Summary

LARP Mini-Workshop on Beam-Beam Compensation 2007

Wolfram Fischer

U.S. LARP

BROOKHAVEN NATIONAL LABORATORY

CARE-HHH-APD Workshop BEAM’07, CERN
1 October 2007

LARP

LHC ACCELERATOR RESEARCH PROJECT SLAC

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Welcome to the LARP Mini-Workshop on Beam-Beam Compensation 2007

July 2 - 4, 2007
Stanford Linear Accelerator Center
Menlo Park, California

Research Office Building, SLAC

The US LHC Accelerator Research Program (LARP) hosts a mini-workshop on beam-beam compensation at SLAC. The workshop will review the experience with beam-beam compensation tests, both long-range and head-on, in existing machines (DCI, SPS, Tevatron, DAFNE, KEKB, RHIC), and outline milestones for the implementation of beam-beam compensation schemes in the LHC. It is also intended to be a platform for young scientists to present their work. The workshop is by invitation only.

SLAC Stanford Linear Accelerator Center, Menlo Park, CA
Operated by Stanford University for the U.S. Dept. of Energy

33 participant from Asia, Europe, America

BNL, CERN, FNAL, KEK, LBNL, LNF-INFN, SLAC, UT Southwestern

Workshop topics:

- Beam-beam performance of circular colliders
- Beam-beam simulations
- New operating modes, theory, unexplained phenomena
- <u>Long-range beam-beam compensation</u>
- <u>Head-on beam-beam compensation</u>

LHC beam-beam effects

- incoherent beam-beam effects
  - *lifetime & dynamic aperture*
- PACMAN effects
  - *bunch-to-bunch variation*
- coherent effects
  - *oscillations and instabilities*

(W. Herr, LHC Design Report, Chapter 5)

beam-beam issues in LHC versions

- nominal LHC

  design criterion, head-on collisions, crossing angle, alternating crossing, long-range beam-beam effects, halo collision, tune footprints, dispersion, noise, strong-strong effects

- early-separation upgrade

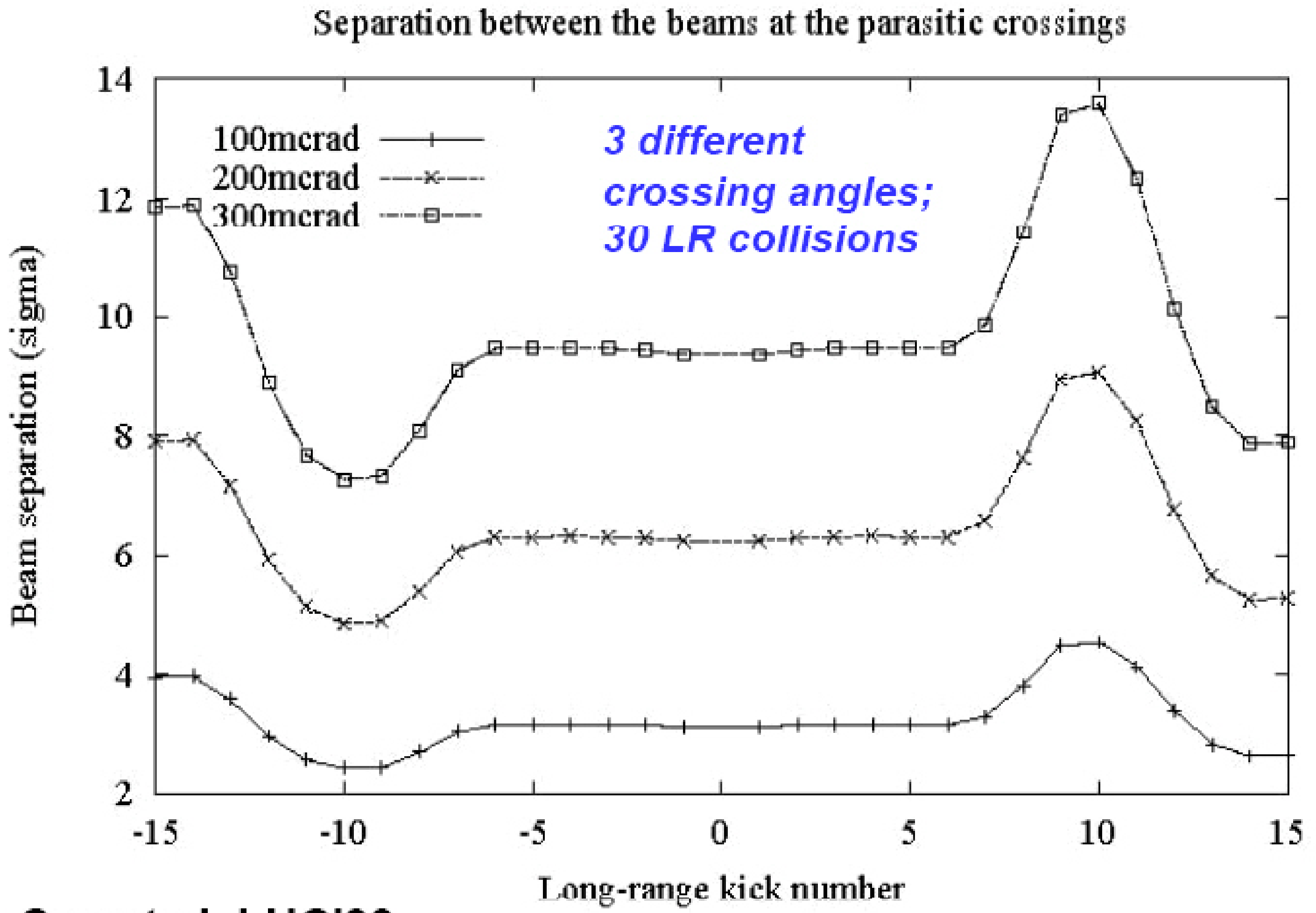
  crab cavity, low-distance parasitic encounters,

  crab waist collisions, emittance growth due to crab noise

- large Piwinski angle upgrade

  new regime for hadron colliders, crab waist collisions, tune shift, wire compensation, emittance growth due to wire noise

long-range separation at IP1 & 5



T. Sen et al, LHC'99

Presentation F. Zimmermann, CERN

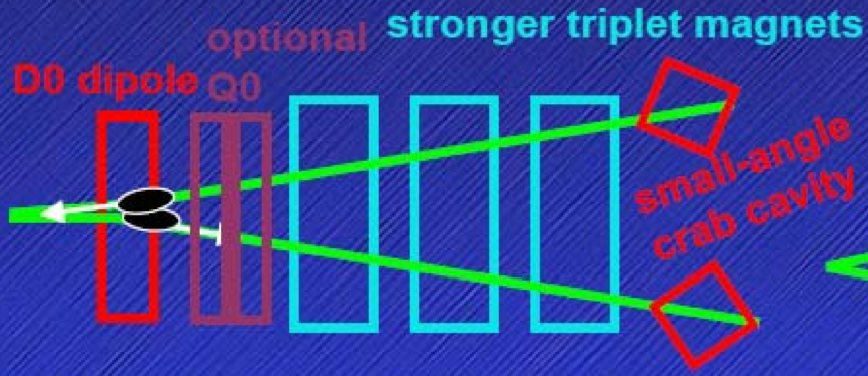
early separation (ES)

- stay with **ultimate LHC beam** (1.7x10^{11} protons/bunch, 25 spacing)
- **squeeze β* to ~10 cm** in ATLAS & CMS
- add early-separation dipoles in detectors starting at ~ 3 m from IP; accept **4 long-range collisions at 4-5σ separation**
- possibly also add quadrupole-doublet inside detector at ~13 m from IP
- and add **crab cavities**

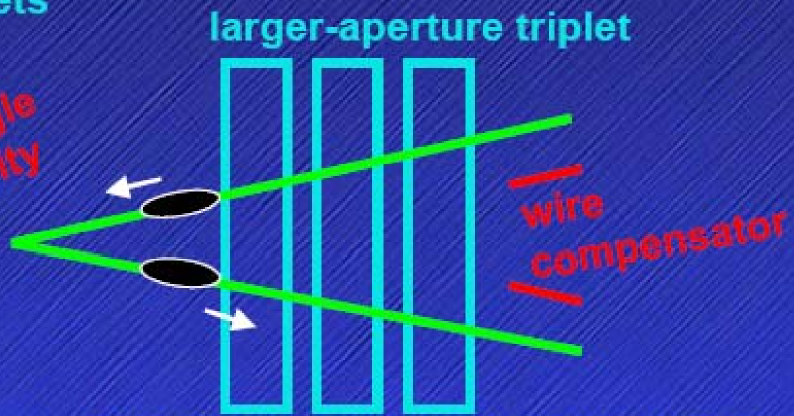
large Piwinski angle (LPA)

- double bunch spacing
- **longer & more intense bunches** with $\phi_{Piwinski}$ ~ 2
- **β*~25 cm**
- no elements inside detectors
- **long-range beam-beam wire compensation**

→ novel operating regime for hadron colliders



ultimate bunches & near head-on collision



long bunches & nonzero crossing angle & wire compensation

Frank Zimmermann, LARP Beam-Beam, SLAC, July 2077

Presentation K.Ohmi, KEK

High bunch current collision

Beam-beam effect dominates for the Luminosity

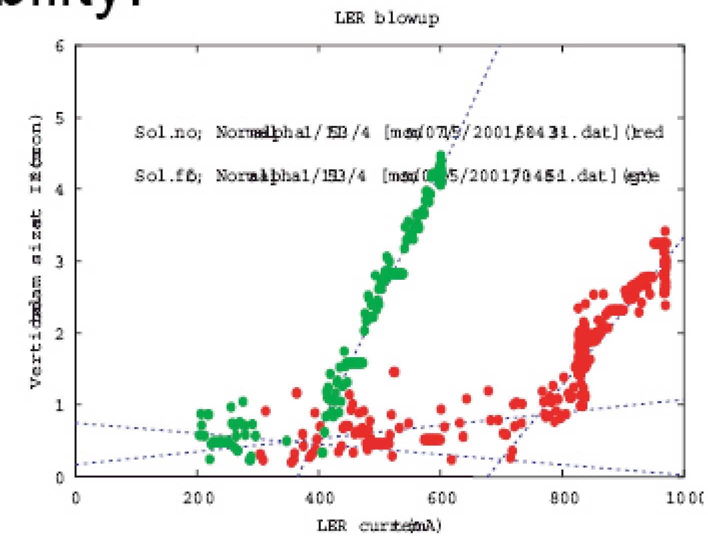
- Beam size blow-up, especially in vertical, arises at the collision.
- Suppression of the blow-up leads to high luminosity.

Understanding of interaction with other effects important:

working point, global linear optics errors, local optics errors at IP, chromatic optics errors, noise source, static and dynamic offsets at IP, feed back noise, e-clouds

Electron cloud effect

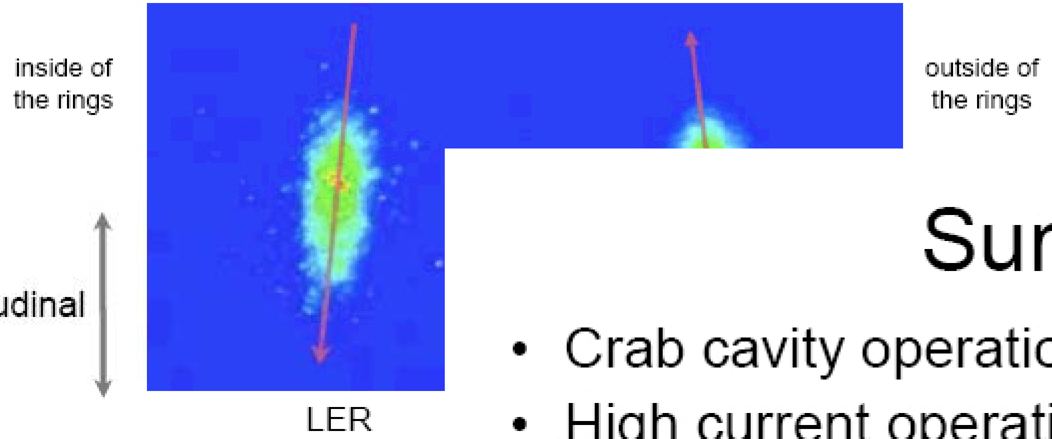
- Luminosity degradation in multi-bunch and high current operation
- Beam size blow-up. Observation of a synchro-beta side band upper the blow-up threshold: i.e., sign of electron cloud induced head-tail instability.



Presentation K.Ohmi, KEK   Crab cavity operation

Beams has indeed tilted!

- Observation with Streak Cameras (H. Ikeda et al, FRPMN035)

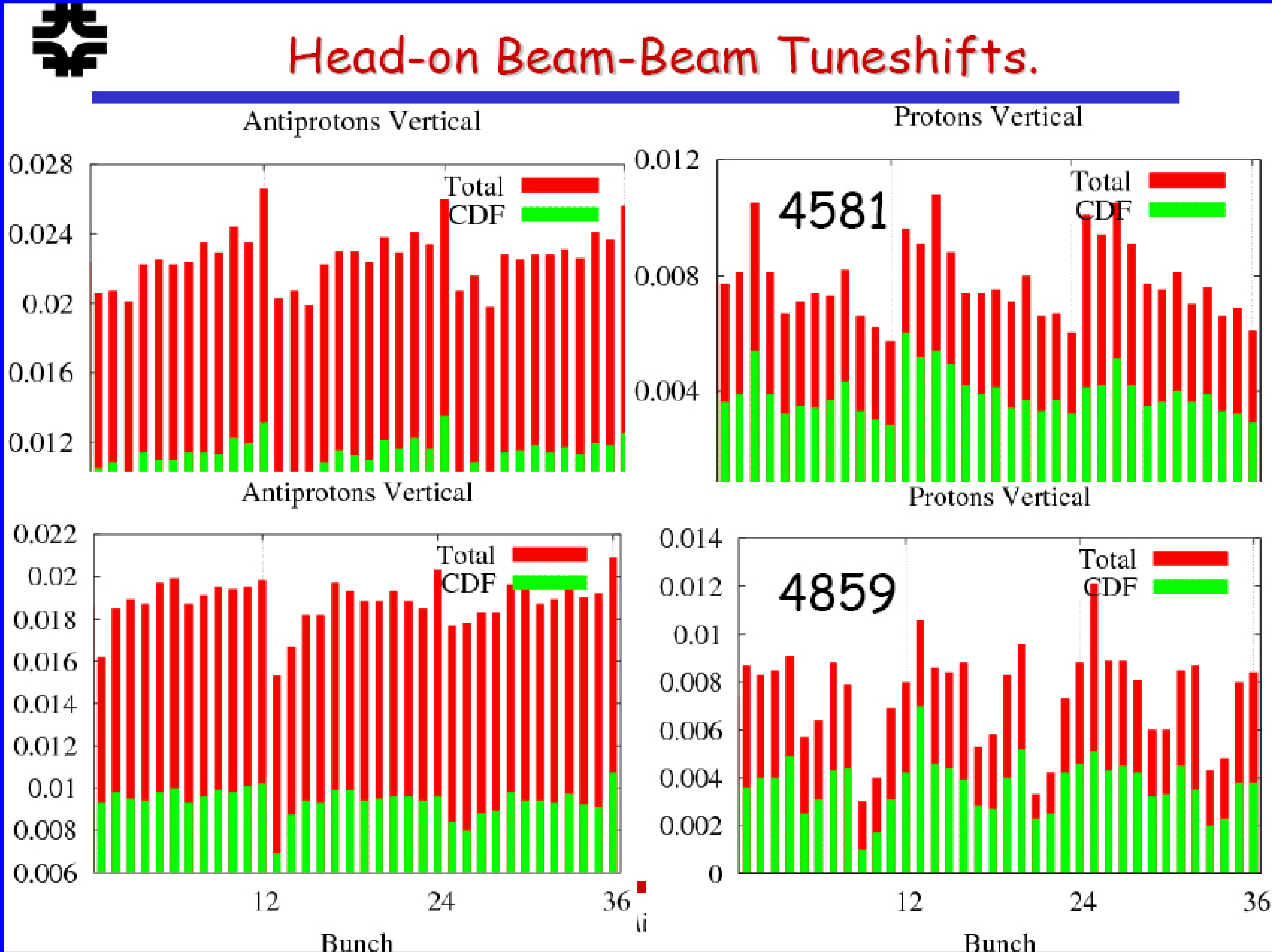


Summary

- Crab cavity operation starts from Feb. 2007.
- High current operation was succeeded, 1.3 A (e+) and 0.7 A(e-).
- RF Phase fluctuation (20 sec period) was seen at high current operation due to the backlash in the coaxial tuner. The fluctuation is seen only in collision mode. Related to beam-beam?
- Luminosity gain is not yet.
- It seems to be essential for me to solve the asymmetry.

Expect increase in beam-beam parameter by factor ~2, based on strong-strong simulations

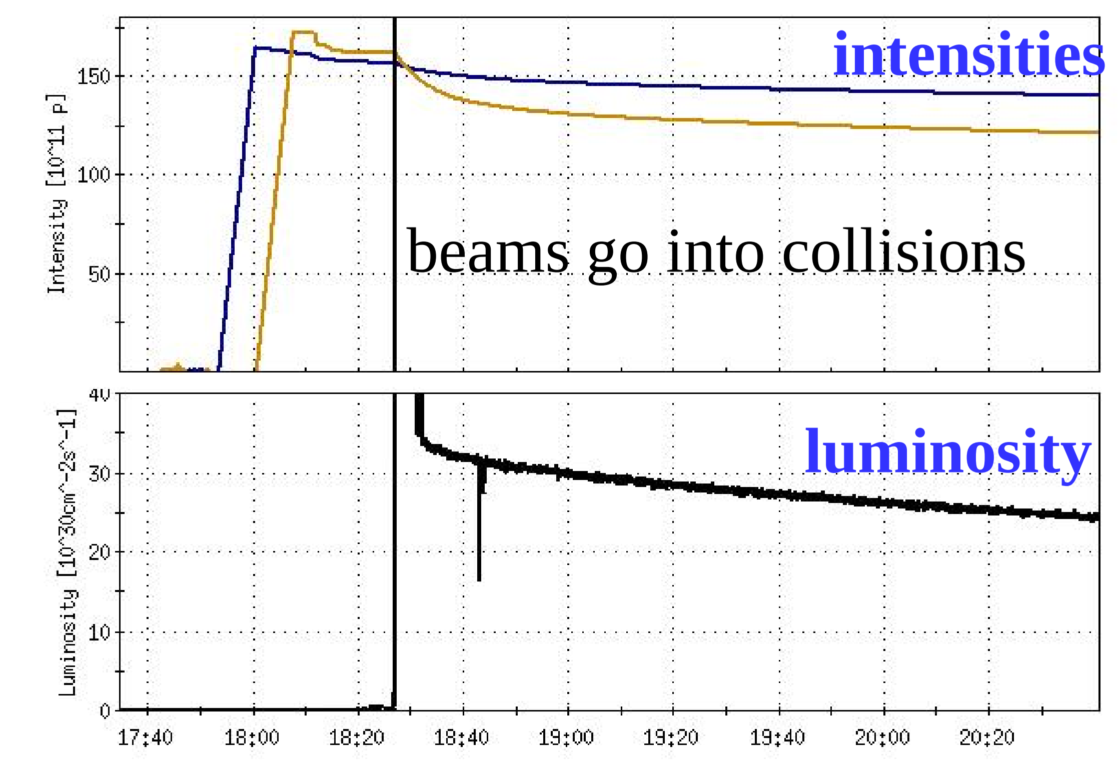
Presentation A. Valishev, FNAL

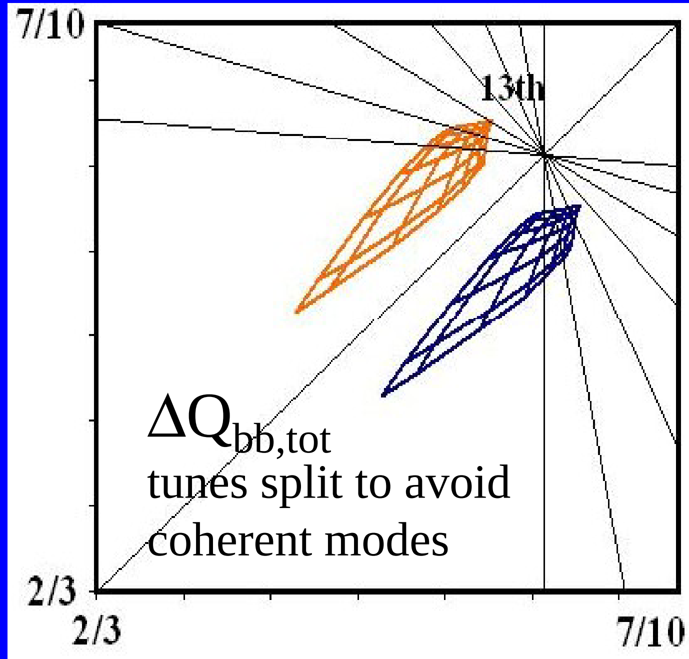


Summary

- Beam-beam effects at injection cause 5-10% beam loss
- At collisions, before 6/06 decrease of intensity lifetime and emittance blowup were caused by long-range effects
- Implementation of the new collision helix with increased separations at particular LR collision points gave improvement of the luminosity lifetime (~16%)
- Currently, beam-beam effects at collisions are dominated by proton losses due to head-on interactions

RHIC p↑- p↑ performance in 2006





- Total beam-beam induced tune spread reached $\Delta Q_{bb,tot} = 0.012$
- Other sources of tune spread: $\Delta Q \approx 0.005$
  - nonlinear chromaticity (correction implemented this year)
  - triplet errors (locally corrected)
- Sources for orbit and tune modulation

Dynamic apertures in σ for tunes below the integer

Will try new WP in RHIC in 2008 with one beam

28.965	5.3	5.3	5.5	5.8	6.0		
28.96	5.6	5.8	6.1	6.3			
28.955	6.0	6.0	6.4				7.1
28.95	6.2	6.1				7.3	6.9
28.945	6.0				6.9	6.9	6.8
28.94				6.4	6.6	6.7	6.8
28.935			6.5	6.5	6.5	6.9	6.9
	27.935	27.94	27.945	27.95	27.955	27.96	27.965

Broad region of large dynamic aperture ($\approx 7\sigma$) below the diagonal.

Requires improvements in orbit and β-beat correction

What is the beam-beam limit in hadron colliders?

- ISR
  - ISR limits were different from SppS/Tevtatron/RHIC: small beam-beam parameter, but coherent instabilities in conjunction with large beam currents, no synchrotron motion
- SppS
  - SppS limit is similar to Tevatron
- Tevatron
  - Long-range effects limit beam lifetime
  - Pacman effect limits lifetime of 3 proton bunches
  - Proton intensity limited by Z-driven instability, but proton beam is close to beam-beam limit
  - Anti-proton intensity limited by injectors
- RHIC
  - Beam lifetime determines ξ_{max}
  - Background has limited intensity in past
- LHC
  - How does radiation damping affect beam-beam limit (e.g. background)?
  - Possible tests at DAΦNE with wiggler off?

Summary of discussion

Presentation A. Kabel, SLAC

Conclusion + Outlook

- Bias-free calculation of observable quantities in proton machines is within our reach
- One needs to be fast, but very careful
- PLIBB code already contains many of the desired properties
- Benchmarking against dedicated RHIC experiments looks promising
- Strong-strong by PIC *is* feasible, but even more care must be exercised

May be in a situation similar to dynamic aperture calculations 10-15 years ago.

Presentation Y. Alexahin, FNAL

FERMI NATIONAL ACCELERATOR LABORATORY

US DEPARTMENT OF ENERGY

Coherent Beam-Beam Effects

at Hadron Colliders

Yuri Alexahin

Some effects observed in both Tevatron and RHIC (marginally stable bunches can become unstable with beam-beam interaction)

BBC @ LHC Workshop, SLAC, CA **July 2, 2007**

Presentation Y. Cai, SLAC

Unexplained Phenomena in

Le

Be

LARP Mini-

Conclusion

- Many progresses in the understanding of beam-beam effect in the lepton machine has been made over the past decay, largely due to the ever increasing of computer power and improvement of new algorithms.
- As usual, it is always a constant struggle to understand the operating accelerators even with good simulation tool.
- It seems that single-bunch effects are quite well understood at least in terms of simulation. The future improvement are most likely come from the subjects that relates to the multiple bunches, parasitic collisions, compensation, and other things that beam encounters in the circular accelerators, such as ions, electron cloud and nonlinearity.

Long-range beam-beam compensation

No of long-range encounters in selected machines

- Tevatron (p⁺p⁺): 70 per turn, distributed
- RHIC (p⁺p⁺): 0 (up to 12 for machine experiments)
- LHC (p⁺p⁺): 30 per IR, localized
- DAΦNE (e⁺e⁻) : 24 in main IR, localized
- KEK-B (e⁺e⁻) : 4 in IR, localized
- PEP II (e⁺e⁻) : 2 in IR, localized

Strategies for reducing long-range effect

- reduce number / increase distance of encounters
  (early separation near IP, crossing angle)
- compensation with electron lens (proposed for Tevatron by v. Shiltsev)
- compensation with wire (proposed for LHC by J.-P. Koutchouk)

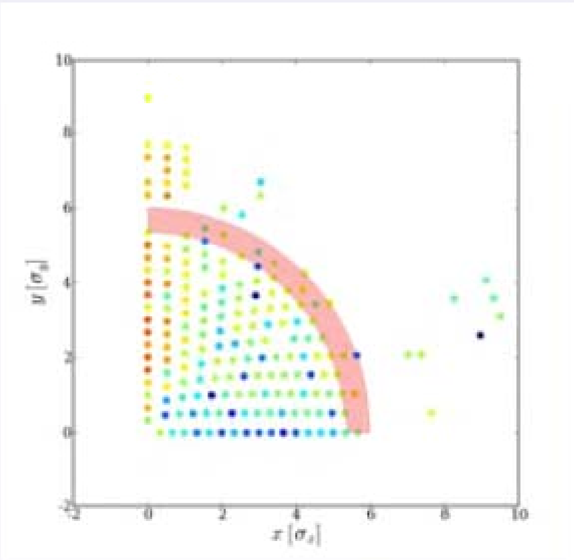
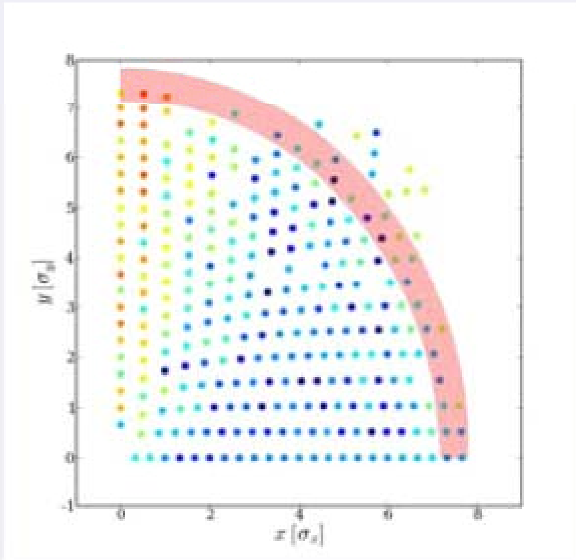
Long-rang beam-beam compensation

Efforts towards long-range compensation in LHC:

- Simulations
- SPS experiments with wires
- DAΦNE operating experience with partial wire compensation
- RHIC experiments with wires
- Benchmarking of all experiments
- Design work for pulsed LHC wire

Presentation U. Dorda, CERN

Simulated dynamic aperture improvement in LHC with long-range wire compensation

Uncompensated	Wire-compensated
	
$DA = 5.4\sigma$	$DA = 7.2\sigma$

The color indicates the tune diffusion.
Lower amplitude particles are also "stabilized".

Presentation F. Zimmermann, CERN

from SPS wire experiments

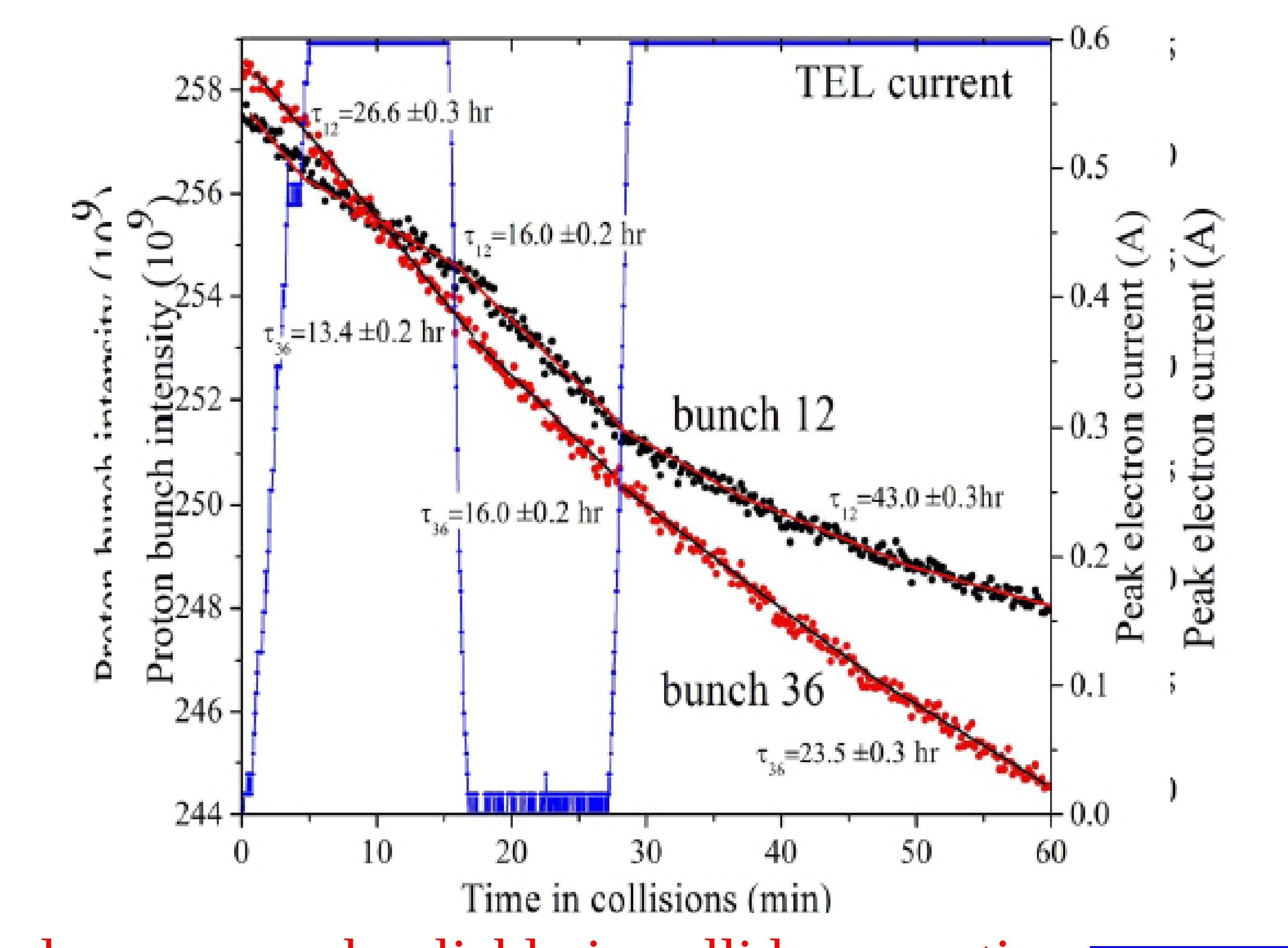
some open questions

- scaling from SPS to LHC
- strong emittance dependence of lifetime (c.f.Tevatron pbar)
- discrepancies between measured & simulated dynamic aperture
- breakdown of 2-wire compensation for $Q_y<0.285$
- why 5th power law? (Tevatron: 3rd power, RHIC: 2nd and 4th power); why different & why not higher power??
- some effect observed at very low wire excitation
- amplitude-dependent diffusion rate
- study sensitivity of final emittance to tune with and without BBLR
- discrepancies between simulated and measured lifetime (improved at higher beam energy?)
- understand parameters which are out of control or introduce intentional large perturbation (excite sextupoles, octupoles) to reconcile experiments and measurements
- wire compensation test with colliding beams (at RHIC) (essential?)
- common observable in experiments & simulations? – dynamic aperture! lifetime?
- demonstrate that 10^{-4} stability of pulsed wire can be achieved
- crossing scheme conclusions?

SPS beam lifetime at 26 GeV/c only 5-10 min.

Presentation V. Kamerdzhiev, V. Shiltsev, FNAL

Beam lifetime improvement for selected proton bunches in Tevatron with electron lens (PACMAN effect, fast tune shift)



Electron lens can work reliably in collider operation

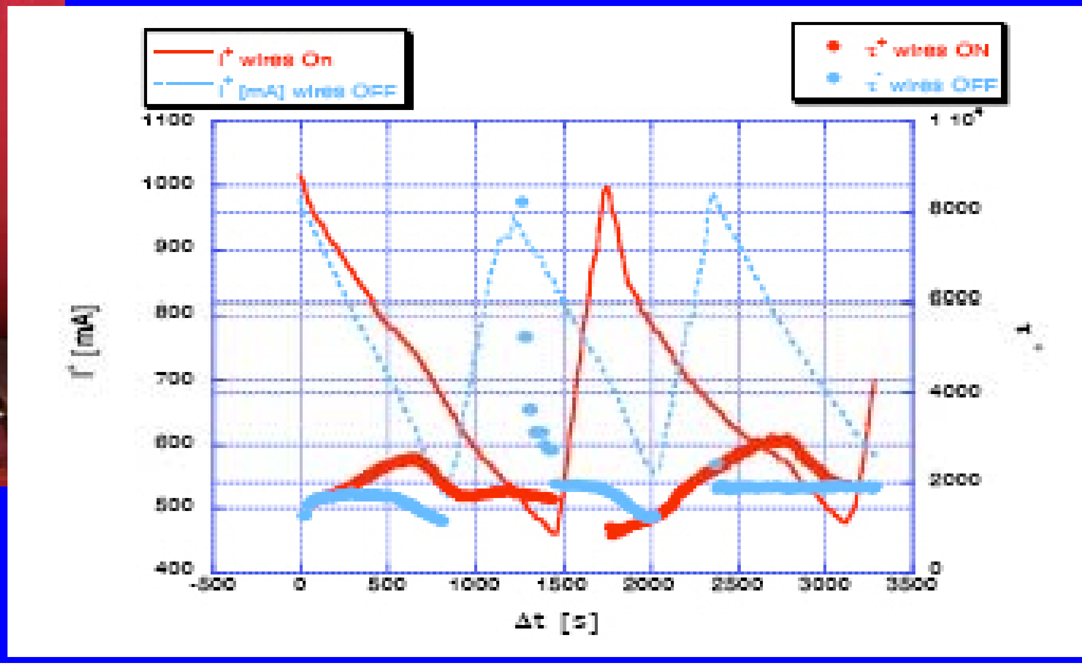
Presentation C. Milardi, LNF-INFN

DAΦNE (e^+e^-), Frascati

24 long-range interactions in main IR

Partial long-range compensation with wire, outside vacuum chamber

Have shown that it is possible to improve the lifetime of the weak positron beam in collision



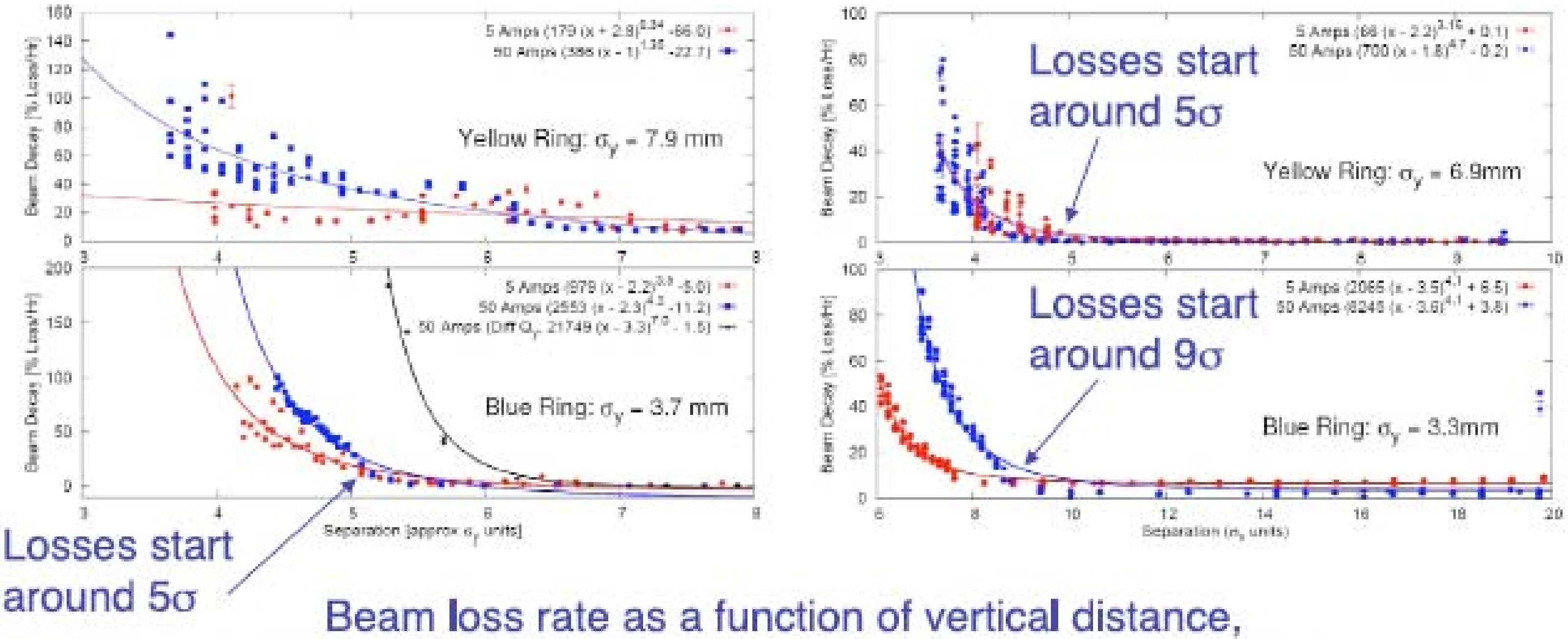
Presentation N. Abreu, BNL

RHIC wire experiments (base beam lifetime better than in SPS)

Beam Decay: position scan

Experiment I:

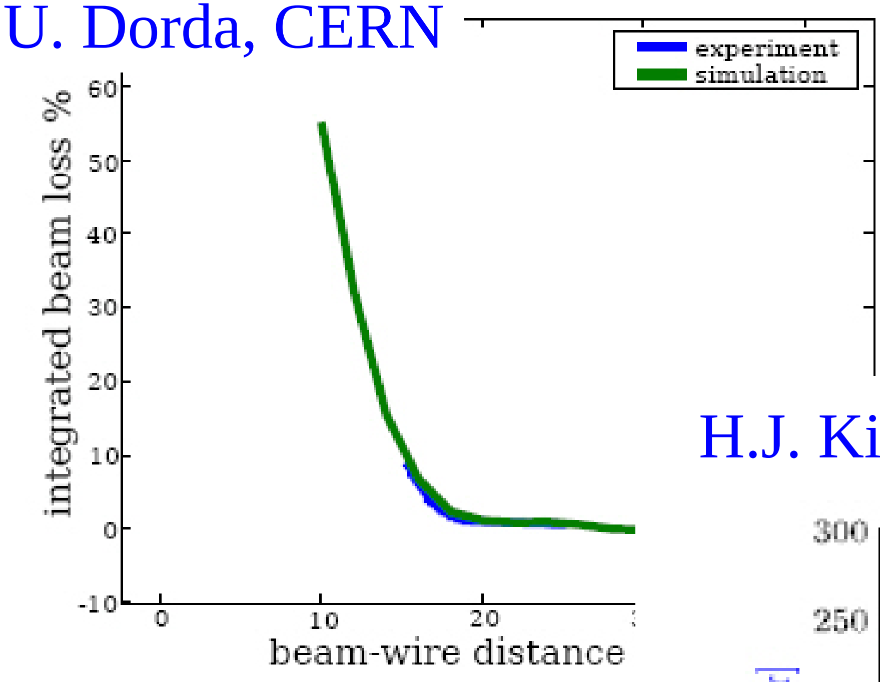
Experiment II:



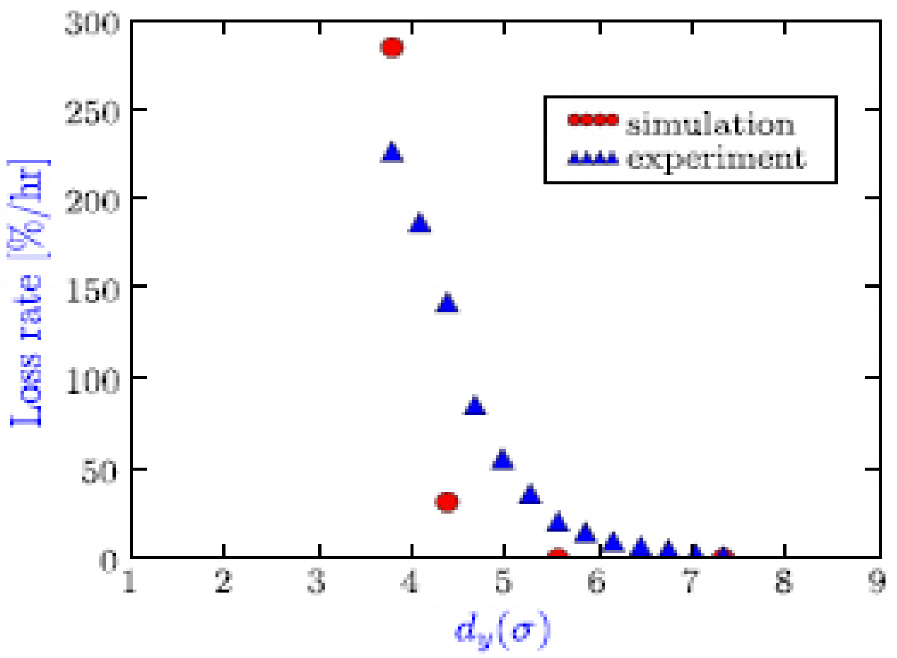
Beam loss rate as a function of vertical distance, in Yellow and Blue ring for experiments I (left) and II (right). The solid lines are power law fits to the respective data.

Benchmark simulations for RHIC experiments

U. Dorda, CERN



H.J. Kim, T. Sen, FNAL



Experimental data have error bars (ε_n-measurement dominates)

Head-on beam-beam compensation

Tune-shift induced by beam-beam collisions in hadron colliders

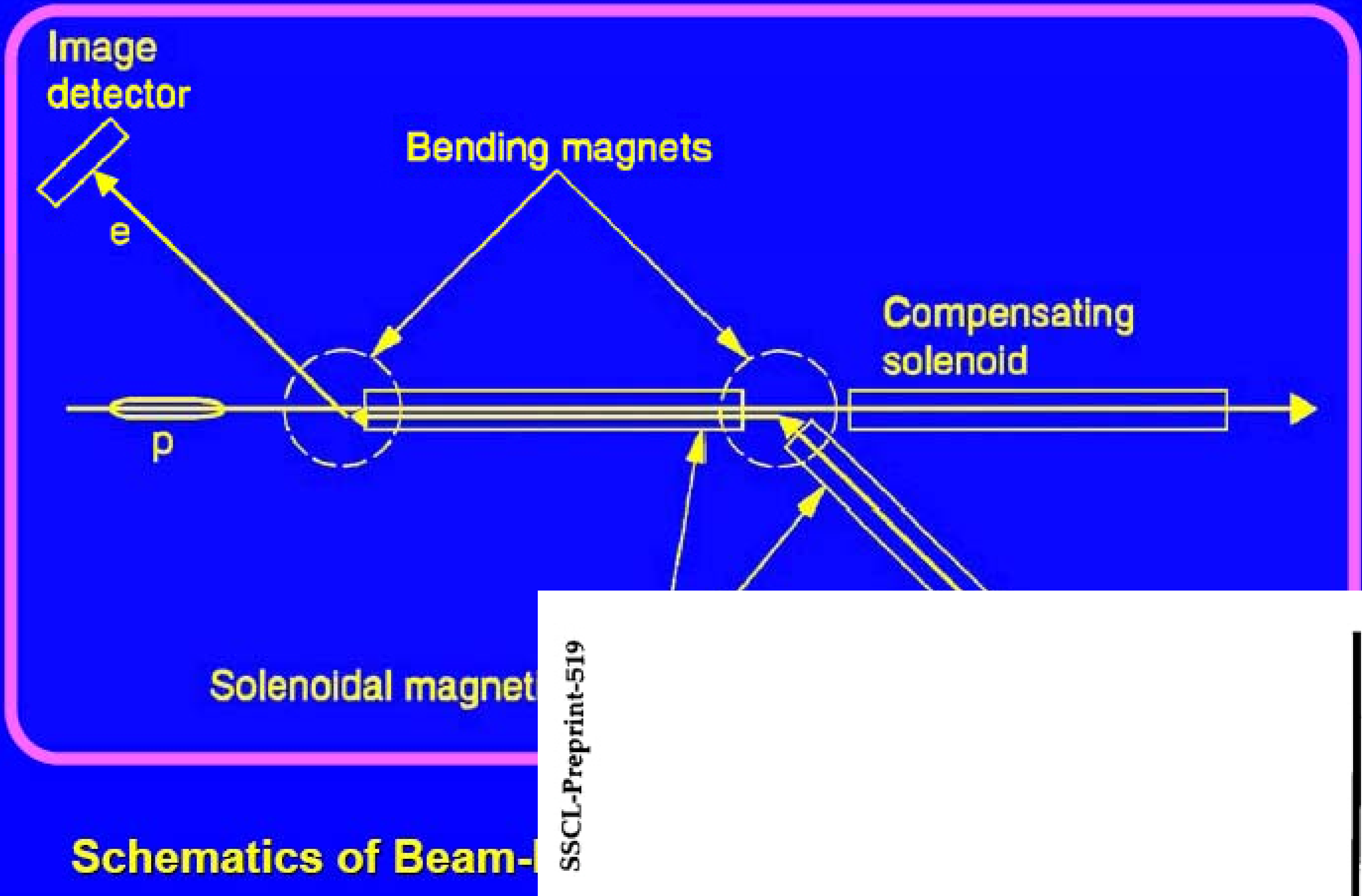
- ISR : $\Delta Q_{bb} = 0.008$
- SPS : $\Delta Q_{bb} = 0.028$
- Tevatron : $\Delta Q_{bb} = 0.024$ (p-bar), 0.010 (p)
- RHIC : $\Delta Q_{bb} = 0.012$
- LHC : $\Delta Q_{bb} = 0.010$

Strategies for reducing head-on effect

- selection of working point
- reduction of other nonlinearities
- <u>compensation with electron-lens</u>
  (reduction of beam-beam induced footprint)

Presentation E. Tsyganov, UT Southwestern

Head-on beam-beam compensation proposed for SSC in 1993



SSCL-Preprint-519

SSCL-Preprint-519
October 1993
Distribution Category: 414

E. Tsyganov
R. Meinke
W. Nexsen
A. Zinchenko

Compensation of the Beam-Beam Effect in Proton-Proton Colliders

Presentation W. Scandale, F. Zimmermann, CERN

- head-on compensation + injector upgrade could double LHC beam brightness
- this increases peak luminosity by factor 2, if the total LHC beam current is kept constant (1/2 number of bunches)
- resulting increase in average luminosity is only ~10-20%, due to two times shorter luminosity lifetime; peak #events / crossing increases 4 times

Head-on compensation more useful if ultimate not yet reached

Technological aspects of Electron Lenses, errors and control

for

LARP Mini-Worl

- ✓ The e-beam quality in both TELs reached the level that made reproducible demonstration of beam-beam compensation possible.
- ✓ Generating dc e-beam does not appear very challenging, however generating pulsed beam (individual compensation of all bunches) does.
- ✓ Though the voltage itself is not a challenge – short rise time and high rep rate requirements make the development of the e-gun driver very challenging.
- ✓ The solid state Marx generator proved to be a reliable electron gun driver (with radiation shielding installed).

RHIC head-on beam-beam compensation with e-lens

N. Abreu, W. Fischer, Y. Luo, C. Montag, G. Robert-Demolaize

J. Alessi, E. Beebe, A. Pikin

1. Introduction
2. Simulation Results
3. Plan

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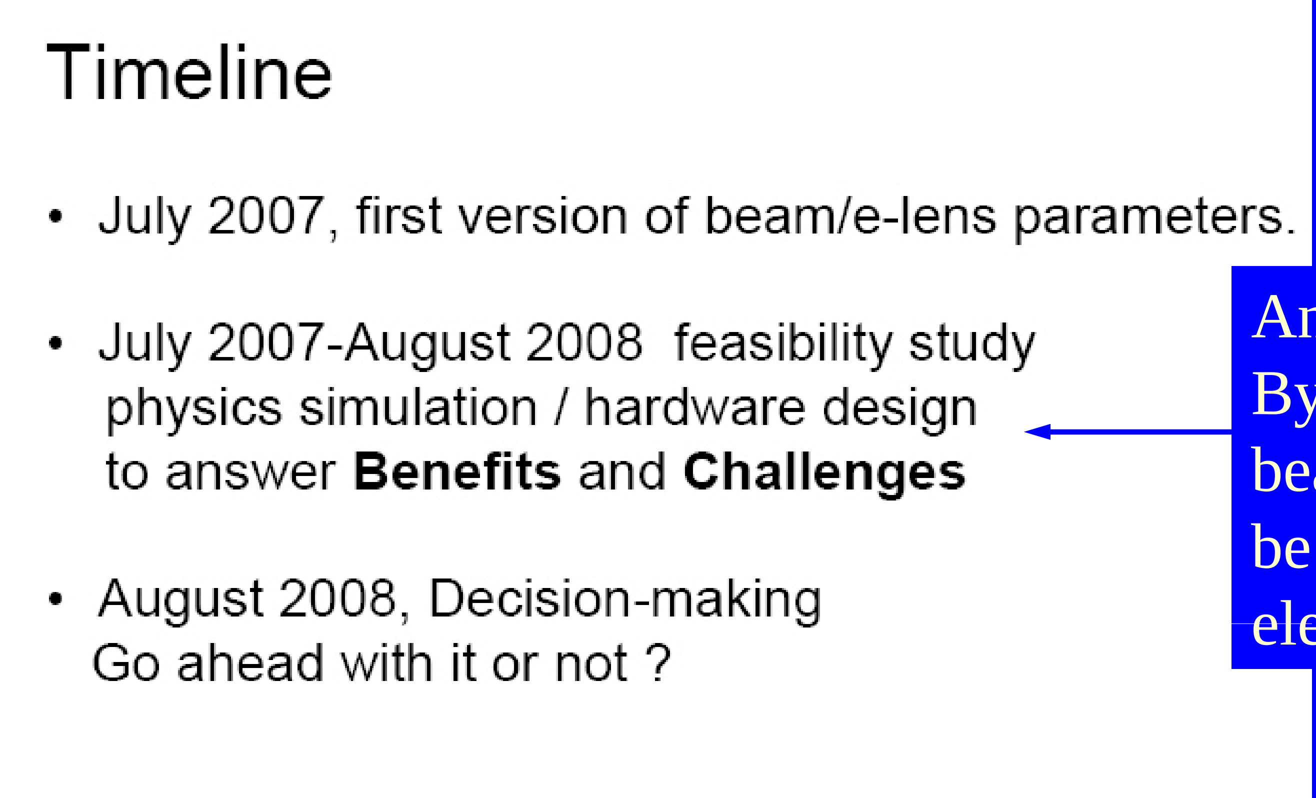
Presentation Y. Luo, BNL



Timeline

- July 2007, first version of beam/e-lens parameters.
- July 2007-August 2008 feasibility study
  physics simulation / hardware design
  to answer **Benefits** and **Challenges**
- August 2008, Decision-making
  Go ahead with it or not ?

Answer:
By how much can beam-beam parameter be increased with electron lens?

At the same time, effort started in LARP, lead by V. Shiltsev
- Numerical simulations for LHC
- Design considerations for LHC electron lens
- Relevant experiments with TEL in Tevatron