Radiochromic Films for dose measurement in BEAST II phase 2

F. Di Capua - Università di Napoli and INFN
C. La Licata- Università di Trieste and INFN
L. Vitale - Università di Trieste and INFN

Italian Belle2 Meeting
Pisa, Nov. 21 2017

Outline

- Dosimetry in BEAST Phase2 with Radiochromic films
- Calibration strategy and first calibration with electrons
- Film installation on the detector
- Future work

Total Dose Measurement

- Use of passive film dosimeters was proposed in BEAST Phase II in June 2017
- Main motivation: simple, reliable total dose measurements at several Belle2 detector positions
- Radio-chromic films are made of single or double layers of radiation sensitive organic microcrystal monomers which provide accurate dose measurement (< 5%)
- Easy handling: pieces of films can be cut and adapted to arbitrary shapes

Used film types

- B3 (3kGy-100 kGy), to be positioned very close to interaction point (very thin (20 µm) foil)

- HDV2 (10 Gy – 1kGy) for intermediate range of doses (90 µm thickness)

- EBT3 (0.1-80 Gy) (300 µm thickness)

GAFCHROMIC™ HD-V2 Dosimetry Film

GAFChromic HD-V2 is a radiochromic dosimetry film designed for the quantitative measurement of absorbed dose of high-energy photons. As a self-developing film, HD-V2 is a perfect fit for the processorless environment. Since radiochromic film requires no post-exposure processing, there are no chemicals to dispose of and the film can be handled and used without need of a darkroom.

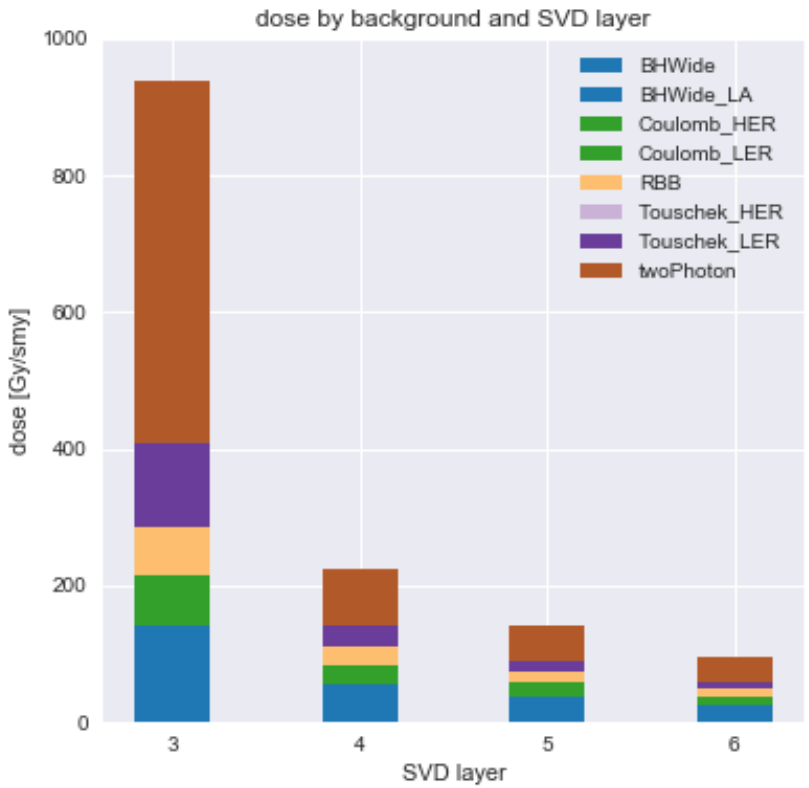
Key technical features of GAFCHROMIC® H-VD2 include:

- Dynamic dose range: 10 Gy to 1000 Gy
- Develops in real time without post-exposure treatment;
- Energy-dependence: minimal response difference from 100keV into the MV range;
- Near tissue equivalent;
- High spatial resolution – can resolve features to 5µm, or less;
- Active coating exposed for detection of low energy photon and electron
- Proprietary new technology incorporating a marker dye in the active layer:
  - Enables non-uniformity correction by using triple-channel dosimetry
  - Decreases UV/light sensitivity;
- Stable at temperatures up to 60°C;

Property	GAFChromic™ EBT3 Film
Configuration	Active layer (28 µm) sandwiched between 125 µm matte-surface polyester substrates
Size	8" x 10", other sizes available upon request
Dynamic Dose Range	0.1 to 20 Gy
Energy dependency	<5% difference in net optical density when exposed at 100 keV and 18 MeV
Dose fractionation response	<5% difference in net optical density for a single 25 Gy dose and five cumulative 5 Gy doses at 30 min. intervals
Dose rate response	<5% difference in net optical density for 10 Gy exposures at rates of 3.4 Gy/min. and 0.034 Gy/min.
Stability in light	$<5x10^{-3}$ change in optical density per 1000 lux-day
Stability in dark (pre-exposure stability)	$<5x10^{-4}$ optical density change/day at 23 °C and $<2x10^{-4}$ density change/day refrigerated
Uniformity	Better than ±3% in sensitometric response from mean; dose uniformity better than ±2% with FilmQAPro and triple-channel dosimetry

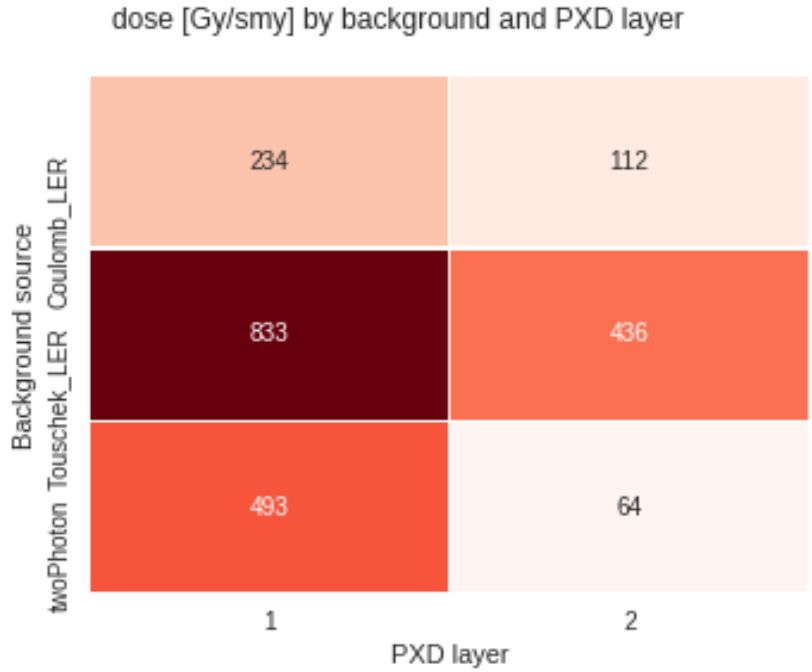
Expected Doses (recent MC studies)

SVD



By P. Kvasnicka,
October 2017 B2GM

PXD



By B. Schwenker,
October 2017 B2GM

Mixed field dosimetry

- Film batch has to be independently calibrated (batch to batch uncertainty is within 10%)
- Calibration needed for all film types with different radiation fields in the view of deployment in the SuperKEKB mixed field
- Electron/Gamma independency of all-considered-film response is reported in literature in the range from few MeV up to 20 MeV
- For EBT3, response independency* also found from 50 keV (X-ray) to 1 MeV (electron and gamma). Same response with 50 MeV protons.

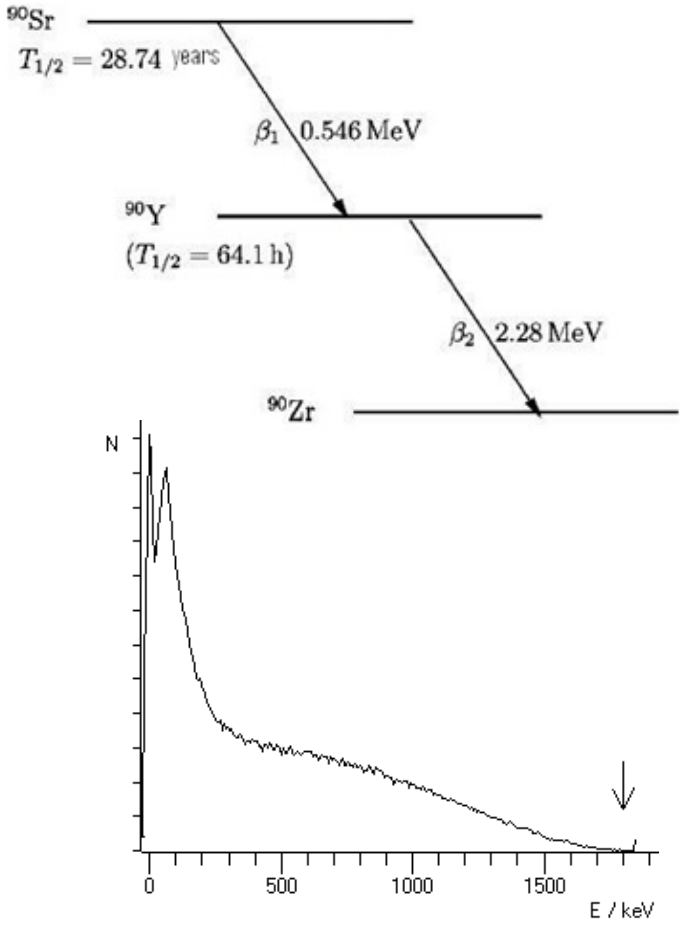
**JINST 12 P08015, "Absolute dose calibration of EBT3 Gafchromic films", L. Campajola, P. Casolaro, F. Di Capua*

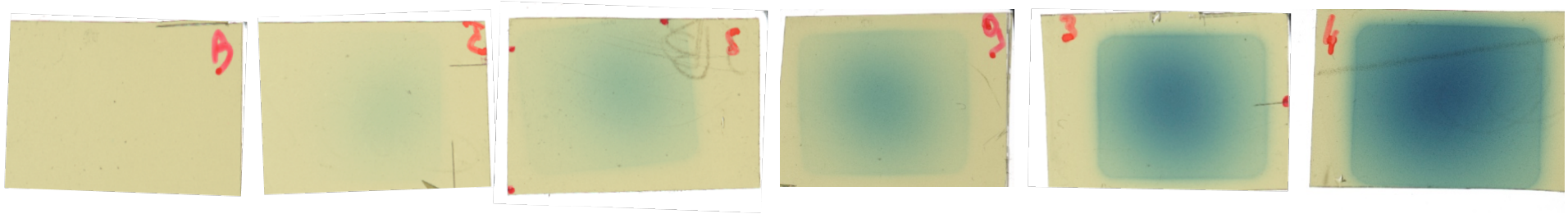
Calibration strategy

- Energy extension of calibration up to GeV: BTF (Frascati) will be available only in late 2018, possibility in Mainz is under investigation
- Fast Neutron contribution to radio-chromic film respons will be investigated with Frascati Neutron Generator (14 MeV n from T(d,n)α) and/or Am-Be source
- Tapiro and Triga reactors @Casaccia for thermal neutrons
- Protons: Tandem and CS (1-62 MeV)
- **We started batch calibrations with low energy electrons**

Film calibration of procured batches

- A first calibration of HDV2 films has been performed with a calibrated beta source (^{90}Sr) at Napoli University (films at 3 mm from source)
- The source mounted on a motorized system provides a previously verified dose (dose/ rate@3mm: 10.4 Gy/h)
- EBT3 will be calibrated in the same way





Blank **11.0 Gy** **34.5 Gy** **77.8 Gy** **248 Gy** **438 Gy**

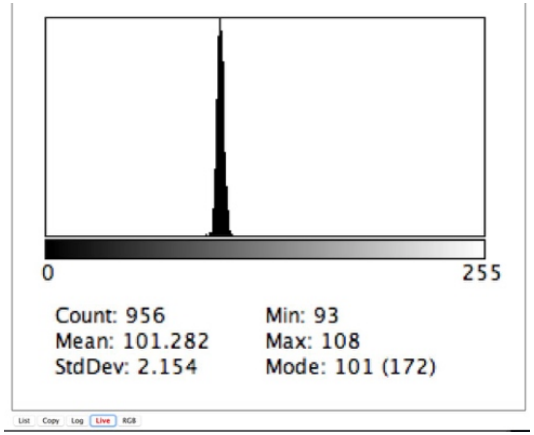
Analysis of images: ImageJ vs ROOT

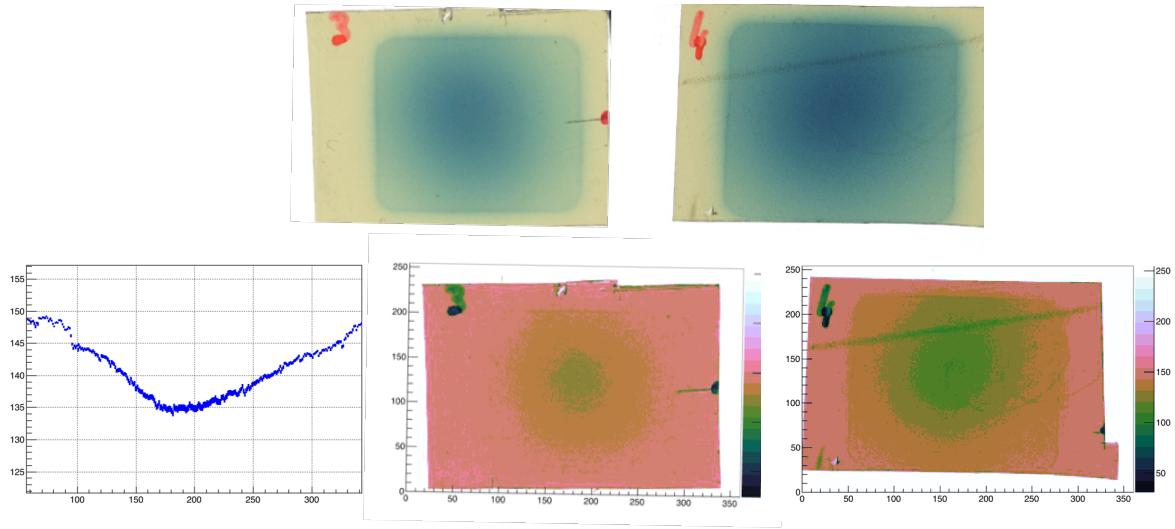
ImageJ

- ImageJ software is a benchmark for film image analysis
- Able to deal with TIFF uncompressed format which preserve image quality
- Produce Gray Level distribution of the pixels (Pixel Value)
- Determination of the Mean and Standard Deviation in a given ROI

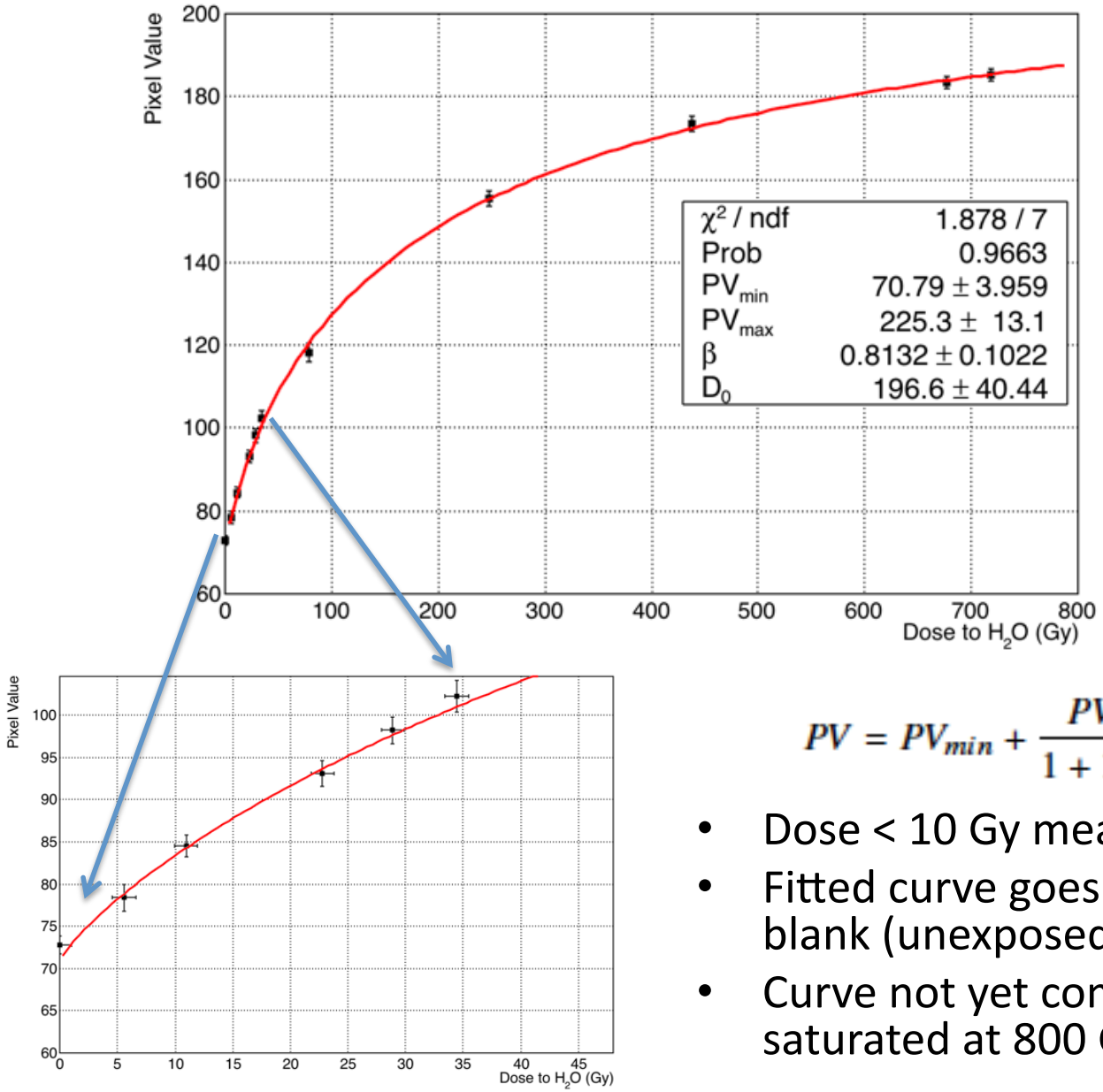
ROOT

- ROOT package have classes for image file reading and analysis
- Read converted JPG format (does not work with TIFF)
- Easy bi-dimensional plotting of Dose distribution
- Preferred for future data analysis and sharing





HDV2 Calibration Curve PV-Dose



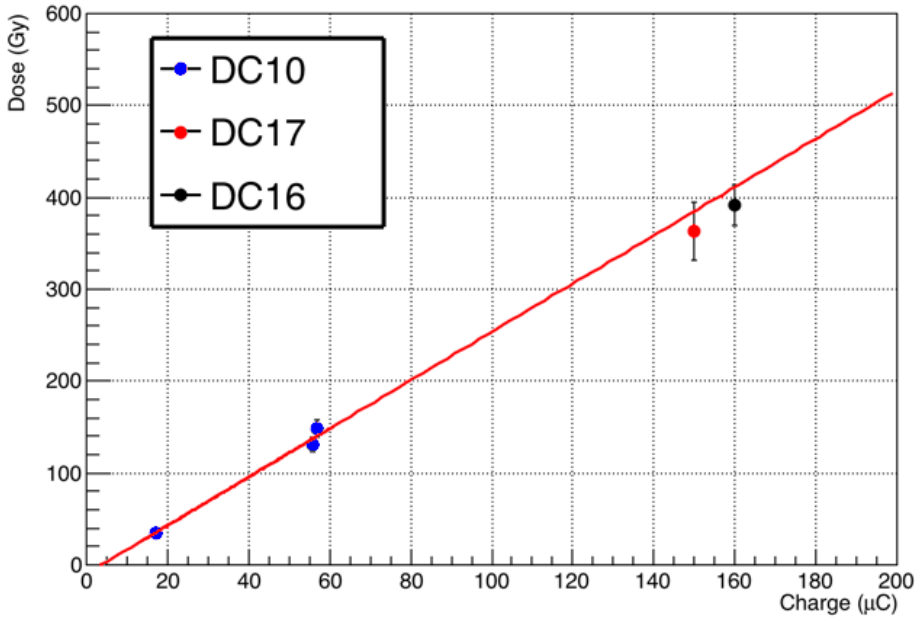
$$PV = PV_{min} + \frac{PV_{max} - PV_{min}}{1 + 10^{\beta(\log D_0 - \log D)}}$$

- Dose < 10 Gy measured
- Fitted curve goes naturally to the blank (unexposed film)
- Curve not yet completely saturated at 800 Gy

Diamonds + films

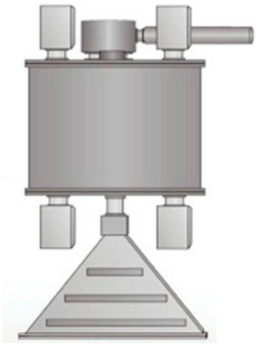
- At Trieste University diamonds have been independently exposed to ^{90}Sr source in the final configurations with radio-chromic films
- Radiation measured by films and by diamonds simultaneously
- Films have been analyzed in Naples
- From calibration curve, the film dose has been measured
- **Excellent agreement with diamond measurements**

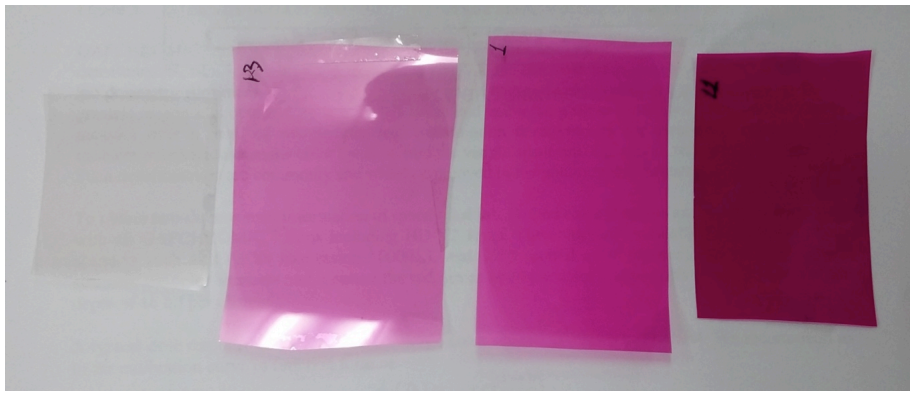
Film Measured Dose Vs Diamond integrated Charge



B3 calibration with electrons

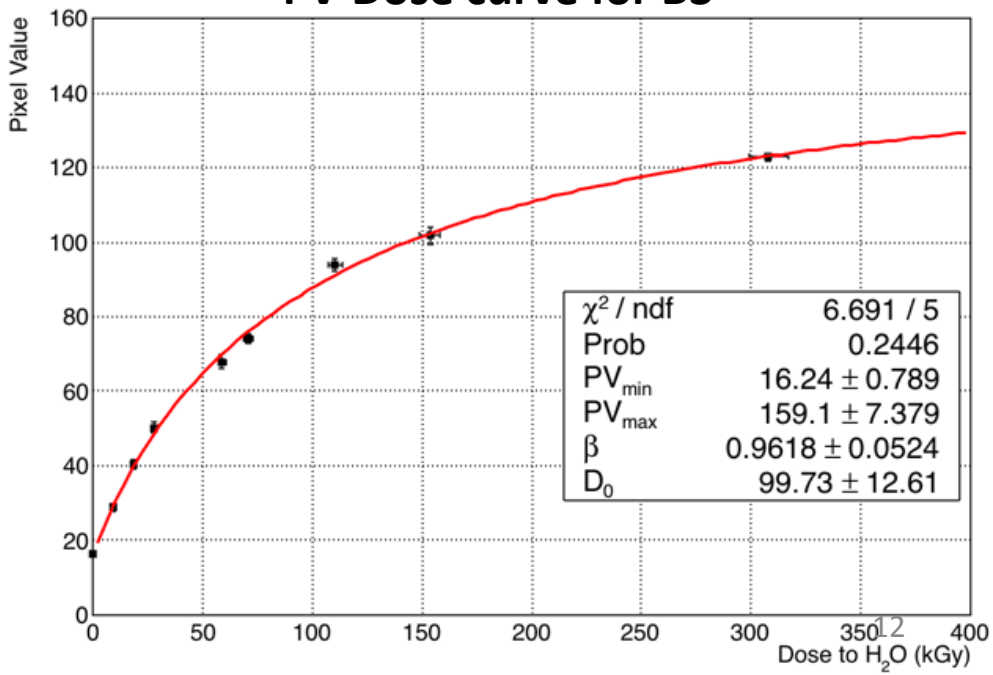
- Irradiation performed at Warsaw ILU-6 accelerator by using 0.7 MeV electrons
- An high-power pulsed-beam accelerator allow to reach high dose in relative short time (kGy/min)



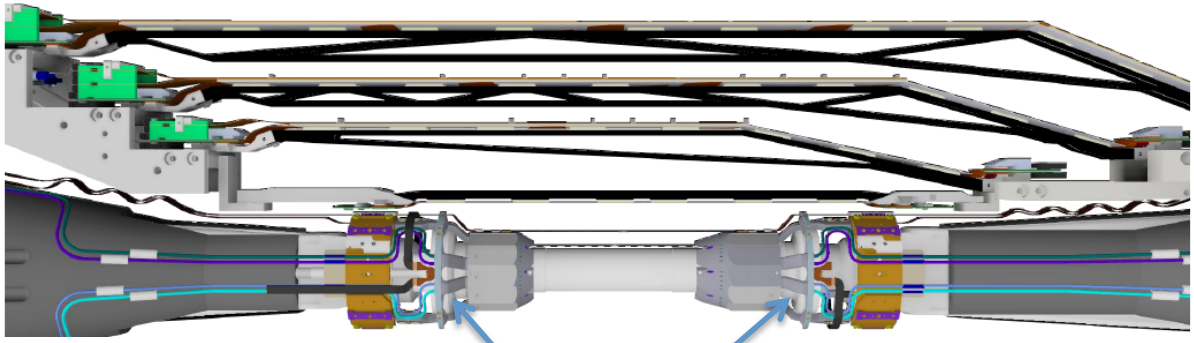


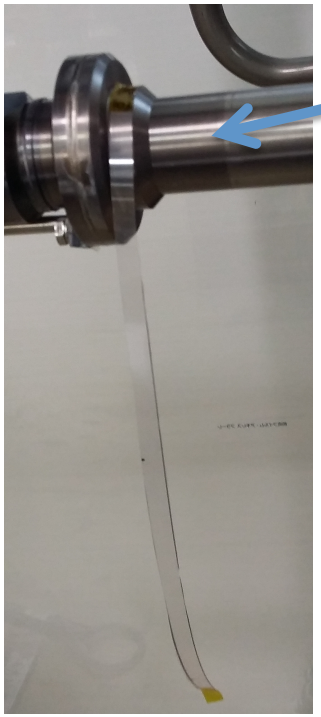
Unexposed **18,5 kGy** **58,6 kGy** **310 kGy**

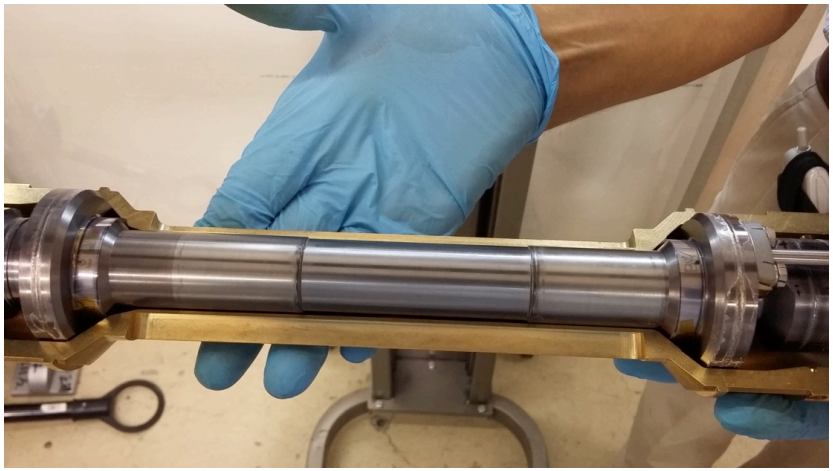
PV-Dose curve for B3



Film on Beam Pipe



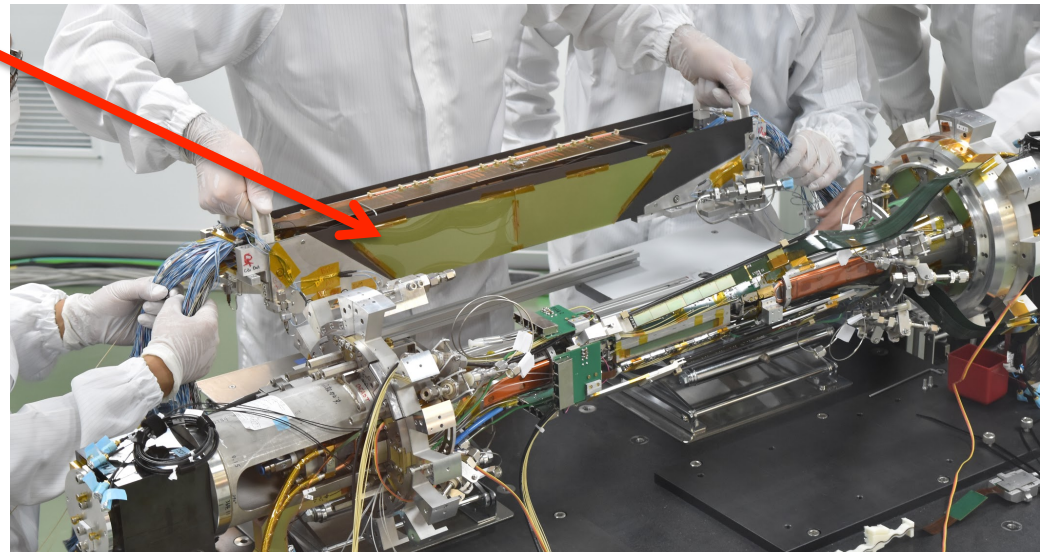


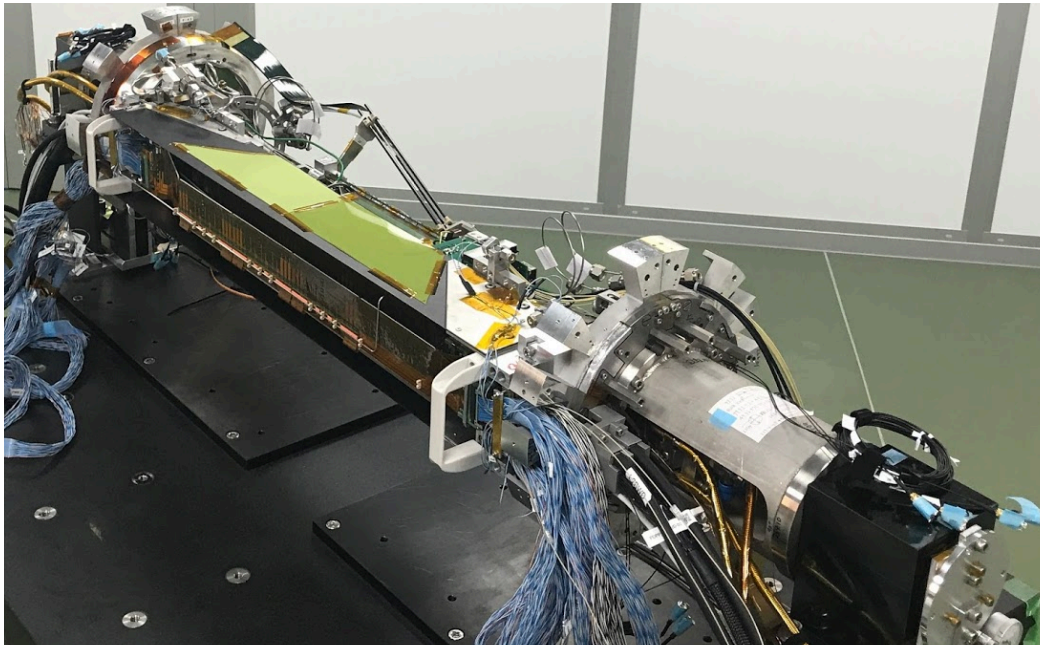


- B3 thin film is very flexible
- wrapped around the Titanium part of the beam pipe
- Strip dimensions 220x6 mm^2 : wrapped three times for redundancy

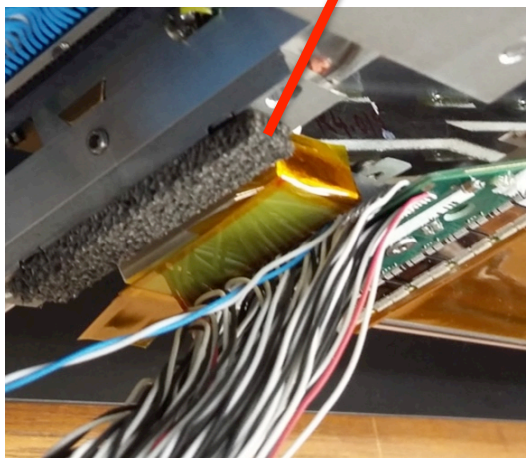
SVD region: cartridge

- Two large films on both sides of the large lateral aluminum cover
- Each film is made overlapping two film types: HDV2+EBT3
- Dose in correspondence of different SVD layers

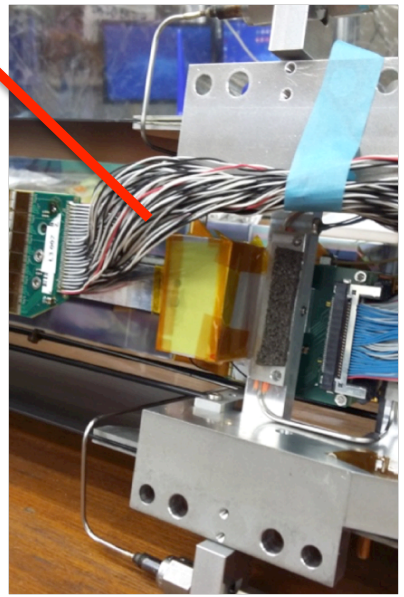




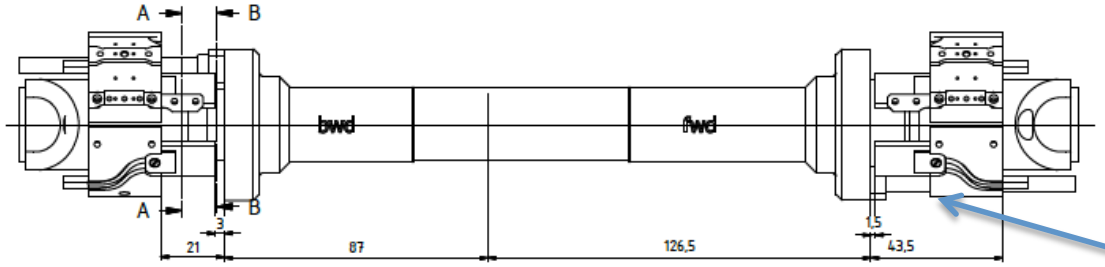
SVD region: cartridge (2)

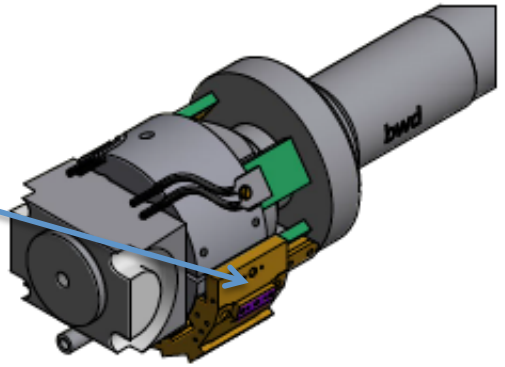


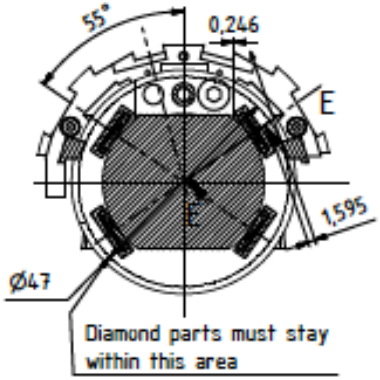
- two other films (each made by B3+HDV2) on the base of cartridge (“fingers”)
- 1) 19.5 x 26 mm^2
- 2) 23,0 x 38 mm^2



SVD region: Diamonds

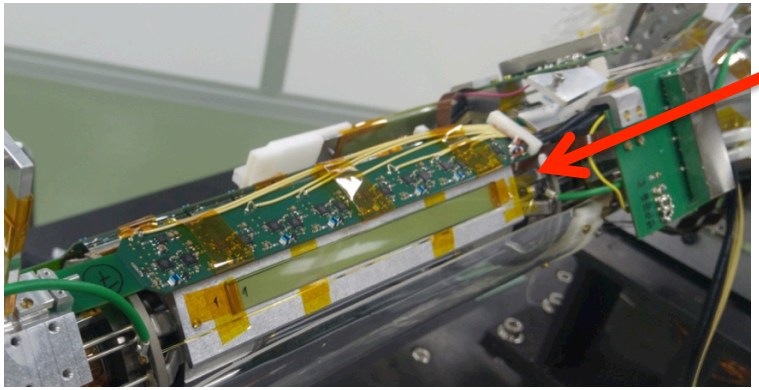


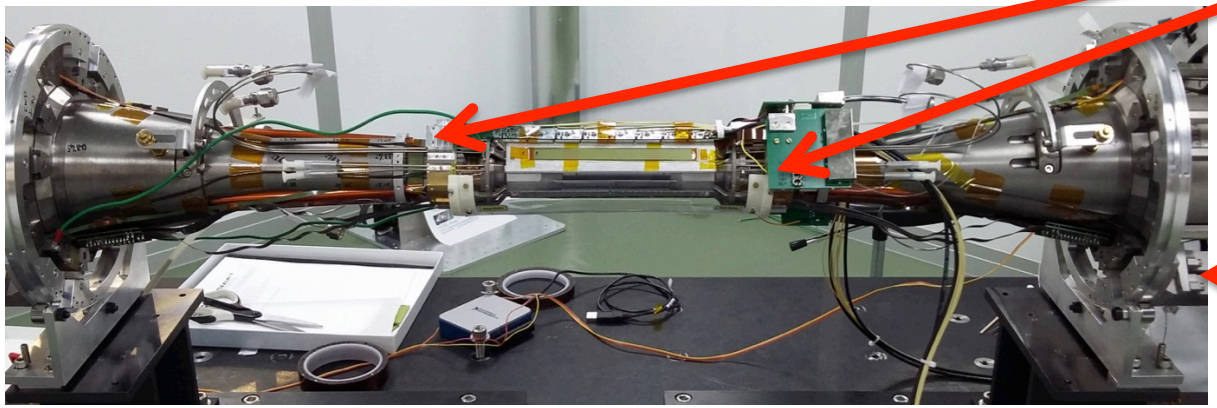




- Eight diamond sensors: four for each side
- HDV2+B3 film type
- Small pieces (18x10 mm^2) positioned on top of the diamond sensor surface
- Diamond and films wrapped with mylar

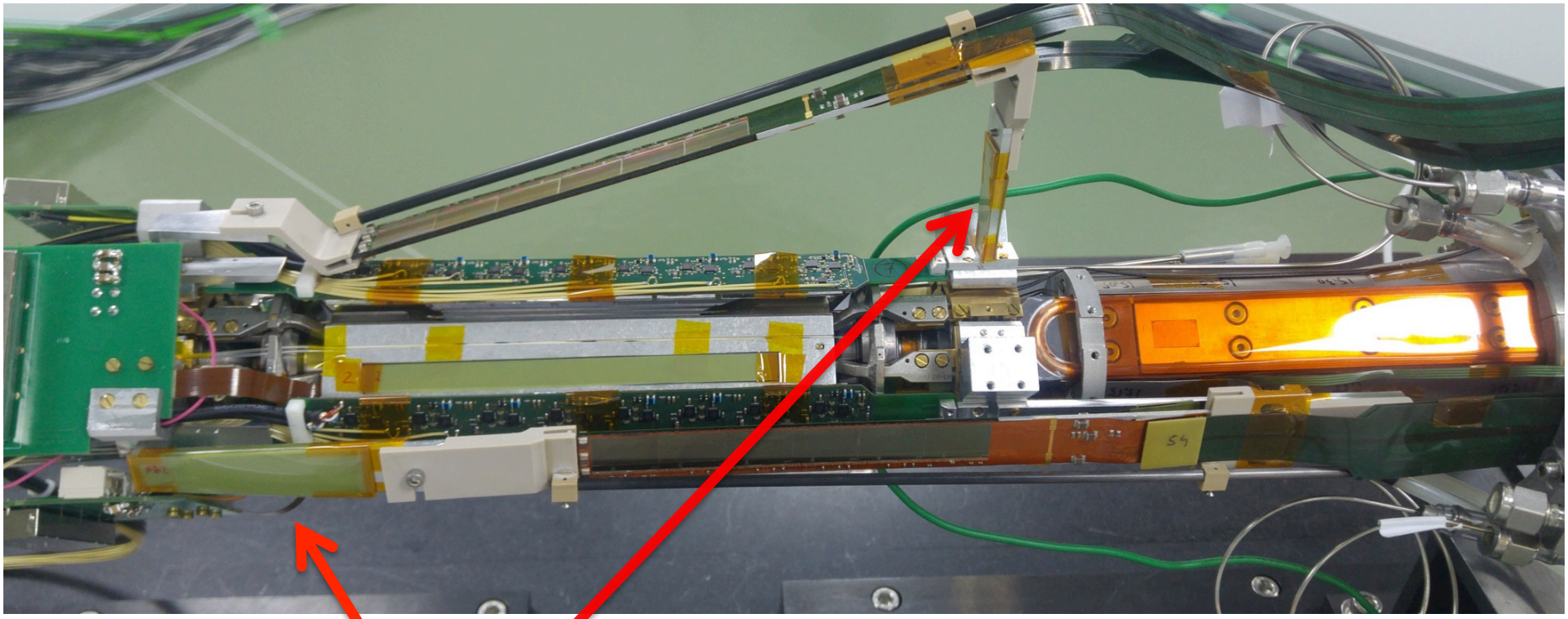
Beast Phase2 Sensors: FANGS



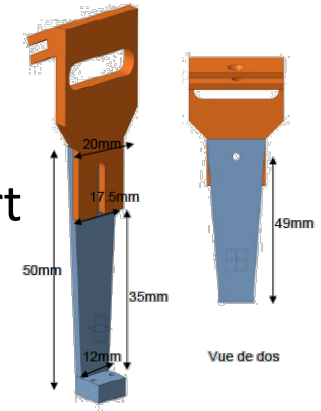


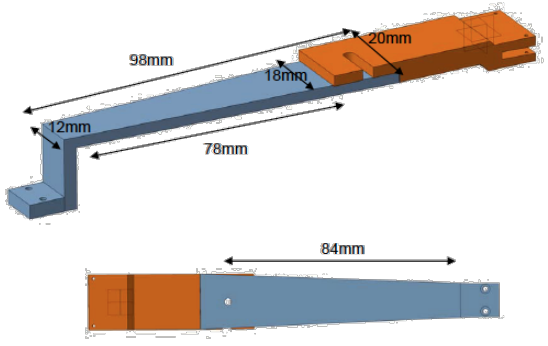
- Strips along three FANG support structures
- Each made by EBT3+HDV2+B3
- Film positioned on the flat aluminum surface
- Strip dimension: 14x1.0 cm^2
- Other 3 films (35x13mm^2) positioned in FANGS proximity
- 8 films (50x30mm^2) positioned on two lateral rings (four for each side)

Beast Phase2 Sensors: PLUME

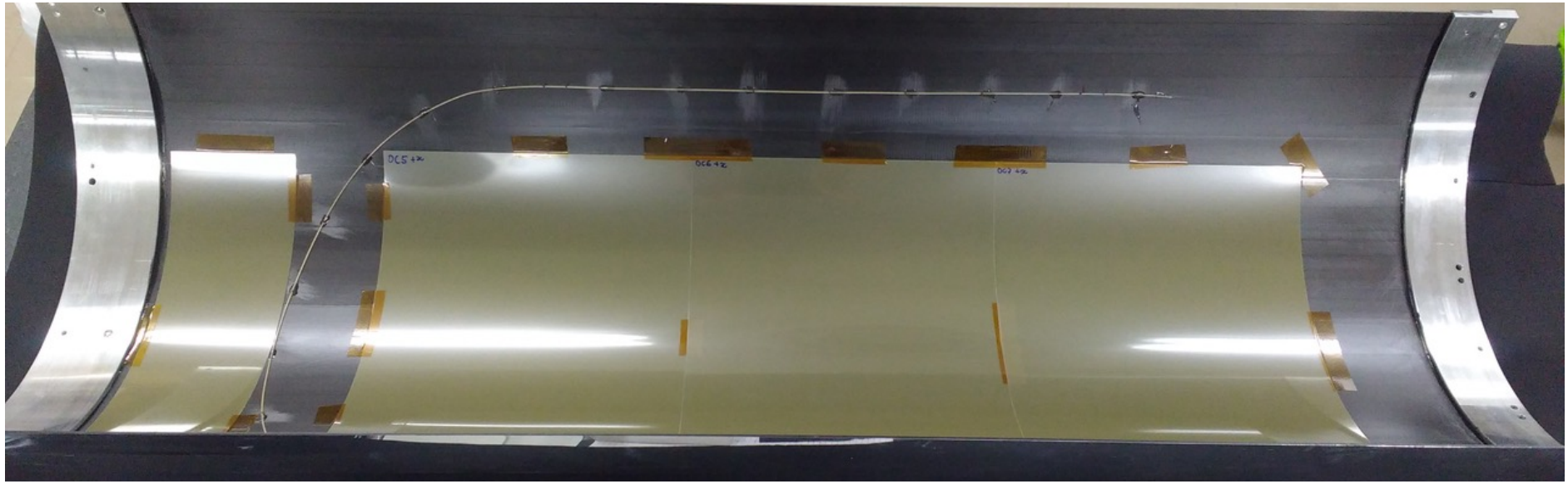


- Films on two support structures
- EBT3+HDV2+B3
- Placed on both sides of aluminum support
- Trapezoidal shape covering full supports



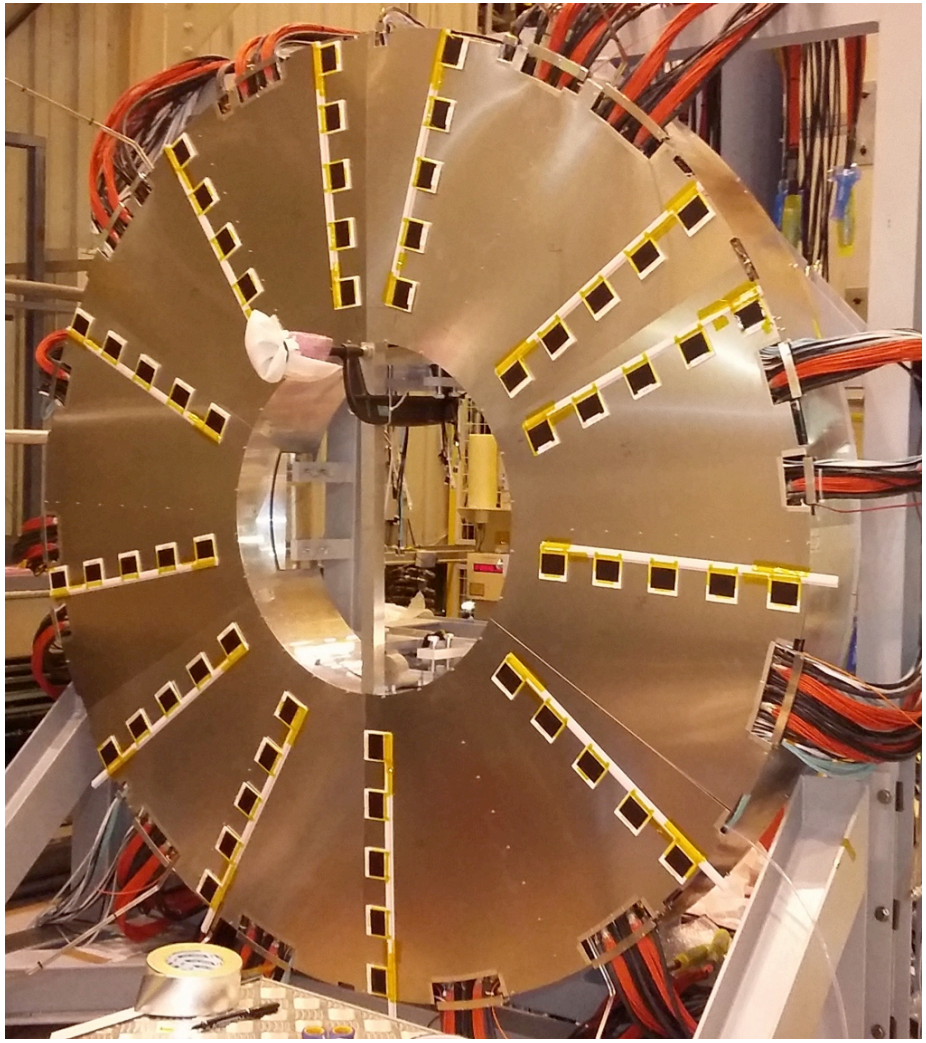


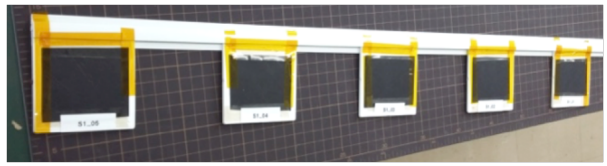
Interaction region



- Large surface covered with EBT3 films on aluminum cover of the whole interaction region

ARICH/ECL





- EBT3 films (0.1-80 Gy sensitivity) positioned on the boundary ARICH/Forward ECL
- Monitor of radiation on CsI crystals during Phase II operations
- 12 plastic strips attached each with 5 tiles
- Basic tile: 5.5x4.5 cm^2 film in a plastic frame
- Layout driven by cables constraint
- On overall 60 tiles with know geometry

Future planned testing activity

- Next week: calibration of HDV2 and EBT3 with 1.25 MeV gamma from ^{60}Co
- Comparative test with diamonds in collaboration with C. La Licata (Trieste)

Conclusion

- Integral dose survey measurement with radiochromic films in BelleII experiment has been started
- Positioned on several sub-detectors and critical regions (more than 6000 cm^2 radiochromic film area)
- Independent dose measurement: cross-check for electronic radiation monitors
- First calibration for HDV2 and B3
- Simultaneous measurements with diamonds

Back-up slides

Radiochromic films: who are they?

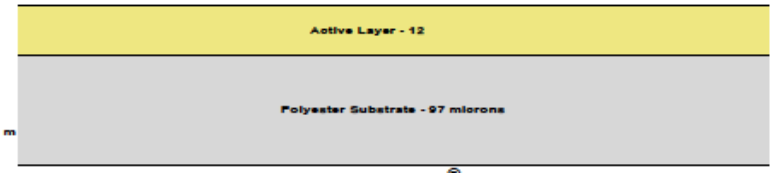
- Single or double layer of radiation-sensitive organic microcrystal monomers, on a thin polyester base with a transparent coating
- energy transferred from radiation to monomer molecule initiates color change due to chemical modifications
- High spatial resolution
- No processing required to develop or fix the image
- Insensitive to visible light
- Several radiochromic film types exist: in all cases darkness of the film increases with increasing absorbed dose
- Applications in medical physics (treatment plan), in industrial radiation processing and reference standard

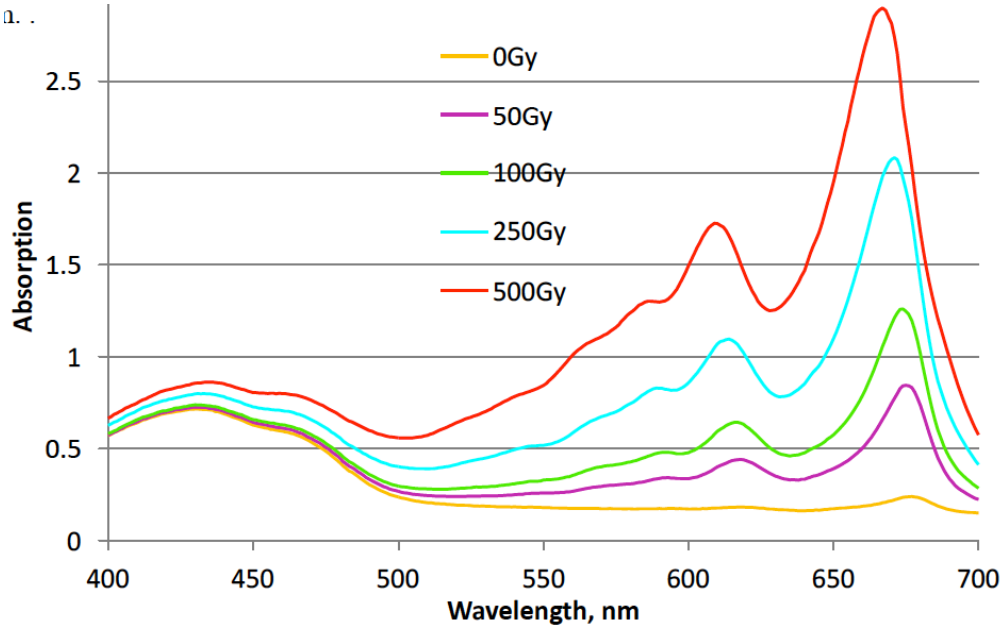
Sensitivity to neutrons

- Due to low budget materials and small cross-section radiochromic films are very low sensitive to neutrons
- Several studies exist to increase sensitivity to neutrons by using converter materials
- Different approach has to be exploited for thermal and fast neutrons
- We plan to perform dedicate test with neutrons in order to study and enhance neutron-sensitivity and apply in Belle II environment

HD-V2

- Active layer (12 µm) coated on a 97 µm polyester substrate
- Dose range (10Gy-1kGy)
- No post exposure treatment
- High spatial resolution
- Dose/rate independent
- Stability in light without exposure
- Readout peak maximum at 670 nm

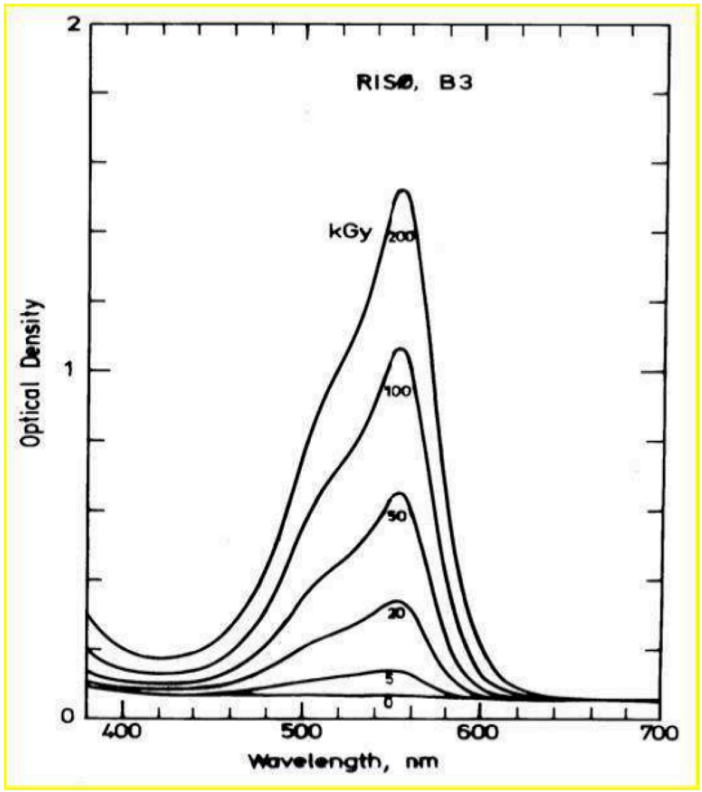




B3 films

- Plastic polyvinyl butyral by Riso laboratory Denmark
- Thickness: 20 µm
- Dose range (3kGy-100 kGy)
- Readout peak at 554 nm

Irradiated region by a wide electron field (Dose: 10 KGy)



Absorption spectrum of Risø B3 dosimeter film Measured at 554 nm,

B3 films

B3 CALIBRATION AND USE

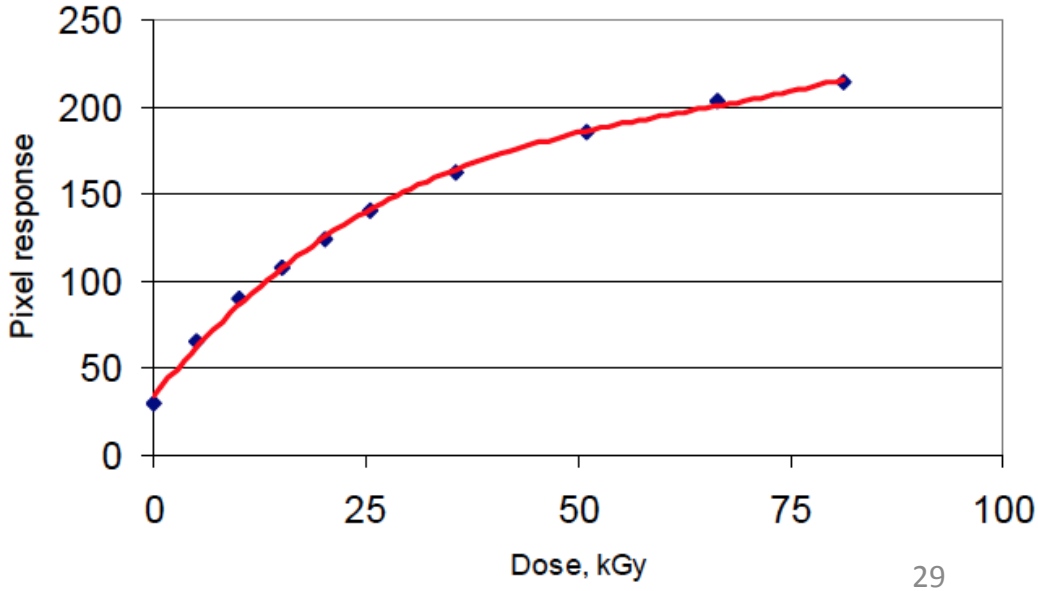
Dosimetry System Application	B3 film and B3 *WINdose* and *DoseStix* dosimeters are intended for use in routine dosimetry systems. In addition, because B3 radiochromic film can be heat treated after irradiation to complete the color development and stabilize response it can also serve as a reference material that can be used for daily checks of the dose measurement system.
B3 Radiation Source Applications	B3 radiochromic film is successfully calibrated and used with a broad array of ionizing radiation sources that include: gamma rays (cesium-137 and cobalt-60), X-ray photons, high energy electrons 1 - 20 MeV, low energy electrons (80 – 600 keV) and UV.
Process Applications	B3 is one of the most popular and fastest growing dosimeters and is used in wide variety of radiation process applications although the bulk of B3 use is found in sterilization process applications followed by crosslinking and curing application. Because of its low profile, B3 film is placed directly on to material surfaces and used to measure dose at product material/material and material/air interfaces as well as for measurements using pre-packaged dosimeters affixed to the outer product packages and box surfaces.
Dose Range Applications	B3 dosimetry systems are calibrated and used to cover dose from well below 1.0 kGy to greater than 150 kGy. Optimum results are achieved by limiting the calibration range.
Calibration	GEX recommends in-situ calibration of B3 *WINdose* and *DoseStix* for optimum performance with lowest overall uncertainty. GEX assists its customers with development of an in-situ calibration practice that can be validated to appropriately capture the temperature and dose rate conditions of routine process conditions for either full calibrations or calibration verification audits of a lab calibration. Uncertainty can be significantly reduced by limiting the curve fit dose range to cover specific application needs. GEX is pleased to assist B3 dosimeter users in designing and planning batch calibrations.
Uncertainty Expectations	An effectively designed and executed dosimeter batch calibration should be expected to result in a calibration that meets predictable uncertainty expectations that can be maintained and re-validated over time. Overall expanded uncertainties at approximately 95% confidence (k=2) should be expected to range from 3.5% to 6.0% dependent on the user's specific metrological practices with their B3 dosimetry system.

Film calibration

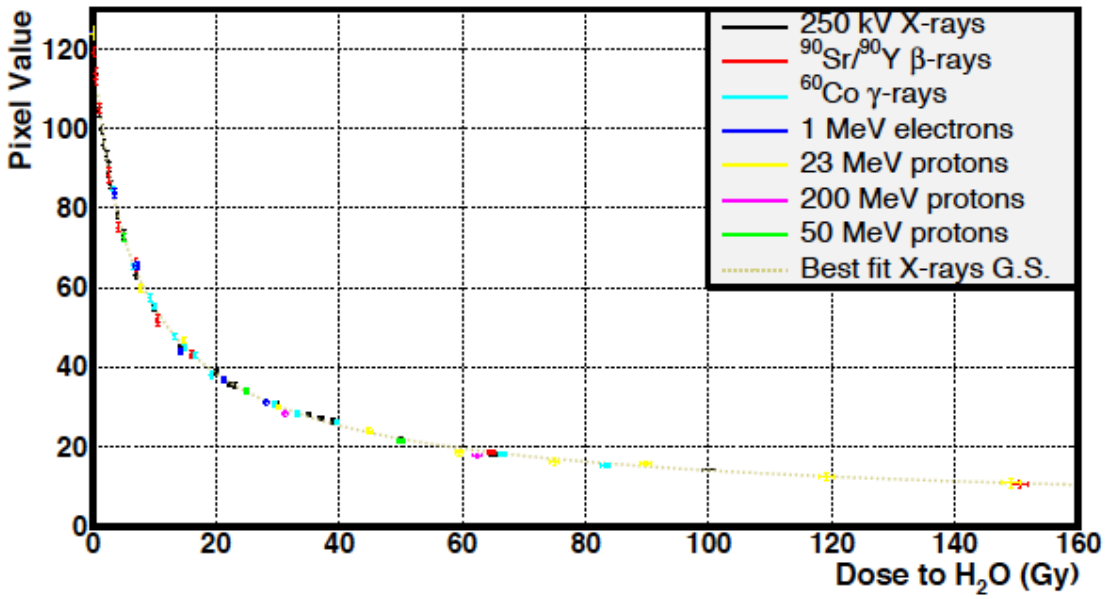
- Films of a given batch need to be calibrated
- Electron or gamma sources can be used

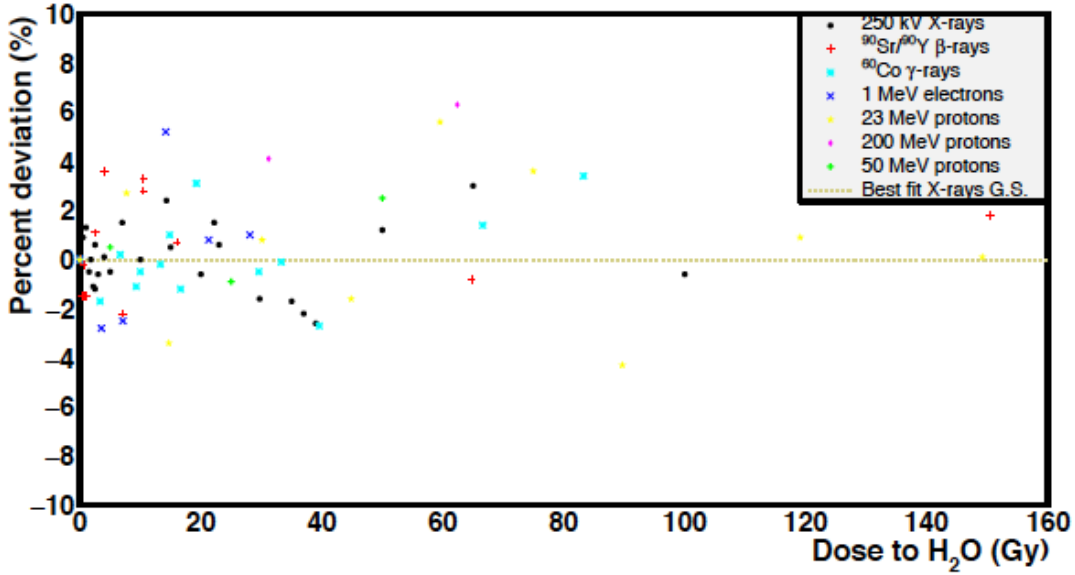
Calibration set exposed to a given dose

Dose determination for a given sample



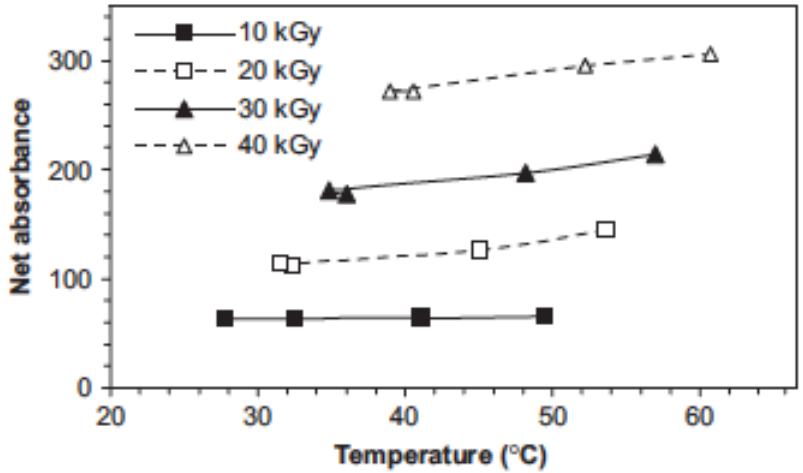
Field dependence studies for EBT3



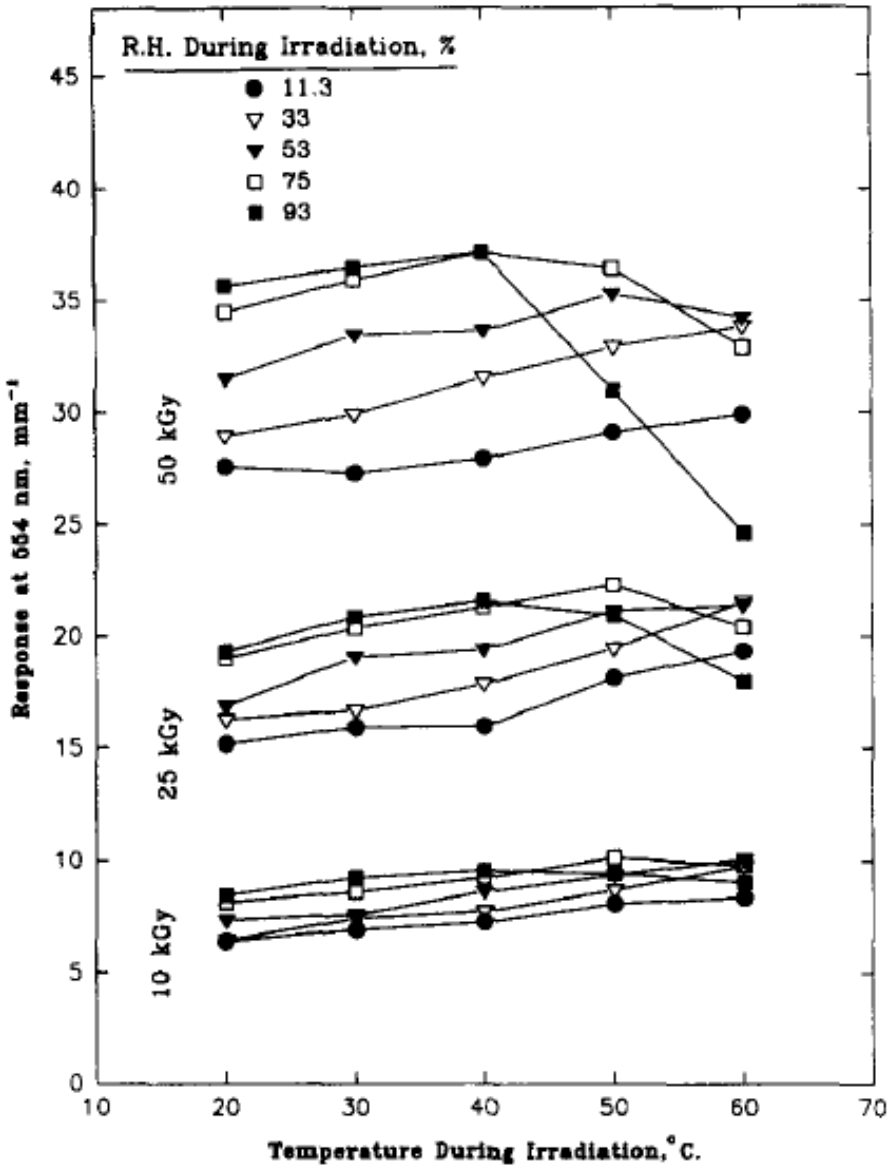


B3 temperature dependence

a

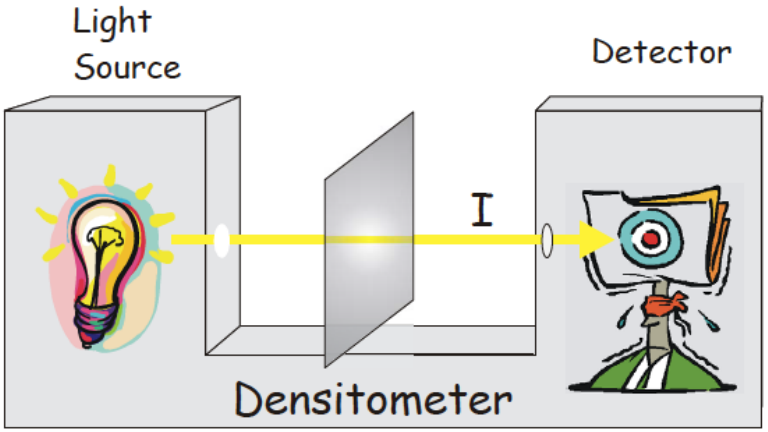


b



Film analysis

- Densitometer
- Scanner
- Spectrophotometer

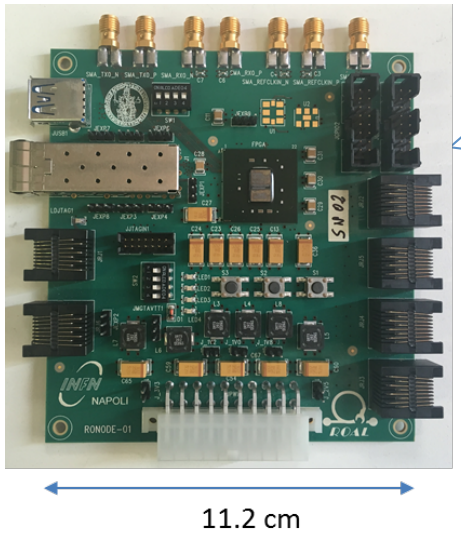


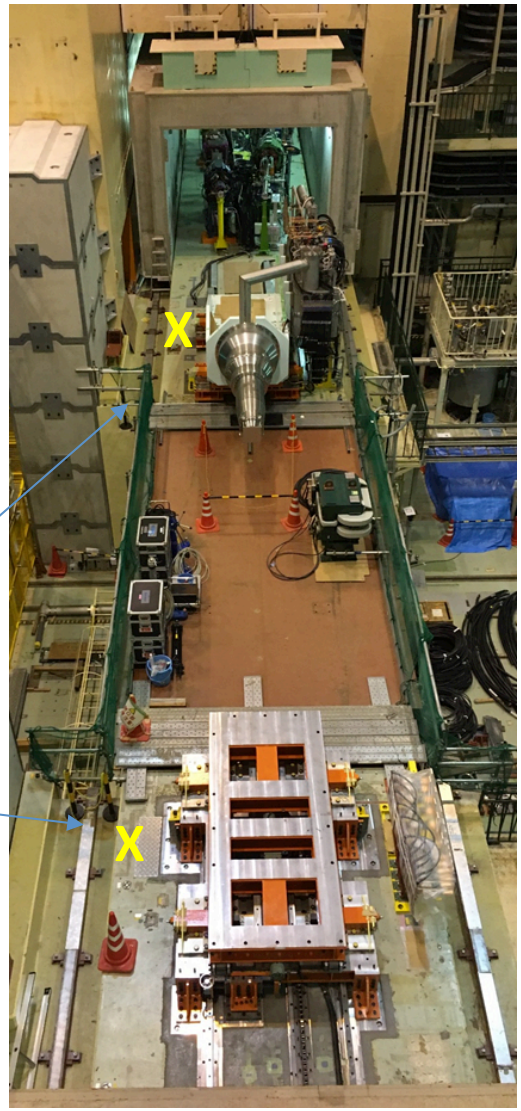
We use a scanner

- Flat-bed EPSON V800 scanner
- Scanner settings with: no color correction, 400 dpi and 24 bit color
- Images saved in TIFF format and analyzed with ImageJ software
- Analysis can be performed in pixel gray values, any pixel has a RGB values, dedicate study to enhance sensitivity in a given range of dose has to be performed
- Scanner response stable (<0.3%) after 10-20 minutes warm-up
- Centering mask to avoid edge non uniformity illumination effects
- Scanner overall introduce uncertainty < 1%

Monitoring dose on FPGA SEU experiment

- Three boards will be installed
- Positions few m from interaction vertex





- EBT3 type (1-60 Gy) will be suitable for such application