*Consiglio di Laboratorio - Preventivi 2019*

*LNF - 2 July 2018*

# SL_COMB2FEL

**Resp. Naz.:**

*E. Chiadroni (LNF)*

**Sezioni proponenti:**

LNF (Resp. Loc.: E. Chiadroni),

Roma1 (Resp. Loc.: A. Mostacci),

Roma2 (Resp. Loc.: A. Cianchi)

Milano (Resp. Loc.: V. Petrillo)

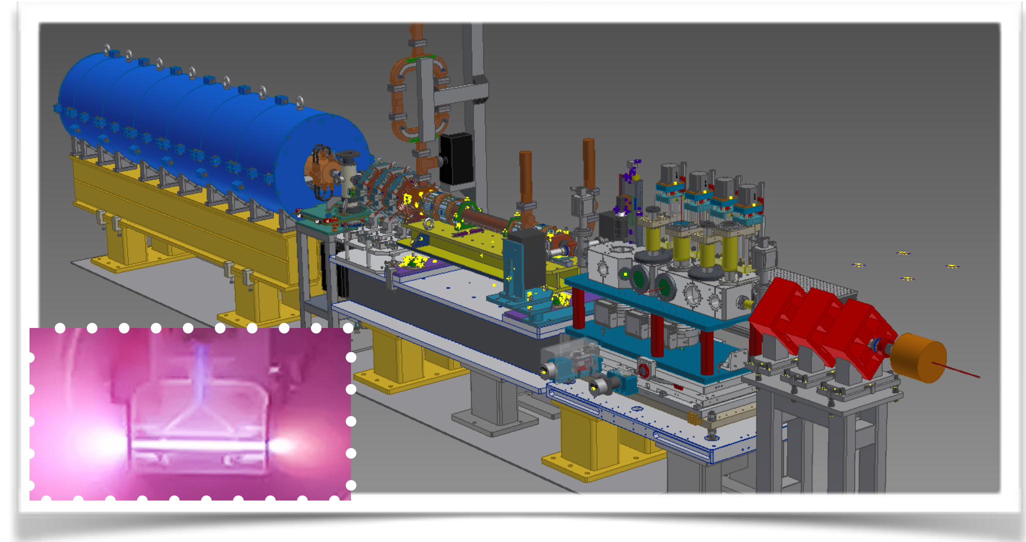
Lecce (Resp. Loc.: A. Lorusso),

Napoli (Resp. Loc.: R. Fedele)

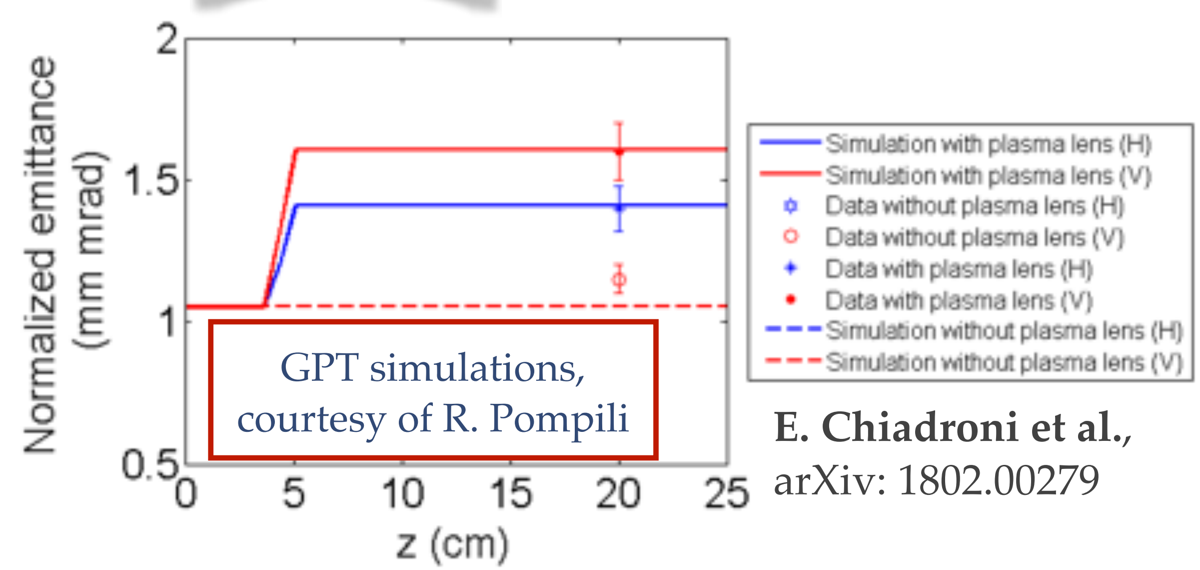
Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

# From SL_COMB…

- **SL_COMB is a CSN5-funded experiment (ending in 2018)** to demonstrate at SPARC_LAB the acceleration of high brightness electron beams in particle-driven plasma wakefield accelerators
  - **Beam dynamics studies with start-to-end simulations**
    - Experimental beam dynamics studies with multi-bunch trains
    - Side effect: **EuPRAXIA@SPARC_LAB Conceptual Design Report**
  - Experimental and theoretical **studies** of final focus and extraction with both PMQs and **active plasma lenses**
  - Experimental and theoretical studies on the **impact of plasma jets**, **gas partial ionization and passive plasma lens on** the preservation of the **emittance**
    - <u>**Code benchmark with measurements**</u>
  - Development of **new capillary design** for the optimization of plasma ramps
    - Plasma diagnostics
  - New cathodes (Yttrium films) fabrication and tests




EuPRAXIA@SPARC_LAB Conceptual Design Report is publicly available and can be downloaded from http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf




**E. Chiadroni et al.**, arXiv: 1802.00279

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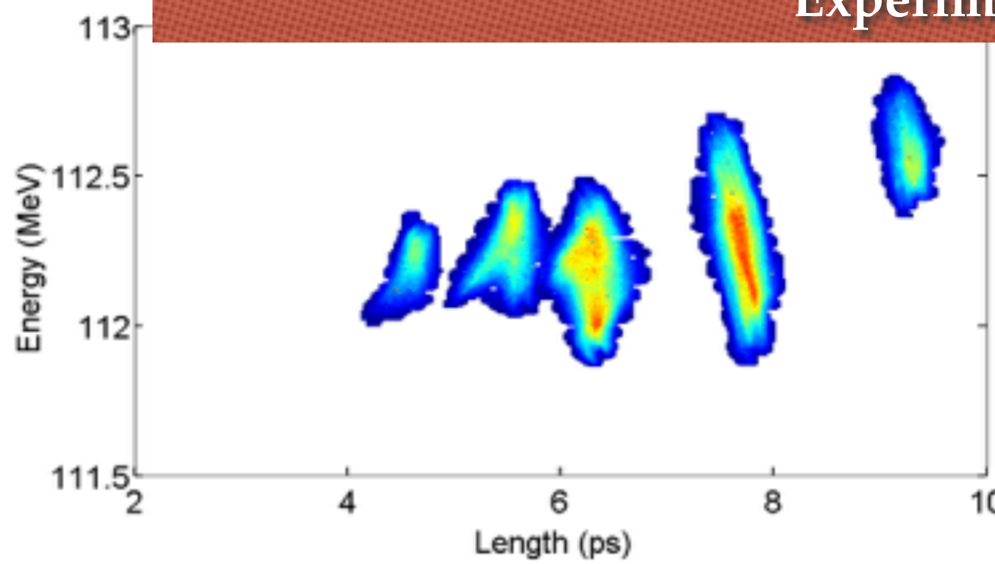
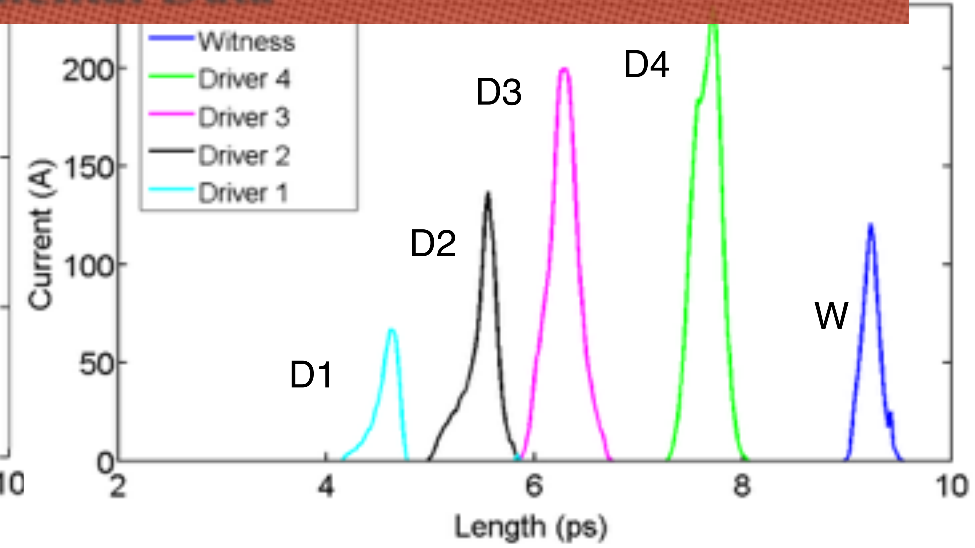
# …Multi-bunch manipulation

**Measured beam parameters**

$Q\ witness = 24$ pC
$Q\ drivers(\text{tot}) \sim 200$ pC
$E = 112$ MeV
$\Delta E/E = 0.1\%$
$\varepsilon_n \sim 1$ mm mrad
$\sigma_t\ drivers < 100$ fs
$\sigma_t\ witness \sim 80$ fs

**Experimental Data**




$n_p = 10^{16} cm^{-3}$
$\sigma_x = 2\ \mu m$

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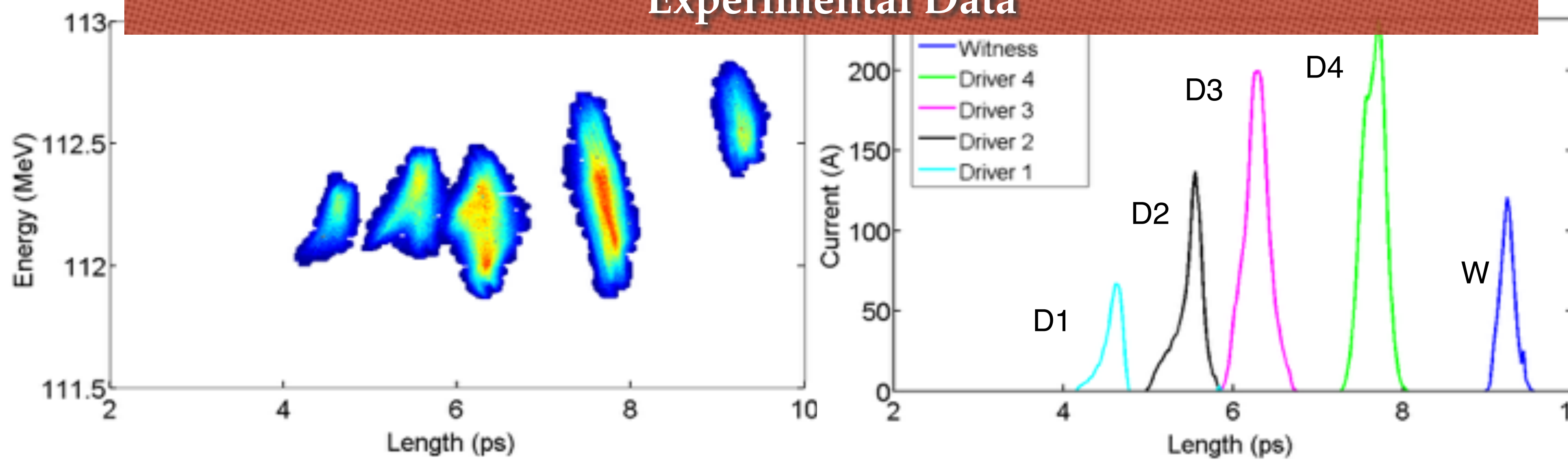
# Weakly non linear regime

**Measured beam parameters**

- Q *witness* = 24 pC
- Q *drivers*(tot) ~ 200 pC
- E = 112 MeV
- $\Delta E / E = 0.1\%$
- $\varepsilon_n$ ~ 1 mm mrad
- $\sigma_t$ *drivers* < 100 fs
- $\sigma_t$ *witness* ~80 fs

$\sigma_t$

**Experimental Data**




**Weakly non-linear regime** → $n_p = 10^{16}\,\mathrm{cm}^{-3}$
$\sigma_x = 2\ \mu\mathrm{m}$

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**E. Chiadroni et al.**,
NIM A **865**, 139-143 (2017)

# Interaction with plasma

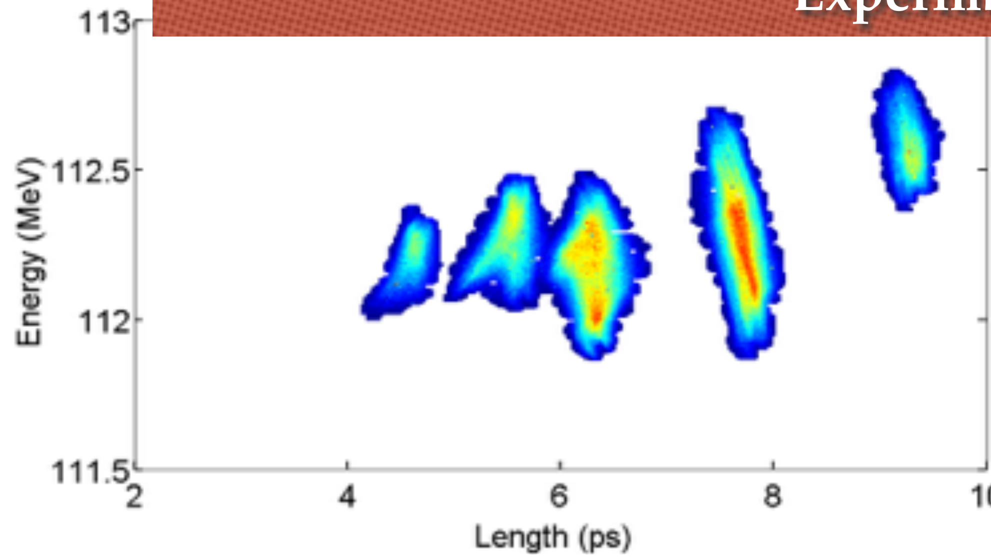
SPARC_LAB

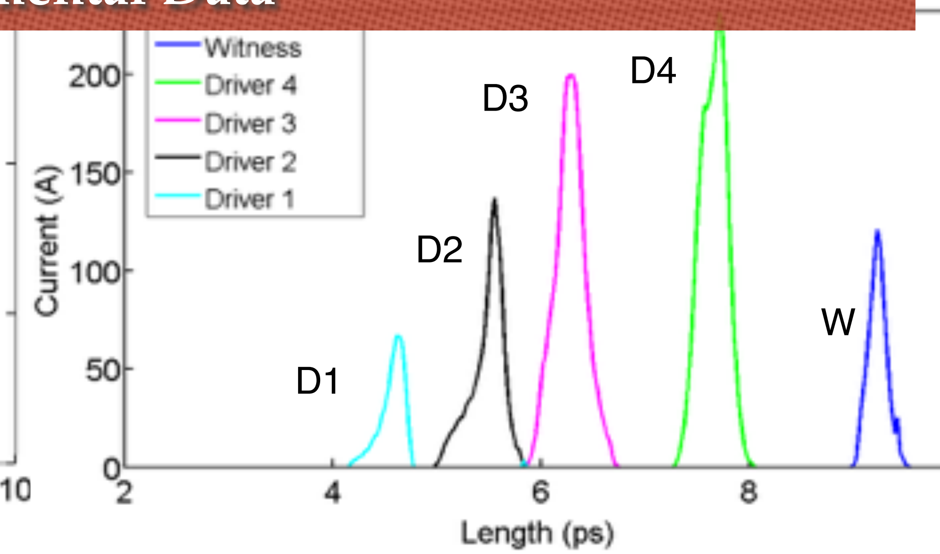
**Hybrid kinetic-fluid simulation by Architect from measured parameters**

**Measured beam parameters**

- Q *witness* = 24 pC
- Q *drivers*(tot) ~ 200 pC
- E = 112 MeV
- $\Delta E/E = 0.1\%$
- $\varepsilon_n$ ~ 1 mm mrad
- $\sigma_t$ *drivers* < 100 fs
- $\sigma_t$ *witness* ~80 fs

**Experimental Data**

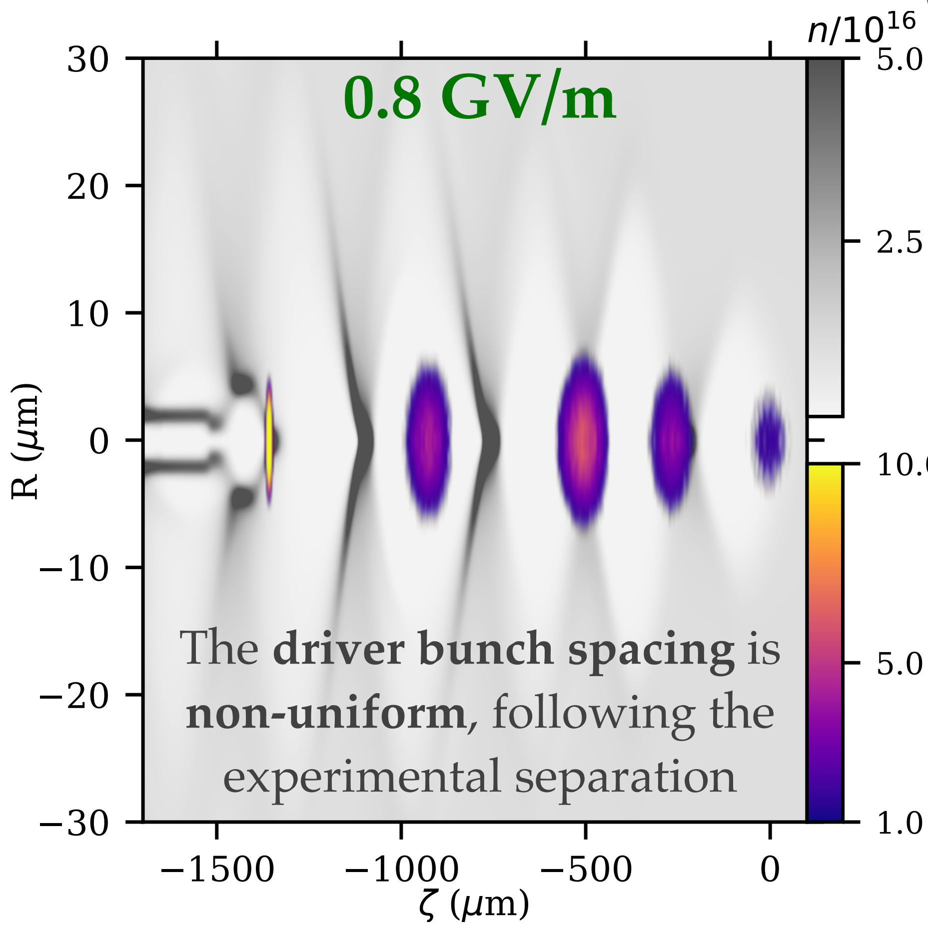


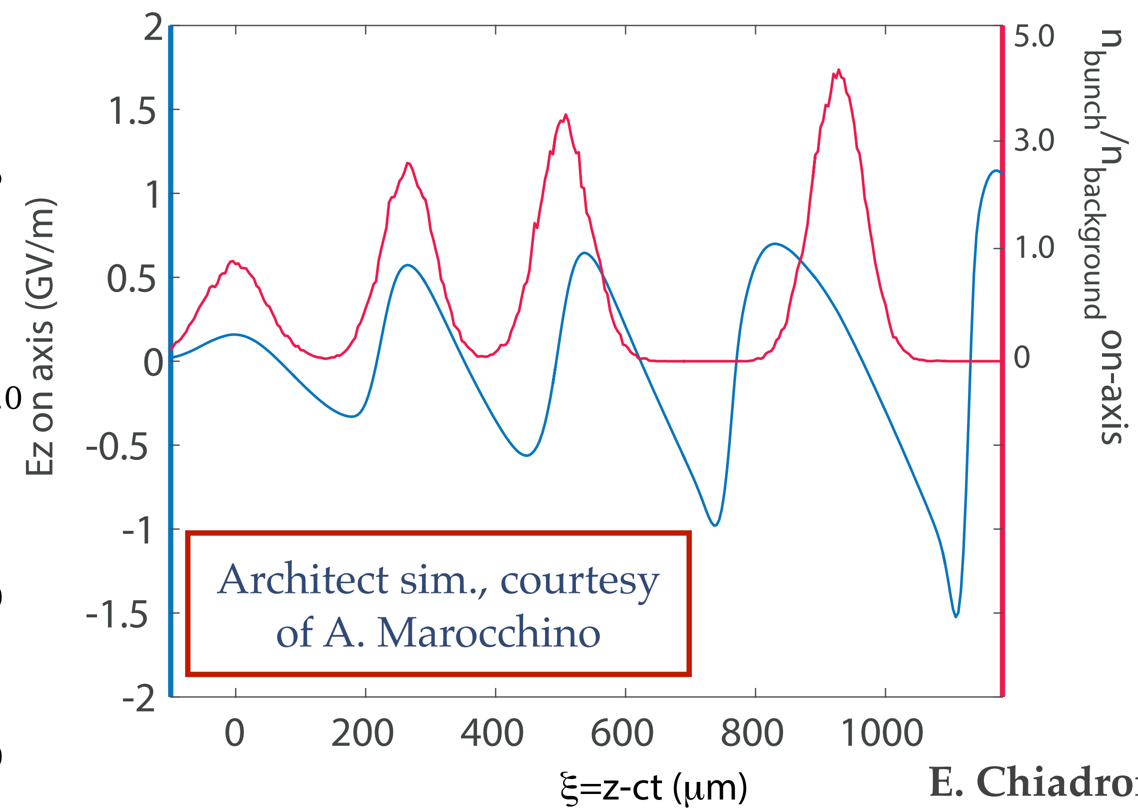




**Weakly non-linear regime**

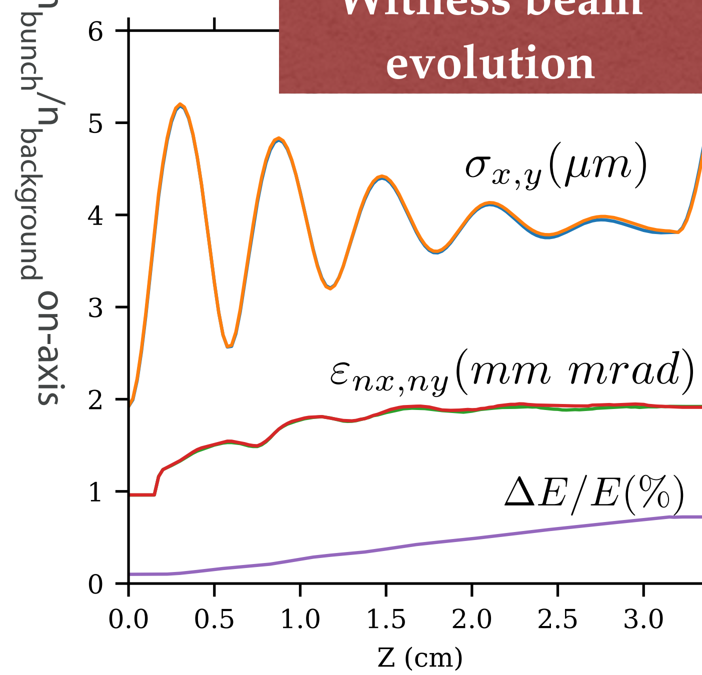
$n_p = 10^{16} cm^{-3}$

$\sigma_x = 2\ \mu m$




**Witness beam evolution**

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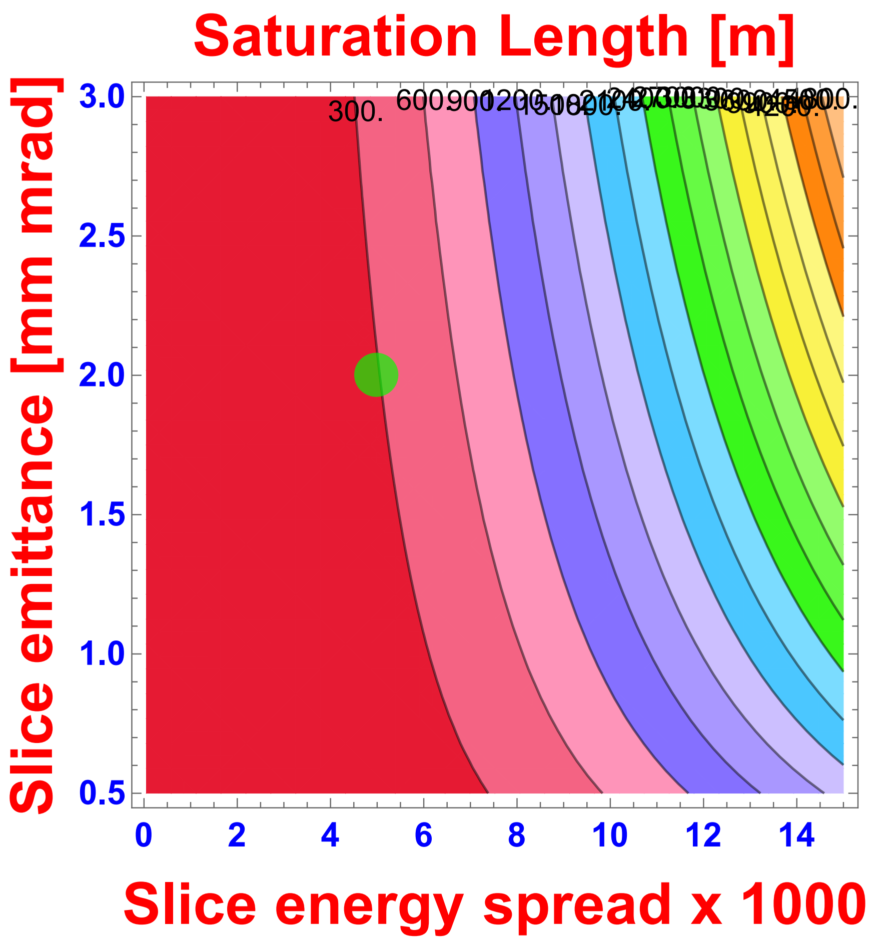
**E. Chiadroni et al.**, NIM A **865**, 139-143 (2017)

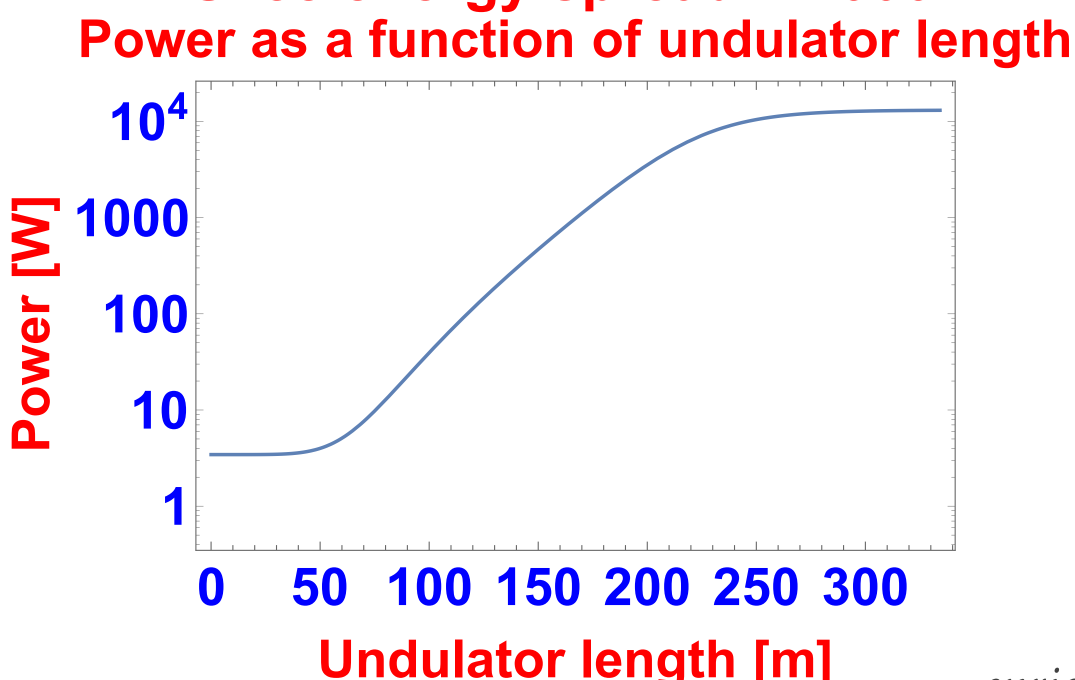
INFN LNF

# Expected FEL Results

$\Delta E/E = 0.5\%$




$$\lambda_r = 555\ nm$$

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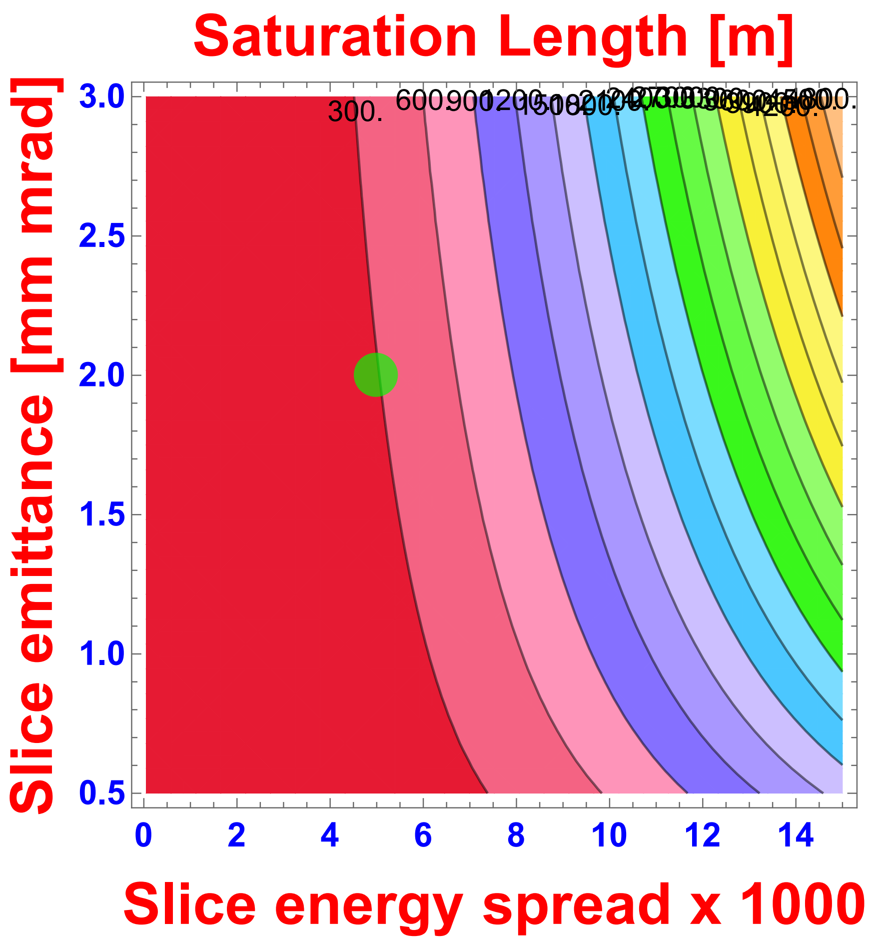
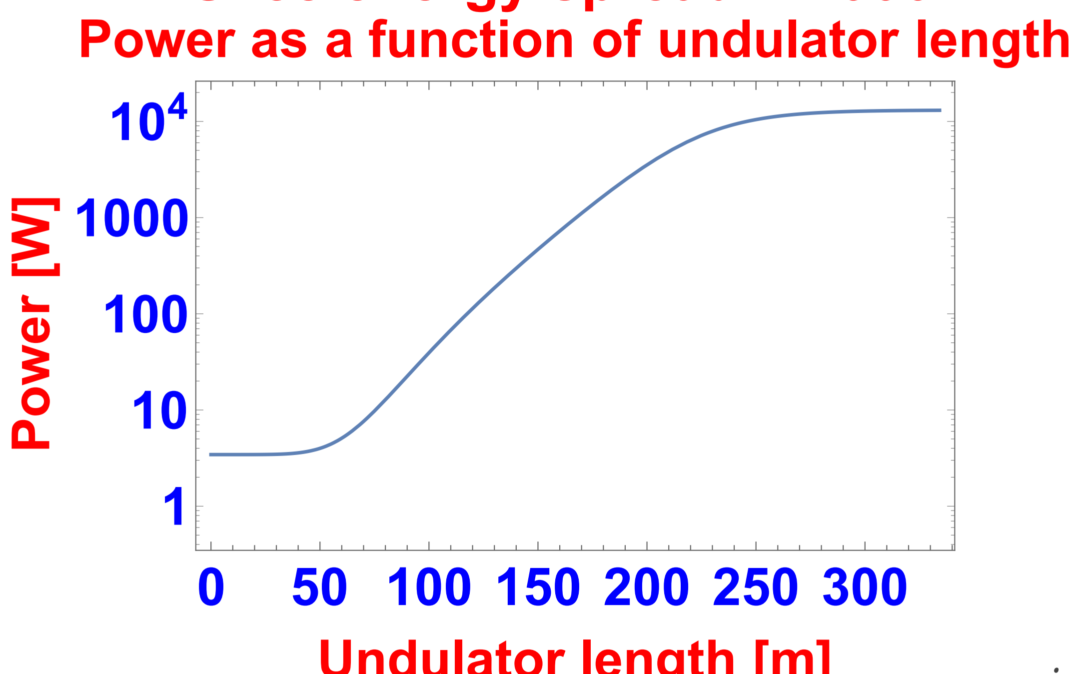
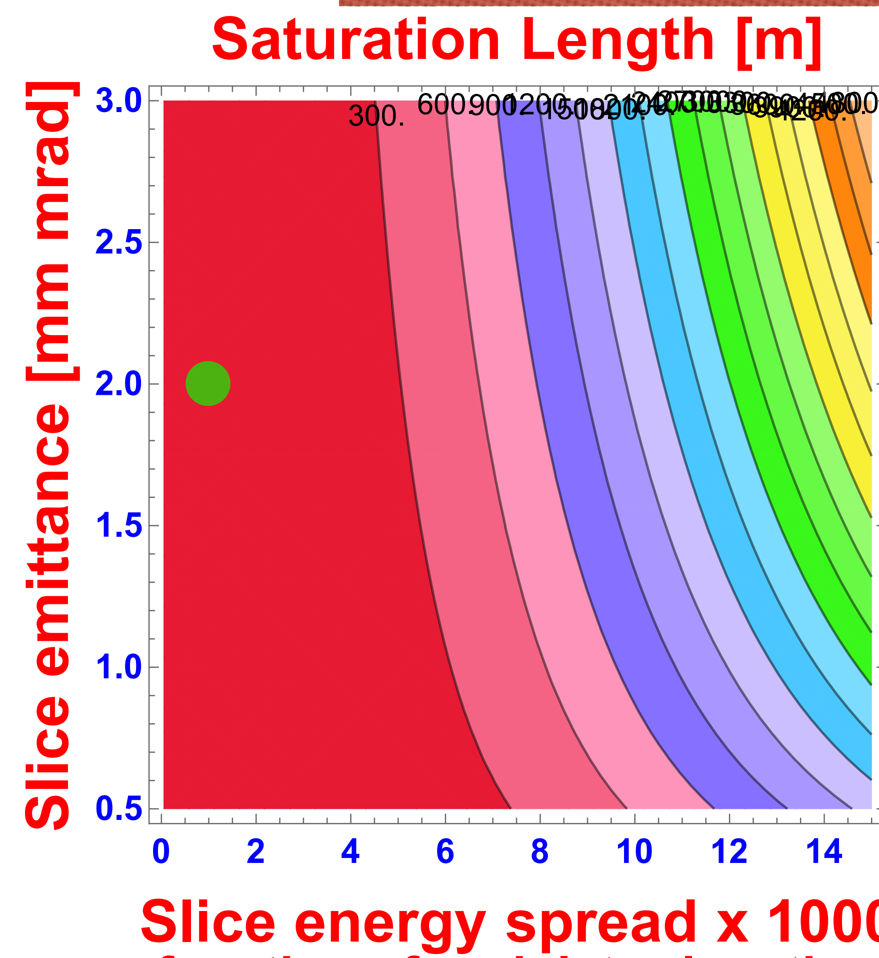
# Expected FEL Results

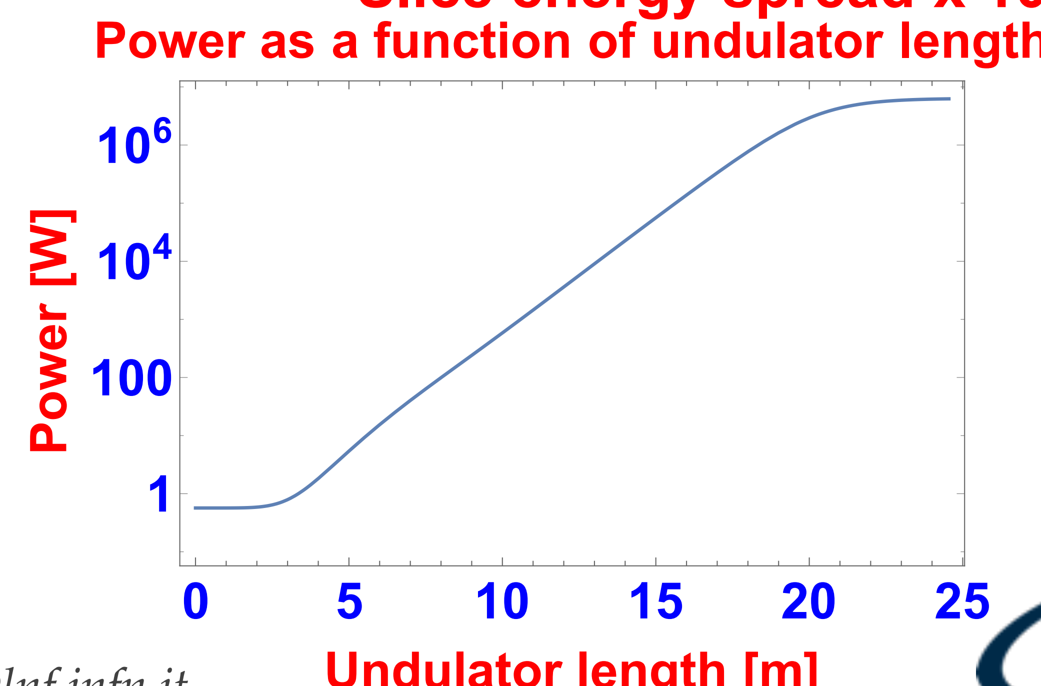
$\Delta E/E = 0.5\%$




$\Delta E/E = 0.1\%$




$$\lambda_r = 555\ nm$$

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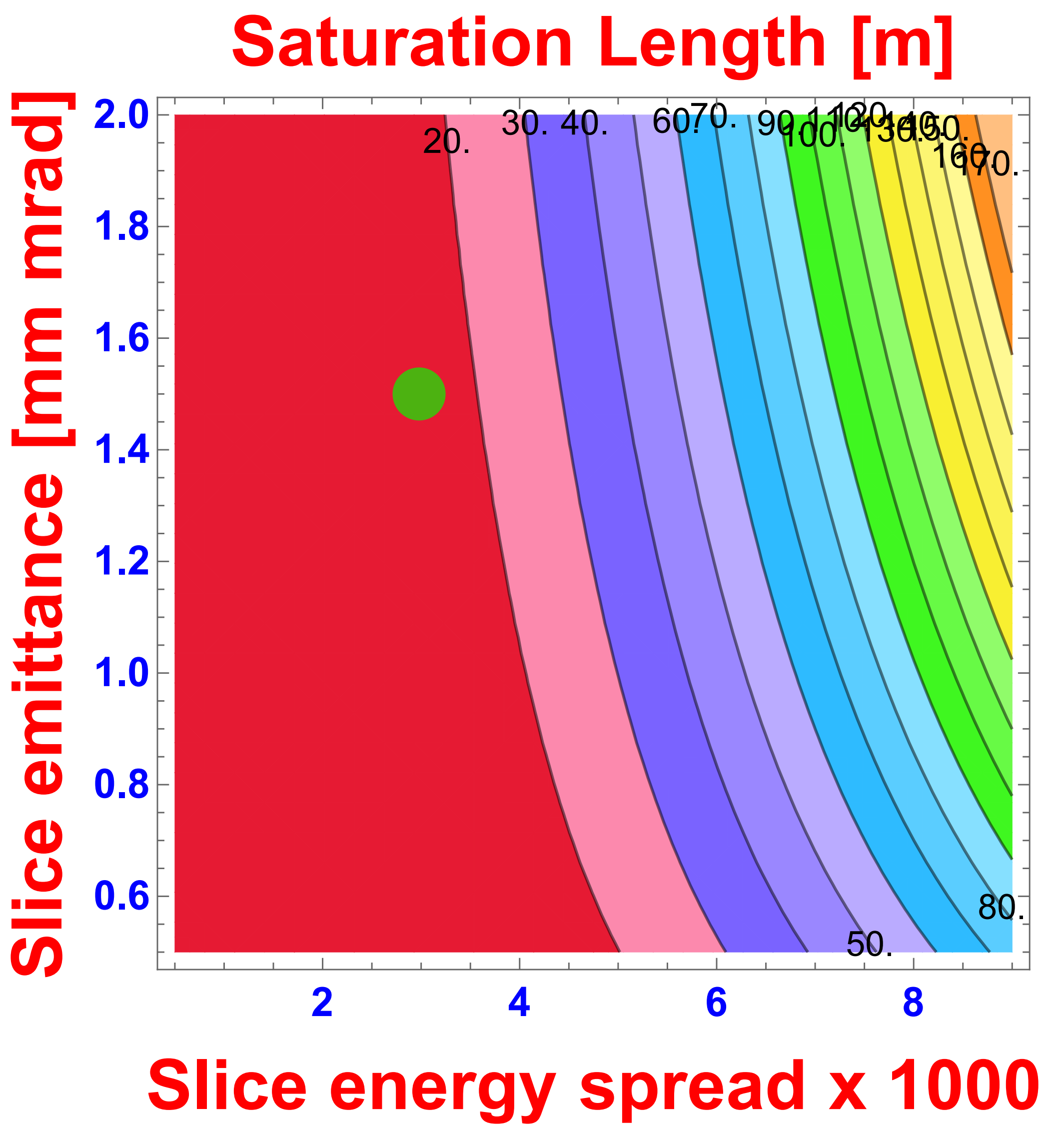
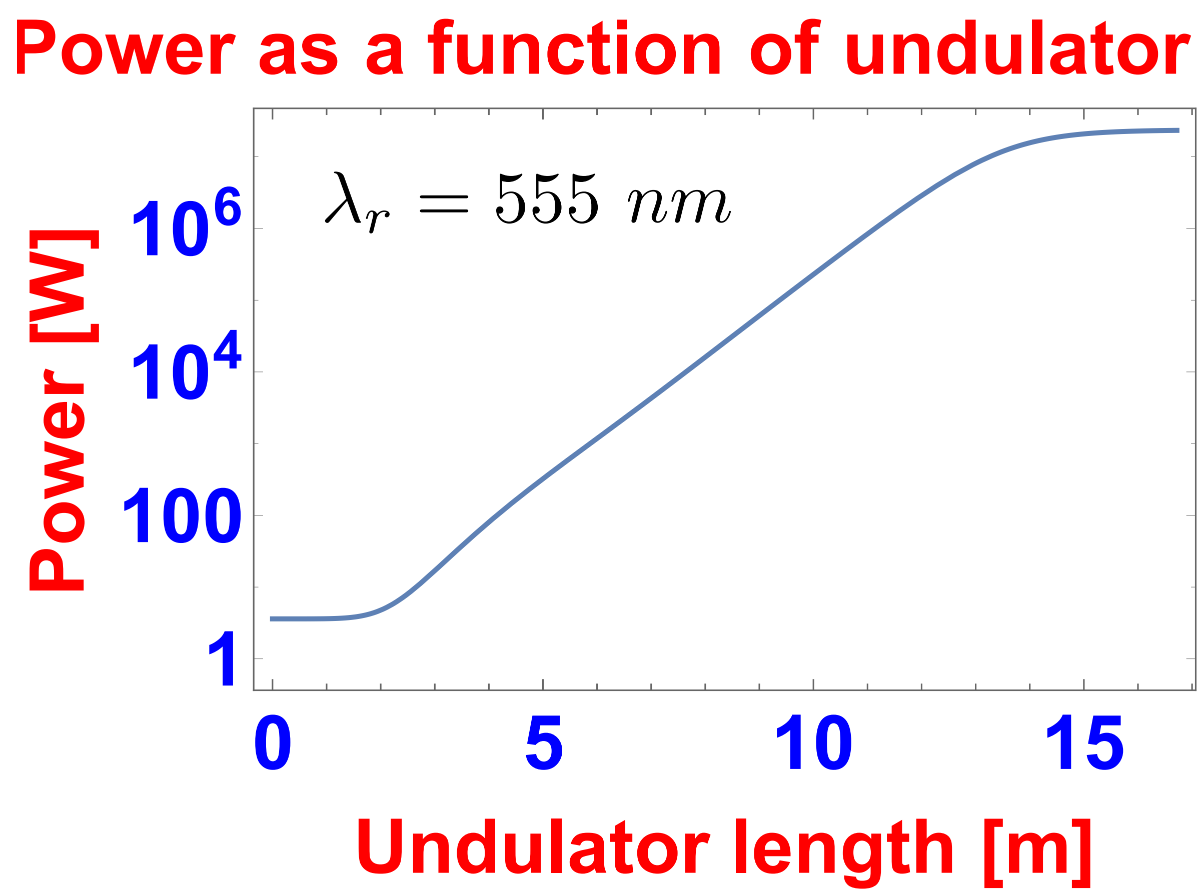
# Optimized FEL Results

$\Delta E/E = 0.3\%$
emit = 1.5 mm mrad
Ipeak = 200 A




**Compatible with SPARC undulator!**

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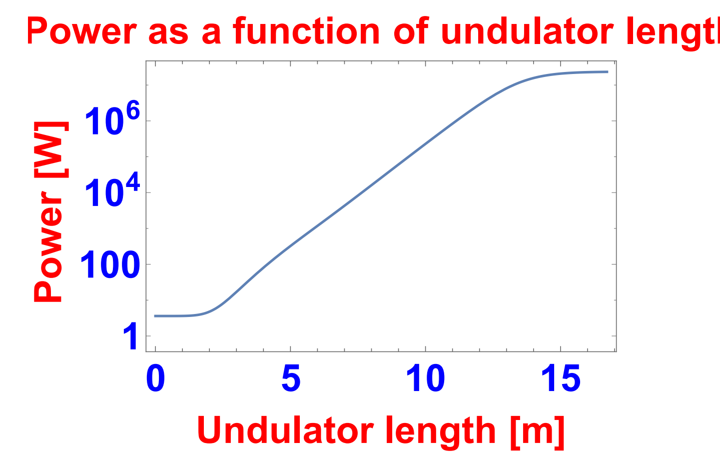
# Why SL_COMB2FEL?

- **SL_COMB2FEL is a five-years experiment proposal** (2019-2023), aiming at
  - Demonstration of high quality of PWFA-electron beam through the final **measurement of the FEL gain curve**
    - Great effort on the transport and matching from plasma to the undulator
  - **Miniaturization** of ancillary components to move towards a **compact facility**
    - accelerating modules, diagnostics, measurement stations, beam position monitors, ..
  - **R&D on diagnostics**




- **Path towards EuPRAXIA@SPARC_LAB test user facility**
  - EuPRAXIA ("European Plasma Research Accelerator with eXcellence In Applications")
    - Horizon 2020 Design Study dedicated to the feasibility study of a **plasma-based** user **facility**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# Description of the Activity

- **Start-to-end simulations** (from cathode to undulator exit) => LNF, Mi
  - study of **plasma ramps** and **real plasma density** profile
  - study and design of the **transfer line from the plasma exit to the undulator**
- **Impact of hydrogen gas flow on the copper photo-cathode Quantum Efficiency**
  - Single layer graphene deposition => Le, LNF
- Extraction transfer line up to the measurement station and to the undulator => LNF, Na
  - **Driver removal**
    - Study of effects of electron scattering in the gas, the effect on the emittance growth and the resulting dose irradiated
  - Plasma lenses (instead of permanent magnet quadrupoles, PMQ) for the injection and the extraction, from the plasma accelerating module to gently focus and capture the accelerated beam
- Demonstration (with measurements) of the high quality of the accelerated beams => LNF, RM2
  - **single shot diagnostics** for bunch length and transverse emittance
- Development of **advanced alignment tools** => LNF, RM1
  - Test bench for X-band integrated beam position monitor (BPM)

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# Financial Requests (in keuro) /Year

| | Missioni | Consumo | Attrezzature scientifiche | Costruzione apparati | TOTAL |
|---|---|---|---|---|---|
| Workshop/Conference/ Collaborations | 10 | | | | |
| Capillaries (Sapphire, plastic, tapered) | | 15 | | | |
| Cathode deposition | | 5 | | | |
| Discharge circuit development | | | 12 | | |
| Cherenkov-based emittance monitor | | | | 12 | |
| Bunch length spectrometer | | | | 10 | |
| X-band integrated BPM | | | | 10 | |
| Compact Cavity BPM | | | | 8 | |
| FEL transfer line and diagnostics | | | 5 | 5 | |
| TOTAL | | | | | 92 |

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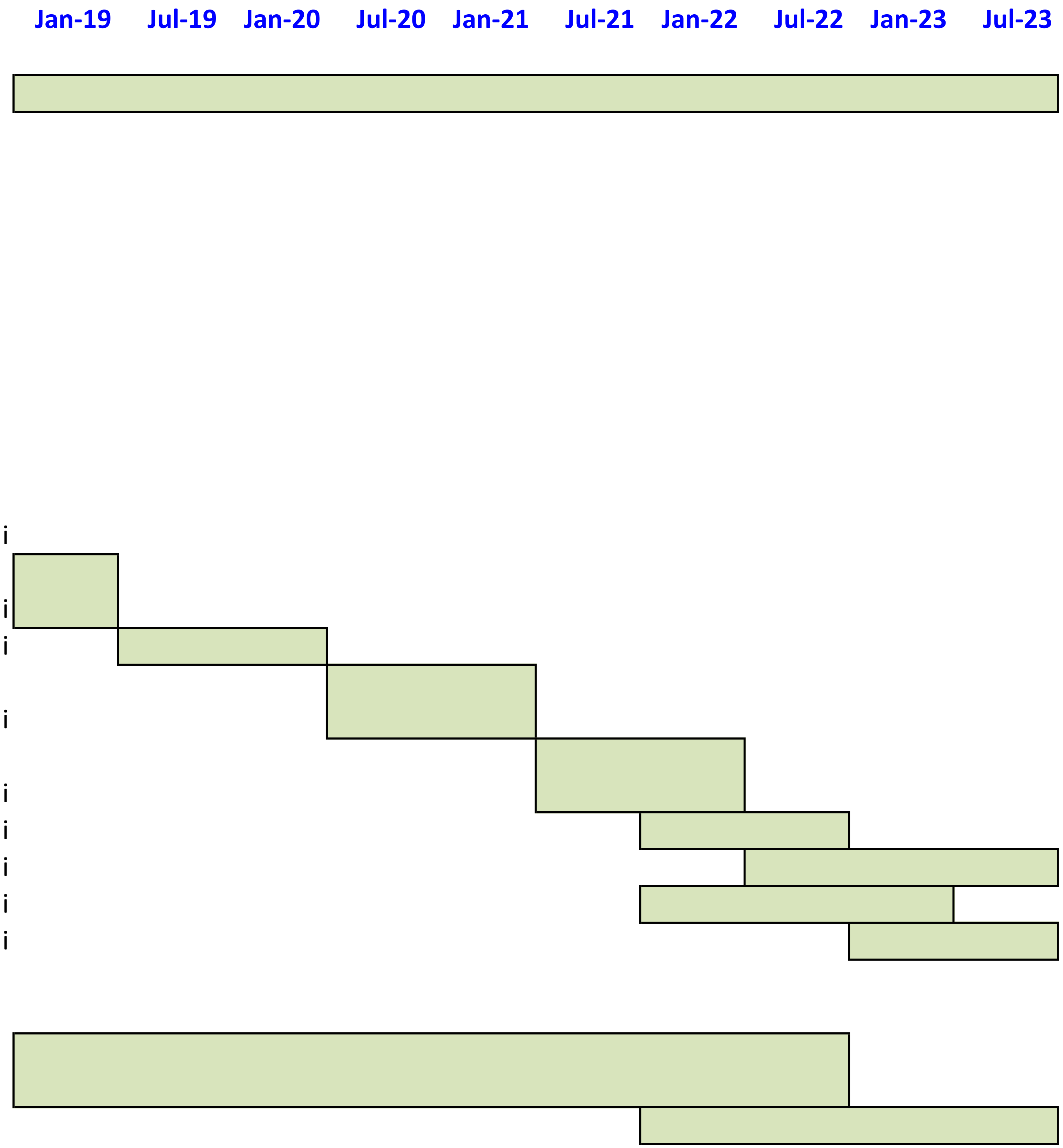
# Timeline

| Tasks | Assigned to |
|---|---|
| **1. Start-to-end simulations** | LNF, Mi, Na, RM1 |
| 1.1 Beam dynamics in the photo-injector for multi-bunch optimization | LNF |
| 1.2 Plasma ramps optimization | Mi, LNF |
| 1.3 Impact of real plasma density profile | LNF, Mi |
| 1.4 Optimization of the transfer line from plasma and matching to the undulator | Mi, LNF |
| 1.4.1 Driver removal (Beam dynamics and GEANT4 simulations) | LNF, Na, Mi |
| 1.5 Impact of wakefields in dielectric capillaries | LNF, RM1 |
| 1.6 FEL studies with SPARC undulator | LNF, Mi |
| **2. Experimental studies** | LNF, RM1, RM2, Mi |
| 2.1 Optimization of driver and witness working point | LNF, RM1, RM2, Mi |
| 2.2 Optimization of witness matching conditions | LNF, RM1, RM2, Mi |
| 2.3 Optimization of witness beam parameters (e.g. emittance and energy spread) out of plasma | LNF, RM1, RM2, Mi |
| 2.4 Driver removal and matching of the witness to the undulator | LNF, RM1, RM2, Mi |
| 2.5 Injection of witness into the undulator | LNF, RM1, RM2, Mi |
| 2.6 Witness beam and undulator field interaction | LNF, RM1, RM2, Mi |
| 2.6.1 FEL transfer line | LNF, RM1, RM2, Mi |
| 2.6.1 Optimization of FEL gain growth | LNF, RM1, RM2, Mi |
| **3. Impact of hydrogen gas flow on Cu surfaces** | LNF, Le |
| 3.1 Development of graphene-deposited Cu cathode | Le |
| 3.2.1 Test of photo-emitted electrons | Le, LNF |

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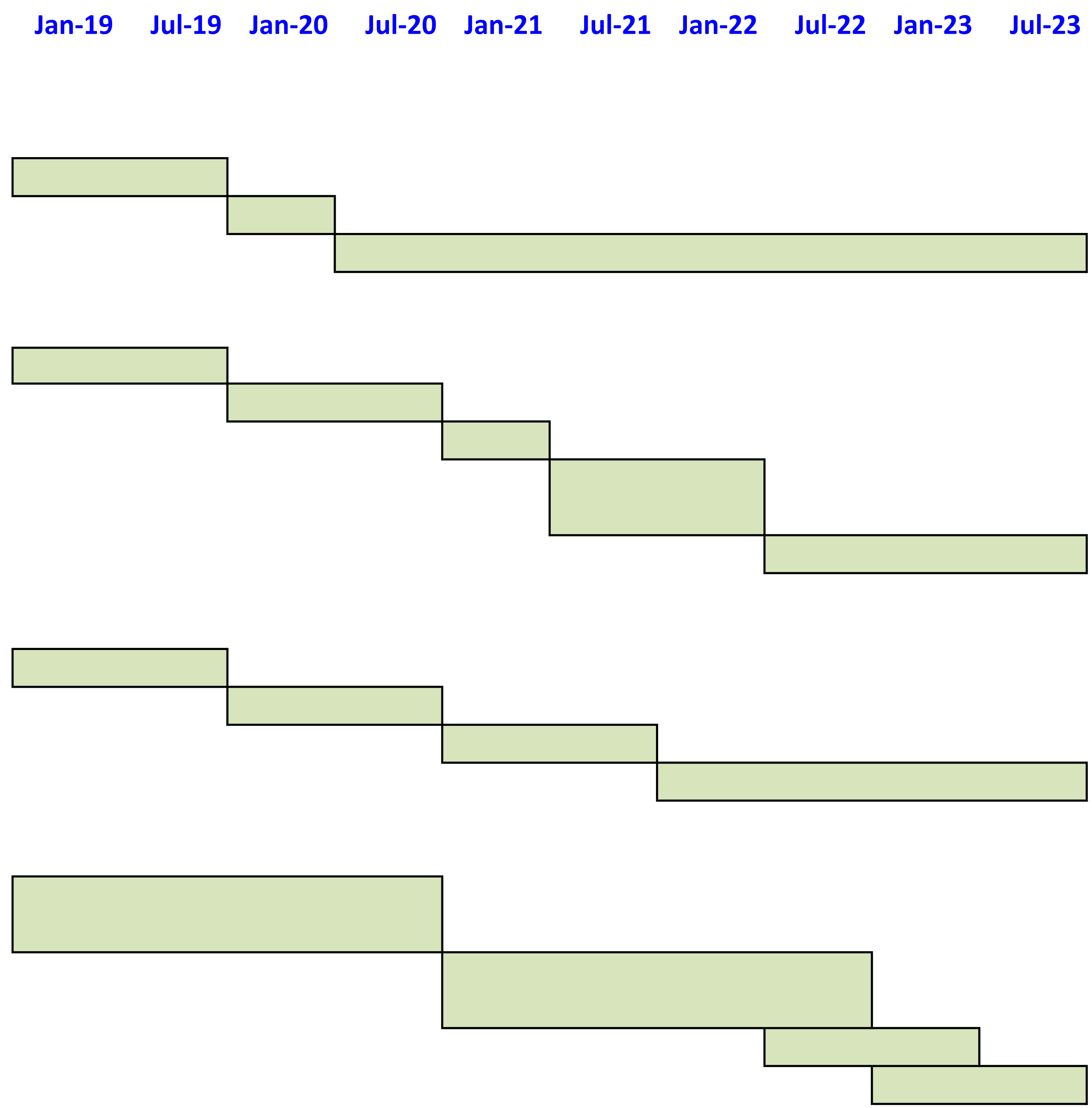
# Timeline

| Tasks | Assigned to |
|---|---|
| **4. Advanced Diagnostics** | LNF, RM2, RM1 |
| **4.1 Compact beam size monitors** | RM2, LNF |
| 4.1.1 Design and construction | LNF, RM2 |
| 4.1.2 Installation | LNF |
| 4.1.3 Commissioning and operation | LNF, RM2, RM1 |
| **4.2 Single shot emittance measurement** | RM2, LNF, RM1 |
| 4.2.1 Study and design of the experimental layout | RM2, LNF |
| 4.2.2 Executive design project | LNF, RM2 |
| 4.2.3 Procurement of the material | RM2 |
| 4.2.4 Construction and installation of the measurement system | LNF |
| 4.2.5 Experimental tests and final measurements | LNF, RM2, RM1 |
| **4.3 Single shot bunch length measurement** | LNF |
| 4.3.1 Study and design of the experimental layout | LNF |
| 4.3.2 Procurement of the material | LNF |
| 4.3.3 Installation of the measurement system | LNF |
| 4.3.4 Experimental test and measurements | LNF |
| **4.4 Advanced beam position and alignment tools** | LNF, RM1, RM2 |
| 4.4.1 Design and project of compact beam position monitors | LNF, RM1 |
| 4.4.2 Construction and procurement of the material | LNF, RM1 |
| 4.4.3 Test bench set up | LNF, RM1, RM2 |
| 4.4.4 Experimental test and measurements | LNF, RM1, RM2 |

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# LNF: Participants and Technical Requests

E. Chiadroni (Ric. 20%)
M. P. Anania (Ric. TD 40%)
M. Croia (Ass. Ric.100%)
F. Ciocci (I Ric. Ass. 20% ENEA)
M. Ferrario (Dir. Ric. 40%)
D. Giulietti (Ass. 50%)
A. Marocchino (Ric. TD, 0%)
R. Pompili (Ric. 30%)
S. Romeo (Ass. Ric. 100%)
J. Scifo (Ass. Ric. 30%)
V. Shpakov (Ric. TD. 40%)
A. Del Dotto (Ass. Ric. 50%)

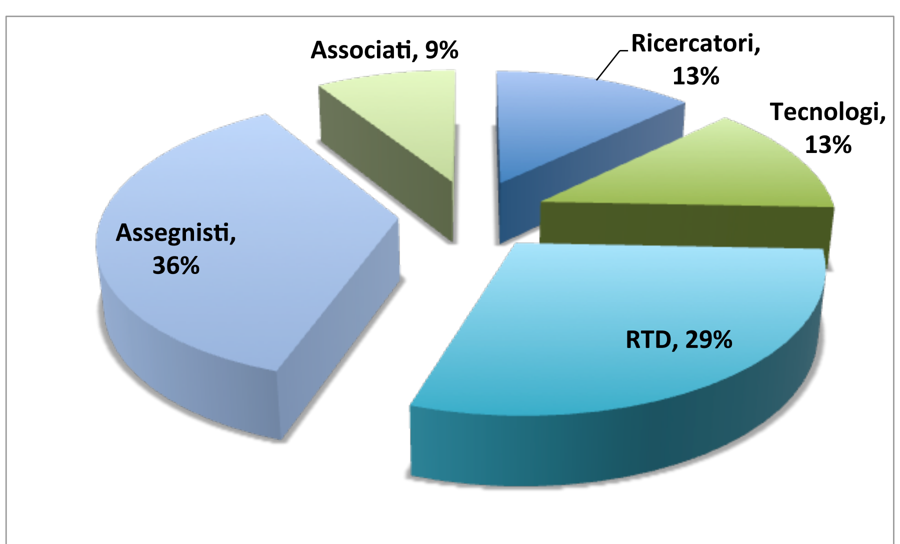
FTE 5.0 (to be finalized)

D. Alesini (I Tecn. 10%)
M. Bellaveglia (Tecn., 10%)
A. Biagioni (Tecn. TD, 40%)
S. Bini (Tecn. TD, 20%)
M. Del Franco (Tecn. TD, 30%)
D. Di Giovenale (Tecn. TD, 30%)
G. Di Pirro (I Tecn., 10%)
A. Gallo (Dir. Tecn., 20%)
A. Ghigo (Dir. Tecn., 10%)
C. Vaccarezza (I Tecn., 20%)
F. Villa (Tecn. TD 30%)
A. Stella (Tecn. 20%)

FTE > 2.3 (to be finalized)

| Resources | FTE/2019 | FTE/2020 |
|---|---|---|
| LINAC | 0.3 | 0.3 |
| Vacuum | 1 | 0.5 |
| Mechanics | 0.5 | 0.5 |
| Fluid plant | 0.2 | 0.2 |
| Electrical plant | 0.2 | 0.2 |
| Diagnostics | 1 | 1 |
| Laser | 1 | 1 |
| Magnets | 0.2 | 0.2 |
| RF | 0.3 | 0.3 |

FTE 4.7 (2019)

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