Simulations of Beam-Beam Effects in DAΦNE and Recent Operation

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Motivation

- Collider performance is affected by interplay of beam-beam and machine features
- Our goal was to implement the complete model of DAΦNE in weak-strong beam-beam simulation in order to
  a) benchmark the modeling tools
  b) guide collider optimization

Why DAΦNE?

- Two-ring collider with multiple bunches colliding at a crossing angle – like LHC.
- Well reproducible and controlled experiments – due to synchrotron radiation damping.
- Strong beam-beam effect ($\xi \approx 0.04$) significantly affecting beam lifetime and specific luminosity.
- Relatively easy access / beam time.

Model Development

- In 2013-2014, Lifetrac functionality was expanded to include the full treatment of machine lattice
  - Tracking through arcs is performed element-by element
  - Lattice is imported directly from MAD-X model
  - All main magnets + multipoles, solenoids, fringe fields, orbit
  - Main IP inside of a solenoid
- Analysis tools – FMA, DA, Specific Luminosity and Beam Lifetime

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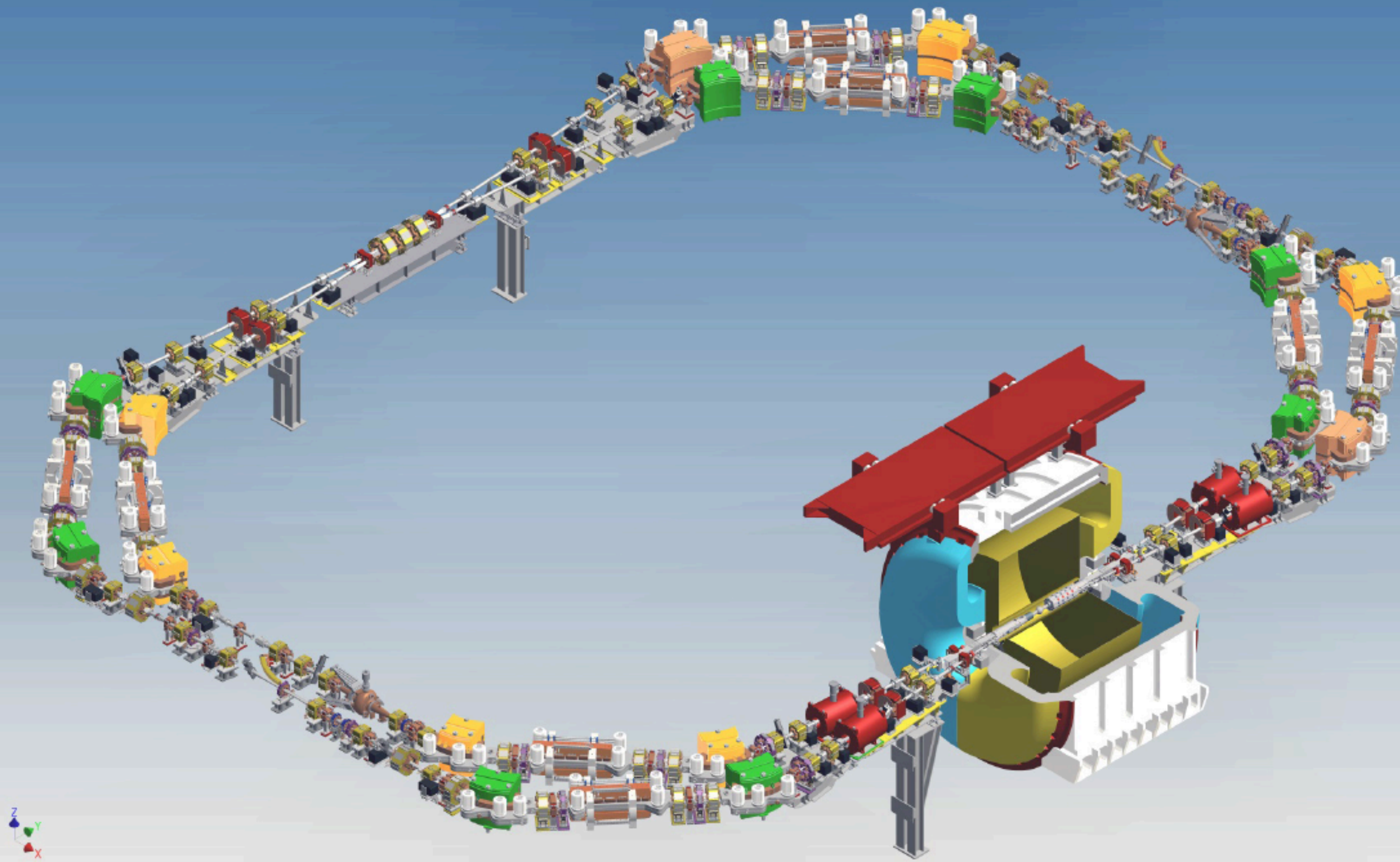
DAΦNE – e+e- factory 1997-now



DAΦNE Parameters

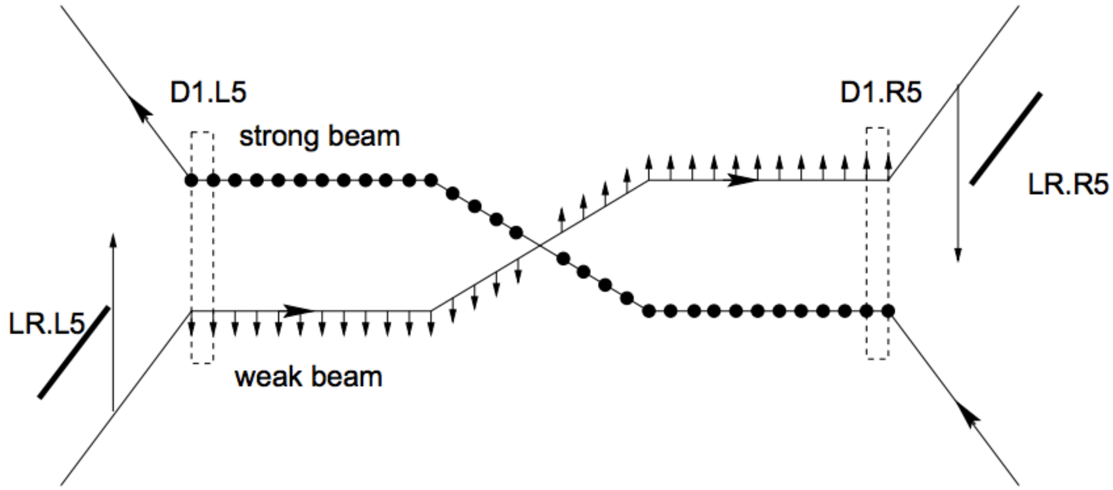
Parameter	Value
Beam energy	510 MeV
Circumference	98 m
Number of bunches	105-110 (max 120)
Beam current	1 A
Crossing angle (full)	50 mrad
Momentum spread	4×10^{-4}
Bunch length	1.2 cm (zero current) 1.6 cm (with lengthening)
Horizontal emittance	0.28×10^{-6} m
Coupling parameter	0.3%
Betatron tunes (x,y)	~5.1, ~5.1
Damping decrements (x,y,z)	$0.76,0.88,1.91\times10^{-5}$
Beta-function at IP (x,y)	0.25, 0.008 m
Maximum luminosity	4.5×10^{32} cm^{-2}s^{-1}

DAΦNE Accelerator Physics Highlights

1. 2005-2006 – Compensation of long-range beam-beam interactions with current wires
2. 2007-now – Crab-Waist collision scheme

Long-Range Compensation

- J.P. Koutchouk, LHC Project Note 223 (2000)
  - This note shows that the long-range beam-beam interactions, presently considered as the most drastic limitation of LHC performance, can be rather accurately corrected for both their linear and non-linear perturbations. The principle of the corrector is simple though departing from classical multipolar lenses. It requires a conductor running parallel to the beam and carrying a current of about 60 A over 2 m or 600 A over 20 cm. Ideally 8 such correctors would be needed, grouped in 4 boxes on either side of IP1 and IP5, placed at about 40 m from the exit face of D2 towards D1.



DAFNE Lifetime Optimization with BBLR

- C. Milardi, D. Alesini, M.A. Preger, P. Raimondi, M. Zobov, D. Shatilov, http://arxiv.org/abs/0803.1544 (2008)
  - … During the operation for the KLOE experiment two such wires have been installed at both ends of the interaction region. They **produced a relevant improvement in the lifetime of the weak beam (positrons) at the maximum current of the strong one (electrons) without luminosity loss, in agreement with the numerical predictions**.

The only demonstration of long-range compensation with wires in collider operations.

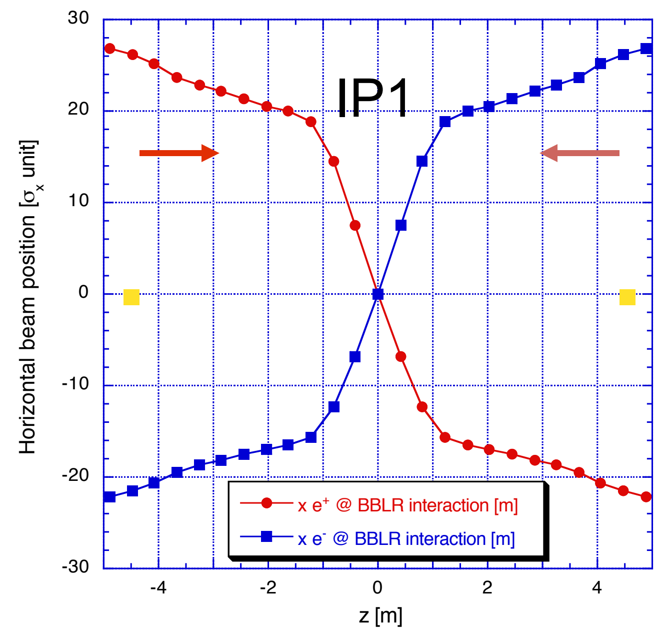
Slide courtesy C.Milardi

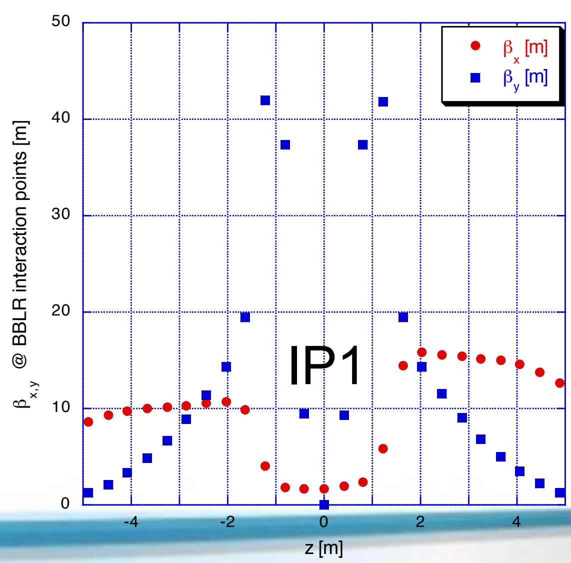
Parasitic Crossings in the DAΦNE IR1

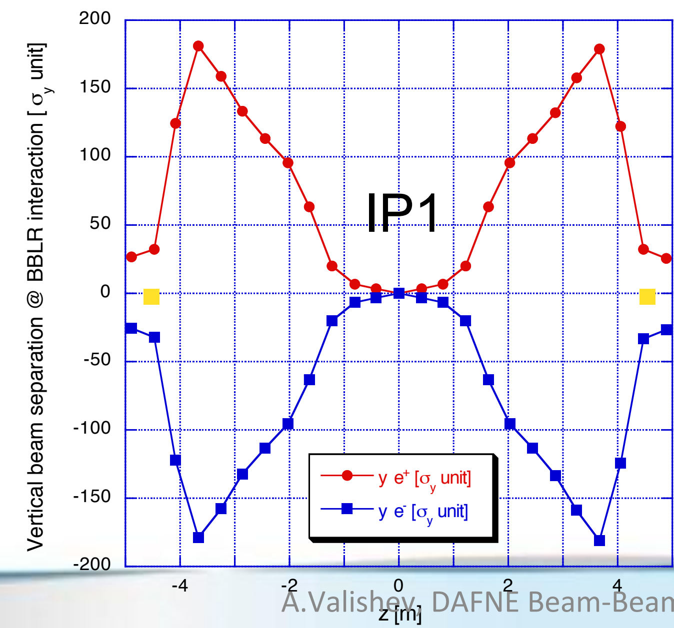
In the DAFNE IRs the beams experience 24 Long Range Beam Beam interactions

Parameters for the Pcs, one every four, in IR1.

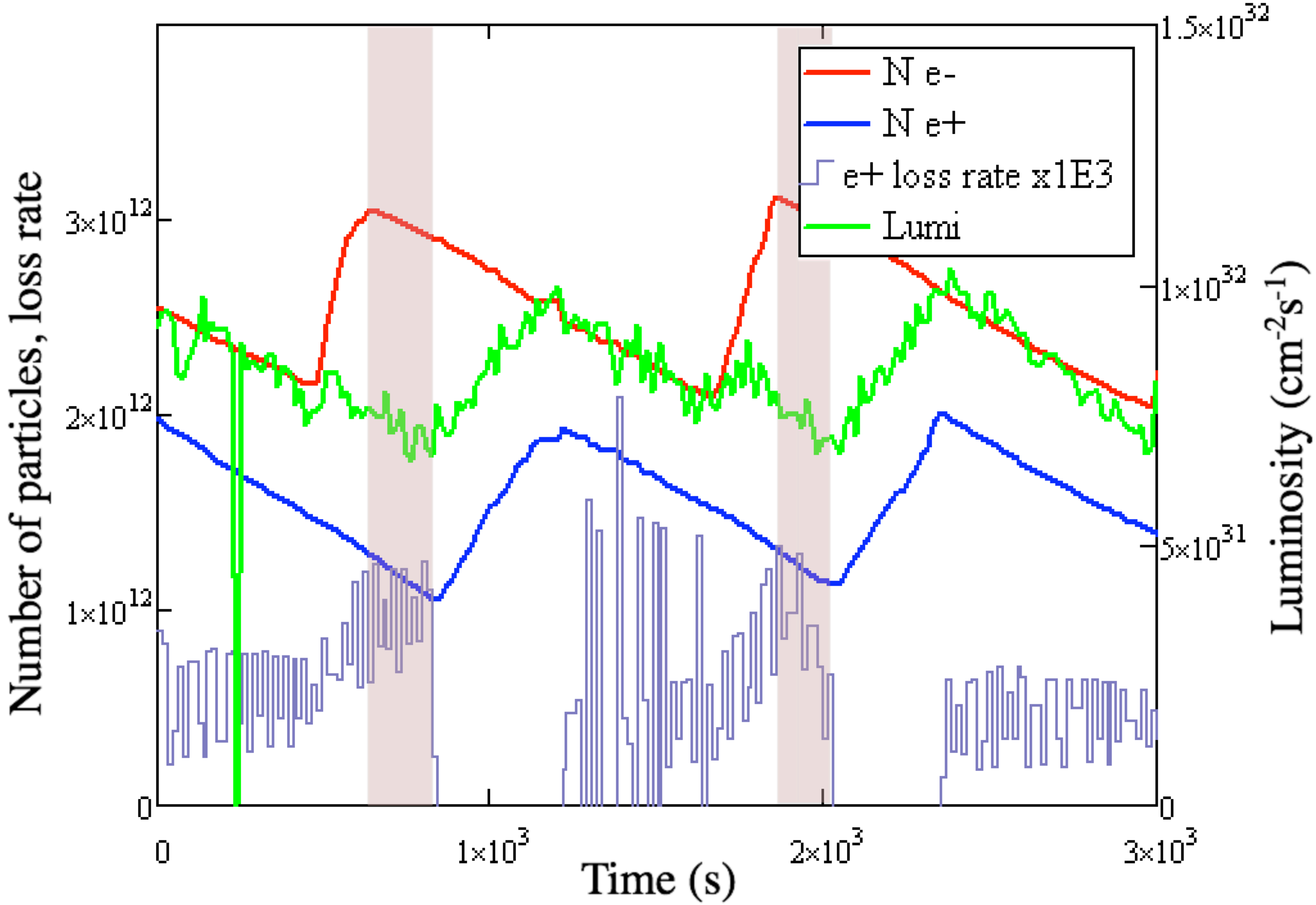
PC order	$Z\text{-}Z_{IP}$ [m]	β_x [m]	β_y [m]	$\mu_x\text{-}\mu_{IP}$	X $[\sigma_x]$	Y $[\sigma_y]$
BB12L	-4.884	8.599	1.210	0.167230	26.9050	26.238
BB8L	-3.256	10.177	6.710	0.140340	22.8540	159.05
BB4L	-1.628	9.819	19.416	0.115570	19.9720	63.176
BB1L	-0.407	1.639	9.426	0.038993	7.5209	3.5649
IP1	0.000	1.709	0.018	0.000000	0.0000	0.0000
BB1S	0.407	1.966	9.381	0.035538	-6.8666	3.5734
BB4S	1.628	14.447	19.404	0.092140	-16.4650	63.196
BB8S	3.256	15.194	6.823	0.108810	-18.7050	157.74
BB12S	4.884	12.647	1.281	0.126920	-22.1880	25.505







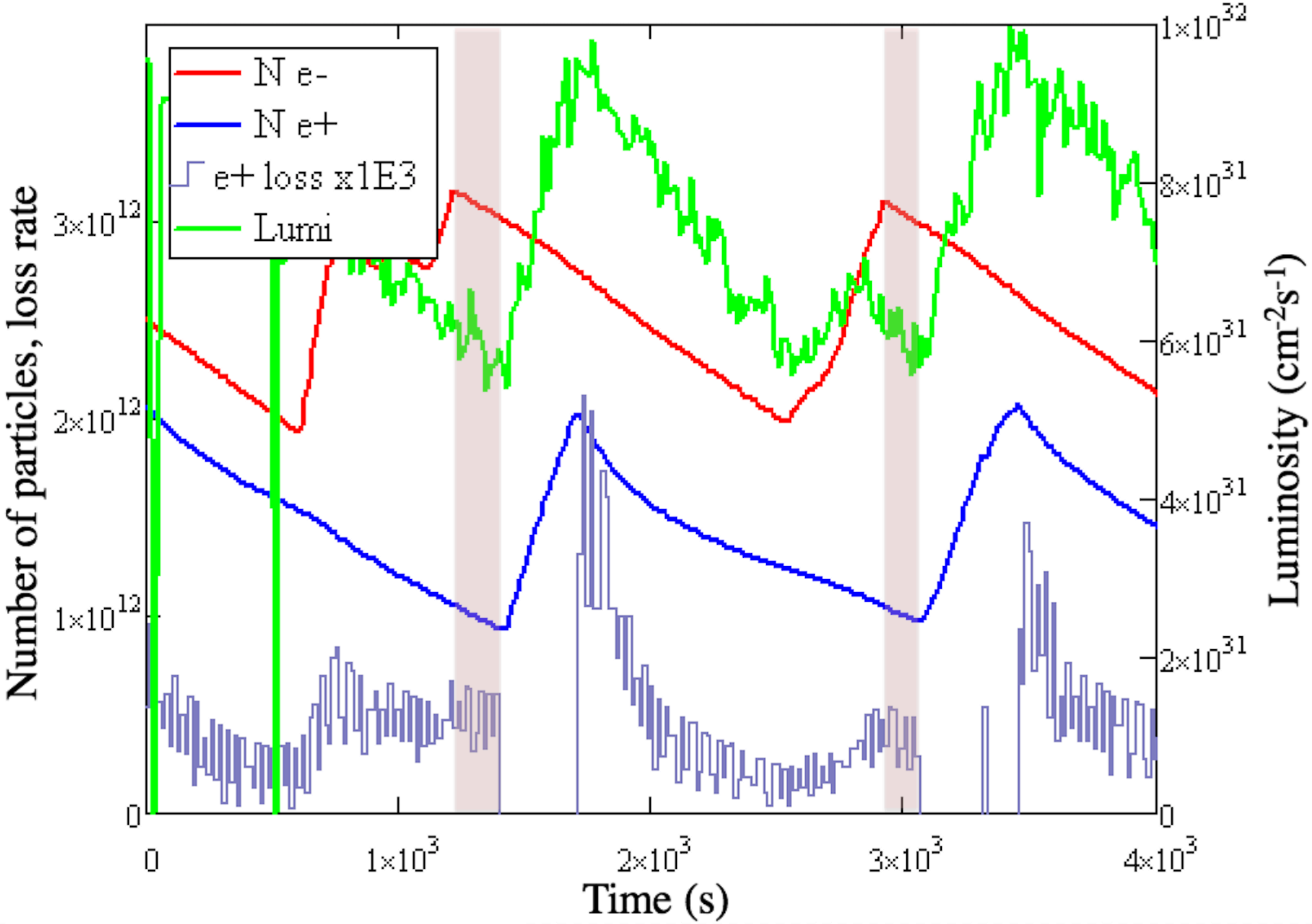
Reduction of Experimental Data



$$\dot{N} = \dot{N}_{Lum} + \dot{N}_{T} + \dot{N}_{BB}$$

WIRES OFF τ_{BB}=1,200 ±175 s

Reduction of Experimental Data



$$\dot{N} = \dot{N}_{Lum} + \dot{N}_{T} + \dot{N}_{BB}$$

WIRES ON τ_{BB}=2,000±360 s

Goals of Simulation Campaign

- In 2005, Lifetrac simulations were used to design the wire compensation. They provided qualitative guidance.
- Our goal was to implement the 2006 machine configuration in the model and reproduce the experimental data quantitatively.

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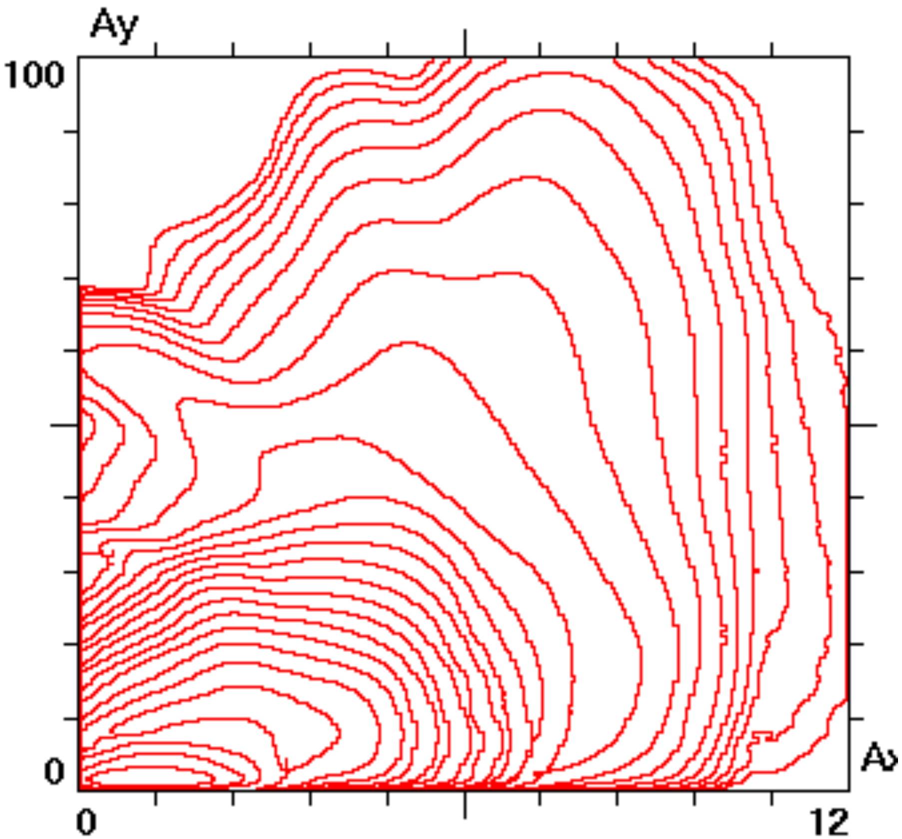
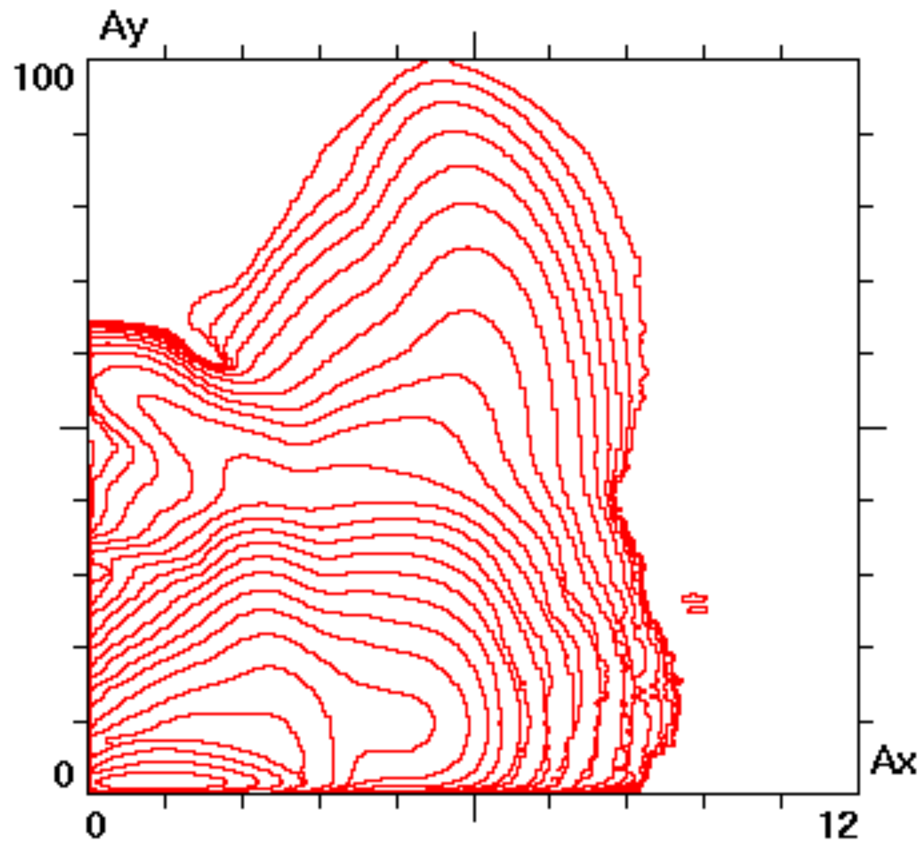
Simulation Results



WIRES OFF

H Aperture 12σ



WIRES ON

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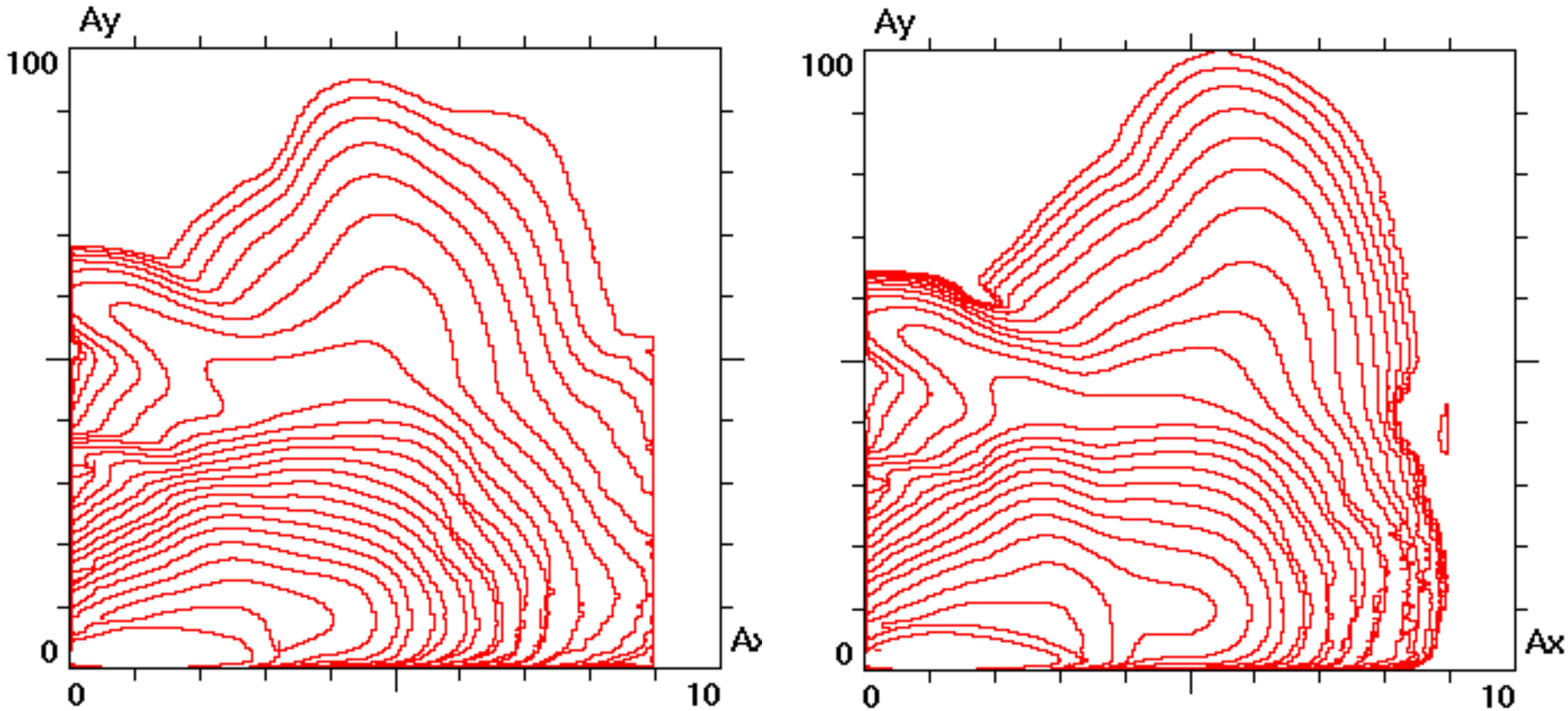
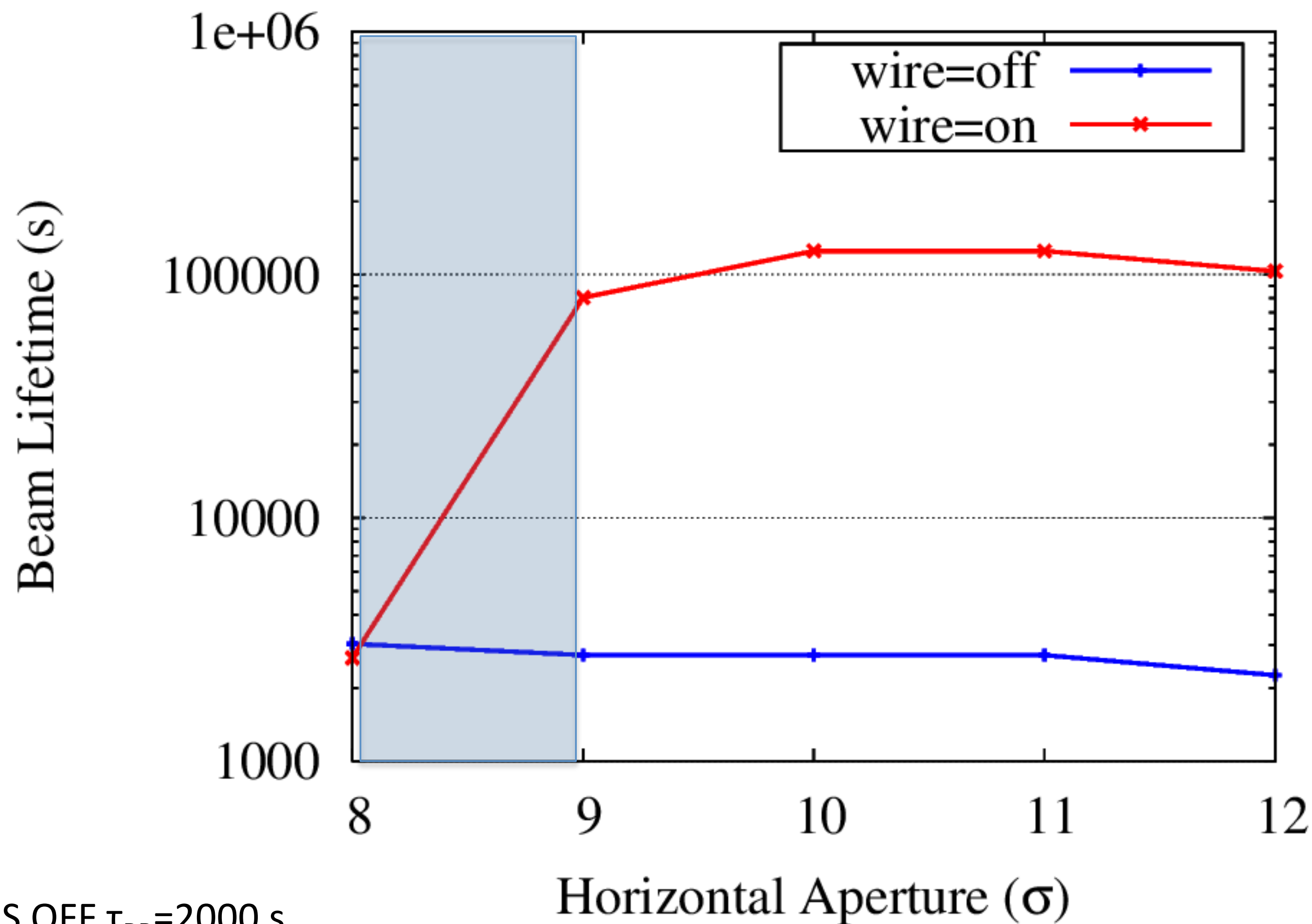
Simulation Results



WIRES OFF H Aperture 9σ WIRES ON

Simulation Results



WIRES OFF τ_{BB}=2000 s

Lifetrac BBLR Simulation Summary

The conclusions of 2005-2006 campaign have been reproduced

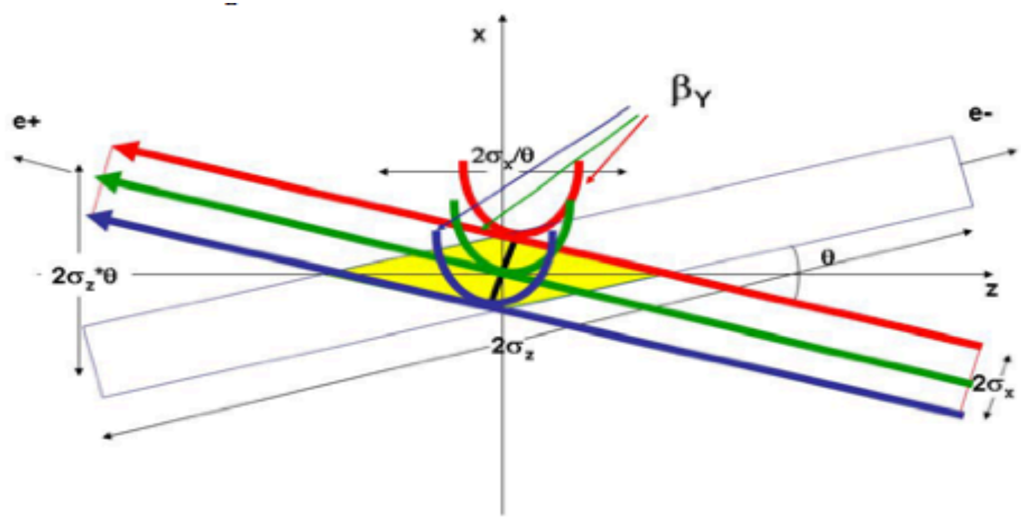
1. Full machine detail does not change the results
   - in particular strong coupling in the IR due to experimental solenoid
   - sextupoles
2. No effect on specific luminosity from BBLR – in quantitative agreement with experiment
3. Aperture model implemented and lifetime effect reproduced quantitatively

Crab Waist Collision Scheme

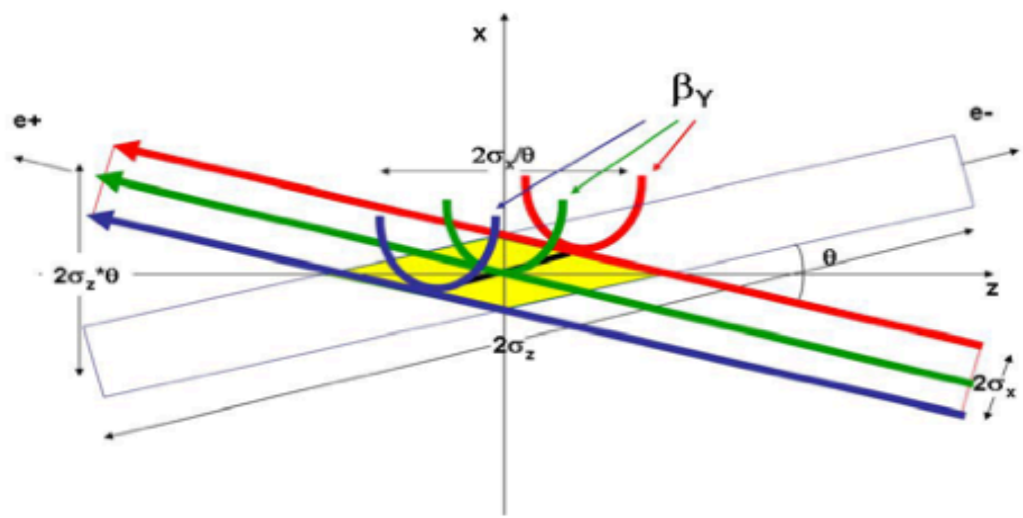
In 2007 the Interaction Region was modified (crossing angle increased) to

a) Remove long-range beam-beam encounters

b) Implement CW scheme



a)



b)

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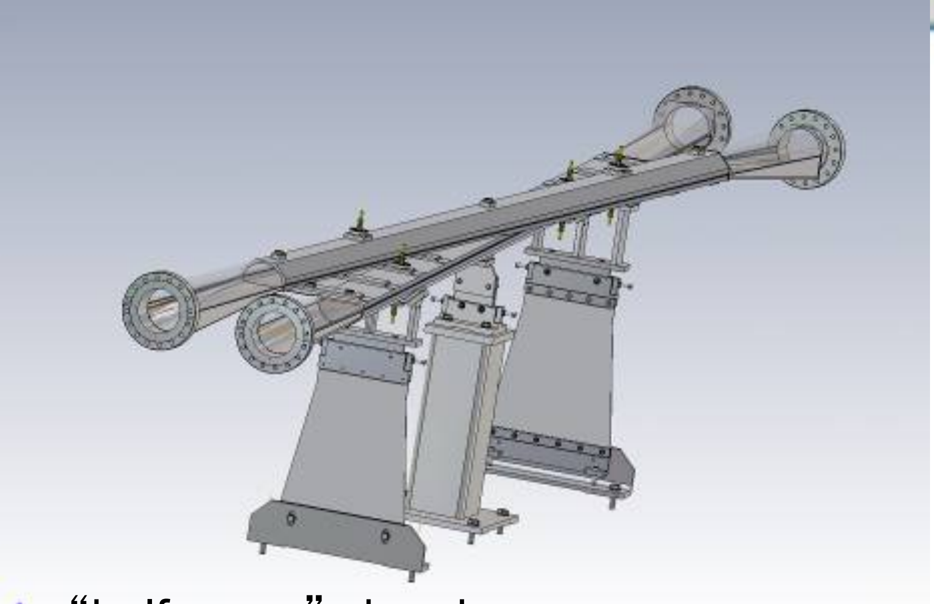
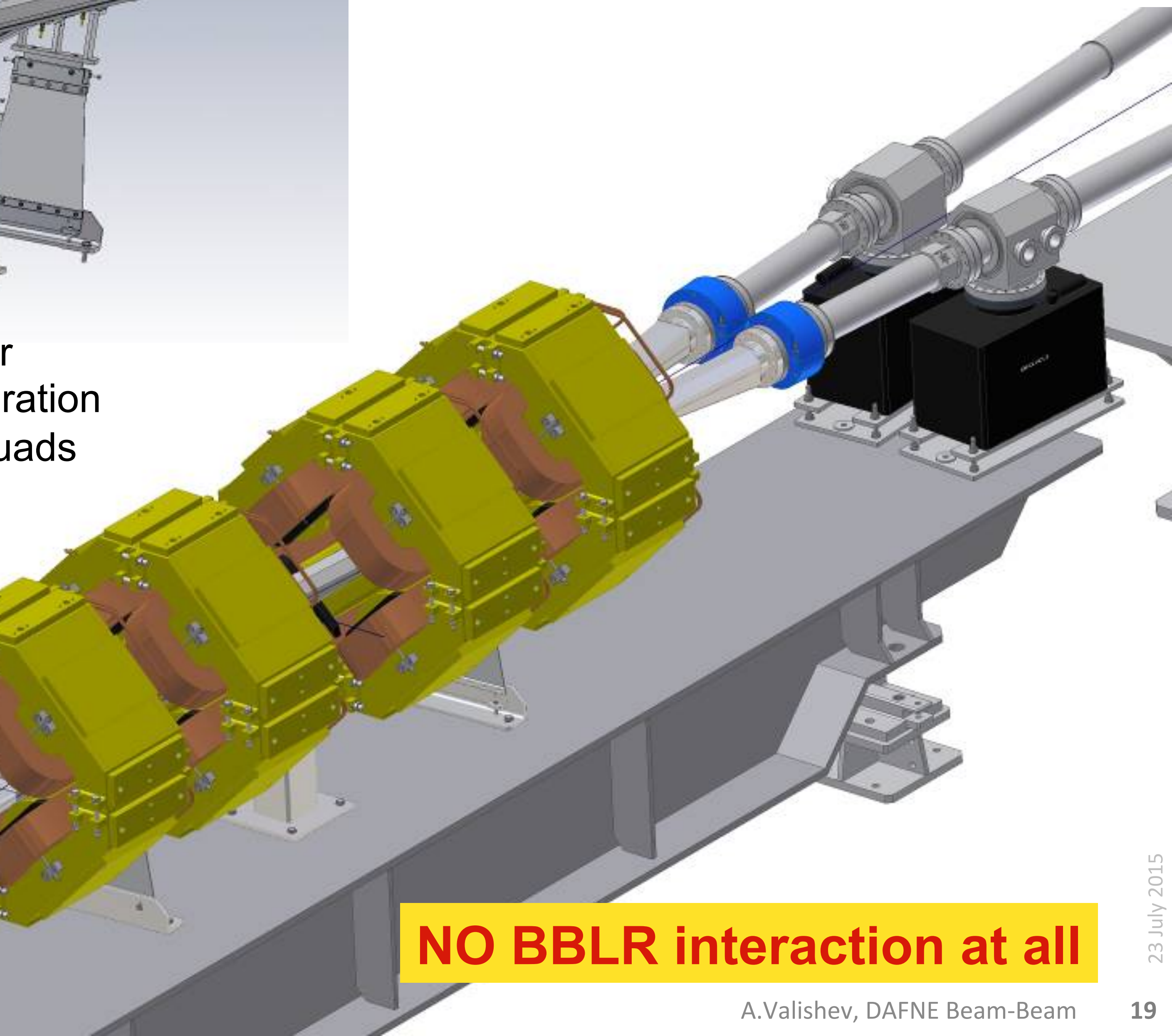
DAΦNE upgrade IR2

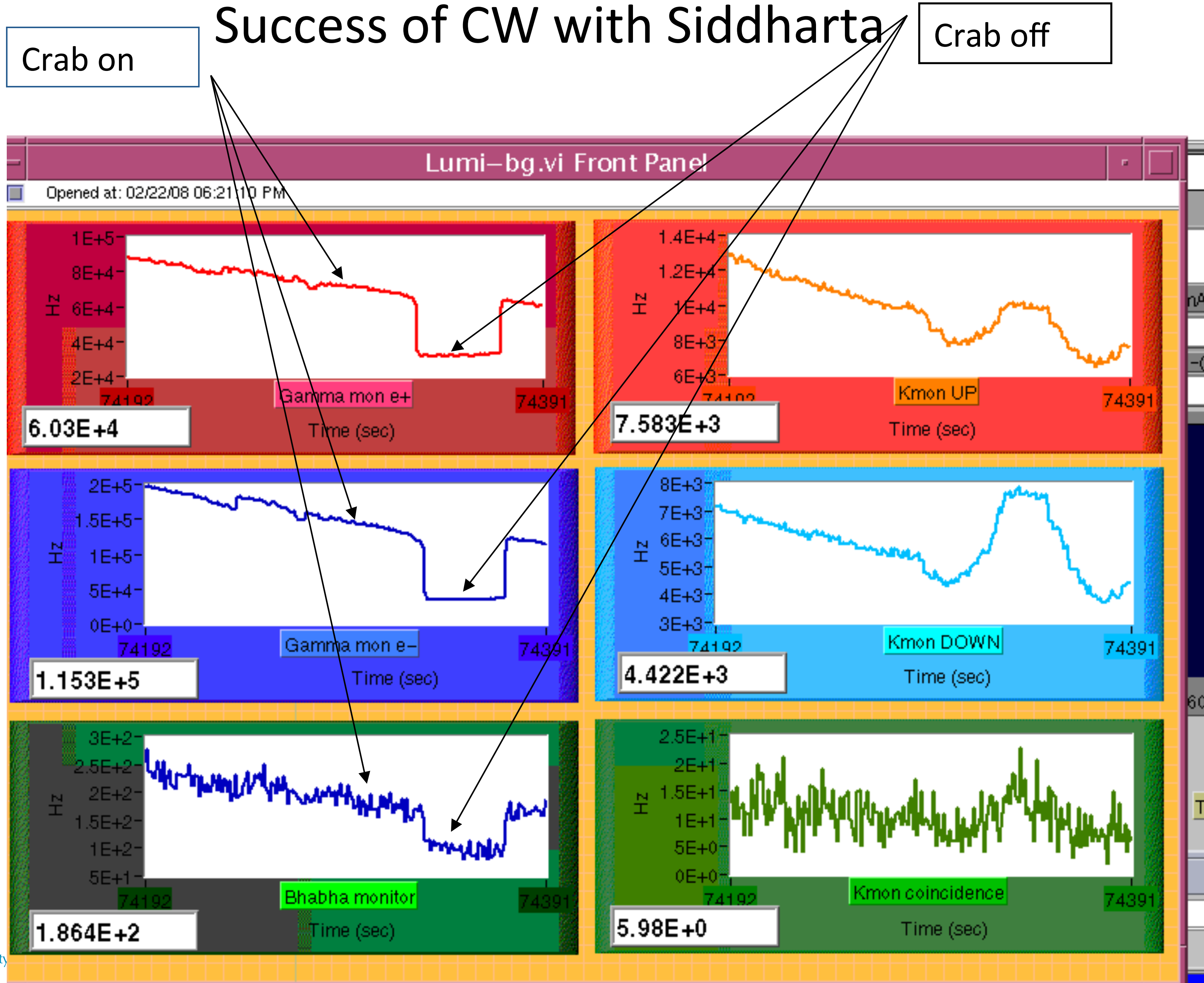


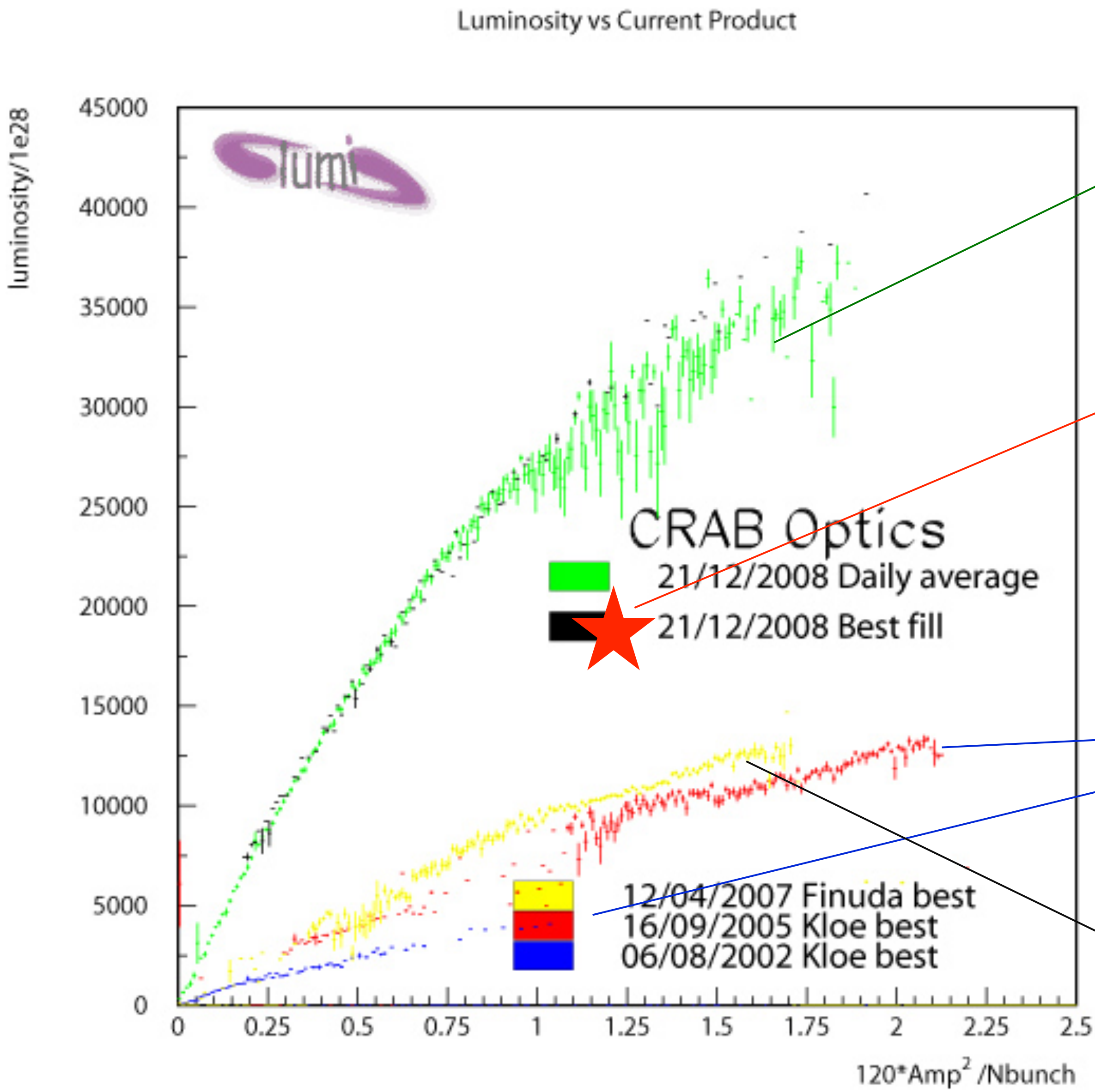
- “half moon” chamber
- complete beam separation
- design fits existing quads



NO BBLR interaction at all

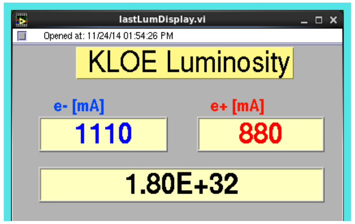
Success of CW with Siddharta





SIDDHARTA with CW

KLOE-2 with CW



24 November 2014

KLOE without CW

FINUDA without CW

Goals of Simulation Campaign

- Evaluate the interplay of beam-beam with CW and machine features
  a) Nonlinearities
  b) Coupling (including IR with solenoidal field)
  c) Chromaticity
  d) Imperfections
- Provide input for luminosity improvement.

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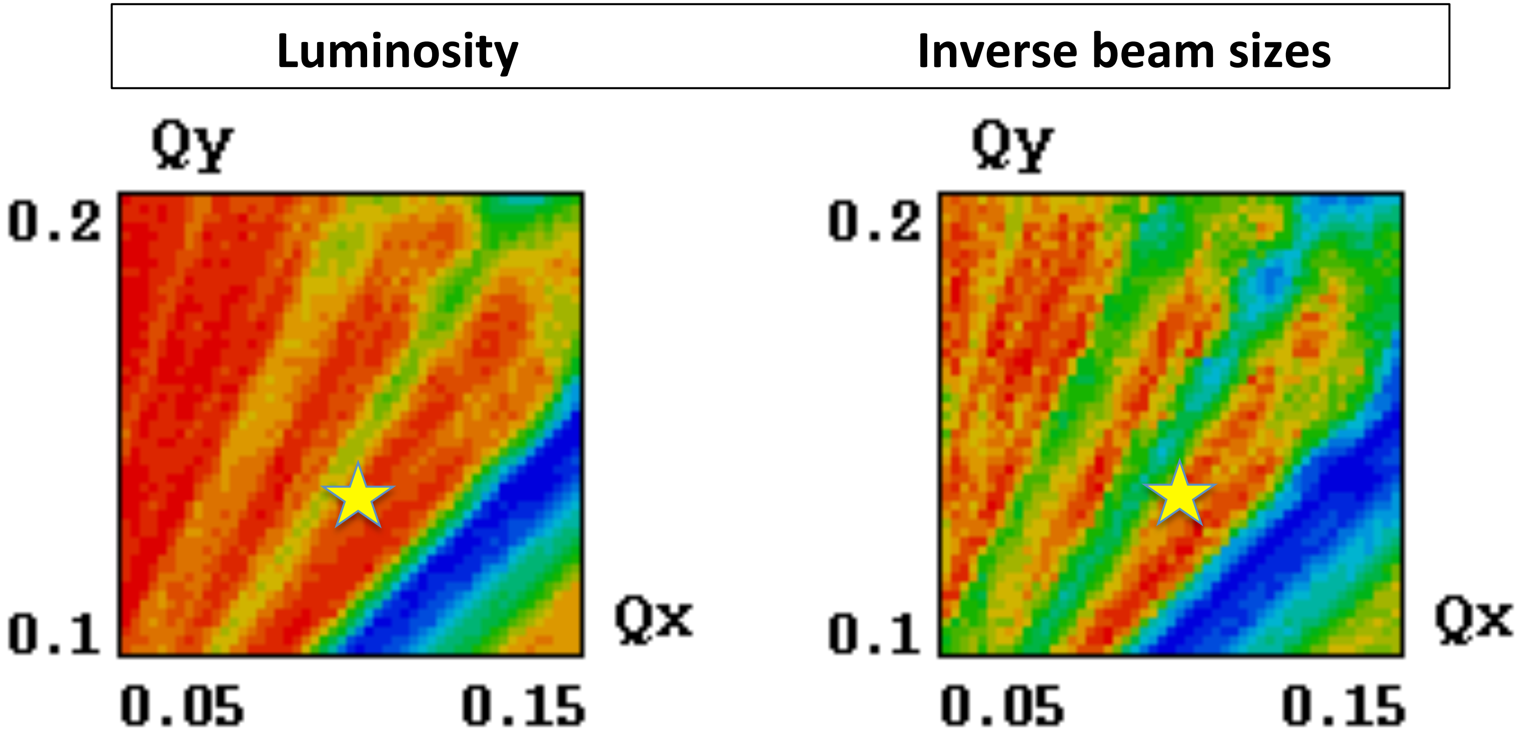
e$^+$ Working Point Scan



e+ ΔQx=0.0980; Qx=0.1305

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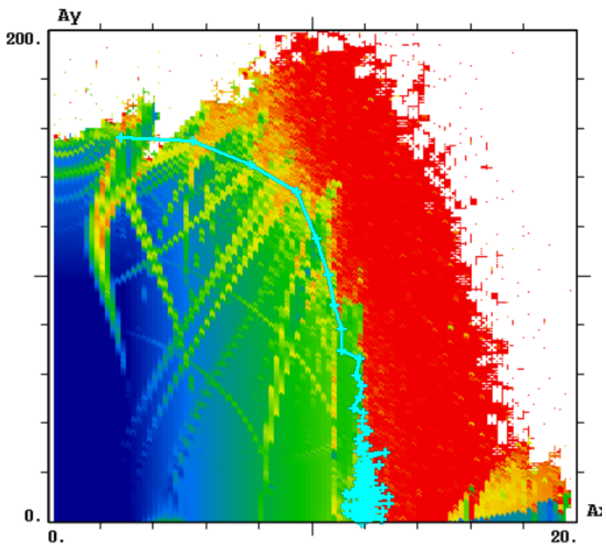
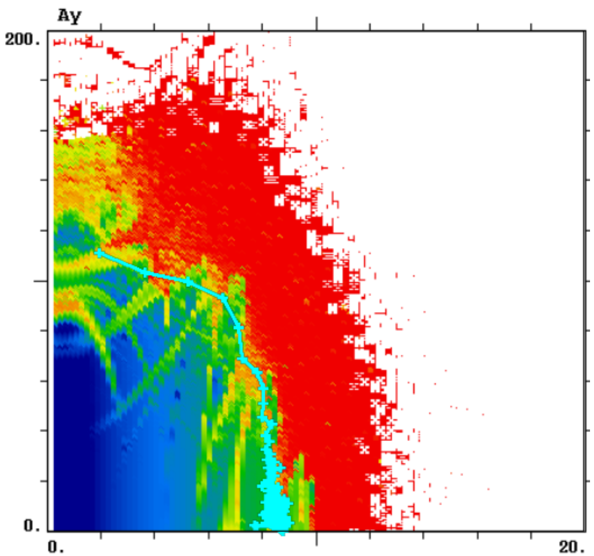
Electron Ring Dynamical Aperture



As=1



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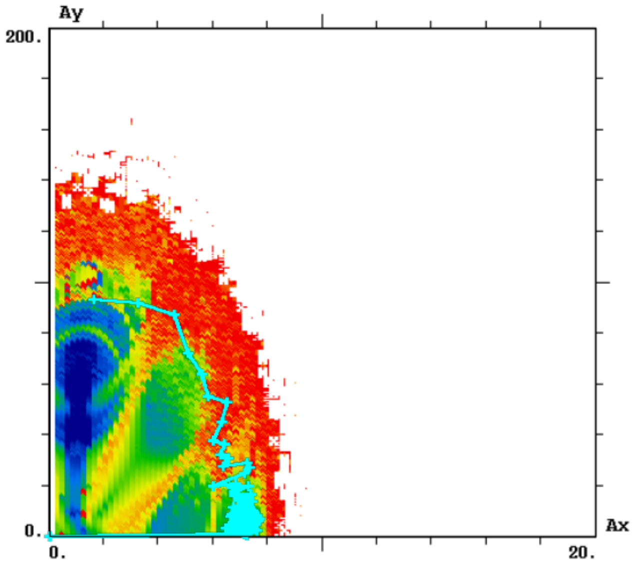

As=9

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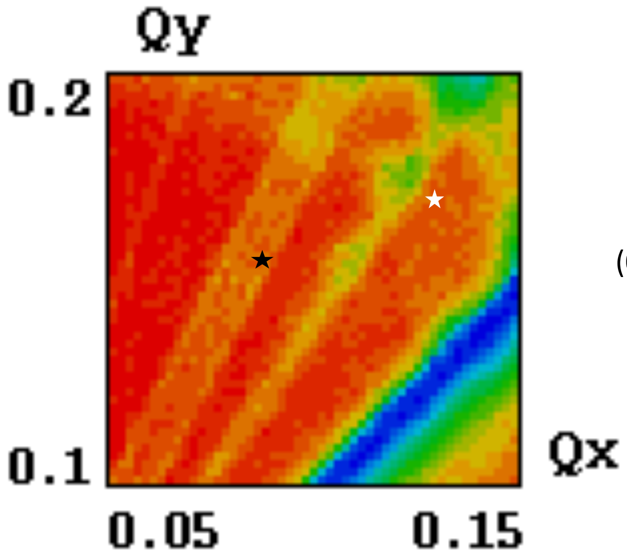
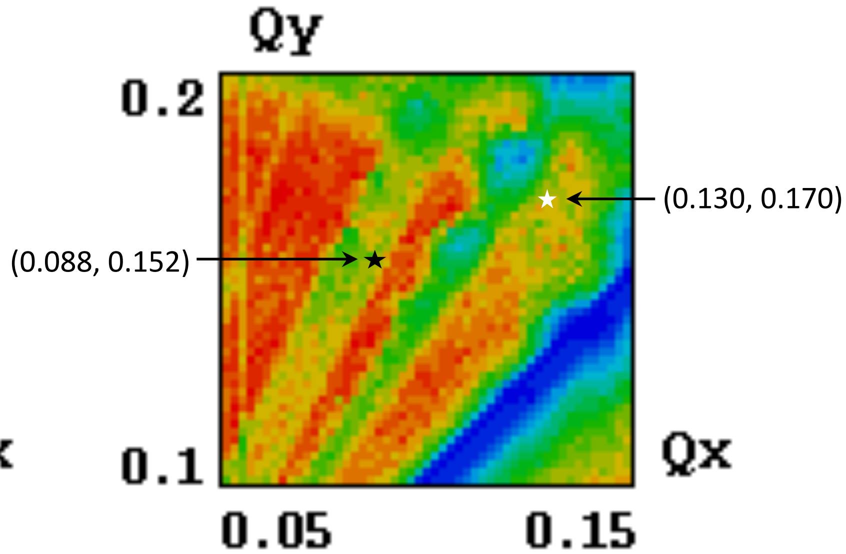
e^- Tune Scan

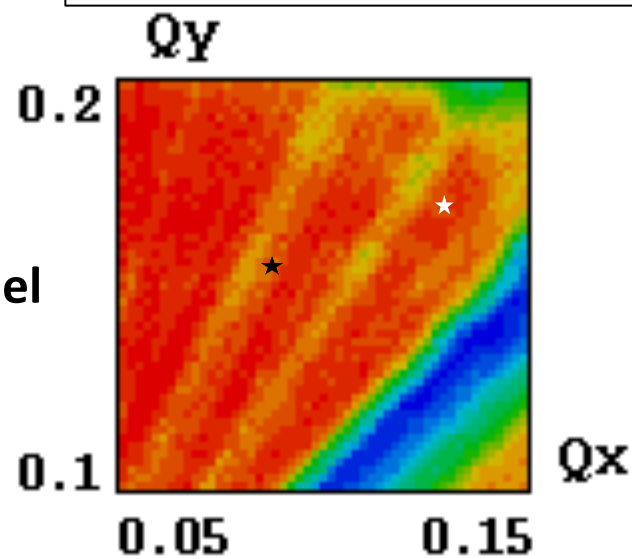
Linear model

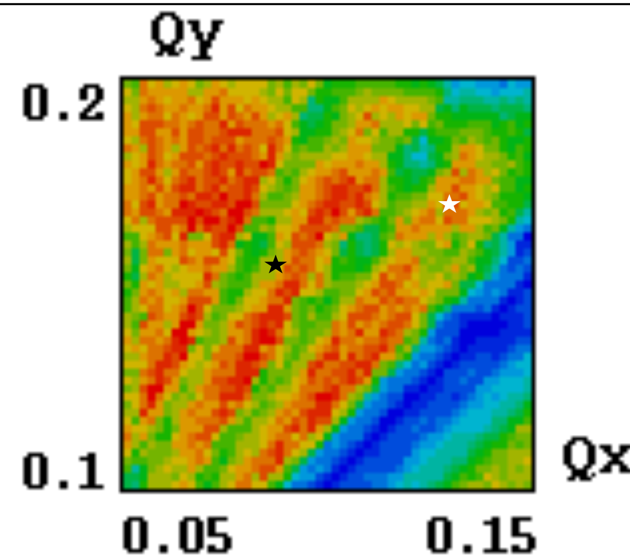




Luminosity | **Inverse beam sizes**

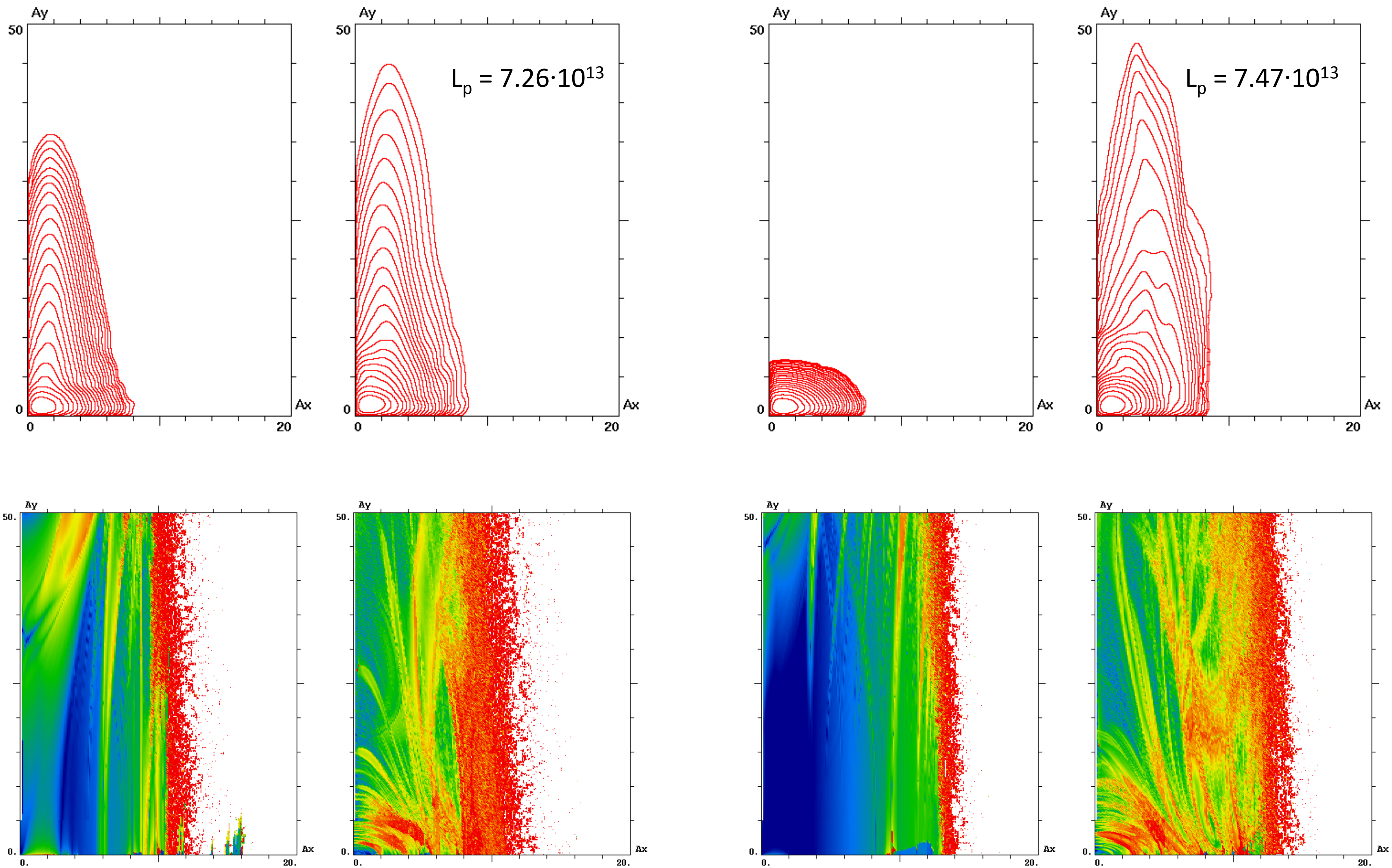
Nonlinear model





(0.088, 0.152) | (0.130, 0.170)

BB Off | BB On | BB Off | BB On



FMA for A_s = 2 sigma

Lifetrac Simulation Summary

- The simulated e- Dynamical Aperture is similar to that simulated and measured in previous KLOE run.
- The simulation using complete machine model indicates that the present e+ working point is optimal.
- For the e- ring, we suggest to move the working point to higher tunes:
  - Moderate increase in luminosity is possible (up to 5%)
  - More importantly, the DA will increase, which will result in better beam lifetime, injection efficiency, and background.
- CW sextupole strength can be optimized yielding moderate luminosity increase. The beam-beam effect is not the most significant limiting factor to achieve luminosity with KLOE-2

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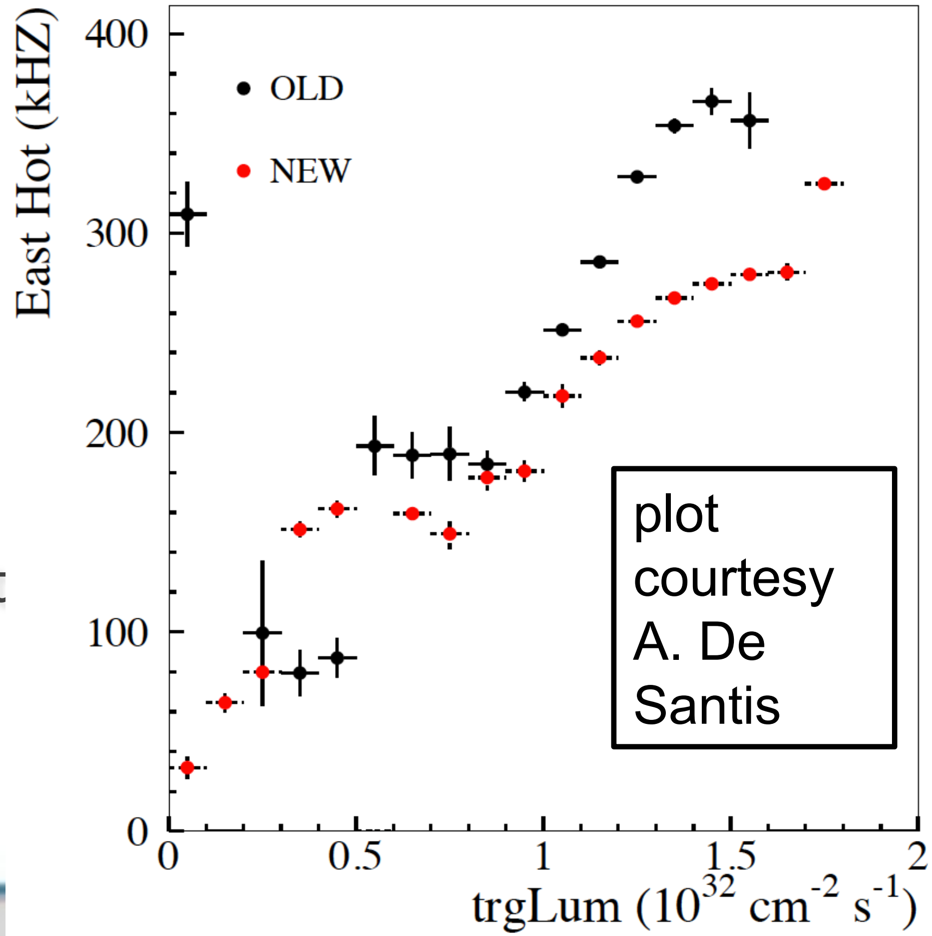
Results of e- Ring Working Point Change

- In about 2 hours of study time, the w.p. was moved to an optimal location
  a) Improved injection efficiency
  b) Higher beam lifetime
  c) Reduced background
  d) Higher luminosity
- Further improvements would be
  - Mitigation of microwave instabilit
  - Feedback noise reduction



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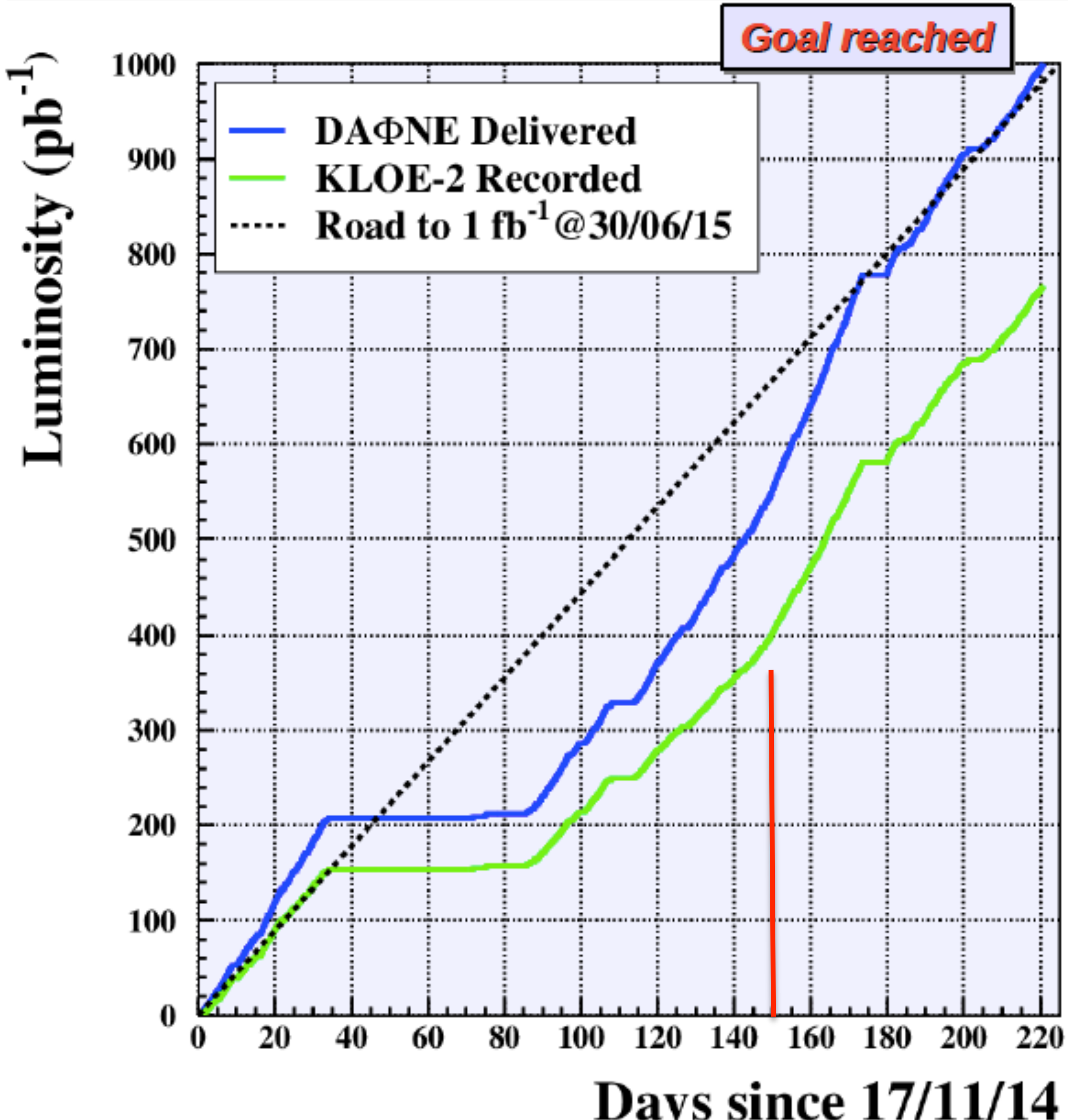
Data delivery progression



DAΦNE began KLOE-2 data delivery on November, 17 with the aim of deliver at least 1 fb^{-1} in the following eight months (48 SciCom recommendations).

Total delivered and acquired integrated luminosity as a function of the time.
The difference between the two (~20%) is due both to beam conditions induced losses and detector fault.

Time scale ends at June, 30.