Experience with RF gun in CTF II, Extrapolations for CTF 3

- **RF guns build for CTF 1+ CTF II**
- **Emittance measurements**
- **Beam loading issues CTF II vs. CTF3**
- **Vacuum effects observed in CTF II**
- **Photocathode performance**
- **Dark current**
- **Frequency tuning**
- **Possible strategy for CTF3 RF gun design**

Hans-H. Braun, CTF3 collaboration meeting, 28.9.2003,
with several transparencies stolen from Guy Suberlucq

CTF Gun type 3

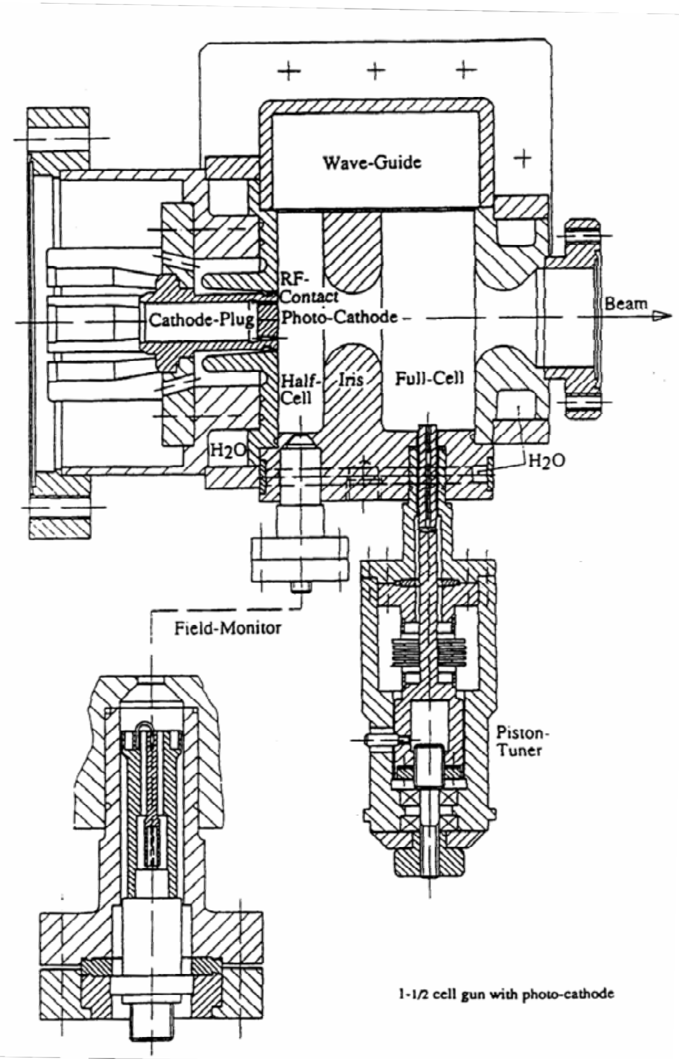
cell geometry copied from BNL design. Used for CTF 1 and CTF II probe beam during many years.

Beam energy 4.5 MeV for 100 MV/m cathode field and 6MW input power..

Operated with up to 120 MV/m cathode field.

Achieved pulse charges of up to 450 nC in 48 bunches

and single bunch charges of up to 35 nC



1-1/2 cell gun with photo-cathode

CTF II, Gun type 4

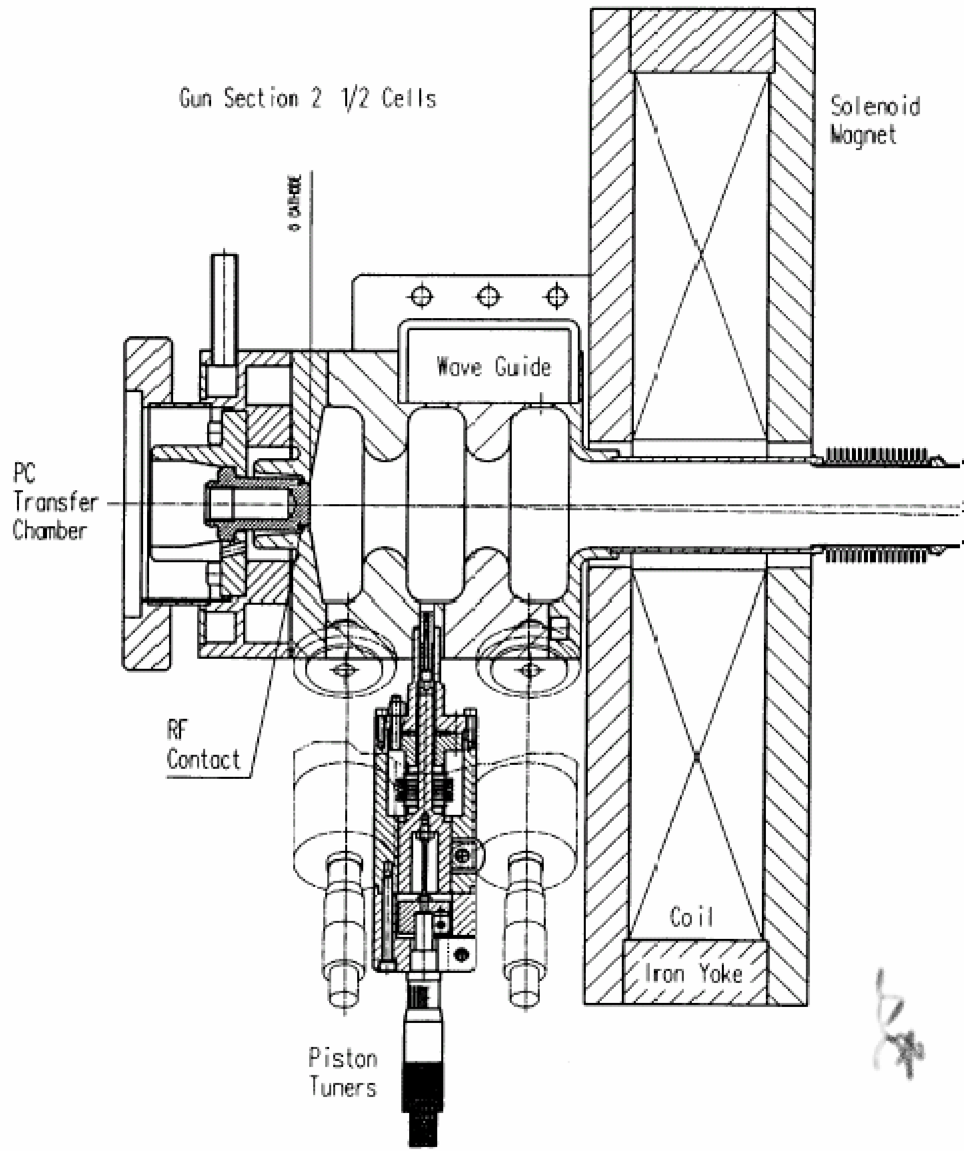
CERN design, optimised for high charge and high stored RF energy, to minimise transient beamloading.

Operated successfully in CTF II for 7 years.

Beam energy 7 MeV for 100 MV/m cathode field and 16 MW input power.

Operated with up to 110 MV/m cathode field.

Achieved pulse charges of up to 750 nC in 48 bunches and single bunch charges of up to 100 nC



<u>CTF II, Gun type 5</u>

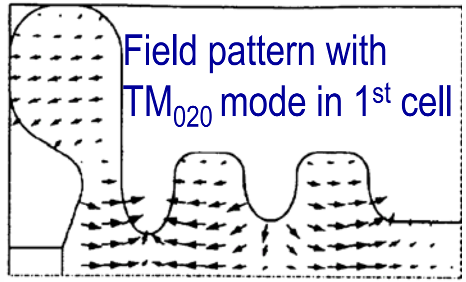
CERN design, optimised for high charge and very high stored RF energy, to minimise transient beamloading.

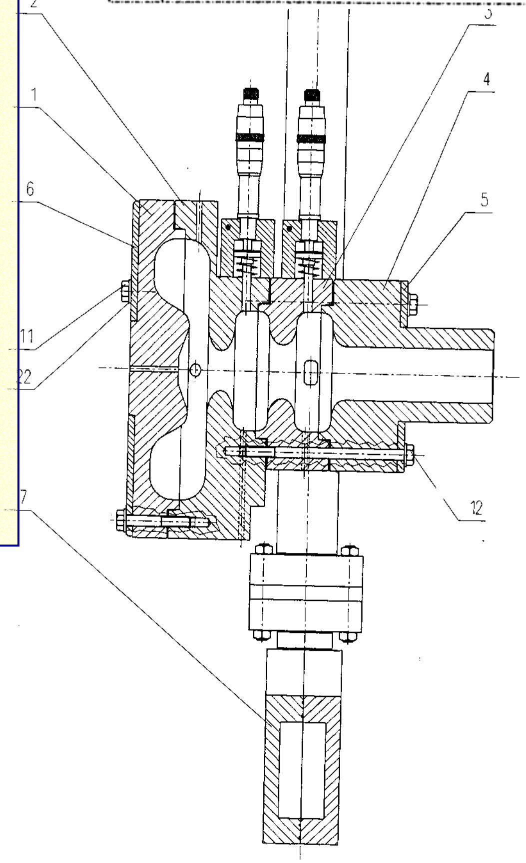
Tested successfully with high power but never with beam.

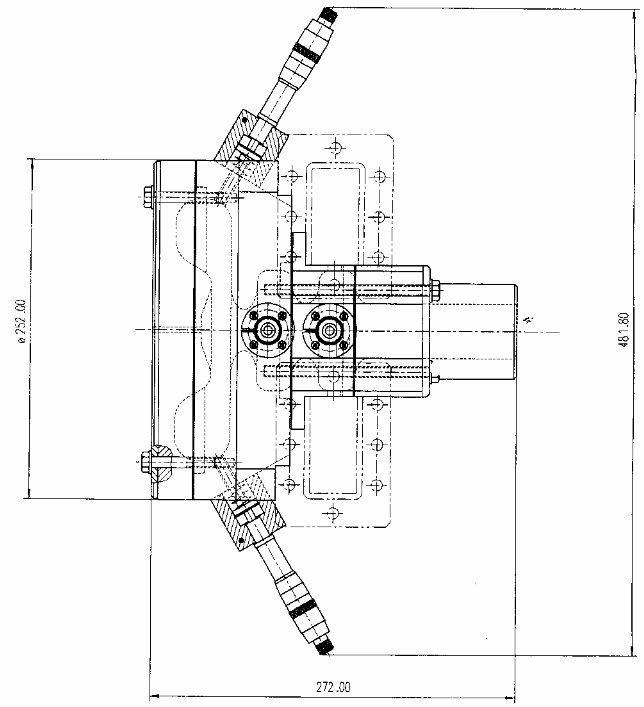
Many interesting features

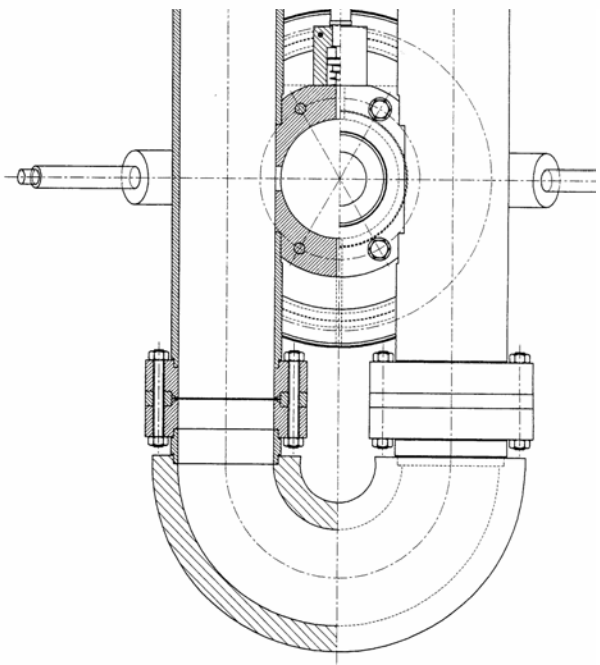
- clever symmetric coupler design
- TM_{020} cell for high stored energy
- elliptic iris shape for low electric surface field

see CLIC note 309/1996
by R. Bossart & M. Dehler







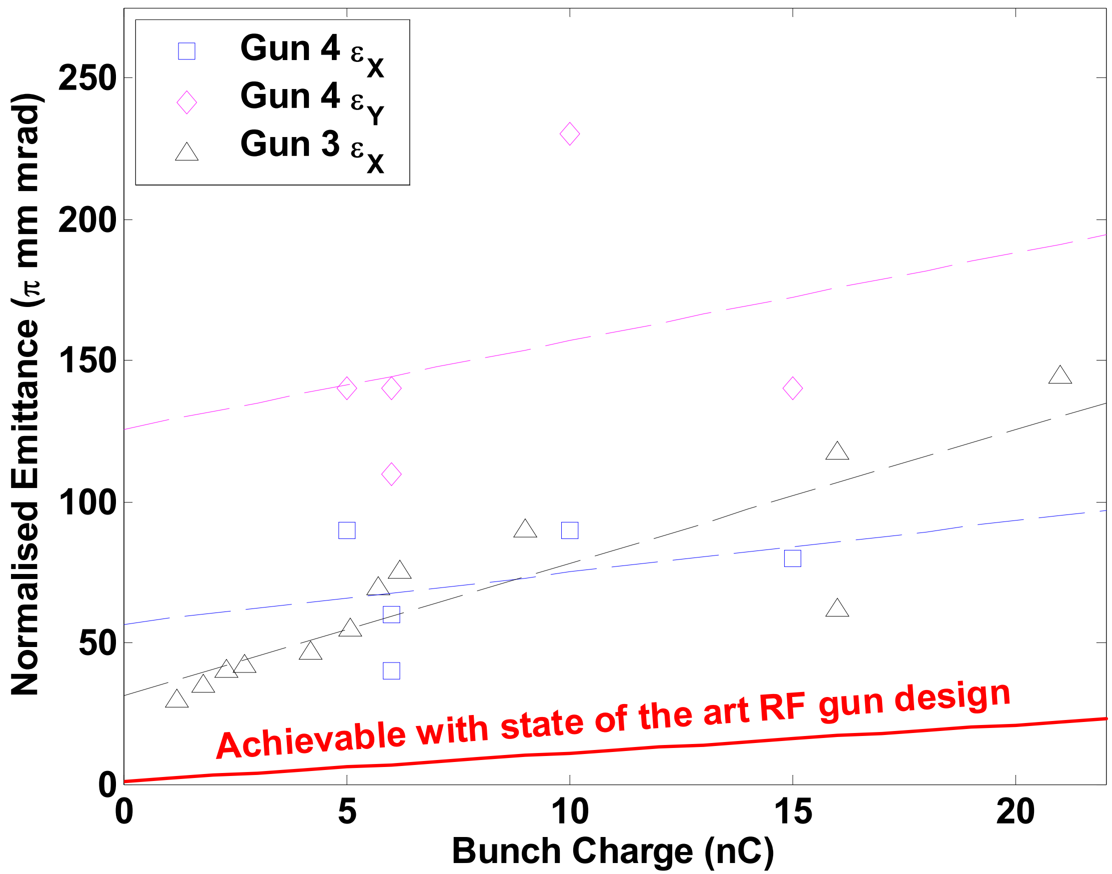


Transverse Emittance

In CTF II not much effort was put on transverse single bunch emittance, because chromatic effects dominated the bunch train emittance.
An RF photo-injector for CTF3 could (and should) do much better !

Proposed changes relative to CTF II / Gun 4

- **Symmetric coupler to reduce time dependent deflecting fields**
- **Magnetic field in RF gun with bucking coil**
- **Emittance compensation in combination with downstream accelerating structures**



Beam loading

Design of CTF II / Gun 4 & 5 based on concept of large W_{STORED} to minimise beam loading.
Beam loading is completely transient. RF coupling ≈1.

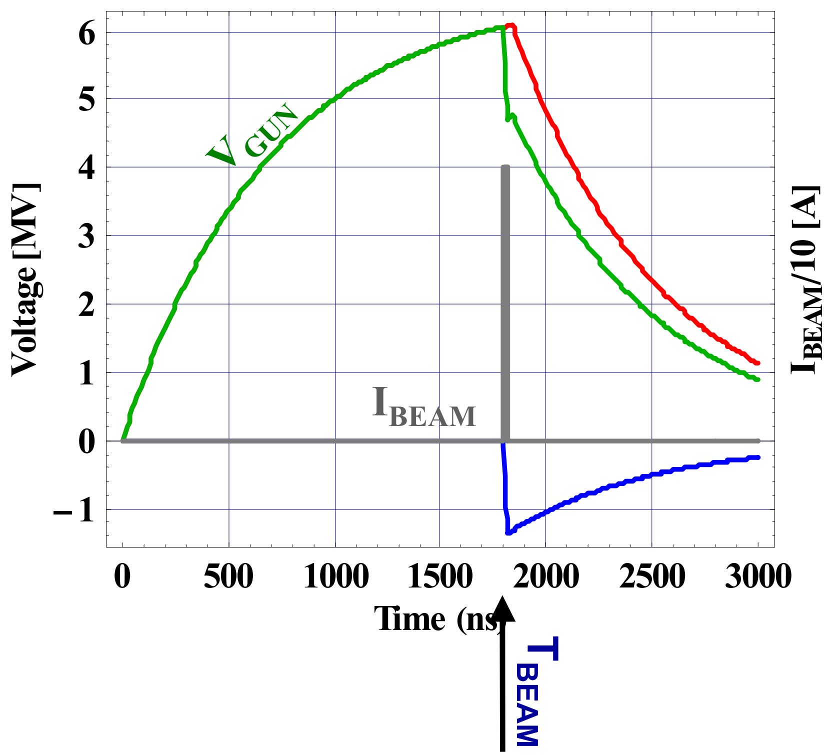
Example Gun 4

I_{BEAM} = 40 A	T_{BEAM} = 6 MeV	$T_{BUNCHTRAIN}$=16 ns	$E_{CATHODE}$=100 MV/m
P_{RF} = 16.5 MW	P_{BEAM} = 240 MW	$\Delta E/E_{BEAMLOADING}$ = 20 %	

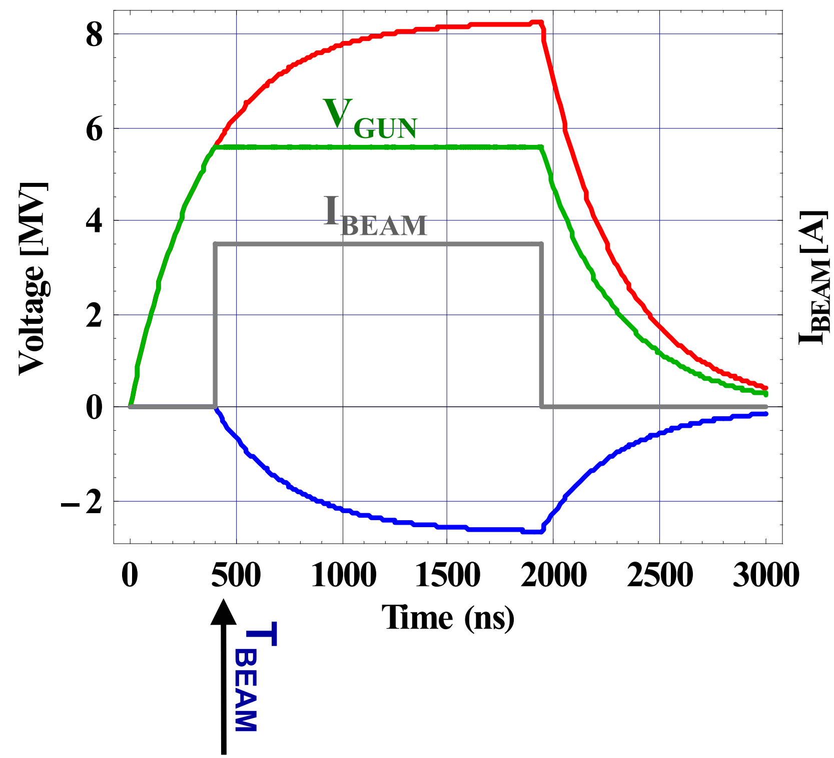
The lower beam current requirements of the CTF 3 injector allows operation in power equilibrium using parameters of Gun 4 geometry but RF coupling β=2.9 gives:

I_{BEAM} =3.5 A	T_{BEAM} = 5.6 MeV	$T_{BUNCHTRAIN}$ = 1540 ns	$E_{CATHODE}$=85 MV/m
P_{RF} = 30 MW	P_{BEAM} = 19.6 MW	$\Delta E/E_{BEAMLOADING}$ ≈ 0 %	

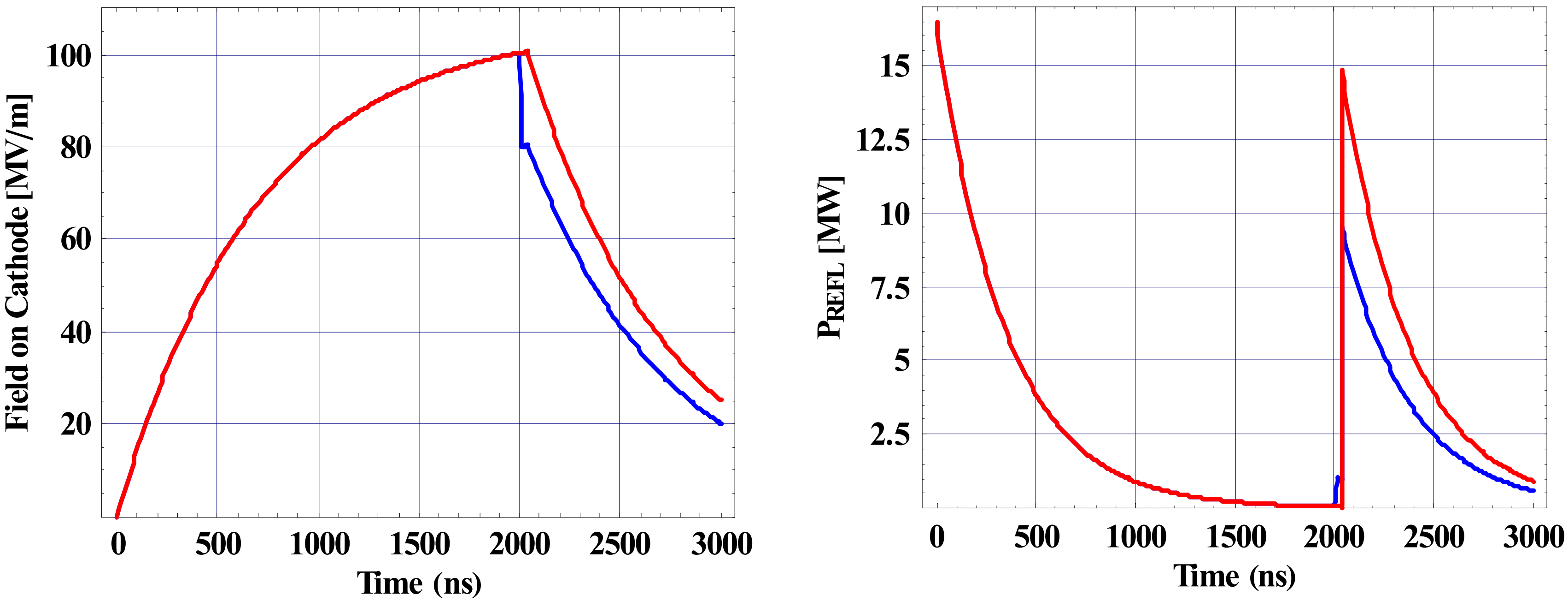
Transient beam loading in CTF II RF-gun



Steady state beam loading for CTF 3 RF-gun

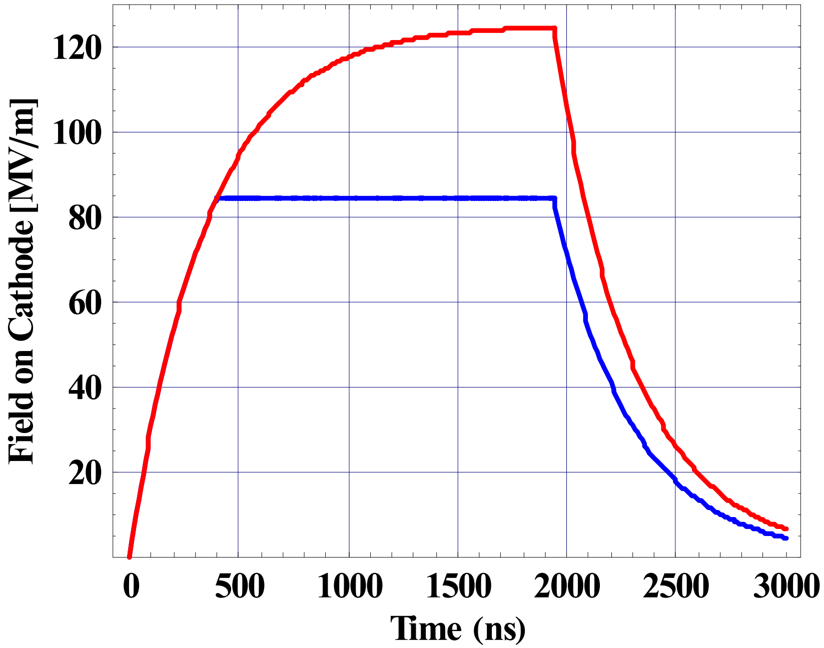


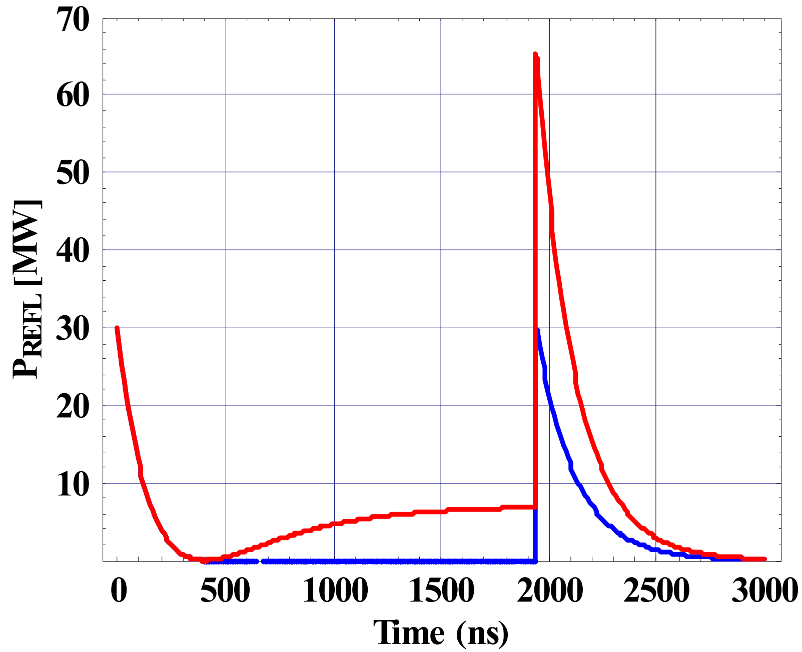
What happened to the gun if the laser didn't fire in CTF II ?



Not much !

What happens to the gun if the laser pulse doesn’t fire in CTF 3 ?





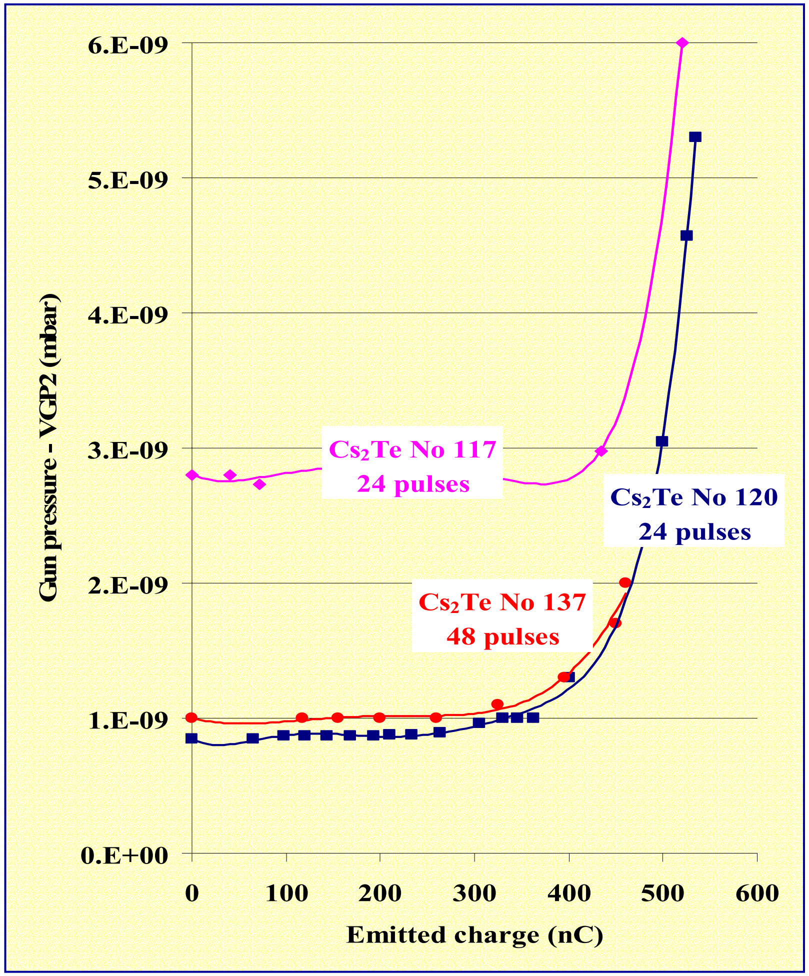
Cathode will be blown off, gun may get damaged, RF windows and circulators may get damaged !

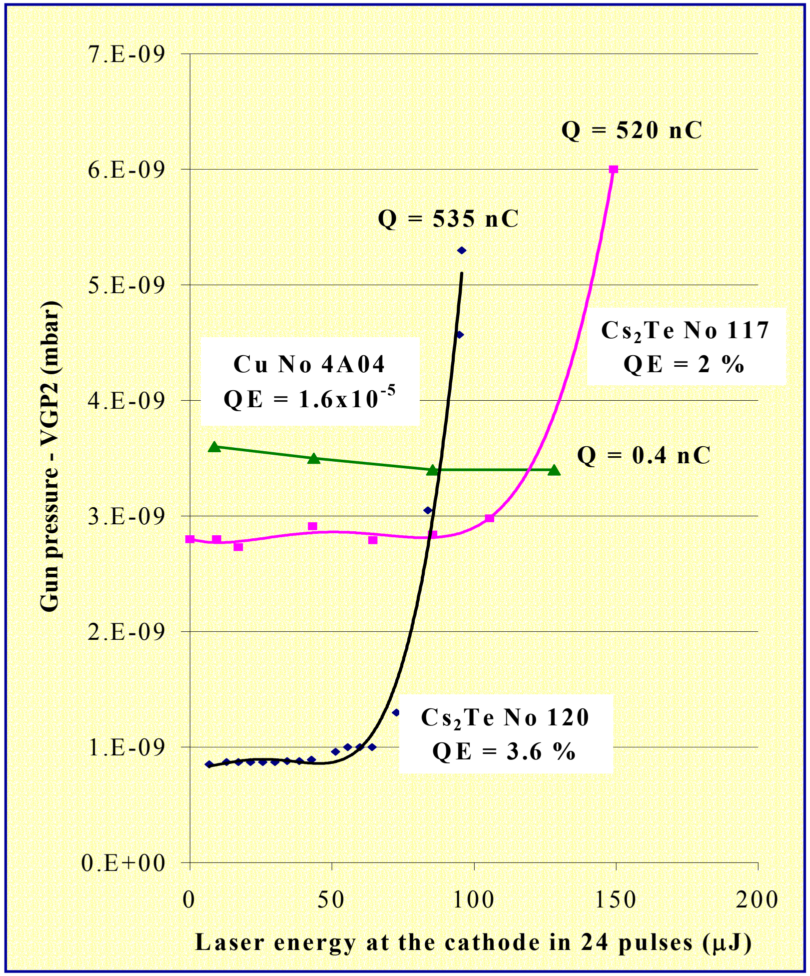
Intra pulse RF interlock will be mandatory !

Dynamique pressure rise in CTF II/ Gun 4 as function of accelerated charge

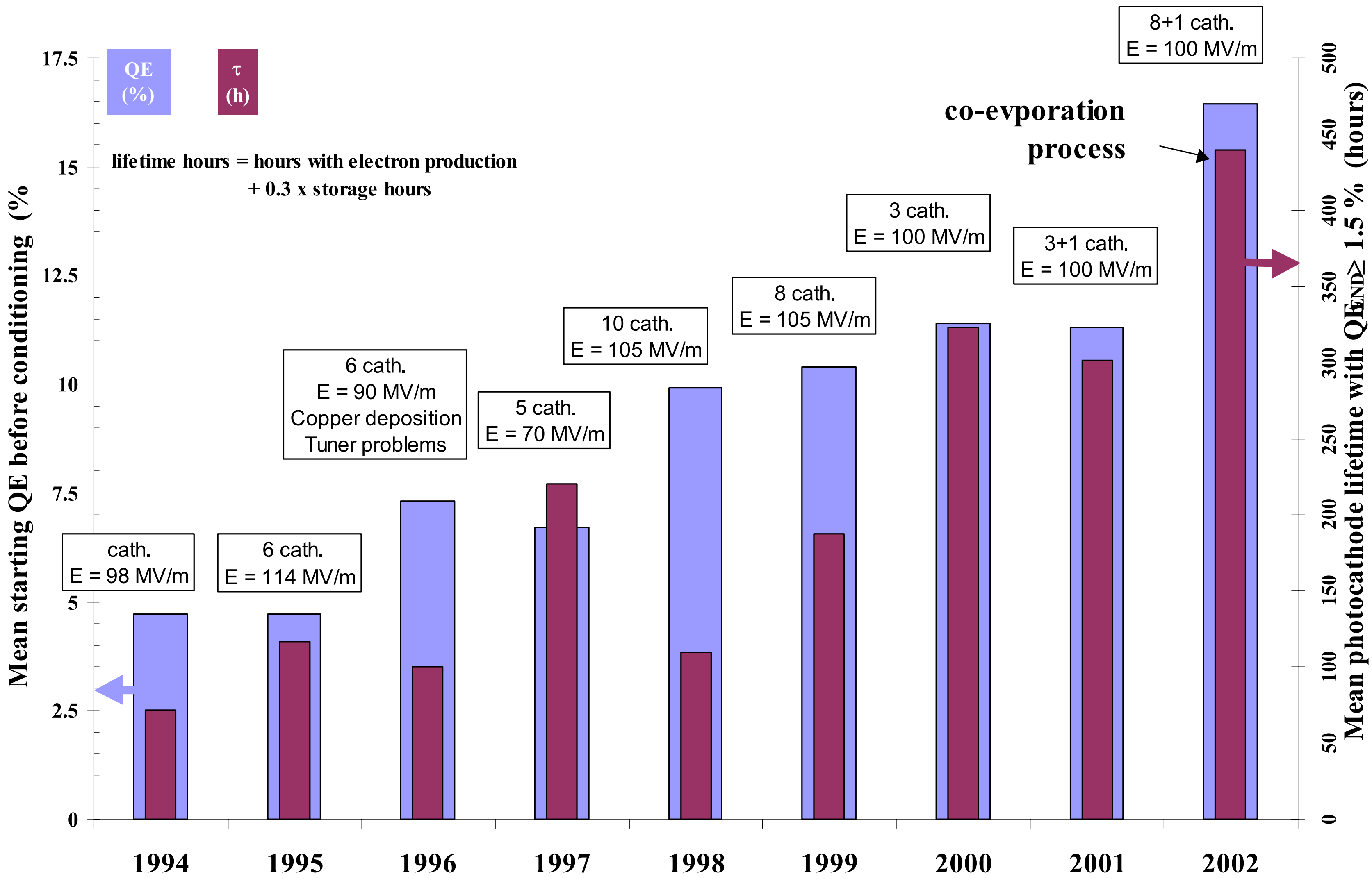
- *Effect has been never fully understood !*
- *Potentially serious problem for CTF3 gun operation and cathode lifetime.*
  10 x pulse charge, 10 x rep. rate compared with CTF II !

⇒ Very good vacuum and pumping properties essential for CTF3 RF gun !





The 58 Cs_2Te photocathodes used in the CTF Drive Beam RF guns



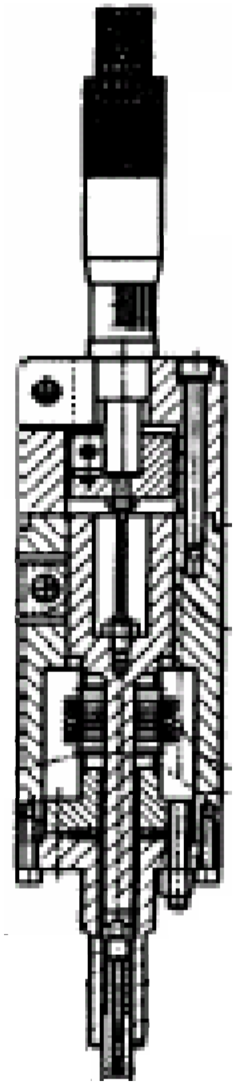
Main results from dark current measurements (1)

- **Standard conditioning process:**

Slow increase of the klystron output power by minimizing break-downs, until 18MW nominal power, corresponding to 100 MV / m. After more than 10 minutes without breakdown, the cathode is considered as conditioned.

	Fresh Cs_2Te photo-cath.	Used Cs_2Te photo-cath	Chemically cleaned copper plug	ICE cleaned copper plug	ICE cleaned used Cs_2Te photo-cath.
ϕ (eV)	3.55	3.55	4.6	4.6	4.6
β From - to	73 - 66	77 - 53	104 - 70	94 - 49	102 - 100
Eq.Radius (nm)	35 - 55	27 - 165	38 - 269	55 - 2616	31 - 37
I_{mean} (mA) at 100MV/m	7.3 – 6.9	6.9 – 6.5	5.2 – 4.8	4.3 – 3.8	3.2

ICE : Argon ion bombardment at $5x10^{-2}$ mbar eq. N_2



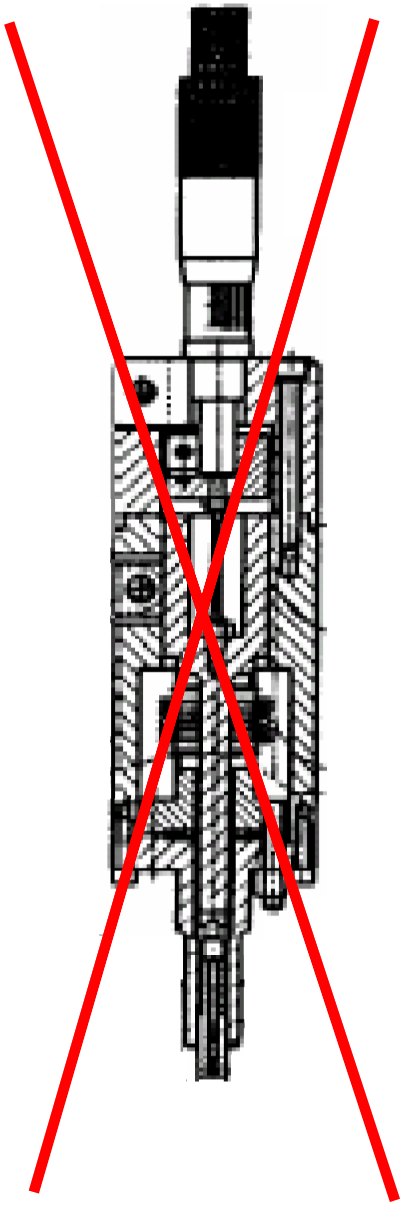
Tuning Pistons used on each cell of CTF II RF guns

Advantages:

- easy tuning after brazing
- easy to correct frequency error introduced by change of photo cathode (frequent operation, introduces typically $\Delta\upsilon \approx \pm$ 150 kHz)

Disadvantages

- introduces asymmetries in field distribution ⇒ emittance growth
- difficult to get sufficient cooling of piston at high repetition rate (> 5Hz)
- incompatible with solenoid around gun
- not good for vacuum
- expensive



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$\Longrightarrow$ **Do tuning for CTF 3 RF gun with dimple tuning after brazing and water temperature for cathode plug compensation !**

Possible strategy for CTF3 RF gun design

- Start from 3 cell geometry of CTF II / Gun 4
- add symmetric power coupler with coupling adapted for beamloading compensation
- add elliptical cell iris shape to reduce surface fields
- add solenoid and bucking coil around cavity
- add high pumping capacity directly at output of gun
- optimise cell lengths for minimum 3D emittance of nominal CTF3 beam
- optimise beam line layout for emittance compensation (incl. accelerating structures)
- don’t forget suitable place for laser window
- omit piston tuners
- add dimple tuners and water temperature control
- omit all but one field measurement loop
- build
- tune
- install
- don’t forget high power circulator