TTF Meeting - Frascati

November 5th - 2001

Perspectives for a X-ray Coherent Source in Italy

L. Serafini - on behalf of the

SPARX Study Group

A collaboration among

CNR - ENEA - INFN - Univ. di Roma 2 “Tor Vergata”

- **The origins of this initiative**
  (Fasella Panel , National Research Plan: 67 M€ allocated to a X-ray laser program)

- **The activity of the Study Group**
  (2 scenarios for a 2 GeV Linac driving a 1.5 nm FEL)

- **A possible site in the roman area**

SPARX Study Group

L. Avaldi, C. Carbone, A. Cricenti, A. Pifferi, P. Perfetti, T. Prosperi, V. Rossi Albertini, C. Quaresima, N. Zema **(CNR).**

R. Bartolini, F. Ciocci, G. Dattoli, A. Doria, F. Flora, G. P. Gallerano, L. Giannessi, E. Giovenale, G. Messina, L. Mezi, P. L. Ottaviani, L. Picardi, M. Quattromini, A. Renieri, C. Ronsivalle **(ENEA/FIS).**

D. Alesini, S. Bertolucci, C. Biscari, R. Boni, M. Boscolo, M. Castellano, A. Clozza, G. Di Pirro, A. Drago, M. Ferrario, V. Fusco, A. Gallo, A. Ghigo, S. Guiducci, M. Incurvati, P. Laurelli, C. Ligi, F. Marcellini, M. Migliorati, C. Milardi, L. Palumbo, L. Pellegrino, M. Preger, R. Ricci, C. Sanelli, F. Sgamma, B. Spataro, A. Stecchi, A. Stella, F. Tazzioli, C. Vaccarezza, M. Vescovi, V. Verzilov, C. Vicario, M. Zobov **(INFN /LNF)**

I. Boscolo, S. Cialdi, C. Maroli ,V. Petrillo, L. Serafini **(INFN /Milano)**

E. Chiadroni, G. Felici, D. Levi, M. Mastrucci, M. Mattioli, G. S. Petrarca **(INFN /Roma1)**

L. Catani, A. Cianchi, C. Schaerf **(INFN /Roma2).**

The Origins of a X-Ray FEL Project in Italy

- **The Fasella Panel**
  The interest for the realization in Italy of a *Ultra-high BrillianceX-ray Source* was firstly formalized in Sept. 1998, during a meeting, held at the Sci. & Tech. Research Dept. (MURST), of a panel lead by **Paolo Fasella**. The preparation of a proposal to the italian government was at that time seriously encouraged by **Björn Wiik**, attending the meeting.

- **The NATIONAL RESEARCH PLAN**
  Funded by 10% of the money raised in the Government Auction run last year for the Next Gen. Cellular Network licences (UMST), it encompasses 10 initiatives (genoma, nanotech., Center for climate studies in the Medit., X-ray laser, etc.) for a total of **1033 M¤** .

The National Research Plan (PNR)

- **Large Infrastructures (a section of PNR)**
  Funds were allocated for 2 initiatives:

  1) *Multi-purpose X-ray Laser at Ultra-High Brilliance* **67 M¤** + 5 **M¤** (80 res. fell.)
  2) *Center for the climate study of the Mediterranean* **21 M¤**

  with the aim to drive and/or consolidate the development of european initiatives/centers

- **The Italian Gov. responded to the recommendation by the Fasella Panel**

  National Res. Institutions were supposed to prepare proposals: **67 M¤** will cover the 70% of the budget (hardware + man power). The additional 30% has to be covered by the selected Institution winning the call for prop.

Which Linac for what FEL λ_r ?

- **This is the first X-ray FEL initiative for which the Linac is not available or provided by other programs**

- **The study group decided to start a broad band investigation to compare different schemes and technologies**

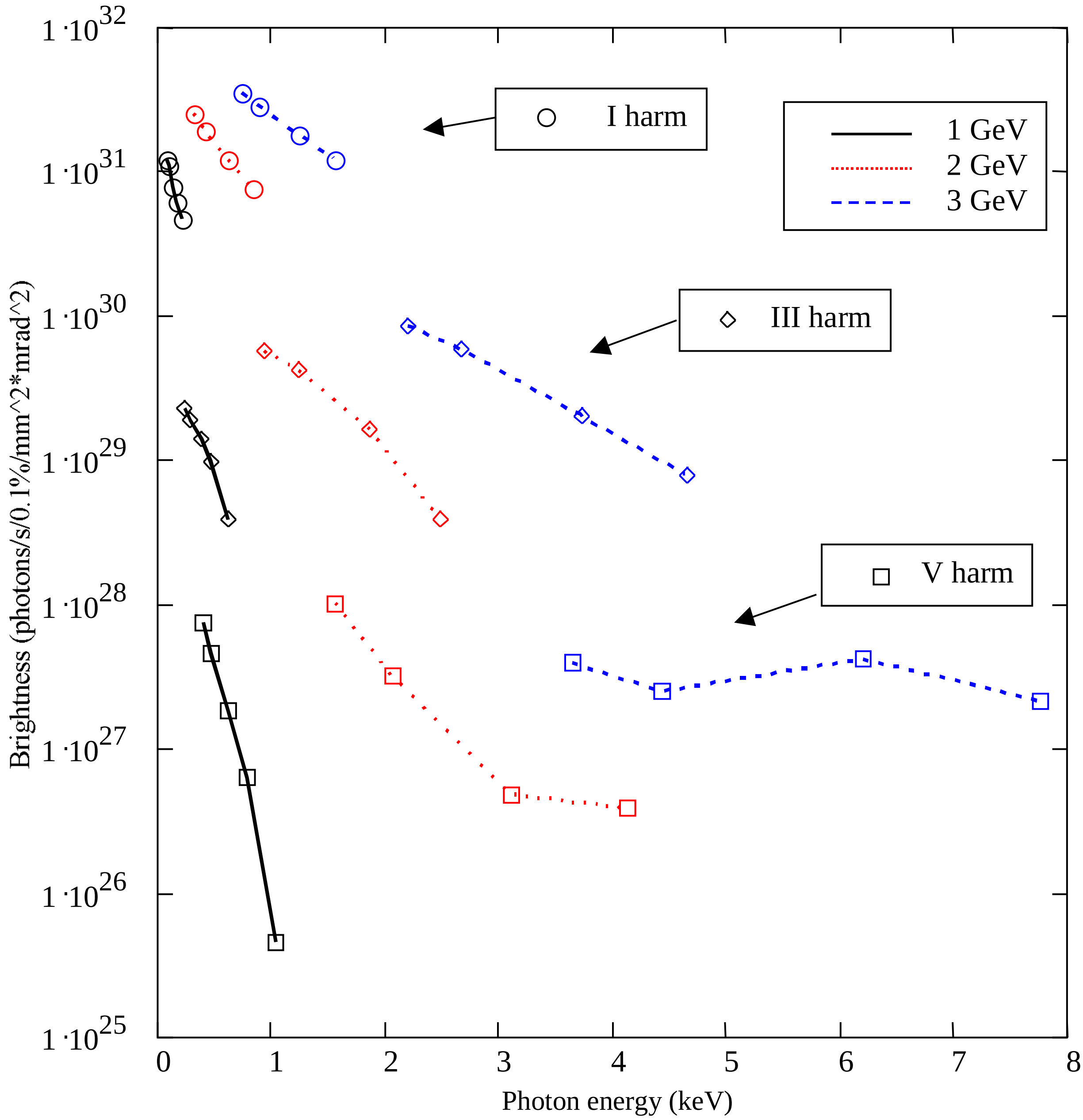
- The aim was to develop a program able to reach a wavelength range of interest (i.e. with a good scientific case), consistent with the available budget (**67 M¤** + **5 M¤** + **29 M¤**)
- As indicated by the Presidents of the collaborating Institutions, the **project is meant to be evolutionary**, that is compatible to a long term upgrade expected to reach the *final goal* of a **1 Å Coherent Radiation Source**

The Scientific Case in the 10 nm ⇒ 1 nm range

- **High Peak Brightness (> 10^{30}) Ultra-short (< 100 fs) radiation pulses are of great interest in various areas**

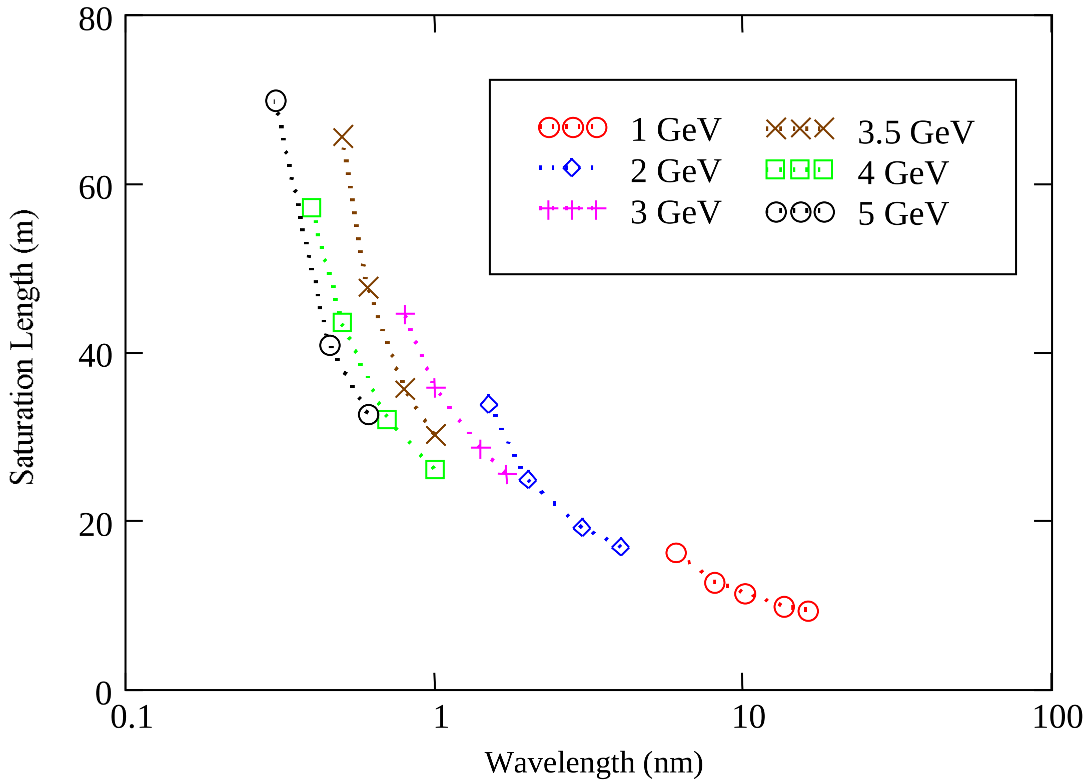
1) **molecular physics** (vibrational modes, bond breaking and formation at λ=10-1 nm, λ<1 Å)
1) **physics of the clusters** (phase transitions at λ=10-1 nm, λ<1 Å)
1) **surface and interfaces** (real time dynamics and phase transitions, λ=10-1 nm)
1) **time resolved chemical reactions** (metastable and transition states, magnetic scattering, confined systems, λ=10-1 nm, λ<1 Å)

first step at 10 and 1.5 nm,
paving the road toward 1 Å (and below)

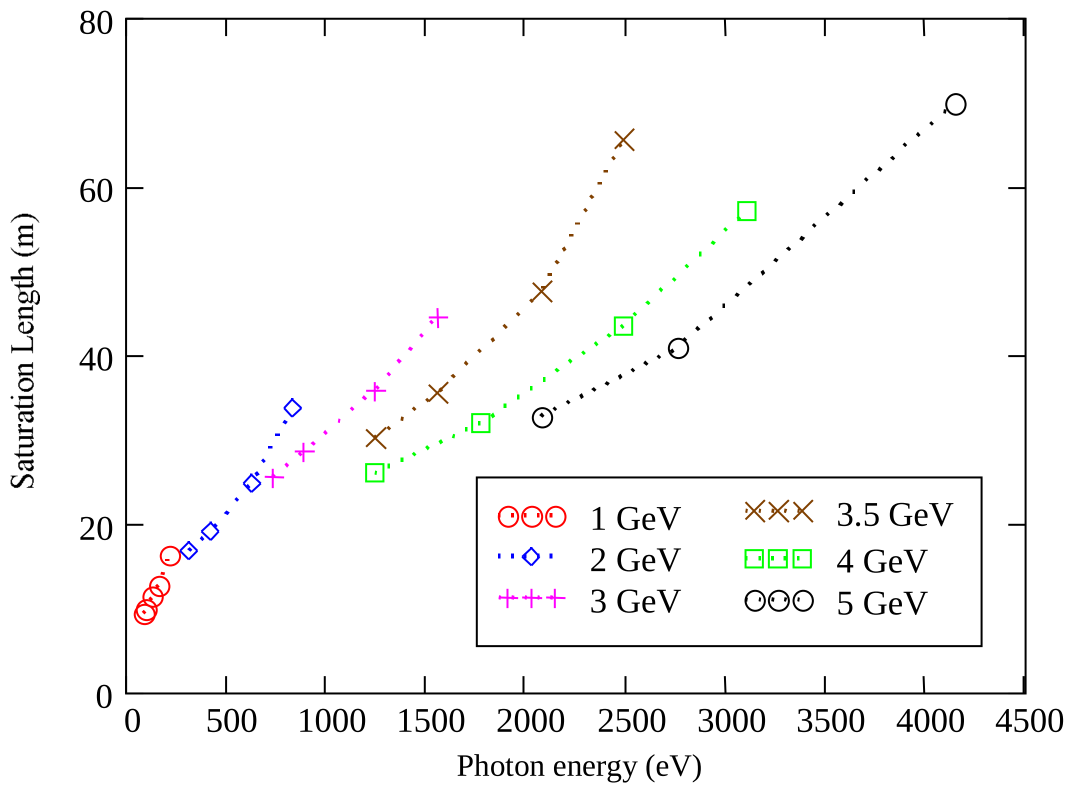


I harm
III harm
V harm
1 GeV
2 GeV
3 GeV
Brightness (photons/s/0.1%/mm^2*mrad^2)
Photon energy (keV)

L. Giannessi



80
60
40
20
0
0.1
1
10
100
Saturation Length (m)
Wavelength (nm)
1 GeV
2 GeV
3 GeV
3.5 GeV
4 GeV
5 GeV



80
60
40
20
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Saturation Length (m)
Photon energy (eV)
1 GeV
2 GeV
3 GeV
3.5 GeV
4 GeV
5 GeV

L. Giannessi

Which technology for a 2 GeV Linac with long term evolution toward 10 GeV ?

- **2 GeV is consistent with λ = 1.5 nm**

	10 nm	**1.5 nm**	$\Rightarrow$	**1 Å**
• **I [kA]**	2	2	$\Rightarrow$	3-5
• ε_n **[μm]**	2 (1)	2(1)	$\Rightarrow$	1
• $\Delta\gamma/\gamma$ **[%]**	$\leq$ 0.3	$\leq$ 0.1	$\Rightarrow$	0.07
• **T [GeV]**	2	2		10

A bird view over the challenges in generating high brightness electron beams

$$B_n = \frac{2I}{\varepsilon_n^2}$$

- **Peak Brightness demands exceed capabilities of modern beam sources, i.e. advanced photoinjectors** (plasma gun ?)
- **No cooling mechanism is available in a Linac for the rms normalized transverse emittance ε_n**
- Need of a device to boost the brightness via bunch compression (peak current increase over the natural 50-100 A delivered by the source)

Continue on challenges

$$B_n = \frac{2I}{\varepsilon_n^2}$$

- **Three Major Tasks to accomplish**

- 1) Minimize all mechanisms leading to degradation of the rms normalized transverse emittance ε_n

- 2) Peak current enhancement by a factor 20-100

- 3) Damp the beam energy spread below the threshold $\Delta\gamma/\gamma < \rho$

DESIGN CRITERIA

- 1) Optimum Emittance Correction accomplished in initial 150 MeV (laminar regime)
  - a) matching to Invariant Envelope
  - b) Ferrario work. point to tune emitt. oscill.
- 2) Optimum Magnetic Compressor Design
  - a) minimize $R_{56} = \delta L / (\Delta\gamma/\gamma)$
  - b) integrate bunch compression into laminar regime using velocity bunching
- 3) Control $\Delta\gamma/\gamma$ via short range longitudinal wake-fields and adiabatic damping

KEY FACTS:

A) Brightness scales up with RF frequency of photoinjector

B) Emittance growth due to CSR scales up with R_{56}

Maximizing Brightness in Laminar Beams

$$B_n = \frac{2I}{\varepsilon_n^2}$$

- A beam is laminar when

$$\gamma \le \frac{\left(I/I_0\right)}{\varepsilon_{nth}\gamma'\sqrt{1+4\Omega^2}} \quad ; \quad \gamma_{lam} = 300 \ \ in \ \ LCLS$$

- Maximum brightness is reached @ $\gamma = \gamma_{lam}$ when the beam is matched on the Invariant Envelope

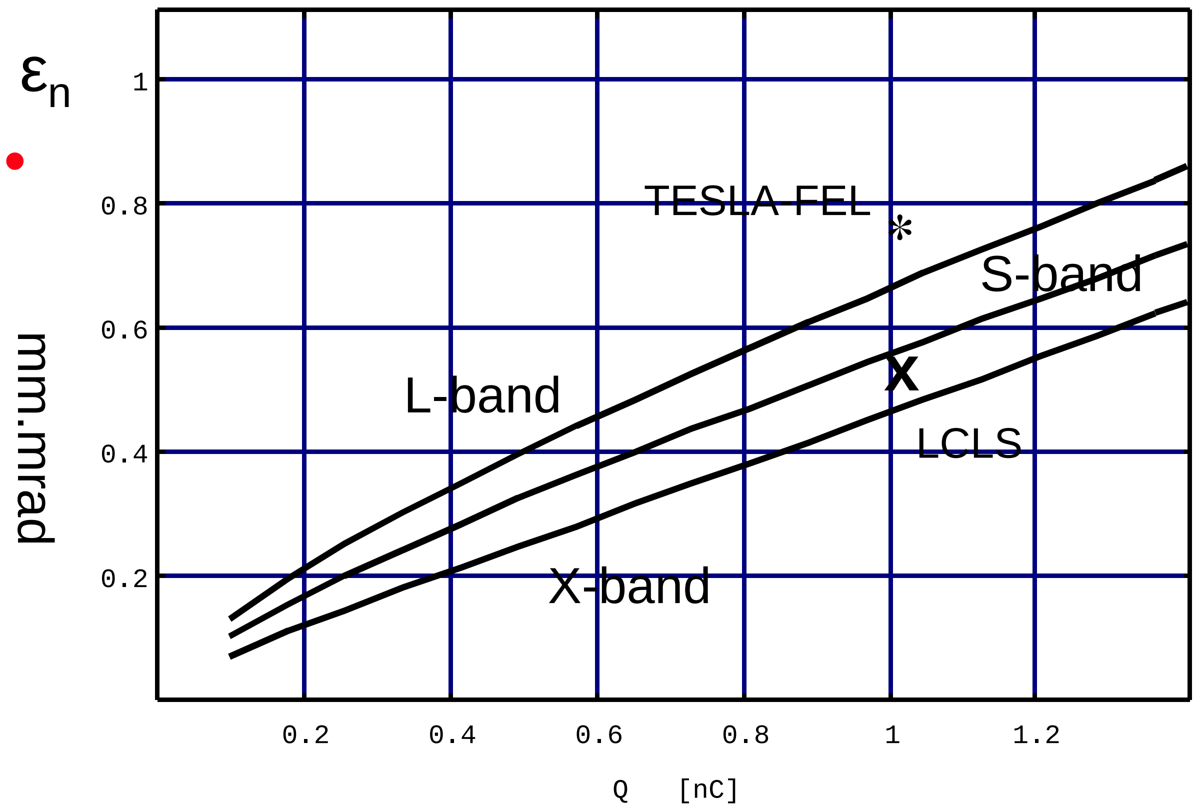
$$\sigma_{INV} = \frac{1}{\gamma'}\sqrt{\frac{2I/I_0}{\gamma\left(1+4\Omega^2\right)}}$$

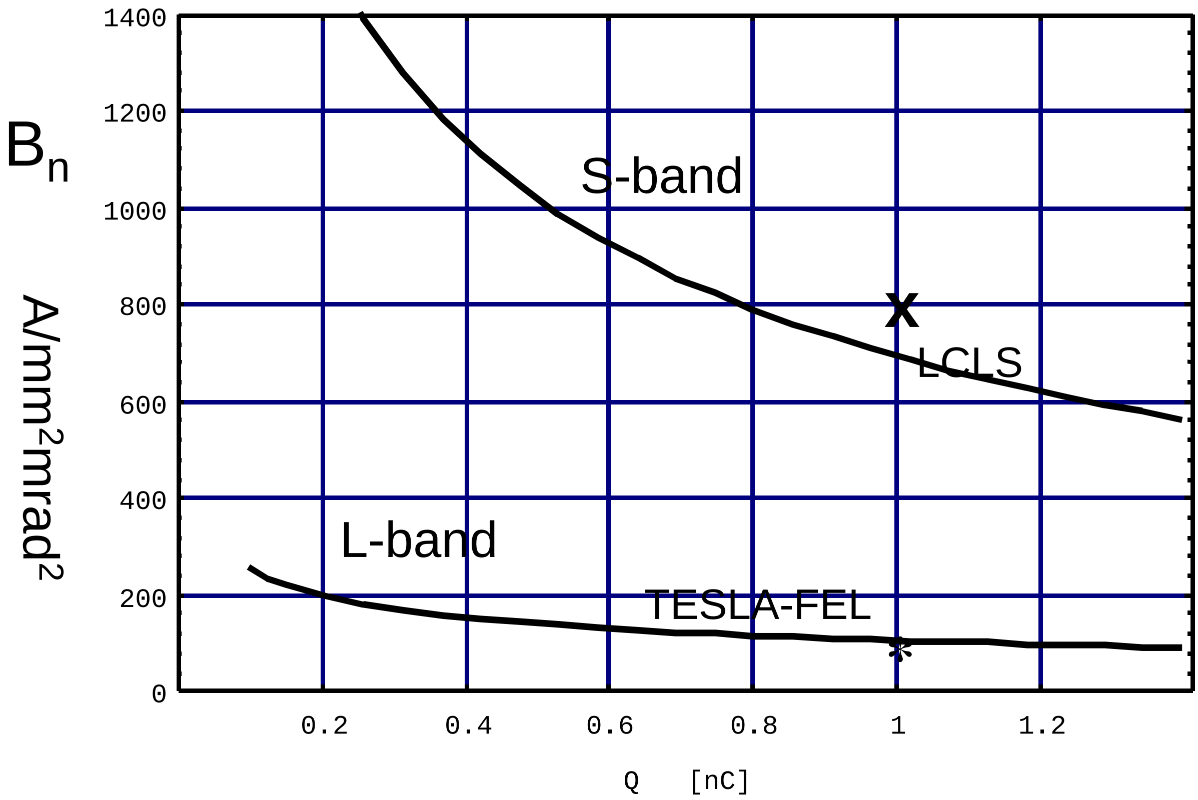
- Implying a condition at the photocathode

nat. scaling

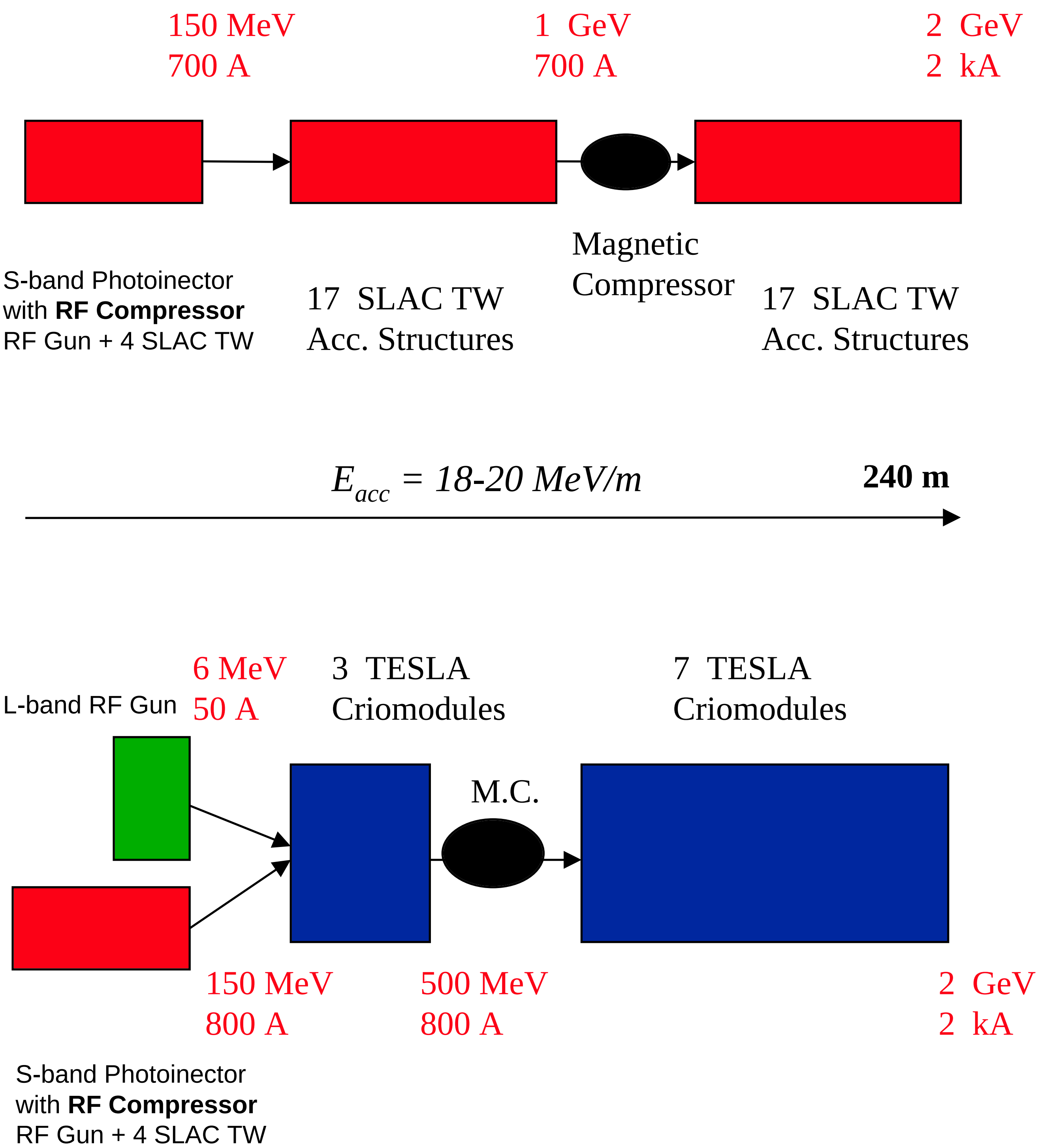
$$\frac{I}{\left(E_0^{RF} R_{cat}\right)^2} = \cos t \qquad \begin{cases} R_{cat} & \lambda_{RF} \\ E_0^{RF} & \lambda_{RF}^{-1} \end{cases}$$

Emittance and brightness scaling

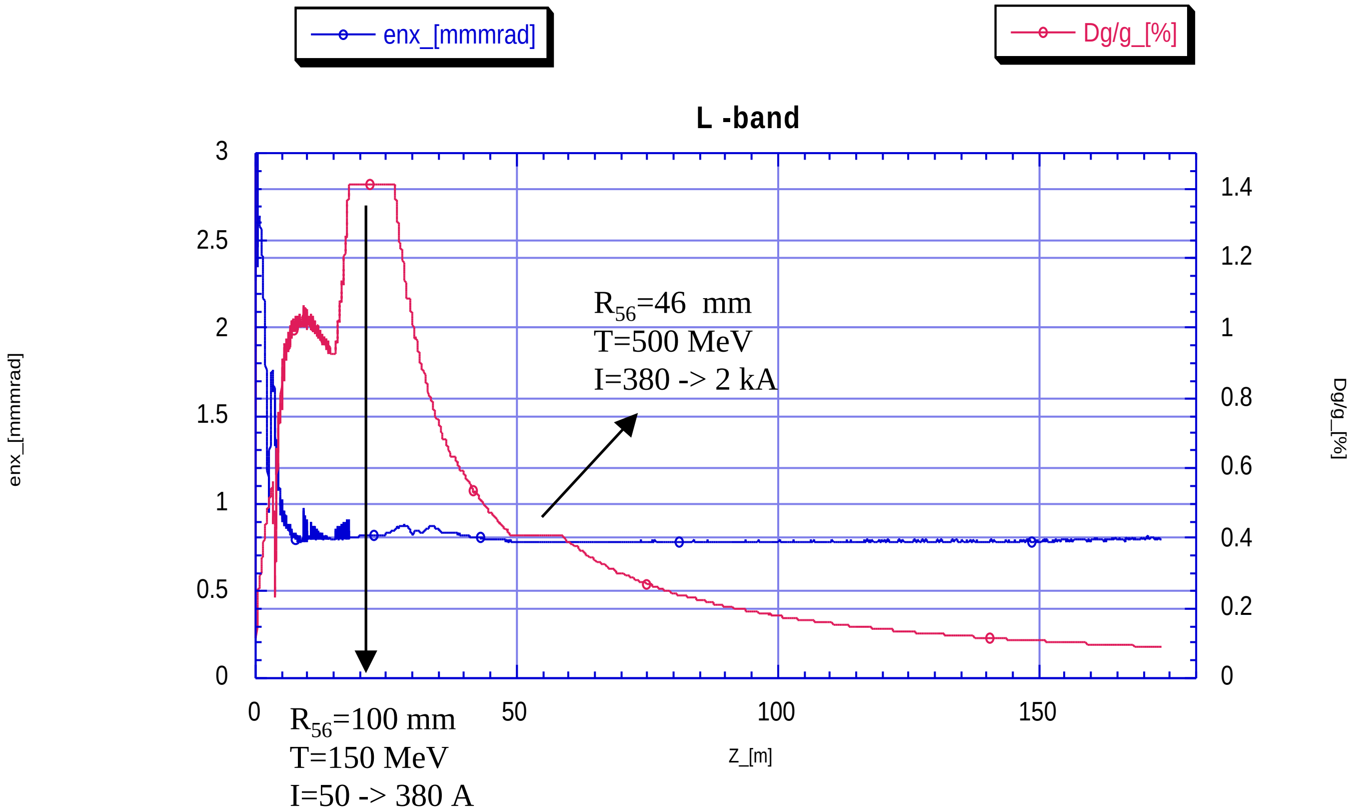




TWO OPTIONS:
S-band Room-Temperature
L-band Super-Conducting

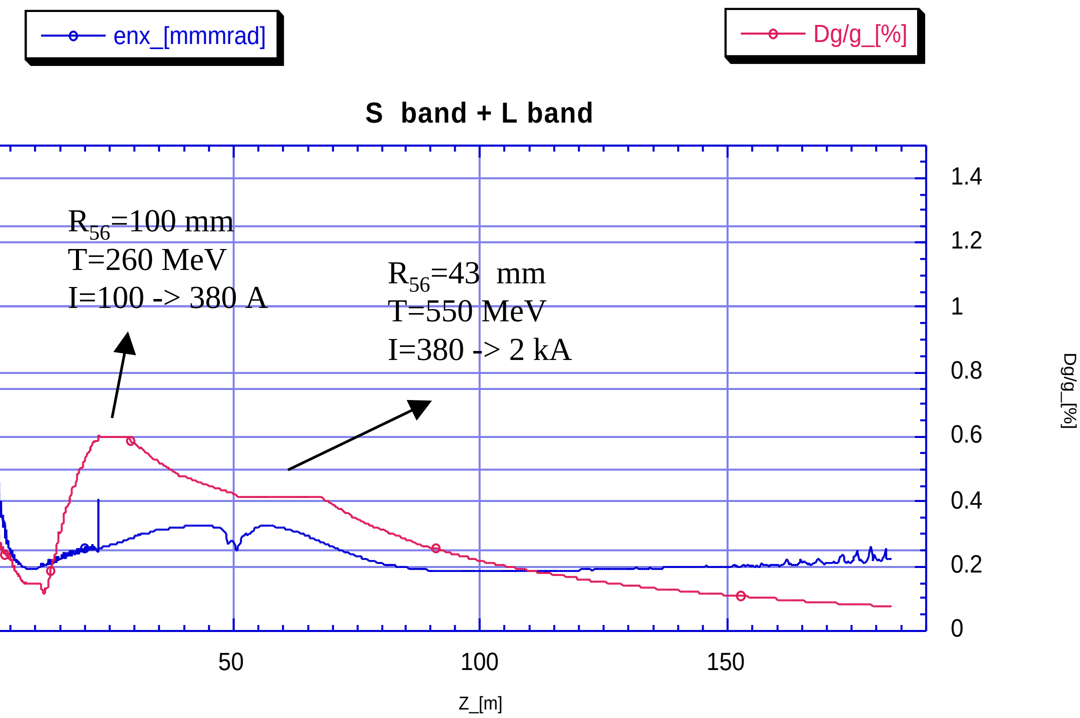


L-band injector + Linac

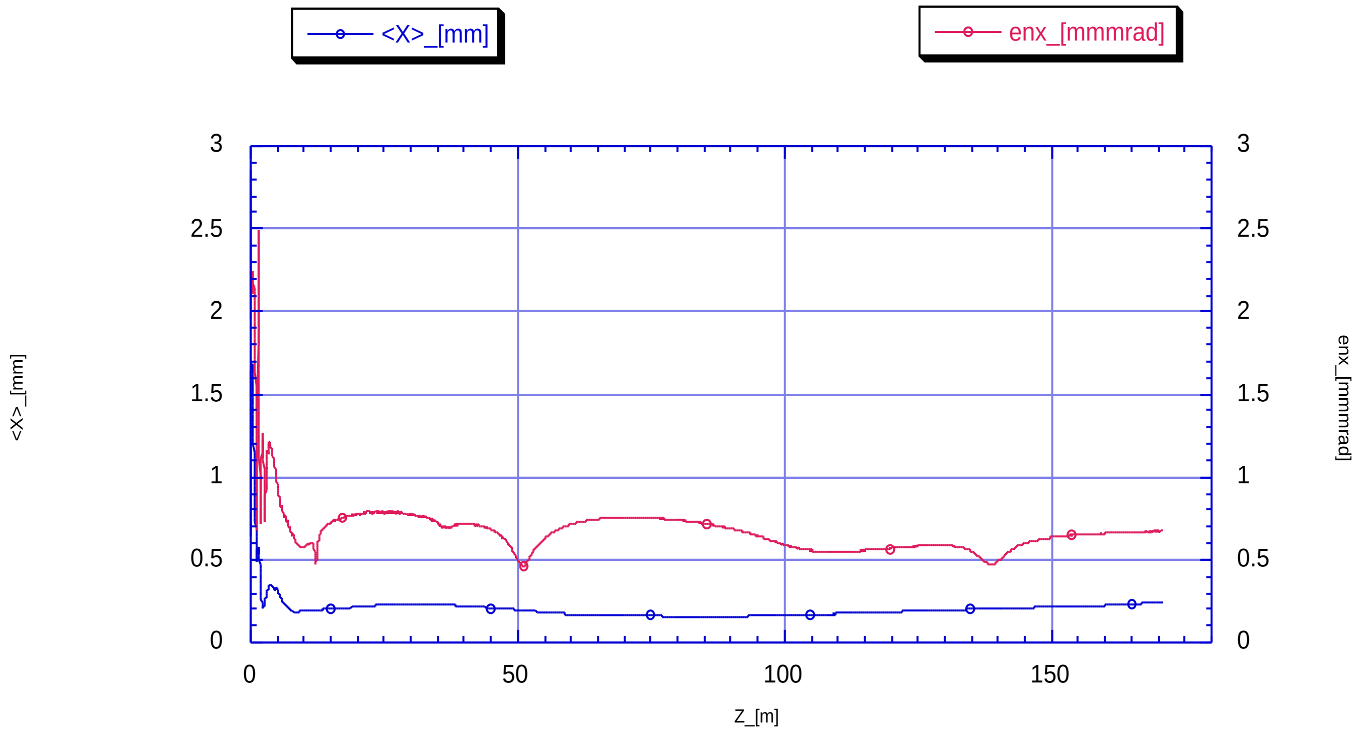


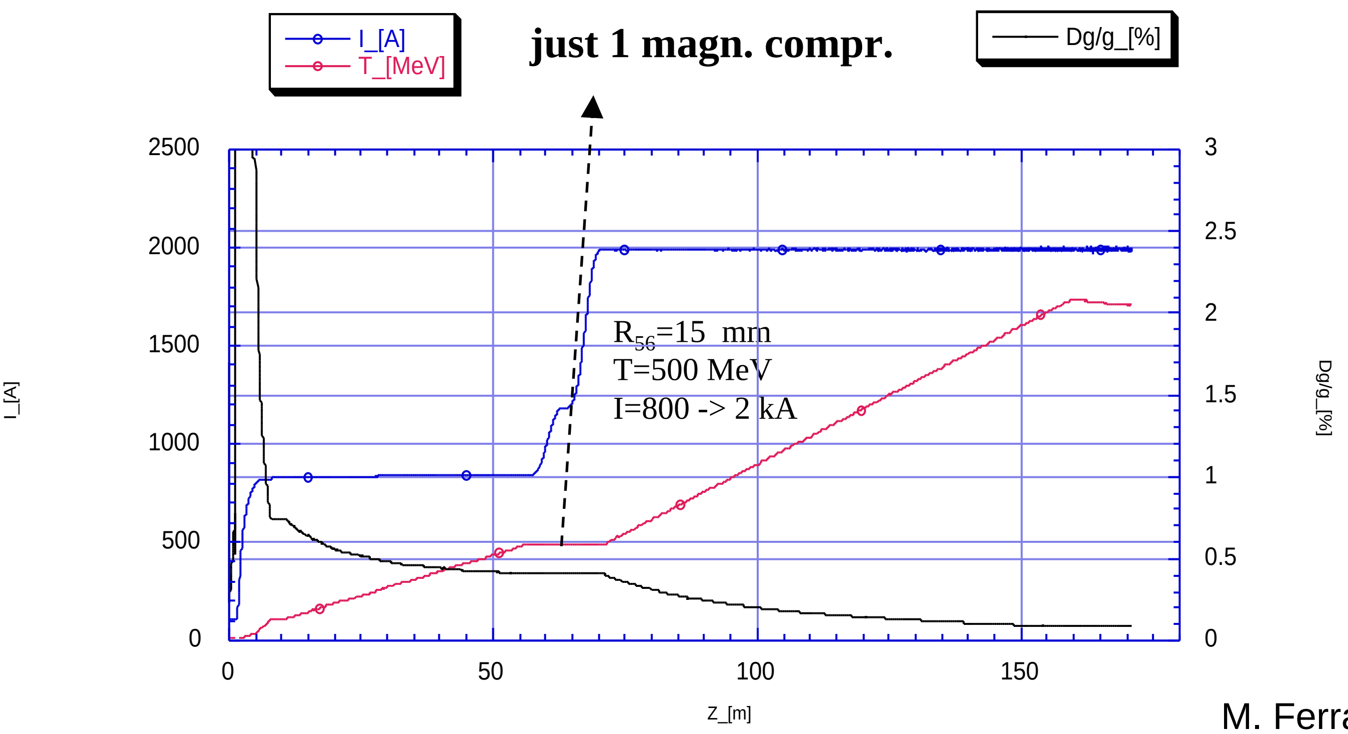
S-band inj. + L-band Linac

M. Ferrario



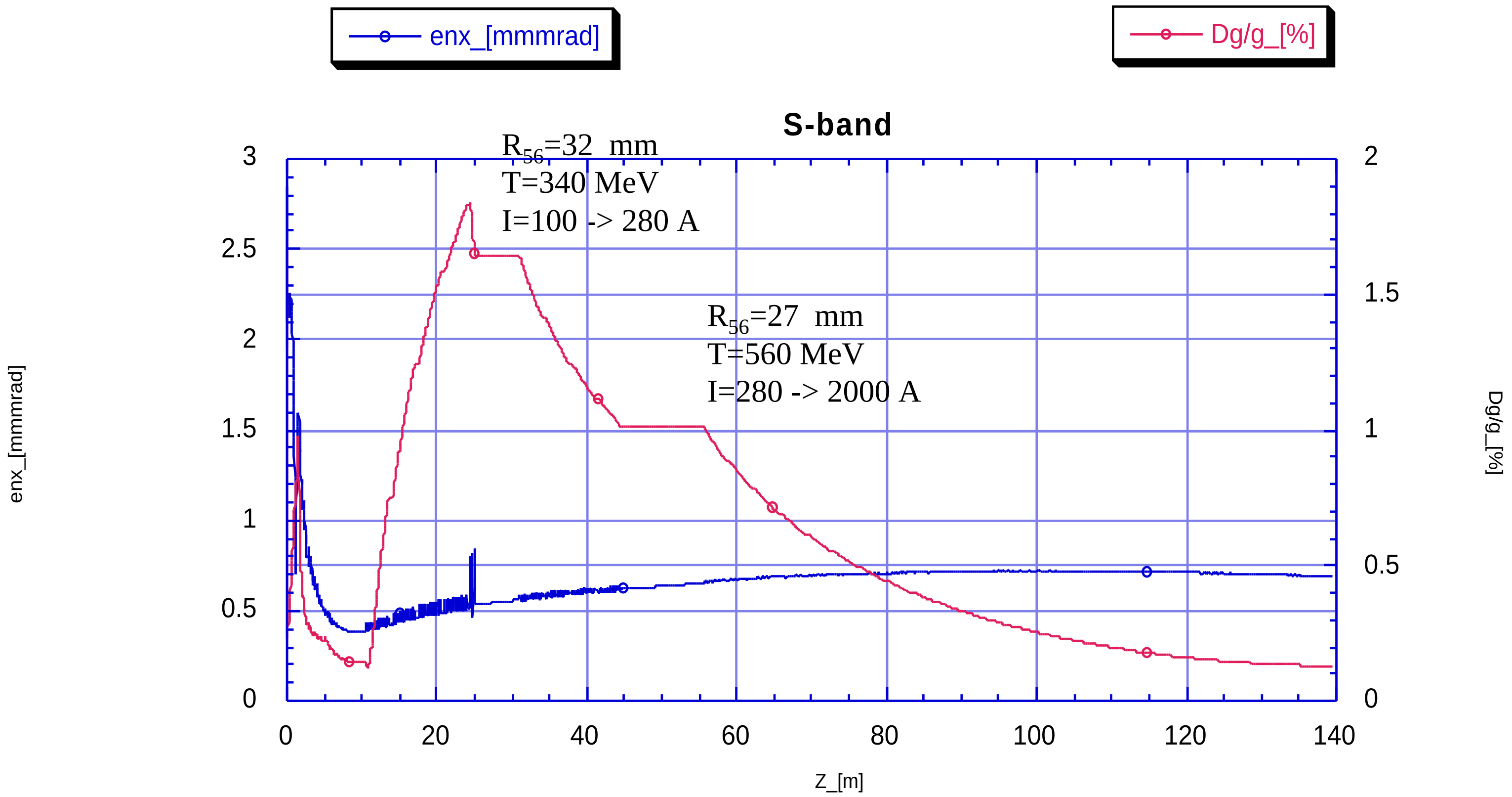
S-band inj. + L-band Linac with RF compressor (velocity bunching)



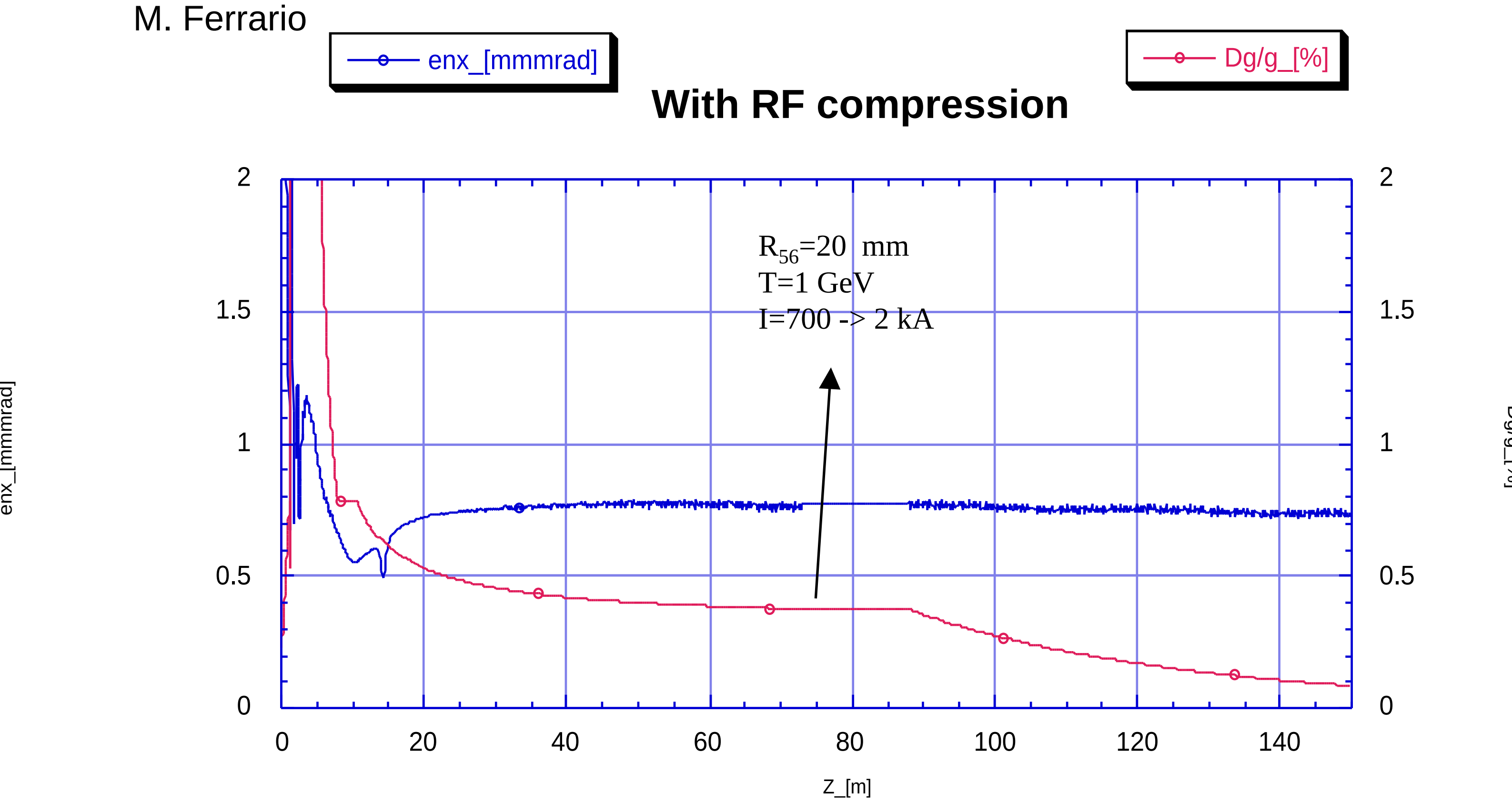


M. Ferrario

S-band inj. + S-band Linac



M. Ferrario



COSTS

- **Costs are expected to be restricted to:**

Linac	34	M¤
Undulators	10	M¤
Radiation beam lines	10	M¤
Contingencies	13	M¤

- **Linac’s Cost Estimates are:**

L-band option	23 M¤
(CW operation)	(33 M¤)
S-band option	21 M¤

\+ a common component

Injector	5 M¤
Diagn. + Opt. + Control	8 M¤

Beam Time Structure

- **S-band option**

RF Pulse	350 ns
Bunch per Pulse	1-10
Rep. Rate	10-100 Hz

- **L-band option**

RF Pulse	1 ms
Bunch per Pulse	10^4 (10^4/sec in CW)
Rep. Rate	5 Hz

- **S-band inj.** + **L-band option**

RF Pulse	5 μs
Bunch per Pulse	1-40
Rep. Rate	10-100 Hz

Max rep. rate from freq. Match 4 MHz with nat. freq. (260 MHz with 2860 and 1300)

Conclusions

- **The budget is consistent with the goal to reach 1.5 nm**
- We have an *innovative solution* for the Linac lay-out which appears to *relax the criticality of beam compression*
- **We have identified two possible options :**
- 1) S-band Linac
  is technologically simpler and less expensive
- 2) L-band Linac with add. S-band injector
  requires a stronger effort and larger cost but offers more flexibility w.r.t. the evolution toward 1 Å in terms of:

Conclusions (cont.)

- Stability in energy jitter
- Multi-user facility (higher RF duty cyle, beam duty cycle is limited by laser / photocathode system performances)
- Better suited for future potentialities of Super-Conducting Photoinjectors
- Compatible with additional S-band injector (this offers higher flexibility to the system and it could be built using additional R&D funds (4-8 M¤) under assignment)
- L-band SC Linac is more evolutionary but more punitive for budget demands in the initial phase

COMUNE DI ROMA - DIPARTIMENTO VI POLITICHE DEL TERRITORIO: UNVERSITA' DEGLI STUDI DI ROMA " TOR VERGATA ".

PIANO PARTICOLAREGGIATO DI TOR VERGATA GENNAIO 2001 ZONIZZAZIONE

Transverse Dynamics of a laminar beam subject to Velocity Bunching

- Assuming a **current growing** at the same rate as the beam energy

$$I = \frac{I_0 \gamma}{\gamma_0}$$

the envelope equation becomes

$$\sigma'' + \sigma' \frac{\gamma'}{\gamma} + \sigma \frac{\Omega^2 \gamma'^2}{\gamma^2} - \frac{I_0}{2 I_A \sigma \gamma_0 \gamma^2} = 0$$

and the *new (exact) solution* is

$$\sigma_{RFC} = \frac{1}{\Omega \gamma'} \sqrt{\frac{I_0}{2 I_A \gamma_0}}$$

RF Compress. Inv. Env.
No beam confinement without external focusing

with same plasma frequency as the IE

$$k_p^{RFC} = \frac{\Omega \gamma'}{\sqrt{2}\gamma}$$