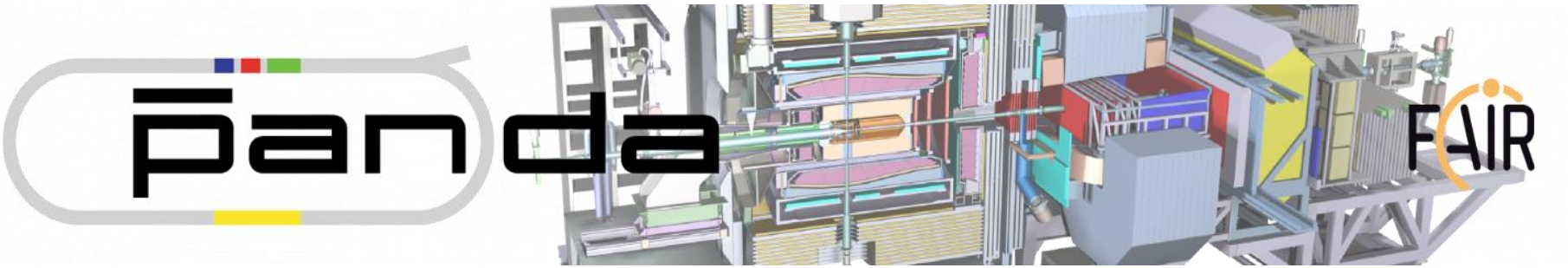
The Electromagnetic Calorimeter for the



Target Spectrometer

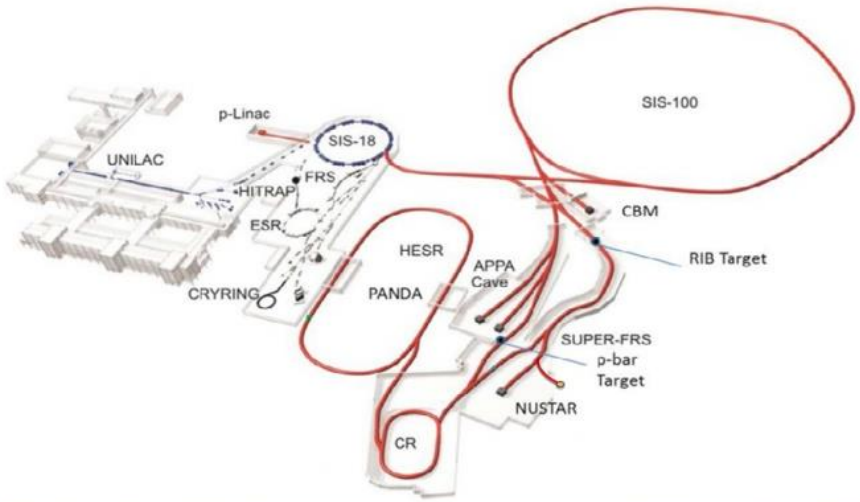
Markus Moritz* for the PANDA collaboration
*2nd Physics Institute, Giessen University, Germany

ISMART 2018

FAIR - Future Facility for Antiproton and Ion Research near Darmstadt

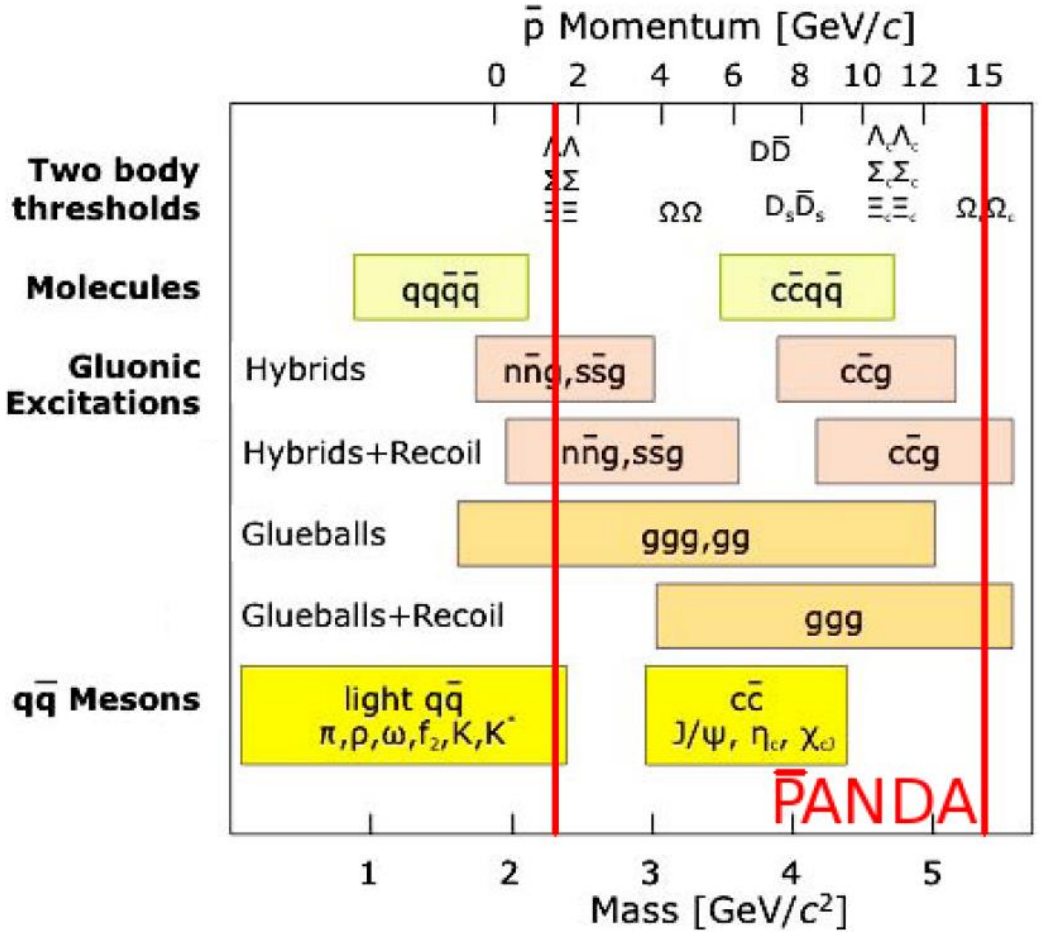
FAIR - Future Facility for Antiproton and Ion Research near Darmstadt

- FAIR a unique facility: various physics programs can be operated in parallel
  - APPA, CBM, NUSTAR …
- Primary beams:
  - Protons up to 30 GeV/c
  - Heavy ions up to 35 GeV/c (U^{92+})
- Secondary beams:
  - Radioactive isotopes
  - Antiprotons up to 15 GeV/c
    - High-energy storage ring (HESR) with stochastic cooling
      - High resolution down to $\Delta p/p=4x10^{-5}$
      - High luminosity up to 10^{32} cm^{-2} s^{-1}
- **PANDA @ HESR** will be one of the key experiments at FAIR



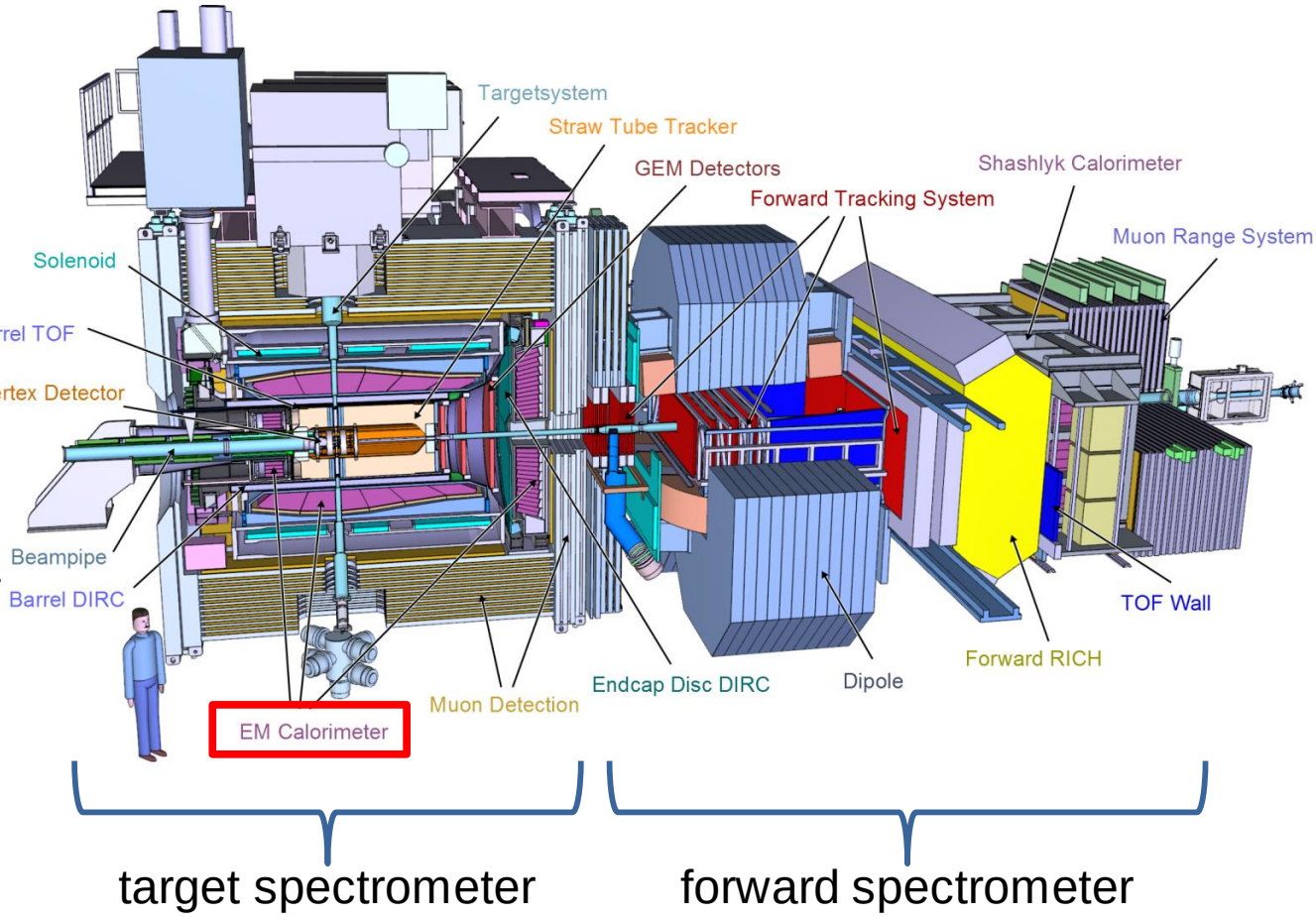
PANDA (Anti-Proton Annihilation at Darmstadt) **Experiment**

- Physics program of PANDA:
  - Charmonium spectroscopy
  - Gluonic excitations
  - In-medium effects of hadronic particles
  - Open-charm spectroscopy
  - Hypernuclei
  - Electromagnetic processes



PANDA Setup

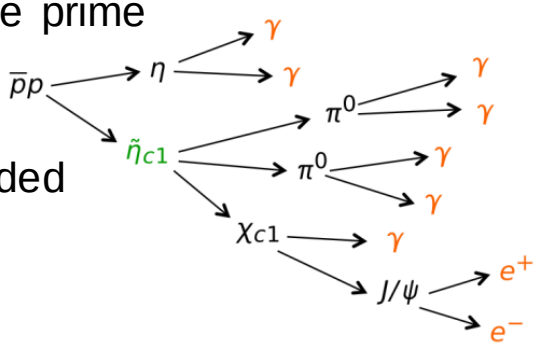
- Cooled antiproton beams between 1.5 GeV/c and 15 GeV/c
- Fixed target experiment
  - Hydrogen and other
- High luminosity
  10^{32} $cm^{-2}s^{-1}$
- Magnets
  - Forward 2 Tm dipole
  - Interaction region 2 T

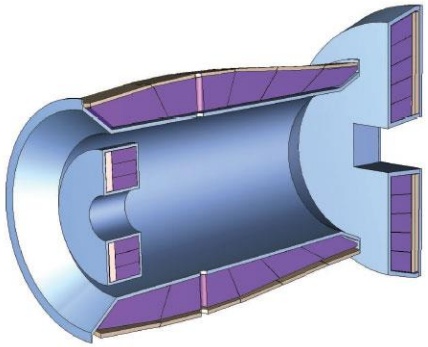


PANDA Target Calorimeter - Main Requirements -

- Final states with many e^+, e^- and γ are the prime signals

  ➡ High geometrical acceptance needed (with forward spectrometer: 4π)





- Inside 2 T superconducting magnet

  ➡ Compact

- High interaction rates up to 10^7 s^{-1}

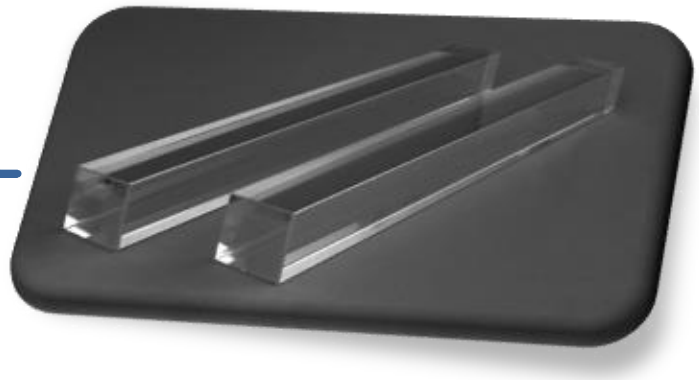
  ➡ Fast response

- Annual dose up to 30 Gy

  ➡ Radiation hard

- Effective background rejection

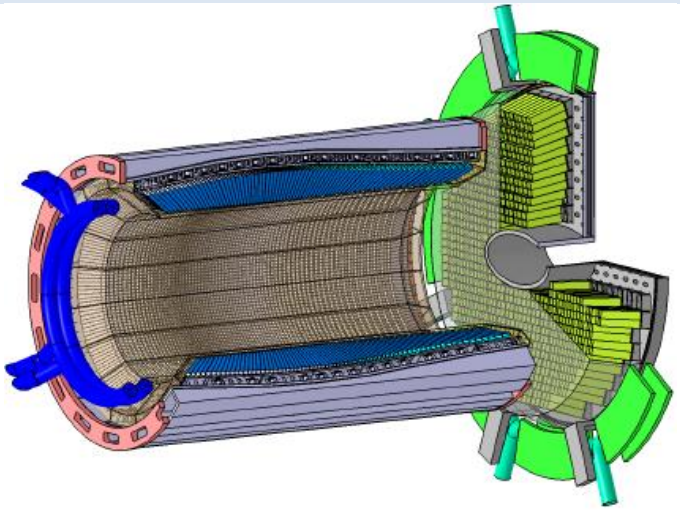
  ➡ Good energy resolution over huge dynamic range from 10 MeV up to 15 GeV



PWO-II

PANDA Target Calorimeter - Scintillator Material -

- Target Calorimeter based on 15,740 high quality PWO-II ($PbWO_4$) crystals
  - Small radiation length X_0= 0.89 cm
  - Short decay time τ=6.5 ns
- Physics goals require improved scintillators



	PWO-I (CMS)	PWO-II (PANDA)
luminescence maximum, nm	420	420
La, Y concentration level, ppm	100	40
expected energy range of EMC	150MeV - 1TeV	10MeV - 10GeV
light yield, phe/MeV at room temperature	8-12	17-22
EMC operating temperature, °C	+18	-25
energy resolution of EMC at 1GeV, %	3,4	2,0

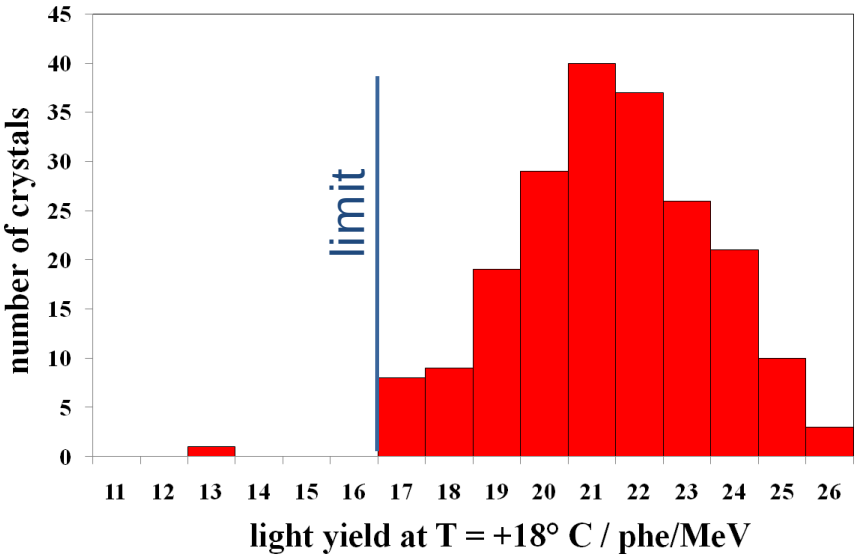
increases LY ~4x further

PANDA Target Calorimeter - Scintillator Material -

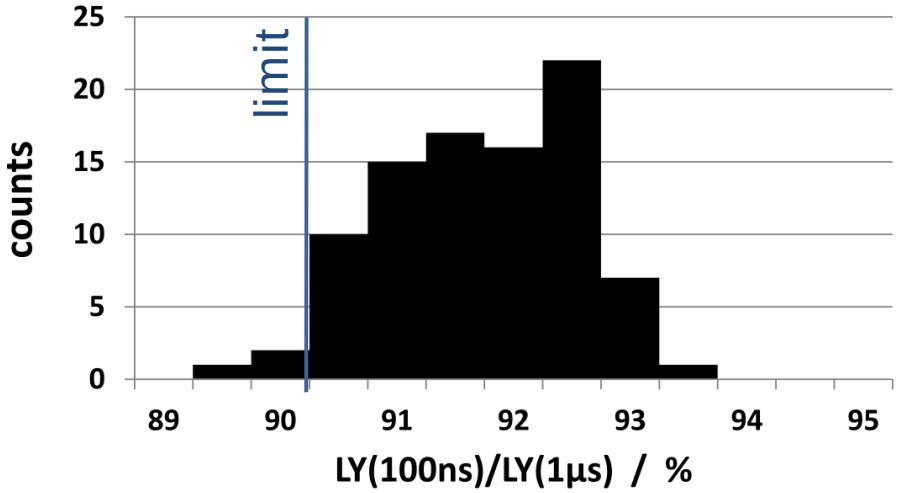
- Main part produced at BTCP (**B**ogoroditsk Plant of **T**echno**c**hemical **P**roducts, Russia)
- Missing 41% of the crystals will be produced at Crytur (Czech Republic)
  - Up to now: 200 PWO-II crystals in PANDA geometry
    - All crystals have been tested at the facilities at Giessen in order to compare the results to the required specifications for PANDA
      - Scintillation yield and kinetics
      - Optical transmission
      - Radiation hardness

Scintillator Material - Light Yield & Decay Kinetics -

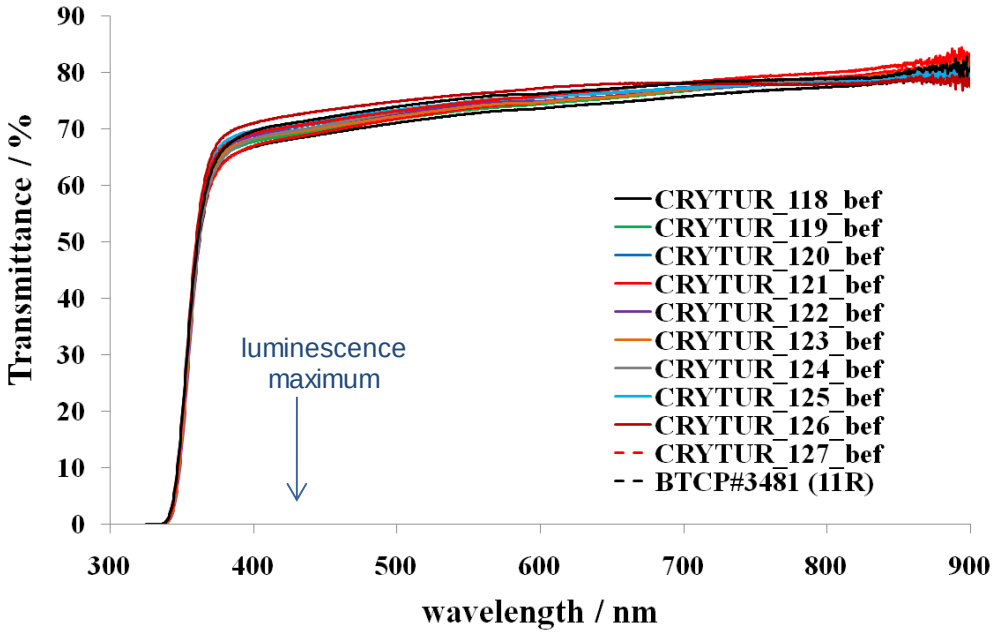
$$LY\left(\frac{phe}{MeV}\right) = \frac{\text{photo peak}}{\text{single } e^{-}\text{peak} \cdot \text{energy}}$$

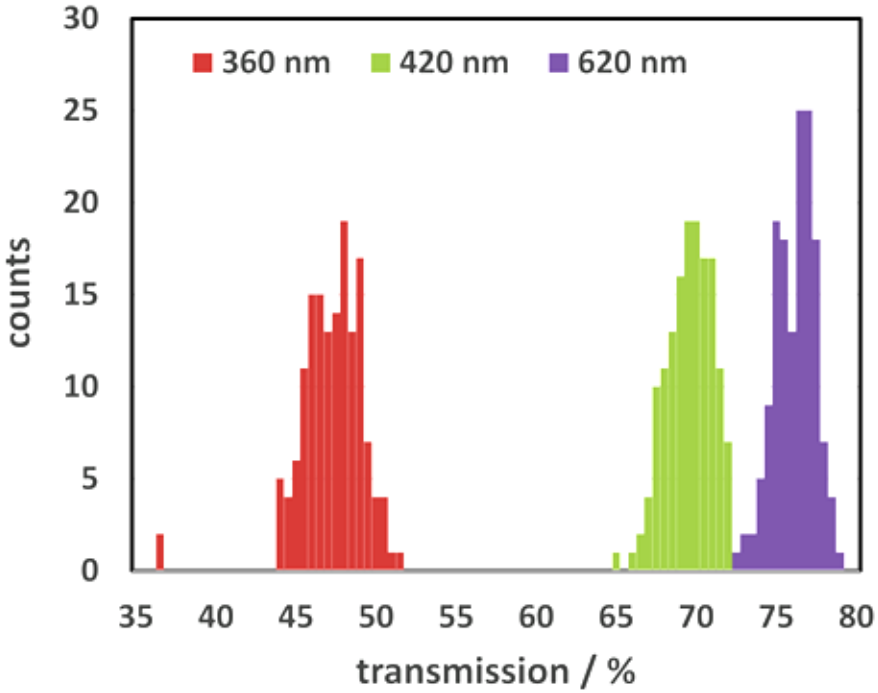


- Almost all preproduction crystals pass the requested spec. limits :
  - LY@18°C > 16 phe/ MeV
  - LY(100ns)/LY(1µs) > 0.9



Scintillator Material - Optical Transmission -





Measured along full length:

- No color centers visible
- Stable absorption edge

PANDA specification limits:

- T @ 620 nm > 70 %
- T @ 420 nm > 60 %
- T @ 360 nm > 35 %

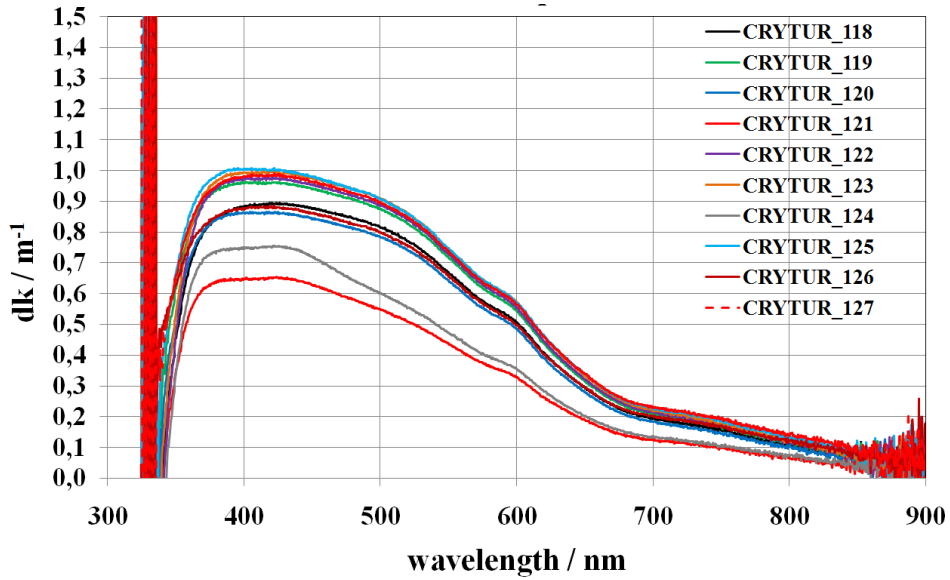
Scintillator Material - Radiation Hardness -

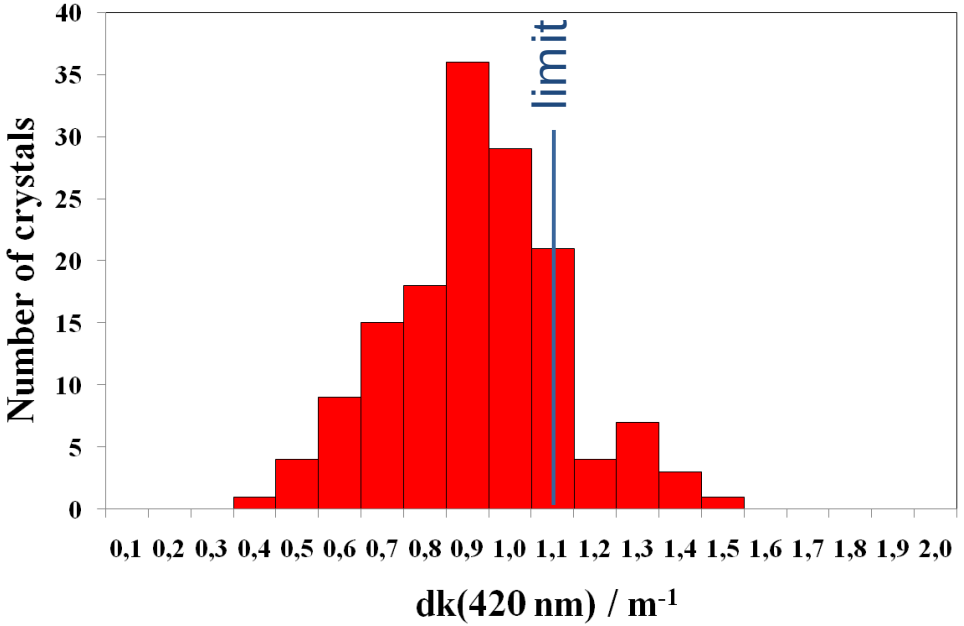
- Set of five ^{60}Co sources
- Crystals irradiated with a dose of 30 Gy within 26 minutes
- Transmission measurement started 30 minutes after irradiation
- Absorption coefficient (k) has been calculated to take crystal dimensions into account $\mathbf{I(x) = I_0 \cdot e^{-kx}}$
- $\Delta k = k_{\text{after rad.}} - k_{\text{before rad.}}$

Scintillator Material - Radiation Hardness -

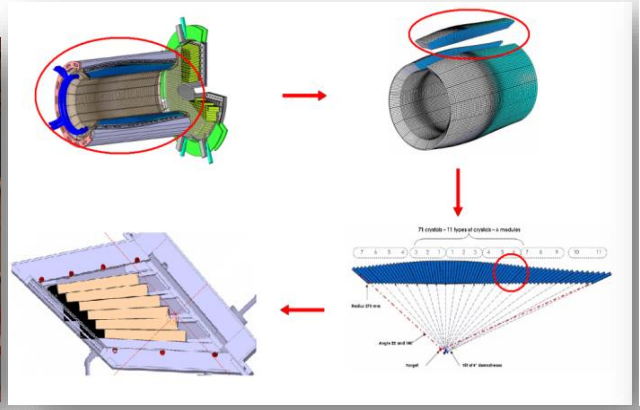
PANDA specification:

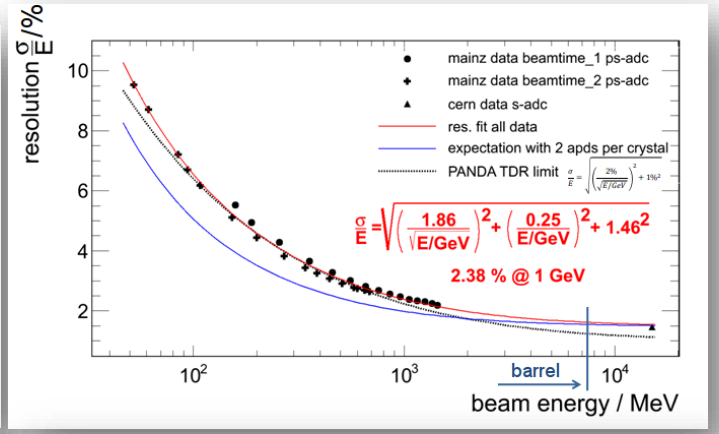
- $\Delta k \leq 1.1\ m^{-1}$ (room temp. & 30 Gy)

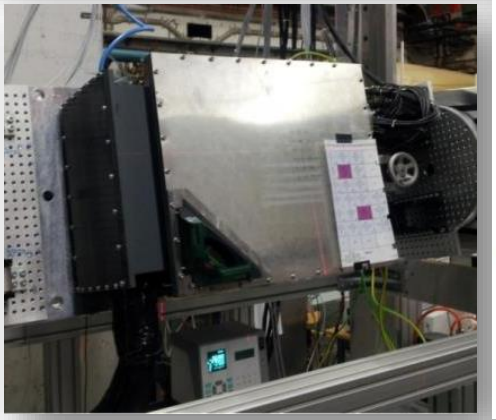


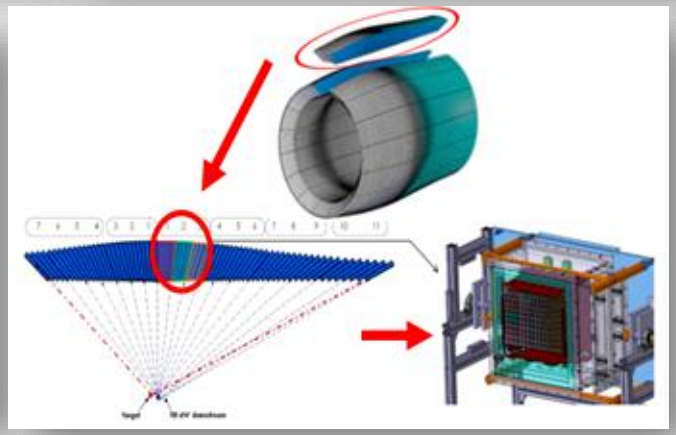


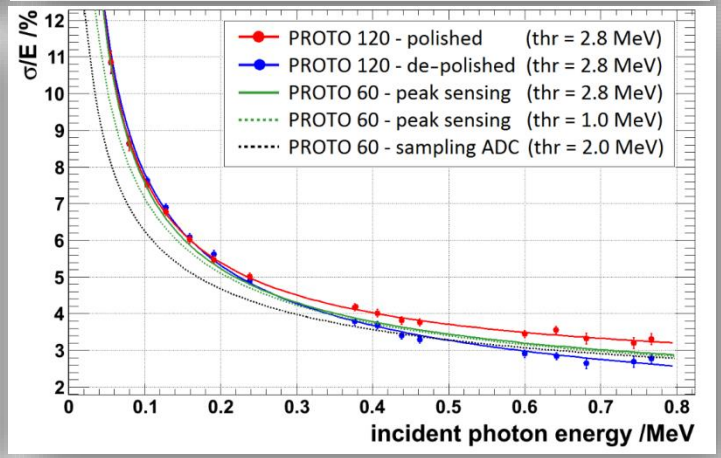
Prototype Tests









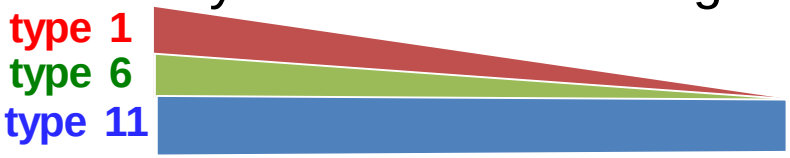


Objectives reached, especially at low energies

1st Full Barrel EMC Slice - Some Milestones -

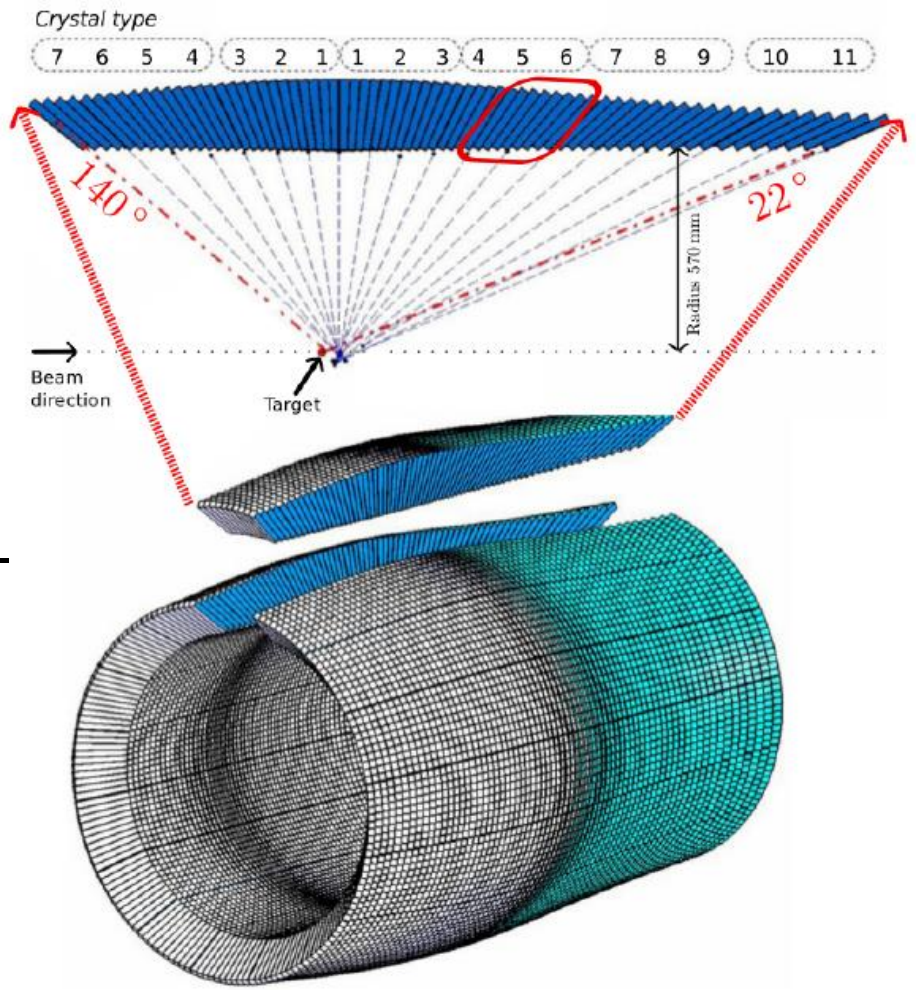
Assembly of:

- 710 Crystals in 11 different geometries



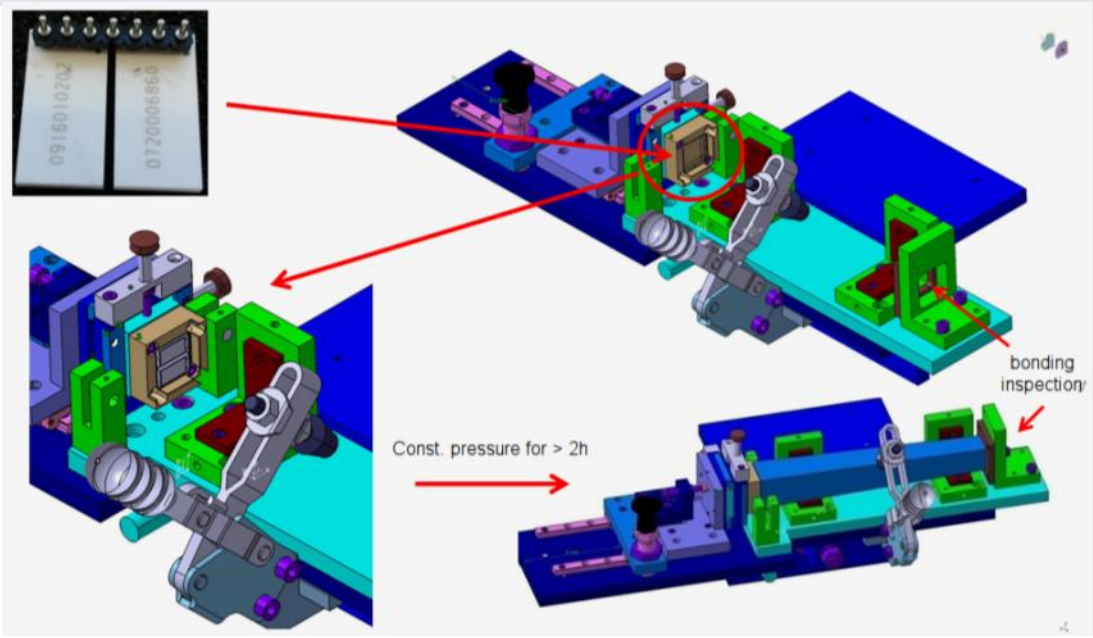
- 1420 matched APDs after 1st screening, gamma irradiation, 2nd screening.
- 360 left- and 360 right-handed APFEL-ASIC flex PCBs
- 178x3 Backplanes for
  - HV distribution and individual adjustments
  - Connection of signal cables, slow control…

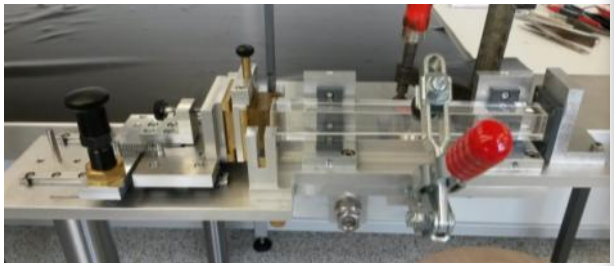
More than 4500 m of signal cables.



Assembly Procedure - Detector Preparations

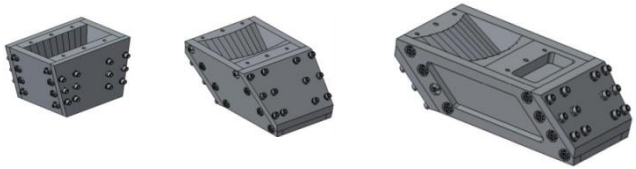
- Gluing:
  - Cleanroom environment
  - Rad. hard optical glue
  - Several stations available for precise and parallel processing
  - At the moment:
    - 40 crystals per week (one module block)
    - 3 slices per year
- Reflective foil wrapping
  - Precise laser-cut foils
- 3D printed capsules



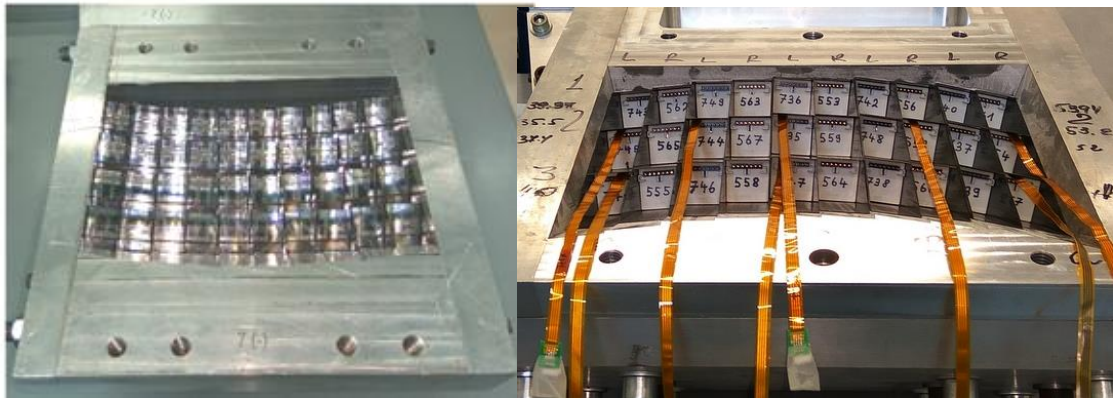


Assembly Procedure - Modules & Temperature Monitoring -

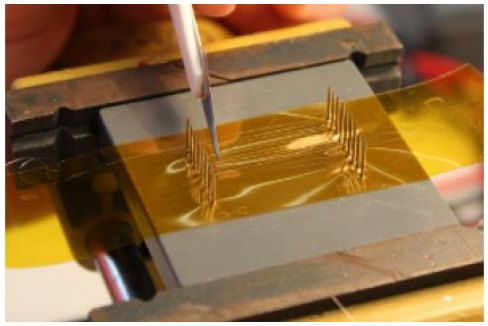
- Crystals inserted into carbon fiber alveoles
- 18 differently shaped alveoli are necessary from 7(-) to 11 (+)

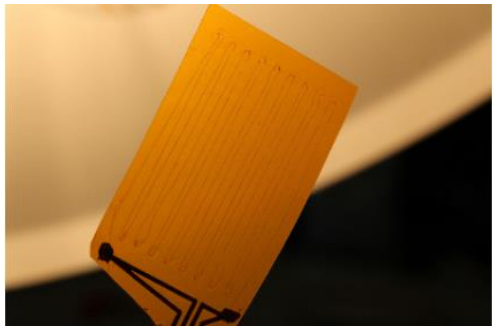


- PWO-II $\Delta LY/°C = 3\ \%$
  - Precise temperature monitoring of whole cooled volume necessary
  - TDR $\Delta T < 0.1$ °C
  - Special ultrathin temperature sensors developed
    - Thickness < 160 µm

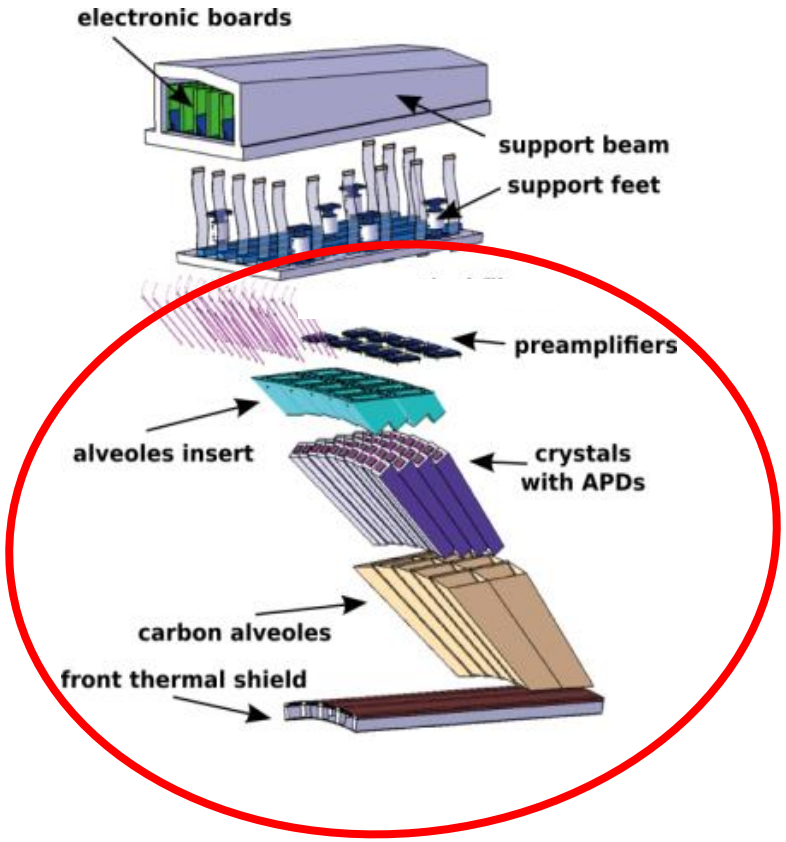


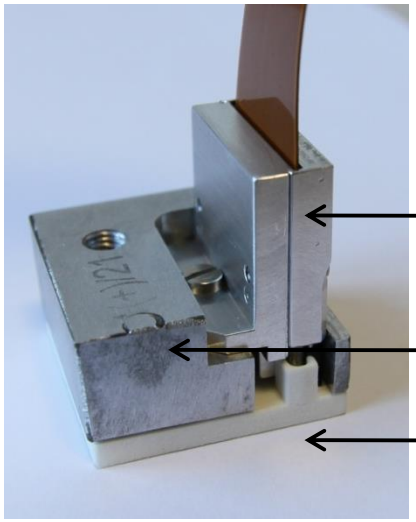
Temp. sensors distributed between crystals



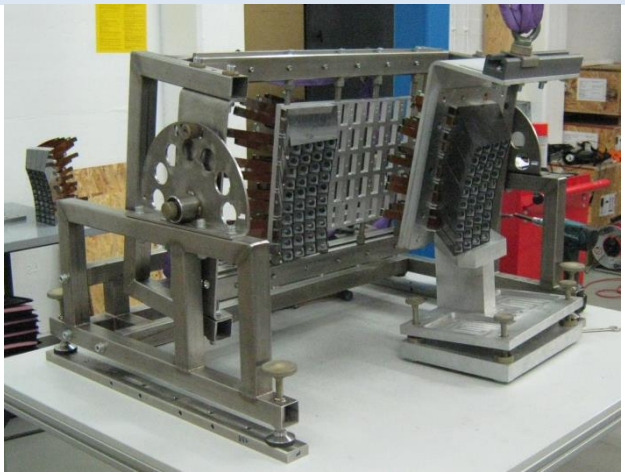


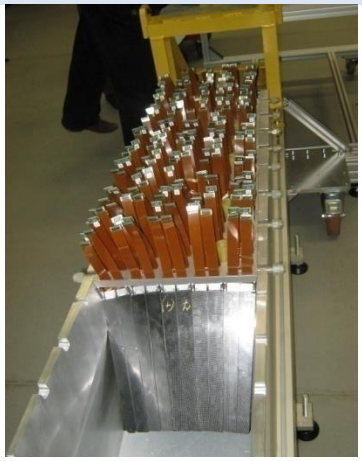
Assembly Procedure - Modules Readout -

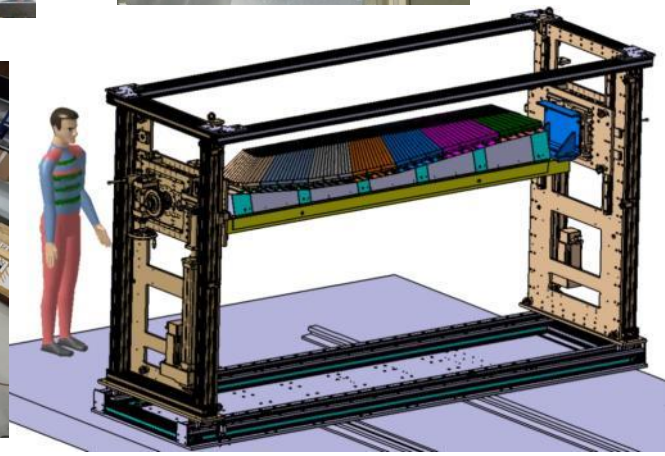




Assembly Procedure - Supermodules & Slice -



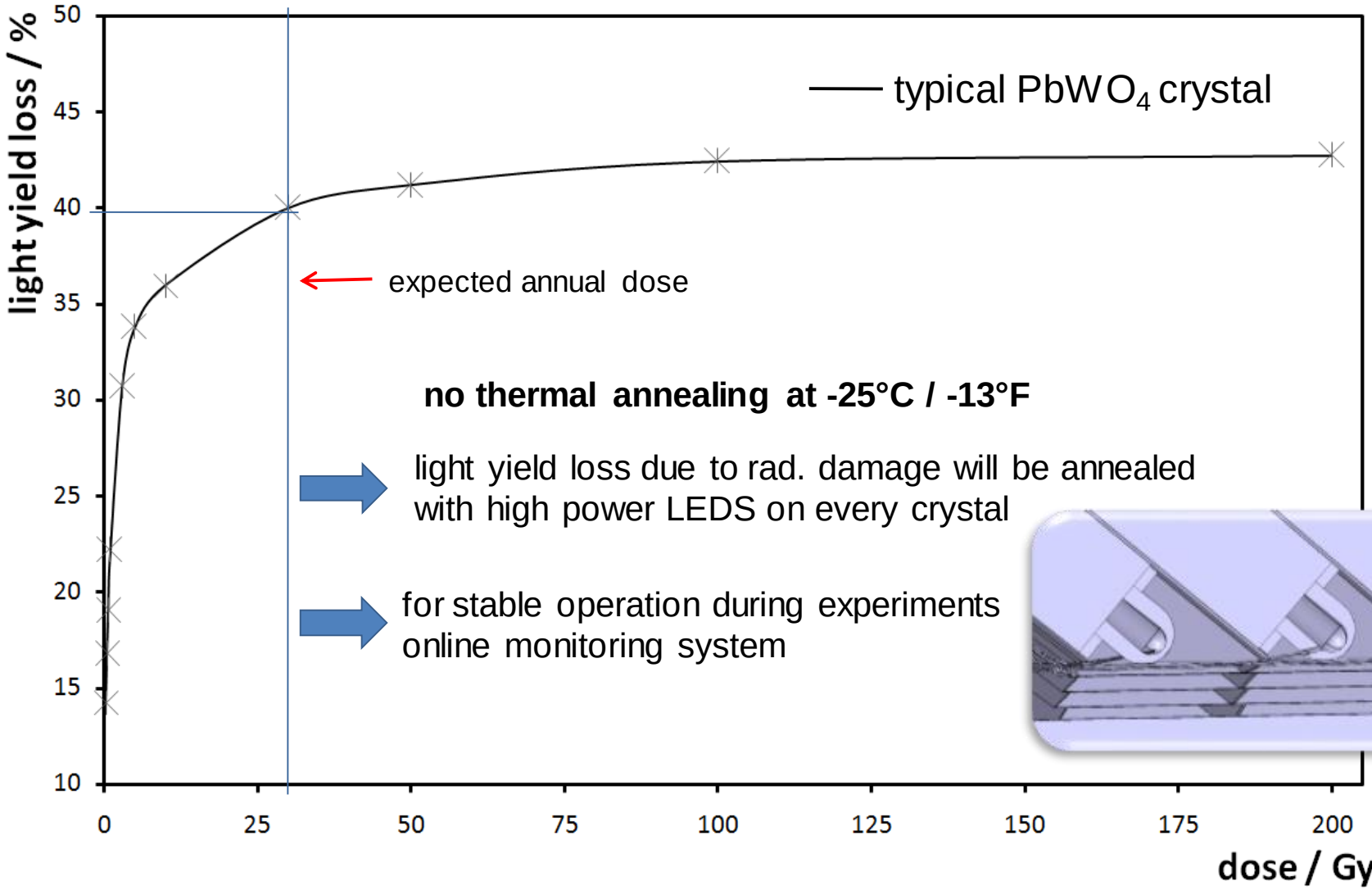




Backplanes will sit inside support beam

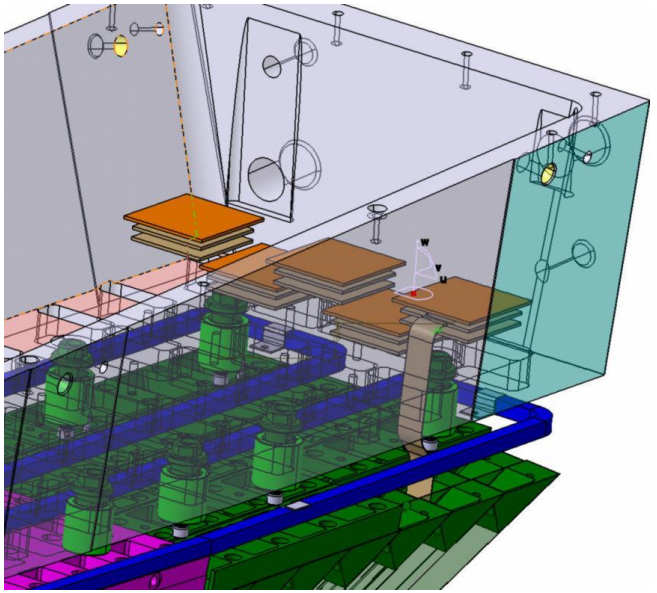
Thermal insulation feet between cooled crystal volume and support beam

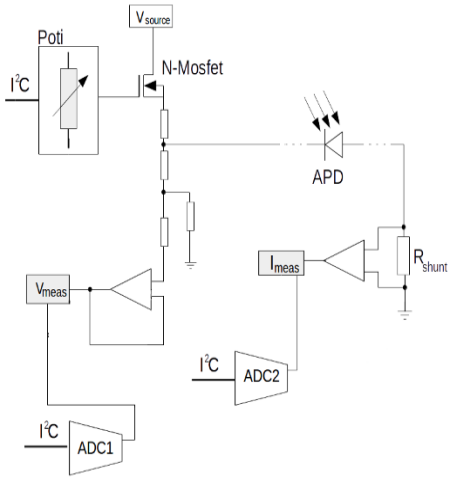
Assembly Procedure - Light Pulser Monitoring -

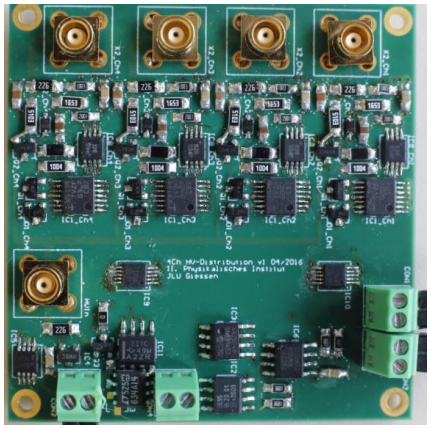


Assembly Procedure - Barrel Backplanes -

- Present design: 3 Layers
  - HV distribution & regulation
    - Adjust bias voltage of 8 APDs
    - 50V from HV input downwards in < 0,1V steps
    - All channels fed from the same HV source
    - Online measurement of APD voltage and current
  - Connector board for ultrathin custom signal cables
  - Board for FlexPCBs / ASICS
    - Connectors to FEs
    - 8x2 Diff. Line drivers
    - APFEL I/F buffers
    - Temp/Humidity sensors



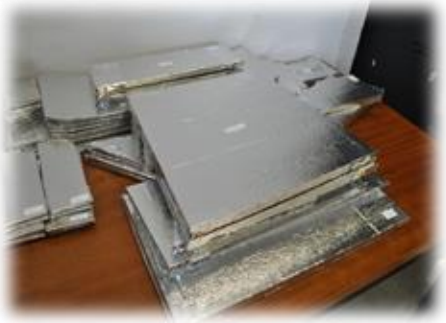


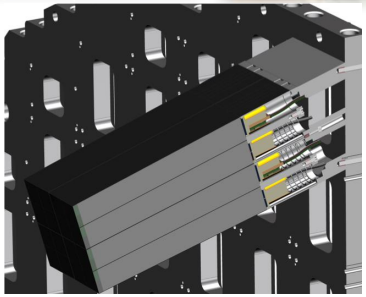


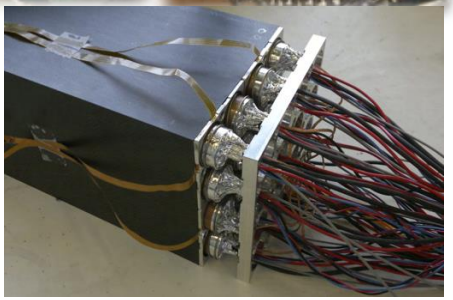
4-ch prototype

Forward Endcap – Mechanics-

- Ready amongst others:
  - Support frame, Mounting plate, stiffener ring, Front & back plate
  - Chillers, pumps & pipes
  - Insulation panels

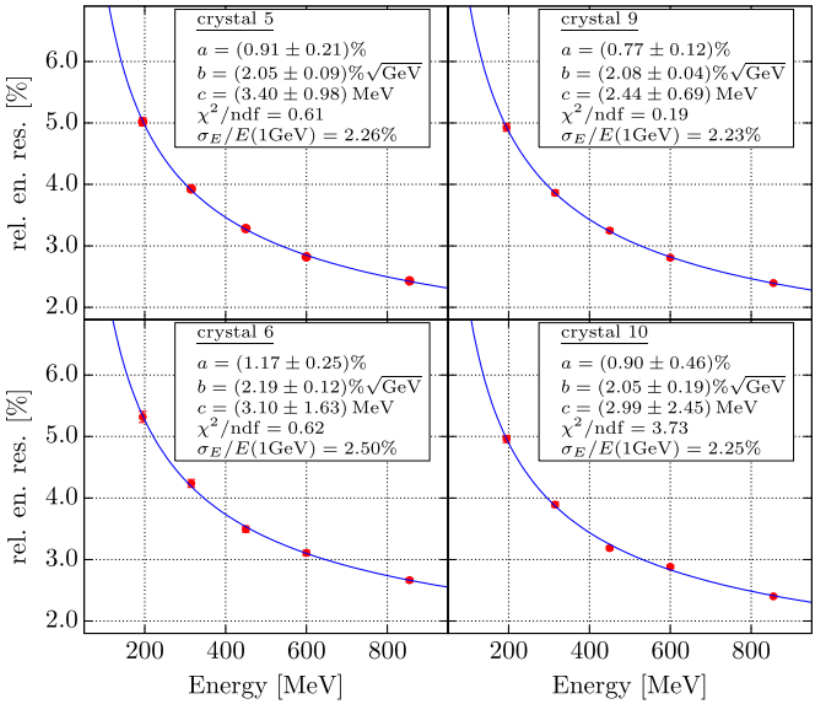


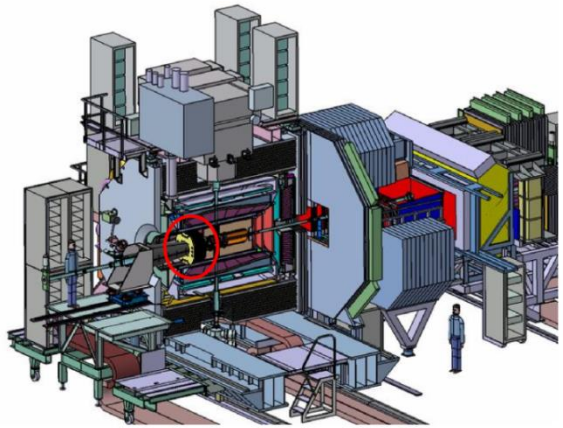


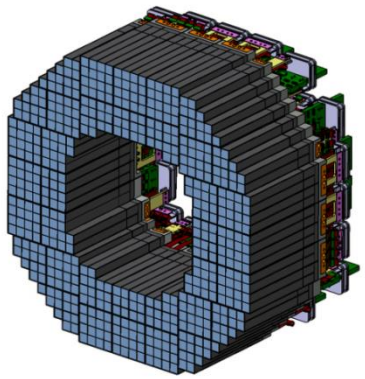


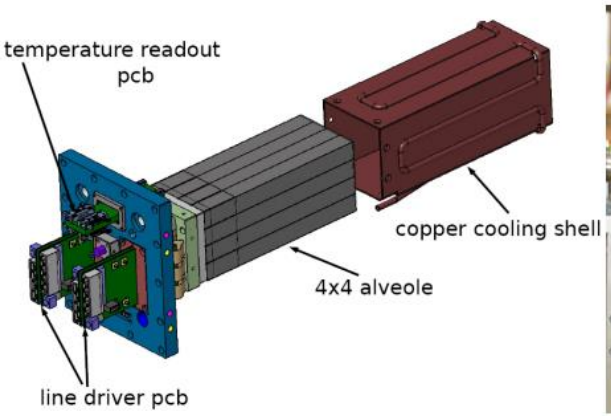
Backward Endcap

- 524 PWO-II crystals
- Readout: APD & ASICS
- Prototypes Studies:









Conclusion & Outlook

- **Crystals:**
  - Crytur produced 200 promising crystals
    - In the beginning some rejection mainly due to rad. hardness
    - All other: already used to build the PANDA detecto

→ **Mass production of the crystals (for the second slice) has started**

- **Barrel:**
  - First slice of the Target Spectrometer Calorimeter is assembled

→ **Mass production of the mechanics will start this year**

- **Forward Endcap:**
  - Workspace & Tools for final assembly ready

→ **Mass production of subunits has been started**

- **Backward Endcap:**
  - New Prototype is used to temporarily upgrade the MAMI electron scattering facility with a calorimeter

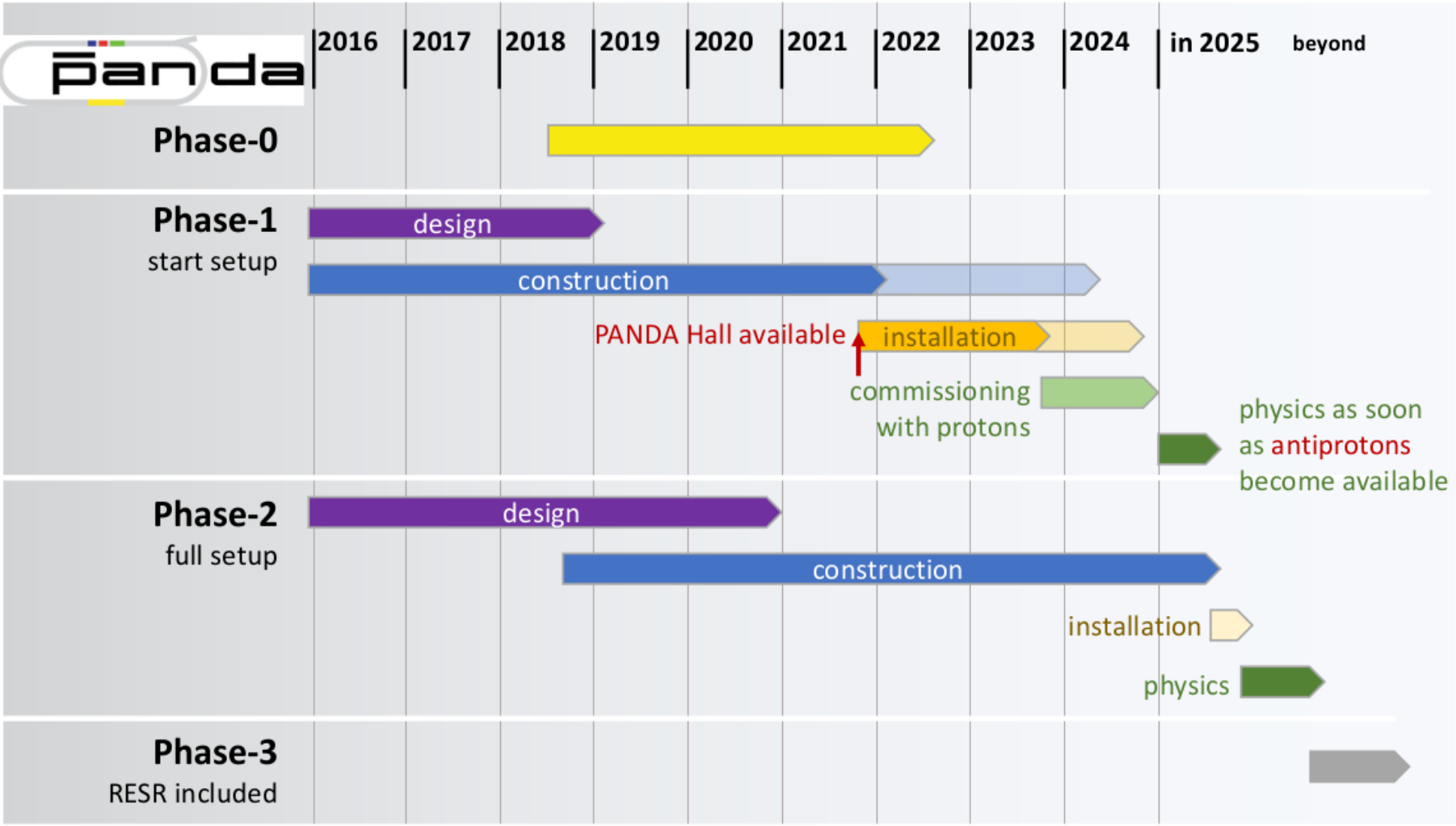
Thank you for your attention

Collaboration

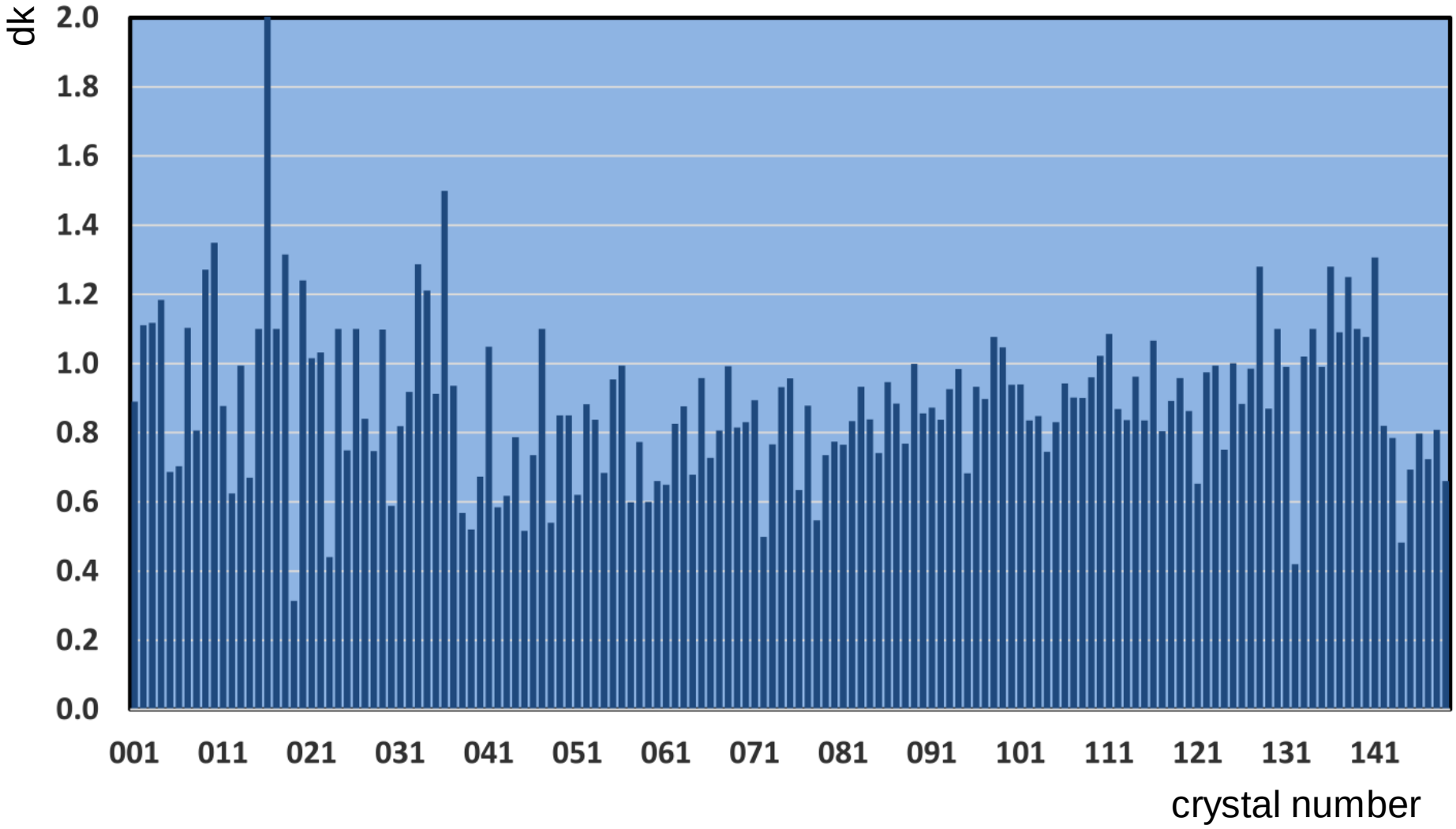
UniVPM Ancona	FIAS Frankfurt	U Mainz	PNPI St. Petersburg
U Basel	U Frankfurt	INP Minsk	West Bohemian U, Pilzen
IHEP Beijing	LNF-INFN Frascati	ITEP Moscow	KTH Stockholm
U Bochum	U & INFN Genova	MPEI Moscow	U Stockholm
U Bonn	U Gießen	BARC Mumbai	SUT, Nakhon Ratchasima
U Brescia	U Glasgow	U Münster	SVNIT Surat-Gujarat
IFIN-HH Bucharest	BITS Pilani KKBGC, Goa	Nankai U	S Gujarat U, Surat-Gujarat
AGH UST Cracow	KVI Groningen	BINP Novosibirsk	FSU Tallahassee
IFJ PAN Cracow	Sadar Patel U, Gujart	Novosibirsk State U	U & INFN Torino
JU Cracow	Gauhati U, Guwahati	IPN Orsay	Politecnico di Torino
U Cracow	USTC Hefei	U Wisconsin, Oshkosh	U & INFN Trieste
FAIR Darmstadt	URZ Heidelberg	U & INFN Pavia	U Uppsala
GSI Darmstadt	FH Iserlohn	Charles U, Prague	U Valencia
JINR Dubna	FZ Jülich	Czech TU, Prague	SMI Vienna
U Edinburgh	IMP Lanzhou	IHEP Protvino	U Visva-Bharati
U Erlangen	INFN Legnaro	Irfu Saclay	SINS Warsaw
NWU Evanston	U Lund	U of Sidney	
U & INFN Ferrara	HI Mainz		

more than 460 physicists from
from 75 institutions in 19 countries

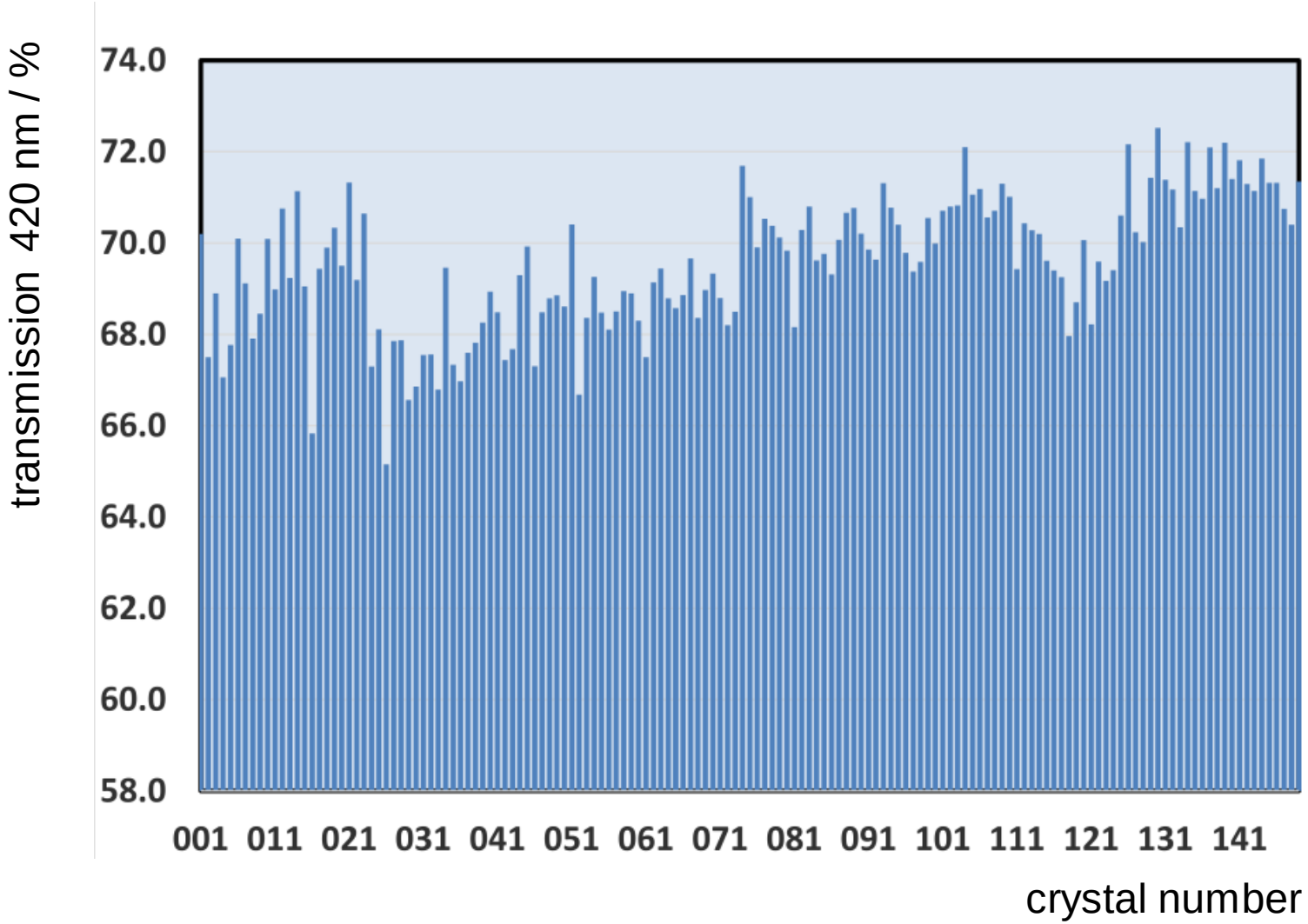
-BACKUP SLIDES-


2016
2017
2018
2019
2020
2021
2022
2023
2024
in 2025
beyond
Phase-0
Phase-1
start setup
design
construction
PANDA Hall available
installation
commissioning
with protons
physics as soon
as antiprotons
become available
Phase-2
full setup
design
construction
installation
physics
Phase-3
RESR included

PANDA Target Calorimeter - Scintillatormaterial -

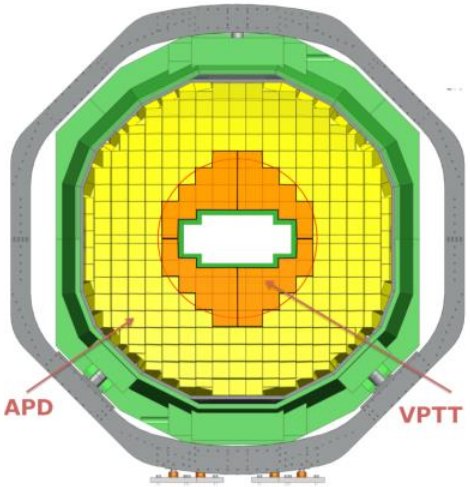


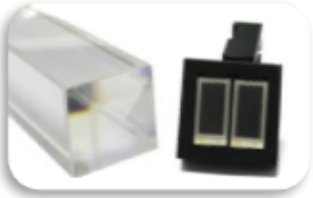
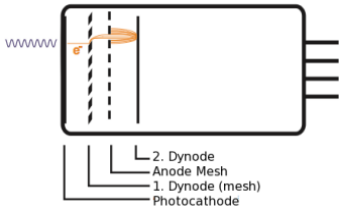
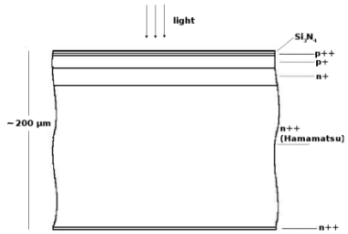
Scintillatormaterial – Optical Transmission -



PANDA Target Calorimeter – Readout-

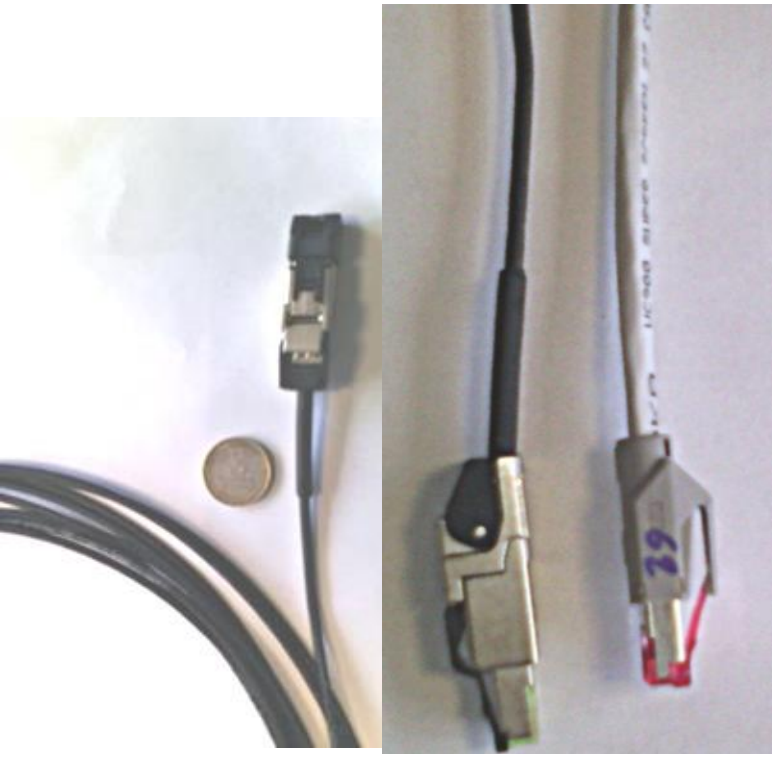
- Barrel & Backward End Cap: LAAPDs
- Forward End Cap
  - Outside: LAAPDs
  - Inside: VPTTs
    - Very high count rates
    - Only 1.05 T

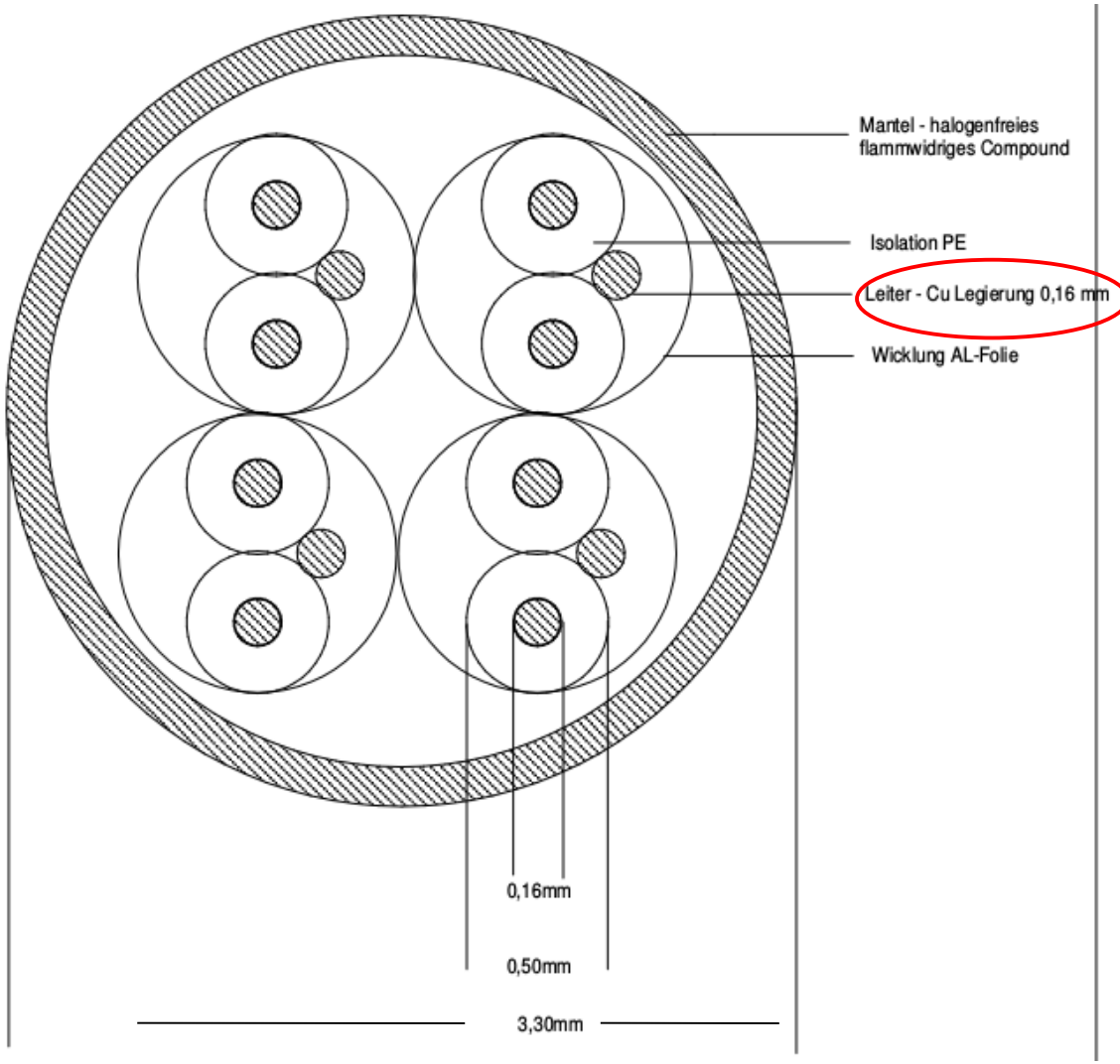


	VPTT	LAAPD
		
		
QE / %	23	80
active area / mm^2	200	95.2
dark current / nA	<1	<40
gain	50	150-200
capacity / pF	22	270

Barrel Routing –Signal Cables-

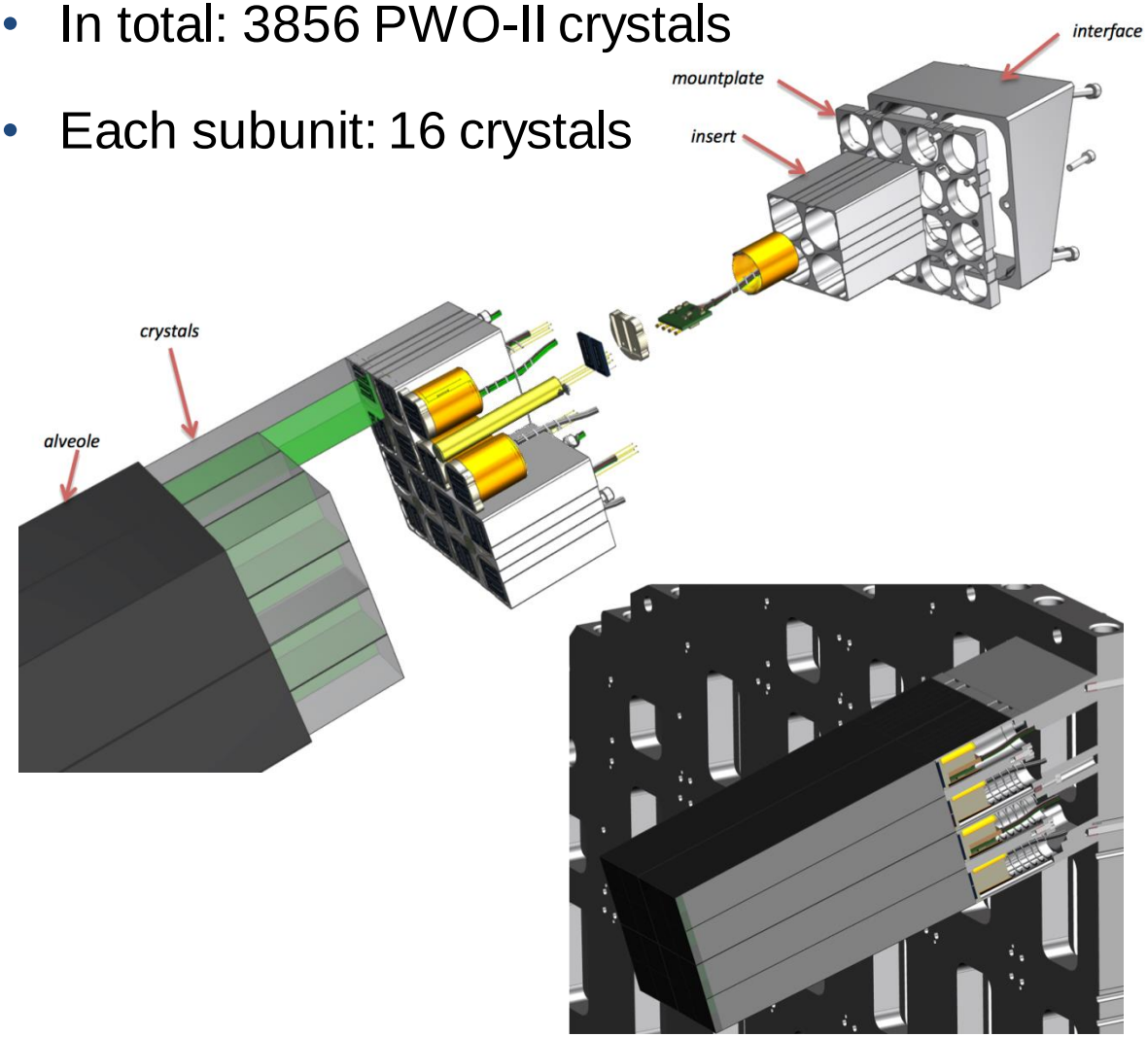
Special Ultra-thin differential cables developed in corporation with company BEDEA (Germany)



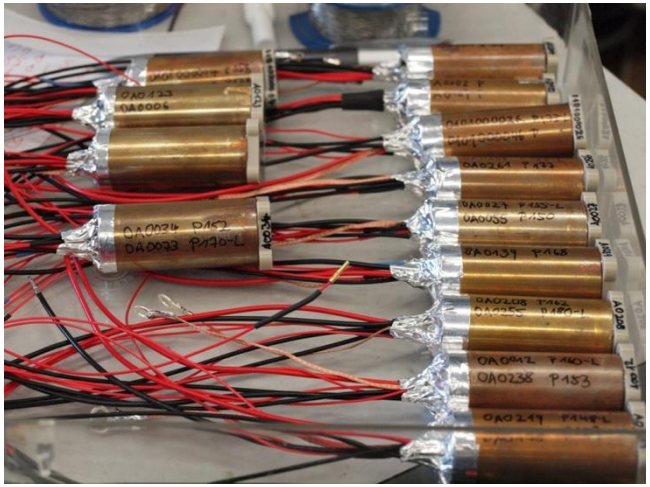


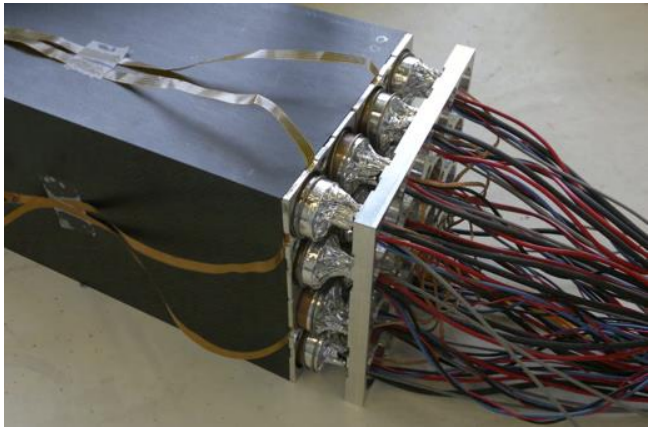
Forward Endcap – Subunits-

- In total: 3856 PWO-II crystals
- Each subunit: 16 crystals

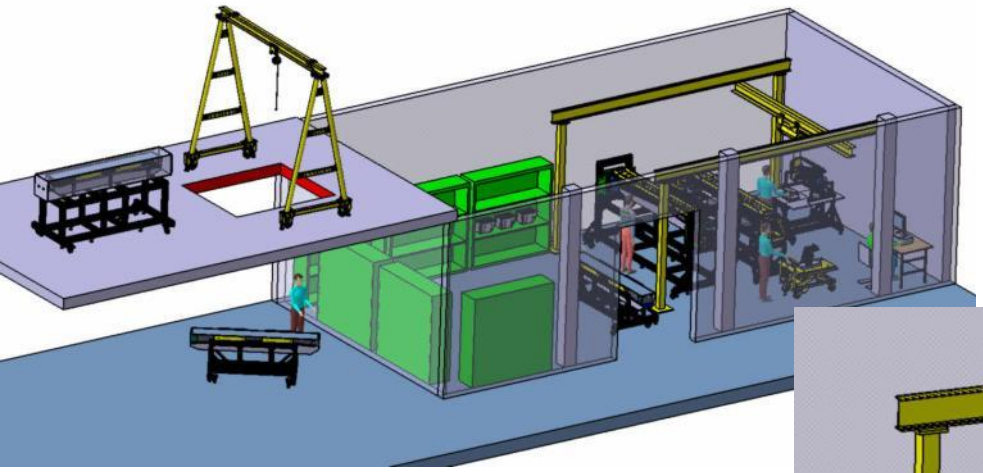


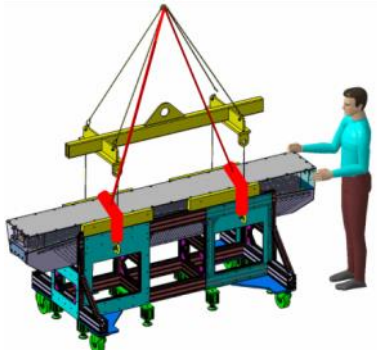
Preamps inside shielding





Assembly Procedure - Supermodules & Slice -





transportation & lifting unit

Slice test turning device

Slice assembly

Supermodule assembly