International MUON Collider Collaboration

MuCol

CERN

Workshop on the Cooling Cell WP8

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CERN

Funded by the European Union (EU). Views and opinions expressed are however those of the author only and do not necessarily reflect those of the EU or European Research Executive Agency (REA). Neither the EU nor the REA can be held responsible for them.

Summary

- Thanks to all the speakers and participants!
- A lot of information gathered, presented and discussed
- 67 registered (both online and in presence)
- Congratulations to US colleagues that connected as from the EU morning!!!\
- https://indico.cern.ch/event/1335151

Goal of the workshop

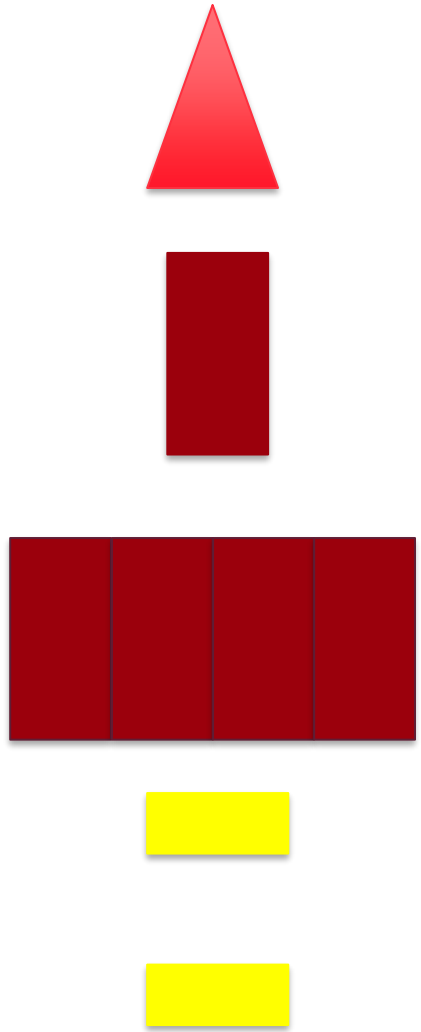
- The goal of WP8 is to produce a full 3D model of a Cooling Cell
- Within our roadmap we want to select the cell to be built, and identify as many issues as possible by the end of the first year
- This workshop prepares the discussions we will have at the annual meeting to endorse the main principle that will guide the design
- We want to hear about opinions, feedback from previous experiences (especially related to things to avoid…)

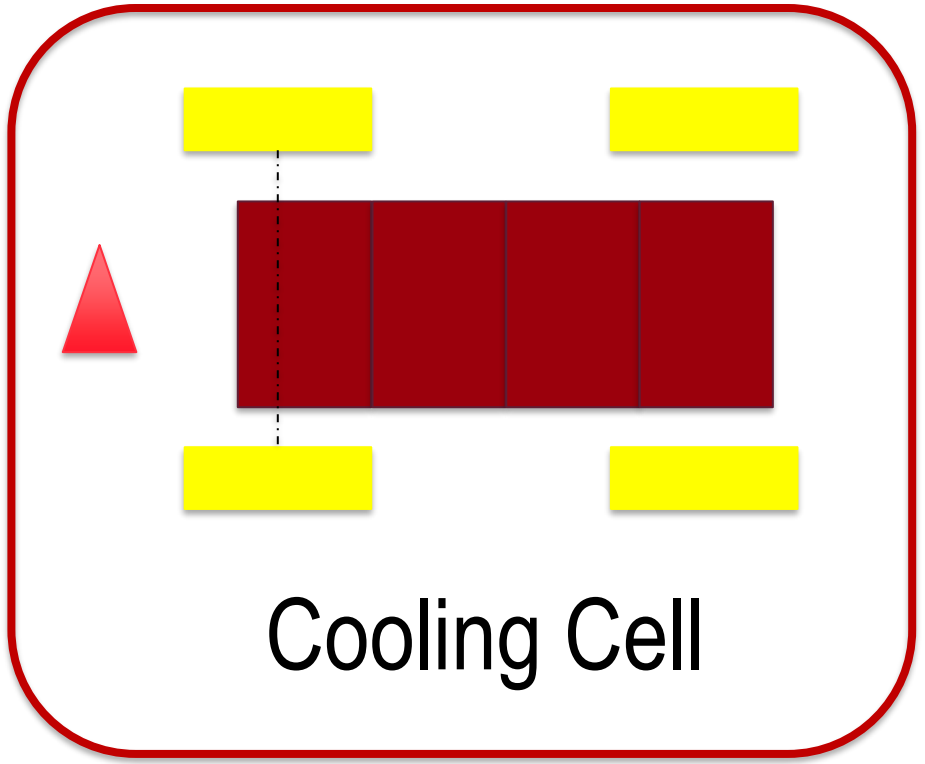
Goal of the workshop

- Some of the questions we have
  - Do we embed everything in a single cryostat, or do we put solenoids in separated cryostats?
  - What is the experience from MAP and MICE?
  - How do we manage the different ancillaries for the RF cells
  - Do we design independent cells or multicell RF Structures?
  - What type of Absorbers to use?
  - Do we have Vacuum Windows that can stand the pulse energy?
  - What specs we have for instrumentation, and what are the possibilities vs needs?

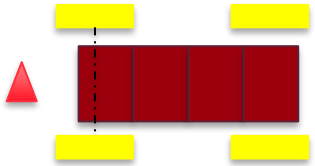
Terminology

- Absorber
- RF Cell
- RF Structure
- Solenoid

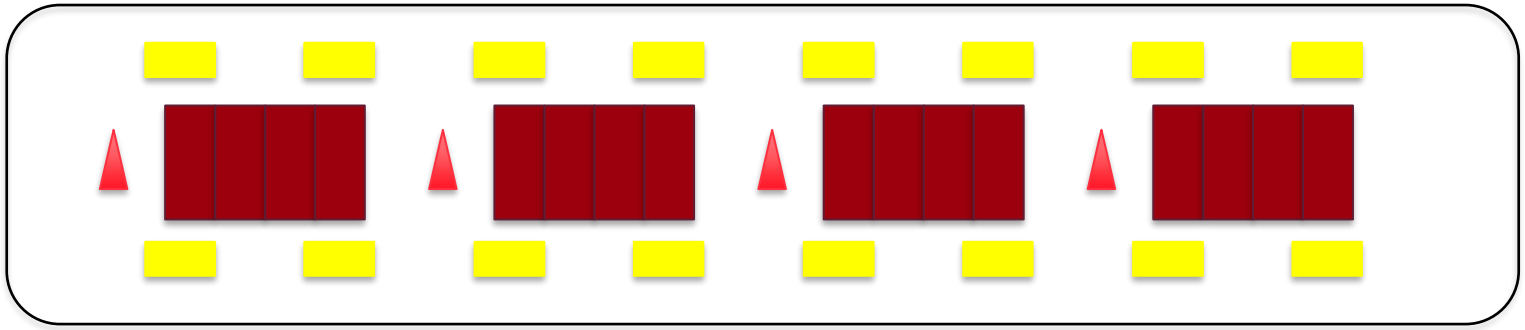




Terminology



- Cooling Cell



- Cooling Module

- Cooling section

Thursday Morning

	Welcome *30/7-018 - Kjell Johnsen Auditorium, CERN*	09:30 - 09:45
	Ionisation cooling and different types of cells — *Chris Rogers* *30/7-018 - Kjell Johnsen Auditorium, CERN*	09:45 - 10:15
10:00	**Magnets for RFMTF** — *Lucio Rossi et al.* *30/7-018 - Kjell Johnsen Auditorium, CERN*	10:15 - 10:45
	3 GHZ RF for the RFMTF — *Giorgio Sebastiano Mauro* *30/7-018 - Kjell Johnsen Auditorium, CERN*	10:45 - 11:15
11:00	**Coffee break** *30/7-018 - Kjell Johnsen Auditorium, CERN*	11:15 - 11:45
	Status of 650 MHZ cavity design — *Dario Augusto Giove* *30/7-018 - Kjell Johnsen Auditorium, CERN*	11:45 - 12:15
12:00	**Status of 704 MHz cavity design** — *Carmelo Barbagallo* *30/7-018 - Kjell Johnsen Auditorium, CERN*	12:15 - 12:45
	Considerations on isolated RF cells or multicells — *Alexej Grudiev* *30/7-018 - Kjell Johnsen Auditorium, CERN*	12:45 - 13:15
13:00	**Lunch**	

Thursday afternoon

	30/7-018 - Kjell Johnsen Auditorium, CERN	13:15 - 14:30
	Review of the experience on RF in magnetic fields — *Guillaume Ferrand et al.* *30/7-018 - Kjell Johnsen Auditorium, CERN*	14:30 - 15:00
15:00	**Feedback from MICE: Magnets** — *Bruce Strauss* *30/7-018 - Kjell Johnsen Auditorium, CERN*	15:00 - 15:30
	Consideration about an Ionisation cooling demonstrator — *Mr Paul Bogdan Jurj* *30/7-018 - Kjell Johnsen Auditorium, CERN*	15:30 - 16:00
16:00	**Coffee break** *30/7-018 - Kjell Johnsen Auditorium, CERN*	16:00 - 16:30
	US situation, feedback from MAP — *Diktys Stratakis* *30/7-018 - Kjell Johnsen Auditorium, CERN*	16:30 - 17:15
17:00		

Friday Morning

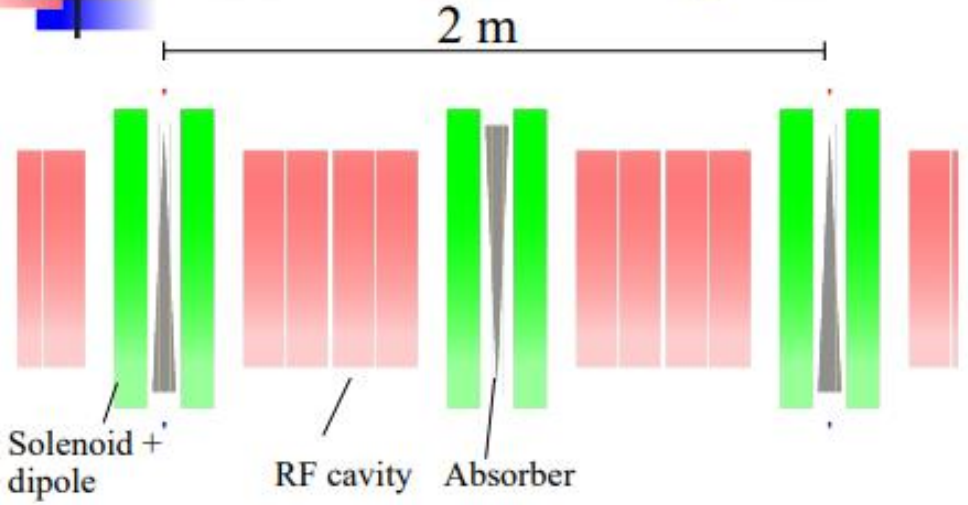
09:00	**Absorbers** — *Rui Franqueira Ximenes* *30/7-018 - Kjell Johnsen Auditorium, CERN* — 09:00 - 09:30	
	Windows — *Dr Jose Antonio Ferreira Somoza* *30/7-018 - Kjell Johnsen Auditorium, CERN* — 09:30 - 10:00	
10:00	**CERN Beam Instrumentation relevant to the Muon Collider Study** — *Inaki Ortega Ruiz* *30/7-018 - Kjell Johnsen Auditorium, CERN* — 10:00 - 10:30	
	Coffee break *30/7-018 - Kjell Johnsen Auditorium, CERN* — 10:30 - 11:00	
11:00	**Discussion and conclusions** — *Daniel Schulte et al.*	
12:00	*30/7-018 - Kjell Johnsen Auditorium, CERN* — 11:00 - 13:00	
13:00		

Happy few!

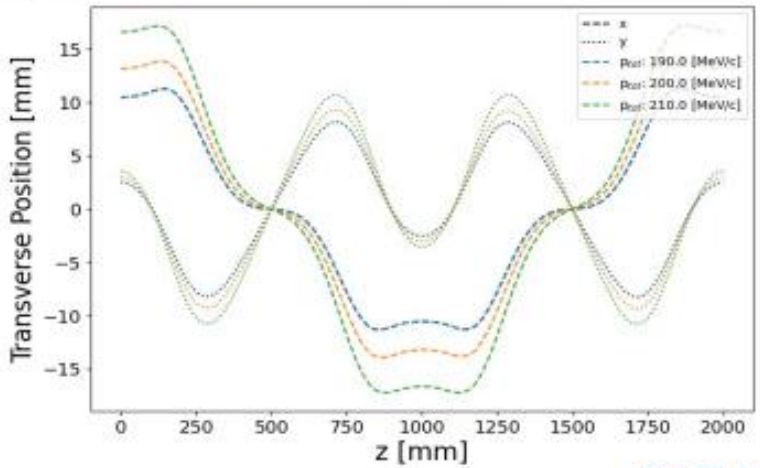
Chris Rogers

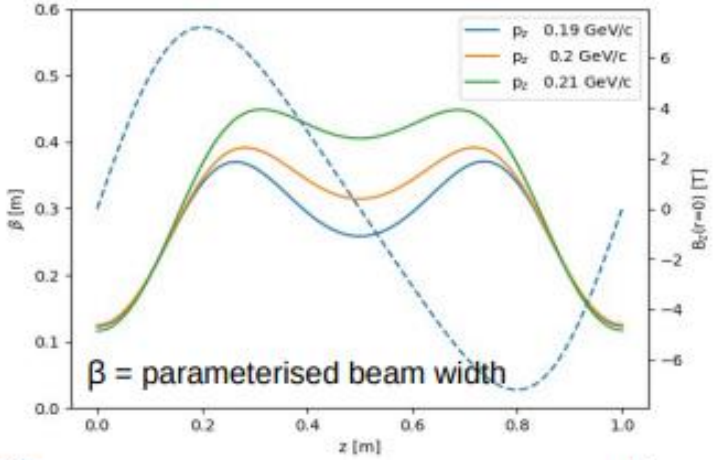
- Proposed to build a B5-like cell
- Not too difficult, not too easy…

Emittance Exchange – Realisation?



Cooling System	
Cell length	2 m
Peak solenoid field on-axis	7.2 T
Dipole field	0.2 T
Dipole length	0.1 m
RF real estate gradient	22 MV/m
RF nominal phase	20°
RF frequency	704 MHz
Wedge thickness on-axis	0.0342 m
Wedge apex angle	5°
Wedge material	LiH

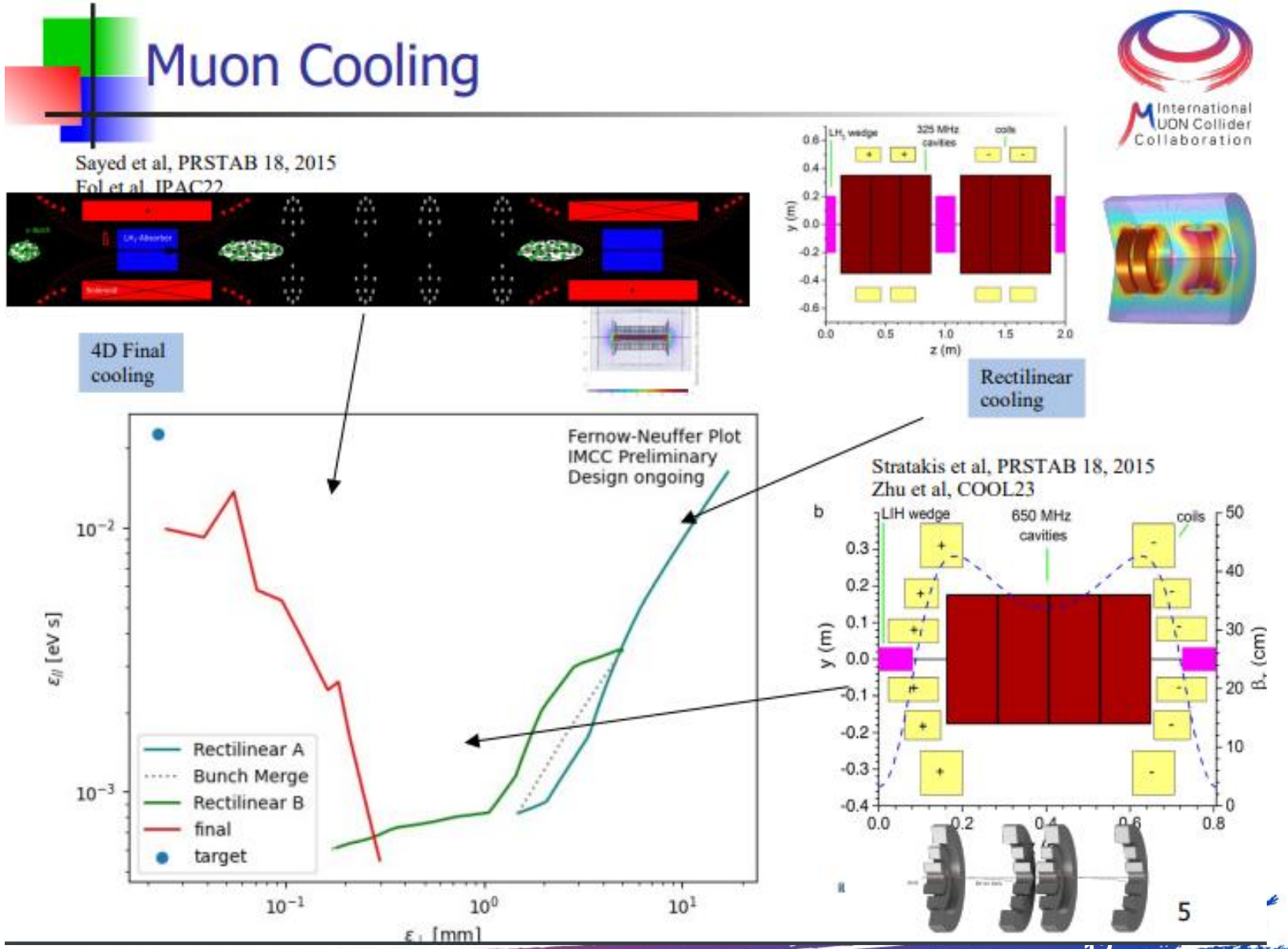




ISIS

Dyktis Stratakis

- Proposed to build a B8-like cell
- The most difficult, to prove we can build the worse…



Marco Statera

- How do we define the most difficult?

Selected features

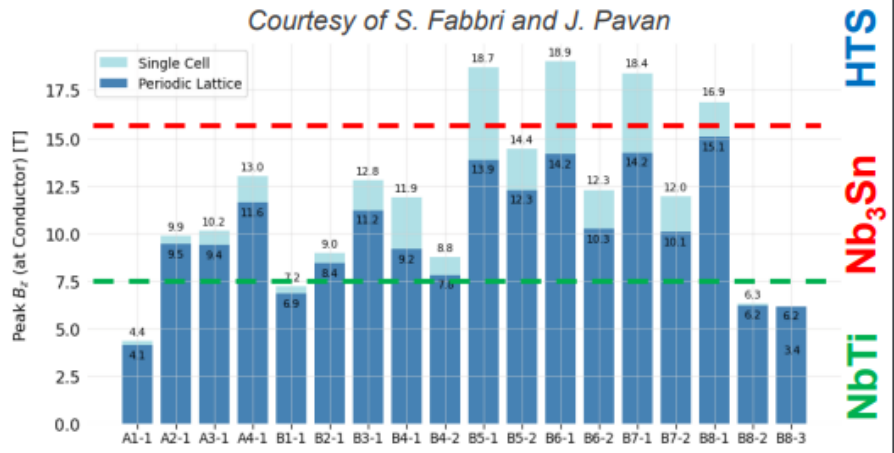
We have a full catalogue based on US MAP original design (field on axis)

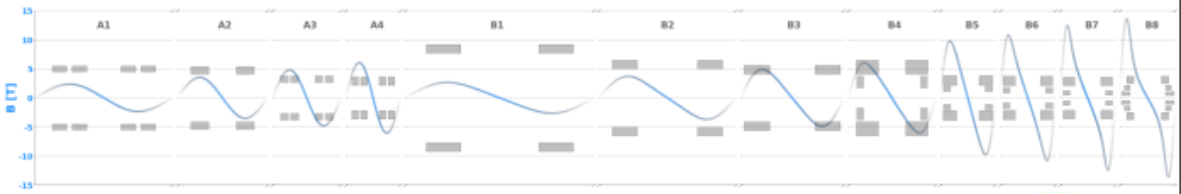
- 12 unique stages:
  - 4 cooling stages *before* bunch recombination (A1-A4)
  - 8 cooling stages *after* bunch recombination (B1-B8)
- *Each stage has a repeating series of a cell type*
- High field, very compact solenoids
- Each cell has symmetric solenoids of opposite polarity

Some stats:

- Fields on axis: 2 to 14 T
- Cell Lengths: 0.8 to 2.7 m
- Total length of all Stages: ~ **2 km**
- Total number of solenoids: 2432

Courtesy of S. Fabbri and J. Pavan





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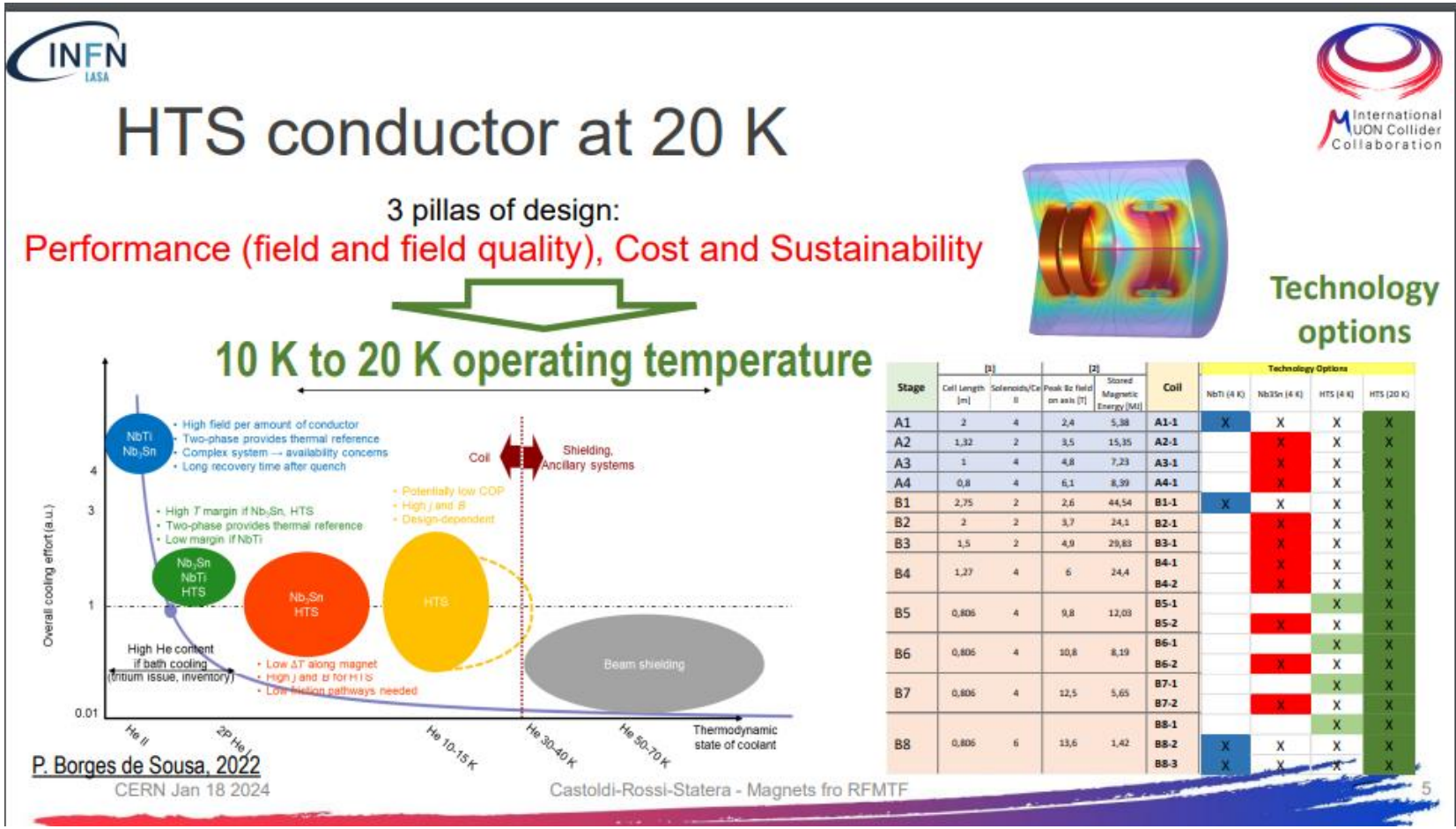
Marco Statera

- Good reasons to use HTS also for «low» field magnets



Stage	[1] Coil Length [m]	[1] Solenoids/Coil	[2] Peak Bz field on axis [T]	[2] Stored Magnetic Energy [MJ]	Coil	Technology Options: NbTi (4 K)	Nb3Sn (4 K)	HTS (4 K)	HTS (20 K)
A1	2	4	2,4	5,38	A1-1	X	X	X	X
A2	1,32	2	3,5	15,35	A2-1		X	X	X
A3	1	4	4,8	7,23	A3-1		X	X	X
A4	0,8	4	6,1	8,39	A4-1		X	X	X
B1	2,75	2	2,6	44,54	B1-1	X	X	X	X
B2	2	2	3,7	24,1	B2-1		X	X	X
B3	1,5	2	4,9	29,83	B3-1		X	X	X
B4	1,27	4	6	24,4	B4-1		X	X	X
					B4-2		X	X	X
B5	0,806	4	9,8	12,03	B5-1			X	X
					B5-2		X	X	X
B6	0,806	4	10,8	8,19	B6-1			X	X
					B6-2		X	X	X
B7	0,806	4	12,5	5,65	B7-1			X	X
					B7-2		X	X	X
B8	0,806	6	13,6	1,42	B8-1			X	X
					B8-2	X	X	X	X
					B8-3	X	X	X	X

Marco Statera

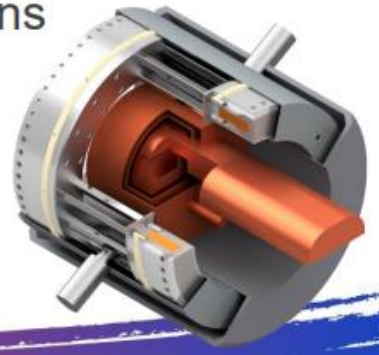
- First step towards a cooling cell design is the RFMTF

To be investigated

We are defining technologies
- Conductor
- Operation condition, i.e. temperature an cooling method

To be investigated
- Conductor performance
- Conductor configuration
- Field quality
- Thermal/mechanical configuration

Why a test stand?
- RF test in field and in field gradient
- Develop coils technology (increase TRL)
- Test of conductor, mechanical and thermal options



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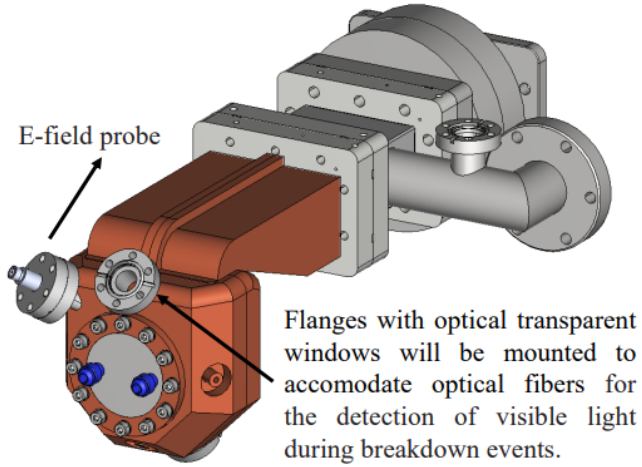
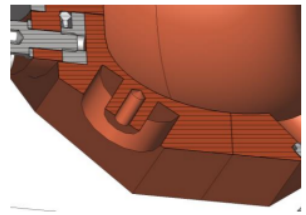
Giorgio Mauro

- First step towards a cooling cell design is the RFMTF

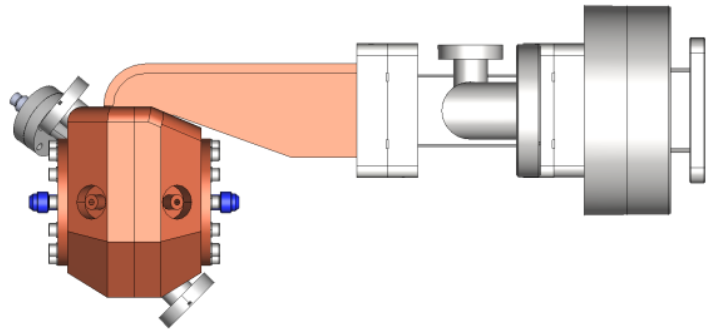
Mechanical model

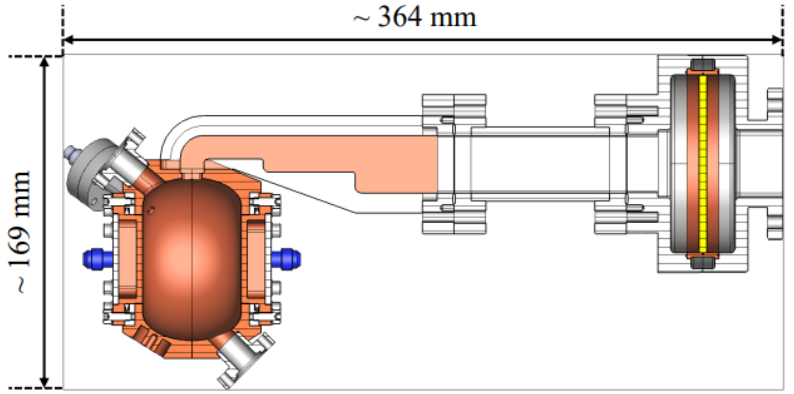


Flanges with optical transparent windows will be mounted to accomodate optical fibers for the detection of visible light during breakdown events.



Cavity is expected to be equipped with five tuners.





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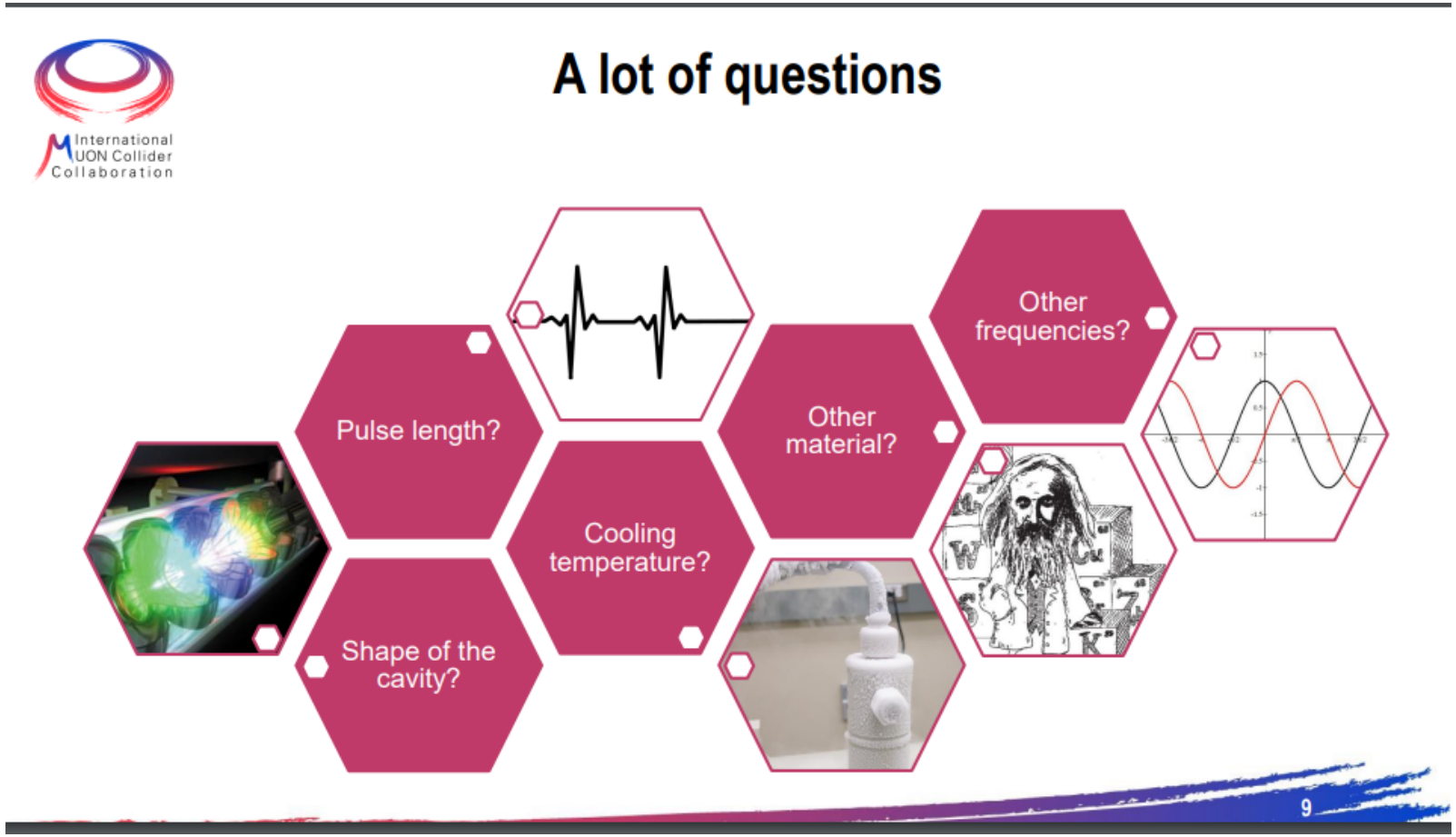
Guillaume Ferrand

- Many parameters to explore
- One or More RFMTF are not luxury!



Dario Giove

- Clear synergy with Cooling cell work…

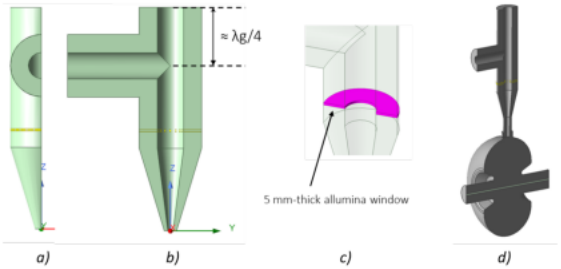
A Normal Conducting 650 MHz cavity for a High Brightness Test Facility

Dario Giove, Giorgio Mauro, Elisa del Core, Rocco Paparella, Daniele Sertore, Angelo Bosotti

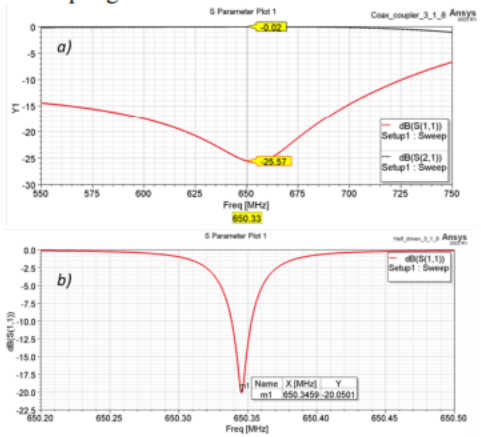
INFN- LASA and INFN-LNS

HB2TF Fundamental Power Coupler

Baseline design: coaxial line coupler, tapered and tuned through a $\lambda g/4$ section, to feed the cavity via the 3 1/8" standard line. Rotatable loop tip to perform magnetic coupling.



Schematic EM layout of the fundamental power coupler of Buncher 1: EM volume cross-sections in *a)* and *b)*, ceramic window detail in *c)* and full-view of the system coupled through a loop at the cavity equator in *d)*.



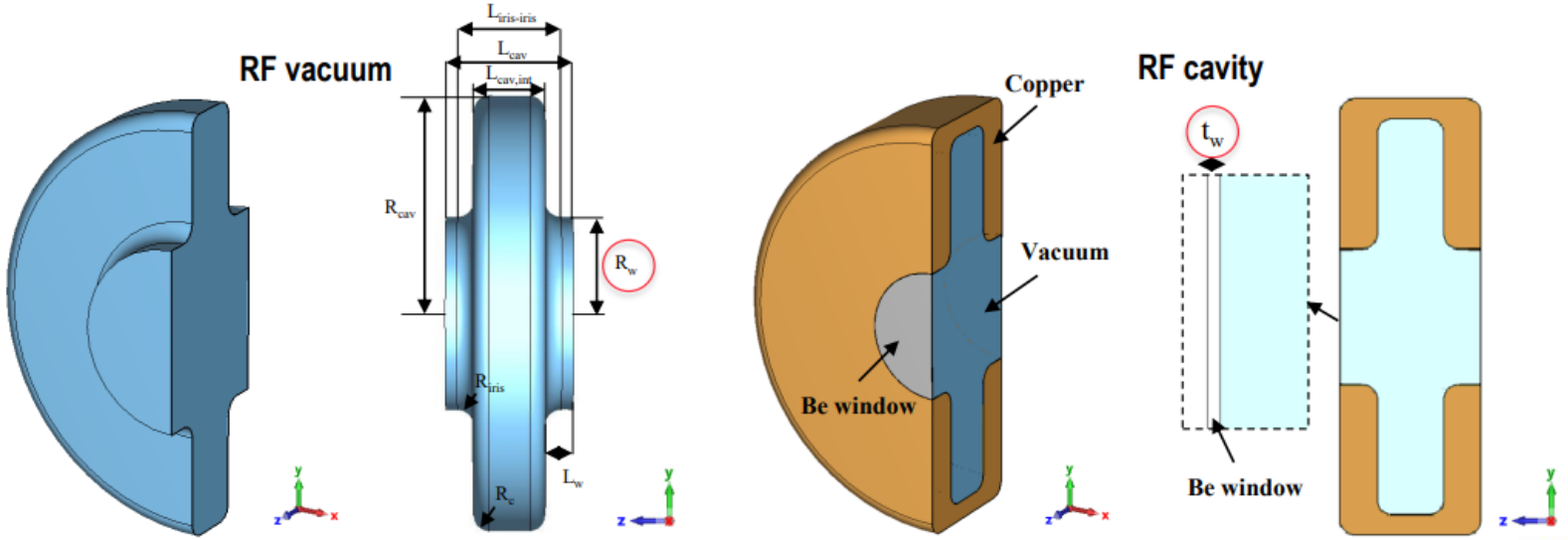
S-parameter analysis of the coupled Buncher 1 with HFSS: plot *a)* refers to the power coupler alone for both transmission (s21) and reflection (s11) coefficients, plot *b)* is instead for the coupler system cavity + coupler.

Carmelo Barbagallo

- Accelerating Gradient 36 MV/m… (44?)

704 MHz Pillbox-type cavity for the Muon Cooling

- The 704 MHz pillbox-type cavity was built based on a design similar to the LBNL 805 MHz pillbox cavity.
- Beryllium (Be) window: 60 mm ($3\sigma_{beam}$) or 120 mm radius ($\mathbf{R_w}$); 60 um or 120 um thickness ($\mathbf{t_w}$)



Carmelo Barbagallo

- Accelerating Gradient 44 MV/m…
- Lorentz Force Detuning is an issue!

Preliminary results: LFD effect on both cavity walls and windows

Total displacement

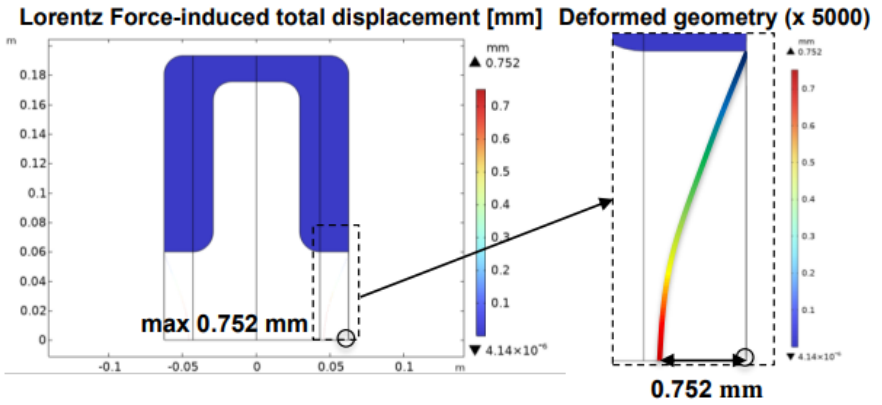
$u_{\max} = 0.752$ mm

Frequency shift

$\Delta f_{LFD} \propto K_L E_{acc}^2$

$\Delta f_{LFD} = -157.26$ kHz at $E_{\text{nom}} = 44$ MV/m

$\Delta f_{3\text{dB}} = 38.7$ kHz



- The frequency shift is **higher** than the 3 dB bandwidth when RF field pressure is applied on both cavity walls and windows. This is due to the large deformation and displacement detected at the Be windows.
- The implemented LFD model is based on the Slater theorem, which is valid only for small deformation.
- The used linear elastic assumption is typically valid within the **2-3% of deformations**. Even the model includes geometric non-linearity, the assumption that a purely elastic material can undergo arbitrary large deformations may not be entirely valid.

Bruce Strauss

Cheap vs. Inexpensive

a. Cheap is a pejorative term in this example. Inexpensive should be the operating term. Specifications should go through an analysis of whether you need it or want it. Is there engineering margin?
b. Finding qualified vendors and limitations of the bidding process.
    i. "Good news and bad news."
    ii. Is there any real QC and QA?
c. What is the best value for the sponsoring institution or funding agency?
d. Laboratory contracting office? Who are they working for?

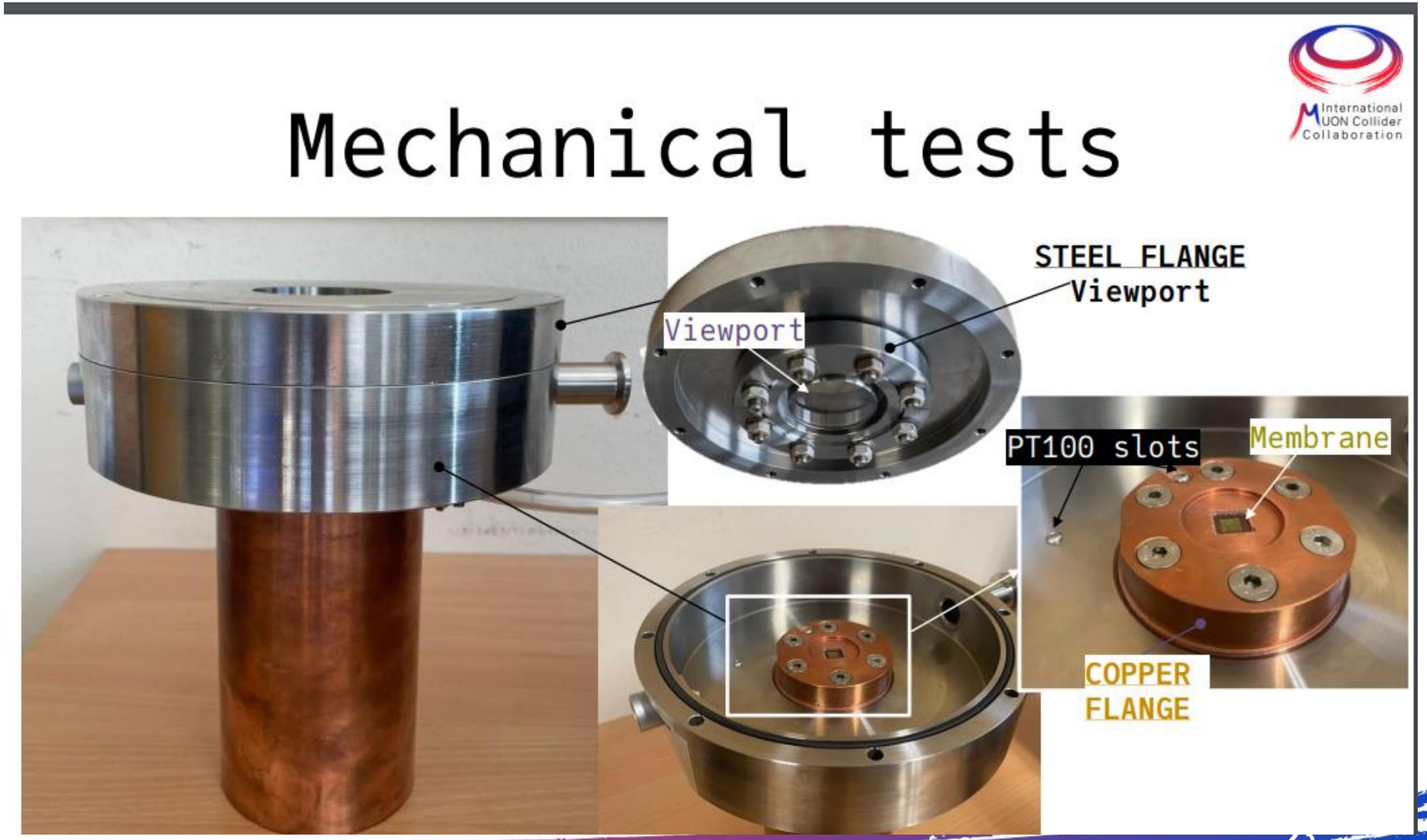
Rui Franqueira Ximenes

LiH considerations

- **Operation**
  - Collect thermal-mechanical-physical properties
  - Need to study what thermo-mechanical conditions LiH will experience in operation
  - Understand what LiH and surrounding equipment can tolerate (temperature, stresses, power dissipation)
  - Need for dedicated beam test?
- **Integration/assembly**
  - Integration of the solid absorber should not be forgotten (taken from the early design stages, even if trivial compared to LH2 absorber or remaining equipment).
  - What tolerances do we want? What can we accept?
- **Procurement/manufacturing**
  - How to procure it ? powder raw form (500 EUR/kg) or final form (not as trivial)?
  - To what extent shall (or need) to develop an in-house manufacturing technique (e.g.HIPing, coating) ?
- **Safety**
  - Define the required safety handling and storage procedures.
  - Define the risks and hazards associated with its operation (and post irradiation)

Jose Antonio Ferreira Somoza

- Testing
- Si_3N_4



Jose Antonio Ferreira Somoza

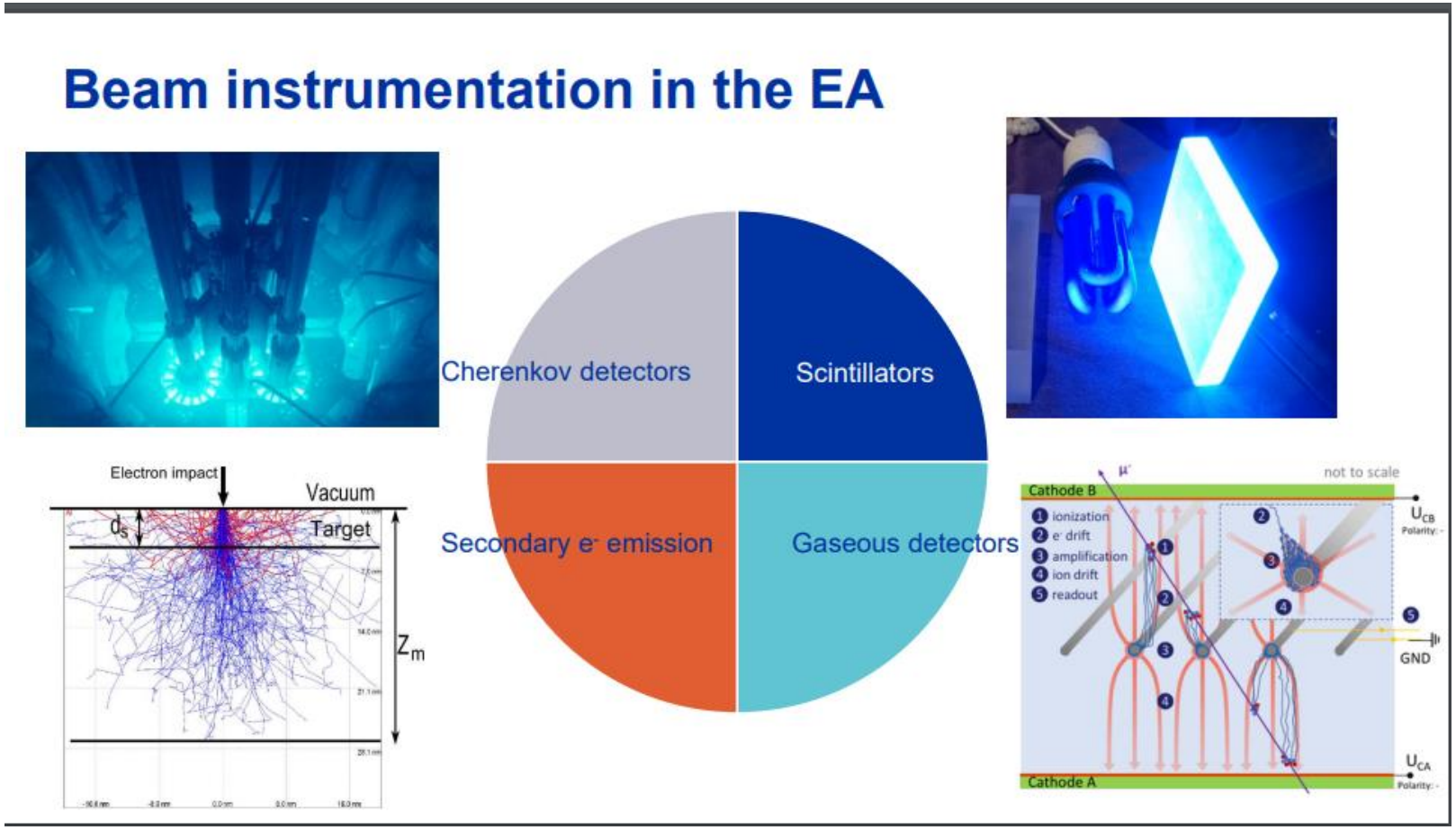
- Testing
- Si_3N_4

Results

- Strong deformation on beam spot (>300 μm?)
- Buckling? Vibrations?
- SEM imaging was not possible (insulator)

Inaki Ortega Ruiz

- We need to develop a roadmap towards specifying what we need in terms of Beam Instrumentation
- No showstoppers expected, but still….



Outcomes and decisions -1

- Prototype cell on which carry on integration exercise: after discussion it si clear that we should not aim at the most difficult one, however, it must be sufficiently complex to contains almost all integration issues:
  Adapted from B5 (2 split coils)

Outcome and decisions - 2

- **Do we embed everything in a single cryostat, or do we put solenoids in separated cryostats?**
- The test facility (RFMFTF) is a single cryostat for conveniency and saving money. However the integration of the prototype will have to be with separate cryostat for the SC coil since vertical passage for RF power and instrumentation & services is the only way to limit aperture of the solenoids (the most important parameter for cost & difficulty).
- The RFMFTF magnet still remain 90-95% relevant

Outcome and decisions - 3

- **What is the experience from MAP and MICE?**
- The main issue was the lack of engineering margin (at least in first design): too pushy everywhere at least for the time: And also the little resources and attention by funding agency. The low-cost choice (including vendor of the magnet) and lack of follow-up was also detrimental (requiring intervention,. Repairs etc…)
- Design with safety and for success; cost-optimization as second step after having shown performance…

Outcome and decisions - 4

- **Do we design independent cells or multicell RF Structures? How do we manage the different ancillaries for the RF cells**
- This has been the most debated issue.
  The decision was to eventually go for an intermediate solution with 2 powering line per RF structure (i.e., one power line for two adjacent RF cells).
- In any case the limit is likely in the couplers so much attention must be devoted to it. Need to be flexible, if the solution of coupled cells will not work, ready to go for single cell powering
- The solution from the cooling prototype might be different than for the demo if we deems so.

Outcome and decisions - 5

- **What type of Absorbers to use?**
- Also this much debated.
  In view of difficulty for liquid or very high-pressure gaseous Hydrogen, we decided to go for the prototype cooling cell toward LiH, the solid absorber.
  We noticed the normal grade LiH is good enough and has good absorbing properties.
- In view of the fact that the final cooling needs anyway (most probably) Hydrogen absorbers, this solution should not be ruled out: hydrogen cells and window need to be developed, demonstrate thechcnally and finally integrated, too.