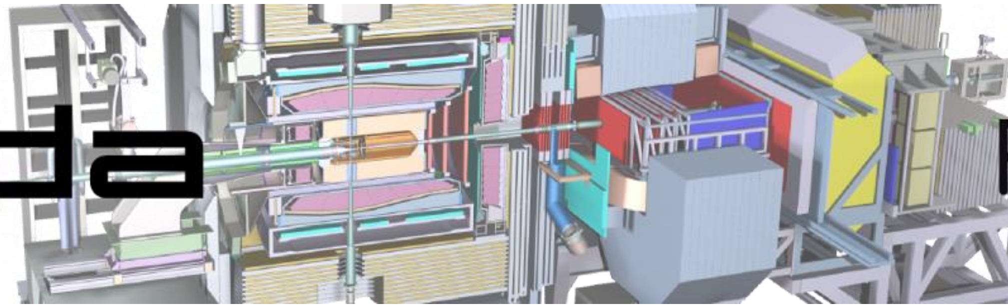
The Electromagnetic Calorimeter for the PANDA Target Spectrometer

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN



GSI

Federal Ministry of Education and Research

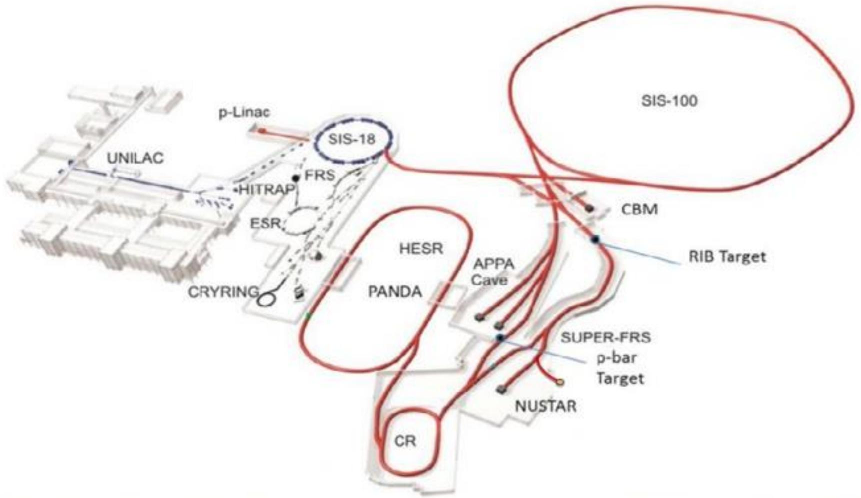
HIC for FAIR
Helmholtz International Center

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

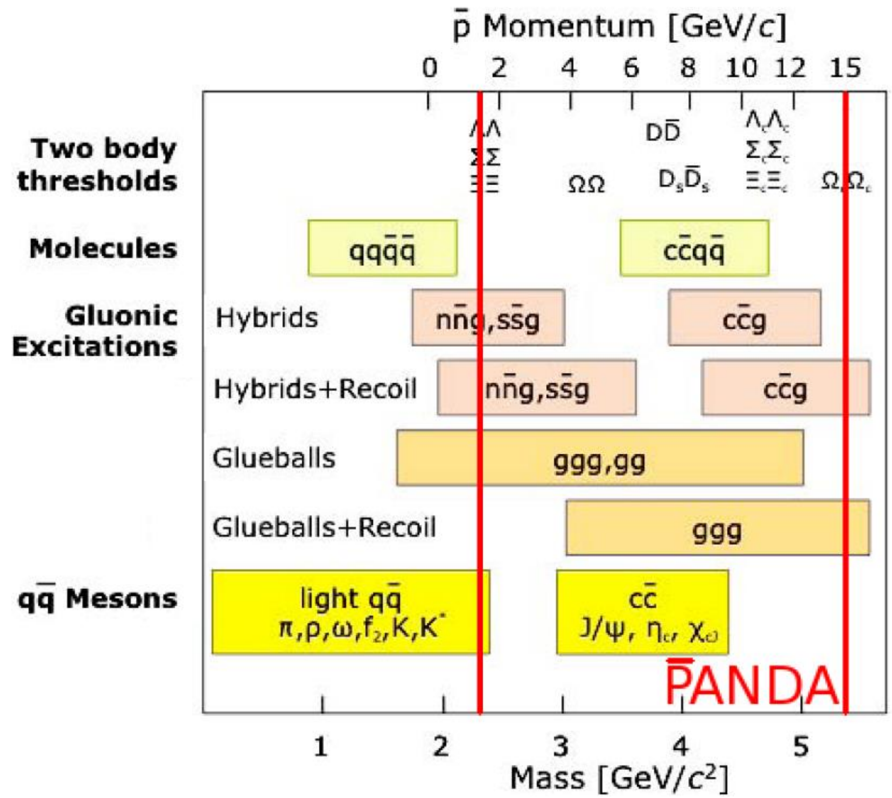
CALOR 2018

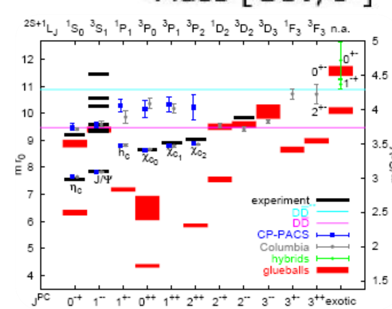

FAIR
2018-05-11 14:45 CET
www.fair-center.eu

- 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 and electron 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



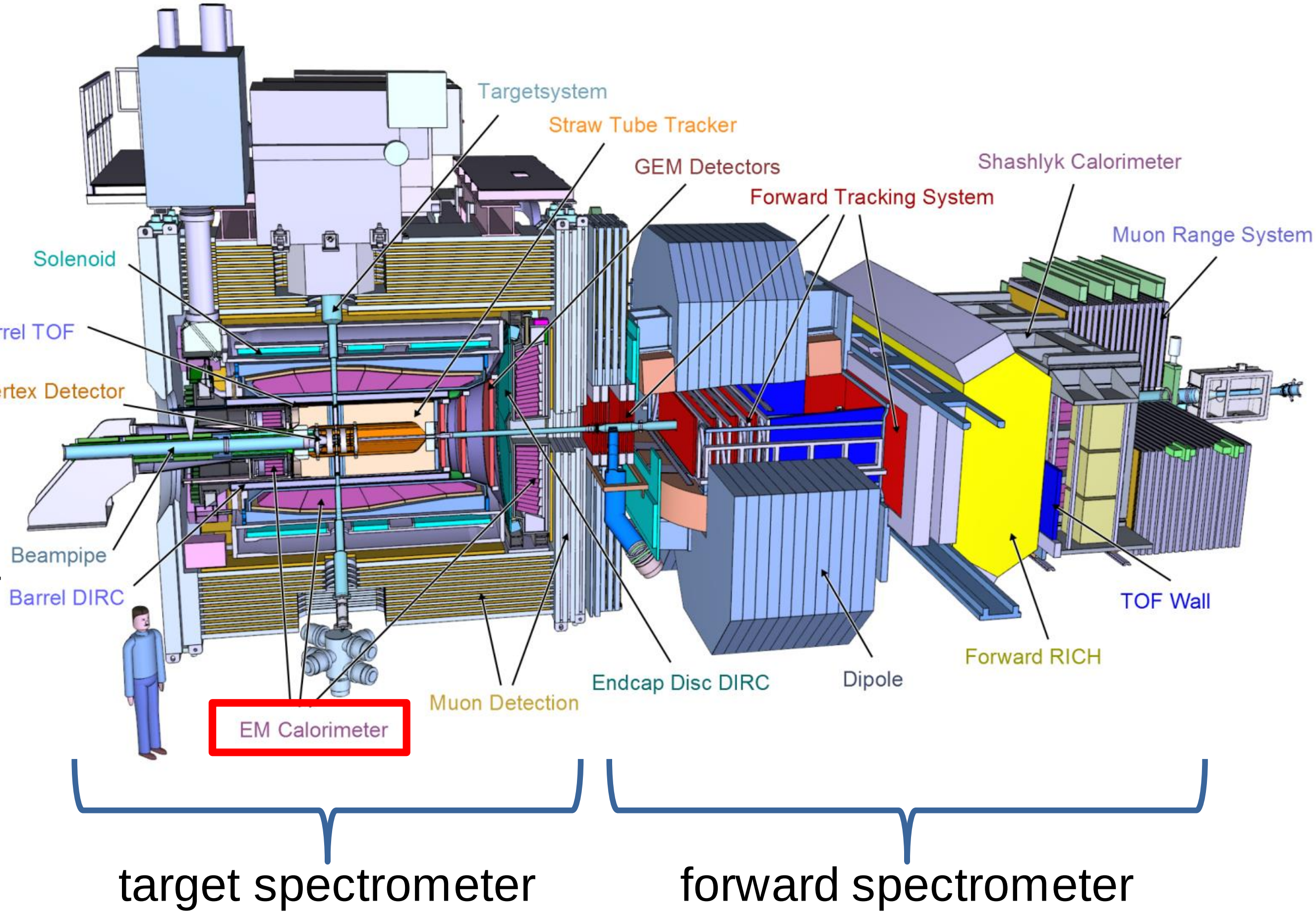
- Physics program of PANDA:
  - Charmonium spectroscopy
  - Gluonic excitations
  - In-medium effects of hadronic particles
  - Open-charm spectroscopy
  - Hypernuclei
  - Electromagnetic processes





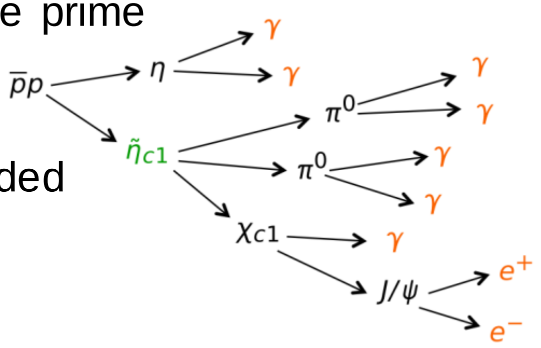
PANDA Setup

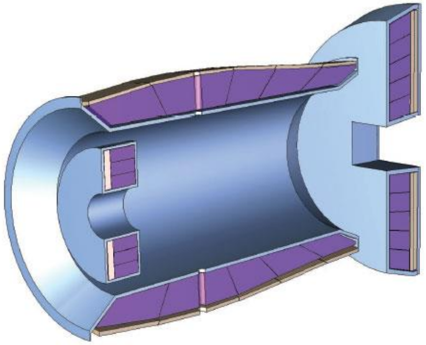
- Cooled antiproton beams between 1.5 GeV/c and 15 GeV/c
- Fixed target experiment
  - Hydrogen and other
- High luminosity
  10^{32} cm^{-2}s^{-1}
- Magnets
  - Forward 2 Tm dipole
  - Interaction region 2 T

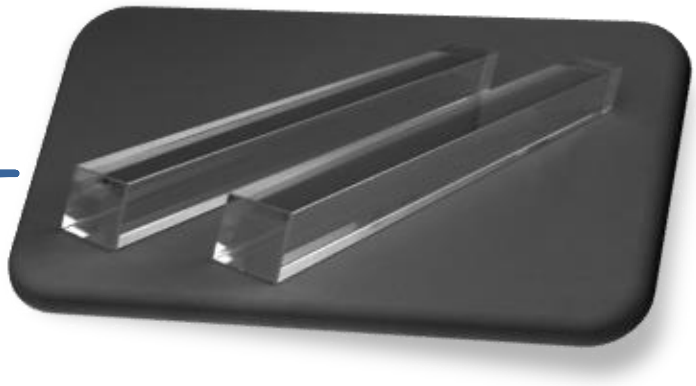


PANDA Target Calorimeter - Main Requirements -

- 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



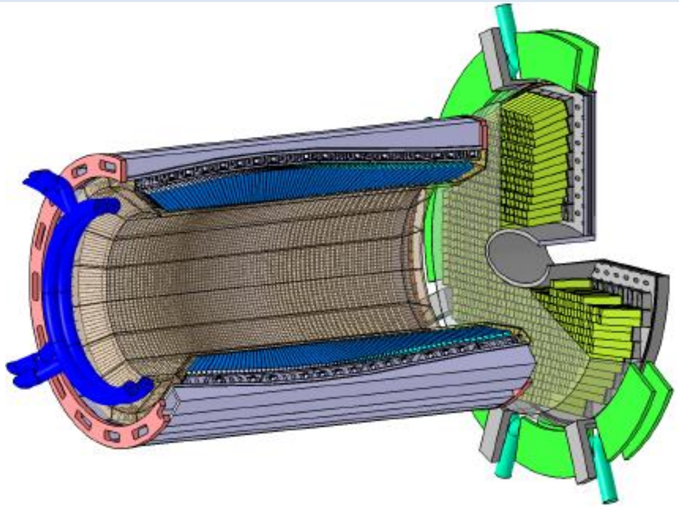




PWO-II

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

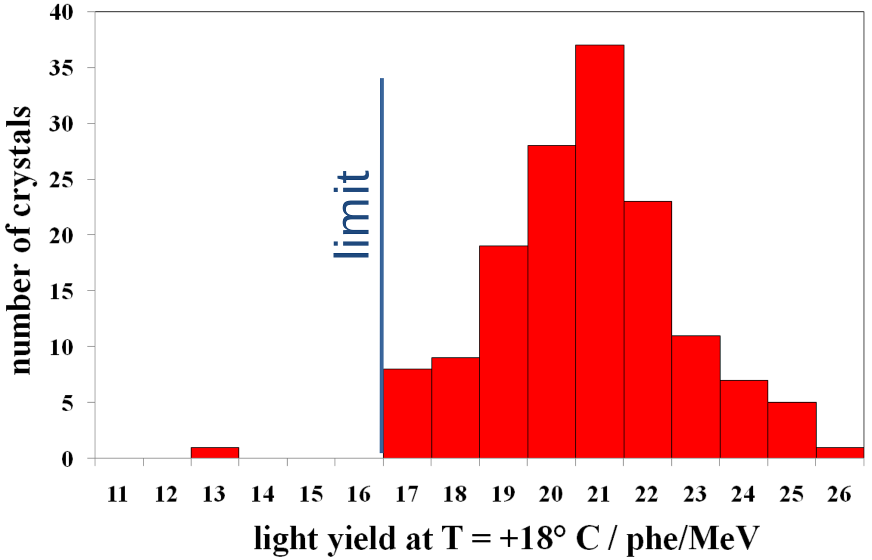
← increases LY ~4x further

PANDA Target Calorimeter - Scintillator Material -

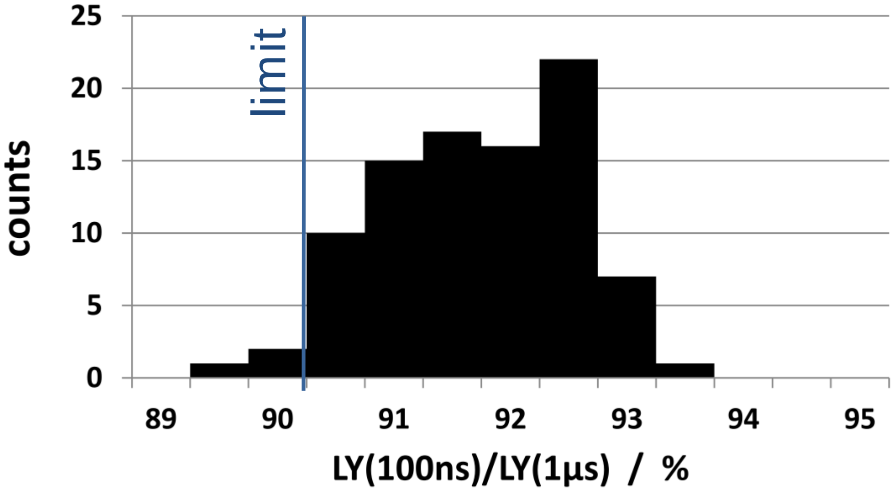
- Main part produced at BCTP (**B**ogoroditsk Plant of **T**echno**c**hemical **P**roducts, Russia)
- Missing 41% of the crystals will be produced at Crytur (Czech Republic)
  - Up to now: 150 preproduction PWO-II crystals in PANDA geometry
    - All crystals have been tested at the facilities at Giessen 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 -

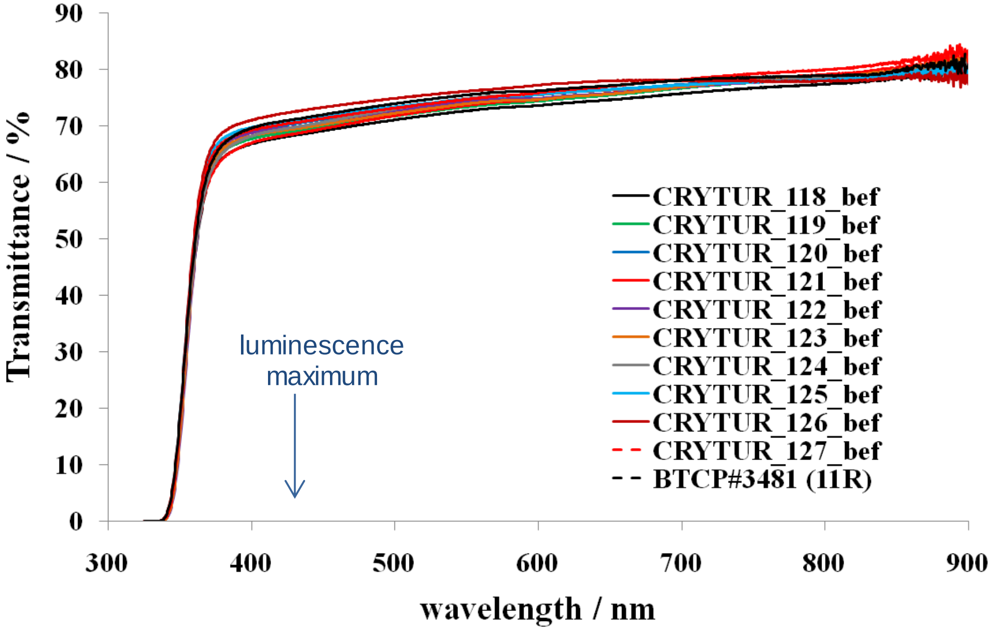
$$LY\left(\frac{phe}{MeV}\right) = \frac{\text{photo peak}}{\text{single } e^{-} \text{peak} \cdot \text{energy}}$$

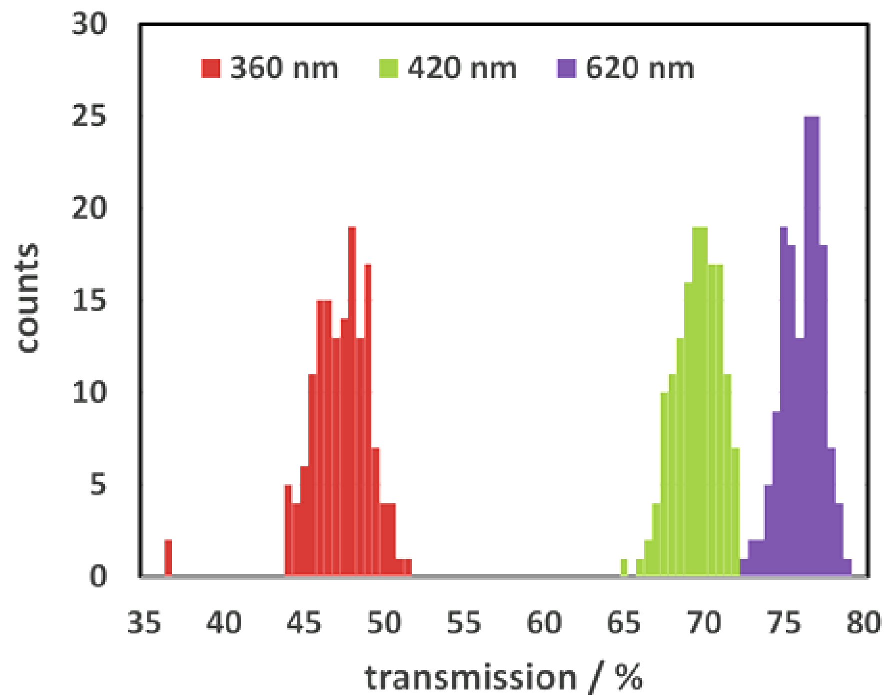


- Almost all preproduction crystals pass the requested spec. limits :
  - LY@18°C > 16 phe/ MeV
  - LY(100ns)/LY(1µs) > 0.9



Scintillator Material - Optical Transmission -





Measured along full length:

- No color centers visible
- Stable absorption edge

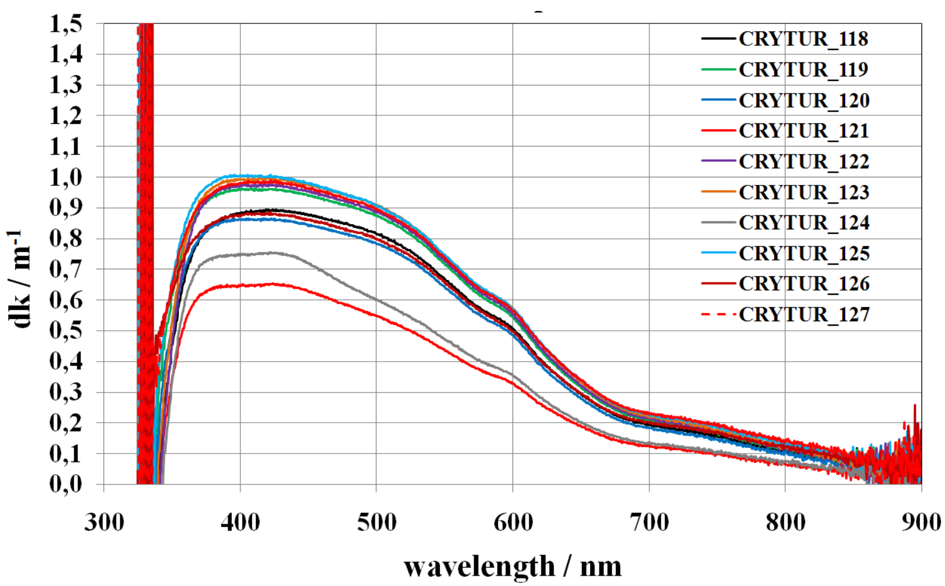
PANDA specification limits:

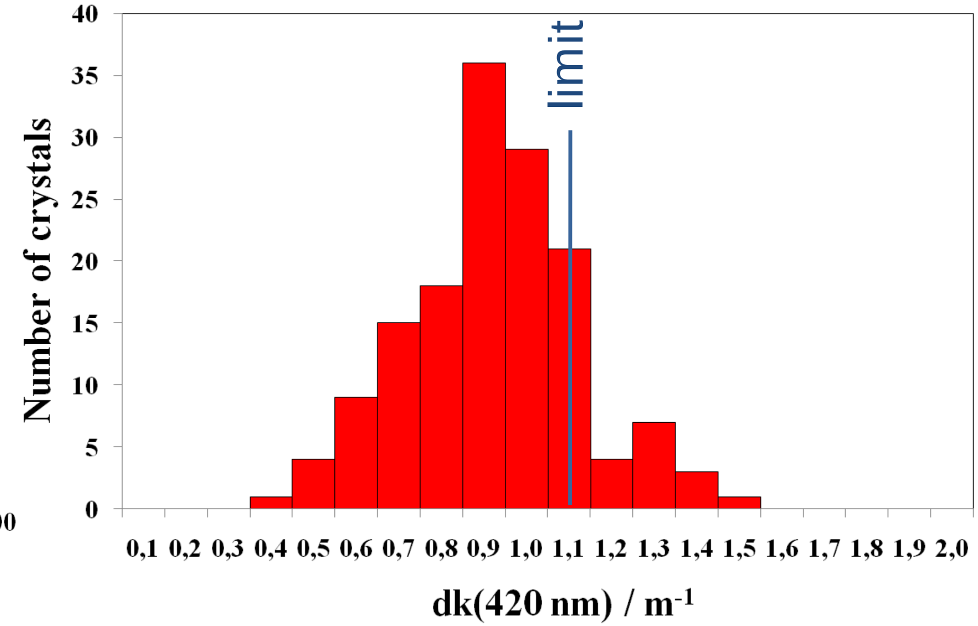
- T @ 620 nm > 70 %
- T @ 420 nm > 60 %
- T @ 360 nm > 35 %

- 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 $\mathbf{I(x) = I_0 \cdot e^{-kx}}$
- $\Delta k = k_{\text{after rad.}} - k_{\text{before rad.}}$

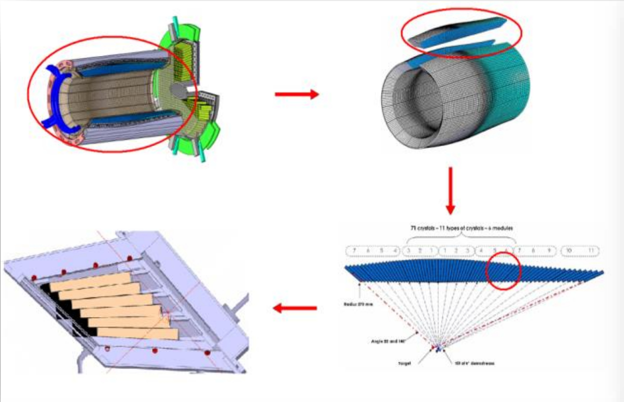
PANDA specification:

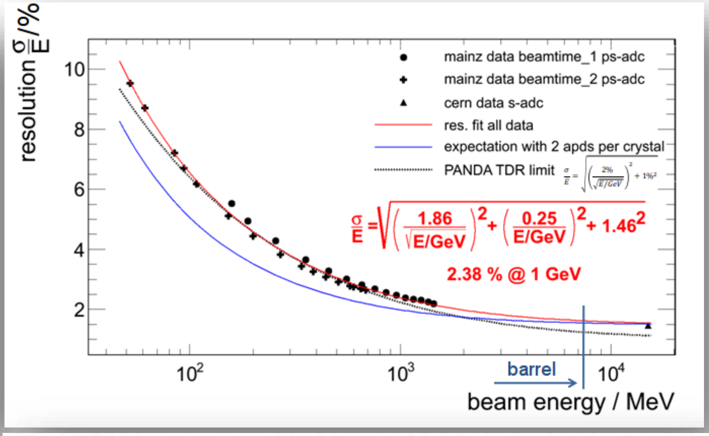
- $\Delta k \leq 1.1\ m^{-1}$ (room temp. & 30 Gy)

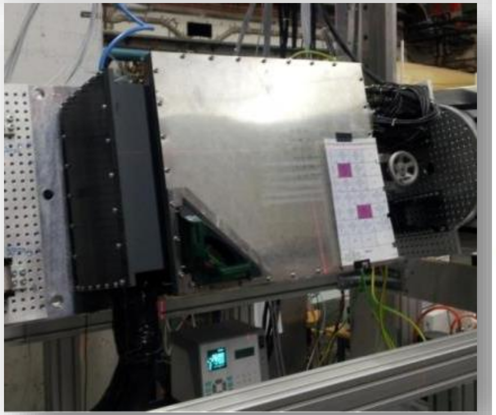


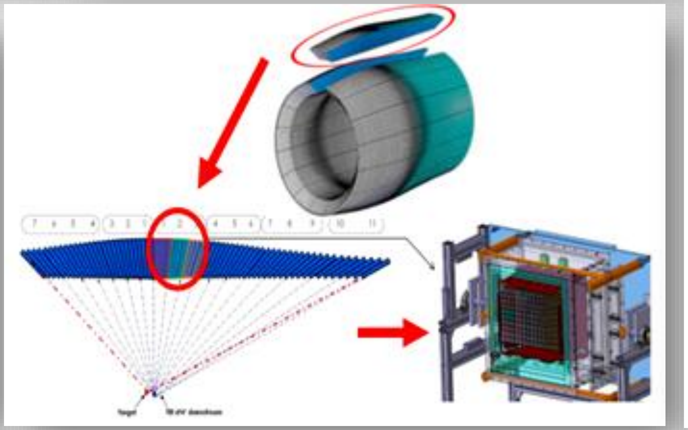


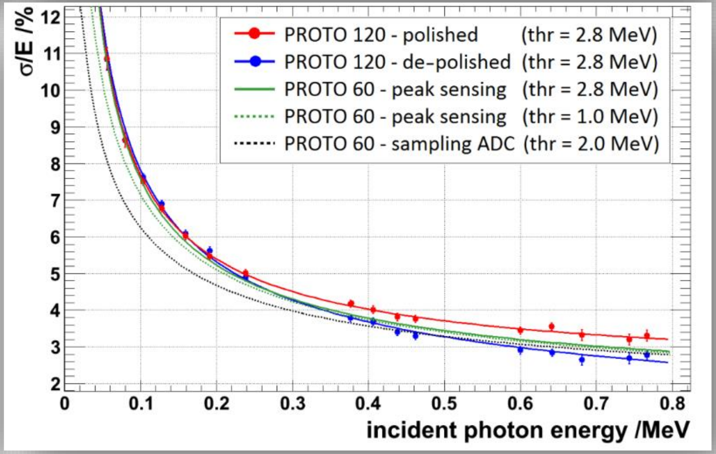
Prototype Tests









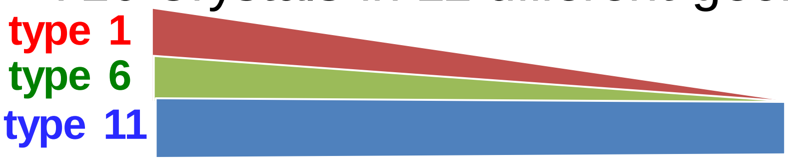


Objectives reached, especially at low energies

1st Full Barrel EMC Slice - Some Milestones -

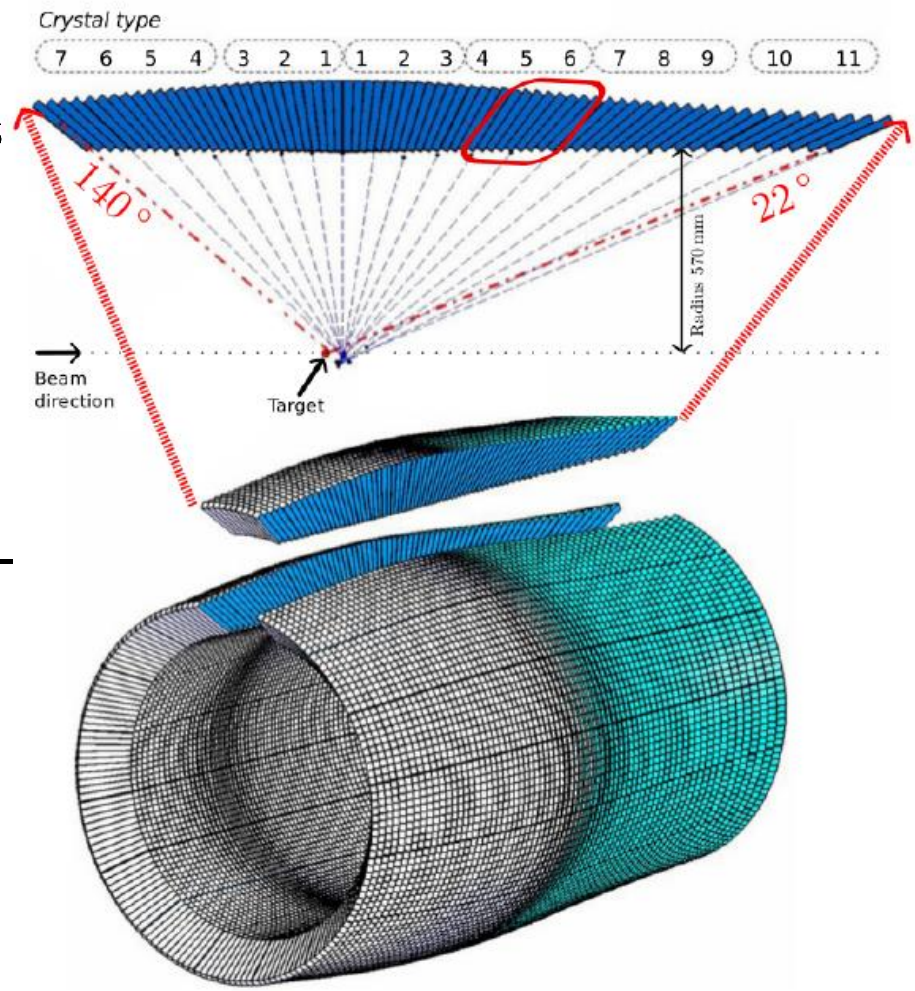
Assembly of:

- 710 Crystals in 11 different geometries



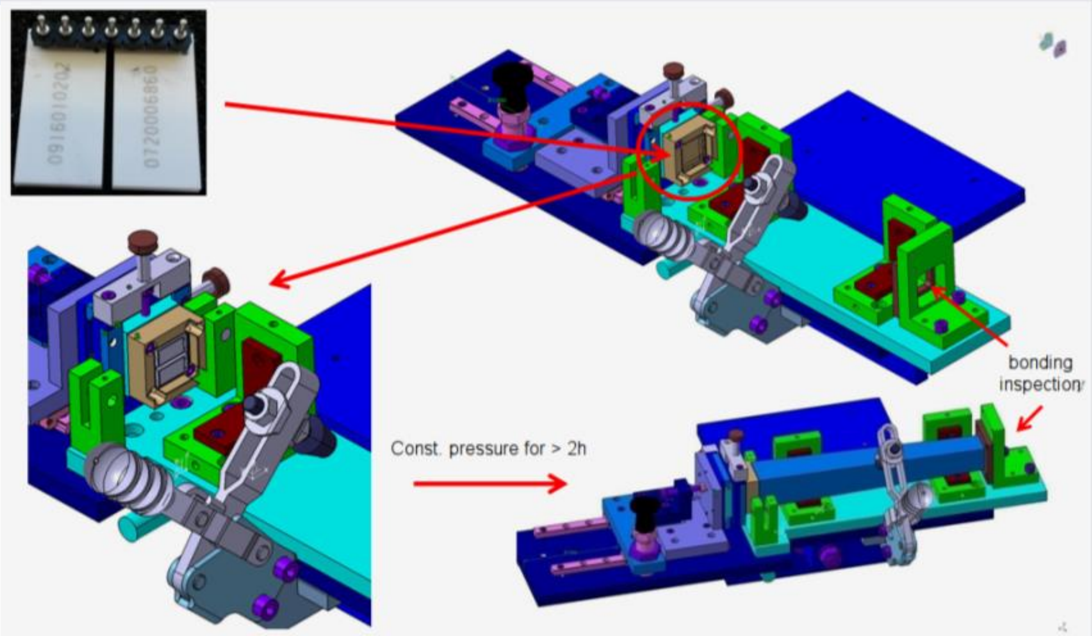
- 1420 matched APDs after 1st screening, gamma irradiation, 2nd screening.
- 360 left- and 360 right-handed APFEL-ASIC flex PCBs
- 178x3 Backplanes for
  - HV distribution and individual adjustments
  - Connection of signal cables, slow control…

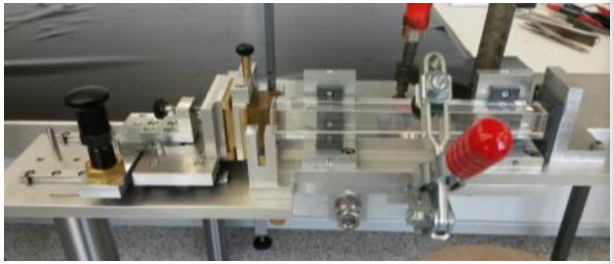
More than 4500 m of signal cables.

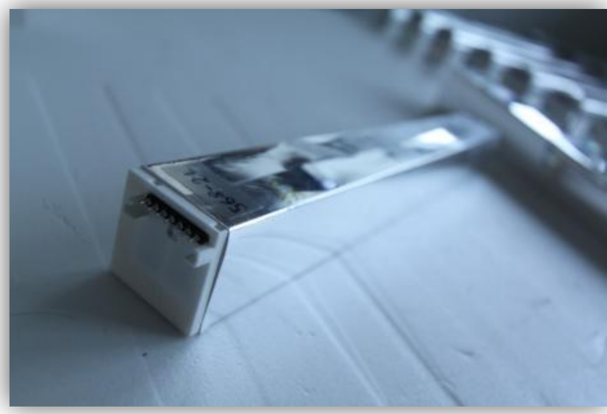


Assembly Procedure - Detector Preparations

- 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

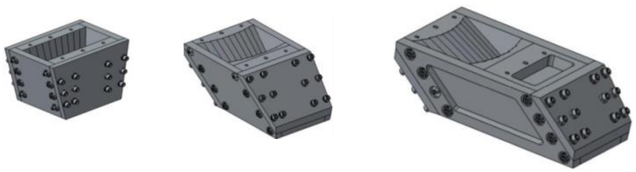




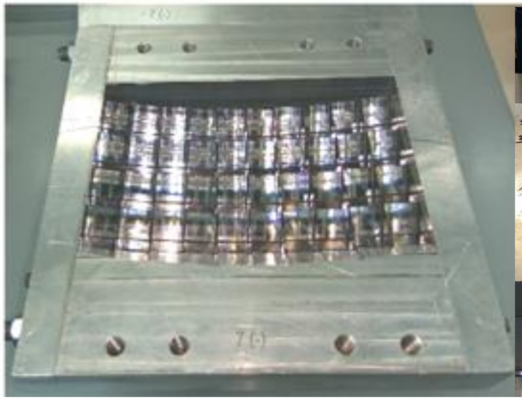


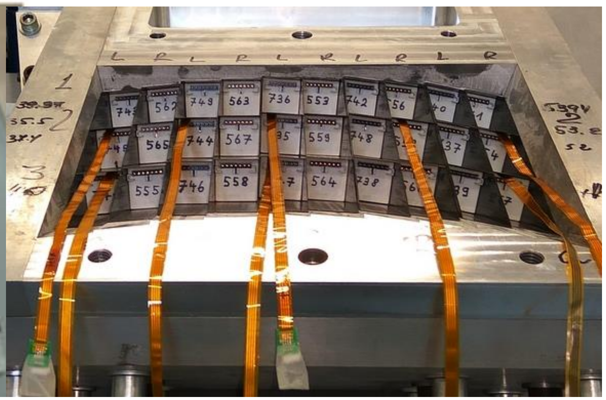
Assembly Procedure - Modules & Temperature Monitoring -

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

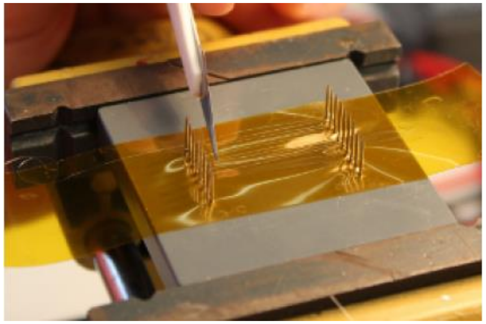


- PWO-II ΔLY/°C = 3 %
  - Precise temperature monitoring of whole cooled volume necessary
  - TDR ΔT < 0.1 °C
  - Special ultrathin temperature sensors developed
    - Thickness < 160 µm

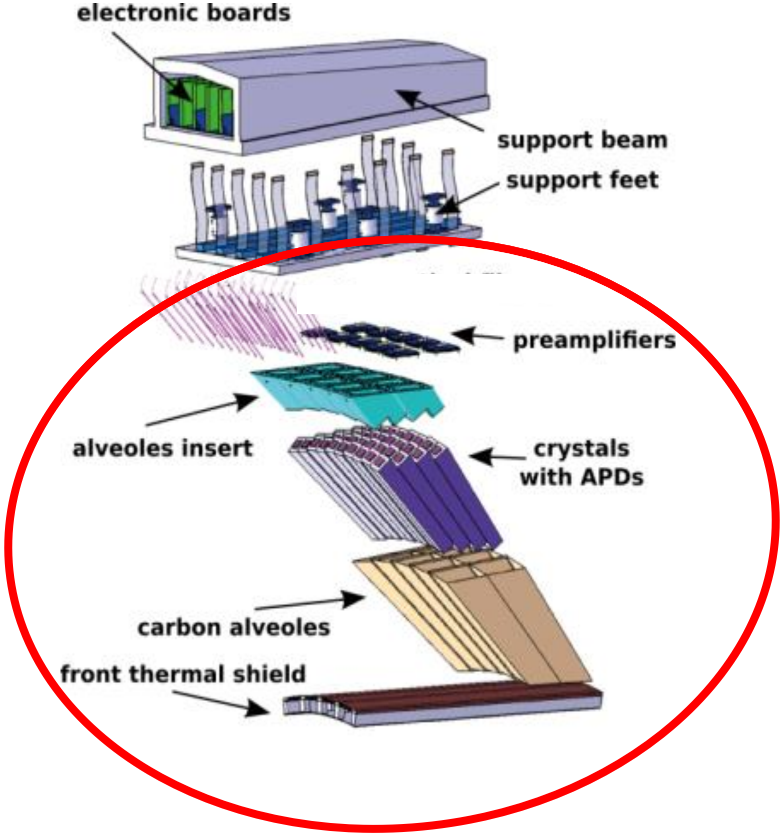


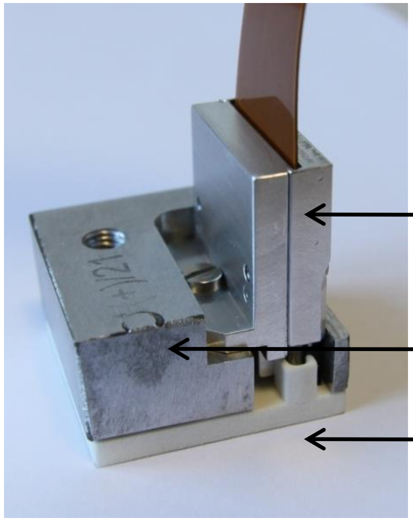


Temp. sensors distributed between crystals



Assembly Procedure - Modules Readout -



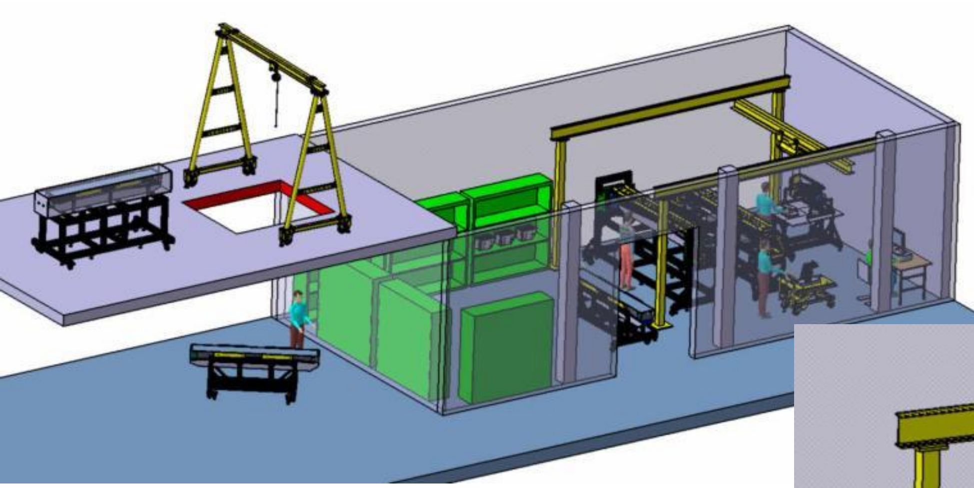


ASIC

insert will be glued to carbon alveole

APD capsule

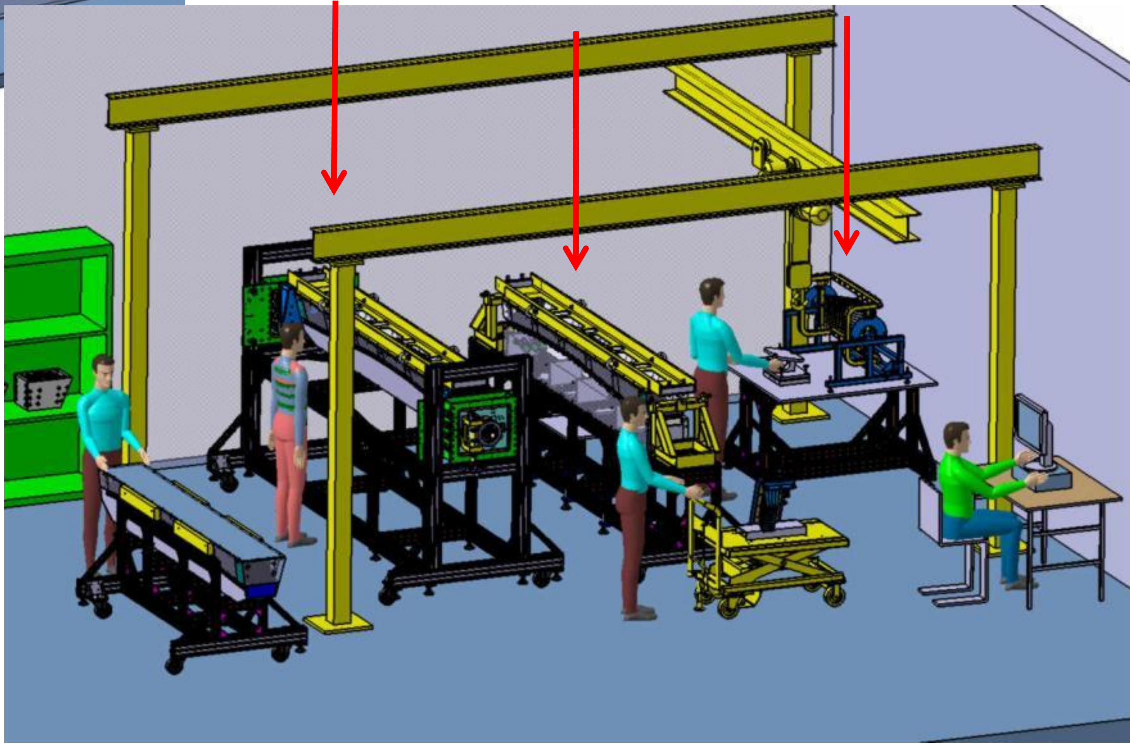
Assembly Procedure - Supermodules & Slice -

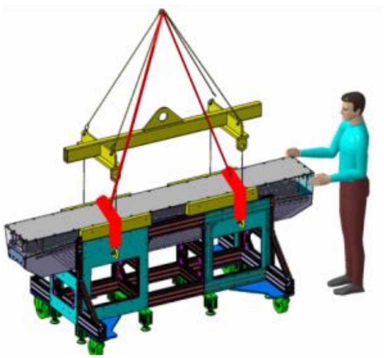


Slice test turning device

Slice assembly

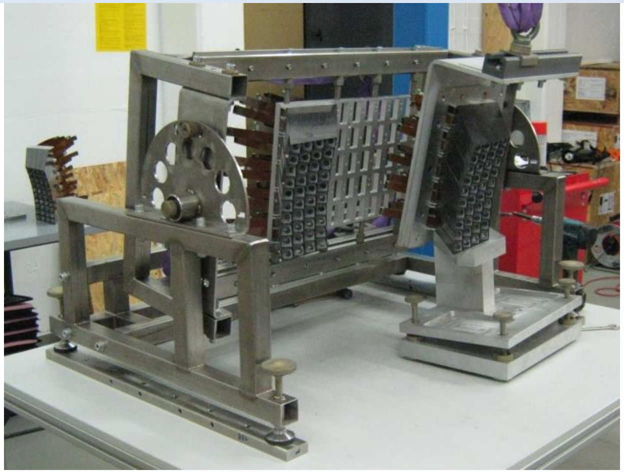
Supermodule assembly

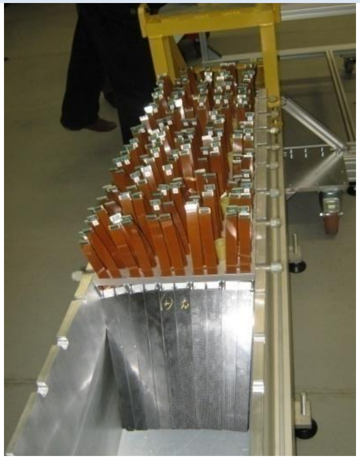


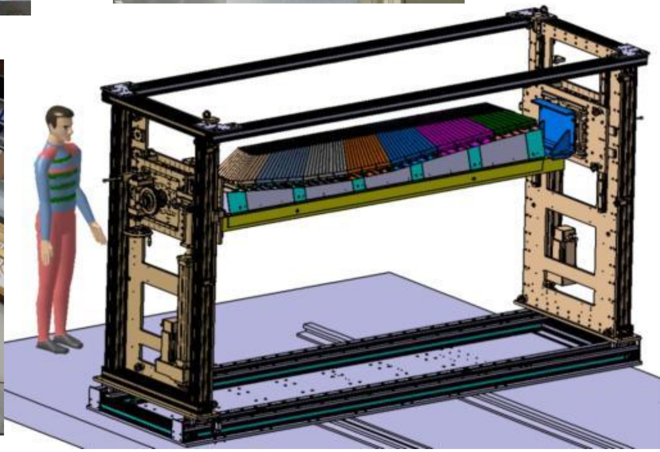


transportation & lifting unit

Assembly Procedure - Supermodules & Slice -



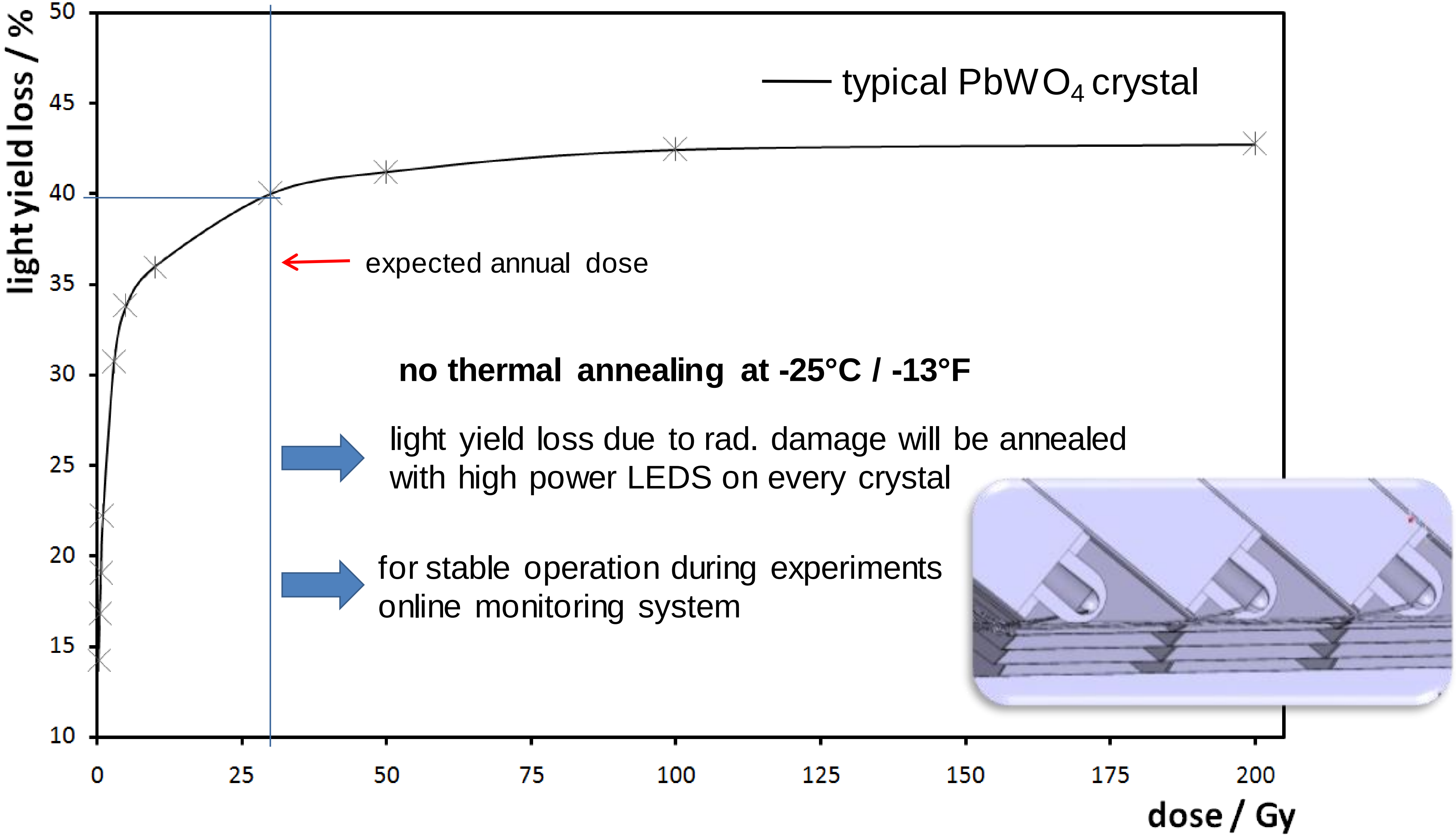



Backplanes will sit inside support beam

Thermal insulation feet between cooled crystal volume and support beam

Assembly Procedure - Light Pulser Monitoring -

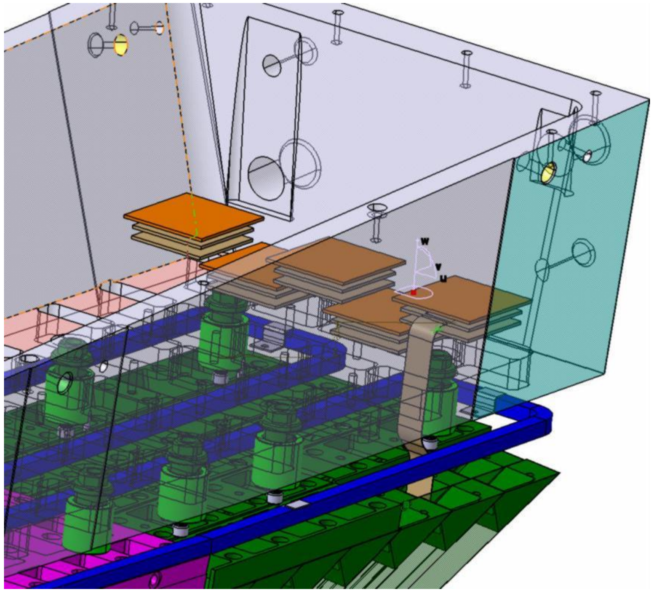


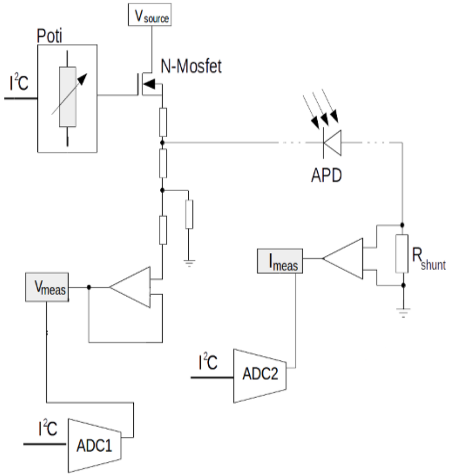
no thermal annealing at -25°C / -13°F

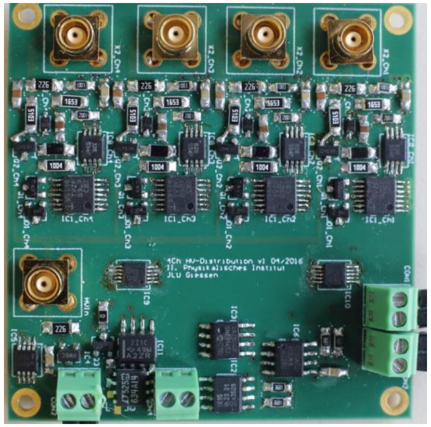
- light yield loss due to rad. damage will be annealed with high power LEDS on every crystal
- for stable operation during experiments online monitoring system

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

- **Crystals:**
  - Crytur produced 150 promising preproduction crystals
    - In the beginning some rejection mainly due to rad. hardness
    - All other: already used to build the PANDA detector

→ **Mass production of the crystals (for the second slice) will start this year**

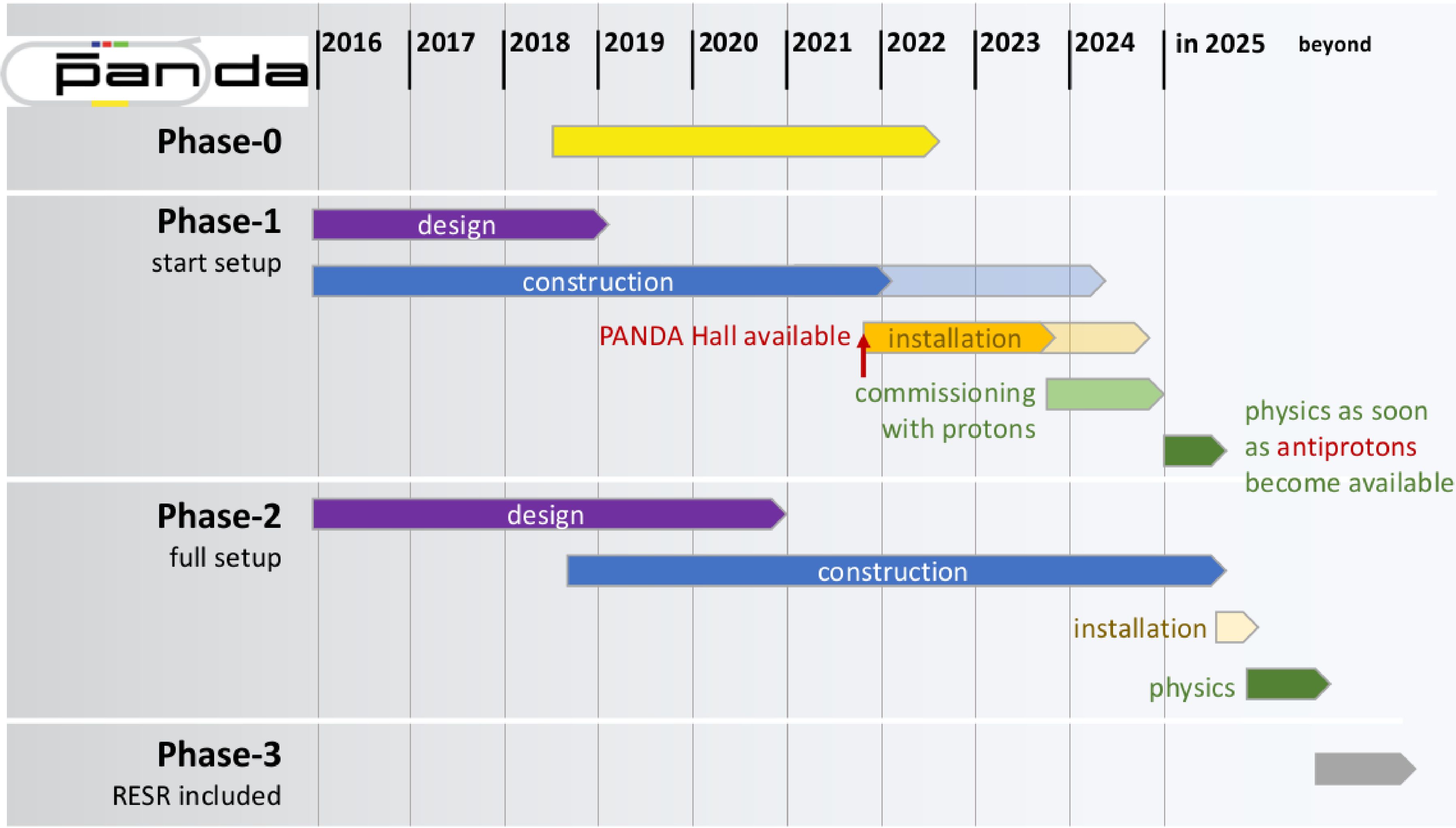
- **Barrel:**
  - **First slice of the Target Spectrometer Calorimeter is assembled**

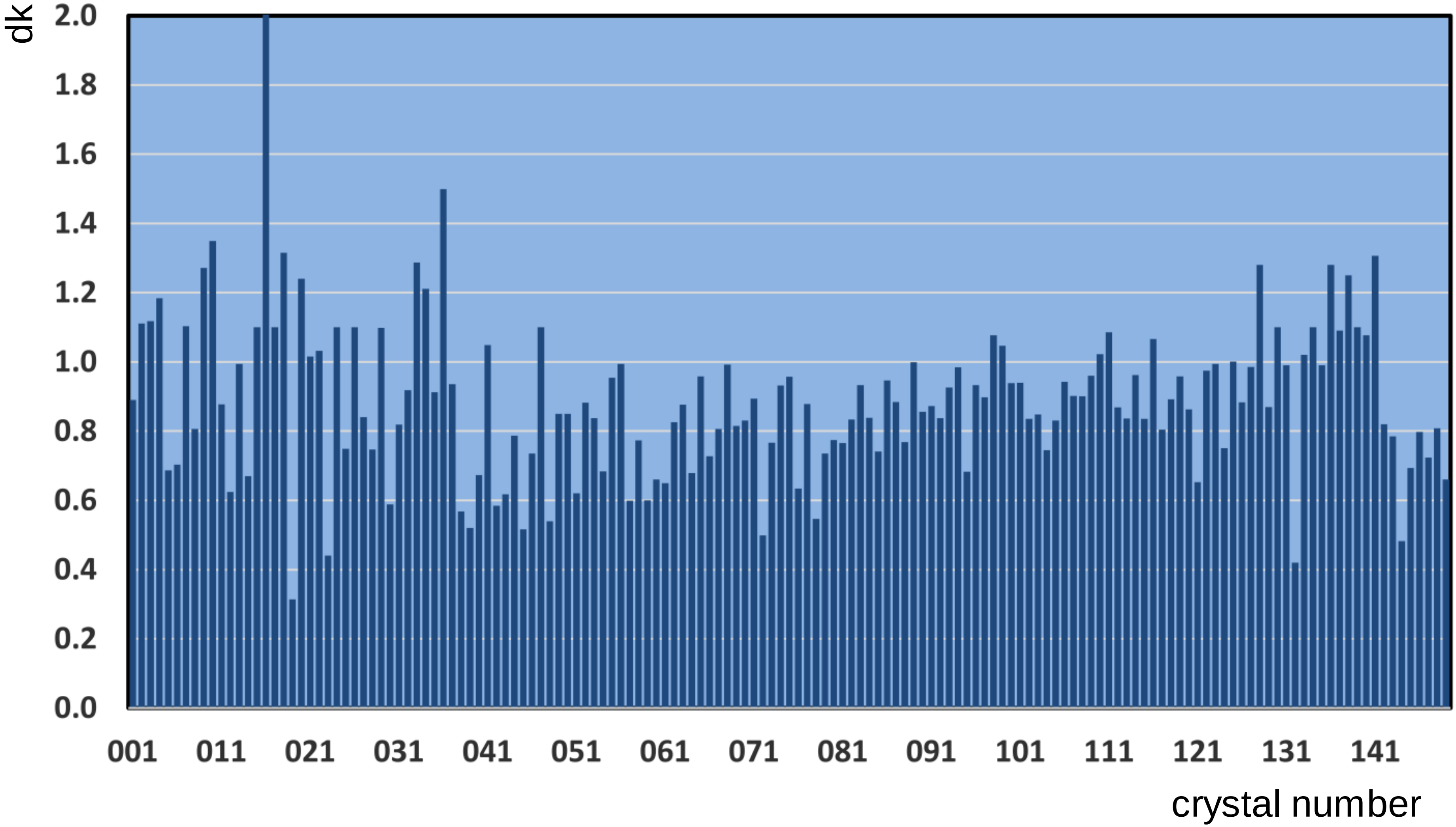
→ **Mass production of the mechanics will start this year**

Thank you for your attention

-BACKUP SLIDES-

PANDA Target Calorimeter




dk
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
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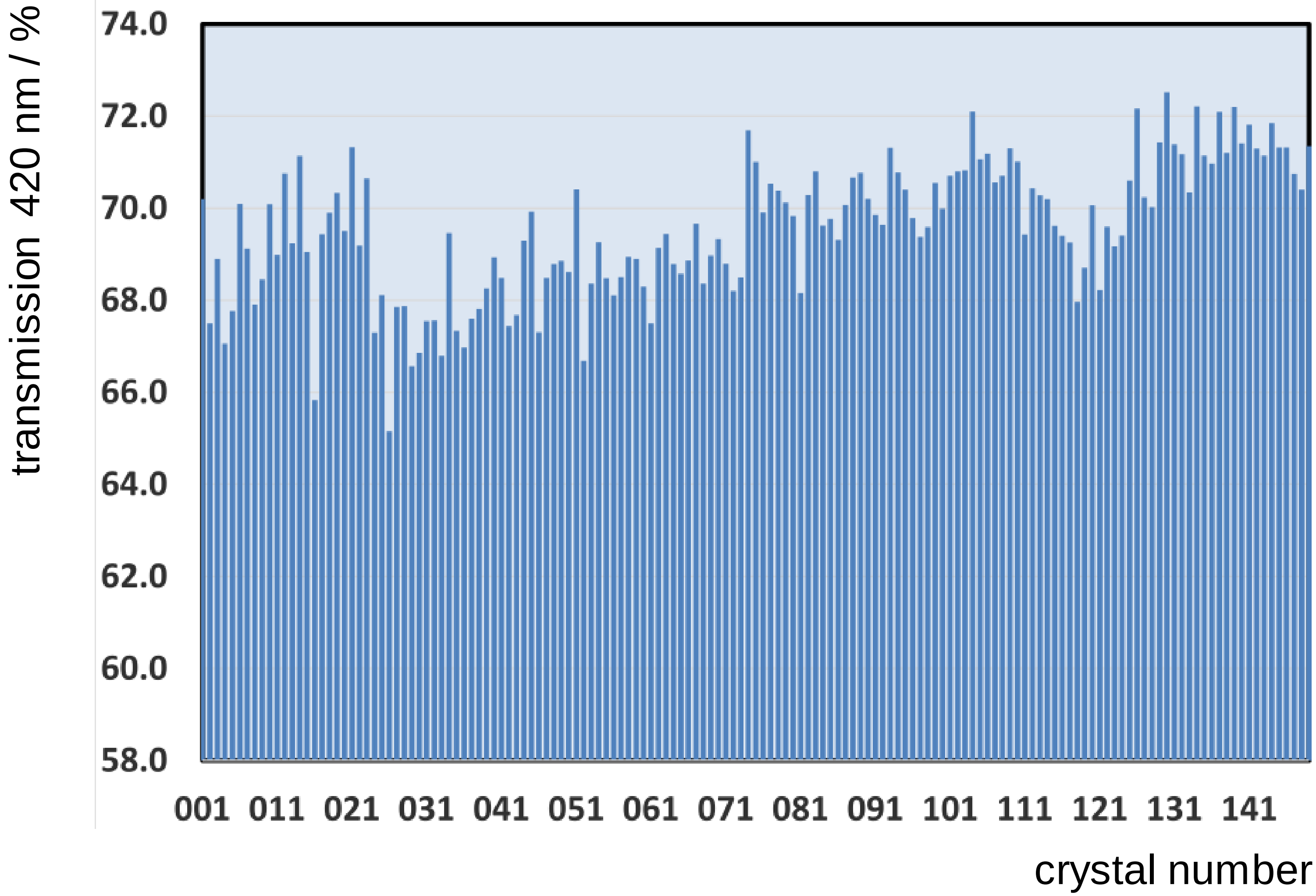
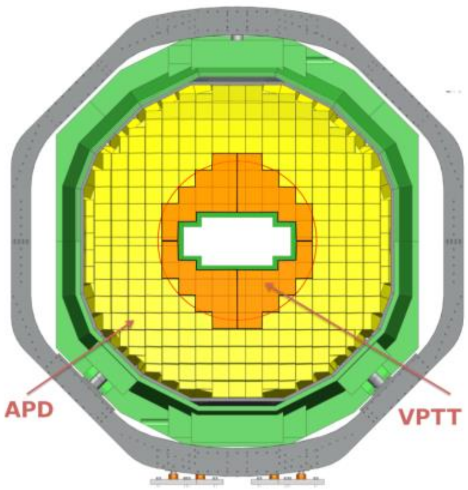
001
011
021
031
041
051
061
071
081
091
101
111
121
131
141
crystal number

Scintillatormaterial – Optical Transmission -

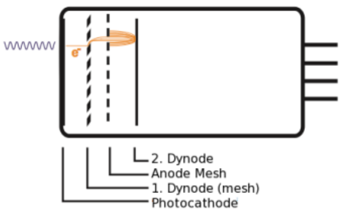


PANDA Target Calorimeter – Readout-

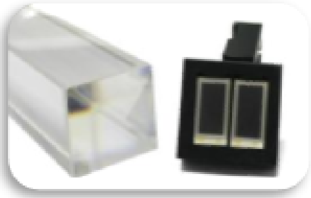
- Barrel & Backward End Cap: LAAPDs
- Forward End Cap
  - Outside: LAAPDs
  - Inside: VPTTs
    - Very high count rates
    - Only 1.05 T

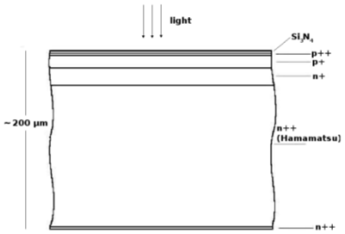


VPTT



LAAPD

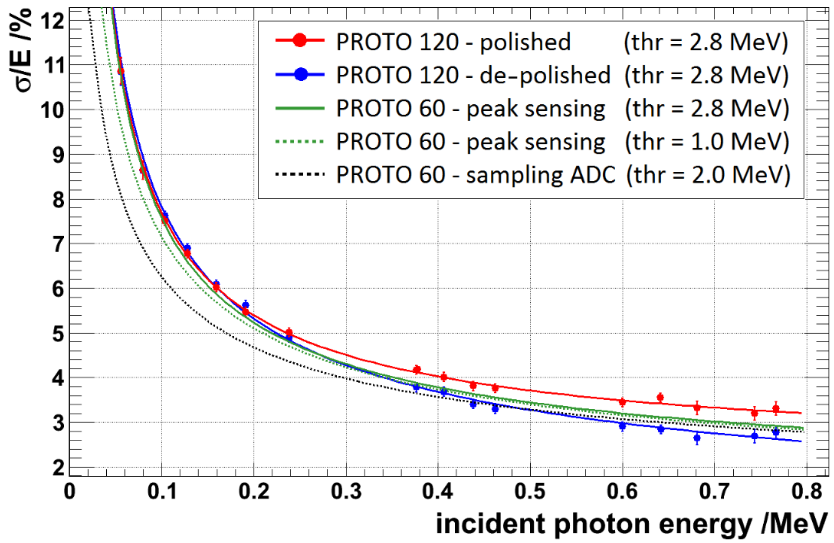




	VPTT	LAAPD
QE / %	23	80
active area / mm^2	200	95.2
dark current / nA	<1	<40
gain	50	150-200
capacity / pF	22	270

PROTO120 –Achieved Energy Resolutions 3X3-

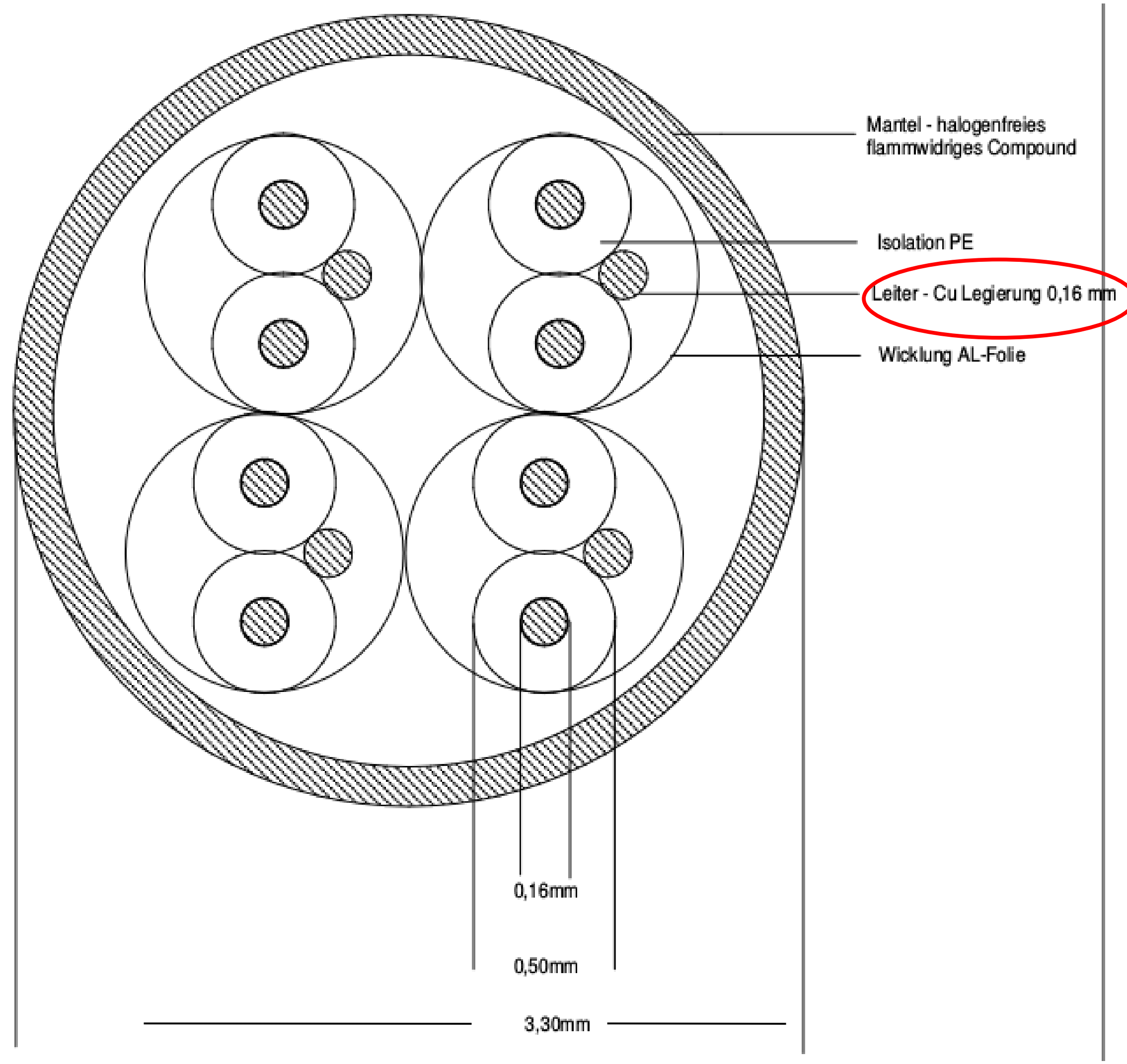
$$\frac{\sigma}{E} = \frac{a}{E/GeV} \oplus \frac{b}{\sqrt{E/GeV}} \oplus c$$



case	ADC	thresh. /MeV	a in %	b in %	c in %
PROTO 60 (type 6)	peak sensing	1.0	0.15	2.16	1.47
PROTO 60 (type 6)	peak sensing	2.8	0.32	2.11	1.6
PROTO 60 (type 6) [KBD11]	sampling	2.0	$< 10^{-4}$	2.01	1.66
PROTO 120 polished	sampling	2.8	0.34	2.07	2.18
PROTO 120 de-polished	sampling	2.8	0.27	2.30	0.5
straight crystals [NDD08]	peak sensing	1.0	$< 10^{-4}$	2.10	1.1

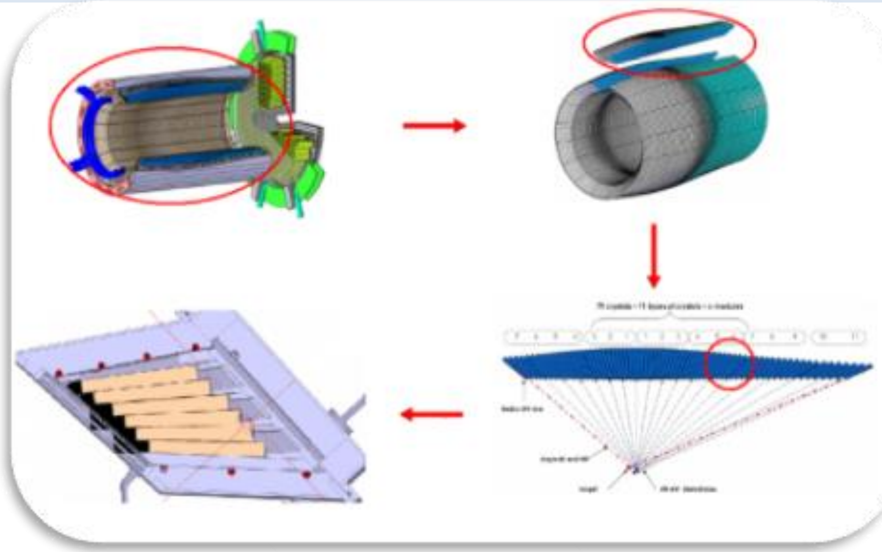
Barrel Routing –Signal Cables-

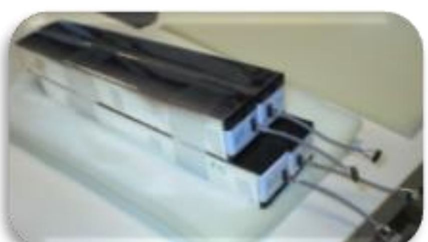
Special Ultra-thin differential cables developed in corporation with company BEDEA (Germany)



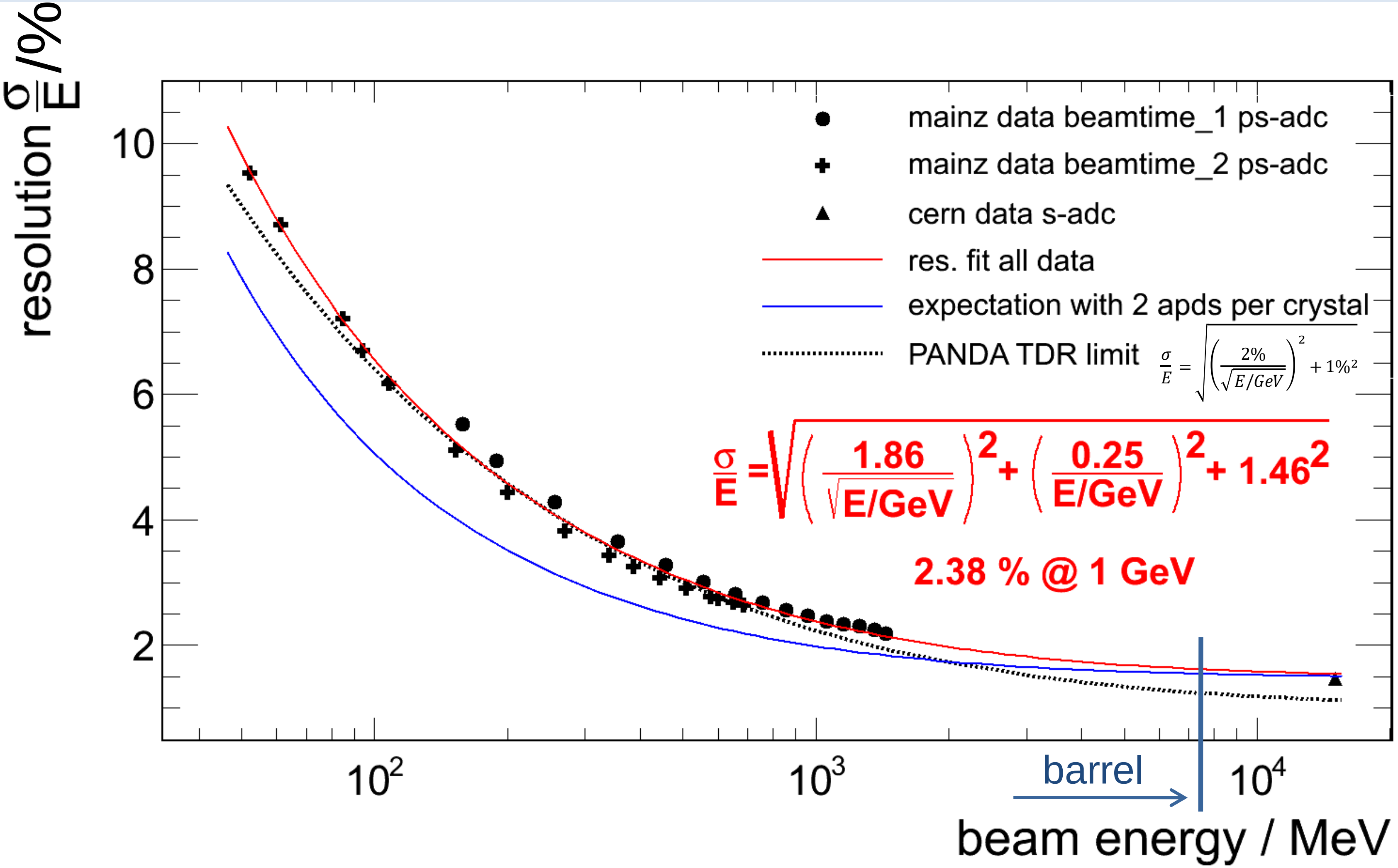
Barrel Prototypes - PROTO60 -

- First prototype for the Barrel EMC
- 60 $PbWO_4$ crystals Type 6 geometry
- Operation temp.: -25°C
- Housing:
  - Thermally insulated
  - Flushed with dry nitrogen
- One LAAPD (10x10 mm^2) per crystal
- Discrete charge preamplifier:
  - Commercial J-FET transistors
  - Low noise
  - Low power





PROT60 - Energy Resolution Achieved With Peak Sensing ADCs -



Prototypes - PROTO120 -

- Close to final design
- 120 $PbWO_4$ crystals
- Operation temp.: -25°C
- Readout:
  - 2 LAAPDs per crystal
  - APFEL ASIC
    - High dynamic range
    - High count rates
    - Low power consumption
  - Sampling ADCs