SPECIFICATIONS AND STATUS OF THE NEW ELECTRON COOLER FOR THE CERN ANTIPROTON DECELERATOR (AD)

A. Rossi, C. Accettura, W. Andreazza, A. Bollazzi, C. Castro Sequeiro, J. Cenede, N. Chritin, Y. Coutron, D. Gamba, L. Joergensen, C. Machado, O. Marqversen, L. Ponce, J. A. Ferreira Somoza, Y. Thurel, A. Frassier, G. Khatri, A. Pikin, M. Sameed, A. Sinturel, T. Todorcevic, G. Tranquille, L. von Freeden

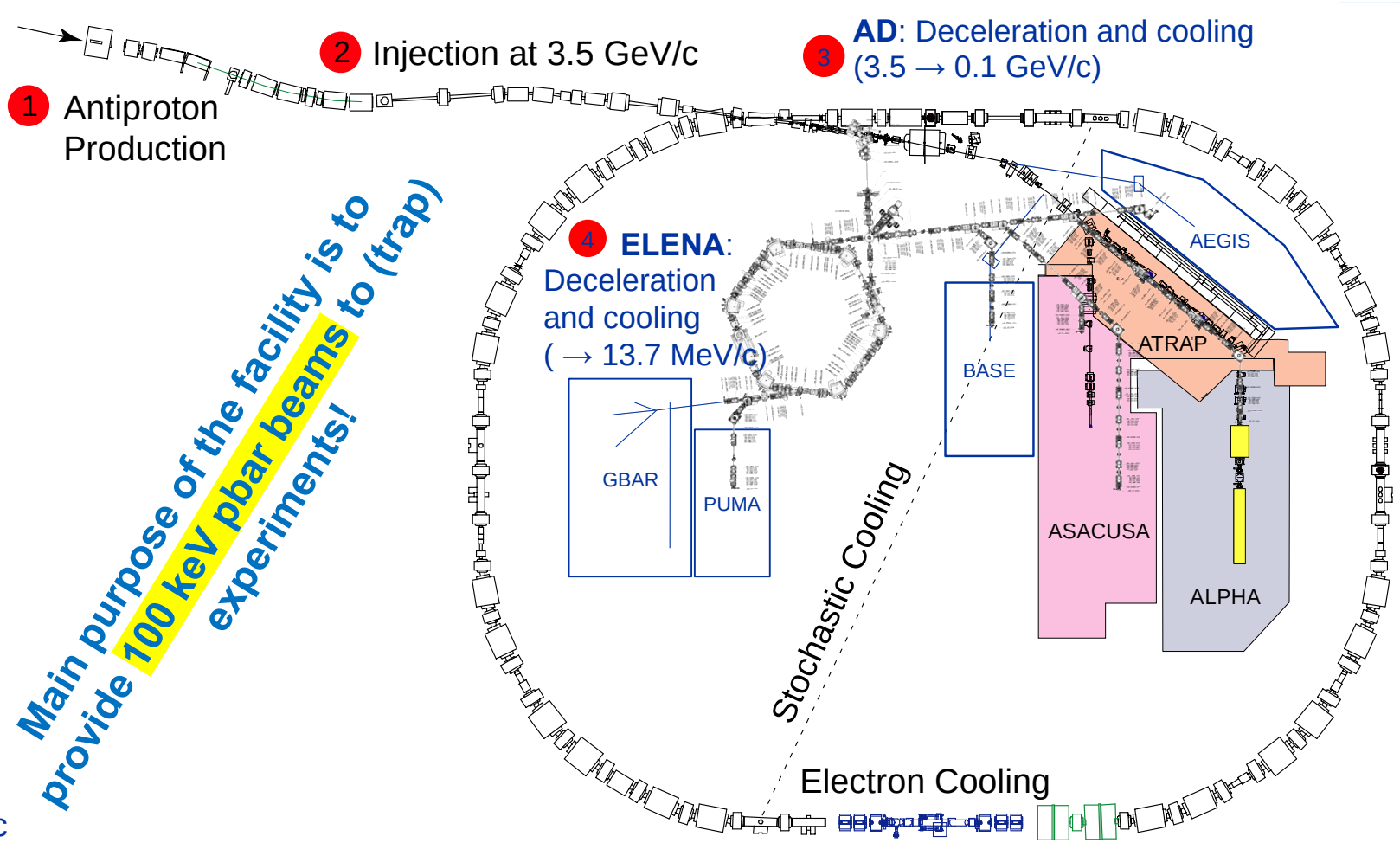
COOL23, 8th - 13th October 2023

Outline

- Context: the AD complex and cycle
- New electron cooler specifications
- Design details and timeline

AD (Antiproton Decelerator) & ELENA (Extra Low ENergy Antiproton ring)

- ~1.5 10^{13} protons (26 GeV) on target
- **~3.5 10^{7} antiprotons** captured in AD
- **Deceleration to the lowest energy**:
  - → 5.3 MeV (AD)
  - → 100 keV (ELENA)
- Antiprotons extracted per cycle:
  - 1 bunch ~3x10^{7} (AD)
  - 4 bunches of ~6x10^{6} p-bars (ELENA)
- **Cycle lengths**:
  - ~100 s (AD)
  - ~15 s (ELENA)
- **Beam cooling**
  - Stochastic → 3.57 and 2.0 GeV/c
  - **Electron (AD) → 300 and 100 MeV/c**
  - Electron (ELENA) → 35 and 13.7 MeV/c



Sketch of the AD (**circumference 182 m**) ELENA (**circumference 30.4 m**) AD/ELENA experiments

Courtesy of Davide Gamba

AD cycle and motivation for a new electron cooler

Figures of merit

-cooling performance)

cs control and s-/**e-cooling** performance)

performance, and **tollerated losses**…)

stems - inc. e-cooling - **reliability**)

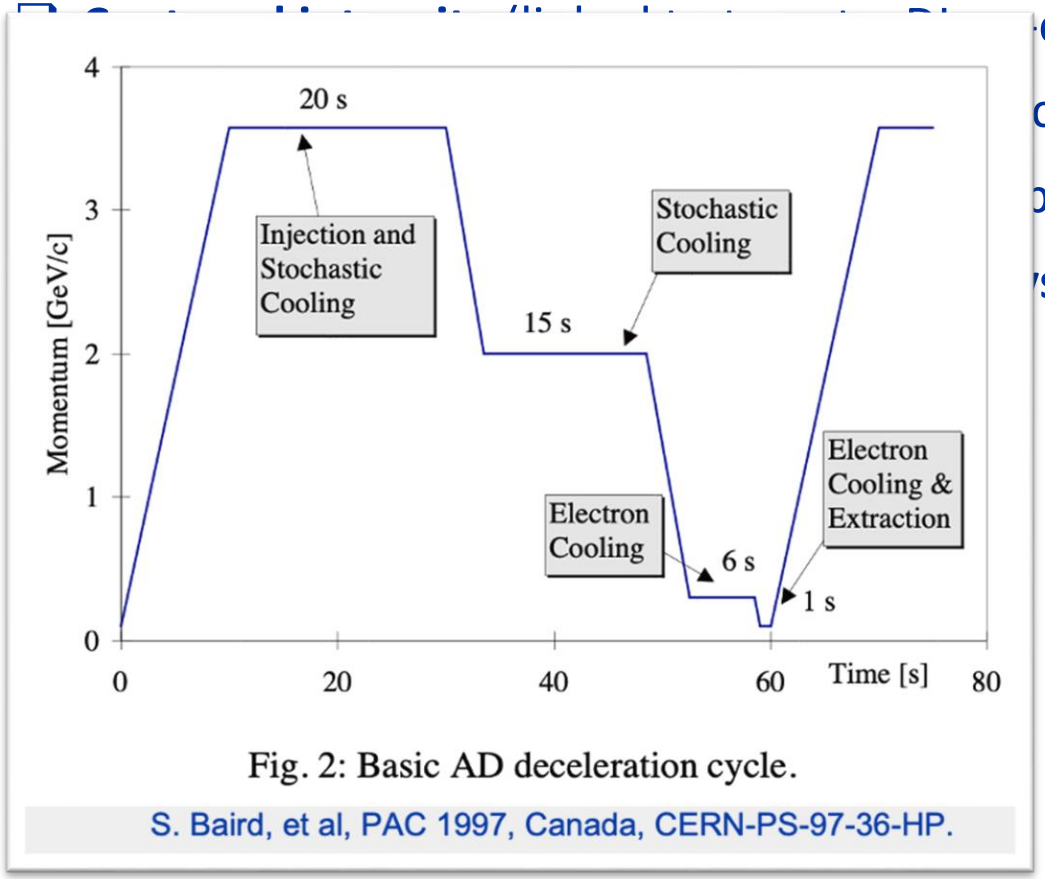
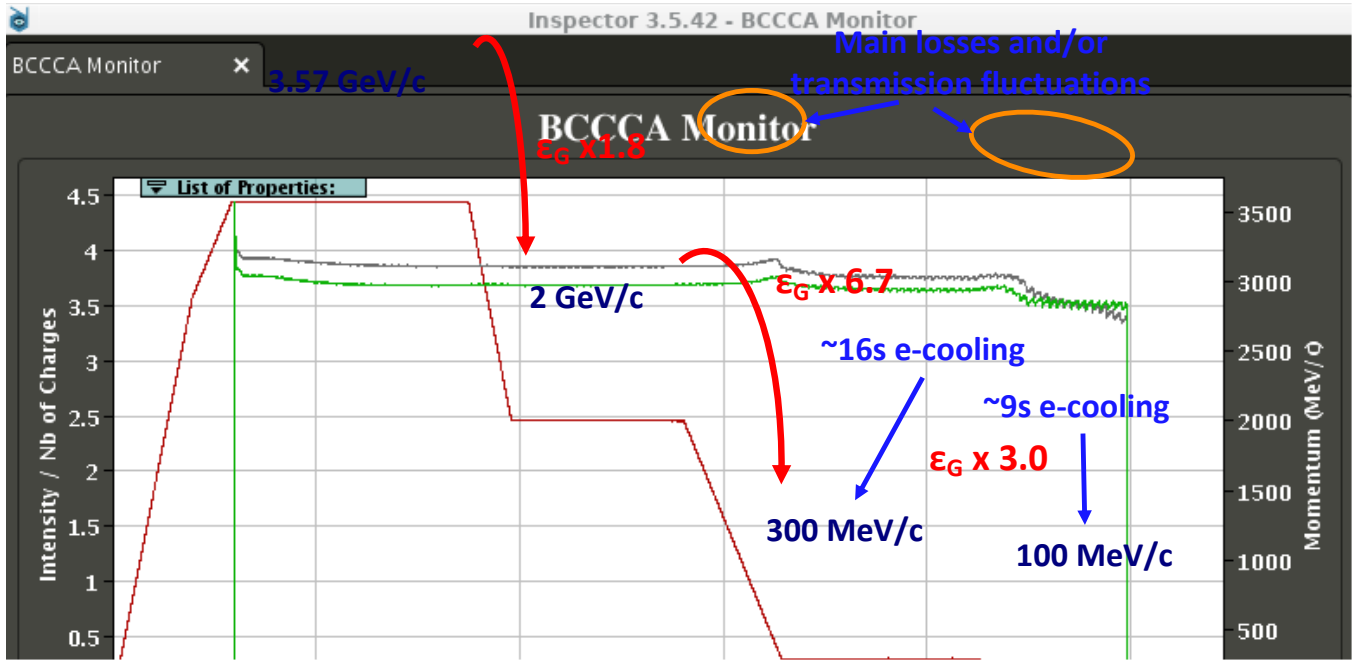


Fig. 2: Basic AD deceleration cycle.

S. Baird, et al, PAC 1997, Canada, CERN-PS-97-36-HP.



Courtesy of Davide Gamba

e-Cooler specifications

	Present	This Spec.
AD ring length [m]	182.43	182.43
Gun magnetic field [G]	600	2400
Gun perveance [μP]	0.58	2.5
Cathode radius [mm]	25	12.5
Toroid field [G]	600	600
Toroid angle ϕ_0 [rad]	0.6283	0.6283
Toroid radius r_{tor} [m]	1.133	1.133
Toroid integrated transverse field [G·m]	~ 160	$\lesssim 160$
Cooling region:		
Length [m]	~ 1	≥ 1
Radius $\geq r_{\text{e-beam}}$ [mm]	25	≥ 25
Drift magnet length [m]	~ 1.5	~ 1.5
Drift magnet field [G]	600	600
max$(B_\perp/B_\parallel)$	10^{-3}	10^{-4}
rms$(B_\perp/B_\parallel)$	n.a.	$< 10^{-4}$
e^- **beam in cooling region:**		
$k_B T_\perp$ [meV]	100	$\lesssim 100$
$k_B T_\parallel$ [meV]	—	$\lesssim 1$
$r_{\text{e-beam}}$ [mm]	—	up to 25
Energy set resolution [eV]	1	$0.1_{\,2.9\,\text{keV}} \div 1_{\,25.5\,\text{keV}}$
Energy stability [eV]	—	$< 0.1_{\,2.9\,\text{keV}} \div < 1_{\,25.5\,\text{keV}}$
Current intensity I_0 [A]	2.4	$2.4_{\text{ nominal}} \div 4.8_{\text{ ultimate}}$
Current intensity stability $[\Delta I/I_0]$	—	$\sim 10^{-4}$
Max relative losses $[\delta I/I_0]$	—	$< 10^{-4}$
Max time to go from 25.5 keV to 2.9 keV [s]	> 5	~ 1
e^- beam start/stop time [s]	—	$\ll 1$
BPMs e^-/pbar relative accuracy [μm]	—	$\lesssim 100$
Vacuum pressure in cooling region [mbar]	$\sim 10^{-10}$	$< 10^{-10}$
E-cooler availability during physics	—	99%

Expansion of the e^- beam by a factor of 2 to reduce transverse energy

CERN EDMS doc.
AD-LNT-ES-0001

More stringent to limit e^- beam heating in the cooling region

$$c\gamma\beta B_\perp/B_\parallel \ll \sqrt{\frac{k_B T_{e\parallel}}{m_e}} < \sqrt{\frac{k_B T_{e\perp}}{m_e}}$$

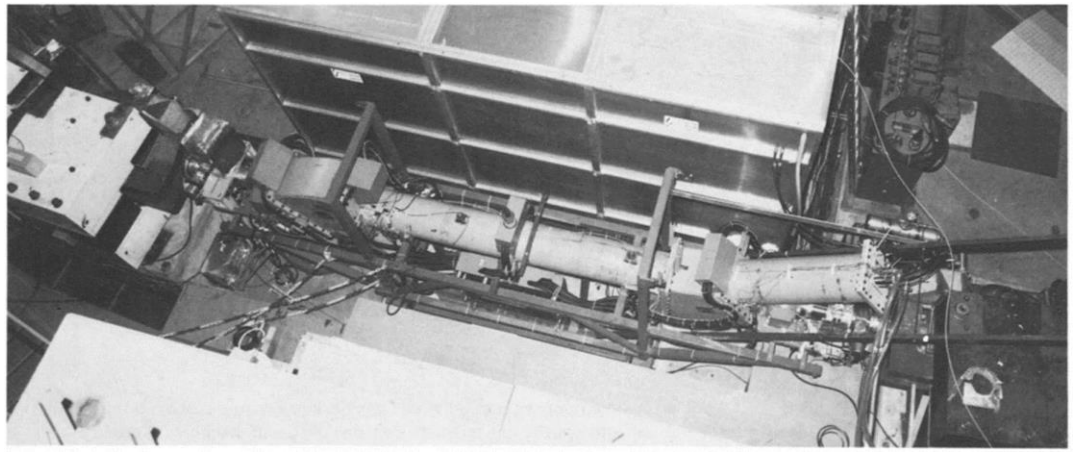
Might be limited by space charge and other effects

Possible via the gun grid

Determines the choice of components/spares

Current e-Cooler

Low Energy Antiproton Ring (1982-1997)



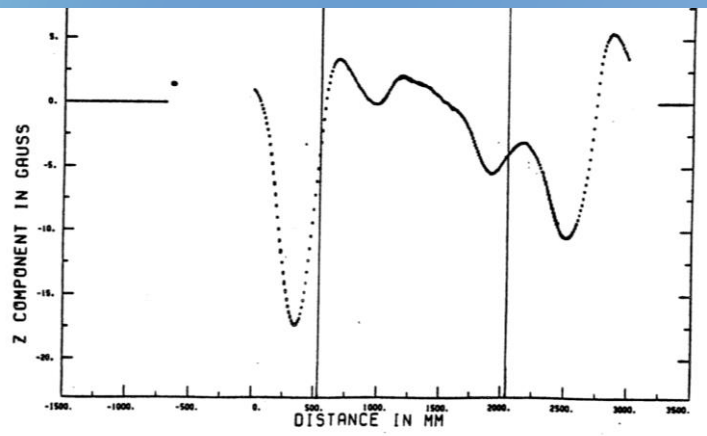
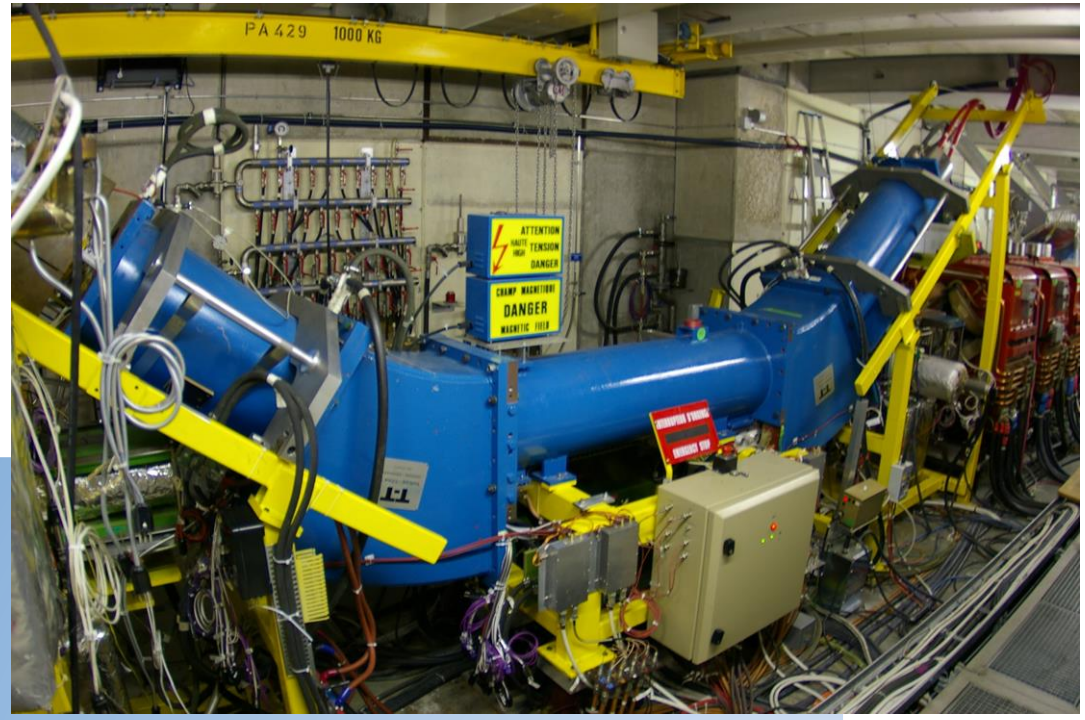


Fig. 16 Magnetic field components measured along the cooling axis (ion trajectory). The vertical lines indicate the limits of the cooling solenoid.

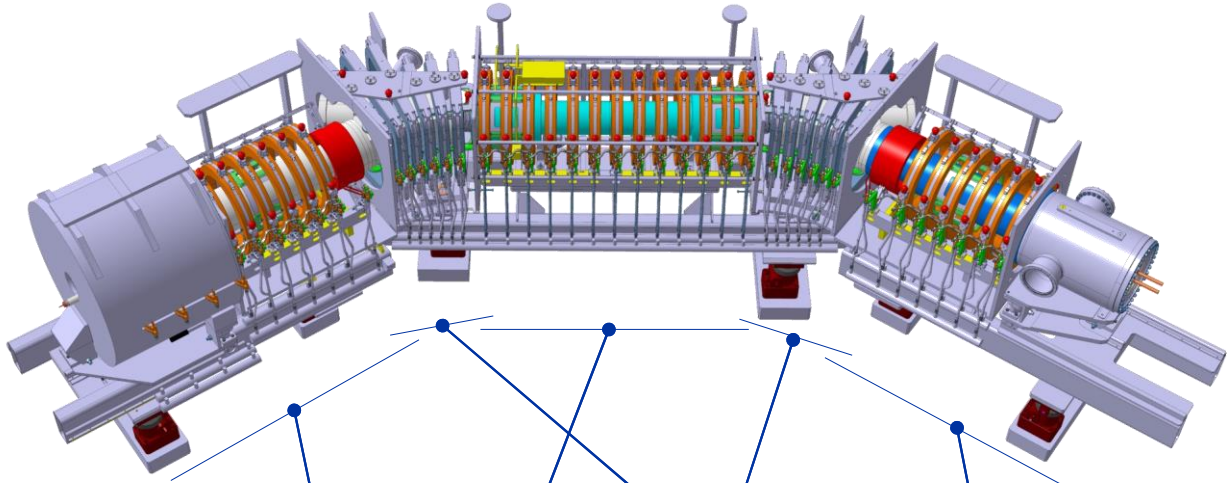
A. Wolf, L. Hütten and H. Poth,
Magnetic field measurements for the electron cooling device for LEAR,
EP Internal Report 84-01

Antiproton Decelerator Ring (2000-today)



Courtesy of Gerard Tranquille

E-Cooler Overview



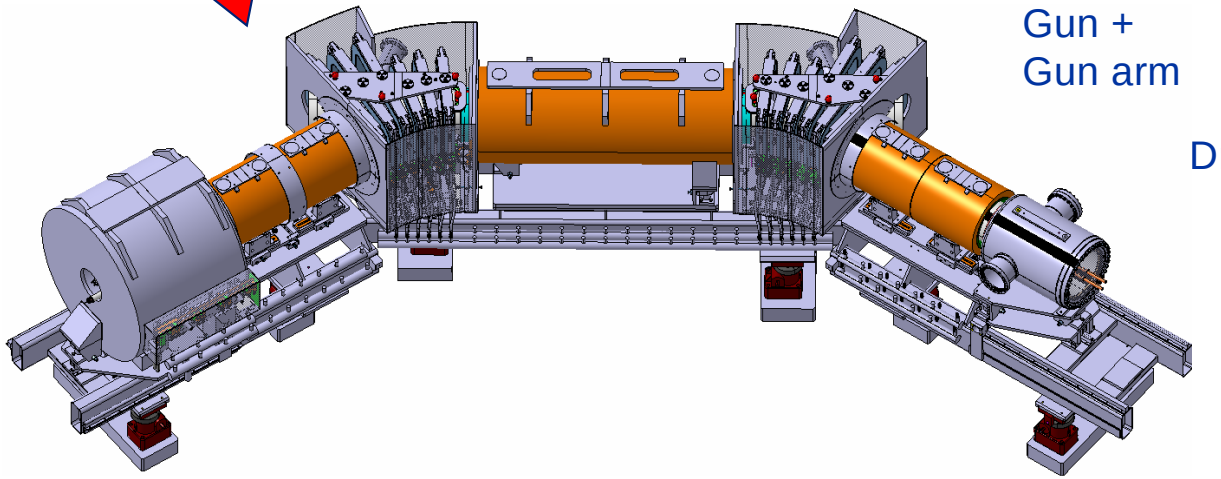
Gun +
Gun arm

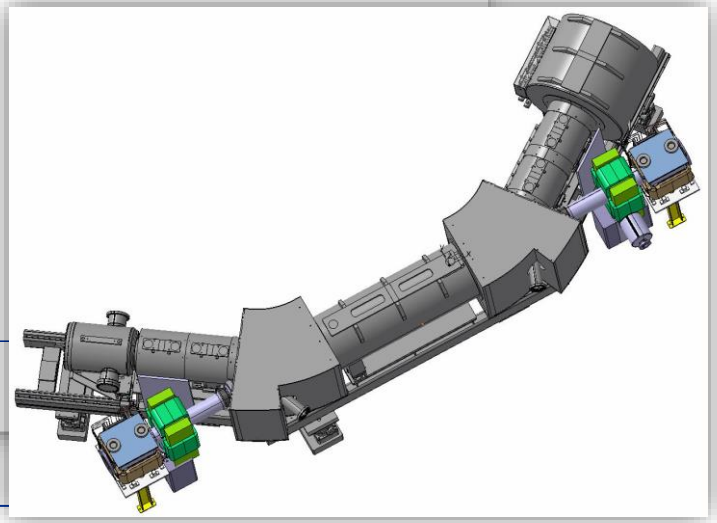
Drift module

Toroid modules

Collector +
Collector arm

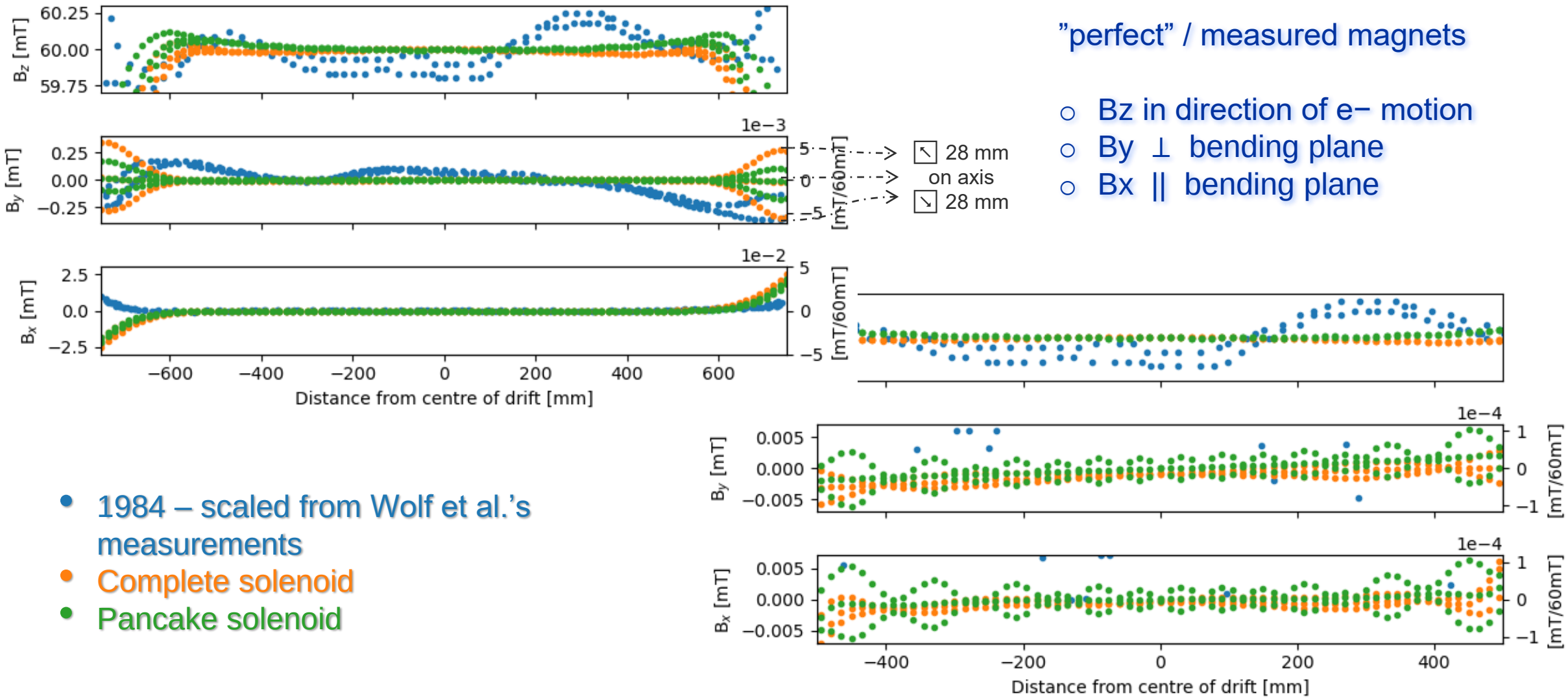
Recent major modification:
Pancakes replaced by full solenoids (short & long)





Courtesy of Nicolas Chritin & William Andreazza

Comparison of the current e-cooler drift to design



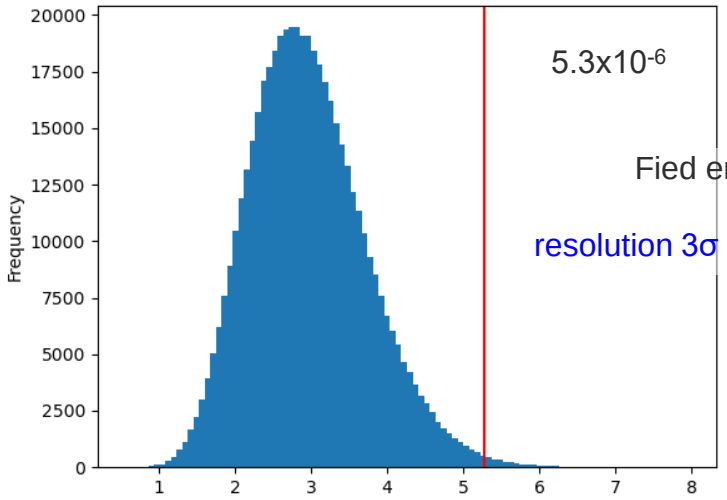
”perfect” / measured magnets

- Bz in direction of e− motion
- By ⊥ bending plane
- Bx || bending plane

- 1984 – scaled from Wolf et al.’s measurements
- Complete solenoid
- Pancake solenoid

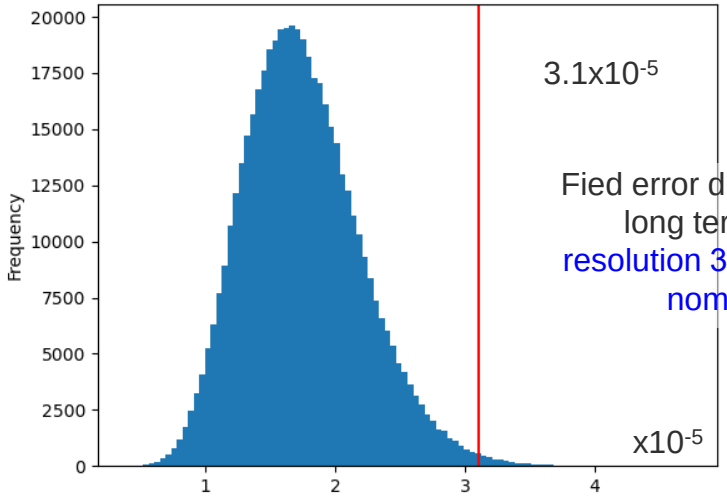
Courtesy of Luke von Freeden

Comparison complete vs. pancake drift solenoid

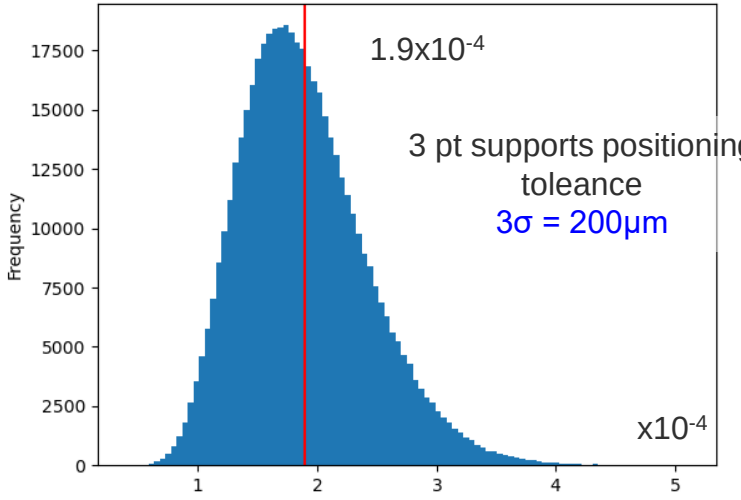


Complete

Fied error due to powering tolerances
resolution 3σ = 5PPM and ripple μ = 1m

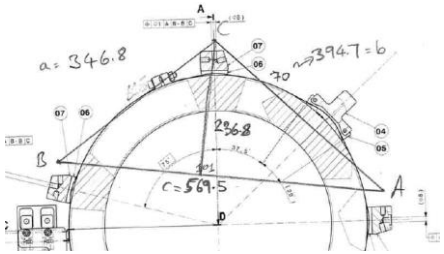


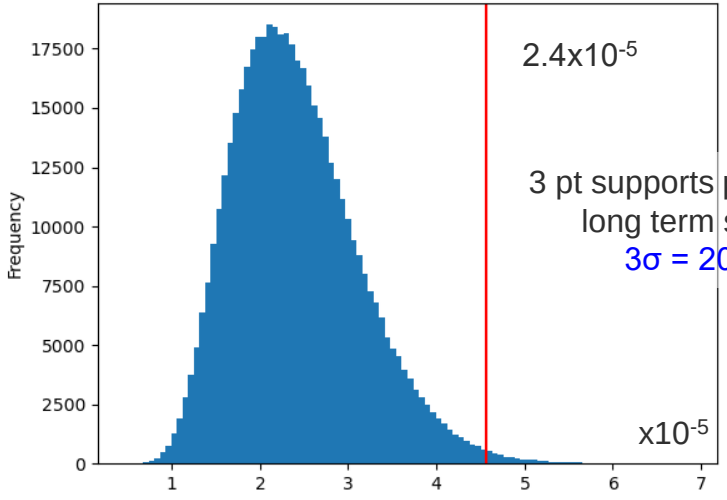
Fied error due to powering long term stability
resolution 3σ = 1000PPM, nom = 75%



3 pt supports positioning toleance
3σ = 200μm

Pancake

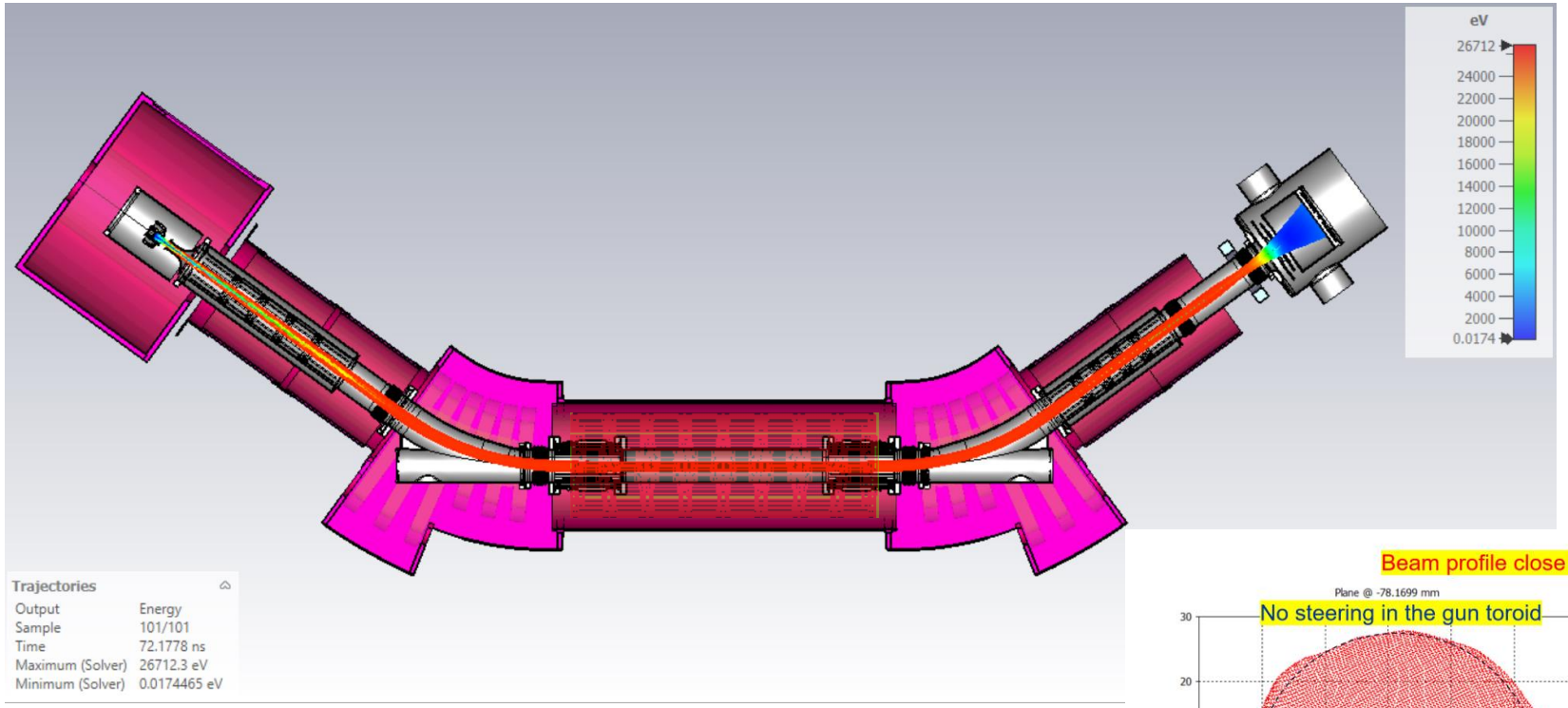


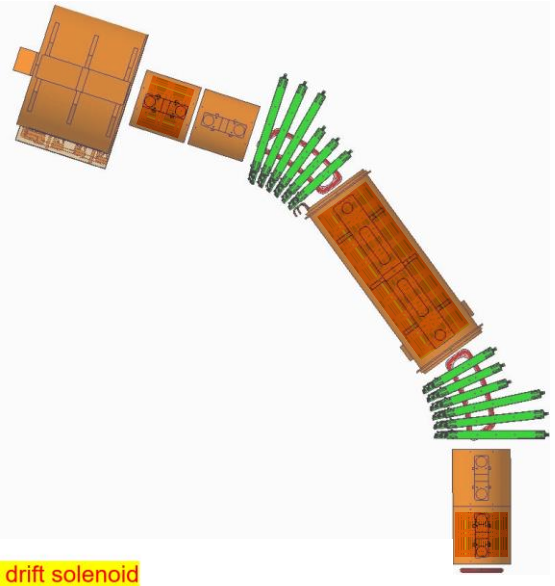


3 pt supports positioning long term stabitly
3σ = 20μm

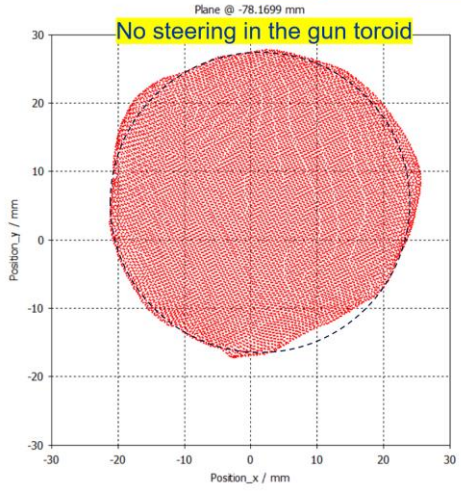
Courtesy of Luke von Freeden

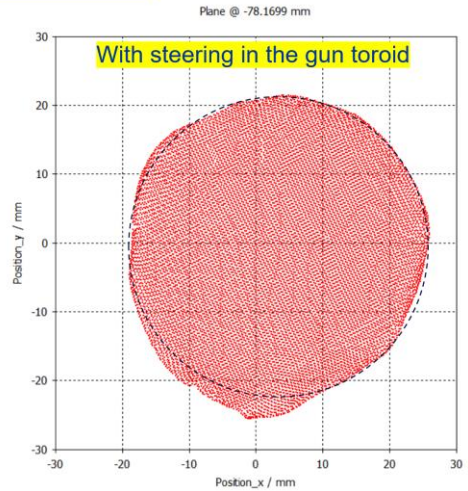
Electron transport simulation to validate design





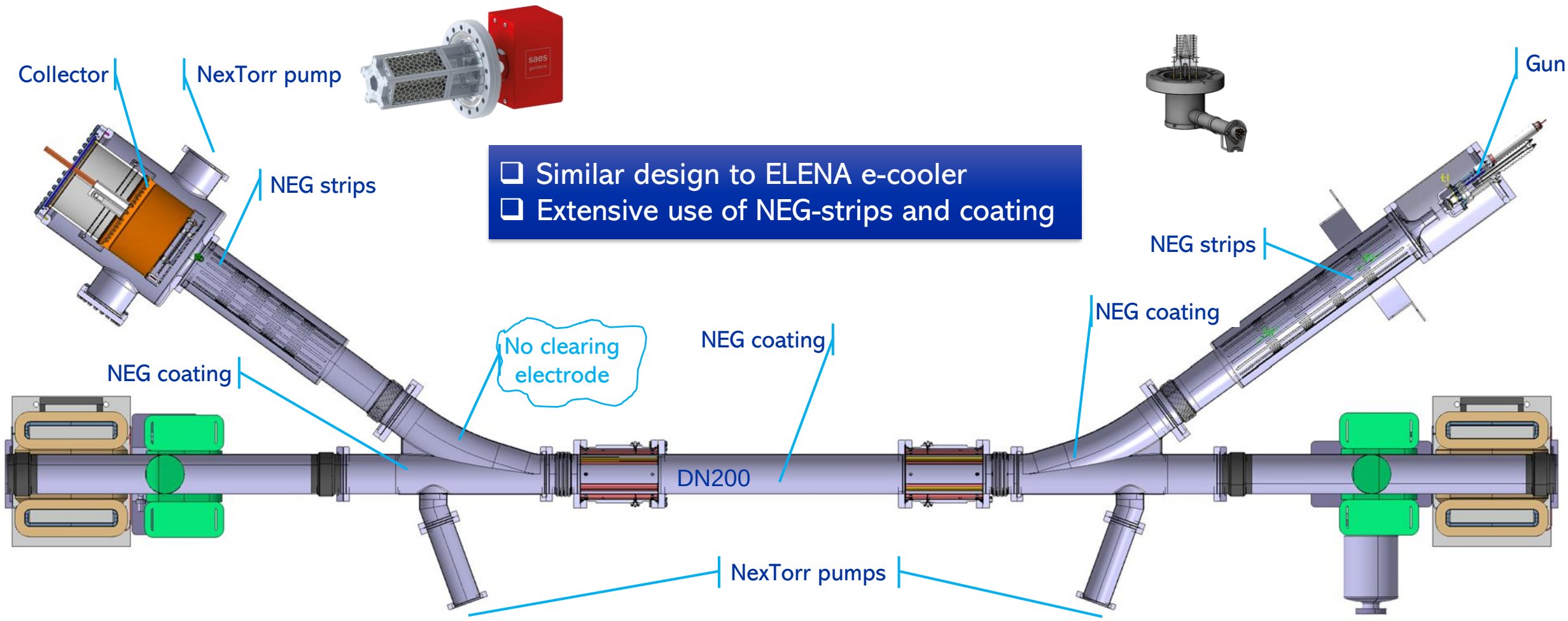
Beam profile close to center of the drift solenoid





Courtesy of Gunn Khatri

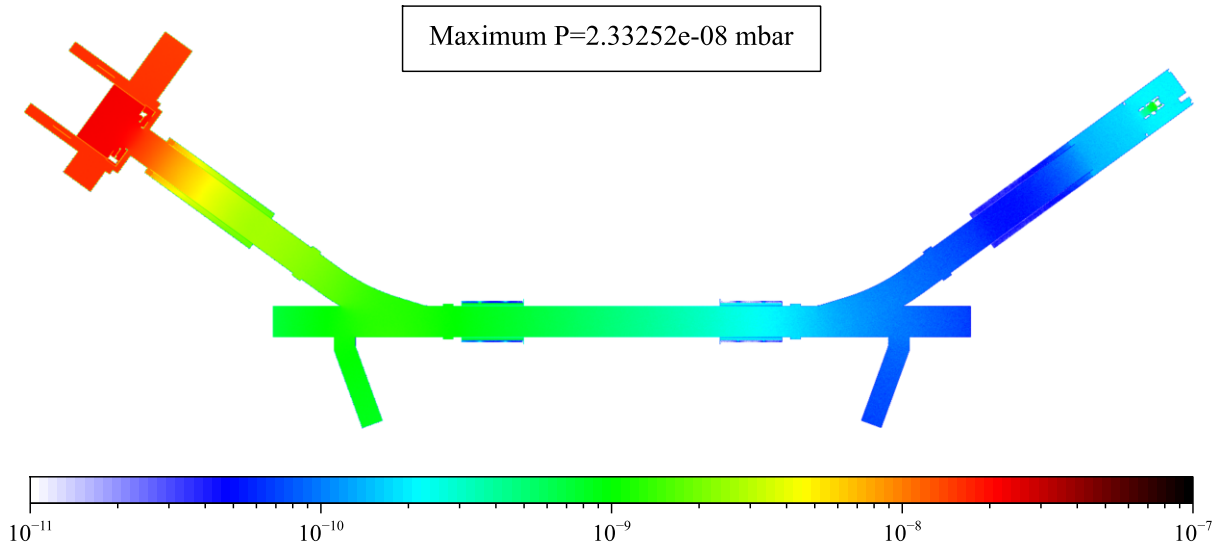
Vacuum

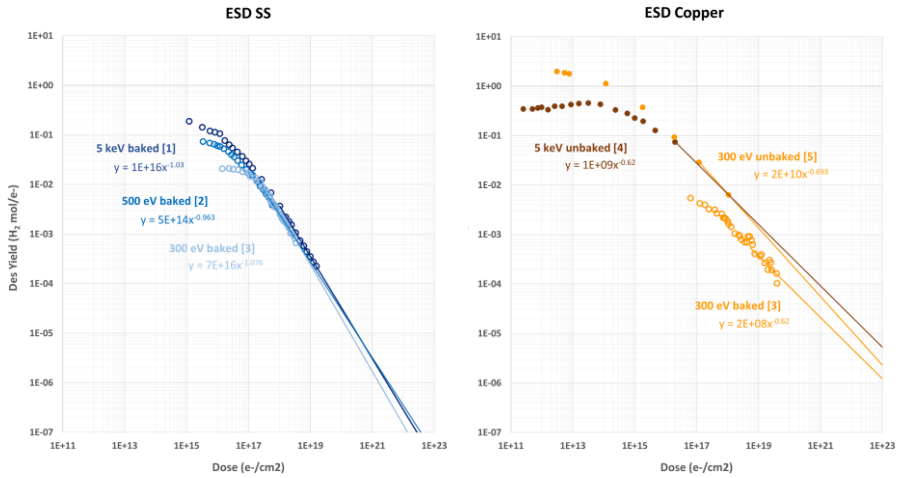


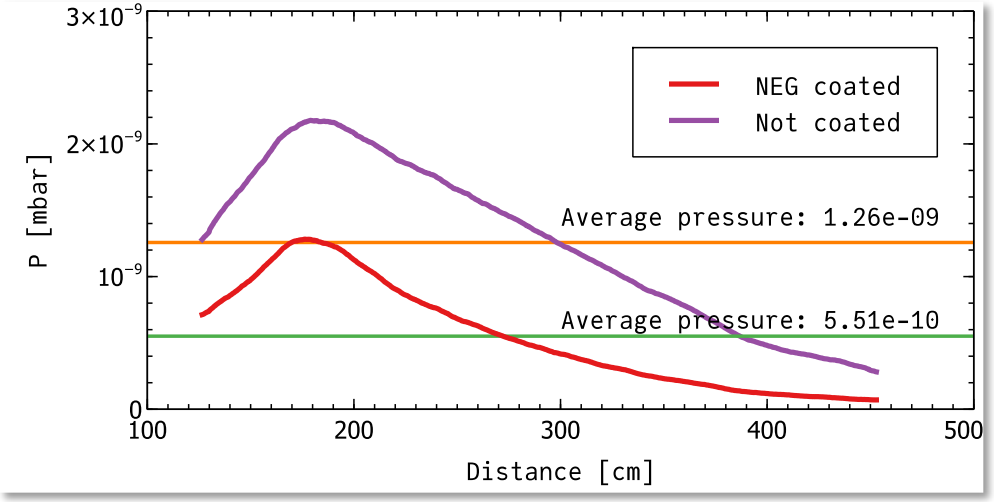
Courtesy of Cristina Castro Sequeiro, Jose A. Ferreira Somoza, Alexandre Sinturel

Results

Gas loads from gun and collector after ≈ 1 day operation

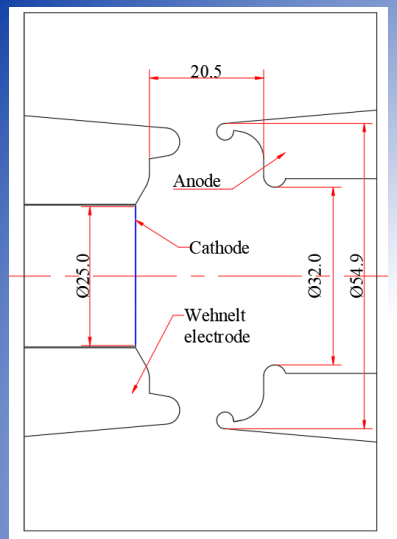


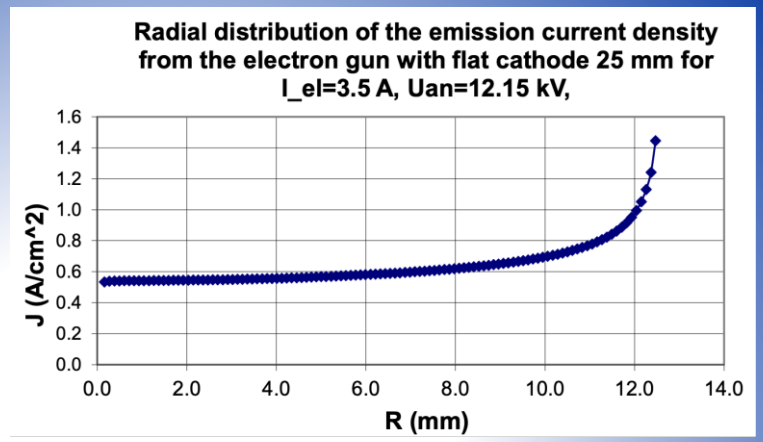




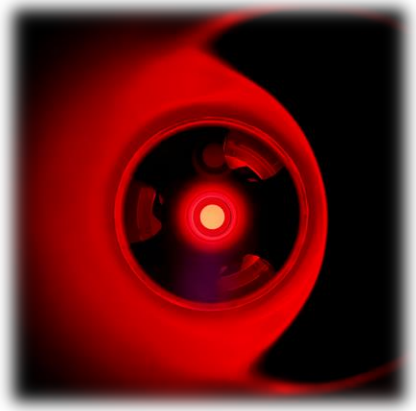
Courtesy of Cristina Castro Sequeiro, Jose A. Ferreira Somoza, Alexandre Sinturel

Gun – prototype

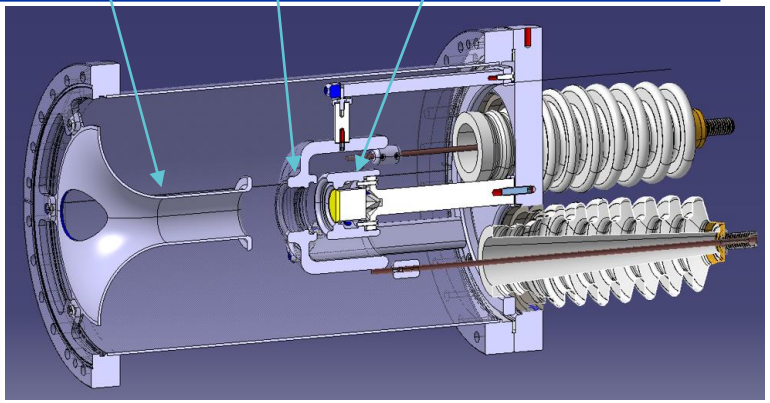




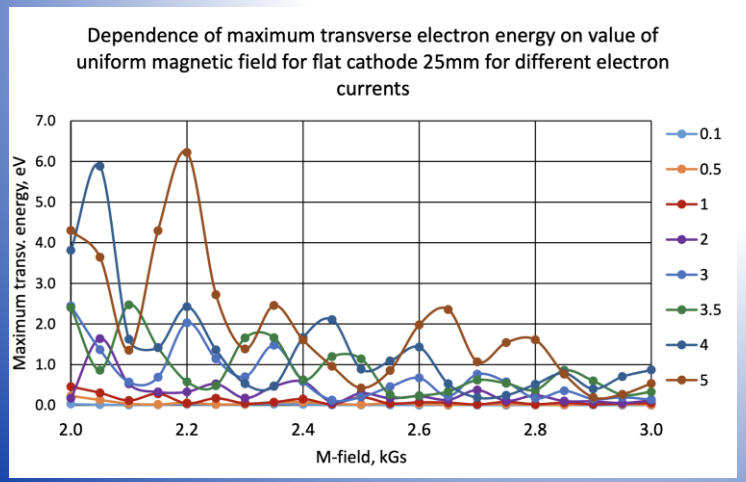
Courtesy of Alexandre Pikin

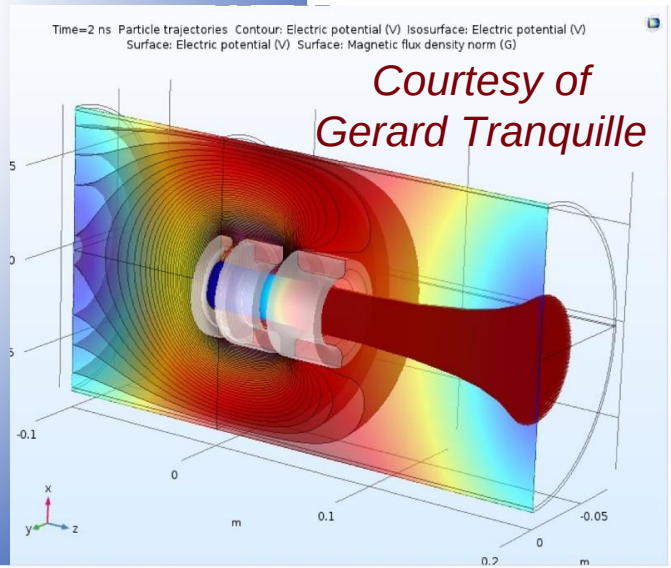


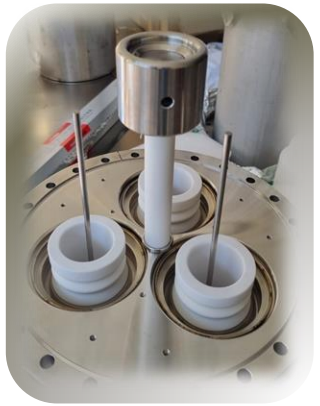
Anode – Grid – Cathode



Courtesy of Jean Cenede

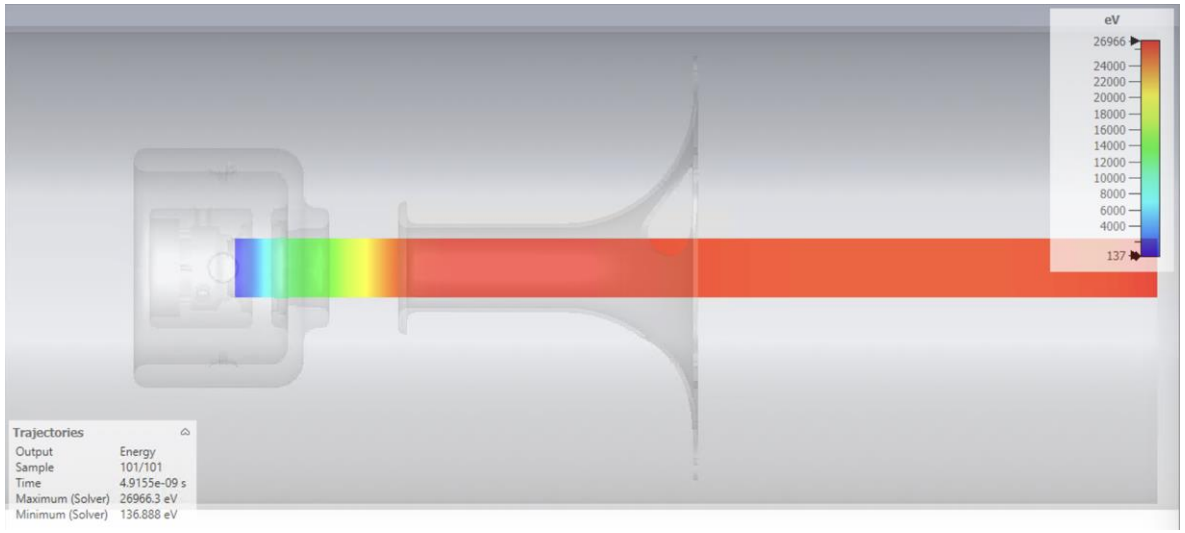


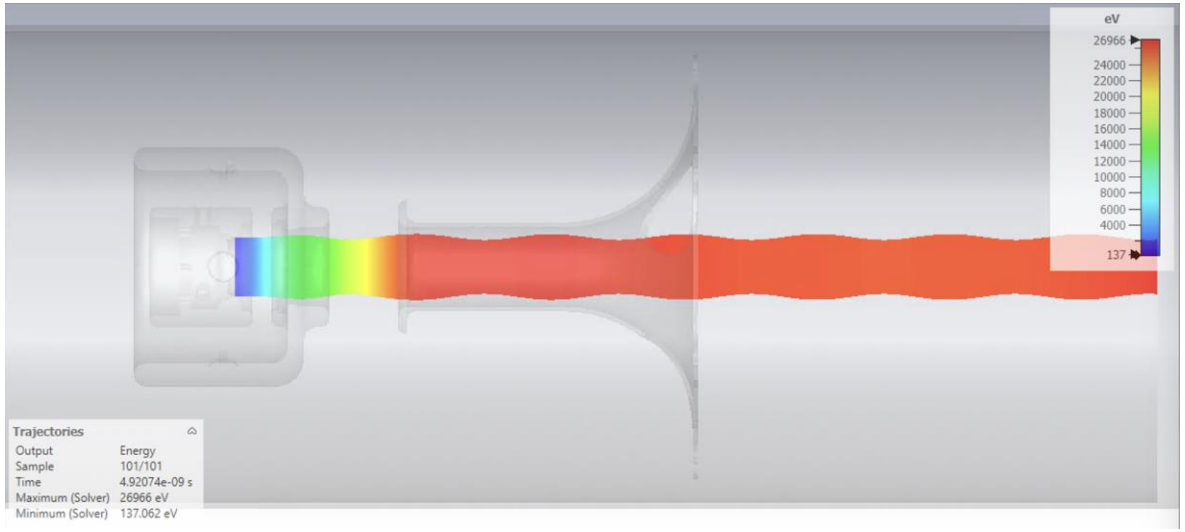


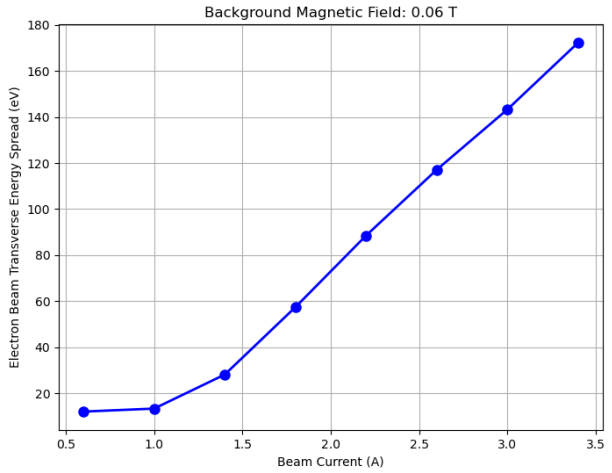


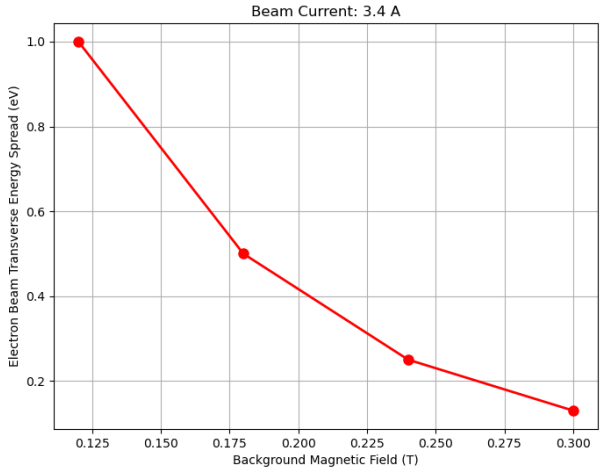
Photos by Giulio Stancari

Gun CST simulations



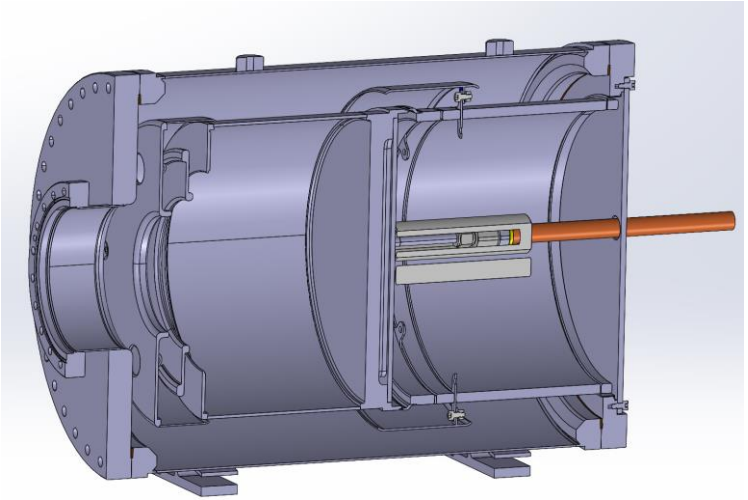




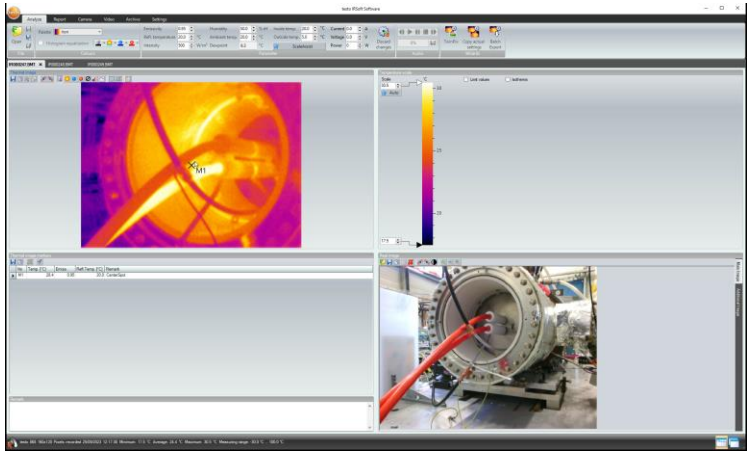


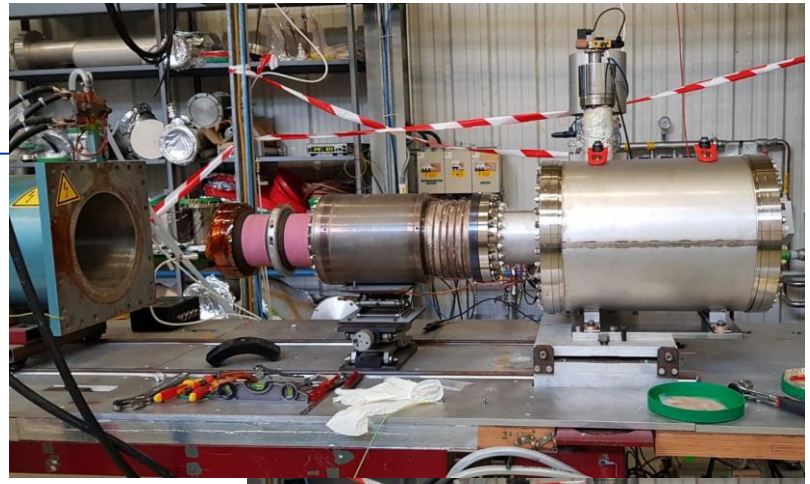
Courtesy of Sameed Muhammed

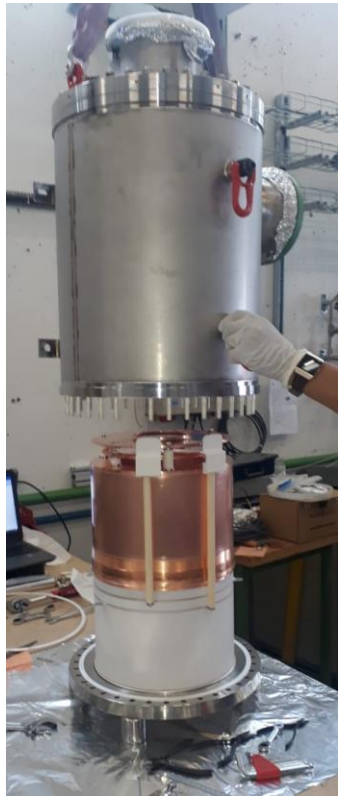
Collector

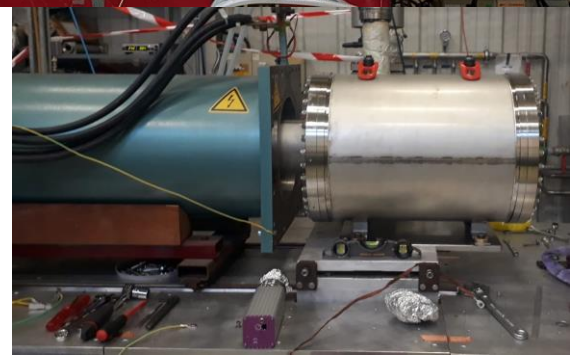


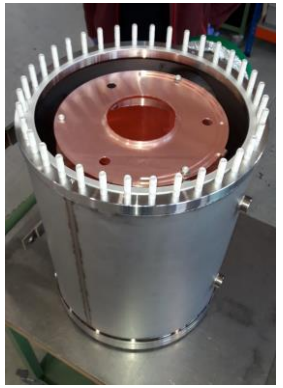
Courtesy of Jean Cenede & Yannick Coutron





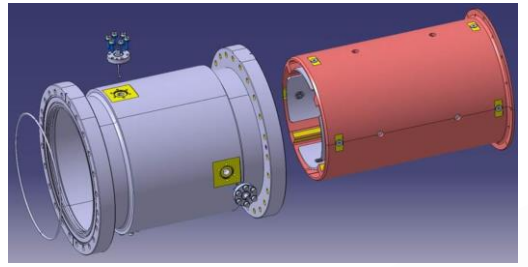




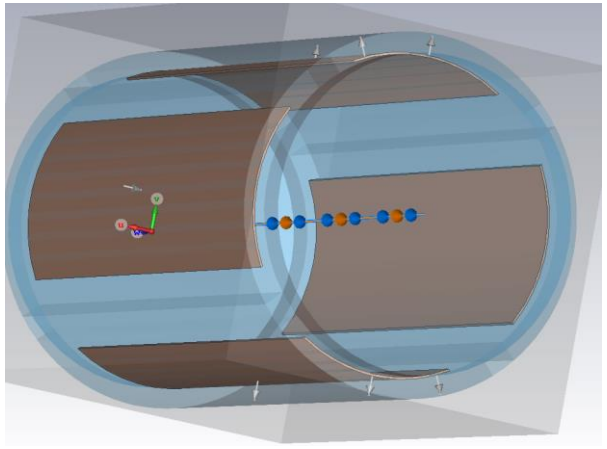


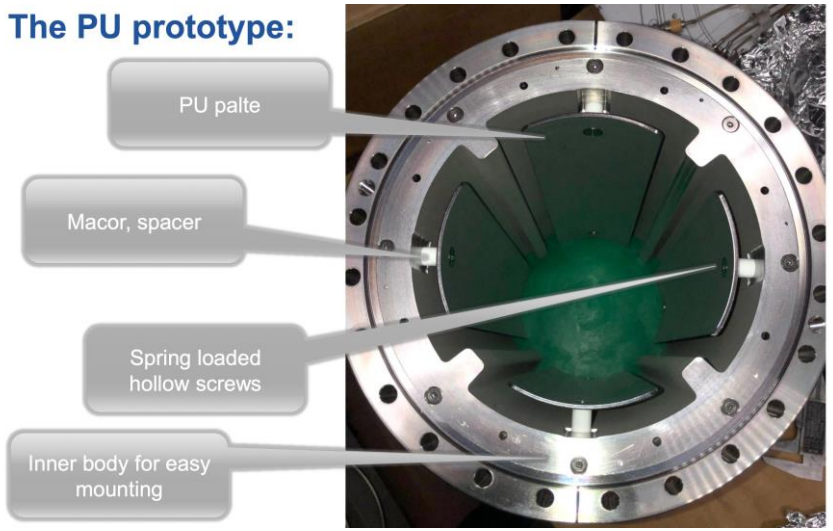
BPM

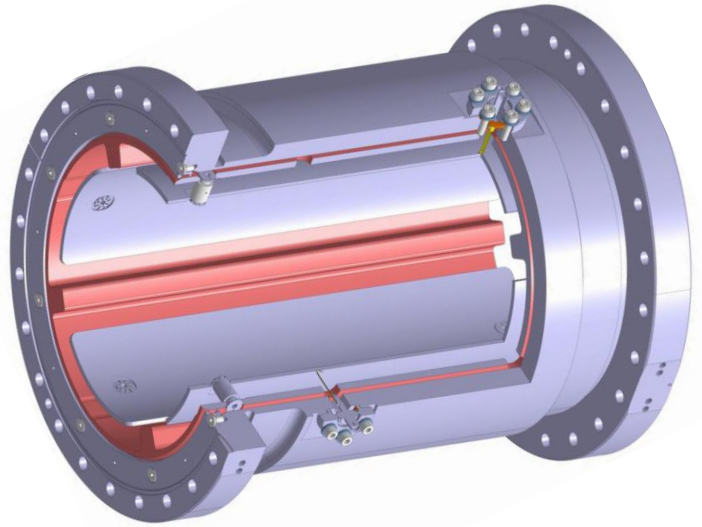
Quantity	Unit	500 MeV/c	300 MeV/c	100 MeV/c
β_e		0.471	0.305	0.106
E_e	[keV]	68.8	26.1	3.16
I_e	[A]	—	$2.4 \div 4.8$	
N_e	$[\times 10^{13}\ \mathrm{m}^{-3}]$	7.9	8.7	4.0
$I_{\bar{p}}$ for $3 \times 10^7\ \bar{p}$	[μA]	3.72	2.55	0.84
F_{rev}	[kHz]	773	500	174



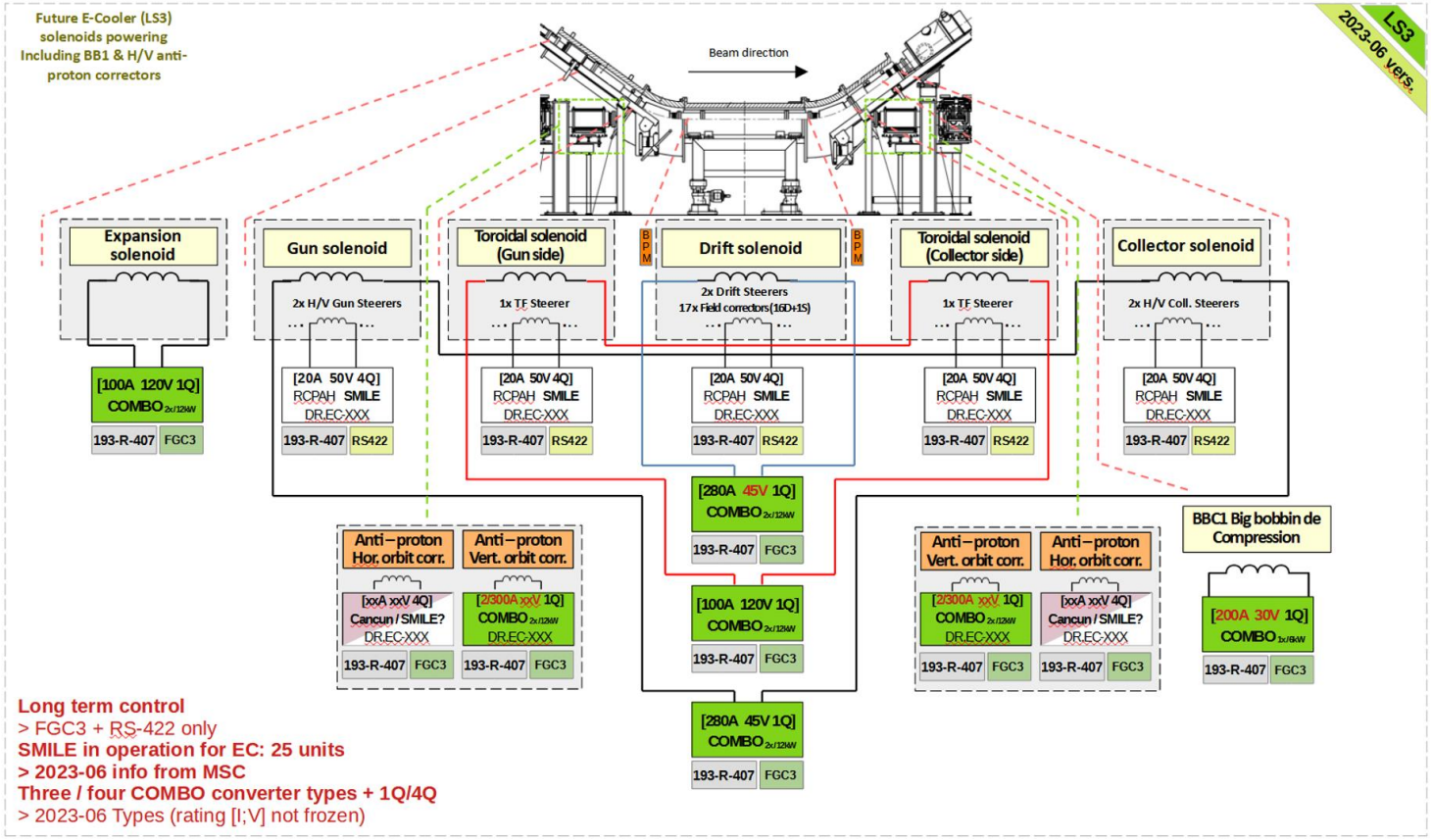
Estimated resolution 90 μm

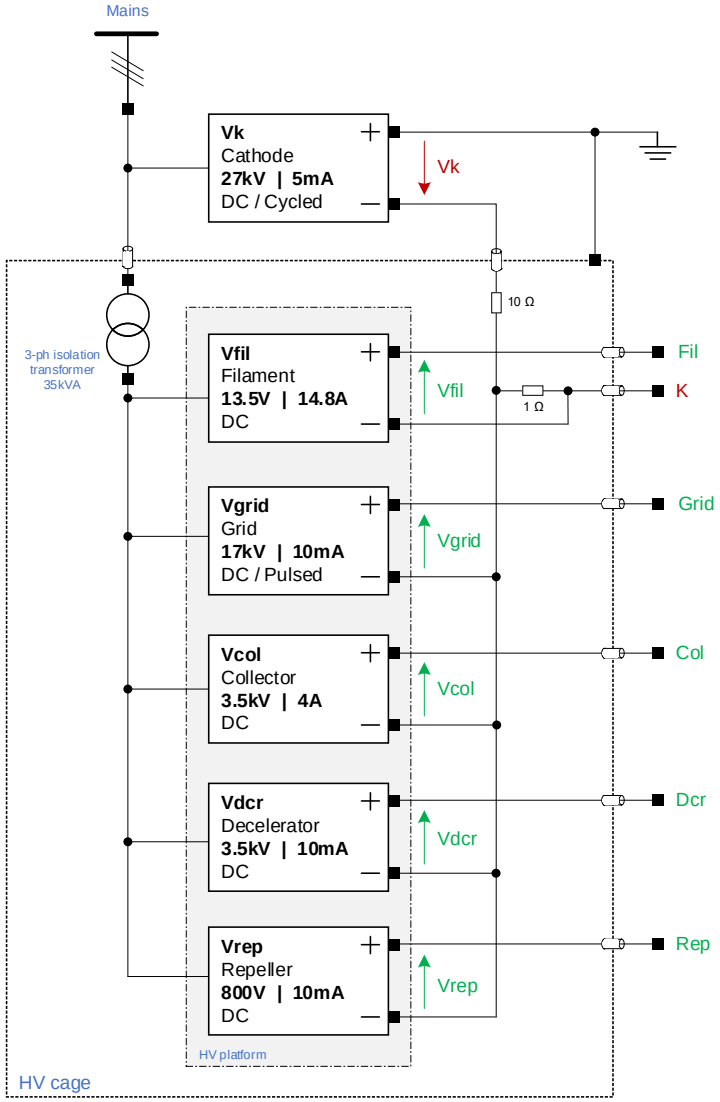






Magnet powering



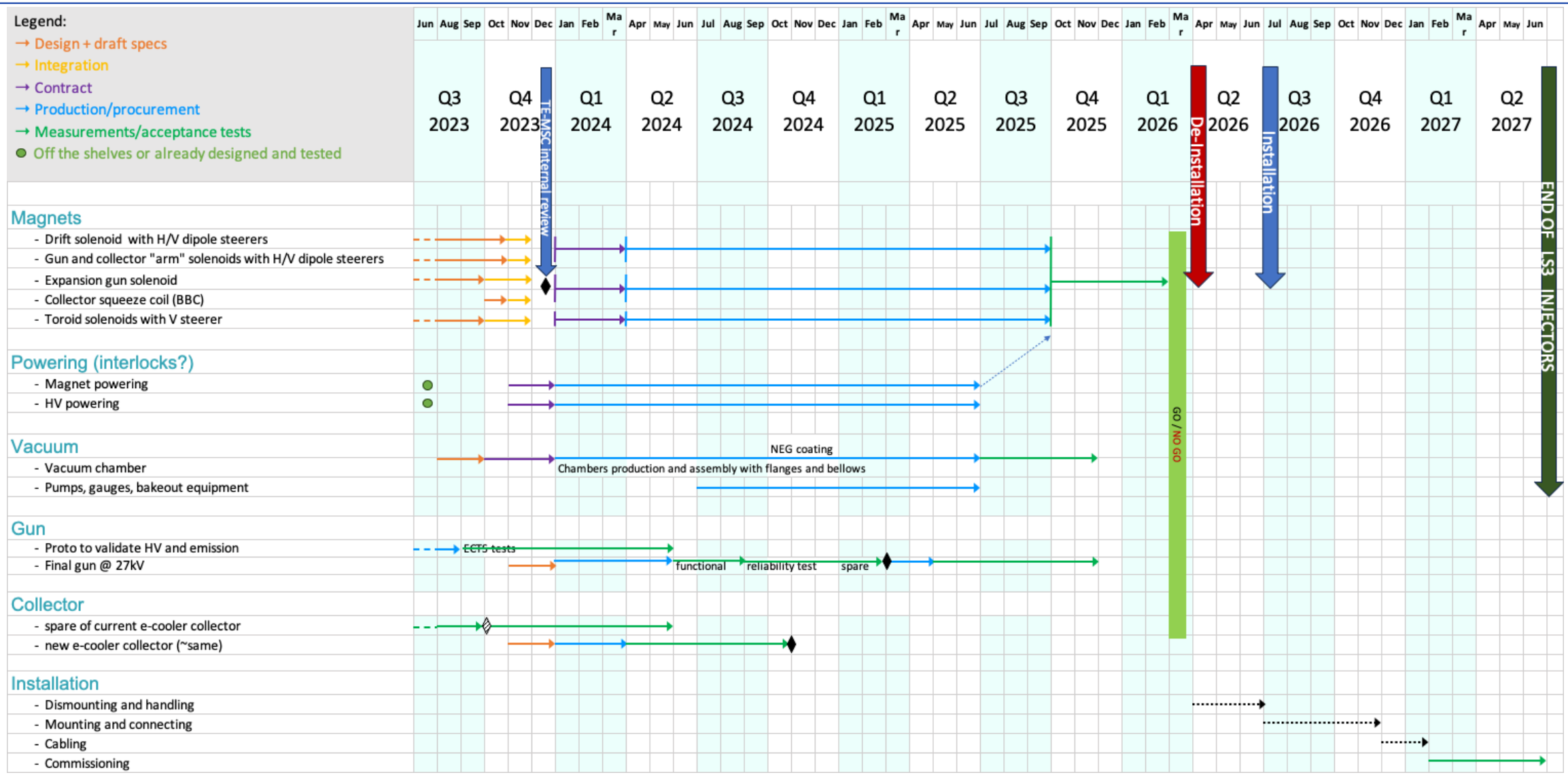


Courtesy of Yves Thurel, Alessio Bollazzi, Christophe Machado, Todor Todorcevic

Test strategy

- Components test separately in labs:
  - Magnets tested individually for acceptance and to tune correctors, plus as an ensamble to measure steering magnets strength and prepare for operations.
  - Gun and collector tested individually, with magnets equivalent to those for the final electron cooler. Possibility of measurements of the e^- beam transverse profile after expansion planned but not yet implemented
  - Vacuum chambers tested individually
  - Powering system tested individually
- Commissioning after installation foreseen to fine tune

Rough planning



Conclusions

- Functional (and engineering) specifications of the new AD electron cooler have been presented
  - The new device aims at improving the current performance with a better magnetic field quality, electron beam magnetic expansion, better measurements of the beams relative position, faster switching of the electron beam on/off
- The design is being finalised
  - The magnetic design has evolved to complete solenoids (apart from the bends), few details to be looked at
  - Gun and collectors prototypes are being tested
  - Powering has been defined
  - Vacuum design is ~completed
  - Individual component testing
- Installation foreseen for 2026 and operation in 2027

Thank you

Main subsystems/components – cartoon

- Gun & Collector — SY-BI
- Magnets — TE-MSC
- Vacuum System — TE-VSC
- BPM — SY-BI
- Support and shielding
- Powering (LV & HV) — SY-EPC
- Ancillaries