Parameter range for protection analysis

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on behalf of the MQXF collaboration

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Motivation

E. Ravaioli

Nominal current (I_{nom}=16.5 kA)			
STEAM-LEDET sims MQXFB, 7.15 m	**Reference parameters**	**Realistic* parameters uniformly distributed**	**Realistic* parameters not uniformly distributed**
No failures	≤615	≤636	≤927
2 QH failures	≤641	≤657	≤920
1 CLIQ and 1 QH failures	≤578	≤604	≤820

Ultimate current (I_{ult}=17.8 kA)			
STEAM-LEDET sims MQXFB, 7.15 m	**Reference parameters**	**Realistic* parameters uniformly distributed**	**Realistic* parameters not uniformly distributed**
2 QH failures	≤816	≤846	≤1167

*Realistic conductor parameters by B. Bordini: Cu/noCu = 1.10-1.25; RRR = 150-250 indico.cern.ch/event/828604/contributions/3471761/
Re-assessment in progress

Initial hot-spot resistance neglected. All simulations run with STEAM-LEDET . Simulations cross-checked by V. Marinozzi (FNAL).

For realistic* parameters, with up to two failures, and **coil ordering**
→ **Worst-case**: U_g<670 V at I_{nom}, U_g<850 V at I_{ult}
Ordering coils within a magnet is needed to keep peak voltages to ground within electrical design criteria

Note: MQXFA values are ~1.7 lower (ordering may not be needed)

Objectives

- Asses our capability to predict the RRR of a coil prior to magnet assembly based on conductor and cable qualification samples (we relay on coil-ordering to keep voltage to ground within electrical design criteria).

- Compare parameter range considered for protection simulations with the available data up to now. Current assumption for simulations:
  - Cu/noCu = 1.10-1.25;
  - RRR = 150-250

CERN – Available data

Bernardo Bordini,
Jerome Fleiter

	CERN
Round samples	For a fraction of the production: ≥ 1/spool Supplier For the rest 3/billet Supplier 1/spool CERN
15 % rolled samples	1/billet CERN 1/billet Supplier
Cable* (qualification samples)	2/billet (1 virgin and 1 extracted) in the cable (4-5 per UL)
Coil** (witness samples)	6/coil (3 virgin and 3 extracted), coming from 3 different billets

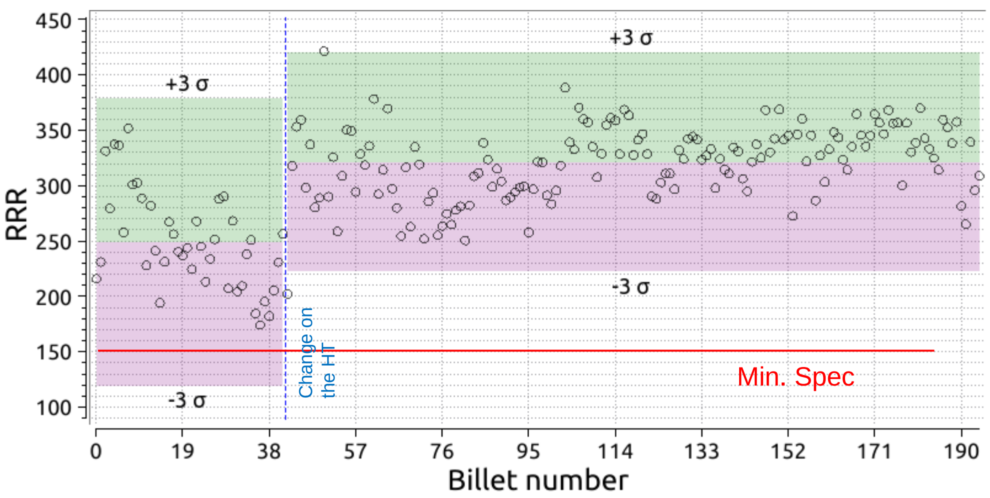
*   Extracted form the cable, reacted by CERN cable team
** Extracted form the cable, reacted with the coil

Bernardo Bordini

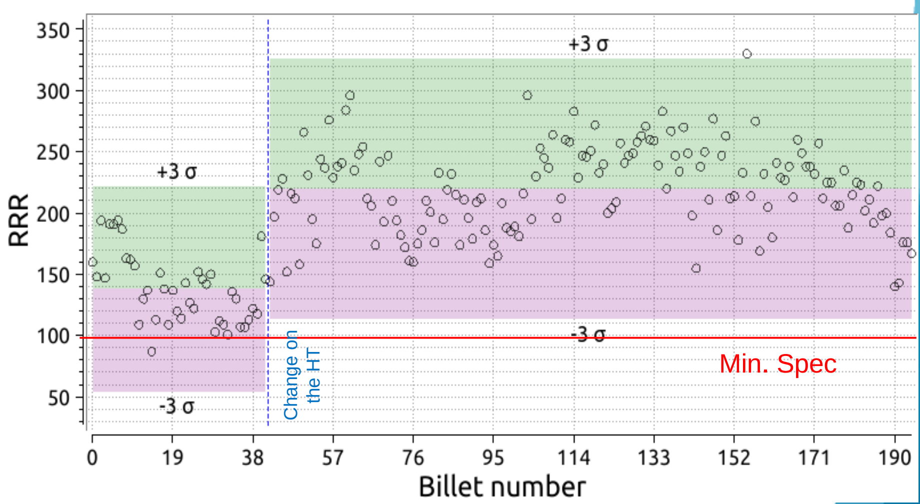
CERN – RRP wire

- CERN measures about 20 % larger RRR in round wire
  - For quench simulations, the range is more important that the absolute value, so a systematic offset is not critical.
- The less aggressive heat treatment (50 hours at 665ºC instead of 72 hours) increased the RRR by ~ 70
- Rolled samples have ~ 100 lower RRR than round samples

Round Samples (Supplier)



15 % Rolled Samples (Supplier)

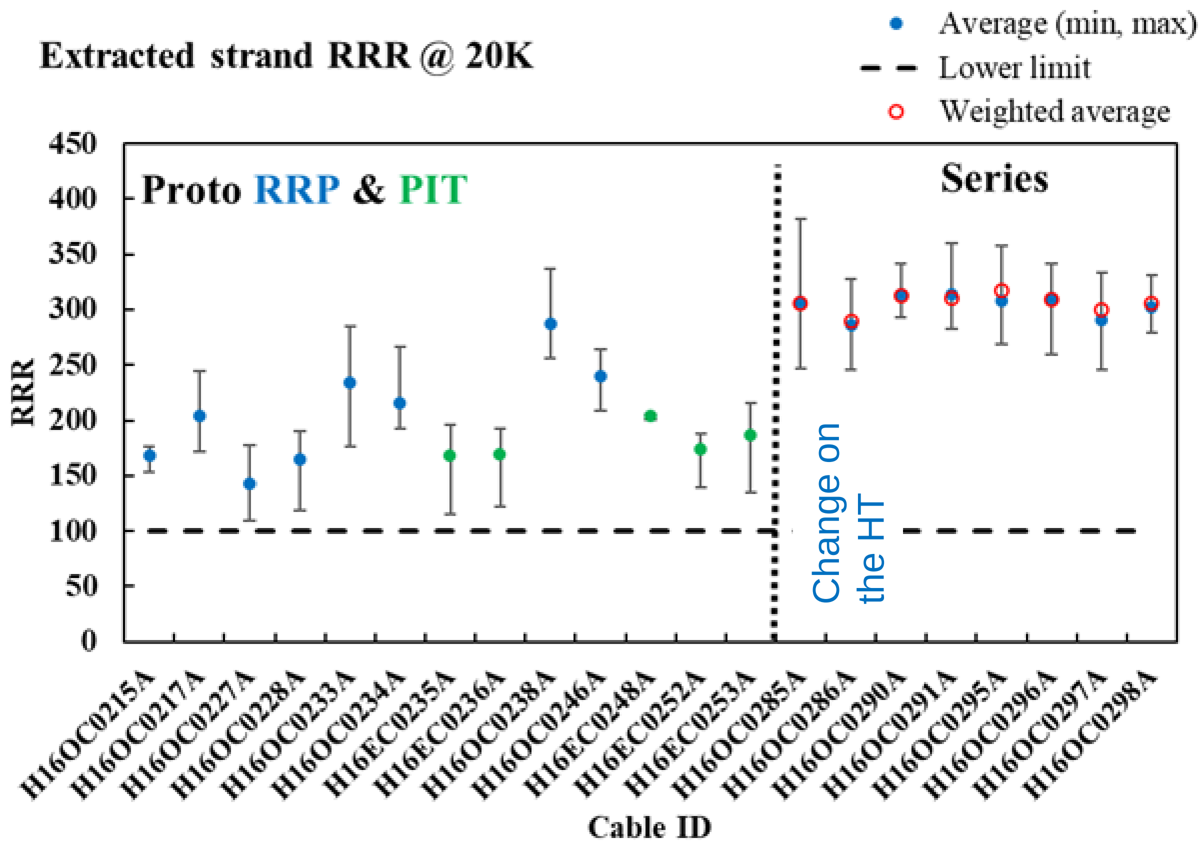


Jerome Fleiter

CERN –cables

- Consistent increase of the RRR by ~ 70 due to the less aggressive heat treatment (50 hours at 665ºC instead of 72 hours)
- Around 20 % cabling degradation when comparing virgin to extracted strands.

Cable qualification strands (Extracted)



Bernardo Bordini

CERN – Estimate coil RRR

- Both qualification and witness samples are considered to compute the RRR, to maximize the amount of information.

Estimated coil RRR = $\bar{R}\bar{Q}$

$\bar{R}$ = weighted average of W/R ratio
$\bar{Q}$ = weighted average of Qualification Extracted Samples

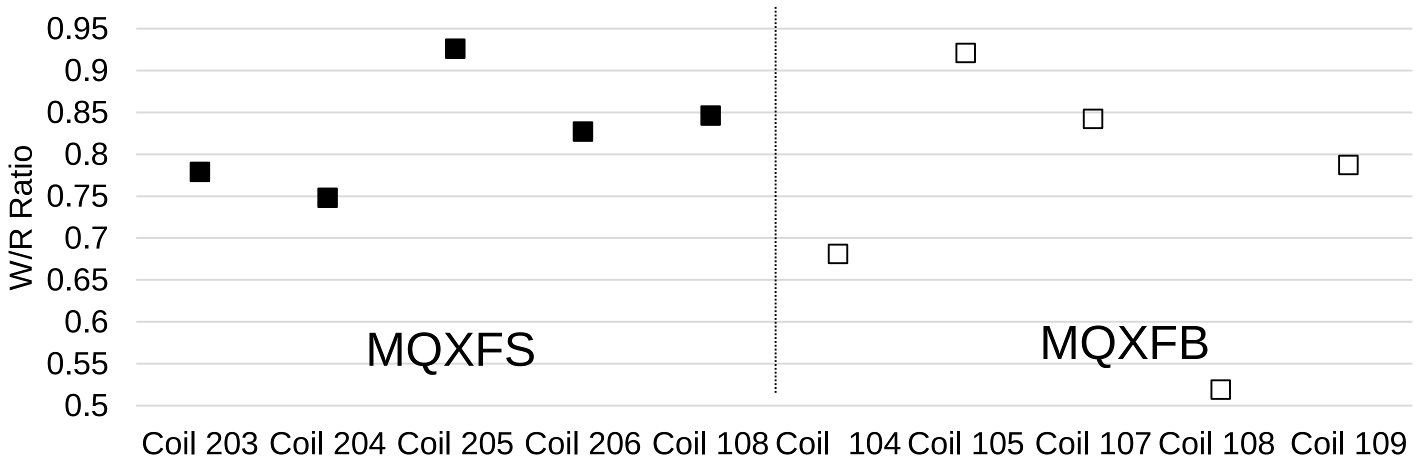
- In average, W/R = 0.8 for the coils produced so far

Extracted from the cable, reacted by CERN cable team

Extracted from the cable, reacted with the coil

Example:

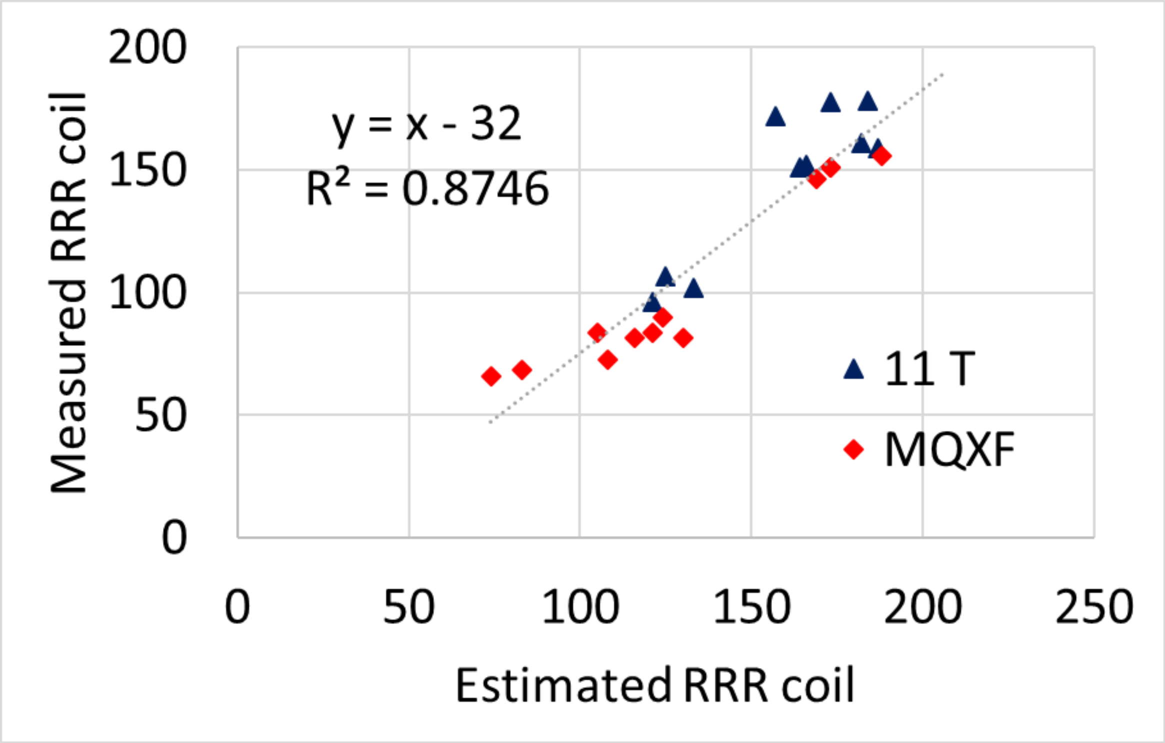
Billet	Number of wires	Qualification Extracted Samples	Witness Extracted Samples	Ratio W/R
89	3	--	--	--
108	7	192	--	--
112	10	209	203	0.971
121	10	197	154	0.782
122	10	266	206	0.774



Can we predict coil RRR?

Jerome Fleiter,
Bernardo Bordini,
Gerard Willering,
Franco Mangiarotti.

- Estimated RRR based on Qualification and Witness samples correlate with the measured coil RRR during cold powering test.
  - Measured coil RRR in the magnet is typically lower



AUP – Available data

L. Cooley, V. Lombardo,
I. Pong, D. Turrioni

	AUP
Round samples	2/3billet Supplier 1/ billet AUP
15 % rolled samples	1/billet supplier
Qualification samples (extracted)	5/cable (major minor edges + 2 straight sections)
Coil** (witness samples)	6/coil (2 virgin and 4 extracted), Tested (1 virgin/ 2 extracted)

From cable P43OL1134	AUP
Round samples	2/3billet Supplier 1/ billet AUP
15 % rolled samples	1/billet supplier
Qualification samples* (extracted)	5/cable (major minor edges + 2 straight sections) by LBNL + 2/cable HT at FNAL
Coil** (witness samples)	6/coil (2 virgin and 4 extracted) Tested (minimum 1 virgin)

*Extracted form the cable, reacted by AUP
** Extracted form the cable, reacted with the coil

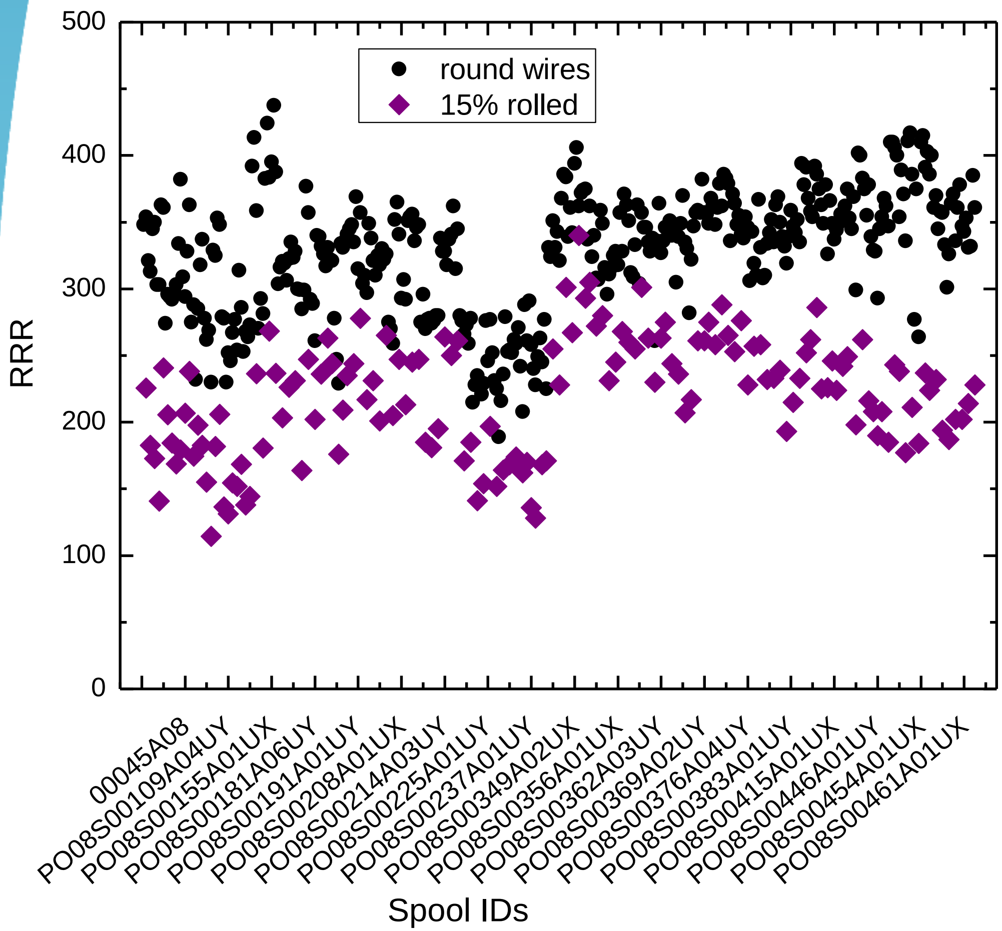
MQXFA magnet: history

Magnets	MQXFAP1	MQXFAP2	MQXFAP1b	MQXFA03
coils	P2, P3, P4, P5	102, 104 105, 106	P2, P3, P4, P6	202, 204, 110, 111
cables	P35OL1060 P47OL1064 P45OL1069 P43OL1070A	P43OL1073 P43OL1081 P43OL1082 P43OL1084	P35OL1060 P47OL1064 P45OL1069 P43OL1095	P43OL1092 P43OL1099 P43OL1091 P43OL1098

- Coil P2 P3 and P4: OST 132-169 and OST 144-169 conductor
- Rest of the coils conductor is OST 108-127
- Extracted strands major and minor edges + 2 straight sections RRR's started from cable P43OL1095
- 15 % rolled started from cable P43OL1070A
- No RRR data from Magnet testing (only coil pairs in MQXFAP1)
- First experimental data from MQXFA03

AUP – Estimate coil RRR

Strand data from vendor up to billet #463



- Rolled samples have around 100 smaller RRR than round wires
- 15% rolled samples RRR are good candidates for coil RRR predictions

RRR prediction

$$\left(\sum_i \frac{RRR_{ri} \; * f_i}{N}\right) * x$$

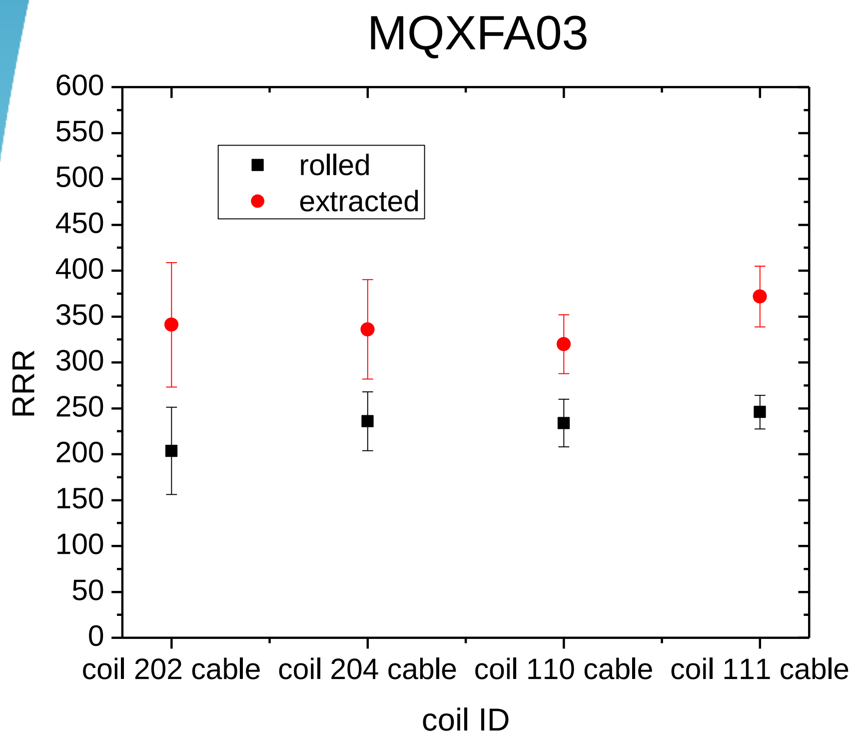
Weighted mean of rolled samples RRR

Scaling factor to be determined by experimental data

L. Cooley, V. Lombardo, I. Pong, D. Turrioni

AUP – Estimate coil RRR: extracted samples

5 wires per cable from the representative spools of a cable



4 set of data: major and minor edges and 2 straight sections.

Assuming R_{300K} to be the same of each section, the RRR of the wire:

$$RRR_{tot} = \frac{4}{\frac{1}{RRR_{min}} + \frac{1}{RRR_{maj}} + \frac{1}{RRR_{s1}} \frac{1}{RRR_{s2}}}$$

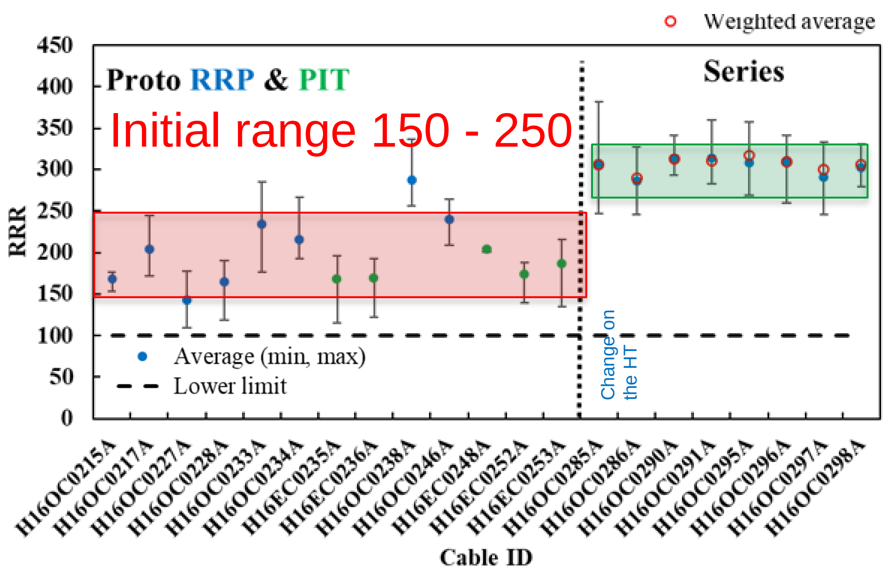
Coil RRR prediction: RRR_{tot} * x → Scaling factor to be determined by experimental data

Coil RRR data from MQXFA03 will be used to identify the best method

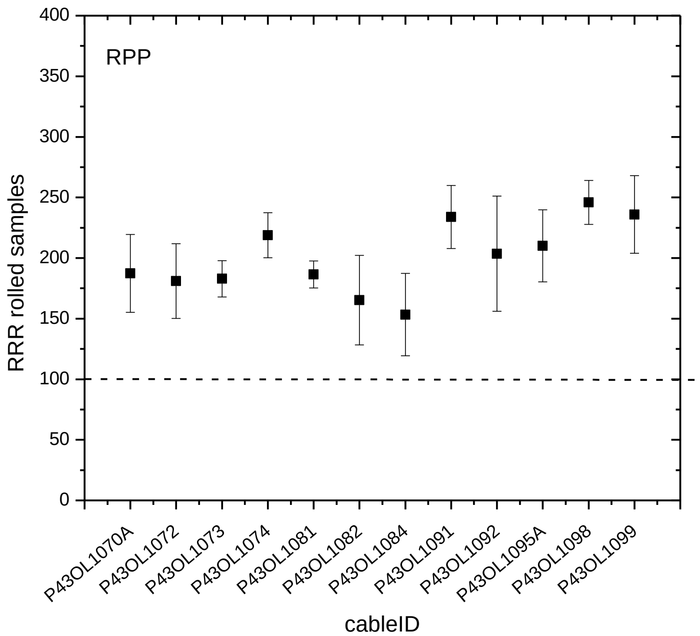
L. Cooley, V. Lombardo,
I. Pong, D. Turrioni

Where we are with respect to initial estimates?

- CERN:
  - Initial range based on prototype experience 150-250
  - Cable from series has a systematic offset of + 70 due to the less aggressive heat treatment.
  - The spread among cables seems a factor 2 smaller, but it is early to update numbers.



- AUP:
  - Initial range based on prototype experience 150-250
  - Rolled and extracted samples are good candidates for RRR predictions
  - Rolled samples are consisted with parameters used in simulations



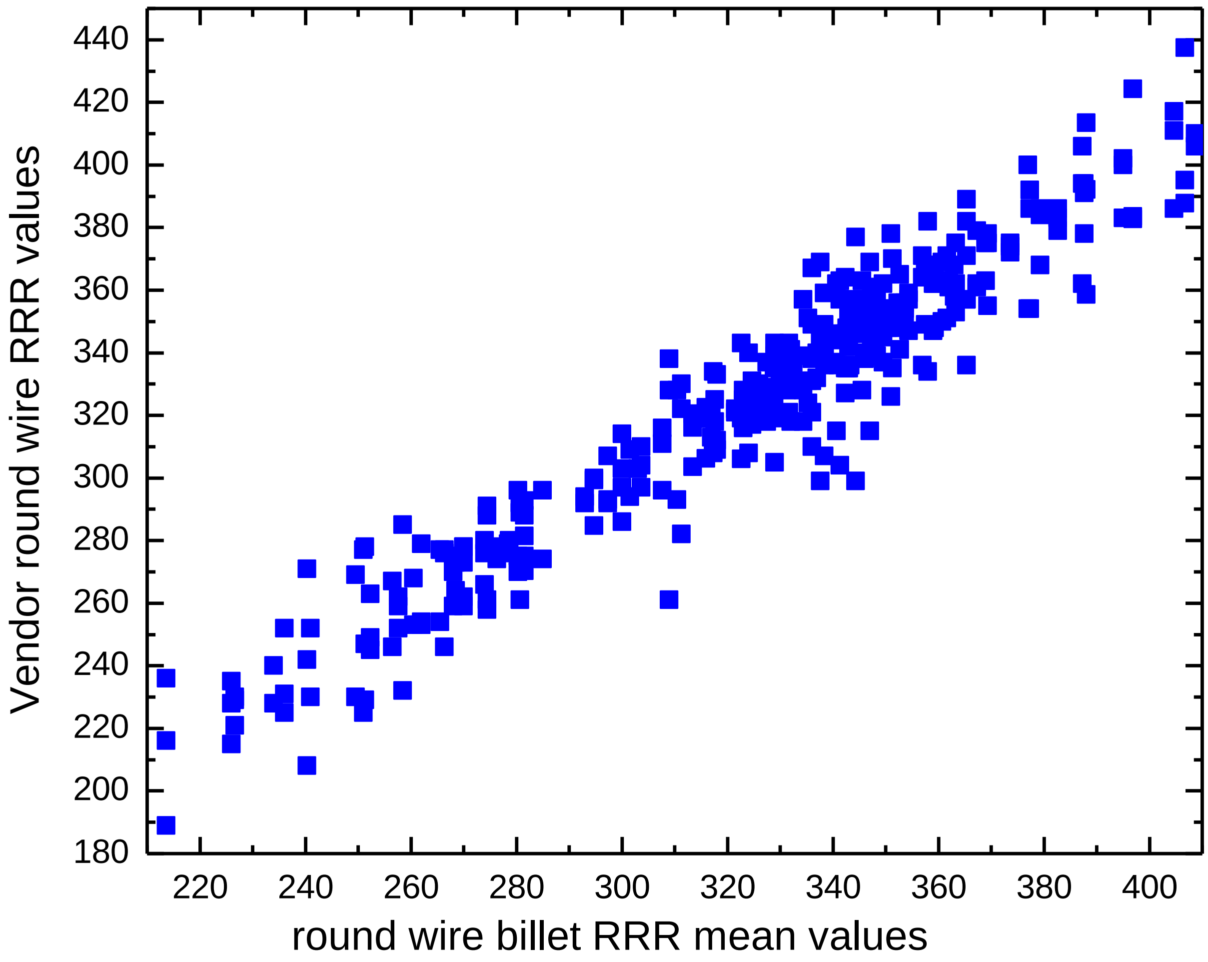
Conclusions

- Based on CERN experience in MQXF and 11 T coils, the RRR of the coil can be predicted prior magnet assembly with the RRR measurements currently included in the QA plan.
  - From virgin to rolled → 100 reduction
  - Rolled are a good representation of the cable qualification strand (might be a bit conservative)
  - From cable qualification strand to average estimated in the coil → - 20 % reduction
  - From average estimate to measured average in the coil → offset of about 30
- Based on AUP experience:
  - From virgin to rolled → 100 reduction
  - Rolled or extracted strands could be a good representation of the cable
- Comparing parameter range with the current assumptions in simulations:
  - At CERN, there is a systematic shift of 70 due to the less aggressive heat treatment, and the spread among cables in series production is smaller. But it is early for an update on the reference parameters.
  - At AUP, verification of predictions will start with MQXFA03

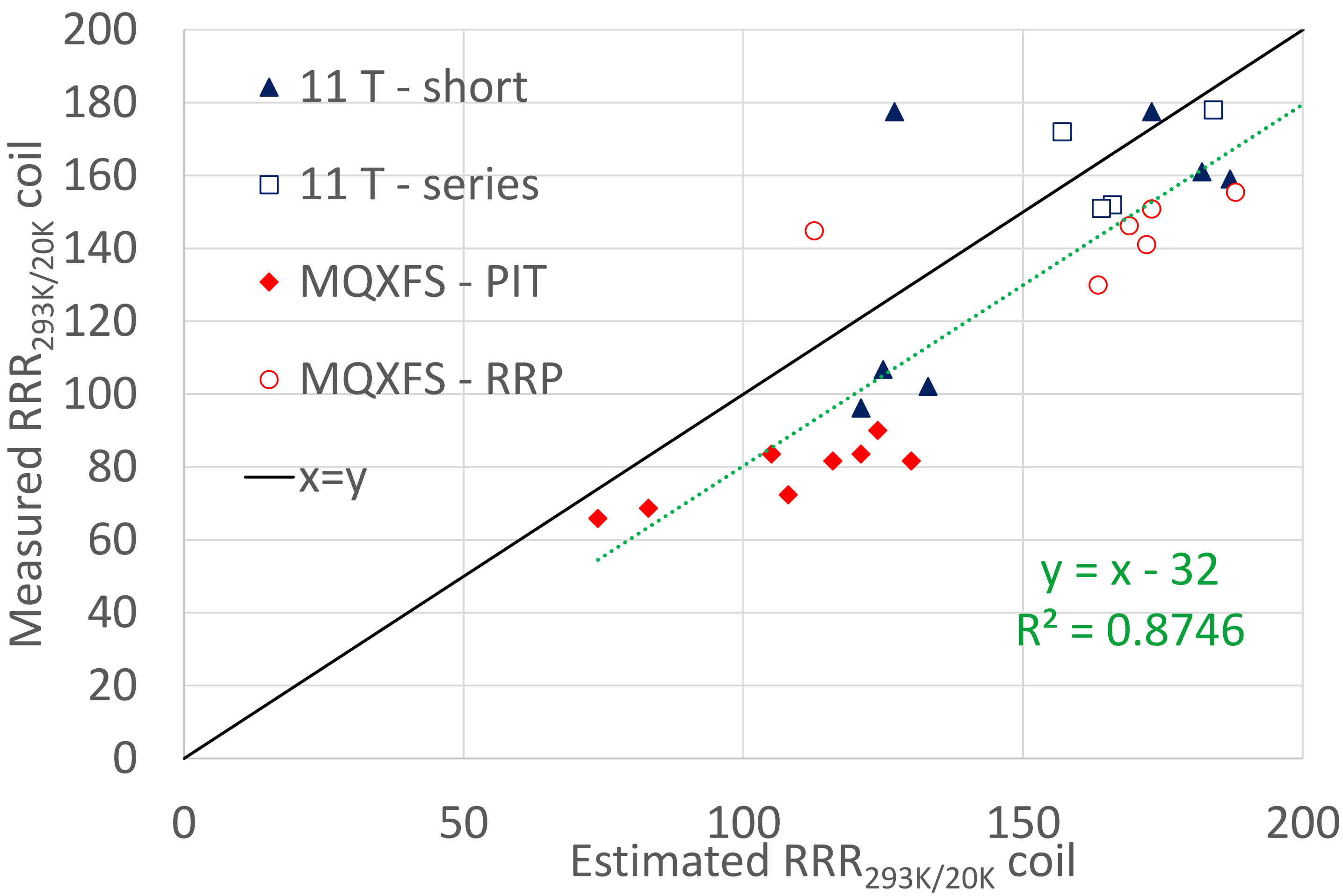
Additional slides

logo area

AUP- RRP spool vs billet



Assumption: Spool RRR values are representative of billet RRR values



200
180
160
140
120
100
80
60
40
20
0
Measured RRR293K/20K coil
11 T - short
11 T - series
MQXFS - PIT
MQXFS - RRP
x=y
y = x - 32
R² = 0.8746
0
50
100
150
200
Estimated RRR293K/20K coil