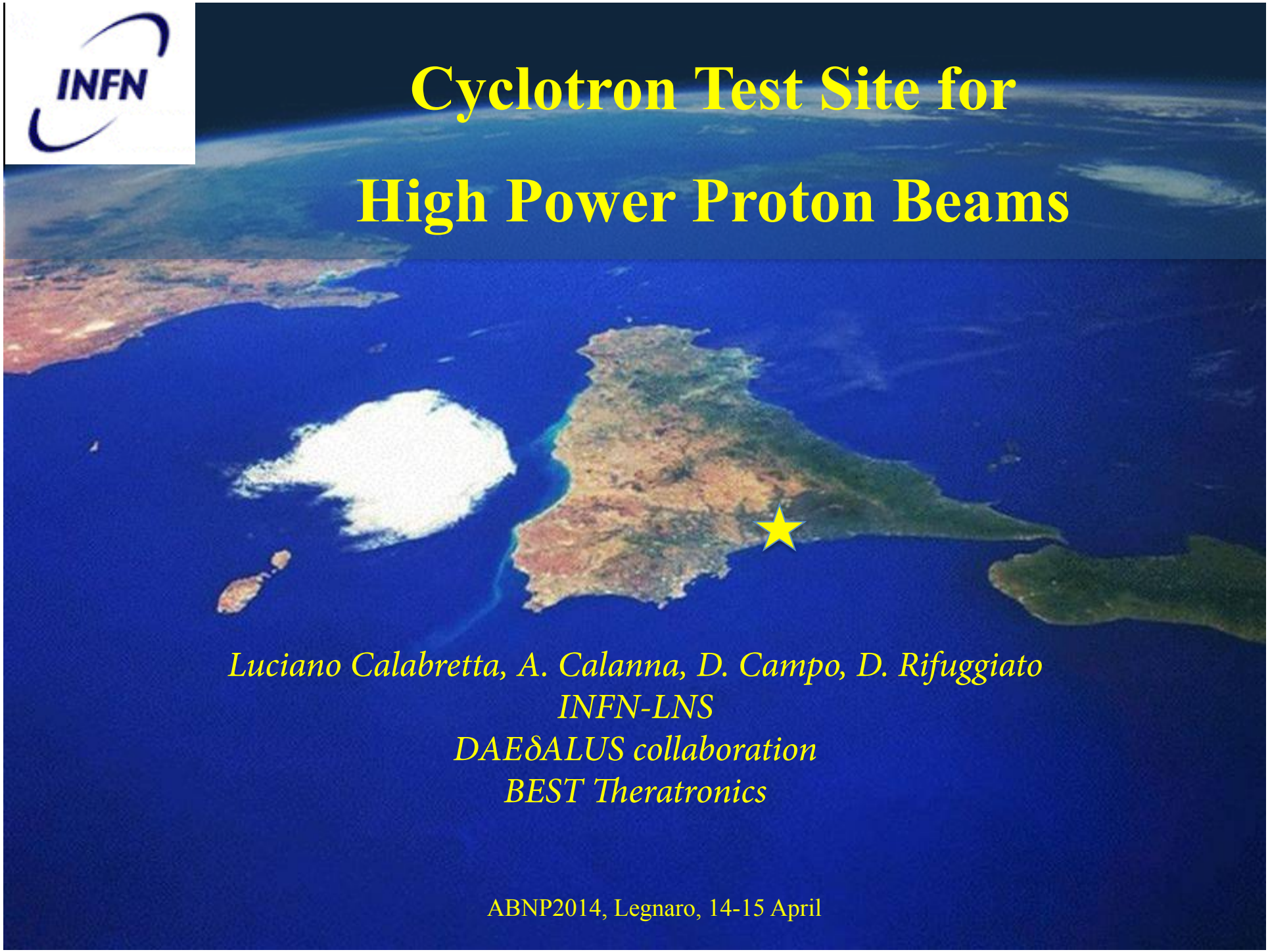
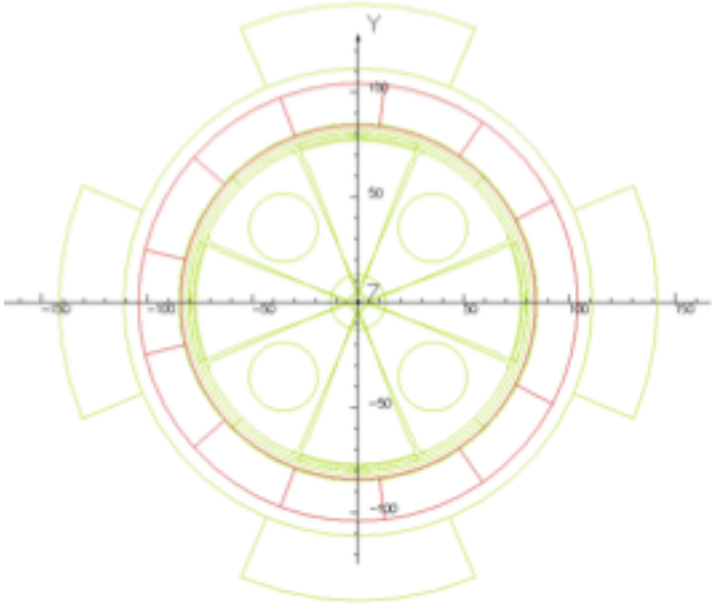
Cyclotron Test Site for High Power Proton Beams

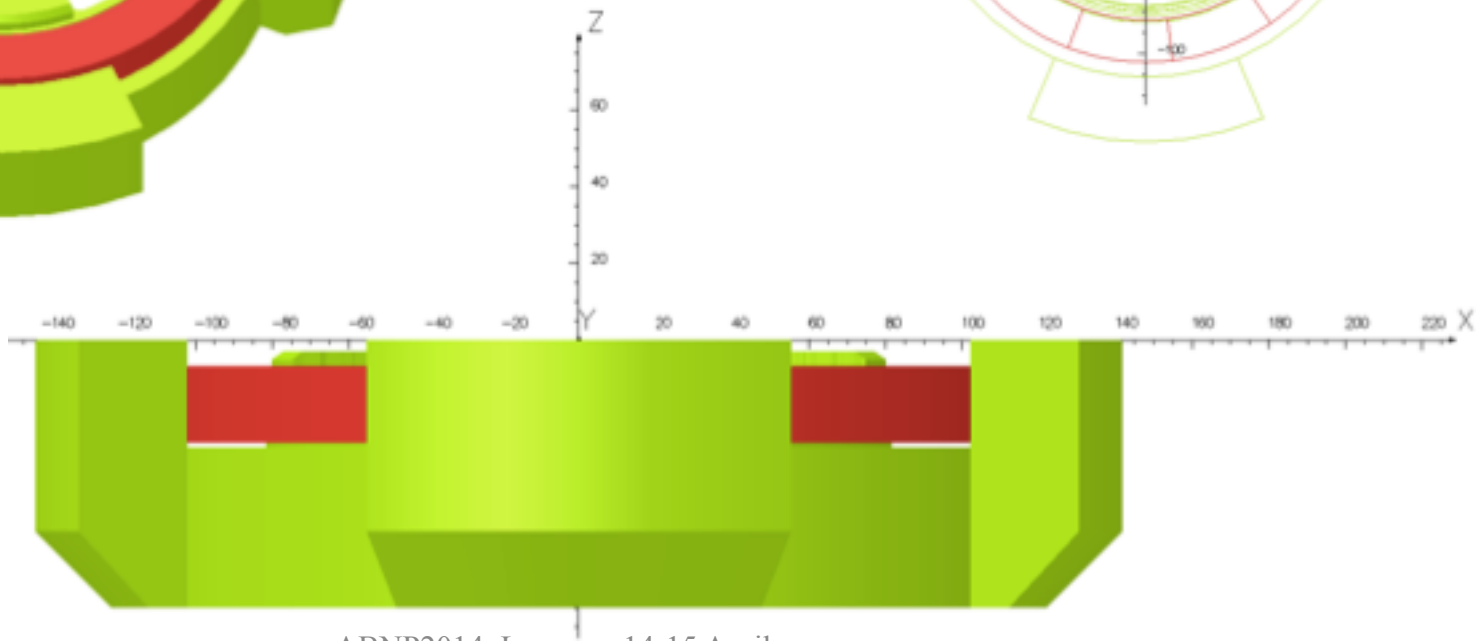


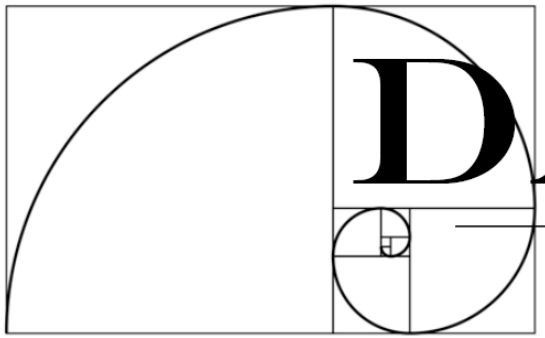
Luciano Calabretta, A. Calanna, D. Campo, D. Rifuggiato
INFN-LNS
DAEδALUS collaboration
BEST Theratronics

ABNP2014, Legnaro, 14-15 April

A CYCLOTRON ABLE TO ACCELERATE H2+, DEUTERON and He^{++} up to 7 MEV/AMU

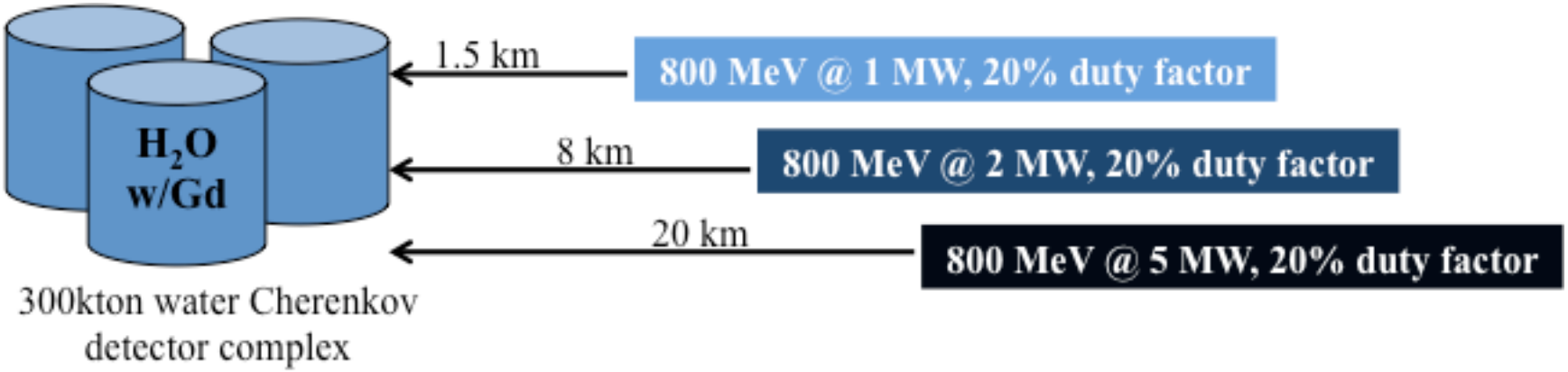






DAEδALUS

Decay **A**t rest **E**xperiment for δ_{cp} studies **A**t the **L**aboratory for **U**nderground **S**cience

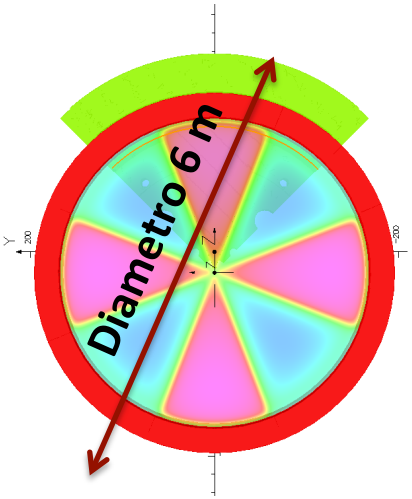


<2 MW> with a peak power of 10 MW or higher

DAEδALUS base module features

Injector Cyclotron

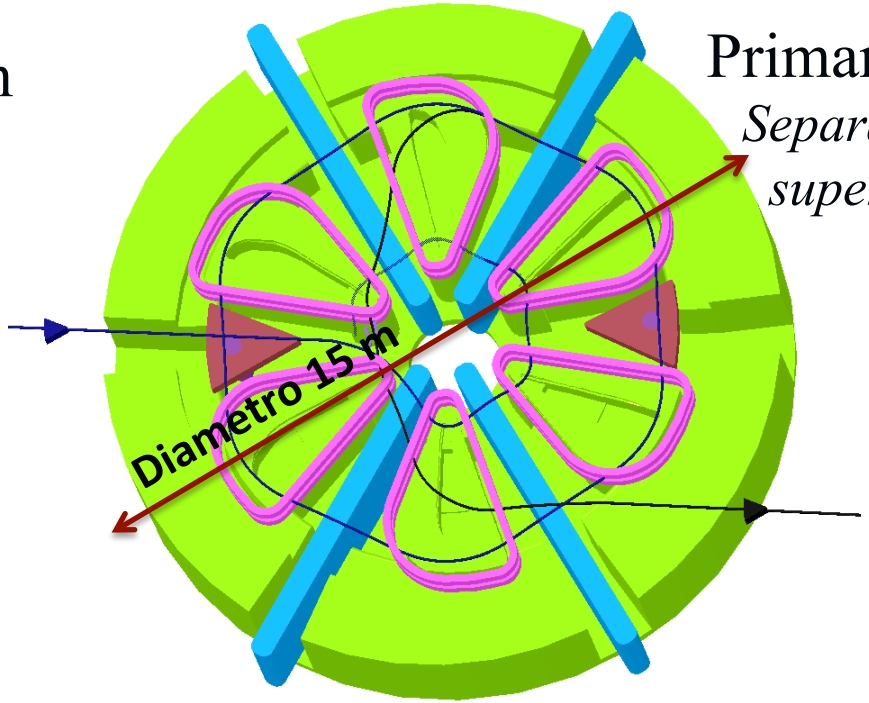
compact, resistive



- < 1 mA> H_2^+ 60 MeV/n
- Peak current 5mA of H_2^+
- Average power 120 kW
- Peak power 600 kW

❖Space Charge effects
❖Electrostatic Deflectors

arXiv.org > physics > arXiv:1207.4895



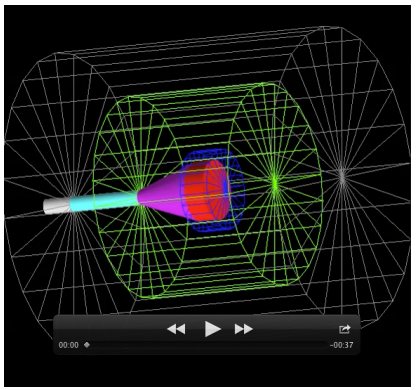
Primary Cyclotron

Separated sectors, superconducting

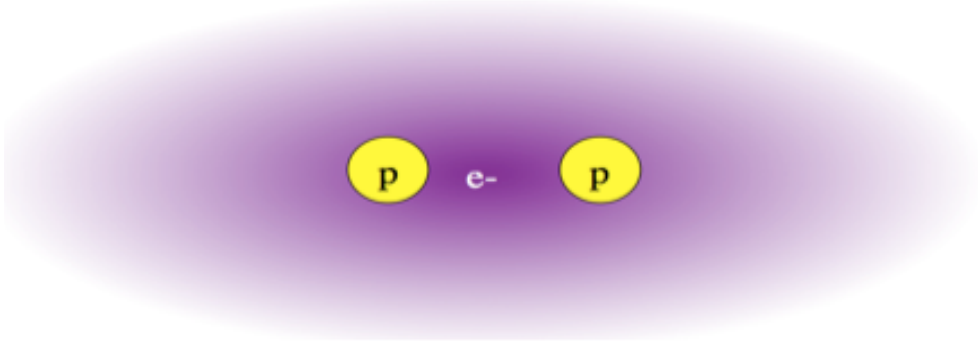
- <1 mA> H_2^+ 800 MeV/n
- Peak Power 10 MW,
- Average power 2 MW
- Beam losses < 200 W!
- Stripping extraction

❖Superconducting Coils
❖Losses due to residual gas
❖Electromagnetic stripping

Target/shielding



Acceleration of H_2^+ ions to produce high intensity proton beam



✓ Two protons for every ion (1 emA = 2 pmA)

The Generalized Perveance measures the space charge effect and it is defined by the Reiser's formula:

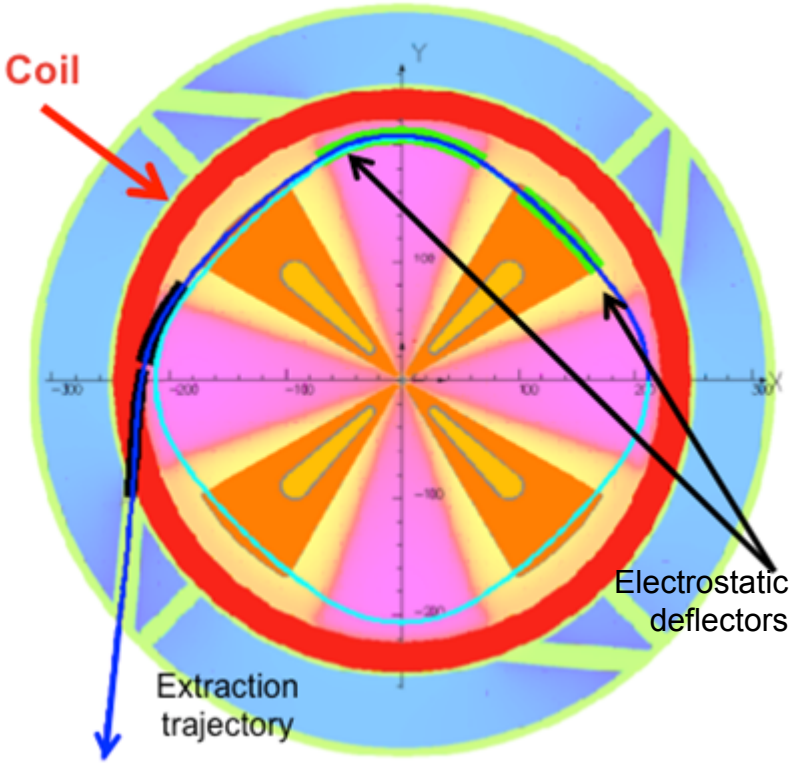
$$K = \frac{qI}{2 \cdot \pi \cdot \varepsilon_o \cdot m \cdot \gamma^3 \beta^3}$$

Perveance of 5 emA H_2^+ at 35 keV/amu same as 2 emA of 30 keV protons

✓ axial injection of 2 emA protons at 30 keV is established

✓ Extraction with stripping foil, because it requires a high-acceptance extraction channel and not a clean turn separation

DAEδALUS Injector Cyclotron



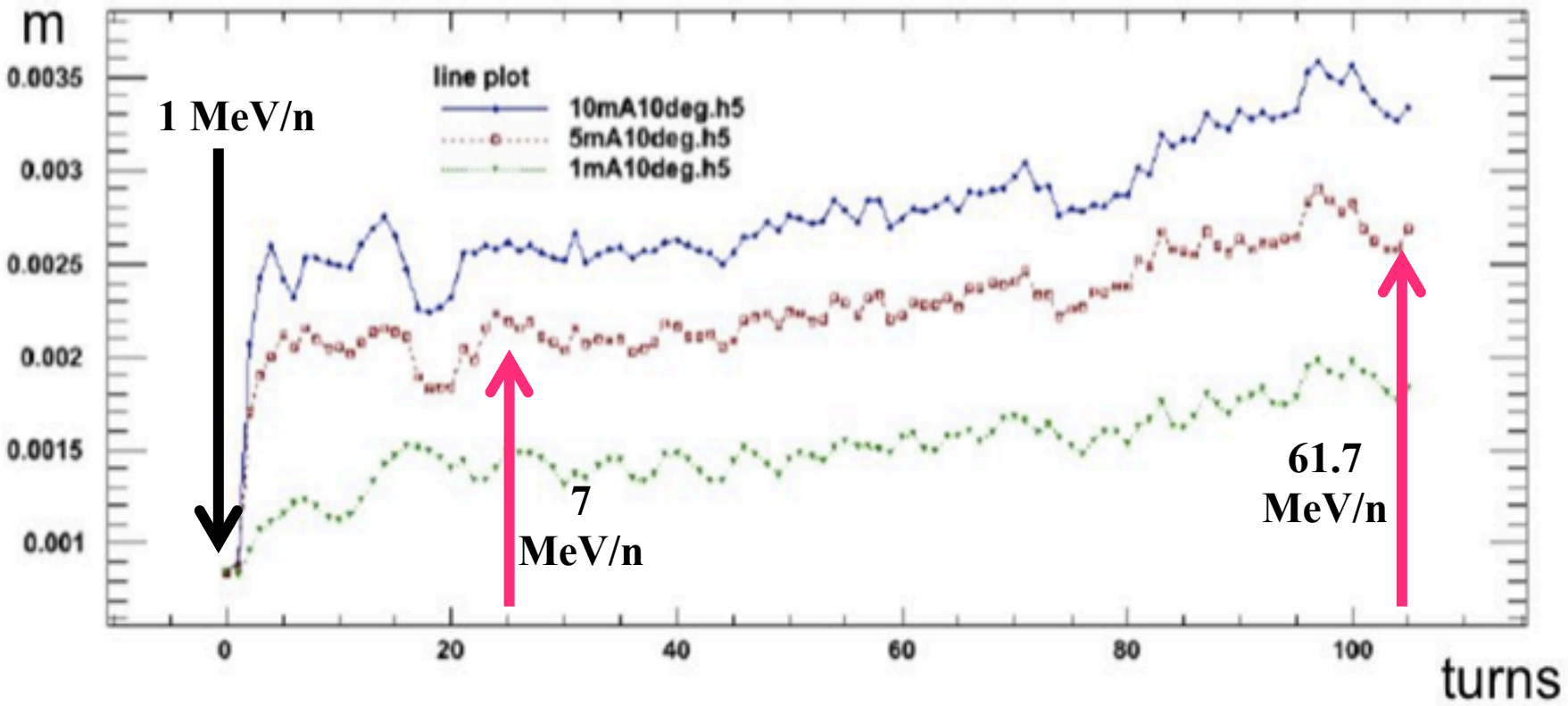
E_{inj}	35 keV/n	E_{max}	61.7 MeV/n
B_0	1.075 T	<B> at R_{ext}	1.166 T
$<R_{inj}>$	51.58 mm	$<R_{ext}>$	2000 mm
N. Sectors	4	Hill width	25.5° ÷ 44.°
Valley gap	1800 mm	Hill gap	100 mm
Diameter	6240 mm	Full height	2700 mm
N. Cavities	4	Cavities λ/2	Double gap
RF Harmonic	4th	RF frequency	32.8 MHz
Acc. Voltage	70÷250 kV	Power/cavity	<160 kW
Coil size	200x250 mm²	Current density	3.17 A/mm²

Peak current 5 mA H_2^+

arXiv.org > physics > arXiv:1207.4895

Beam dynamics in DAEδALUS Injector Cyclotron

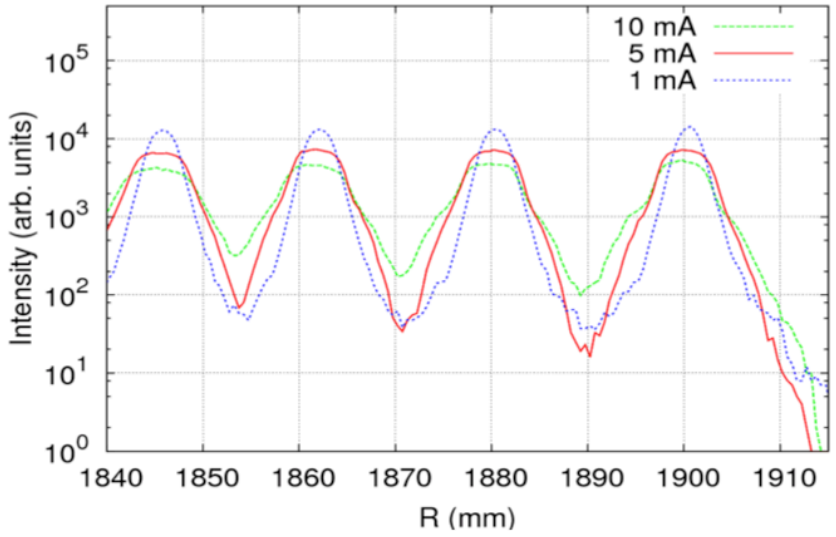
Simulation made by J. Yang and A. Adelman @ PSI, using OPAL code.

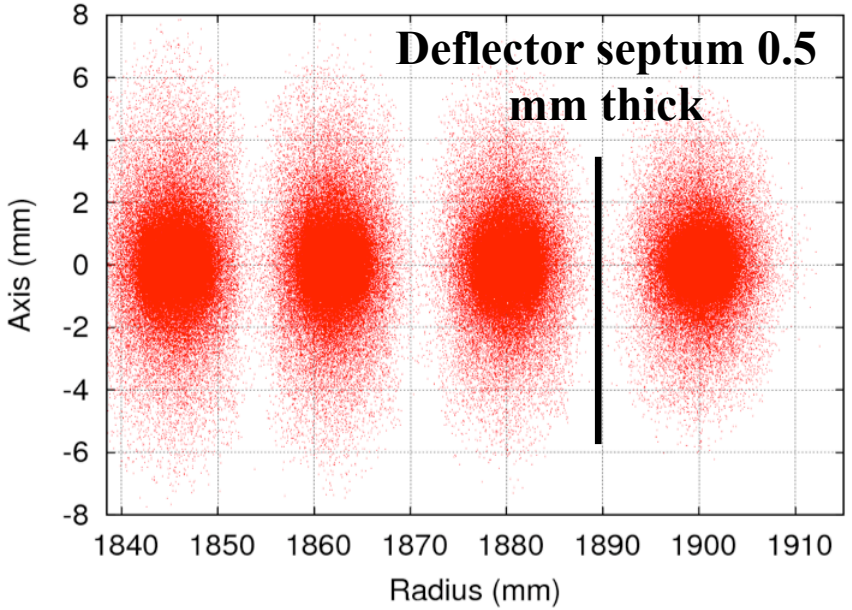


Vertical beam size vs. turns number for different beam currents

Due to the space charge effects the emittance increases
initial rms normalised emittance 0.6 π mm.mrad → 4 π mm.mrad

Beam dynamics in DAEδALUS Injector Cyclotron



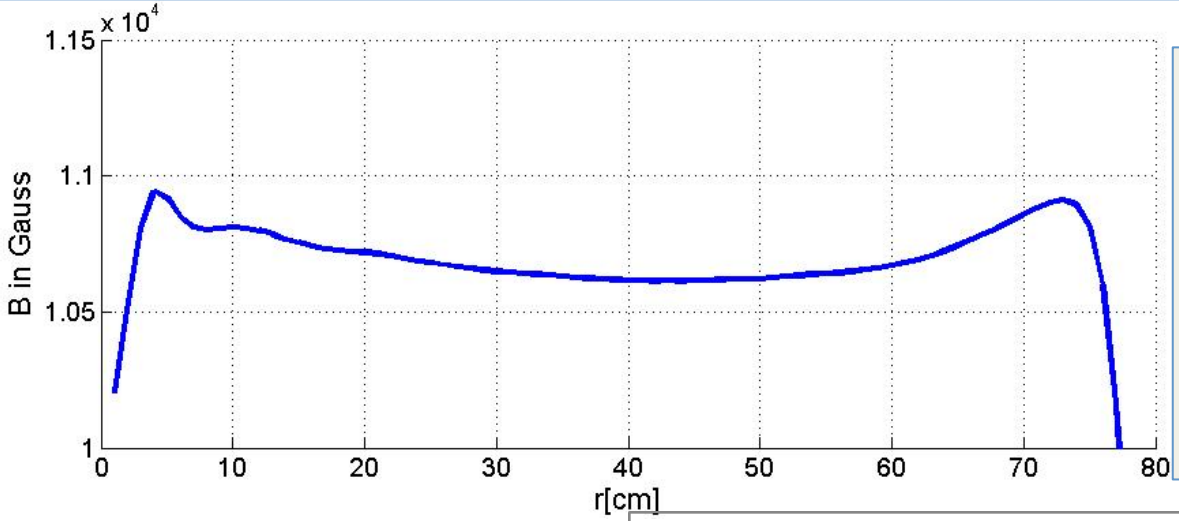


60 MeV Cyclotron
Extraction efficiency 99.98%,
if beam power is 600 kW on
the septum 120 W!

At 7 MeV/amu interturn
separation is about14 mm!

Extraction efficiency 99.9%
With beam power 70 kW
Power on the septum 70 W!

A CYCLOTRON TEST SITE FOR H2+
5 mA up to 7 MEV/AMU

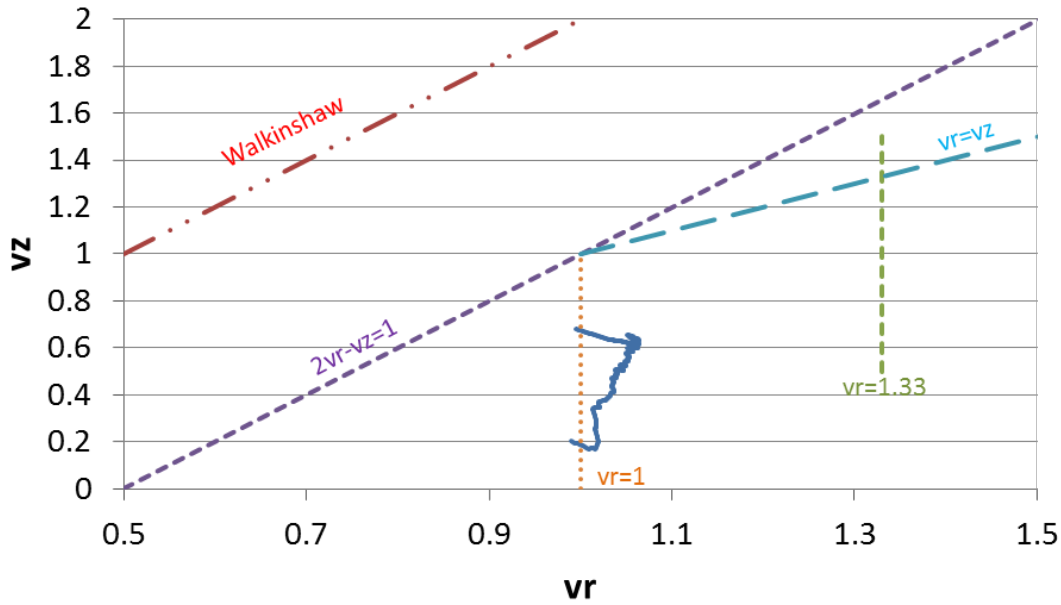


Average field

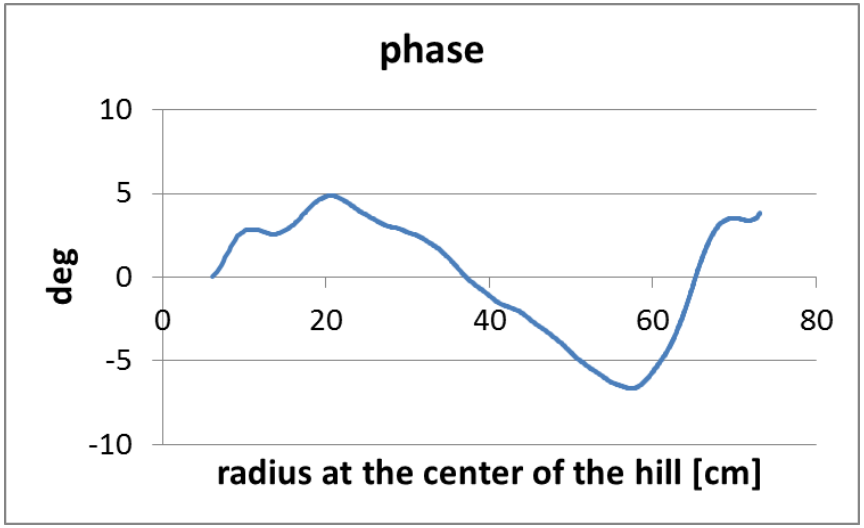
&

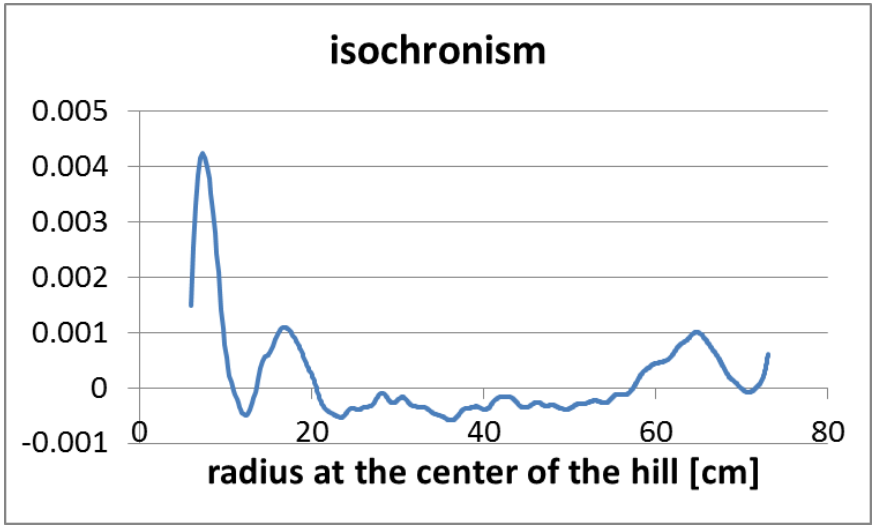
Working diagram

No dangerous resonances are crossed



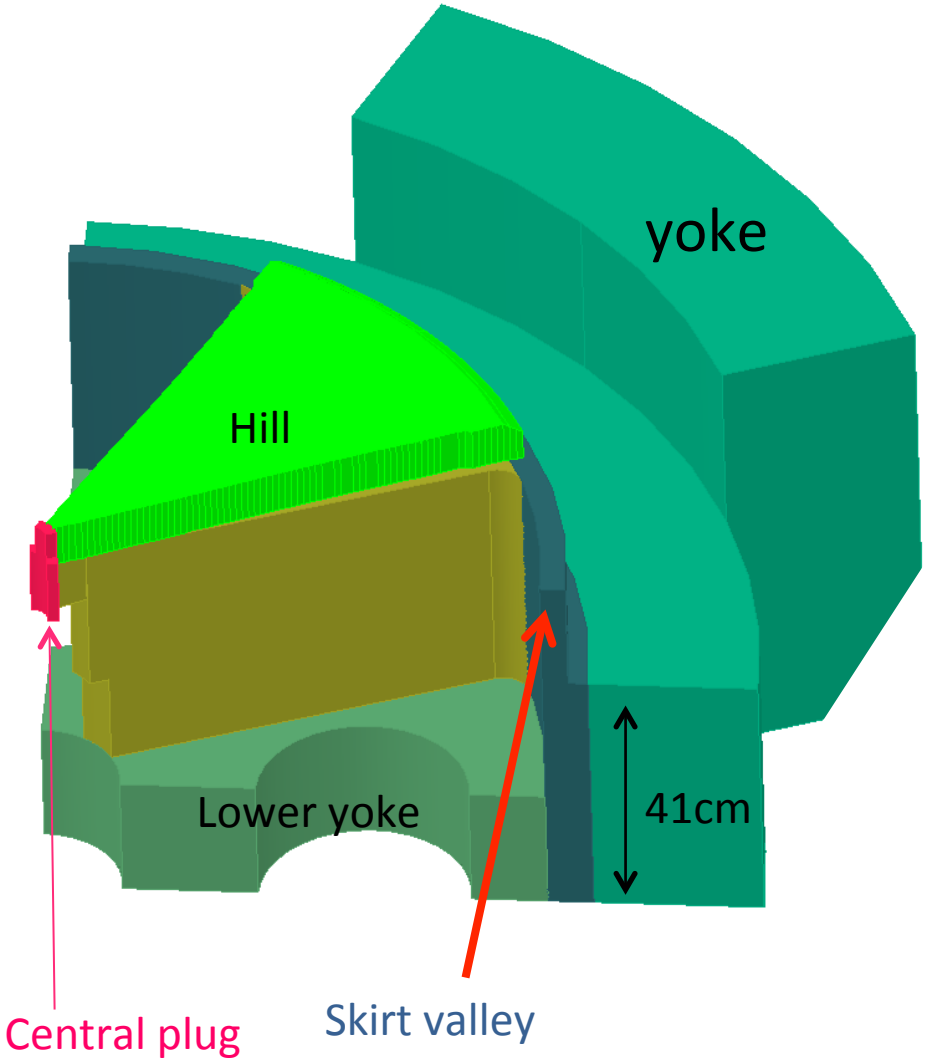
Phase & isochronism





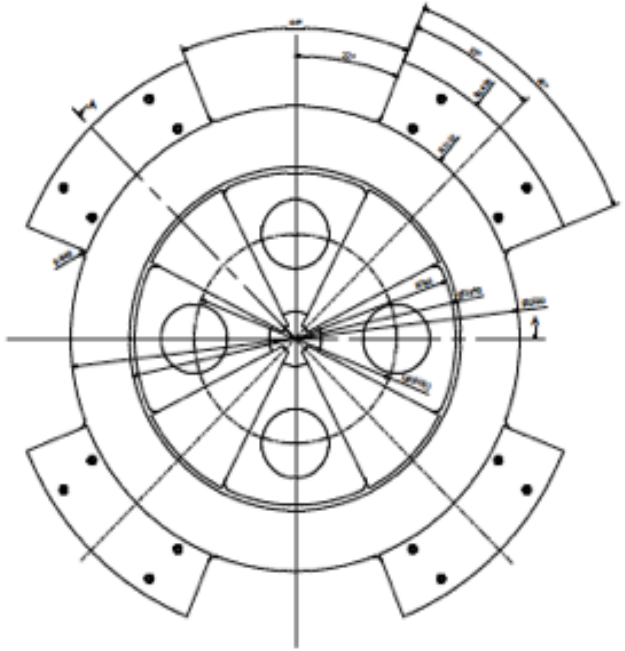
- Between -7 deg and 4 deg

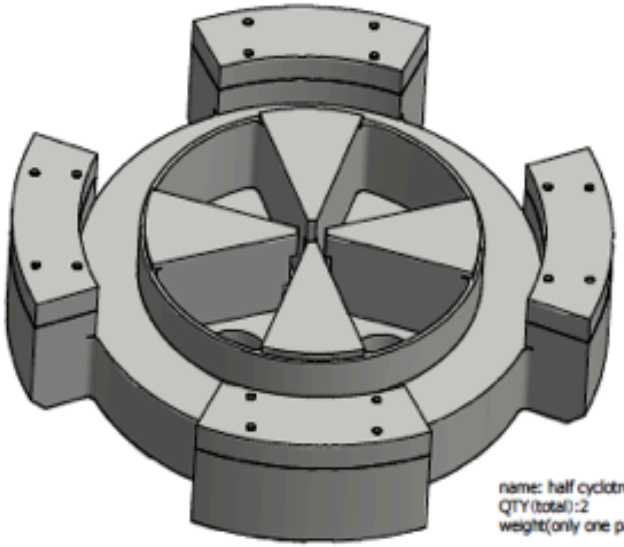
- Almost everywhere in the order of 0.1%



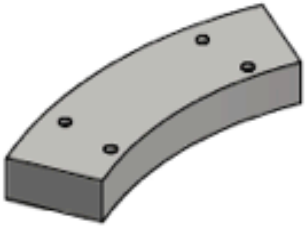
Courtesy by Alessandra Calanna

- **Cyclotron half height 70 cm**
- **Valley 50 cm from M.P.**
- **External radius 142 cm (yoke thickness 31cm)**
- **Skirt valley starts 10 cm from the median plane and his thickness is 4cm**
- **Inner hole r=13cm,**
- **Valley holes r=16.3cm**
- **Inner radius of the central plug 2.8cm**
- **Central plug distance from the median plan 3cm (min), 7.8 cm (max)**

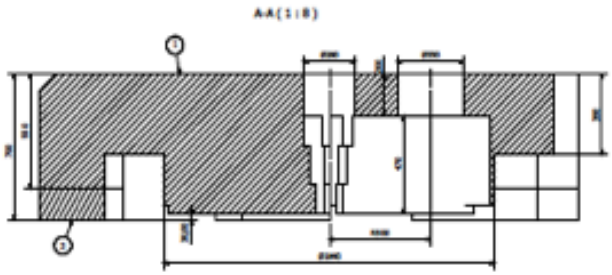


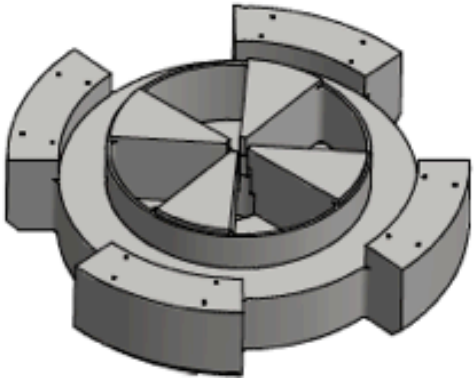


name: half cyclotron
QTY(total):2
weight(only one part): 18.5ton



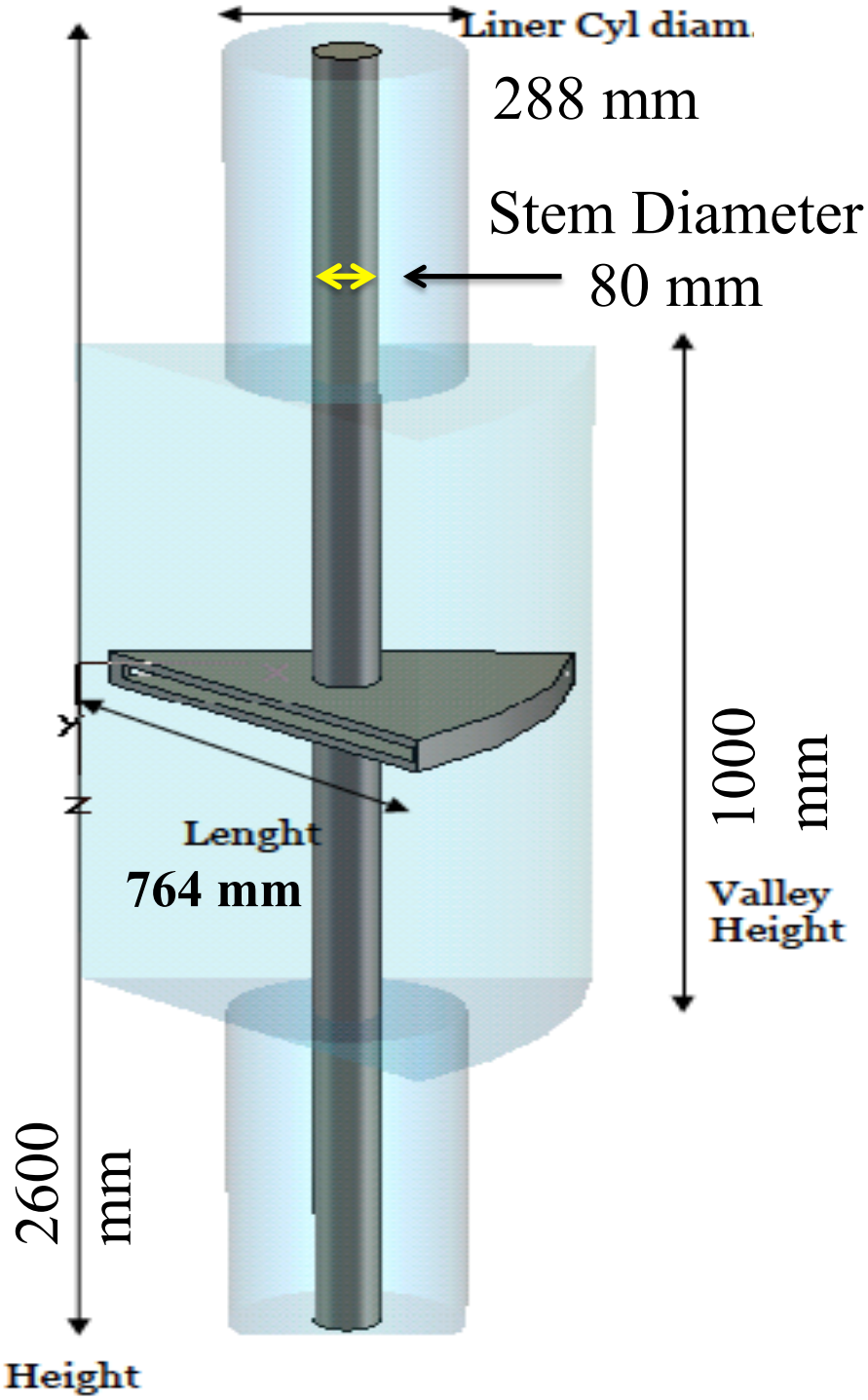
part 2
name: yoke-c
QTY(total): 8
weight(only one part): 380kg





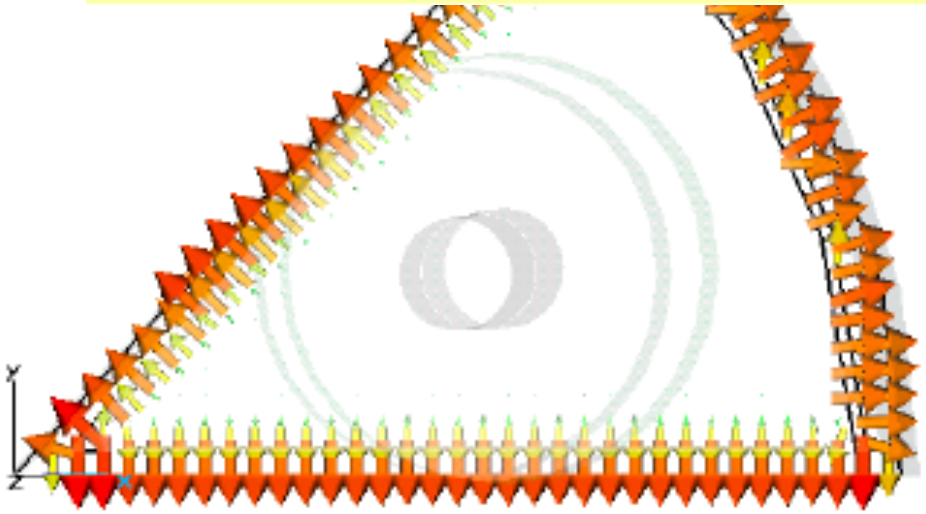
part 1
name: pole
QTY(total): 2
weight(only one part): 16.9ton

Full weight <38 tons

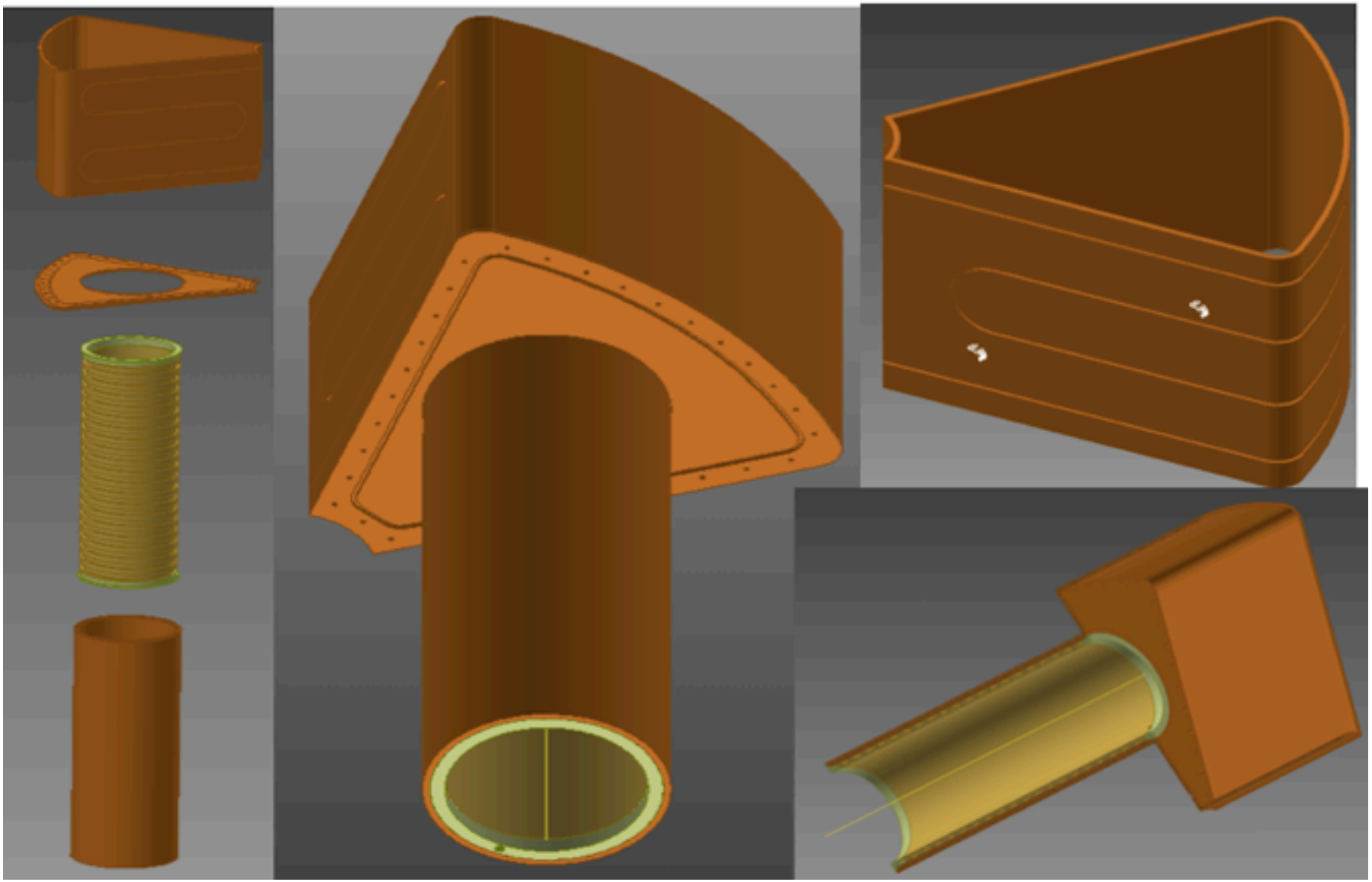


RF Cavity parameters

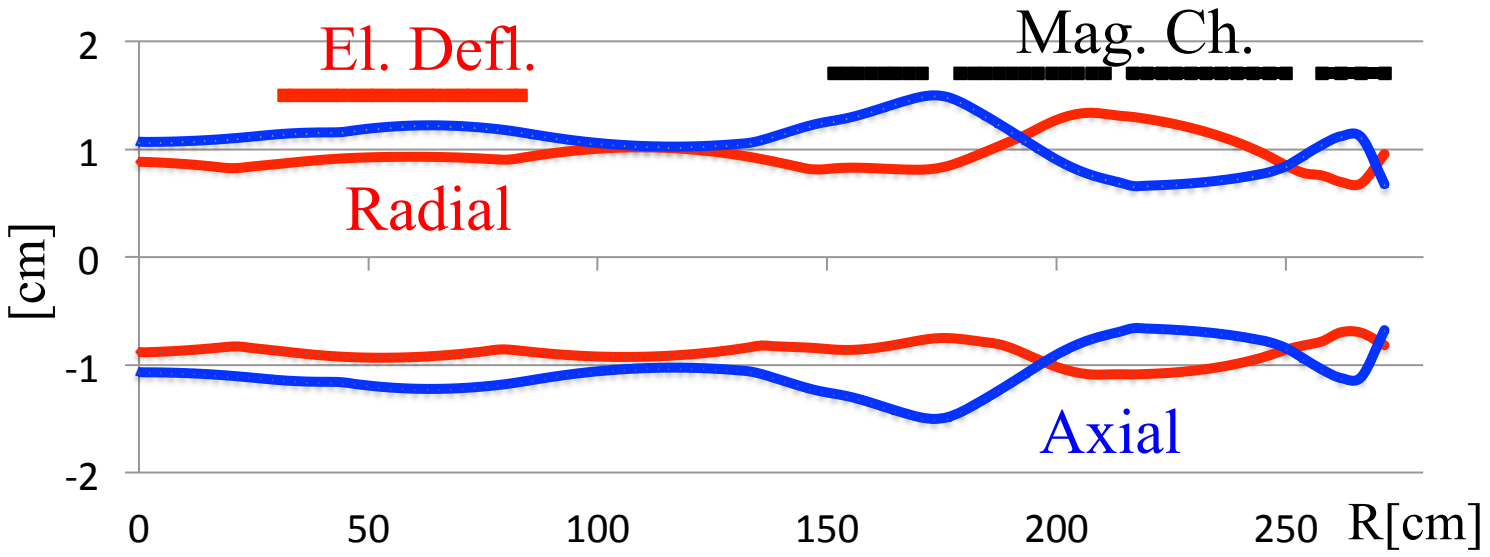
B28 Cavity Performances	
Resonant Frequency	≈ 31.7 MHz
Quality Factor	≈ 6'869
Power dissipation	≈ 10.58 kW
Max Surface Current	≈ 49 A/cm
Max Electric Field	≈ 5 MV/m
Voltage Distribution on a gap	≈ 70-70 kV
Dee Radial Extension (Length)	= 735 mm
Stem Diameter/Liner Cyl Diameter	= 80/288 mm
Dee Gap	= 30 mm



RF Liner and outer coaxial



Beam Envelope

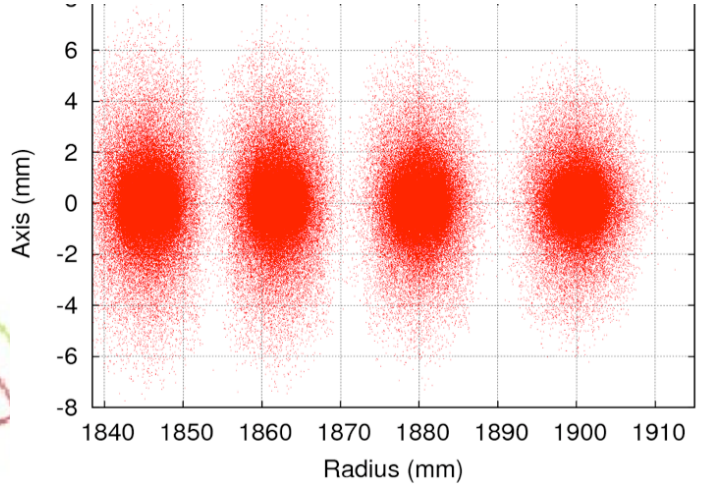


Normalized Emittance 13 π mm.mrad >> 4 π mm.mrad

Electrostatic Deflector	Gap	Field	Gradient kGaus/cm	θ_i	θ_f
Electrostatic Deflector	20 mm	27 kV/cm	------	26°	70°
Magnet channel 1	20 mm	3 kGauss	1.2	120°	134°
Magnet channel 2	20 mm	4 kGauss	1.6	140°	162°
Magnet channel 3	20 mm	4 kGauss	.4	166°	186°
Magnet channel 4	20 mm	12 kGauss	1.25	190°	196°

At 7 MeV/amu,
4 RF cavities @70 kV
At R=70 cm
ΔR/turn=14 mm

Ist harmonic precession
ΔR/turn → 16-18 mm

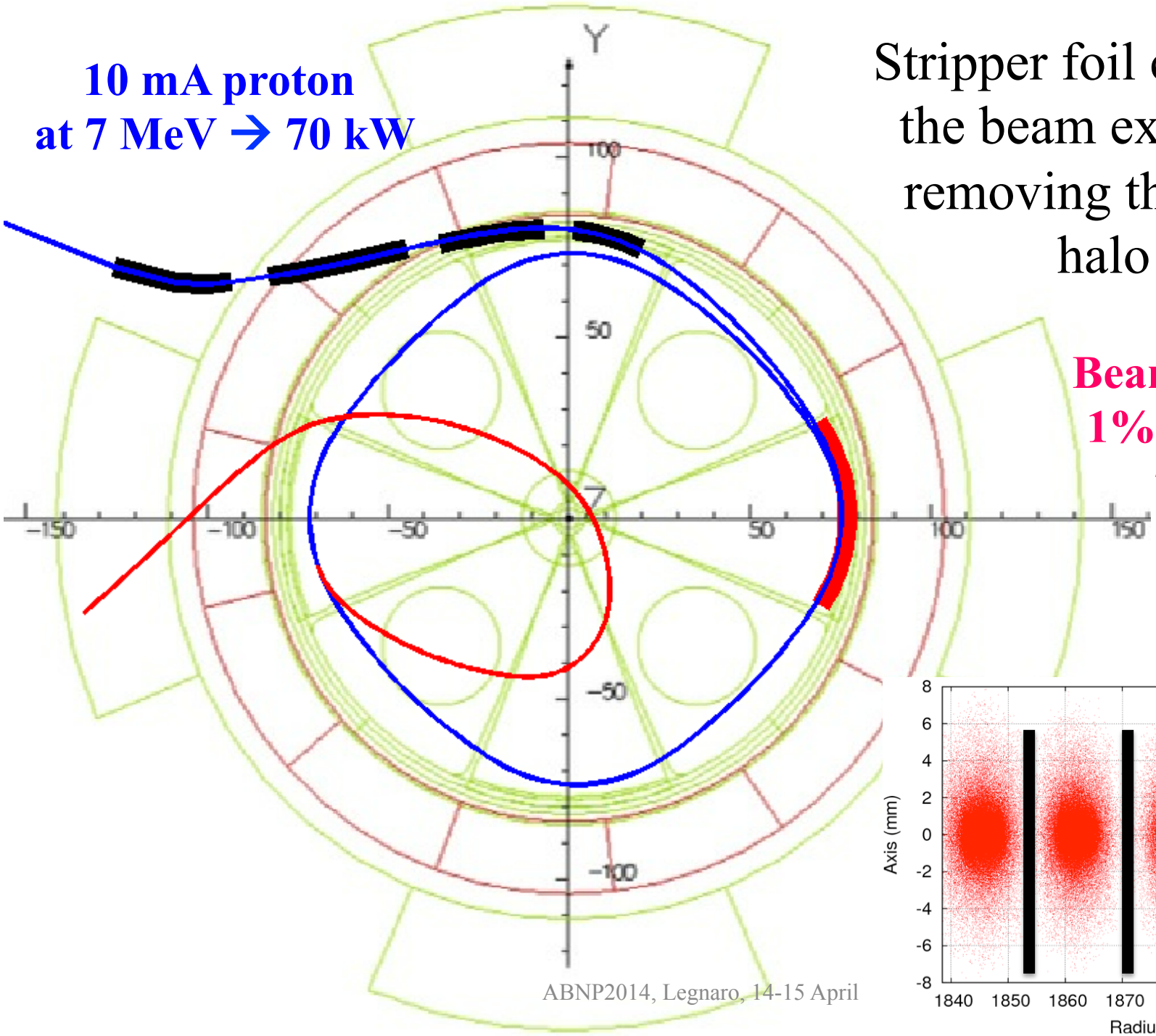


If turn separation is
ΔR/turn=16 mm,
The amount of beam on the Deflector septum can be less than 0.1% about 70 W!

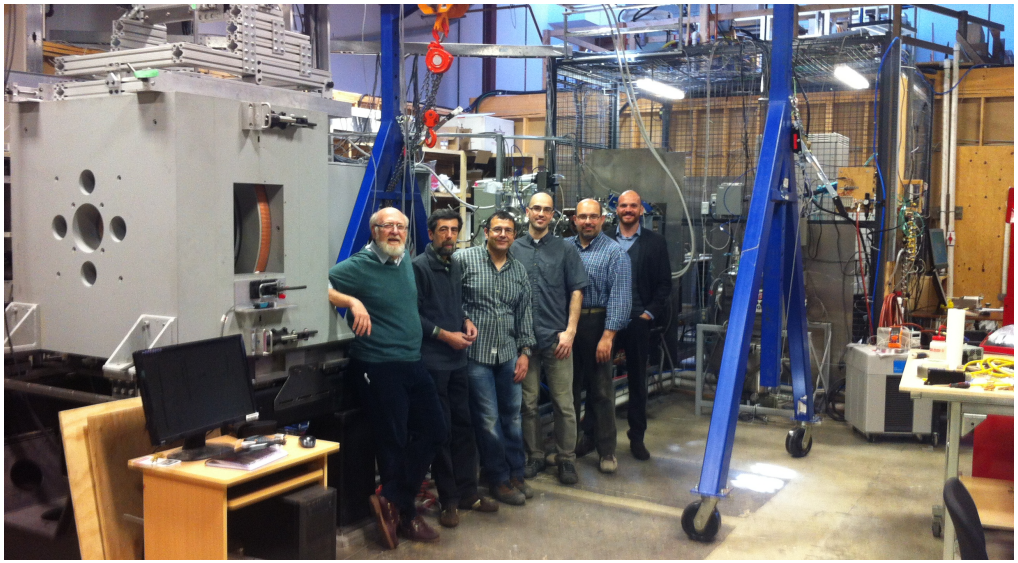
10 mA proton
at 7 MeV → 70 kW

Stripper foil can clean the beam extraction removing the beam halo!

Beam stripped
1% of 70 kW
700 W



Ion Source, Injection Tests



- How much H_2^+ can we get from a proton source? (VIS Catania)
- How much can we capture in central region?
- Tests performed at Best Cyclotron Systems development Lab, Vancouver BC, Summer 2013