Beam dynamics of high brightness beams in RF photoinjector

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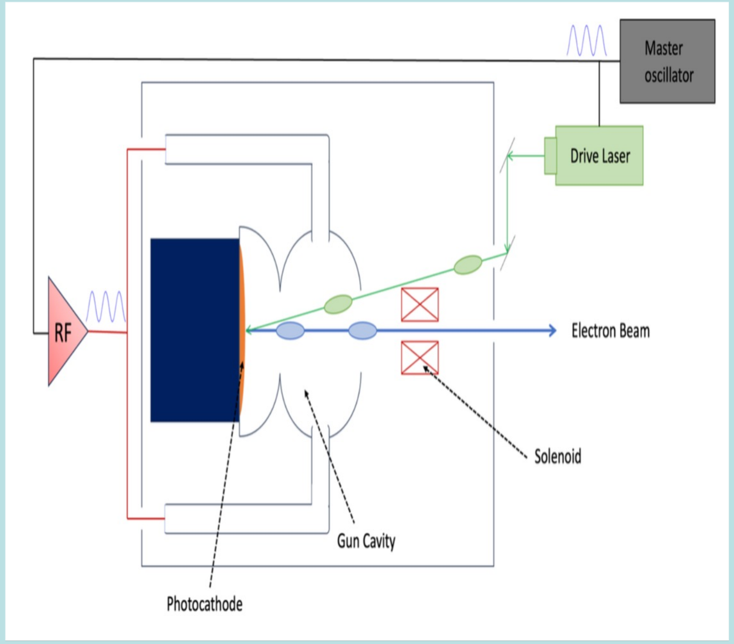
Context:

Beam dynamics of high brightness beams in RF photoinjector

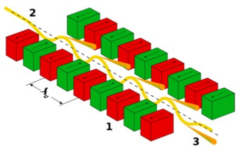


$$B_{6D} \propto \frac{Ne}{\varepsilon_{nx}\varepsilon_{ny}\sigma_t\sigma_{gamma}},$$

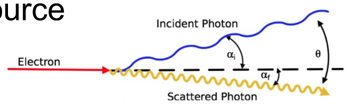
Goal:

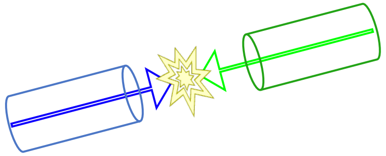
- Low emittance
- Low energy spread
- Short beam → High current

APPLICATION:



- Free Electron Laser (FEL)
- Inverse Compton Scattering source





- Linear collider

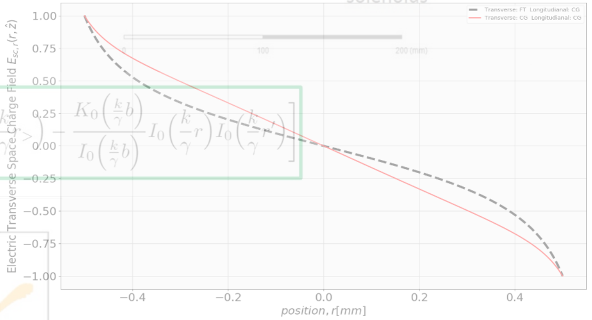
UC-XFEL

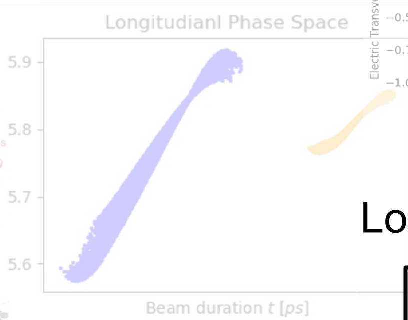
DARPA-GRIT

Outline

- C-Band Hybrid photoinjector:
  - Beam dynamics
  - Envelope equation: the Triple waist approximation
  - Emittance compensation:
    - Multi-slice model and Double emittance minimum
    - Laser distribution: space charge analytical model
- SPARC_LAB:
  - Gun conditioning
  - Witness-Driver configuration
  - Experimental results
- UCLA Experience:
  - MITHRA's Gun Characterization
  - COMB beam with Hybrid Injector

$$\sigma_x'' = \frac{k}{\sigma_x^2}$$





Look at the icons here:

: From Literature

: From group results

Outline

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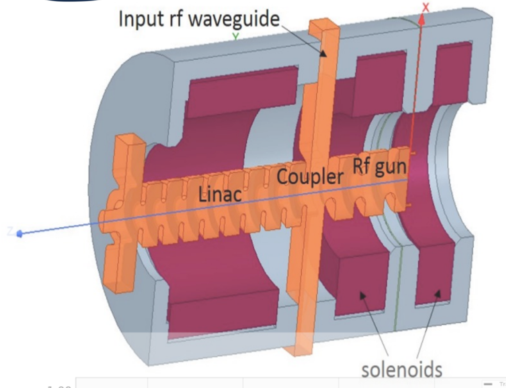
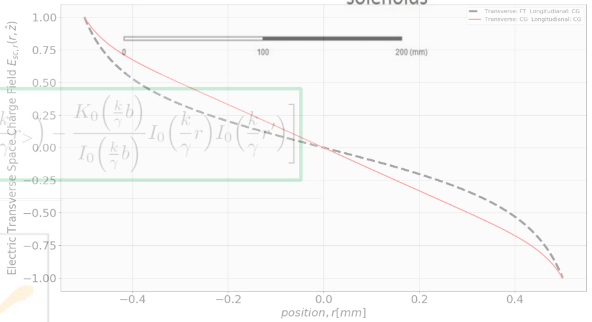
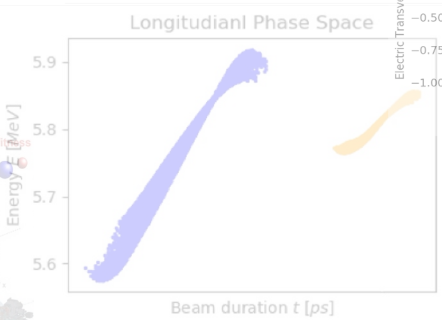




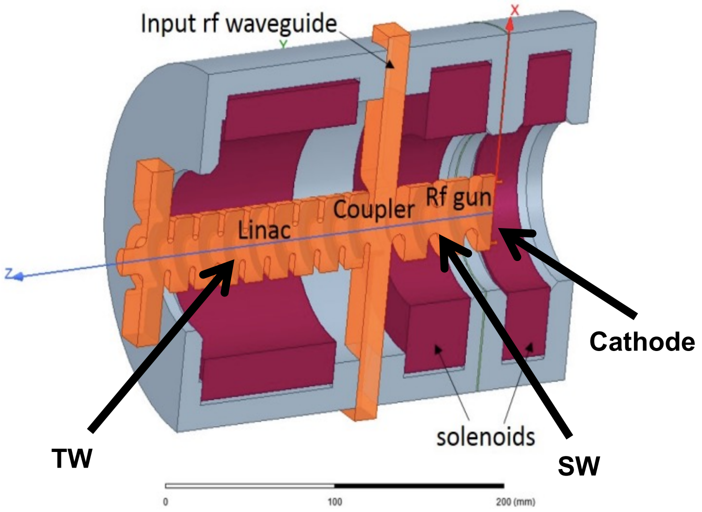


C-band Hybrid photoinjector

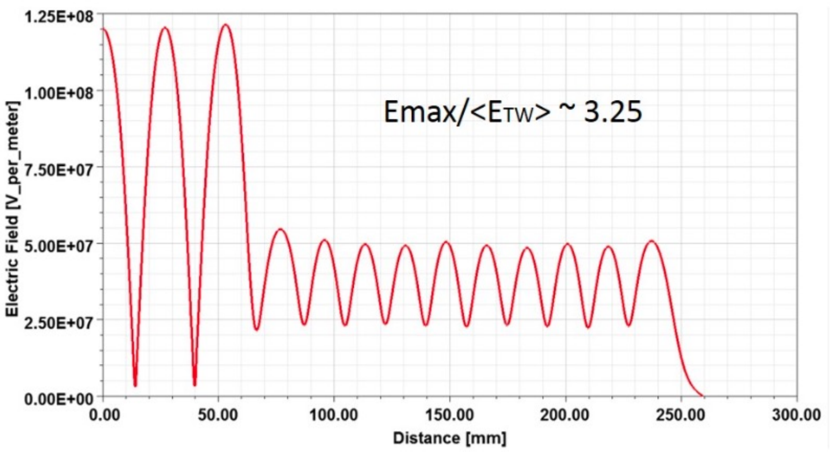
**Courtesy of Luigi Faillace

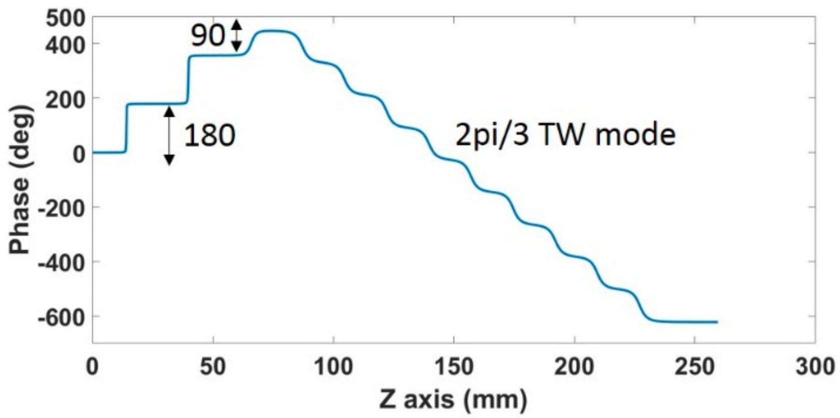
DARPA-GRIT Project:

UCLA · Sapienza Università di Roma · INFN · RadiaBeam



- **C-Band**: $5.712\ GHz$
- No circulator is needed;
- Enabling the scaling to C-band allows exploitation of the natural scaling of photoinjector brightness with RF wavelength, i.e. $B_e = 2I/\epsilon_n^2 \sim \lambda^{-2}$;
- Possibility of obtaining ultra-short electron bunches due to ***velocity bunching*** (VB) between the SW and TW sections





[*]L. Faillace, J. B. Rosenzweig et al., High field hybrid photoinjector electron source for advanced light source applications. Phys. Rev. Accel. Beams, 25:063401, Jun 2022. doi: 10.1103/PhysRevAccelBeams.25.063401.

[*] L. Serafini and Massimo Ferrario. Velocity bunching in photo-injectors. Proc. AIP, 581, 08 2001. doi: 10.1063/1.1401564

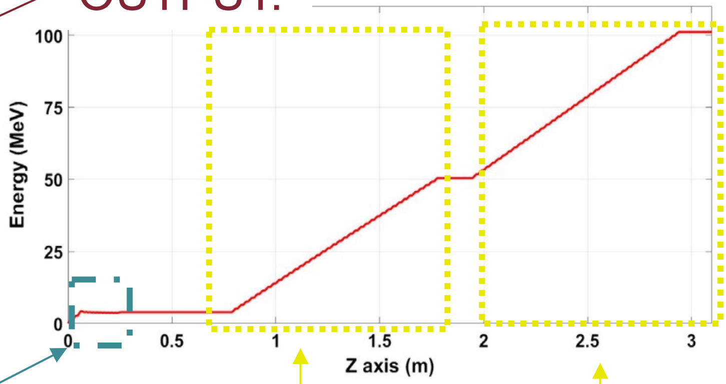
C-band Hybrid photoinjector: Beam Dynamics

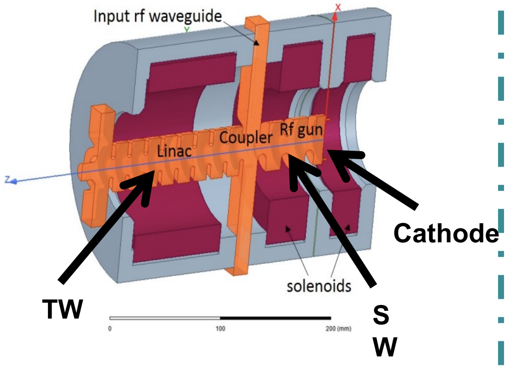
INPUT:

Table 1: Main Input Electron Beam Parameters

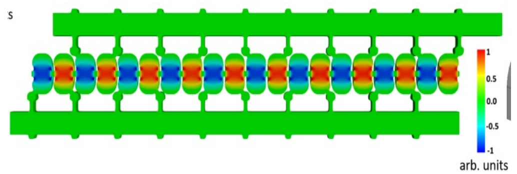
Parameter	Value
Beam Charge, Q	250 pC
Spot Size, $\sigma_{x,y}$ (cut at 1 σ)	0.5 mm
Bunch Length, σ_z	0.5 ps
E-field at cathode, E_0	120 MV/m
Number of macro-particles	50 000

OUTPUT:

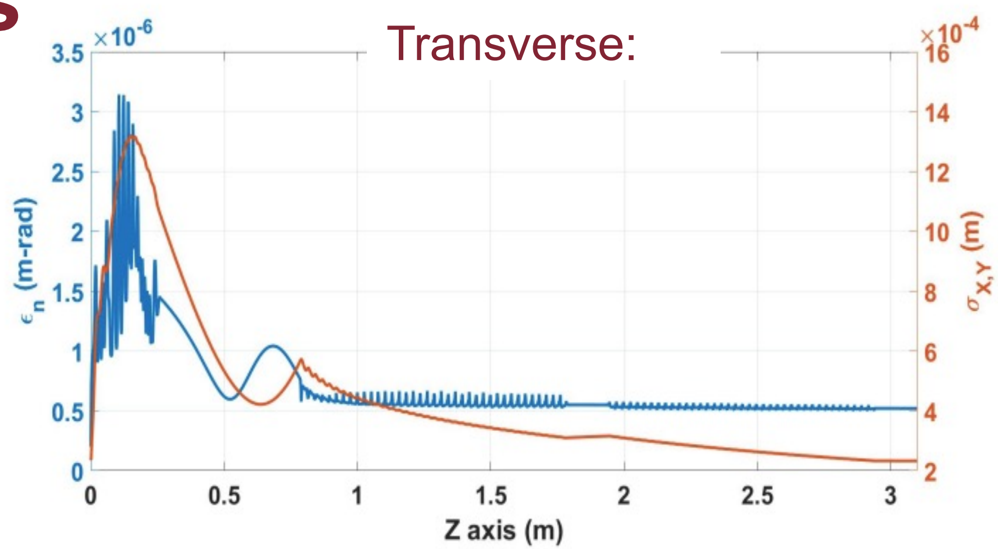




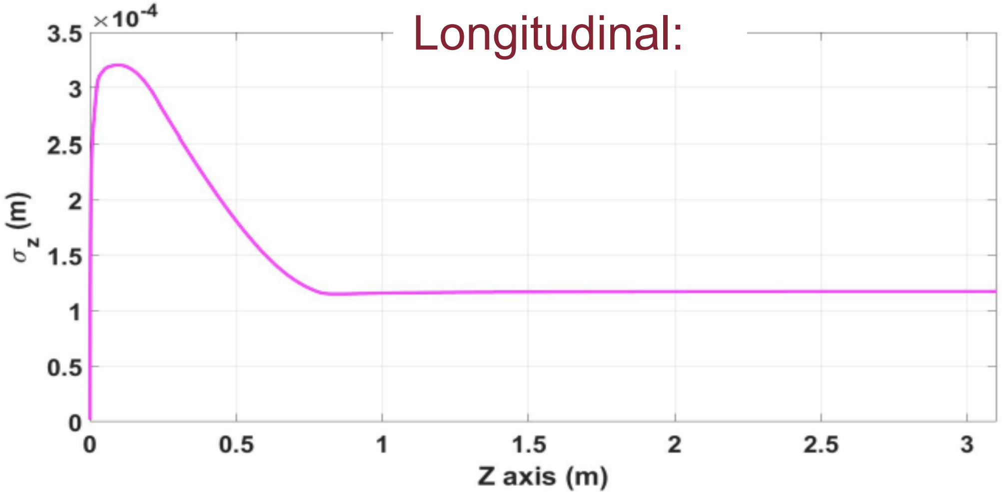
Distributed-coupling linear accelerator structure by Sami Tantawi



Transverse:



Longitudinal:



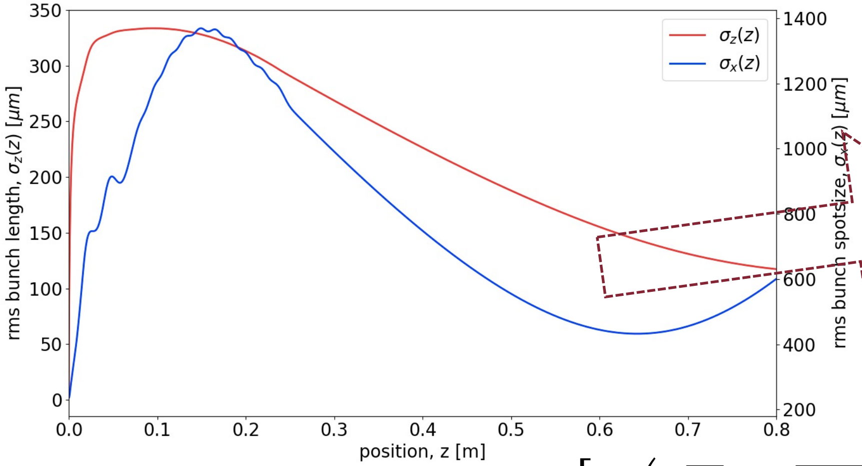
[*]L. Faillace et al. Start-to-End Beam-Dynamics Simulations of a Compact C-Band Electron Beam Source for High Spectral Brilliance Applications. In Proc. IPAC'22, number 13 in International Particle Accelerator Conference, pages 687–690. JACoW Publishing, Geneva, Switzerland, 07 2022. ISBN 978-3-95450-227-1

[*]Sami Tantawi, Mamdouh Nasr, Zenghai Li, Cecile Limborg, and Philipp Borchard. Distributed coupling accelerator structures: A new paradigm for high gradient linacs. arXiv preprint arXiv:1811.09925, 2018.

Envelope analysis in the drift: Triple waist approximation

[*]O. Kellogg,Foundation of Potential Theory. Dover, UK:Springer, 1953.

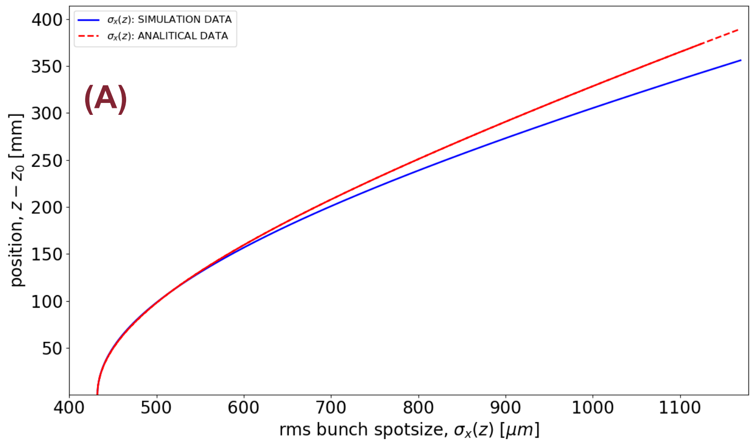
Drift region: space charge term is dominant on emittance pressure $\sigma_x'' = \frac{\kappa_p}{\sigma_x} \longrightarrow \kappa_p = \frac{k}{\sigma_z}$ with $k = \frac{N r_e f}{\sqrt{2\pi}\,\gamma^3}\frac{\sigma_{x,0}}{\sigma_{z,0}}$ $\quad \boldsymbol{\sigma_x'' = \frac{k}{\sigma_x \sigma_z}}$



Triple waist approximation:

$\sigma_z \sim \sigma_x$

$$\sigma_x'' = \frac{k}{\sigma_x^2}$$

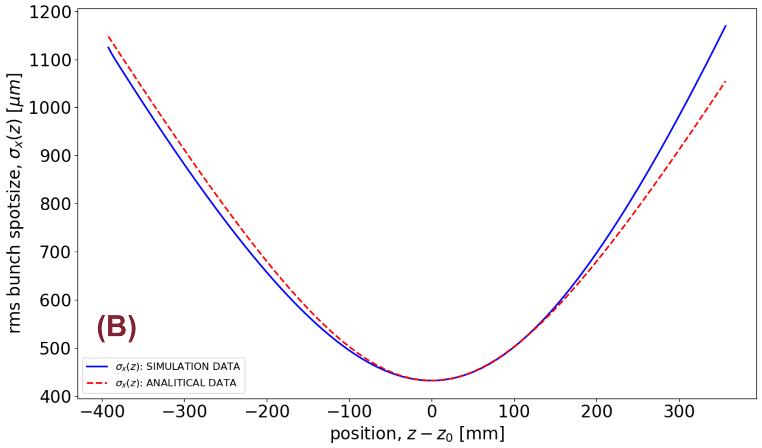


- **Exact solution:** $z = \frac{\sigma_0^{3/2}}{\sqrt{2k}}\left[ln\left(\sqrt{\frac{\sigma}{\sigma_0}}+\sqrt{\frac{\sigma}{\sigma_0}-1}\right)+\sqrt{\frac{\sigma}{\sigma_0}\left(\frac{\sigma}{\sigma_0}-1\right)}\right]+z_0$

  (A)

- **Perturbative solution:** $\sigma(z) = \sigma_0\left[\sqrt{\frac{k}{2\sigma_0}}\left(\frac{z}{\sigma_0}\right)\cdot\tan^{-1}\left(\sqrt{\frac{k}{2\sigma_0}}\left(x\,\frac{z}{\sigma_0}\right)\right)\right]$

  (B)



[*] M. Carillo et al., "Three-dimensional space charge oscillations in a hybrid photoinjector", presented at the 12th Int.Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May2021, paper WEPAB256

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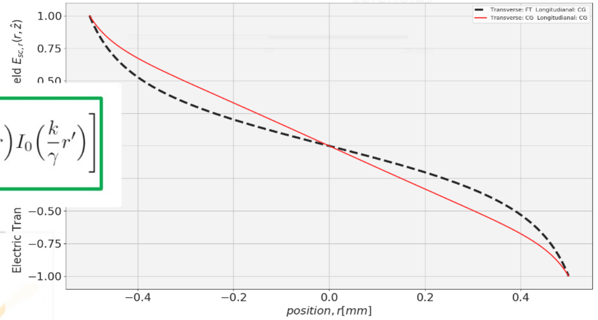
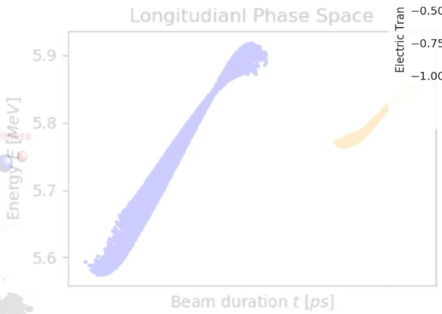


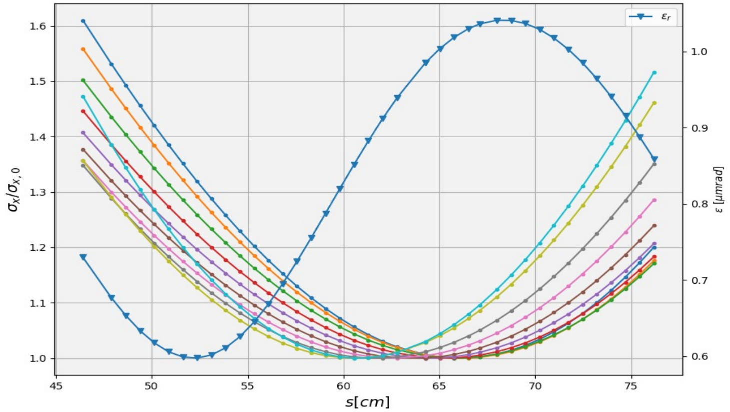
$$\tilde{G}(r,r',k) = \frac{1}{2\pi\epsilon_0}\left[I_0\left(\frac{k}{\gamma}r_<\right)K_0\left(\frac{k}{\gamma}r_>\right) - \frac{K_0\left(\frac{k}{\gamma}b\right)}{I_0\left(\frac{k}{\gamma}b\right)}I_0\left(\frac{k}{\gamma}r\right)I_0\left(\frac{k}{\gamma}r'\right)\right]$$



Double emittance minimum

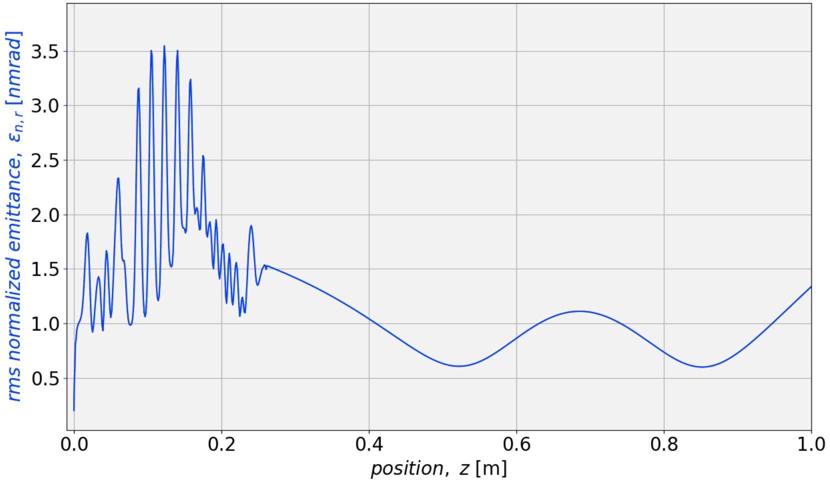
Serafini and Rosenzweig:
In the space charge dominated regime, mismatches between the space charge correlated forces and the external rf focusing produce slice envelope oscillation

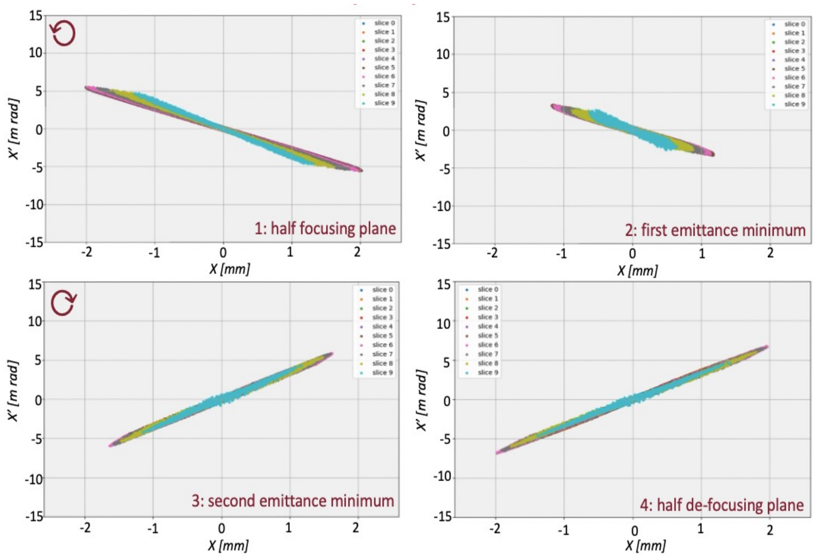
[*] L. Serafini, J. B. Rosenzweig, Phys. Rev. E 55, 7565- 7590 (1997)



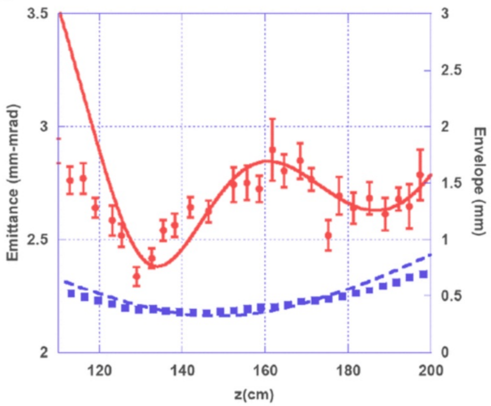
the space charge dominated waist is rached at different position by the head and the tail slices of the bunch

[*] M. Ferrario et al., SLAC-PUB-8400, (2000)
[*] C. Ronsivalle et al., Proceedings of EPAC08, Genoa, Italy MOZAG01



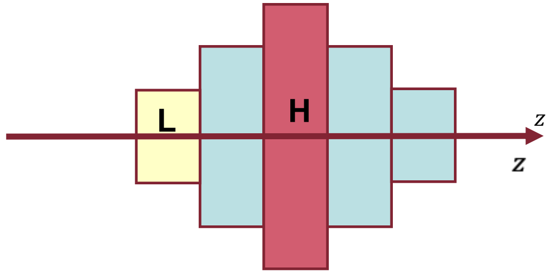


[*]Ferrario, M.; et al. Direct measurement of the double emittance minimum in the beam dynamics of the sparc high-brightness photoinjector. Phys. Rev. Lett. 2007, 99, 234801.



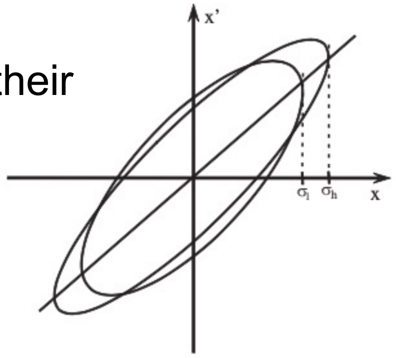
Correlated slice emittance

Double emittance minimum: Floettmann



The emittance of the beam is formed by a superposition of the slices with their respective orientation and form in phase space

↓

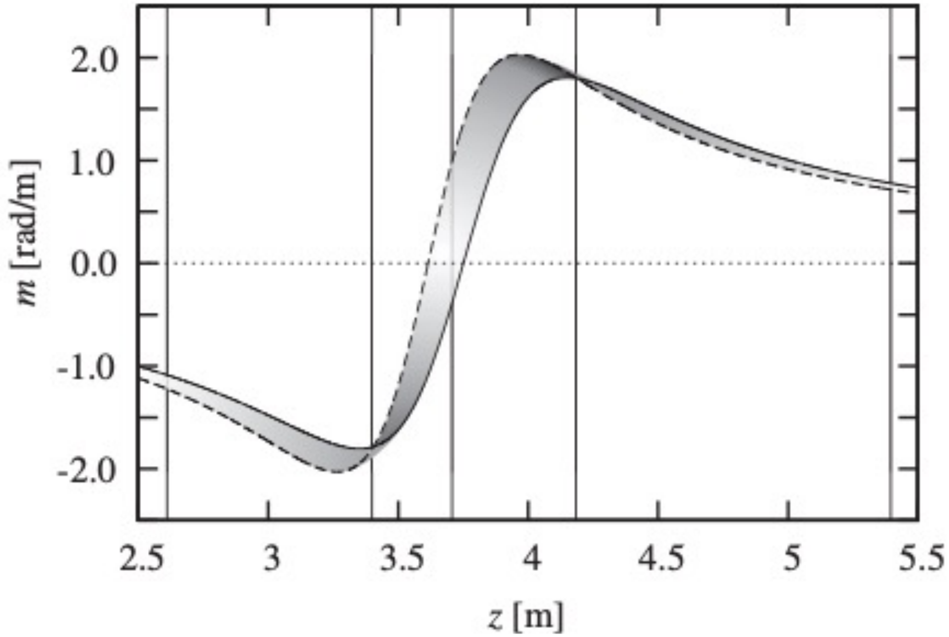


To understand the emittance growth $m = \frac{\langle xx' \rangle}{\langle x^2 \rangle} = \frac{\sigma'}{\sigma}$

When Δm is small → the fanlike structure in the phase space is close: the slices are aligned in the phase space

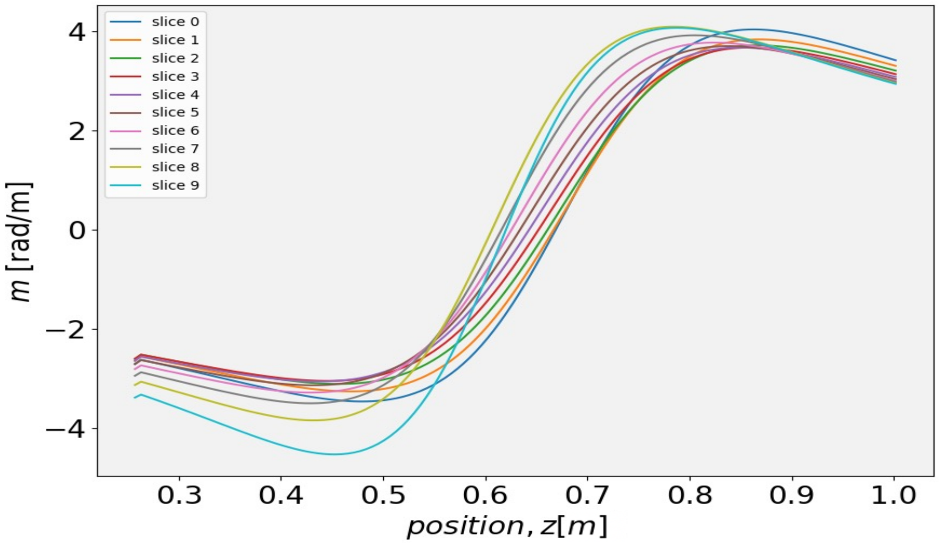
The condition for the emittance minimum is $\boldsymbol{\Delta m = 0}$

In the case of two slices, this condition becomes a quadratic equation in z, so we have two solutions and so two positions for minimum emittance



[*] K. Floettmann, Emittance compensation in split photoinjectors, Phys. Rev. Accel. Beams 20, 013401 (201

Multi slice model



$$\varepsilon_{rms}^2 = \sigma_x^2\sigma_{p_x}^2 - \sigma_{x,p_x}^2 = \dots = \sum_{i=j}\left(\frac{M_i}{N}\right)^2 {\varepsilon_{rms}}_i^2 + \sum_{i\neq j}\frac{M_iM_j}{N^2}\left({\sigma_{x,i}}^2\sigma_{p_{xj}}^2 - \sigma_{xp_{x,i}}\sigma_{xp_{x,j}}\right)$$

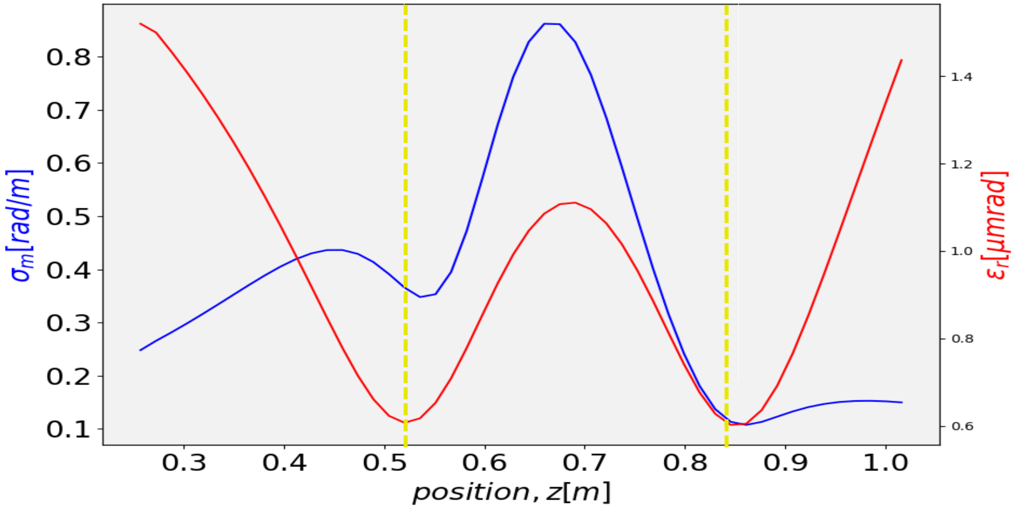
- M_i: number of particles in $i-th$ slice
- N: number of particles in the bunch
- S: number of slices

Correlated emittance

$$\boldsymbol{\varepsilon_{corr}^2 = \frac{1}{2S^2}\sum_{i\neq j}\left(\sigma_i\sigma_j' - \sigma_j\sigma_i'\right)^2}$$

To connect ε_{corr} with m: $\sigma_i' = m_i\sigma_i$

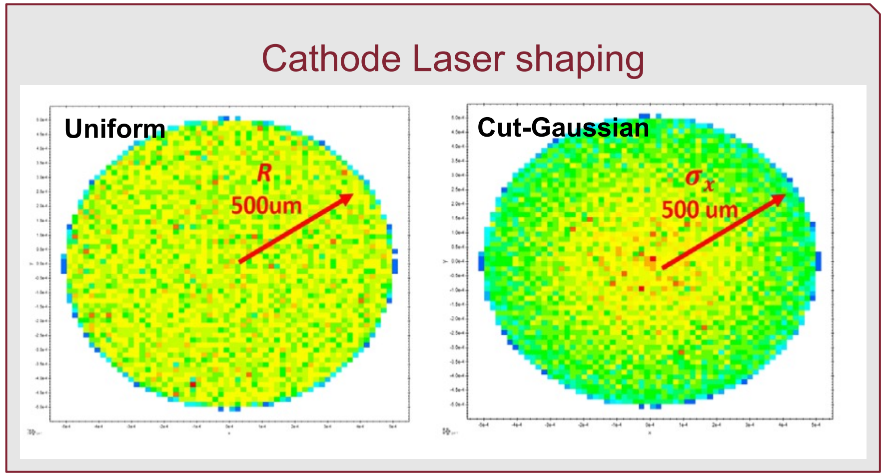
$$\varepsilon_{corr}^2 = \frac{1}{2S^2}\sum_{i\neq j}\left(\sigma_i m_j\sigma_j - \sigma_j m_i\sigma_i\right)^2 = \frac{1}{2S^2}\sum_{i\neq j}\sigma_i^2\sigma_j^2\left(m_i - m_j\right)^2$$

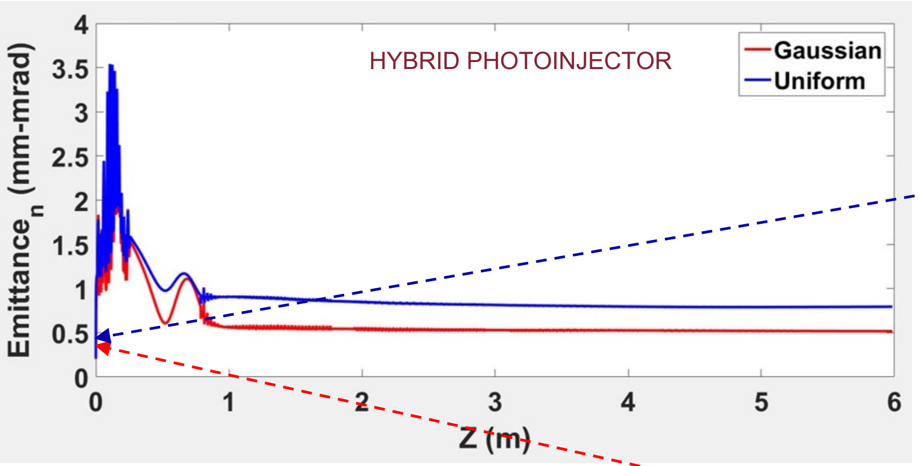


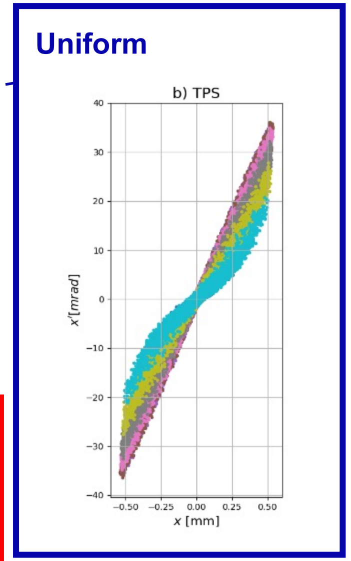
[*] M. Carillo et al., "Space Charge Analysis for Low Energy Photoinjector", presented at the 13th Int.Particle Accelerator Conf. (IPAC'22), Bangkok, Thailand, June2022

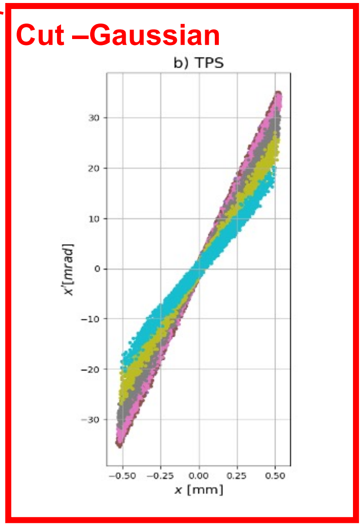
Emittance trend from transverse laser distribution

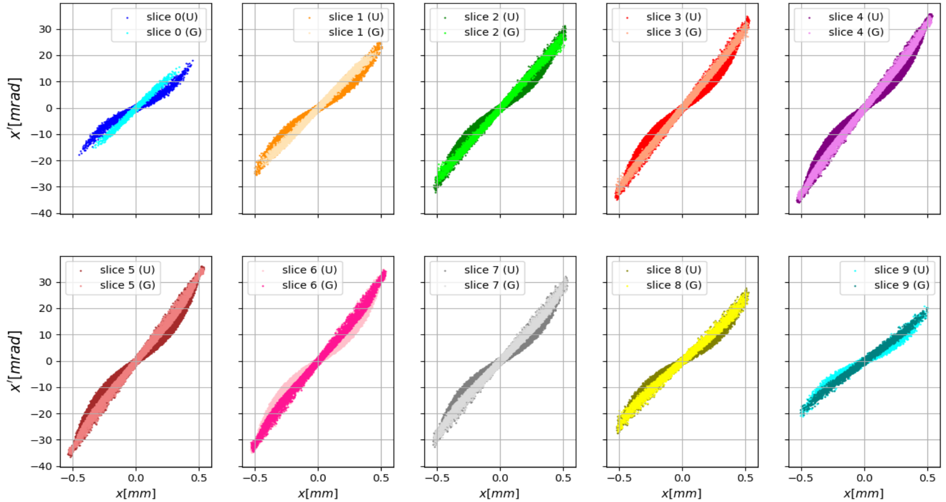
[*] M. Carillo et al., “Space Charge Analysis for Low Energy Photoinjector”, presented at the 14th Int.Particle Accelerator Conf. (IPAC’23), Venice, Italy (2023)











[*] L. Faillace, et al., *“High field hybrid photoinjector electron source for advanced light source applications”*, Phys. Rev. Accel. Beams 25, 063401 (2022).

Depending on **the laser distribution** sent **to the cathode**, the **non-linear** components of the **space charge** forces can degrade the quality of the beam.

How do the space charge forces depend on the distribution?

Space charge forces: analytical approach

Inhomogeneous wave equation: $$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\phi = -\frac{\rho}{\epsilon_0}$$

Green function-based methods can be used to describe arbitrary beam distributions: $$\phi(r,z) = \int d\tau' G(r,r',z-z')\rho(r',z')$$

Green function for a ring of a unitary charge: $$-\epsilon_0 \, \Box^2 \, G(\mathbf{r},\mathbf{r}') = \frac{\delta(r-r')}{2\pi r'}\delta(z-z')$$

Solution in terms of zero-th order modified Bessel function: $$\tilde{G}(r,r',k) = \frac{1}{2\pi\epsilon_o}\left[I_o\left(\frac{k}{\gamma}r_<\right)K_0\left(\frac{k}{\gamma}r_>\right) - \frac{K_0\left(\frac{k}{\gamma}b\right)}{I_0\left(\frac{k}{\gamma}b\right)}I_0\left(\frac{k}{\gamma}r\right)I_0\left(\frac{k}{\gamma}r'\right)\right]$$

Where $r_< = \min\{r,r'\}$ and $r_> = max\{r,r'\}$

N.B.: this solution is expressed as superposition of the direct and the image charge contribution.

$$\boldsymbol{\phi(r,z) = \int d\tau' G(r,r',z-z')\rho(r',z') = \int dS' \int \frac{dk}{2\pi} e^{ikz}\,\tilde{G}(r,r',k)\tilde{\rho}(r',k)}$$

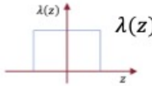
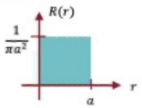
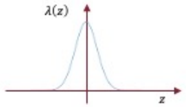
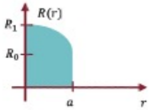
Assuming a separable form for the charge density (e.g., low energy approximation): $$\rho(r,z) = QR(r)\lambda(z) \leftrightarrow \tilde{\rho}(r,k) = QR(r)\tilde{\lambda}(k)$$

For any separable distribution:

$$\phi(r,z) = Q\int \frac{dk}{2\pi}e^{ikz}\tilde{\lambda}(k)\times\int 2\pi\tilde{G}(r,r',k)R(r')r'dr'$$

Where

$$S(r,k) = \int 2\pi\tilde{G}(r,r',k)R(r')r'dr'$$

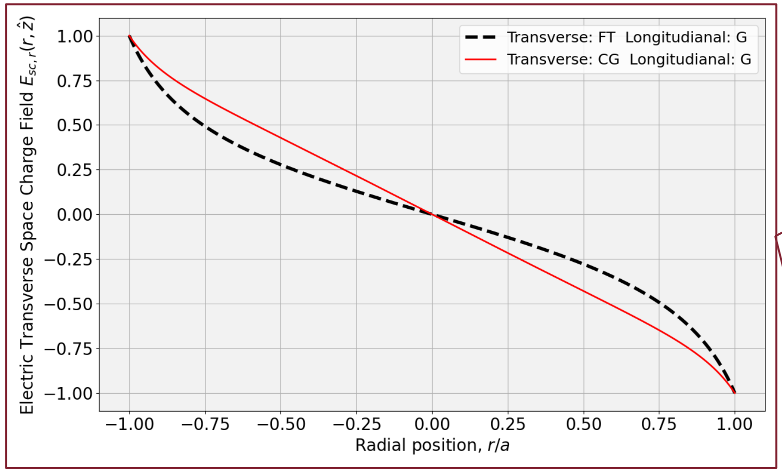
Longitudinal distribution	Trasverse distribution
Uniform  $\lambda(z) = \frac{1}{L}\begin{cases}1, & \lvert z\rvert \le \frac{L}{2} \\ 0, & otherwise\end{cases}$	Uniform  $R(r) = \frac{1}{\pi a^2}\begin{cases}1, & 0 < r \le a \\ 0, & otherwise\end{cases}$ $S(r,k) = \frac{1}{\epsilon_0 \pi a^2 k^2}[1 - kaK_1(ka)I_0(kr)]$
Gaussian  $\lambda(z) = \frac{e^{-\frac{z^2}{2\sigma_z^2}}}{\sqrt{2\pi}\sigma_z}$	Cut-Gaussian  $R(r) = \begin{cases}R_0 + (R_1 - R_0)\left(1 - \frac{r^2}{a^2}\right) = R_1 - \Delta R\left(1 - \frac{r^2}{a^2}\right), 0 \le r \le a \\ 0, r > a\end{cases}$ $S(r,k) = \frac{1}{\epsilon_0 a^2 k^4}\begin{bmatrix}(4 + k^2r^2)R_0 + \lfloor -4 + k^2(a-r)(a+r)\rfloor R_1 + \\ akI_0(kr)\begin{vmatrix}2ak(-R_0 + R_1)K_0(ak) - \\ (4R_0 + a^2k^2R_0 - 4R_1)K_1(ak)\end{vmatrix}\end{bmatrix}$

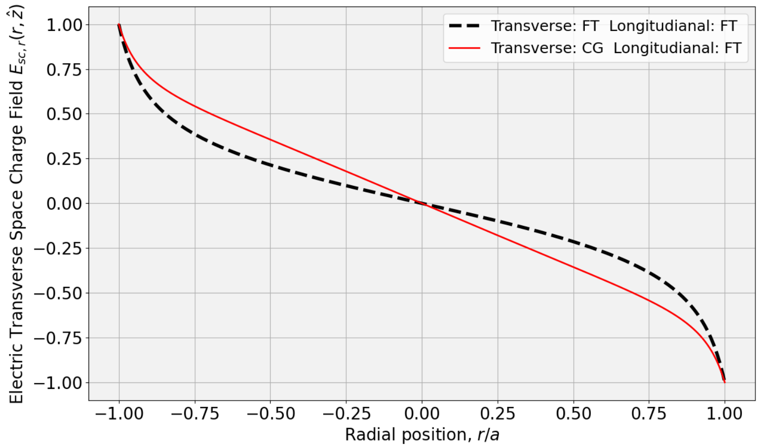
Space charge forces: Electric Field

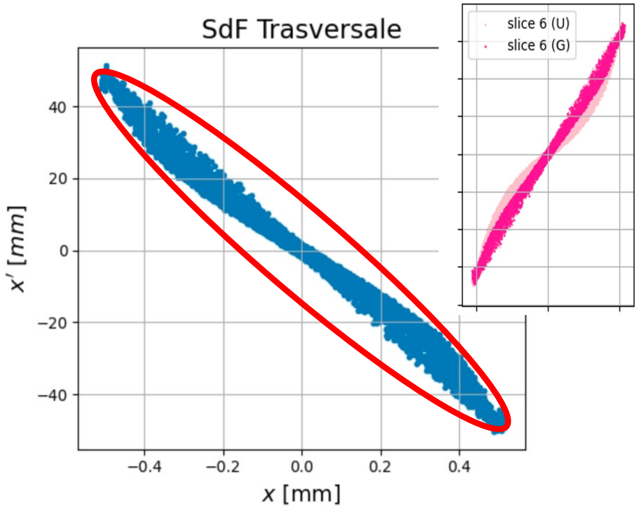
[*] Feng Zhou et al., “Impact of the spatial laser distribution on photocathode gun operation”, SLAC National Accelerator LABORATORY

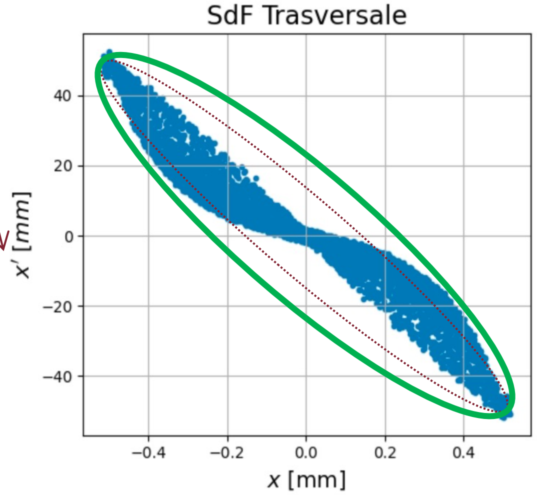
[*] Han Chen et al., “Analysis of slice transverse emittance evolution in a very-High-frequency gun photoinjector”, Accelerator laboratory, Department of Engineering Physics, Tsinghua University, Beijing, China

Pancake like regime ($L \ll R$)

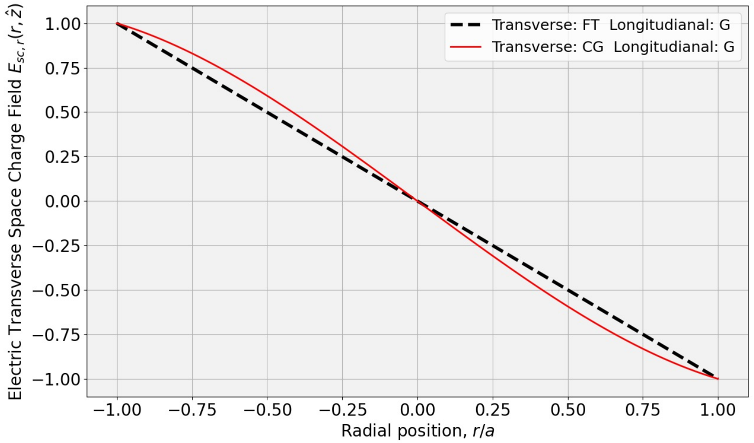


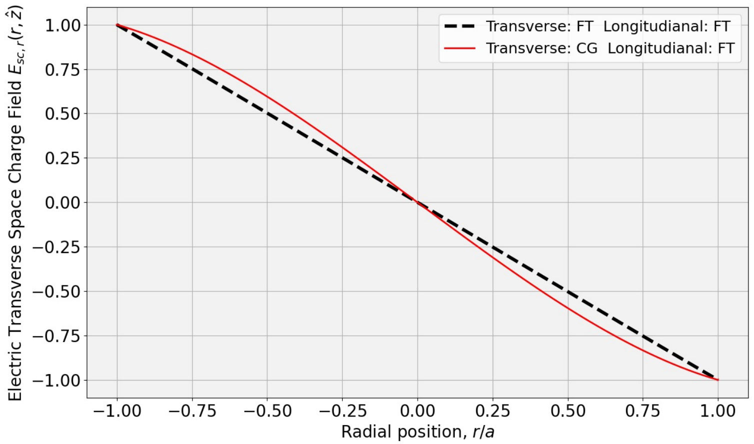






Cigar like regime ($R \ll L$)





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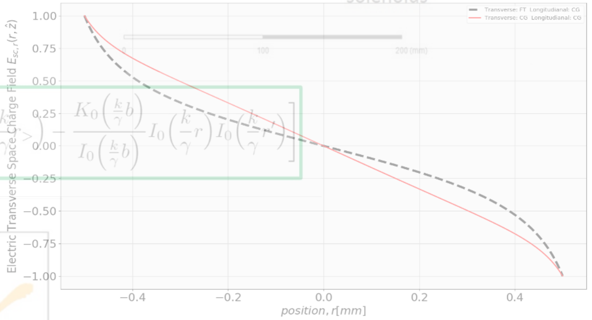
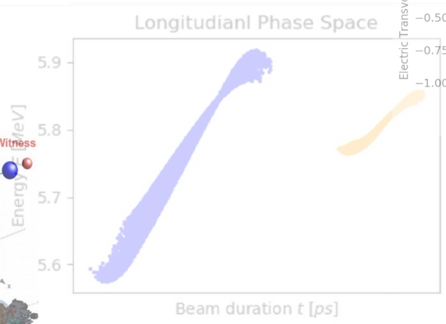
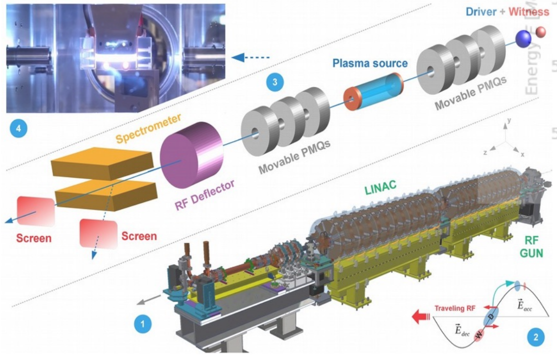
$$\sigma_x'' = \frac{k}{\sigma_x^2}$$

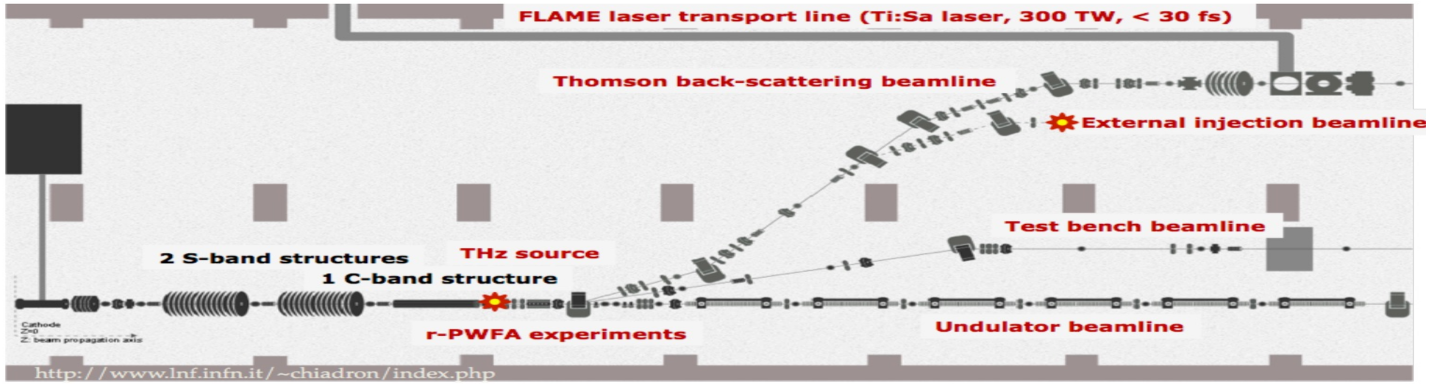




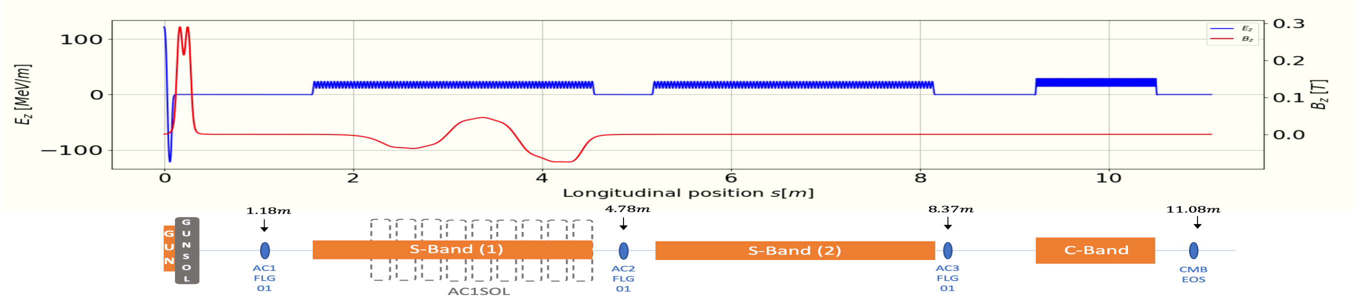


SPARC_LAB: the facility

SPARC_LAB is a test-facility operating at the **Frascati National Laboratories of INFN (LNF-INFN)** devoted to advanced radiation sources and innovative acceleration techniques.



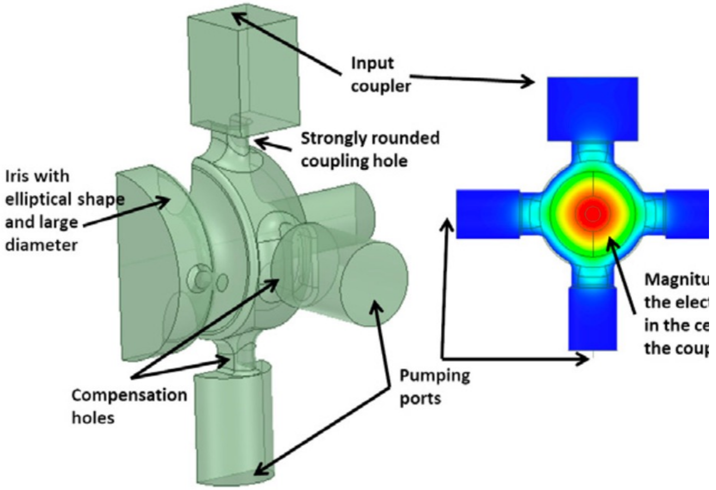
Sources for **P**lasma **A**ccelerators and **R**adiation **C**ompton with **L**asers **A**nd **B**eams

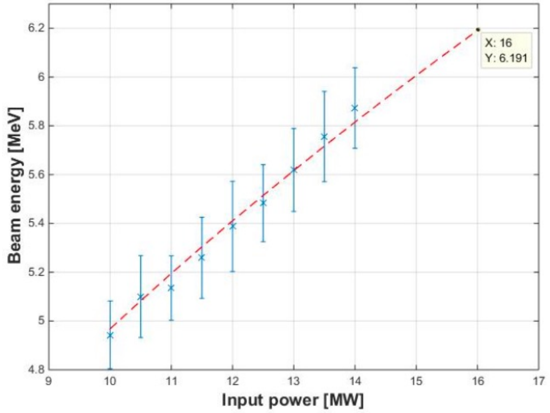


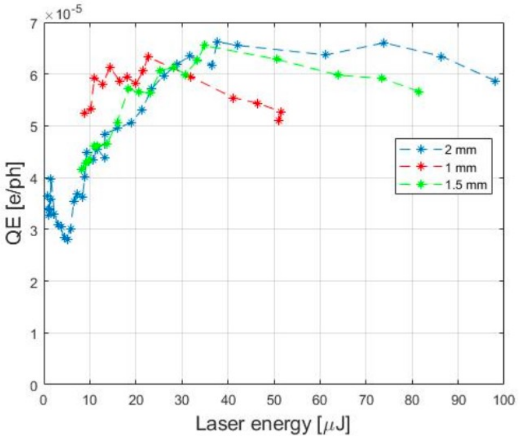
[*] M. Ferrario et al., SPARC_LAB present and future, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Volume 309, 2013.

SPARC_LAB: gun conditioning

[*] D. Alesini et al., *The New SPARC_LAB RF Photo-Injector*, in proceedings of the *13th International Particle Accelerator Conference (IPAC'22)*, Bangkok, Thailand, 12–17 June 2022, JACoW Publishing, Geneva, Switzerland (2022), pp. 671–674

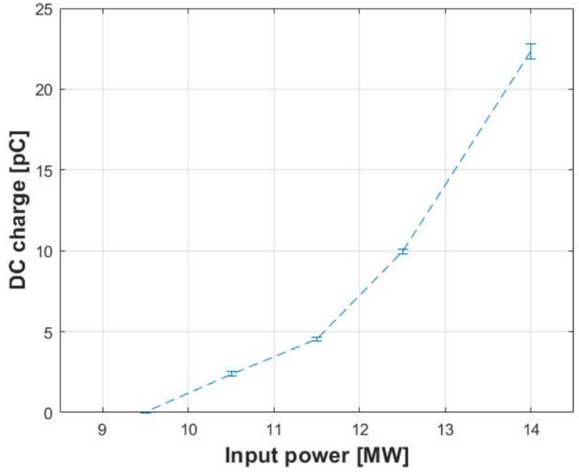


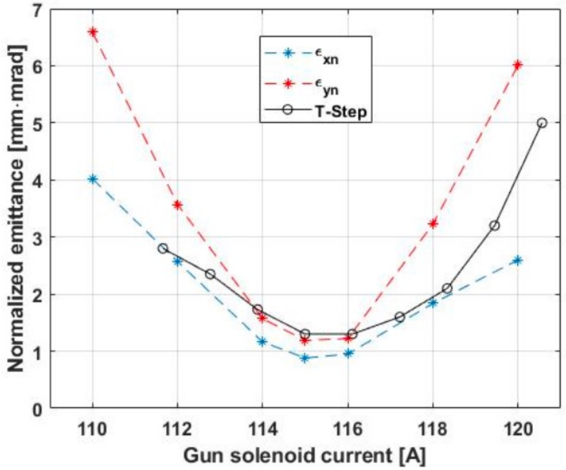


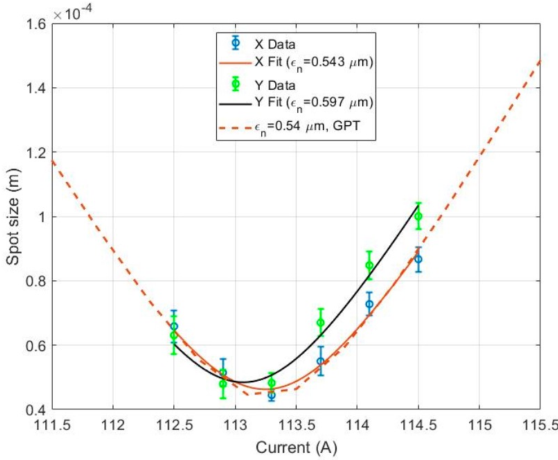


[*] V. Shpakov *et al*, Design, optimization and experimental characterization of RF injectors for high brightness electron beams and plasma acceleration 2022 *JINST* **17** P 12022

QE	$\sim 10^{-5}$ e/ph
DC	~ 22 pC
No Discharge time	$24 + $ h
Norm. Emittance 200pC,1.4 ps long	$1\ mm \cdot mrad$
Intrinsic Emittance	$\sim 0.5\ mm \cdot mrad$







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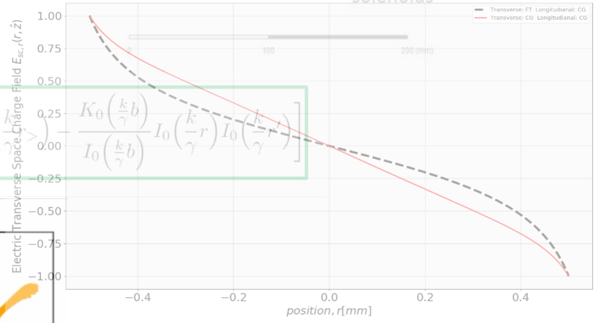
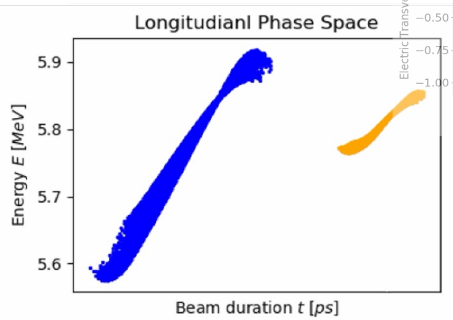
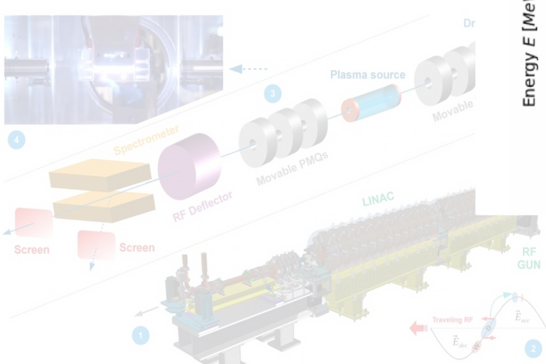
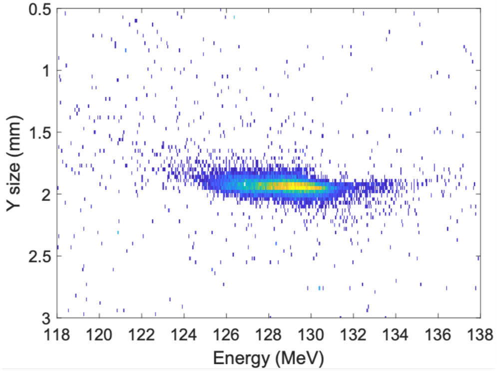
$$\sigma_x'' = \frac{k}{\sigma_x^2}$$

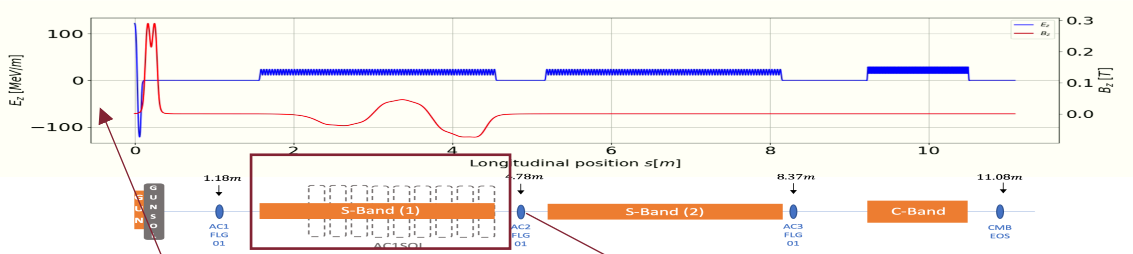




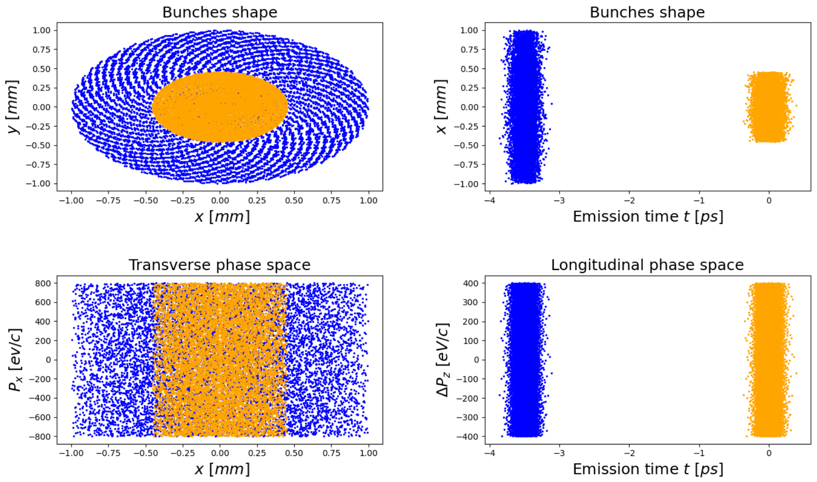




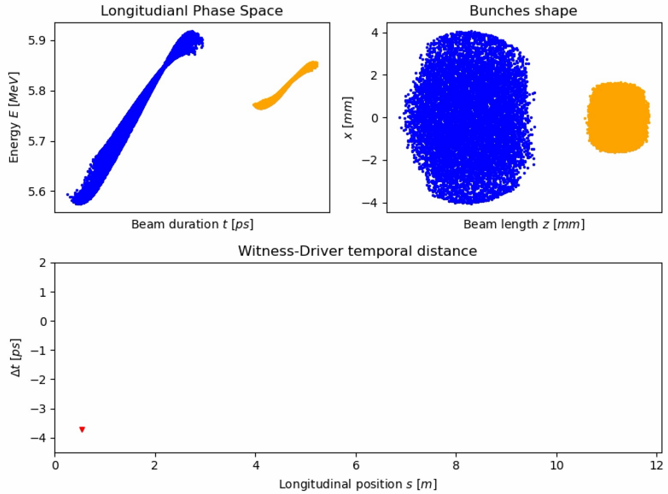
SPARC_LAB: Witness-Driver configuration

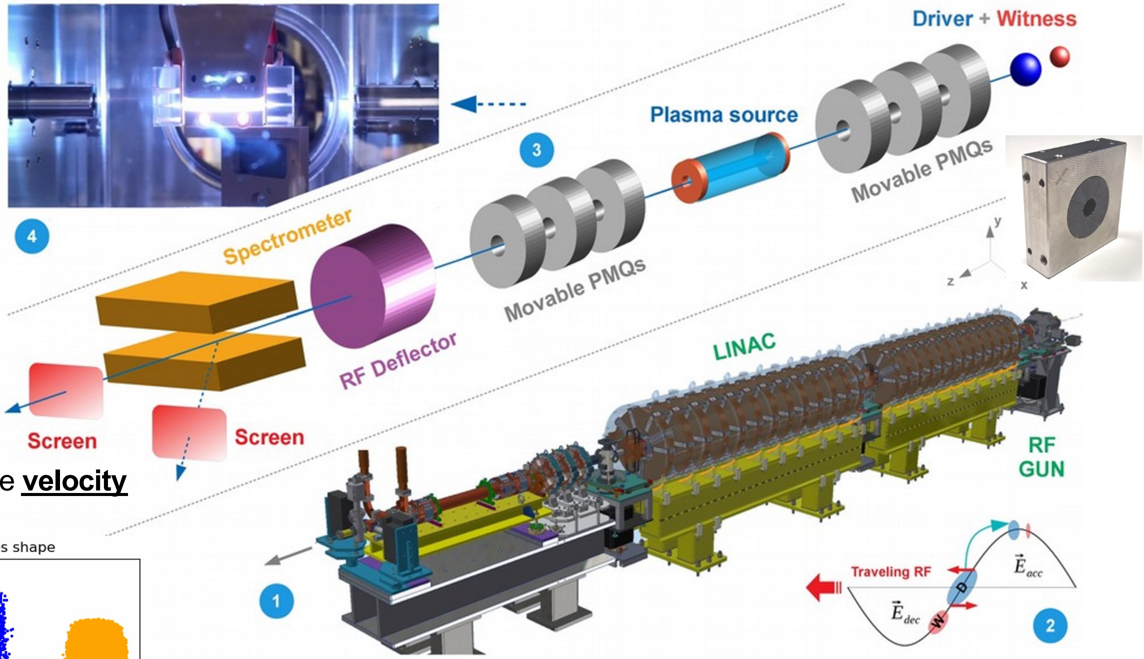


Two-bunches configuration produced directly at the cathode with **laser-comb technique** $(500pC + 50pC)$



The first section of the LINAC works in the **velocity bunching** configuration





[*] L. Serafini and Massimo Ferrario. Velocity bunching in photo-injectors. Proc. AIP, 581, 08
2001. doi: 10.1063/1.1401564

[*] M.Carillo et al., BEAM DYNAMICS OPTIMIZATION FOR HIGH GRADIENT BEAM DRIVEN PLASMA WAKEFIELD ACCELERATION AT SPARC-LAB, presented at the 14th Int.Particle Accelerator Conf. (IPAC'23), Venice, Italy (2023)

SPARC_LAB: High brightness beams dynamics

High brightness beam:

Both plasma acceleration and its application requires ***low emittance beam*** and ***short bunch***

Driver
- *Charge*: $\mathbf{500\ pC}$
- *Spot radius*: **???**
- Laser duration: $\mathbf{100\ fs\ (rms)}$

Witness
- *Charge*: $\mathbf{50\ pC}$
- *Spot radius*: **???**
- Laser duration: $\mathbf{100\ fs\ (rms)}$

Distance
- *witness before driver @ cathode*: **???**

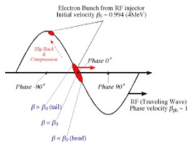
High brightness Beam:
- *Low emittance*
- High current
- Low energy spread

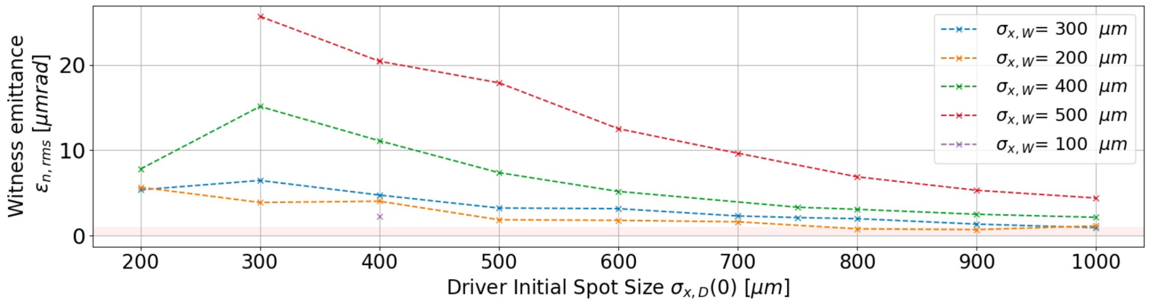
- "Pancake" or "blowout" regime (theoretically described by Luiten in 2004)

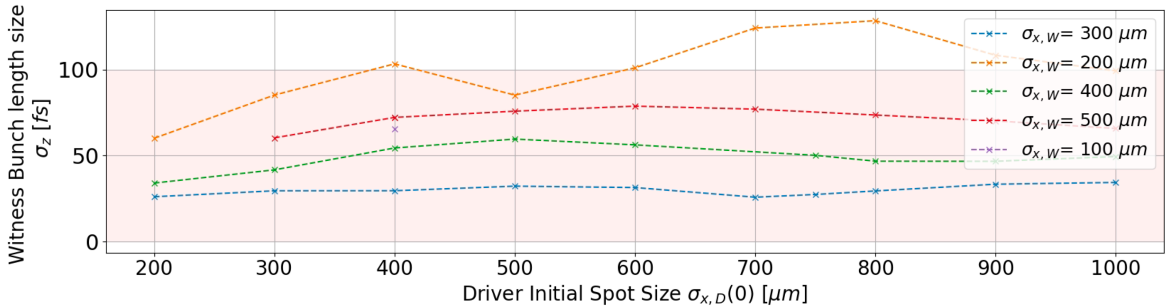
$$\frac{eE_0\tau_L}{m_e c} \ll \frac{\sigma_0}{\epsilon_0 E_0} \ll 1$$

- E_0 ($E_0 = E_{peak}\sin(\phi)$) is the effective field on the cathode: Large Field – large launch phase
- τ_L is the laser duration: Short bunch
- σ_0 is the surface charge density: Large transverse spots

- Two beam evolution: velocity bunching
  - *The temporal distance between witness and driver*
  - *Short bunches*
- Improve plasma booster performances
  - *High charge → High plasma gradient*
  - Bunches distances: @10^{16} plasma density → 1 ps







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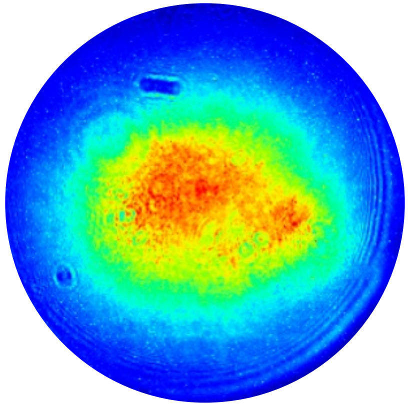
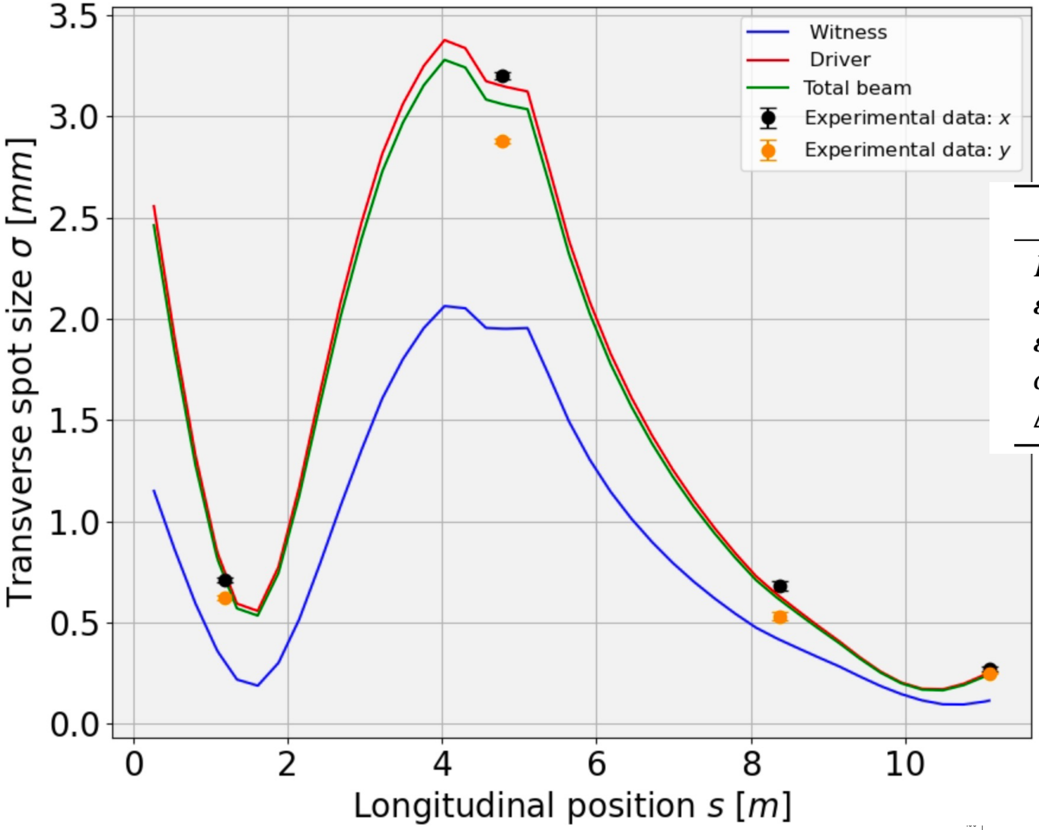
SPARC_LAB: Beam dynamics comb results

Driver
- *Charge*: $\mathbf{500\ pC}$
- *Spot radius*: $\mathbf{500\mu m\ (rms)}$
- Laser duration: $\mathbf{100\ fs\ (rms)}$

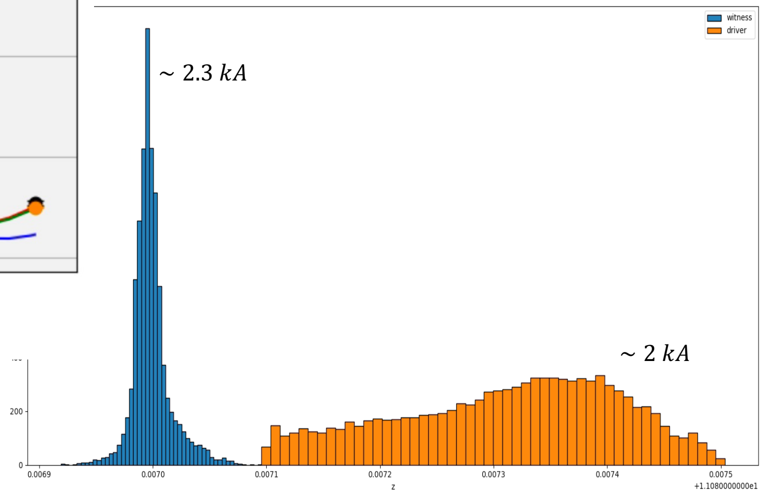
Witness
- *Charge*: $\mathbf{50\ pC}$
- *Spot radius*: $227(\mathbf{rms})$
- Laser duration: $\mathbf{100\ fs\ (rms)}$

Distance
- *witness before driver @cathode*: $\mathbf{3.5\ ps}$





	Simulation	Data	Error [%]
$E[MeV]$	95.4	96.44 ± 0.38	1.1
$\varepsilon_x[\mu mrad]$	6.8	10.0 ± 3.18	32.0
$\varepsilon_y[\mu mrad]$	6.8	6.05 ± 2.55	4.6
$\sigma_z[fs]$	570	545	4.6
$\Delta t[ps]$	1.05	1.10	4.5



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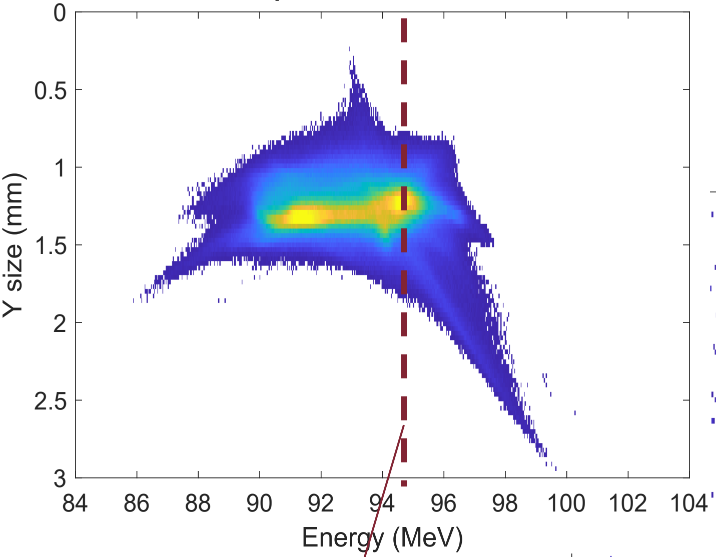
SPARC_LAB: Experimental results

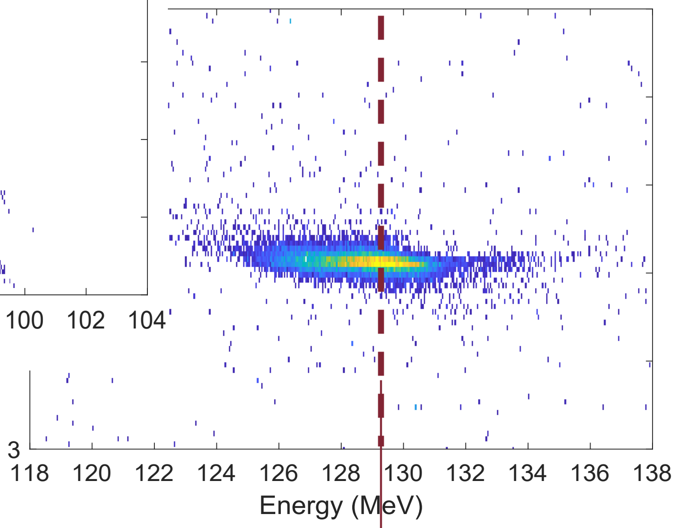
Without plasma section:



95.5 ± 0.2 MeV

High Gradient plasma acceleration

With plasma section:

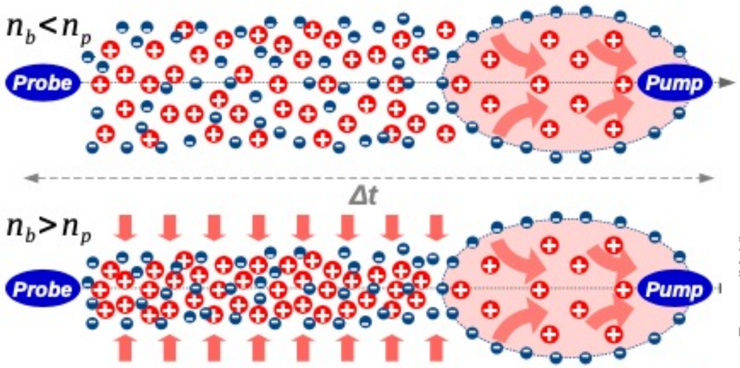


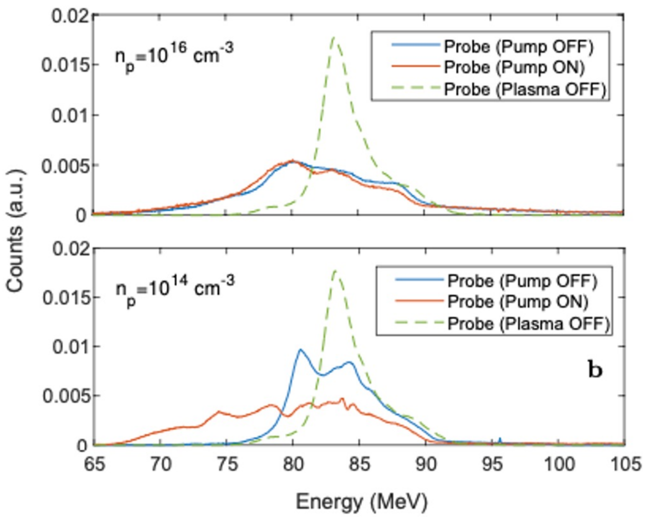
129.7 ± 0.5 MeV

3cm long capillary:
Gain energy 1.1 GeV

NB: this results is important in the framework of EuPRAXIA@SPARC_LAB, where the aim is to achieve gradients of the order of 1.2 GeV/m in 40 cm capillary length

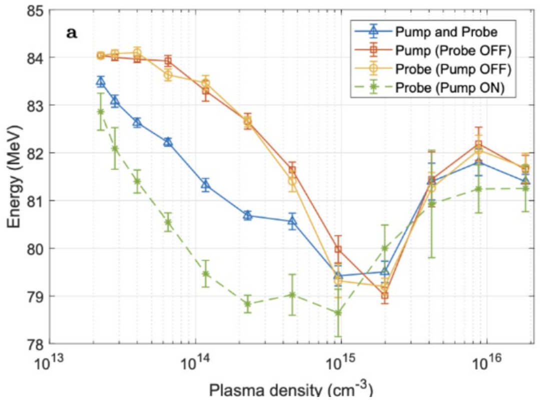
Repetition rate for PWFA

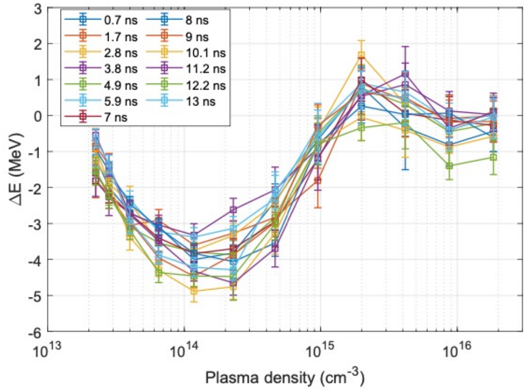




[*] R. Pompili et al., Toward gigahertz repetition rates for plasma-wakefield accelerators . Submitted on PRL

A parametric study exploring a wide range of plasma density ($n_p \approx [10^{13}, 10^{16}] cm^{-3}$) and pump and probe delay ($\Delta t = [0.7 - 13]\, ns$)





Δt < 0.7ns

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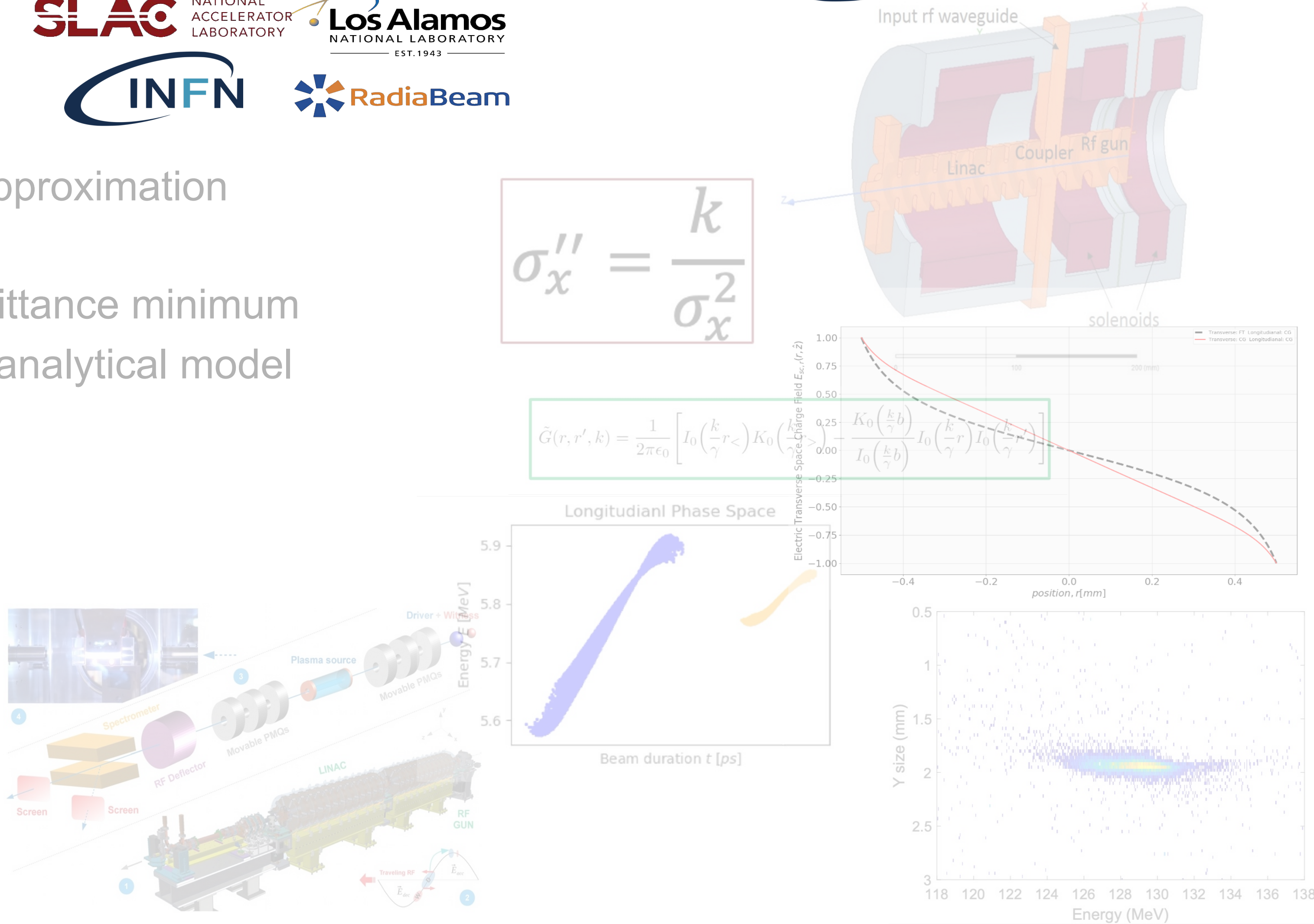
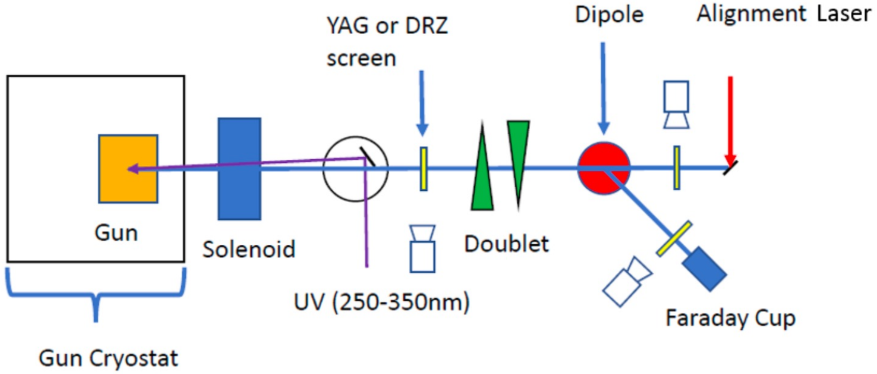


UCLA Accelerator Laboratories

MOTHRA Lab

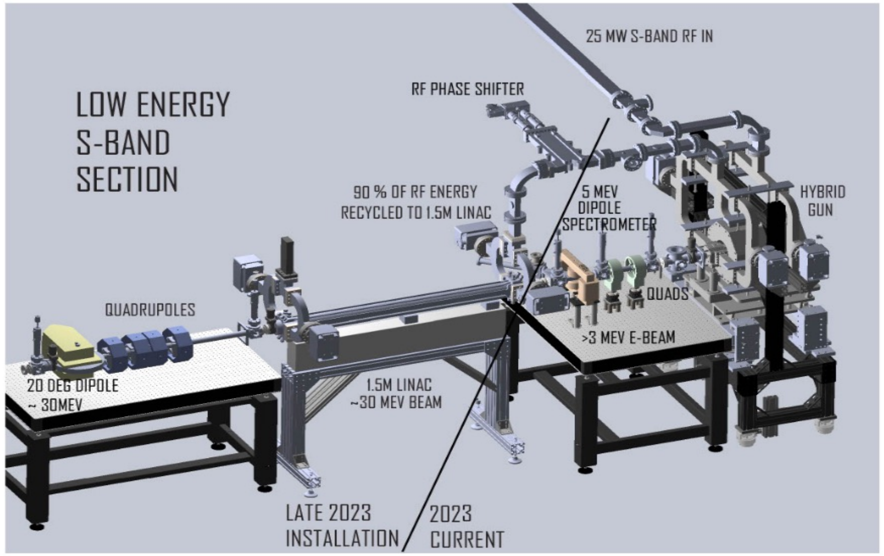


Development of ultra-high gradient RF accelerators and infrastructure development towards an ultra-compact X-ray free electron laser.

Quantify the potential improvements in brightness achievable at the cathode when operated at cryogenic temperatures.

[*]Lawler, G. E., A. Fukasawa, N. Majernik, J. R. Parsons, J. B. Rosenzweig, Y. Sakai, and A. Suraj. 2022. "CrYogenic Brightness-Optimized Radiofrequency Gun (CYBORG)." In *Proc. IPAC'22*, 2544–47. International Particle Accelerator Conference 13. JACoW Publishing, Geneva, Switzerland.

MITHRA Lab



MITHRA is a under construction electron linear accelerator test facility situated on UCLA's southwest campus in Westwood

The facility will conduct initial proof-of-principle experiments in areas such as the ultra-compact X-ray free-electron laser, advanced dielectric wakefield acceleration, bi-harmonic nonlinear inverse Compton scattering, and various radiation detectors.

[*] O. Williams, et al., Overview and Commissioning Status of the UCLA MITHRA Facility, submitted on MDPI

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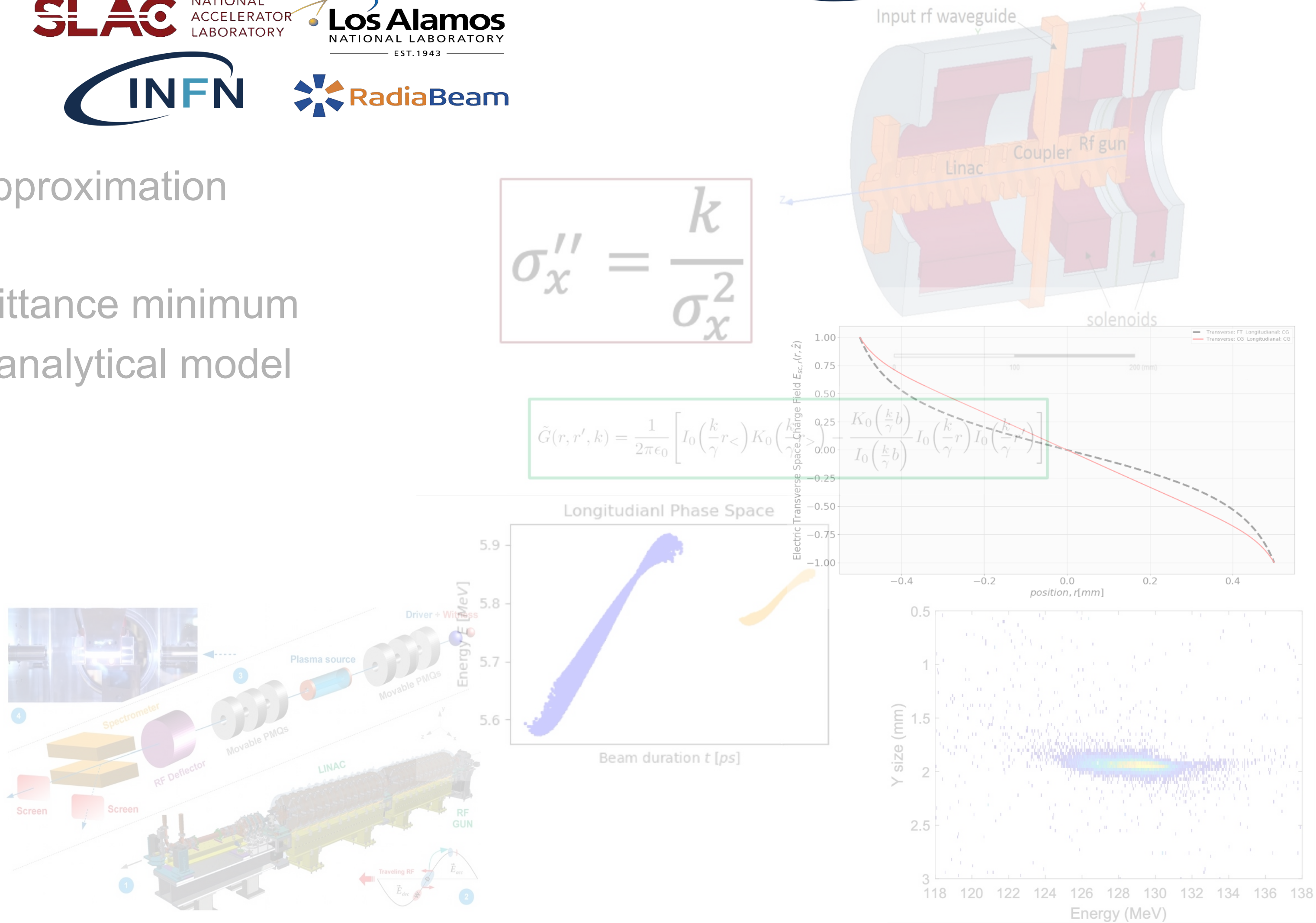
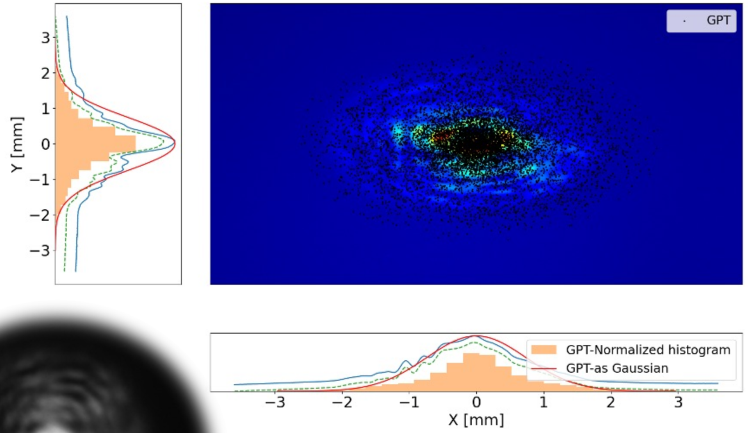
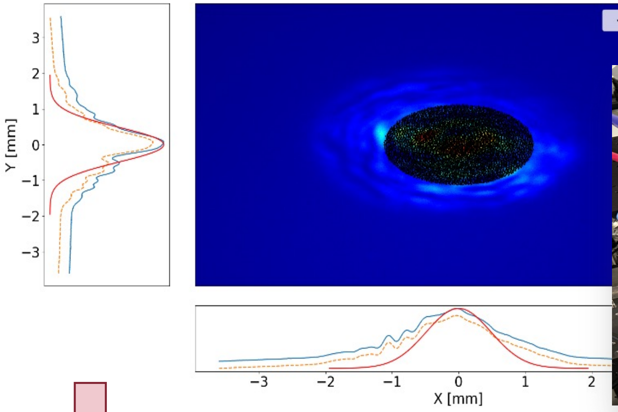
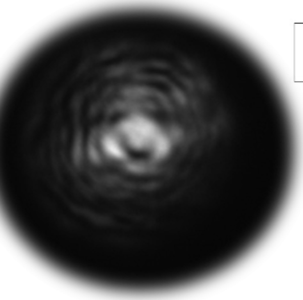
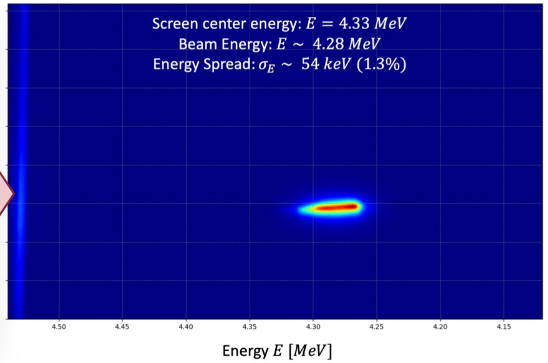


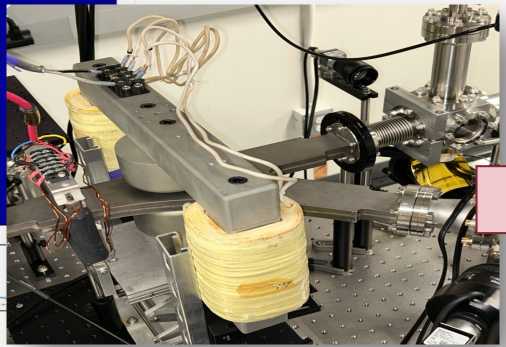
MITHRA's Gun Characterization

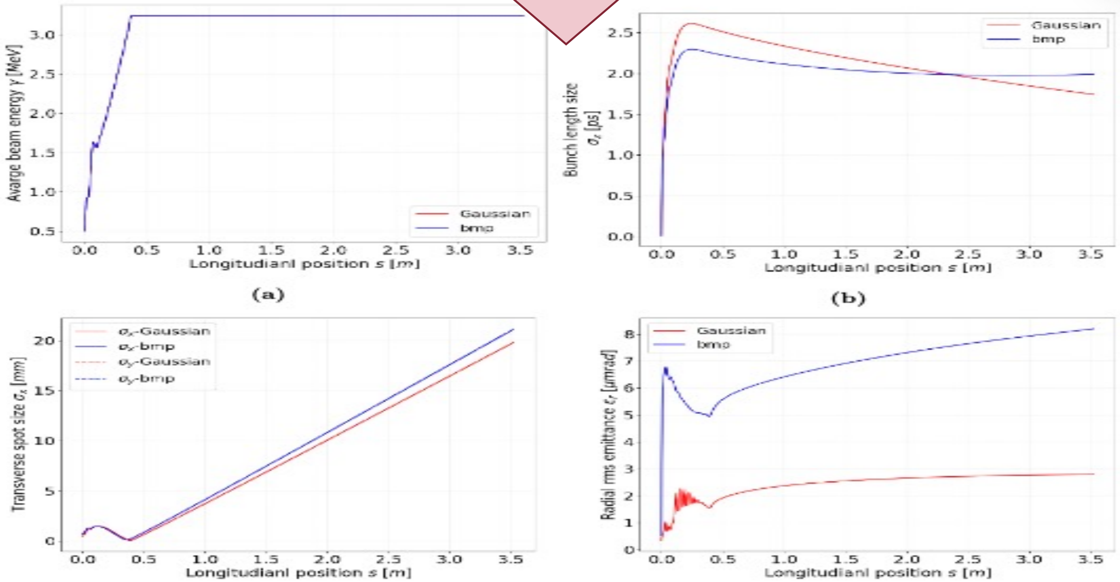






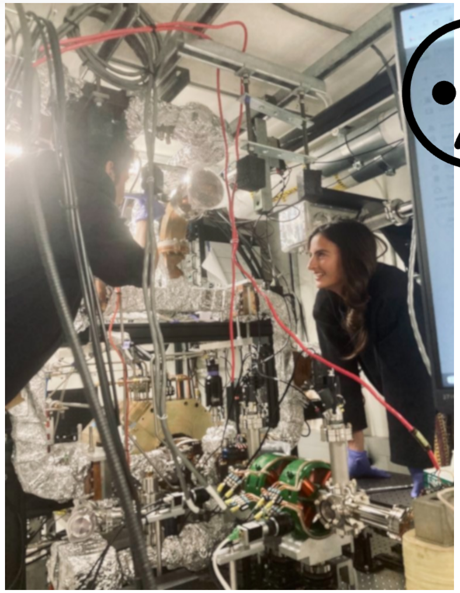






(a) (b)

(c) (d)



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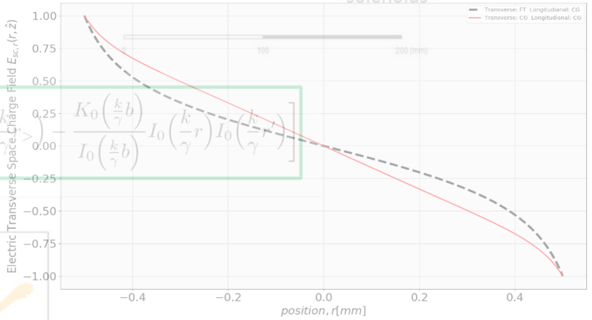
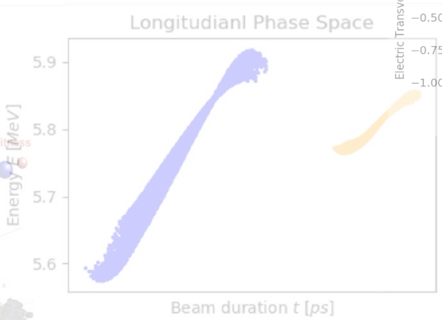


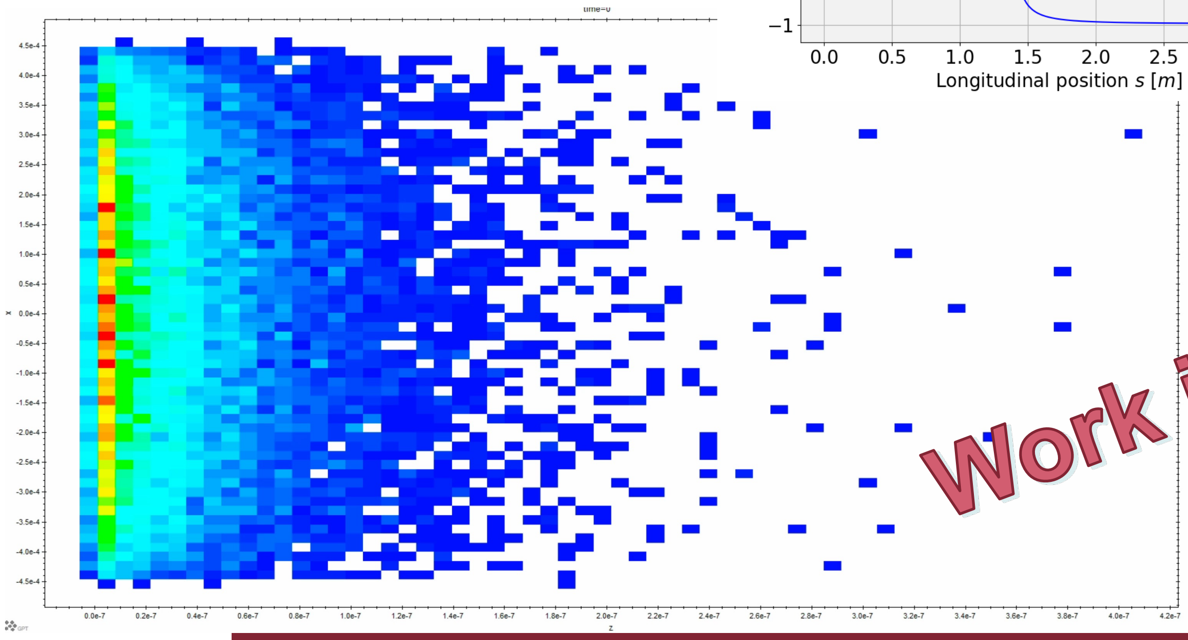


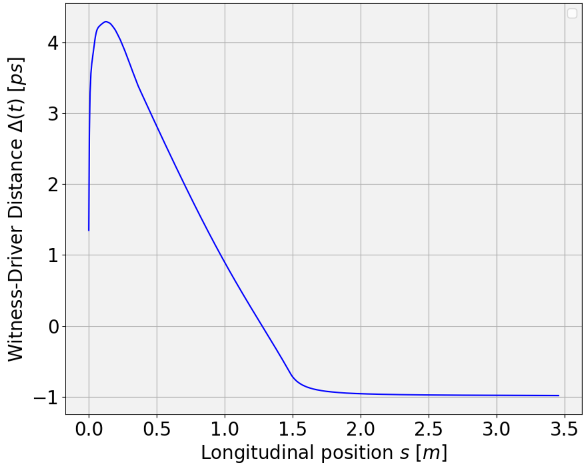
Witness and Driver beams with Hybrid Photoinjector

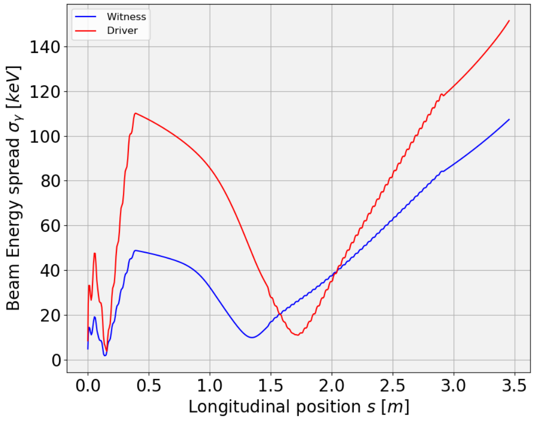
Beam generation parameters:

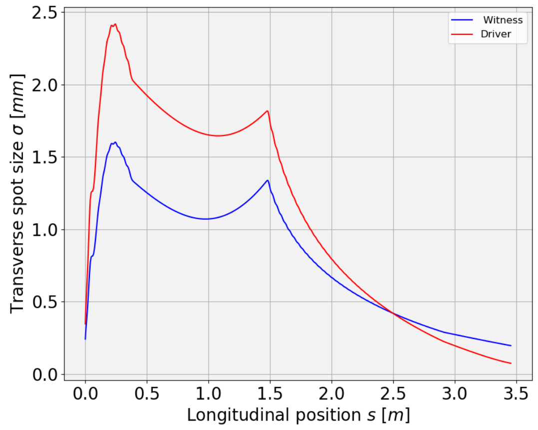
Qd = 100 # Driver charge (pC)
Qw = 20 # Witness charge (pC)
Drad = 0.65e-3 # Driver radius 1e-3
Wrad = 450e-6 # Wit ness radius 630
Tlend = 100e-15 # Driver duration
Tlenw = 100e-15 # Witness duration
Dwt = 3.4e-12 # D-W distance

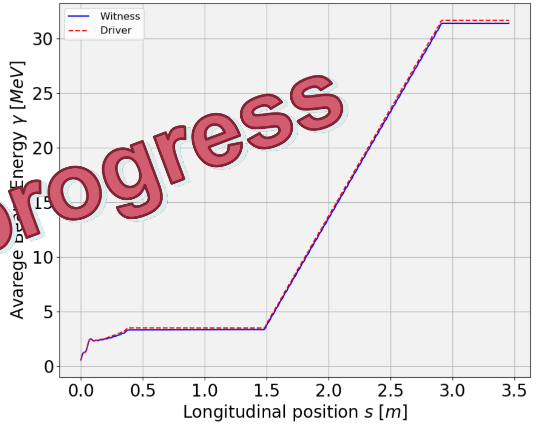
HGUN_E0 = 45e6 # Max E field at cathode in the hybrid gun. [V/m]
HGUN_PHASE = 30 #40(standard phase) # Phase of the hybrid gun defined sine-like. [deg]

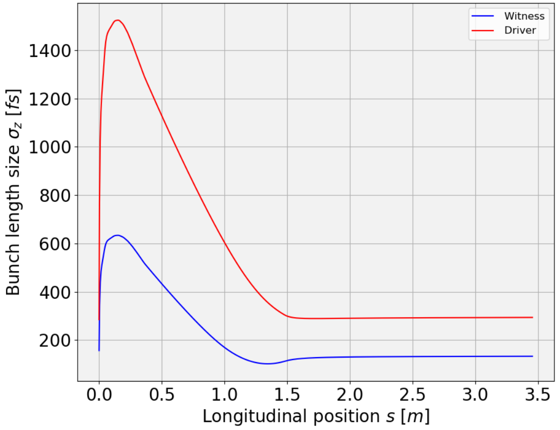












Work in progress

Conclusion

- C-Band Hybrid photoinjector:
  - Beam dynamics
  - Envelope equation: the Triple waist approximation
  - Emittance compensation:
    - Multi-slice model and Double emittance minimum
    - Laser distribution: space charge analytical model
- SPARC_LAB:
  - Gun conditioning
  - Witness-Driver configuration
  - Experimental results
- UCLA Experience:
  - Magnetic Characterization
  - MITHRA's Gun Characterization
  - COMB beam with Hybrid Injector

Optimization and deep understanding of hybrid gun beam dynamics thanks to analytical models developed

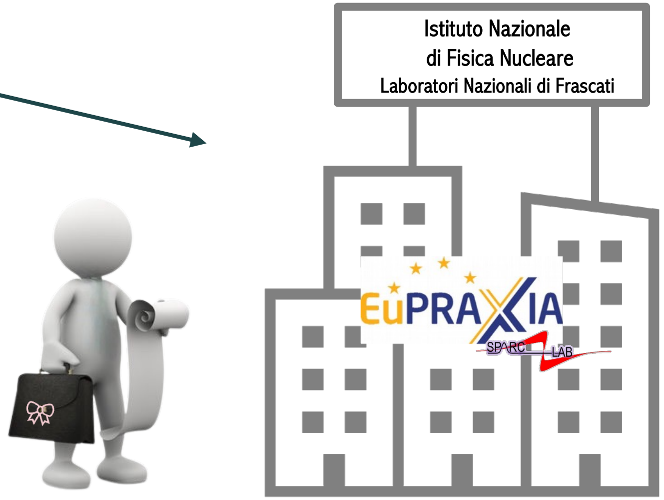
New gun installing for beam dynamics performance improvement + beam dynamics parameter optimization ⇨ *Successful experimental results*

Visiting period: Introduction to beamline characterization (Magnetic and Beam dynamics)

Future Development:

Plasmonic-like surface oscillation

Connection between Non-Linearities field and emittance degradation



Scientific Publications

Conference Volume

- July 2023: Fabio Villa, David Alesini, Maria P. Anania, Marco Angelucci, Alberto Bacci, Antonella Balerna, Marco Bellaveglia, Angelo Biagioni, Bruno Buonuomo, Sergio Cantarella, Fabio Cardelli, **Martina Carillo,** et al. “EuPRAXIA @ SPARC LAB status update”, Proceedings Volume 12581, X-Ray Free Electron Lasers: Advances in Source Development and Instrumentation VI; 125810H (2023) `doi:10.1117/12.2668643`
- June 2022: **M. Carillo**, M. Behtouei, F. Bosco, O. Camacho, E. Chiadroni, L. Faillace, et al.,“Space Charge Analysis for Low Energy Photoinjector”,in Proc. 13th International Particle Accelerator Conference (IPAC’22), Bangkok, Thailand, Jun. 2022, pp. 2272–2275. `doi:10.18429/JACoW-IPAC2022-WEPOMS017`
- June 2022: L. Faillace, R.B. Agustsson, M. Behtouei, F. Bosco, D.L. Bruhwiler, O. Camacho, **M. Carillo**, et al., “Start-to-End Beam-Dynamics Simulations of a Compact C-Band Electron Beam Source for High Spectral Brilliance Applications”, in Proc. 13th International Particle Accelerator Conference (IPAC’22), Bangkok, Thailand, Jun. 2022, pp. 687–690. `doi:10.18429/JACoW-IPAC2022-MOPOMS023`
- June 2022:,M. Behtouei, F. Bosco, **M. Carillo**, F. Di Paolo, L. Faillace, S. Fantauzzi, et al., “Studies of a Ka-Band High Power Klystron Amplifier at INFN-LNF”, in Proc. 13th International Particle Accelerator Conference (IPAC’22), Bangkok, Thailand, Jun. 2022, pp. 683–686. `doi:10.18429/JACoW-IPAC2022-MOPOMS022`
- June 2022: F. Bosco, O. Camacho, **M. Carillo**, et al., “Modeling and Mitigation of Long-Range Wakefields for Advanced Linear Colliders”, in Proc. 13th International Particle Accelerator Conference (IPAC’22), Bangkok, Thailand, Jun. 2022, pp. 2350–2353. `doi:10.18429/JACoW-IPAC2022-WEPOMS045`
- June 2022: D. Alesini, M.P. Anania, A. Battisti, M. Bellaveglia, A. Biagioni, F. Cardelli, **M. Carillo** et al., “The New SPARC-LAB RF Photo-Injector”, in Proc. 13th International Particle Accelerator Conference (IPAC’22), Bangkok, Thailand, Jun. 2022, pp. 671–674. `doi:10.18429/JACoW-IPAC2022-MOPOMS019`
- June 2022: L. Giuliano, D. Alesini, M. Behtouei, M.G. Bisogni, F. Bosco, **M. Carillo,** et al., “Proposal of a VHEE Linac for FLASH Radiotherapy”, in Proc. 13th International Particle Accelerator Conference (IPAC’22), Bangkok, Thailand, Jun. 2022, pp. 2903–2906. `doi:10.18429/JACoW-IPAC2022-THPOTK054`
- May 2021**: M. Carillo**, M. Behtouei, F. Bosco, L. Faillace, L. Ficcadenti, A. Giribono, et al., “Three-Dimensional Space Charge Oscillations in a Hybrid Photoinjector”, in Proc. IPAC’21, Camp- inas, SP, Brazil, May 2021, pp. 3240–3243. `doi:10.18429/JACoW-IPAC2021-WEPAB256`
- May 2021: L. Faillace, R.B. Agustsson, M. Behtouei, F. Bosco, **M. Carillo,** A. Fukasawa, et al.,“Beam Dynamics for a High Field C-Band Hybrid Photoinjector”, in Proc. IPAC’21, Campinas, SP, Brazil, May 2021, pp. 2714–2717. `doi:10.18429/JACoW-IPAC2021-WEPAB051`
- May 2021: F. Bosco, M. Behtouei, **M. Carillo**, et al.,“Modeling Short Range Wakefield Effects in a High Gradient Linac”,in Proc. IPAC’21, Campinas, SP, Brazil, May 2021, pp. 3185–3188. `doi:10.18429/JACoW-IPAC2021-WEPAB238`
- May 2021: L. Giuliano, D. Alesini, M. Behtouei, F. Bosco, **M. Carillo,** G. Cuttone, et al.,“Preliminary Studies of a Compact VHEE Linear Accelerator System for FLASH Radiotherapy”, in Proc. IPAC’21, Campinas, SP, Brazil, May 2021, pp. 1229–1232. `doi:10.18429/JACoW-IPAC2021-MOPAB410`

Articles

- September 2023: F. Bosco, O. Camacho**, M. Carillo**, et al.,“Fast models for the evaluation of self-induced field effects in linear accelerators”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 1056,(2023)`doi:10.1016/j.nima.2023. 168642.`
- February 2023: L. Giuliano, F. Bosco, **M. Carillo**, G. Felici, L. Ficcadenti, A. Mostacci, M. Migliorati, L. Palumbo, B. Spataro and Luigi Faillace, “RF Design and Measurements of a C-Band Prototype Structure for an Ultra-High Dose-Rate Medical Linac”, Instruments 2023, 7, 10. `doi.org/10.3390/instruments7010010`
- December 2022: V. Shpakov, D. Alesini, M.P. Anania, M. Behtouei, B. Buonomo, M. Bellaveglia, A. Biagioni, F. Cardelli, **M. Carillo,** E. Chiadroni, A. Cianchi, G. Costa, M. Del Giorno, L. Faillace, M. Ferrario, M. Del Franco, G. Franzini, M. Galletti, L. Giannessi, A. Giribono, A. Liedl, V. Lollo, A. Mostacci, G. Di Pirro, L. Piersanti, R. Pompili, G. Di Raddo, S. Romeo, G.J. Silvi, A. Stella, C. Vaccarezza, F. Villa and A. Vannozzi, “Design, optimization and experimental characterization of RF injectors for high brightness electron beams and plasma acceleration”, Journal of Instrumentation, Volume 17, December 2022 `doi:10.1088/1748-0221/17/12/P12022`
- November 2022: L. Faillace, D. Alesini, G. Bisogni, F. Bosco, **M. Carillo**, P. Cirrone, G. Cuttone, D. De Arcangelis, A. De Gregorio, F. Di Martino, V. Favaudon, L. Ficcadenti, D. Francescone, G. Franciosini, A. Gallo, S. Heinrich, M. Migliorati, A. Mostacci, L. Palumbo, V. Patera, A. Patriarca, J. Pensavalle, F. Perondi, R. Remetti, A. Sarti, B. Spataro, G. Torrisi, A. Vannozzi, L. Giuliano, “Perspectives in linear accelerator for FLASH VHEE: Study of a compact C-band system”, Physica Medica 104 (2022) 149–159. `doi:10.1016/j.ejmp.2022.10.018`
- June 2022: L. Faillace, R. Agustsson, M. Behtouei, F. Bosco, D. Bruhwiler, O. Camacho, **M. Carillo**, et al., “High Field Hybrid Photoinjector Electron Source for Advanced Light Source Applications”, Phys. Rev. Accel. Beams 25, 063401 (2022). `doi:10.1103/PhysRevAccelBeams.25.063401`
- September 2021: M. Behtouei, B. Spataro, L. Faillace, **M. Carillo**, M. Comelli, A. Variola, M. Migliorati, “A Novel method to calculate the magnetic field of a Solenoid generated by a surface current element”, arXiv, (2021). `doi:10.48550/arXiv.2109.04464`
- September 2021: B. Spataro, M. Behtouei, F. Cardelli, **M. Carill**o, V. Dolgashev, L. Faillace, M. Migliorati, L. Palumbo, “A hard open X-band RF accelerating structure made by two halves”, arXiv, (2021). `doi:10.48550/arXiv.2109.03954`
- September 2021: Journal paper, M. Behtouei, B. Spataro, L. Faillace, **M. Carillo**, A. Leggieri, L. Palumbo, M. Migliorati, “Relativistic approach to a low perveance high quality matched beam for a high efficiency Ka-Band klystron”, arXiv, (2021). `doi:10.48550/arXiv.2109.03520`

Attended Conference

- May 2021: **International Particle Accelerator Conference 2021**- online conference, Three-Dimensional Space Charge Oscillations in a Hybrid Photoinjector, Poster presentation.
- June 2022: **International Particle Accelerator Conference 2022**, Bangkok, Thailand, Space charge analysis for low energy photoinjector, Poster presentation.
- September 2022: **108° Congresso Nazionale,** Società Italiana di Fisica, Milano, Italy, Space charge analysis for photoinjector emittance compensation, Oral presentation.
- September 2022: **EuroNNAc Special Topics Workshop**, La Biodola Bay, Isola d'Elba, Italy, A novel analytical model of space charge forces in RF-guns, Poster presentation. Student grant winner.
- May 2023: **International Particle Accelerator Conference 2023**, Venice, Italy,
  - Beam dynamics optimization for high gradient beam driven plasma wakefield acceleration at SPARC-LAB, Contributed Oral Talk.
  - A Space Charge Forces analytical model for emittance compensation ,Poster presentation.

  Student grant winner.
- June 2023: **Physics and Applications of High Brightness Beam Workshop**, San Sebastian, Spain, An Analytical Study of Space Charge Fields in the Emittance Compensation Process, Poster presentation. Student grant winner.
- September 2023: **109° Congresso Nazionale, Società Italiana di Fisica**, Salerno, Italy, Beam dynamics optimization for high gradient beam driven plasma wakefield acceleration at SPARC_LAB, Oral presentation.
- September 2023: **6th European Advanced Accelerator Concepts workshop**, La Biodola Bay, Isola d'Elba, Italy, Witness-driver beam dynamics optimization in the SPARC_LAB photoinjector, Poster presentation. Student grant winner.
- October 2023: **15th workshop on breakdown science and high gradient technology**, HG2023, Frascati National Labs of INFN, (Rome), Italy. Local Organize Committee

Talk

- May 2023: **International Particle Accelerator Conference 2023**, Venice, Italy, Contributed Oral Talk
- July 2023: **SLAC National Accelerator Laboratory (SLAC**), San Francisco, USA, Scientific seminary and in-person interview

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