Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | INFN

Betatron radiation from accelerated electrons: an analytical study

Poster ID: 268

Andrea Frazzitta[1,2*], Alberto Bacci[1], Arianna Carbone[1], Alessandro Cianchi[3,4], Alessandro Curcio[5], Illya Drebot[1], Massimo Ferrario[5], Vittoria Petrillo[6,1], Marcello Rossetti Conti[1], Sanae Samsam[1], Luca Serafini[1] and Andrea Renato Rossi[1]

[1]INFN - Milan, [2]University of Rome "La Sapienza", [3]University of Rome "Tor Vergata", [4]INFN - Roma Tor Vergata, [5]Laboratori Nazionali di Frascati, [6]University of Milan

SAPIENZA UNIVERSITÀ DI ROMA | iFAST | EuPRAXIA Advanced Photon Sources | EUROPEAN NETWORK FOR NOVEL ACCELERATORS EuroNNAc4 NPACT supported by EU via I-FAST

INTRODUCTION

X-rays production through betatron radiation emission from electron bunches is a valuable resource for several research fields. The EuAPS (EuPRAXIA Advanced Photon Sources) project, within the framework of the EuPRAXIA project, aims to provide 1-10 keV photons (soft X-rays) using a compact plasma based system designed to exploit self-injection processes that occur in highly nonlinear laser-plasma interaction (LWFA) to drive electron betatronic oscillations. While numerical analysis is being pursued, we also aim to gain insights into the emission process through an analytical approach. By generalizing well-known results (I. Kostyukov, S. Kiselev, and A. Pukhov), we derive a comprehensive analytical expression for the emission spectrum in solid angle for single particles subjected to constant longitudinal force and linear transverse force moving in a planar trajectory. Model's approximations are presented, along with intensity plots on the detector and trends in critical frequency for some plasma wiggler strength and longitudinal force values.

ANALYTICAL MODEL

$$\frac{d^2I}{d\omega d\Omega} = \frac{e^2\omega^2}{4\pi^2 c}\left|\int_{-\infty}^{\infty} \vec{n}\times(\vec{n}\times\vec{\beta})\, e^{i\Psi}\, dt\right|^2 \qquad \Psi = \omega\left[t - \frac{x(t)\sin\theta\cos\phi + z(t)\cos\theta}{c}\right]$$

EQUATIONS OF MOTION

$$\dot{p} := \dot{p}_s = const \qquad F_x = kx \qquad \tilde{k} = ck \qquad \zeta = A\sqrt{1+Bt} \qquad \gamma \approx \frac{p}{mc} \qquad \dot{\gamma} \approx \frac{\dot{p}}{mc}$$

$$\frac{dp_{x,s}}{dt} = m\dot{\gamma}v_{x,s} + m\gamma a_{x,s} = F_{x,s}$$

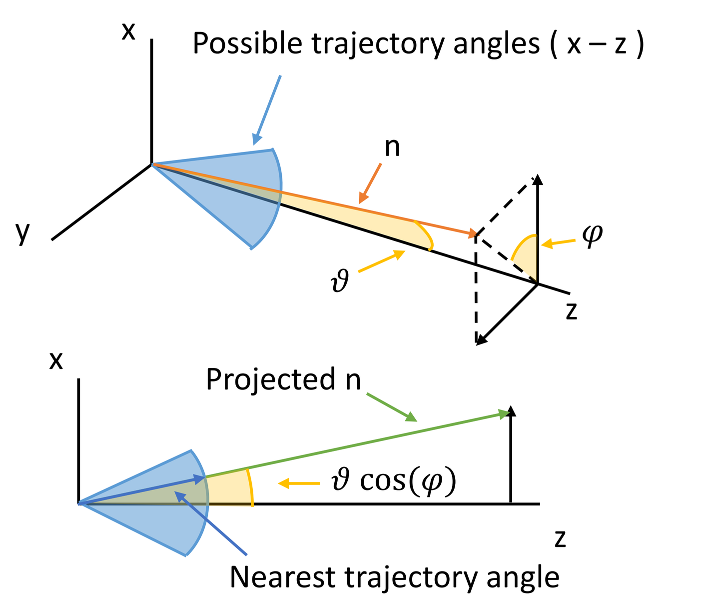
$$\ddot{x} = -\frac{\dot{x}\dot{p} + \tilde{k}x}{p_0 + \dot{p}t} \;\Rightarrow\; x(t) = CJ_0(A\sqrt{1+Bt}) = CJ_0(\zeta)$$

$$\ddot{s} = \frac{\dot{p}(c-\dot{s})}{p_0+\dot{p}t} \;\Rightarrow\; s(t) = ct + \frac{k_1}{\dot{p}}\ln(p_0+\dot{p}t) + k_2$$

$$\dot{z} = \sqrt{\dot{s}^2 - \dot{x}^2} \approx \dot{s} - \frac{\dot{x}^2}{2\dot{s}} \approx c - \frac{cA^2}{\zeta^2}(1-\beta_0) - \frac{A^4B^2C^2J_1^2(\zeta)}{8c\zeta^2}$$

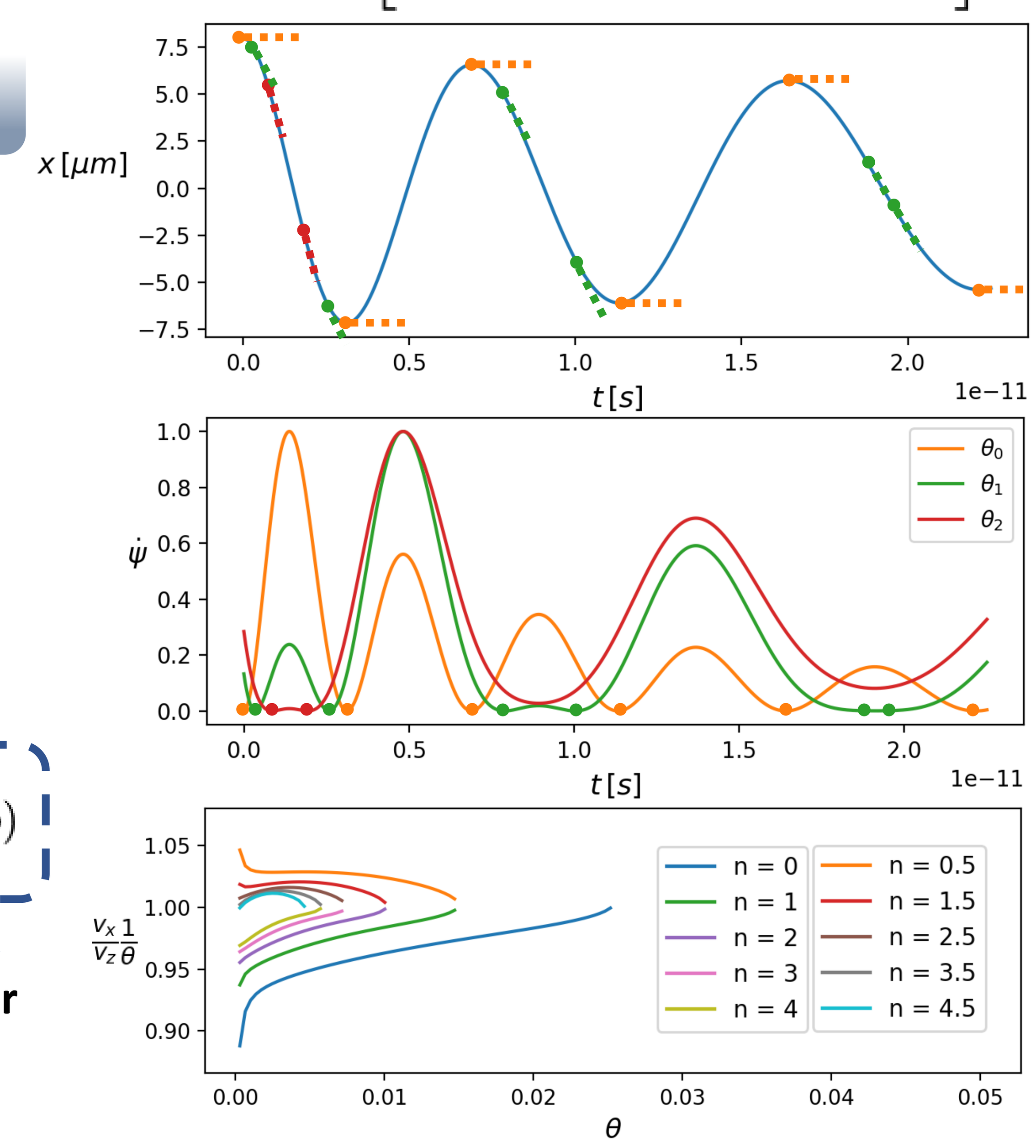
$$z(t) = \int \dot{z}\, dt = \mathcal{A}\frac{\zeta^2}{2} + \mathcal{B}\ln(\zeta) + \mathcal{C}\frac{1}{2}(1 - J_0^2(\zeta) - J_1^2(\zeta))$$

NEARLY STATIONARY PHASE



$$\frac{v_x}{v_z} \approx -\frac{A^2BCJ_1(\zeta)}{2c\zeta} \equiv \tan(\theta\cos\phi)$$

3° degree equation for stationary points



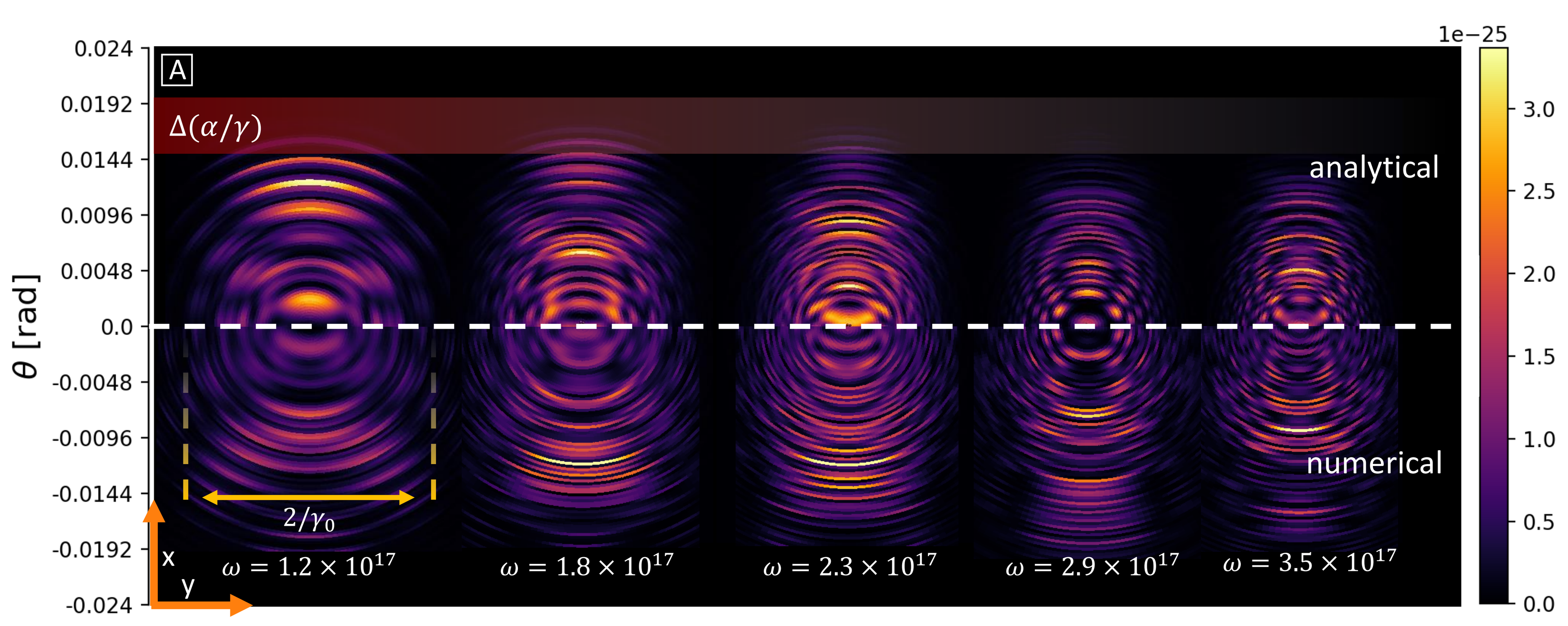
BESSEL APPROXIMATION

$$J_{1_n}(\zeta) \approx J_1(\zeta_{0_n})\sin\left(\pi\frac{\zeta - \zeta_{1_n}}{\zeta_{1_{n+1}} - \zeta_{1_n}}\right)$$

BHĀSKARA APPROXIMATION

$$\sin\zeta \approx \frac{16\zeta(\pi-\zeta)}{5\pi^2 - 4\zeta(\pi-\zeta)}$$

RESULTS

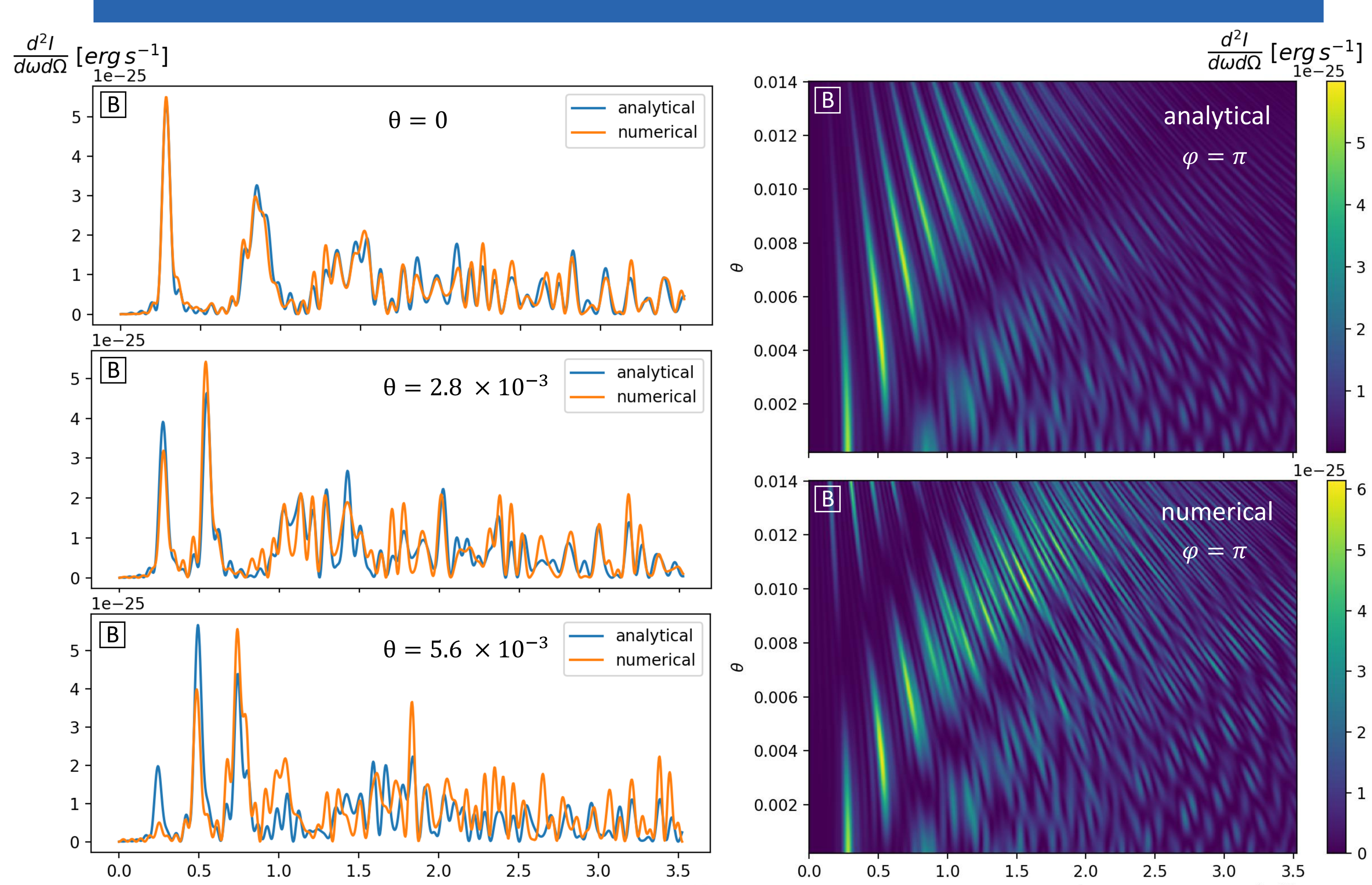


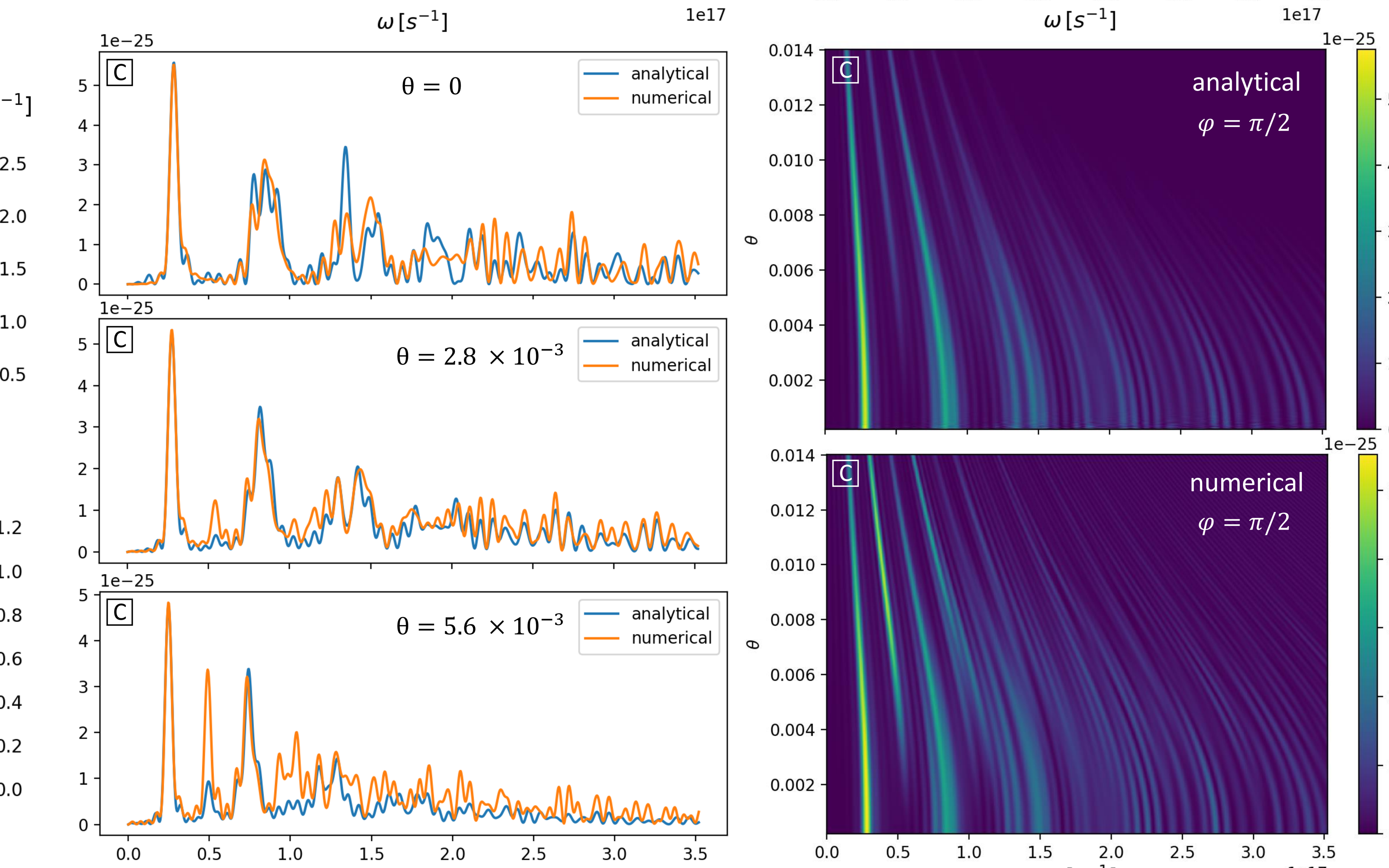
A: Analytical VS numerical radiation spots for several frequencies around istantaneous synchrotron critical frequency for accelerated case: expected divergencies along x and y axis, whose upper limit is given by particle initial energy, are observed. Slight discrepancies appear for growing frequency.

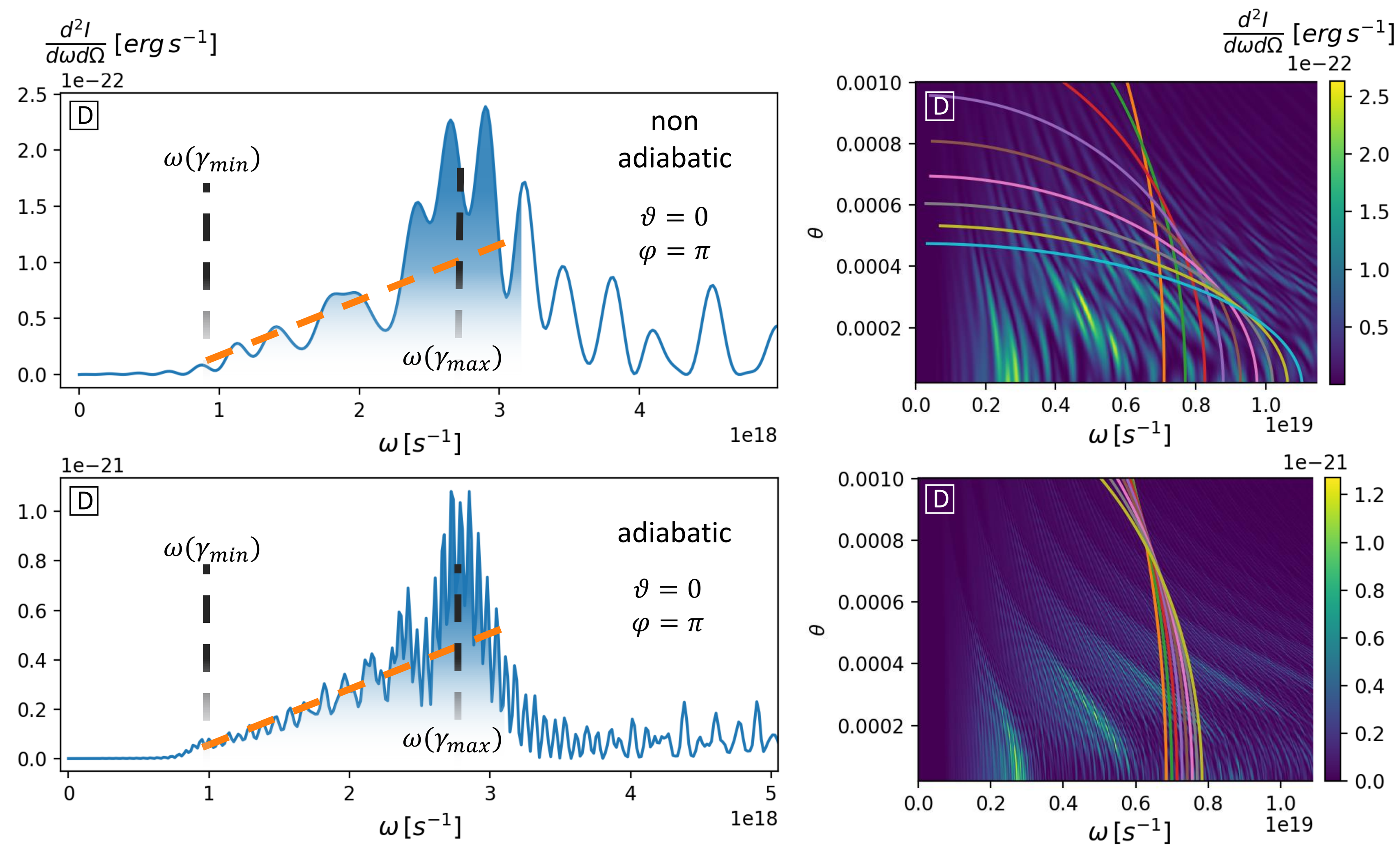
B: Intensity comparison between analytical model and numerical calculation along x axis (parallel to trajectory plane), with detailed spectrum profiles for some angles: spectra were calculated from an accelerated trajectory with initial plasma wiggler strength $\alpha = 2$, making the harmonics distinguishable.

C: Same as B but along y axis (perpendicular to trajectory plane).

D: Comparison between spectra emitted by non adiabatic (top) and adiabatic (bottom) acceleration in the same particle energy range: the full lines on the right plots show the istantaneous synchrotron critical frequency VS angle for several consecutive trajectory 'periods'. On the left plots, a neat linear trend in the spectrum profile is highlighted, extending across the first harmonic frequencies related to initial and final particle energy. For higher harmonics overlaps occur.







[1] M. Ferrario, R. Assmann, L. Avaldi, P. Bolognesi, R. Catalano, A. Cianchi, P. Cirrone, A. Falone, T. Ferro, L. Gizzi, M. G. Iungo, L. Labate, C. Mustarelli, G. Petringa and A. R. Rossi. EuPRAXIA Advanced Photon SourcesPNRR_EuAPS Project
[2] Esarey, E., Shadwick, B. A., Catravas, P., & Leemans, W. P. (2002). Synchrotron radiation from electron beams in plasma-focusing channels. Phys. Rev. E, 65(5), 056505. https://doi.org/10.1103/PhysRevE.65.056505
[3] Kostyukov, I., Kiselev, S., & Pukhov, A. (2003). X-ray generation in an ion channel. Physics of Plasmas, 10(12), 4818–4828. https://doi.org/10.1063/1.1624605

ACKNOWLEDGEMENT - This poster presentation has received support from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730.