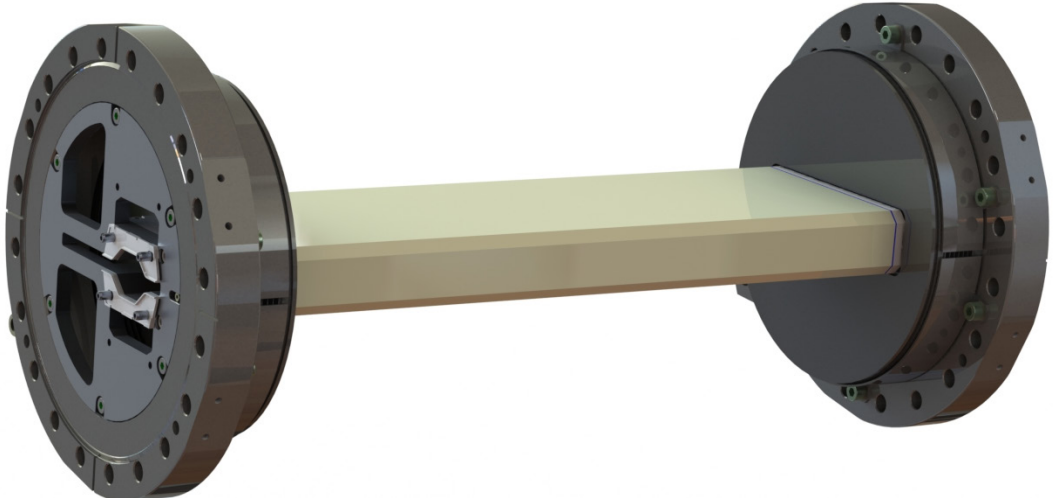
MEDSI 2023
Beijing
Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation

KICKER CHAMBERS FOR ESRF-EBS STORAGE RING

Th. Brochard, L. Eybert, C. Maccarrone, S. White*



ESRF | The European Synchrotron

* brochard@esrf.fr
The European Synchrotron | ESRF

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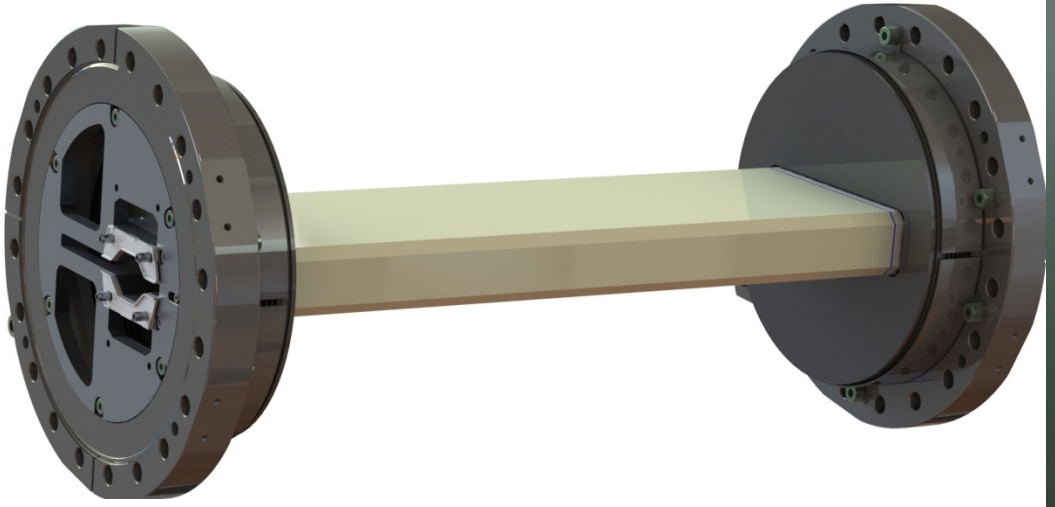

Presented by ***Laurent Eybert***

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ESRF | The European Synchrotron

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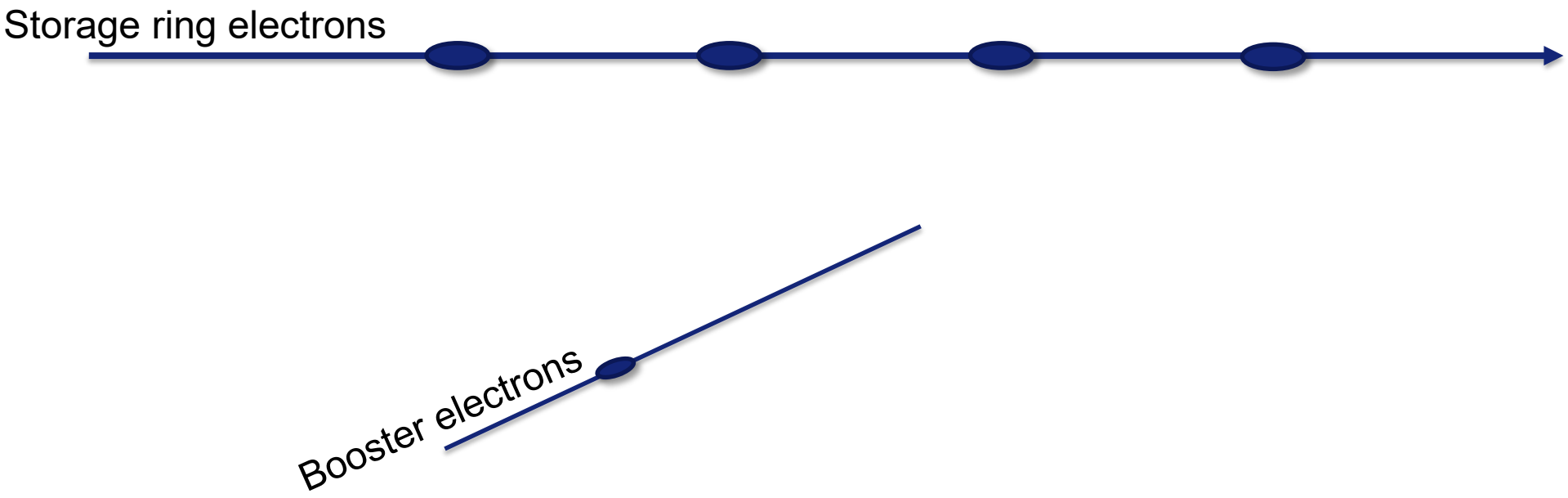
OUTLINE

- Off axis injection
- Kicker chamber design
- Vacuum leak during beam commissioning
- Kicker chamber new design
- Ceramic chambers manufacturing
  - Isostatic pressing
  - Machining
- Conclusion

OFF AXIS INJECTION

The multi-turn off-axis injection, where one or several bunches are injected over several turns and accumulated one after the other. This is typically done in the storage rings



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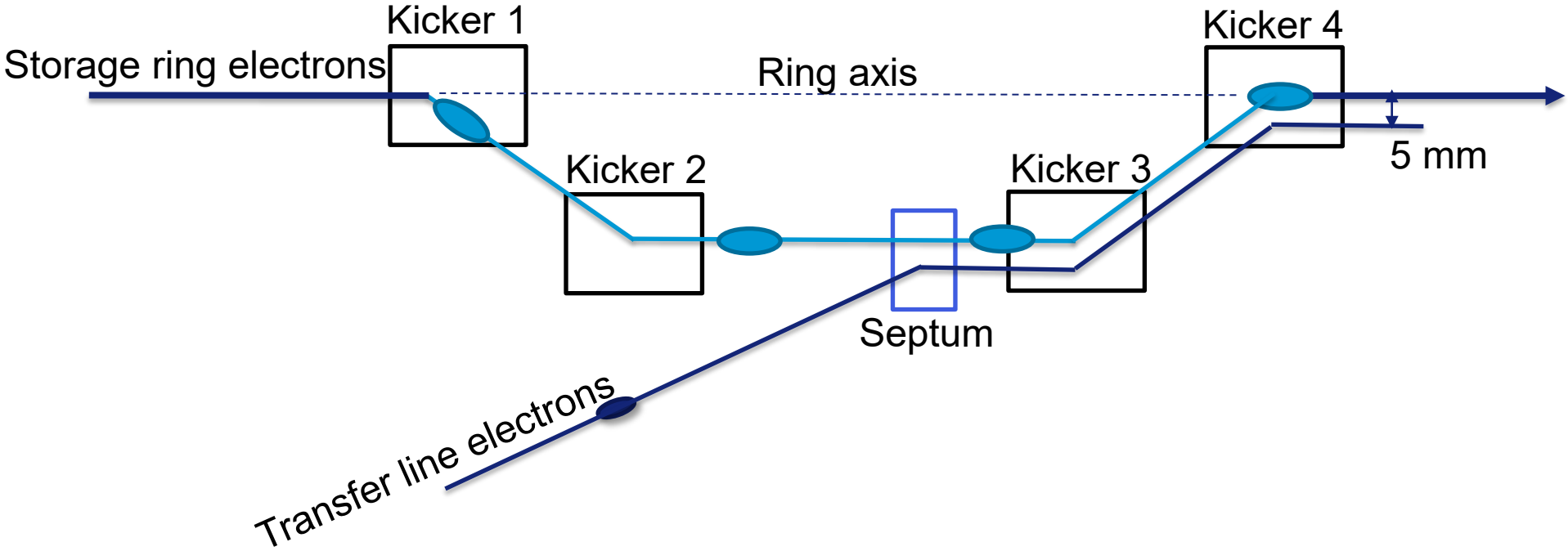

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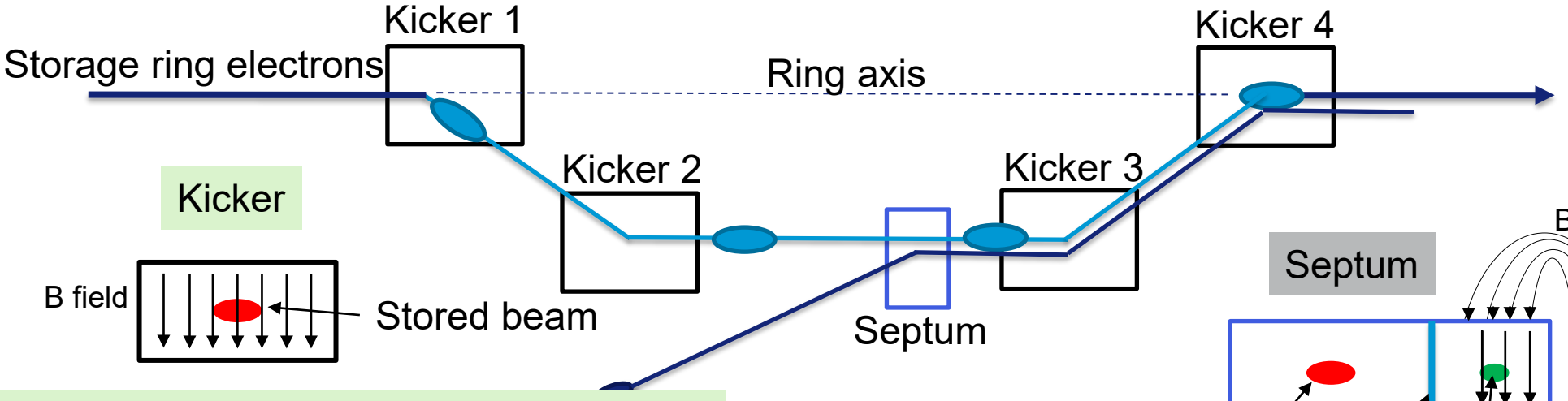
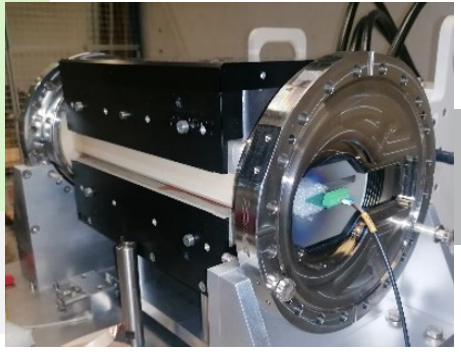


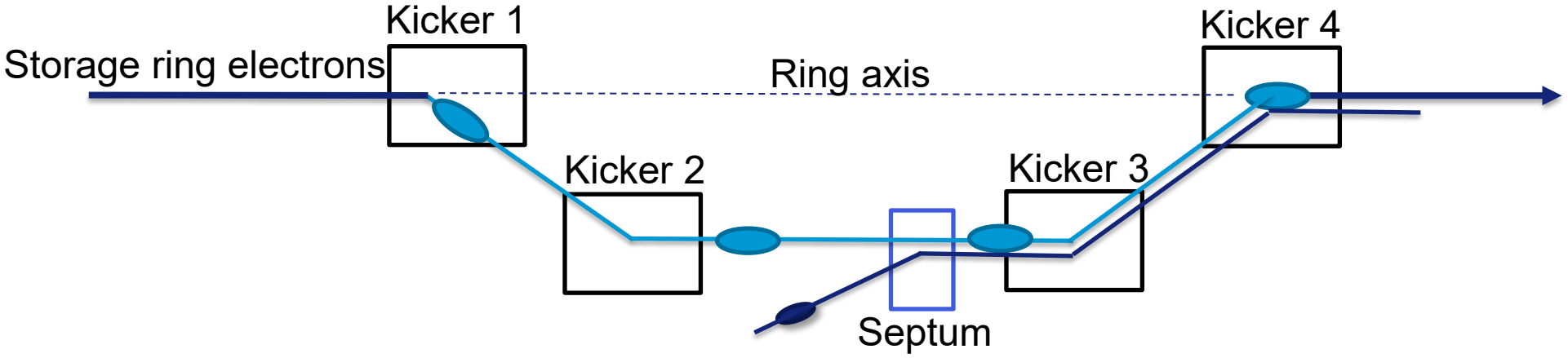
Fast dipoles with homogeneous field over the vacuum chamber cross section. Pulsed magnets operating at 4 Hz with fast raising and falling times required to control the timing of interaction with the beam.



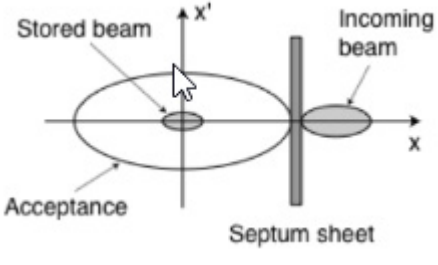
Kicker magnet with chamber on measurement bench

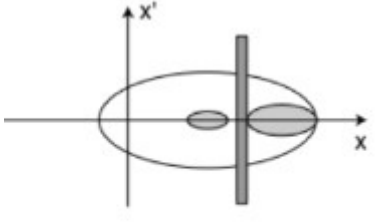
Dipole on one side of the blade, no field on the other side.

OFF AXIS INJECTION

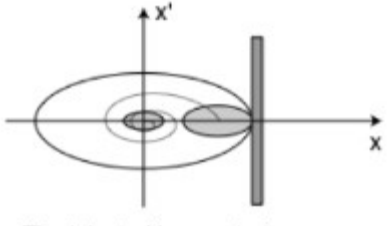


- A bump reduces the distance between stored and injected beam
- After a few damping times, the injected electrons occupy the center of the density distribution and have freed the phase space at the outer areas of the acceptance.
- The sequence is repeated until we have sufficient current.





The bump moves the acceptance to catch the injected beam

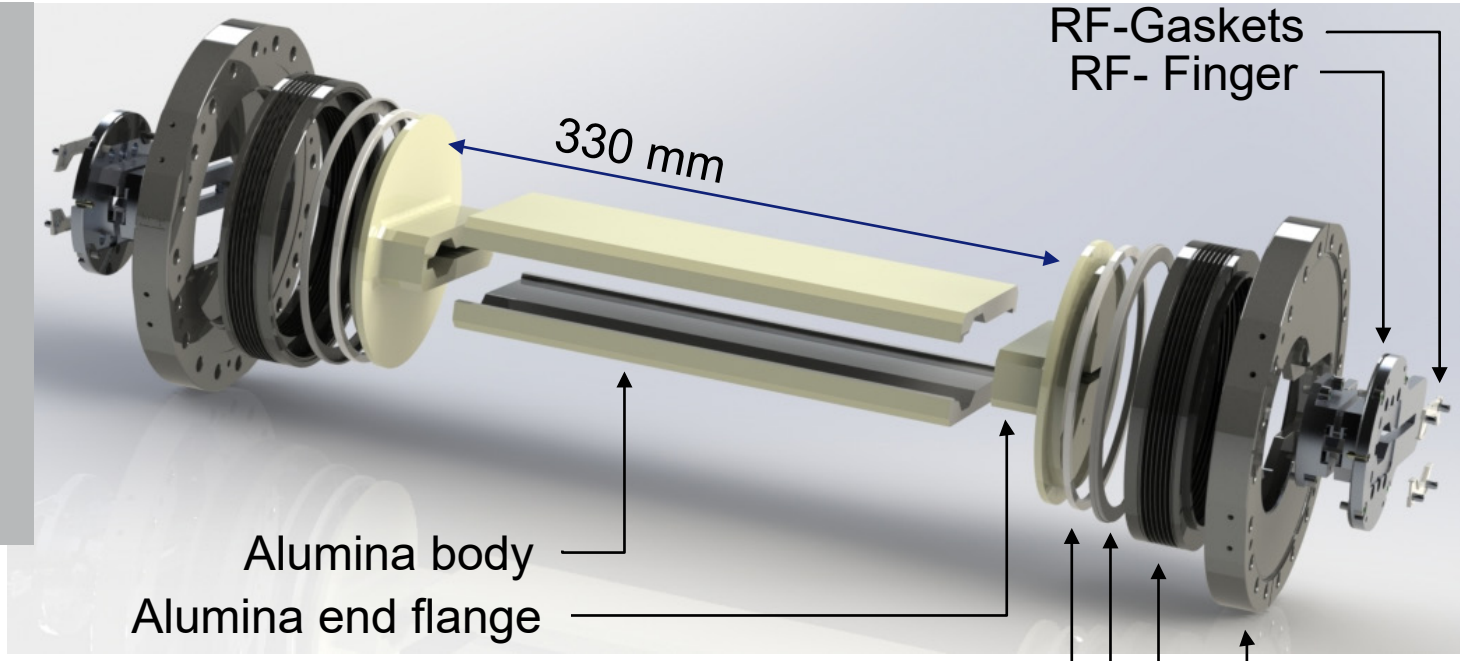


The injected beam starts to spiralize

ESRF-EBS KICKER CHAMBER DESIGN

Assembly process:

- Alumina assembly made by glazing (melted glass)
- Kovar brazed to alumina
- SS Bellows TIG welded to Kovar



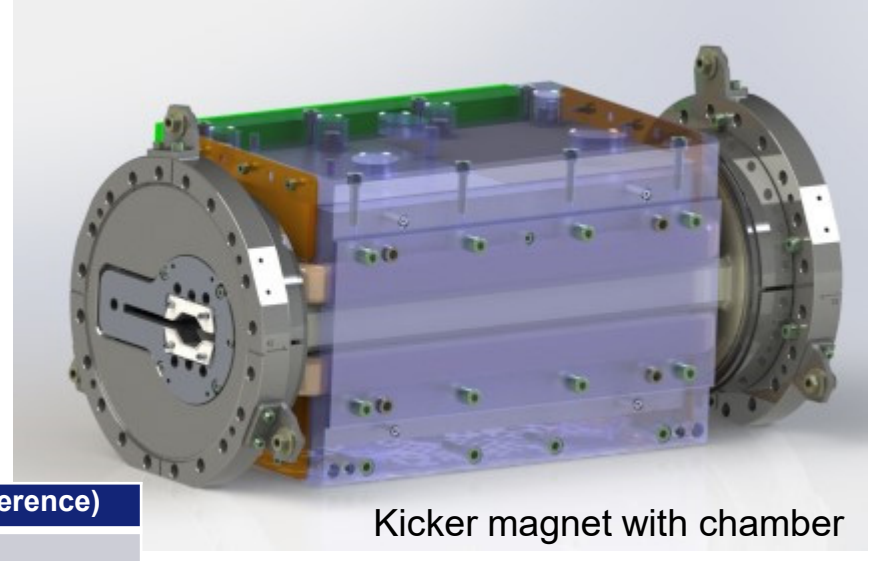
- 8 chambers ordered in 2017 to FRIATEC
- Price ≈ 42 k€ / chamber
- Delivery end 2019

ESRF-EBS KICKER CHAMBER DESIGN

Why alumina?

- Magnetic transparency
- Machinable
- Brazable to metallic pieces
- Vacuum tight

Field in the magnet (without any chamber)	**Delay: 0 ns (reference)**
Field in the ceramic chamber without coating	Delay: 6.8 ns
Field in the ceramic chamber with 4.7 Ohm Ti coating (2µm)	Delay: 18 ns



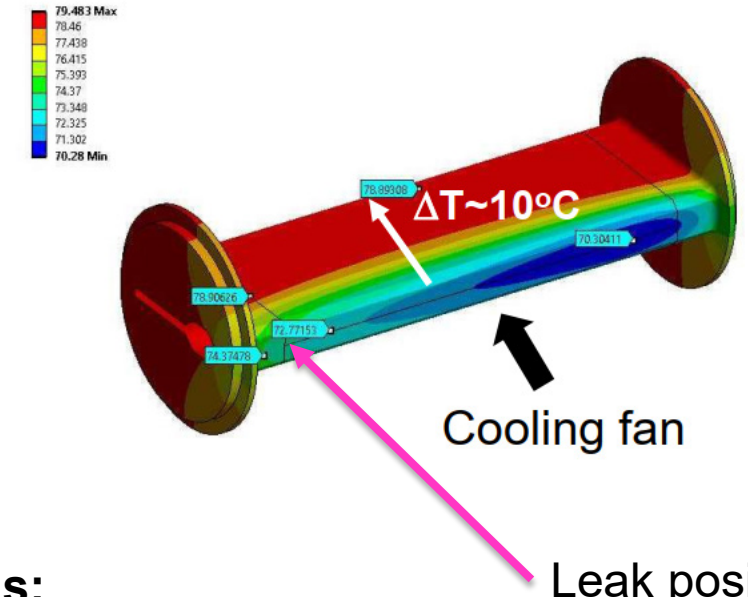
Kicker magnet with chamber

Also possible to use Sapphire, but more expensive

Ti coating is needed for the electrical continuity along the chamber to minimize the beam coupling impedance

KICKER CHAMBERS – VACUUM LEAK 2020

- Air leak on K3 while attempting to rump-up in 16 bunch mode to 90 mA
- Leak coming from glazing joint ceramic-ceramic



Possibles causes:

➢ Too much power deposited on chambers 16 bunch mode = worst case (12 times higher than uniform filling mode @200mA

$$P_{tot} = K\, I_{tot}^2\, R_{sq}\, \frac{1}{n_b}$$

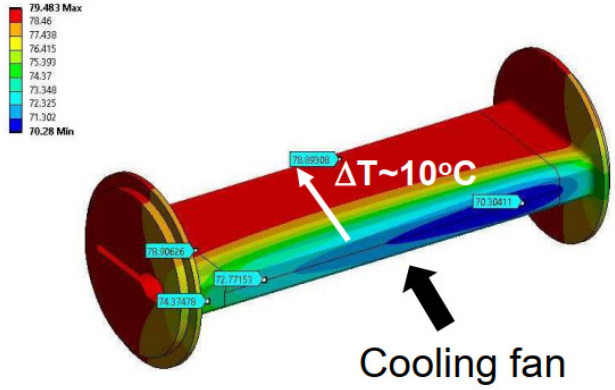
P_{tot} : deposited power
I_{tot} : total beam current
R_{sq} : Surface resitance of the coating
n_b : number of bunches
K : chamber shape factor

Actions:

➢ Limitation to 70 mA in 16 bunch mode (instead of 90 mA)
➢ Increase of the Ti coating to reduce the deposited power

KICKER CHAMBERS – VACUUM LEAK 2020

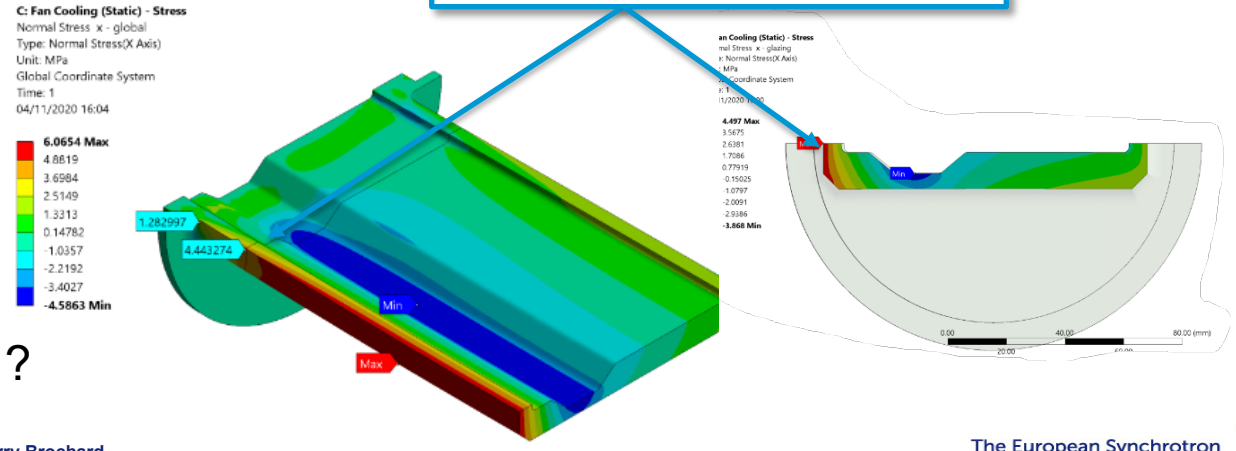
Power distribution for full current in 16 bunches mode used in ANSYS for thermal and mechanical simulations



The chamber asymmetry and cooling fans introduce a temperature gradient and mechanical stress on the chamber

Tensile stress in glazing
$\sigma_{x,max}$ = 4.5 MPa

Values obtained are too low to explain crack for perfect chamber



➡ Weakness in glazing ?

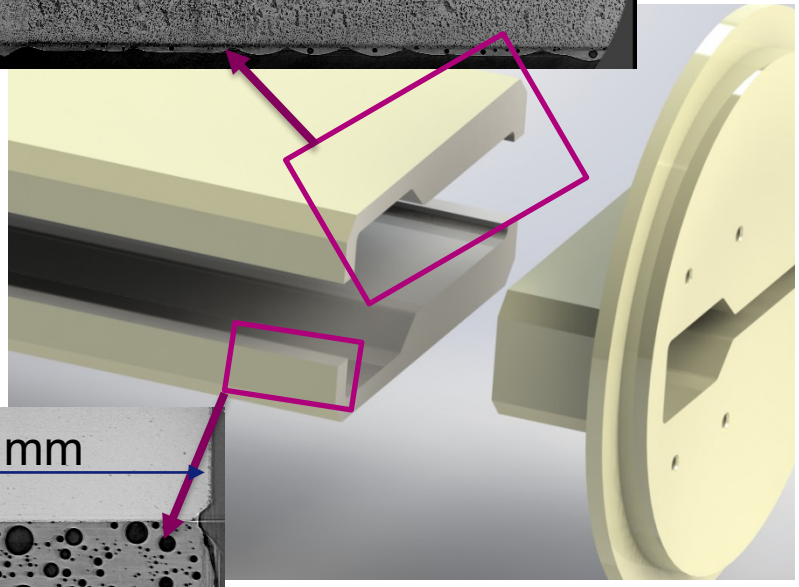
ESRF-EBS KICKER CHAMBER

Thermal cycles:

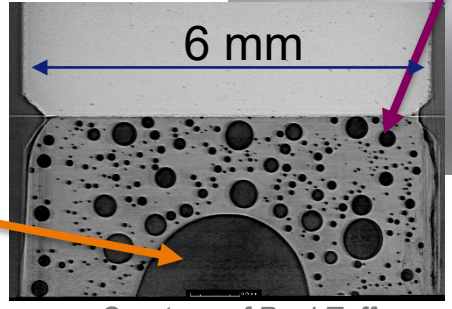
- Glazing of 2 half bodies at 1200 °C
- Glazing of Al_2O_3 flanges at 1000 °C
- Brazing of Kovar pieces at 800 °C

2 different glazing glue are used between step 1 and step 2

Possible problem : thermal oven regulation during 1st cycle



Computed tomography image made on BM05 (ESRF)
Pixel size 5x5 µm2

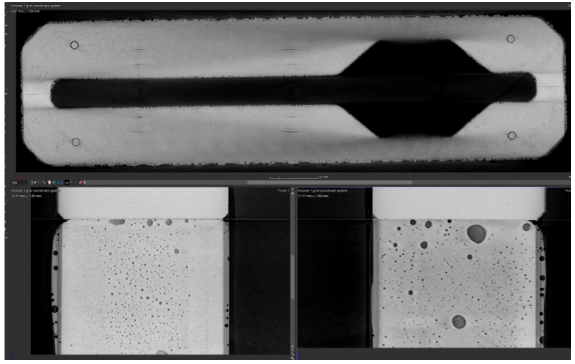


Bubble size ≈ 40% of contact surface

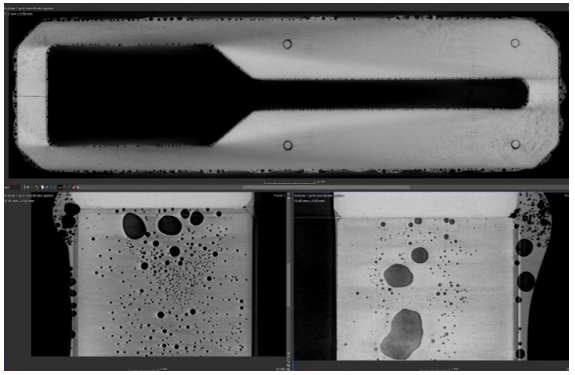
Courtesy of Paul Tafforeau

ESRF-EBS SPARE CERAMIC CHAMBERS

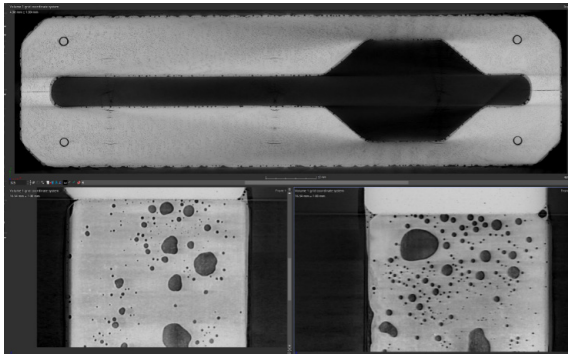
Computed Tomography images of spare ceramic chambers at glazing interface



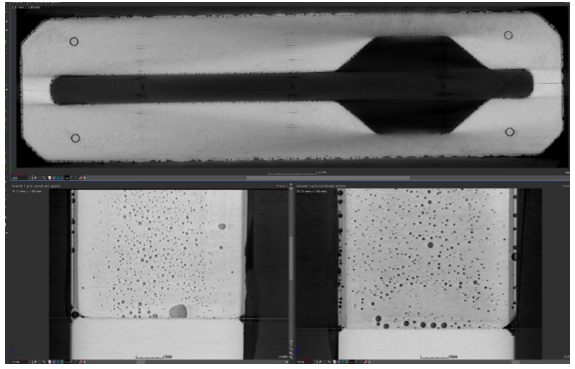
SHAKER SN: 1440 (exit)



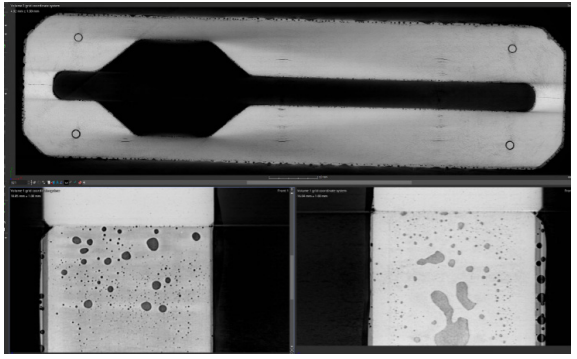
KICKER SN: 1661 (K2-K3)



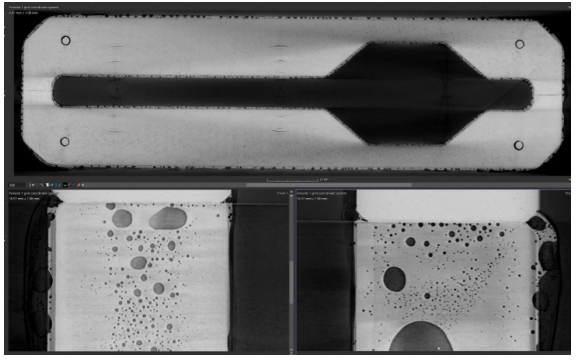
KICKER SN: 1667 (K1-K4)



SHAKER SN: 1440 (entrance)



VKICKER SN: 1669



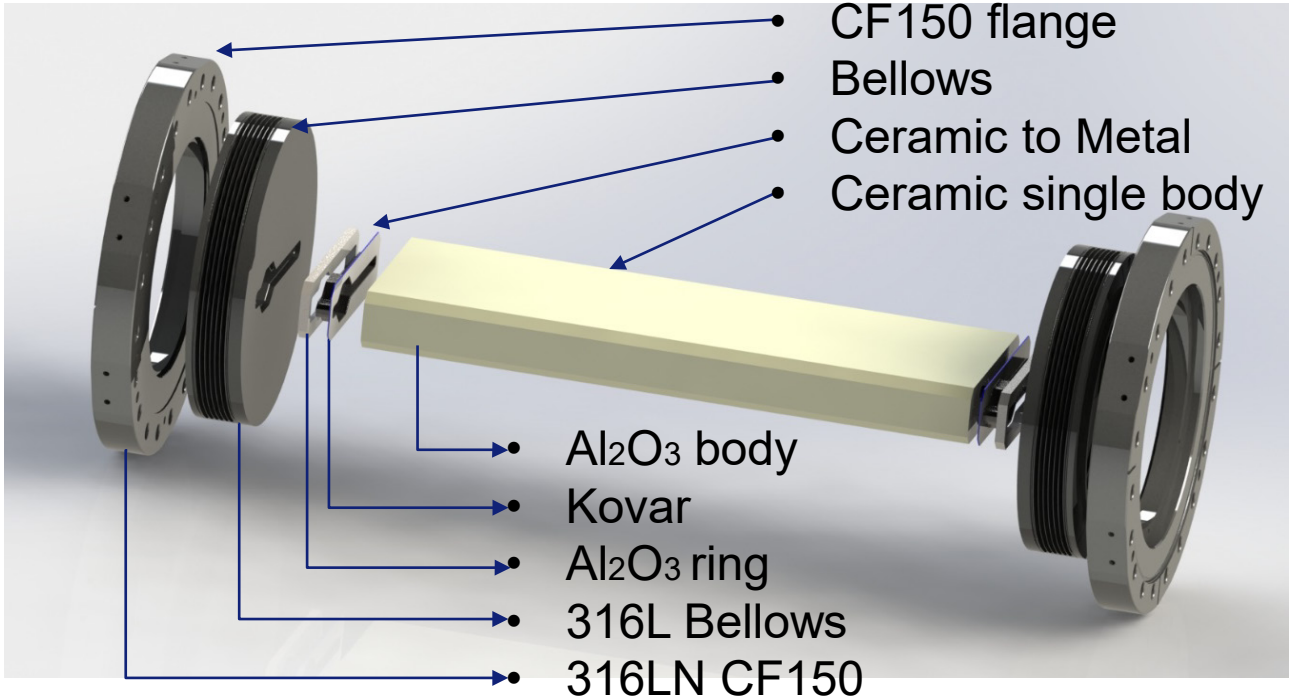
KICKER SN: 1667 (K1-K4)

Courtesy of Paul Tafforeau

ESRF-EBS NEW KICKER CHAMBER

To avoid glazing weak point, we propose to manufacture new kicker chambers based on the manufacturing on the alumina body from a single bloc.

	New design
Glazing	✗
Brazing	✓
Welding	✓



ALUMINA SINGLE BODY MANUFACTURING

BODY SHAPE	TECHNOLOGY	pros	cons
SINGLE BODY	**ISOSTATIC PRESSING**	• Roughness: Ra < 1	• Internal dimensions (shrinkage 17%) • Taper angle of 0.5 %
	MACHINING	• Internal dimensions	• Difficult to machine • Possible internal steps (tools vibrations)
	3D PRINTING	• Easy solution	• Internal dimensions • Roughness: Ra >1 • Internal machining needed afterward
	Extrusion	• ?	• Cost => no supplier

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	~~**Extrusion**~~	• ?	• Cost => no supplier

Contacted suppliers :

Morgan Advanced Materials, SCT, KYOCERA, CTTC Centre de transfert de technologies céramiques, CeramTec THE CERAMIC EXPERTS, anderman, SOLCERA Advanced Materials, 3DCERAM, MICROCERTEC ADVANCED CERAMICS & GLASS FOR THE HIGH-TECH, AVIGNON CERAMIC, FINAL ADVANCED MATERIALS, PMB ALCEN, nanoker

And more …

ALUMINA SINGLE BODY MANUFACTURING

December 2020

Isostatic pressing

CTTC

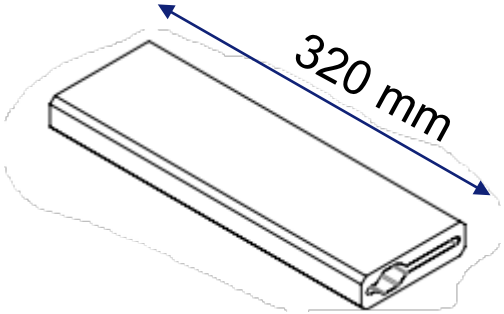
anderman
CÉRAMIQUE INDUSTRIELLE

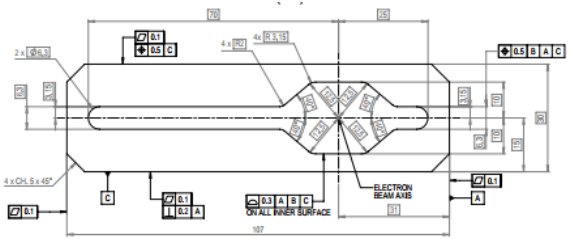
nanoker

Machining

SOLCERA
Advanced Materials

Feasibility tests launched with several companies with 2 different technics
S

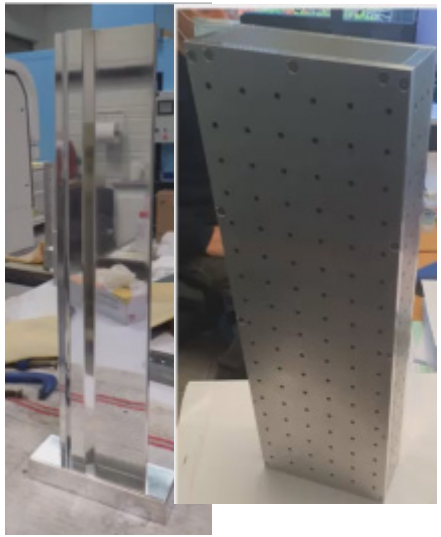




ISOSTATIC PRESSING

Powder preparation → Shaping → Pressing over 2000 bars → Pre sintering @1000°C

powder of Al_2O_3



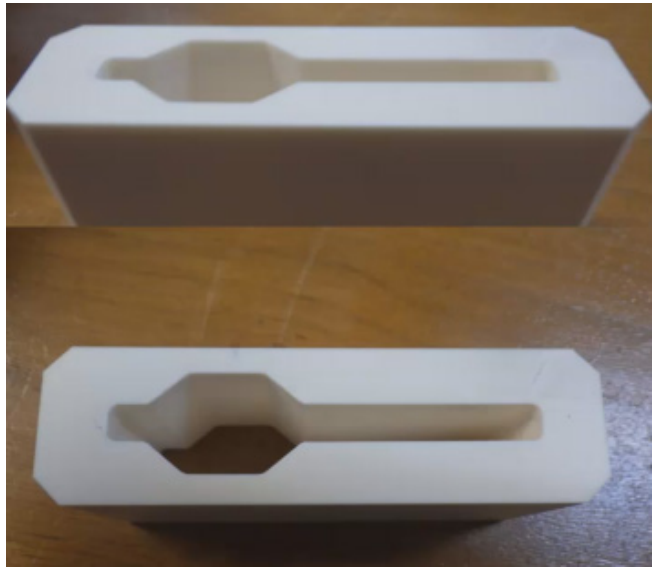
Mandrel and mold

0.5% taper needed on mandrel for extraction

ISOSTATIC PRESSING

Sintering @2000°C → Grinding

- **≈ 17% scale reduction**



Difficult to guarantee internal geometry

ISOSTATIC PRESSING

Sintering @2000°C

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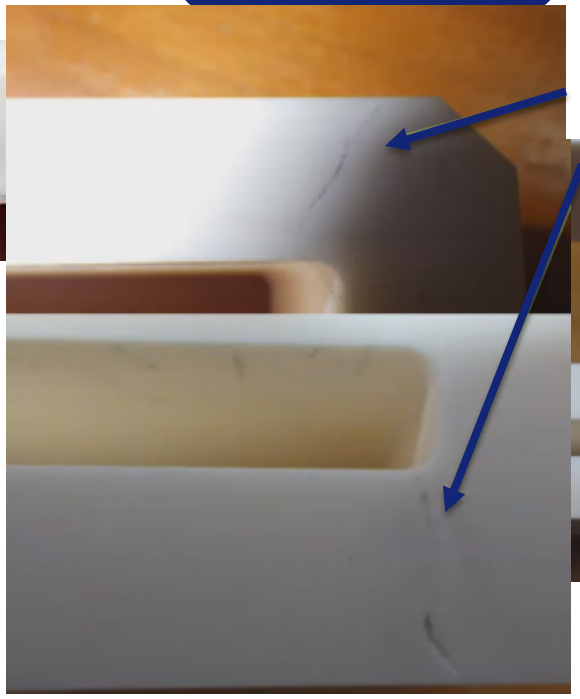
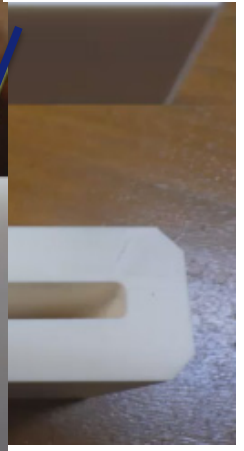
Difficult to guarantee internal geometry

Grinding

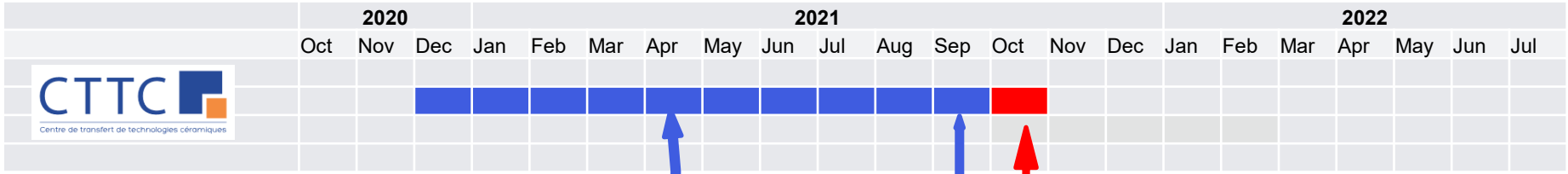


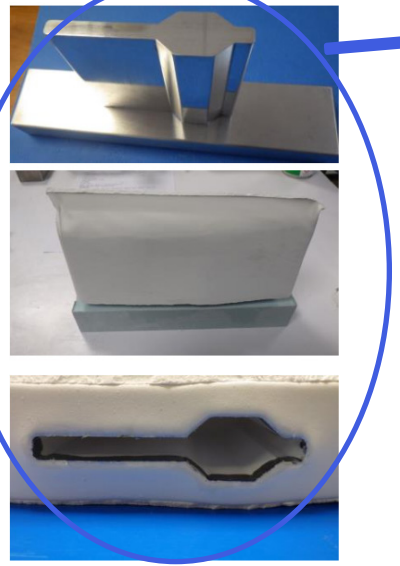
Not visible before grinding on some pieces



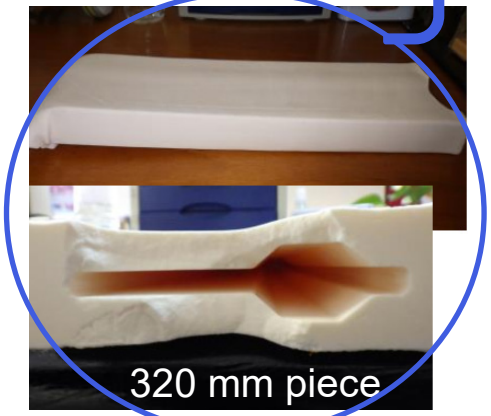
Alumina is a hard material, but extremely fragile

ISOSTATIC PRESSING





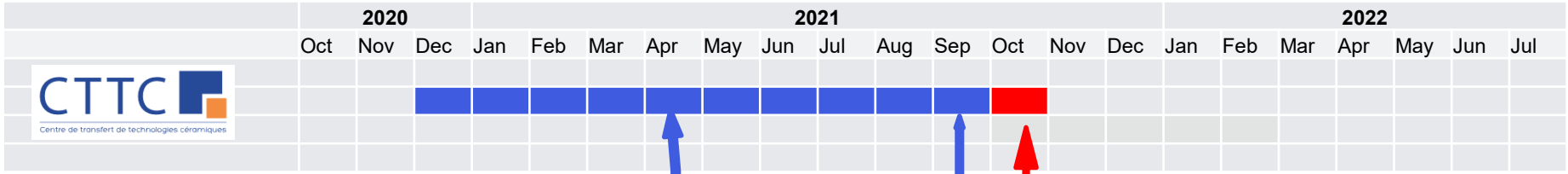
Production of 50mm pieces as prototypes

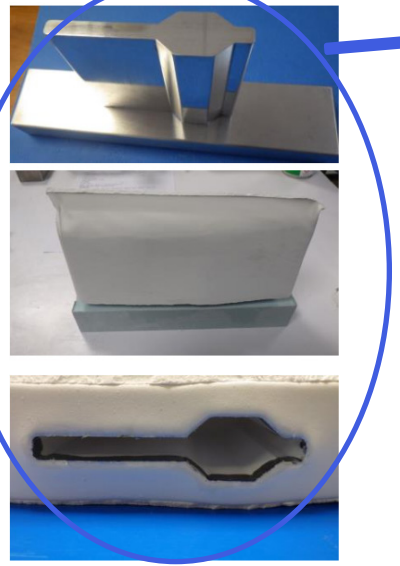


Production of 320 mm pieces

Additional tests to visualize cracks

ISOSTATIC PRESSING





Production of
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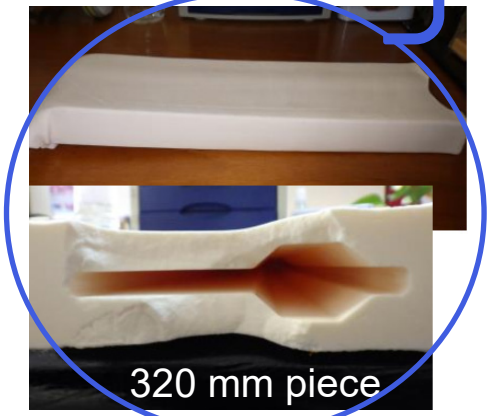


Production of
320 mm pieces

Additional tests to
visualize cracks

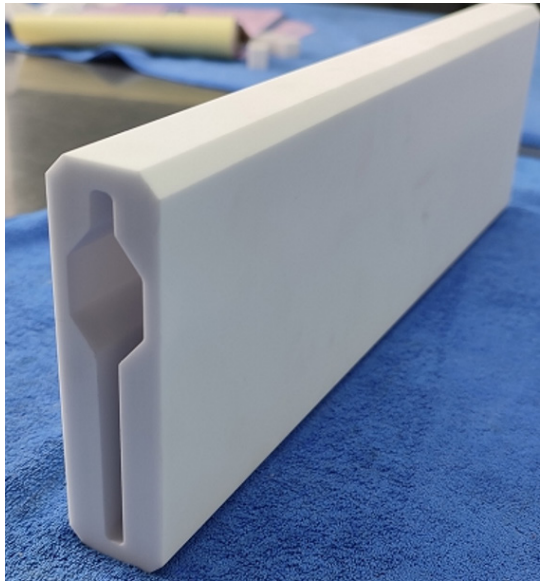
Isostatic test feasibility

- Cracks after sintering

Test stopped

ISOSTATIC PRESSING

	2020			2021												2022						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul



Isostatic test feasibility

- ✓ Chamber 330 mm long
- ✓ Vacuum leak test < 1.10-10 mbar.l.s-1
- ✓ Magnetic response : 2 ns (6.8ns for actual chambers)
- ✓ Dimensional control ok
- ✓ Internal roughness Ra >> 100 µm -> to be improved

➢ First test promising, but impossible to go to series production due to supplier availability

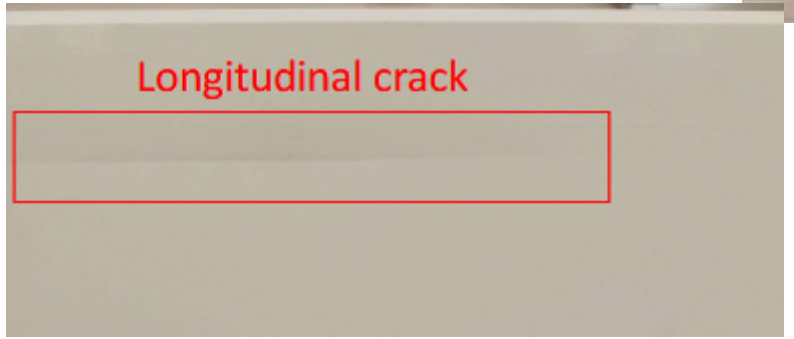
ISOSTATIC PRESSING

	2020			2021												2022						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
nanoker																						

After pressing

Green machining

Sintering



Isostatic test feasibility

- Cracks after sintering

Test stopped

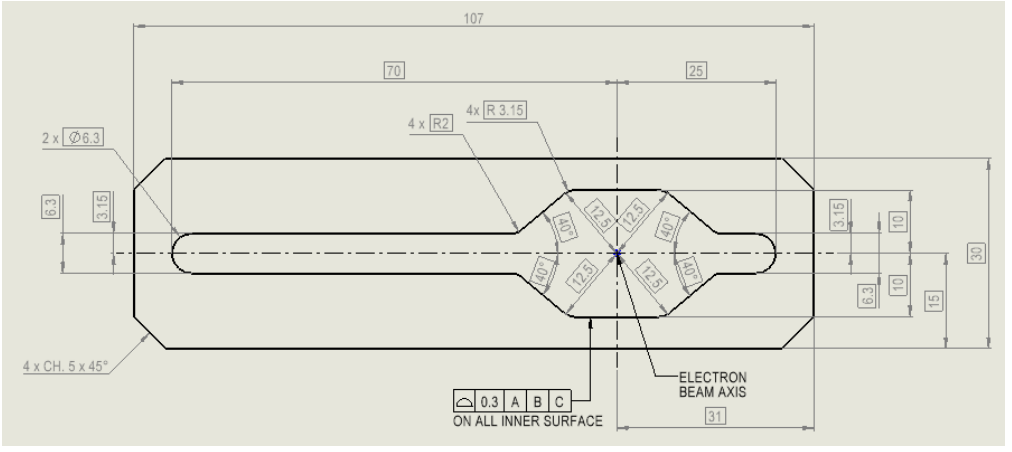
MACHINING

Main difficulty:

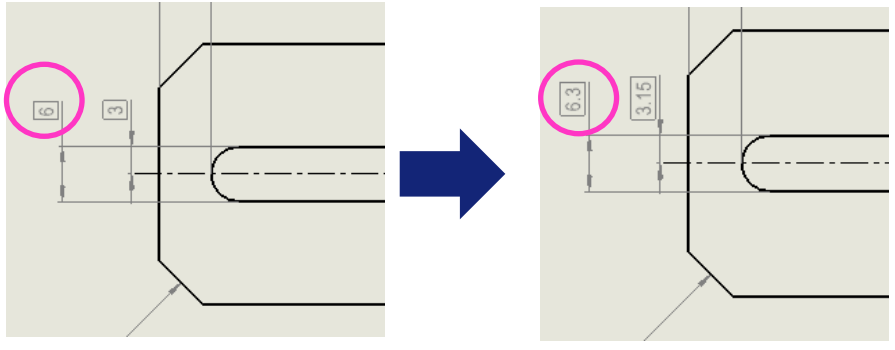
Perform the machining over 320 mm.

SOLCERA has developed a dedicated tool to perform the machining over 320 mm of Alumina blocs.

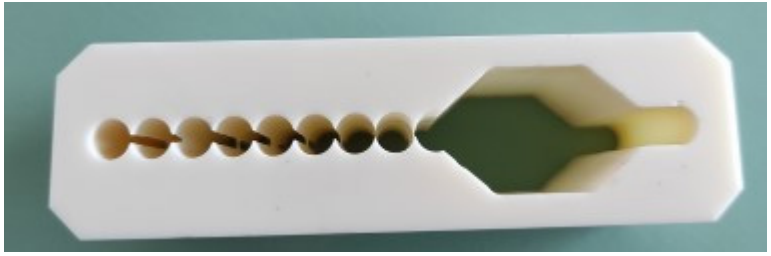
ESRF has to relax a dimension 6 -> 6.3



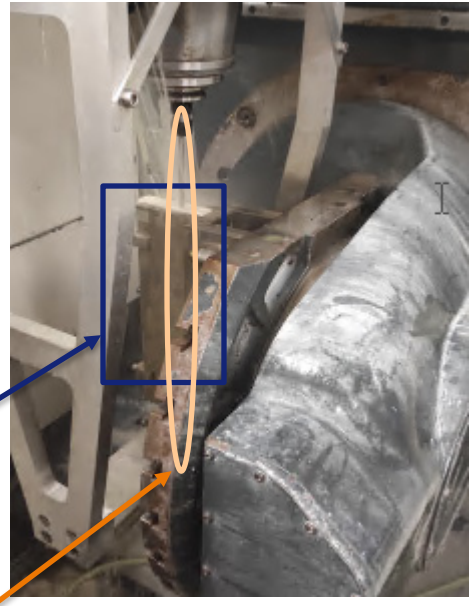
Length = 320 mm



MACHINING



Step 1: Removal of material by drilling from a solid block of alumina.



Step 2: internal shape fine machining, by using diamond tools.

For the first test, machining time about 35 hours.

MACHINING

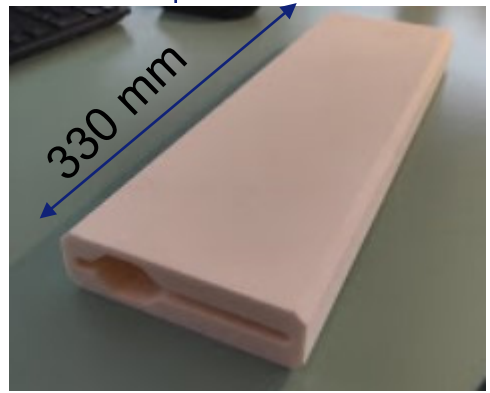
	2020			2021												2022						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
SOLCERA Advanced Materials																						

January 2022: First machining test on 190 mm long piece, by machining from both ends.

- Quality of internal surface very bad at the junction level.

April 2022: Seconf machining test on 320 mm long piece, by machining through all.

- Quality of internal surface very good Ra < 0.1



ALUMINA SINGLE BODY MANUFACTURING

Machining test feasibility

- ✓ Chamber 330 mm long
- ✓ Vacuum leak test < 1.10-10 mbar.l.s-1
- ✓ Magnetic response : 3 ns
- ✓ Dimensional control ok
- ✓ Internal roughness Ra < 0.1

- ✓ Brazing of Kovar end pieces
  - ➢ Max positioning error Kovar / Alumina ±70 µm

Contract on going… waiting for the welding

CONCLUSION

- The procurement of Ceramic chambers has to be anticipated well in advance. The scale is several years. Synchrotrons are just marginal customers in the technical ceramic world compared to other business fields as medical, army, space, agri-food industry.

- Machining of Alumina pieces, up to 320 mm long, is finally possible and can be a good alternative to replace an assembly made by glazing of machined Alumina pieces.

MANY THANKS FOR YOUR ATTENTION