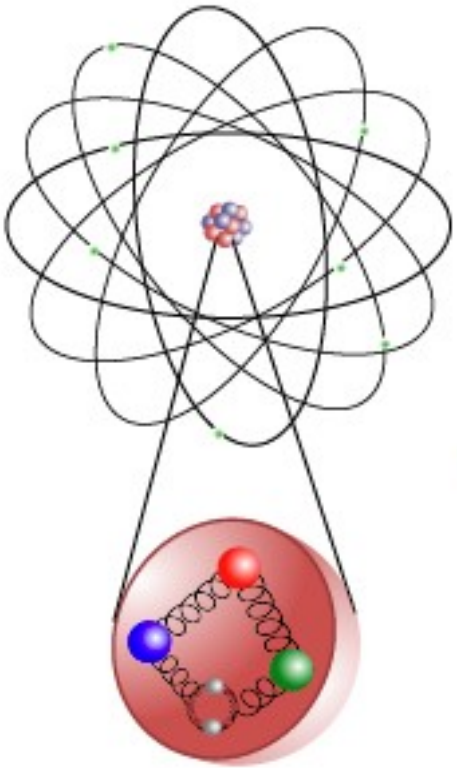
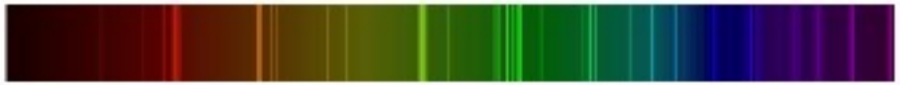
Upgrade of the Crystal Barrel Detector

Michael Lang
for the CBELSA/TAPS Collaboration

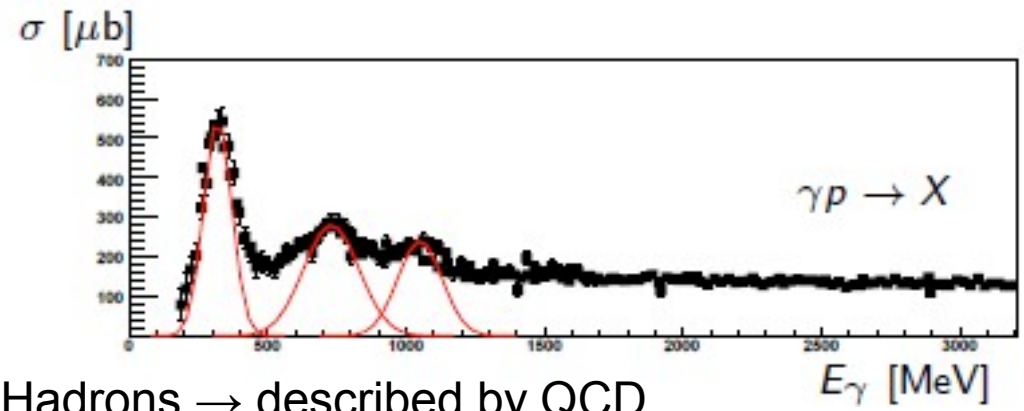
Motivation – Structure of Matter

→ Spectroscopy reveals structures





Atoms → described by QED

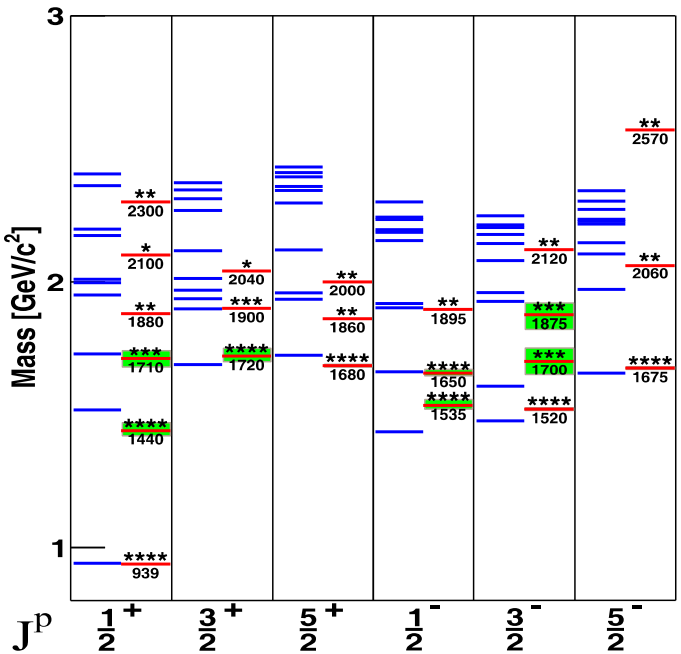


Hadrons → described by QCD

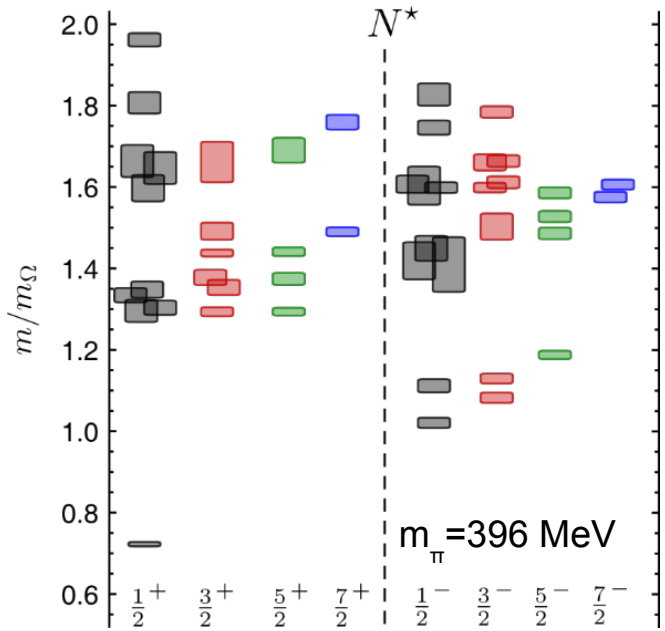
Excitation spectrum gives information on nucleon dynamics (quarks and gluons).

→ **Requires baryon excitation spectrum to be understood!**

Motivation – Theoretical Predictions



[Löring et al. EPJ A 10, 395 (2001)]
[K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014)]



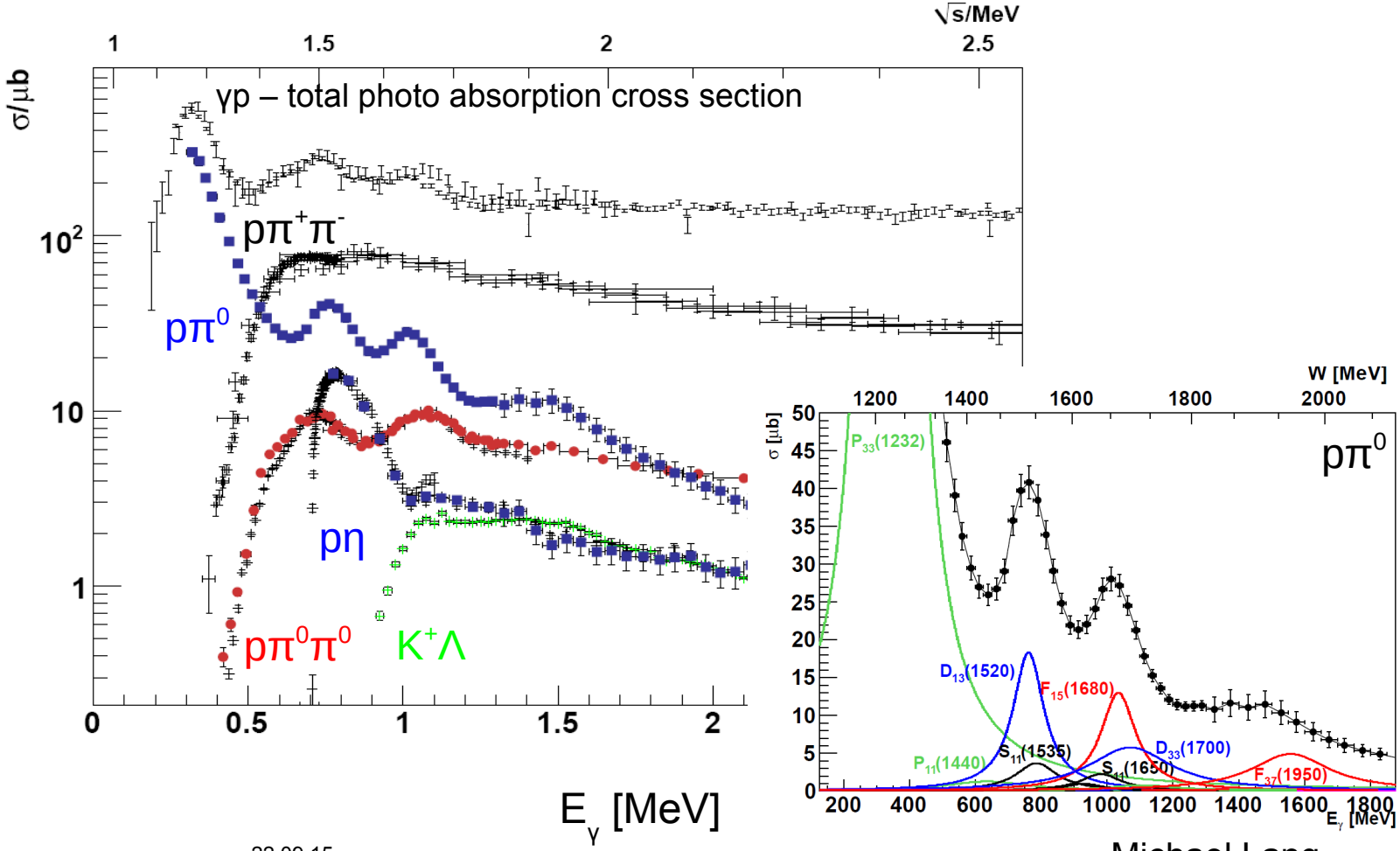
[Edwards et al. Phys. Rev. D 84, 074508]

- Compare predictions with experiment data,
- more predicted excited states than found by experiment,
- understand relevant degrees of freedom by exploring
  - contributing initial and final production states,
  - polarization observables.

Motivation – Total Cross Section

Common effort of ELSA, JLab and MAMI:

- Data available for different final states ($p\pi^0$, $n\pi^+$, $p\eta$, $K^+\Lambda$, $p\pi^0\pi^0$, …),
- resonances overlap strongly with different strengths and widths,
- weak resonance contributions difficult to measure.



Motivation – Resonance Contributions

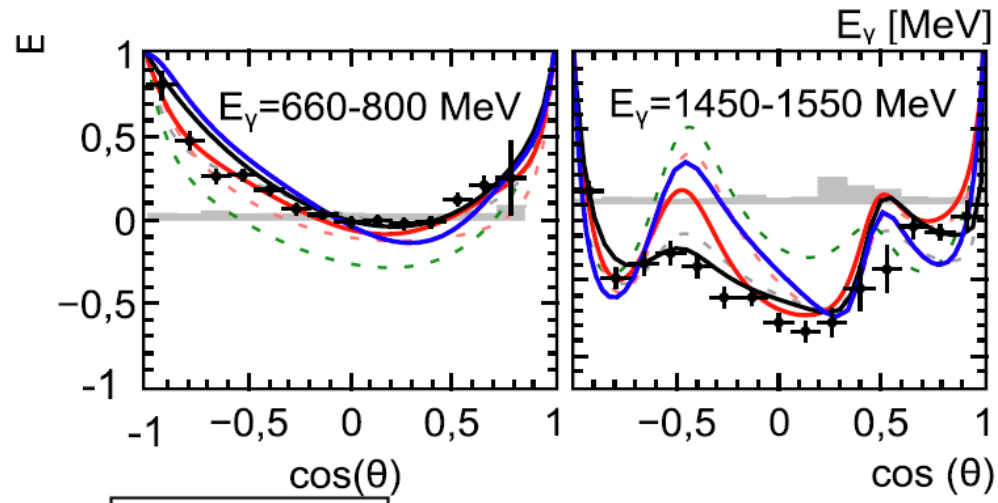
- Angular distributions show structures leading to resonance contributions.

- Investigate different final states of photoproduction on the nucleon.

- Investigate polarization degrees of freedom.

- find unique solution in PWA analysis

Remember talk of R. Beck on Baryon Resonances from friday.



New:
- SAID-CM12
- BnGa14-02
- BnJu 15B

Old:
- SAID-SN11
- BnGa11-02
- MAID

Data: [Gottschall et al. PRL 112, 012003]
[pwa.hiskp.uni-bonn.de]
[Workman et al. PRC 85, 025201]
[Rönchen et al. arXiv:1504.01643]

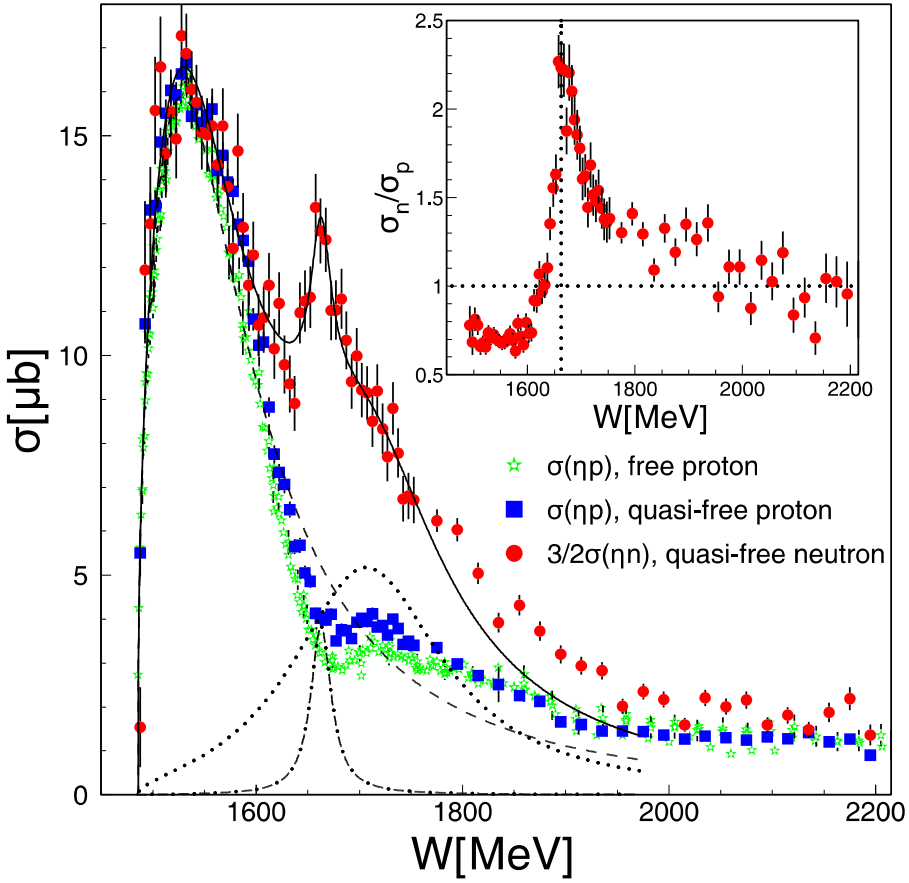
[Workman et al. PRC 85, 025201]
[Anisovich et al. EPRA 48:15]
[Drechsel et al. EPJA 34, 69 (2007)]

- Lot of data from ELSA, JLab and MAMI available or currently investigated on the proton on a wide range of energy, but few information available on the neutron.

→ **Do experiments on the neutron.**

Motivation – Production on the Neutron

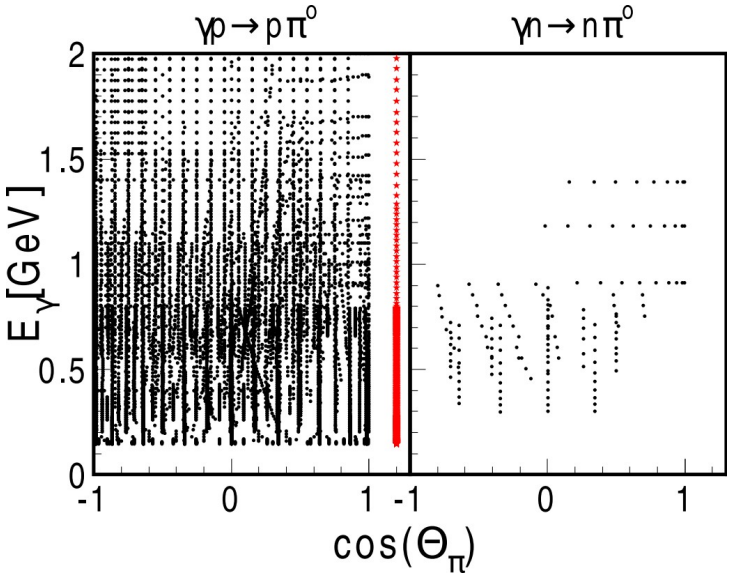
Why measure on the neutron?



[I. Jaegle et al., Phys. Rev. Lett. 100 (2008) 252002]

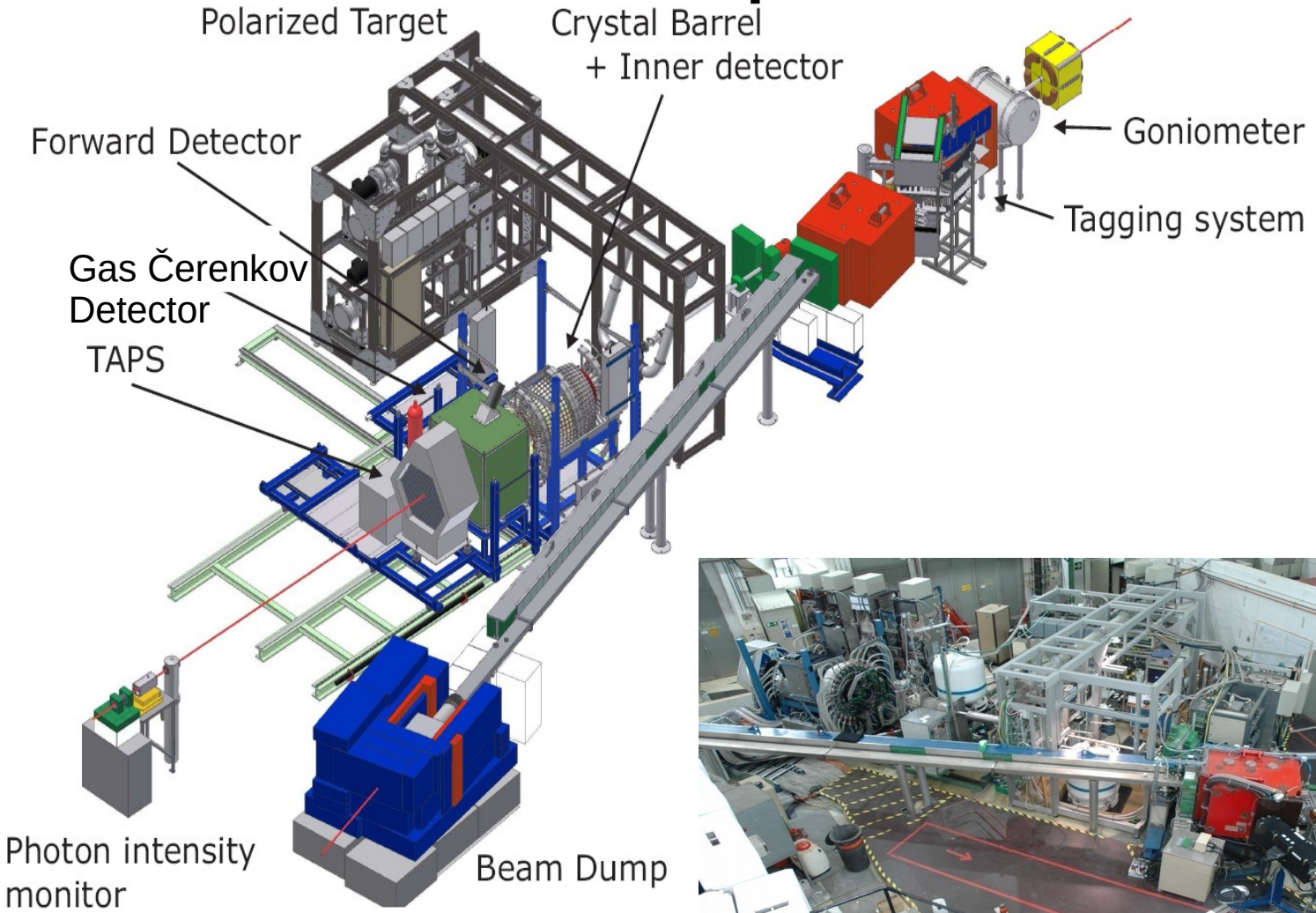
- Resonances couple differently to proton and neutron,
- much less data available.

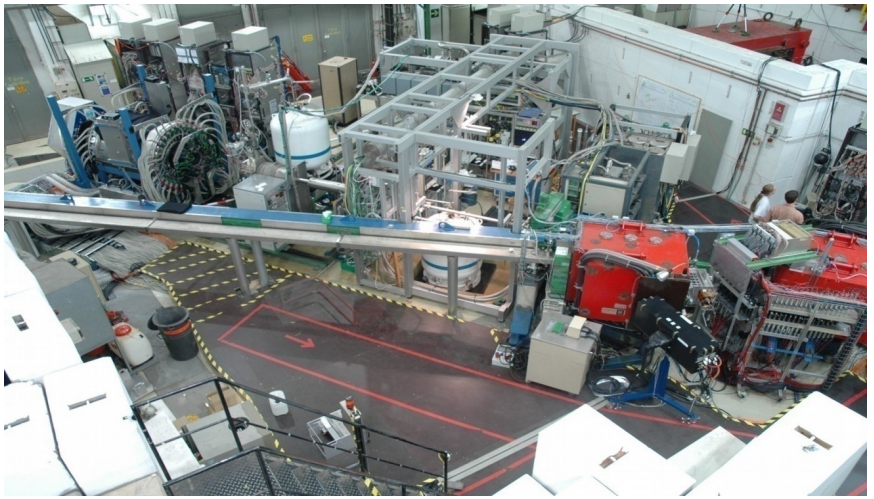
Database Overview



[Krusche EPJ ST198, 199 (2011)]

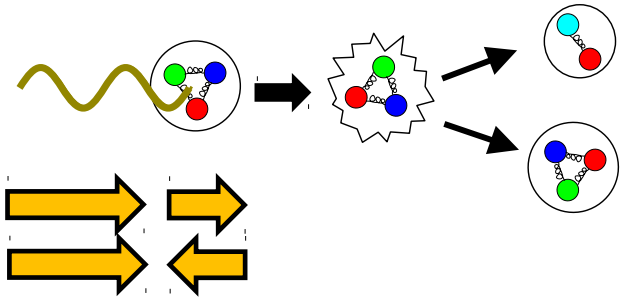
CBELSA/TAPS Setup at ELSA

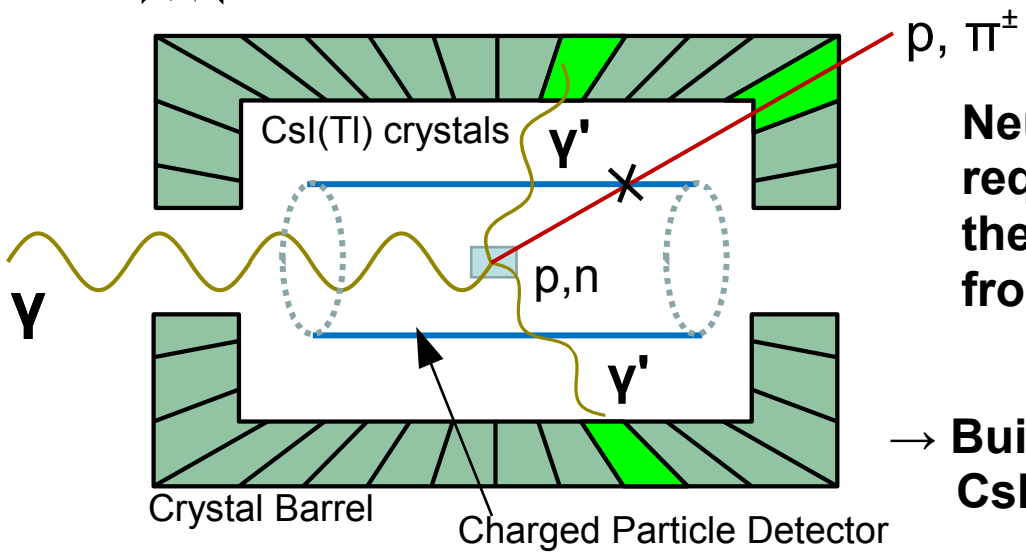




Motivation – Event Detection

- Previous state:
  - single & double polarization experiments with proton & neutron target (hydrogen, deuterium, butanol, dbutanol),
  - only charged products start trigger (p, $\pi^{\pm}$),
  - blind for fully neutral channels, e.g. $\gamma n \rightarrow n\pi^0$ (i.e. no trigger)

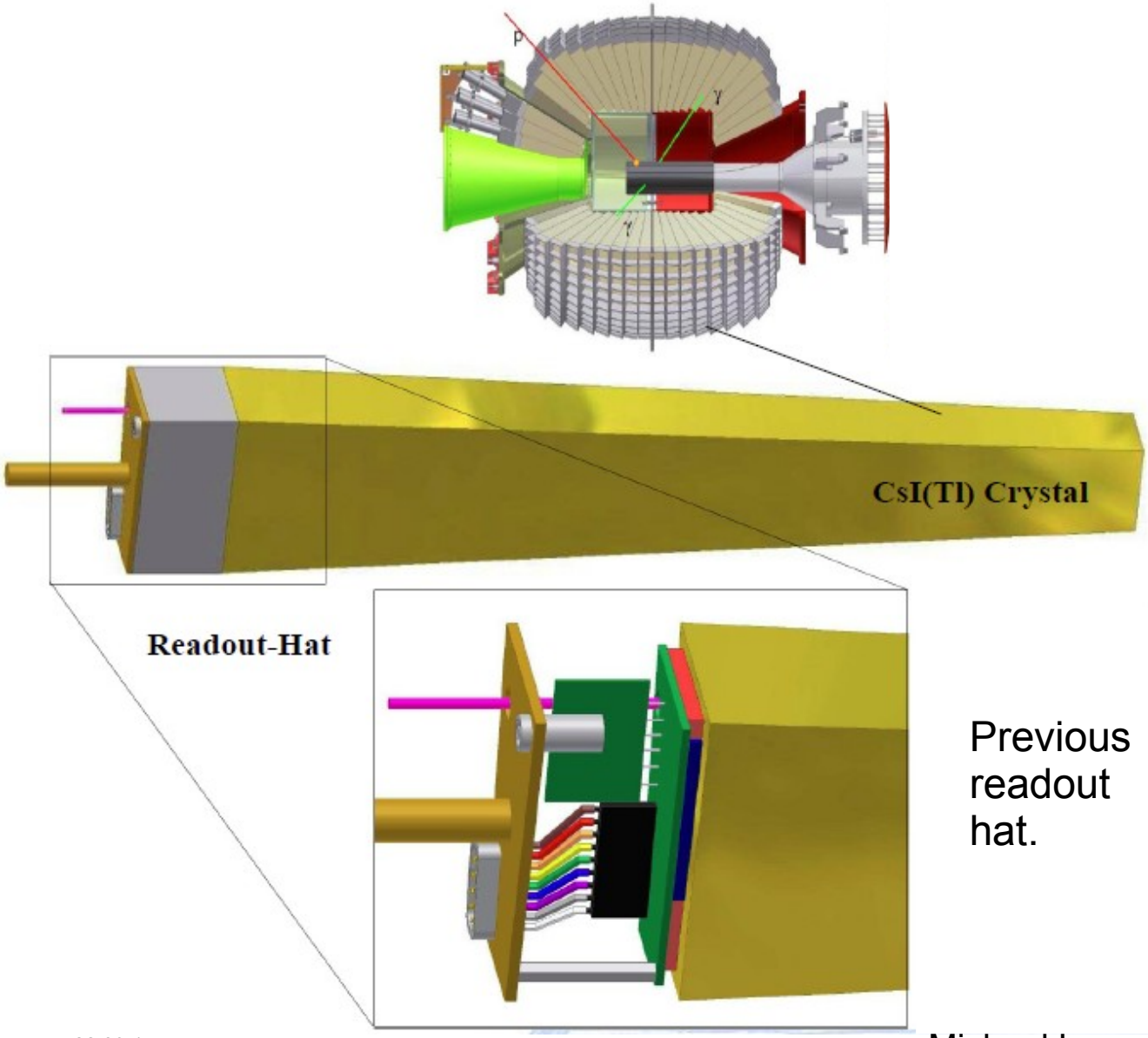




Neutral channels require trigger on the photon(s) e.g. from $\pi^0 \rightarrow \gamma\gamma$!

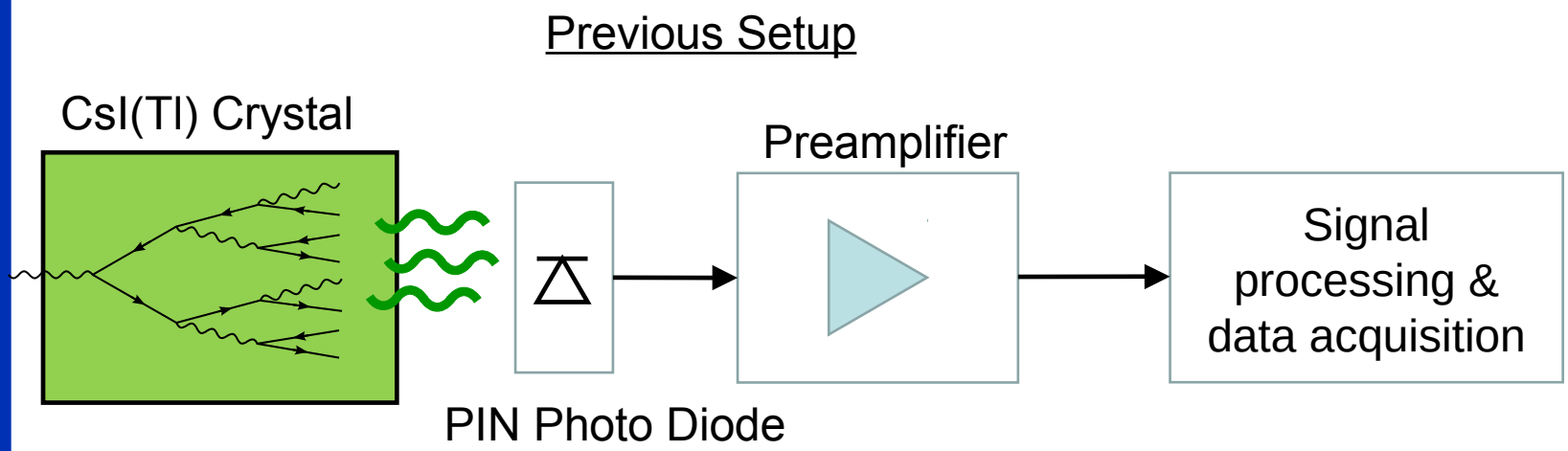
→ Build neutral trigger based on CsI(Tl) crystals of CB.

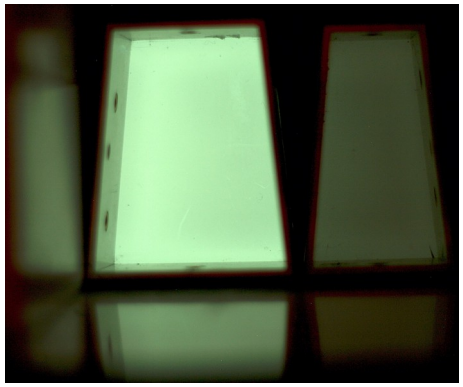
Detector Upgrade – Crystal Arrangement



Previous readout hat.

Detector Upgrade – Overview



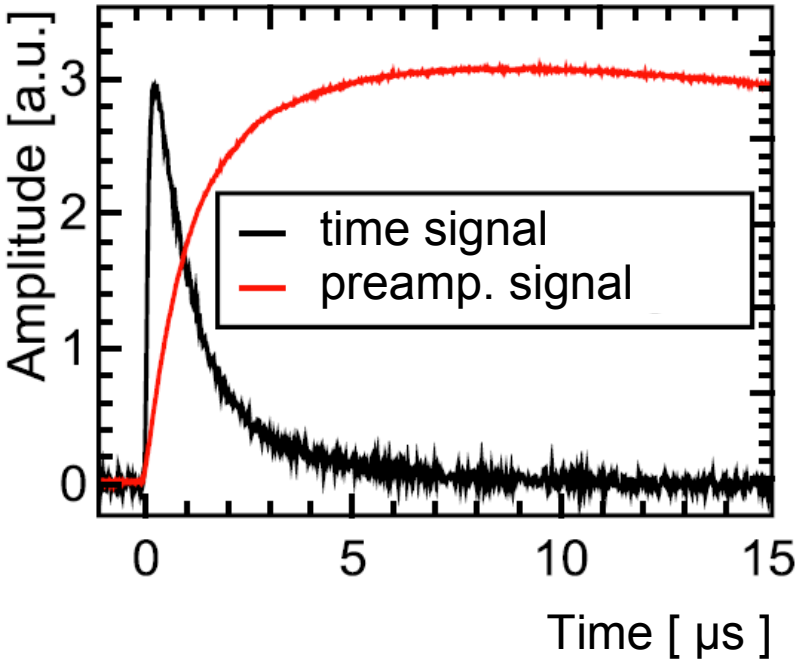


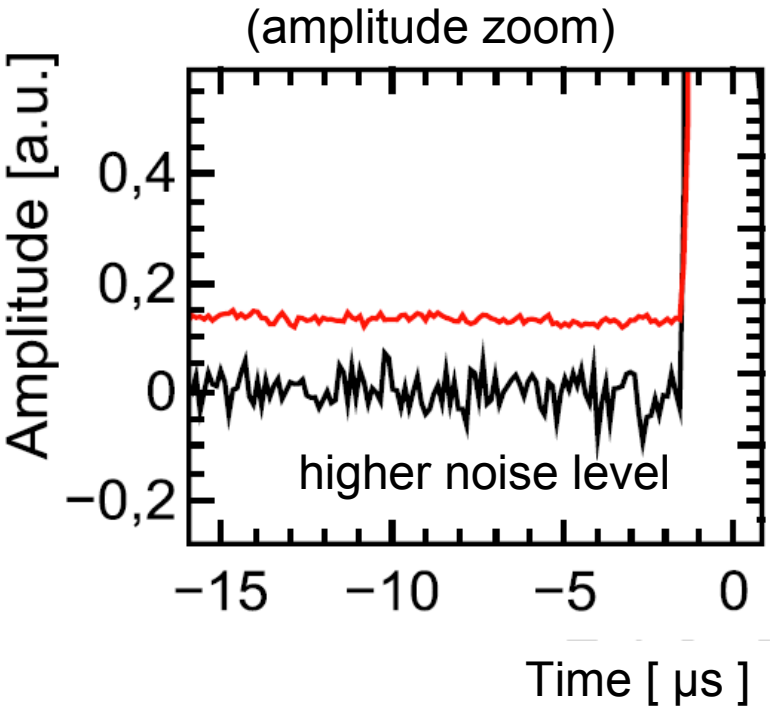
^{137}Cs source irradiation of CsI(Tl) crystal.

- CsI(Tl) bright, but slow,
- require fast signal component for a detector trigger.

Detector Upgrade – Noise Contribution

- Slow crystals (several µs signal rise time),
- filter slow component,
- small signal-to-noise ratio in high frequency components (i.e. time signal),
- high detection threshold required.

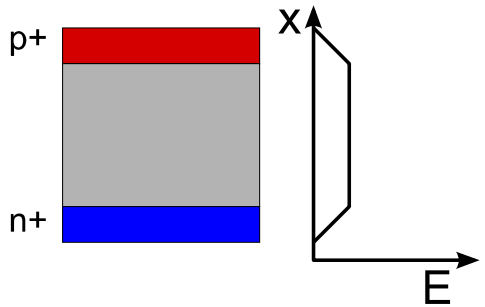




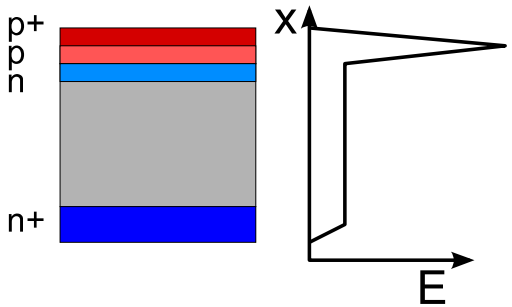
Low detection threshold required for suitable trigger time.
→ use avalanche photo diodes for signal amplification getting a bigger SNR for the time signal.

Detector Upgrade – PIN Diode versus APD

PIN-Diode



APD (Reverse Type)

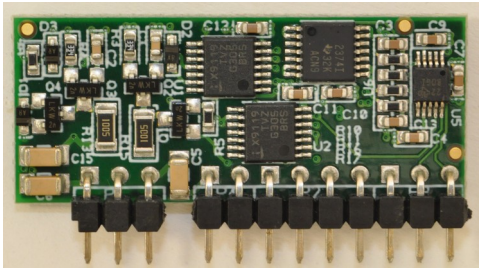


- APD signal amplification by avalanche effect,
- Comparison:

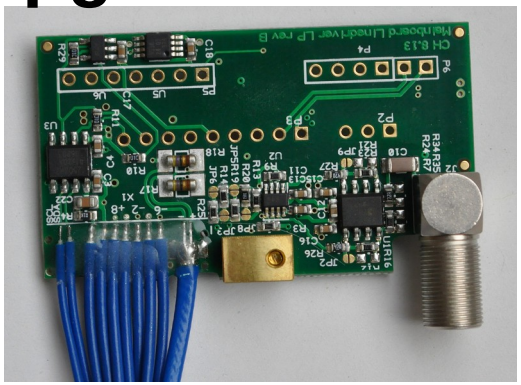
	PIN-Diode	APD
U_{bias} / V	10	400
Thermal dep.	low	high
U_{bias} dep.	low	high

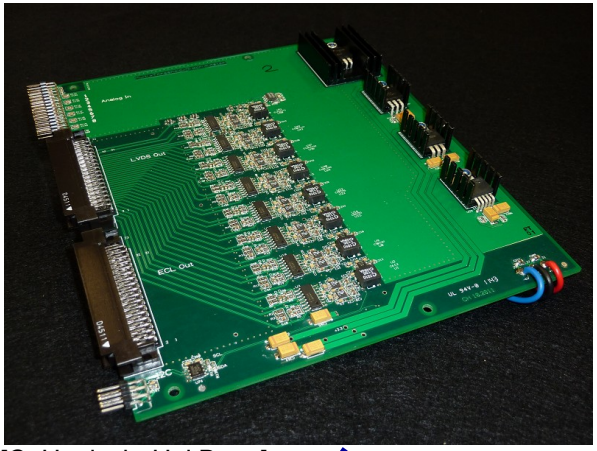
- Full exchange of readout electronic is required,
- Test of every new component, determination of output properties such as energy and time resolution.

Detector Upgrade – New Readout Chain

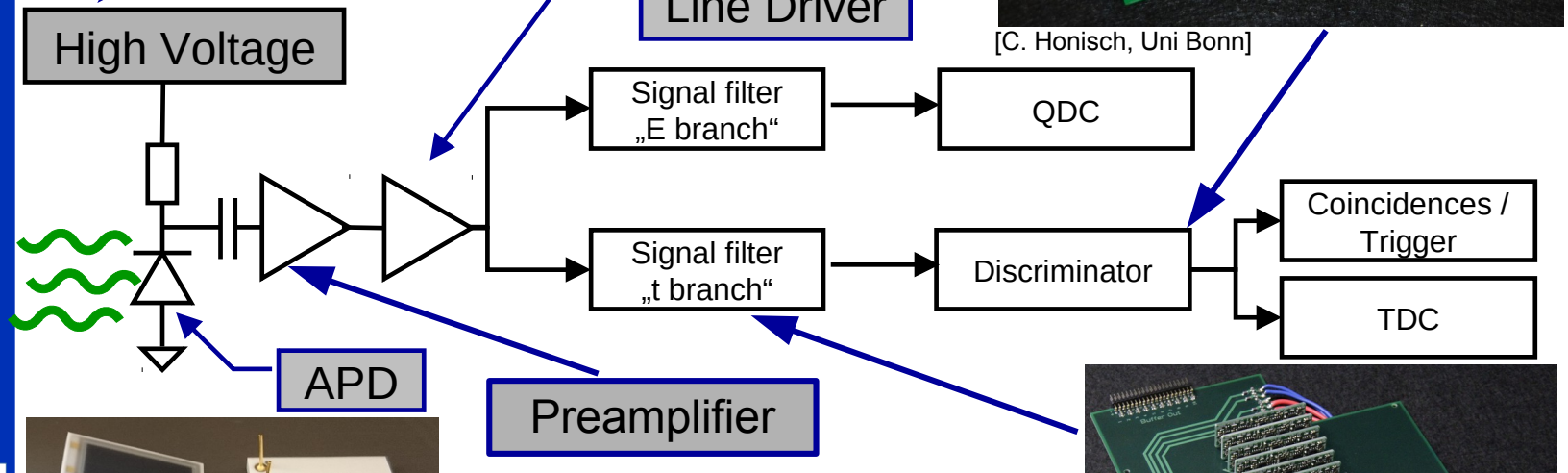


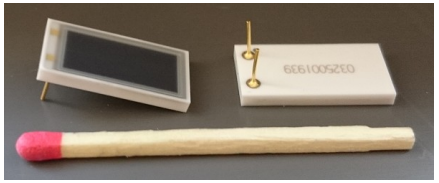
[C. Honisch, Uni Bonn]





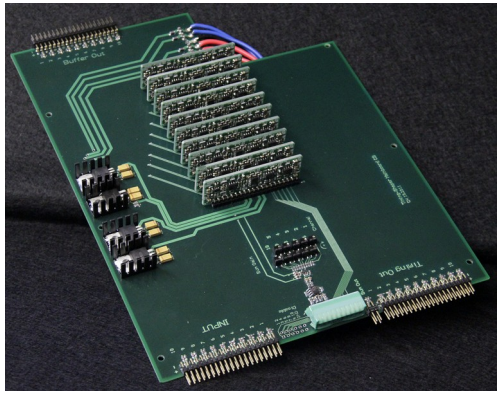
[C. Honisch, Uni Bonn]





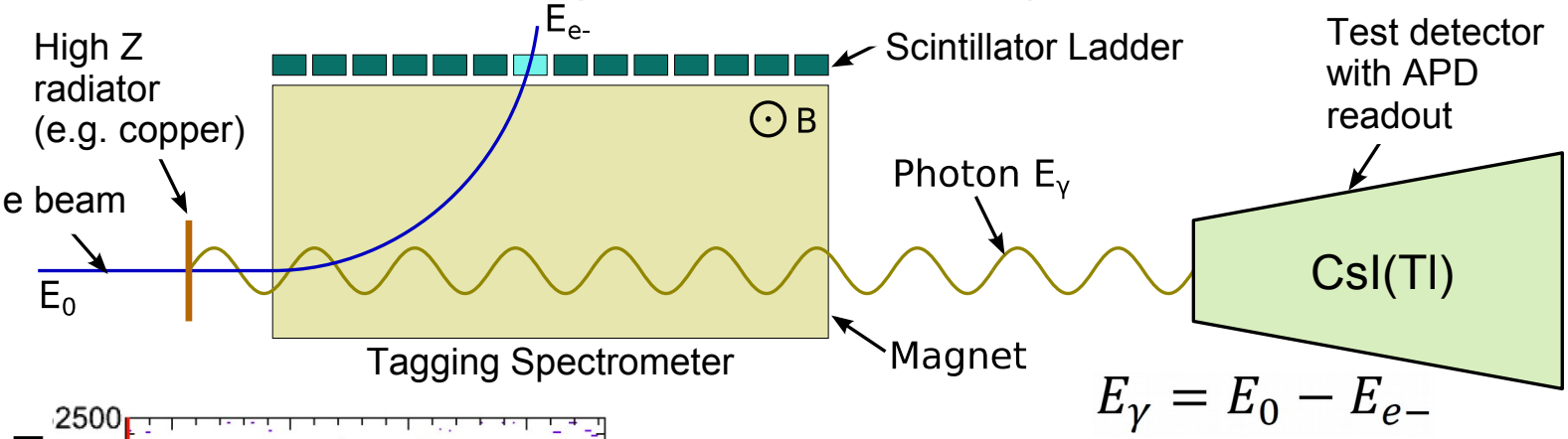
[S11048: Hamamatsu Photonics]

[M. Steinacher, Uni Basel]

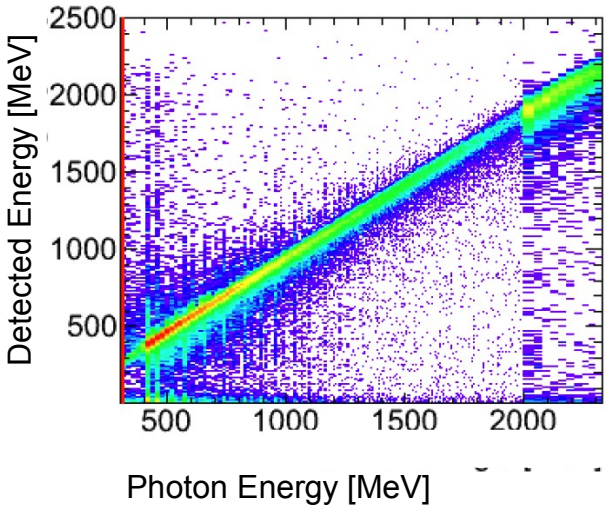


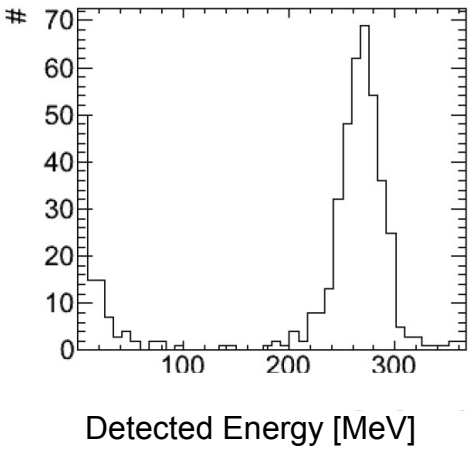
[C. Honisch, Uni Bonn]

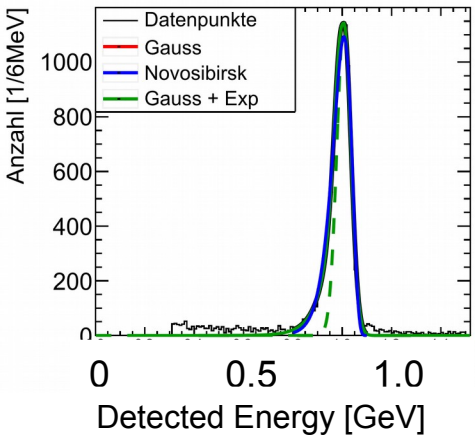
Detector Upgrade – Energy Resolution



$$E_\gamma = E_0 - E_{e-}$$

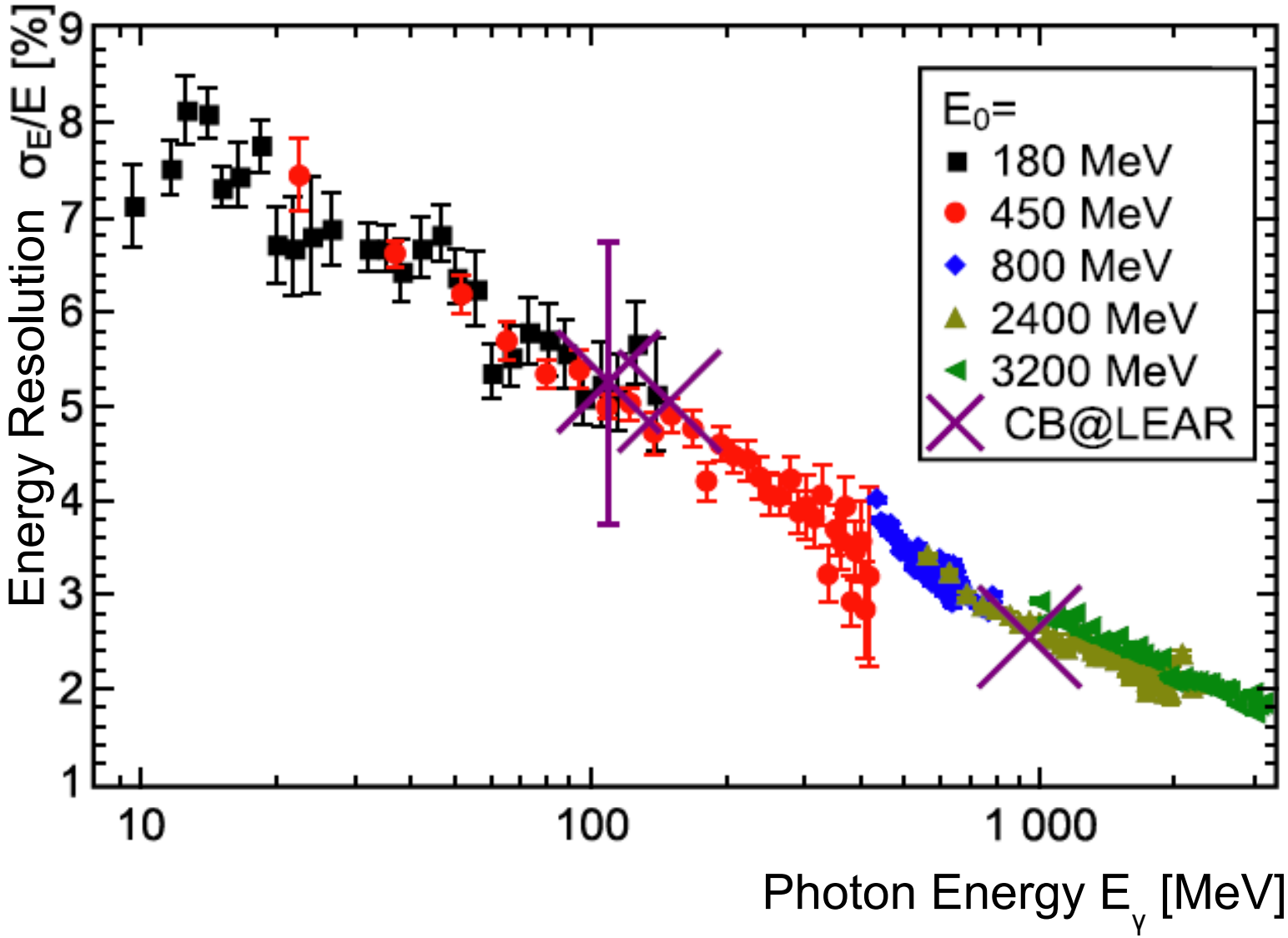




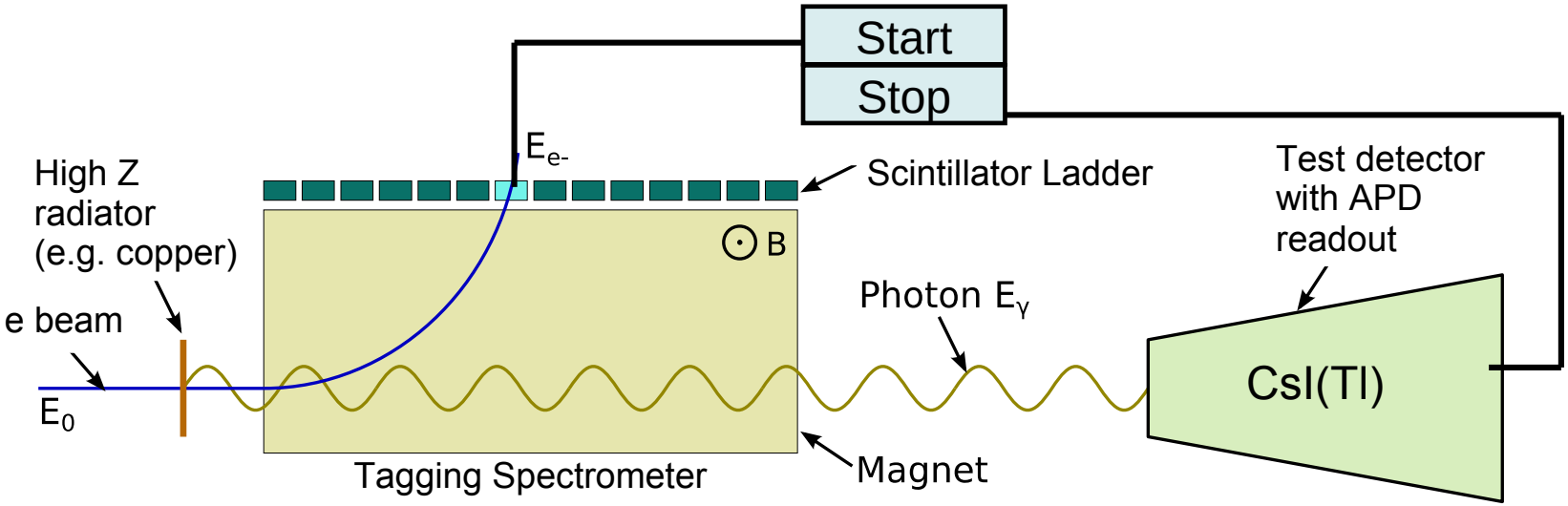


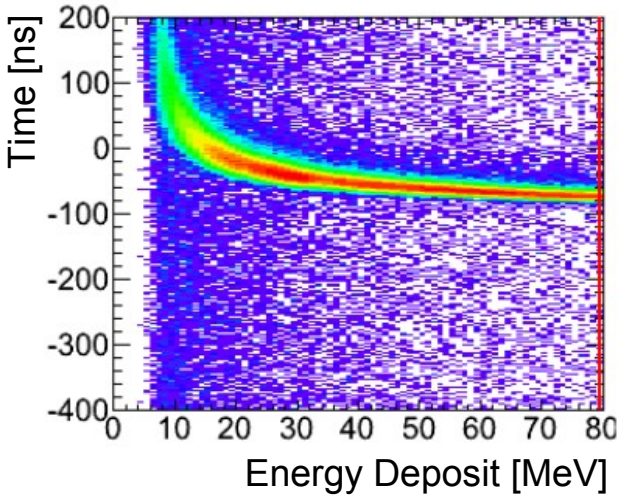
- Energy range for tests: 10 MeV – 3 GeV.
- Measured at MAMI (A2) and at ELSA.

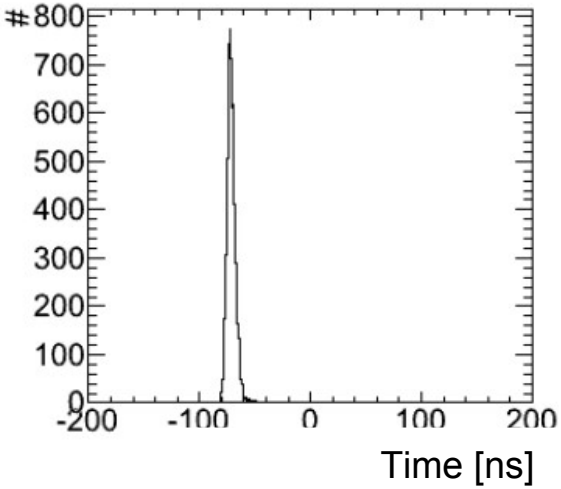
Detector Upgrade – Energy Resolution



Detector Upgrade – Time Resolution

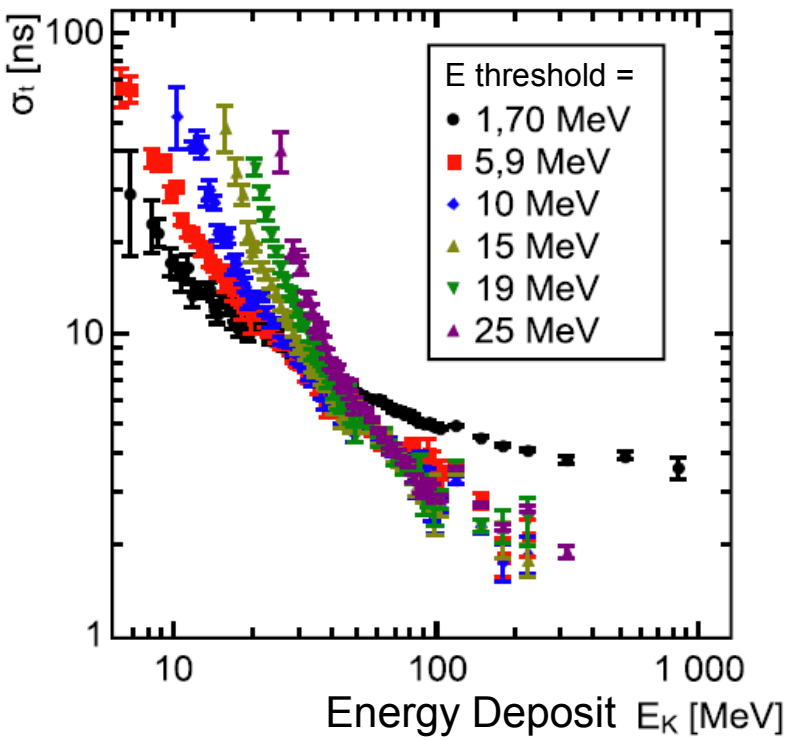




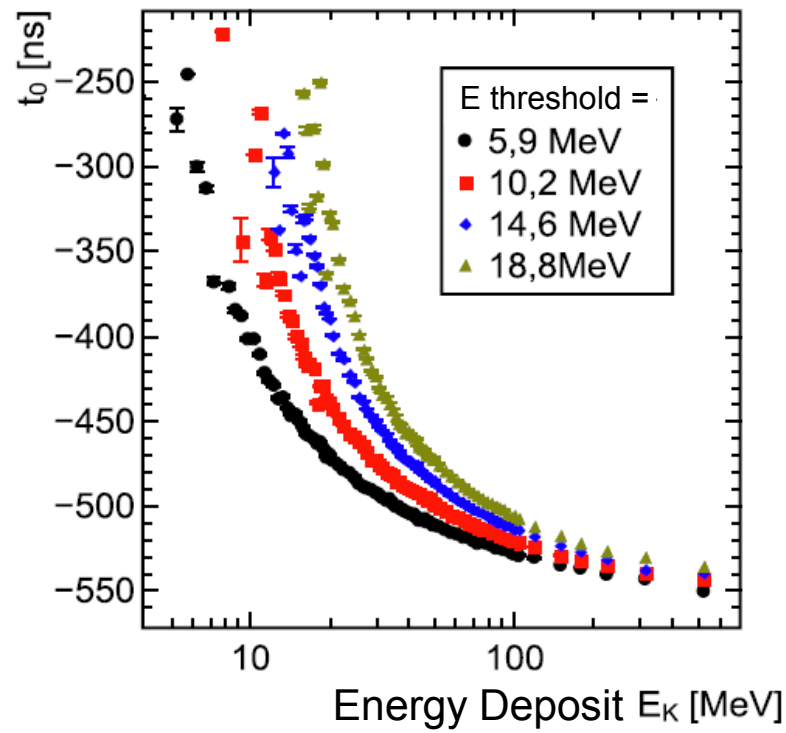


Detector Upgrade – Time Resolution

Resolution



Latency

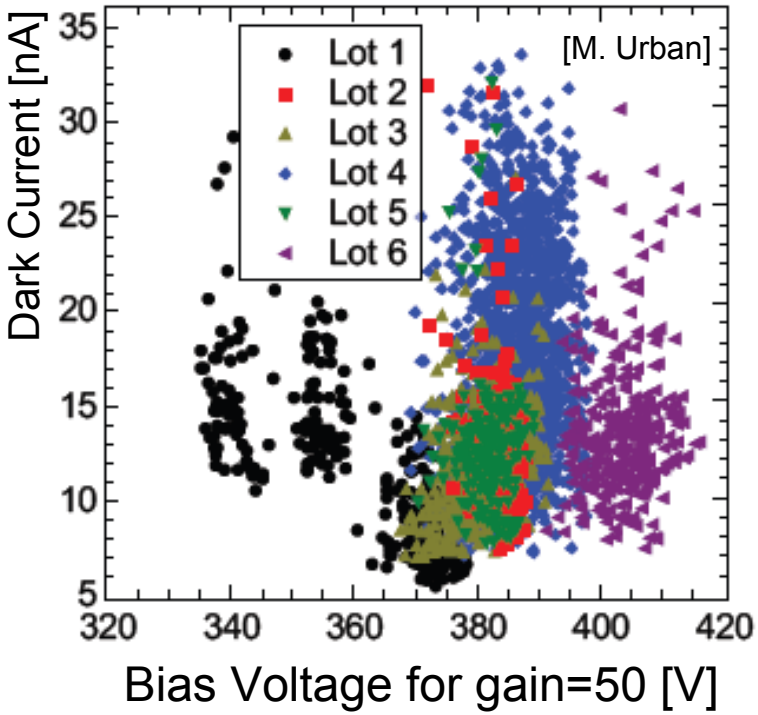


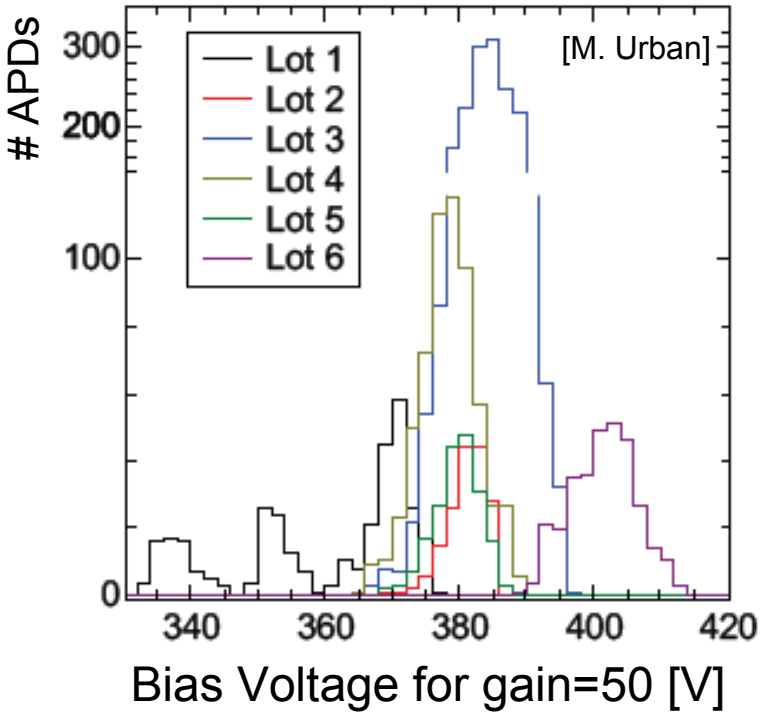
Time resolution reached: 3 ns for E_k > 100 MeV.

→ **Energy and time resolution within the demands for experiments with CB, therefore APD upgrade initiated.**

Detector Upgrade – APD Characterization

- Characterization of 3500 APDs.
- Done in Bonn with self-developed characterization station.
- The Crystal Barrel detector consists of 1320 (current setup) CsI(Tl) crystals,to be equipped with 2 APDs each.

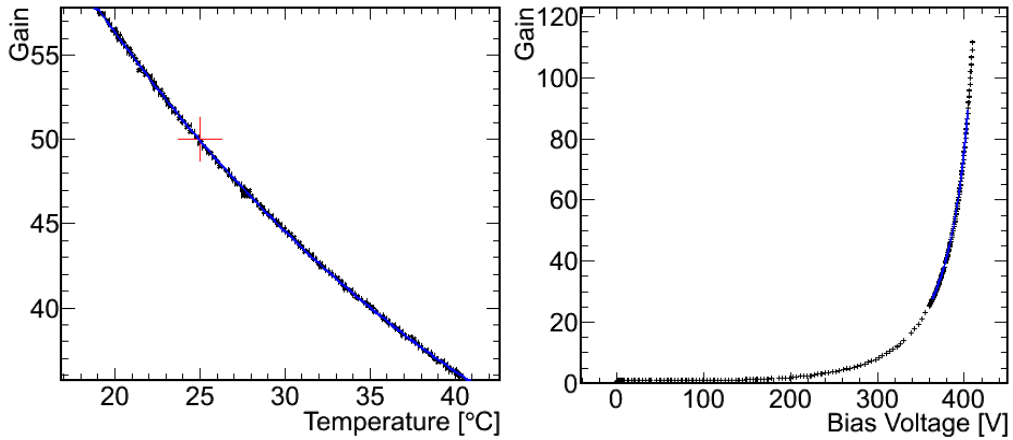


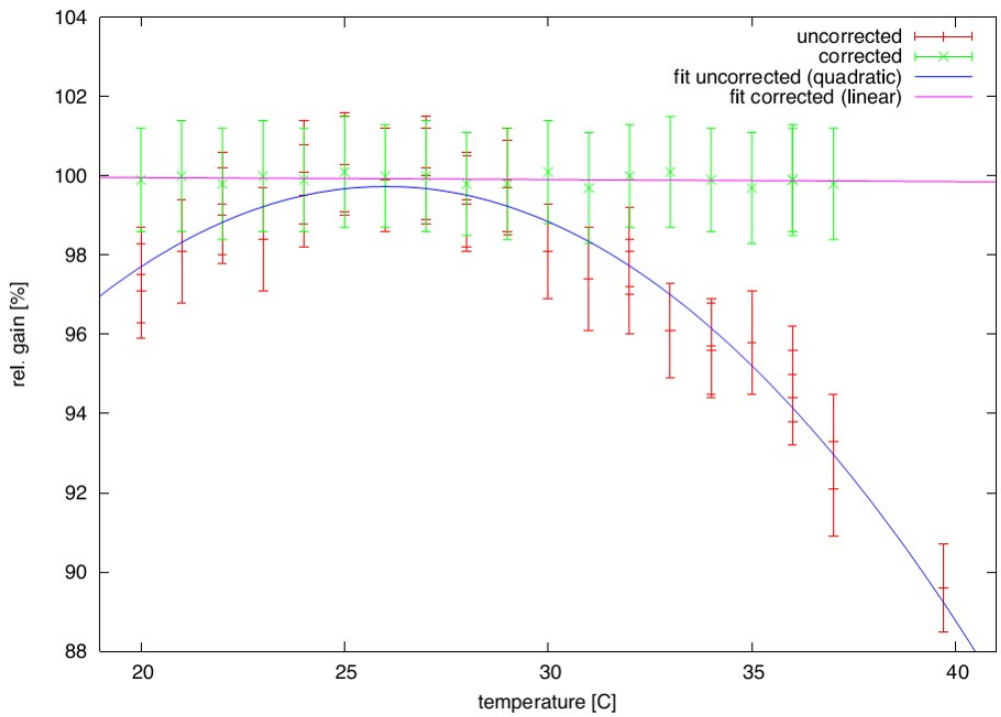


- APD properties vary due to production tolerances.
- An APD set of 2640 items with tightest parameters was selected.

Detector Upgrade – APD-Gain Control

Gain Characteristics of an APD (Hamamatsu S11048(X3))



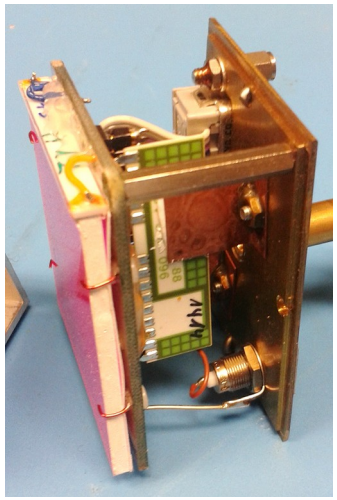


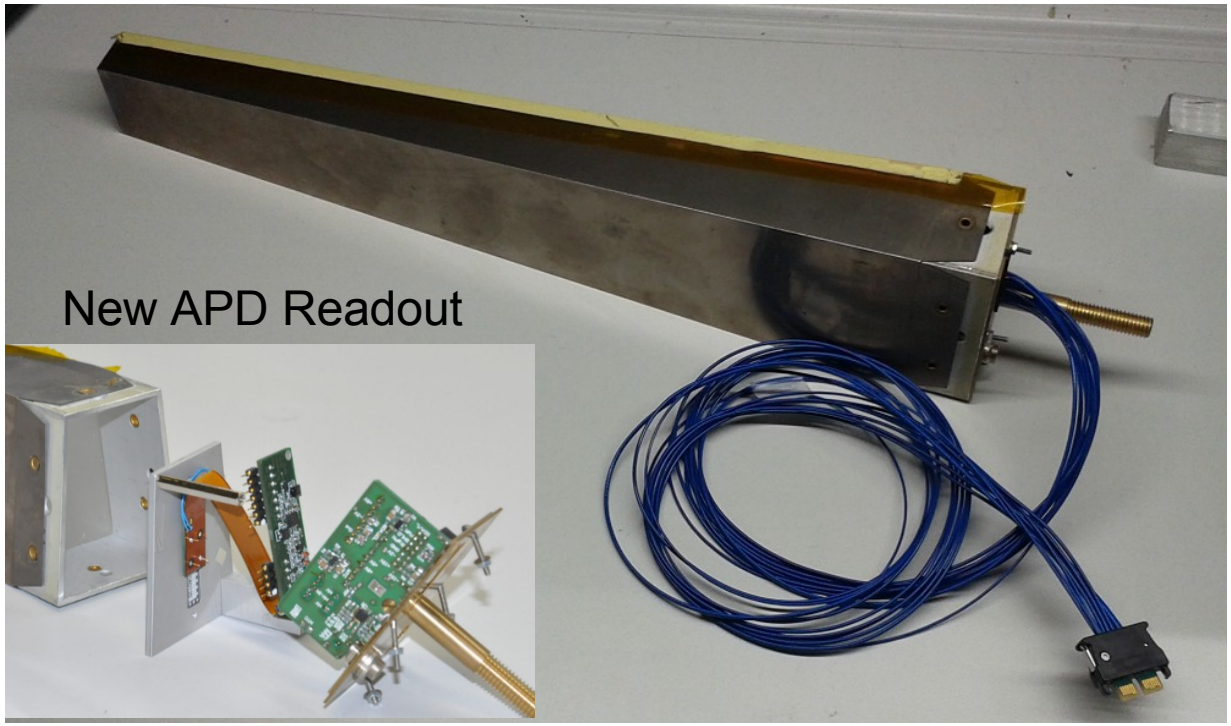
- Analogue electronics with NTC controls bias voltage, based on environment temperature (uncorrected).
- Optimized by additional active digital control via thermal sensor and programmable potentiometer (corrected).

Detector Upgrade – Readout Modification

- 1320 CsI(Tl) crystal readout hats require to be replaced, tested and adjusted. 1104 are already finished (3 Sep 2015).
- CB consists of two detector halfs. First half with 630 crystals already finished and back in beam position.
- Tests are accompanied by massive data logging and cross checking of each electronics component involved (data base, redundant S/N, …).

Previous PIN-Diode Readout





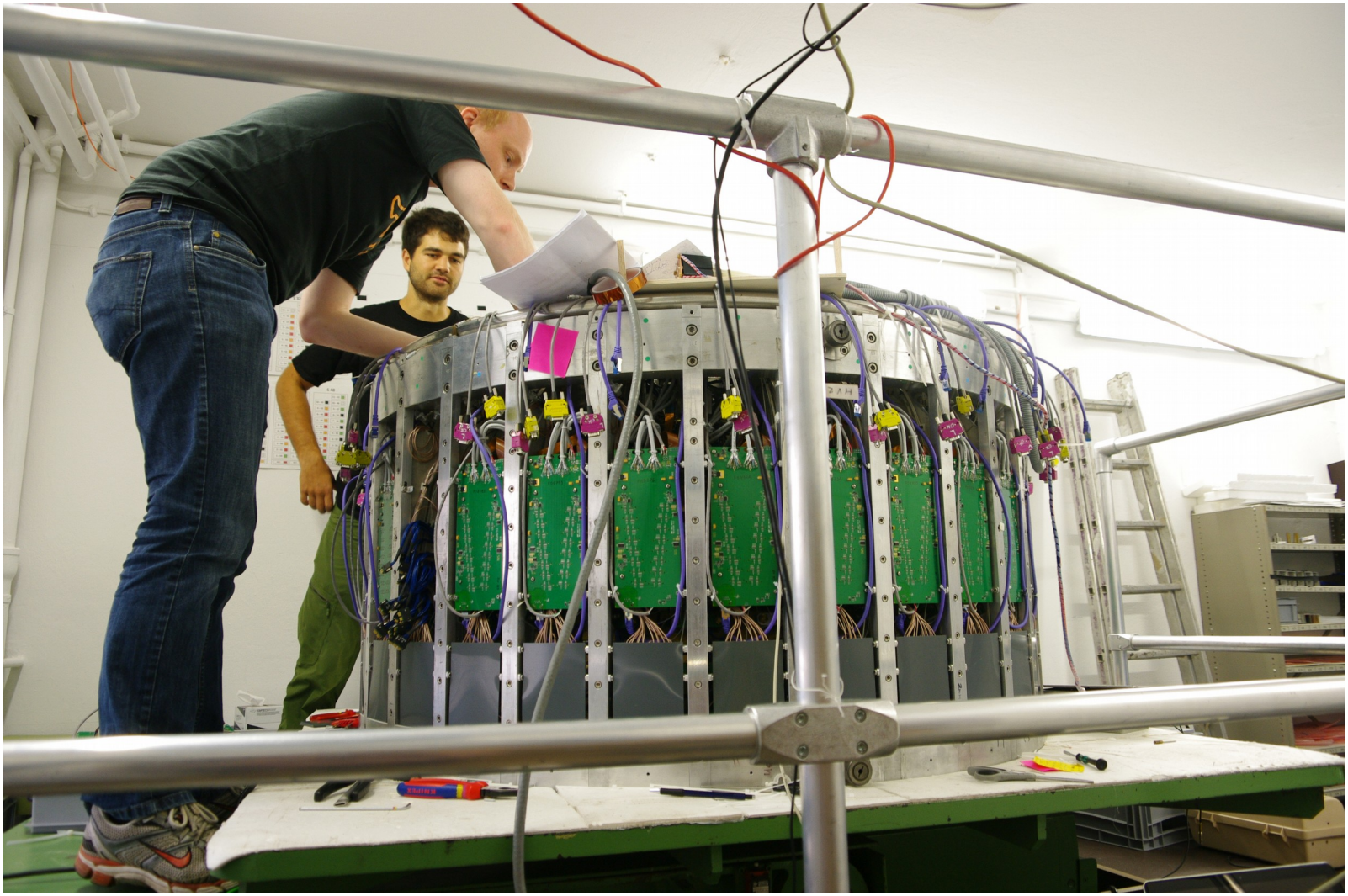
Detector Upgrade – Readout Modification

… lost in shelf ...

Detector Upgrade – Installation

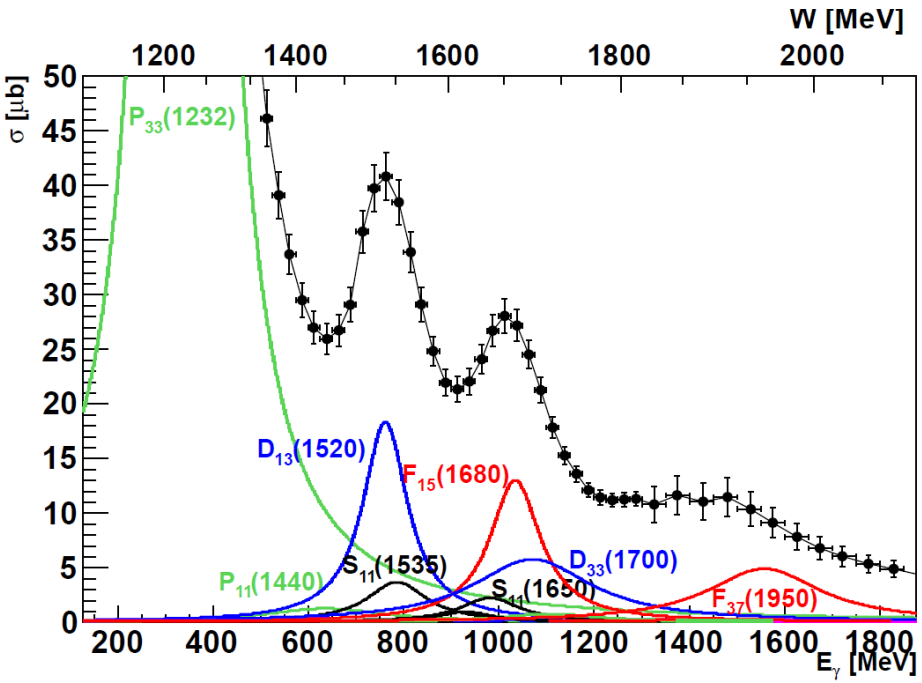
… almost ready ...

Detector Upgrade – Installation



… ready for transport.

Electronics Upgrade - Trigger



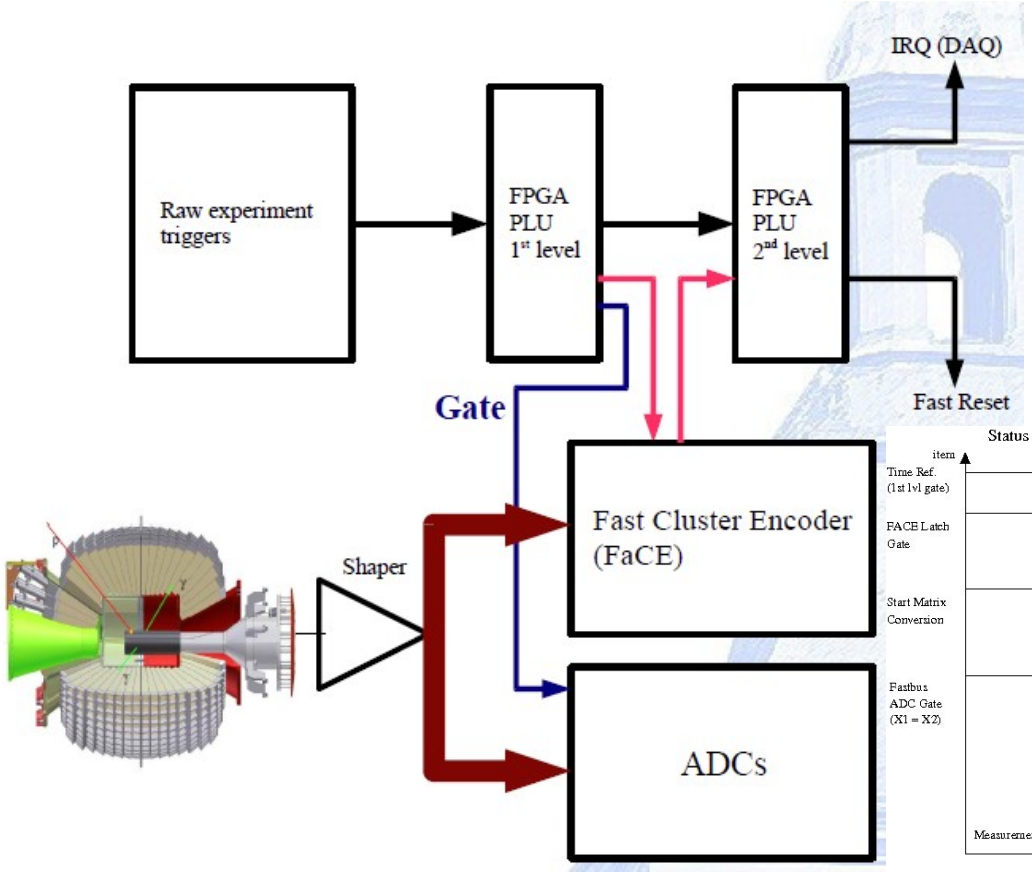
- Cross sections require very high statistics in order to fullfill the precision demands e.g. for PWA analysis. (i.e. total c.s., ang. distrib. ...)

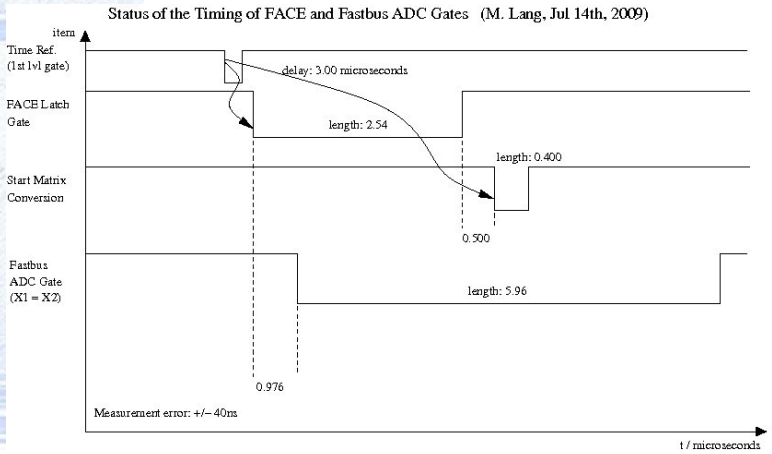
- Requires high hadron event rate.

- Small overall experiment dead time required.

- Major dead time contributions:
  - trigger processing time,
  - readout time.

Electronics Upgrade – Trigger (Old)

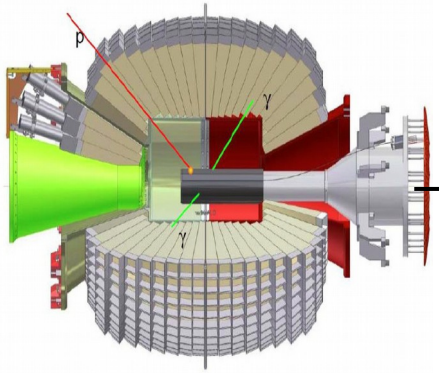




- two stage trigger,
- cluster finder FACE requires min. of 3 µs.

- Fast Reset in the trigger causes long dead times → build single stage trigger to avoid.

Electronics Upgrade – Trigger (New)



Buffered Splitter

Shapers (modified)

FB-QDCs

FACE (old)

sADCs

sADCs Controller

DAQ

Discr.

Further Experiment Components:
- TAPS,
- ChaPI,
- FP Vetos,
- Tagger.

Trigger FPGA (single stage)

FACE2

pTDC

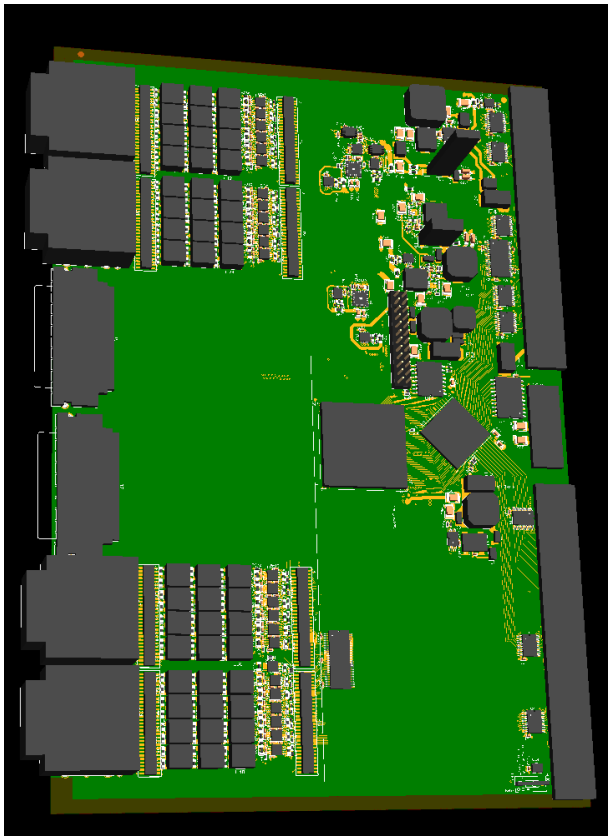
Implemented in Xilinx Spartan 6 FPGA.

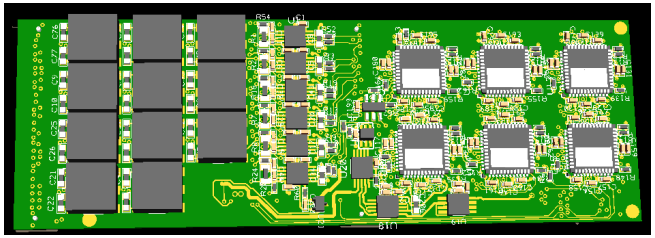
new

old

New Backend Electronics

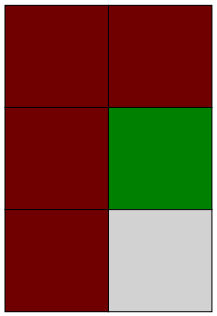
- Timing branch
  - Timing filter (NIM Module, 23 channels)
  - Discriminator module (VME, 92 channels per module)
    - 2 thresholds per channel
    - Integrated TDC
    - First step of clustering
  - Cluster finder
    - FPGA based
    - Custom module

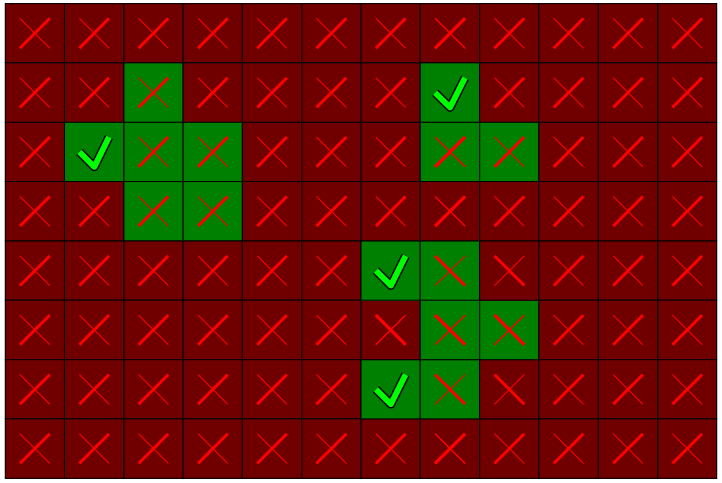




New Backend Electronics – Cluster Finder

- Existing:
  - Precise counting of clusters
  - Gated Mode, Latency $t = 0.8\ \mu s + n \cdot 0.8\ \mu s$
- Goal: Latency < 300 ns → Major improvement required
- New method:
  - Estimation of clusters via corner detection





  - Latency: **~65 ns** (assuming 200 MHz FPGA clock)
  - Free running!
  - Simulation results are promising

New Backend Electronics – sADC

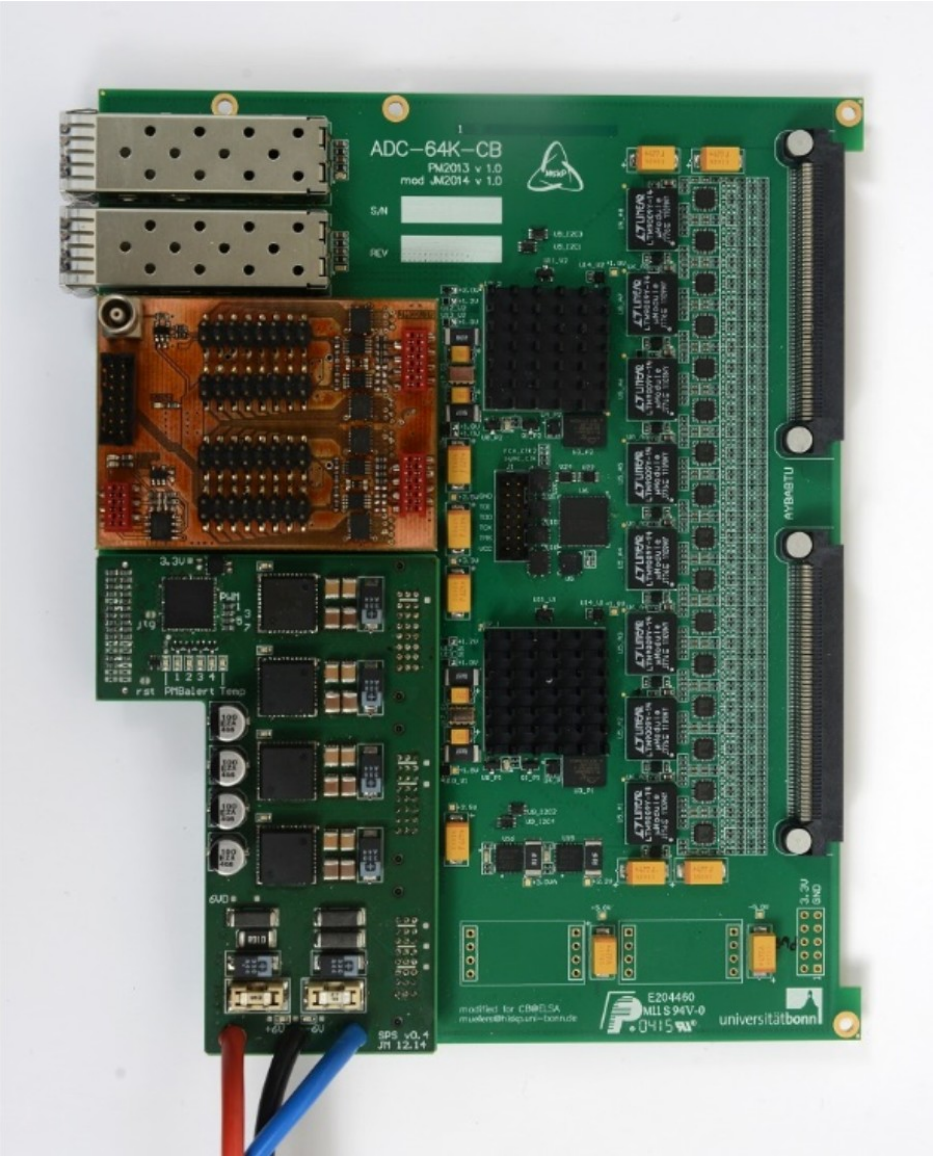
Energy branch

Stage 1: use previous
Fastbus QDCs

Stage 2: use sADCs

Properties:

- design forked from sADC for PANDA EMC,
- 64 channels per NIM unit,
- 25W power consumption,
- 80 … 125 MSPS, 14 Bit,
- 2 x Xilinx Kintex 7,
- 2 x Gigabit Ethernet SFPs.



Summary

- The Crystal Barrel Detector gets upgraded in order to provide a trigger for fully neutral final states.

- The previous PIN diodes do not offer a sufficient SNR to extract a reliable time signal for a trigger.

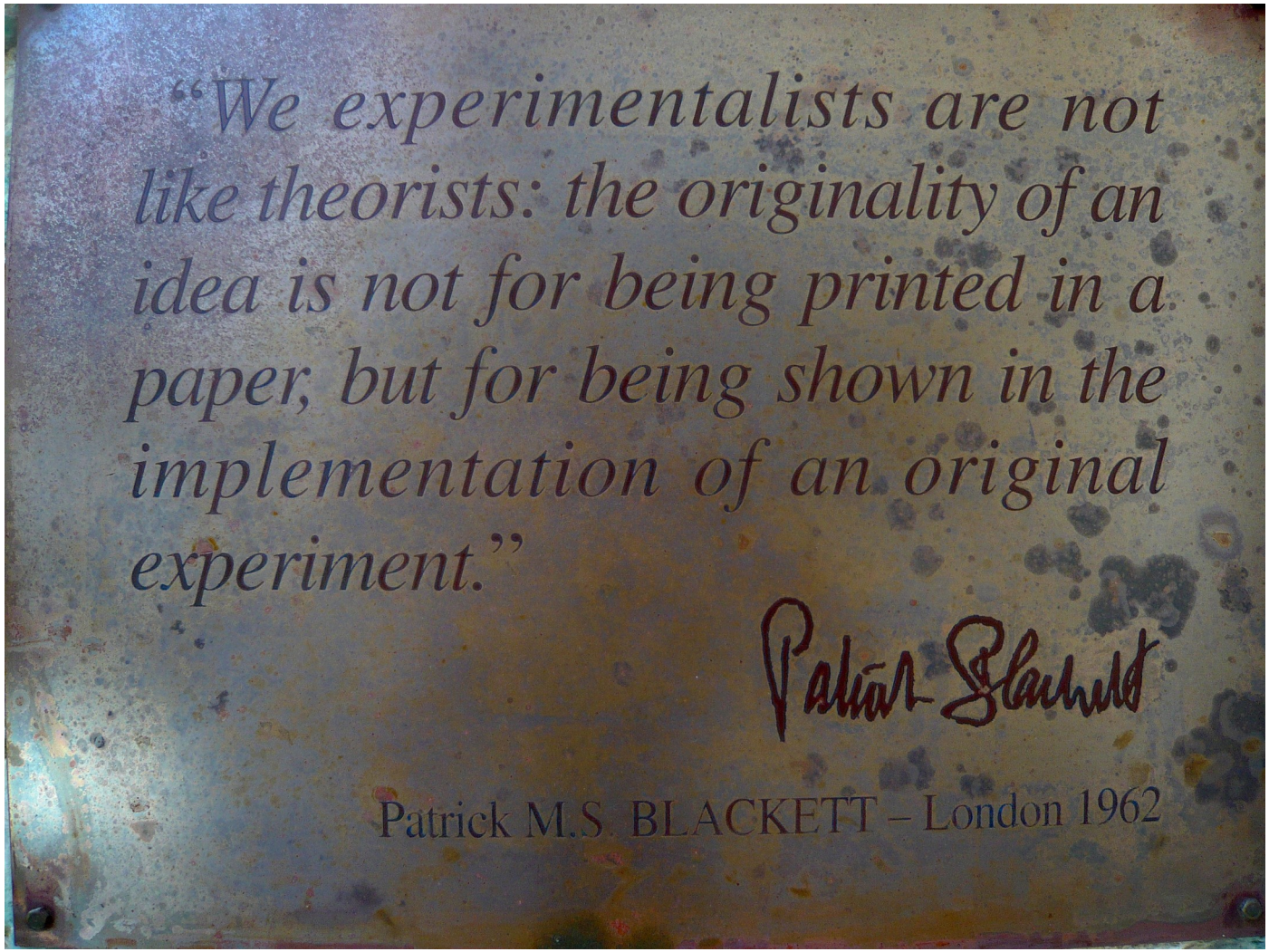
- APDs are chosen, operating at an intrinsic gain of 50.

- The strong APD gain dependency on temperature and voltage gets controlled by means of electronics, including a gain monitoring.

- Besides approx. 200 crystals, all readout hats are already modified.

- A high rate single stage trigger is developped in parallel to provide a better exploit of hadron events. This allows investigation of small cross section contributions.

- Experiment comissioning starts beginning of 2016.


"We experimentalists are not like theorists: the originality of an idea is not for being printed in a paper, but for being shown in the implementation of an original experiment."
Patrick M.S. BLACKETT – London 1962

Thank you!