Conception of photo-injectors for the CTF3 experiment

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Plan

1. Introduction
2. Drive Beam photo-injector (financed by CARE, JRA PHIN)
   - RF simulations
   - Beam dynamic simulations
3. Probe beam photo-injector
4. Conclusion

SERA

Introduction

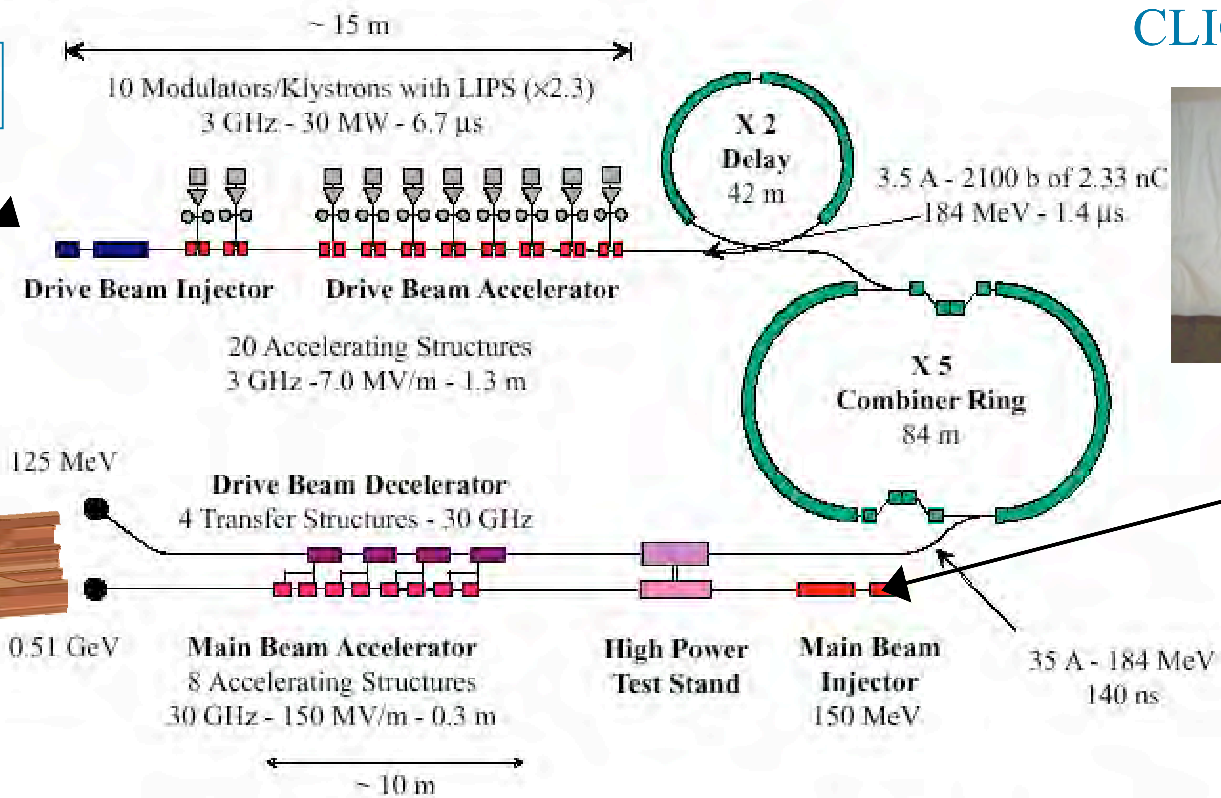
- Past: two 1.5 cells photo-injectors built, CANDELA in 1987, ELYSE in 2002

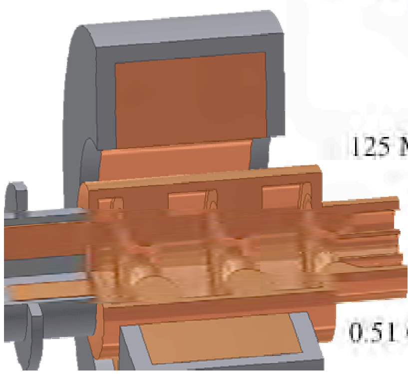
- Now: one 2.5 cells RF gun αX for Strathclyde University

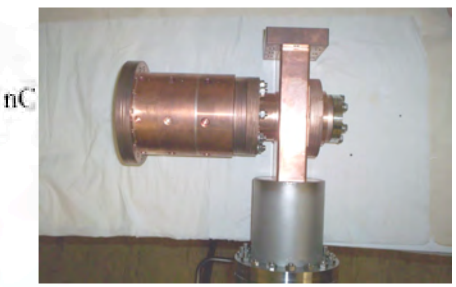
fabrication: J. Rodier

Two 2.5 cells RF gun for the CLIC-Test-Facility 3 at CERN: valid the concepts of the CLIC linear collider

RF photo-gun





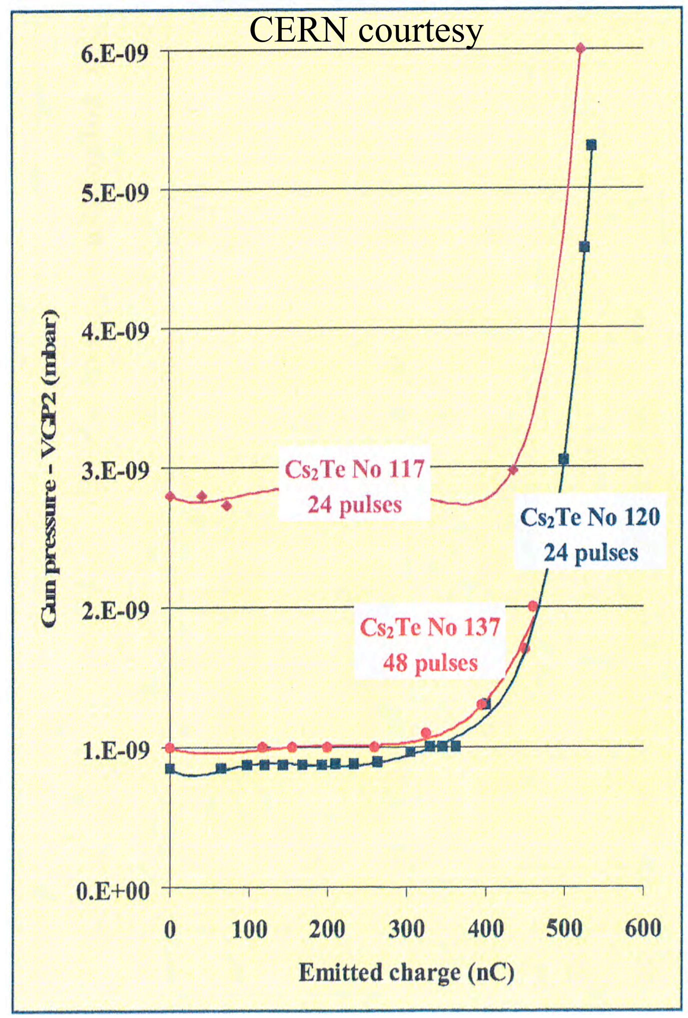


RF photo-gun

Drive beam specifications

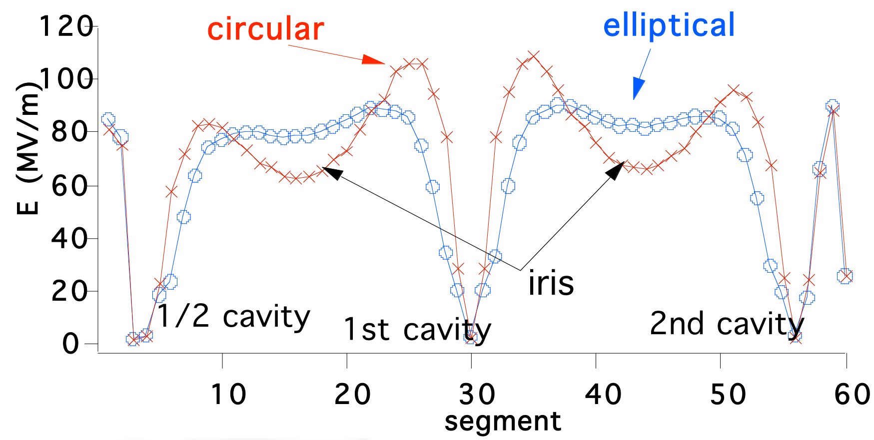
HF frequency (GHZ)	2.99855
HF Power (MW)	30
Beam energy (MeV)	5 – 6
Beam current (A)	3.51
Charge/bunch (nC)	2.33
Macro-pulse duration (µs)	1.548
total extracted Charge (µC)	5.43
Bunch length FWHM (ps)	10
Energy spread rms (%)	< 2
normalised emittance (πmmmrad)	< 25
Residual pressure (mbar)	2.10^{-10}

1 Gun type 4 used in CTF2 as a start point
2 Symmetrical coupling taking into account beamloading
3 No tuners
4 Coils for emittance compensation
5 Improve the vacuum: critical issue

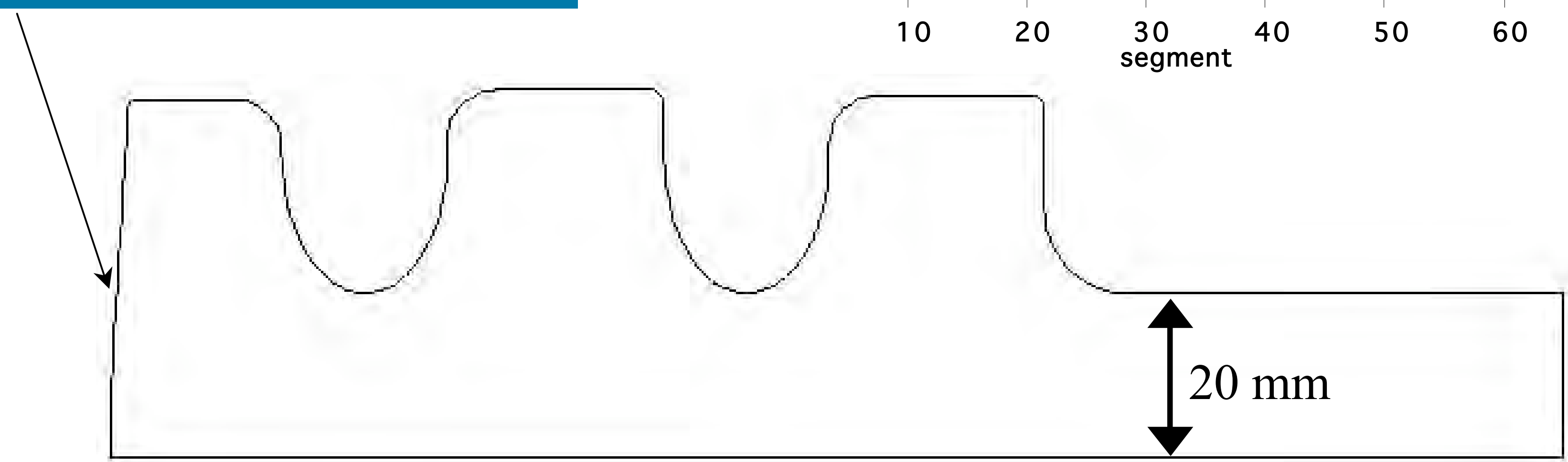


Worrying!

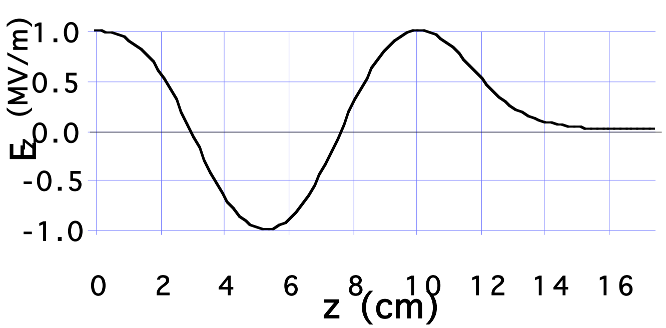
2D HF simulation: Superfish



Angle of the wall
⇒Emittance slightly improved
For I = 5 A



$F_r = 3.003$ GHz
$R_s = 6\ M\Omega$
Q = 14530



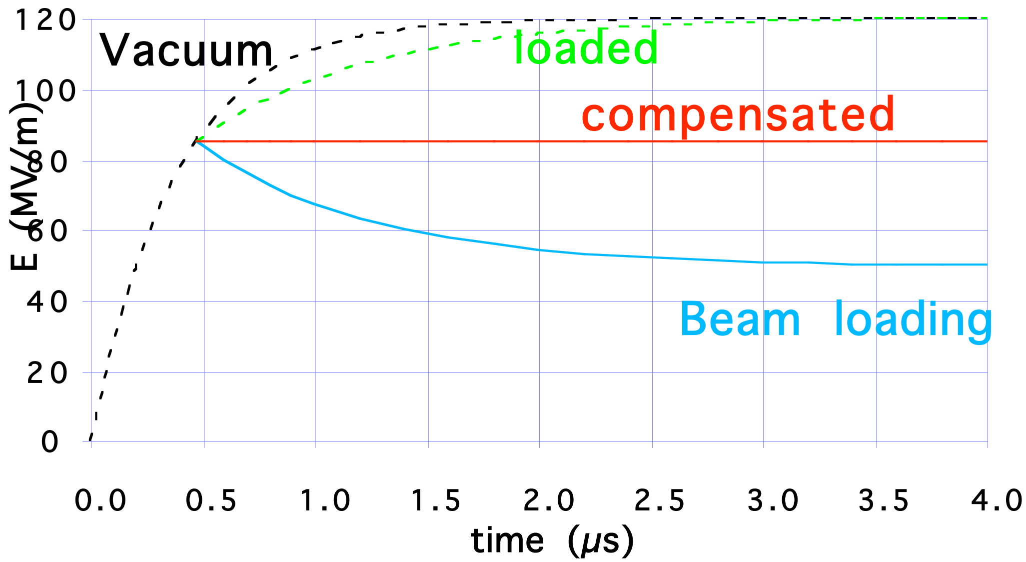
Beam loading and coupling

$$V_{ind}(t) = V_{sat}(1 - \exp(-\frac{t}{\tau}))$$

$$V_{sat} = \frac{R_s T^2 I_{harm}}{(1+\beta)}$$

$$\tau = \frac{2Q_c}{\omega_r}$$

$$Q_c = \frac{Q_0}{1+\beta_1+\beta_2}$$



$$\beta = \frac{\beta_0}{1+\beta_{beam}} \text{ with } \beta_{beam} = \frac{P_{beam}}{P_{cav}}$$

$$P_{beam} = 3.51\,\mathrm{A} \times 5.5\,\mathrm{MV} = 19.3\,\mathrm{MW}$$

$$P_{cav} \approx 10\,\mathrm{MW} \text{ for } 85\,\mathrm{MV/m}$$

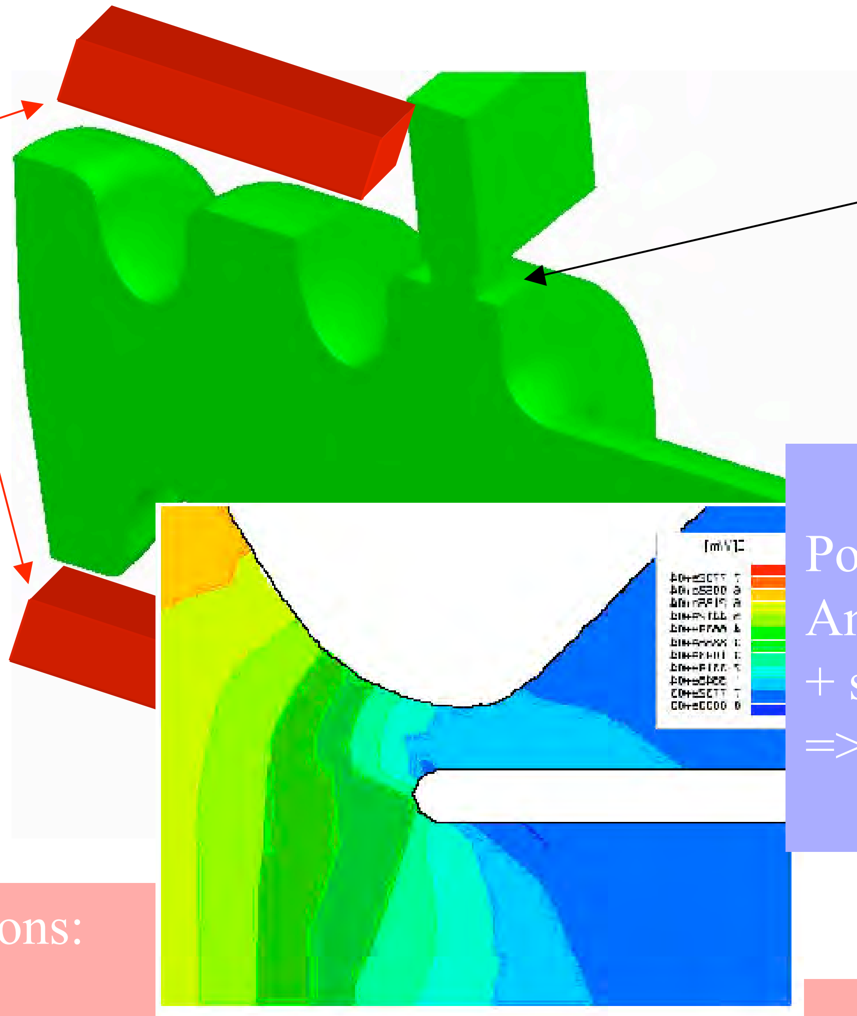
$$\beta = \frac{\beta_0}{1+1.9}$$

$\beta = 2.9$ to match the gun in presence of the beam

& $P_{RF} = 30$ MW

3D HF simulations: HFSS

Coils



Hole coupling:
- overcoupled
- symmetrical

Coaxial coupling

Possible but:

Antenna goes deeply into the gun

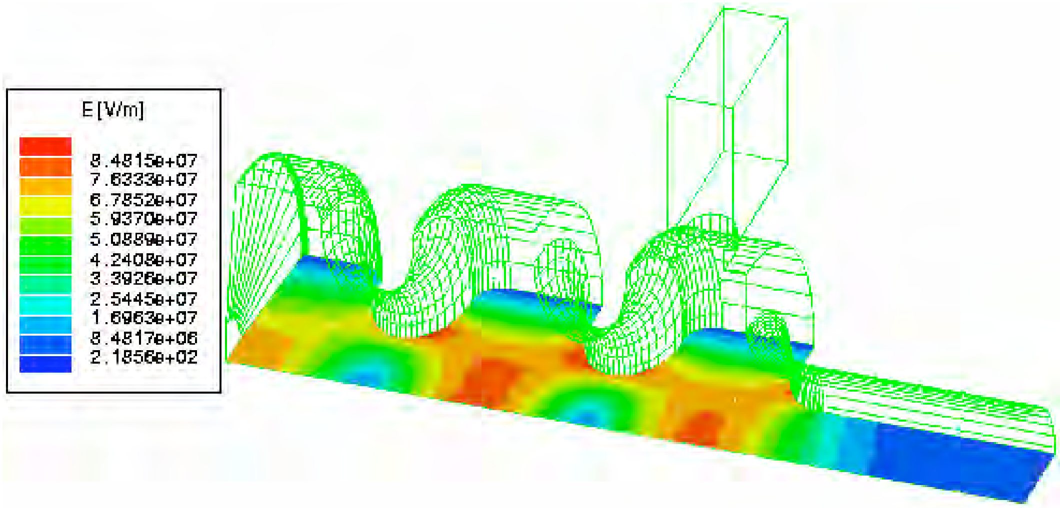
+ strong gradient

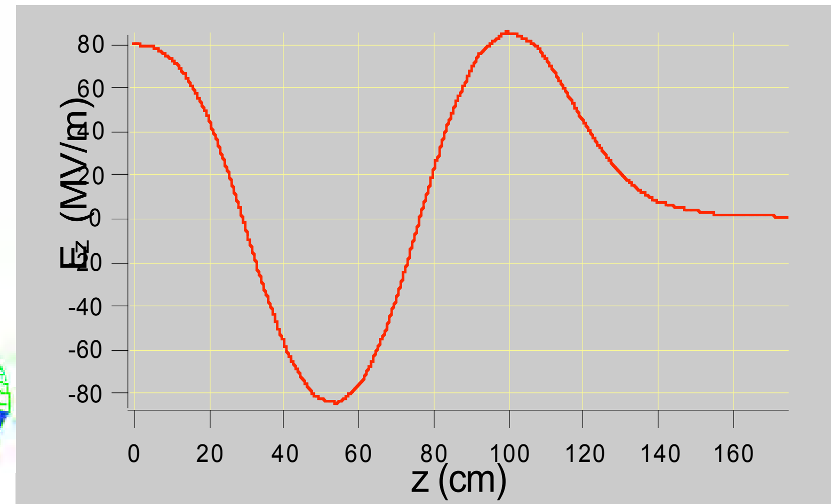
=> Breakdown hazards _ _

3 conditions:
- F_r
- Coupling
- Field equilibrium

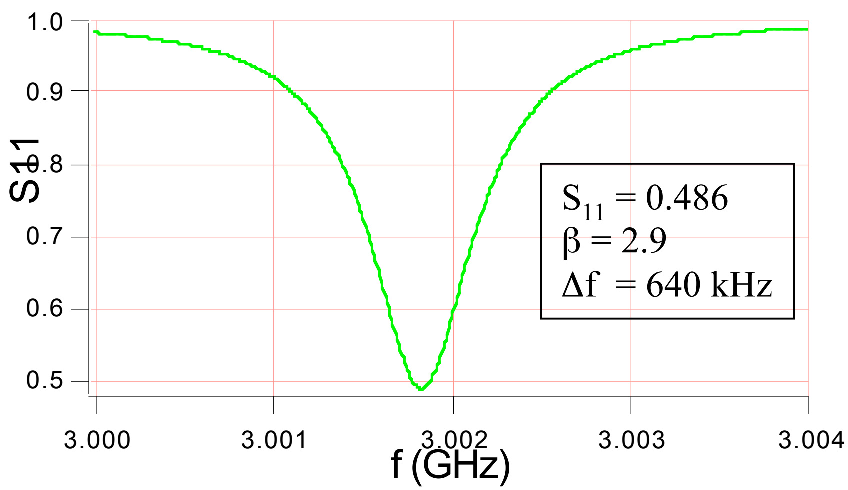
Dimensions of the cells and of the coupling hole

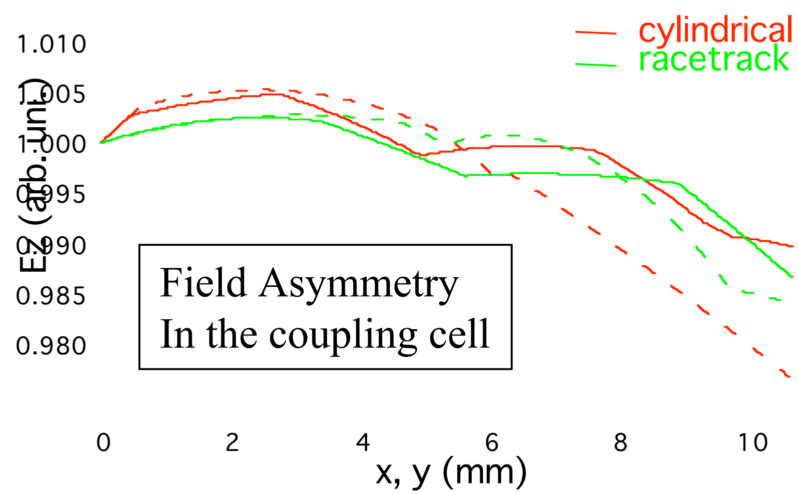
Results of the HFSS simulations



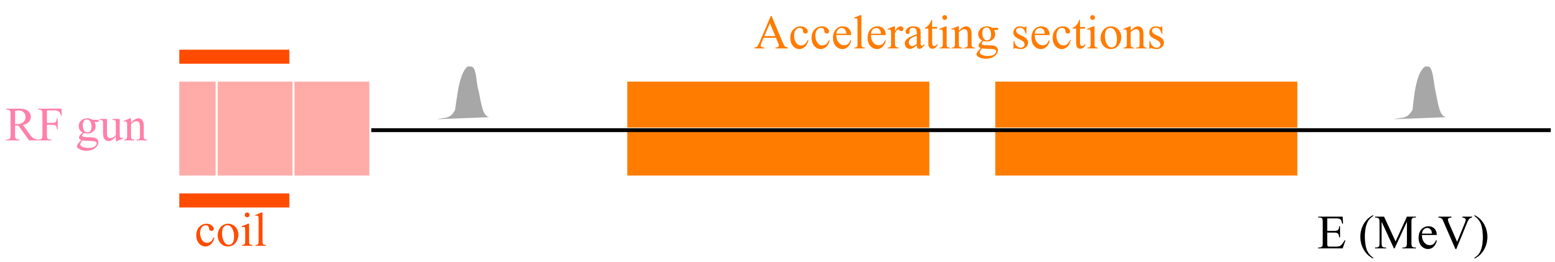


$R_{1/2}$ = 43.9 mm R_1 = 44.7 mm R_2 = 43.6 mm coupling hole: 25x10 mm





Dynamic of the electron beam

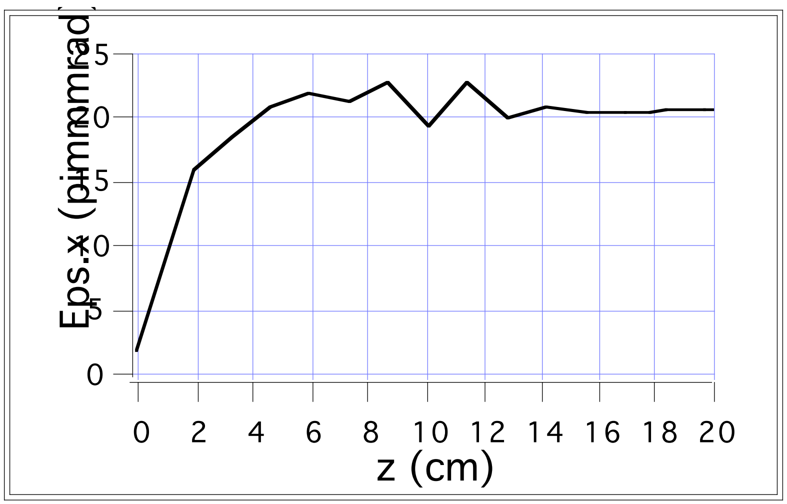


Electric field
From Superfish

→ PARMELA →

I = 3.51 A

E (MeV)	5.45
ε_x (πmmmrad)	19.6
σ_x (mm)	3.2
σ_z (ps)	3.56
σ_γ/γ (%)	0.36



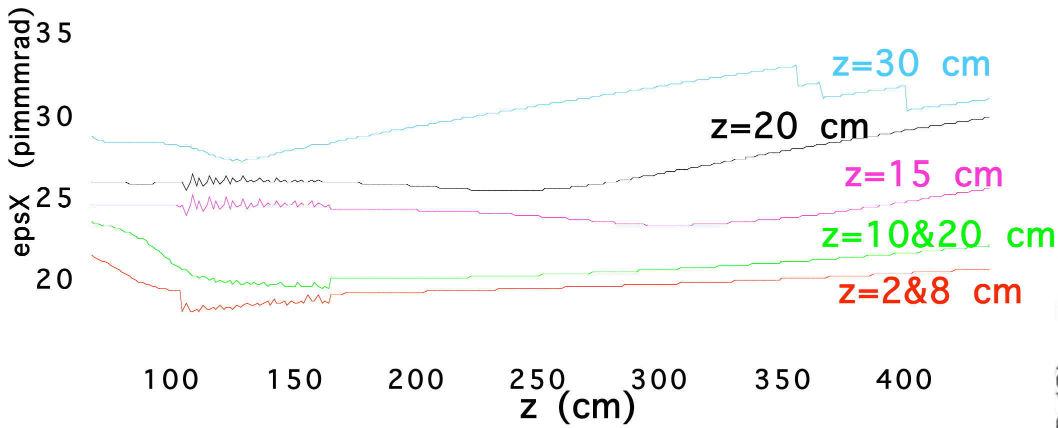
But increase continuously due to
Space charge forces

σ_{laser}(mm)	**0.6**	**0.8**	**1**	**1.4**	**2.8**
Particle loss (%)	1	0.3	0.3	0	0
ε_x (πmmmrad)	13.5	16	17.6	19.6	21.0
σ_l (ps)	11	9.6	9	8.4	7.9
σ_γ/γ (%)	0.5	0.4	0.4	0.36	0.41

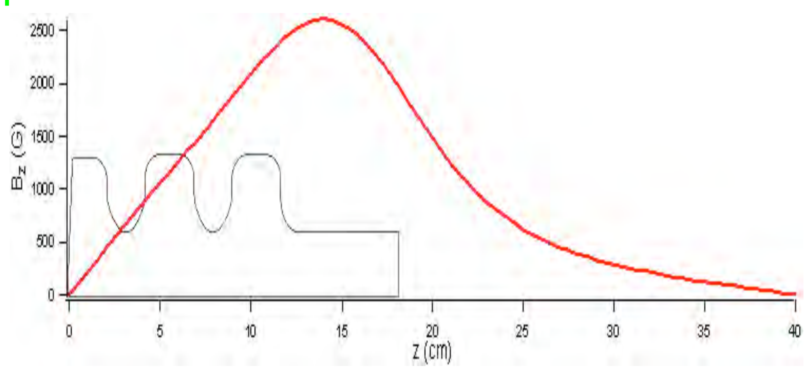
Φ_{opt} = 35 °

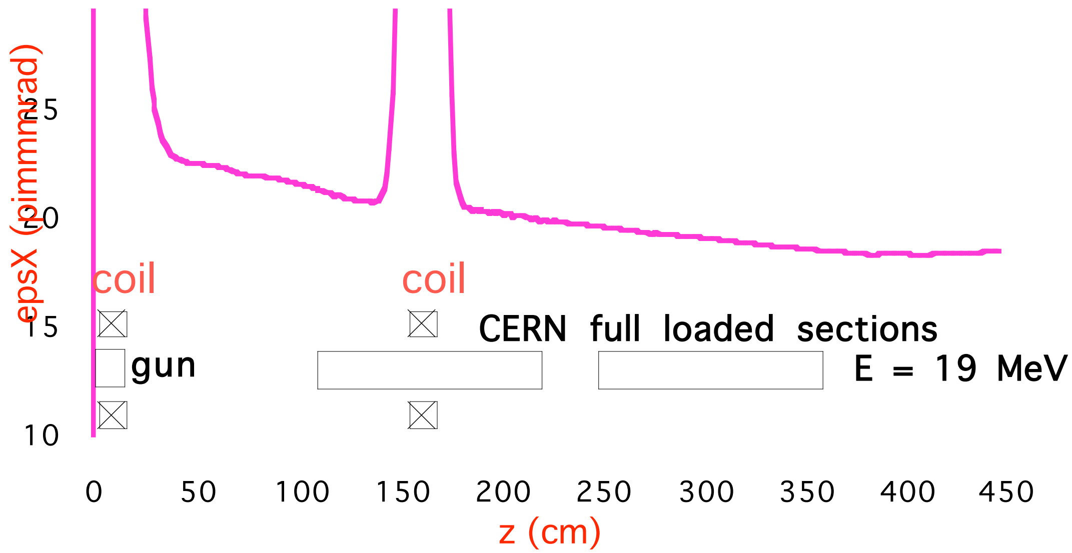
E_{RF} = 85 MV/m set by beamloading!

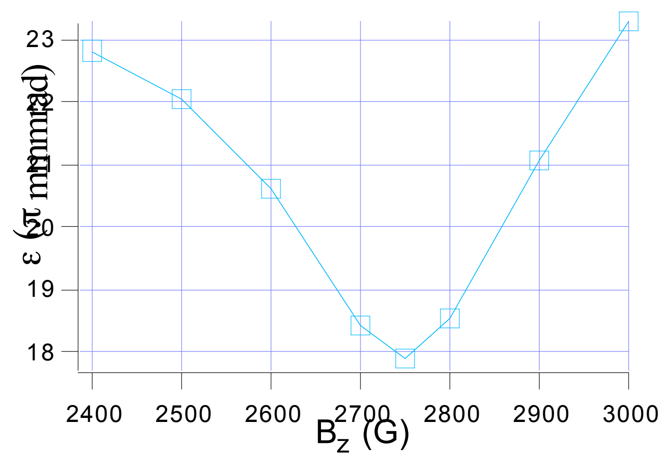
Compensation of the emittance growth due to space charge



Optimum:
Coils on the gun

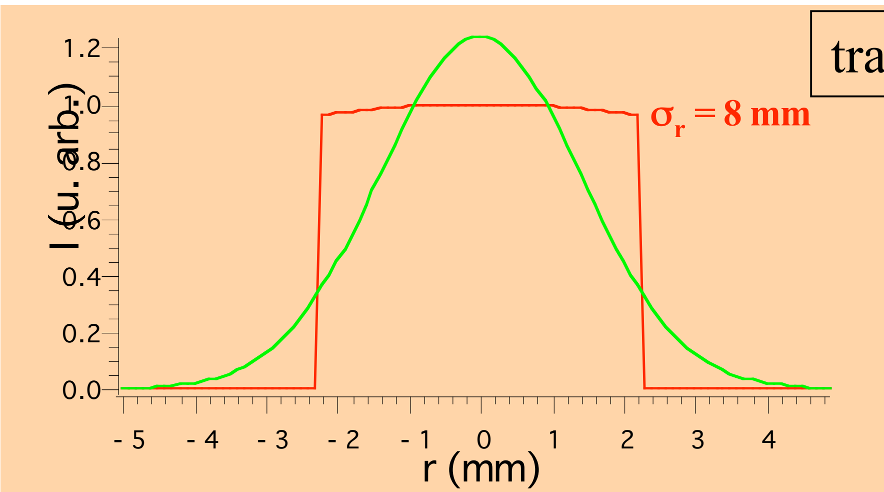






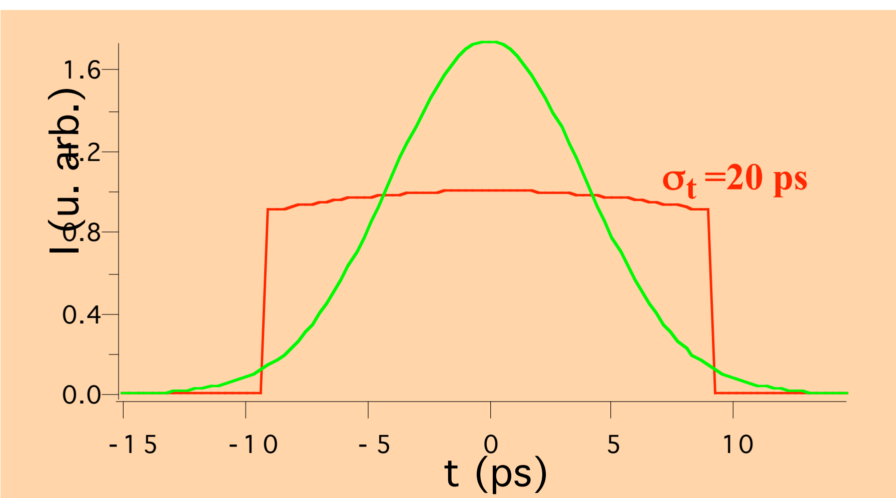
Influence of the laser profile's shape

Start point, gaussians: $\sigma_z = 3.56$ ps, $\sigma_\gamma/\gamma = 0.36$ %, $\varepsilon_x = 19.6$ πmmmrad, $\varepsilon_y = 20.7$ πmmmrad



transversally flat, longitudinal profile is gaussian

$\varepsilon_x = 14$ πmmmrad
$\varepsilon_y = 14.2$ πmmmrad
$\sigma_z = 3.7$ ps
$\sigma_\gamma/\gamma = 0.36$ %

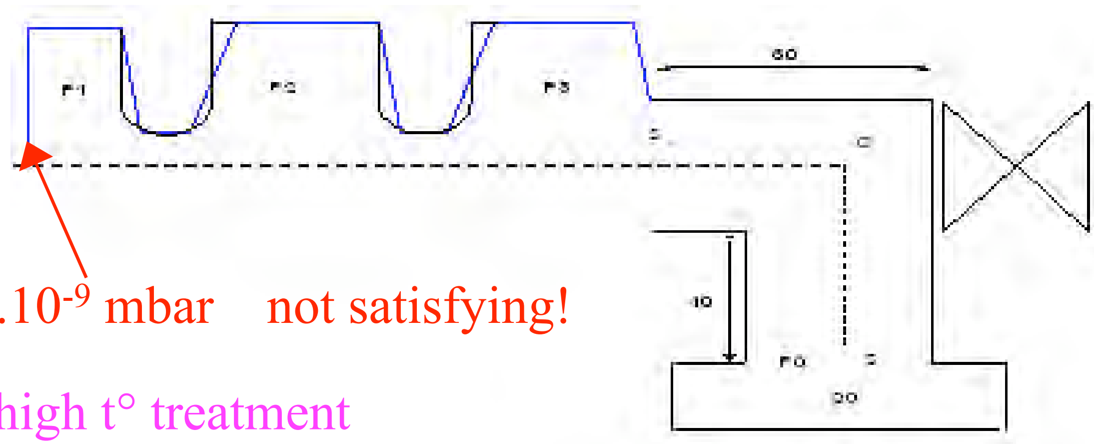


All profiles are flat

$\varepsilon_x = 10.8$ πmmmrad
$\varepsilon_y = 10.9$ πmmmrad
$\sigma_z = 4.6$ ps
$\sigma_\gamma/\gamma = 0.5$ %

Vacuum

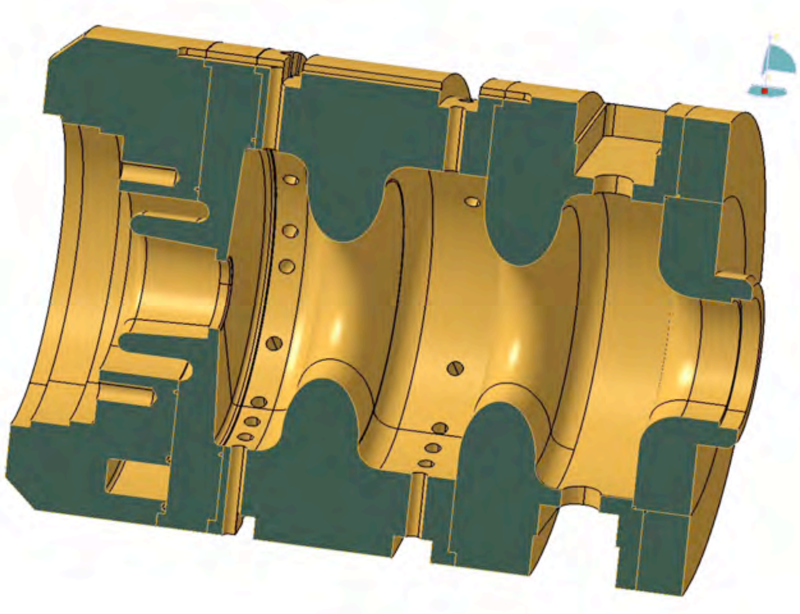
Monte-Carlo based Simulations
of the residual pressure

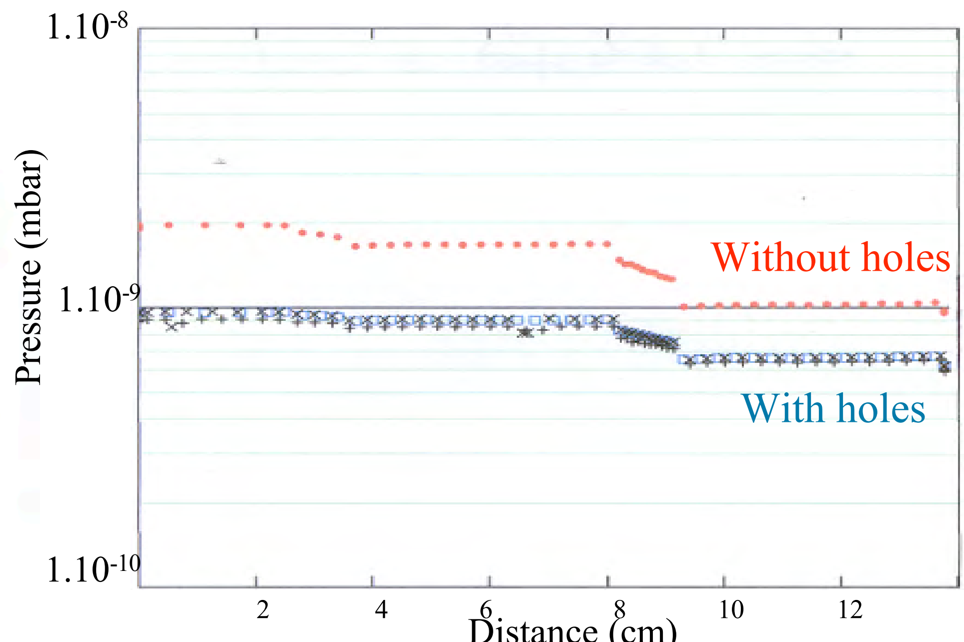


Weak conductance => ~ 2.10^{-9} mbar not satisfying!

Solutions: NEG pumping + high t° treatment

42 holes, ϕ = 4 mm,
NEG coated envelop around the gun





Baking at 500°C => P < 10^{-10}

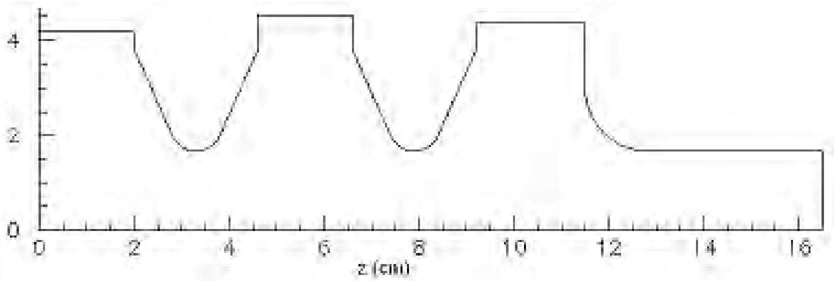
Probe beam photo-injector

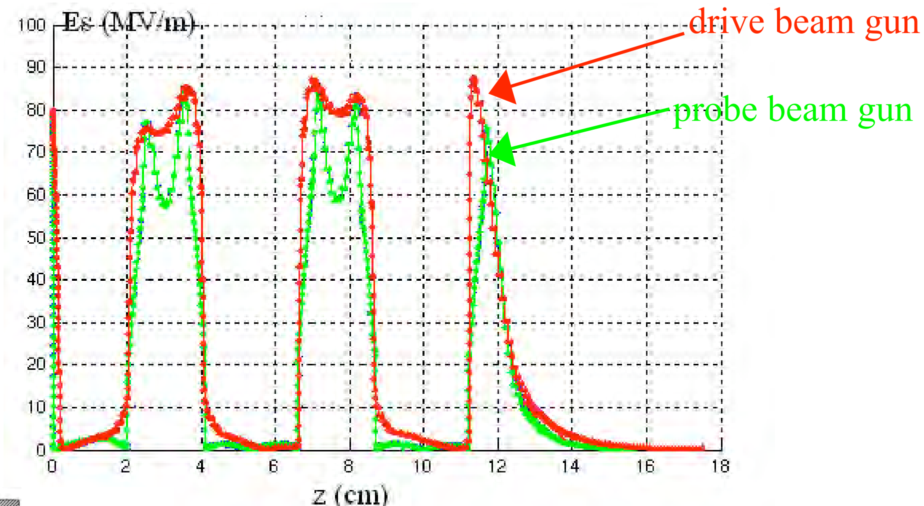
Specifications are the same as for the drive beam except:

-charge/bunch = 0.5 nC

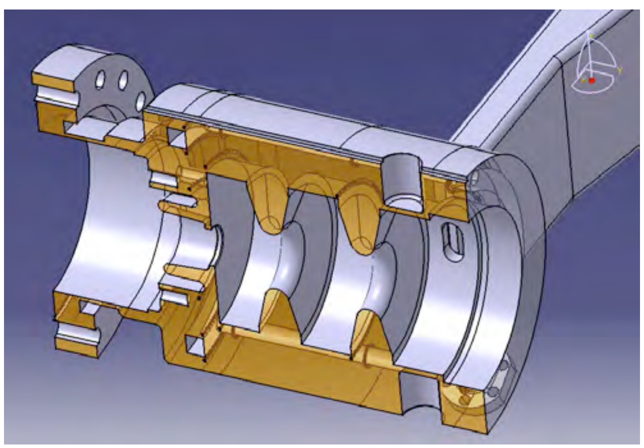
-bunches 1-64 => No beamloading

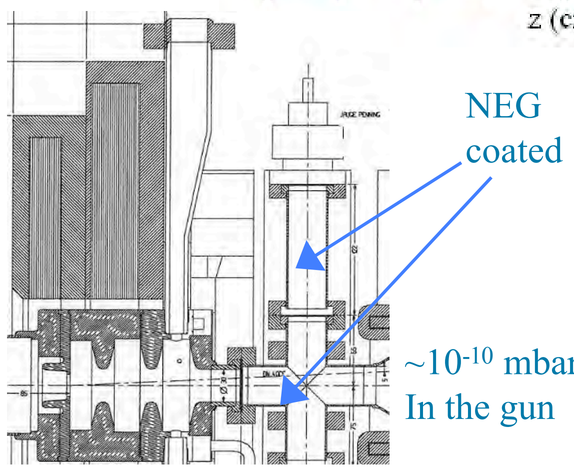
→ Constraints less severe → Simplified design





Q = 14400, R_s = 7.84 MW => P_{HF} = 5.2 MW for 80 MV/m





E (MeV)	5.35
σ_r (mm)	2.33
$FWHM_z$ (ps)	8
σ_γ/γ rms (%)	0.33
ε (πmmmrad)	6.5

Conclusion & Perspectives

1) Drive beam photo-injector

Prototype is due to be delivered very soon, the RF gun fully equipped should be installed in the CTF3 drive beam linac before summer 2006.

2) Probe beam photo-injector

- HF simulations almost finished
- Electron beam simulations are still under way
- Technical drawings should be ready by the end of the year
- Call for tenders in January 2006
- Delivery in the beginning of 2007