

Development and Characterization of the CBM Neutron Calorimeter (NCAL)

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GGSB 2026



About me

HS - Komarovi199, FLEX

BA - FUT, GTU

M.Sc. - Free University of Berlin

Ph.D. - Ruhr University of Bochum

Affiliations - FZJ IKP1, RUB, GSI

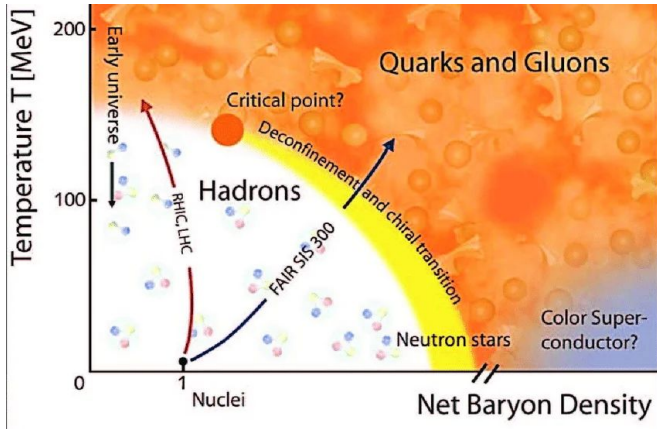
Outline

Goal: A realistic look at Ph.D. work in Particle/Detector physics, blending my personal experience with core field duties.

- PhD topic
 - Compressed Baryonic Matter, GSI
 - Neutron Detection at CBM
 - mCBM and Prague experiments
- PhD Experience
 - Studying/Living abroad
 - Role of GGSB
 - PhD in particle physics - Reality vs Expectations

Compressed Baryonic Matter (CBM) experiment at GSI FAIR

- Exploring dense nuclear matter
- Searching for phase transitions
- Measuring rare diagnostic probes



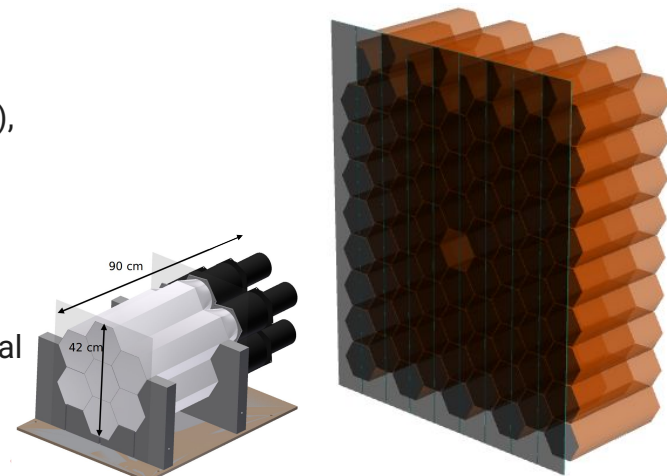
Compressed Baryonic Matter experiment: Neutron Calorimeter - NCAL

- **Heavy Ion physics**
 - Reaction plane
 - Collective flow
 - Impact parameter
 - Synergy with Forward Spectator Detector
- **Exclusive Hadronic physics**
 - Neutron Tagging
 - Benchmarking channel
$$Dp > pp + n_{\text{spec}}$$

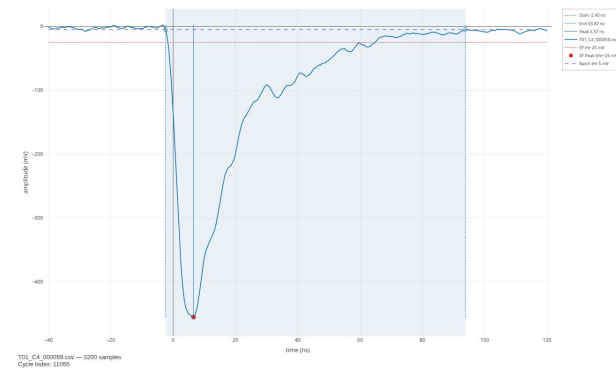


Neutron Calorimeter - NCAL

- **Scintillator:** BC-416 plastic (Polyvinyltoluene-based, $(C_9H_{10})_n$), C:H ratio = 9:10
- **Geometry:** Hexagonal (side ≈ 8.14 cm, length: 45 cm). 86 planned modules (7 in test setup).
- **Photodetector:** Photonis XP4592/PA PMTs, coupled via optical silicone gel.
- **Deployment:**
 - a. **mCBM:** Located ~ 4 m from target. Used in 5 beamtime runs (test NCAL).
 - b. **CBM:** ~ 12 -16 m, 35-45 mrad coverage
- **Efficiency:** Simulated neutron detection efficiency: $\sim 50\%$ (matches $\sim 40\%$ from COSY).



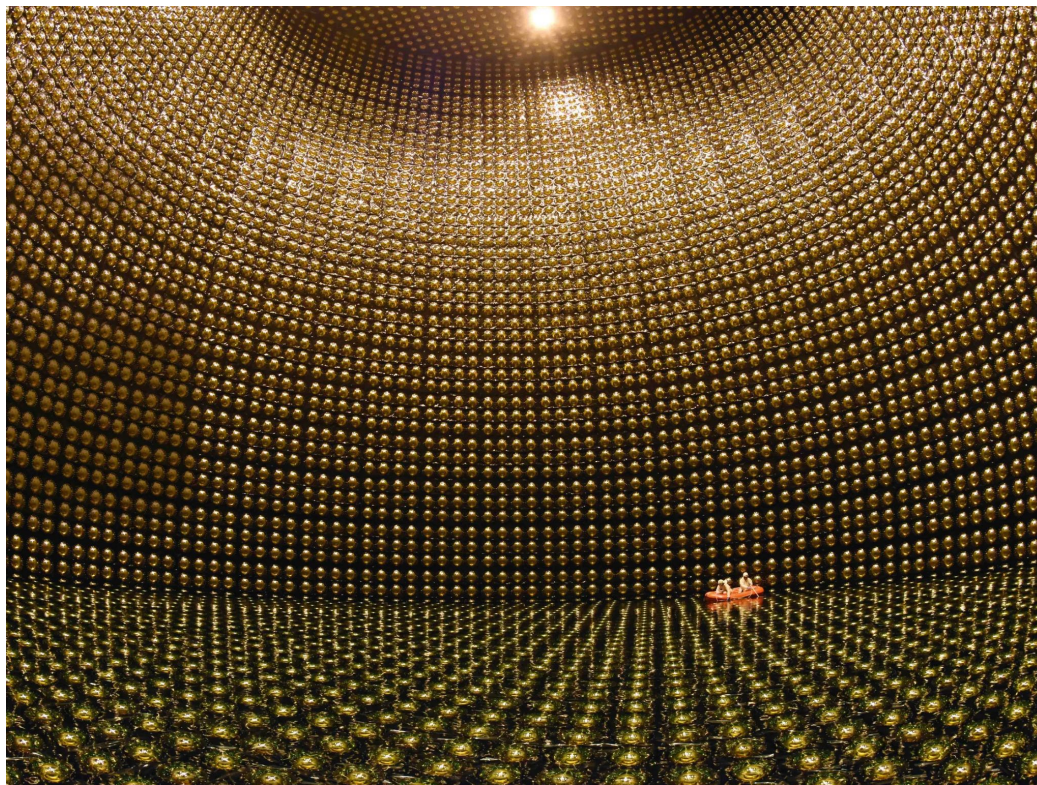
1. Saint-Gobain Crystals (2018). BC-400, BC-404, BC-408, BC-412, BC-416 Data Sheet: Plastic Scintillators.
2. Photonis Technologies S.A.S. Photomultiplier Tube XP4592/PA Data Sheet.



Examples of Experiments using PMTs - IceCube



Examples of Experiments using PMTs - Super-Kamiokande



Development & Characterization of the NCAL

Preliminary experiments:

- **mCBM** at GSI
- Neutron tests at **UJV Řež**

VETO detector at mCBM

- **Purpose:** Detect and veto charged particles before NCAL for neutral selection.
- **Scintillator:** Thin plastic plate (50 cm × 10 cm × 0.4 cm) BC-404/BC-412).
- **Geometry:** Five vertically hanging, slightly tilted modules in front of NCAL with 1 cm overlap.
- **Photodetectors:** ET Enterprises 9954B PMTs on each end allow for position estimation.
- **Readout:** Integrated with the same RICH readout chain using Time-over-Threshold (ToT) digitization.

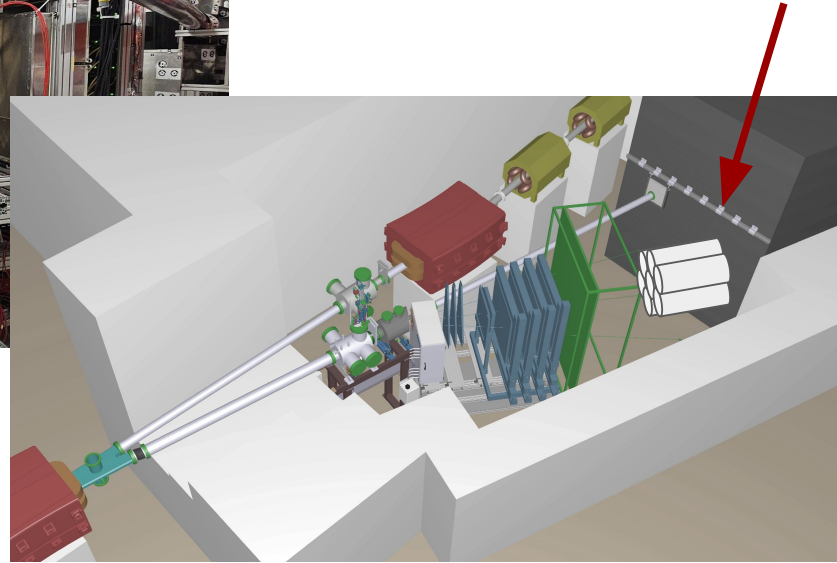
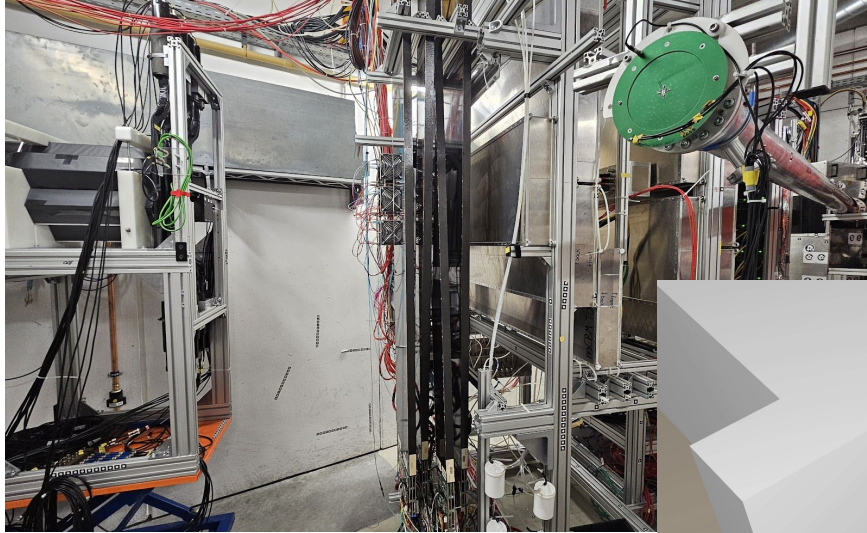


Veto Detector at mCBM

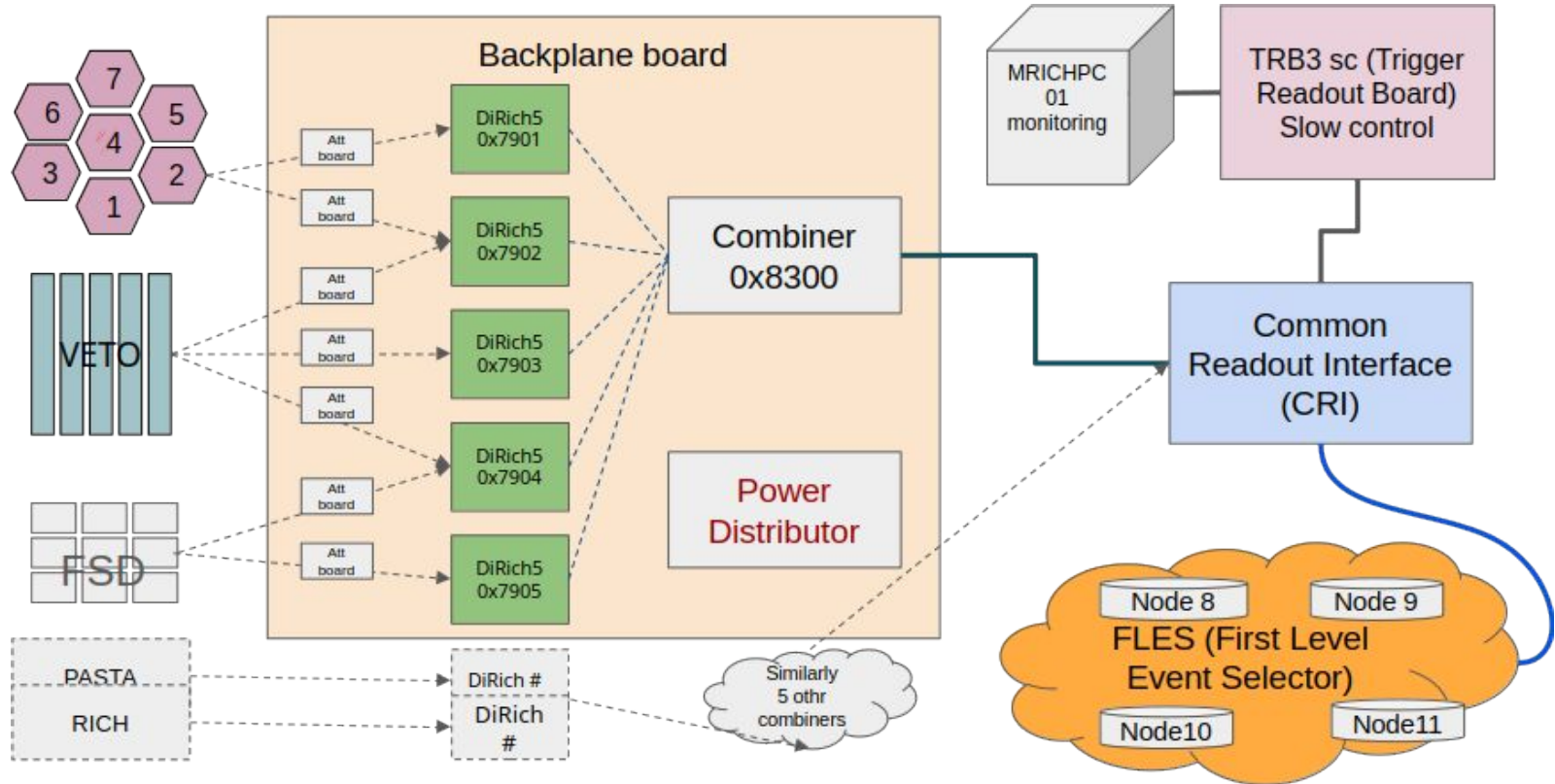
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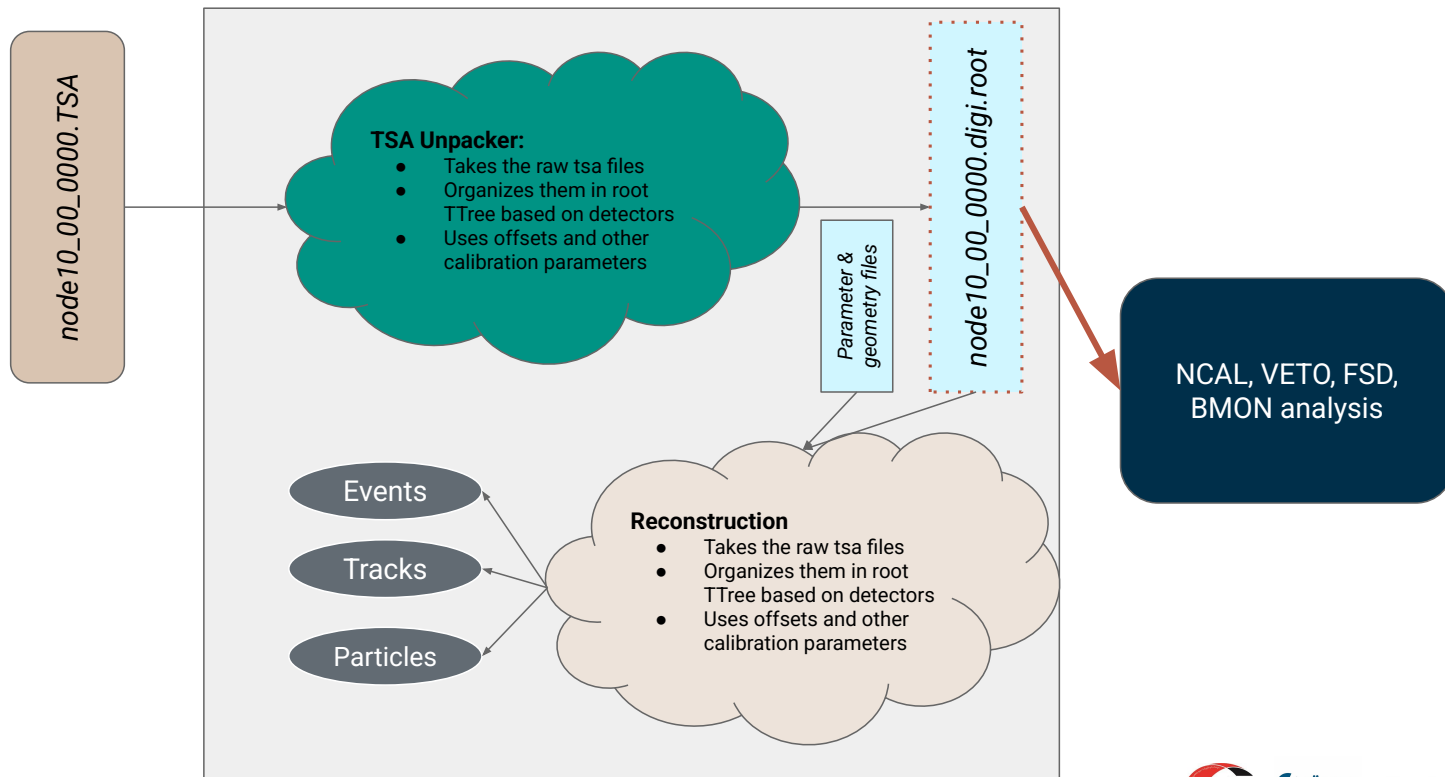
NCAL at mCBM cave



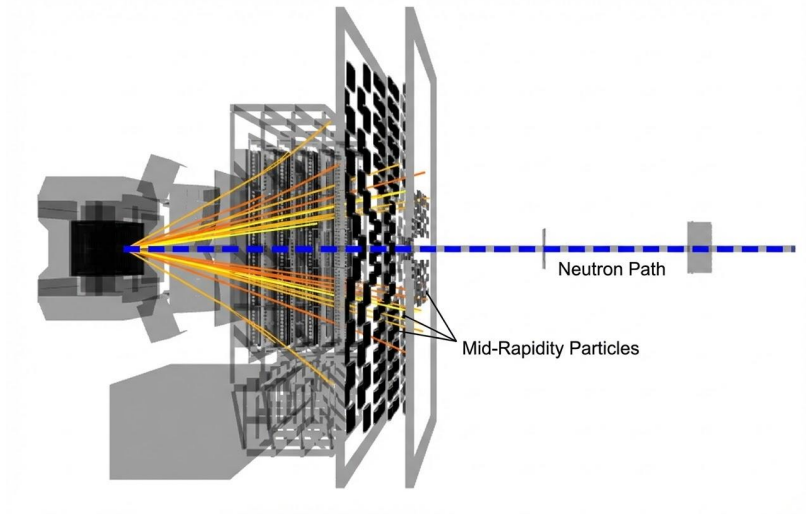
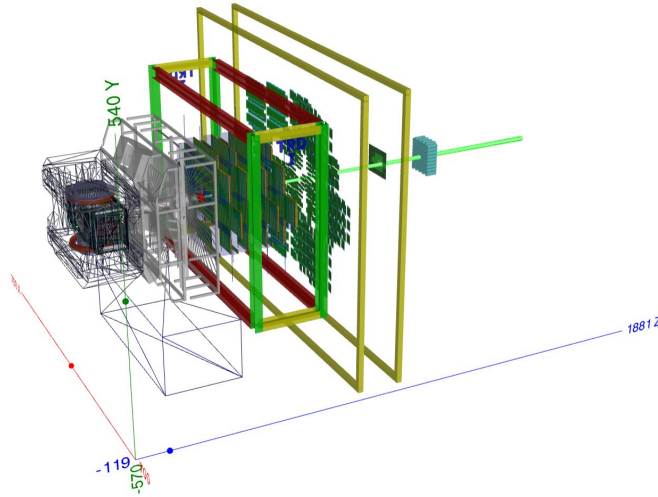
DAQ Diagram



mCBM Data Analysis Flow

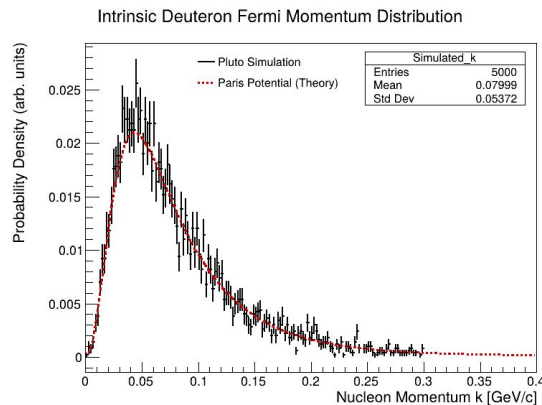
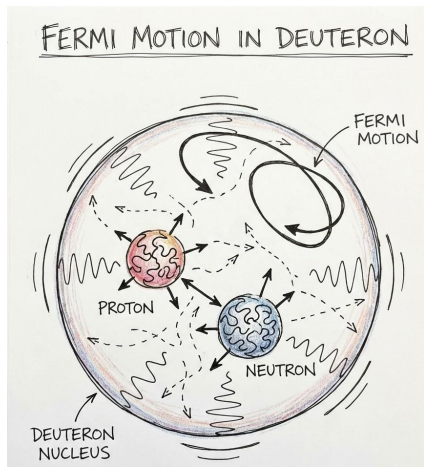


Monte-Carlo simulations / Geant4

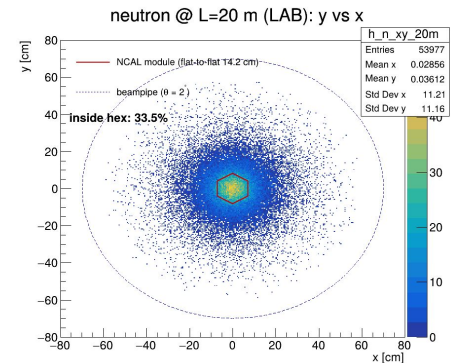
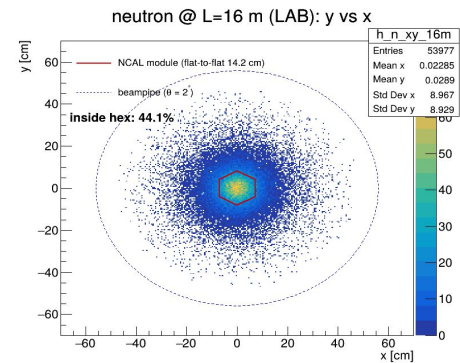
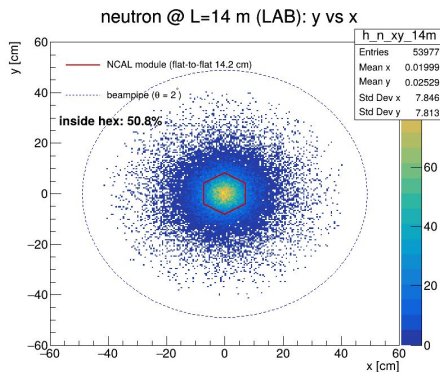
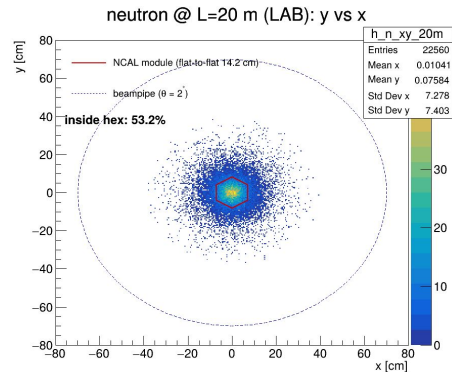
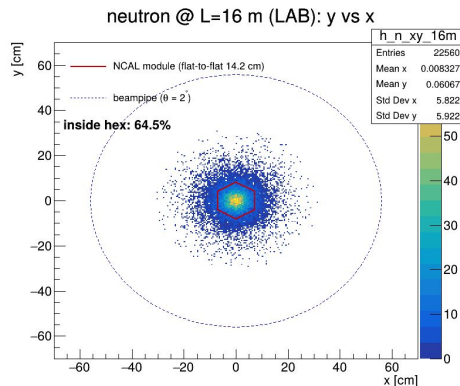
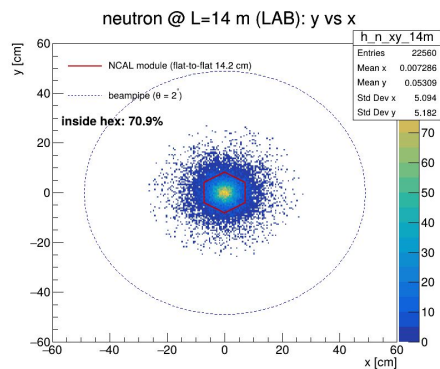


Monte-Carlo simulations / Geant4 - Example task

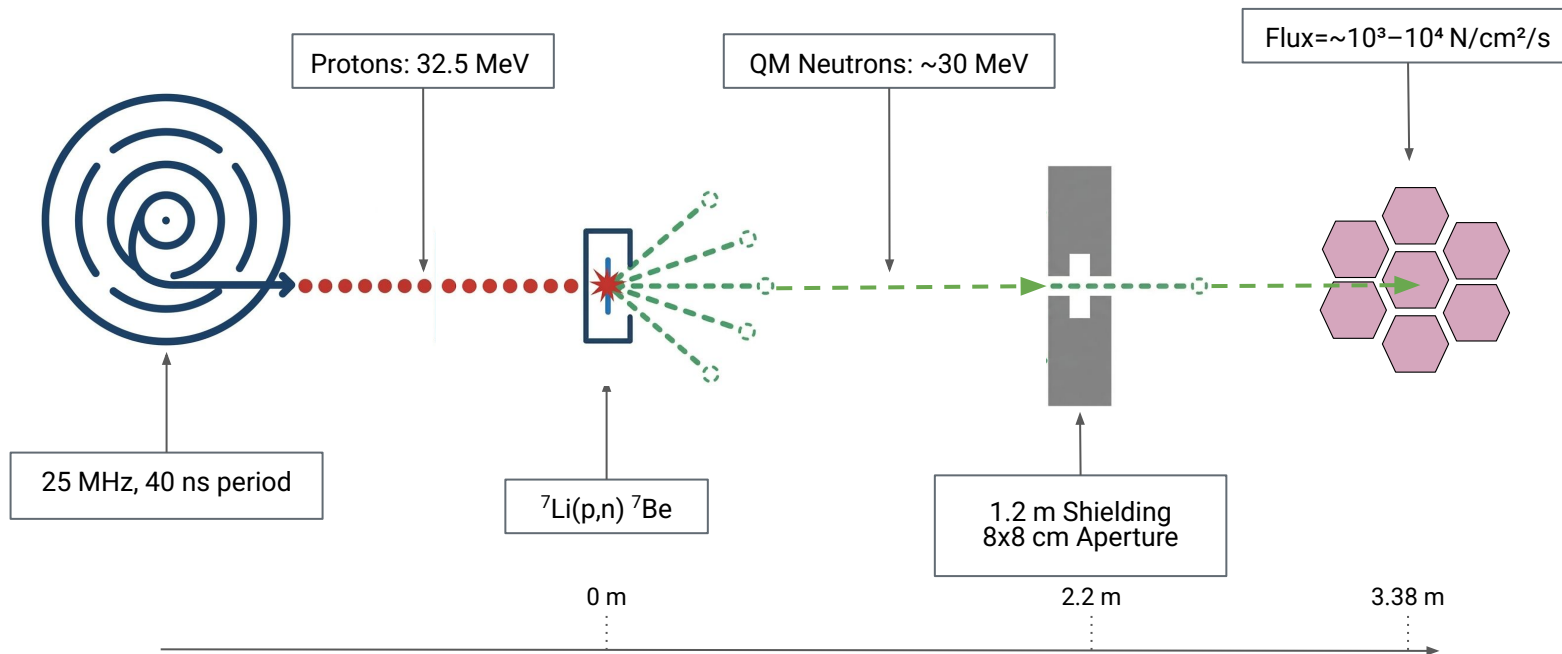
- Use deutereron as the neutron source
- Protons/neutrons get a “kick”
- Can we measure this “kick” using our detector to help us understand the true momentum of the contributor particle?



Monte-Carlo simulations / Geant4 - Example task



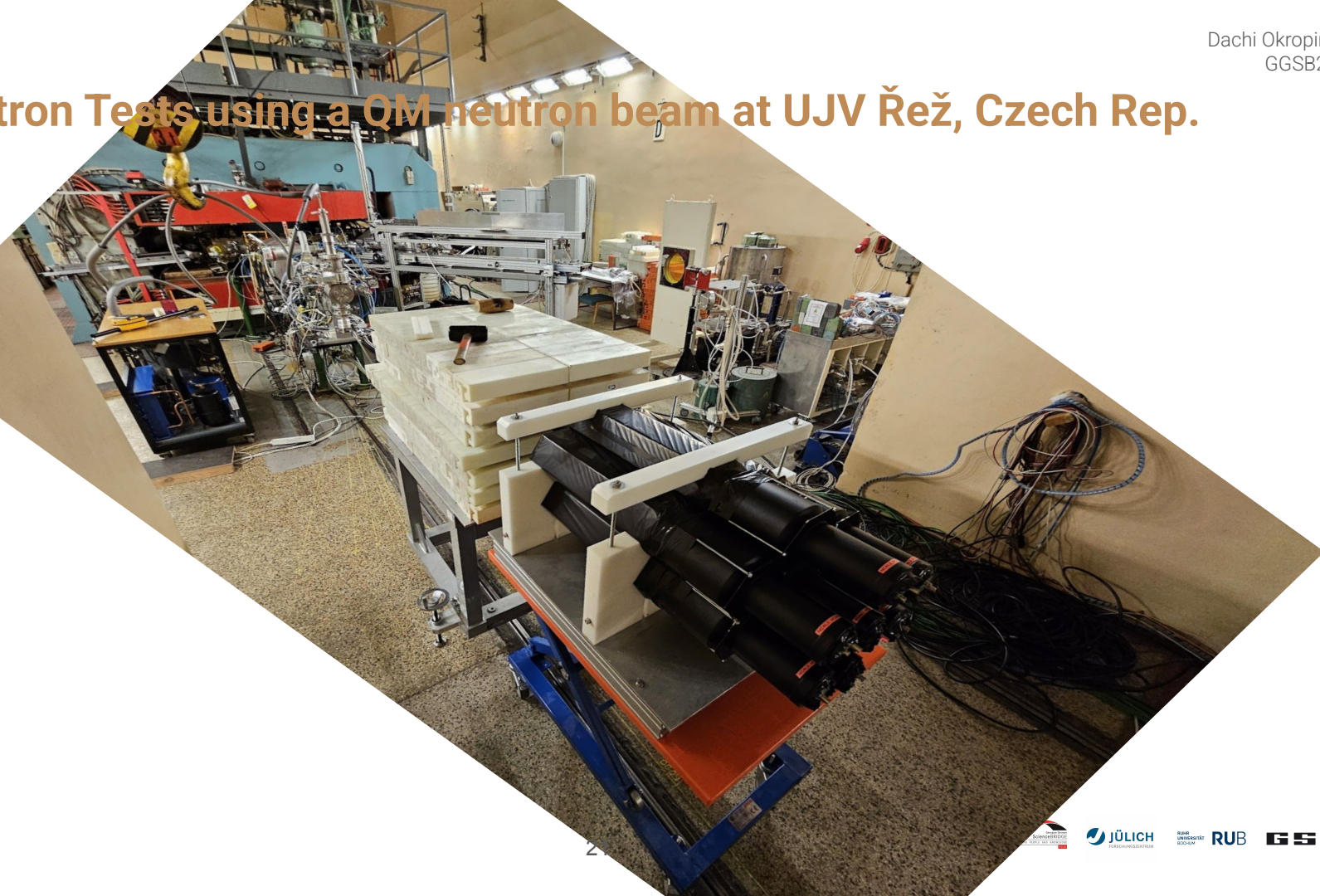
Neutron Tests using a QM neutron beam at UJV Řež, Czech Rep.



Neutron Tests using a QM neutron beam at UJV Řež, Czech Rep.



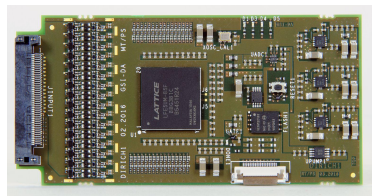
Neutron Tests using a QM neutron beam at UJV Řež, Czech Rep.



DAQ

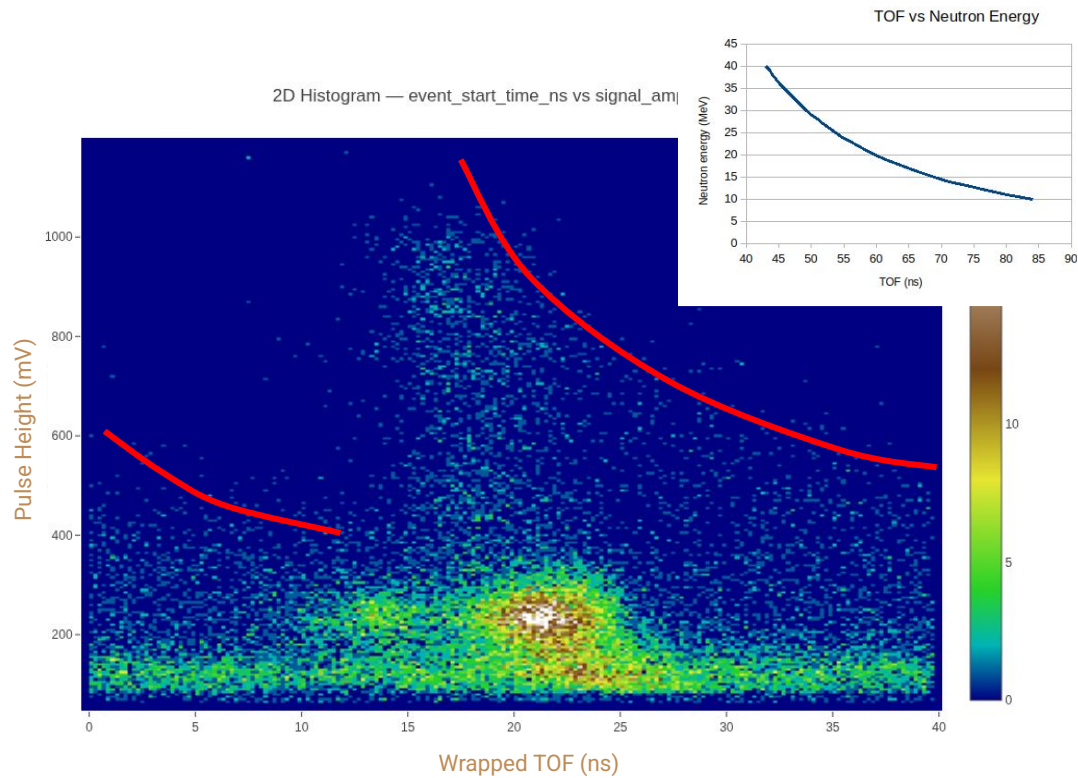
Main DAQ units

- Dogma
- Dirich
- Caen
- Lecroy Waverunner



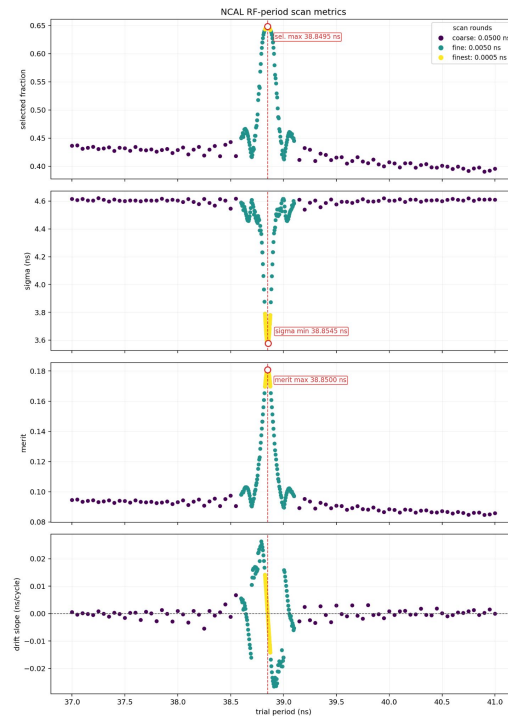
Neutron Tests at Rez: TOF separation

- Cyclotron RF 25 MHz = 40 ns period
- 40 ns modulo wrap applied on TOF
- PSD unsuccessful
- TOF shows distinctive patterns of Gamma and Neutron distributions

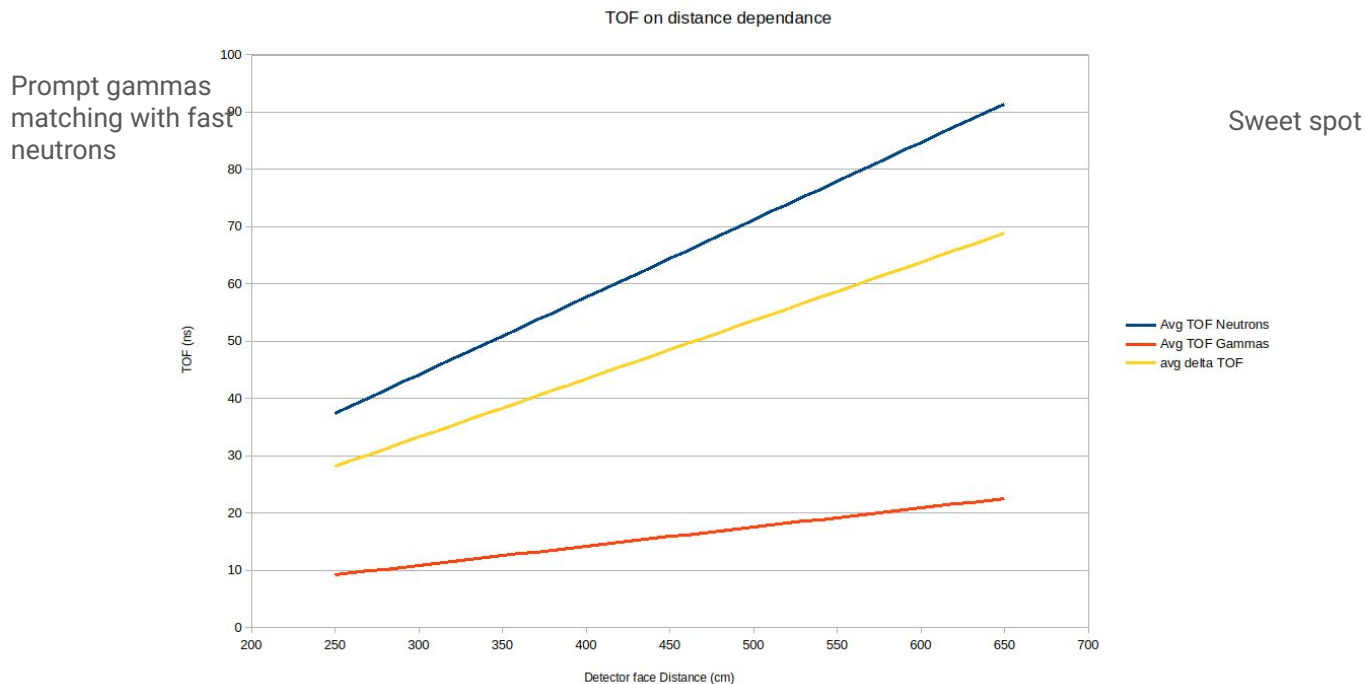


Lots of Analysis work all the time!

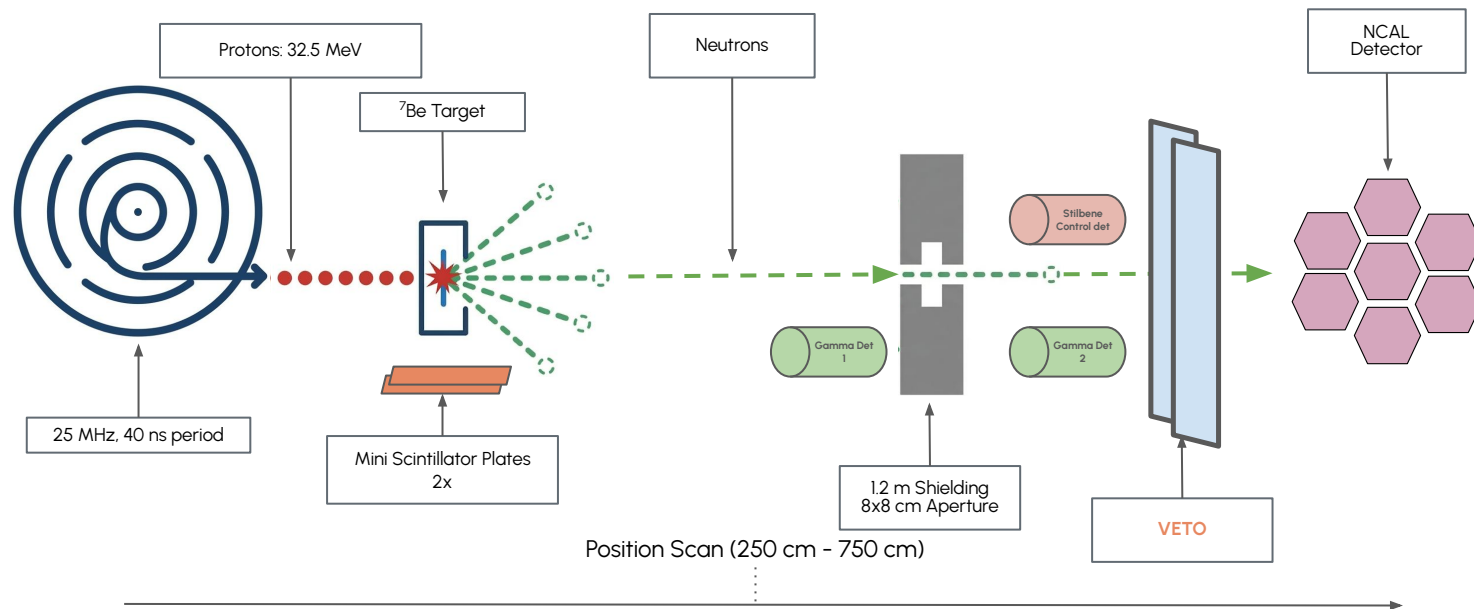
- Pick one valid ch0 pulse in each trigger window as the common time zero.
- Test a trial RF period by folding score-channel hit times modulo that period.
- Find the main folded peak and refine its center from the clustered hits.
- Repeat for many trial periods and keep the one with the sharpest, most populated peak.
- Small side wings are expected finite-window Dirichlet sidelobes from a limited number of RF buckets.



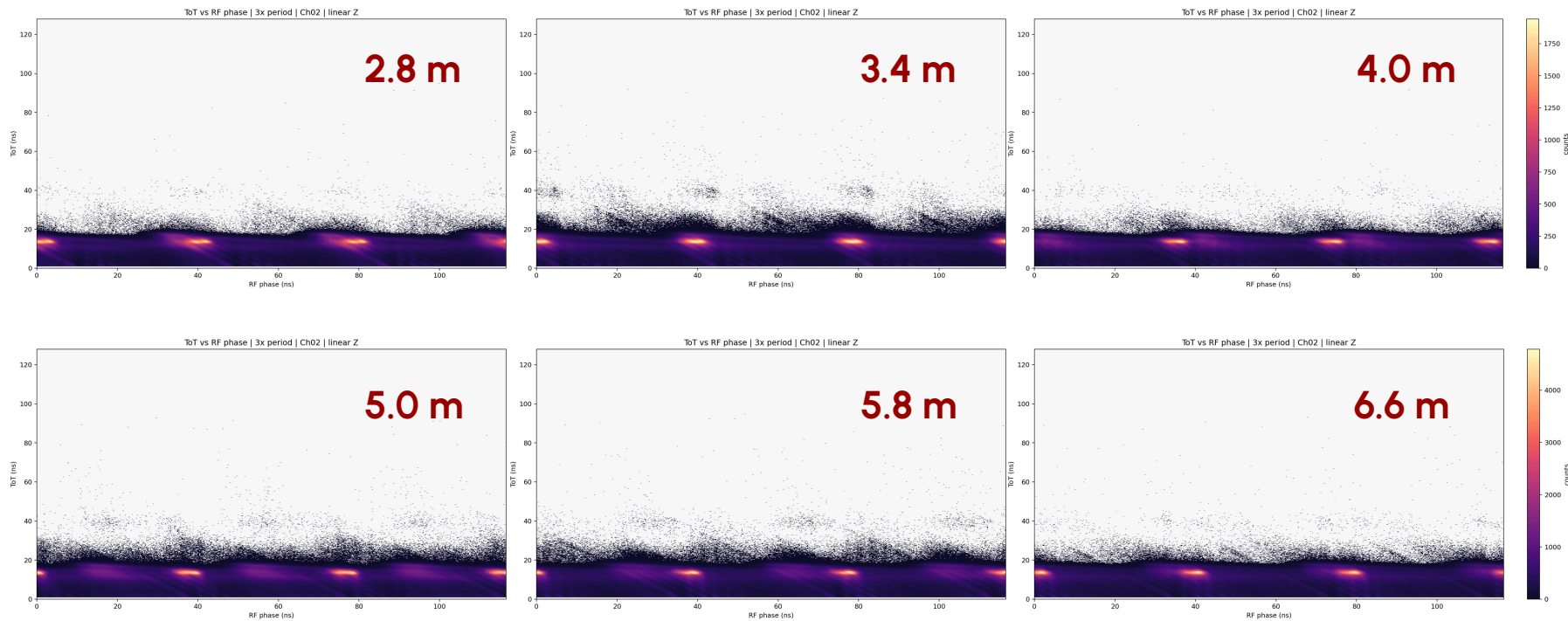
Neutron Tests at Rez: TOF theoretical estimations



Take 2



Results



Summary

- Hardware work - 2 mini detectors created and almost finished full scale NCAL
 - Pmt
 - scintillator
- Calibrations (cosmics, sources)
- DAQ systems
- Simulations
- Experiments at Rez and mCBM
- Data analysis
- Software development for CBM (cbmroot)



What is it like to make a PhD
in particle physics?

What can a PhD in particle physics like?

- Very subjective (project, supervisor, topic)
- Duties:
 - Hardware
 - Software
 - DAQ
 - Analysis
 - Electronics
 - Simulations
 - Theory
 - Beam Times
 - Writing
 - Thesis / Papers
 - Conferences / Seminars / Workshops



Study/Living Challenges

- Housing
- Cultural differences
- Language
- Finances/Funding



Role of GGSB

- Decades of partnership history
- Amazing Community
- Shared Funding
- Increased chances for Georgian students
- Access to the top-tier research infrastructure
- Opportunity to work with the best scientists and projects



Questions

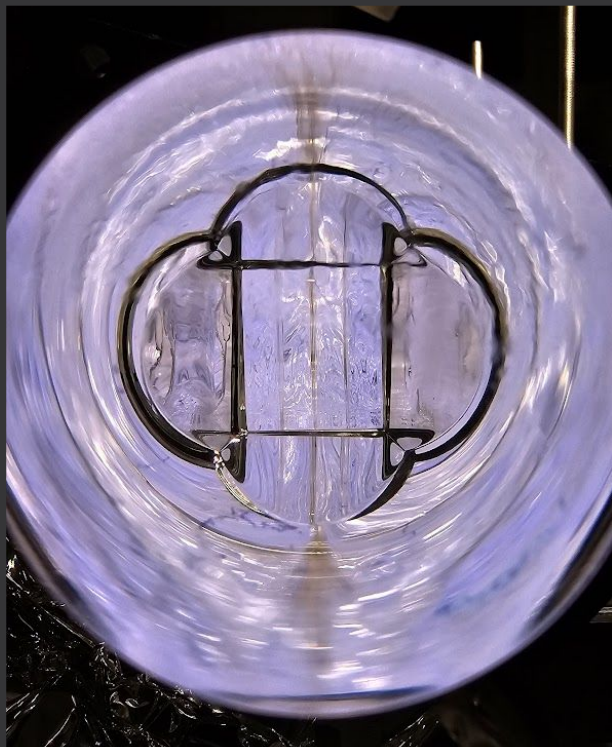
A close-up, circular view of a mechanical component, possibly a lens or a filter, with a central circular opening and concentric rings. The image is dark and has a vintage, slightly grainy quality. The central opening shows a series of vertical lines, possibly a filter or a lens element. The surrounding rings are metallic and show some wear and tear.

Thank you for your attention!

References

- [1] Saint-Gobain Crystals. BC-400, BC-404, BC-408, BC-412, BC-416 Data Sheet, 2018. Plastic Scintillators.
- [2] Photonis Technologies S.A.S. Photomultiplier Tube XP4592/PA Data Sheet.



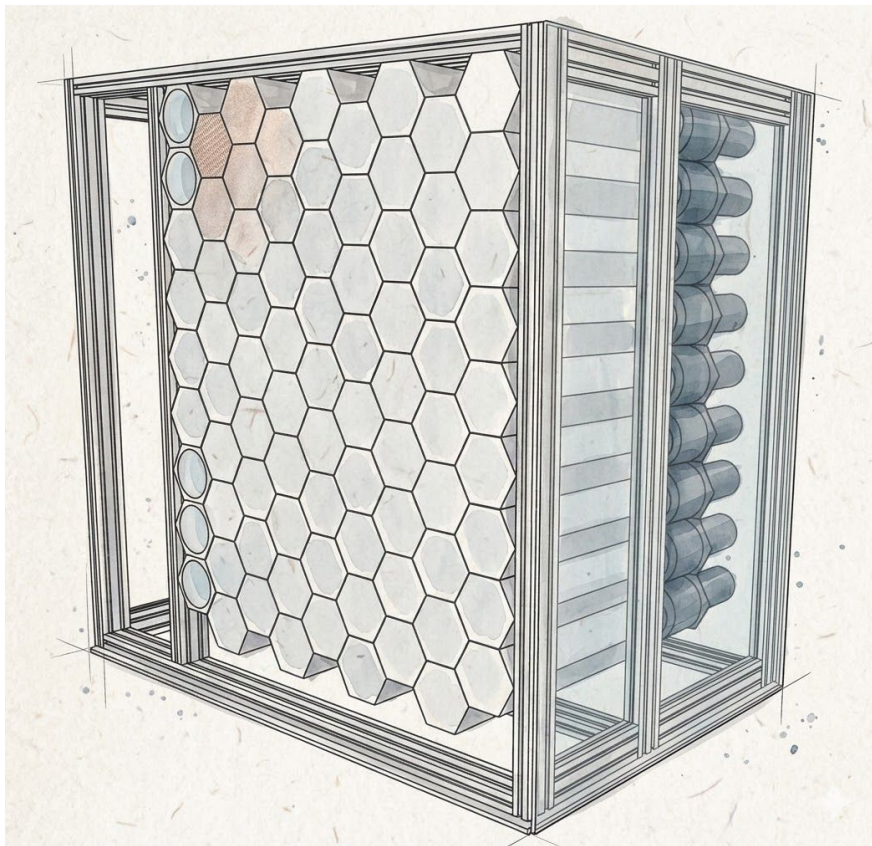


Development of the Neutron Calorimeter at CBM

Backup Slides

Outlook

- Further Data analysis
- Rez Experiment with position scans
- Simulation
- Full-scale NCAL development (2026)
- CBM software integration



Neutron Tests - estimations

detector face ($L = 3.37$ m), using the chart's flux at 4.00 m scaled by $1/r^2$, with 100% efficiency.

Row labels

- Continuous (broader spectrum, 1 MeV width): the smaller-flux row $\rightarrow 9.38e2 \text{ cm}^{-2} \text{ s}^{-1}$ at 4 m
- QM (quasi-mono peak, 1 MeV width around 14 MeV): the larger-flux row $\rightarrow 1.88e3 \text{ cm}^{-2} \text{ s}^{-1}$ at 4 m

Scale to the distance (3.37 m)

- Scale factor from 4.00 m $\rightarrow$ 3.37 m: $(4.00/3.37)^2 \approx 1.4096$
- Flux at 3.37 m (average over cycle):
 - Continuous: $9.38e2 \times 1.4096 \approx 1.322e3 \text{ cm}^{-2} \text{ s}^{-1}$
 - QM: $1.88e3 \times 1.4096 \approx 2.650e3 \text{ cm}^{-2} \text{ s}^{-1}$

At the detector face (area $A \approx 172 \text{ cm}^2$; flat-to-flat 14.1 cm), average rates

- Continuous: $R_{\text{avg}} \approx 1.322e3 \times 172 \approx 227.4 \text{ kHz}$
- QM: $R_{\text{avg}} \approx 2.650e3 \times 172 \approx 455.8 \text{ kHz}$

Active (in-burst) rates (duty $d = 0.2 \rightarrow$ divide by 0.2)

- Continuous: $R_{\text{burst}} \approx 1.137 \text{ MHz}$
- QM: $R_{\text{burst}} \approx 2.279 \text{ MHz}$

Counts per 1 ms trace

- Average-equivalent:
 - Continuous: ≈ 227.4
 - QM: ≈ 455.8
- In-burst:
 - Continuous: $\approx 1,137$
 - QM: $\approx 2,279$

Counts over your 62 ms (62 traces)

- Average-equivalent:
 - Continuous: $\approx 14.1\text{k}$
 - QM: $\approx 28.3\text{k}$
- In-burst:
 - Continuous: $\approx 70.5\text{k}$
 - QM: $\approx 141.3\text{k}$



Neutron Calorimeter - NCAL

Scintillator Material:

BC-416 plastic scintillator

→ Polyvinyltoluene-based, Chemical formula: $(C_9H_{10})_n$

→ C:H ratio = 9:10

Geometry:

→ side ≈ 8.14 cm, side to side 7.1 cm, Length: 45 cm

→ Hexagonal cross-section, $A \approx 172.13$ cm²

→ Modules: 86 planned; test setup uses 7 modules

→ Mounted on mobile, height-adjustable frames

Photodetector:

→ Photonis XP4592/PA PMTs

→ Coupled via optical silicone gel

Readout Electronics:

→ RICH readout system, using Time-over-Threshold (ToT)

→ Requires calibration for energy conversion

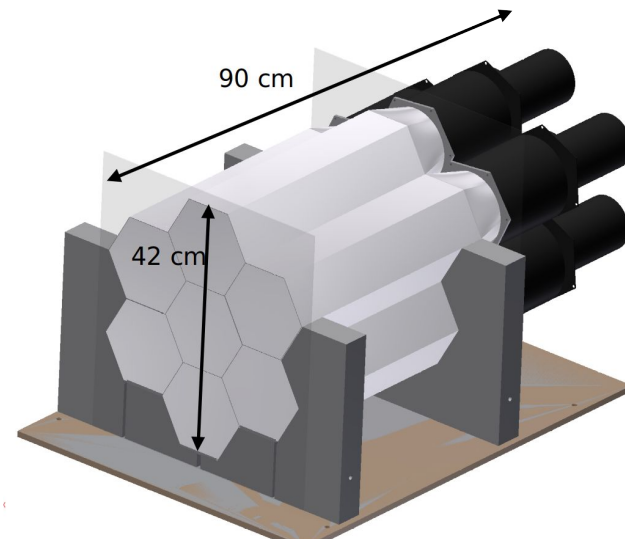
Deployment:

→ Distance from target: ~ 4 m

→ Participated in 5 beamtime runs (Au, Ni, Ag at 1.2–1.5 AGeV)

Simulated Neutron Detection Efficiency:

→ $\sim 50\%$ (matches $\sim 40\%$ from COSY at 2.7 GeV/c)



VETO detector

Purpose:

- Detect charged particles before NCAL and veto them (neutral particle selection)

Scintillator Material:

Plastic scintillator (type not explicitly specified, likely BC-404/BC-412 equivalent)

- Thin plate: **50 cm × 10 cm × 0.4 cm**

Geometry:

- Vertically hanging, **5 modules** in front of NCAL
- **1 cm overlap**, modules slightly tilted for full coverage

Photodetectors:

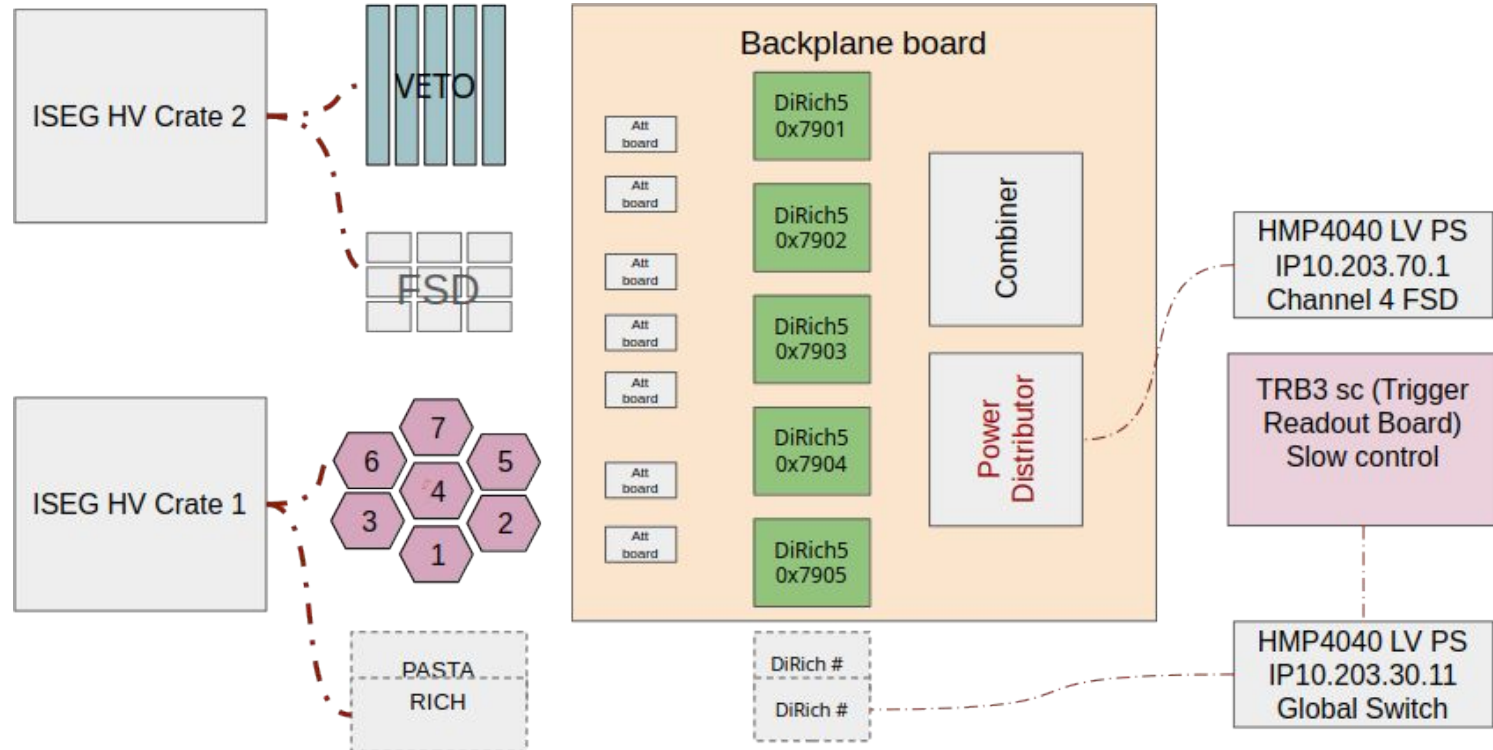
- **ET Enterprises 9954B** PMTs (one on each end of each plate)
- Allows for **position estimation via timing difference**

Integration:

- Uses same **RICH readout chain**, ToT-based signal digitization



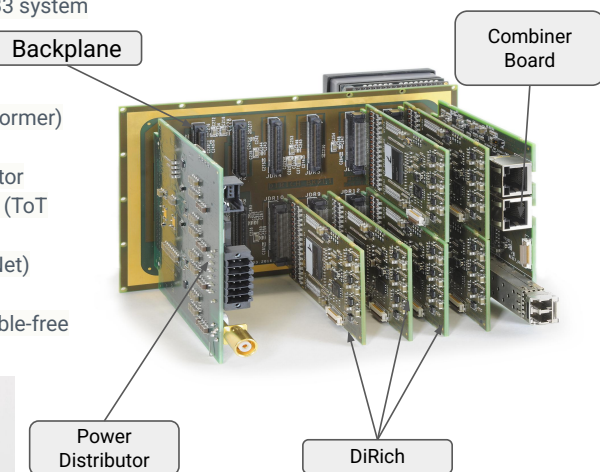
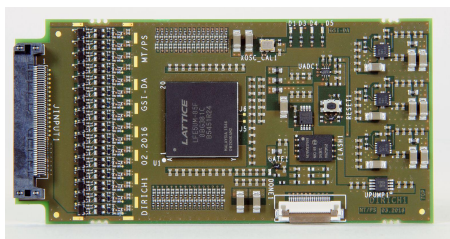
High Voltage Diagram



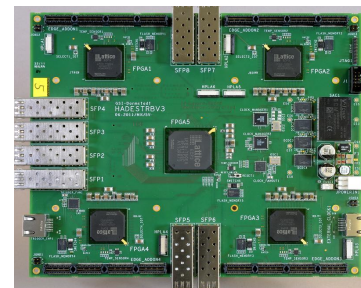
DiRich, TRB, Combiner.

The DiRich board serves as a data acquisition platform that interfaces with photon detectors, collecting and digitizing signal information. It performs time measurement using Time-to-Digital Converters (TDCs) to accurately record signal arrival times. The board then transmits the processed timing data to the TRB3 system for synchronization and event building.

1. 32 channels
2. galvanic isolation of PMT to FEE (transformer)
3. ~factor 30 gain amplifier, 12mW
4. individual threshold for each discriminator
5. TDC with ~10ps intrinsic time precision (ToT measurement)
6. data acquisition system included (TRBNet)
7. data is sent out on the same connector
8. only one connector for everything => cable-free system



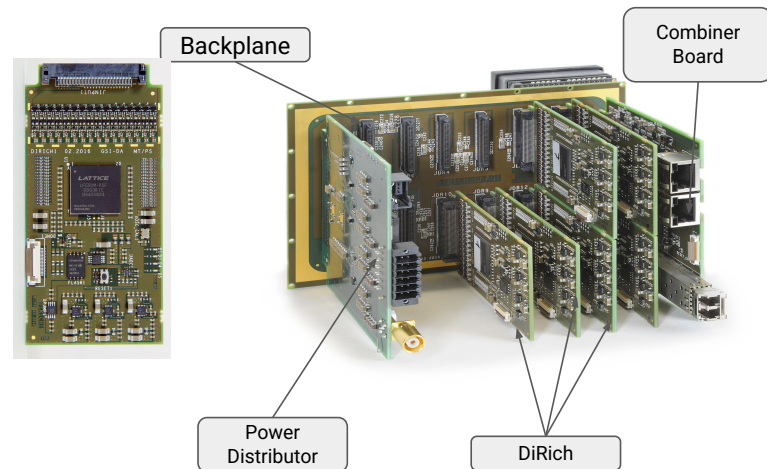
In the DiRich scheme for CBM, the TRB3 serves as the central trigger and data acquisition platform. It generates timing signals, collects data from the DiRich detectors, and synchronizes the data streams. The TRB3 aggregates the data into coherent events and transmits them to the Eventbuilder for further processing. It also manages system control, monitoring, and error detection, ensuring smooth operation during experiments.



Electronics

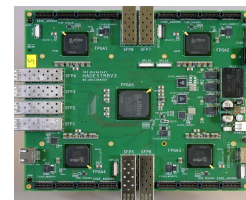
DiRich Board (DAQ)

- **Channels:** 32 (with individual TDC discriminators)
- **Timing:** TDC with **~10ps** precision (ToT measurement).
- **Data Flow:** to TRB3 for synchronization/event building.
- **Design:** Cable-free (single output connector).

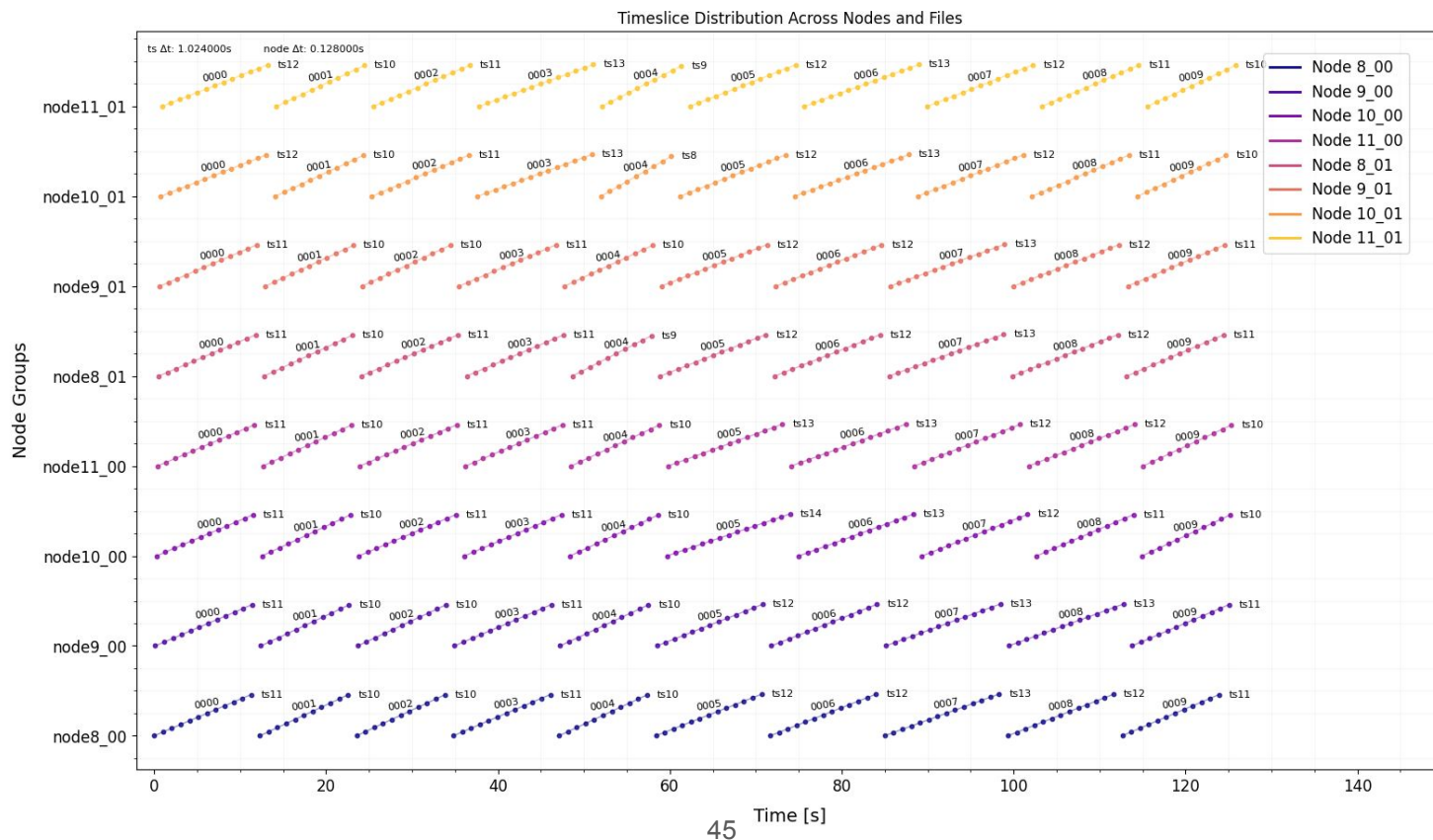


TRB3 Role (DiRich Scheme): Central trigger and data acquisition platform.

- Generates timing signals.
- Collects and synchronizes data streams from DiRich detectors.
- Aggregates data into coherent events and sends to Eventbuilder.
- Manages system control, monitoring, and error detection.



mCBM Data Structure



Neutron Tests using Quasi monoenergetic neutron beam

Neutron Source:

Reaction: ${}^7\text{Li}(p,n)$

Target: Solid lithium (Li) foil

Proton Beam Energy: 32.5 MeV

Beam Structure: Gaussian bunches (FWHM 2–3 ns),
25 MHz $\rightarrow$ ~ 40 ns period

Intensity Range: 0.1–5.0 μA (adjustable in seconds)

Detector Positioning:

Detector Face Distance from Target:

Detector Aperture: $8 \times 8 \text{ cm}^2$

Shielding Wall Location: Starts at 2.179 m, ends at 3.26 m

Expected Neutron Flux (QM Peak):

At 3.38 m and 5 μA beam current: interpolated between tabulated values
($\sim 10^3$ – $10^4 \text{ n/cm}^2/\text{s}$)

Measurement System:

Oscilloscope, DiRich, Digitizer: CAEN 8-channel waveform digitizer (4 ns sampling period)

Triggering: Reference RF signal from cyclotron (25 MHz, $\sim 40\text{ns}$, $\sim 300 \text{ mV}$)

