TOF neutron spectrometer with compact neutron detectors

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LHEP / JINR

Aim of neutron measurements

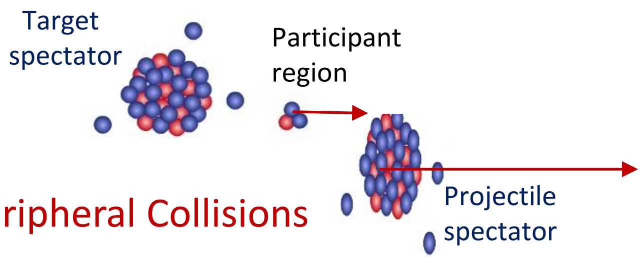
- ✓ Neutron production double differential cross sections
- ✓ Neutron multiplicity
- ✓ Centrality dependence of neutron emission
- ✓ Dependence of neutron emission on size of colliding nuclei
- ✓ Contribution of different sources and stages of nuclear system decay
- ✓ Estimation of temperature and velocity of neutron sources

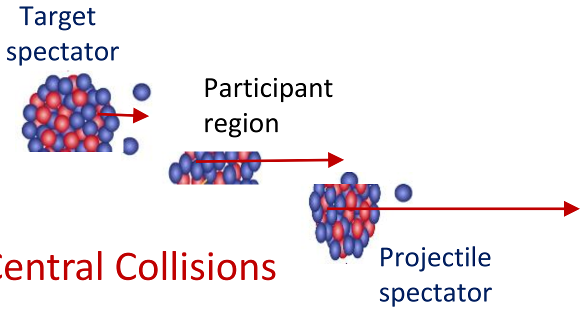
Main features of the spectrometer

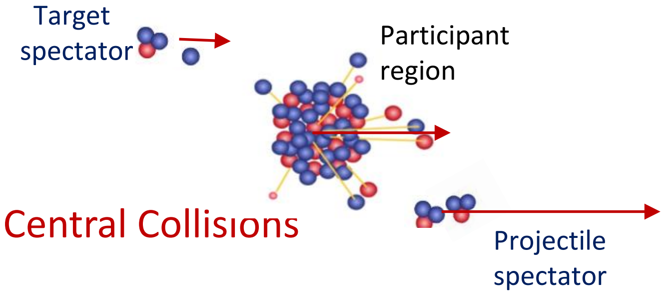
- ✓ Small flight path
- ✓ High time resolution (σ_t ~ 100 – 150 ps)
- ✓ Suppression of gamma-ray background using stilbene and PSD method

Sources of neutron emission

Centrality of Collision	Neutron sources
Peripheral Collisions	**Decay of Target spectator remnant** Decay of Participant region **Decay of Projectile spectator remnant**
Semi-Central Collisions	**Decay of Target spectator remnant** **Decay of Participant region** **Decay of Projectile spectator remnant**
Central Collisions	Decay of Target spectator remnant **Decay of Participant region** Decay of Projectile spectator remnant

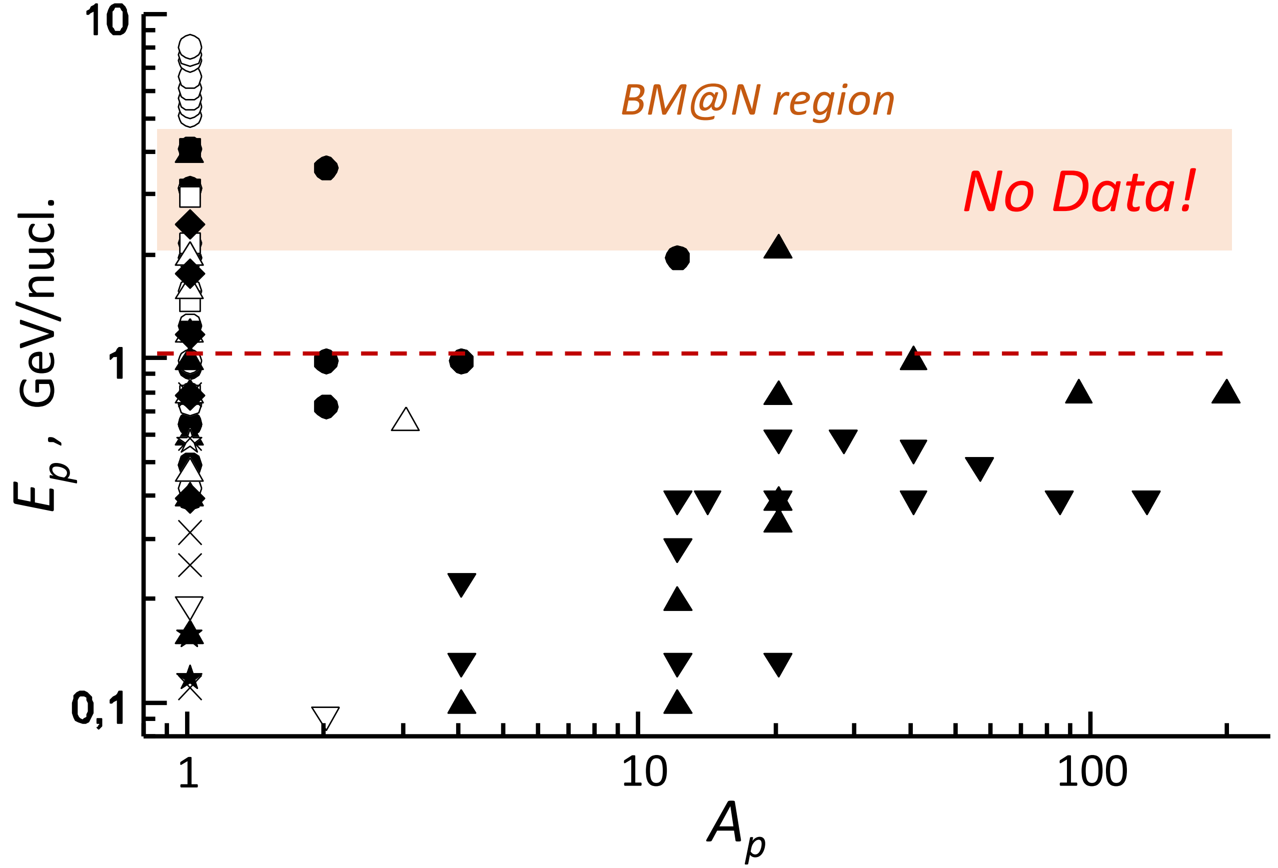




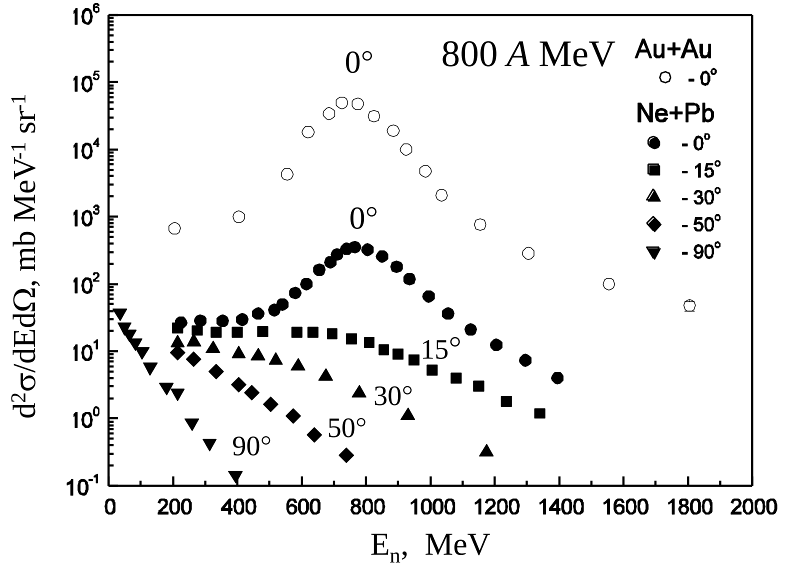


Status of neutron data

- Mainly the data were obtained with proton beam
- Neutron spectra measurements without selection on centrality
- No data above 1 GeV/nucleon for collisions of heavy nuclei



Example of neutron energy spectra
(BEVALAC experiments)



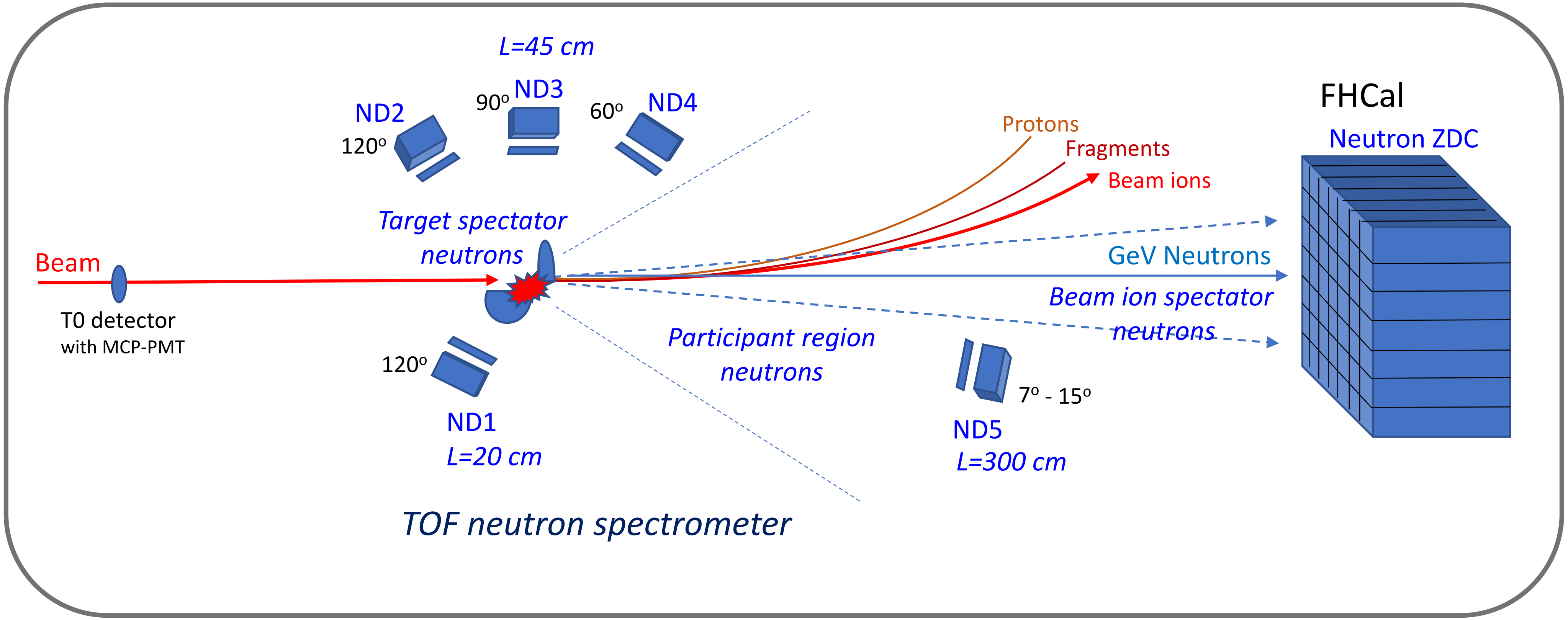
TOF measurements of neutron spectra

p + *A* collisions
(LANL, SATURNE, JINR, ITEP, KEK, CERN)

A + *A* collisions
(LBNL, JINR, HIMAC, GSI, AGS, CERN)

Neutron spectra were measured with min. bias trigger (no selection on centrality)

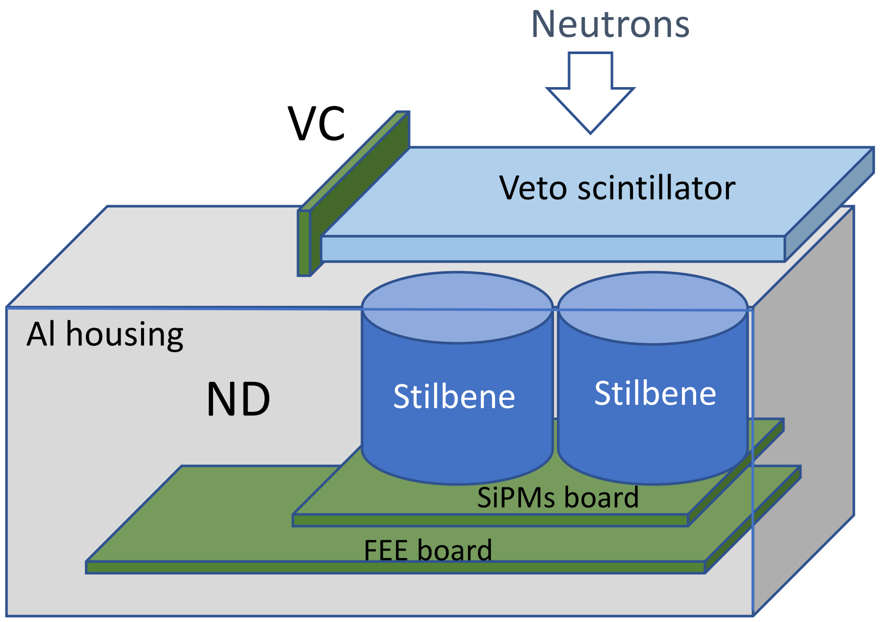
A scheme of neutron measurements with BM@N setup



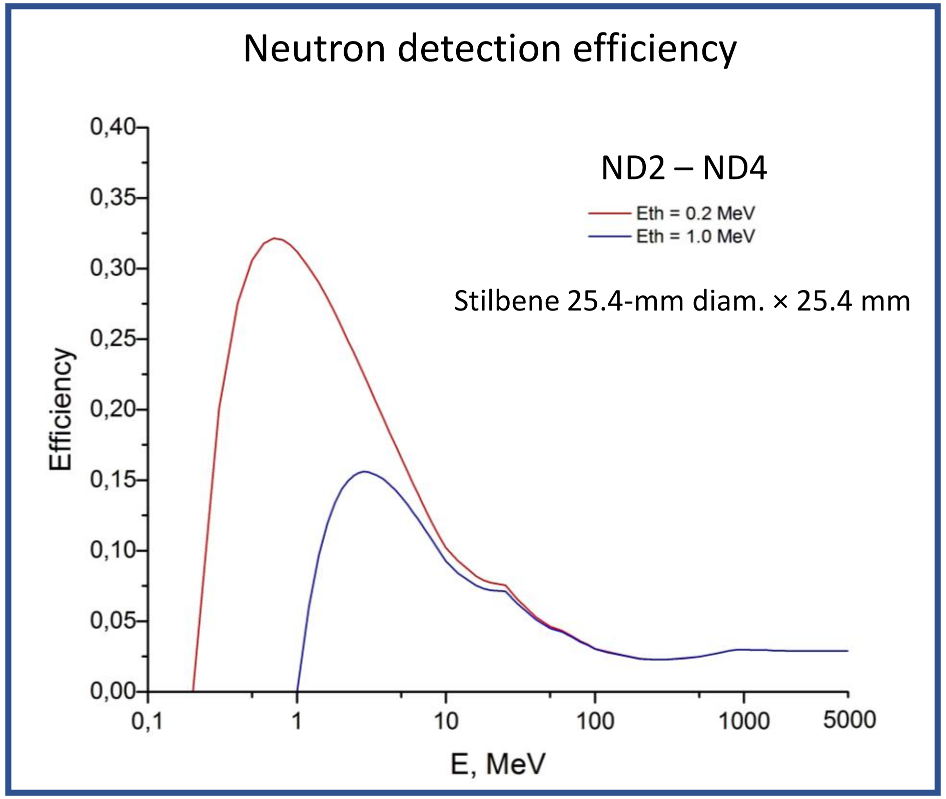
Study of neutron emission in *AA*- collisions

System decayed (neutron sources)	Stages of decay	Energy & Angular range	Measured value	Detectors
Target spectator decay *Lab. frame*	Multifragmentation Evaporation	$E_n < 100$ MeV Large angle emission	$d^2\sigma/dE_n d\Omega$	TOF spectrometer
Participant region decay *Moving frame*	Hadron cascade Fireball decay	50 MeV $< E_n <$ 4000 MeV Forward hemisphere	$d^2\sigma/dE_n d\Omega$	
Projectile spectator decay *Beam frame*	Multifragmentation Evaporation	Beam-energy neutrons in narrow cone around 0^o	M_n Neutron distribution over NZDC modules	nZDC

Neutron Detector



A scheme of Veto counter and Neutron Detector with 2 stilbene crystals

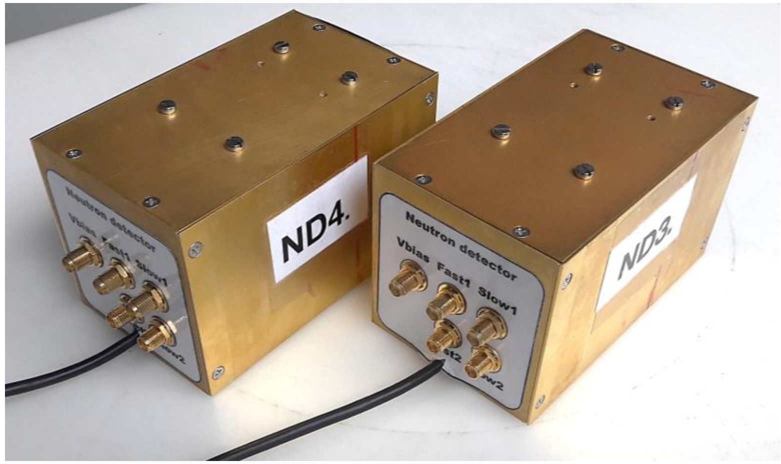


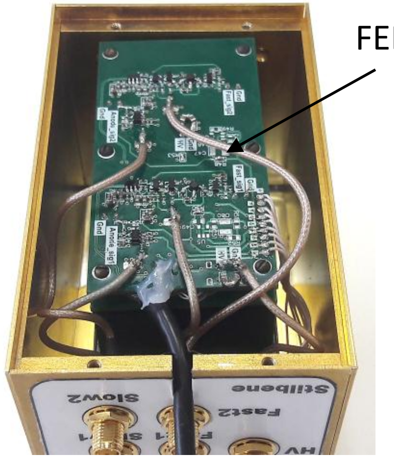
Scintillation photons are detected with SiPMs 6 x 6 mm^2 , J ser. SensL :

- 4 SiPMs – coupled with stilbene crystal
- 2 SiPMs – coupled with Veto-scintillator

Neutron Detector

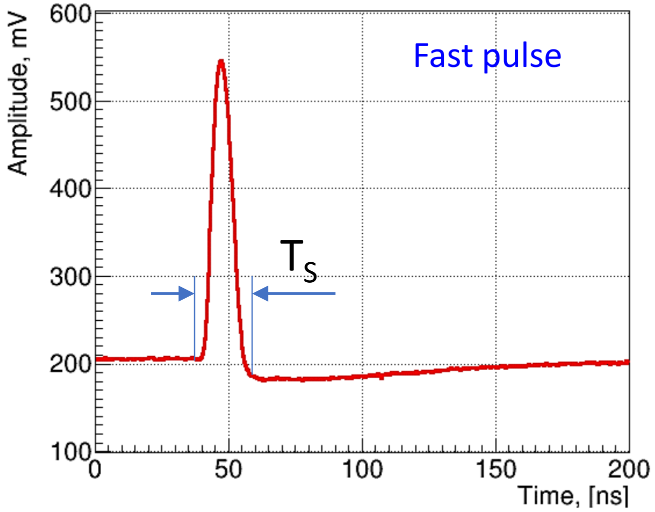
Neutron detectors

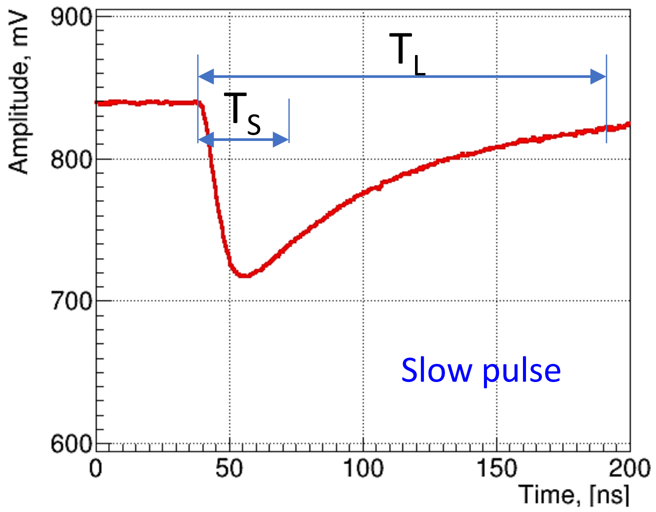




FEE board

ND output pulses





ND1 with stilbene crystals 30-mm diam. × 10 mm

ND2, ND3, ND4 with stilbene crystals 25.4-mm diam. × 25.4 mm

N5 with stilbene crystals 30-mm diam. × 20 mm

SensL SiPMs have fast and slow outputs

The fast pulse has the best timing characteristics and it used for TOF measurements

For n/γ- discrimination with PSD method both pulses are used

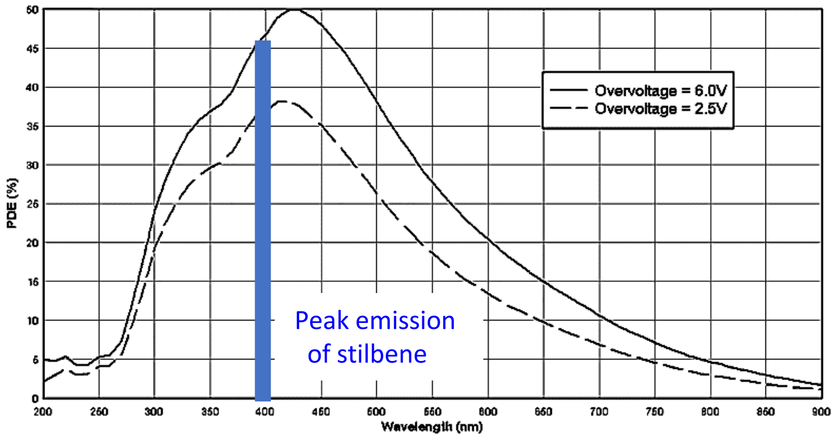
Pulse shape discrimination (PSD) with T_S ~ 20 ns, T_L ~ 200 ns, SiPM overvoltage ~ 3 V

[Christian Wysotzki (2018)]

Characteristics of Stilbene

	Density gm/cm^3	Wavelength nm	Refractive index	Decay time ns	Light yield Photons/MeV n	γ
Stilbene	1.25	390	1.626	3.5–4.5	10,700	14,000

Photon detection efficiency of SensL SiPM

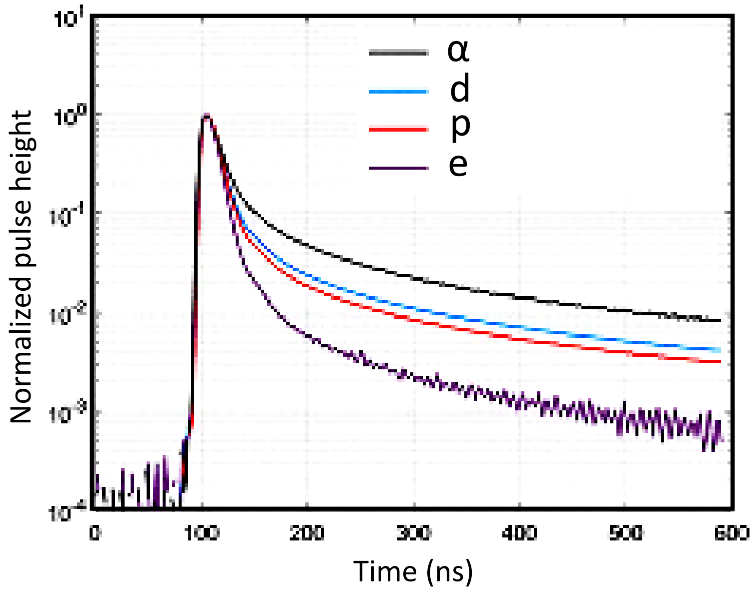


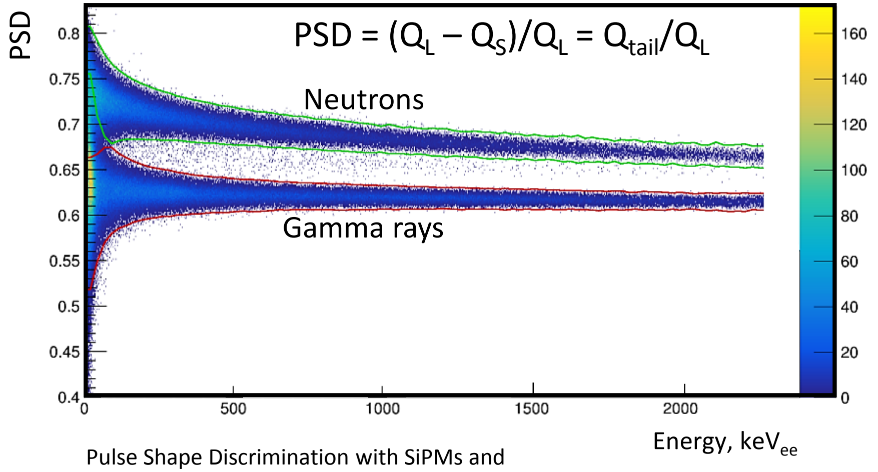
Decay time components of stilbene

Particle specie	Fast [ns]	Intermediate [ns]	Slow[ns]
gamma	5.21 (95 %)	21.33 (3 %)	134.77 (2 %)
neutron	5.01 (95 %)	27.70 (4 %)	253.19 (1 %)

H.D. Kim et al. "Characteristics of a stilbene scintillation crystal in a neutron spectrometer". In: Radiation Measurements 58 (Nov. 2013), pp. 133–137.

Pulse shape for different particles



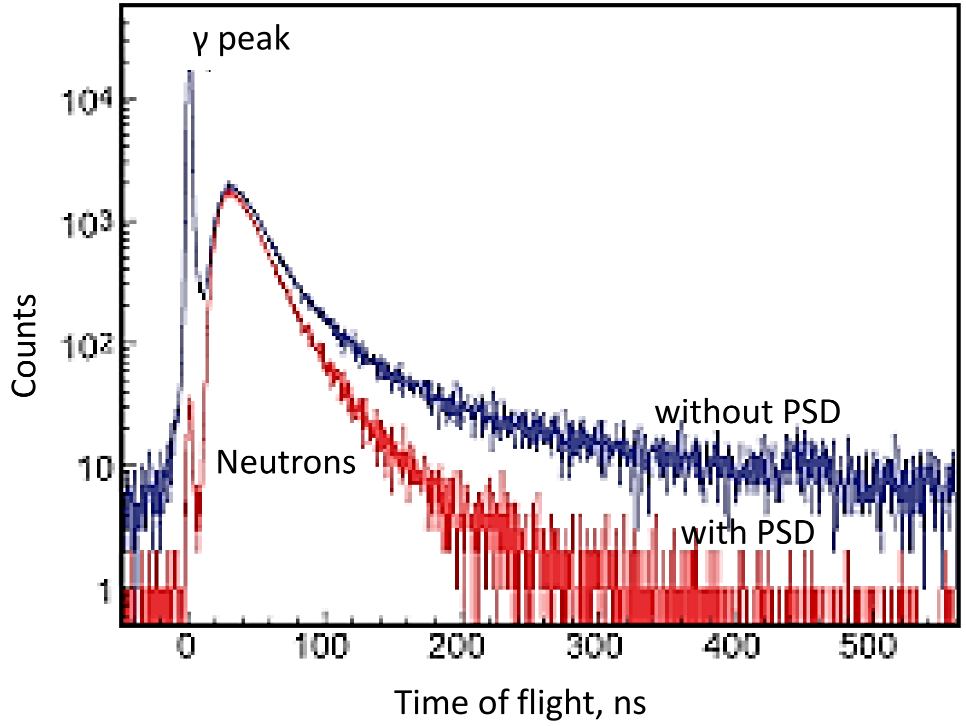


Pulse Shape Discrimination with SiPMs and Stilbene Crystals for Neutron Imaging

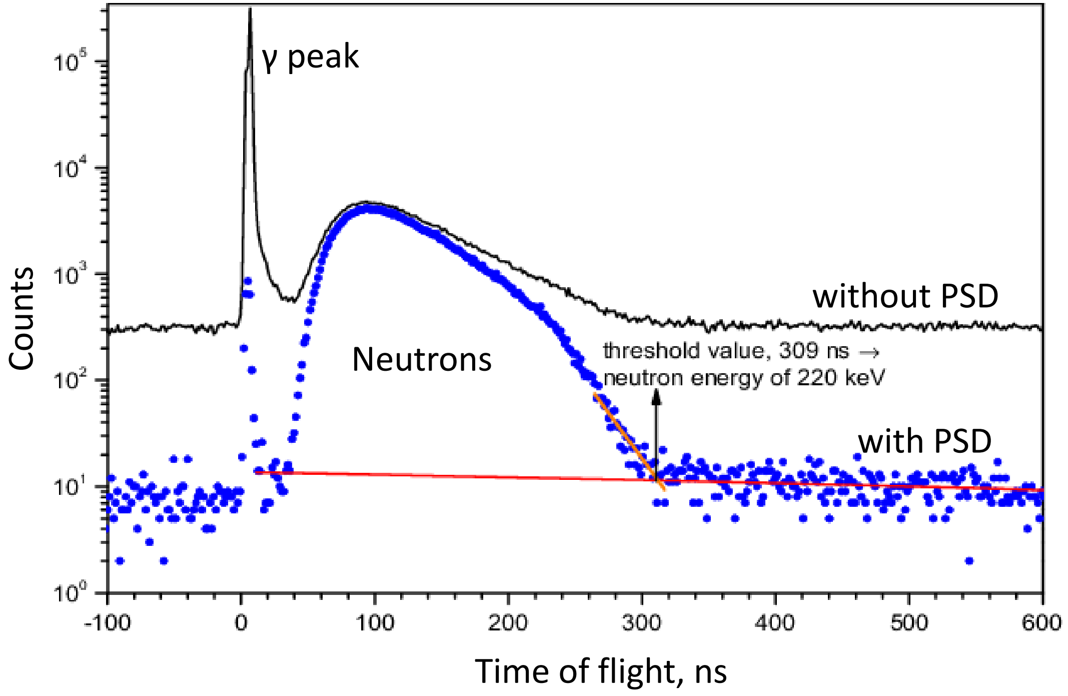
Christian Wysotzki (2018)

Suppression of gamma-ray background with pulse shape discrimination (PSD)

Examples of TOF neutron spectra with PSD background suppression



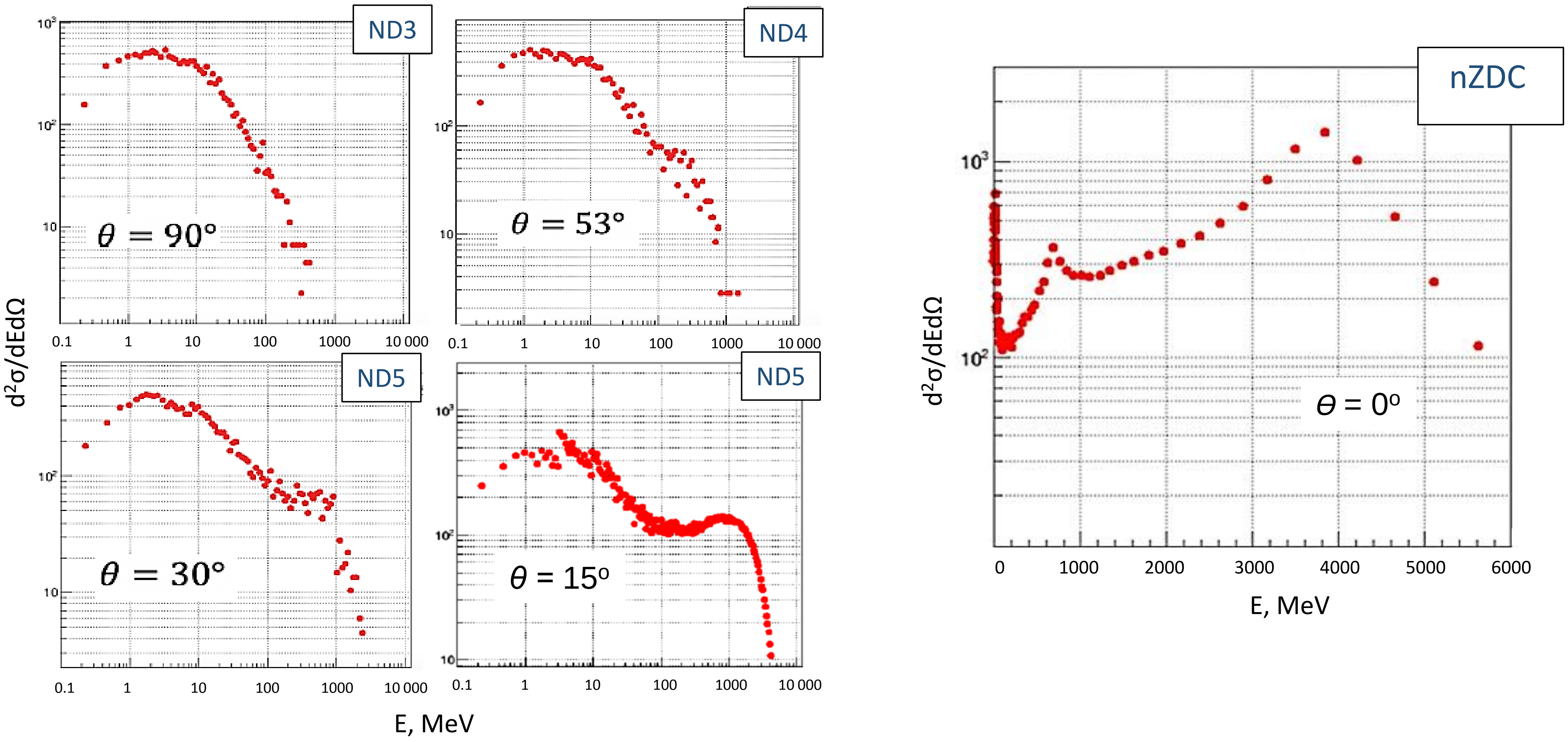
^{252}Cf time of flight (TOF) spectra



Neutron energy spectra

Au + Au , 4.2 *A* GeV

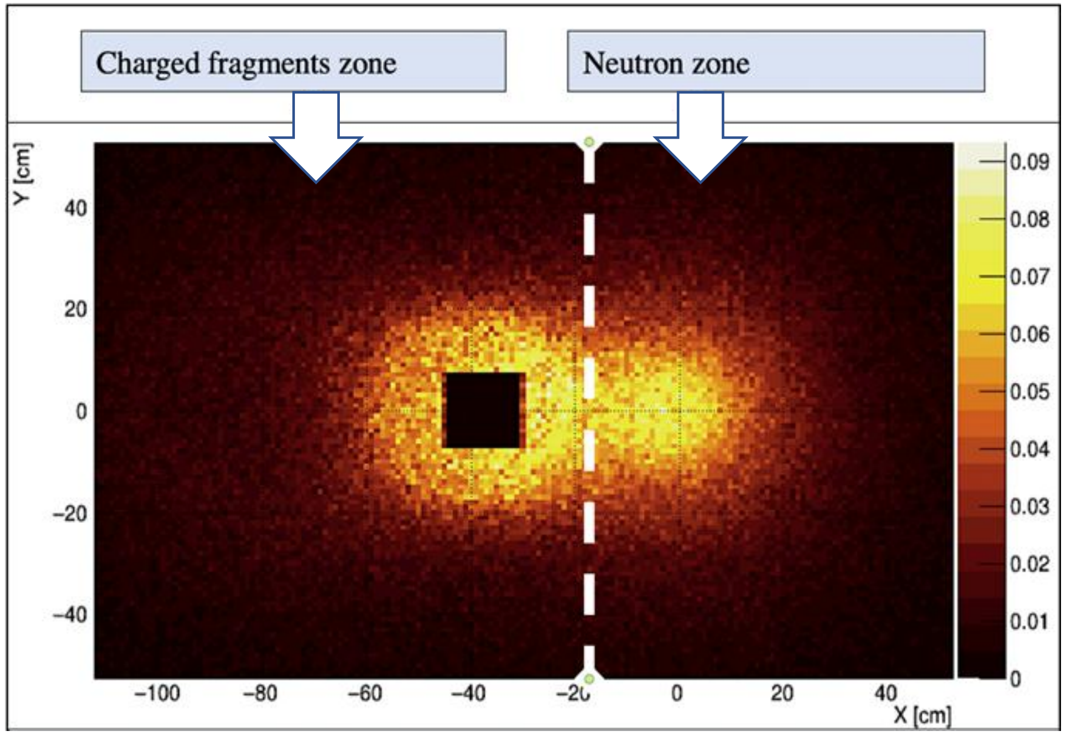
DCM-QGSM simulation
N. Lashmanov



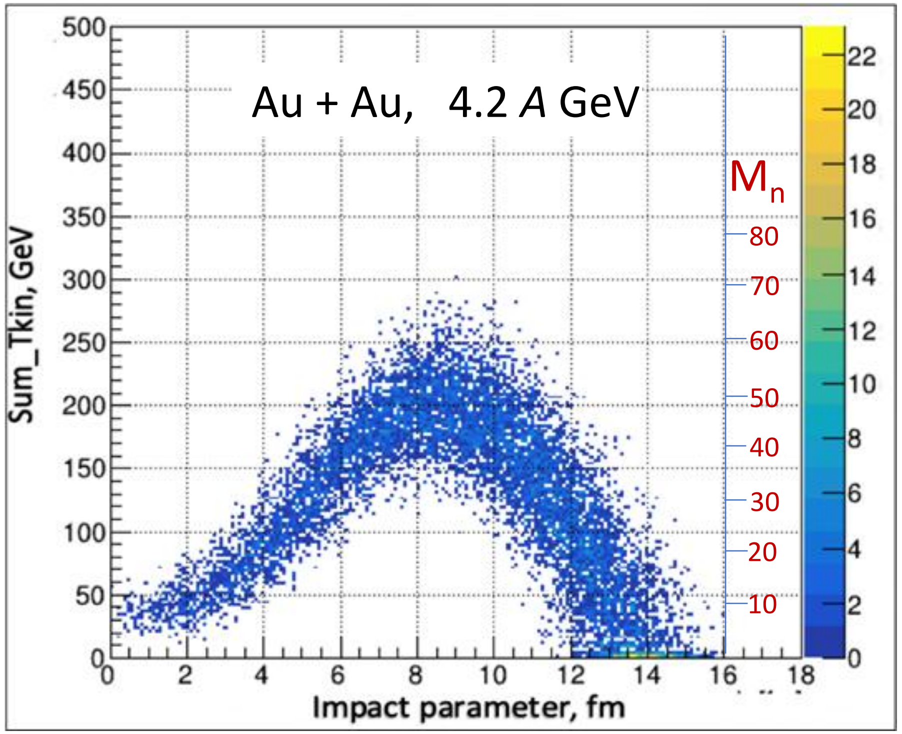
Neutron Zero-Degree Calorimeter (nZDC)

DCM-QGSM simulation
N. Lashmanov

Neutron multiplicity from beam spectator decay



Incoming energy of fragments in FHCal



Estimation of neutron event statistics

DCM-QGSM simulation
N. Lashmanov

Au + Au
1% target
10^6 ion/spill

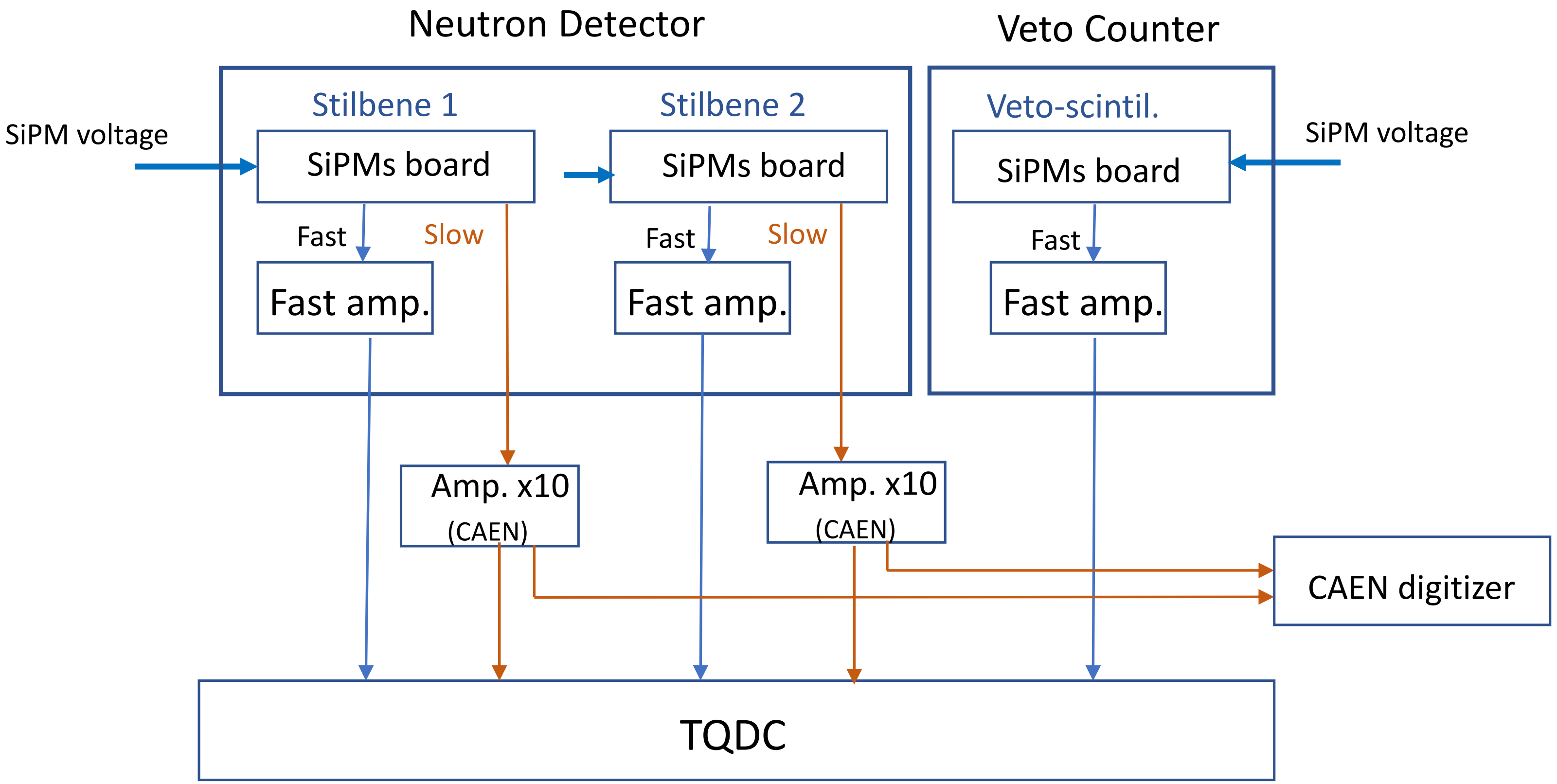
	ND5		ND4	ND3	ND2	ND1
Angle θ (deg.)	7	15	60	90	120	120
L (cm)	300	300	45	45	45	20
per spill N_n	637	172	615	244	151	1066
per spill N_{ev}	15.9	4.3	61.5	24.4	15.1	84
N_{ev} *per day* (20 hours)	115*10³	31*10³	443*10³	176*10³	109*10³	606*10³

$N_{ev} = \varepsilon N_n$

ε – neutron detection efficiency

for **Xe + CsJ**
we need 1.5 - day run
to get the same statistics

Neutron spectrometer electronics



DAQ electronics: 2 TQDC modules (5 ch. per ND + VC)

Status of ND spectrometer

Detectors

- ND1 – ND4 detectors have been produced and currently they are in test measurements with cosmic rays
- ND5 will be produced in October
- Veto counters – in production
- Mechanical support – in production

Electronics

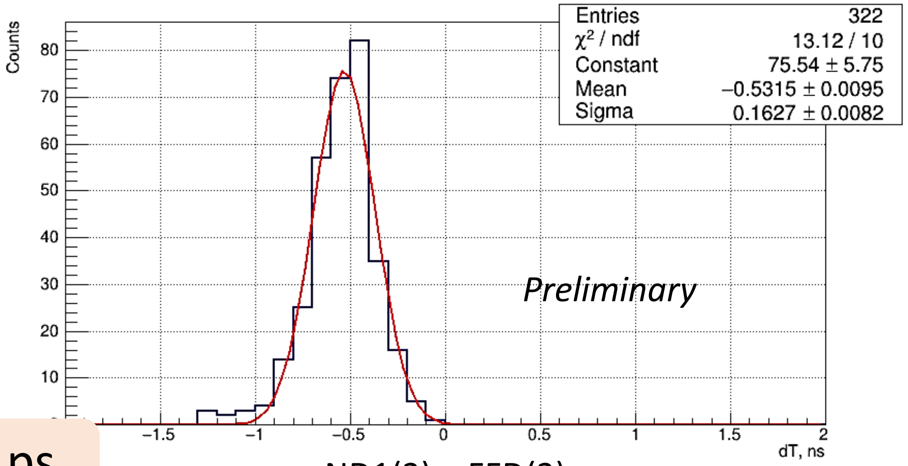
- SiPM power supply – produced and tested
- Fast amplifiers (CAEN module) - available
- TQDC (2 modules) – available
- Cables are ready for use

The spectrometer will be ready to run in the end of October

Test measurements with cosmic rays

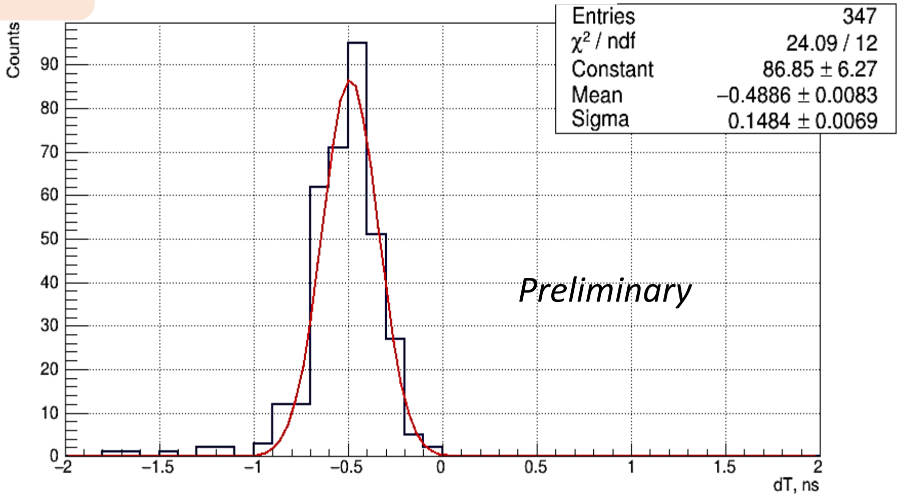
(in progress)

ND1(1) – FFD(1)



$\sigma_t \approx 140$ ps

ND1(2) – FFD(2)



Thank You for Attention !