Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Status of the Detector Development for a Double-Differential Cross Section (DDX) Experiment with the Emission of Light Charged Particles from High Energy Neutrons

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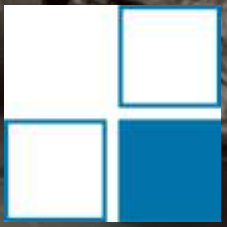


2nd ARIEL Scientific Workshop and Progress Meeting, NPL, 16th Mar 23

Motivation in Neutron Dosimetry: DDX for neutron-induced emission of light charged particles

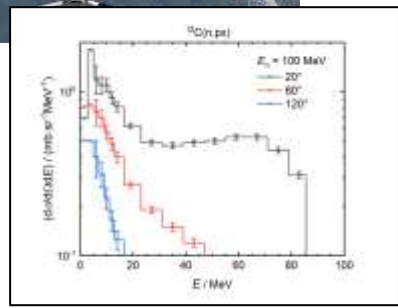
High-energy secondary neutrons produced
- in hadron therapy: E_n up to 200 MeV / 400 MeV for proton / carbon beams
- by cosmic radiation: E_n up to GeV

Absorbed dose calculations require
- DDX data for (n, px) (n, dx) (n, αx) …
- for tissue constituents (C, N, O)

➤ Particularly important for young patients of radiation therapy

(Si: Radiation damage in aircraft and space instrumentation)

Present situation:
- Only few DDX data for emission of H and He ions from C, N, O, Si above 50 MeV
- Complex product particles still a challenge for the INC model



Status of DDX data for carbon

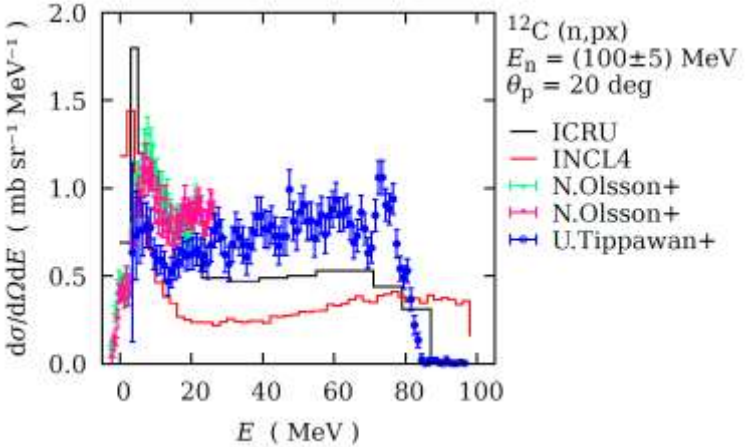
Experimental data above 20 MeV:

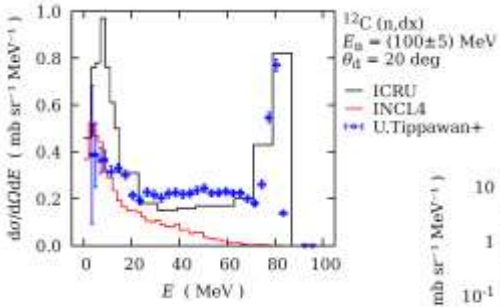
- DDX for the emission p, d, t, ^{3}He, ^{4}He
- Few datasets, at selected neutron energies, only up to 100 MeV

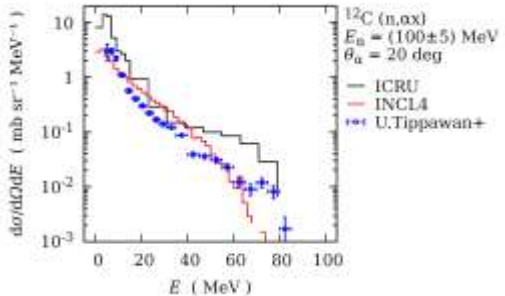
➤ Evaluations not based on experimental data

Nuclear model calculations (INC models)

- Modelling of the emission of composite ejectiles needs ad-hoc treatment
- Experimental data above 100 MeV are necessary for benchmarking, especially for alpha particles
- Carbon DDX calculation: discrepancies with experimental data, especially (n,dx) (n,αx)





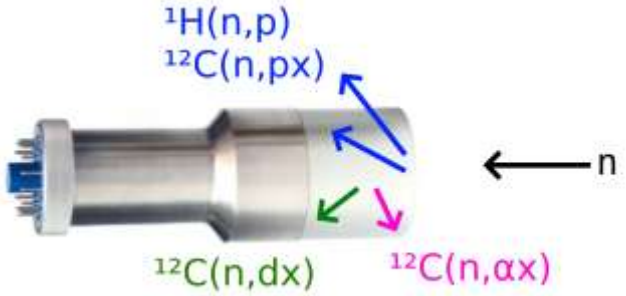


Additional Motivation: Simulation of Neutron Detectors

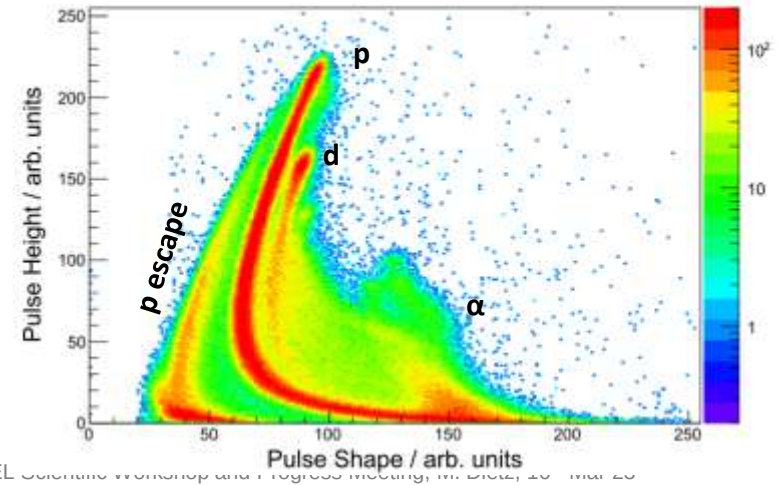
Response of a liquid scintillator to monoenergetic neutrons

- 2”× 4” BC501A (H:C = 1.212)
- E_n = 62.3 – 65 MeV

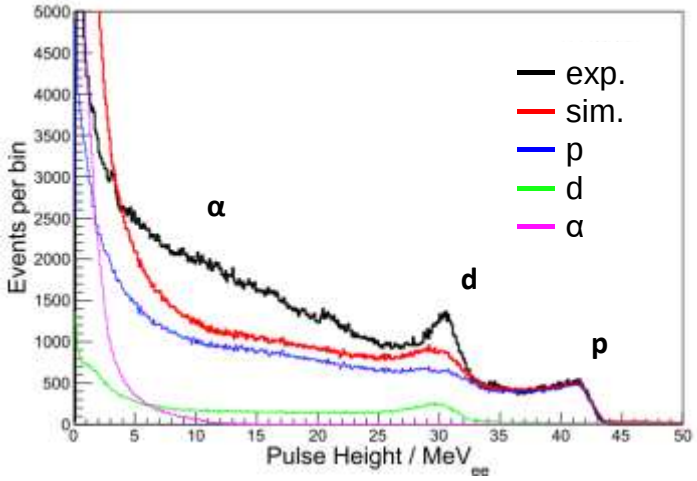
➤ pulse height response dominated by ^{12}C breakup reactions



Experimental data



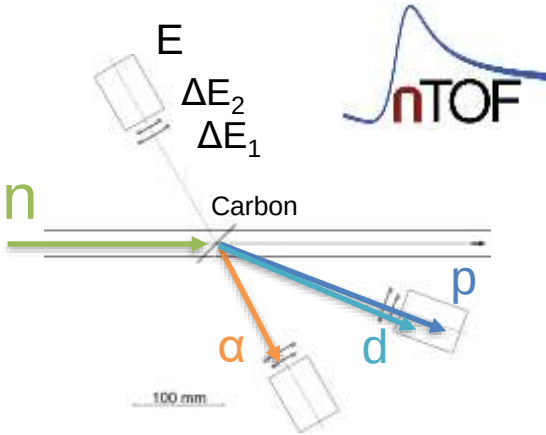
Simulation (LA150 - statistical model)



^{12}C(n, lcp x) @ n_TOF

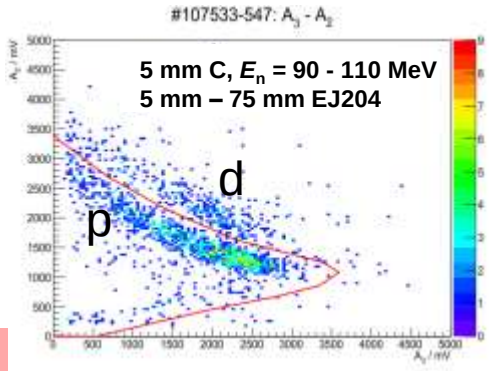
Measurements of DDX on carbon under emission of light charged particles at n_TOF for neutron energies between 20 MeV and 200 MeV

→ Development of ΔE^2-E telescopes (particle identification)
→ Simultaneous detection of p, d, t, ^{3}He, α (vacuum chamber)



Experience from previous ^{235}U(n,f)/^{1}H(n,n) experiment at n_TOF:

→ Recoil proton telescopes based on plastic scintillators worked up to 150 MeV



Demonstrated experience at n_TOF (2018)

Steps of development:

- Better resolution → Si-diodes + preamps?
- Lower Thresholds:
  Thin ΔE detectors for He-ions → 50-60µm thin Si-diode
- Higher max. neutron energy:
  up to 200 MeV → CeBr3 or long plastic scintillator

⇒ Prototype experiment to evaluate feasibility of DDX measurements above 100 MeV at n_TOF

Development of a Test Setup

Conversion of an old scattering chamber for test experiments at PIAF and n_TOF (2022)

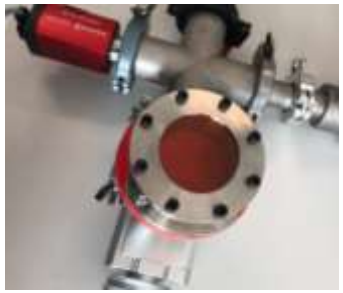
Chamber Features:

- 70mm height and 400mm diameter
- 47mm openings at every 45° angle

Chamber Improvements:

- extended height to 150mm to house diode + holders
- equipped with Kapton windows for beam/particles exits
- ground plate adjustable for beam experiment.

Used for test experiments with radioactive sources and p,α-beams at PIAF (PTB)



Development of detectors (I)

Procurement of detectors in 2020 and 2021:

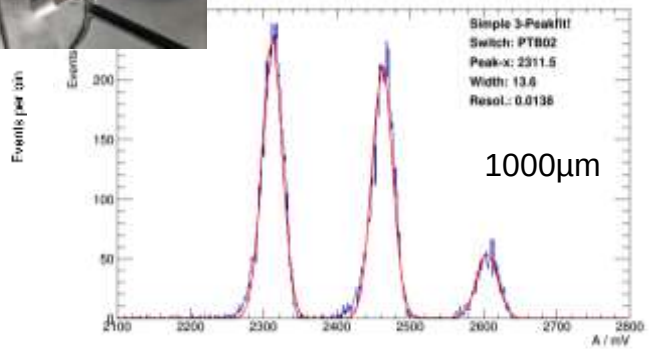
- Si diodes from MICRON and CANBERRA
  (50 µm, 60µm, 300µm, 500µm and 1 mm in thickness)
- 2″ × 3″ $CeBr_3$ with standard PMT

Resolution of diodes studied with alpha particles (5.2 MeV) from $^{239}Pu/^{241}Am/^{244}Cm$-source with different analog shaping

I. pre-amplifier Canberra 2004 + Tennelec TC242 amplifier (std. µs-long signal)

II. Integrated pre-amplifier-shaper combination like Cividec Cx-L series or CAEN A1425 (hundred-ns signal)

III. Pre-amplifier Canberra 2004 + fast-filter amplifier ORTEC 579 (flexible signal)

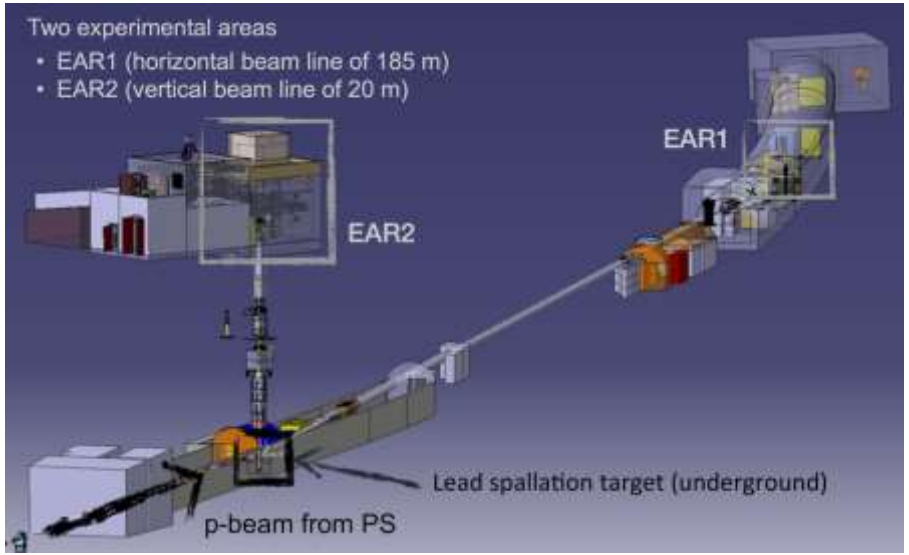


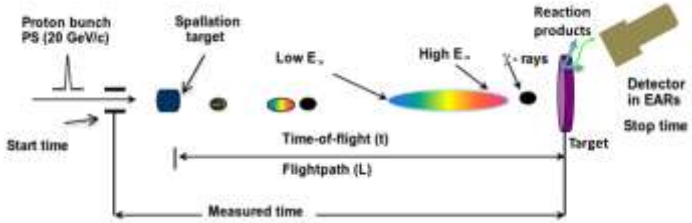
Resolution (%)	M1000	M500	M60	C500
PA2004 + TC242	0.6 %	0.9 %	1.3 %	0.6 %
PA2004 + Ortec579	2.6 %	2.4 %	2.6 %	1.8 %
Cividec Cx-L	**1.1 %**	**1.3 %**	**2.6 %**	**1.2 %**
Cividec + Switch	1.3 %	1.5 %	3.1 %	1.3 %
CAEN A1425	2.1 %	2.9%	3.0 %	2.2 %

Conclusions:

- TC242 offers best resolution <1%, but inapplicable for nTOF
- Cividec offers good resolution with fast shaping required for nTOF

n_TOF @ CERN





$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1-\beta^2}} - 1\right) \quad \text{with} \quad \beta = \frac{L}{t_n c}$$

n_TOF EAR1:

- large energy range: 25 meV – 1 GeV
- high energy resolution: $\Delta E/E = 10^{-4}$
- low repetition rate < 0.8 Hz → low average flux
- high instantaneous flux
  typical bunch:
  $7 \cdot 10^{12}$ protons × 300 neutrons/proton
- intense γ-flash

n_TOF: Only neutron source above 100 MeV in Europe

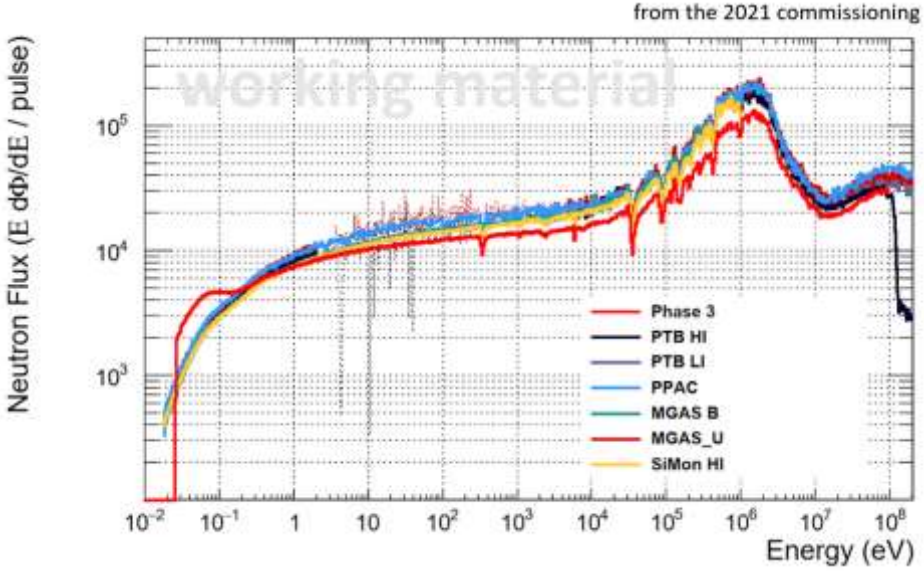
High-energy DDX for ^{12}C(n, lcp x) @ n_TOF?

⇒ Prototype experiment to evaluate feasibility of DDX measurements above 100 MeV at n_TOF

tof_n / ns	En / MeV
614	γ-flash
720	8.58E+02
900	3.45E+02
1200	1.54E+02
2000	4.76E+01
5000	7.16E+00
8000	2.78E+00
13000	1.05E+00
15000	7.88E-01
20000	4.43E-01
50000	7.08E-02
80000	2.77E-02
100000	1.77E-02
500000	7.08E-04
1.00E+06	1.77E-04

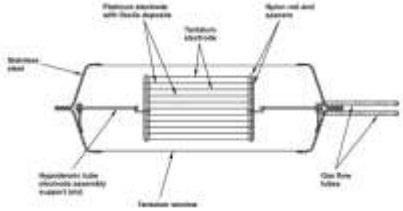
MeV
13µs →
keV
420µs →
eV

n_TOF Commissioning 2021



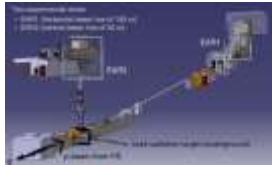
Fission Ionisation Chamber H19: (^{235}U)

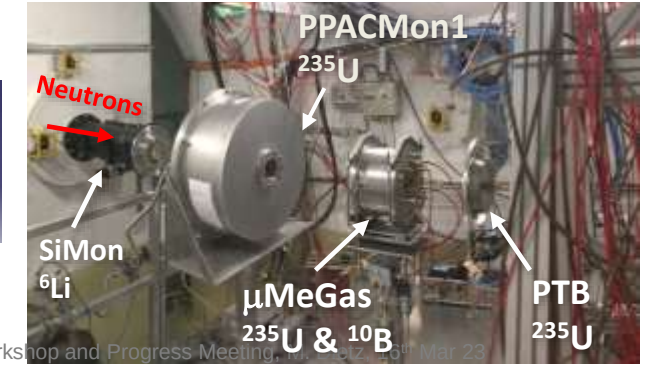
- m_u = 201 mg
- A_{235U} = 1.62E+04 Bq
- 99.9183% ^{235}U



Analysis of neutron fluence / proton-pulse:

- Threshold and Zero-Bias efficiency
- High energy correction for secondary neutrons (n,xn) --- MCNP

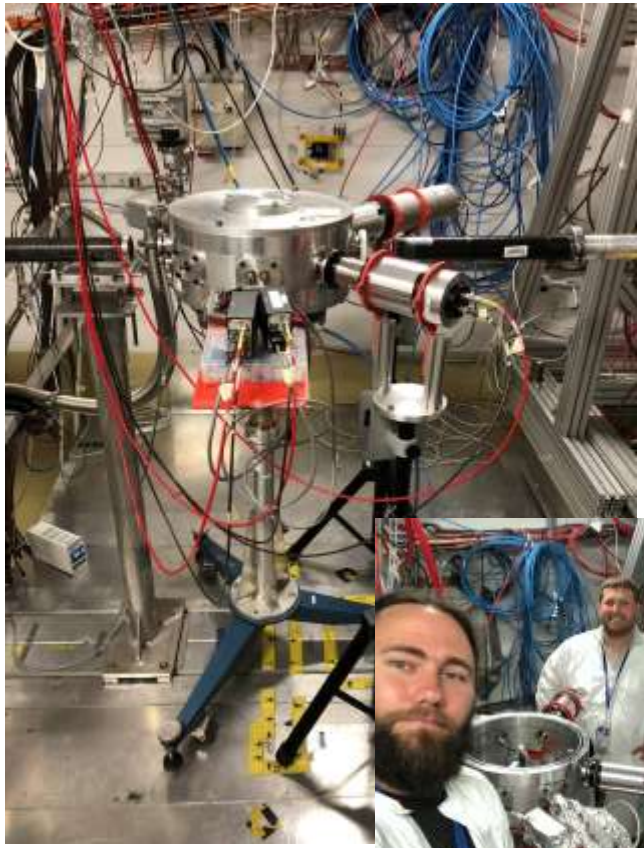


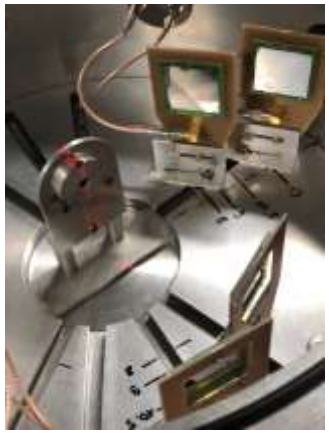


→Final DDX experiment will run with additional neutron fluence monitor

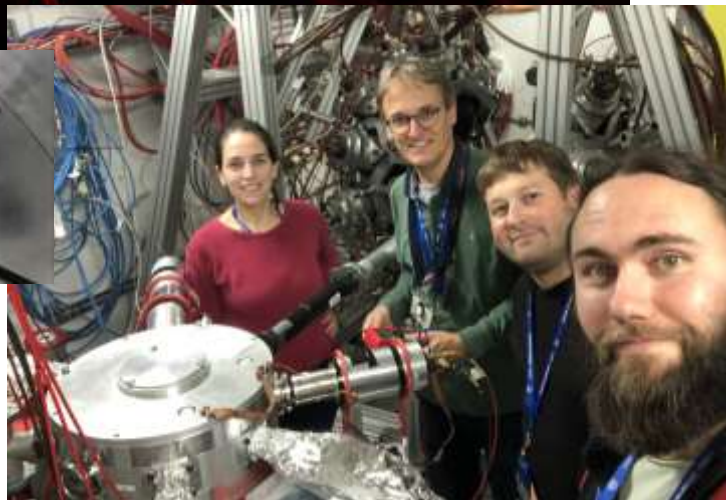
- Experience from previous measurements

DDX Tests @ n_TOF (05/22 + 11/22)





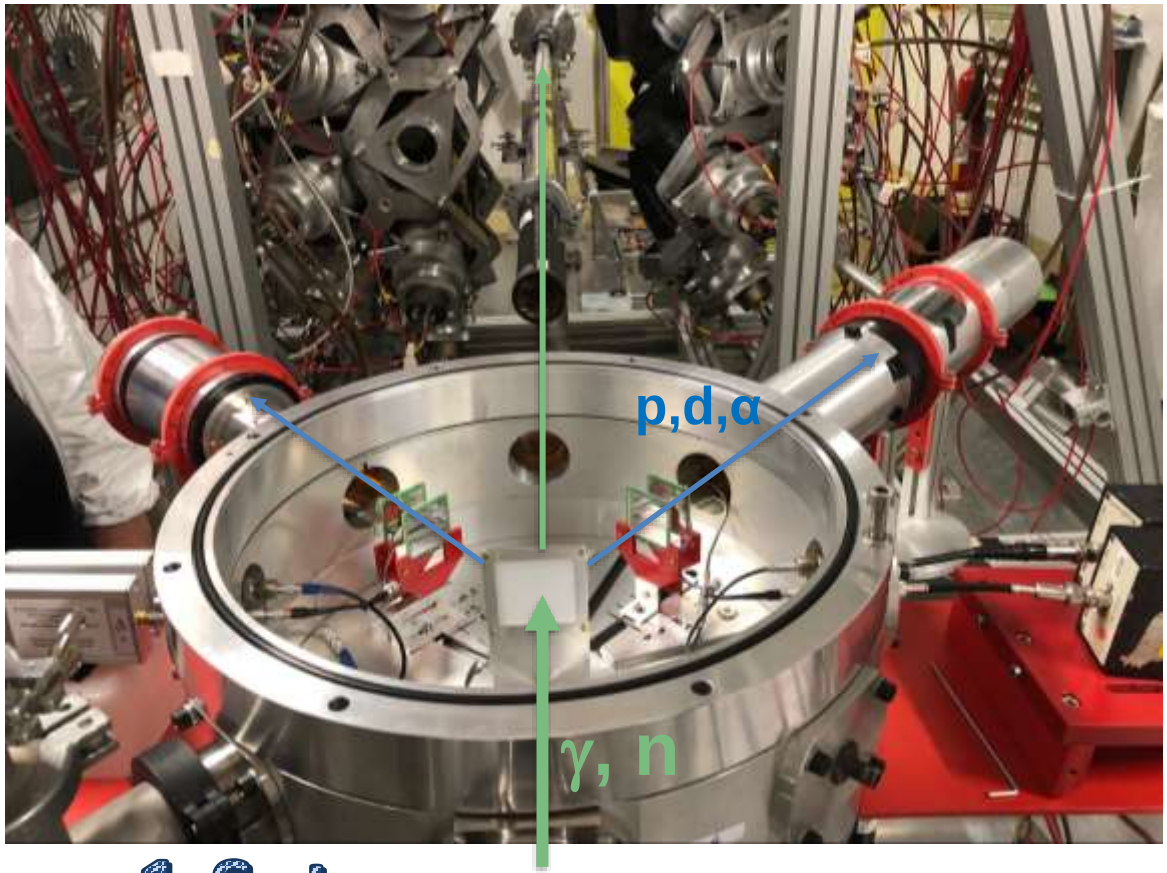
Setup, Calibration, Alignment, Switch device…



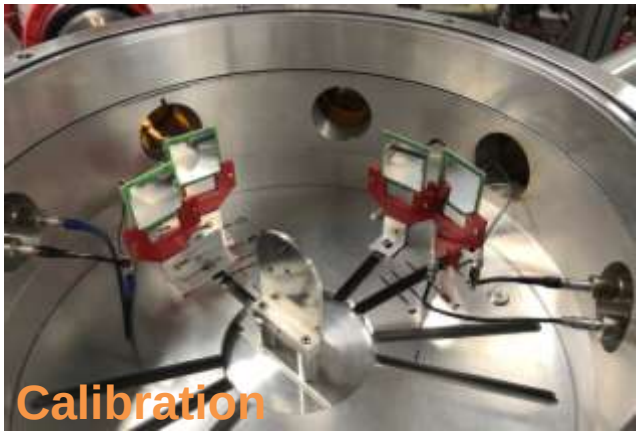
DDX on ^{12}C(n, lcp x) @ n_TOF

Goals:

- Detector response of γ-flash
- Maximum neutron energy detectable
- Particle identification possibilities
- Test of electronics (amplifiers/shaping)
- Background, …

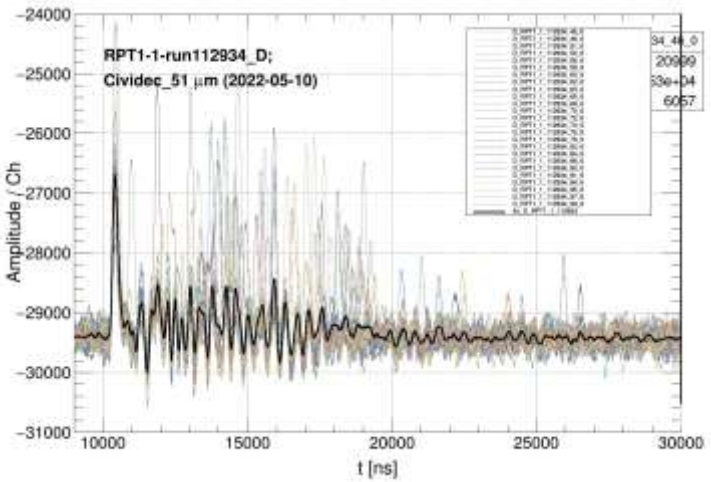


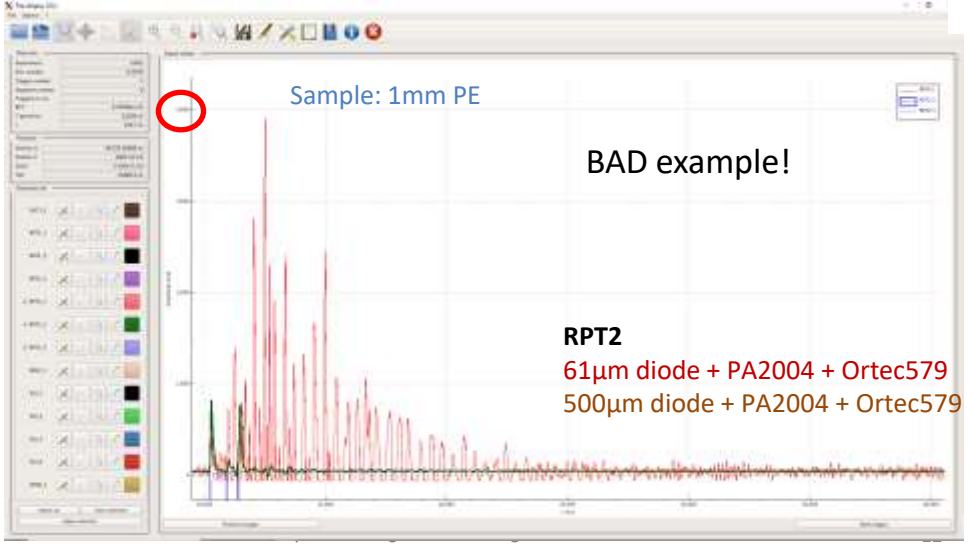
1.Setup

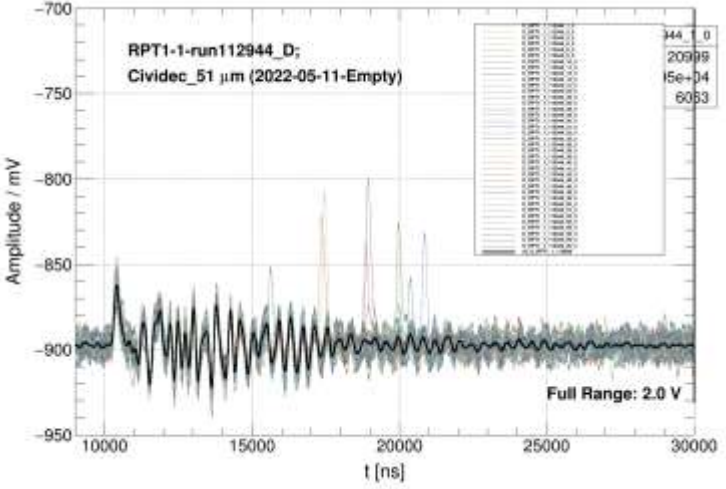


Waveforms I (May 22)

- Tried out different configurations (Cividec, Canberra2004, Switch, Cremat, …)
- **Beam induced RINGING** (10µs, 3 to 5 MHz) =>Oscillations with different amplitude, similar patterns, independent of samples

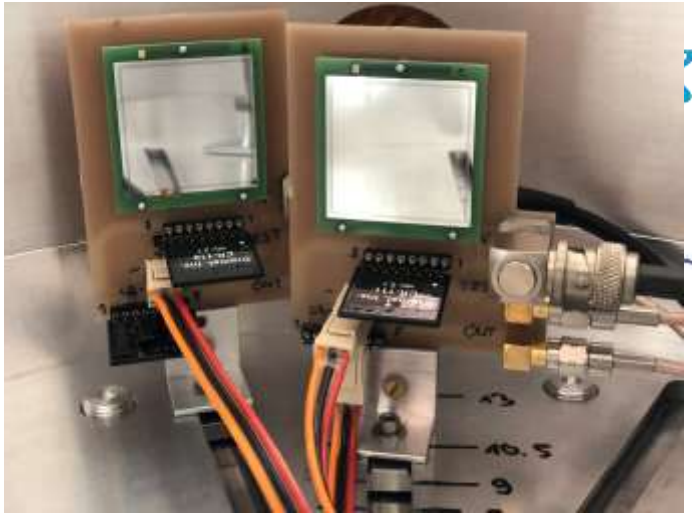


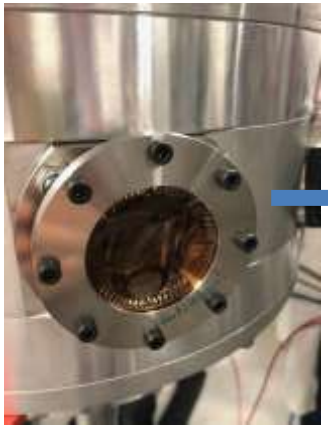


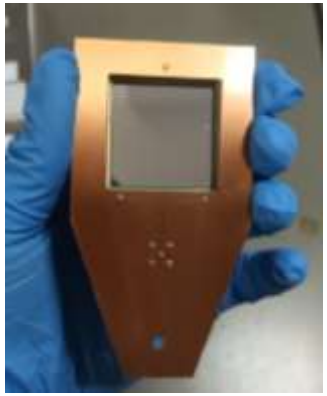


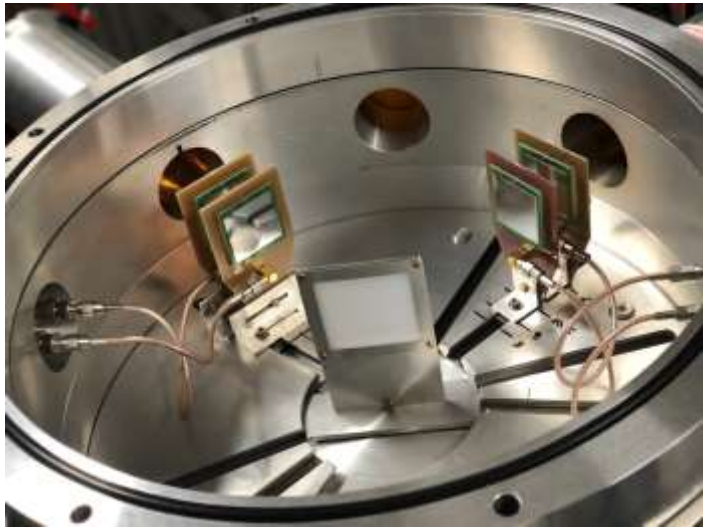
3 Main Improvements

- Aluminium shielding (100-200µm) of kapton windows (RF-tight)
- SMA cabling inside chamber
- New diode holder with option for preamp inside

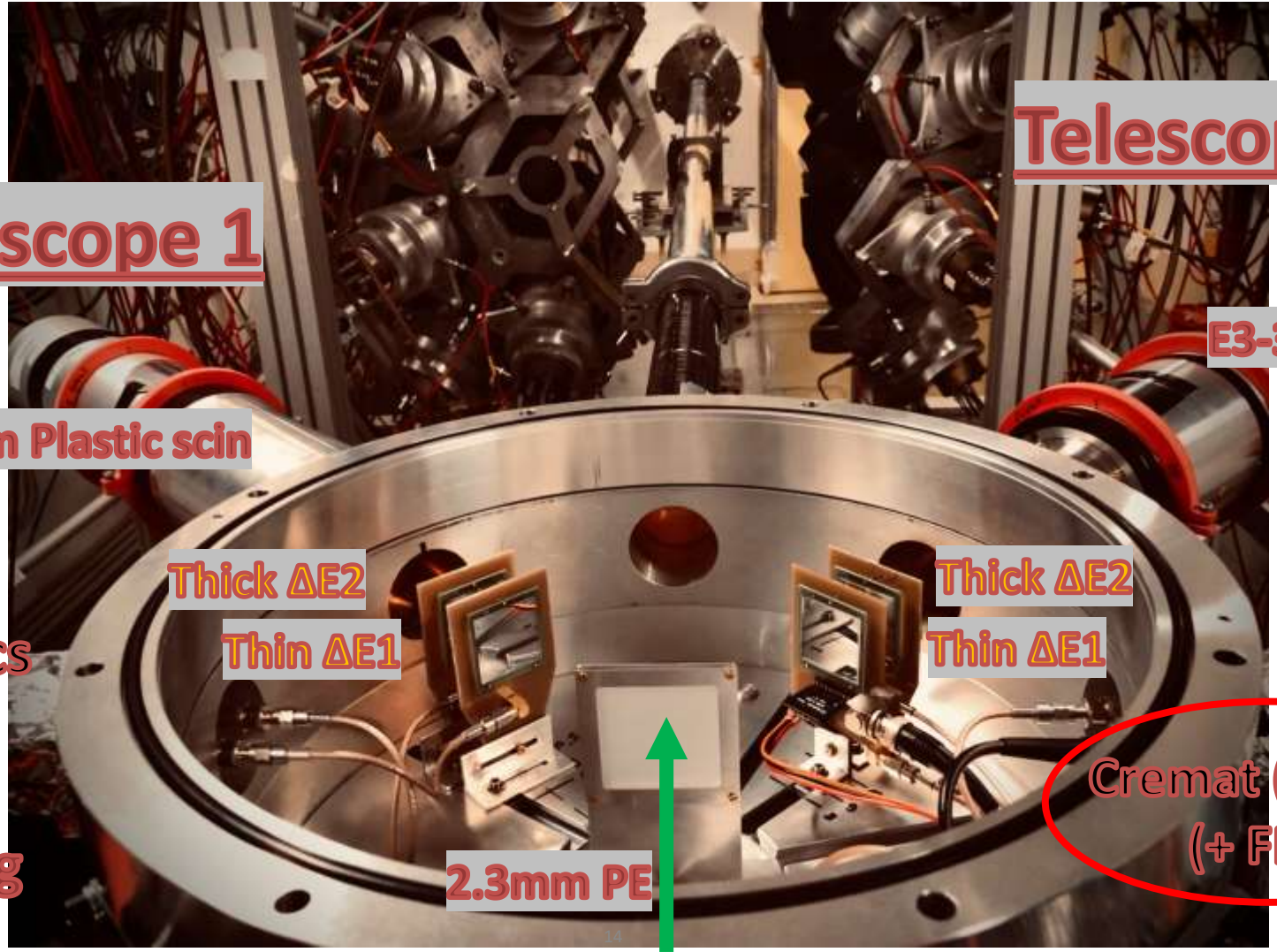




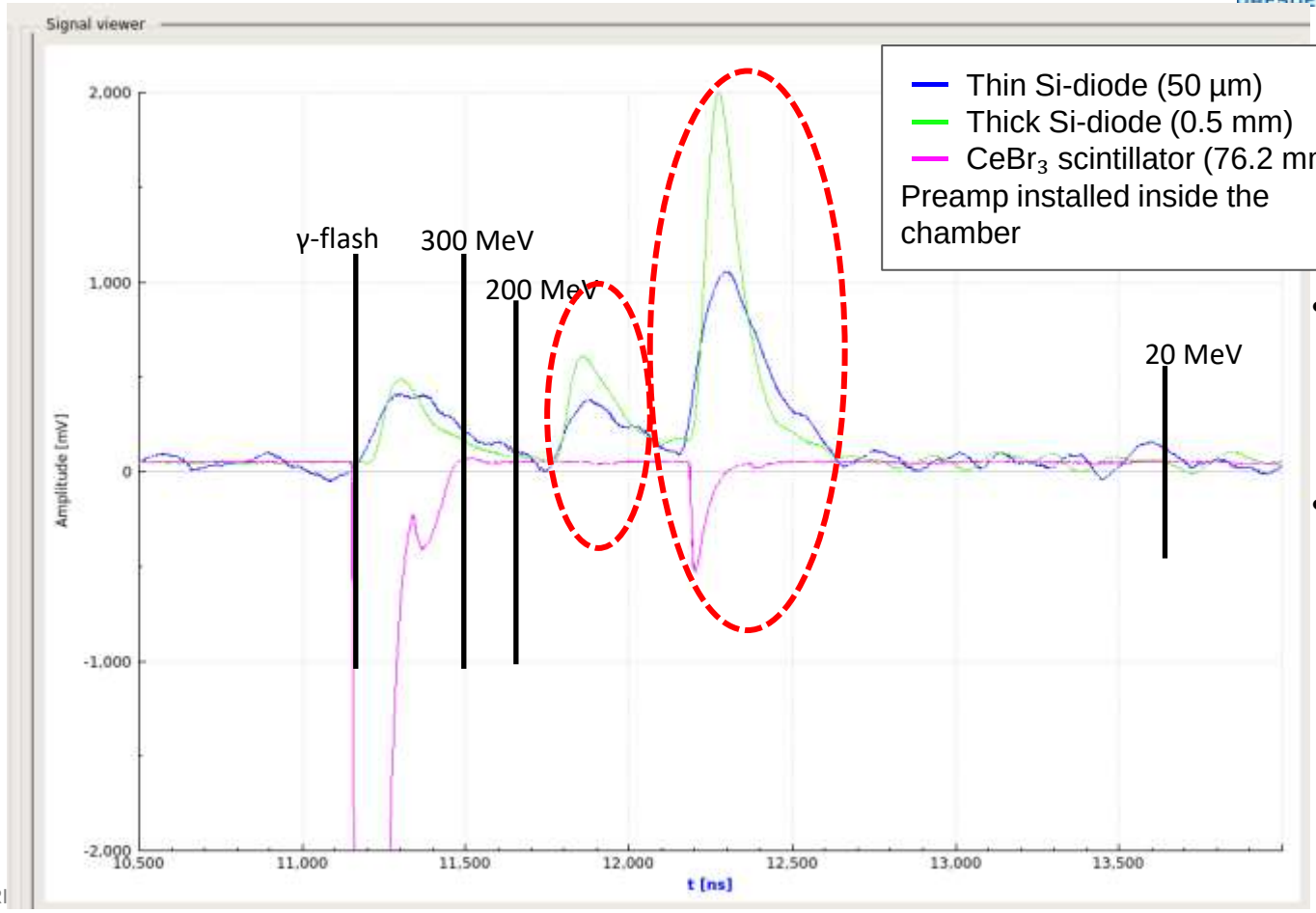




SETUP
Nov 22


Telescope 1
Telescope 2
E3-3´´ CeBr3
E3-150mm Plastic scin
PA2004
+ FFA
Thick ΔE2
Thick ΔE2
Thin ΔE1
Thin ΔE1
Cividecs
Cremat (inside)
(+ FFA)
Pumping
downstairs
2.3mm PE

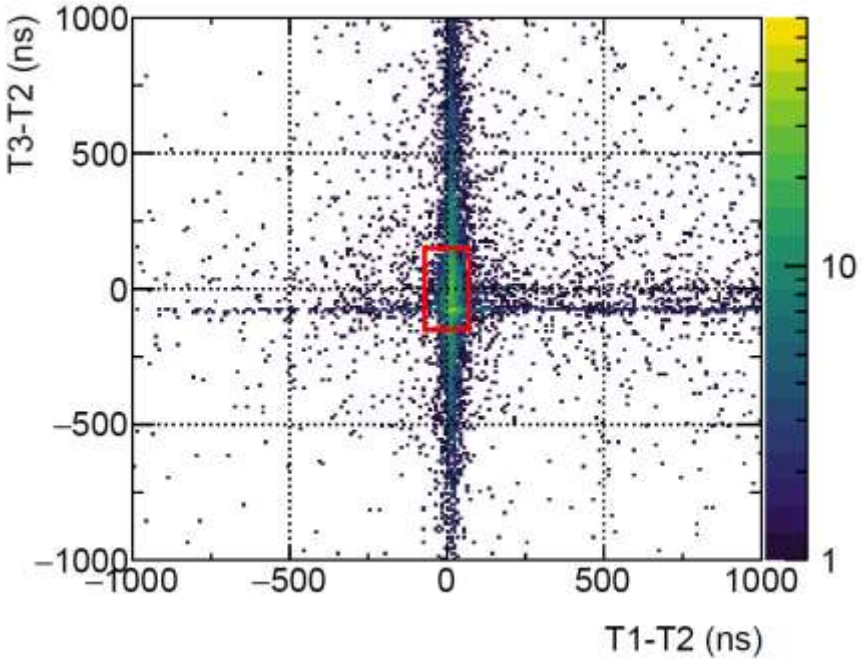
Waveforms II (Nov. 2022)



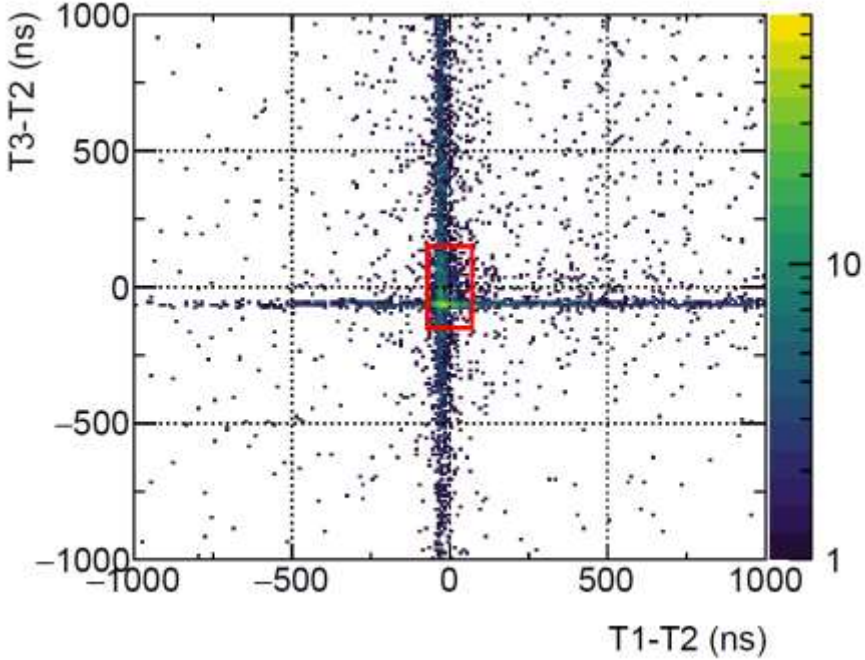
- Ringing under control (only random noise)
- Nice coincidences between 2 or 3 detectors identified

Coincidence Patterns

RPT1: 50-1000-Cividecs + Plastic



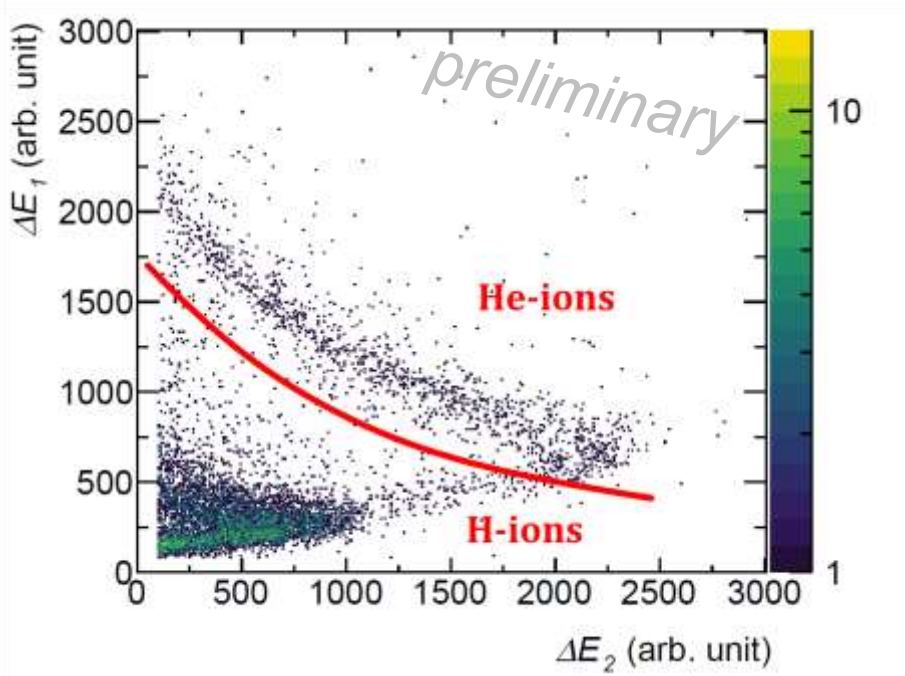
RPT2: 50-Cremat+500-Canberra + CeBr3



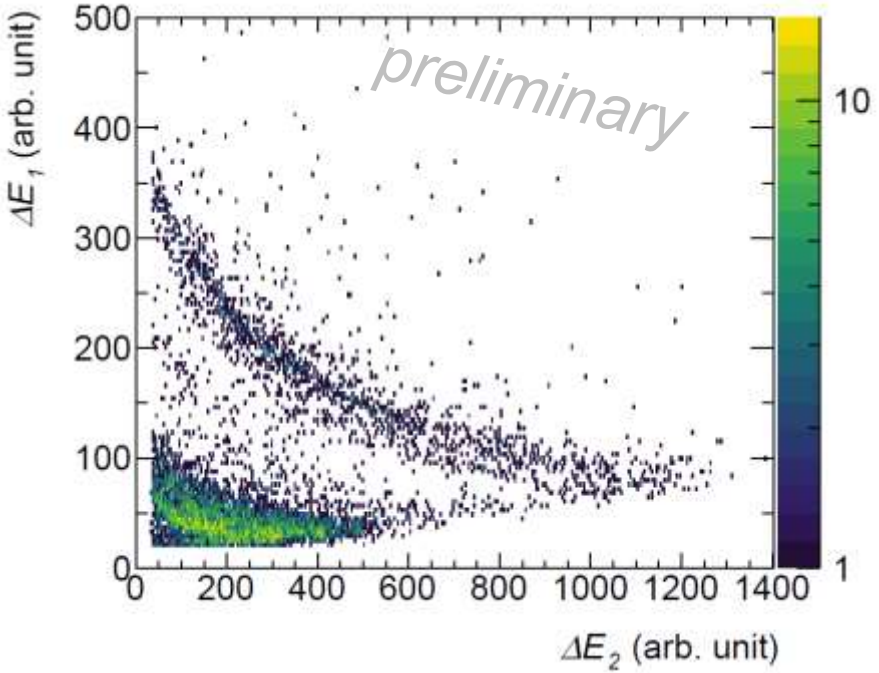
- Coincidence patterns depends on electronic amplification chain
- So far, ΔT is minimised and small amplitude cuts are applied.

DDX Spectra from Carbon (I)

Cremat

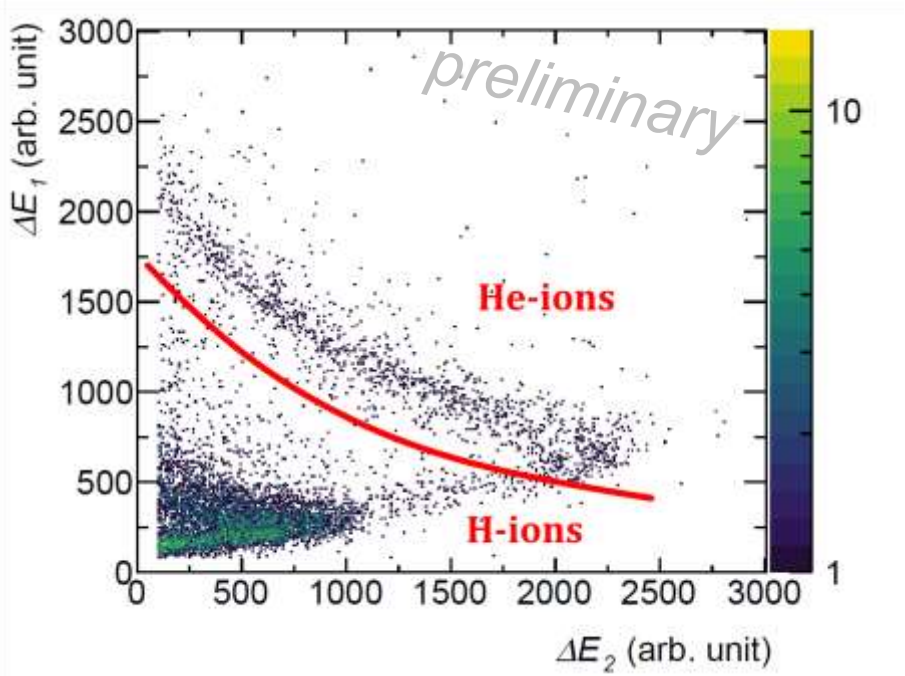


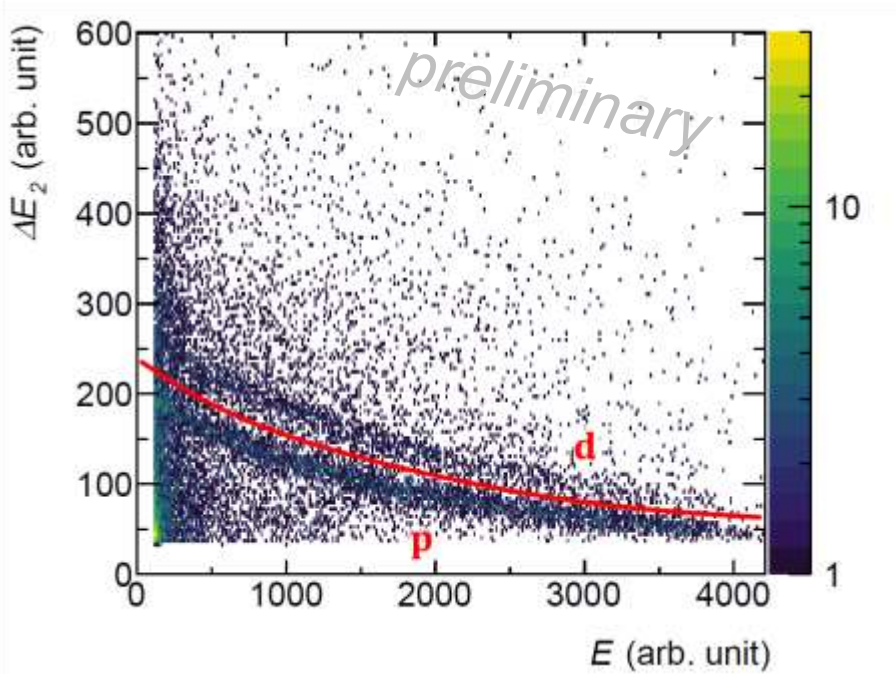
Cividec



- Comparable diode results; but Cividec still needs special baseline correction
- Financial aspect: Cremat are much cheaper option than Cividec

DDX Spectra from Carbon (II)





- Particle separation is possible up to E_n ~200 MeV
- Choosing detectors with low intrinsic noise is fundamental

Future plans

Construction of a new vacuum chamber

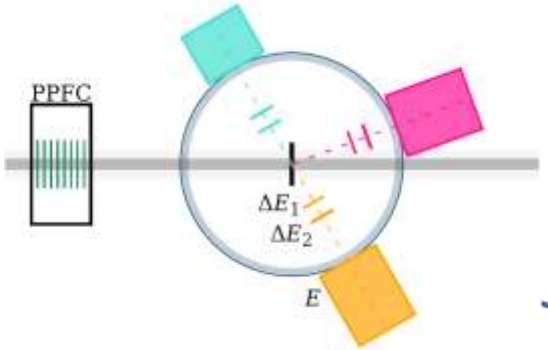
Improvement of resolution / noise level of ΔE-detectors:

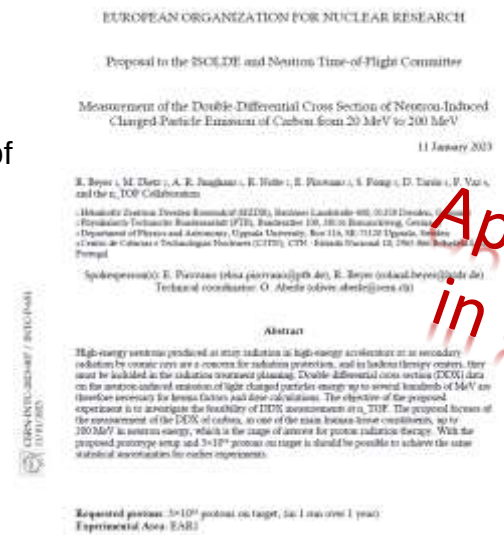
- Analog vs. digital shaping
- Diode size / capacity <-> noise

Approved Beam time 2023/2024 @ n_TOF EAR1:

- 3×10^{18} protons on spallation target (≈ 30 days)
- Sample: 2 mm C (+ 0.5 mm C)
- Setup of three ΔE^2-E telescopes
- Neutron energy range of interest: 100-200 MeV
- Expected statistical uncertainty of DDX data should be comparable to that of previous experiments (TSL; E_n = 100 MeV, ΔE_n = 10 MeV) :
  - ≈ 10% per energy bin for ^{1}H
  - ≈ 20% - 30% per energy bin for ^{4}He
  - neutron energy resolution $\Delta E_n/E_n$ ≈ 10%

Goal: provide data to support improvement of INC models





EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the Double-Differential Cross Section of Neutron-Induced Charged-Particle Emission of Carbon from 20 MeV to 200 MeV

11 January 2023

Abstract

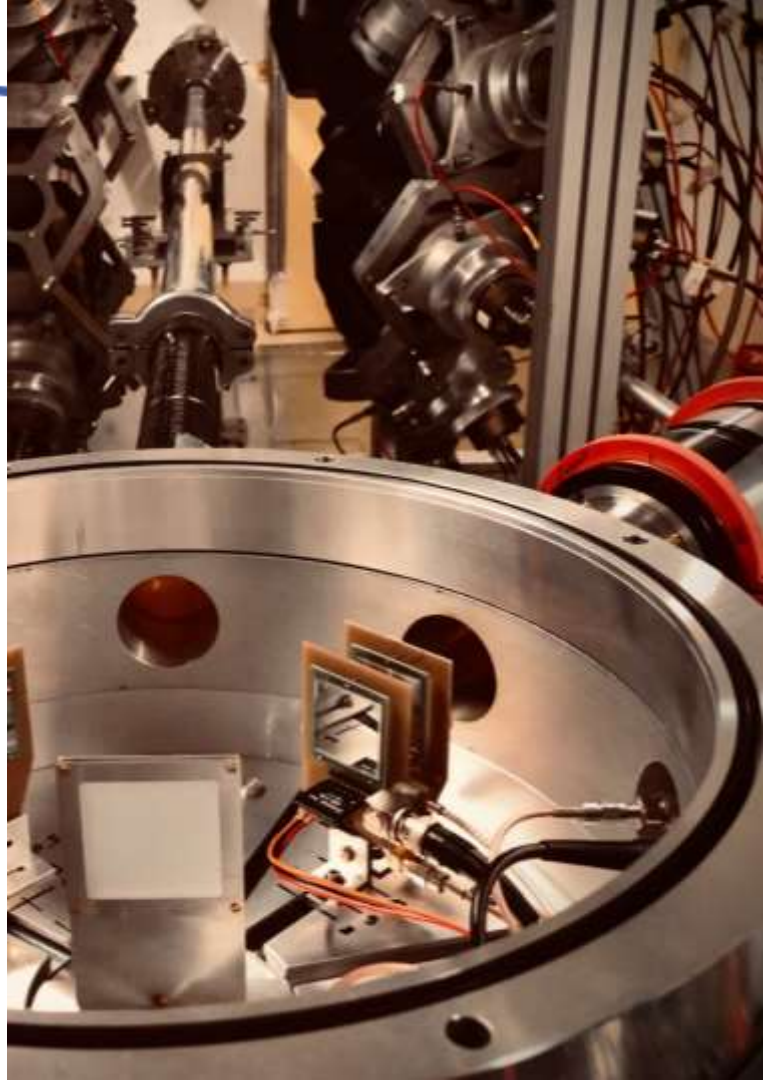
Approved in 02/23

Summary

- Detector development for particle telescopes with shielded preamplifiers / vacuum chamber
- Particle identification seems possible from test data

- Proof-of-principle experiment for the measurement of DDX data for carbon in EAR1, focused on E_n >100 MeV
  - INTC **approved beam time of 30 days** in the future
  - According to the estimates, the statistical uncertainties should be comparable to that of previous experiments, at least at forward angles

- **New kind of measurement at n_TOF**, in a largely unexplored energy range
- If successful, future measurements could include: N, O, detector materials



Acknowledgement:
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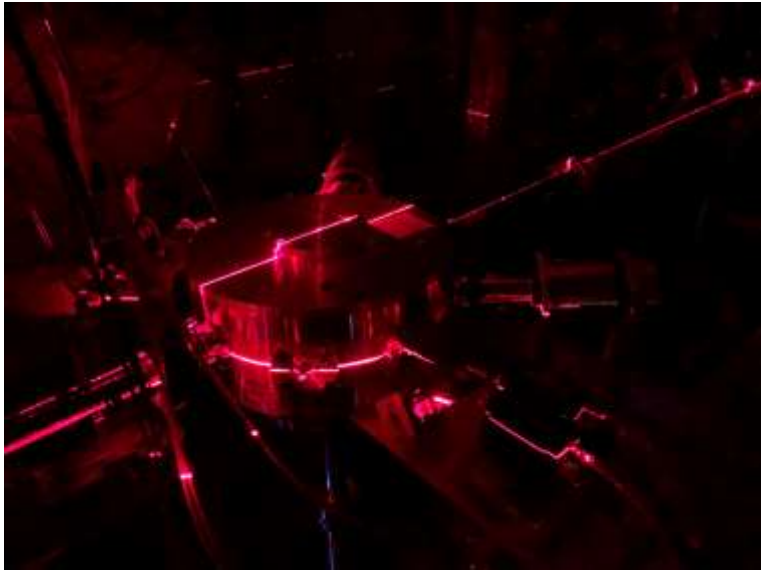
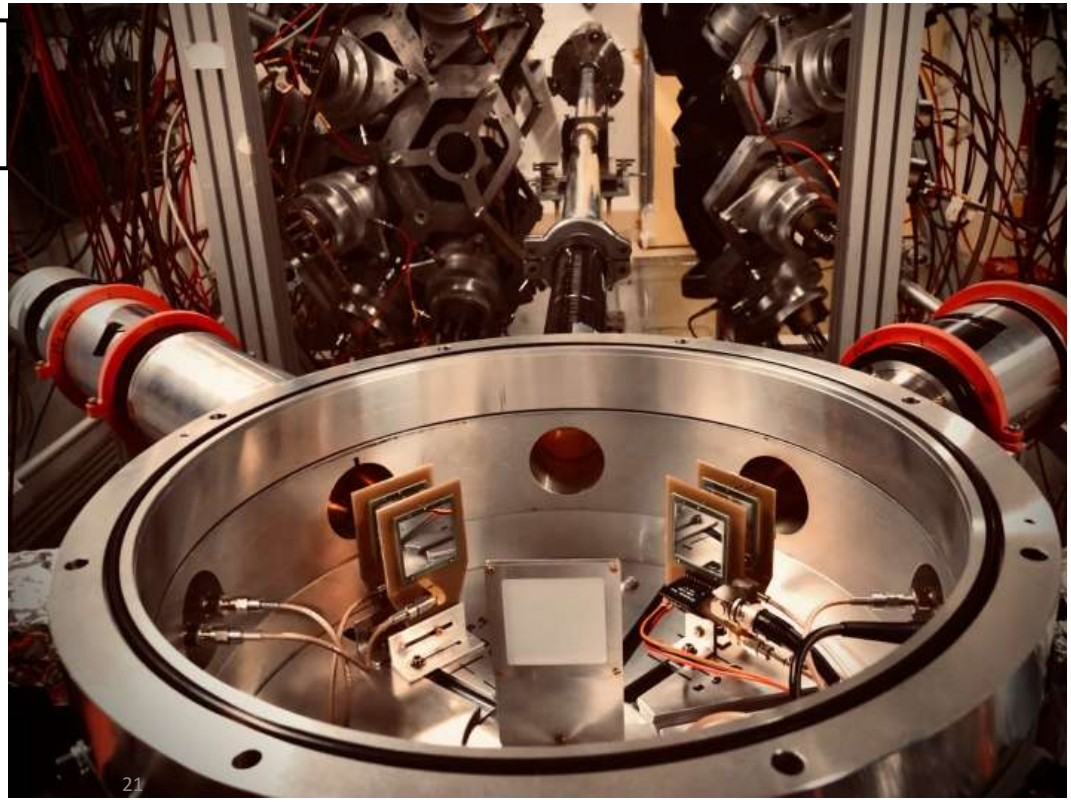
- HZDR colleagues
- PTB Transport Service
- PTB Workshop and electricians
- Local team
- Shifters
- n_TOF
- RP (PTB + CERN)

THANK YOU!





QUESTIONS ???

APPENDIX / EXTRA SLIDES

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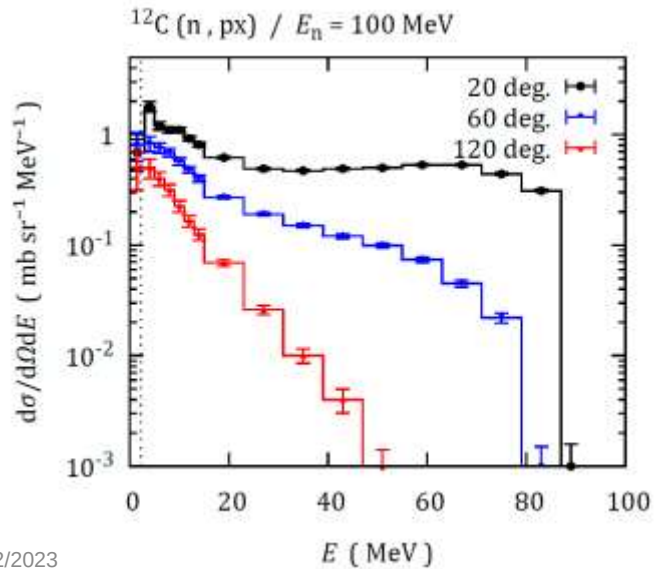
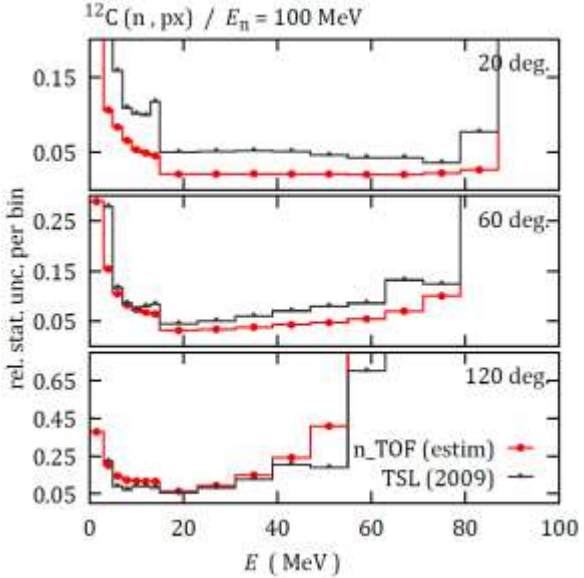
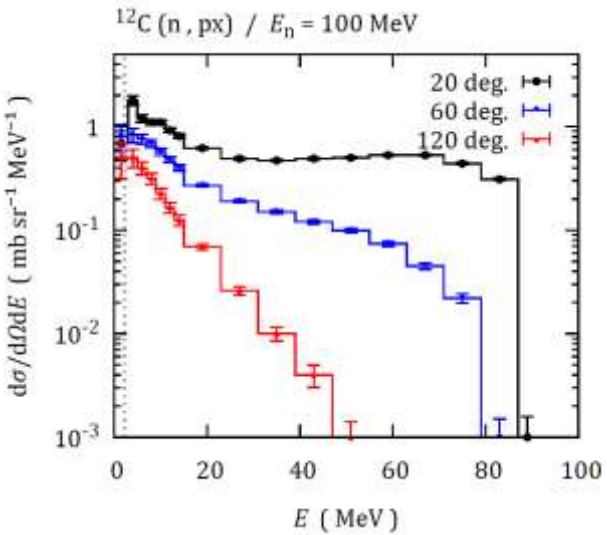
Count rate estimates

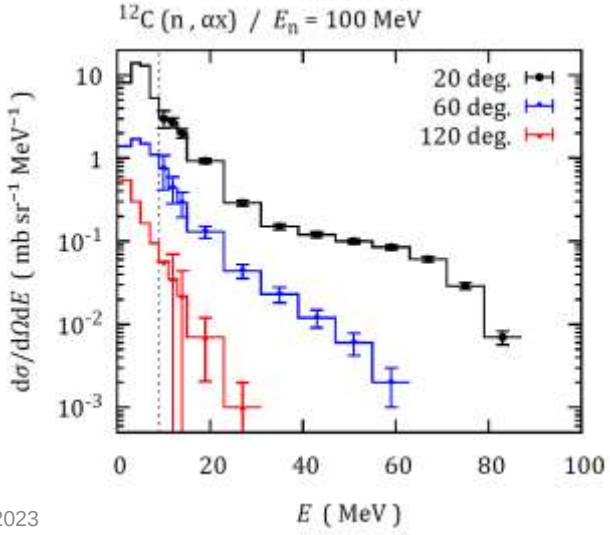
- 25×10¹⁷ protons / 2 mm sample
  + 5×10¹⁷ protons / 50 µm sample
- Comparison with measurement at TSL, E_n = 100 MeV, ΔE_n = 10 MeV
- Cut-off energy determined by thickness of ΔE_1 detector (50 µm Si)

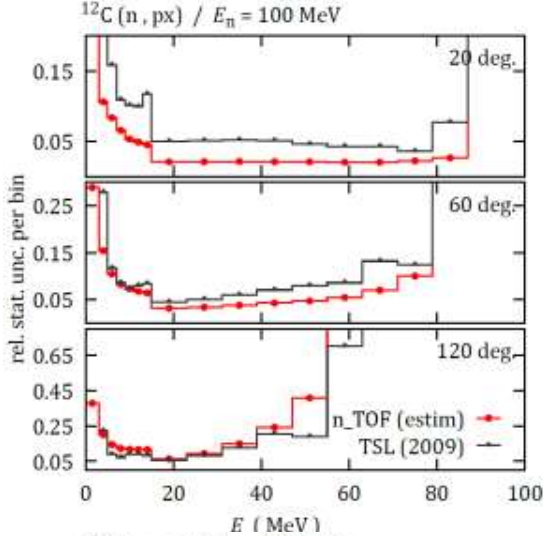


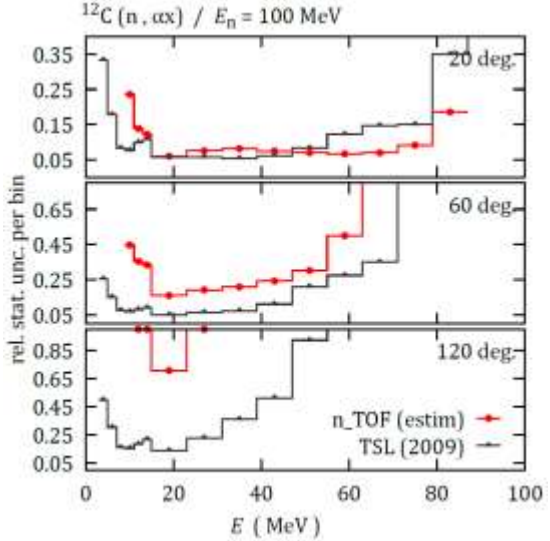


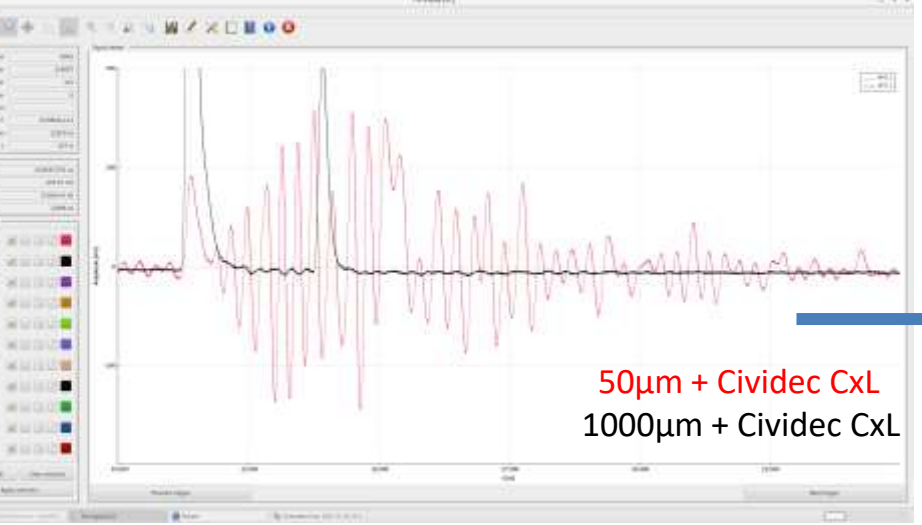
Count rate estimates



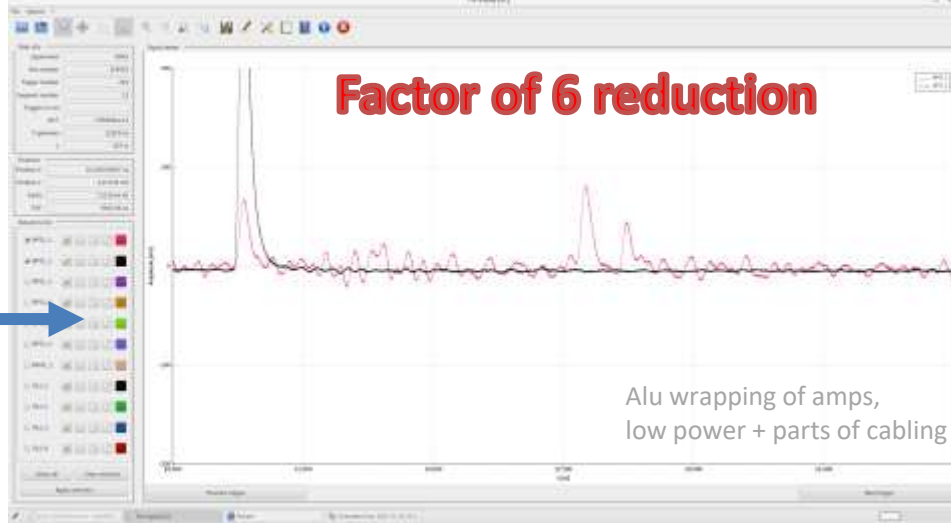






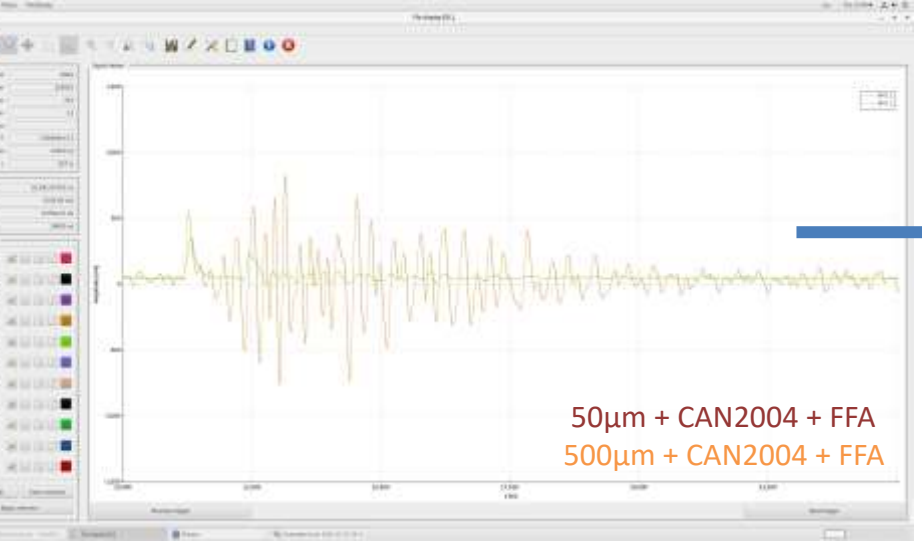


50µm + Cividec CxL
1000µm + Cividec CxL

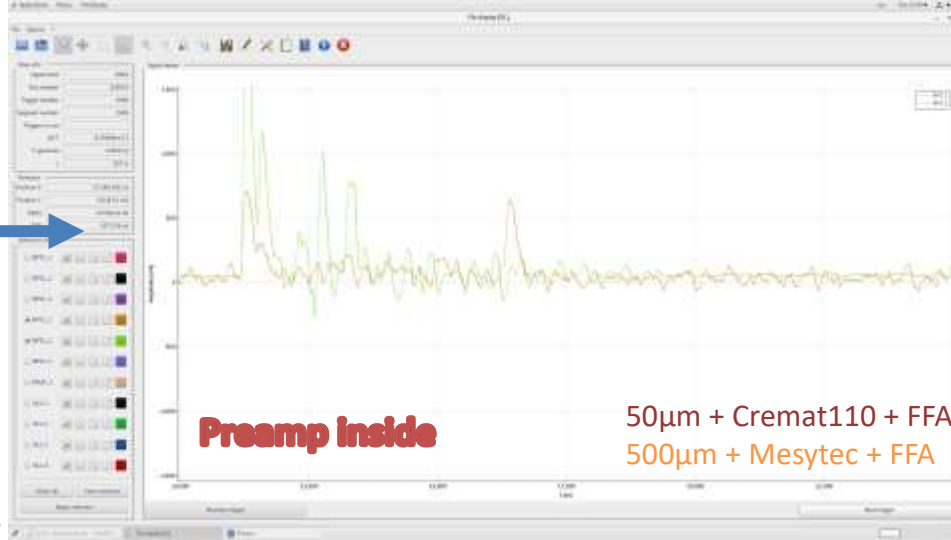


Factor of 6 reduction

Alu wrapping of amps,
low power + parts of cabling



50µm + CAN2004 + FFA
500µm + CAN2004 + FFA



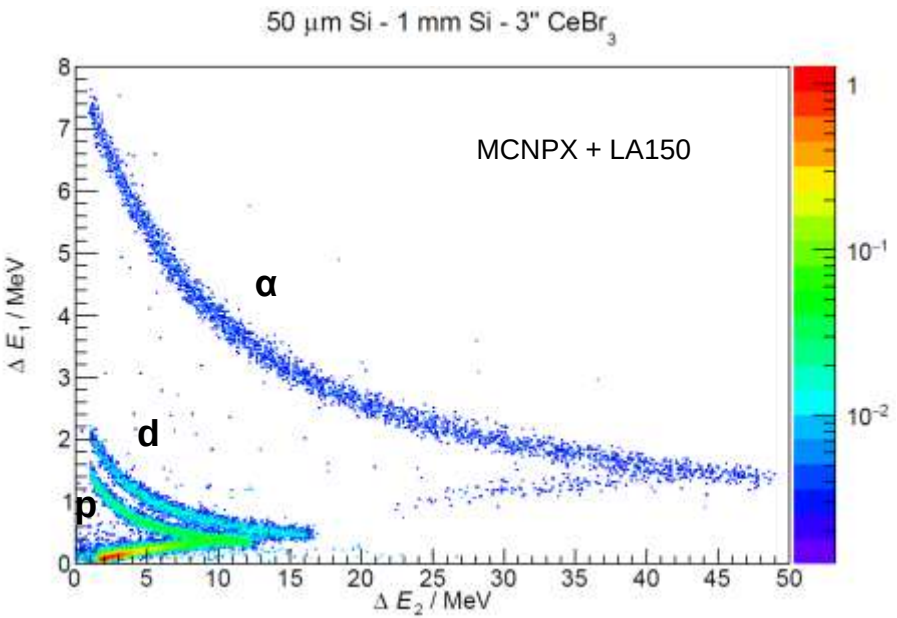
Preamp inside

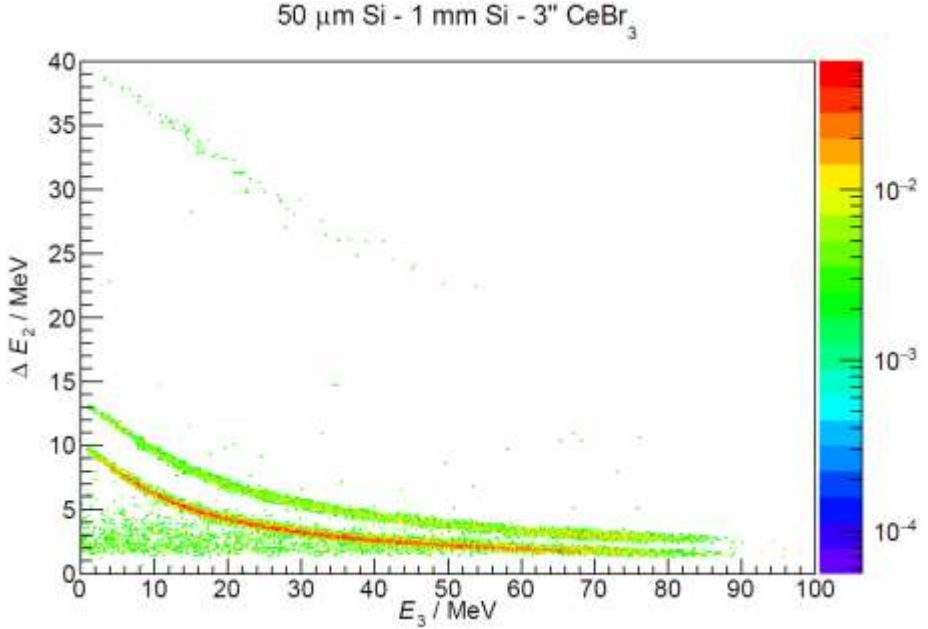
50µm + Cremat110 + FFA
500µm + Mesytec + FFA

Expectation: Monte-Carlo studies (I)

E_n = 100 MeV, 1.0 mm graphite sample, θ = 45°

ΔE_1-ΔE_2-E Telescope:
50 µm Si – 1 mm Si – 76 mm $CeBr_3$





Conclusions:

- Particle identification is possible under current diode resolution results

Status of WP 2, Subtask 2.6.2

WP1, Subtask 1.4: Preparation

- Test of detector and read-out technologies under n_TOF conditions
- Successful LOI to the INTC for test beam time
- Development of a detector set-up under given financial constraints

WP2, Subtask 2.6.2: Measurements of DDX for light charged particles at n_TOF at E_n > 100 MeV

- First of this kind at n_TOF
- Final experiment not before 2023
- Acceptance of the proposal by the INTC required

Deliverable:

- D.2.10 Report on measurements of DDX for (n, lcp x) at n_TOF (M48)