



WP6

S-band based linac option status and linac modelling for FELs

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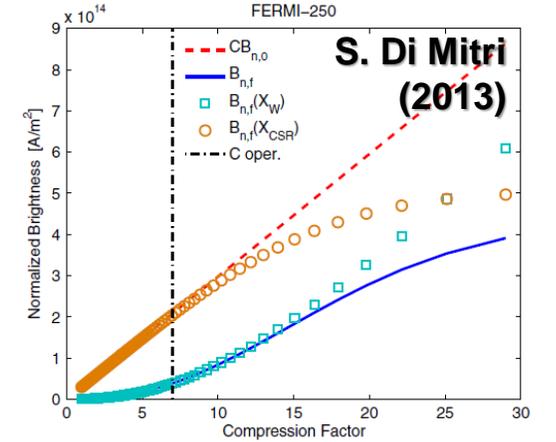
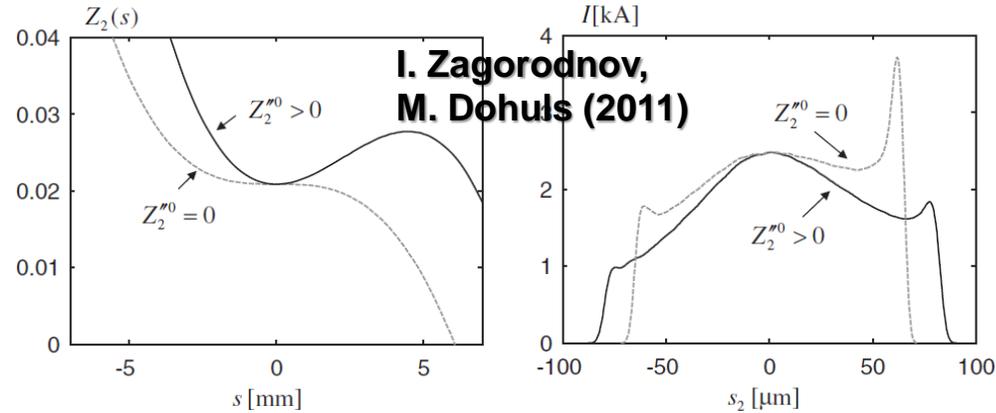
E. Marin, R. Munoz Horta – ALBA CELLS

A. Faus Golfe, Y. Han – LAL

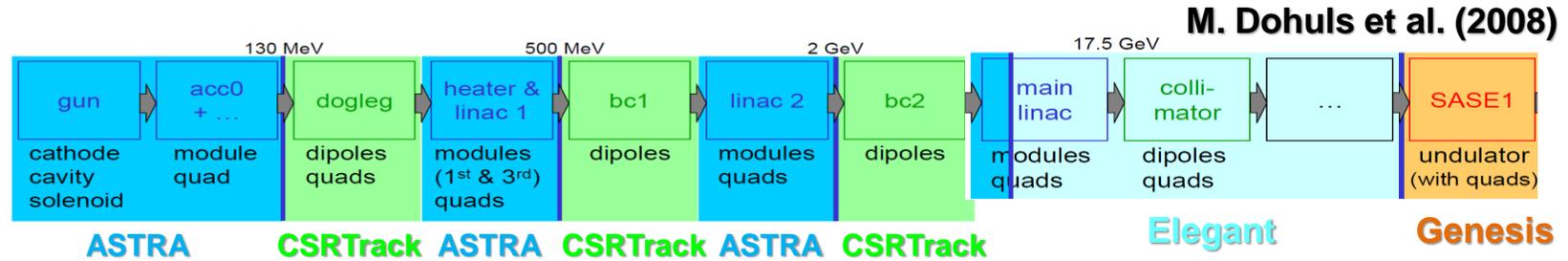


Codes

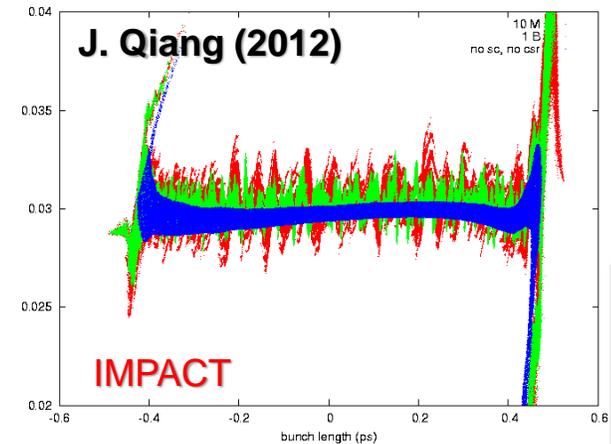
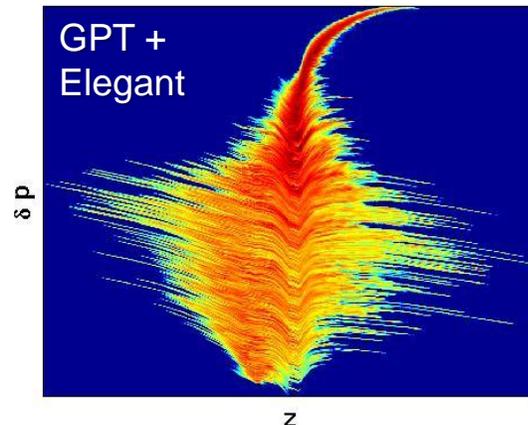
1. **Semi-analytical** models of beam collective dynamics provide guidance to a first step-machine design.



2. **Chains of specialized codes** allow to balance accuracy vs. CPU time in S2E simulations.



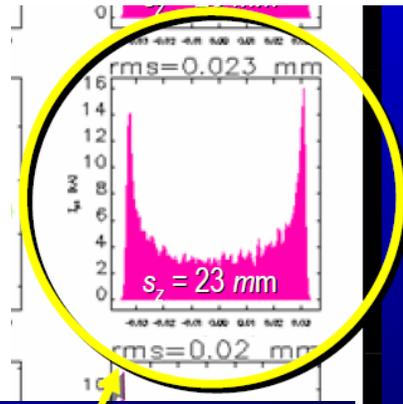
3. **PIC** codes allow tracking with **real number** of electrons, e.g. from 0.4 to 5 billion or so.



Geometric (RF) Wakefields

- ❑ Geometric and RW wakefields can be computed accurately, and imported into tracking codes.
- ❑ Strong wake potential + magnetic compression = multi-kA current spikes at bunch edges.
 - Spikes drive CSR & microbunching instability, and RW wake in low-gap pipe.
 - Spikes magnitude

P. Emma for
LCLS (2009)



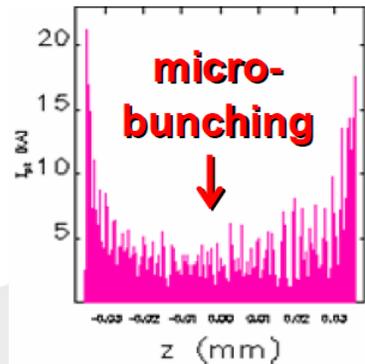
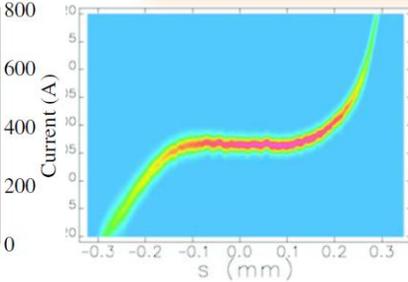
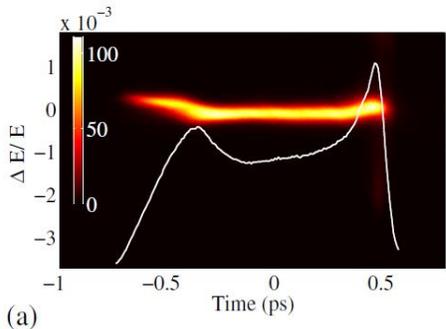
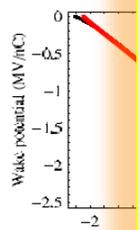
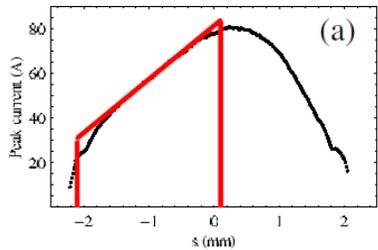
Wakefields data (to be made available):

- S-band Injector*
- X-band Linac*
- Resistive Wall wake in Undulator ?*

wakefield.

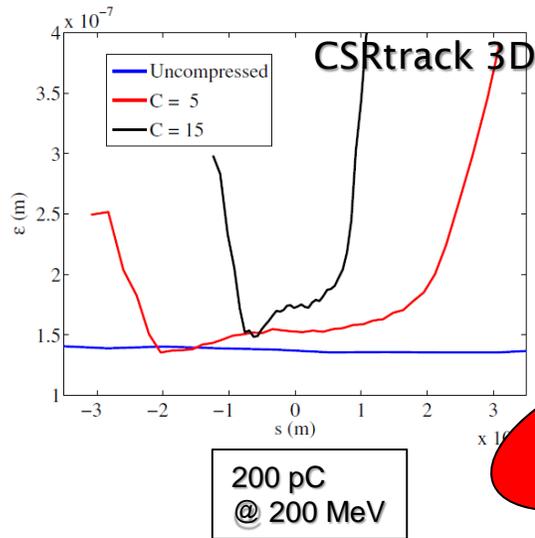
and on details of injector distribution

M. Cornacchia et al. (2011)
G. Penco et al. @ FERMILAB

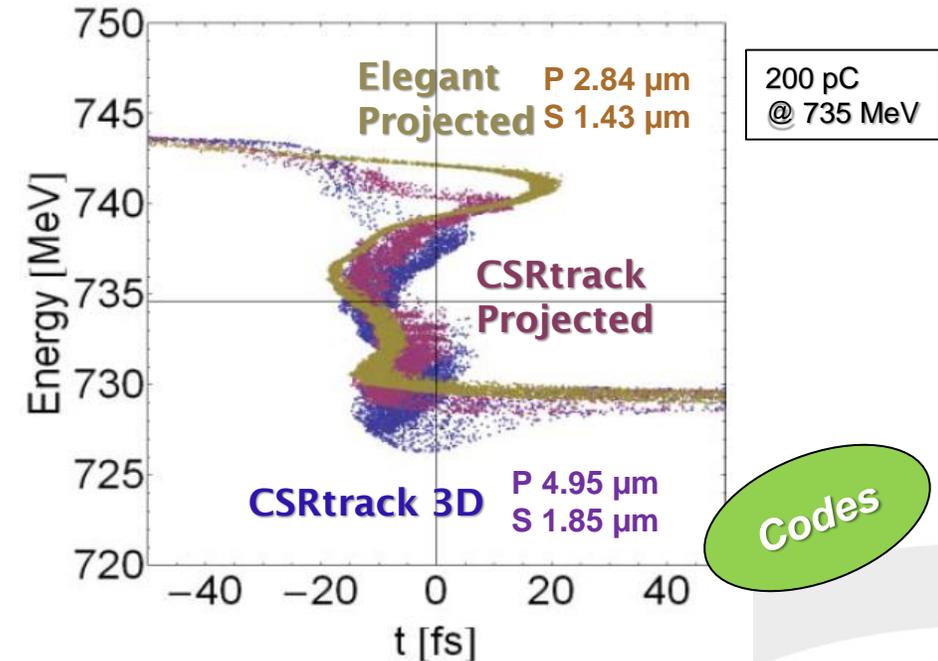
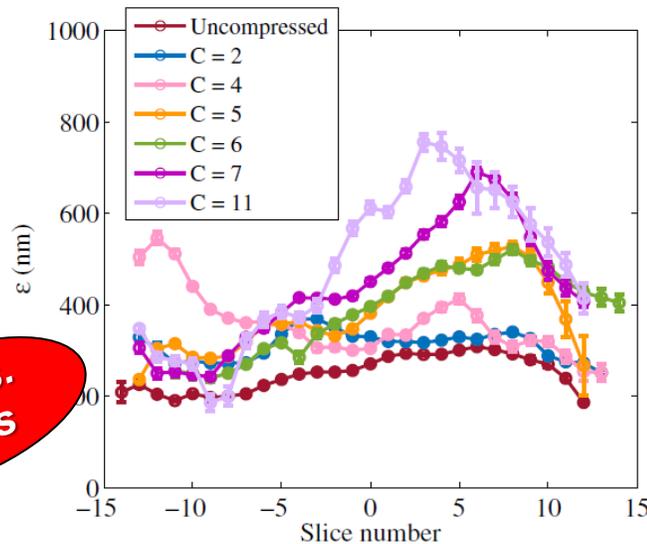


CSR – 1D vs. 3D

- ❑ Projected emittance control is favoured by **uniform slice Twiss** parameters → injector optimization.
- ❑ Slice norm. emittance is typically perturbed at $< 0.05 \mu\text{m}$ level. Can be much worse at **full compression**.
- ❑ **3-D codes** needed to predict slice emittance growth. 1-D runs typically over-estimate the final projected emittance.



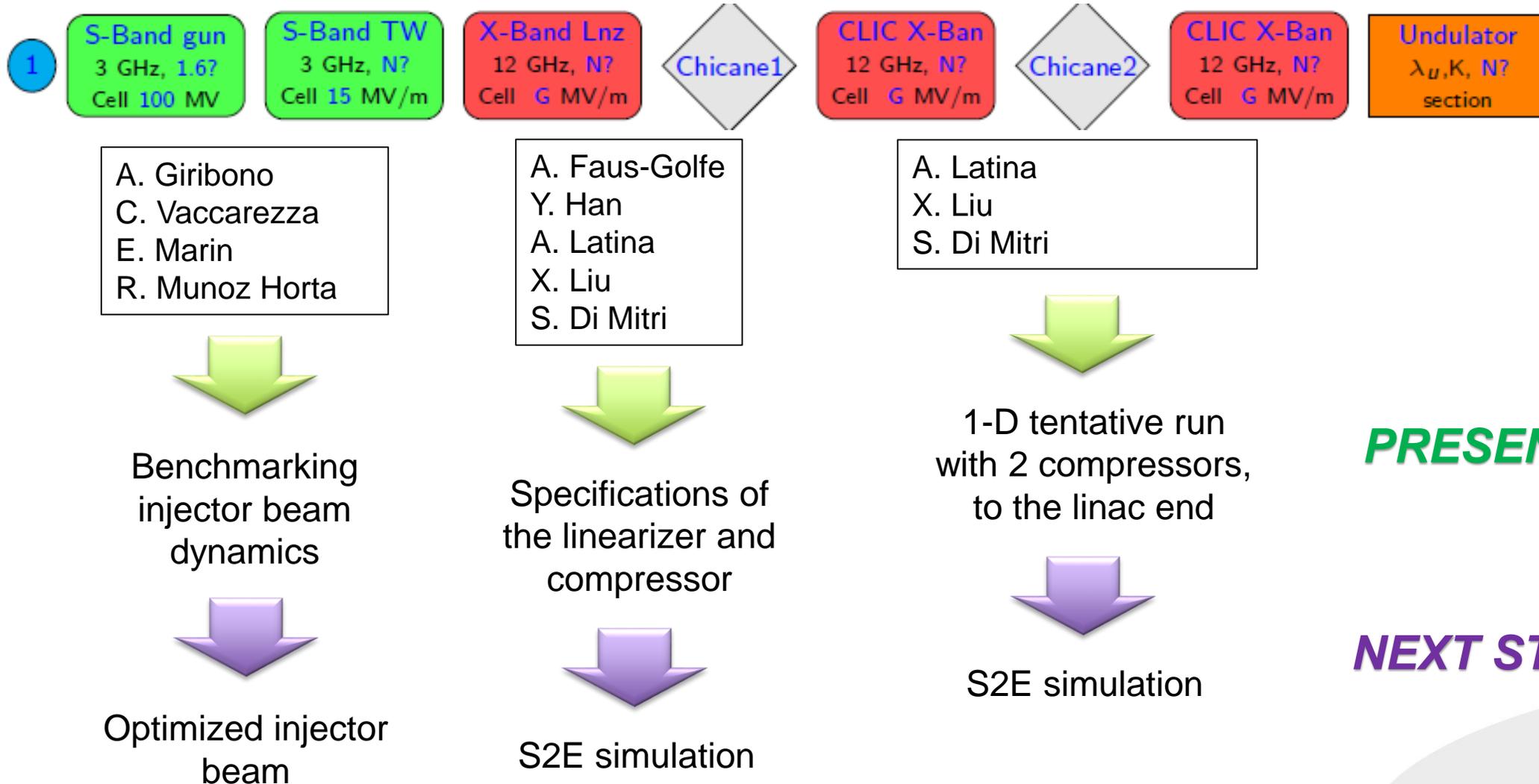
S. Bettoni et al., PRAB (2016)



H. Owen et al. for NLS (2008)

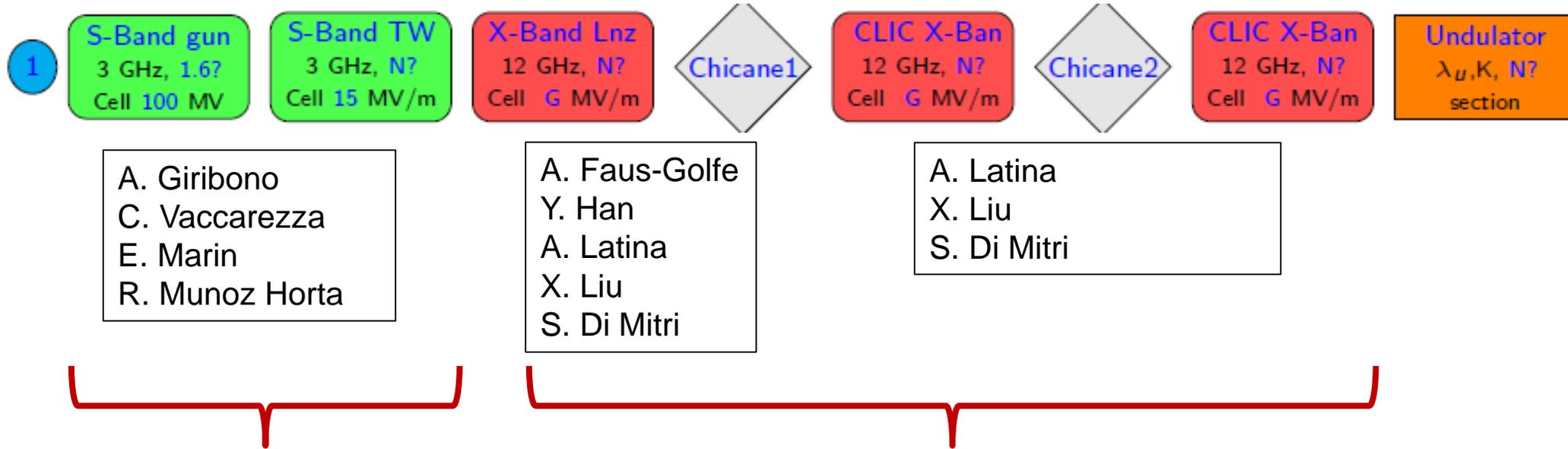


Work Plan, 2.A option





Codes – Our Choice



□ TStep

- GPT
- Astra
- RFTrack

- 3-D Space-charge
- // and \perp geometric wakefields

□ Placet

- LiTrack
- Elegant
- GPT

- // and \perp wakefields
- CSR (3-D)
- Microbunching instability



Charge

$$I = Q/(\sqrt{12}\sigma_t) \text{ for parabolic charge distribution}$$

$$\epsilon_n [\mu m rad] \approx \sqrt{Q [nC]} \text{ for S-band NC Gun, w/o RF bunching, long bunches}$$

$$\lambda_{min, SX} = 0.7 \text{ nm}$$
$$\lambda_{min, HX} = 0.05 \text{ nm}$$

+

$$E_{f, SX} = 4 \text{ GeV}$$
$$E_{f, HX} = 9 \text{ GeV}$$

=

$$\epsilon_{n, SX} \approx 0.4 \mu m rad$$
$$\epsilon_{n, HX} \approx 0.07 \mu m rad$$



$$Q_{SX} < 160 \text{ pC}$$
$$Q_{HX} < 5 \text{ pC}$$

(FEL specs)
(FEL specs)

(assumption from
preliminary FEL
scaling laws)

(diffraction limit,
 $\epsilon_n \leq \gamma\lambda/(4\pi)$)

- Spec on #ph/pulse suggests:
 $Q > 50 \text{ pC}$ anyhow, and **$I_f > 2 \text{ kA}$**
- 3-D simulation:
minimize ϵ_n at the expense of σ_t



$$Q = 75 \text{ pC}$$
$$\sigma_t \sim 1 \text{ ps}$$
$$\epsilon_n \sim 0.2 \mu m rad$$
$$I_i \sim 15 \text{ A}$$

&

$$CF \sim 150$$



RF bunching $\times 5$
Chicane 1 $\times 30$



Chicane 1 $\times 15$
Chicane 2 $\times 10$

Injector (\rightarrow 100 MeV)

This slide by:
A. Giribono (INFN)

ONGOING

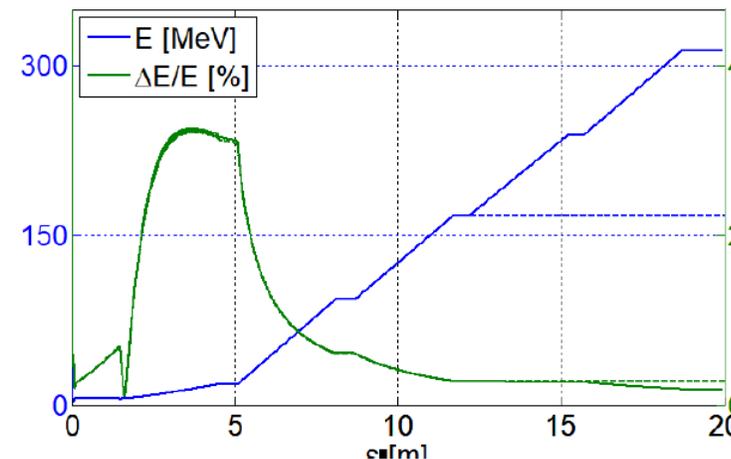
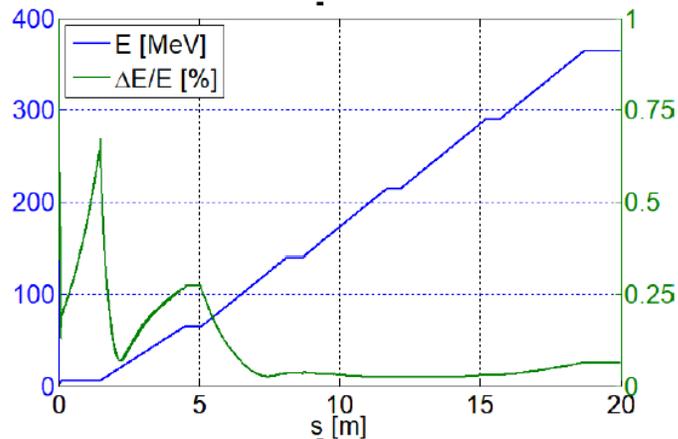
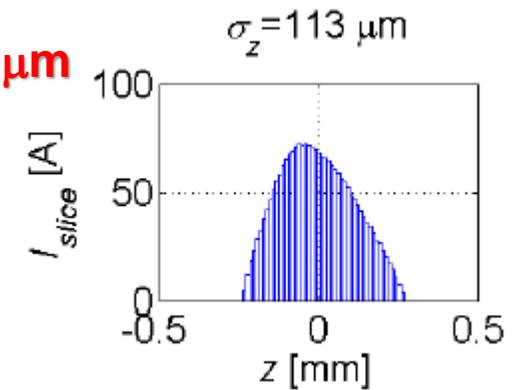
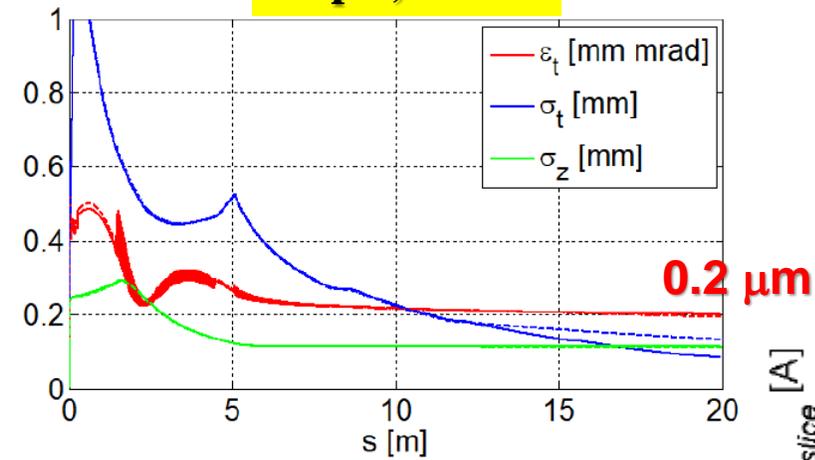
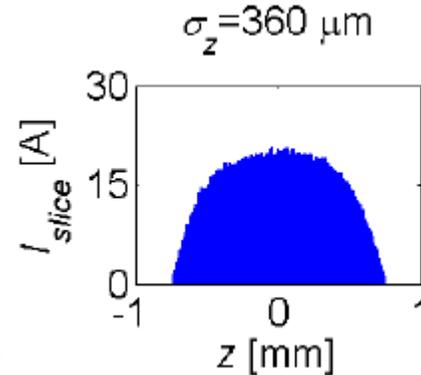
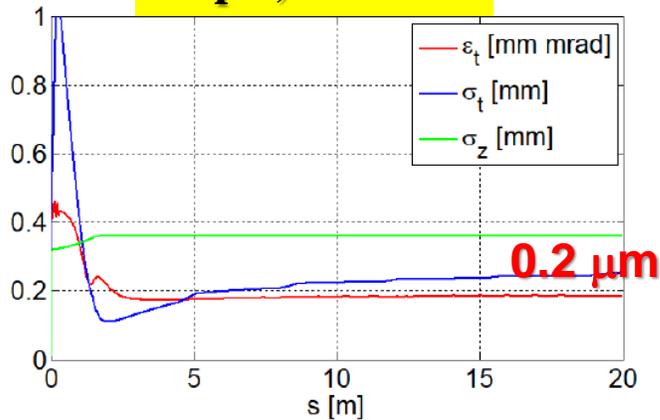
3-D codes (space charge) benchmarking:
TStep vs. GPT vs. Astra

Nominal beam parameters:
optimization w & w/o VB

75 pC, w/o VB

DONE

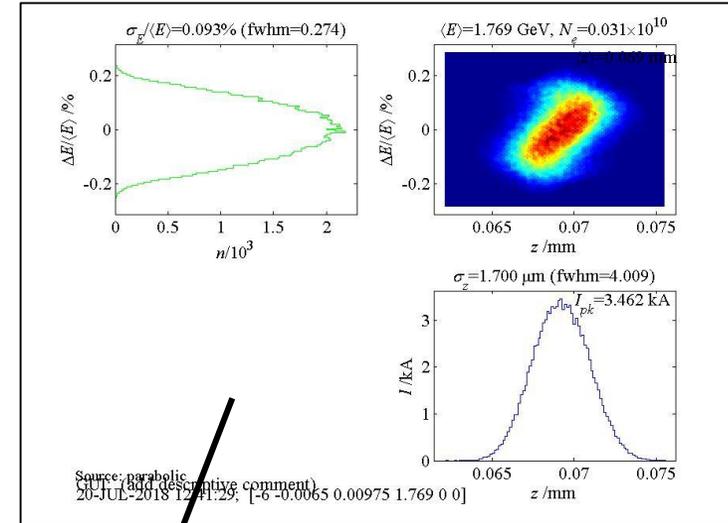
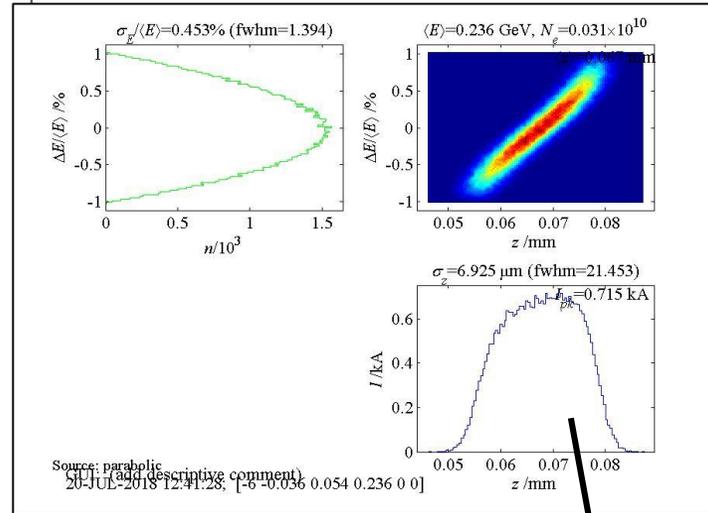
75 pC, w VB





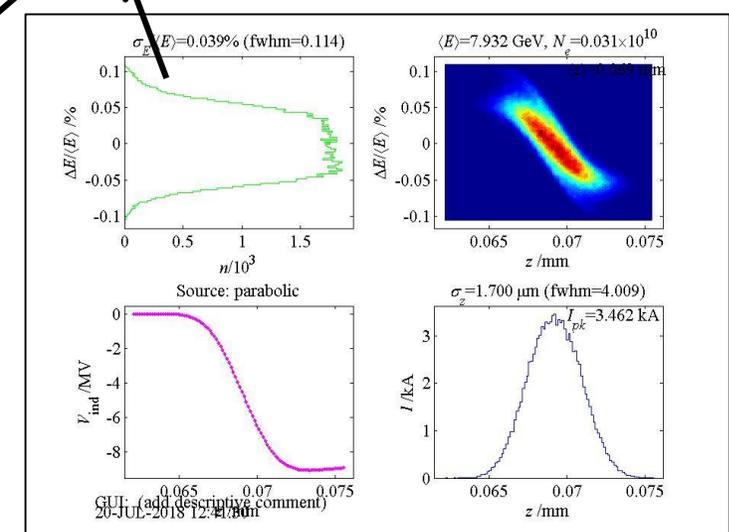
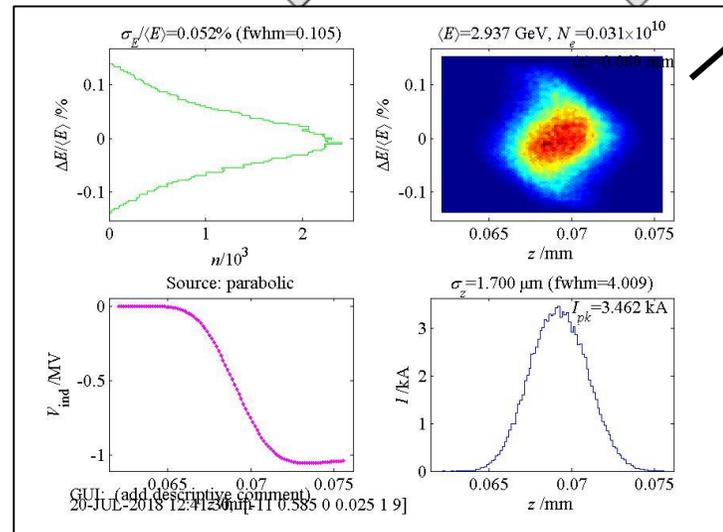
Main Linac (\rightarrow GeVs)

$Q = 50 \text{ pC}$
 $I_i \sim 30 \text{ A}$
 $CF = 20 \times 5$



EXERCISE

- One injector beam for both SX and HX
- One linac setting for both SX and HX
- SX-beam extracted at intermediate energy



Lessons Learned & Status

1. $Q = 75$ pC is a starting point. S2E runs will tell us if $\epsilon_x \sim 0.2$ $\mu\text{m rad}$ & $I \sim 3$ kA are good enough for SX FEL.
2. HX FEL specs are *critical* (75 pC, 0.1 $\mu\text{m rad}$, 9 kA !!!).
3. X-band longitudinal wakefields impose off-crest acceleration for energy chirp compensation (manageable).
4. CF ~ 150 most likely. CSR-induced projected emittance growth might become an issue (reduction of FEL gain) for CF > 100 .



- S-band injector file with optimized emittance/current @ 75 pC soon available (*INFN*)
- GPT vs. Astra vs. TStep benchmarking soon finalized (*ALBA, INFN*)
- S2E run with GPT ongoing (*ALBA*)
- 1-D run (*Elettra*) and S2E run (*ALBA, CERN*) follow



SX FEL – F. Nguyen 18 Oct.'18

<i>Undulator parameters</i>	
undulator period	1.7 cm
undulator gap	3 mm
deflection parameter (RMS)	1.9
<i>Bunch parameters</i>	
beam energy	4 GeV
pulse duration (FWHM)	10 fs
bunch charge	20 pC
peak current	1.9 kA
norm. emittance	0.12 mm×mrad
energy spread	0.01 %
<i>Potential reach</i>	
FEL wavelength ($\hbar\omega$)	0.66 nm (1.9 keV)
N_γ /pulse	5.6×10^{11}
E_{FEL} /pulse	0.2 mJ
saturation length	21 m

Small increase in E_{beam} allows to reach for 0.6 nm (2 keV) comfortably

Emittance stays well between Pellegrini's and Di Mitri's limits

Variable polarization & Two Colours operations require careful feasibility studies with these undulator parameters, in particular at small period:

H. M. Castaneda Cortes is tackling this issue in WP5 and is greatly acknowledged

Please, stay FEL-tuned



HX FEL – F. Nguyen 18 Oct.'18

<i>Undulator parameters</i>	
undulator period	1.3 cm
undulator gap	3 mm
deflection parameter (RMS)	1.17
<i>Bunch parameters</i>	
beam energy	9 GeV
pulse duration (FWHM)	7.5 fs
bunch charge	75 pC
peak current	9 kA
norm. emittance	0.12 mm×mrad
energy spread	0.01 %
<i>Potential reach</i>	
FEL wavelength ($\hbar\omega$)	0.05 nm (25 keV)
N_γ /pulse	2.5×10^{11}
E_{FEL} /pulse	1 mJ
saturation length	25 m

Stay in the middle!

Hard to reach for 1 mJ energy/pulse with much lower charge or much higher emittance

Hard to achieve much lower emittance with such a charge

Bottom line: this is our choice, but feel free to round up values at your convenience and risk!