Accelerator-development related activities

D. Barna (barna.daniel@wigner.hu, http://wigner.hu/~barna), K. Brunner, D. Veres, M. Szakály, M. Koszta, T. Vaszary, Zs. Simon
Wigner Research Centre for Physics (+worldwide)

V. Mertinger, V. Kárpáti, M. Sepsi, G. Szabó, M. Szűcs, E. Nagy
University of Miskolc, Institute of Physical Metallurgy, Metalforming and Nanotechnology


Accelerator-related activities in Hungary - overview

CERN

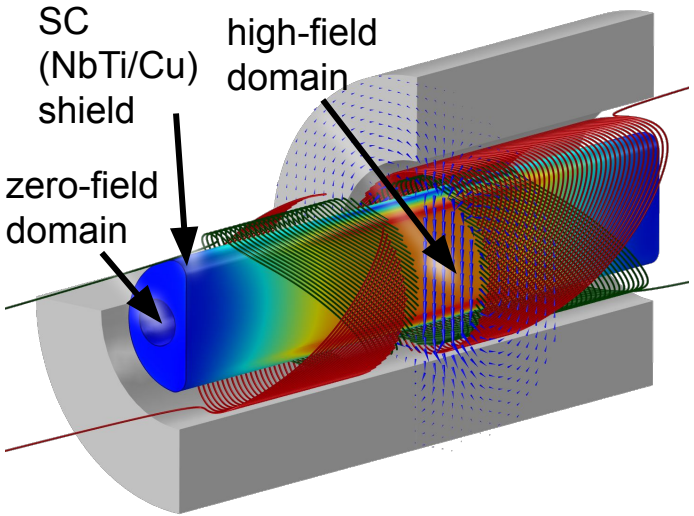
- 2014-2016 (D. Barna, CERN TE-ABT)
  - CERN ELENA (Extra Low ENergy Antiproton ring) electrostatic transfer lines: simulation, design, construction, commissioning
  - FCC-hh beam extraction concepts → Superconducting Shield (SuShi) septum idea

Hungary - from scratch

- 2016-2022
  - Wigner RCP signs FCC MoU, “SuShi septum for the FCC” project: CERN(💰 🎓)-Wigner (🛠️ 💡 💰)
    - University of Miskolc joins the project & FCC (💰 🎓 🛠️ 💡): NbTi/Cu multilayer superconducting sheet R&D
  - University of Miskolc joins hi-lumi LHC (Nb rolling tests for crab cavities) 🛠️
  - I.FAST (Innovation Fostering in Accelerator Science and Technology) EU(💰), Wigner RCP (💰 🛠️)
  - HITRIPlus (Heavy Ion Therapy Research and Infrastructure) - EU(💰), Wigner RCP (💰 🛠️)

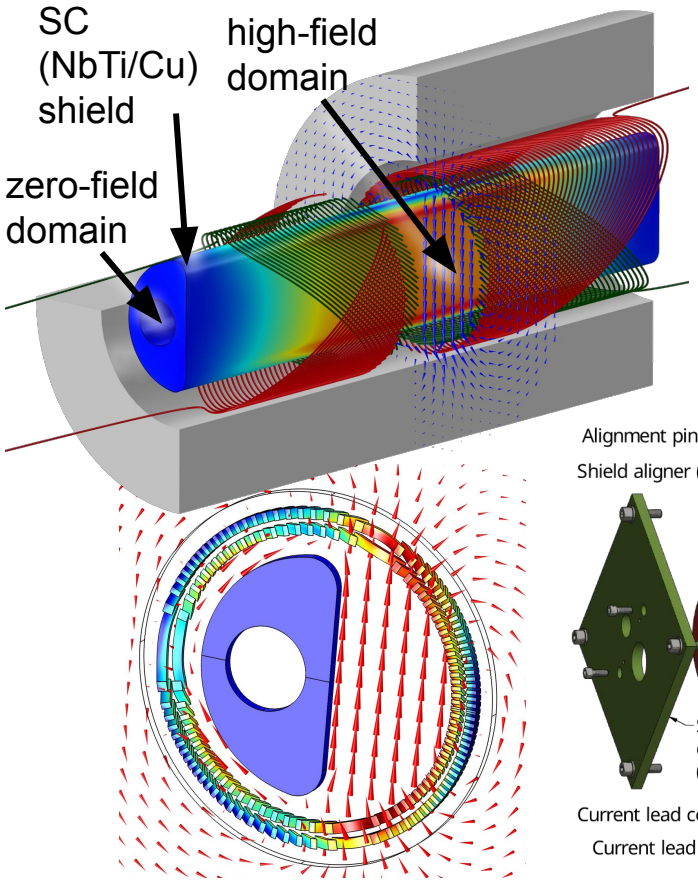
A single initial flagship project branched into several new activities, pulling in new partners and resources

SuShi septum for the FCC (CERN-Wigner RCP)

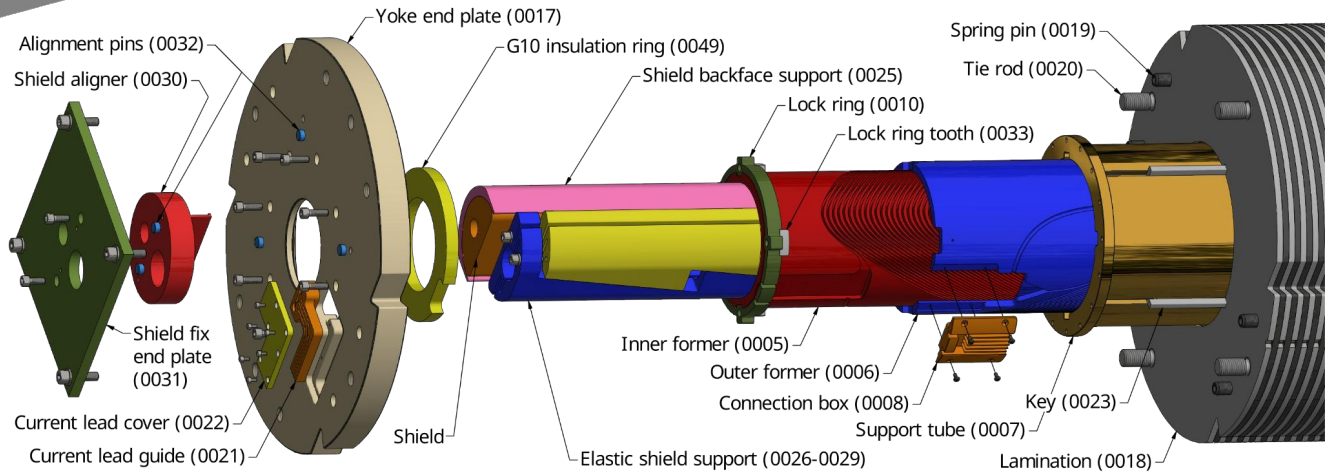


- Extraction of 8 GJ proton beam from FCC
- Concept: canted cosine theta (CCT)-like winding + SC shield
- Flagship project, starting a brand new activity at Wigner RCP (and in Hungary)

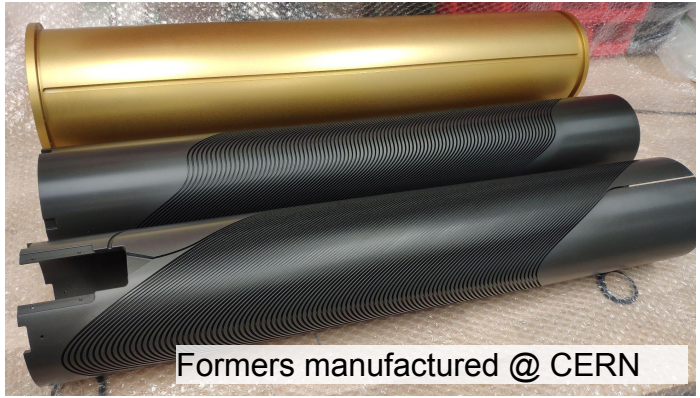
SuShi septum for the FCC (CERN-Wigner RCP)

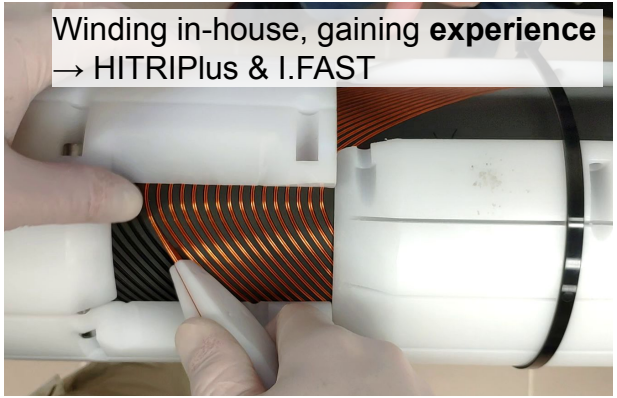


- Extraction of 8 GJ proton beam from FCC
- Concept: canted cosine theta (CCT)-like winding + SC shield
- Flagship project, starting a brand new activity at Wigner RCP (and in Hungary)



SuShi septum for the FCC (Wigner RCP)

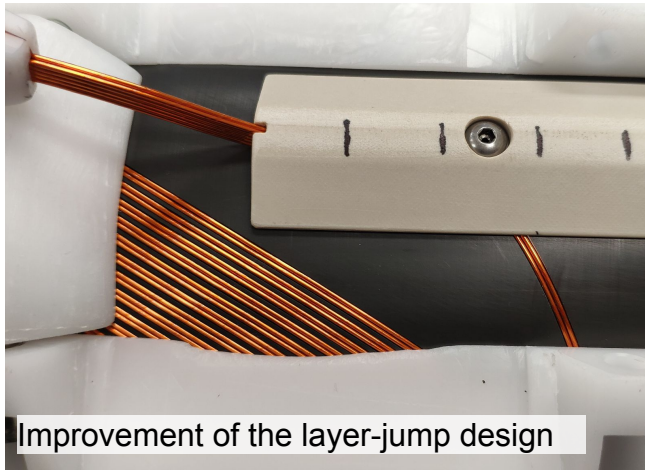

Formers manufactured @ CERN

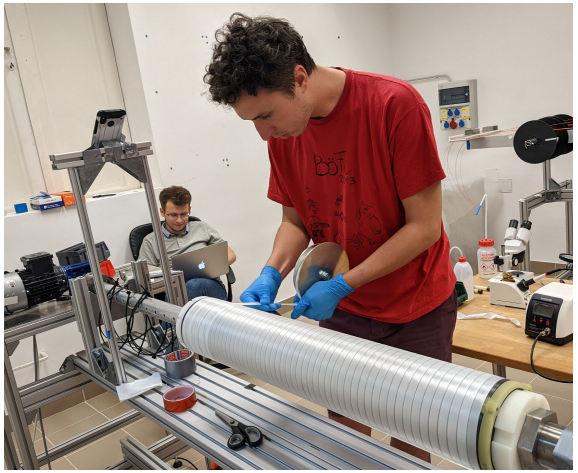

Winding in-house, gaining **experience** → HITRIPlus & I.FAST

CERN: continuous support (know-how, drawings, winding training, etc) Glyn Kirby, b.927 team

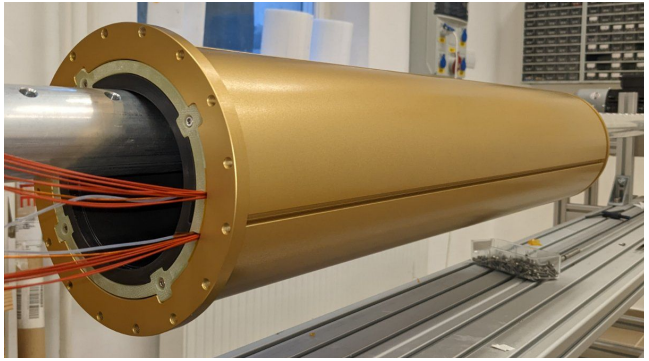
In return: feedback on design improvements, R&D, etc

Winding completed, waiting for wax impregnation


Improvement of the layer-jump design



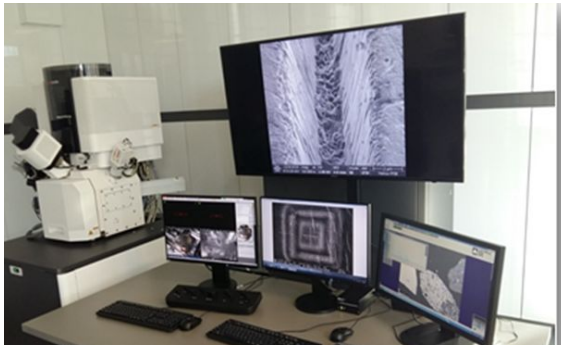
Testing: 2022 FREIA/Uppsala, 2023 CERN (with shield)



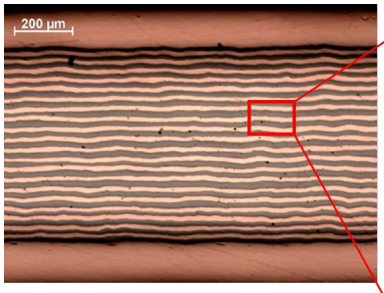
Superconducting NbTi/Cu multilayer R&D (Univ. Miskolc)

SuShi needs NbTi/Nb/Cu multilayer sheet (Nippon Ltd) - **very** expensive, and discontinued

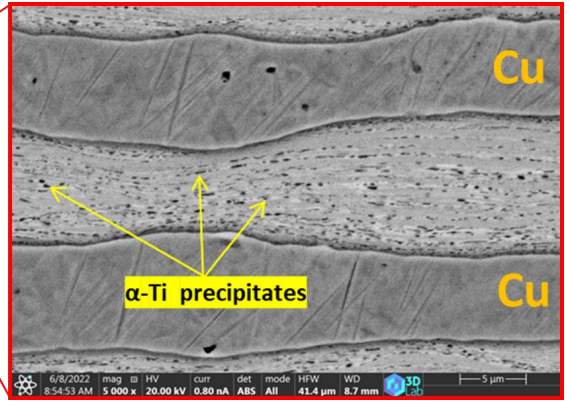
Akira Yamamoto → workshop with Nippon engineers to keep and improve know-how → called Uni. Miskolc (HU)



- Development of cost-effective **manufacturing technology** (rolling, forging, SPD metal forming)
- **Theory** (modelling, thermodynamic modelling, fine structure analysis)
- **Excellent research infrastructure**: 3D LAB @ Univ. Miskolc
- Secured **resources**: Thematic Excellence Program, Cooper. Doctoral Program



laminated structure



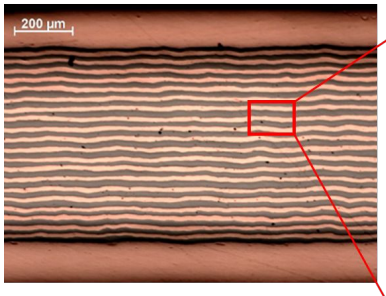
Superconducting NbTi/Cu multilayer R&D (Univ. Miskolc)

SuShi needs NbTi/Nb/Cu multilayer sheet (Nippon Ltd) - **very** expensive, and discontinued

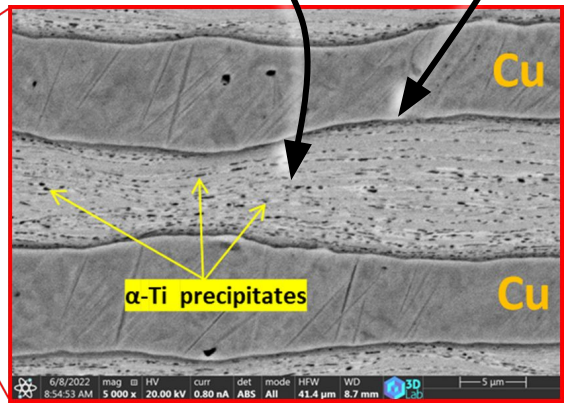
Akira Yamamoto → workshop with Nippon engineers to keep and improve know-how → called Uni. Miskolc (HU)

- Development of cost-effective **manufacturing technology** (rolling, forging, SPD metal forming)
- **Theory** (modelling, thermodynamic modelling, fine structure analysis
- **Excellent research infrastructure**: 3D LAB @ Univ. Miskolc
- Secured **resources**: Thematic Excellence Program, Cooper. Doctoral Program

- Eliminated the Nb layer (diffusion barrier)
  - cheaper & better
- α-Ti precipitates similar to Nippon (on-going J_c tests)



laminated structure



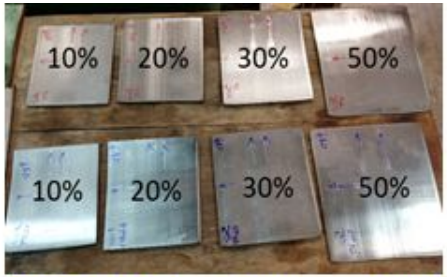
Hi-lumi LHC / Nb rolling tests for crab cavities (Univ. Miskolc)

Von Roll rolling mill

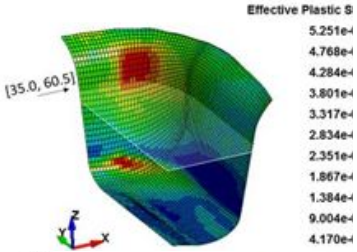
cross

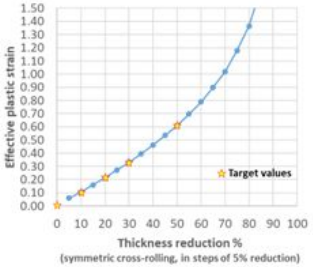
	10% HT		10% No HT		20% HT		20% No HT		30% HT		30% No HT		50% HT		50% No HT	
Pass number	Nominal Thickness	Nominal Thickness reduction	Measured Thickness	Thickness reduction	Measured Thickness	Thickness reduction	Measured Thickness	Thickness reduction	Measured Thickness	Thickness reduction	Measured Thickness	Thickness reduction	Measured Thickness	Thickness reduction	Measured Thickness	Thickness reduction
	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
	4		4.08		4.08		4.08		4.08		4.08		4.10		4.09	
1	3.8	5	3.92	3.92	3.91	4.17	3.93	3.68	3.93	3.68	3.92	3.92	3.93	4.15	3.92	4.39	3.93	3.91
2	3.6	10	3.63	11.03	3.62	11.27	3.66	10.29	3.69	9.56	3.66	10.29	3.70	9.76	3.66	10.73	3.67	10.27
3	3.4	15					3.43	15.93	3.42	16.18	3.41	16.42	3.41	16.83	3.42	16.59	3.42	16.38
4	3.2	20					3.21	21.32	3.20	21.57	3.19	21.81	3.20	21.95	3.19	22.20	3.19	22.00
5	3	25									2.97	27.21	3.00	26.83	2.98	27.32	2.98	27.14
6	2.8	30									2.81	31.13	2.81	31.46	2.76	32.68	2.77	32.27
7	2.6	35													2.60	36.59	2.57	37.16
8	2.4	40													2.39	41.71	2.38	41.81
9	2.2	45													2.20	46.34	2.19	46.45
10	2	50													2.01	50.98	2.01	50.86

extensive parameter space scans



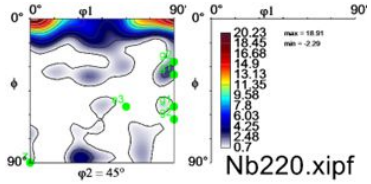
φ: 0.12 0. 24 0.37 0.70



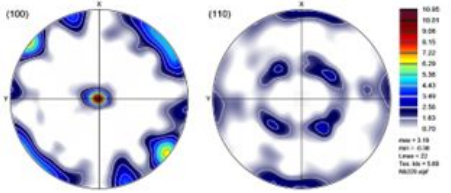


Nondestructive full texture characterisation

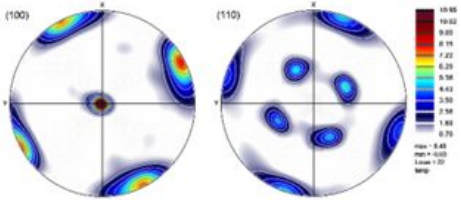
50%

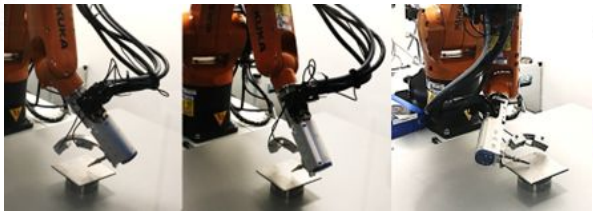


measured



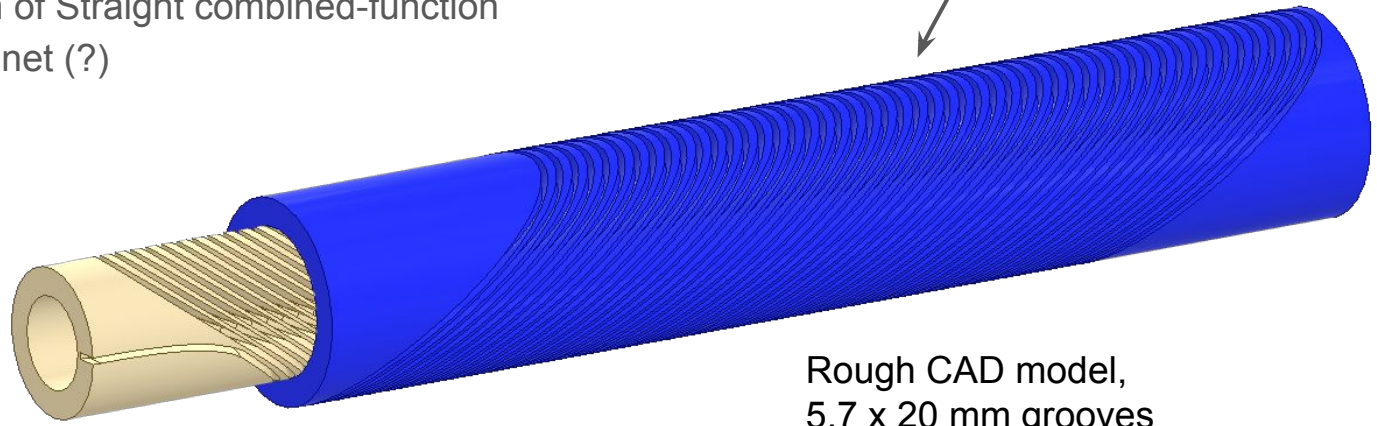
simulated





I.FAST project - Wigner RCP

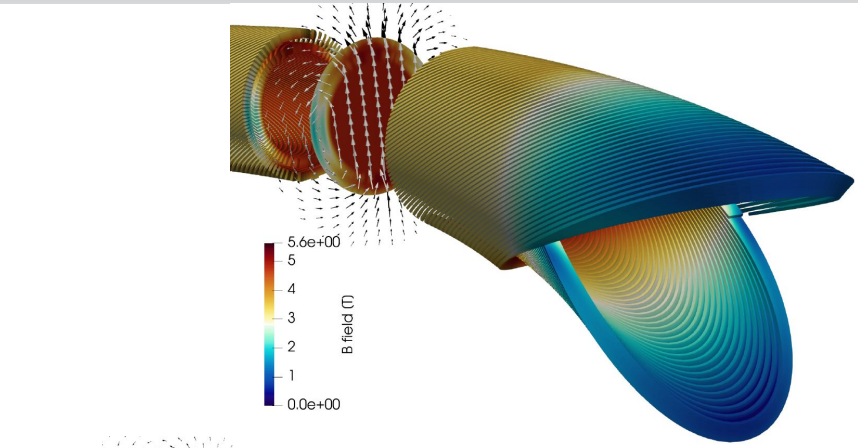
- WP8 - Innovative Superconducting Magnets
  - Combined-function straight NbTi CCT magnet prototype
  - Straight HTS CCT magnet prototype
- Tasks
  - Design, winding tests (+development of wax impregnation method…)
  - After the withdrawal of 2 industrial partners
    → construction of Straight combined-function NbTi CCT magnet (?)

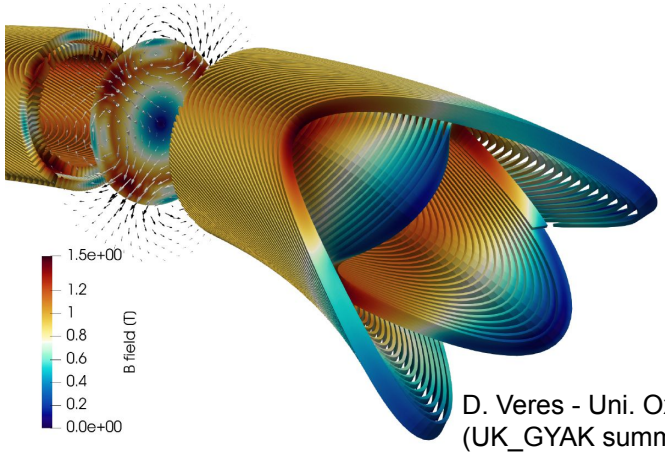


Rough CAD model,
5.7 x 20 mm grooves

HITRIPlus project - Wigner RCP

- Compact (8x8 m) SC synchrotron for **hadron therapy**
- WP8 - magnet design
  - Curved SC CCT magnet (ring, gantry)
- Our tasks
  - Winding geometry optimization (IEEE TAS 32 (2022), 4900914. doi: 10.1109/TASC.2022.3162389)
  - Magnetic design
  - Engineering design (task leader)
  - Do winding testing
  - Contribute to construction
  - Development of wax impregnation method

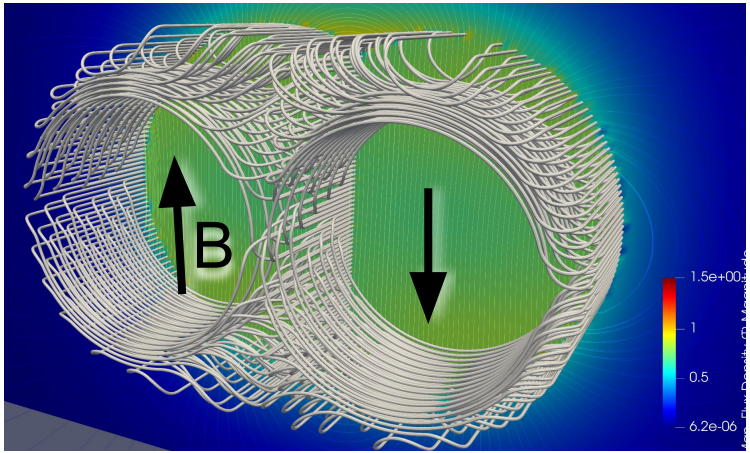


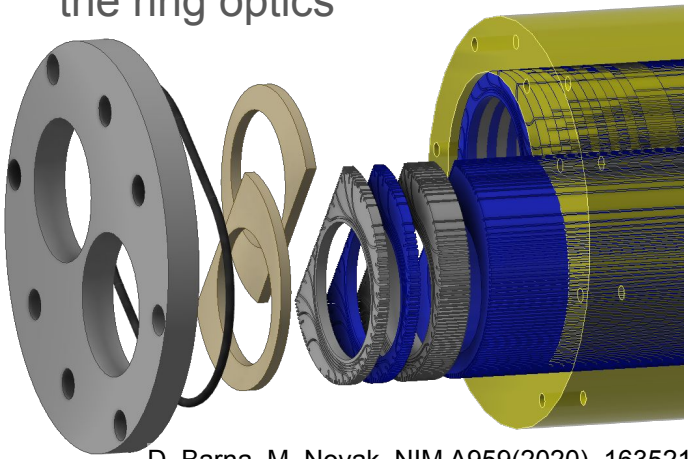


D. Veres - Uni. Oxford, Wigner RCP (UK_GYAK summer internship)

Complementing HITRIPlus: opposite-field septum magnet

- Opposite-fields in the two apertures
  - No magnetic force on the wall
  - Can be made very thin, even with high fields
- Extraction system can be **very compact** (key goal for HITRIPlus)
- Non-zero field in both apertures → part of the ring optics

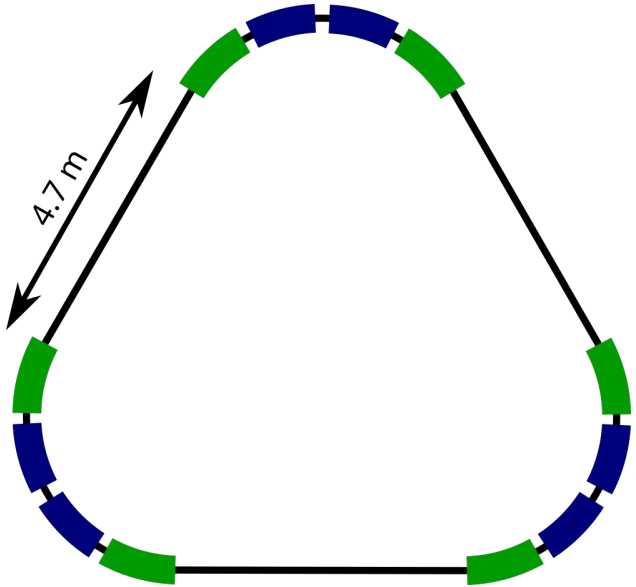




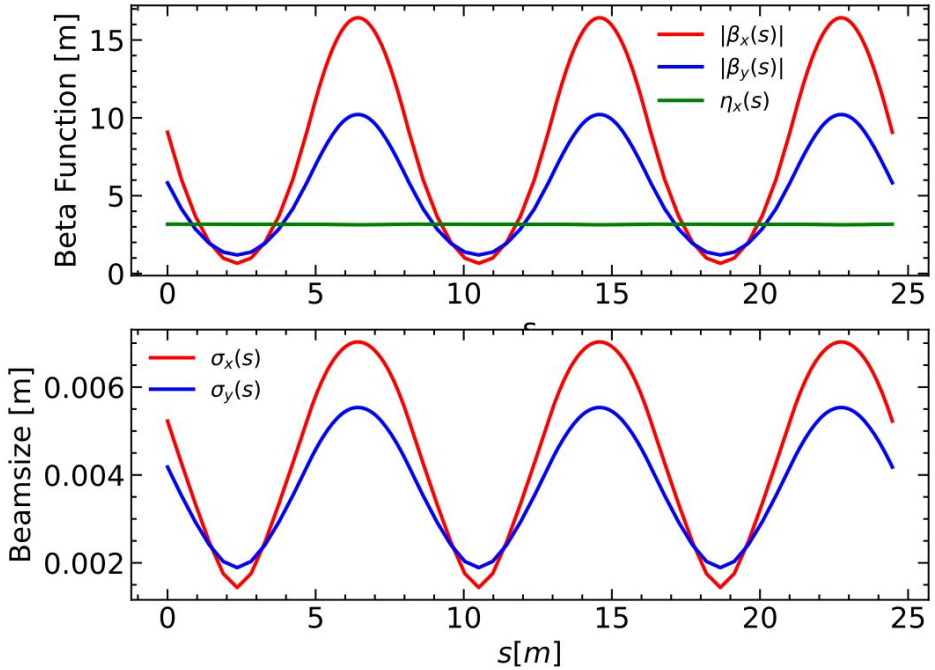
- **Accelerator-grade** field quality
- All-PEEK construction (no eddy currents, high ramp rate). Novel material in SC magnets.
- **Proposal** submitted to I.FAST Innovation Fund (Wigner RCP, University of Miskolc, Camilleon Ltd)

D. Barna, M. Novak, NIM A959(2020), 163521;
M. Szakály - Uni. Oxford, Wigner RCP (UK_GYAK internship report, unpublished)

HITRIPlus - optics design

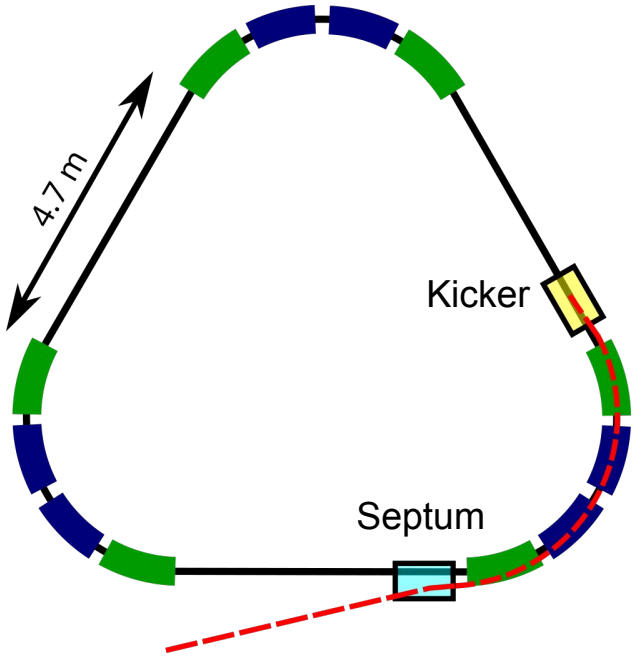


- Work out the optics for the triangular ring
- Weak focusing may give simplest configuration and smallest beamsize
- On-going work…

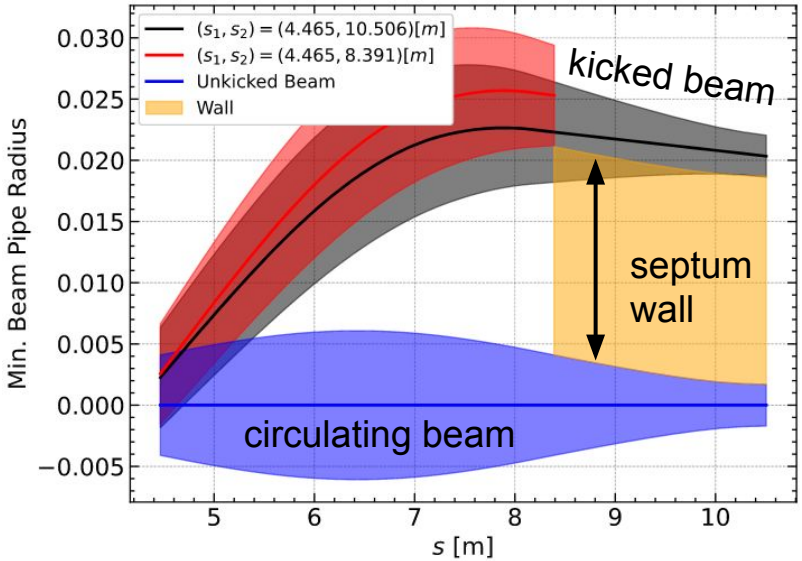


M. Koszta - Imp. College London, Wigner RCP (UK_GYAK internship), E. Benedetto (Tera Found.)

HITRIPlus - optimize the extraction optics



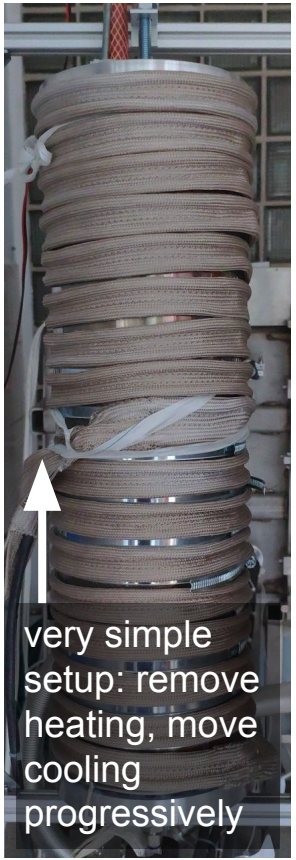
- Straight sections far too short
  - Best kicker+septum arrangement: before/after bending section
- → Kicked beam must traverse dipoles - aperture?
- Proposed opposite-field septum may be the key (minimal wall thickness)

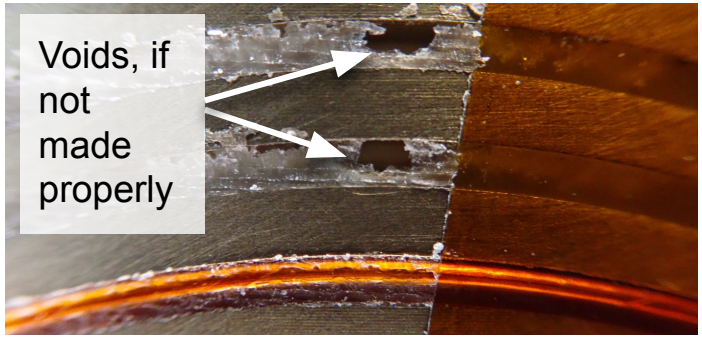


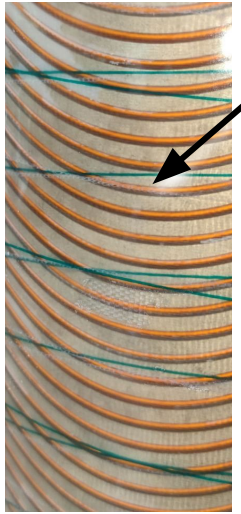
M. Koszta - Imp. College London, Wigner RCP (UK_GYAK internship), E. Benedetto (Tera Found.)

Wax impregnation R&D

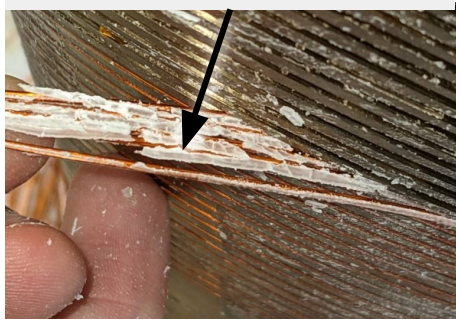
- Experiments @ PSI: wax-impregnated short Nb_3Sn sample - no training!
  (M. Daly, et al., Supercond. Sci. Tech. 35, 055014)
- SuShi prototype right before impregnation → volunteer to be one of the first wax'ed CCT magnet
  - R&D for void-free impregnation of complex geometry
- Several other projects can benefit
  - HITRIPlus ring magnets
  - I.FAST HTS CCT magnet (HTS is prone to delamination if epoxy-impregnated)
  - Opposite-field septum magnet
  - CERN/Spain "Fusillo" project







Latest: perfect filling (transparent!) even between the strands if made well.



Resources - budget

Budget [kCHF]	R&D infrastructure	SuShi septum	NbTi/Cu multilayer R&D	HITRIPlus	Opposite-field septum	I.FAST	Wax impregnation testing
FCC Study [250] - Wigner							
HITRIPlus [18] - Wigner							
I.FAST [25] - Wigner							
OTKA [39] - Wigner							
UK_GYAK - Wigner (5 x 3 summer-student-months)							
Specific infrastructure grants [~20] - Wigner							
Thematic Excellence Program [240] - Miskolc							
Cooperative Doctoral Program [75] - Miskolc-Wigner							
Matching funds + misc. [~(Wigner) (manpower, consumables, infra, etc)							

Organization of activities into projects is sometimes artificial (everything is cross-linked)

Diverse financing scheme

Financing issues, strategy

- Accelerator R&D is costly, complex and expensive
  - The field must find societal application → justification of costs
  - ..and a market → to lower prices, become affordable/sustainable
- Accelerator (technology) R&D financing is difficult
  - not fundamental research
  - has a difficult market - few accelerators only
- Grants often encourage (require)
  - Collaboration with industry 👍
  - Delivery of a marketable product + business plan/revenue by the end of the project 👎
    - Accelerator components are often 1-off, no big market
    - Key benefits: technology, know-how accumulating at industrial partner, collaboration and involvement (→ business capital)

Resources - manpower, organization

Wigner Research Centre for Physics (5 years history) - **application**, integration in accelerators, magnetic design, simulation, **concepts**, assembly and construction, etc	
Manpower	Infrastructure
• 2 researchers (PhD) • 1 technician • 1 BSc • regular undergraduate summer students from the UK • several high-school students with their teacher (student demo projects)	• CCT magnet winding machine • Vacuum impregnation system • COMSOL simulation framework • In-house mechanical workshop
University of Miskolc - material and manufacturing **technology**	
Manpower	Infrastructure
• 1 professor • 2 dedicated PhD student • 4 staff + technicians	• Von Roll rolling mill, hot/cold rolling • X-ray diffractometers • Optical microscopy • SEM, TEM • Micro CT • Thermal analysis - DSC, DTA • PVD magnetron sputtering

Strategy

- Have both long-term and short-term visions:
  - FCC – an excellent environment (secured 💰, organized networking □, support novel ideas 💡)
  - Societal applications: HITRIPlus (hadron therapy) & I.FAST

overlapping activities, common technologies, perfect synergy

- Target very specific, well-defined goals with short-term deadlines.
- Join activities with/of leading players of the field, contribute missing resources (manpower, concepts) – “market(academia)-driven” approach
  - Ensures proper integration into, and application in justified projects
  - Basis for a mutually beneficial collaboration: 🎓→ HU, 🛠️💡 → partner
- Concentrate on small and innovative projects
  - Significant added value
  - Requiring moderate infrastructure (w.r.t. standard “big science”)
  - Involve industrial partners - (S)MEs with sufficient resources but no big inertia
- Concentrate on students (starting from high school!)
- Collaborate, diversify know-how and capabilities

Acknowledgments

- FCC Study Group
- Ministry of Innovation / Hungarian National Research, Development and Innovation Office
  - OTKA K124945
  - 2019-2.1.6-NEMZ KI-2019-00008
  - TKP-17-1/PALY-2020
  - Co-operative Doctoral Program of the Ministry of Innovation and Technology financed from the National Research, Development and Innovation Fund
  - UK_GYAK (summer students from abroad)
- European Union's Horizon 2020 research and innovation programme
  - 101008548 (HITRIPlus)
  - 101004730 (I.FAST)