

Transverse pressure sensitivity of state-of-the-art Nb₃Sn Rutherford cables



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1. Experimental

- Set-up @ UTwente
- Samples

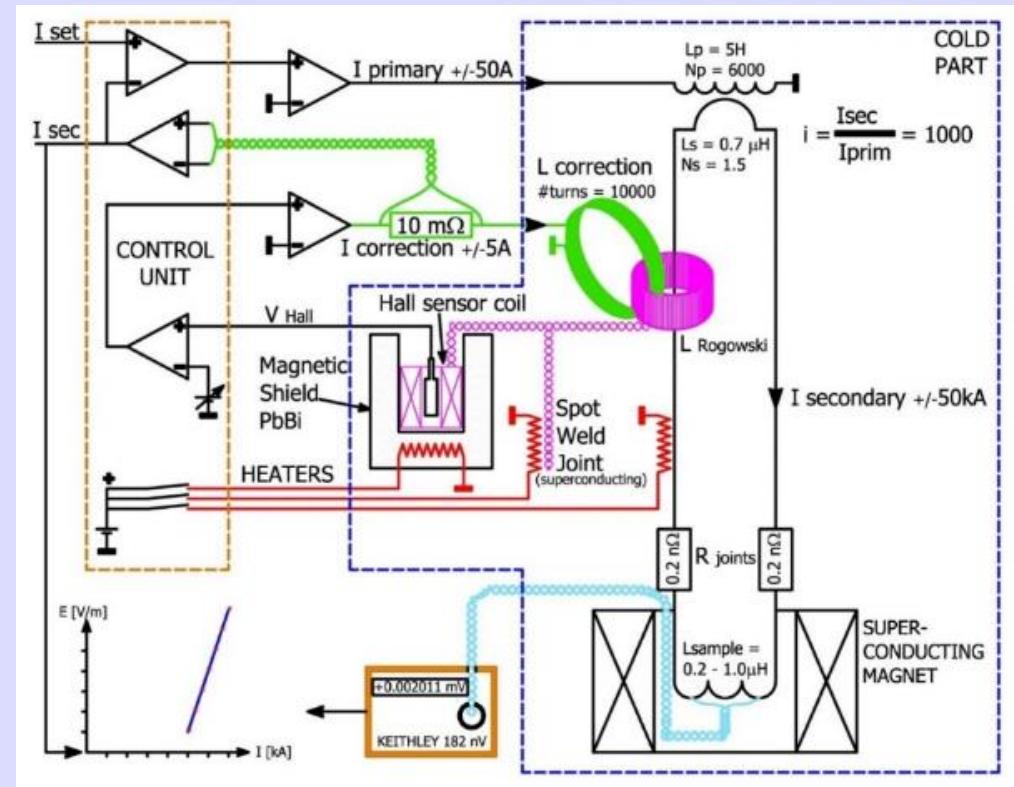
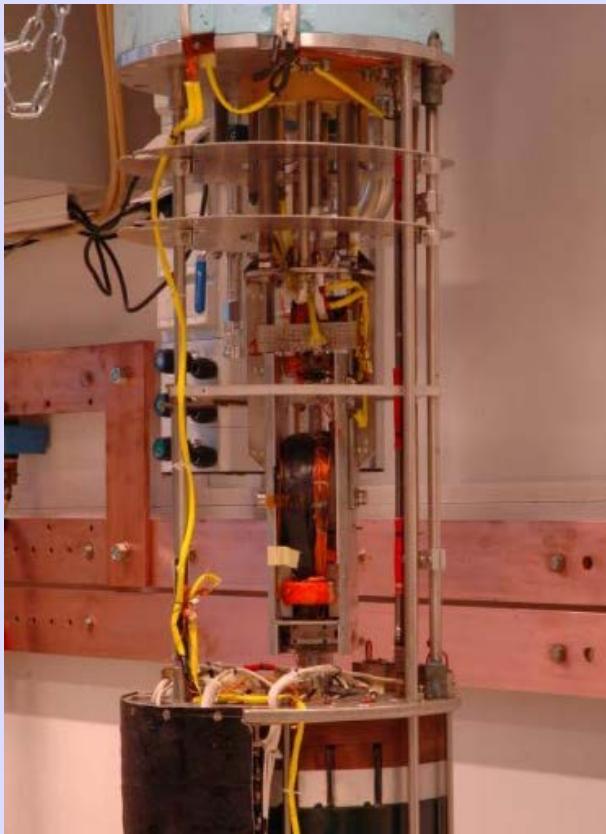
2. Results

- DS cables
- SMC cables

3. Conclusions

1. Experimental: the set-up @ UTwente

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Van de Klundert, 1981

50 kA superconducting transformer in 11T solenoid

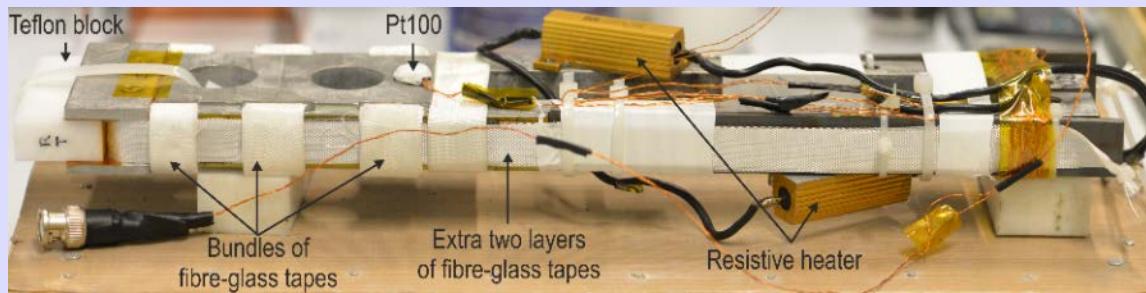
1. Experimental: the set-up @ UTwente



Heat treatment ...



... transfer ...



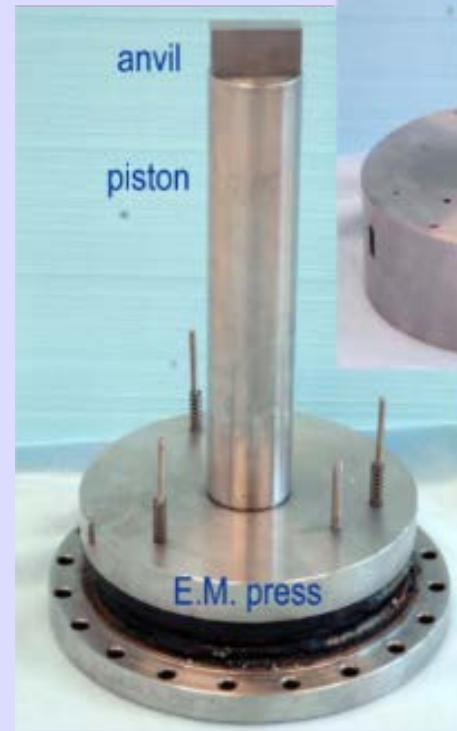
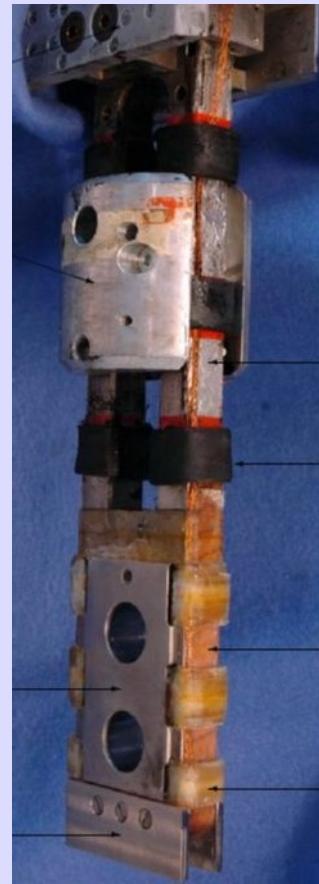
... impregnation

'hairpin'- type samples

1. Experimental: the set-up @ UTwente

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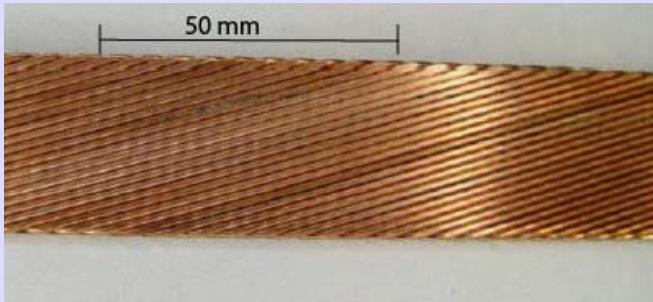
- 240 kN E.M. cryo-press
- custom-cut pushing anvil (w. strain gauges)
- Displacement read-out



1. Experimental: State-of-the art cable samples

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Sample	cross section (mm ²)	strand type	# of strands	keystone (°)	transposition length (mm)
DS-RRP	14.7 × 1.25	RRP-108/127	40	0.75	100
DS-PIT-1	14.7 × 1.25	PIT-114	40	0.71	100
DS-PIT-2	14.7 × 1.25	PIT-114	40	0.71	100
SMC-RRP-1	10 × 1.8	RRP-132/169	18	0	63
SMC-RRP-2	10 × 1.8	RRP-132/169	18	0	63
SMC-PIT-1	10 × 1.8	PIT-192	18	0	63
SMC-PIT-2	10 × 1.8	PIT-192	18	0	63



Strand	diameter (mm)	Cu / non-Cu ratio
RRP-108/127	0.7	1.19
PIT-114	0.7	1.25
RRP-132/169	1	1.22
PIT-192	1	1.22

Impregnation

- DS : MY740/HY906/DY062 (100/90/02)
- SMC : CTD101-K (A/B/C = 100/90/1.5)

1. Experimental

- Set-up @ UTwente
- Samples

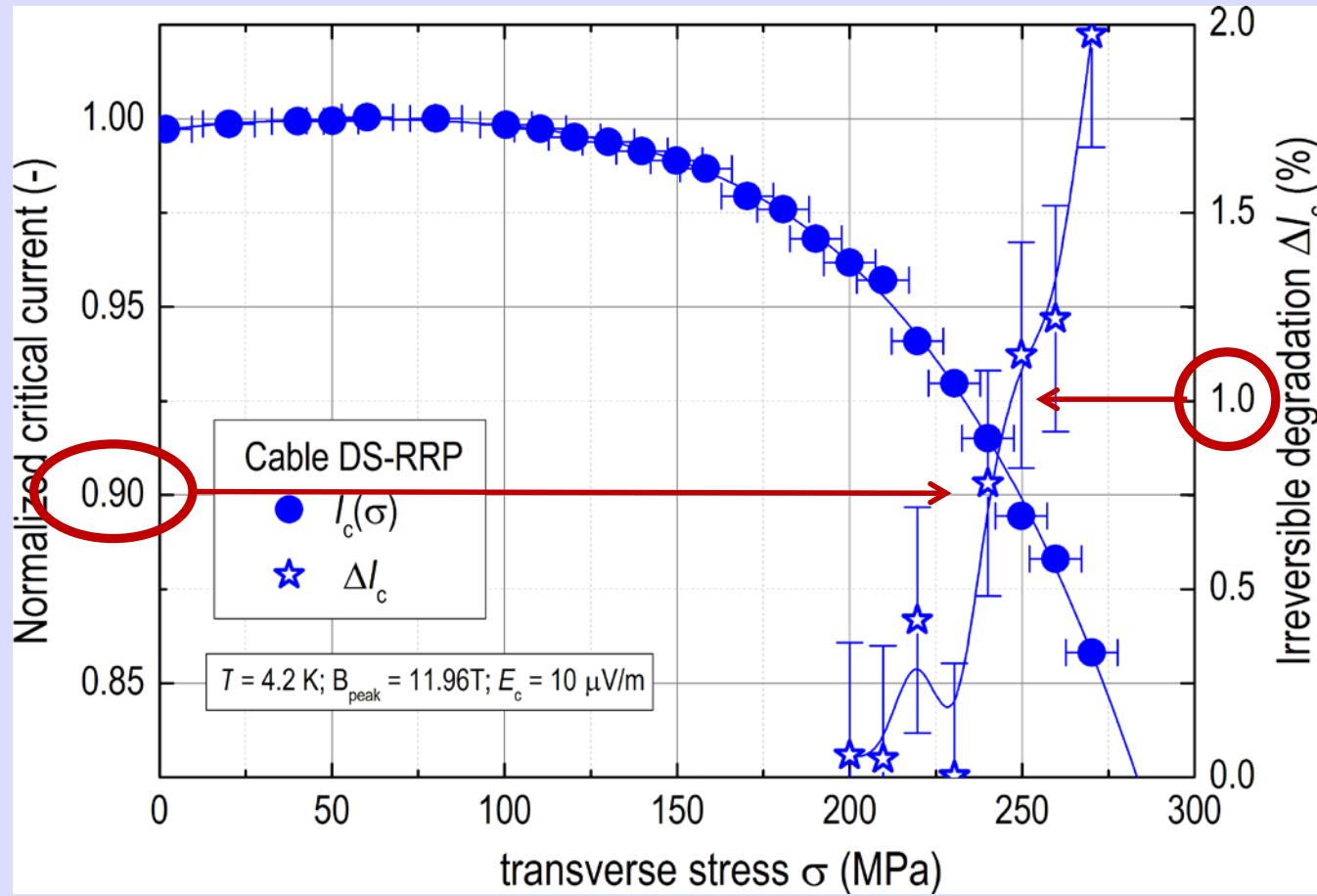
2. Results

- DS cables
- SMC cables

3. Conclusions

2. Results

DS RRP cable

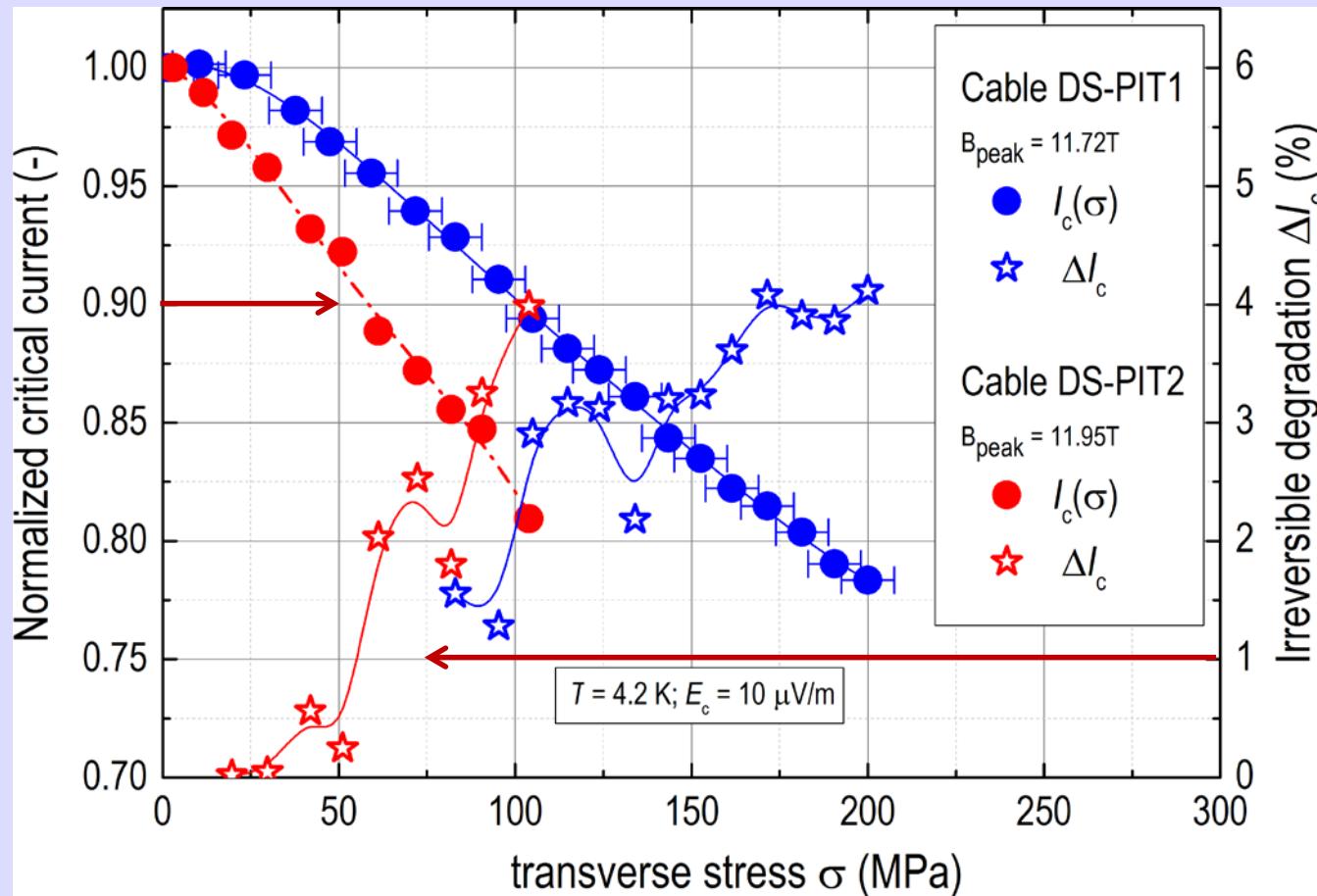


van de Camp, 2012

$\sigma_{-10\%} \approx 240 \text{ MPa}$; $\sigma_{-1\%, \text{ irr.}} \approx 250 \text{ MPa}$

2. Results

DS PIT cables

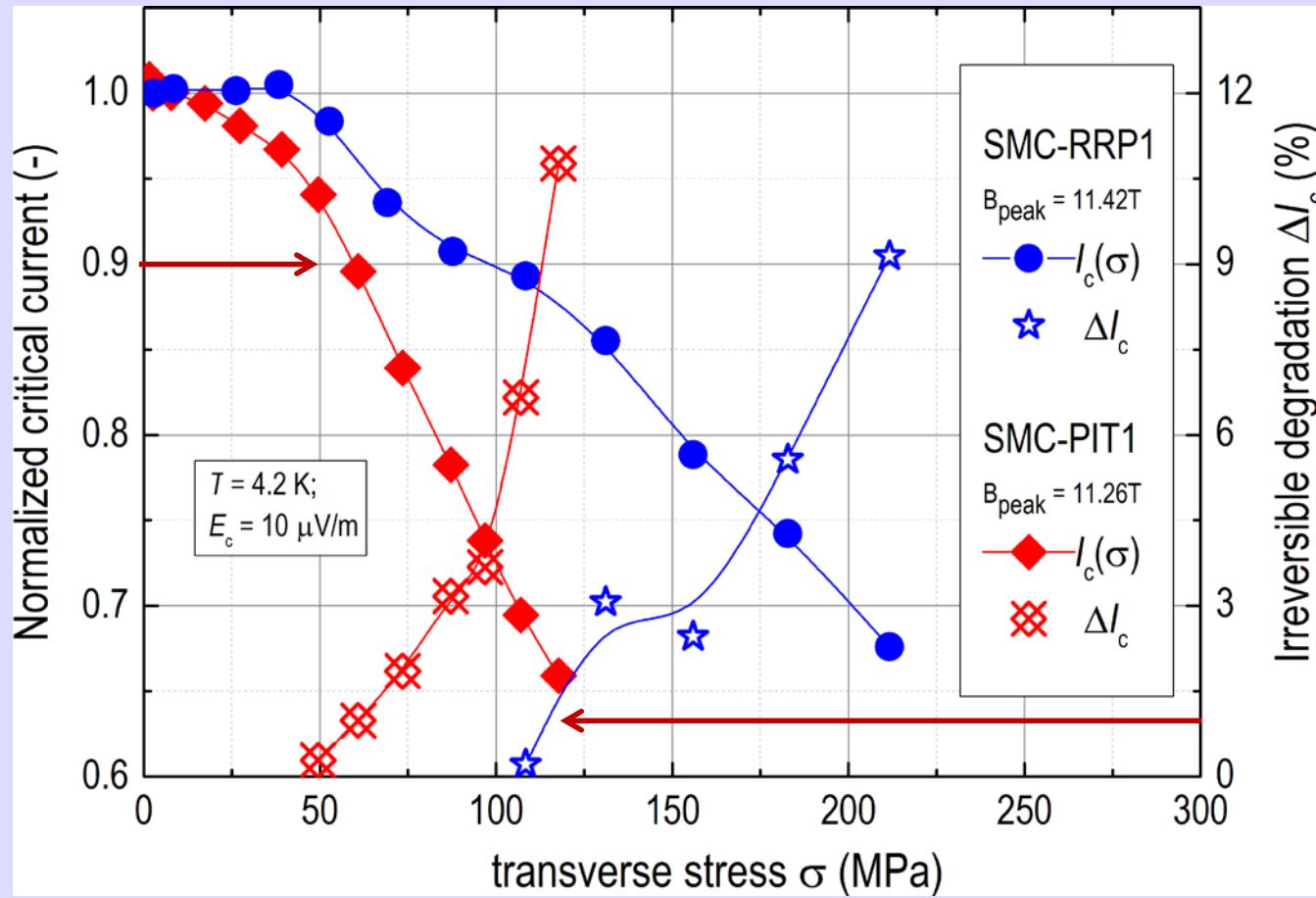


Gao, 2017

$\sigma_{-10\%} \approx 70\text{-}100 \text{ MPa} ; \sigma_{-1\%, \text{ irr.}} \approx 50 \text{ MPa}$

2. Results

SMC cables

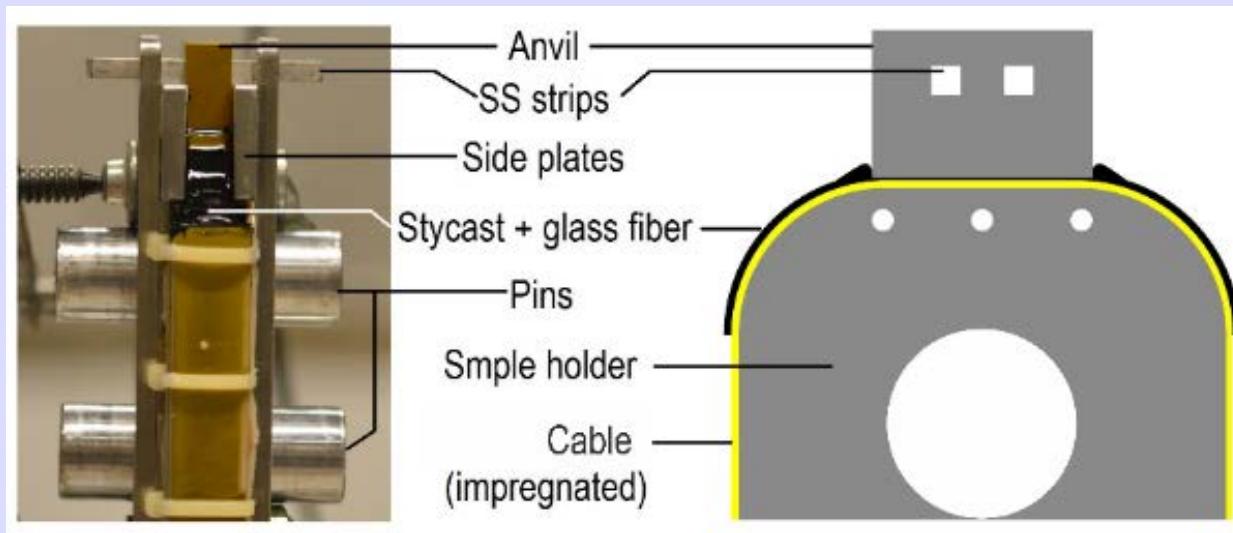


Gao, 2017

$\sigma_{-10\%} \approx 70-100 \text{ MPa} ; \sigma_{-1\%, \text{ irr.}} \approx 70-120 \text{ MPa}$

Benchmarking exercise :

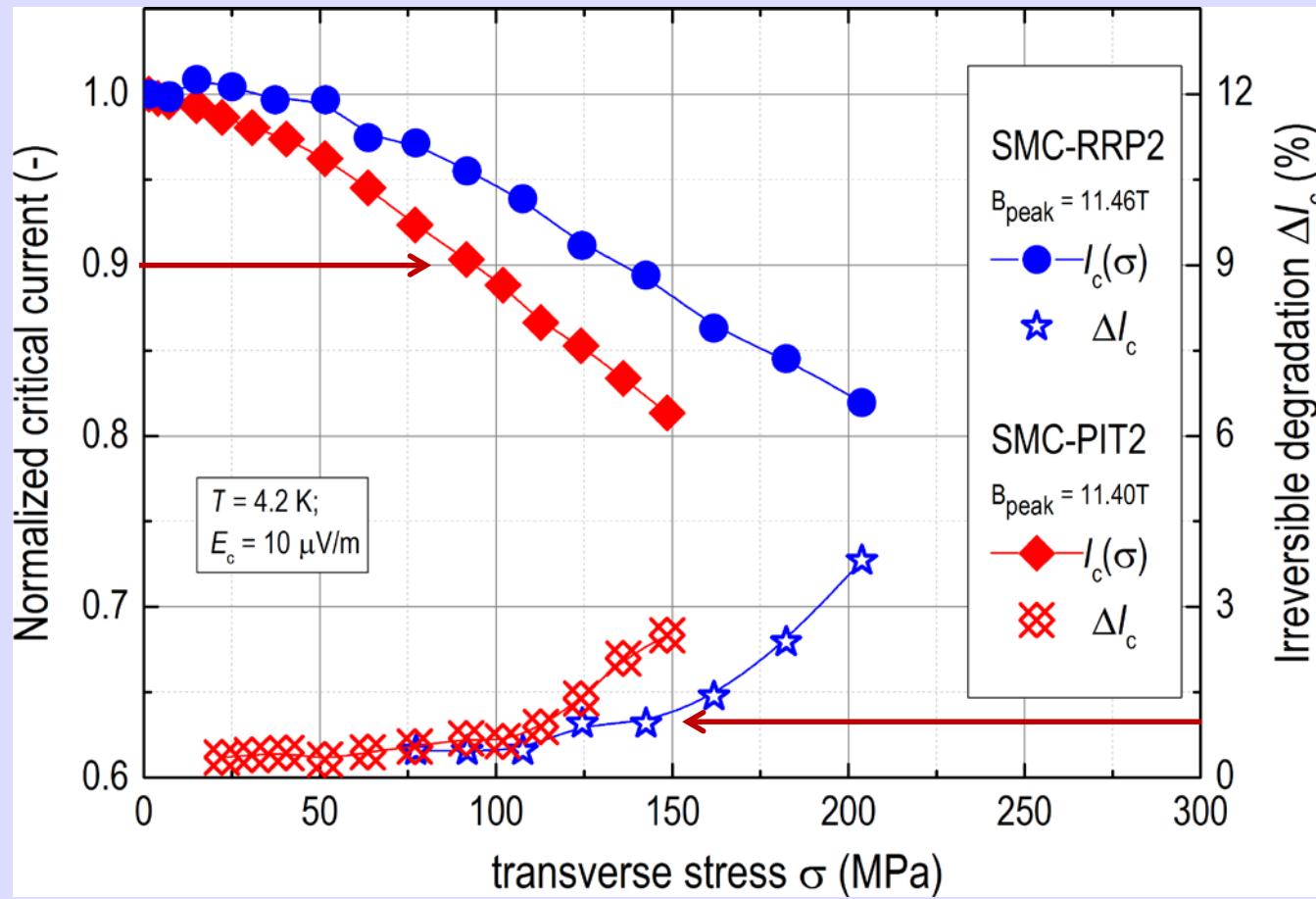
- SMC comparison with CERN data inconsistent
- Problem was identified as parallelism issue (**just 0.2° !**) between anvil and cable sample
- Remedied with extra tooling & 2nd impregnation step



2. Results

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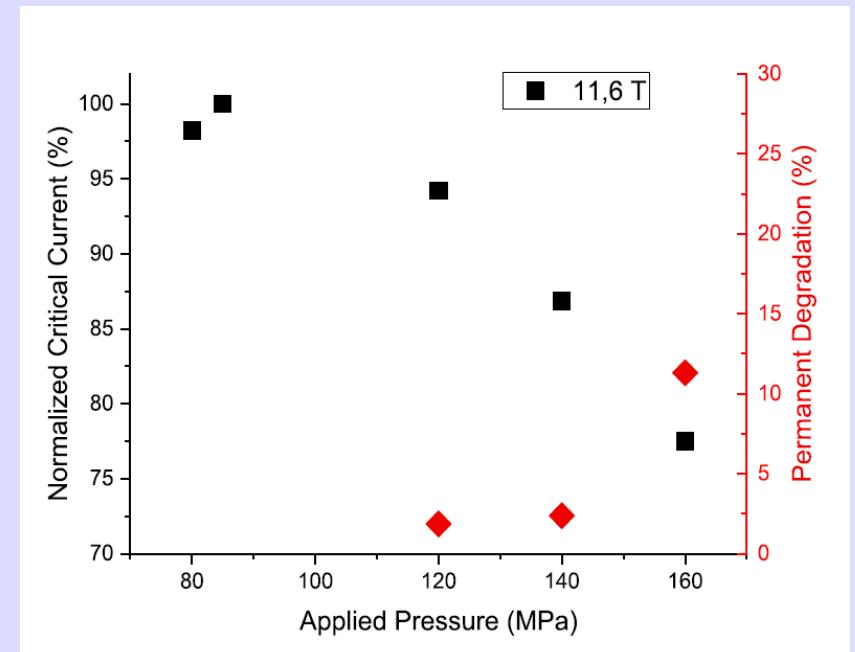
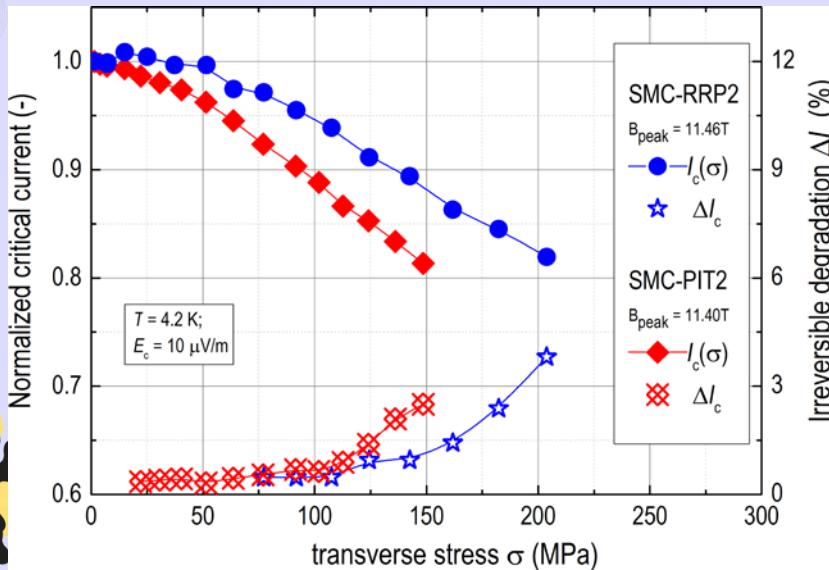
New SMC cables (of same strand material) after 2nd impregnation



Gao, 2018

$\sigma_{-10\%} \approx 100\text{-}140 \text{ MPa}$; $\sigma_{-1\%, \text{ irr.}} \approx 120\text{-}150 \text{ MPa}$

Benchmarking SMC RRP between UTwente & CERN



Duveauchelle, 2018 (CERN, RT loading)

UTwente:

$$\Delta I_c = -10\% \text{ @ } \sigma \approx 135 \text{ MPa}$$

$$\Delta I_{c, irr} = -1\% \text{ @ } \sigma \approx 150 \text{ MPa}$$

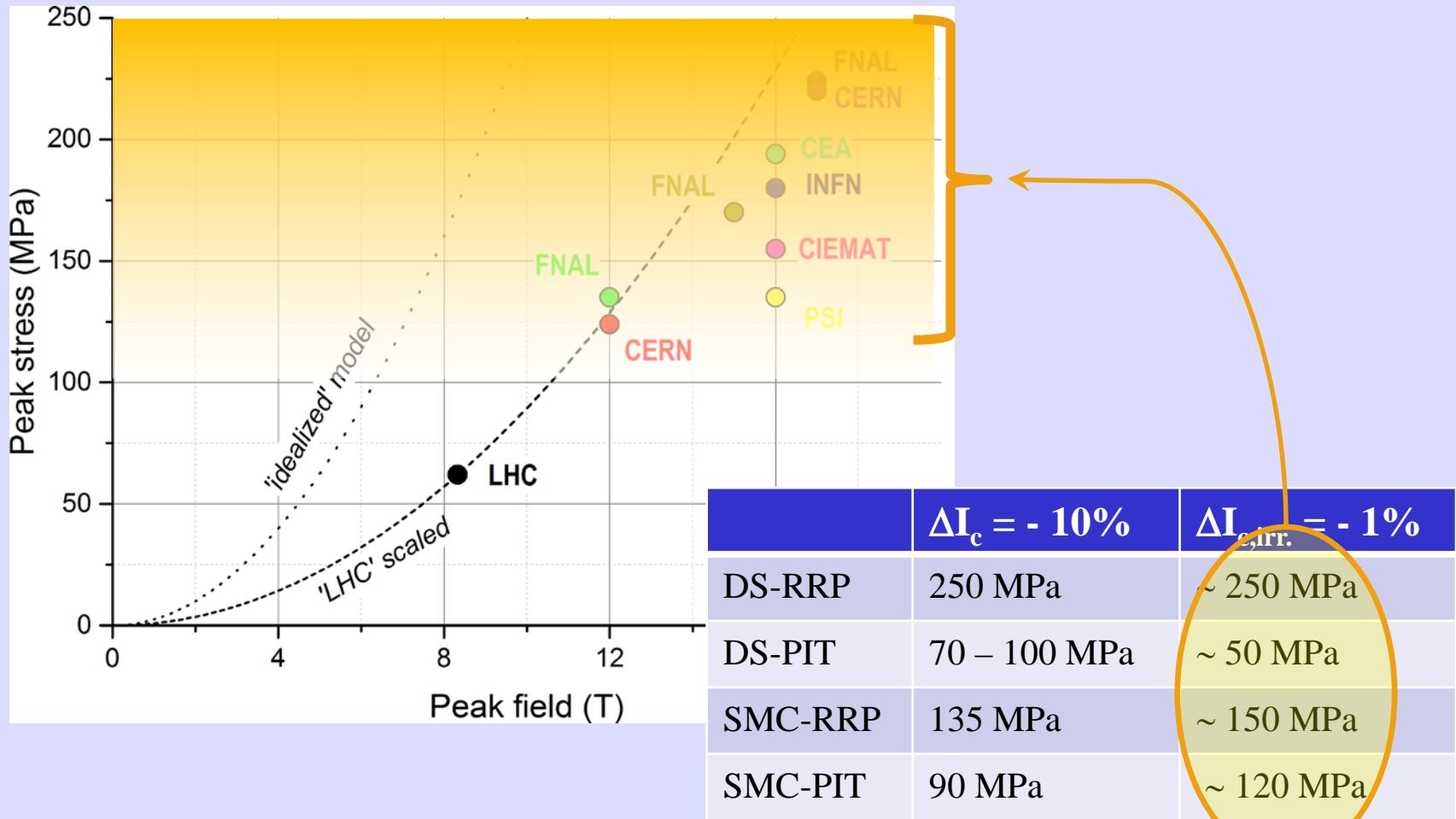
CERN:

$$\Delta I_c = -10\% \text{ @ } \sigma \approx 130 \text{ MPa}$$

$$\Delta I_{c, irr} = -1\% \text{ @ } \sigma \approx 150 \text{ MPa}$$

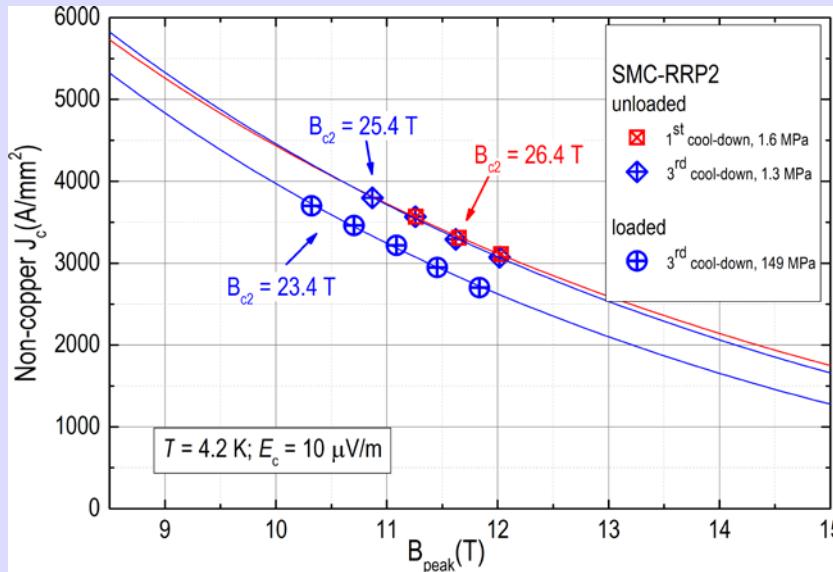
2. Results

Summary so far:

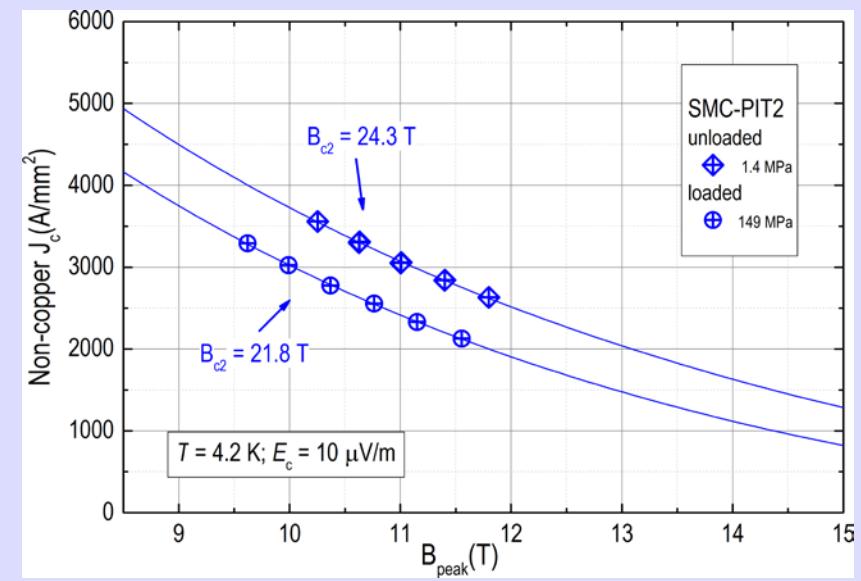


2. Results

To be investigated further :

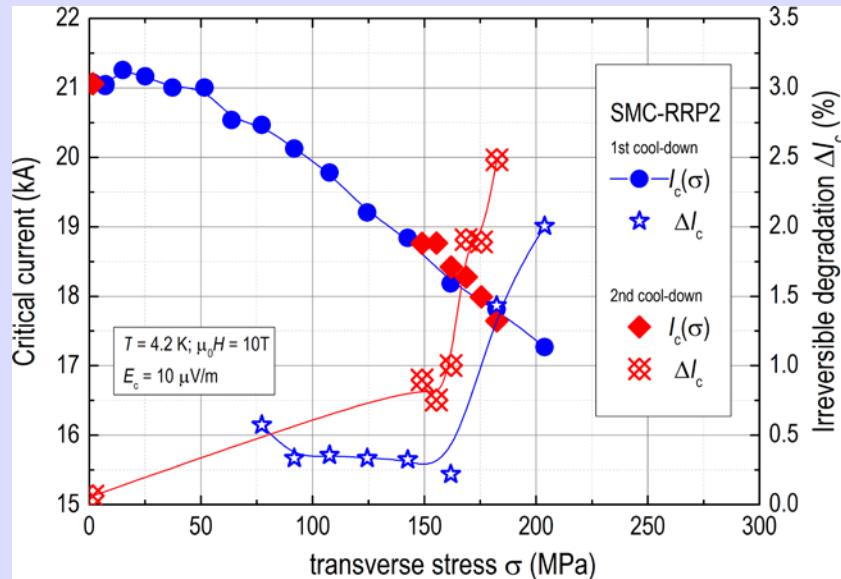


Reversible effect on B_{c2} ...



2. Results

To be investigated further :



Effect of thermal cycling & mechanical cycling

Cycle	SMC-PIT2 (1 st cool-down)		
	$I_c(149 \text{ MPa})$ (kA)	$I_c(1.6 \text{ MPa})$ (kA)	ΔI_c irrev. (%)
1	14.78	17.57	-3.22
2	14.73	17.57	-3.22
3	14.74	17.53	-3.43
4	14.73	17.52	-3.50
5	14.75	17.51	-3.52

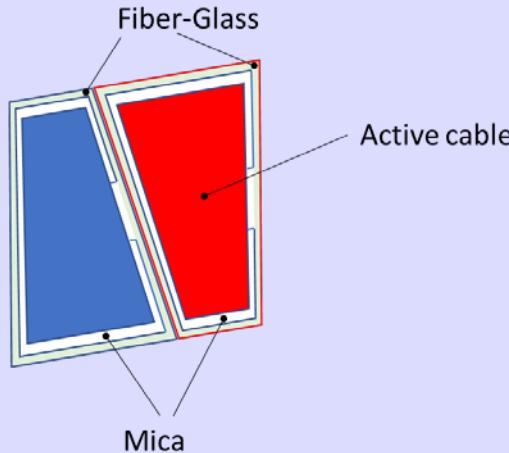
Cycle	SMC-RRP2 (2 nd cool-down)			SMC-RRP2 (3 rd cool-down)		
	$I_c(149 \text{ MPa})$ (kA)	$I_c(1.6 \text{ MPa})$ (kA)	ΔI_c irrev. (%)	$I_c(175 \text{ MPa})$ (kA)	$I_c(1.4 \text{ MPa})$ (kA)	ΔI_c irrev. (%)
1	18.67	20.86	-1.00	18.14	21.11	+0.16
2	18.91	20.87	-0.97	18.05	21.08	+0.02
3	18.72	20.90	-0.80	18.12	21.10	+0.11
4	18.76	20.88	-0.90	18.13	21.06	-0.07

2. Results

Ongoing:
11T High-Lumni cable

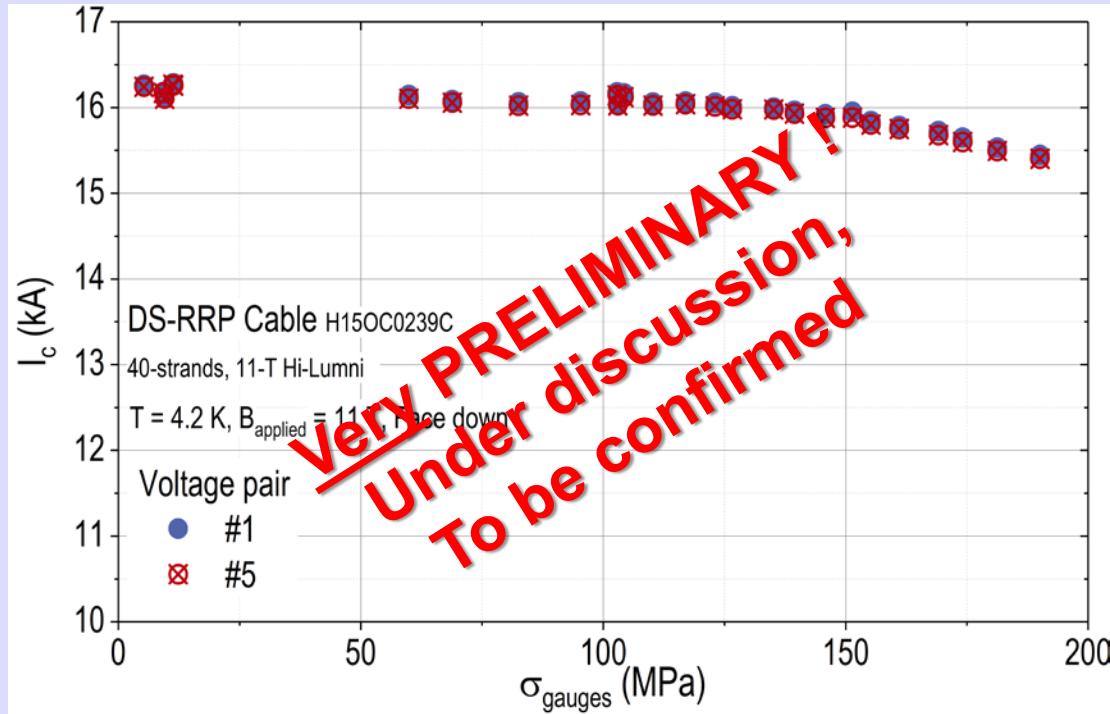
H15OC0239C

Production length:	235m
Transposition pitch:	100mm
Mid thickness:	1.254mm ($\sigma = 0.000$)
Width:	14.695mm ($\sigma = 0.002$)
Keystone angle:	0.784° ($\sigma = 0.014$)
N. of strands:	40
Core width:	12mm
Core thickness:	25 μm
Strand diameter:	0.70mm
Production date:	23/11/2017

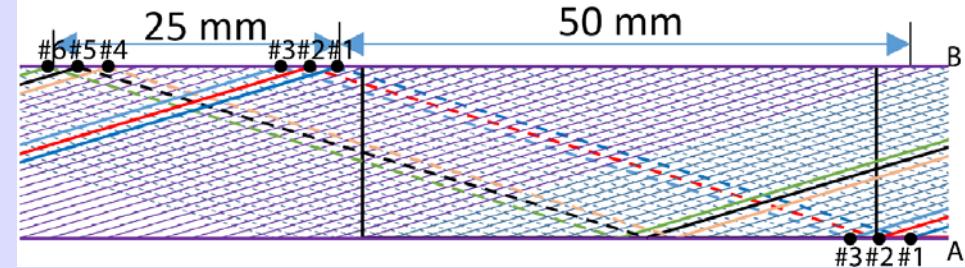


2. Results

Ongoing: 11T High-Lumni cable



Very PRELIMINARY!
Under discussion,
To be confirmed



3. Conclusions

- 16T-class magnets imply transverse pressures of $\sim 150 - 200$ MPa, cable data are scattered (!), but indicate this is ambitious;
- Better understanding of *local* stress distribution (and the parameters involved!) is needed (and evolving);
- Benchmarking exercises remain very useful;
- Stringent magnet-production quality-control will be essential.