Vacuum and mechanical design of ILC DR

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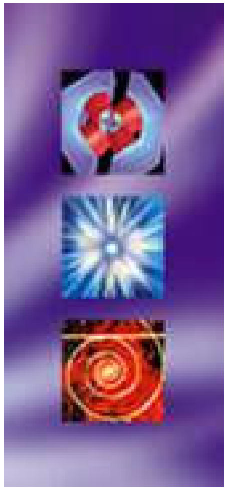


Low Emittance Ring Workshop 2010
12-15 January 2010

Integration design: usual consideration

field	parameter	implication
Beam dynamics	Beam aperture Impedance/wake field BPM	Vacuum chamber aperture, Shape, material, coatings BPM design
SR power	Power, photon reflectivity	SR power absorber design, cooling
Vacuum design	SR induced gas desorption	Pumping scheme, vacuum chamber material, coatings
Fast ions (in e^- DR)	Gas density specification Ion collection	UHV pumping scheme Mechanical design
Mechanical solutions	Mechanical design, component integration, mechanical stability, etc.	Shape, material, supports, cooling, welding, brazing, feedthroughs, etc.
Cost	Cost optimisation	All systems

Integration design: specific problems in e$^+$ rings

field	parameter	implication
Ion induced pressure instability	Rapid gas density grow Residual gas ionisation Ion energy, ISD yield	Vacuum design: Requires greater pumping speed and low outgassing walls
E-cloud mitigation	PEY (minimising a number of photoelectrons in beam pipe)	Shape, antechamber, SR absorbers, coatings, low photon reflectivity
	SEY (minimising)	Wall material, Coating, Grooves, electrodes
	Residual gas ionisation	UHV pumping scheme
	Electron simulated gas desorption	Low outgassing walls
Mechanical solutions		More complicate integration
Cost	Guaranteed performance at the lowest cost	Challenging

Vacuum required for ILC DRs

- The need to avoid the fast ion instability leads to very demanding specifications for the vacuum in the electron damping ring [Lanfa Wang, private communication]:
  - < 0.5 nTorr CO in the arc cell,
  - < 2 nTorr CO in the wiggler cell and
  - < 0.1 nTorr CO in the straight section
- In the positron damping ring required vacuum level was not specified and assumed as 1 nTorr (common figure for storage rings)

Ideal vacuum chamber for vacuum design

for the electron ring and, where possible, for the positron ring:

- Round or elliptical tube
  - Cheapest from technological point of view

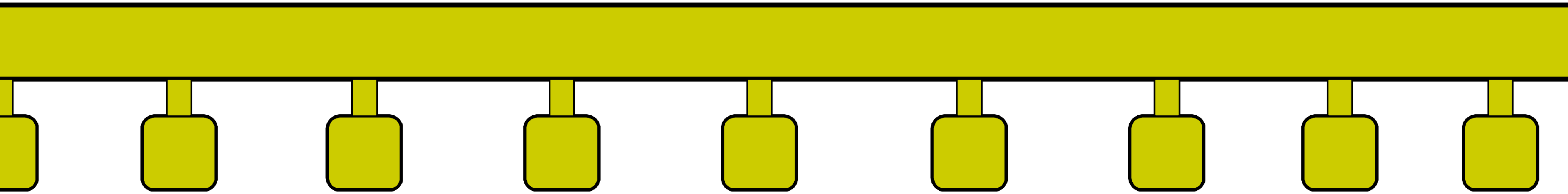
- No antechamber if SR power can absorbed with vacuum chamber wall cooling
  - Beam conditioning is most efficient
  - Easy geometry for NEG coating

- NEG coated
  - Requires less number of pumps with less pumping speed
  - 160°C for NEG coating activation instead of 220-300°C bakeout
  - Choice of vacuum chamber material (stainless steel, copper and aluminium) does not affect vacuum in this case
  - Residual gas CH_4 and H_2 (almost no CO and CO_2)

Pumping scheme along the ILC DR arc

An aluminium tube after bakeout at **220°C** for 24 hrs and 100 Ahr beam conditioning:

- a pump with **S_{eff} = 200 l/s every 5 m**
- H_2, CO and CO_2

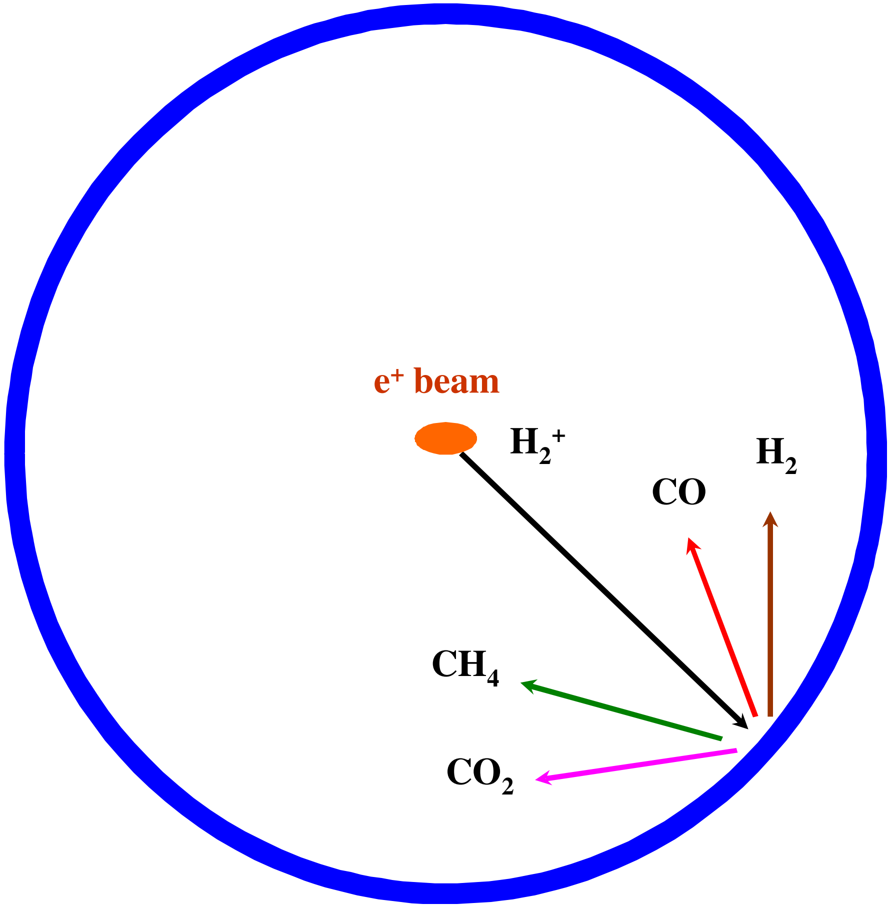


Inside a NEG coated tube after activation at **160°C** for 24 hrs and 100 Ahr beam conditioning: a pump with **S_{eff} = 20 l/s every 30 m**

- H_2 and CH_4

O. Malyshev. Vacuum Systems for the ILC Damping Rings. EUROTeV Report-2006-094.

Ion induced pressure instability in ILC positron DR



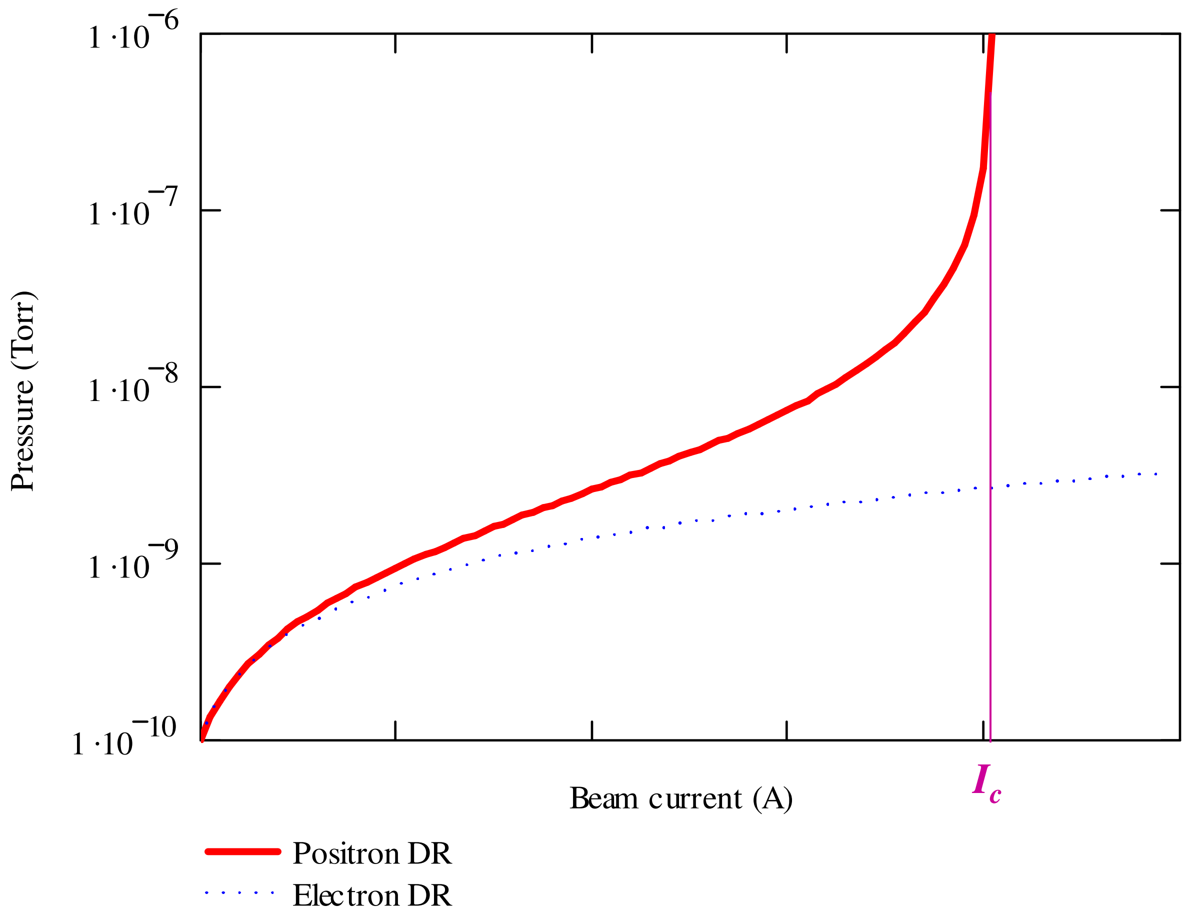
$$P = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

where
Q = gas desorption,
S_{eff} = effective pumping speed,
χ = ion induced desorption yield
σ = ionisation cross section,
I = beam current.

$$\chi = f\left(E_{ion}, M_{ion}, material, bakeout, \ldots\right)$$

$$E_{ion} = f\left(N_{bunch}, \tau, T, \sigma_x, \sigma_y, \ldots\right)$$

Critical current



Critical current, I_c, is a current when pressure (or gas density) increases dramatically.

Mathematically, if

$$P = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

when $S_{eff} > \chi \frac{\sigma I}{e}$

Hence $I < I_c$,

where $I_c = \frac{S_{eff} e}{\chi \sigma I}$

The ion stability for different vacuum chamber materials, I_{max}=0.4 A

Vacuum chamber	I_c, (A)	I_c / I_{max}	Domin. gas	Stable or not
Distance between pumps L = 6 m, ID = 50 mm				
316LN	1.0	2.5	CO	Yes
Pure Al	0.5	1.25	CO	No
Ti alloy	1.1	2.8	CO	Yes
Distance between pumps L = 6 m, ID = 60 mm				
316LN	1.24	3.1	CO	Yes
Pure Al	0.64	1.6	CO	No
Ti alloy	1.4	3.5	CO	Yes
Distance between pumps L = 10 m, ID = 50 mm				
316LN	0.47	1.2	CO	No
Pure Al	0.24	0.6	CO	No
Ti alloy	0.53	1.3	CO	No
Distance between pumps L = 40 m, ID = 50 mm				
NEG coated	5	12.5	CH_4	Yes

Pressure instability conclusions:

- Ion energy = ~300 eV, but could be larger for a smaller beam
- For given parameters and large uncertainties, there is a possibility of ion induced pressure increase and even ion induced pressure instability in positron damping ring if pumping is insufficient.
- **Use of NEG coating fully eliminates the probability of the ion induced pressure instability.**

O.B. Malyshev. Study of Ion Induced Pressure Instability in the ILC Positron Damping ring. EUROTeV Report-2008-058.

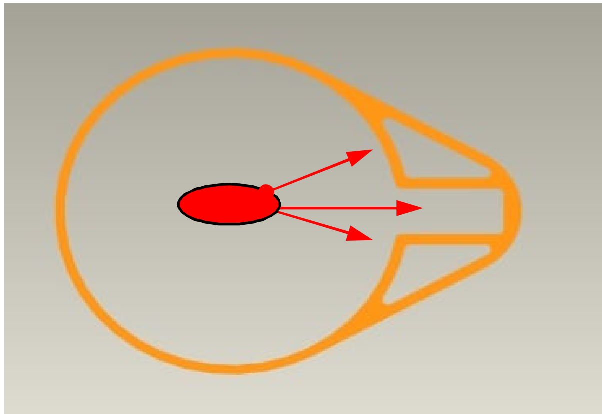
Electron cloud

- Three sources of electrons:
    - Photoelectrons
    - Secondary electrons
    - Gas ionisation

Photoelectrons

- Photoelectrons:

  PEY = κ F Γ R, where Γ is a total SR flux.



  - A photon flux absorbed in beam chamber can be minimised with an antechamber, F is an antechamber efficiency
  - Lower photon reflectivity, R, helps as well
  - Choice of material, surface treatment, conditioning, coating (ex.: **TiZrV**) allows to reduce photo-electron emission yield, κ

O.B. Malyshev and W. Bruns. ILC DR vacuum design and e-cloud. Proc. of EPAC08, p.673,
and references with in the paper.

PEY for different types of vacuum chamber

Beam pipe	**Inside magnets, B ≠ 0**		**Downstream straights near the magnet, B = 0**		
	Tube	Antechamber	Tube	Solenoid	Antechamber
Estimated achievable PEY					
Dipole SR	$3\cdot10^{-4}$–0.065	**$3\cdot10^{-6}$**–$6.5\cdot10^{-3}$	0.01–0.1	0.01–0.1	10^{-4}– 0.01
Wiggler SR	$3\cdot10^{-3}$ – 0.65	**$3\cdot10^{-5}$**–$6.5\cdot10^{-2}$	0.1–1	0.1–1	10^{-3}– 0.1
Required maximum PEY from e-cloud modelling					
Dipole	$\sim10^{-4}$		?		
Wiggler	$\sim10^{-4}$		?		

Secondary electrons

- Secondary electron yields, e-cloud and mitigation techniques are intensively studied in many places, see all other talks on this session.
- Secondary electron
  - Choice of material (intrinsic SEY for flat and dense surface)
  - Surface treatment to modify surface micro-structure (air bake, anodisation, ion bombardment, etc.)
  - Low SEY coatings: material *and* its surface micro-structure: **TiZrV or TiN or Amorphous C coatings**
  - Geometrical electron traps (ex.: grooves)
  - Field suppression:
    - Magnetic material coatings
    - Biased electrodes
    - Solenoid field

Gas ionisation

- Ionisation cross section of heavy molecules is higher:
  - $\sigma(CO_2)=12\ \sigma(H_2)$

- Ionisation in ILC DR can be neglected when CO pressure is below 10^{-8} Torr
  - Surface treatment and conditioning
  - Low outgassing coating (ex.: **TiZrV** coating)
  - Better pumping (ex.: **TiZrV** coating or more pumps)

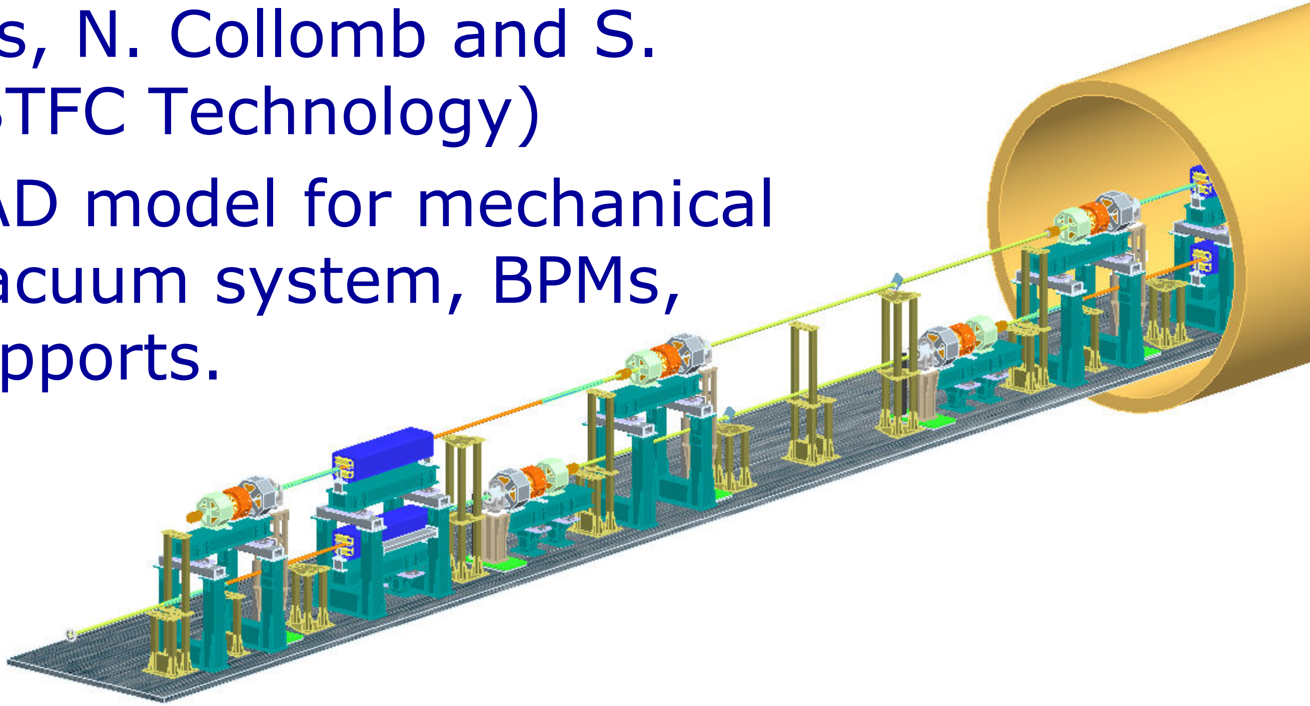
O.B. Malyshev and W. Bruns. ILC DR vacuum design and e-cloud. Proc. of EPAC08, p.673.

Selecting an e-cloud mitigation

- A complex solution required:
  - Good solution against Photo-electrons or Secondary electrons might lead to higher gas density and higher gas ionisation, and vice versa, best pumping solution might compromise PEY and SEY mitigation.
  - NEG coating is the best choice for UHV systems.
  - NEG coating + grooves might be sufficient in many places
  - Using other coatings and other mitigation techniques increases a cost of DR and should be only used where it is essential.

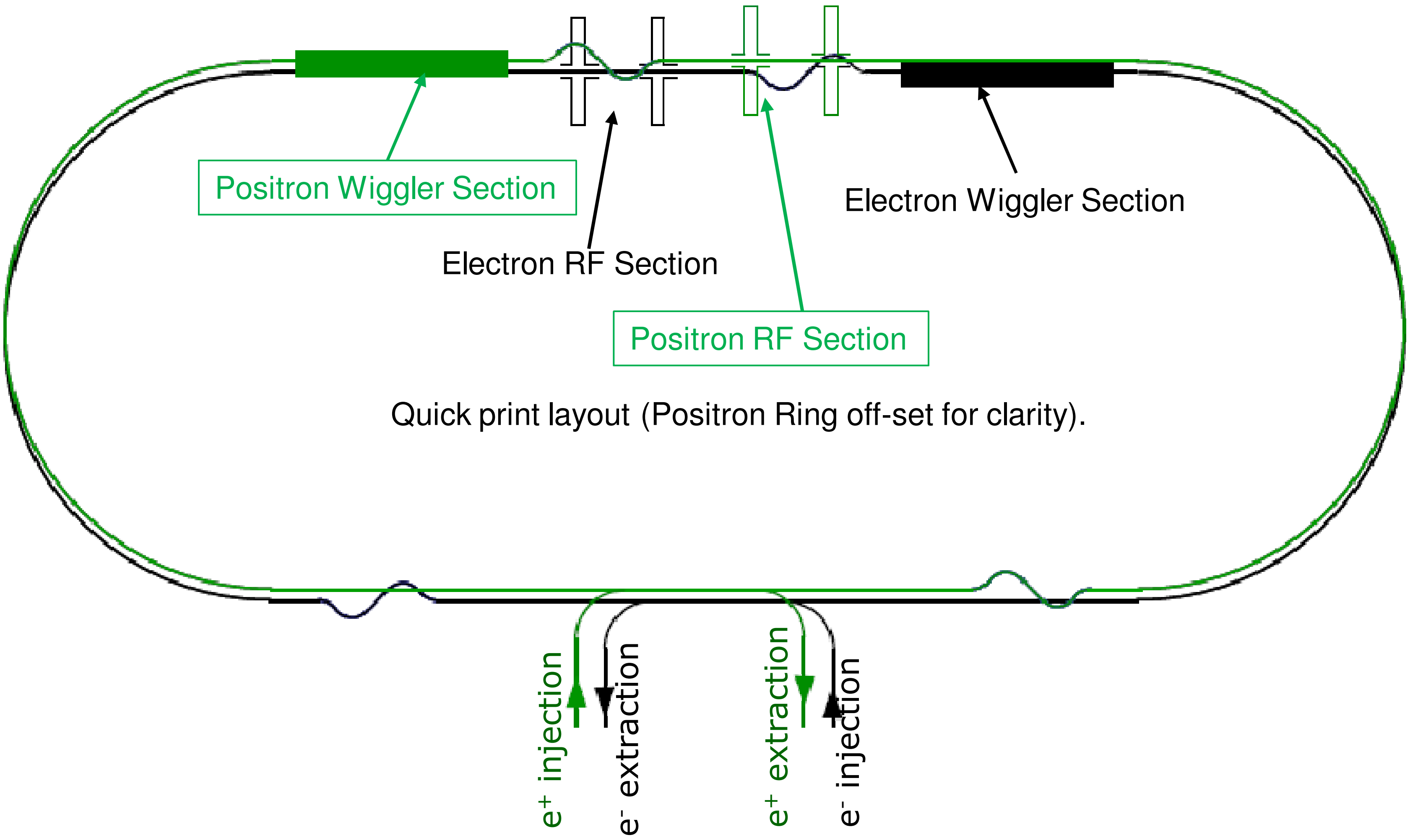
Engineering Model

- Work by J. Lucas, N. Collomb and S. Postlethwaite (STFC Technology)
- Developing a CAD model for mechanical integration of vacuum system, BPMs, magnets and supports.



- Goals:
  - to demonstrate engineering feasibility of both the Electron & Positron Damping Ring Periodic Arc Cells;
  - to provide a basis for further design and beam
  - dynamics studies and costing of vacuum, magnets, conventional facilities, etc.

DC04 Overall Layout (simplified)



Positron Wiggler Section

Electron RF Section

Electron Wiggler Section

Positron RF Section

Quick print layout (Positron Ring off-set for clarity).

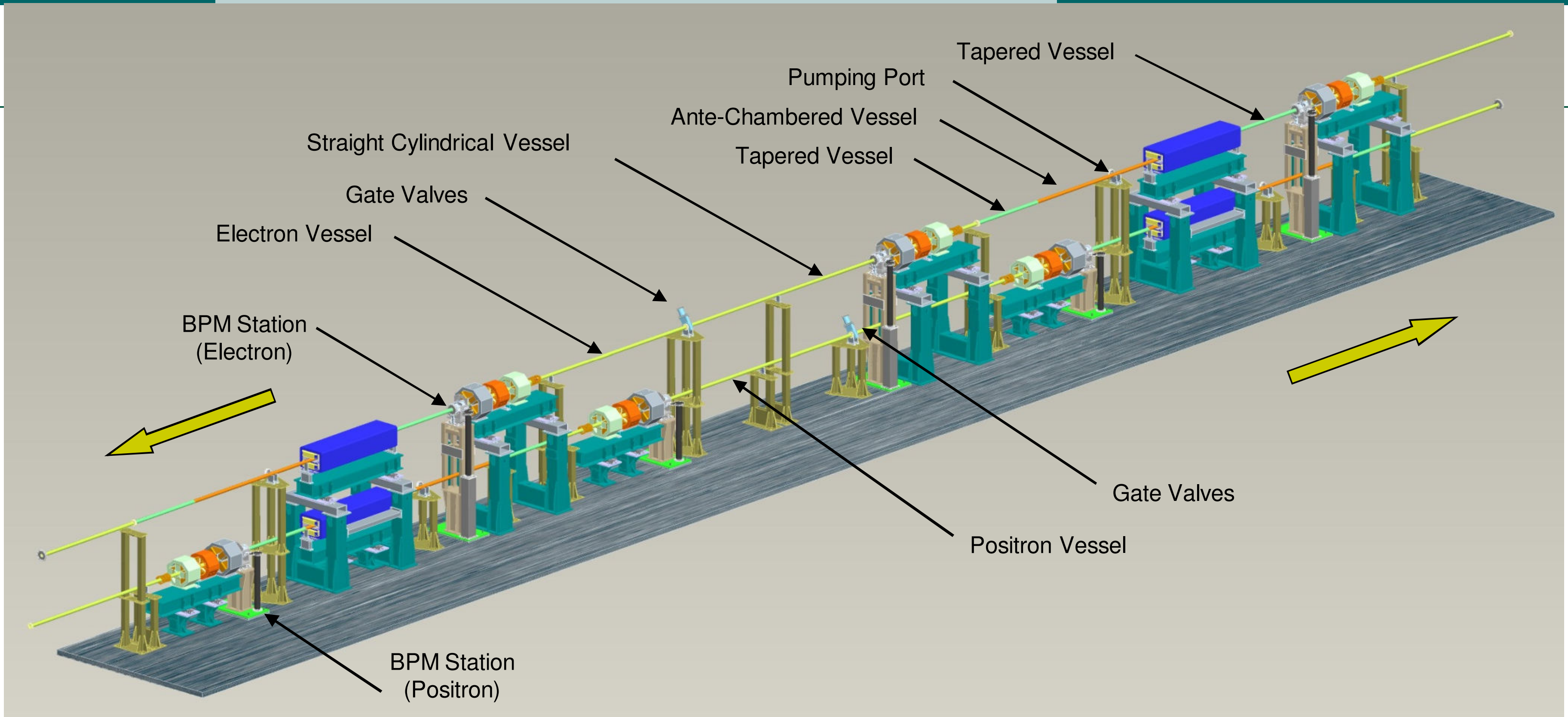
e^+ injection

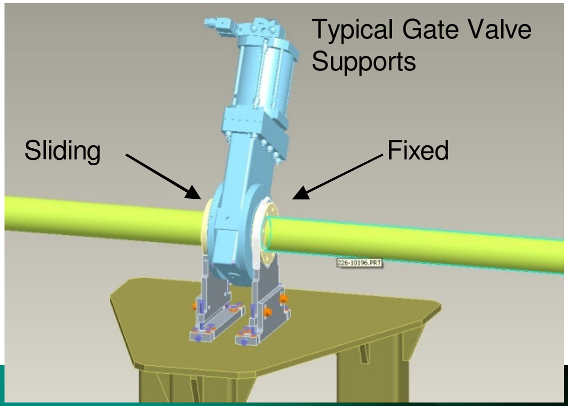
e^- extraction

e^+ extraction

e^- injection

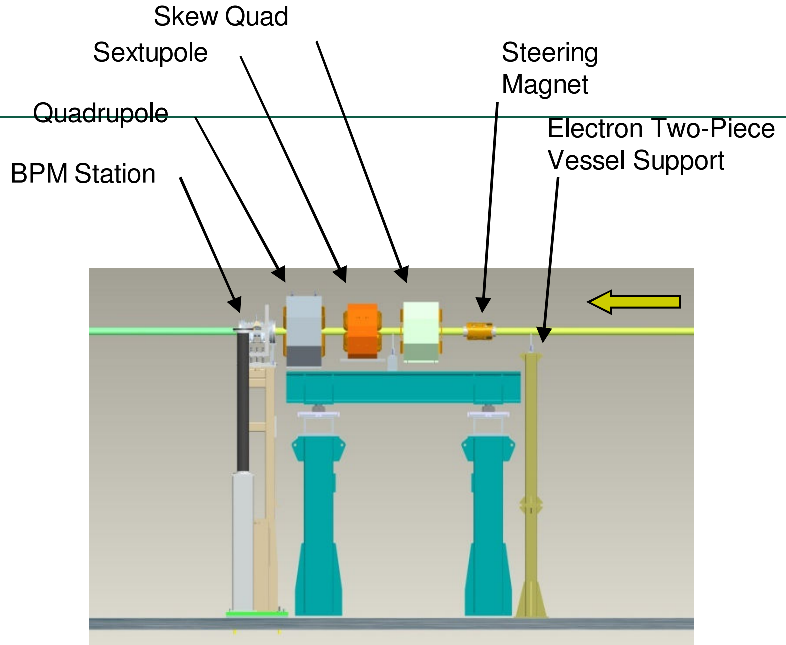
Arc Cell Components



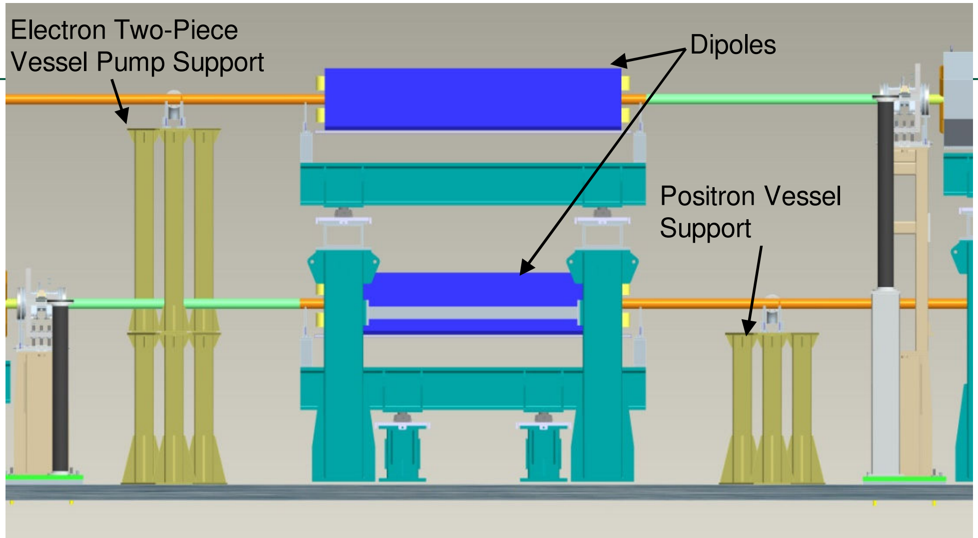


- •Work has focused on developing the model for a Single Arc Cell (Linear)
- One Gate Valve per 5 Arc Cells
- Gate Valve supports consist of one fixed and one sliding
- Bellows allow for 4.5 mm/meter thermal expansion (NEG activation at 160-180℃).

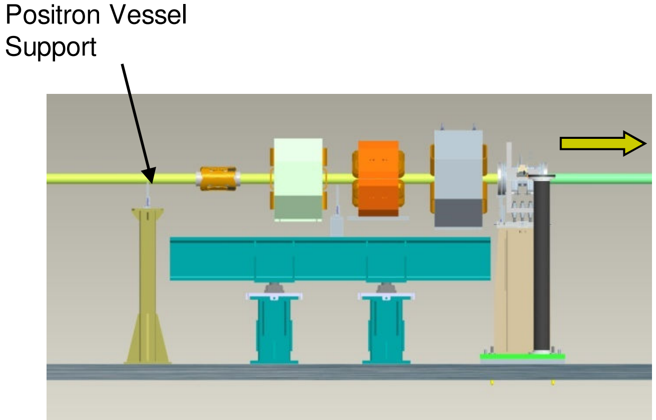
Arc Cell Components Cont'd



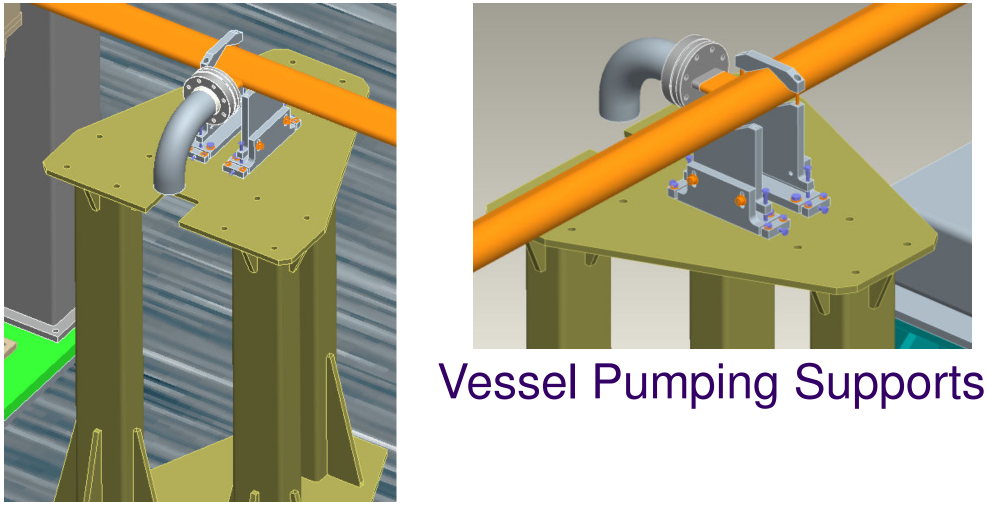
Magnet & Supports – (Electron)



Dipoles & Supports



Magnet & Supports



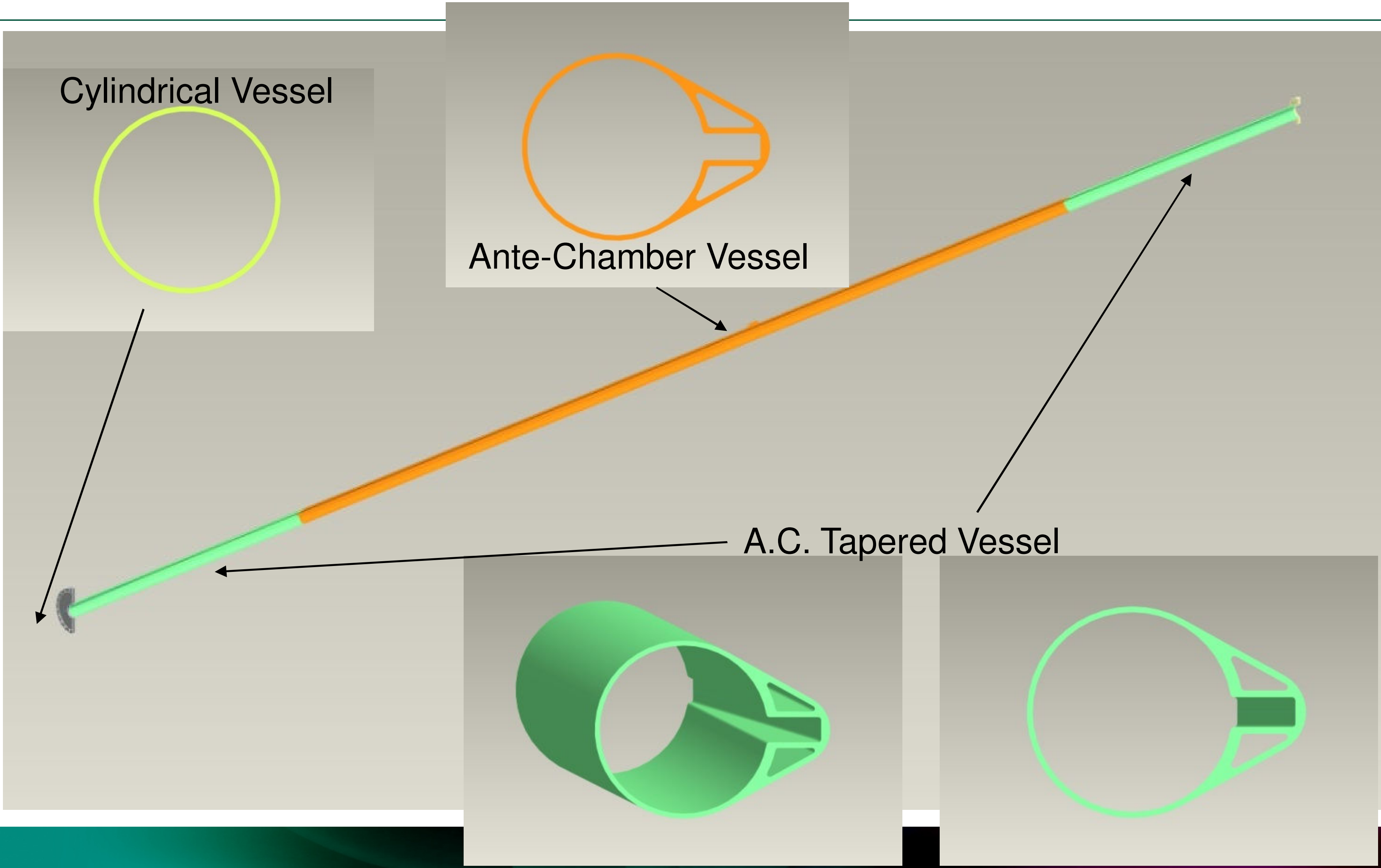
Vessel Pumping Supports

Vacuum system: key features

- Vacuum chamber mostly consists of straight cylindrical tube.
  - Internal diameter 60 mm, wall thickness 2 mm.

- Antechamber and cooling provided in dipoles and a few meters downstream.
  - Intended to reduce build-up of electron cloud by reducing the number of photons in the beam chamber.
  - Dipole chamber will consist of extruded vessel with antechamber, welded to machined "taper" sections.
  - A pumping port is included in antechamber downstream of dipole.
- All vacuum chambers are NEG coated

Vacuum Vessel Profiles

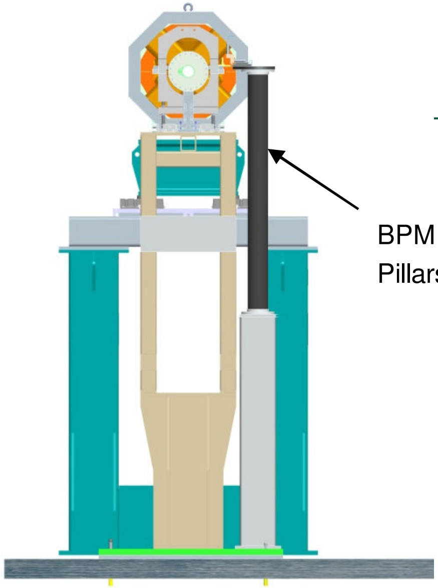


Cylindrical Vessel

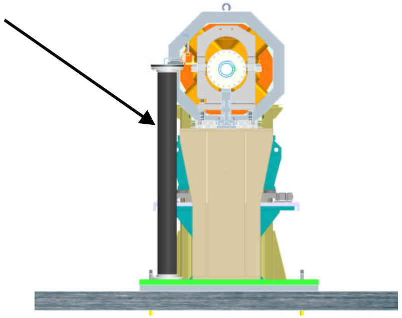
Ante-Chamber Vessel

A.C. Tapered Vessel

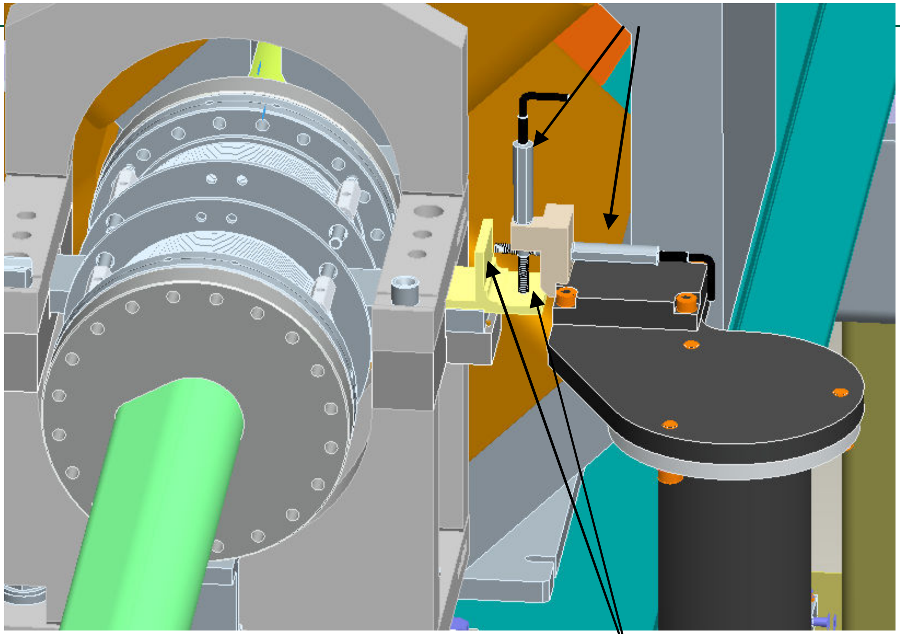
Vacuum Vessel BPM Stations



Electron End View

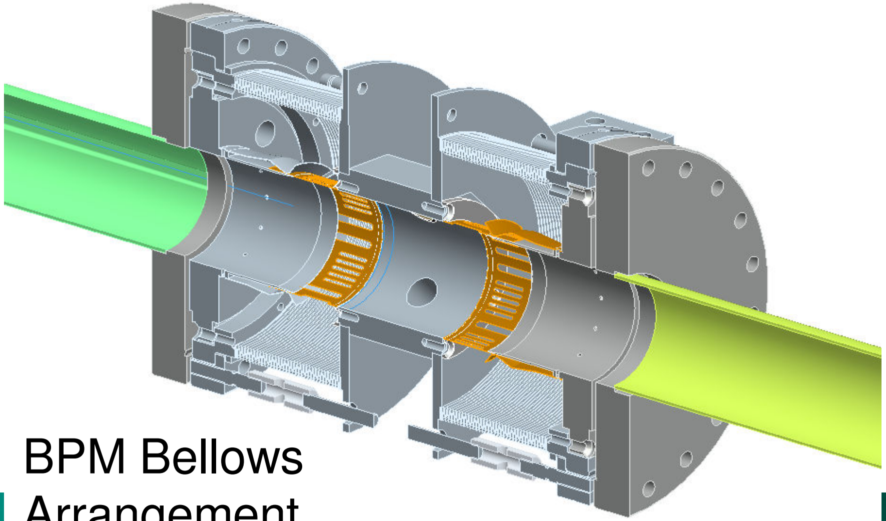


Positron End View



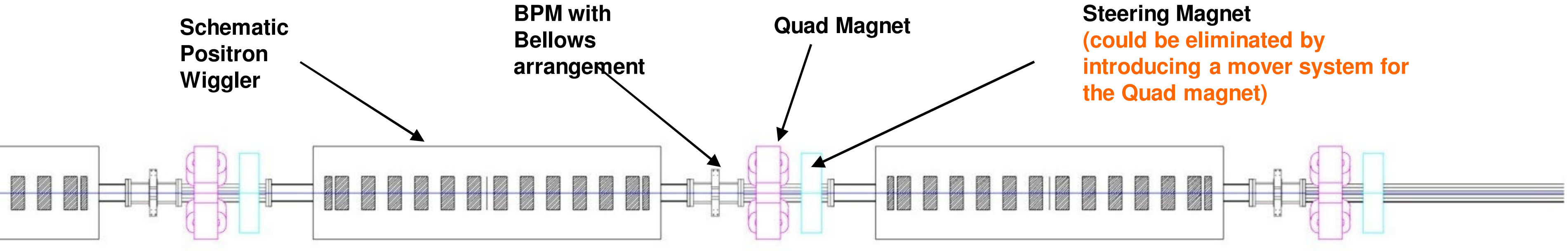
Position Encoders

- Fitted on all BPM Blocks
- Reference Pillar provides reference points for the beam orbit.
- Position Encoders monitor any motion of BPMs from thermal or mech effects



BPM Bellows Arrangement

DC04 Wiggler Section



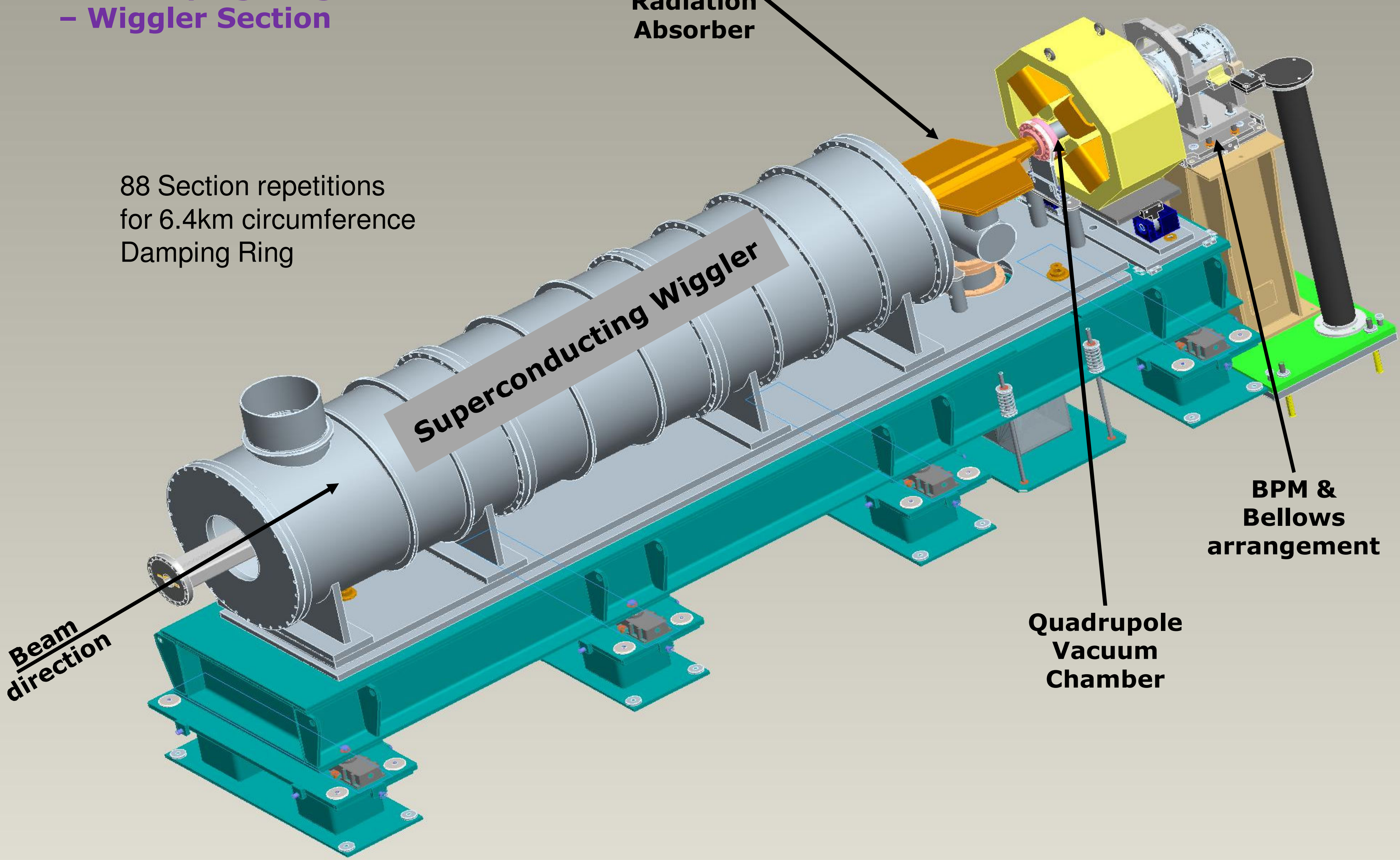
Challenges in a wiggler section design:

- SR power absorption – up to ~40 kW per wiggler
  - Power dissipation calculation by K. Zolotarev (BINP)
- Minimising a number of SR photons hitting beam chamber inside a wiggler to provide low PEY
  - Antechamber and shadow
- Grooved top and bottom and TiN coating to provide low SEY
- Sufficient pimping (NEG strips + SIPs)
- Impedance calculation by M. Korostelev (CI and Liverpool University)

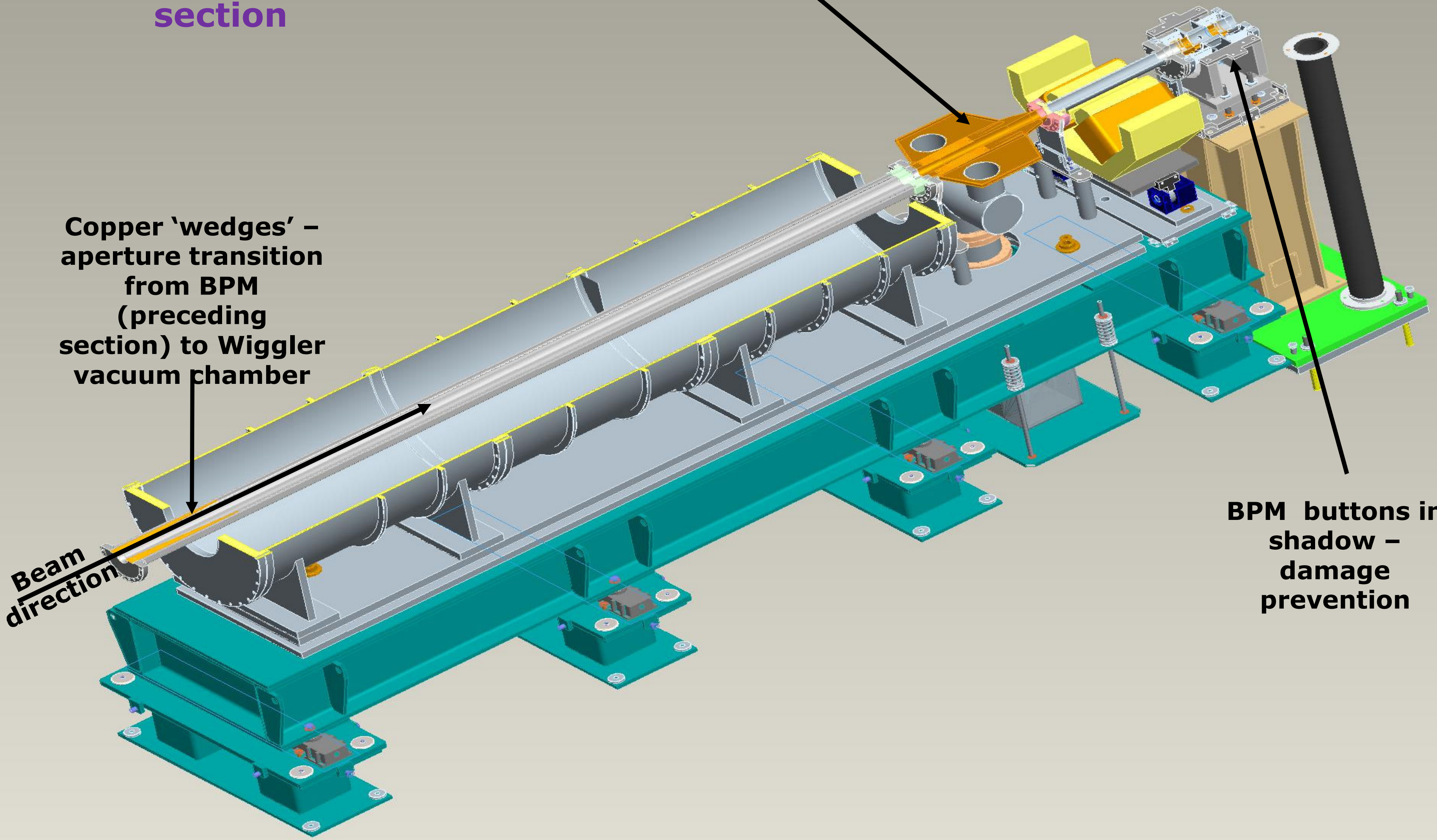
Big thank to Cornell and LBNL for their information on the CESR-TA wiggler design.

ILC Damping Ring – Wiggler Section

88 Section repetitions
for 6.4km circumference
Damping Ring



ILC Damping Ring - Wiggler Section - Vacuum Chamber cross-section

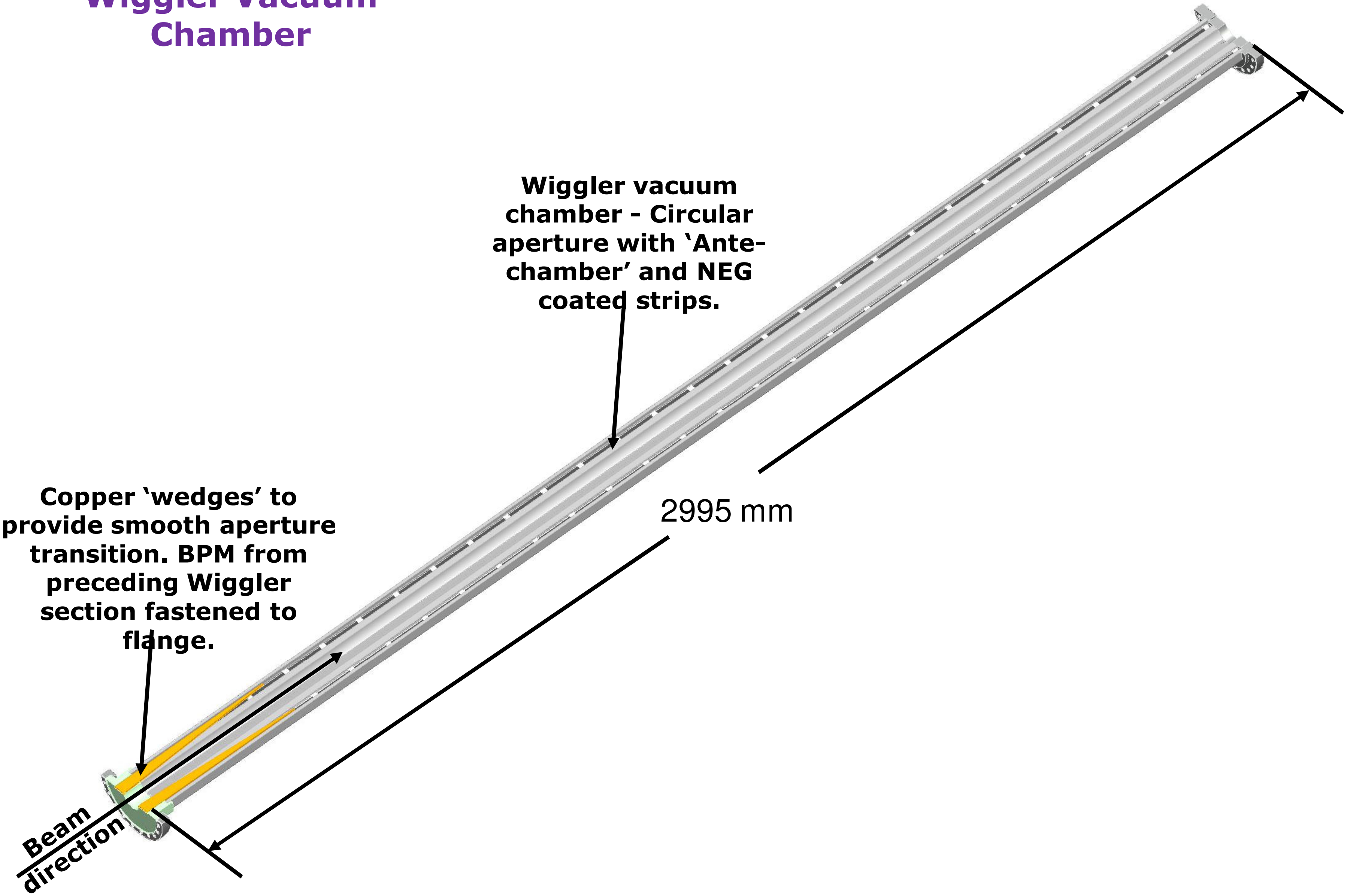


High Power Synchrotron Radiation Absorber

Copper 'wedges' – aperture transition from BPM (preceding section) to Wiggler vacuum chamber

BPM buttons in shadow – damage prevention

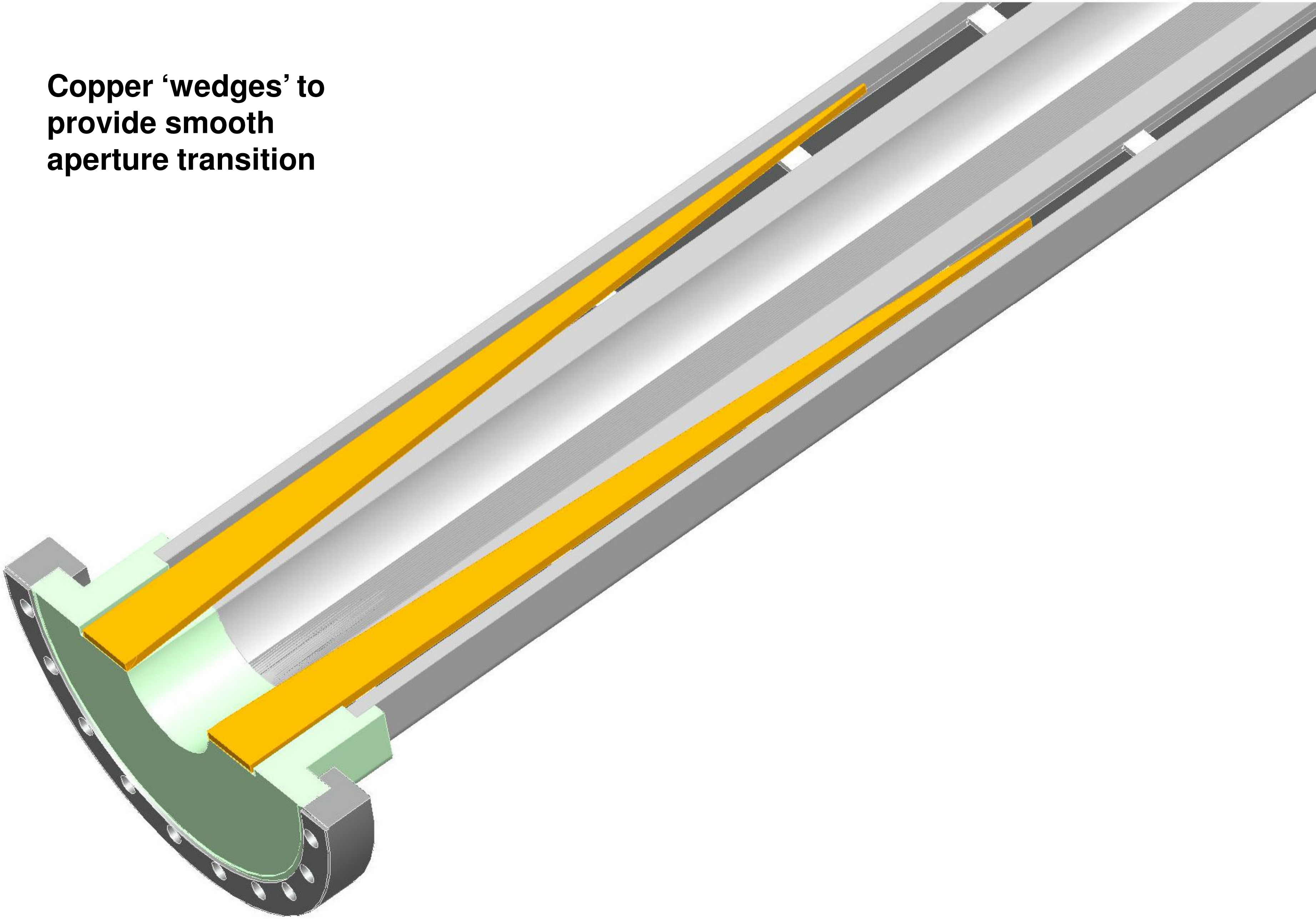
ILC Damping Ring – Wiggler Vacuum Chamber



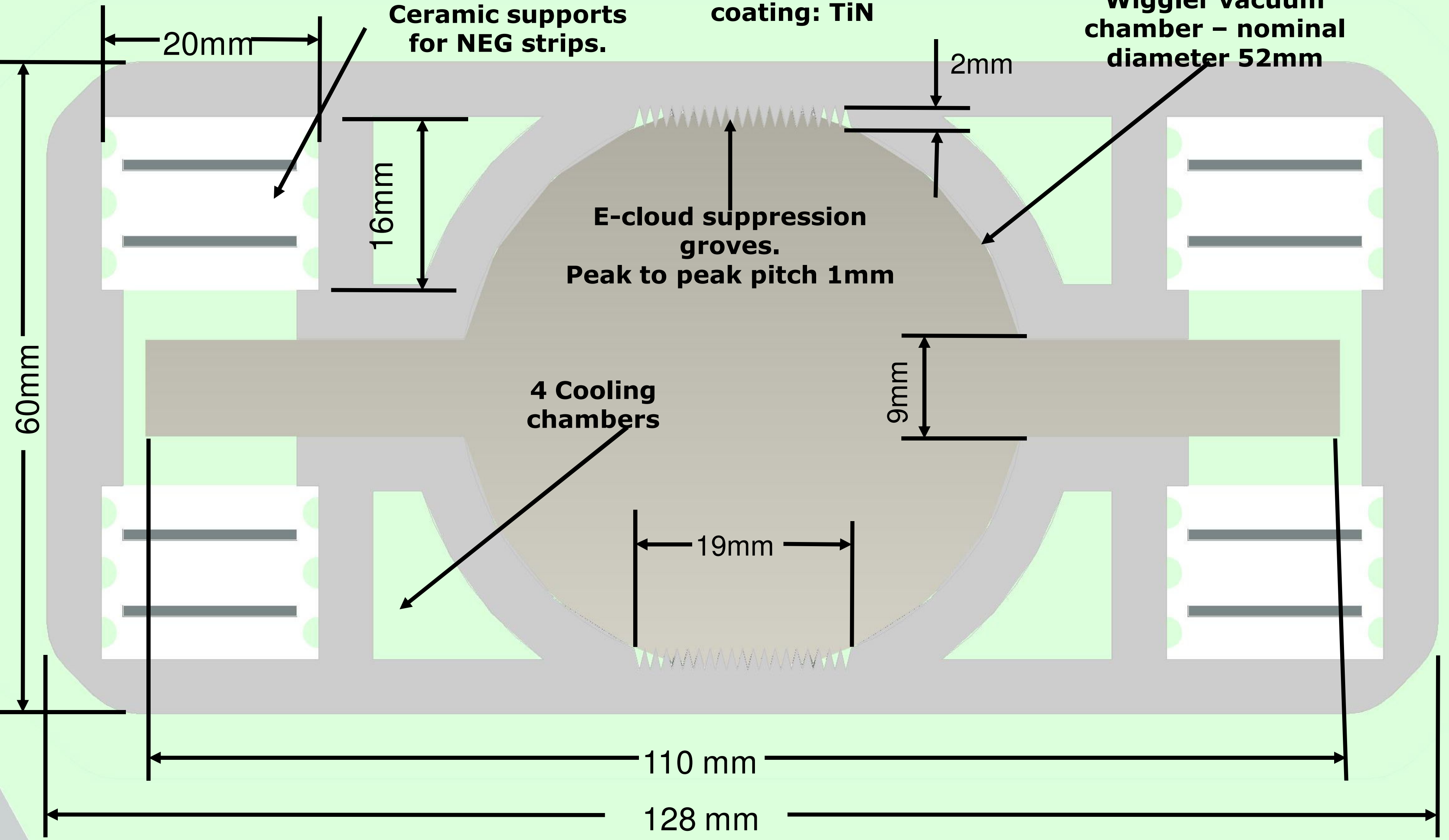
Wiggler vacuum chamber - Circular aperture with 'Ante-chamber' and NEG coated strips.

Copper 'wedges' to provide smooth aperture transition. BPM from preceding Wiggler section fastened to flange.

Copper ‘wedges’ to provide smooth aperture transition



ILC Damping Ring – Wiggler Vacuum Chamber detail



Ceramic supports for NEG strips.

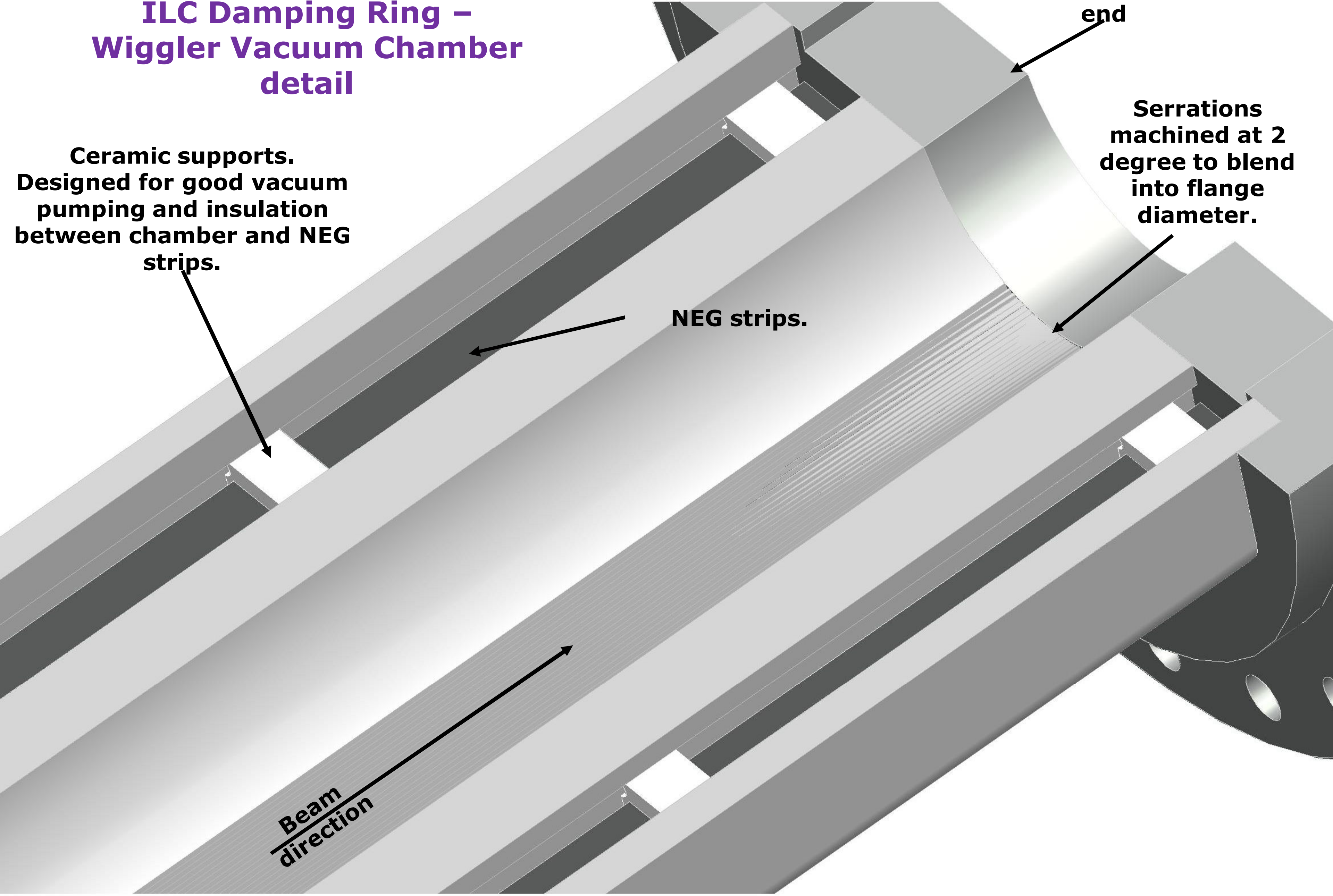
Internal Chamber coating: TiN

Wiggler vacuum chamber – nominal diameter 52mm

E-cloud suppression groves.
Peak to peak pitch 1mm

4 Cooling chambers

ILC Damping Ring – Wiggler Vacuum Chamber detail

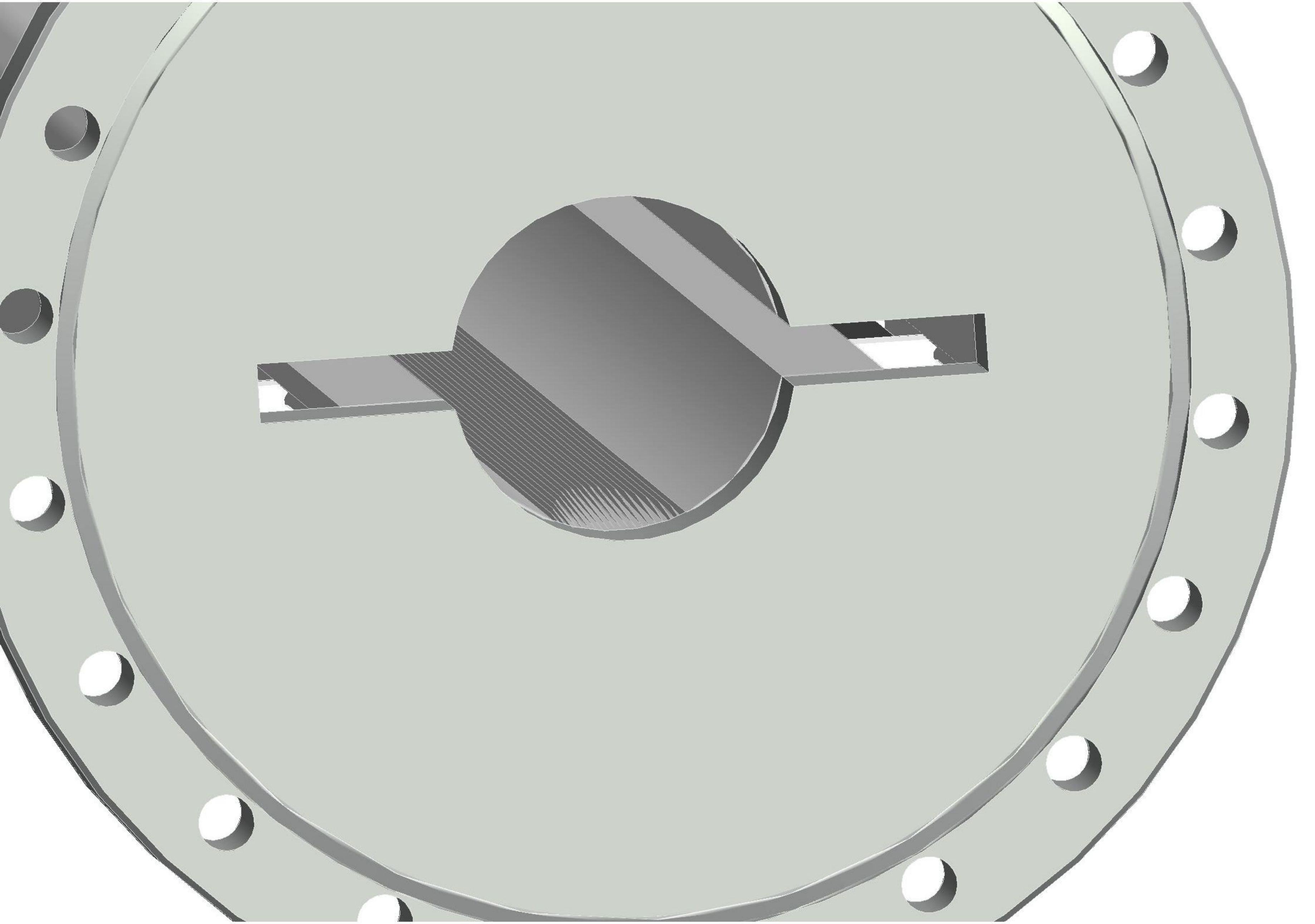


Absorber flange end

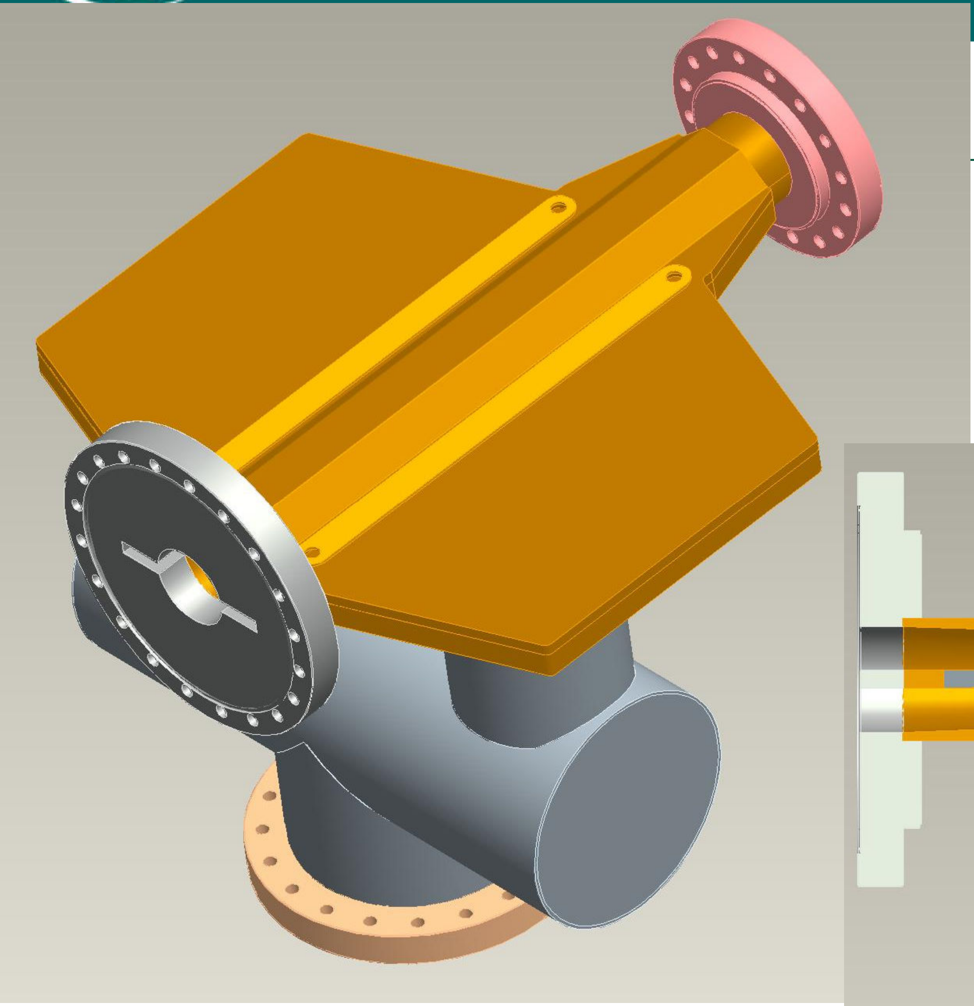
Serrations machined at 2 degree to blend into flange diameter.

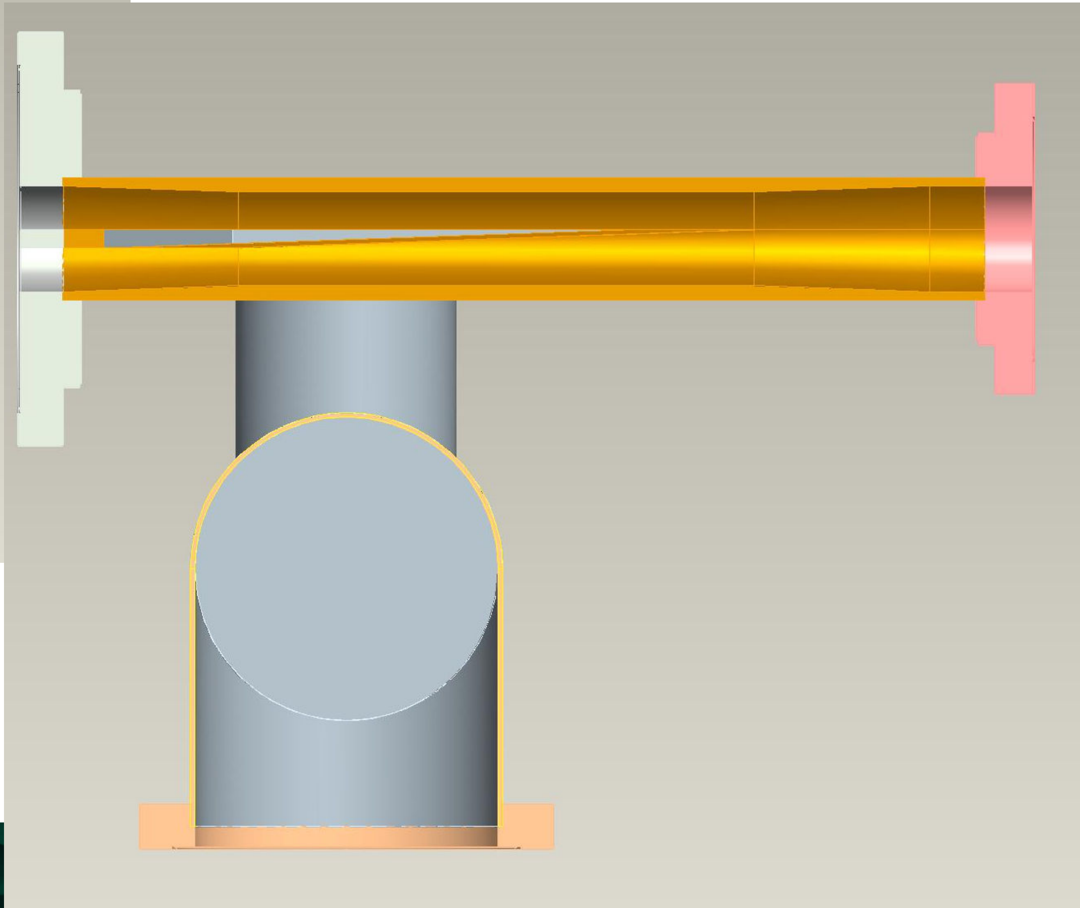
Ceramic supports. Designed for good vacuum pumping and insulation between chamber and NEG strips.

NEG strips.

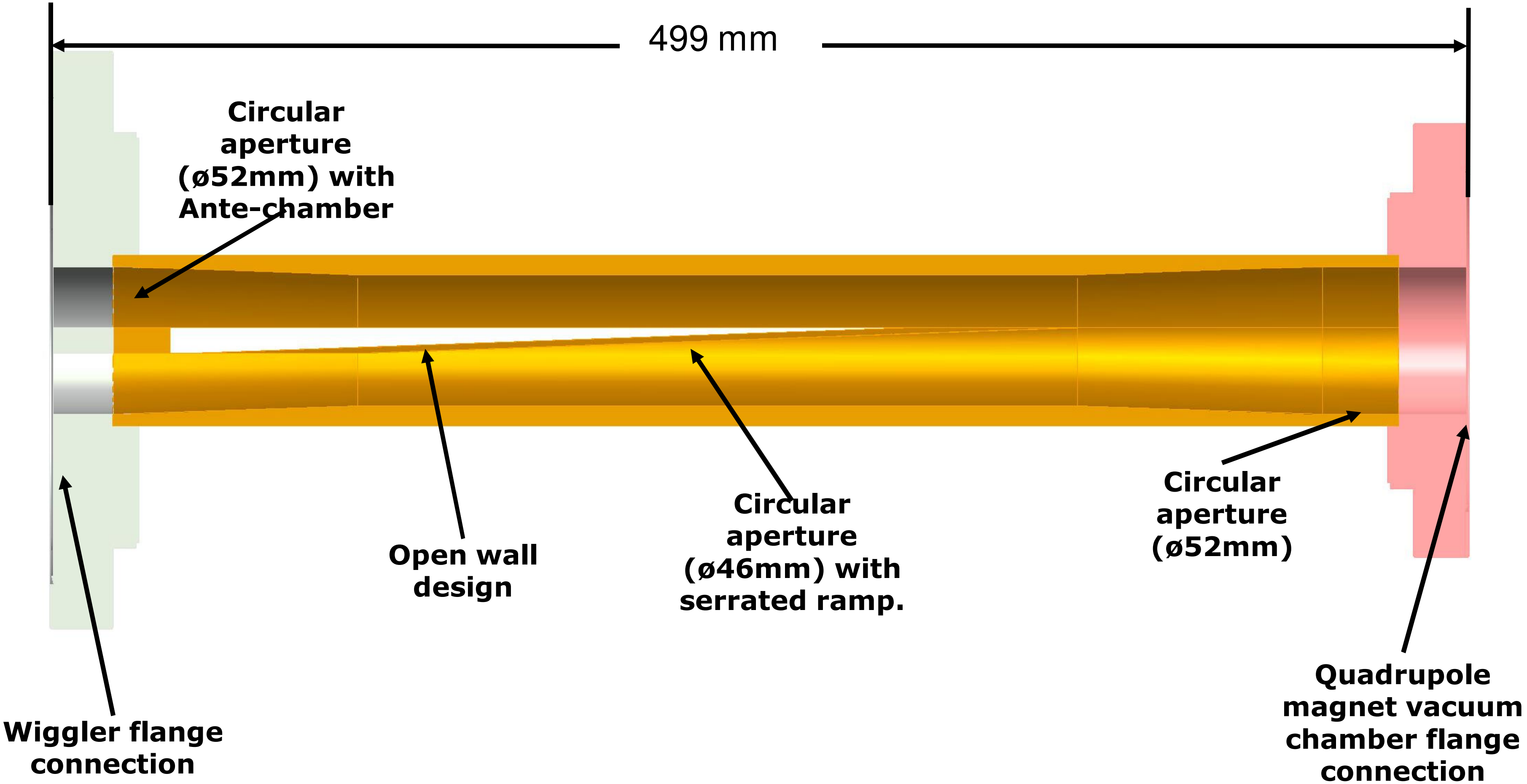


ILC Damping Ring – SR Absorber detail





ILC Damping Ring – SR Absorber detail



Circular aperture (ø52mm) with Ante-chamber

Open wall design

Circular aperture (ø46mm) with serrated ramp.

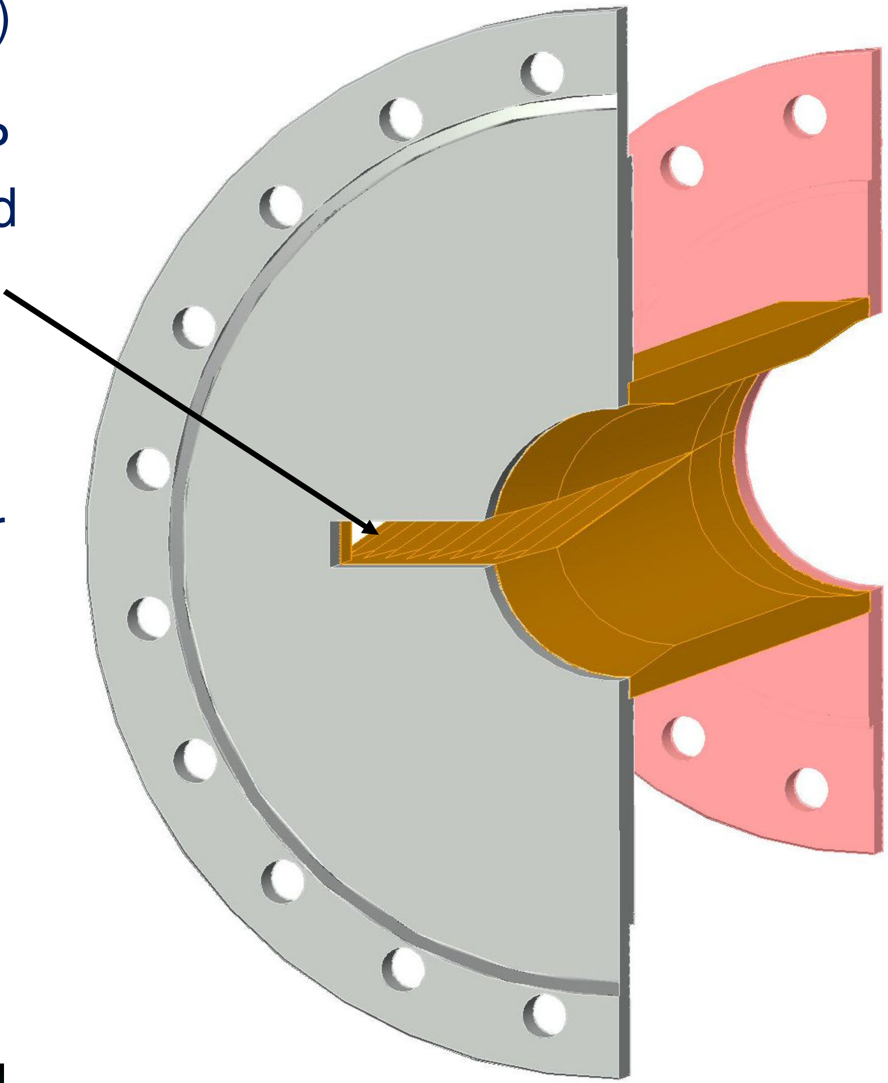
Circular aperture (ø52mm)

Wiggler flange connection

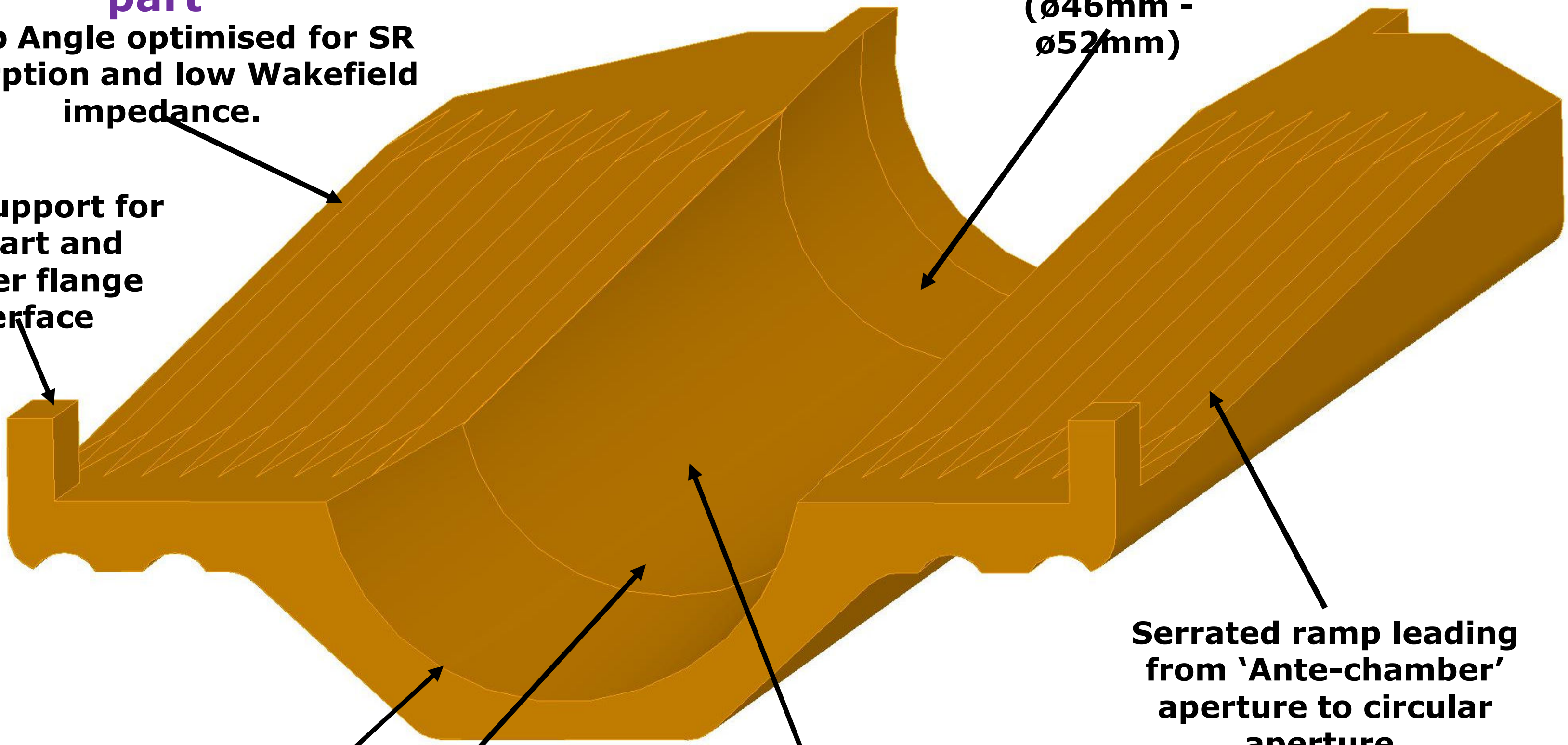
Quadrupole magnet vacuum chamber flange connection

The ramped (or sow tooth) absorber geometry was originally invented at BINP for SR absorbers designed for Siberia-2 LS (Russia)

This geometry was also used for a crotch absorber in the Diamond LS (UK)



ILC Damping Ring – SR Absorber detail Bottom manufactured part



Ramp Angle optimised for SR absorption and low Wakefield impedance.

Pillar support for top part and Wiggler flange interface

Circular aperture (ø46mm - ø52mm)

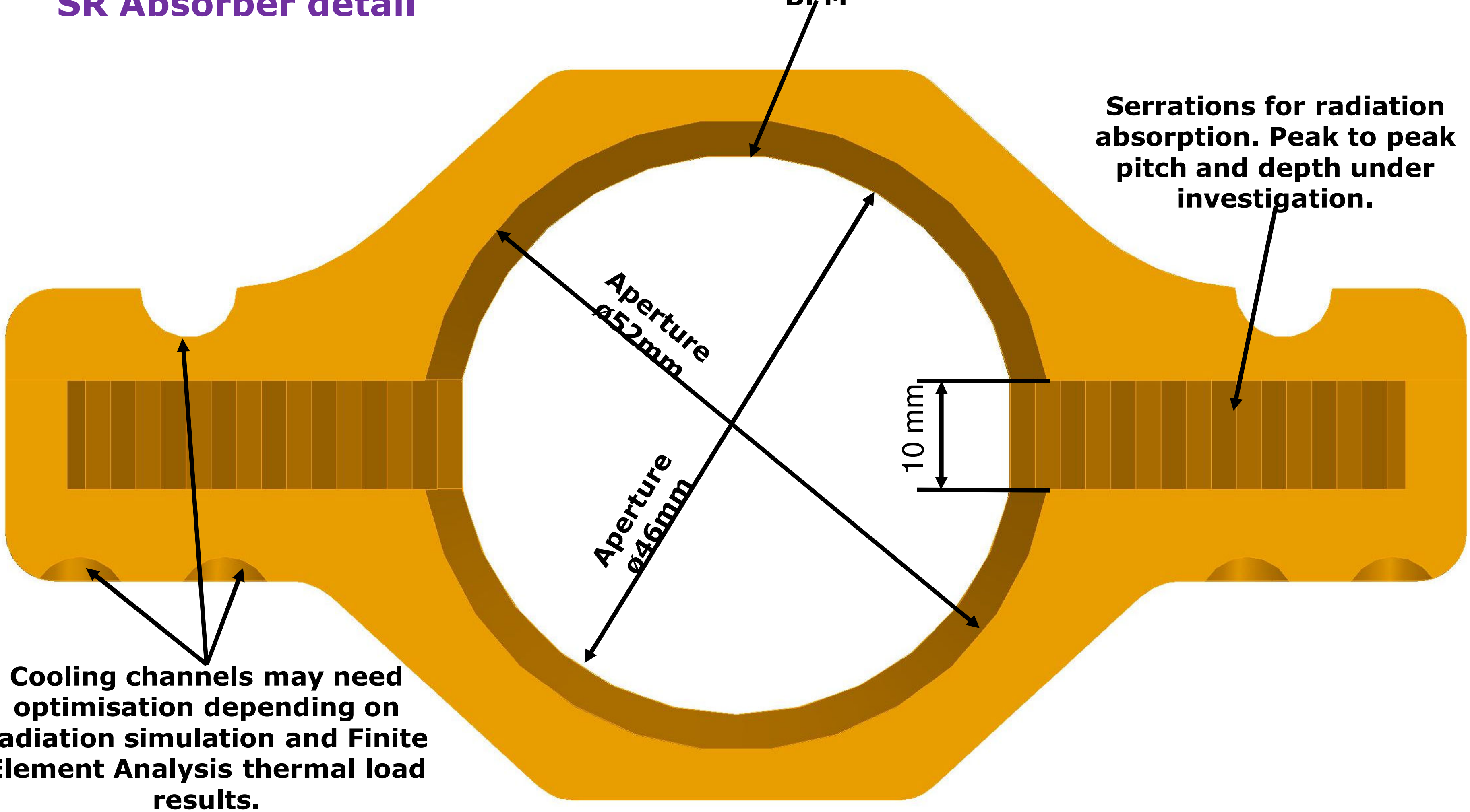
Serrated ramp leading from ‘Ante-chamber’ aperture to circular aperture.

Circular aperture (ø52mm – ø46mm) with Ante-chamber

Beam direction

Circular aperture (ø46mm) with serrated ramp.

ILC Damping Ring – SR Absorber detail



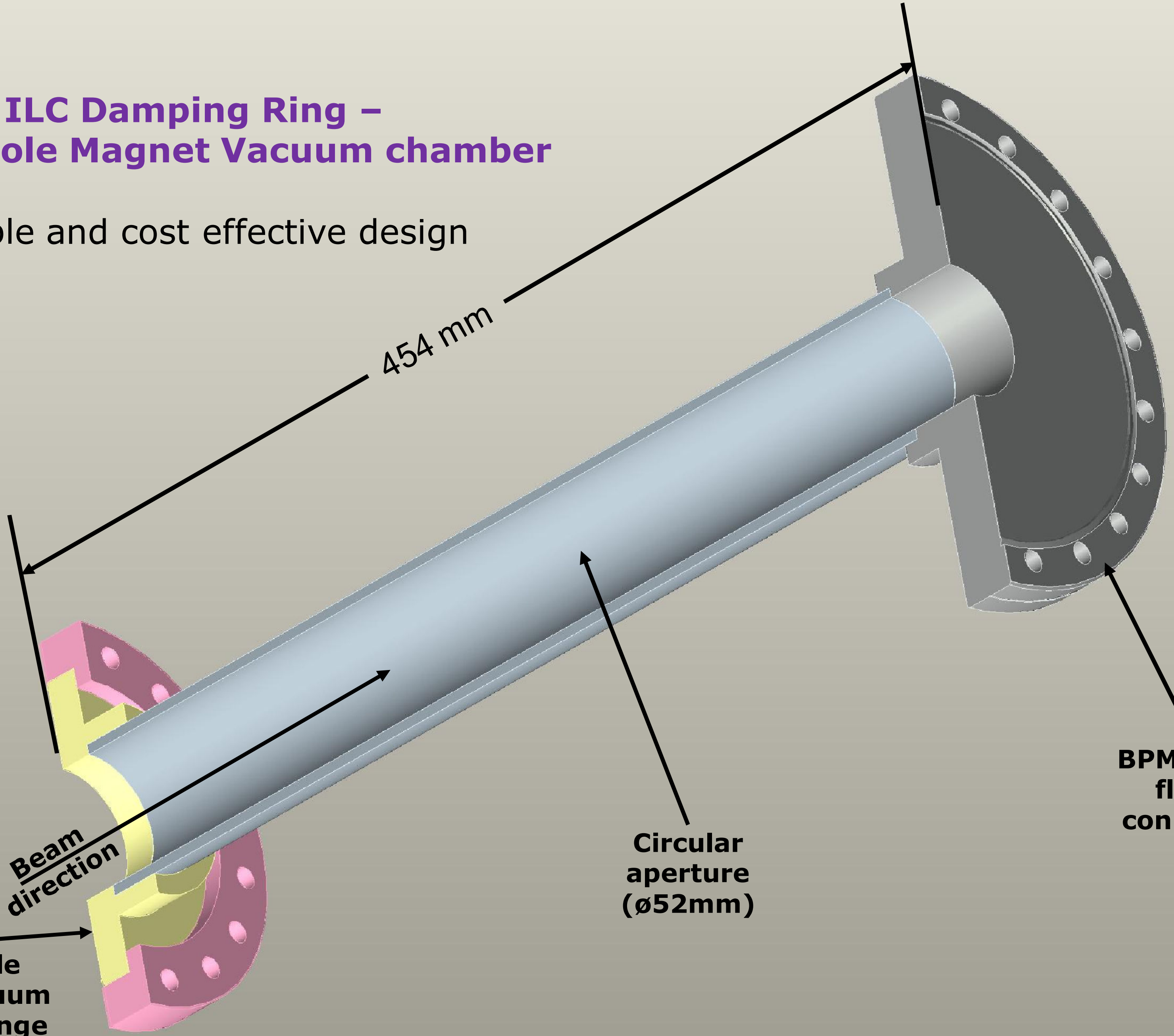
Smaller aperture provides shadow for BPM

Serrations for radiation absorption. Peak to peak pitch and depth under investigation.

Cooling channels may need optimisation depending on radiation simulation and Finite Element Analysis thermal load results.

ILC Damping Ring – Quadrupole Magnet Vacuum chamber

Simple and cost effective design

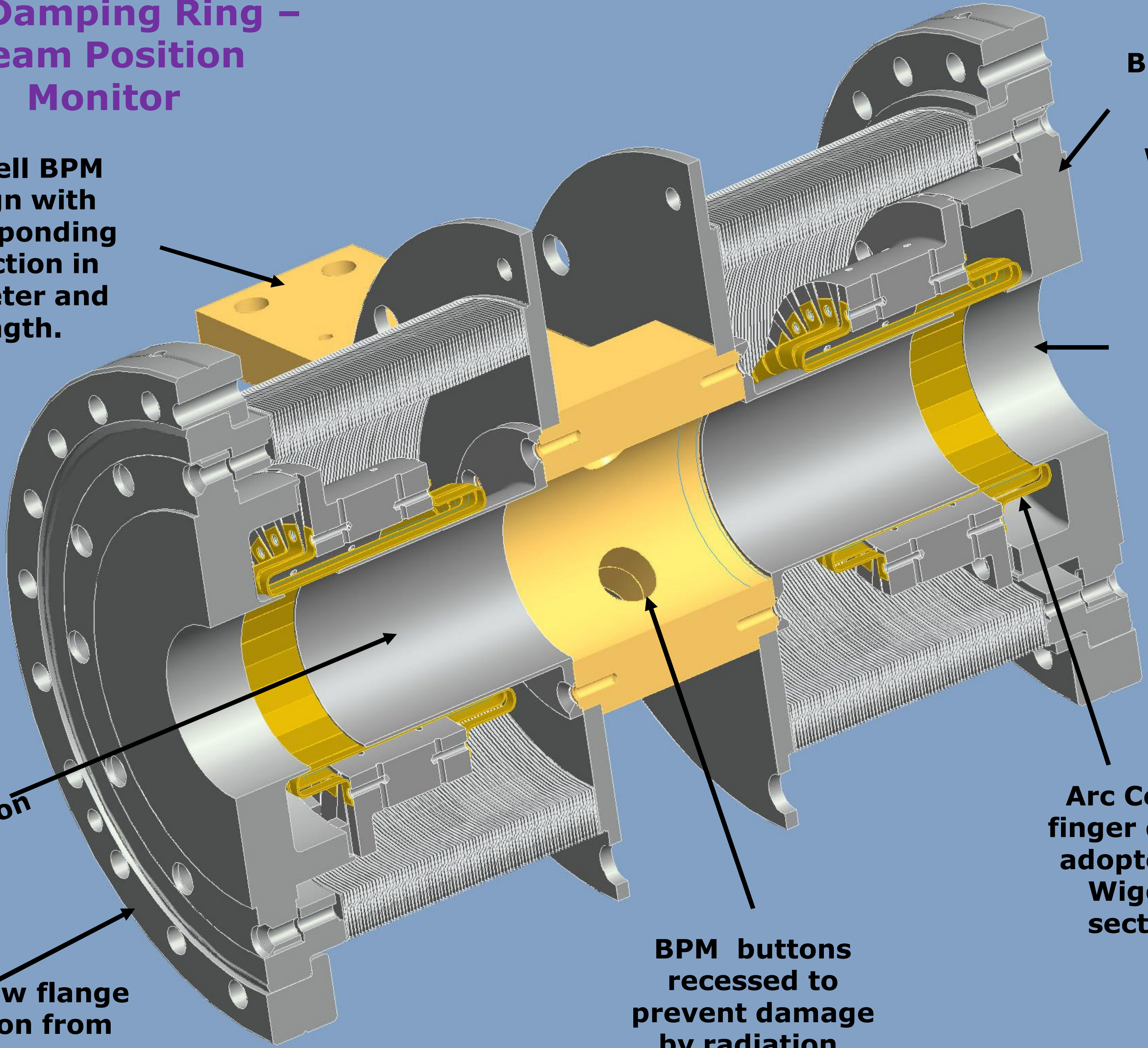


Circular aperture (ø52mm)

BPM Bellow flange connection

Quadrupole magnet vacuum chamber flange connection

ILC Damping Ring – Beam Position Monitor



Arc Cell BPM design with corresponding reduction in diameter and length.

BPM Bellow flange connection to proceeding Wiggler section.

Circular aperture (ø52mm)

Beam direction

Arc Cell RF finger design adopted for Wiggler section.

BPM buttons recessed to prevent damage by radiation.

BPM Bellow flange connection from Quad vacuum chamber

Conclusions

- Mechanical design of ILC DR vacuum vessel includes requirements from
  - Impedance, e-cloud, power absorption and vacuum models
  - Low cost
- Drawing of vacuum vessel of ILC DR are available to be used for the next run of modelling.
  - Impedance and wake field calculation
  - e-cloud modelling
  - Vacuum system design
- Although the design is made for 6.4-km ring, most of the components could be used for 3.2-km rings models.