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Fast Timing for Nuclear Reaction Studies at R³B



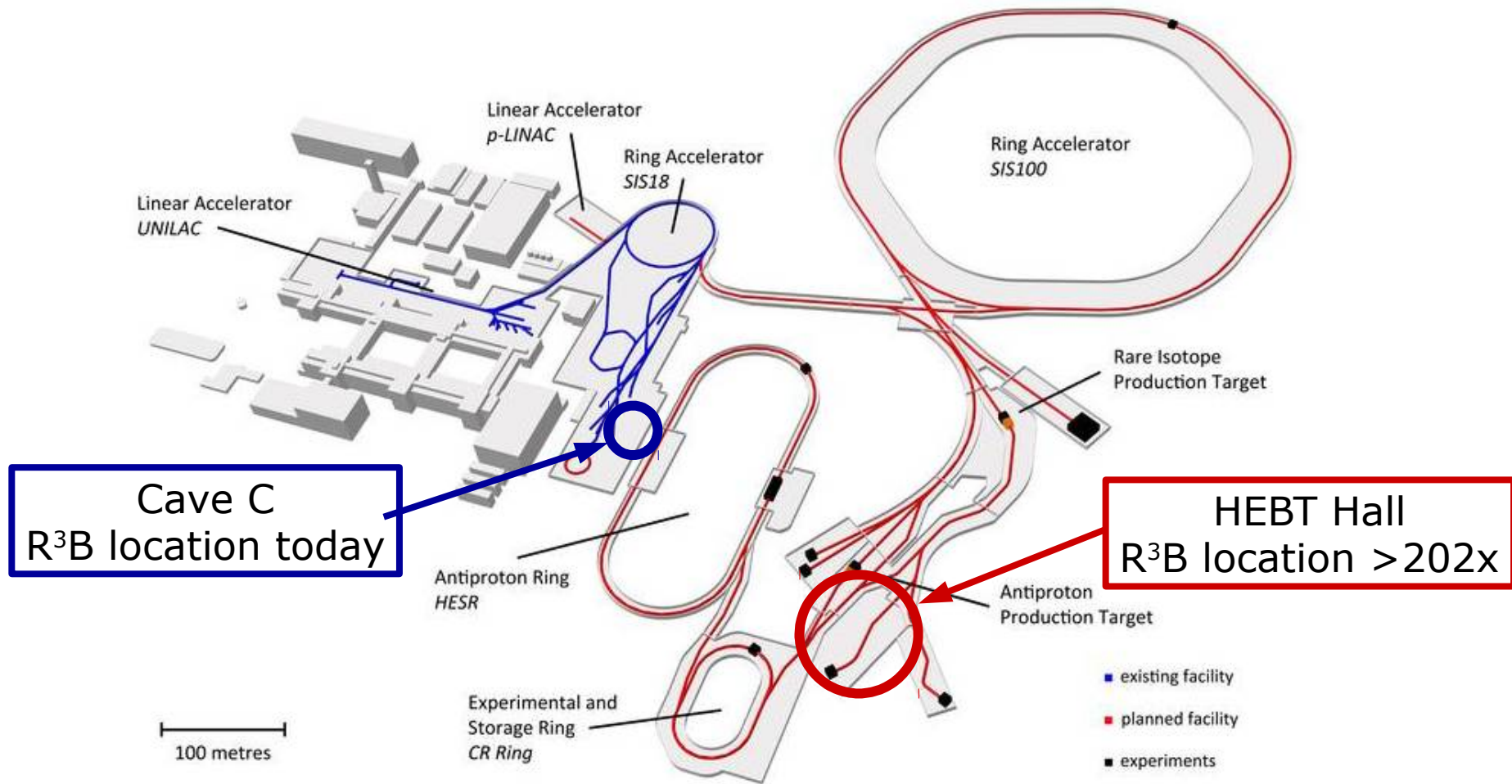
Matthias Holl for the R³B Collaboration

- The R³B Setup
 - Introduction
 - R³B Phase-0
- Fast timing applications at R³B
 - Heavy-Ion Tracking
 - Measurement of fast neutrons

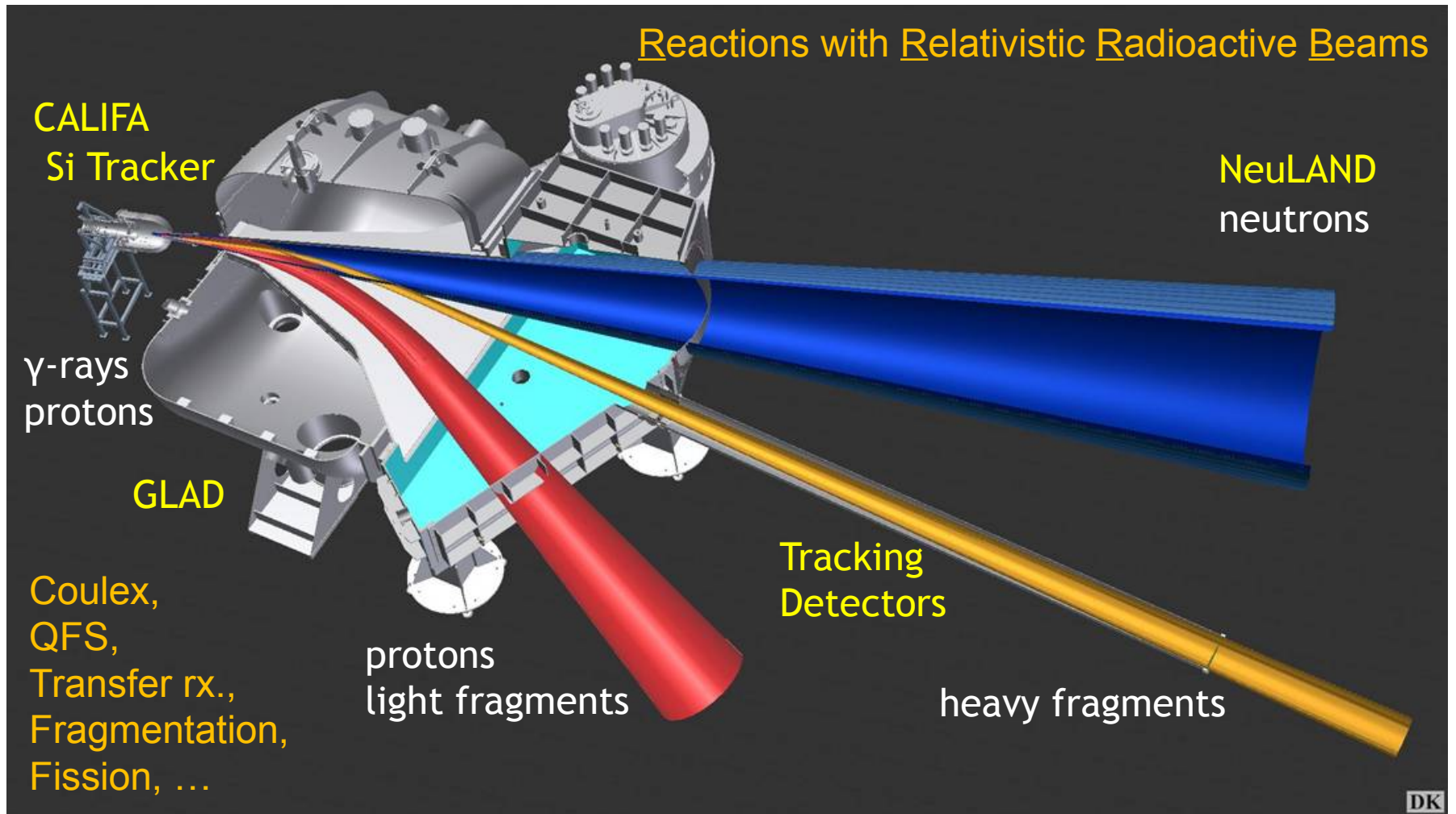
GSI and FAIR complex



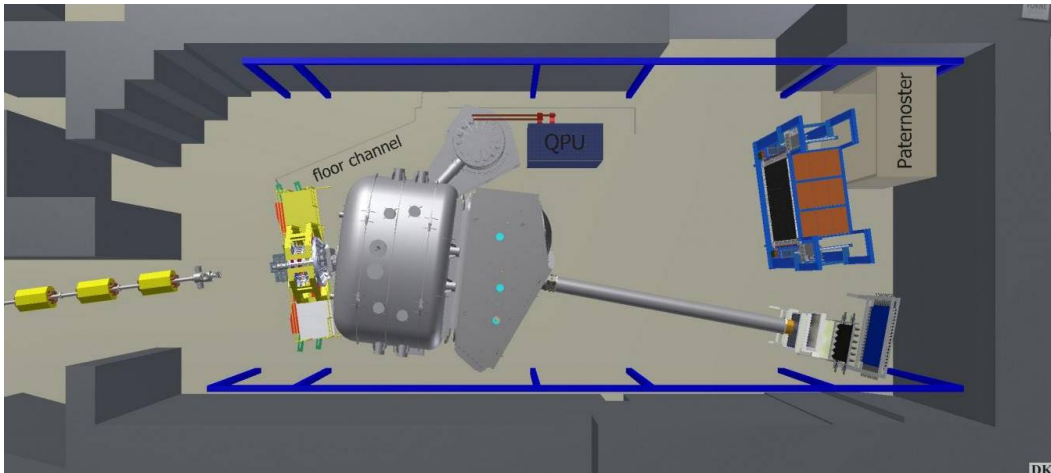
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R³B Overview



R³B Phase-0

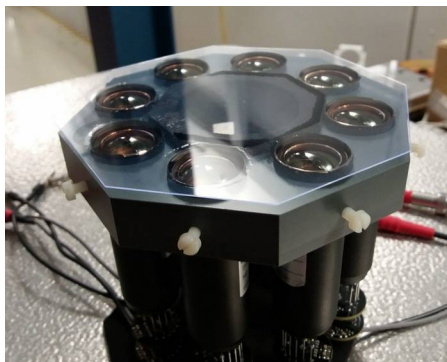


- Commissioning and physics runs in late 2018/early 2019
- First runs with newly developed detectors and GLAD dipole magnet
- Engineering runs with Ar and Ag beams
- Commissioning experiment with ^{12}C
- Experiments using ^{16}O and ^{120}Sn
- Analysis in early stage

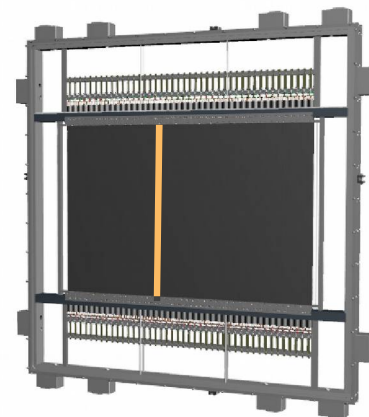
Heavy Ion Tracking at R³B



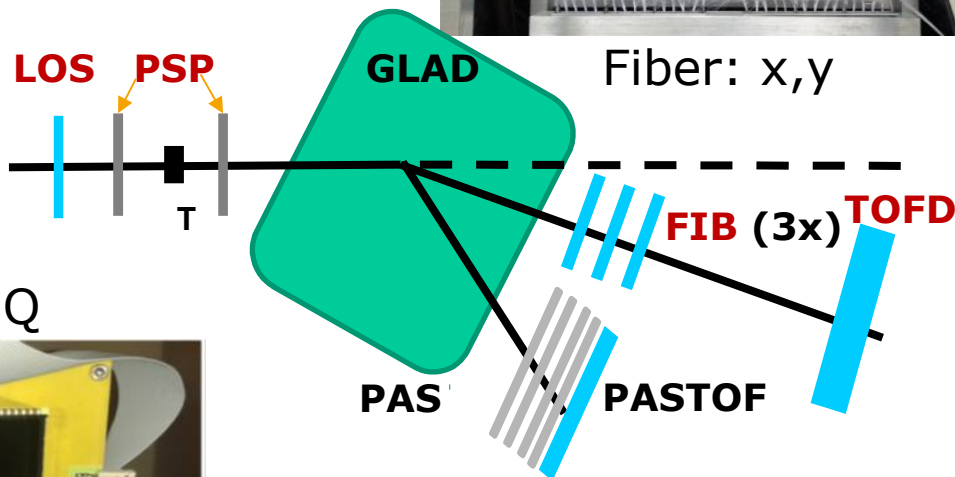
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$$\frac{A}{Q} = \frac{B\rho}{\beta\gamma}$$

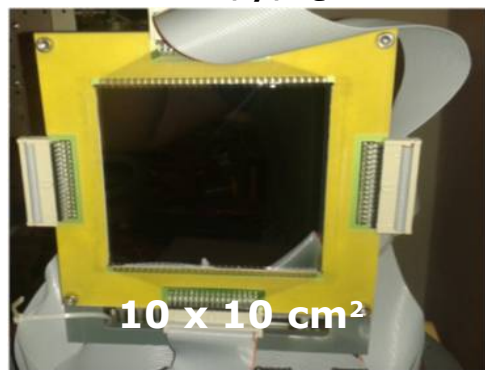


LOS: x, y, Q, t



TOF: Q, t

PSP: x, y, Q



10 x 10 cm²

Timing requirements for PID

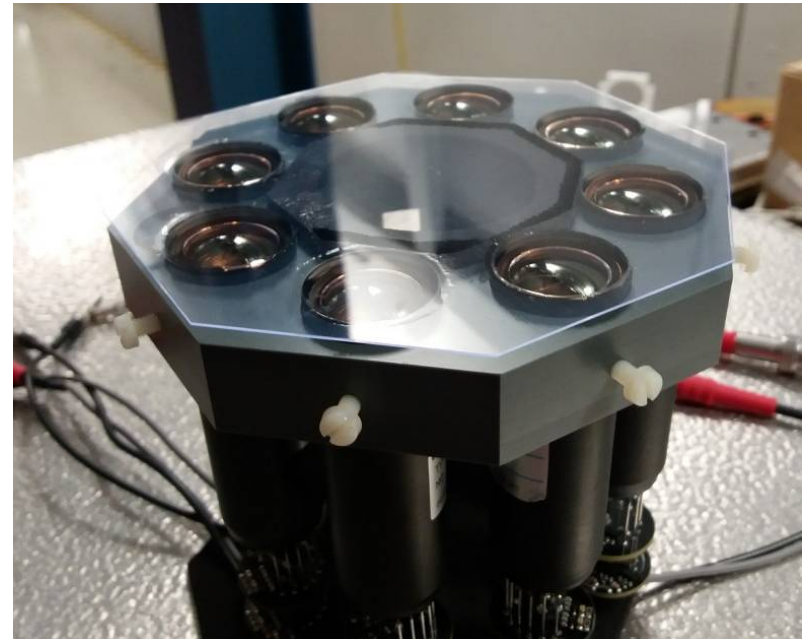
- Incoming beam: ~ 15 ps
- Fragments: ~ 30 ps
- **up to a rate of 1 MHz**

The Start Detector LOS

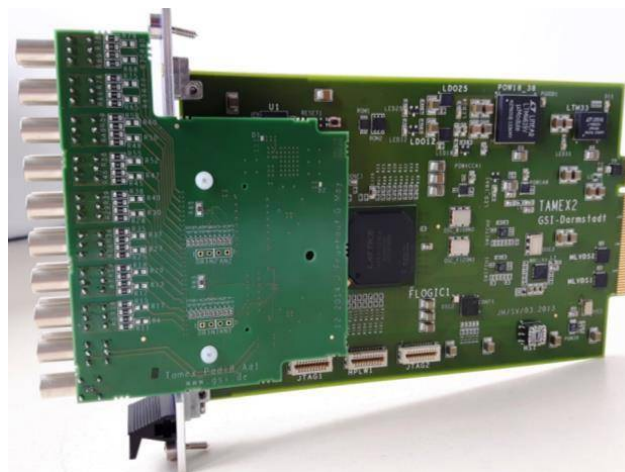


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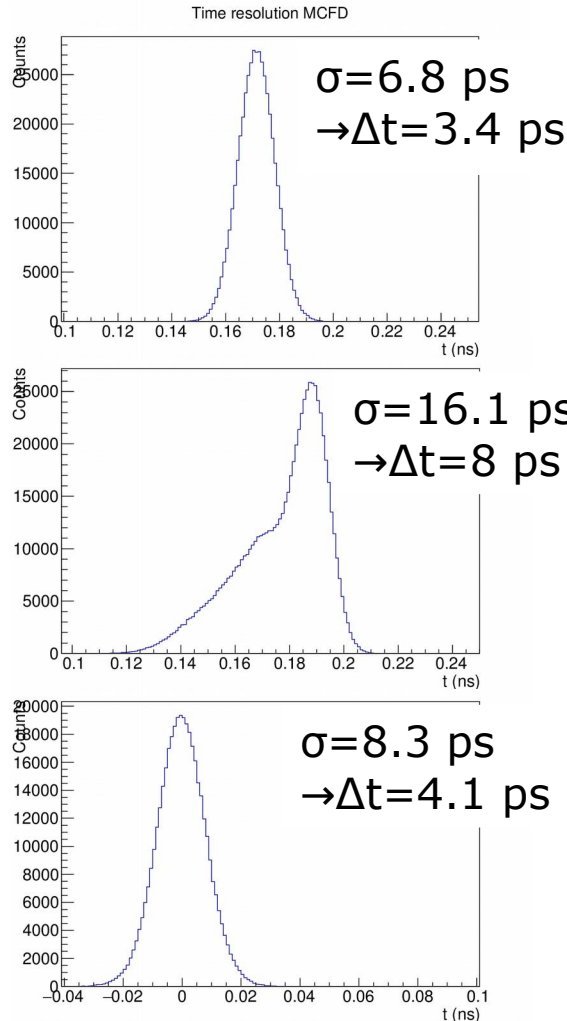
- Octagonal scintillator EJ232.
- Thickness 500 μm or less.
- Read out by 8 PMTs.
- CFD electronics and charge read-out for walk correction
- PMTs mounted on backside of scintillator
 - For $d \ll L$ more light is collected
 - More compact design, easier mounting



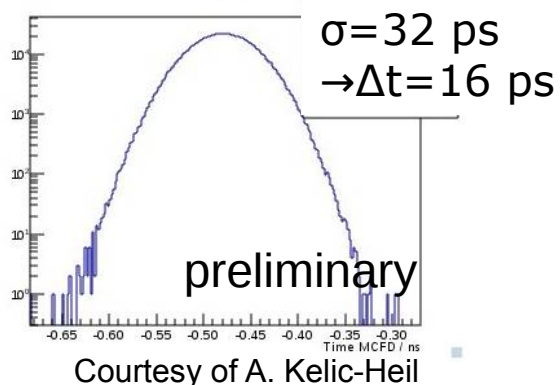
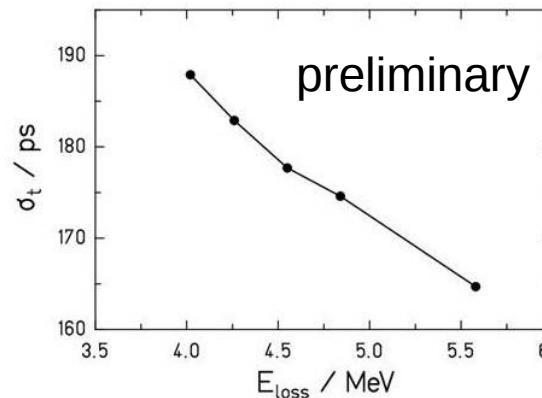
- Two read-outs
 - VFTX + MCFD
 - TAMEX
- VFTX, TAMEX:
 - FPGA TDCs
 - tapped delay line method
 - more flexible than ASIC solutions
- Electronic resolution:
 - VFTX: 8 ps
 - TAMEX 13 ps
- TAMEX allows energy measurement via time-over-threshold
 - resolution comparable to measurement with ADC
 - Advantages: Multi-hit capable, no trigger synchronisation necessary
 - => no global dead time



LOS Performance Tests

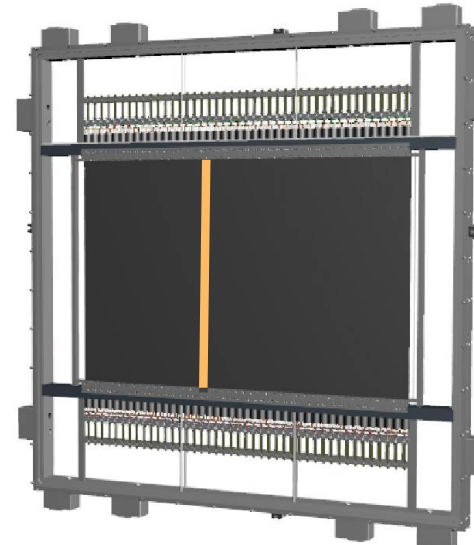


- Tests with UV laser
 - timing precision good but walk corrections necessary when intensity varies
- Tests with beam
 - ^{12}C : timing precision good, governed by photon statistics
 - ^{120}Sn : precision within requirements



TOF Wall

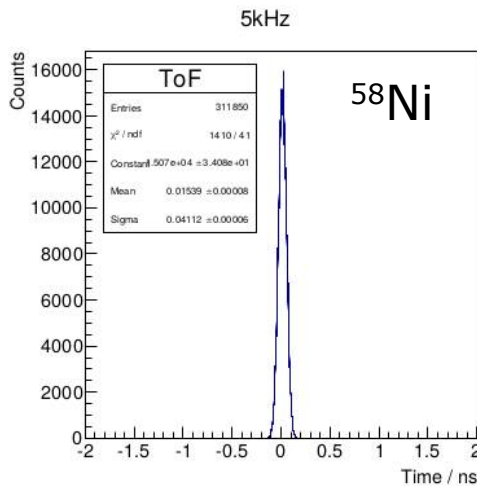
- Final detector in heavy-ion tracking arm
- Size: 120 x 100 cm²
- Scintillator E204
- Total of 176 paddles, arranged into 4 layers
- No light guide, PMT R8619 coupled directly to scintillator
- Movable holding structure to sweep TOF wall across beam
 - sweep runs allow to calibrate for position dependent energy measurement
- Readout using FQT-TAMEX, provides timing and energy loss via ToT
- Required energy resolution $\sigma_E < 1\%$ up to a rate of 1 MHz



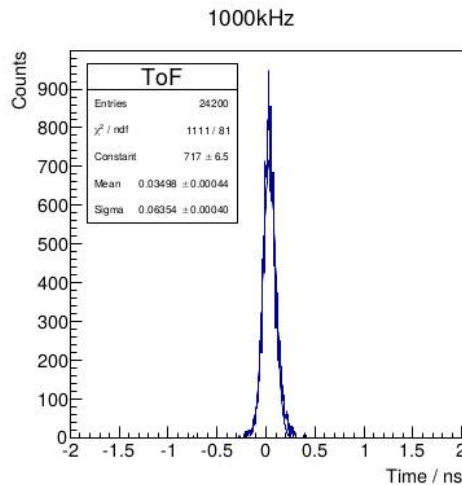
Courtesy of M. Heil

Beam	Energy [AGeV]	σ_{ToF}/ToF [%]	σ_{ToF} [ps]
¹² C	0.5	14.56	1280
⁵⁸ Ni	0.5	2.67	235
¹³² Sn	0.5	0.93	82
²⁰⁸ Pb	0.5	0.44	38
²³⁸ U	0.5	0.33	29
¹² C	1.0	7.99	609
⁵⁸ Ni	1.0	1.46	112
¹³² Sn	1.0	0.51	39
²⁰⁸ Pb	1.0	0.24	18
²³⁸ U	1.0	0.18	14

Performance with beam



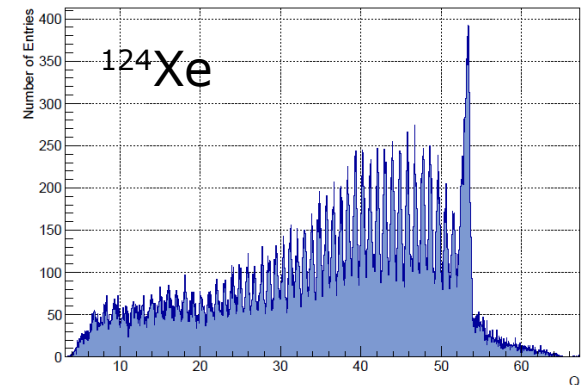
- Test experiments using ^{58}Ni , ^{124}Xe , ^{194}Bi
- Energy resolution from ToT good enough for charge identification
- Timing resolution fulfills design goals even at high rates
- Detector successfully used during Phase-0 runs



Rate / kHz	σ_t / ps	σ_t^{det} / ps
5	41	14
59	41	14
375	45	16
1000	64	23

Beam	Energy / AMeV	σ_t / ps	σ_t^{det} / ps	σ_t^{needed} / ps
^{58}Ni	500	41	14	235
^{124}Xe	600	31	11	75
^{194}Bi	700	22	8	31

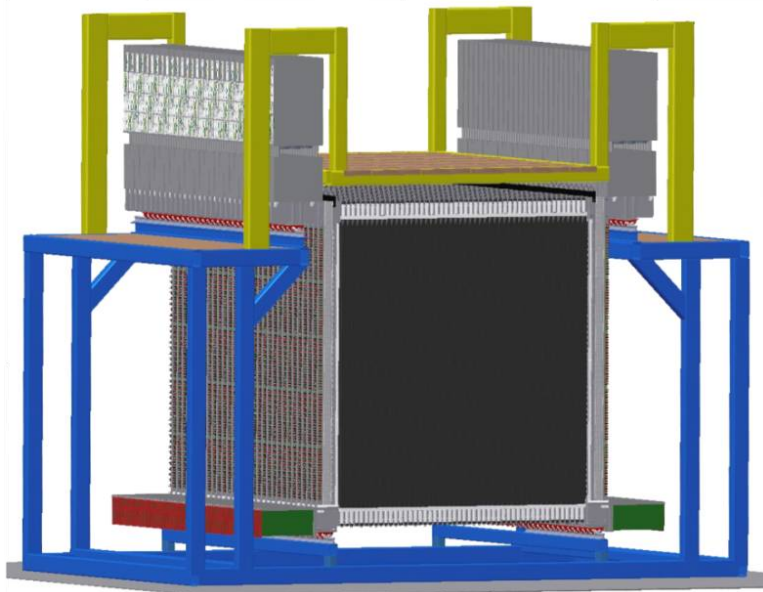
Courtesy of M. Heil



Detection of Fast Neutrons



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Design goals:

- >90% efficiency for 0.2-1.0 GeV neutrons
- multi-hit capability for up to 5 neutrons
- invariant mass resolution down to $\Delta E < 20$ keV at 100 keV above thr.

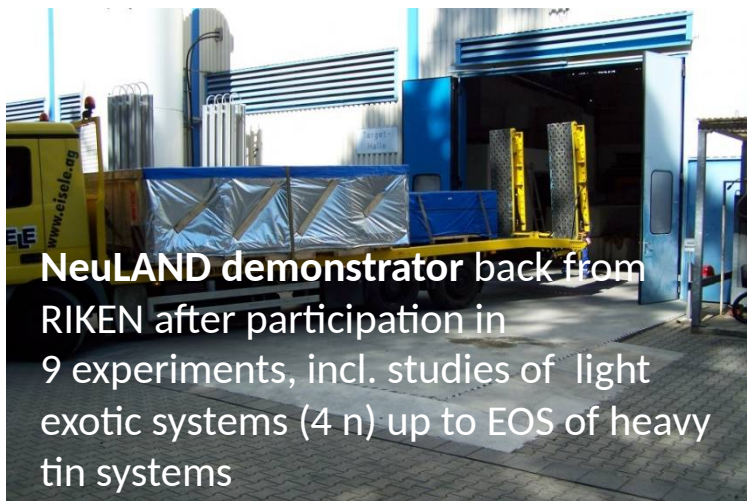
NeuLAND detector parameters:

- full active detector using RP/BC408
- face size 250x250 cm²
- active depth 300 cm
- 3000 scintillator bars + 6000 PMTs
- 32 tons
- $\sigma_{x,y,z} \approx 1\text{cm}$ & $\sigma_t < 150$ ps



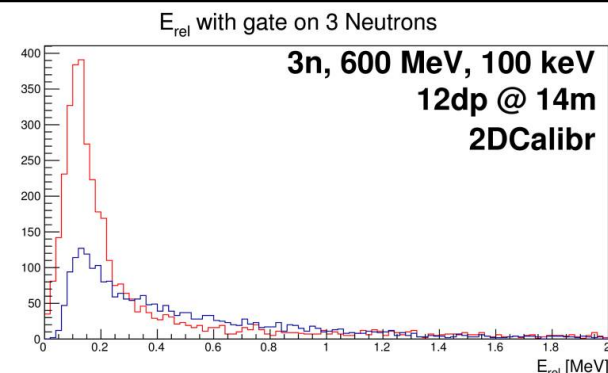
double plane 11 during bar mounting

NeuLAND: Status



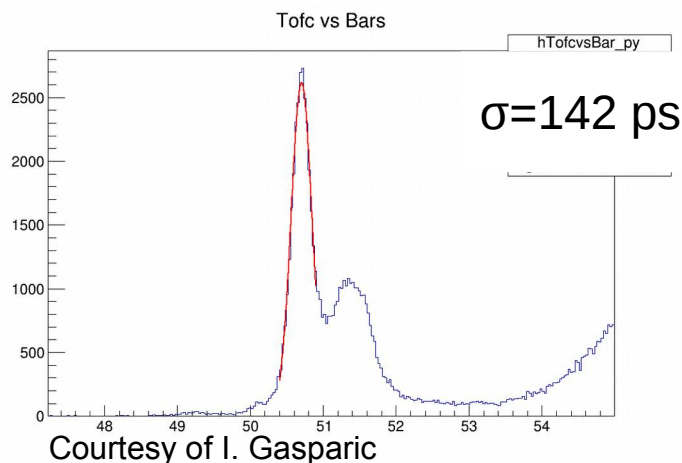
NeuLAND Phase 0

- 130 cm active depth
- 2600 channels >40% detector



simulation prediction: **reconstruction efficiency** of the order of 20% for 3 n, 10 % for 4 n (600 MeV, preliminary)

Courtesy of K. Boretzky



test of NeuLAND electronics

- multichannel front-end electronic card TAMEX for high-resolution time and charge measurements
- required timing precision of 150 ps reached both at RIKEN and in commissioning run at GSI



Summary

- The R3B setup is currently under construction at GSI
- It is designed to allow for kinematically complete measurements of reactions with fast radioactive beams
- Fast timing plays a key role for achieving the necessary precision for heavy-ion tracking and neutron energy measurement
 - Timing measurements can replace energy measurements using FQT or ToT
- Detectors and electronics have been developed and successfully tested in the recent FAIR-phase0 experiments

The R³B Collaboration



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Thank you for your attention!



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