Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

DAΦNE Activity Report

Catia Milardi
on behalf of the DAΦNE Team

67th Scientific Committee Meeting May 27th, 2024

DAΦNE Team

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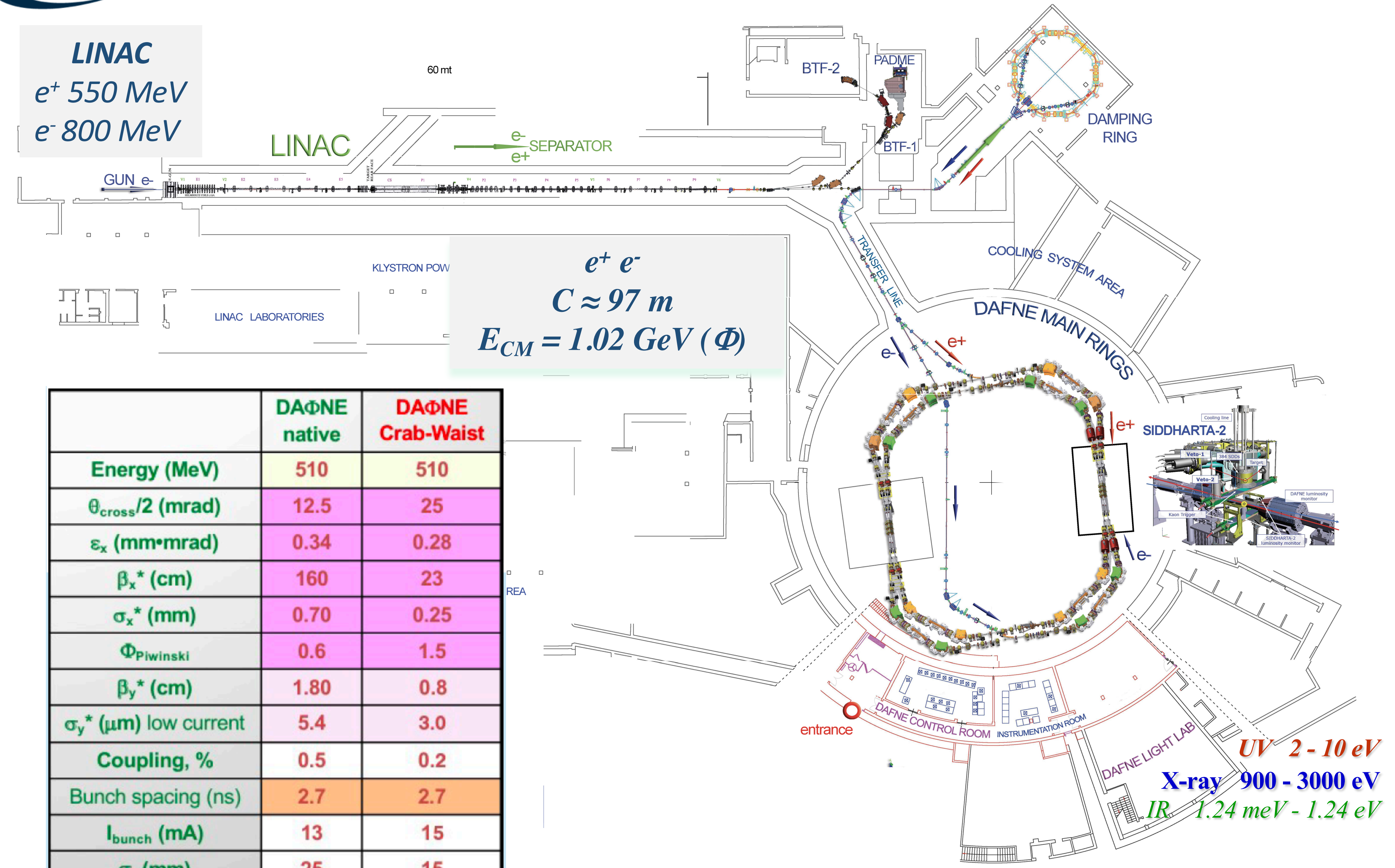
S. Ozdemir, (master student from Izmir University, Turkiye).

The DAΦNE Accelerator Complex

LINAC

e^+ 550 MeV

e^- 800 MeV



$e^+\ e^-$

$C \approx 97\ m$

$E_{CM} = 1.02\ GeV\ (\Phi)$

	DAΦNE native	DAΦNE Crab-Waist
Energy (MeV)	510	510
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm•mrad)	0.34	0.28
β_x^* (cm)	160	23
σ_x^* (mm)	0.70	0.25
$\Phi_{Piwinski}$	0.6	1.5
β_y^* (cm)	1.80	0.8
σ_y^* (μm) low current	5.4	3.0
Coupling, %	0.5	0.2
Bunch spacing (ns)	2.7	2.7
I_{bunch} (mA)	13	15
σ_z (mm)	25	15
h	120	120

UV 2 - 10 eV

X-ray 900 - 3000 eV

IR 1.24 meV - 1.24 eV

Outline

Run overview

Linear and non-linear optics tuning

Beam Dynamics studies and optimizations

Performances: luminosity and background achievements

Overlook of the deuterium run

Short term plan

Conclusions

Since the 66th Scientific Commettee

Nov 8th – Dec 13th 2023	collisions
Dec 14th	end of **Run-2** calibration,
Dec 21st	winter shutdown.
Jan 22nd 2024	operations resumed,
Feb 5th	SIDDHARTA target filled with D, start of **Run-3**
Apr 12th	end of Run-3 target filled with H,
Apr 12th	**Run-H**
May 5th – 11th	DAΦNE periodical maintenance
May 18th	LNF Open Day

Fixing some issues affecting: CDHEL201, WGLEL101, and klystron of the LINAC RF plant B

May 24th	full operability recovered

About L and Background Diagnostics

DAΦNE **luminosity** measurement relies on two devices:
CCAL (Crystal CALorimeters), and Gamma monitors, used for machine tuning.

The absolute measurement of the collider luminosity is provided by the SIDDHARTA-2 detector based on charged kaon flux measurement.

The **background** level on the experimental apparatus (BCK) is monitored, in real-time, by counters based on Kaon over Minimum Ionising Particle rate (Kaon/MIP), and Kaon over Silicon Drift Detector rate (Kaon/SDD) also provided by the SIDDHARTA-2 experiment.
CCAL also provides a powerful BCK diagnostics, mostly in injection.

Kaon/SDD is actually used as a main data quality parameter, $\mathbf{L_{HQ}}$, to discriminates whether data can be used for physics analysis or not.

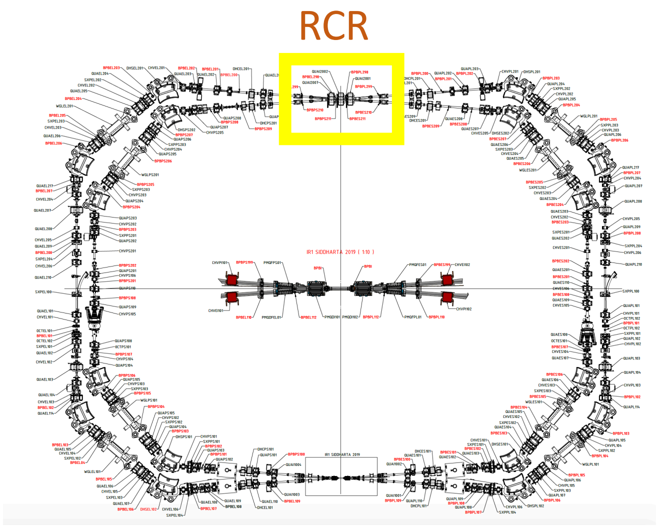
$$\mathbf{L_{HQ} \geq 0.6.}$$

Linear and non-linear Optics

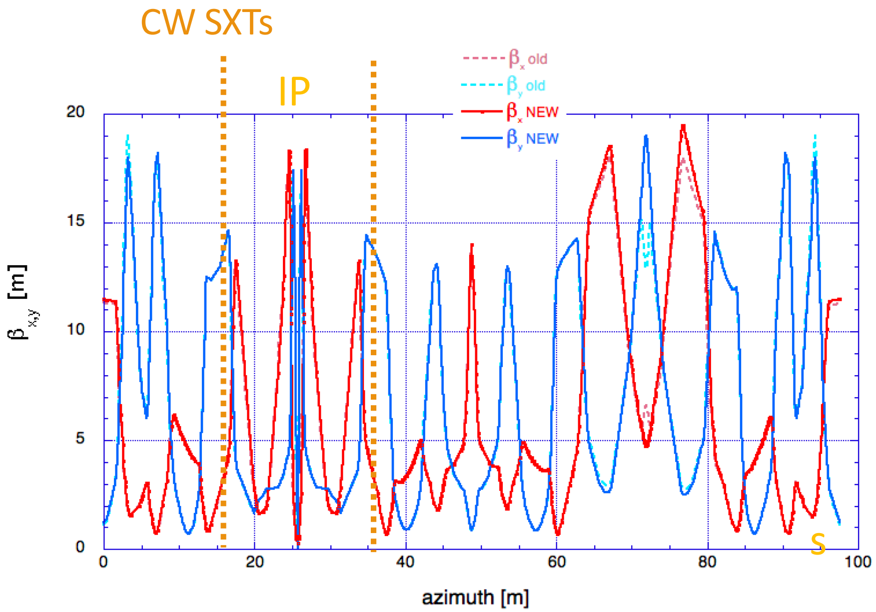
Main Rings Optics

New **Crab-Waist ring optics**

- symplified focusing structure in the RCR,
- 2 QUADs where beams pass off-axis are switched off, thus eliminating spurious component in the QUADs magnetic field,
- Same optics parameters in the IR.



New optics improves closed orbit correction allowing to reduce the total strength of the used steering magnets, thus also contributing to minimize vertical dispersion



$\beta_y^* = 0.008$ m

$\beta_x^* = 0.23$ m

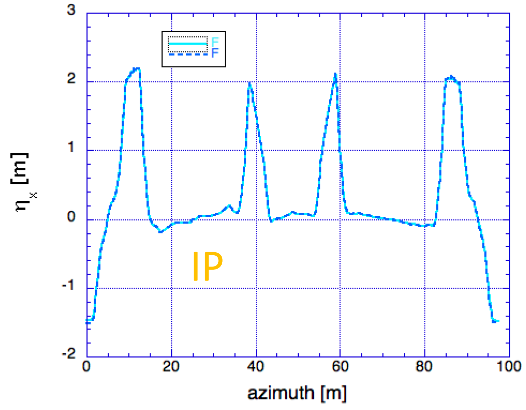
MRs working point:

$Q_x^- = 0.103$

$Q_y^- = 0.162$

$Q_x^+ = 0.114$

$Q_y^+ = 0.180$



Non-linear Optics

The strengths of ***Crab-Waist Sextupoles*** have been progressively increased, up to **77% of their nominal value**. This allowed to improve instantaneous luminosity and background level control.

$$k_s = \frac{\chi}{2\theta}\frac{1}{\beta_y^*\beta_y^{sext}}\sqrt{\frac{\beta_x^*}{\beta_x^{sext}}}$$

Chromatic sextupole and octupole set-points have been **refined** according a comprehensive iterative optimization process, implemented experimentally, during data delivery, increasing:

- injection efficiency,
- beam lifetime,
- dynamic aperture,
- energy acceptance.

Positron Ring

ξ_x -0.938

ξ_y 1.534

compaction 0.0190

368.667000 center frequency

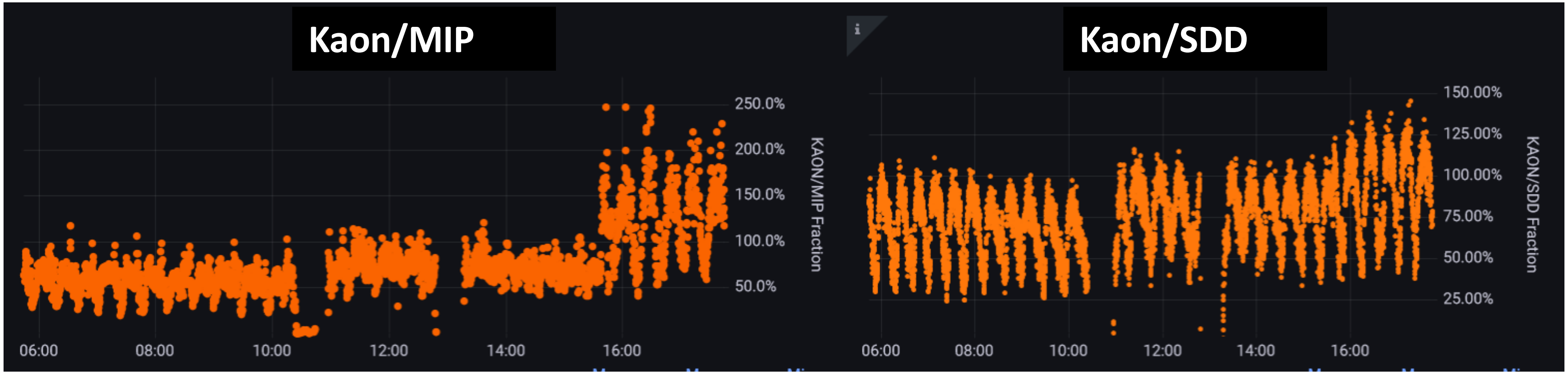
Energy aperture A_E

$$-3.8\text{ MeV }(-0.8\%) \leq A_E \leq 3.1\text{ MeV }(0.6\%)$$

This procedure led to a remarkable reduction of the background affecting the measurements, how it will be shown in the following.

Background Improvement

Non-linear optics tuning allowed to increase energy acceptance, and dynamic aperture, leading to gain almost a factor of 2, and 1.45 in terms of Kaon/MIP, and Kaon/SDD rates respectively.



Main Rings Beam Dynamics

DAΦNE

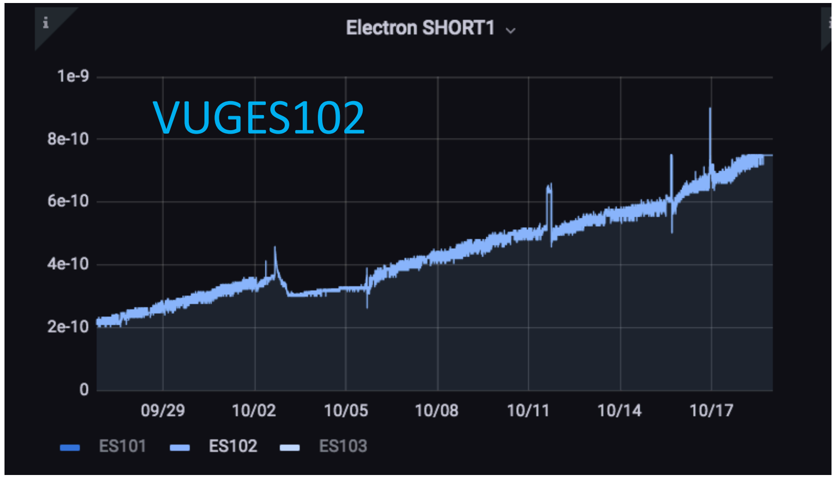
MRe Beam Dynamics

Vacuum

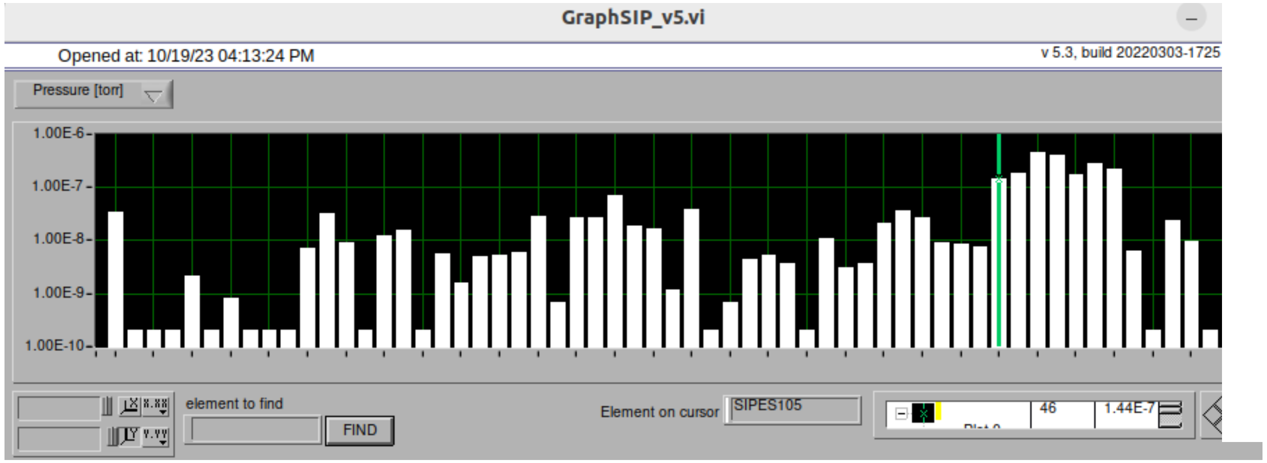
Electron beam dynamics observations

- *Vertical tune had to be lowered wrt the nominal one*.
- Strong vertical instability appeared, even in single beam mode, it was damped by beam-beam only for current of the e+ beam lower than 750 mA, above this threshold the e- beam blew up vertically, luminosity dropped as background increased suddenly.
- Poor lifetime.
- Flip-flop.
- Sudden beam losses above 1.5 A.

All these *effects were largely mitigated by decreasing the number of bunches from 110 to 95.*



Electron beam was clearly affected by ion trapping although there was no clear evidence of vacuum issues.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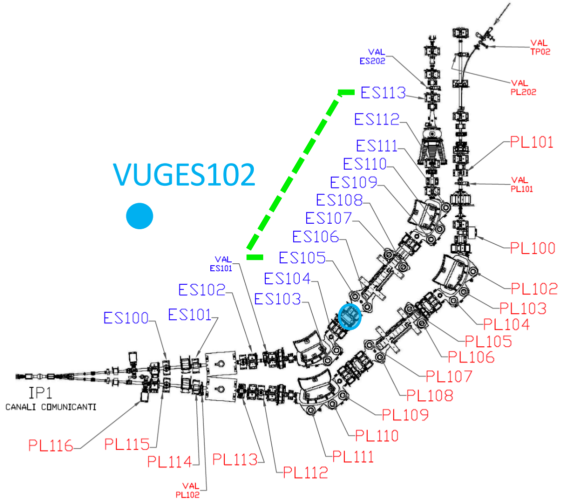
v 5.3, build 20220303-1725

Element on cursor: SIPES105

46

1.44E-7



MRe Beam Dynamics

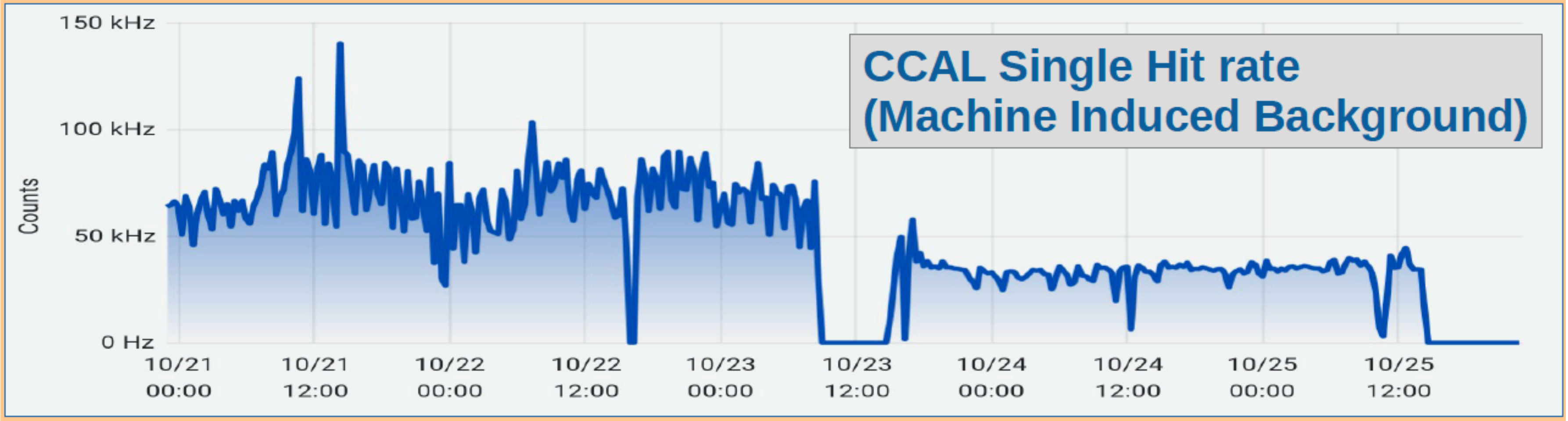
Vacuum

Machine was operated with standard luminosity

$L_{peak} \sim 1.8\ 10^{32}\ cm^{-2}s^{-1}$

but it caused higher background rates on the detector

Vacuum leak mitigated in Oct 2023, and again in Jan 2024 leading to further background improvements and to use 110 in collisions.

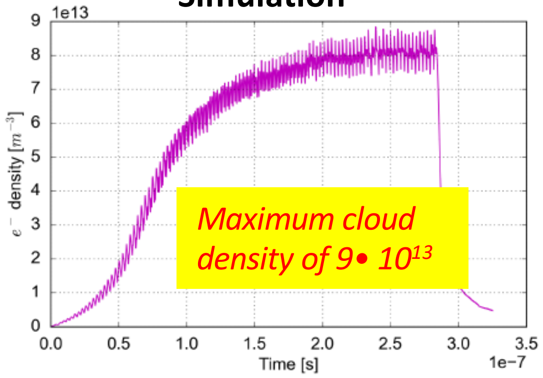


E-cloud studies in MRp

Tune-shift measurements

- The **electron-cloud instability** is a major limitation for positron beams at DAΦNE.
- The horizontal **transverse feedback** can be used as a **diagnostic tool** to evaluate this instability.
- Bunch transverse oscillations digitized by the ADC are analyzed to **compute the fractional tunes,** which is determined with a **resolution of 10^{-5}.**

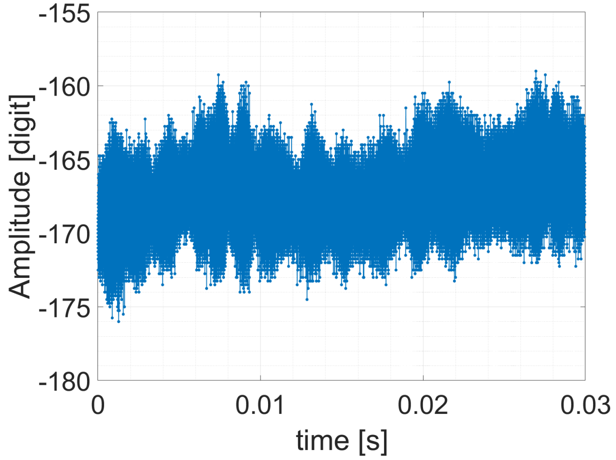
Simulation



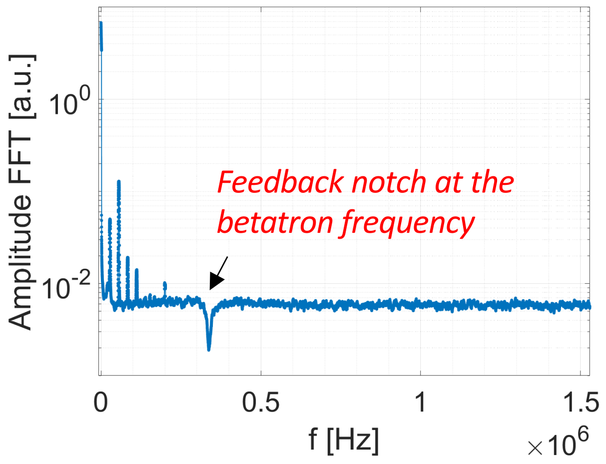
Maximum cloud density of 9• 10^{13}

Example with 105 positron bunches in DAFNE, 800 mA average current, feedback on

Horizontal oscillations for bunch 1

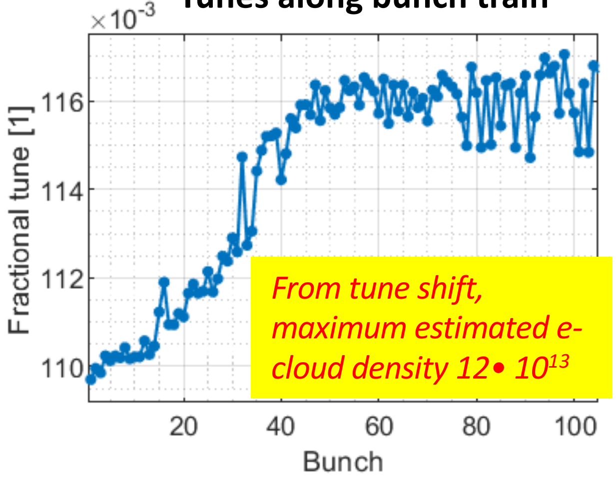


FFT of the oscillations



Feedback notch at the betatron frequency

Tunes along bunch train



From tune shift, maximum estimated e-cloud density 12• 10^{13}

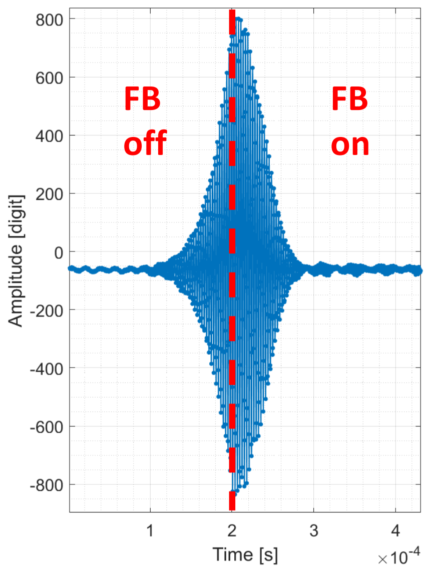
E-cloud studies in MRp

Grow-damp measurements

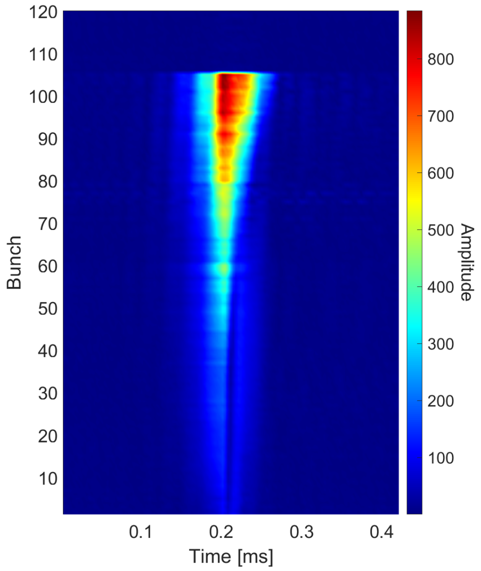
- ❑ Grow-damp measurements: feedback off for a certain time, then on.
- ❑ A quasi-online analysis computes the grow rates of the coupled-bunch modes.
- ❑ This analysis is a useful diagnostic tool able to evaluate the strength of the electron-cloud instability using different currents and filling patterns.

Example with 105 positron bunches in DAFNE, 720 mA average current, feedback off for 0.2 ms

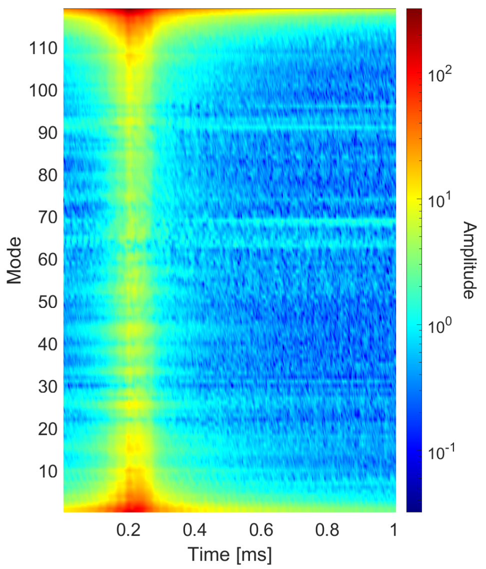
Oscillations of bunch 105



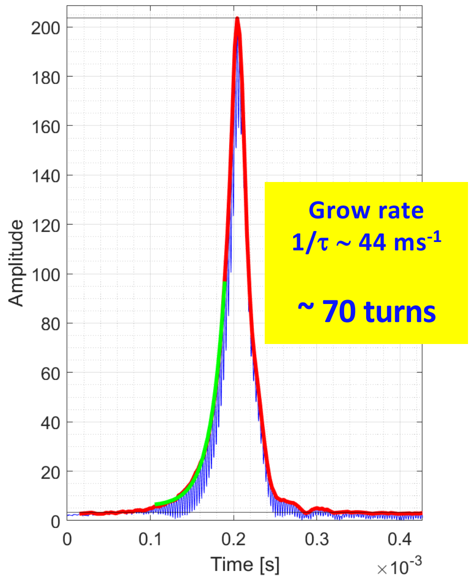
Oscillation amplitudes



Mode amplitudes



Amplitude of mode 119



Grow rate
$1/\tau \sim 44\ \mathrm{ms}^{-1}$

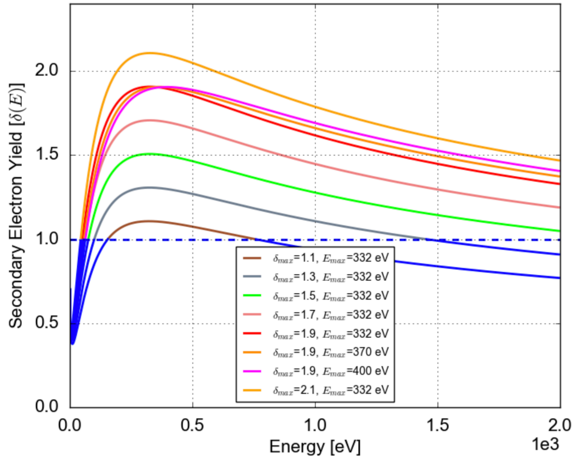
~ 70 turns

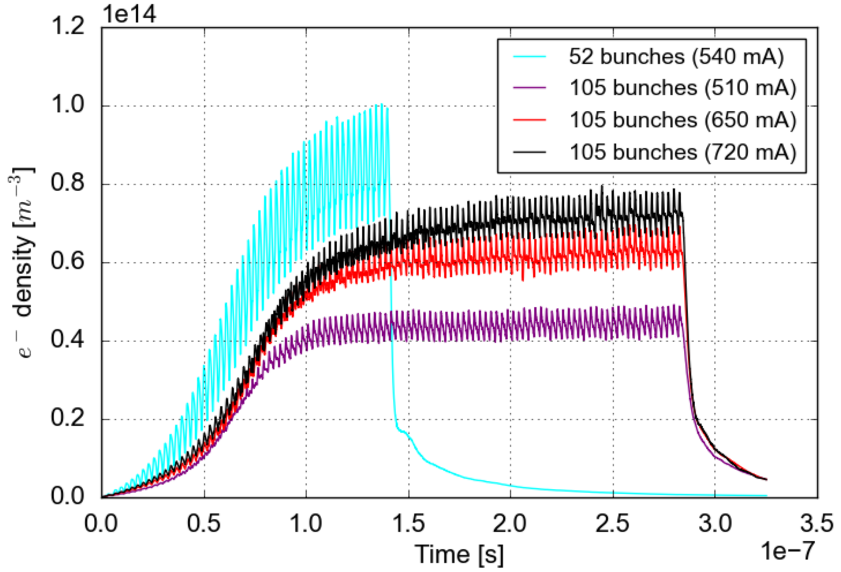
E-cloud Simulations

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





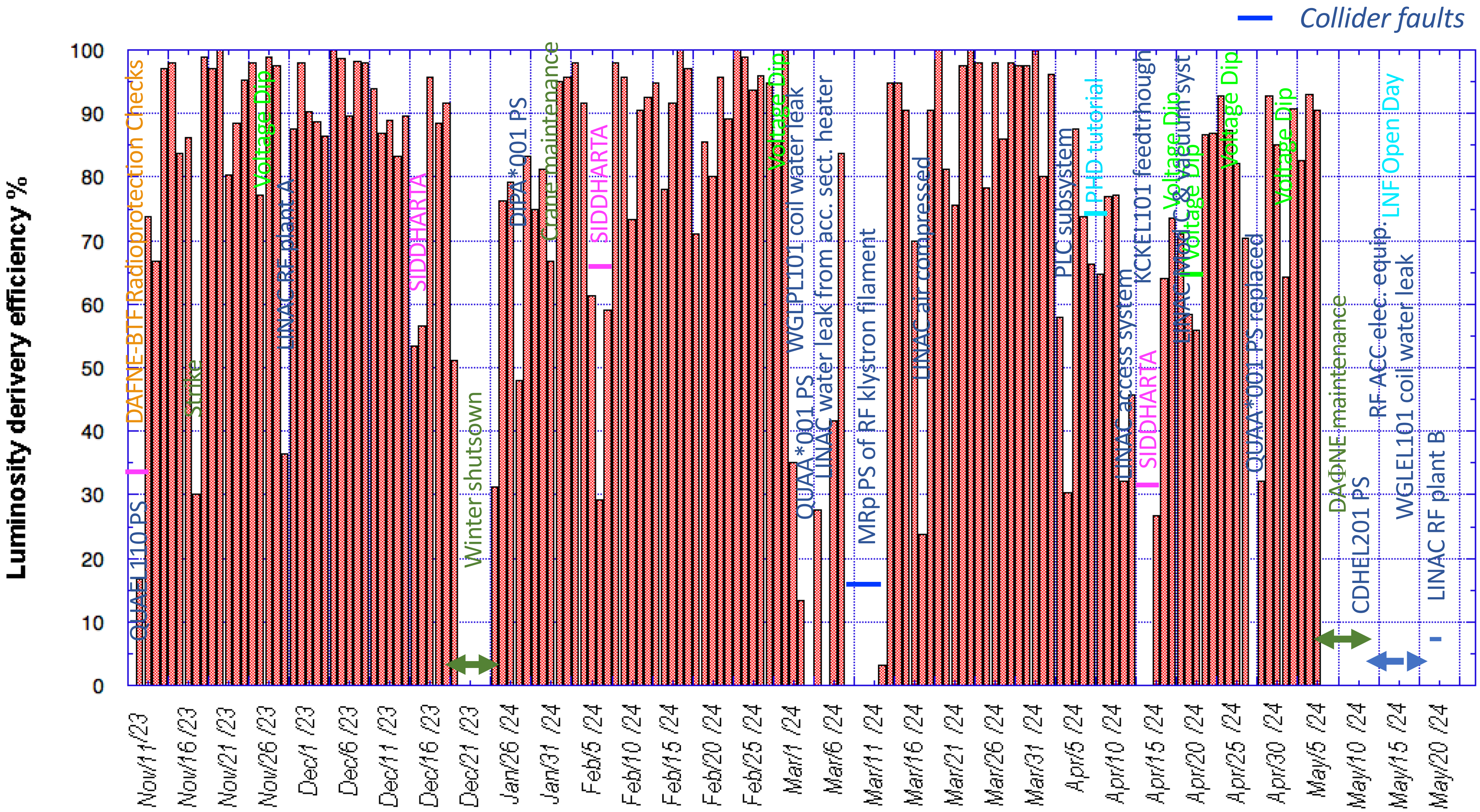
	Meas	Simulated
Bunch no	**Growth rate**	**e^- density**
105 bunches [720 mA]	44 ms^{-1}	0.8×10^{14} m^{-3}
105 bunches [650 mA]	22 ms^{-1}	0.7×10^{14} m^{-3}
105 bunches [510 mA]	6 ms^{-1}	0.5×10^{14} m^{-3}
52 bunches [540 mA]	18 ms^{-1}	1.0×10^{14} m^{-3}

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}

DAΦNE Performances

Luminosity-delivery Efficiency (Uptime)

Collider efficiency in delivering luminosity is defined as the fraction of time the collider has been able to deliver a *luminosity exceeding* $10^{32}cm^{-2}s^{-1}$ after each beams refill.



DAFNE Uptime

DAΦNE Downtime includes not only collider fault events.

It includes:

machine stops caused by external events independent from the DAFNE reliability:

- radioprotection tests,
- LNF infrastructure serving the DAFNE accelerator complex,
- voltage dips,
- outreach activities

Experiment requirements:

- target gas refill,
- calibrations,
- dewar refill,
- apparatus and acquisition faults.

Faults impact
(10 Nov 23 ÷ 24 May 24)

System	*hours*
LINAC	276
WGL magnets	173
PSs	275
Ring RF cavities	156

In the period 10 Nov 23 ÷ 24 May 24 collider faults have had the following impact in terms of time:

- 13 events < 1 day
- 7 events ≥ 1 day

90% of PS faults are due to Damping Ring devices, which have been appointed as critical components since long time.

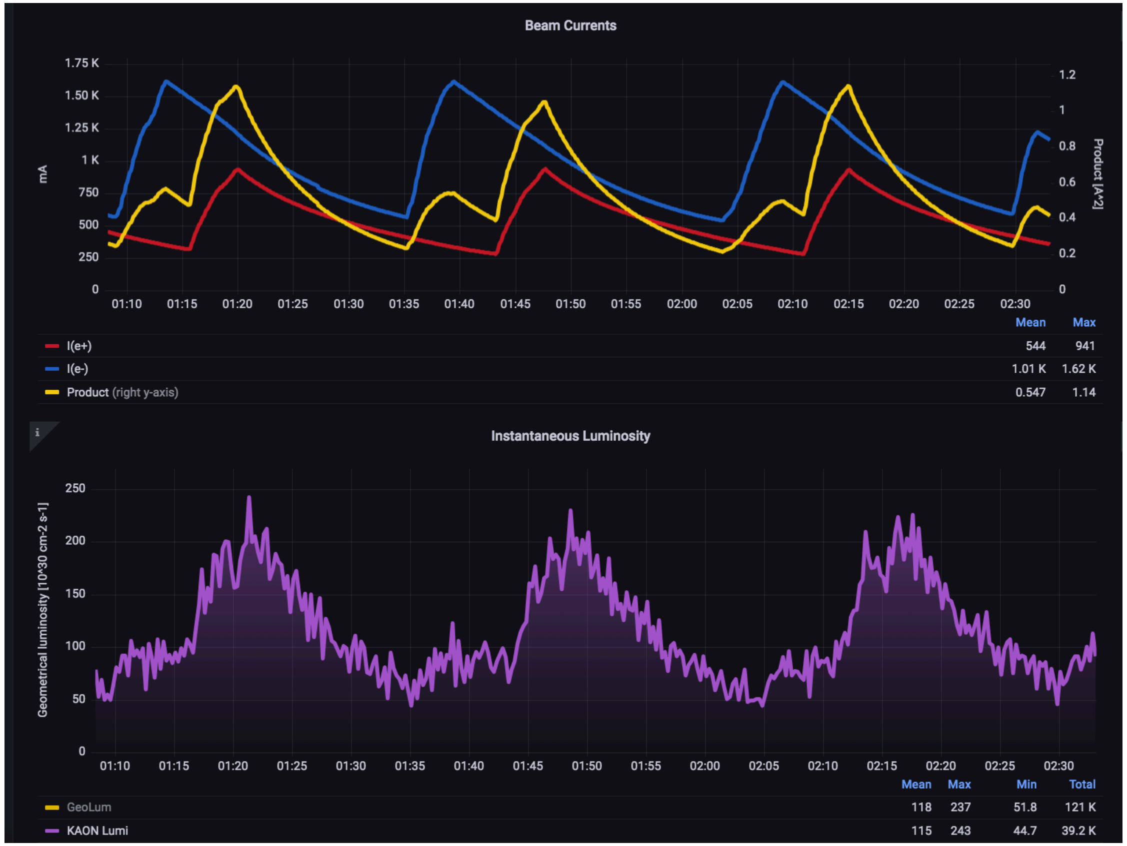
In the period (10 Nov 23 ÷ 5 May 24) DAΦNE net L uptime was about 75%

Luminosity Achievements

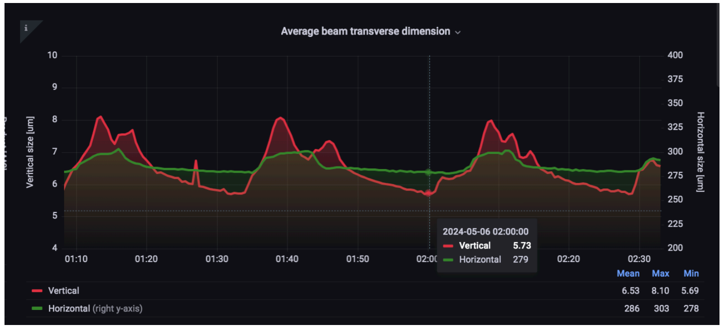
$L_{peak} = 2.4 \bullet 10^{32}\ cm^{-2}s^{-1}$

$I^{-}_{peak} = 1.14$ A

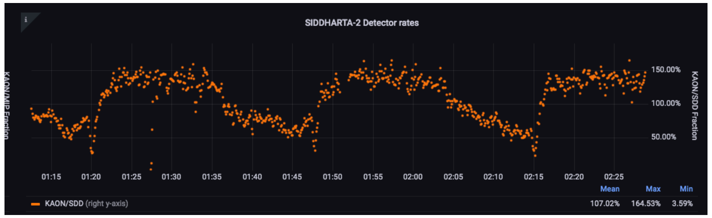
$I^{+}_{peak} = 0.89$ A



Average value of the convoluted transverse beam dimensions



Kaon/SDD



L_{HQ} ~ 97%

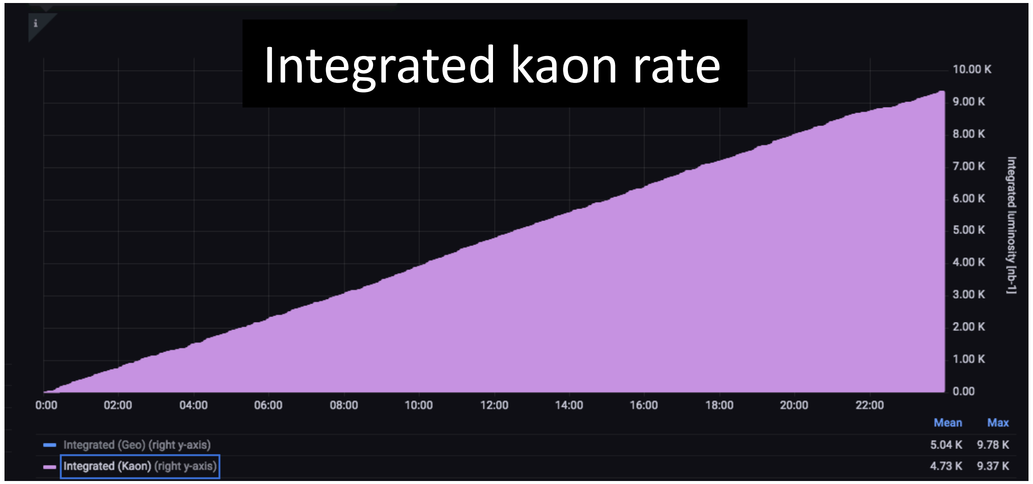
Luminosity Achievements

Daily integrated luminosity

$$\int_{day} L = 9.4\ pb^{-1}$$

$I^-_{MAX} = 1.65$ A

$I^+_{MAX} = 1.0$ A

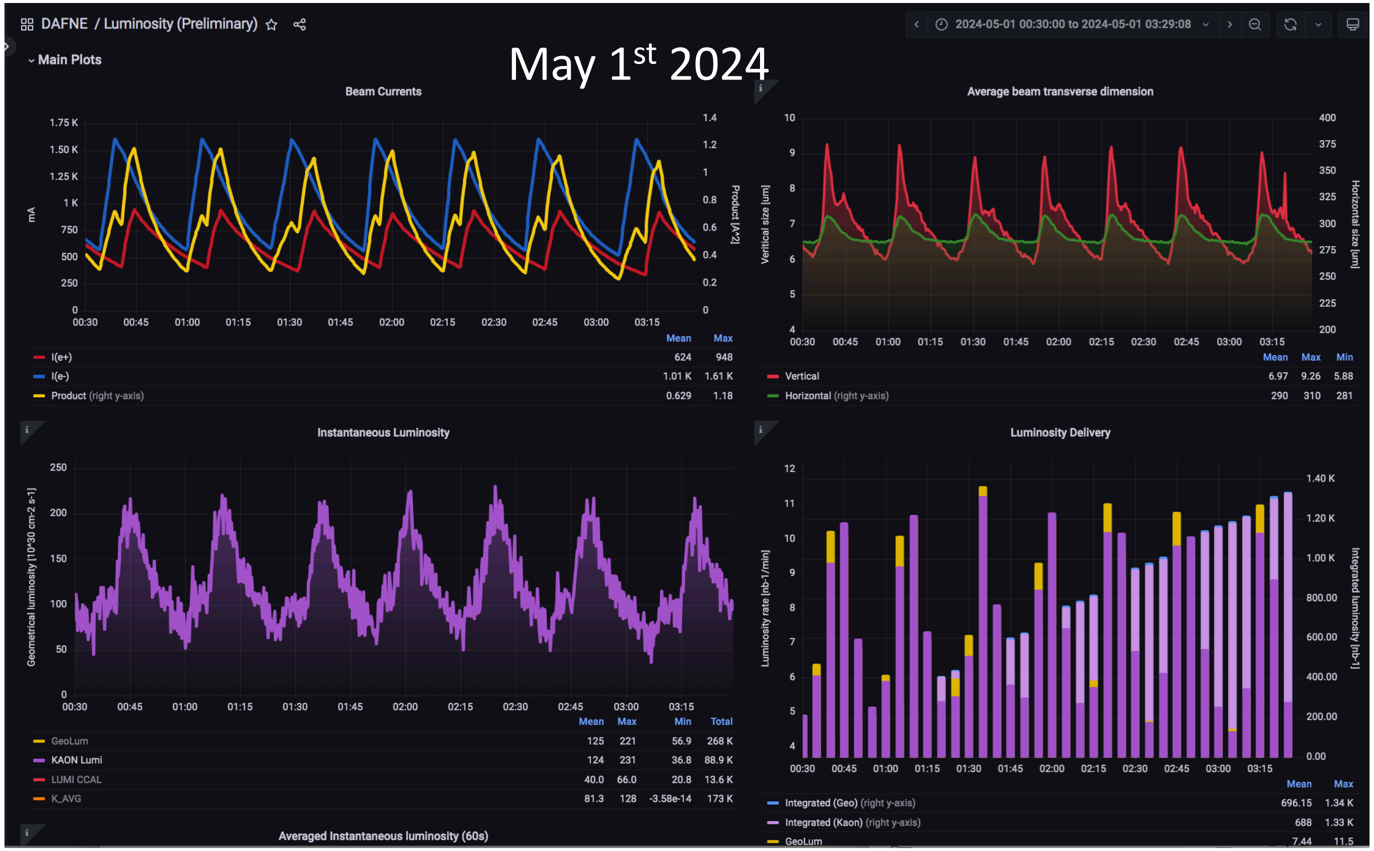

Integrated kaon rate

$L_{HQ} \sim 96\%$

Luminosity Achievements

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

Optimal BCK levels, and L_{HQ} factor.



May 1st 2024

Beam Currents

	Mean	Max
I(e+)	624	948
I(e-)	1.01 K	1.61 K
Product (right y-axis)	0.629	1.18

Average beam transverse dimension

	Mean	Max	Min
Vertical	6.97	9.26	5.88
Horizontal (right y-axis)	290	310	281

Instantaneous Luminosity

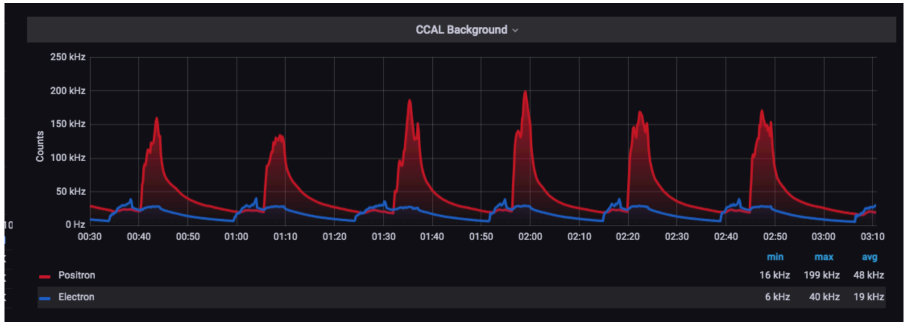
	Mean	Max	Min	Total
GeoLum	125	221	56.9	268 K
KAON Lumi	124	231	36.8	88.9 K
LUMI CCAL	40.0	66.0	20.8	13.6 K
K_AVG	81.3	128	-3.58e-14	173 K

Luminosity Delivery

	Mean	Max
Integrated (Geo) (right y-axis)	696.15	1.34 K
Integrated (Kaon) (right y-axis)	688	1.33 K
GeoLum	7.44	11.5

MRs Injection

LINAC works at 25 Hz
Injection in MRs:
2 Hz for e-
1 Hz for e+



In a collider there are two different kinds of backgrounds produced during the injection and costing phase respectively.

They require completely different analysis and mitigation approaches.

Injection background has been considerably reduced by optimizing injection efficiency, and by properly steering the stored beam orbit in the injection sections. This reduced the background down to acceptable levels for the e^- beam, but it did not work as well for e^+ one.

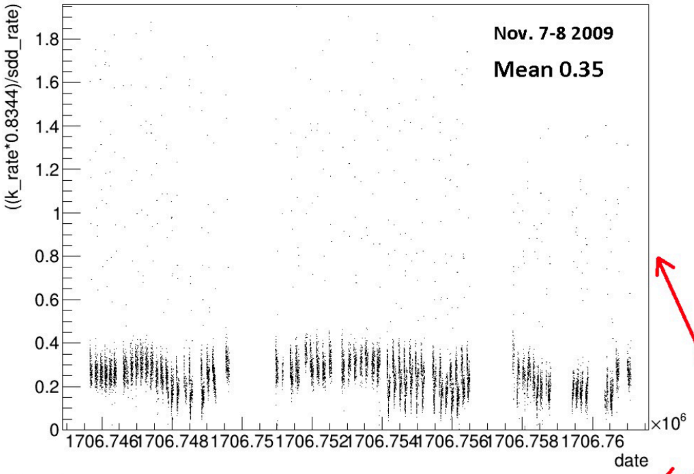
For this reason, vertical dimension of the e^- beam are artificially increased during injection, by using a calibrated skew quadrupoles bump. In order to reduce the beam-beam kick on the weak e^+ beam, thus avoiding rapid lifetime drops and sudden background bursts.

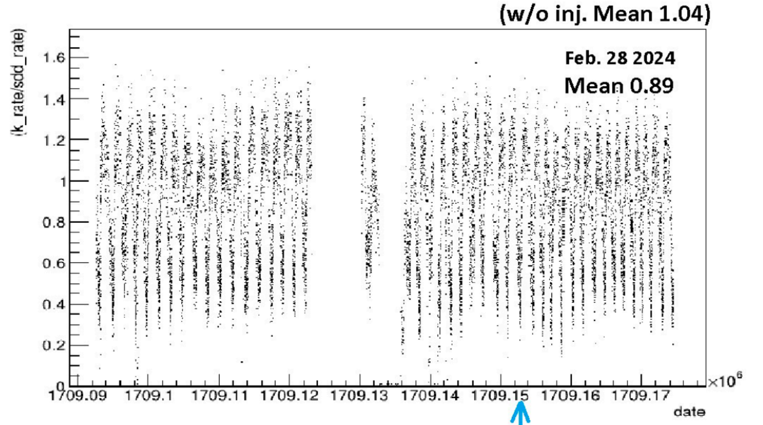
Background Improvement

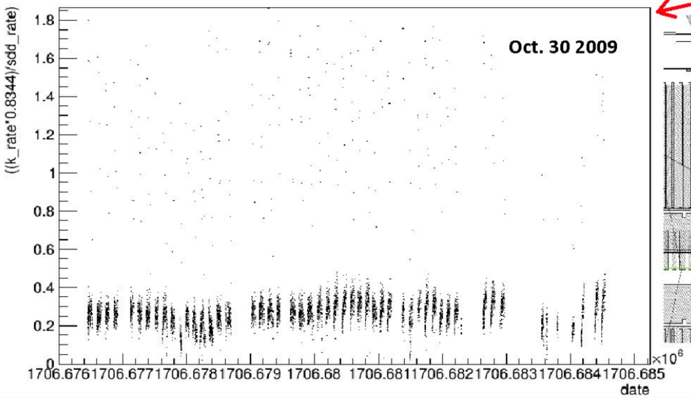
Physics events delivered to SIDDHARTA-2 experiment exhibit now a signal to noise ratio 3 time higher w.r.t. the 2009 run. This was evaluated taking into account the acceptance of the new detector components: kaon trigger, and SDD. Other analysis parameters such as trigger efficiency, and veto system have not been included.

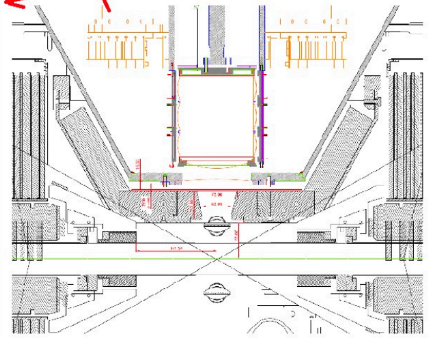
Preliminary analysis indicates this improvement is in large part due improvements is in large part due to the collider configuration, and to the new design of the PMQD installed in the low-beta of the interaction region.

SIDDHARTA Data quality (r)evolution 2009-2024

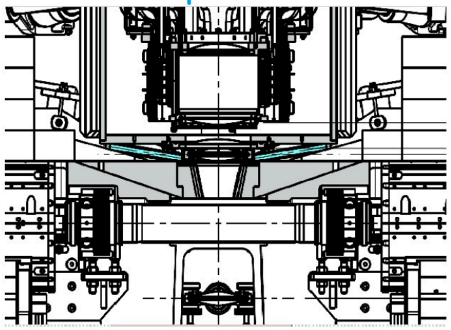








SIDDHARTA

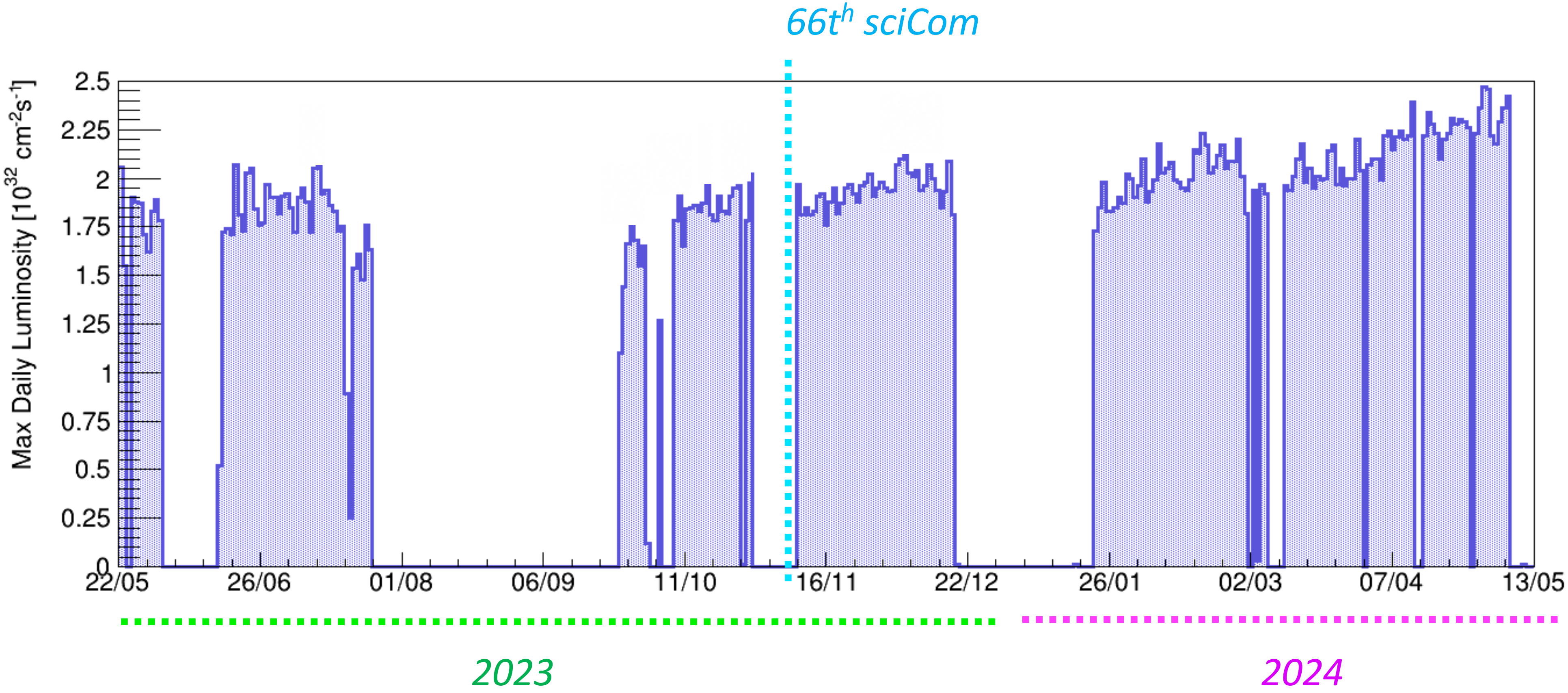


SIDDHARTA-2

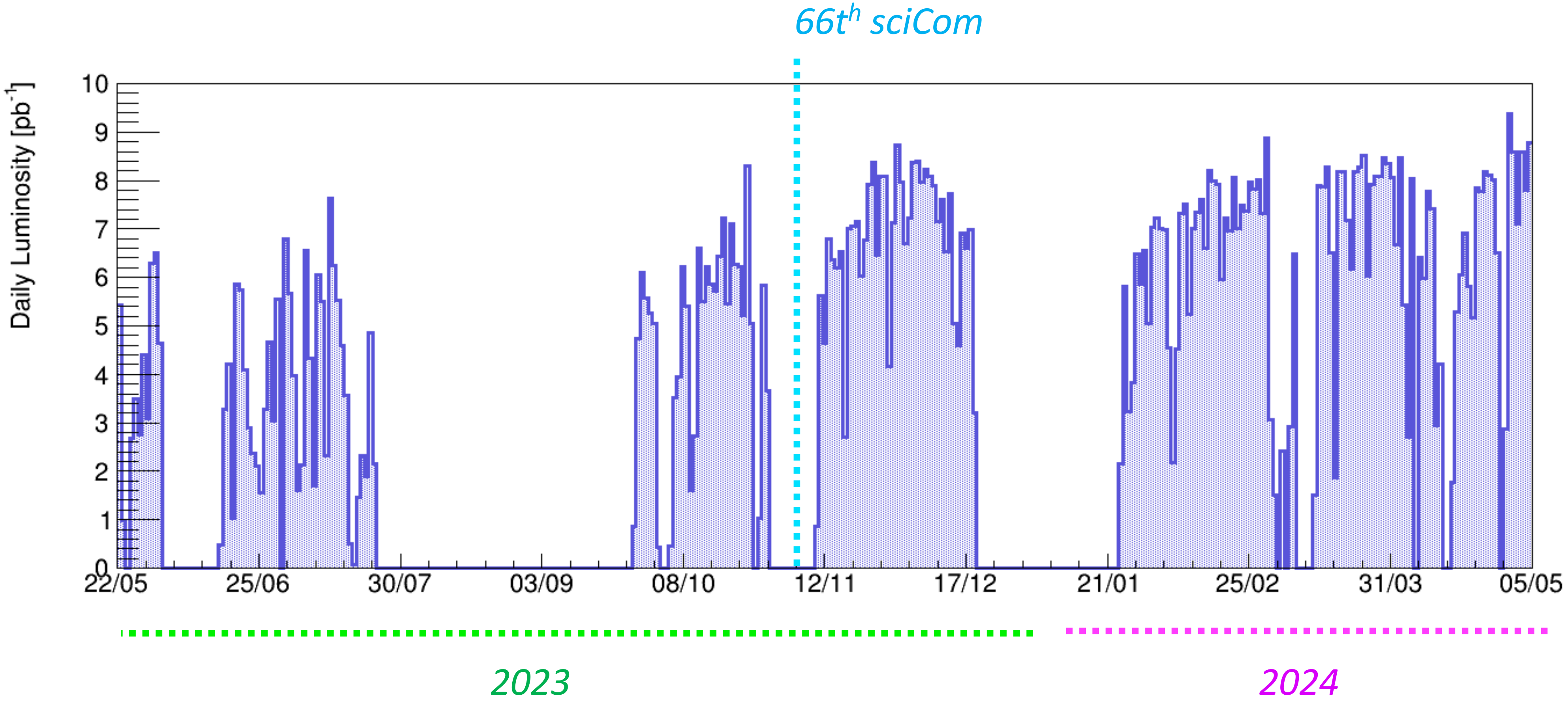
(Analysis from M. Iliescu)

Overlook of the Deuterium Run

Daily Peak Luminosity trend



Daily Integrated Luminosity trend



66th sciCom

2023

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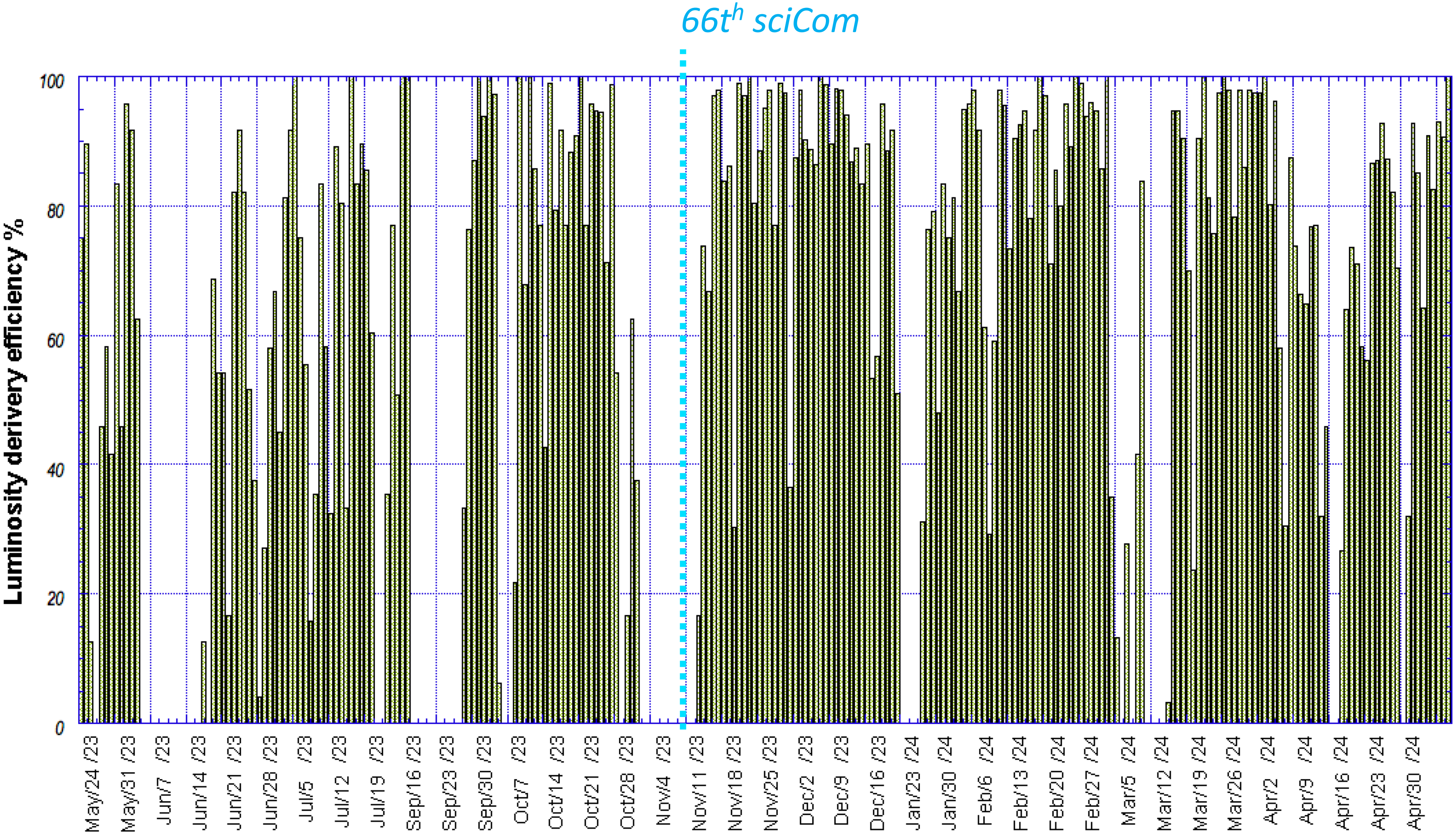
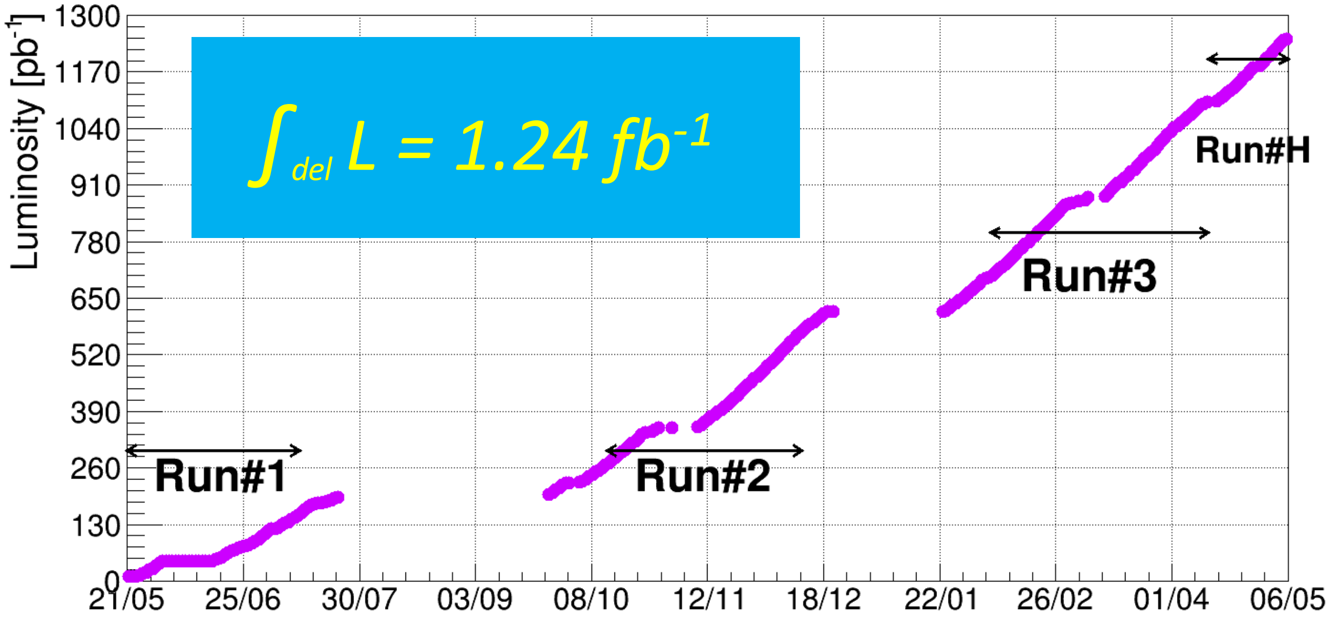
Luminosity-delivery Efficiency (Uptime)



Total Integrated Luminosity

DATE	L_{acq} [pb^{-1}]	L_{acq} [pb^{-1}] $L_{HQ} \geq 0.6$	Good Data %
Run-1 (21/05/23 ÷ 21/07/23)	196	164	84
Run-2 (13/10/23 ÷ 11/12/23)	344	276	80
Run-3 (06/02/24 ÷ 12/04/24)	435	375	86
Run-H for calibration (12/4/24 ÷ 6/5/24)	153	140	91,5
Total	1128	955	85

The fraction of high-quality data increased significantly along the time thank to collider adiabatic tuning, and machine studies.



Short Term Plan

Presently, data taking is going on in order to study the detector response as a function of the target gas density in view of the physics analysis.

Before closing the present run, we agreed to perform a selected set of machine studies aimed at:

- providing references for future lepton colliders (crab waist, e-cloud)-FCC-ee, CEPC, Super Charm-Tau factories,
- characterizing the colliders (bunch lengthening, dynamics aperture, beam current limits),
- training young personnel and people working for the FCC projects,
- disseminating our experience: articles, workshops, conference papers.

In this context operations will continue till the end of June, with the possibility to be extended to the first week of July, in the case of favorable weather conditions.

Machine studies

Study of the current limits in the two beams.
Bunch length measurements as a function of single bunch current
Dynamic aperture measurements

Impact of e-cloud induced effects on the e^+ beam dynamics in single beam and in collision.

Characterization of Crab-Waist collisions:

- Σy measurement,
- collisions at low currents, and with different bunch patterns
- luminosity measurements as a function of α_y at the IP.

Conclusions

DAΦNE operated continuously, ensuring physical opportunities to all its users: SIDDHARTA-2, BTF, DAFNE-Light.

The DAΦ NE lepton collider has delivered to the SIDDHARTA-2 detector using a deuterium gas target a data sample of the order of 1.24 fb^{-1}, well beyond the experiment request.

Large part of these data, about 85 %, have very high quality: Kaon/SDD ≥ 0.6.

Such remarkable results have been achieved thanks to the continued machine tuning, and to few selected machine studies.

Presently, data taking is going on, in order to study the detector response as a function of the target gas density in view of the physics analysis.

Acknowledgments

Many thanks to the **Staff of the Accelerator and Technical Divisions**. Their commitment allowed to achieve the present DAΦNE performances.

Special thanks to the ***Operators*** for taking care of the DAFNE infrastructure 24h a day, and for their continuous efforts in optimizing **collisions**, **BTF runs**, **synchrotron radiation** beams for the DAFNE-Luce laboratory.

Warm acknowledgment to the **SIDDHARTA Team** for their fruitful cooperation.

Thank you

Spare Slides

Update about Operation Group

The **LNF Accelerator Operation Group** provides support systematically to the experimental activities on:

DAΦNE collider,
BTF (2 lines),
LDS,
TEX,
SPARCLab.

In the last 3 years the **Accelerator Operation Group** lost several highly experienced Technicians.

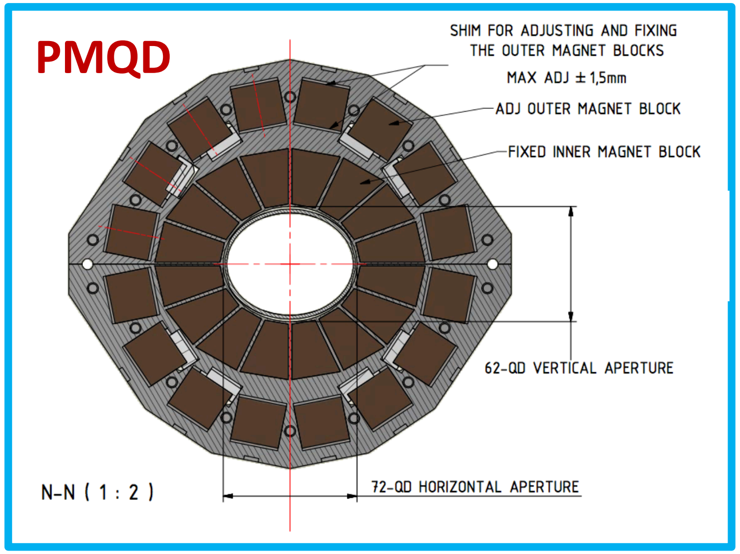
Shifts relies on 7 crews of 4 technicians each

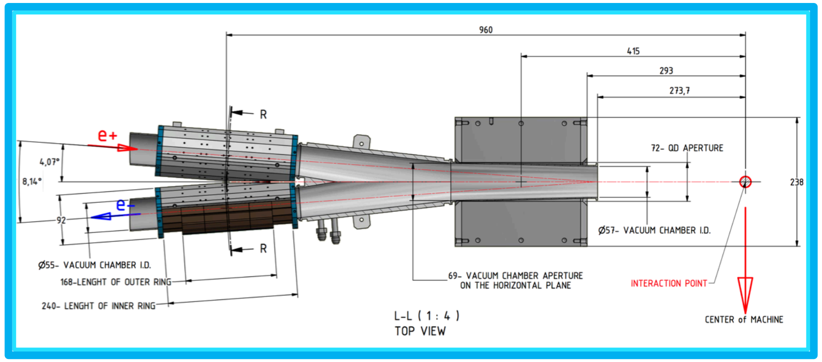
In the last months 4-5 operators have been missing
By the end of the year one more colleague will retire.

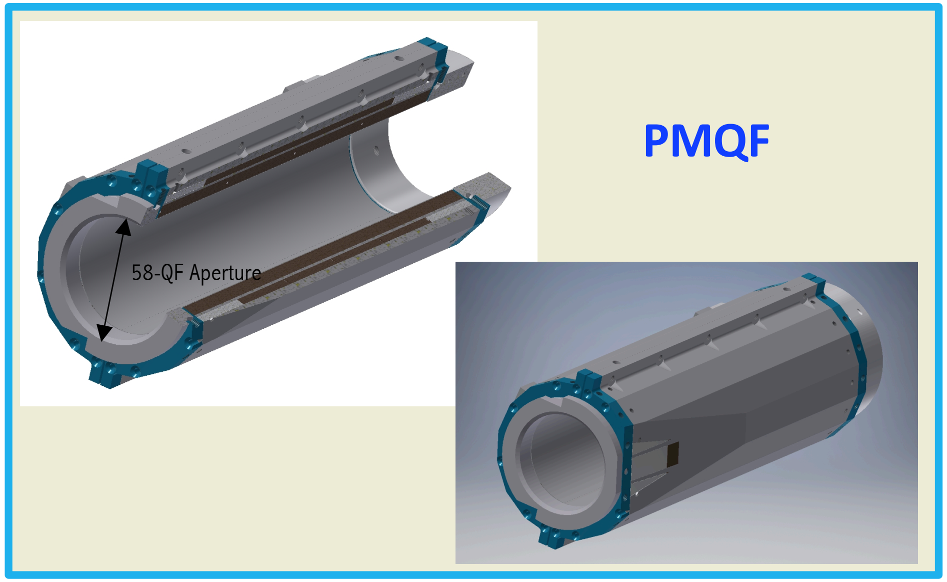
PMQs specifications

New PMQs are Halbach type magnets made of SmCo2:17

PMQs have been designed in collaboration with the ESRF magnet group.


PMQD




PMQF

	PMQD	PMQF
Beam Pipe Aperture H-V (mm) at IP (I row) and at Y (II row) side	57 69 - 55	54
Inner Apert. With Case H-V (mm)	72 - 62	58
Outer Diameter H-V (mm)	238 - 220	95.6
Mech. Length Inner-Outer (mm)	220	168 - 240
Nominal Gradient (T/m)	29.2	12.6
Integrated Gradient (T)	6.7	3.0
Good Field Region (mm)	±20	±20
Integrated Field Quality |dB/B|	5.00E-4	5.00E-4
Magnet Assembly	2 halves	2 halves