CERN

Beam Commissioning of the HIE-ISOLDE post-accelerator

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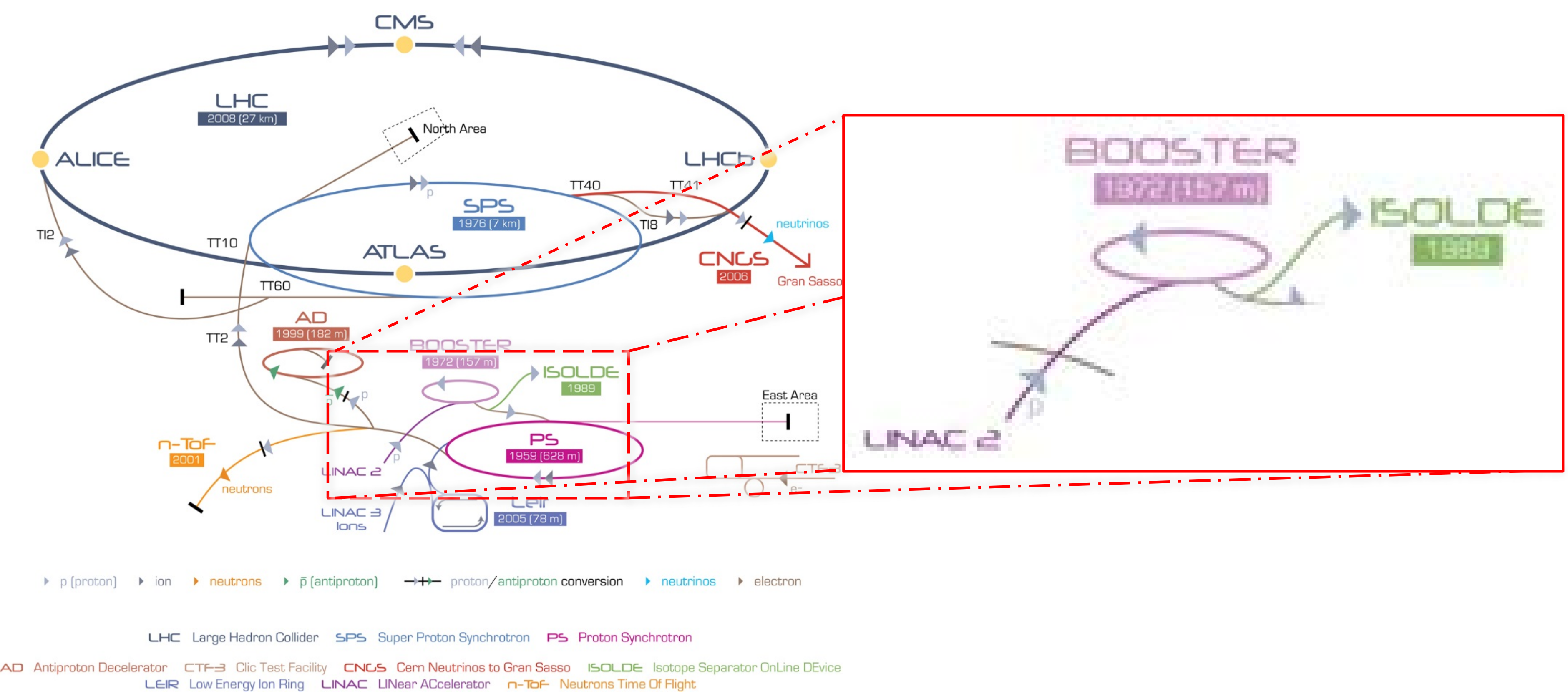
on behalf of the HIE-ISOLDE project

Content:

- Introduction
- Beam commissioning stages
- Beam characteristics
- Physics campaign
- Summary and future plan

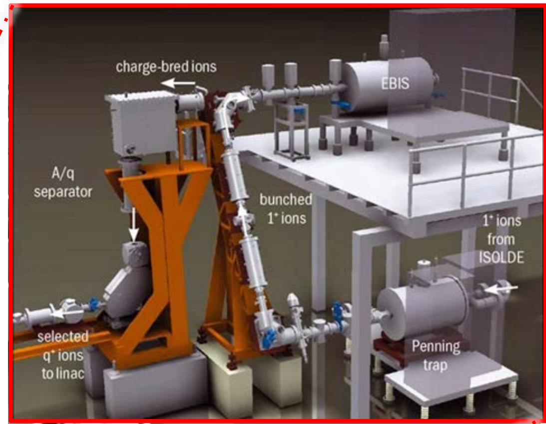
Introduction:

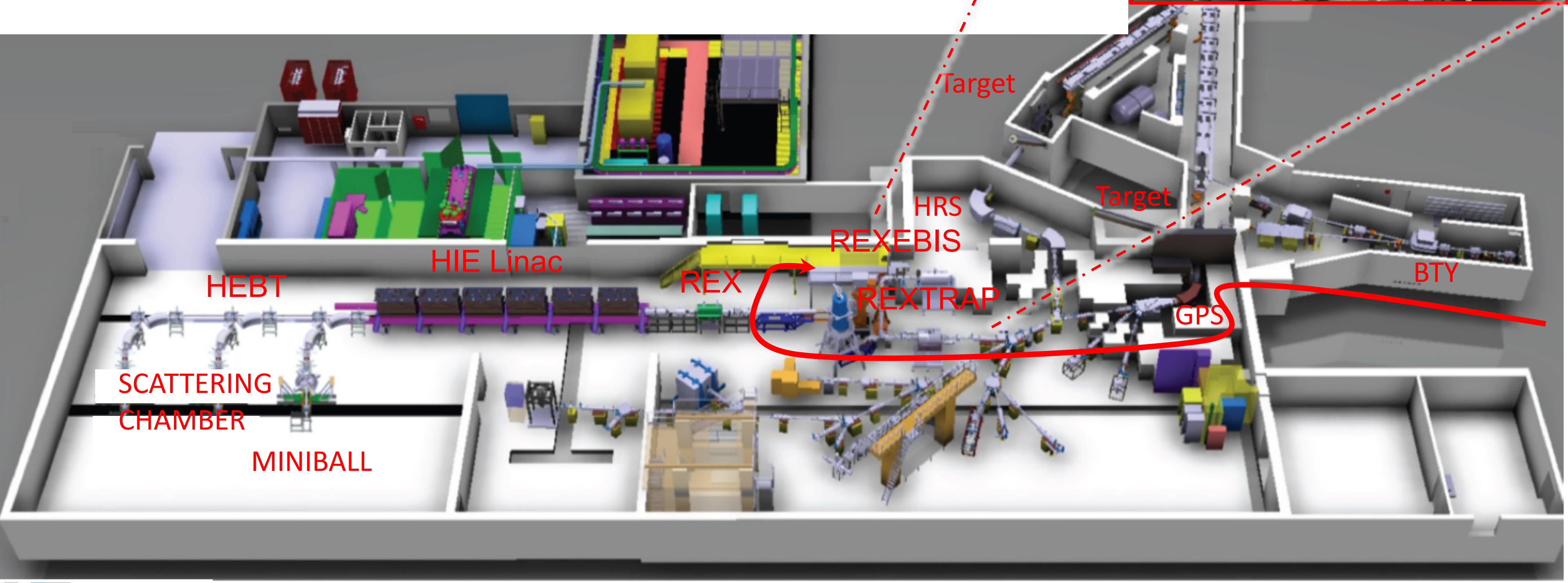
- Located at CERN, ISOLDE is one of the world leading research facilities in the field of nuclear physics
- Protons from the PS Booster at 1.4 GeV are transferred to the facility
- Approximately 50% of the protons accelerated in the PS Booster are delivered to ISOLDE (~ 3E13 protons per pulse every 1.2 s or multiples)



Introduction:

- Radioactive Ion Beams (RIBs) are produced when the protons impact in one of the two targets in the facility
- The RIB of interest is selected in one of the separator lines (GPS, HRS) and transported to a low energy experimental station for study
- Alternatively, the RIB can be accelerated after it is accumulated and transversely cooled in the REXTRAP and charge bred in the REXEBIS





Introduction:

The REX normal conducting linac:

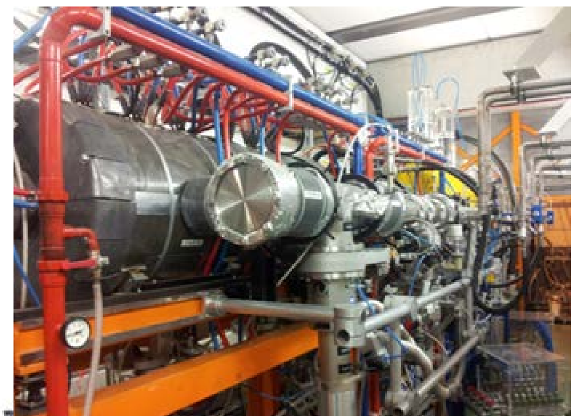
- Beam from the charge breeder with 5 keV/u energy is accelerated to 2.85 MeV/u
- Seven RF structures: f = 101.28 MHz (except for 9gap) with 10% maximum duty cycle

RF Systems:

RF structure	E_f [MeV/u]	β_f [%]	P [kW] for A/q=4.0
RFQ	0.3	2.5	29
Buncher	0.3	2.5	1.3
IHS	1.2	5.1	40
7gap1	1.55	5.7	60
7gap2	1.88	6.3	60
7gap3	2.2	6.8	60
9gap	2.85	7.8	71

Magnets:

Triplets	6
Doublets	1
Steerers	1H, 1V

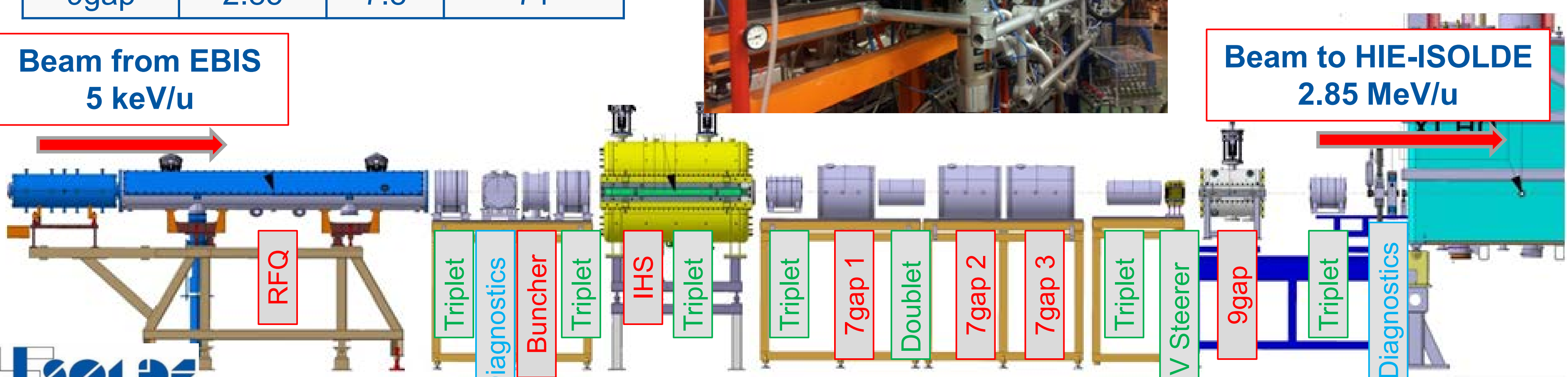


Diagnostics:

REX
FC MCP Collimator apertures Beam attenuators
HIE-ISOLDE
FC Si detector Scanning Slits Collimator apertures

Beam from EBIS
5 keV/u

Beam to HIE-ISOLDE
2.85 MeV/u



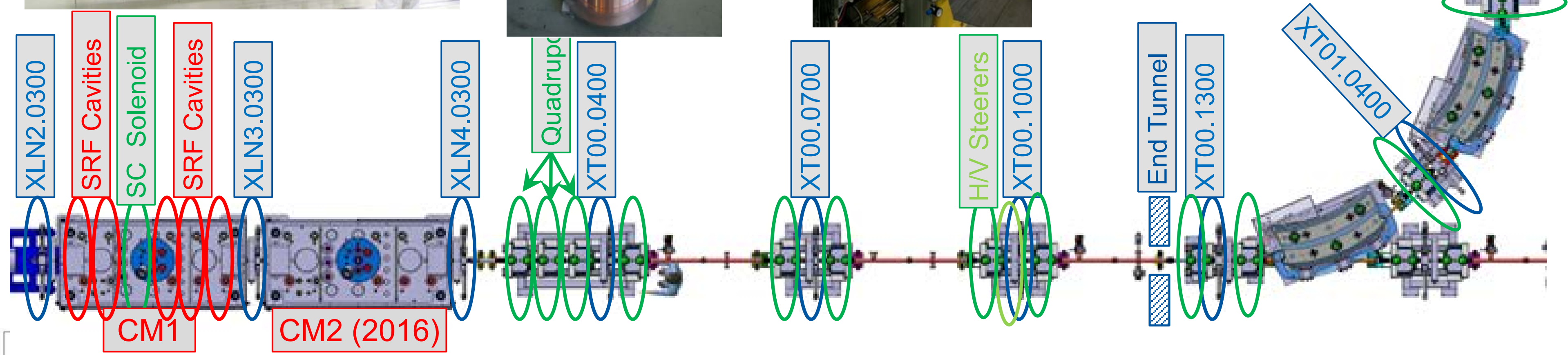
Introduction:

The HIE-ISOLDE super conducting linac and HEBT lines:

- Phase 1a of HIE-ISOLDE completed in 2015: first cryomodule (5 x QWR cavities, 1 x SC solenoid) and two high energy transfer lines
- QWR: copper substrate with niobium sputtered surfaces (β_g = 0.103, E_{acc} = 6 MV/m)
- Cryomodule: common insulation and beam vacuum

Maximum beam energy [MeV/u]

Phase:	1a	1b	2a	2b
A/q=2.5	5.9	8.9	11.8	14.5
A/q=4.5	4.3	6.0	7.7	9.3



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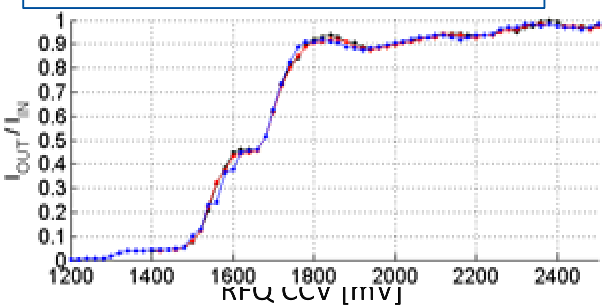
Beam Commissioning Stages:

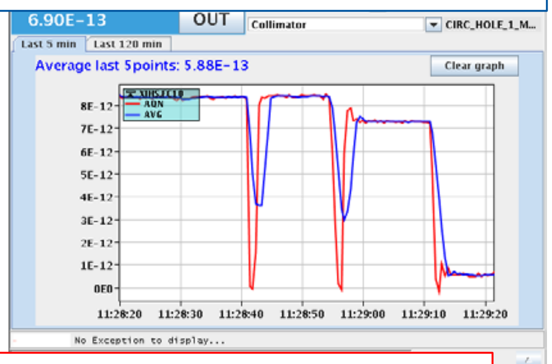
REX diagnostics box:

- ✓ Beam commissioning started in June after the renewing many systems in REX
- ✓ Beam from the charge breeder was accelerated to 0.3 MeV/u in the RFQ and used to re-commission the REX diagnostic box
- ✓ Beam transmission through RFQ was measured for different power levels and used to determine the operational settings of the RF structure

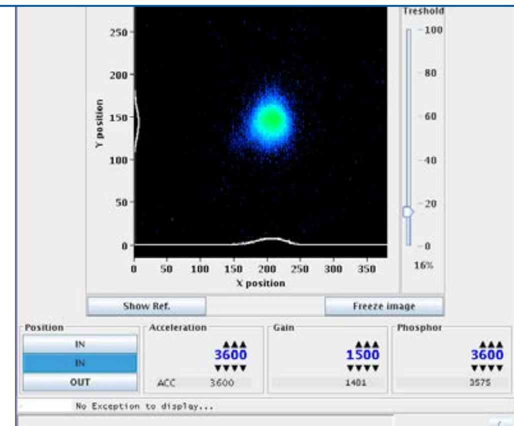
Beam transmission through the RFQ for different RF power levels



Beam in FC after RFQ for different collimator aperture sizes

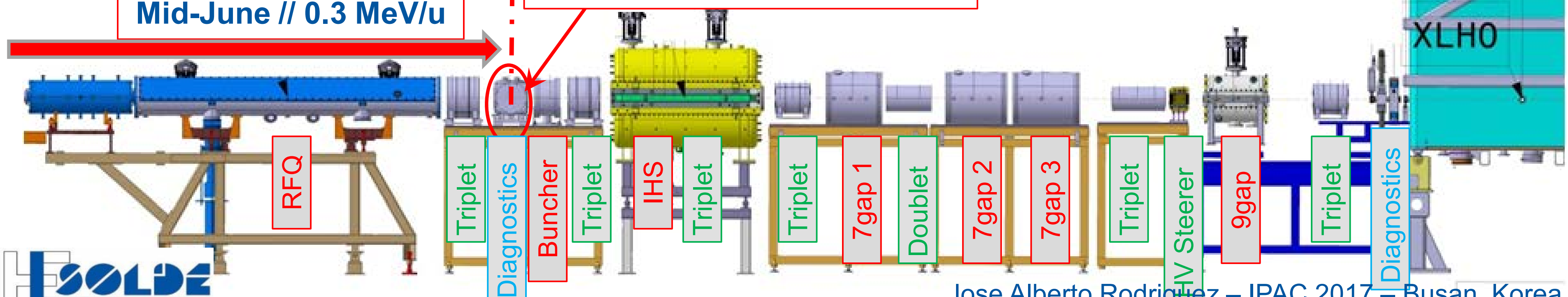


MCP image of the beam after the RFQ



Diagnostic box: FC, MCP, Collimators, Beam attenuators

Mid-June // 0.3 MeV/u

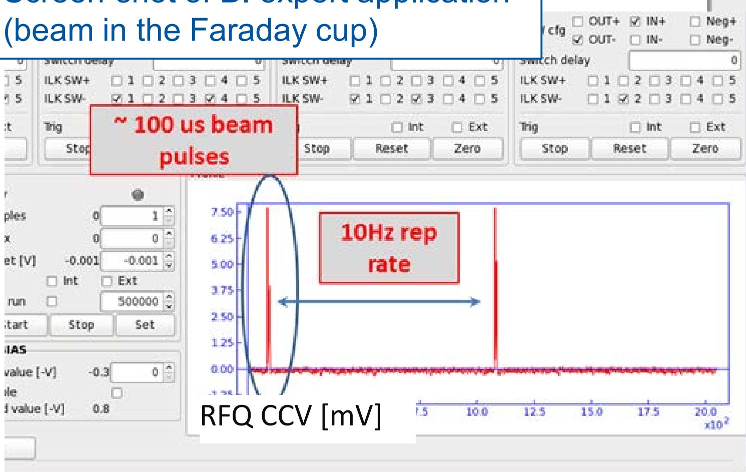


Beam Commissioning Stages:

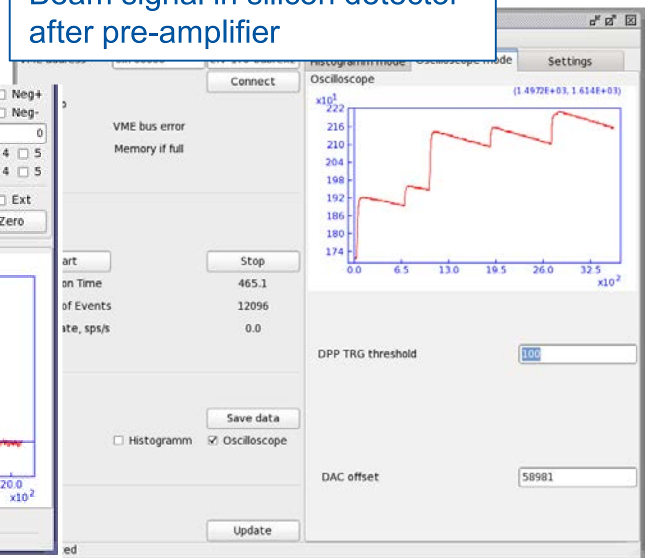
First HIE-ISOLDE diagnostics box:

- ✓ First beam with 0.3 MeV/u energy to FC and to the silicon detector in July
- ✓ Systematic tests confirmed that all the devices behave as planned
- ✓ BI expert applications also tested

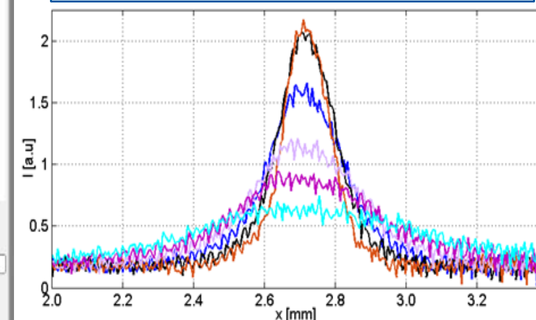
Screen-shot of BI expert application (beam in the Faraday cup)



Beam signal in silicon detector after pre-amplifier

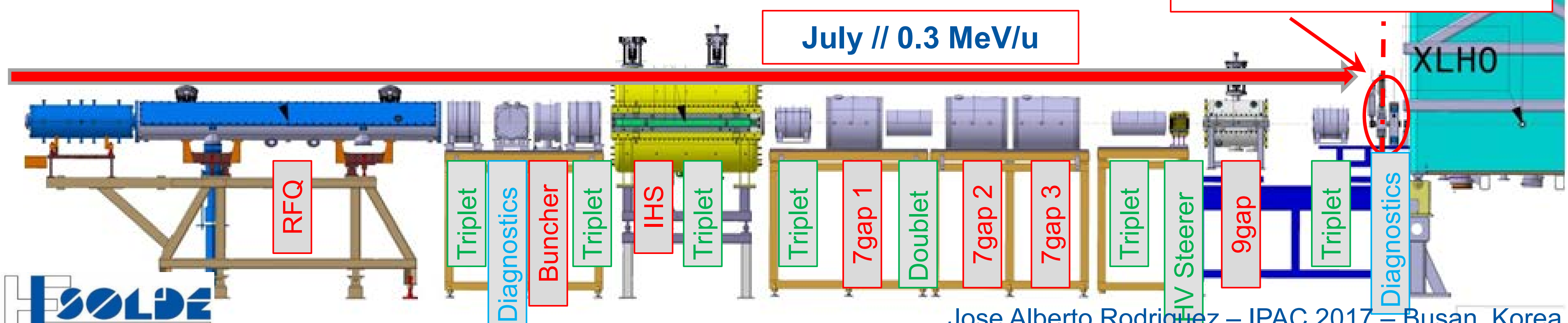


Quad scan using scanning slits (I = 15 pA)



Diagnostic box: FC, Si detector, Scanning slit, Collimator slit

July // 0.3 MeV/u

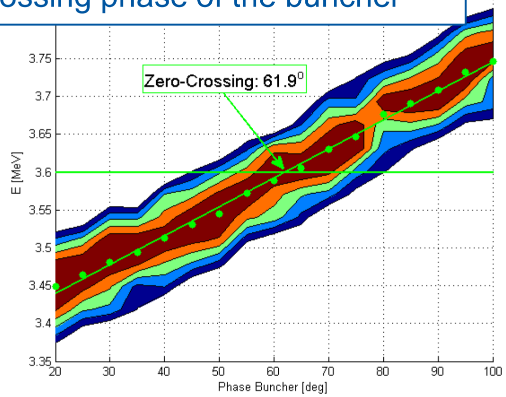


Beam Commissioning Stages:

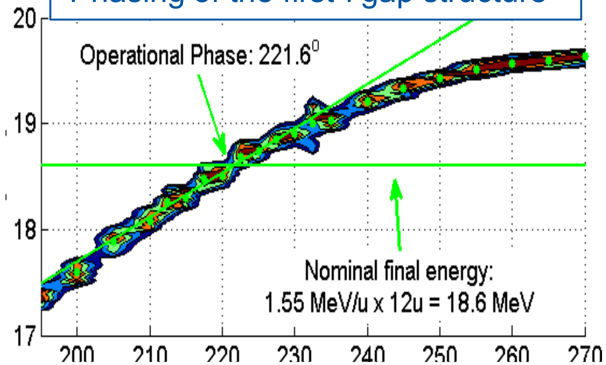
Phasing of the RF systems in REX:

- ✓ Commissioning of the other RF systems started in July
- ✓ Several problems were discovered and solved during this time (phase shifters, cooling…)
- ✓ New operational settings for all RF cavities were determined using the silicon detector (necessary because of work on LLRF and connection to new reference line)
- ✓ Beam at 2.85 MeV/u ready for HIE-ISOLDE beam commissioning at the end of August

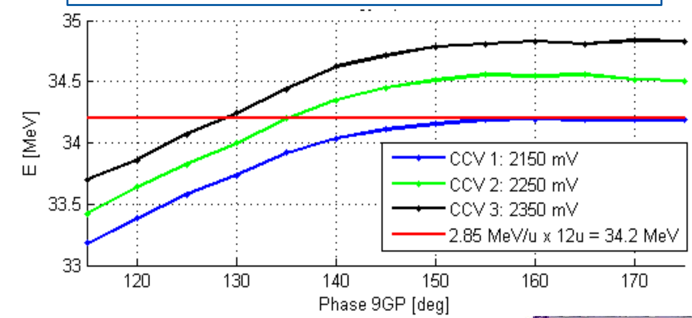
Energy spectrum around zero-crossing phase of the buncher



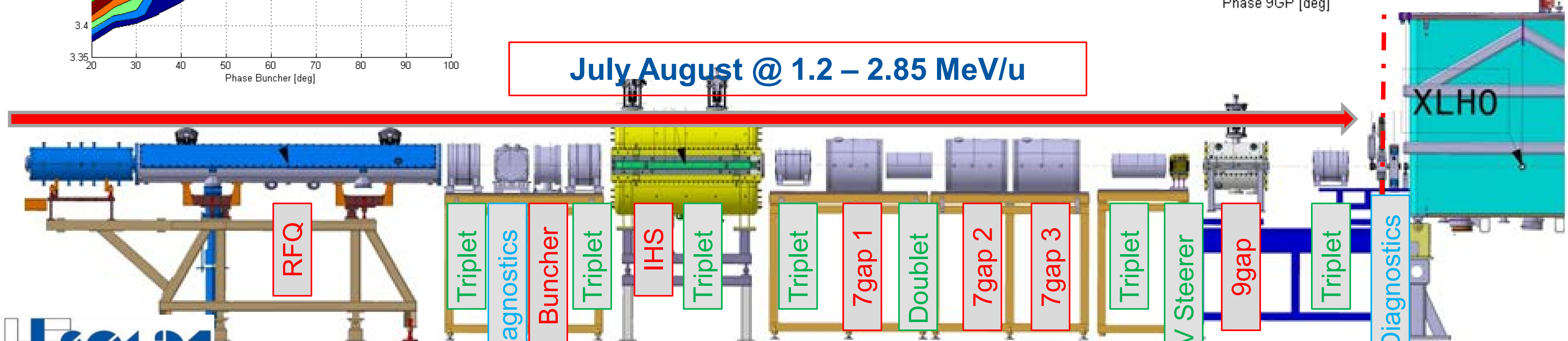
Phasing of the first 7gap structure



Energy of the beam for different phases and amplitudes out of the 9gap



July August @ 1.2 – 2.85 MeV/u



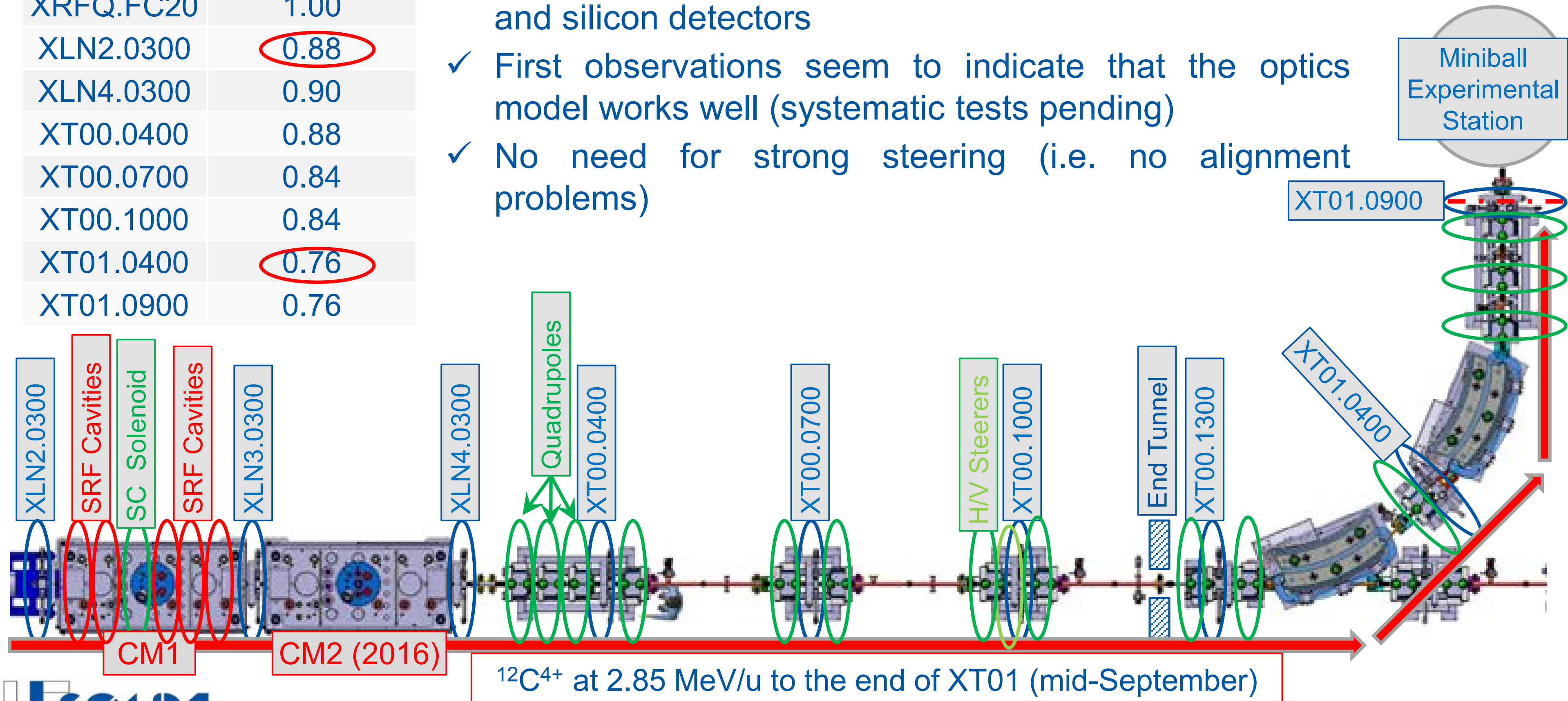
Beam Commissioning Stages:

First High Energy Beam Transfer (HEBT) line:

- ✓ Beam drifted through CM1 to the end of the first HEBT line in mid-September
- ✓ Overall transmission ~ 76% after a few hours optimization. Transmission through REX ~ 88% (note DC beam before RFQ). Other losses concentrated in the dipoles (probably due to longitudinal beam mismatch)

FC	Transmission
XRFQ.FC20	1.00
XLN2.0300	0.88
XLN4.0300	0.90
XT00.0400	0.88
XT00.0700	0.84
XT00.1000	0.84
XT01.0400	0.76
XT01.0900	0.76

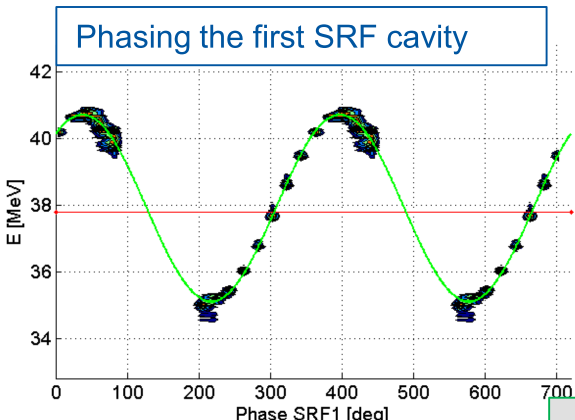
- ✓ No mayor problems found with optical elements, FCs and silicon detectors
- ✓ First observations seem to indicate that the optics model works well (systematic tests pending)
- ✓ No need for strong steering (i.e. no alignment problems)

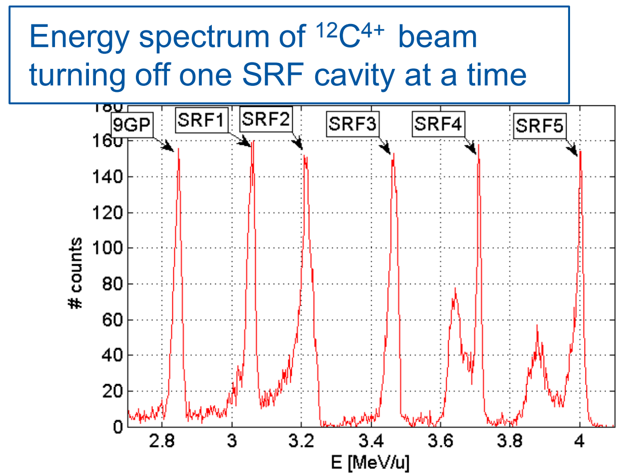


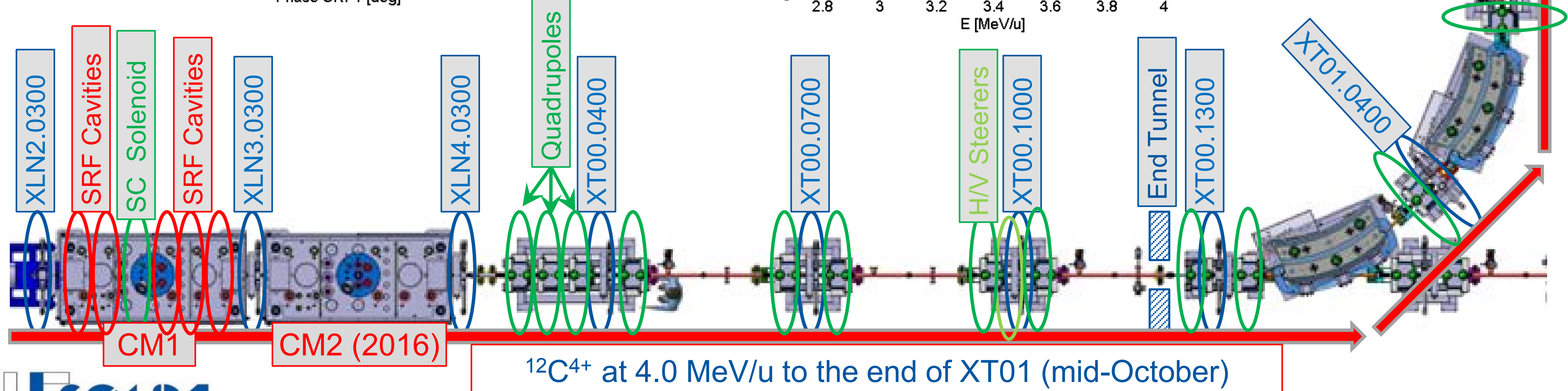
Beam Commissioning Stages:

SRF cavities:

- ✓ First acceleration using SRF cavities at the beginning October
- ✓ Two weeks of work to optimize the SRF systems (power and stability)
- ✓ All cavities phased using a silicon detector at the end of the tunnel ($^{12}C^{4+}$ at 4 MeV/u)
- ✓ Accelerated beam transported to the end of the first HEBT line by mid-October







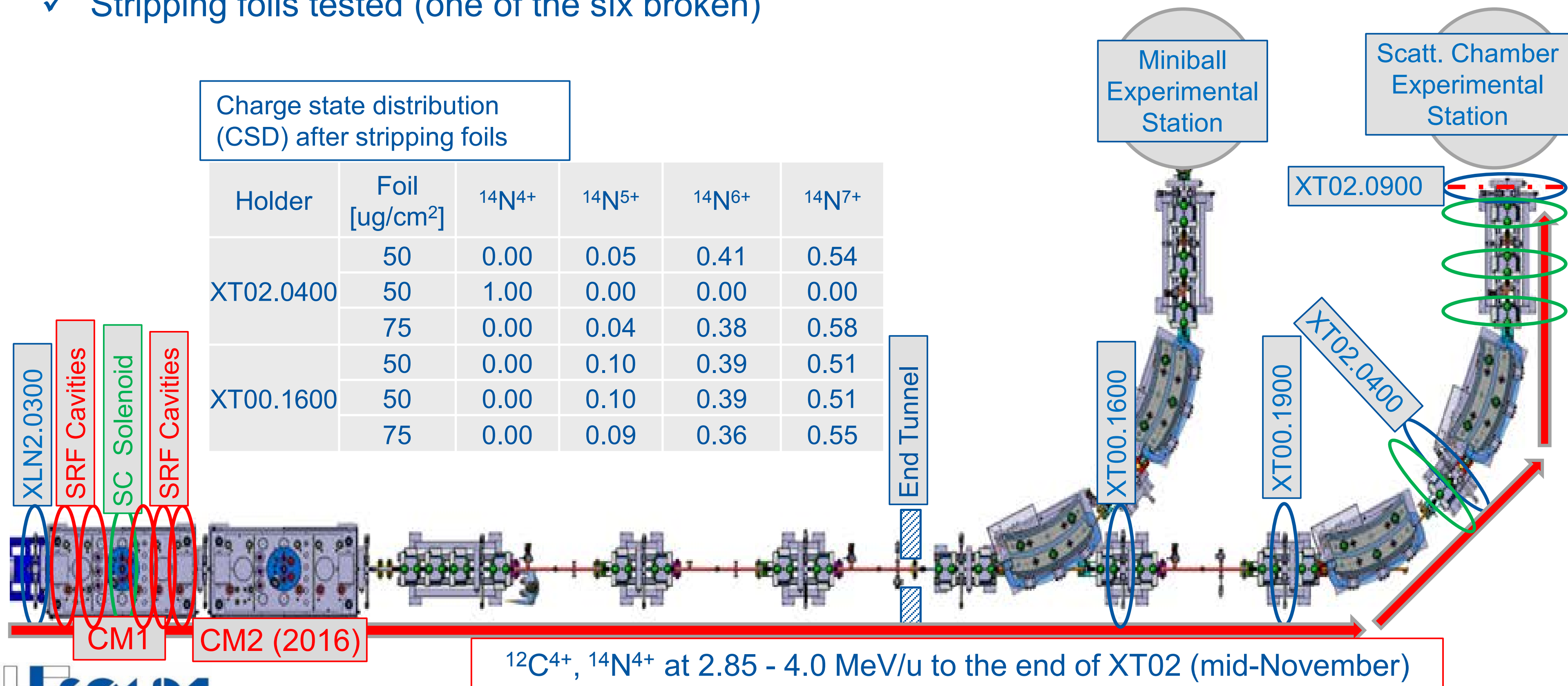
Beam Commissioning Stages:

Second High Energy Beam Transfer (HEBT) line:

- ✓ First beam to the end of the line in November (after physics campaign with RIBs was completed
- ✓ Transmission to the end of the line ~ 79% without optimization
- ✓ No mayor problems found with optical elements and FCs
- ✓ First observations seem to indicate that the optics model works well
- ✓ No need for strong settings for correctors
- ✓ Stripping foils tested (one of the six broken)

Charge state distribution (CSD) after stripping foils

Holder	Foil [ug/cm^2]	$^{14}N^{4+}$	$^{14}N^{5+}$	$^{14}N^{6+}$	$^{14}N^{7+}$
XT02.0400	50	0.00	0.05	0.41	0.54
	50	1.00	0.00	0.00	0.00
	75	0.00	0.04	0.38	0.58
XT00.1600	50	0.00	0.10	0.39	0.51
	50	0.00	0.10	0.39	0.51
	75	0.00	0.09	0.36	0.55



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Beam Characteristics:

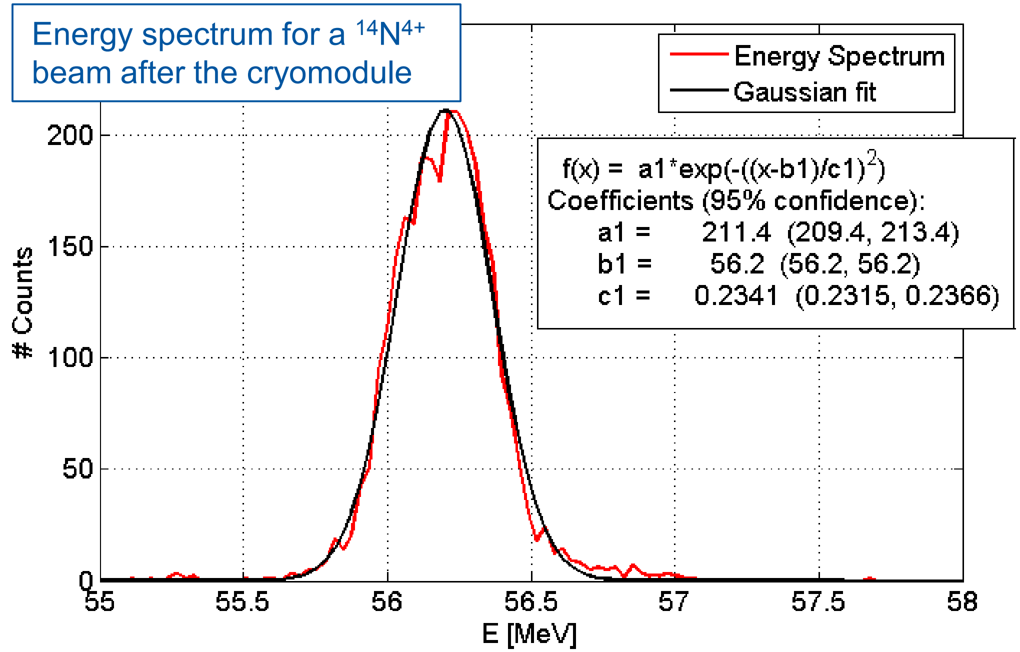
Beam energy and energy spread:

The three methods consistent within 2-3%

Several options for beam energy measurements:

- Si detector: Time consuming / uncertainty in the absolute calibration
- Dipole magnet: Need fairly high beam current / uncertainty in the absolute calibration
- RF cavities: Need precise knowledge of the operating phase (i.e. time consuming)
- TOF system: Will be used together with the previous methods (will be available in 2016)
- Si detector after dipole magnet: Low beam current is sufficient / relatively quick measurements (will be available in 2016)

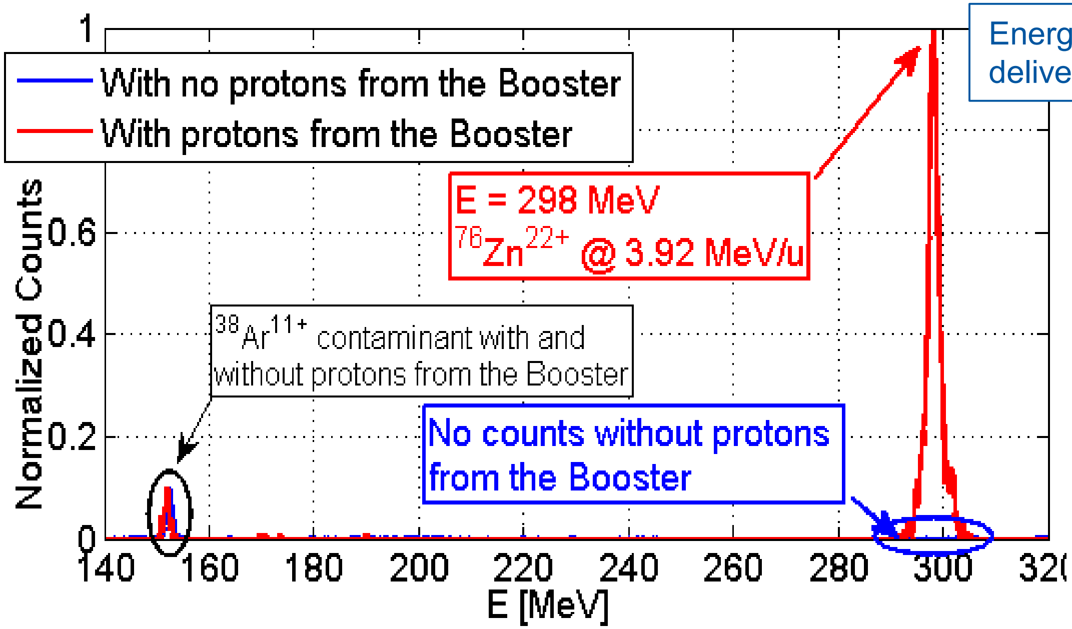
Energy spectrum for a $^{14}N^{4+}$ beam after the cryomodule



Beam Characteristics:

Beam contamination:

- The silicon detectors can be used to estimate the beam contamination from the charge breeder
- We can use this information to adjust the separator and the timing of the TRAP / EBIS
- Unfortunately, this type of measurements can be very time consuming and cannot be conducted as often as desired
- The silicon detector are not useful to measure isobaric contamination from the target since the total energy is very similar



Energy spectrum of the beam delivered to the experimental station.

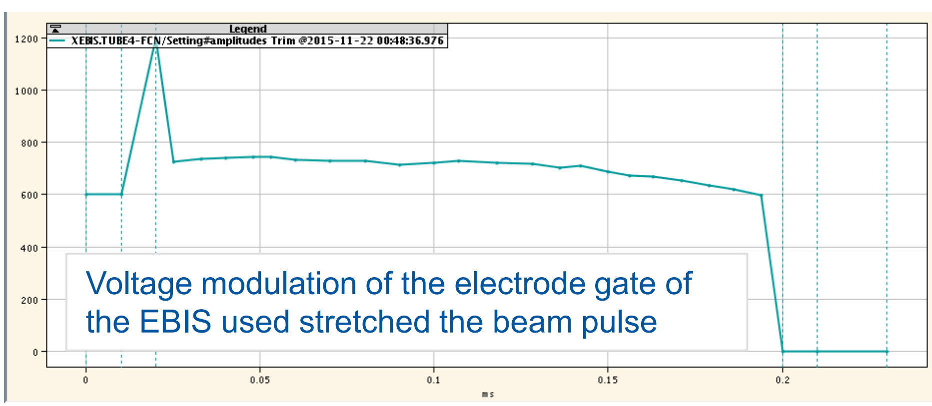
Beam Characteristics:

Time macrostructure:

- The limits in the maximum power in the SRF cavities and out of the temporary 9gap amplifier introduced constrains in the time macrostructure. Problem with couplers has now been solved and the new 9gap amplifier has been installed. It should not be an issue in the future.

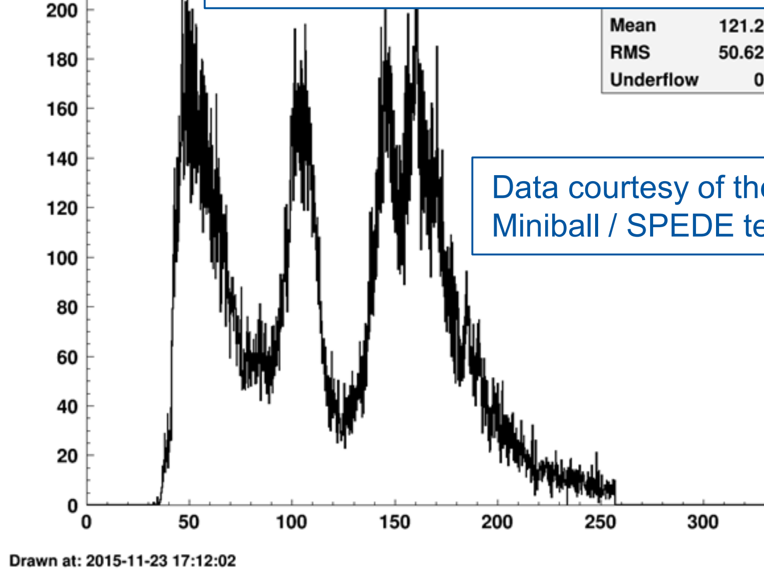
Limits on peak power of SRF and 9gap → Limits on the maximum A/Q of the beam → Longer breeding times → Lower repetition rates → Lower effective beam current → Longer experiments

- Slow extraction from the charge breeder using the new timing hardware was tested and used during the physics campaign
- New software tools are currently being developed and will allow better control of the time macrostructure this year



Voltage modulation of the electrode gate of the EBIS used stretched the beam pulse

Time structure of the beam out of the EBIS after pulse was stretched



Data courtesy of the Miniball / SPEDE teams

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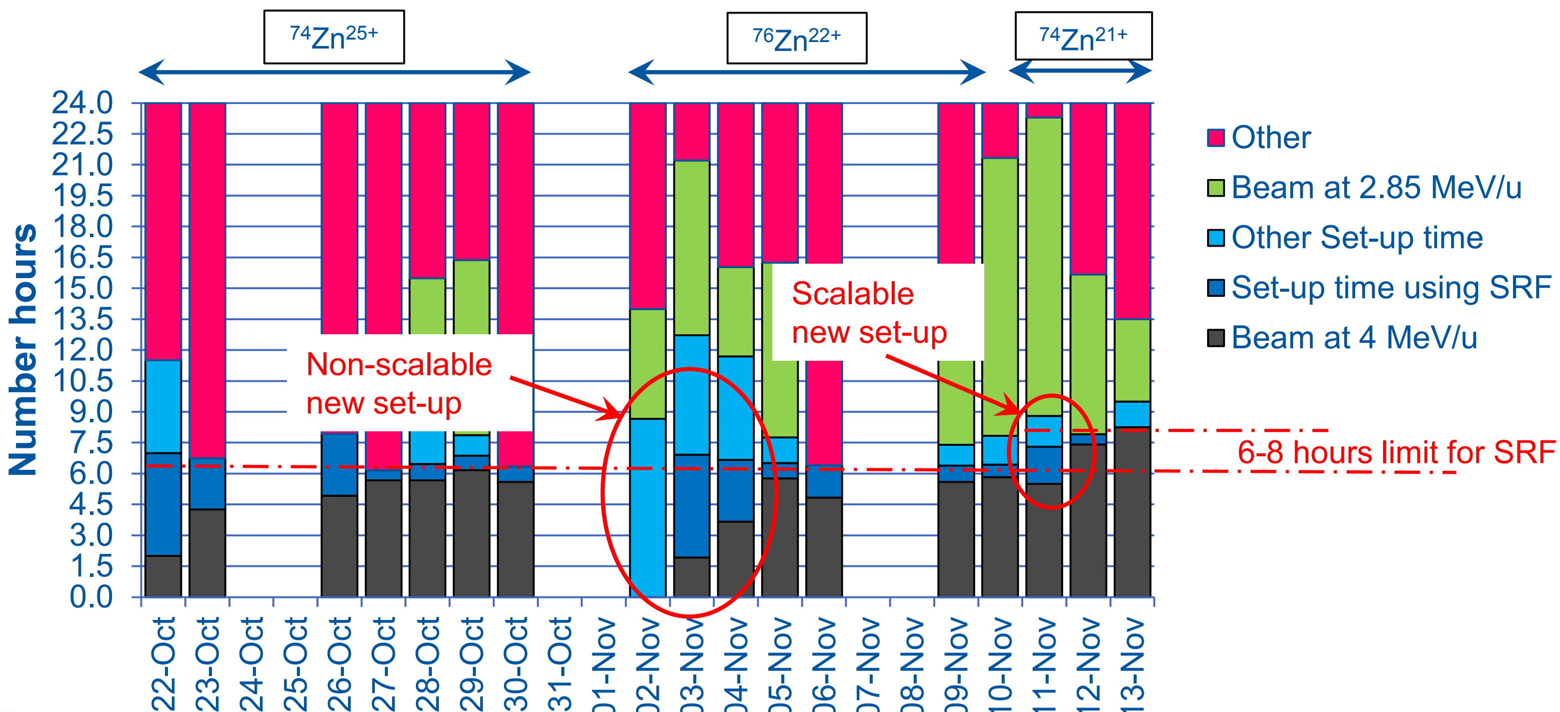
Physics Campaign:

- Short (5 weeks), but very useful, physics campaign at the end of 2015 (more information at TUPMR023)
- Two RIBs (^{74}Zn, ^{76}Zn) to Miniball experimental station
- Two energies: 4 MeV/u and 2.85 MeV/u (due to heating problem of the SRF couplers)
- In addition, stable beam were used for beam commissioning of the experimental stations

Beam	To:	Energy [MeV/u]	Time [hours]
$^{22}Ne^{7+}$	Miniball	2.85	~ 60
$^{74}Zn^{25+,21+}$	**Miniball**	**2.85 / 4**	**~ 90**
$^{76}Zn^{22+}$	**Miniball**	**2.85 / 4**	**~ 90**
$^{14}N^{4+}$	Scat. Ch.	2.85 / 4	~ 2
$^{12}C^{4+}$	Scat. Ch.	4	~ 2
$^{133}Cs^{39+}$	SPEDE	2.85 / 4	~ 110



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Summary and Future Plan:

WEPMB051

- Cryomodule CM1 and two HEBT lines installed in 2015
- Hardware commissioning followed (problems with SRF couplers found)
- A reduced beam commissioning program was completed. Due to time constrains, focus only on items critical systems to start the physics campaign. Work still needed in:
  - Systematic tests of optical elements and some of the diagnostic devices
  - Better characterization of beam properties
  - Optics model benchmarking
- Short Physics campaign (5 weeks) completed in 2015

TUPMR023

2016	Mar. – May.	Installation of the CM1(with new couplers) and CM2 cryomodules
	May – Jul.	Hardware commissioning of CM1 and CM2 Beam re-commissioning of the REX normal conducting linac
	Jul. – Aug.	Beam commissioning of CM1 and CM2
	Aug. – Nov.	**Physics campaign (11 weeks)**
2017	Jan. – Feb.	Installation of CM3 and re-arrangement of the HEBT lines
	Feb. – Apr.	Hardware commissioning
	Apr. – May	Beam commissioning
	May – Nov.	**Physics campaign (25 weeks)**

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