Physics and applications of Thomson/Compton back scattering

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June 5, 2013

Thomson/Compton sources
for the production of
high brilliance X/γ rays.

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Introduction to
Thomson and Compton
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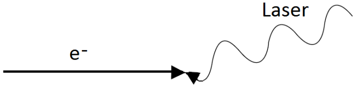
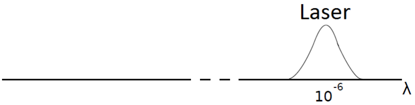
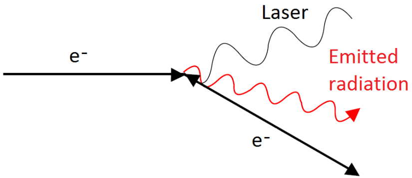
SPARCLAB
(Pulsed and Amplified Source
of Coherent Radiation LAB)
ELI-NP
(Extreme Light Infrastructure
Nuclear Physics)

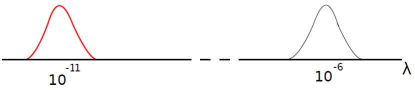
Scattering between relativistic electrons and laser light

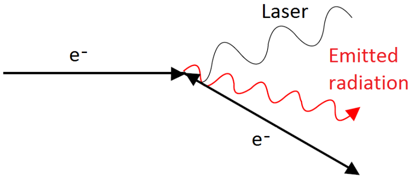




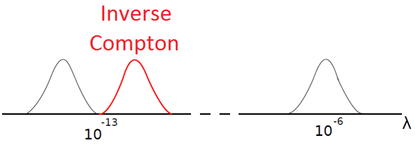


Classical effect



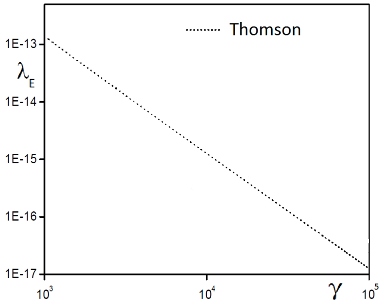


Classical + Quantum effect



Considering electrons and laser perfectly counterpropagating:

$$\lambda_E = \frac{\lambda_L}{4\gamma^2}$$



Considering electrons and laser perfectly counterpropagating:

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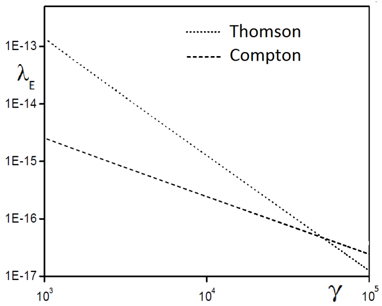

Considering electrons and laser perfectly counterpropagating:

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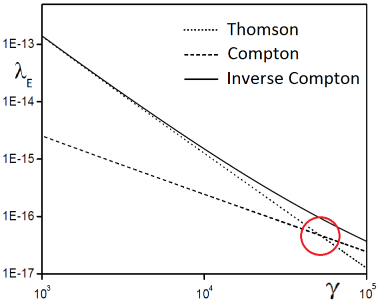
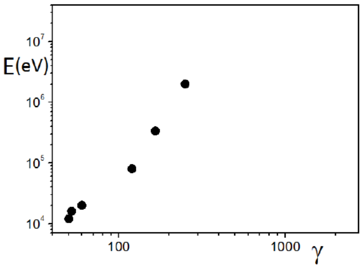
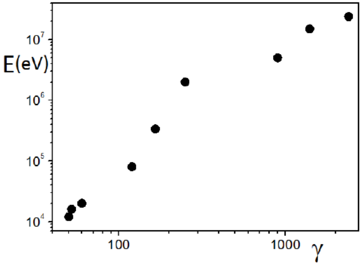




Source	γ	*E*
CLS	50	12 *keV*
PhoeniX	50-60	12-20 *keV*
Pleiades	40-200	20-500 *keV*
SPARCLAB	60-300	20-500 *keV*
LSS (ATF)	240	80 *keV*
FMega-ray	500	2 *MeV*



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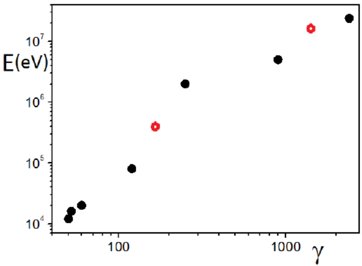

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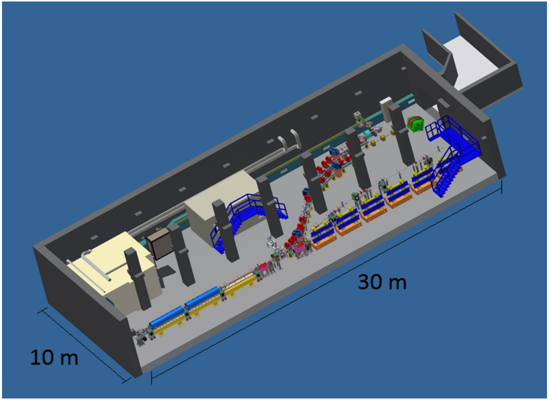
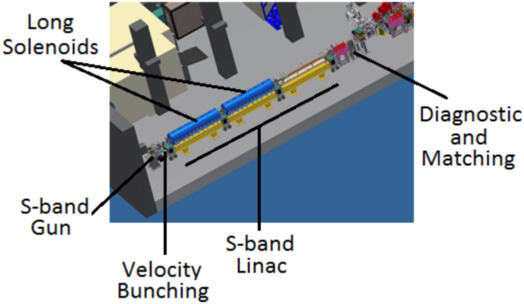
SPARCLAB (Pulsed and Amplified Source of Coherent Radiation LAB) at National Laboratories Frascati (Rome)





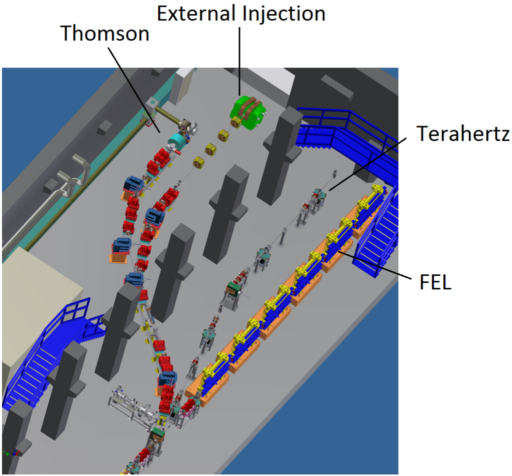
Charge
$$Q = 0.25 - 1 \cdot 10^{-9} C$$

Energy
$$E = 30 - 150\ MeV$$

Energy spread
$$\frac{\Delta\gamma}{\gamma} = 7 \cdot 10^{-4}$$

Emittance
$$\epsilon = 0.8 - 1.5\ mm - mrad$$

SPARCLAB



Thomson source

Electrons energy
$E = 30\ MeV$

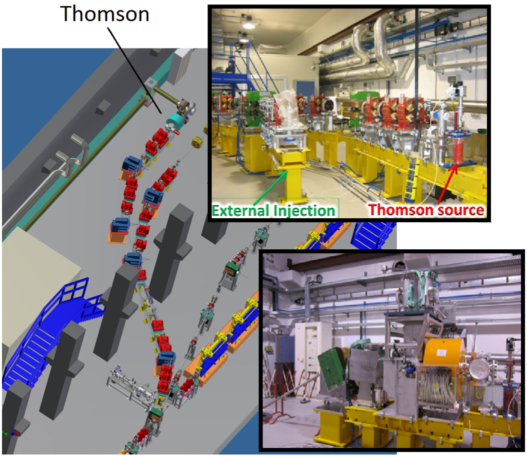
Laser wavelenght
$\lambda_L = 0.8\ \mu m$

High brilliance X rays
$\lambda_E = 6.2 \cdot 10^{-11}\ m$

Emitted radiation energy
$E_f = 20\ keV$

Number of Photons
$N = 2 \cdot 10^9$

Luminosity
$$L = \frac{N_L N_e}{2\pi(\sigma_x^2 + \frac{w_0{}^2}{4})} f = 10^{38}\ \frac{1}{sm^2}$$



Classical Electrodynamics: from the electron orbits and the Lienard-Wiechert potential in the far zone, the radiation field for one electron is

$$\frac{d^2 W_i}{d\omega d\Omega} = \frac{e^2}{4\pi^2 c} \left| \int_{-\infty}^{+\infty} dt e^{i\omega t} \frac{\vec{n} \times \left[\vec{n} - \vec{\beta}(t') \times \dot{\vec{\beta}}(t') \right]}{(1 - \vec{n} \cdot \vec{\beta}(t'))^3} \right|^2 = \hbar\omega \frac{d^2 N_i}{d\omega d\Omega}$$

where $\vec{\beta}$ and $\dot{\vec{\beta}}$ are respectively the velocity and the acceleration of the incoming electron, $\vec{n}$ the direction of the emitted radiation and $t' = t - \frac{1}{c}[\vec{n}r - \vec{r}(t')]$, with $\vec{r}$ position of the electron, is the retarded time.

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Integrating over the solid angle and taking into account the characteristics of the baems we obtain the spectrum of the emitted radiation.

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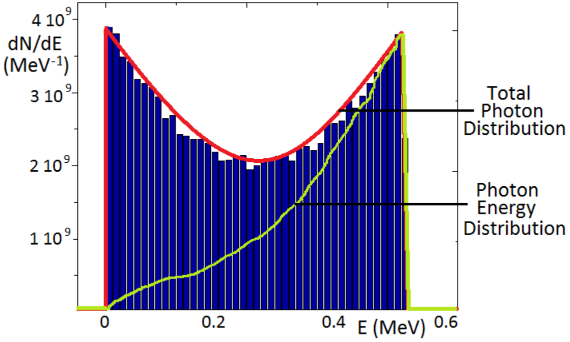
Application of the 20 keV X-rays: MAMMOGRAPHY.

High monochromaticity $\rightarrow$ ratio between the signal and the dose absorbed by the patient is much higher than the one of Röntgen tubes.

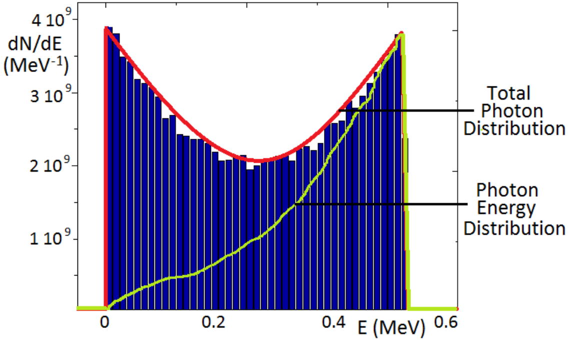
Reduced dimensions $\rightarrow$ quality of the radiation similar to synchrotron light but the machine is much smaller, easy to install in a hospital.

Thomson at 150 *MeV*



Submitted to APJ

Thomson at 150 MeV



$$\frac{dN_{ph}}{dE} \approx \frac{3}{\Delta E}\left[\left(\frac{E-E_{min}}{\Delta E}\right)^2 - \frac{E-E_{min}}{\Delta E} + \frac{1}{2}\right] \cdot H(E_{max}-E) \cdot H(E-E_{min})$$

Submitted to APJ

Electron distribution P after the scattering.
Model: Chapman-Kolmogorov master equation for Markov processes

$$\frac{\partial P(E,t)}{\partial t} = \alpha \left(\int dE' W(E,E') P(E',t) - P(E,t) \right)$$

with

$$W = \frac{dN_{ph}}{dE}$$

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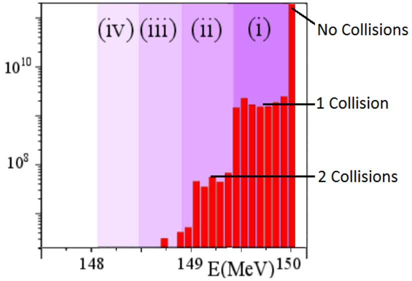

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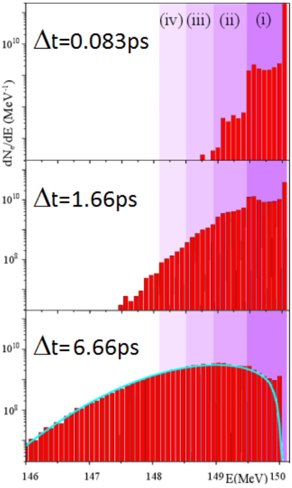

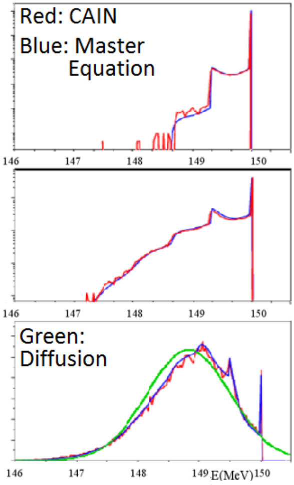

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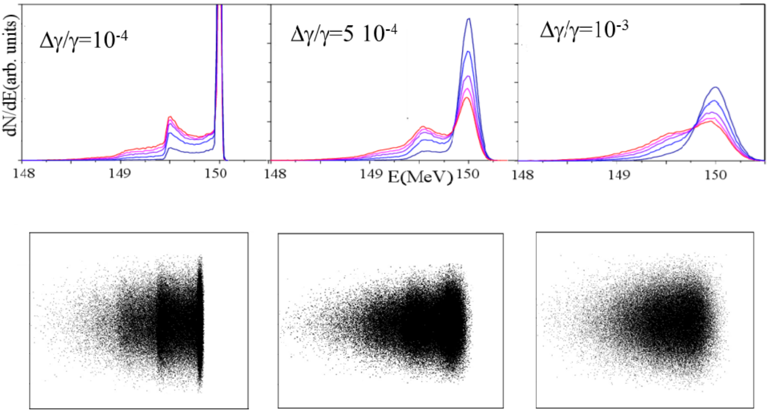

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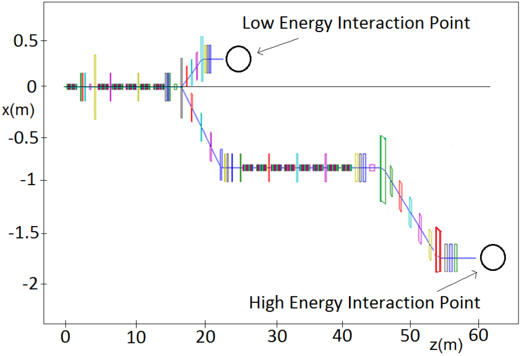
ELI-NP (Extreme Light Infrastructure - Nuclear Physics) to be developed at Magurele (Romania)



A. Bacci *et al.*, J. App. Phys.l **113**, 194508 (2013).

Electrons energy
$E = 360 - 720\ MeV$

Laser wavelenght
$\lambda_L = 0.5\ \mu m$

High brilliance γ rays
$\lambda_E = 10^{-13}\ m$

Emitted radiation energy
$E_f = 1 - 20\ MeV$

Number of Photons
$N = 2 \cdot 10^5$

Luminosity

$$L = \frac{N_L N_e}{2\pi(\sigma_x^2 + \frac{w_0^2}{4})} f = 10^{39}\ \frac{1}{sm^2}$$

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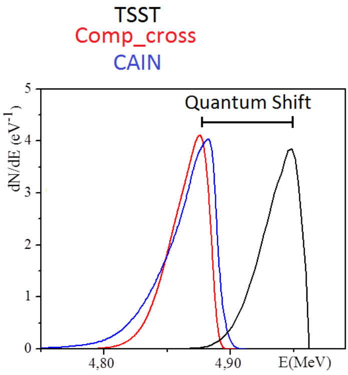
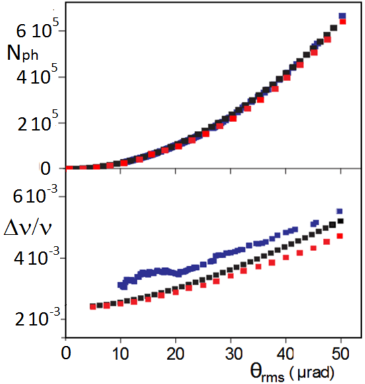
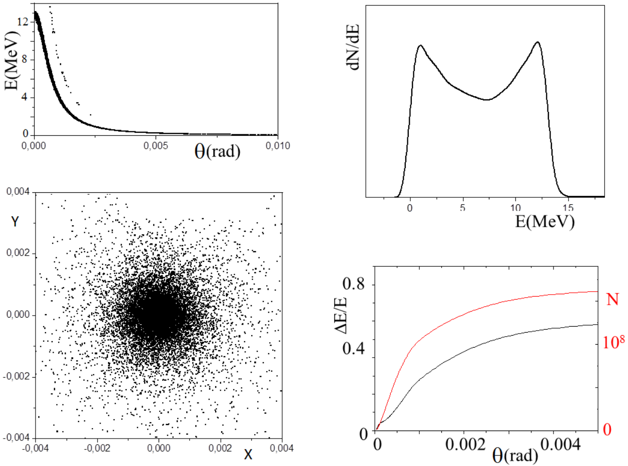
Codes: semi-analytical quantum Comp-cross developed by V. Petrillo and quantum code CAIN based on a Monte Carlo method.





V. Petrillo *et al.*, Nucl. Instrum. Methods Phys. Res. A **693**, 109-116 (2012).


12
8
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0
E(MeV)
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0,005
0,010
θ(rad)
dN/dE
0
5
10
15
E(MeV)
0,004
Y
0,002
0,000
-0,002
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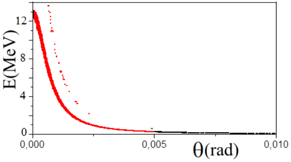
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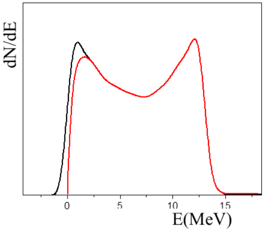
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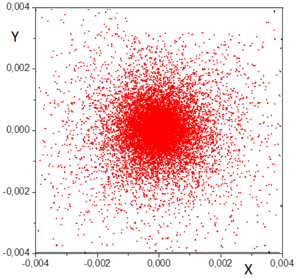
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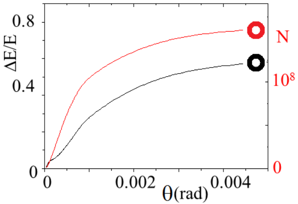
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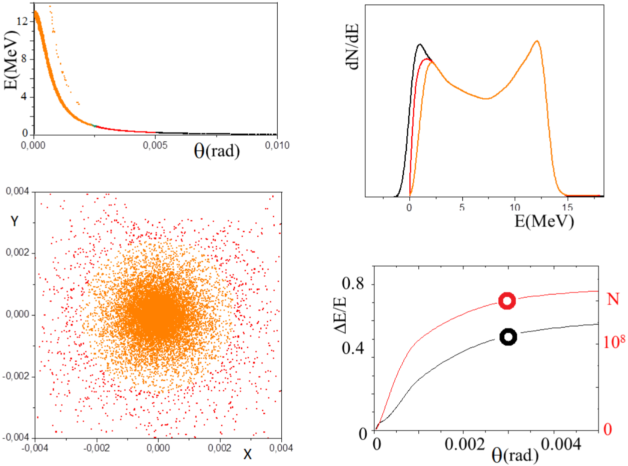
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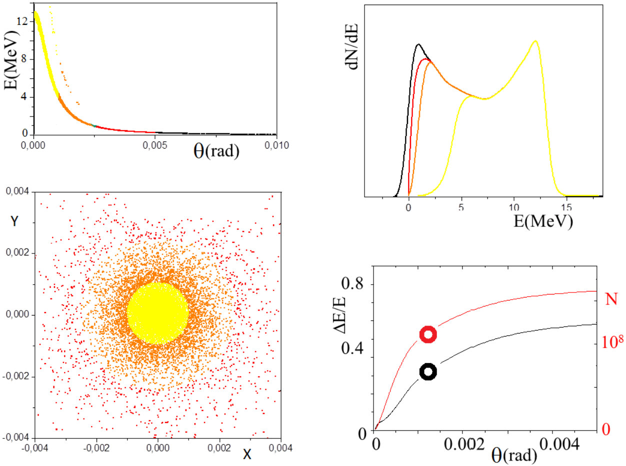
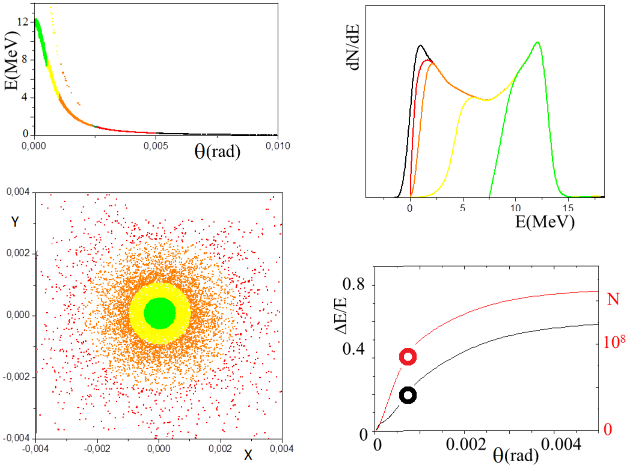
Simulations

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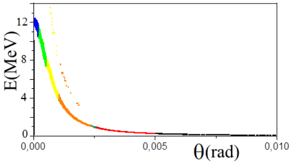

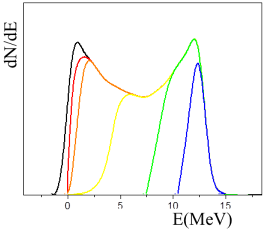

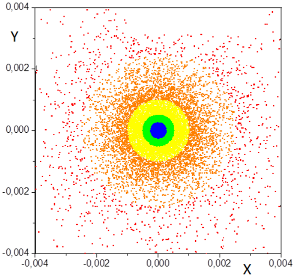

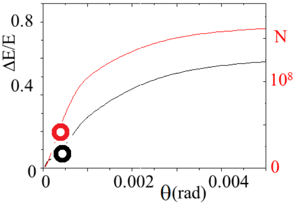

SPARCLAB: S-band Gun operating at 120 MV/m

$+$

2 S-band TW accelerating cavities,
each 3 m long operating at 22 MV/m

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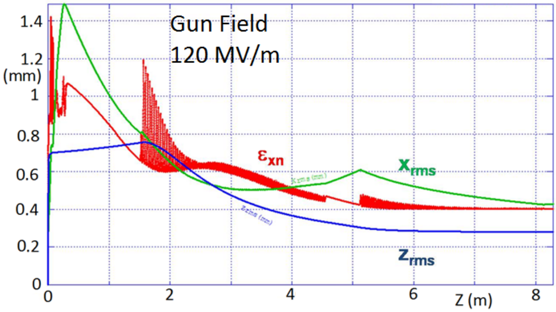

Values at 8 m
$\varepsilon = 0.407$
$\Delta E/E = 1.7\%$
$\sigma_z = 280\ \mu m$

A. Bacci *et al.*,
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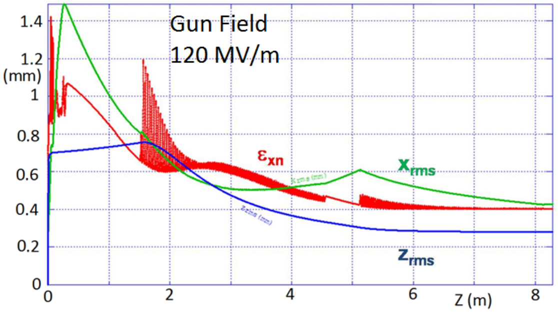

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Same design proposed for ELI-NP.

Study: C-band Gun operating at 170 MV/m

+

3 C-band TW accelerating cavities,
each 1.5 m long operating at 35 MV/m

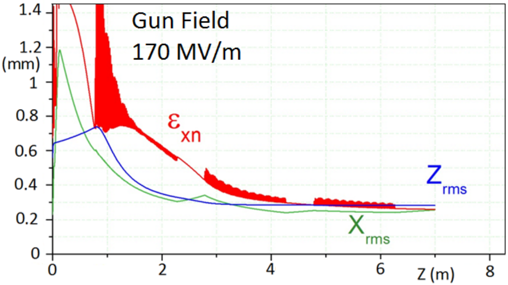
No velocity bunching

Study: C-band Gun operating at 170 MV/m

$+$

3 C-band TW accelerating cavities,
each 1.5 m long operating at 35 MV/m

No velocity bunching



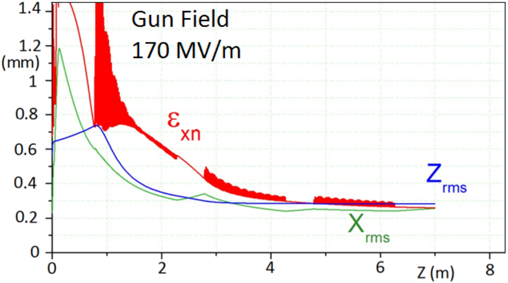
Values at 8 m
$\varepsilon = 0.245$
$\Delta E/E = 0.4\%$
$\sigma_z = 245\ \mu m$

Study: C-band Gun operating at 170 MV/m

+

3 C-band TW accelerating cavities,
each 1.5 m long operating at 35 MV/m

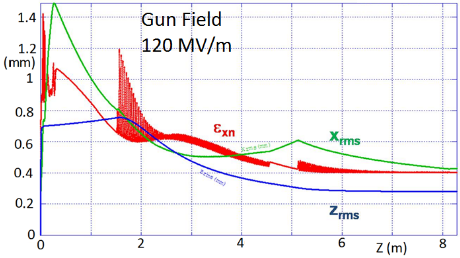
No velocity bunching



Values at 8 m
$\varepsilon = 0.245$
$\Delta E/E = 0.4\%$
$\sigma_z = 245\ \mu m$

Next SPARCLAB upgrade.

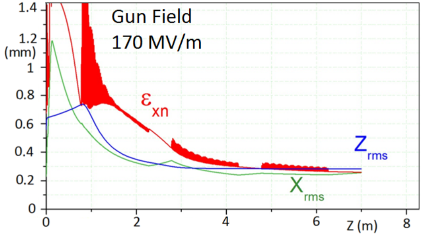
S-band



Values at 8 m
$\varepsilon = 0.407$
$\Delta E/E = 1.7\%$
$\sigma_z = 280\ \mu m$

A. Bacci *et al.*, J. App. Phys.l **113**, 194508 (2013).

C-band



Values at 8 m
$\varepsilon = 0.245$
$\Delta E/E = 0.4\%$
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C-band Gun+Photoinjector proposed for the SPARCLAB upgrade →

- Acceleration needed for Thomson scattering in less than 2 m
- Lower values of emittance, energy spread, beam size

C-band Gun+Photoinjector proposed for the SPARCLAB upgrade	→	• Acceleration needed for Thomson scattering in less than 2 m • Lower values of emittance, energy spread, beam size
Electrons distribution after the scattering	→	Important for future e-γ and γ-γ colliders
Rigorous method to calculate the Inverse Compton cross section	→	Foundamental issue

C-band Gun+Photoinjector proposed for the SPARCLAB upgrade	→	• Acceleration needed for Thomson scattering in less than 2 m • Lower values of emittance, energy spread, beam size
Electrons distribution after the scattering	→	Important for future e-γ and γ-γ colliders
Rigorous method to calculate the Inverse Compton cross section	→	Foundamental issue
Thomson at SPARCLAB just started operating (electrons transport)	→	Sperimental datas to compare with the theoretical previsions soon available

- V. Petrillo *et al.*, Nucl. Instrum. Methods Phys. Res. A **693**, 109-116 (2012).
- A. Bacci *et al.*, J. App. Phys.l **113**, 194508 (2013).
- J. D. Jackson. *Classical Electrodynamics*. John Wiley & Sons, Inc. (1998)

Thank you for your attention!