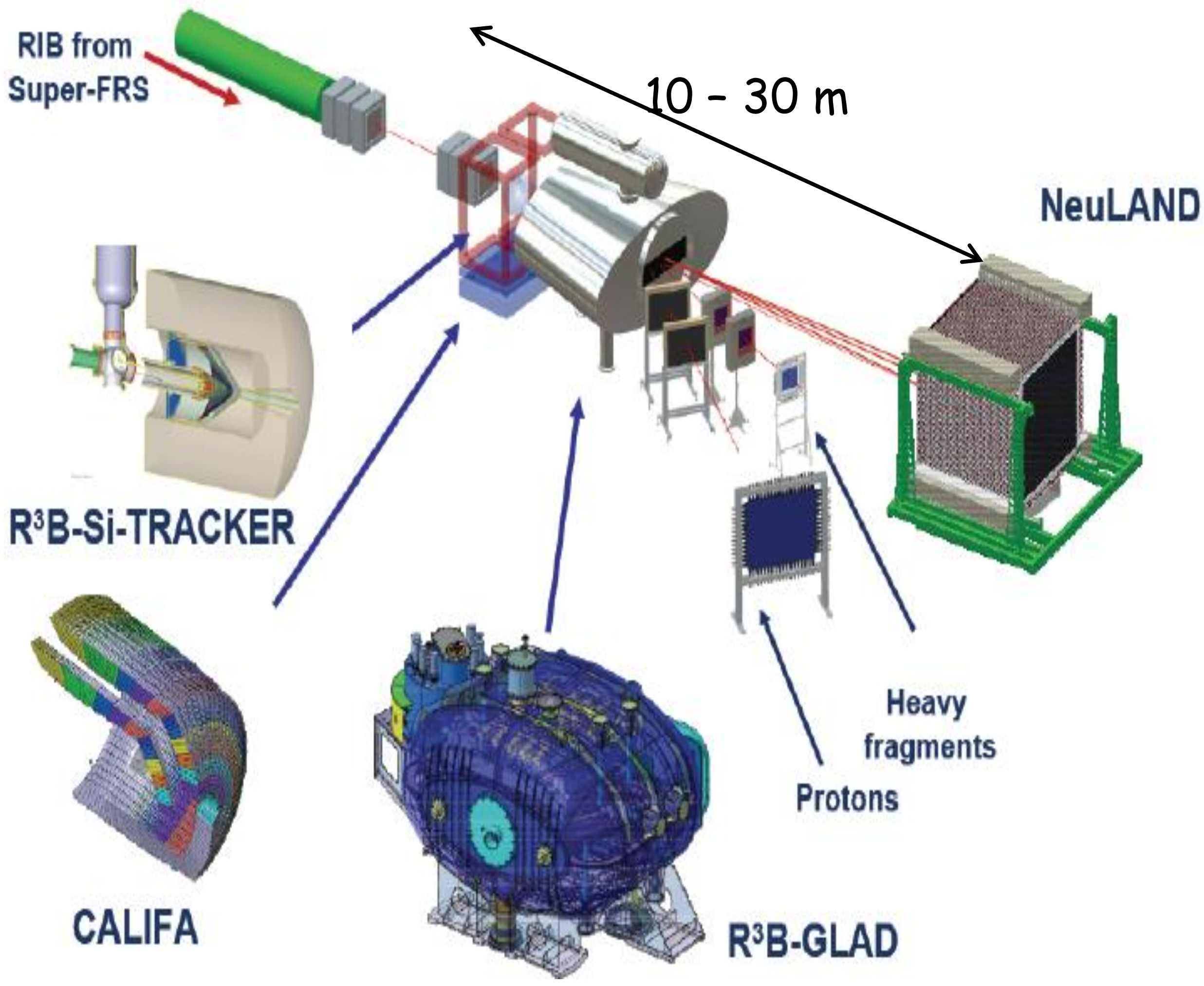
Time-of-Flight detectors for neutons. The NeuLand neutron Spectrometer of the R3B Collaboration.

Viacheslav Kuznetsov
Seminar HEPD, PNPI, November 3 2015

R^{3}B –Reactions with Relativistic Radioactive Beams



R3B facility:
Kinematically overdetermined detection of reaction products.

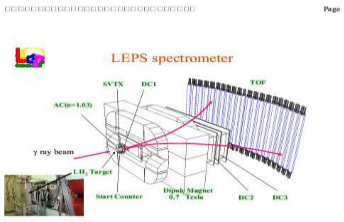
NeuLand:
Detection of
0.2 – 1 GeV neutrons

Requirements:

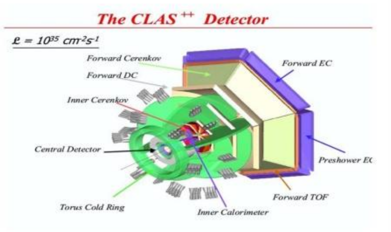
1) Excellent momentum and angular resolutions;
2) High efficiency ~90%
3) Multiplicity of neutrons up to 6-10

Two main types of neutron detectors

Arrays of long plastic-scitillator counters



LEPS forward wall

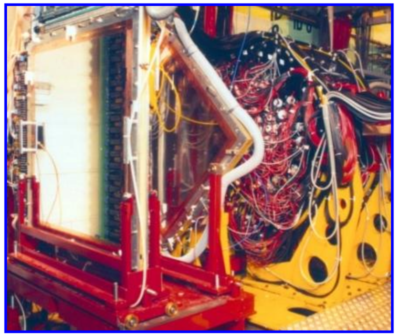


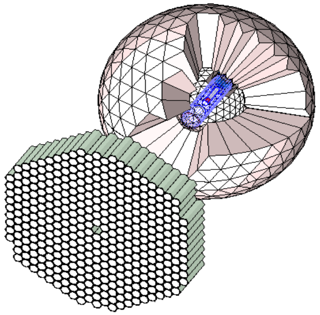
CLAS E-calorimeter

The Forward wall at GRAAL
(``The Russian Wall")

Low costs, large acceptance -> located at long distance from a target -> **appropriate energy/momentum resolution from measured time-of-flight**

Arrays of crystal blocks



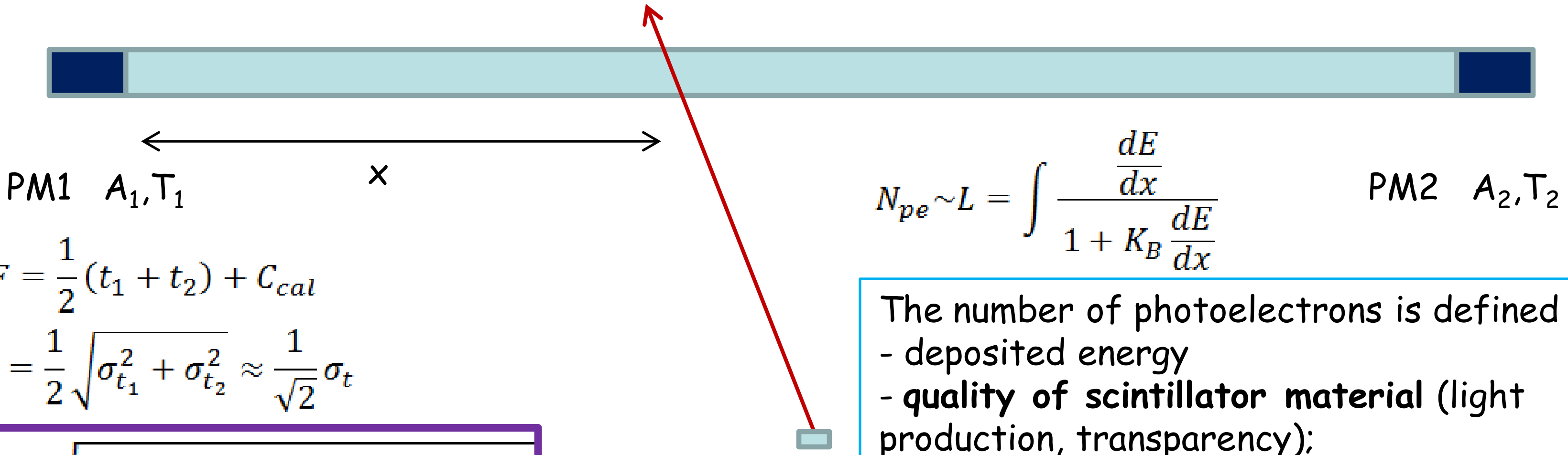


BGO Ball: GRAAL and BGO-OD experiments

TAPS and Crystall Ball: A2@MaMic Collaboration

Multi-purpoce detectors, high price, low acceptance. No energy information for neutrons

Some basics for TOF detectors



$$TOF = \frac{1}{2}(t_1 + t_2) + C_{cal}$$

$$\sigma_{TOF} = \frac{1}{2}\sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2} \approx \frac{1}{\sqrt{2}}\sigma_t$$

$$\boxed{\sigma_t = \sqrt{\frac{\sigma_{sc}^2 + \sigma_{LT}^2 + \sigma_{PM}^2}{N_{pe}} + \sigma_{el}^2}}$$

$$N_{pe} \sim L = \int \frac{\frac{dE}{dx}}{1 + K_B \frac{dE}{dx}}$$

The number of photoelectrons is defined by:
- deposited energy
- **quality of scintillator material** (light production, transparency);
- quality of polishing and wrapping;
- light collection by light guides and PMs

- light decay constant σ_{sc} for BC408 is 2.1 ns;
- light transportation uncertainty σ_{LT} is ~1.8ns $\sqrt{x}$
- transit time spread σ_{PM} (TTS) depends on phototubes and varies from 0,3 to 3 ns

Calibration Uncertainty

In reality

$$TOF = \frac{1}{2}(t_1 + t_2) + C_{real} + \Delta C_{cal}$$

where ΔC_{cal} *is the error of calibration*

If a detector consists of many counters, Δc_{cali} *varies from counter to counter.*

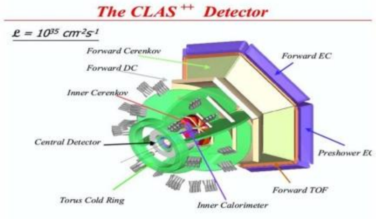
$$\sigma_{tof\_det} \sim \sqrt{\frac{\sigma_{sc}^2 + \sigma_{LT}^2 + \sigma_{PM}^2}{N_{pe}} + \sigma_{el}^2 + \sigma_{cal}^2}$$

Russian Wall at GRAAL

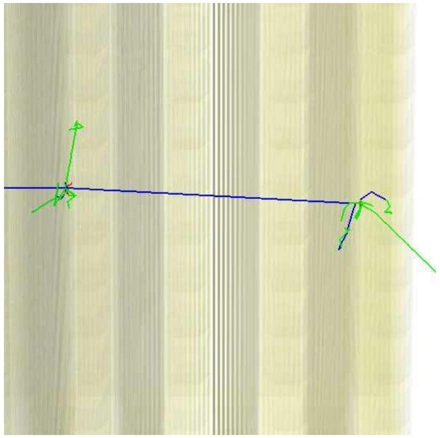
σ_{cal} ~10- 20 ps

Ecal at CLAS@JLAV

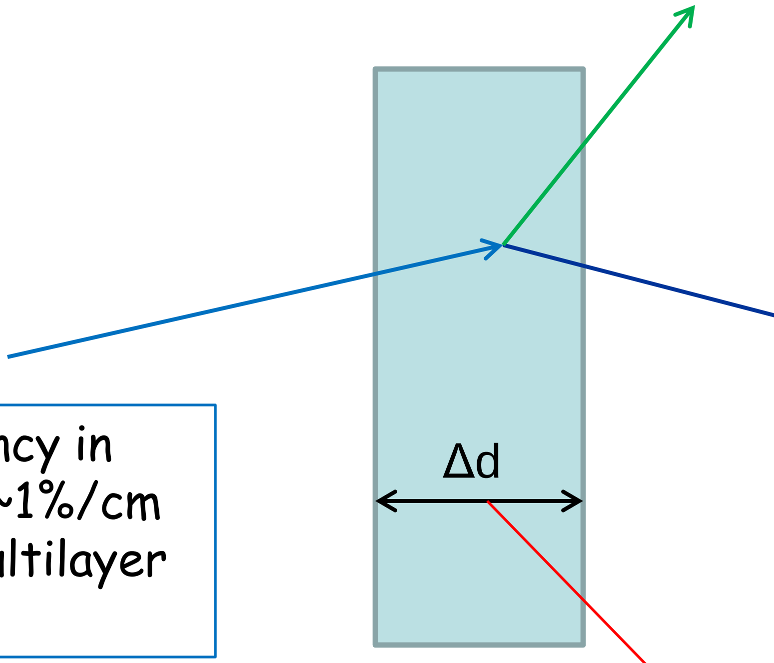
σ_{cal} ~200- 500 ps



Neutron detection: Specific features

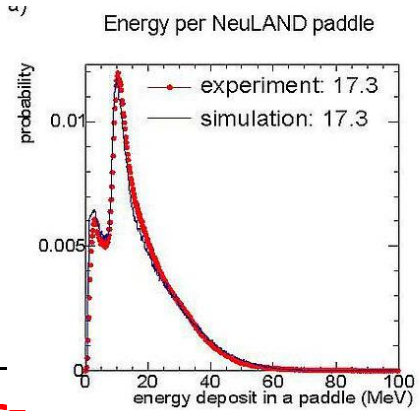


Neutrons interact inside detector volume mostly through knock out of recoil protons.



Detection efficiency in scintillator bars is ~1%/cm -> Need for thick multilayer detector

$$\sigma_{tof\_det} \sim \sqrt{\frac{\sigma_{sc}^2 + \sigma_{LT}^2 + \sigma_{PM}^2}{N_{pe}} + \sigma_{el}^2 + \sigma_{cal}^2 + \sigma_{neut}^2}$$



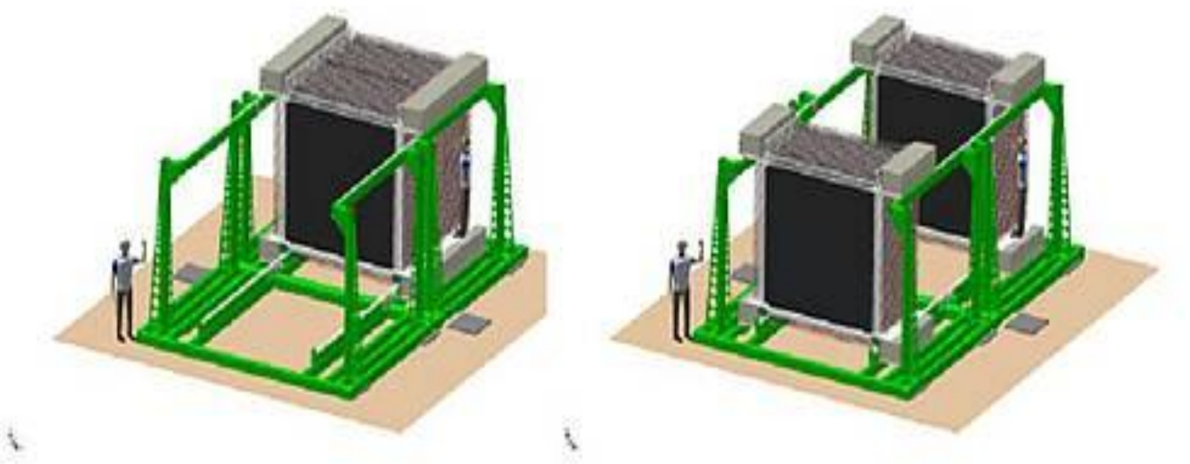
Wide range of deposited energy -> Need for low threshold to increase efficiency

Specific requirements for neutron detectors

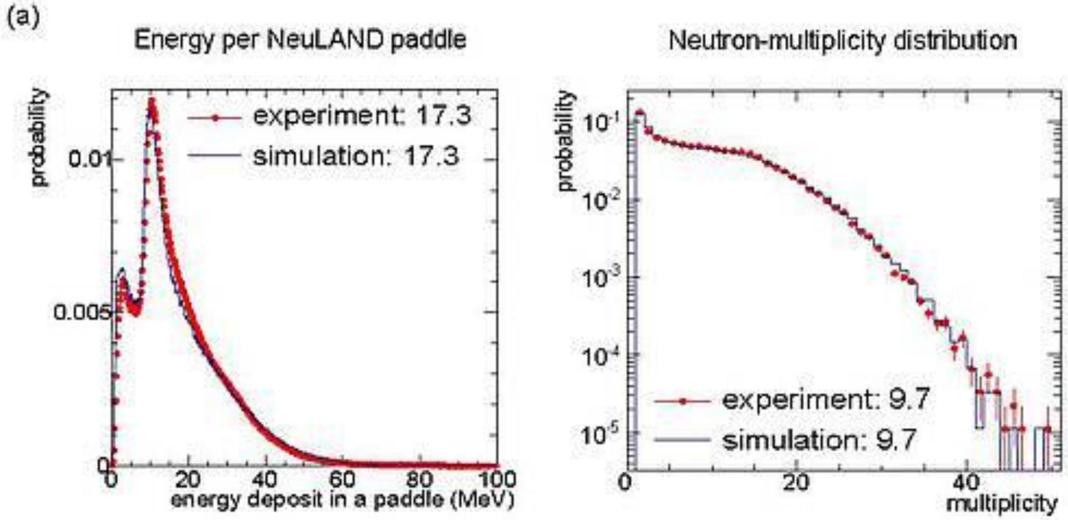
- Enough thickness to provide required detection efficiency;
- High granularity;
- Extended range of pulse heights and low threshold;
- Less requirements to phototubes.

NeuLand Detector

NeuLand will consist of 3000 individual submodules with a size of 5x5x250 cm3, arranged in 30 double planes with 100 submodules providing an active face size of 250x250 cm2 and a total depth of 3 m. NeuLAND can be divided into two detectors for special applications and will be placed at different distances from the target, in order to meet specific experimental demands. A momentum resolution of $\Delta p/p$ of 10-3 similar to that for is desired, resulting in resolution requirements for the time of flight of $\sigma(t) < 150$ ps and a position resolution of $\sigma(x,y,z) \approx 1.5$ cm for given flight paths in the range from 10 to 35 m. Apart from the excellent energy resolution of NeuLAND, the enhanced multi-neutron recognition capability with an efficiency of up to ~50% for a reconstructed five-neutron event at 1 GeV will constitute a major step forward.



Simulated detection efficiency



200 MeV	Generated					
Detected	%	1n	2n	3n	4n	5n
	1n	**88**	31	6	1	0
	2n	2	**62**	37	10	2
	3n	0	5	**49**	38	14
	4n	0	0	8	**48**	54
	5n	0	0	0	3	**26**

1000 MeV	Generated					
Detected	%	1n	2n	3n	4n	5n
	1n	**89**	12	1	0	0
	2n	7	**78**	23	3	0
	3n	0	8	**63**	26	5
	4n	0	0	12	**63**	40
	5n	0	0	0	7	**46**

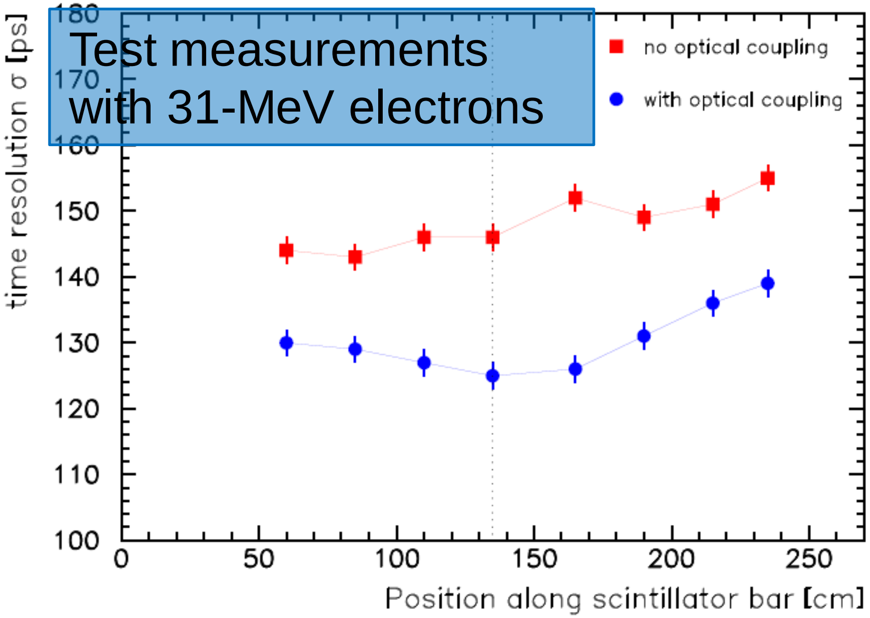
Scintillator counters

Cost-effective solution for PMs:

Hammamatsu Photonics R8619

- Rise time - 2.5 ns
- Transition time spread - 1.2 ns
- HV at anode sensitivuty 100 A/Lm - ~1000 V
- Expected operating HV 700 – 900 V

Requirements for PMs from the HV system HV <1500V.



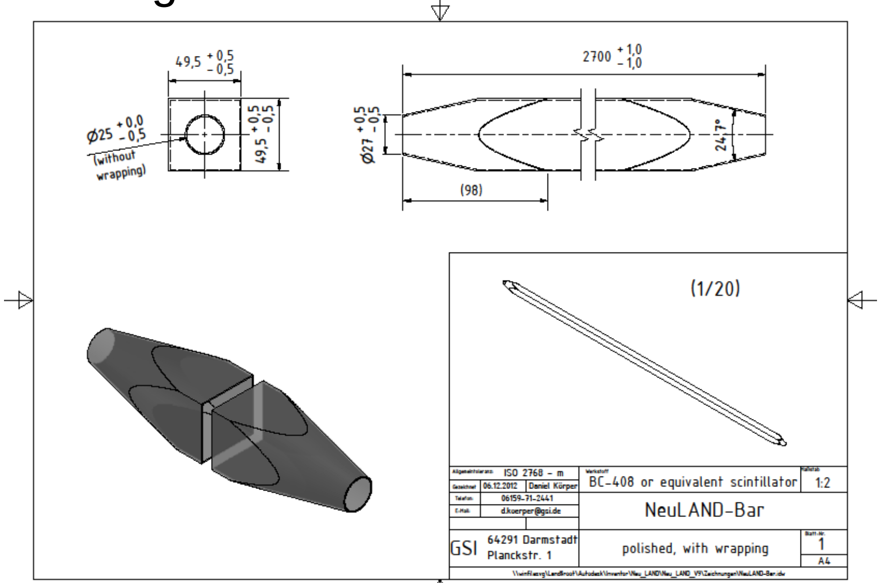
Test measurements with 31-MeV electrons

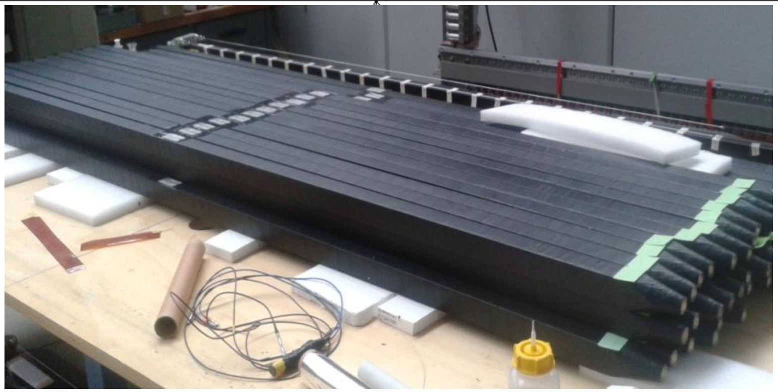
BC408 scintillator bars

Light decay – 2.1 ns

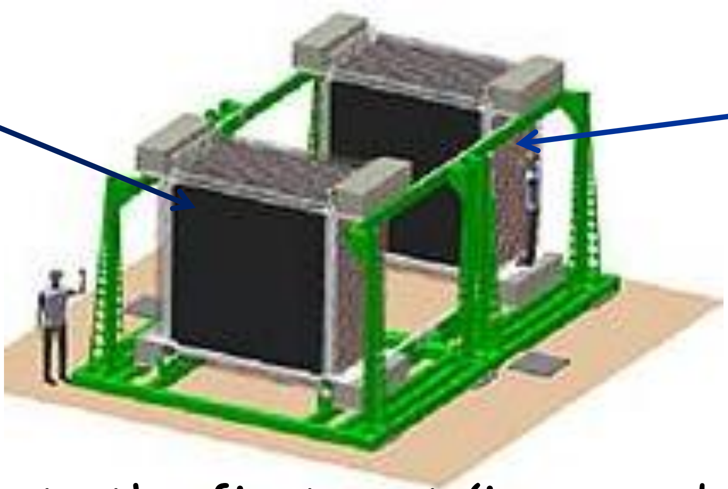
Light output – 60% relative to antracene

Bulk light attenuation ~ 4 m





Detector Construction



First part
1500 counters
2018 - 2019

Second part
1500 counters
~2022

Russian Contribution to the first part (in accordance with previous agreement) – 700 scintillator bars

Our suggestion: 700 scintillator counters (bars + PMs)

Current situation: deliverance of two prototype counters to GSI by the fall of 2015, discussion of a large contract in the first half of 2016.

Scintillator Bars at PNPI

two roughly-cut BC-408 bulks from Saint-Gobaine have been purchased, machined and polished at the PNPI workshop

Two bars are ready and now to be examined, wrapped and tested.

MELZ Photomultipliers

MELZ offered newly-designed phototubes FEU-115 MKZ and FEU-85B with plane and spherical photocathodes

FEU -115 MKZ
HV at anode sensitivity 100 A/Lm
obtained in April - ~1500 V
obtained in October – ~1150 V

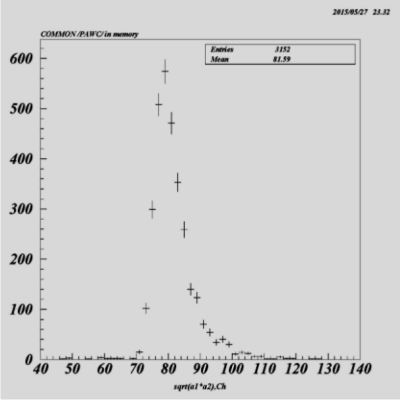
FEU-85b
HV at anode sensitivity 100 A/Lm
~900V

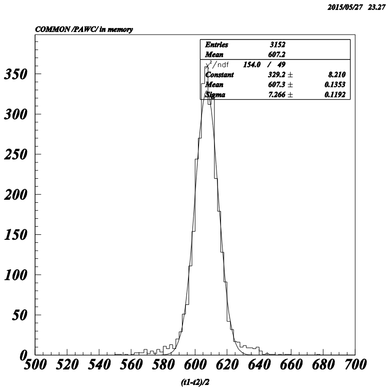
Tests at PNPI

Several tests at the pion beam line and by using ^{90} SR source.

Encouraging but slightly contradictory results (not discussed)

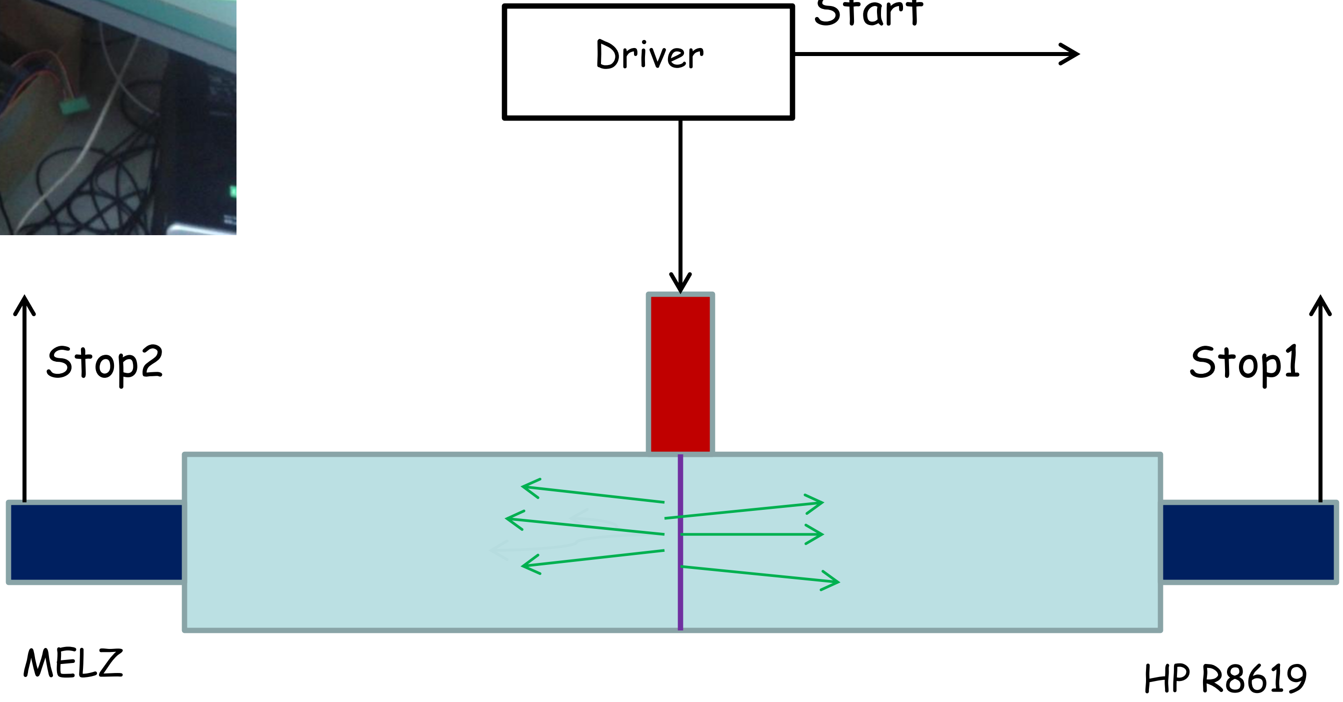
⇨ Tests with UV laser at GSI



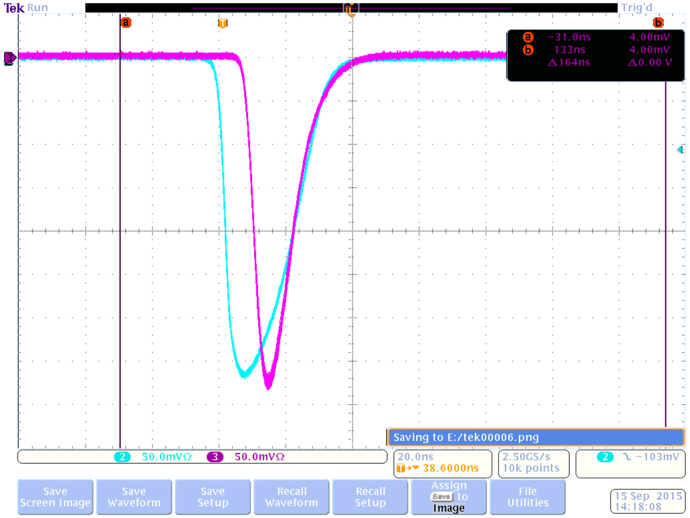


Tests at GSI

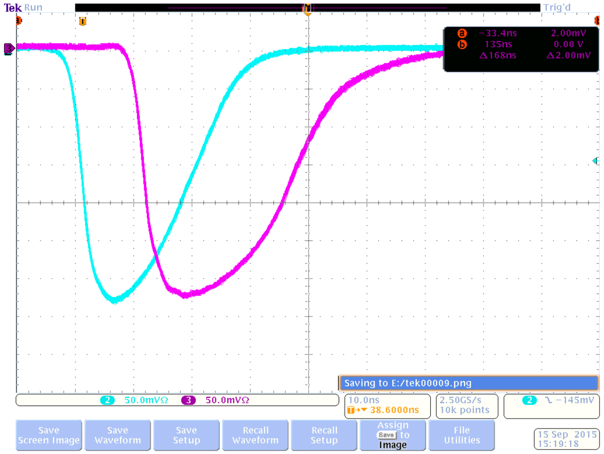
Laser driver:
PicoQuant PDL 800-B
Laser head LDH-P-C-375B
370 nm, 100ps pulse duration



Comparison of MELZ (magenta) and HP R8619 (green)pulse shapes

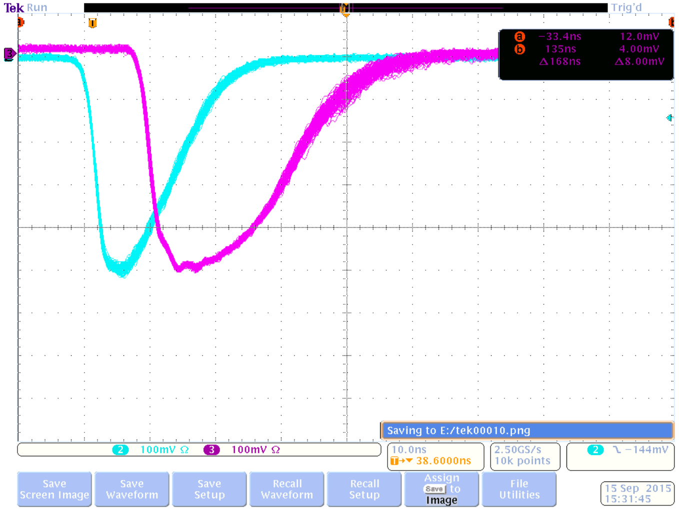


FEU-115MKZ vs R8619



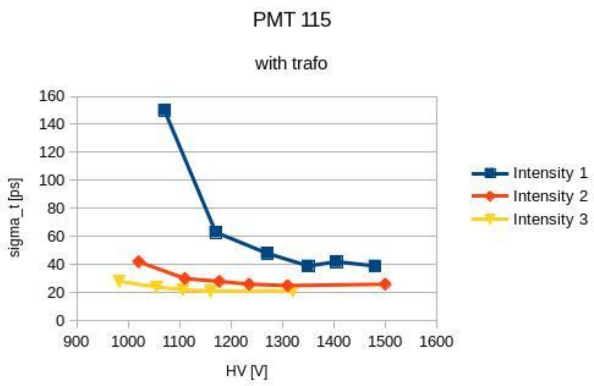
FEU-85B vs R8619

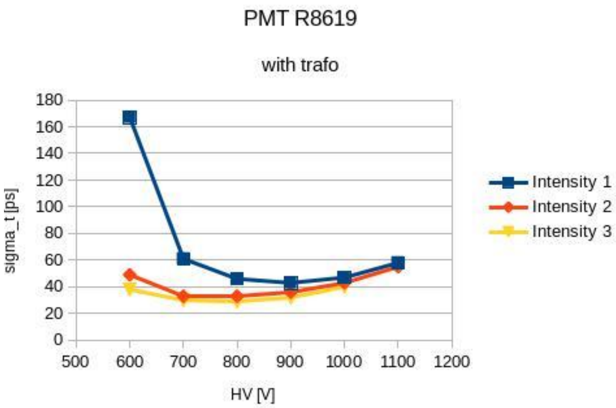
FEU-185B(magenta) vs R8619 at HV=900V

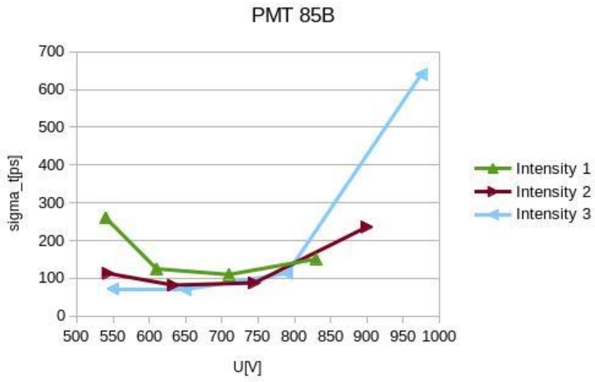


Timing resolution at different HV and light intensities

HVs have been adjusted to get the same pulse height







Excellent timing performance of FEU115MKZ PM!

PM under study fits the requirement HV<1500 V.

Next step: Test of four other FEU115MKZ PMs

Conclusions and plans

- FEU 115MKZ look very promising for the remaining parts on NeuLand;
- More checks are needed to determine long-term stability and variation of parameters between different PMs;
- Scintilltor bars can be manufactured at PNPI, but the time schedule has to be understand;
- Potentially, PNPI reseachers (N.Kozlenko and myself) could contribute to the NeuLand calibration using the experience from the explotation of the Russian Wall at GRAAL.

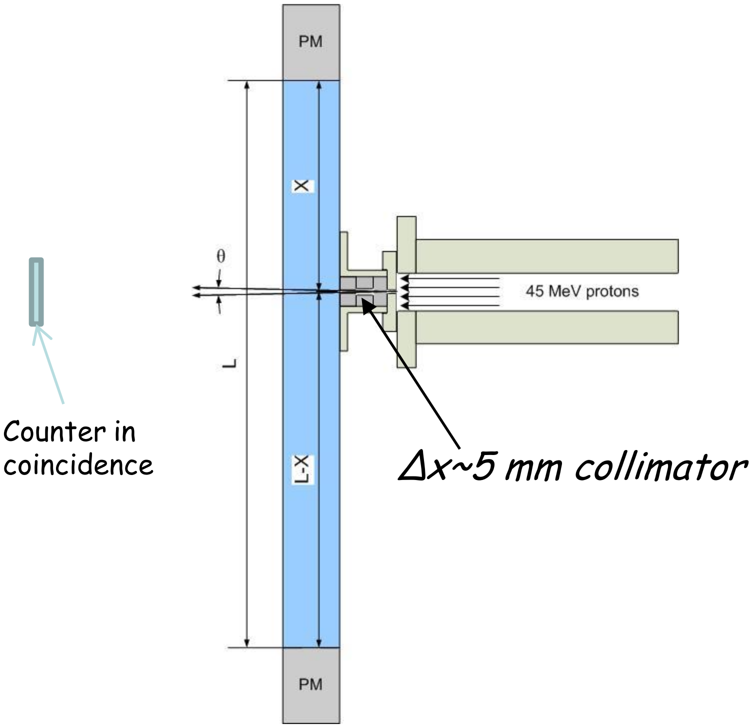
Testing Facility at PNPI

- *We have created a testing facility at the pion beam line of the PNPI synchrothron;*
- *Comparative tests of timing performance of scintillator* counters *equipped with different photomultipliers;*

Measured PM times are defined by the following relations

$$t1 = TOF + x/v + Const\ ; \quad t2 = TOF + (L-x)/v + Const;$$

Where TOF is time-of-flight of pions from a certain point (target), x is a hit position along the counter axis, L is the counter length, v is the efficient speed of light propagation inside the counter, Constants originate from cable and electronic delays.



$$TOF = (t1+t2)/2 + Const; \quad x/v = (t1-t2)/2 + Const;$$

TOF resolution $\sigma_{TOF} = \sigma((t1+t2)/2) =$

$$\mathrm{sqrt}(\sigma^2_{t1} + \sigma^2_{t2})/2;$$

Variation of $(t1-t2)/2$

$$\boxed{\sigma((t1-t2)/2) \approx \sigma_{TOF} + \Delta x/v}$$

where Δx is the size of the beam spot.

For a point-like beam ($\Delta x \sim 0$)

$$\boxed{\sigma((t1-t2)/2) \approx \sigma_{TOF}}$$

TOF resolution of a scintillator counter can be directly extracted from measured spectra of (t1-t2)/2

Thanks so much!

V.Kuznetsov et al, CTOF review,

Measured PM times are defined by the following relations

$t1=TOF+x/v+Const\ ; \quad t2=TOF+(L-x)/v+Const;$

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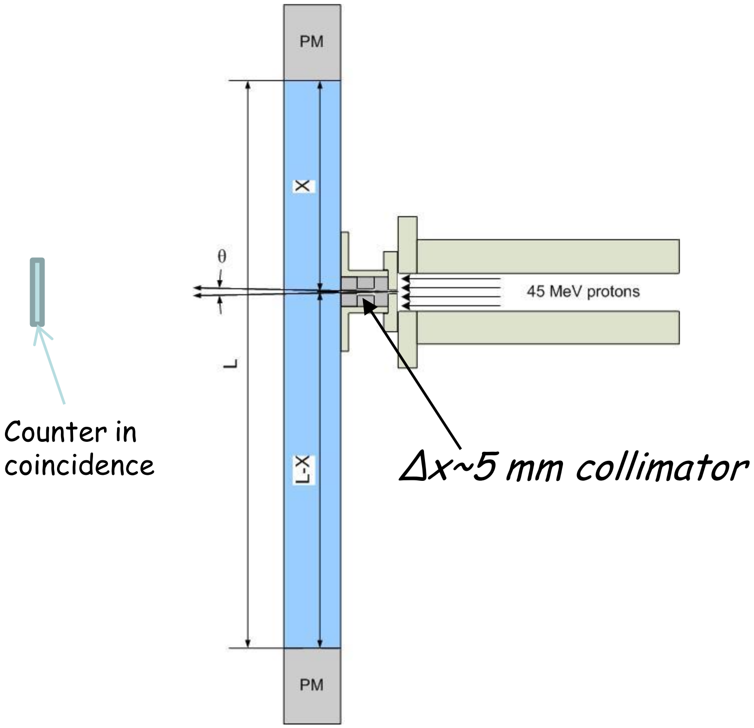

Counter in coincidence

Δx~5 mm collimator

$TOF=(t1+t2)/2+Const;\ x/v=(t1-t2)/2+Const;$

TOF resolution $\sigma_{TOF} = \sigma((t1+t2)/2)=$

$sqrt(\sigma^2_{t1}+\sigma^2_{t2})/2;$

Variation of (t1-t2)/2

$\sigma((t1-t2)/2) \approx \sigma_{TOF}+\Delta x/v$

where Δx is the size of the beam spot.

For a point-like beam (Δx~0)

$\sigma((t1-t2)/2) \approx \sigma_{TOF}$

TOF resolution of a scintillator counter can be directly extracted from measured spectra of (t1-t2)/2