Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

SANDA
Supplying Accurate Nuclear Data for energy and non-energy Applications

HORIZON2020

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

(DDX experiment at n_TOF EAR1)

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E. Pirovano, S. Pomp, D. Tarrío, P. Vaz
and the n_TOF collaboration

Neutron-induced emission of light charged particles at 100-200 MeV

High-energy secondary neutrons produced
- in hadron therapy: E_n up to 200/400 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

Present situation:
- Only few data for E_n >50 MeV
- Modelling of composite ejectiles is challenging

Status of DDX data for carbon

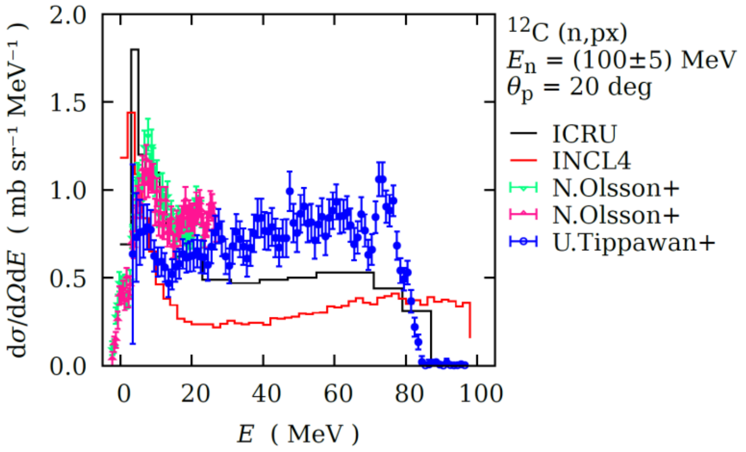
Experimental data above 20 MeV:

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

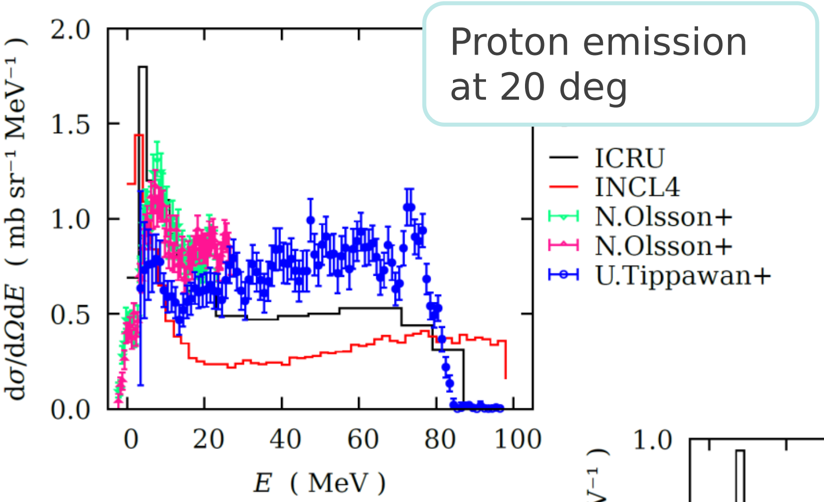
➤ Evaluations not based on experimental data

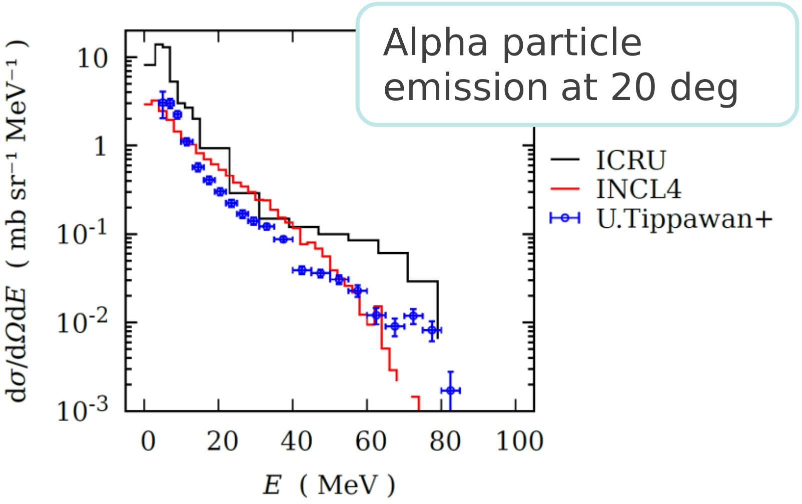
Nuclear model calculations (INC models)

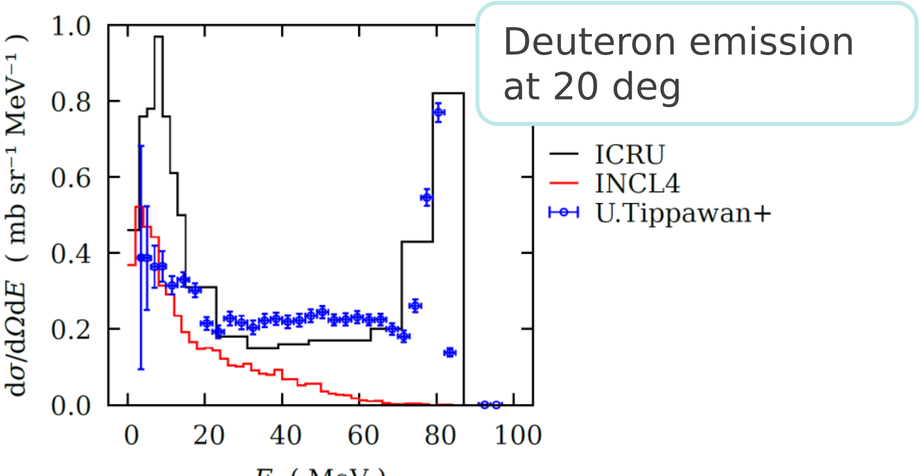
- Modelling of the emission of composite ejectiles needs ad-hoc treatment
- Experimental data above 100 MeV are necessary for benchmarking, especially for alpha particles
- Carbon DDX calculation: discrepancies with experimental data, especially (n,dx) (n,αx)



n+C measurements at E_n = (100±5) MeV





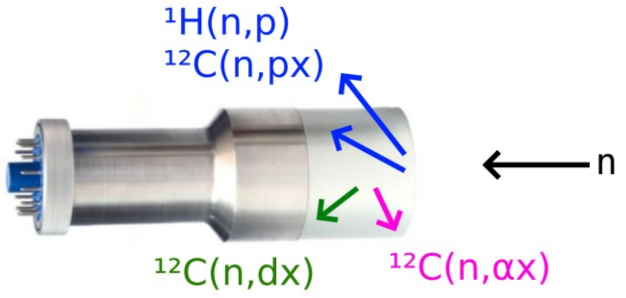


Additional Motivation: Simulation of Neutron Detectors

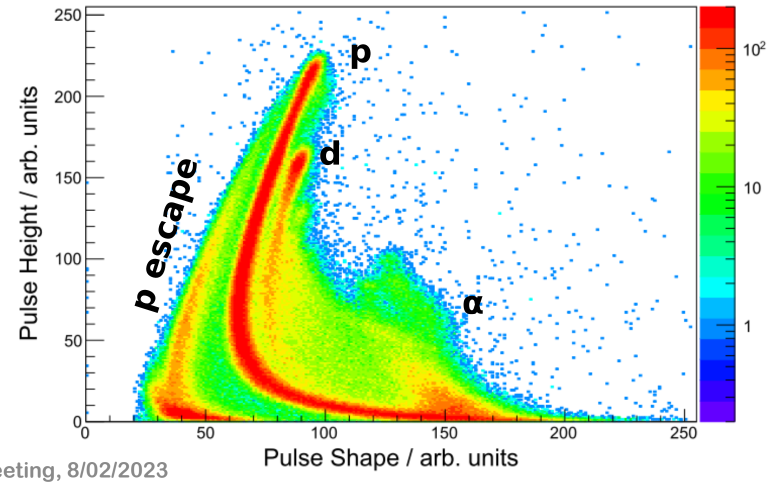
Response of a liquid scintillator to monoenergetic neutrons

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

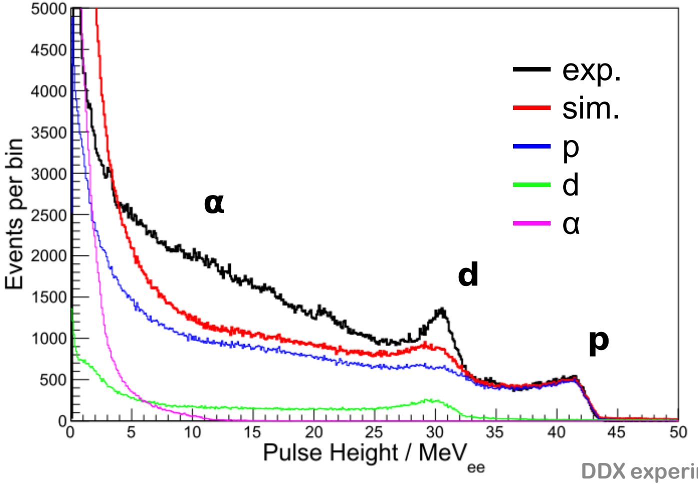
➤ pulse height response dominated by ^{12}C breakup reactions



Experimental data



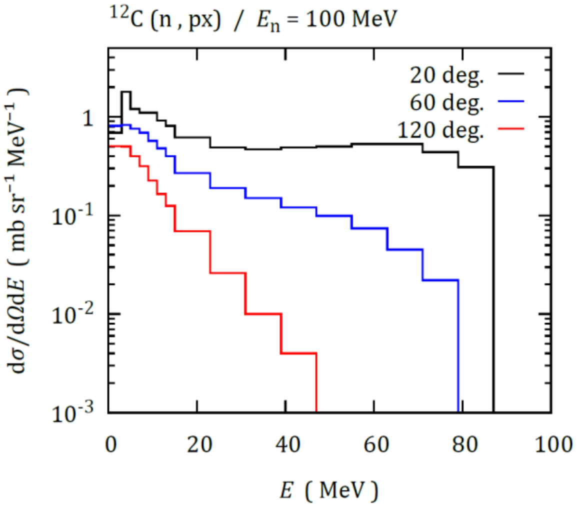
Simulation (LA150 - statistical model)



DDX measurements at n_TOF?

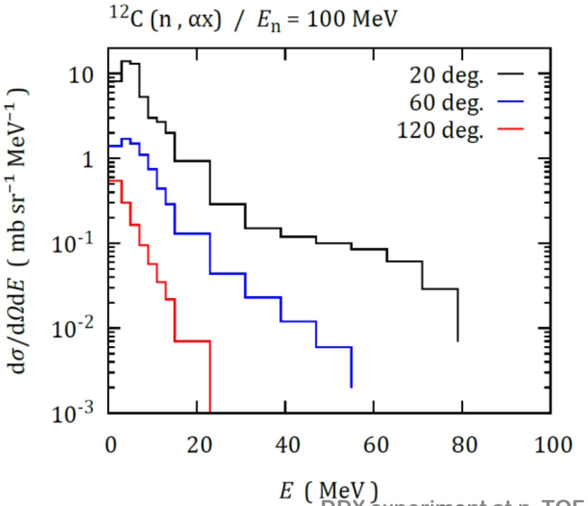
Study of the feasibility of DDX measurements at n_TOF

- Prototype experiment with carbon, E_n = 20 MeV - 200 MeV, for the emission of p, d, t, α
- focus on E_n >100 MeV
- aiming at stat. uncertainties similar to that of previous experiments, at least at forward angles



Detector test beamtime (LOI of Sep 2020)

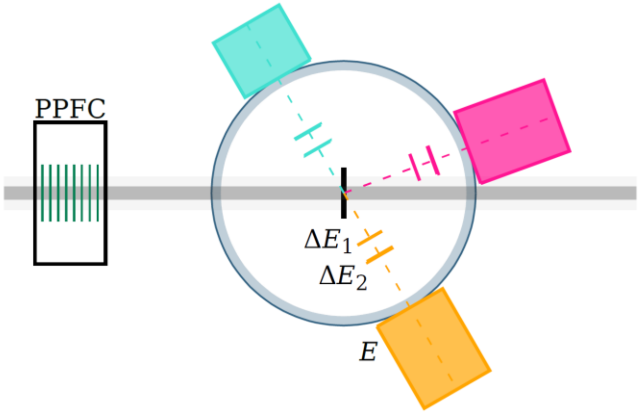
- Study the interaction with the γ flash
- Test particle identification techniques
- However: large energy ranges, low interaction probabilities



➤ To determine if DDX measurements are possible, and under which limitations, a longer beamtime is necessary!

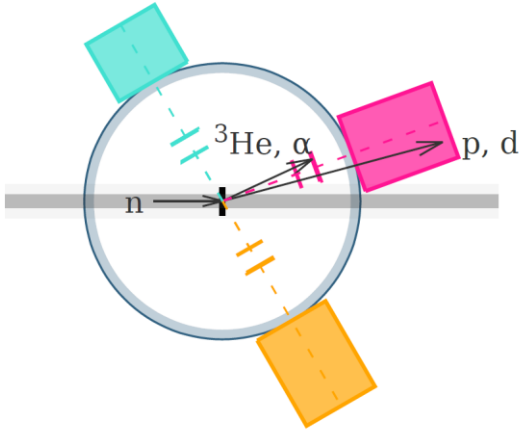
Proposed experimental setup

- Installed in EAR1
- Vacuum chamber &
  3× triple-stage telescopes ΔE_1-ΔE_2-E
  at 20°, 60°, 120°
- ΔE detectors: Si-diodes (50 – 1000 µm)
  E detectors: plastic & $CeBr_3$ scintillators
- Two graphite samples: 50 µm and 2 mm
- PPFC (^{235}U) as neutron monitor



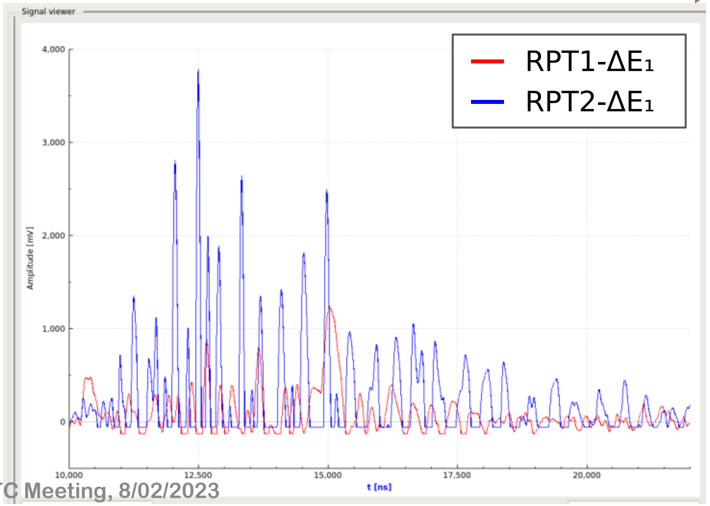
➤ Particle identification:
double/triple coincidences combined with the ΔE-E technique

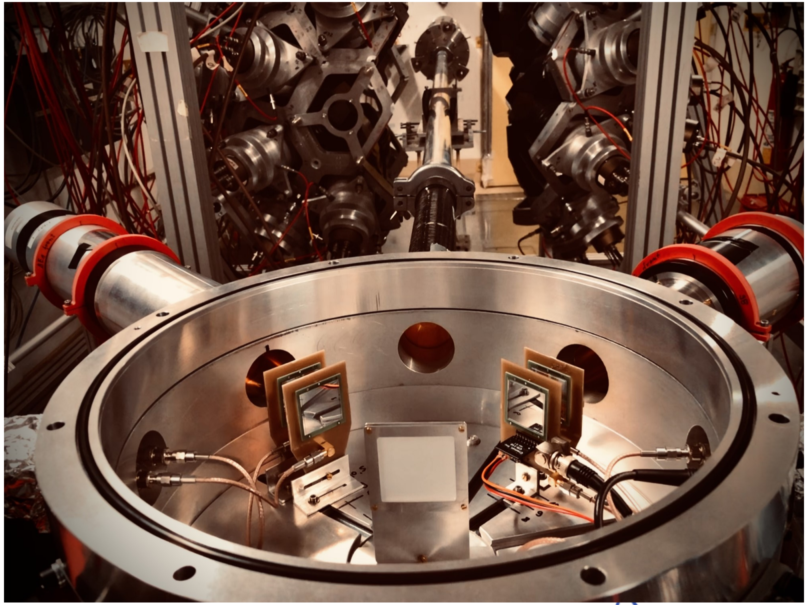
➤ Two samples: investigation of correction of the energy distributions due to losses in the graphite sample



Prototype setup & test beamtime

- Vacuum chamber from ‘old’ experiments
- ΔE_1 diodes: 50/60 µm
- ΔE_2 diodes: 500/1000 µm
- Scintillators: 150-mm plastic & 76.2-mm $CeBr_3$
- Main difficulty: γ-flash induced e.m. interferences





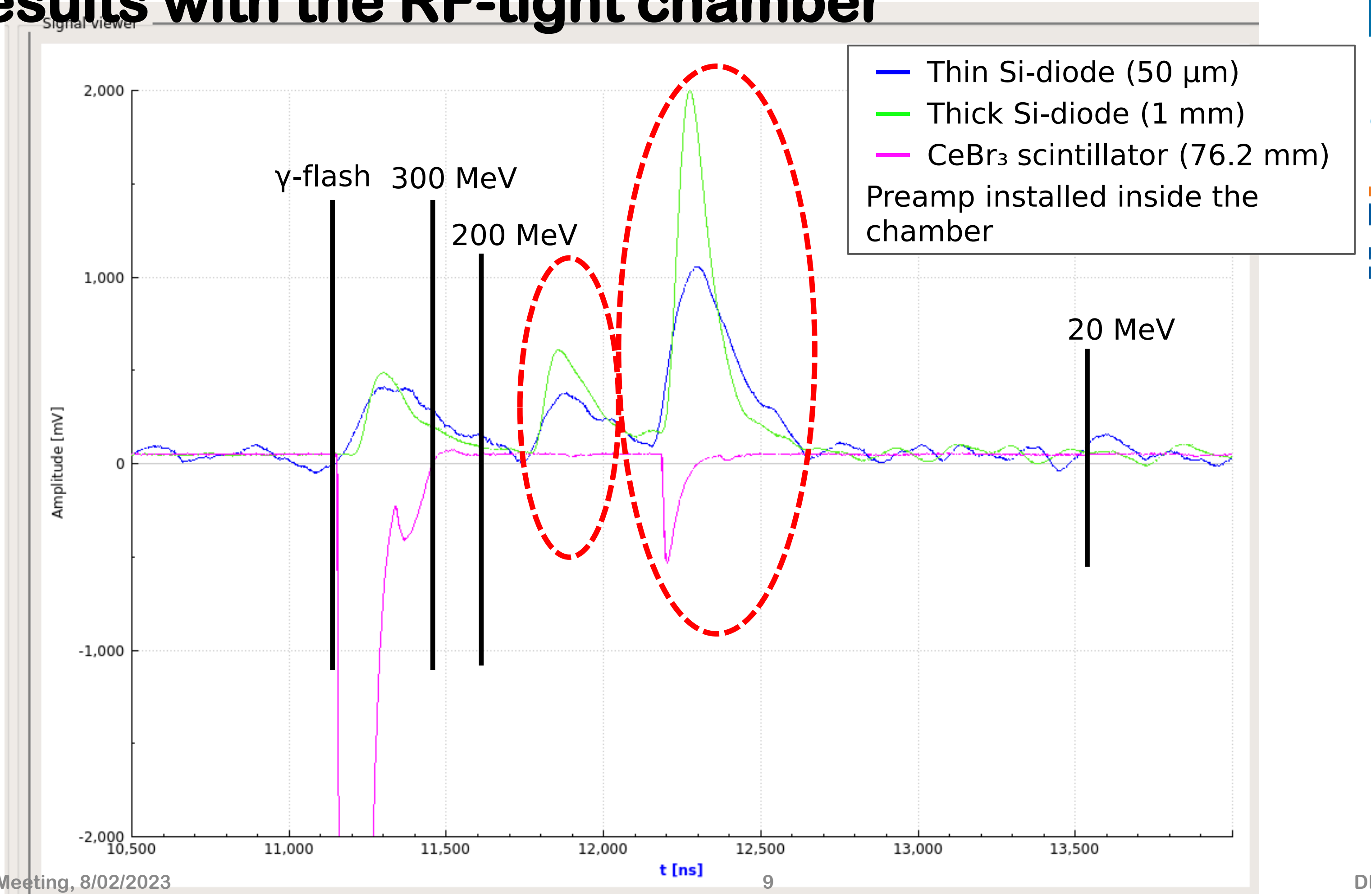
Solutions

- Shielded preamplifier, improved grounding, short cables

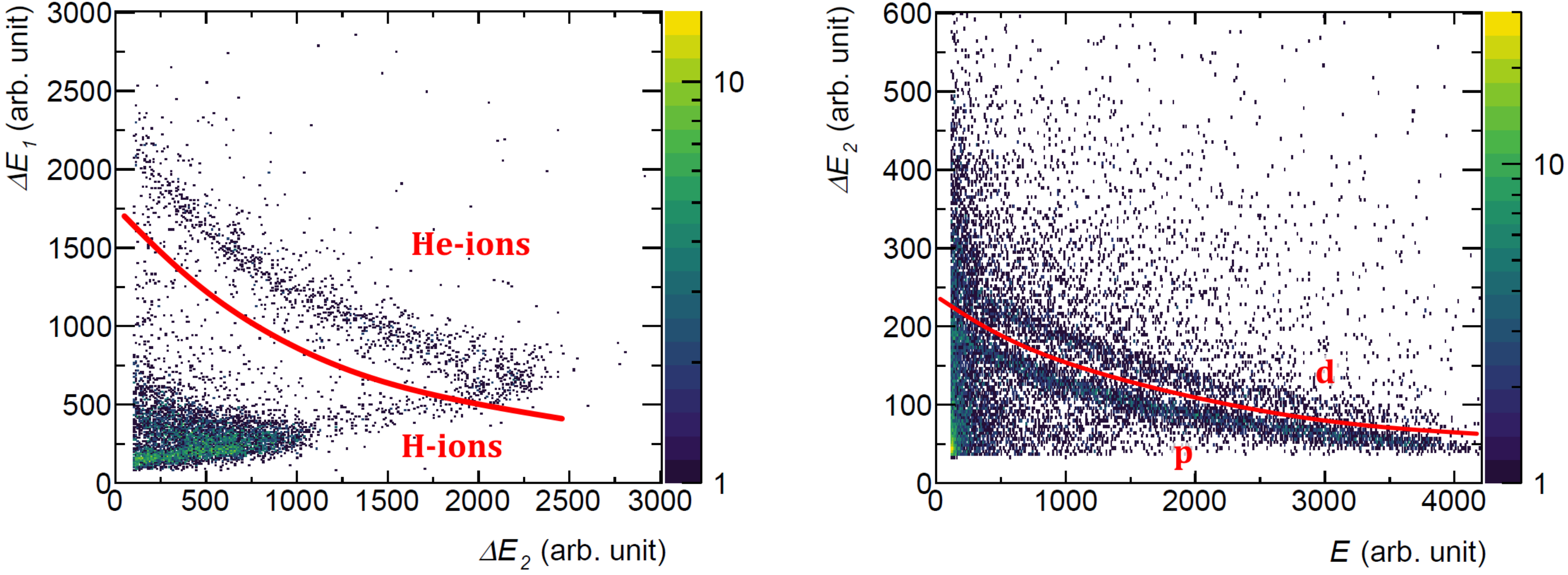
➤ Preamp inside the chamber, directly under on the Si diodes

➤ RF tight chamber (windows included)

Results with the RF-tight chamber



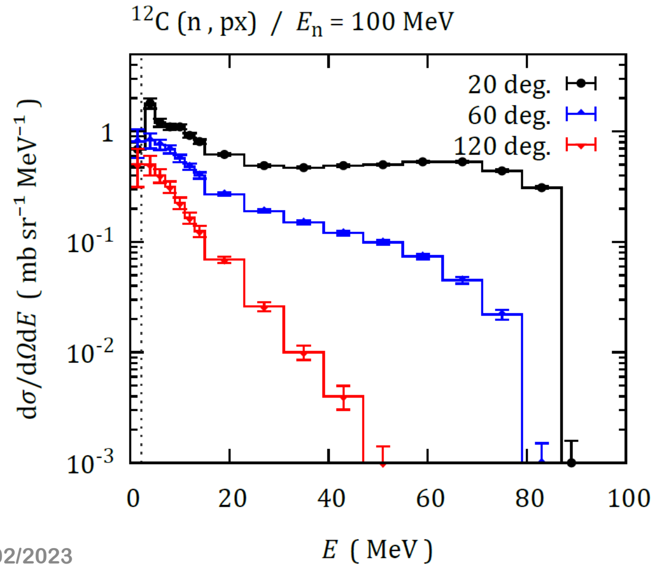
Particle identification

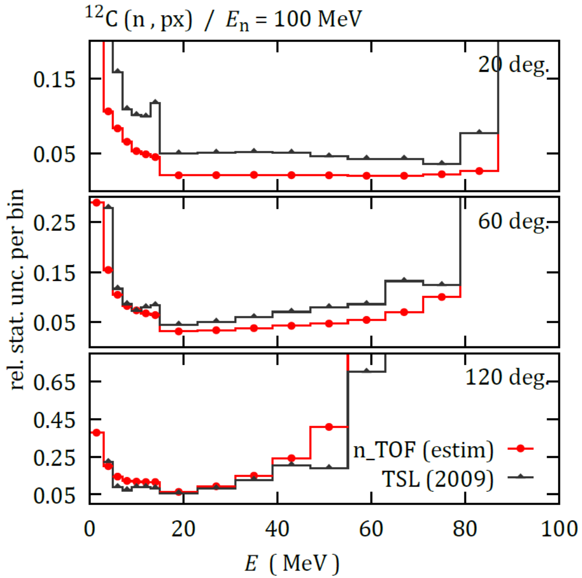


- Particle separation is possible up to E_n ~200 MeV
- Choosing detectors with low intrinsic noise is fundamental

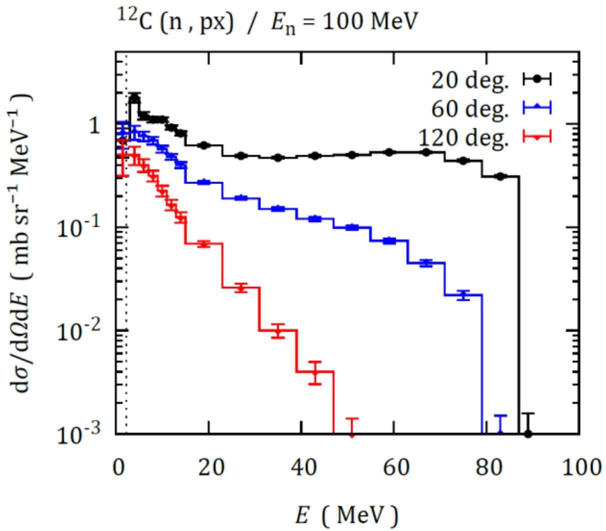
Count rate estimates

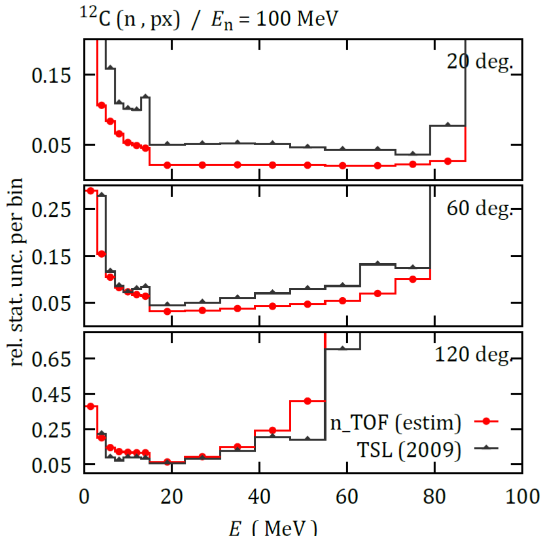
- 25×10^{17} protons / 2 mm sample
  + 5×10^{17} protons / 50 µm sample
- Comparison with measurement at TSL, E_n = 100 MeV, ΔE_n = 10 MeV
- Cut-off energy determined by thickness of ΔE_1 detector (50 µm Si)

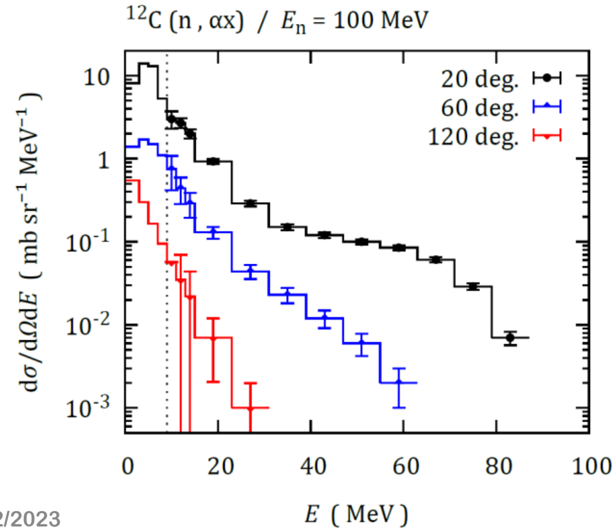


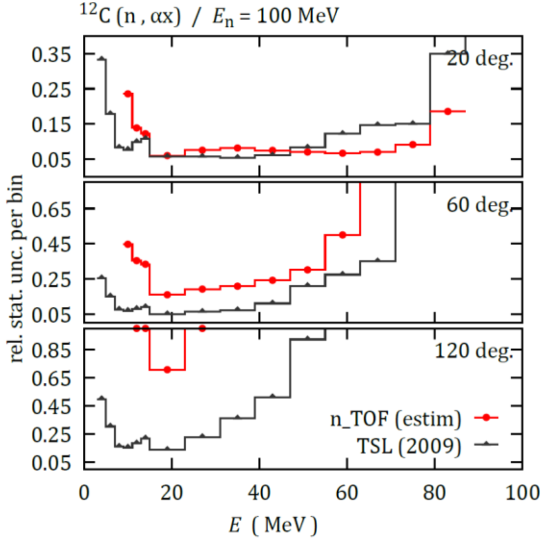


Count rate estimates









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nTOF

Summary and outlook

- Proof-of-principle experiment for the measurement of DDX data for carbon in EAR1, focused on E_n >100 MeV
- New kind of measurement at n_TOF, in a largely unexplored energy range
- If successful, future measurements could include: N, O, detector materials
- According to the estimates, the statistical uncertainties should be comparable to that of previous experiments, at least at forward angles
- Requested protons: **3×10^{18}**