Test beam results from the prototype SiPM dRICH readout

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INFN Bologna

weekly meetings on Friday morning
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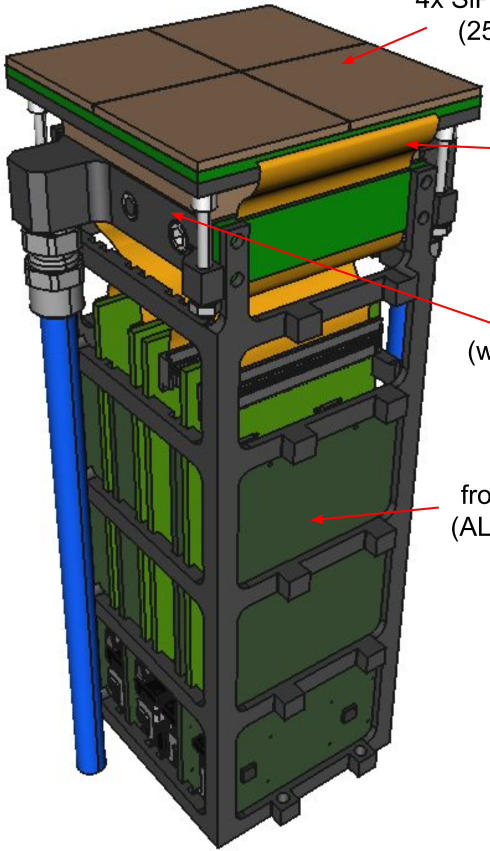
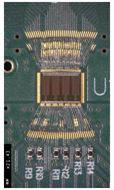
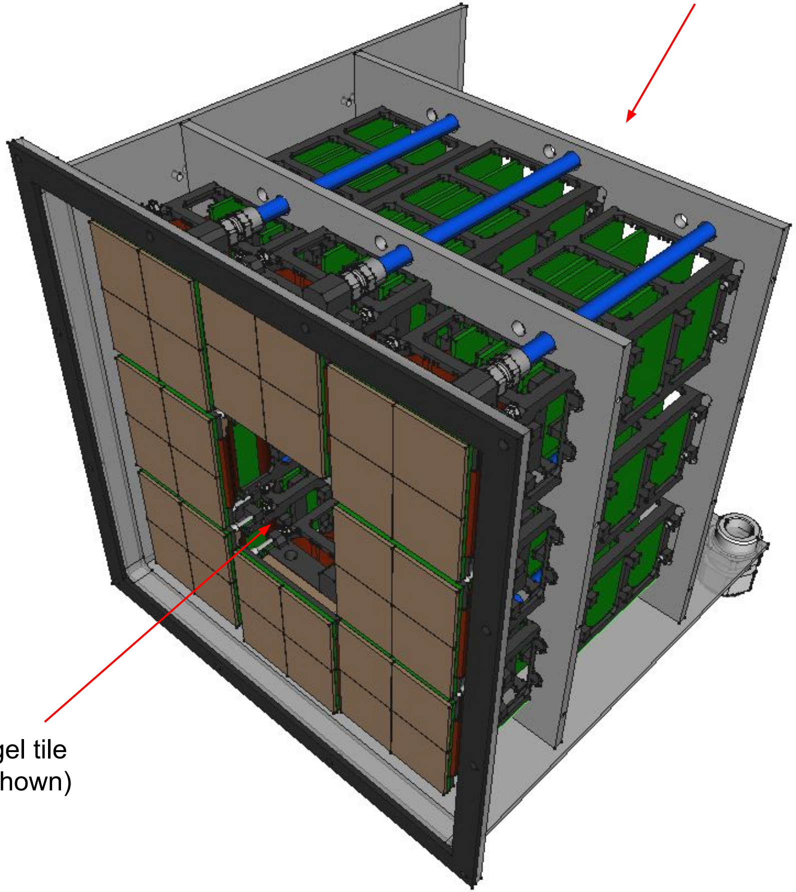
EIC ePIC-dRICH SiPM photodetector prototype





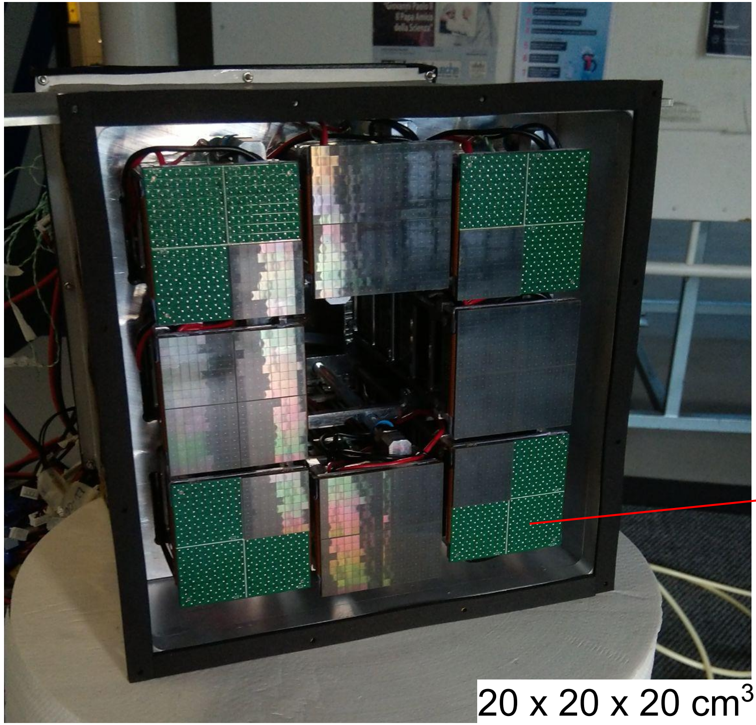
PhotoDetector Unit (PDU)



Readout Box

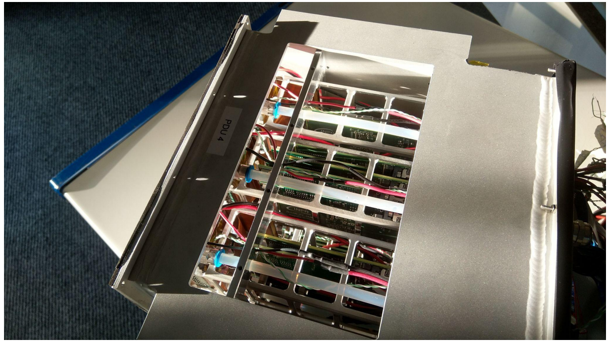
EIC ePIC-dRICH SiPM photodetector prototype

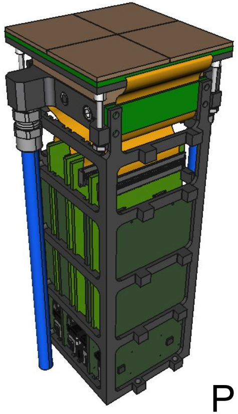
Readout Box (front)



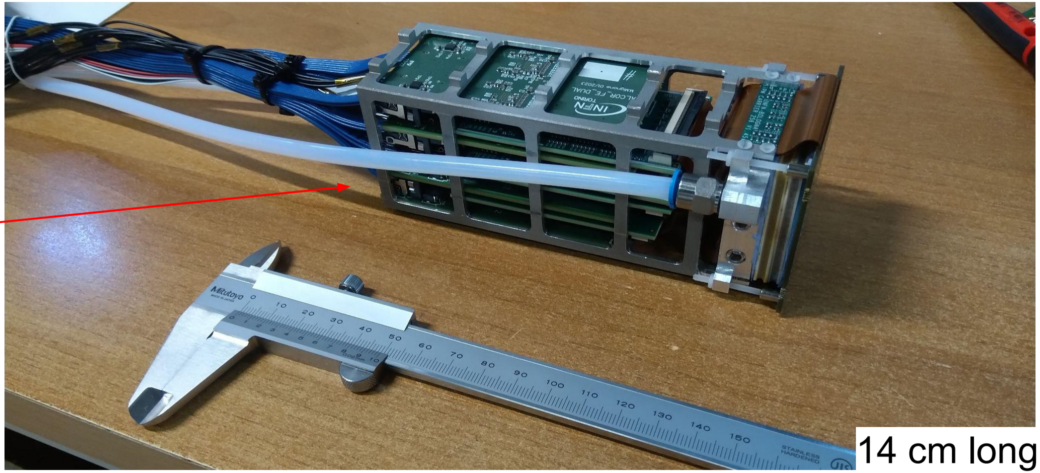
20 x 20 x 20 cm^3

(top)



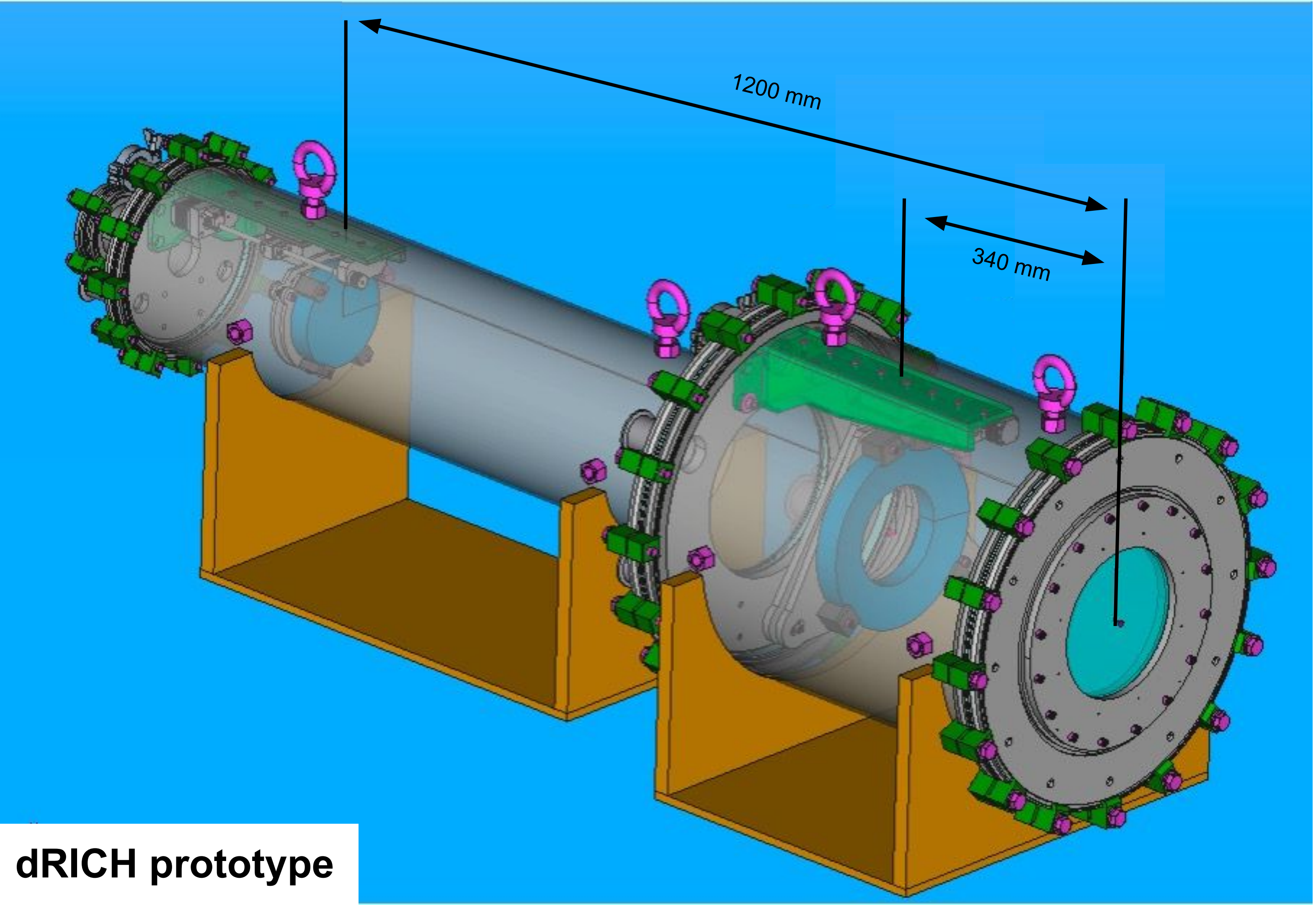


PDU

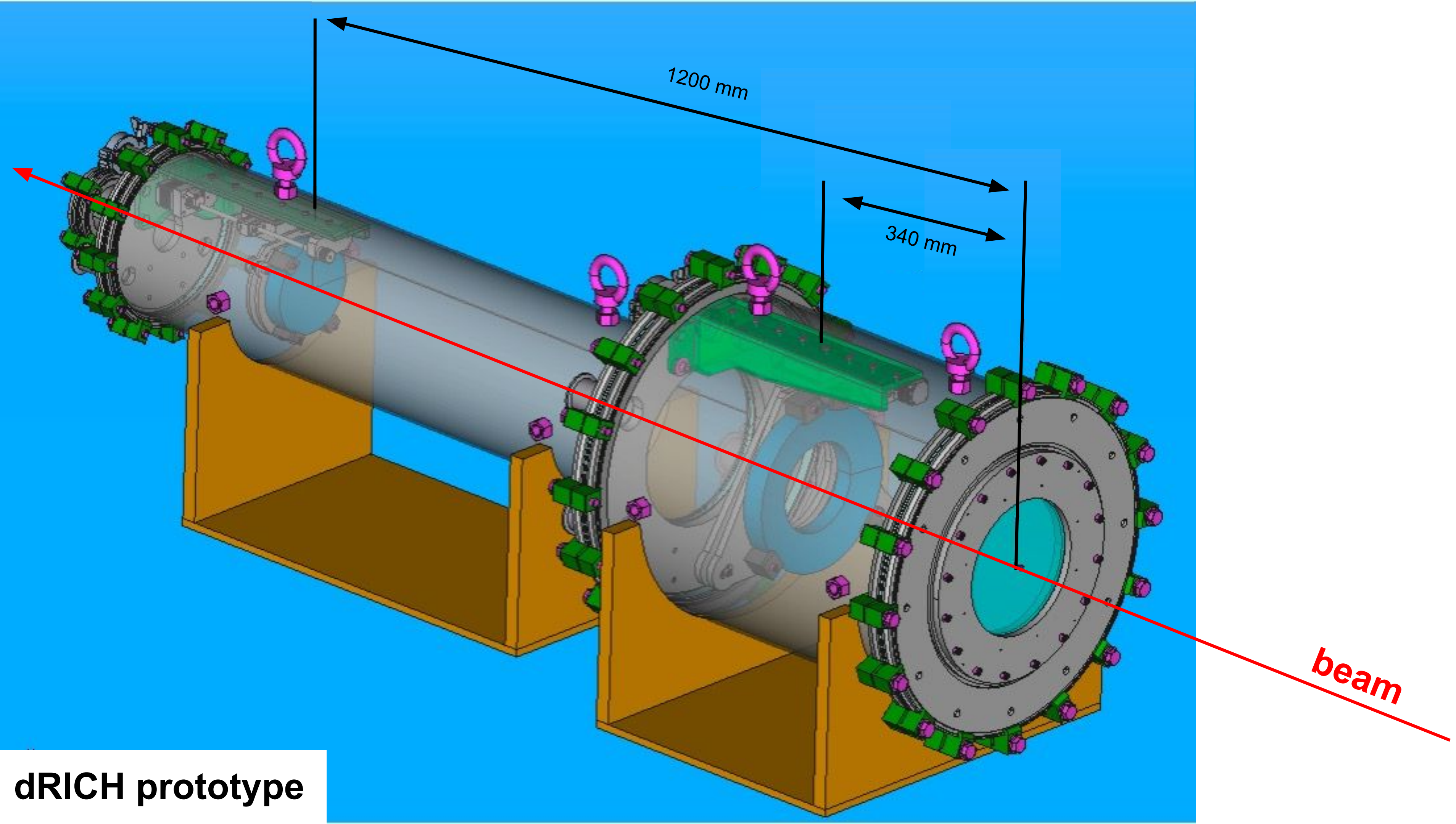


14 cm long

fully-equipped 1280-channels SiPM readout surface



dRICH prototype



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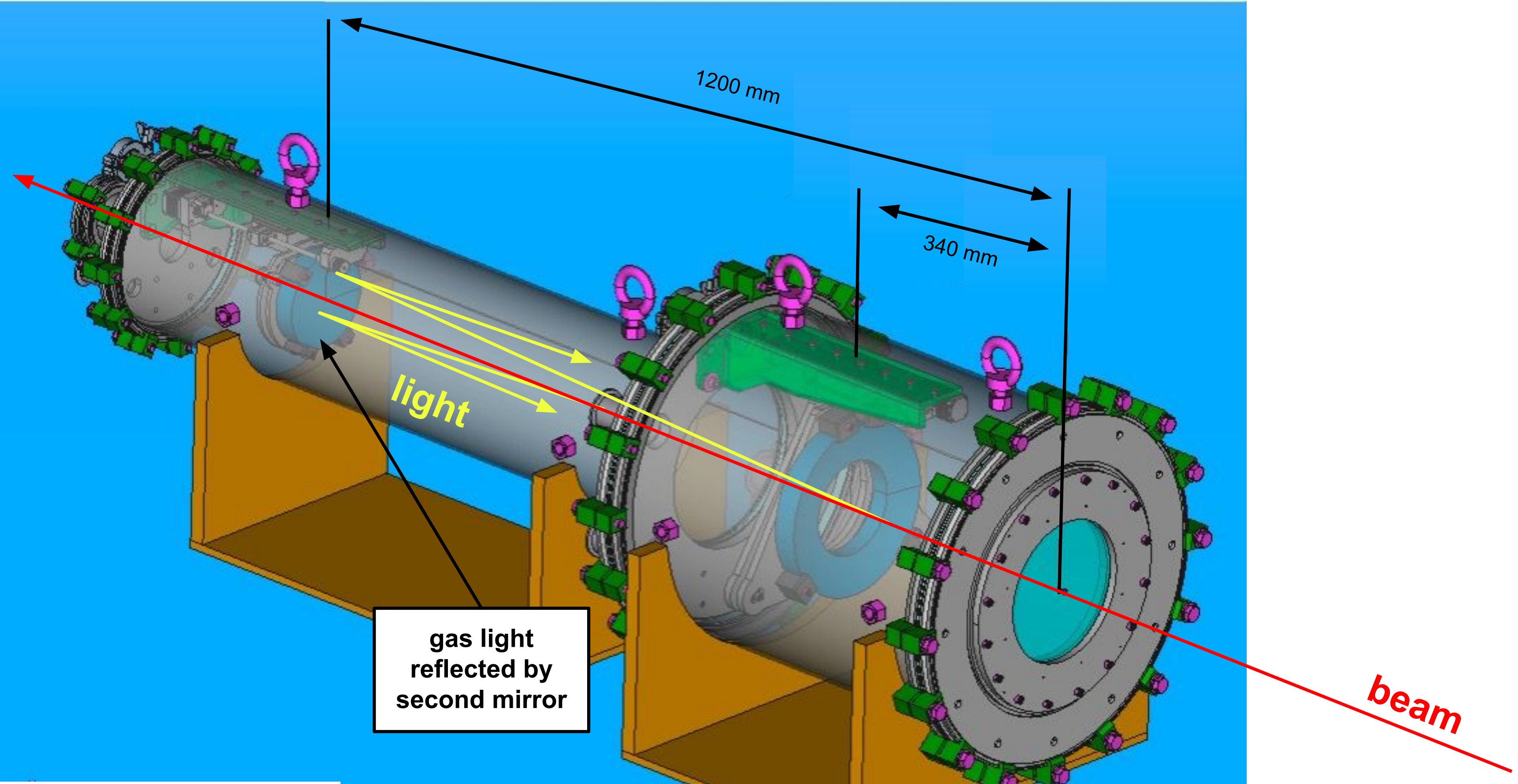

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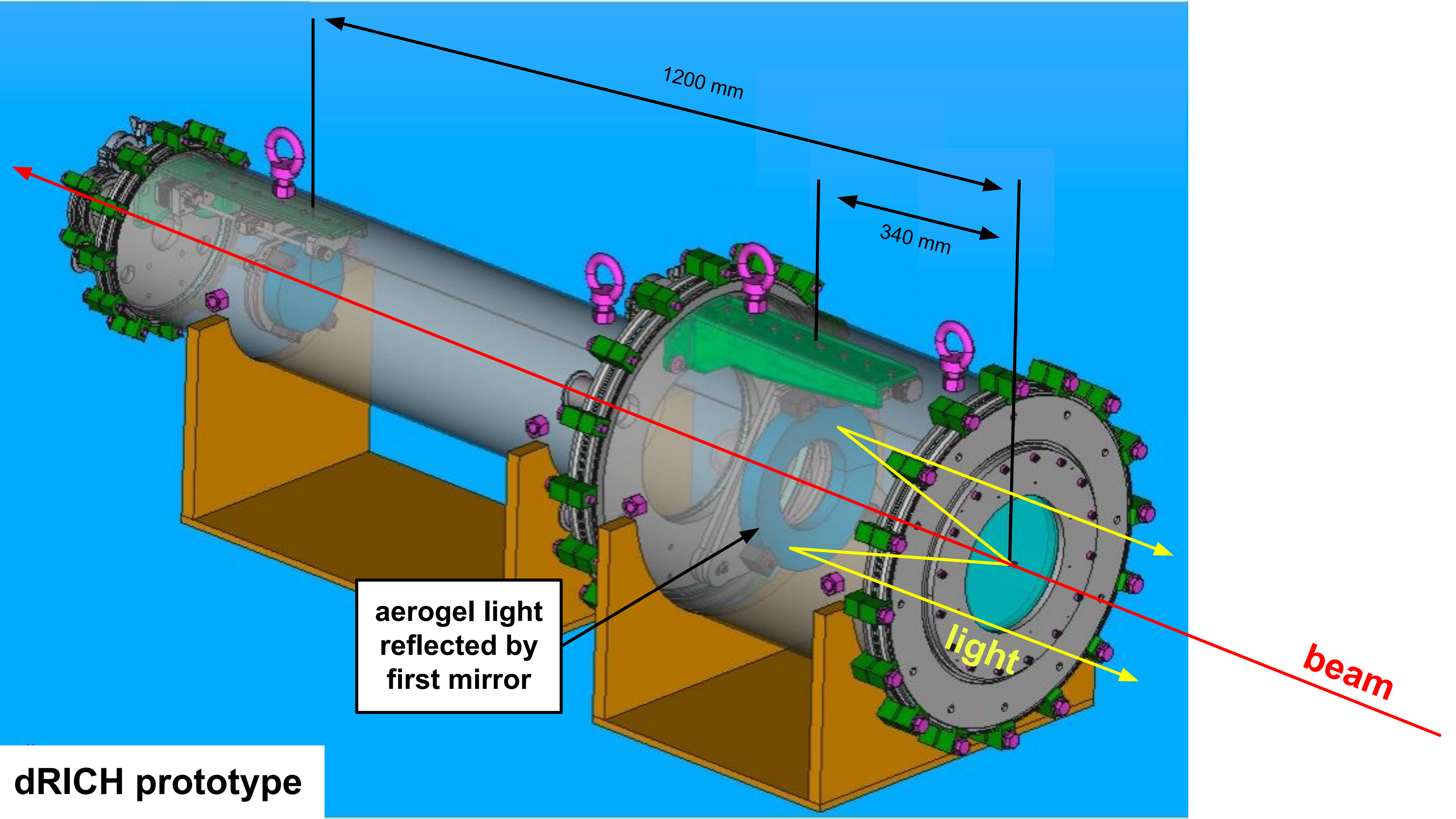

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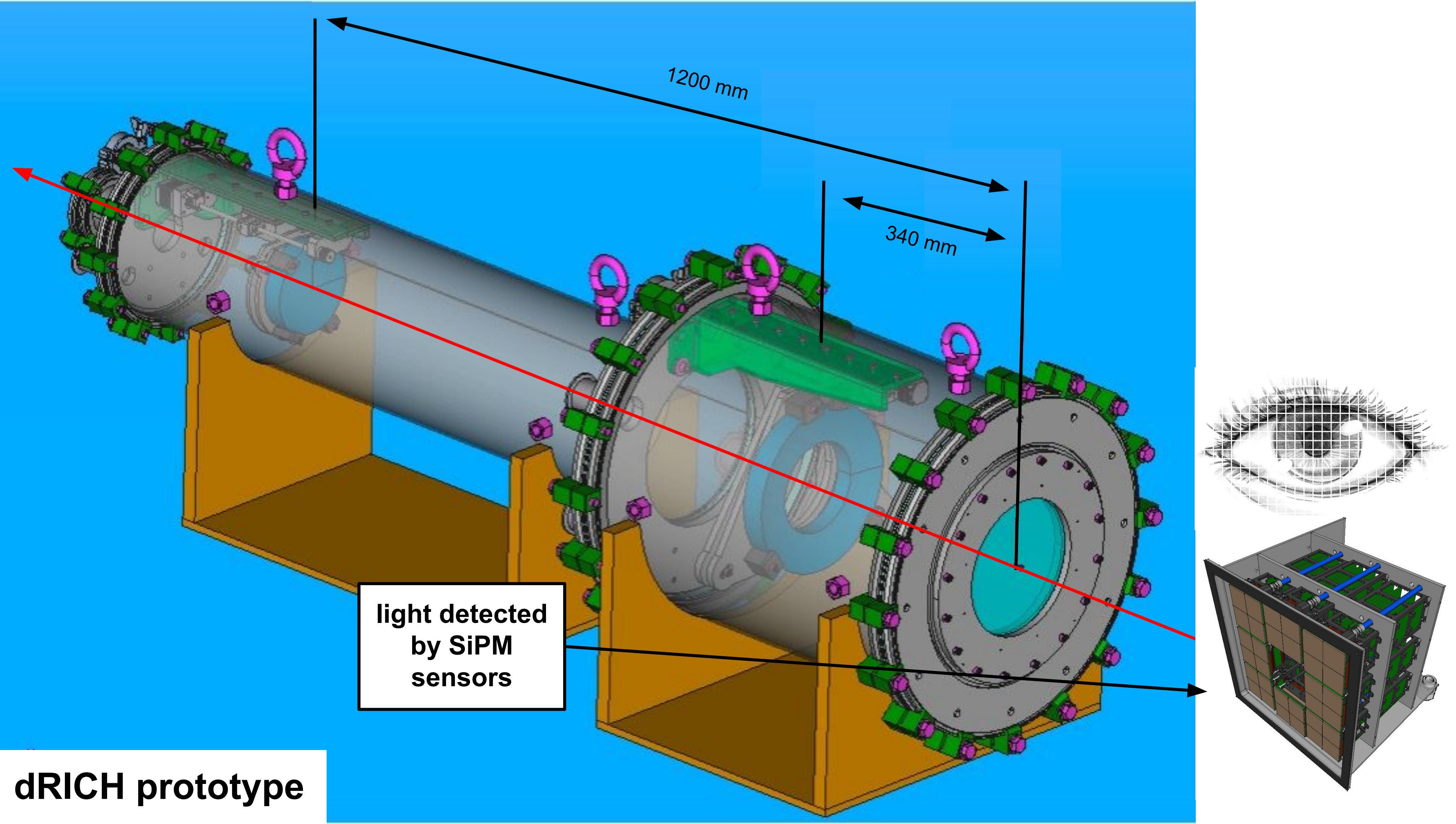


dRICH prototype

dRICH prototype on the T10 beam line at CERN-SPS

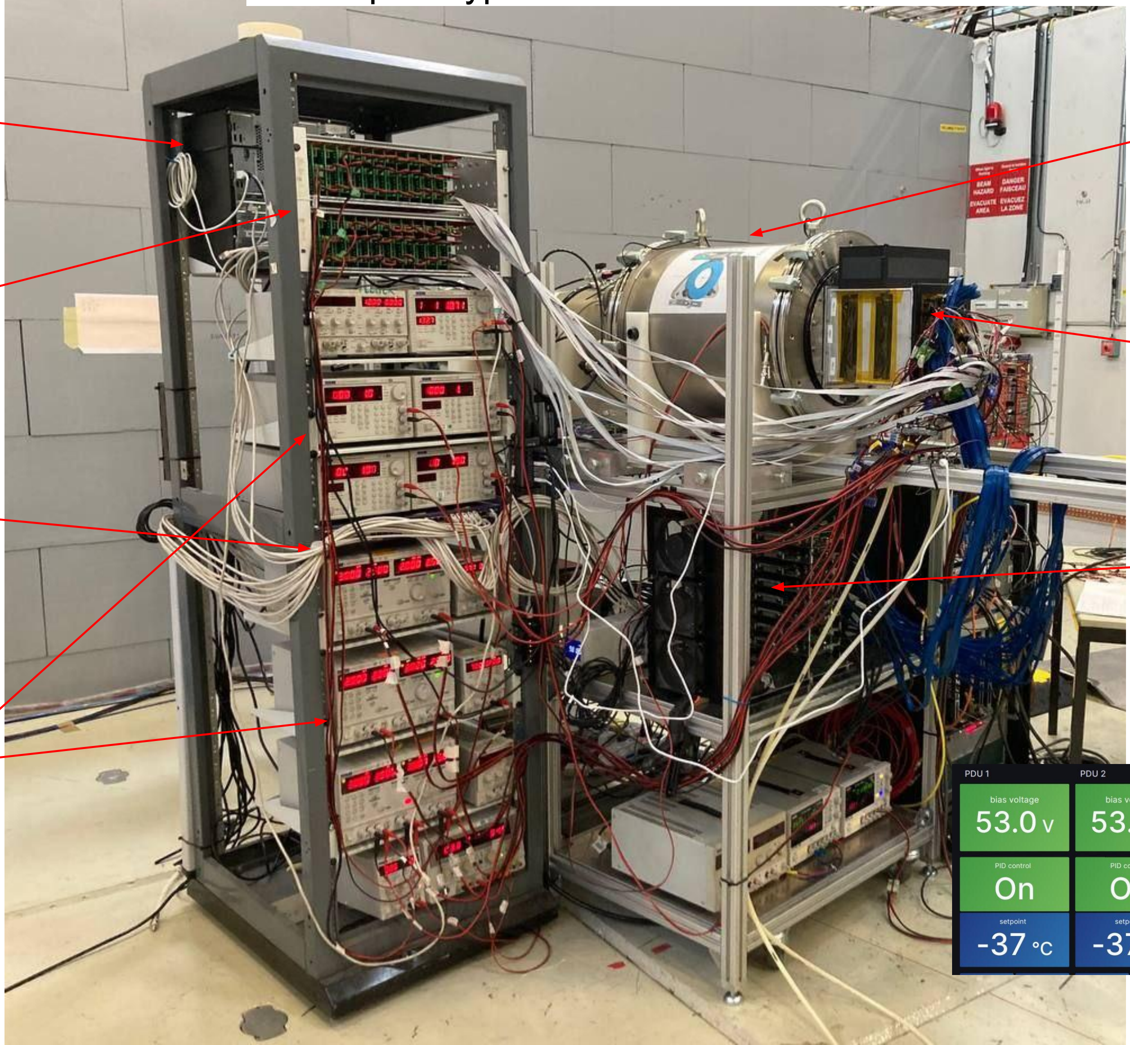
INFN

DAQ and DCS computers

auxiliary control electronics crates

gigabit ETH switch for DAQ and DCS

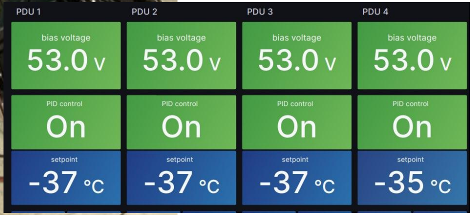
low voltage and high voltage power supplies



dRICH prototype

SiPM photodetector readout box

DAQ FPGAs and clock distribution



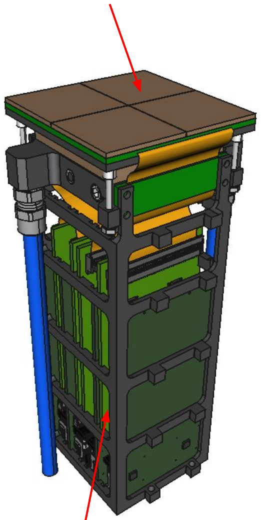
SiPM at low temperature

2023 test beam at CERN-PS

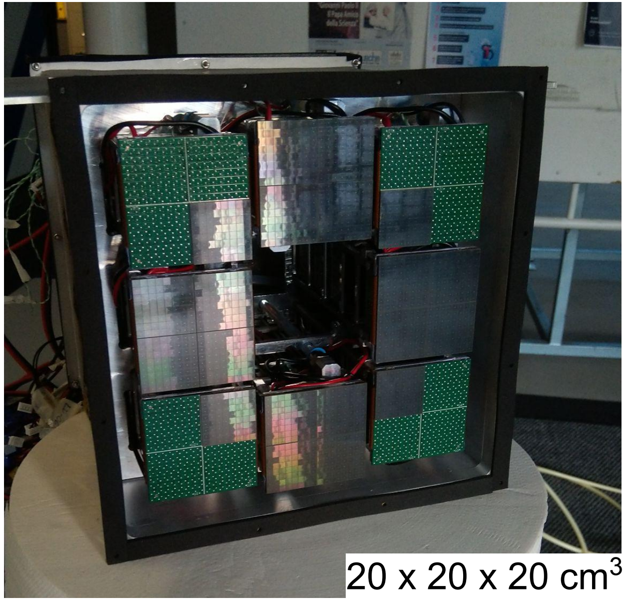
successful beam test with prototype SiPM photodetector units (CERN-PS, ended on 18th October)

PDU

4x SiPM matrix arrays
(256 channels)



front-end electronics
(ALCOR ASIC inside)



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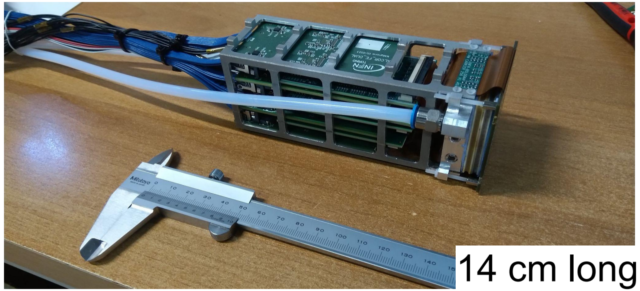
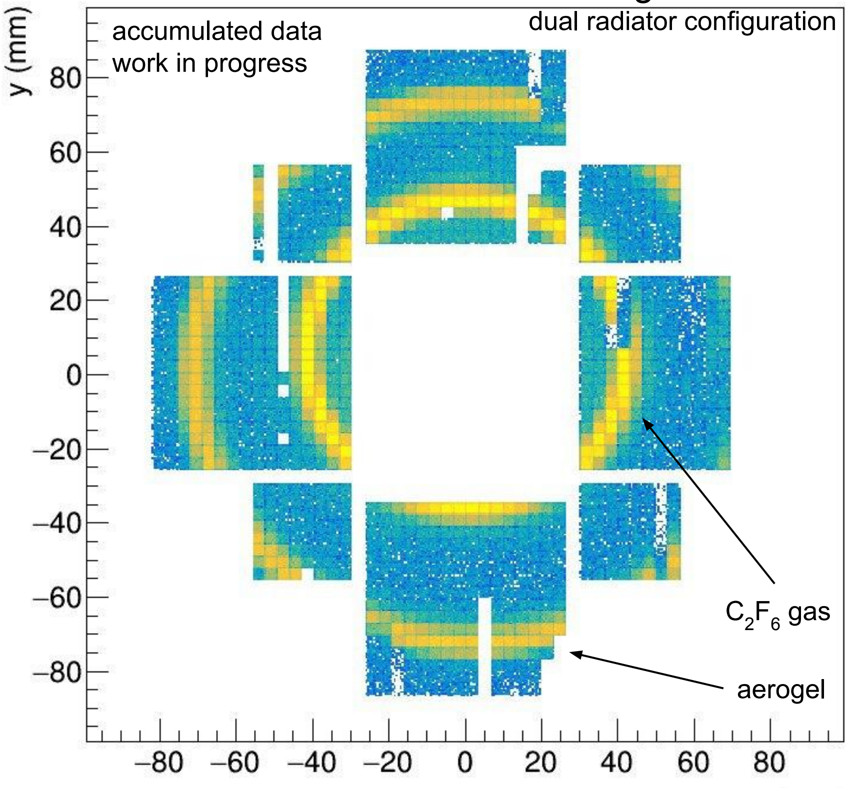


14 cm long

10 GeV negative beam



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successful beam test with prototype SiPM photodetector units (CERN-PS, ended on 18th October)

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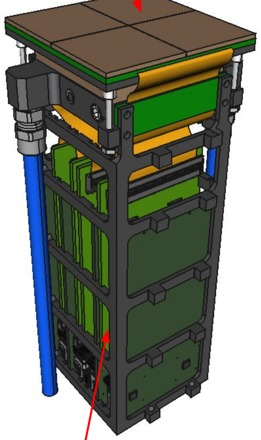

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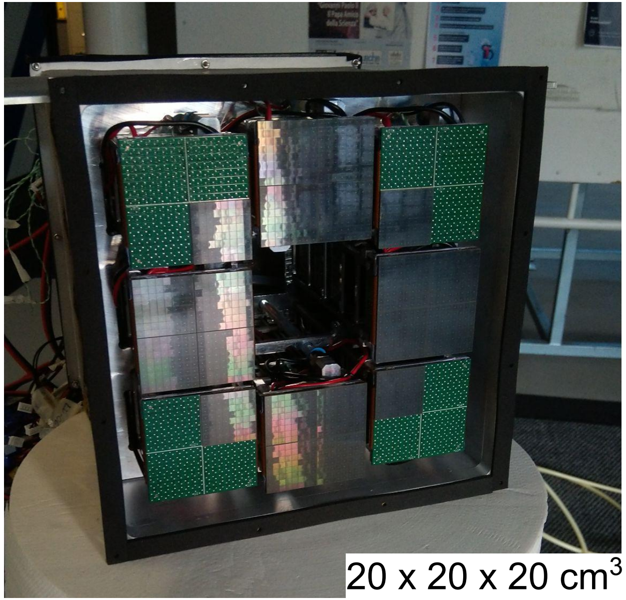

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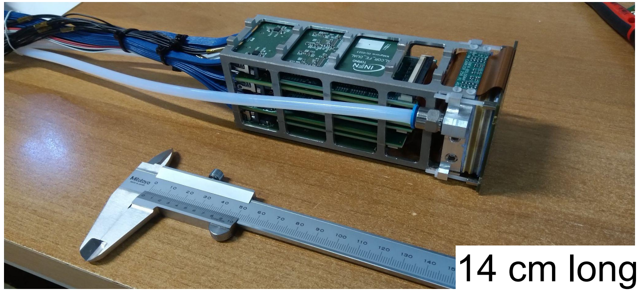

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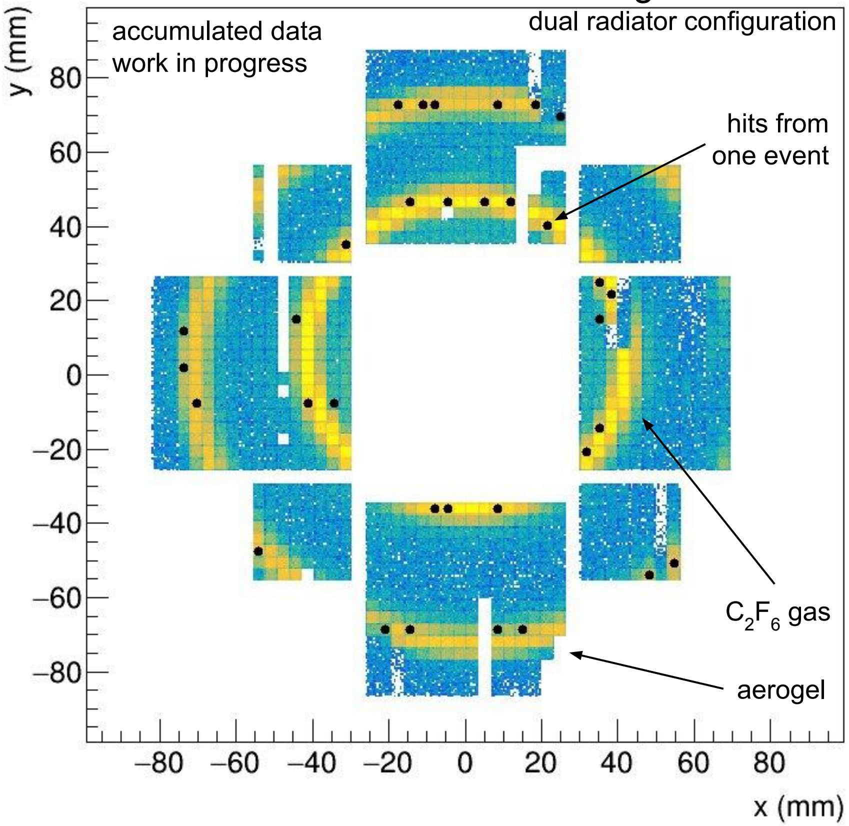
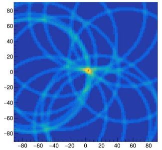


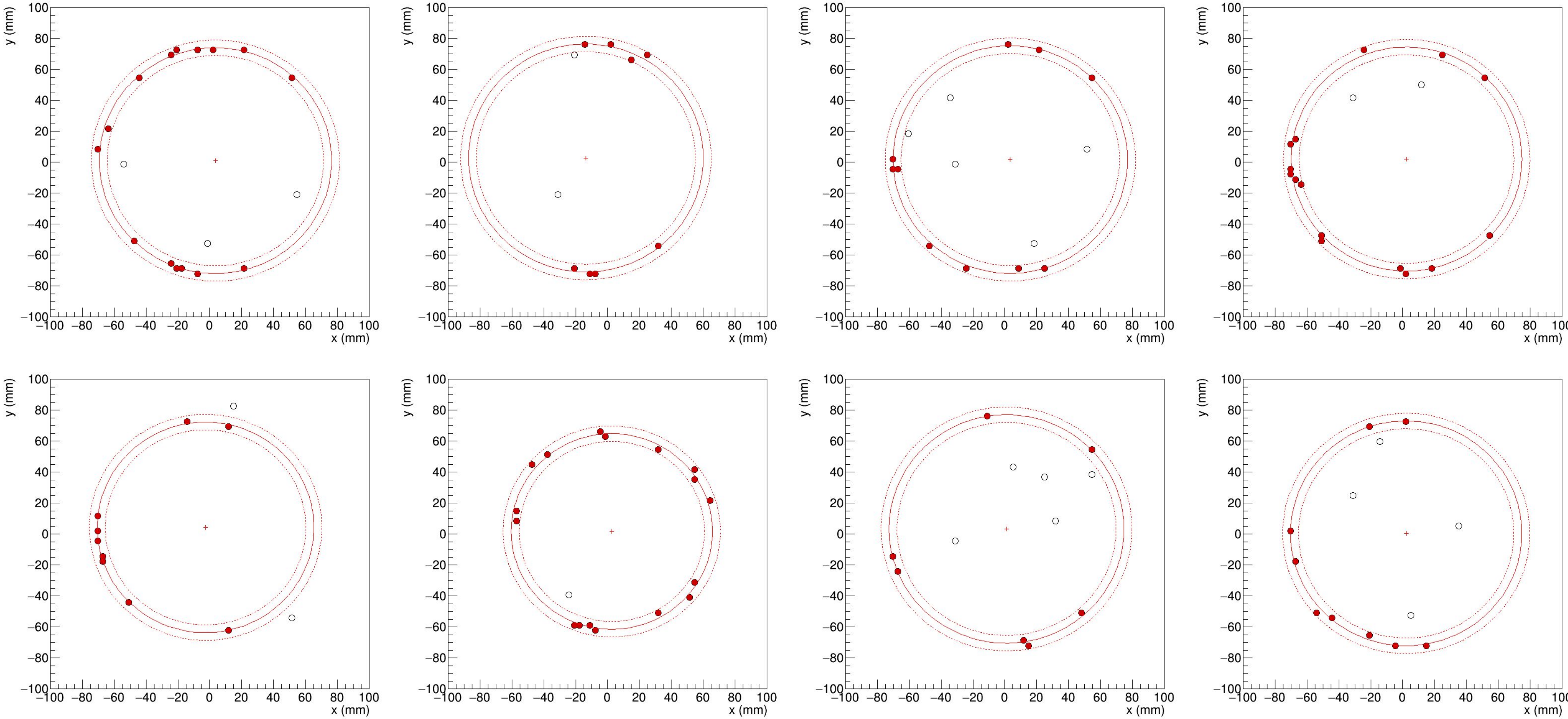
2023 test beam data analysis ongoing

event-by-event ring reconstruction: Hough Transform Method



10 GeV negative beam

only aerogel radiator



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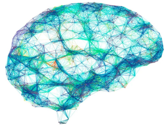
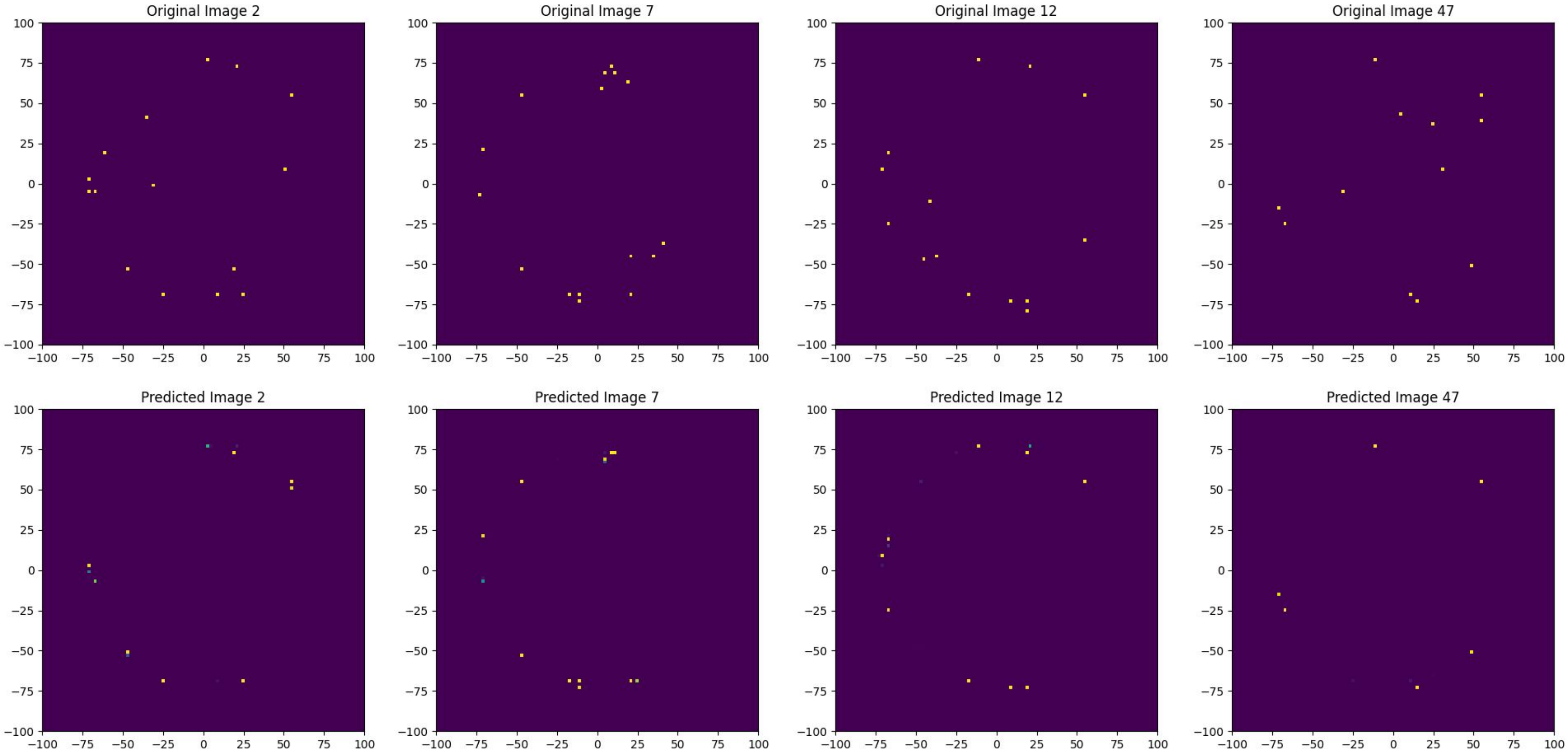


event-by-event ring reconstruction: Machine Learning

10 GeV negative beam
only aerogel radiator

input image

ML prediction



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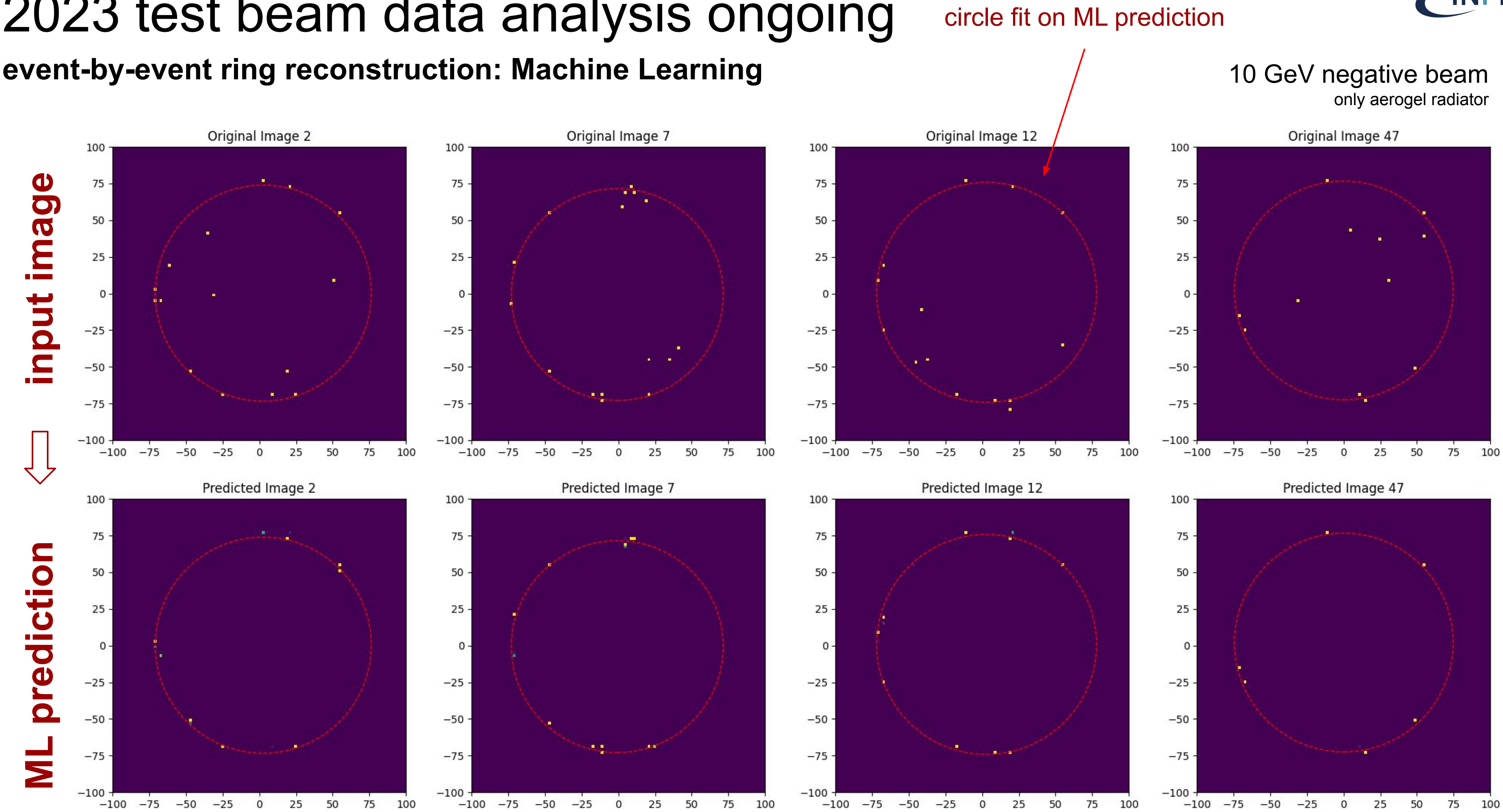
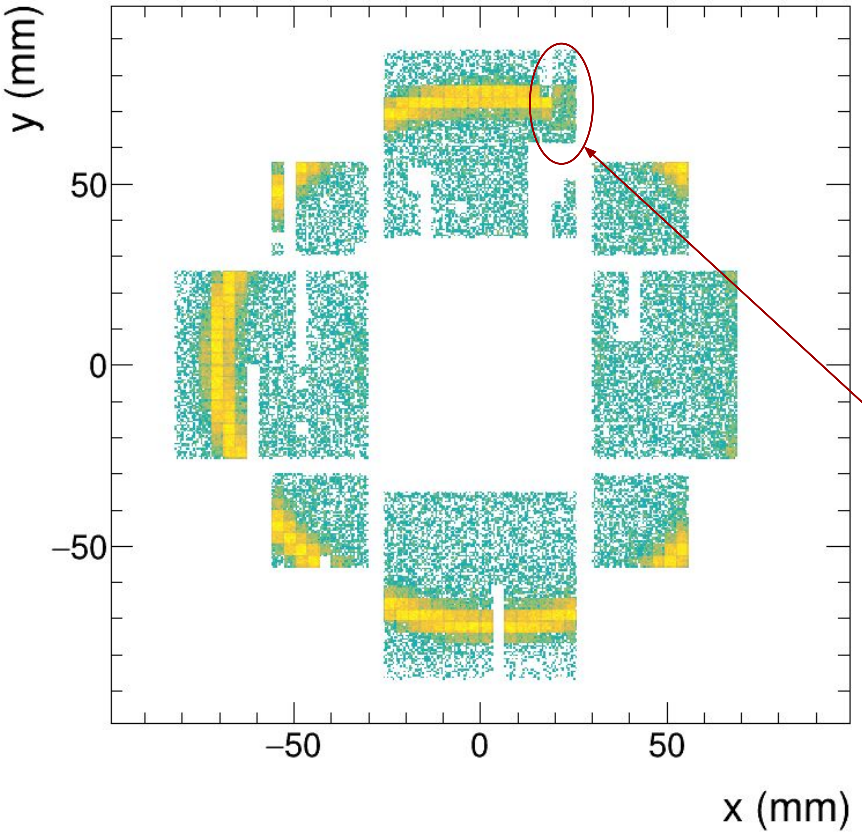
only aerogel radiator



Analysis on number of photoelectrons

Hit map – run 20231010-084623

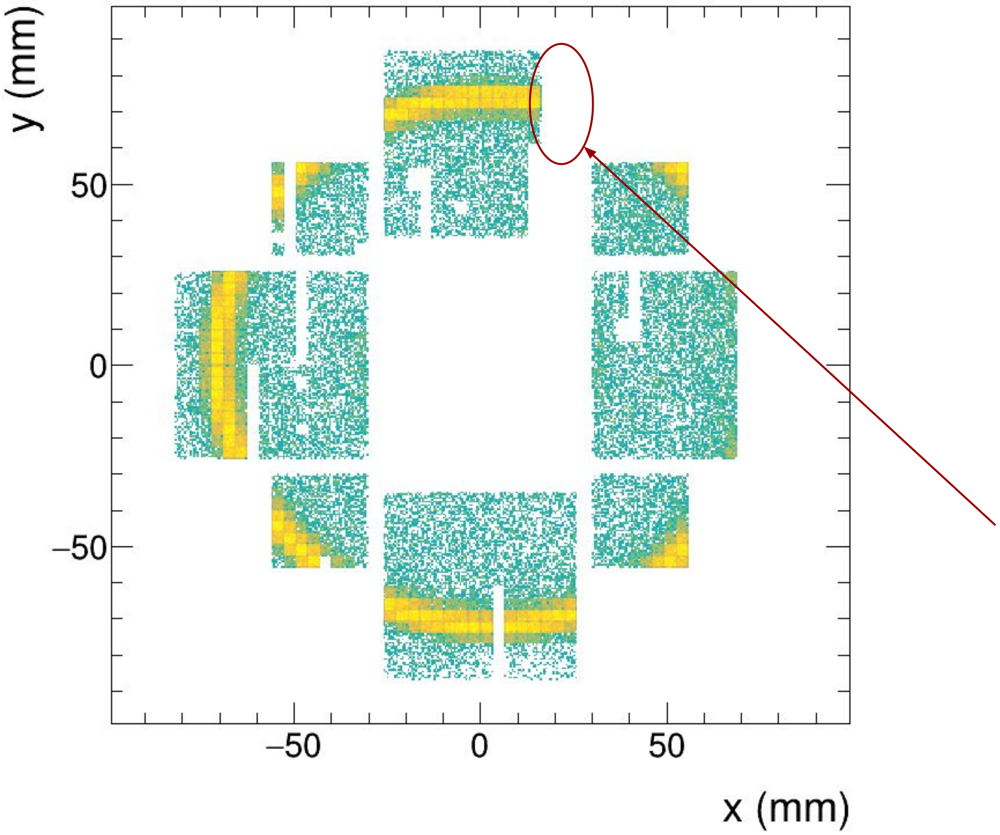


`recodata.root` file
timing cut: -10 < t < 40 ns

this image is just for visualisation
(x,y) position of hits uniformly smeared within the 3x3 mm^2 SiPM active area

there is clearly a problem in this region, therefore it will be excluded from the analysis

Hit map – run 20231010-084623



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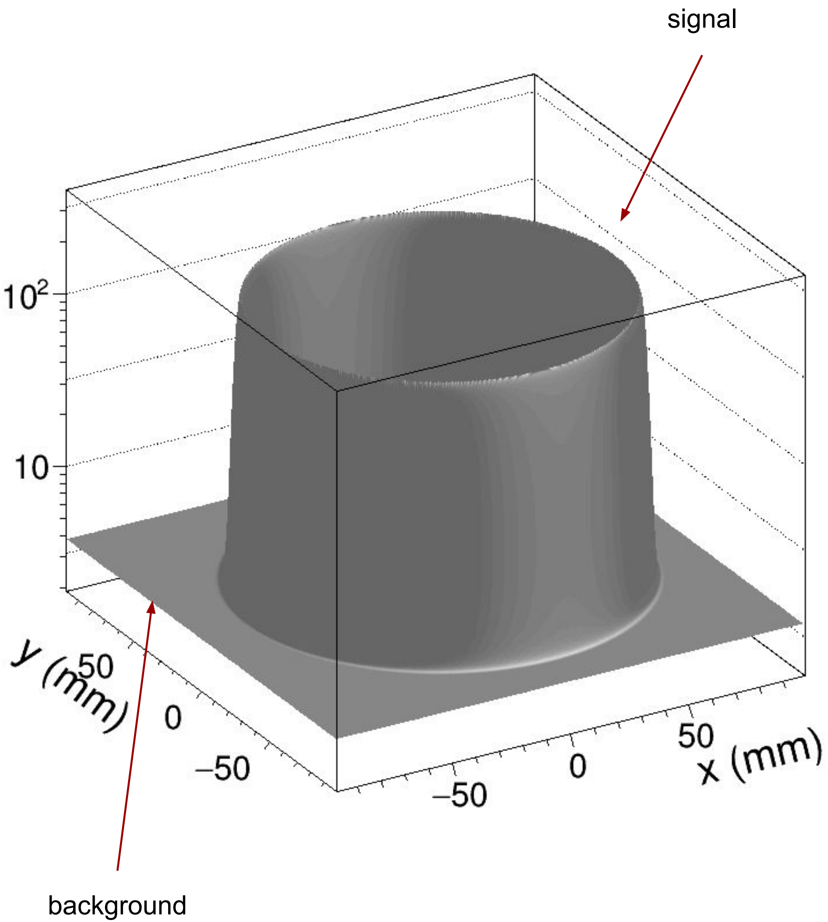
Fit function



2D fit function

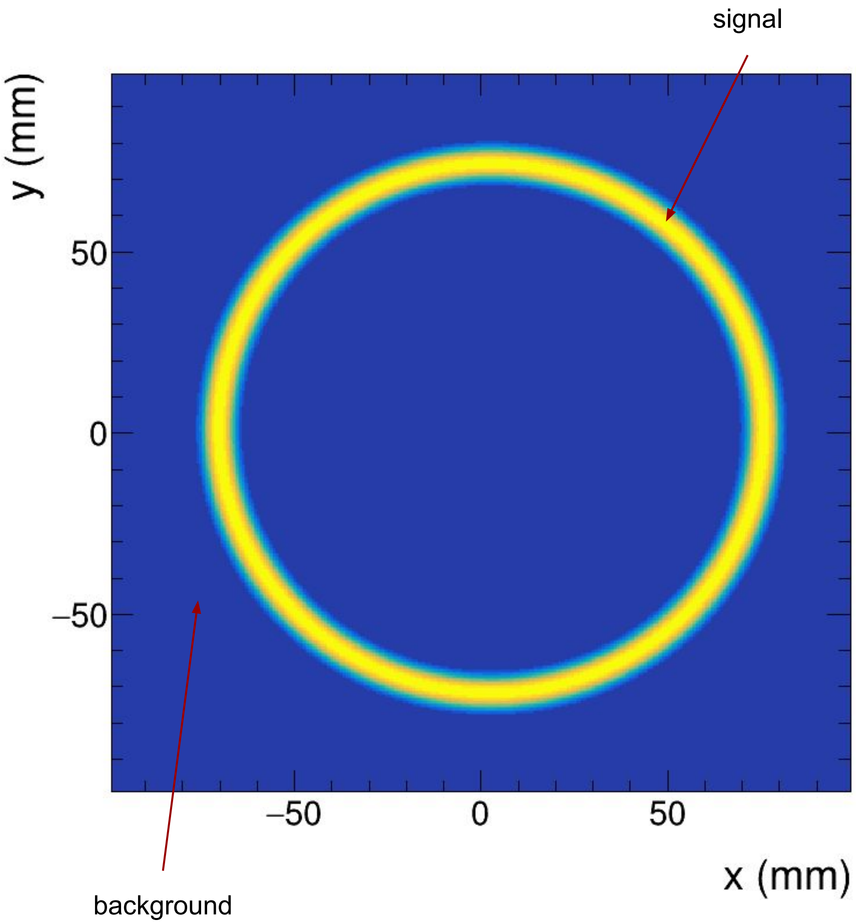
- signal: circle with gauss smearing
- background: flat

fit performed with χ^2 minimisation

- integrates function to properly take into account of SiPM active area
- accounts for errors properly

fit performed over the data accumulated in full run

Fit function



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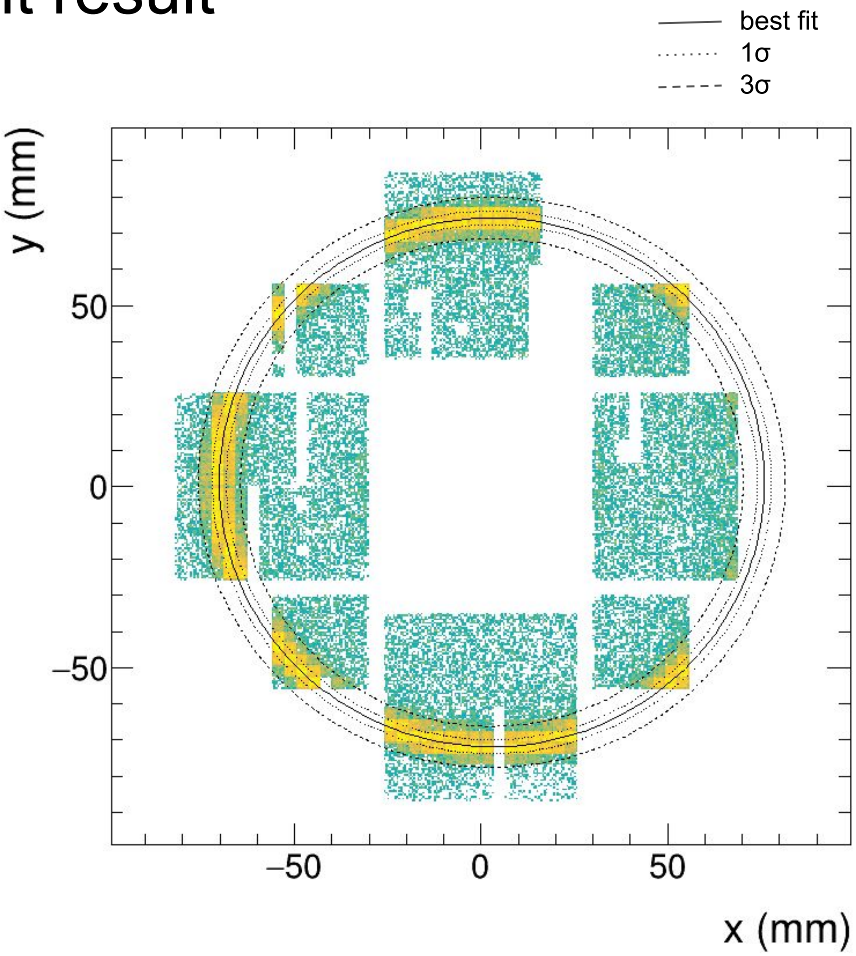
Fit result



norm	=	749.84	+/-	2.22088
X0	=	2.86829	+/-	0.0116219
Y0	=	1.18674	+/-	0.00828781
R	=	73.0474	+/-	0.00755383
sigmaR	=	1.88541	+/-	0.00599587
bkg	=	3.79583	+/-	0.0220657

the gaussian is normalised to unity therefore `norm` is the average number of photons per unit of circumference

the run has 14567 selected events
$\Rightarrow \langle dN/ds \rangle = 2.22088 \pm 0.00015$

integrating over the circumference S
$S = 2\pi R$

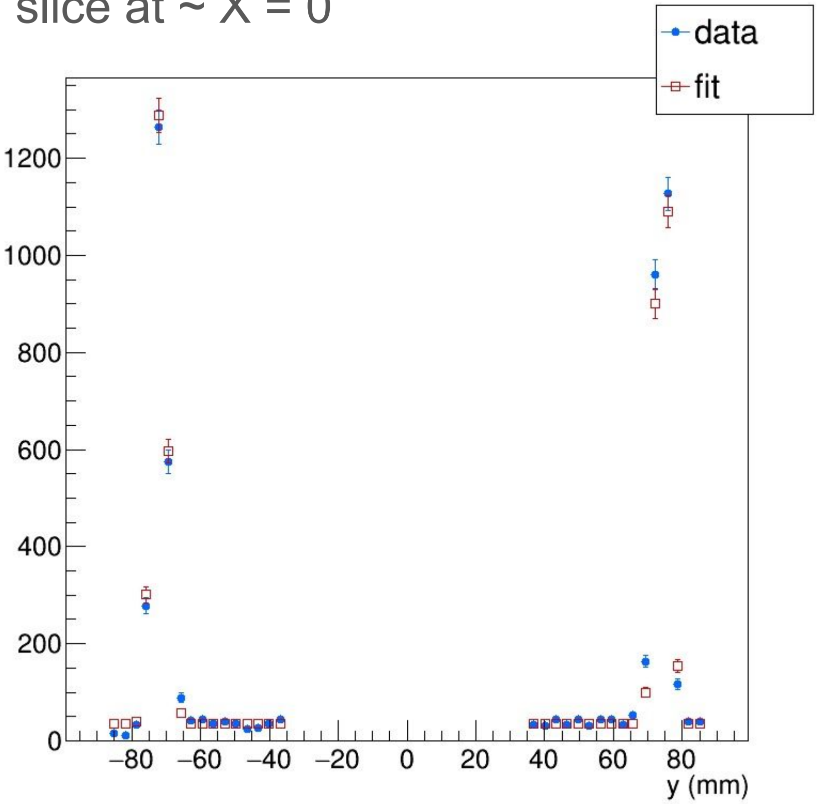
$\Rightarrow \langle N \rangle = 23.62 \pm 0.07$

this is the average number of photons we would see with a full-acceptance readout plane, including SiPM efficiency

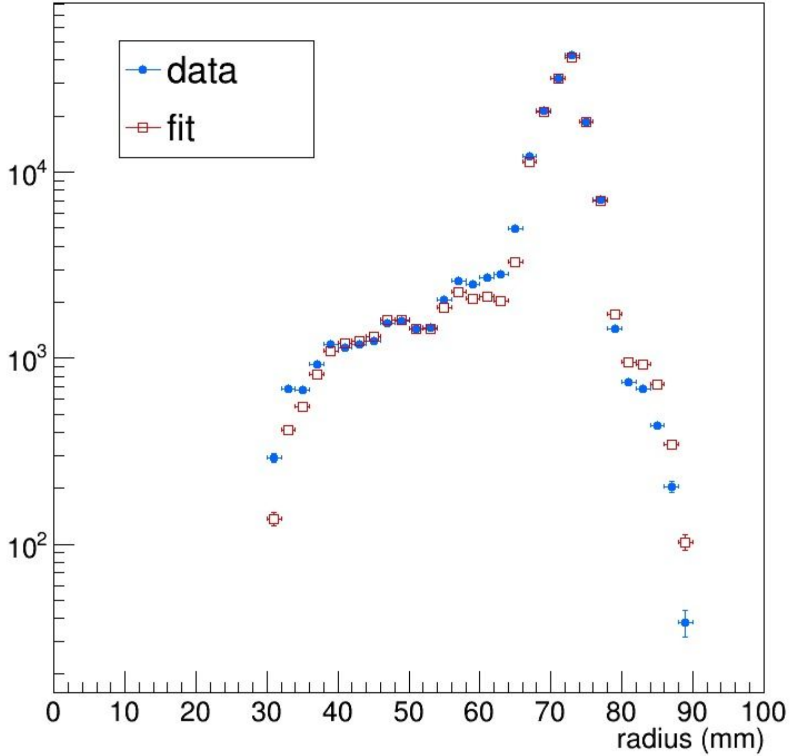
Fit cross-checks

fit reproduces data rather well

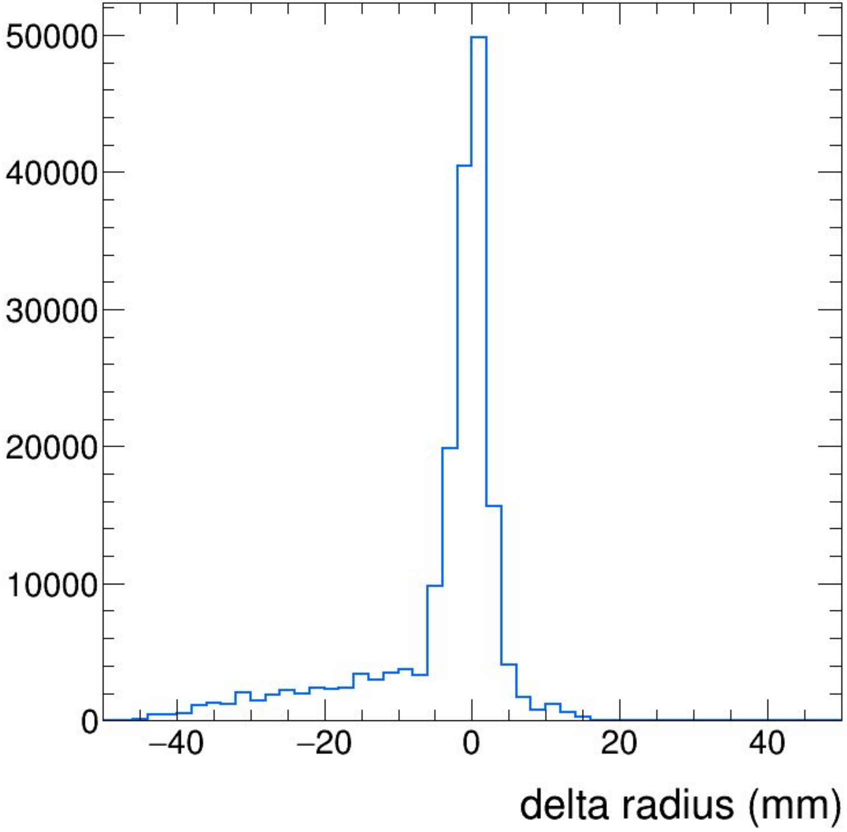
slice at ~ X = 0



radius



Fit result

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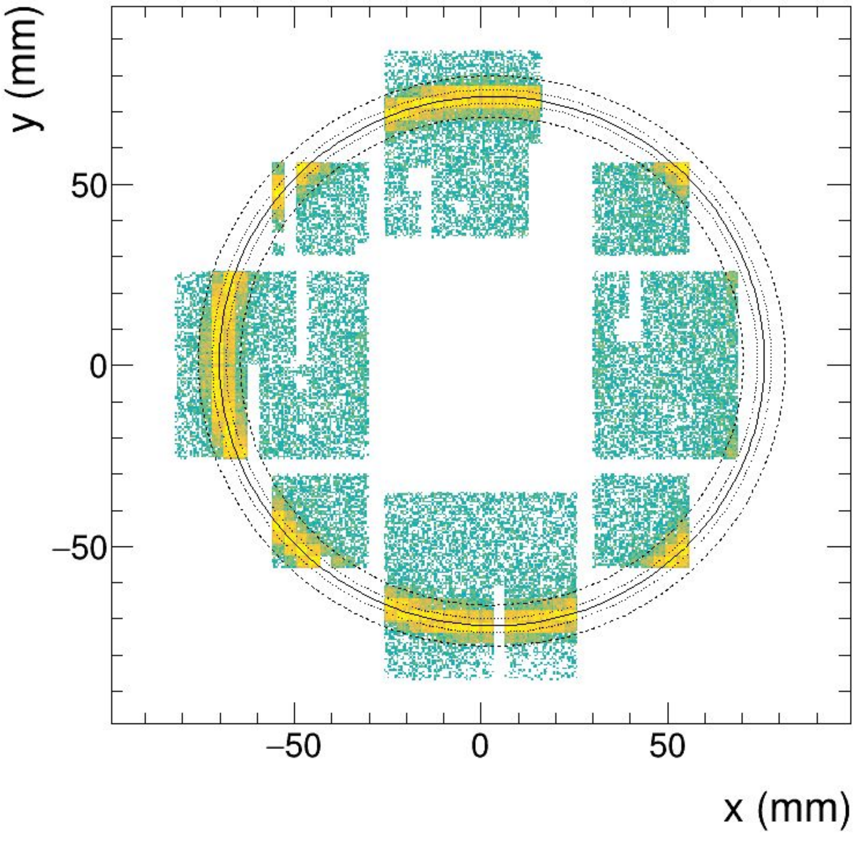
```

the deviation of the hit radius from the radius of the fitted circle is very narrow and is consistent with σ = 1.88 mm

let's use these as fixed ring parameters and perform event-by-event analysis of number of photons in the ring

count number of hits falling within 3σ of the fitted radius

Background



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R	=	73.0474	+/-	0.00755383
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bkg	=	3.79583	+/-	0.0220657

`bkg` is the average number of background hits per unit of area

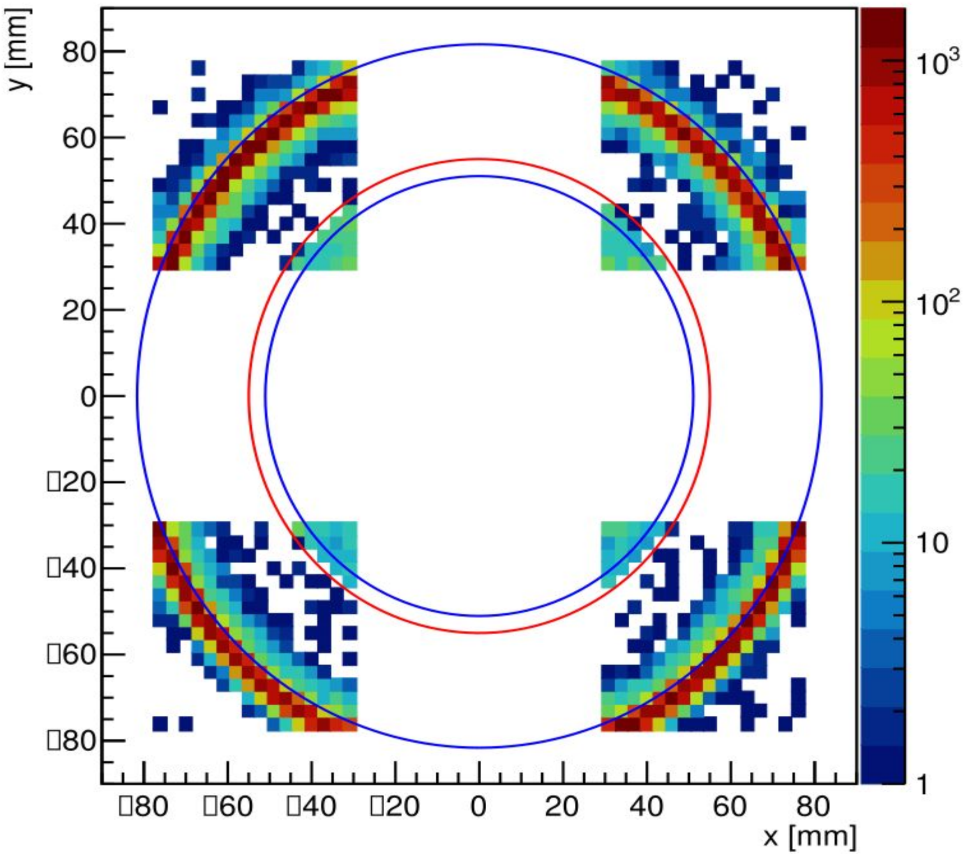
the run has 14567 selected events
$\Rightarrow \langle dB/da \rangle = 0.0002606 \pm 0.0000015$

integrating over the area of the ring within ±3σ
$A = \pi R_{+3\sigma}^2 - \pi R_{-3\sigma}^2$

$\Rightarrow \langle B \rangle = 1.353 \pm 0.008$

this is the average number of background hits that fall within 3σ of the ring over a full-acceptance readout plane
to be compared with $\langle N \rangle = 23.62 \pm 0.07$

Comparison with MAPMT



the dRICH prototype has also taken data with a "standard" readout based on Hamamatsu MAPMT and MAROC electronics (from CLAS12 RICH)

estimates on the number of fotons in the MAPMT full ring are

$\Rightarrow \langle N_{MAPMT} \rangle = 10.7$

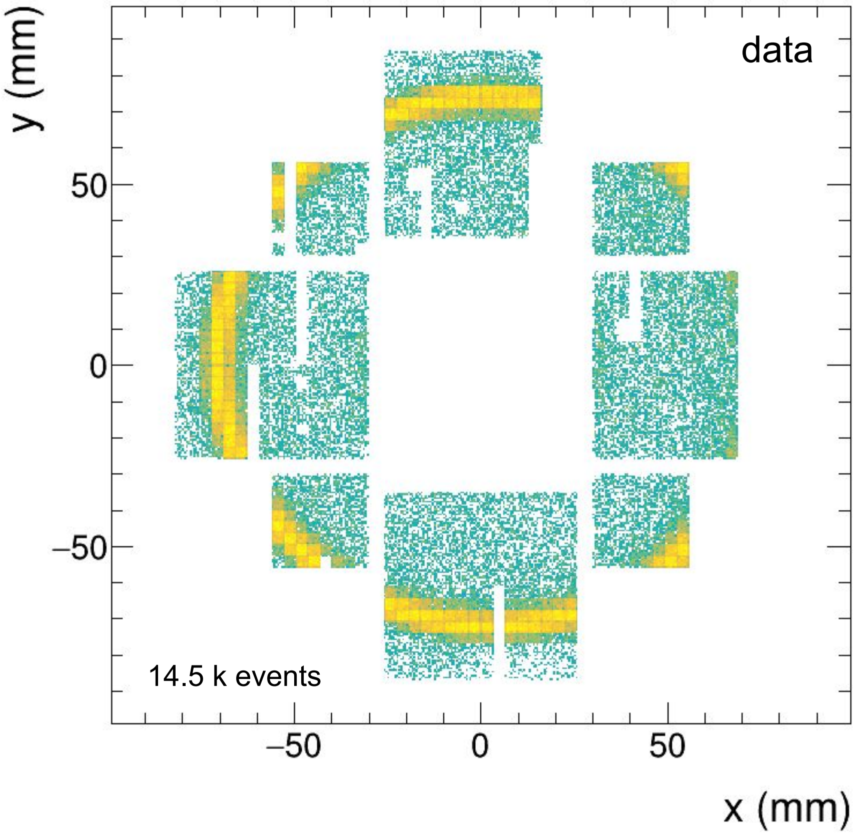
to be compared to the SiPM readout

$\Rightarrow \langle N_{SiPM} \rangle = 23.62 \pm 0.07$

there is a factor 2.2 more light detected with the SiPM readout than with the standard MAPMT readout

Fast Monte Carlo simulation

Fast simulation

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R         =   73.0474   +/-   0.00755383
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bkg       =   3.79583   +/-   0.0220657
```

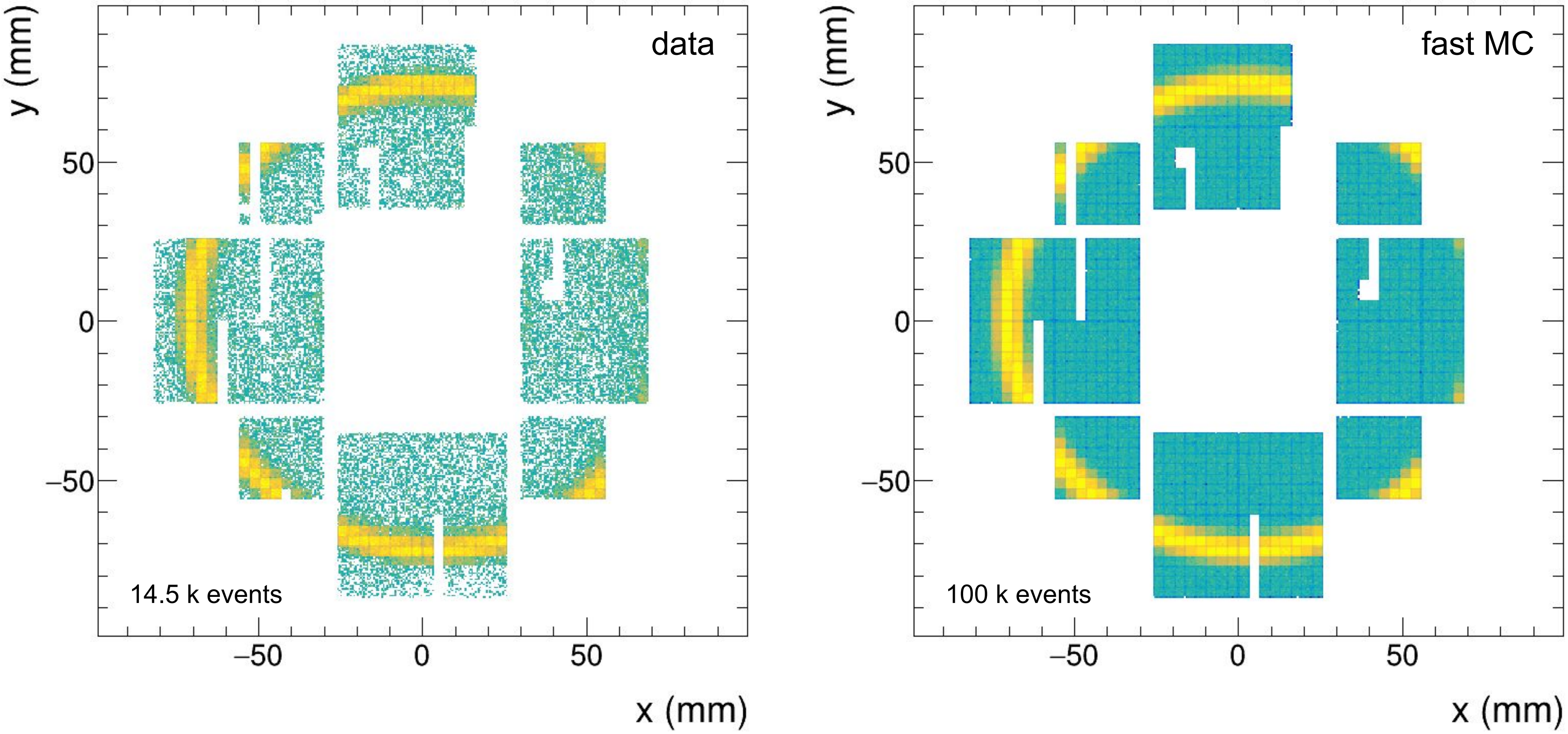
use the parameters from the 2D fit to the data to randomly generate rings and background

hit on the readout surface digitised according to the SiPM position and 3x3 mm^2 active area

if generated photons falls into the SiPM area the position assigned is the centre of the SiPM

fast simulation output has same structure as `recodata.root`

Fast simulation

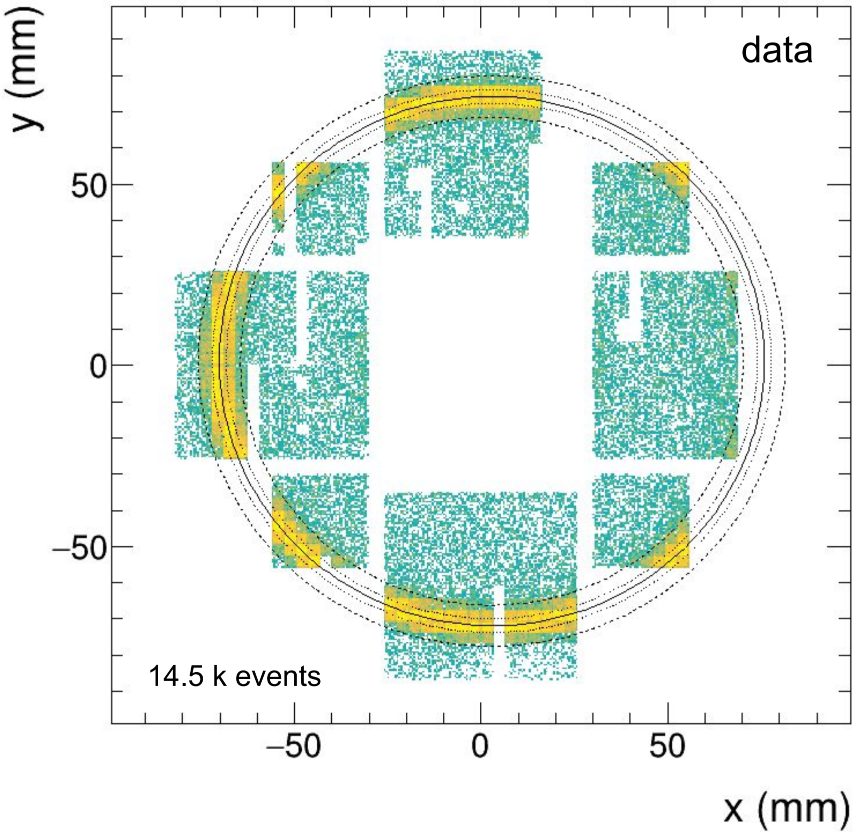


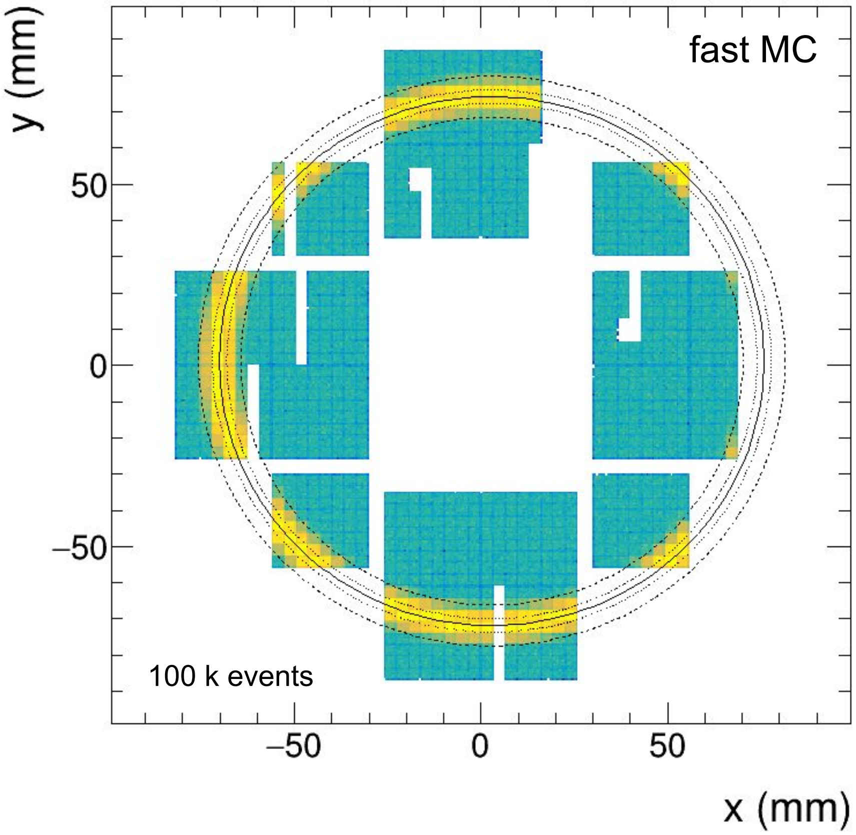
Fast simulation – 2D fit

2D fit parameters match accurately fast MC input

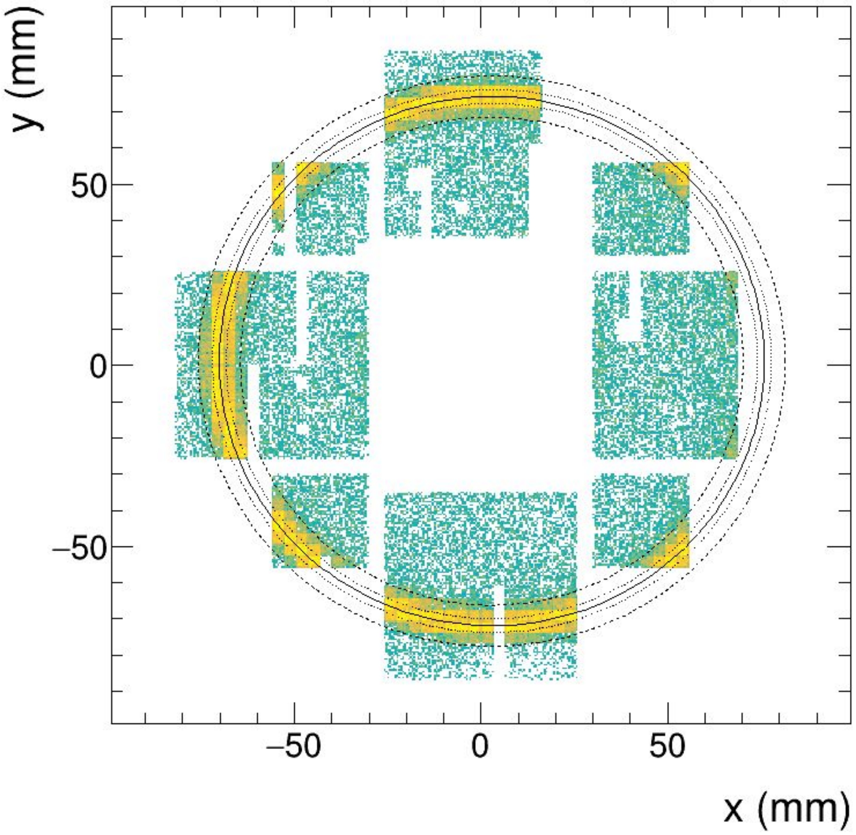
notice redefinition of Nsig and Nbkg

```
Nsig      =   23.6048   +/-   0.0154101
X0        =   2.87125   +/-   0.00255149
Y0        =   1.18834   +/-   0.00193679
R         =   73.0013   +/-   0.00166626
sigmaR    =   1.88591   +/-   0.00123206
Nbkg      =   10.3538   +/-   0.0133316
```





Event-by-event

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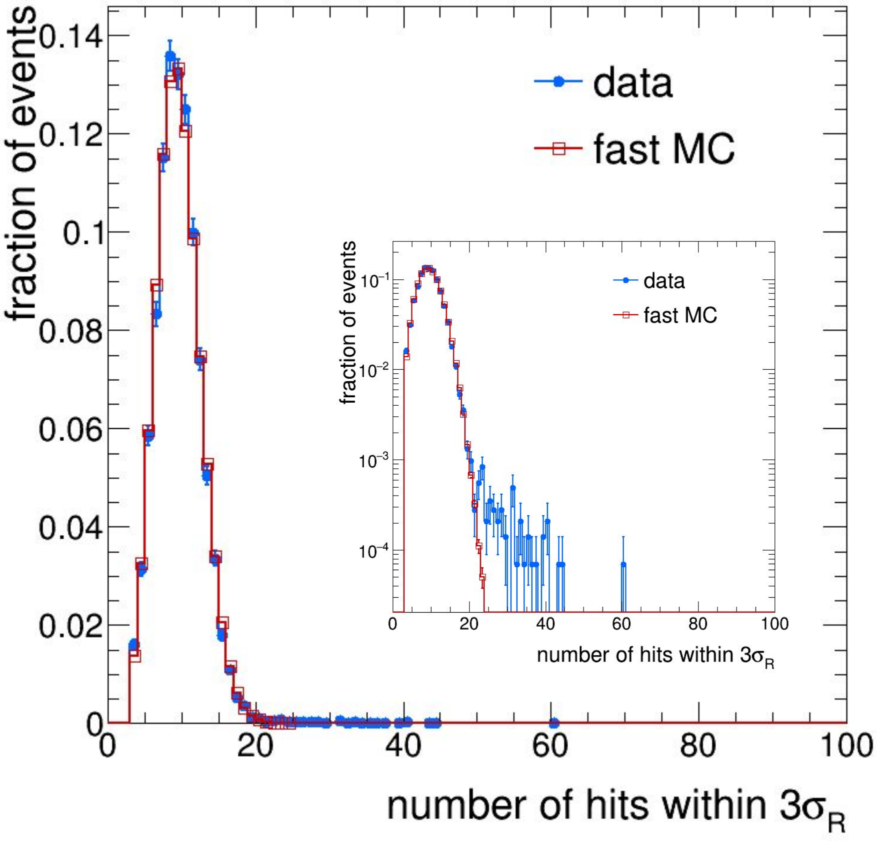
```

let's use these as fixed ring parameters and perform event-by-event analysis of number of photons in the ring

how: count number of hits falling within 3σ of the fitted radius

caveat: we will also count background hits

Event-by-event



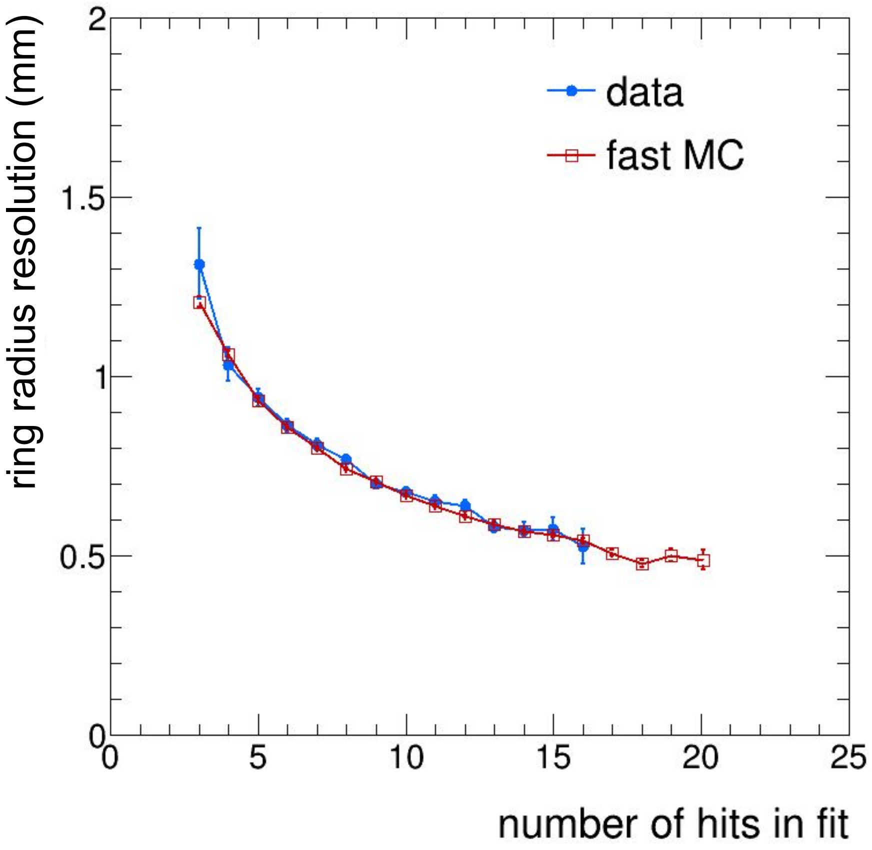
event-by-event distribution of the number of detected hits within 3σ of the globally-fitted ring radius

excellent agreement between data and fast simulation

⟨N⟩ = 9.056 ± 0.025

tail of events with an excess of hits can be nicely appreciated comparing data and fast MC

Ring radius resolution

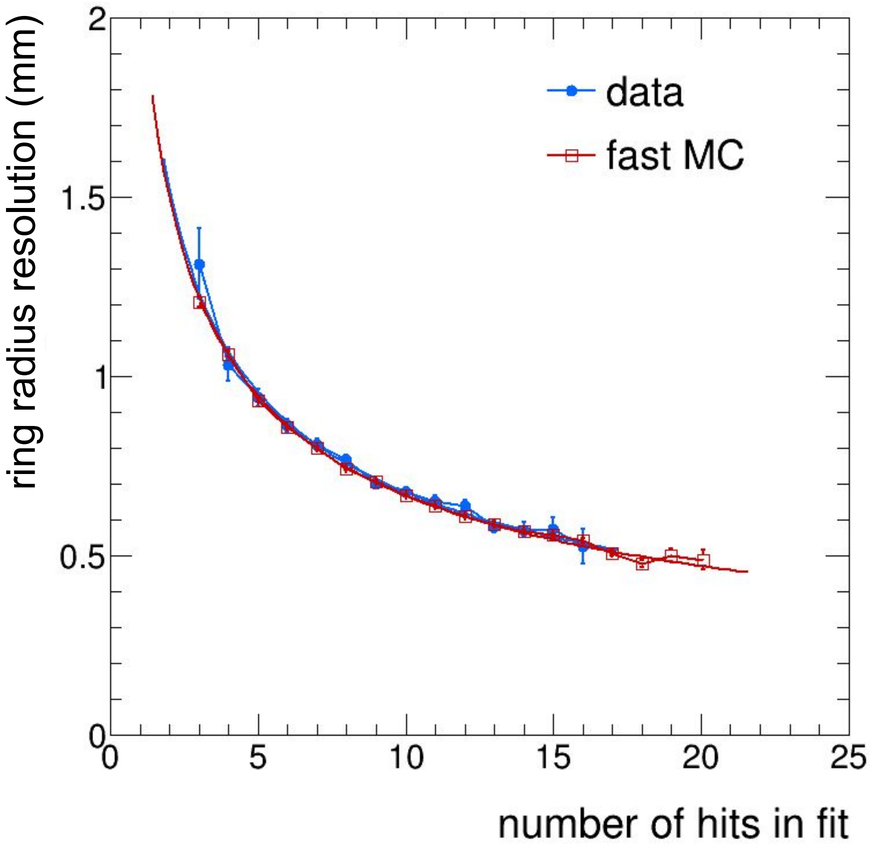


fitting with a circle the hits that fall within 3σ of the globally-fitted ring radius

X_0 and Y_0 parameters fixed, R free
this gives the best radius resolution, try if you do not believe it

excellent agreement between data and fast simulation

Ring radius resolution



fitting with a circle the hits that fall within 3σ of the globally-fitted ring radius

X_0 and Y_0 parameters fixed, R free
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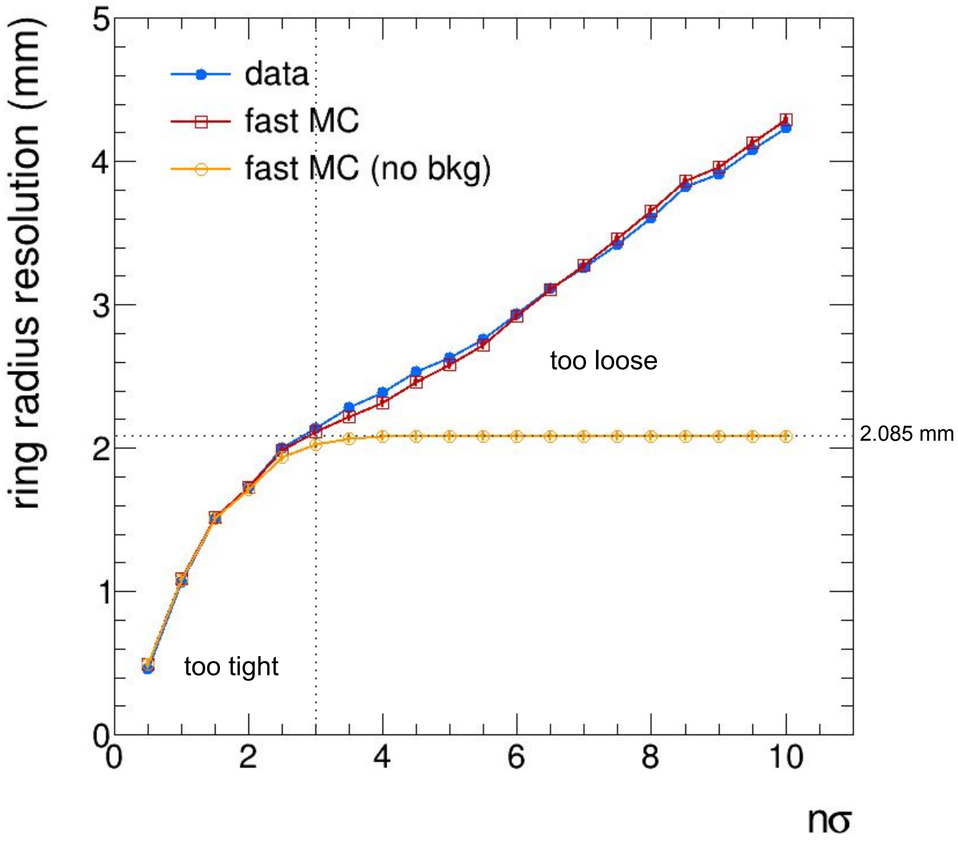
A / √N fit to data and fast MC yield consistent single photon resolution

$\sigma_{R,1pe}$ = 2.141 ± 0.014 mm

Resolution vs. nσ cut



fitting with a circle the hits that fall within nσ of the globally-fitted ring radius

X_0 and Y_0 parameters fixed, R free
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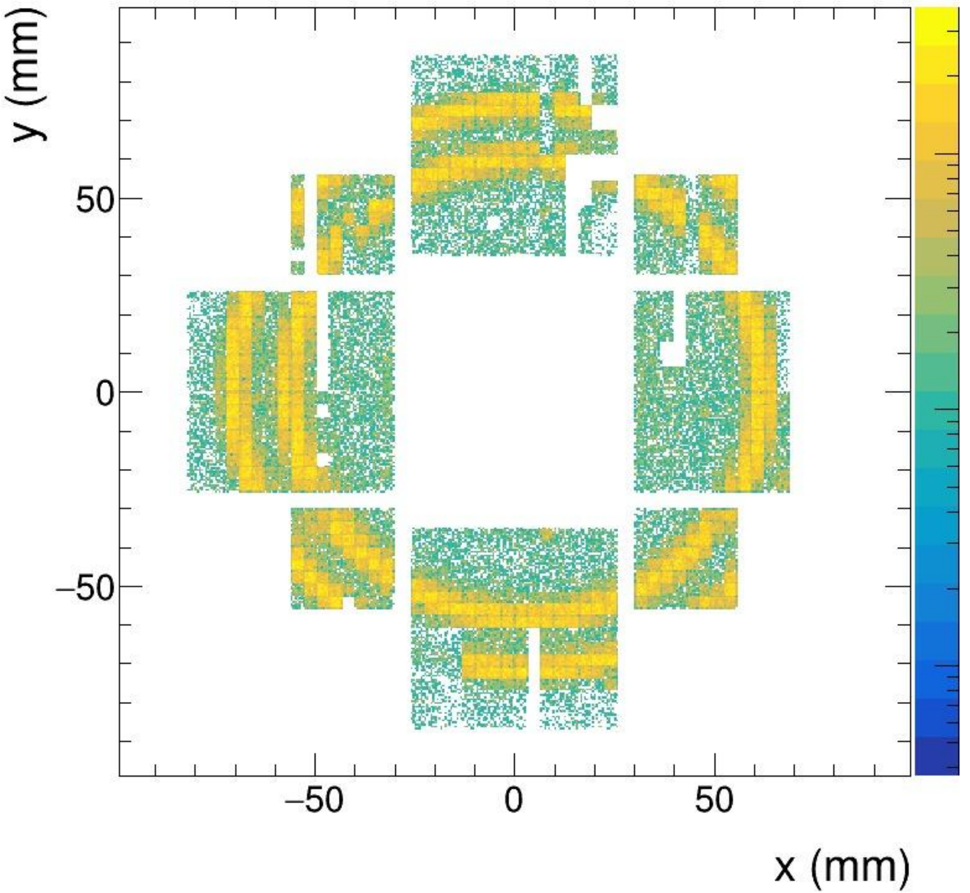
excellent agreement between data and fast simulation

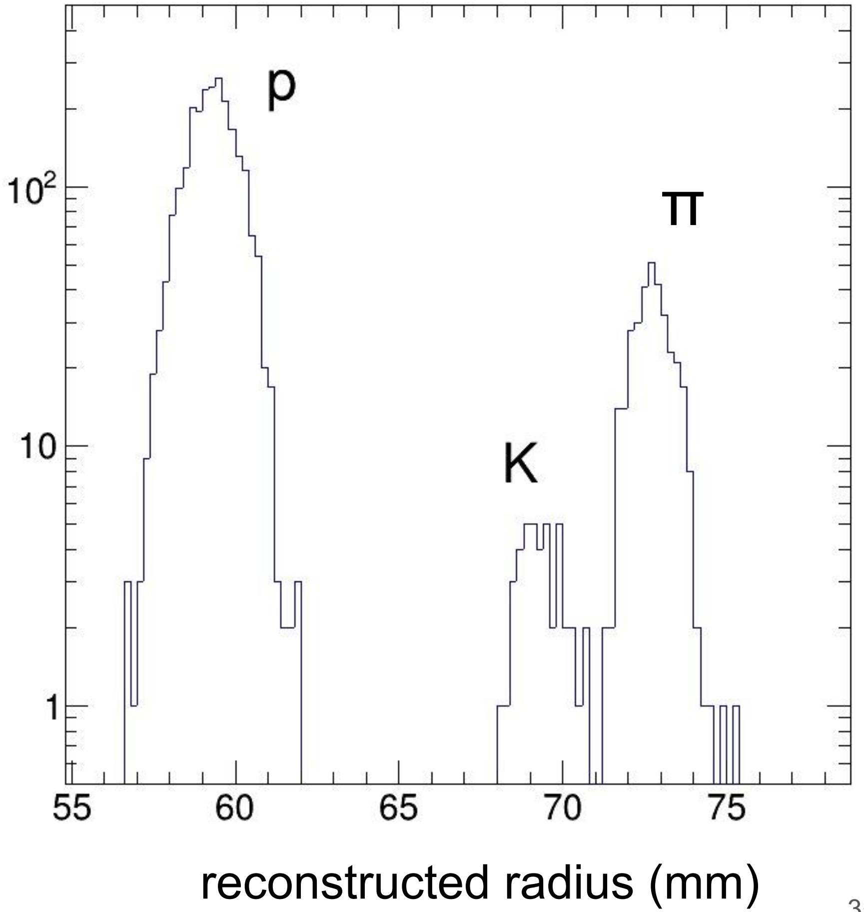
tight cut → bias
loose cut → bkg contamination
no apparent sweet spot

must understand background and if possible cut into it
might be difficult because it seems to happen "in time" with the Cherenkov light, perhaps it is Cherenkov light scattered in the aerogel, in which case it could be an irreducible background

Teasers for futute meetings

8 GeV/c positive beam data



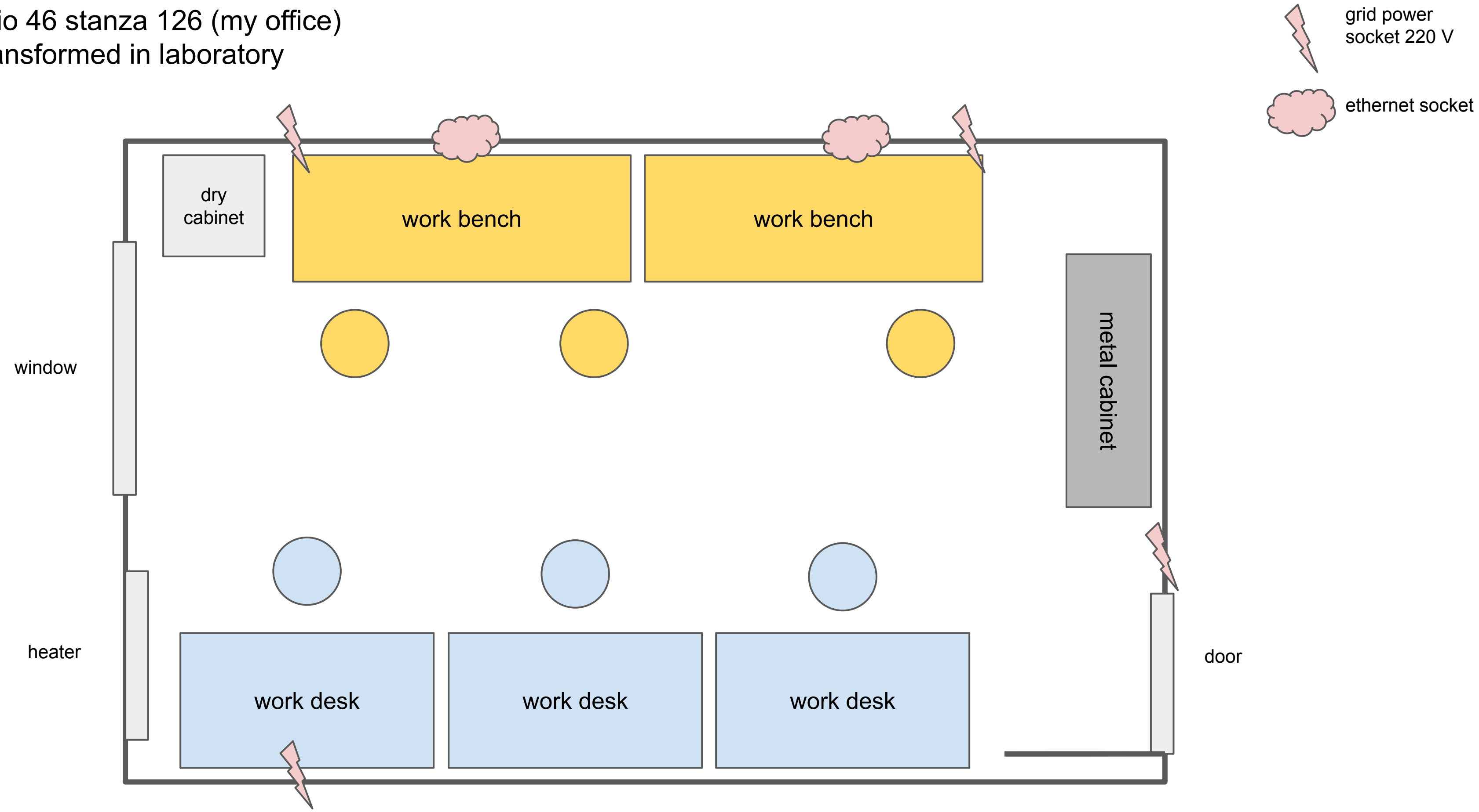


Summary

- **number of detected photons**
  - this is an important number to take out of the beam test data
  - preliminary average number of photons obtained
    - $\langle N \rangle = 23.62 \pm 0.07$
    - includes SiPM efficiency
    - assumes full detector acceptance
  - several cross-check performed, must evaluate systematic uncertainty
  - SiPM readout sees much more light than MAPMT-MAROC readout
    - a factor 2.2 larger
- **fast Monte Carlo simulation**
  - very useful tool, generating simulation data at the speed of light
    - code compiled to run on NVIDIA GPU makes the trick
  - excellent agreement between data and fast Monte Carlo
    - event-by-event quantities
    - further details of ring resolution and performance
- **this talk is only a microscopic fraction of the beam test results**

The ePIC lab

DIFA, via Irnerio 46 stanza 126 (my office)
will soon be transformed in laboratory



this is the current project for a change in layout and function of the room
it will not be a office, it will be a lab with desk tables lab-oriented activities


the lab will not start empty, office is already full of boxes with equipment to be installed