Experience with DAΦNE Upgrade Including *Crab-Waist*

Catia Milardi

(on behalf of the DAΦNE Commissioning Team)

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DAΦNE Commissioning Team

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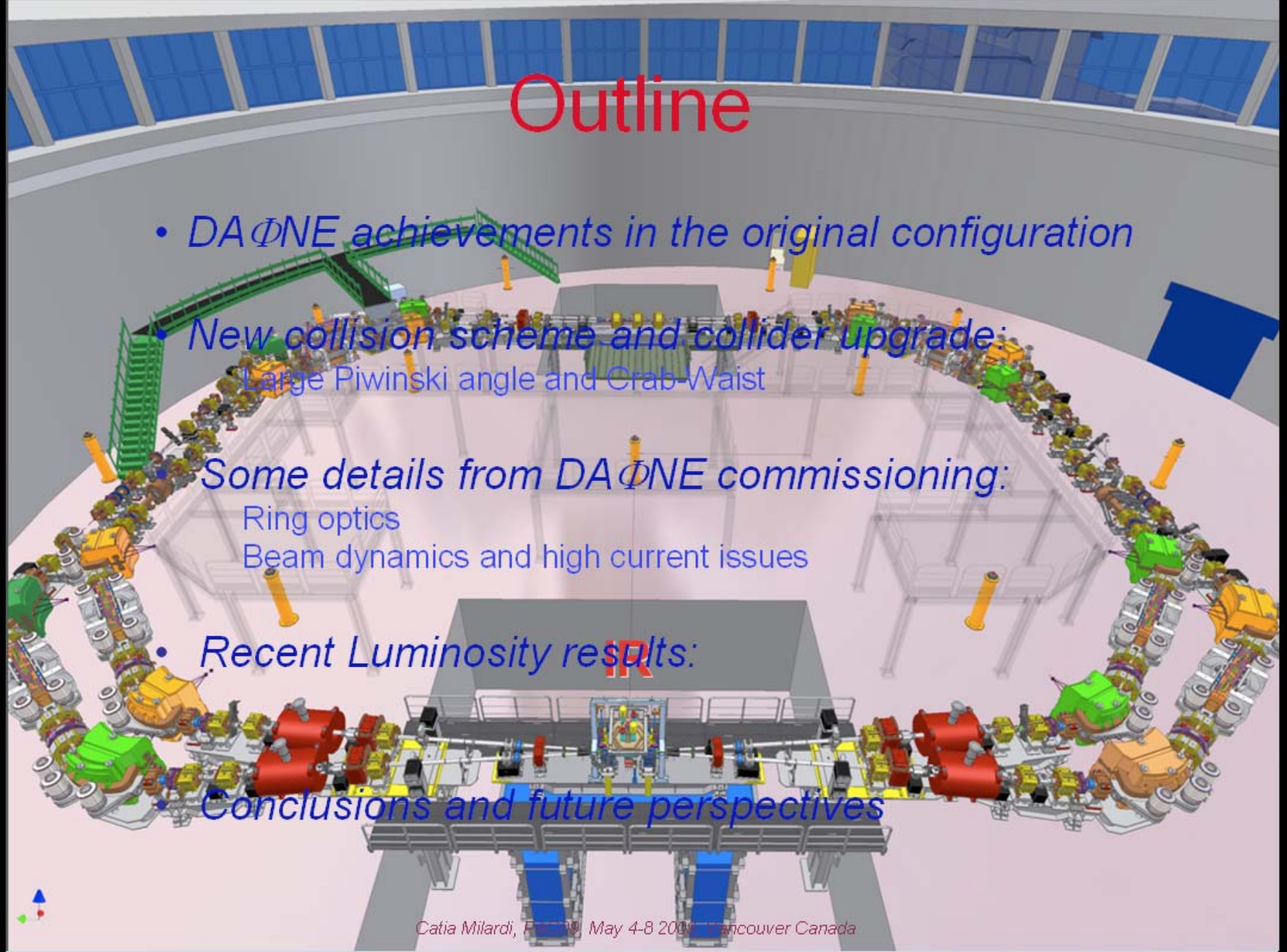
Outline

- *DAΦNE achievements in the original configuration*
- *New collision scheme and collider upgrade:*
  - Large Piwinski angle and Crab-Waist
- *Some details from DAΦNE commissioning:*
  - Ring optics
  - Beam dynamics and high current issues
- *Recent Luminosity results:*
- *Conclusions and future perspectives*

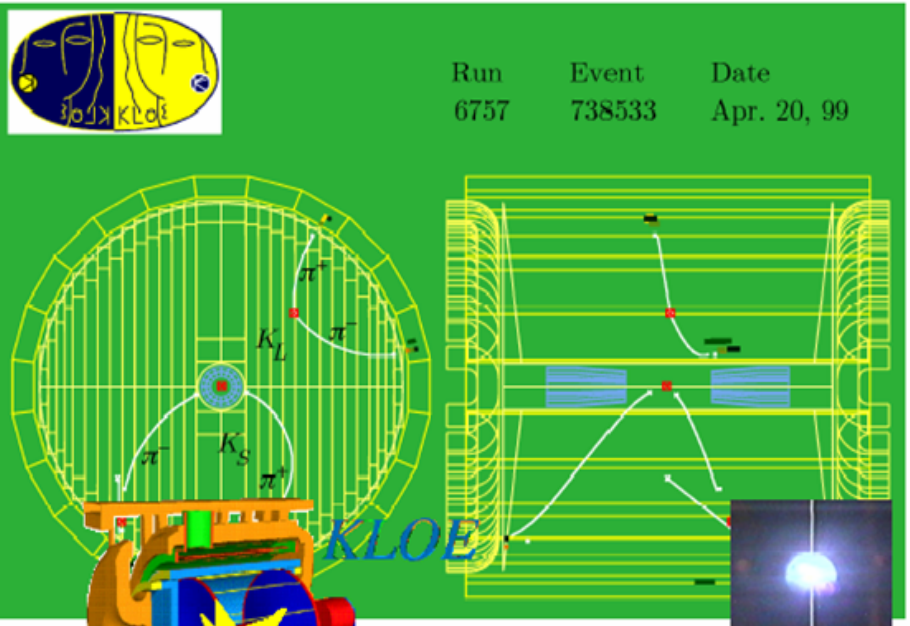


DAΦNE

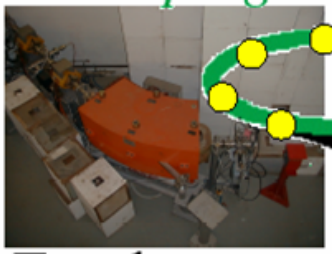
e^+e^-

$C = 97$ m

$E = 0.51$ GeV (Φ)



Damping ring



Test beam

Main rings

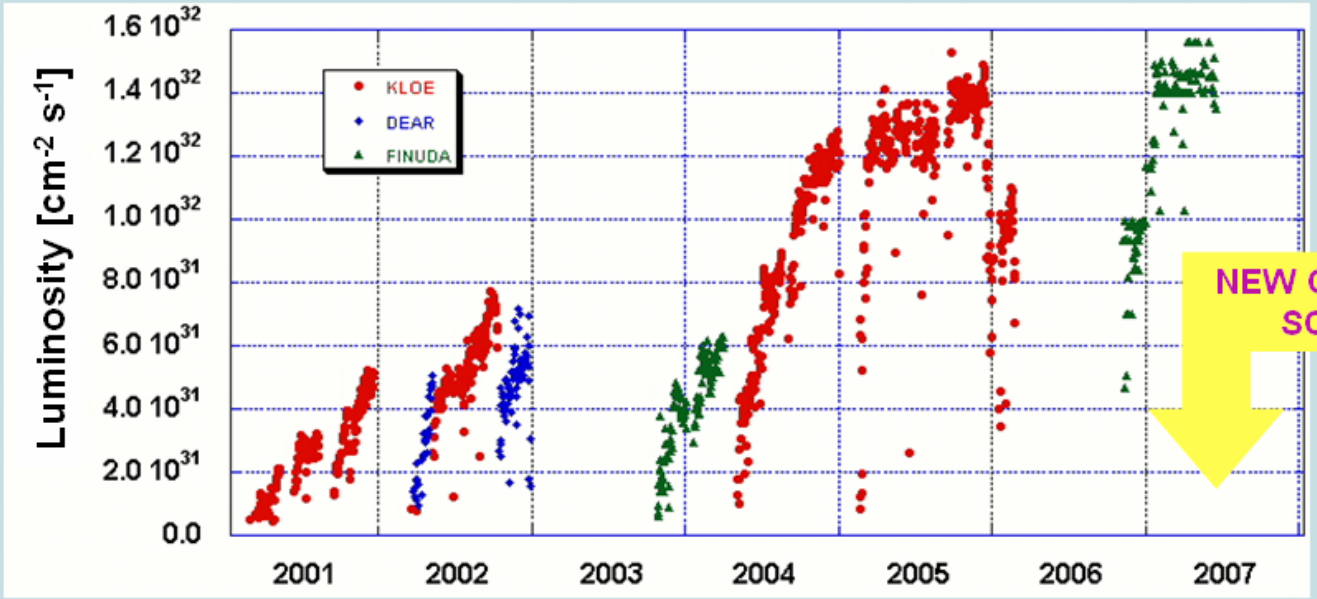
DAFNE-Light

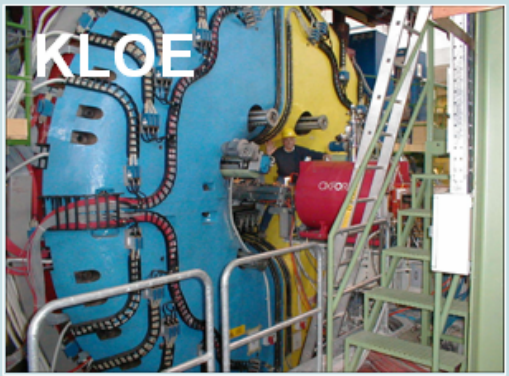
Linac

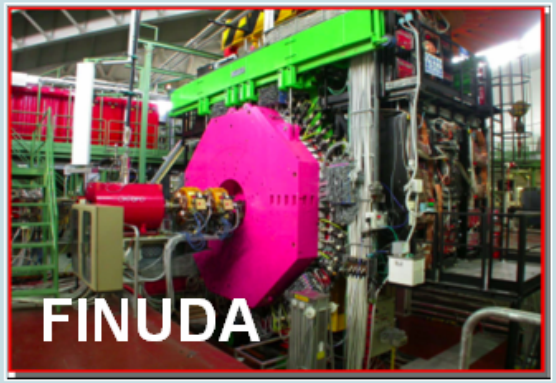
DEAR
&
FINUDA

L_{peak} at DAΦNE 2001 ÷ 2007

L_{peak} had a remarkable evolution mainly due to several machine upgrades







L_{logged} (fb^{-1}) 2001÷2007

KLOE	3.0
FINUDA	1.2
DEAR	0.2

DAΦNE gave a good opportunity for testing and using a new collision scheme

Physics program

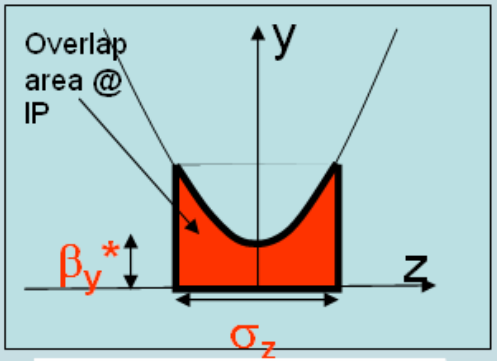
- Shutdown in mid 2007 for SIDDHARTA installation
- Experimental groups asking for new physics programs

Collider Upgrade

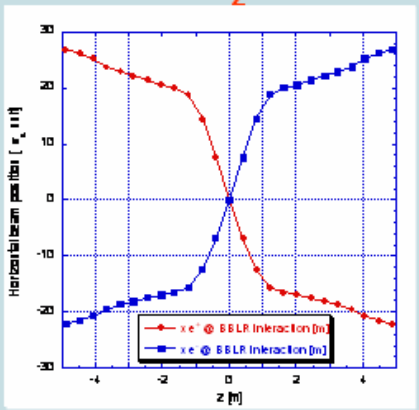
- Required Limited time and resources
- Introduced several simplifications suitable for beam dynamics

Rationale for the Upgrade

L_{peak} ~ 1.6 10^{32} cm^{-2} s^{-1} was the maximum luminosity achievable in the original DAΦNE configuration due to:



- $\beta^*_y \sim \sigma_z$ to avoid hourglass effect
- Long-range beam-beam interactions causing τ^+ τ^- reduction limiting I^+_{MAX} I^-_{MAX} and consequently L_{peak} and $L_{\int}$
- Transverse size enlargements due to the beam-beam interaction



A new conceptual approach was necessary to reach $L \sim 10^{33}$
Collision scheme based on **Large Piwinski** angle and **Crab-Waist**

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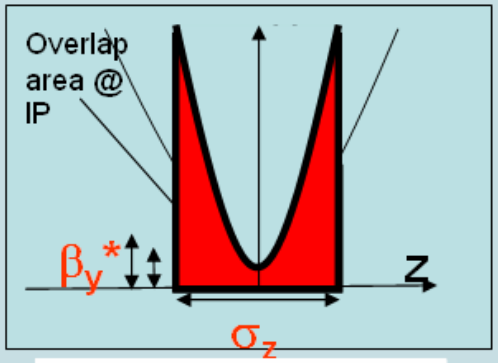

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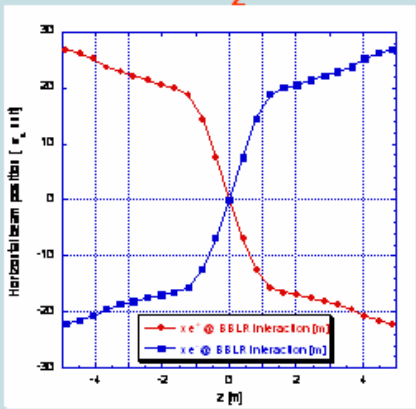

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Collision scheme based on **Large Piwinski** angle and **Crab-Waist**

Large Piwinski angle

Large Piwinski angle Φ obtained by:

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

small σ_x

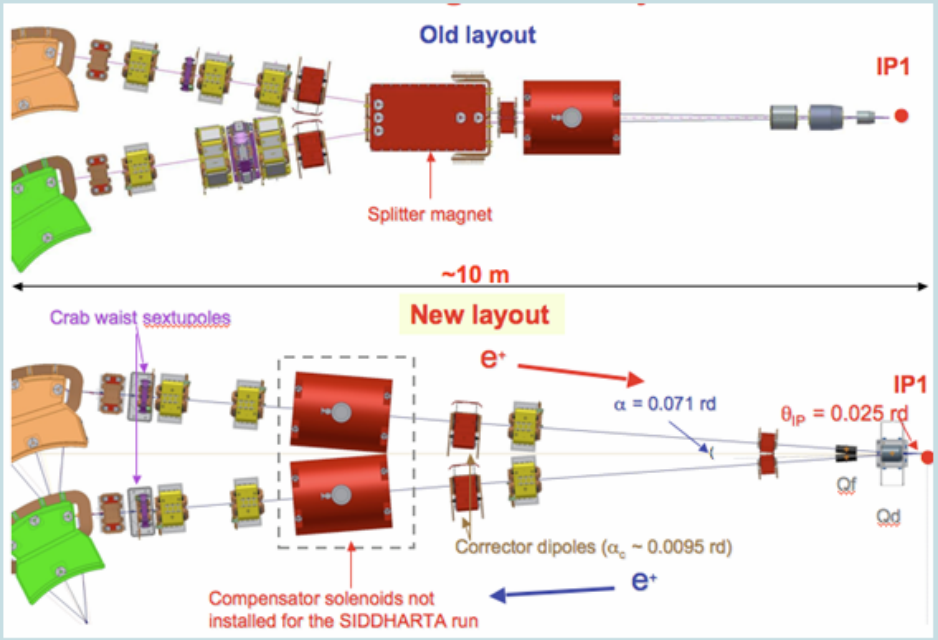
large θ

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

- low ζ_x
- $L_{geometric}$ gain
- no parasitic crossing

New IR magnetic layout

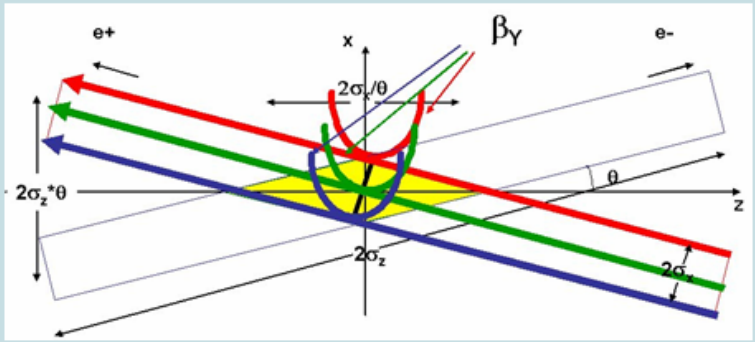
- splitter magnets and compensator solenoids removed
- New low-β
- Sector dipols around IP rotated
- large collision angle ~ 50 mrd
- four C type corrector dipoles used to mach the vacuum chamber in the arc



Lower β^*_y possible

Small β_y^* in fact the bunch overlap lenght Σ is:

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



- $L_{geometric}$ gain
- low ζ_y
- Vertical synchro-betatron resonances suppression

New low-β section

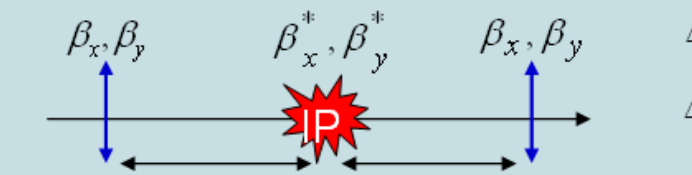
- *low-beta* section based on PM QUADs:
  - K_{QD} = -29.2 [T/m]
  - K_{QF} = 12.6 [T/m]
- e^+ e^- vacuum chambers separate after Q_D

Crab-Waist compensation

Collision with large Φ is not a new idea …..

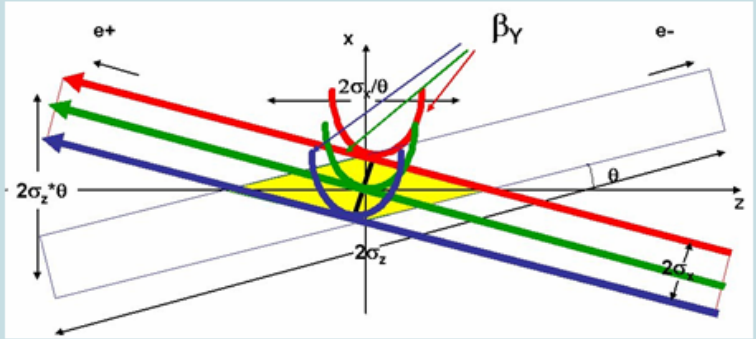
Crab-Waist transformation is !
(P.Raimondi et al., 2006)

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



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

- $L_{geometric}$ gain
- x-y synchro-betatron and betatron resonance suppression



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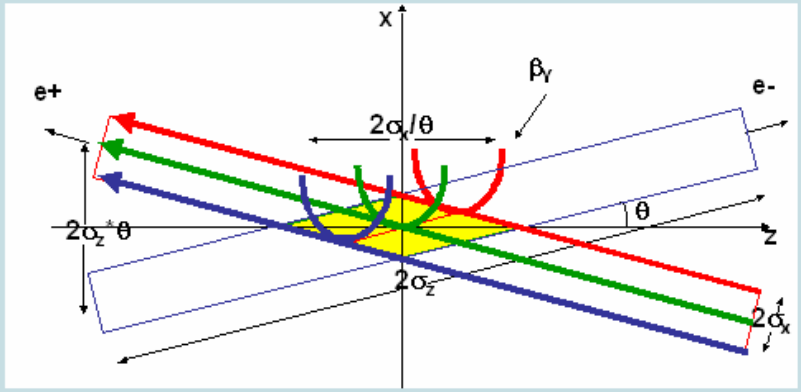
sextupole (anti)sextupole

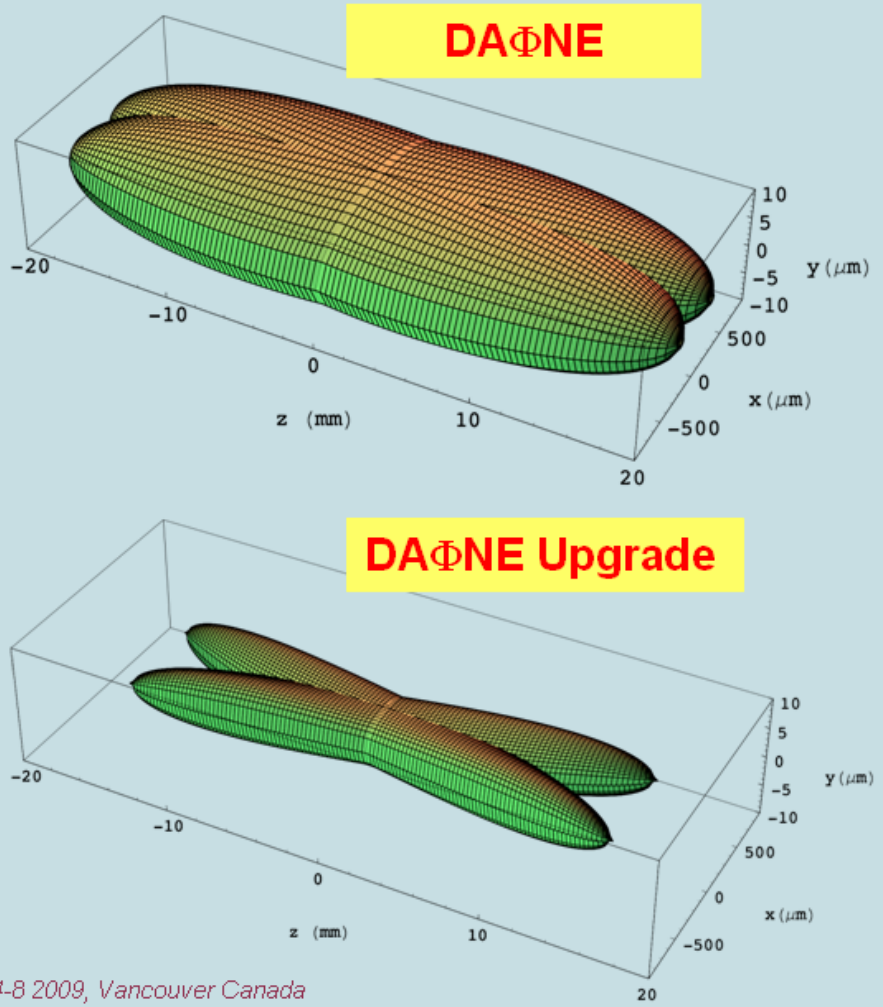
$$\Delta\nu_x = \pi$$
$$\Delta\nu_y = \frac{\pi}{2}$$



DAΦNE upgrade parameters

	DAΦNE KOE	DAΦNE Upgrade
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mmxmrad)	0.34	0.26
β_x^* (cm)	160	26
σ_x^* (mm)	0.70	0.26
$\Phi_{Piwinski}$	0.6	1.9
β_y^* (cm)	1.80	0.85
σ_y^* (μm) low current	5.4	3.1
Coupling, %	0.5	0.5
I_{bunch} (mA)	13	13
σ_z (mm)	25	20
N_{bunch}	110	110
L ($cm^{-2}s^{-1}$) x10^{32}	1.6	5

Beam distribution @ IP



Early commissioning milestones (N0v 07 ÷ Jul 08)

- The new collision scheme implementation took ~ **five months**
- ***Commissioning*** started at the end of November 2007
- February 2008 ***Crab-Waist sextupoles in operation***
- February 11th ***Luminosity monitor installation***
- Beginning of March first $L \sim 10^{32}$ cm^{-2} s^{-1} measured
- March 10th ***SIDDHARTA installation*** *(preliminary setup)*
- First half of March new ***transverse horizontal feedback installed in the MRe*** ring
- May 2008 $L_{peak} \sim 2.2 * 10^{32}$ cm^{-2} s^{-1} ***measured.***

Ring Optics Commissioning

Ring Optics optimization required to:

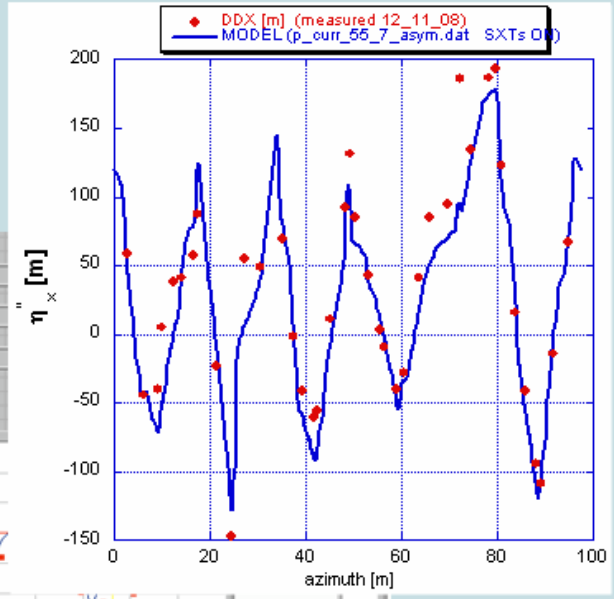
- *adjust the position of the low-β PM QUADs*
- *fix misalignment errors in some elements*
- *correct transverse betatron coupling mainly by rotating the PM focusing QUADs in the IR*
- *minimize η_y by correcting the global orbit and centering the beam vertical position in the arc SXTs*
- *add 2 electromagnetic QUADs around the IP in order to meet the phase advance requirements imposed by the Crab-Waist collision scheme*
- *establish procedure for the CW SXTs alignment in single beam operation mode in order to have $\nu_{x,y}$, κ, τ and background constant when they are switched on*

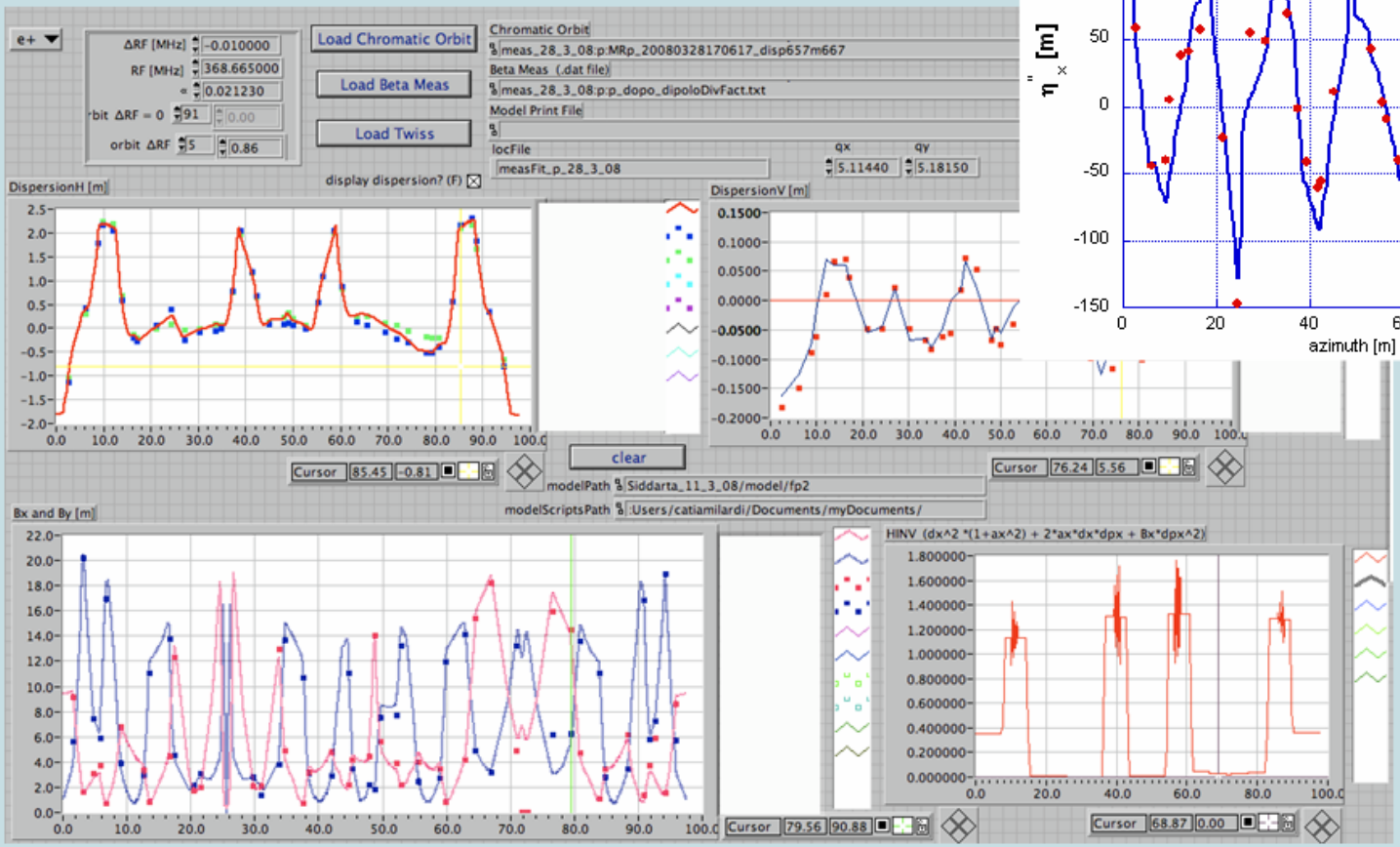
Ring Optics model

Ring model matches now quite well beam measurements in terms of:

linear optics $\nu_{x,y}$, $\beta_{x,y}$, η_x , ε_x

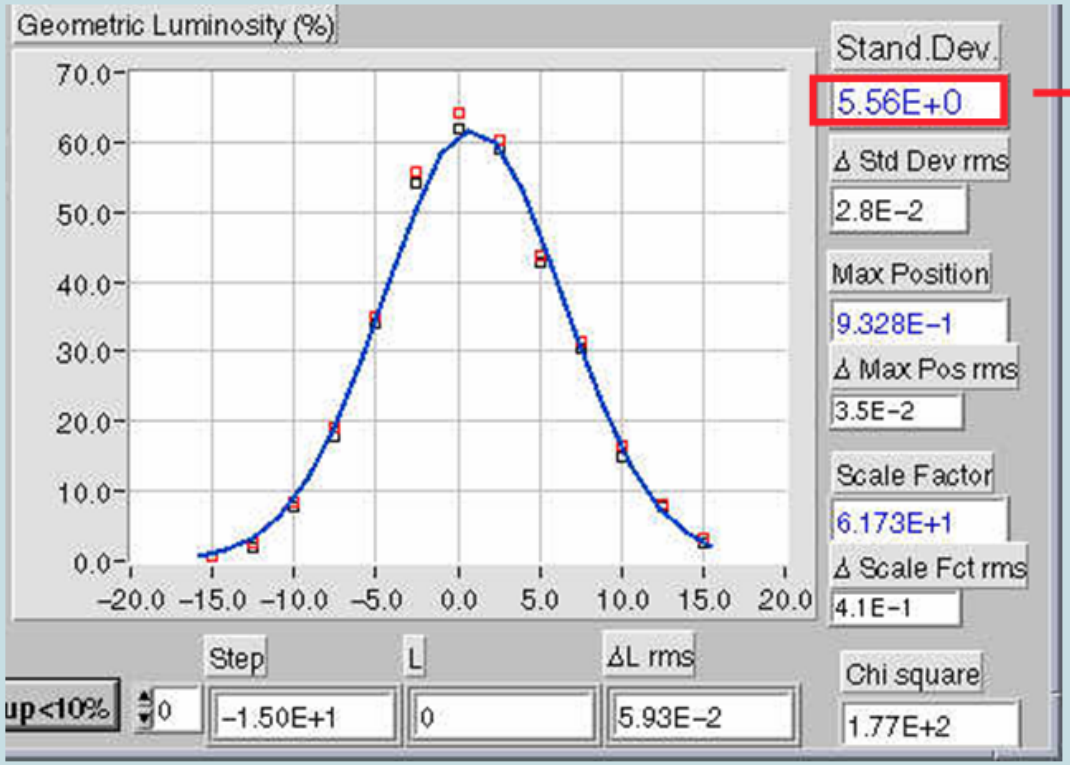
non-linear optics energy acceptance and η''_x,





Vertical beam-beam *Luminosity scan*

$$\Sigma_y = \sqrt{\sigma_{yp}^2 + \sigma_{ye}^2} \qquad \Sigma_y = \Sigma_y^{meas} * 0.88$$



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

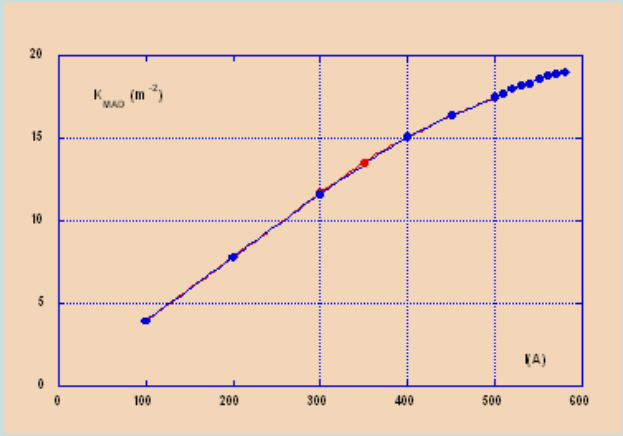
Design value 3.1 μm

July 1st 2008

Crab-Waist sextupoles parameters

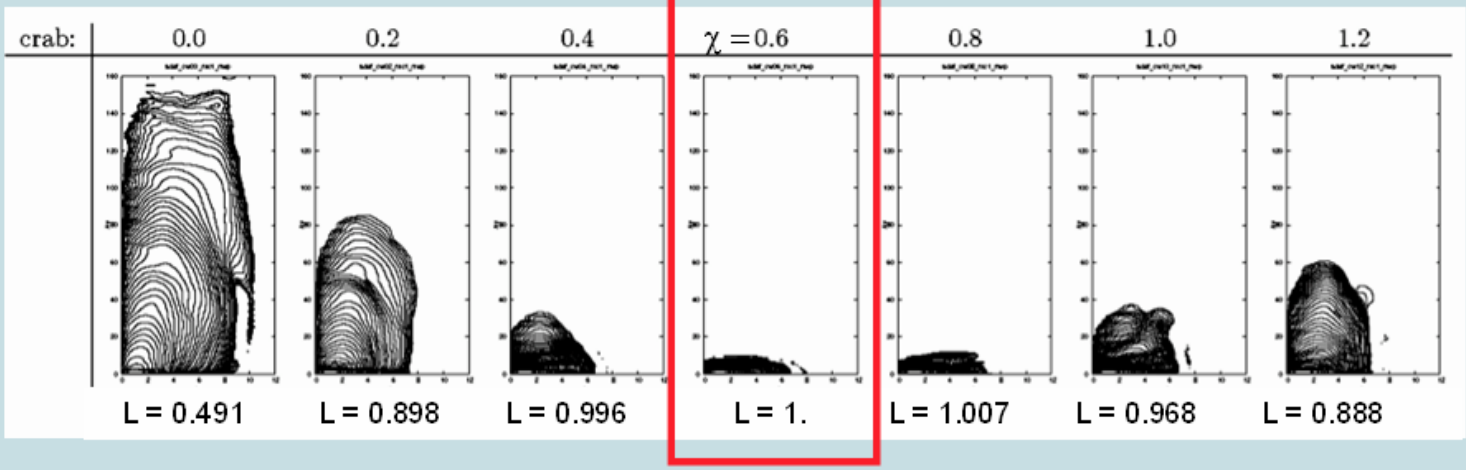
On June 2008 CW SEXTUPOLES replaced with more powerful magnets

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



χ nominal 0.6

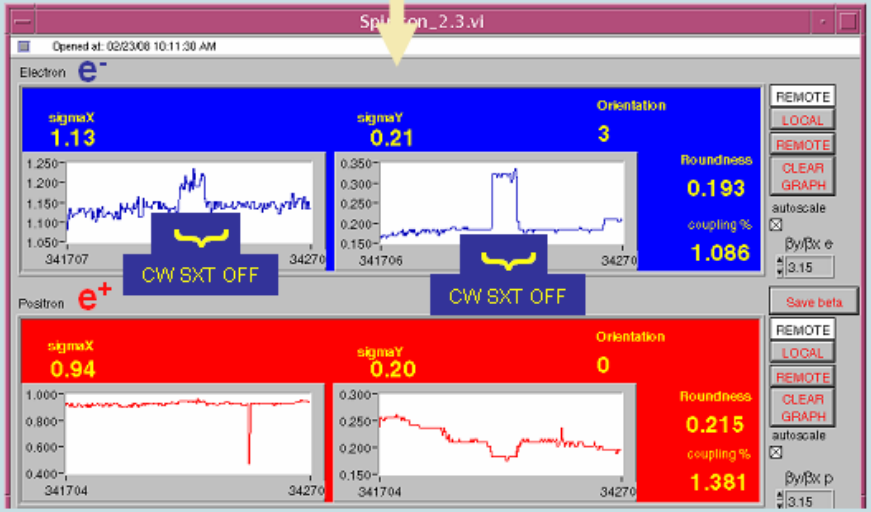
χ **present value 0.5**



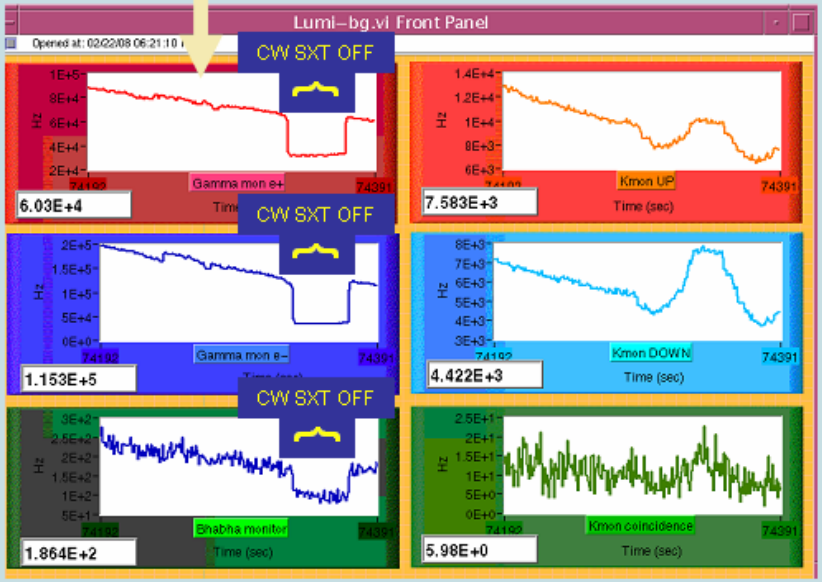
Luminosity (arbitrary unit) ***and Beam tails versus waist rotation*** χ

Crab-Waist compensation first experimental evidence

Beam transverse size measured at the synchrotron light monitor



Luminosity measured by 2 different monitors



Transverse size (left) and luminosity dependence (right) on the CW sextupole excitation in the e^- ring

Crab Sextupoles are working since the first time they have been tested

DAΦNE operations (Sep ÷ Dec 2008)

- *August **SIDDHARTA** final setup installation*

- *some components of the **e⁺ longitudinal feedback** have been substituted (delay lines, phase shifter, etc.)*

- $I^{+}_{treshold} \leq$ **0.8 A** seemed to be due to a fast transverse horizontal instability

  About the instability:

  - ✓ *It has been observed even before the DAΦNE upgrade but it was less harmful*
  - ✓ *It is compatible with the e-cloud effect*
  - ✓ Solenoidal winding installed the e⁺ ring

- ***Studies* aimed at sorting out other possible sources of instability:**
  - ✓ *anomalous wake field in the e⁺ vacuum chamber*
  - ✓ *trapped high order mode*
  - ✓ *nothing wrong found!*

- **Second transverse horizontal feedback implemented**

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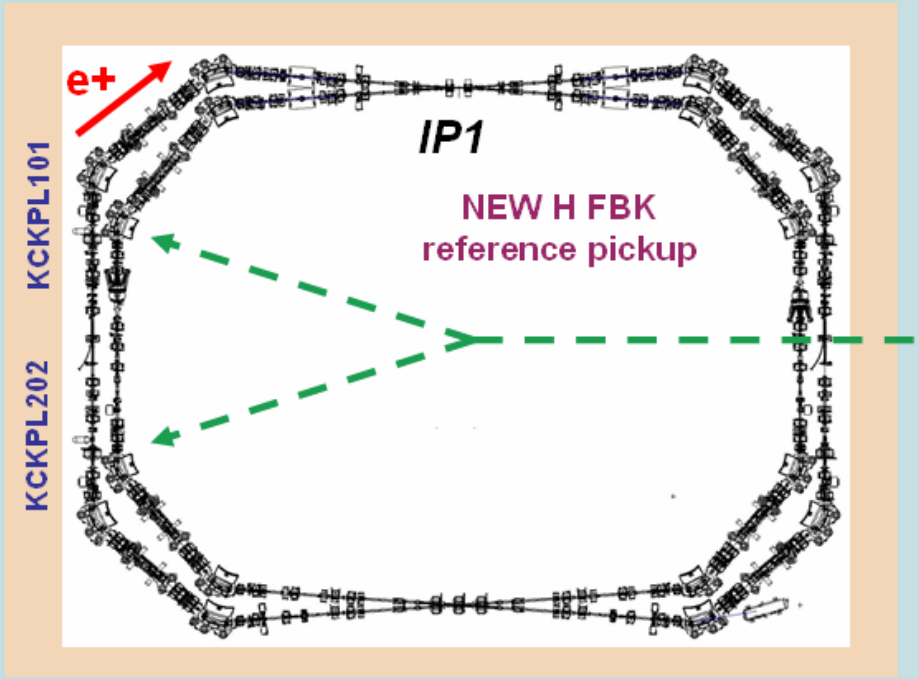
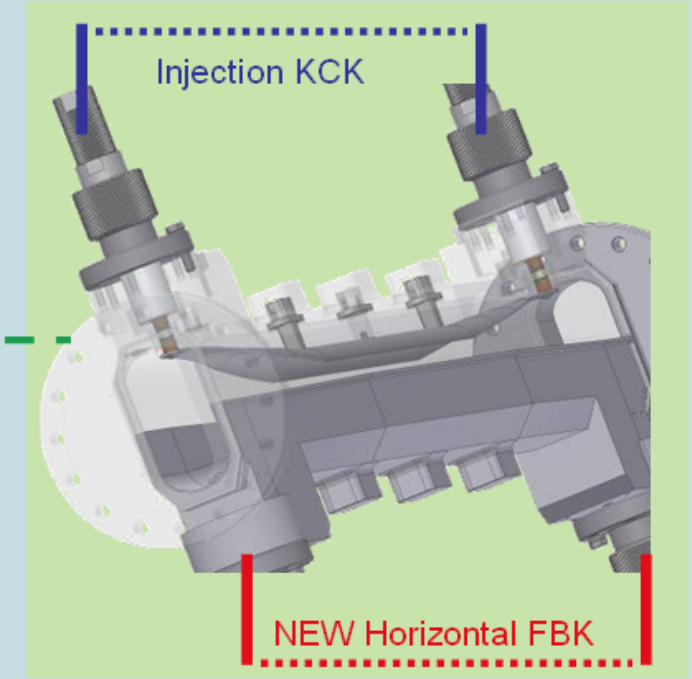
Poster TH5RFP057 A. DRAGO

- **Second transverse horizontal feedback implemented**

New e+ Transverse Horizontal Feedback

A second transverse horizontal feedback has been implemented in the positron ring





The damping times of the two feedbacks add up linearly

Damping time measured:

80 ms^{-1} (1 FBK $t_{damping}$ ~ 10 μs)

200 ms^{-1} (2 FBKs $t_{damping}$ ~ 5 μs)

The **2 feedbacks system is very efficient** since:

The strip-line shunt impedance is larger at the low frequencies typical of the unstable modes

The feedback kick strength scales as the square root of the applied power

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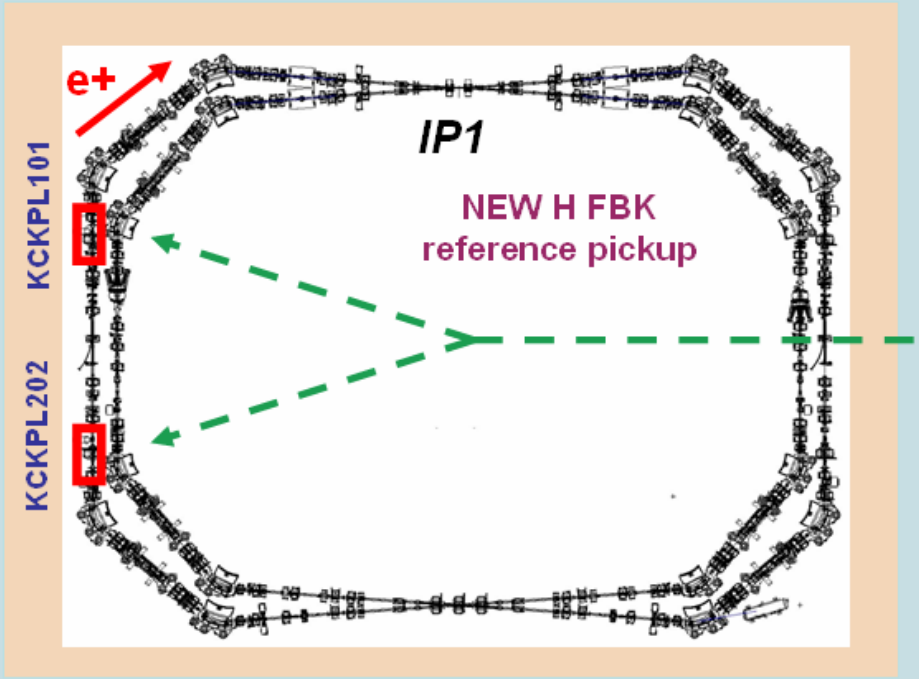

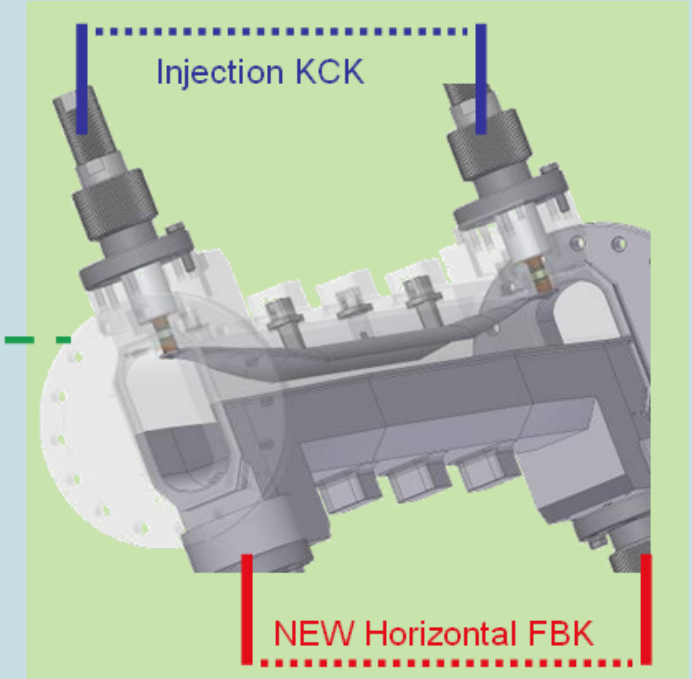

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Poster TH6REP072 A. DRAGO

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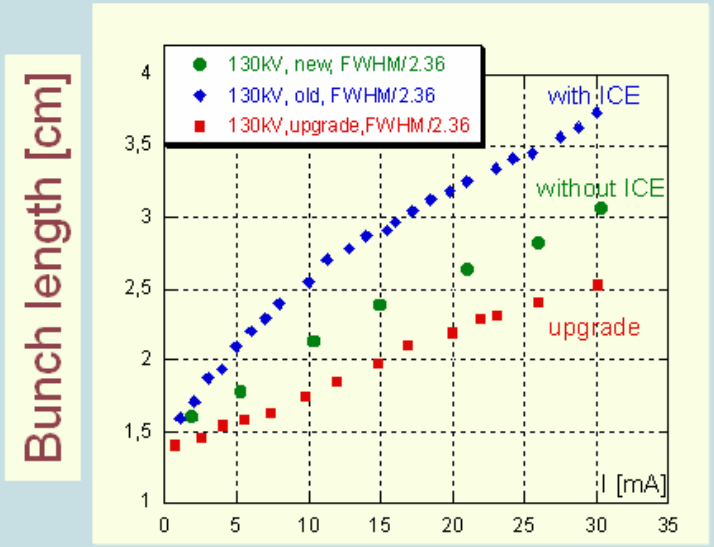
Further performance optimization

Another improvement in the high current operation has been obtained by:

- pointing out and mitigating a 50 Hz noise propagating throughout the ground system and affecting:
  - Some beam instrumentation (DCCT)
  - e+ longitudinal and transverse feedbacks
  - RF system
- Understanding a 2-beams barycentric instability occurring at high current when both the '0-mode' feedback in the LLRF are working, the effect has been presently avoided by switching off the 0-mode' feedback in the e+ ring.
- Implementing a new dedicated feedback to keep under control a two degree peak to peak phase jitter from the RF klystron

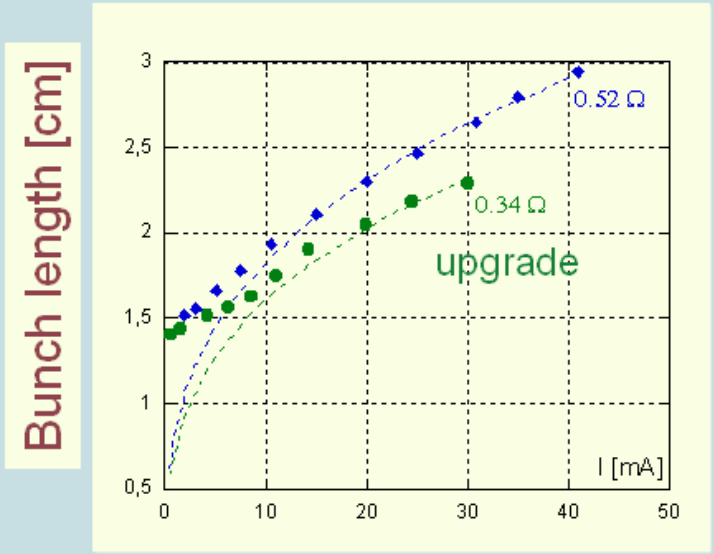
Bunch Lengthening in the Main Rings



e^-

20% bunch length reduction @ $I_{bunch} \sim 10$ mA due to:

- ICE removal
- new injection kickers
- new bellows

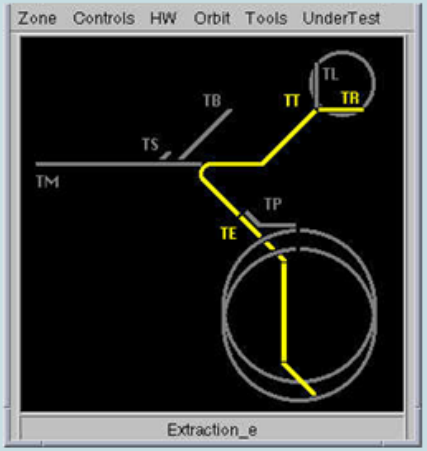


e^+

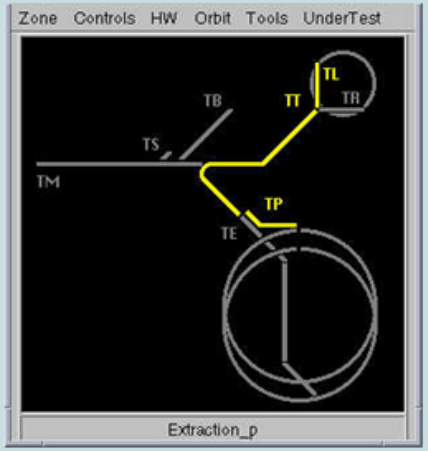
Few % reduction in bunch length due to:

- new injection kickers
- new bellows

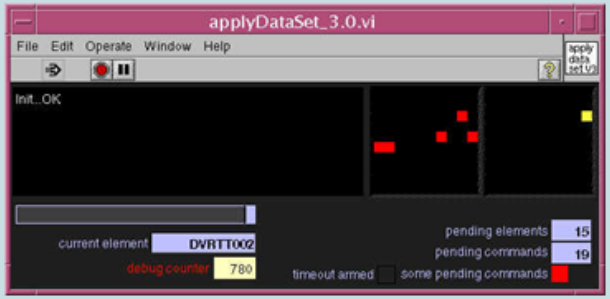
Injection System fast switch



Switch time
150 [s] --> 40 [s]

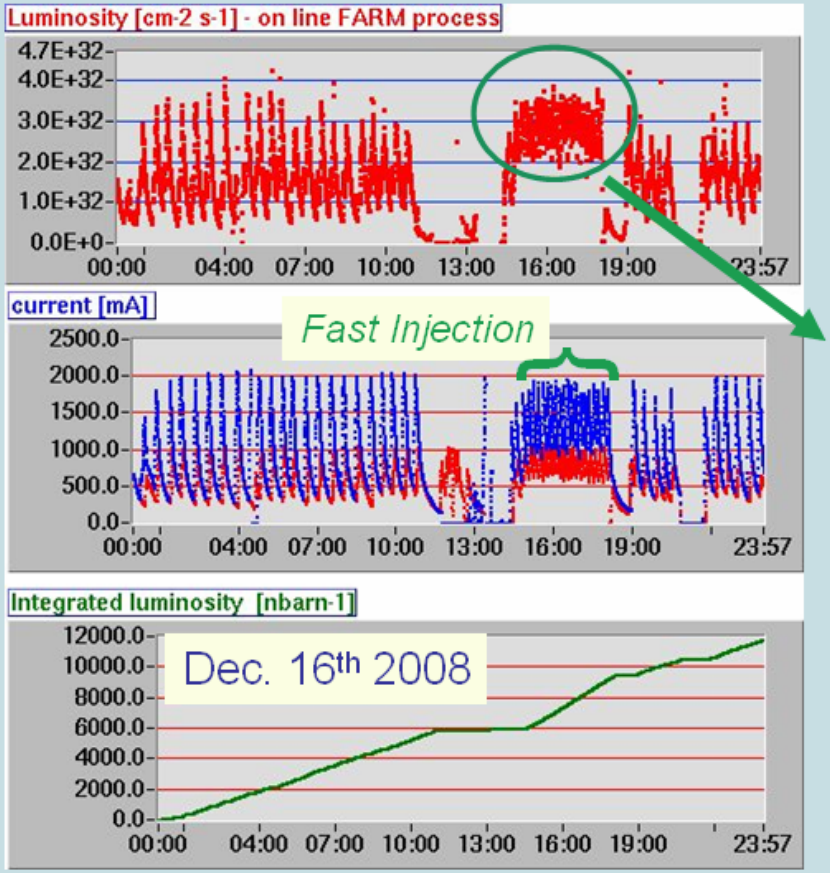


Obtained by executing in parallel the commands of the switch procedure



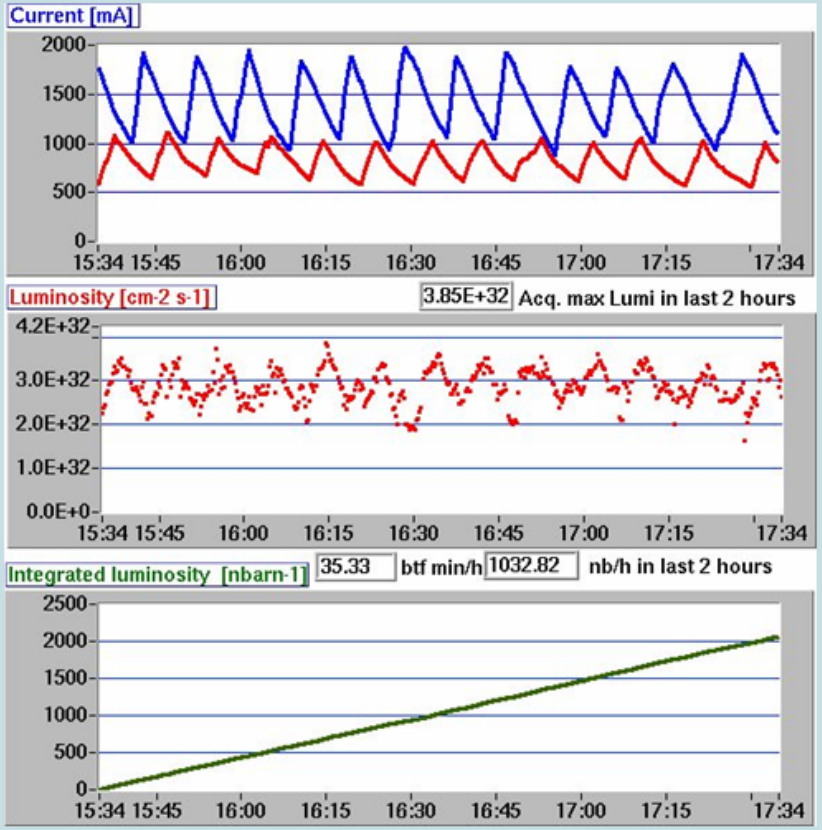
The maximum number of pulses injected in the Accumulator has been increased:
15 --> 17 $\Delta I \sim +13\%$ in the Accumulator (measured)
In order to speed up the injection in the Main Rings.

Best hourly integrated luminosity



$L_{\int 1\ hour} = 1.033\ pb^{-1}$

- *High rate injection regime*
- *105 colliding bunches*
- *Very **useful for a future KLOE run***



Fast injection is not compatible with the SIDDHARTA operations!

Perspectives

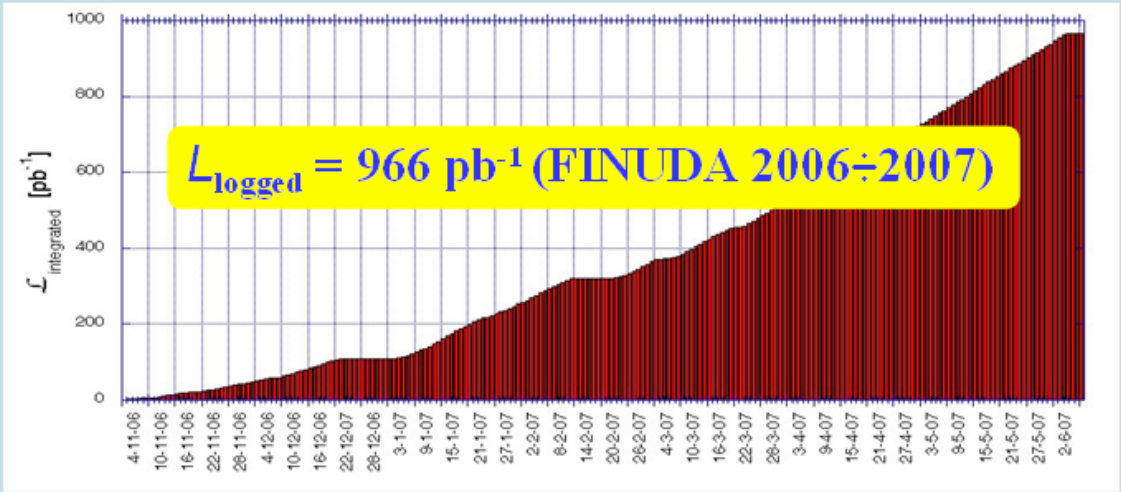
Scaling the present data from the luminosity monitor:

$L_{\int 1\ hour} = 1.033\ pb^{-1}$

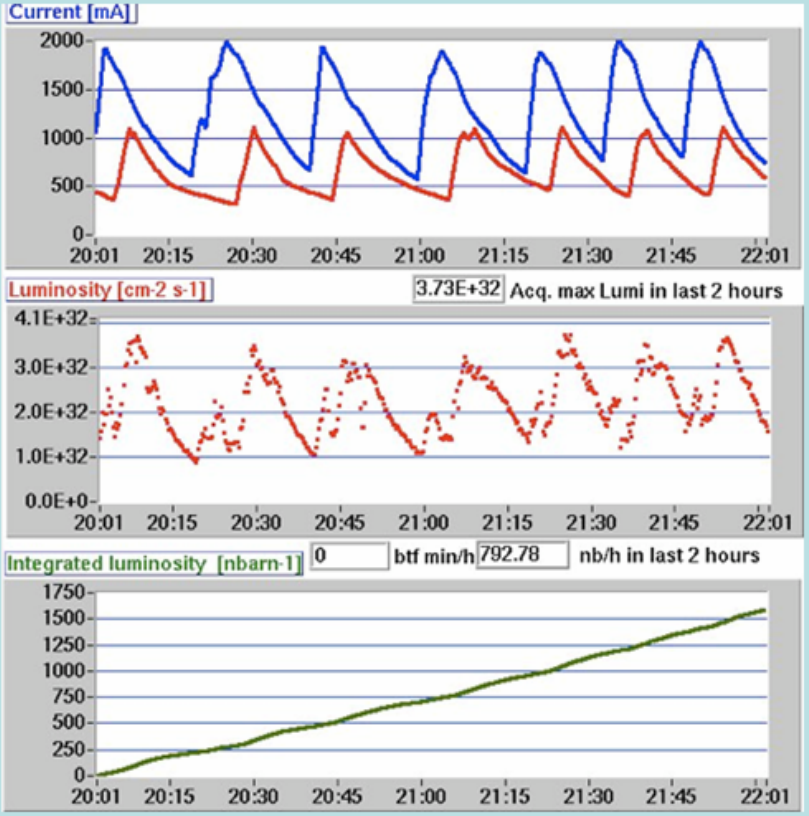
$L_{\int day} \geq 20.\ pb^{-1}$ *seems possible!*

Assuming 80% collider uptime $\Rightarrow$ $L_{\int month} \sim .5\ fb^{-1}$

….. in fact a new KLOE run has been approved, the detector should roll back on next fall



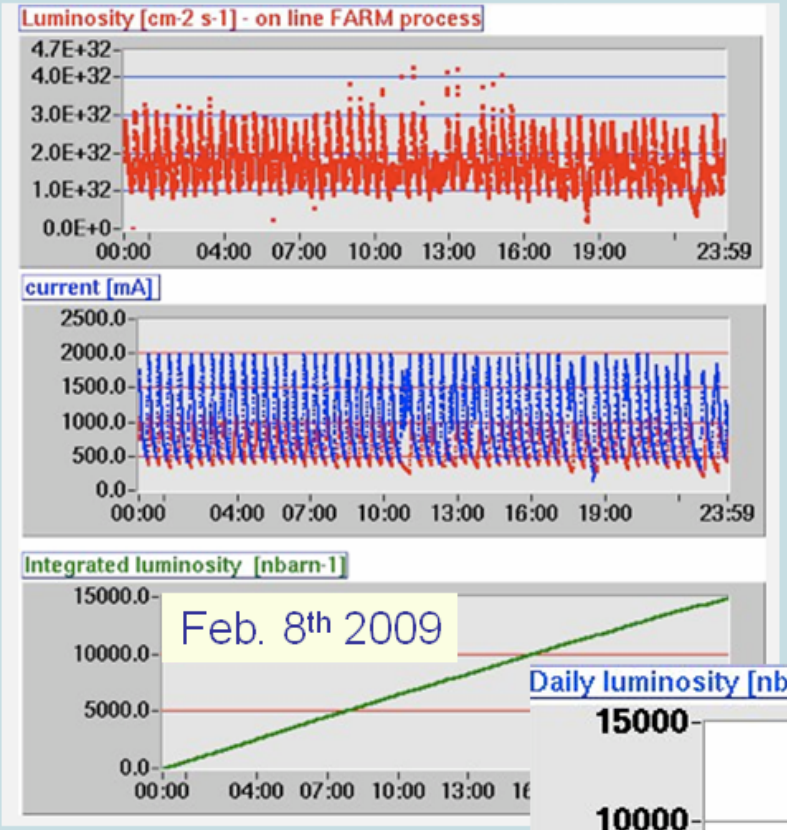
Best hourly integrated luminosity during the SIDDHARTA data-taking



$L_{\int 1\ hour} = .79\ pb^{-1}$

- *Best hourly integrated luminosity* ***compatible with the SIDDHARTA data taking***
- *moderate injection rate regime*
- *105 colliding bunches*

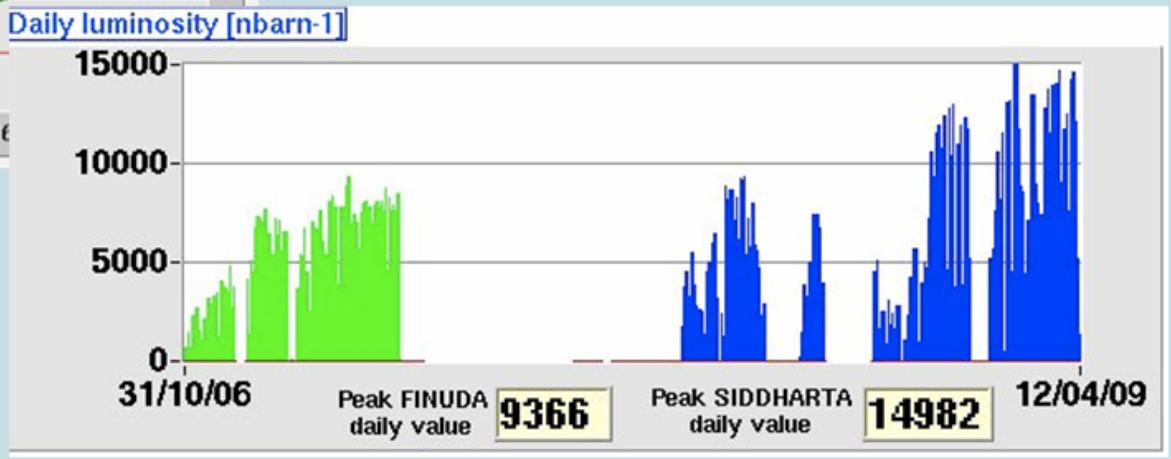
Best daily integrated luminosity



$L_{\int day} = 15.\ pb^{-1}$

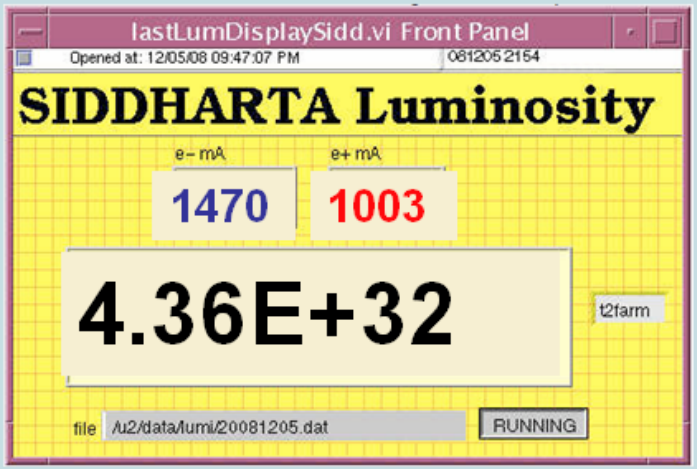
- *moderate injection rate regime*
- *105 colliding bunches*
- $L_{\int hour} = 0.62\ pb^{-1}$

+ 60 % FINUDA 2007



Peak luminosity

105 bunches



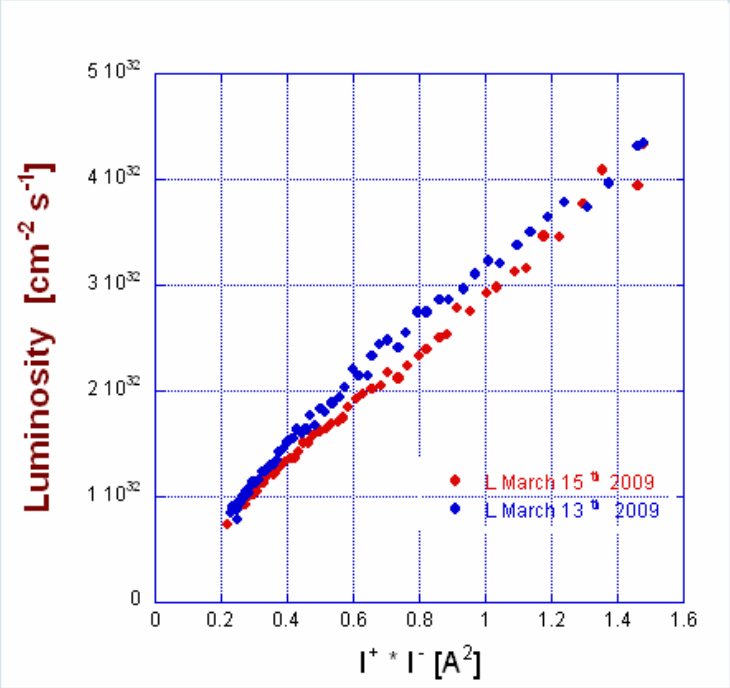
A luminosity in excess of $4 \cdot 10^{32}$ $cm^{-2}s^{-1}$ is measured almost in every run when operating the collider in optimized conditions.

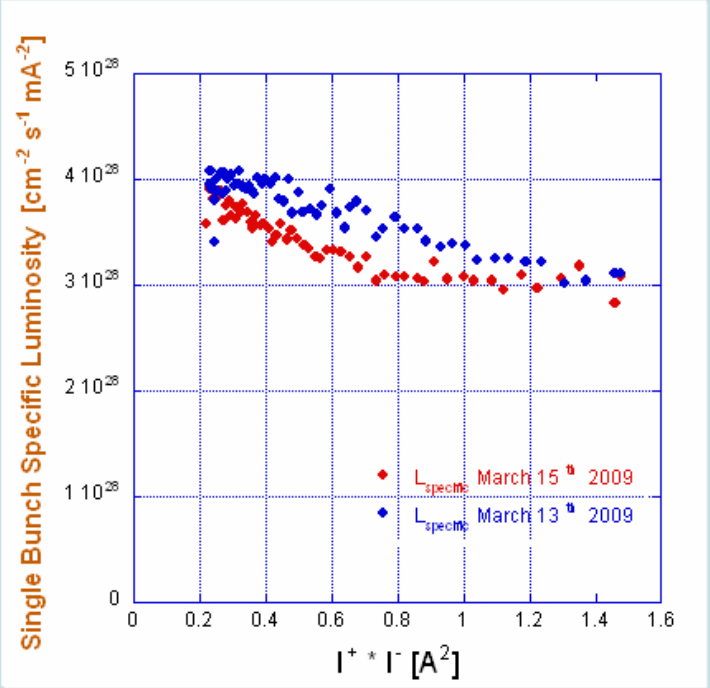
ξ_y (MAX) ~ 0.042

ξ_y(MAX) is a factor ~1.5 higher than the best achieved without Crab-Waist compensation

The collider has the same damping time as in the past

Luminosity during two of the best runs





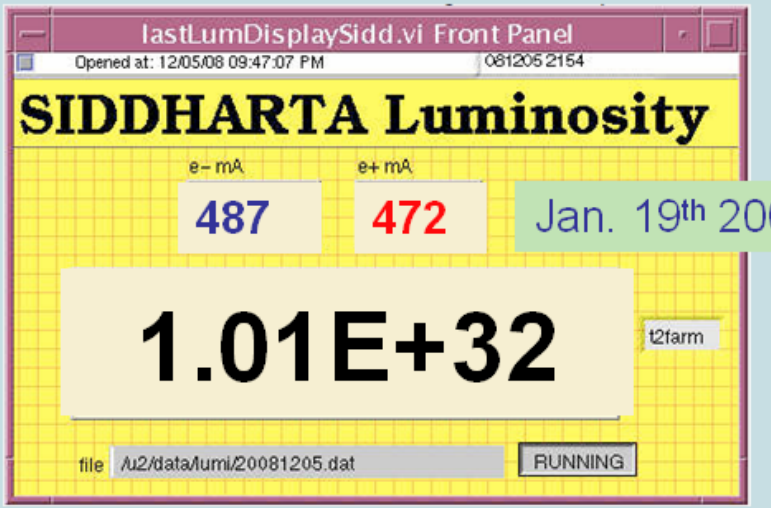
L$_{specific}$

- Drops with the product of the colliding currents due to:
  - beam-beam blow up
  - bunch lengthening
- At low currents is four times higher than in the past
- The reduction is underestimated since collisions are optimized mainly at high *I*, it has been considerably reduced during the collider commissioning

Luminosity in weak-weak and strong-weak regime

Specific luminosity at intermediate currents is a factor of four higher than in the past

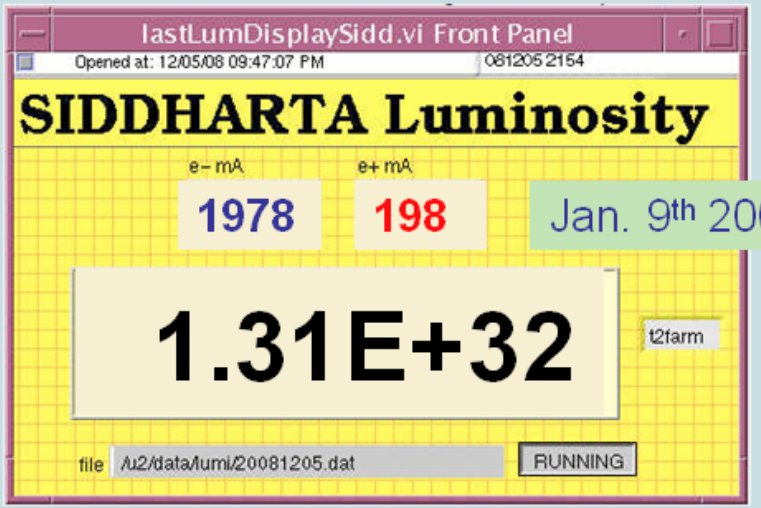
ξ_y (MAX) ~ 0.020



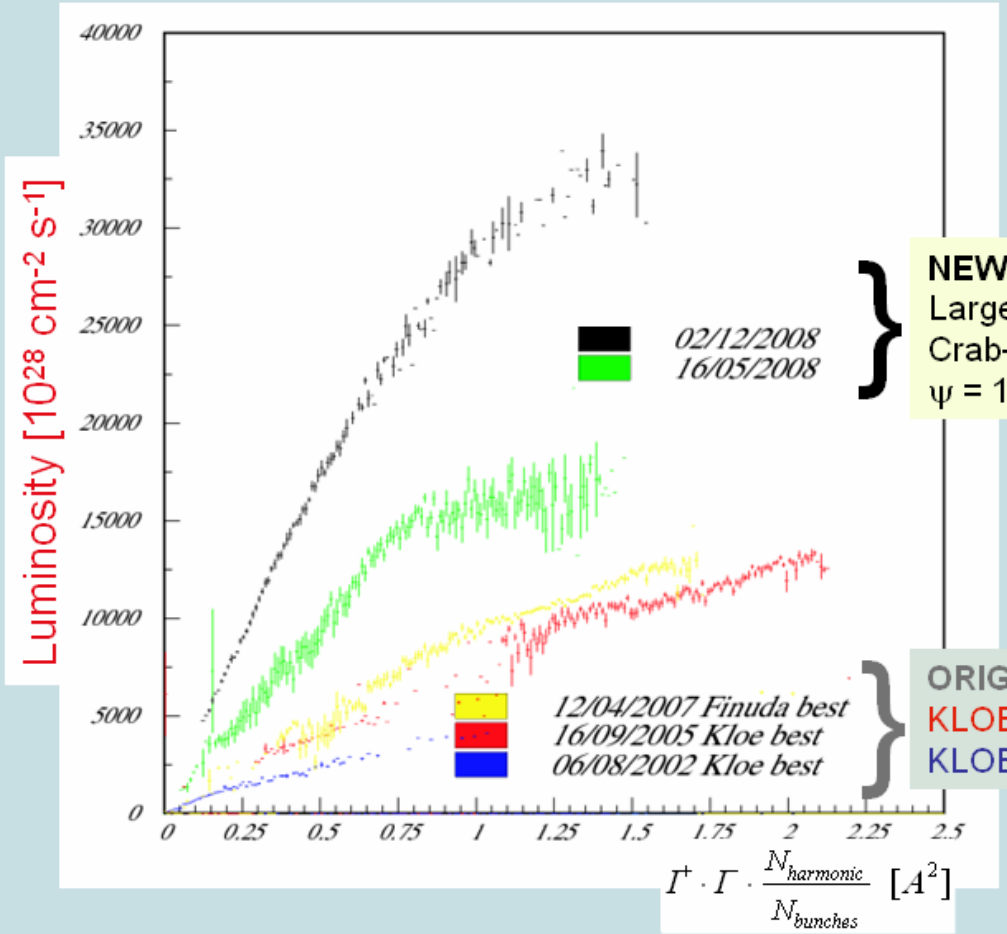
Asymmetric currents

ξ_y(MAX) ~ 0.0626

Crab-Waist compensation works in strong-strong regime



Luminosity gain from large Piwinski angle and low-β in the DAΦNE original configuration

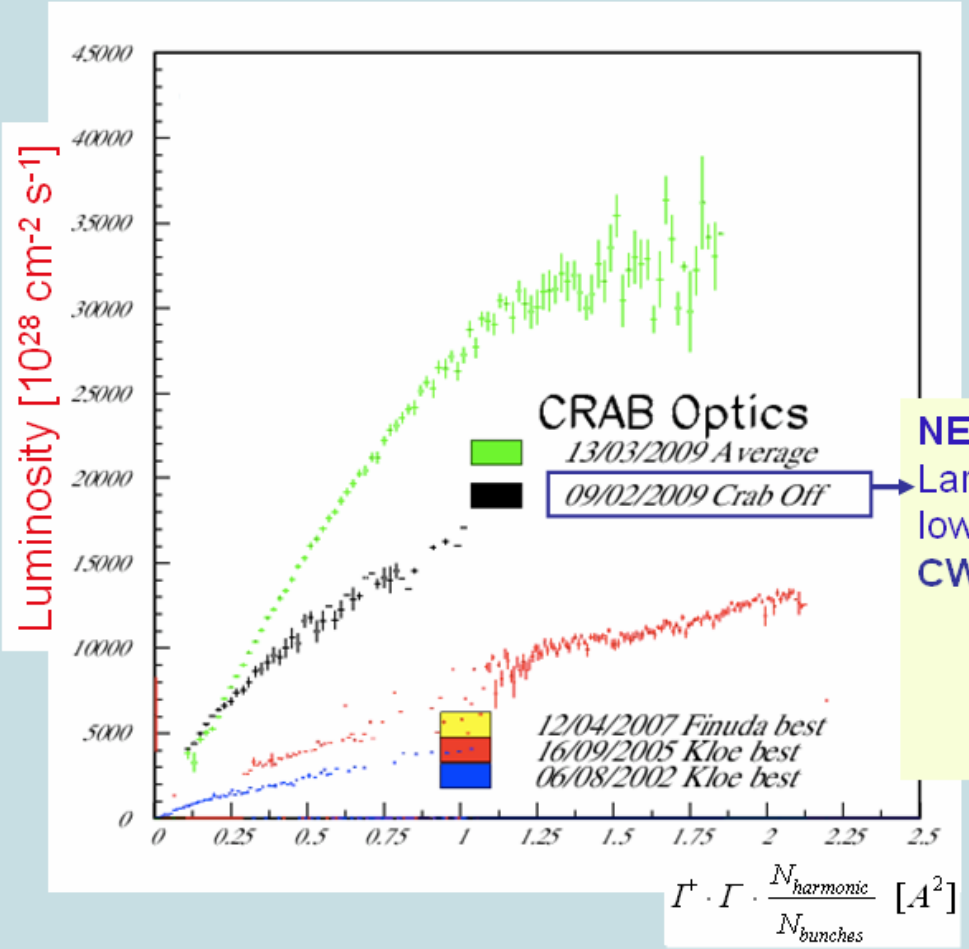


NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation
$\psi = 1.9 \quad \beta^*_y = 9.0$ [mm]

ORIGINAL COLLISION SCHEME:
KLOE 2005 $\psi = 0.6$ $\beta^*_y = 18.$ [mm]
KLOE 2002 $\psi = 0.3$ $\beta^*_y = 25.$ [mm]

L evaluated by the BHABHA monitor in May 2008 was underestimated (~ 15%) due to the insertion of new shields which required a new evaluation of the monitor geometric acceptance.

Crab-Waist Sestupoles & luminosity gain



NEW COLLISION SCHEME:

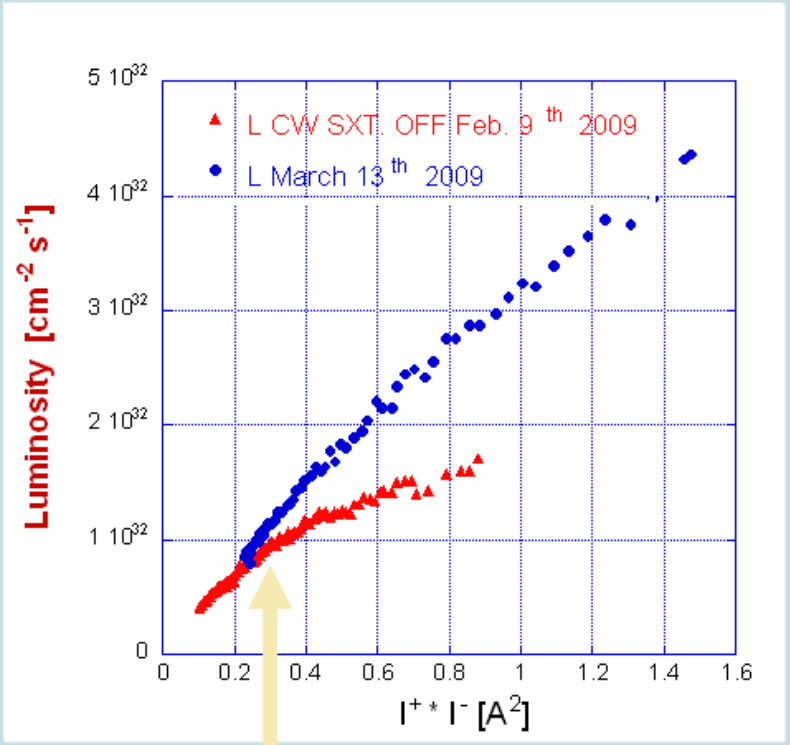
Large Piwinski angle ψ = 1.9

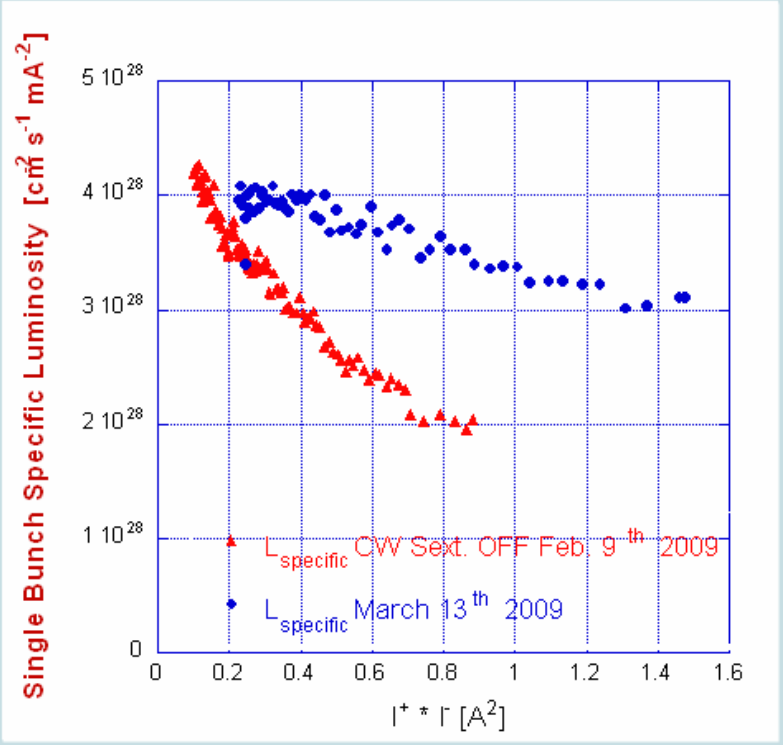
low–β β^*_y = 9.0 [mm]

CW sextupoles off

- Larger transverse beam size blowup
- Sharp lifetime reduction

Crab-waist compensation and luminosity





- Transverse beam blow-up
- Lifetime reduction

DAΦNE present achievements

	DAΦNE upgrade SIDDHARTA	DAΦNE KLOE	DAΦNE FINUDA
L_{peak} [$cm^{-2}s^{-1}$]	$4.36 \cdot 10^{32}$ ($5.0 \cdot 10^{32}$)	$1.5 \cdot 10^{32}$	$1.6 \cdot 10^{32}$
$L_{\int day}$ [pb^{-1}]	14.98	9.8	9.4
$L_{\int 1\ hour}$ [pb^{-1}]	1.033	0.44	0.5
I^-_{MAX} in collision [A]	1.47	1.4	1.5
I^+_{MAX} in collision [A]	1.0	1.2	1.1
$N_{bunches}$	105	111	106
ξ_y	0.042	0.025	0.029

However collider performances are still limited by:

- *e-cloud*
- *ion trapping*
- *RF stability*

Short term developments

- *Improve vacuum condition in order to get 110 bunches in collision*
- *Systems stability optimization (RF, FBKs)*
- *Optics refinements in order to optimize:*
  - L_{peak}
  - $L_{integrated}$
  - ***Beam lifetime***
  - ***Background hitting the experimental detector***
- *Further investigation about the e^+ instability source*
- *transfer-lines collimator commissioning*
- *Standard tuning*

Long term developments

- *Installation of a new dedicated kicker for the second transverse horizontal feedback in a position with higher β_x (β_x = 3 [m] -> 17 [m]) in order to increase the feedback dynamic range by a factor > 2*
- *Equip the second transverse horizontal feedback with two power amplifiers providing 500W output (now 250W)*
- *Install modified wigglers to improve beam lifetimes and reduce wall plug power consumption*

DAΦNE run schedule

- ***SIDDHARTA*** *experiment is taking data with a good Luminosity background ratio*
- *SIDDHARTA run should be completed by the end of July 2009*
- *Operation for the* ***KLOE*** *experiment might be resumed by the end of 2009 and are presently scheduled for three years*

Conclusions

- *The DAΦNE collider, based on a new collision scheme including Large Piwinski angle and Crab-Waist, has been successfully commissioned and is presently delivering luminosity to the SIDDHARTA detector*
- *Large crossing angle and Crab-Waist scheme proved to be effective in:*

  Increasing luminosity, now a factor 2.7 higher than in the past

  controlling transverse beam blow-up due to the beam-beam
- *Work is in progress to reach the ultimate design luminosity goal*

  $5.0 \cdot 10^{32}\ cm^{-2}s^{-1}$
- *The new collision scheme is the main design concept for a new project aimed at building a* ***Super-B factory*** *(talk MO3RAC04 M. Biagini) that is expected to achieve a luminosity of the order of* $10^{36}\ cm^{-2}\ s^{-1}$ *and it has been also taken into account to upgrade one of the LHC interaction regions.*