US LHC Accelerator Research Program

BNL - FNAL- LBNL - SLAC

LARP Accelerator Physics

19 June 2008

LARP+LAUC DOE Review, LBNL

Wolfram Fischer/BNL

Accelerator Physics Tasks in FY2008

1. Electron cloud studies – M. Furman (LBNL)

2. Beam-beam wire compensation – W. Fischer (BNL)
3. Beam-beam simulations – T. Sen (FNAL)
4. Electron lenses – V. Shiltsev (FNAL)

5. Crab cavities – R. Calaga (BNL)
6. New initiatives – T. Markiewicz (SLAC)

Total AP effort: ~ 4-5 FTEs

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Task: Electron cloud studies (M. Furman, LBNL)

Goal: simulate electron cloud effects in the LHC and the LHC injectors in order to optimize the operation and design of these machines when limited by electron clouds.

Activities in reporting period:

- Benchmark WARP vs. HEADTAIL (emittance evolution)
- Benchmark POSINST(2D) vs. WARP(2D) and (3D) (build-up)
- E-cloud build-up simulation of SPS strip detector measurement
- SPS feedback simulations (started)

Task: Electron cloud studies (M. Furman, LBNL)

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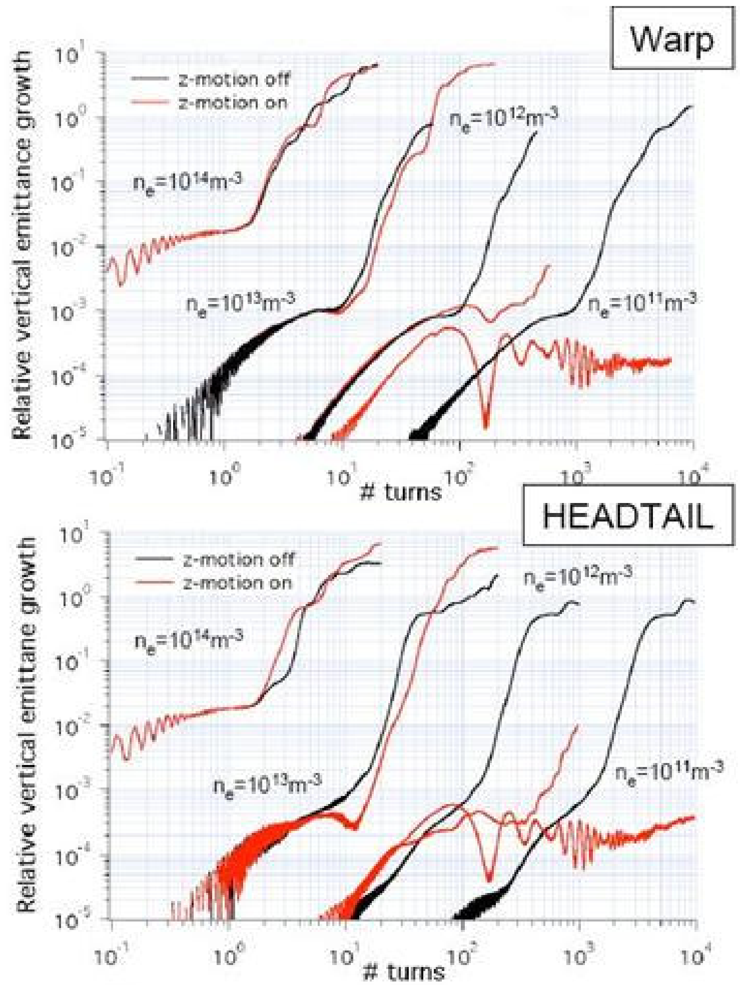
Benchmark WARP vs. HEADTAIL-3 for incoherent emittance growth

- LHC
  - γ=479.6
  - $N_p=1.1\times10^{11}$
  - continuous focusing
    - $\beta_{x,y}$ = 66.0, 71.54
    - $\nu_{x,y,z}$ = 64.28, 59.31, 0.0059
    - $\alpha = 3.47\times10^{-4}$
    - $\sigma_p/p = 4.68\times10^{-4}$
    - $\text{chrom}_{x,y}$ = 2, 2
  - $n_e=10^{11}$–10^{14} m^{-3}
  - N_{stn} ecloud station/turn=10-100
  - dipole magnetic field effect: frozen x-motion of electrons
  - same initial distribution of macro-protons with initial offset of $0.1\sigma_y$
  - threshold 2-particle model for TMCI:

$$\rho_{\text{thre}} = \frac{2\gamma Q_s}{\pi r_p C \beta_{x,y}} \approx 6.4\times10^{11}\ m^{-3}$$



Task: Electron cloud studies (M. Furman, LBNL)

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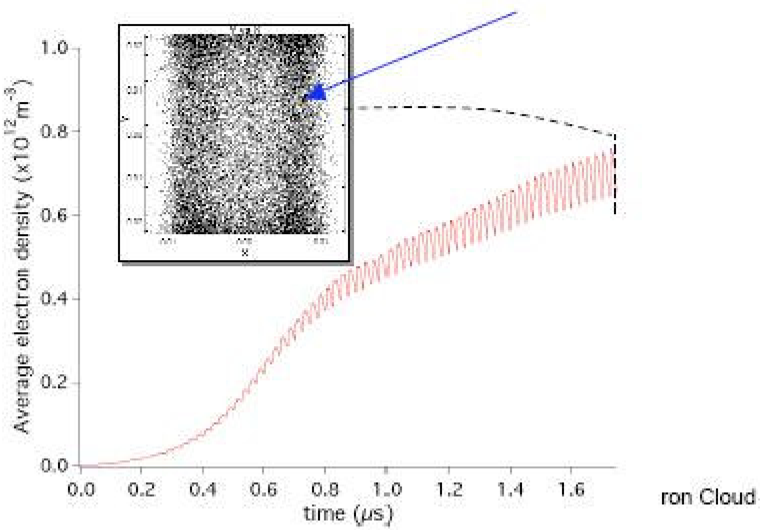
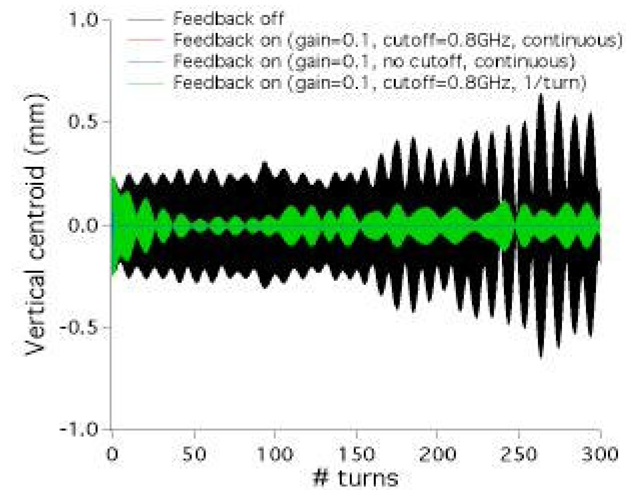
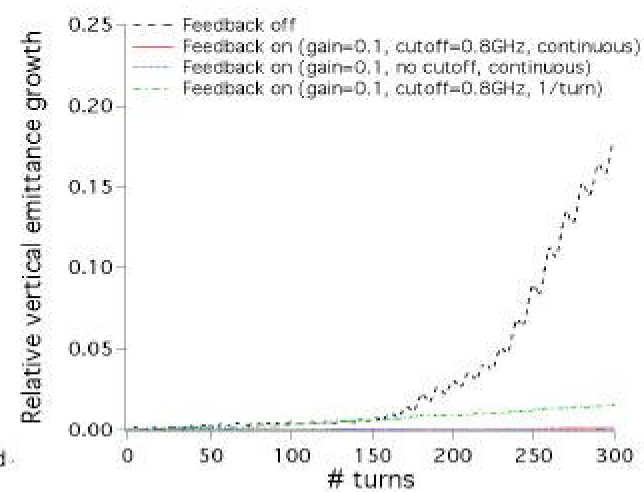
Preliminary simulation study of SPS feedback

- SPS at injection (E_b=26 GeV)
  - γ=27.729
  - $N_p=1.1\times10^{11}$
  - continuous focusing
    - $\beta_{x,y}$= 33.85, 71.87
    - $\nu_{x,y}$= 26.12, 26.185
    - ν_z= 0.0059
  - N_{stn} ecloud station/turn=100
  - Initial EC dist. From Posinst







Tentative electron cloud task for FY2009

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Consolidate new and existing electron cloud activities

Emphasis on instability remedies in SPS

SPS performance with LHC design beams marginal due to electron cloud induced instability

Design of an instability feedback (J. Fox, SLAC)

Simulations in support of feedback design (M. Furman, LBL)

Test of grooved chambers (M. Pivi, SLAC)

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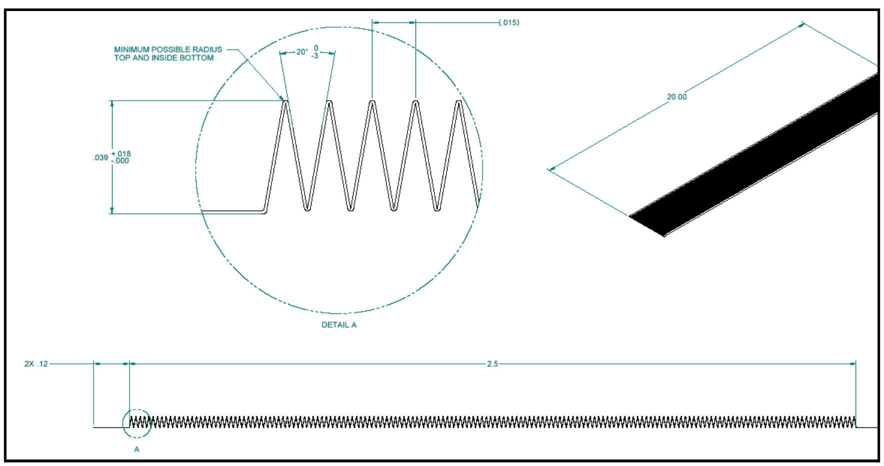
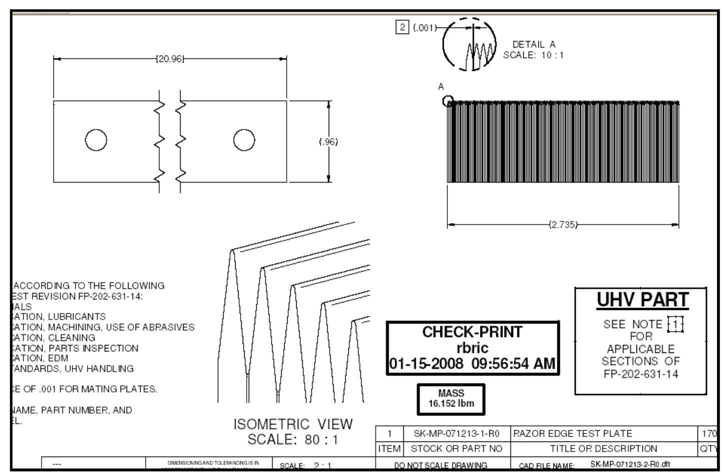
Tentative electron cloud task for FY2009

GROOVE TESTS IN THE SPS: A number of electron cloud mitigation test chambers are in preparation for installation in a new dedicated 4-magnet chicane in the SPS. At CERN/SLAC, we are manufacturing groove insertions to fit in one of the test chamber. The stringent requirements for a largest possible SPS chamber aperture call for a maximum 1mm height of the groove insertion. This requirement imposes tight tolerances on the sharpness of the groove tips and valley to reduce the secondary electron yield. We are investigating the manufacturing feasibility with different techniques: grounding (CERN), metal folding (SLAC), razor blades (SLAC).

People: Venturini, Furman (LBNL), Pivi, Wang (SLAC) Arduini, Chapochnikova, Taborelli (CERN).



Metal Folding: Form multiple folds. [EMEGA Company, USA]



Brazed-up Assembly: Use individual razor type foil blades

Task: Beam-beam wire compensation (W. Fischer, BNL)

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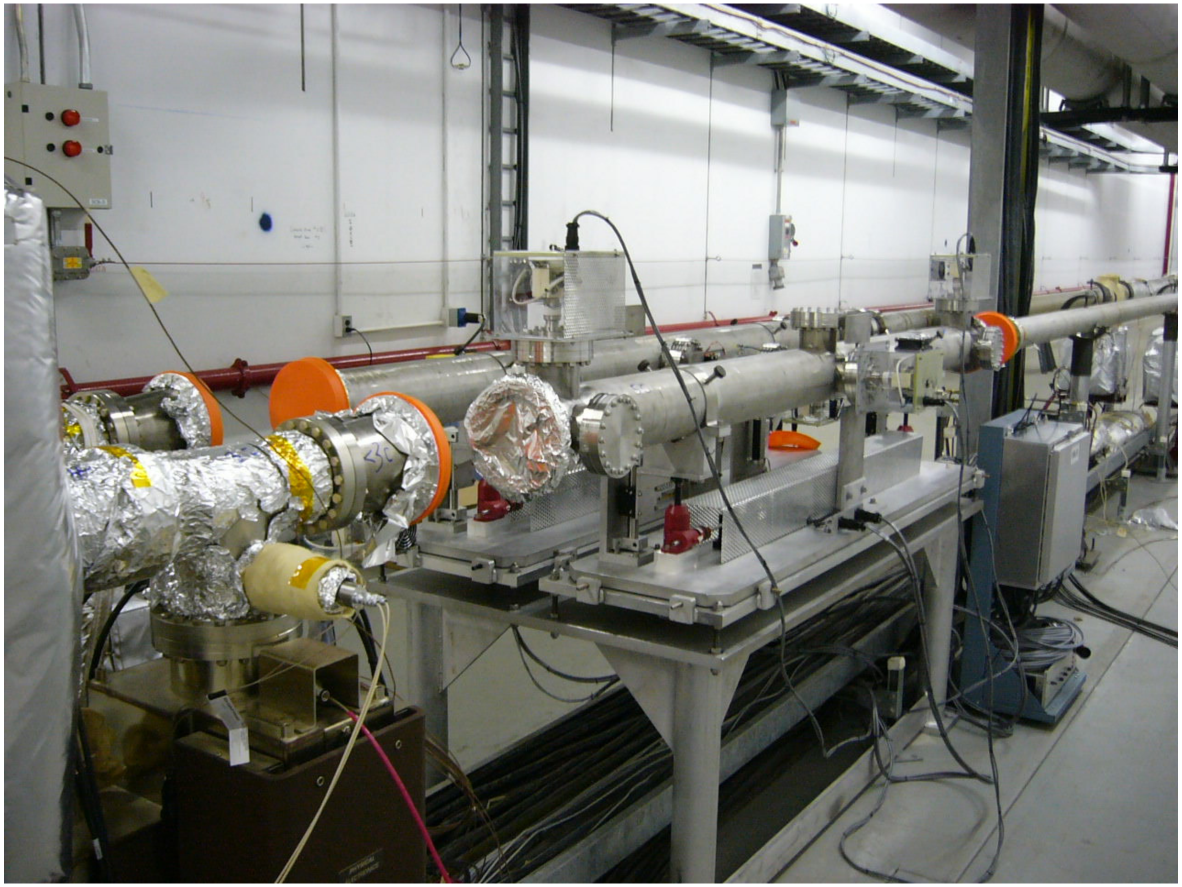
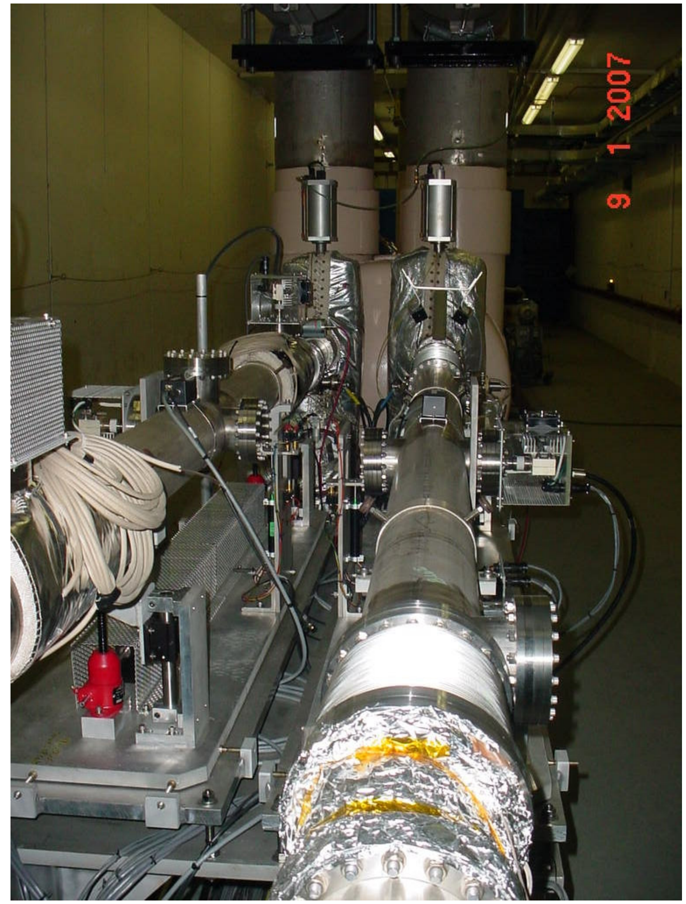
Goal: provide experimental data for long-range beam-beam effects as strong as in the LHC that can be used to benchmark beam-beam simulation codes

- No existing hadron machine has a long-range beam-beam effect as strong as LHC (~30 long-range interactions per IP)
- 2 wires designed, constructed and installed in RHIC to create strong long-range beam-beam effect
- Measurements done with Au and *d* beam so far (loss rate vs. distance, current, tune chromaticity)
- Proton measurements outstanding, task then finished

Task: Beam-beam wire compensation (W. Fischer, BNL)

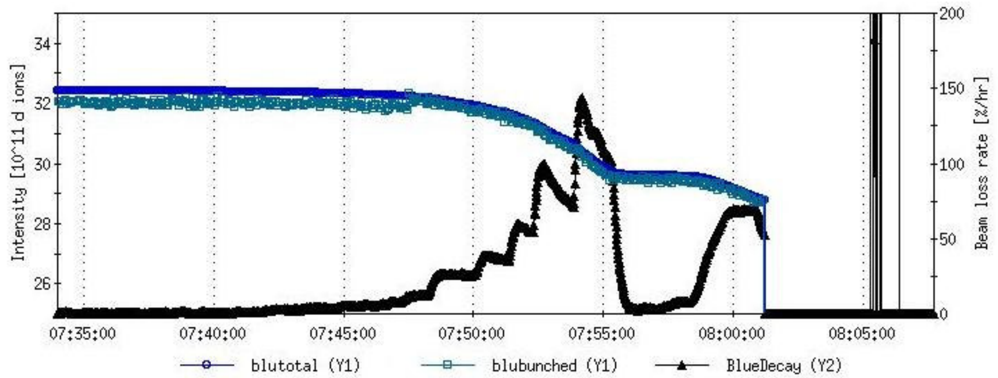


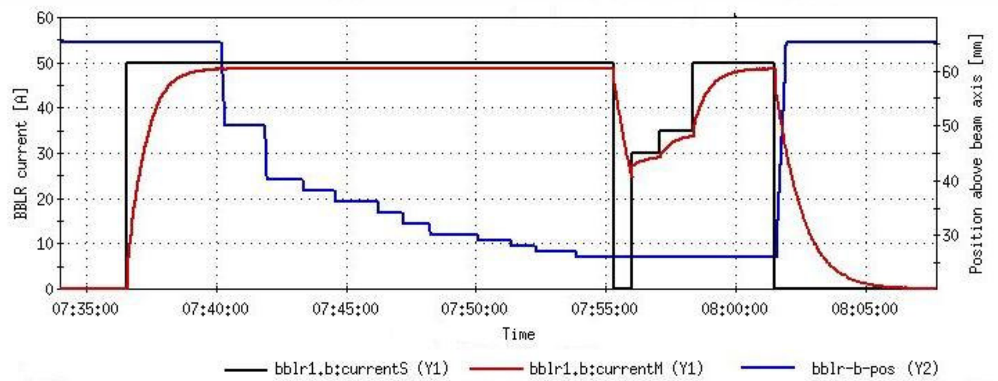


Vertically movable wires in RHIC tunnel.
Max integrated strength 125 Am (80 Am needed for compensators in LHC, 2x/IP).

Task: Beam-beam wire compensation (W. Fischer, BNL)

Beam loss rate vs. wire position and current with *d* beam in Jan. 2008





Had also planned to make scans with p and including head-on effect.
But only short (3.5 wks) RHIC physics run with protons – no experimental time.
Plan to perform proton scans in FY2009.

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Task: Beam-beam simulations (T. Sen, FNAL)

Goal: benchmark beam-beam simulations codes with experimental data, currently primarily from RHIC, and evaluate the LHC beam-beam performance with long-range and head-on beam-beam compensation as well as for crab cavities.

FNAL – H.J. Kim and T. Sen (BBSIM)

Weak-strong, for SPS and RHIC wire experiments

SLAC – A. Kabel (PlibB)

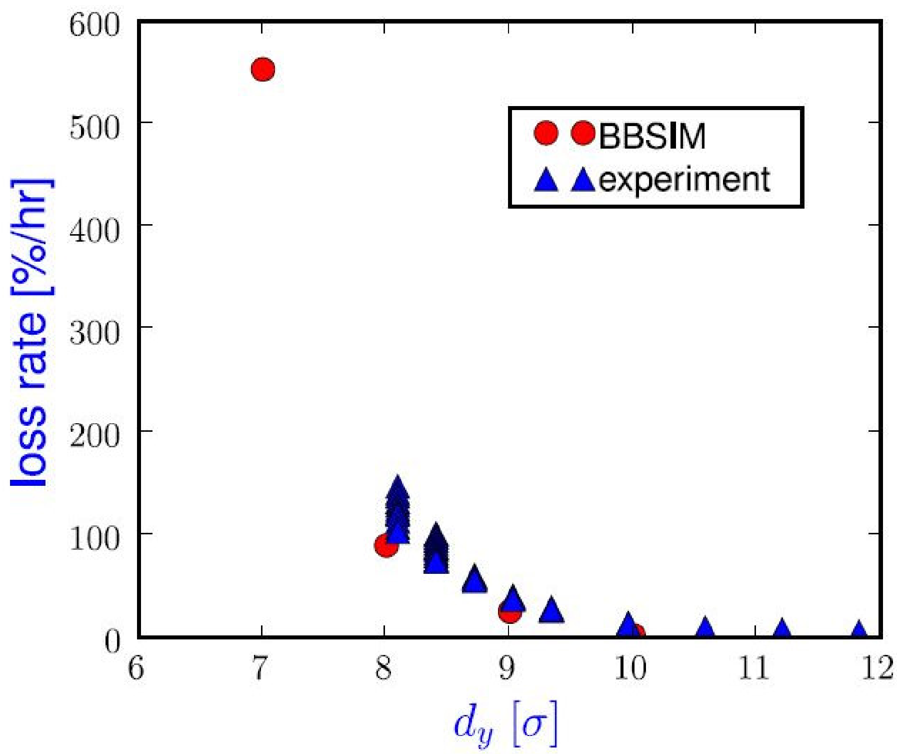
Weak-strong, for RHIC wire experiments and e-lens

LBL – J. Qiang (Beambeam3D)

Strong-strong, for RHIC and LHC emittance growth

Task: Beam-beam simulations (T. Sen, FNAL)

Simulated and measured beam loss rate as function of wire distance (RHIC *d* scan, 1/2008)



Courtesy H.J. Kim, T. Sen, FNAL

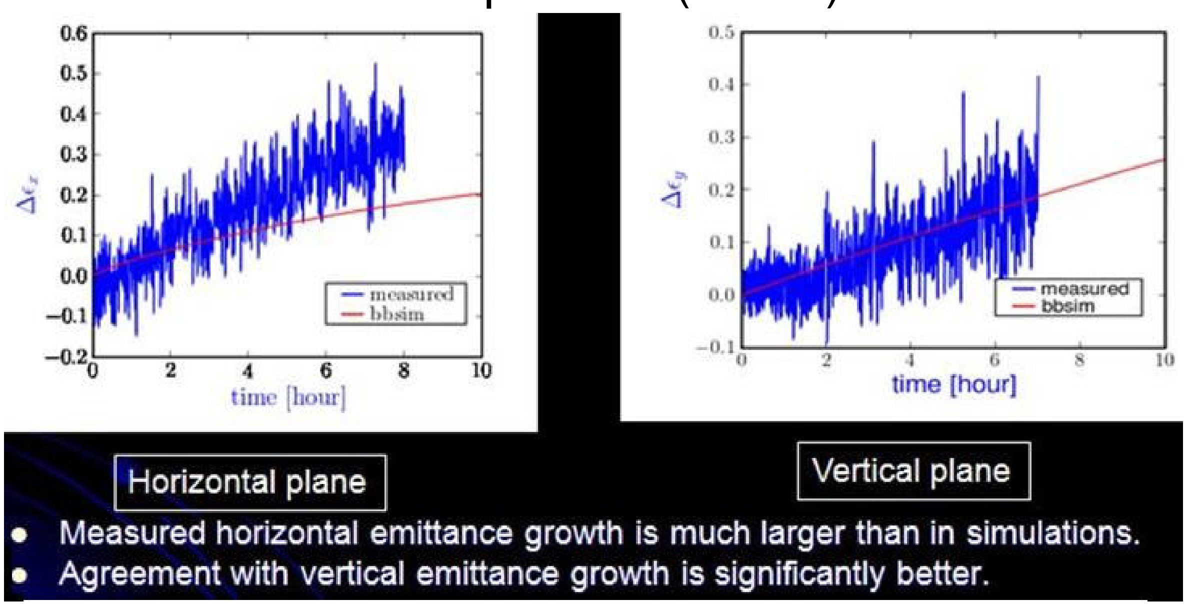
Onset of increased beam loss rate could be reproduced within 1σ for a number of the RHIC scans made.

(independently also by U. Dorda, CERN, with Code BBTrack)

Task: Beam-beam simulations (T. Sen, FNAL)

Emittance growth from diffusion coefficients

- Emittance growth may be driven by diffusive processes in the core, dynamics in the tails, which determine lifetime, may not be diffusive
- Calculate diffusion coefficients from BBSIM and use as input in independent diffusion solver
- Evolve density and moments to find emittance growth and lifetime over relevant time periods (hours)



RHIC *d* beam (store 9572)

Courtesy H.J. Kim, T. Sen

Task: Beam-beam simulations (T. Sen, FNAL)

Physics additions to simulation programs (recent or future):

BBSIM (FNAL)

- Coupling (Edward-Teng)
- Resistive wall wakefield
- Symplectic synchro-beam map

PlibB (SLAC)

- MAD-X lattice input (i.e. full LHC files)
- Intrabeam scattering
- Electron lens

BeamBeam3D

- Crab cavities – impact of phase noise

Task: Beam-beam simulations (T. Sen, FNAL)

Planned work for FY2009:

- Evaluate wire compensation in LHC and benefit to luminosity
- Simulate wire compensation in RHIC and compare with measurements in FY2009
- Improve the diffusion model: add other sources of diffusion in tracking, use diffusion equation in 3D action space. Extend the comparison to other stores.
- Evaluate the impact of crab cavities in the LHC with weak-strong and strong-strong simulations. Set tolerances on noise parameters.
- Evaluate electron lenses in the LHC

Task: Electron lenses (V. Shiltsev, FNAL)

Goal: evaluate the LHC luminosity improvement with electron lenses for head-on beam-beam compensation, and other possible applications of electron lenses

Reducing tune footprints is not sufficient

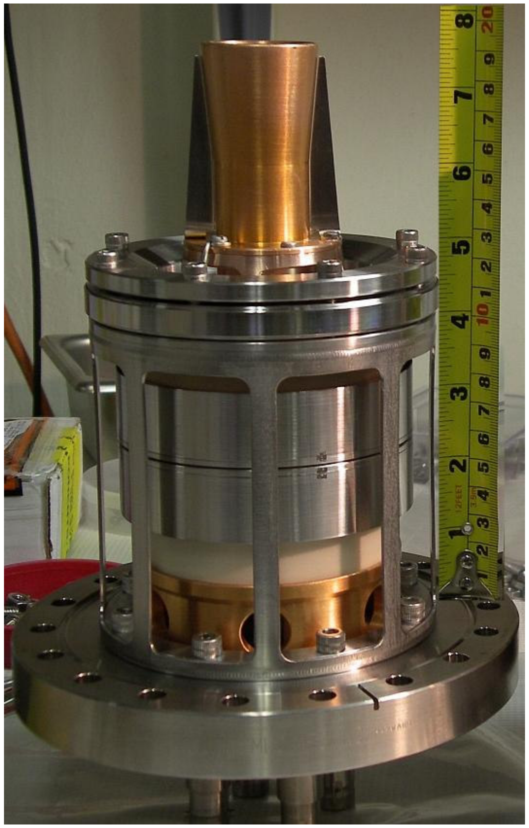
Work includes

- Experiments in the Tevatron with a Gaussian profile lens
- Numerical simulations
- Theoretical analysis

Electron lenses could be included in the Phase II LHC IR upgrade.

Task: Electron lenses (V. Shiltsev, FNAL)

- Need Gaussian gun for head-on compensation
- Current TEL lenses have flat profile with soft edges
- Built Gaussian profile gun for test (awaiting installation)



Planned Tevatron experiments:

- Effect on of e-lens on tune spread
- Determine tolerable noise levels (position, current)

Courtesy V. Kamerdzhiev

Task: Electron lenses (V. Shiltsev, FNAL)

Numerical simulations, approach

- Show that beam-beam effect becomes unacceptable above certain beam-beam parameter ξ
- Turn on electron lenses to see improvement

Not straight forward to determine acceptable beam-beam parameter ξ

Figures of merit investigated:

- Short-term measures (tune footprint, tune and action diffusion, chaotic boarders) are all inconclusive when taken alone
- Dynamic aperture not a good measure for beam-beam problems
- Emittance growth probably too noisy signal in simulation
- Beam lifetime most promising but need a good model and sufficient CPU time

Task: Electron lenses (V. Shiltsev, FNAL)

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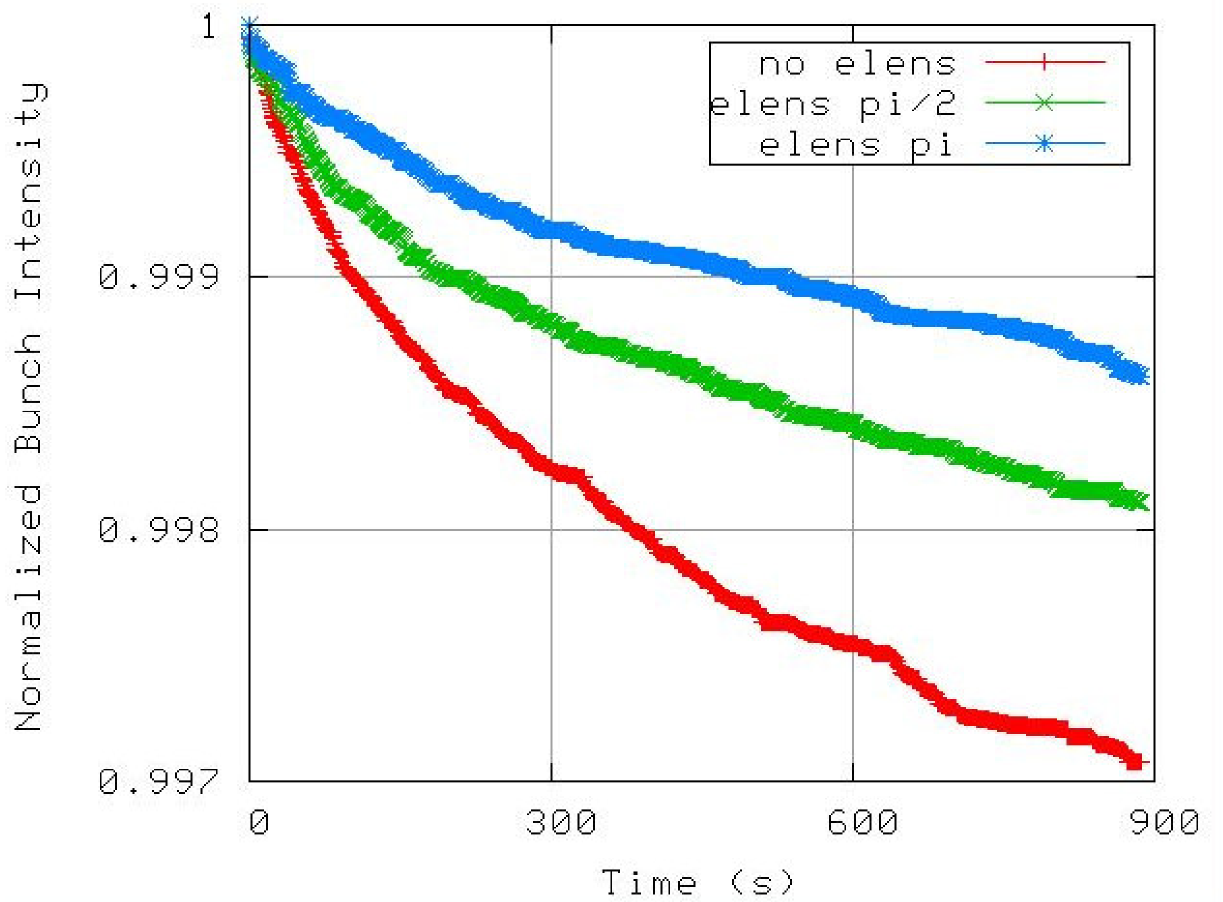
LHC simulation with LIFETRACK
different phase advances between IP and e-lens
($\Delta\varphi = \pi$ with linear lattice and ideal e-lens is optimum)



Lifetime simulations need benchmarking with existing machines (Tevatron, RHIC)

Courtesy
A. Valishev

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Task: Electron lenses (V. Shiltsev, FNAL)

May 6, 2008

Related work: e-lens simulation study at RHIC – Y. Luo

Stability of single particle motion
with head-on beam-beam compensation in the RHIC

Y. Luo, W. Fischer and N. Abreu
Brookhaven National Laboratory, Upton, NY 11973, USA

To compensate the large tune shift and tune spread generated by the polarized proton run in the Relativistic Heavy Ion Collider (RH beam with a Gaussian transverse profiles to collide head-on with a weak-strong beam-beam interaction model, we investigate the s presence of head-on beam-beam compensation. Tune footprints, tu 10^6 turn dynamic apertures are calculated and compared between compensation. A tune scan is performed and the possibility of in The cause of tune footprint foldings is discussed, and the tune diffus compared.

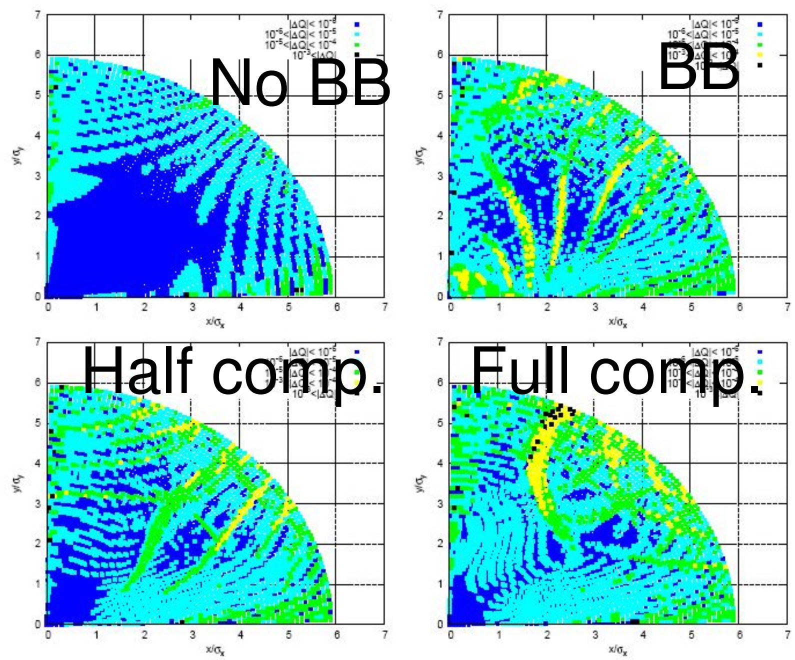

Figure 3: Tune diffusion maps of on-momentum particles for working point (28.685, 29.695): Top-left: without BB; Top-right: with BB; Bottom-left: with BB and half BB compensation; Bottom-right: with BB and full BB compensation.

Tentative beam-beam task for FY2009

RHIC wire experiments are winding down

Electron lens effort is ramping up

Plan to consolidate all 3 existing beam-beam tasks into one

Emphasis on electron lenses

Simulation support also shifting from RHIC wire experiments to electron lenses and crab cavities

Task: Crab cavities (R. Calaga, BNL)

Goal: design, construction and installation of a crab cavity in the LHC, and the evaluation of its potential for luminosity upgrades.

Crab cavities necessary for early separation scheme (D0)

800 MHz cavity under design ($\theta_c < 0.6$ mrad), could be built by AES/BNL with SBIR grant (no SBIR grant this year) – workshop CC'08

Study items

- Emittance growth from rf noise
- Collimation and machine protection

Aim for late 2009 workshop at CERN after which CERN commits to install a single prototype at IP4 (rf section) in 2013.

Task: Crab cavities (R. Calaga, BNL)

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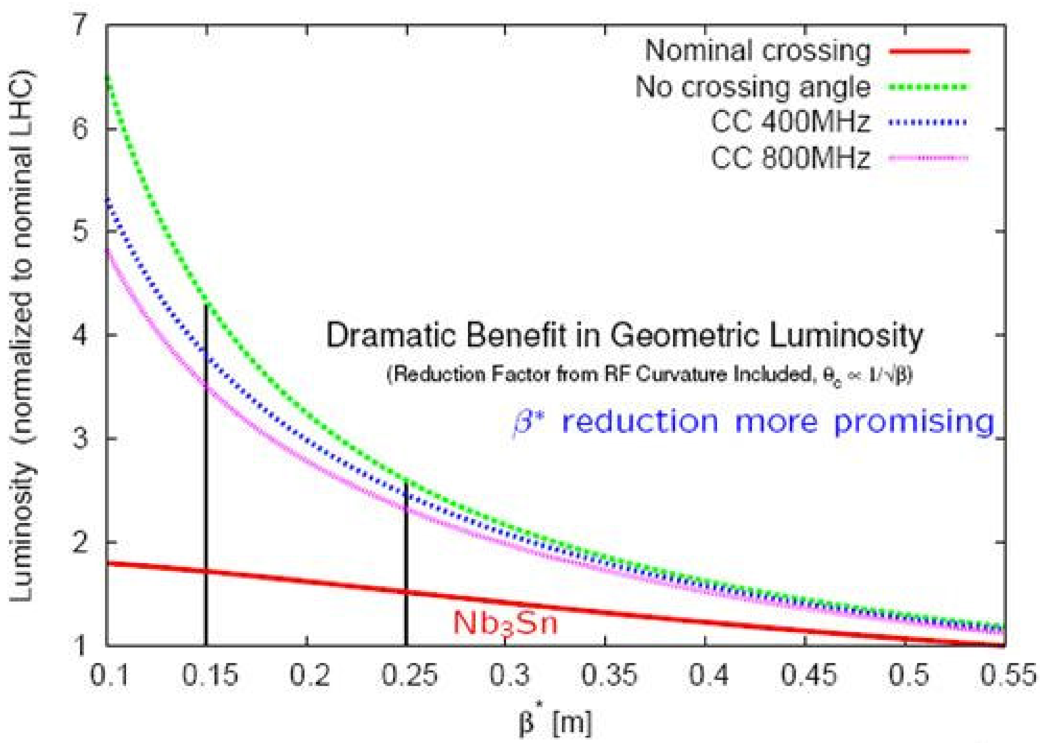
In upgrade version with D0 crab cavities increase luminosity, especially with small β^* (unlike KEKB no increase in beam-beam parameter targeted)

$$\theta_c \text{ Reduction Factor: } \frac{L}{L_c} \approx \left[1 + \left(\frac{\sigma_z}{\sigma_x^*}\tan(\theta_c/2)\right)^2\right]^{1/2}$$

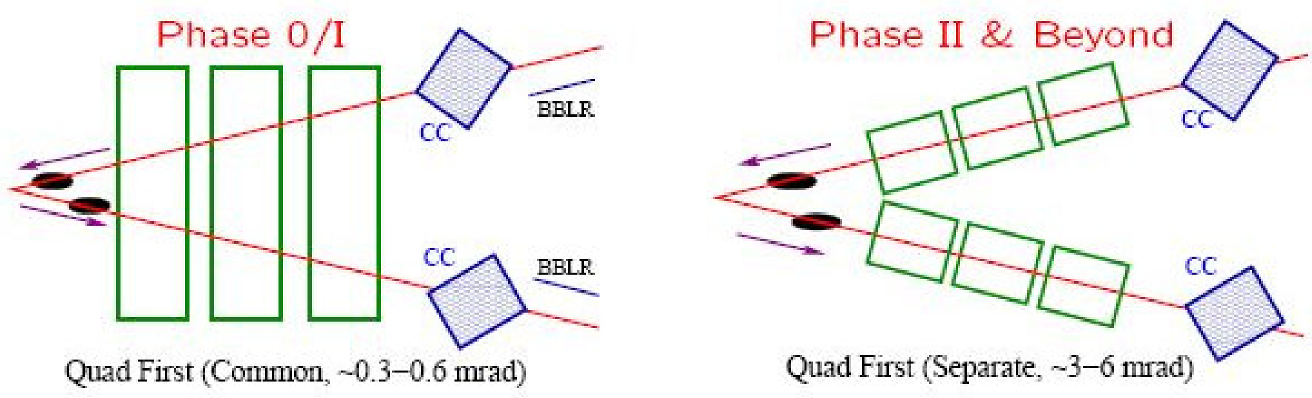


Larger θ_c: Alleviate Long range beam-beam, Simple IR design (Sep. Quads, NbTi) & machine tuning...

Task: Crab cavities (R. Calaga, BNL)

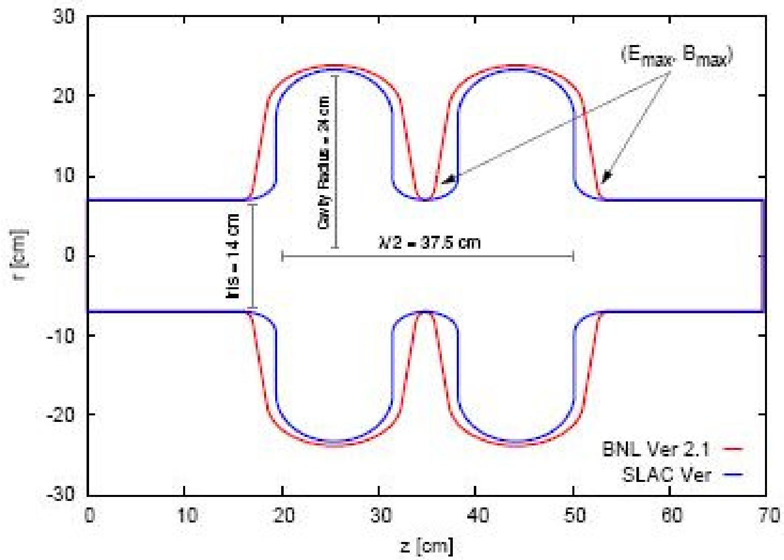
Phased test and upgrade plan

- Phase 0 (Nominal LHC):
  - One crab structure/beam (global cavities @IP4, circa 2010-11)
  - Test SRF limits in deflecting mode & beam testing in LHC
- Phase I (Minimal β^* IR Upgrade, circa 2012-13)
  - New IR optics & magnet parameters to accommodate local cavities (800 MHz)
  - Only VV crossing scheme possible, else compact concepts
- Phase II (Complete IR Redesign, circa 2016 or beyond)
  - Larger transverse beam separation (>30cm) envisioned
  - Compact cavities available ? Perhaps separate quad channels ?



Task: Crab cavities (R. Calaga, BNL)

Cavity design status



Need approx 2-3 MV (2 cell cavity)

Parameter	Crab Cavity	
	BNL v2.1	SLAC
Frequency [MHz]	800	800
Iris Radius, R_{iris} [cm]	7.0	7.0
Wall Angle, α [deg]	6.0	0.0
Eq. Ellipse, $R = \frac{B}{A}$	0.8	1.0
Iris Ellipse, $r = \frac{b}{a}$	2.0	0.8
Cav. wall to iris, d [cm]	0.8	3.375
$\frac{1}{2}$ Cell, $L = \frac{\lambda\beta}{4}[cm]$	18.75	18.75
Eq. Height, D [cm]	23.8	23.3
Cavity Beta, $\beta = v/c$	1.0	1.0

- Two semi-optimized designs already exist
- Fine tuning to reduce peak surface fields ($\sim$ 2 months)

$$B_{pk} < 120 \text{ mT}, \; E_{pk} < 40 \text{ MV/m}$$

- All geometries (mafia files) available on tWiki
- Dedicated meeting to review final design

Tentative Accelerator Physics Tasks in FY2009

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1. Electron cloud studies – M. Pivi (SLAC)
   - SPS instability feedback design
   - Simulations
   - Grooved chambers in SPS
2. Beam-beam – ?
   - Electron lenses
   - Simulations
   - Wire compensation
3. Crab cavities – R. Calaga (BNL)
   - Cavity and cryostat design
   - Couplers and tuners
   - Simulations
4. CERN PS2 studies – U. Wienands (SLAC)
   - With participation of BNL, LBL, FNAL, SLAC

New Task: CERN PS2 studies (U. Wienands, SLAC)

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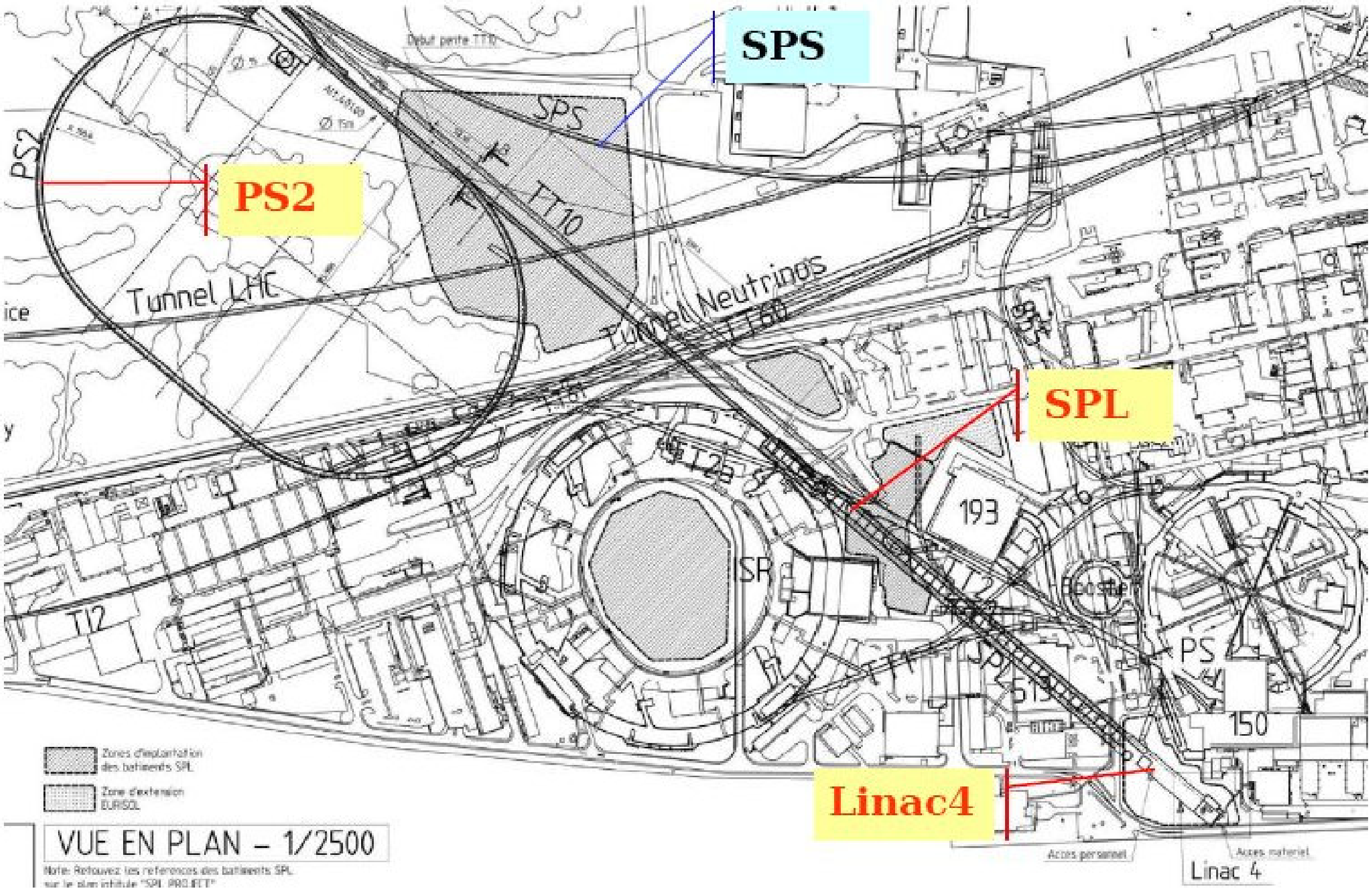
Goal: Support the design of the PS2 (replacement machine for the PS).



Design of PS2 approved by CERN Council in June 2007.

New Task: CERN PS2 studies (U. Wienands, SLAC)

Scope and budget are under discussion

Synergies with the FNAL MI upgrade

Interest from all 4 LARP labs

Involvement of one Toohig Fellow (R. DeMaria)

Critical issue is loss control (1W/m – FODO lattice vs. imaginary γ_t)

3 possible packages

1. Tracking, nonlinearities, space charge, halos, H^- injection
2. Intensity effects, instabilities
3. RF system

LARP could make a visible contribution.

Summary – LARP Accelerator Physics

Two themes:

1. Consolidation of existing tasks:

   Electron cloud task

   new focus on SPS instability, supporting instability feedback design, chamber R&D and simulations

   Beam-beam task

   all beam-beam work in one task (so far 3), new focus on e-lenses

2. New or significantly larger tasks:

   Crab cavities, supporting design of cavity

   CERN PS2, design studies, scope and budget under discussion