Status of the Acculinna-2 RIB Fragment Separator

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The Acculinna-2 Fragment separator

In-flight RIB separator

Acculinna-2 Selector → Selected RIB(s) → F5 Target adds ^{1}p / ^{0}n → Unstable nucleus → Decay → Decay nuclei, (Protons), (Neutrons) → 0° dipole Detectors measurement

RIBs Projectile fragments ≅ direction ≅ energy

Projectile fragmentation

F1 Target

Primary beam

U400

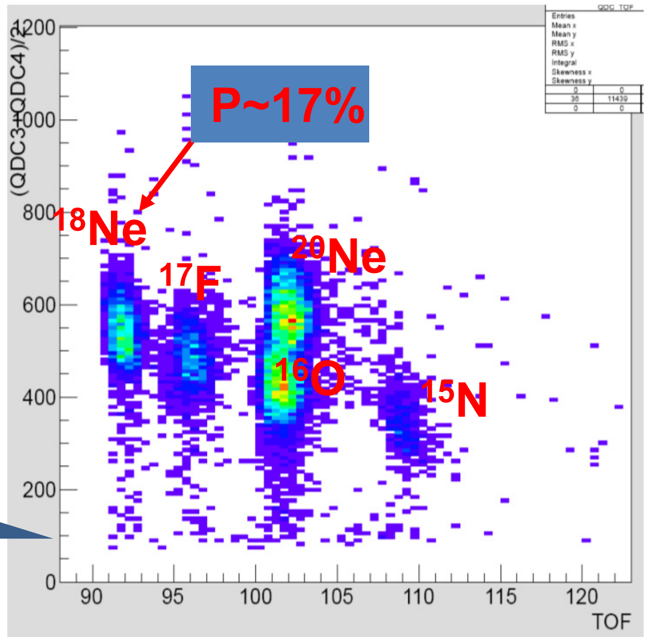
Acculinna-2 Selector → ^{18}Ne → ^{18}Ne (p,d) ^{17}Ne* → ^{17}Ne* → Decay → ^{15}O, ^{1}p, ^{1}p

^{18}Ne + others

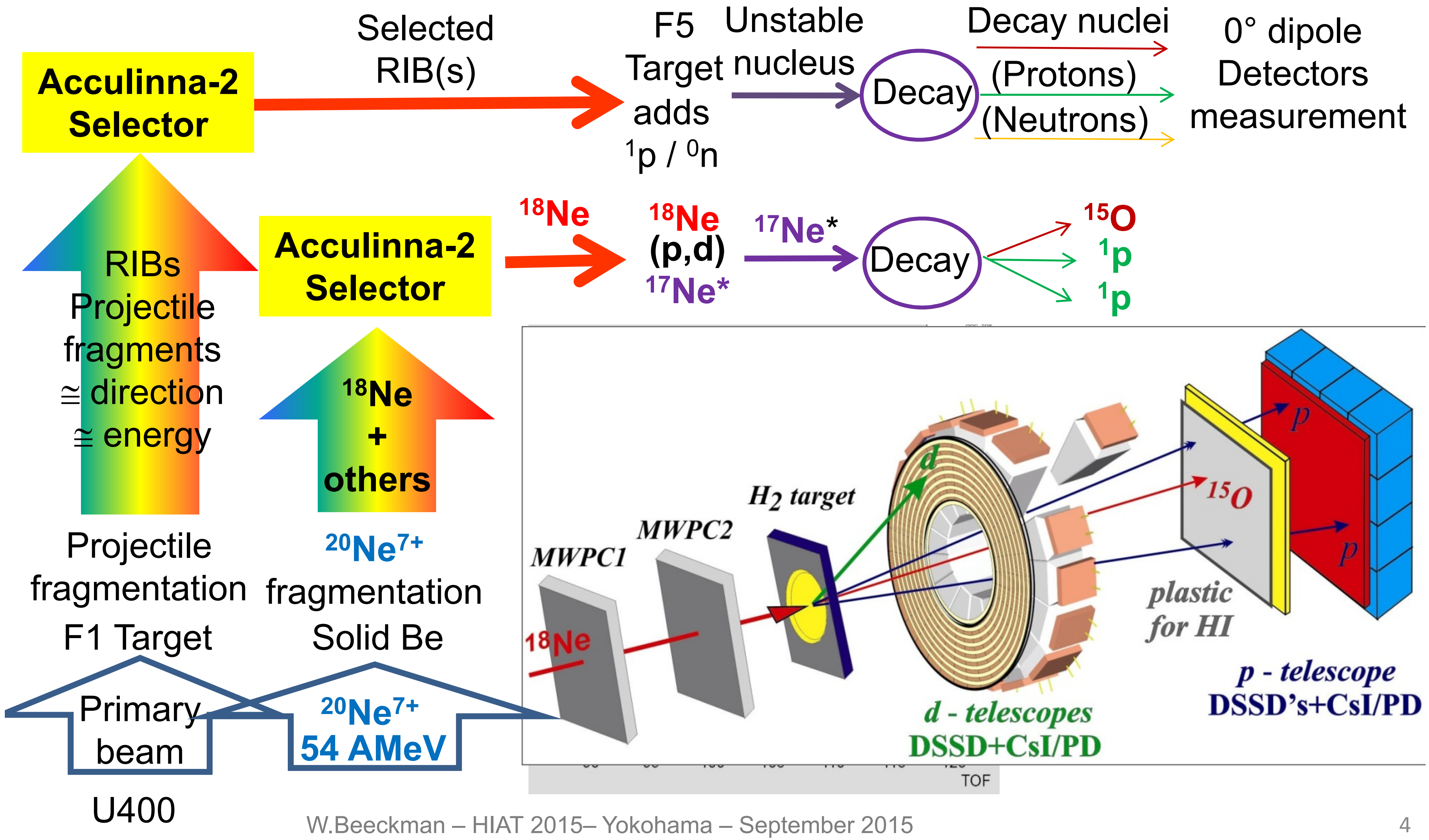
$^{20}Ne^{7+}$ fragmentation

Solid Be

$^{20}Ne^{7+}$ 54 AMeV



In-flight RIB separator



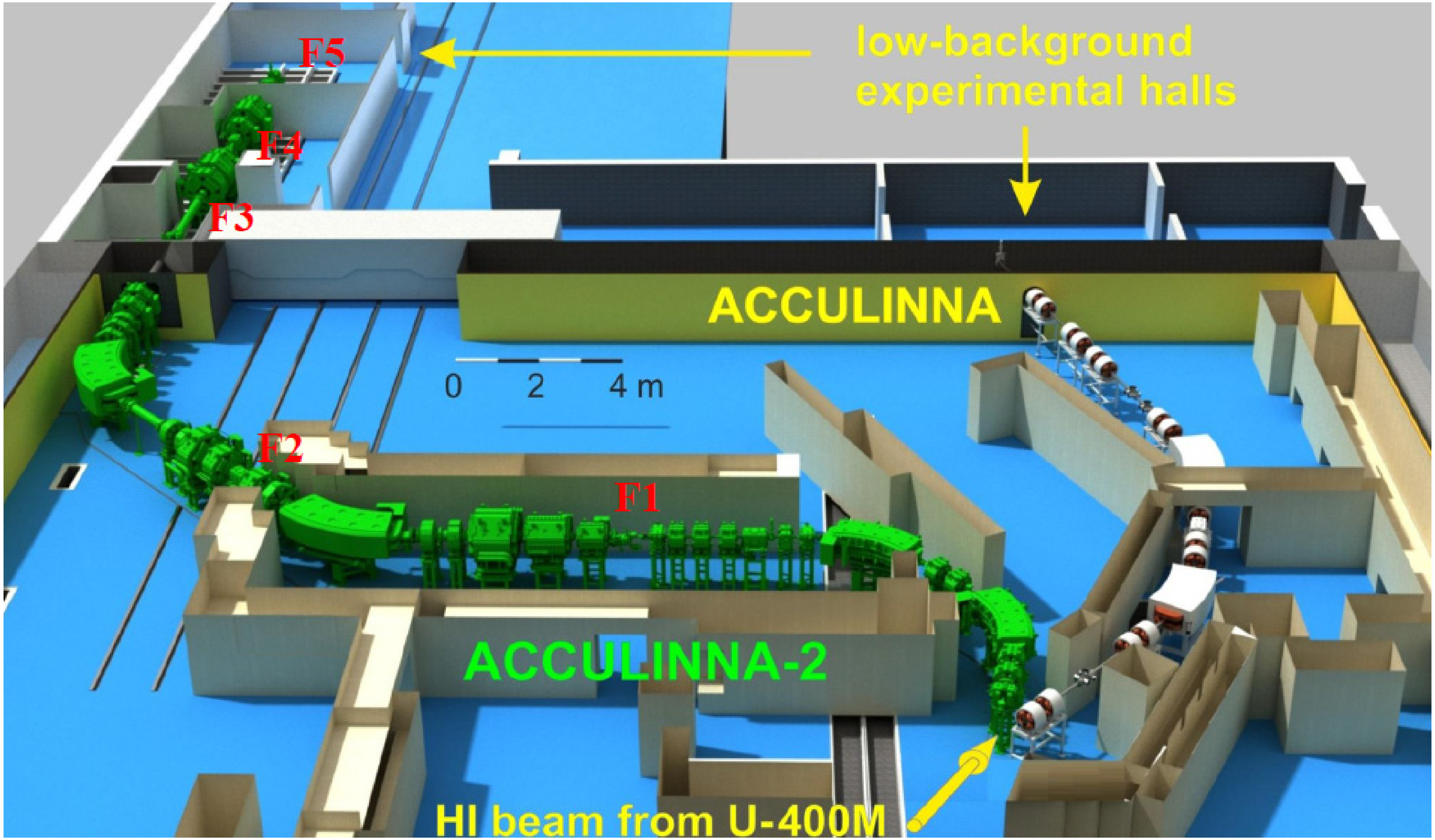
Acculinna2 in perspective

Characteristics of existing and new in–flight RIB separators

(ΔΩ and Δp/p are angular and momentum acceptances, Rp/Δp is the first-order momentum resolution when 1 mm object size is assumed)

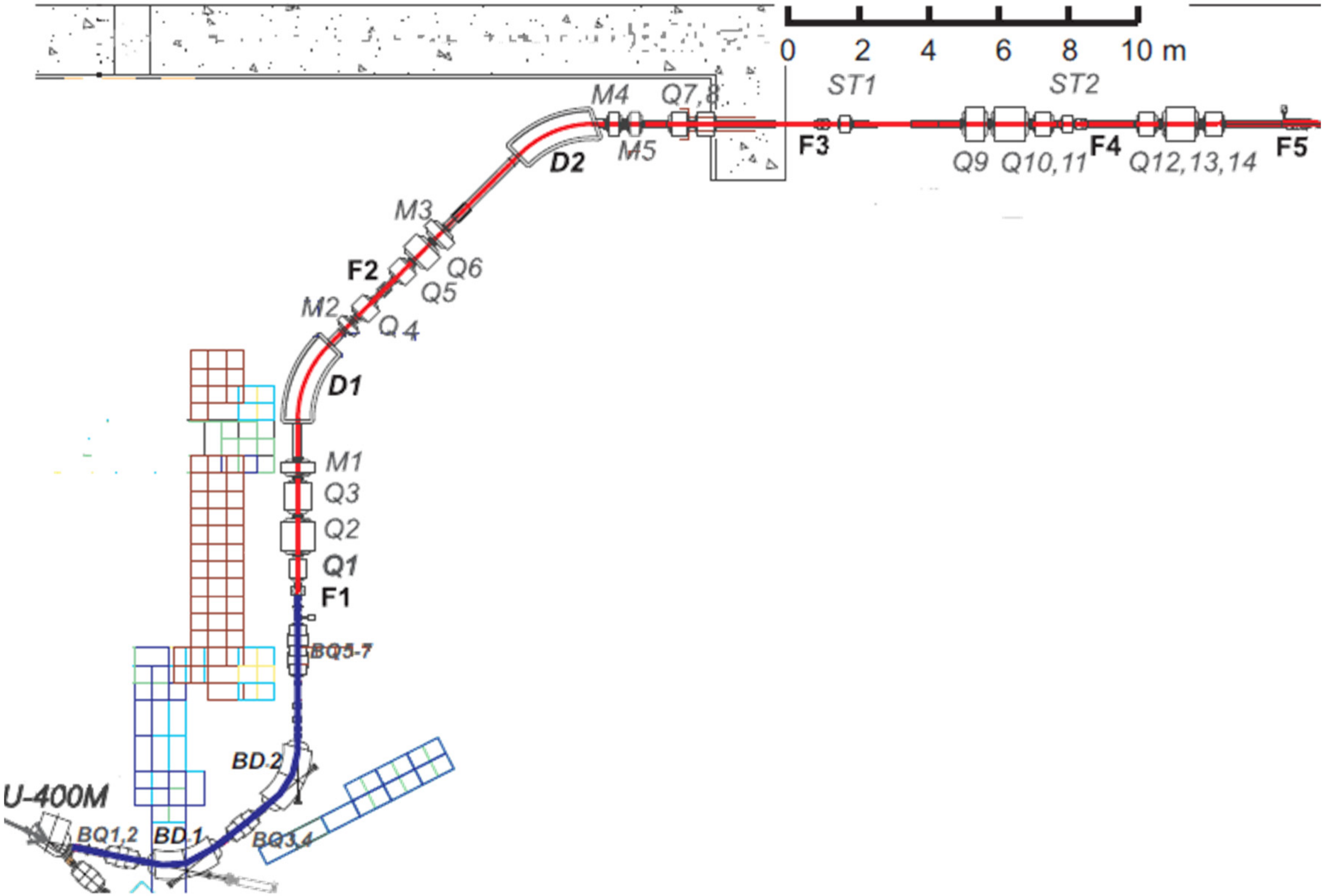
	ACC / ACC-2 FLNR JINR	RIPS / BigRIBS RIKEN	A1900 MSU	FRS / SuperFRS GSI	LISE3 GANIL
ΔΩ, msr	0.9 / 5.8	5.0 / 8.0	8.0	0.32 / 5.0	1.0
Δp/p, %	± 2.5 / ± 3.0	± 3.0 / 6.0	± 5.5	± 2.0 / 5.0	± 5.0
Rp/Δp	1000 / 2000	1500 / 3300	2915	8600 / 3050	2200
Bρ, Tm	3.2 / 3.9	5.76 / 9.0	6.0	18 / 18	3.2 - 4.3
Length, m	21 / 38	27 / 77	35	74 / 140	19(42)
E, AMeV	10÷40 / 6÷60	50÷90 / 350	110÷160	220÷1000/1500	40÷80
Additional RIB Filter	No / RF-kicker	RF-kicker / S-form	S-form & RF- kicker	S-form / Preseparator	Wien Filter

Layout

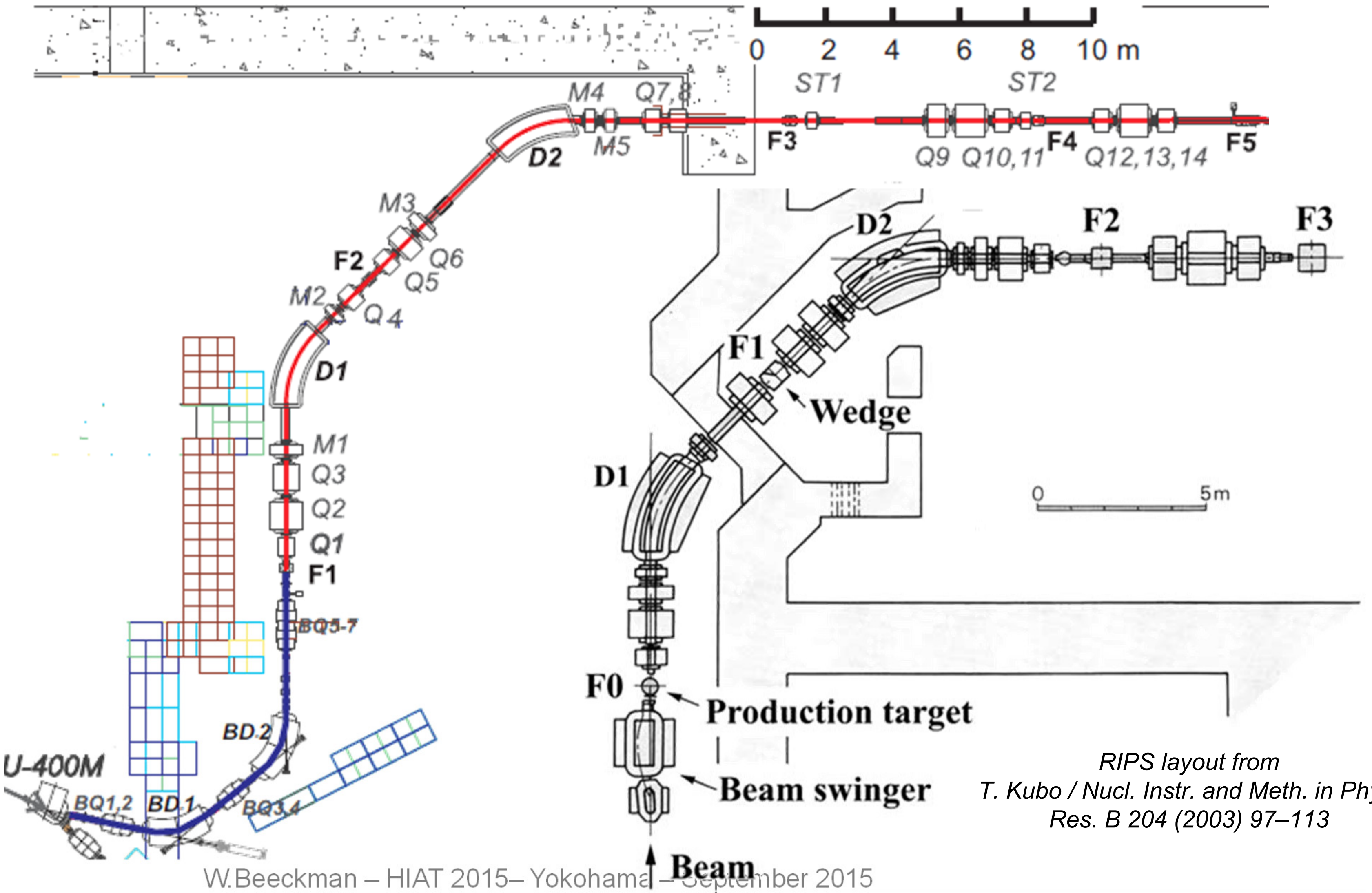


F5
low-background
experimental halls
F4
F3
ACCULINNA
0 2 4 m
F2
F1
ACCULINNA-2
HI beam from U-400M

A tribute to RIPS
… in its country

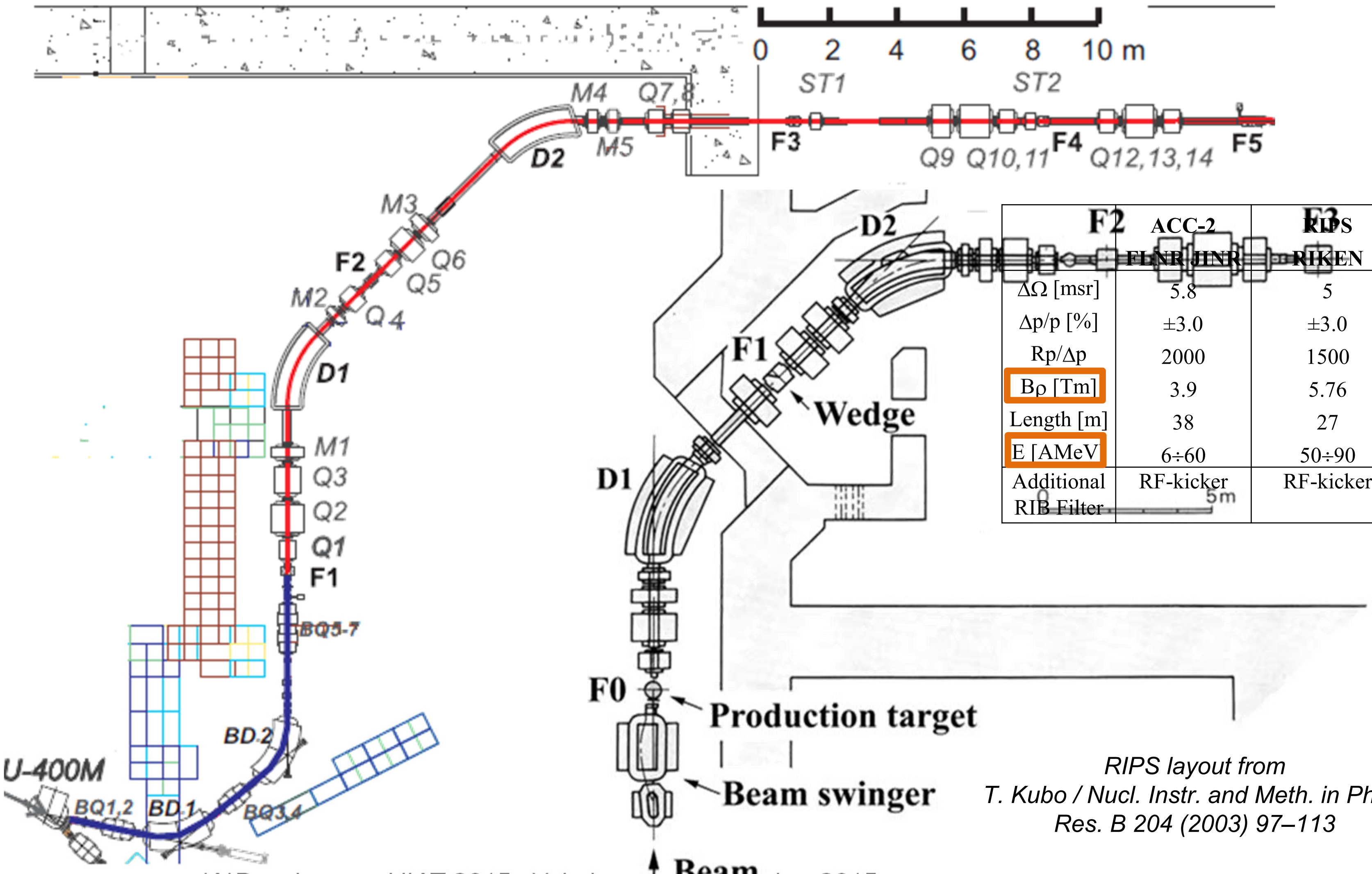


A tribute to RIPS
… in its country



RIPS layout from
T. Kubo / Nucl. Instr. and Meth. in Phys. Res. B 204 (2003) 97–113

A tribute to RIPS
… in its country



	ACC-2 FLNR JINR	RIPS RIKEN
ΔΩ [msr]	5.8	5
Δp/p [%]	±3.0	±3.0
Rp/Δp	2000	1500
Bρ [Tm]	3.9	5.76
Length [m]	38	27
E [AMeV	6÷60	50÷90
Additional RIB Filter	RF-kicker	RF-kicker

RIPS layout from
T. Kubo / Nucl. Instr. and Meth. in Phys. Res. B 204 (2003) 97–113

From contract to installation
October 2011 to December 2013

Scope of responsibility Optimization

1. Optics check
2. All magnets
3. All power supplies
4. All vacuum
5. Installation
6. Alignment

Being in control of these 4 techniques gives full freedom for an **optimized design** leading to an **energetically efficient** and **cost effective** facility

Optimization candidates

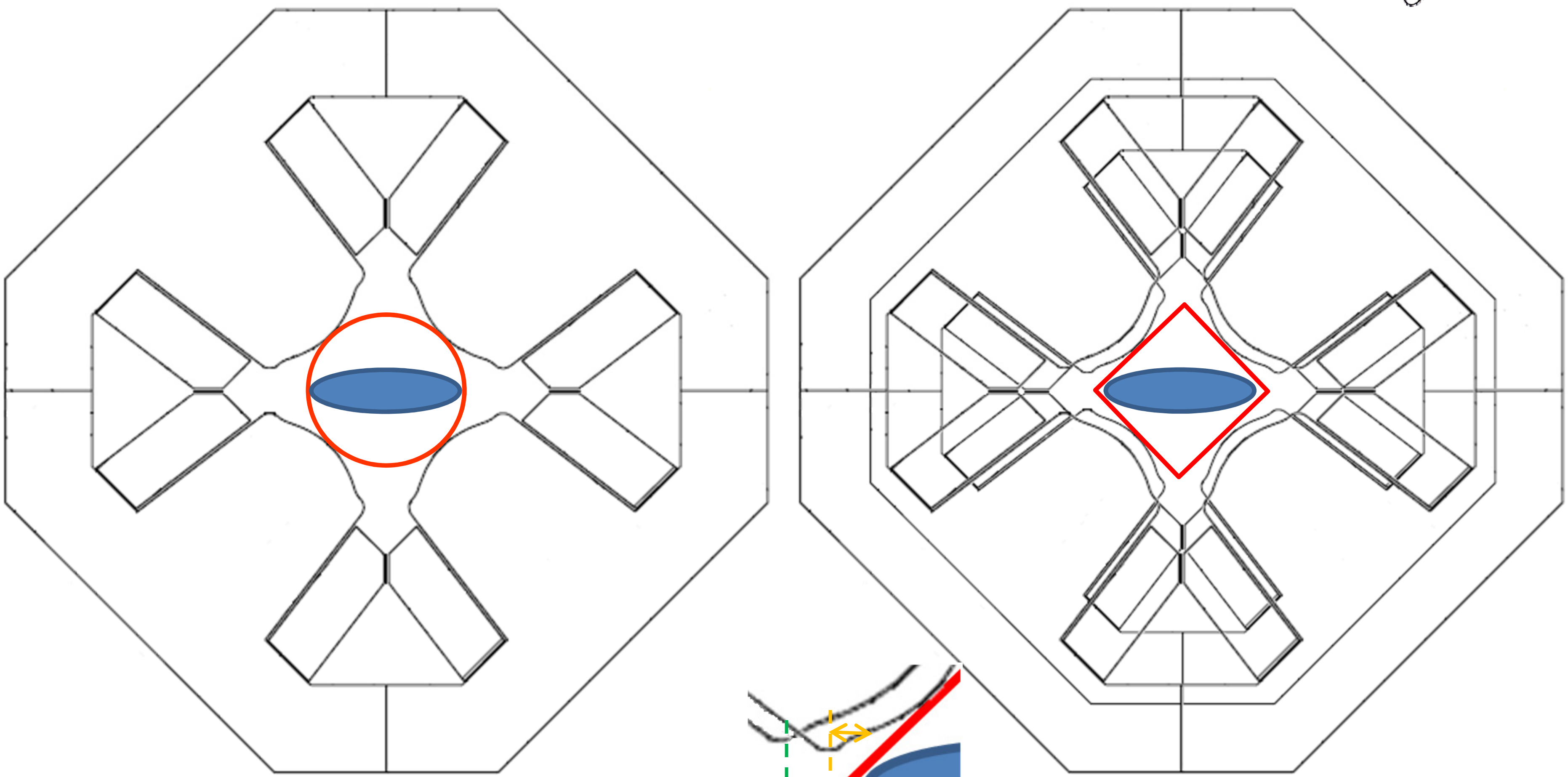
- Shaping chambers to reduce bores
- Trading gradient for length
- Standardizing magnets … within limits
- Trading current for turns
- Trading copper for voltage
- Using standard power supplies
- …

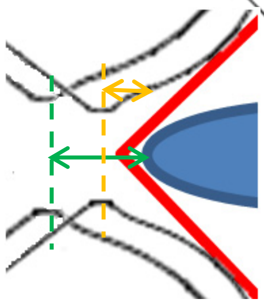
Figures of merit

- Power consumption
- Cost of
  - design
  - material
  - fabrication
- Standardization

But above all **preserve functional specs**

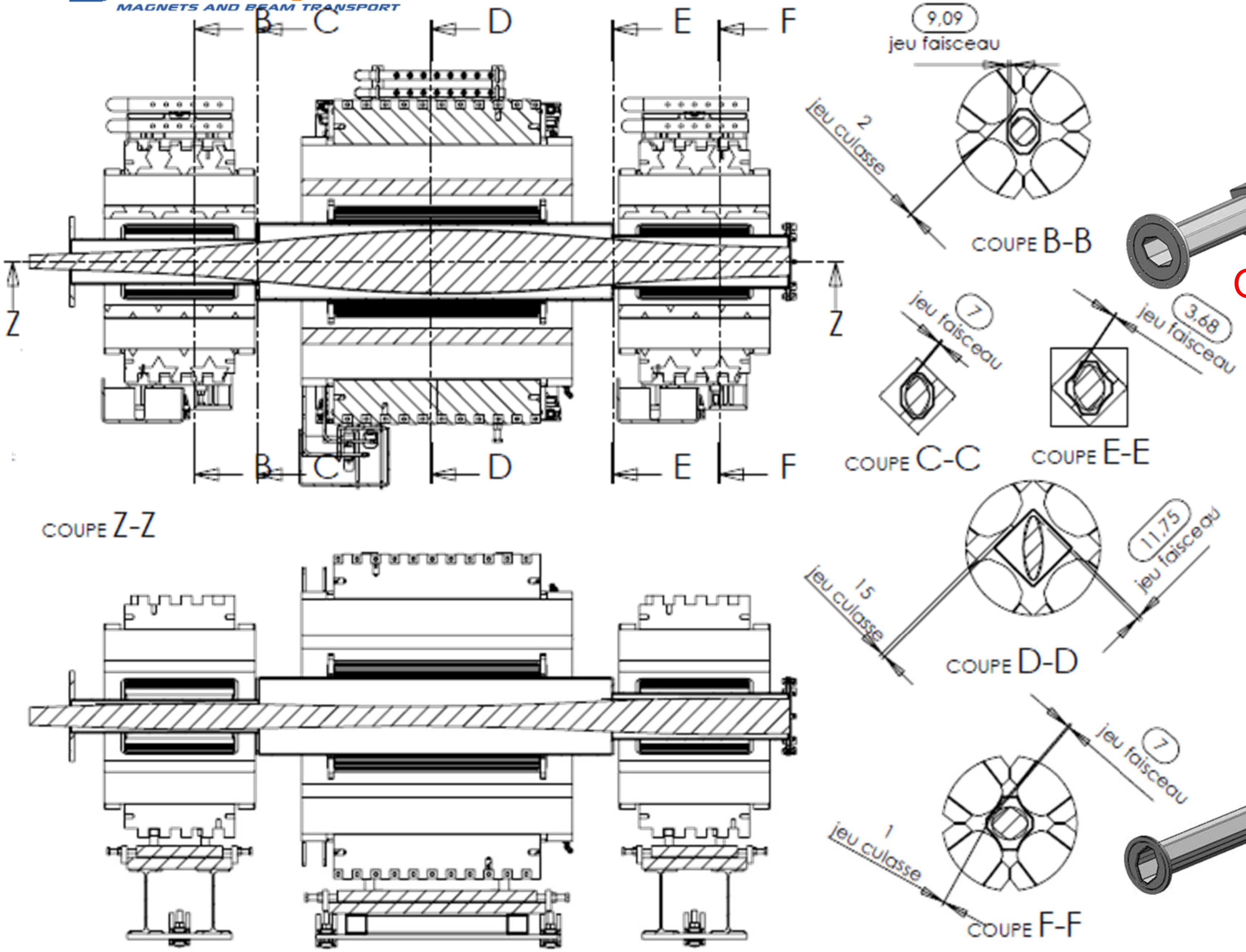
Shaping chambers to reduce bore

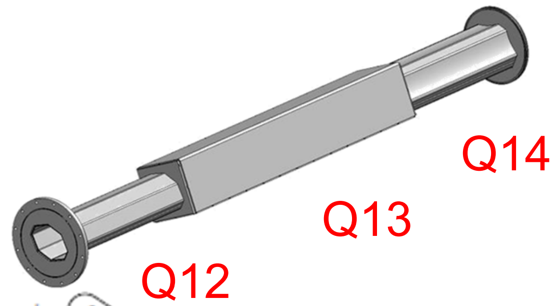


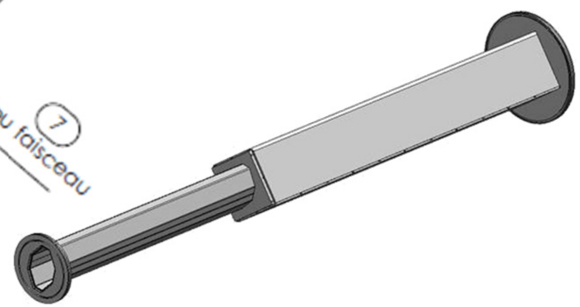


Good field region much closer to pole edge.
Great care in design

Shaping chambers to reduce bore







Trading
Power supply vs coil

Current – Copper (#Turns)

$$g = \frac{2\mu_0 nI}{r^2}$$

For the same gradient
- More current less turns
  cheap coil
  demand is on PS
- More turns less current
  more expensive coil
  reduced PS

Voltage – Copper (Section)

For static magnets, voltage is decided by Ohm's law $U = RI$
and Pouillet's law states $R = \rho l/s$
The length of the wire *l* mainly depends on pole geometry but its section *s* can be freely chosen. Increasing *s* makes *U* drop therefore also the power

Good choice

- (*U*,*I*) in the range of an **existing** PS — One of
- Aim at low Power — Recurrent
- Larger coil — One of
- Aim at standardization for coils — One of

Gradient - Length

INTEGRATED gradient i.e. gradient times length is important to the beam

Gradient can be traded for length if
- Optics remains OK
- Space between elements permits

Standardization Grouping

Standardization groups objects with “similar” properties

Advantages

- Huge reduction in cost for design, tooling and fabrication
- Exchangeability and servicing

Drawbacks

- Slightly sub-optimal design
- Higher material costs

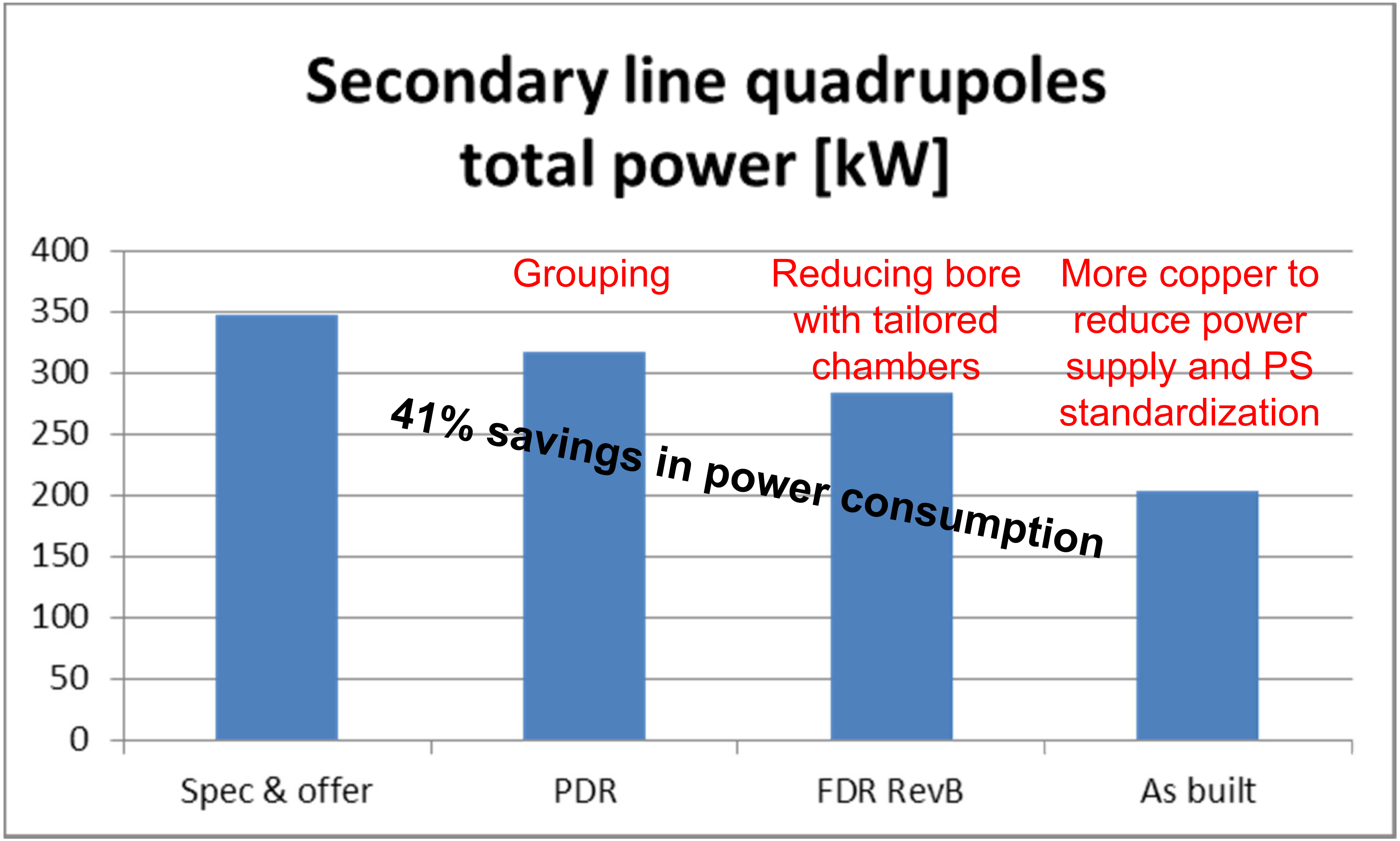
PARTIAL standardization might already help a lot keeping most of the advantages while taming drawbacks

Example of Secondary quadrupoles

1 lamination, 1 length, 1 coil	QM11 (1 item) = Q1
1 lamination, 2 lengths, 2 coils	QM21 (1 item) = Q2 QM22 (7 items) = Q4,Q5,Q7,Q8,Q11,Q12,Q14
1 lamination, 2 lengths, 2 coils	QM31 (1 item) = Q3 QM32 (4 items) = Q6,Q9,Q10,Q13

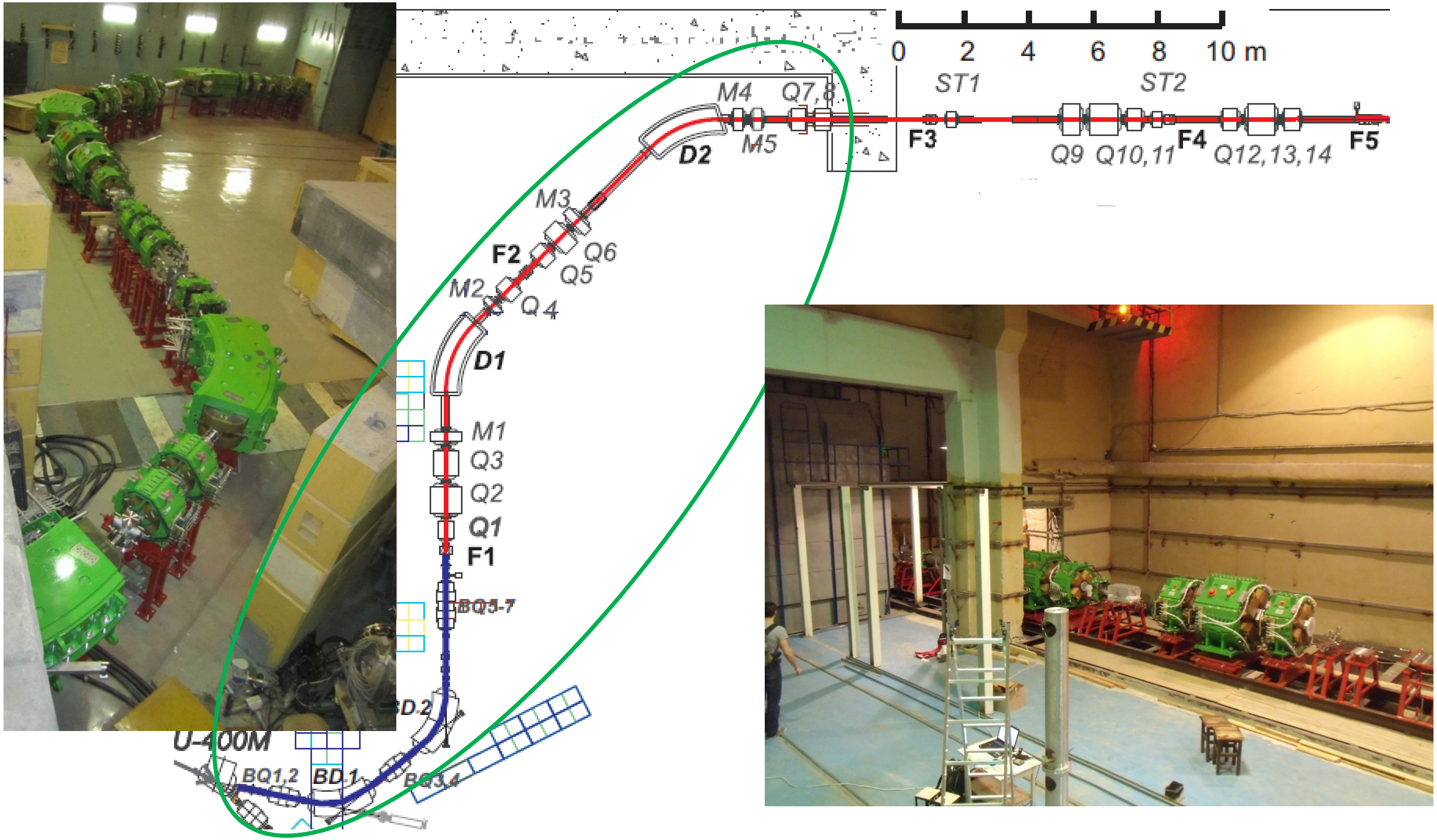
3 lamination, 5 coils, 5 designs instead of 14

Optimization reduces operation costs for years



Installation from start to end
January 2014 – March 2015

Room 1



0 2 4 6 8 10 m
ST1
ST2
M4
Q7,8
M5
D2
F3
Q9
Q10,11
F4
Q12,13,14
F5
M3
F2
Q6
Q5
M2
Q 4
D1
M1
Q3
Q2
Q1
F1
BQ5-7
D2
U-400M
BQ1,2
BD1
BQ3,4

« In the beginning, there was Chaos »

Greek Mythology – The Creation

Area & floor preparation 1st delivery

Installation Stands

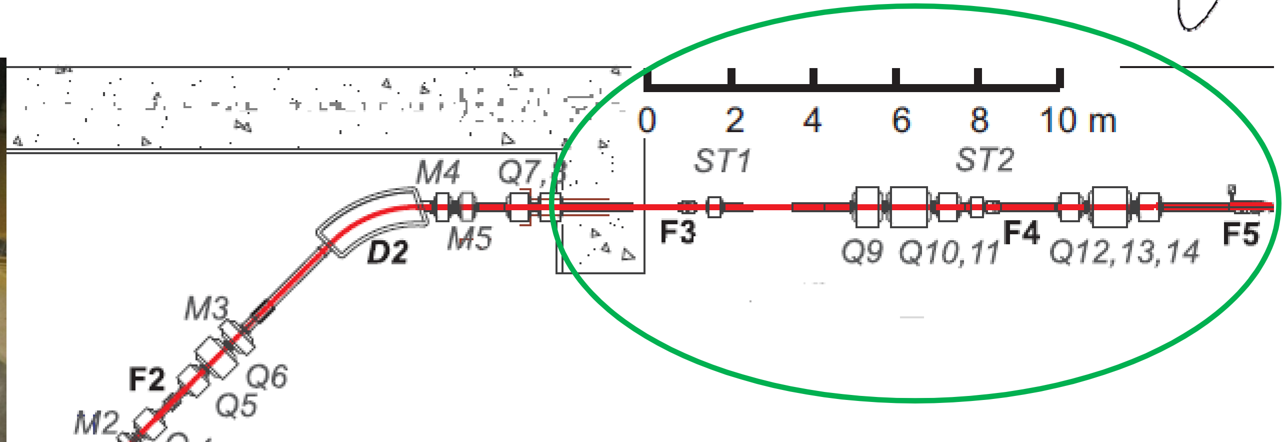
Installation & Alignment
Available magnets

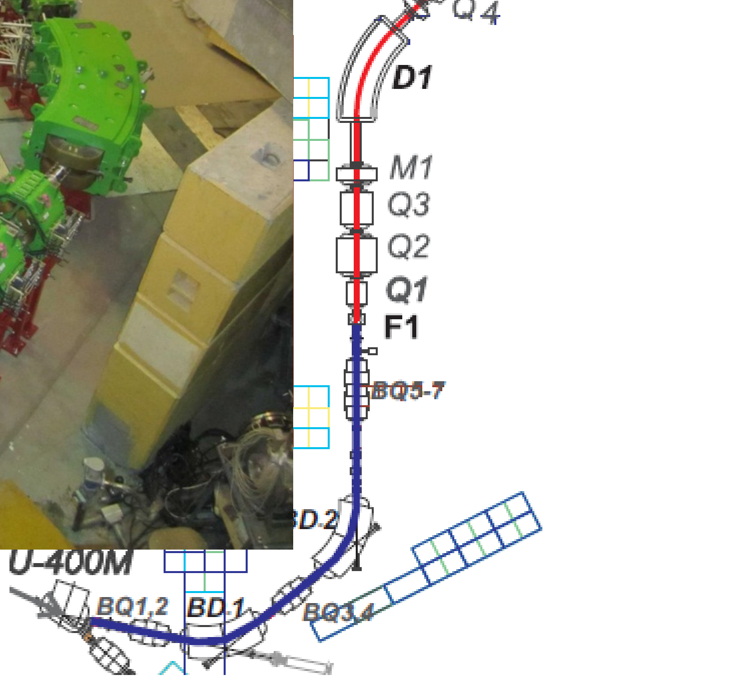
Installation
All power supplies

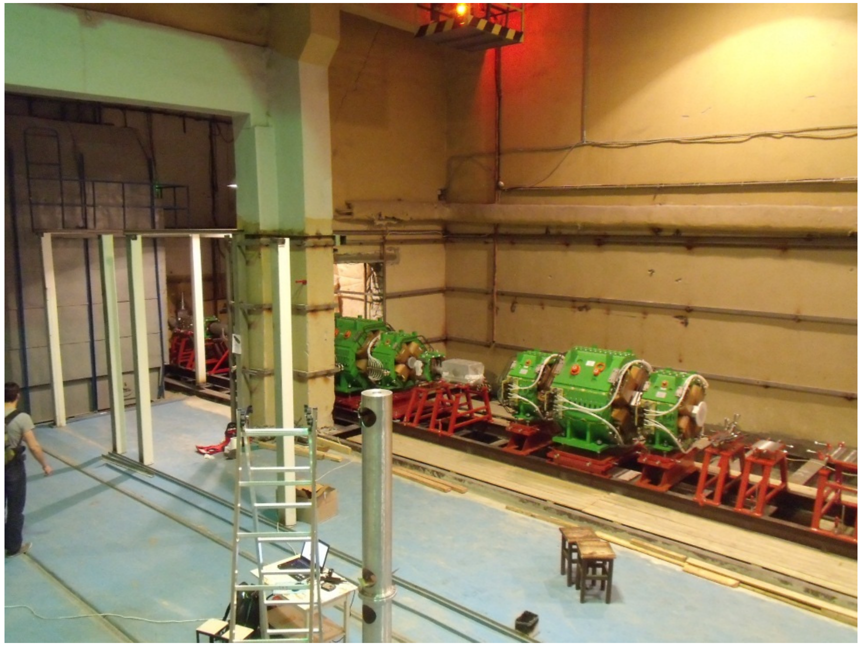
Installation & Alignment
All magnets and vacuum

Installation
Out of reach of the crane

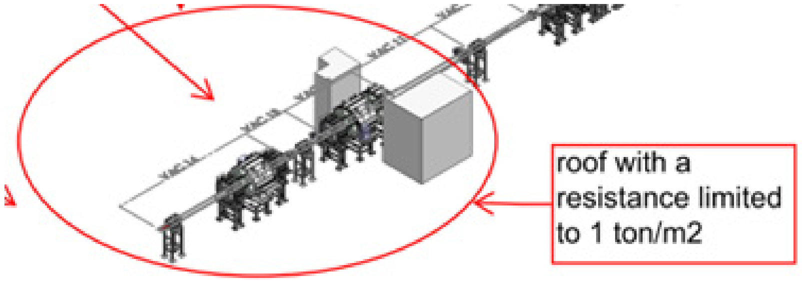
Room 2

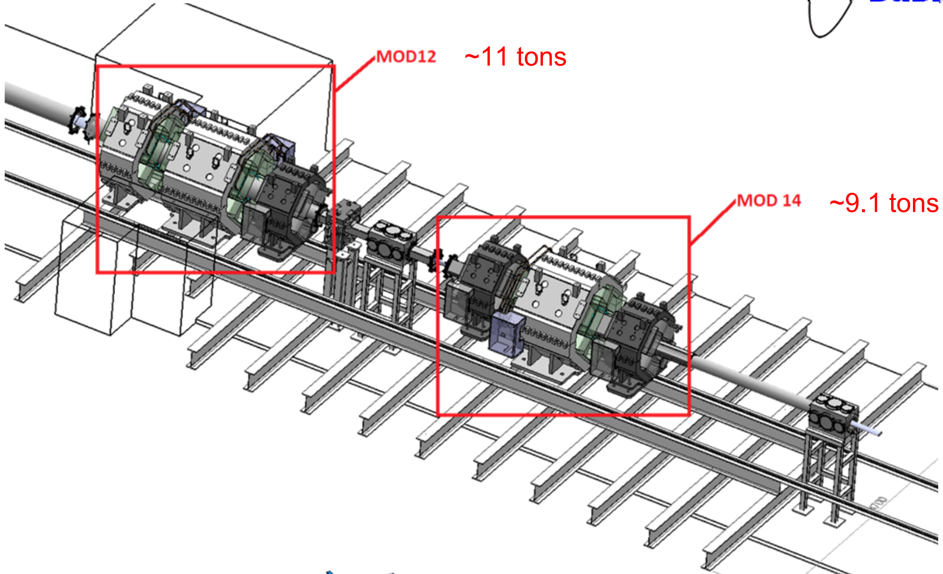

0
2
4
6
8
10 m
ST1
ST2
M4
Q7,
M5
D2
F3
Q9
Q10,11
F4
Q12,13,14
F5
M3
Q6
F2
Q5

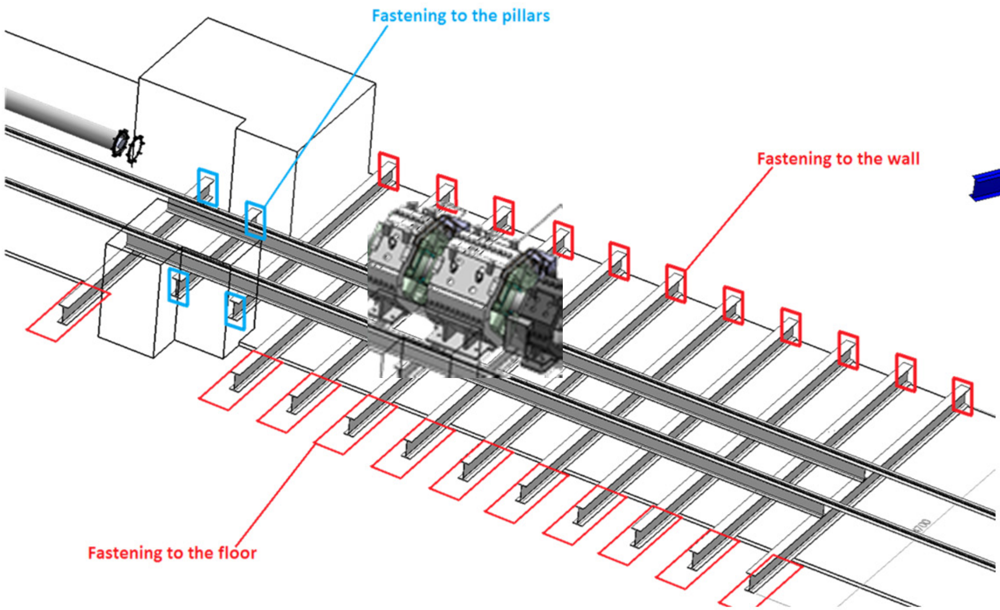

M2
Q4
D1
M1
Q3
Q2
Q1
F1
BQ5-7
D2
U-400M
BQ1,2
BD1
BQ3,4

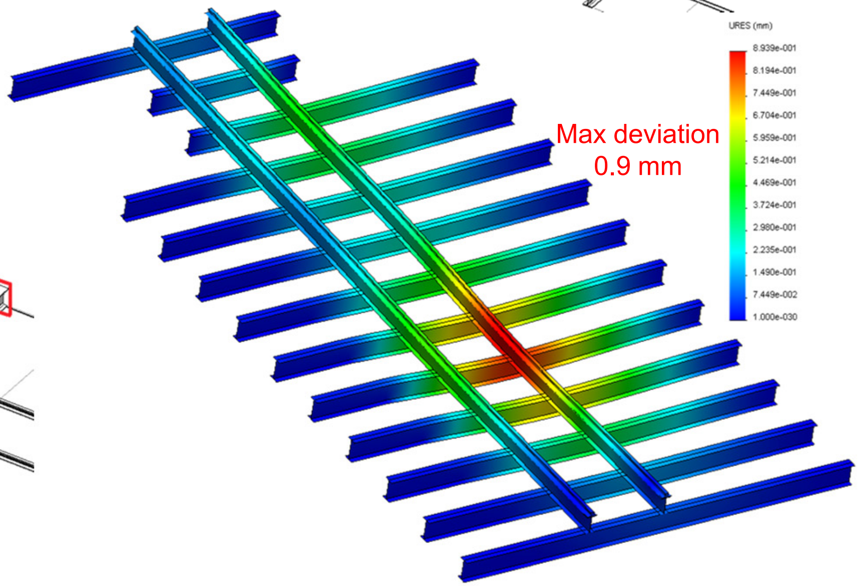


Room 2
Floor reinforcement





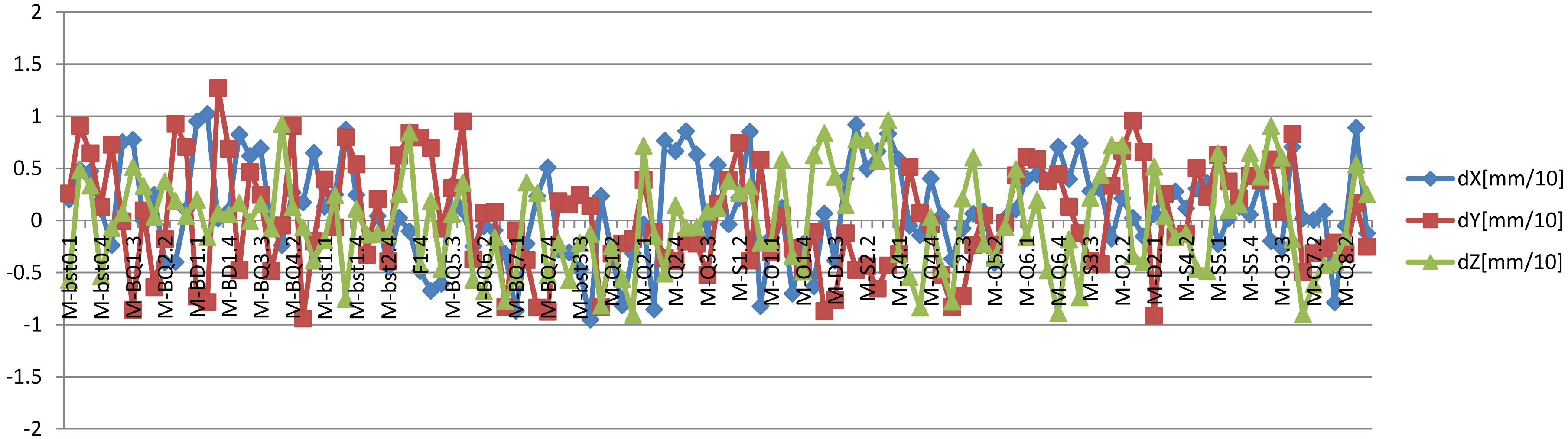




Room 2
Floor reinforcement

Alignment

- Leica laser tracker AT401
- Alignment accuracy within ± 0.1 mm



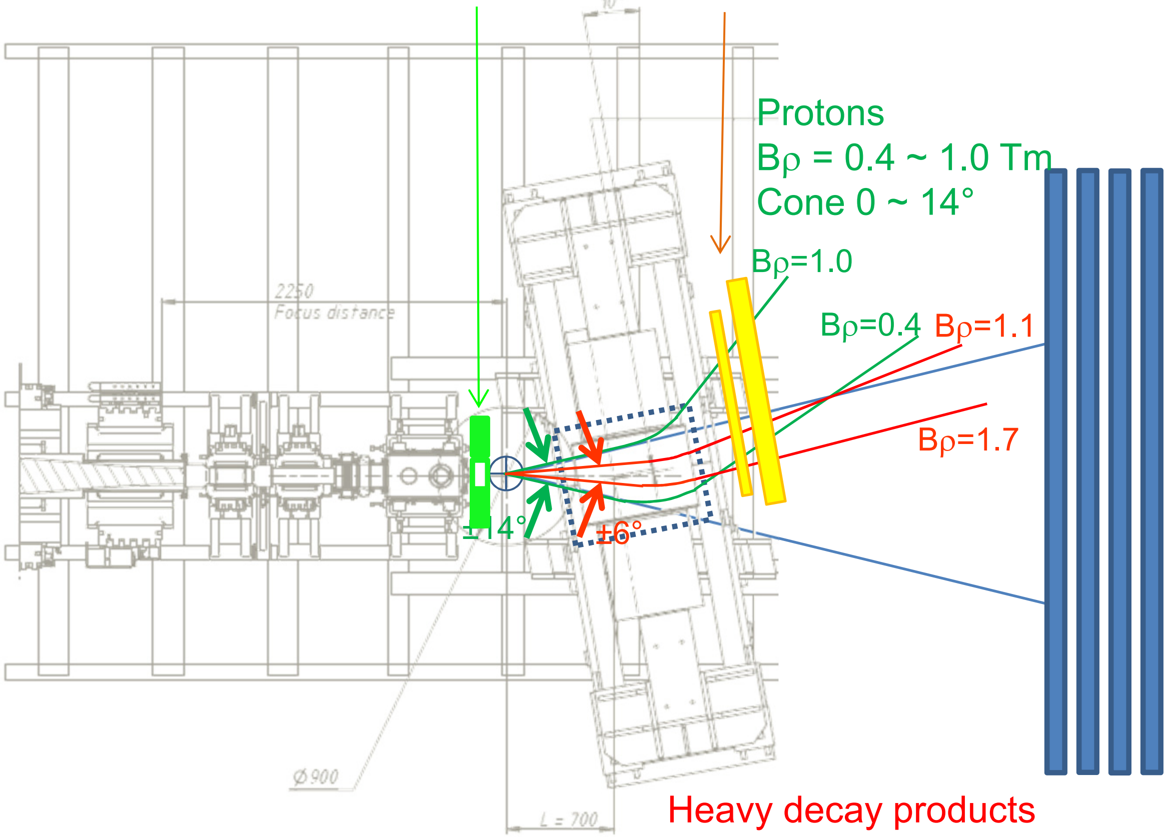
The near future

2016 First runs

2016 Zero angle spectrometer (status reported)

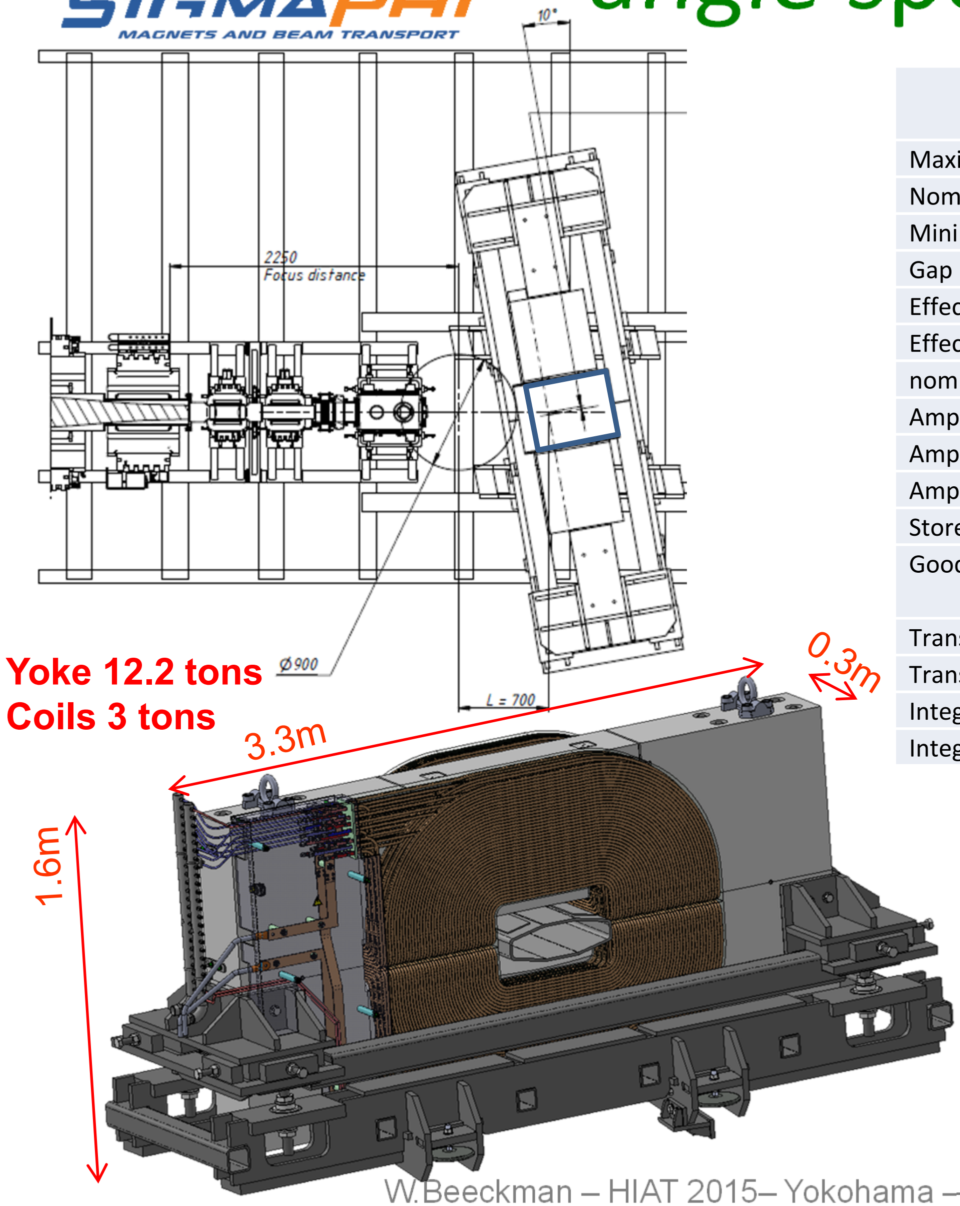
2017 Cryogenic tritium target

The zero angle spectrometer

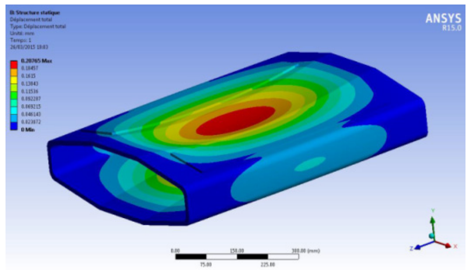


Neutron detector
Stylbene crystals
scintillator array
distance to F5 > 3m
TOF accuracy 1%

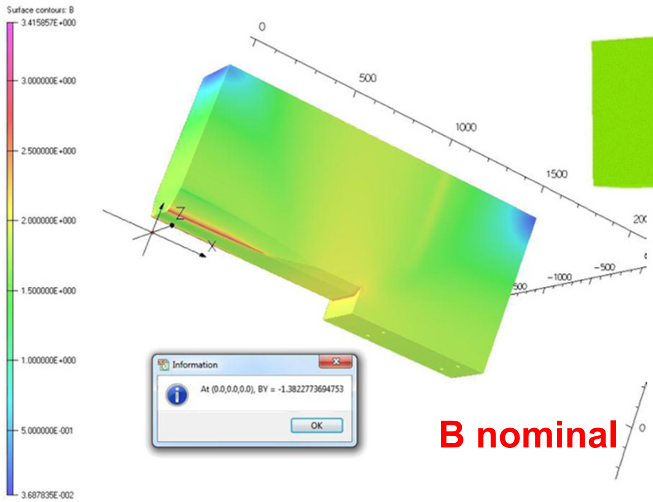
Status of the zero angle spectrometer

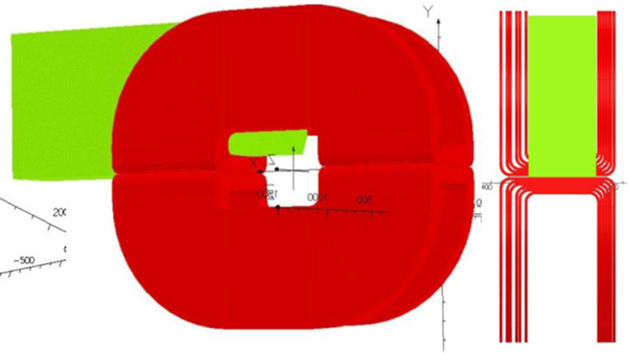


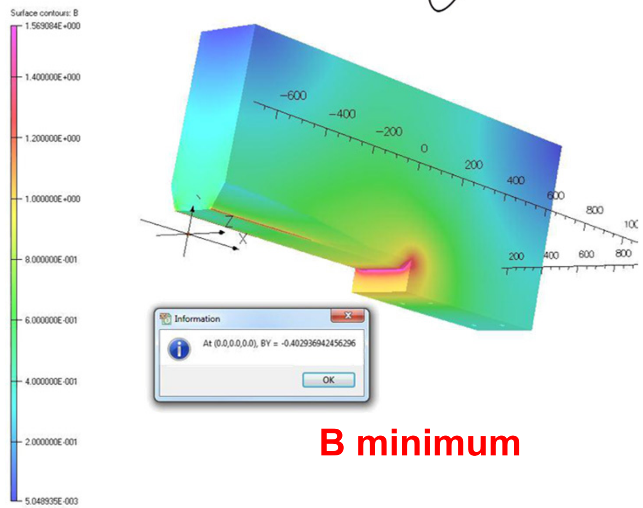
PARAMETERS	JINR Specification	SIGMAPHI Calculation
Maximum field - Bmax	≤1.5T	1.382T
Nominal field - Bnom	1.2T	1.207T
Minimum field - Bmin	0.4T	0.403T
Gap	180mm	180 mm
Effective length for Bnom	≤525mm	522.58mm
Effective length variation Bnom - Bmin	Not specified	5.56mm
nominal integrated field – Blnom	Not specified	630.65T.mm
Ampere turns per pole for Bnom	Not specified	93540A.t
Ampere turns per pole for Bmin	Not specified	29376A.t
Ampere turns per pole for Bmax	Not specified	115200A.t
Stored Energy for Bmax	Not specified	99500J
Good field region dimensions	H ±250mm V not specified	H ±250mm V ±65mm (info)
Transverse Field homogeneity @ Bnom	$0/3.0x10^{-3}$	$0/2.7x10^{-3}$ Midplane
Transverse Field homogeneity @ Bmin	$0/3.0x10^{-3}$	$0/2.2x\ 10^{-3}$ Midplane
Integrated Field homogeneity @ Bnom	$-2.5x10^{-3}/4.5x10^{-3}$	$-1.53x10^{-3}/1.22x10^{-3}$
Integrated Field homogeneity @ Bmin	$-2.5x10^{-3}/4.5x10^{-3}$	$-1.39x10^{-3}/1.06x10^{-3}$

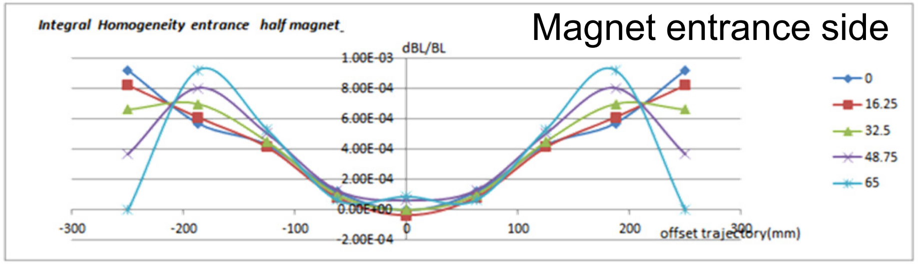


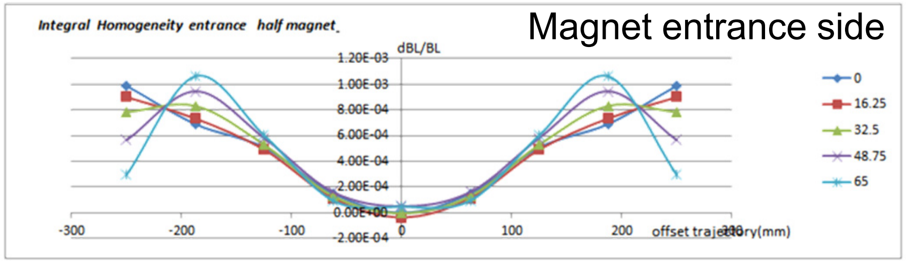
Status of the zero angle spectrometer



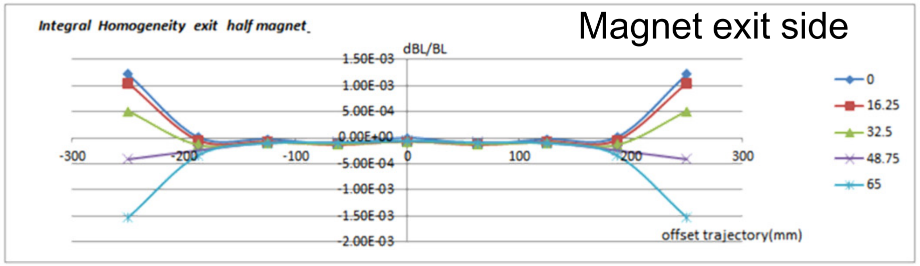


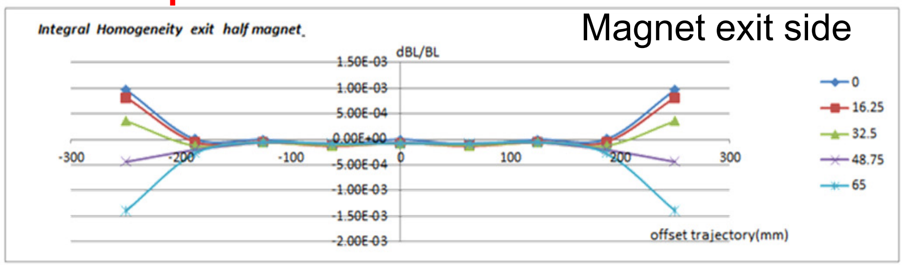






Influence of the coils outputs

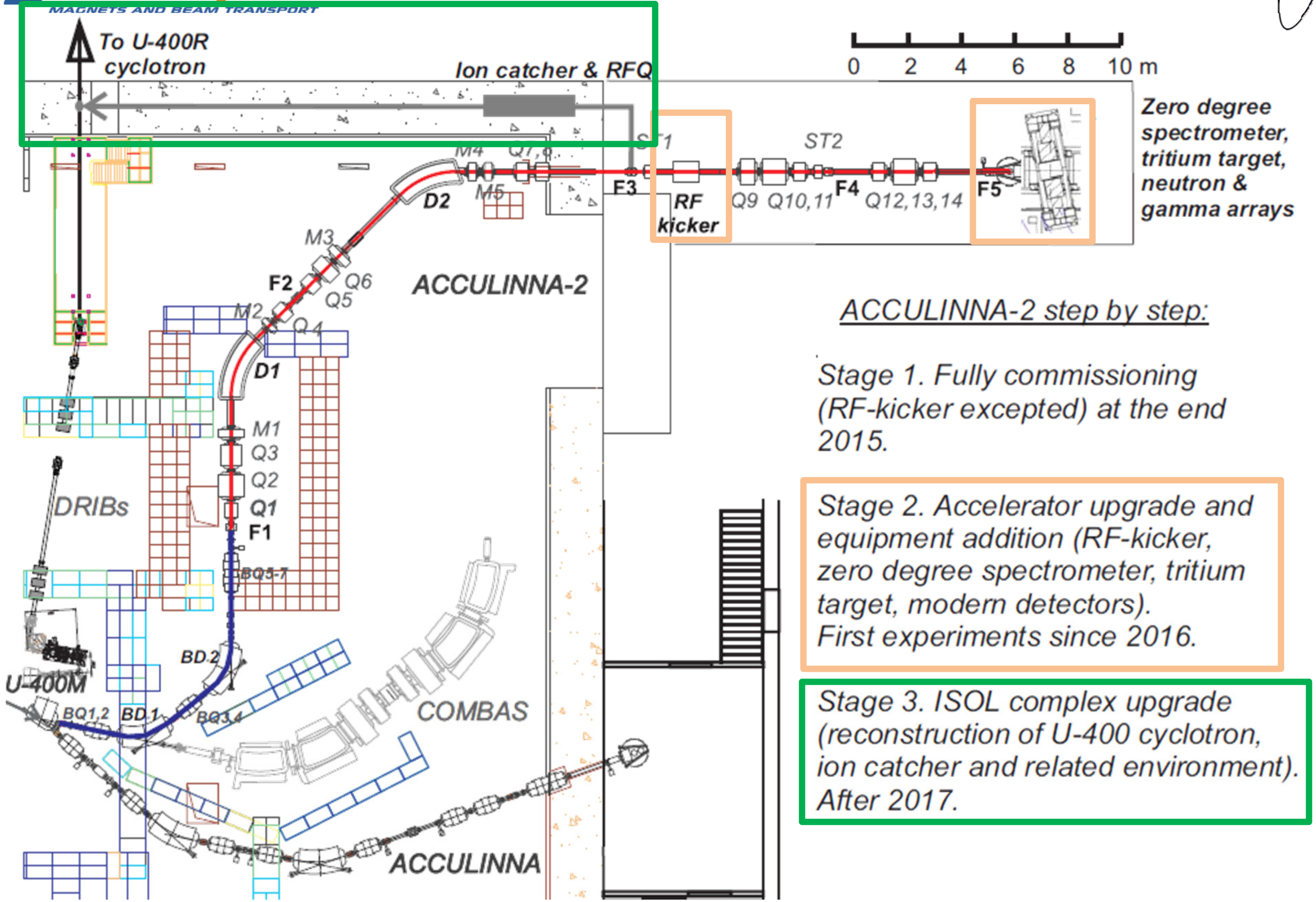




The far future

2018 and beyond

Future plans



<u>ACCULINNA-2 step by step:</u>

Stage 1. Fully commissioning (RF-kicker excepted) at the end 2015.

Stage 2. Accelerator upgrade and equipment addition (RF-kicker, zero degree spectrometer, tritium target, modern detectors). First experiments since 2016.

Stage 3. ISOL complex upgrade (reconstruction of U-400 cyclotron, ion catcher and related environment). After 2017.

We also built friendship

На здоровье АКУЛИНА-2
Cheers ACCULINNA-2

Conclusions

- ACCULINNA-2 is fully installed and commissioned. First runs should start by end 2015
- It is on time and on budget.
- A global contract for all hardware has opened the possibility for thorough optimization and drastic improvements of the long term operation costs.
- The zero-angle dipole is currently under study and production should start soon.
- A wonderful human experience!

Thank you for your attention

Costs

		In M$
	Costs coincides vey well with early predictions	
Known	The separator itself (same cost for RIPS at RIKEN)	5
	All communications (electricity, water, vacuum)	0.1
	Zero degree spectrometer	0.3
Estim'd	Civil constructions (new cabin, production target and radiation shell)	0.25
	Beam diagnostics and vacuum control (Faraday cups, slits, profilometers, tof-detectors, valves etc)	0.15
	RF kicker (in the plan for the next 7 years)	1
	New tritium target (gas-vacuum system, safety surroundings etc)	1
	Total for ALL planned equipment	7.8

Relatively low cost of our setup is explained by

- existing infrastructure (cyclotron, experimental hall, communications etc);
- simple and cost effective design (no SC elements, no high tech, optimized system)

A pigmy compared to FAIR (~1200 M€), FRIB (450 M$), BigRIPS or SPIRAL2

Some references

Acculinna webpage + list of publications
http://aculina.jinr.ru/acc-2.php

An extended study of the Acculinna2 configuration with LISE++
http://lise.nscl.msu.edu/9_4/acculinna2/9_4_acculinna2.pdf

Research program for the radioactive beams of the ACCULINNA-2 separator
http://aculina.jinr.ru/pdf/Research%20Program%20for%20the%20Radioactive%20Beams%20of%20the%20ACCULINNA-2%20Separator.pdf

The status of new fragment separator ACCULINNA-2 project and the first day experiments
http://aculina.jinr.ru/pdf/epjconf_inpc2013_11021.pdf