DAΦNE Future

Antonio De Santis

On behalf of

DA StorageRing team

Scientific Committee Recommendations

68th SciCom Meeting (Nov 24)

The committee encourages the DAΦNE team, in collaboration with the CERN FCC-ee project team, to **identify and prioritize a set of activities and tests, to be conducted at the collider (or its complex)**, that could be validate models, concepts, hardware choices considered for FCC-ee. Feasibility, possible timelines and resources requirements should be evaluated. Compatibility with physics operation should be assessed.

We suggest **involving the younger members of the DAΦNE team in this process** as they are expected to implement it. An analysis of the necessary maintenance and consolidation of the DAΦNE complex should be conducted and possible descoping options identified with the associated risks.

The results of the above work should be presented at the next SC to allow sufficient time for decisions, preparation and implementation.

69th SciCom Meeting (May 25)

Document the resource requirements for DAΦNE consolidation and possibly evaluate options for descoping or reprofiling, taking into account the possible modes of operation of the collider for experimental particle physics, future collider test facility, user facility for photon science. **A review of the proposed programme might be desirable**.

Define the operational model for EuPRAXIA and the other LNF facilities post-2031 to complement the analysis of the opportunities offered by DAΦNE and assess the compatibility of its operation in parallel to those other facilities extending beyond 2030 the resource-loaded plan covering the period until 2030.

Storage ring team

Circular Collider expert from Accelerator Division organized a dedicated team in order to drive the DAΦNE Test-Facility proposal.

A. De Santis (Coordinator)

S. Bilanishvili, M. Boscolo, A. Ciarma, G. Franzini, A. Gallo, C. Milardi, D. Quartullo, M. Zobov.

The “White Paper”

Chapters

- **DAΦNE Present Status**
- **Collider-Mode Activity**
  - Monocromatization
  - Beam-Beam & Feedback study
  - eCloud and Background models validation
- **Single Ring-Mode Activity**
  - Pulse stretcher
  - Synchrotron light source
  - Longitudinal Injection
  - Crystal collimations with leptons

Outline

- DAΦNE Present Status
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Monochromatization

Outline

- DAFNE Present Status
- Collider-Mode Activity
  - **Monocromatization**
  - & Feedback study
  - lidation
- S
  - Longitudinal Injection
  - Crystal collimations with leptons

Compatible with Physics operations (e.g. EXCALIBUR)
Short runs (few months)
Activity-driven consolidation needed
Under study for FCCee (Special run)
Never tested – Large impact

Monochromatization: general theory

$$\sigma_E(beam) = E_b\delta$$

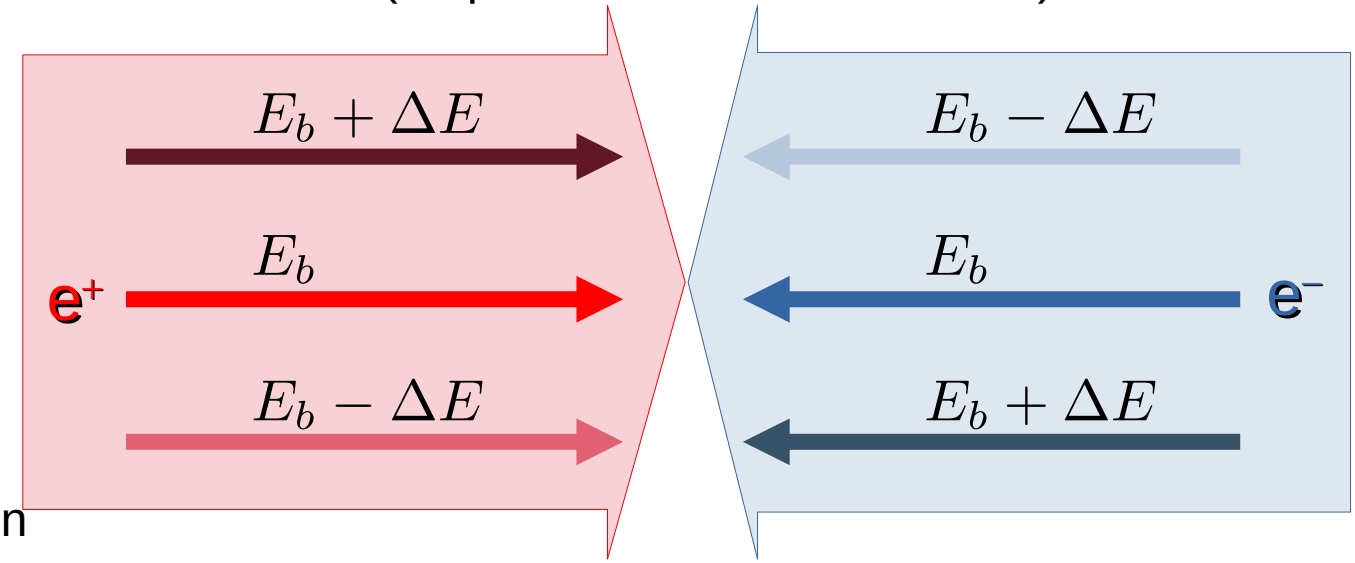
Usually:

$$w = 2E_b$$

$$\sigma_w = \sqrt{2}\delta E_b$$

Proposed by
A. Renieri 1975 (ADONE)

Monochromatization scheme
(Dispersion at Interaction Point)



Effect on energy resolution

$$w = 2E_b$$

$$\sigma_w = \frac{\sqrt{2}\delta E_b}{\lambda}$$

$$\lambda = \sqrt{1 + \delta^2\left(\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}}\right)}$$

Monochromatization: Crab-Waist edition

$$\sigma_E(beam) = E_b\delta$$

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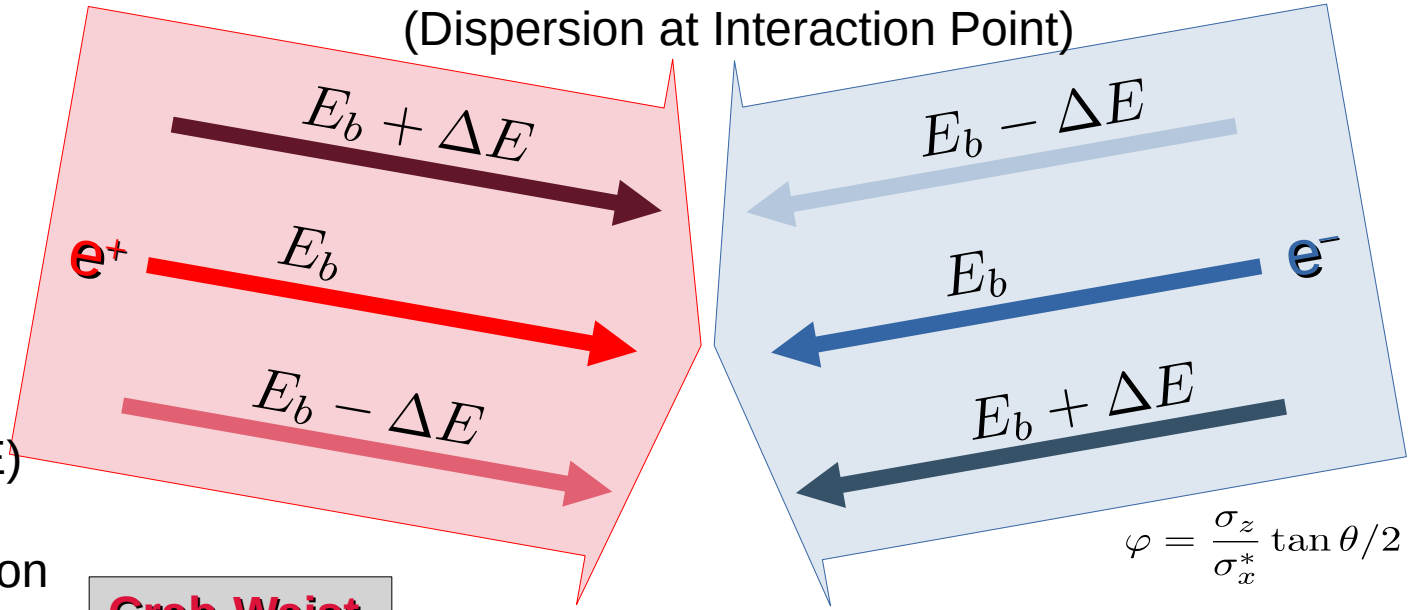


Effect on energy resolution

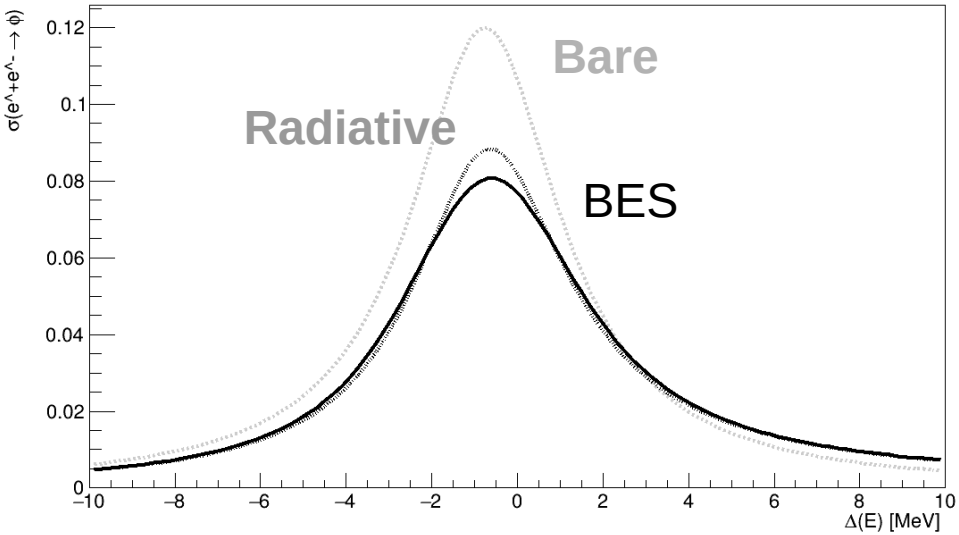
$$w = 2E_b$$

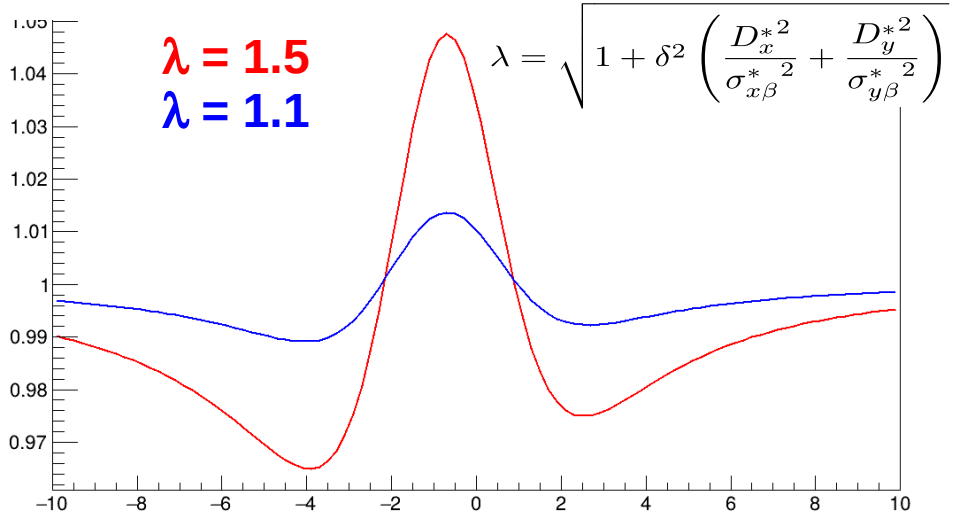
Crab-Waist

$$\sigma_w = \sqrt{2}\delta E_b \sqrt{\left(\frac{\sigma_\delta \cos(\theta_c/2)}{\lambda^2}\right)^2 + \sigma_{x'}^* \sin(\theta_c/2)}$$

$$\lambda = \sqrt{1 + \delta^2 \left(\frac{{D_x^*}^2}{{\sigma_{x\beta}^*}^2(1+\varphi^2)} + \frac{{D_y^*}^2}{{\sigma_{y\beta}^*}^2}\right)}$$

Observable definition



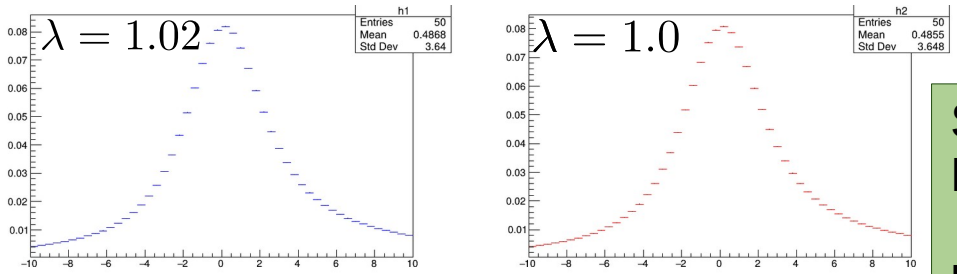


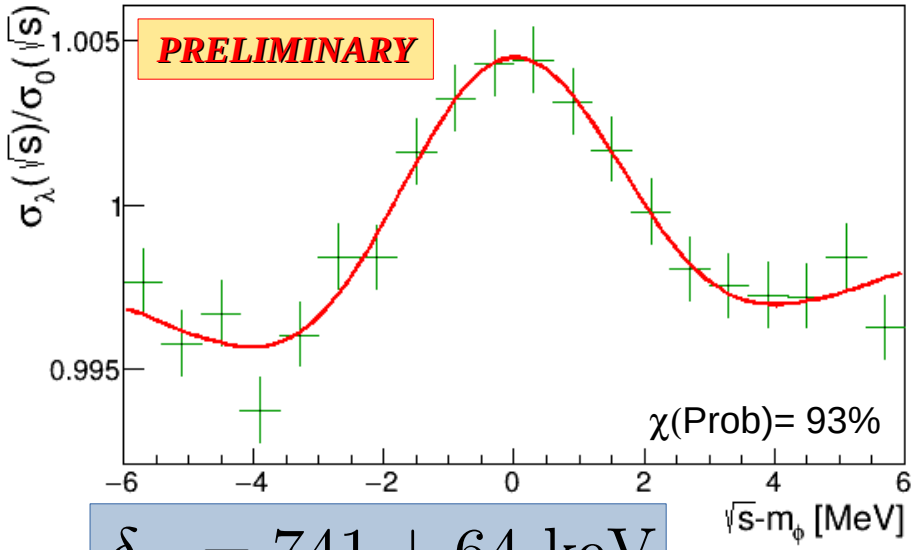
The impact of Beam Energy Spread (BES) on the line-shape is moderate
Different λ implies different run length (sensitivity)

$$\left.\frac{N(K^{\pm})}{N_{Bha}}(\sqrt{s})\right|_{\lambda=\lambda_0} \Big/ \left.\frac{N(K^{\pm})}{N_{Bha}}\right|_{\lambda=1}(\sqrt{s})$$

Using the "double-ratio" method allows to cancel out most of the systematics

Measurement simulation





$$\delta_E = 741 \pm 64 \text{ keV}$$
$$\lambda = 1.021 \pm 0.003$$

Statistical uncertainty is related only to the KAON counting.

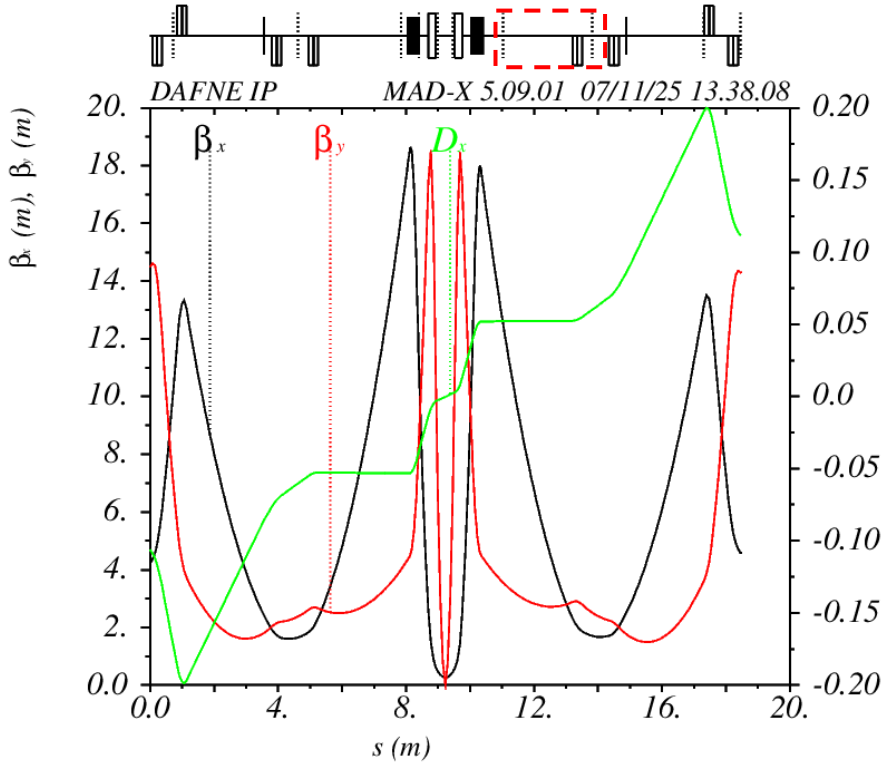
DAFNE Luminometer and KAON Trigger (SIDDHARTA-2) counting rate assumed

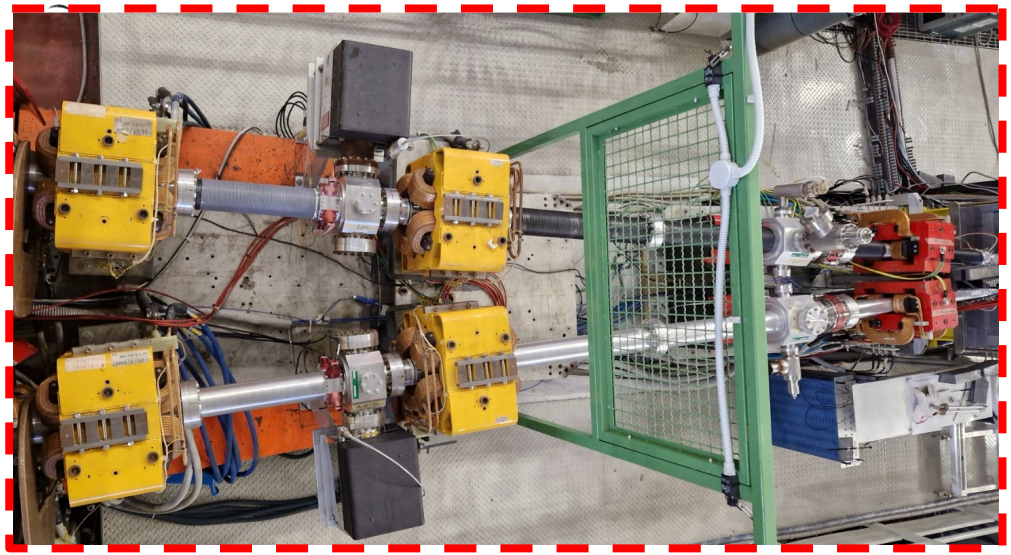
Several energy range and collected statistics have been simulated with **λ = 1.02**

Accuracy of ~10-15% requires 60-80 days of collisions operations @ 10^{32} $cm^{-2}s^{-1}$

Luminosity drop with dispersion included (beam size increase)

Interaction Region lattice



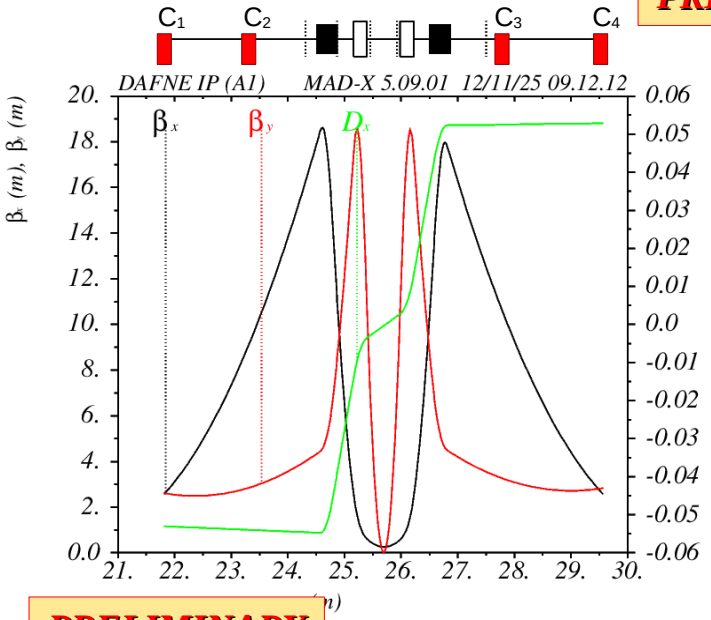


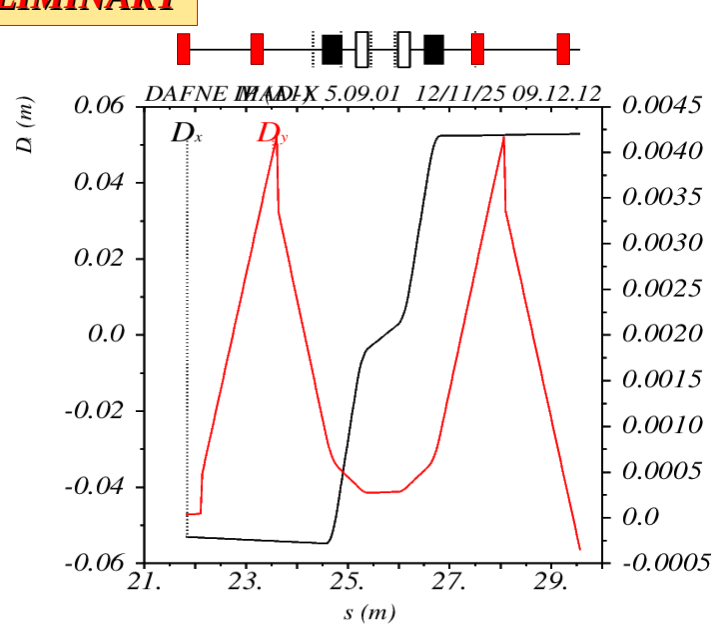
Interaction Region (IR) of DAΦNE has limited space for new magnets.
In the central region (Between QFs and QDs) the two beams have common beam pipe.

Vertical Dispersion at IP

New Correctors: D_y bump at IP

PRELIMINARY





PRELIMINARY

Magnet Strengths: (mrad)
θ_1: -2.3
θ_2: 5.0
θ_3: 5.0
θ_4: -2.3

$$D_y@\mathrm{IP} = 0.36\ \mathrm{mm} \Rightarrow \lambda \sim 1.01$$ **Still not at the target**

In any case deeper study on the optics and beam dynamics mandatory

Storage Rings activity: PADME-X17

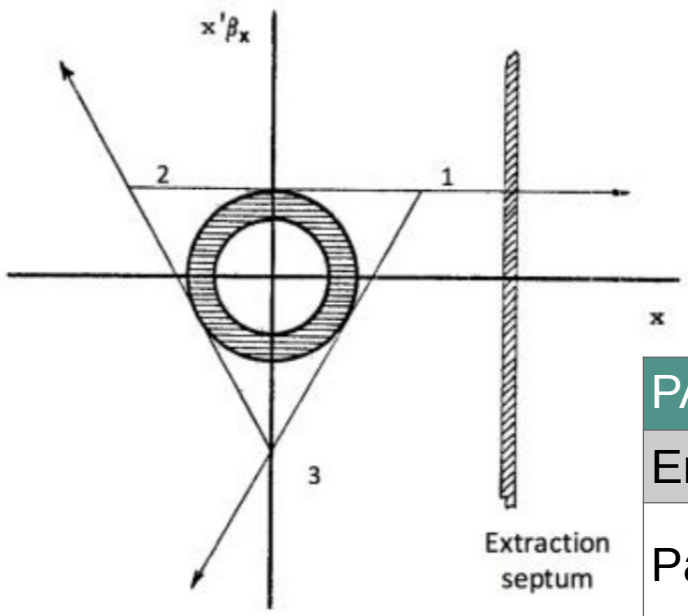
Outline

- DAFNE Present Status
- Single Ring-Mode Activity
  - **Pulse stretcher**
  - Synchrotron light source
  - Longitudinal Injection
  - Crystal collimations with leptons

Driven by PADME-X17 Run-III result
Case study to be ready in case of non conclusive results of Run-IV
Design based on PADME requirements
Potentially of interest to increase BTF beam variety

Resonant extraction: recap

P. Valente, INFN/17-15-LNF
S. Guiducci, IPAC2018-THPAK023



Separatrix:
Inside triangle – Stable
Outside - Unstable

Already proposed for PADME (POSEIDON-2017)

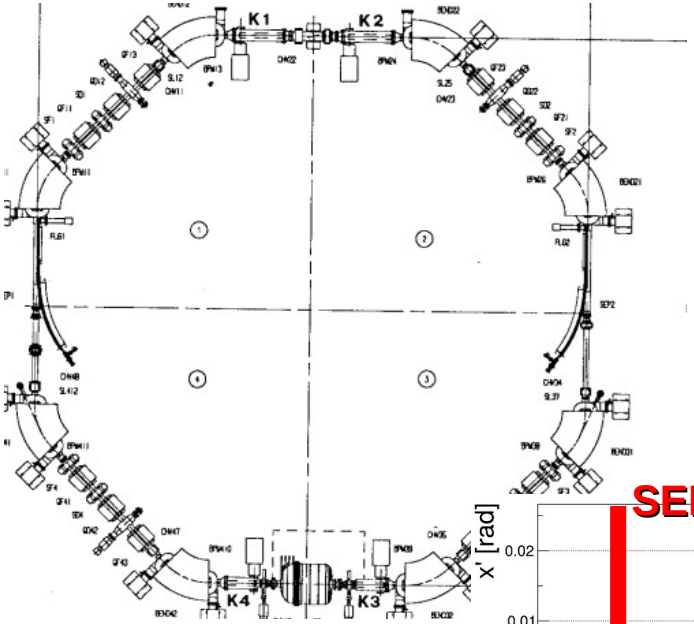
Third order resonant extraction

Main aspects described with Kobayashi Hamiltonian

Resonant conditions reached naturally by loosing energy for synchrotron radiation

PADME-X17 Beam requirements (Courtesy of M. Raggi)	
Energy (MeV)	280 ± 30 (tunable 1 MeV step)
Particle flux	1 POT/ns (max) $4x10^6$ POT/s (min avg)
Energy spread	0.3% (max)
Divergence (target)	1 mrad (max)
Beam Spot (target)	1x1 mm^2

Slow extraction from DAFNE damping ring



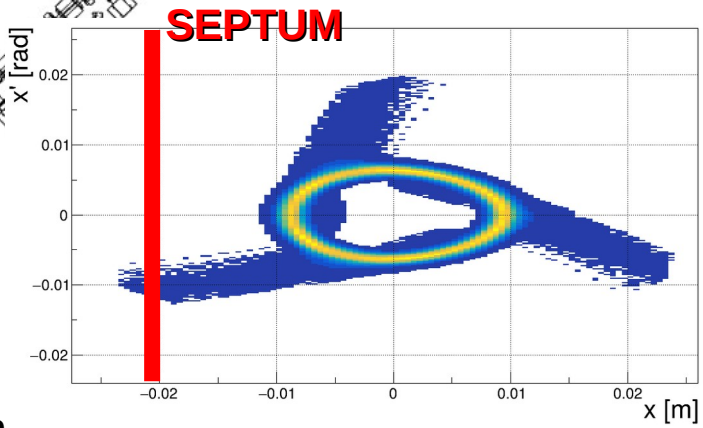
Small ring with **large energy acceptance** ☺

Already **existing extraction septum** ☺

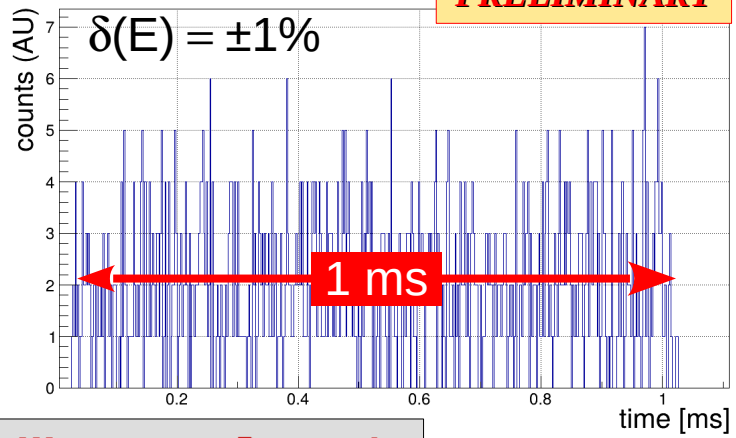
Quadrupoles and Sextupoles in family ☹

Common Injection/Extraction transfer lines ☹

Ring parameters:
E_0 = 300 MeV
Q_x = 0.325
ξ_x = -6.0
U_0 = 0.65 keV/turn



PRELIMINARY



1 POT/ns×1ms = 10^6 POT/Spill ⇒ 5x10^7 POT/s

Conclusion

DAΦNE Future WG settled & operative

Several items under consideration

Monochromatization lattice under study

Study for pulse stretching with DR started

PLANS

DAΦNE Future WG:

Monochromatization:

- Define basic optics and evaluate impact
- Perform beam dynamics study including beam-beam

DR pulse stretching:

- Define resonant extraction optics @ 510 MeV
- Perform full tracking simulation
- Define experimental activity to measure extracted beam

Thank you!

Spare Slides

General considerations

- DAFNE is a collider
  - Collisions related studies (*Monocromatization, beam-beam interaction, feedback study, beam induced background*)
- DAFNE has intense beams
  - Positron beam dynamics (*eCloud mitigations and diagnostics*)
  - Electron beam dynamics (ion simulation codes)
- DAFNE has two storage rings + Synchrotron light lines
  - Innovating technologies (e.g. *longitudinal injection, crystal collimation*)

Monochromatization

Possible LNF/CERN collaborations

At DAFNE possible test of monochromatization

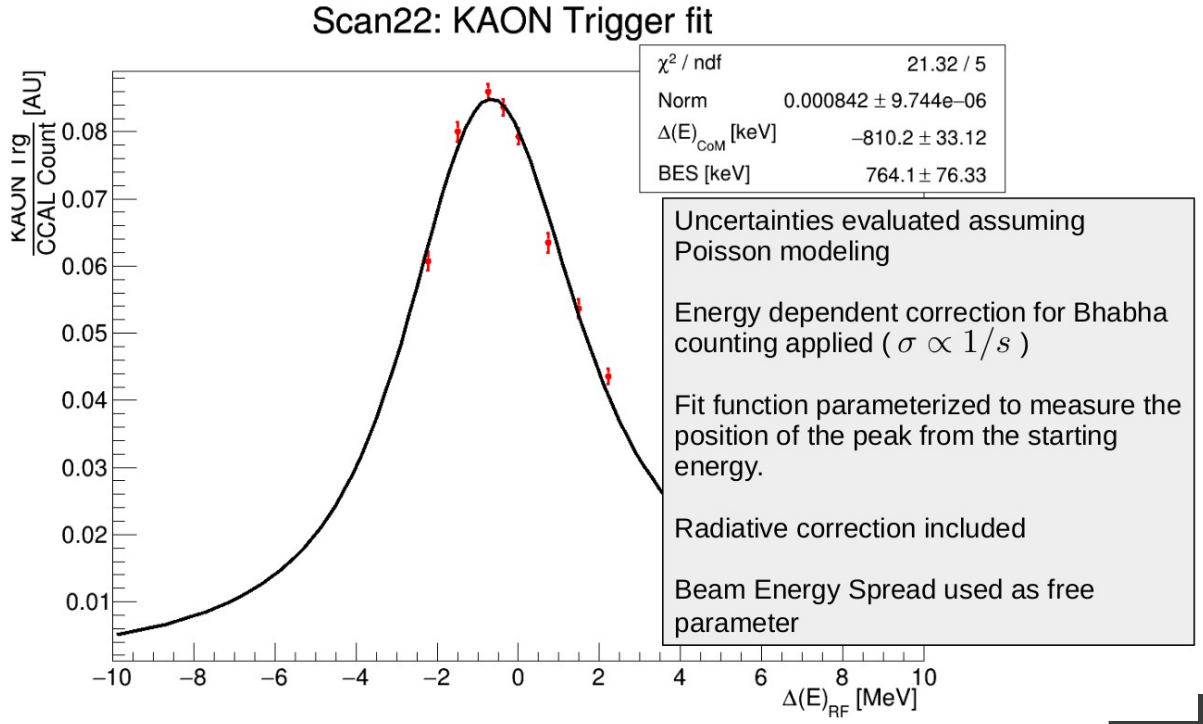
Simultaneous measurement of Kaon Rate and Bhabha scattering events rate at different energy.

Observable:

Beam Energy Spread

Similar measurement performed with KLOE and SIDDHARTA for the ϕ-meson lineshape to verify the working point of the collider.

HIGH IMPACT ACTIVITY NEVER TESTED



Some algebra

$$\lambda = \sqrt{1 + \delta^2 \left(\frac{{D_x^*}^2}{{\sigma_{x\beta}^*}^2} + \frac{{D_y^*}^2}{{\sigma_{y\beta}^*}^2} \right)}$$

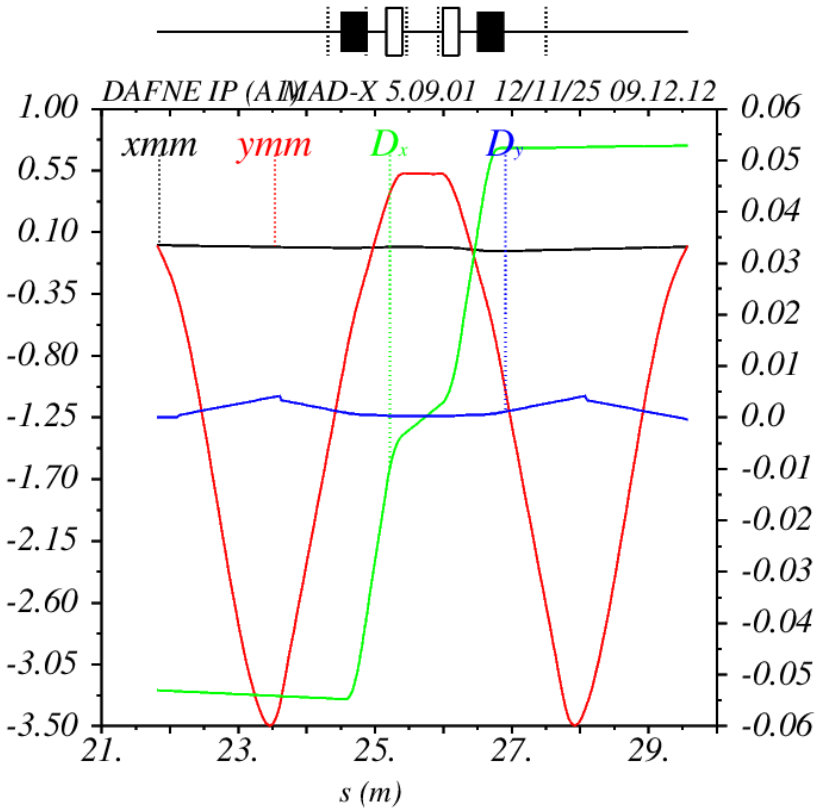
$$\delta = \frac{760 \text{ keV}}{\sqrt{2}\, 510 \text{ MeV}} \simeq 10^{-3}$$ **Observed 2022**

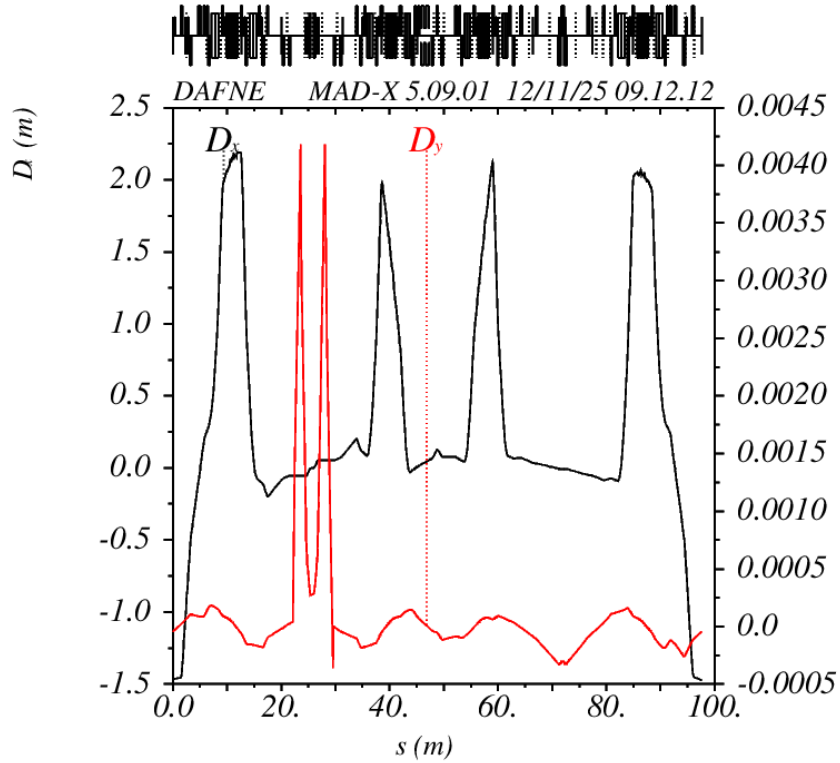
$$\sigma_{y\beta}^* = 3.5 \mu\text{m}$$ **Measured 2024**

$$\sigma_{x\beta}^* = 210 \mu\text{m}$$

$$\lambda = 1.1 \Longrightarrow D_y^* = 1.6 \text{ mm} \quad \lambda = 1.5 \Longrightarrow D_y^* = 3.9 \text{ mm}$$

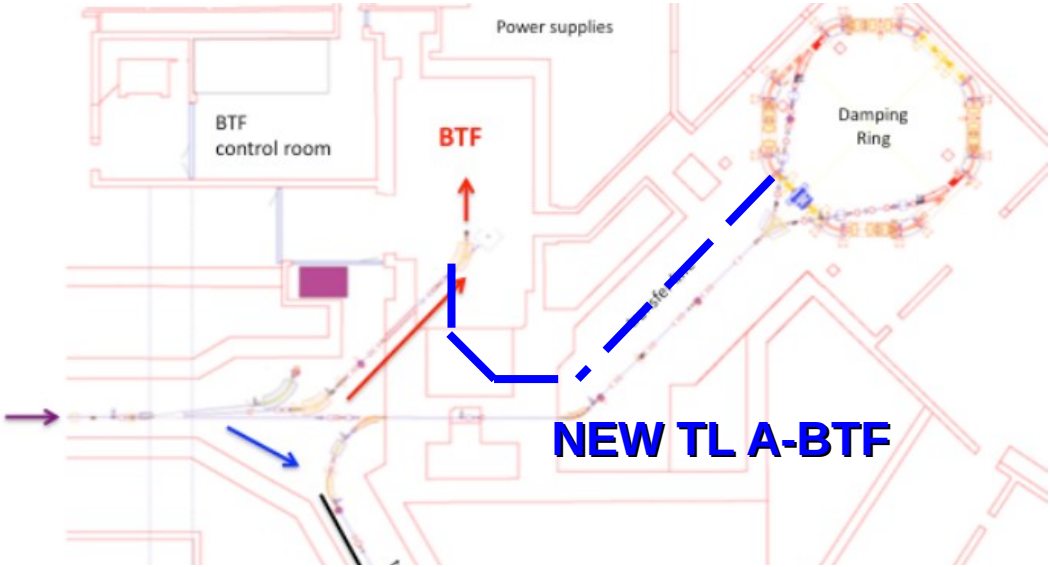
$$\lambda = 1.1 \Longrightarrow D_x^* = 9.6 \text{ cm} \quad \lambda = 1.5 \Longrightarrow D_x^* = 23 \text{ cm}$$


DAFNE IP (A IV)
MAD-X 5.09.01 12/11/25 09.12.12
xmm
ymm
D_x
D_y
xmm, ymm
1.00
0.55
0.10
-0.35
-0.80
-1.25
-1.70
-2.15
-2.60
-3.05
-3.50
0.06
0.05
0.04
0.03
0.02
0.01
0.0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
21.
23.
25.
27.
29.
s (m)


DAFNE
MAD-X 5.09.01 12/11/25 09.12.12
D_x
D_y
D_x (m)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.0045
0.0040
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0
-0.0005
0.0
20.
40.
60.
80.
100.
s (m)

Beam Stretcher

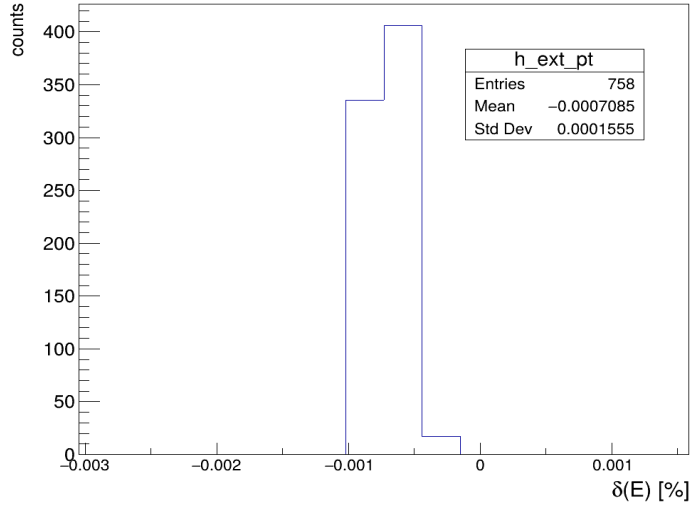
Slow extraction from DAFNE damping ring



Extracted beam needs a dedicated Transfer Line

Damping Ring hall does not allow any new experimental setup (too tight)

Resonant extraction: beam properties



Feedback study

Beam-Beam and FBK systems

Injection of controlled noise

Two methods to provide controllable excitation to the beam in the transverse plane through stripline kickers.

- **Frequency domain**.
  - Band-limited **white noise**.
  - Generated by a **custom electronics** developed at LNF.
  - **Highly optimized** for current DAFNE operational setups.
  - Usually used to measure the **betatron tunes**.
  - 2 MHz bandwidth adjustable within $20 f_{rev}$ (currently centered at $117 f_{rev}$).
  - **Not bunch-by-bunch**, i.e. about the same excitation for all the bunches.

- **Time domain**.
  - Excitation signals available: sine, square, DC.
  - Tunable frequencies and amplitudes
  - Generated by the DIMTEL feedback electronics.
  - **Bunch-by-bunch.**

Latest DAFNE Feedback activities

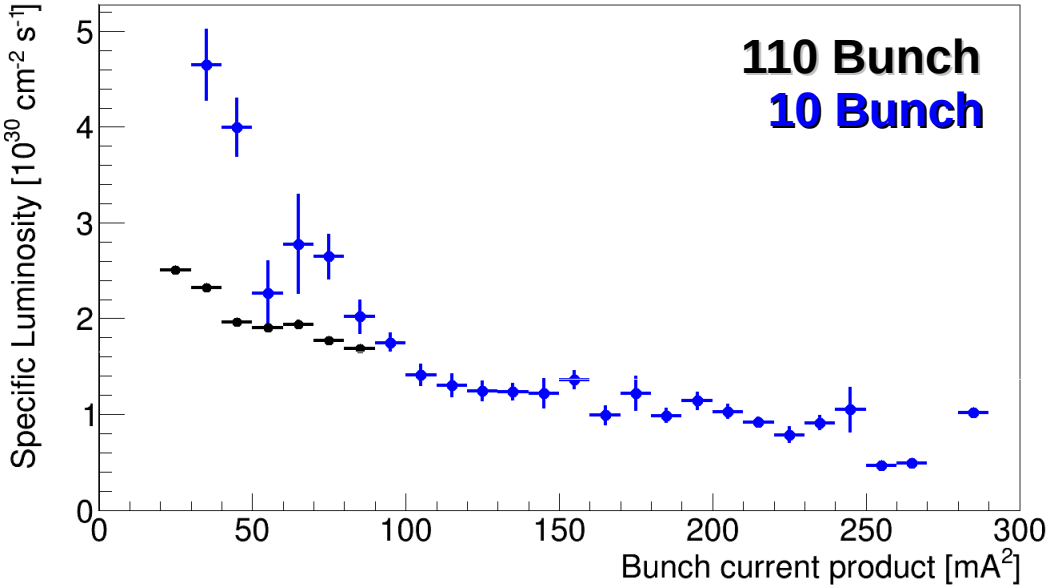
04/03/24.
Multi-bunch longitudinal beam-dynamics code for the DAFNE rings.
I.FAST Workshop
https://indico.kit.edu/event/3742/contributions/15423/

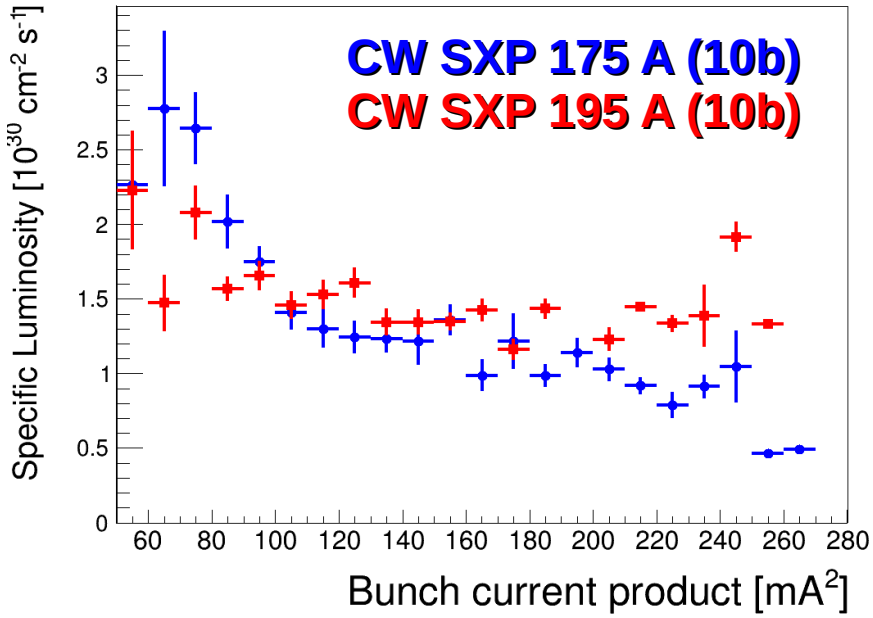
06/04/24.
Multi-bunch longitudinal beam-dynamics code for the DAFNE rings: intro.
Laboratorio Acceleratori 2024.
https://agenda.infn.it/event/40135/

11/12/24.
Bunch-by-bunch feedback system used as a diagnostic tool for multi-bunch beams in the DAΦNE collider.
Proceedings of IBIC24 Conference.
https://inspirehep.net/literature/2869902

19/03/25.
Bunch-by-bunch feedback system used as a diagnostic device for multi-bunch instabilities in the DAΦNE collider.
I.FAST Workshop.
https://indico.kit.edu/event/4809/contributions/19297/

Collision characterization: 10 bunches luminosity

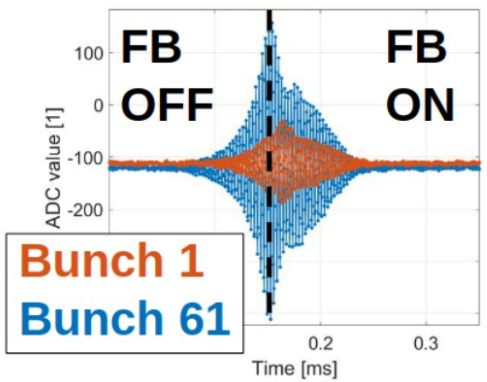


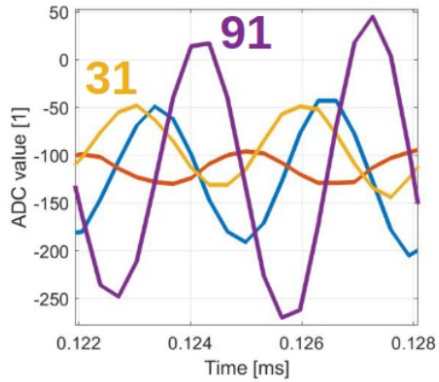


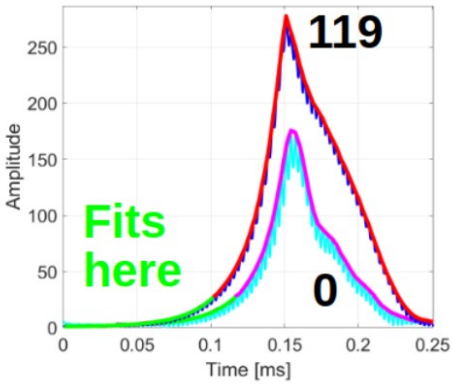
In the normal operations the single bunch current is strongly limited
Neglecting collective effects (10 bunches collisions) the specific luminosity is almost twice the one normally obtained with 110 bunches

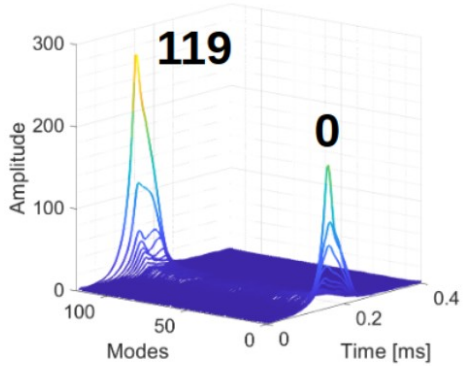
With higher value of the Crab-Waist sextupoles it is possible to reach even higher specific luminosity at high bunch current.

Positron beam dynamics: Grow-Damp measurement



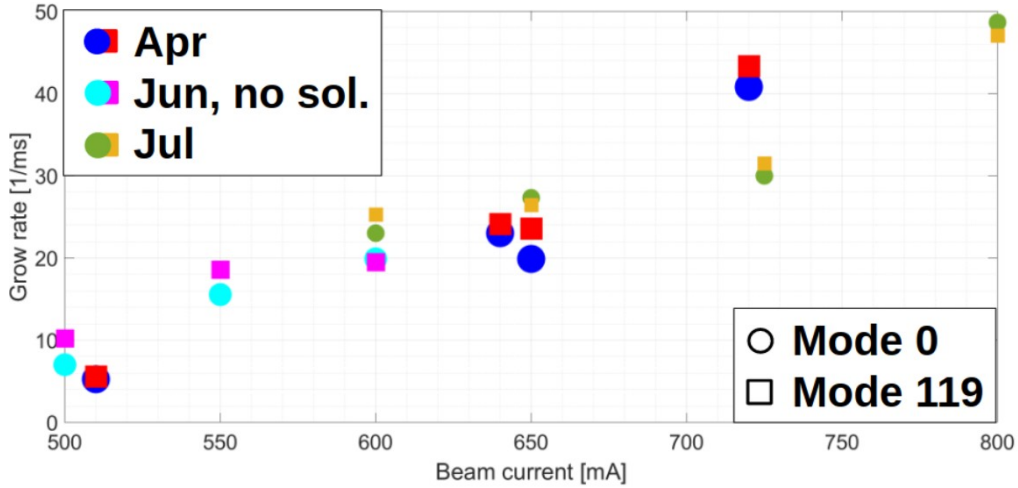






Grow-damp measurements with modal analysis to characterize the horizontal multi-bunch instabilities.

For 105 bunches at 800 mA, the dominant mode is 119, followed by mode 0.



- Exponential fits of the modes envelopes.
- Grow rates increase with higher beam currents, as expected.

Presented at IBIC2024 - THP65

sCloud

Validation of simulation code

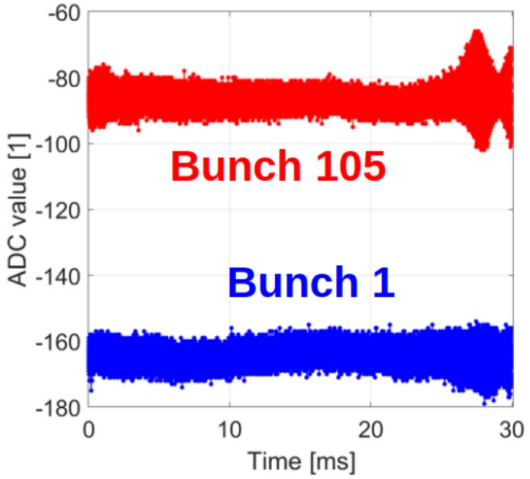
PhD thesis
Electron cloud studies in positron storage rings with special emphasis on the DAFNE Collider and the FCC-ee pre-Injector Damping Ring

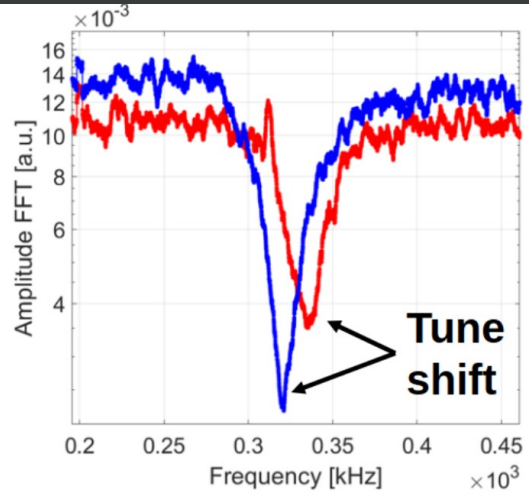
Proceeding of IPAC24 Conference.
ELECTRON CLOUD STUDIES FOR DAΦNE COLLIDER AND FCCee DAMPING RING
S. Ozdemir, et al.

Paper submitted on April 2025
Electron Cloud Studies for DAFNE Collider Ring and Future Circular Collider-e+ e- Damping Ring.
O. Etisken, D. Quartullo, S. Ozdemir, G. Franzini, C. Milardi, M. Zobov, A. De Santis, R. Ciftci

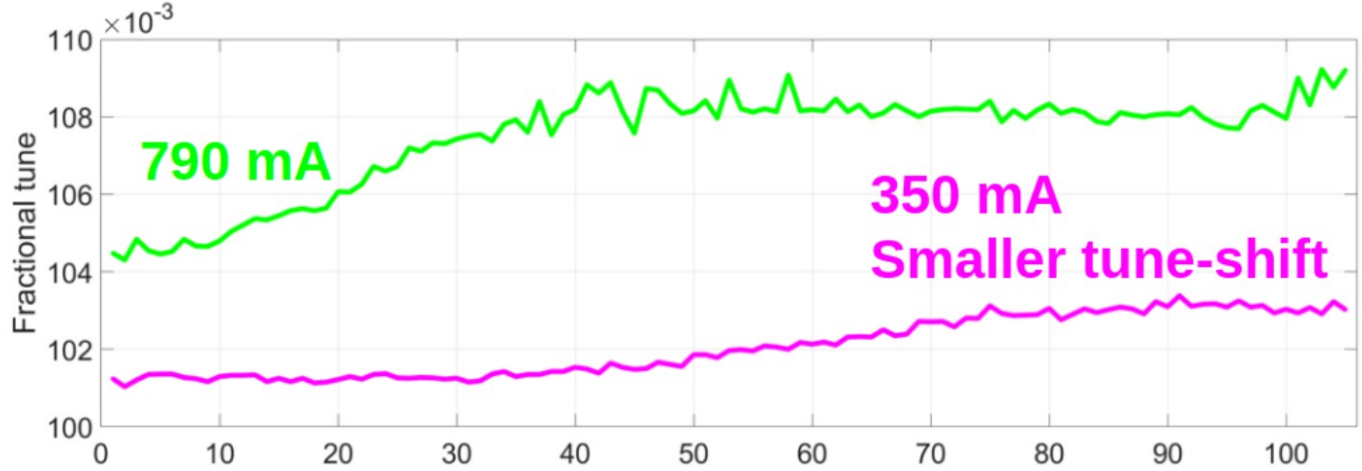
Ongoing developments about instabilities simulation

Positron beam dynamics: MRp tune shift measurement





Presented at IBIC2024 - THP65

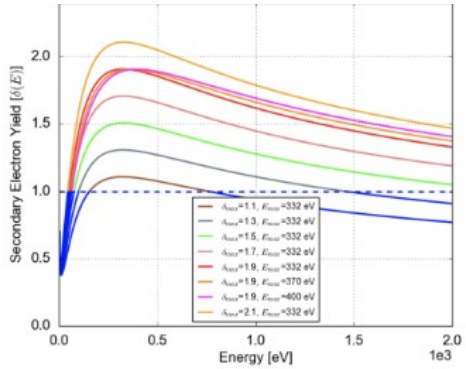


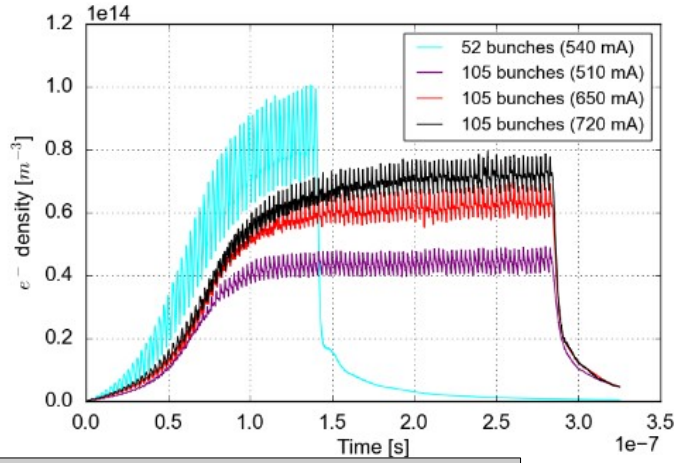
Ring characterization: eCloud simulation

E-cloud build-up simulation by using PyECLOUD code.

E-cloud formation depends on many parameters: external magnetic fields, geometry, chamber surface, bunch spacing, bunch intensity, bunch length, bunch number, beam sizes, and Secondary Electron Yield (SEY).

SEY for Al surface: δ_{max} =1.9 and E_{max} = 332 eV





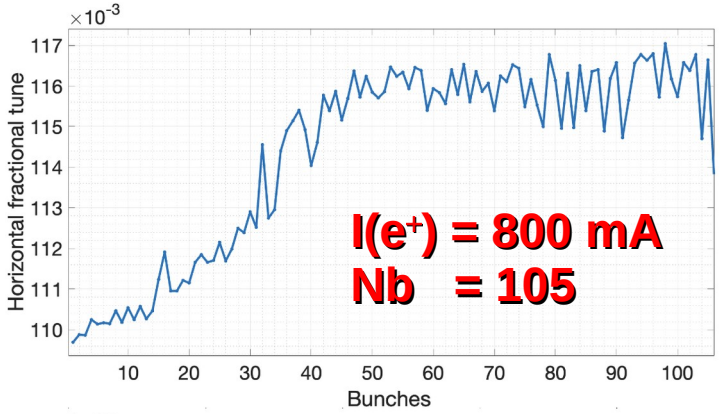
	Meas	Simulated
Bunch no	**Growth rate**	**e^- density**
105 bunches [720 mA]	44 ms^{-1}	0.8×10^{14} m^{-3}
105 bunches [650 mA]	22 ms^{-1}	0.7×10^{14} m^{-3}
105 bunches [510 mA]	6 ms^{-1}	0.5×10^{14} m^{-3}
52 bunches [540 mA]	18 ms^{-1}	1.0×10^{14} m^{-3}

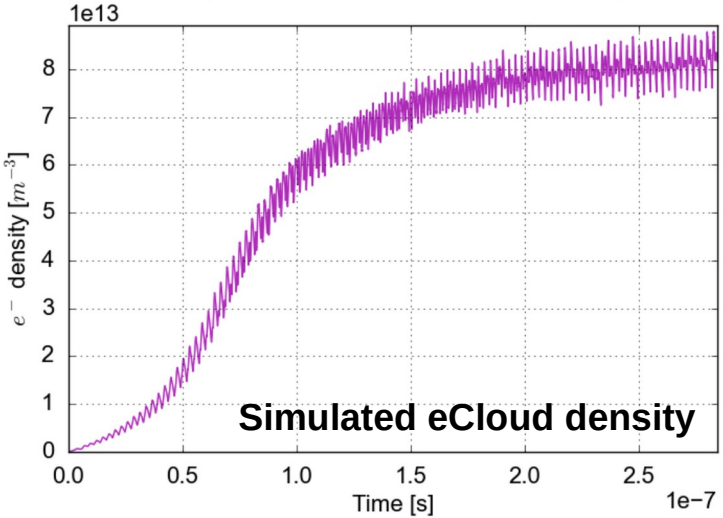
Beam current	**Measured tune shift**	**e^- density**
800 mA	7.0×10^{-3}	8.8×10^{13} m^{-3}
750 mA	6.3×10^{-3}	8.0×10^{13} m^{-3}
600 mA	4.8×10^{-3}	6.0×10^{13} m^{-3}
400 mA	3.3×10^{-3}	3.5×10^{13} m^{-3}

Pub: NIMA-D-25-00412R2

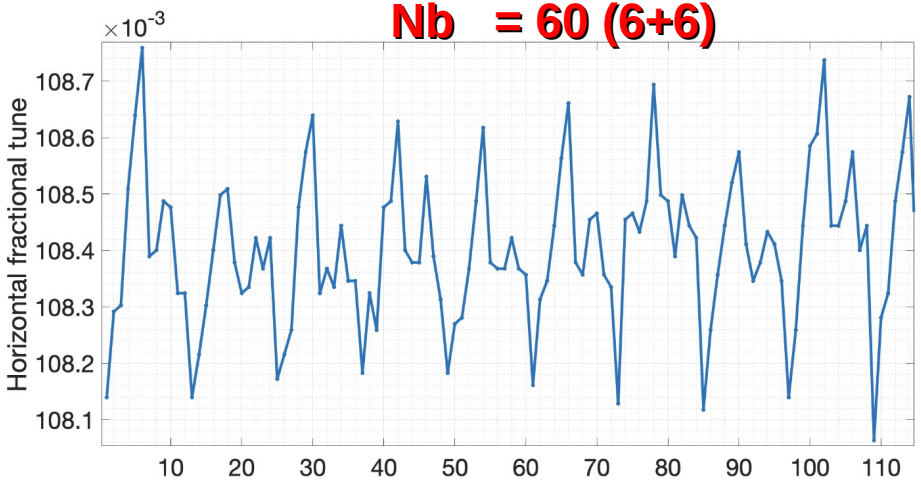
Presented at IPAC2024-WEPR08

Ring characterization: eCloud simulation

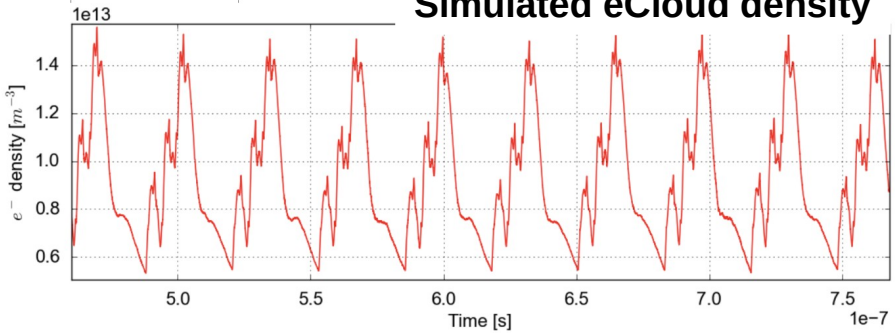




I(e+) = 290 mA
Nb = 60 (6+6)



Simulated eCloud density



Pub: NIMA-D-25-00412R2

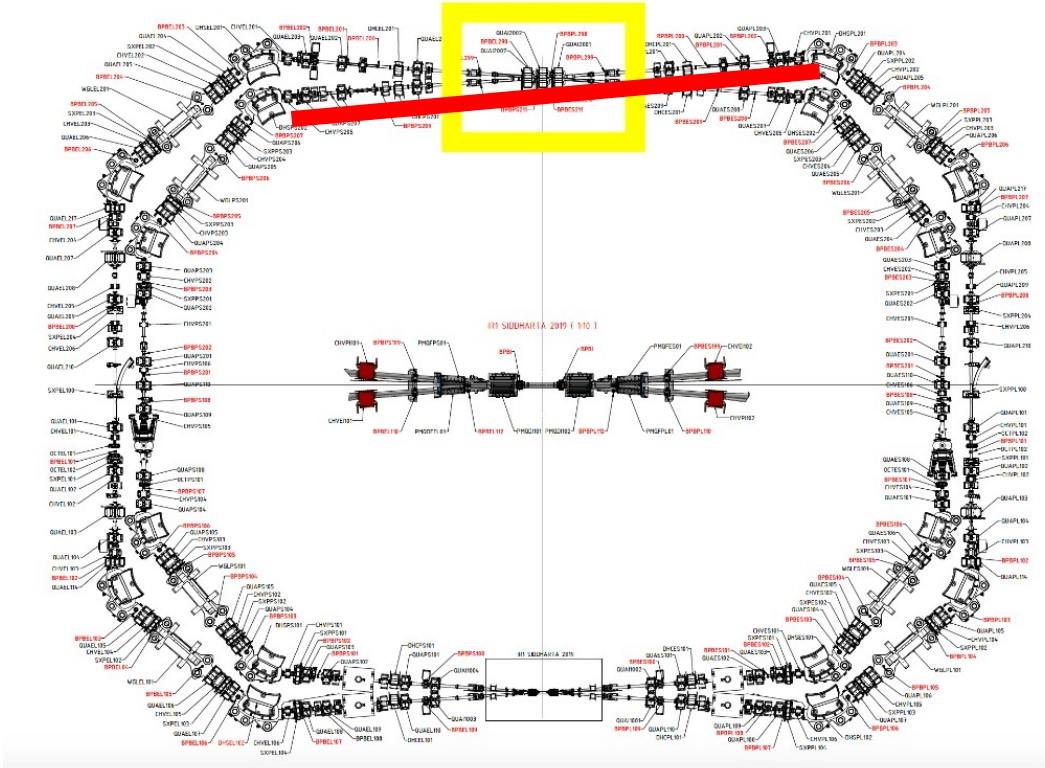
Presented at IPAC2024-WEPR08

Novel vacuum chamber

Test of the **novel FCC-ee vacuum chamber** with winglets and photon stops at the DAFNE positron ring. Possible placement in the RCR region just after the arc in the “FINUDA” straight.

CERN Vacuum Experts (R. Kersevan) suggest that this could easily be implemented and would be extremely useful.

The vacuum group has prototype chambers to be directly installed.



Simulation codes

Backgroound simulation

Developed the first Xsuite-based simulation of Touschek scattering for the DAFNE e^+ ring

Computed the ring local momentum aperture which is used as input for Touschek scattering simulation,

Compared the simulated MC versus the Piwinski scattered rate

Evaluated Touschek scattering loss map,

Tousheck lifetime (t ~ 65.33 min.).

G. Broggi [CERN]

The above simulations with extracted scrapers

Longitudinal injection

Longitudinal injection

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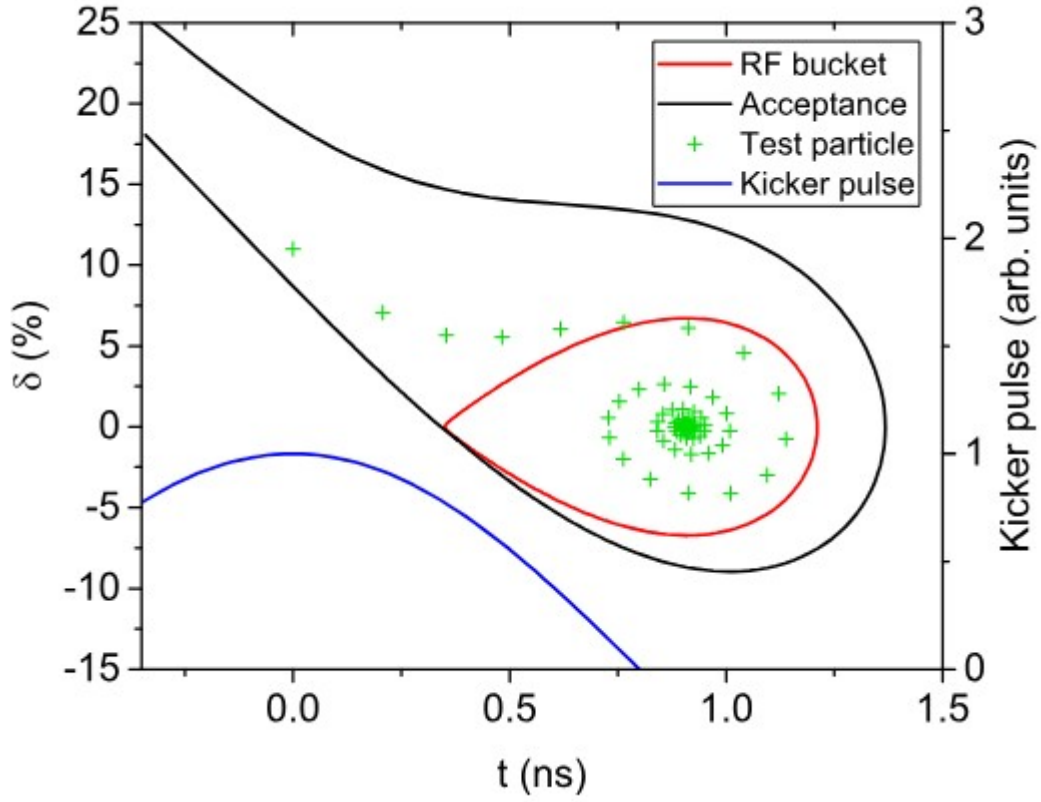
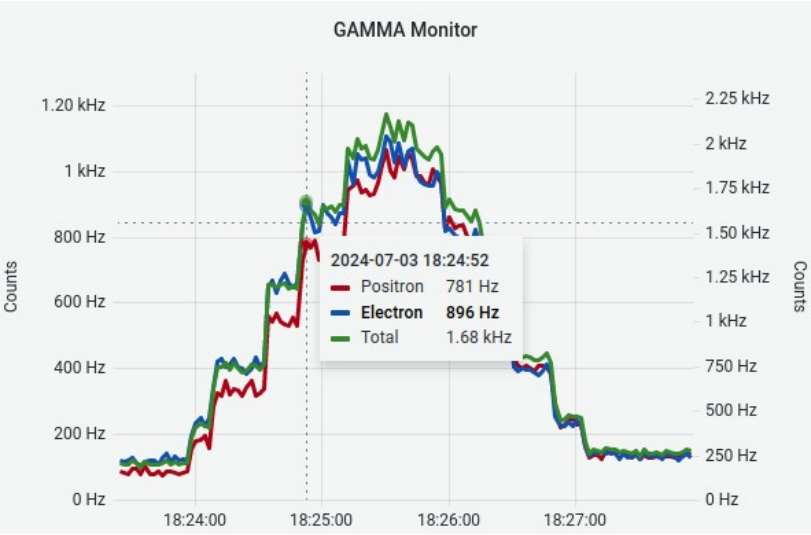
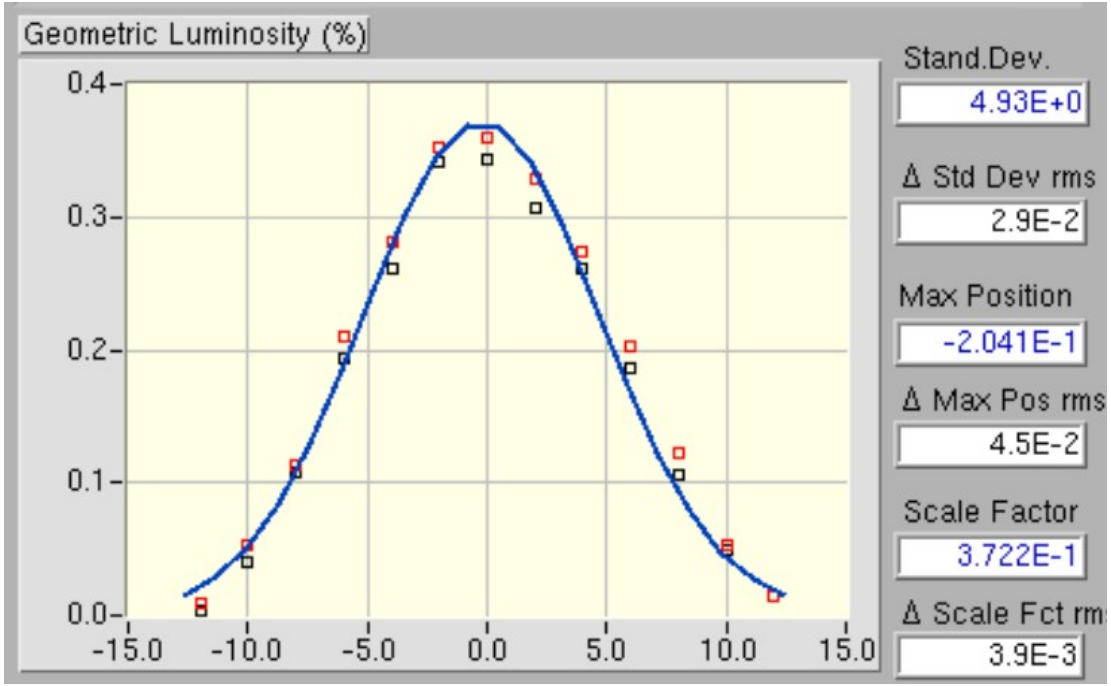


Latest Activity on DAFNE

Verical beam-beam scan



Beam-Beam scan with calibrated bump



I_{beam}: 80 mA
Σ_{SLM} = 150/135 μm
Σ(extrapolated) = 4.2 μm
Σ(collision) = 5.0 μm (convoluted)
σ^{+-}(single) = 3.5 μm

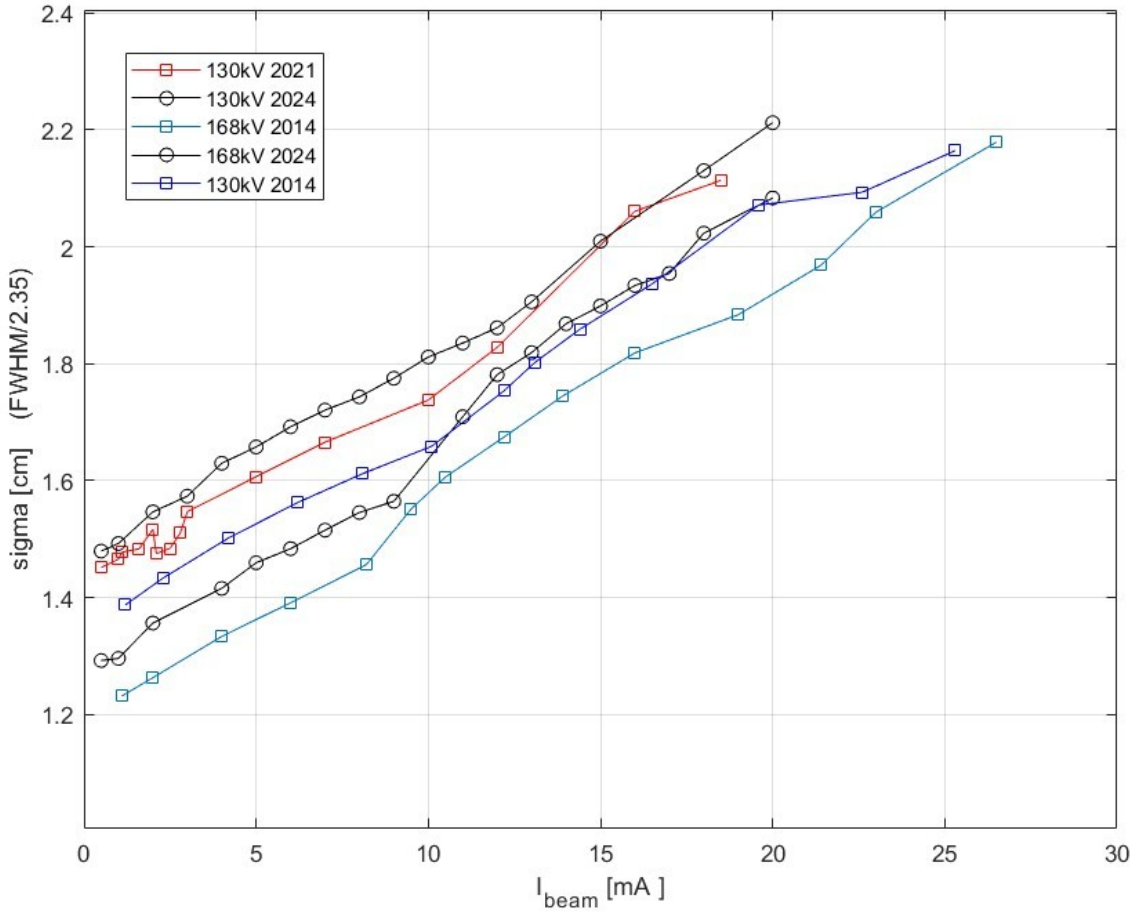
Ring characterization: bunch length vs Ibeam and VRF

The bunch length increase linearly with the bunch current at low RF voltage (130 kV)

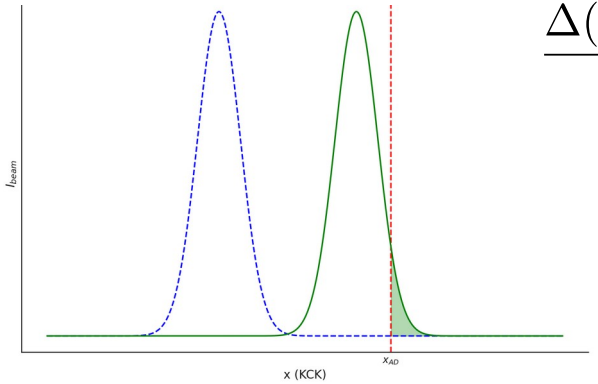
For higher values (170 kV) microwave threshold lowers and non linear effects is observed

Considering the different machine setup (optics, scrapers) the results appears compatible along the time.

Further investigation in specific positions (direct inspection of bellows) where temperature rises have been observed could be useful.

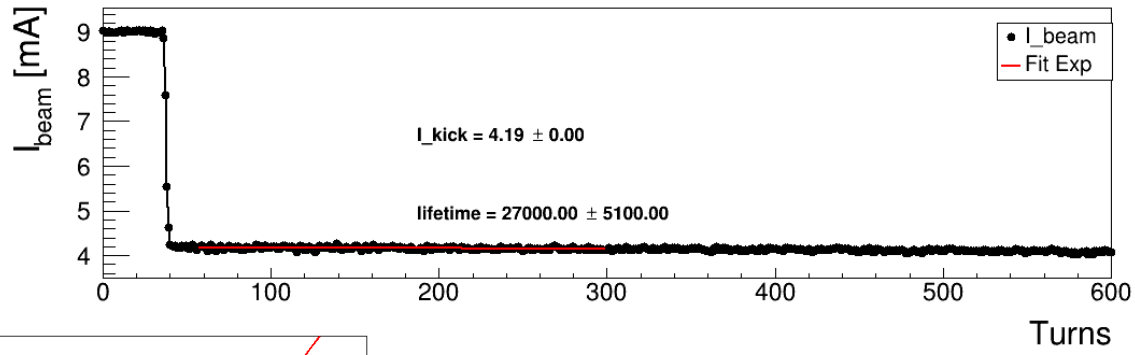


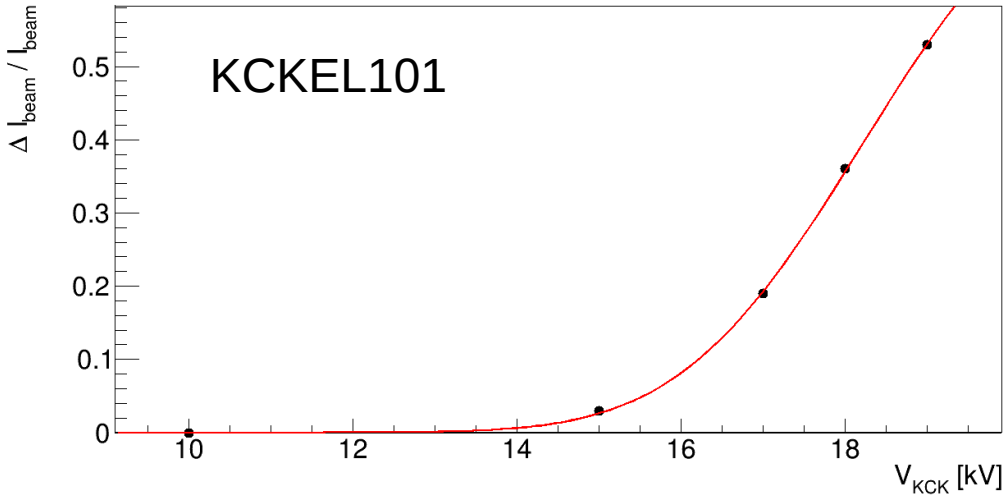
Dynamic Aperture measurement



$$\frac{\Delta(I_0 - I_{KCK})}{I_0} \propto \int_{x_{AD}}^{\infty} \mathcal{G}_{beam}(x;\sigma)dx$$

BPBES204





Measurement with:

- SCRAPER OFF
- Crab-Waist SXP OFF

Luminosity achievements

Best $\int_{3h} L = 1.33\ pb^{-1}$

Uptime (67th SciCom)