PMT Candidates for SSD

Challenge for PMTs in air-shower detection
highest linear dynamic range

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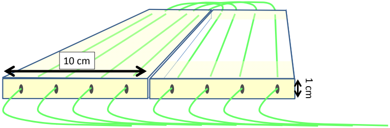
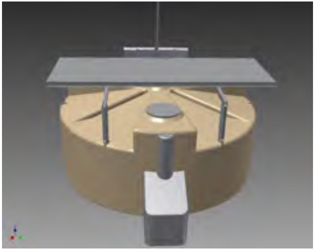
bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

Auger Prime SSD

- Scintillation detector on top of surface detector
- Goal: More precise composition analysis by measuring em-component
- $2 \times 2\,\mathrm{m}^2$ plastic scintillator
- Read out with WLS fibers (Kuraray Y11 / SaintGobaint BCF-91A)
- 48 fiber 'cookie' to photon detector





Photon Detector Requirements

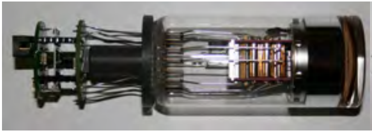
- Photon detector for scintillating fiber
- Main request: high linearity
- Up to 20.000 MIPS?
- MIP signal of about 12PE expected
- Timescale of pulses O(100ns)
- Low power consumption (CAEN HV module $2100\mathrm{V}$, $110\mu\mathrm{A}$)

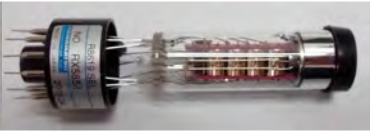
Range	Intent	Dynamic range																			
bits		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
LowGain	MIP	AnodeX32																			
HighGain	Showers								Anode/4												
Ipeak (mA)		0.0006				0.01			0.1				1.25			10				160	
Vpeak (mV)		0.03				0.5			4				62.5			500				8000	
Npart (MIP)		0.07				1.2			10				156			1250				20000	

Photomultiplier Candidates

	Ham. R9420(-100)	Ham. R8619
Size	1.5"	1"
Photocathode	(super-)bialkali	bialkali
min. Effective Area [mm]	∅34	∅22
Dynode Structure/Stages	lin. focused/ 8	lin. focused/ 10
Gain	3.7×10^5	2.6×10^6
Supply Voltage [V] typ.	1300	1000
max.	1500	1500
Dark Current [nA] typ.	10	2
max.	100	15
Cathode Sens. [mA/W]	110	90?
Q.E.$_{\text{at peak wavelength}}$	27% (35%)	27%?
Rise Time [ns]	1.6	2.5

Photomultiplier Candidates



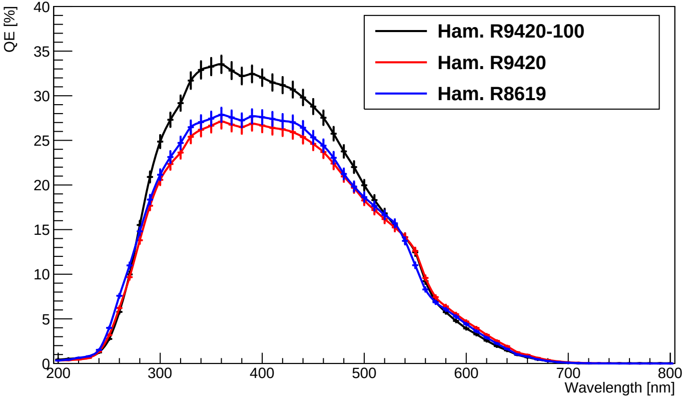


Combining best of both PMTs: R11920-100

- Developed by CTA/Hamamatsu
- Dynode structure of R8619
- R9420-100 tube, super-bialkali
- Low afterpulsing

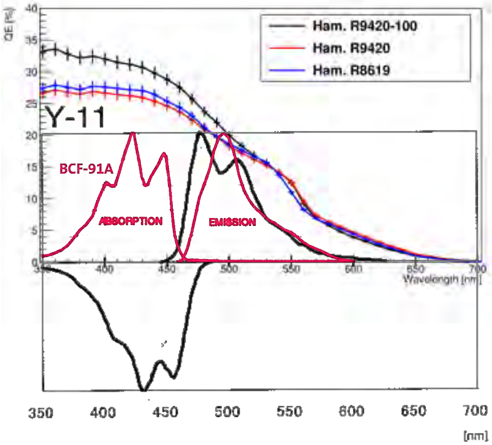
For SSD: Too complicated to mount cookie

QE Measurement



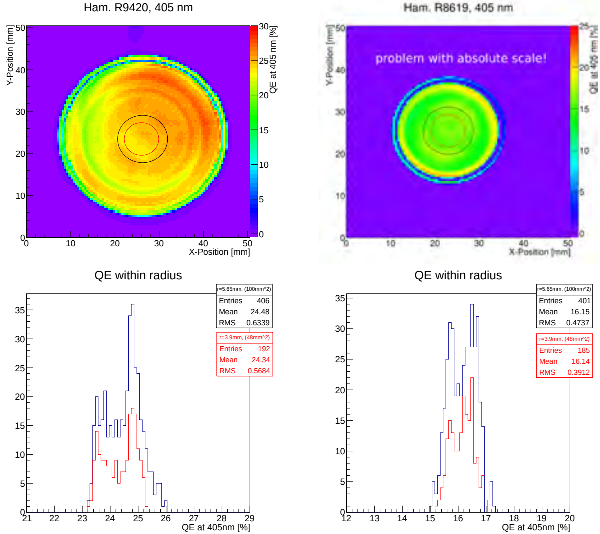
- Measurement in reference to a calibrated photodiode
- Super-bialkali benefit insignificant $> 500\,\text{nm}$

QE Measurement



- Emission spectrum for two different WLS fibers $> 500\,\text{nm}$
- Lower wavelength ($< 500\,\text{nm}$) of Kuraray Y-11 favorable for PMTs

Uniformity R9420 - R8619

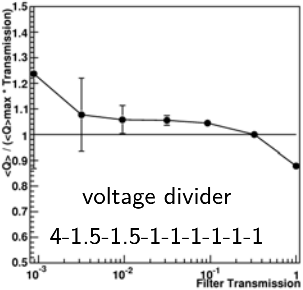


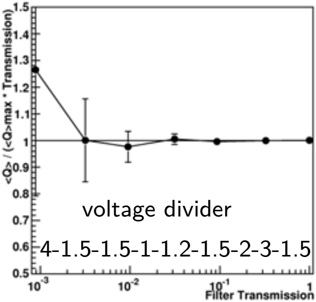
black circle r=5.65mm radius (ca. 100mm^2), red r=3.9mm (ca. 48 mm^2)

Linearity R9420-100

Linear relation between charge and light

- Important for energy estimation
- Depends on voltage divider
- Measured with calibrated attenuation filters
  - Resistor ratio optimized





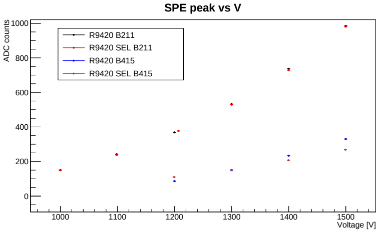
Linearity R9420

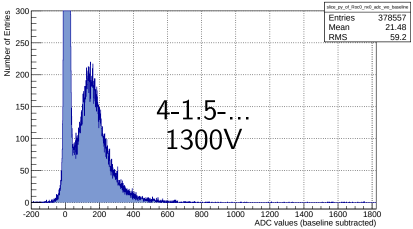
For SSD test setup:

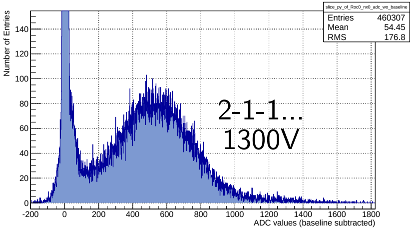
- Extend linearity measurement to $O(10^5)$
- Linearity measured with different attenuation filters
- Calibration by single photon peak
- Test new dividers
  - FD base, active
  - Hamamatsu/Torino Base w/ low power consumption, passive
- Compare PMTs selected for high linearity to standard batch
- Setup for constant light and pulses
- 3 Setups (2 @ BUW, 1 @ Lecce):
  - Auger FD test-setup, variable pulse length $>$100ns
  - CBM SPE setup with $<$100ps laser-pulses
  - 2-LED setup, similar to Hamamatsu, only deviation for x2

SPE Measurement

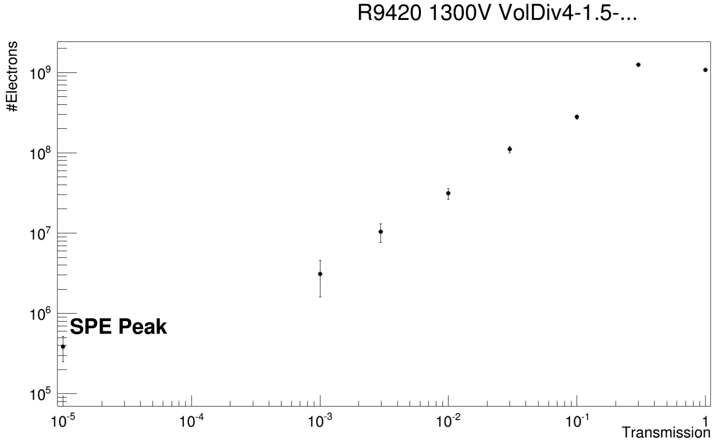
- SPE measurement with n-XYTER
- light attenuated for small fraction of single photon hits
- 211-base has higher/steeper gain than FD base





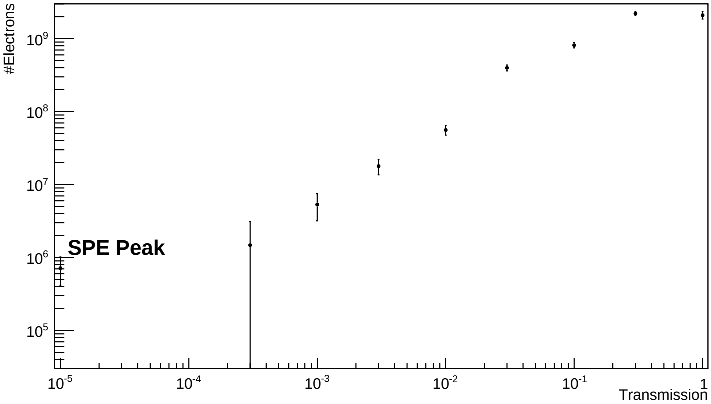


Linearity Tests, R9420 - 4-1.5...



- Combination of different attenuation filters
- SPE position 'arbitrary'
- SPE gives gain
- Saturation visible?

Linearity Tests, R9420 - 2-1-1...



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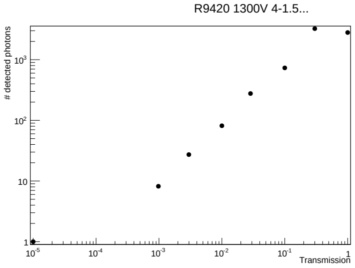
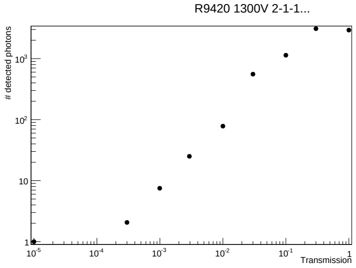
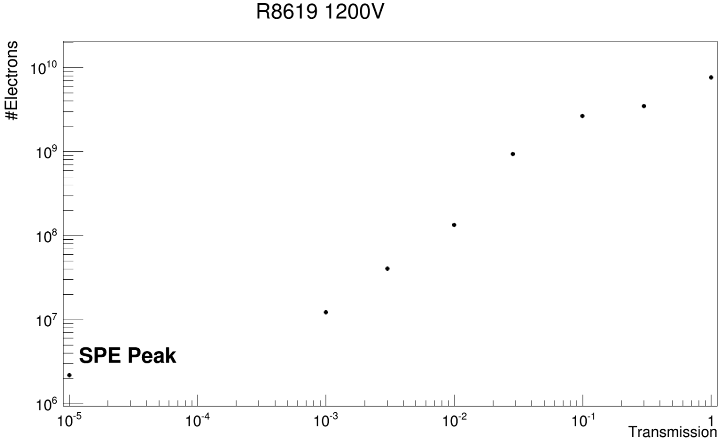
Linearity tests, R9420





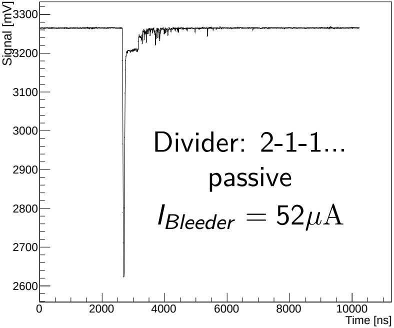
- First rough calculation
- Despite different gain, 'saturation' at same level
- No favorable base identified yet
- Further investigation on HV/Gain dependence
- Improve/automate test setup

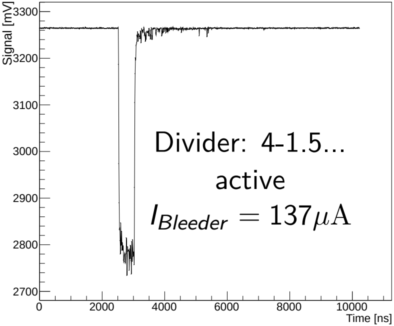
Linearity tests, R8619 - 3-1



- First test of R8619
- Even higher gain (10-stages)

Pulse Stability

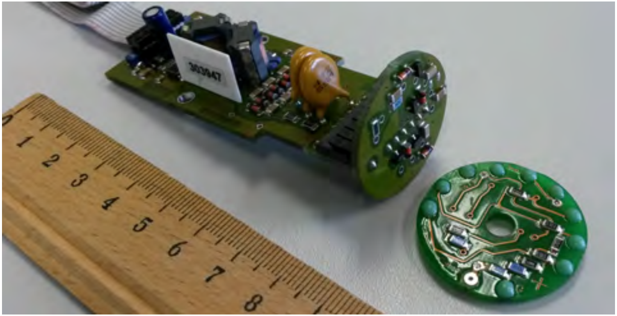




- Too small bleeder current for passive base
- Additional supporting capacitor at 4th and 5th dynode?
- Active base still capable but needs to be modified to match $I < 100\mu A$
- Afterpulsing for R9420 visible

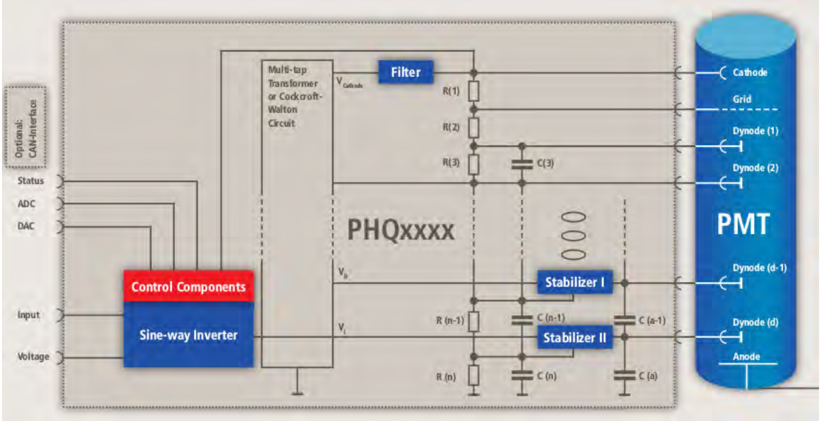
Integrated Base by ISEG

- Similar 8-stage PMT XPS 2960
- Used by H.E.S.S. for years
- Low power consumption
- Cost attractive (<60€)



Integrated Base by ISEG

- stabilized by direct conection to stages of the Cockcraft-Walton



Integrated Base by ISEG

Technical Data:

Cathode voltage V_{OUT}		0 to 1600 V		
Stability ΔV_{OUT}		$<1 * 10^{-4}$		
Temperature coefficient		$<5 * 10^{-5}$		
Ripple and noise		$<10\ mV_{P-P}$		
Power Dissipation P_V		400 mW)[1] at V_{OUT}=1600 V		
Power requirements		+12 V	(< 25 mA)	
		-5 V	(< 25 mA)	
Analog control Input voltage V_{SET}		0 ... 4 V	($V_{OUT} \Rightarrow$ 0 to 1600 V)	
Analog control	V_{MON}	0 ... 4 V	$V_{OUT} \Rightarrow$ 0 to 1600 V	Ri = 10 kΩ
Output voltages	I_{MON}	0 ... 5 V	$I_V = I_{Voltage\ Divider} + I_{PMT} \Rightarrow$ 0 to 200 µA	Ri ~ 150 kΩ
Digital remote control	HV-off-1	Input 1	TTL-Level: Low = HV-off	
	HV-off-2	Input 2	High or nc = HV-on)[2]	
	HVstat	Output	TTL-Level: High = V_{OUT} according V_{SET}	
			Low = regulation error	
Protection		Current limit)[3]		
		Voltage limit)[4]		
		Monitoring Power requirements		

)[1]: I_{PMT} is generated at V_{OUT} with a efficiency at ~ 75%. The Total Power Dissipation can increased by 20 to 50 mW according to I_{PMT}.

)[2]: Attention! If you shut on V_{OUT} with this signals, the rate of change of V_{OUT} is ~ 5 V/ms.

)[3]: Integral Output current is limited at 200µA

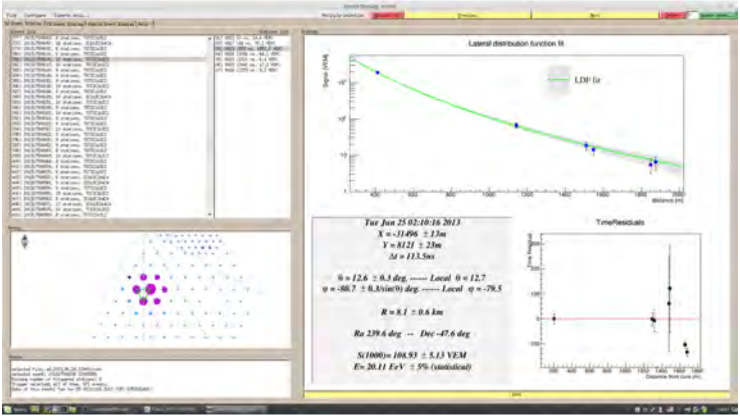
)[4]: $V_{OUT\ max}$ = 1700 V ; independent limit

Summary & Outlook

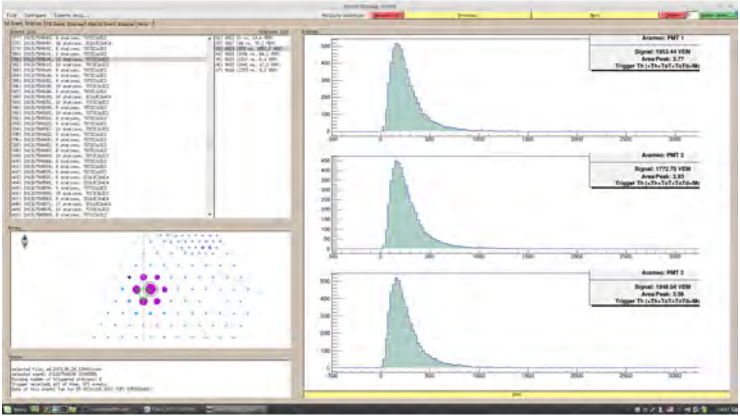
- Hamamatsu PMTs R9420 and R8619
- R9420 slightly less homogeneous
- Active base with tapered divider build for R8619 & R9420
- Tapered divider suitable for single photon/MIP signal
- Pulses $<$100ps linear up to 3k PE
  - Test setup to be improved and automated
- Pulse-length longer than 100 ns $\rightarrow$ active base
- Base with integrated HV (optimized stability) by ISEG as used e.g. by H.E.S.S. an attractive option!

BackUp Slides

Pulselength close to axis?

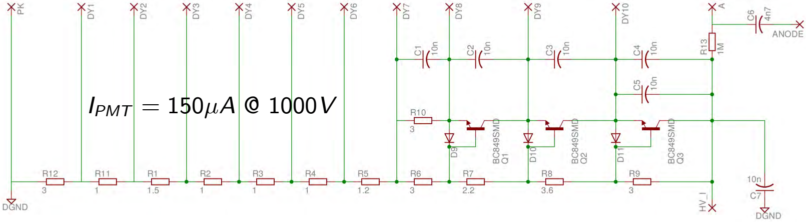


Pulselength close to axis?



Linearity R8619

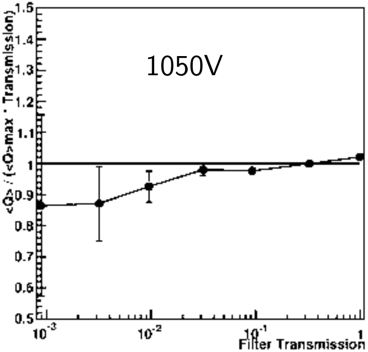
- tapered voltage divider for improved linearity
- low power consumption → active base

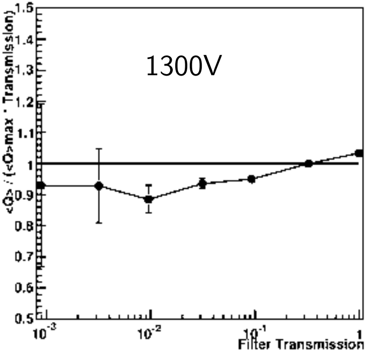


$I_{PMT} = 150\mu A$ @ $1000\,V$

Linearity R8619

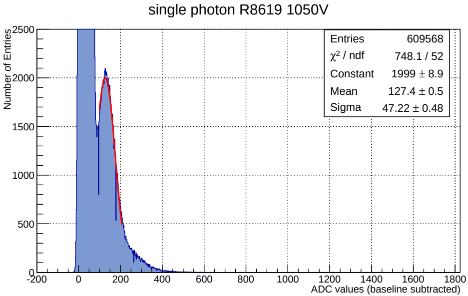
- tapered voltage divider for improved linearity
- low power consumption $\rightarrow$ active base

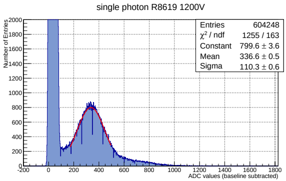


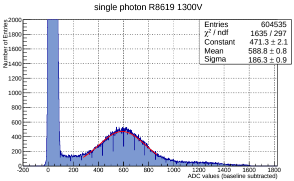


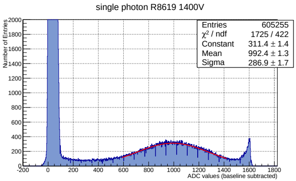
Single Photon Pulse R8619

- single photon spectra for different voltages
- tapered, active voltage divider
- pile-up at 1400V



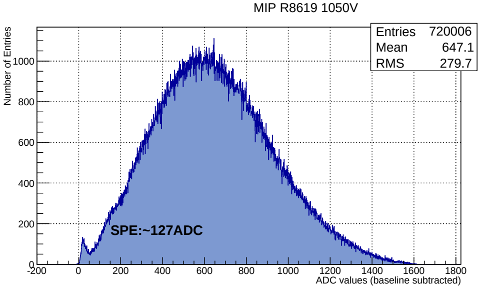


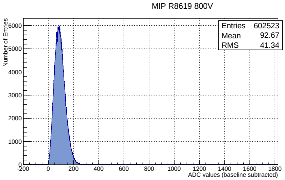


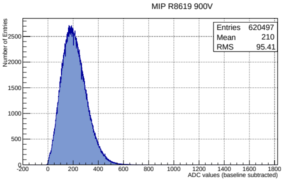


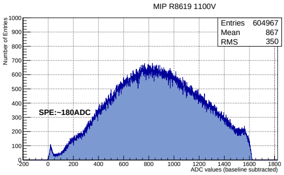
MIP Signal R8619

- mean MIP signal: $\sim 5\times$ SPE peak
- tapered, active voltage divider



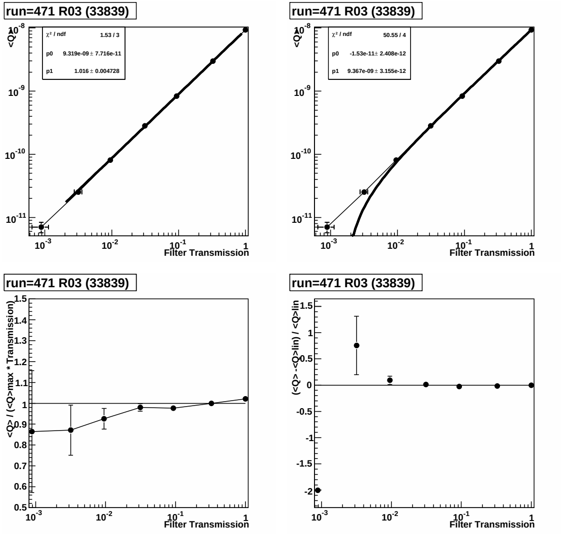




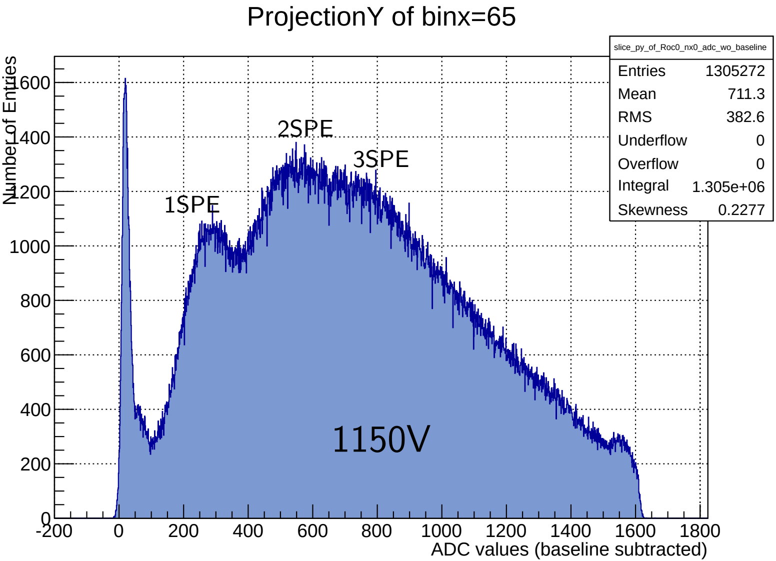


Linearity R8619

Linearity measurement at 1050V

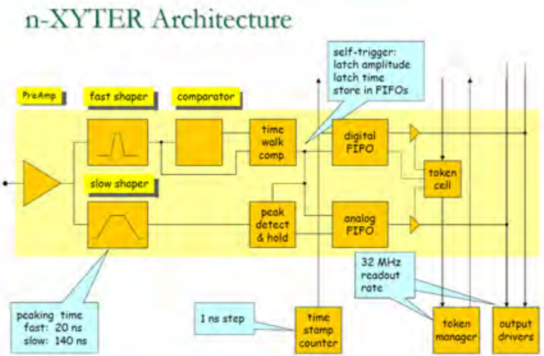


Multi-Photon Pulse R8619



n-XYTER ASIC

- mixed signal chip
- 128 channels
- 18ns fast shaper
- 140ns slow-shaper
- process: AMS 0.35μm CMOS
- programmable dead time
- dynamic range: 120000e
- Timing resolution 2-3ns
- self triggered, data driven de-randomizing, sparcifying readout at 32MHz



Pulser Calibration