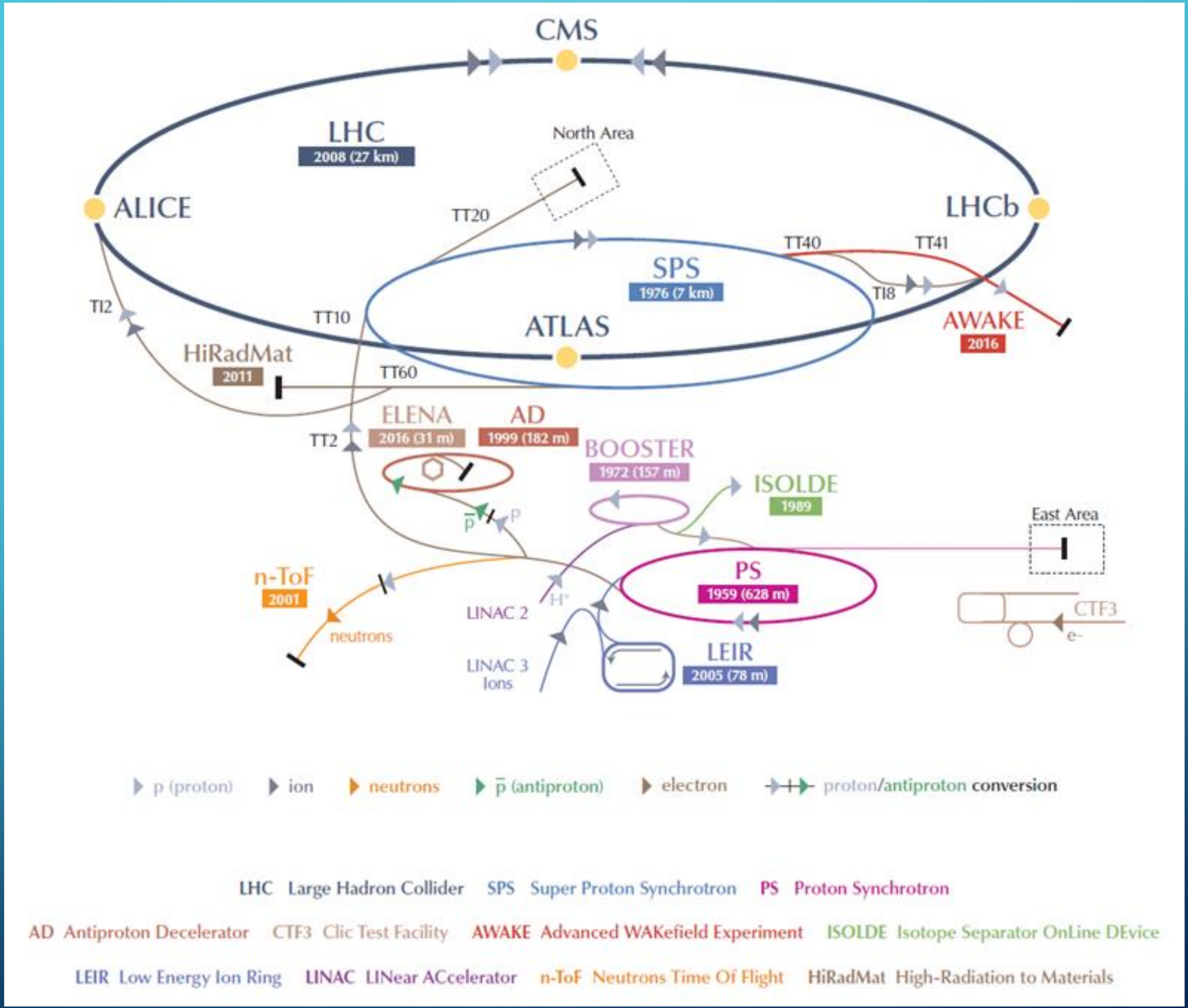
COLD ELECTRON SOURCE FOR PARTICLE BEAM COOLING

GERARD TRANQUILLE, BE-BI-EA, CERN, SWITZERLAND

The twenty two Member States of CERN

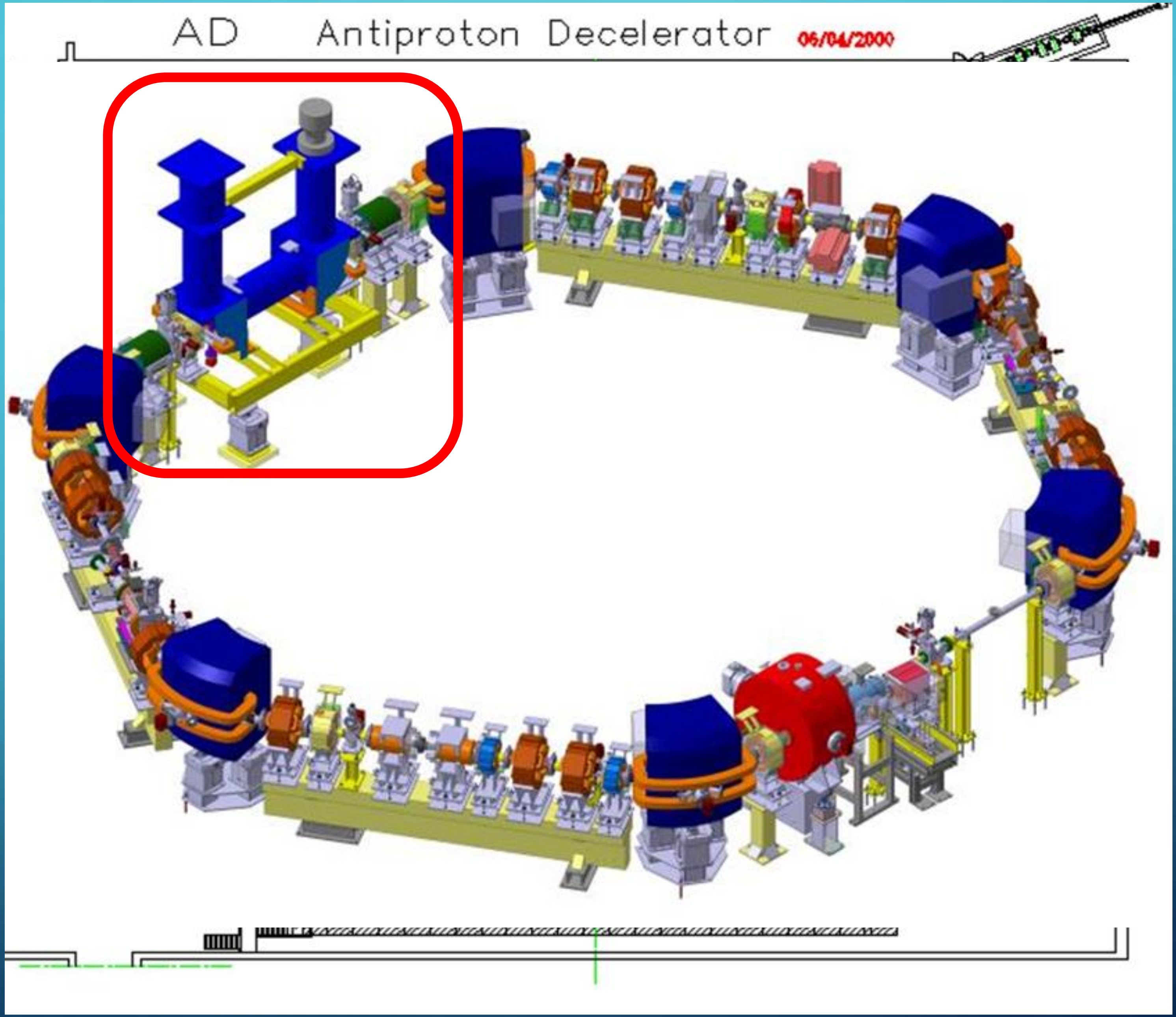
Member States (date of accession)

- Austria (1959)
- Belgium (1953)
- Bulgaria (1999)
- Czech Republic (1993)
- Denmark (1953)
- Finland (1991)
- France (1953)
- Germany (1953)
- Greece (1953)
- Hungary (1992)
- Israel (2014)
- Italy (1953)
- Netherlands (1953)
- Norway (1953)
- Poland (1991)
- Portugal (1986)
- Romania (2016)
- Slovakia (1993)
- Spain (1961-1968, 1983-)
- Sweden (1953)
- Switzerland (1953)
- United Kingdom (1953)


CMS
LHC
2008 (27 km)
North Area
ALICE
TT20
LHCb
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
BOOSTER
1972 (157 m)
TT2
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
CTF3
e–
neutrons
LINAC 2
LINAC 3
Ions
LEIR
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
electron
proton/antiproton conversion
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron
AD Antiproton Decelerator
CTF3 Clic Test Facility
AWAKE Advanced WAKefield Experiment
ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring
LINAC LINear ACcelerator
n-ToF Neutrons Time Of Flight
HiRadMat High-Radiation to Materials

THE ELENA PROJECT

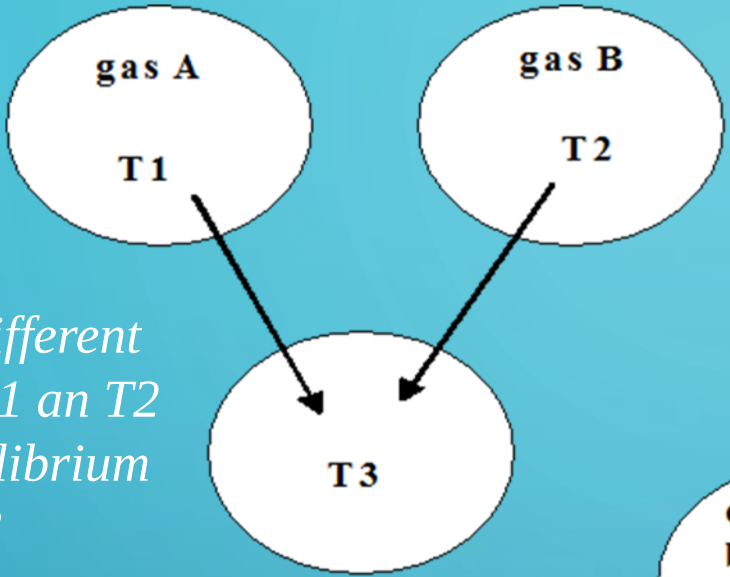
ELENA (Extra Low Energy Antiprotons) is a 30 m circumference ring for cooling and further deceleration of 5.3 MeV antiprotons delivered by the CERN Antiproton Decelerator (AD) down to 100 keV, where the physics programme consists of trapping antiprotons to create anti-hydrogen atoms after recombination with positrons. The ultimate physics goal is to perform spectroscopy on these antiatoms at rest and to investigate the effect of the gravitational force on matter and antimatter. With the current set-up without ELENA, antiprotons are sent directly from the AD with an energy of 5.3 MeV to the experiments, which decelerate them using degrader foils or a Radio Frequency Quadrupole Decelerator (RFQD) before capturing them in ion traps. Most (>95 %) of the antiprotons produced are lost due to the deceleration process. By deceleration using a ring equipped with beam cooling, an important increase in phase-space density and a high experiment injection efficiency can be obtained, resulting in an increased number of trapped antiprotons. With the construction of the ELENA ring, the AD experiments expect improvements of up to two orders of magnitude. In addition, ELENA will be able to deliver beams almost simultaneously to up to four experiments resulting in an essential gain in total beam time for each experiment. This also opens up the possibility of accommodating an extra experimental zone.


AD Antiproton Decelerator
06/04/2000

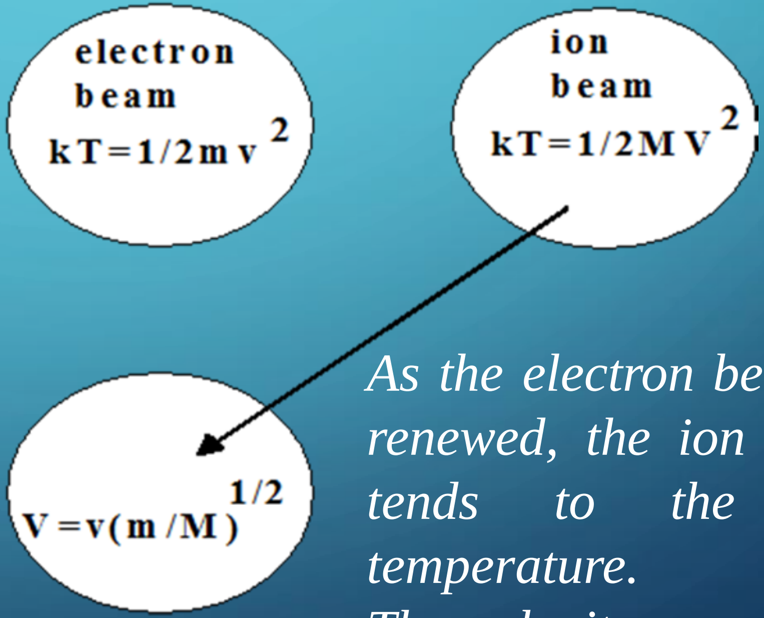
WHAT IS ELECTRON COOLING ?

- Means to increase the phase space density of a stored ion beam.
- Mono-energetic cold electron beam is merged with ion beam which is cooled through Coulomb interaction.
- Electron beam is renewed and the velocity spread of the ion beam is reduced in all three planes.

Analogy with the mixing of gases



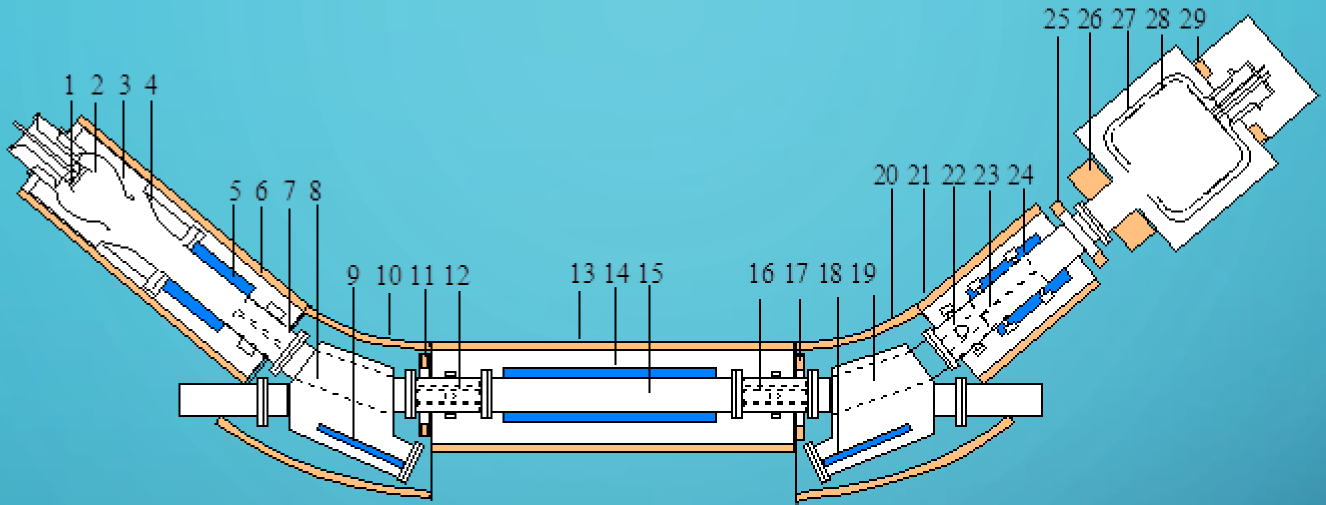
Two gases of different temperatures T1 an T2 tend to an equilibrium temperature T3



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 SETUP



- **Electron gun: thermocathode, Pierce shield, accelerating anodes**
  - ***final current given by Child's Law:*** **I = $\rho V^{3/2}$**
  - ***the parameter ρ is the perveance and is given by $7.3\mu P\ (r/d)^2$***
- **Interaction section**
- **Collector**
- **The whole system is immersed in a longitudinal field**

THE NEED FOR ELECTRON COOLING

- Electron cooling essential in ELENA to counter emittance blow-up caused by the deceleration process.
- To prepare bunches with sufficiently low emittance for extraction to the experiments via the long electrostatic extraction lines.
- Cooling needed at 2 momenta: 35 MeV/c and 13.7 MeV/c.
- Expected emittances prior to cooling: @ 35 Mev/c:

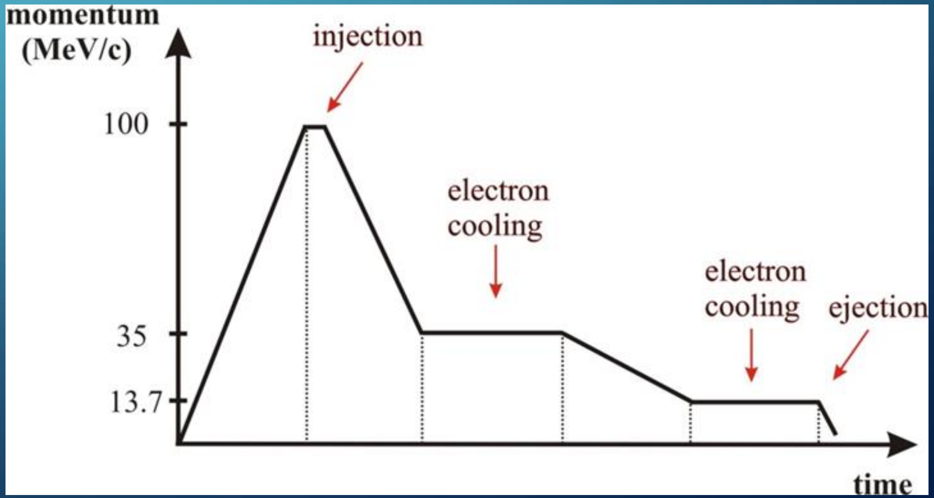
  $\varepsilon \sim 50\ \pi$ mm mrad

  $(\Delta p/p) = \pm 2 \times 10^{-3}$

- Needed emittances at extraction:

  $\varepsilon \leq\ \sim 3\ \pi$ mm mrad

  $(\Delta p/p) \leq \pm 1 \times 10^{-3}$

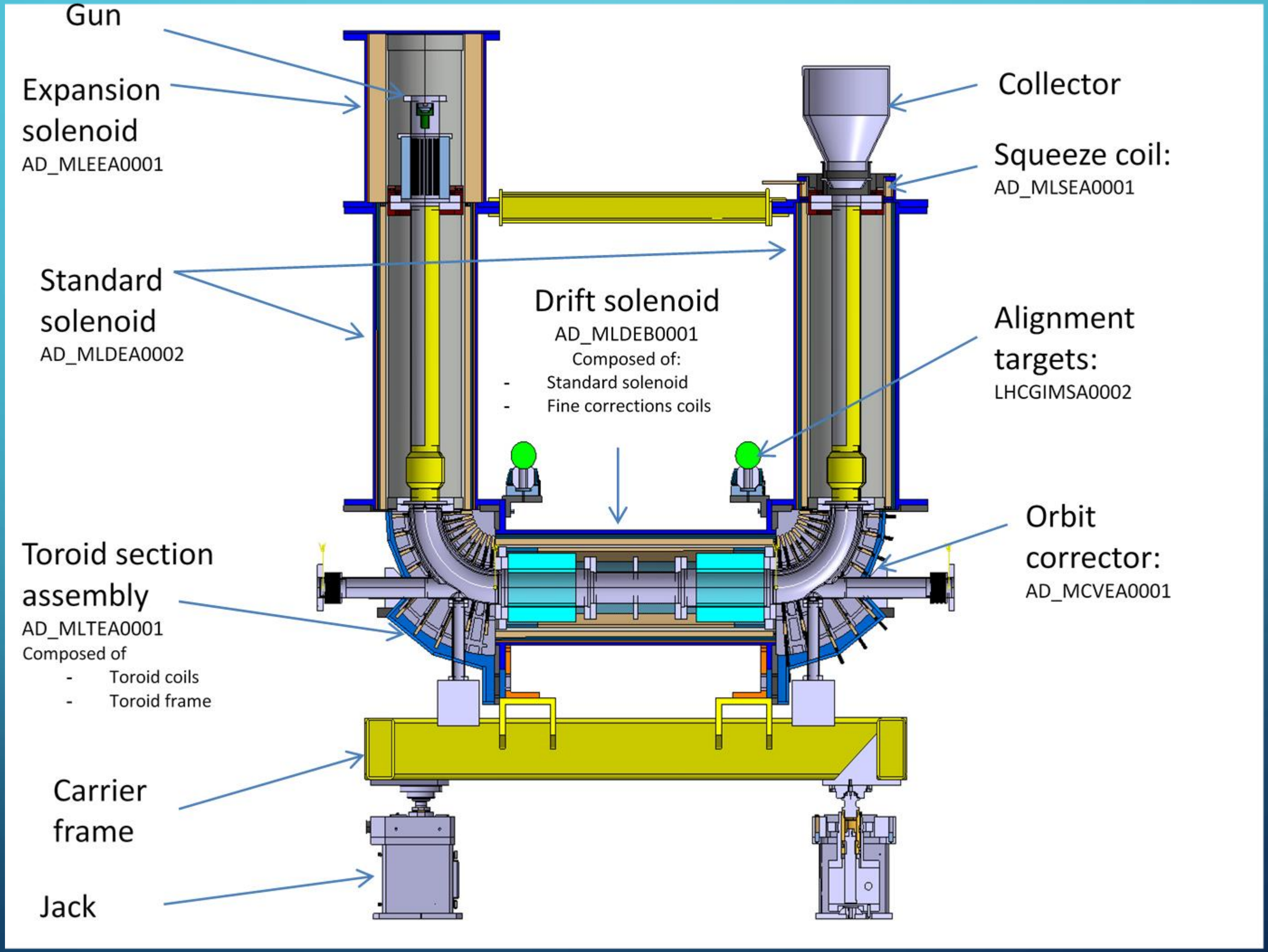


ELECTRON COOLER PARAMETERS

Momentum (MeV/c)	35	13.7
β	0.037	0.015
Electron beam energy (eV)	355	55
Electron current (mA)	5	2
Electron beam density (m^{-3})	1.38×10^{12}	1.41×10^{12}
B_{gun} (G)	1000	
B_{drift} (G)	100	
Expansion factor	10	
Cathode radius (mm)	8	
Electron beam radius (mm)	25	
Twiss parameters (m)	β_h=2.103, β_v=2.186, D=1.498	
Flange-to-flange length (mm)	2330	
Drift solenoid length (mm)	1000	

ELECTRON COOLER DESIGN

Electron cooler assembly: **AD_LNTML0001**

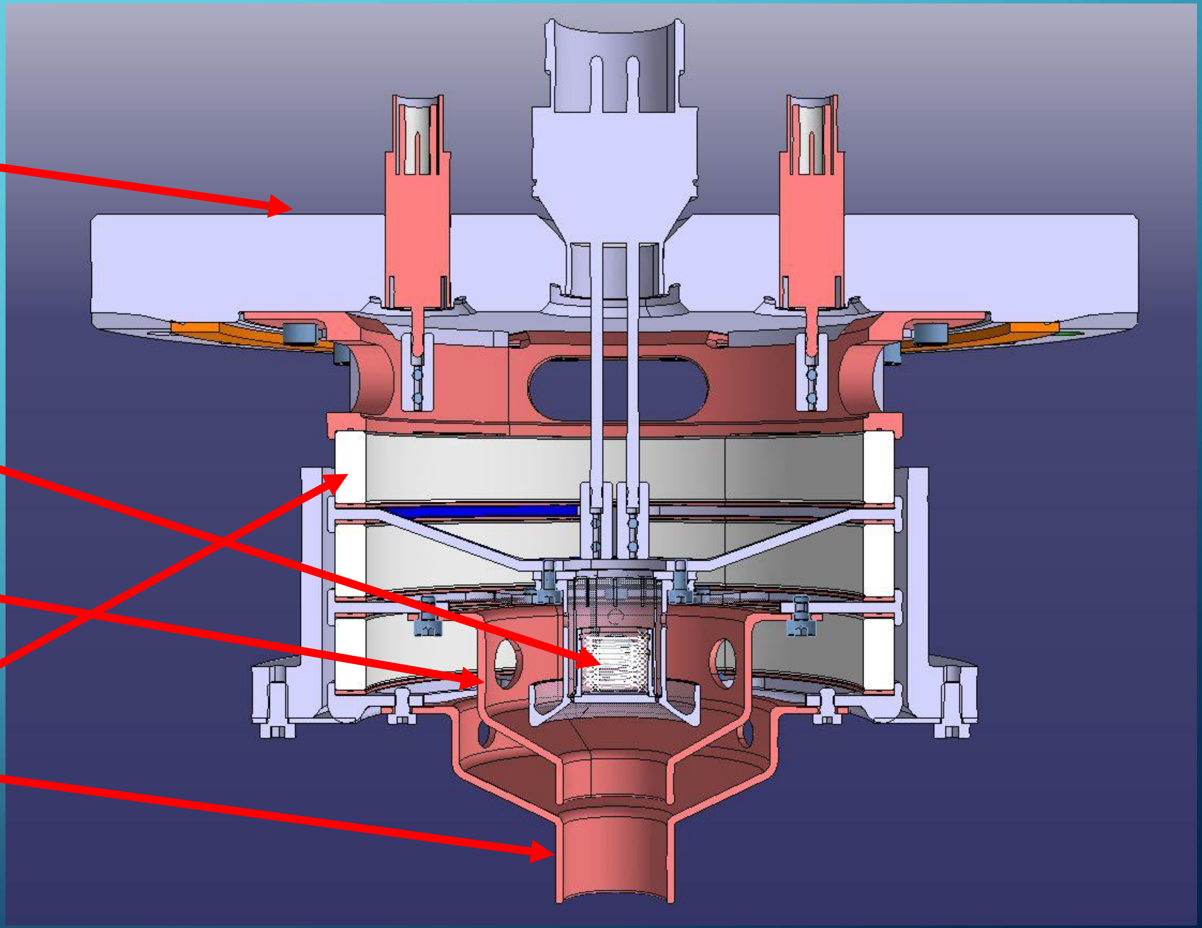


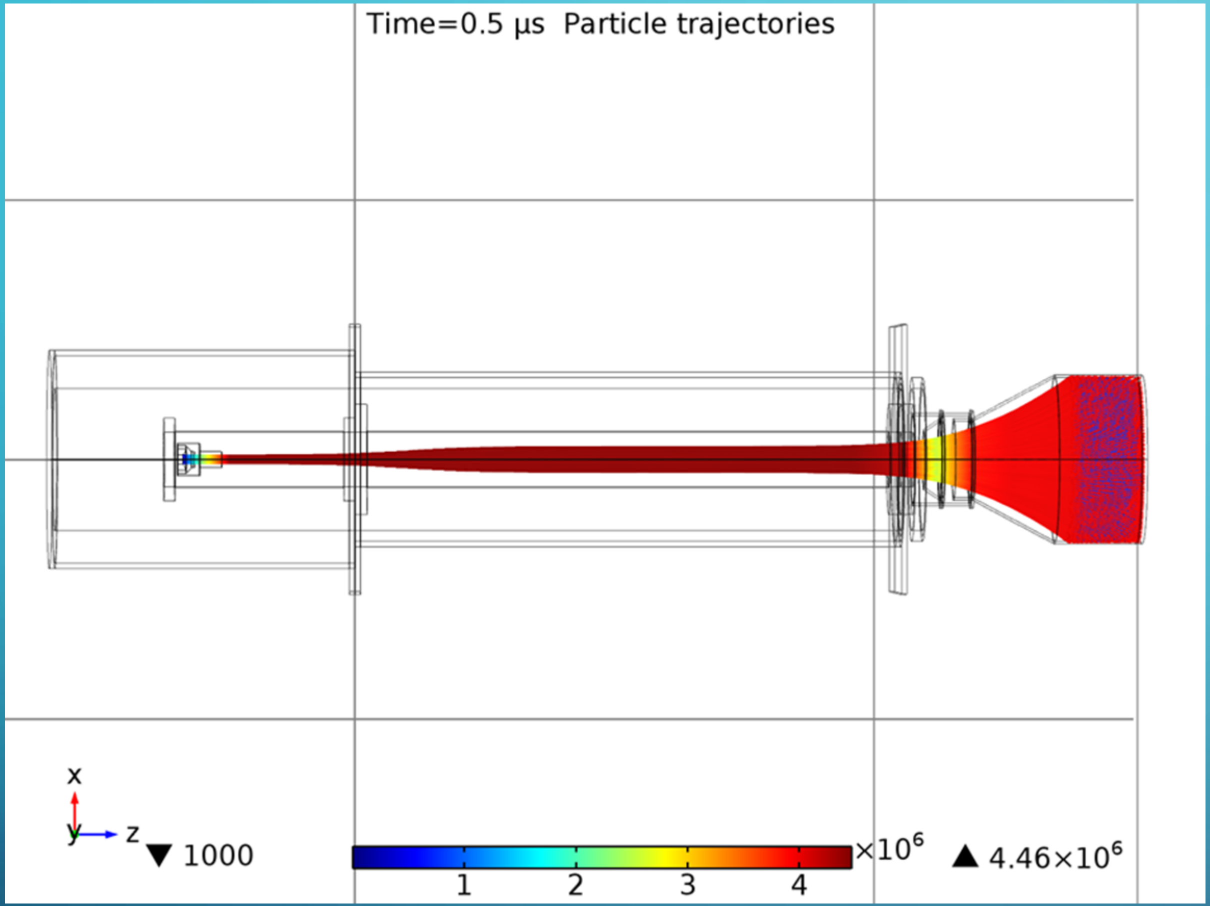
THE ELECTRON GUN

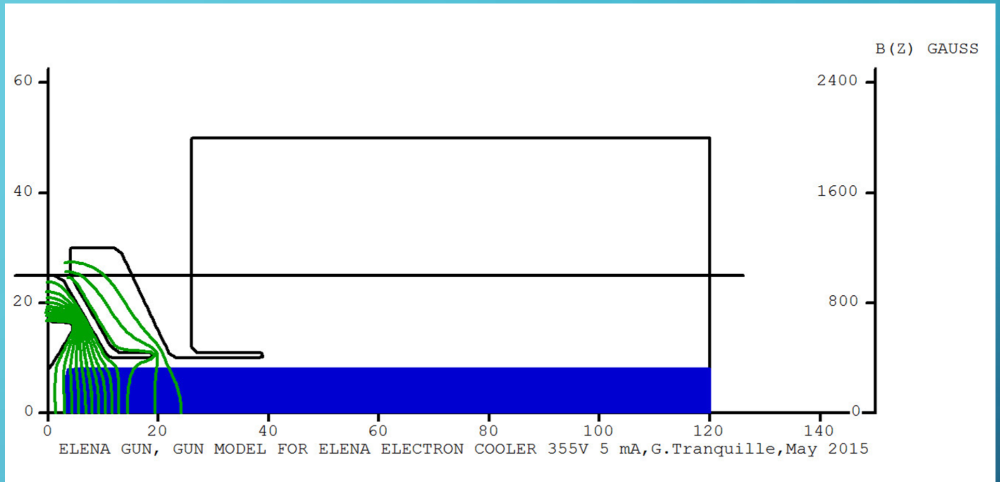
- Gun Flange

(DN100CF + BNC + Fil. connector)

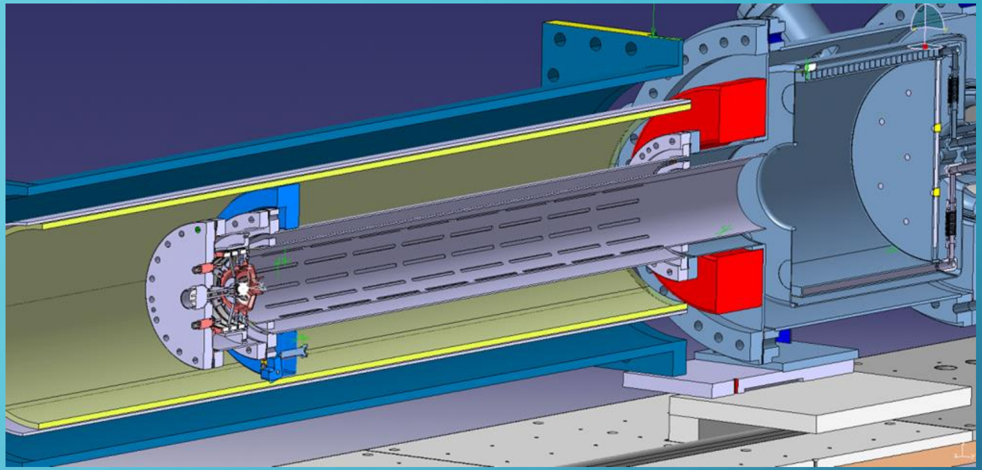
- Cathode Assembly
- Grid Electrode
- Anode
- Ceramic Insulator





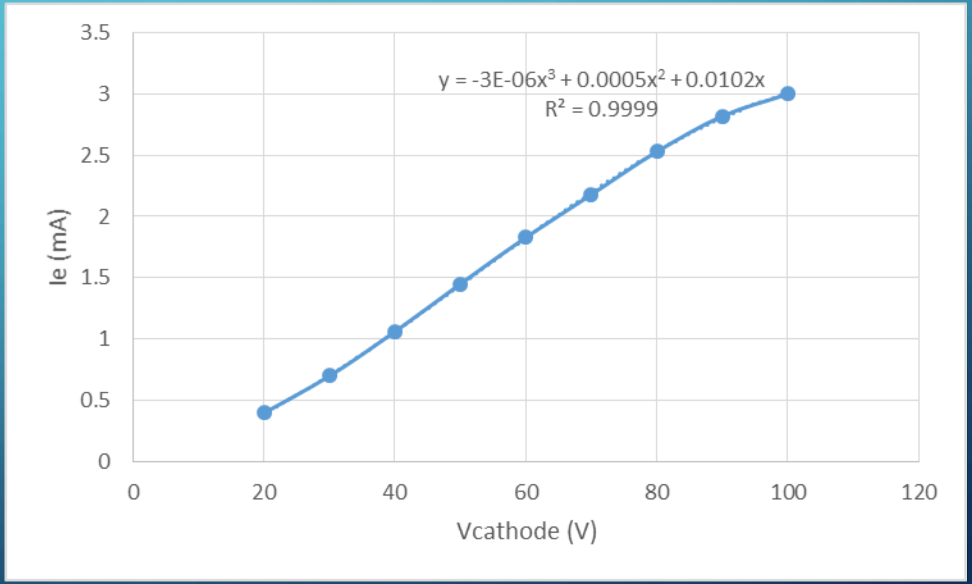


Gun and collector design optimization performed with EGUN and COMSOL Multiphysics



New gun tested on linear test stand (solenoid field of 100 G)

Vcath (V)	Ie (mA)	Perveance
20	0.395	4.416234256
30	0.698	4.247892724
40	1.06	4.1900179
50	1.45	4.101219331
60	1.83	3.937533069
70	2.18	3.722283383
80	2.53	3.535782489
90	2.82	3.302823334
100	3	3



Measured electron current and perveance

WHY A “COLD” CATHODE?

Source types:

- Thermionic
- Photoemission
- Schottky/cold field emission

Thermionic emission requires heat to provide the energy to remove an electron from a material

Photocathodes require a pulsed laser and have short lifetimes

Field emission only requires an electric field (& a little heat for Schottky)

Most coolers use thermionic cathodes :

- Cathode heated to >1200°C
- Complicated connections
- Large energy spread in the electron beam (up to kT)
  - adiabatic expansion used to reduce the transverse temperature
  - longitudinal velocity spread reduced due to acceleration

Photocathodes

Complicated setup (laser, photocathode handling)

- Energy spread about 10 meV, can be reduced with expansion and acceleration
- Short lifetime

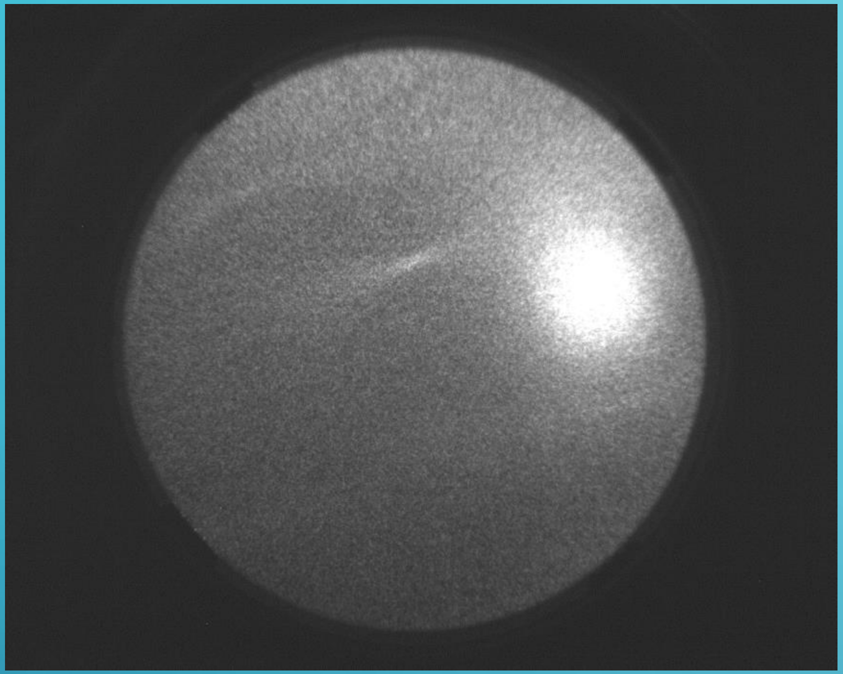
Cold cathodes

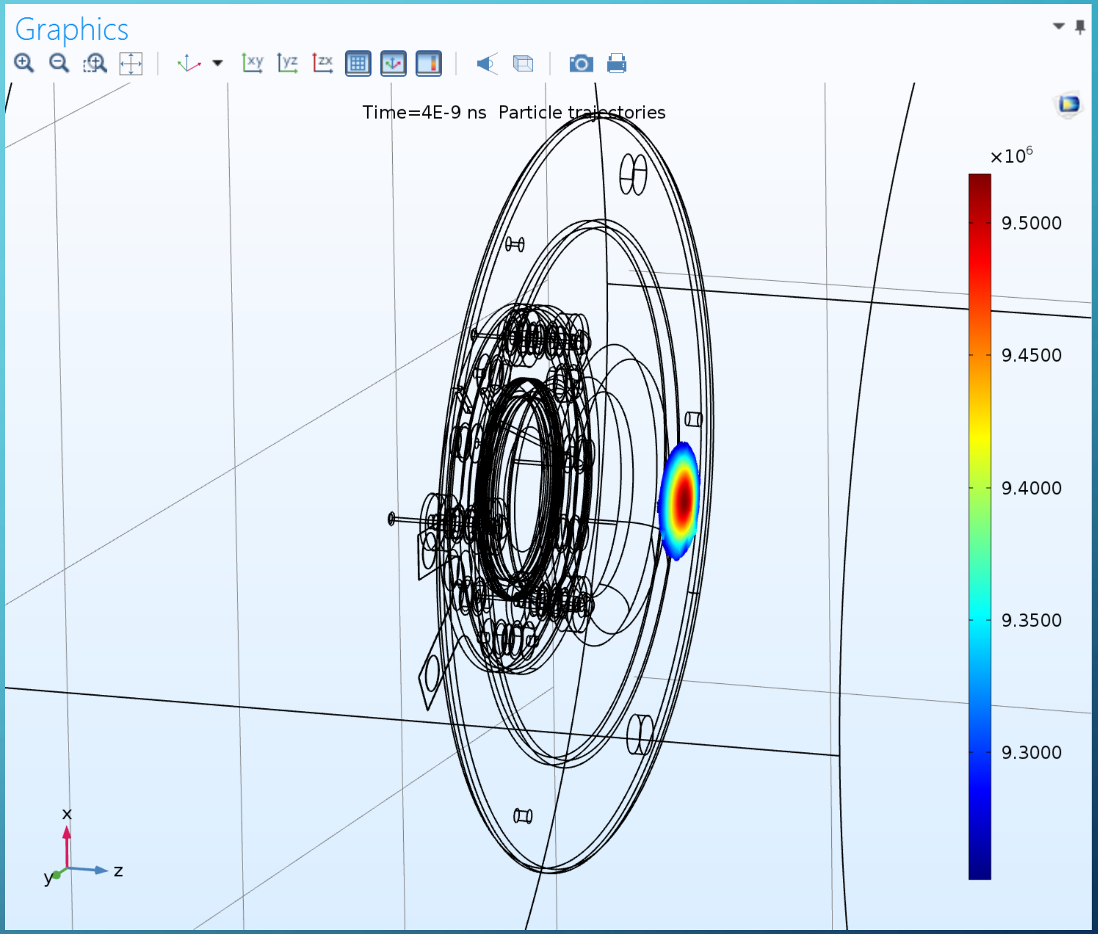
- Simple to operate
- Long lifetime
- High brightness source

Look into all possible technologies to produce an electron gun for the ELENA electron cooler that does not require a heated source

Photocathode technologies
Investigate FE sources
Electron generator array (or MCP)

Simulation of beam generation and transport
Measurement of beam characteristics on the ecool test stand
Cooling test on ELENA





First electron beam produced with an EGA