Measurements of Compton and neutron scattering in liquid xenon with the MainzTPC

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ETAP seminar
04 July 2016

HELMHOLTZ ASSOCIATION
Alliance for Astroparticle Physics

Symmetry Breaking

PRISMA

Person

How did I get here:

- Study of physics at JGU
  - Interested in topics concerning astrophysics and cosmology
  - Exchange studies at KTH Stockholm → courses about space / astroparticle physics
  - Diploma thesis in XENON group
- currently: PhD-student in XENON group

Technical aspects of my work include:

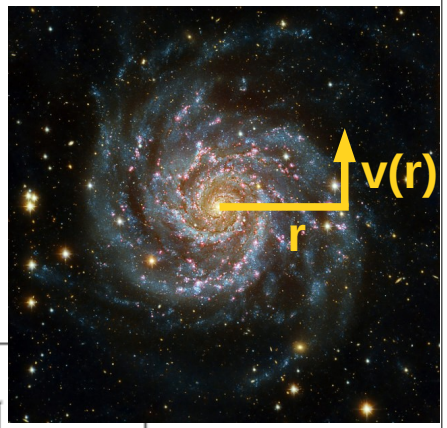
- VME electronics (mainly data acquisition)
- ROOT, C, Geant4
- data acquisition / analysis
- cryogenics, vacuum / gas system, electronics, different sensors

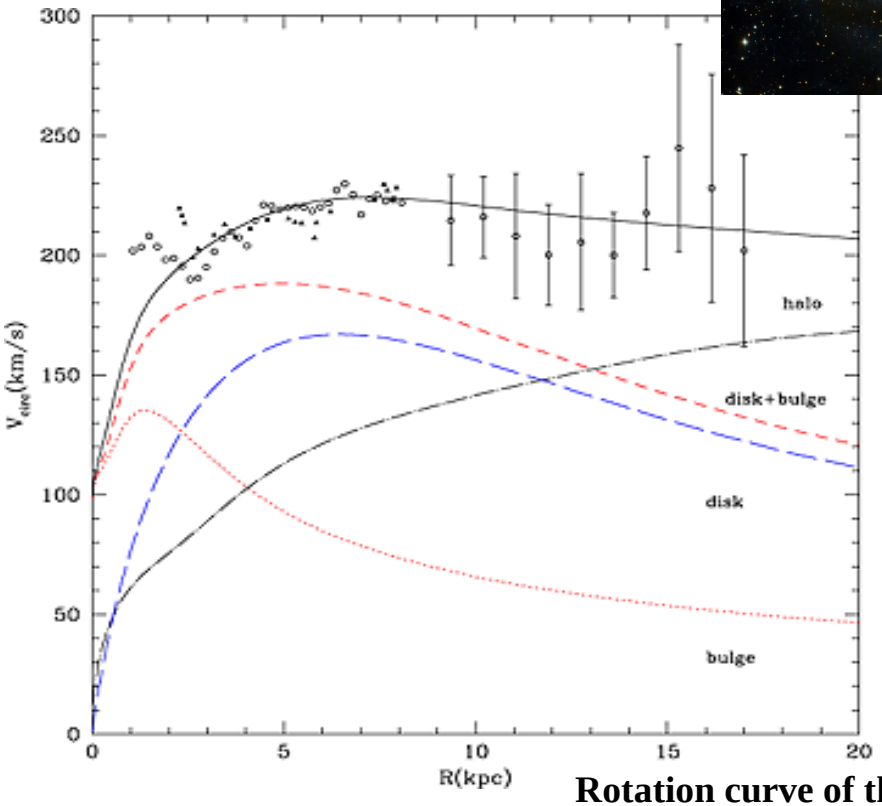
Overview

- Dark Matter
- Principle of Dual-Phase Xenon Time Projection Chambers
- MainzTPC:
  - Compton Setup @ Mainz
  - Neutron Setup @ Dresden
- Analysis / Results
- Outlook

Dark Matter

- Gravitational evidences on different scales:
  - **Rotational curves**
    Motion in galaxy clusters
    Universal structure formation

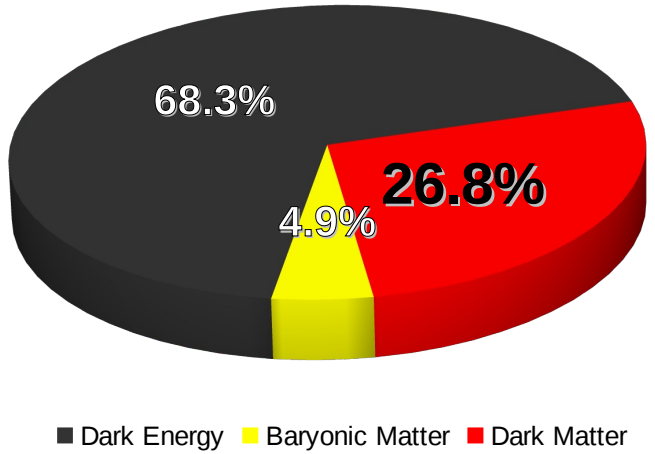




Rotation curve of the Milky Way
(A. Klypin et. al, ApJ. 573, 2002)

- Dark Matter particle:
  - massive (gravitational interaction)
  - non-baryonic
  - stable
  - weakly interacting?

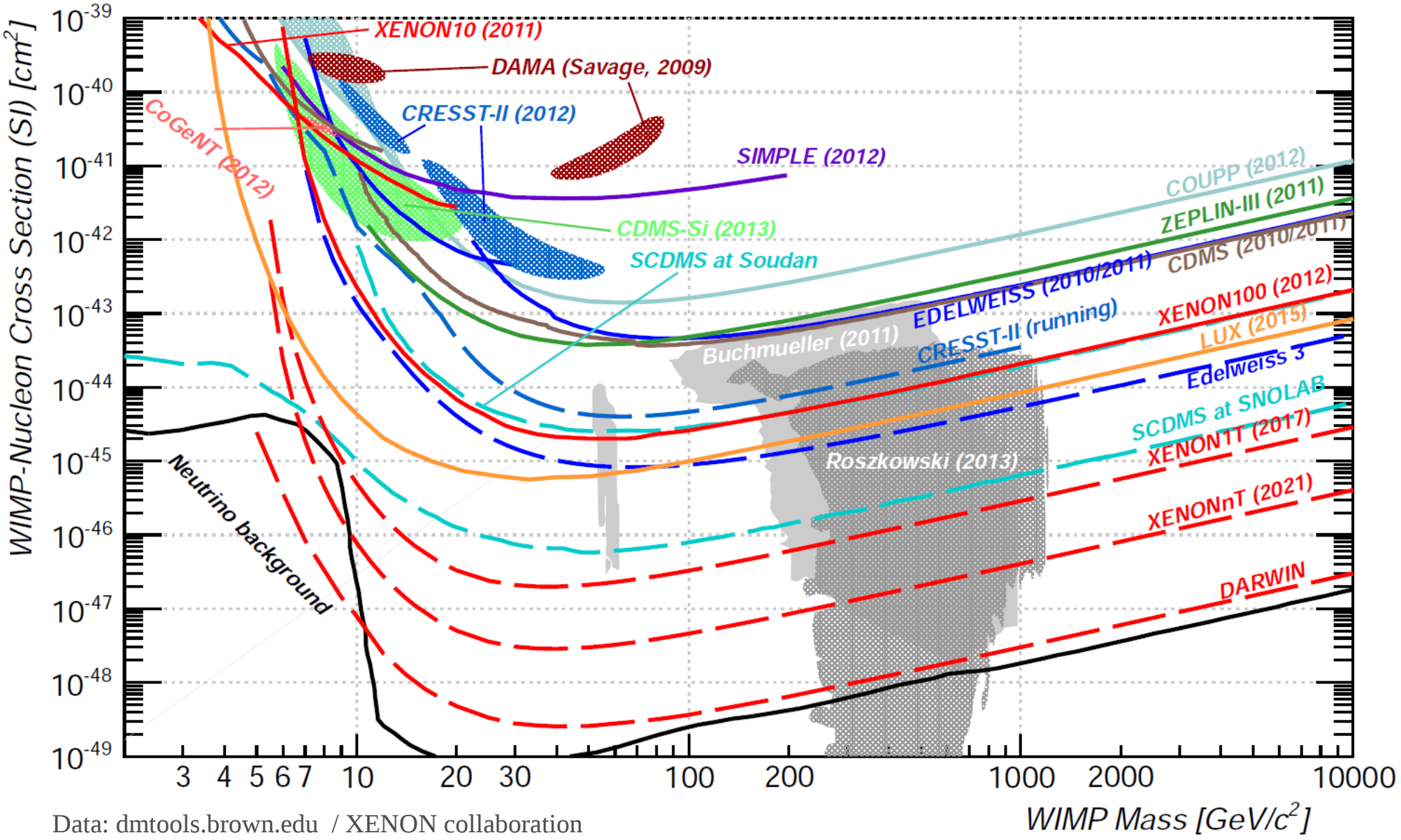
→ **WIMP**



Data: Planck collaboration

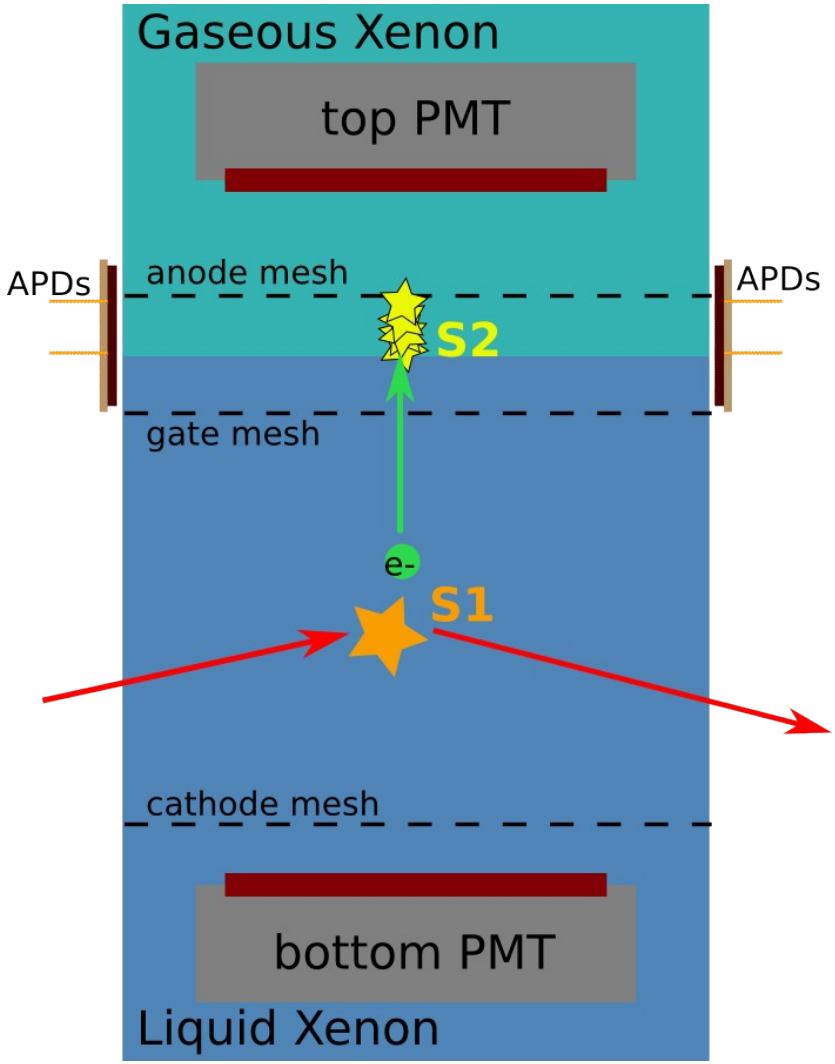
- Search for Dark Matter:
  - **Direct Detection**
  - Indirect Detection
  - Production at colliders

Direct Dark Matter searches: Status and future goals

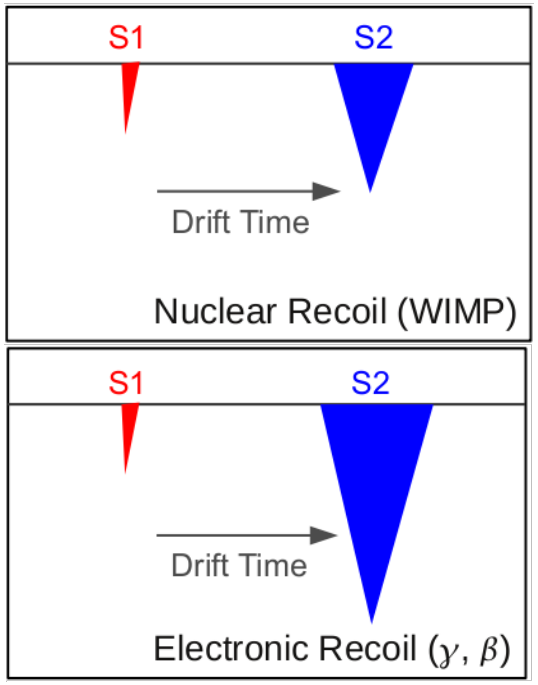


Data: dmtools.brown.edu / XENON collaboration

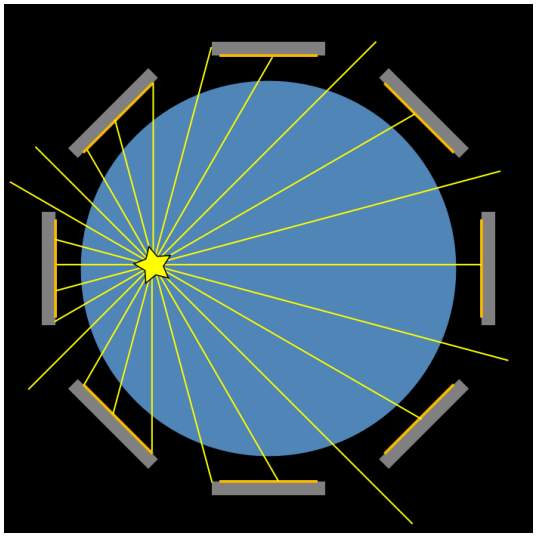
Principle of a Dual-Phase Xenon TPC



z-position
reconstructed by electron drift time:
$z = \Delta t \cdot v_{drift}$

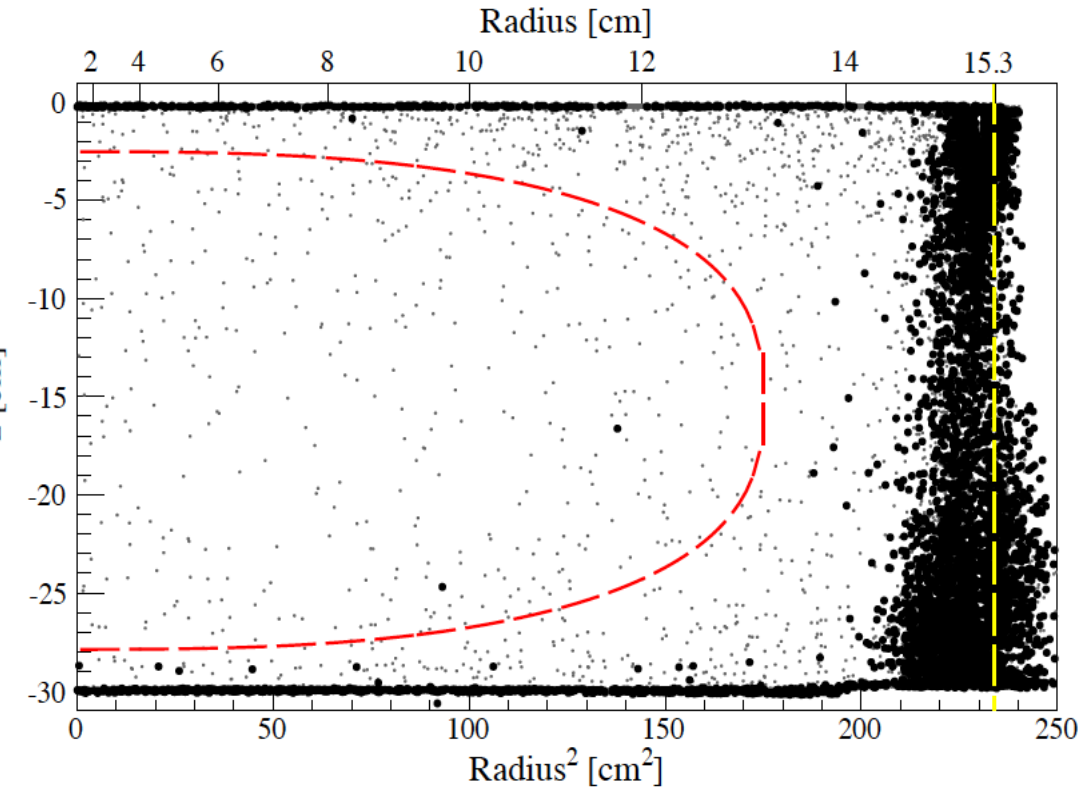


x/y-position
position of S2 detected by a photosensor array

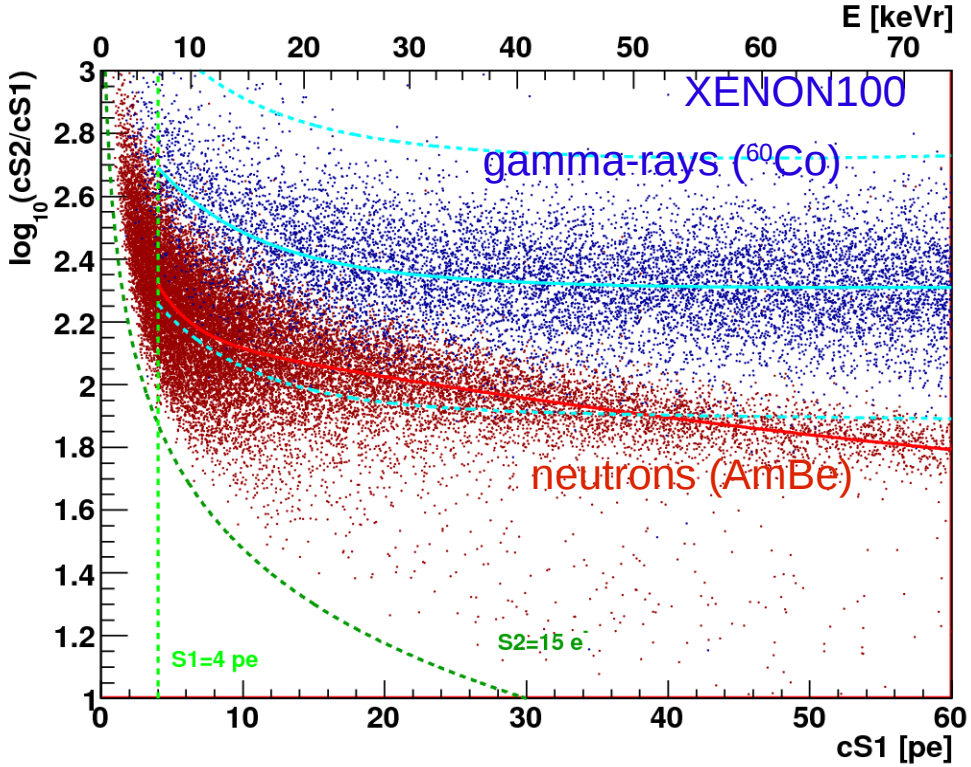


Background discrimination

3D Position Reconstruction: fiducial cut, singles/multiples



Ionization/Scintillation Ratio S2/S1



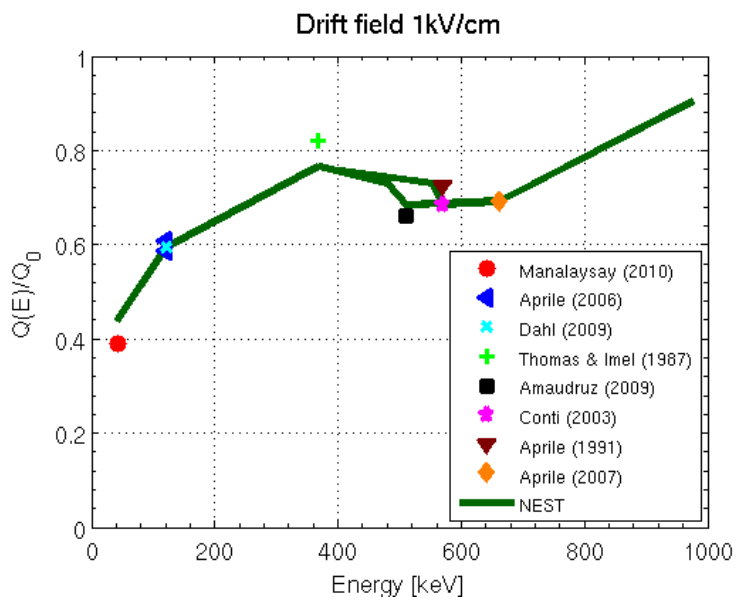
Plots: XENON collaboration

Light and Charge Yields: Status

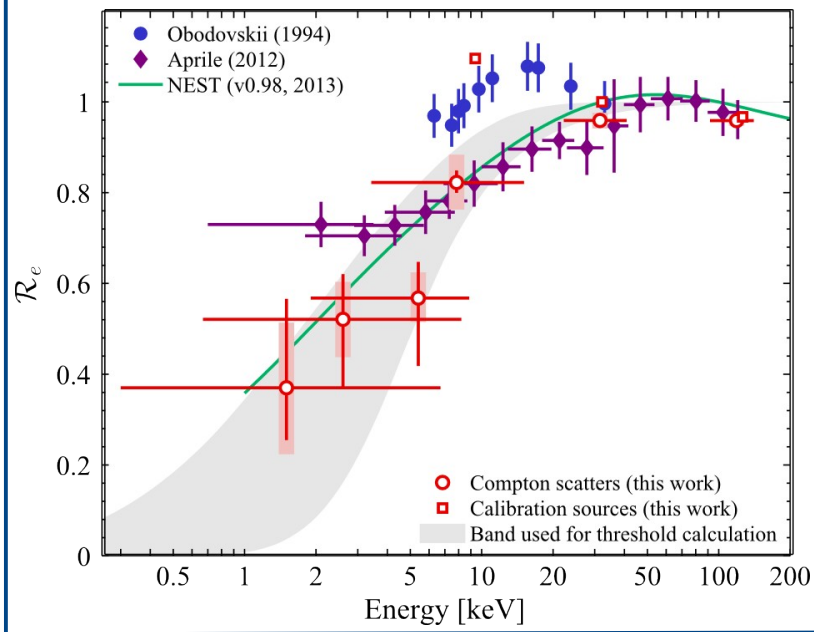
charge yield

scintillation yield

electronic recoils

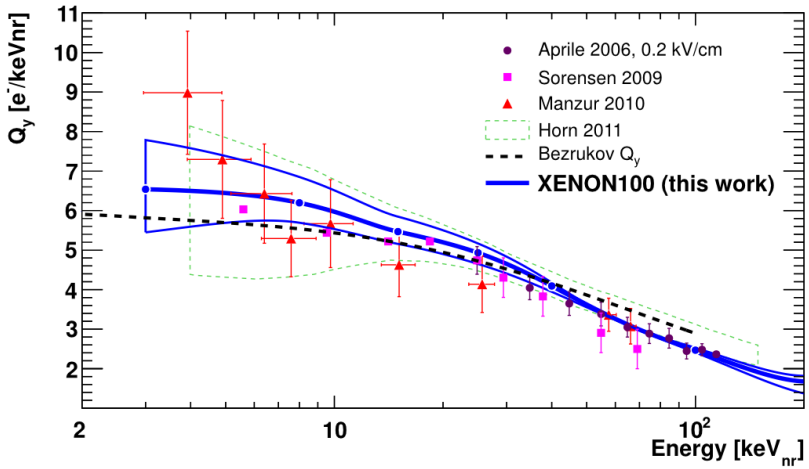


Data collected from: JINST 6 p10002 (2011)

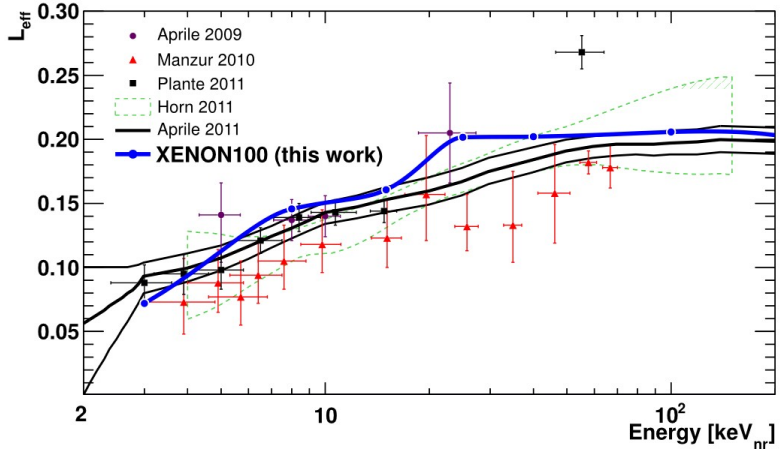


Phys.Rev.D 87, 115015: L. Baudis et al.

nuclear recoils



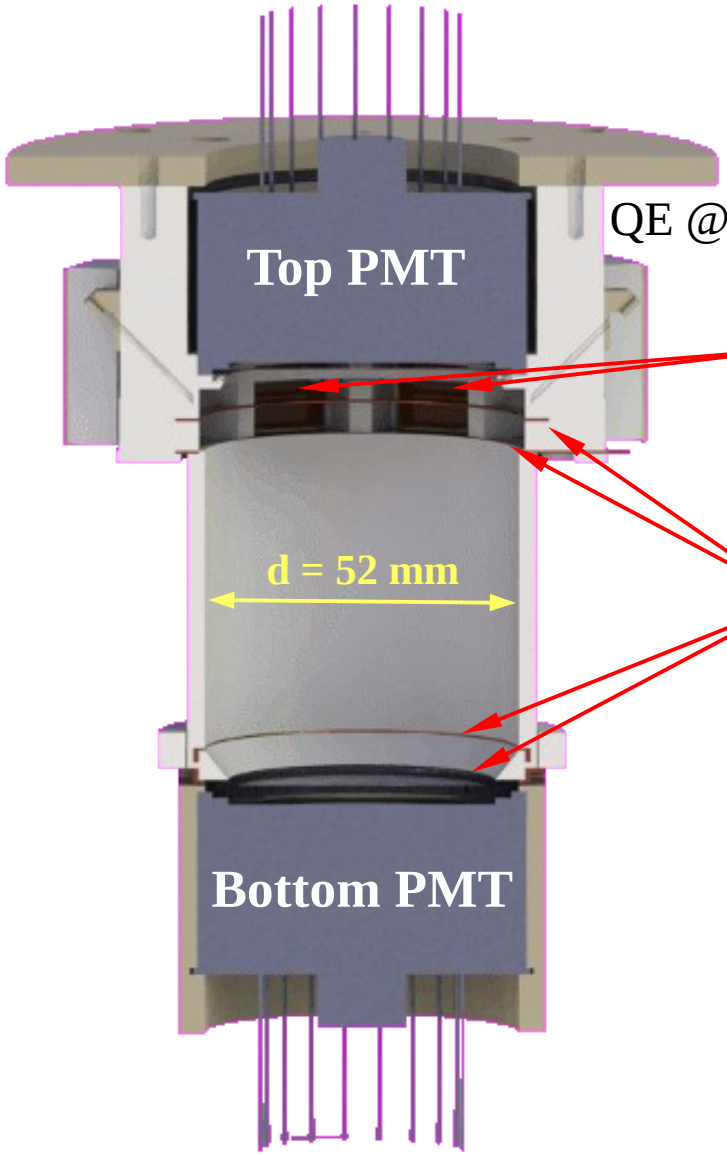
Phys.Rev.D 88, 012006: E. Aprile et al. (XENON100 Collab.)



Phys.Rev.D 88, 012006: E. Aprile et al. (XENON100 Collab.)

Design of the MainzTPC

Optimized setup for single scattering:



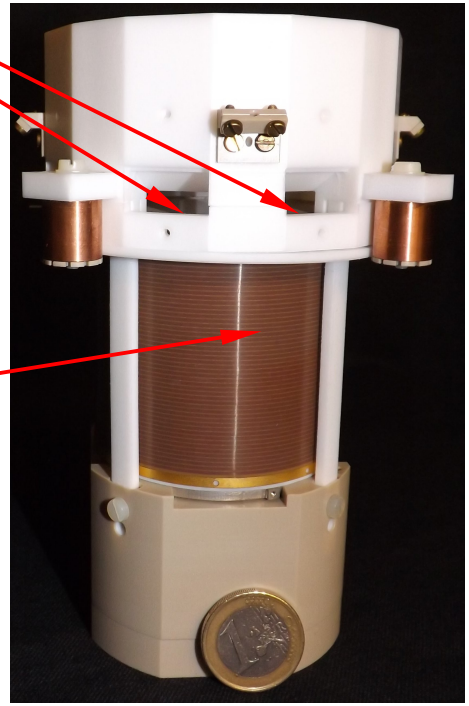
2 PMTs
QE @ 178 nm ~ 30 %

8 APDs
x/y position resolution

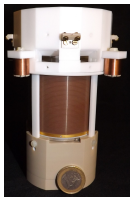
Meshes
high transparency
fine pitch

Field Cage
PCB => low passive mass

- high light yield (high reflectivity materials)
- small size (active mass ~300g)
- 3D position resolution ($\Delta d_{xy} \leq 1.3$mm; $\Delta d_z \approx 1$mm)
- small amount of passive material

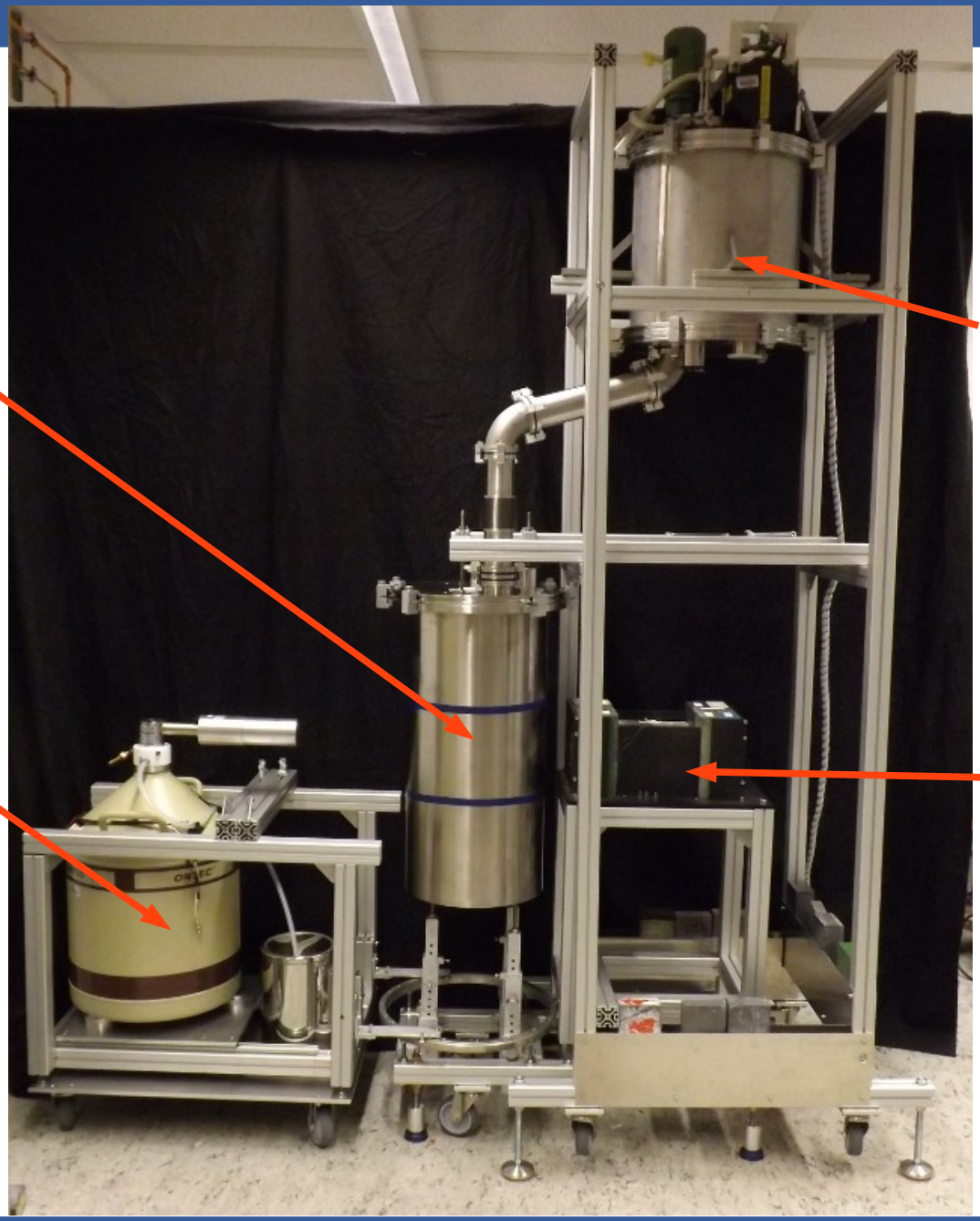


The MainzTPC Compton Setup (@Mainz)



TPC inside cryostat

Ge-detector

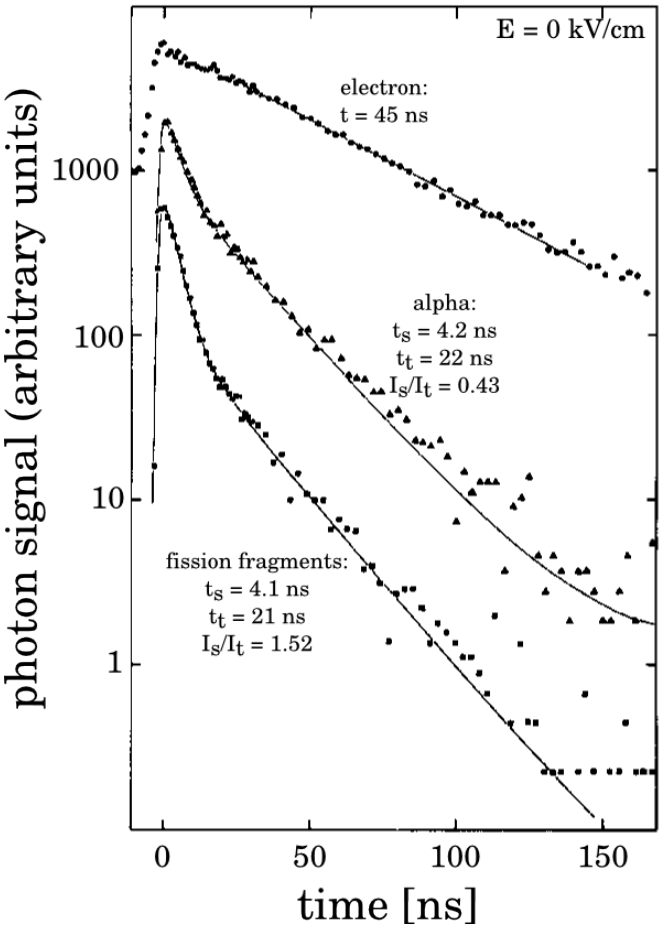


pulse tube refrigerator + LN2 emergency cooling

collimator for γ-source

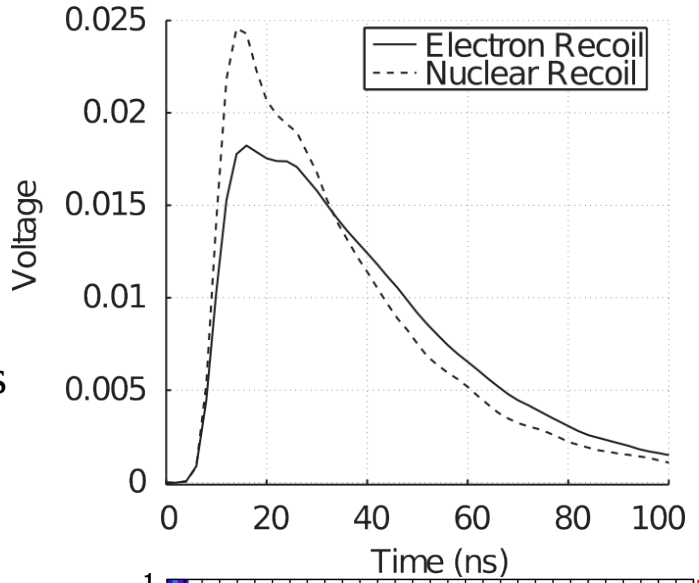
Scintillation Pulse Shape

Complementary background discrimination method:

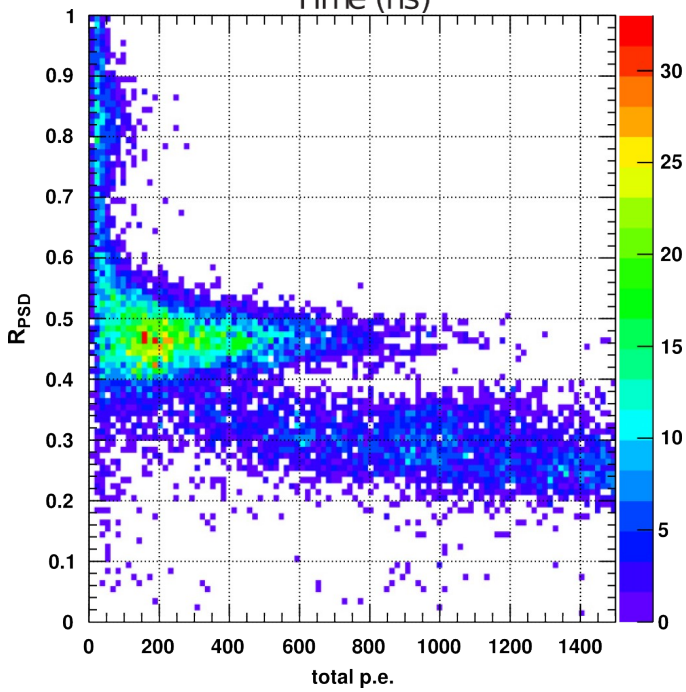


- LXe has 2 decay components (singlet, triplet state of Xe_2^*)
- Fast component ≈ 2 ns
- Slow component ≈ 27 ns
- Pulse shape is dependent of the applied electric field
- works already well in LAr
- challenging in LXe

Phys. Rev. B 27, 5279 1983

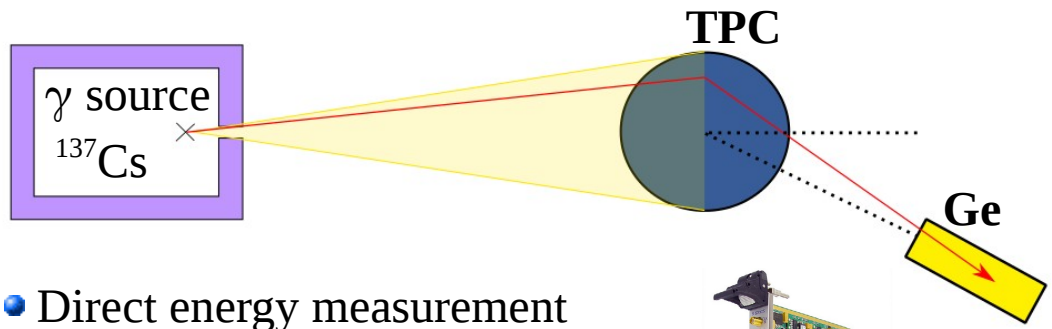


NIM A612(2010): J. Kwong et al.



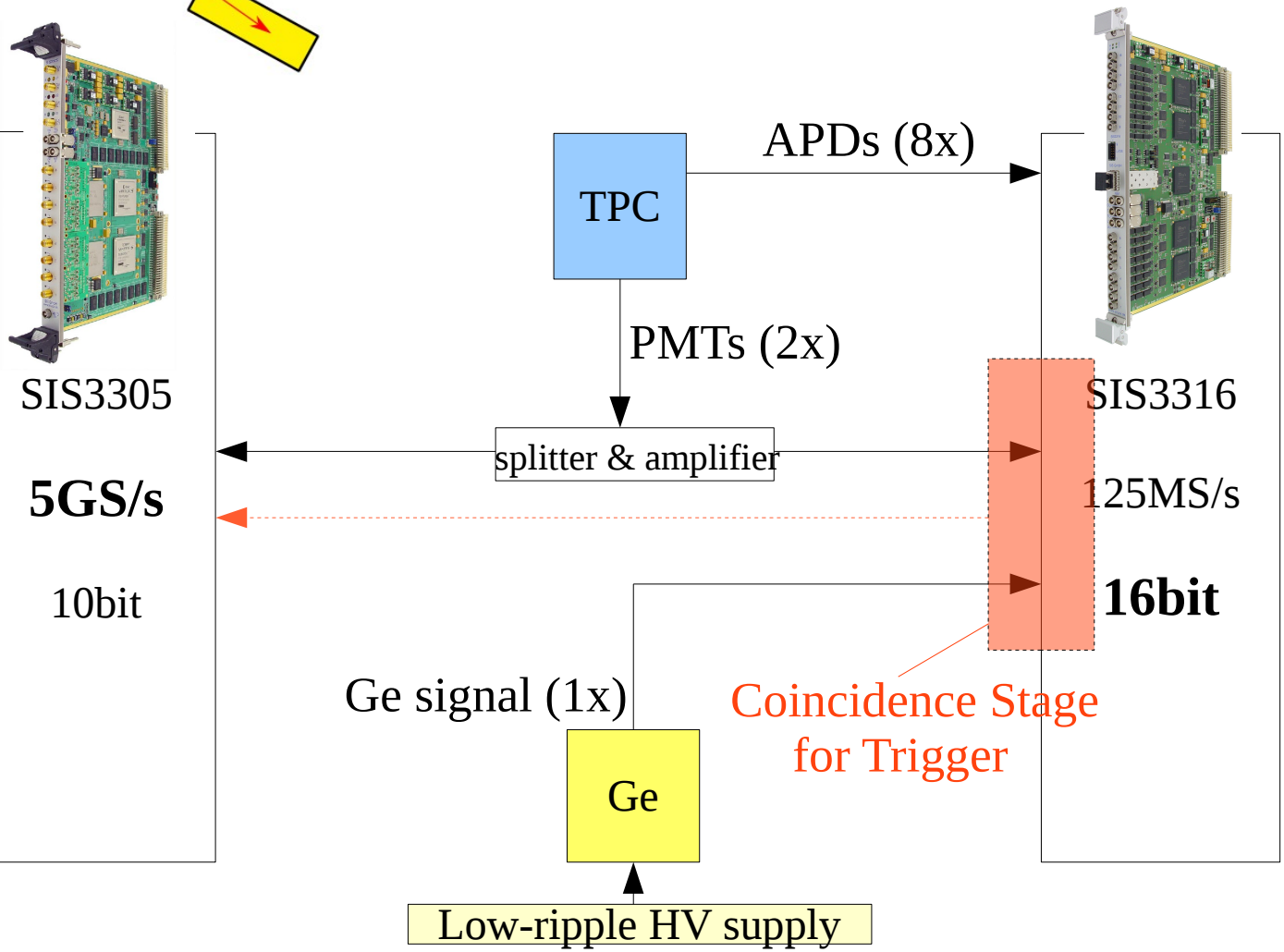
NIM A659(2011): K. Ueshima et al.

Compton Setup

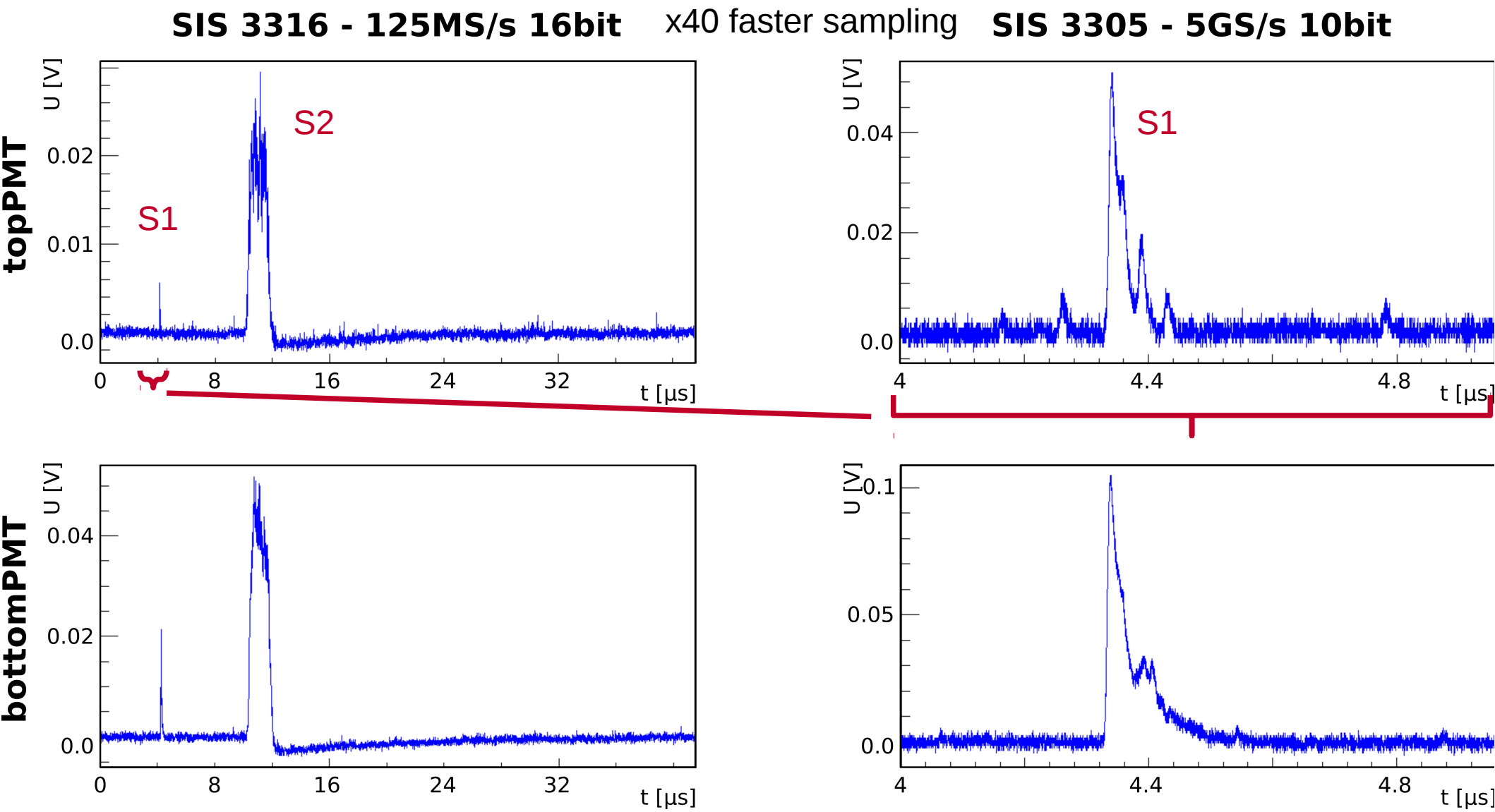


- Direct energy measurement with Ge detector

- DAQ with fast and slow ADC



MainzTPC signal: Small gamma event



Measurements at the HZDR

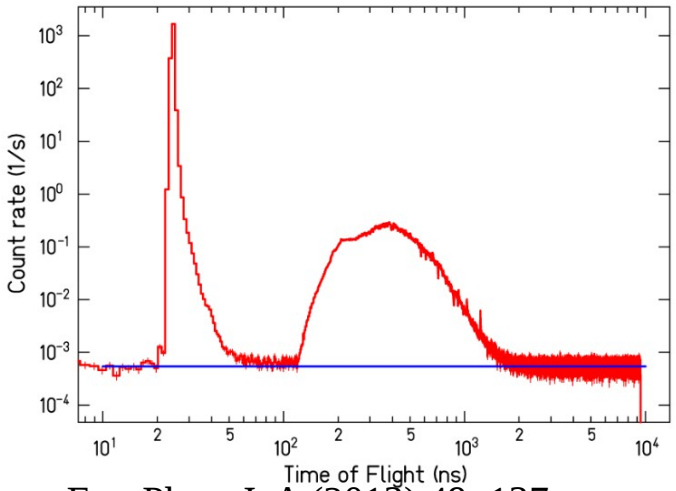
HZDR: **H**elmholtz **Z**entrum **D**resden **R**ossendorf

nELBE: Neutron measurement facility at the
Electron **L**inac for beams with high **B**rilliance and low **E**mittance

- Neutron generation:

  pulsed electron beam on a
  liquid lead target

  → neutrons and bremsstrahlung



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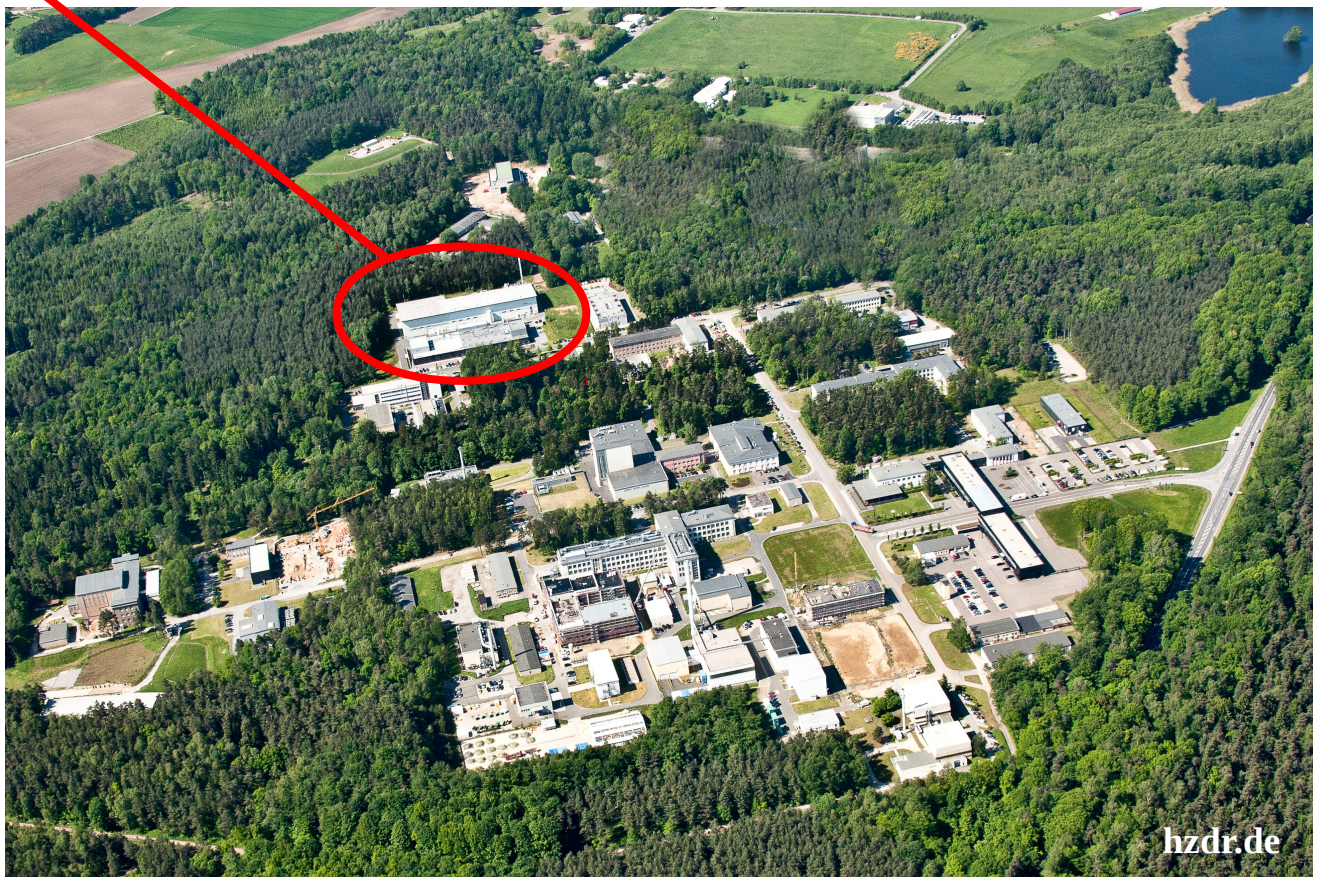
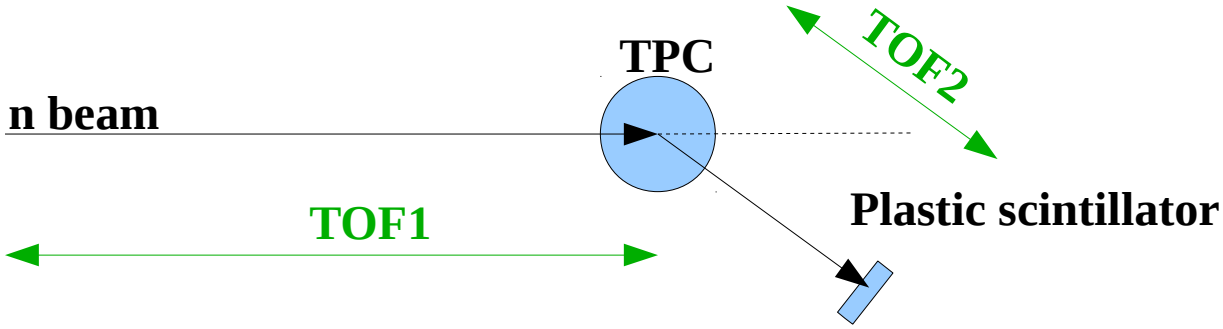


Required changes for neutron measurements

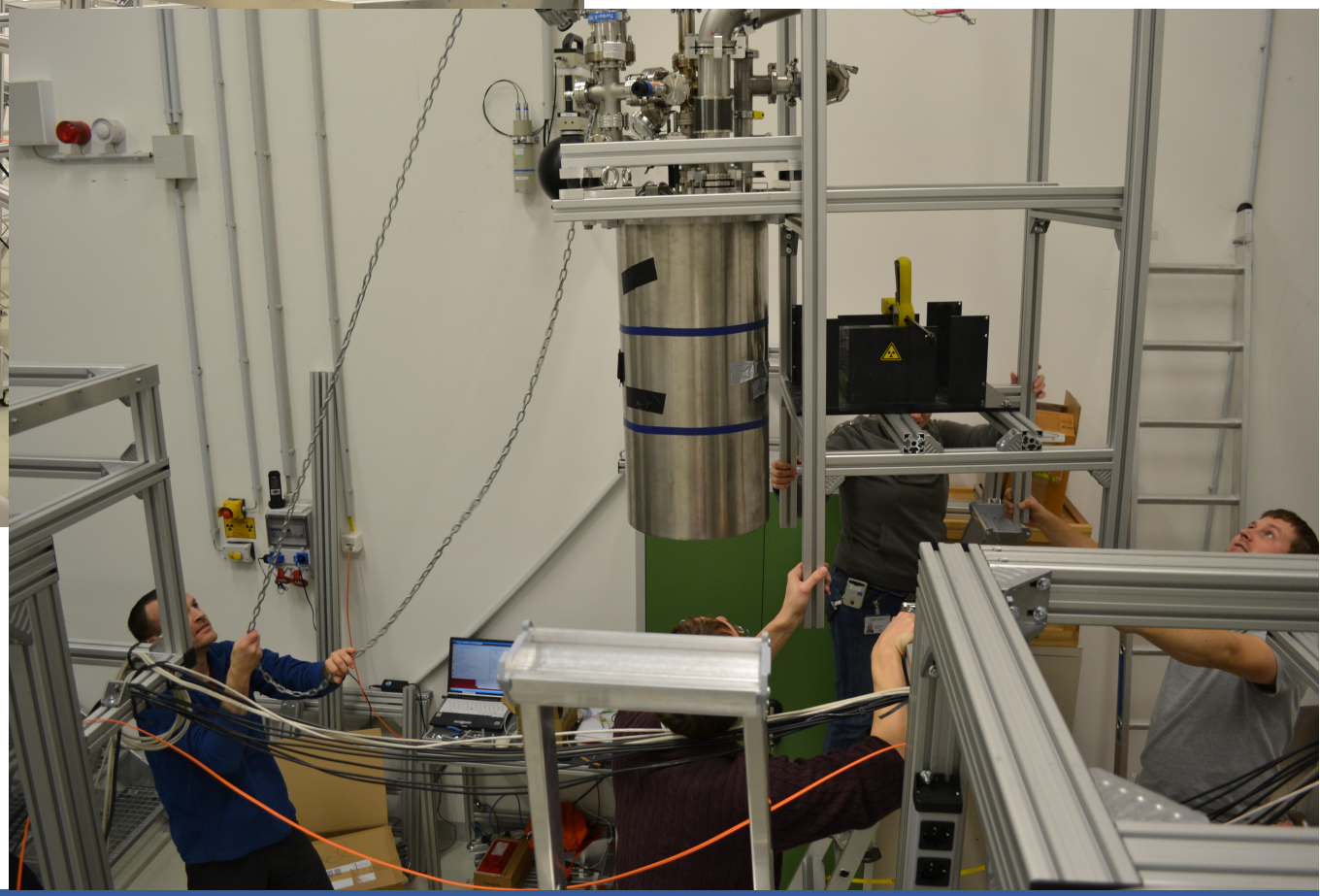
- Difficulty: measurement of neutron energy
- Two possibilities:
  - Measurement of scattering angle
  - **Time-of-Flight** measurement



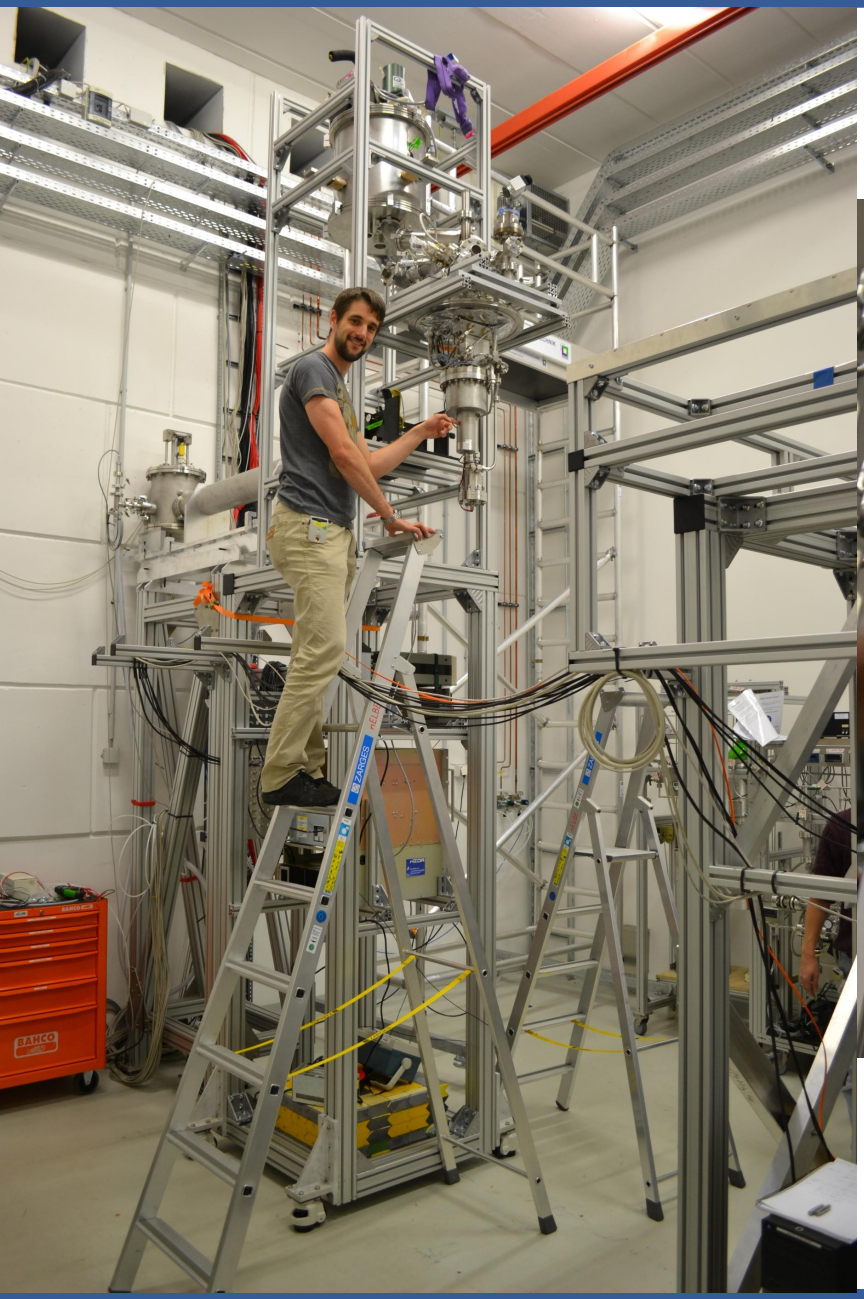
- Changes in setup:
  - Extension of DAQ: Time-to-Digital-Converter (TDC), new data format
  - NEW Trigger system (using a logic board)
  - Ge detector → plastic scintillators (from HZDR)
  - TPC has to be mounted to beam line

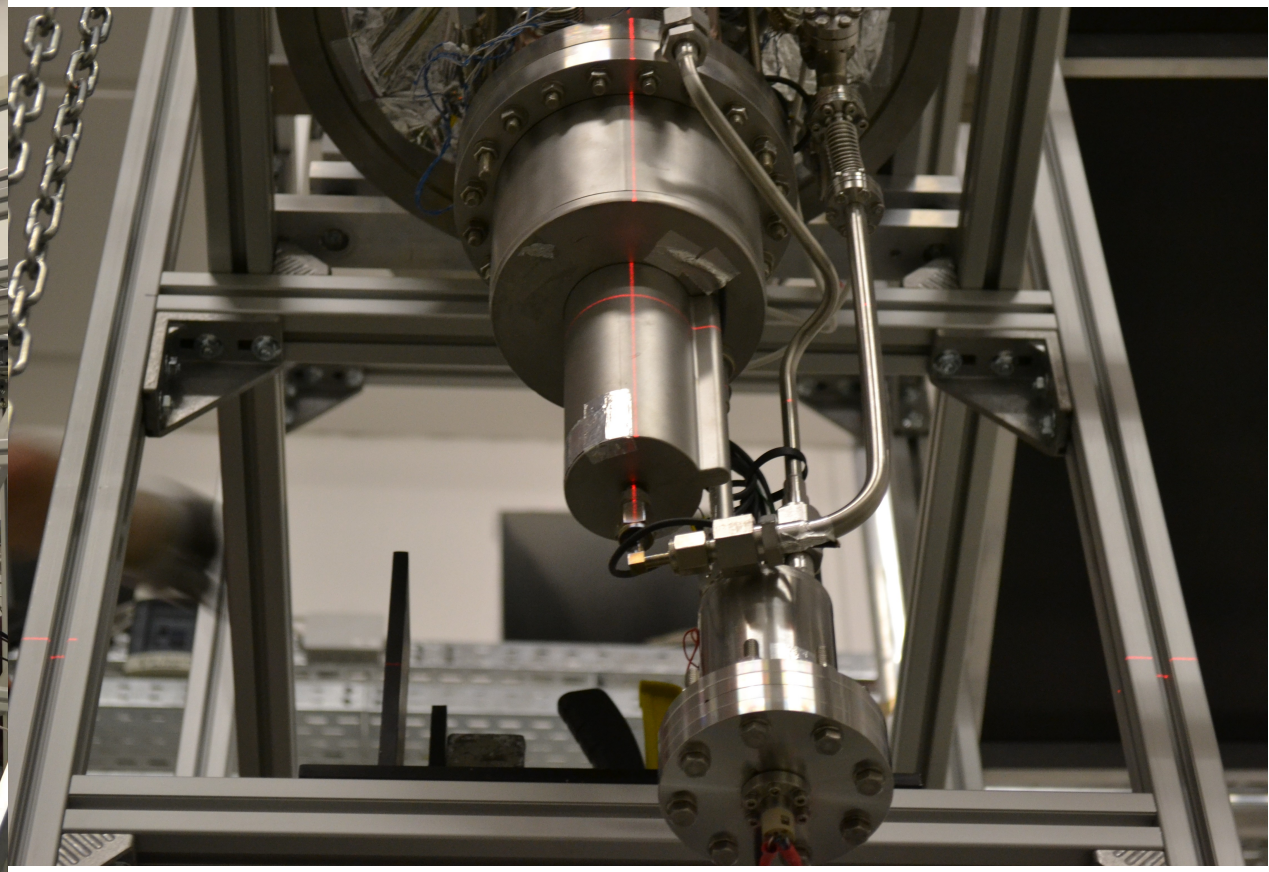
From Mainz to Rossendorf

The MainzTPC Setup @HZDR

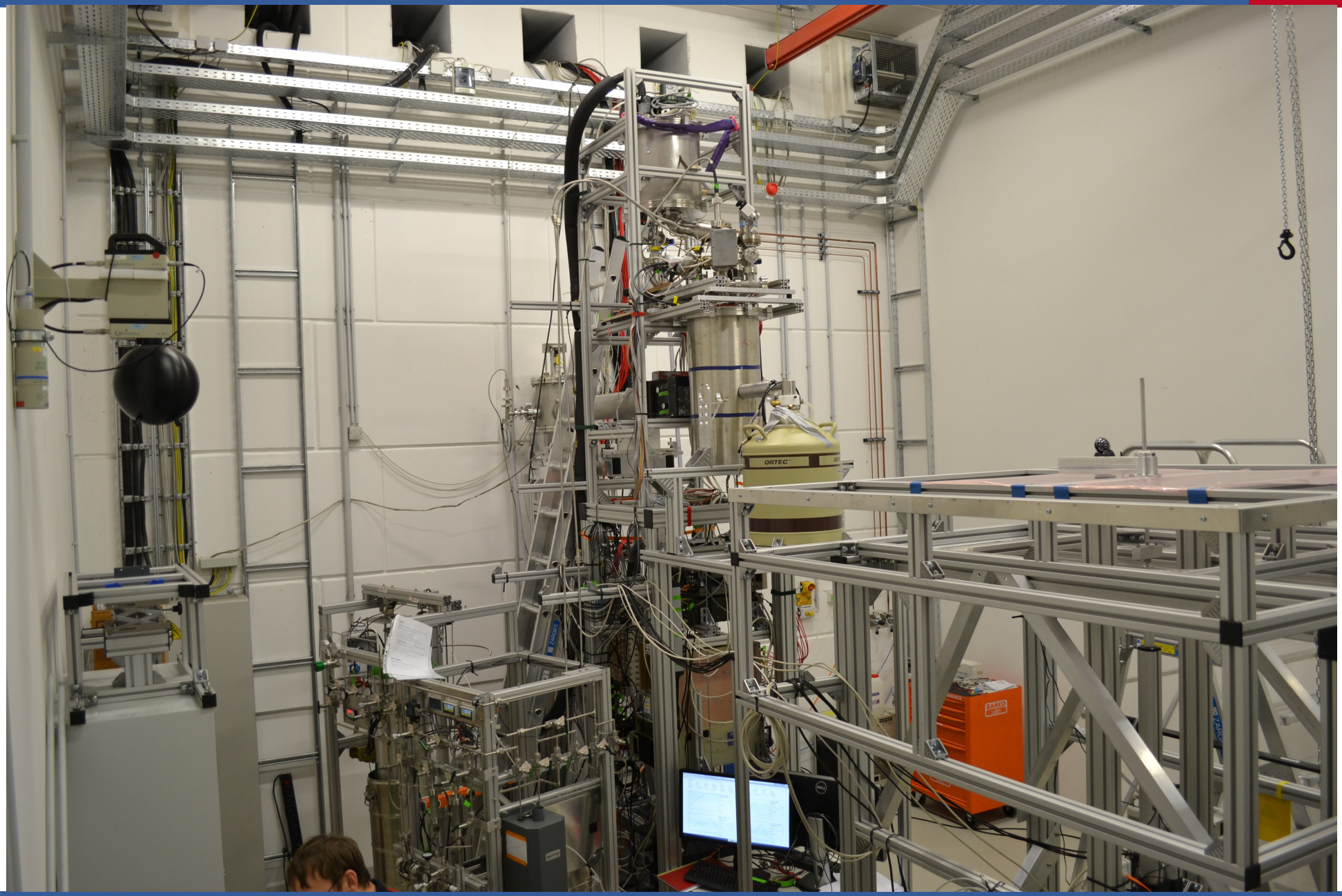


The MainzTPC Setup @HZDR

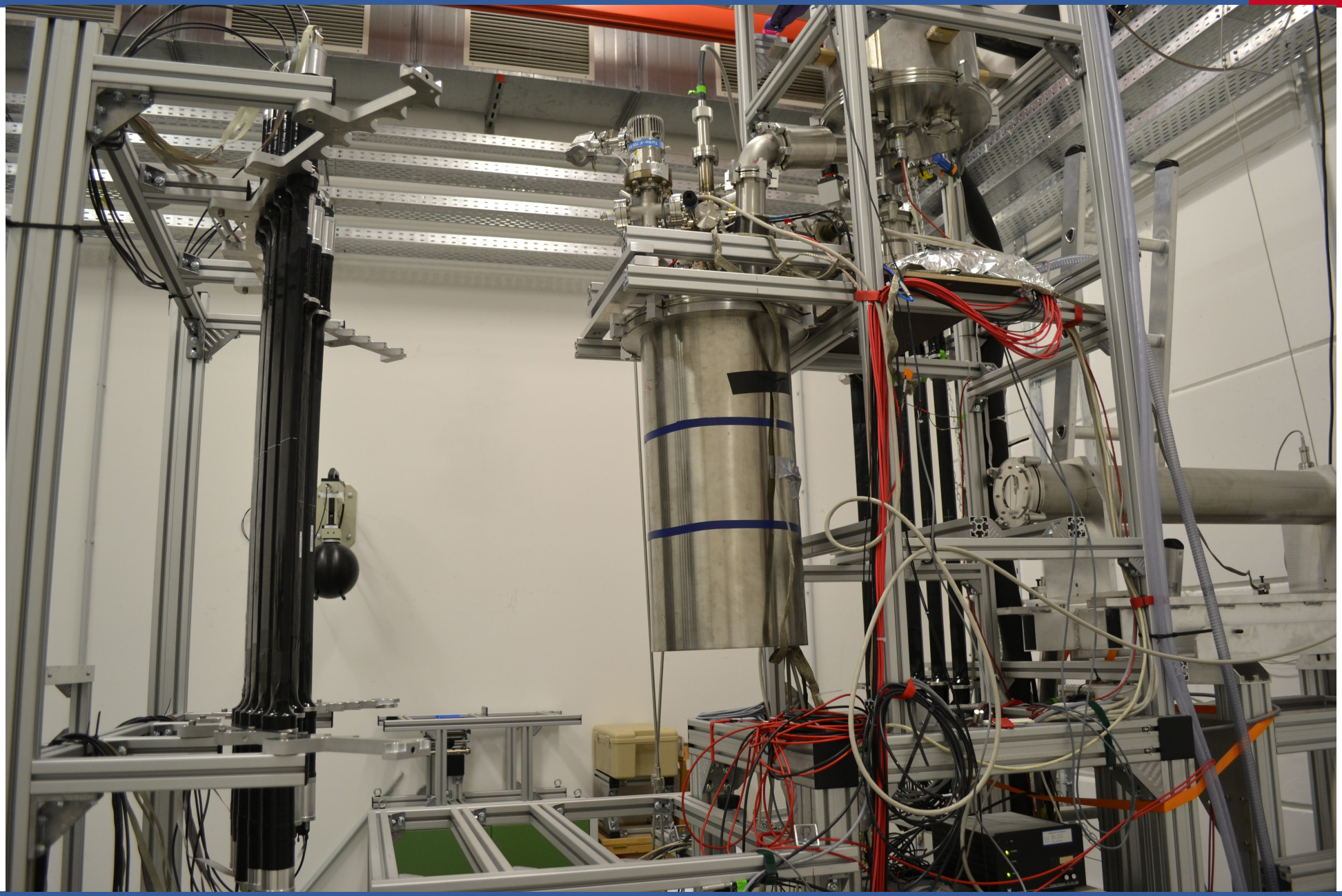




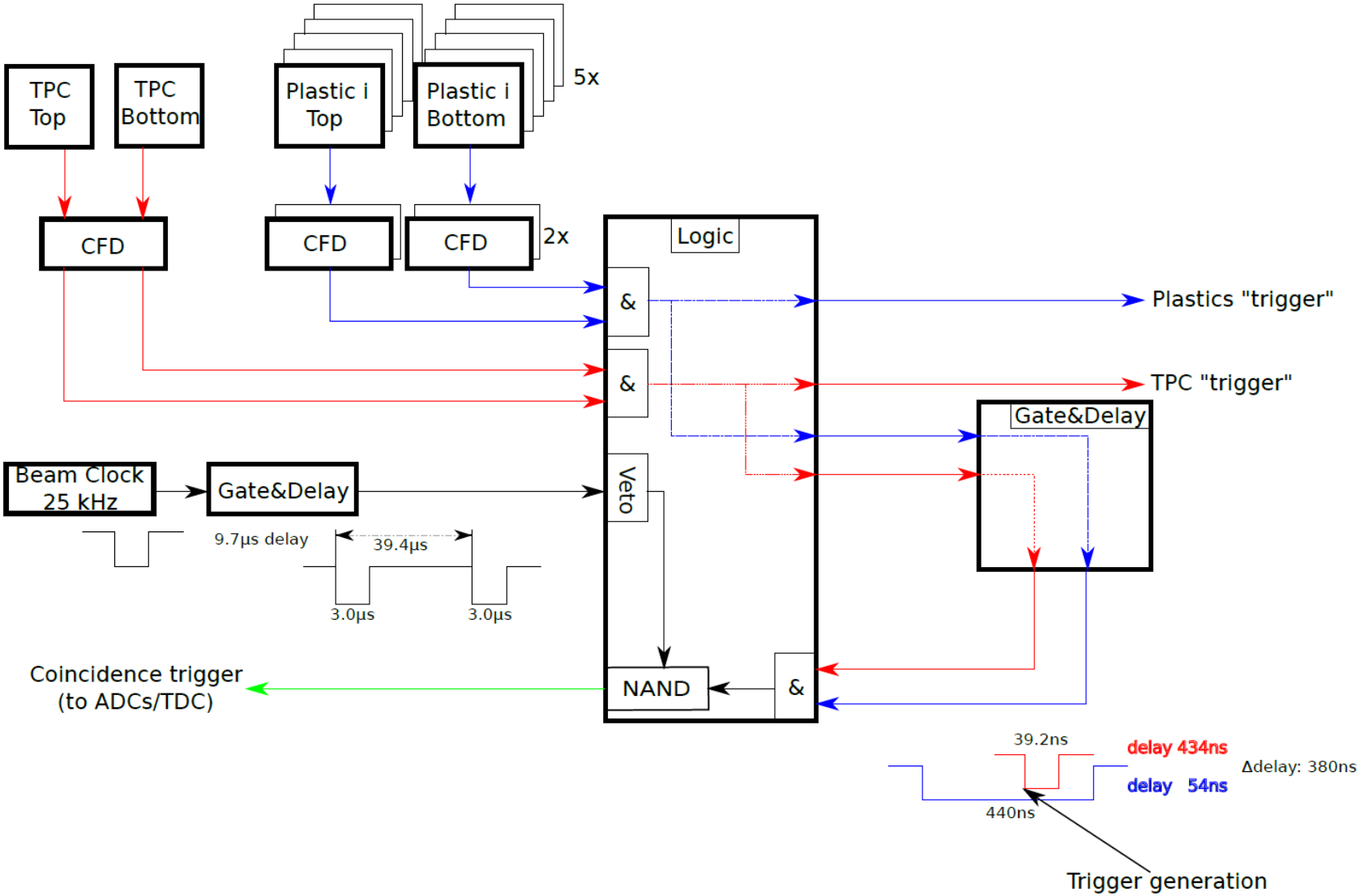
Compton Setup (@HZDR)



Neutron Setup (@HZDR)



Trigger system (neutron setup)

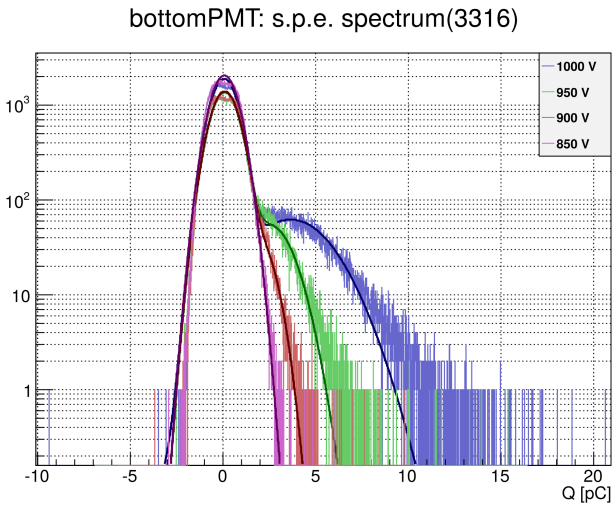


Analysis / Results

- Detector calibrations
- TPC calibration with Compton scattering
- Neutron Time-of-Flight
- S1 Pulse Shape

Detector calibrations

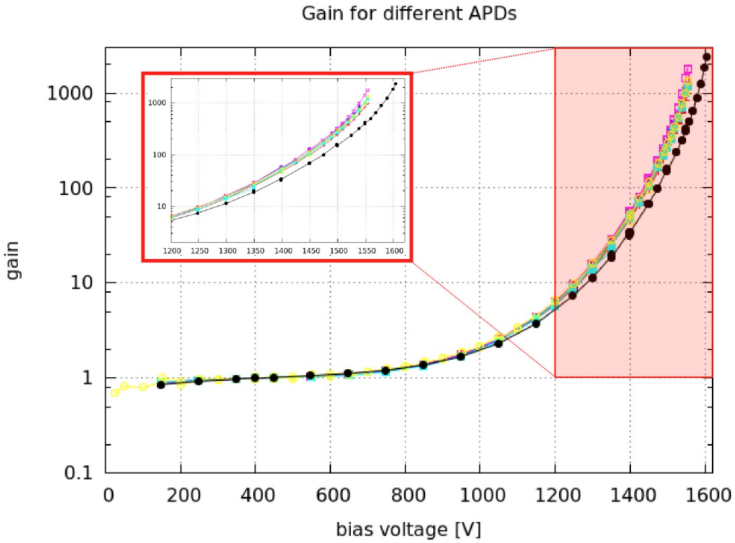
PMT calibration



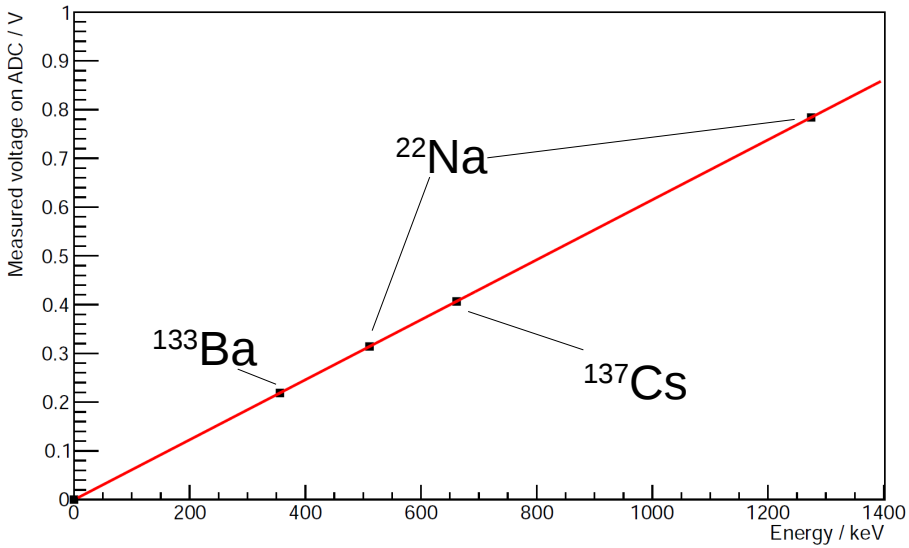
SPE spectra

Relative gain for different amplifications

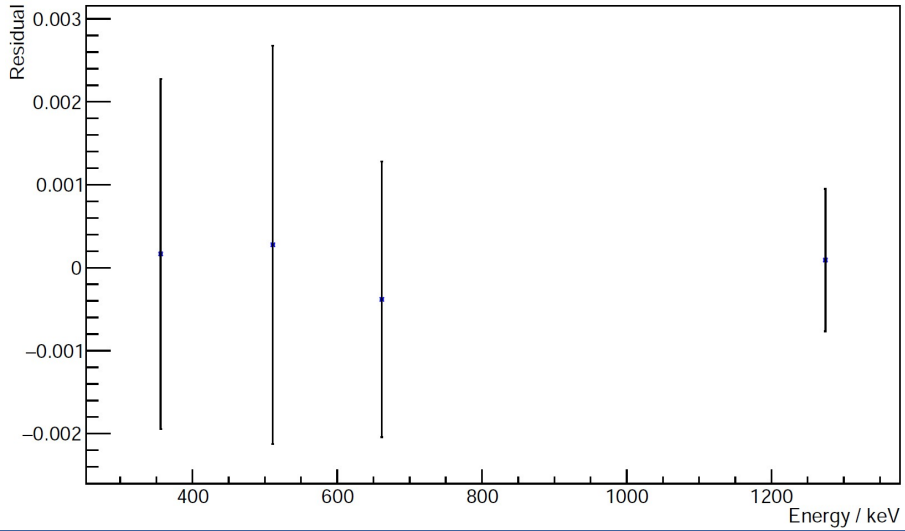
APD calibration



Ge detector calibration



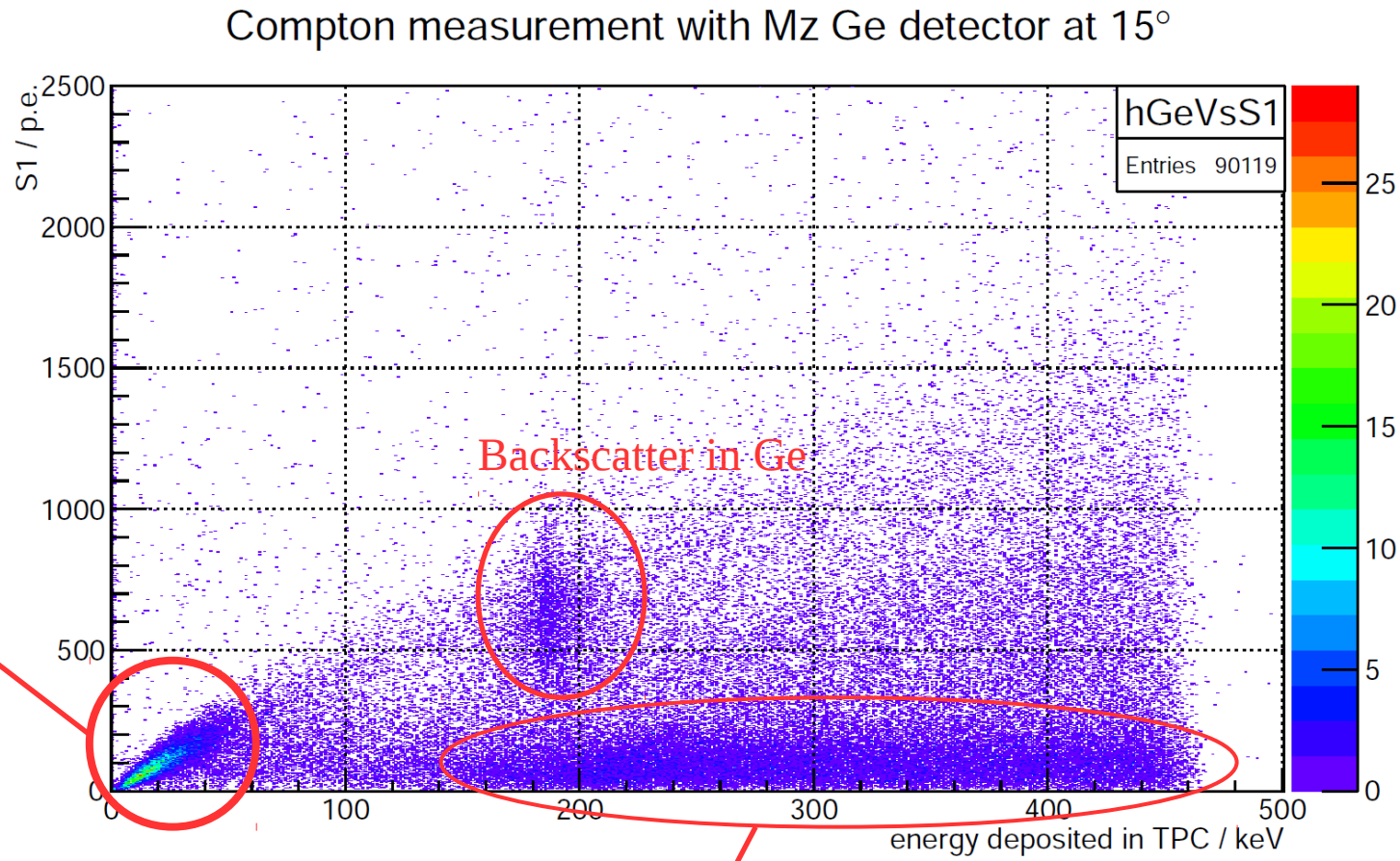
Residual plot

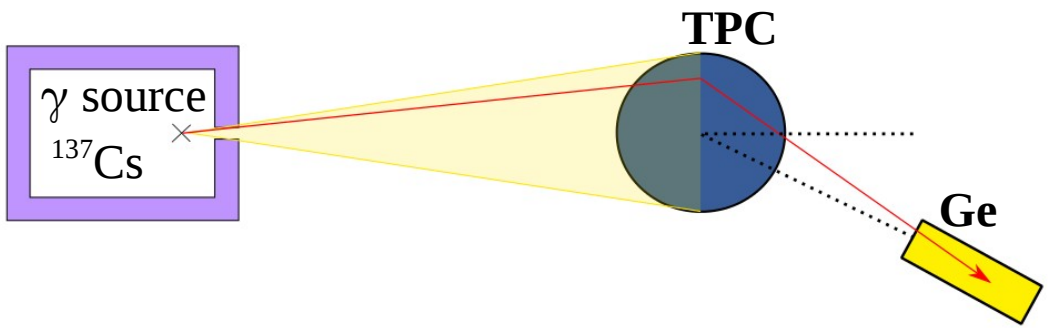


TPC calibration: Compton measurements

- Calibration of TPC:

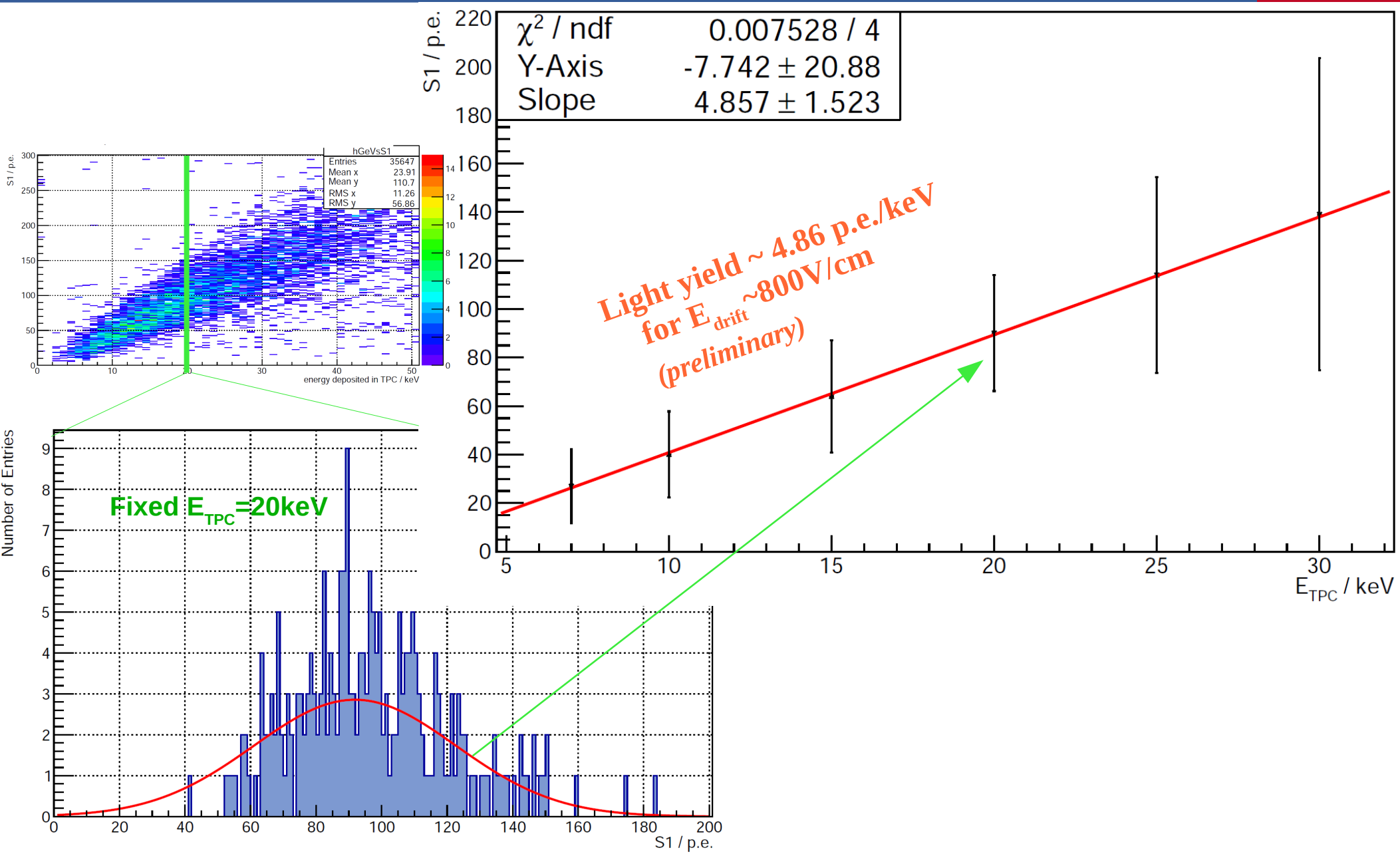
  deposited energy
  → measured light



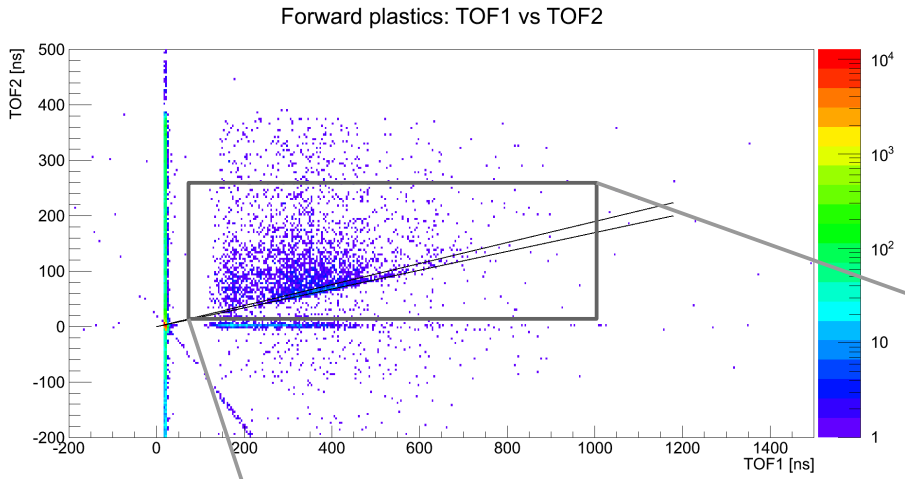


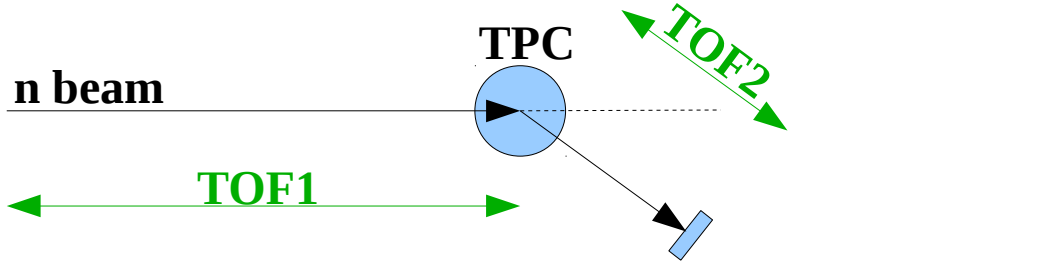
Compton scattering,
γ not absorbed in Ge detector

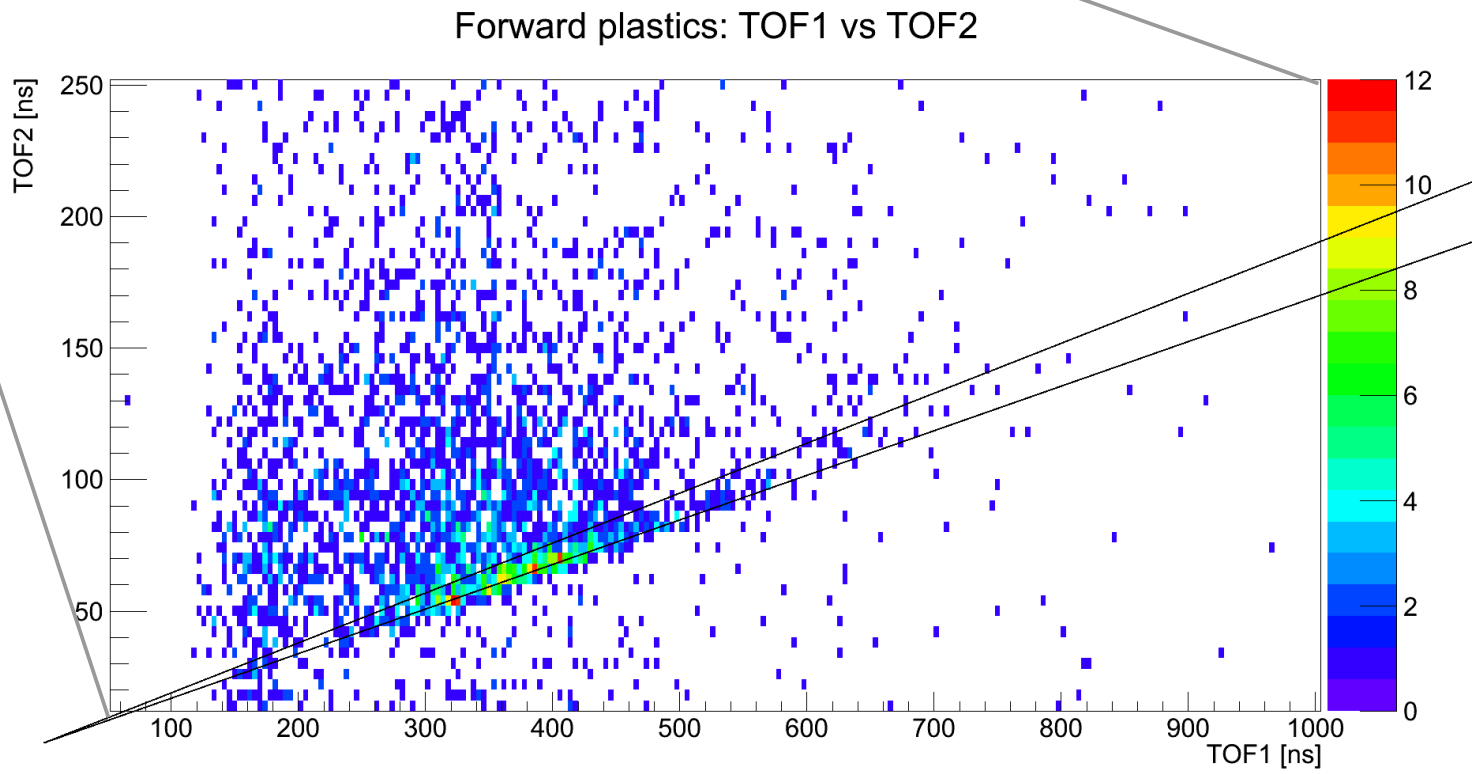
TPC calibration: Compton measurements



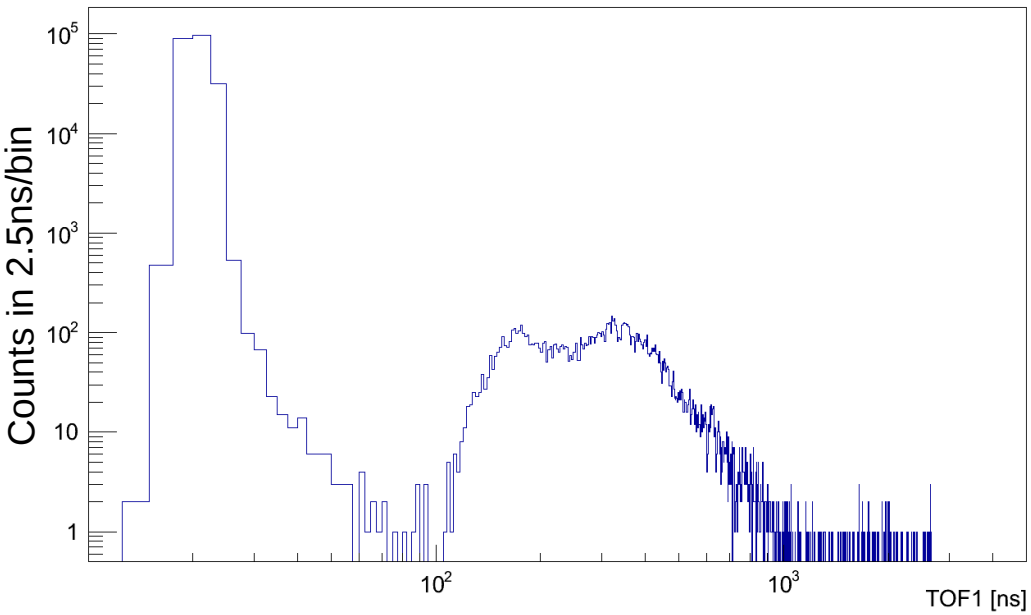
Neutron scattering: Time-of-Flight @ nELBE







Time-of-Flight spectra *(preliminary)*



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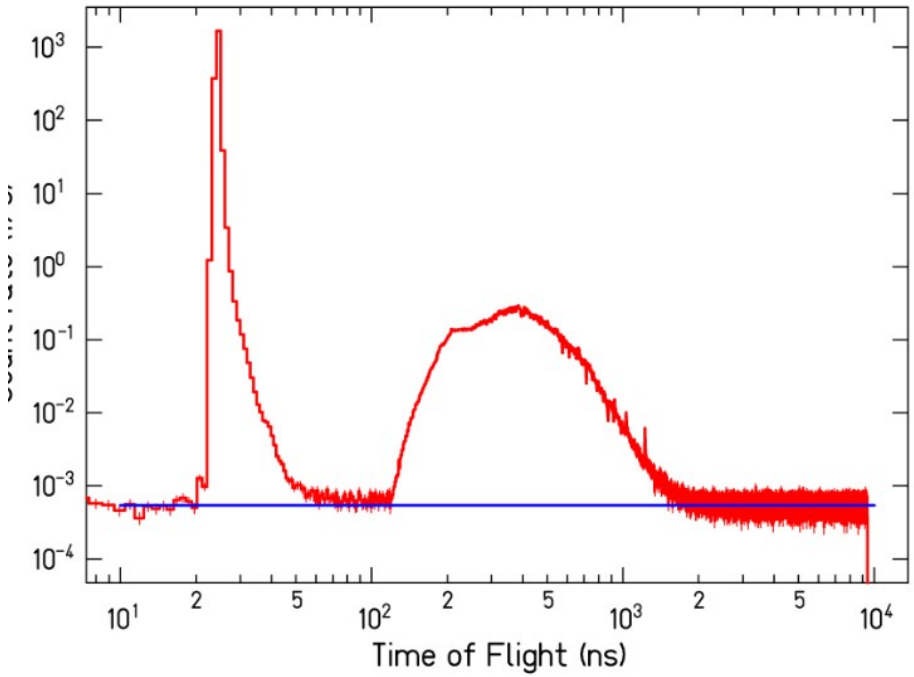
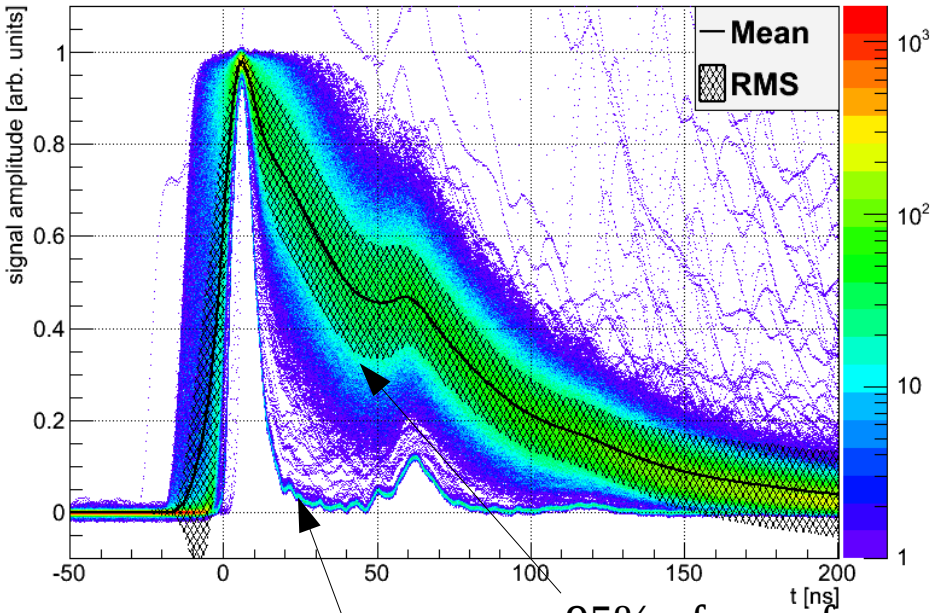


- TOF spectrum from Dresden slightly different from ours:

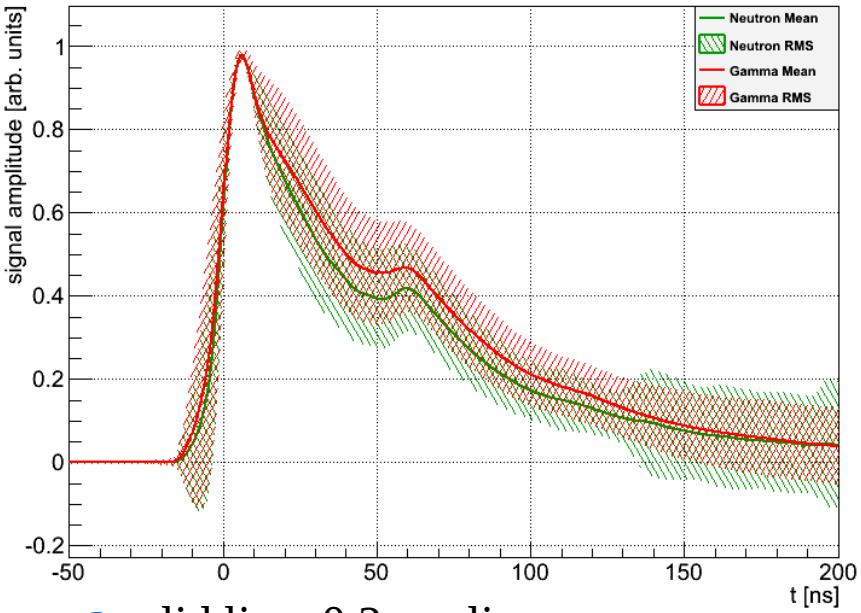
  → effects as inelastic scatterings etc.

Pulse Shape of S1 signals *(very preliminary)*

- no field – 500-800mV amplitude
- Gammas



- no field – 500-800mV amplitude
- Gammas vs neutrons



- solid line: 0.2 ns slice: mean
- hatched area: 0.2 ns slice: RMS

Summary & Outlook

- MainzTPC: small dual-phase time projection chamber for xenon R&D
- data was taken in Compton and neutron scatter experiments

- First results:
  - Detector calibrations
  - TPC calibration from Compton data → Light / Charge Yield for electronic recoils
    (plus further improvements by implementing of 3D position resolution)
  - Time-of-Flight from neutron data → Light / Charge Yield for nuclear recoils
  - S1 signal pulse shape → possible new background discrimination method?

- Analysis ongoing...

Any questions?

Thanks to my Mainz collaborators:

Bastian Beskers
Christopher Hils
Melanie Scheibelhut
Rainer Othegraven
Cyril Grignon
Uwe Oberlack

Also thanks to our HZDR collaborators:

Roland Beyer
Arnd Junghans

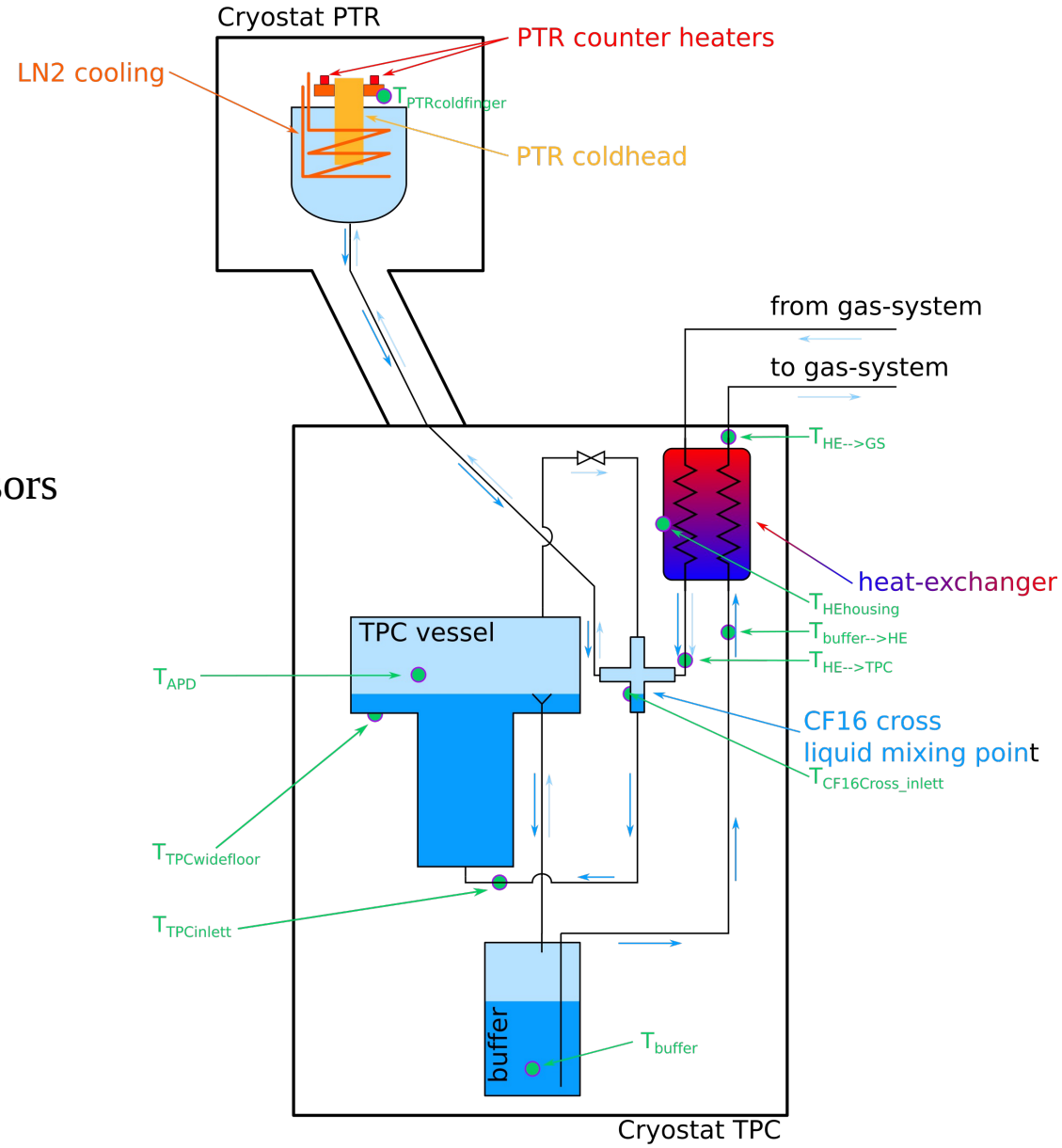
Pierre Sissol
sissol@uni-mainz.de

Backup

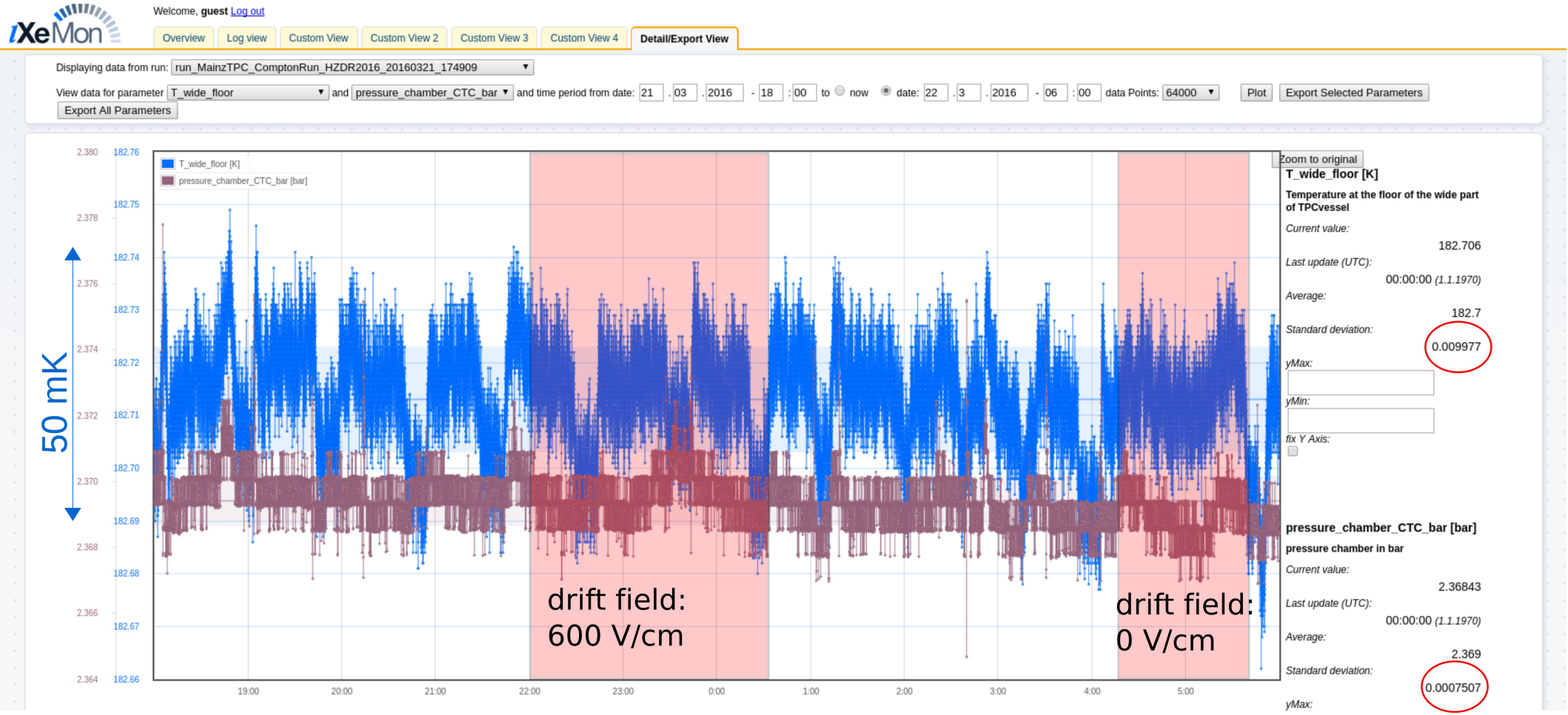
MainzTPC: Cooling system

- Cooling only in upper vessel
- Definition of liquid level via a weir
- Sophisticated system of liquid and gas connections

  → stable conditions for measurements
- Multiple pressure and temperature sensors for monitoring



MainzTPC @ nELBE: Thermodynamical stability

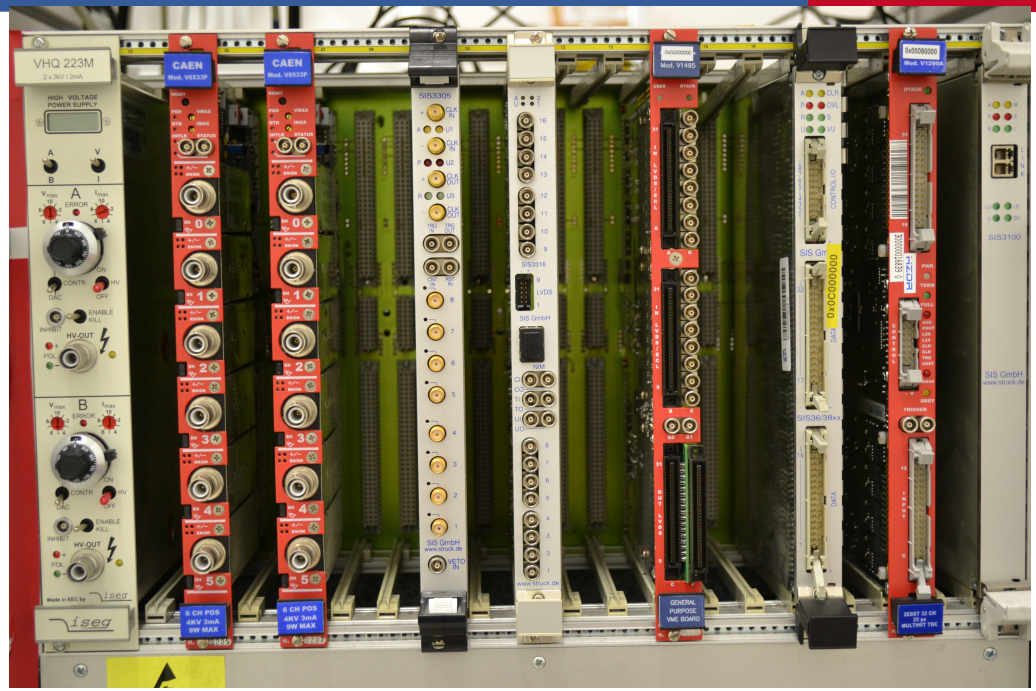


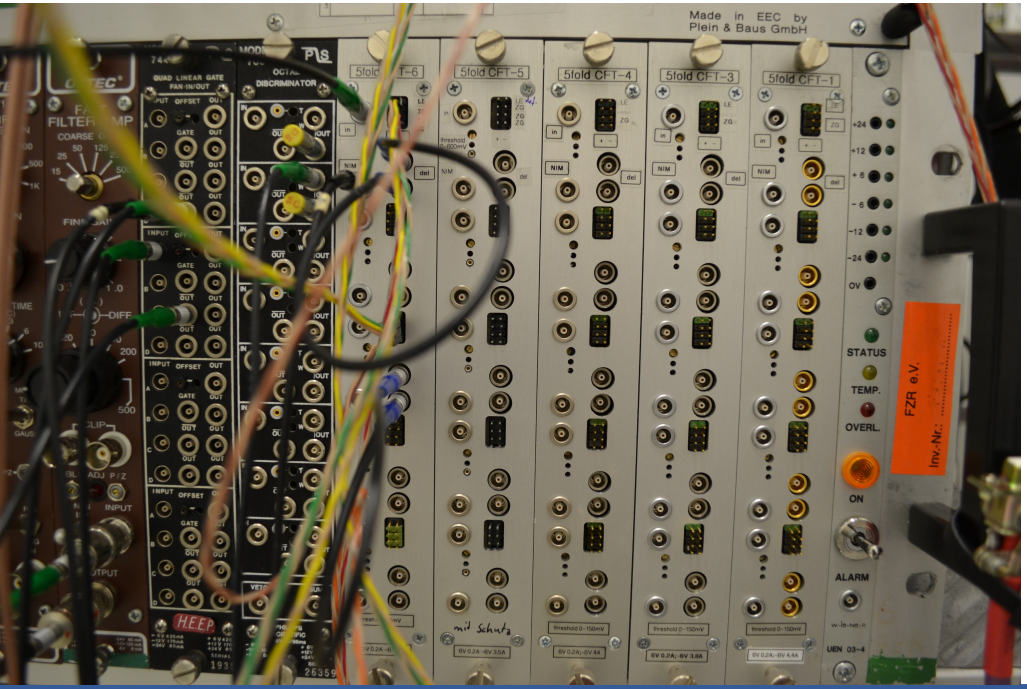
Slow Control / Monitor lXeMon
(written as Bachelor thesis by Elvar Kjartansson!)

Electronics

VME:

- HV modules
- ADC (fast / slow)
- Logic board
- Scaler
- TDC

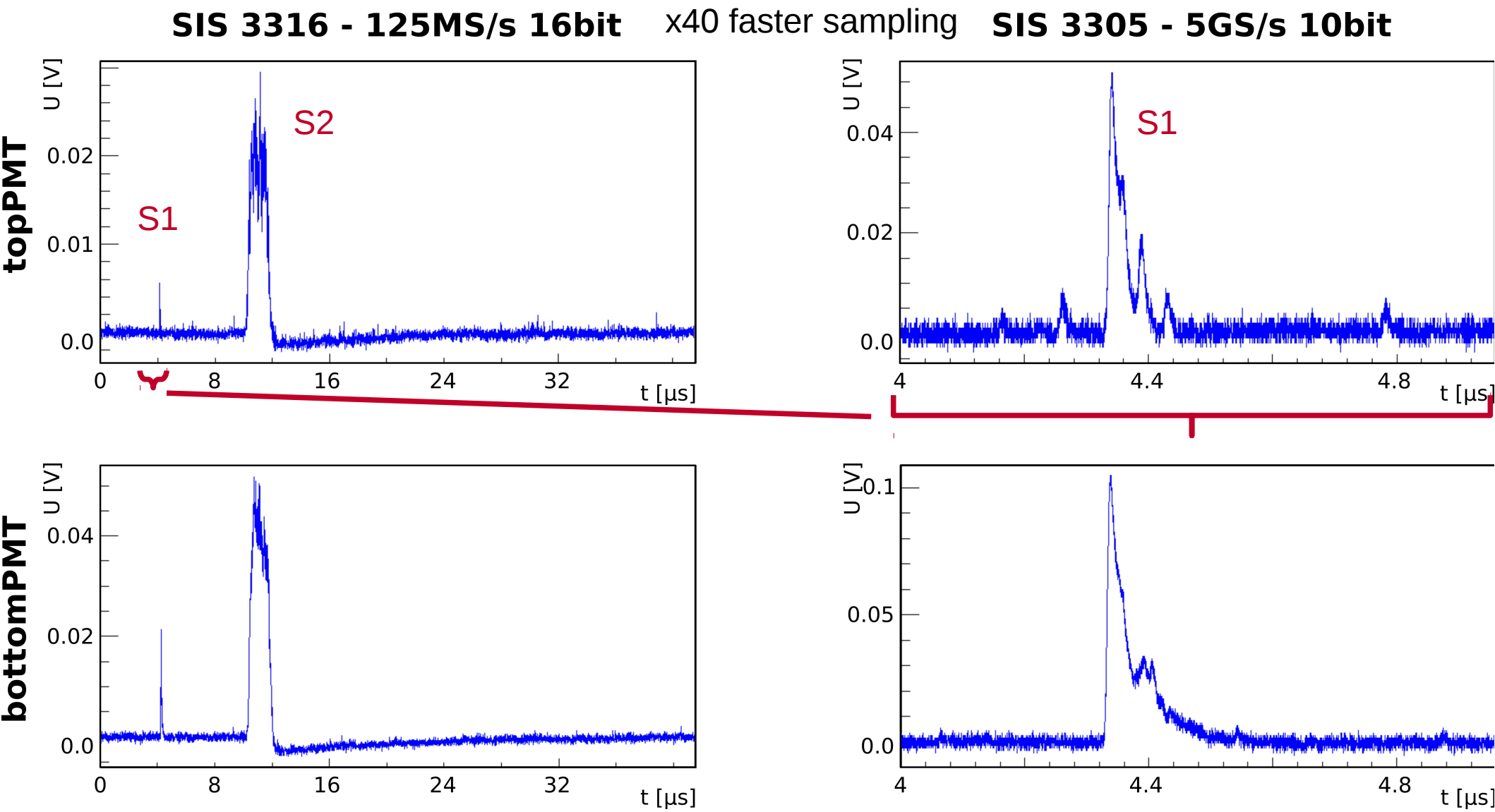




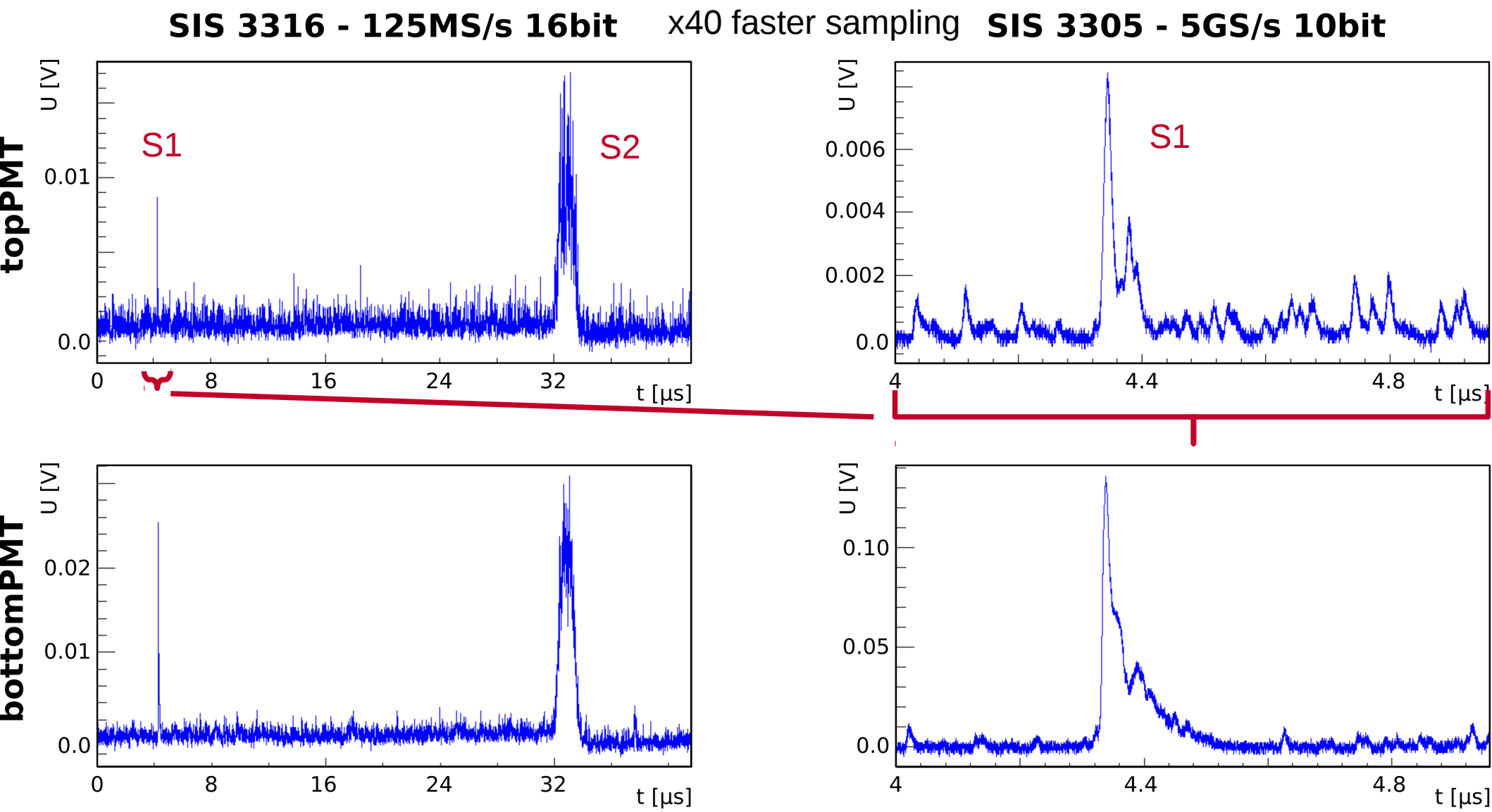
NIM:

- CFD modules
- Gate&Delay generator
- Amplifier etc.

MainzTPC signal: Small gamma event



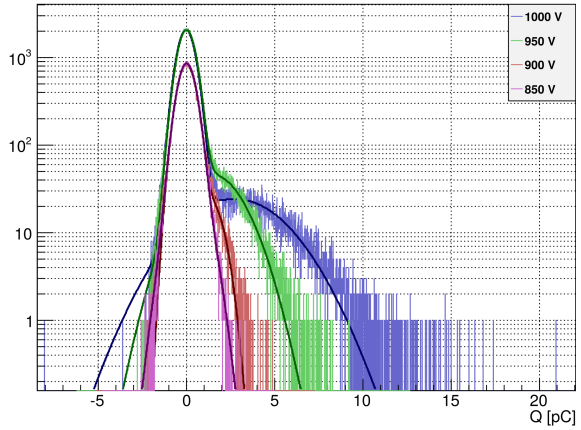
MainzTPC signal: Small neutron event



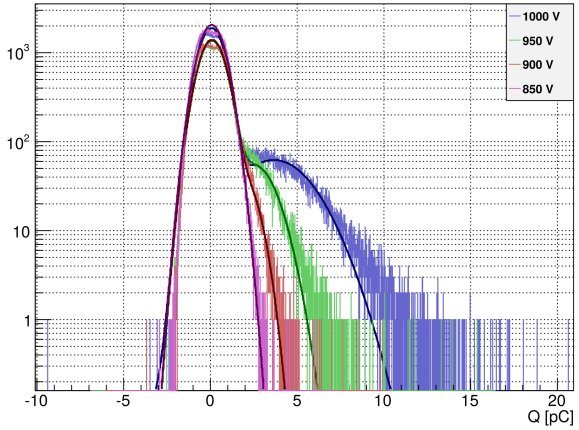
MainzTPC – PMT calibration

with 10.5x amplifier

topPMT: s.p.e. spectrum



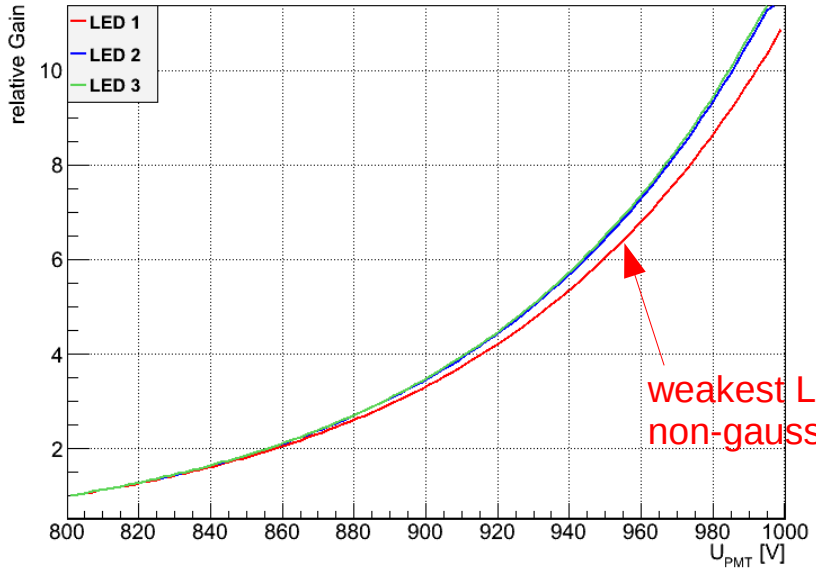
bottomPMT: s.p.e. spectrum(3316)



spe (1000V, 10.5x): 2.74 pC
spe (1000V, noAmp): 0.261 pC =>
gain(1000V) = 1.63e6

spe (1000V, 10.5x): 3.66 pC
spe (1000V, noAmp): 0.349 pC
=> gain(1000V) = 2.18e6

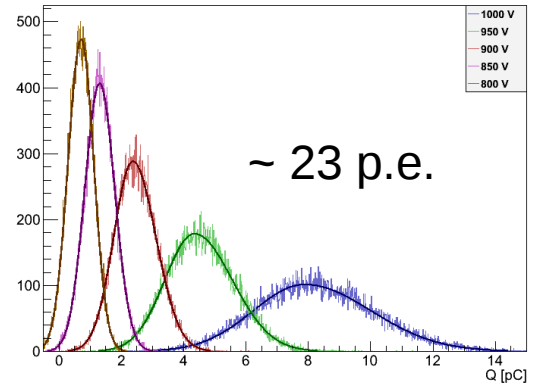
bottomPMT



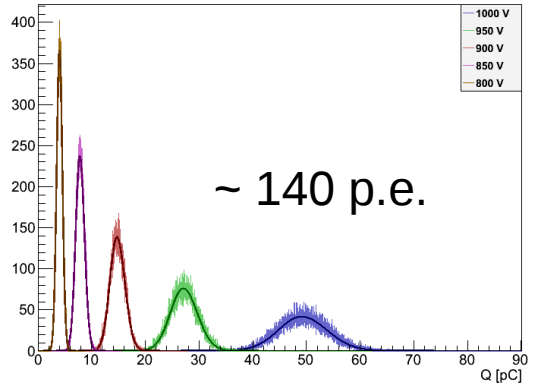
weakest LED:
non-gaussianity strongest

no amplifier – stronger LEDs

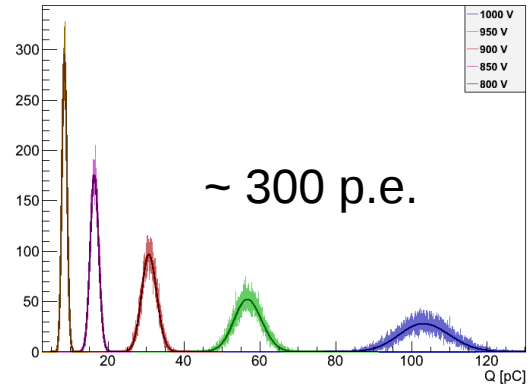
bottomPMT - LED 1



bottomPMT - LED 2

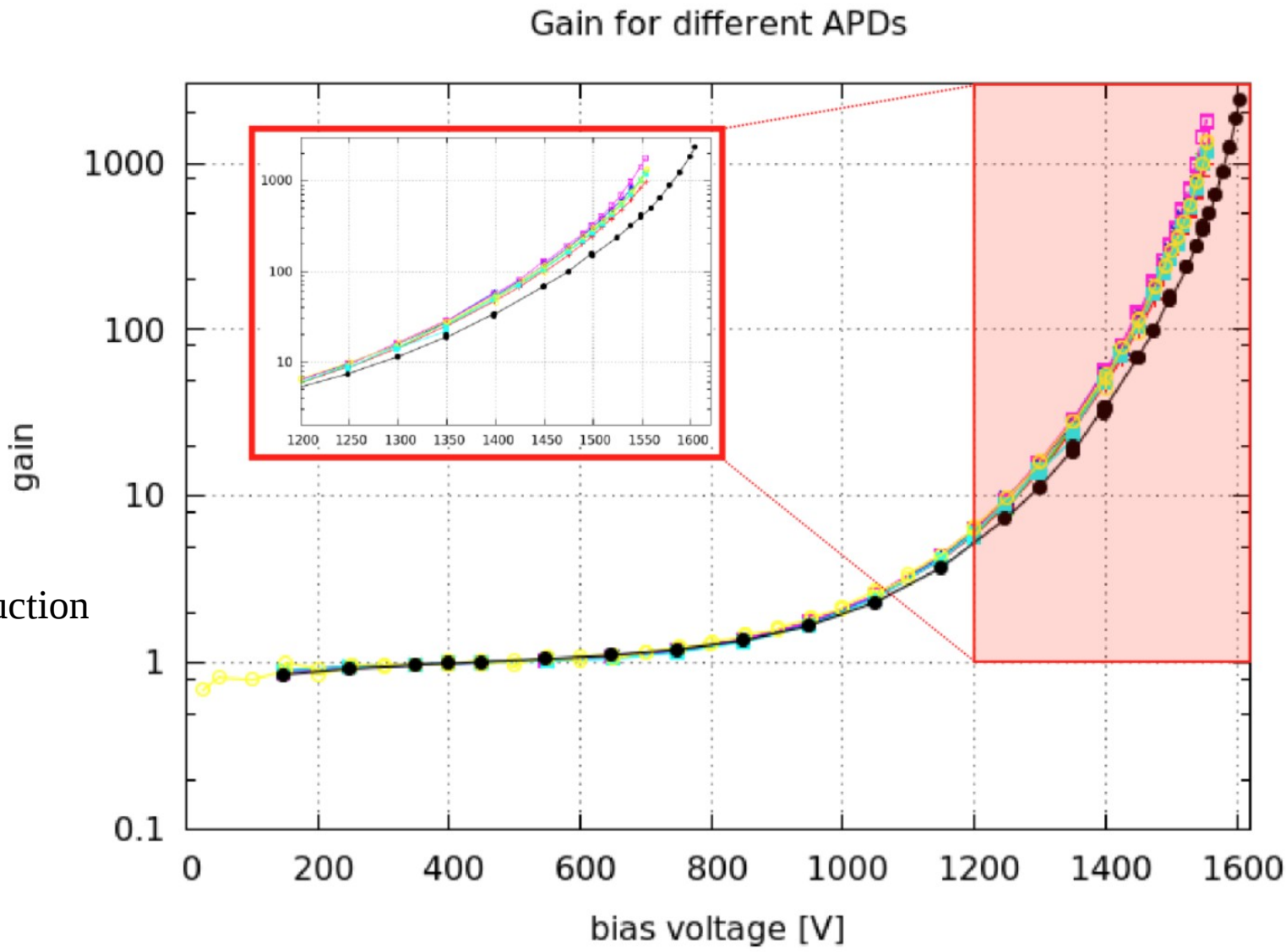


bottomPMT - LED 3



MainzTPC – APD calibration

- 8 APDs
- for 3D position reconstruction ***(not yet done)***
- Detection of S2

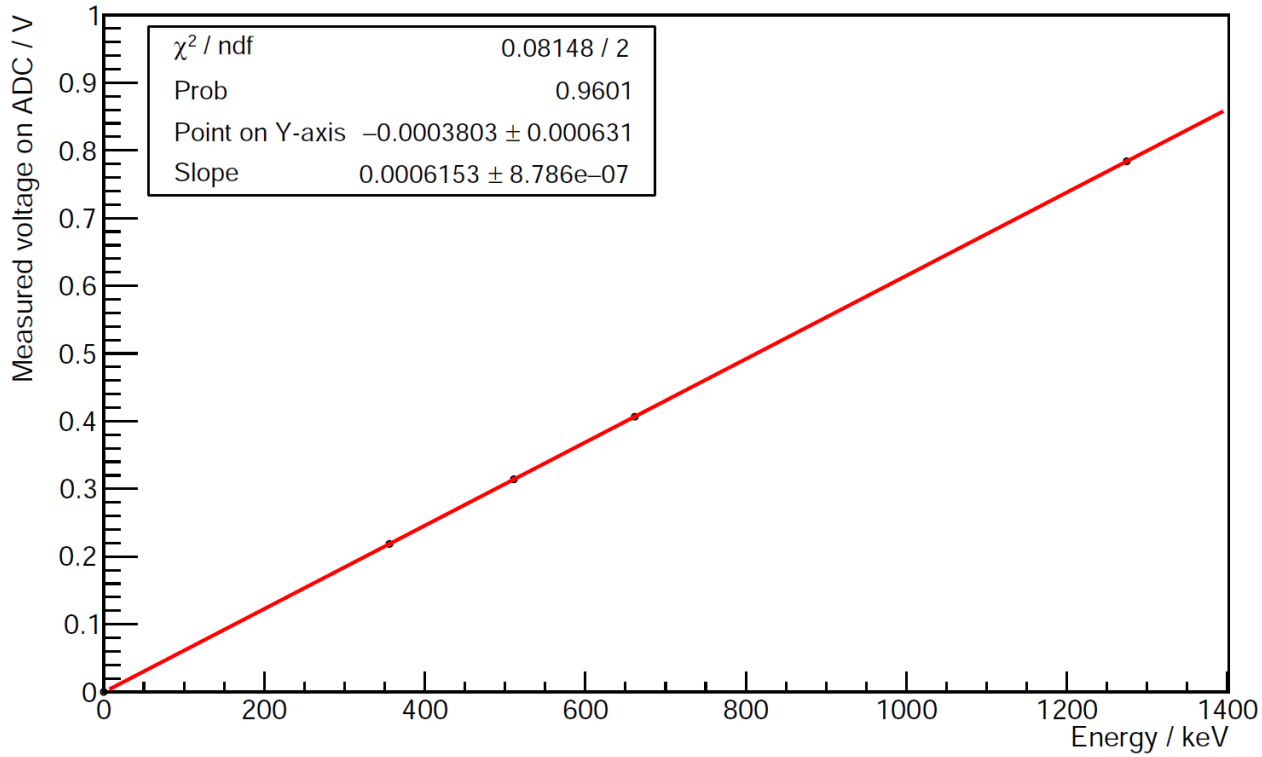


MainzTPC – Ge detector calibration

- Radioactive sources:
  - Cs-137
  - Na-22
  - Ba-133

- Energy resolution has important impact:
  - energy deposit in the TPC

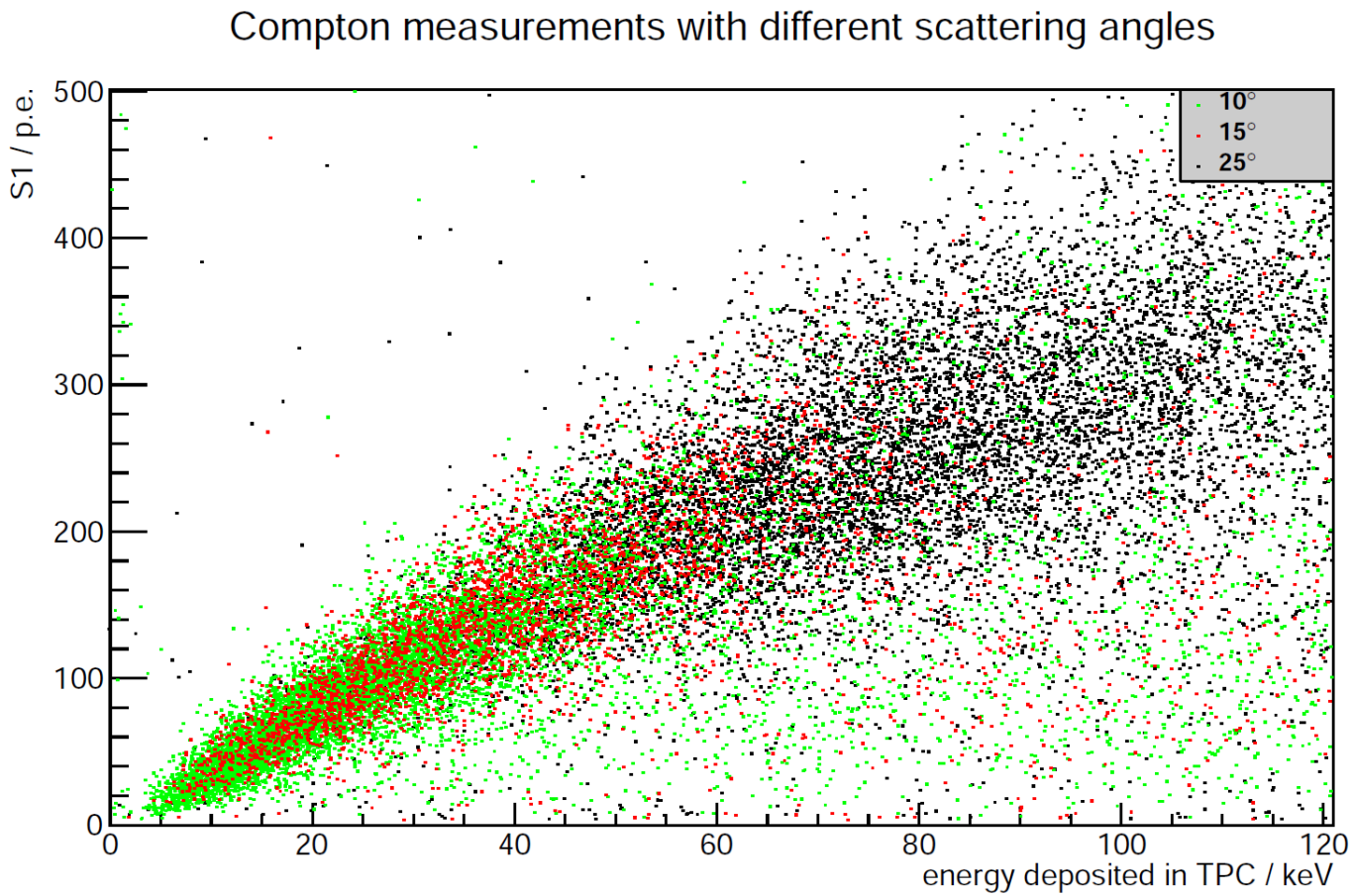
$$E_{TPC} = E_{source} - E_{gamma}$$



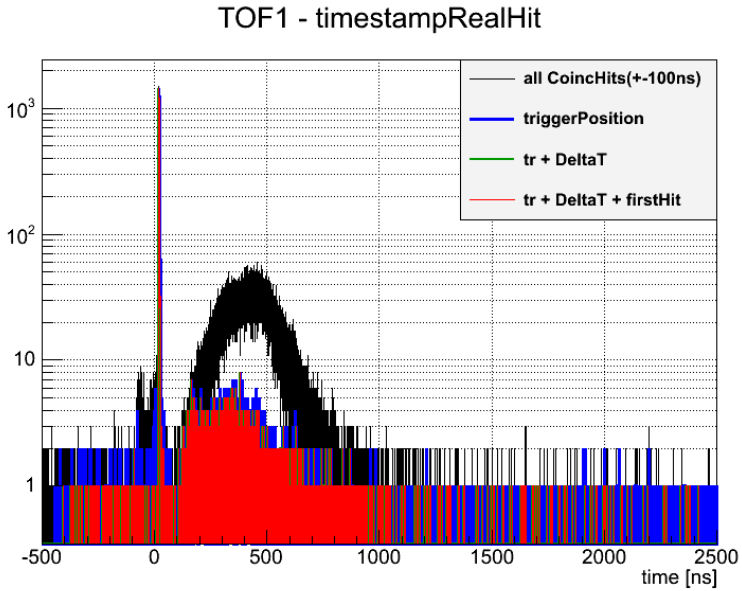
Compton measurements

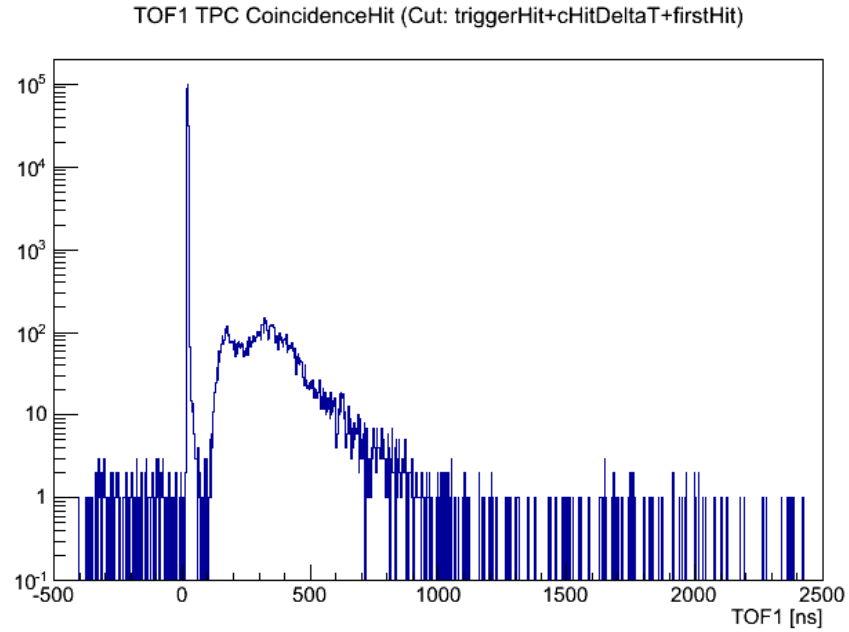
Gammas
- Compton energy

Neutrons
- TOF
- Pulse shape



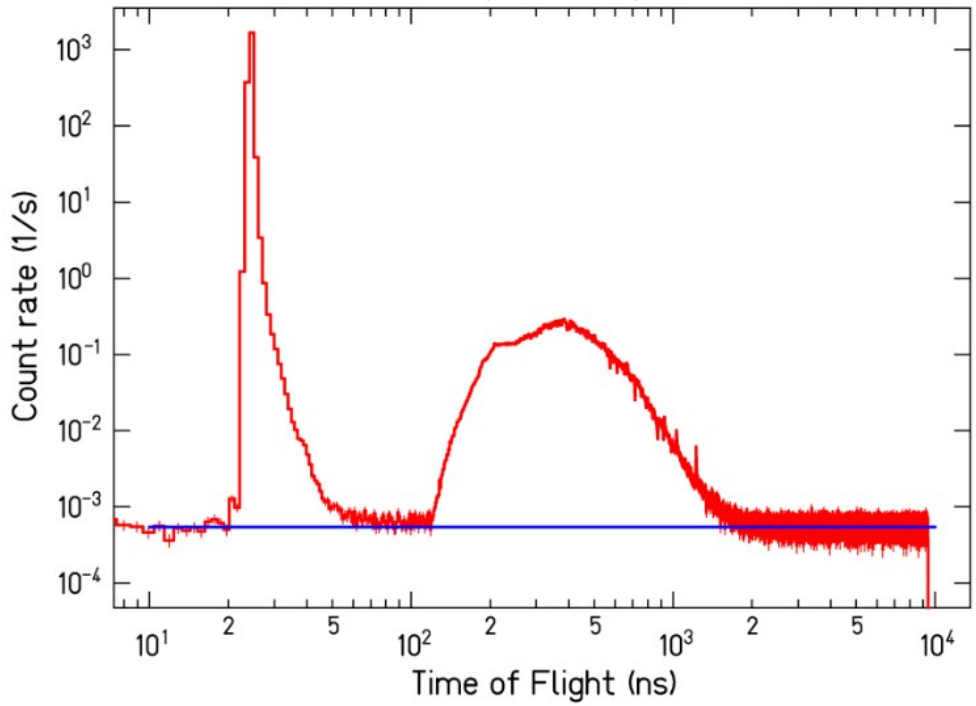
Time-of-Flight spectra *(preliminary)*





- TOF spectrum from Dresden slightly different from ours

TOF (nELBE)



Pulse Shape of S1 signals *(very preliminary)*