Experimental investigation of ~ 130 keV kinetic energy antiprotons annihilation on nuclei.

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LEAP 2013 - Uppsala, June 11th 2013

Physical motivation

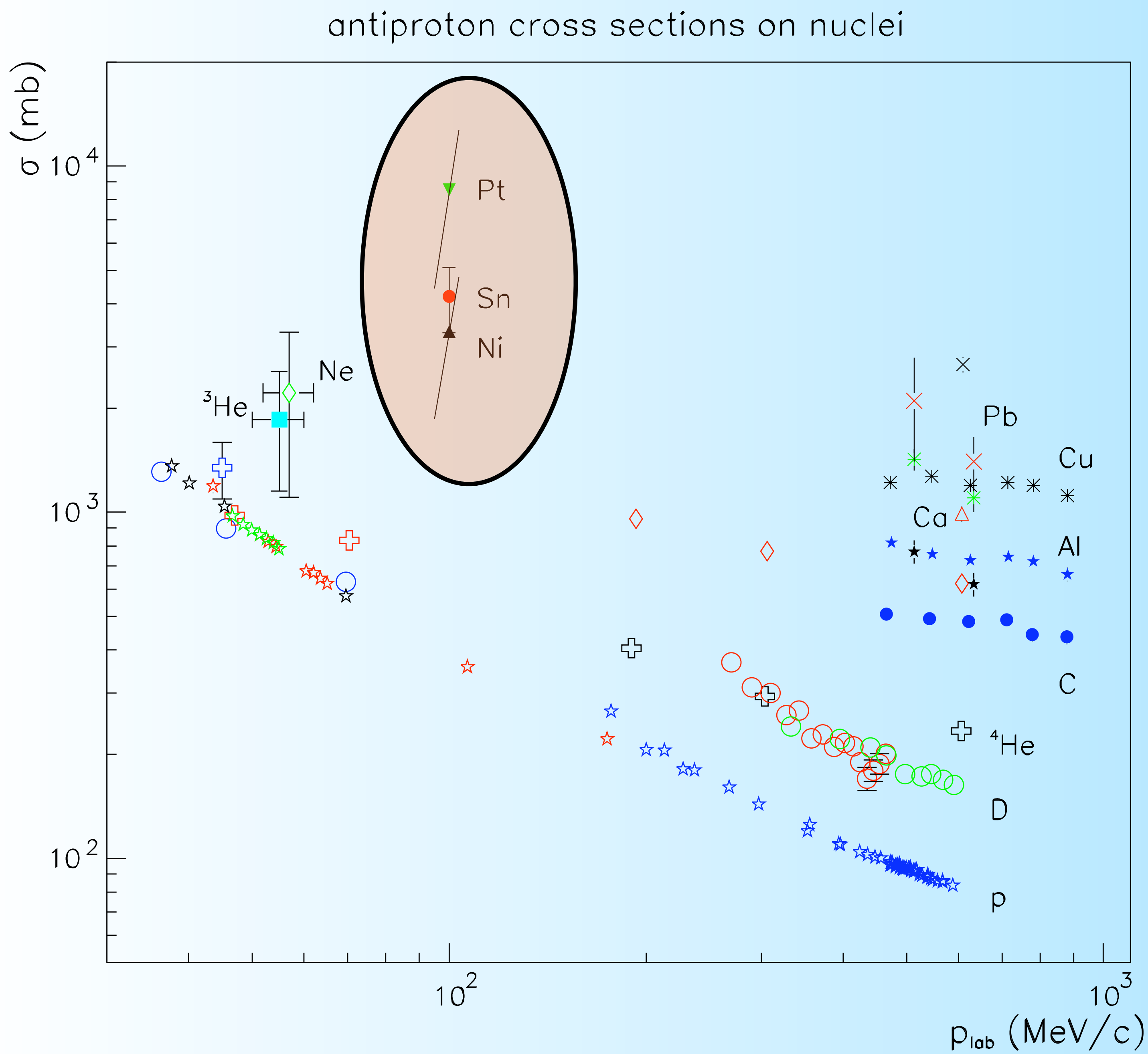
- **Existing data** of antinucleon-nucleon annihilation cross section are **confined to energies about 1 MeV** and mostly with **light nuclei**. Data taken at LEAR (CERN) in the '80s and '90 do not increase with A as expected showing a saturation effect.

- Both potential models and phenomenological analyses states that the NN and N-nucleus annihilation mechanism occurs in a thin region placed just outside the nuclear volume. For this reason, the annihilation process has to be considered a **valuable tool for probing the external region of the nucleus** where for example the neutron/proton ratio or the extraction energy of the peripheral nucleons can be determined.

- The knowledge of the annihilations cross sections for antinucleons, especially on light nuclei, can be important also for **cosmology** (despite that a matter-antimatter symmetric universe has been certainly ruled out: see Cohen, De Rùjula, Glashow, APJ 495:539-549, 1998, and yesterday's talks).

Previous measurements

@ 5 MeV



A. Bianconi et al., Phys. Lett. B 704, (2011) 461

The pbar cross section on medium/heavy nuclear targets in this energy range have been measured for the first time, and the results are **in agreement with the black disk model with the contribution of the Coulomb interaction** between the antiproton and the nucleus at low energy.

$$\sigma = \pi R^2 \left[1 + \frac{Ze^2 (m+M)}{4\pi \epsilon_0 ERM} \right]$$

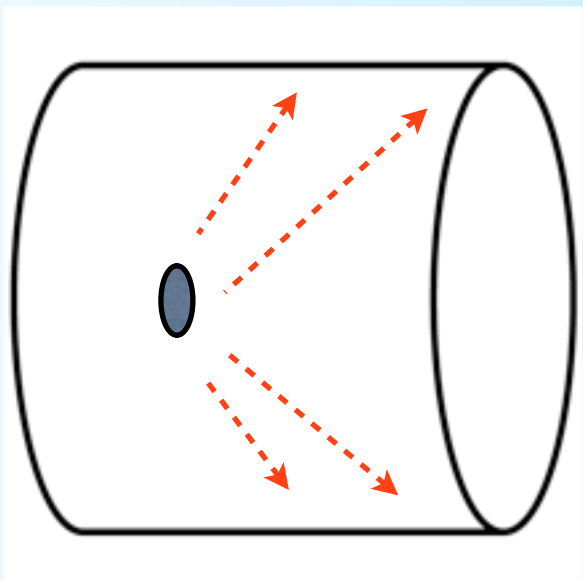
Coulomb term

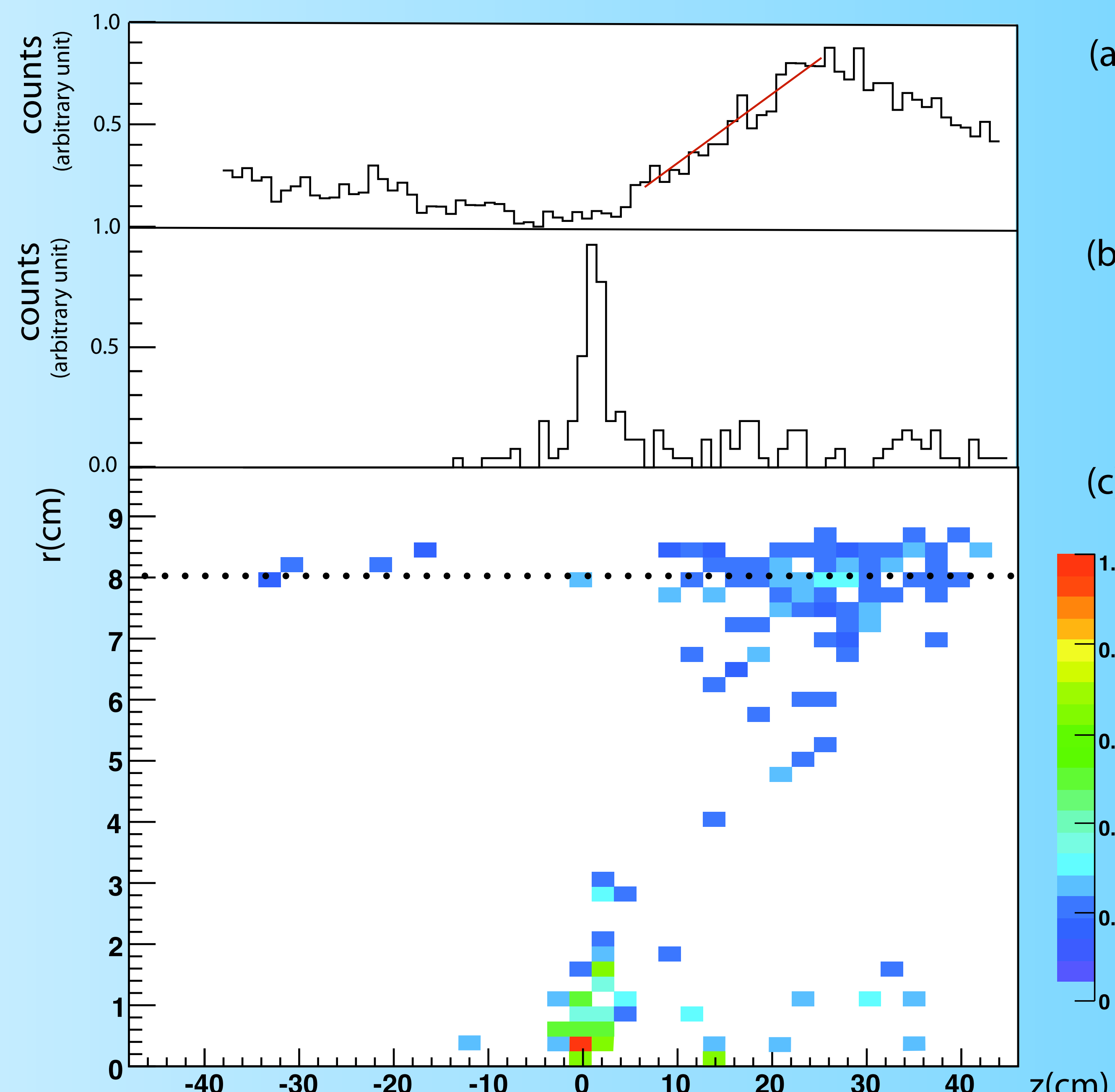
$$\sigma_{Sn} = (4.2 \pm 0.9)\, barn$$
$$\sigma_{Ni} = (3.3 \pm 1.5)\, barn$$
$$\sigma_{Pt} = (8.6 \pm 4.1)\, barn$$

The cross section measurements @ 5 MeV were performed by comparing the annihilations on the target to the annihilations of the Rutherford-scattered antiprotons

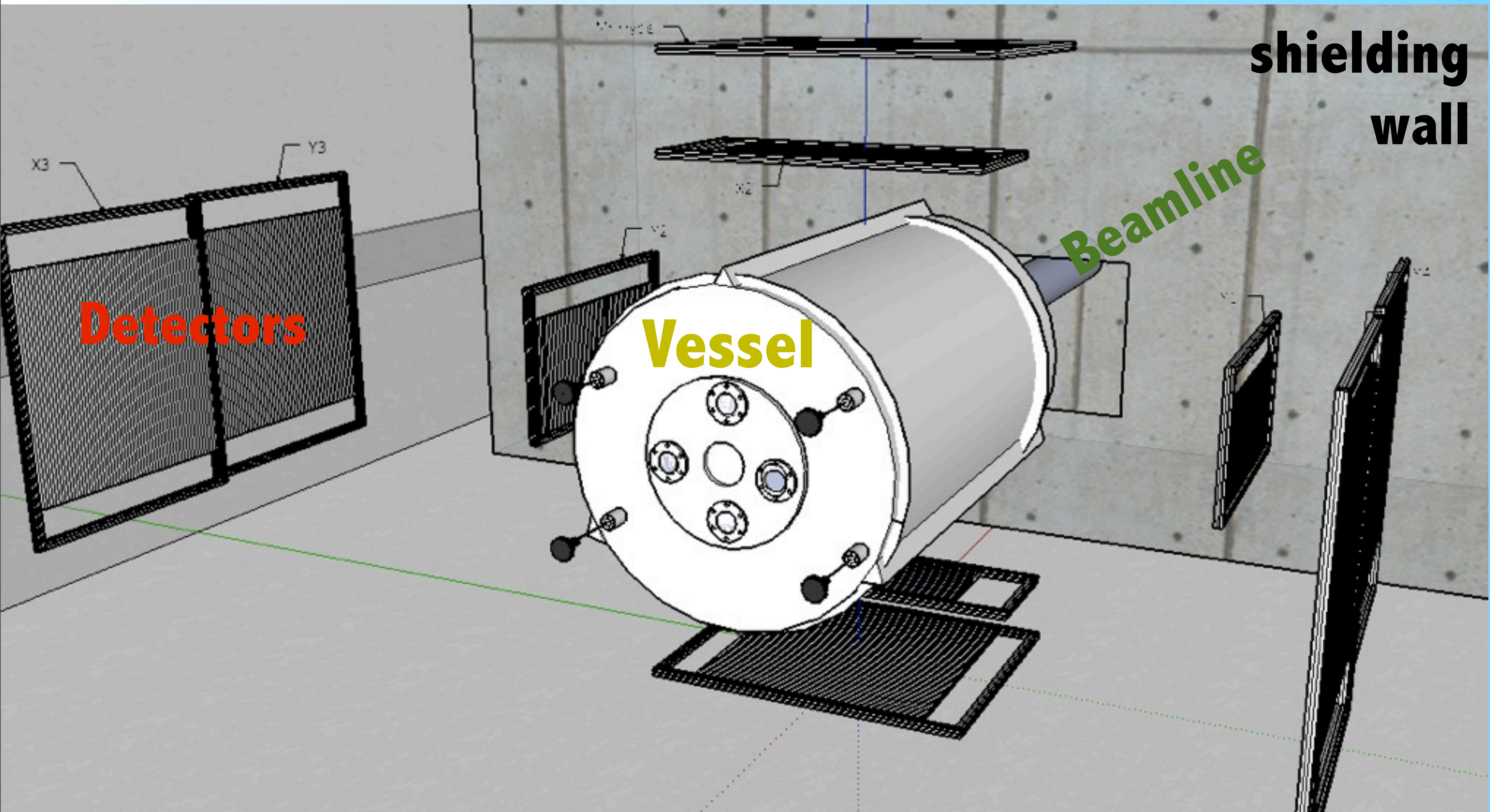
$$\frac{d\sigma_{Ruth}}{d\Omega} = \left(\frac{Ze^2}{16\pi\epsilon_0 E}\right)^2 \frac{1}{\sin^4(\frac{\theta}{2})} \longrightarrow \frac{dN_{wall}}{dz} = N_{\bar{p}} n l Z^2 \frac{\pi}{2}\alpha^2 \left(\frac{\hbar c}{E}\right)^2 \frac{1}{R^2} f\left(\frac{z}{R}\right)$$

$$\text{with} \quad f\left(\frac{z}{R}\right) = \left(\frac{1+2(\frac{z}{R})^2}{\sqrt{1+(\frac{z}{R})^2}} + 2\frac{z}{R}\right)$$

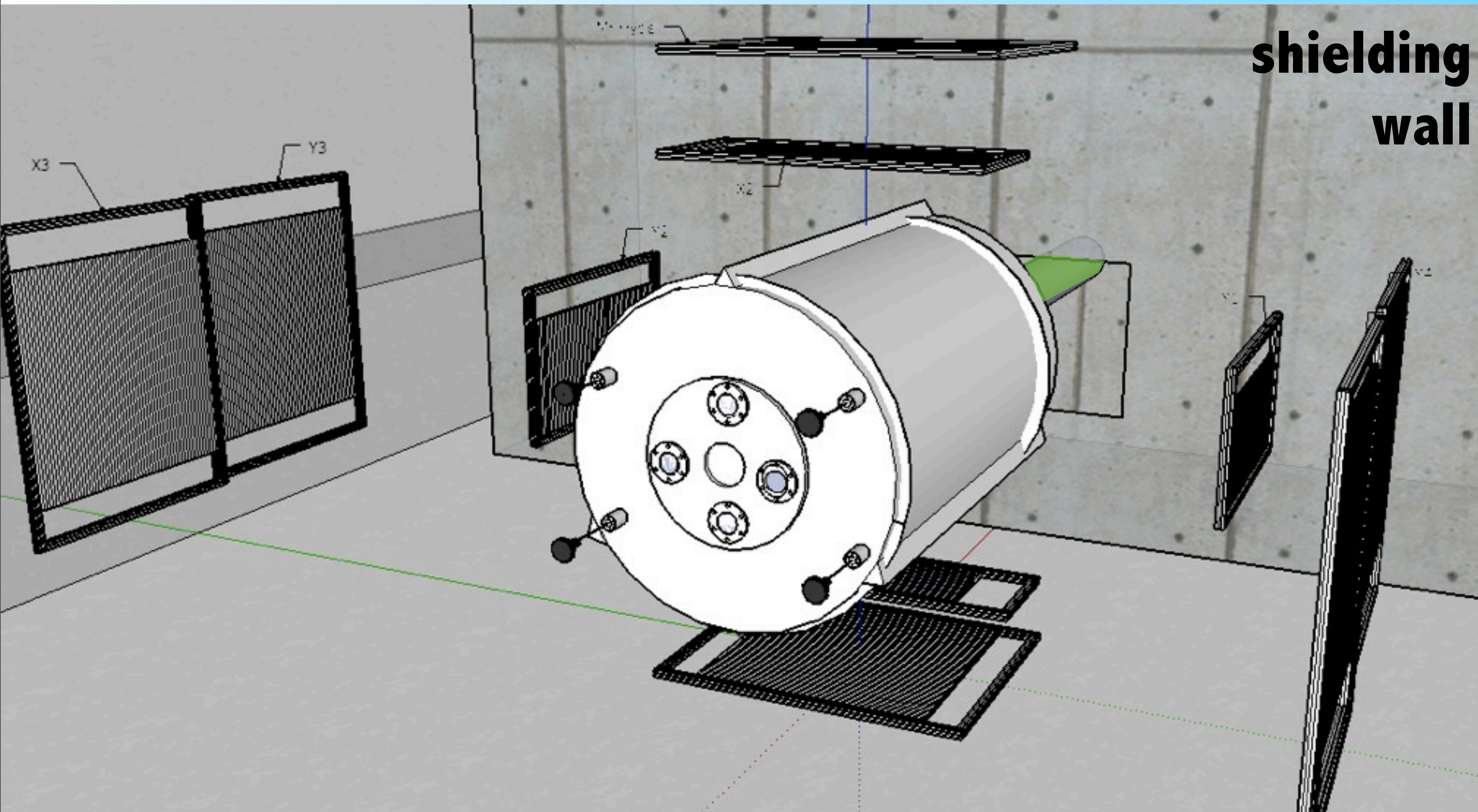




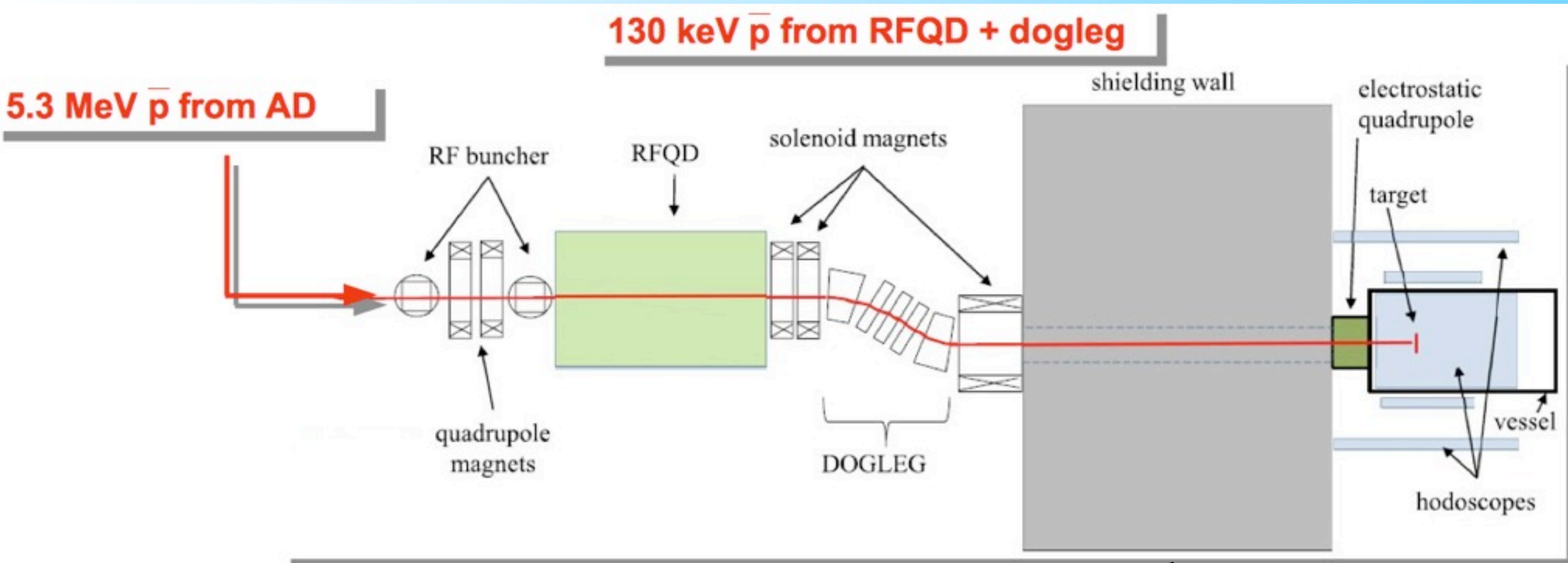
Experimental setup



Beamline



AD, ASACUSA RFQD
and "dogleg" magnetic spectrometer



The thick (~ 1 m) shielding wall is necessary to avoid

$\pi \rightarrow \mu \rightarrow$ e events

A huge work of optimization and focusing has been needed to bring a collimated beam of antiprotons to the target

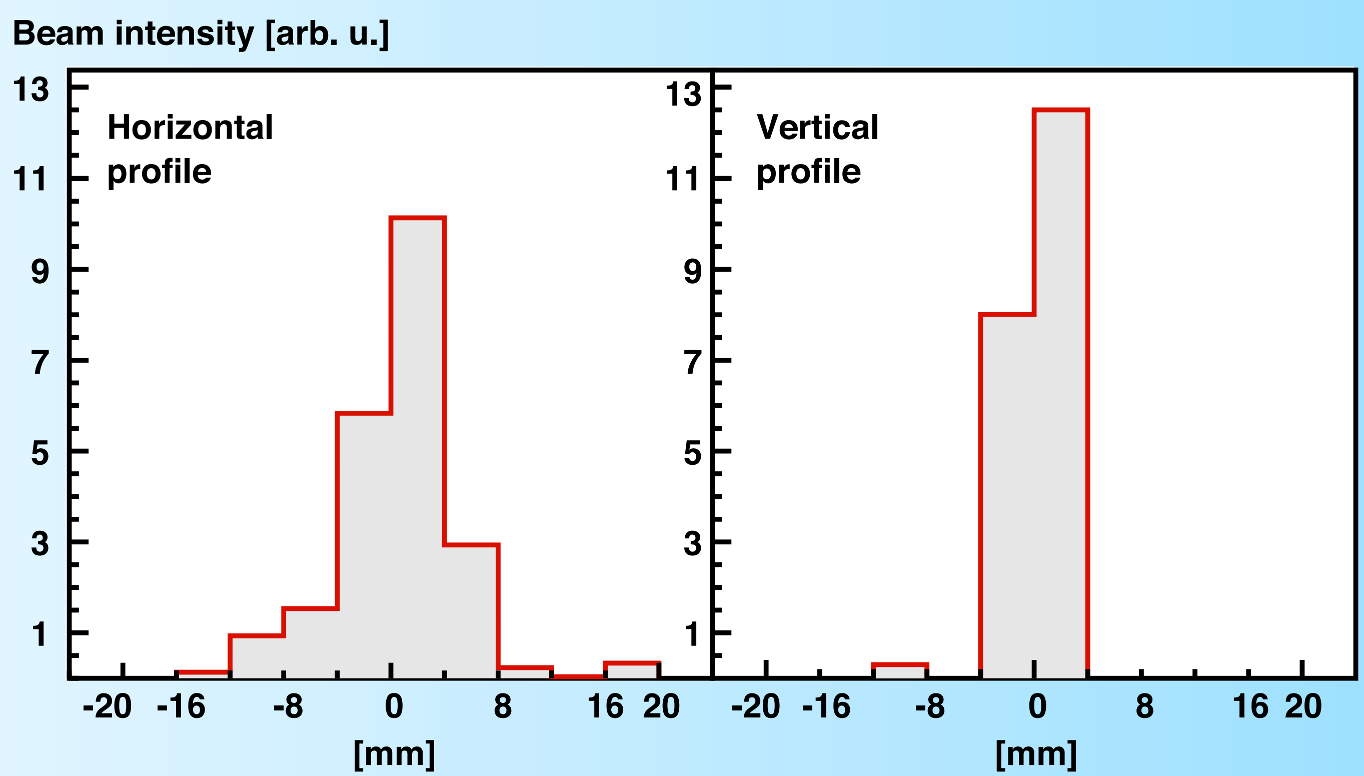
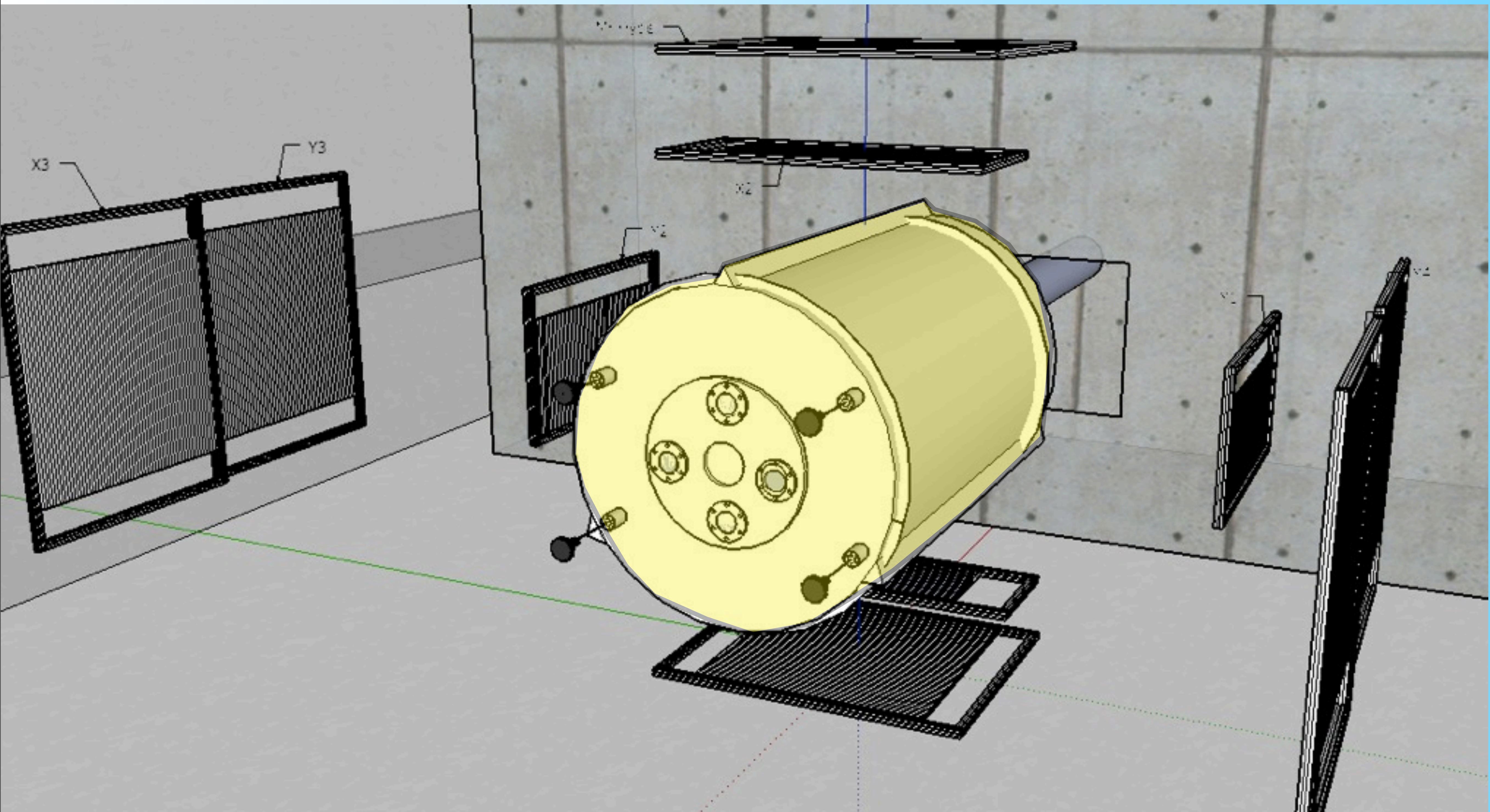


Fig. 2. The $\bar{p}$ beam profile (x, y) on the target, z being around 67 cm from the entrance of the target vessel.

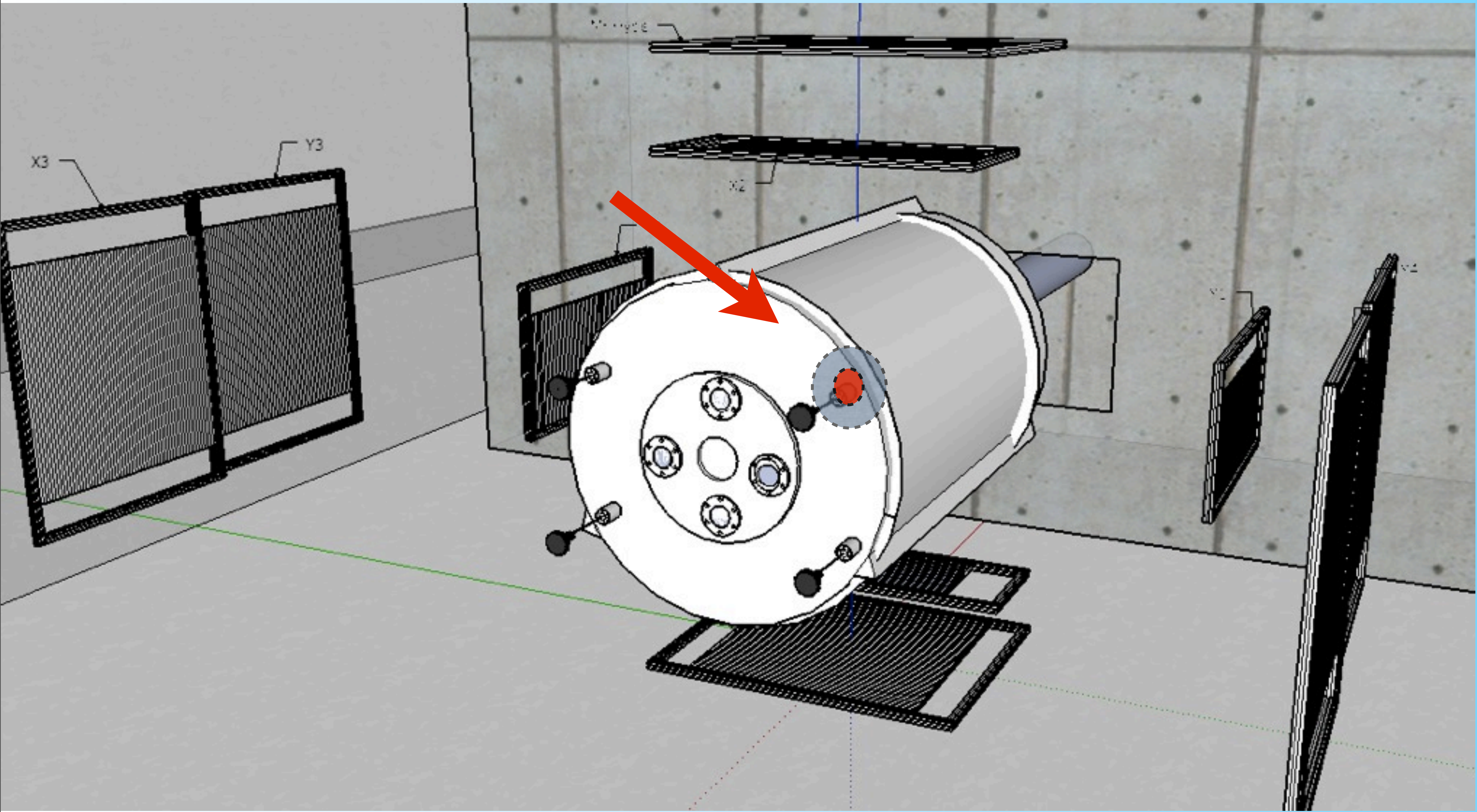
Vessel



The vessel is a cylinder of stainless steel (5 mm thick) with length = 170 cm and diameter = 120 cm

pressure inside the vessel < 10^{-7} mbar

Targets

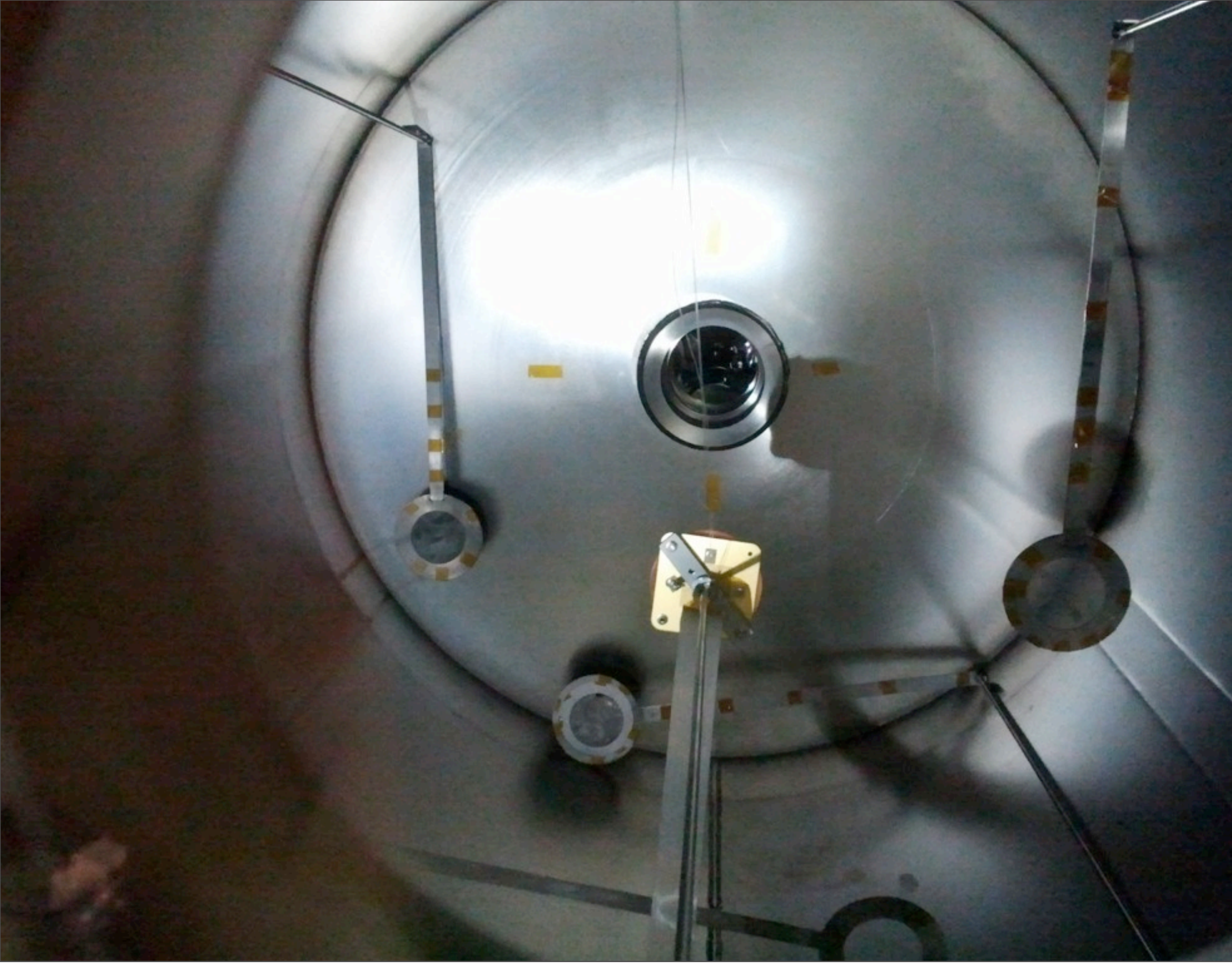


Targets

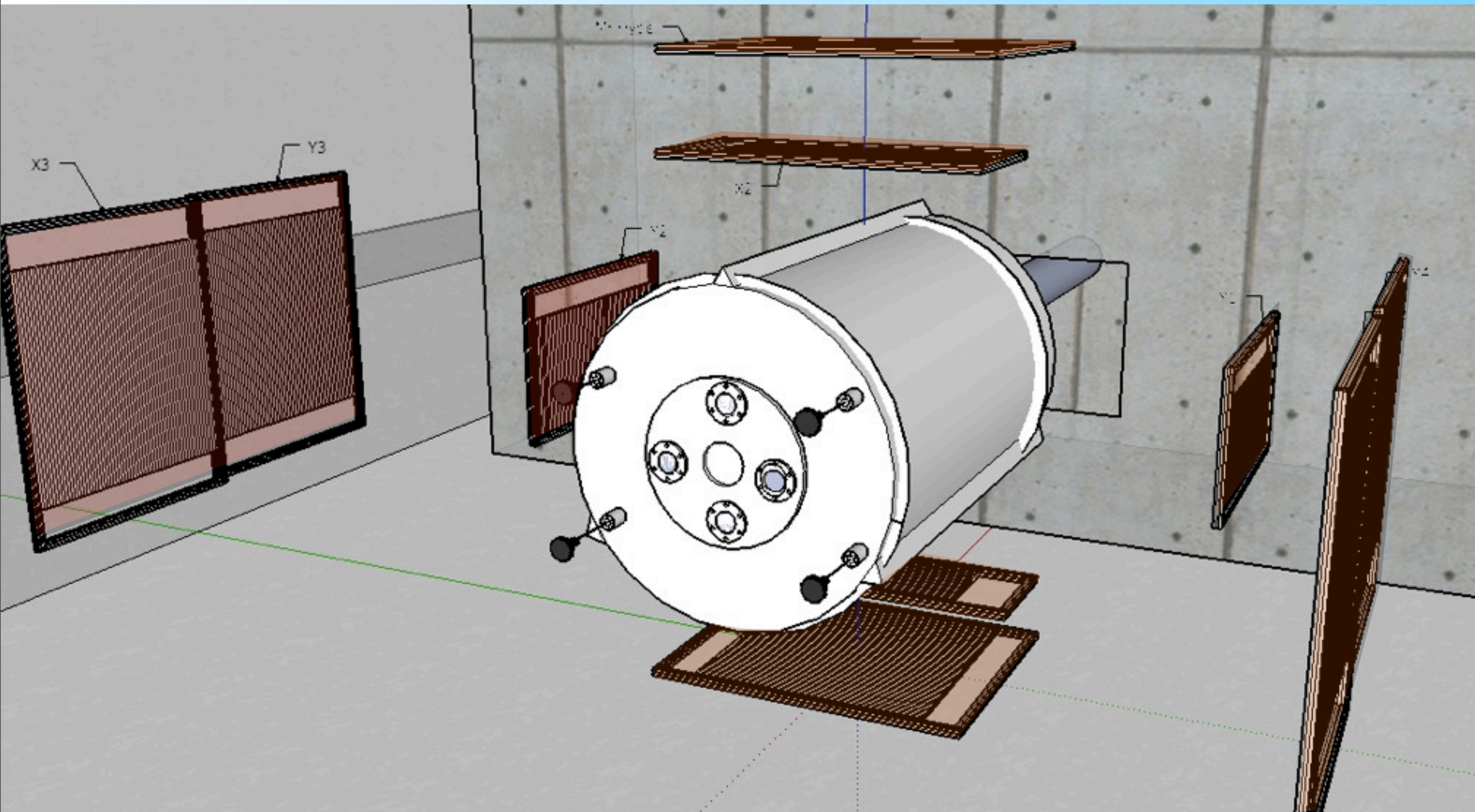
Three different targets were used (+ empty frame):

Target	(A, Z)	Description	Equivalent thickness (nm)	Relative Rutherford
Empty		8 cm diameter frame only		
C	$(12, 6)$	~70 nm carbon foil fixed to the frame	70	1
Pd	$(106, 46)$	~19 nm Pd sputtered on the ~70 nm carbon foil	130+70	16+1
Pt	$(195, 78)$	~5 nm Pt sputtered on the ~70 nm carbon foil	70+70	12+1

Each target consisted in a disk of the mentioned thickness of material (diameter = 8 cm) fixed on a ring-shaped frame with external diameter = 13 cm

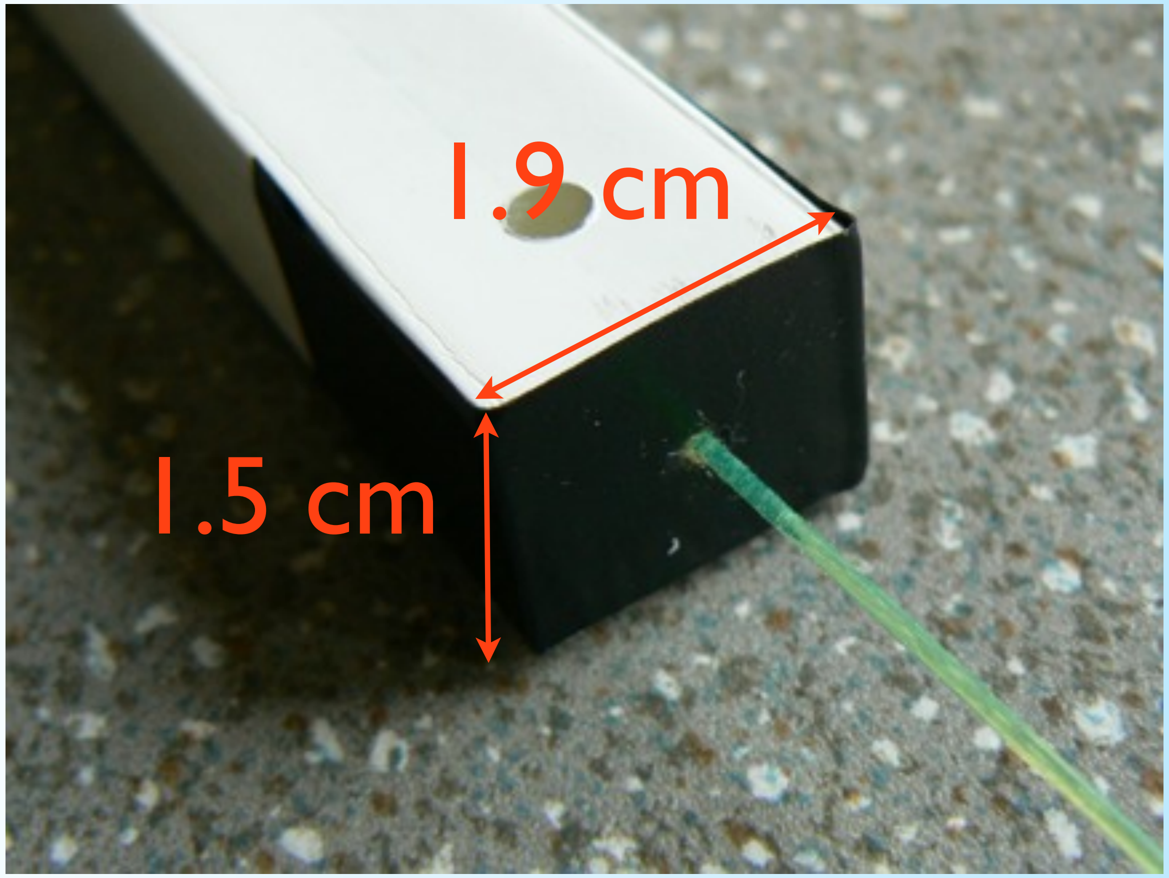


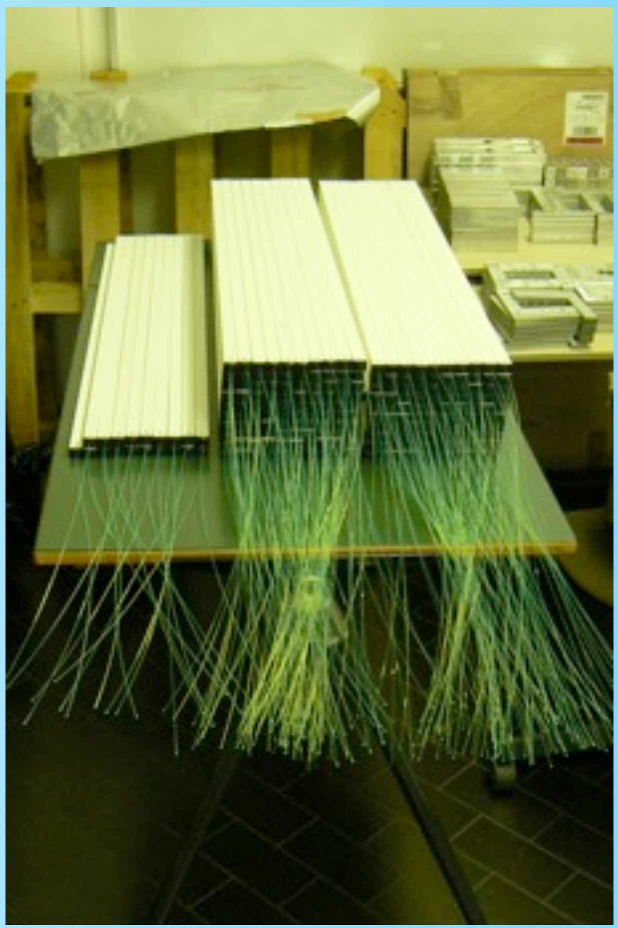
Detectors



The detectors consist in several independent modules made by an array of scintillating bars

The sensing element is a scintillating rod 96cm x 1.9cm x 1.5cm with a hole 2 mm in diameter, containing a “clear” fiber, with glue (ε>90%), read by a 64-channels photomultiplier

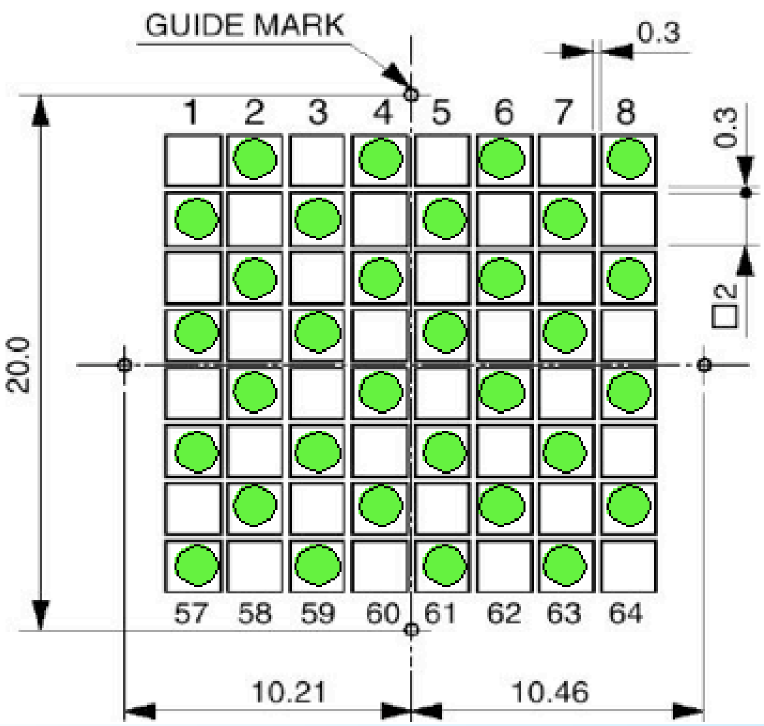


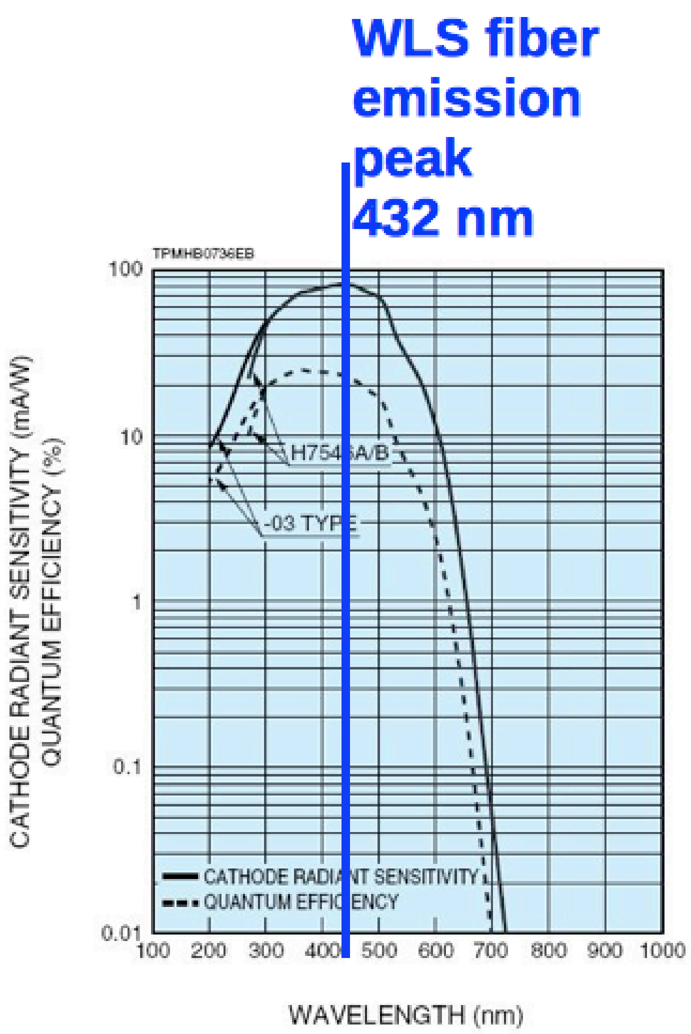


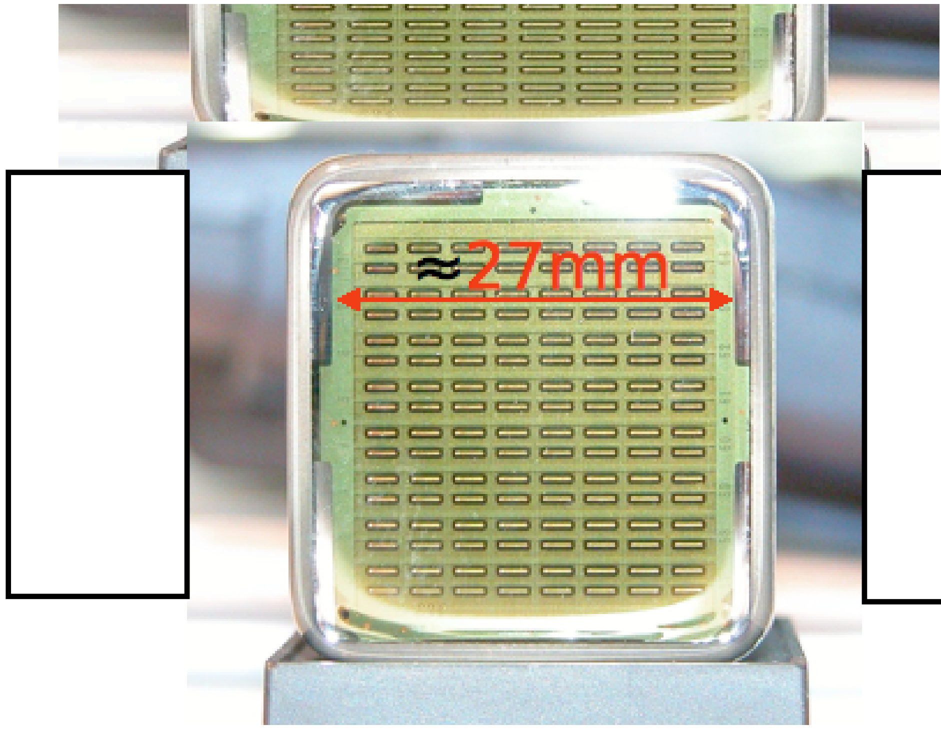
Light readout

64 channel MULTIANODE PHOTOMULTIPLIER:

- Hamamatsu H7546B
- Q.E. @ 420 nm = 20%
- Anode = 2x2 mm^2
- Gain @ -800 V = 3 10^5
- Rise time = 1.0 ns
- Gain uniformity = 1-2.5
- Crosstalk (opt.+ele.) = 1-2%







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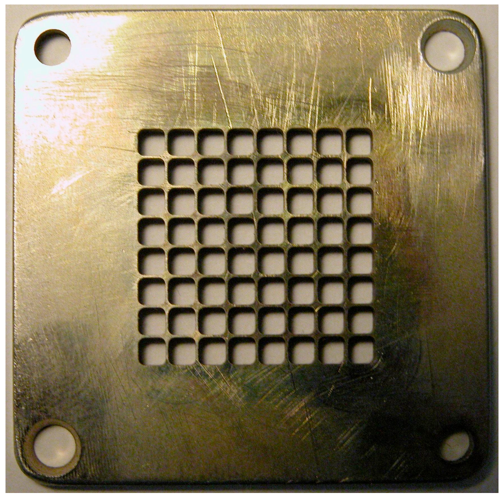

Light readout

64 chann

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- Q.E. @
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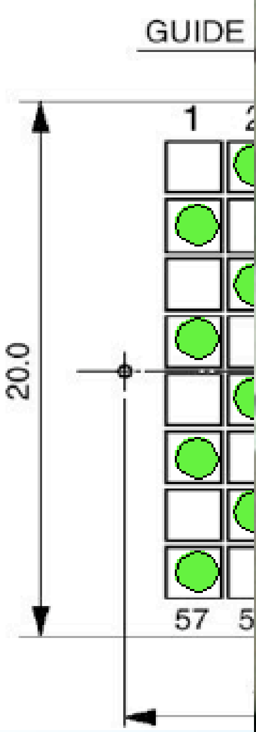
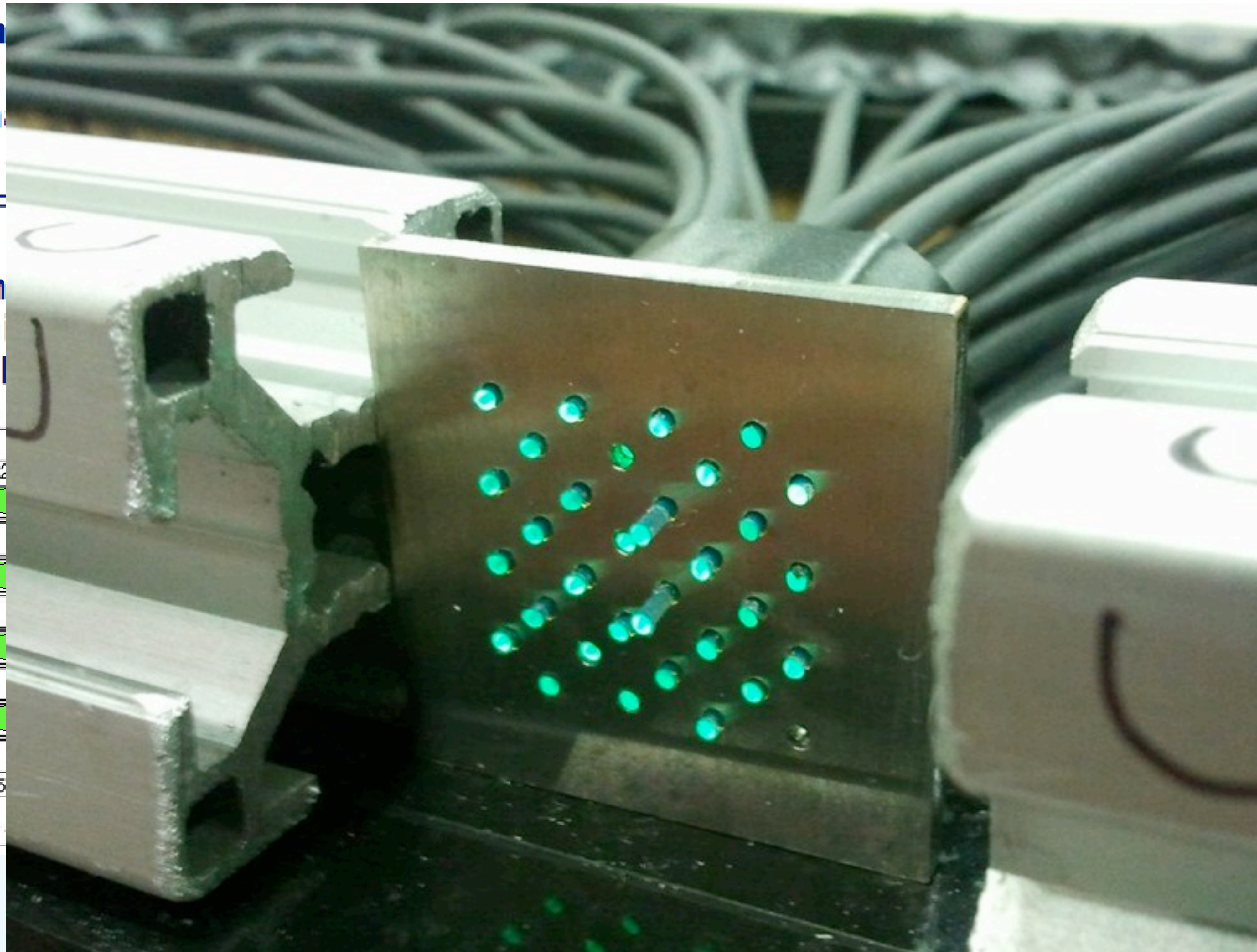




In total, ve used ~600 plastic scintillators arranged in different planes all around the target vessel.

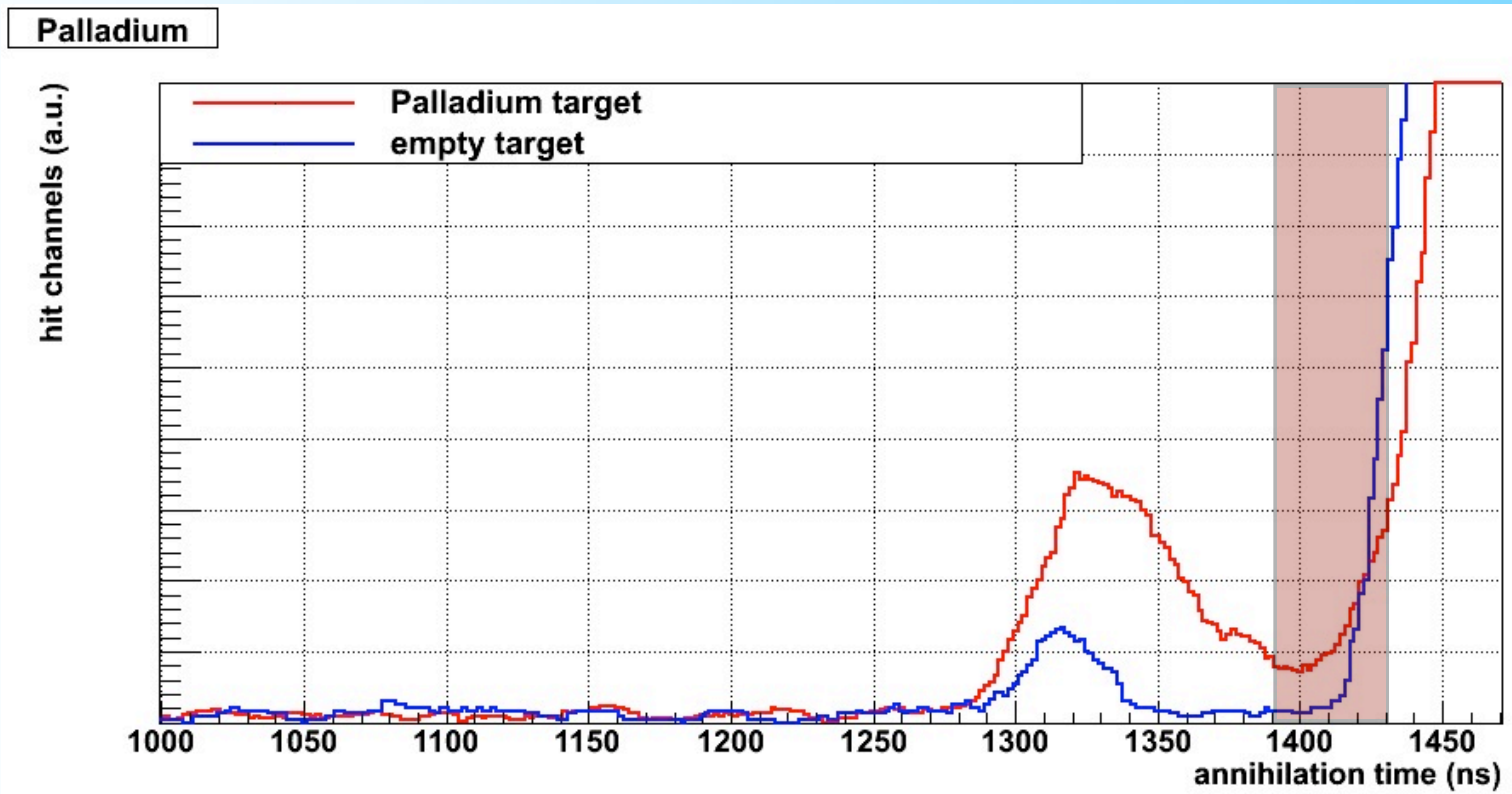
~80% of them were readout by multianode PMTs as described previously.

the remaining ~20% were readout by and MPPCs.

Results

- Annihilation time signal
- Reconstructed annihilation vertices

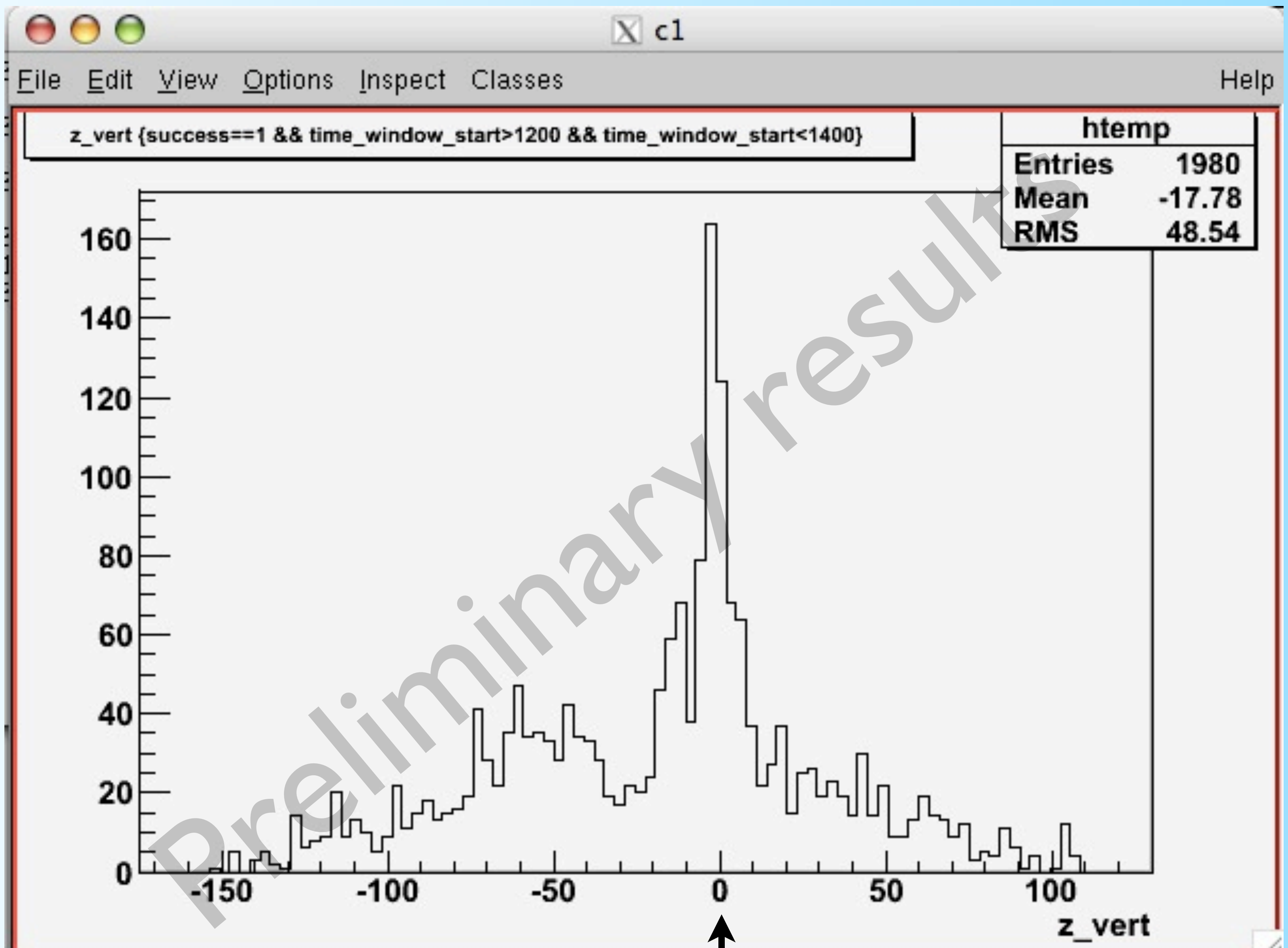
Annihilation time


Palladium
Palladium target
empty target
hit channels (a.u.)
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
annihilation time (ns)

Vertices

With two different modules, it is possible to track back the annihilation position

counts per bin (a.u.)



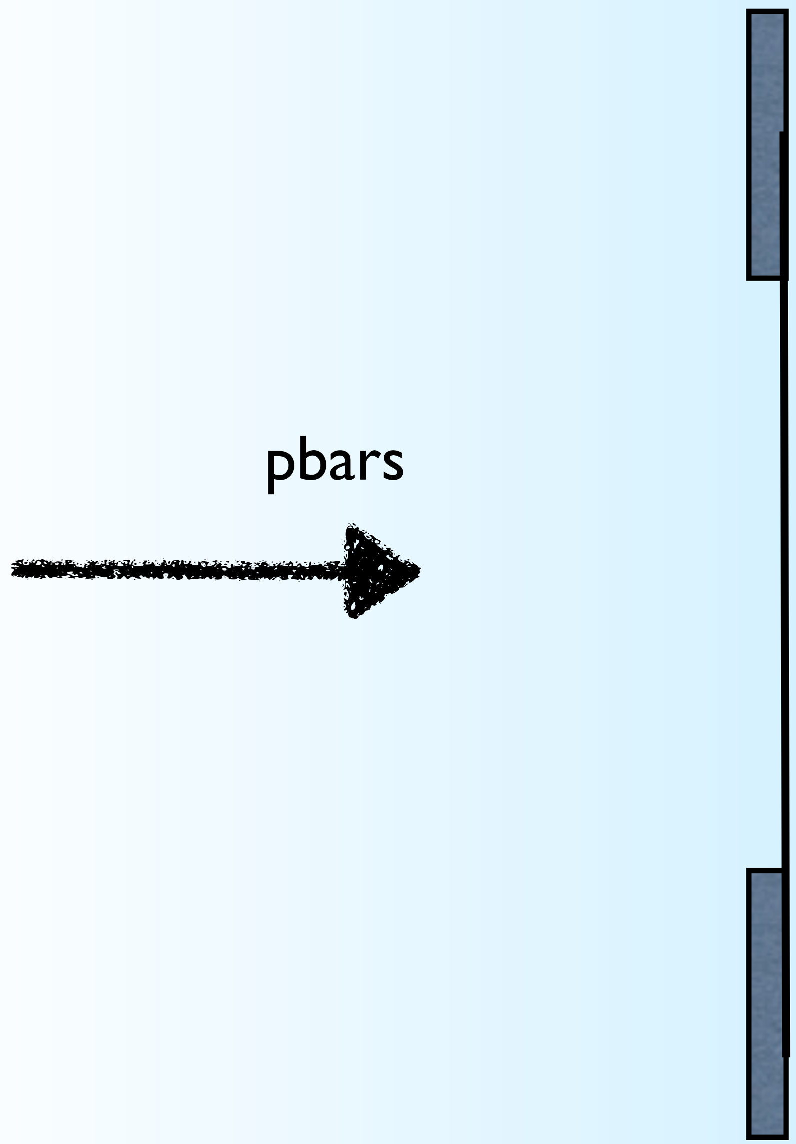
(annihilations on C-target)

axial coordinate (cm)

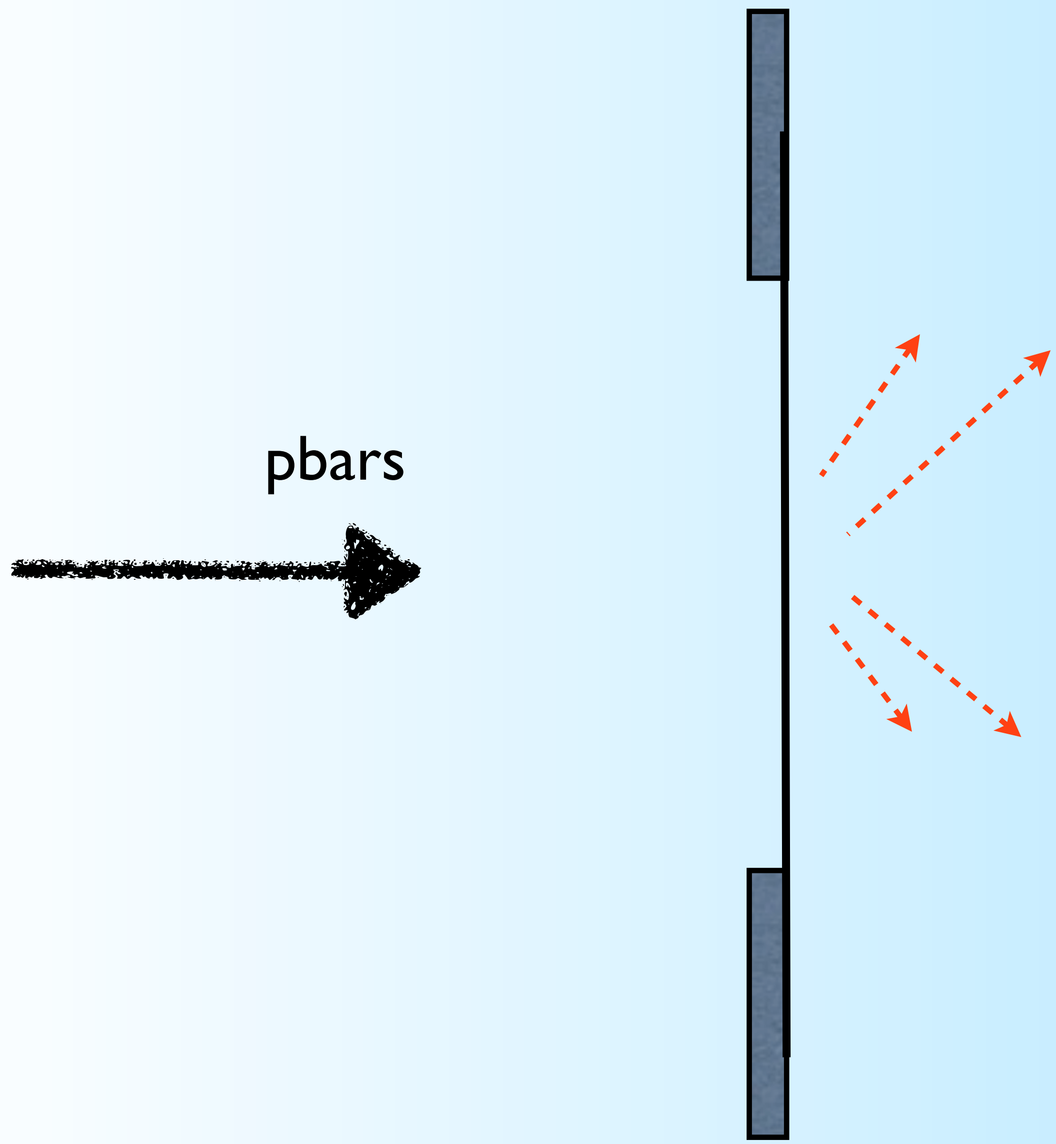
TARGET position

martedì 11 giugno 2013

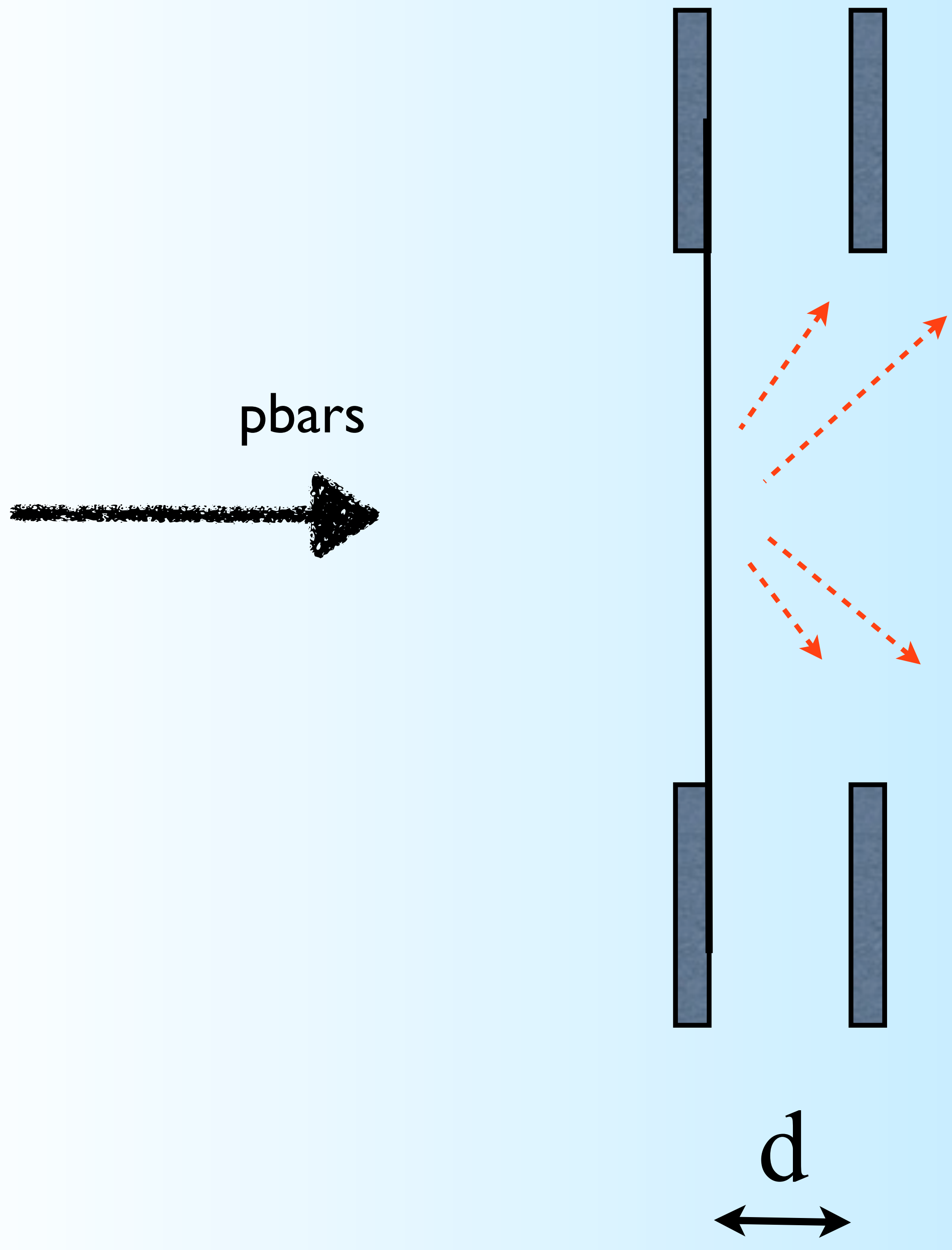
Measurements
“with extra-frame”

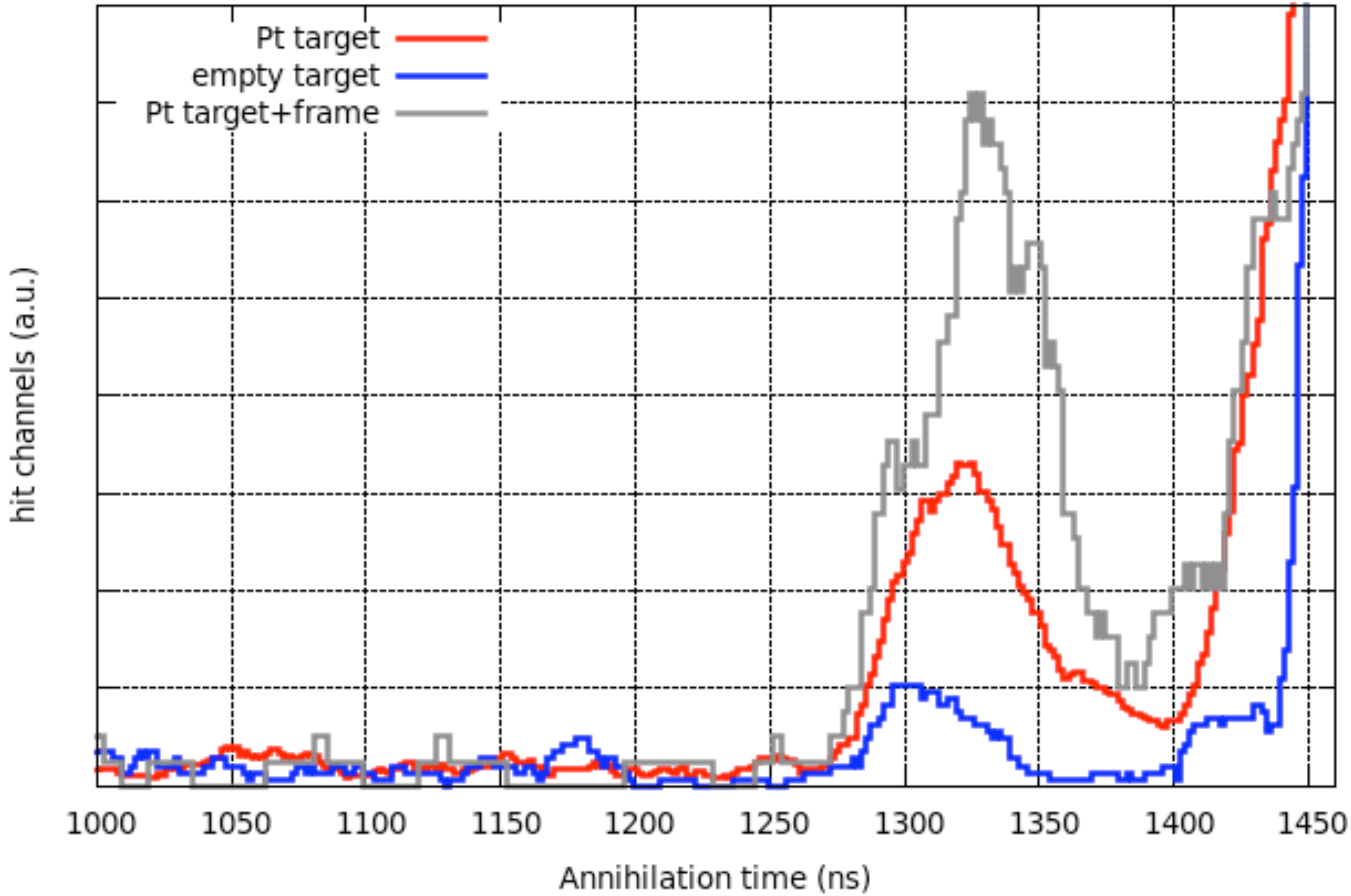


Measurements
“with extra-frame”



Measurements
“with extra-frame”




Pt target
empty target
Pt target+frame
hit channels (a.u.)
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
Annihilation time (ns)

Conclusions

- we reported the first observation of in-flight antiproton-nucleus annihilations at an extremely low energy of 130 keV kinetic energy
- the experimental outcomes demonstrate that with the used technique the measurements of antiproton annihilation cross-section are feasible in the 100 keV region.
- the data analysis is still underway

Thank you!