

Simulations for photoinjectors

C.Limborg

1- GTF Simulations

Parmela modeling improvements

Comparison to experimental results: 2ps & 4ps

Sensitivity study

Plans for future simulations

2- LCLS Injector Simulations

New optimized injector with gun @120MV/m

Sensitivity study

3- Parmela/PIC codes Gun Studies

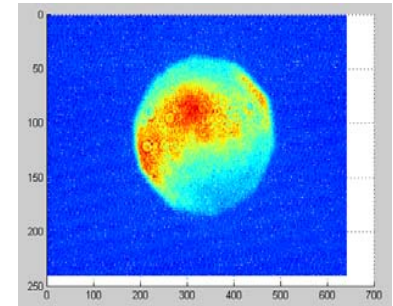
Image charge (PIC code vs Parmela)

Wakefield in gun (PIC codes)

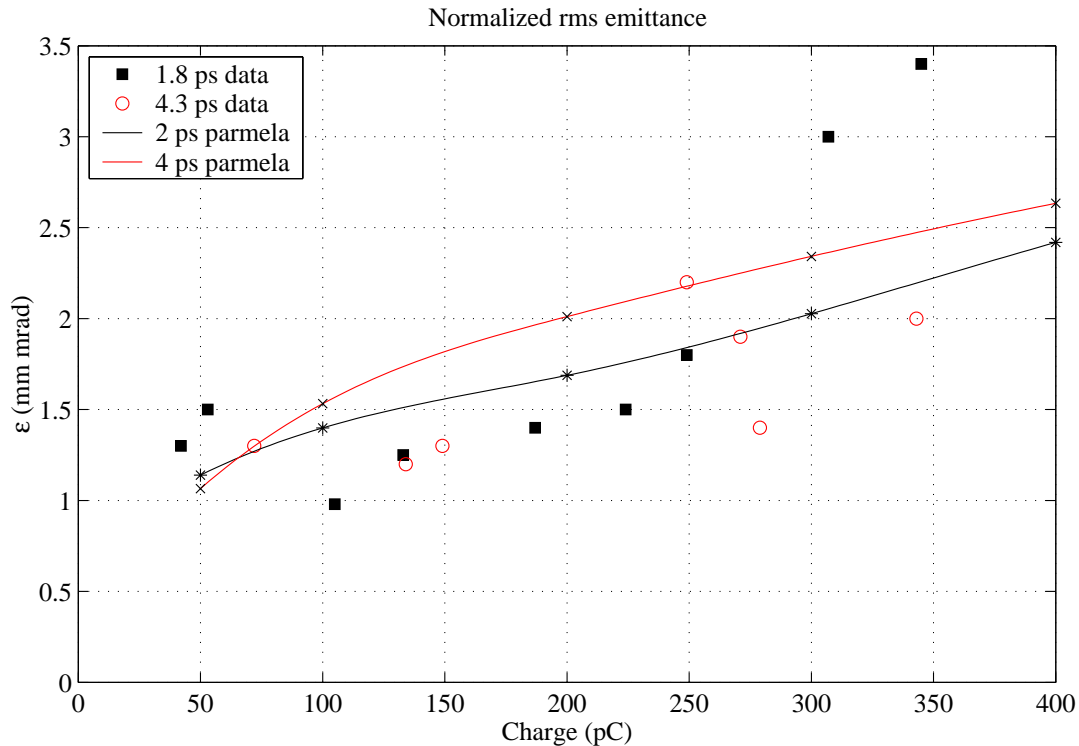
1- Simulations for GTF

A – Upgrades in Parmela modeling of the GTF set-up

- Solenoid field map uses measurements rather than Poisson calculation
(offset +2.55cm for real solenoid compared with field from initial Poisson map)
Variation of ε (mm.mrad) from 1.3 to 1.9 (at real location) (for 200pC)
- Generation of initial distributions from measured laser profile
(transverse and longitudinal) and input them in Parmela
- Parmela-LANL now performs 3-d space charge computation
and can compute effects of non-uniform profiles
- Quad Scan with Parmela



B- Comparison to experimental results: ϵ vs Q for 2ps-4ps pulses



Parameters

Cathode Field = 110MV/m

$\phi_{\text{gun}} \approx 40^\circ$

$r = 1\text{mm}$

$B_{\text{solenoid}} \approx 2\text{kG}$

Linac Gradient = 8.55 MV/m

Cathode-to-Linac Distance = 90 cm

- “Good agreement” with Parmela
- Quad Scan with Parmela gives 15% smaller emittance with 5% truncation of tails (similar truncation used in experiment)

Why 2ps is lower than 4ps:

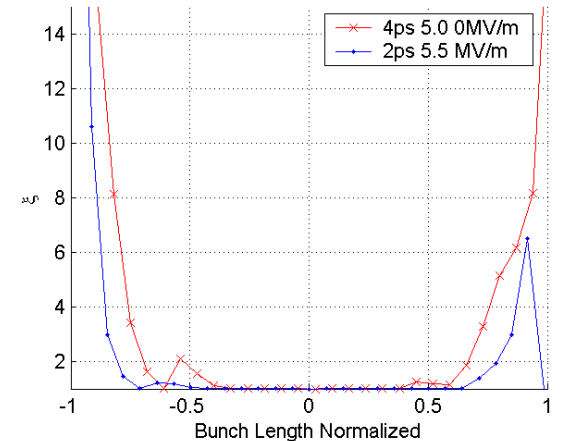
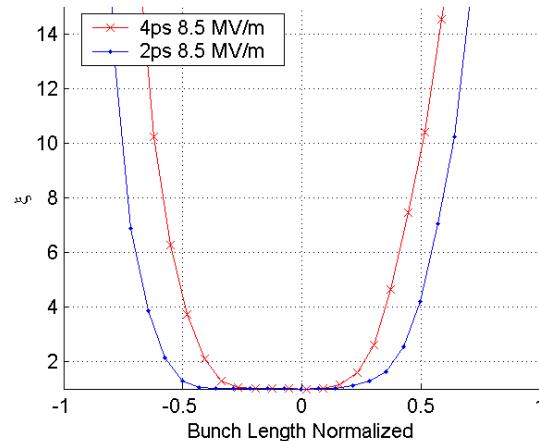
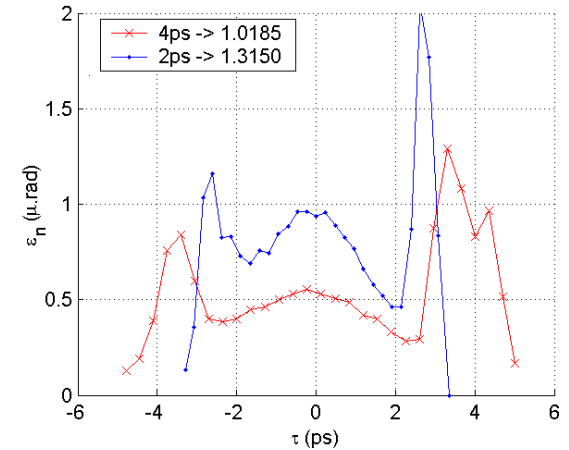
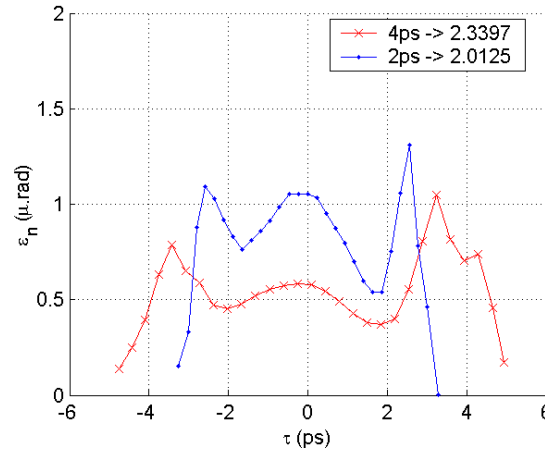
for the 300pC case

- 4ps core emittance lower than 2ps
- Matching of slices better for 2ps at standard booster gradient
- Matching is improved with lower gradient for both 4ps and 2ps
- With better matching

$$\epsilon_{4ps} < \epsilon_{2ps}$$

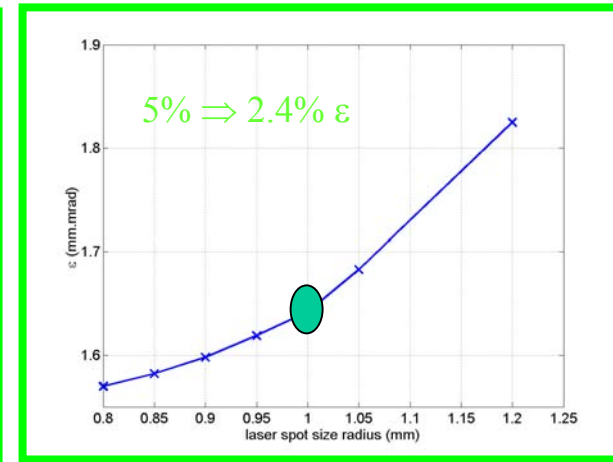
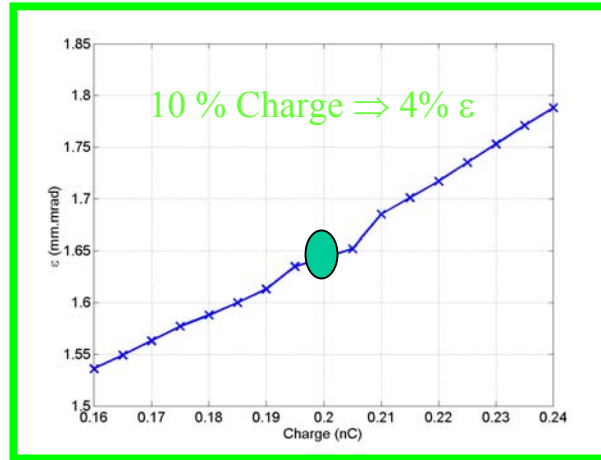
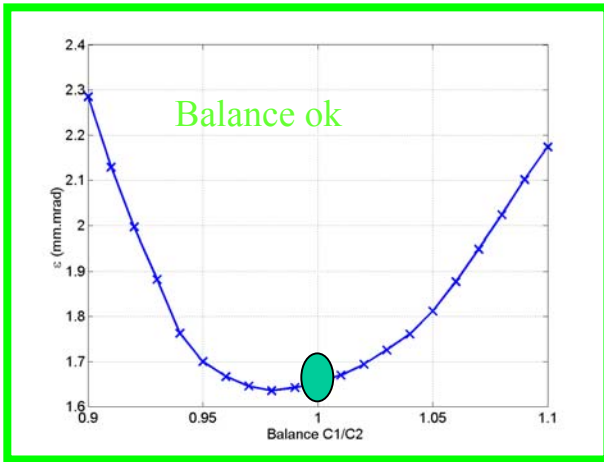
Mismatch parameter

$$\xi = \frac{1}{2} (\gamma_0 \beta - 2\alpha \alpha_0 + \beta_0 \gamma)$$

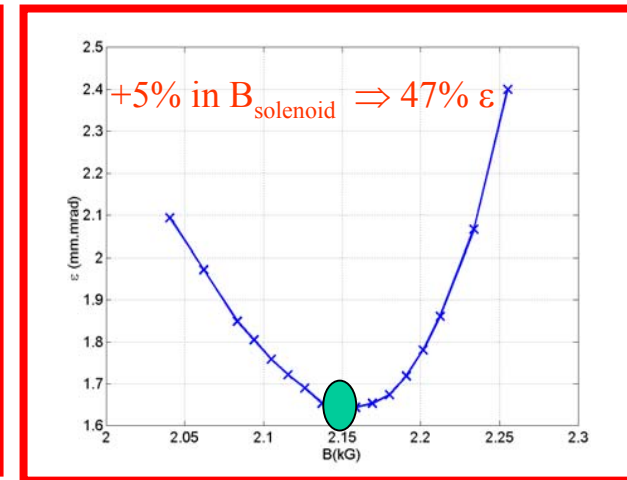
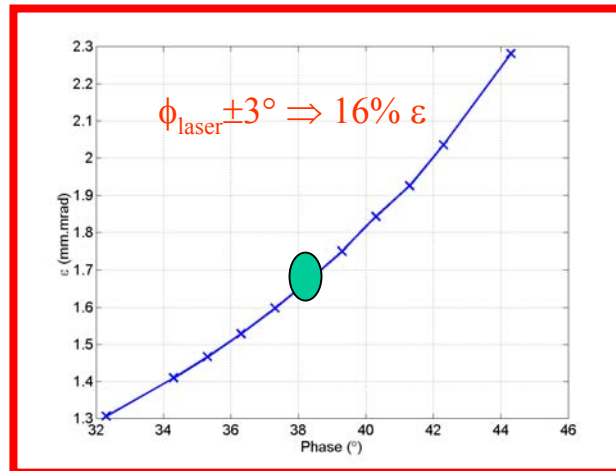
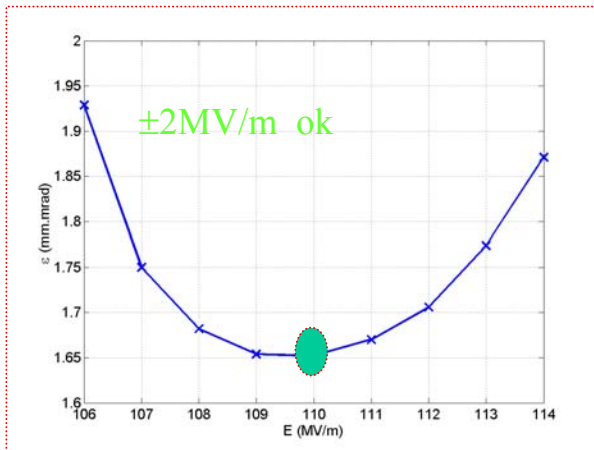


C- Sensitivity study

For 200pC, 2ps pulse , values at 20cm from exit of booster

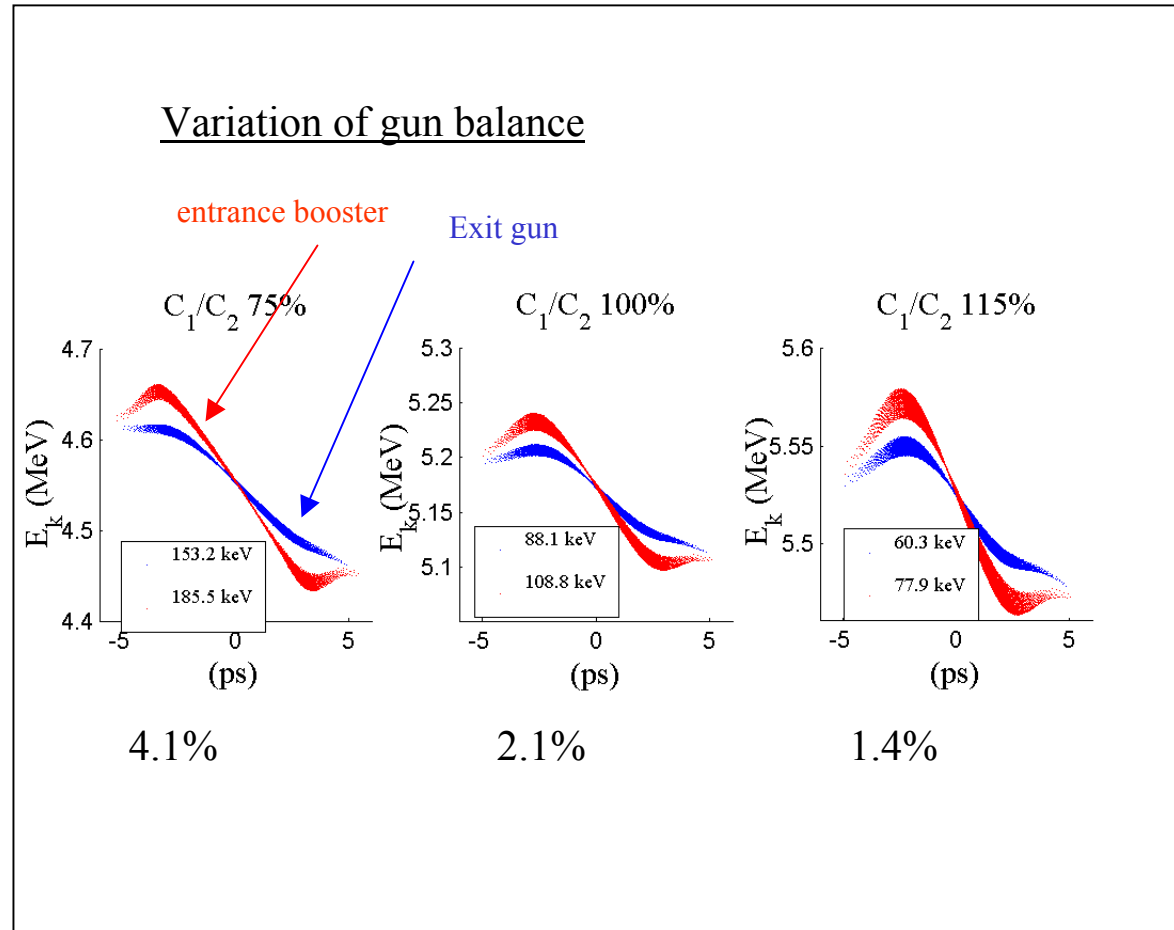


ϕ_{laser} & I_{solenoid} have tight tolerances



D- Energy Spread Experiment vs Simulations

- Measurements give
400 keV (7.7%) at booster entrance
- Simulations give 109 keV (2.1%)
- Suspects:
 - gun balance ?
 - wakefields ?



E- Summary simulations for GTF

- Major simulation result

“Good Agreement” with experimental data

1 mm.mrad emittance for 100 A should be achievable with present GTF configuration by

- operating the booster at specific gradient for minimum ε
- or running at $\phi = 30^\circ$

- Program of Simulations for sake of experiments

- Systematic comparison of :

Beam size, Twiss parameters, ε while scanning B_{solenoid} , Linac Gradient, Laser Phase

- Systematic Parmela Quad Scans
 - Transverse profile as input distributions (and 3D simulations)
 - Comparison with more longitudinal emittance measurements (study balance and wakefield)
 - Other facilities data (more comparisons with Parmela)

2- Tuning LCLS beamline

A- Tuning Gun 140MV/m (Fall 2000)

1nC, 10ps flat top pulse with 0.35/0.7 ps rise time

Hard edge flat transverse spot size with $r = 1\text{mm}$

Added second solenoid around traveling wave section

Gun			Solenoid 1		Linac1			Solenoid 2	
r spot size (mm)	ϕ (°)	E (MV/m)	Position (cm)	B (kG)	Position (m)	ϕ (°)	E (MV/m)	Position (m)	B (kG)
1.0	32	140	0	3.15	1.4	2	24.1	1.43	1.5

for $\epsilon_{\text{th}} = 0.3\text{ mm.mrad}$

	ϵ (mm.mrad) for 20 k particles	ϵ (mm.mrad) for 100k particles
Rise time 0.35 ps	0.80	0.78
Rise time 0.71 ps		0.95

B- Gun 120MV/m: Strategy followed

- Homdyn tuning:

With $\varepsilon_{th} = 0.3$ mm.mrad optimization gave $\varepsilon = 0.41$ mm.mrad

(Parmela using same parameters gave 1.6 mm.mrad)

Homdyn gives good range of solenoid field but cannot give fine tuning

- Parmela tuning:

1. With spot size radius of 1 mm, best emittance places linac at 2.2 m from cathode

2. Cathode-to-Linac distance can be reduced to 1.4m by

- Increasing radius spot size (from 1mm to 1.2 mm) to reduce space charge effect without increasing too much RF effects
- Lowering gradient field in Linac 1 to smoothly match to system gun + solenoid beam (too high gradient => strong focusing kick at entrance => loss of laminar flow)

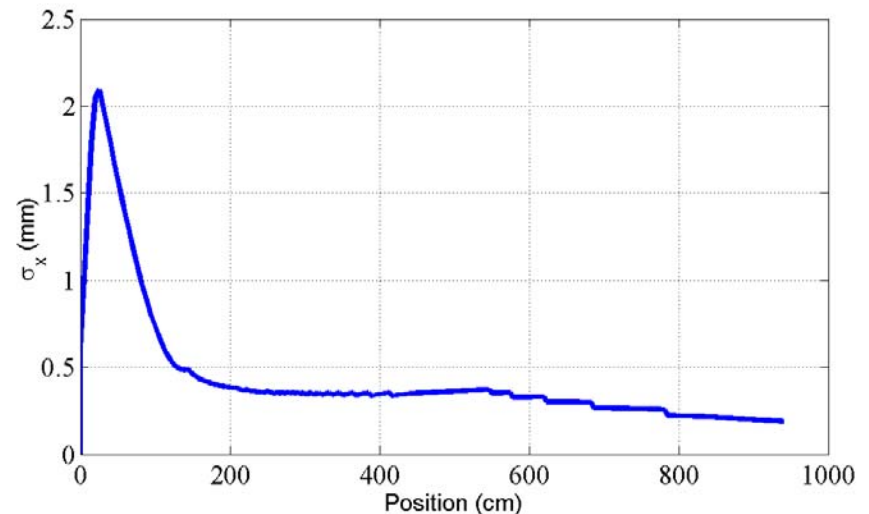
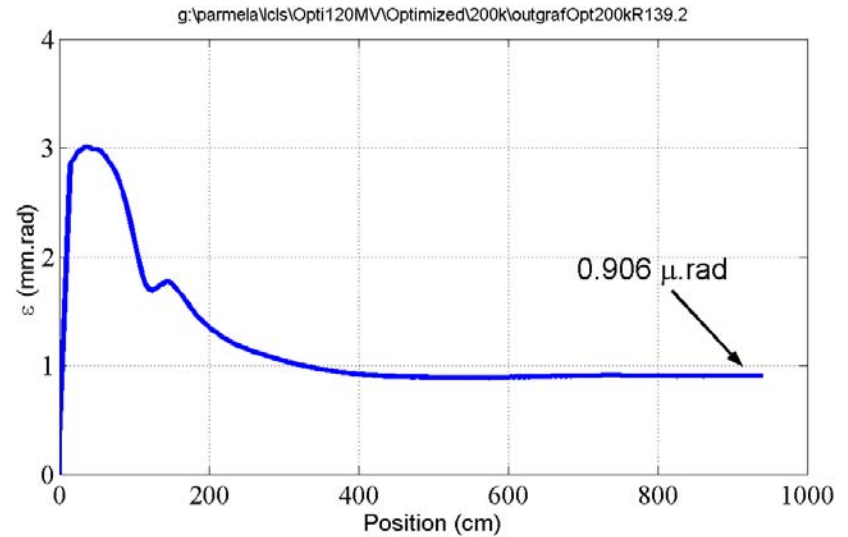
See also L.Serafini/J.B.Rosenzweig matching condition

$$\gamma' = \frac{2}{\sigma_w} \sqrt{\frac{\hat{I}}{3I_o\gamma}}$$

Optimization deck with gun at 120MV/m

- Nicely converging beam
- Linac 0-1 at 1.4m (as case gun 140MV/m)
but with gradient at 18MV/m
- Two solutions for gradient of second linac
 1. Final energy 150 MeV
(Linac 0-2: 30.5 MV/m)
 2. Final energy 130 MeV
(Linac 0-2: 24.1 MV/m)
- Parmela-LANL 3D showed no emittance growth along diagnostics-transfer line for initial deck

no emittance growth expected even at 130MeV, but still needs to be checked



C- Summary deck with Gun 120MV/m Nov-2001:

For 1nC, 10ps pulse flat top with 0.7 ps rise time, uniform transverse disk

Gun			Solenoid 1		Linac			Solenoid 2	
r mm	ϕ (°)	E MV/m	Position cm	B kG	Position m	ϕ (°)	E MV/m	Position m	B kG
1.2	27.3	120	0	2.7079	1.42 m	2	18	1.40	0.75

150 MeV (Linac 0-2: 30.5MV/m)

ϵ at 20 cm from exit Linac0-2	ϵ (mm.mrad) 10 k particles	ϵ (mm.mrad) 200k particles
$\epsilon_{th} = 0.3$ mm.mrad	0.929	0.919
$\epsilon_{th} = 0.5$ mm.mrad	0.956	0.958

130 MeV (Linac 0-2: 24.1M/m)

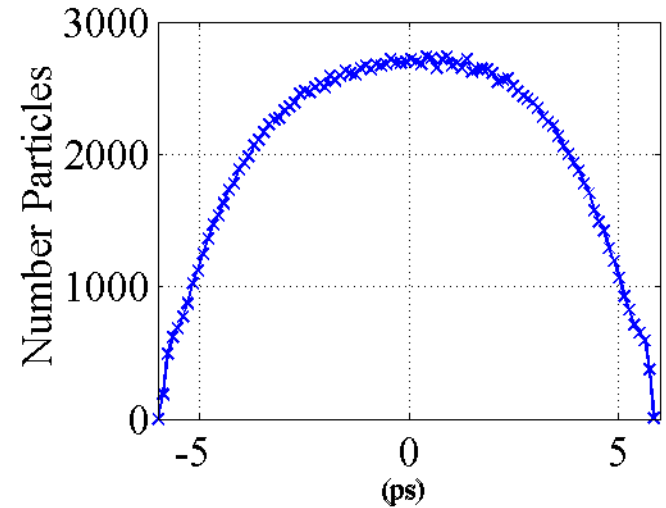
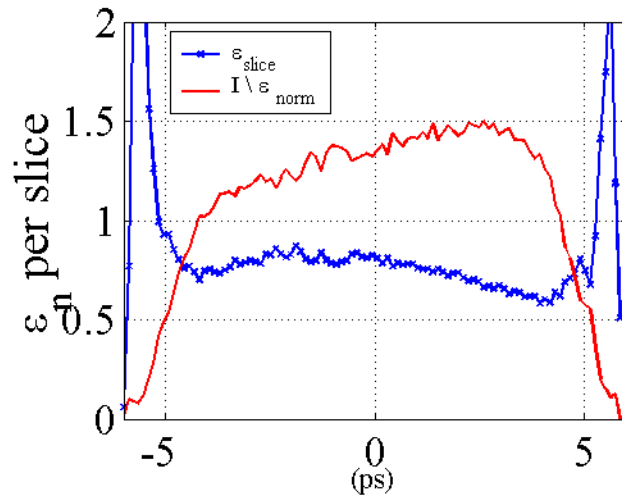
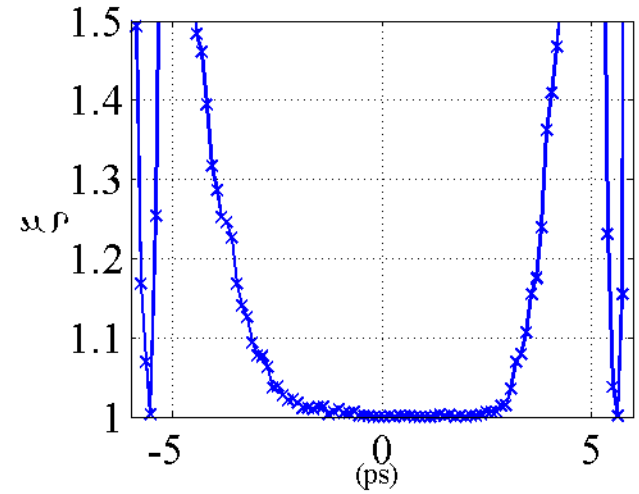
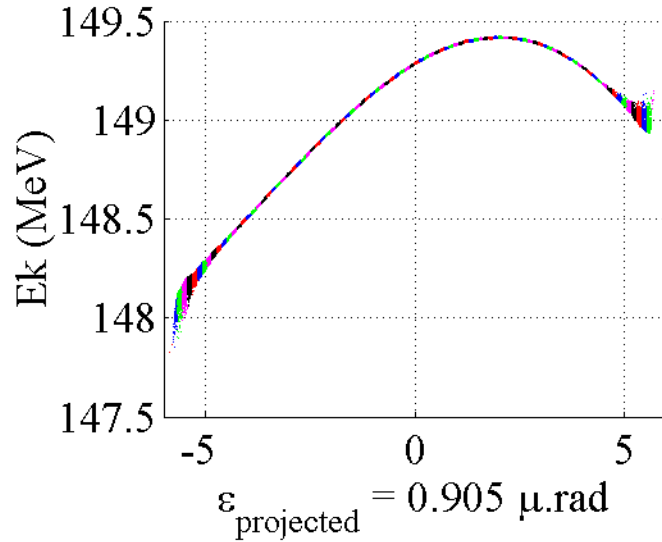
	ϵ (mm.mrad) 10 k particles	ϵ (mm.mrad) 200k particles
$\epsilon_{th} = 0.3$ mm.mrad	0.915	0.921
$\epsilon_{th} = 0.5$ mm.mrad	0.956	0.960

D- Beam quality:

Slice ε
 97% part. $\varepsilon_i < 1$
 95% part. $\varepsilon_i < 0.9$
 71% part. $\varepsilon_i < 0.8$

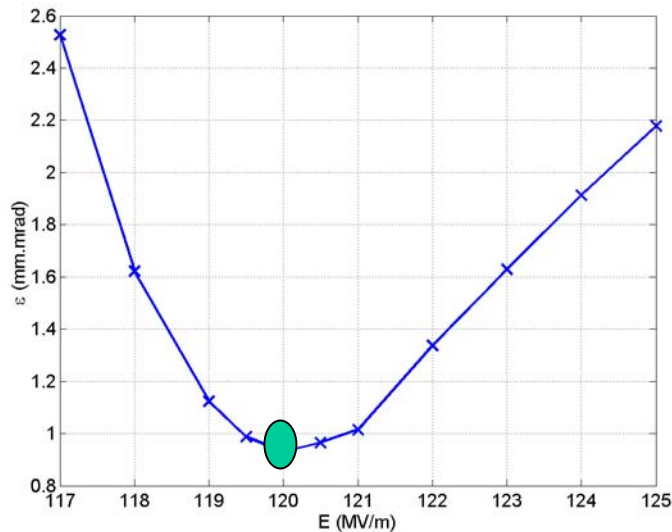
$$\xi = \frac{1}{2}(\gamma_0\beta - 2\alpha\alpha_0 + \beta_0\gamma)$$

Matching parameter



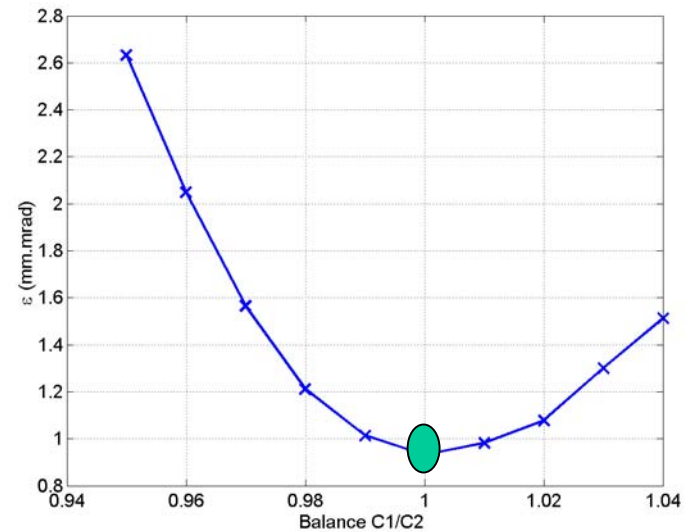
E- Sensitivity study on optimized deck (gun 120MV/m)

E field (MV/m)



No more than 0.5MV/m

Gun Balance (ratio $E_{\text{cell1}} / E_{\text{cell2}}$)

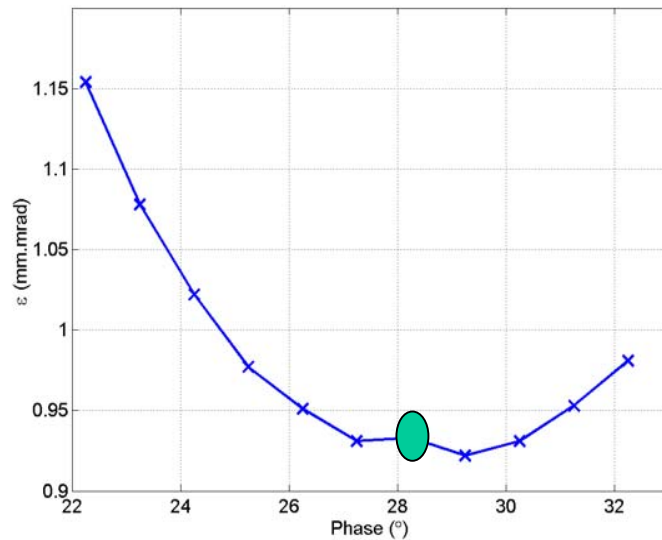


Balance cannot vary by more than 1%

Future work: will re-optimize with gun balance ratios of 0.95 and 0.8

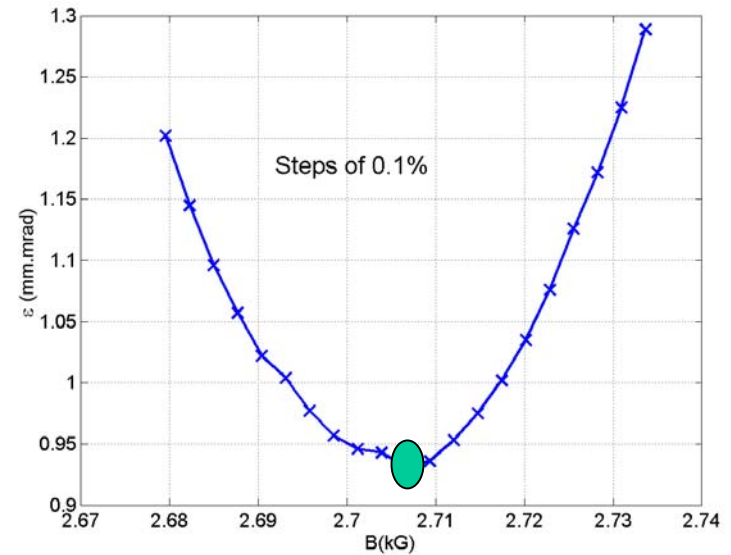
E- Sensitivity on optimized deck (gun 120MV/m)

Laser Phase



+/- 3 ° ok

Solenoid field

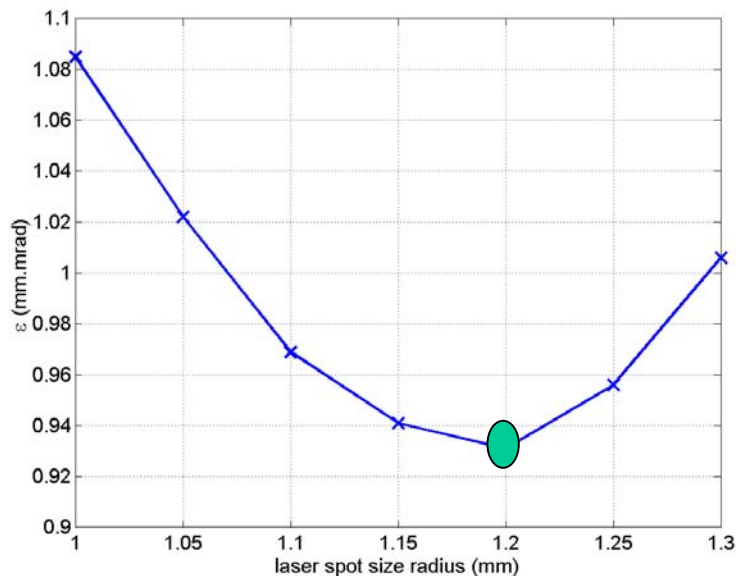


No more than +/- 0.3 %

Future work will scan solenoid position and length

E- Sensitivity on optimized deck (gun 120MV/m)

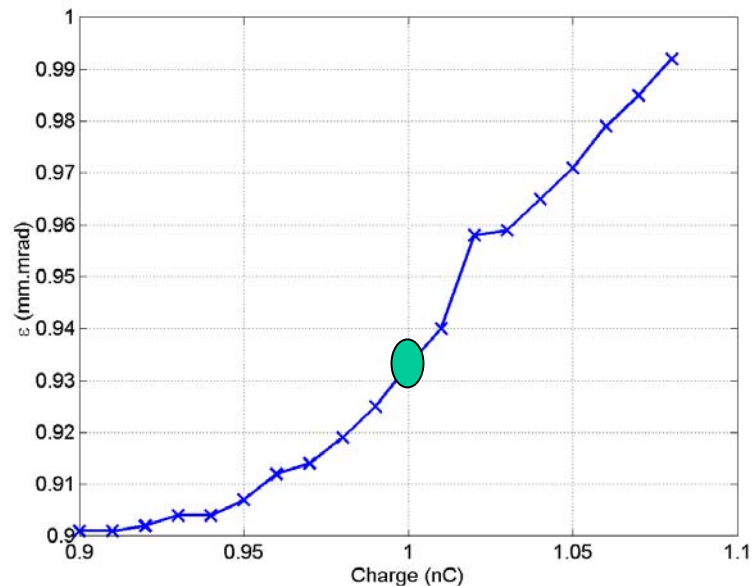
Spot size radius



Weak sensitivity

+/- 0.1 mm ok

Charge



Jitter 10% on charge ok

Sensitivity study to be completed with
Variations on longitudinal distributions
Variations on transverse distributions

3- Parmela/PIC codes: Gun Studies

A- Image charge- shear of velocities (V.Ivanov- E.Colby-C.Limborg)

First 40 ps after extraction when static field 100MV/m on cathode:

- image charge on cathode

=> Parmela includes image charge while PIC code solves Maxwell equations

- shear of velocities

=> Parmela computes in frame of reference particle at a stage where spread in velocities is large; the shear of velocities is not a problem despite the coarse approximation made in Parmela

Good agreement between all 4 codes for transverse emittances & beam sizes

2 PIC codes: Magic2D and Maxwell-T and

2 parmela versions: Parmela-UCLA and Parmela-LANL

PIC codes give emittances smaller than those from Parmela by 20%

B- 3D map of fields

- 3D map including the 2 ports: very small quadrupole component whose effect (less than 1%) is in the accuracy of the numerics

results from Parmela-UCLA run with 3D Mafia map (from Zenghai Li)

	(1) 150pC, r = 1mm	(2) 50 pC r = 5mm	(3) No SC, No Bsol, r = 5mm
2D / 3D σ_x (cm)	0.849 / 0.878	3.626 / 3.589	4.002 / 3.581
%	3.30	-1.02	-10.52
2D / 3D ϵ_x (mm.mrad)	0.3867 / 0.3904	3.3188 / 3.689	4.2504 / 3.831
%	1.20	10.04	-9.87
2D / 3D γ	10.7516 / 11.0589	10.8482 / 11.0125	10.7189 / 11.0125
%	2.78	1.49	2.67

- Plans to test effects of feed from a single side

(analytic- PIC code in time domain)

C- Comparison full Gun- PIC Code vs Parmela

- Task force (V.Ivanov, E.Colby, C.Limborg, P.Krejcik) working on PIC code simulations of the entire gun for determining the effect of wakefields

choice of codes: Maxwell-T (2.5D) : author in house

 Magic 2D: possible migration to 3D

- If PIC code simulations show that wakefield effects cannot be neglected in the gun, a transfer from the PIC code output to Parmela input will be made at the end of the gun
- Need to study ways to include Schottky effect

Summary

- Simulations vs experiments

- “Good agreement” with experiments for transverse emittances measured at GTF
- Tools developed for systematic comparison with experimental data
(quad scan- 3D to include transverse profile- many simulation diagnostics)
- Need to explain fully discrepancy with measured energy spread
- Comparisons with other facilities data

- LCLS tuning

- Good flexibility of present set-up
(accommodates gun 120MV/m and 140MV/m with same linac position)
- Very good slice emittance (< 0.8 mm.mrad)
- Sensitivity study nearly completed

- PIC code / Parmela task force

- Work carried on to answer wakefield question