

Conception of photo-injectors for the CTF3 experiment

R. Roux

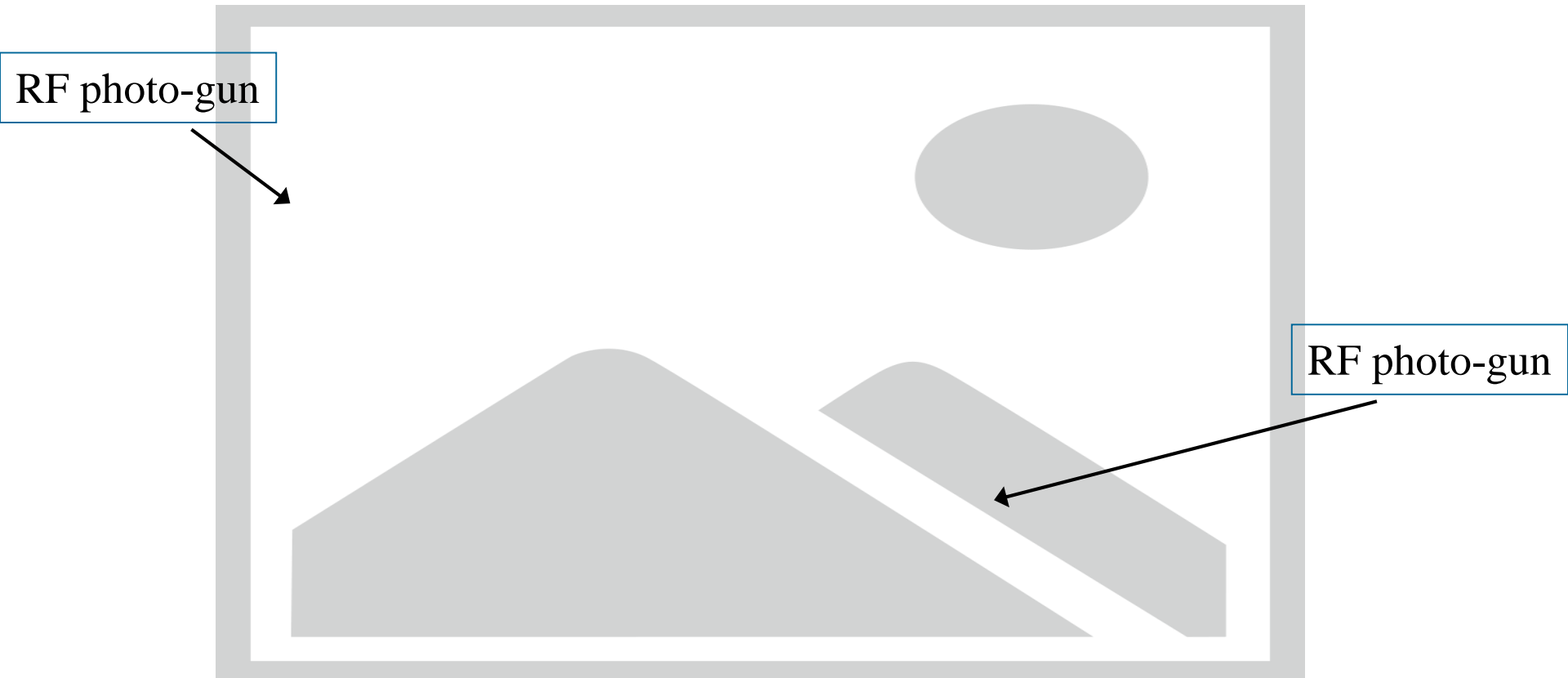
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Plan

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

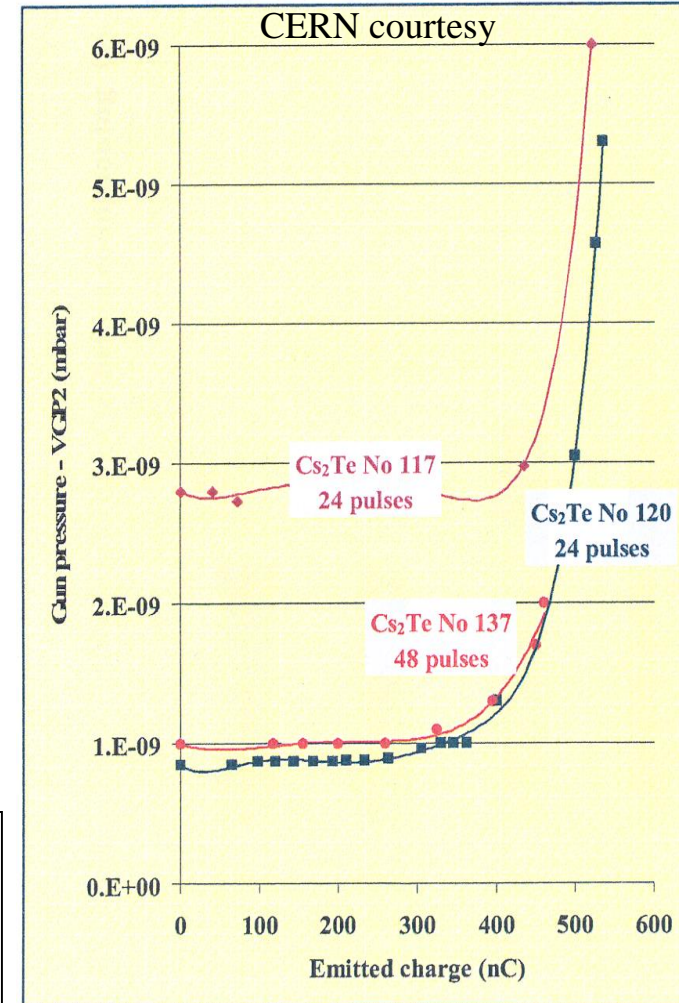
Introduction

- Past: two 1.5 cells photo-injectors built, CANDELA in 1987, ELYSE in 2002
- Now: CLIC-Test-Facility at CERN: valid the concepts of the CLIC linear collider



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 (μ s)	1.548
total extracted Charge (μ C)	5.43
Bunch length FWHM (ps)	10
Energy spread rms (%)	< 2
normalised emittance (π mmrad)	< 25
Residual pressure (mbar)	2.10^{-10}

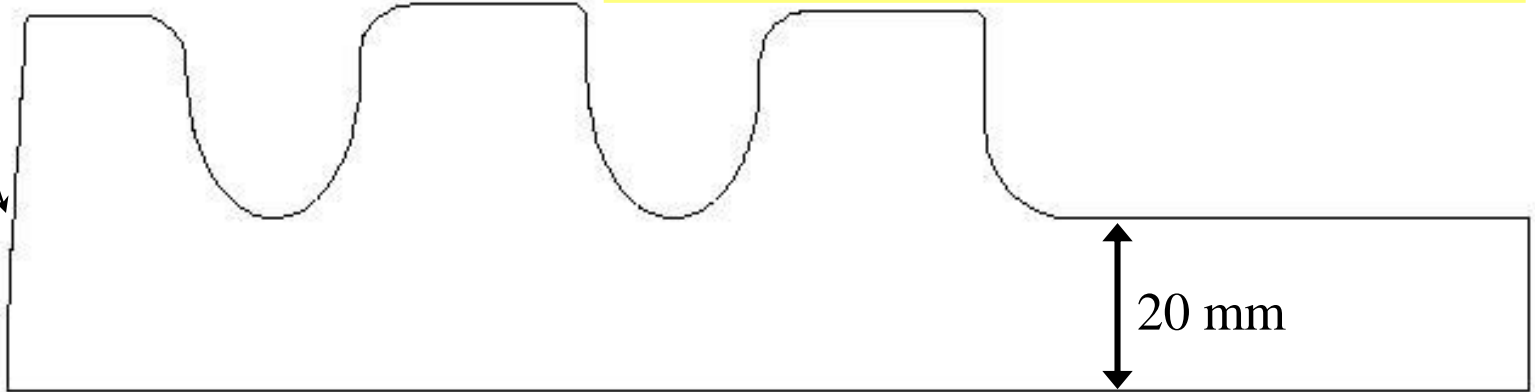
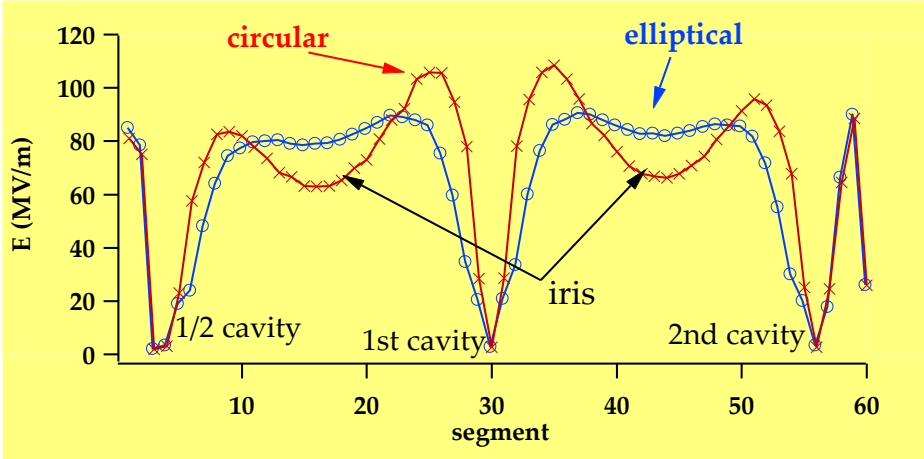


- 1 Gun type 4 used in CTF2 as a start point
- 2 Symmetrical coupling taking into account beamloading
- 3 No tuners
- 4 Coils for emittance compensation
- 5 Improve the vacuum: critical issue

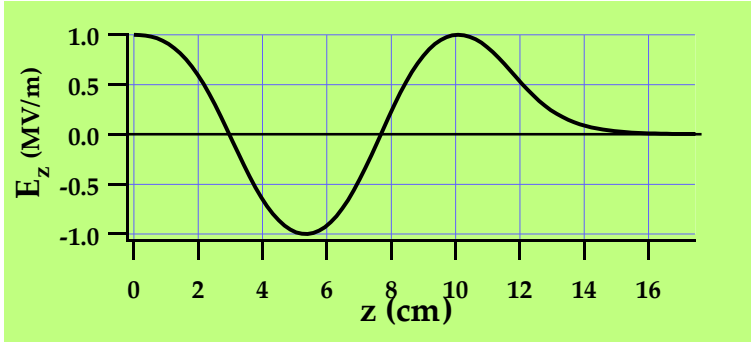
Worrying!

2D HF simulation: Superfish

Angle of the wall
 ⇒ Emittance slightly improved
 For $I = 5 \text{ A}$



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



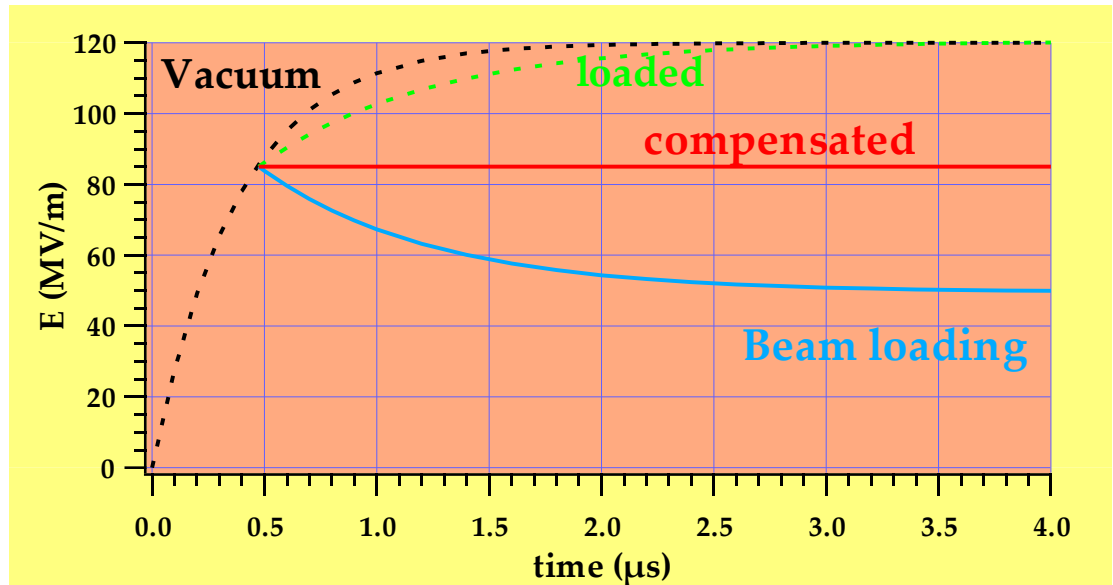
Beam loading and coupling

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

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

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

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



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

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

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



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

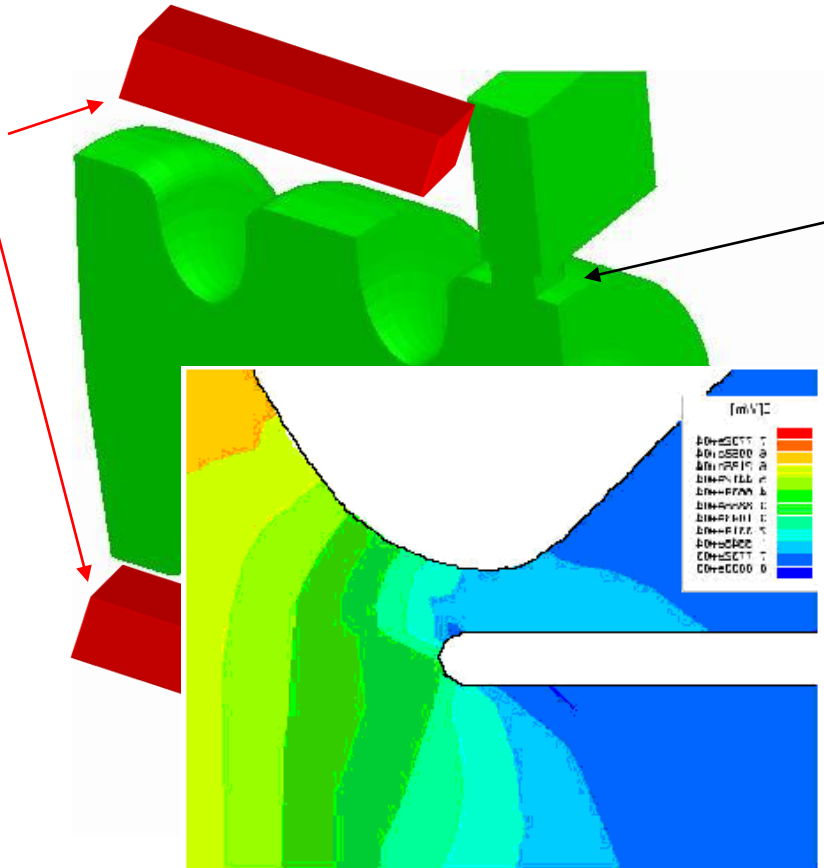


$\beta = 2.9$ to match the gun
in presence of the beam

& $P_{\text{RF}} = 30 \text{ MW}$

3D HF simulations: HFSS

Coils



Hole coupling:
•overcoupled
•symmetrical

Coaxial coupling

Possible but:

Antenna goes deeply into the gun
+ strong gradient
=> Breakdown hazards ↑ ↑

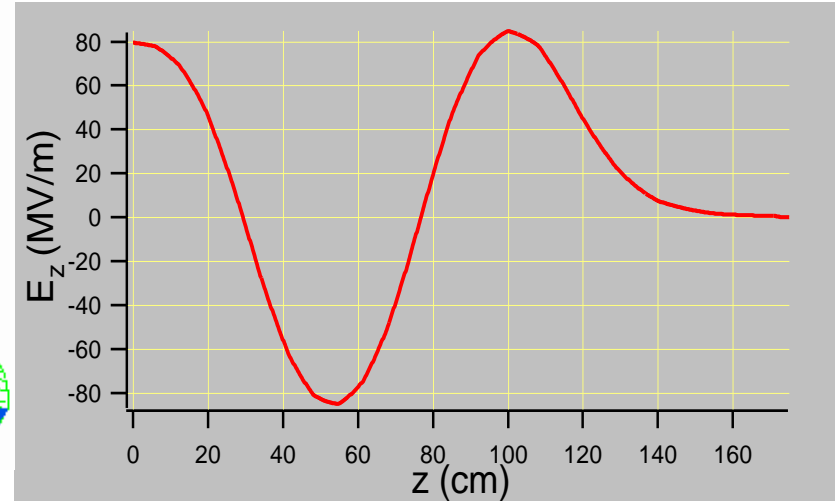
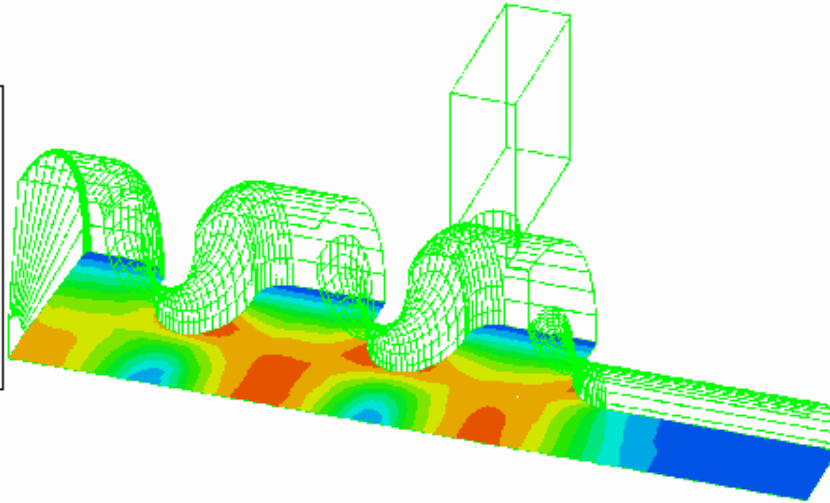
3 conditions:

- F_r
- Coupling
- Field equilibrium

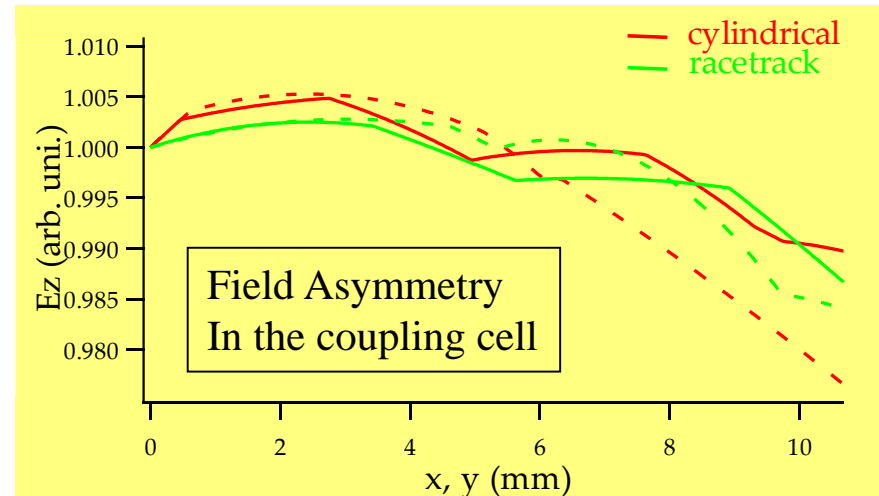
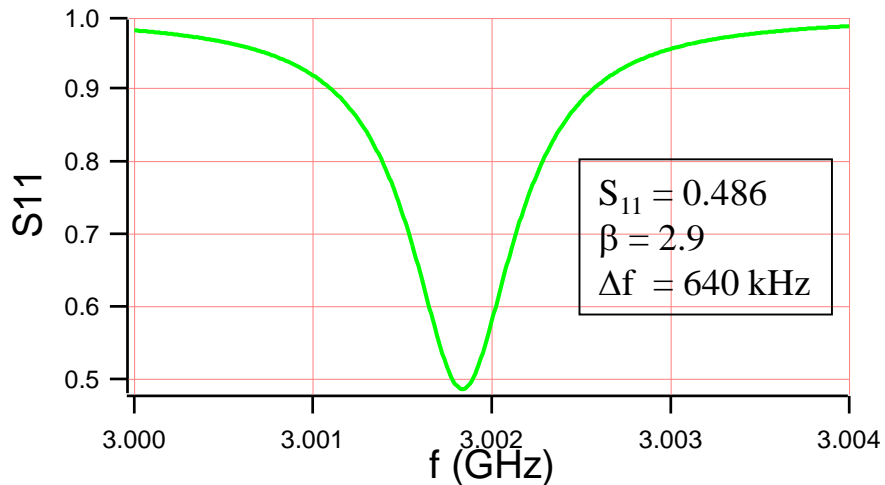


Dimensions
of the cells and of the coupling hole

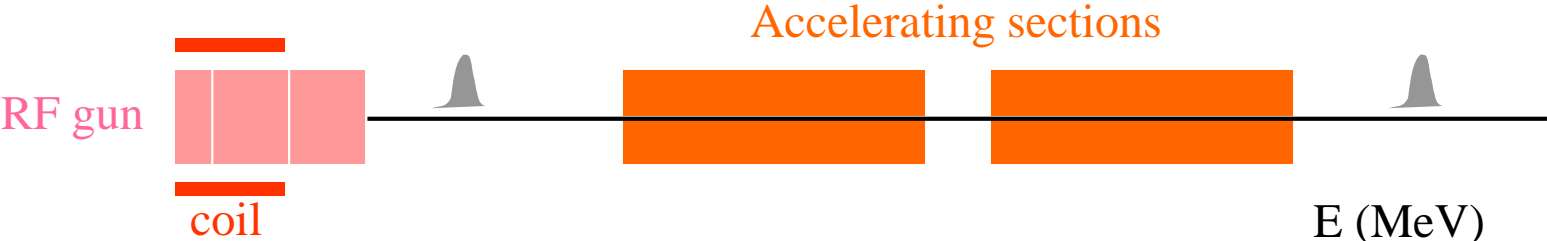
Results of the HFSS simulations



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



Dynamic of the electron beam

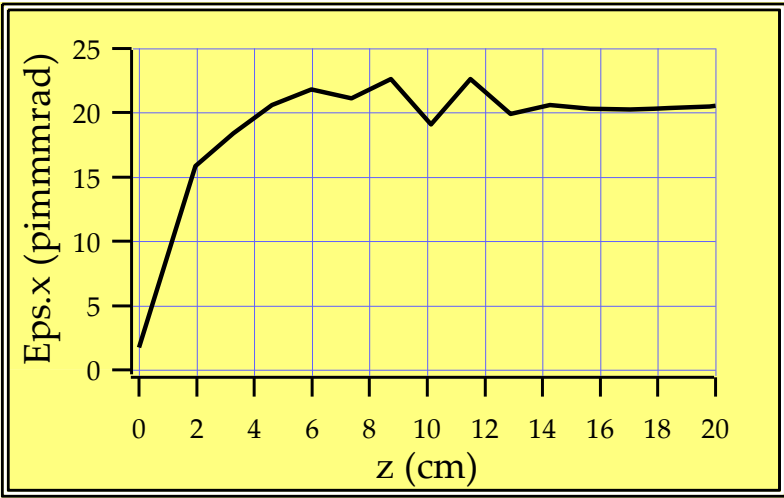


Electric field
From Superfish

PARMELA

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

$I = 3.51 \text{ A}$

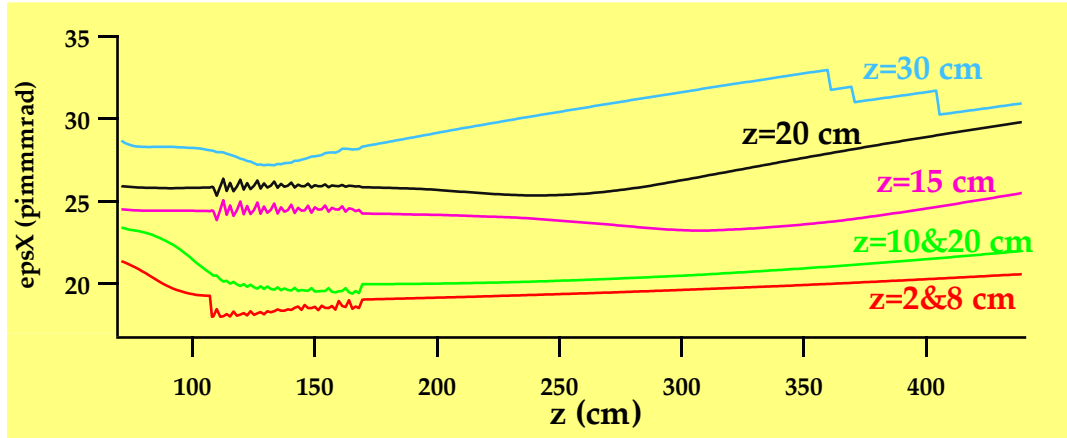


But increase continuously due to
Space charge forces

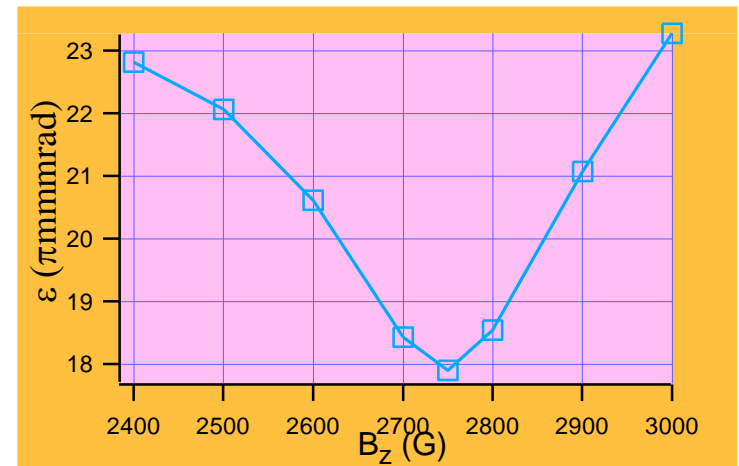
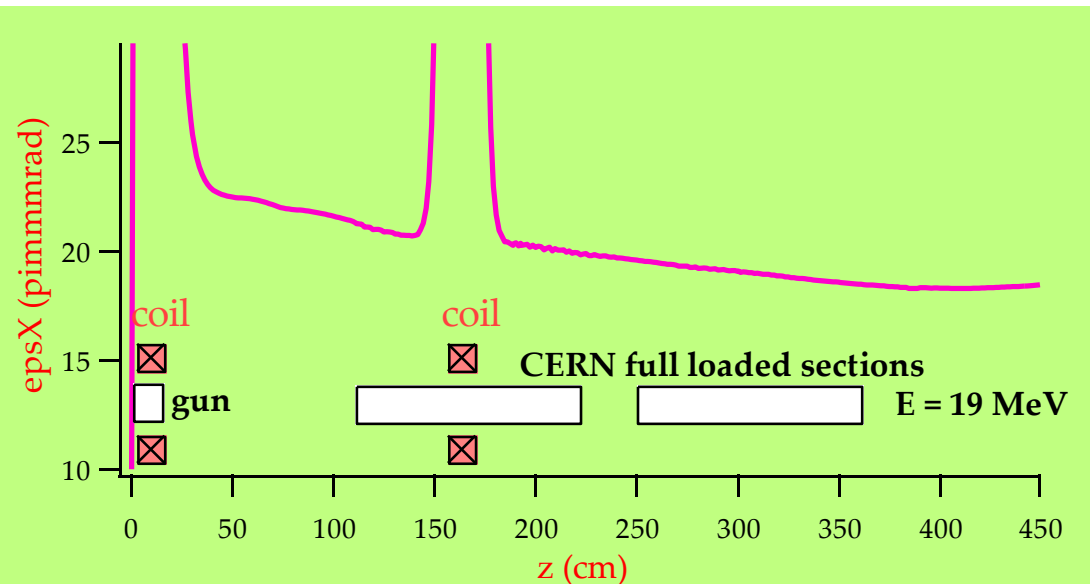
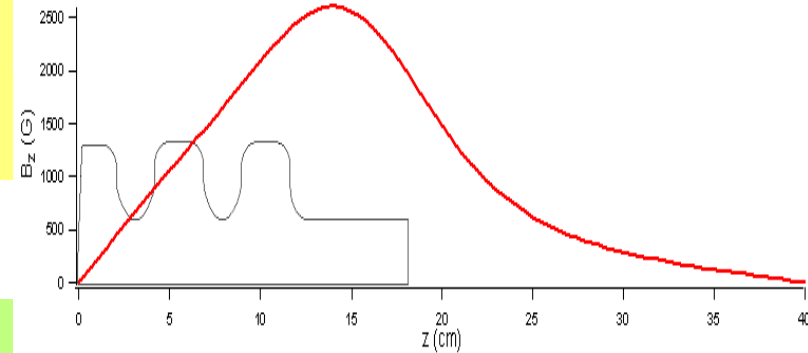
σ_{laser} (mm)	0.6	0.8	1	1.4	2.8
Particle loss (%)	1	0.3	0.3	0	0
ϵ_x (π mmrad)	13.5	16	17.6	19.6	21.0
σ_l (ps)	11	9.6	9	8.4	7.9
σ_γ / γ (%)	0.5	0.4	0.4	0.36	0.41

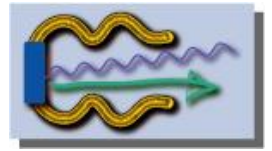
$\Phi_{\text{opt}} = 35^\circ$
 $E_{\text{RF}} = 85 \text{ MV/m}$ set by beamloading!

Compensation of the emittance growth due to space charge

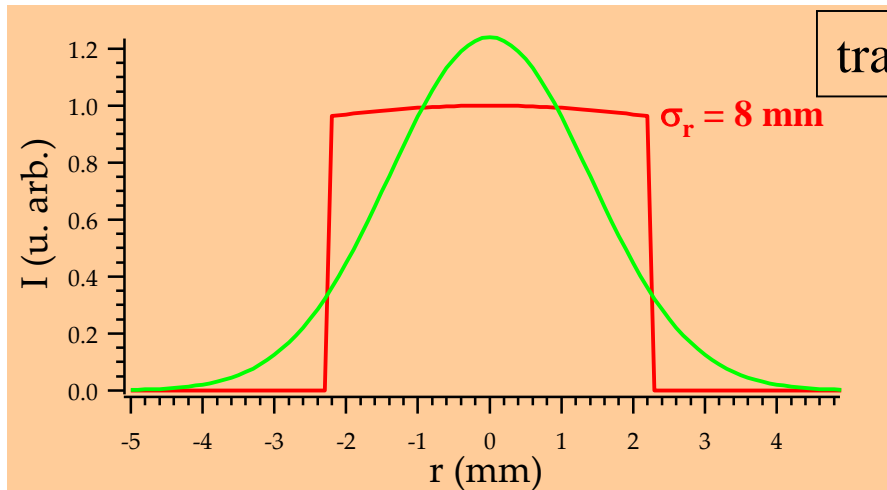


Optimum:
Coils on the gun





Start point, gaussians: $\sigma_z = 3.56$ ps, $\sigma_\gamma/\gamma = 0.36$ %, $\epsilon_x = 19.6$ π mmrad, $\epsilon_y = 20.7$ π mmrad



transversally flat, longitudinal profile is gaussian

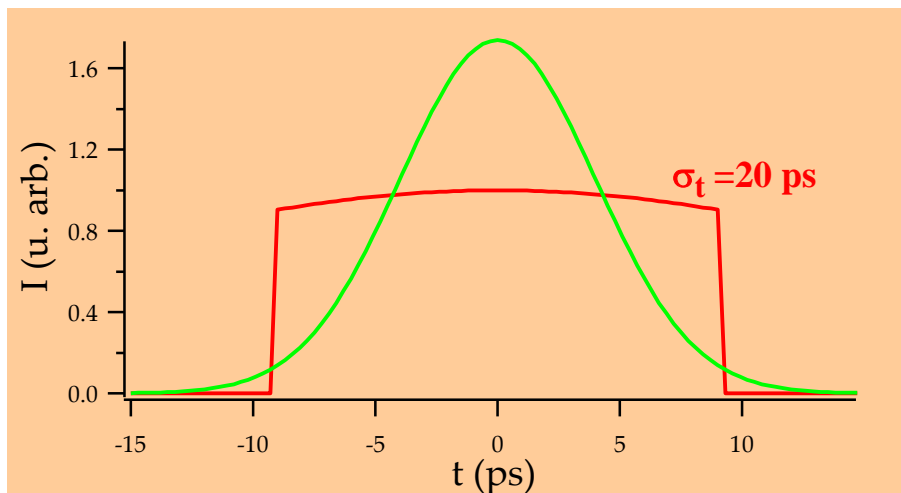


$$\epsilon_x = 14 \pi \text{mmrad}$$

$$\epsilon_y = 14.2 \pi \text{mmrad}$$

$$\sigma_z = 3.7 \text{ ps}$$

$$\sigma_\gamma/\gamma = 0.36 \%$$



All profiles are flat



$$\epsilon_x = 10.8 \pi \text{mmrad}$$

$$\epsilon_y = 10.9 \pi \text{mmrad}$$

$$\sigma_z = 4.6 \text{ ps}$$

$$\sigma_\gamma/\gamma = 0.5 \%$$

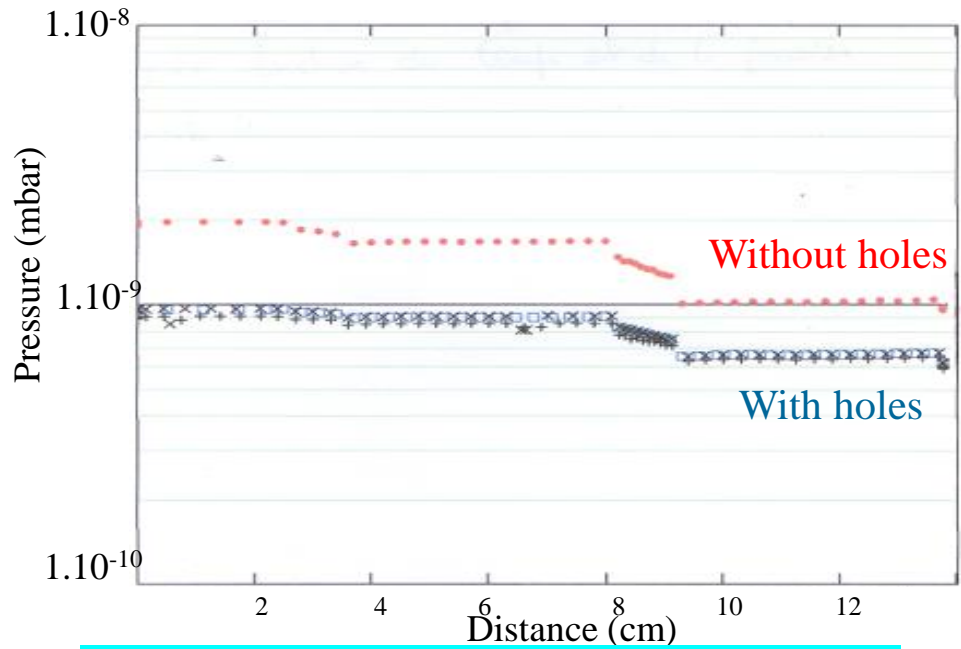
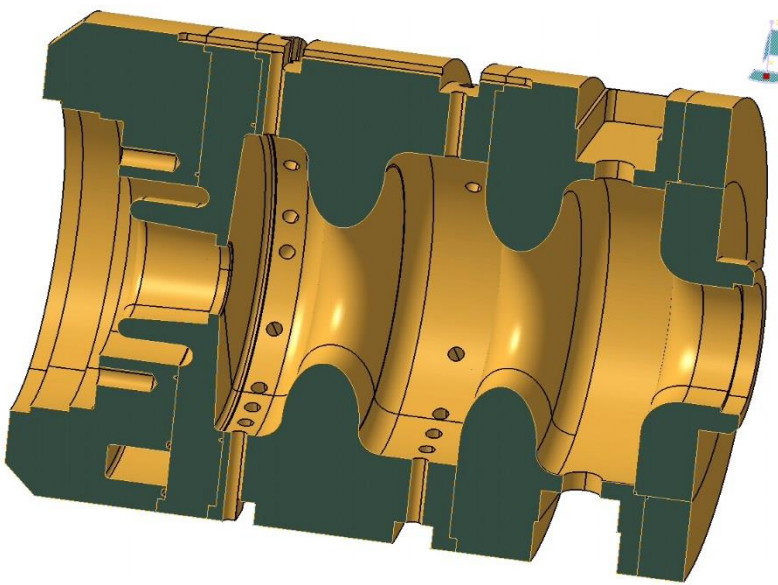
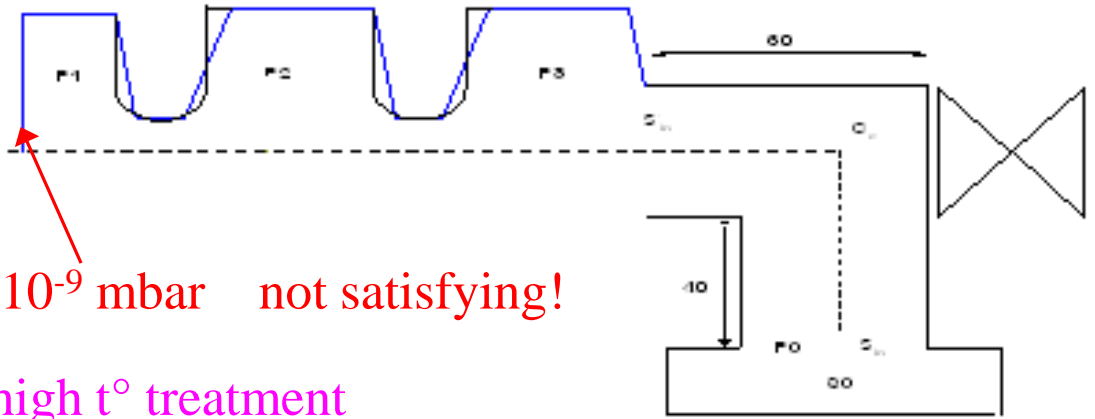
Vacuum

Monte-Carlo based Simulations of the residual pressure

Weak conductance => $\sim 2 \cdot 10^{-9}$ mbar not satisfying!

Solutions: NEG pumping + high t° treatment

42 holes, $\phi = 4$ mm,
NEG coated envelop around the gun



Baking at 500°C => $P < 10^{-10}$

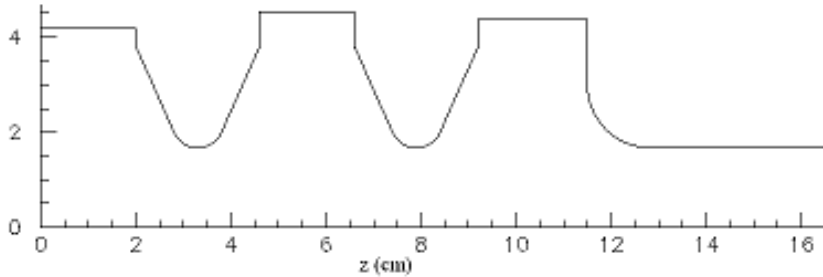
Probe beam photo-injector

Specifications are the same as for the drive beam except:

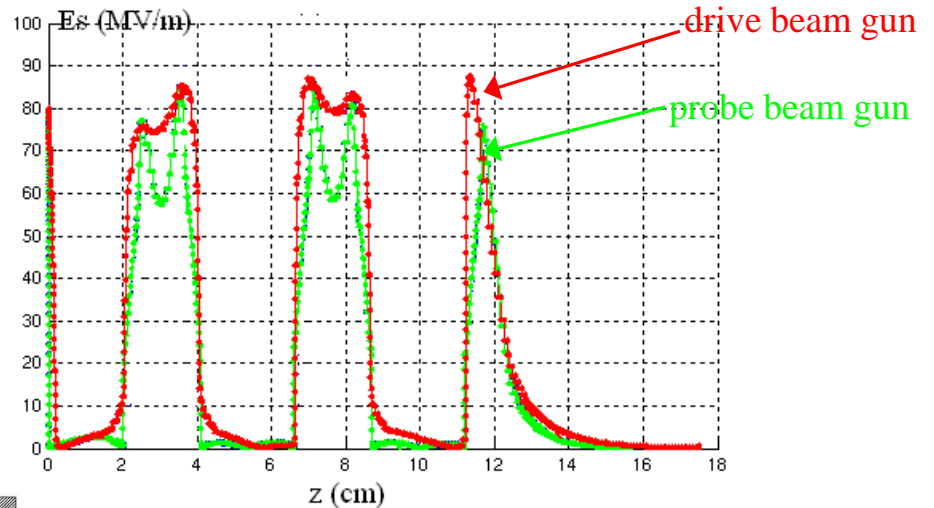
- charge/bunch = 0.5 nC
- bunches 1-64 => No beamloading



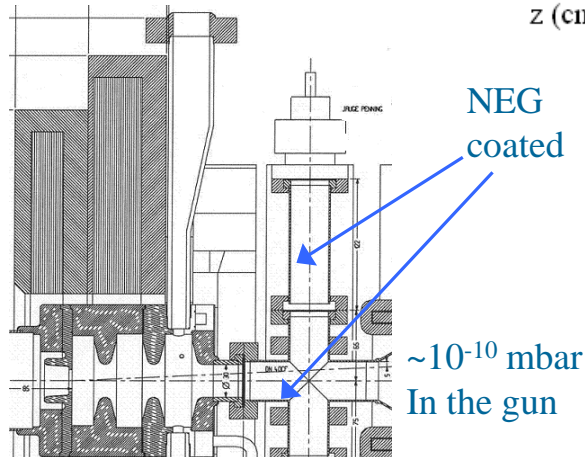
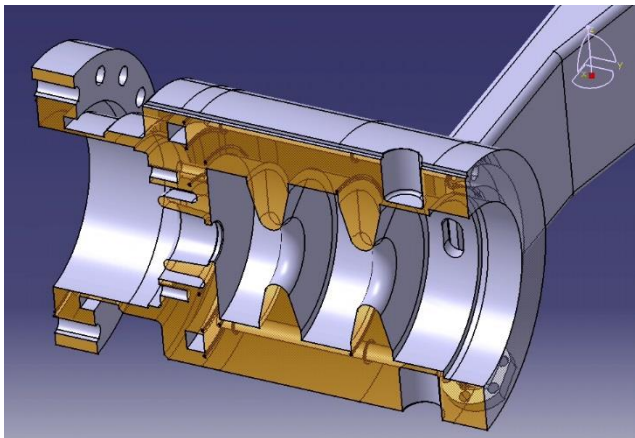
Constraints less severe



Simplified design



$$Q = 14400, R_s = 7.84 \text{ MW} \Rightarrow P_{\text{HF}} = 5.2 \text{ MW} \text{ for } 80 \text{ MV/m}$$



E (MeV)	5.35
σ_r (mm)	2.33
FWHM _z (ps)	8
$\sigma_{\gamma/\gamma}$ rms (%)	0.33
ε (π mmrad)	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