Status of the Project PLASMONX and the Experiment LILIA

Luca Serafini - INFN/Mi and INFN/LNF

• High Brightness Photoinjector SPARC – High Intensity (5 J, 300 TW) laser FLAME – both running at INFN-LNF

• Advanced stage of commissioning of 20-500 keV X-ray Thomson Source (march 2012): first dedicated source in Europe

• Proton/Light ions TNSA production at LNF in FLAME target area: the LILIA experiment (june 2012)

SPARC = Pulsed and Amplified Source of Coherent Radiation

Undulators

\[ \lambda_u = 2.8 \text{ cm} \]

\[ K_{\text{max}} = 2.2 \]

\[ \lambda_r = 500 \text{ nm} \]

Diagnostic and Matching

150 MeV S-band linac

Velocity Bunching

S-band Gun

Long Solenoids

Seeding

THz Source

15 m

Beam energy
155–200 MeV

Bunch charge
1 nC

Rep. rate
10 Hz

Peak current
100 A

\[ \varepsilon_n \]

\[ \varepsilon_n(\text{slice}) \]

\[ \sigma_\gamma \]

Bunch length (FWHM)

0.2%

10 ps

TERASPARC:
Terahertz Radiation through the Free-Electron Laser

SPARC = Pulsed and Amplified Source of Coherent Radiation

\[ \lambda_u = 2.8 \text{ cm} \]

\[ K_{\text{max}} = 2.2 \]

\[ \lambda_r = 500 \text{ nm} \]
200 fs electron bunch with low emittance demonstrated at SPARC!

COULOMB-11, Bologna, 04/11/2011
The Electron Beam Brightness Chart \[ \frac{A}{(m \cdot \text{rad})^2} \]

\[ B_n = \frac{2I}{\varepsilon_n^2} \]

\[ I \text{ [kA]} \]

\[ \varepsilon_n \text{ [\mu m]} \]

- Self-Inj
- Ext-Inj
- LCLS
- \( 10^{18} \)
- \( 10^{17} \)
- \( 10^{16} \)
- \( 10^{15} \)
- \( 10^{14} \)
- \( 10^{13} \)

\( X\)-FEL @ 1 pC
\( X\)-band Hyb Gun

COULOMB-11, Bologna, 04/11/2011
10th June 2009 – “Cold” laser installation

21st September 2009 – laser front-end switched on

December 2009 – main amplifier switched on

November 2010 – First Laser Accelerated Electrons (100 MeV)!

June 2010 – low power pulse transported into target area, compressed to 25 fs and focused to 20 μm
FLAME building – general layout

H interna (sottotrave) = 6,90 m

laboratorio
sup=220.00 m²

LASER CLEAN ROOM

YAGs POWER SUPPLIES
FLAME laser: specifications

- Repetition Rate: 10 Hz
- Energy (after compression): up to 6 J (typ. exp. 5.6J)
- Wavelength: 800 nm
- Pulse duration: down to 20 fs (typ. 23 fs)
- Peak power: up to 300 TW
- ASE contrast: < $10^{10}$
- Pre-pulse contrast: < $10^{-8}$
FINAL AMPLIFIER: FULL ENERGY

Final amplifier operational with all YAG pump lasers

Pulse energy: 7.34 J (before compression)

MP3 Stability (100% of shots)
0.89% RMS

Times (min)
LNF-FLAME: first propagation test

September 2010: propagation control

PLASMA - CHANNEL

Top view

Set up

Impulso laser FLAME
Gas-Jet supersonico
Ugello tipo Laval
Plasma
Fascio di elettroni

L. Gizzi

COULOMB-11, Bologna, 04/11/2011
PRELIMINARY ENERGY SPECTRUM

Recent spectra acquired at 1 J laser energy on target and 35 fs: expected intensity at focus: 7E18 W/cm²

Energy dispersion with a 0.9 T magnetic dipole

Electrons at lanex screen

Energy of LPA electrons entering the multi 100 MeV range
FLAME commissioning

- **June 2011.** All FLAME amplifiers working. Phase measurements at full energy: problems detected with Ti:Sa crystal cooling.
- **Settembre 2011.** Radioprotection final permission close to be cleared: full authorization for full energy operation of FLAME and Target Area by end of November
- **Ottobre 2011.** Acquisition procedure for Adaptive Optics

**In Progress**

- Implementation of new Ti:Sa crystal cooling set-up (November 2011)
- Self-Injection Acceleration Test at full power (200-250 TW) (December 2011)
- Installation of Adaptive Optics, to reach $10^{21}$ W/cm$^2$ (March 2012)
The Laser Pulse Intensity Chart

\[ a_0^2 = 3.7 \frac{\lambda^2 [\mu \text{m}]}{w_0^2 [\mu \text{m}]} P[TW] \]

\[ p^\text{el} \approx a_0 m_0 c \text{ (relativistic) mom. of plasma electrons} \]

COULOMB-11, Bologna, 04/11/2011
C. Benedetti

Studies for the SITE

- 3D sim. “GeV-class” \( (L_{gasjet} = 4 \text{ mm}) \)

\[
\begin{align*}
Q &\approx 0.6 \text{ nC} & \sigma_z &\approx 1.8 \text{ \( \mu \)m} \\
ct & = 2500 \mu \text{m} & I &\approx 45 \text{ kA} \\
ct & = 3200 \mu \text{m} & \sigma_x &\approx 0.5 \text{ \( \mu \)m} \\
ct & = 4000 \mu \text{m} & \varepsilon_n &\approx 2 \text{ \( \mu \)m}
\end{align*}
\]

COULOMB-11, Bologna, 04/11/2011
Asymptotic linear growth of norm. emittance with distance, as predicted by formula

\[ \varepsilon_n = \langle \gamma \rangle \sigma_\varepsilon \sigma_x^2 \]

Which gives, for C. Benedetti’s simulations of SITE, 500 mm.mrad per meter of free space drift (matches upper plot in first 10 cm drift before quadrupoles)

COULOMB-11, Bologna, 04/11/2011
Photon sources with plasma acceleration?

Emittance from LPWA with μm source size and mrad rms divergence can be of same order as from conventional beam source:

$$\gamma \varepsilon = 1 \text{mm} \cdot \text{mrad} \cdot \frac{\sigma_0}{\mu \text{m} \cdot \text{mrad} \cdot 10^3}$$

$$\sigma_0 \quad \theta \quad \gamma \quad \frac{\sigma_p}{p}$$

$L = \text{focal length}$

Chromatic emittance dilution is not negligible!

$$\Delta \gamma \varepsilon = 10 \text{mm} \cdot \text{mrad} \cdot \frac{\sigma_p}{p} \% \left( \frac{\theta}{\text{mrad}} \right)^2 \frac{L}{m} \frac{\gamma}{10^3}$$

Challenges and possible progress with all photon source drivers, including plasma-based ones!

Courtesy R. Brinkmann - DESY
Now the Two Pillars of SPARC-LAB are successfully working, independently. We must make them work together!

SPARC-LAB was recently approved by INFN as a national research infrastructure @ LNF (High Brightness Beams, Laser-Plasma Acceleration, Advanced Radiation Sources)

SPARC-LAB = Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams
Commissioning of Thomson Source

A. Ghigo, A. Zolla

COULOMB-11, Bologna, 04/11/2011
Hollow Dielectric Waveguide Capillaries

With LPGP Orsay, Brigitte Cros et al.

Recent achievements

- Optimisation of laser guiding using capillary tubes (10cm):
  - Vacuum or under-dense plasmas
  - Relevant for moderate intensities in laser wakefield schemes
  - Active control of laser properties to improve coupling

- Measurement of a plasma wave in the wake of an intense laser beam guided in a capillary tube over 8 cm, using optical diagnostics. Measured field up to 7 GV/m over 8 cm.
Envelope evolution

- Longitudinal
- Transverse

Transverse normalized emittance

<table>
<thead>
<tr>
<th>ε_n [mm mrad]</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Position [µm]

x x 10^4

COULOMB-11, Bologna, 04/11/2011
Lay-out  External Injection  
Plasma Target: Glass Capillary

Electron Beam through Off Axis Parabola  
(F=75 cm, \( \Phi_{\text{hole}} < 8 \text{ mm} \)), sinergy with COMB

Adiabatic Matching of injected beam down to  
3 \( \mu \text{m} \) spot-size into plasma wave

\[ \sigma_{x}^{\text{LENS}} = 2F \sigma_{x}^{\text{INJ}} / \sqrt{\gamma \lambda_p} \]

\[ \sigma_{x}^{\text{INJ}} = \sqrt{\frac{\varepsilon_n \lambda_p}{2\sqrt{\gamma}}} \propto \sqrt{\frac{\varepsilon_n}{E_{\text{acc}} \sqrt{\gamma}}} \]

\[ \varepsilon_n = 0.6 \ \mu \text{m} \ ; \ \lambda_p = 110 \ \mu \text{m} \]

\[ \Rightarrow \sigma_{x}^{\text{INJ}} = 1.4 \ \mu \text{m} \]
External Injection of a 10 fs 15 pC electron bunch generated by SPARC photoinjector into a LWFA

\[ \langle E \rangle = 2.01 \text{ GeV} \]
\[ \Delta E/E = 0.8\% \text{ rms} \]
\[ \varepsilon_n = 0.6 \mu m \]
Brightness good enough to drive a X-ray FEL

$B_{\text{peak}} = 2l/e^2 = 3.5 \times 10^{16} \text{A/m}^2$

COULOMB-11, Bologna, 04/11/2011
FEL’s and Thomson Sources common mechanism: collision between a relativistic electron and a (pseudo)electromagnetic wave.

- 1-25 GeV electrons
- 100-0.5 Å Photons (0.12-24 keV)
- 20-150 MeV electrons 0.8 µm laser λ
- 20-500 keV photons

Laser Synchrotron Light Source

Thomson Limit: electron recoil negligible (<< natural spectral bandwidth)
FEL resonance condition

\[ \lambda_R = \frac{\lambda_w}{2\gamma^2} \left(1 + a_w^2 + \gamma^2 \theta^2\right) \]  
(magnetostatic undulator)

Example: for \( \lambda_R=1A, \lambda_w=2cm, E=7\ GeV \)
\[ a_w = 0.93 \lambda_w [cm] B_w [T] \]

\[ \lambda_R = \frac{\lambda}{4\gamma^2} \left(1 + a_0^2 + \gamma^2 \theta^2\right) \]  
(electromagnetic undulator)

Example: for \( \lambda_R=1A, \lambda=0.8\mu m, E=25MeV \)
\[ a_0 = 4.8 \frac{\lambda[\mu m]\sqrt{P[TW]}}{R_0[\mu m]} \]  
\( \rightarrow \) laser power
\( \rightarrow \) laser spot size
APPLICATIONS of Thomson Source @ LNF, 20-500 keV

1. Mammography
2. Low-dose lung CT
3. Identification of fissile materials
4. Cristallography
5. Microdensitometry 3D for cultural her.

*Single Shot Imaging at psec time scale*
(not accessible to FELs for hv > 20 keV precluded to Sync. Light Sources, CW)
Thomson interaction region

F. Bosi, D. Giove

COULOMB-11, Bologna, 04/11/2011
Spettro

$\theta = 6$ mrad

$\theta = 1$ mrad

$N_{\text{tot}} = 1,69 \times 10^9$

$\Delta \omega / \omega \ (\text{FWHM}) = 10.5\%$

$\Delta \omega / \omega \ \text{rms} = 5.2\%$

$\text{div} \ (\text{FWHM}) = 22 \text{ mrad}$

$\text{div rms} = 5.3 \text{ mrad}$

V. Petrillo
Energia dei fotoni @ 75 cm dal punto di interazione

Fluenza @ 75 cm dal punto di interazione

Profilo orizzontale e verticale della distribuzione dei valori di energia a 75 cm dal punto di interazione

Profilo orizzontale e verticale della fluenza a 75 cm dal punto di interazione
SPARC Hall update:
SPARC Hall update:

PLASMA IP

THOMSON
Brilliance of X-ray radiation sources

SASE-FELs will allow an unprecedented upgrade in Source Brilliance

Covering from the VUV to the 1 Å X-ray spectral range: new Research Frontiers

Compact Thomson Sources extend SR to hard X-ray range allowing Advanced Radiological Imaging inside Hospitals

First Collisions and X-ray generation expected by march 2012
Plasma Wakefield Acceleration (PWFA)

- *Electron beam* shock-excites plasma
- Same scaling as Cerenkov wakes, maximum field scales in strength as

\[ E \propto N_b k_p^2 \propto N_b \sigma_z^{-2} \]

- In “blowout” regime, plasma e⁻’s expelled by beam.
  Ion focusing + EM acceleration= plasma linac
Laser Comb: a train of THz bunches

Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation (MeV).

- M. Ferrario, M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)
Bunch spacing/plasma density condition:
\[ \Delta z = \lambda_p \text{ (resonance) } \sigma_z << \lambda_p \]
\[ \Delta z' \approx (m+1/2)\lambda_p, \text{ } m=0,1,2 \ldots \]
Plasma wavelength:
\[ \lambda_p = \frac{2\pi c}{\omega_{pe}} \]
Plasma angular frequency, density \( n_e \):
\[ \omega_{pe} = \left( \frac{n_e e^2}{\varepsilon_0 m_e} \right)^{1/2} \]

Wake fields add up (linear theory):
\[ E_z \text{ } N \text{ bunches} \approx N \times E_z \text{ 1 bunch} \]

Finite energy spread \( \Delta E/E << 1 \), beam acceleration

P. Muggli, HBEF Workshop, 11/17/09
Multibunch PWFA

Bunch Train @ Resonance

Ramped Bunch Train

Transformer Ratio: \( R = \frac{E_+}{E_-} \)

Energy Gain: \( \leq RE_0 \)

2D Linear Calculations: \( \alpha_f = 125 \mu \text{m}, n_e = 1.8 \times 10^{16} \text{ cm}^{-3} \)

\( Q = 30 \text{ pC/bunch}, \Delta z = 250 \mu \text{m}\alpha_p \)

\( \Delta z' = 375 \mu \text{m}\approx 1.5\alpha_p \)

\( R = 7.9 \Rightarrow \text{gain 8x incoming energy a single PWFA stage!} \)

Linear regime, theory (\( n_b/n_e, \delta n_e/n_e, E_z/E_{WB} \ll 1 \))
LILIA (Laser Induced Light Ions Acceleration)

LILIA is an experiment of light ions acceleration through laser interaction with thin metal targets to be done at the FLAME facility, which is now running in Frascati.

Participant Groups: Milano, Milano Bicocca, Bologna, LNS, Lecce
• LILIA, in particular, is finalized to study, design and verify a scheme which foreseen the production, the characterization and the transport of a proton beam toward a stage of post acceleration (high frequency compact linacs).

• As of now the maximum intensity is limited to $10^{19}$ W/cm$^2$ due to the lack of a parabola with focal length shorter than the present one. In this configuration, according to performed numerical simulations, we expect a proton beam with maximum energy up to 5 MeV and total intensities up to $10^{10}$-$10^{12}$ protons/shot.

• Although these values are modest compared to the present state of art, we aim at playing a role as a test facility focused on emission process control and repeatability, and post acceleration tests.
LILIA PHASE I

• A parametric study of the correlation of the maximum TNSA accelerated proton energy, with respect to the following parameters:
  • Laser pulse intensity (in the range $10^{18} - 5 \times 10^{19}$ W/cm$^2$)
  • Laser pulse energy (in the range 0.1-5 J)
  • Laser pulse length (in the range 25 fs- 1ps)
  • Metallic target thickness (in the range 1-100 microns).
• In such a frame we would like to deeply investigate the experimental scale rules within the possibilities offered by the FLAME facility. Moreover, this will provide the opportunity to get experience in the development of diagnostic techniques and in target optimization.
LILIA PHASE I

• The possibility to produce a real proton beam able to be driven for significant distances (50-75 cm) away from the interaction point and which will act as a source for further accelerating structures.

COULOMB-11, Bologna, 04/11/2011

Courtesy C. Demartinis
LILIA PHASE II

• When FLAME phase II performances will be available, we might select a bunch at $E = 30$ MeV with a narrow spread $\Delta E$ and still have a reasonable number of protons ($10^7 \sim 10^8$). This opens a very interesting perspective for applications such as hadrontherapy in connection with a post-acceleration stage in order to reach energies up and beyond 100 MeV. Indeed if a sufficient current intensity can be reached at 30 MeV with a narrow spread $\Delta E/E \sim 1\%$ and a good beam quality after transport, energy selection and collimation, the protons bunch might be post-accelerated after injection in a high field linac, as the one developed for the INFN ACLIP project [suitable for medical applications.}

Courtesy C. Demartinis
ACLIP – a candidate for boosting the proton beam in a hybrid scheme of post-acceleration with 3 GHz RF linac (5 MeV over 40 cm)

Courtesy C. Demartinis
END OF PRESENTATION
A Thomson spectrometer has been designed and realized within the LILIA collaboration. An extensive description can be found in [12].

The main characteristics may be so summarized:

- Analysis of proton and carbon beams (Q=+1 to +6) from 0.1 to 10 MeV
- Very compact design [160x144x150 mm3]
- High magnetic field (tunable) up to 1850 gauss
- High electric field (tunable) up to 20kV/cm
END OF PRESENTATION
Europe is going to invest 280 M€ on ELI-NP in 2012-2015, to launch the Nuclear (and sub-Nuclear) Photonics Program.
ELI – Nuclear Physics Research

- Nuclear Physics experiments to characterize laser – target interactions
- Photonuclear reactions.
- Exotic Nuclear Physics and astrophysics – complementary to other NP large facilities (FAIR, SPIRAL2).
- Nuclear methods and techniques based on high intensity laser and very brilliant γ beams.
ELI-NP “Start-up” Activities

- **February 2010**
  Workshop Scientific case

- **April 2010**
  “White Book” (100 scientists, 30 institutions) (www.eli-np.ro)
  editors: D. Habs et al.

- **August 2010**
  Feasibility Study:  280 Meuro
  80 Mil. Lasers and beam transport
  60 Mil. γ beam
  60 Mil. Construction
  24 Mil. Experiments
  23 Mil. Personnel

COULOMB-11, Bologna, 04/11/2011

Courtesy Victor Zamfir
Some Potential Nuclear Photonics NRF Applications of MEGa-rays

HEU Grand Challenge
- detection of shielded material

Nuclear Fuel Assay
- 100 parts per million per isotope

Waste Imaging & Assay
- non-invasive content certification

INDUSTRIAL NDE

Precision Imaging
- micron-scale & isotope specific

Medical Imaging
- low density & isotope specific

Dense Plasma Science
- isotope mass, position & velocity
$^{138}$Ba at $E^* < 8.5$ MeV. The measured elastic $E1$ (open histogram) and $M1$ (solid histogram) cross sections, integrated over 200 keV bins, are shown in the upper part of Fig. 3. As can be seen at excitation energies below the particle emission threshold, the $E1$ transitions in $^{138}$Ba are distributed in a broad, resonancelike structure. The observed concentration of $1^-$ states is characterized by the high level density which increases steeply towards the threshold. In this connection, the multiphonon QPM calculations which account for nonharmonic effects, are important for reproducing the fragmentation pattern. The calculations show that the $1^-$ QRPA states are fragmented over 130 multiphonon states below $E^* = 8.5$ MeV. This agrees very well with the number of experimentally observed $1^-$ states in this energy range. In contrast, the magnetic dipole transitions which result from the decay of single-particle states, are much more isolated and they are concentrated at well specified regions. For example, a group of $1^+$ excited states, located at $E^* = 6–7.5$ MeV, is connected to the dissipation and fragmentation of the $1^+_2$ QRPA state. Above 8 MeV the $1^+$ states are characterized predominantly by multiphonon configurations, incorporating only a few percent of the strength of the $1^+_3$ QRPA state (indicating the maximum of the QRPA $M1$ strength). In the energy range $E^* = 6–8.5$ MeV 19 $1^+$ states with transition

FIG. 2 (color online). Upper panel: Elastic ($\sigma_{\gamma\gamma}$), inelastic ($\sigma_{\gamma\gamma'}$), and total absorption cross sections ($\sigma_{\gamma}$) in $^{138}$Ba below the one-neutron-separation energy ($S_n = 8.6$ MeV) averaged over the beam energy spread of about 3%. The actual beam energy spread is shown as horizontal bars. Lower panel: the present total absorption cross section ($\sigma_{\gamma}$) is combined with the ($\gamma$, $xn$) data from the GDR [28].
END OF PRESENTATION
Ultra-short XFEL pulses: motivation and feedback to HEP

- Investigations at atomic electron spatio-temporal scales
  - Angstroms-nanometers (~Bohr radius)
  - Femtoseconds (electronic motion, Bohr period)
  - Femtochemistry, etc.
- 100 fs accessible using standard techniques
- Many methods proposed for the fsec frontier
- Use “clean” ultra-short electron beam
  - Myriad of advantages in FEL and beam physics
  - PWFA...
**FEL performance: 1 pC, 2 fs e⁻ bunch**

- Single spike with some structure
- $>1$ GW peak power at saturation (30 m)
- 480 attosecond rms pulse at 2 nm at SPARX

$D\omegaDt = 1.67$
Ultra-short beam application:

**IR wavelength PWFA**

- Ultra-high brightness, fs beams impact HEP also!
- Use 20 pC LCLS beam in high $n$ plasma
- In “blowout” regime: total rarefaction of plasma e$^{-}$s
  - Beam denser than plasma
  - Very nonlinear plasma dynamics
  - Pure ion column focusing for e-s
  - Linac-style EM acceleration
- General measure of nonlinearity:

$$\tilde{Q} \equiv \frac{N_b k_p^3}{n_0} = 4 \pi k_p r_e N_b$$

\[ \begin{align*}
\ll 1, & \quad \text{linear regime} \\
> 1, & \quad \text{nonlinear "blowout"}
\end{align*} \]

MAGIC simulation of blowout PWFA case

**COULOMB-11, Bologna, 04/11/2011**
Optimized excitation

- With 2 fs LCLS beam we should choose
- For 20 pC beam, we have $\tilde{Q} = 7.5$ $n_0 = 7 \times 10^{19}$ cm$^{-3}$
- 1 TV/m fields (!)

Teravolt-per-meter plasma wakefields from low-charge, femtosecond electron beams

J. B. Rosenzweig*, G. Andonian*, P. Bucksbaum†, M. Ferrario¹, S. Full*,
A. Fukusawa*, E. Hemsing*, M. Hogan†, P. Krejcik†, P. Muggli², G. Marcus*,
A. Marinelli*, P. Musumeci*, B. O’Shea*, C. Pellegrini*, D. Schiller*, and G. Travish*

*Department of Physics and Astronomy, University of California Los Angeles, Los Angeles, California 90095, USA
†Stanford Linear Accelerator Center, Menlo Park, CA
¹ Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati, via Enrico Fermi 40, Frascati (RM) Italy and
²University of Southern California, Dept. of Engineering Physics, Los Angeles, CA

(Dated: November 12, 2009)

Recent initiatives in ultra-short, GeV electron beam generation have focused on achieving sub-fs pulses for driving X-ray free-electron lasers (FELs) in single-spike mode. This scheme employs very low charge beams, which may allow existing FEL injectors to produce few-100 as pulses, with high brightness. Towards this end, recent experiments at SLAC have produced $\sim$2 fs rms, low transverse emittance, 20 pC electron pulses. Here we examine use of such pulses to excite plasma wakefields exceeding 1 TV/m. We present a focusing scheme capable of producing <200 nm beam sizes, where the surface Coulomb fields are also $\sim$TV/m. These conditions access a new regime for high field atomic physics, allowing frontier experiments, including sub-fs plasma formation for wake excitation.

PACS numbers: 41.60.Cr, 41.75.-l, 41.85.Gy, 42.60.Jf
Sub-fs $e^{-1}$ pC bunches @ SPARC
First attempt (A. Bacci with gen. algorithm)

\[
\sigma_t \approx 0.9 \text{ fs (0.28 } \mu\text{m)}
\]

\[
\frac{\Delta \gamma}{\gamma} \approx 0.1\%
\]

Comp $\geq 100$!
• **PWFA:**

1. A *driver* (electron) bunch *creates a wakefield* in the plasma
2. A *trailing/witness* (electron) bunch *accelerates in the wakefield*

⇒ Is it possible to accelerate the witness keeping a good beam quality?
END OF PRESENTATION