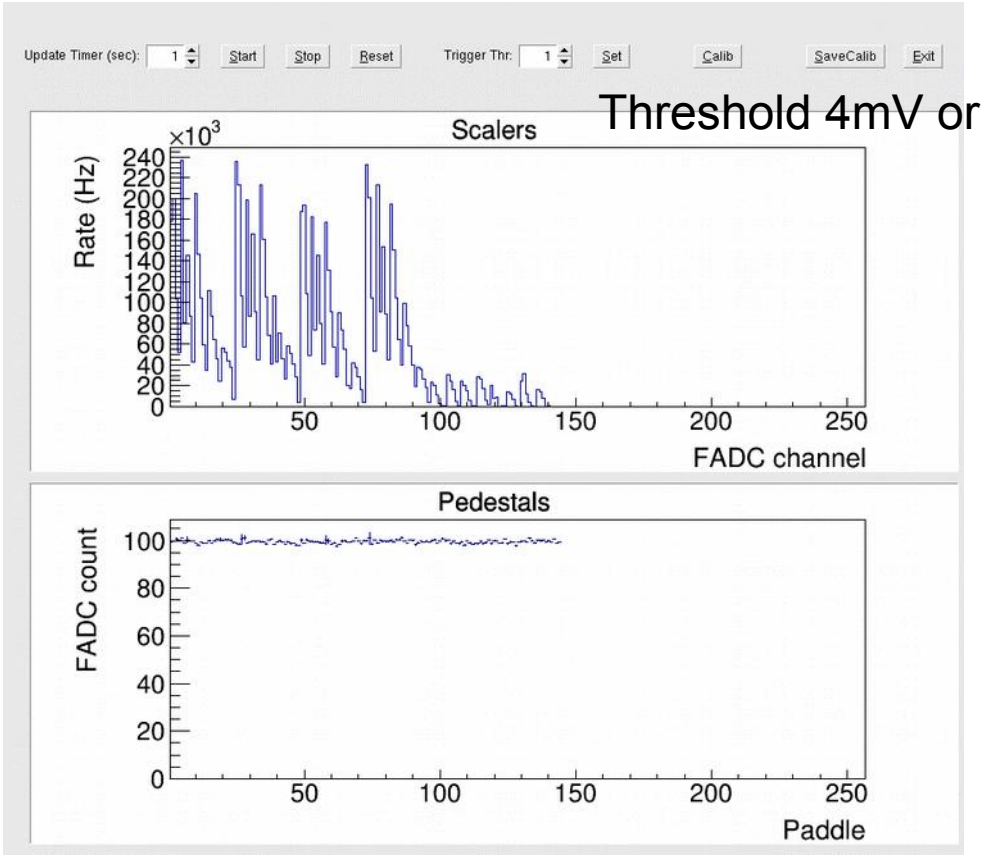


- Built a 12x12 detector for more detailed studies compared to quick checks with the 3x3 prototype
  - Allows for studies of energy resolution in wide energy range, stability, rate dependence, etc.
  - But, not as flexible as 3x3 since cannot run in parasitic mode and has to be installed in the beamline - requires scheduling, crane installation, alignment, slow controls, integration to data stream...

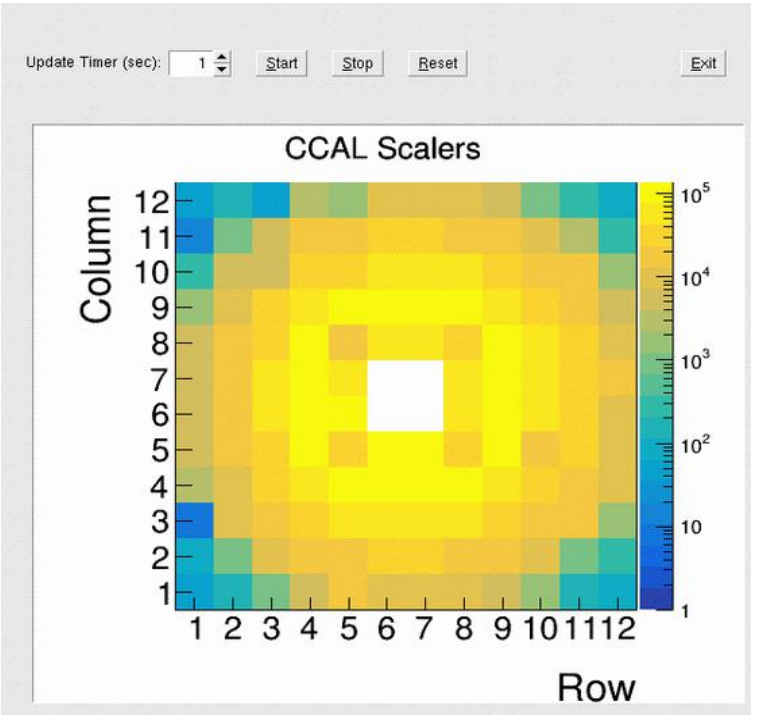
Detector design major components:

- 12x12 Matrix (140 crystals)
- NPS HV divider
- 250 fADC readout
- Environment control:
  - Temperature, humidity, light sensors
- Monitoring system consisting of LED and α-source
- Moving platform

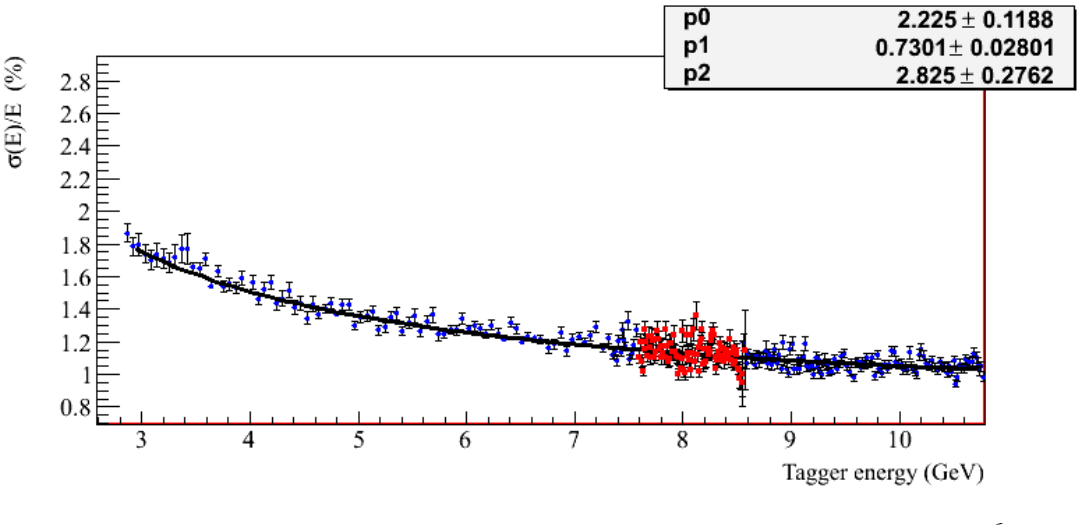
12x12 NPS prototype beam test results



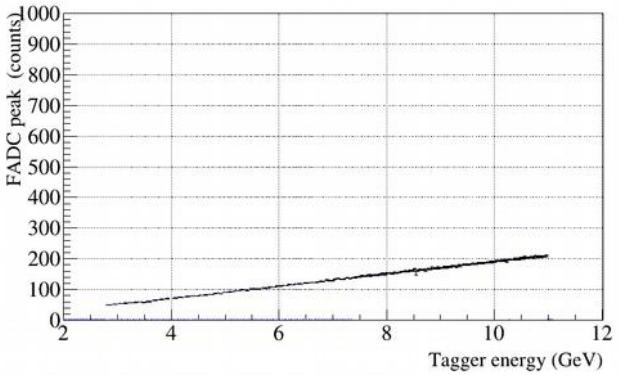
Threshold 4mV or 12MeV



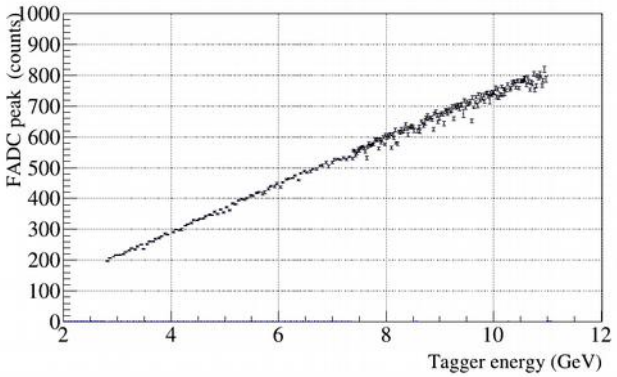
- Beam test program completed in 2019
  - Initial results show energy resolution: **~2.83%/E+2.23%/√E+0.73%**
  - Ongoing studies to improve linearity
  - Preparing publication on beam test results – to be submitted to NIMA in next few months

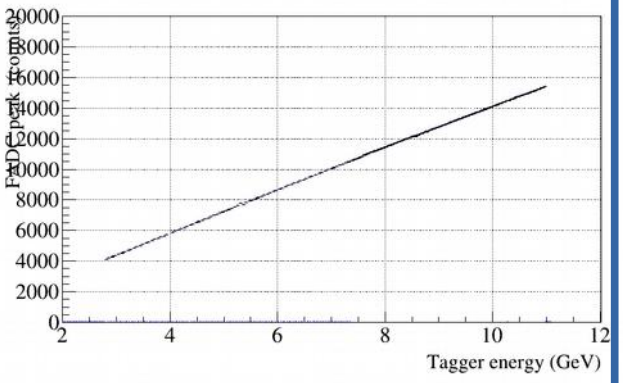


Shower leakage for 3x3 cluster

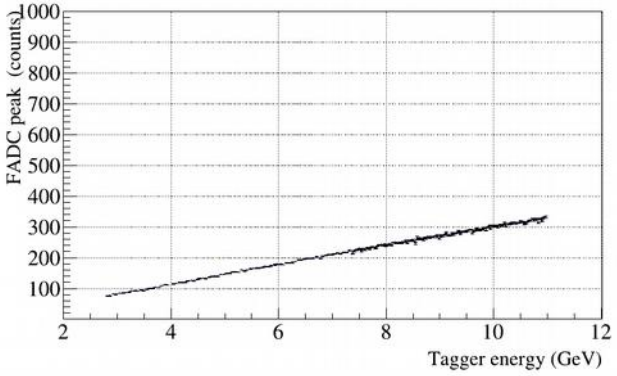


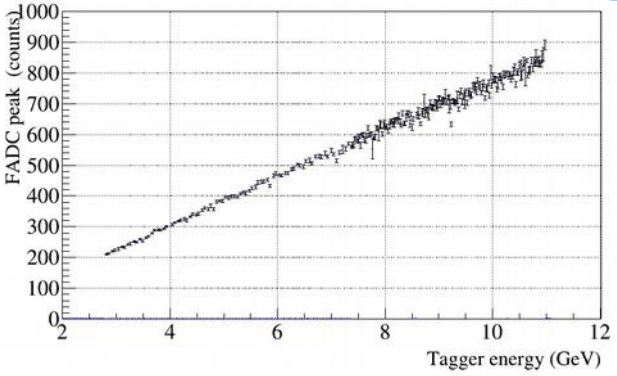
- 12x12 prototype beam tests spring 2019
- Detector inserted in the beam line
- Beam hit center module of 3x3 cluster (bypassed preamps)
- Gain adjusted by snake scan calibration
- Amplitude integral in ~100ns time window
- Plotted fit mean value in each energy beam

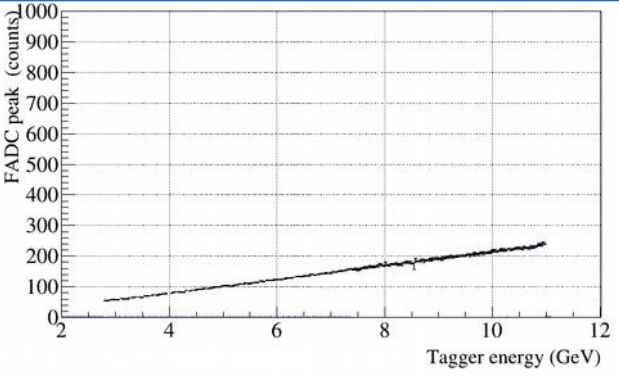




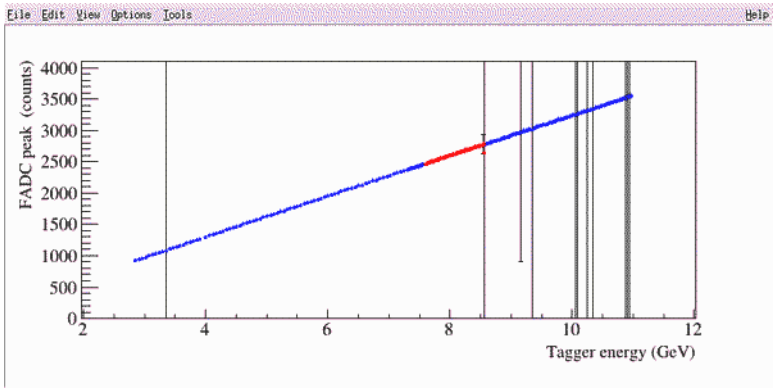
- For bypassed divider:
  - ~80% energy of shower in central cell
  - ~16% central cross
  - ~4% corners
- For original divider with gain x25
  - ~86% in central cell, low amplitudes suppressed



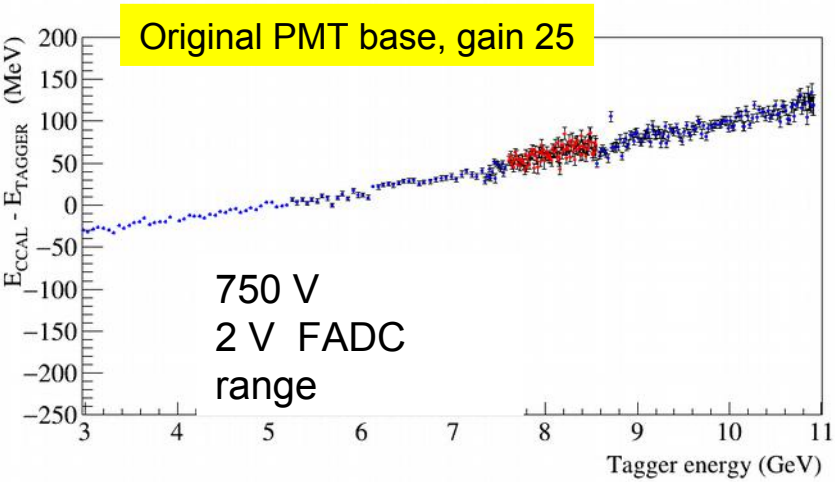


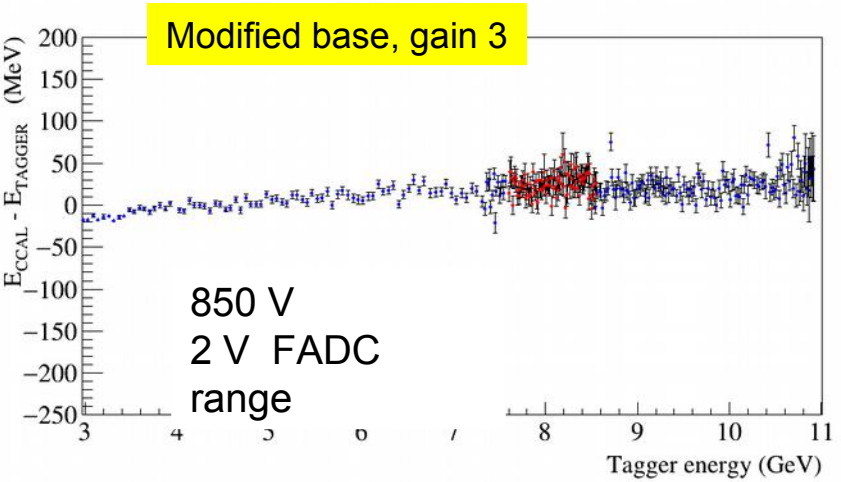


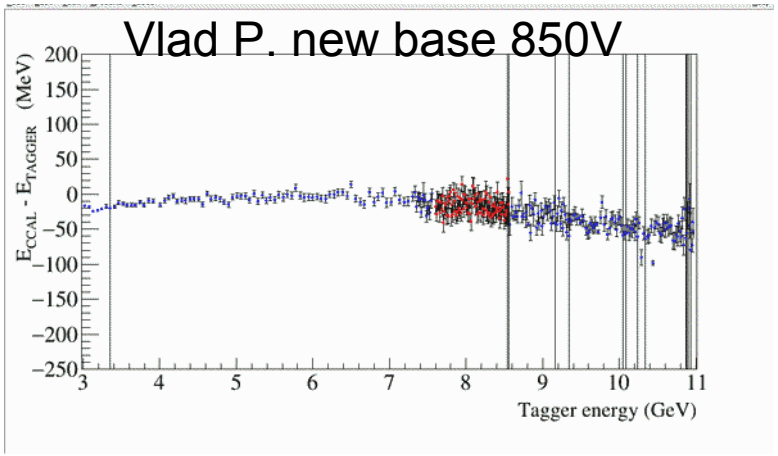
Non linearity studies



- Differential non-linearity curves for different HV setting and bases types with Tagger Hodoscope/Microscope







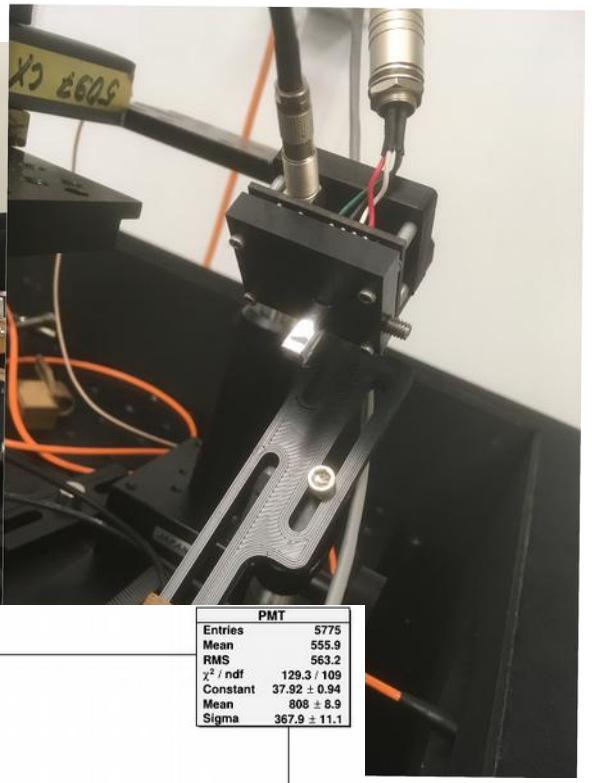
- The linearity can be improved by reducing the amplifier gain and increasing HV.
- Some tuning of the PMT base are required

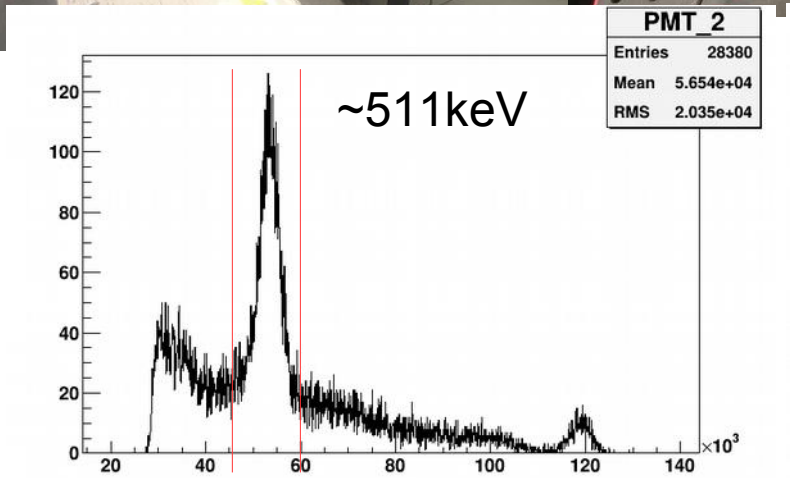
Non linearity studies summary

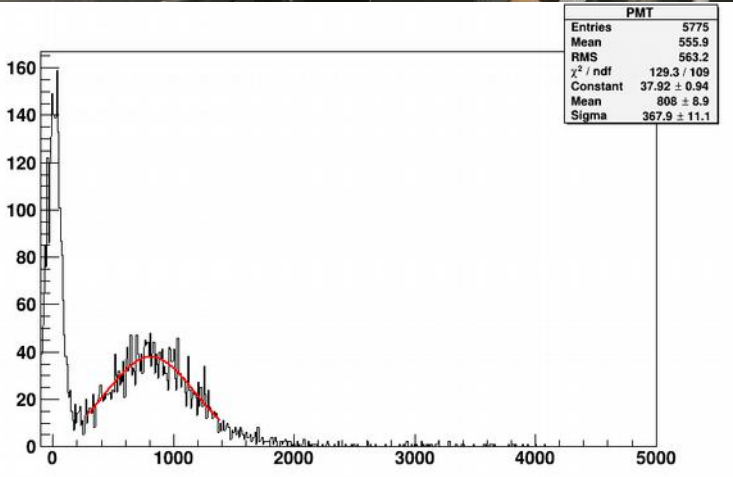
HV Base type	Gain coefficient	Applied voltage	Differential non linearity	Energy resolution	Amount of dividers
Original	25x	~700V	~(5-6)%	~(15-20)% reduction	1100 (Ohio) 140+ (Jlab)
Bypassed	1x	~1000V	~(1-2)%	1	9 (installed) 9 (3x3 prot) 12 (test stand)
Reduced_gain_v1	**6x**	~800V	~(2-3)%	-	1
Reduced_gain_v2	3x	~800V	~(2-3)%	-	1
Vlad_P_modified_1	~6x	~850V	~(1-2)%	-	1
Vlad_P_modified_2	~6x	~850V	~(1-2)%	-	1
Vlad_P_modified_3	~6x	~850V	~(1-2)%	-	1

New measurement setups: Light Yield in NPS cleanroom

- New setup with SiPM+LYSO trigger arm, Na-22 source, fast 2in PMT Hamamatsu
- Good for quick QA of Crytur crystals, no need to move offsite
- Temperature not controlled
- Useful for R&D projects (glass ceramic studies, SiPM calorimeter readout and etc.)

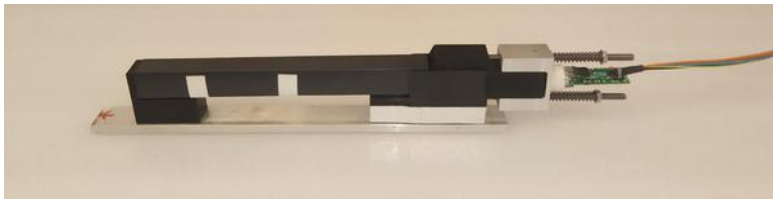


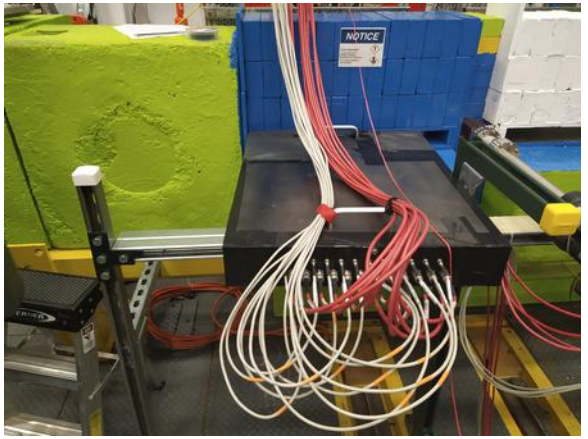




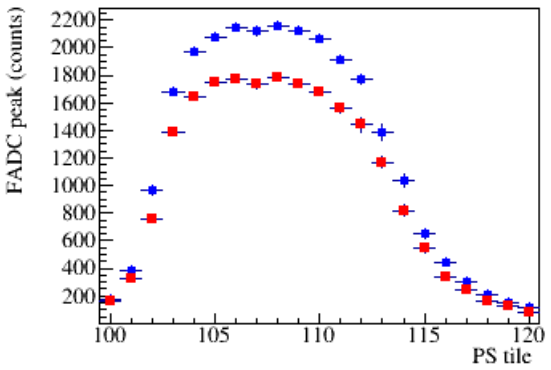
New measurement setups: Crystal test stand behind PS in HallD

- Installed 12x1 crystal test stand
- Quick tests of questionable crystals
- Readout optimization tests
- Different kinematic points
- Tests of light guides, cookies, crystal wrapping methods
- Different scintillation materials test (PWO, glass and etc.)

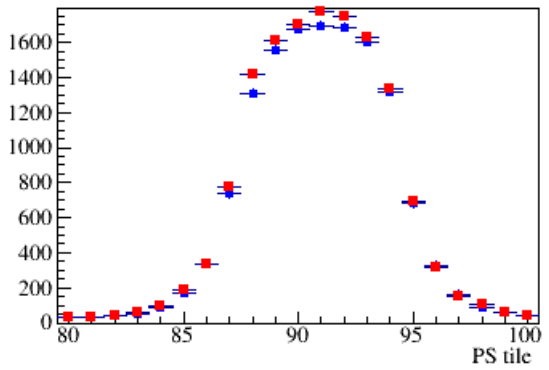




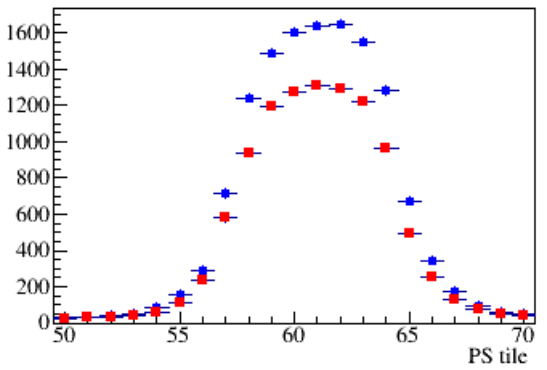
Module 3 (with LG)



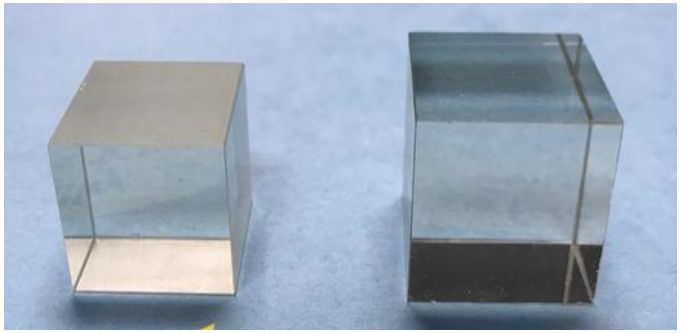
Module 5 (no LG)



Module 9 (with LG)



Prospects with glass scintillators

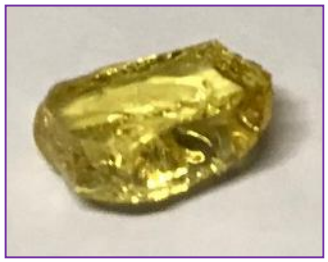


STTR Phase 1 was awarded!

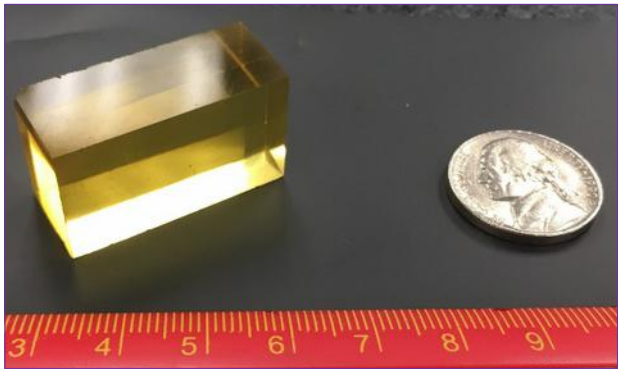
SCINTILEX

Example: SC1 glass

1cm x 1cm x 0.5cm (test size)



2cm x 2cm x 4cm (medium size)



2cm x 2cm x 20cm (large size)

* Unpolished, Bubbles on surface only – will be removed during cutting and polishing

1cm x 1cm x 0.5cm
2019

Up to 4cm x 4cm x 40cm
2023

Summary

- Continue working with PWO crystals vendors:
  - Continue receiving crystals from CRYTUR (up to 30-40 crystals/month) – no rejection so far
  - Working with collaborators from HallD and China trying to optimize QA procedures at SICCAS site, preselection before shipping at the lab
- 714 CRYTUR and 300 SICCAS crystals expected to be ready for assembly in fall 2020
- Preparing to send 10 CRYTUR crystals to IPN-Orsay for irradiation check
- Based on nonlinearity studies detector became more linear when amplifier gain is reduced and voltage increased, run conditions (anode current) need additional studies before making final choose of the preamp gain
- Glass scintillator development ongoing - progress promising, SBIR/STTR awarded