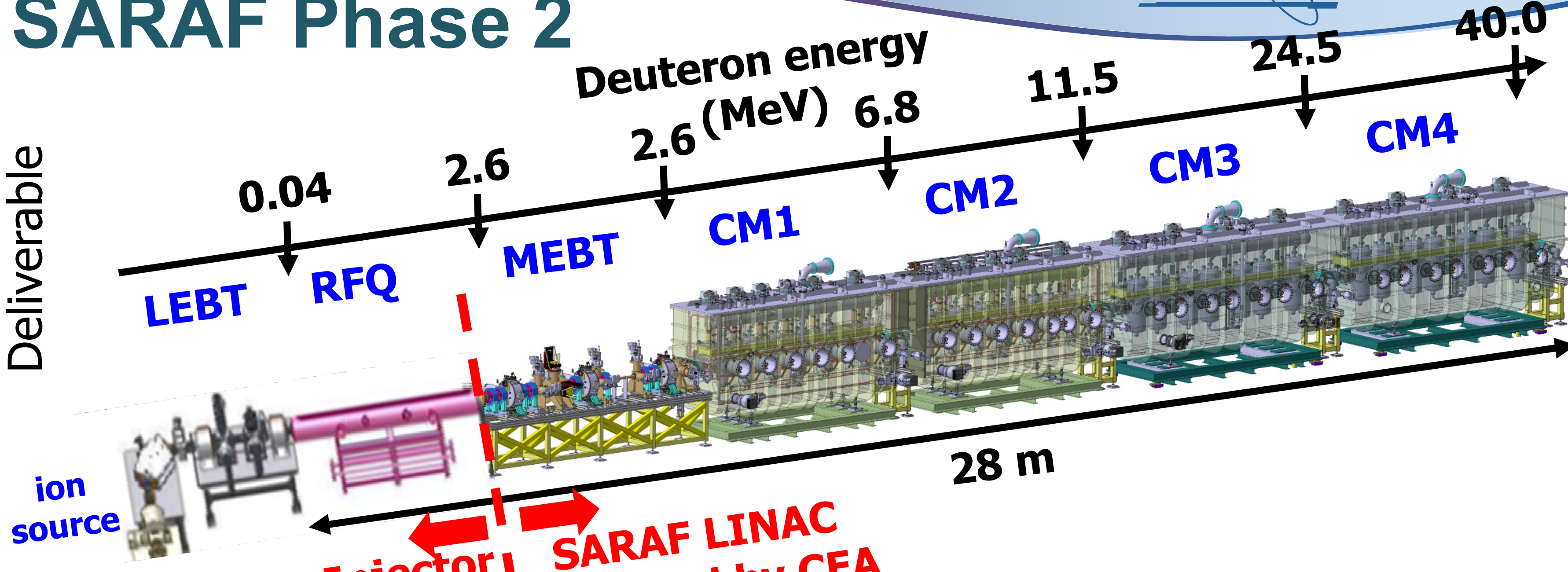
Upgrade of SARAF 4 rods RFQ & the Design of the new Linac

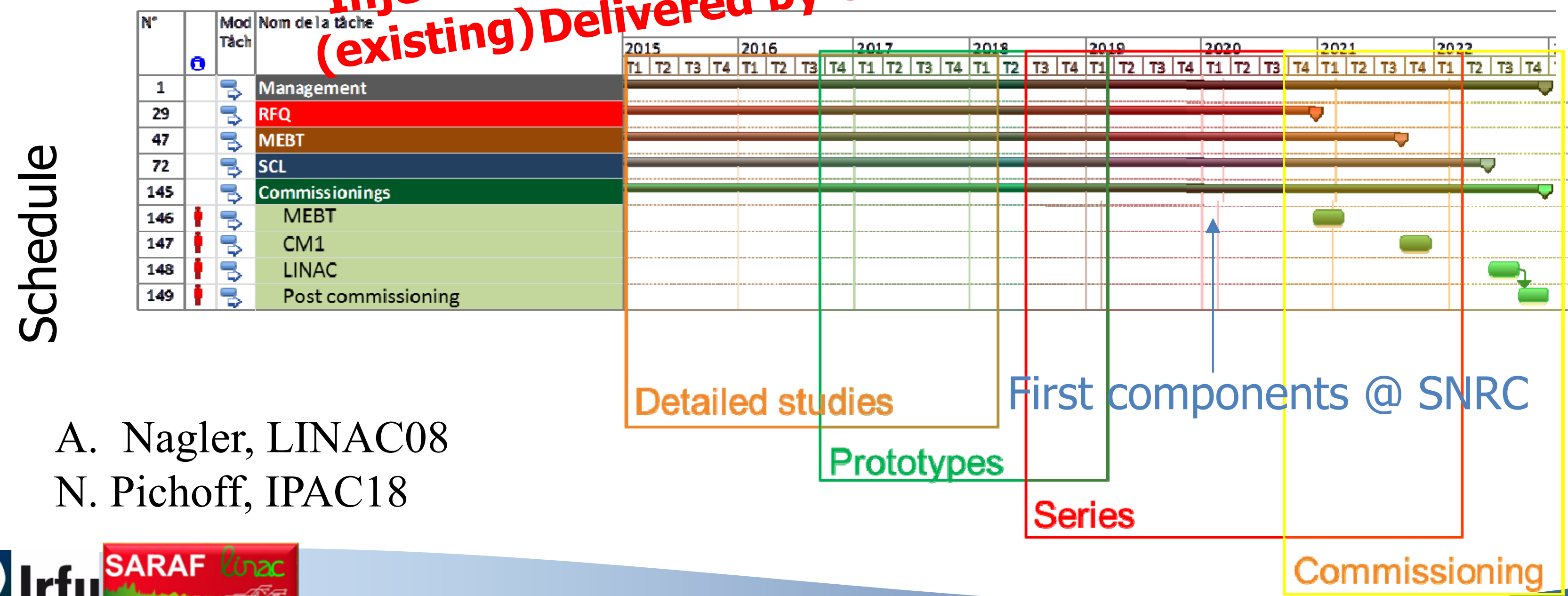
A. Perry and N. Pichoff on behalf of SARAF, CEA's SARAF-LINAC and NTG teams

<u>Outline</u>:

- Overview of SARAF Phase 2 Project
- Upgrade of SARAF 4-rods RFQ
  - Motivation for upgrade
  - Installation & RF conditioning
  - Beam characterization with pulsed beams
  - High intensity CW deuteron beam acceleration
  - Summary and future improvements
- Status of SARAF-LINAC development by CEA:
  - MEBT/ Rebuncher
  - SC HWR
  - RF Couplers
  - Solenoids
  - Cryomodules
  - Teststands
- Summary

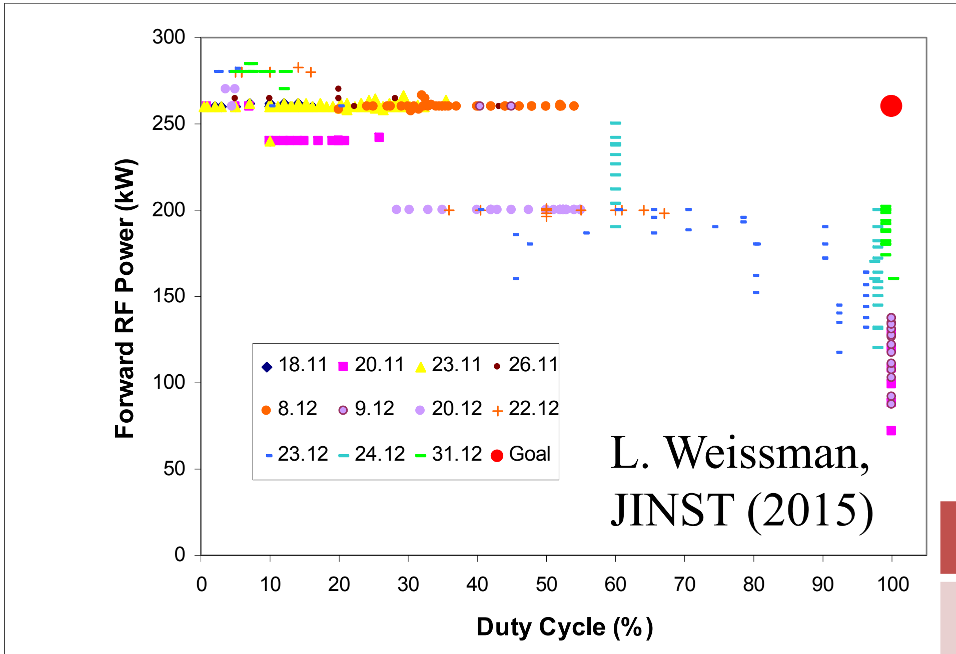
SARAF Phase 2





A. Nagler, LINAC08
N. Pichoff, IPAC18

Motivation for RFQ Upgrade



Original RFQ:

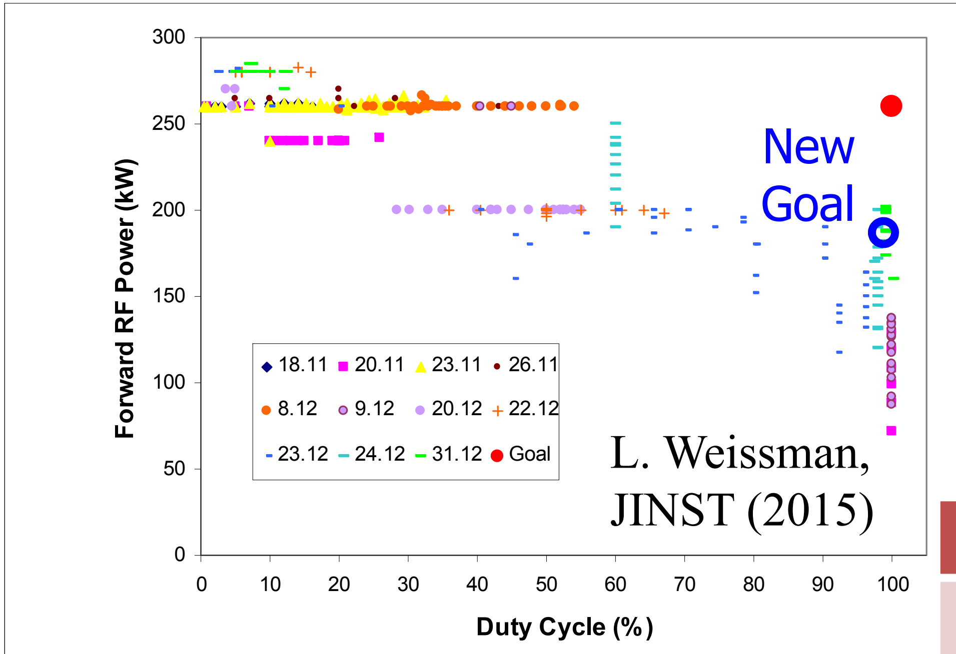
- Design by Univ. Frankfurt, built by ACCEL (RI) GmbH and NTG GmbH
- In operation since 2008
- Stable operation for high intensity CW proton beams
- Stable operation for deuterons only at low DC (<20%)

For (A/Q=2)		Original	new
Power	kW	250	185
Inter-electrode voltage	kV	65	56
Kilpatrick		1.54	1.52
Exit energy	MeV/u	1.50	1.28
Aperture radius	mm	4	3.4
RF couplers		1	2
Frequency	MHz	176	176

New RFQ:

- Series of gradual improvements: tuners, end flanges, o-rings, pumping…
- In 2016 – splitting of RF power (J. Rodnizki Linac16)
- In 2017 – new rod modulation (Design by A. Shor)

Motivation for RFQ Upgrade



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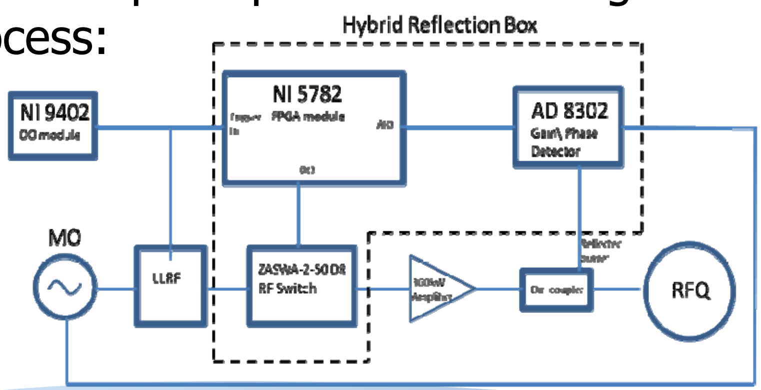
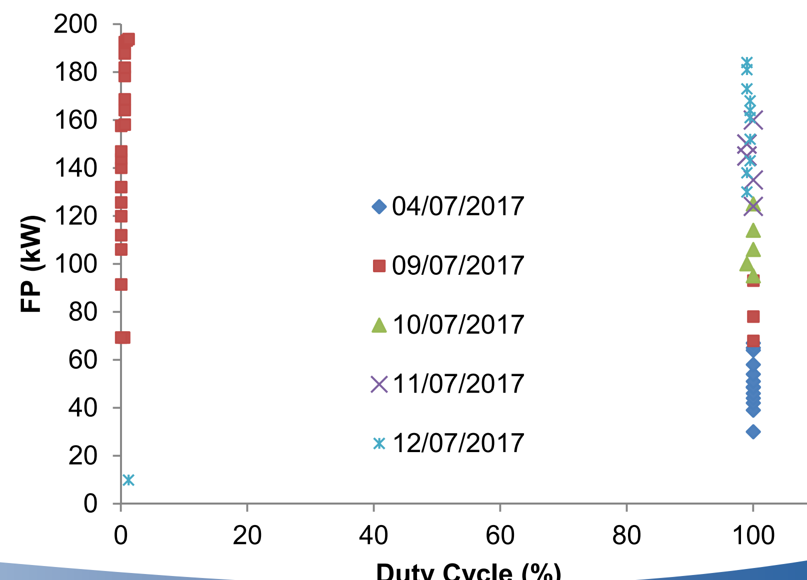
Installation and RF Conditioning

- New rods fabricated by NTG GmbH
- Installation took place in June17
- After 36 net hours – 180kW CW (6 hours w/o trip)
- Additional 35 net hours – 205kW CW (~1 trip per hour)
- In terms of the electric field: 200kW in new RFQ ←→ 260kW in the old RFQ

Utilization of new reflection protection scheme sped up the conditioning process:





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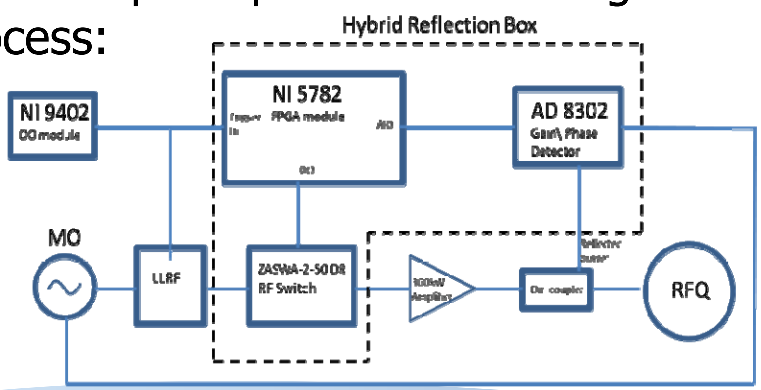
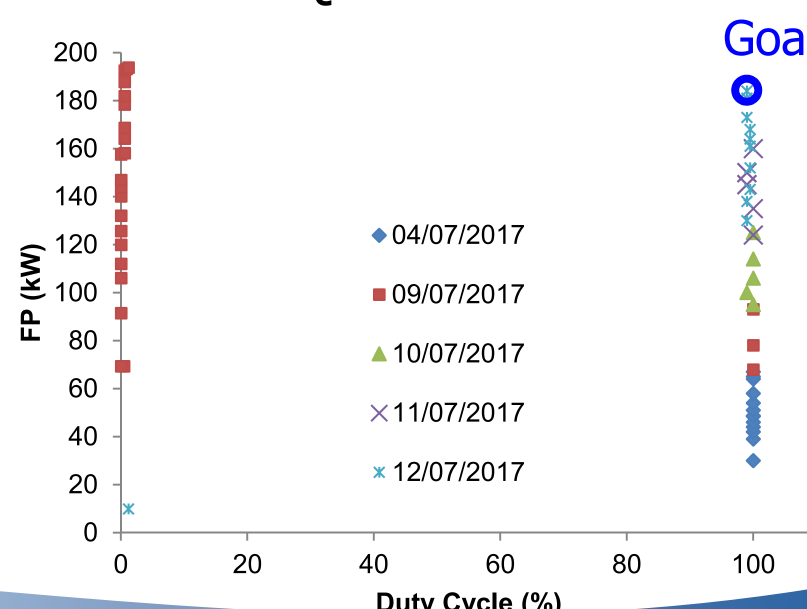
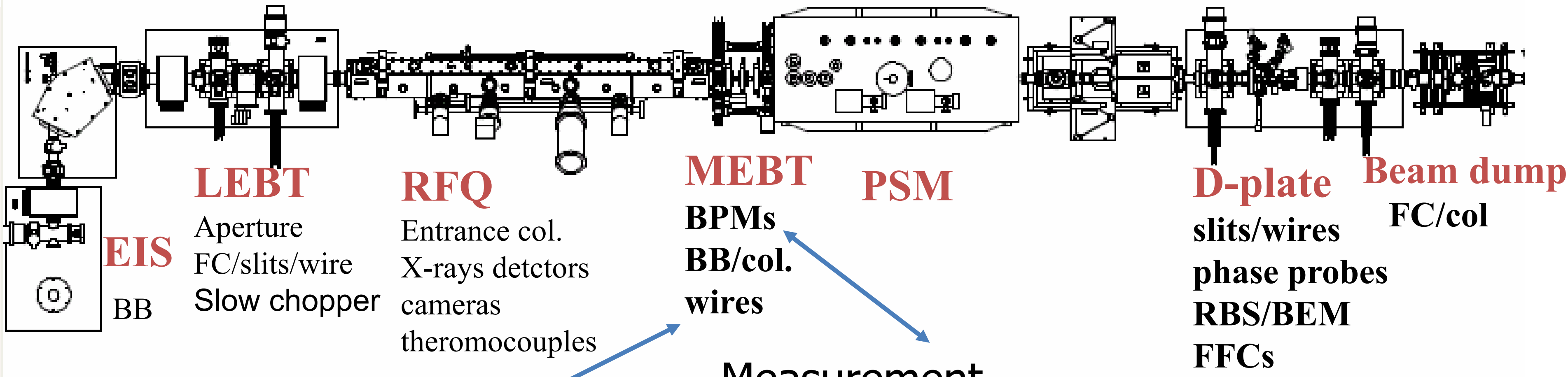


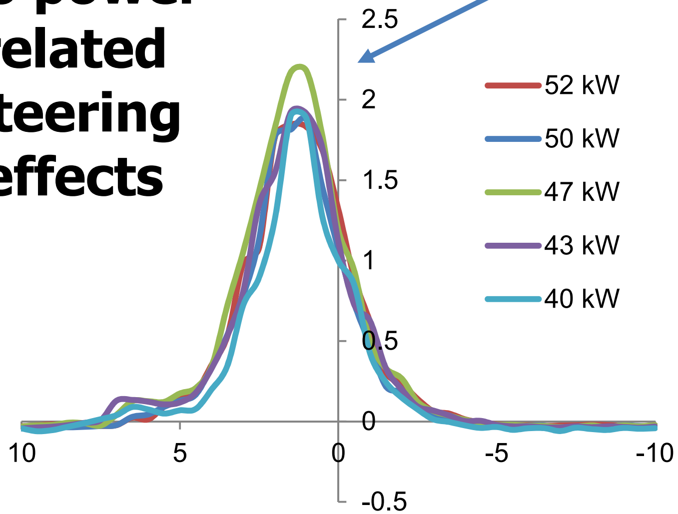


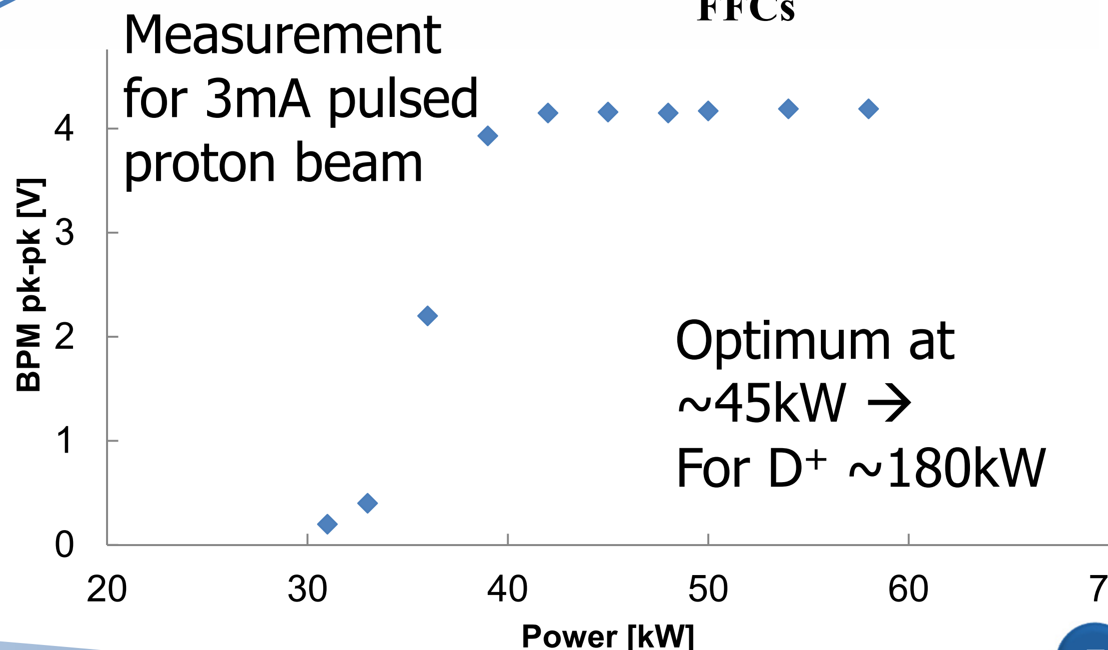
Beam Characterization (MEBT)

Layout of the diagnostic elements:



No power related steering effects





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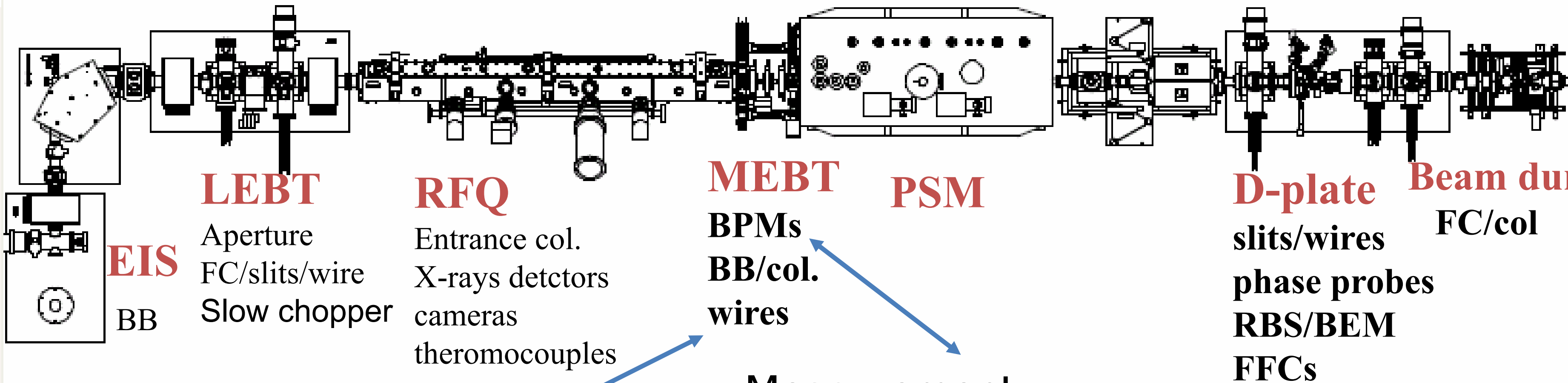
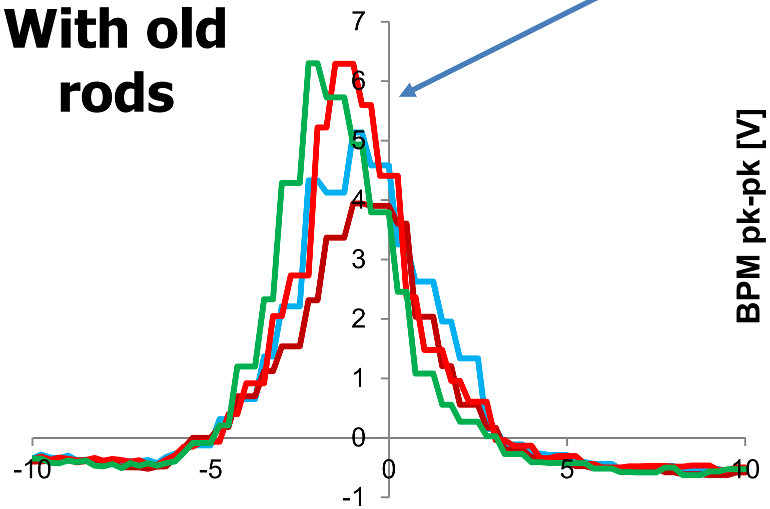
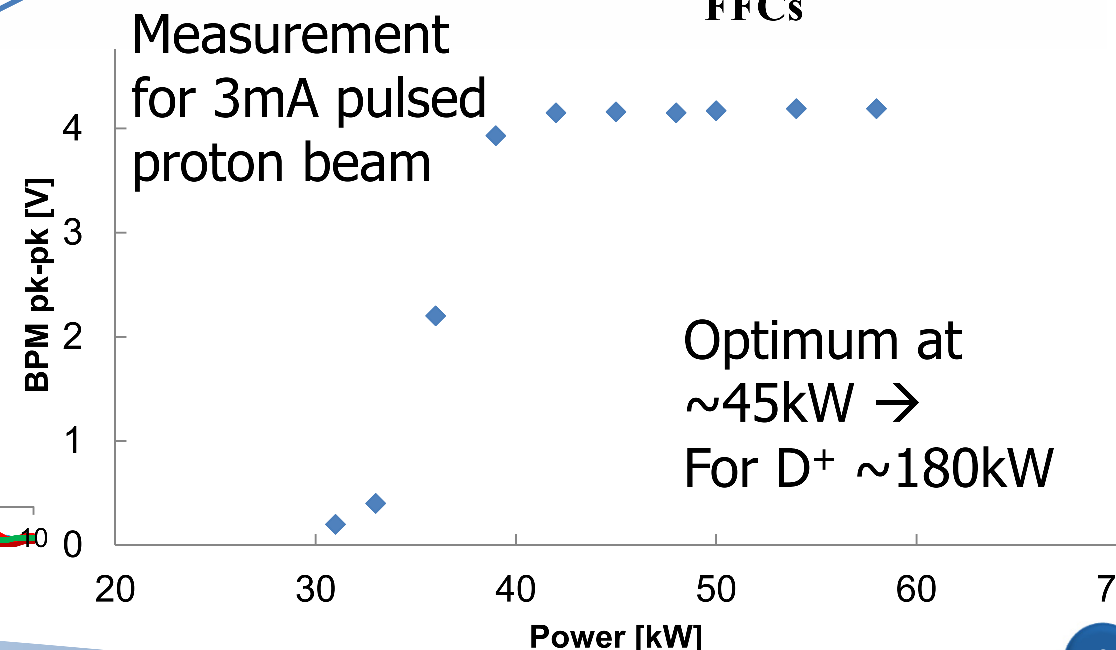


With old rods

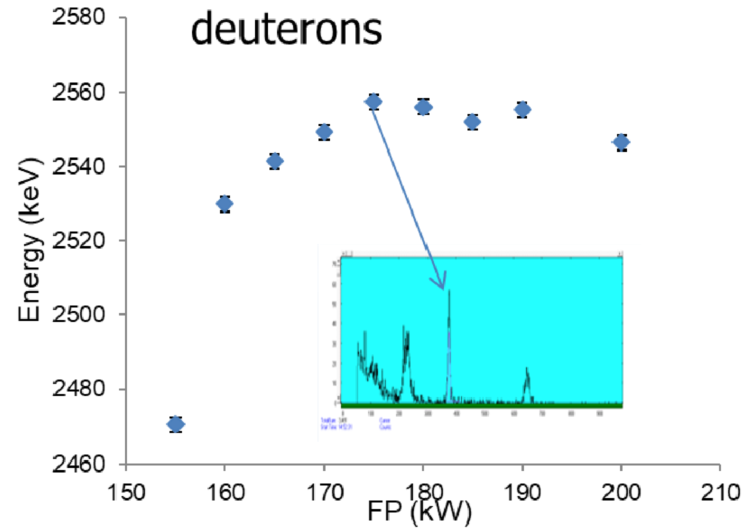


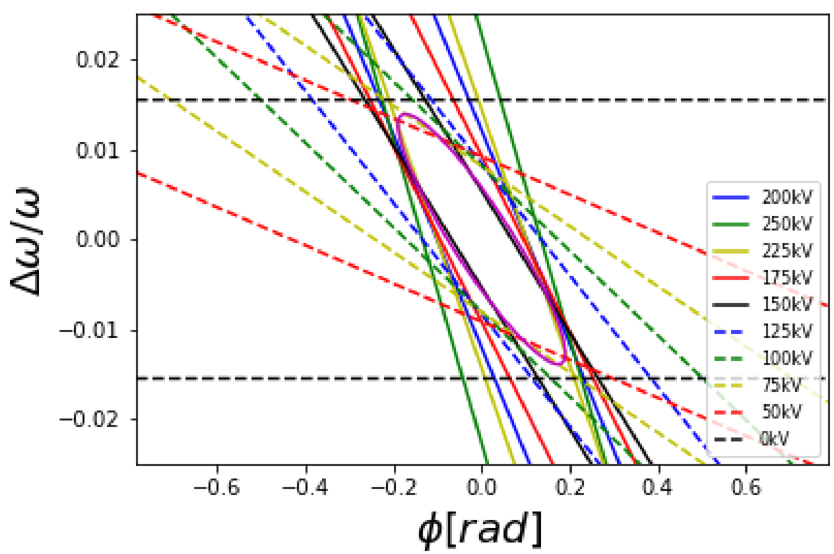


Beam Characterization (D-plate)

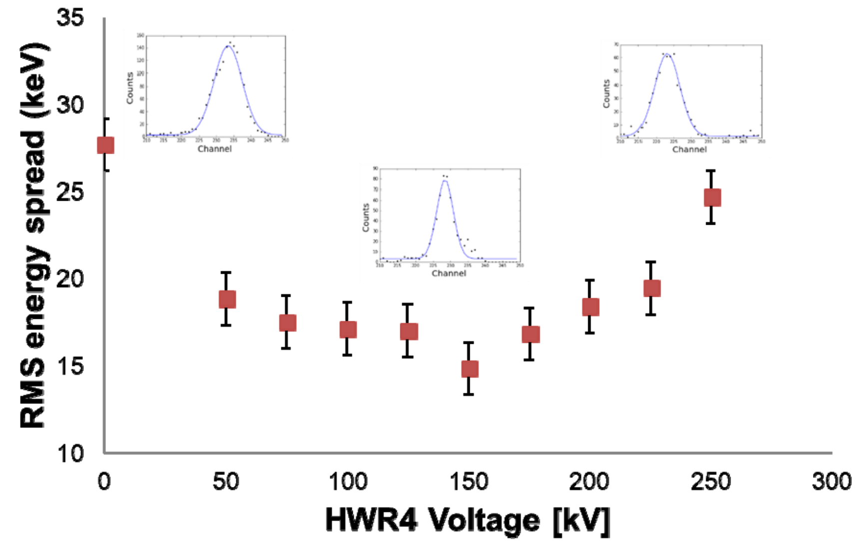
- Energy measured with RBS apparatus †
- Output energy 1.275 MeV/u agrees with design value
- RBS also provides information on energy spread

→Use HWRs and apply Gradient Variation to extract long. Emittance



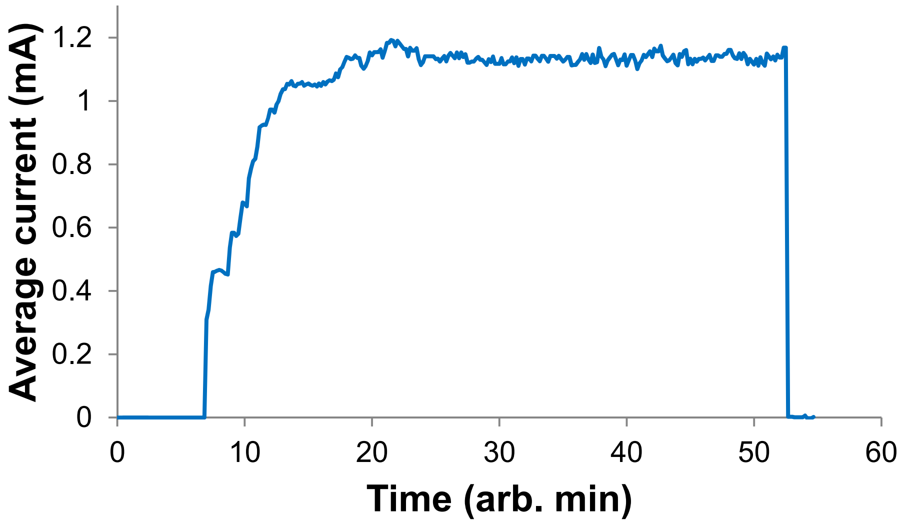


$\varepsilon_{z,\,RMS} = 1.3\,\pi$ keV/u nsec



†L. Weissman, DIPAC (2009)

CW Deuteron Beam Acceleration



RFQ at pseudo CW 99.5 %

1.15 mA low duty cycle pulsed deuteron beam to the dump

Increased beam DC to 98 % and kept beam on the dump for ~ 30 min

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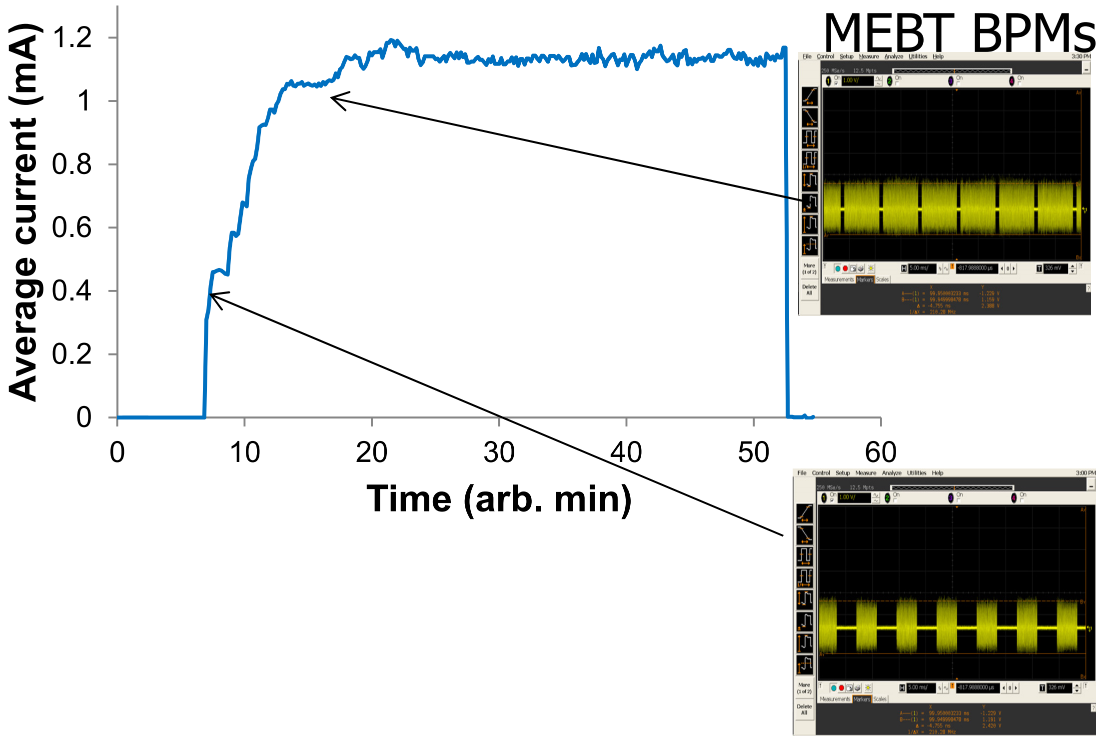

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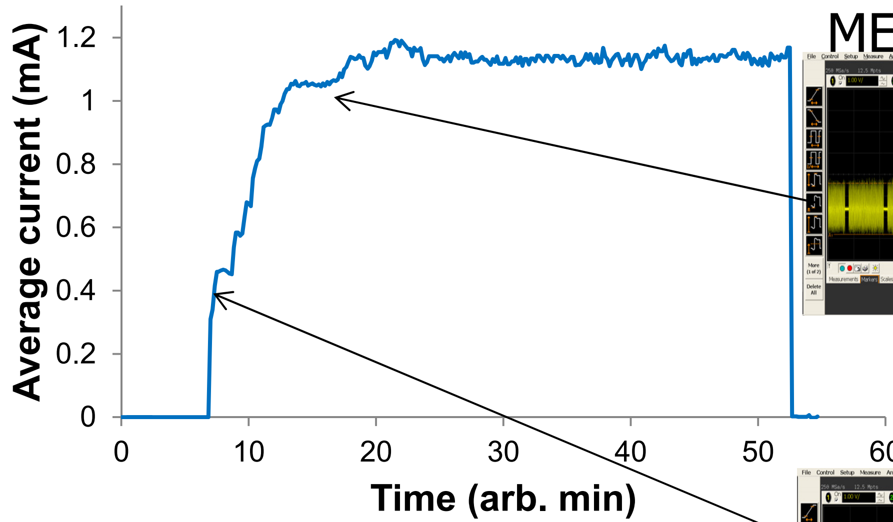
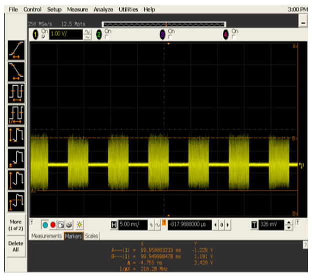


MEBT BPMs



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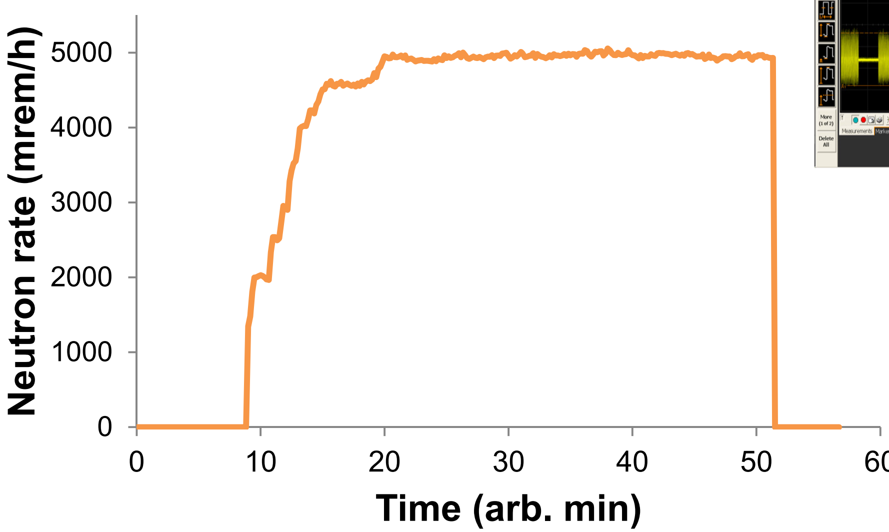
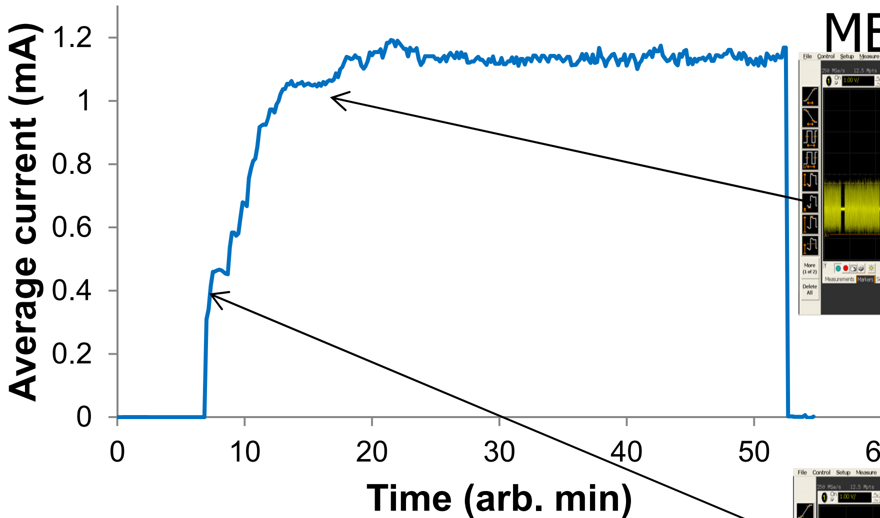


Neutron dosimeter ~10 m away from the beam dump

CW Deuteron Beam Acceleration



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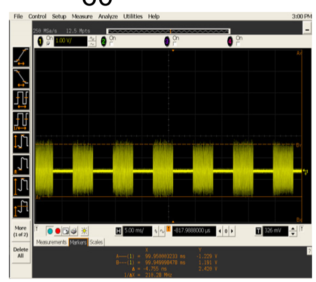

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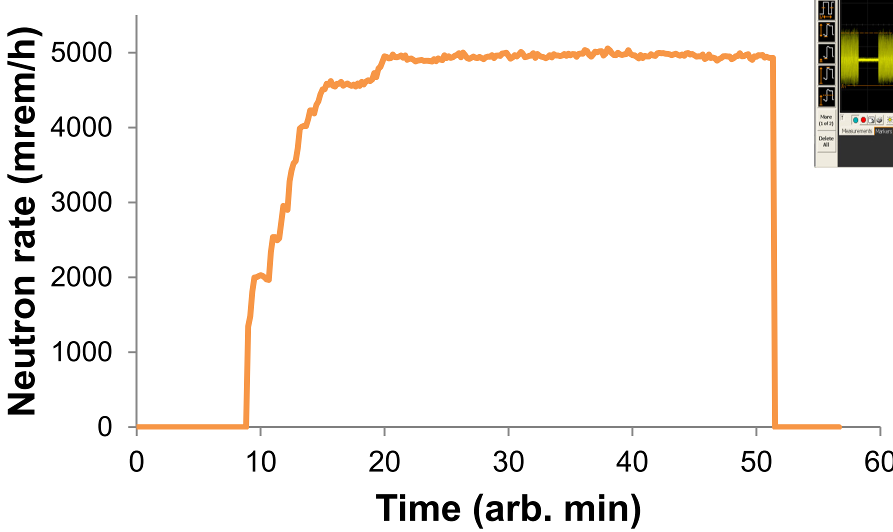


Neutron dosimeter ~10 m away from the beam dump

First deuteron CW beam !

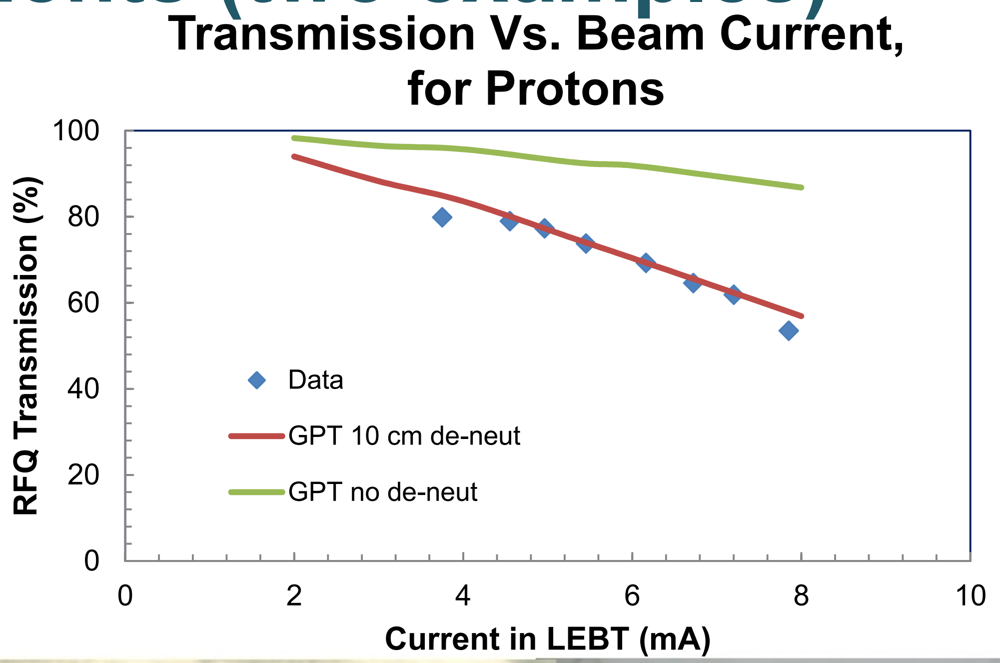
Summary of the RFQ Commissioning Results

Parameter	Design value (for 5mA)	Measured value
Energy (MeV/u)	1.275	1.275(5)
Working power protons (kW)	46.5	45-50
Working power deuterons (kW)	186	180-190
Transmission protons (%)	93	**60** (for 5 mA)
Transmission deuterons (%)	93	**70** (for 5 mA)
Transversal emittance protons (π·mm·mrad)	0.2	≤0.2 (for 5 mA)
Transversal emittance deuterons (π·mm·mrad)	0.2	≤0.2 (for 5 mA)
Longitudinal emittance protons (π keV/u nsec)	0.85 (1.3 for low current)	1.1 (low current)

Future Improvements (two examples)

Improving RFQ Transmission

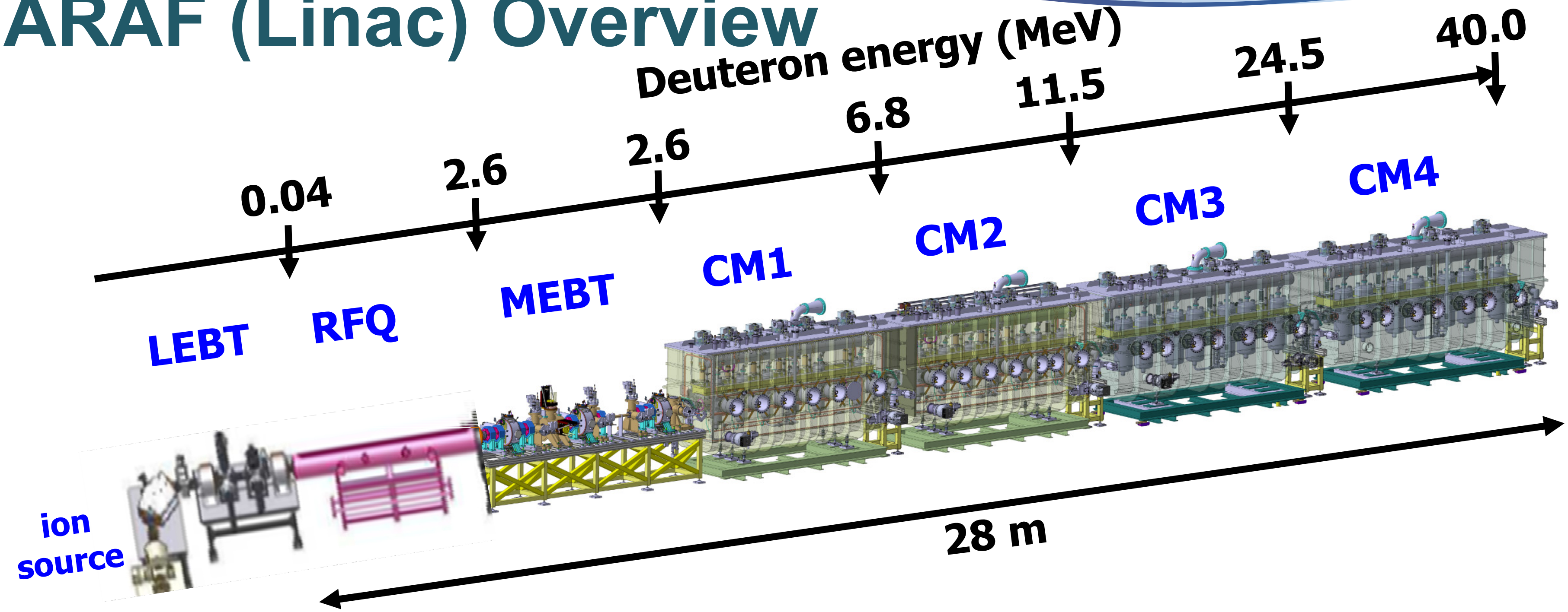
- Neutralization loss at RFQ entrance? (L. Weissman, ICIS17)
- Insufficient matching in the LEBT?
- Dipole effect inside RFQ?

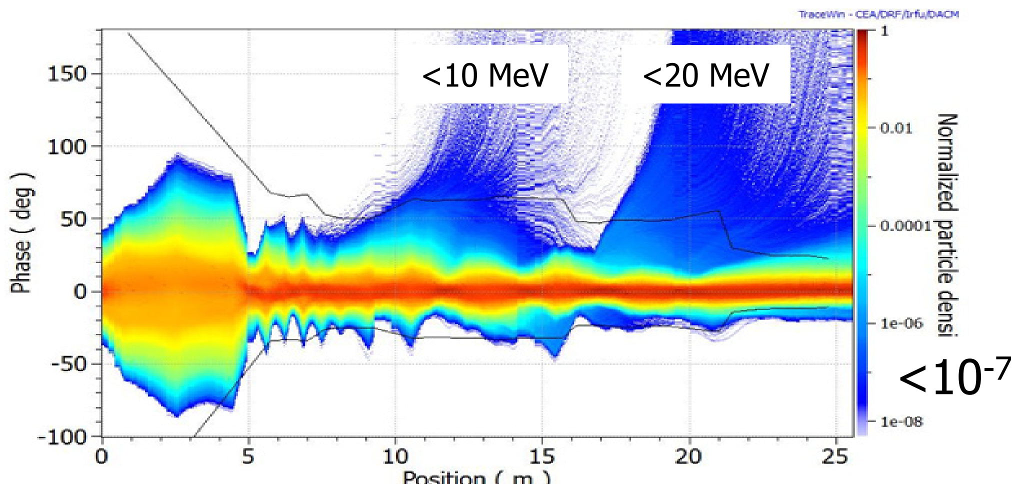


Improvement of O-ring sealings

RFQ vented 3 times due to rupture of o-rings during high power operation

SARAF (Linac) Overview





Major challenge : Beam Losses

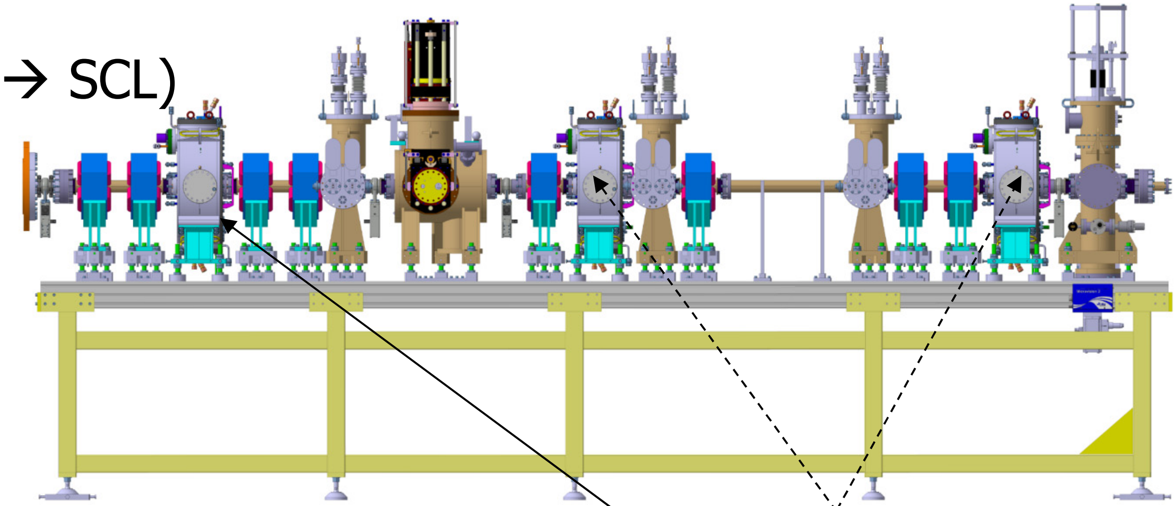
< 40 nA/m (~8.10^{-6}) above 5 MeV

< 5 nA/m (~1.10^{-6}) above 10 MeV

< 1 nA/m (~2.10^{-7}) above 20 MeV

MEBT / 176 MHz Rebuncher (by SDMS)

MEBT:
Match/Steer the beam (RFQ → SCL)
Measure/clean the beam
Minimize gas flow → SCL
Allow beam fast chopper



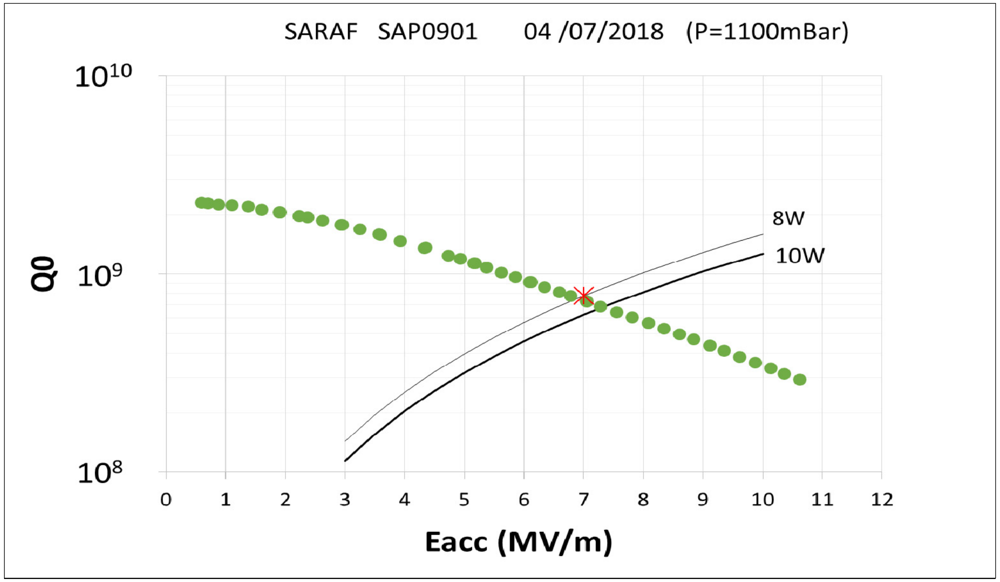
Rebunchers:
120 kV; < 5 kW
Manufactured by SDMS (copper-coated stainless steel)
RB1 Mechanical FAT in September 2018, then:
- RB1 copper coating + RB2&3 manufacturing
- RB1 RF SAT + RB2&3 Mechanical FAT
- RB2&3 copper coating
- RB2&3 RF SAT

SC 176 MHz HWR (by RI)

13 Low-β (0.091) HWR
Status → RF performances measured, He jacketting
Field >> specification (10.6 MV/m > 7 MV/m)
He consumption ~ requirement (8 W @ 7 MV/m)

14 High-β (0.181) HWR
Status → Prototype frequency trimming

LB-prototype for test in VC



LB-prototype HWR RF performances

HB-prototype trimming @ RI

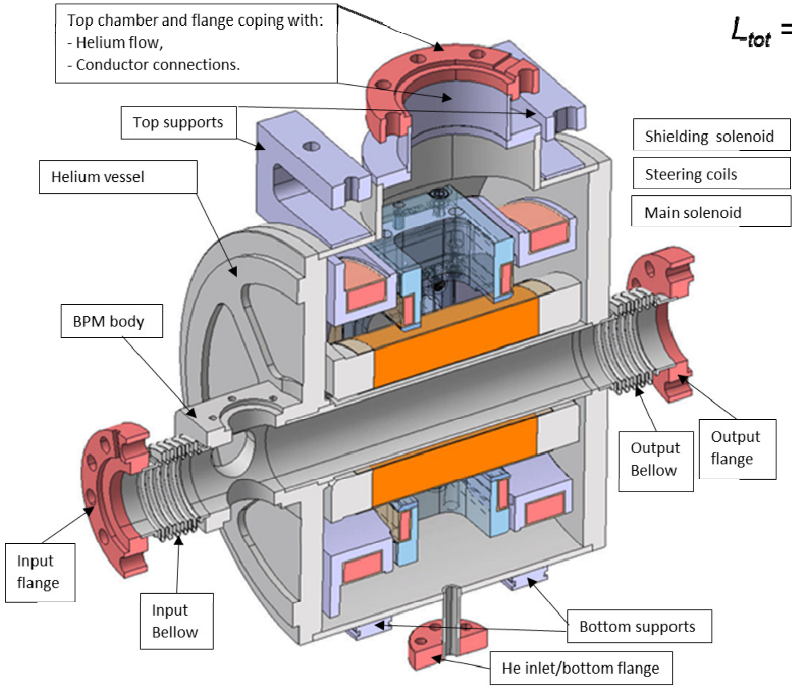
RF couplers (TETD)

27 RF couplers
20 kW RF power
<1 W consumption in 4 K

<u>Status</u> → Two prototypes in SAT

Solenoid package (Elytt)

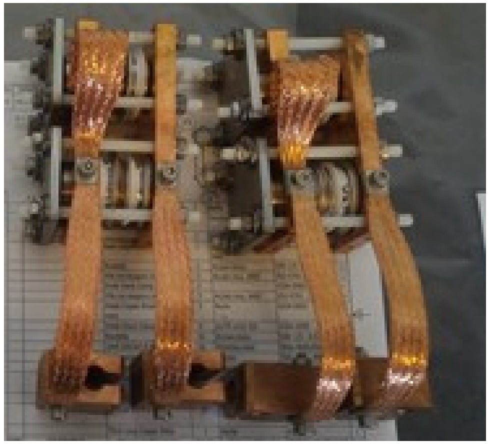
20 solenoid packages (focusing + steering)
3.5 T^2.m / 8 T.mm
<1 W consumption in 4 K
<u>Status</u> : Prototype being built by Elytt



L_{tot} =

20 current leads
<u>Status</u> : Prototype being built by CRIOTEC

60 power supplies (20×100 A + 40×±20 A)
<u>Status</u> : Technical specifications ready

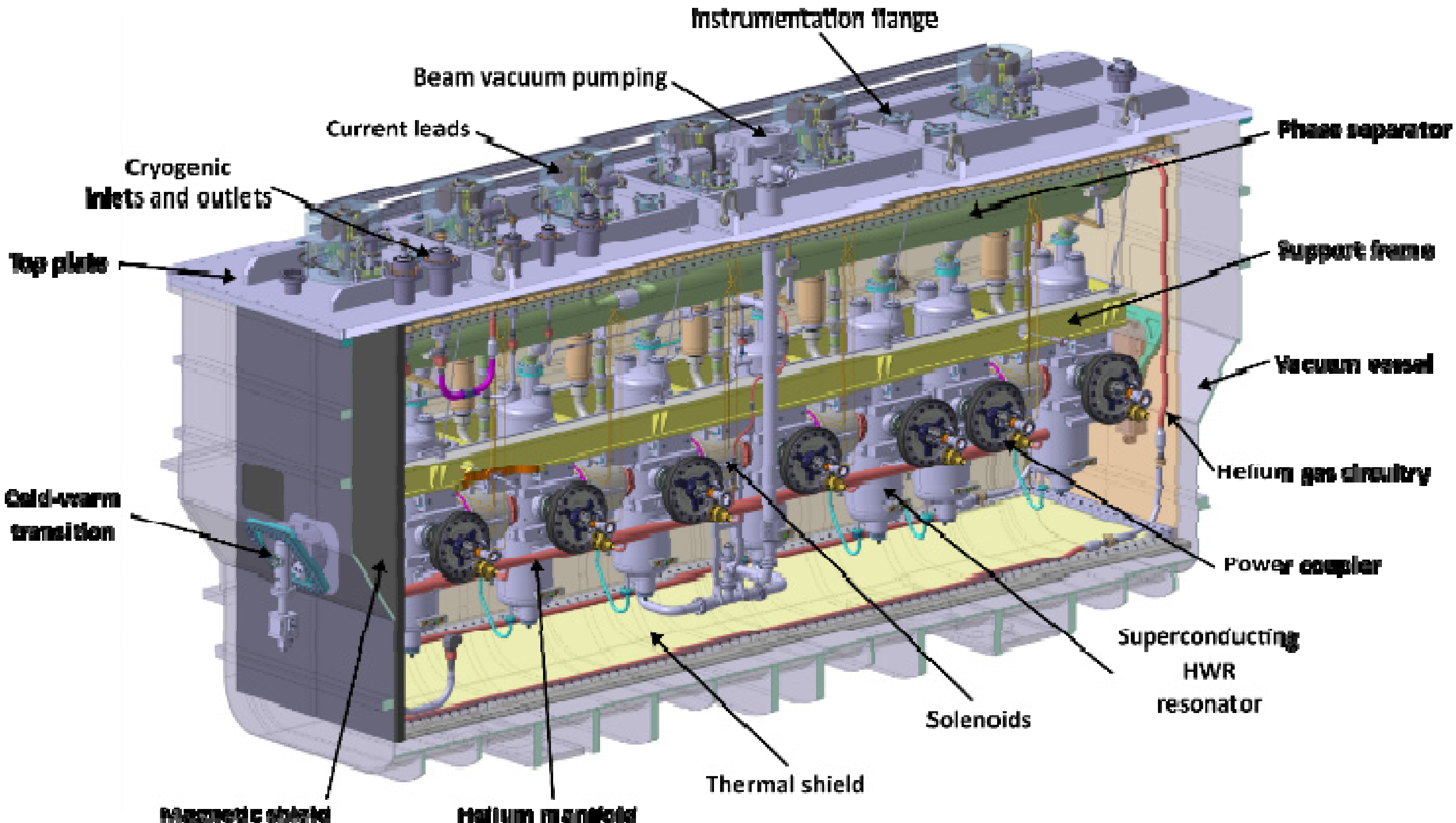


Current leads protection

Cryomodules

4 cryomodules : CM1&2 for LB HWR and CM3&4 for HB HWR

Status : CDR passed in March, tendering process.



More details : HB2018 workshop

Test Stands (@ Saclay)

Rebunchers

RBTS : ReBunchers

HWRs

CVTS : Vertical Cryostat

ECTS : Equipped Cavities

Couplers

C2TS : Coupler Conditioning

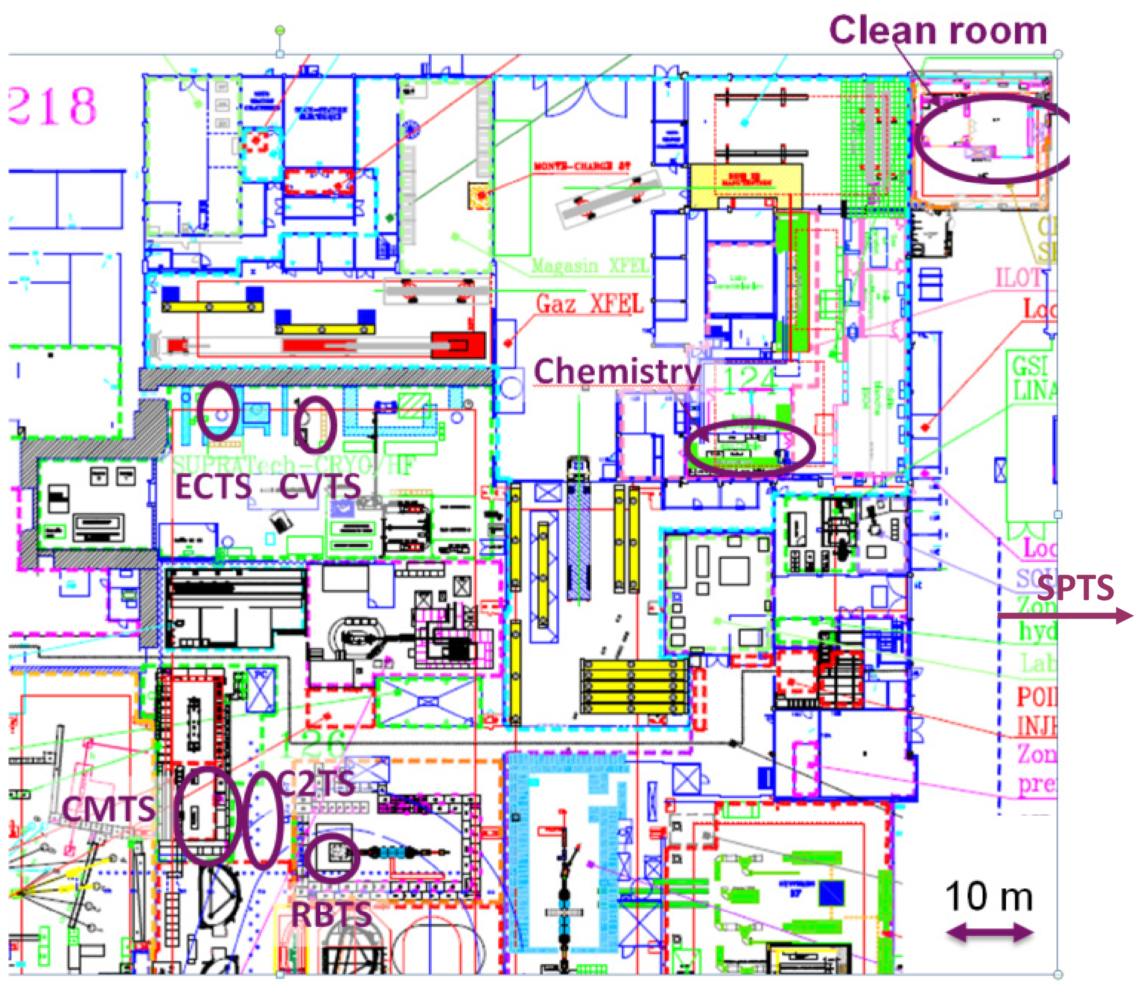
Solenoid Packages

SPTS : Solenoid Package

Cryomodules

CMTS : CryoModule

+ Chemistry + Clean rooms



Saclay DACM infrastructure

Conclusion

- RFQ Upgrade
  - ✓ New rods fabricated and installed
  - ✓ Conditioning to 180kW CW in ~5 days
  - ✓ Measured beam parameters agree with design values
  - ✓ First acceleration of a CW deuteron beam at SARAF
- SARAF LINAC Development:
  - ✓ Design stage complete, enter production stage
  - ✓ SC HWR prototype: Low β first tests OK, high β – frequency trimming
  - ✓ Rebuncher 1 – Mechanical FAT in September
  - ✓ Solenoid package prototype – being built
  - ✓ RF Couplers prototypes in SAT
  - ✓ Cryomodules – CDR passed, now tendering
  - ✓ Testing of all components at dedicated test-stands in Saclay