EuPRAXIA@SPARC_LAB

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

WA6 Status Report – FEL Integration & Performance

TDR Review Committee Meeting, June 6th 2022

Federico Nguyen on behalf of the WA6 Working Group

Istituto Nazionale di Fisica Nucleare

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

UNIVERSITÀ DEGLI STUDI DI MILANO

Fermilab

Workflow

1. Undulator specifications (→ see A. Petralia's talk)
2. FEL Layout definition (→ see A. Ghigo's talk)
3. Beam optics analysis (→ this talk)
4. Baseline parameters simulation (→ this talk)
5. Tolerance analysis (→ to-do list)
6. Start to end simulation (→ to-do list)

FEL Layout definition

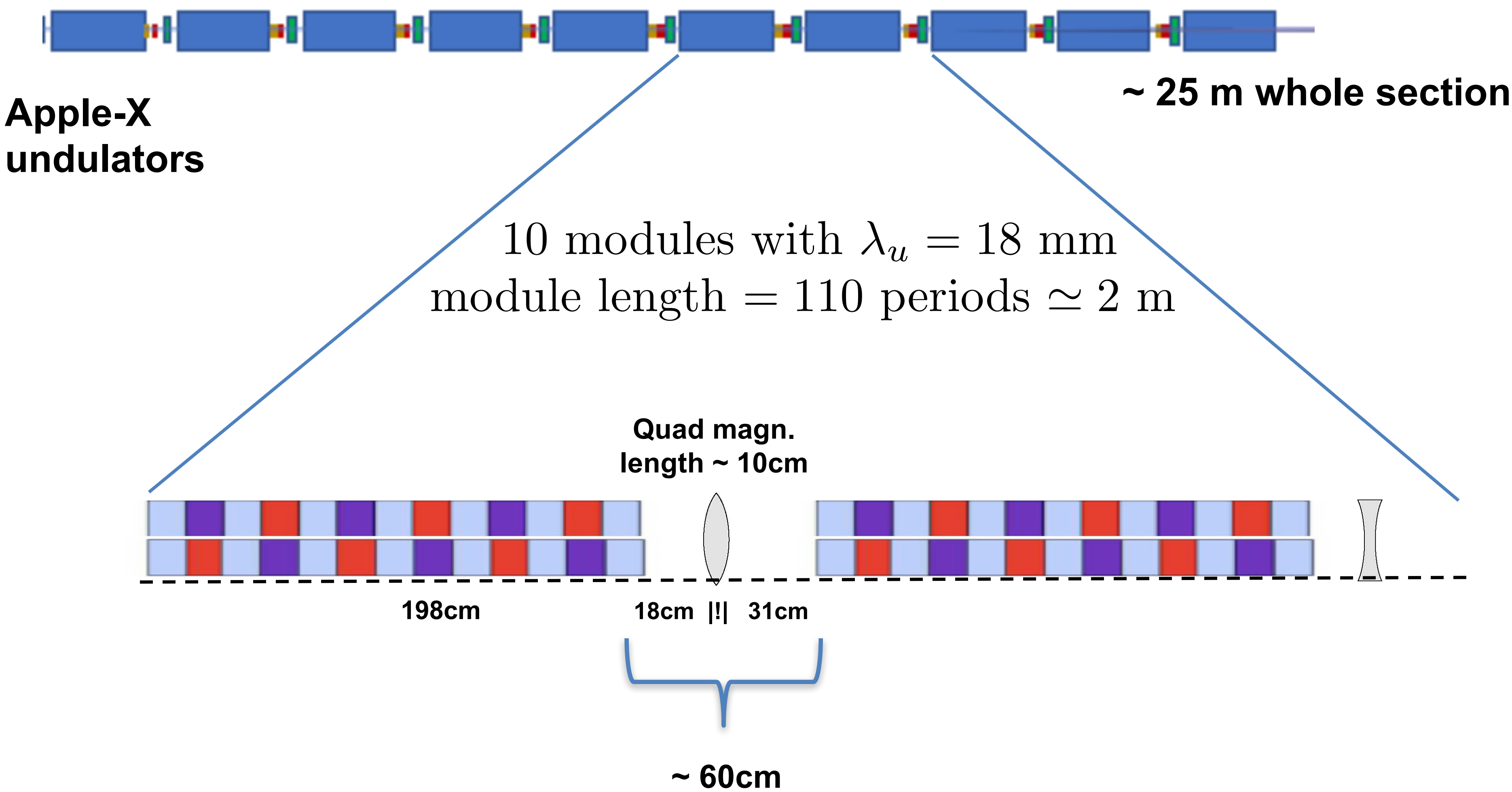
From the baseline electron beam parameters and the frozen undulator specifics

→ Design of the undulator section, intra-module distance and FODO properties

→ Focus on the red rectangle beam parameters (see WA1 C. Vaccarezza's talk)

			LINAC			LINAC + PWA	
Parameter	**Symbol**	**Units**	**A**	**B**	**C**	**D (CDR)**	**E**
Charge	Q	pC	200	200	30	30	30
Energy	E	GeV	**0.996**	**1**	1	1	1
Peak current	I_{peak}	kA	**1.6**	**0.7**	?	**1.8**	**800**
Bunch length	σ_z	μm	**18.3**	**100**	?	**2**	**5**
Proj. norm. emittances (x/y)	$\varepsilon_{n,x,y}$	mm-mrad	1.85	?	?	**1.7**	3/4
Slice, norm. emittances (x/y)	$\varepsilon_{n,x,y}$	mm-mrad	**0.5**	**0.5**	?	0.8	3/4 **(1/1.2 at linac)**
Proj. energy spread	$\sigma_{\delta p}$	%	0.09	?	?	0.95	1.5
Slice Energy spread	$\sigma_{\delta s}$	%	**0.02**	**0.01**	?	**0.05**	**0.06**
			AQUA	**ARIA**		**AQUA/ARIA**	

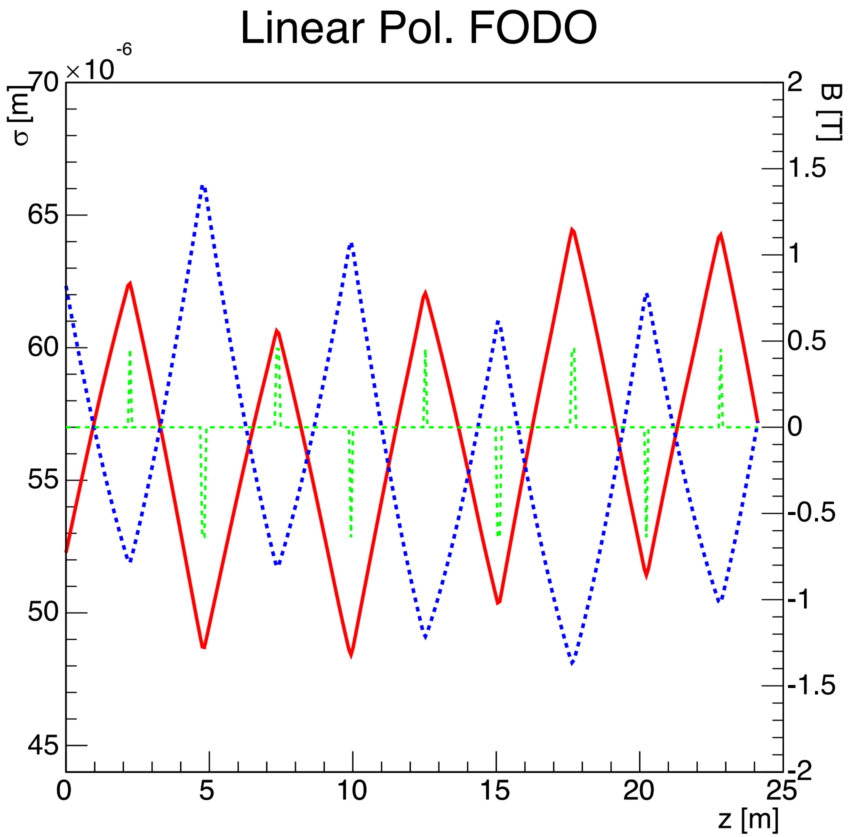
AQUA undulator magnetic lattice

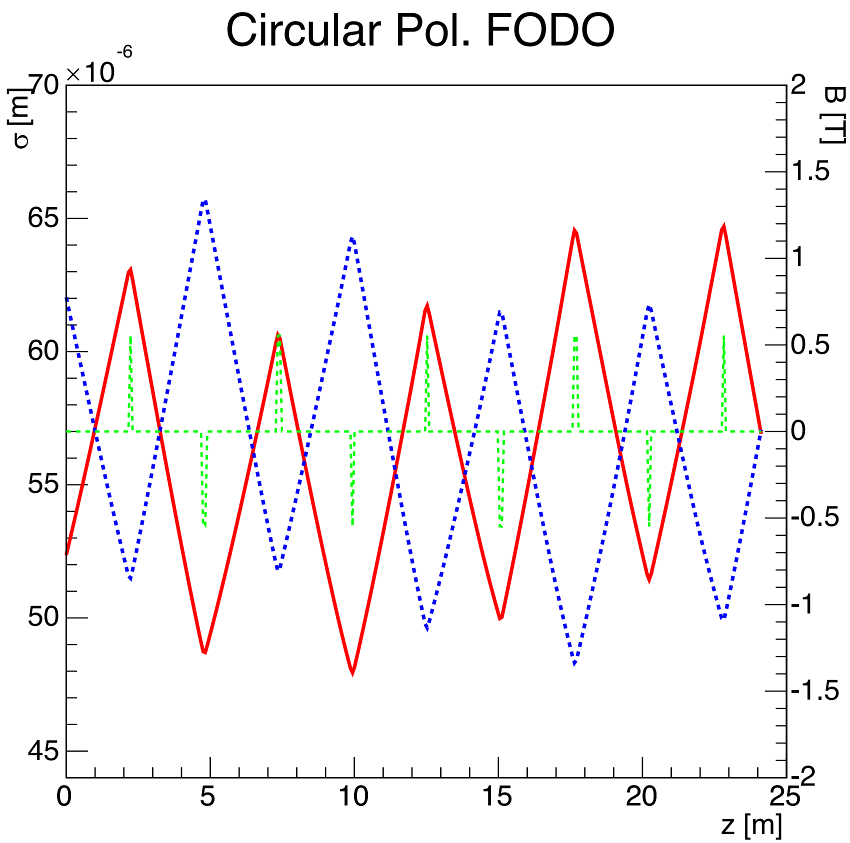


AQUA @4nm with Apple-X: selectable polarization

focusing: $h_x = 2.3,\ h_y = -0.3$

focusing: $h_x = h_y = 1$





$K = 1.189$

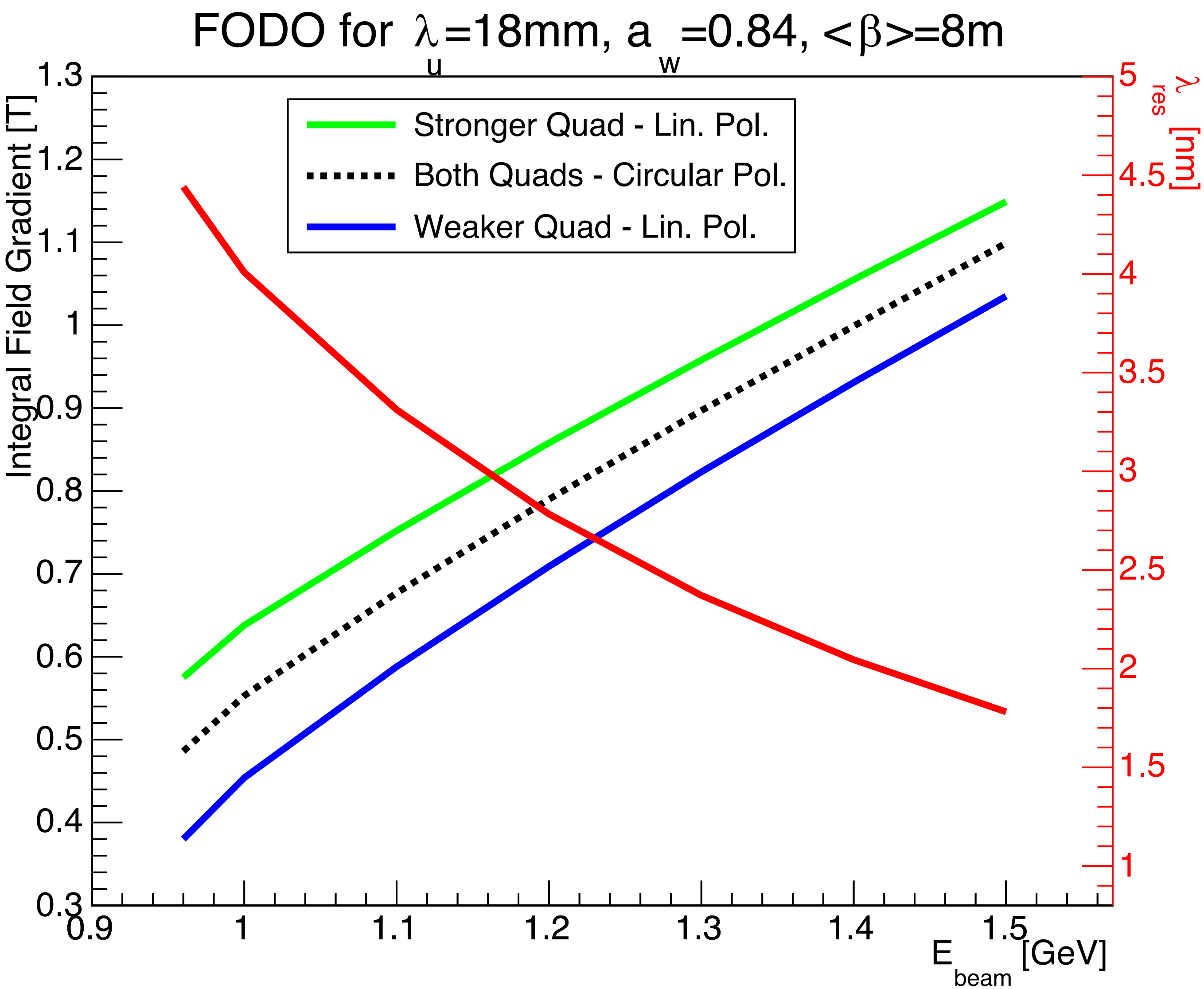
$a_w = 0.84$

- **Slightly asymmetric Quad field strengths in Linear**
- **Twiss values at und. entrance for the electron beam to match → constrain the upstream transfer line**

$K = a_w = 0.84$

$\lambda_R = 4\,\mathrm{nm}$

Quadrupole integral fields vs. E_{beam}



Quad integral field gradients should be such to sustain even higher beam energies →

Possible to reach for 3nm with the same undulator and quadrupole devices, if E_{beam} ~ 1.2 GeV

Towards approval of the adopted solution

The process towards *Blessing* of the chosen configuration has started (see A. Falone's talk)

Draft of the Physics Interface Document will be circulated soon, to be scrutinized for approval

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DocID	Rev.	Validità
EUPRAXIA-WAx-WPx-type-00x0	1.0	Approvato

EuPRAXIA

Data 01/06/2022

Layout of the APPLE-X undulator section for the AQUA beamline

The AQUA beamline of the EuPRAXIA@SPARC LAB is driven by an electron beam with 1 GeV energy accelerated by a plasma wakefield stage, with the goal to deliver variable polarization photons in the 3-4 nm wavelength range. The undulator makes use of the APPLE-X variable polarization permanent magnet technology with 18 mm period length.The full undulator section and the associated magnetic lattice design are discussed.

Autore	Verificato da	Approvato da
F.Nguyen, A. Ghigo, L. Giannessi, A. Petralia, et al.	Management Team EUPRAXIA	M.Ferrario

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DocID	Rev.	Validità
EUPRAXIA-WAx-WPx-type-00x0	1.0	Approvato

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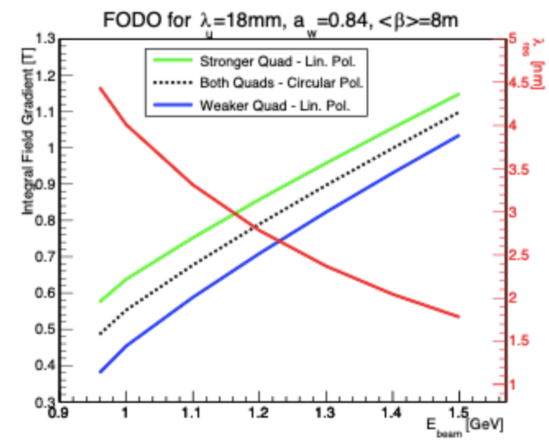
Lista di distribuzione:

- Documento pubblico



Storico delle Revisioni

Rev.	Data	Descrizione delle modifiche	Autore/Editore
0.1	30/08/18	Prima stesura	A.Falone

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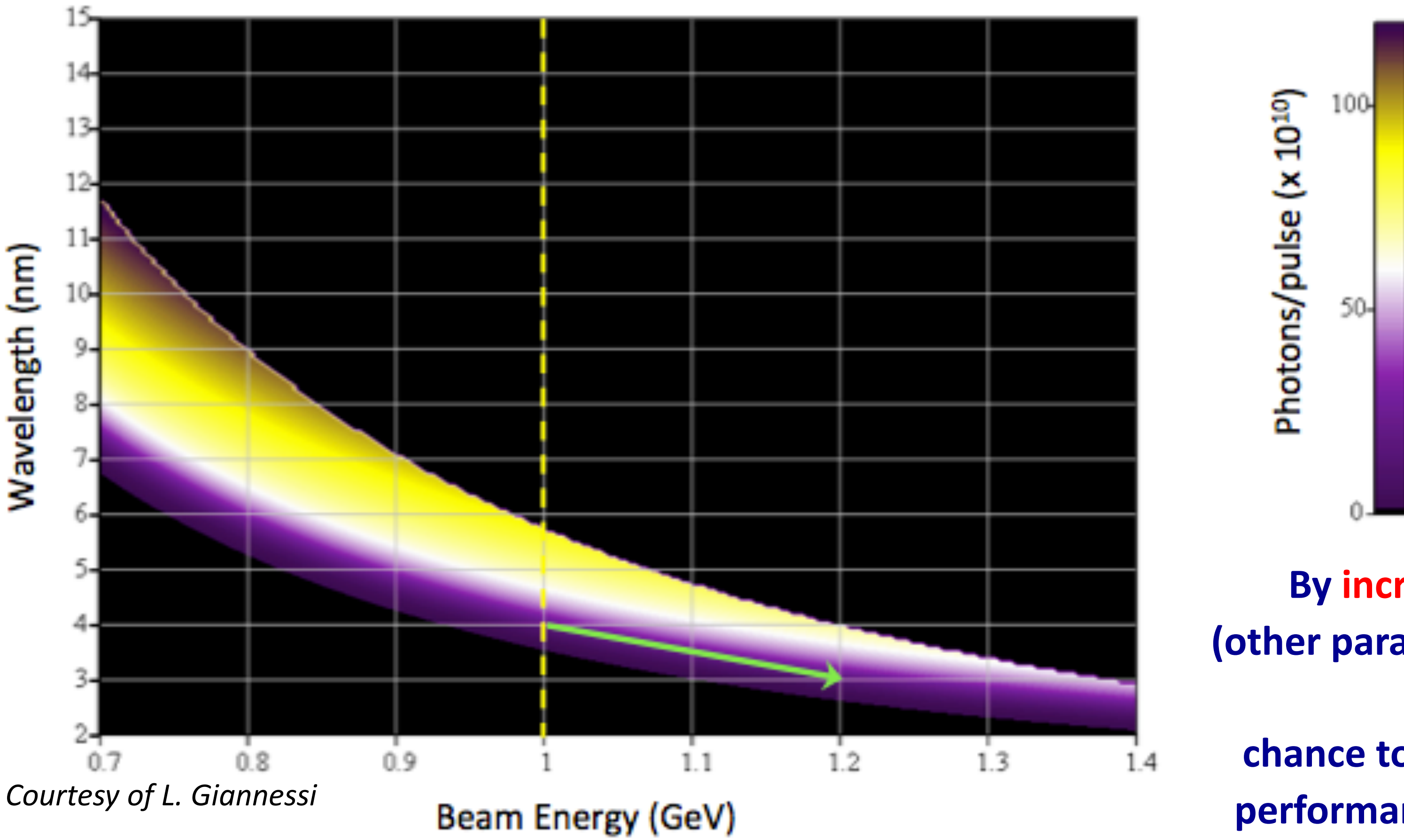
Linear Pol. Apple-X overall FEL performance

$$\lambda_{res} = \frac{\lambda_u}{2\gamma^2}\left[1 + \frac{K^2(g_u)}{2}\right]$$

Tunability both in beam energy $\gamma m_e c^2$ and in undulator gap g_u weighted for N_γ/pulse



Courtesy of L. Giannessi

Undulator gap gives limited lever arm:

shorter λ_{res} ⟷ lower K values ⟷ lower N_γ/pulse

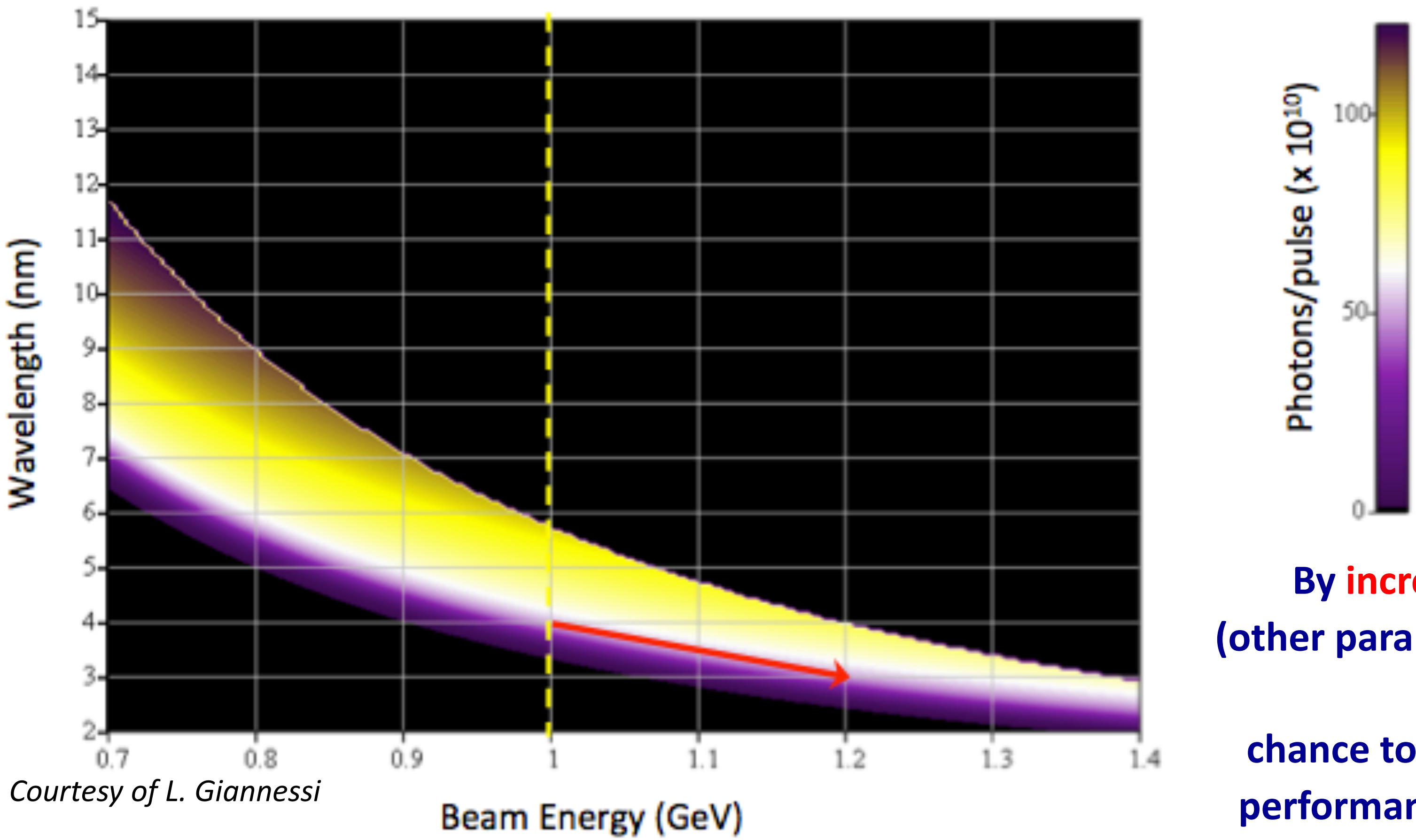
By increasing beam energy (other parameters constant) →

chance to reach for 4nm with performance similar to longer wavelengths

Circular Pol. Apple-X overall FEL performance

$$\lambda_{res} = \frac{\lambda_u}{2\gamma^2}\left[1 + K^2(g_u)\right]$$

Tunability both in beam energy $\gamma m_e c^2$ and in undulator gap g_u weighted for N_γ/pulse



Courtesy of L. Giannessi

Circular Polariz.: wider undulator gap tunability than Linear →

"water window" wavelengths probed with higher N_γ yield

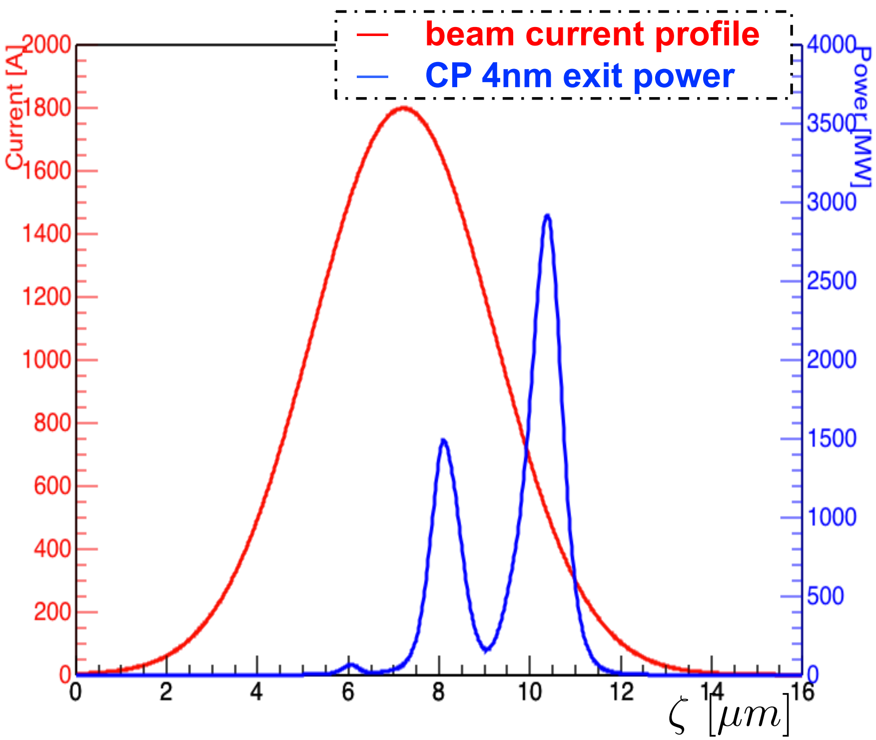
By increasing beam energy (other parameters constant) →

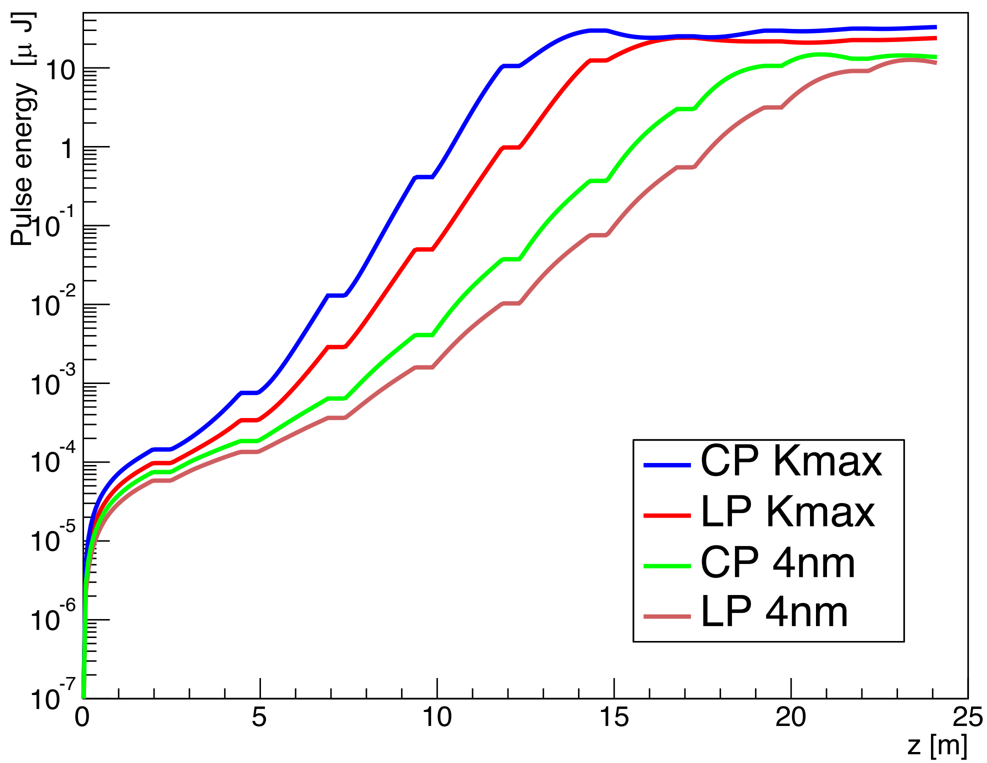
chance to reach for 3nm with performance similar to longer wavelengths

Electron beam used for FEL performance

- **Average electron beam slice parameters are used to perform 3D time dependent simulations with the `Genesis1.3_V2` code in 4 undulator + related magnetic lattice configurations: Linear & Circular polarizations, targeting 4nm & 5.75nm (K_{max})**

- **An ideal Gaussian current profile is assumed with I_{peak} = 1.8kA and Q = 30pC**





AQUA FEL results with average beam parameters

working point	LP K_{max}	LP 4nm	CP K_{max}	CP 4nm
resonant λ [nm]	5.75	4.01	5.75	4.01
photon energy [eV]	215	309	215	309
matching $\langle\beta\rangle$ [m]	6	8	6	8
Pierce ρ_{1D} [10^{-3}]	1.81	1.35	2.04	1.46
gain length$_{1D}$ [m]	0.559	0.788	0.405	0.566
satur. length [m]	16.78	23.40	14.33	20.81
satur. $\langle$power$\rangle$ [GW]	0.394	0.236	0.486	0.277
exit E_{pulse} [μJ]	23.90	11.56	32.95	13.73
exit bandwidth [%]	0.154	0.088	0.223	0.117
exit pulse length$_{\rm RMS}$ [fs]	6.10	3.50	6.12	3.76
exit divergence [mrad]	0.032	0.023	0.031	0.022
exit trans. size [μm]	195	133	190	132
exit N_γ/pulse [10^{11}]	6.93	2.33	9.53	2.77

Conclusions & outlook

- ✓ AQUA undulator line is designed, featuring the magnetic lattice, intra-module distance and FODO quadrupole integral strengths → same line is able to sustain E > 1 GeV beam energies

- ✓ Design of the full undulator line is going through the approval/blessing certification process

- ✓ Ideal reference electron beam values are used to perform 3D time dependent simulations: both LP and CP APPLE-X, at 4nm and at 5.75nm K_{max} → CP at 5.75nm allows to enter the realm of $O(10^{12})$ N_{γ}/pulse → to be achieved at shorter λ with higher E_{beam} (or improved parameters → WA1)

- ✓ Now focus on the tolerance study and on the full S2E with electron macroparticles (*V. Petrillo, N. Mirian, M. Opromolla & A. Selce* will contribute on these)

Please, stay FEL-tuned!
Thank you!