Istituto Nazionale di Fisica Nucleare
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Status and Perspective of the DAΦNE Lepton Collider

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Turkish Physical Society 8th Internationally Participated Congress On Particle Accelerators And Applications

Sep 5 – 7, 2022, Bodrum, Türkiye.

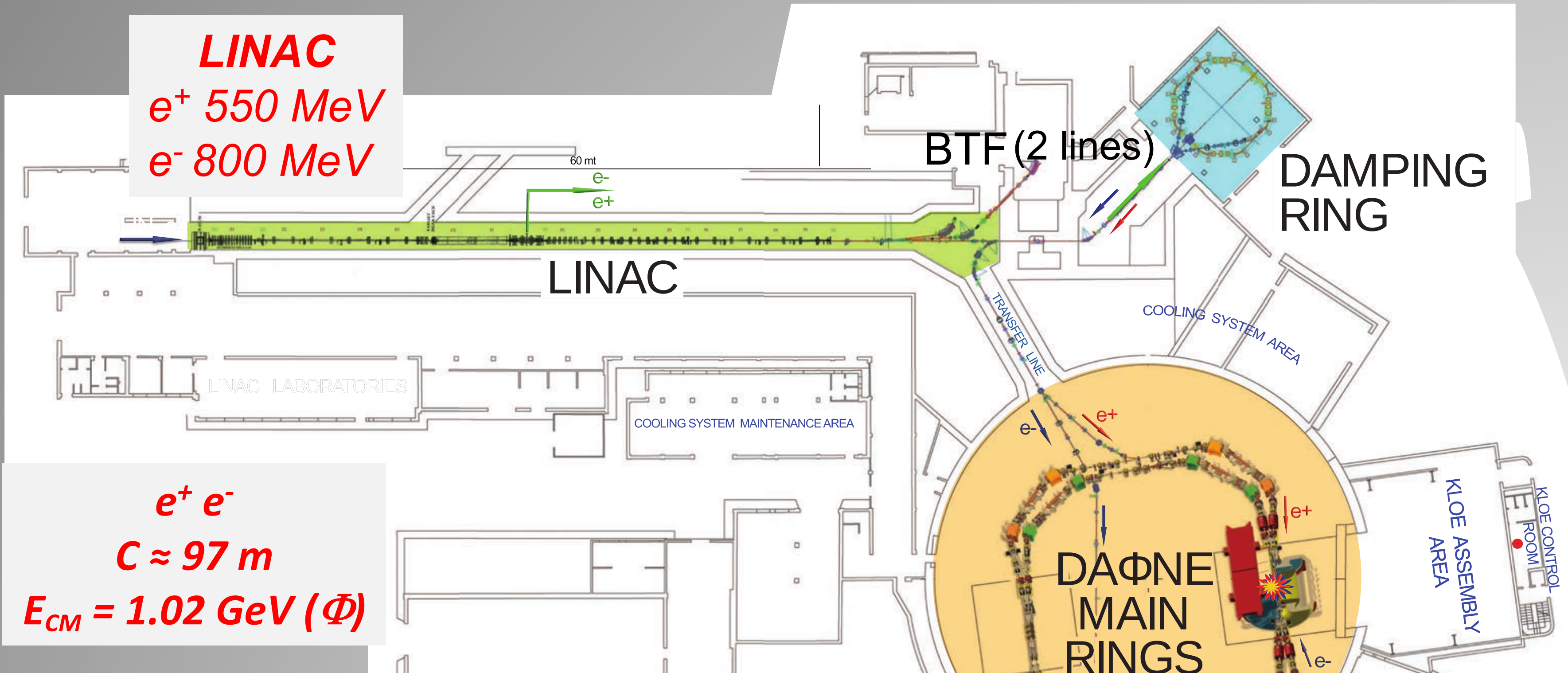
Outline

- *DAΦNE overview*
- *Collider performances in the native configuration*
- *Large Piwinski angle and Crab-Waist Collision Scheme*
- *Performances of Crab-Waist collisions for the SIDDHARTA and KLOE-2 detector*
- *The present SIDDHARTA-2 run*
- *Future possible perspective*
- *Conclusions*

The DAΦNE Accelerator Complex

LINAC
e^+ 550 MeV
e^- 800 MeV

$e^+ e^-$
C ≈ 97 m
E_{CM} = 1.02 GeV (Φ)



The Φ resonance

The interest on Φ resonance relies on the fact that **this resonance is a source of monochromatic colinear KK pairs**:

Φ --> K^+K^- 49%

$K^0_S\, K^0_L$ 33%

$\rho\pi$ 13%

usually:

K^0_L --> 3π

K^0_S --> 2π

in the case of CP violating decay:

K^0_L --> 2π (0.3% of decays)

Neutral kaon have been used by the **KLOE** experiment to study

CP, CPT, rare decays

Charged kaons have been used by:

FINUDA to produce Hypernuclei

DEAR – SIDDHARTA to study K-N scattering lenghts

DAΦNE History & Plans

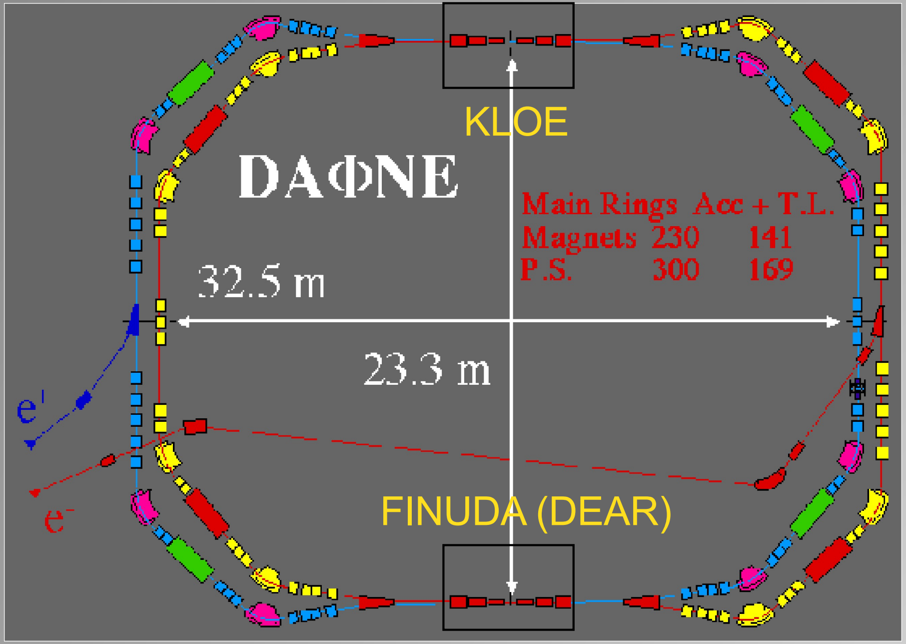
- DAΦNE is an electron-positron collider designed in the mid '90s, it came into operation in 2000

- It has been providing data in consecutive data-taking periods to:
  KLOE, **DEAR** and **FINUDA** experiments until 2007
  SIDDHARTA in 2008 ÷ 2009
  again for the upgraded **KLOE-2** detector between November 2014 and March 2018

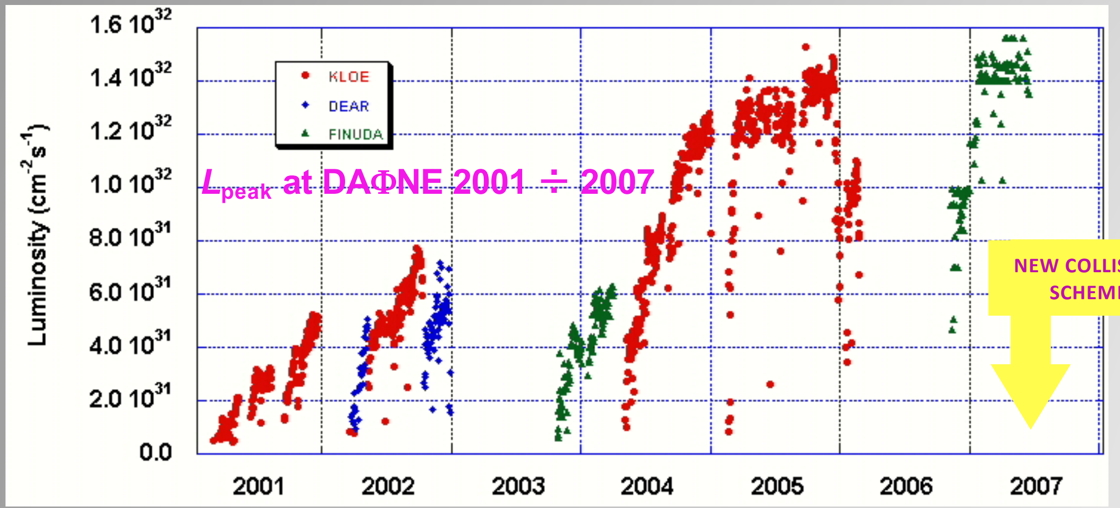
- Presently DAΦNE powers:
  SIDDHARTA-2 experiment as a collider
  DAFNE-light Facility
  DAΦNE LINAC is securing data to the **PADME** experiment and to two **BTF lines**

*By the end of **2023** it should be decided **if*** DAΦNE *will run as a collider for other 3-5 years in order to fulfil the scientific program proposed by the **Kaonic Physics Community**.*

DAΦNE Luminosity Achievements (native configuration)



"Proposal for a Φ-factory", G. Vignola et al., LNF-90/031 (IR),1990.



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

L_{logged} (fb^{-1}) 2001÷2007

KLOE	3.0
FINUDA	1.2
DEAR	0.2

Conventional Approach to High Luminosity

$$L = N_b f_0 \frac{N^2}{4\pi\sigma_x^*\sigma_y^*} \qquad \xi_{x,y} = \frac{N r_e}{2\pi\gamma} \frac{\beta_{x,y}^*}{\sigma_{x,y}^*(\sigma_x^* + \sigma_y^*)} \qquad L = N_b f_0 \frac{\pi\gamma^2 \xi_x \xi_y \varepsilon_x}{r_e^2 \beta_y^*}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)^2$$

Small $\boldsymbol{\beta_y^*}$

Higher number of particle per bunch $\boldsymbol{N}$

More bunches $\boldsymbol{N_b}$

Higher tune shift $\boldsymbol{\xi_{x,y}}$

Greater horizontal rms beam size $\boldsymbol{\sigma_x}$

Small crossing angle $\boldsymbol{\theta_x}$

Small Piwinsky angle $\boldsymbol{\Phi = \frac{\sigma_z}{\sigma_x} \tan\frac{\theta_x}{2} < 1}$

Conventional Approach Meets Limitations

$\beta_y^* \sim \sigma_z$ to avoid hourglass effect

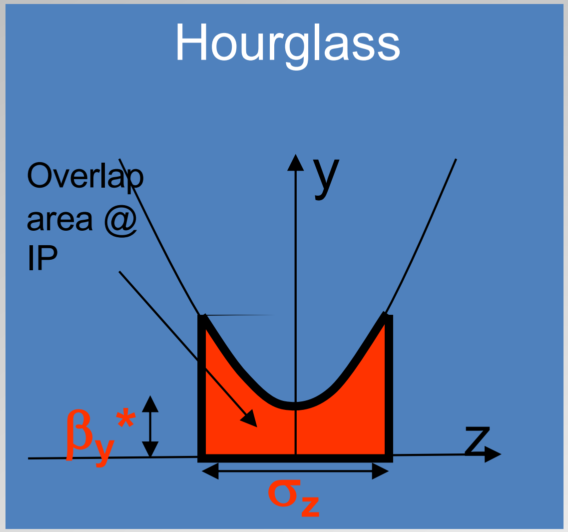
σ_z reduction led to:
- single bunch instability
- bunch lenghtening and microwave instabilityies
- CSR production

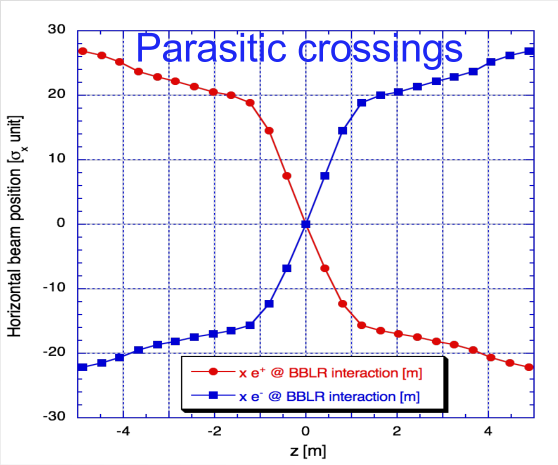
Higher N and N_b
- led to enhanced power losses
- increase wall plug power requirements
- causes coupled bunch instabilities

Tune shifts $\xi_{x,y}$ are constrained by beam-beam limit

Larger σ_x conflicts with
- beam stay clear and dynamical aperture requirements

Long-range beam-beam interactions causing τ^+ τ^- reduction limiting I^+_{MAX} I^-_{MAX} and -> L_{peak} and $L_\int$





Large Piwinski Angle and
Crab-Waist Collision Scheme

Large Piwinski angle

Horizontal crossing angle θ

Large Piwinski angle Φ

$$\Phi \approx \frac{\sigma_z}{\sigma^*_x}\frac{\theta}{2}$$

large θ
small σ_x

New IR layout
Lower beam ε

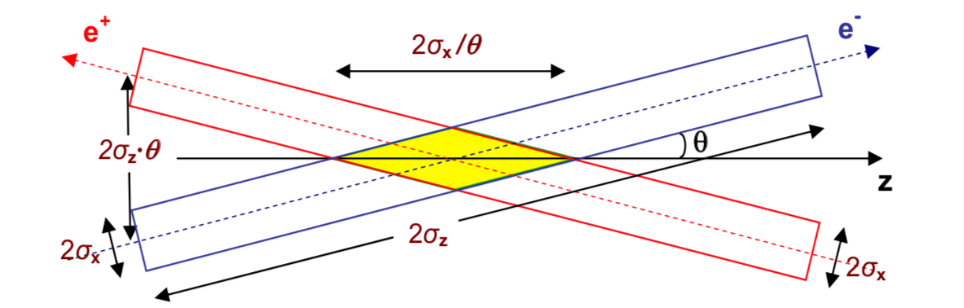
$$\zeta_y \propto \frac{N\sqrt{\beta^*_y}}{\sigma_z\theta} \qquad \zeta_x \propto \frac{N}{(\sigma_z\theta)^2} \qquad L \propto \frac{N\zeta_y}{\beta^*_y}$$

- lower ζ_x (tune shift)
- $L_{geometric}$ gain

$\boldsymbol{\beta^*_y}$ can be reduced for sake of the beams overlap region Σ

New low-β section
Ad hoc low-β optics

$$\Sigma \propto \frac{\sigma_x}{\theta} \qquad \beta_y \propto \frac{\sigma_x}{\theta} << \sigma_z$$



P. Raimondi et al., LNF-07/003 (IR) 29 Gennaio 2007

- L_{geo} gain with the same I_b
- lower ζ_y
- vertical *Synchro-Betatron resonances* suppression
- ζ_y *reduction* with the synchrotron oscillation amplitude

Crab-Waist Transformation

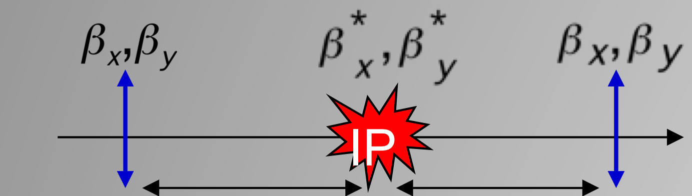
Collisions with large θ is not a new idea

Crab-Waist transformation is

P. Raimondi , 2° *SuperB Workshop, March 2006,*
P.Raimondi, D.Shatilov, M.Zobov, physics/0702033,
C. Milardi et al., Int.J.Mod.Phys.A24, 2009.

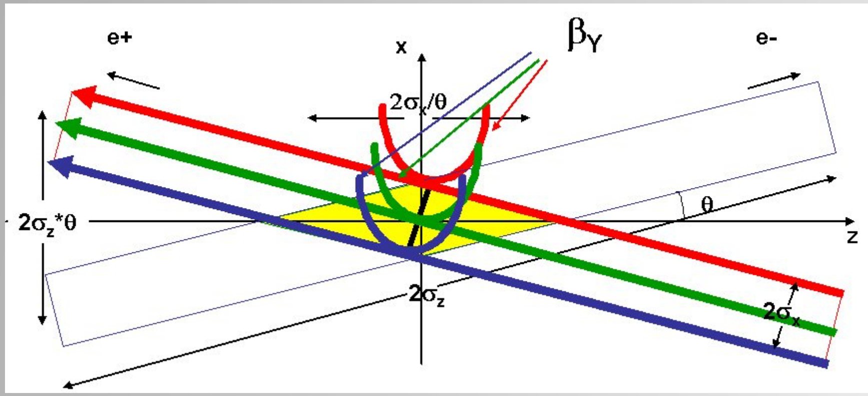
Powerful Sextupoles
Proper IR optics

$$y = \frac{xy'}{2\theta}$$



$$\Delta\nu_x = \pi \qquad \Delta\nu_y = \frac{\pi}{2}$$

- $L_{geometric}$ gain
- X-Y synchro-betatron and betatron resonance suppression



without CW Sextupoles

Large Piwinski angle

Collisions with large θ is not a new idea

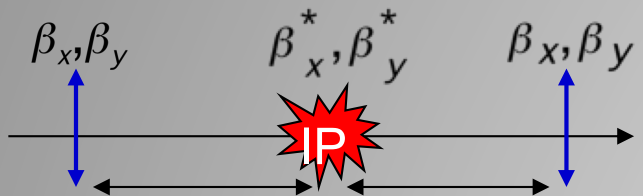
Crab-Waist transformation it is

P. Raimondi , 2° *SuperB Workshop, March 2006,*
P.Raimondi, D.Shatilov, M.Zobov, physics/0702033,
C. Milardi et al., Int.J.Mod.Phys.A24, 2009.

$$y = \frac{xy'}{2\theta}$$

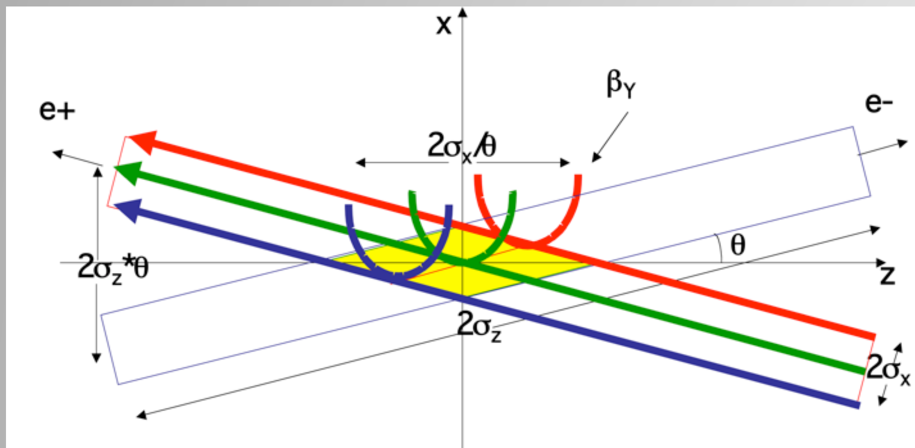
Powerful Sextupoles
Proper IR optics

sextupole (anti)sextupole



$$\Delta\nu_x = \pi$$
$$\Delta\nu_y = \frac{\pi}{2}$$

- $L_{geometric}$ gain
- X-Y and synchro-betatron resonances suppression

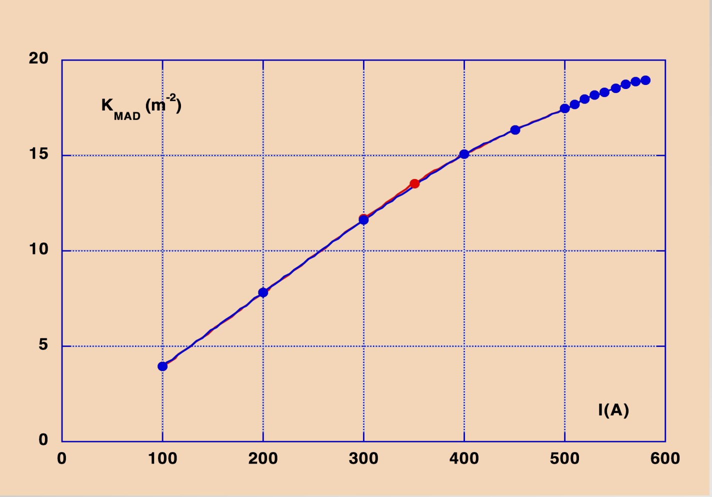


with CW Sextupoles

Crab-Waist Sextupole Parameters at DAΦNE

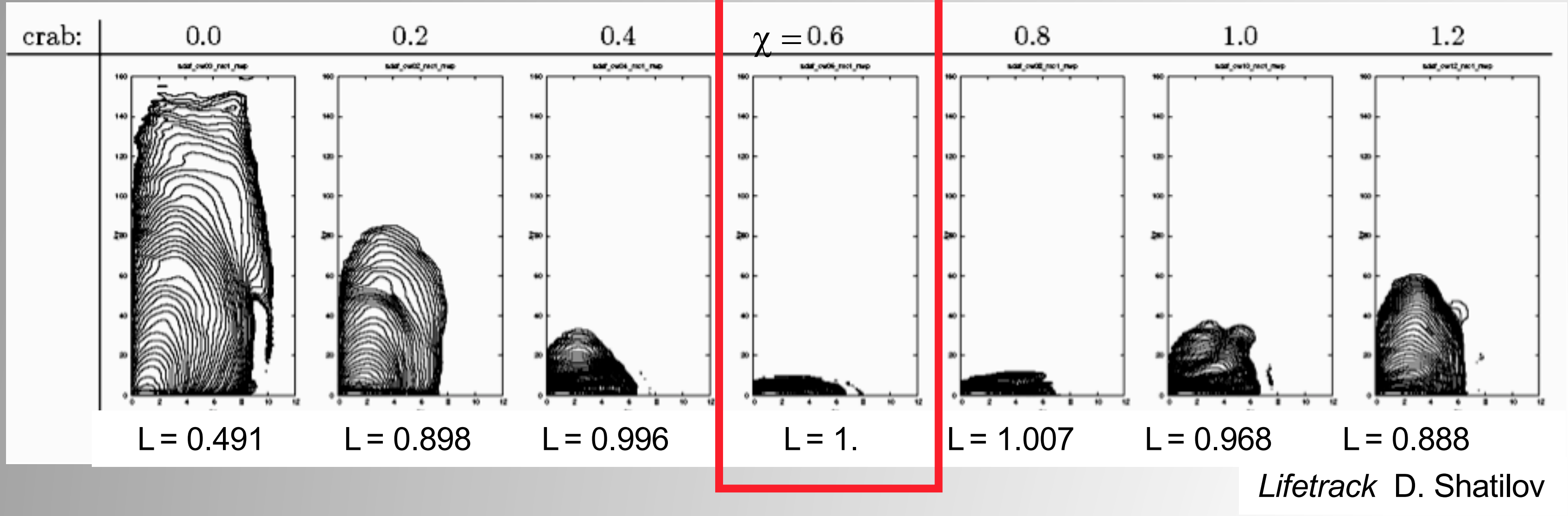
CW-Sextupoles are high strength magnets

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



χ nominal 0.6

χ **used value 0.5**



Luminosity (arbitrary unit) *and* ***Beam tails versus waist rotation*** χ

Crab-Waist IR

Large Piwinski angle Φ obtained by:

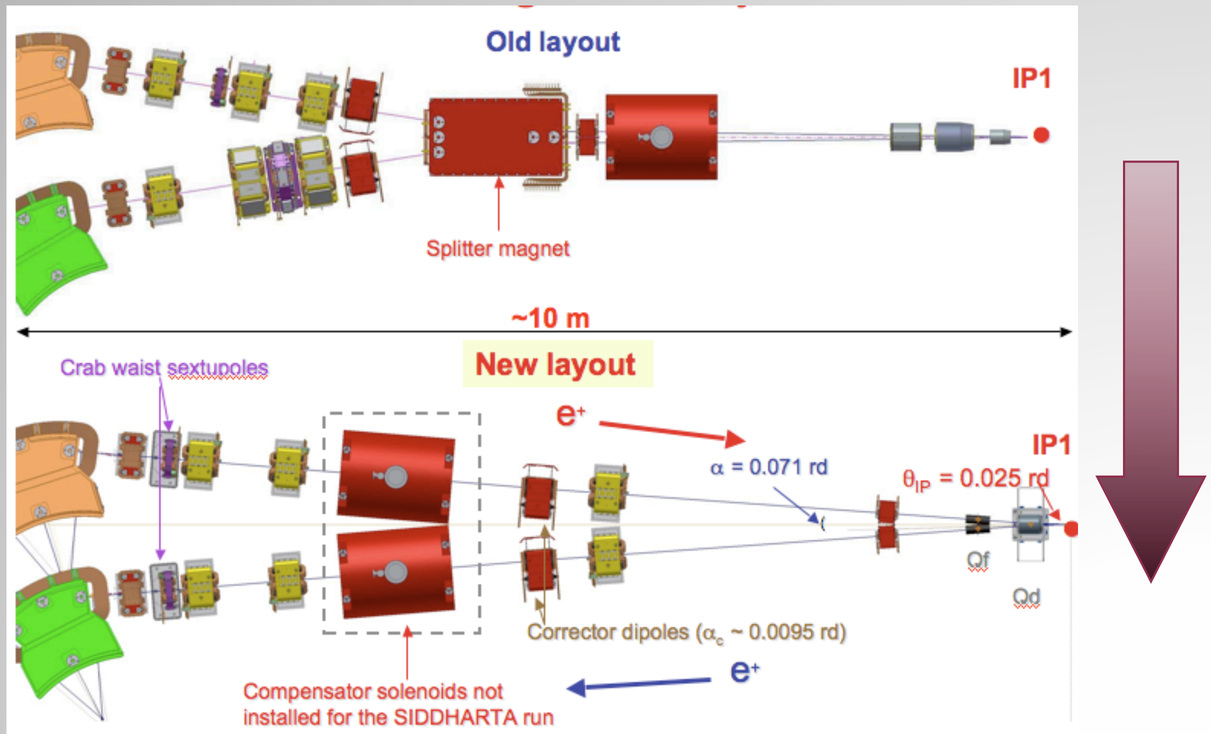
$$\Phi \approx \frac{\sigma_z}{\sigma^*_x}\frac{\theta}{2}$$

small σ_x

large θ

New IR magnetic layout

- Splitter magnets and compensator solenoids removed
- New low-β
- Sector dipols around IP rotated
- large collision angle ~ 50 mrd
- Four C type corrector dipoles used to mach the vacuum chamber in the arc

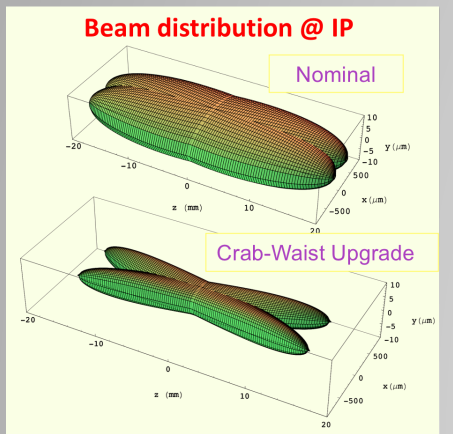


Crab-Waist Test Results during the SIDDHARTA Run

(2007 – 2009)

Crab-Waist Collision Test Run

Tested with the SIDDHARTA detector in 2008÷2009



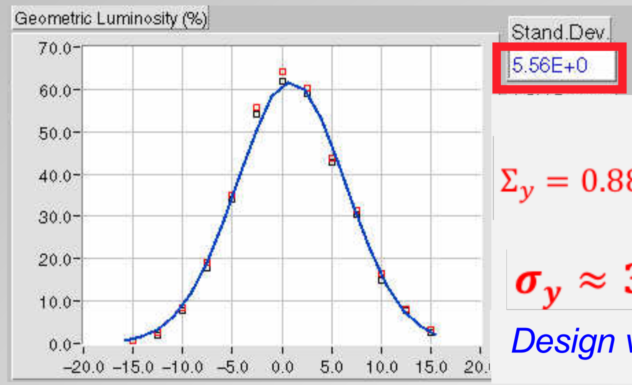
	DAΦNE native	DAΦNE *Crab-Waist*
Energy (MeV)	510	510
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm•mrad)	0.34	0.28
β_x^* (cm)	160	23
σ_x^* (mm)	0.70	0.25
$\Phi_{Piwinski}$	0.6	1.5
β_y^* (cm)	1.80	0.85
σ_y^* (μm) low current	5.4	3.1
Coupling, %	0.5	0.5
Bunch spacing (ns)	2.7	2.7
I_{bunch} (mA)	13	13
σ_z (mm)	25	15
N_b	120	120

Crab-Waist collisions and SIDDHARTA

- Large crossing angle and *Crab-Waist* collisions proved to be effective in *increasing luminosity by a factor 3.*

- The DAΦNE collider, based on the new collision scheme including Large Piwinski angle and *Crab-Waist*, has been successfully commissioned achieving record performances.

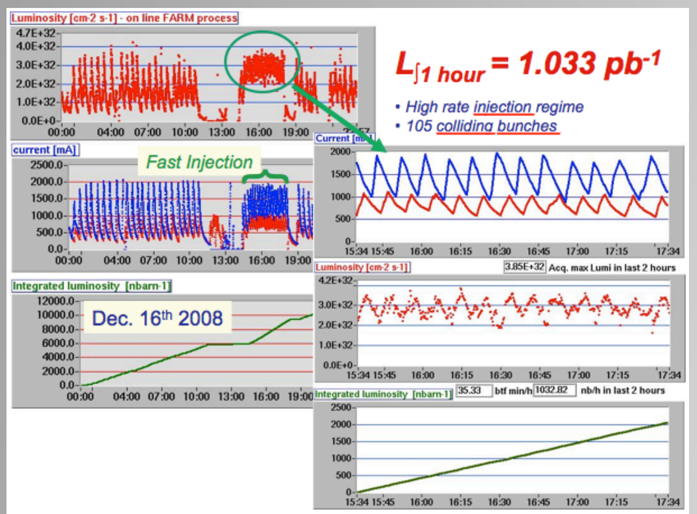
L_{peak}= 4.5*10^{32} cm^{-2} s^{-1}
$L_{\int 1\ day}$= 15.0 pb^{-1}
$L_{\int 1\ hour}$ = 1.033 pb^{-1}
$L_{\int run}$~ 2.8 fb^{-1} (delivered in 18 months)

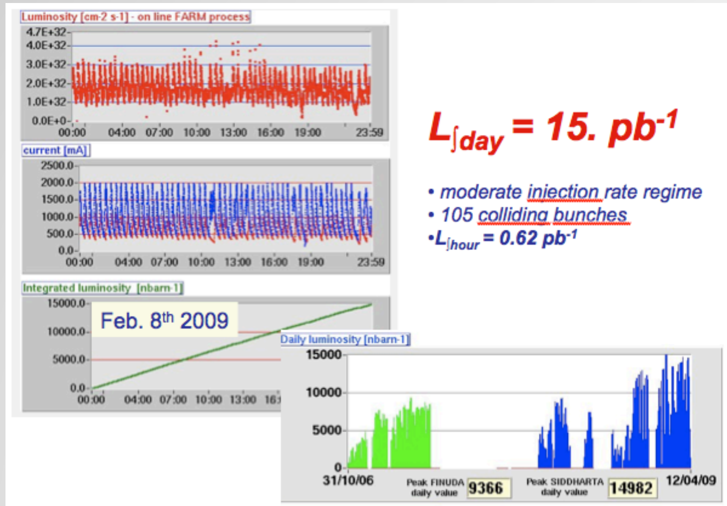


$$\Sigma_y = 0.88\sqrt{\sigma^2_{Ypos} + \sigma^2_{Yele}}$$

$$\sigma_y \approx 3.5\mu m$$

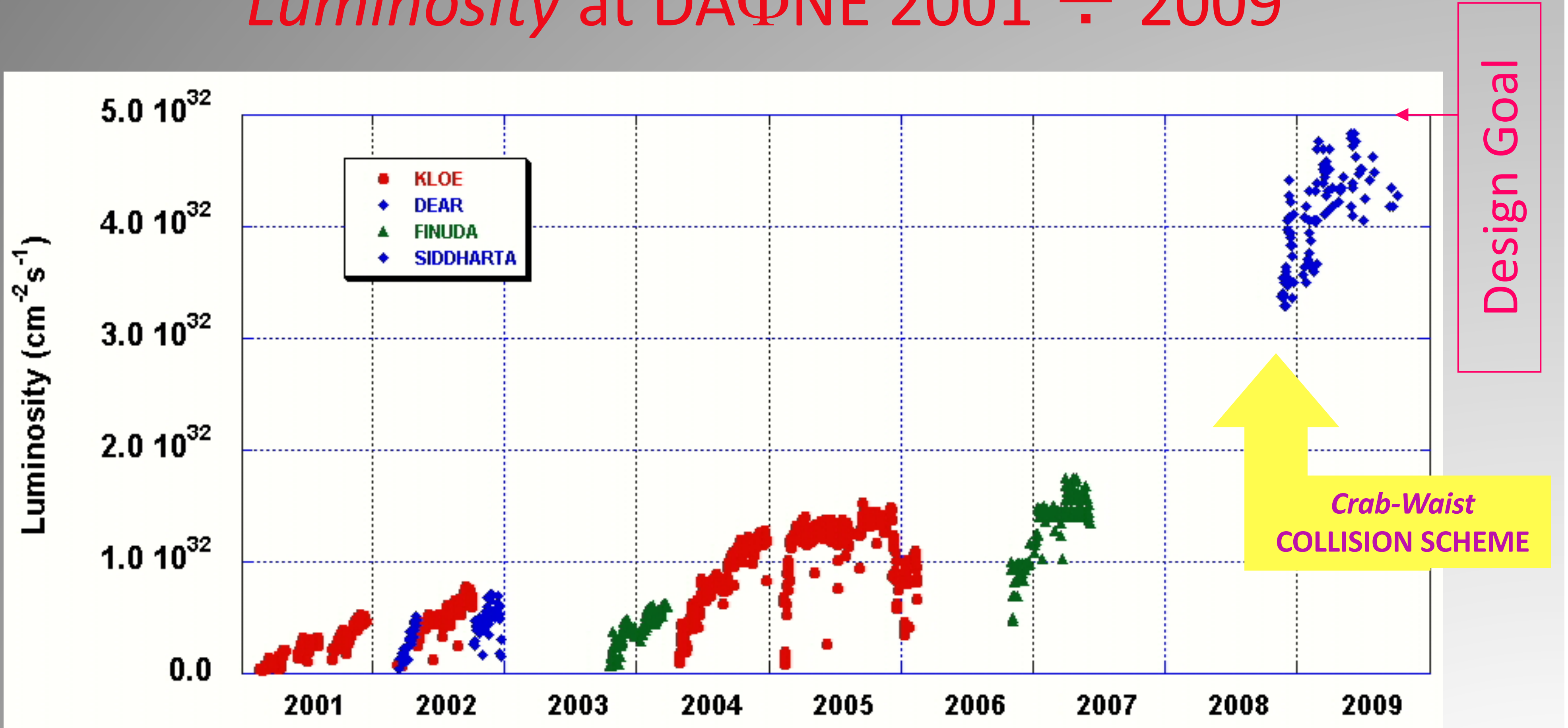
Design value 3.1μm





M. Zobov et al., Phys.Rev.Lett.104:174801, 2010.

Luminosity at DAΦNE 2001 ÷ 2009



A factor 3 higher luminosity achieved without increasing beam currents

No evidence of vertical BB saturation with *CW-Sextupoles* on (ξ_y = 0.044)

LRBB interaction almost cancelled

Crab-Waist Collisions for the KLOE-2 Run

CW-Collision scheme for the KLOE detector

Integrating the high luminosity collision scheme with a large experimental detector introduces new challenges in terms of IR layout, optics, beam acceptance, coupling correction

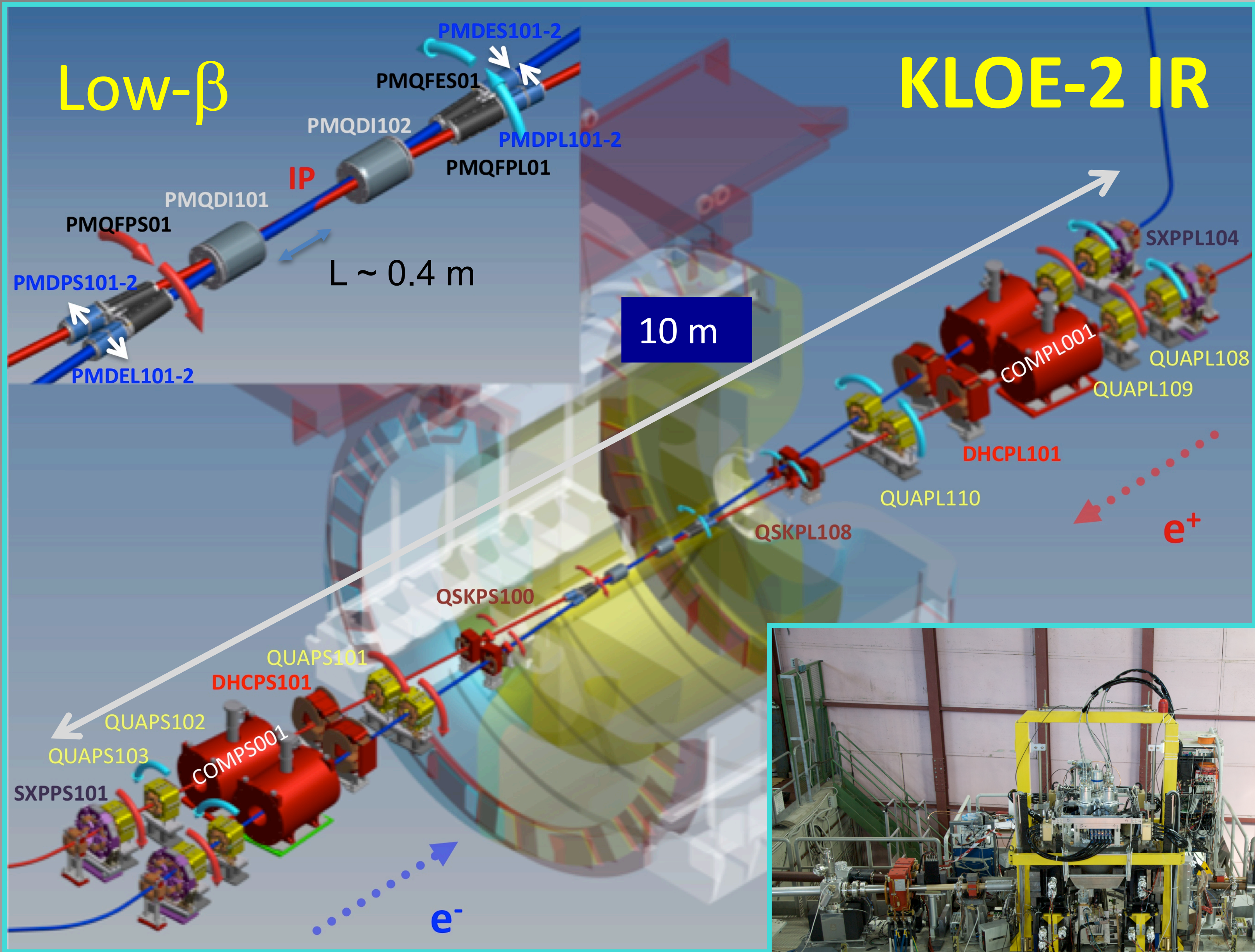
Crucial Points:

IR optics complying with:

- Low-β
- ***Crab-Waist*** collision scheme
- Coupling compensation
- Beam trajectory control

IR mechanical design allowing:

- Large crossing angle
- Early vacuum pipe separation after IP
- Mechanical stability of the low-β doublet



C. Milardi *et al* 2012 *JINST 7 T03002.*

Betatron Coupling correction

$\int_{KLOE} B \bullet dl$ canceled by 2 anti-solenoids for each beam

$$\int_{KLOE} B \cdot dl = 2.048 \quad [Tm] \quad \rightarrow \quad I_{KLOE} = 2300.[A]$$

$$\int_{comp} B \cdot dl = \pm 1.024 \quad [Tm] \quad \rightarrow \quad I_{comp} = 86.7[A]$$

In order to have coupling compensation also for off-energy particles

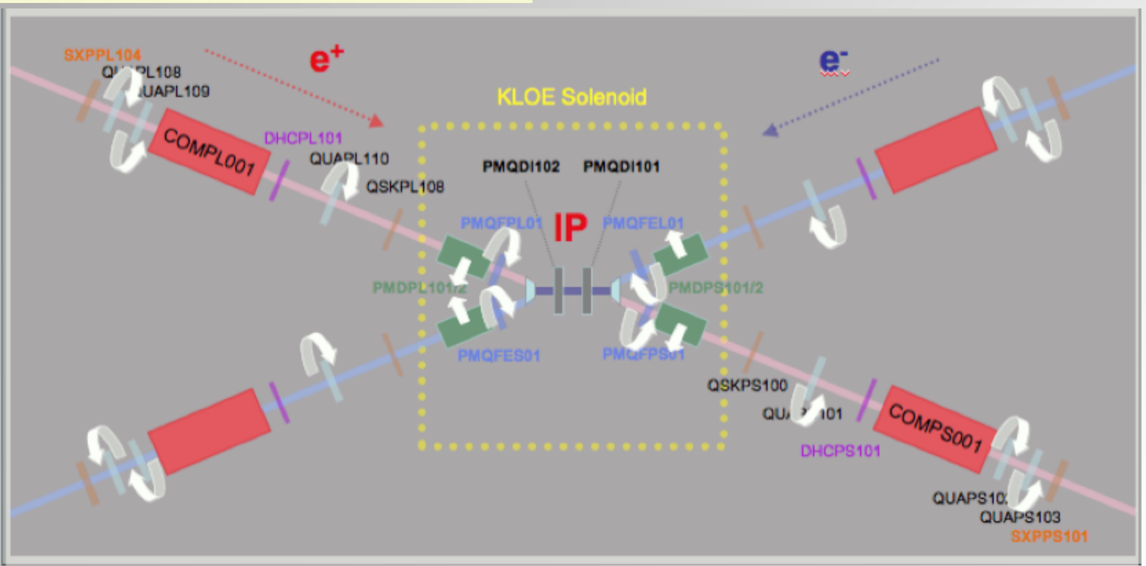
Fixed QUAD rotations

K is expected to be lower than for KLOE past

$$K_{KLOE1} = 0.2 \div 0.3 \%$$

	Z from the IP [m]	Quadrupole rotation angles [deg] *Anti-solenoid current [A]*
PMQDI101	0.415	0.0
PMQFPS01	0.963	-4.48
QSKPS100	2.634	used for fine tuning
QUAPS101	4.438	-13.73
QUAPS102	8.219	0.906
QUAPS103	8.981	-0.906
COMPS001	*6.963*	*72.48 (optimal value 86.7)*

C. Milardi *et al 2012 JINST 7 T03002.*



DAΦNE Activity Program for KLOE-2

Preliminary Test Phase *fall 2010 ÷ Dec 2012*

Collider Consolidation

KLOE-2 detector layers installed *Dec 2012 ÷ Jun 2013*

KLOE-2 data taking

I Run *Nov 16th 2014 ÷ Jul 3rd 2015*

goal 1 fb^{-1}

II Run *Spt 28th 2015 ÷ Jun 29th 2016*

goal 1.5 fb^{-1}

III Run Spt 12nd 2016 ÷ Aug 1st 2017

goal 2 fb^{-1}

IV Run *Spt 6th 2017 ÷ Mar 31st 2018*

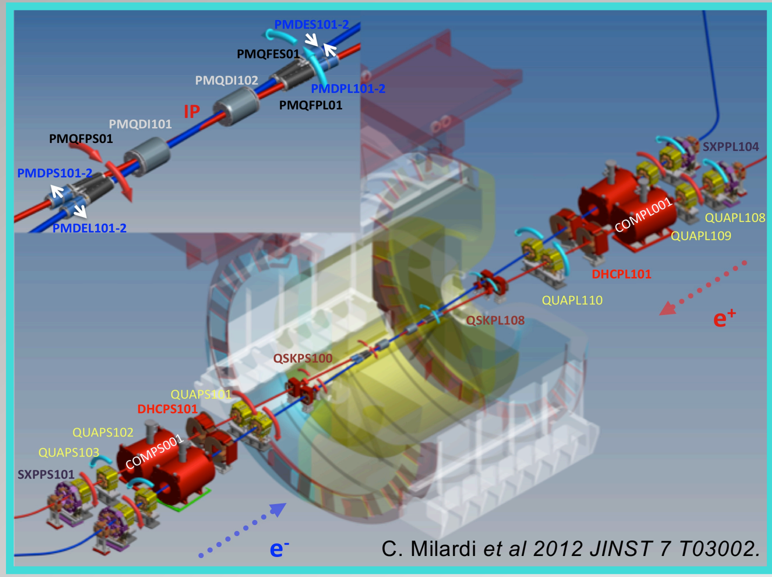
goal 1.5 fb^{-1}

Crab-Waist Collision with KLOE-2

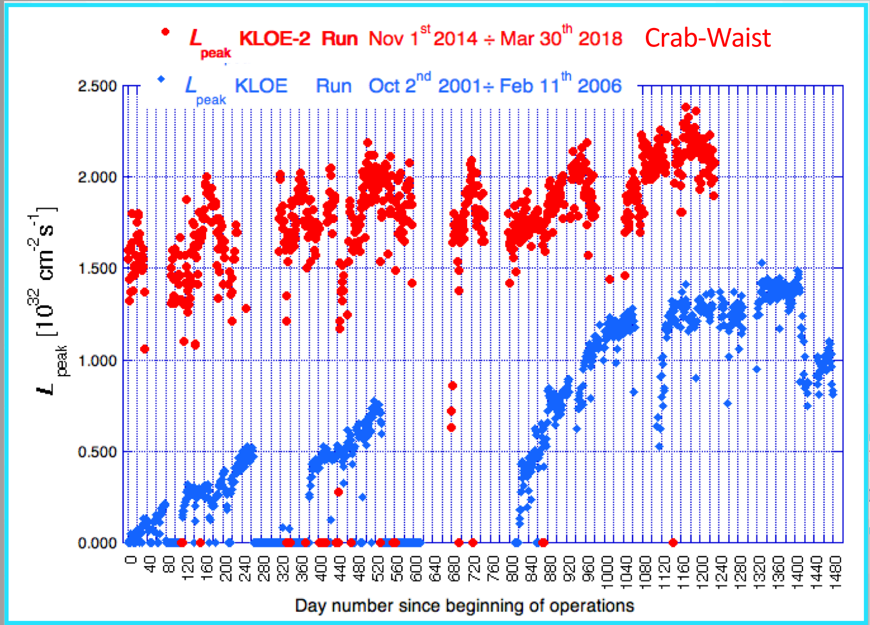
***Crab-Waist collision scheme** implemented for the first time with a large detector* including a high intensity axial field

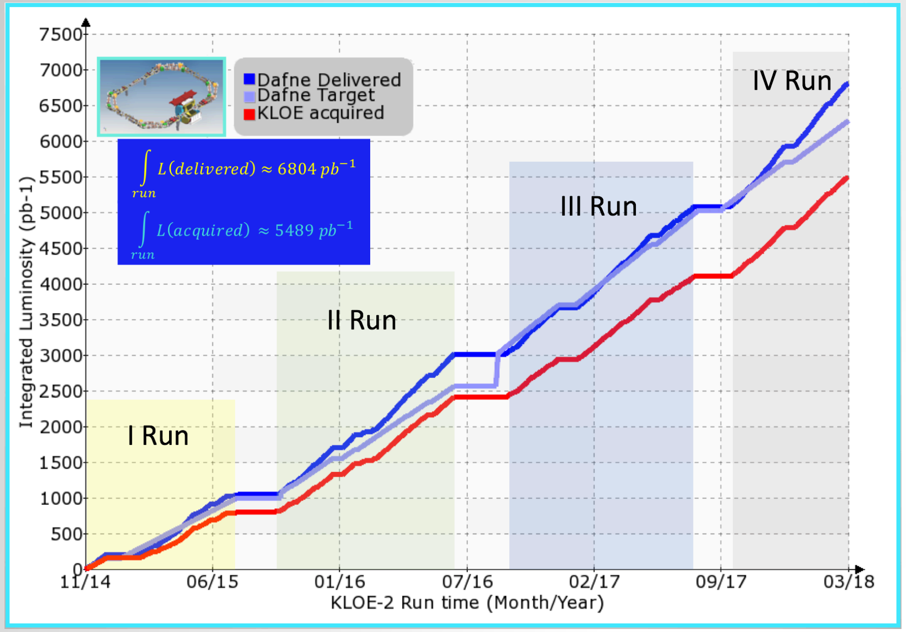
The new approach to collision provided a **~60% improvement** in terms of $\boldsymbol{L_{peak}}$

Background compatible with efficient data-taking.

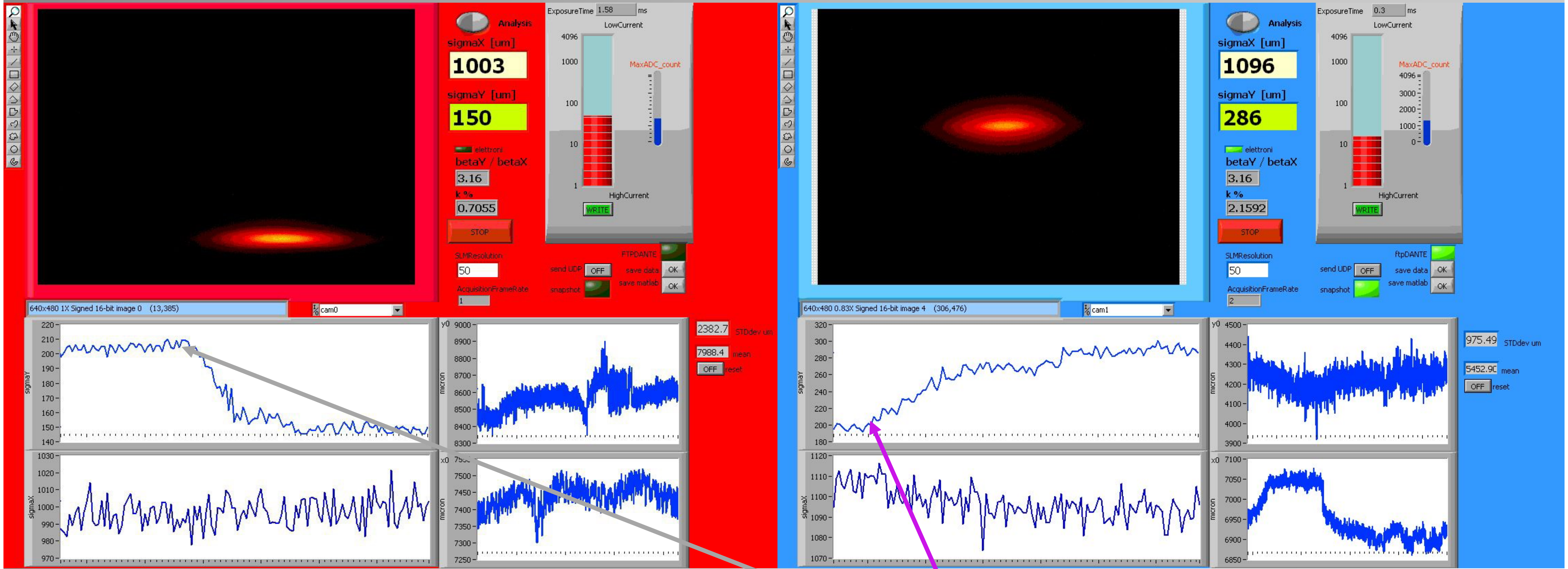


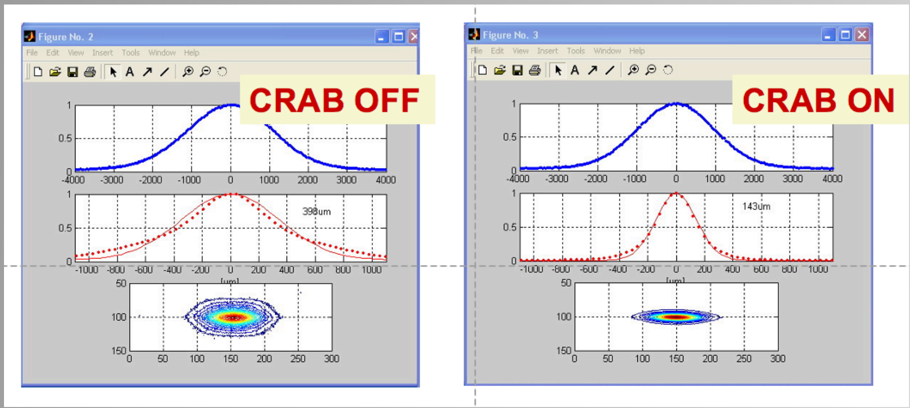
C. Milardi *et al* 2012 *JINST 7 T03002.*





Crab Waist Sextupoles Test (during KLOE-2 run)

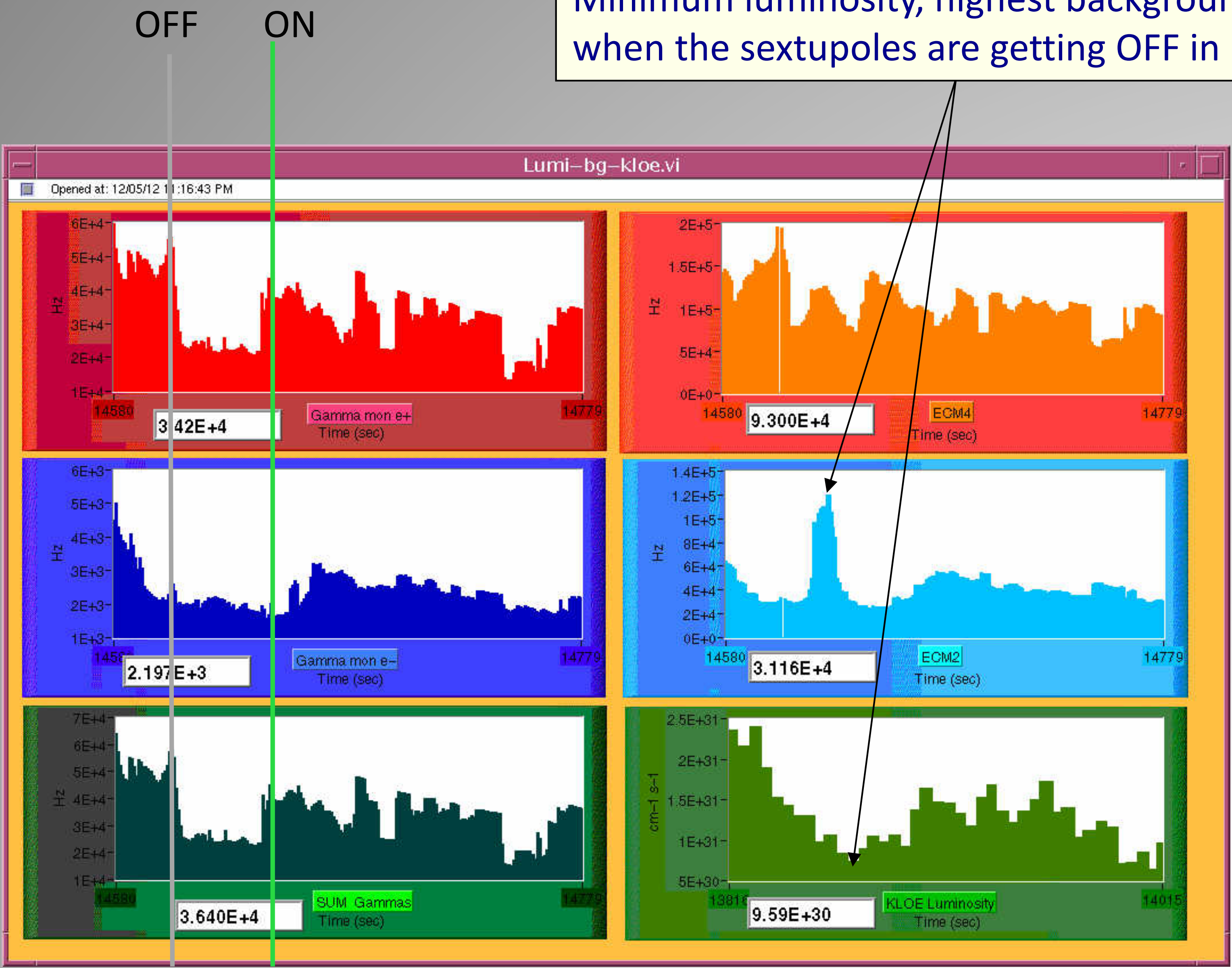




Switching off the CW sextupoles in the electron ring only (200 A -> 150 A):

- Beam sizes increase
- Beam-beam tails appear

Minimum luminosity, highest background when the sextupoles are getting OFF in MRe



Crab-Waist collision scheme helps in keeping under control background.

DAΦNE Luminosity Achievements

Luminosity achieved at DAΦNE is considerably higher than the one obtained at other colliders operating in the low energy range

	DAΦNE CW upgrade tested with SIDDHARTA (2009)	**DAΦNE** KLOE (2005)	**DAΦNE (CW)** KLOE-2 (2014)
L_{peak} [$cm^{-2}s^{-1}$]	**$4.53 \cdot 10^{32}$**	$1.50 \cdot 10^{32}$	**$2.38 \cdot 10^{32}$**
I^- [A]	**1.52**	1.4	**1.18**
I^+ [A]	**1.0**	1.2	**0.87**
ε_x [mm mrad]	**0.28**	0.34	**0.28**
$N_{bunches}$	**105**	111	**106**
$\int_{1h} L$ [pb^{-1}]	**0.79**	0.4	**0.67**
$\int_{day} L$ [pb^{-1}]	**14.98**	9.8 (seldom)	**14.3**
ξ_y	0.0443 - 0.09	0.0245	--

L_{peak} exceeds by ~ 60% the best luminosity ever achieved, at DAΦNE, during operations for an experimental apparatus including high field detector solenoid.

Crab-Waist Interaction Region for SIDDHARTA-2 Run

SIDDHARTA-2 Scientific Goal

*The experiment aims at performing the first measurement ever of **kaonic deuterium X-ray transition** to the ground state (1s-level) induced by the strong interaction, such as to determine its **shift** and **width**.*
***Combined** analysis of **kaonic deuterium** and **kaonic hydrogen** measurements.*

Why do study this physics at DAΦNE?

*DAΦNE is unique source of kaons in the world, it delivers **low momentum** (< 140 MeV) **nearly monochromatic charged kaons** generated from the ϕ meson decay produced by the electron-positron annihilation.*
DAΦNE collisions are ideal for experimental studies concerning low-energy kaon-nucleon/ nuclei interactions.

SIDDHARTA-2 Collaboration

Silicon **D**rift **D**etectors for **H**adronic **A**tom **R**esearch by **T**iming **A**pplication

- LNF-INFN, Frascati, Italy
- SMI-ÖAW, Vienna, Austria
- Politecnico di Milano, Italy
- IFIN –HH, Bucharest, Romania
- TUM, Munich, Germany
- RIKEN, Japan
- Univ. Tokyo, Japan
- Victoria Univ., Canada
- Univ. Zagreb, Croatia
- Univ. Jagiellonian Krakow, Poland
- ELPH, Tohoku University

(C. Curceanu, 63rd LNF Scientific Committee Meeting)

INFN LNF
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

HadronPhysics2
Study of Strongly Interacting Matter

STRONG-2020

HadronPhysics I3
Study of Strongly Interacting Matter

HrZZ
Croatian Science Foundation

FWF Der Wissenschaftsfonds.

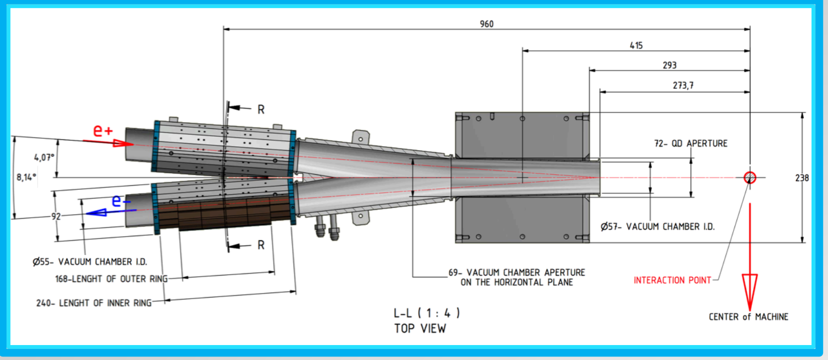
Farnesina
Ministero degli Affari Esteri e della Cooperazione Internazionale

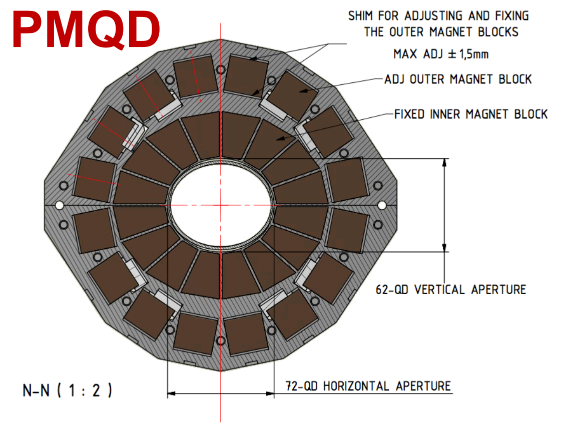
New low-β PMQs

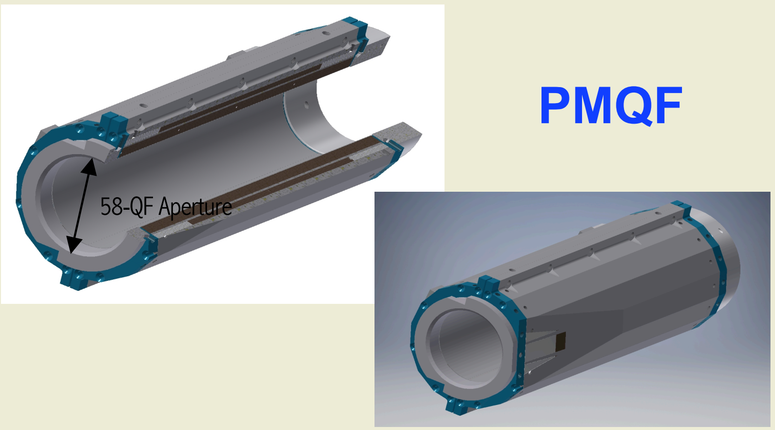
New PMQs are Halbach type magnets made of SmCo2:17
PMQs have been designed and realized, in collaboration with the ESRF magnet group, in order to improve :

- good field region,
- gradient uniformity,
- aperture,
- mechanic assembly.

New low-b vacuum chamber design







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

DAΦNE IR and SIDDHARTA-2 detector

SIDDHARTA-2 Run Program

Pilot run in 2021 with reduced experimental setup: **SIDDHARTINO**.

Pilot run aimed at:

- commissioning the DAΦNE collider after modifications;
- optimizing run conditions by:
  - implementing collider luminosity measurements,
  - understanding background by outlining the more efficient indicators and figure out how to improve detector shielding,
  - tuning trigger systems,
  - tuning X-ray SDD detectors;
- optimize the detector degrader used to maximize the fraction of kaons stopped inside the gaseous helium target.

The pilot SIDDHARTINO run also allowed to obtain the most precise measurement of kaonic helium transitions in a gaseous target.

SIDDHARTA-2 final setup has been installed on spring 2022.

On June 1st the He target has been replaced with the ^2H one.

The run dedicated to study the kaonic deuterium transition is scheduled for 2023.

Main Rings Optics

Several new optics configurations have been developed for the DAΦNE main rings and sequentially applied..

- ***Detuned Optics***, β^{IP}_x = 0.27 [m], and β^{IP}_y = 0.049 [m], in order to:
  inject beams
  test the magnets alignment in the two branches of the new Interaction Region
  closed orbit and feedback systems preliminary optimization
  improve ring optics model
  store beam currents suitable for vacuum conditioning.

- ***Low-β optics***, β^{IP}_x = 0.28 [m], and β^{IP}_y = 0.009 [m], used for
  transverse betatron coupling correction in both rings,
  non-linear optics refinements.

- ***Crab-Waist optics*** having:
  β^{IP}_x = 0.26 [m] β^{IP}_y = 0.008 [m],
  proper phase advance **between IP and Crab-Waist Sextupoles: $\Delta\nu_x = \pi$ and $\Delta\nu_y = \pi/2$**.
  In order to:
  switch on Crab-Sextupoles,
  setup collisions,
  start background optimizations.

MRe Twiss Functions

(Crab-Waist Optics)

$\beta^*_y = 0.008$ m
$\beta^*_x = 0.26$ m

$\nu_x = 5.0913$ $\nu_y = 5.1592$

$\Delta\nu_x = \pi$ $\Delta\nu_y = \frac{\pi}{2}$ IP1 – CW SXTs

$\alpha^*_y = -2.08$ E-07
$\alpha^*_x = 5.6$ E-05

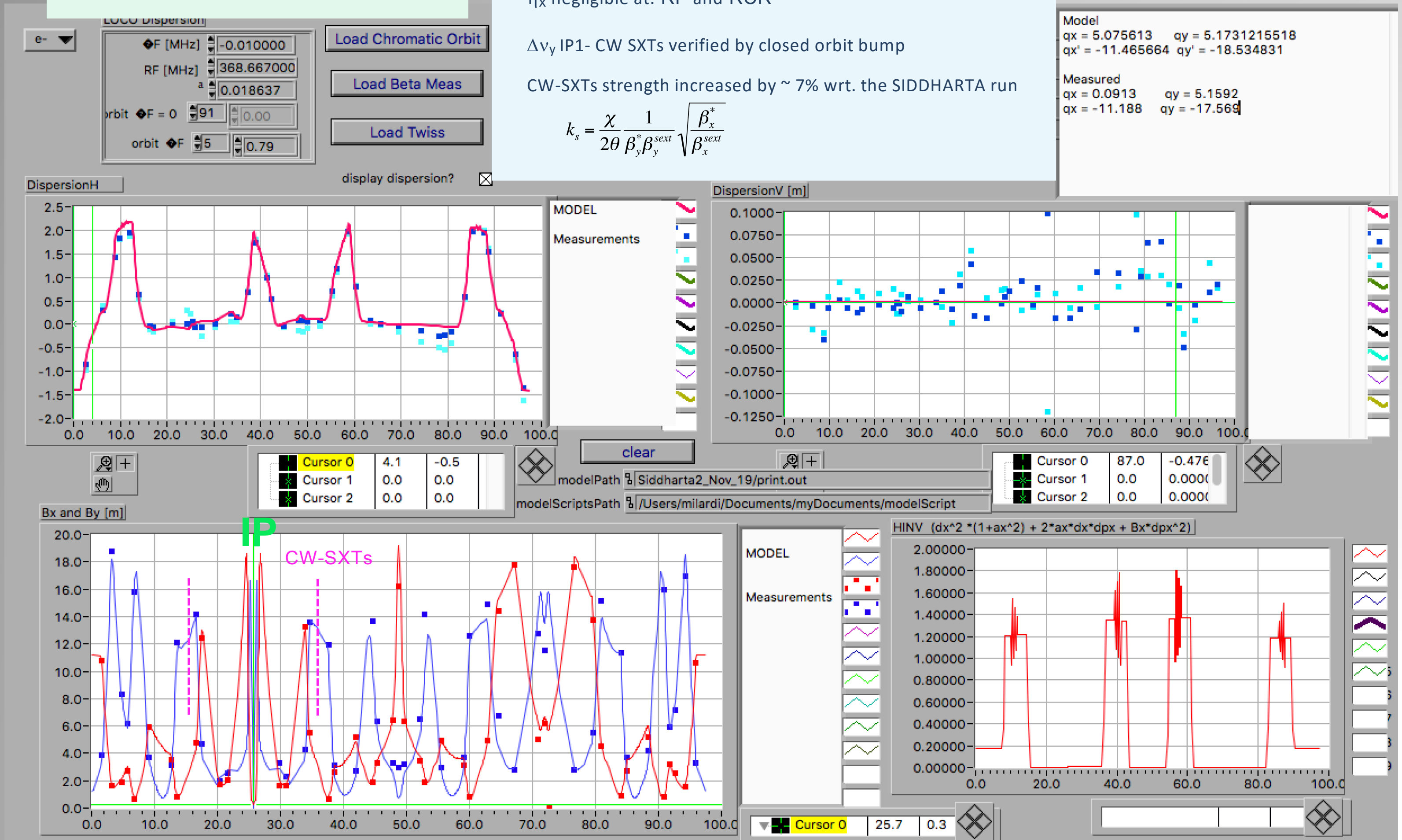
$\eta^*_x = \eta'^*_x = 0.0$

$\beta^{septum}_x = 11.52$ m
$\Delta\nu_x = \pi$ (between Injection KCKs)
η_x negligible at: RF and RCR

$\Delta\nu_y$ IP1- CW SXTs verified by closed orbit bump

CW-SXTs strength increased by ~ 7% wrt. the SIDDHARTA run

$$k_s = \frac{\chi}{2\theta}\frac{1}{\beta^*_y\beta^{sext}_y}\sqrt{\frac{\beta^*_x}{\beta^{sext}_x}}$$



MRp Twiss Functions

(Crab-Waist Optics)

$\beta^*_y = 0.008$ m
$\beta^*_x = 0.26$ m

$\nu_x = 5.0962$ $\nu_y = 5.1644$

$\Delta\nu_x = \pi$ $\Delta\nu_y = \frac{\pi}{2}$ IP1 – CW SXTs

$\alpha^*_y = -2.08$ E-07
$\alpha^*_x = 5.6$ E-05

$\eta^*_x = \eta'^*_x = 0.0$

$\beta^{septum}_x = 11.52$ m
$\Delta\nu_x = \pi$ (between Injection KCKs)
η_x negligible at: RF and RCR

$\Delta\nu_y$ IP1- CW SXTs verified by closed orbit bump

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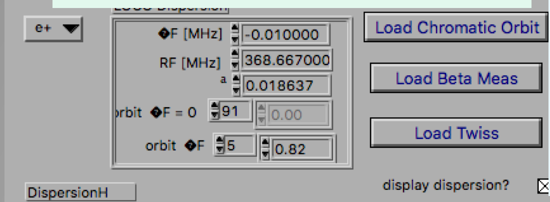
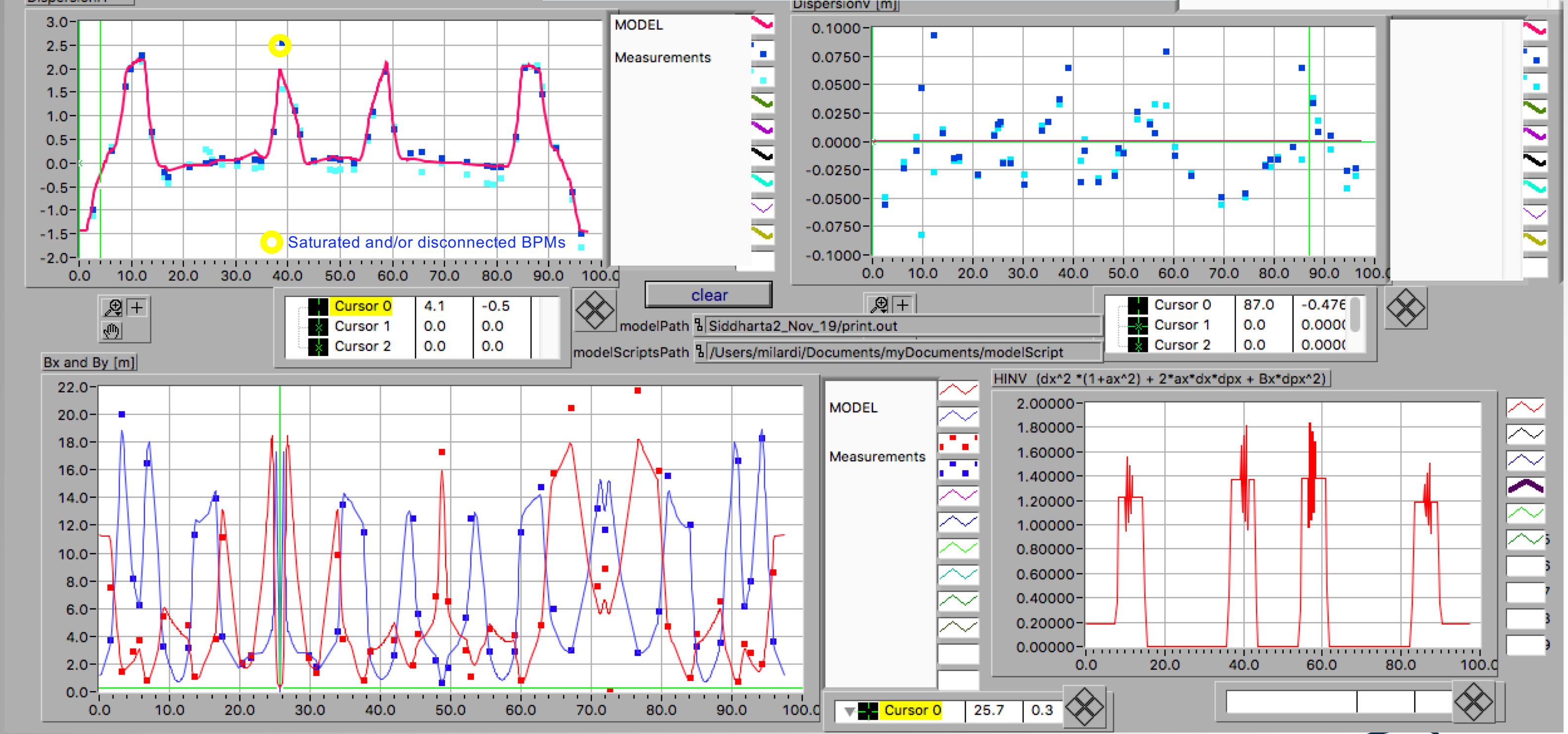


Model
qx = 5.091827 qy = 5.160318
qx' = -11.337957 qy' = -19.152442

Measured
qx = 0.0962 qy = 5.1644
qx = -14.056 qy = -16.070

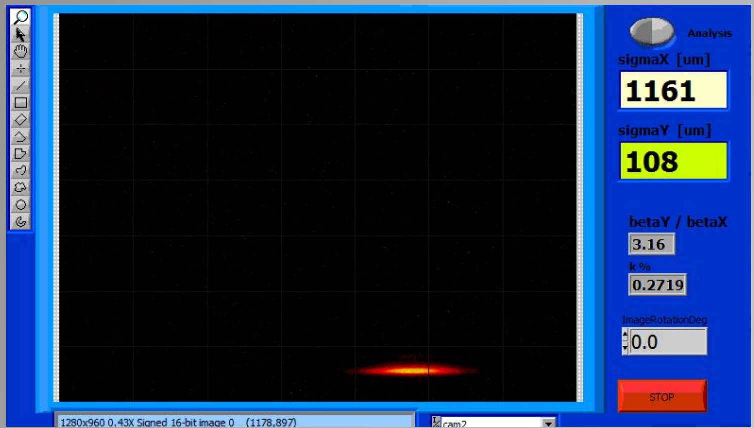


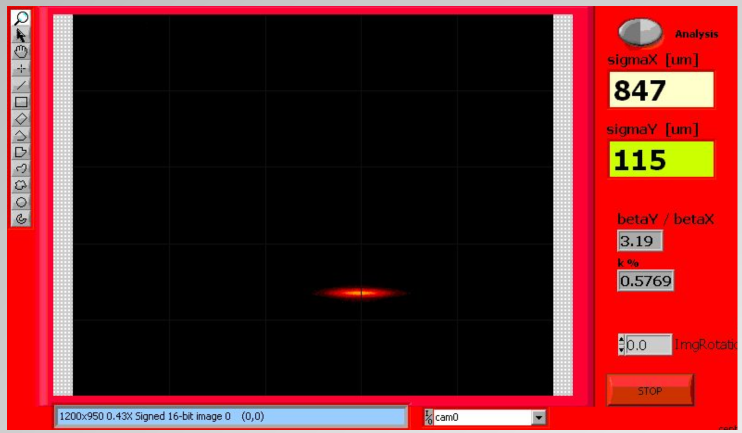
C. Milardi, IPAC 2021, May 24-28, LNLS/CNPEM, Campinas, Brasil

Betatron Coupling Correction

Crab-Waist Optics

Linear lattice

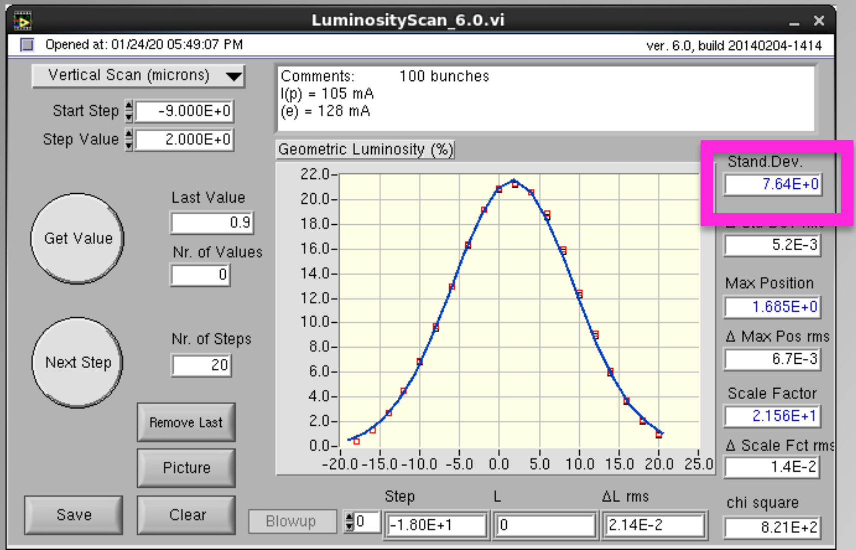




Betaron coupling correction has been done after carefully align the new IR.
After correction:

κ ~ .3 % for both beams

Low Current Vertical Beam-Beam Scan



$I^- = 128$ mA

$I^+ = 105$ mA

- **Scan provides a clear evidence of an optimal beam-beam interaction**
- Measurement is in agreement with the one previously done with the low-β optics

Σ expected

$\varepsilon = 0.28\ 10^{-6}$ [m rad]

$\beta_y = 0.008$ [m]

$\kappa \sim 1\%$ (conservative assumption)

$\Sigma = 6.7\ 10^{-6}$ [m]

Measurements

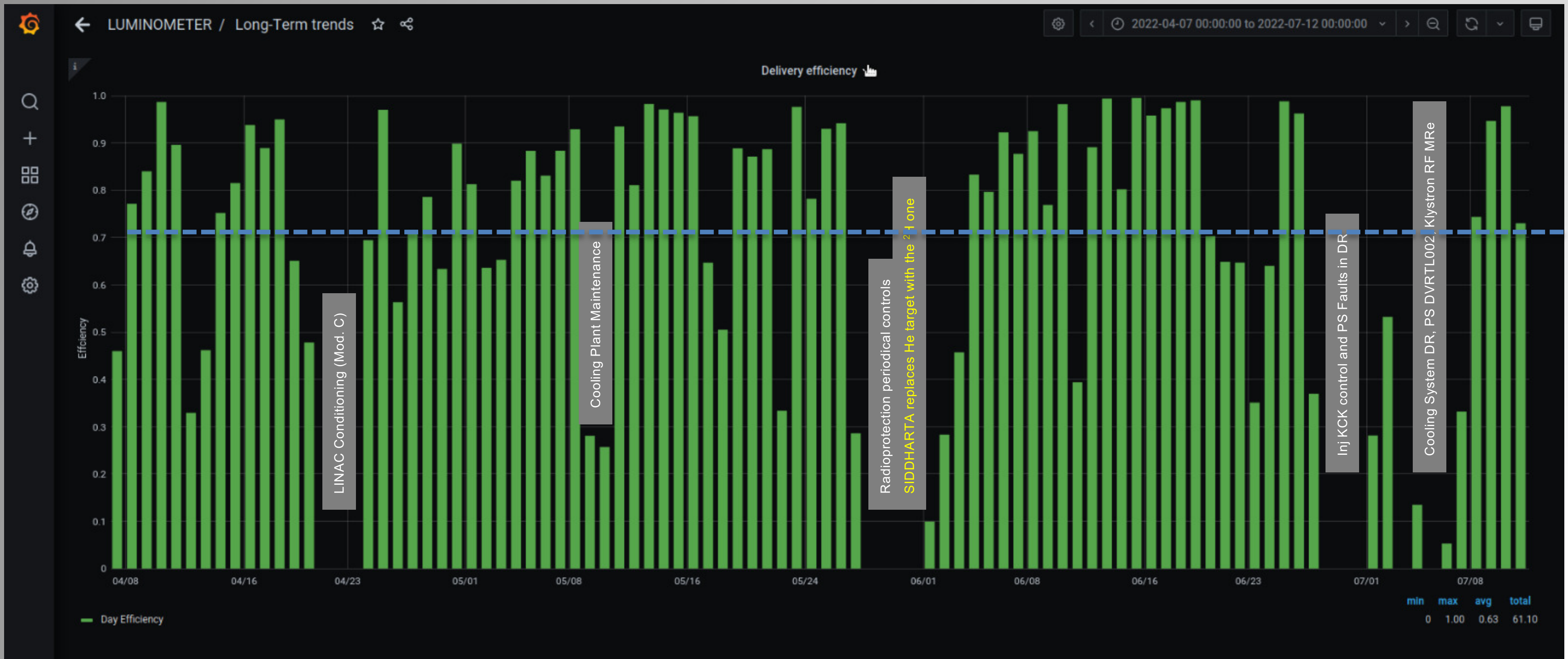
$\Sigma_y^{meas} \sim 7.6\ \mu m$

$$\Sigma_y = \sqrt{\sigma_{yp}^2 + \sigma_{ye}^2}$$

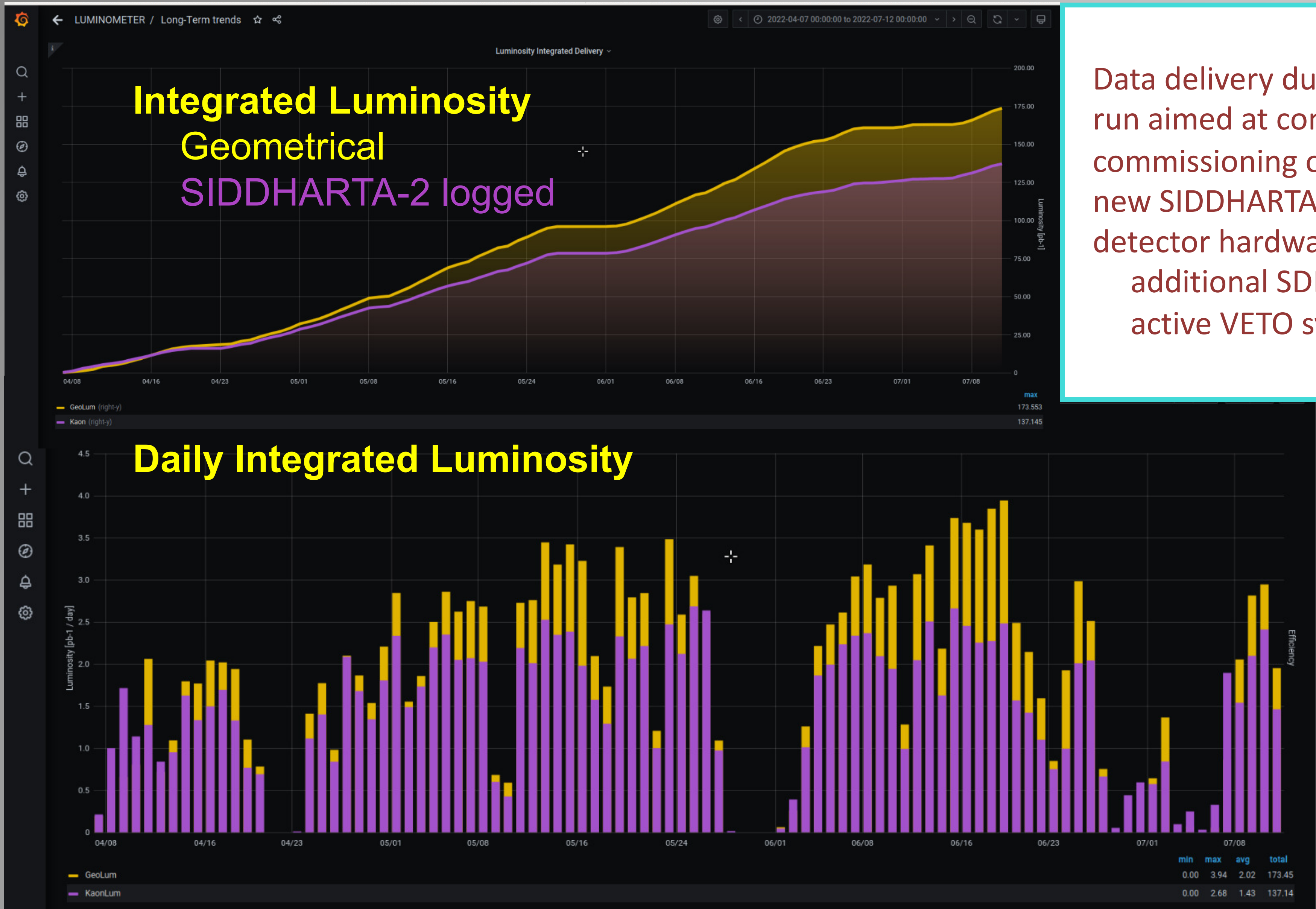
$\sigma_y \sim 5.37\ \mu m$

DAΦNE Uptime (2022)

DAΦNE uptime during operations devoted to setup and test of the SIDDHARTA-2 apparatus.
Uptime is about 71%, excluding stops for scheduled interventions.



Data Delivery during SIDDHARTA-2 Run



Data delivery during the run aimed at completing commissioning of the new SIDDHARTA-2 detector hardware:

- additional SDD,
- active VETO system.

DAΦNE achievements and contributions to the physics of particle accelerators

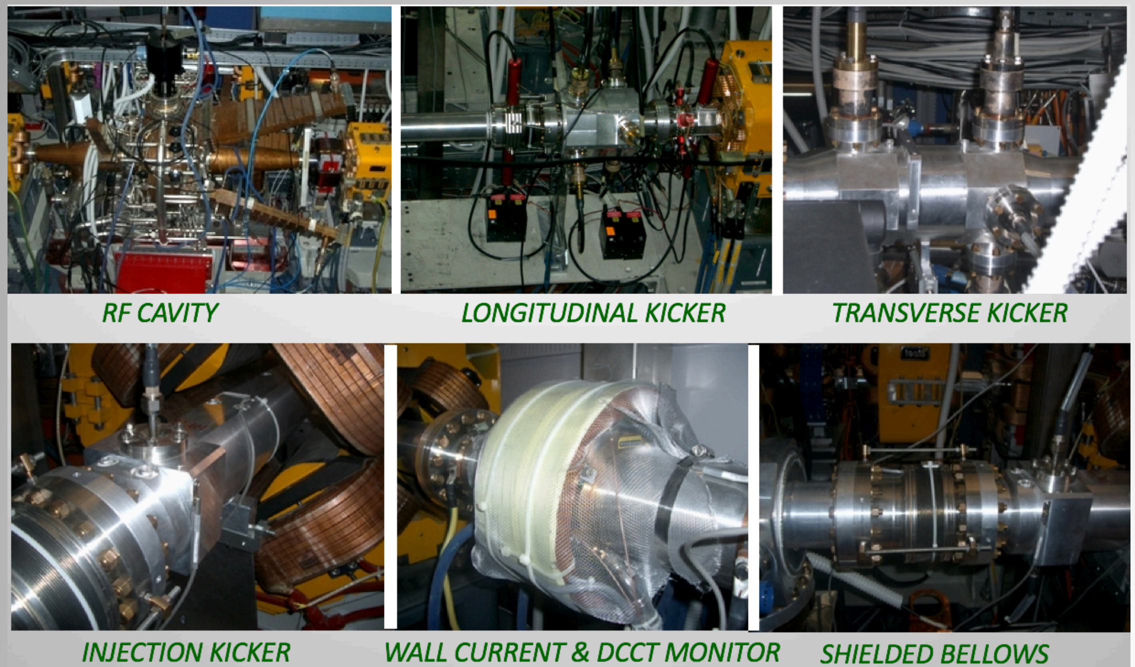
DAΦNE Vacuum Chamber Elements

Optimized to: avoid heating, reduce impedance, and damp HOM

Impedance budget is a factor of 80 lower than in similar storage ring (EPA)

Longitudinal feedback kicker designed for DAFNE have been adopted at: KEKB, BESSYII, PLS, SLS, HLS, ELETTRA, KEK Photon Factory, PEP II

This R&D effort largely contributed to improve beam dynamics and beam-beam performances



D. Alesini, Boni, A. Drago, A. Gallo, A. Ghigo, M. Serio, A Stella, M. Zobov, F. Marcellini, P. Raimondi

Beam Currents stored at DAΦNE

Lepton Beam Currents achieved so far

	beam current I [A]	bunch population N_b [10^{11}]	rms bunch length [mm]	bunch spacing [ns]	comment
PEP-II	2.1 (e^-), 3.2 (e^+)	0.5, 0.9	12	4.2	closed
superKEKB	**2.62 (e^-), 3.6 (e^+)**	**0.7, 0.5**	**7**	**6**	**running**
DAFNE	**2.4 (e^-), 1.4 (e^+)**	**0.4, 0.3**	**16**	**2.7**	
BEPC-II	0.8	0.4	<15?	8	
CesrTA	0.2	0.2	6.8	4	
VEPP-2000	0.2	1	33	80 (1 b)	
LHC (des)	0.58	1.15	75.5	25	
ESRF	0.2	0.04	6.0	2.8	
APS	0.1	0.02	6.0	2.8	
Spring8	0.1	0.01	4.0	2.0	
SLS	0.4	0.05	9.0	2.0	

R&D about *e-cloud* suppression at DAΦNE

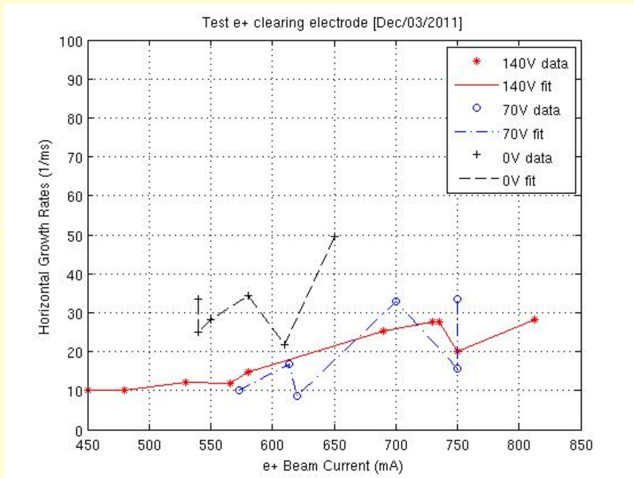
DAΦNE has been the first collider operating routinely with electrodes, for e-cloud mitigation, ECE.
ECE provided stable operation with the e^+ beam, and allowed unique measurements such as:

e-cloud instabilities growth rate
transverse beam size variation
tune shifts along the bunch train

demonstrating their effectiveness in restraining e-cloud induced effects.

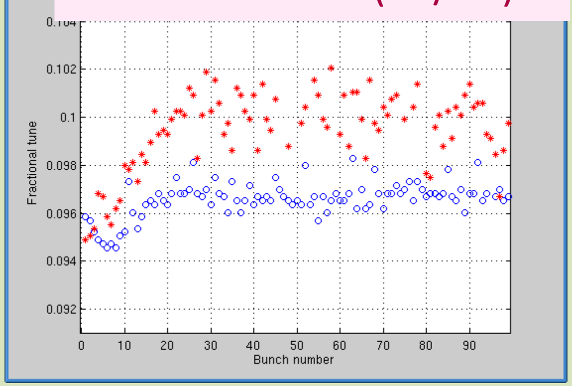
(D. Alesini et al, Phys. Rev. Lett. 110, 124801 (2013)

Horizontal Instability Growth Rate as a function of the ECE voltage measured by using bunch-by-bunch FBK frontend

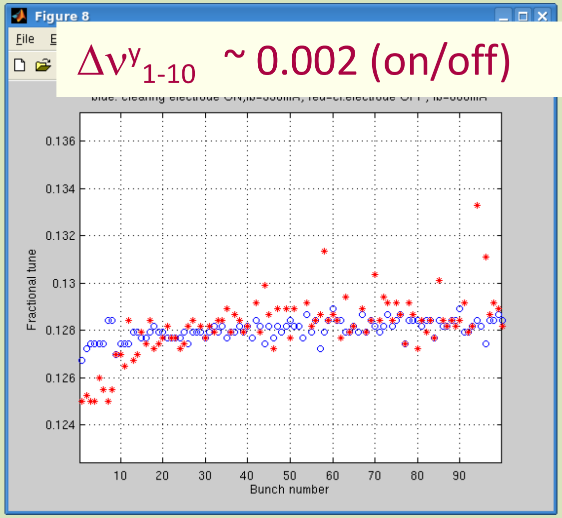


Tune Spread measurements

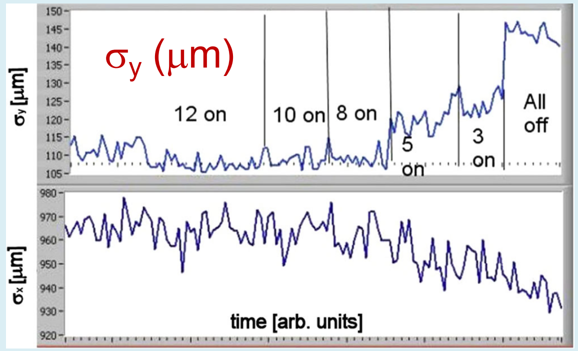
$\Delta\nu^x_{1\text{-}100}$ ~ 0.006 (off)
$\Delta\nu^x_{1\text{-}100}$ ~ 0.003 (on)
$<\Delta\nu^x>$ ~ 0.0065 (on/off)



$\Delta\nu^y_{1\text{-}10}$ ~ 0.002 (on/off)



Vertical Beam Size



Feedback R&D and Instability Cures at DAΦNE

High current performances in a low energy machine greatly depend on bunch by bunch feedback systems.
DAΦNE performances are assured by the **3 feedbacks installed in each ring in order** to dampen coupled-bunch instabilities both in the longitudinal and transverse plane

DAΦNE FBKs are based on **iGp** (Integrated Gigasample Processor) digital bunch-by-bunch hardware developed by a **KEK / SLAC / INFN-LNF joint collaboration**.

The **total pow**er available for each apparatus is of the order of **500 W** and **750 W** for transverse and longitudinal feedbacks respectively

Transverse FBKs have been equipped with **in house developed new kickers** having doubled strip-line length and providing larger shunt impedance at the low frequencies typical of the unstable modes.

Beam current limits observed

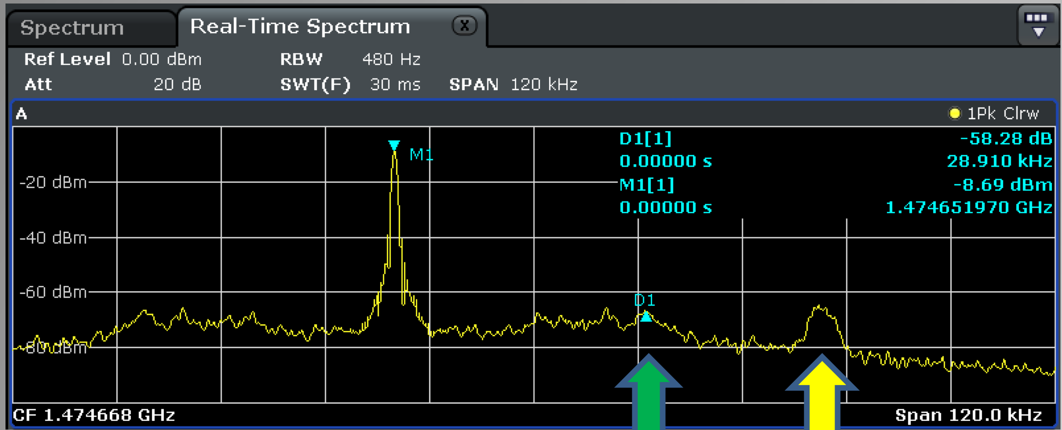
- longitudinal mode-0 & quadrupole oscillations
- noise coming from pickups (harmful for beam vertical size)
- e-cloud effects (in the e+ ring)

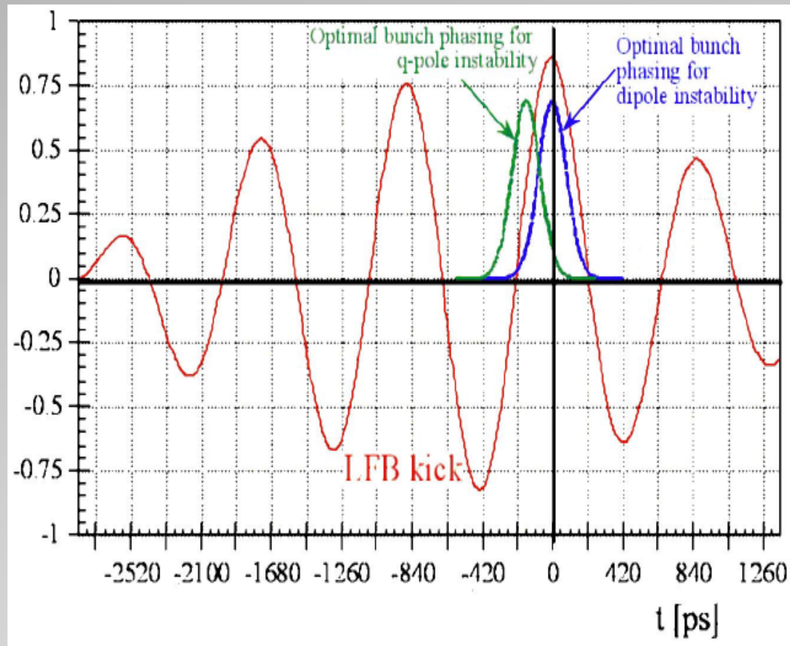
Solutions:

- Longitudinal quadrupole control by a special technique implemented at DAΦNE in the dipole feedback system
- Transverse low noise front end (in collaboration with KEK)

Longitudinal Quadrupole Oscillations

@ $f \sim 2 \cdot f_{sync}$

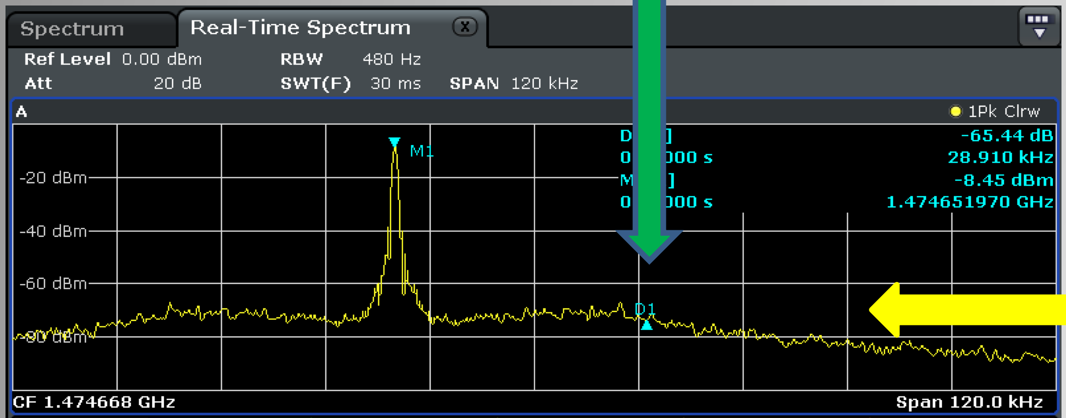




Revolution harmonic

Quadrupole oscillation

Synchrotron (dipole) oscillations damped by Long FBK

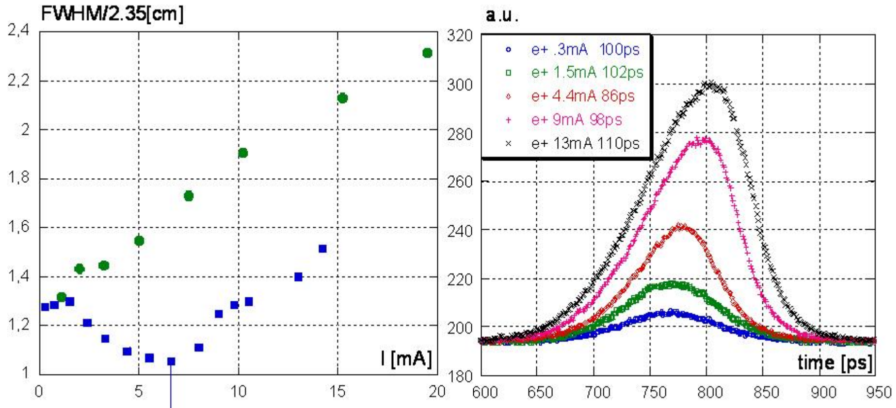


This instability, if not controlled, saturates the longitudinal feedback

(A.Drago, et al., PRST-AB, 6, 052801-1-11, 2003)

$\alpha_c < 0$ at DAΦNE

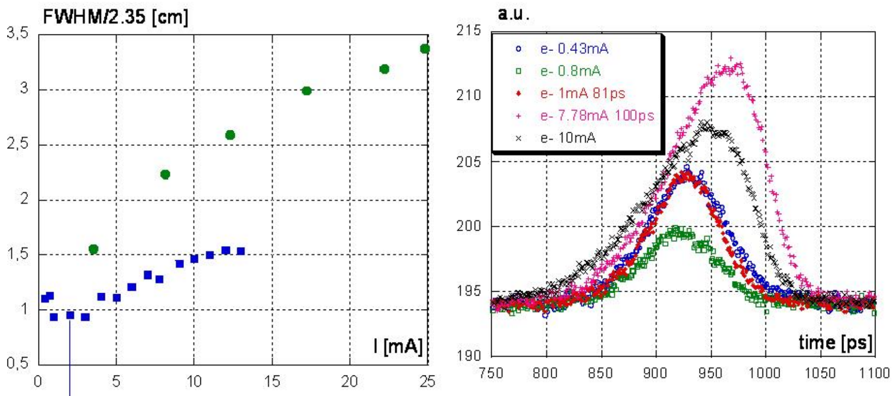
Bunch Shortening in the Positron Ring



I_{th} = 7 mA at $\alpha_c < 0$

I_{th} = 9 mA at $\alpha_c > 0$

Bunch Shortening in the Electron Ring



Low microwave instability threshold

(M. Zobov et al.. physics/0607036)

Experimental Results

- DAΦNE flexible optics

$$-0.036 \leq \alpha_c \leq +0.034$$

- Bunches shorten as predicted by numerical simulations.
- It was possible to store high bunch current with large negative chromaticity

I_b ~40 mA

- Stable multibunch beams with ***I > 1 A***
- **Specific luminosity gain of about 25%** till 300 mA per beam without SXTs
- Higher current beam-beam collisions failed due to s_y^- above the microwave instability threshold

Collisions with $\alpha_c < 0$ have never been tested elsewhere

Other contributions to particle accelerator physics

Ideas and studies aimed at improving beam dynamics and beam-beam performances:

- short pulse PS for injection kickers
- non-linearities mitigation in magnet fields especially in wigglers
- **parasitic crossing compensation by current carrying wires**
- collisions with very high crossing angle
- strong RF focusing

Proposals:

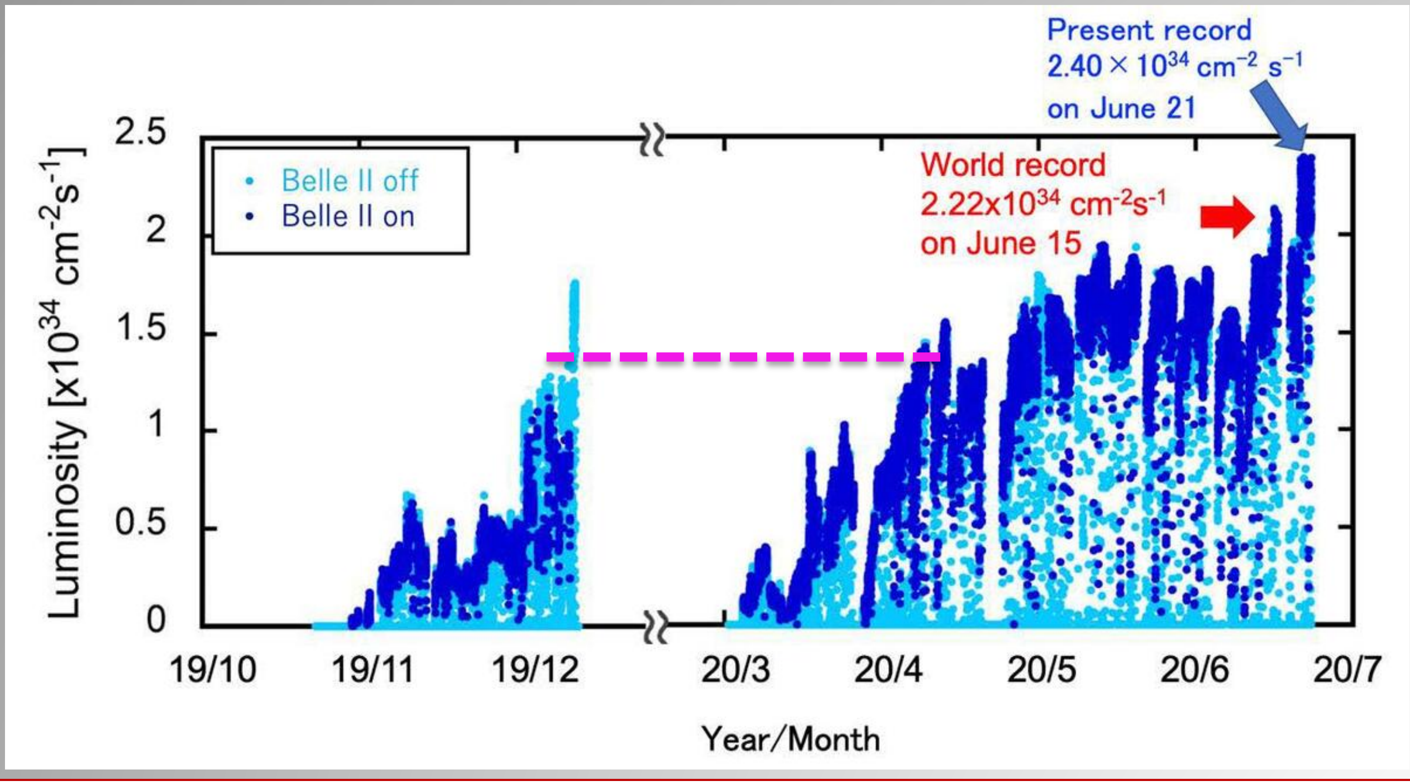
- DANAE (1.02 GeV ÷ 2.4 GeV)
- Bunch lenght modulation experiment
- DAFNE-VE (0.6 GeV ÷ 3 GeV with CW)

Crab-Waist Colliders

Colliders	Location	Status
DAΦNE	Φ-Factory Frascati, Italy	***In operation since 2007*** *(SIDDHARTA, KLOE-2, SIDDHARTA-2)*
SuperKEKB	B-Factory Tsukuba, Japan	*Crab Waist optics since April 2020*
SuperC-Tau	C-Tau-Factory Novosibirsk, Russia	Russian mega-science project
FCC-ee	Z,W,H,tt-Factory CERN,Switzerland	100 km, CDR released in December 2018
CEPC	Z,W,H,tt-Factory China	100 km, CDR released in September 2018
HIEPA	2-7 GeV China	Considered base line option

An outlook on other Lepton Collider Impact of Crab-Waist

SuperKEKB collider achieves the world's highest luminosity



(KEK press release of June 26th 2020)
"…The most recent improvement was completed in April 2020, with the introduction of the "crab waist", first used at the DAΦNE accelerator in Frascati, Italy, in 2010, and which reduces the beam size and stabilizes collisions…"

Future Plans

The DAΦNE-TF Opportunity

DAΦNE-TF could be the only facility in Europe to provide a positron beam.

DAΦNE-TF would operate when CERN won't have beams

- during each of the long stops *LS3 (2024, HL-LHC installation*) and *LS4 (2030)*

In this context the availability of DAΦNE-TF for accelerator studies will be even more interesting.

Possible activities

- ***Study of low SEY (Secondary Electron Yield) elements and impedances; Graphitization of chambers and other technologies.***
- ***Accelerator components realized with 3D printers.***
- ***High gradient tuneable permanent magnets***
- ***High power solid state RF amplifiers***
- ***High-power positron sources: peak Energy Deposition Density in the targets, wide aperture capture, accelerating sections in S Band***

Possible activities

- ***Components for future SLED and pulse flatness compensation***
- ***Components for accelerators (vacuum chambers, collimators, masks, kickers) and innovative beam diagnostic techniques***
- ***Emittance manipulation***
- ***Beams interacting with amorphous materials, crystals, lasers, plasma***

Possible activities

DAΦNE-TF might also host **small-size experiments in the field of fundamental and applied physics** requiring a small-size data sample. The qualifying element of every possible proposal in this field is the ***time scale***.

Among the possible proposals there are the measurement of processes with high effective cross sections, which are feasible with small experimental set-ups such as study of interactions K^0_L or K charged with specific materials or small-angle scattering, where interesting possibilities of testing small-angle detection systems in vacuum exist, e.g. with Roman Pot detectors highly demanding in terms of spatial and temporal resolution, high rate, radiation resistance, etc ....

DAFNE-TF Workshop 2018

17 December 2018
INFN - Laboratori Nazionali di Frascati

HOME | PROGRAM TIMETABLE | PARTICIPANTS | ACCOMMODATION | PARTICIPANT LIST | INFORMATIONS | HOW TO REACH US | CONTACT

ICFA Mini-Workshop on
DAFNE as Open Accelerator Test Facility in year 2020

The workshop will take place on December 17th, 2018 at the Touschek Auditorium, Frascati Laboratory of INFN, Italy.
The workshop is intended to discuss the interest from scientists to access the DAFNE $e^+ e^-$ complex, which will conclude its physics program as collider in 2020. An infrastructure almost unique, that could open as Test Facility (DAFNE-TF) to the international community for studies of accelerator technologies and beam physics, for small experiments, and to be used as a test bed for enterprises active in the sector of components for accelerators.

Invitation Letter of Prof. Lenny Rivkin, Chair of the International Scientific Committee
INFN-18-10-LNF - "Proposal for a possible use of DAFNE as an open infrastructure (DAFNE-TF) for the study of physics and innovative technologies for accelerators"

Scientific Committee
L. Rivkin (EPFL and PSI, chair), C. Bloise (INFN-LNF), Y. Cai (SLAC), A. Ghigo (INFN-LNF), M. Giovannozzi (CERN), C. Milardi (INFN-LNF), N. Pastrone (INFN-Torino), A. Variola (INFN-LNF)

Organizing Committee
O. R. Blanco Garcia (INFN-LNF), S. Caschera (INFN-LNF), A. De Santis (INFN-LNF), A. Drago (INFN-LNF, chair)

Secretariat
D. Ferrucci (INFN-LNF), M. Luciani (INFN-LNF)

email dafne-tfw2018@lists.lnf.infn.it

Webmaster: S. Reda

https://agenda.infn.it/event/16334/

25 proposals

96 participants from: CERN, Switzerland, Italy, Germany, Austria, Japan, China, USA

Possible Future Physics run at DAΦNE

The **Kaonic Physics Community** made a solid and mature proposal aimed at performing **fundamental physics studies at the strangeness frontier**.

***High Precision Kaonic Atoms Measurements** at DAΦNE*

The search program includes unique measurements on kaonic atoms along the periodic table: **the strangeness Mendeleev table.**
Such studies will contribute to understand a variety of hot topics ranging from **Strong Interaction** (symmetry breaking) to **Neutron Stars**, and from **Dark Matter** to **Physics BSM**, setting LNF in forefront in these studied.

A strong international community is supporting this realistic and feasible programme, in particular in terms of the **required integrated luminosity, which can be delivered within the upcoming 3-5 years**, with support from National and European projects.

https://arxiv.org/pdf/2104.06076.pdf

Scientific Program

- selected light and heavy kaonic atoms transitions (proposals KA1, KA2, KA3),
- low-energy kaon-nucleon scattering processes (proposal KN1),
- low-energy kaon-nuclei interactions (proposal KN2),

Part. and Nuclear physics
QCD @ low-energy (KA1, KA2, KN1)

Astrophysics
EOS Neutron Stars (KA2, KN1, KN2)

Kaonic atoms kaon-nuclei high precision measurements

Dark Matter studies (KN1, KN2)

Fundamental physics
New Physics (KA1, KA3)

Theoretical support from (but not only):

(KA1, KA2, KN1, KN2) STRONG-2020 EU, i.e. THEIA WP Strange Hadrons and the Equation-of-State of Compact Stars; ISNEUMAT-INFN,…

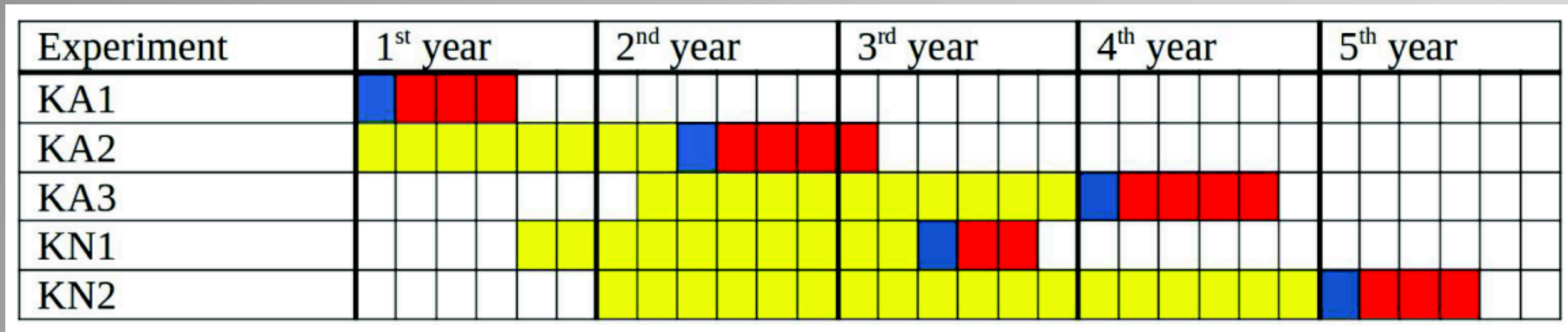
(KN1, KN2) Merafina, Yamazaki, Akaishi…

(KA1, KA3) Pospelov; Pohl, Indelicato…

(C. Curceanu, 63rd LNF Scientific Committee Meeting)

Tentative Program

Possible schematic schedule of the proposed measurements



Schematic Gantt Chart for Fundamental physics at the Strangeness Frontier at the DAΦNE Proposal.
Yellow: preparation phase, blue: installation phase, red: data taking.

https://arxiv.org/pdf/2104.06076.pdf

(C. Curceanu, 63rd LNF Scientific Committee Meeting)

Conclusions

DAFNE is the Lepton Collider where the Large Piwinski angle and *Crab-Waist* Collision Scheme has been tested for the first time and used to deliver data to three experiments having a completely different setup.

- *It has been succesfully tested and routinelly used during the SIDDHARTA run when a factor ~3 higher instantaneous luminosity has been measured.*
- *It has also been the leading concept in designing the new IR for the KLOE-2 experiment, which during data-taking profited from a daily integrated luminosity comparable with the best ever measured at DAΦNE, despite the instantaneous luminosity gain was not as high as the one measured with the SIDDHARTA configuration. NO TIME for MD!*
- *KLOE-2 run has clearly stated the Crab-Waist* collision scheme effectiveness even in presence of a large detector including high intensity longitudinal field at low energy colliding beams

The new collision scheme including Large Piwinski angle and Crab-Waist compensation of the beam-beam interactions has proved to be a viable approach to increase the luminosity,

The Crab –Waist has become one of the main design concept in developing the future circular lepton collider

Operations with Crab-Waist at DAFNE have been a unique opportunity to develop and benchmark simulation codes.

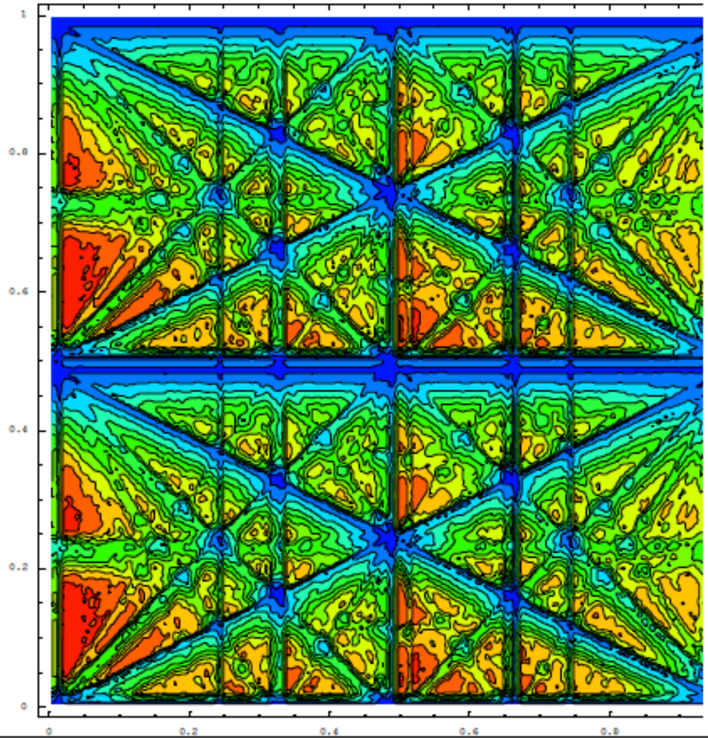
Thank you for your attention

Spare Slides

Suppression of X-Y Resonances

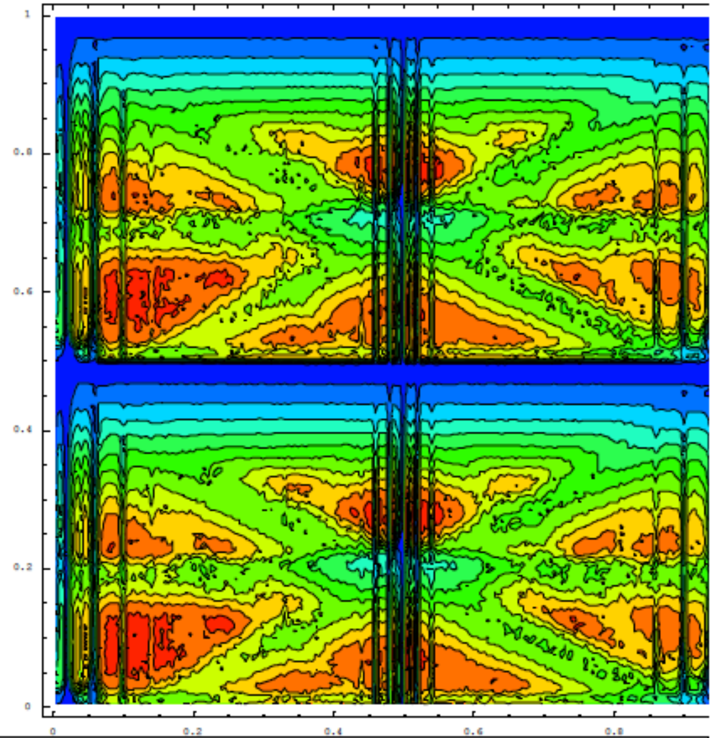
NO

Much higher luminosity!



Typical case (KEKB, DAΦNE etc.):

1. low Piwinski angle $\Phi < 1$
2. β_y comparable with σ_z



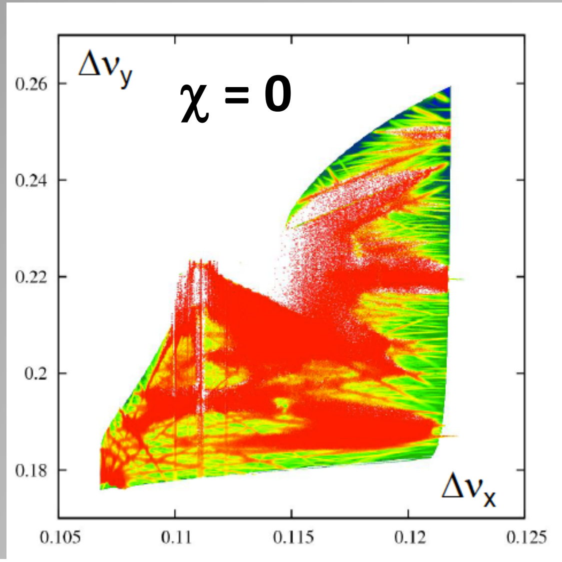
Crab Waist On:

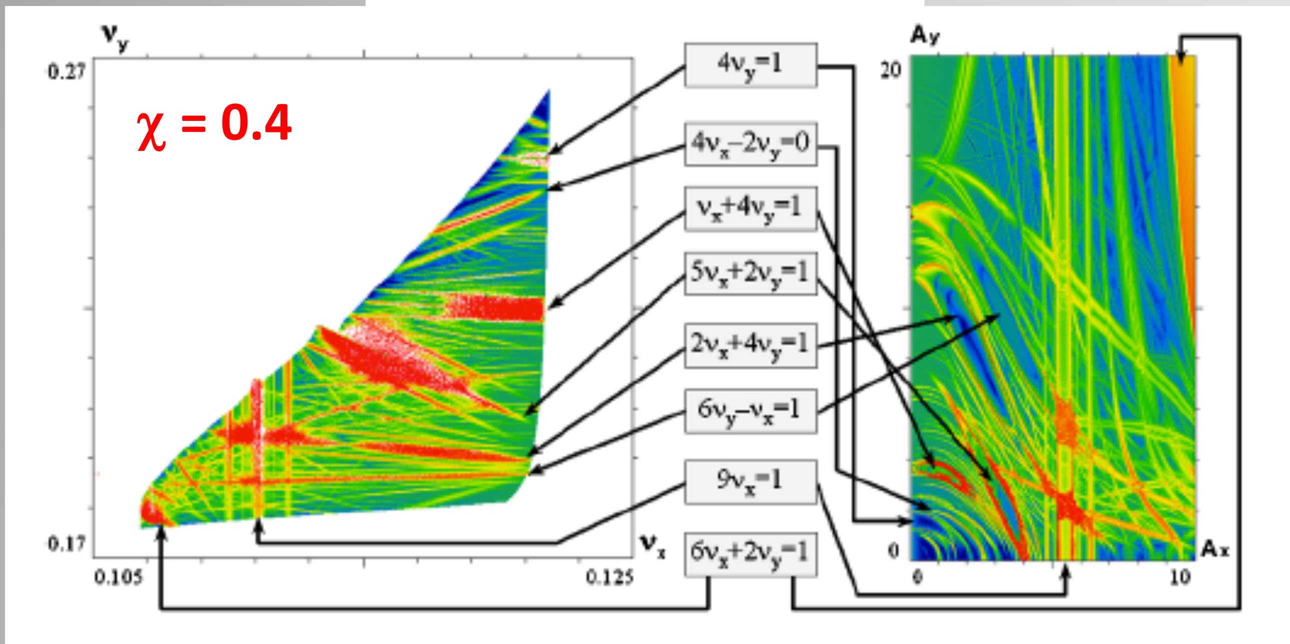
1. large Piwinski angle $\Phi >> 1$
2. β_y comparable with σ_x/θ

Frequency Map Analysis of *BB* Interaction

NO

DAΦNE simulations

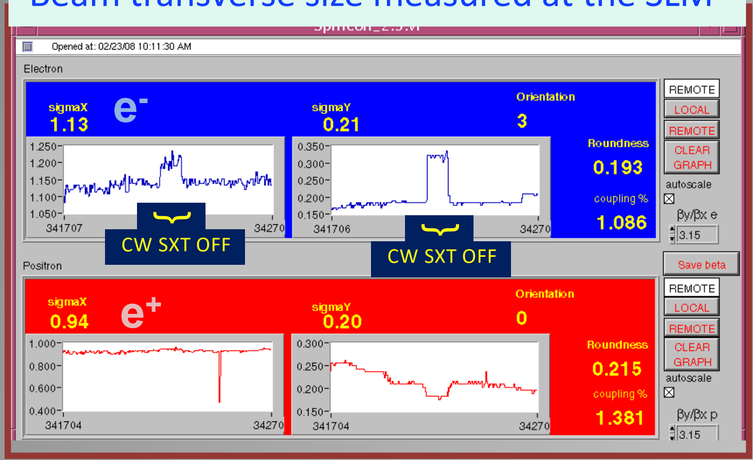




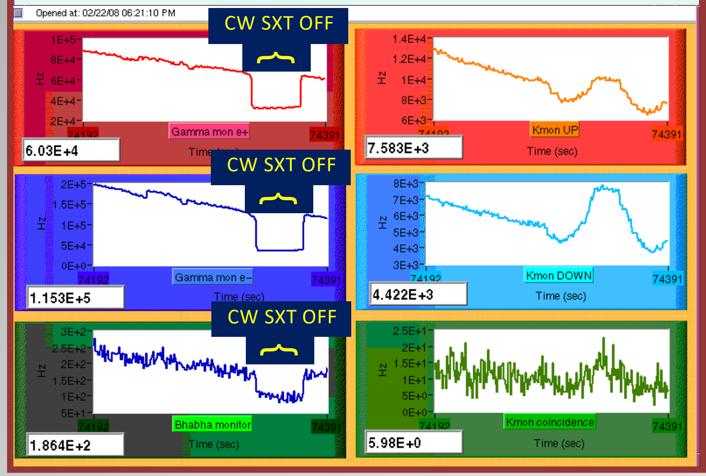
(D. Shatilov et al., Phys.Rev.ST Accel.Beams 14 (2011) 014001)

Crab-Waist Compensation First Experimental Evidence

Beam transverse size measured at the SLM

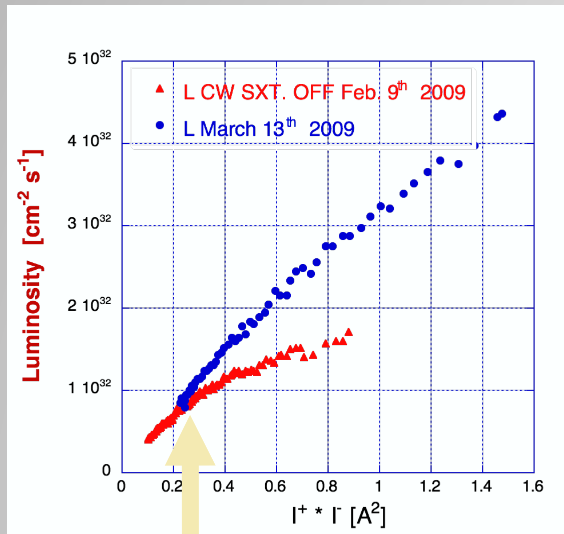


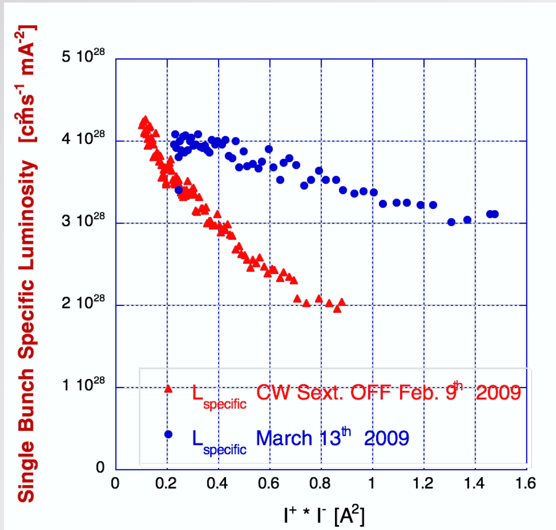
Luminosity from 2 different monitors



Transverse sizes (left) and **luminosity** (right) dependence on the ***CW-Sextupole*** **excitation** in the e⁻ ring

Luminosity as a function of colliding currents *CW-Sextupole* excitation



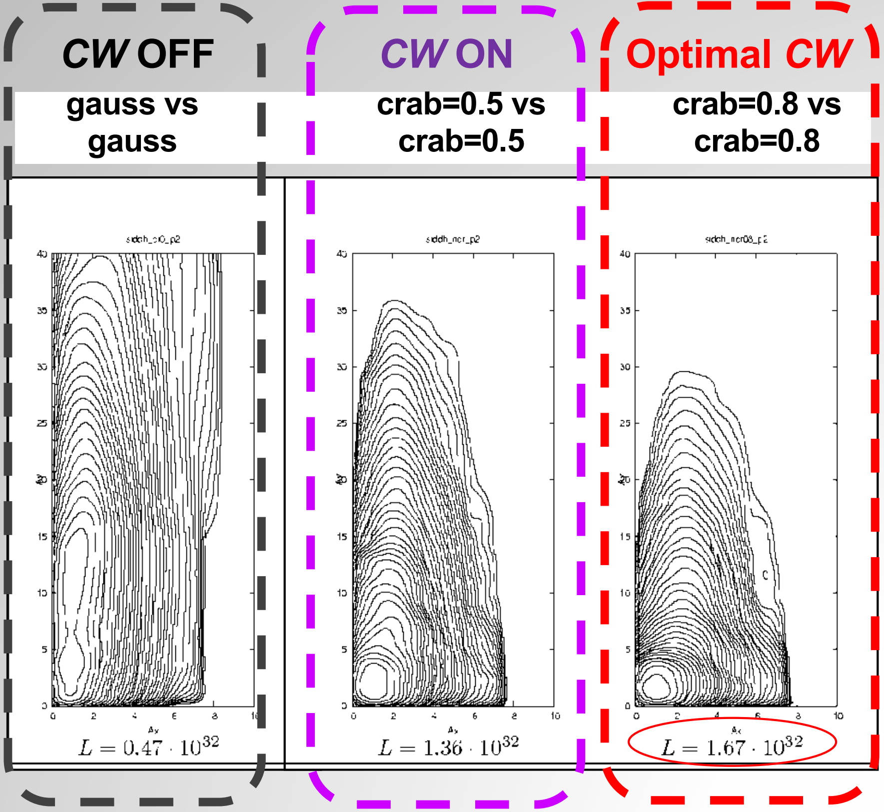


- Transverse beam blow-up
- Lifetime reduction

Weak-Strong Simulations

Crab-Waist compensation works in weak-strong regime also, and measured luminosity is in good agreement with *Lifetrack* code (D. Shatilov) predictions
Strong beam crabbed

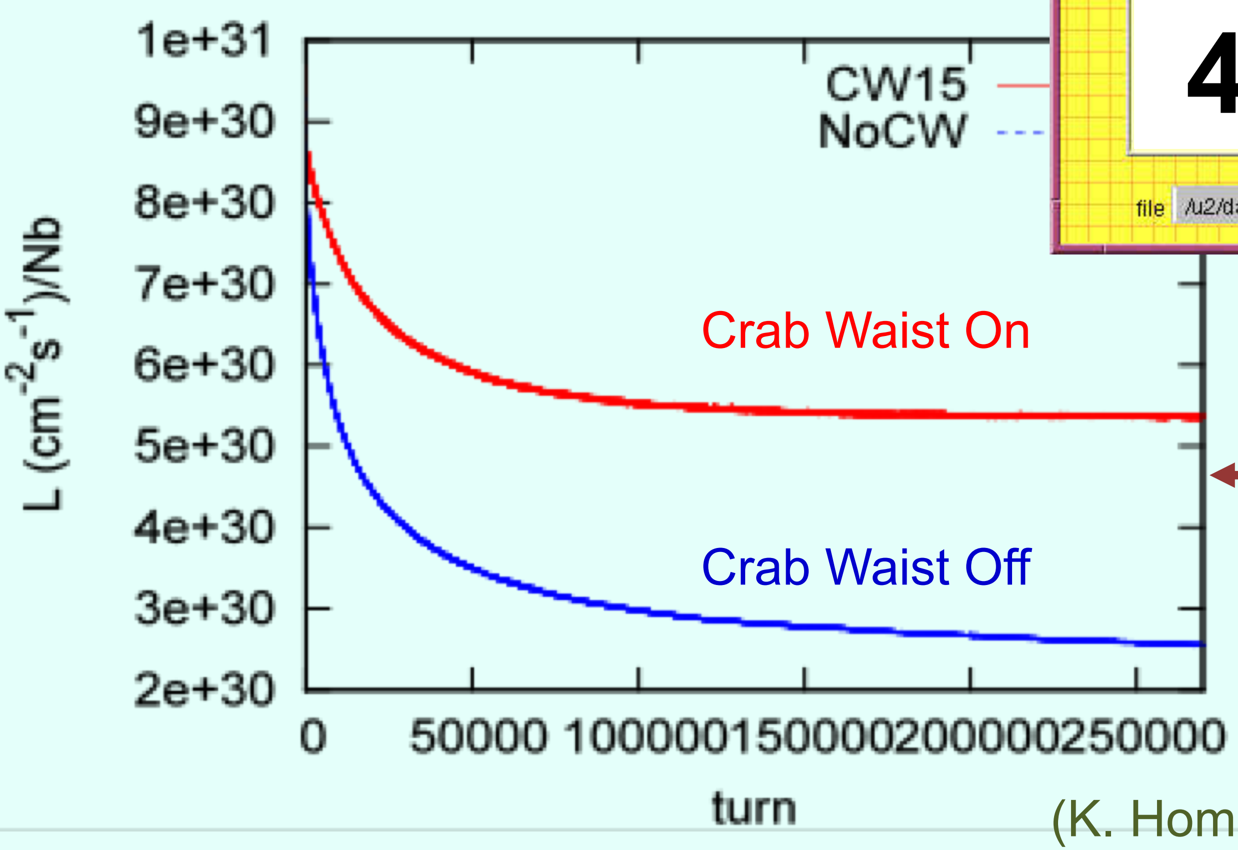
$\xi_y = 0.09$

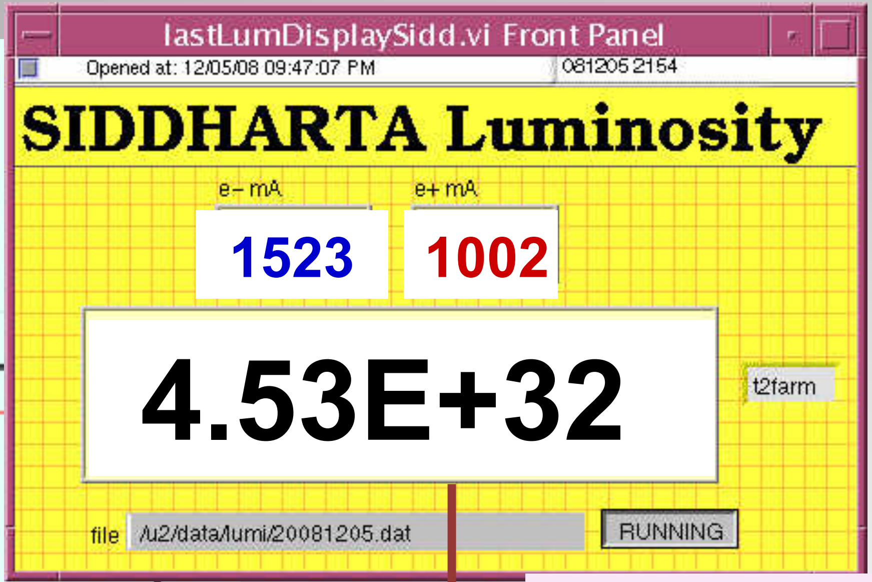


Strong-Strong Beam-Beam Simulations

Single Bunch Luminosity

(Damping time = 110.000 turns)



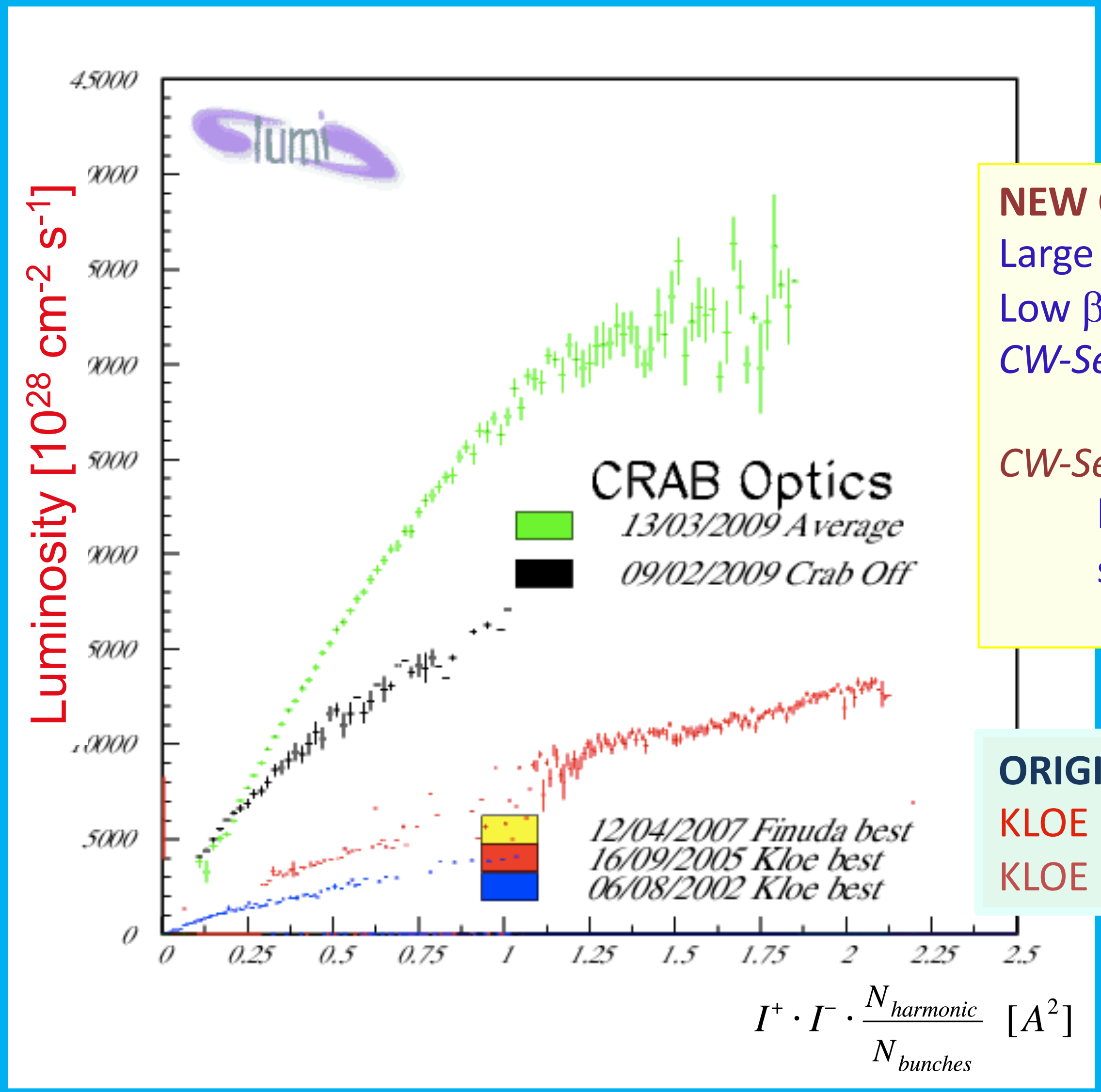


(K. Homi)

105 bunches

about 20% lower

Crab-Waist Collision Scheme & Luminosity



NEW COLLISION SCHEME:

Large Piwinski angle $\psi = 1.9$

Low β^*_y $\beta^*_y = 9.0$ [mm]

CW-Sextupoles $\chi = 0.6$

CW-Sextupoles off

larger transverse beam size blowup

sharp lifetime reduction

ORIGINAL COLLISION SCHEME:

KLOE 2005 $\psi = 0.6$ $\beta^*_y = 18.$ [mm]

KLOE 2002 $\psi = 0.3$ $\beta^*_y = 25.$ [mm]

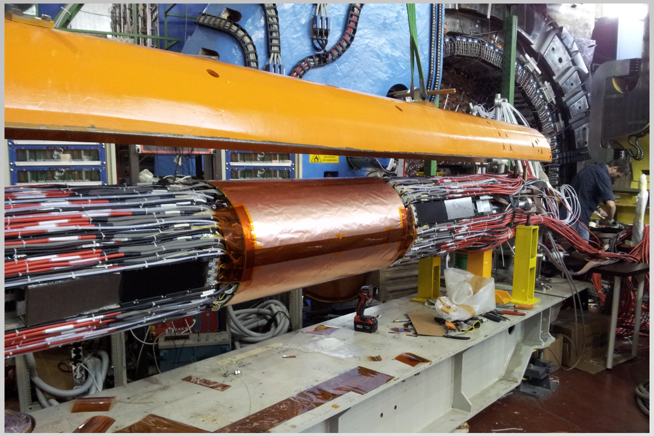
20% L reduction at high currents because of bunch lengthening due to the ring impedance. L $\propto 1/\sigma_z$ in Large Piwinski Angle & Crab-Waist regime.

DAΦNE Luminosity and Tune Shift

	KLOE (Spt 2005)	FINUDA (Apr 2007)	SIDDHARTA *CW* (Jun 2009)
Luminosity [10^{32} cm^{-2}s^{-1}]	1.53	1.6	**4.53**
I(ele) [A]	1.38	1.50	1.52
I(pos) [A]	1.18	1.1	1
n_b	111	106	105
ε_x [mm mrad]	0.34	0.34	0.28
β_x [m]	1.5	2.	0.25
β_y [cm]	1.8	1.9	0.9
$\xi_{x(y)}$	0.0245	0.0291	**0.0443 (0.09)**

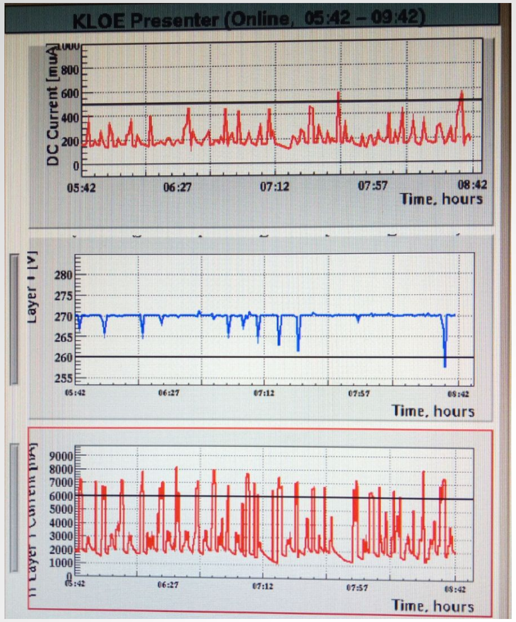
Background Control

The new detector layers installed around the beam pipe posed new tight requirements on background level and control.



Criteria for acceptable background became:

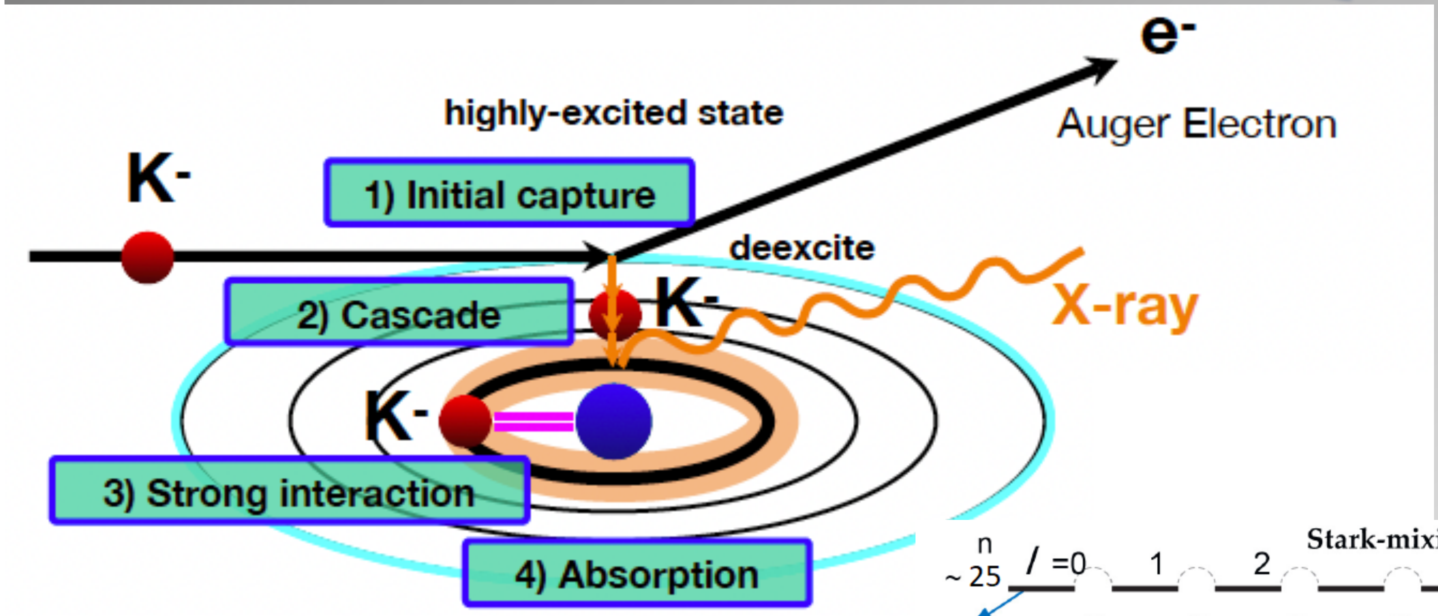
- counting rate on the detector endcaps
- current amplitude measured by the different drift chamber sectors
- discharge threshold on the innermost IT layer

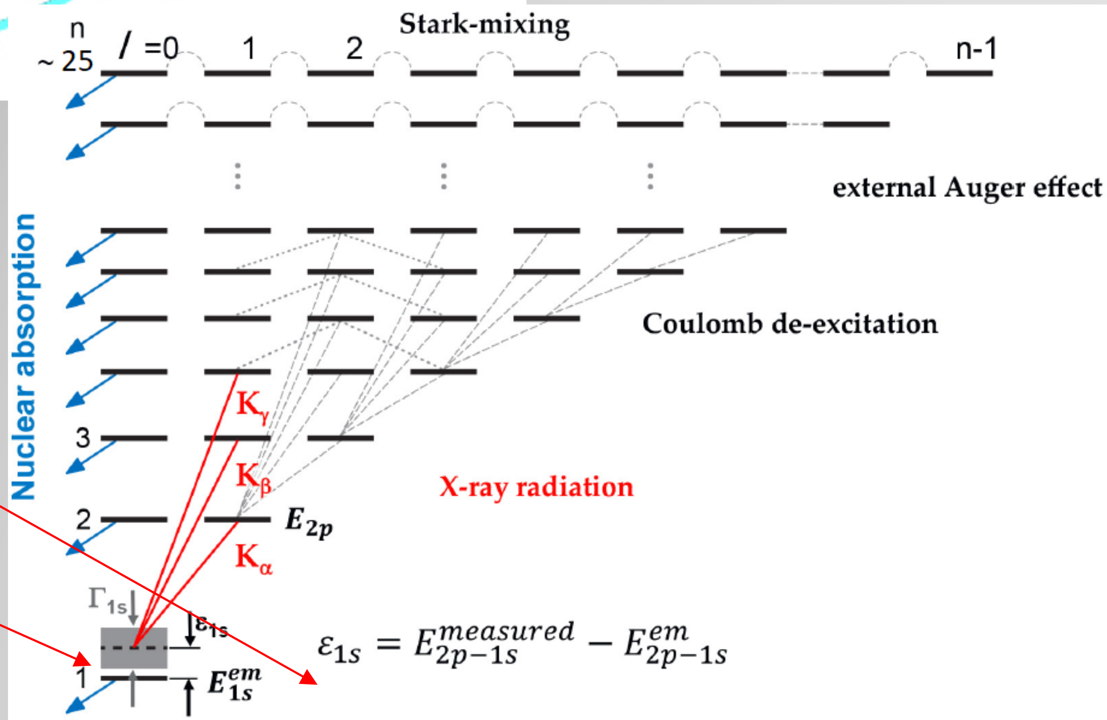


Background on the IT was heavily dependent on the injection process which had to be accurately optimized and stabilized

Even small drifts in the energy of the incoming beam, 0.01 ÷ 0.02 %, were causing unaffordable background level.

Kaonic atoms and the QCD effects





Width Γ and shift ε obtained by measuring the X-rays emitted

(C. Curceanu, 63rd LNF Scientific Committee Meeting)