Final Concept and Performance
of the
Electromagnetic Target Calorimeter
of the
PANDA Detector at FAIR based on $PbWO_4$

Rainer W. Novotny, on behalf of the PANDA Collaboration
2nd Physics Institute, University Giessen

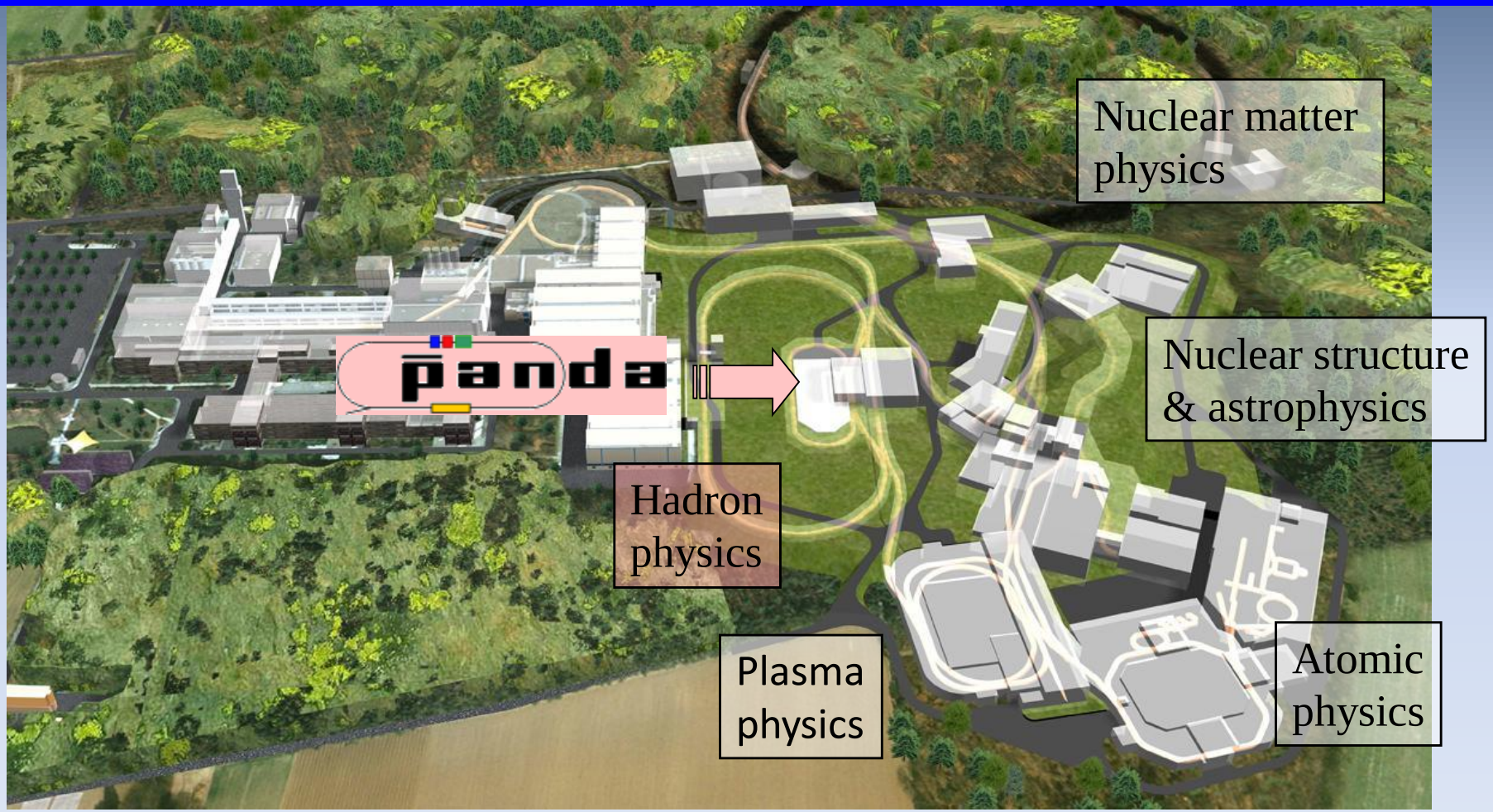
- **The PANDA detector and the EMC**
- **$PbWO_4$ – the chosen inorganic scintillator**
- **The detector design**
- **The achieved performances**
- **The steps towards a final design**
- **Summary and outlook**

Primary beams: SIS100/300

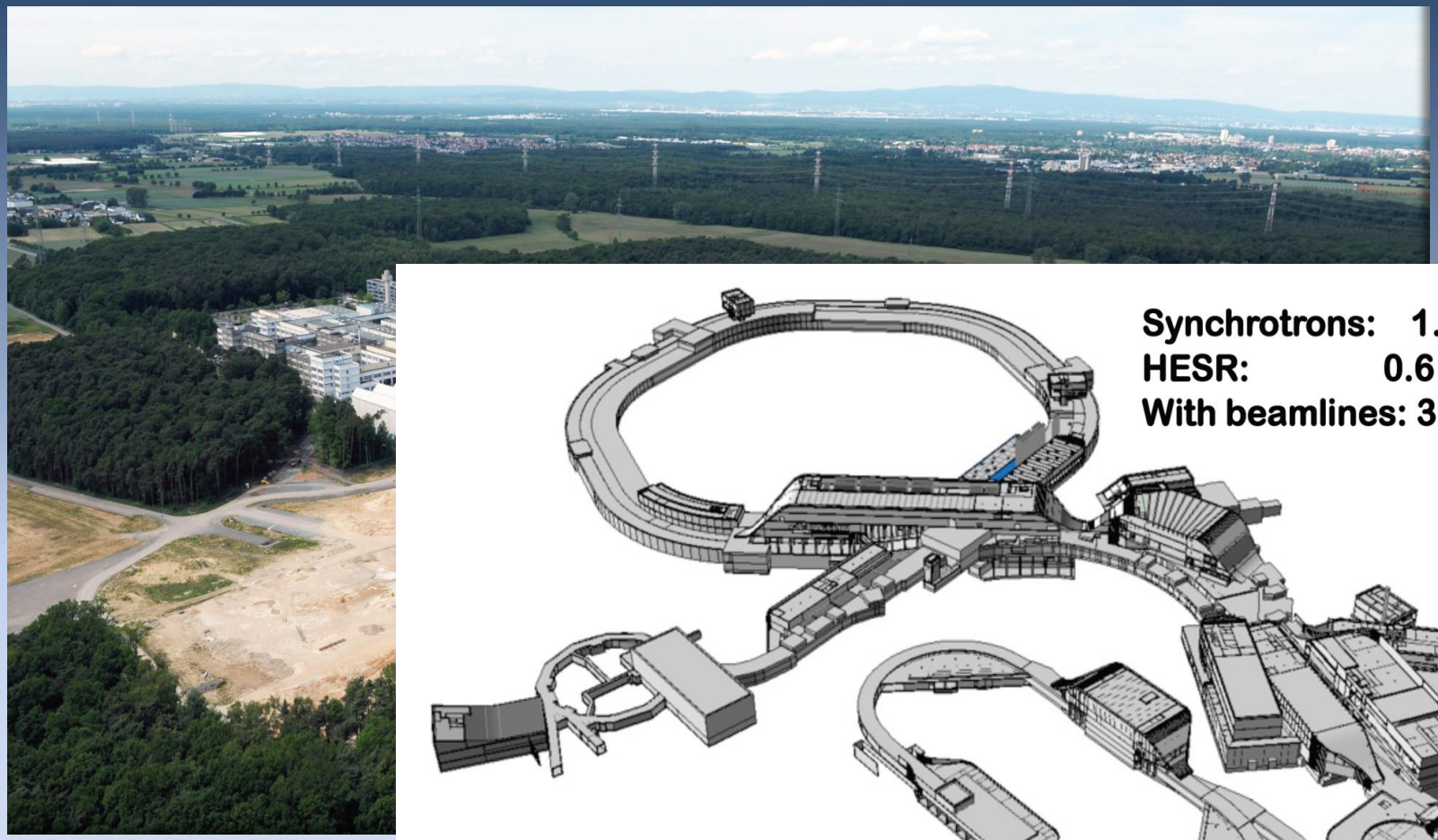
- p: $2 \cdot 10^{13}$/s up to 29 GeV
- U^{28+}: 10^{12}/s up to 2.7 GeV/u
- U^{92+}: 10^{10}/s up to 35 GeV/u

Secondary beams

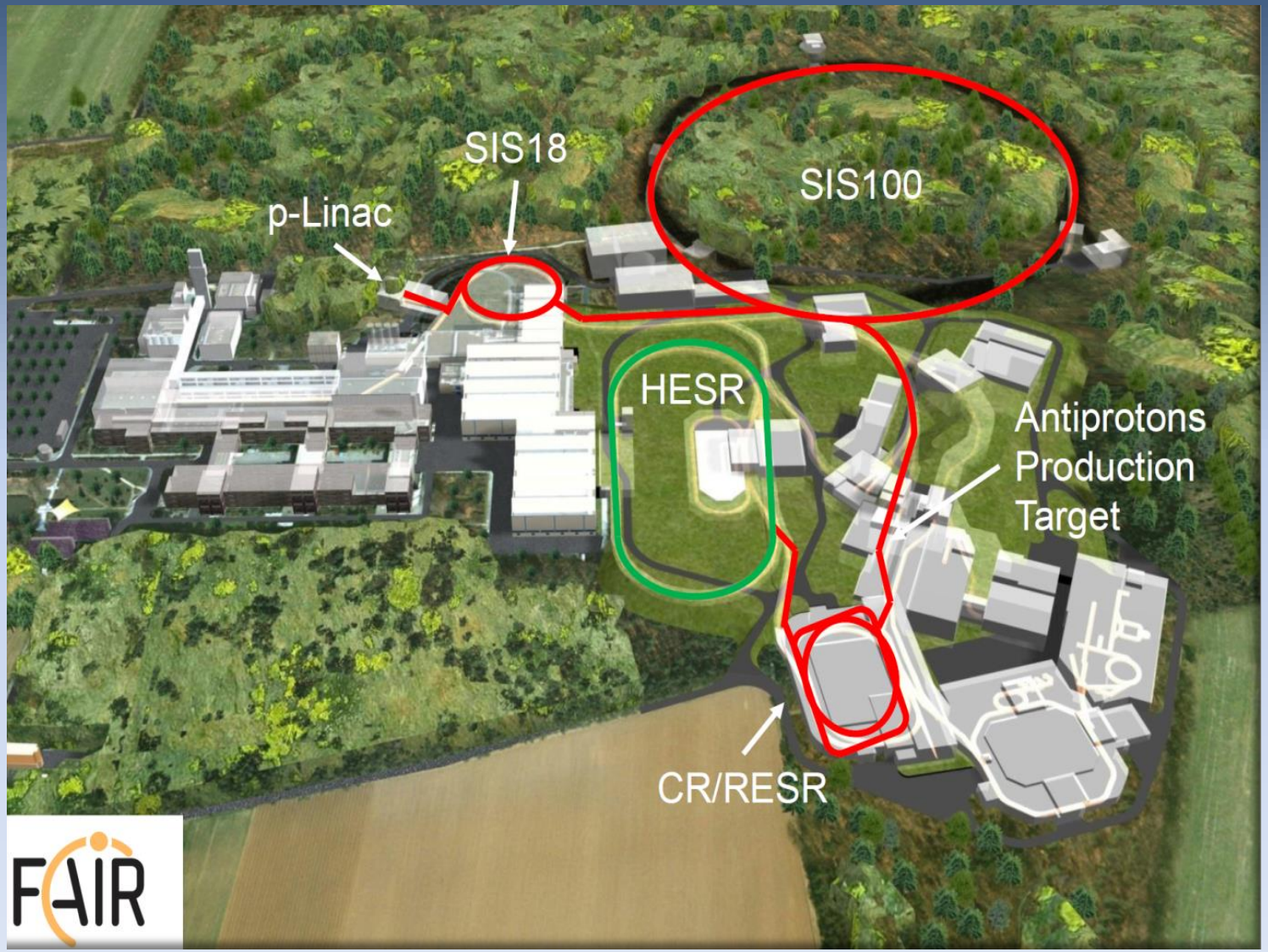
- RIBs up to 2 GeV/u
- Antiprotons up to 15 GeV/c
- Storage and cooler rings



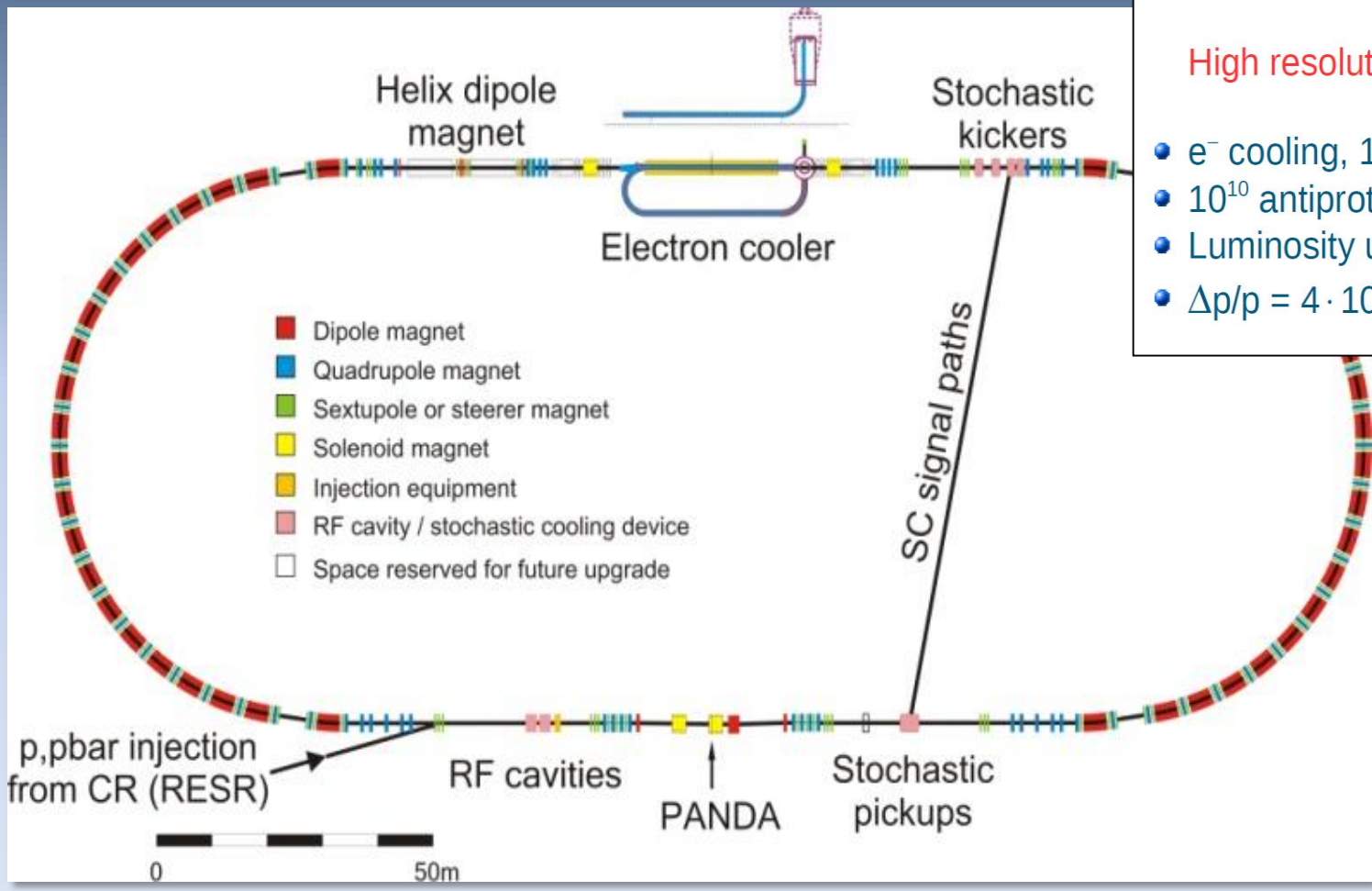
• the ongoing activities …



- **the delivery of anti-protons (1)**



• the delivery of anti-protons (2)



High intensity mode

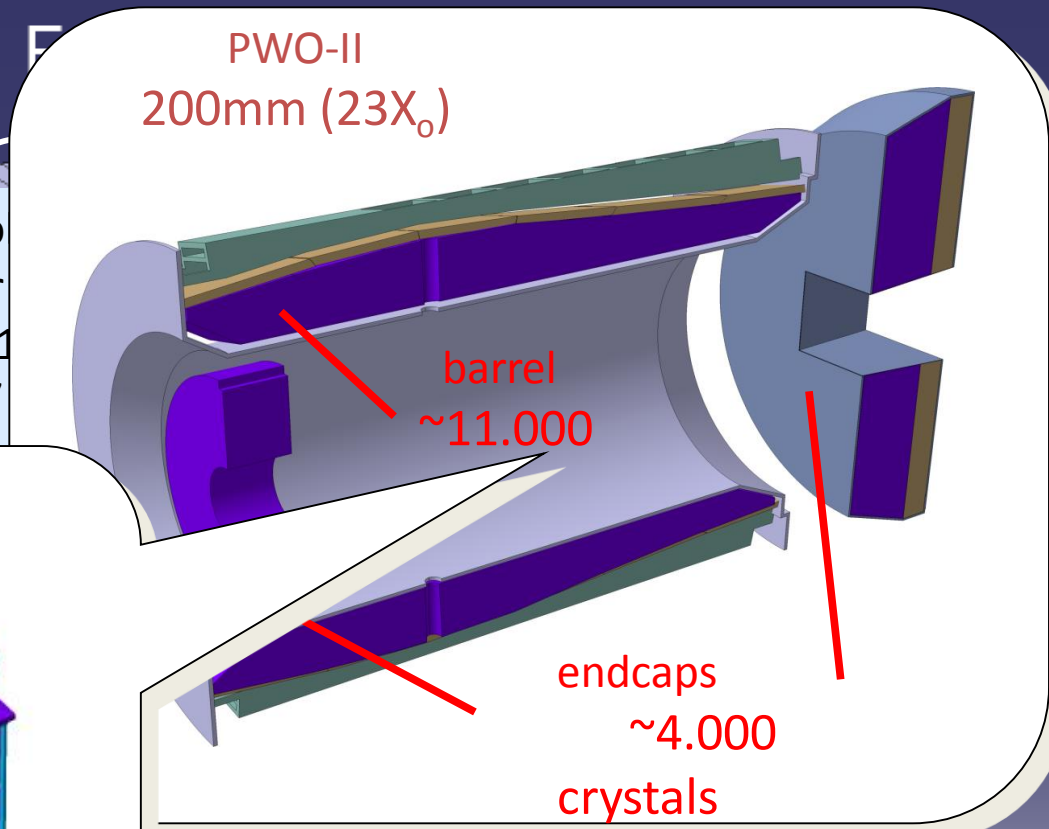
- Stochastic cooling, $p \geq 3.8$ GeV/c
- 10^{11} antiprotons stored
- Luminosity up to $2 \cdot 10^{32}$ cm^{-2} s^{-1}
- $\Delta p/p = 2 \cdot 10^{-4}$

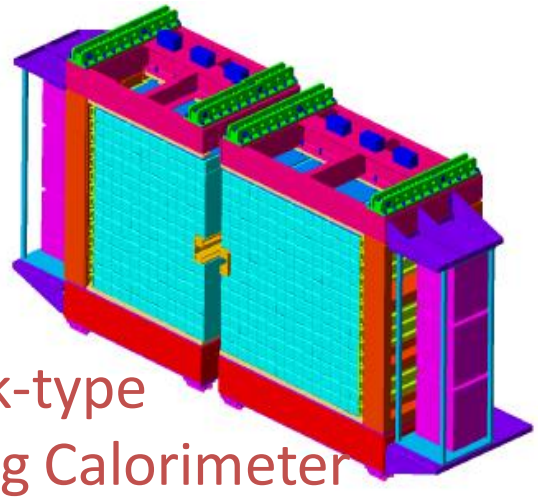
High resolution mode

- e^- cooling, $1.5 \leq p \leq 8.9$ GeV/c
- 10^{10} antiprotons stored
- Luminosity up to $2 \cdot 10^{31}$ cm^{-2} s^{-1}
- $\Delta p/p = 4 \cdot 10^{-5}$

• the PANDA detector at FAIR

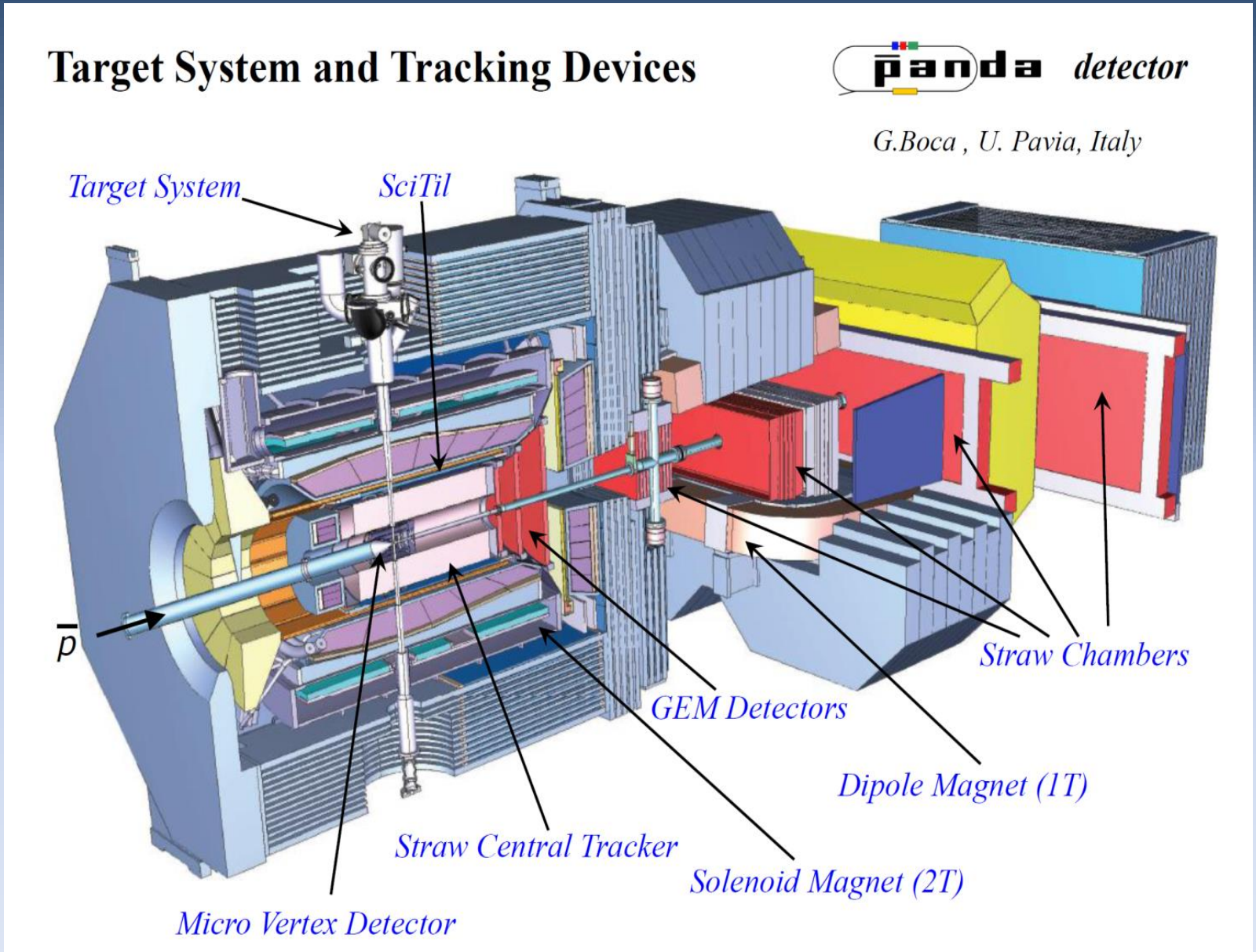
- photon detection with high reso
over
10MeV < E_γ < 1
- high count-rate capability ($2 \cdot 10^7$



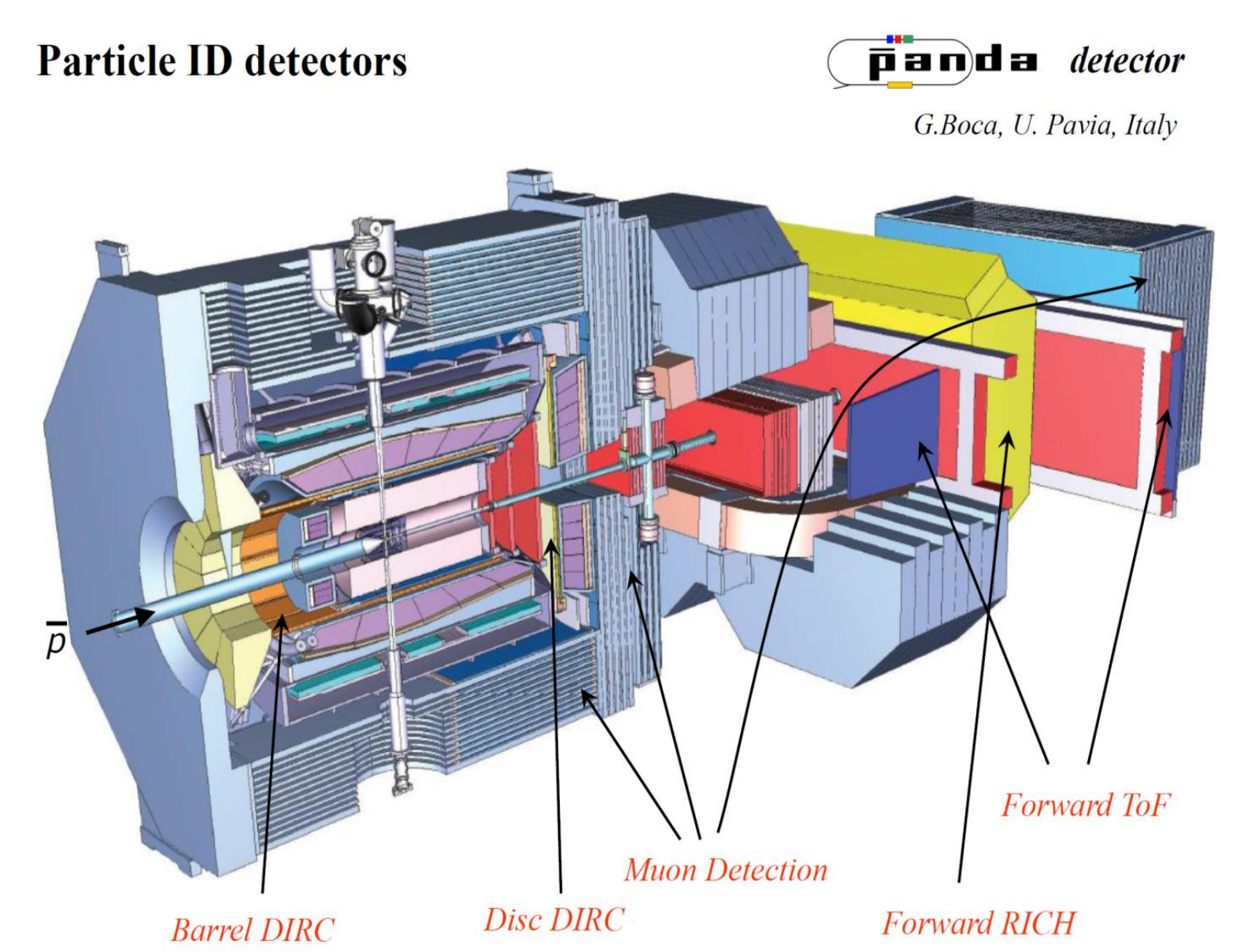


4π detector for spectroscopy and reaction dynamics with antiprotons

• additional components (1)

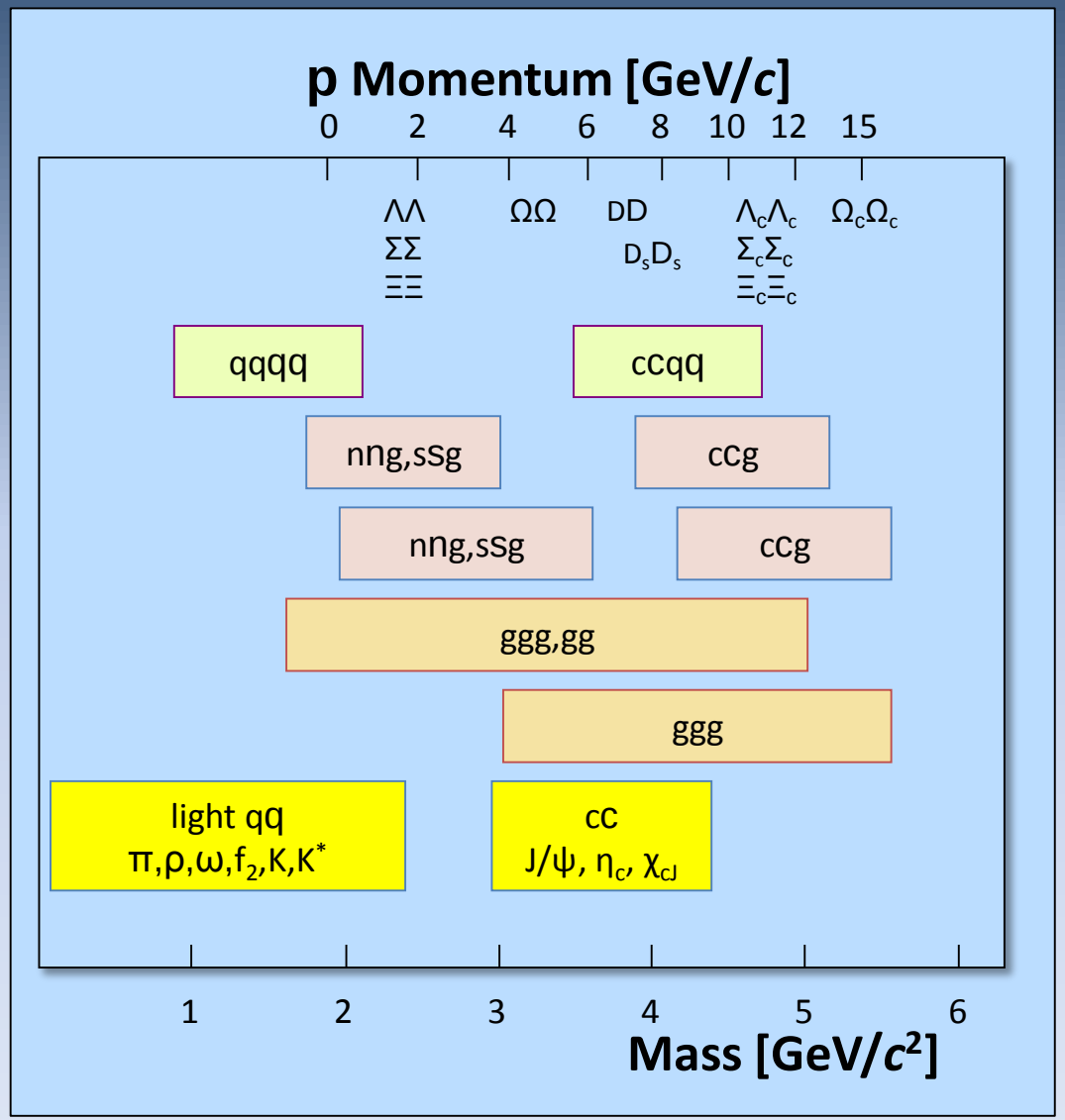


• additional components (2)



• the physics program

- Nucleon structure
- E.M. processes
- Meson spectroscopy
  - light mesons
  - charmonium
  - exotic states
    - glueballs
    - hybrids
    - molecules/multiquarks
  - open charm
- Baryon/antibaryon production
- Charm in nuclei
- Strangeness physics
  - Hyperatoms
  - S = -2 nuclear system
    - Ξ^- nuclei
    - $\Lambda\Lambda$ hypernuclei



the Target Spectrometer:

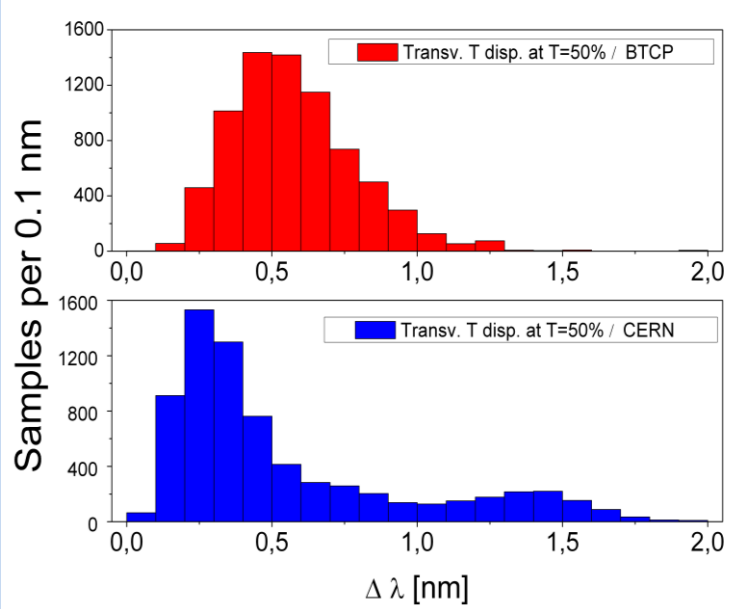
based on high-quality PWO-II

- physical goals of PANDA require further development

	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

- **quality control and performance**

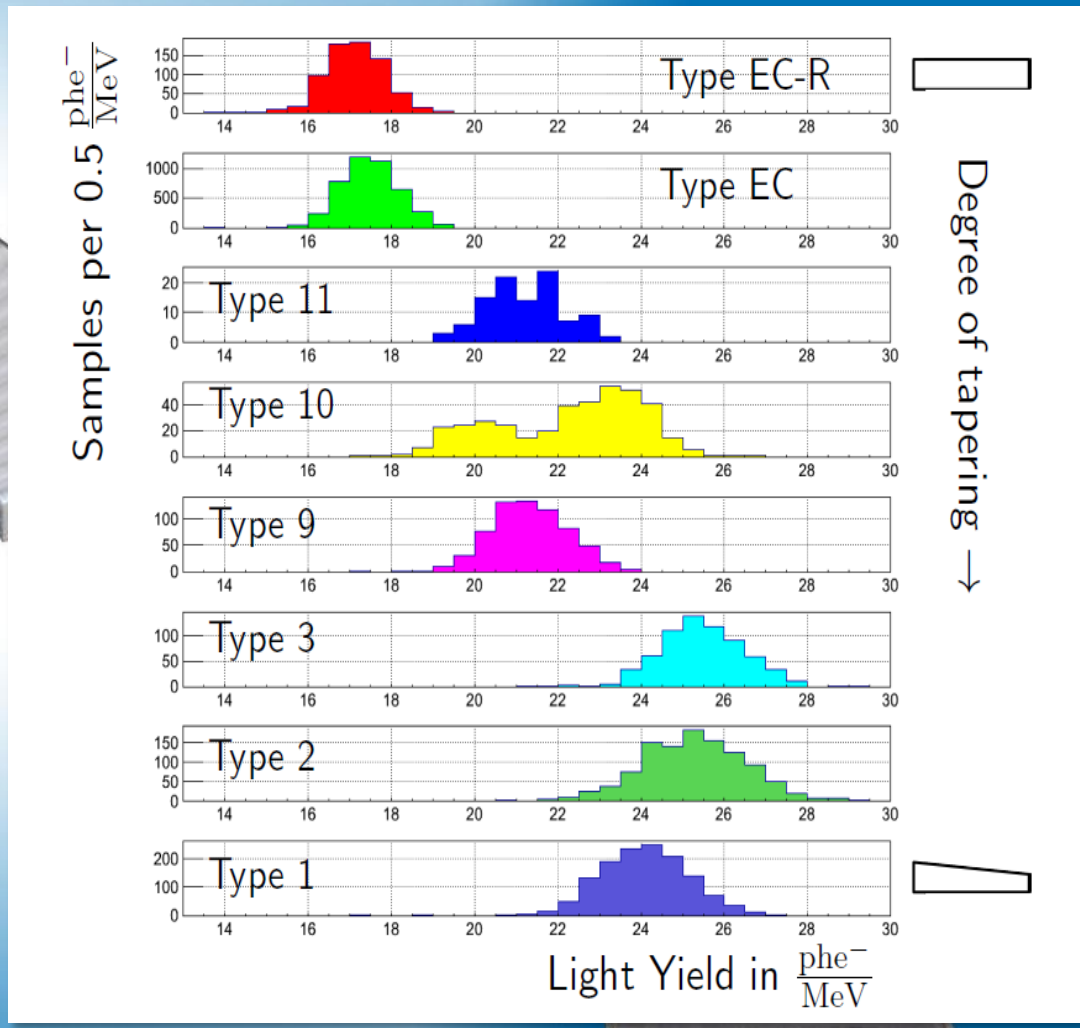
• optical longitudinal transmission



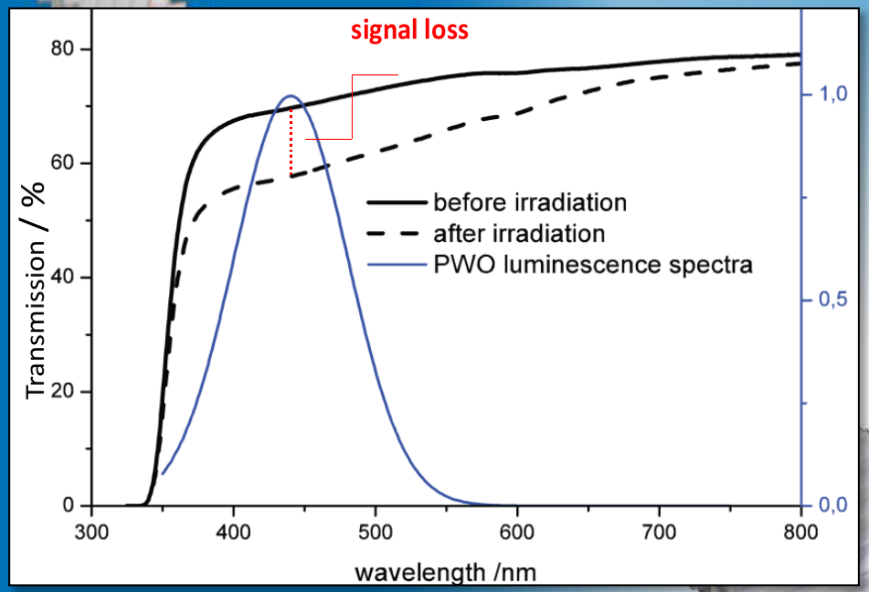
longitudinal homogeneity

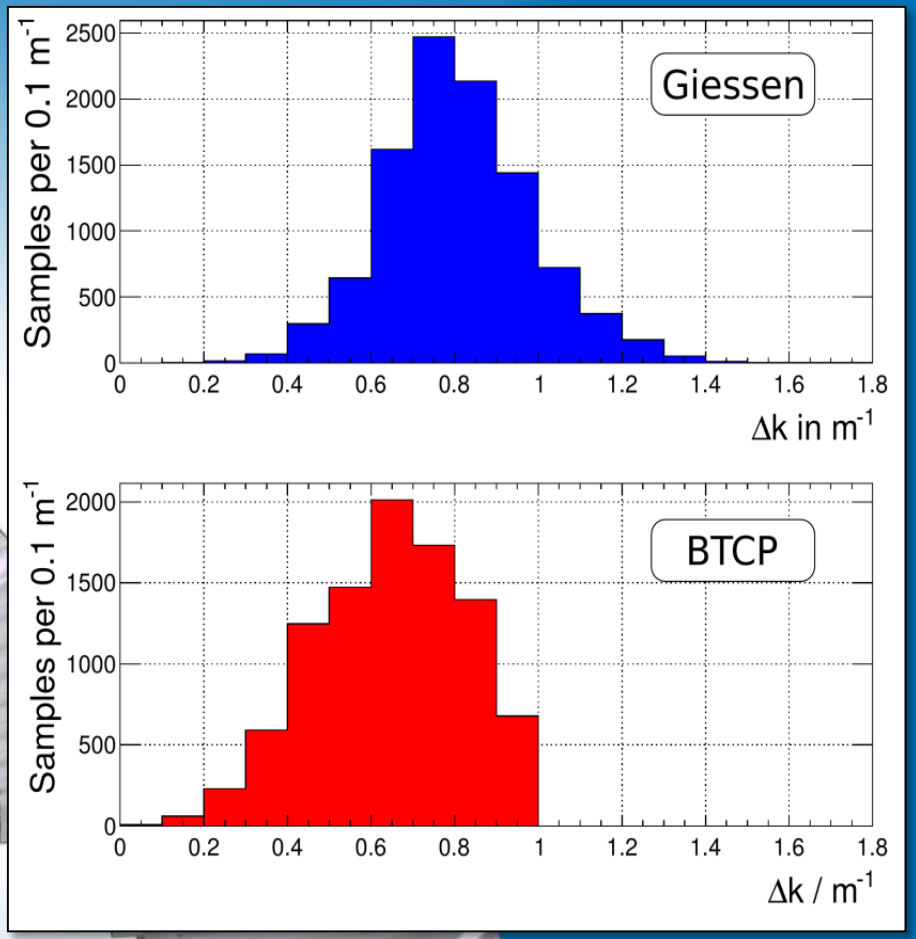
property	condition	specification
longitudinal transmission	at 360nm	$\geq 35\%$
	at 420nm	$\geq 60\%$
	at 620nm	$\geq 70\%$
uniformity of transv. transmission	wavelength at $T = 50\%$	$\Delta\lambda \leq 3$nm

• light yield @ 18°C



• radiation hardness





tested using γ-rays: ~ 1.2 MeV ^{60}Co

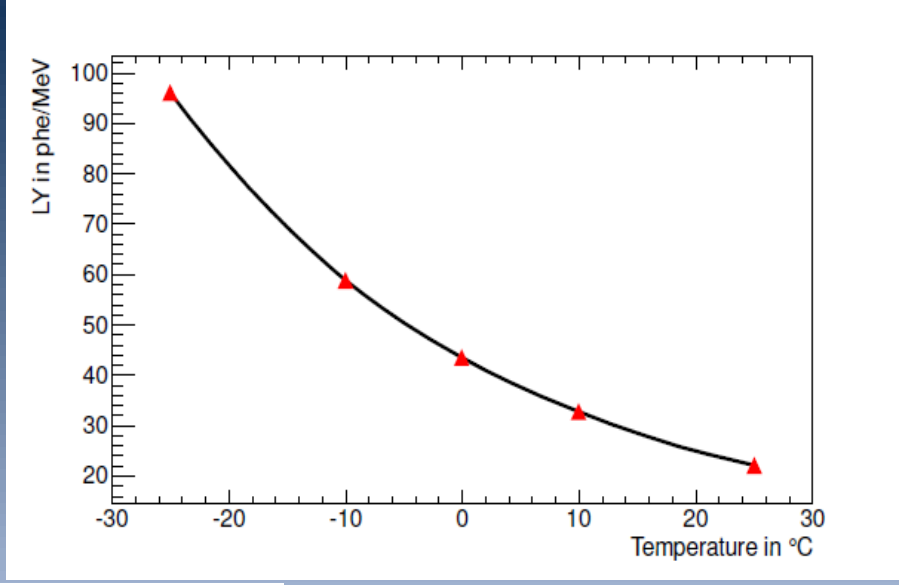
integral dose: 30Gy

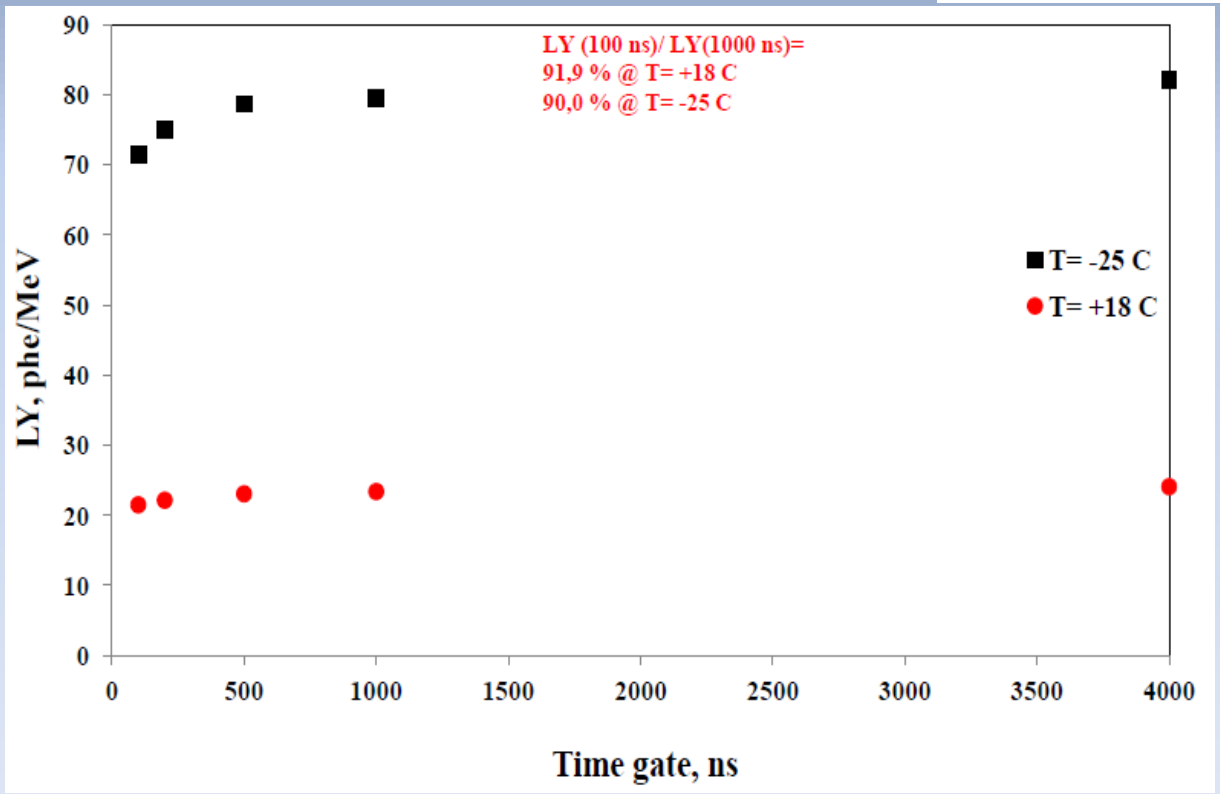
$$\Delta k = \ln\left(\frac{T_{bef}}{T_{after}}\right)\cdot\frac{1}{d}$$

acceptance limit: $\Delta k < 1.1\ m^{-1}$

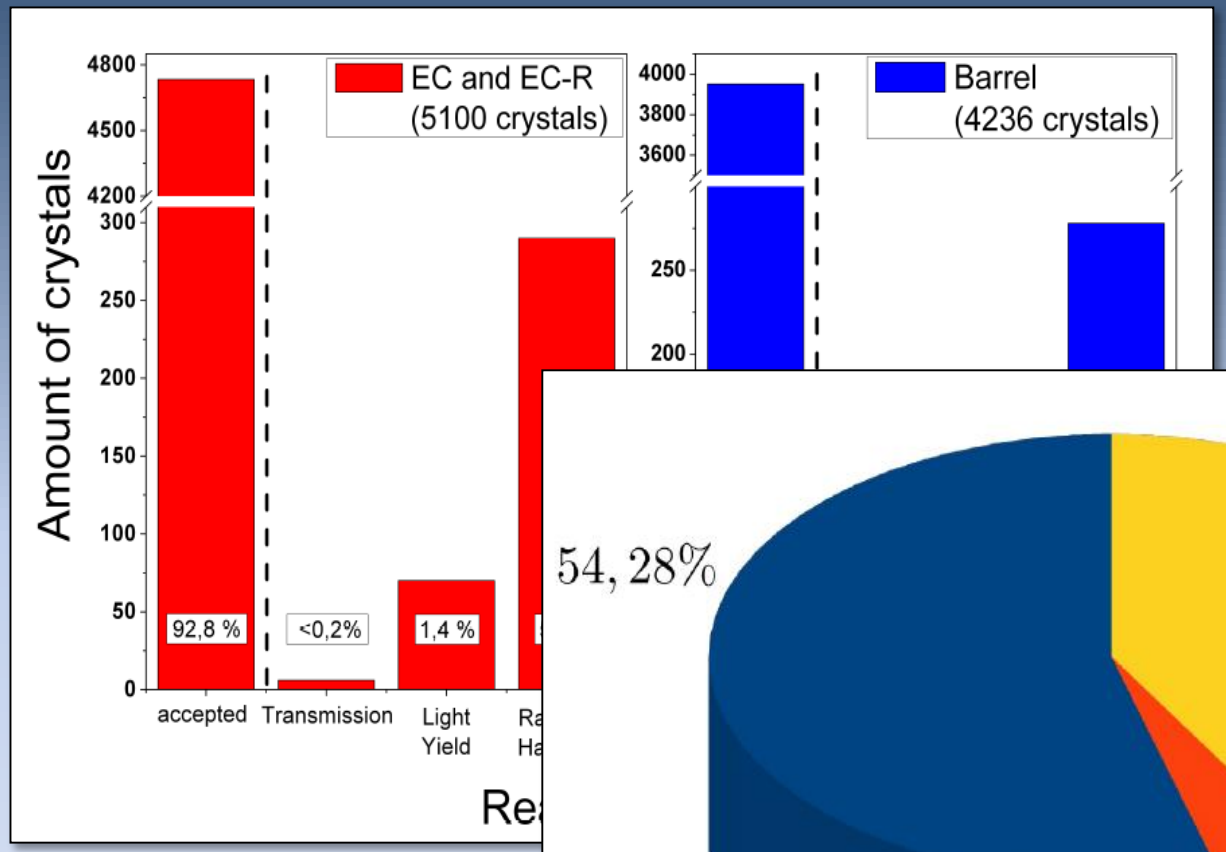
• light yield measurement

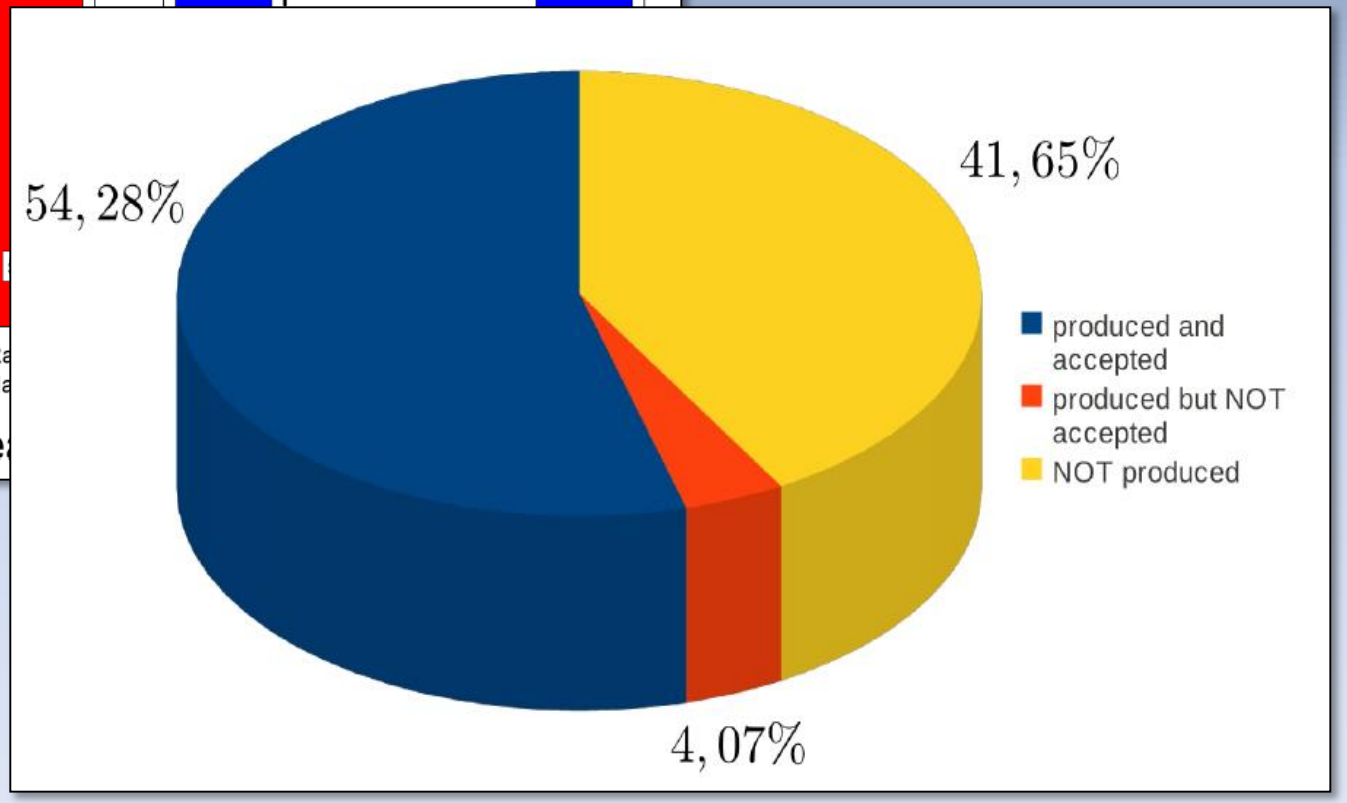
temperature dependence of luminescence





• overall quality of the available BTCP crystals





• remaining PWO manufacturer

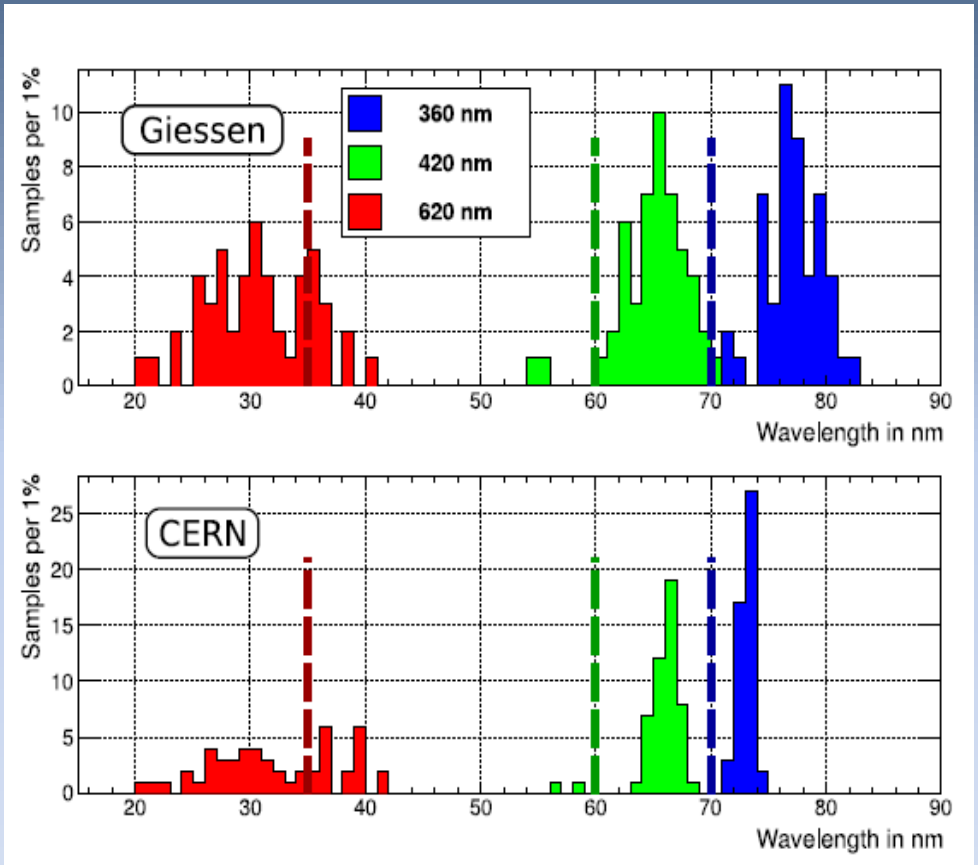
SICCAS – Shanghai, China

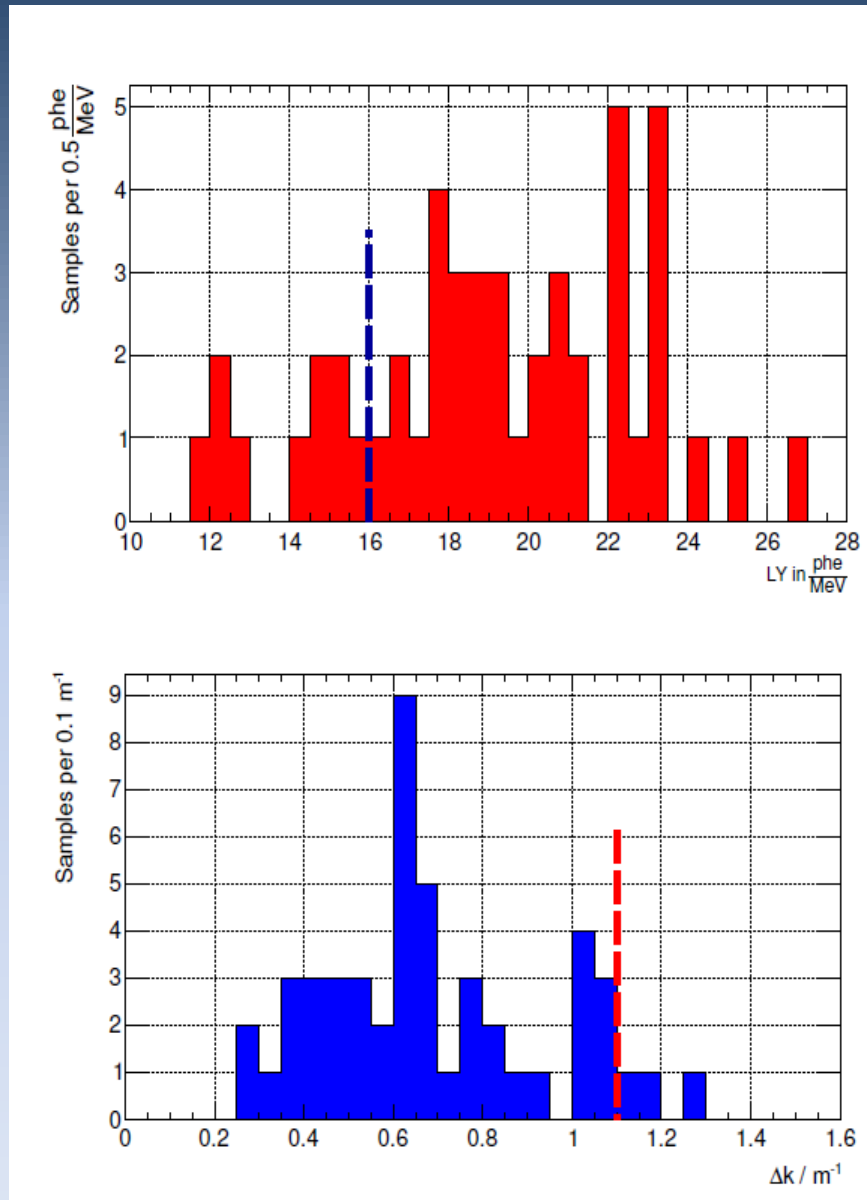
- R&D continued in parallel
- Bridgeman technology (not comparable to BTCP)
- fully acceptable crystals delivered in the past
- presently search for appropriate raw material
  and optimization of technology

CRYTUR – Turnov, Czech Republic

- R&D phase just started (June 2014)
- Czochralsky technology (identical to BTCP)
- know-how and raw material still available

• former production @ SICCAS



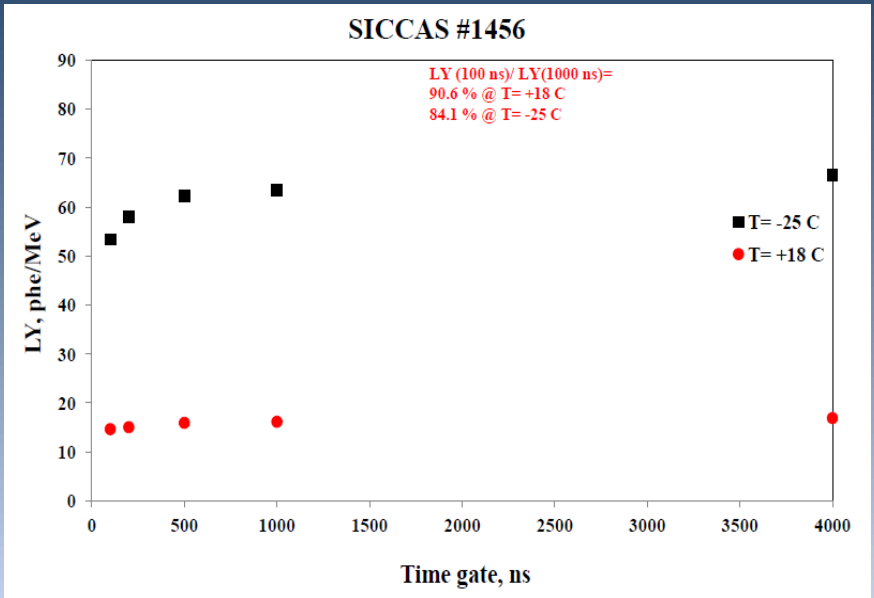


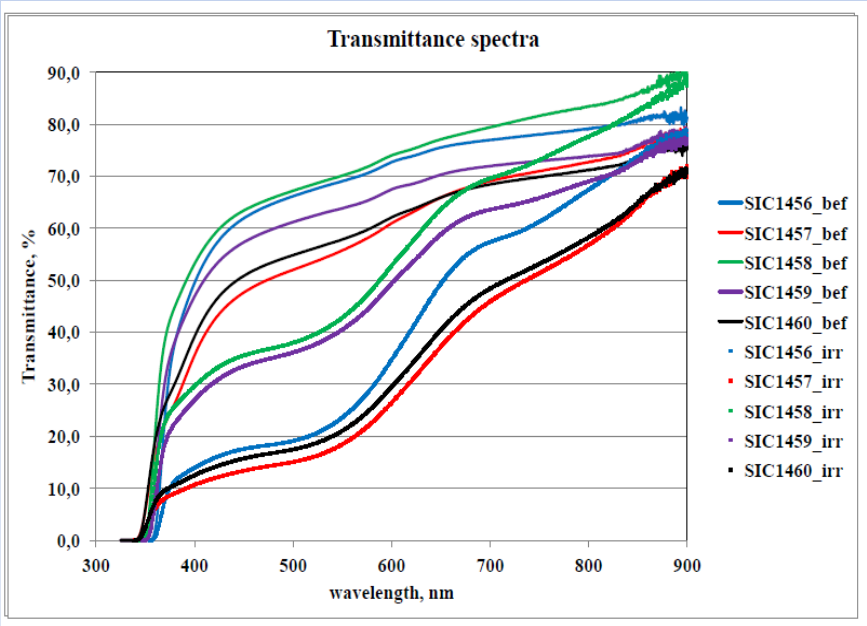
• recent delivery from SICCAS (2014 - 2015)

SICCAS ID	T(360	T(420	T(620	LY(T= +18 C, t=100	LY(100	dk(420 nm)
	%	%	%	phe/MeV	at T=18C, %	m^{-1}
limits	≥ 35	≥ 60	≥ 70	≥ 16	> 90	< 1.1
1466	31,2	56,9	72,0	23,4	90,1	0,86
1467	20,6	55,8	71,1	21,4	90,4	0,71
1468	21,5	56,5	69,7	19,9	89,9	0,65
1469	26,9	56,9	69,0	21,2	90,7	0,44
1470	25,5	56,2	70,3	22,8	90,0	1,33
1471	24,7	57,8	70,8	20,6	90,5	0,80
1472	33,6	59,1	72,1	20,7	90,1	0,16
1473	22,2	60,3	72,2	20,8	90,7	0,71
1474	23,2	60,5	72,2	20,3	89,9	0,59
1475	35,0	65,2	78,0	22,0	91,4	0,84

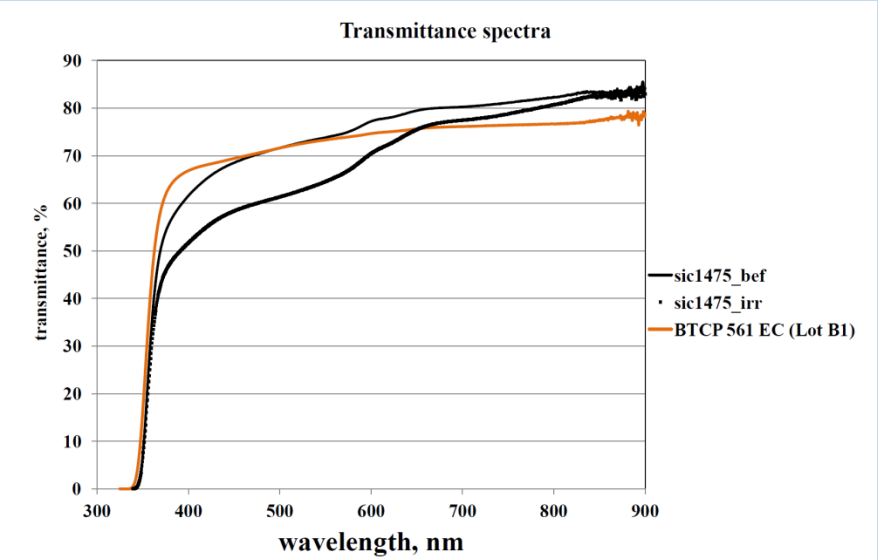
1471	24,7	57,8	70,8	20,6	90,5	0,80
1472	33,6	59,1	72,1	20,7	90,1	0,16
1473	22,2	60,3	72,2	20,8	90,7	0,71
1474	23,2	60,5	72,2	20,3	89,9	0,59
1475	35,0	65,2	78,0	22,0	91,4	0,84

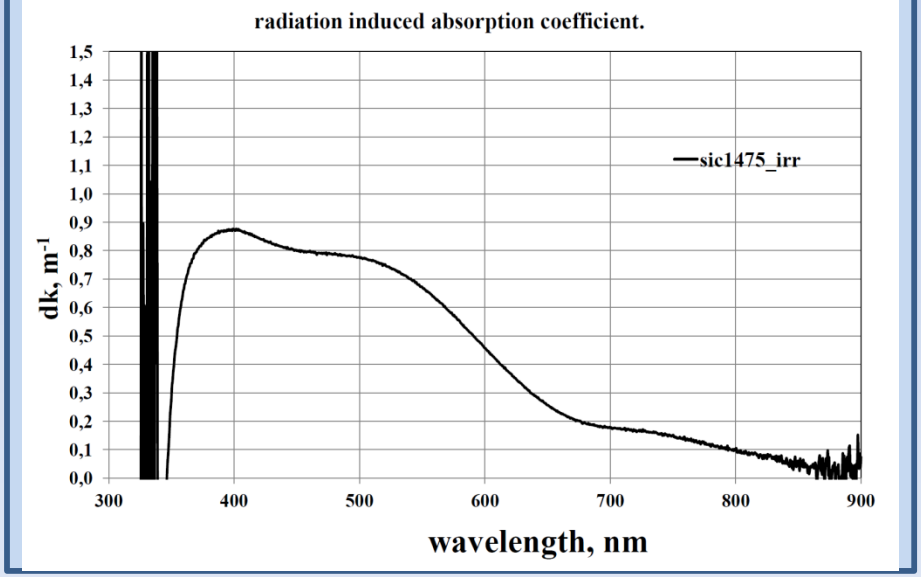
• recent delivery from SICCAS





SICCAS 1475

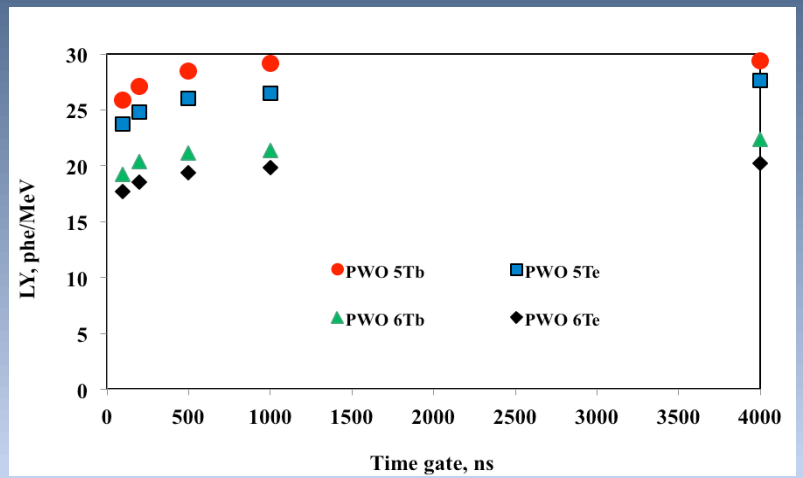


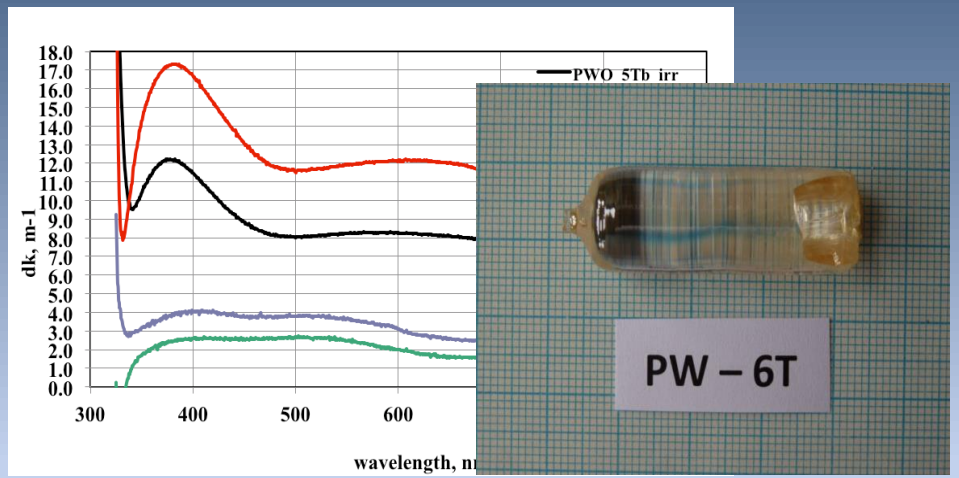


• start results @ CRYTUR (1)

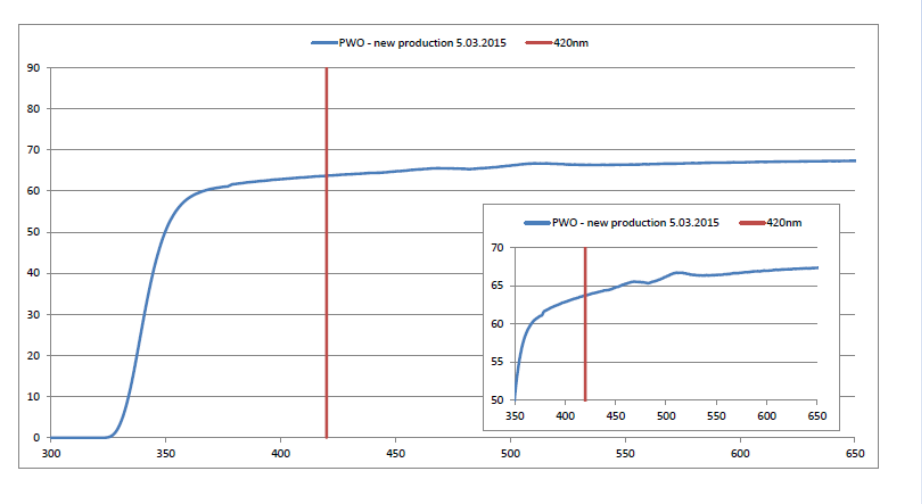
supported by: RINP Minsk: **M. Korjik**
NEOCHEM, Moscow: **Dosovitskyi**

• first experiences under different conditions: small test samples



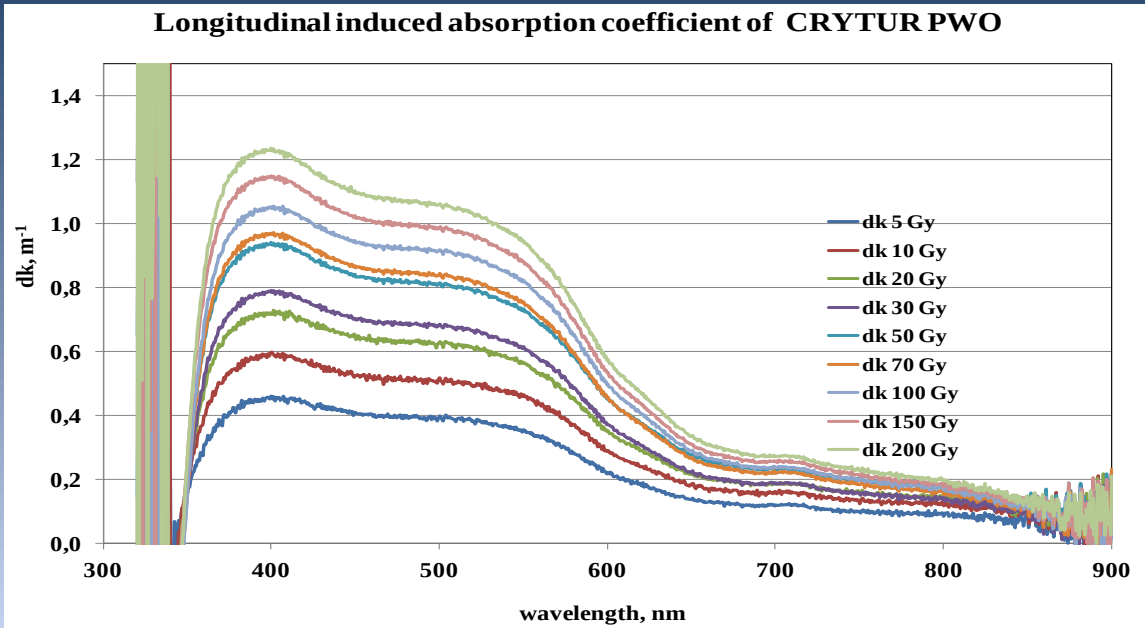


• **first and second full size ingot (~ 23cm long)**

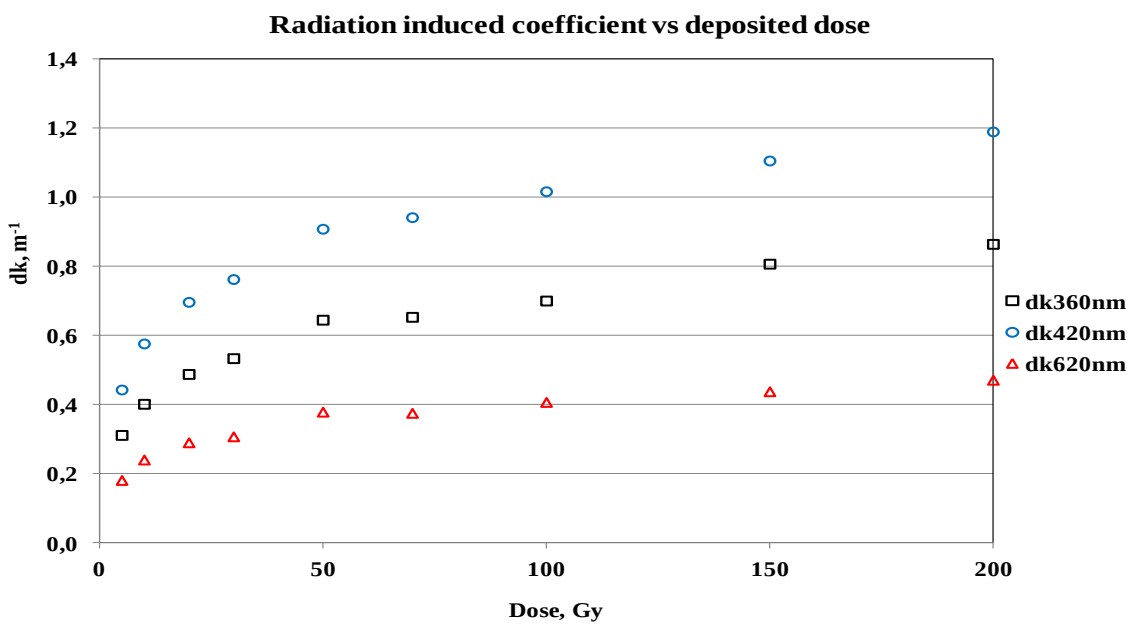


• start results @ CRYTUR (2)

test crystal:
20 x 20 x 200 mm^3



- **longitudinal inhomogeneity**
  scattering centers
- **sufficient light yield**
- **radiation hard**

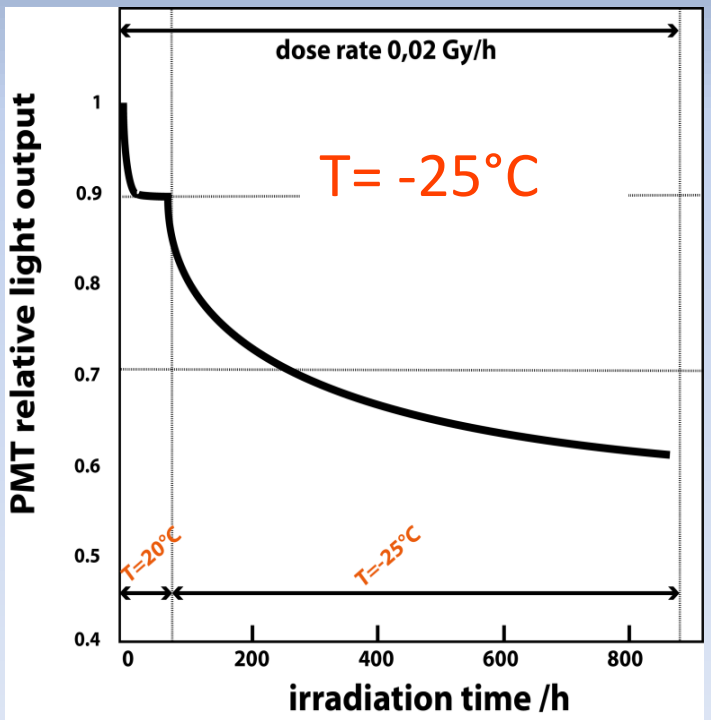


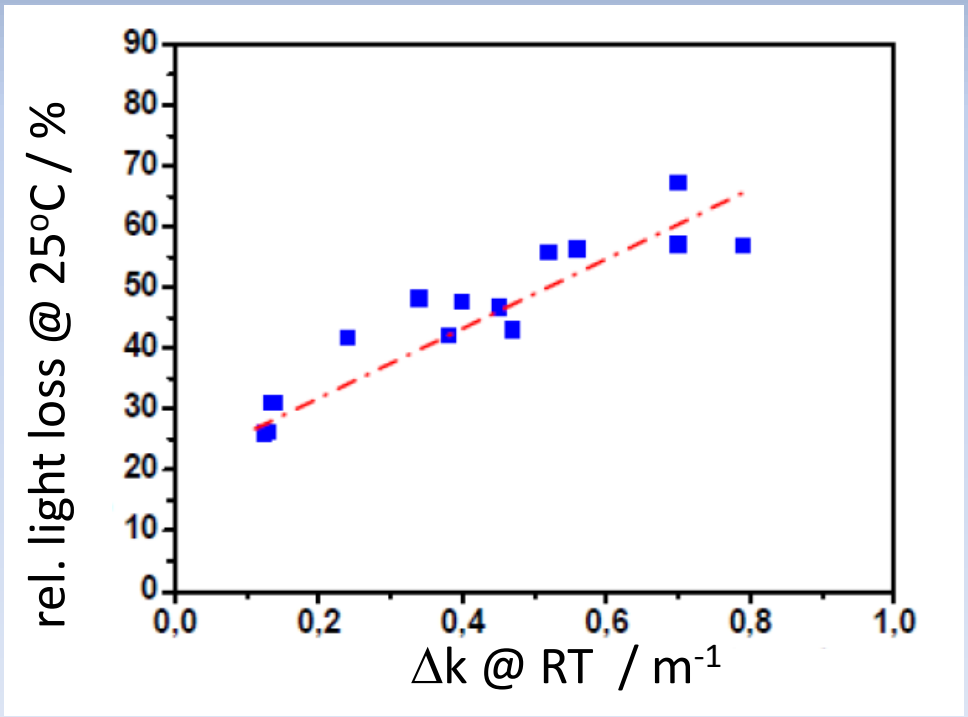
• consequences of cooling

- **fast decay kinetics even at T=-25°C:** LY(100ns)/LY(1µs) > 0.9
- **constant temperature gradient:** LY(-25°C)/LY(+18°C) ~ 3.9

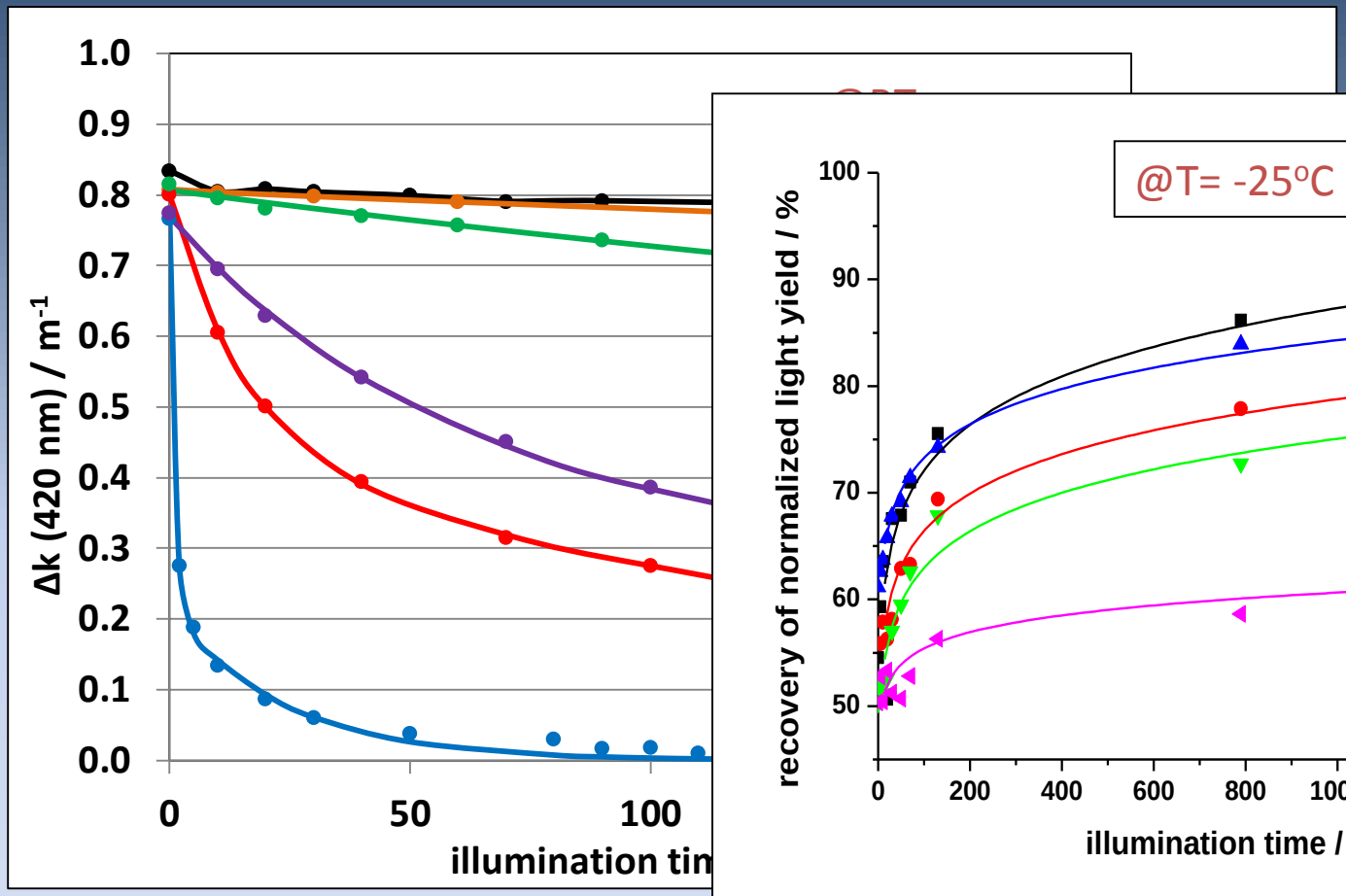
- **„no“ statistical recovery of radiation damage at T=-25°C**

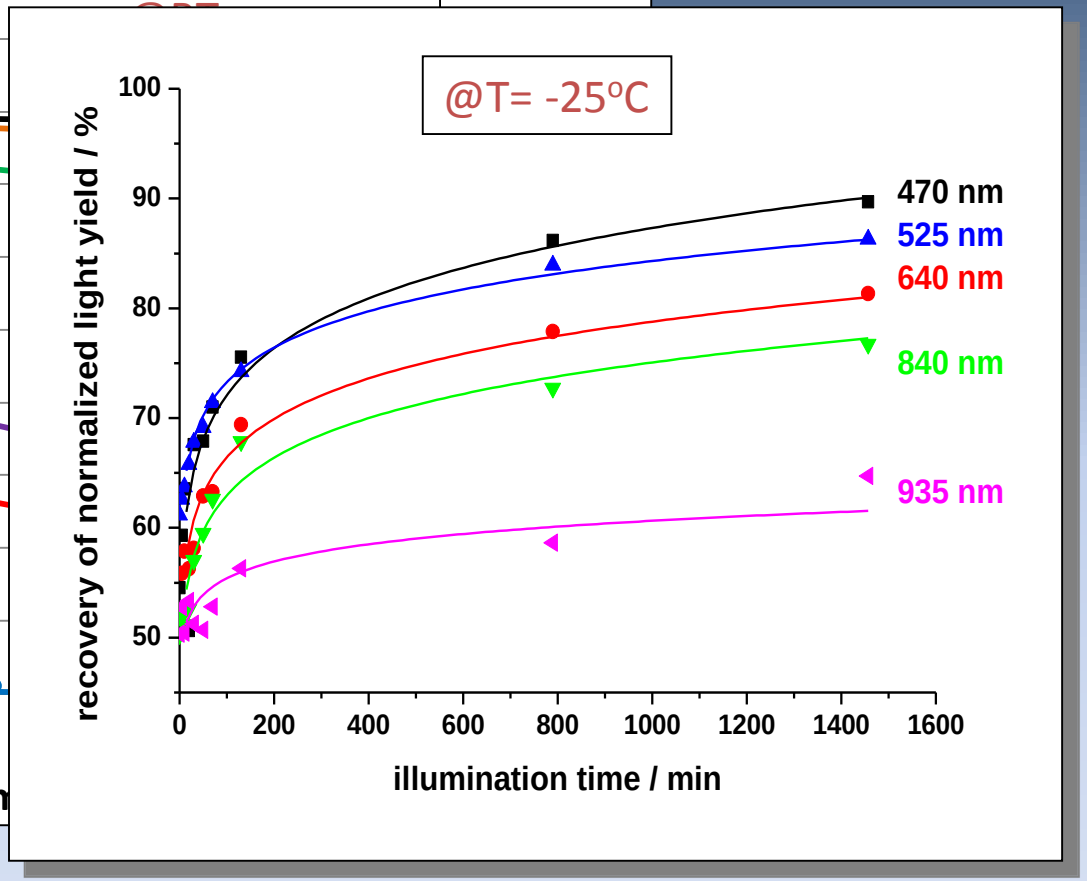
  asymptotic light loss correlated with Δk (@RT)





• *stimulated recovery* of radiation damage

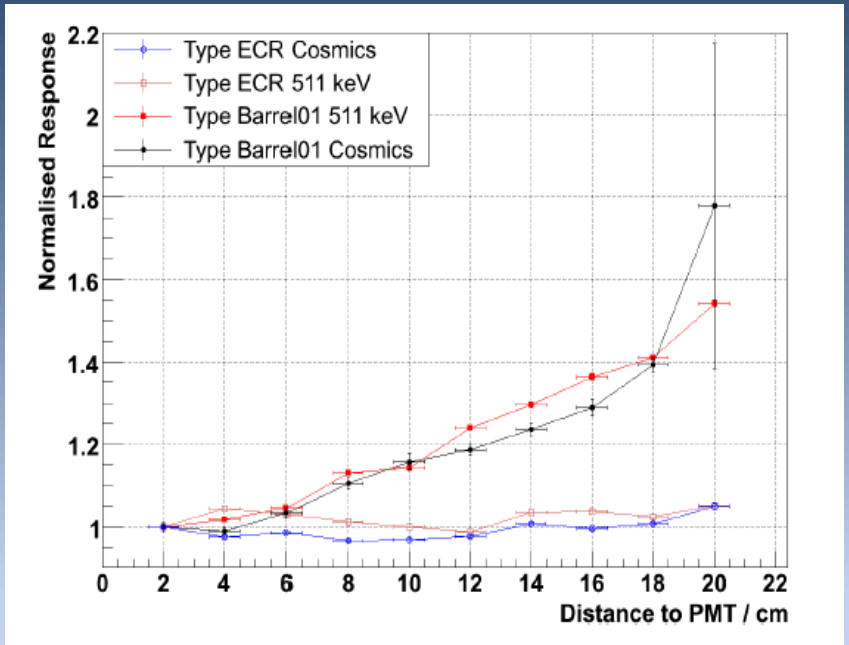


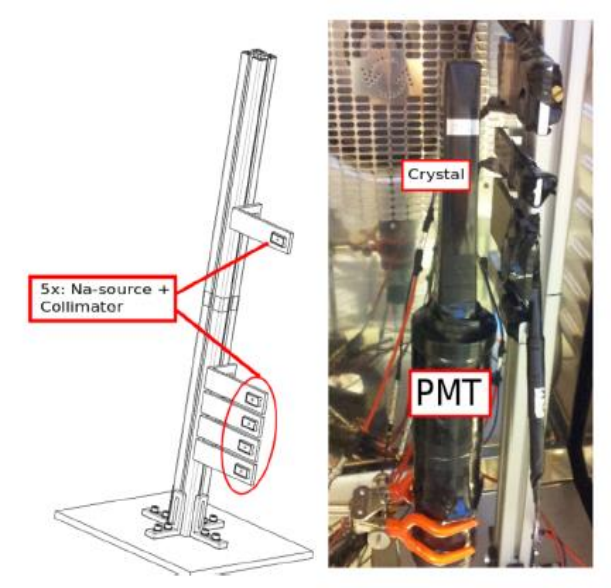


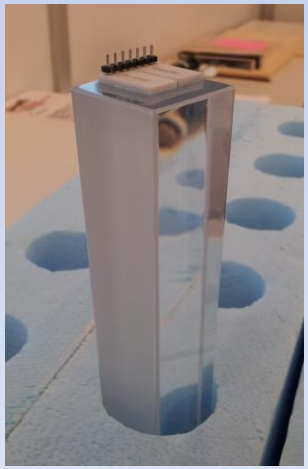
exposed to integral dose of ^{60}Co: D = 30Gy

V. Dormenev et al., NIM A623 (2010) 1082

• light collection in tapered crystals





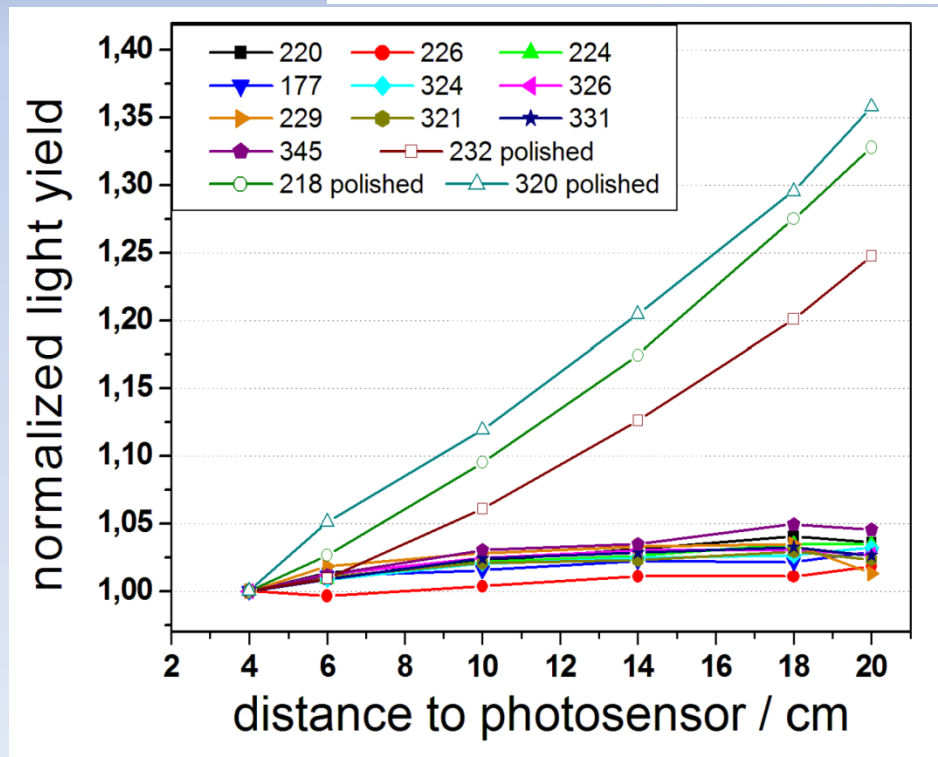


linearization achieved via de-polishing of one side face roughness: R = 0.3 µm

(E. Auffray, CERN)

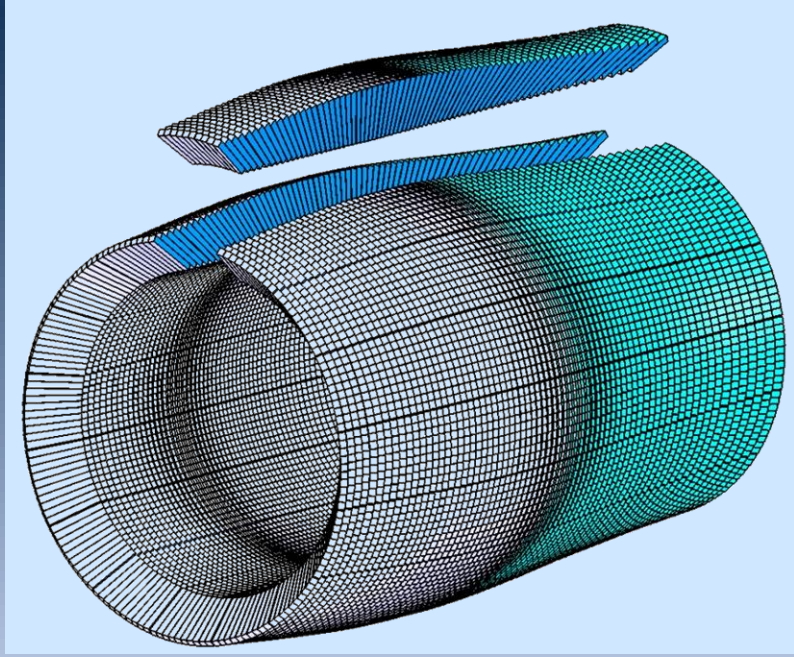
but: loss of light

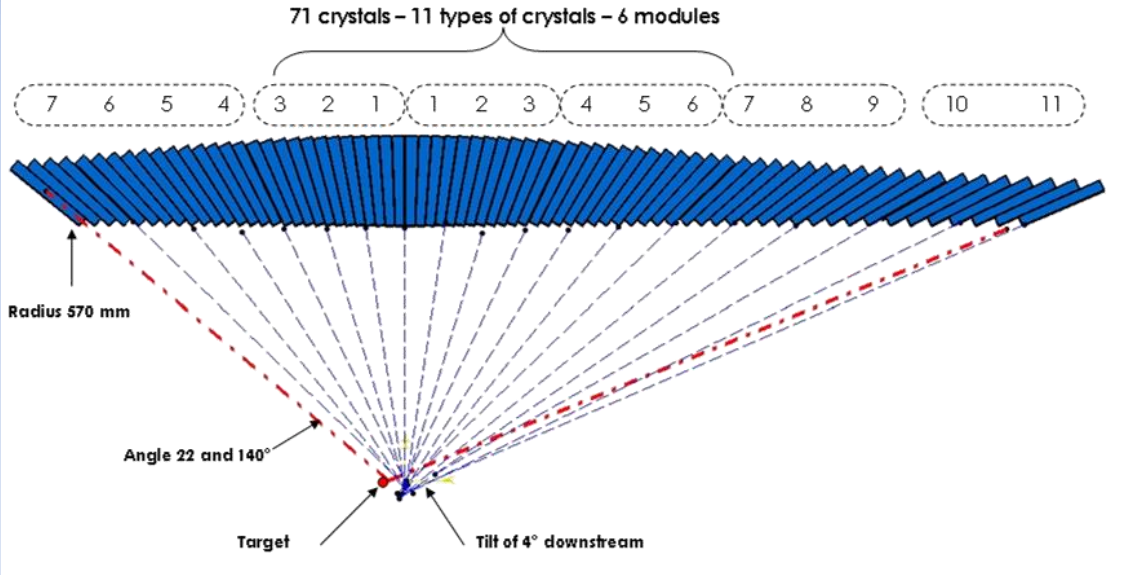
independent of radiation damage

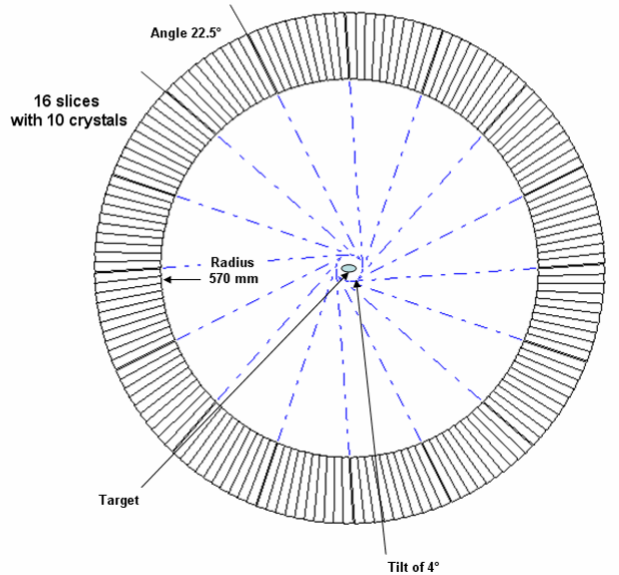


• the Target Spectrometer: Barrel

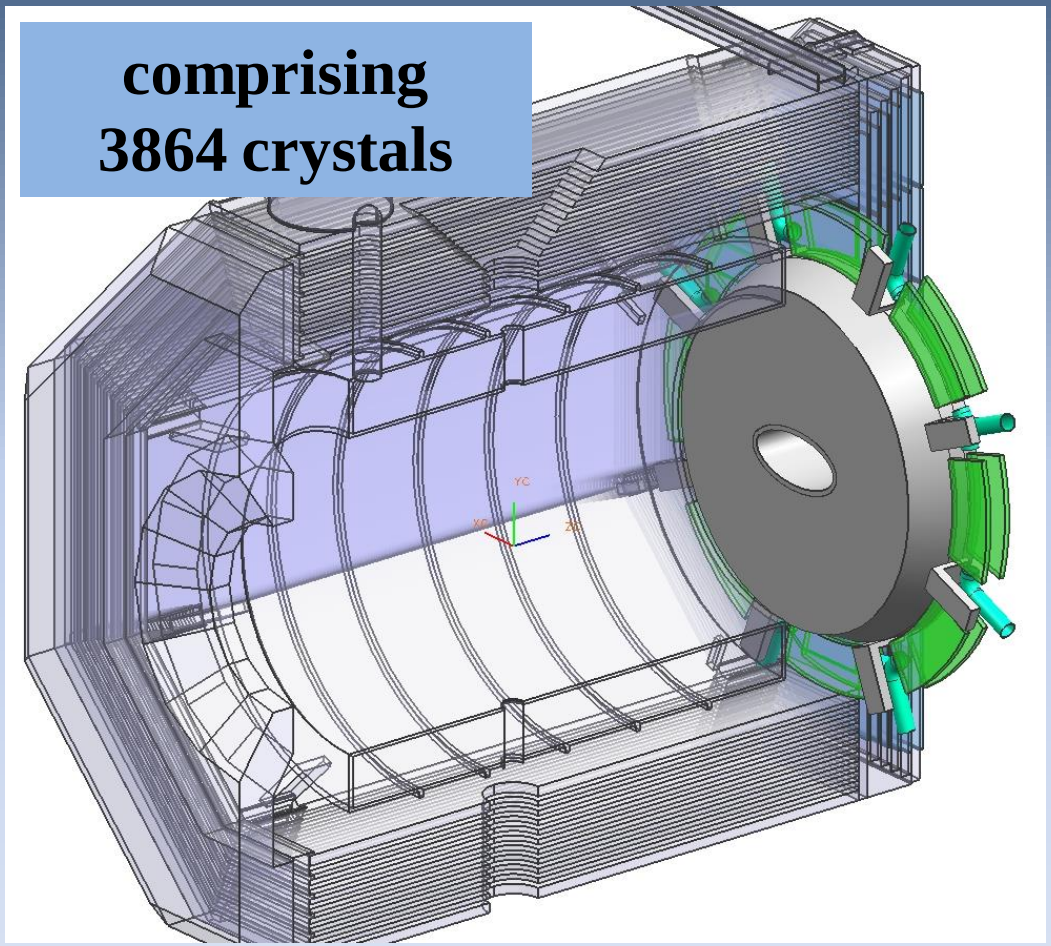
- 16 slices
- pointing off-target
- 11 360 crystals
- 200mm long ($22X_o$)
- 2 x 11 tapered shapes

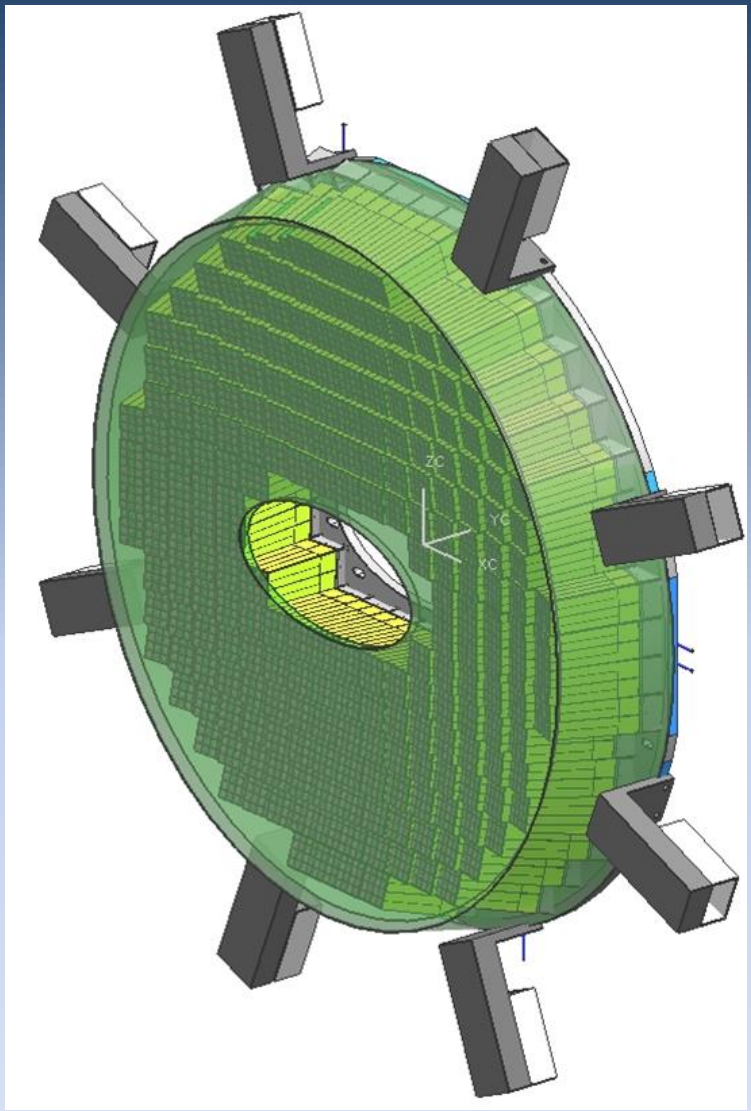




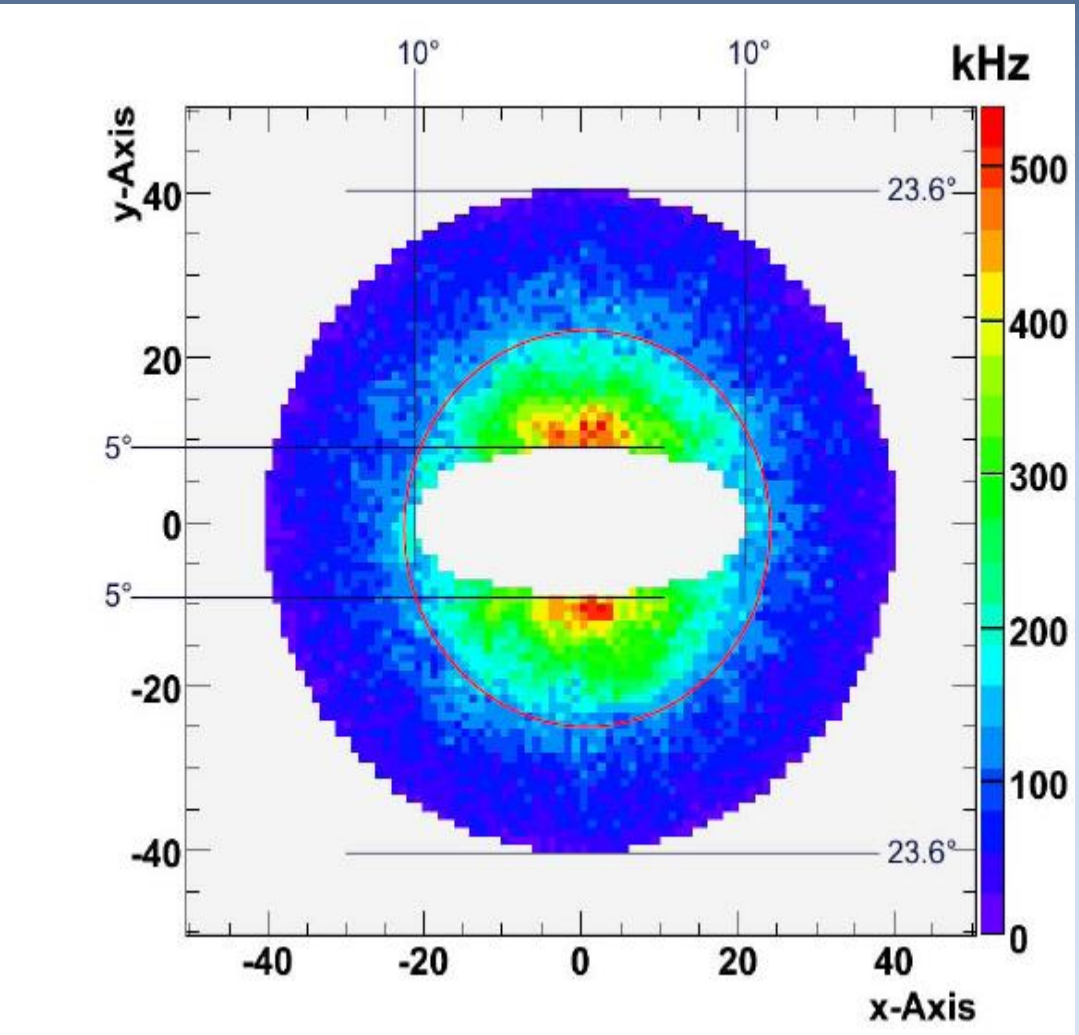


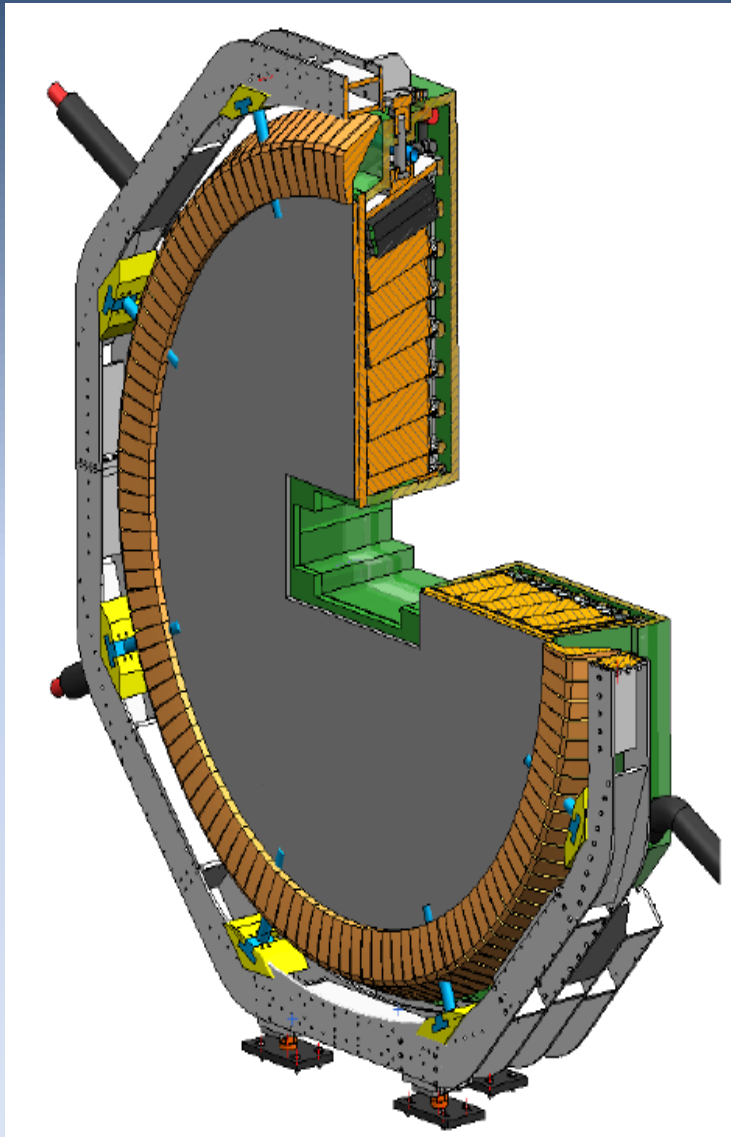
• the Target Spectrometer: Forward Endcap





• the Target Spectrometer: Forward Endcap

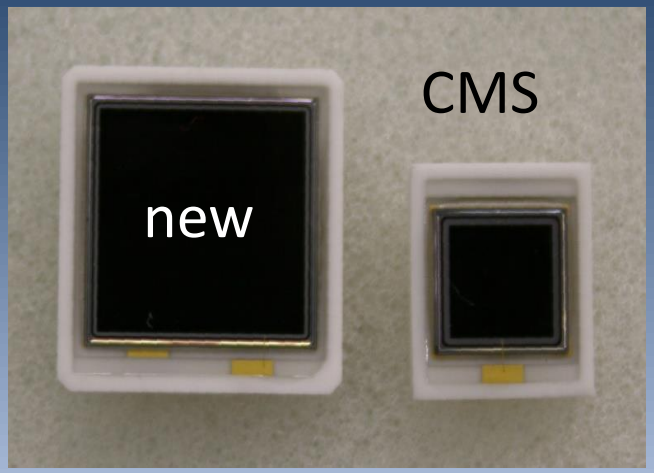




• photosensors Large Area Avalanche Photo Diodes (LAAPD)

in collaboration with *Hamamatsu Photonics*

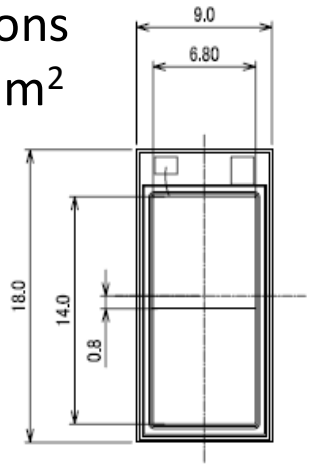
- **excellent performance**
  @ RT and T = –25°C
- **radiation resistent**
  up to 10^{13} protons
  in particular at T = -25°C

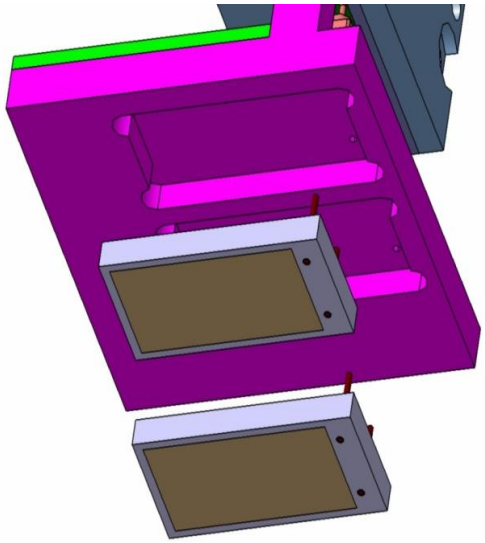


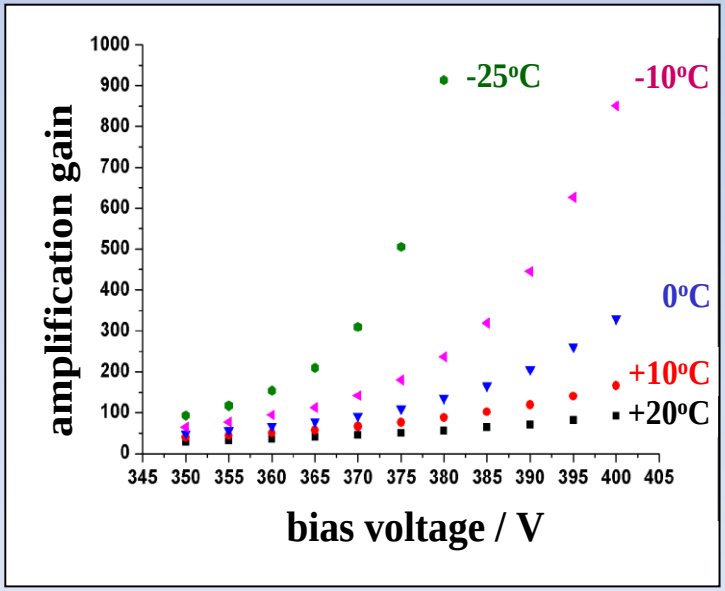
10x10mm² **5x5mm²**

final concept: **2 LAAPDs/crystal**
individually readout

dimensions
7 x 14 mm²

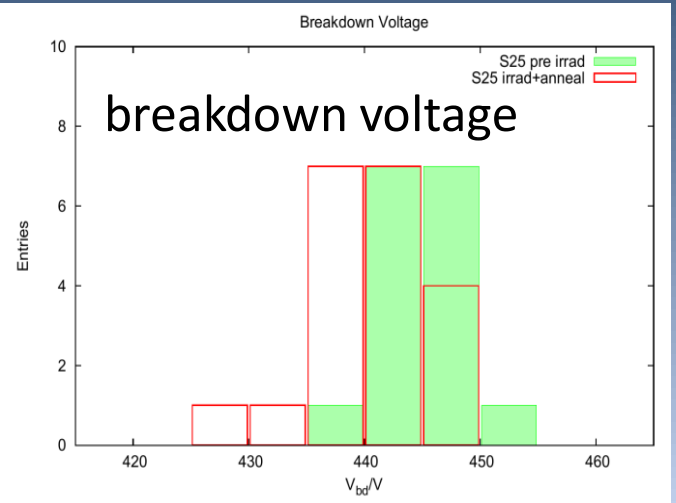




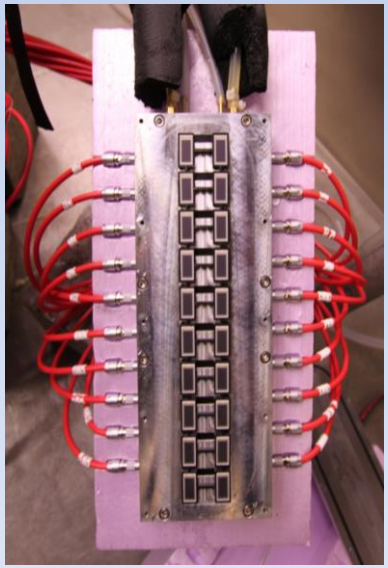


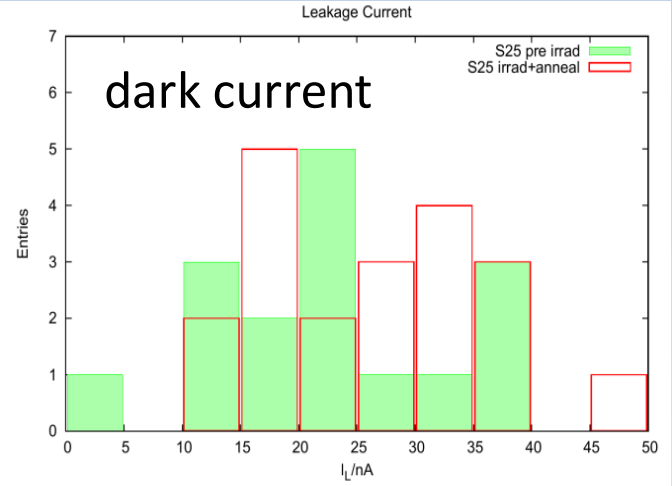
• screening of mass production LAAPD

after irradiation:



irradiation with γ-rays @ GI



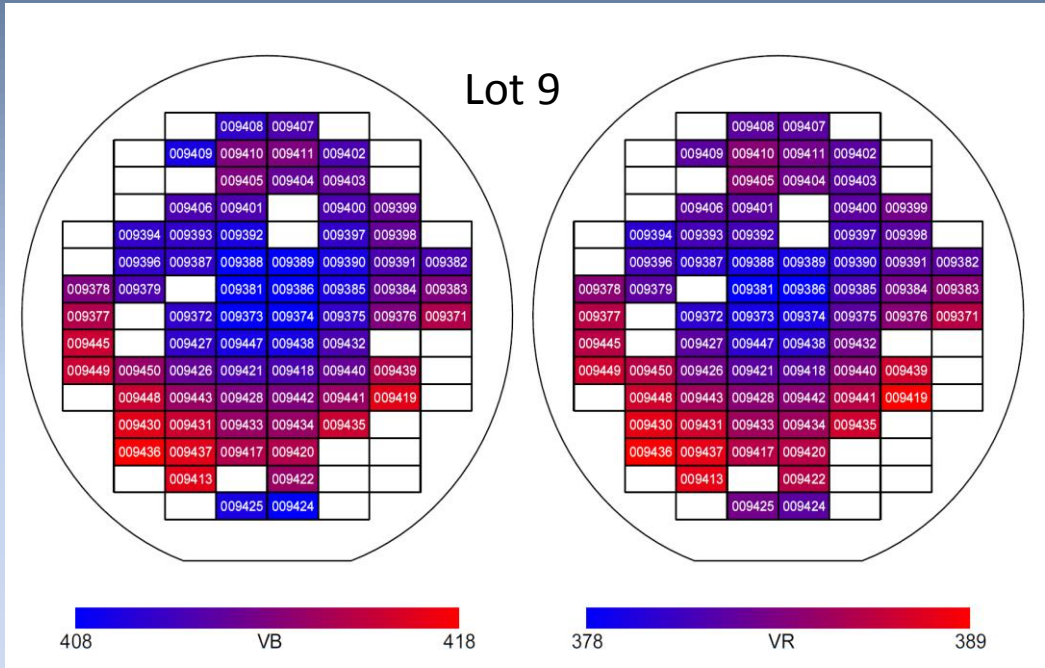


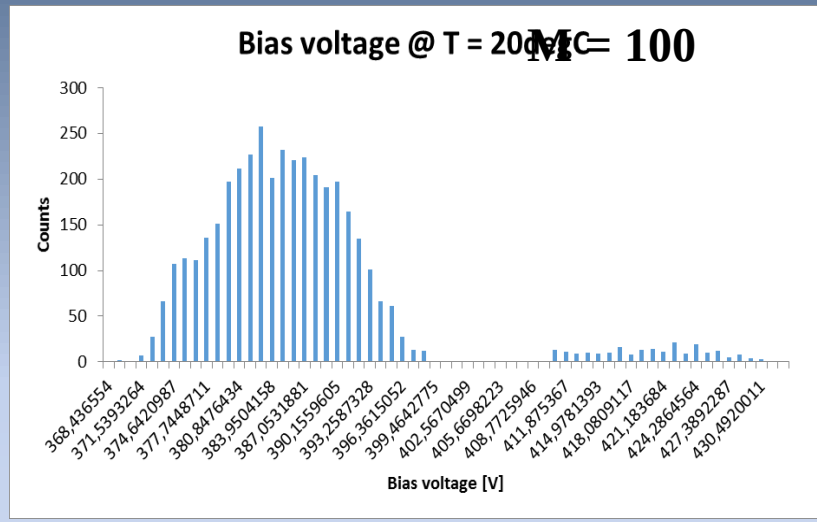
• APD screening at APD-Lab @ GSI

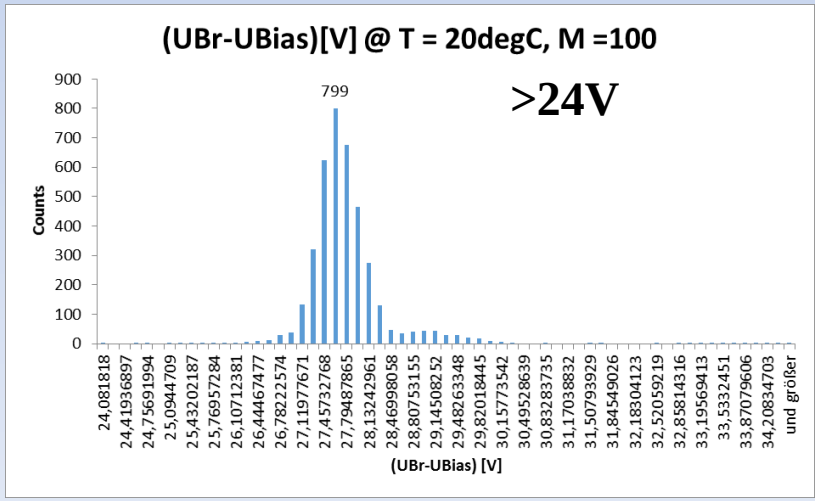
A. Wilms

data provided by Hamamatsu @ 20°C :

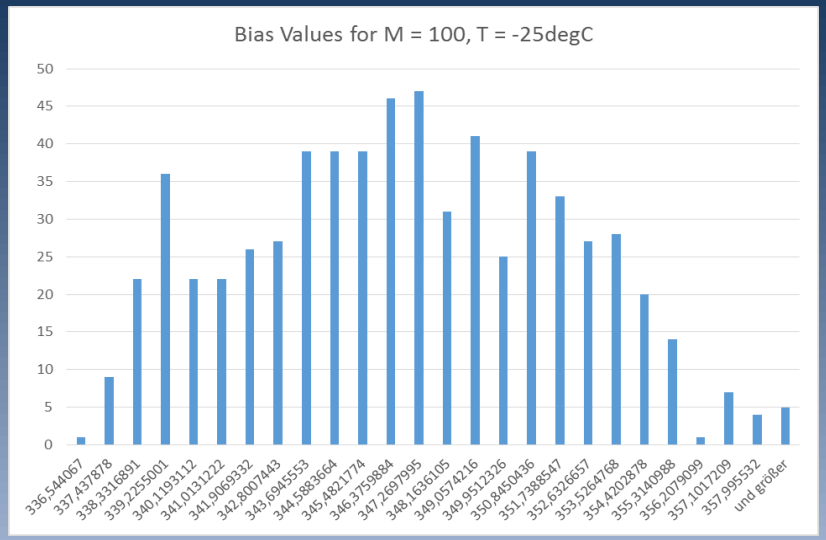
V_R for gain 100 and breakdown voltage V_B

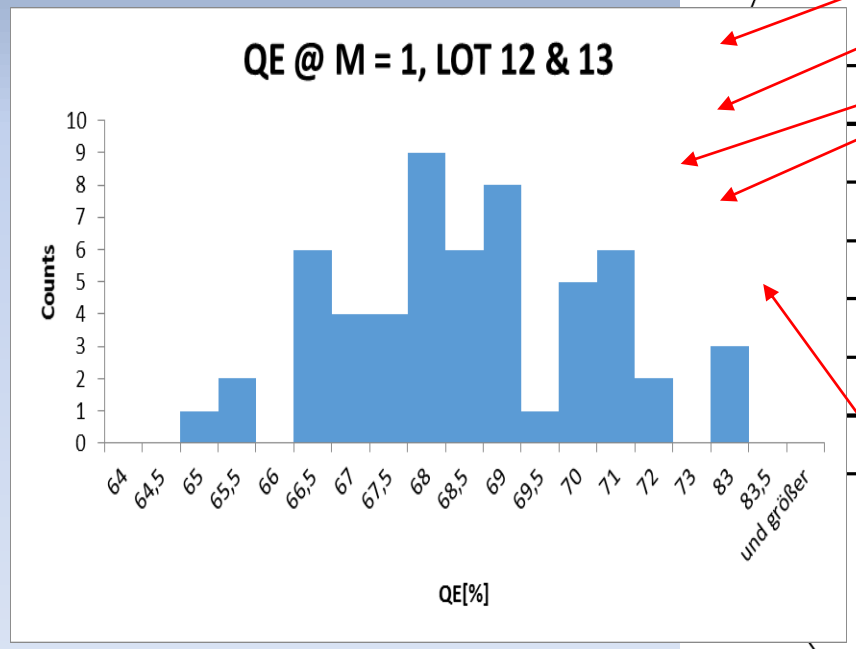


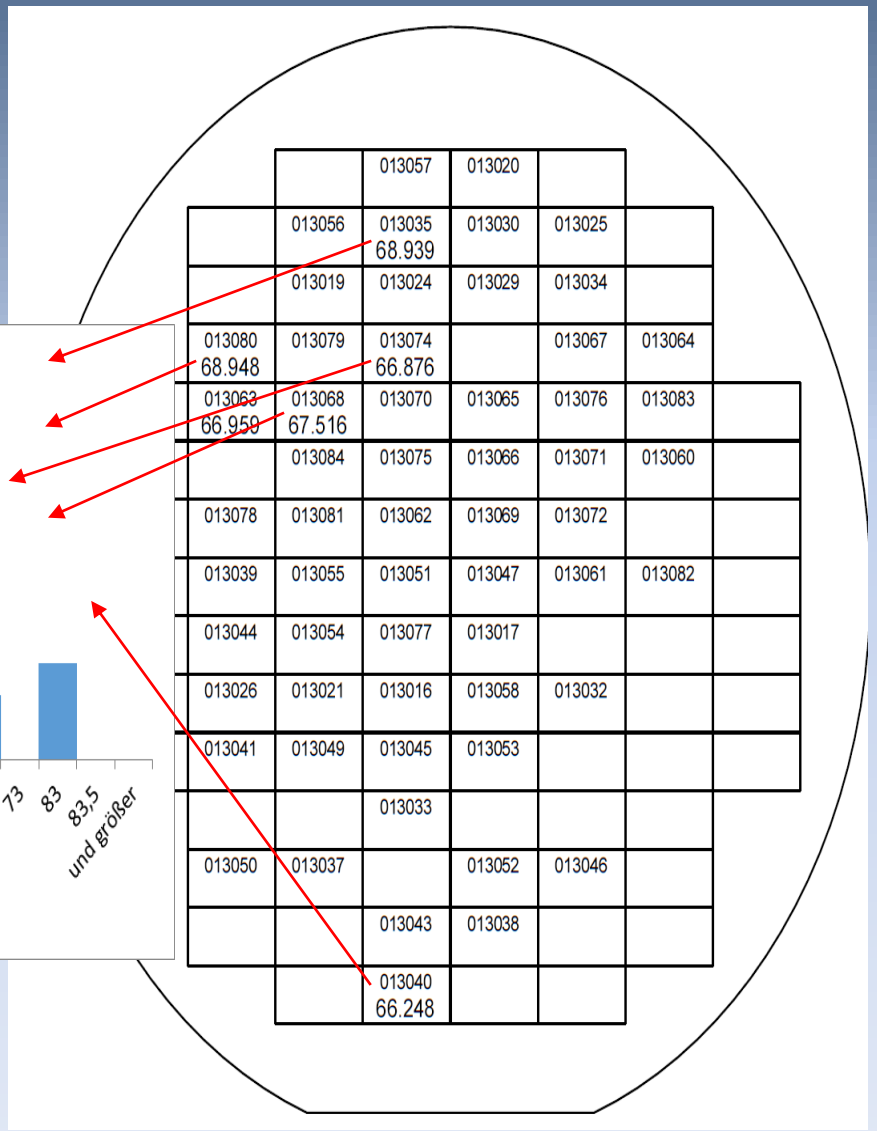




V_R @ M = 100 and T=-25ºC





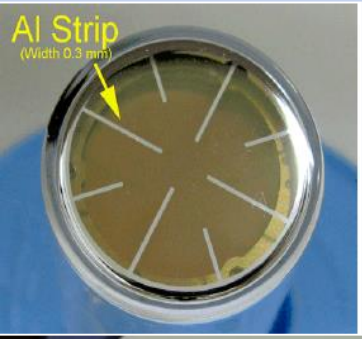


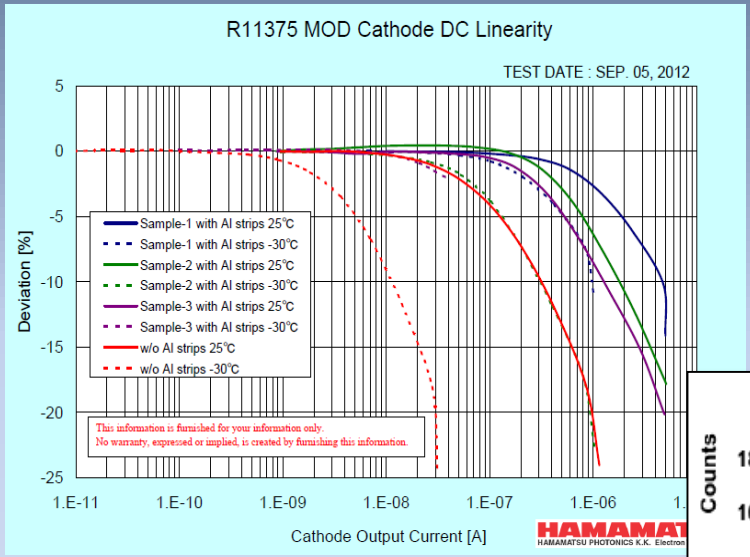
65% < QE < 90% @ M = 1

• photosensors (2): vacuum photo tetrodes (VPTT)

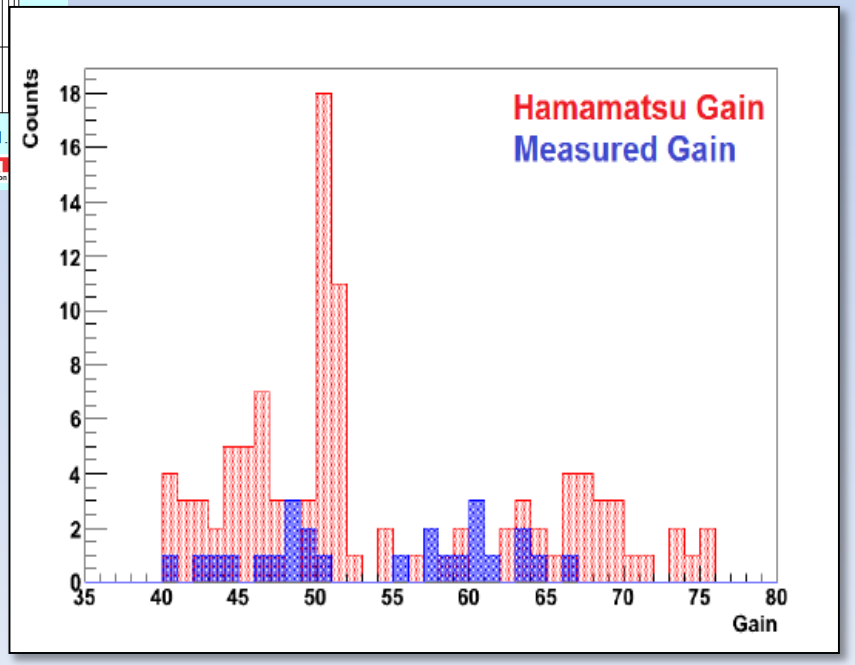
- to adapt to higher countrates (>>500kHz) in forward direction
- faster response – better timing options

✓new development of Hamamatsu: **higher gain, better rate capability**



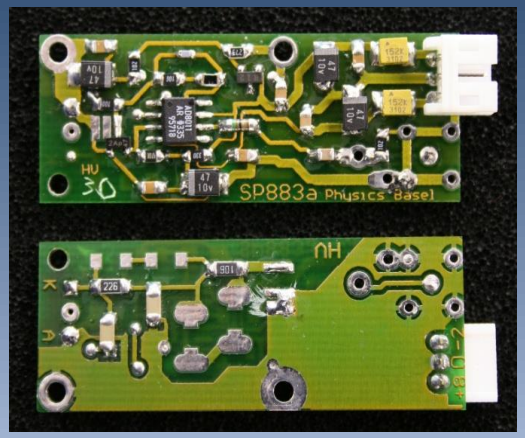


- **mass production completed**
- **gain loss in magnetic strayfield << 50%**



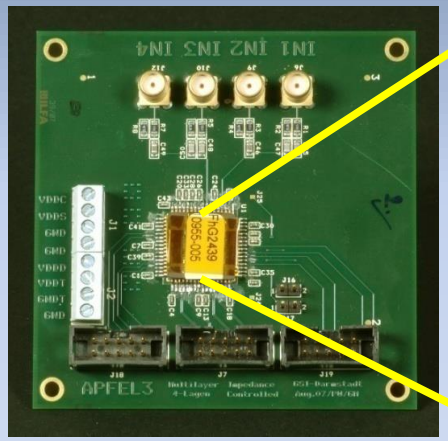
• development of low noise/power preamplifiers

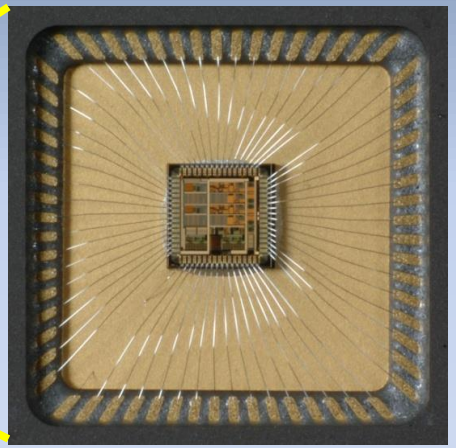
• design of descrete components
for forward endcap (APD,VPTT)



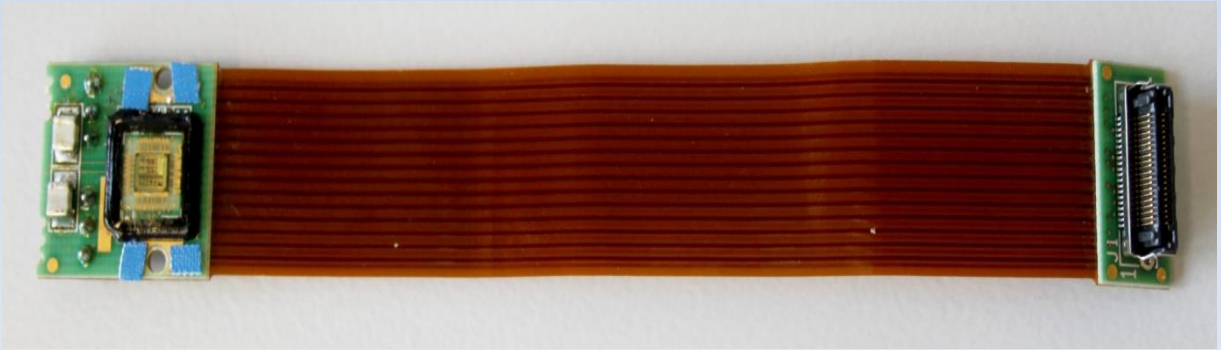
18mm

• ASIC (APFEL) large dynamic range



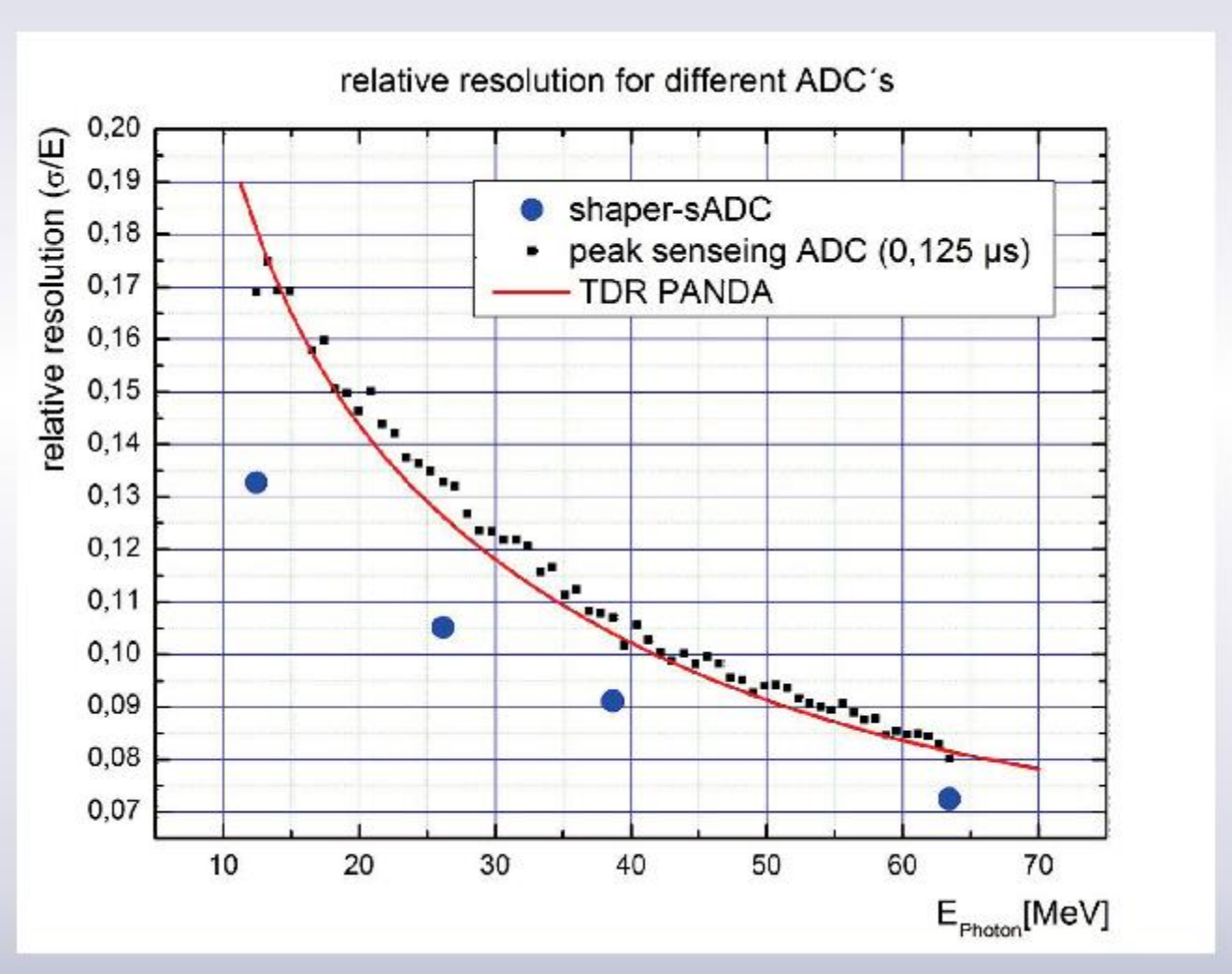


- **2 channels / 2 ranges**
- **overall range 1 – 10.000**
- **noise level (cooled)**
  << 2 MeV

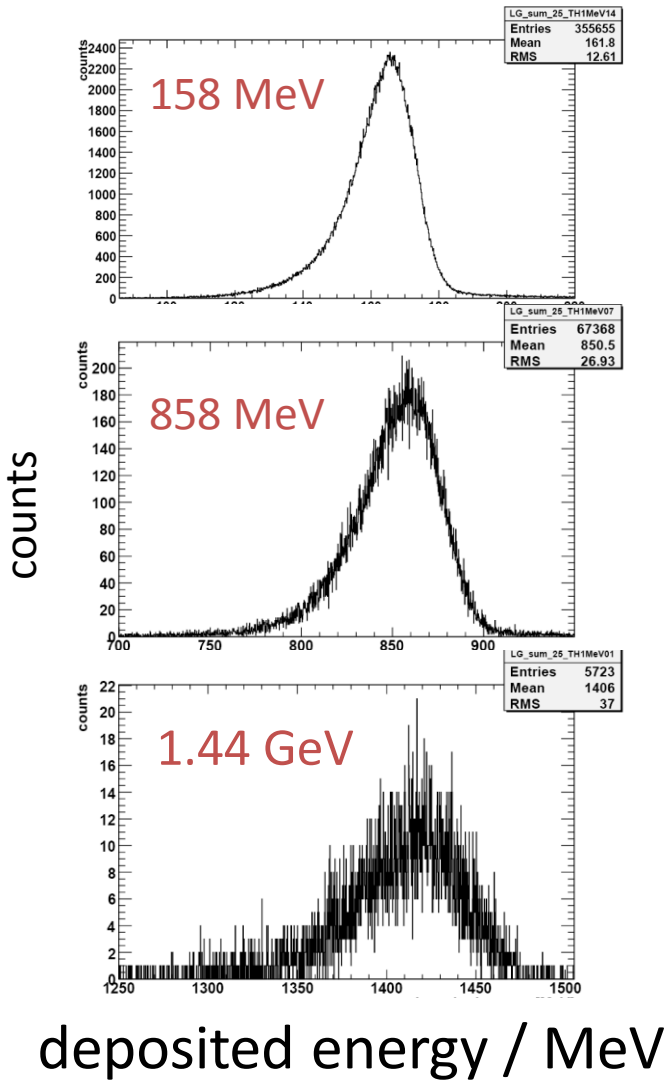


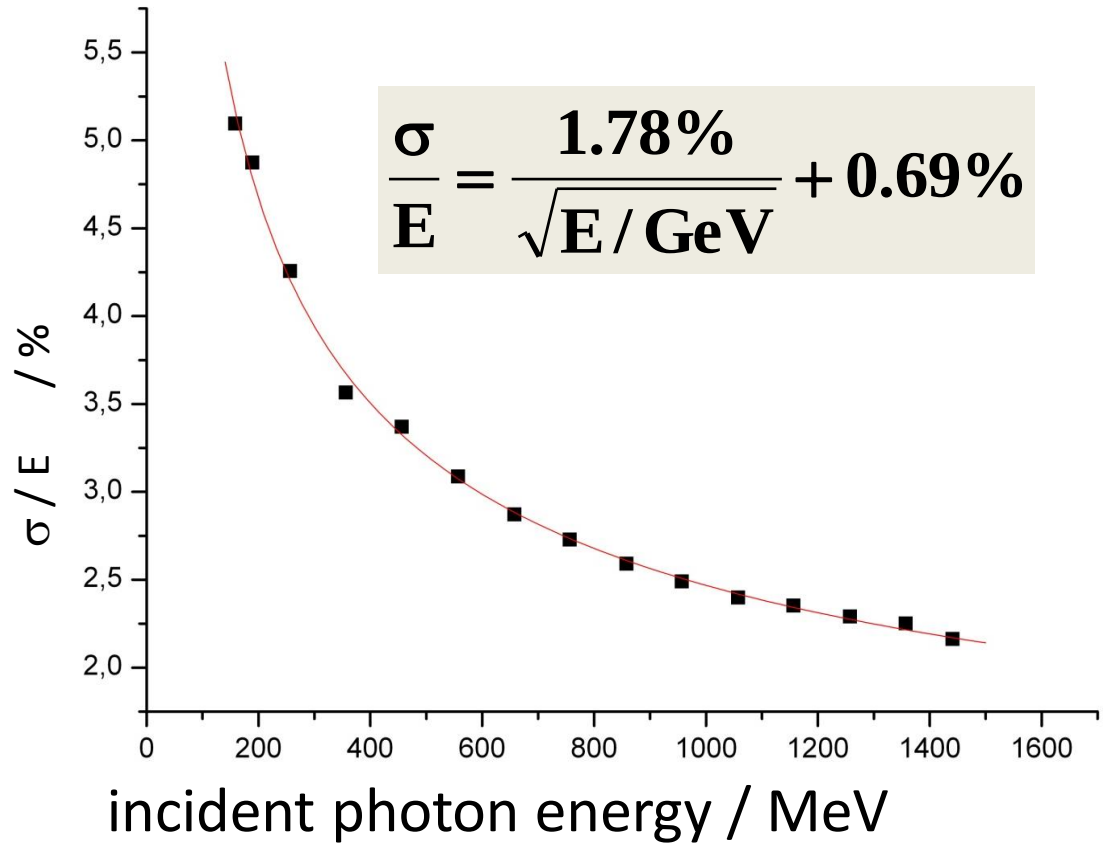
• the required and achieved performances

- based on prototypes



prototype performance PROTO 60

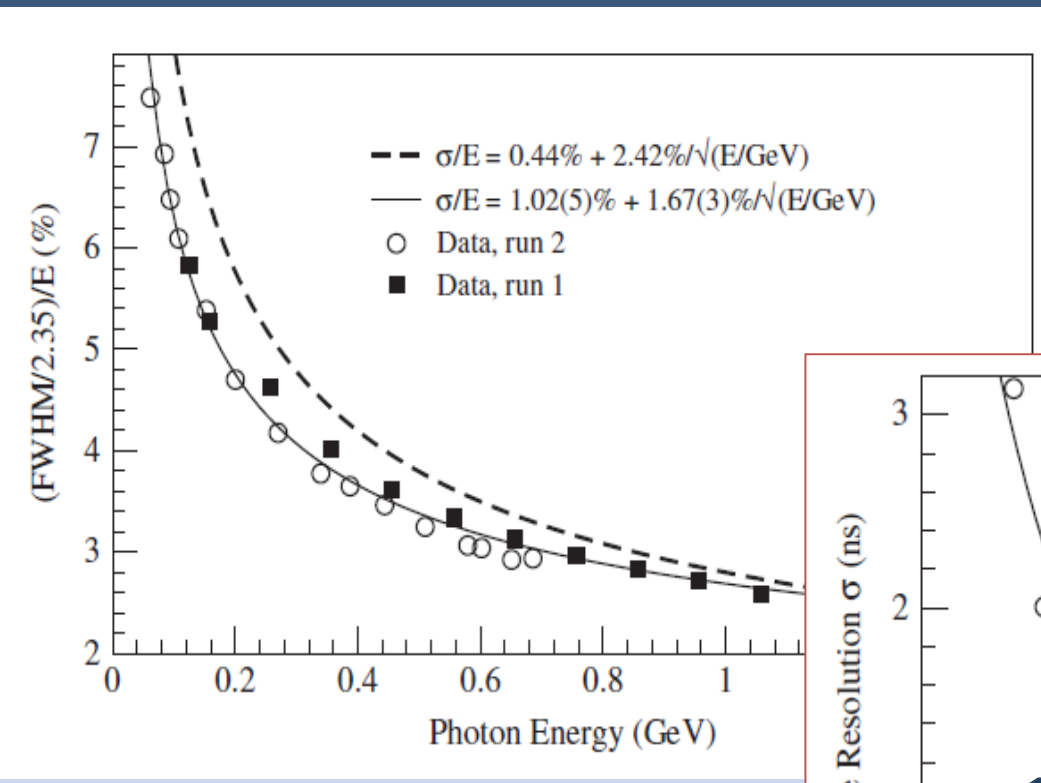




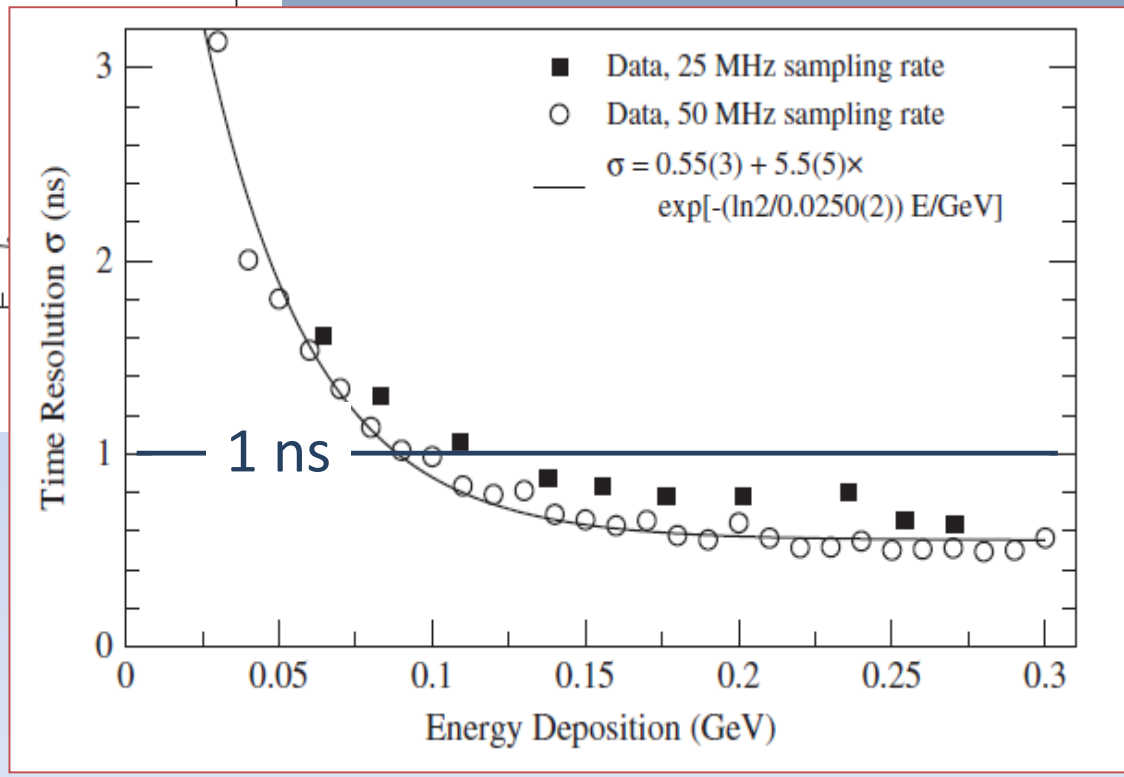
$$\frac{\sigma}{E} = \frac{1.78\%}{\sqrt{E/\mathrm{GeV}}} + 0.69\%$$

- digitization:
  shaping /peak-sensing ADC

readout via SADC: → further improvement

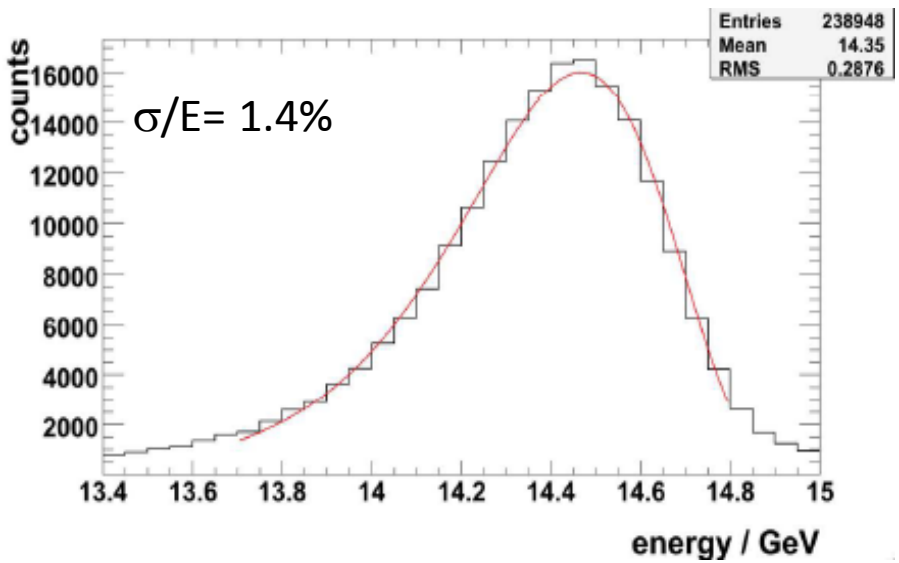


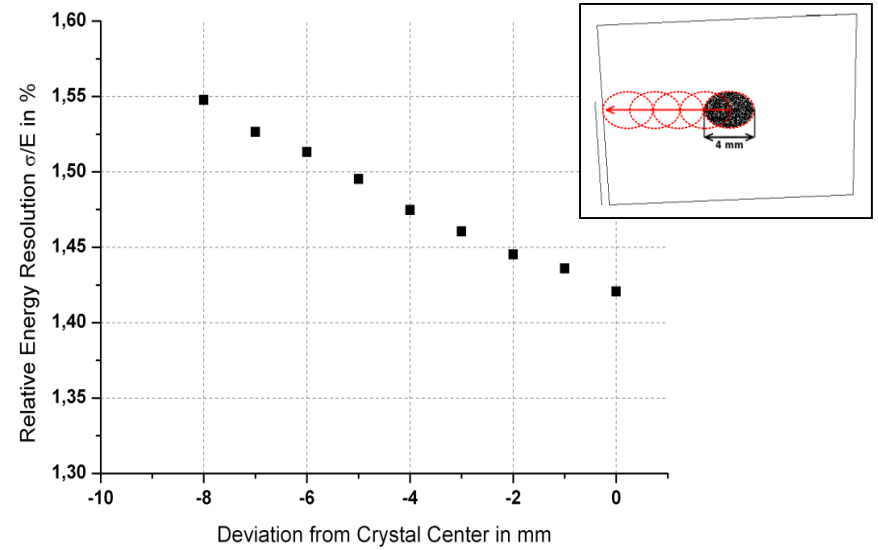
energy-resolution
(3x3 **matrix**)

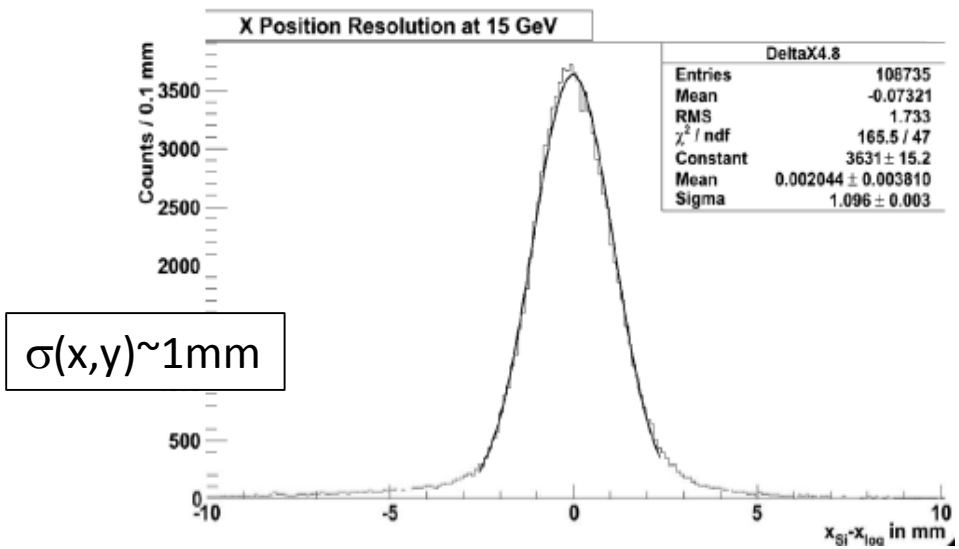


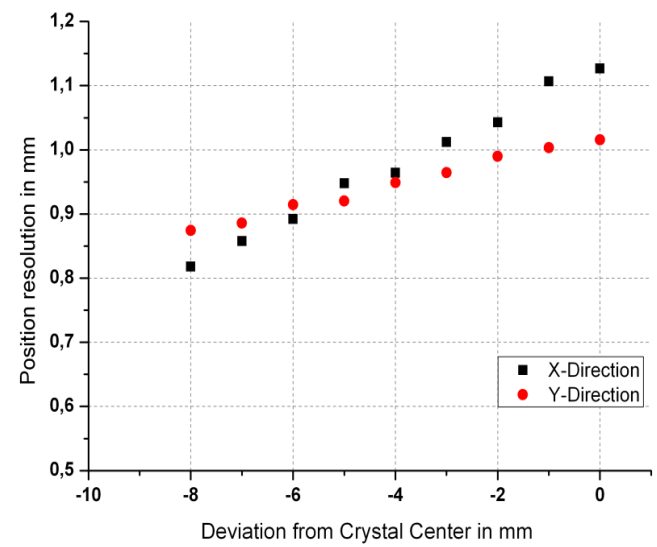
time resolution

• prototype performance PROTO 60 15 GeV positrons

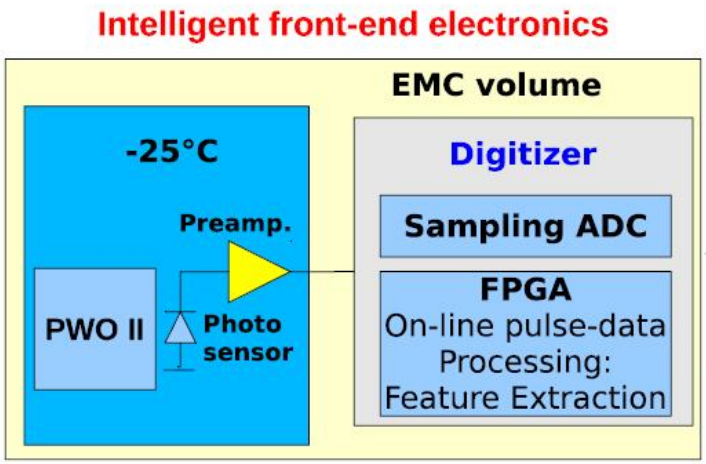


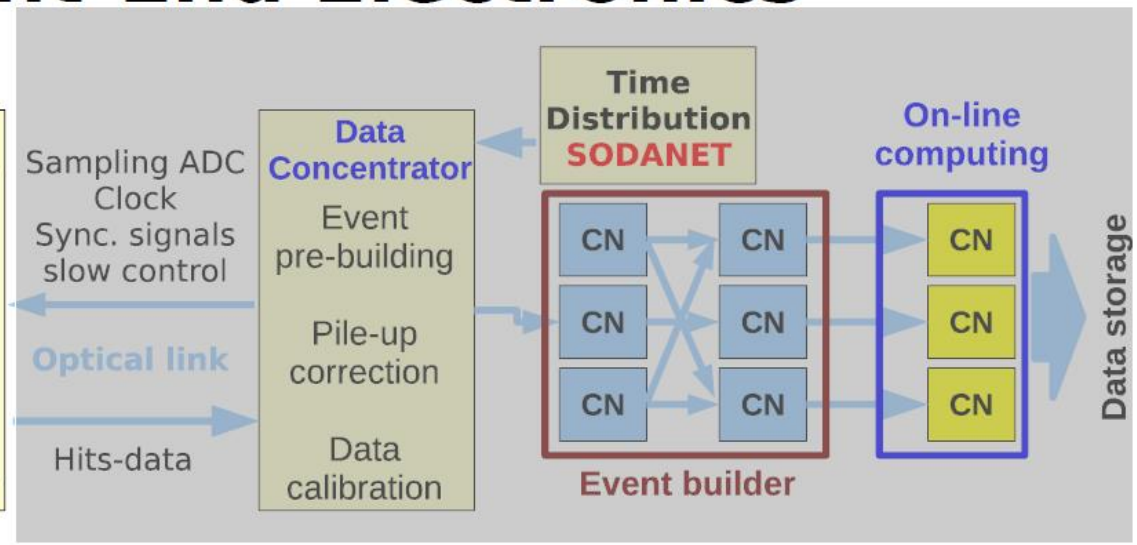






EMC Front-End Electronics



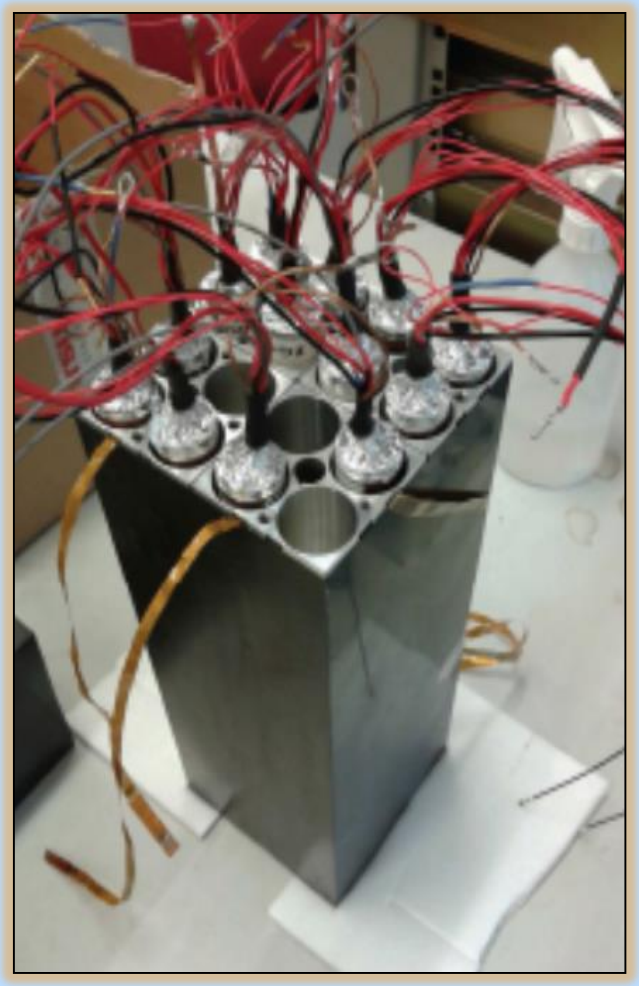


EMC digitizer:

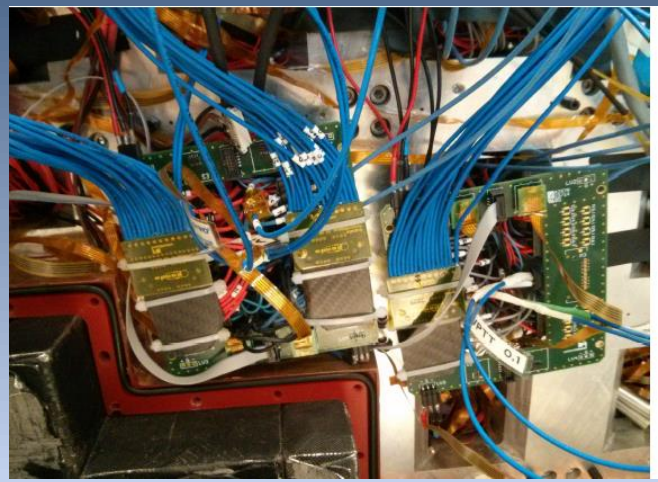
- 64 ADC channels (32 dual-gain readout channels)
- 14 bit resolution
- 80-125 MHz sampling rate
- On-line detection of hits, extraction of hit information, pulse pile-up recovery by two Xilinx Kintex-7 FPGAs

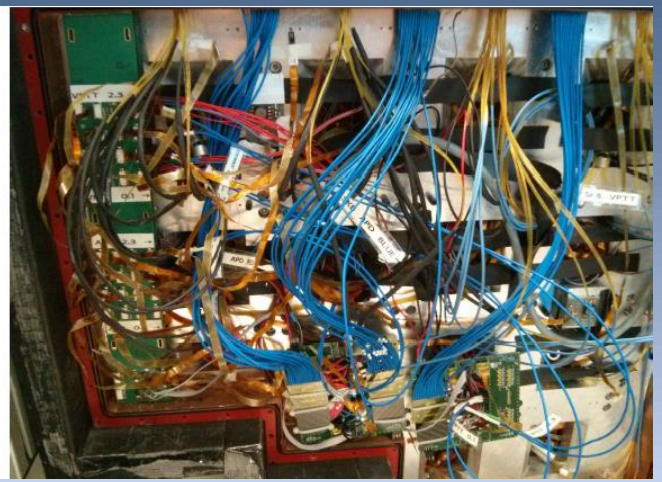
Digitizers are located in radiation area → precautions have to be taken against configuration changes and SEU in FPGAs

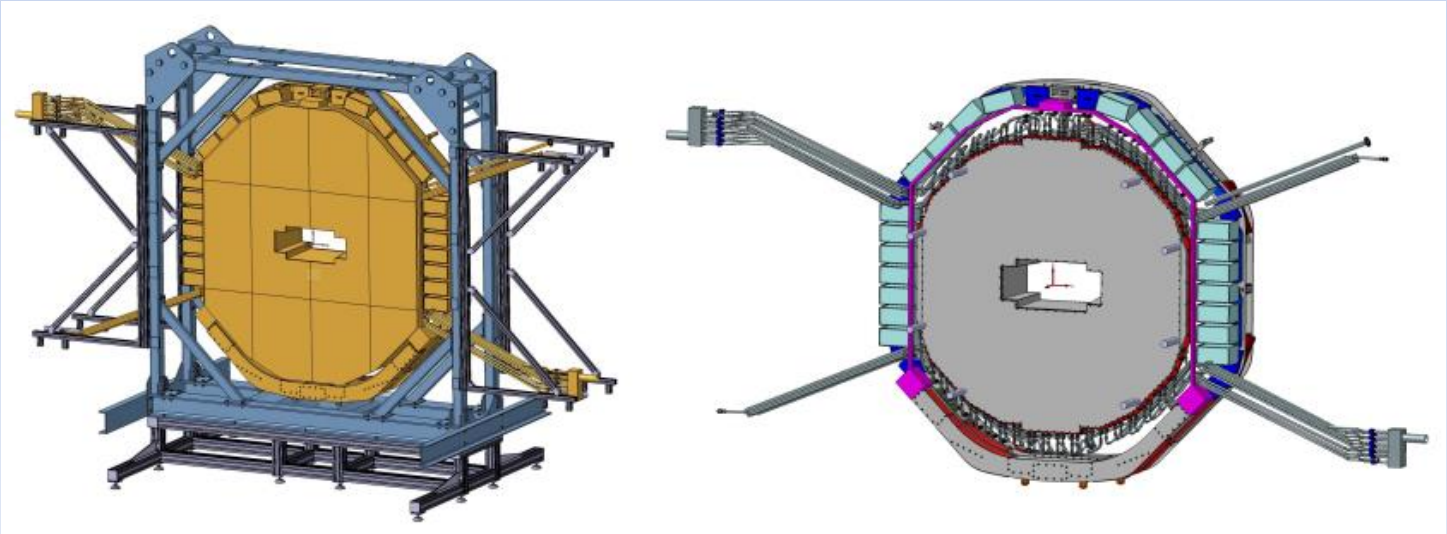
- **the realization of the Forward Endcap**



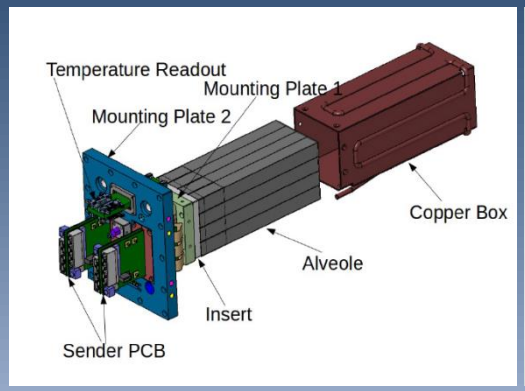
- **the Forward Endcap**

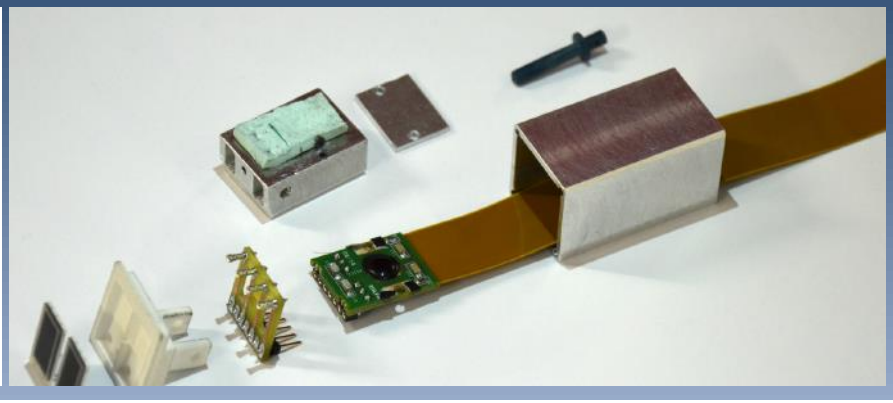


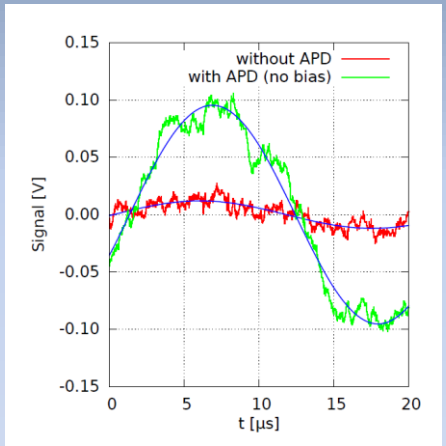


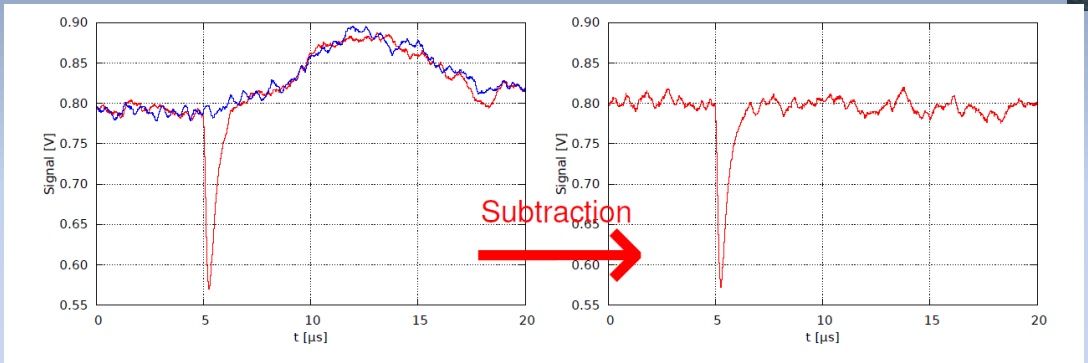


• the Backward Endcap

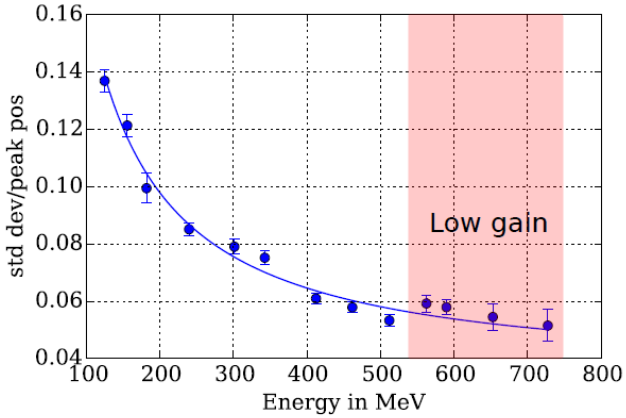






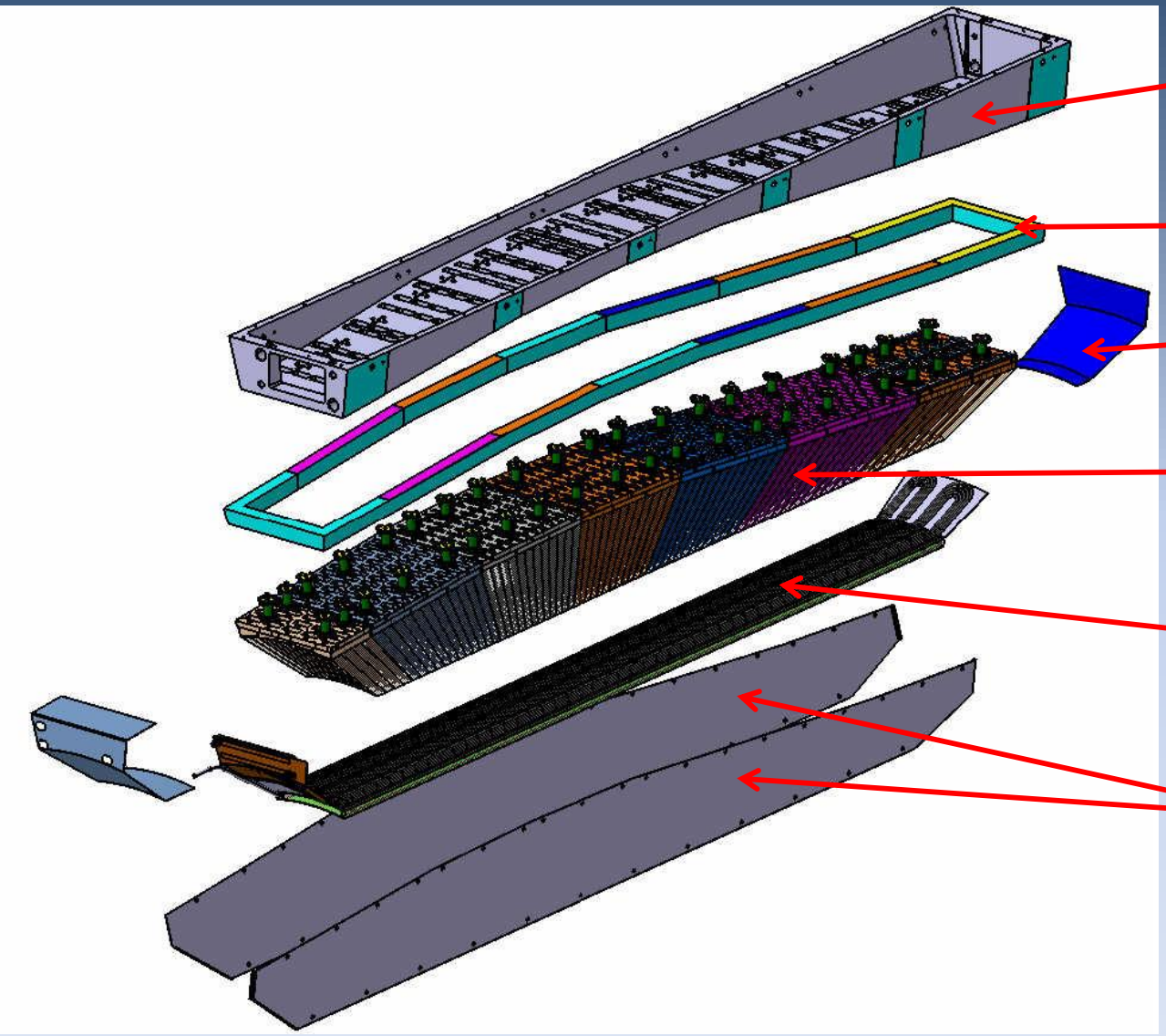


Relative energy resolution:

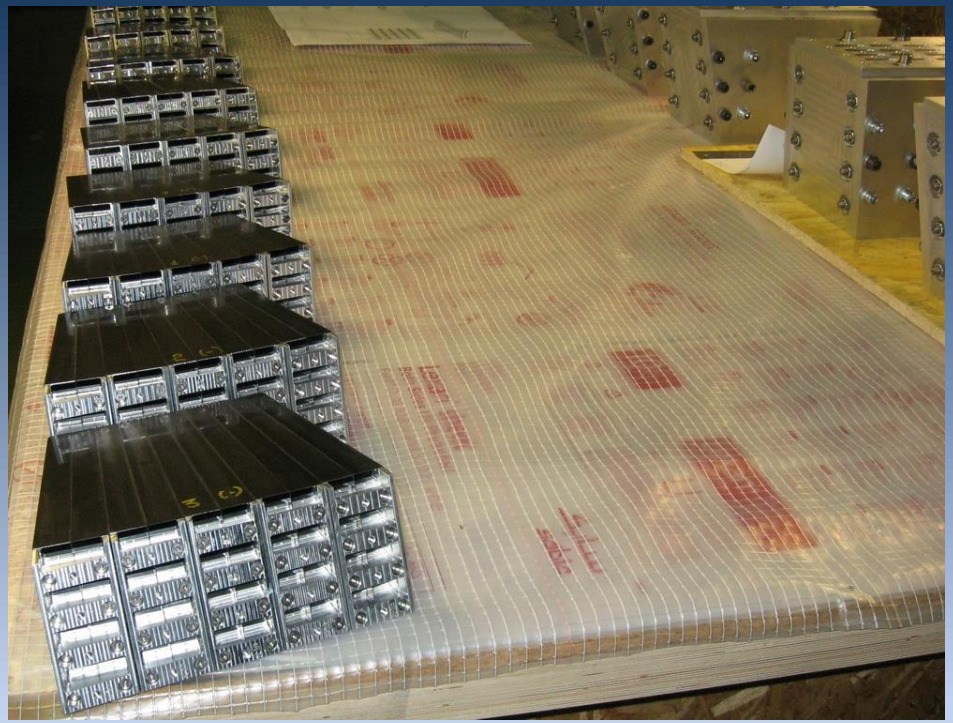


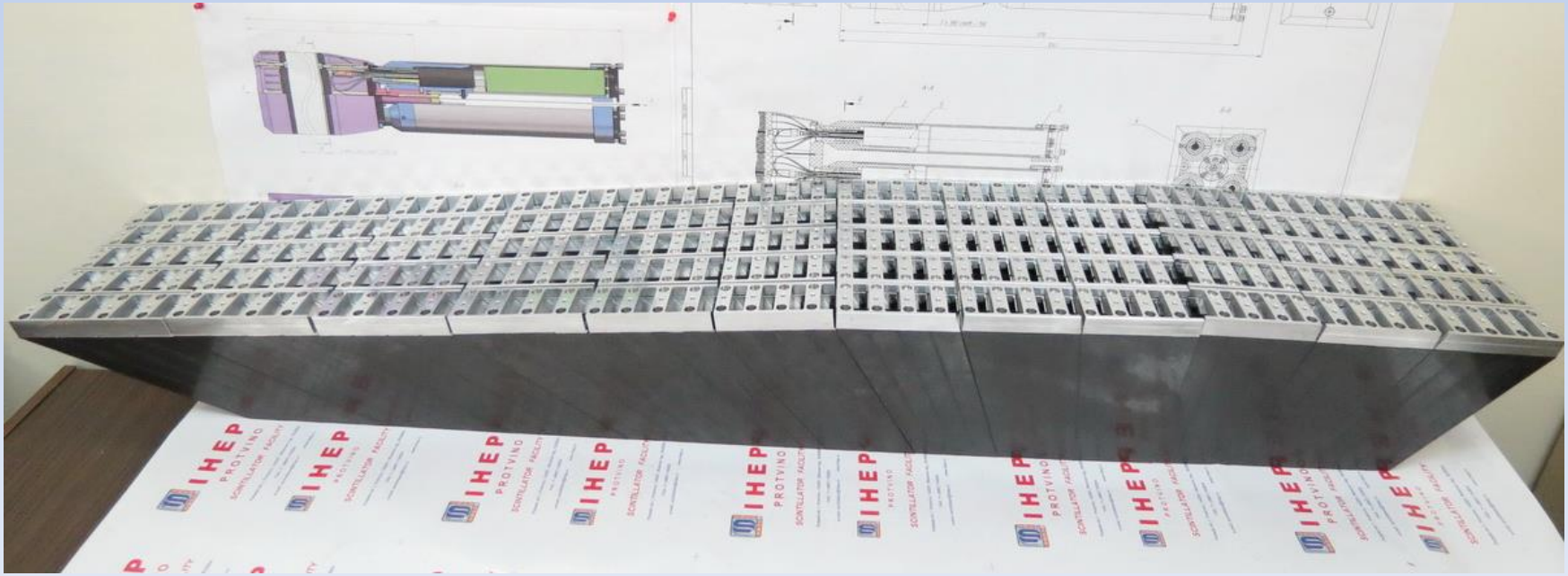
- 2-windows filter used
- good linearity (ASIC high/low gain ratio to be improved)
- relative energy resolution at 1 GeV: 4.5%
- E_{xtl} used: 11 MeV (conservative!)

• the Barrel


Aluminum Support Beam
Foam
Back Cover
Super-Modules
Cooling System
Side Covers

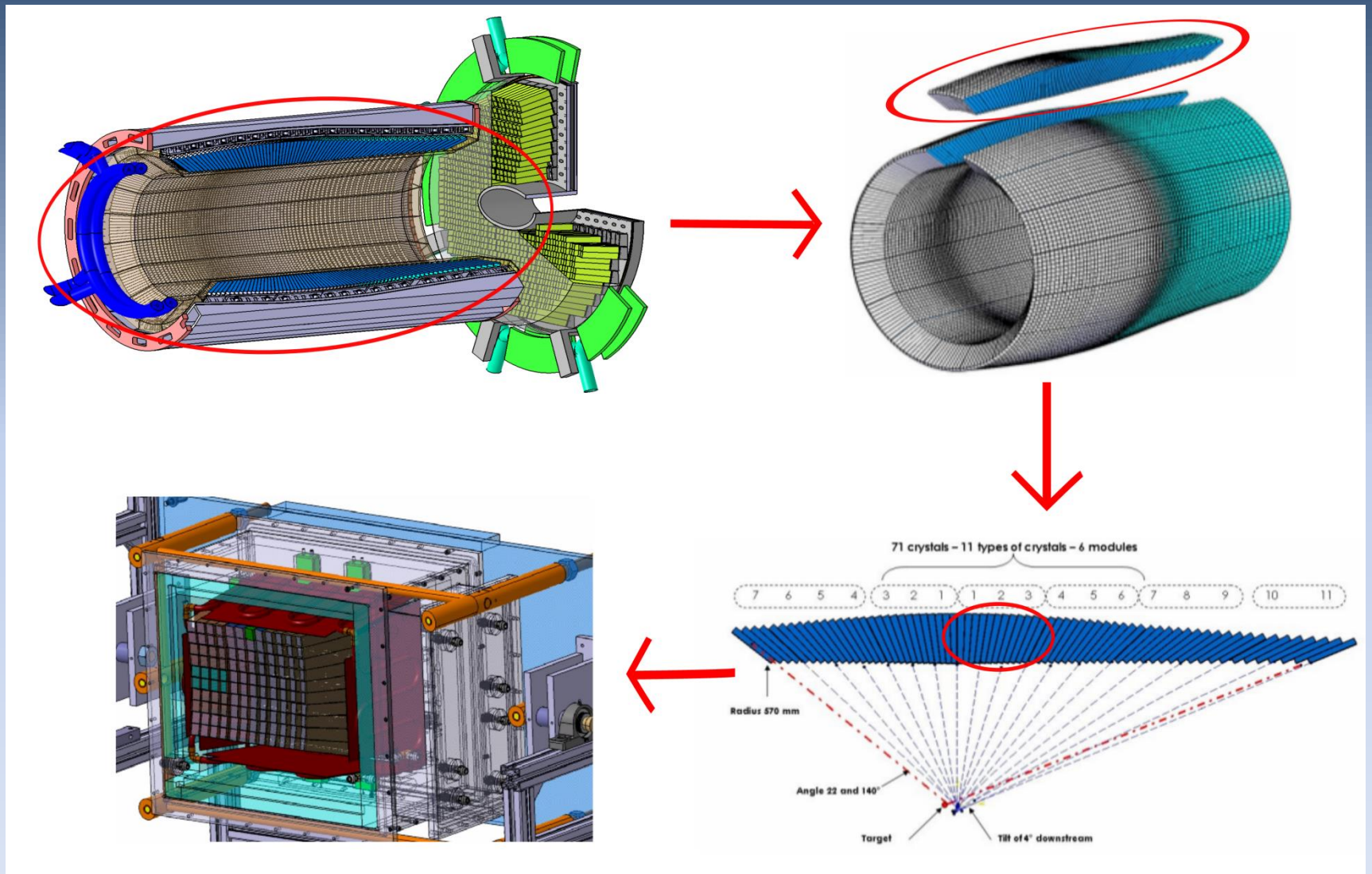
- **the Barrel**





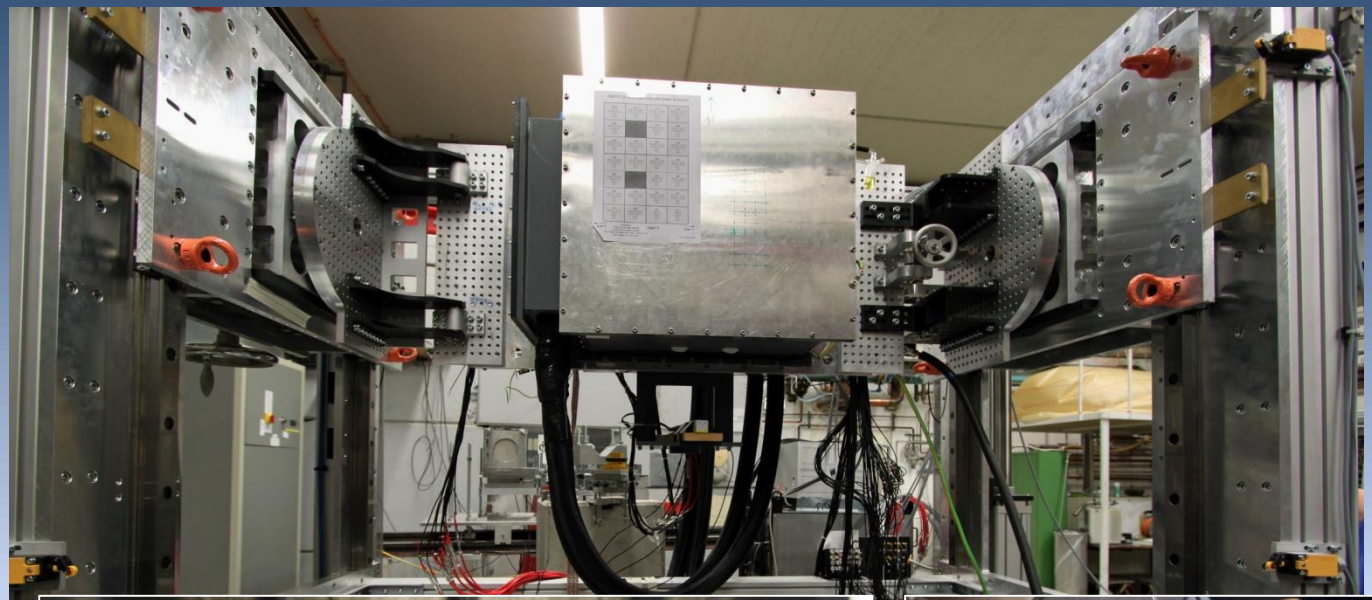
• the Barrel

PROTO120

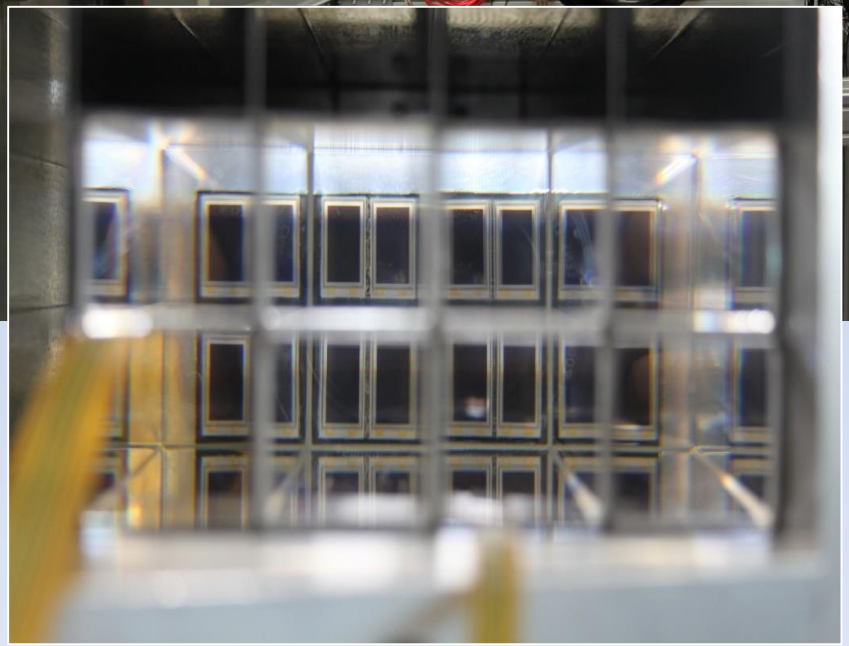


• the Barrel

PROTO120

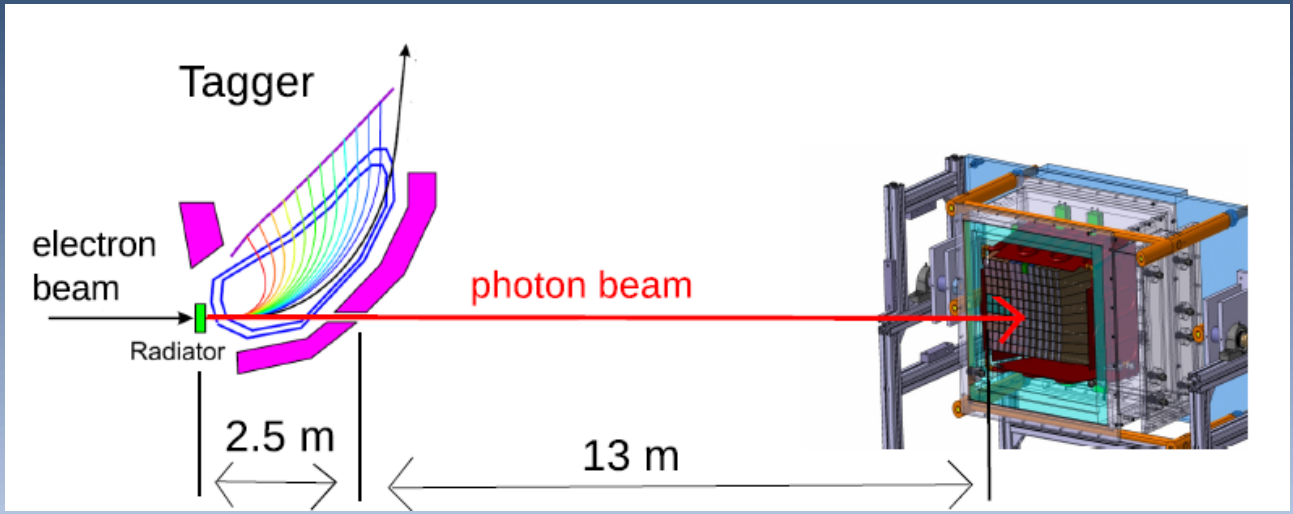


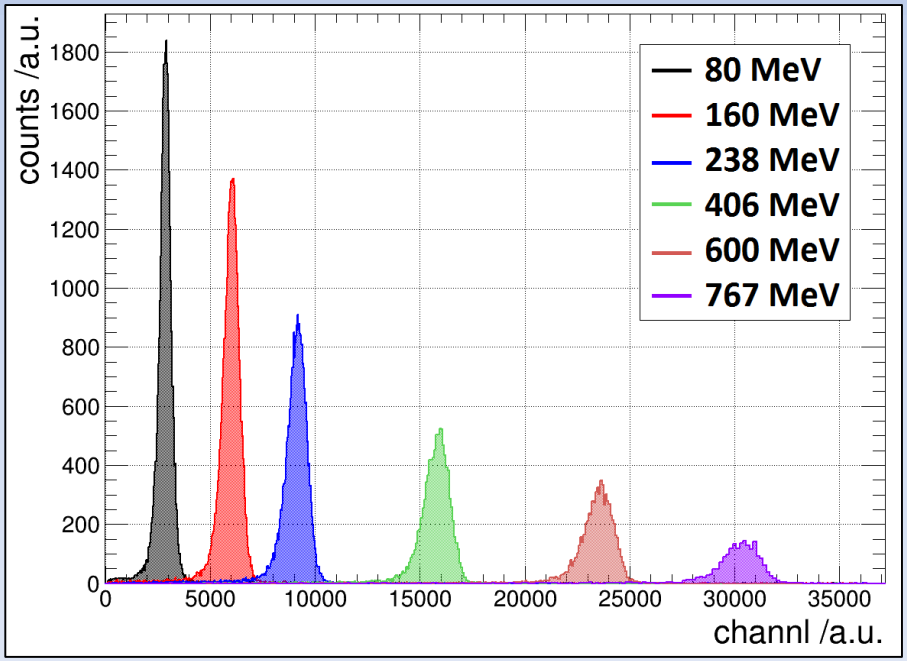
@ MAMI
Mainz

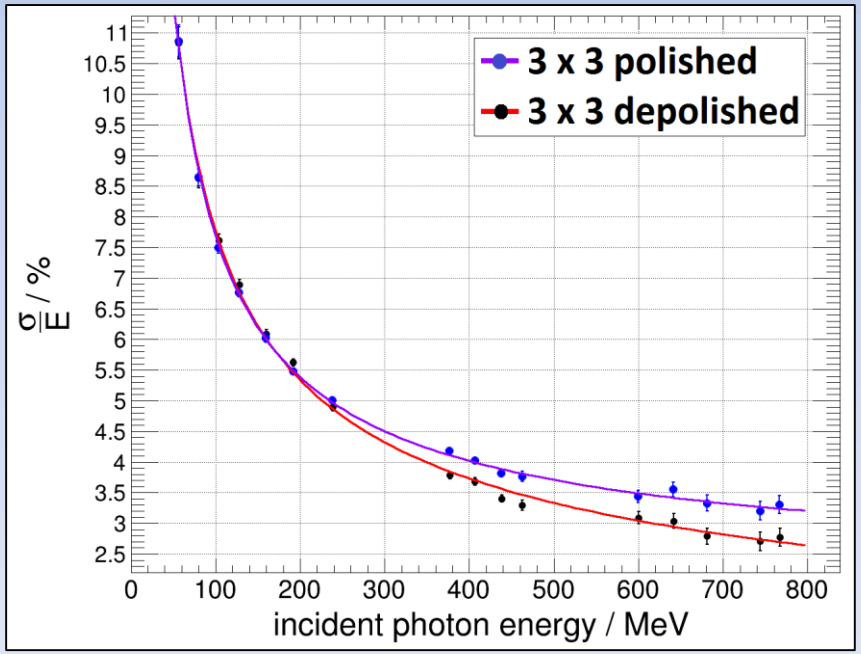


• the Barrel

PROTO120







- **Status and timelines**

- major components of **Forward Endcap** delivered, assembly has been started
- final design of **Backward Endcap** in 2015
- **Barrel**:
    - design completed end of 2015
    - missing crystals / LAAPDs
    - mechanics being manufactured
- **completion possible until end of 2018/19**

ongoing discussion of a
ge of program
nce
-.

Thanks for your attention

Facility
of

and
Ion
Research