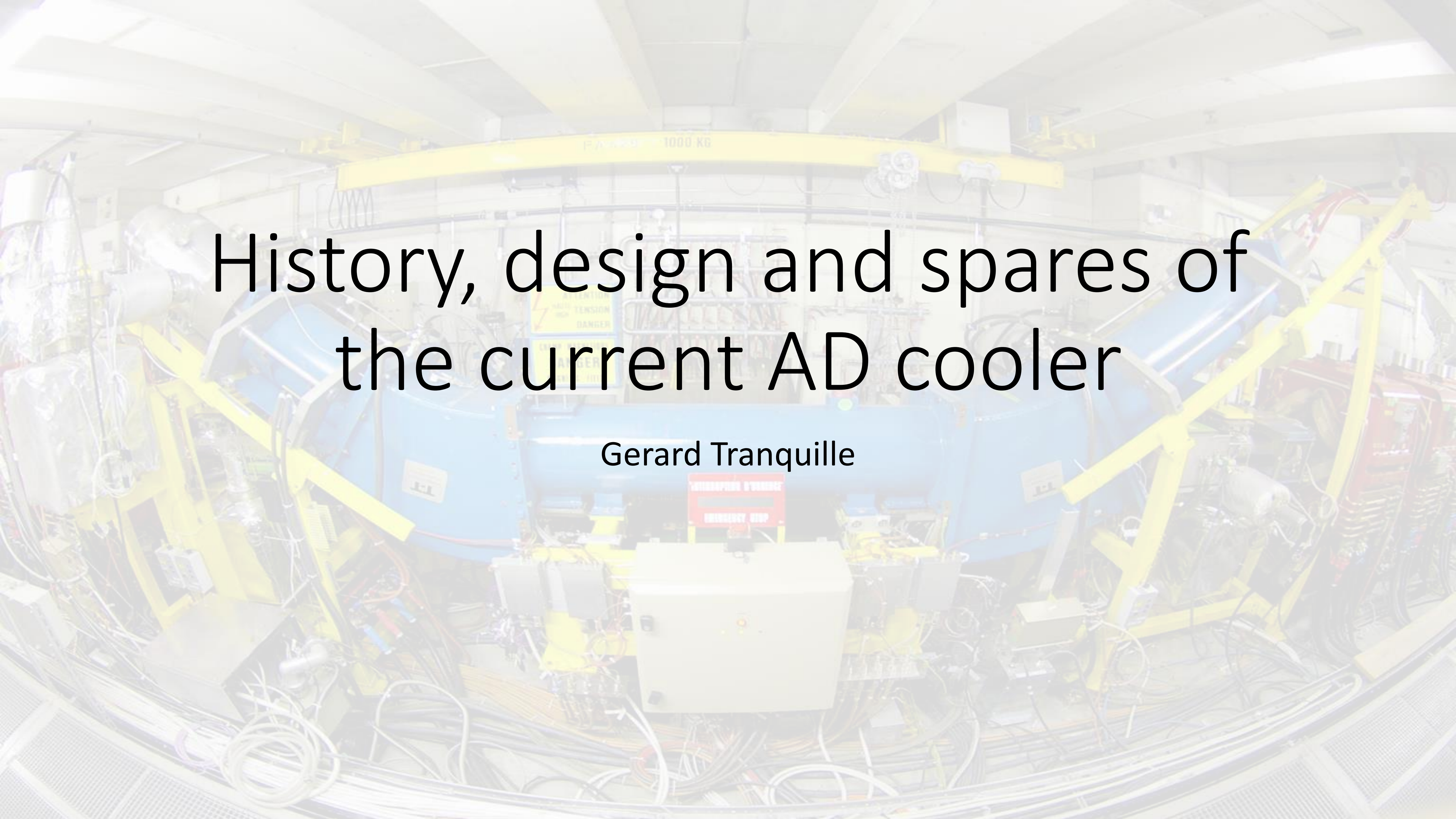


History, design and spares of the current AD cooler

Gerard Tranquille

What is Electron Cooling?

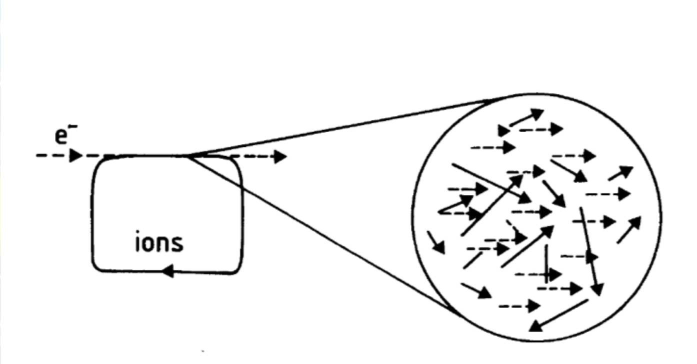
- A fast process to shrink the size, divergence and energy spread of a stored charged particle beam without the loss of intensity.
  - Phase-space compression.
- Proposed by G. Budker in 1966.
- First demonstration on the NAP-M ring in Novosibirsk.

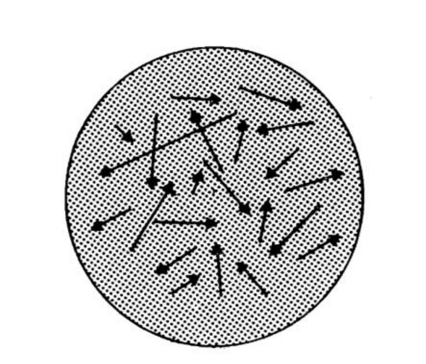
Why use Electron Cooling?

- Loss free compression of ion beams
  - Accumulation of rare species of charged particles
  - Luminosity increase for colliding beam experiments
  - Smaller spot sizes for fixed-target experiments
  - High resolution experiments with internal targets
- Compensation of beam heating effects
  - Intrabeam, residual gas and internal target scattering
- Electron target for precision experiments e.g. recombination

How?

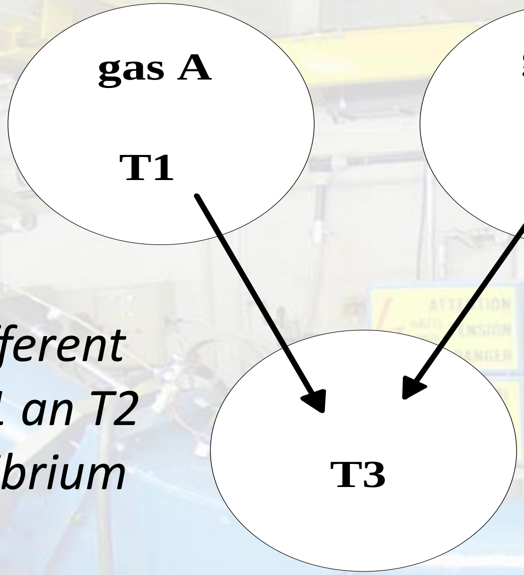
To cool a stored ion beam with electrons a monochromatic electron beam is overlapped with the ion beam in a straight section of the ring.
The velocity of the electrons is made to match the average velocity of the ion beam.



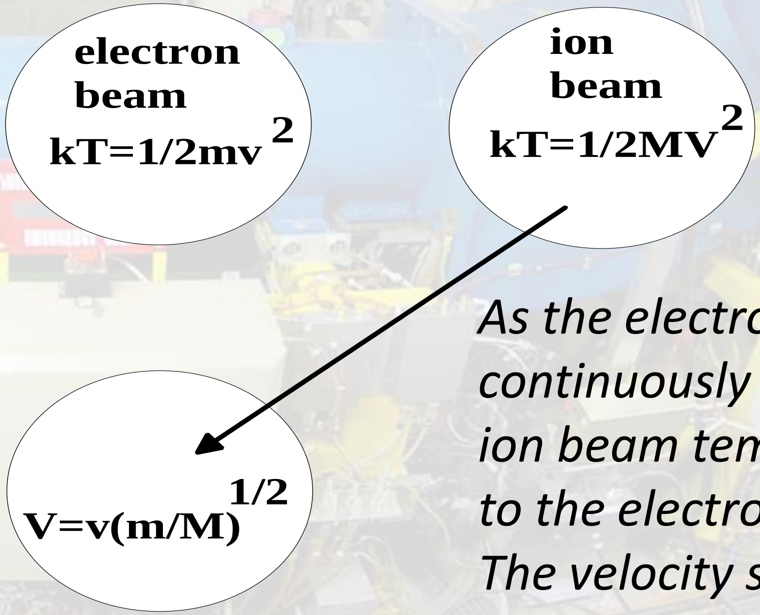


In the rest frame of the electrons the ions are seen as passing through the electron gas with a variety of velocities
The ions transfer their energy to the electrons through Coulomb scattering.
The electrons are continuously renewed -> heat exchanger

Analogy with the mixing of gases



Two gases of different temperatures T1 an T2 tend to an equilibrium temperature T3



As the electron beam is continuously renewed, the ion beam temperature tends to the electron beam temperature. The velocity spread is reduced by a factor $(m/M)^{1/2}$

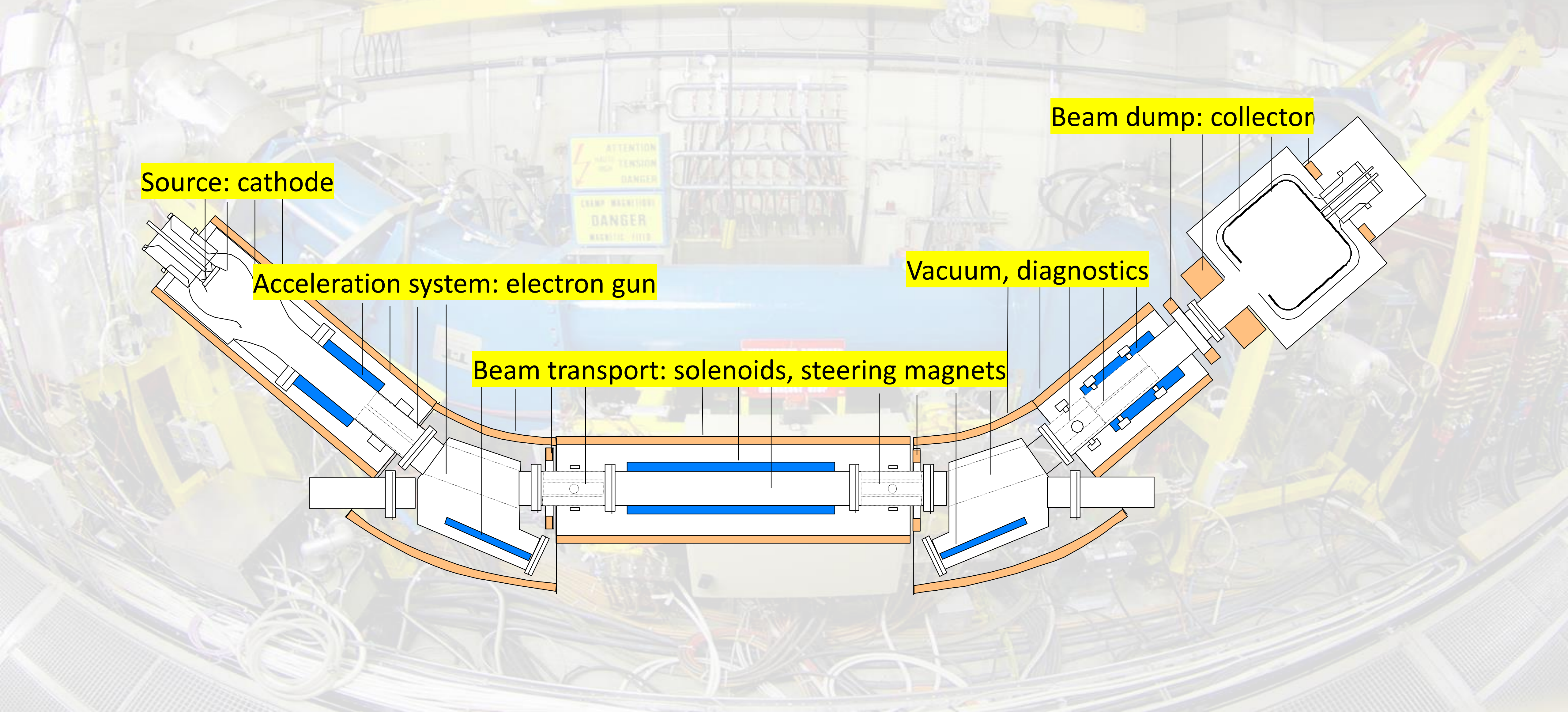
- Electron cooling theory gives :

$$\tau \propto \frac{\boldsymbol{\theta^3}}{\boldsymbol{\eta I_e}} \frac{A}{Z^2} \gamma^5 \beta^4$$

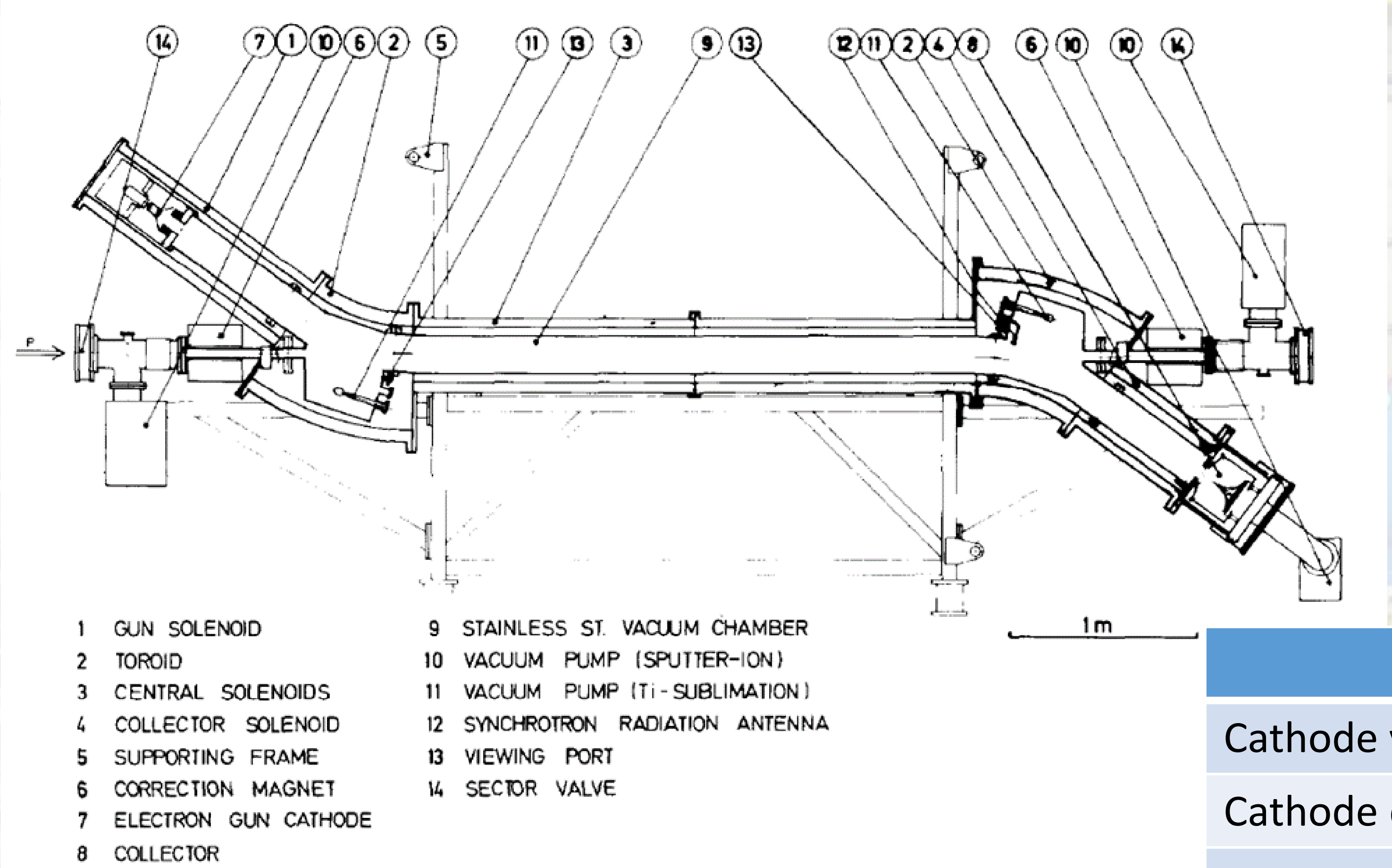
  - where θ is the relative difference in angle between the ions and electrons (θ_i - θ_e), [$\theta_i=\sqrt{(\varepsilon/\beta)}$]
  - the parameter $\eta = L_{cooler}/L_{machine}$
  - and I_e is the electron current.

“Electron cooling: theory, experiment, application”, Helmut Poth, CERN-EP-90-04

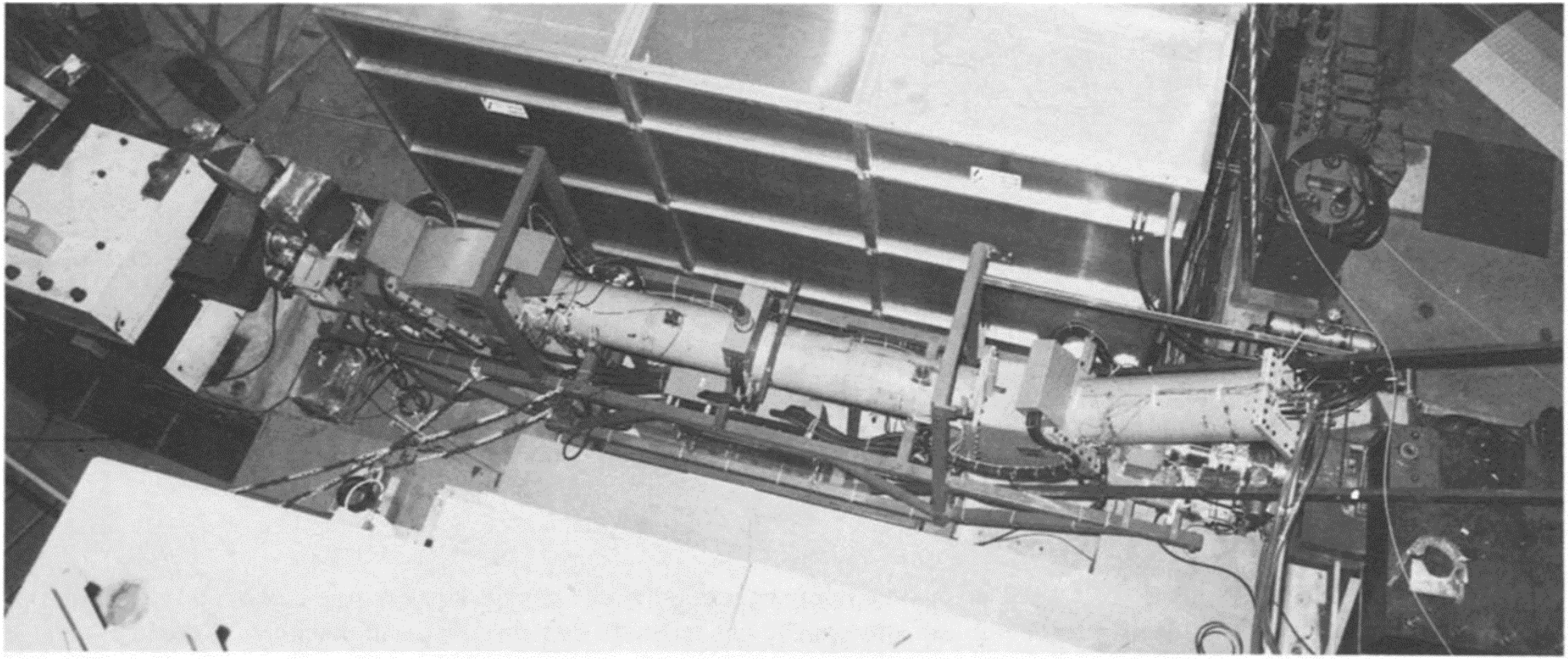
Electron Cooling Hardware

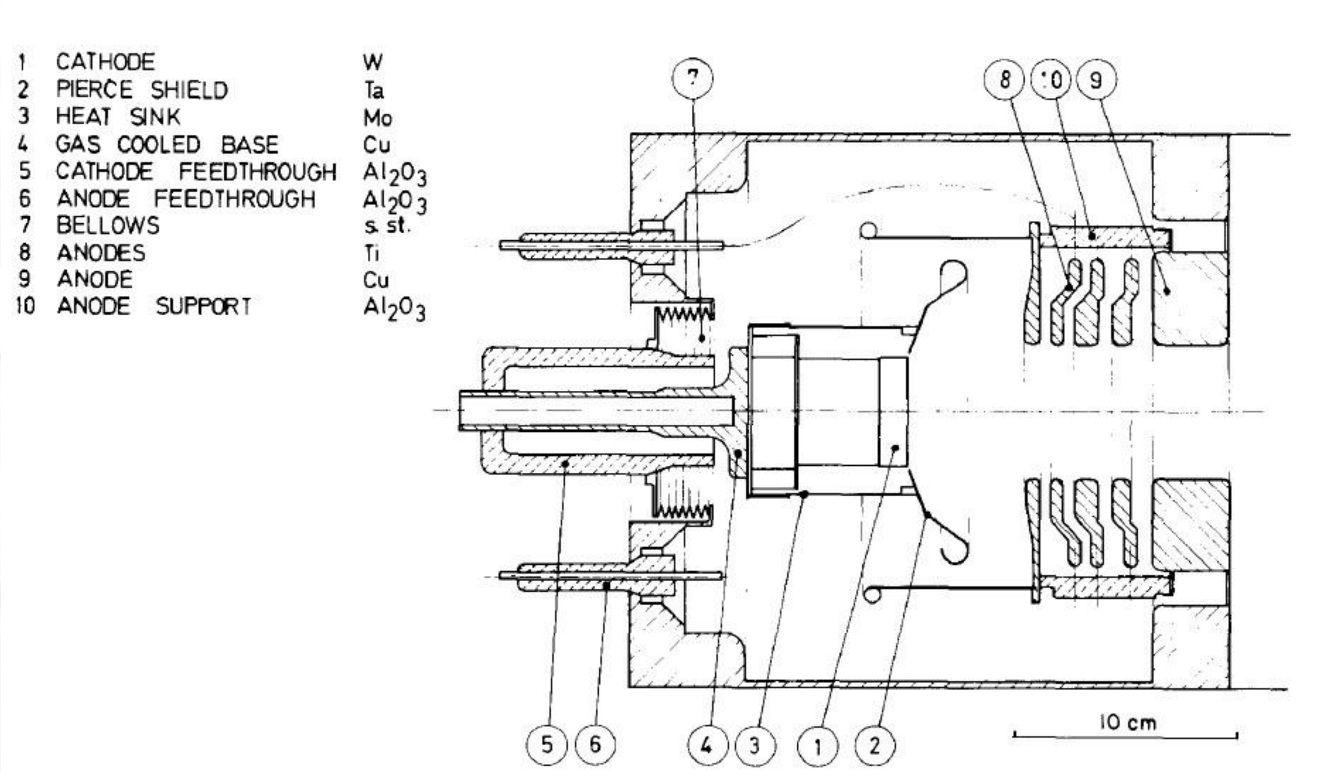


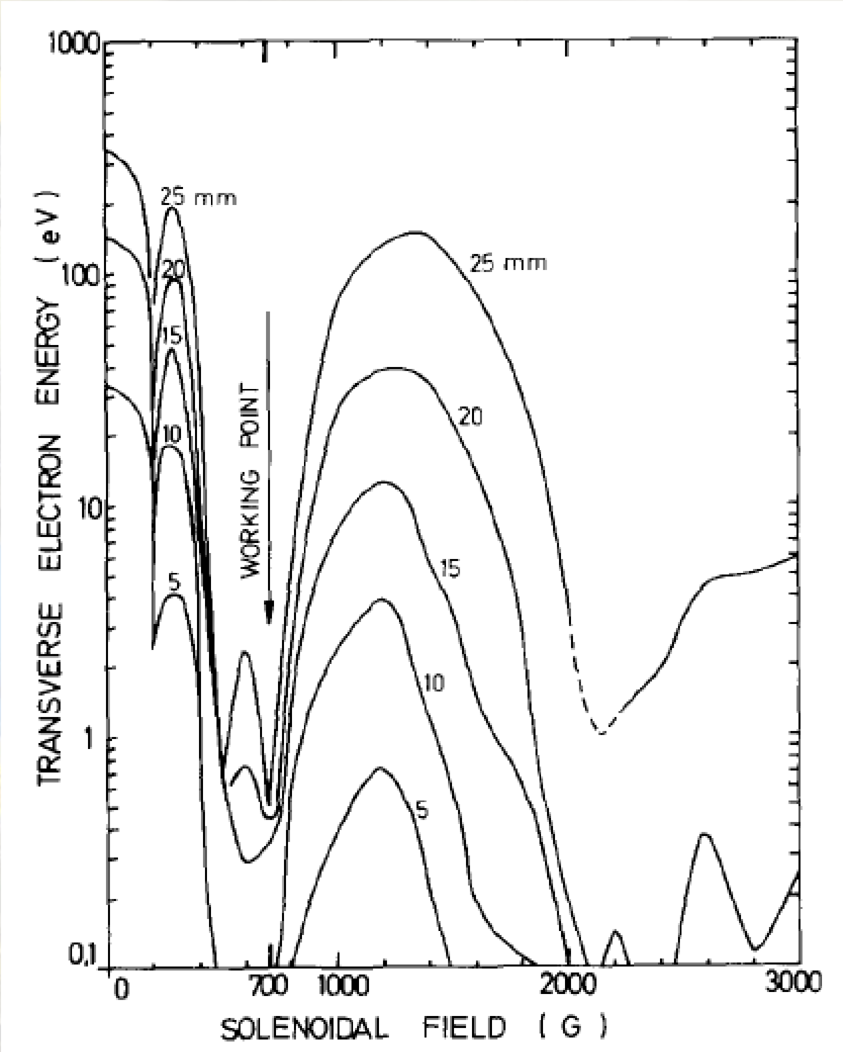
Initial Cooling Experiment (1977-1980)



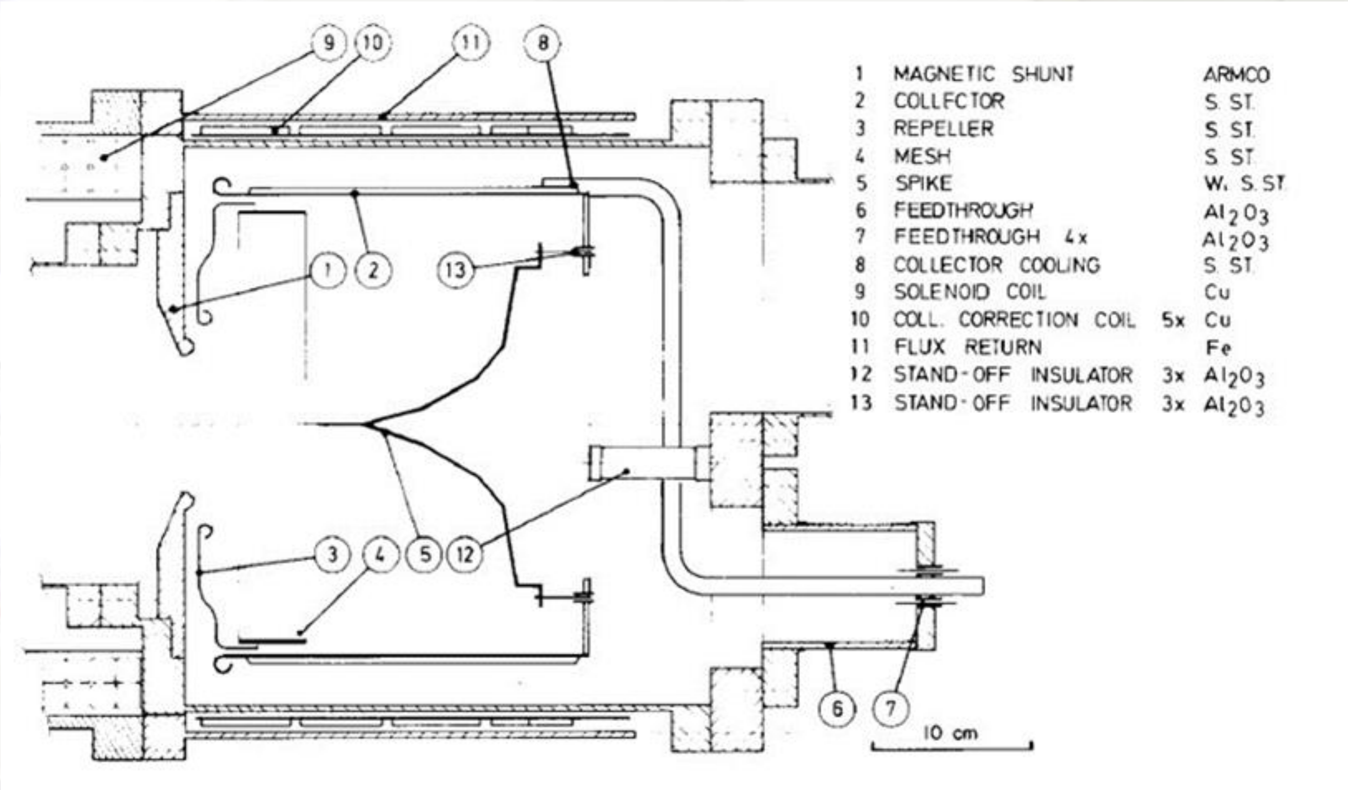
	Design	Operational
Cathode voltage	-60 kV	-26 kV
Cathode diameter	5.08 cm	
Electron current	8.3 A	1.3 A
Cooling length	3 m	
Magnetic field	700 G	500 G

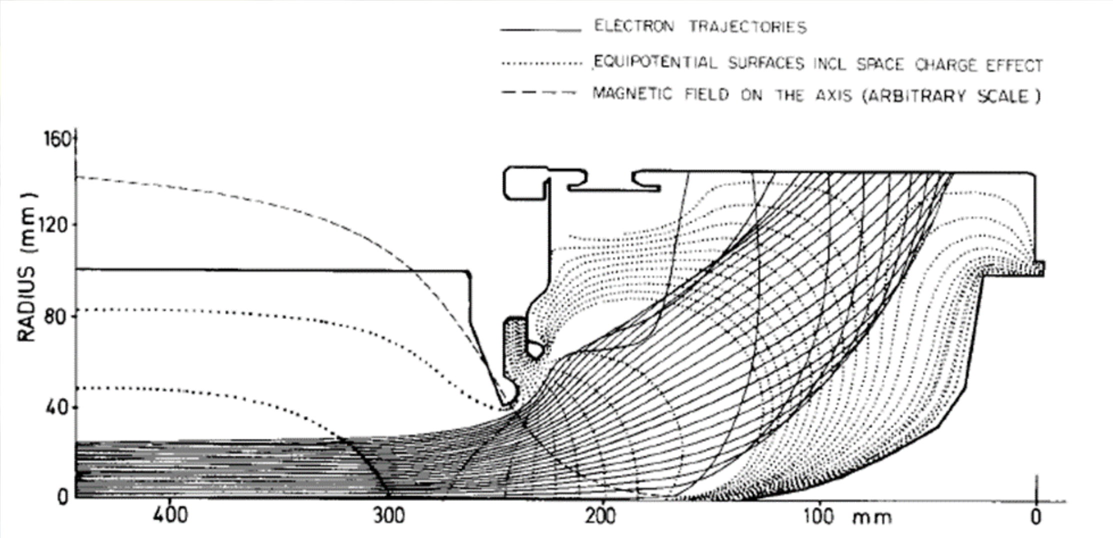






- 2” cathode surrounded by a Pierce shield
- Five iris shaped electrodes set on increasing potentials
- Four operational modes :
    - full perveance
    - half perveance
    - quarter perveance
    - temperature limited
- Resonant optics



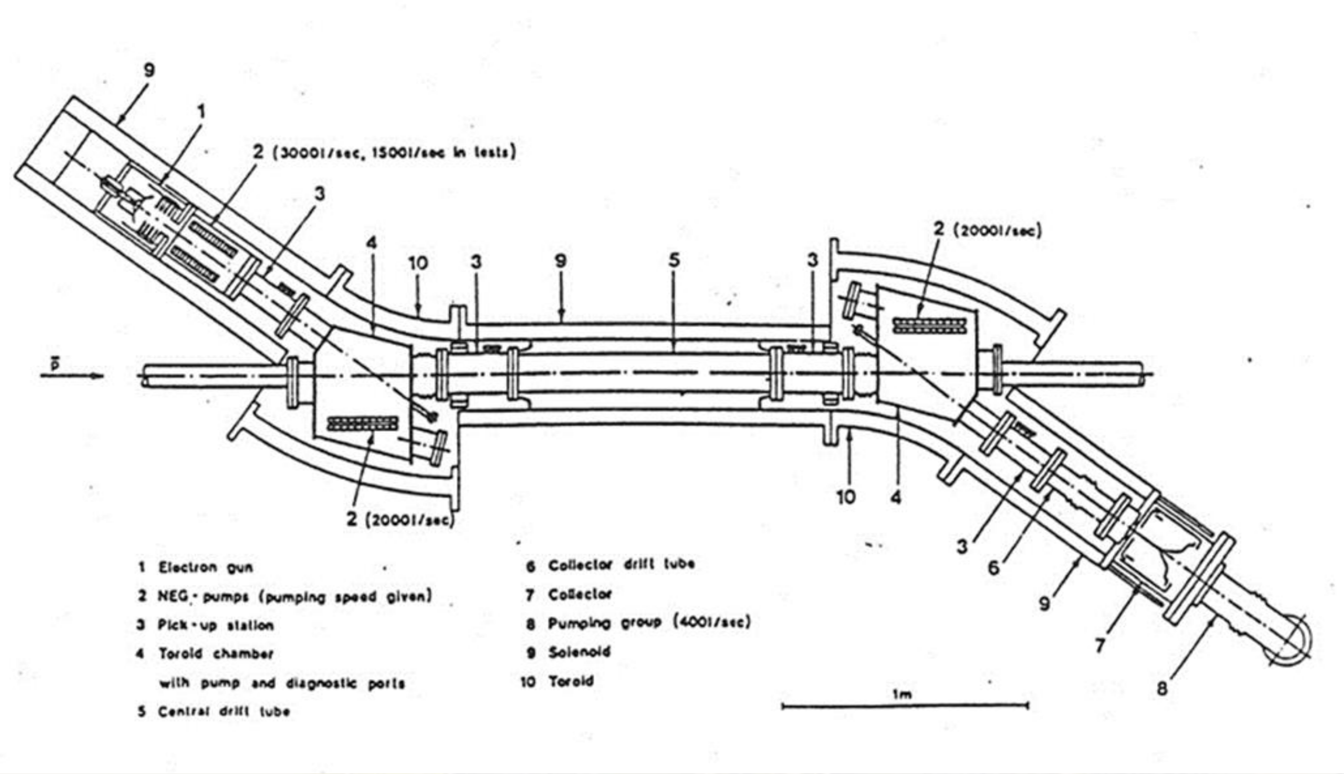


- Cylindrical water-cooled anode for absorbing the electrons
- Iris shaped shunt at entrance to reduce the magnetic field
- Repeller electrode to decelerate the electrons (set a few kV above V_{cath})
- The spike refelects electrons towards the collector
- Mesh electrode repels the low energy secondaries

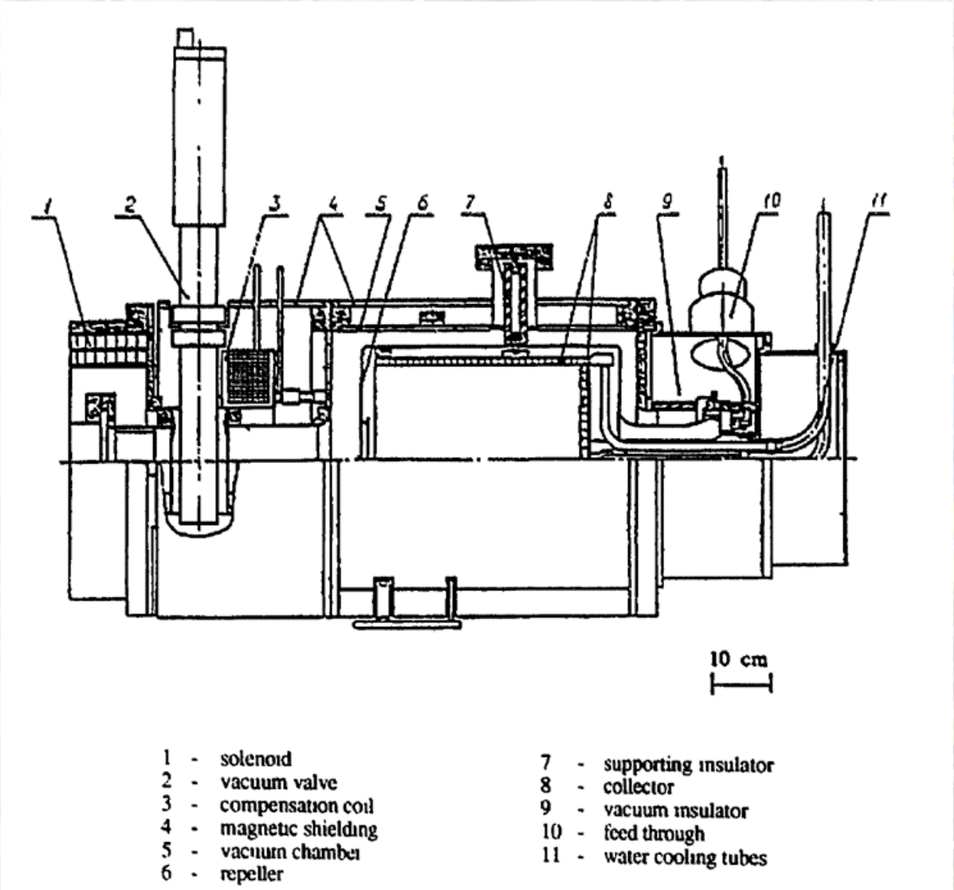
Low Energy Antiproton Ring (1982-1997)

The required static vacuum level of less than 10^{-11} torr meant that the cooler needed a major upgrade of its vacuum system.

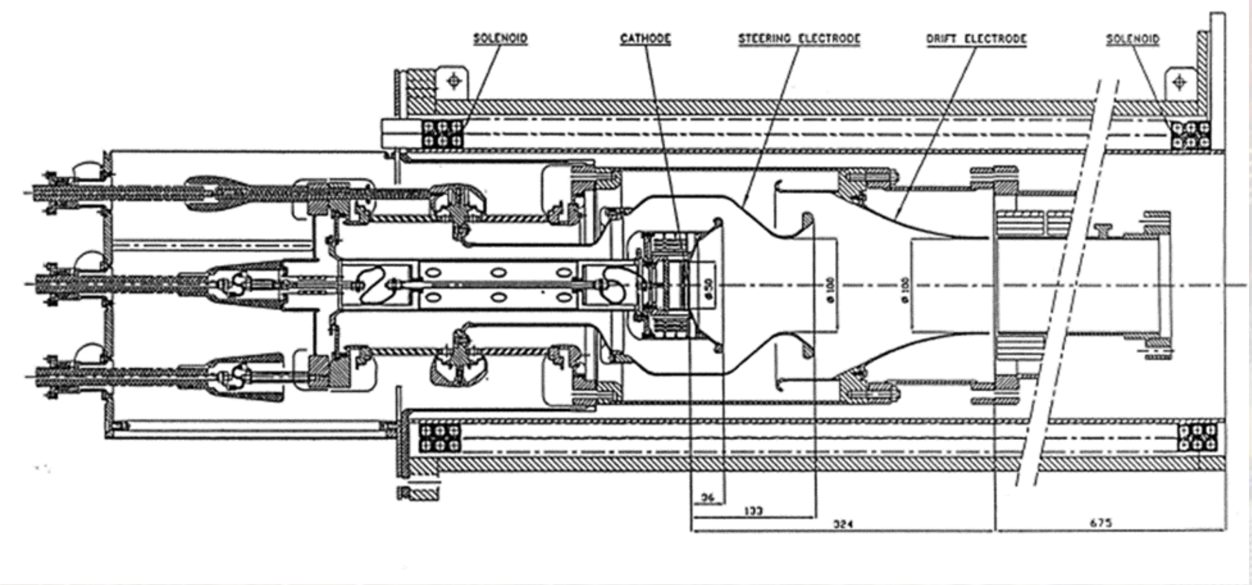
- best obtainable vacuum was in the order of 10^{-9} torr on ICE
- the complete vacuum envelope was re-designed and built using high quality AISI 316LN stainless steel
- designed to be bakeable at 300˚C in situ (permanently installed jackets)
- use of NEG (non evaporable getter) strips



- New electron collector for reliable operation with full perveance gun (1991)
- New electron gun allowing the online control of the electron beam intensity (1992)
- Electron beam energy feedback system



Adiabatic optics
Fixed magnetic field of 600 G (easier for operation)
5 cm Cathode
«grid» electrode to give the desired current
Anode (drift) at ground potential



- First electron cooler to be used in operation

- Extensive studies with anti(protons), H^-, oxygen and lead ions
  - First cooling/stacking of ions
  - Instabilities – development of a damper
  - Influence of lattice parameters on beam cooling
  - Electron beam neutralisation
  - Recombination of ions

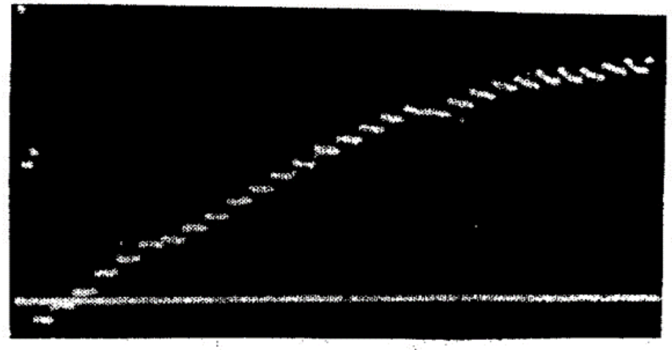
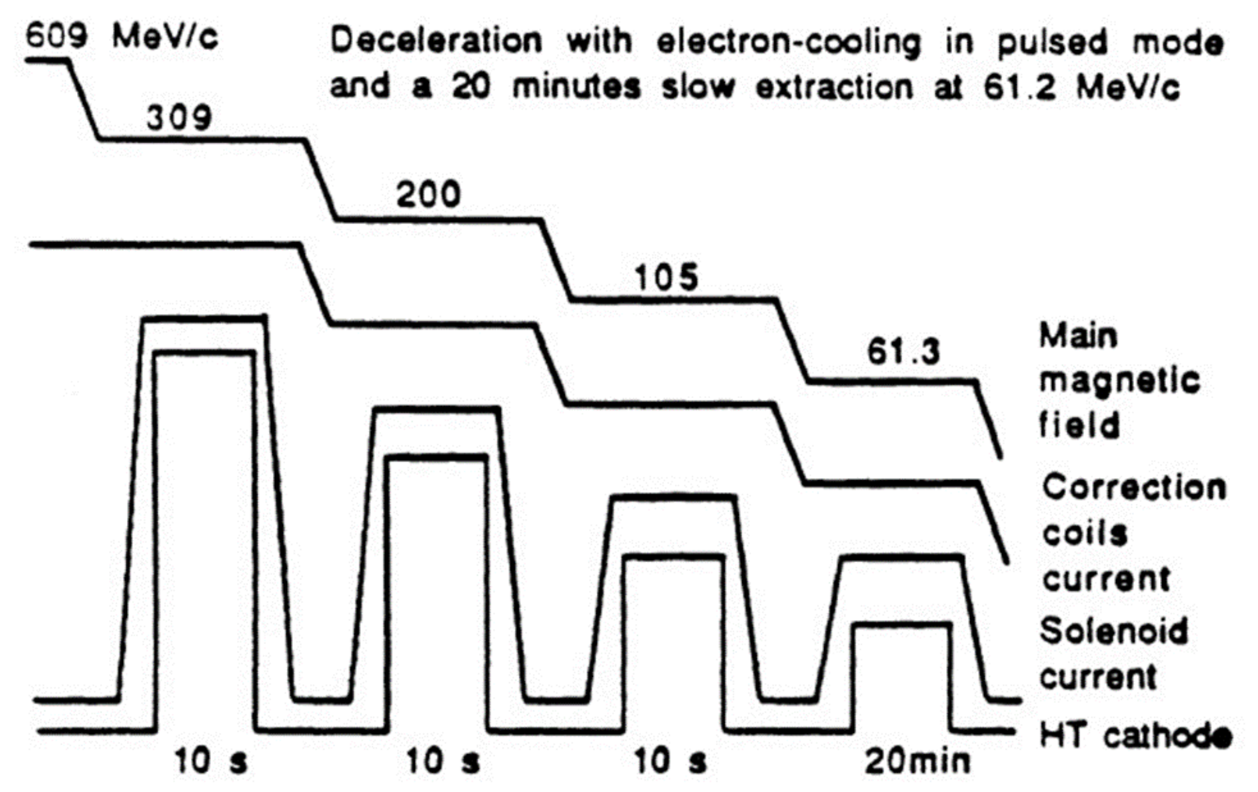
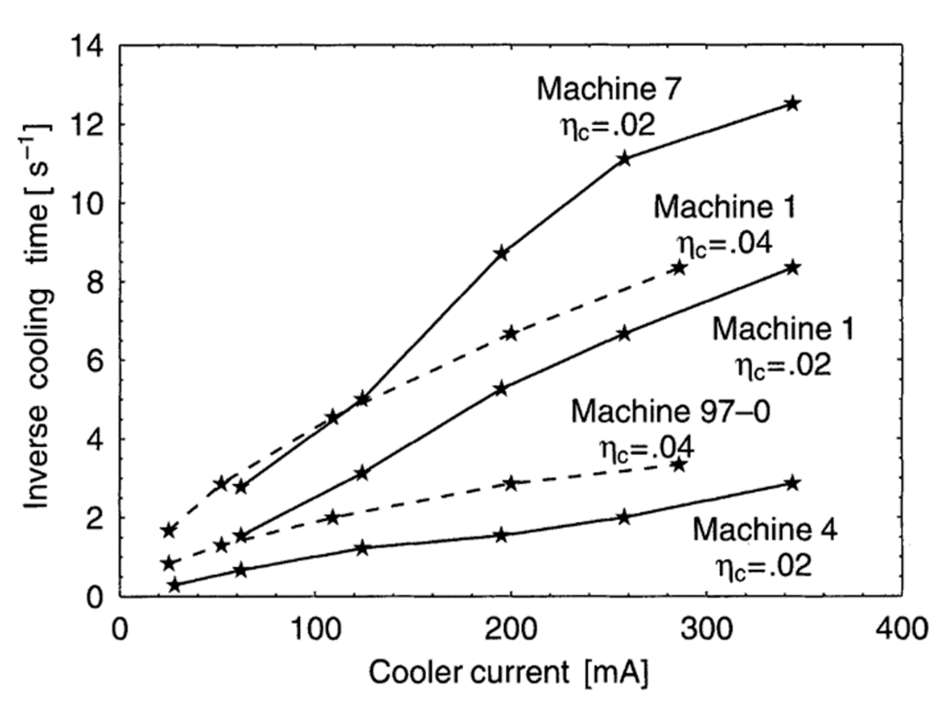
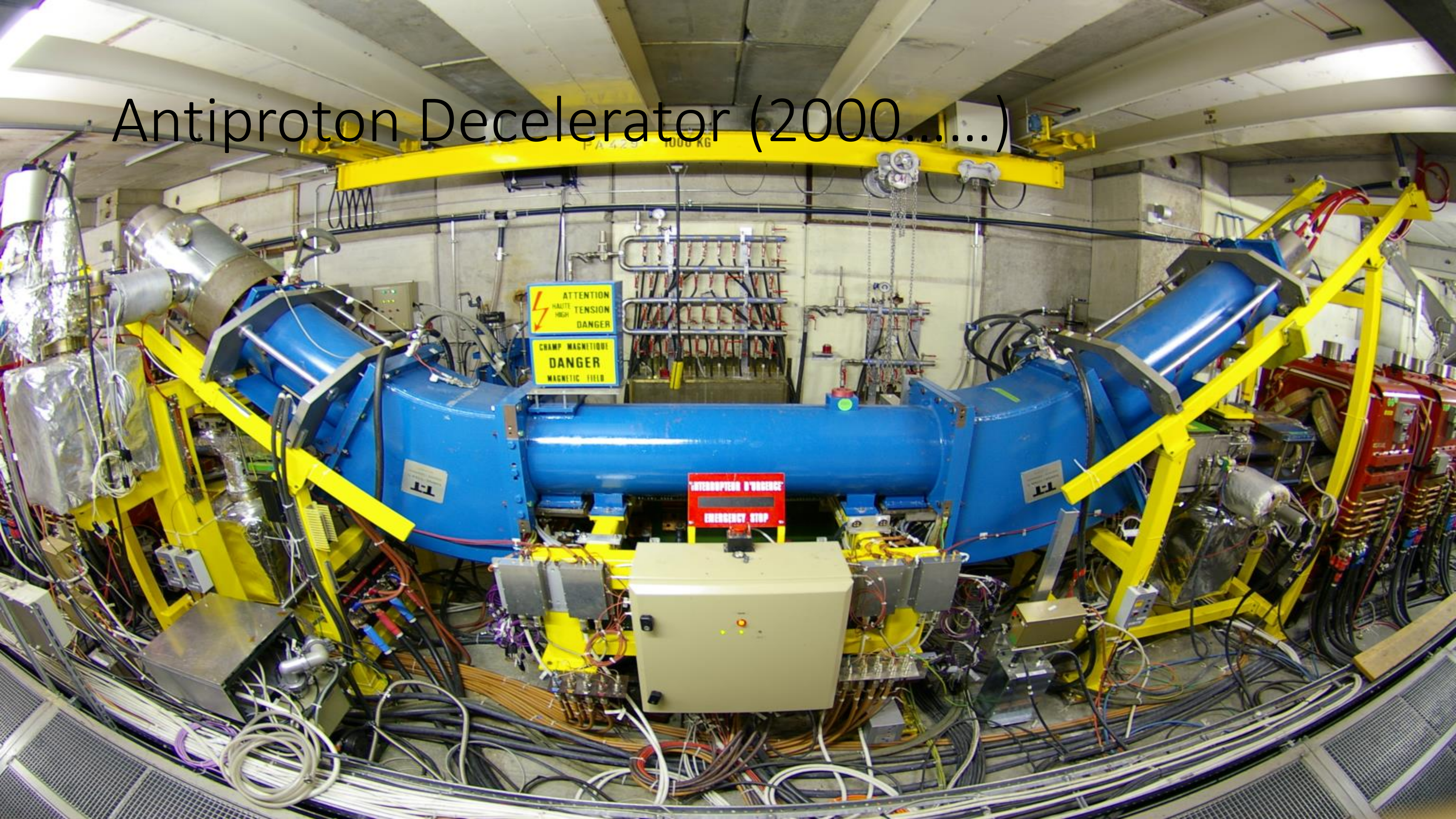


Figure 1: Current transformer reading during injection sequence. The repetition rate has been set to 7.2 seconds. Saturation occurs when the losses are of the same magnitude as the injected batch.

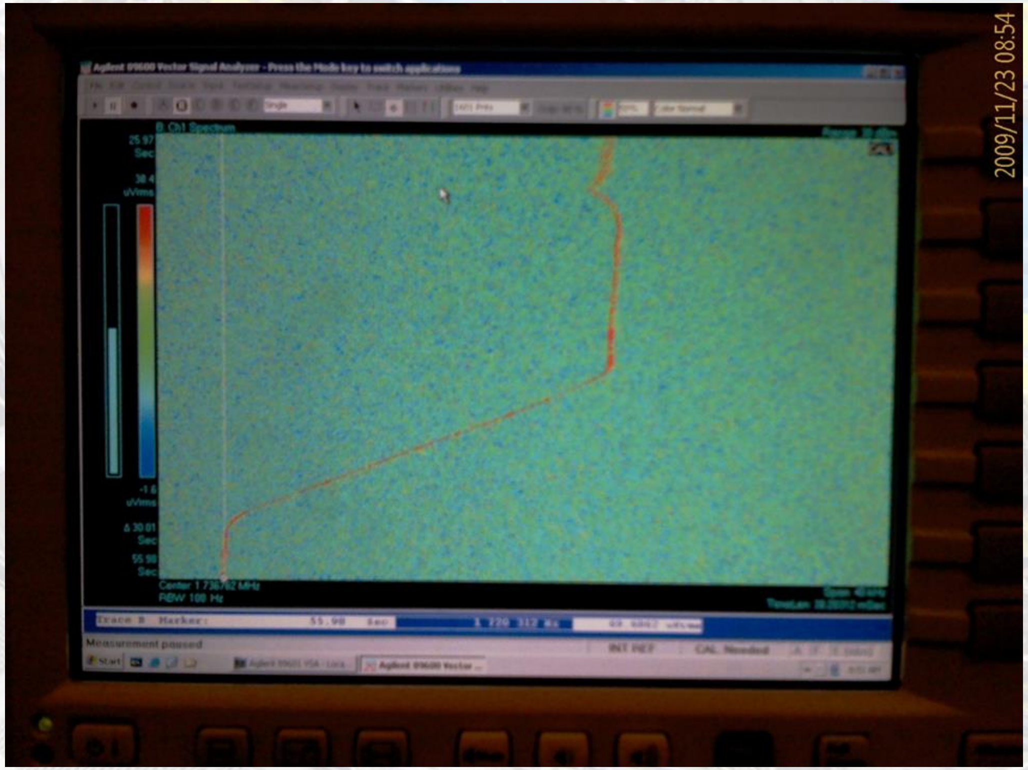


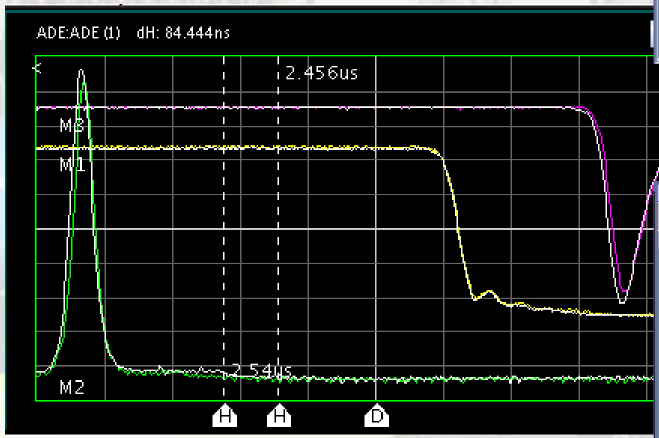


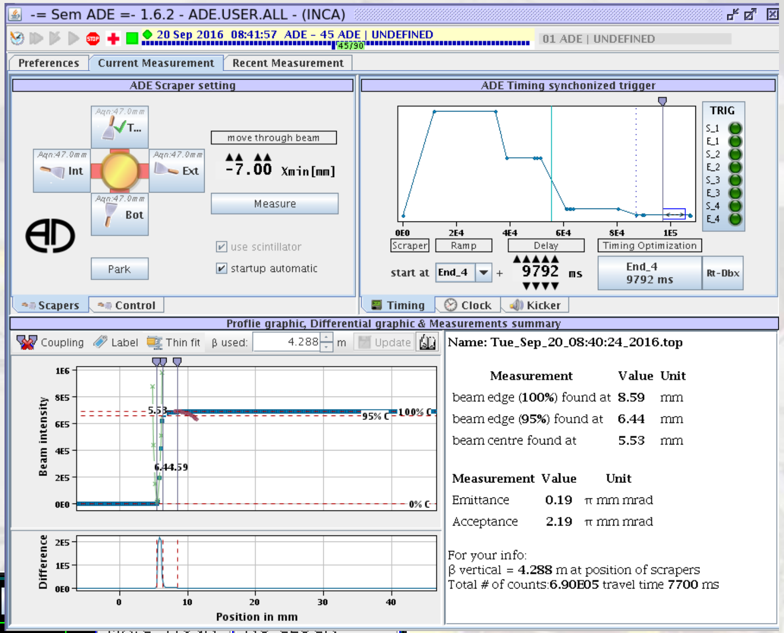
Antiproton Decelerator (2000……)

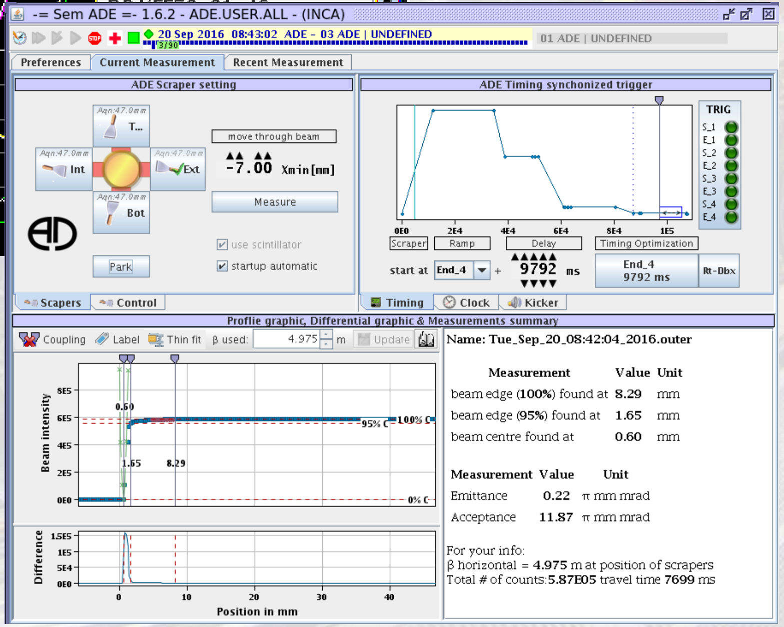


- Change from S to U (AD beam height lower than at LEAR)
- New supporting structure (alignment problems, magnetic material)
- Has performed flawlessly until last year
    - Cooling at 300 MeV/c (26.5 keV, 2.5A) and 100 MeV/c (3.2 keV, 100mA)
    - Ecool deceleration (100 MeV/c to 95.3 MeV/c)
    - Implementation of a fast switch for the electron beam control









SPARES			
Electron gun		✓	Spare unit and cathodes available.
Collector		✓ ✗	Spare unit has been repaired. New collector construction.
Magnets:	gun sol	✗	
	toroid	✗	
	drift sol	✓	Used on test stand. Power connections to be modified.
	col sol	✗	
Vacuum system		✓ ✗	Complicated toroid chamber
Power supplies		✓	Responsibility of TE/EPC.

Principle cause of concern is the lack of spare magnets.
More than one year stop in case of magnet problem (e.g. short circuit)
Any vacuum intervention takes a long time because accessibility and bake-out.