EXTRACTION BEAMLINES FOR ELENA:

ELECTROSTATIC DEFLECTORS AND LENSES

Daniel Barna
(University of Tokyo, Asacusa exp.)

Outline

- Misc. comments/thoughts on the beamlines (layout, switching, etc)
- Experience from our visit to ELISA (Aarhus, Denmark)
- Electrostatic deflectors in general,
  design in ELISA,
  manufacturing considerations
- Electrostatic quadrupoles: ELISA design, prototype in ASACUSA
- Magnetic shielding

Requirements

- Shielding against stray magnetic fields of strong superconducting magnets (+ think about optimizing beamline path?)
- Manufacturing: easy & cheap
- Bakeable
- Electrodes inside the beampipe should be precisely positioned w.r.t. outside references (CF flange?)
- Insulators should not be 'visible' by the beam.
- UHV-compatible (NEG coating? Avoid structures blocking the pumping)
- High voltage
- Fast switching between experiments

Some general remarks

- Extraction beamlines: single-pass → alignment + vacuum probably less critical than in a ring.
- Beam optics study should estimate the needed precision (fields, electrode positions)
- Choose a design accordingly
- Tolerances highly influence manufacturing prices even for the same design (CERN Main Workshop refused to give any estimate without tolerances)

- Electrostatic beamlines are now routinely operated at several places. One could/should reuse existing designs to cut R&D costs.

Electrostatic or magnetic beamline?

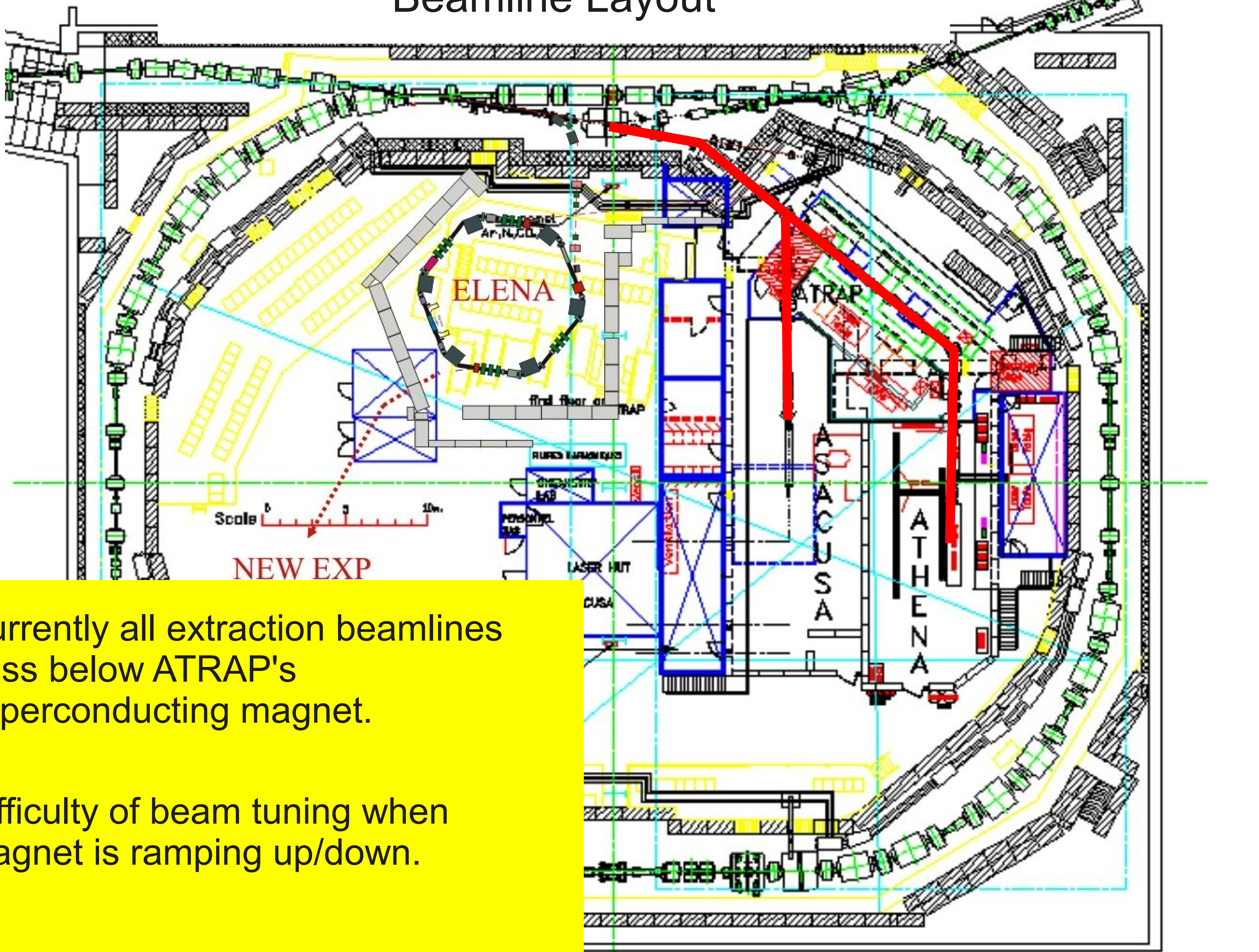
ADVANTAGES of electrostatic:

- No hysteresis
- Better stability. Switch on and go.
- No currents. Cheap materials (inox) and cheap contacts.
- No cooling needed
- Compact. No stray fields outside (beampipe shields everything)

DISADVANTAGES (easy to solve)

- Safety with high-voltage

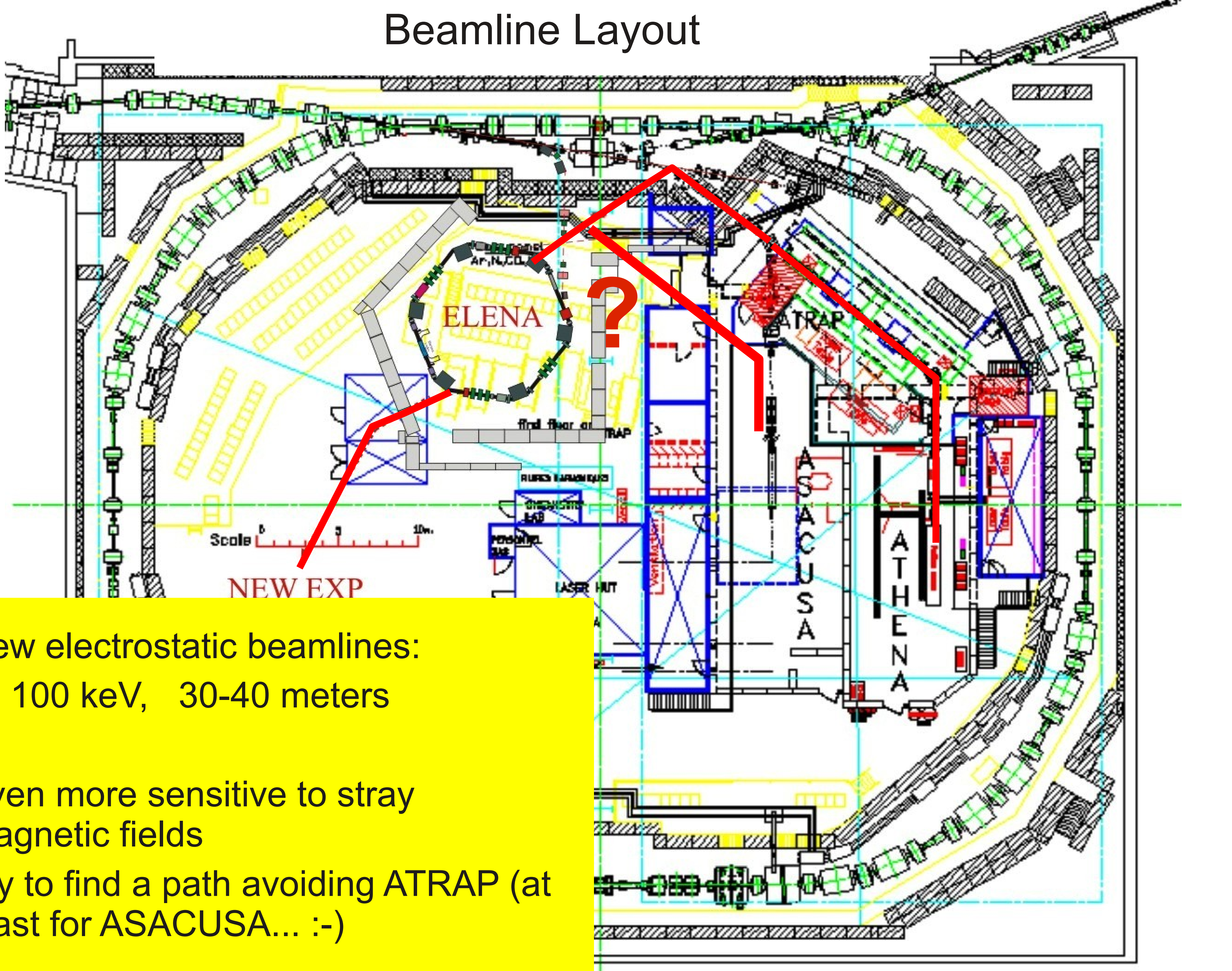
Beamline Layout



Currently all extraction beamlines pass below ATRAP's superconducting magnet.

Difficulty of beam tuning when magnet is ramping up/down.

Beamline Layout



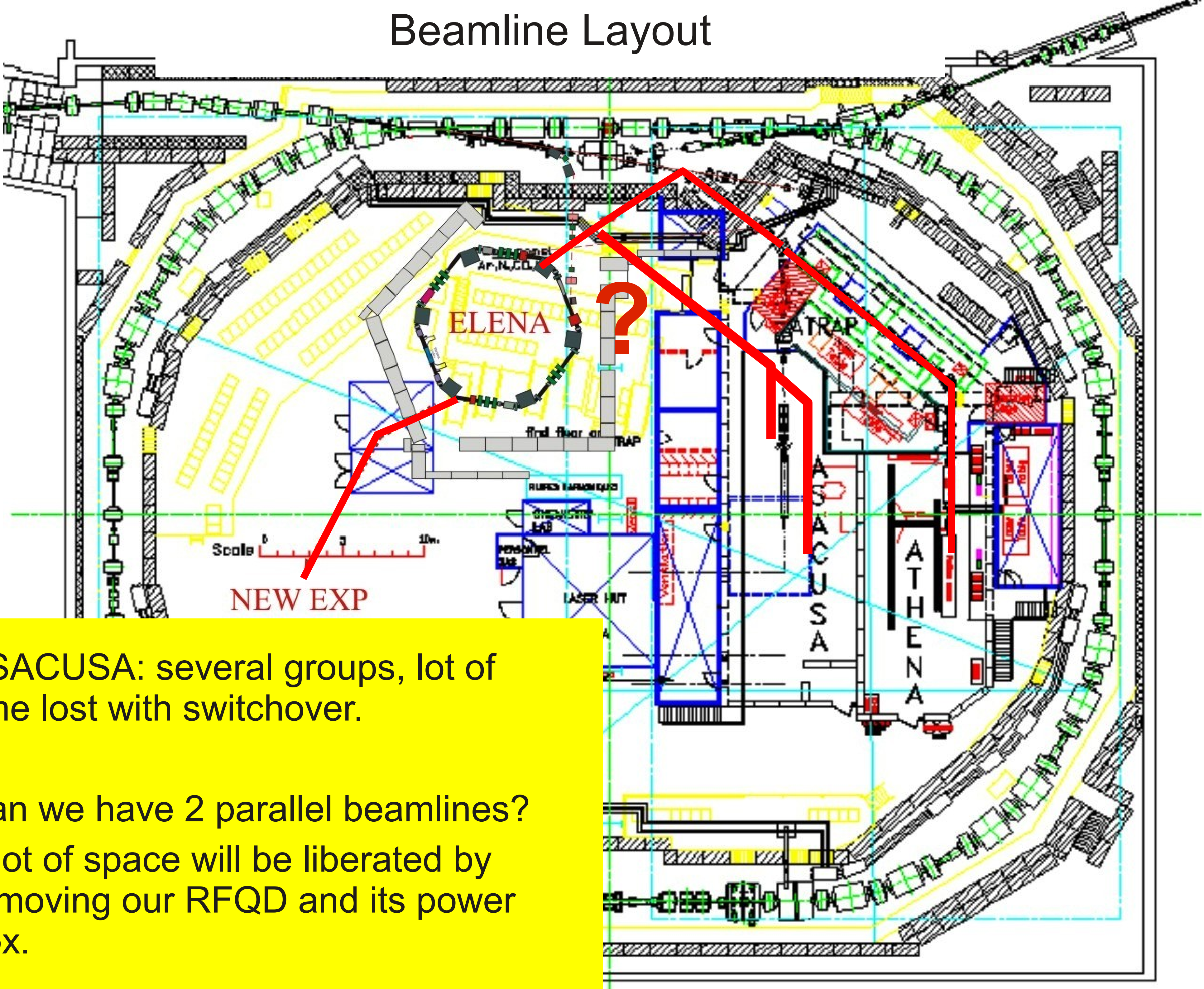
New electrostatic beamlines:

@ 100 keV, 30-40 meters

Even more sensitive to stray magnetic fields

Try to find a path avoiding ATRAP (at least for ASACUSA... :-)

Beamline Layout

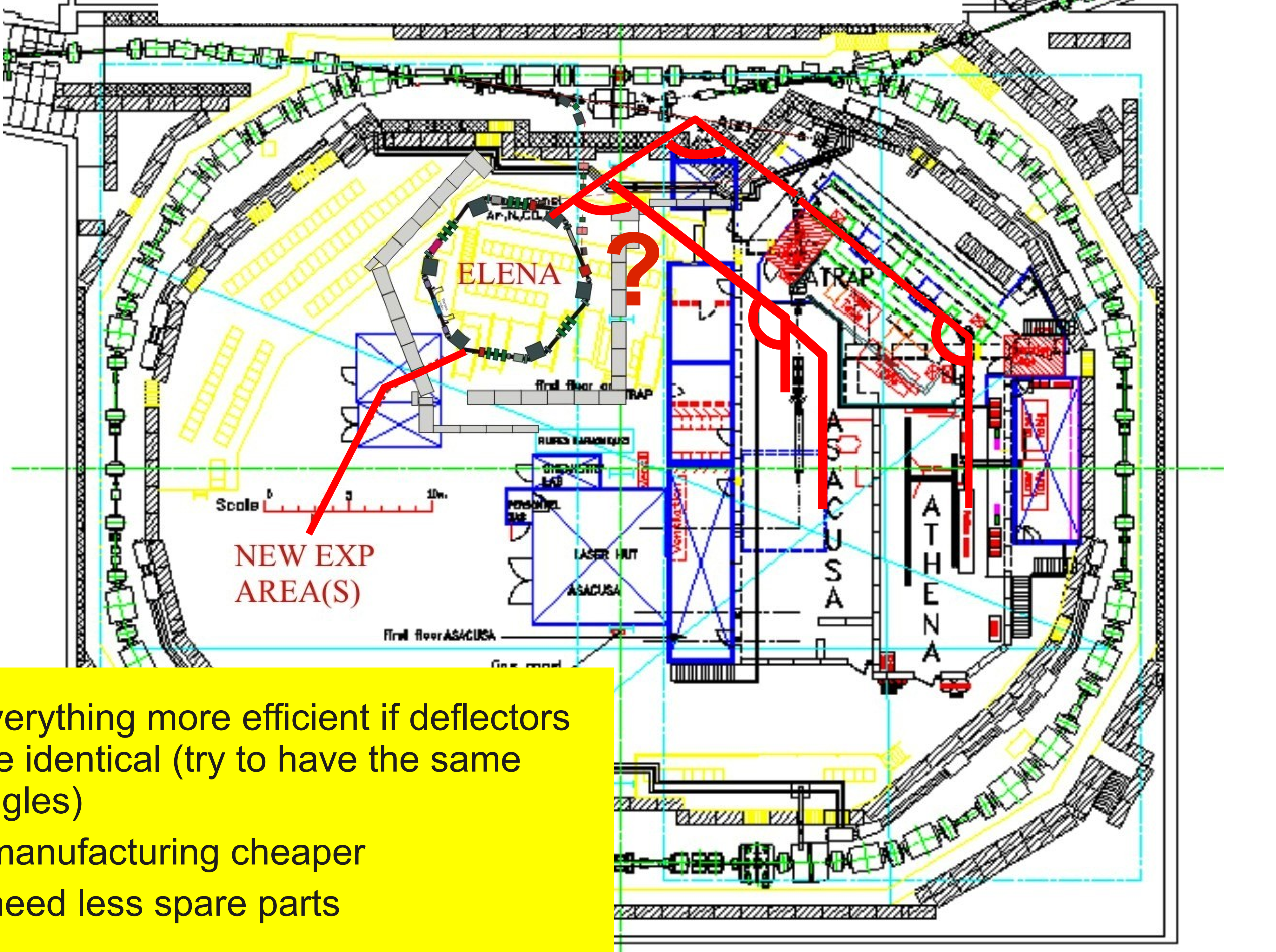


ASACUSA: several groups, lot of time lost with switchover.

Can we have 2 parallel beamlines?

A lot of space will be liberated by removing our RFQD and its power box.

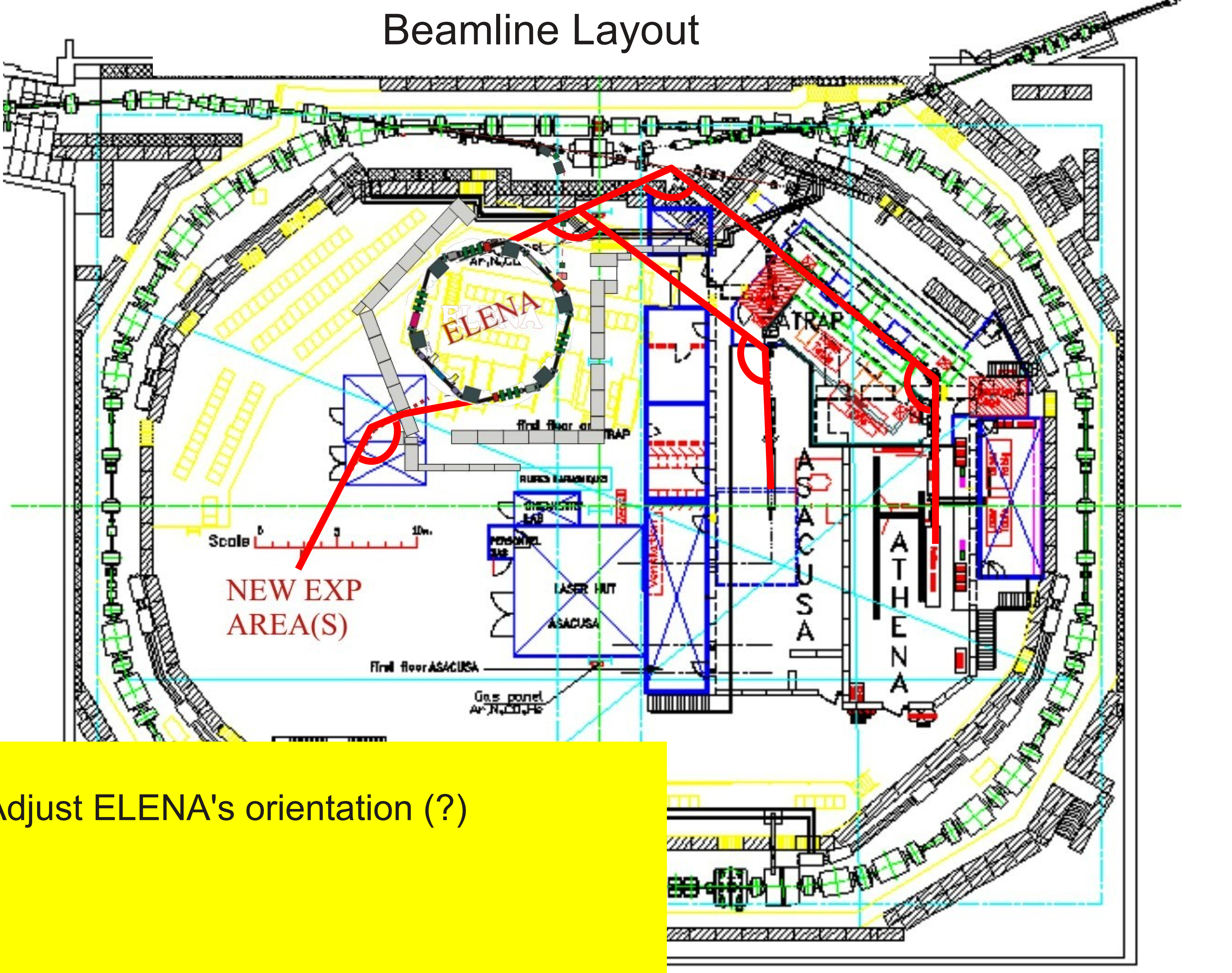
Beamline Layout



Everything more efficient if deflectors are identical (try to have the same angles)

- manufacturing cheaper
- need less spare parts

Beamline Layout

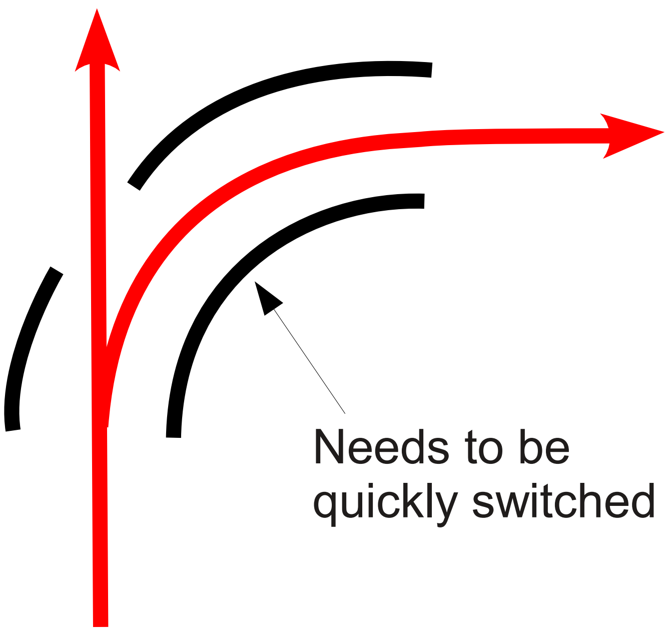


Adjust ELENA's orientation (?)

Switching between experiments

If all bunches of ELENA are extracted at once:
need quick switching (~µs) in the beamline

<u>Use the deflectors to switch</u>



- Larger capacitance, longer rise-time
- Deflectors are not identical
- More complicated geometry

Switching between experiments

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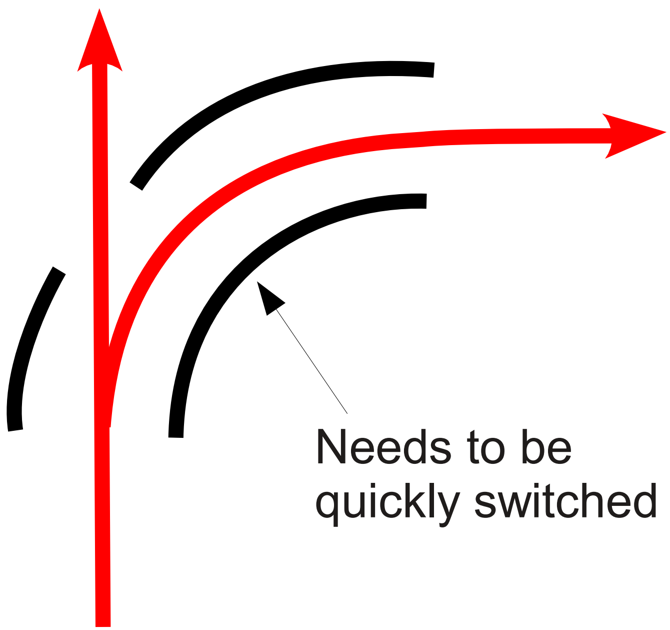
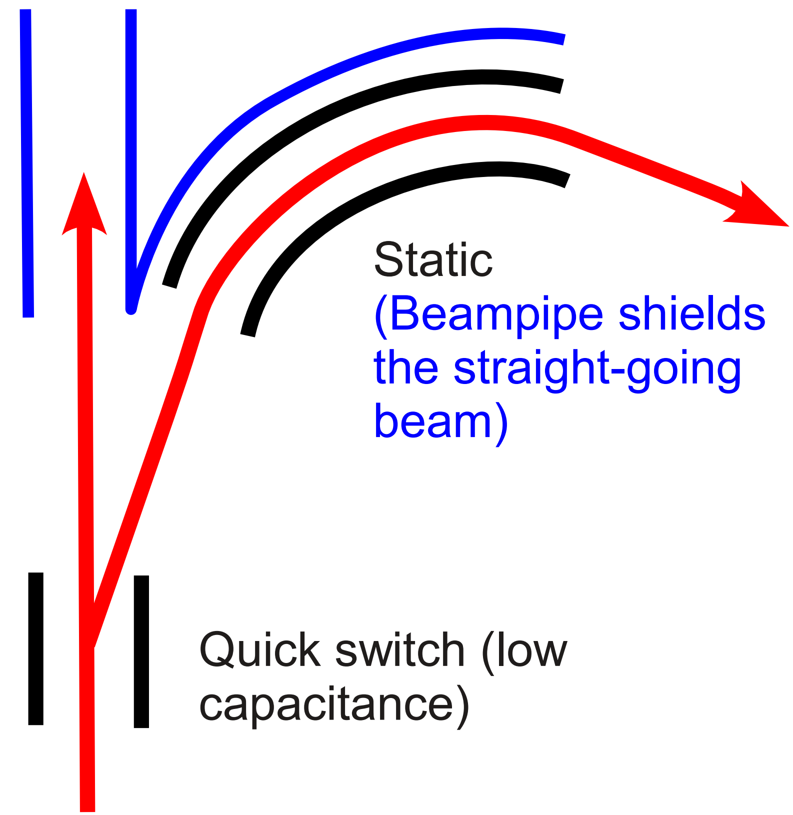
need quick switching (~μs) in the beamline

Use the deflectors to switch



- Larger capacitance, longer rise-time
- Deflectors are not identical
- More complicated geometry

Use separate kickers to switch



- Smaller capacitance, shorter rise-time
- Deflectors are identical

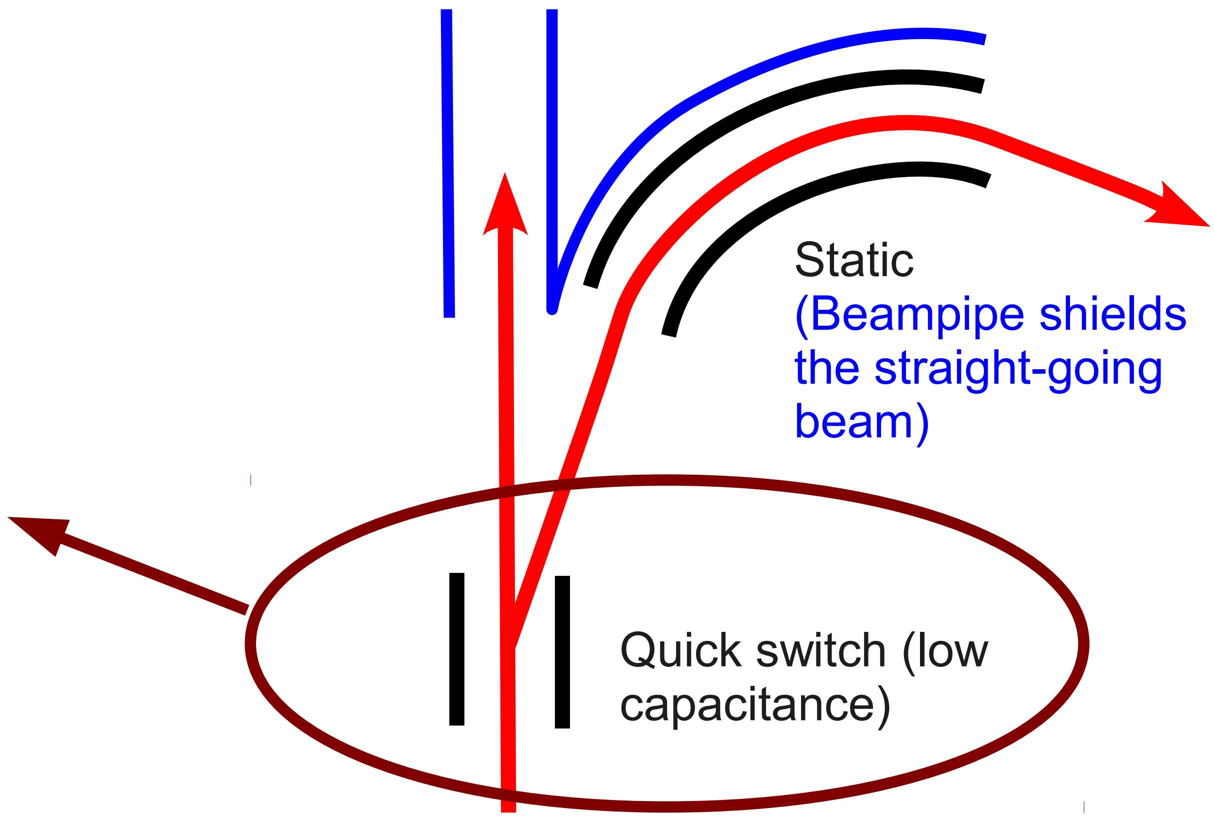
Switching between experiments

If all bunches of ELENA are extracted at once:
need quick switching (~μs) in the beamline

Needs R&D

Reuse it as the ejection kicker from ELENA?

Use separate kickers to switch



- Smaller capacitance, shorter rise-time
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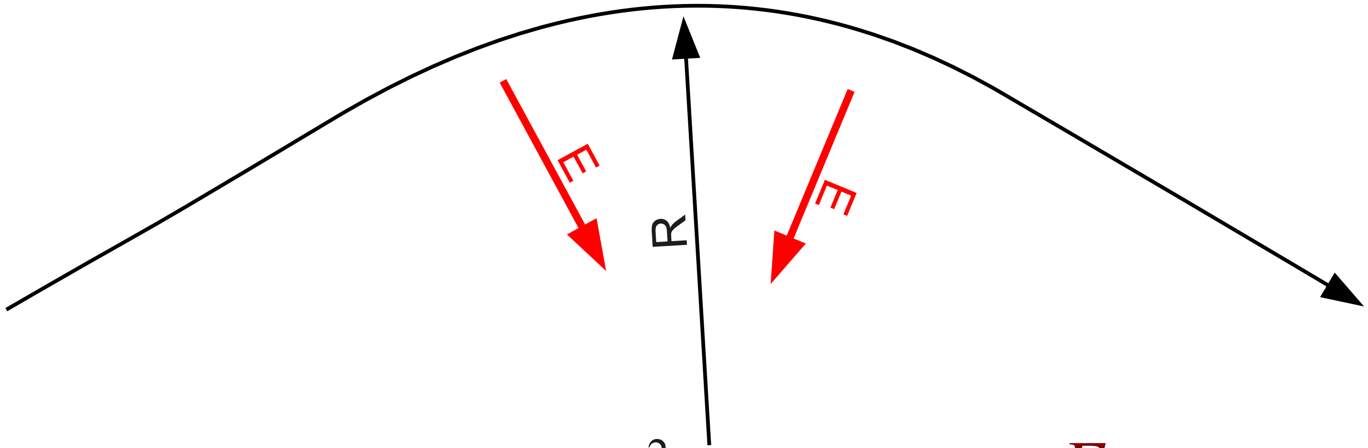
Electrostatic Bending



$$F = qE = ma = m\frac{v^2}{R} \rightarrow R = \frac{2}{E}\frac{E_{kin}}{q}$$

Bending radius depends only on the $\mathbf{E_{kin}/q}$ of the particle.
Independent of mass.

Learn from other devices with similar E_{kin}/q

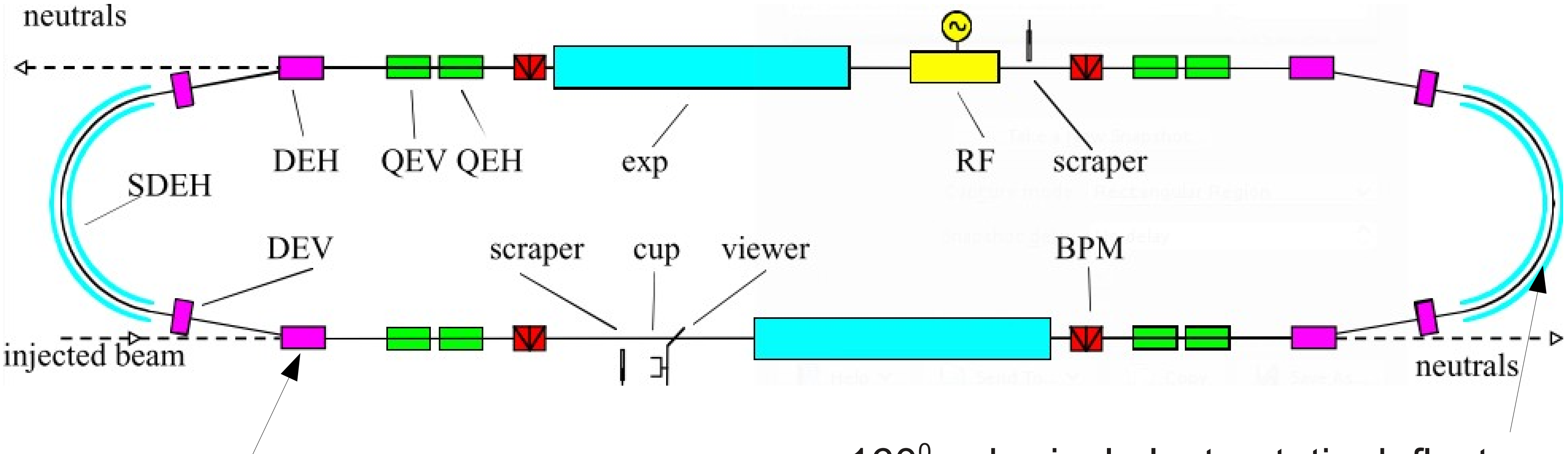
Visited the ELISA storage ring @ University of Aarhus.

ELISA @ University of Aarhus

ELISA @ University of Aarhus, Denmark

(ELectrostatic Ion Storage Ring, Aarhus)

15 π mm mrad, 25 keV ions (A=4-840 - atoms or molecules)
[*S.P.Møller, NIM A394 (1997) 281*]



10^0 paralell-plate deflector, injection kicker

160^0 spherical electrostatic deflector, later replaced by cylindrical ones

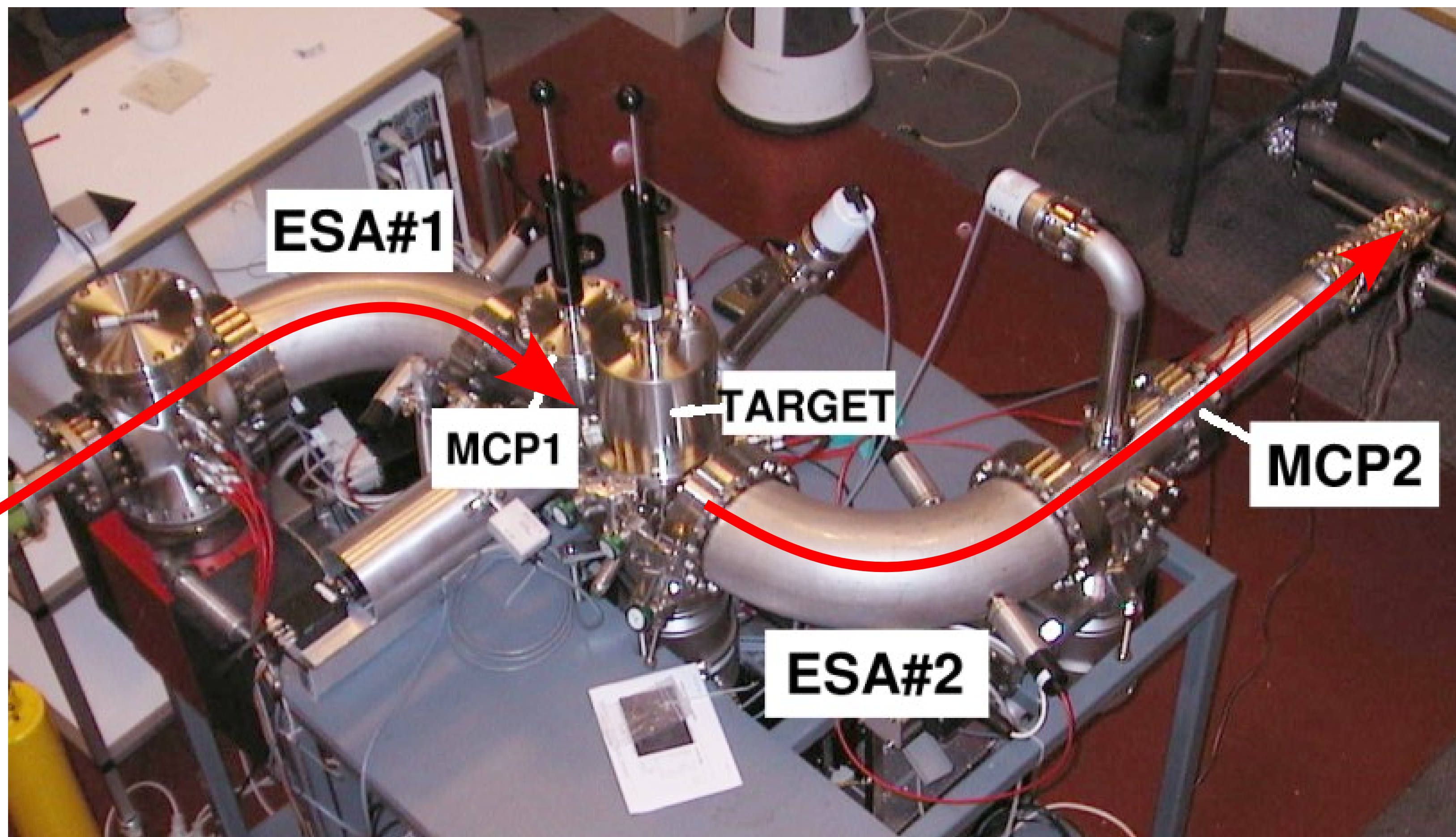
ELISA @ University of Aarhus

ELISA @ University of Aarhus

- Know what you really need
- Keep it simple, do not invent something more precise/fancy than what you need.
- No need for alignment possibility of electrodes within the beampipe.

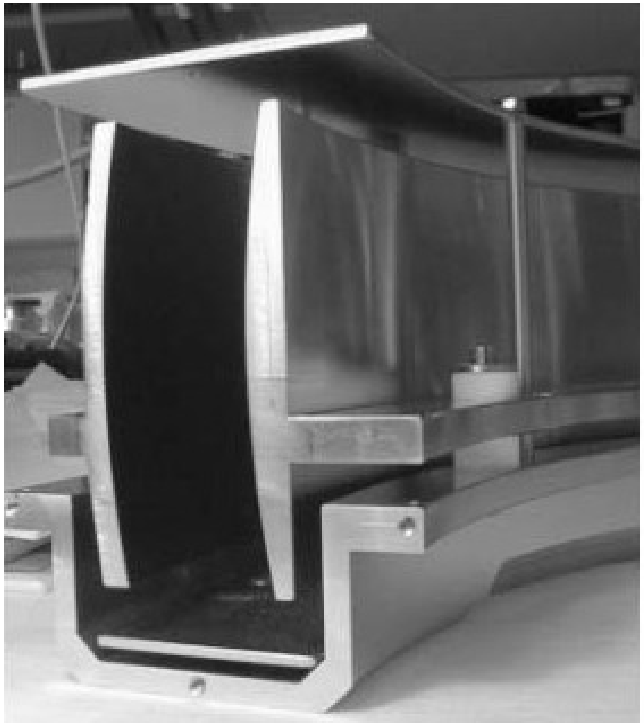
Electrostatic spectrometer (Aarhus group @ ASACUSA)

To measure the energy loss of low-energy antiprotons in matter



Antiproton beam from RFQD (few-10 keV - 120 keV)

Electrostatic spectrometer Aarhus group @ ASACUSA



A. Csete: Experimental Investigations of the Energy Loss of Slow Protons and Antiprotons in Matter

(PhD.Thesis, ASACUSA experiment)

Not used anymore.
If there is interest, we can get this device from Aarhus.

Materials

<u>METALS</u>: standard & cheap materials: stainless steel, aluminium

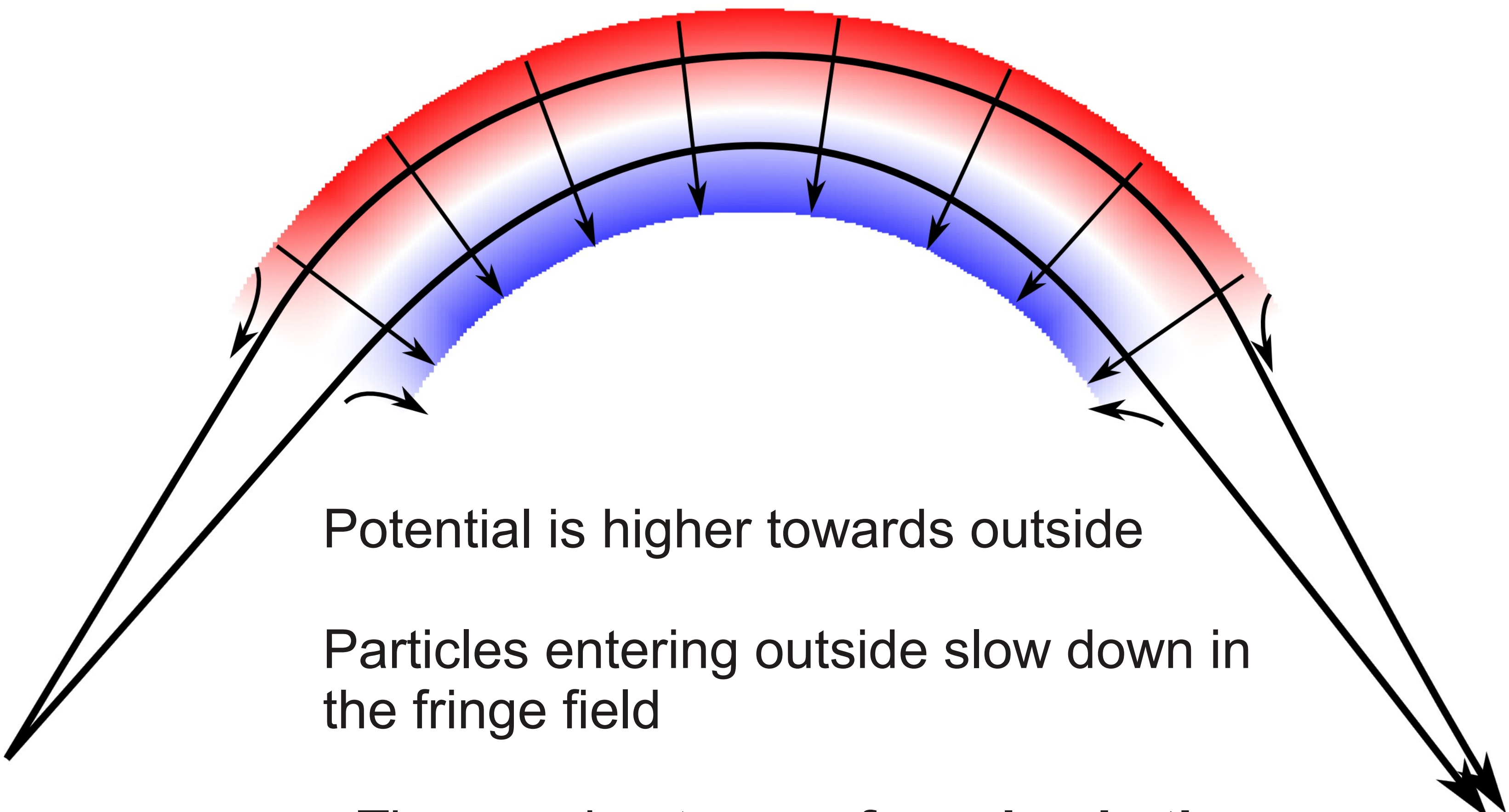
- ELISA uses gold-plated electrodes (avoid insulating oxide layers & voltage drops through them) We did not hear a really convincing argument for this.
- NEG coating (?) - compatible with both materials.
- Thermal expansion differences (inox-aluminium) during baking.

<u>INSULATORS</u>:

- Macor & ceramic (alumina) is used/suggested by both ELISA and our japanese collaborator company (which is building a quadrupole for us - see later)
- Low outgassing, cheap, easy to machine, bakeable.

ELECTROSTATIC DEFLECTOR

Electrostatic deflectors: dynamics



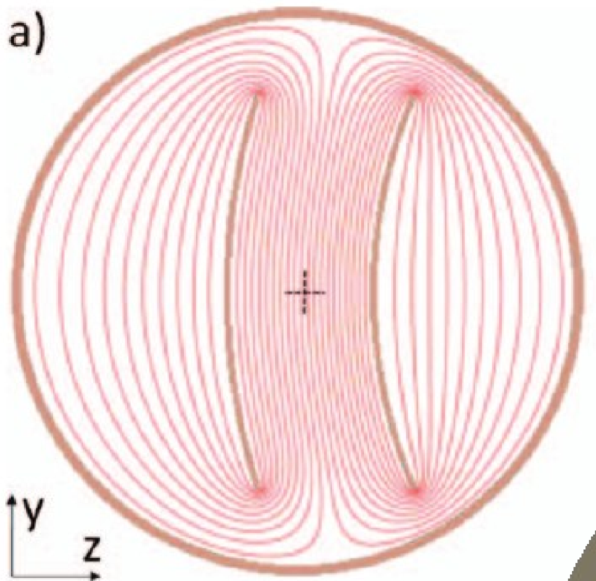
Potential is higher towards outside

Particles entering outside slow down in the fringe field

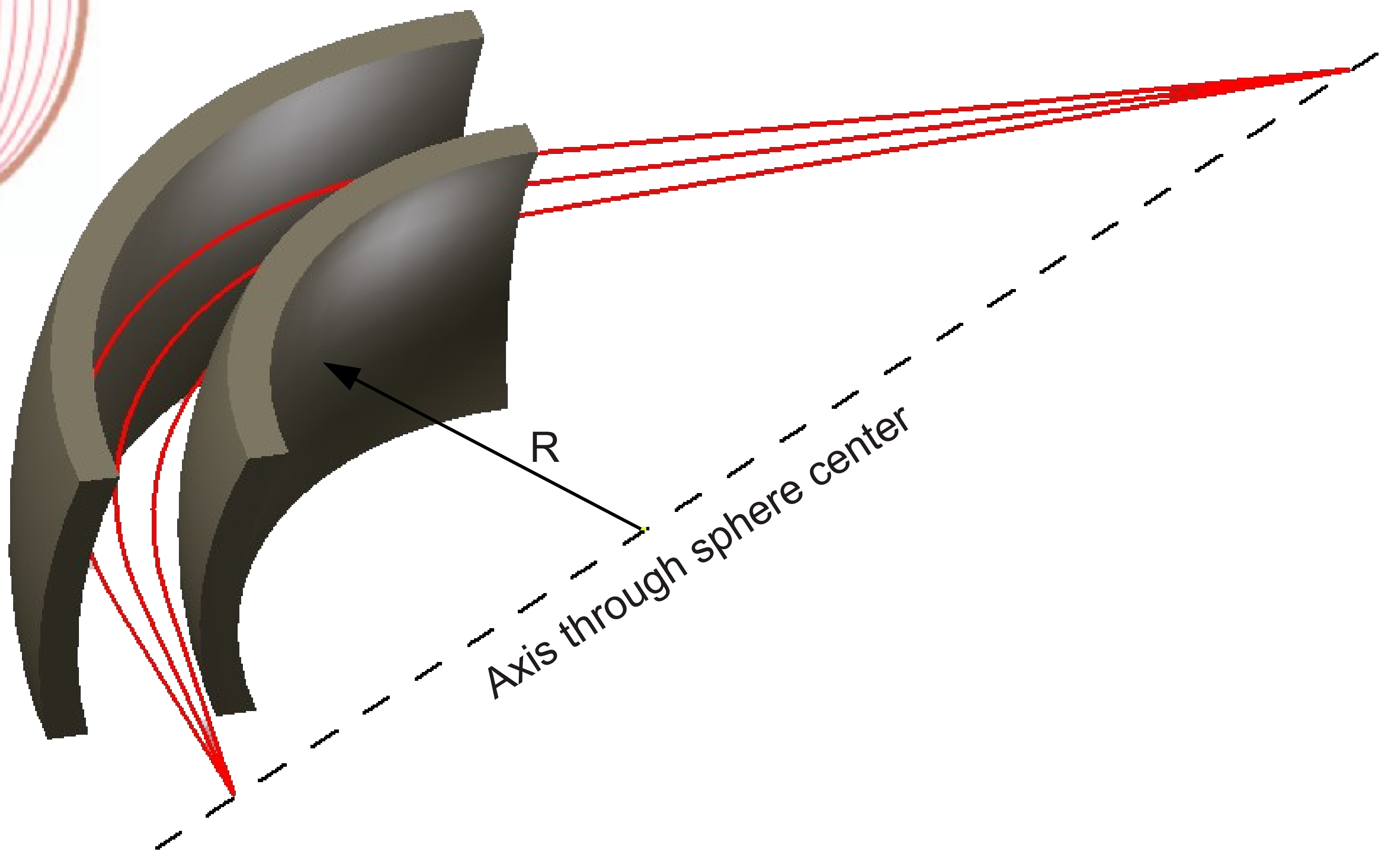
- They are bent more: **focusing in the bending plane**

- Transverse and longitudinal motions are **coupled**

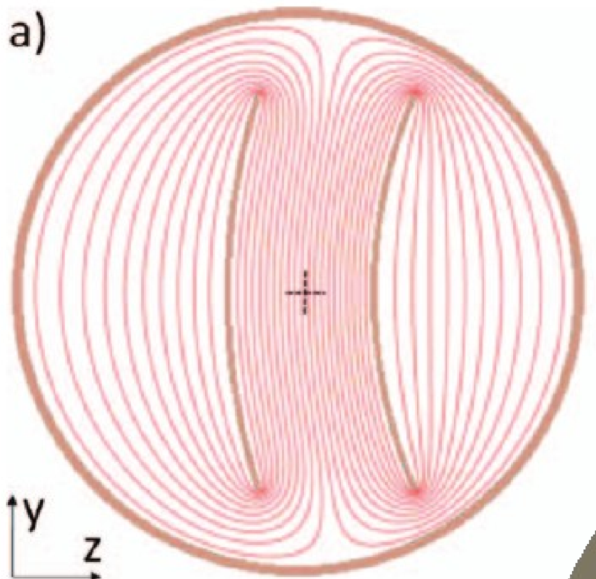
Spherical deflector



$$E_r = E_0 \frac{R_0^2}{r^2}$$



Spherical deflector



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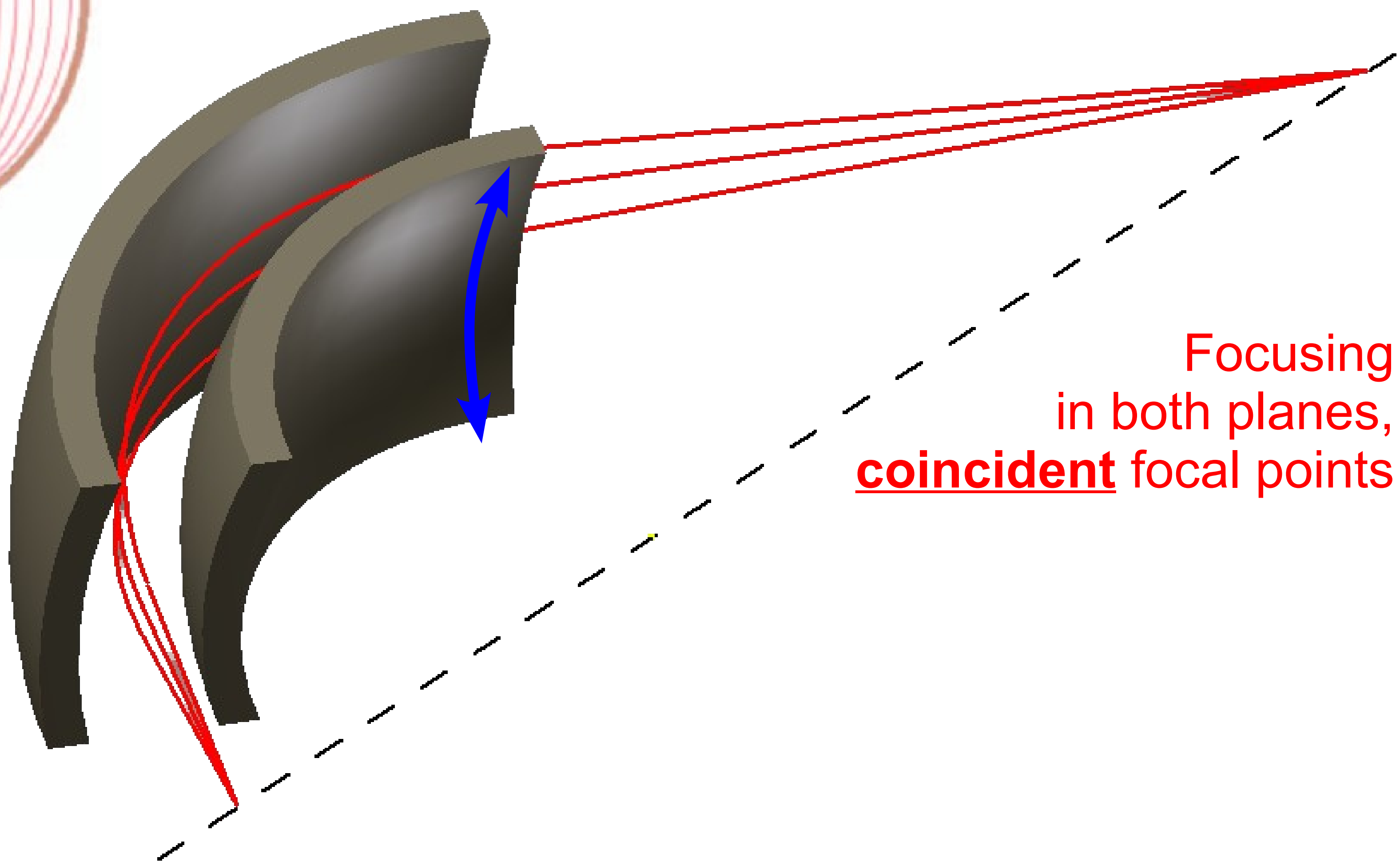
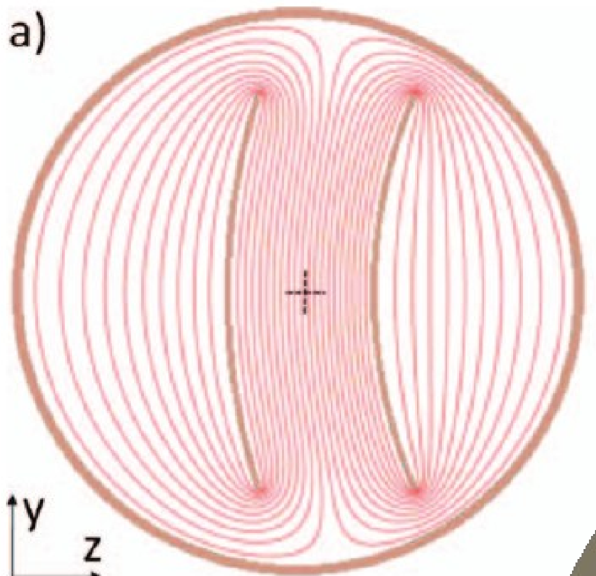


Focusing
in both planes,
coincident focal points

Spherical deflector



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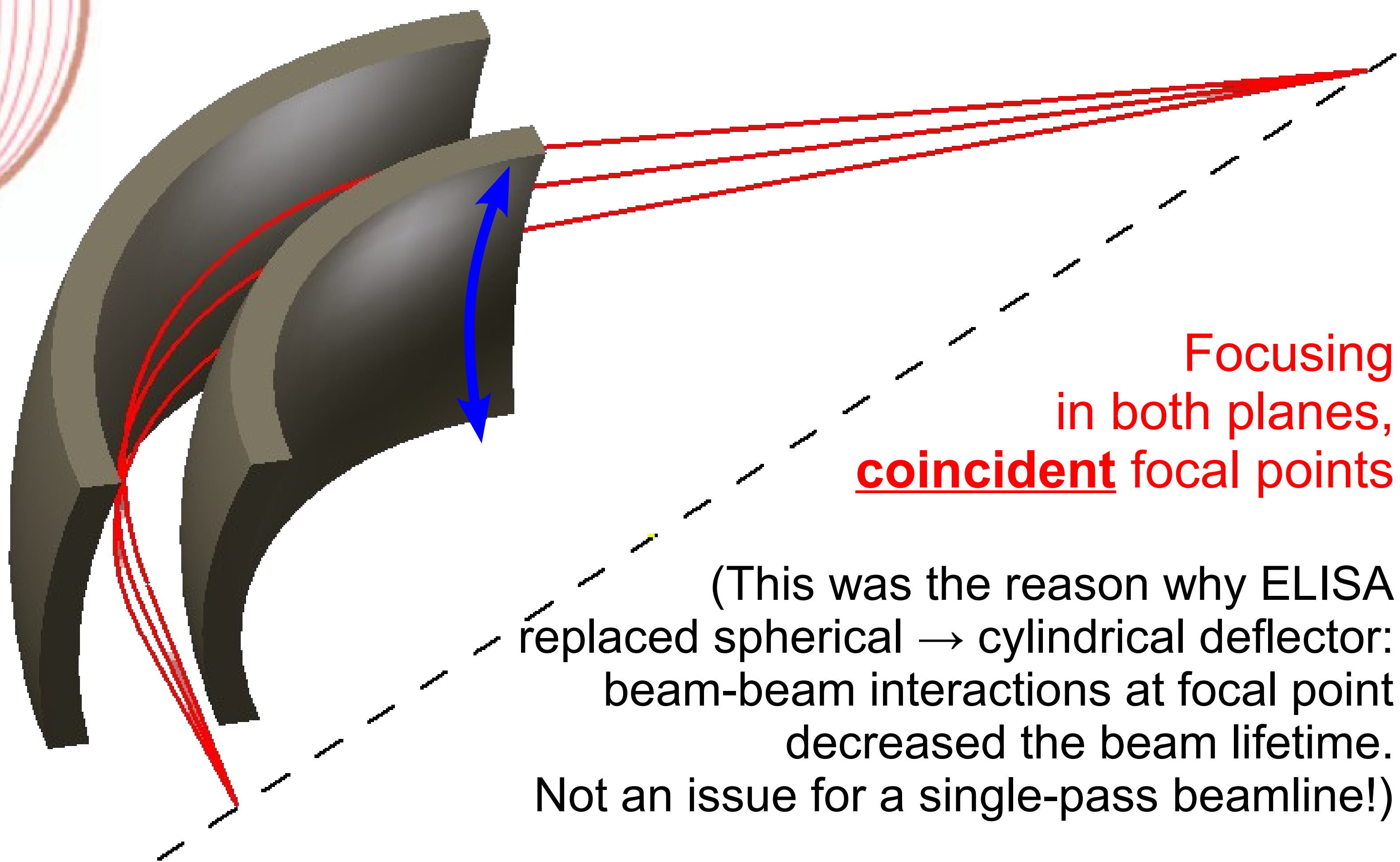
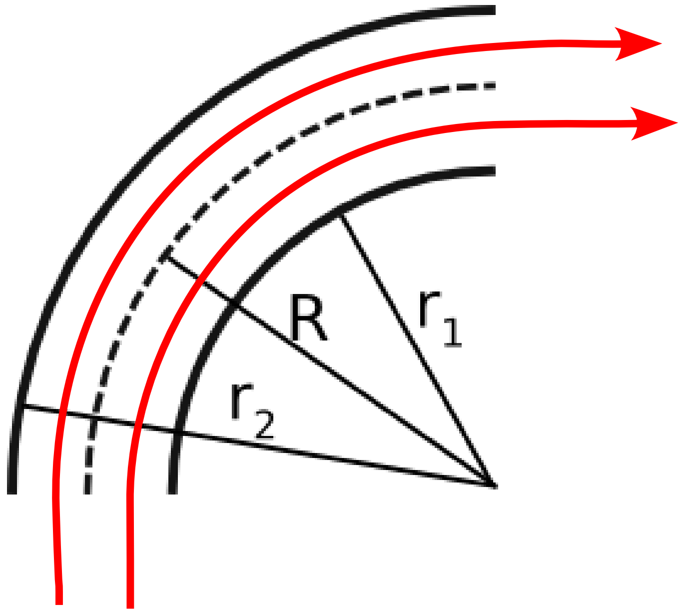


Focusing
in both planes,
coincident focal points

(This was the reason why ELISA
replaced spherical → cylindrical deflector:
beam-beam interactions at focal point
decreased the beam lifetime.
Not an issue for a single-pass beamline!)

Cylindrical deflector



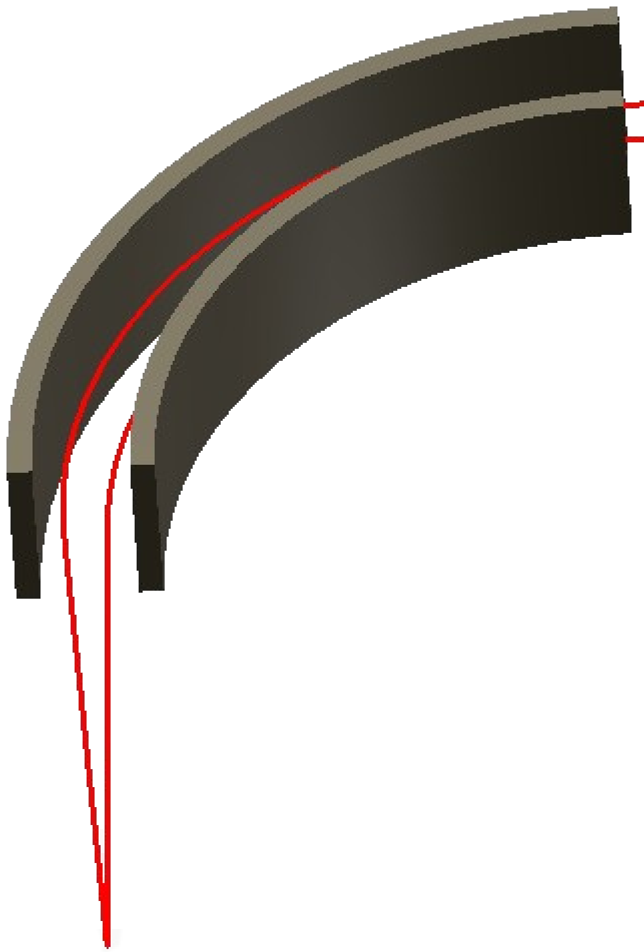
$$E = E_0 \frac{R}{r}$$

Condition of circular orbit (r):
(independent of r)

$$\frac{m v^2}{r} = F = q E_0 \frac{R}{r}$$

A parallel, monoenergetic (E_{kin} = $qE_0R/2$) beam remains parallel

Cylindrical deflector



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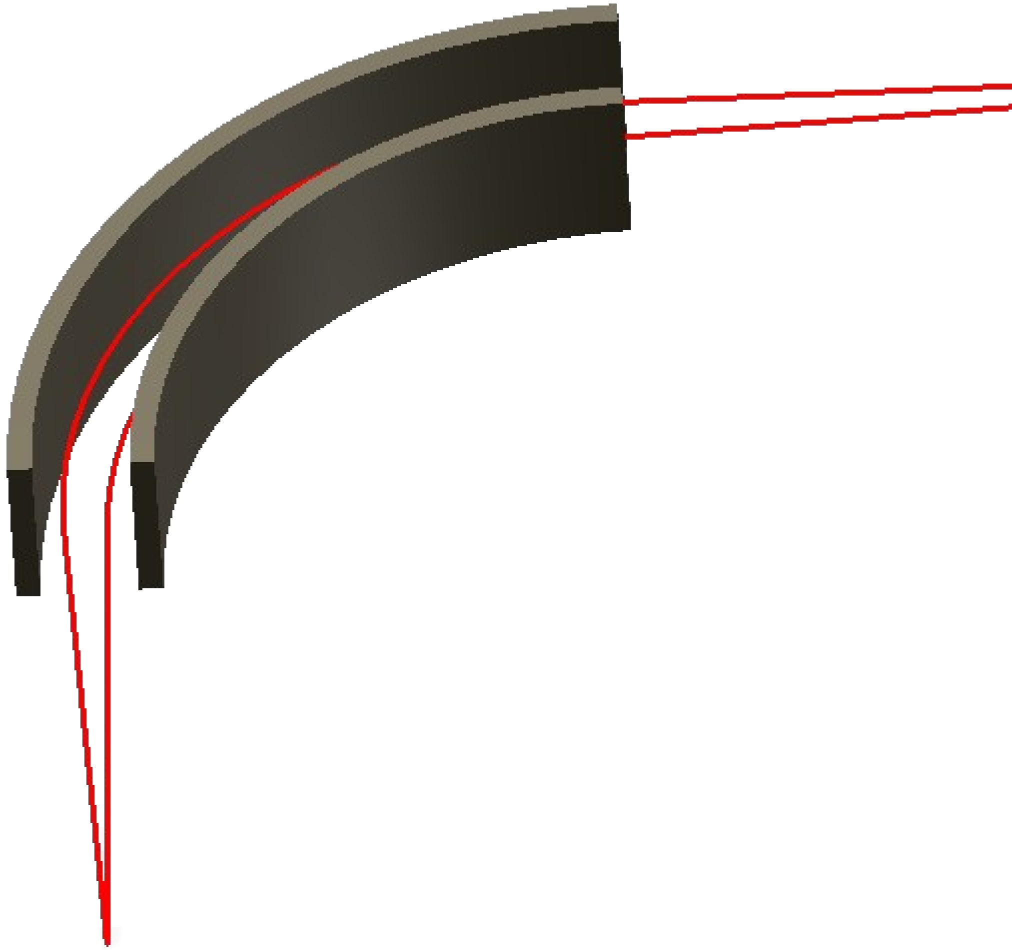
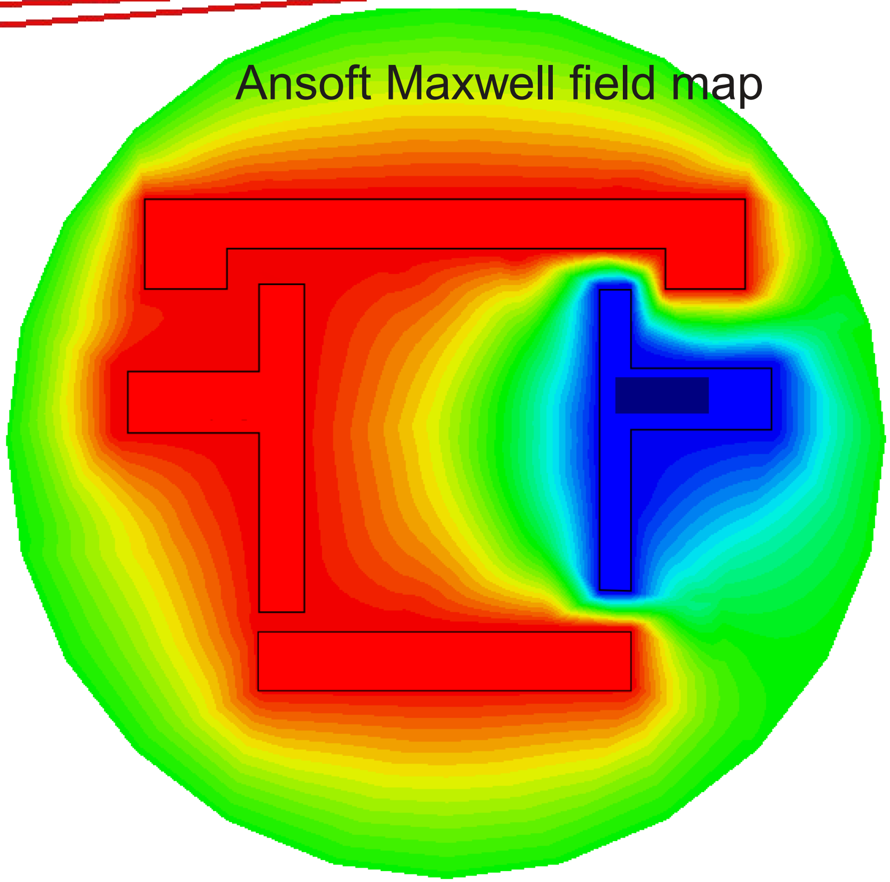
Focusing due to fringe fields (only in the bending plane)

Cylindrical deflector

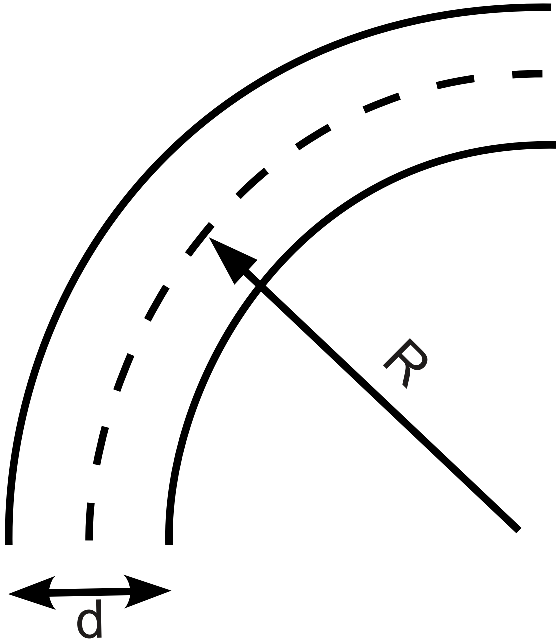




2 more electrodes with proper dimensions & voltages:
focusing in both planes, coincident focal points
[*Fishkova, Ovsyannikova, NIM A363 (1995) 494*]

Deflectors

Electrode voltages: $\pm \frac{E_{kin} d}{q R}$



@ 100 keV	R = 1 m	R = 0.5 m	R = 0.2 m
d = 8 cm	± 8 kV	± 16 kV	± 40 kV
d = 6 cm	± 6 kV	± 12 kV	± 30 kV
d = 4 cm	± 4 kV	± 8 kV	± 20 kV

To lower the voltage (cheaper, safer) → use the largest bending radius & smallest electrode spacing which is possible

Deflector: beampipe

CERN Main Workshop: no in-house capability. Need standard parts from outside.

(http://kohler.ch)

Beampipe inner diameter	200 mm
Bending radius	500 mm
Price	595 chf - CERN Discount

R-1655

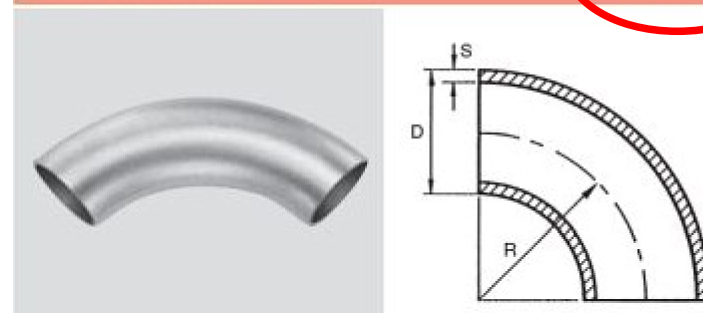
Bogen 90°, 5D (R~2,5×D)

Coudes 90°, 5D (R~2,5×D)

5D

grösster Radius

rayon maxi.

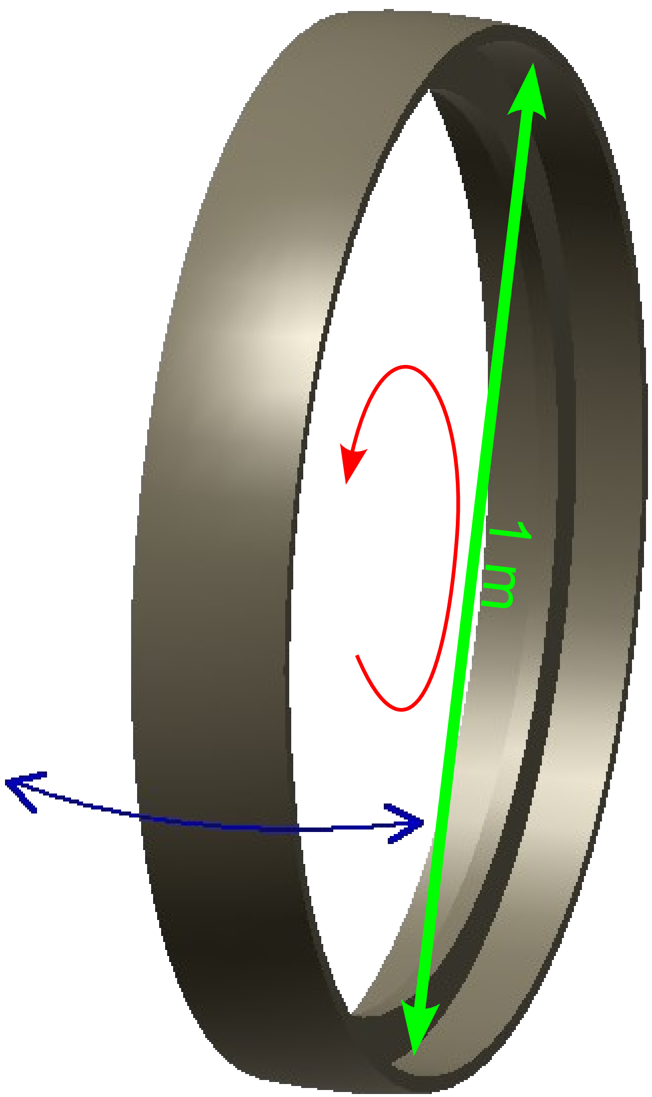


D×S mm	geschweisst *soudé* CHF / Stk *CHF / pce* 1.4307 304L	geschweisst *soudé* CHF / Stk *CHF / pce* 1.4404 / 32 316L	R mm	Gewicht *poids* kg
17,2×1,6		28.–	43	0,04
21,3×1,6	11.–	12.–	42,5	0,06
×2		12.–	42,5	0,08
×2,6	12.–	13.–	42,5	0,10
26,9×1,6	14.–	15.–	58	0,10
104 ×2		156.–	250	1,90
114,3×2,6	121.–	131.–	270	3,00
129 ×2		290.–	313	3,10
139,7×2,6		328.–	330	4,30
154 ×2		345.–	375	4,40
168,3×2,6		398.–	390	6,05
204 ×2		595.–	500	7,95
219,1×3		746.–	510	13,30
273 ×3		1392.–	650	20,80
323,9×3		1580.–	775	29,40
356 ×3			850	36,00
406 ×3	Ab Werk / *de l'usine*		970	46,00
508 ×4			1245	98,00

Electrode voltages:

@ 100 keV	R = 0.5 m
d = 8 cm	± 16 kV
d = 6 cm	± 12 kV
d = 4 cm	± 8 kV

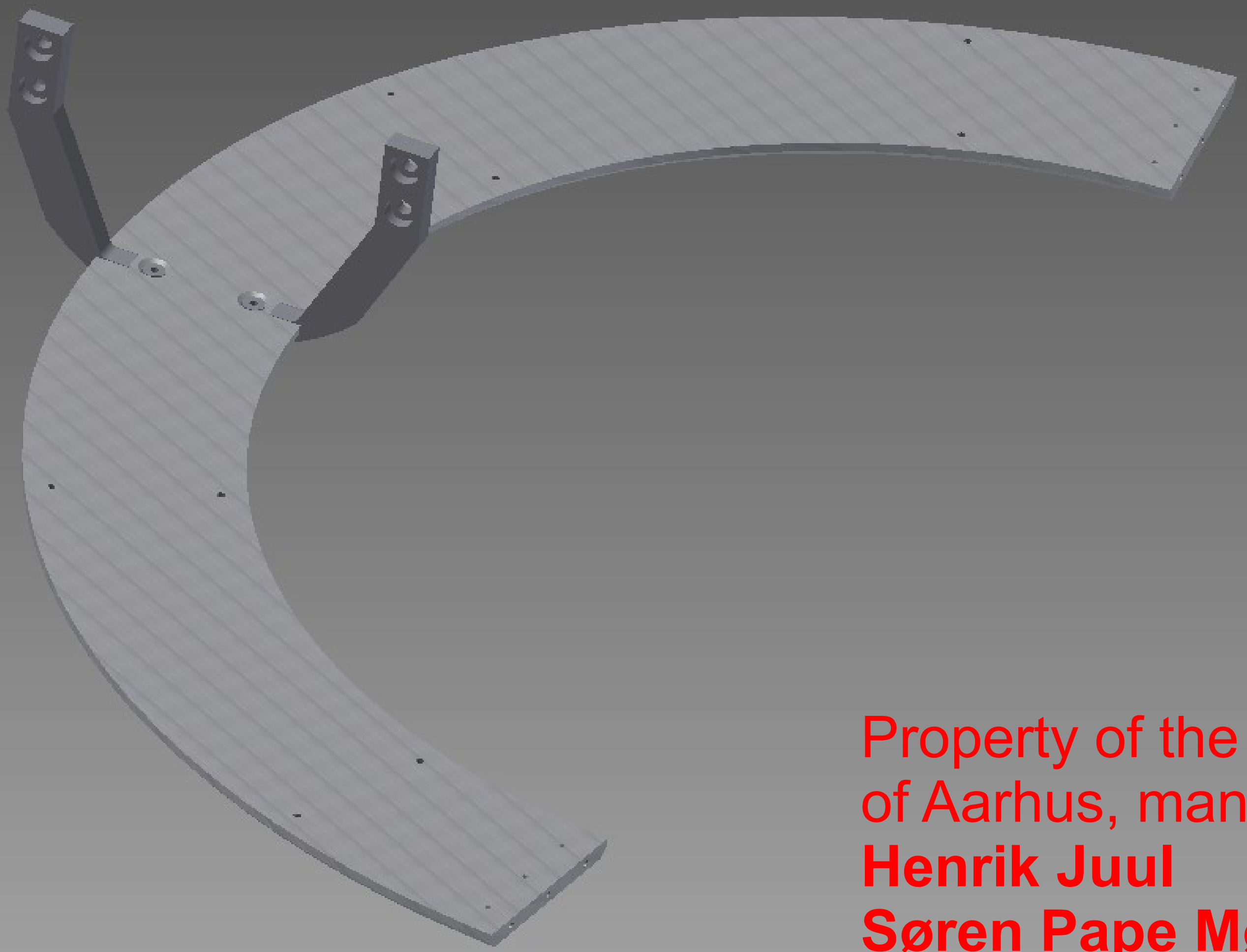
Fabrication of electrodes (CERN Main Workshop)



- Machining of these electrode/support profiles is not a problem
- Flat or curved (cylindrical or spherical) - does not make a too big difference
- Cut into sections: several electrodes can be machined in one go.
- No price estimation yet (they need more exact dimensions, tolerances)
- Price would ~ scale with size.
- Stresses in the material? Ring can elastically spring-back when cut. Annealing?

Deflector @ ELISA

Stainless steel
bottom-plate and
central support



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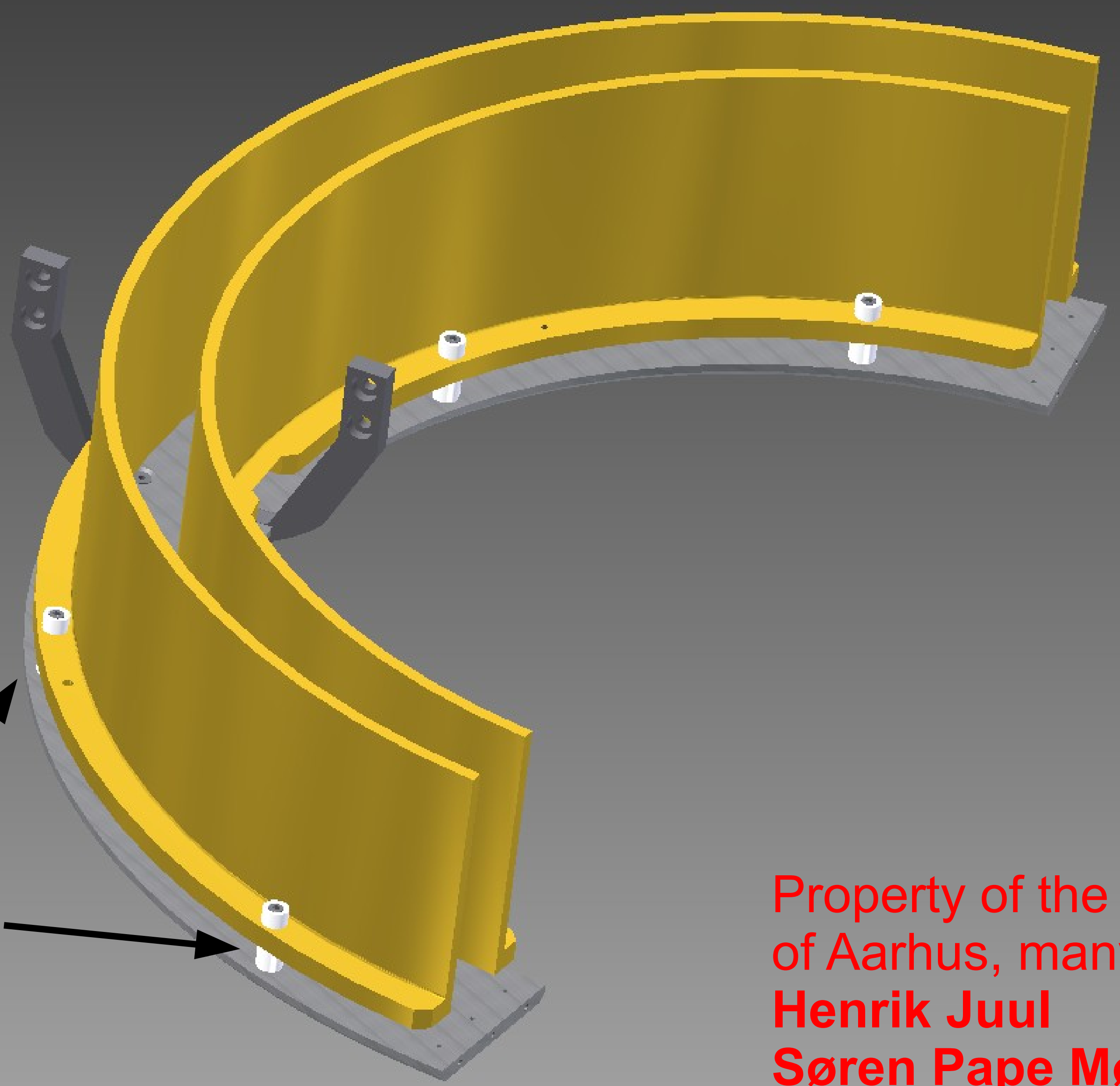
Henrik Juul
Søren Pape Møller

Deflector @ ELISA



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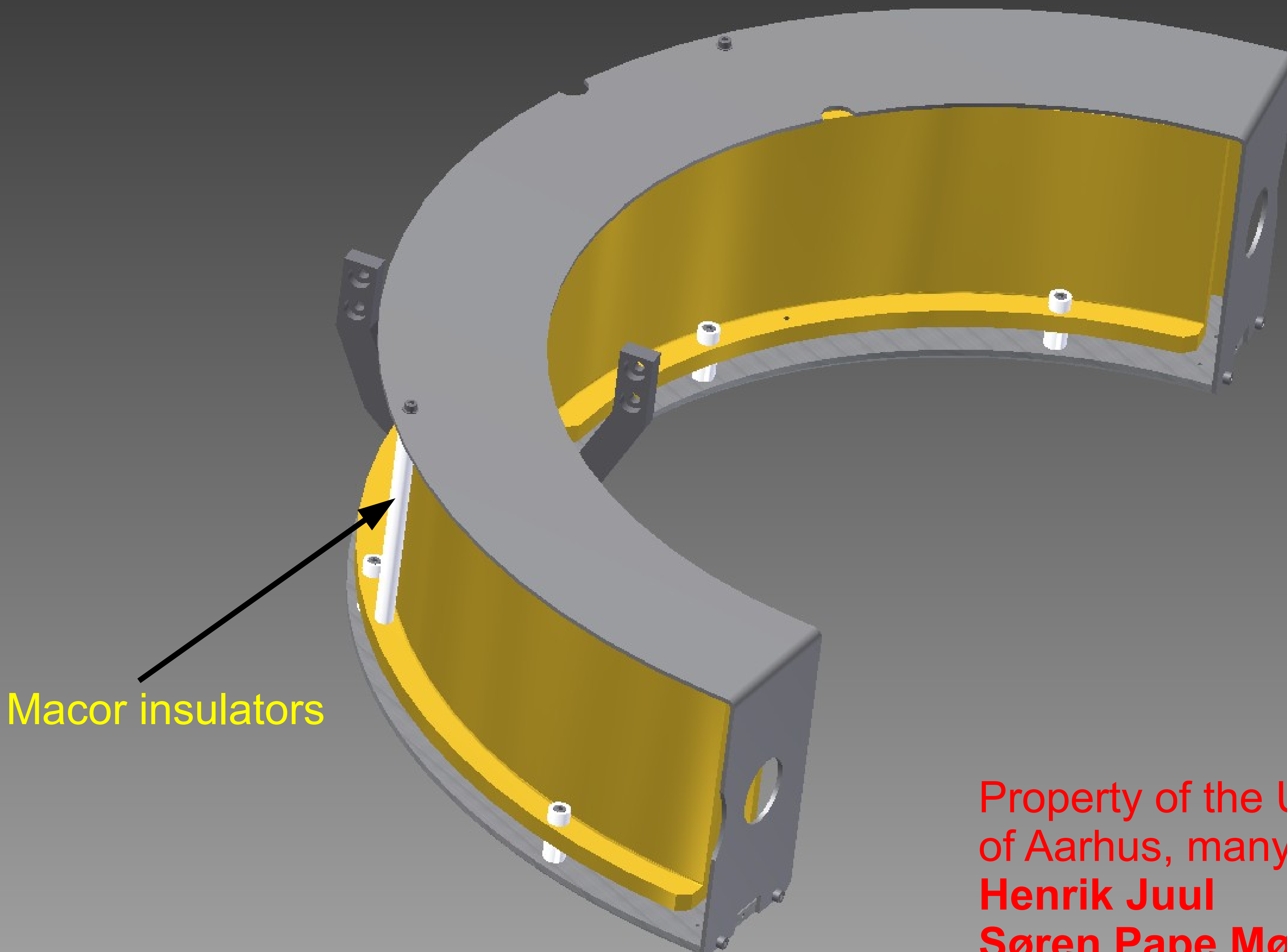

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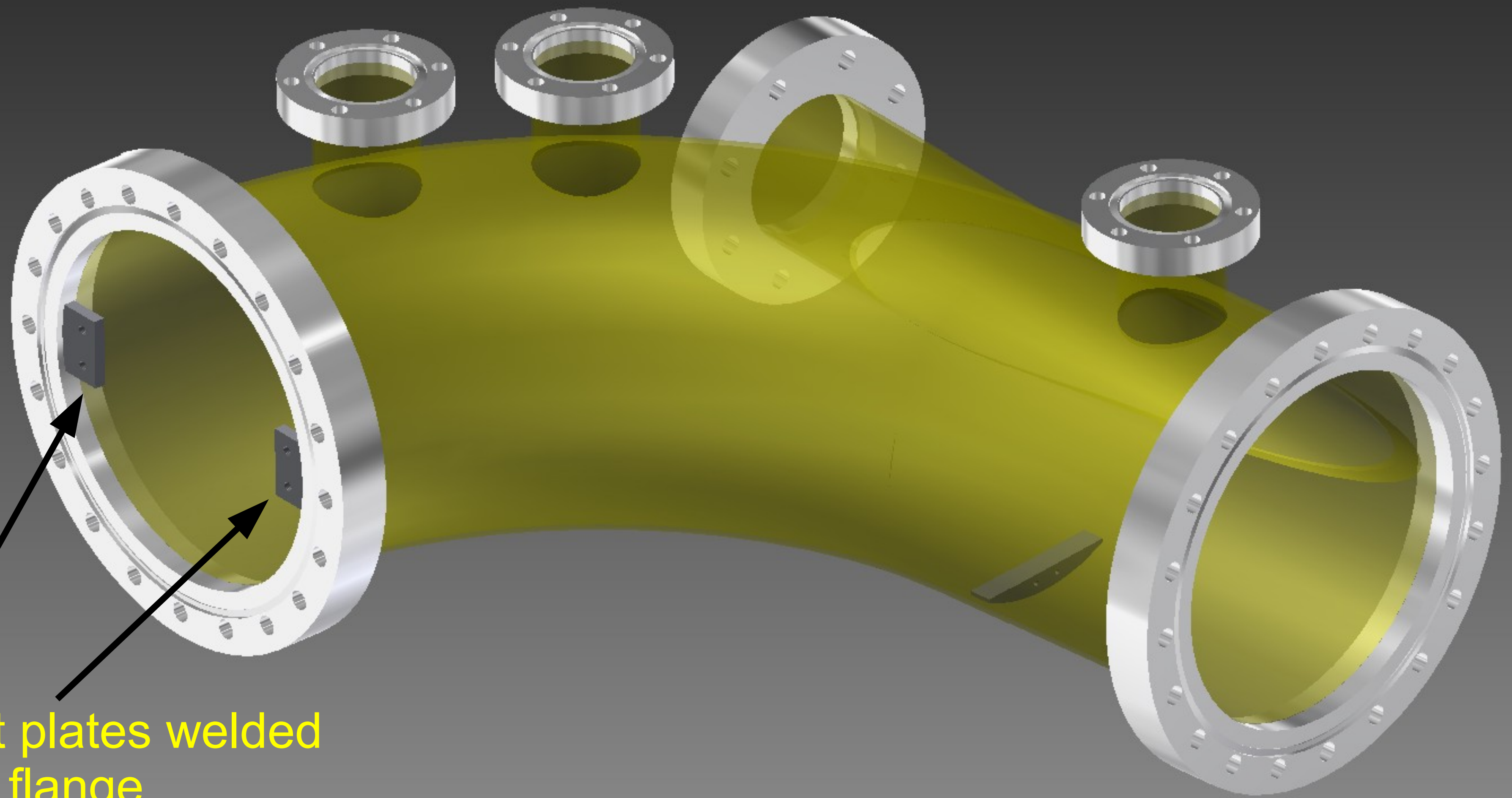

Support plates welded into the flange.
Holes (defining the position) drilled w.r.t. flange

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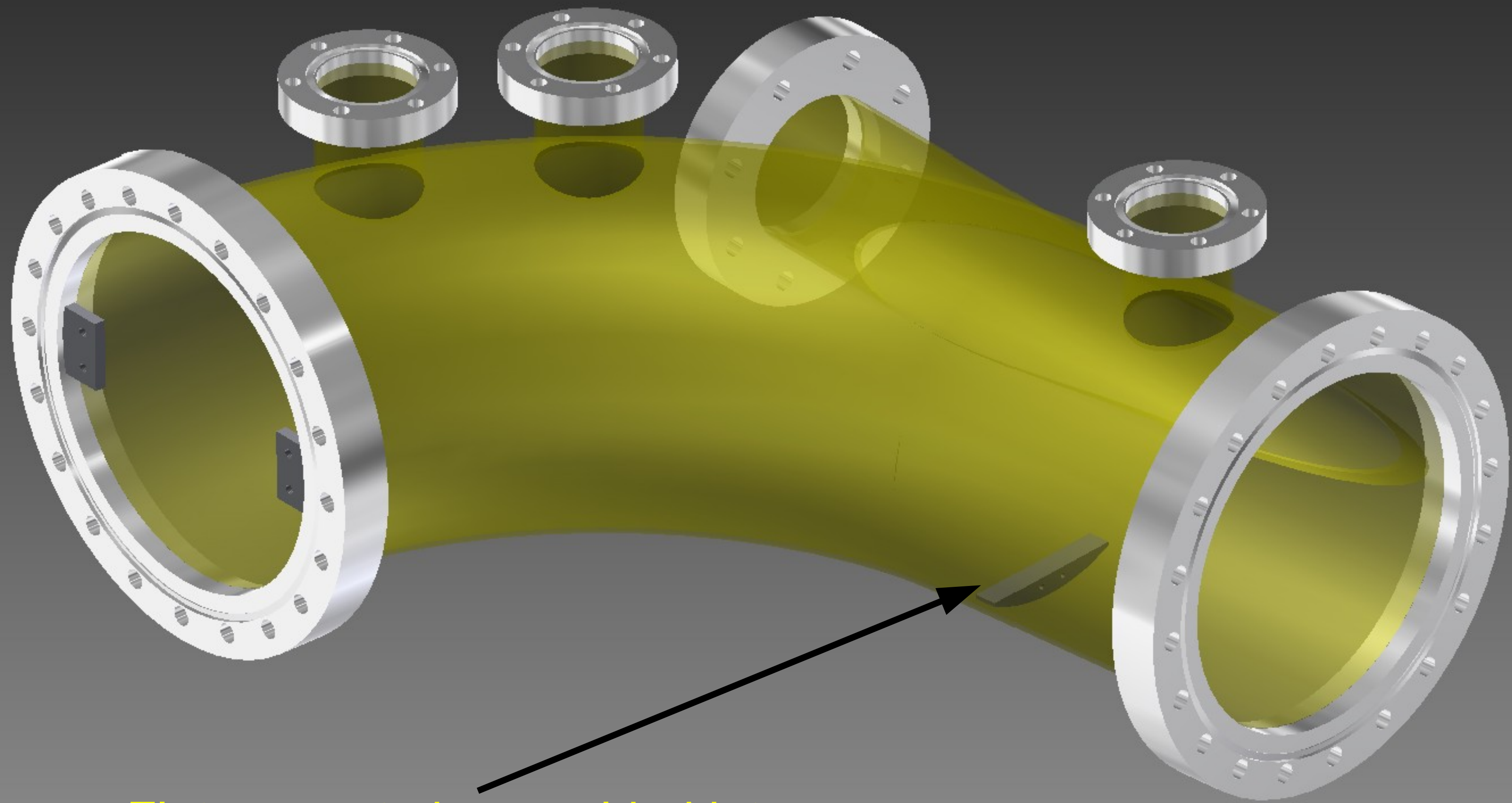
Deflector @ ELISA



Flat support piece welded into
vacuum pipe (unprecise).
Then remachined w.r.t. flange

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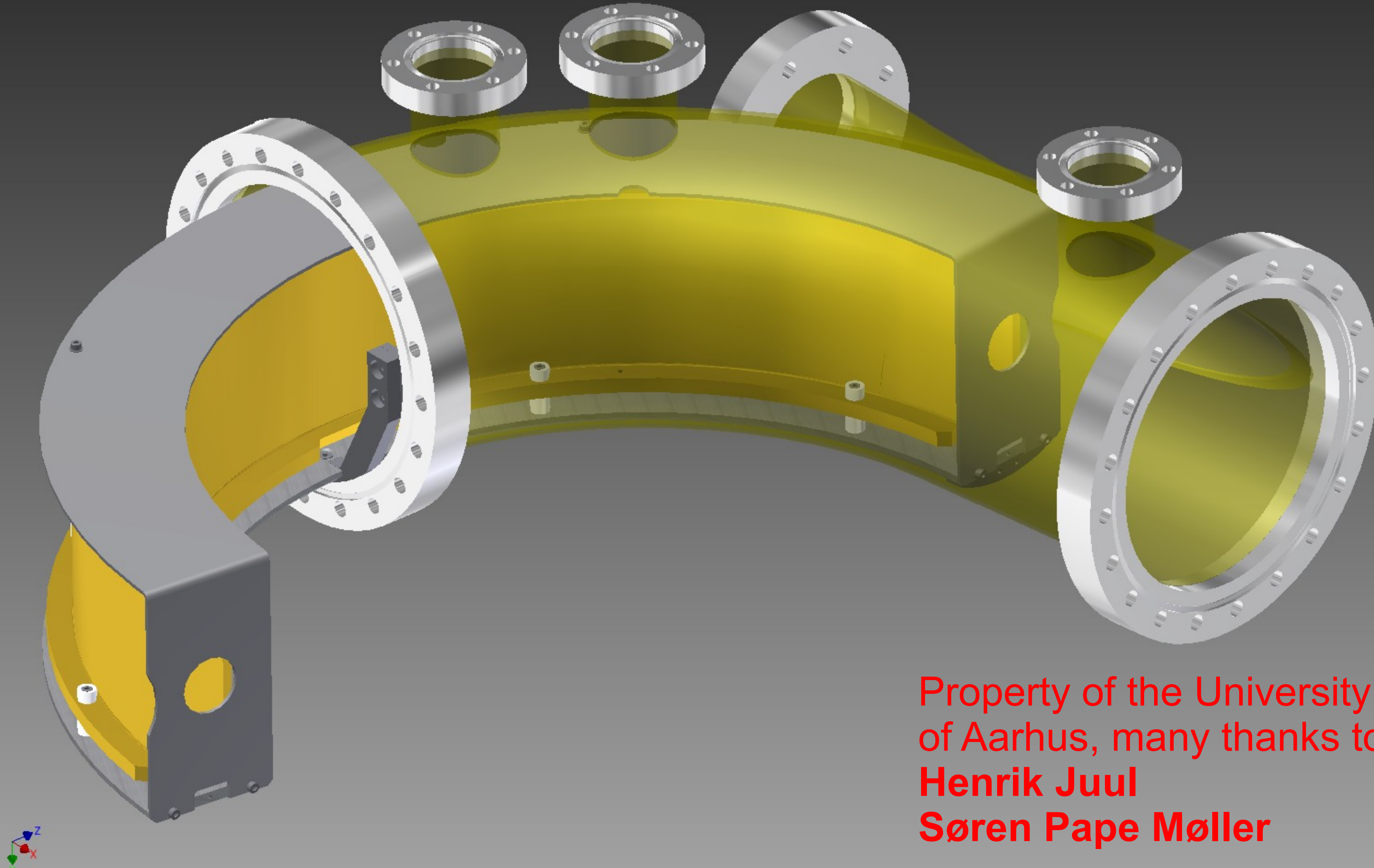

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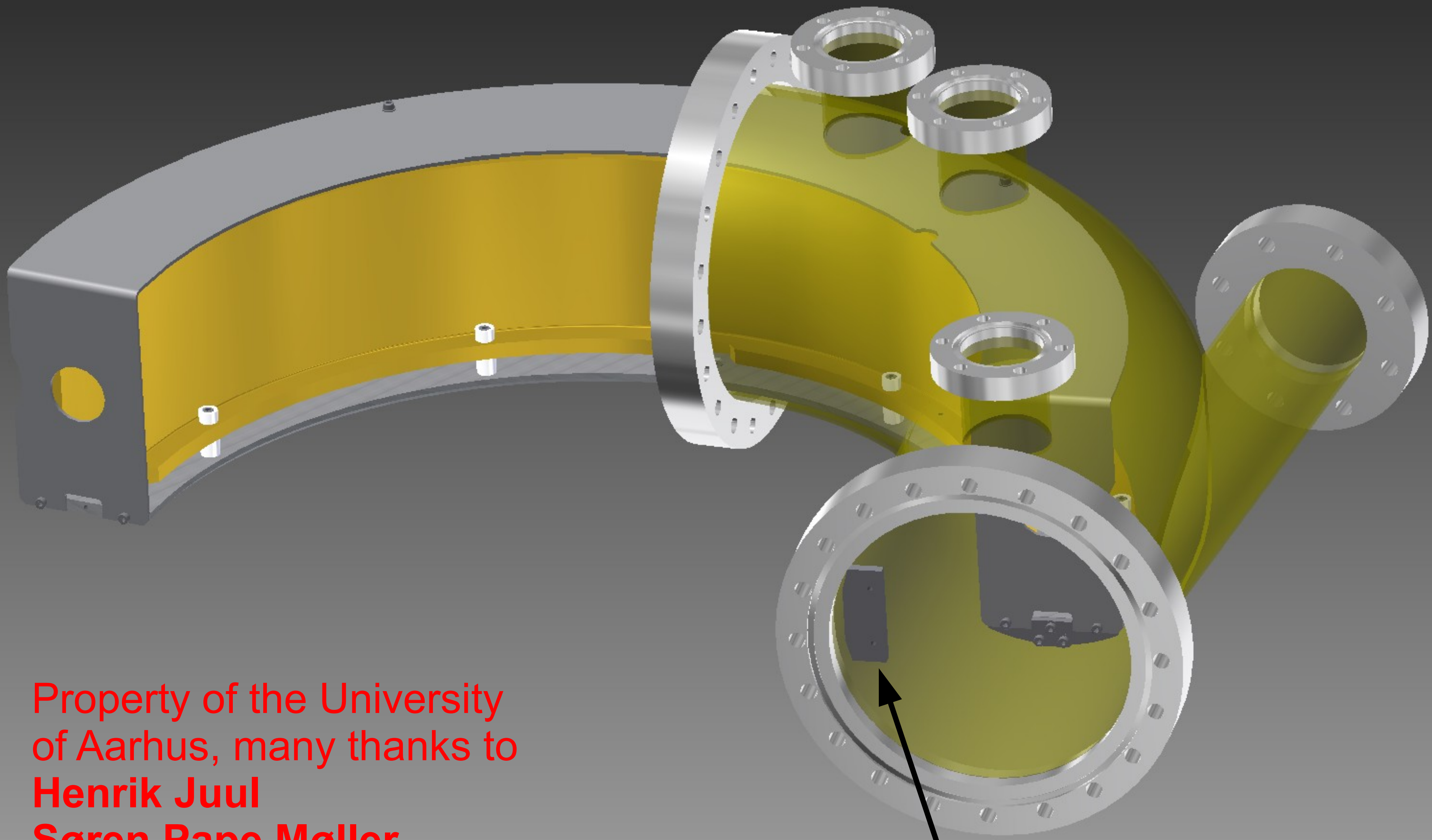

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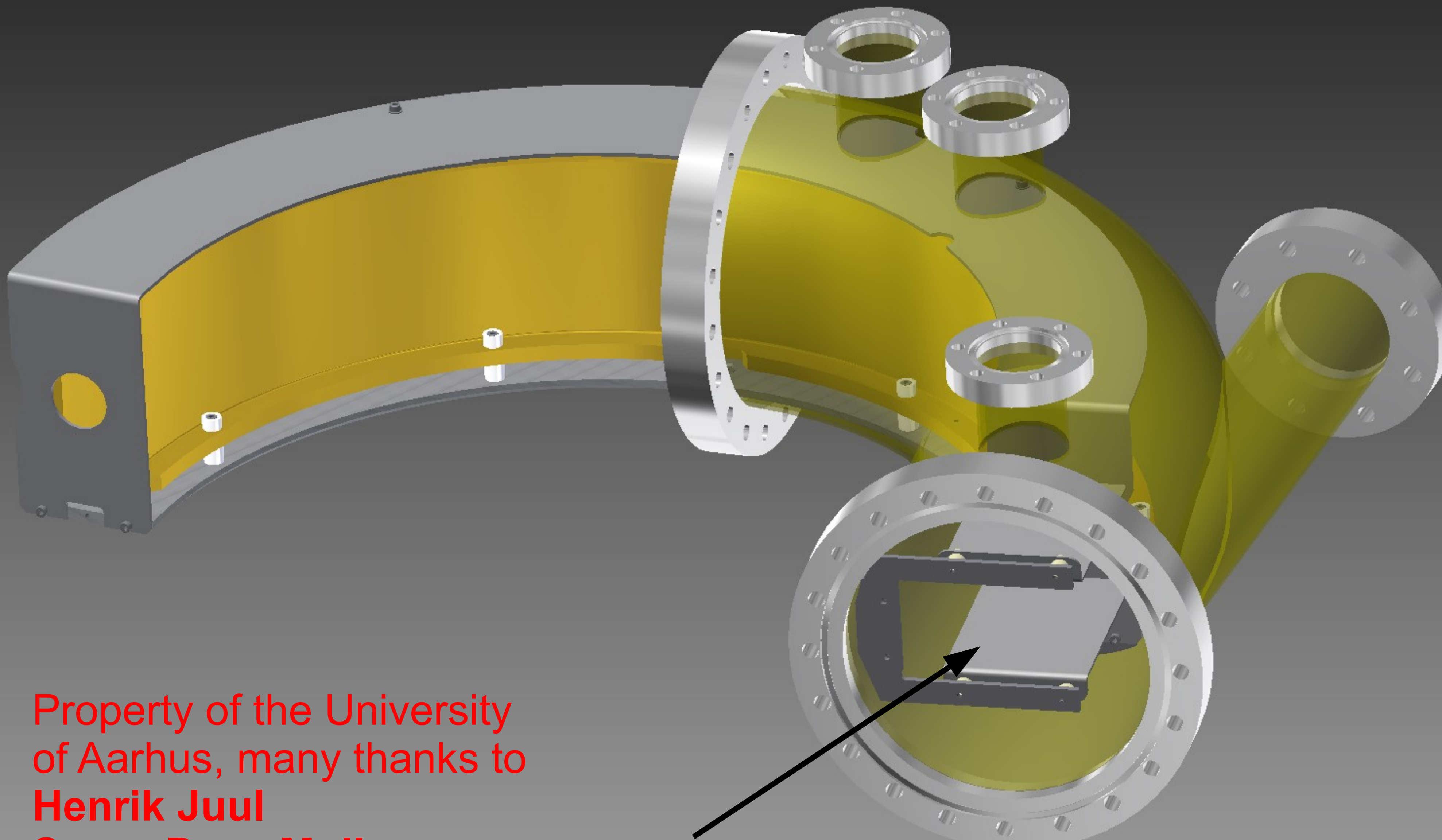

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QUADRUPOLE

Quadrupole: electrode shape

Dayton et.al. [Rev.Sci.Instrum. 25, 485 (1954)] - experimentally for a DC magnet:

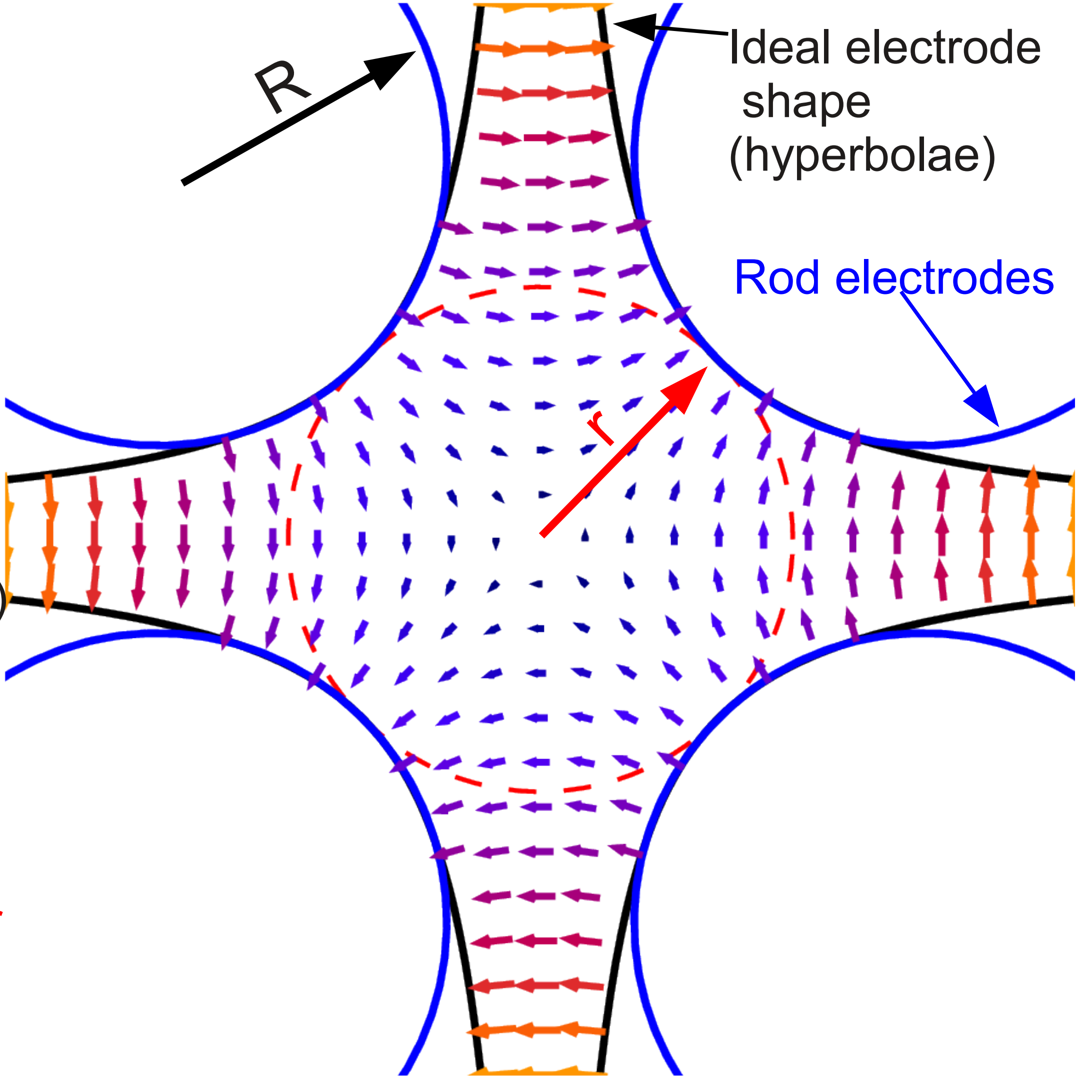
Best quad. field: **R/r = 1.15**

W. Paul [Zeit. Phys. 152, 143 (1958)] - for the quadrupole mass filter:

Misquotes Dayton et.al.:
R/r = 1.16
(Many subsequent publications/experiments use this bad value while referencing Dayton!)

D. J. Douglas et.al.
[Tech.Phys. 44, 1215 (1999)] (or many other)

R/r ~ 1.145, only weekly depending on the housing (beampipe) diameter



Quadrupole: electrode shape

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Best quad. field: **R/r = 1.15**

W. Paul [Zei
the quadrup

Mis
R/r
(Ma
pub
bac

D. J. Dougla
[Tech.Phys.

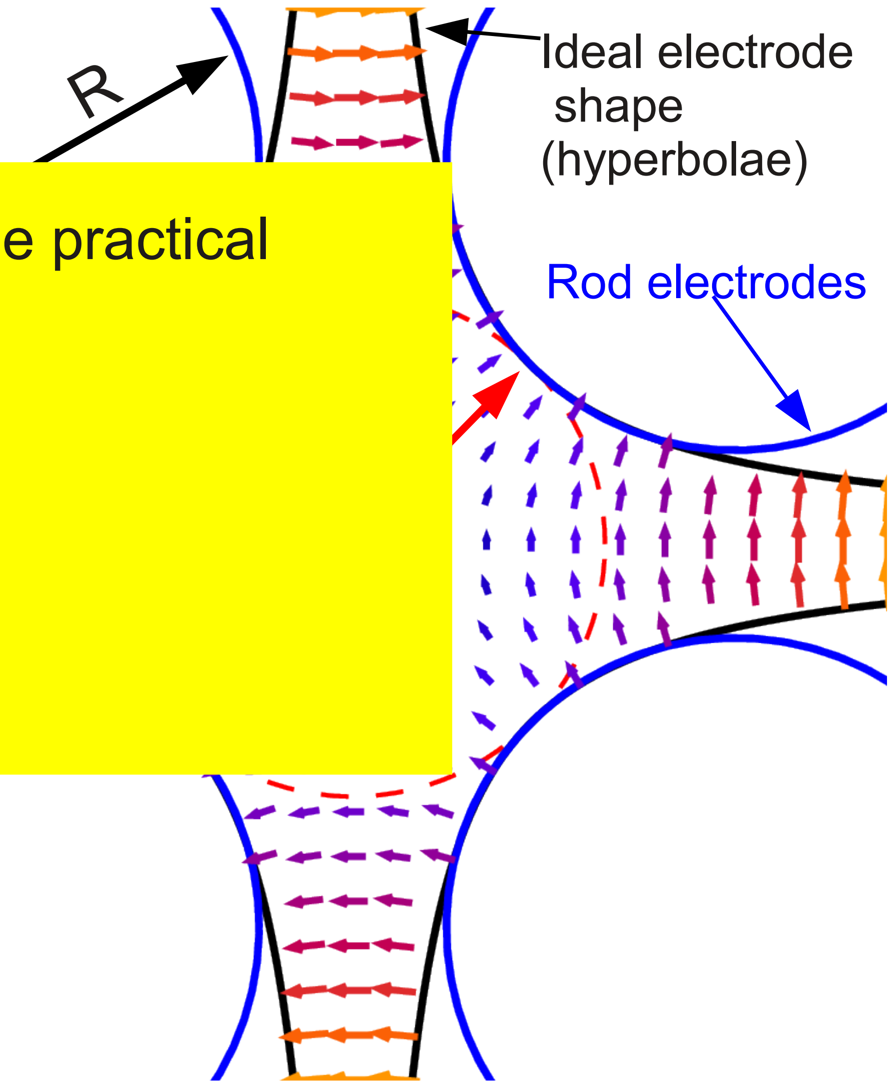
R/r ~ 1.145, only weekly depending on the housing (beampipe) diameter

Only a historical anecdote, of little practical interest.

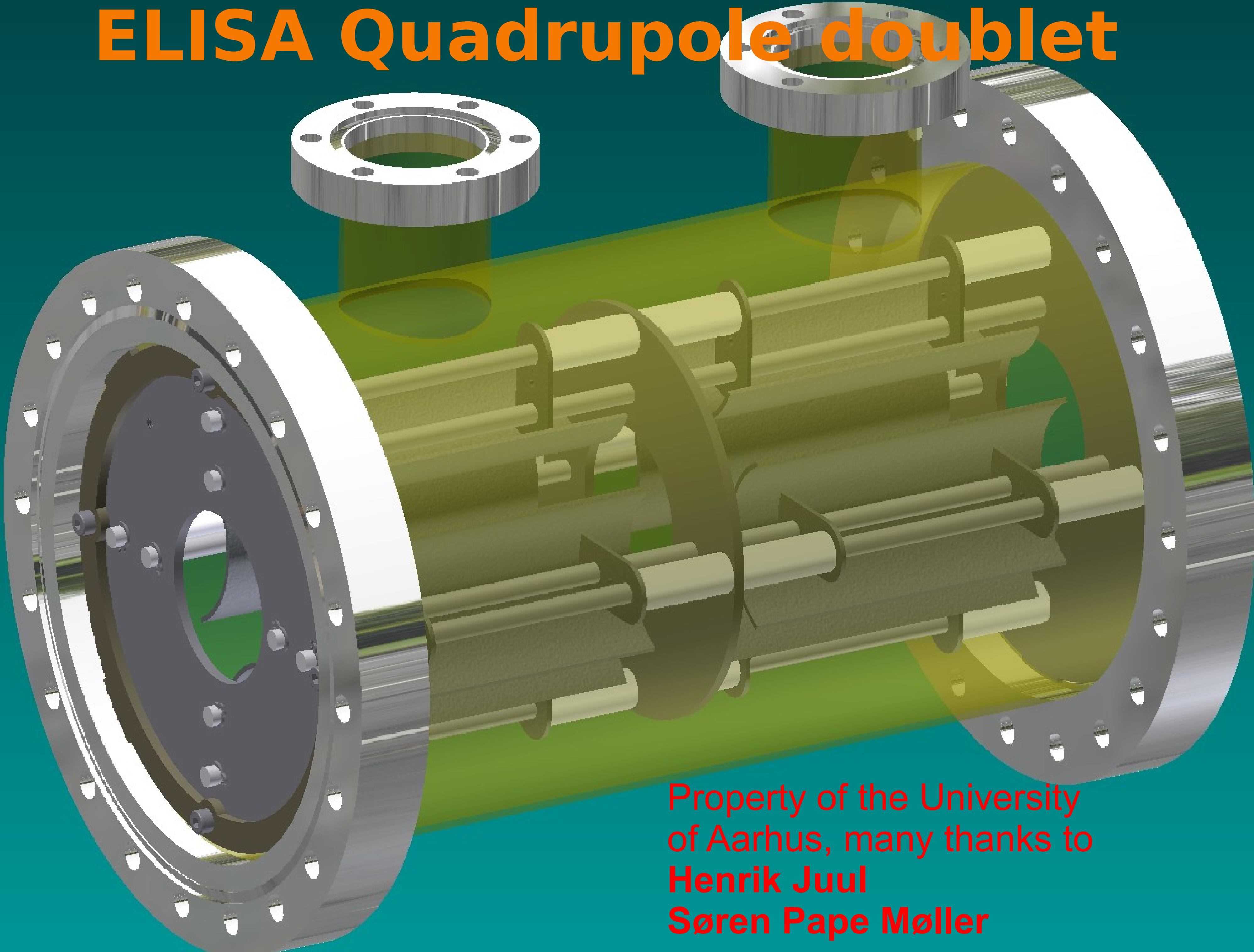
True for infinitely long quads.

For short ones: R/r = 1.65

(Thanks to R. Baartman)



ELISA Quadrupole doublet



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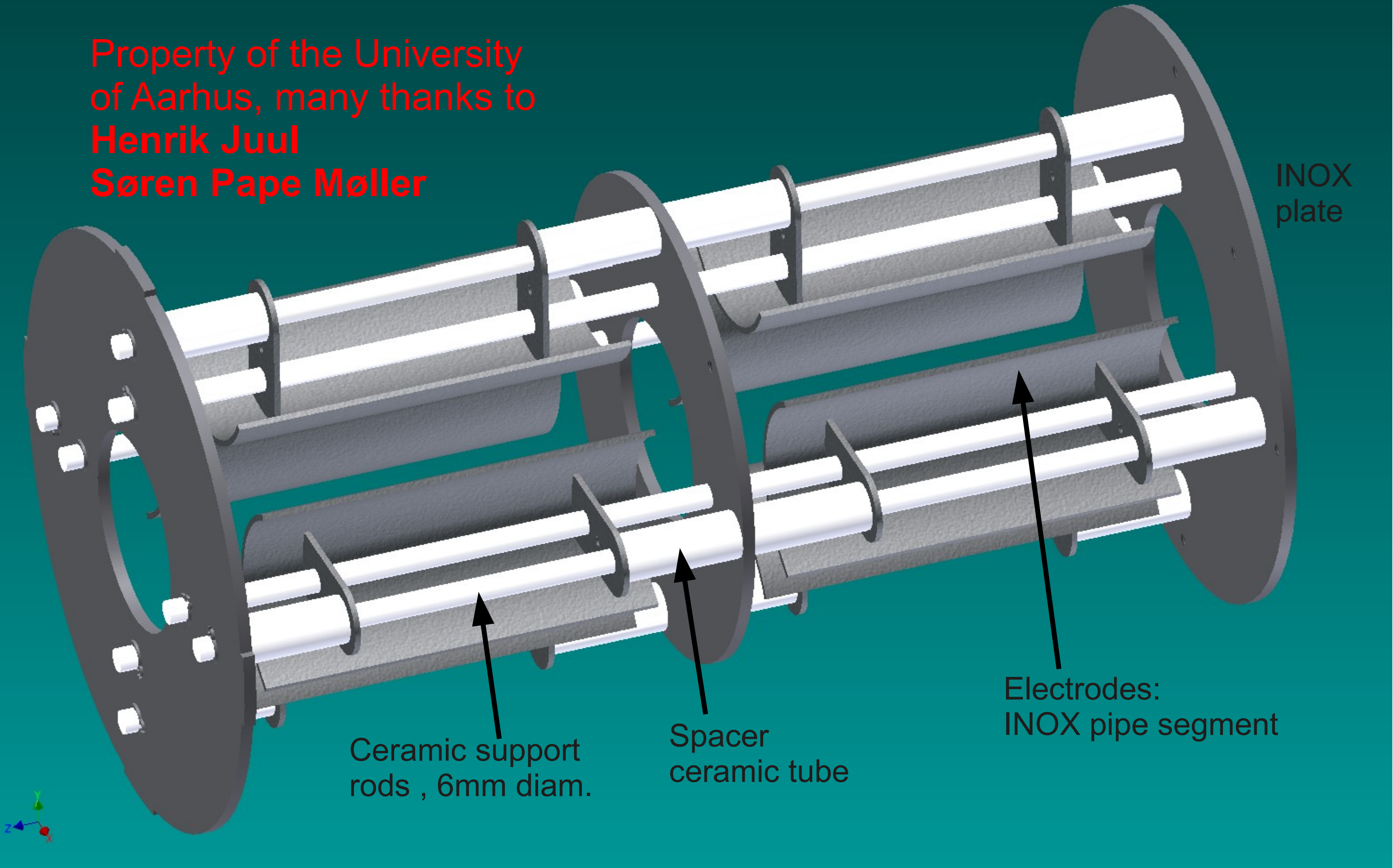

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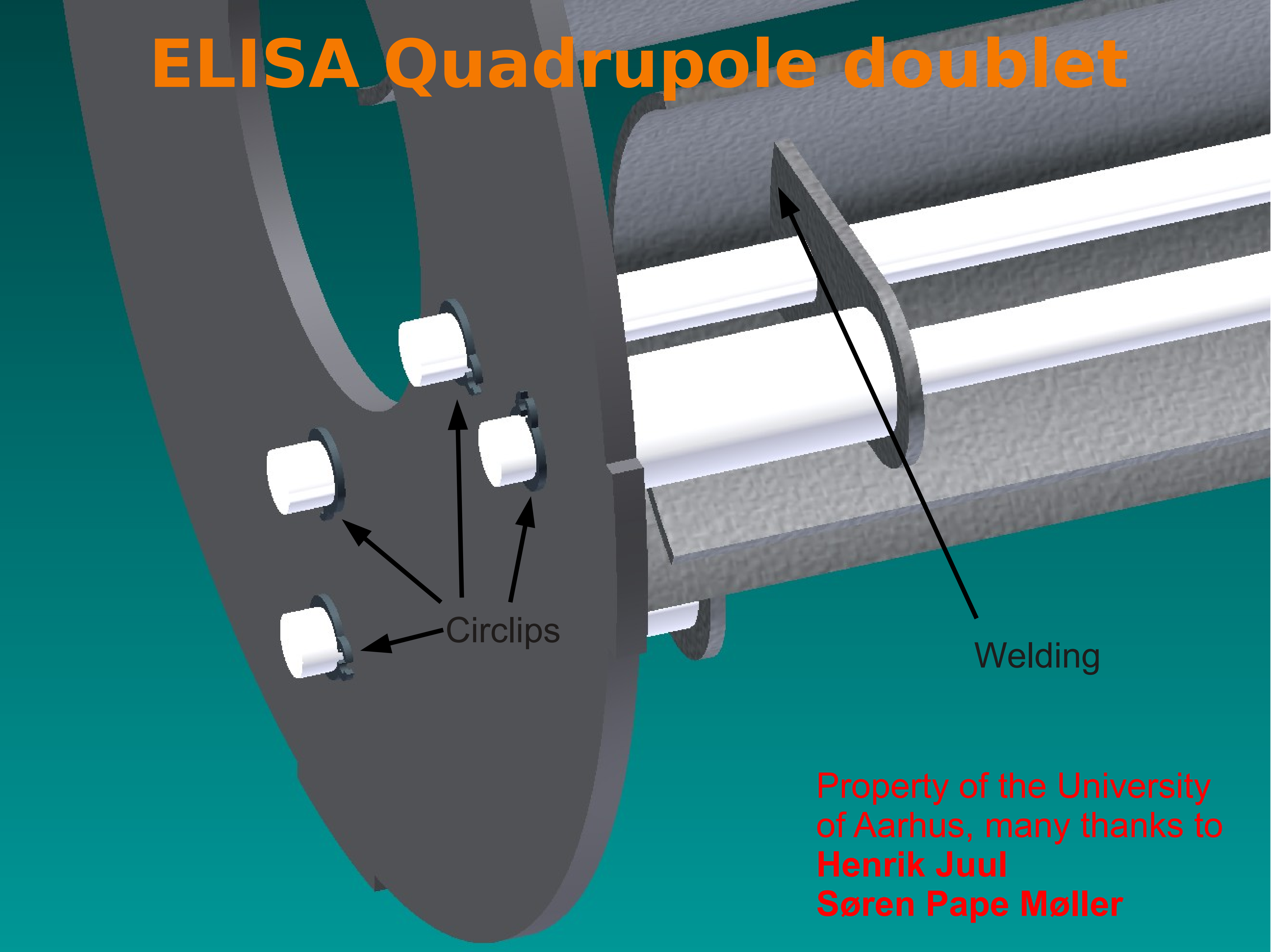

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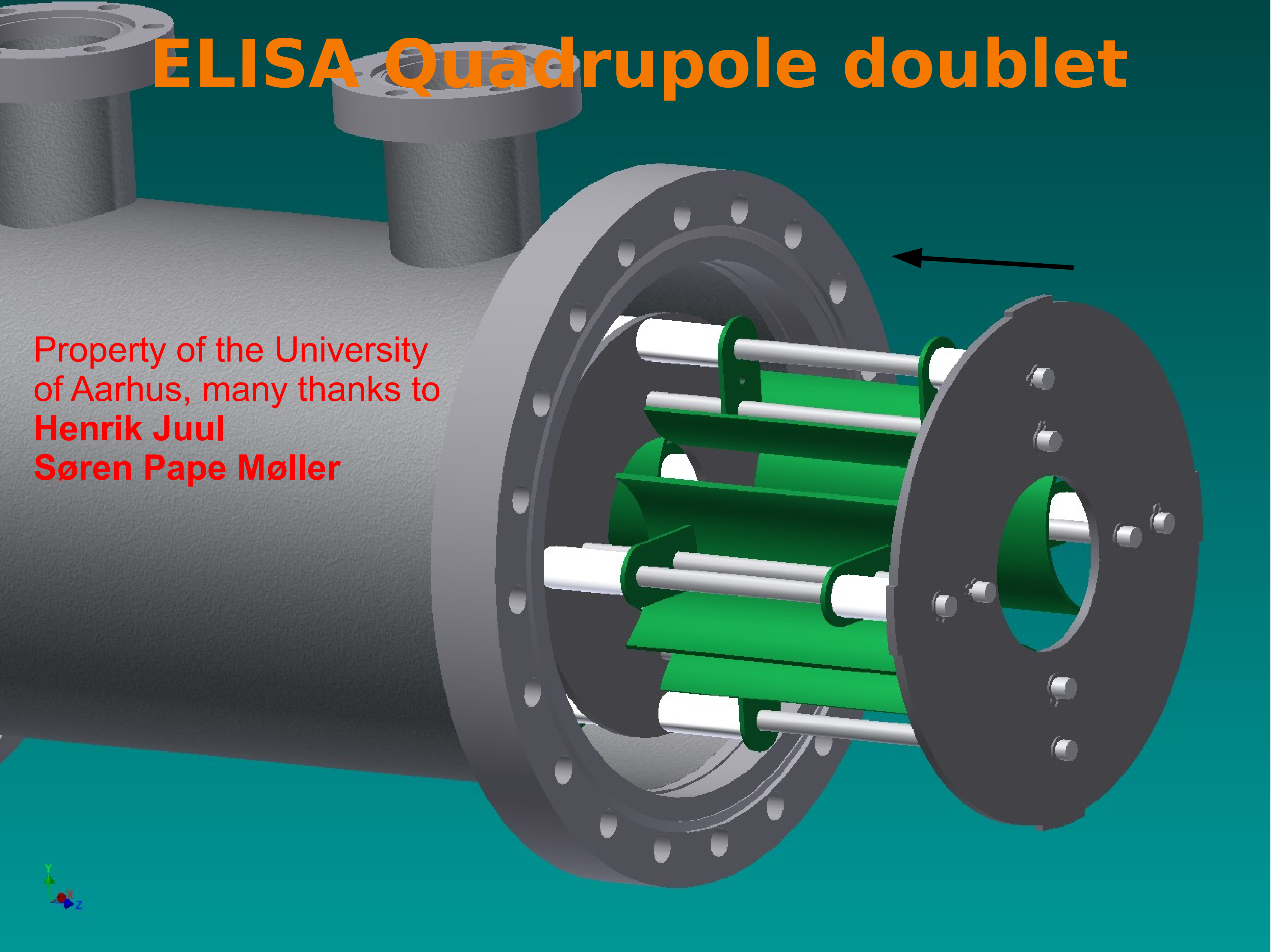

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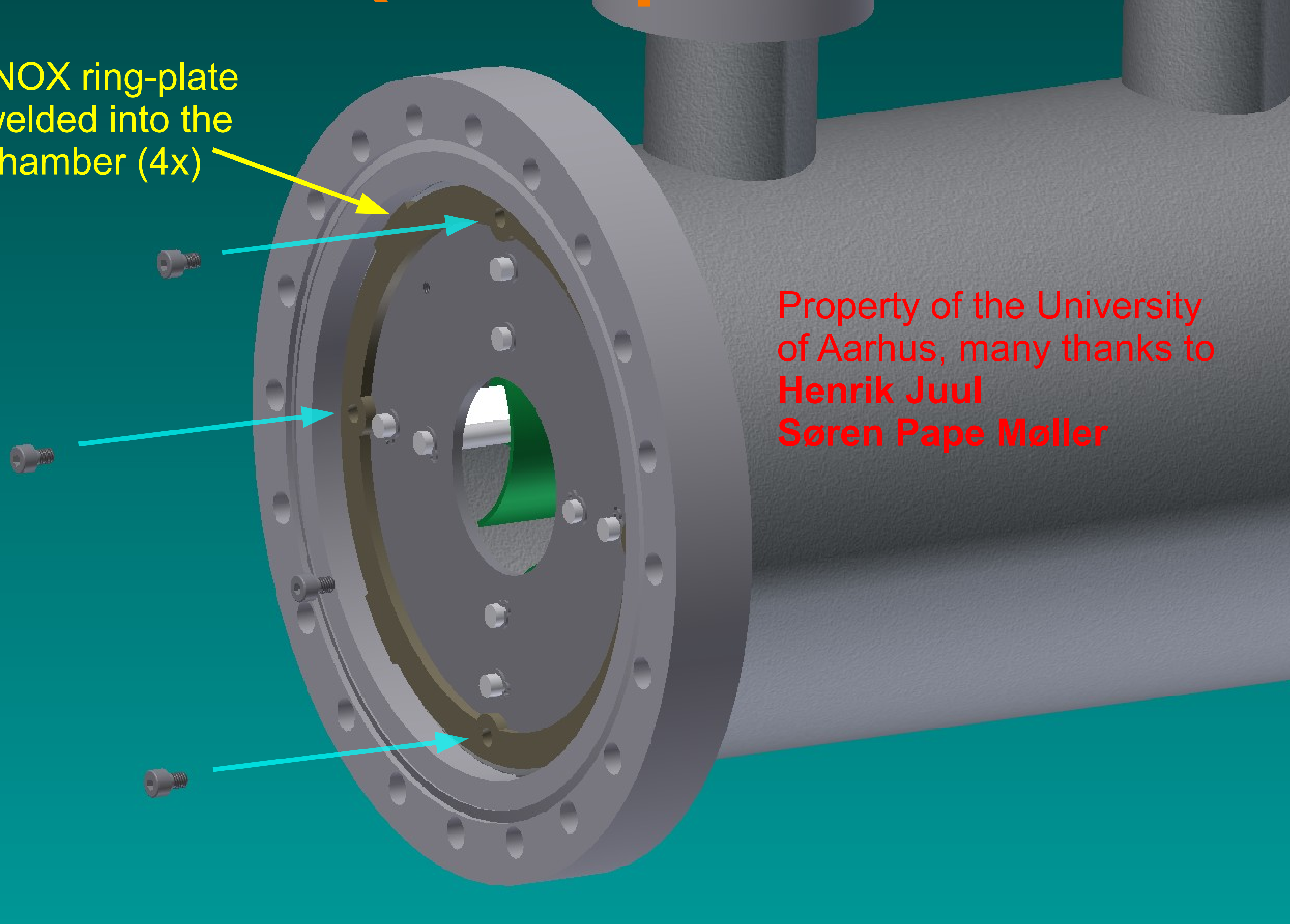
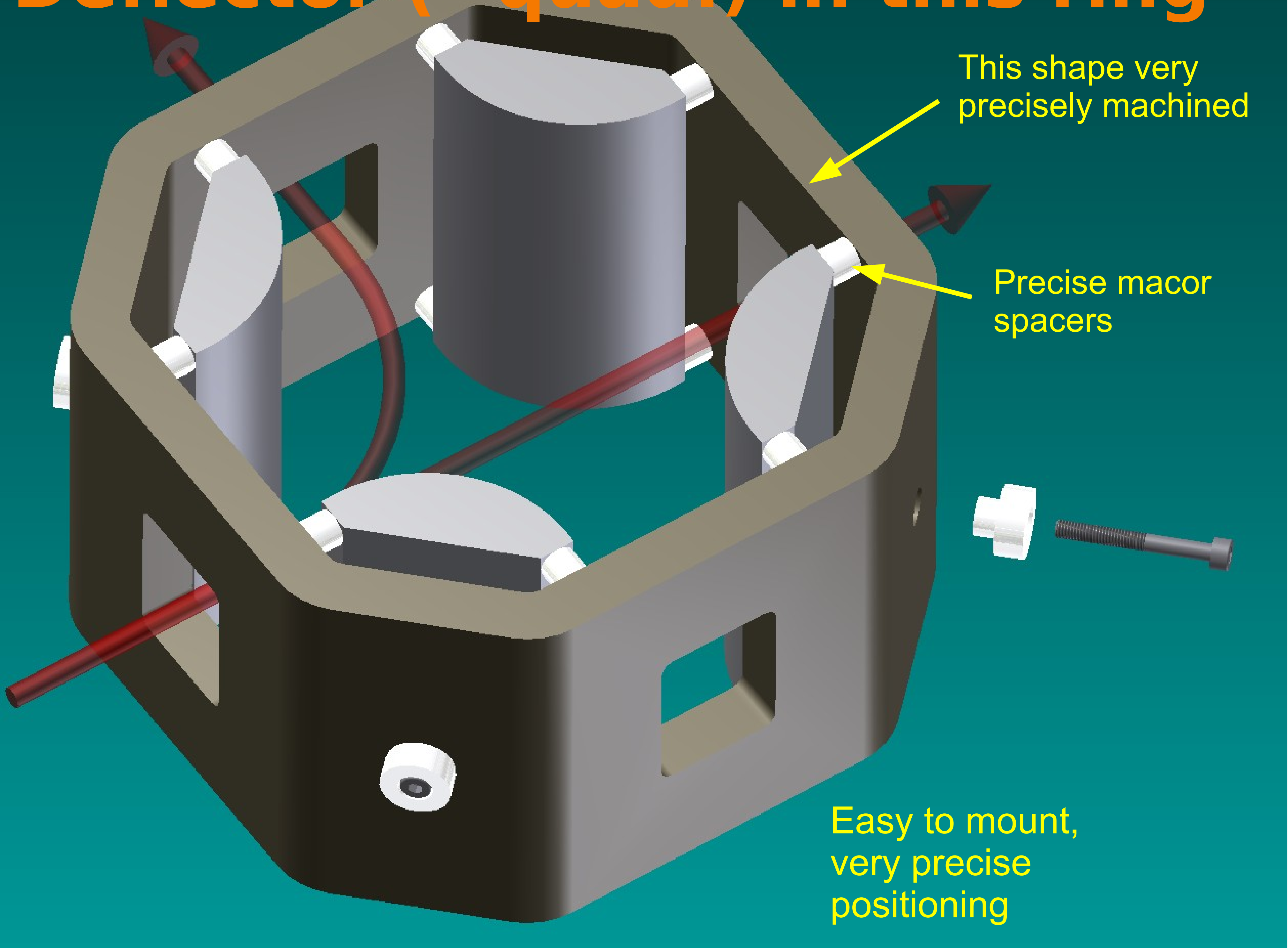


Another storage ring @ Aarhus

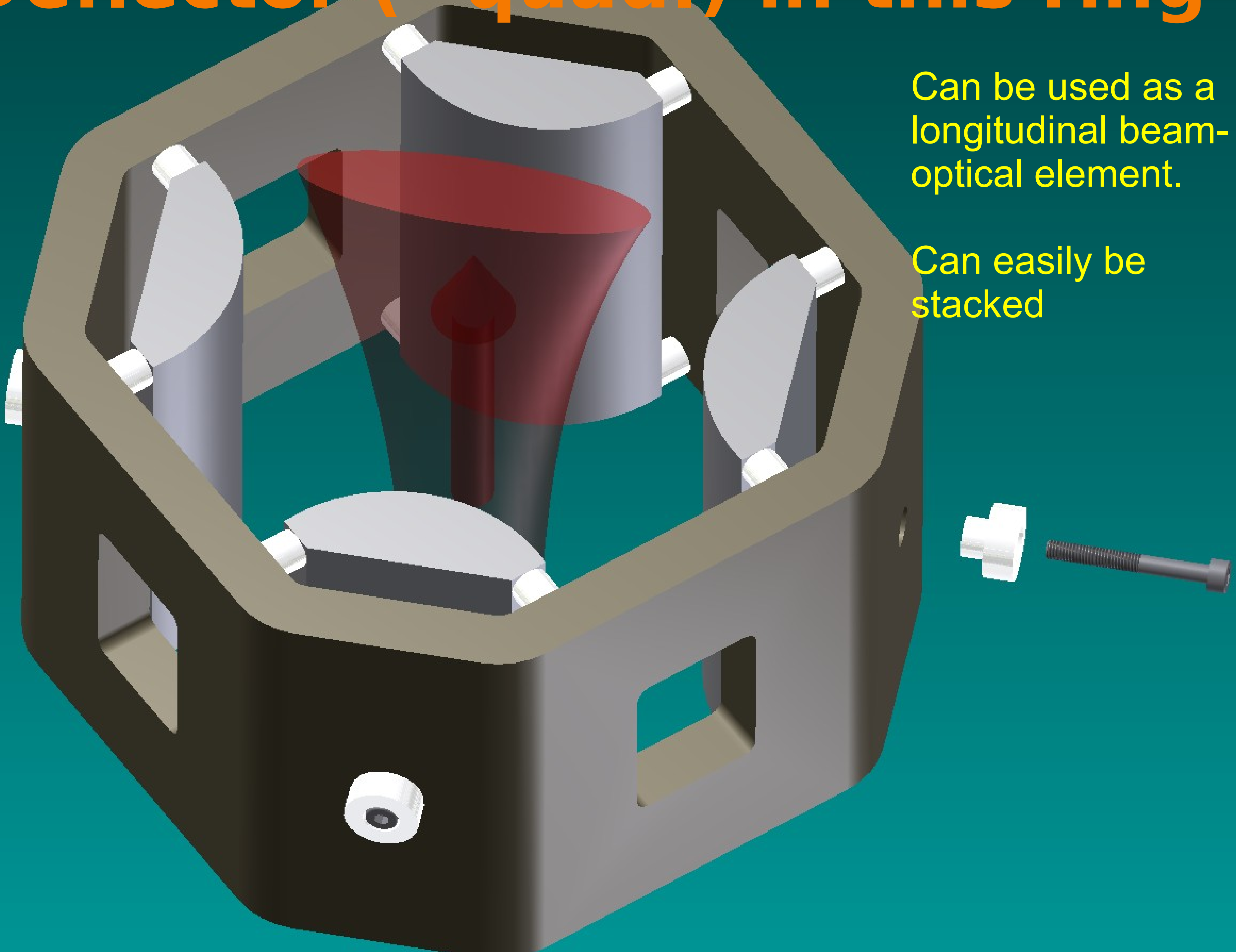
SAPHIRA - 20 keV ions
(wide mass range)

(Picture by Wolfgang Bartmann)

Deflector (=quad.) in this ring



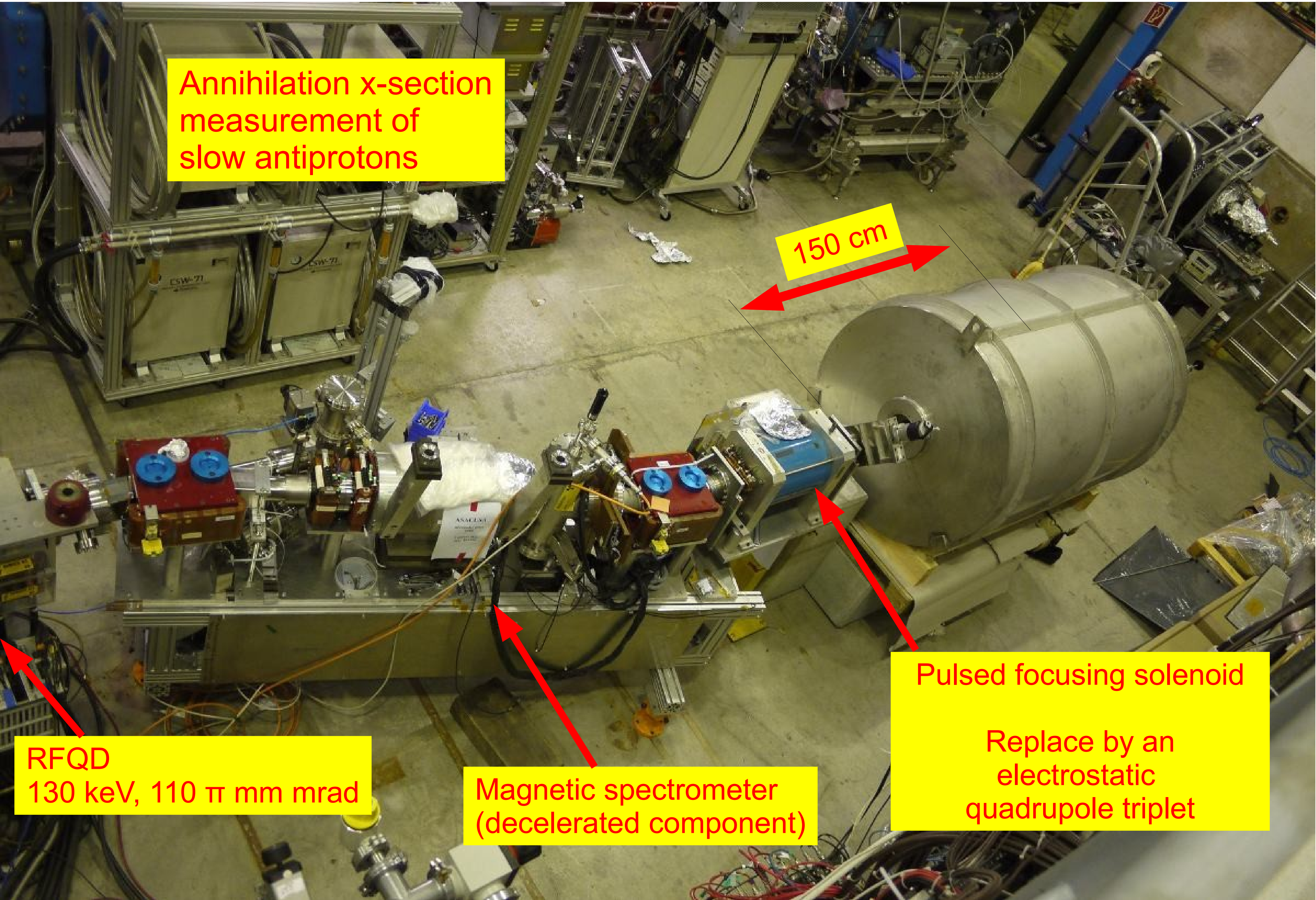
Deflector (=quad.) in this ring



Can be used as a longitudinal beam-optical element.

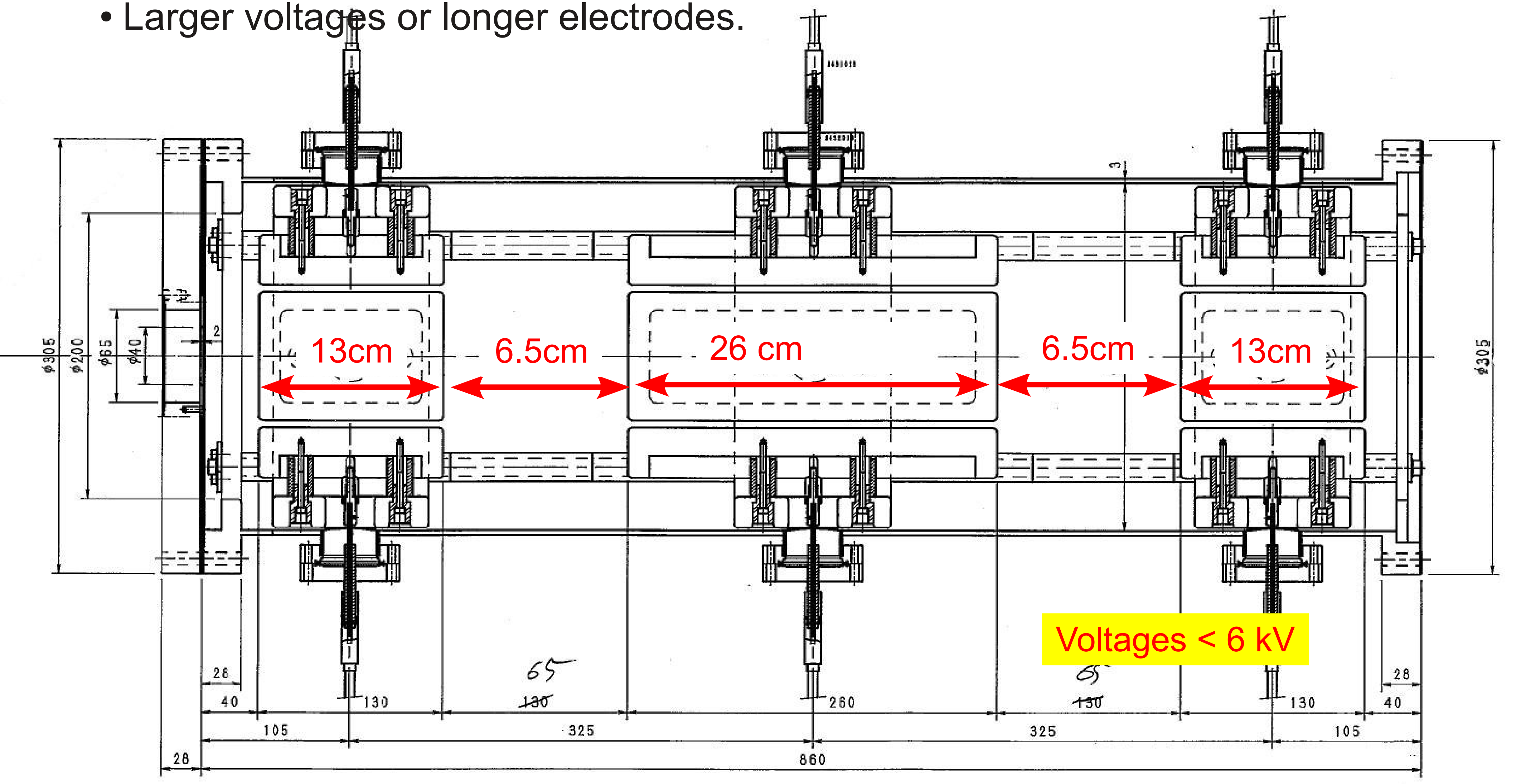
Can easily be stacked

Electrostatic quadrupole @ ASACUSA

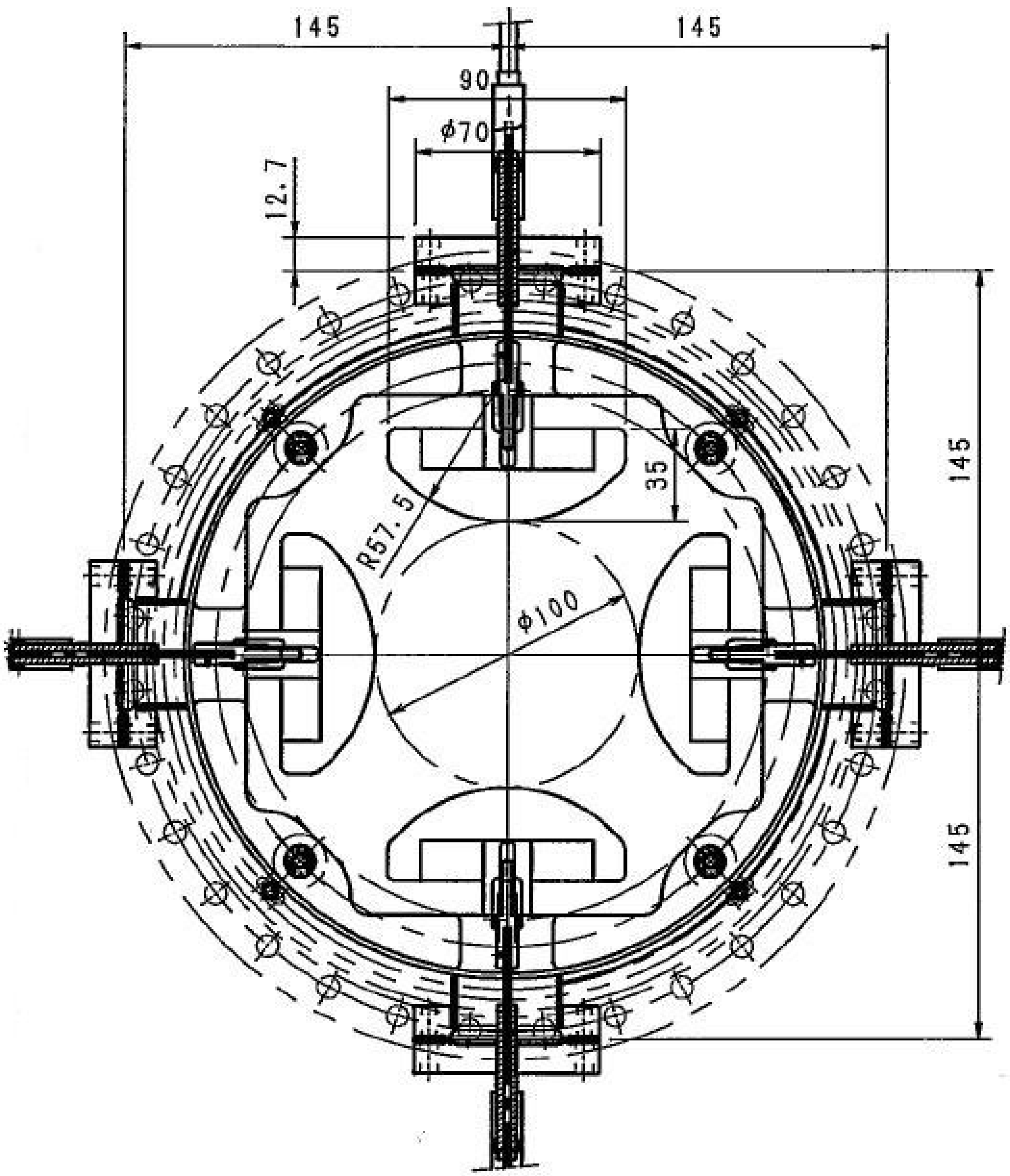


Quadrupole prototyping @ ASACUSA

- Challenge: beam emittance > 100 pi mm mrad
- Need larger aperture than in ELENA beamlines
- Larger voltages or longer electrodes.



Quadrupole prototyping @ ASACUSA

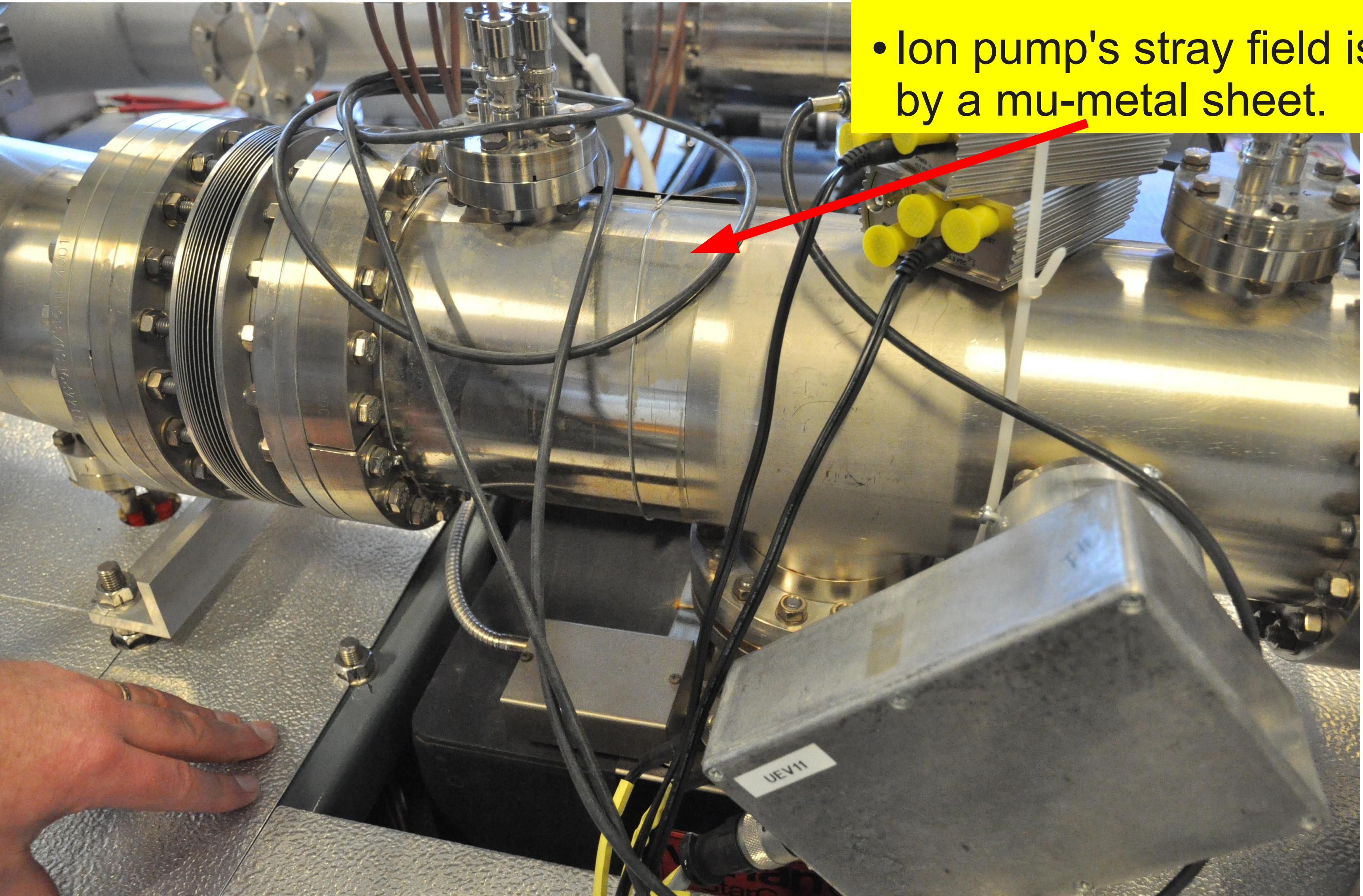


- Install in April
  Use with beam in May
- We will keep you informed about our experiences.

MAGNETIC SHIELDING

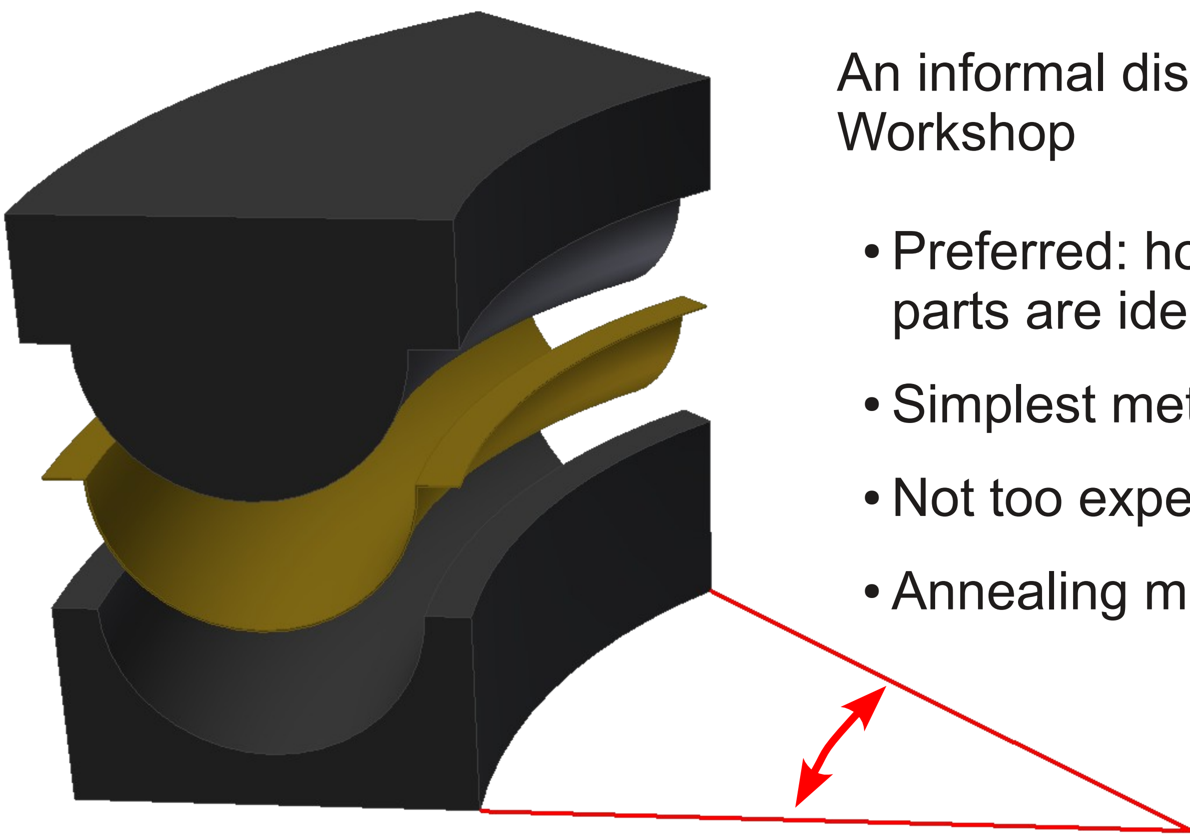
ELISA solution

- Static fields (Earth), can be compensated by steerers
- Ion pump's stray field is shielded by a mu-metal sheet.



Magnetic shielding @ ELENA

- More difficulties: changing fields (superconducting magnets ramping up/down)
- Can not rely on compensation with steerers, need more serious shielding.
- Easy for the straight sections, more complicated for the deflectors.



An informal discussion with the CERN Main Workshop

- Preferred: horizontal cut (top and bottom parts are identical)
- Simplest method: press-forming
- Not too expensive if all parts identical.
- Annealing mu-metal after forming.

Acknowledgements

CERN Main Workshop

- Jean-Marie Geisser
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AARHUS

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- Søren Pape Møller
- Henrik Juul

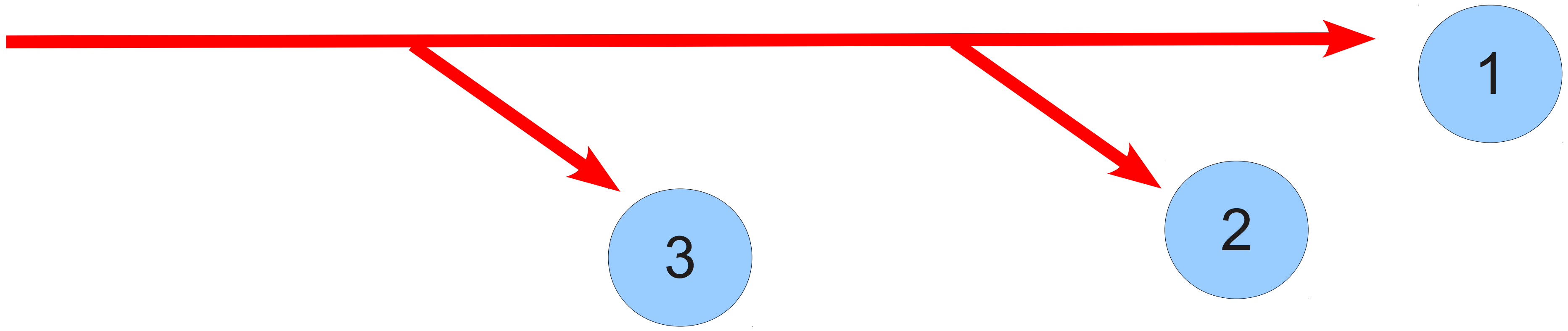
ASACUSA

- Masaki Hori
- Yasunori Yamazaki

Backups

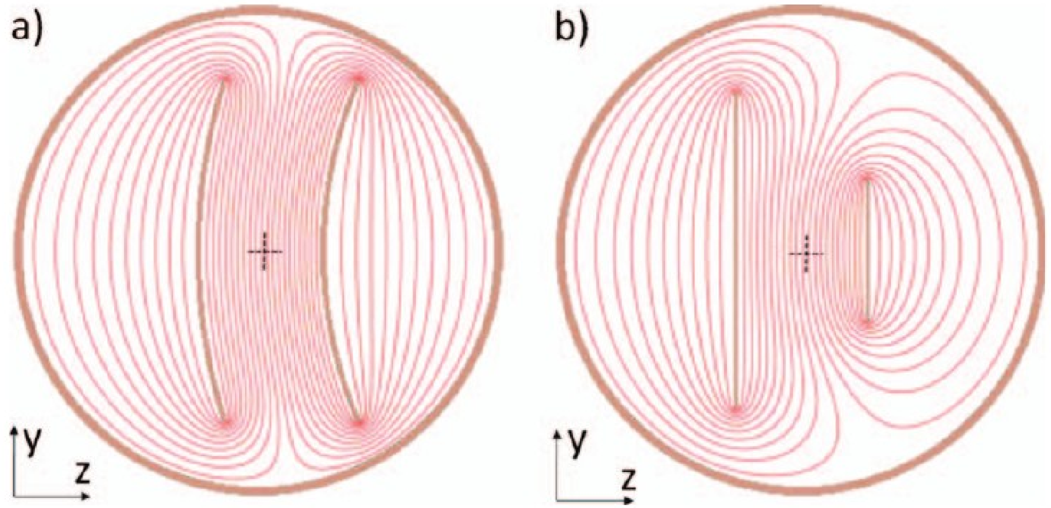
Switching between experiments

With the right sequence, only the risetime of the pulses is important.



Deflectors

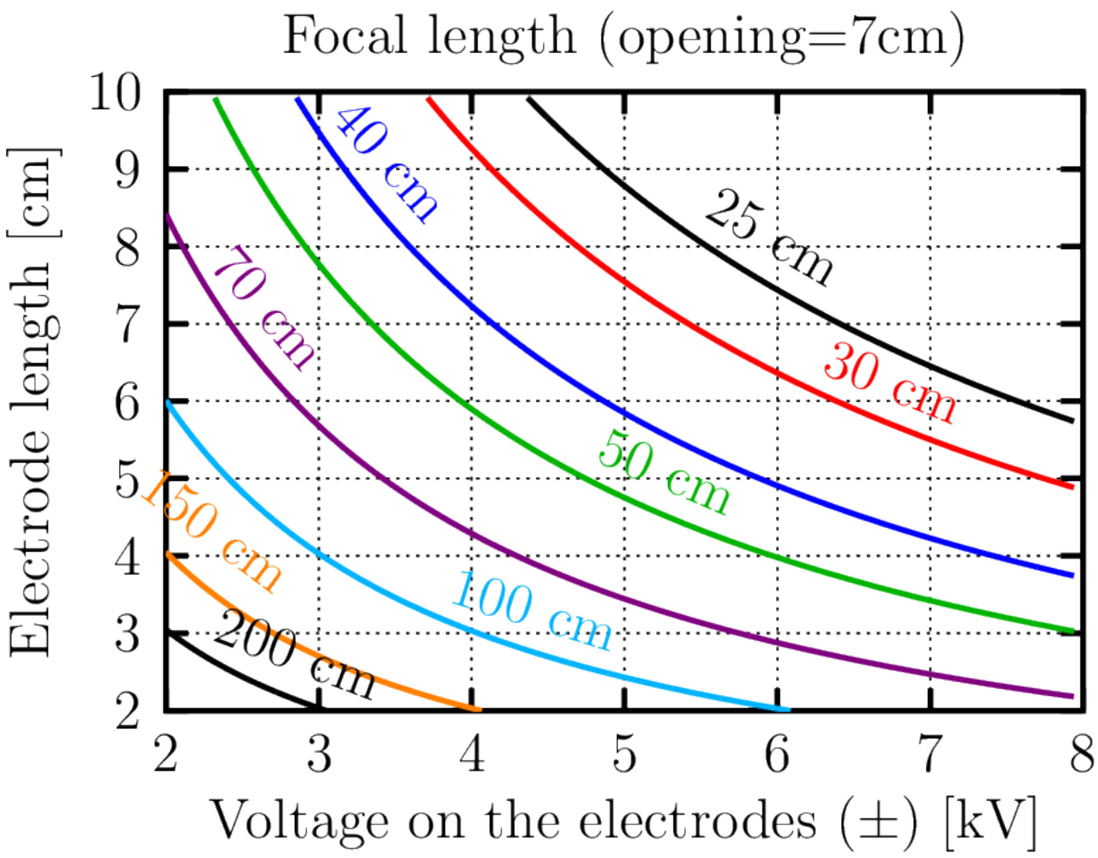
An alternative geometry for vertical+horizontal focusing:



"True" spherical deflector

Cylindrical capacitor with different electrode heights. [*Rev.Sci.Instrum.81(2010)063304*]

Quadrupole: voltage & electrode length



Few cm long electrodes and moderate voltages are sufficient