A European Proposal for the Compton Gamma-ray Source of ELI-NP

C. Vaccarezza
on behalf of the collaboration

Outline

- *The European Collaboration*
- *The Source design*
- *The electron & laser beam parameters*
- *The Source layout*
- *The Photoinjector + Linac scheme*
- *S2e simulation results for the electron beam*
- *The laser system*
- *Future options to increase luminosity*
- *Conclusions*

ELI-NP: F-I-UK Proposal

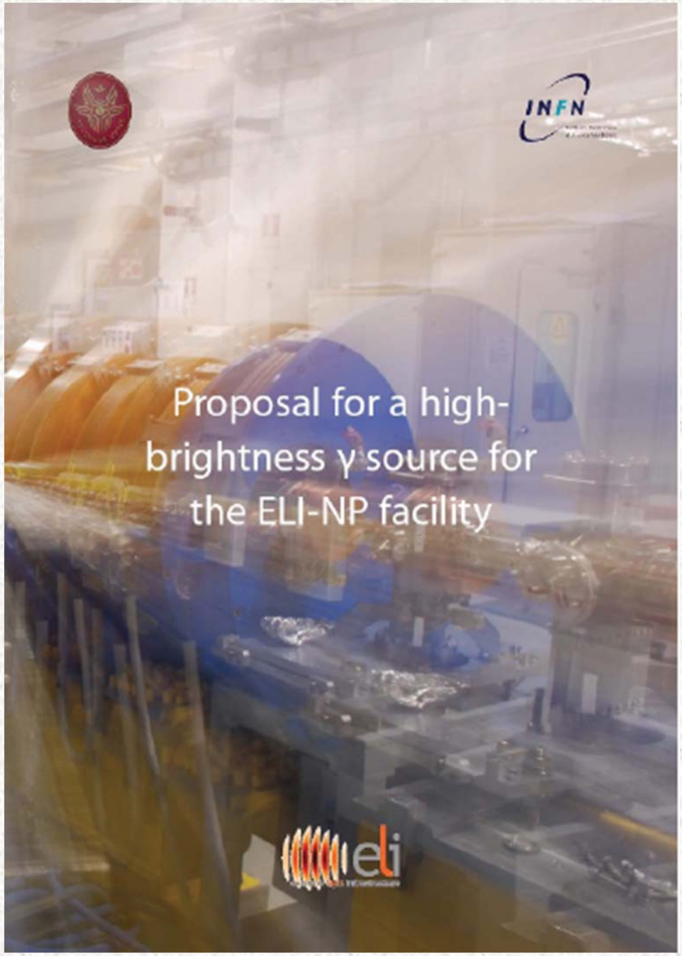
European Collaboration for the proposal of the gamma-ray source:

- ✓ Italy: INFN,Sapienza
- ✓ France: IN2P3, Univ. Paris Sud
- ✓ UK: ASTeC/STFC

~ 80 collaborators elaborating the CDR/TDR

Covering

- ✓ Underlying physics & Best machine layout
- ✓ Technical realization
- ✓ Infrastructure concern
- ✓ Management structure
- ✓ Costs & Timing and Schedulling
- ✓ Training and education
- ✓ Implementation



Gamma Beam Source

The Challenge we are facing: design the ***most advanced*** Gamma Beam System based on ***state-of-the-art*** components, to be commissioned and delivered to users ***by the end of year 2016***, reliable, cost-effective, compatible with present lay-out of ELI-NP building and ready for future evolutions → Warm RF Linac vs Pulsed Recirculated Laser

Prototype of a New Generation (Light) Gamma-ray Sources: Bright, Mono-chromatic (0.3%), High Spectral Flux (> 10^4 ph/sec/eV), Tunable (1-20 MeV), Highly Polarized, based on Compton Back-Scattering of High Phase Space Density Electron Beams by Lasers

Table 1: Summary of Gamma-ray beam Specifications

Photon energy	1-20 *MeV*
Spectral Density	> 10^4 *ph/sec.eV*
Bandwidth (rms)	< 0.3%
# photons per shot within FWHM bdw.	$2\text{-}6 \cdot 10^5$
# photons/sec within FWHM bdw.	$0.5\text{-}1.5 \cdot 10^9$
Source rms size	10 - 30 μm
Source rms divergence	25-250 μrad
Peak Brilliance ($N_{ph}/sec \cdot mm^2 mrad^2 \cdot 0.1\%$)	$2.0 \cdot 10^{22}$ - $1.1 \cdot 10^{24}$
Radiation pulse length (rms, *psec*)	0.7-1.5
Linear Polarization	> 95 %
Macro rep. rate	100 *Hz*
# of pulses per macropulse	< 25
Pulse-to-pulse separation	> 15 *nsec*

Nuclear Resonance Fluorescence

Nuclear Photo-fission

Isotope Detection -> toward Nuclear Photonics

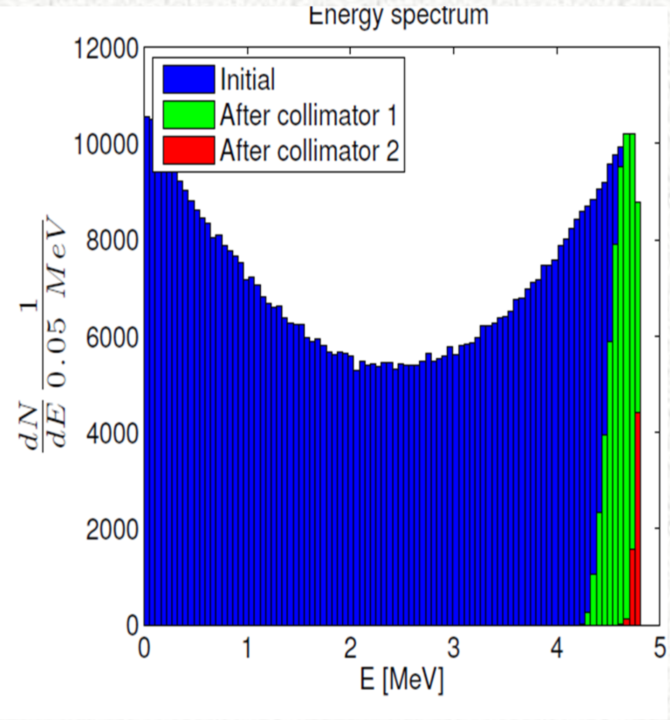
Compton Scattering process

A simple model has been derived by L. Serafini, V. Petrillo predicts the number of photons scattered within the desidered bandwidth:

$$N_{\gamma}^{bw} = 1.2 \cdot 10^{9} \frac{U_L[J]Q[pC] f_{RF} n_{RF}}{h\nu[eV]\sigma_x^2[\mu m]} \Psi^2$$

$$scattered - ph/sec \quad within \quad \Psi \equiv \gamma\vartheta$$

$$\frac{\Delta\nu_\gamma}{\nu_\gamma} \approx \Psi^2$$



L. Serafini

The spectral density (Serafini-Petrillo)

Spectral density for the considered bandwidth $\frac{\Delta\nu_\gamma}{\nu_\gamma}$:

$$SPD = 1.67 \cdot 10^{8} U_L Q\, f_{RF}\, n_{RF} \frac{\sqrt{\left(\frac{\Delta\nu_\gamma}{\nu_\gamma}\right)^2 - 4\left(\frac{\Delta\gamma}{\gamma}\right)^2 - \left(\frac{\varepsilon_n}{\sigma_x}\right)^4 - \left(\frac{\Delta\nu_L}{\nu_L}\right)^2 - \left(\frac{M^2\lambda_L}{2\pi w_0}\right)^4 - \left(\frac{a_{0p}^2}{3}\right)^2}}{\gamma^2 \frac{\Delta\nu_\gamma}{\nu_\gamma}\left(4\sigma_x^2 + w_0^2\right)\sqrt{1+\phi^2\left(\frac{\sigma_z^2 + c^2\sigma_t^2}{4\sigma_x^2 + w_0^2}\right)}}$$

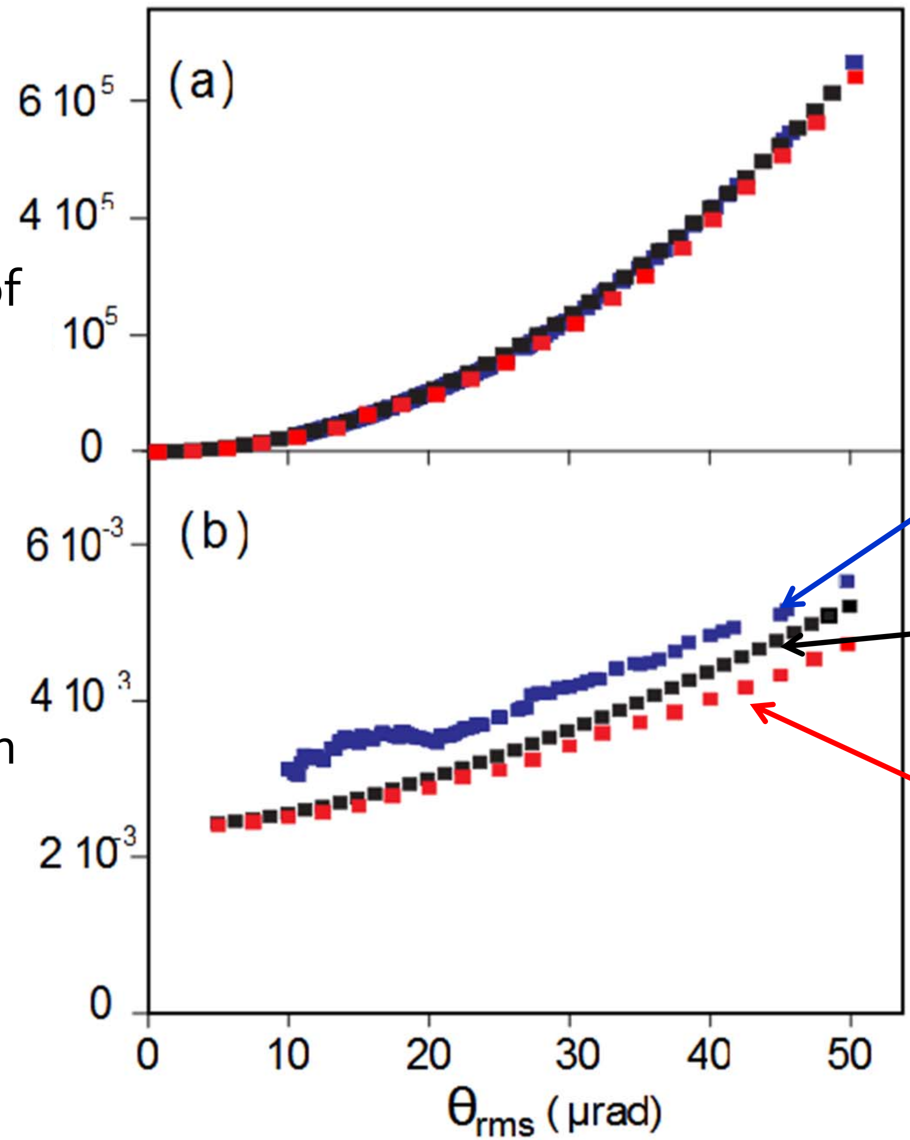
$$for\ ELI - NP\ must\ be\ \frac{\Delta\nu_\gamma}{\nu_\gamma} = 0.003 \quad and \quad SPD = 10^4$$

$f_{RF} =$ 100 Hz $U_L =$ Laser pulse energy (J) $h\nu =$ laser photon energy=2.4 eV

$n_{RF} =$ bunches per RF pulse $Q =$ el. bunch charge (pC) $\phi =$ collision angle

$\sigma_x =$ e- beam focal rms spot size in μm w_0 = laser focal spot size in μm

Analytical model vs. classical/quantum simulation



Number of photons

bandwidth

CAIN (quantum MonteCarlo) Run by I.Chaichovska and A. Variola

TSST (classical) Developed by P. Tomassini

Comp_Cross (quantum semianalytical) Developed by V.Petrillo

V. Petrillo

Electron & laser beams

Table 2: Electron beam parameters at Interaction Points: general characteris

all values are rms	
Energy (*MeV*)	200-720
Bunch charge (*pC*)	25-400
Bunch length (μm)	100-450
$\varepsilon_{n\_x,y}$ (*mm-mrad*)	0.2-0.8
Bunch Energy spread (*%*)	0.04-0.08
Focal spot size (μm)	10-30
# bunches in the train	< 25
Bunch separation (*nsec*)	15-20
energy variation along the train	0.1 %
Energy jitter shot-to-shot	0.1 %
Emittance dilution due to beam breakup	< 10%
Time arrival jitter (*psec*)	< 0.5
Pointing jitter (μm)	1

Electron & laser beams

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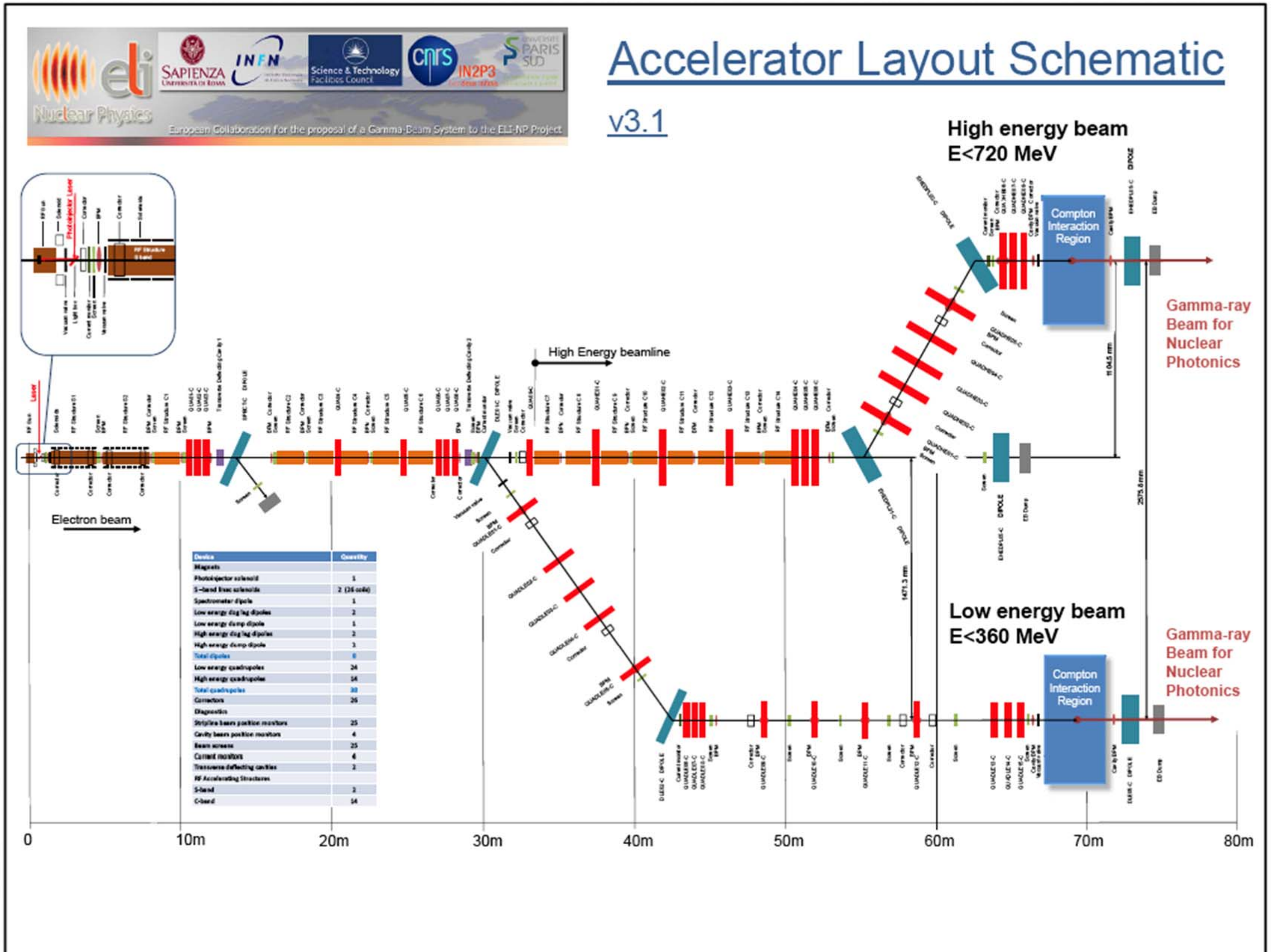
Time arrival jitter (*psec*)	< 0.5
Pointing jitter (*μm*)	

Table 3: Laser beam parameters

	Low Energy Interaction	High Energy Interaction
Pulse energy (*J*)	0.5	0.5
Wavelength (*eV*)	2.4	2.4
FWHM pulse length (*ps*)	2-4	2-4
Repetition Rate (*Hz*)	100	100
M^2	< 1.2	< 1.2
Focal spot size w_0 (*μm*)	25-40	20-35
Bandwidth (rms)	0.05 %	0.05 %
Pointing Stability (*μrad*)	1	1
Sinchronization to an ext. clock	< 1 *psec*	< 1 *psec*
Pulse energy stability	1 %	1 %

Baseline for the Linac



Device	Quantity
Magnets	
Photoinjector solenoid	1
S-band linac solenoids	2 (26 coils)
Spectrometer dipole	1
Low energy dog leg dipoles	2
Low energy dump dipole	1
High energy dog leg dipoles	2
High energy dump dipole	1
Total dipoles	8
Low energy quadrupoles	24
High energy quadrupoles	14
Total quadrupoles	38
Correctors	26
Diagnostics	
Stripline beam position monitors	25
Cavity beam position monitors	4
Beam screens	25
Current monitors	4
Transverse deflecting cavities	2
RF Accelerating Structures	
S-band	2
C-band	14

N. Bliss

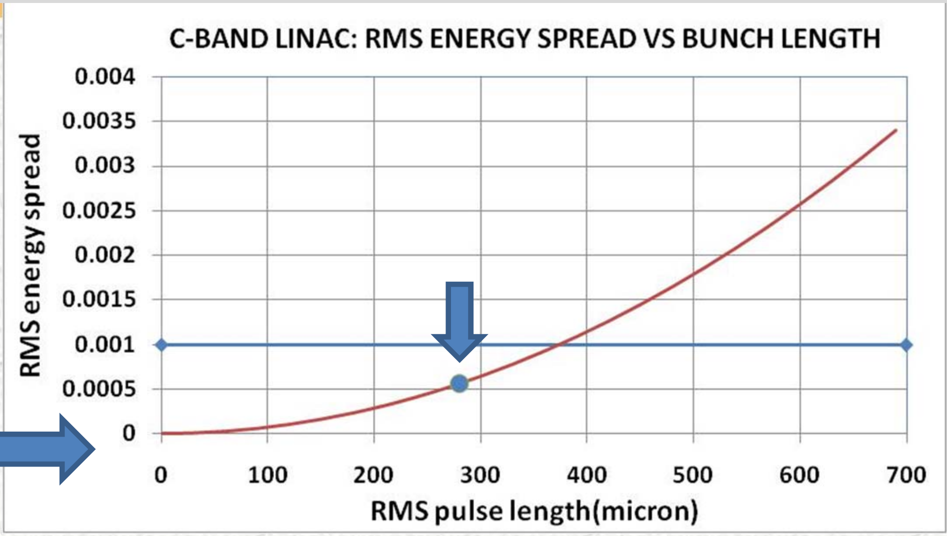
The hybrid scheme for the Linac

➢ *Operation criteria:*

- Long bunch at cathode for high phase space density :

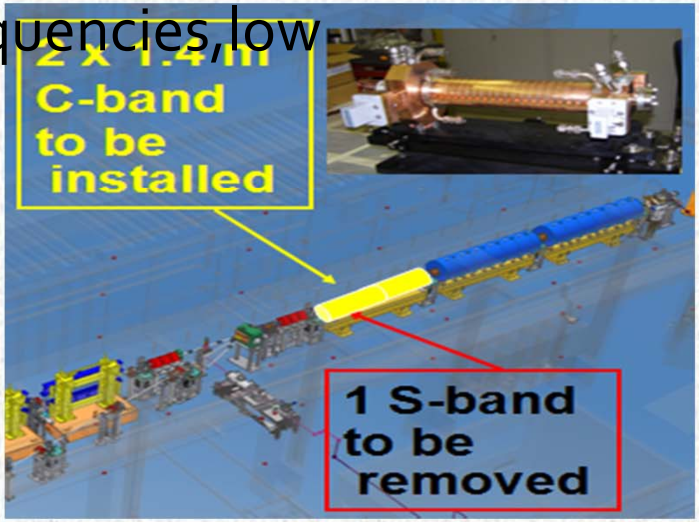
  $Q/\varepsilon_n^2 > 10^3\ \mathrm{pC}/(\mu\mathrm{rad})^2$

- Short exit bunch (280 μm) for low energy spread **(~0.05%)**



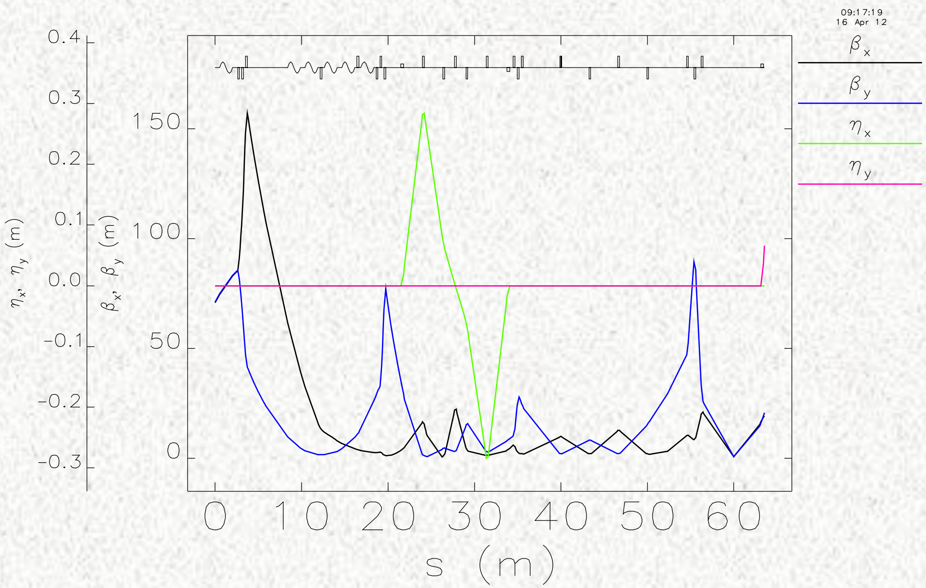
➢ *Advantages:*

- Moderate risk (state of art RF gun, reduced multibunch operation problems respect to higher frequencies,low compression factor<3)
- Economic
- Compact (the use of the C-band
- booster meets the requirements on
- the available space)
- Possibility to use SPARC as test stand



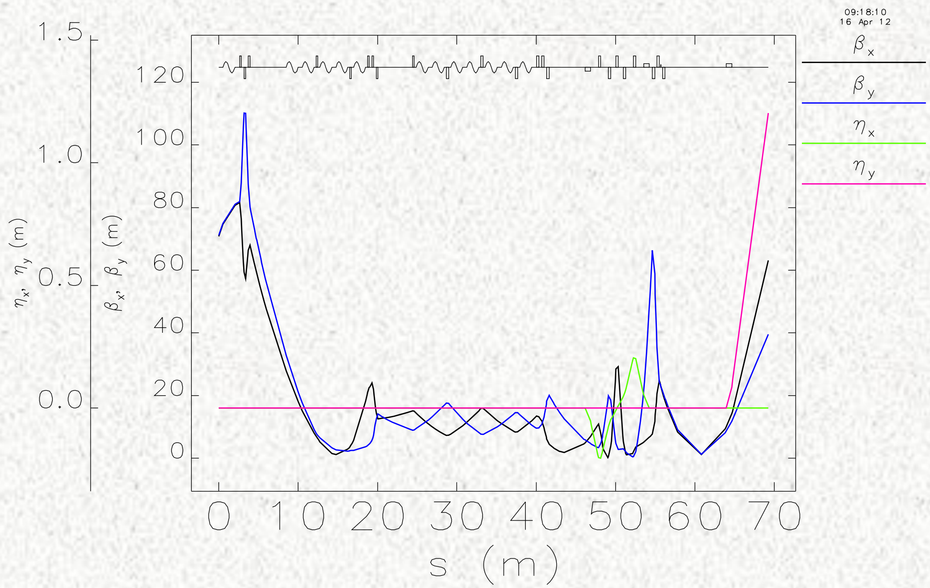
Linac & TL

Low Energy



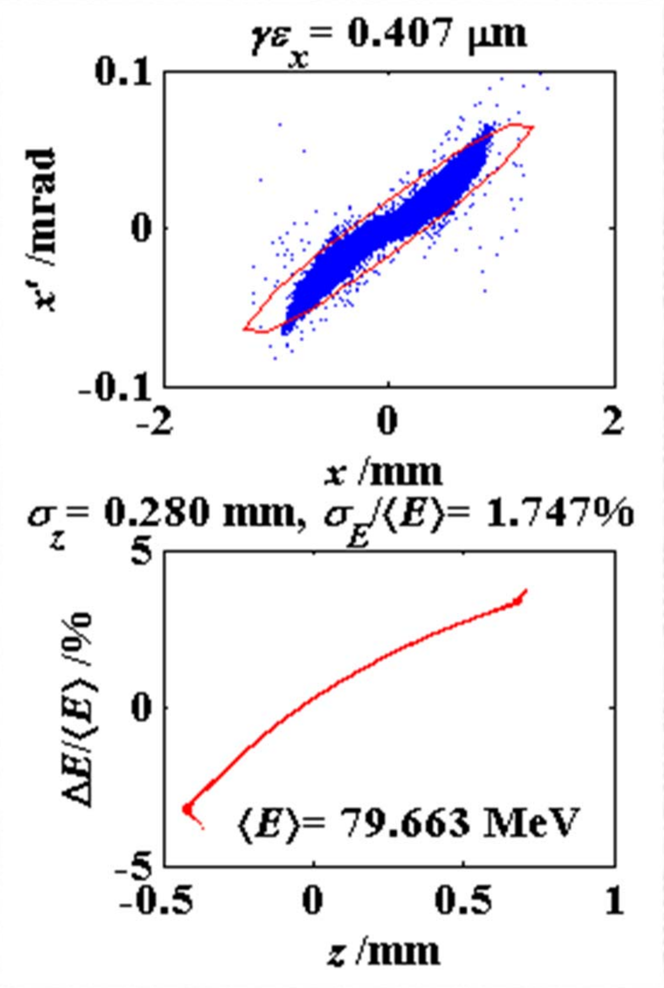
Twiss parameters for eli_lowen_double_WP_28_3

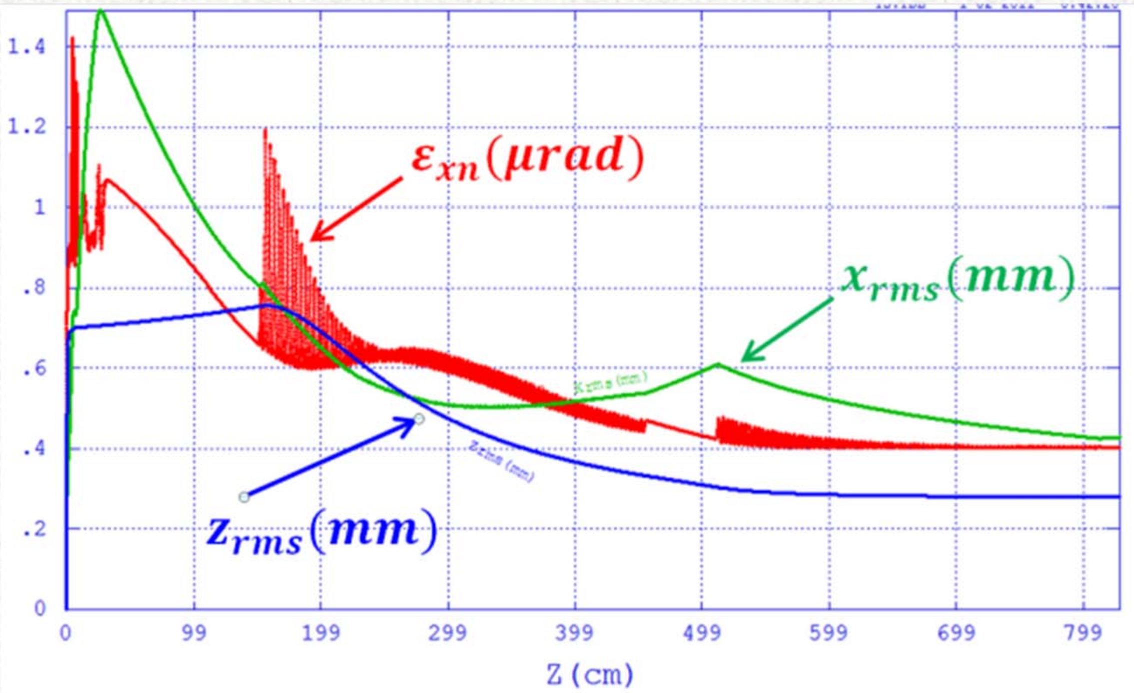
High Energy



Twiss parameters for eli_highen_double_WP_28_3

WP_{ref} from the photoinjector



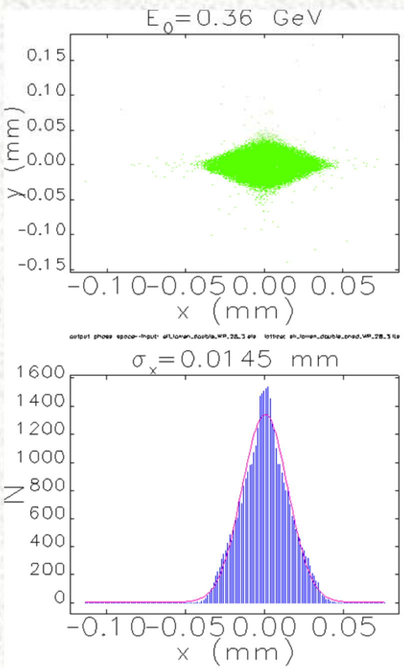


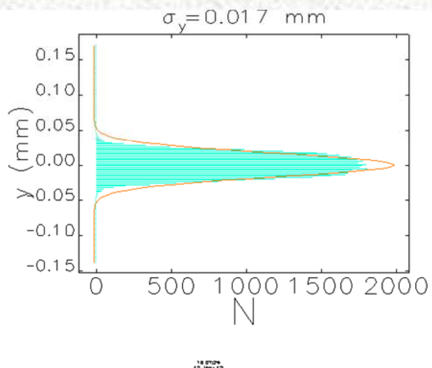
Egun=120 MV/m
E(S1)=E(S2)=21 MV/m
Q=250 pC

C. Ronsivalle

SB-Transverse beam size & distribution

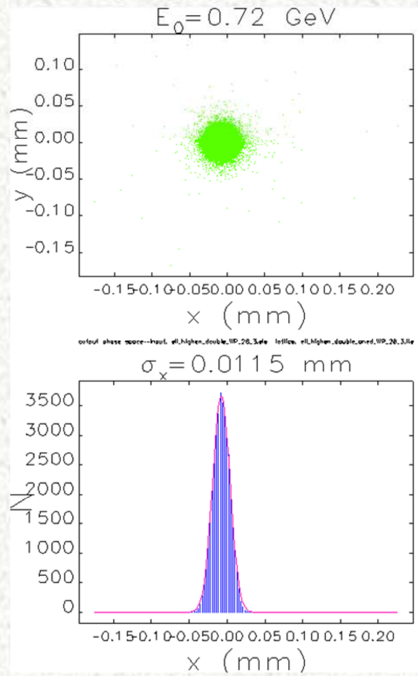
Lowen

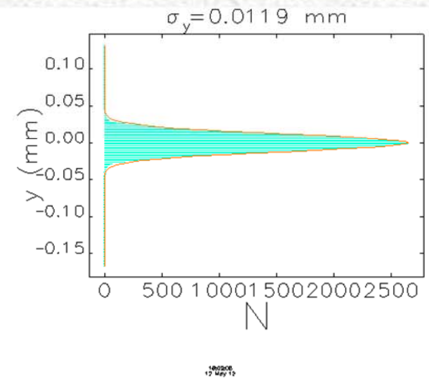




$\sigma_{x\ rms}$=$\sigma_{y\ rms}$= 15 μ

Highen



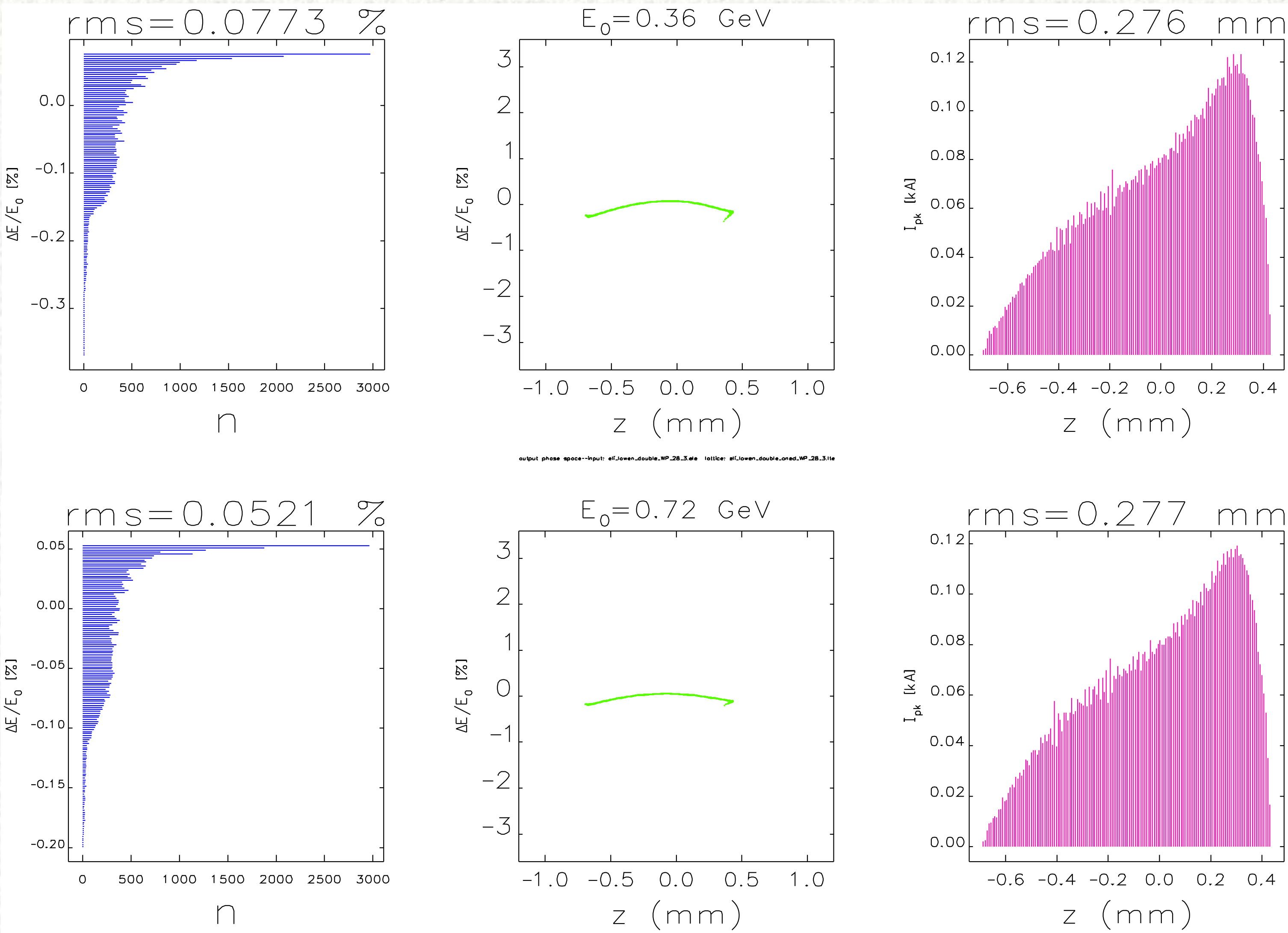


$\sigma_{x\ rms}$=$\sigma_{y\ rms}$= 12 μ

WPref_SB-energy spread & current

Lowen

Highen



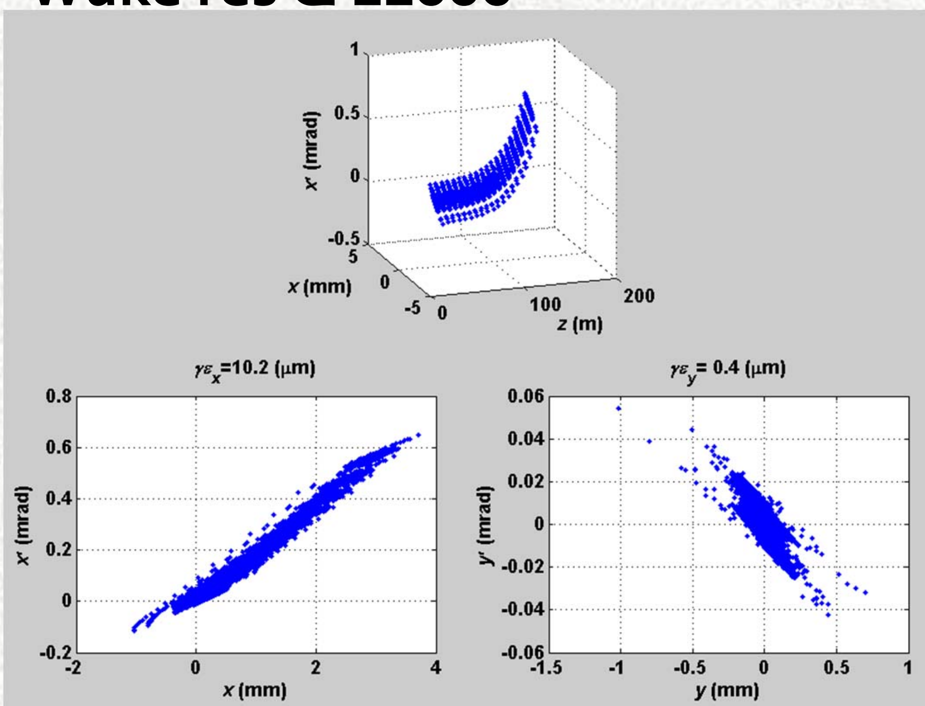
Wake on Δx=500 µm

Transverse wake of a single cell from:

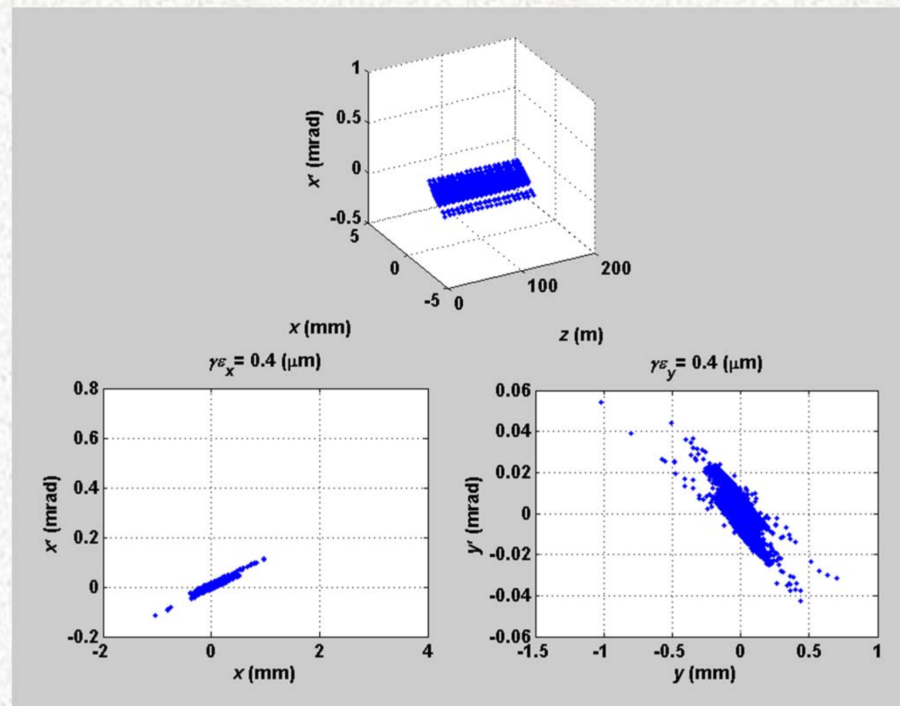
$$W = ae^{-t/\tau}\sin(\omega_{RF}\tau)\,V/C/m$$

with: $a = 245\,V/pC/m$, $\omega_{RF} = 2\pi \cdot 8.398 \times 10^9$

Wake res Q 11000

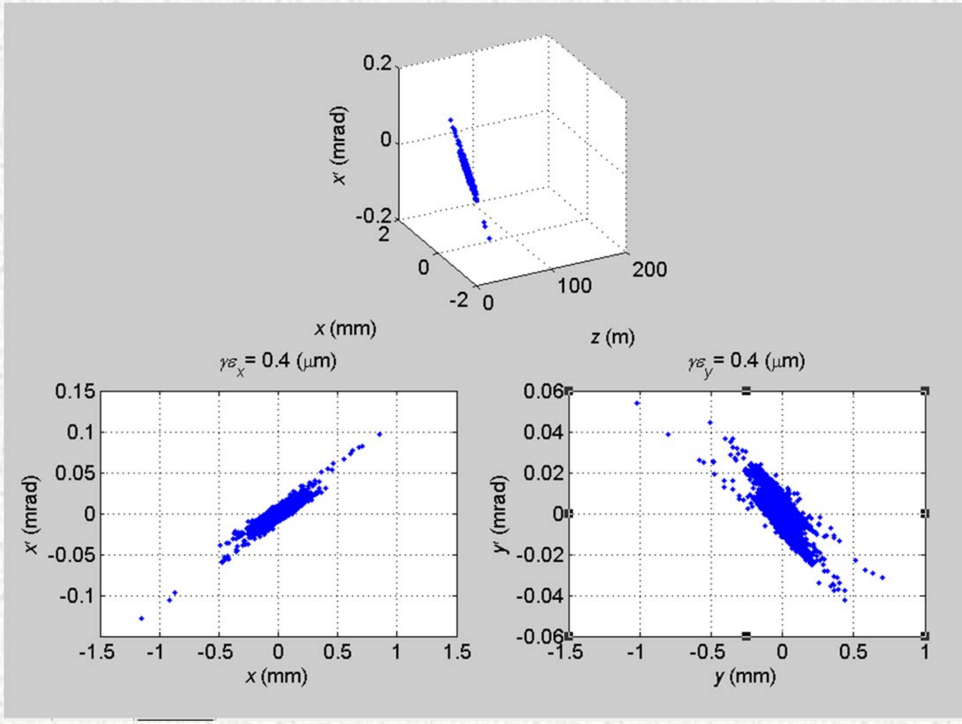


Wake res Q 100

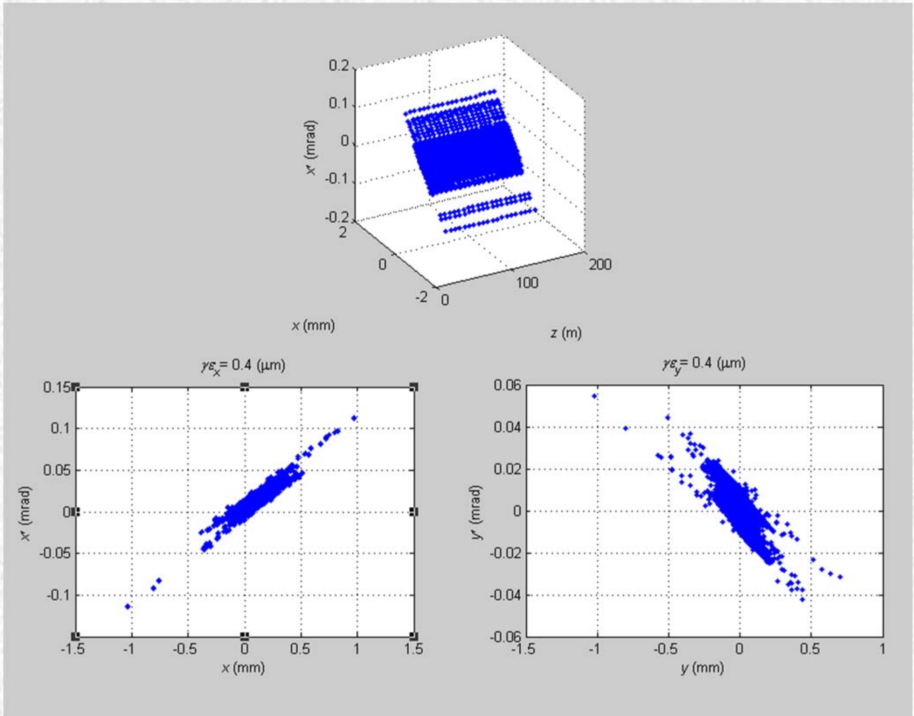


Wake on Δx=500 µm

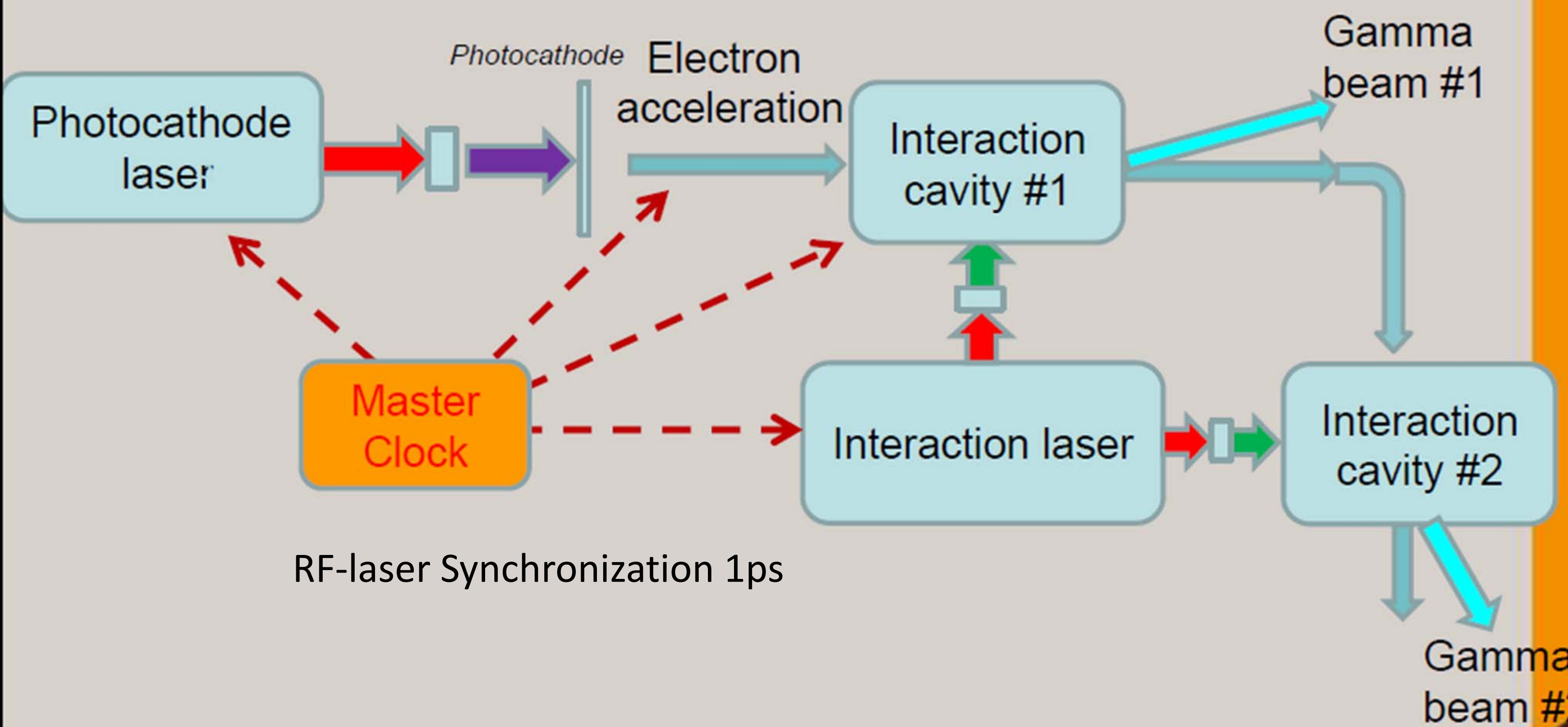
SB



Wake res Q 100

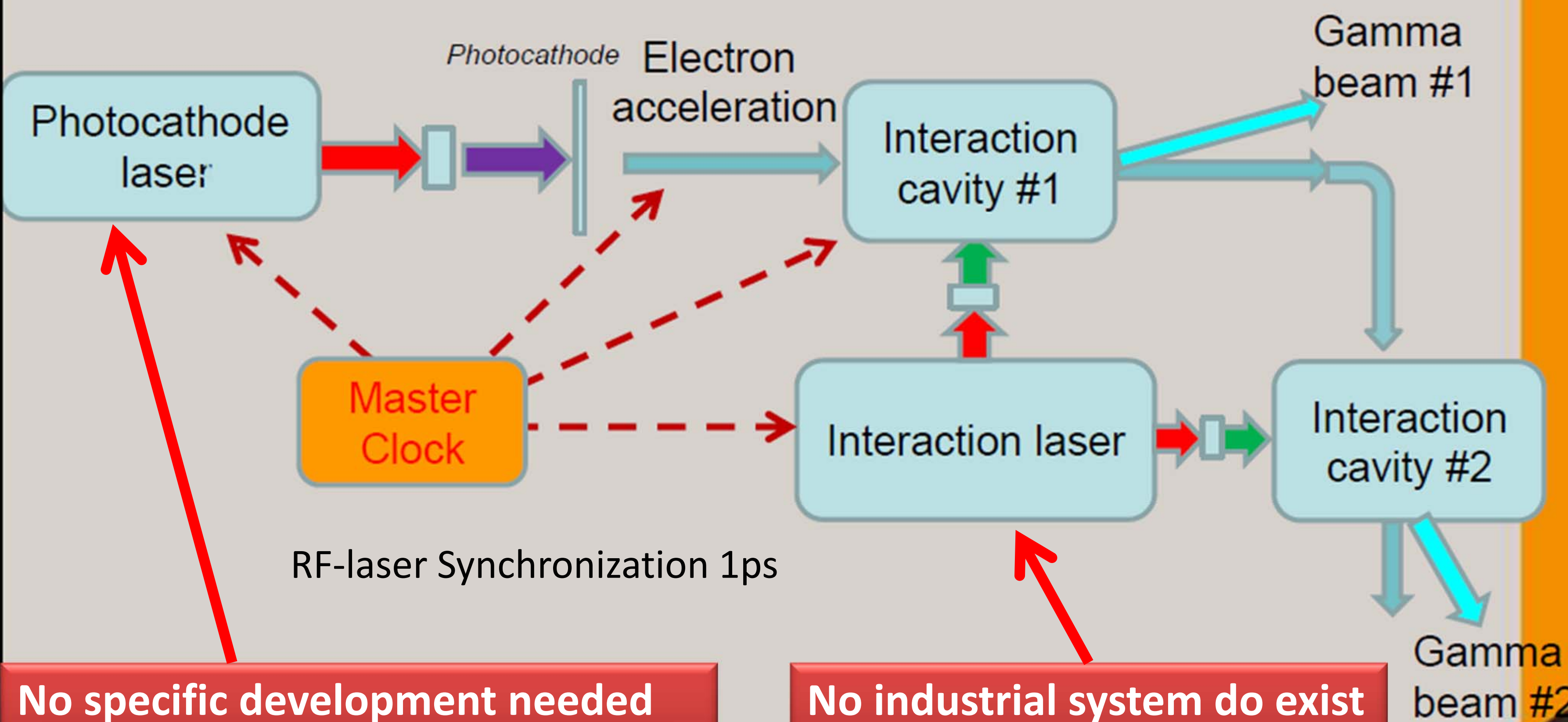


The laser systems



RF-laser Synchronization 1ps

The laser systems



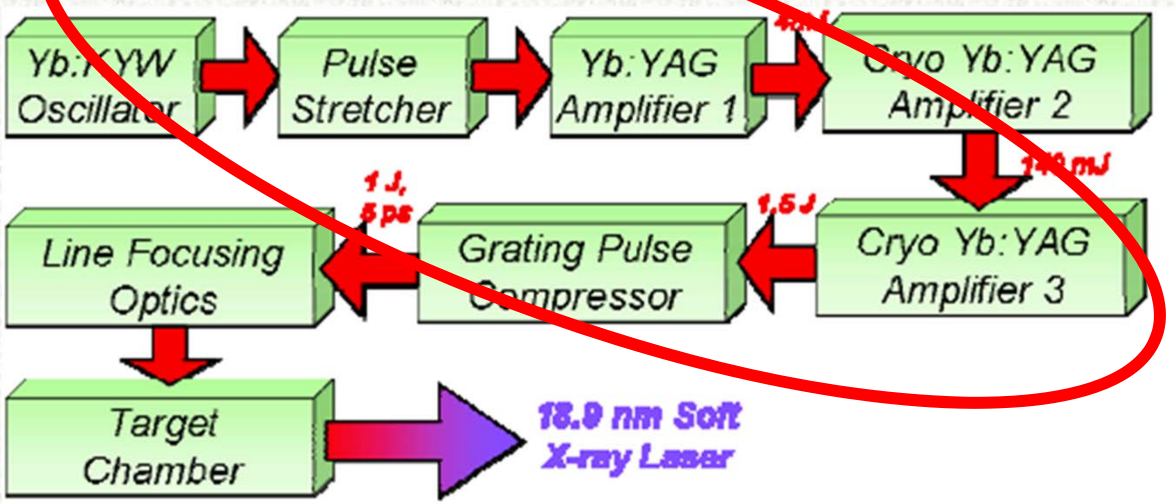
No specific development needed
➔ Industrial deliverable (Ti:sapph)

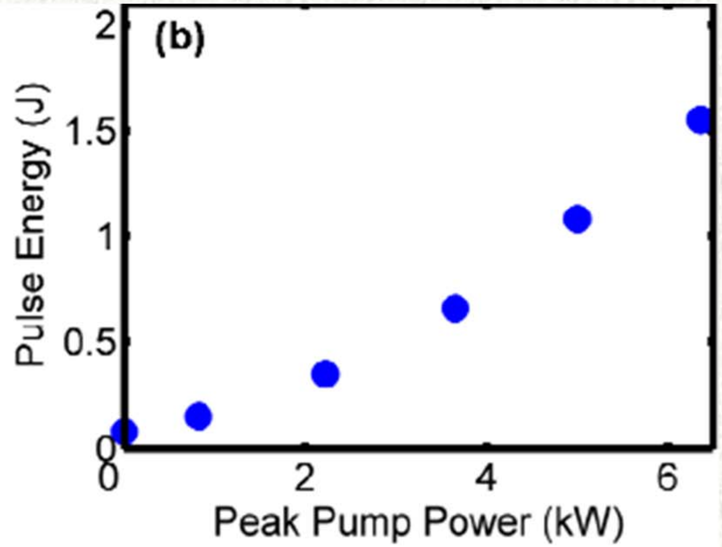
No industrial system do exist
➔ specific development

State of the art cryogenic amplifier around 100Hz

Reagan et al., Colorado State Univ. CLEO 2012 (results shown last week)

λ=1µm,1J@50Hz, 5ps



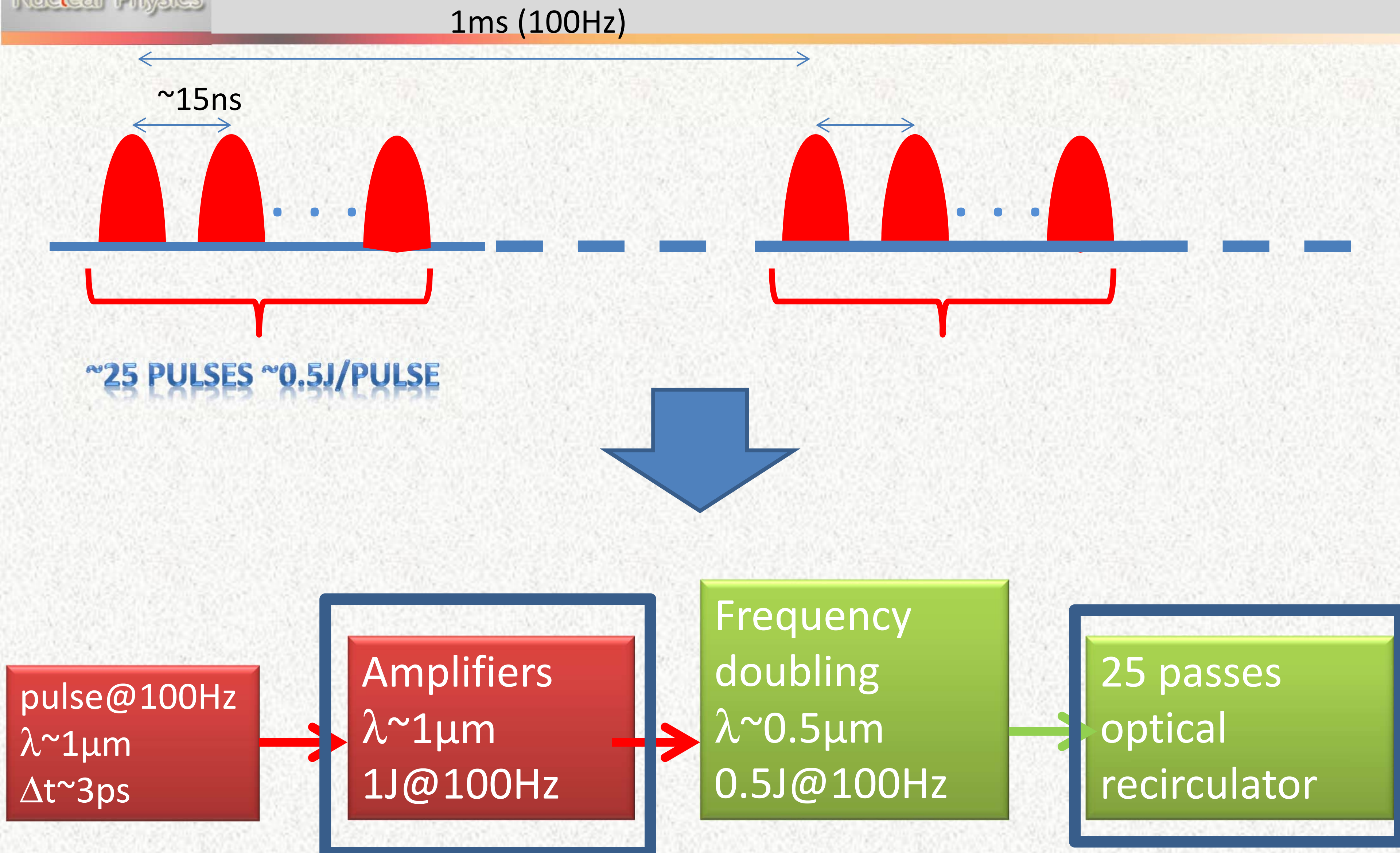


This is the solution we are following

- **Already 2 beams @ 50Hz & optical switch @100Hz fits the requirement**
- **Pushing 50Hz→100Hz is feasible**

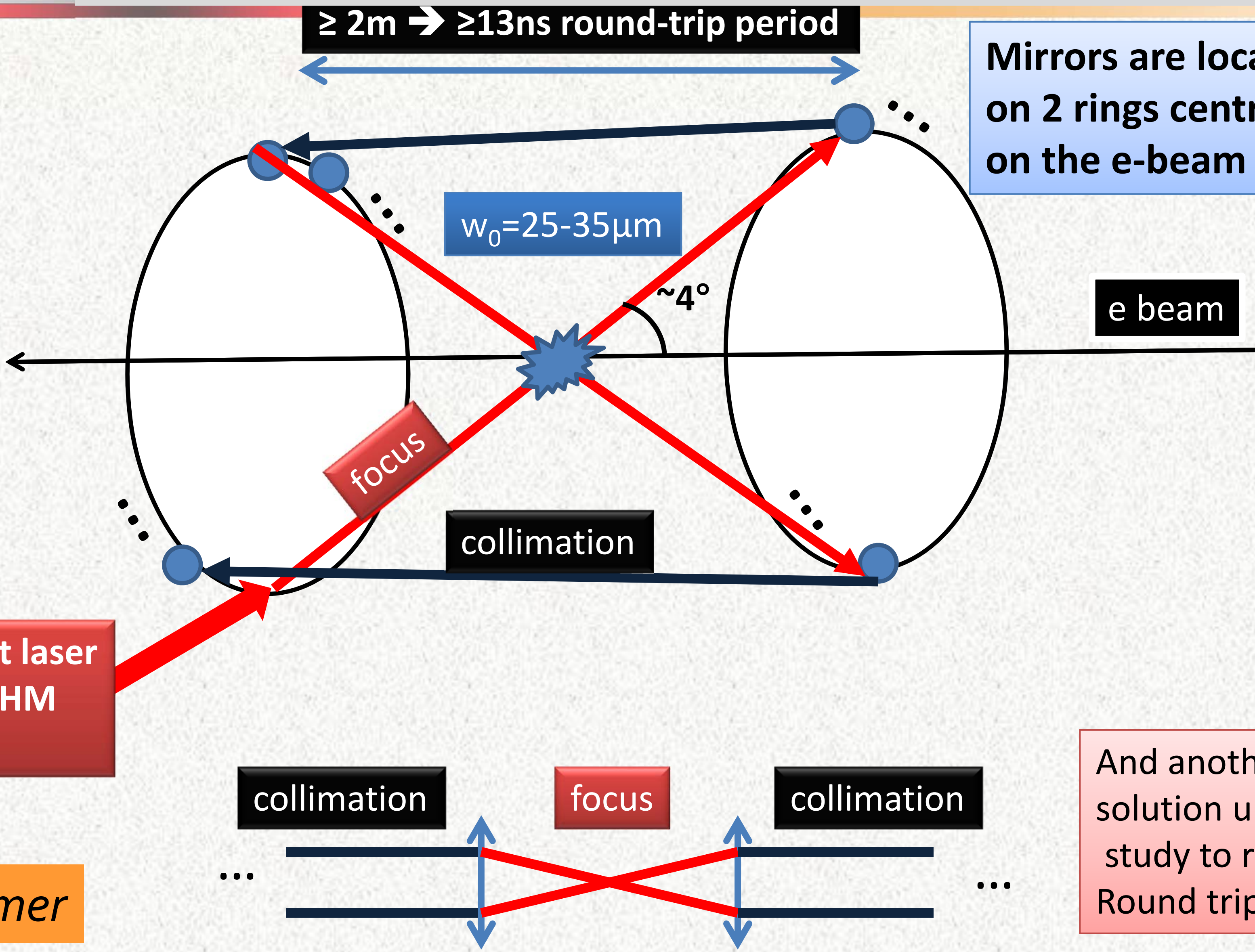
F. Zomer

Laser request at the Compton IP



Solution : a laser beam recirculator made of individual spherical mirrors

Mirrors are located on 2 rings centred on the e-beam axis



Incident laser
3ps FWHM
515nm

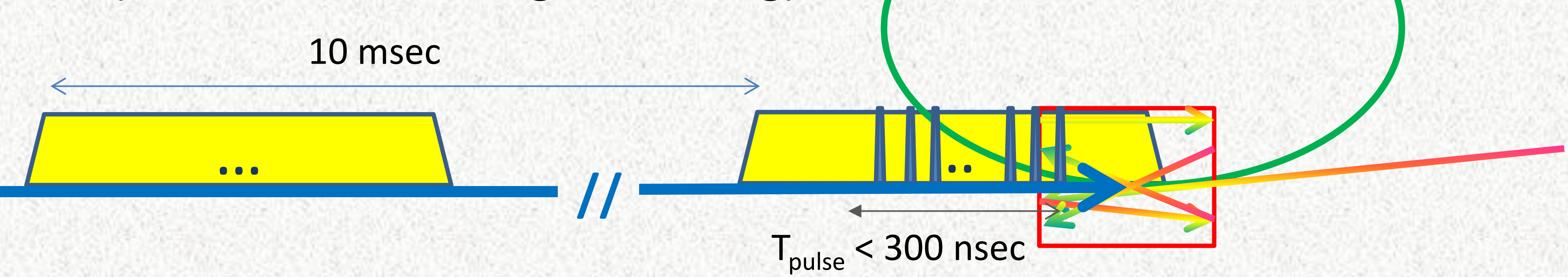
And another solution under study to reach 50 Round trips

F. Zomer

Future option for Luminosity increase

- ***Increase the number of interactions per pulse by recirculating N_{turns} times the beam in a ring***

$L_{ring} \geq T_{pulse}$
(one train circulating in the ring)

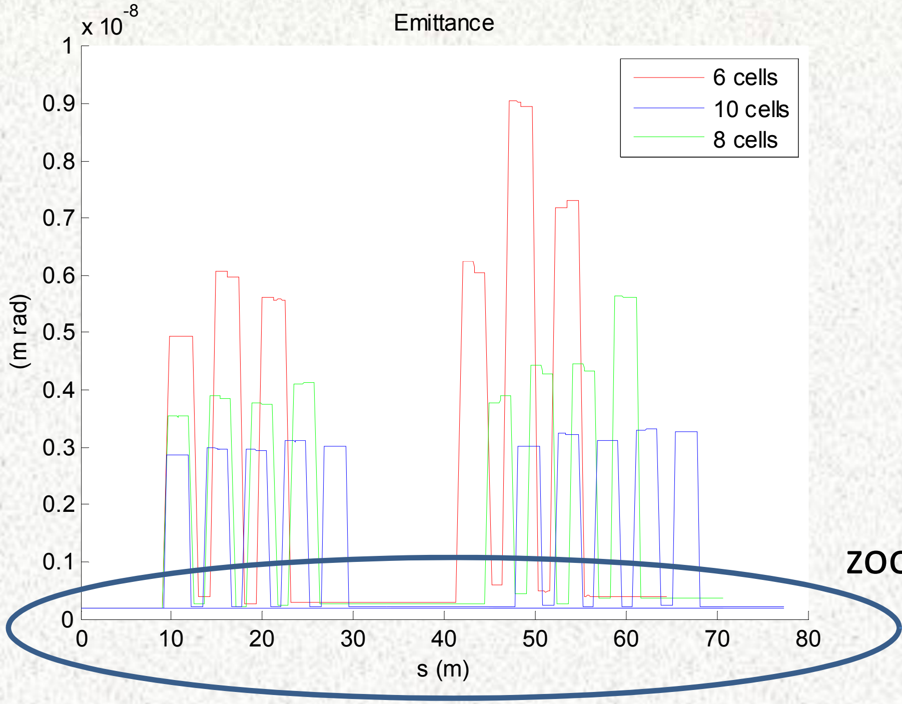


NO e- beam recirculation:
Laser beam recirculations (N_{lr}) = bunches in the train (N_b)

$N_{turns} \geq 1 \Rightarrow N_{lr} > N_b * N_{turns}$

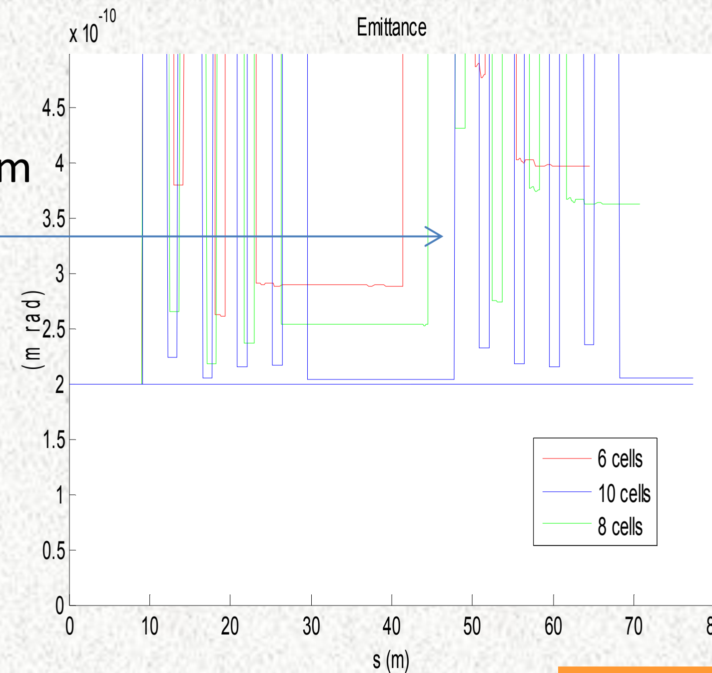
C. Biscari

Horizontal emittance degradation



Strong influence of bending angle
Space requirements against emittance increase

zoom



One turn

No chromatic effect correction
No shielding
6 cells: 100% increase ε_x
8 cells: 80%
10 cells: 5%

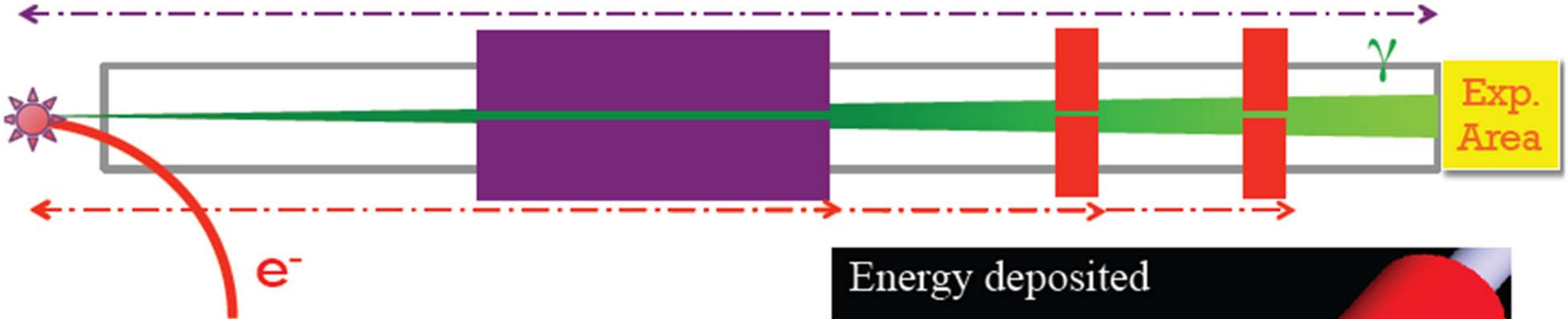
C. Biscari

Conclusions

- The E-Gammas-Source has been designed with his main features for feasibility, performance and cost effectiveness.
- Electron beam SB and MB beam dynamics studies have been performed and are close to be completed.
- The laser system and recirculator baseline has been defined the design finalization is on going.
- Tolerance studies have been started and their completion is on going.
- An electron recirculating ring is under study to improve luminosity.

Collimation system 1/2

Geant4 collimation line simulation



- Collimator 1 [Cu]

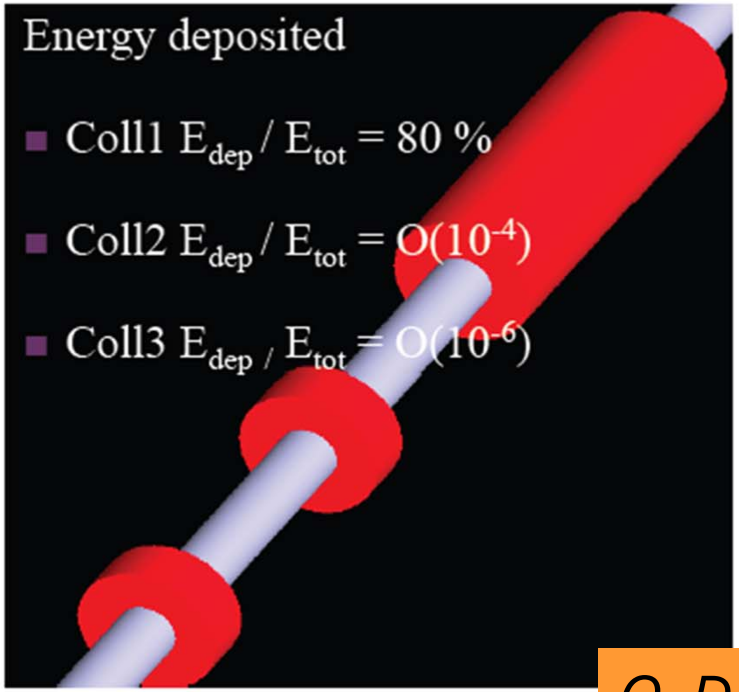
  d = 6 m, r = 0.4 mm, l = 30 cm
  used @ E166 (r = 0.425 mm)

- Collimator 2 & 3 [W]

  d = 6.5 & 7.0m, r = 0.4 mm, l = 4 cm

- Beam pipe [Fe]

  r = 2 cm, t = 0.1 cm

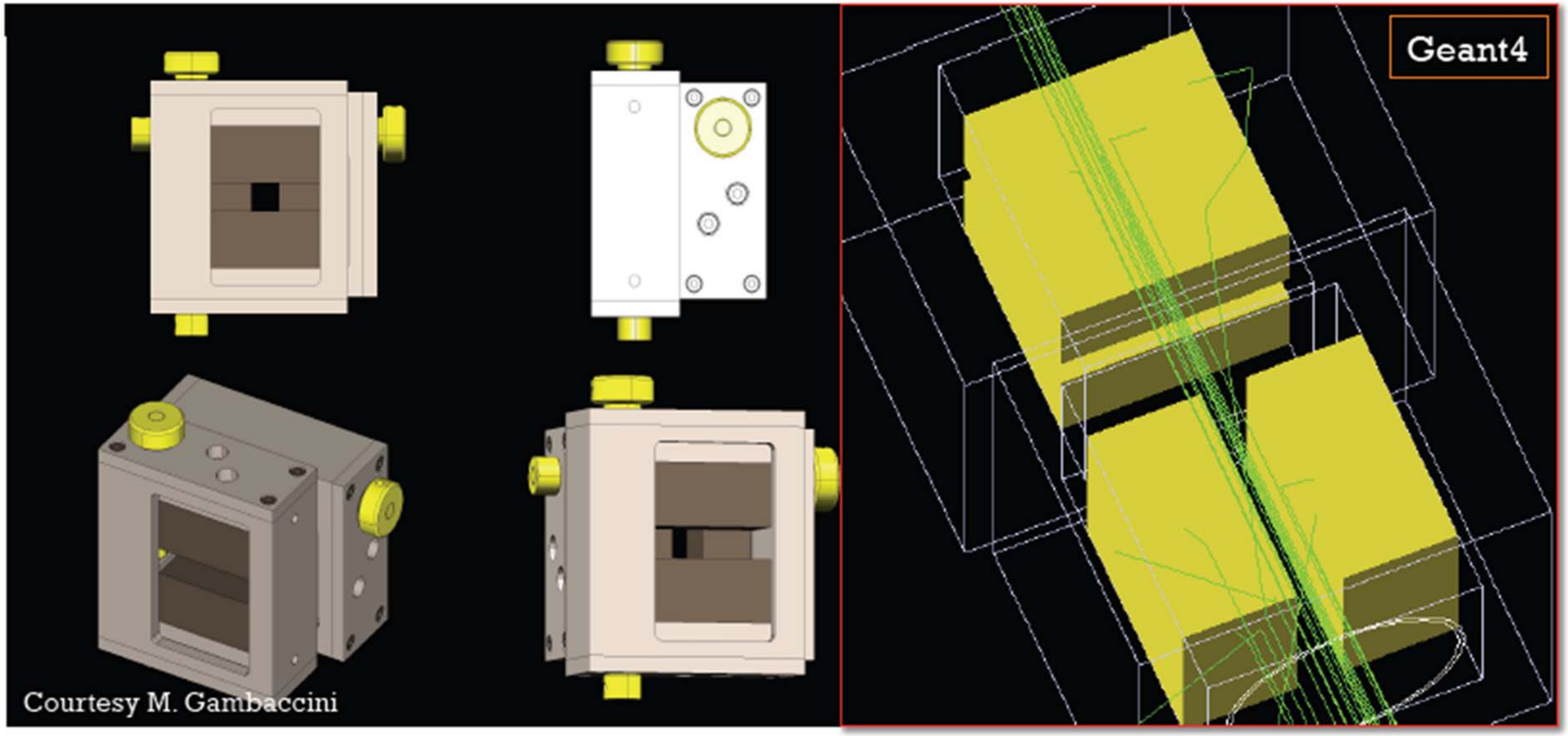


O. Dadoun

Collimation system 2/2

Other type : dual slit collimator [W]

used with 5 MeV linac X-ray beam



A solution was found with 4×2 collimators

- Collimation length greater
- Gamma yield smaller (~3 times less)

O. Dadoun