

# *A high-resolution VUV beamline @ SPARC*

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*INFN – LNF & USTC, Chinese Academy of Science*

# **Collaborative research for a high-resolution VUV Free Electron Laser User Facility at SPARC**

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# Pulse energy at different wavelengths (*achieved*)

Mode of operation	SASE	Seeded		
Wavelength	500 nm	200nm	133 nm	66nm
Energy/pulse (~ 100 fs)	~100 $\mu$ J	~10 $\mu$ J	~1 $\mu$ J	~100 nJ
# photons	$2.5 \times 10^{14}$	$1.0 \times 10^{13}$	$6.7 \times 10^{11}$	$3.3 \times 10^{10}$

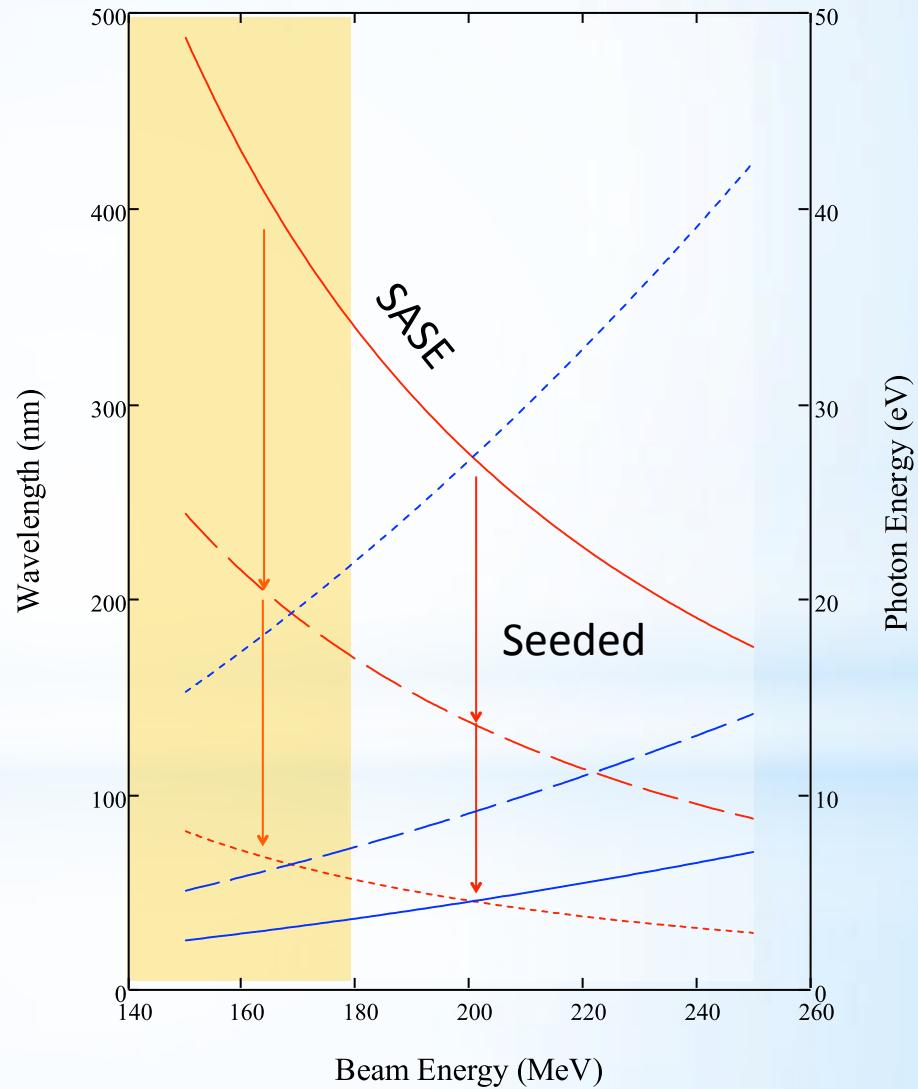
Energy	178 MeV (max)
Current	50-60A (max in seeded mode)
Emittance	~ 2-3 mm mrad

*courtesy L. Giannessi*

Seeding with a 1 stage cascade  
@ 400 nm & 266 nm

3° harmonic in the cascade

Direct Seeding  
with harmonics generated in gas  
@ 200nm,  
160nm,  
133nm,  
114nm,  
100nm



*courtesy L. Giannessi*

# Seeded

- \* The same schemes used at 400 nm to extend the wavelength range down to 40 nm may be applied at 266 nm:
  - \* Superradiant cascade
  - \* Harmonic cascade

- \* Higher beam energy improves seeding efficiency at 266 nm and at shorter wavelengths
  - \* Seeding with 5° and 7° harmonics generated in gas
  - \* Seeding with high even harmonics generated in gas

400	200	133.3	100	80	66.7	57.1	50	44.4
266.7	133.3	88.9	66.7	53.3	44.4	38.1	33.3	29.6
200	100	66.7	50	40	33	28	25	22
160	80	53.3	40	32	26.7	22.9	20	17.8
133.3	66	44	33	26	22	19	16	14
114.3	50	38.1	28.6	22.9	19	16.3	14.3	12.7

All these wavelengths fall in the UV to XUV range

Measured

Observable with available diagnostics

Additional diagnostics required

Very low energy

# SPARC FEL source

- seeding results confirm the possibility to work with harmonics in the UV/VUV domain: **400-66 nm @ 178 MeV**
- repetition rate: **1-10 Hz**
- radiation spectrum slightly **tunable**
- higher harmonics **linearly polarized** sources of high temporal and spatial coherence
- pulse duration: **100 fs**

# VUV monochromators@SPARC

Two possible uses of monochromators:

- as instruments to monochromatize radiation before a sample to increase the spectral purity of the fundamental (i.e., increase the FEL resolution), select high-order FEL harmonics and suppress the fundamental, filter out the background
- as spectrometer for the analysis of the radiation after the interaction radiation/ sample

Le caratteristiche della radiazione SPARC in saturazione (emissione alla fondamentale)

Lunghezza d'onda (nm)	Dimensioni sorgente ( $\mu\text{m}$ rms)	Divergenza (mrad rms)	Energia per impulso ( $\mu\text{J}$ )	Fotoni per impulso
400	400	0.3	5.5	
266	400	0.2	5	
160	400	0.1	2.5	
114	400	0.06	1.5	
60 (H3 di 180 nm)	400	0.06	$1 \cdot 10^{-3}$	
40 (H3 di 120 nm)	400	0.04	$1 \cdot 10^{-5}$	

# *Scientific case*

- *Atomic and molecular physics*
- *Free clusters*
- *Time resolved experiments*
- *Imaging*

# WUTA08 meeting

- Atomic and molecular physics
- Astronomy
- Raman
- Instrumentation
- Nanostructure
- Anelastic scattering
- Biology and astrobiology
- UV induced damaging
- Photochemistry
- Quantum coherence and entanglement

## WUTA08 1<sup>st</sup> Italian Workshop on UltraViolet Techniques and Applications

Frascati, 8-10 ottobre 2008  
LNF - Aula Bruno Touschek

The workshop is aimed at reviewing the state of the art of Italian experiments using UV radiation and to pave the way for future applications. Scientists working with UV radiation in astrophysics, biology, metrology, physics, chemistry, materials science, interferometry, optics and detectors are invited to present their contribution. Emphasis will be given to SR and FEL applications, but contributions based on conventional sources are welcome.

### Scientific Committee

Emanuele Pace (Università' di Firenze - INFN, Firenze)  
Augusto Marcelli (INFN LNF, Frascati)  
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<http://www.Inf.infn.it/conference/wuta08>





# Monochromator

High-resolution  
High-spectral purity

5m McPherson  
Normal Incidence  
UV-VUV monochromator

from SRS-Daresbury,  
beamline 3.2

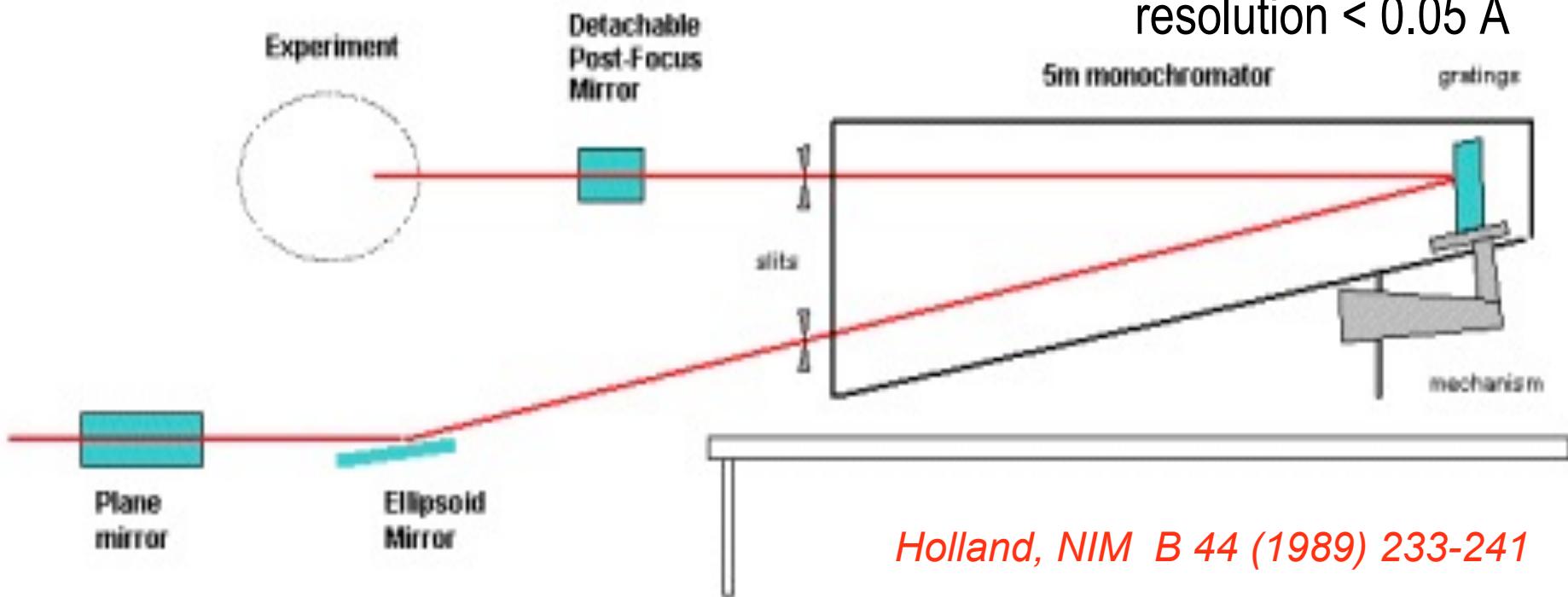
# FEL VUV

## Monochromator

2 concave gratings

Spectral range 300 - 2500 Å (30-250 nm)

resolution < 0.05 Å



*Holland, NIM B 44 (1989) 233-241*

*This normal incidence monochromator with 2 gratings that may cover the photon energy range 5–35 eV (250 - 35 nm) with a best achievable resolution of 2 meV (0.005 nm) may open unique opportunities in many fields and in particular in spectroscopy. It fits quite well the energy range available at SPARC.*

# 5 m monochromator

Laboratory for  
UV and X-ray

Optical Research



- 1200 gr/mm grating
- 0.17 nm/mm dispersion
- Only high resolution
- Long pulse at the output (ps range above 100 nm)

wave (nm)	slit aperture (mm)		FWHM DT (ps)
	0.4	0.2	
resolution	resolution		
250	3750	7500	10
150	2250	4500	3
100	1500	3000	1.2
75	1120	2250	0.7
50	750	1500	0.3
30	450	900	0.1

# FEL resolution

Laboratory for  
UV and X-ray  
Optical Research



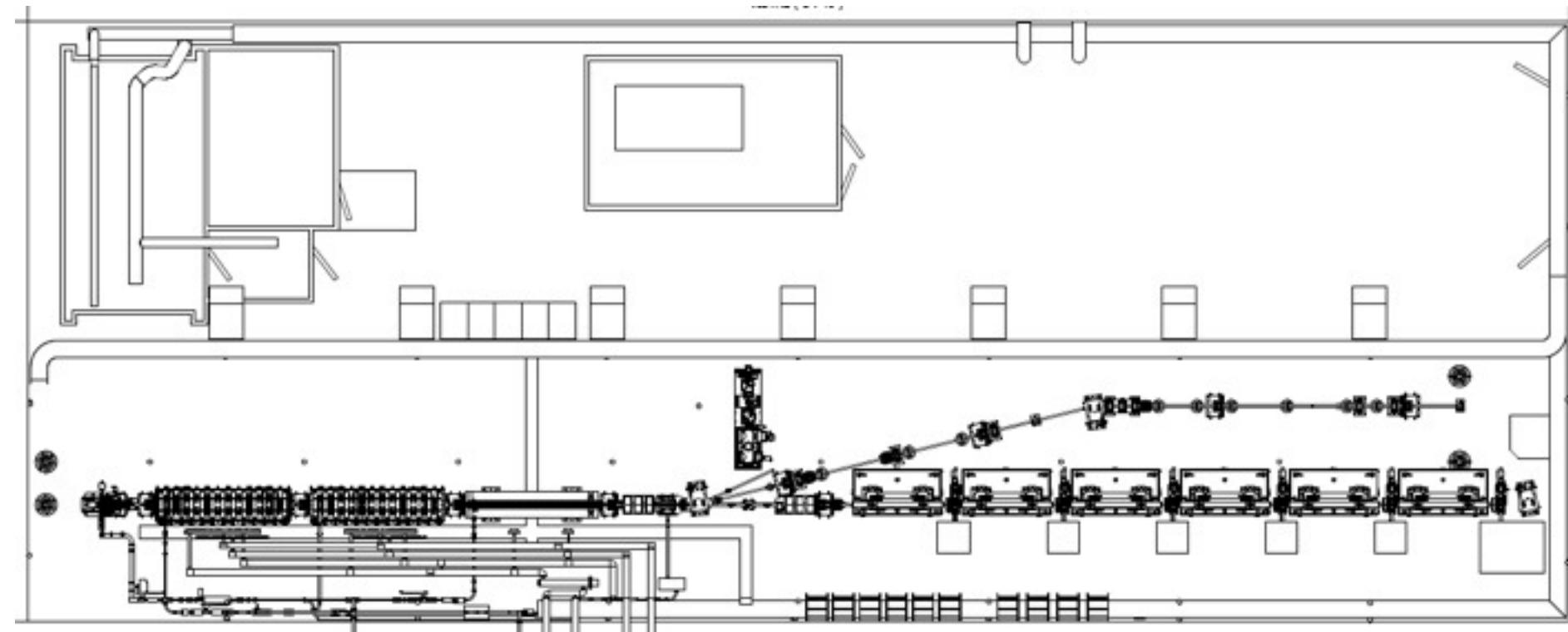
- SASE FEL: 0.5% ( $\lambda/\Delta\lambda = 200$ )
- SEEDED FEL: 100 fs, 1.5 above Fourier limit

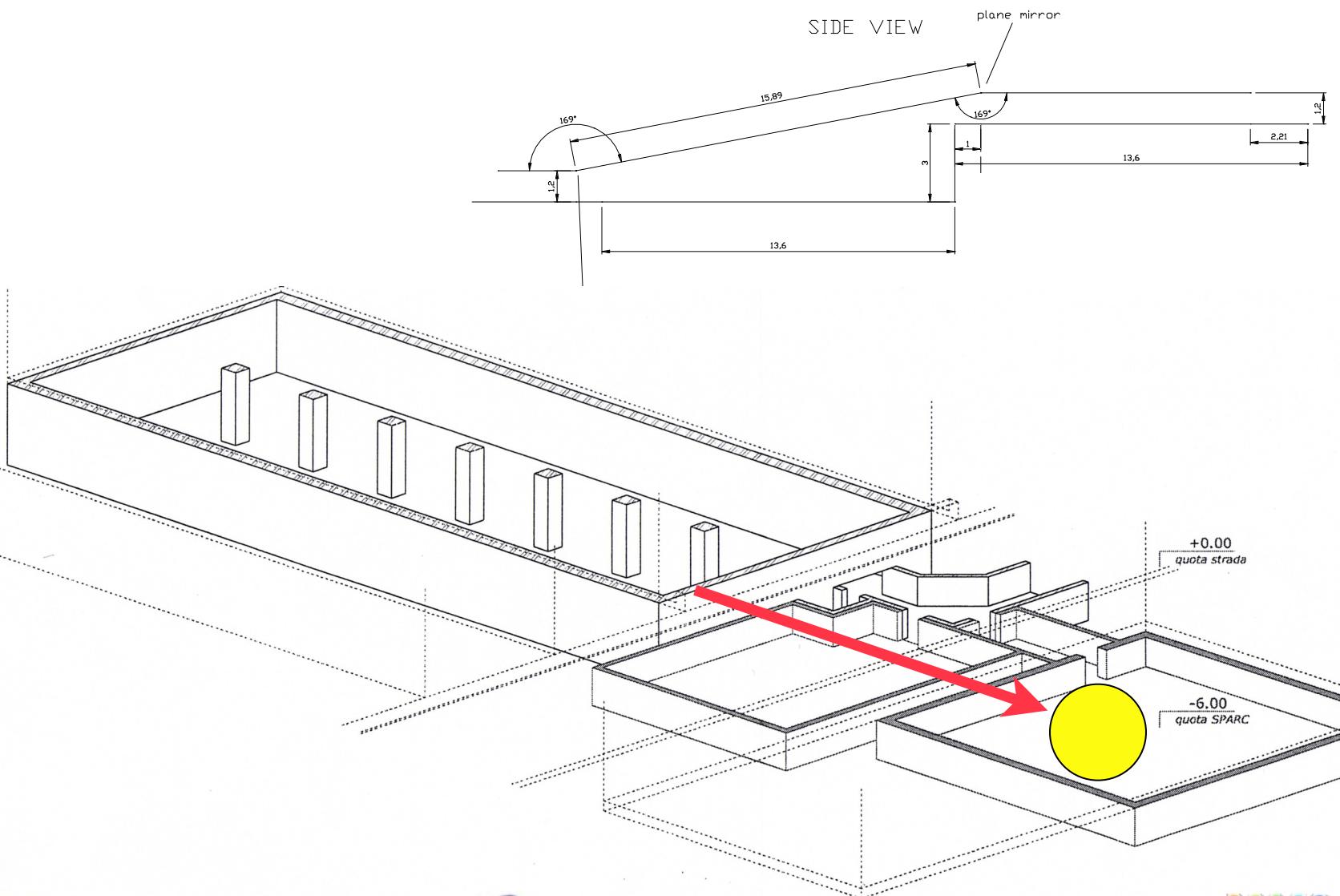
## 5 meter monochromator

Mirror demagnification before entrance slit)  
Source on slit 0.16 mm FWHM

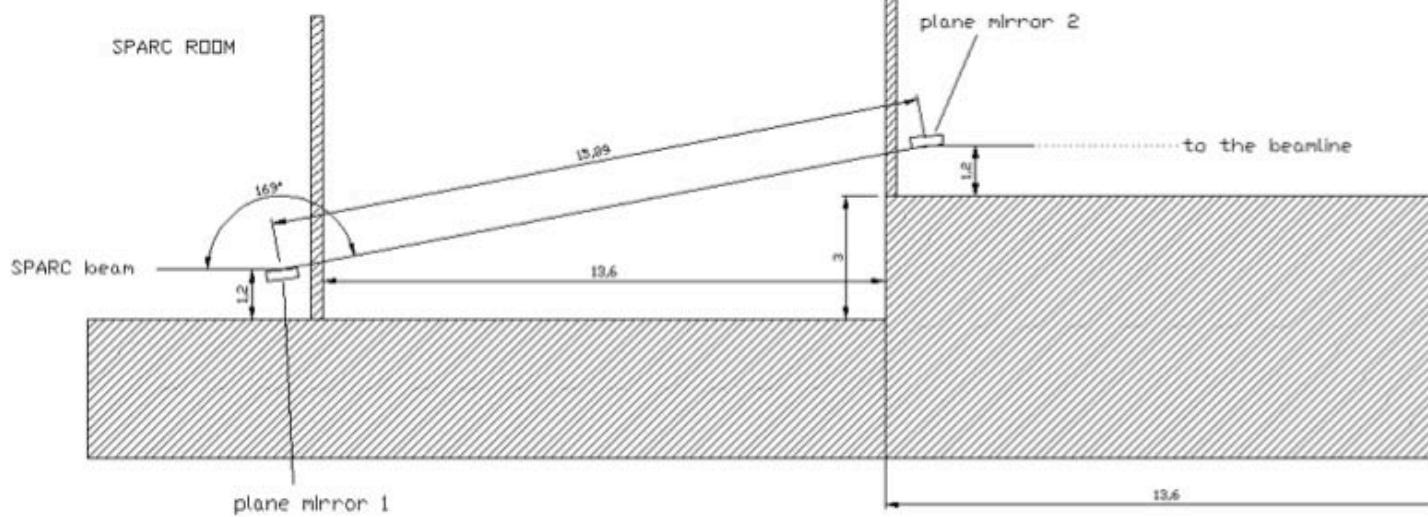
Arm 5000 mm Grating 1 1200 gr/mm  
Plate factor 0.17 nm/mm

wave (nm)	SEEDED FEL resolution	SASE FEL resolution	slit aperture (mm)			
			0.4 resolution	0.2 resolution	=FWHM	DT (ps)
250	180	200	3750	7500	10.0	12000
150	300	200	2250	4500	3.0	6000
100	450	200	1500	3000	1.2	3600
75	600	200	1120	2250	0.7	2700
50	910	200	750	1500	0.3	1800
30	1510	200	450	900	0.1	1080

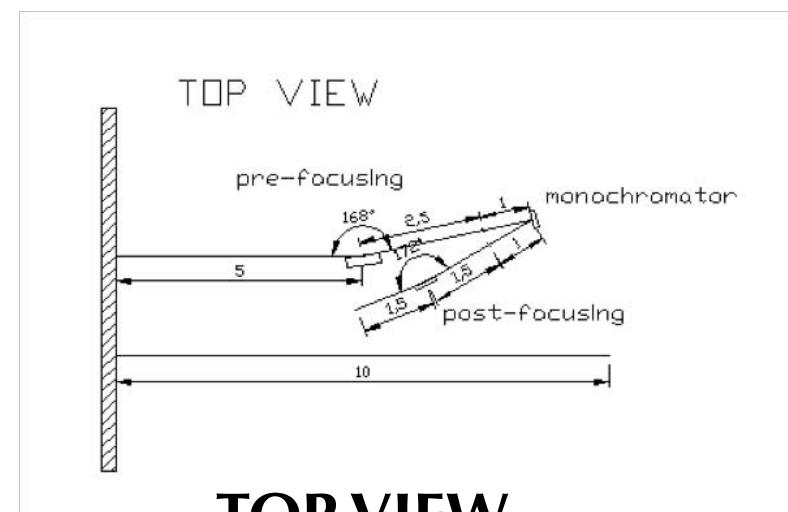




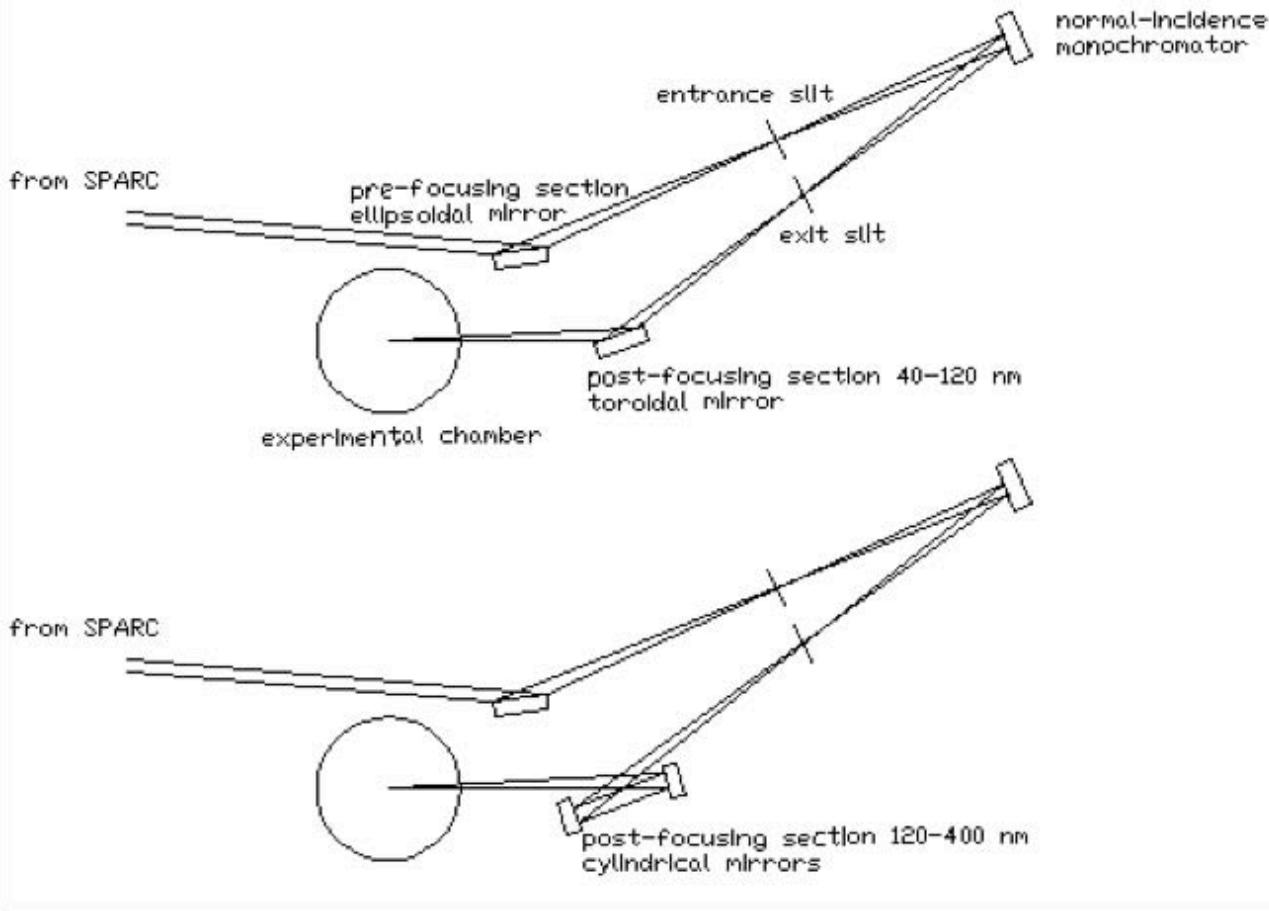
# SIDE VIEW



La parte iniziale della beamline potrebbe essere costituita da 2 specchi piani in incidenza radente e riflessione in polarizzazione s che permettono di trasportare la radiazione dal laboratorio SPARC al laboratorio LIFE, superando il dislivello di 3 m tra i pavimenti. Questa soluzione evita di abbassare il livello del laboratorio LIFE fino al livello SPARC e di richiedere come unico collegamento tra i due laboratori un tubo in vuoto per il trasporto della radiazione FEL. Inoltre, anche i requisiti per la sicurezza sono soddisfatti, in quanto la presenza degli specchi di deviazione evita di dover lavorare nella linea diretta del fascio FEL così come esce dagli ondulatori. Si potrebbero utilizzare specchi con ricoprimento in platino, che garantisce all'angolo di incidenza utilizzato (84.5°) una riflettività' tra 0.85 (a 40 nm) e 0.95 (a 400 nm).



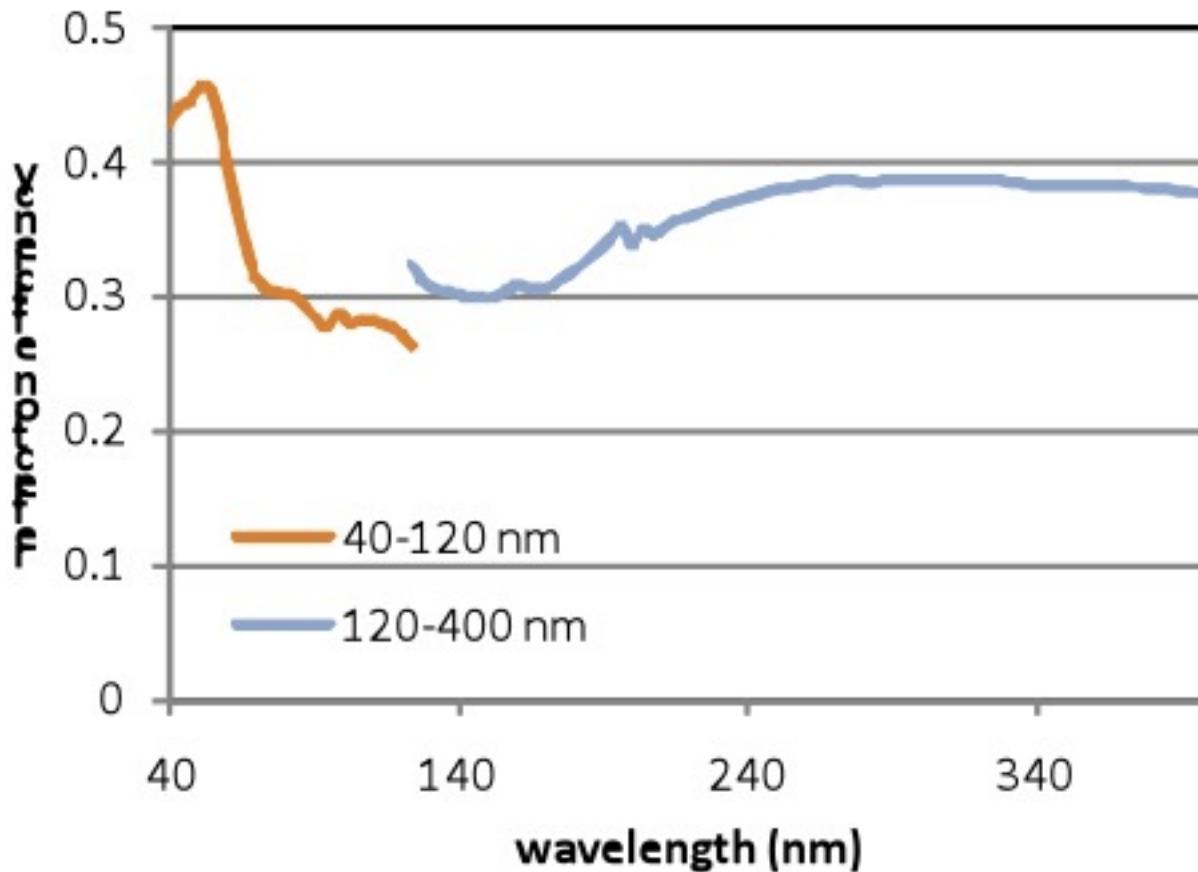
**TOP VIEW**



La beamline con le ottiche di focalizzazione ha un primo specchio (ellissoide) in incidenza radente illuminato in polarizzazione p che focalizza la radiazione sulla fenditura di ingresso del monocromatore. Una demagnificazione di un fattore 10 è necessaria per diminuire la dimensione della sorgente (da 400  $\mu\text{m}$  rms a 40  $\mu\text{m}$  rms) e per aumentarne la divergenza, in modo da illuminare un'area sufficientemente estesa sul reticolo di diffrazione.

Il pre-monocromatore potrebbe essere un Hilger da 1 m (600 gr/mm o 1440 gr/mm e 18° di angolo). Il monocromatore può essere utilizzato come filtro della radiazione FEL, e.g., 3<sup>a</sup> armonica <100 nm e filtrare la fondamentale, oppure come sezione di relay ottico sostituendo uno dei reticolli con uno specchio sferico. Con una demagnificazione di 10, le fenditure di ingresso ed uscita per trasmettere tutta la radiazione focalizzata sono di 200  $\mu\text{m}$  con un allungamento temporale dell'impulso.

# Efficiency beamline



**Is an alternative solution  
possible within a short term?**

# Beamline VUV@LI2FE

LI2FE beamline:

- Monochromatic beamline operating in the 50-400 nm region
- Experimental chamber for time-resolved experiments
- High-resolution 5-m monochromator to analyze emitted radiation

The LIFE beamline can be installed on the roof of the SPARC entrance tunnel.

The SPARC radiation can be transported with three plane mirrors at 45° on the roof of the tunnel.

The linear polarization of the light is maintained.

*1st hypothesis*

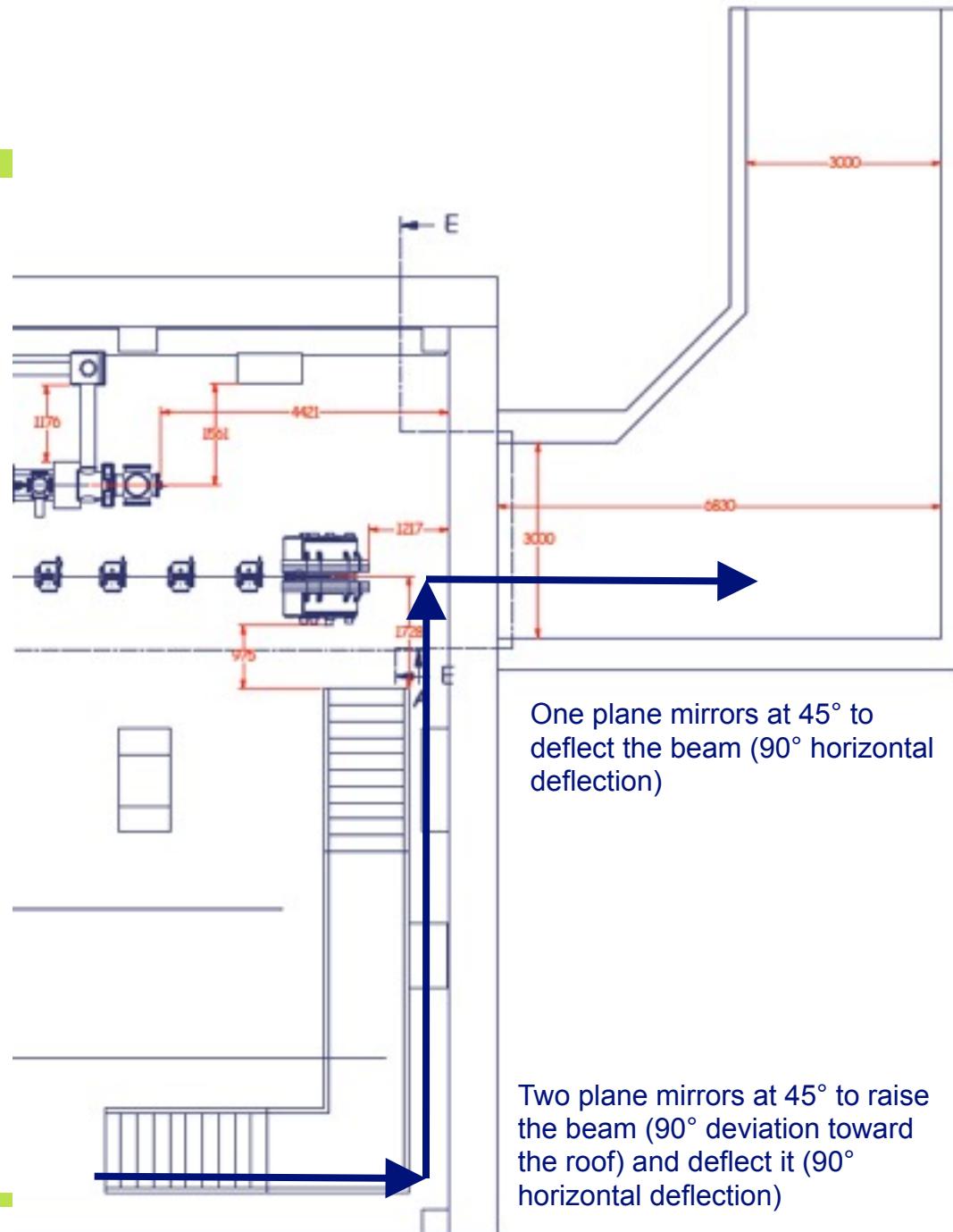
# Beam transport

Three plane mirrors to transport the beam from the experimental hall to the roof of the tunnel

The plane polarization is maintained

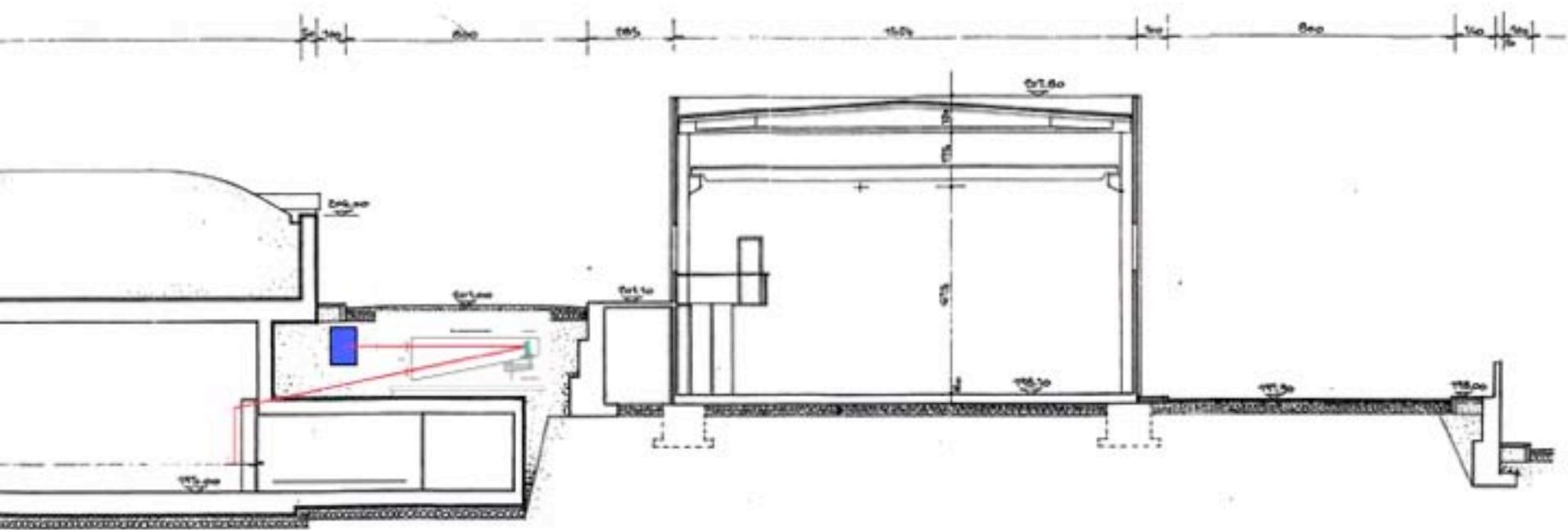
Transport efficiency >70% for radiation above 110 nm (<11 eV)

Transport efficiency <10% for radiation below 110 nm (>11 eV)



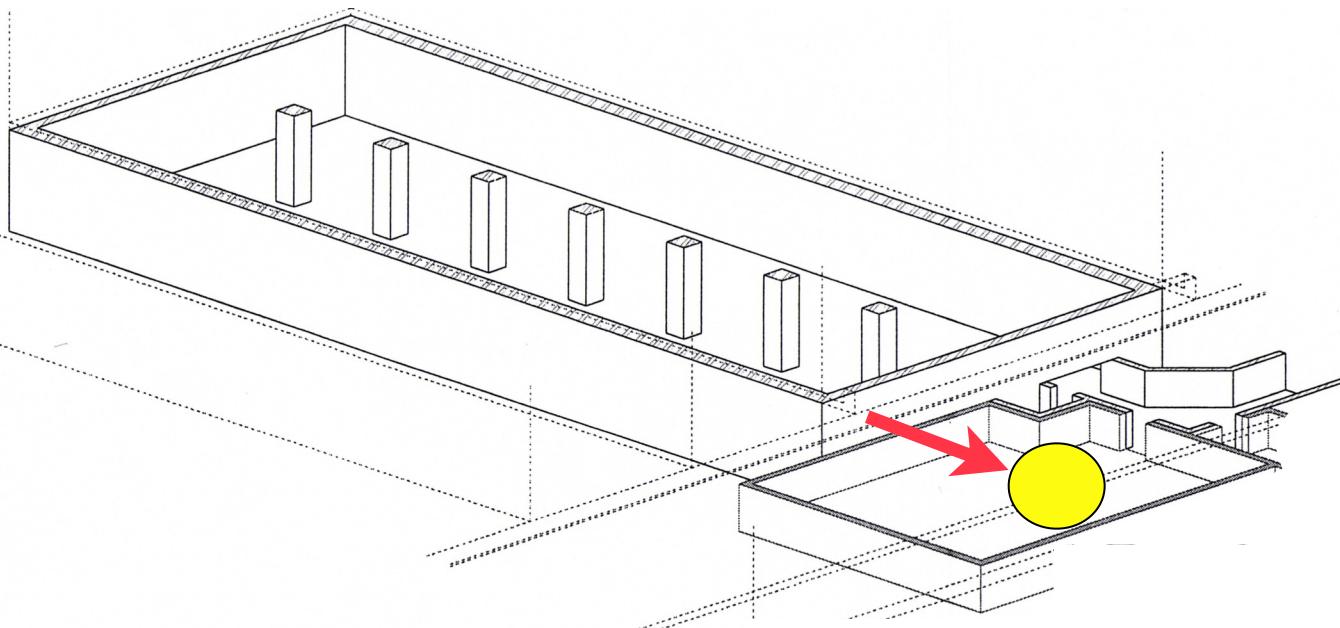
— + fm pi sea x

SEZIONE C-C



SEZIONE B-B

## *2nd hypothesis*



# *Conclusioni*

- *5m NIM compatibile con la sorgente SPARC*
- *Case scientifico esistente*
- *Ampia comunità (italiana) interdisciplinare interessata a ricerche UV ad alta risoluzione*
- *Interesse INFN e consolidata in house expertise*
- *Installazione compatibile solo con una nuova area sperimentale*

# Gruppi coinvolti

# FEL VUV

- *A. Marcelli, M. Benfatto, M. Castellano, M. Cestelli Guidi, R. Cimino, D. Di Gioacchino, G. Dipirro, M. Ferrario* (INFN)
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