PEP-II Status and Future Plans

John T. Seeman

For the PEP-II Team

KEK Visit

February 2004

Thanks

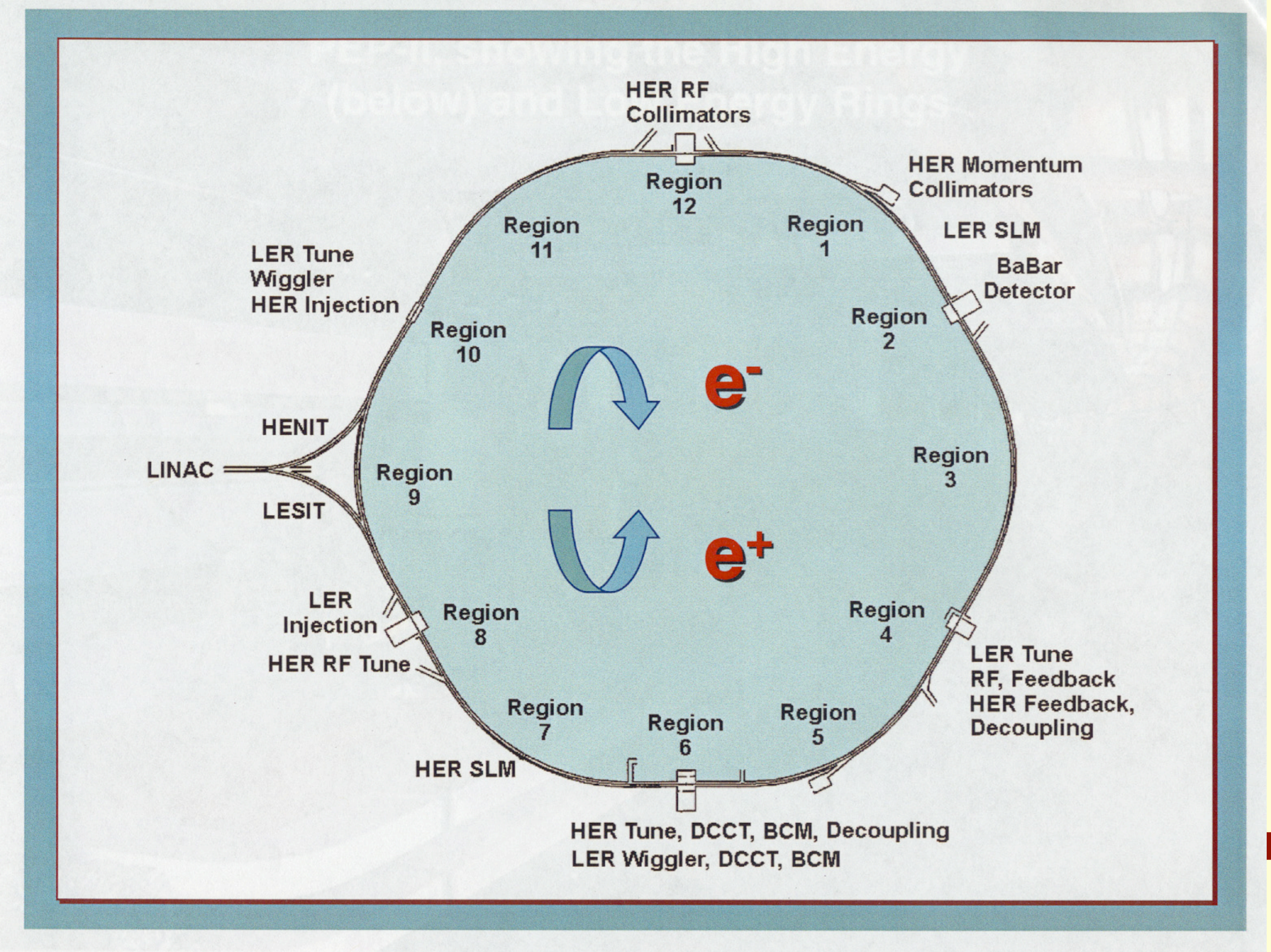
- Many people helped with the results here:
  - A few of them: M. Sullivan, U. Wienands,
  - S. Novokhatski, S. Heifets, S. Ecklund, A. Fisher,
  - Y. Cai, Y. Nosochkov, D. Hitlin, A. J. S. Smith,
  - J. Fox, D. Teytelman, Y. Yan
  - and the PEP-II team

Topics

- PEP-II status
- PEP-II near future plans (next 5 years)
- Study plans for a Higher luminosity B-Factory
- Conclusions

PEP-II e^+e^- Collider

-



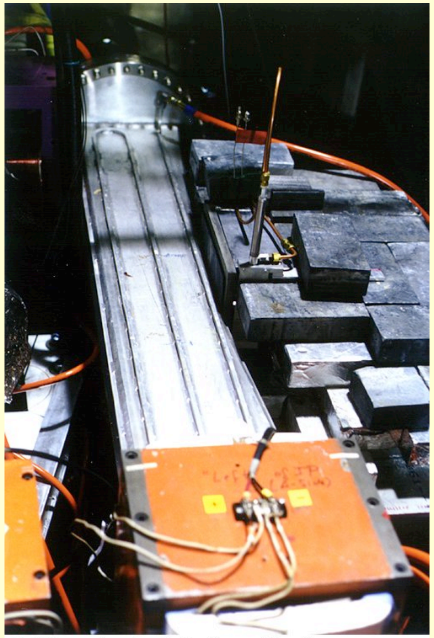
The PEP-II e^+e^- asymmetric collider

Fast Luminosity Monitor

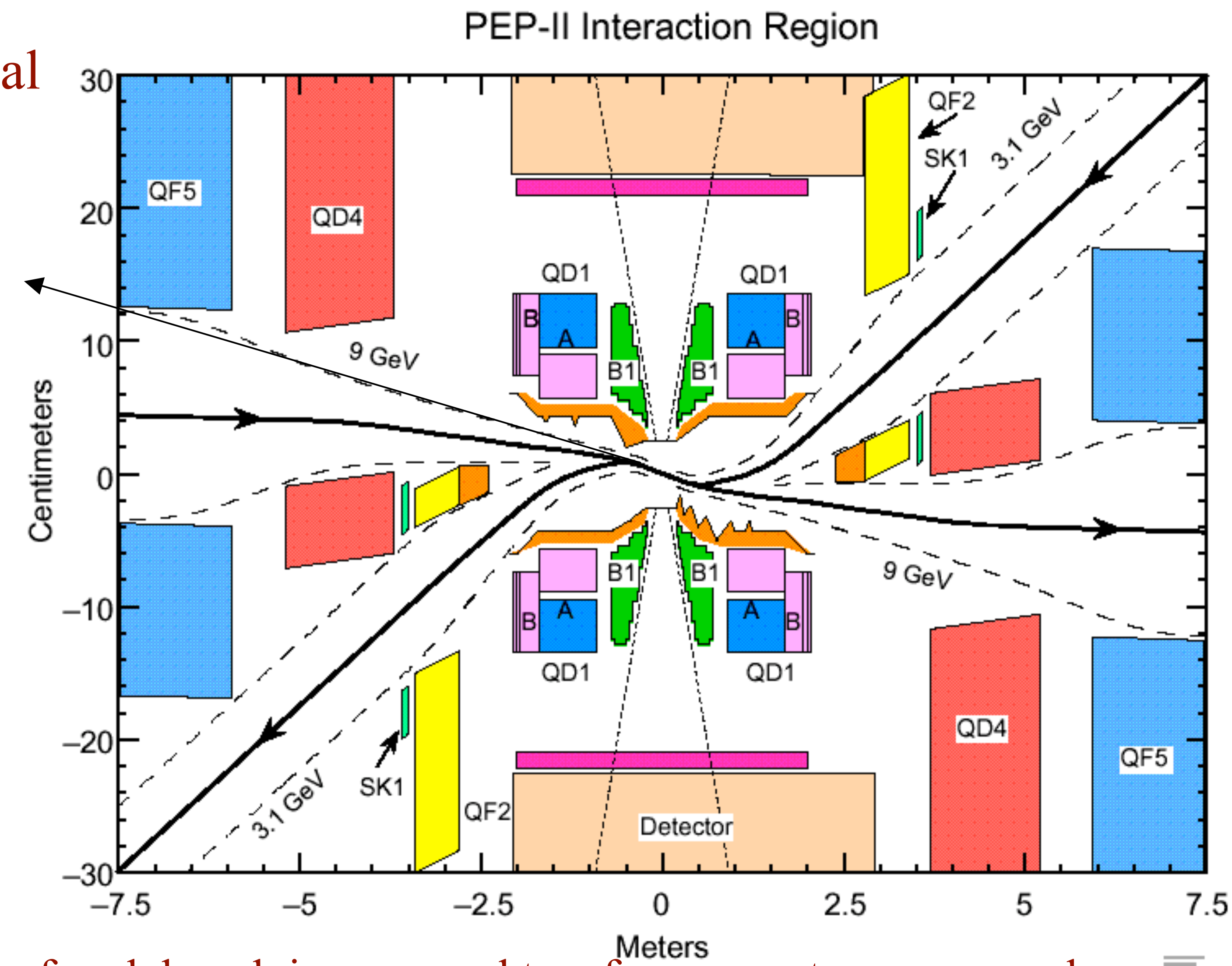
Luminosity signal

$e^+e^- \rightarrow e^+e^-\gamma$

γ



JS_140 Luminosity Monitor and Chamber 10/26/98

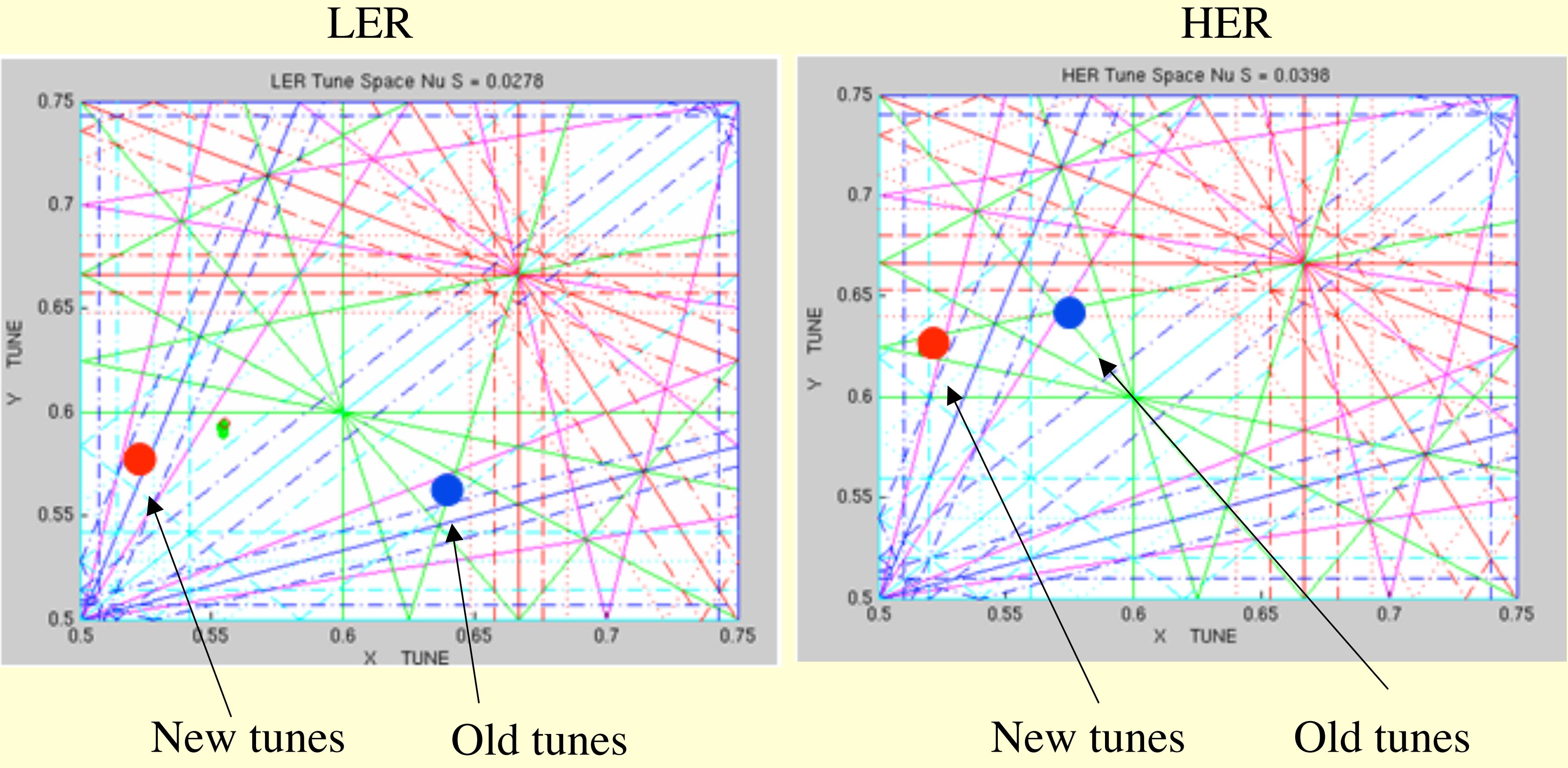


The luminosity of each bunch is measured to a few percent every second.

PEP-II Summer 2003 Projects

- New HER # 8 RF station (+200 mA).
- New HER collimator (30 m upstream).
- Improved low level RF feedback circuits (higher I).
- More x-y BPMs in IR2 region.
- LER straight section and Arc 11 solenoid upgrade.
- Octupoles for tune shift with amplitude studies.
- Bellows fans on all LER bellows (~240)
- IR4 HOM damper

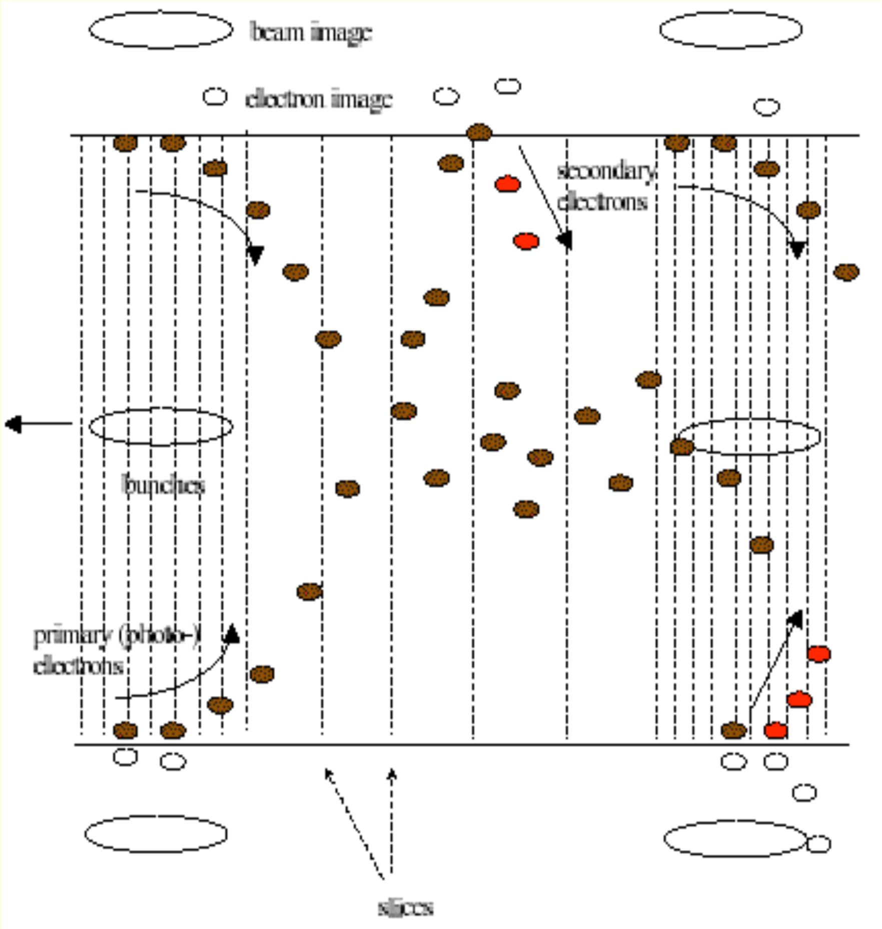
PEP-II Betatron Tune Locations

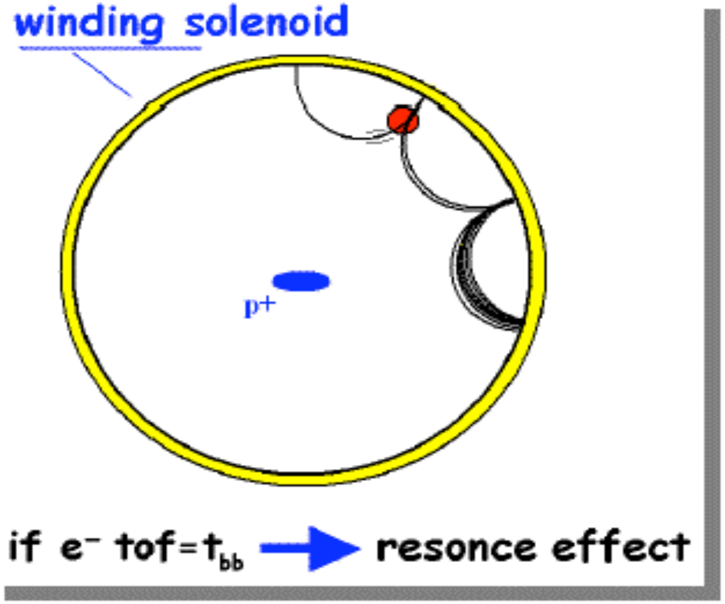


Fall –Winter 2003-2004 Improvements

- Number of bunches:
  - June 2003: 1030 bunches in the by-3 pattern.
  - February 2004: 1366 bunches in the by-2 pattern.
- HER and LER RF stations added to beam.
  - I^- to 1376 mA peak.
  - I^+ to 2430 mA peak.
- Trickle charging (Continuous injection)
  - All data now taken in trickle charge mode (LER only).
  - HER trickle studies are underway.
- HER beta-y*
  - Beta-y* lowered from 12 to 10 mm in January.

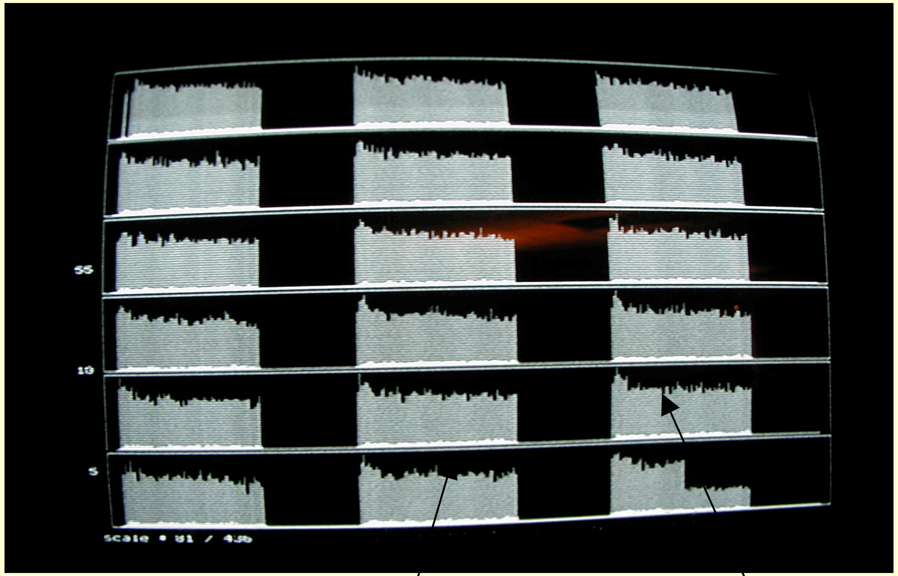
Electron Cloud Instability and Multipacting

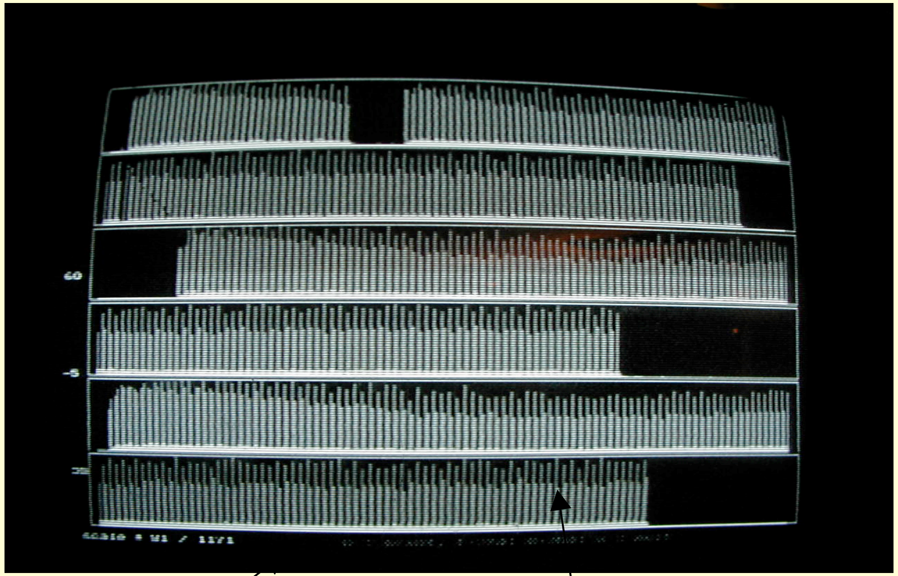




Resonance multipacting in solenoid field when the electron time of flight is equal to the bunch spacing

Observed effects of ECI in early PEP-II





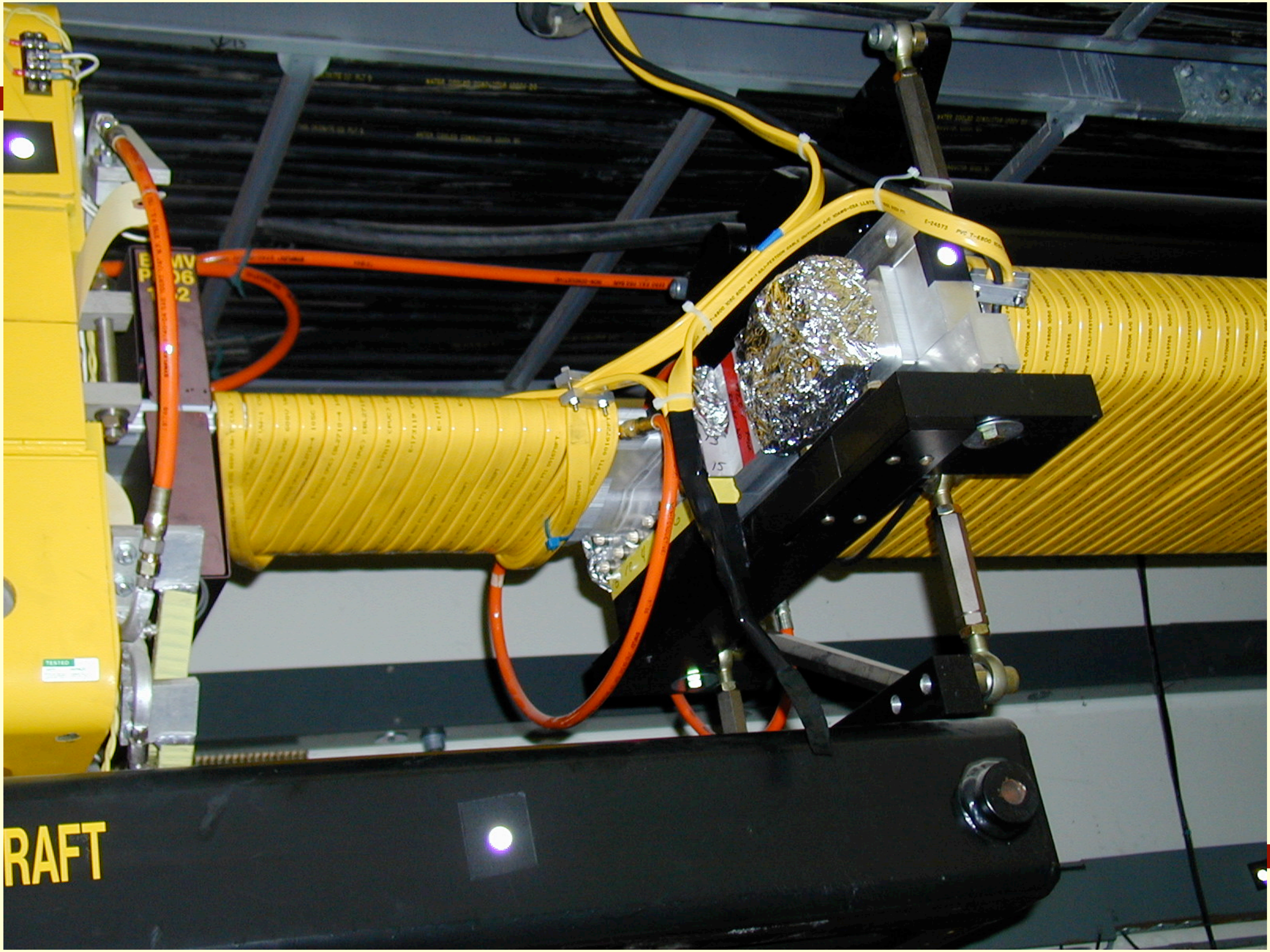
ECI effects increase along the bunch mini-train. Gaps reduce the electron density.

Luminosity along the bunch train

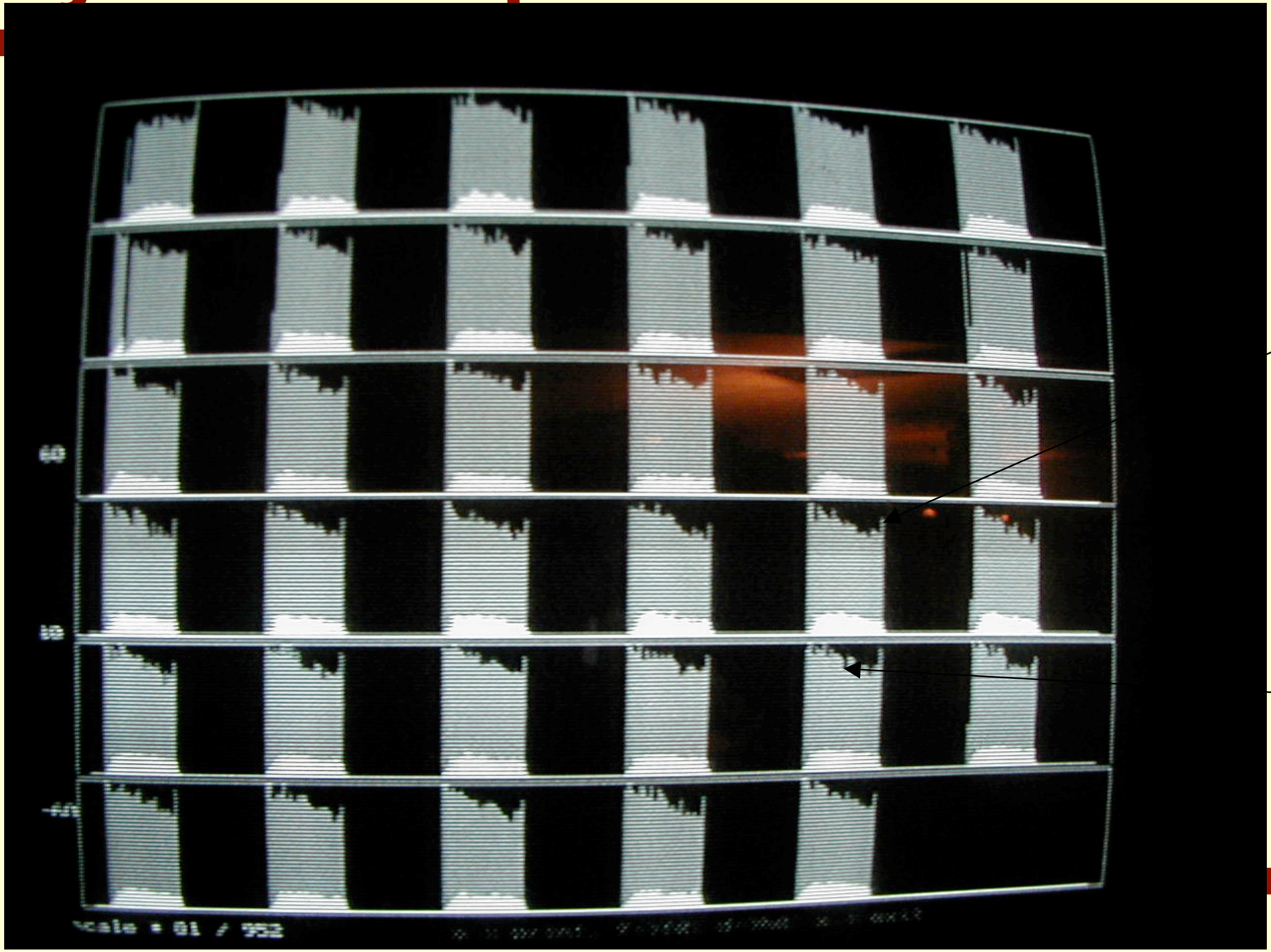
Every second bunch is affected by ECI!

50 Gauss solenoid section

“No sextupole” and arc chambers



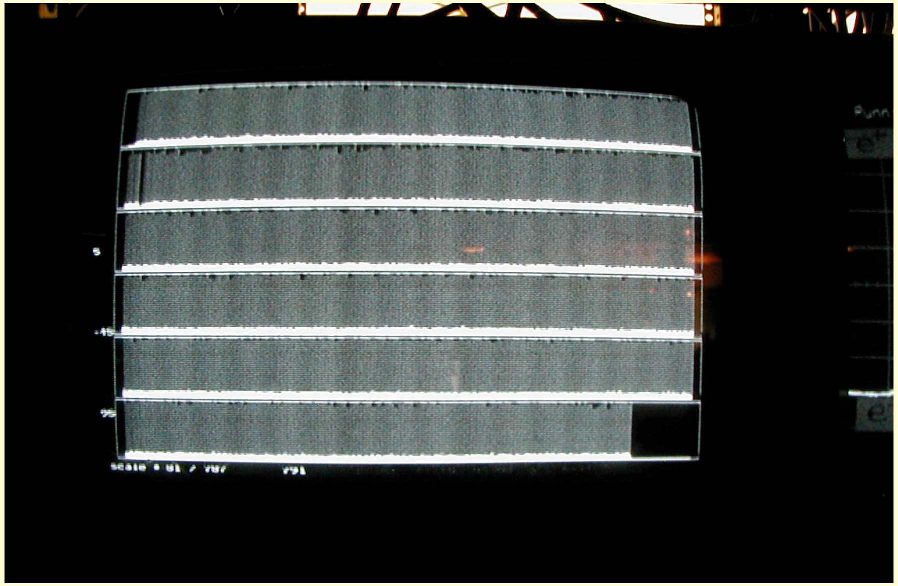
By-2 bunch pattern in October



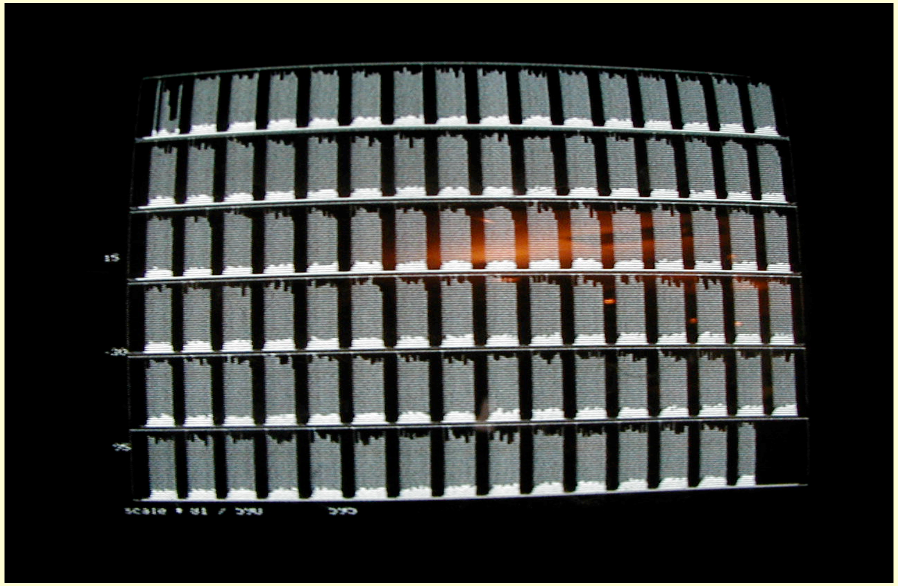
Parasitic collision effect

ECI, HOMs, ????

Solenoid fields have reduced the ECI effect

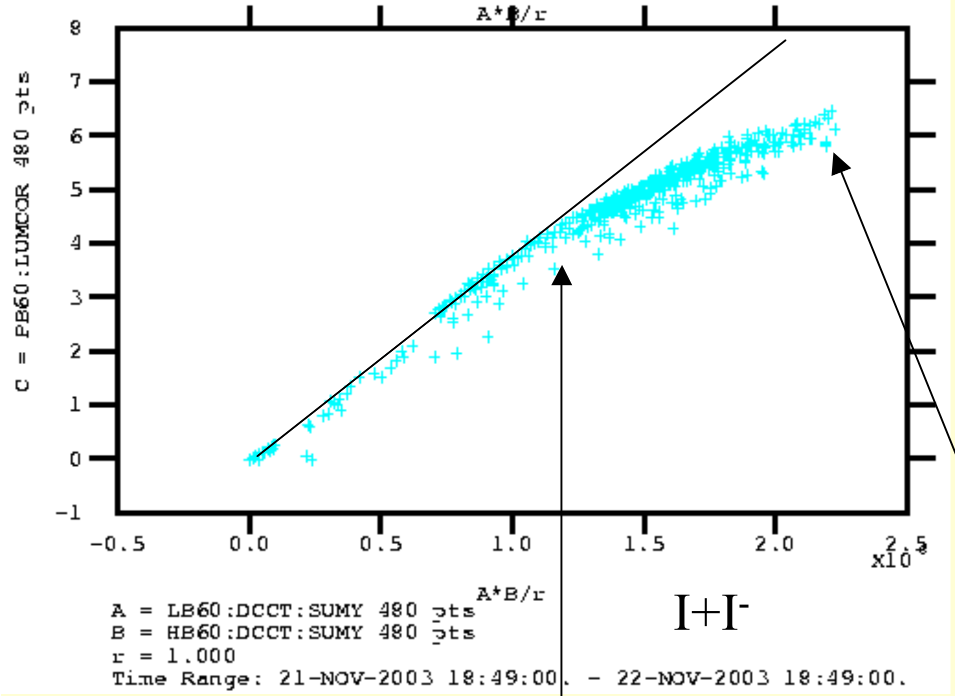


Fall 2003: by-3 bunch pattern (6 ns) shows very little ECI.

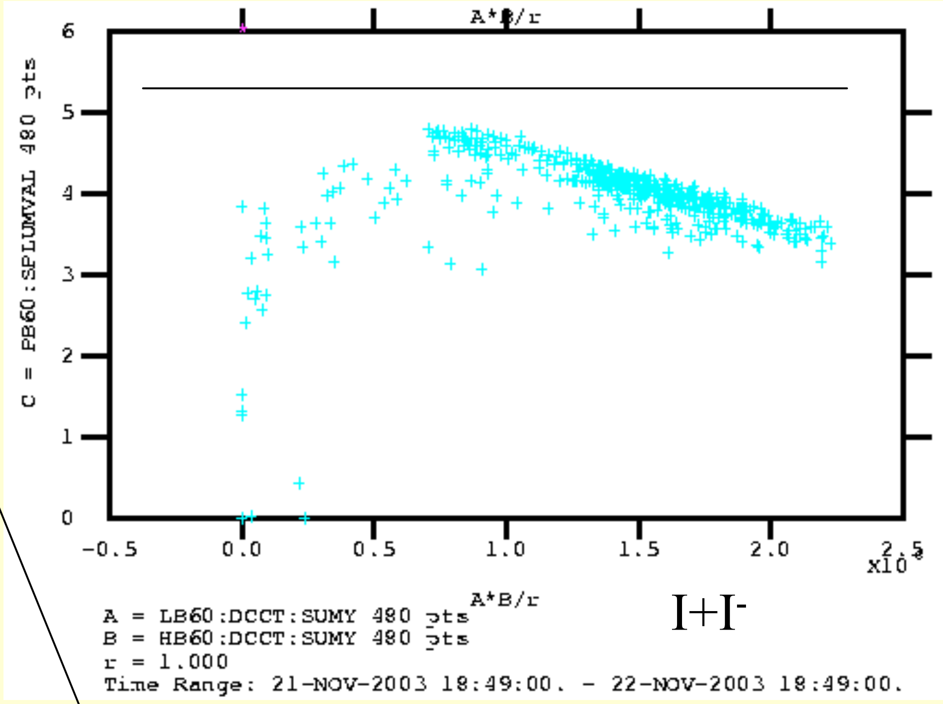


November 2003: by-2 pattern (4 ns) with short mini-trains show little ECI.

PEP-II operates in a beam-beam limited regime



Luminosity vs I^+I^-

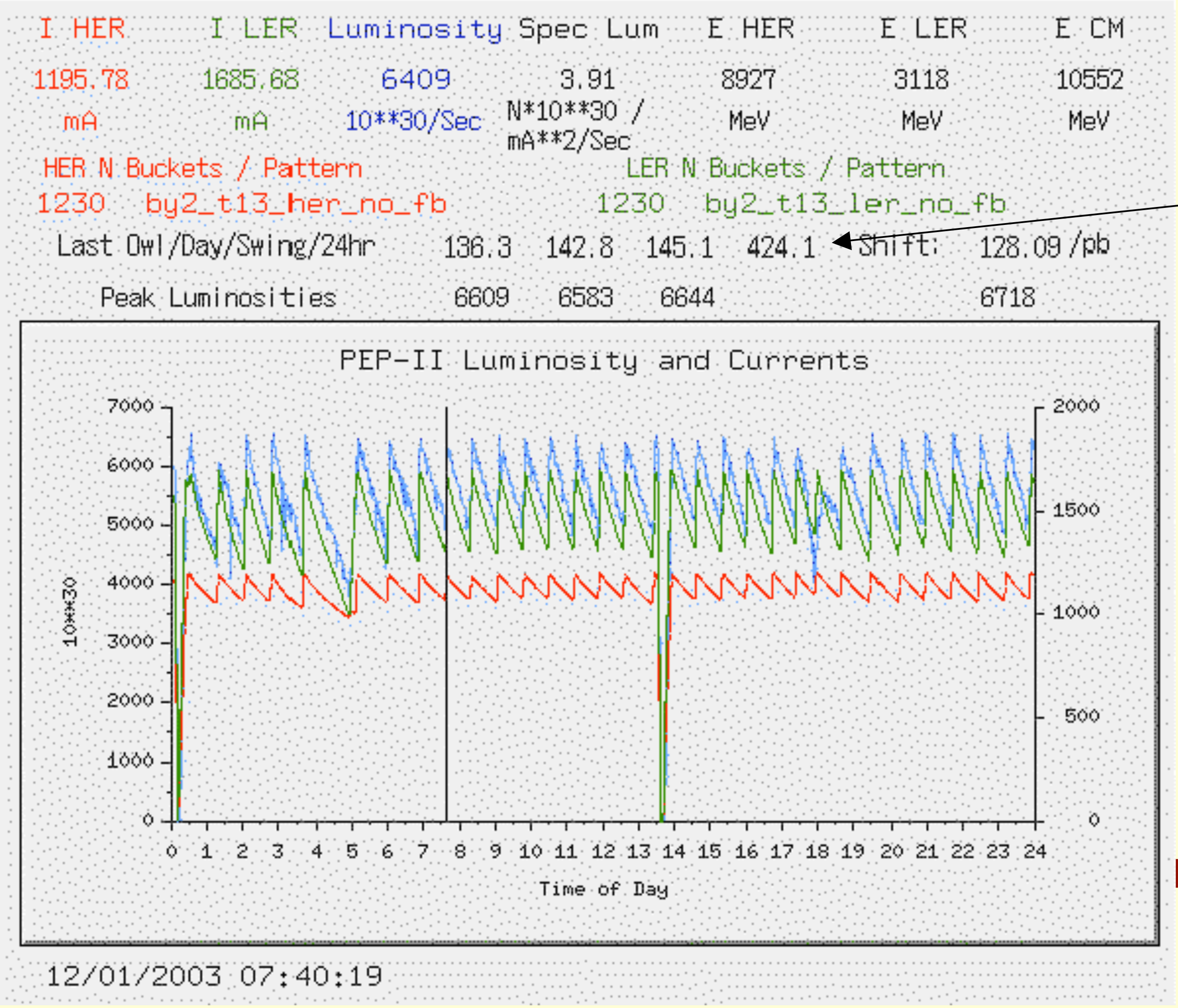


Specific Luminosity vs I+I$^-$

Beam-beam parameter limit

Background/lifetime limit

Best Day before Continuous Injection



I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1195.78	1685.68	6409	3.91	8927	3118	10552
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern
1230 by2_t13_her_no_fb

LER N Buckets / Pattern
1230 by2_t13_ler_no_fb

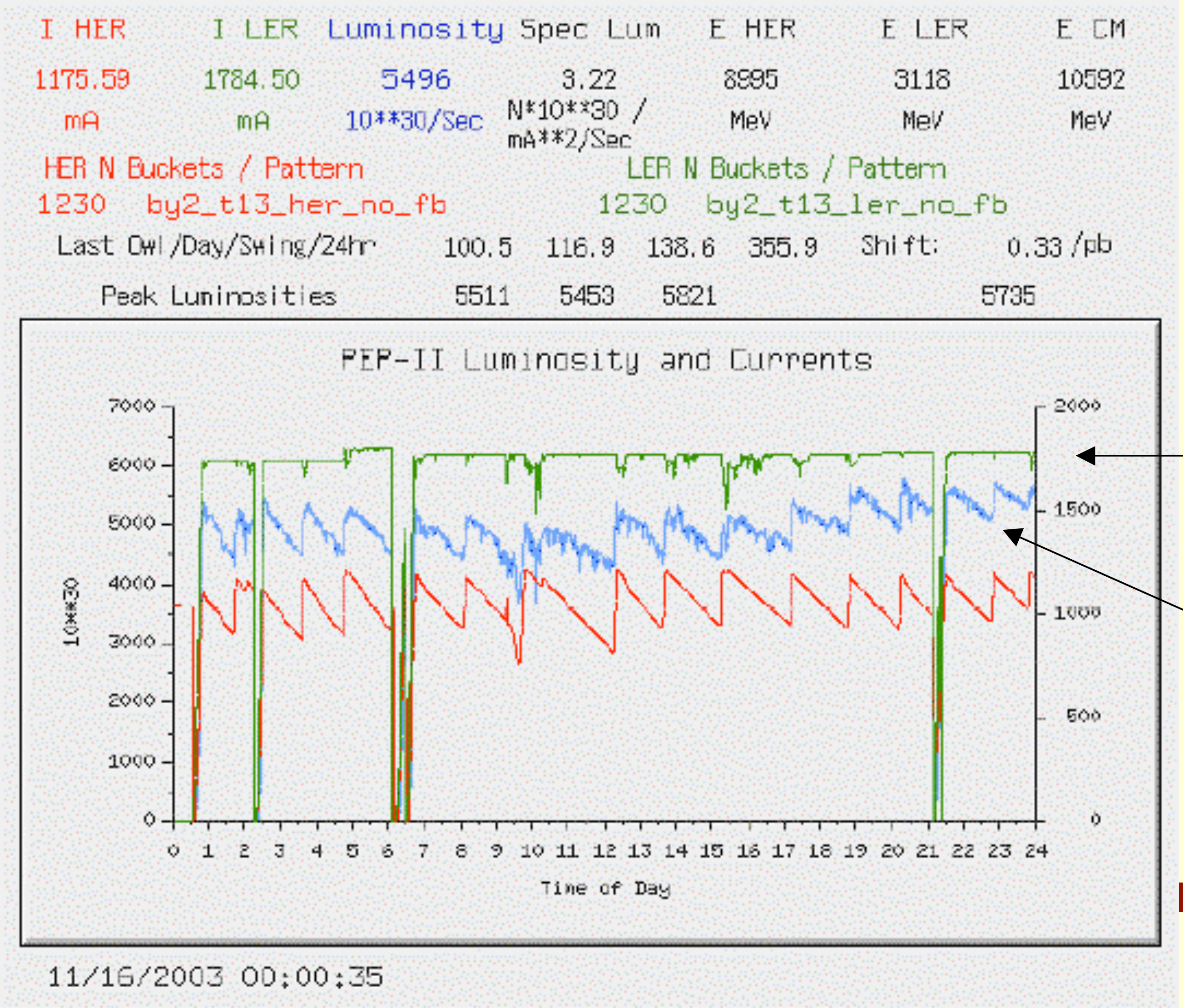
Last Owl/Day/Swing/24hr 136.3 142.8 145.1 424.1 Shift: 128.09 /pb

Peak Luminosities 6609 6583 6644 6718

12/01/2003 07:40:19

424/pb

Continuous injection of LER with BaBar running



I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1175.59	1784.50	5496	3.22	8995	3118	10592
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern LER N Buckets / Pattern

1230 by2_t13_her_no_fb 1230 by2_t13_ler_no_fb

Last Owl/Day/Swing/24hr 100.5 116.9 138.6 355.9 Shift: 0.33 /pb

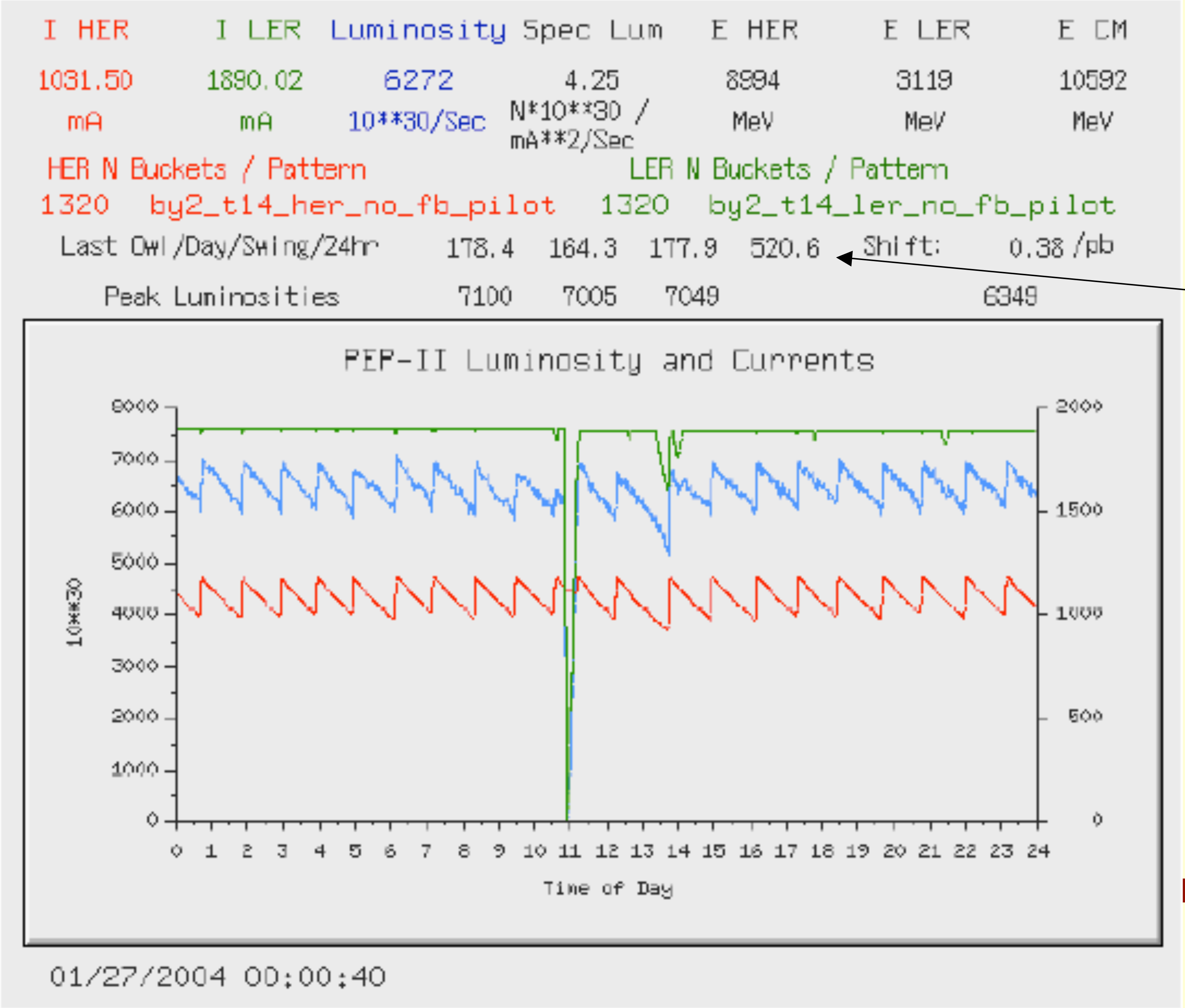
Peak Luminosities 5511 5453 5821 5735

11/16/2003 00:00:35

November 2003

Constant LER e^+ current

Luminosity is more constant



I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1031.50	1890.02	6272	4.25	8994	3119	10592
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern LER N Buckets / Pattern

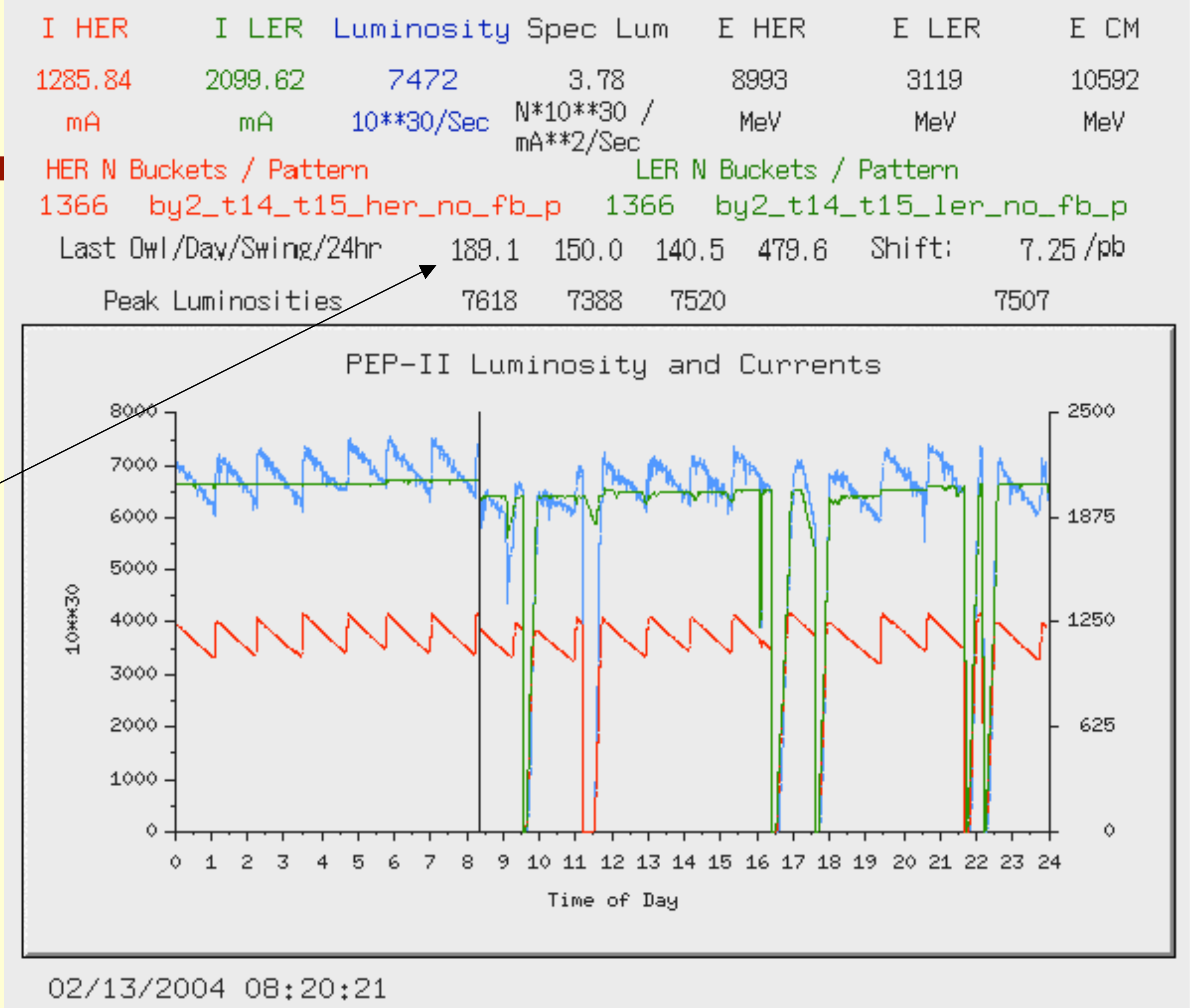
1320 by2_t14_her_no_fb_pilot 1320 by2_t14_ler_no_fb_pilot

Last Owl/Day/Swing/24hr 178.4 164.3 177.9 520.6 Shift: 0.38 /pb

Peak Luminosities 7100 7005 7049 6349

01/27/2004 00:00:40

Best day



I HER	I LER	Luminosity	Spec Lum	E HER	E LER	E CM
1285.84	2099.62	7472	3.78	8993	3119	10592
mA	mA	10**30/Sec	N*10**30 / mA**2/Sec	MeV	MeV	MeV

HER N Buckets / Pattern LER N Buckets / Pattern

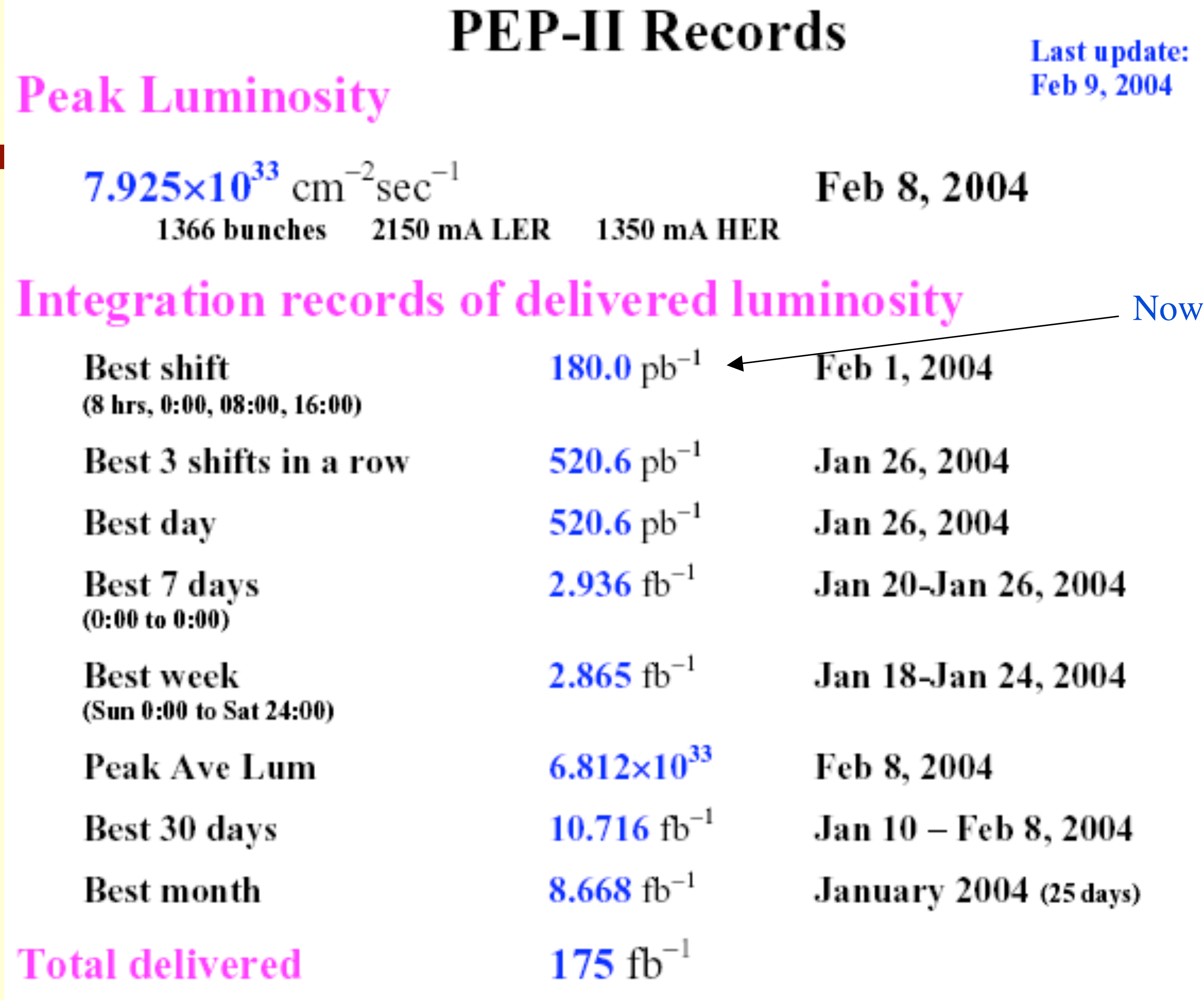
1366 by2_t14_t15_her_no_fb_p 1366 by2_t14_t15_ler_no_fb_p

Last Owl/Day/Swing/24hr 189.1 150.0 140.5 479.6 Shift: 7.25 /pb

Peak Luminosities 7618 7388 7520 7507

02/13/2004 08:20:21

New shift record



PEP-II Records

Last update: Feb 9, 2004

Peak Luminosity

7.925×10^{33} cm^{-2}sec^{-1} **Feb 8, 2004**

1366 bunches 2150 mA LER 1350 mA HER

Integration records of delivered luminosity

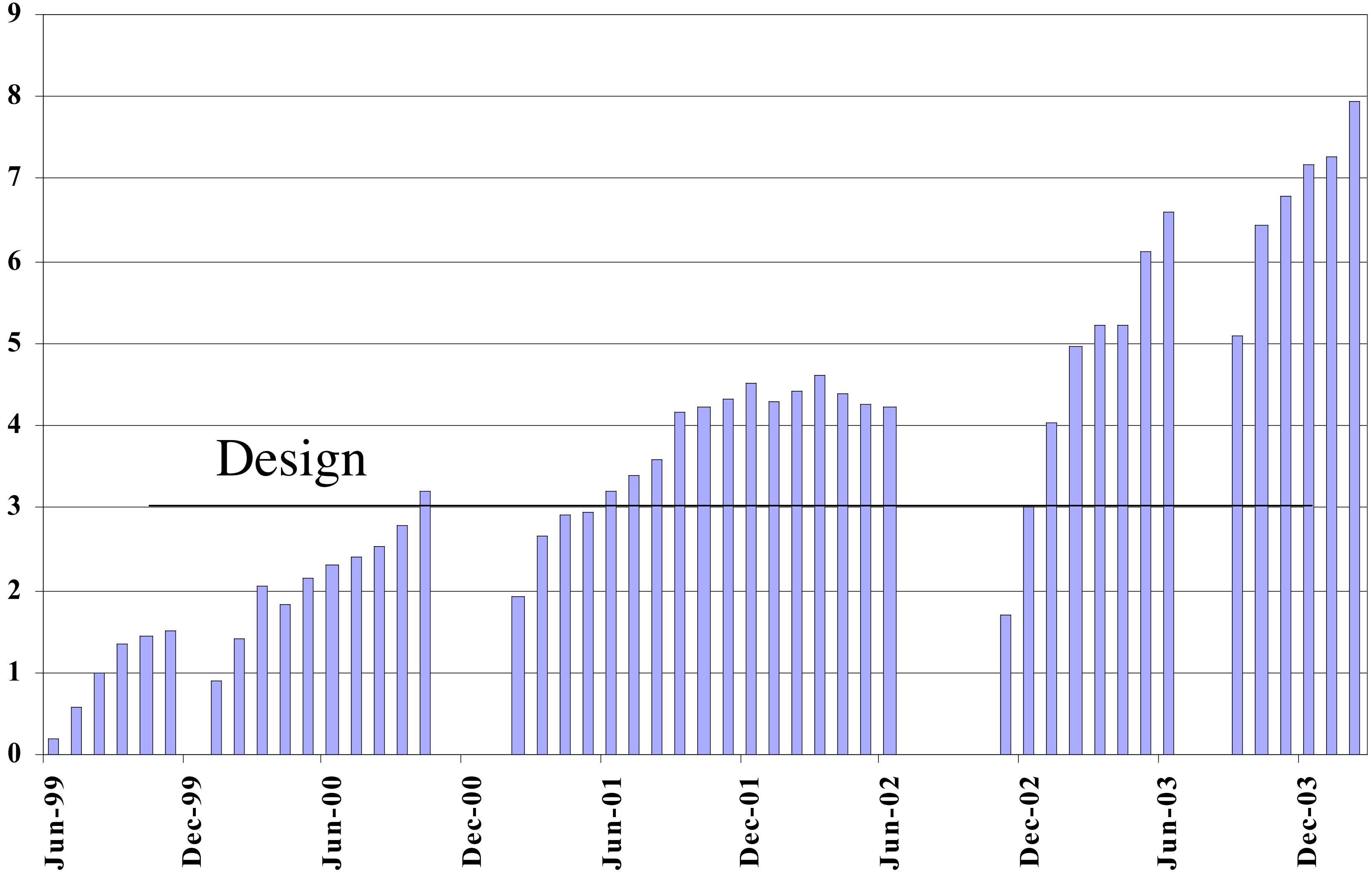
Best shift **(8 hrs, 0:00, 08:00, 16:00)**	180.0 pb^{-1}	**Feb 1, 2004**
Best 3 shifts in a row	520.6 pb^{-1}	**Jan 26, 2004**
Best day	520.6 pb^{-1}	**Jan 26, 2004**
Best 7 days **(0:00 to 0:00)**	2.936 fb^{-1}	**Jan 20-Jan 26, 2004**
Best week **(Sun 0:00 to Sat 24:00)**	2.865 fb^{-1}	**Jan 18-Jan 24, 2004**
Peak Ave Lum	6.812×10^{33}	**Feb 8, 2004**
Best 30 days	10.716 fb^{-1}	**Jan 10 – Feb 8, 2004**
Best month	8.668 fb^{-1}	**January 2004 (25 days)**

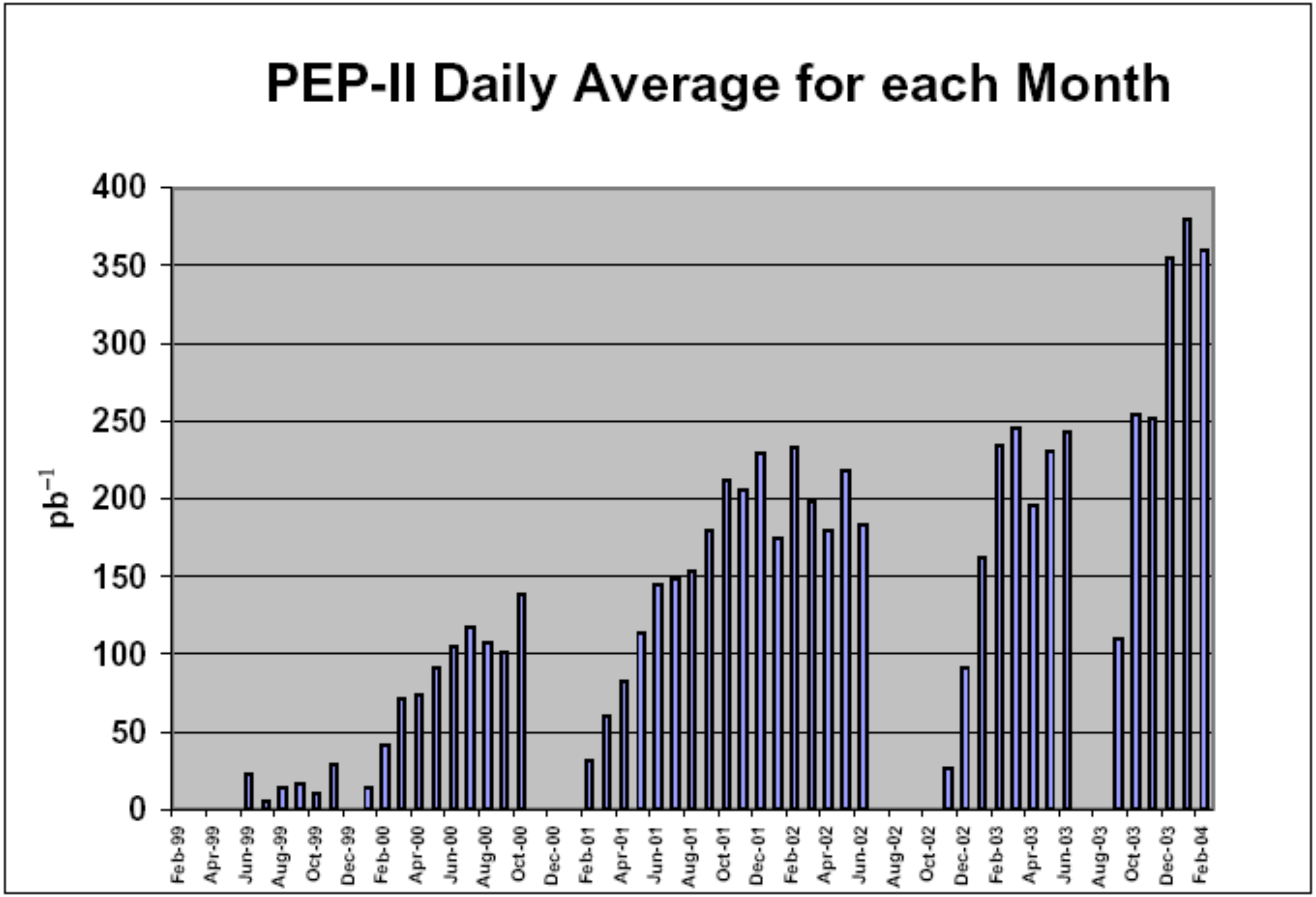
Now 189

Total delivered

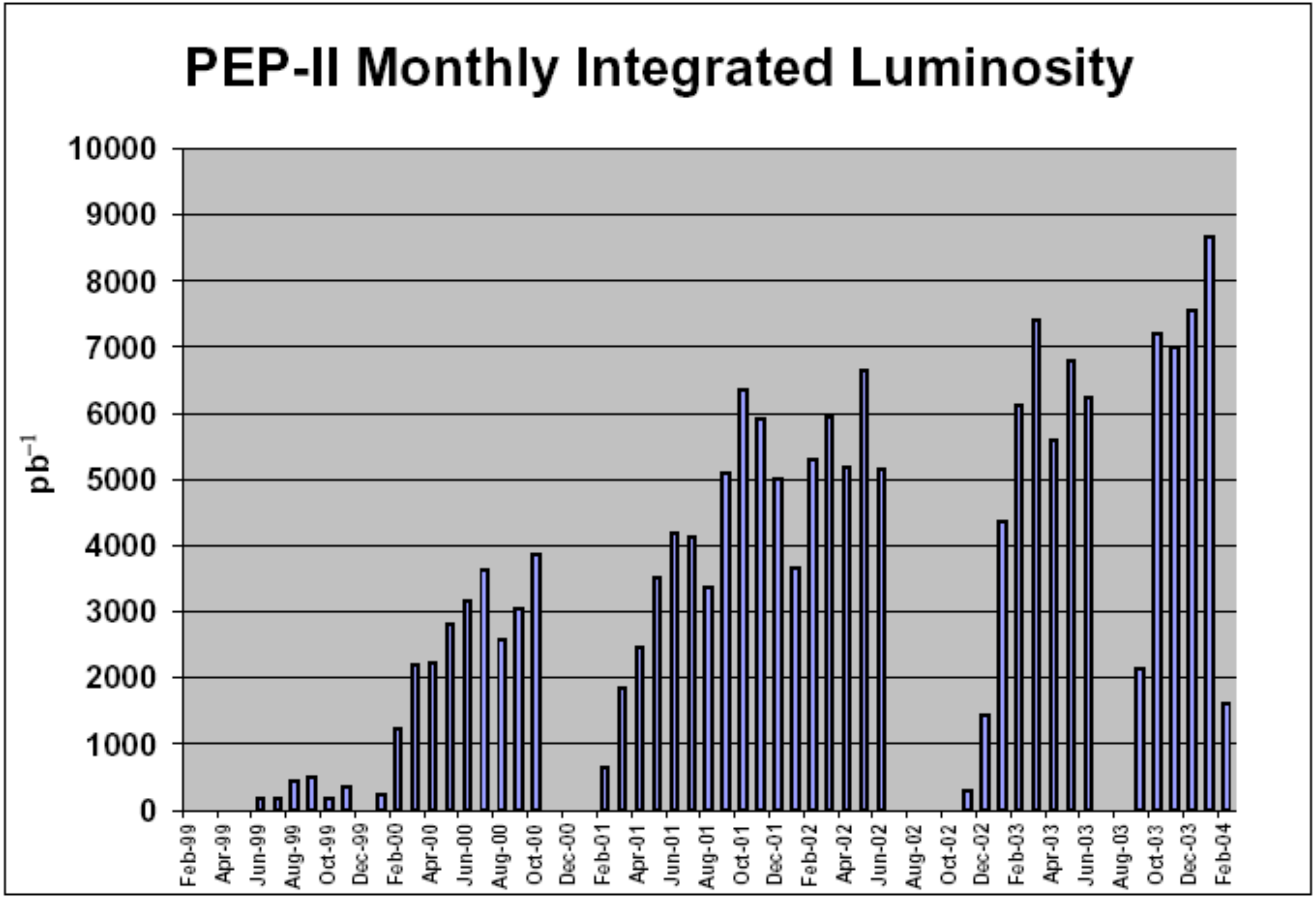
175 fb^{-1}

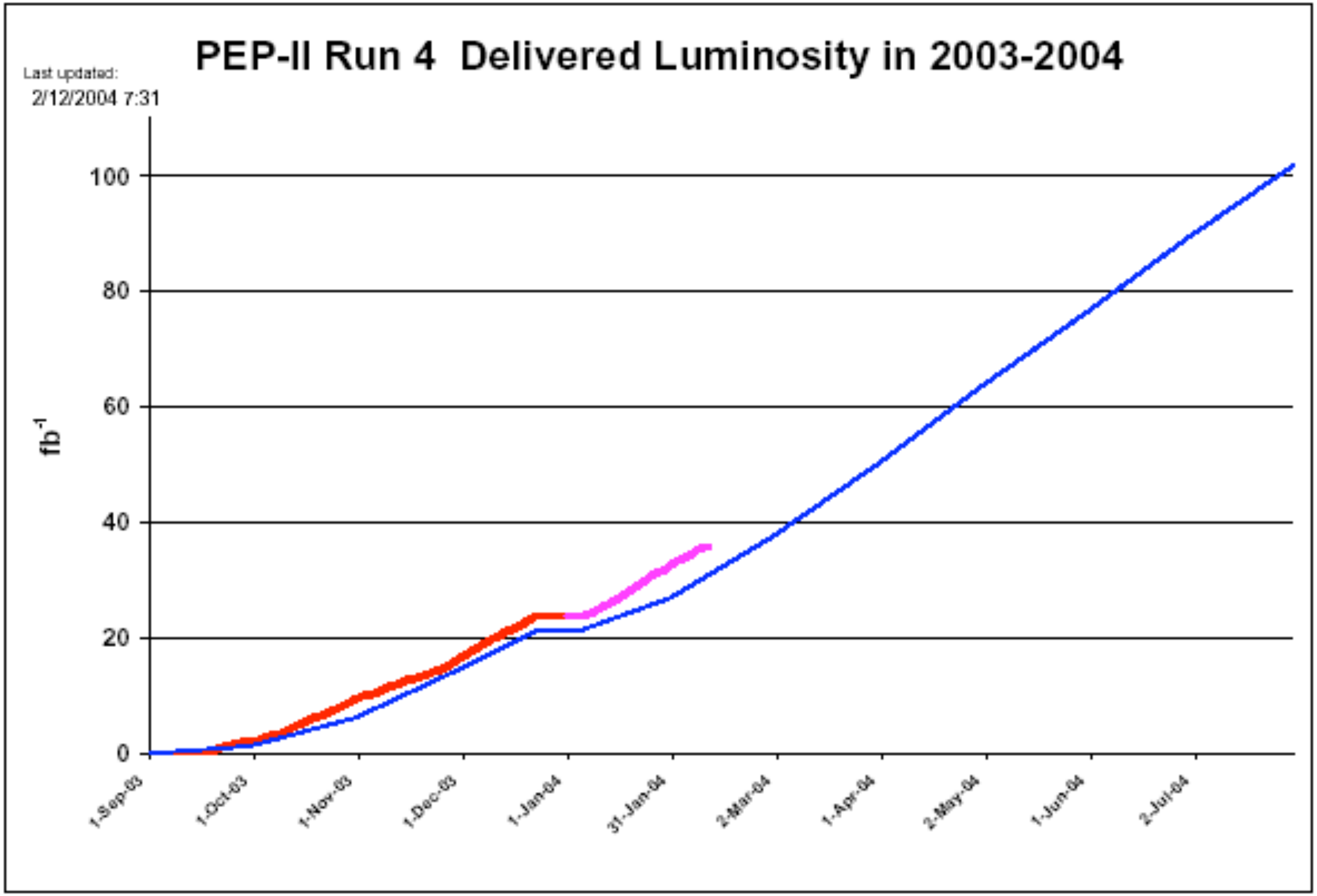
Peak PEP-II Luminosity (x1E33) per Month





PEP-II Daily Average for each Month


PEP-II Monthly Integrated Luminosity
pb^{-1}
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Feb-99
Apr-99
Jun-99
Aug-99
Oct-99
Dec-99
Feb-00
Apr-00
Jun-00
Aug-00
Oct-00
Dec-00
Feb-01
Apr-01
Jun-01
Aug-01
Oct-01
Dec-01
Feb-02
Apr-02
Jun-02
Aug-02
Oct-02
Dec-02
Feb-03
Apr-03
Jun-03
Aug-03
Oct-03
Dec-03
Feb-04



PEP-II Run 4 Delivered Luminosity in 2003-2004

Last updated:
2/12/2004 7:31

Beam aborts average about 5 per day

- 2.5 are RF related
  - 41% High power RF
  - 25% Low level RF
  - 14 % Longitudinal instability
  - 11% RF setup
  - 3% Transverse instability

- 1.5 BaBar radiation related
  - 33% SVT radiation
  - 33% Trapped dust in HER (manual abort)
  - 33% Injection backgrounds
- 1.0 Other sources
  - Power supplies
  - Vacuum temperature monitors
  - Personnel Protection System
  - Tune management

Overall Parameters and Goals

Parameter	Units	Design	Typical in collision	Best	Future in 2007
I+	mA	2140	2350	2430	4400
I-	mA	750	1350	1370	2000
Number bunches		1658	1366	1700	1700
β_y*	cm	15-20	11	10	7
ξ_y		0.03	0.04-0.08	0.09	0.11
Luminosity	x1E33	3.0	7.6	7.93	20-30
Integrated lumi / day	pb^{-1}	130	480	520	1200 to 1800

Four times design!

PEP-II Collision Parameters in the By-2 Pattern

IP Parameter	Design	Peak performance (Jun 03)
C-M energy (GeV) (e^+: 3.1 ; e^-: 9.0)	10.58	10.58
Crossing angle (mrad)	0.0	< 1.0
Luminosity (x $10^{33}/cm^2/s$)	3.00	7.93
Number of bunches	1658	1366
LER current (mA, e^+)	2146	2150
HER current (mA, e^-)	750	1350
LER/HER current ratio	2.9/1	1.6/1
β_y^*/β_x^* (cm/cm)	1.5 / 50	1.1 / 45, 1.0 / 25
Emittance (nm-rad) (y/x)	1.5 / 49	1.56 / 30+, 1.9 / 49-
IP rms beam size σ_y/σ_x (μm)	4.7 / 157	3.7 / 113
LER tunes (x/y)	38.64 / 36.57	38.512 / 36.57
HER tunes (x/y)	24.62 / 23.64	24.517 / 23.62
Beam-beam parameter (vertical +/-)	0.03	0.066 / 0.037
Beam-beam parameter (horizontal +/-)	0.03	0.083 / 0.038

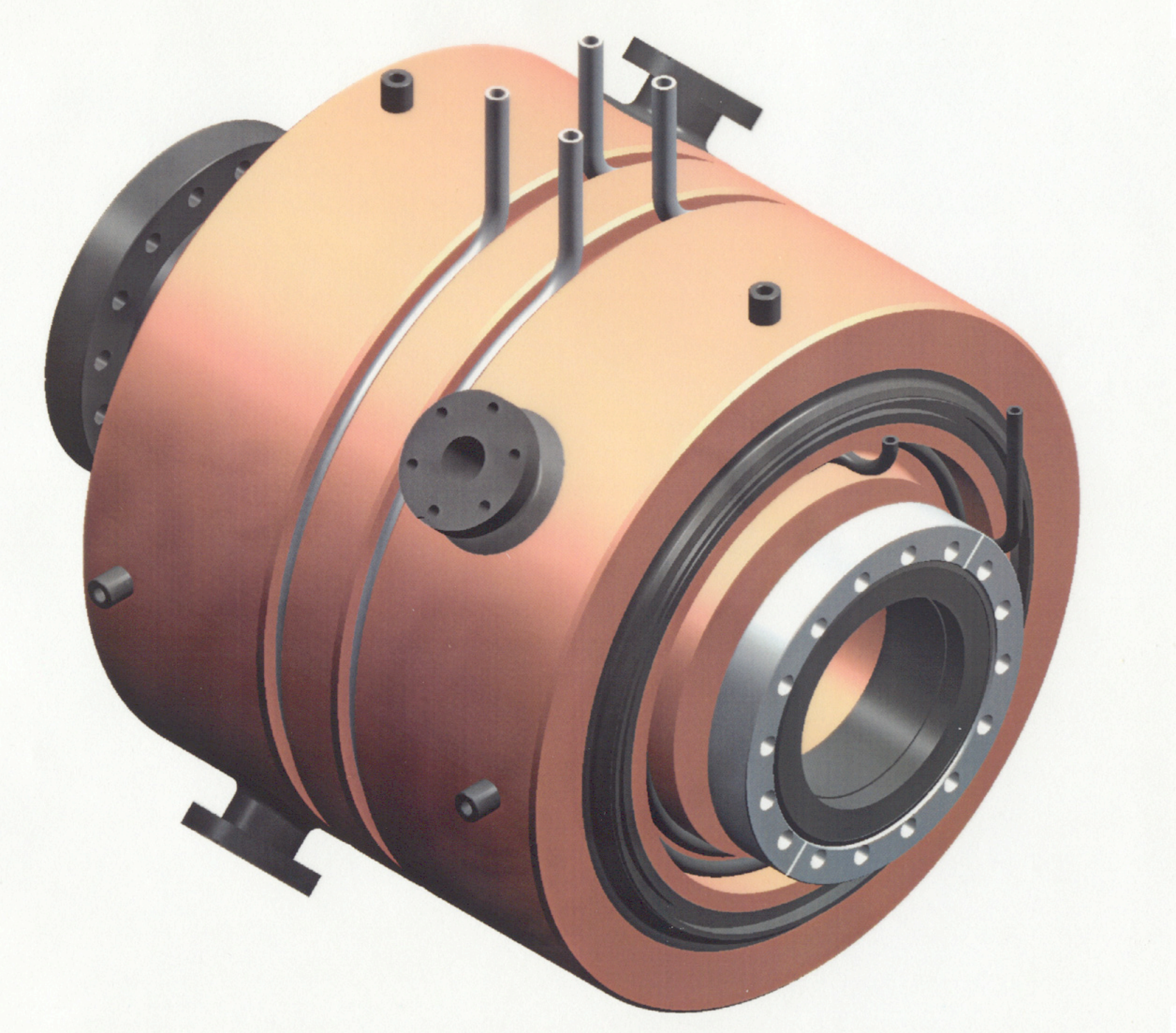
2003 improvements to come:

- Fix HER beta beat
- Lower LER β_y* from 12 to 10 mm
- Online model updates
- Power additional LER solenoids when needed
- Use HER/LER octupoles
- Raise beam currents (+20% available for both)
- Increase number of bunches (1366 → 1500)
- Improve optical corrections (dispersion …)

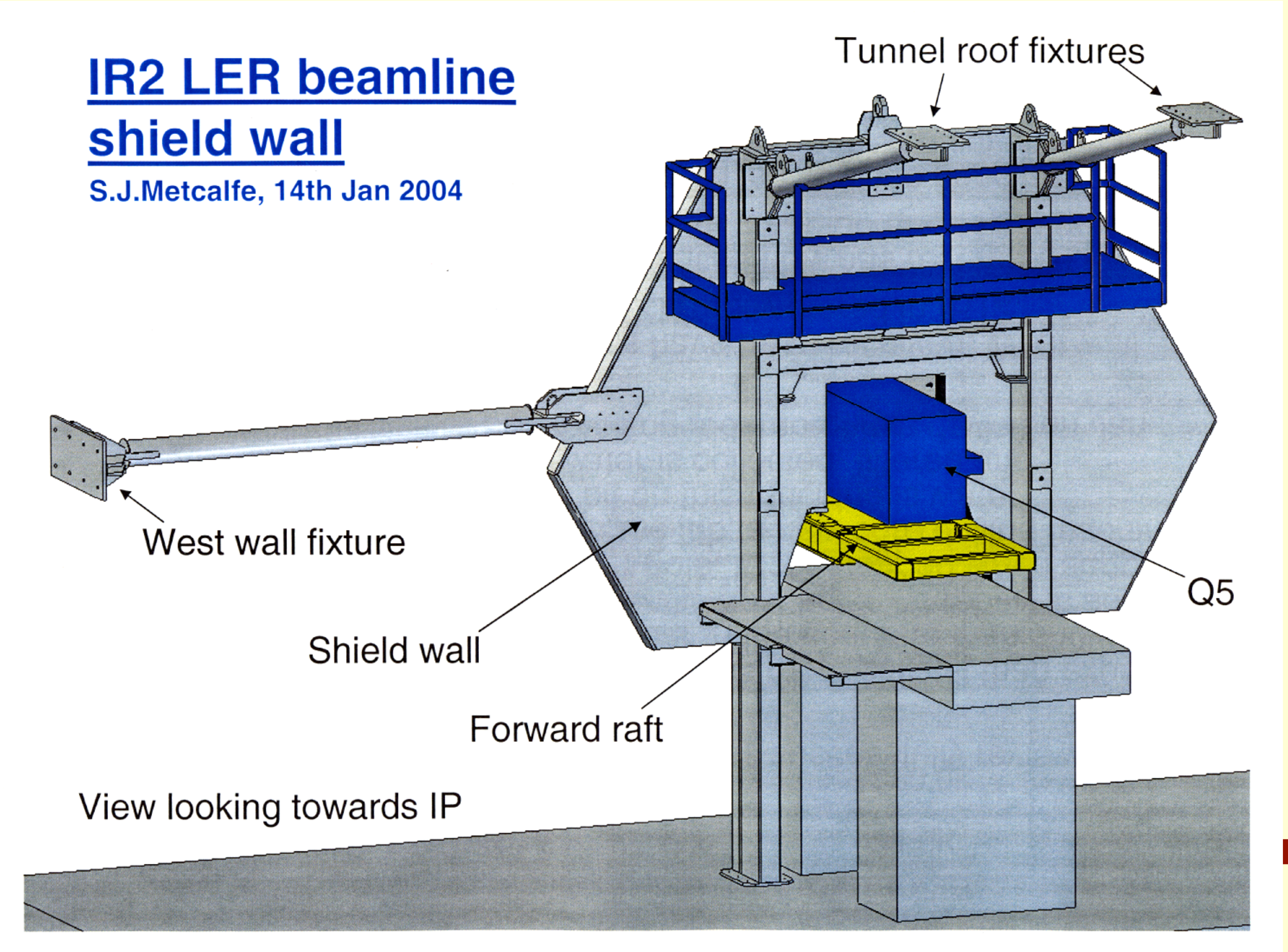
New transverse kicker electrodes

Old Longitudinal Kicker

New Longitudinal Feedback Kicker Assembly



New IR2 Shield Wall for BaBar IFR



IR2 LER beamline shield wall

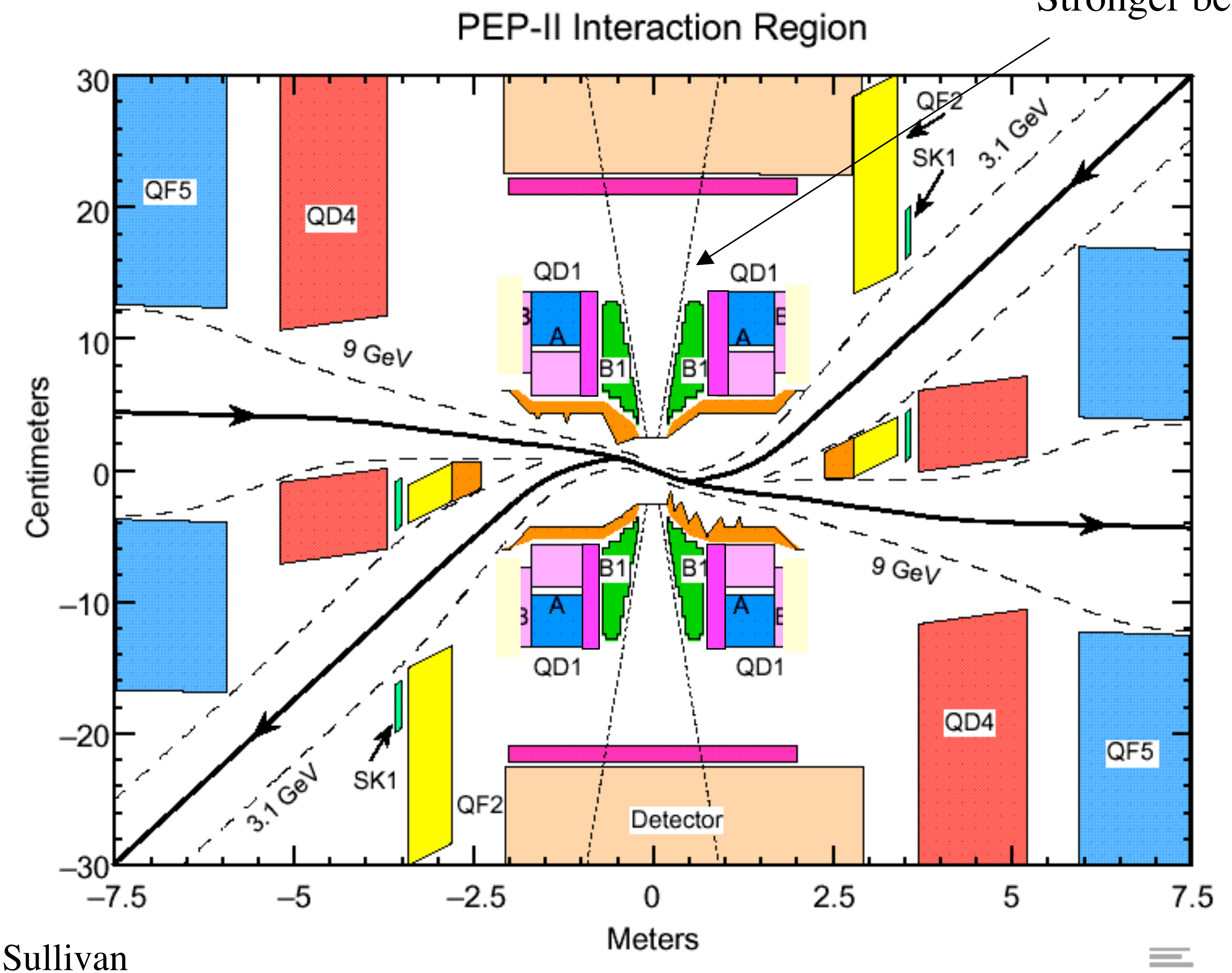
S.J.Metcalfe, 14th Jan 2004

PEP-II Beam Parameters Goals

- June 2003: 1.45A x 1.1 A β_y*=12 mm 1034 bunches L=6.6E33
- July 2004: 2.7A x 1.6 A β_y*=9 mm 1450 bunches L=10.1E33
- June 2005: 3.6A x 1.8 A β_y*=8.5 mm 1500 bunches L=18.2E33
- July 2006: 3.6A x 2.0 A β_y*=6.5 mm 1700 bunches L=23.0E33
- July 2007: 4.5A x 2.2 A β_y*=6 mm 1700 bunches L=33.E33

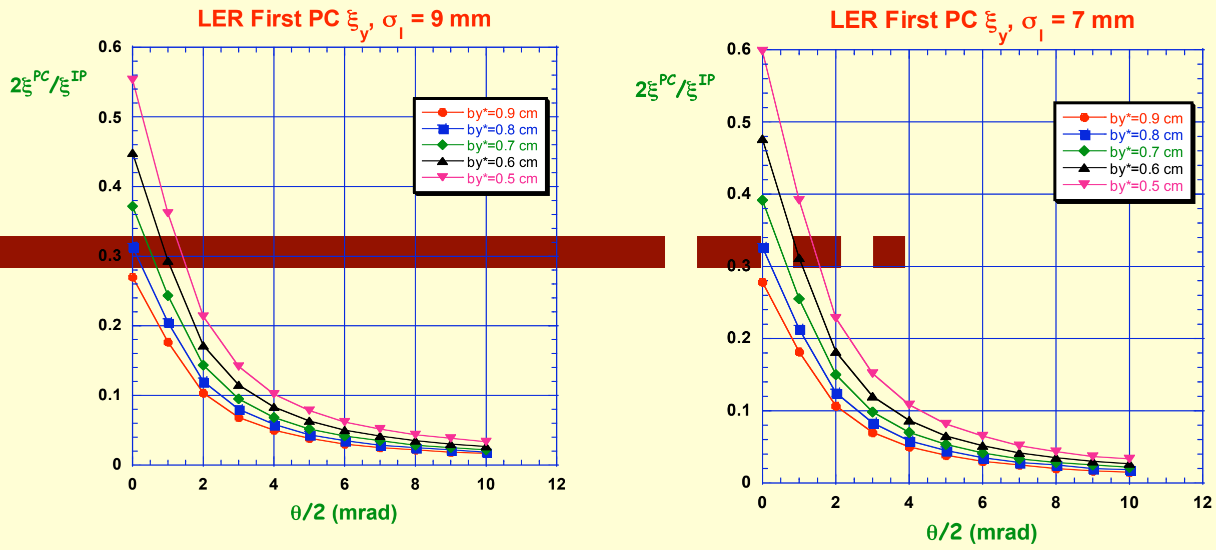
- With good integration reliability:
- 100 fb^{-1} more integrated by Summer 2004.
- 500 fb^{-1} total integrated by Fall 2006.
- About 1 to 1.4 ab^{-1} integrated by Fall 2009.

Modified Head-on design

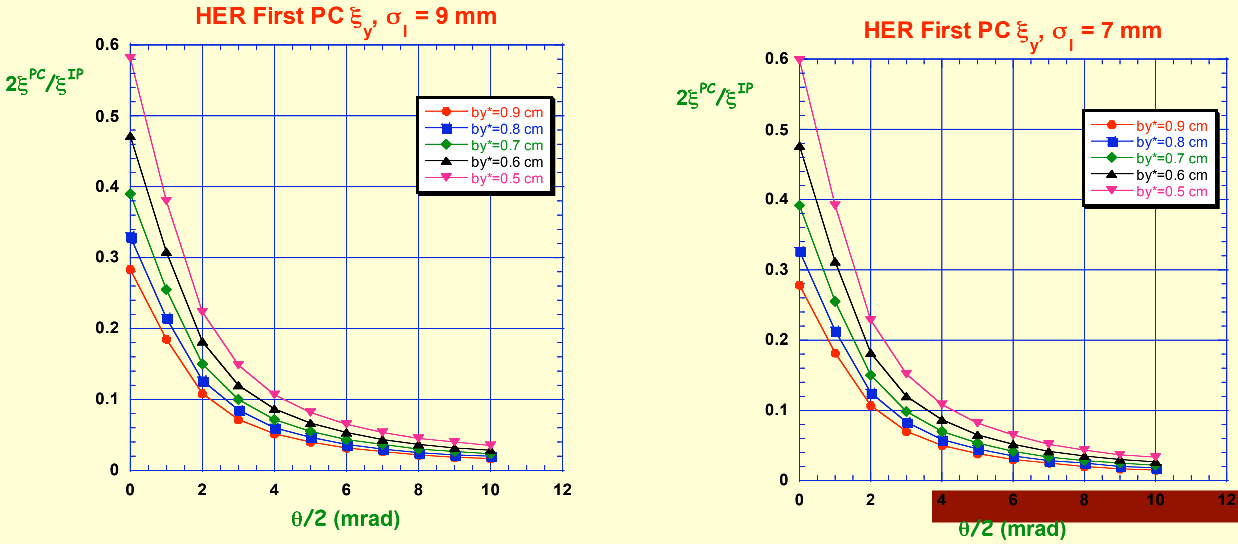


Stronger bends

Sullivan



LER PC tune shifts vs θ/2 for different β_y^* normalized to the IP tune shift for σ_l (bunch length) = 9 and 7 mm



HER PC tune shifts vs θ/2 for different β_y^* normalized to the IP tune shift for σ_l = 9 and 7 mm

The tune shift from the first parasitic crossing normalized to the main collision tune shift as a function of crossing angle and plotted for various β_y^* values for PEP-II (courtesy of Marica Biagini)

First parasitic crossing

		HER forward power
◆0 angle	3.217 mm	24.24 kW
◆Upgrade w/o energy chng	3.443 mm	
◆ +/- 0.25 mrad xing angle	3.532 mm	
◆Upgrade w enrgy chng	3.543 mm	26.08 kW
◆Stronger B1 (G slice=1.2)	3.662 mm	27.28 kW
◆Stronger B1 (H slice=1.2)	3.771 mm	28.80 kW
◆ +/- 0.5 mrad xing angle	3.847 mm	

Planning for the Far Future of PEP-II

- Finish near term upgrades (~2005-2006)
- Run until 2009
- Decide soon what far future PEP-II configuration to concentrate on.

Recent Activities for Far Future

- SLAC Scenarios Studies gave much attention to participation in a Super-B-Factory.
- "May" Particle Physics Workshop with High Luminosity e^+e^- Colliders in May 2003
- ICFA Beam Dynamics Workshop on High Luminosity Colliders October 2003
- "October" Particle Physics Workshop with High Luminosity e^+e^- Colliders in October 2003
- PEP-II-BaBar Roadmap Committee started.
- Hawaii Super-B Workshop in January 2004
- E-CLOUD Workshop (Napa) in April 2004

Luminosity Equation

- When vertical beam-beam parameter is limited.
- $\xi_y \sim 0.06$ in PEP-II and KEKB.
- To raise luminosity: lower β_y^*, raise I & ξ_y.

$$\xi_y^+ = \frac{r_0 N_b^- \beta_y^{*+}}{2\pi\gamma^+ \sigma_y^{*-} \sigma_x^{*-}} (flatbeams)$$

$$L = 2.17x10^{34} \frac{n\xi_y E I_b}{\beta_y^*}$$

Lessons learned from the present B-Factories

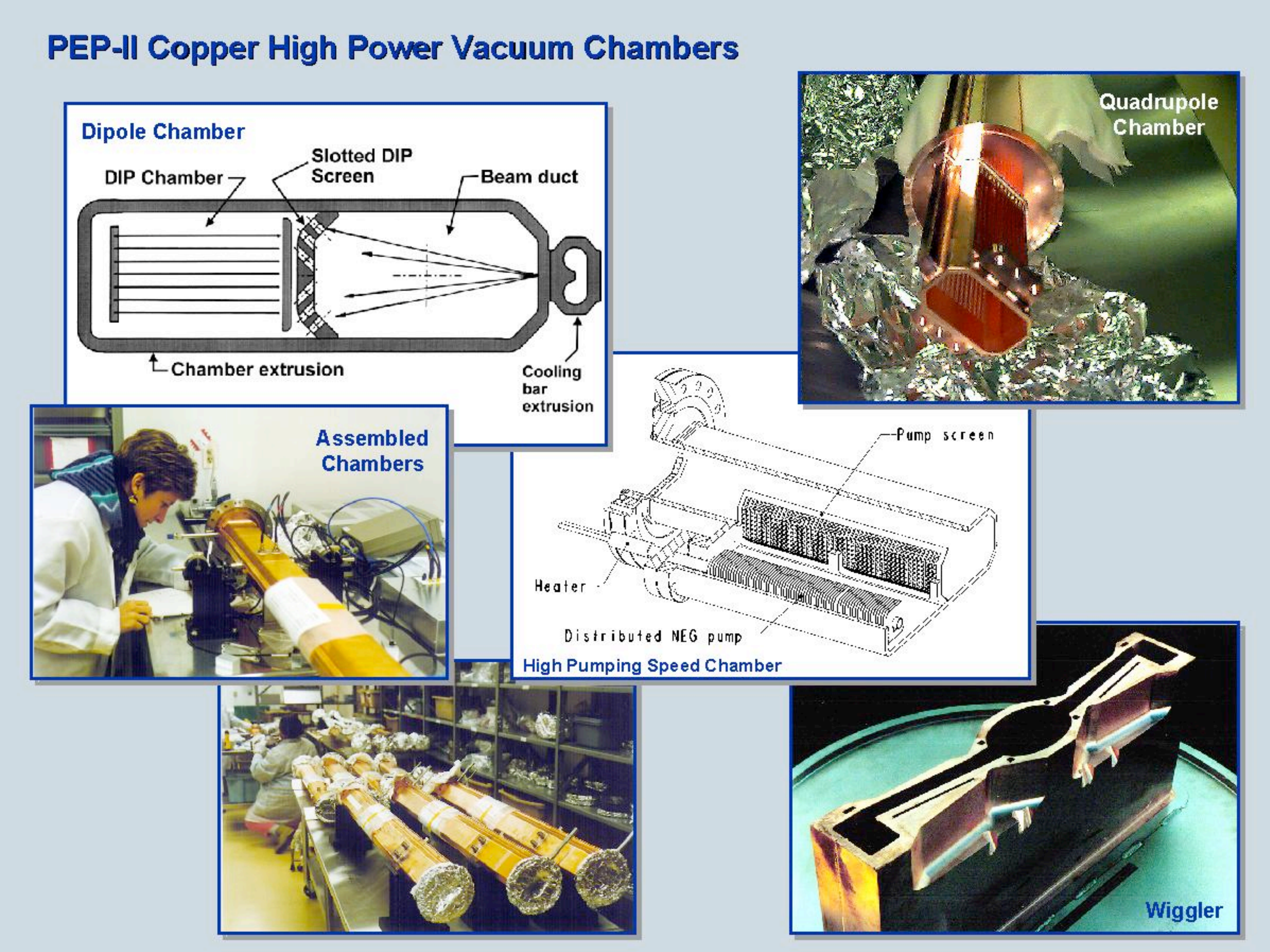
- Asymmetric beam energies work well.
- Energy transparency conditions are relatively weak.
- Asymmetric interaction regions can be operated.
- IR backgrounds can be handled though are not easy.
- High current RF can be operated. (1A x 2 A).
- Bunch-by-bunch feedbacks work (4 nsec spacing).
- Beam-beam tune shifts reached 0.08 (v) to 0.10 (h).
- Injection rates good. Continuous injection feasible.
- Electron Cloud Instability (ECI) ameliorated for now!

New techniques of the Next Generation B-Factory

- Beam lifetimes will be low → continuous injection. (Seeman)
- Very low β_y^* (6 to 10 mm→2 to 3 mm). (Sullivan)
- Higher tune shift (trade beam-beam lifetimes for tune shifts) (Seeman)
- Higher beam currents (x 10 or so). (Novokhatski, Teytelman)
- Higher frequency RF (more bunches). (Novokhatski)
- Bunch-by-bunch feedbacks at the 1 nsec scale. (Teytelman)
- Very short bunch lengths (2 mm). (Novokhatski)
- High power vacuum chambers with antechambers and improved or no bellows. (Soon to start)
- Reduce energy asymmetry to save wall power.

PEP-II Copper Vacuum System: 3 A at 9 GeV

4.8 A at 8 GeV



PEP-II Copper High Power Vacuum Chambers

Cu chambers absorbing 100 W/cm of synchrotron radiation

Total SR power = 5 MW in the HER

LER Magnets and Aluminum Vacuum System: 3 A at 3.5 GeV

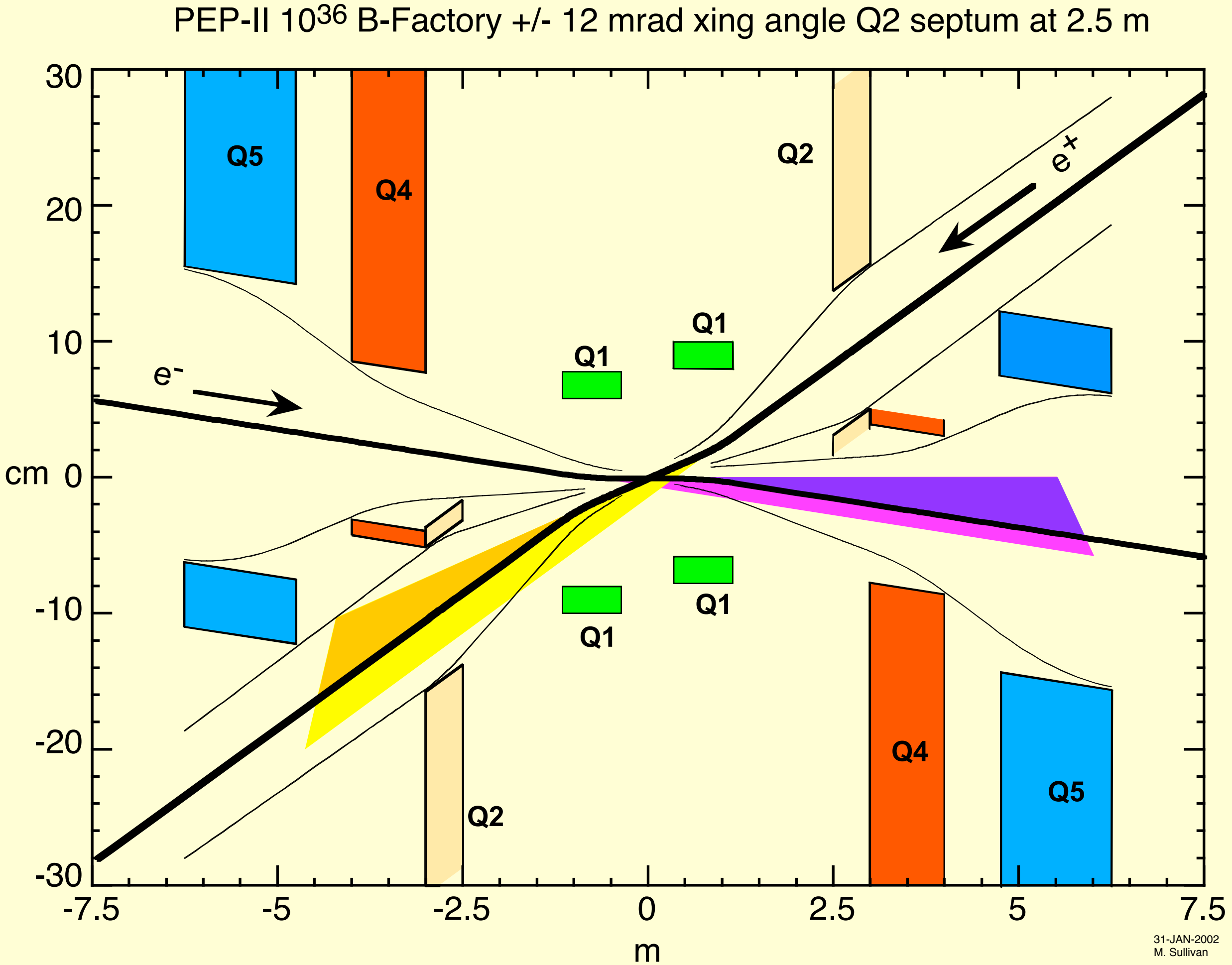
Magnets made by our Chinese IHEP collaborators

Antechambers Reduce Electron-Cloud-Instability

High power photon stops

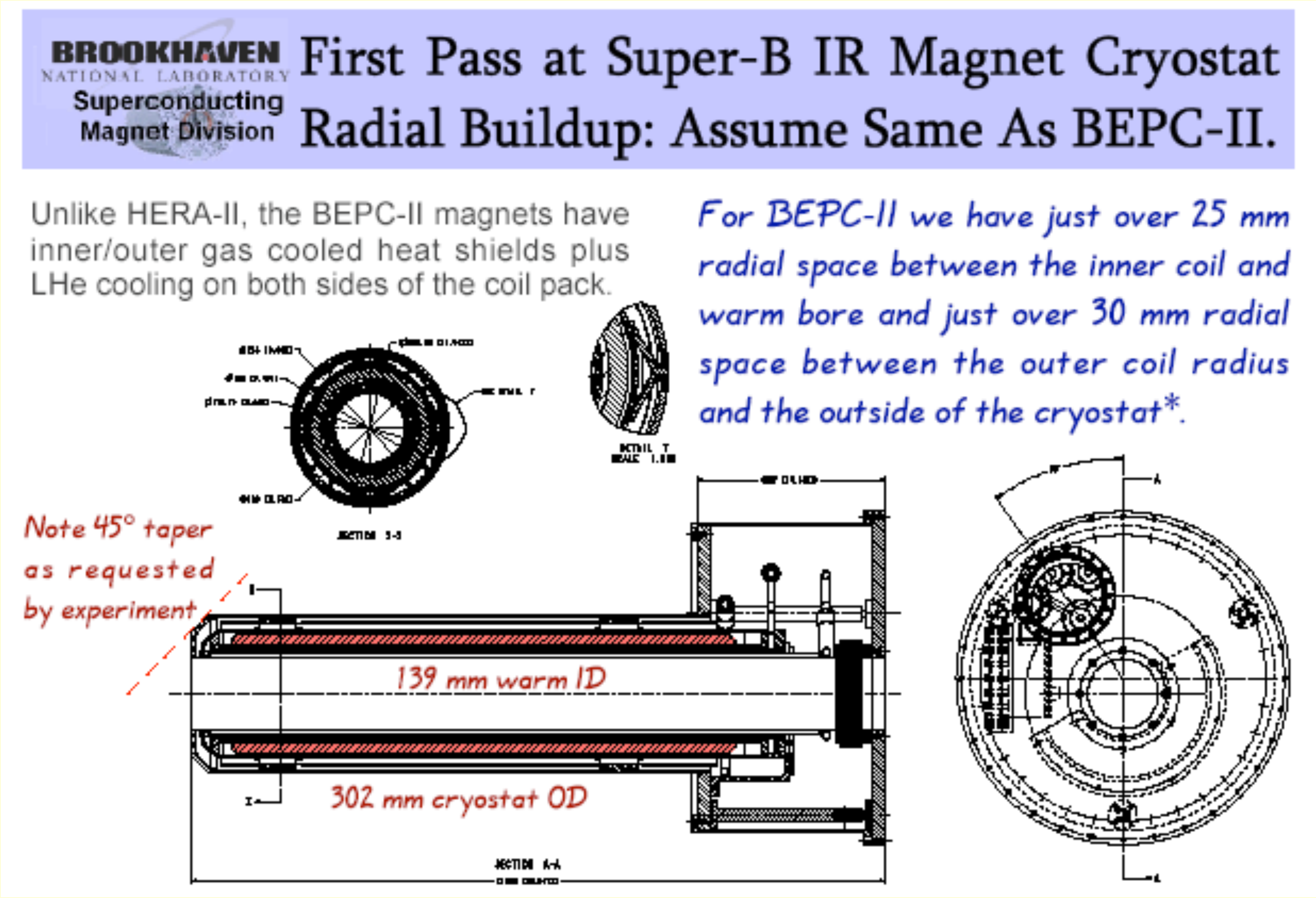
LER SR power = 2 MW.

IR for a 10^{36} B-Factory



Sullivan

New IR magnet design (Parker)



BROOKHAVEN
NATIONAL LABORATORY
Superconducting Magnet Division

First Pass at Super-B IR Magnet Cryostat Radial Buildup: Assume Same As BEPC-II.

Unlike HERA-II, the BEPC-II magnets have inner/outer gas cooled heat shields plus LHe cooling on both sides of the coil pack.

For BEPC-II we have just over 25 mm radial space between the inner coil and warm bore and just over 30 mm radial space between the outer coil radius and the outside of the cryostat.*

Note 45° taper as requested by experiment

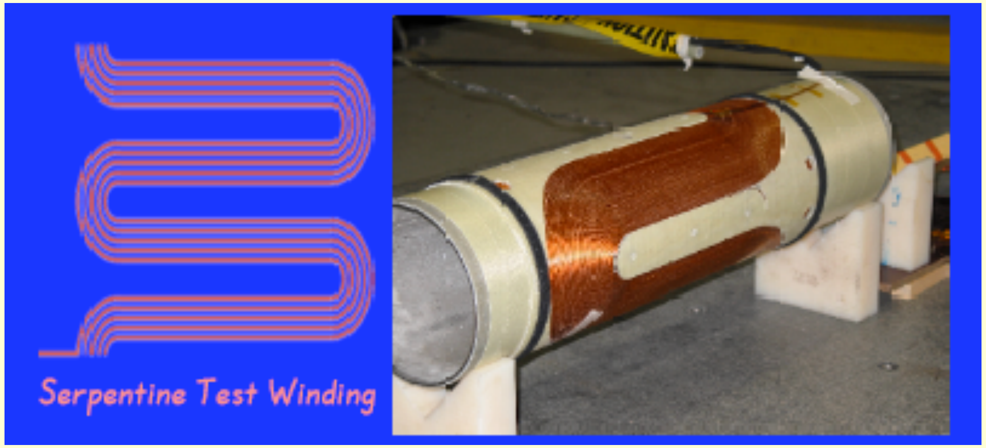
139 mm warm ID

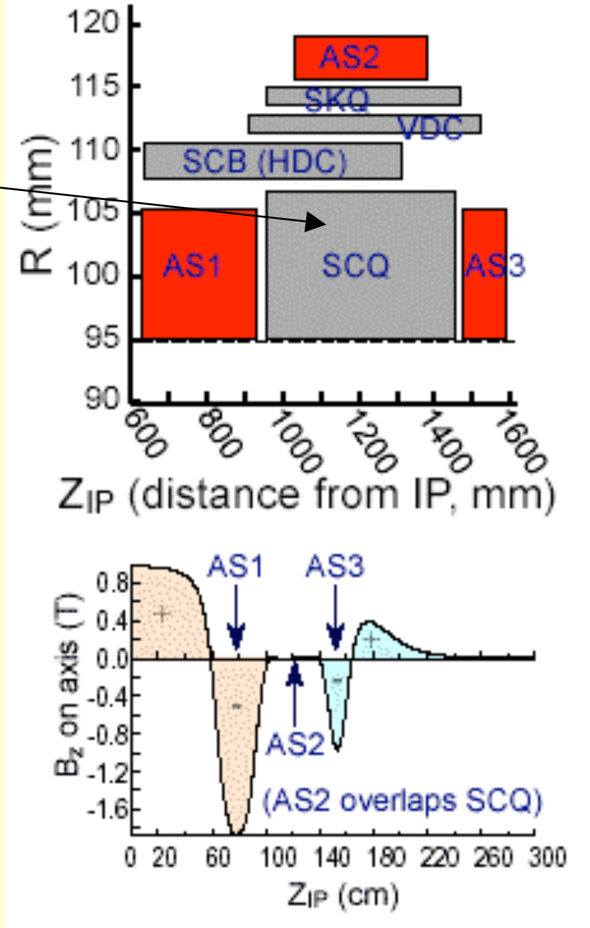
302 mm cryostat OD

New IR magnet design

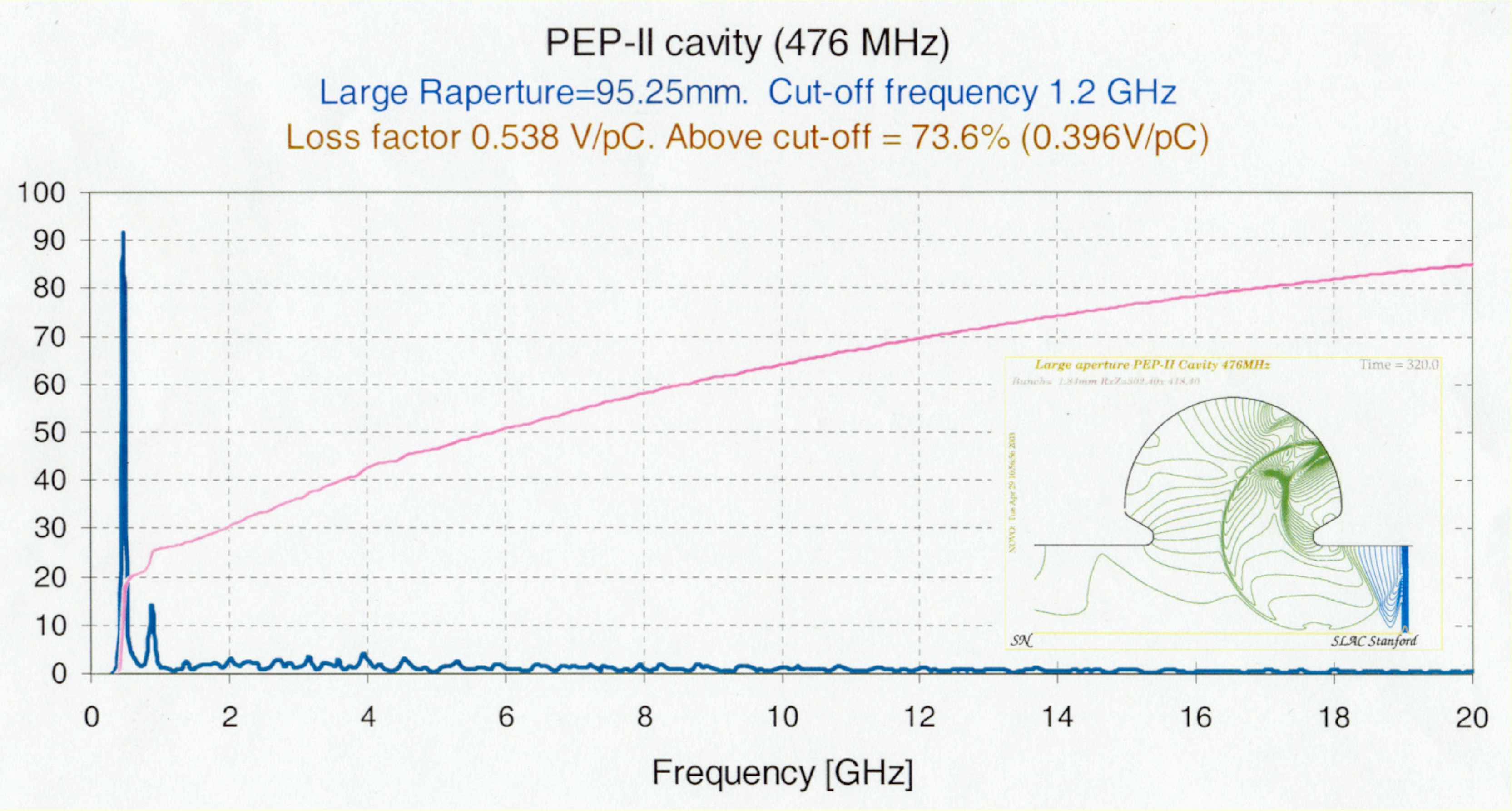
Quadrupole, anti-solenoid, skew quadrupole, dipole and trims located in one magnet.

All coils numerically wound on a bobbin.



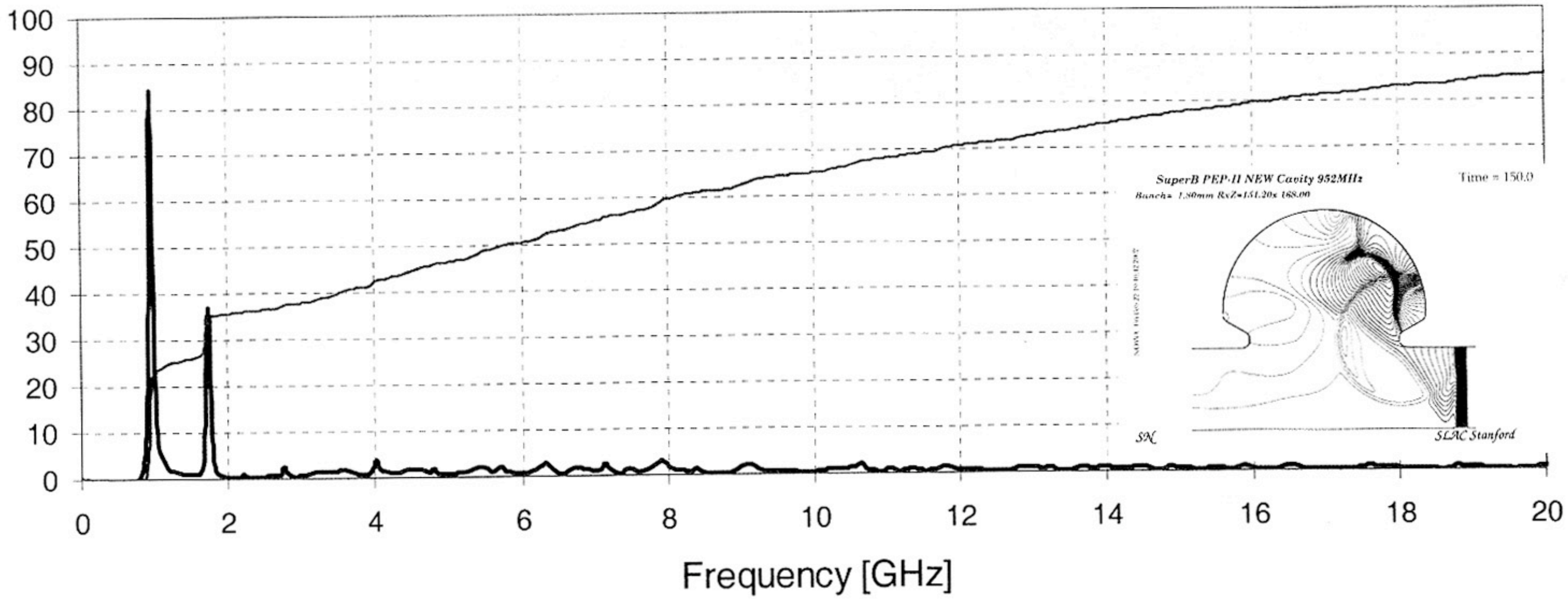


HOM Calculation for a 476 MHz Cavity with a larger beam opening (Novokhatski)



New PEP-II cavity (952 MHz)

Large Raperture=47.6mm. Cut-off frequency 2.41 GHz
Loss factor 0.748V/pC. Above cut-off = 65% (0.4862V/pC)



Cavities for
Super B
04/30/02

$\sigma_z =$ 1.8 mm

Current 24.5 A

Cavity type	Freq [MHz]	Total loss [V/pC]	Aperture Cut-off freq.	HOMs above cut-off [V/pC]	Bunch charge (N bunches)	HOMs power [kW]	
PEP-II "classical"	476	1.217	47.6mm 2.41GHz	0.7545 (62%)	53 nC (3400)	980	
Shintake TM02	476	1.236	47.6mm 2.41GHz	0.8158 (66%)	53 nC (3400)	1059	+97kW main mode
Twice small PEP-II	952	1.717	23.8mm 4.82GHz	0.8585 (50%)	26.5 nC (6800)	557	
Twice small Shintake	952	1.706	23.8nn 4.82GHz	0.8359 (49%)	26.5 nC (6800)	543	+97 kW main mode
TESLA type	952	0.8956	47.8mm 2.4GHZ	0.6269 (70%)	26.5 nC (6800)	407	
New PEP-II	952	0.748	47.6mm 2.41GHz	0.4862 (65%)	26.5 nC (6800)	316	
2/3 new PEP-II	1428	0.912	31.8mm 3.61GHz	0.52 (57%)	17.7 nC (10200)	225	

Super B Factory using PEP-II RF Frequency

- Keep present RF frequency = 476 MHz.
- Go to 8 x 3.5 GeV with 11 A x 4.8 A.
- HER current limited to 4.8 Amps using present vacuum chamber.
- New LER vacuum chambers with antechambers for higher power (x 4). LER current limited to 11 Amps to match HER beam-beam.
- Keep present LER arc magnets but add magnets to soften losses.
- New bunch-by-bunch feedback for 3400 bunches (every bucket) at 2 nsec spacings. (We are presently designing a feedback system for 0.6-0.8 nsec spacing.)
- Push β_y^* to 4 mm: need new IR (SC quadrupoles)

Super B Factory with 476 MHz RF Frequency

- $E^- = 8$ GeV
- $E^+ = 3.5$ GeV
- I- = 4.8 A
- I+ = 11 A
- $\beta_y^* = 3.7$ mm
- $\beta_x^* = 25$ cm
- Bunch length = 4 mm
- Crossing angle = ~15. mrad
- Beam-beam parameters = 0.10
- N = 3450 bunches
- $L = 2 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Site power with linac and campus = ~85 MW.

Super B Factory with New RF Frequency

- Higher RF frequency provides for more bunches.
- Better for resistive wall losses, Touschek lifetime, single bunch instabilities, lower beam emittance, perhaps lower parasitic beam-beam effects, less peak synchrotron radiation heat stress, …
- Choose frequency related to linac frequency 2856 MHz:
  - A good choice is 952 MHz.

Advanced B Factory with 952 MHz RF Frequency

- E^+ = 8 GeV
- E^- = 3.5 GeV
- I+ = 6.8 A
- I- = 15.5 A
- β_y^* = 1.5 mm
- β_x^* = 15 cm
- Bunch length = 1.8 mm
- Crossing angle = ~15. mrad
- Beam-beam parameters = 0.11
- N = 6900 bunches
- L = 7 x 10^{35} $cm^{-2}s^{-1}$
- Site power with linac and campus = ~100 MW.

Advanced B Factory with 952 MHz RF Frequency

- $E^+ = 8$ GeV
- $E^- = 3.5$ GeV
- I+ = 10.1 A
- I- = 23.0 A
- $\beta_y^* = 1.5$ mm
- $\beta_x^* = 15$ cm
- Bunch length = 1.8 mm
- Crossing angle = ~15. mrad
- Beam-beam parameters = 0.11
- N = 6900 bunches
- $L = 1 \times 10^{36}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Site power with linac and campus = ~120 MW.

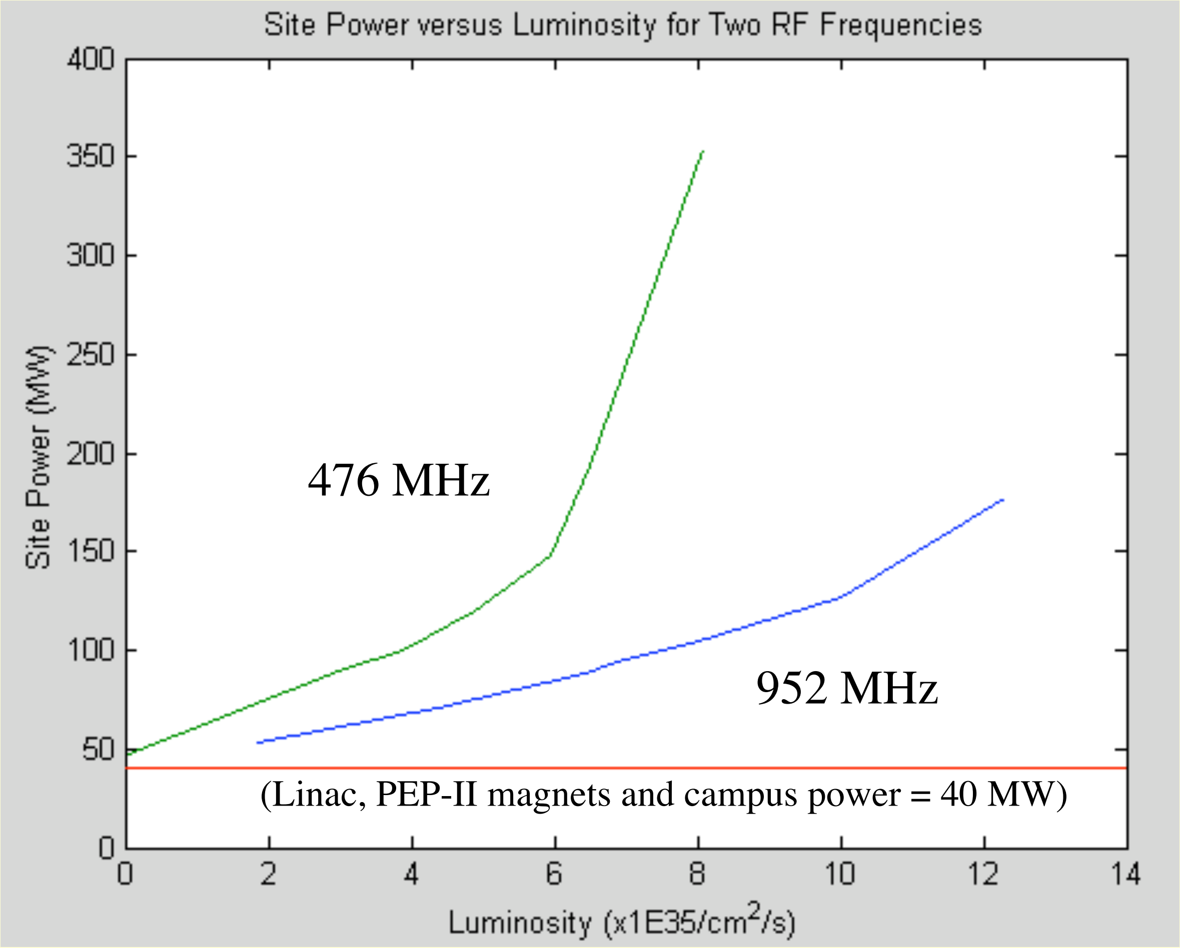
Power Scaling Equations

- Synch rad ~ $I E^4/\rho$
- Resistive wall ~ $I^2_{total}/r_1/f_{rf}/\sigma_z^{3/2}$
- Cavity HOM ~ $I^2_{total}/f_{rf}/\sigma_z^{1/2}$
- Cavity wall power = 50 kW
- Klystron gives 0.5 MW to each cavity
- Magnet power ~ gap~r_1

Calculation of the Total Site Power vs Luminosity and RF frequency

- Assume the Campus, SPEAR, Linac plus PEP-II magnets sums to 40 MW (~35 MW now).
- Beam power losses come from the resistive wall effect, synchrotron radiation, and higher order mode losses in the cavities and other chambers.
- Assume bunch lengths are fixed.
- Assume the number of bunches are fixed.
- Scale the currents linearly with the luminosity adjusting the emittance to keep the beam-beam parameters at 0.11.
- Assume the RF power supply and RF klystron have a combined efficiency of 45% and that a klystron delivers 450 kW to each cavity.

Site Power including Linac and Campus for Two RF Frequencies

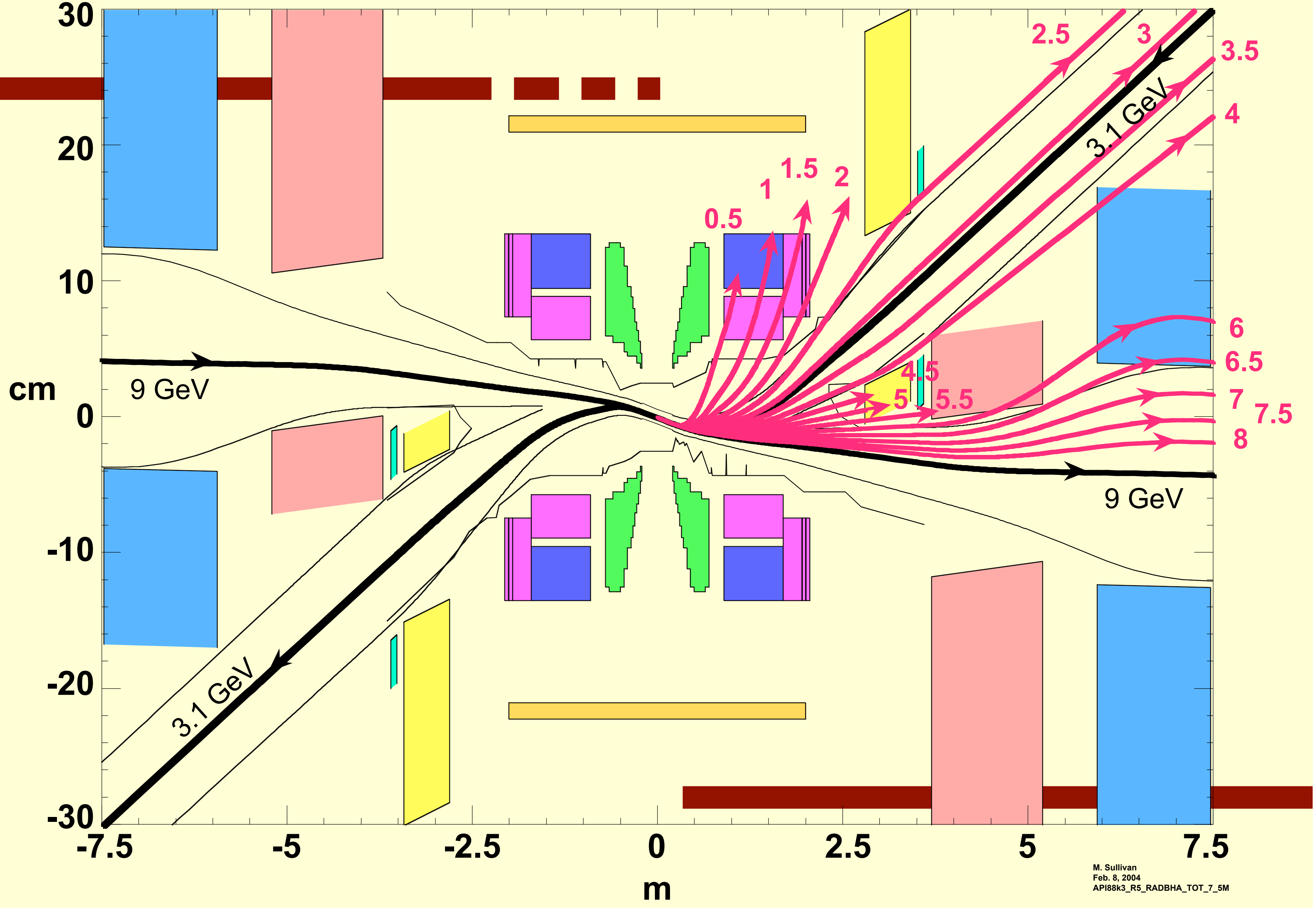


Study of luminosity related backgrounds

- BaBar sees luminosity related backgrounds.
- Background proportional to luminosity.
- Mostly e+e- → e+e-γ

HER Radiative Bhabhas

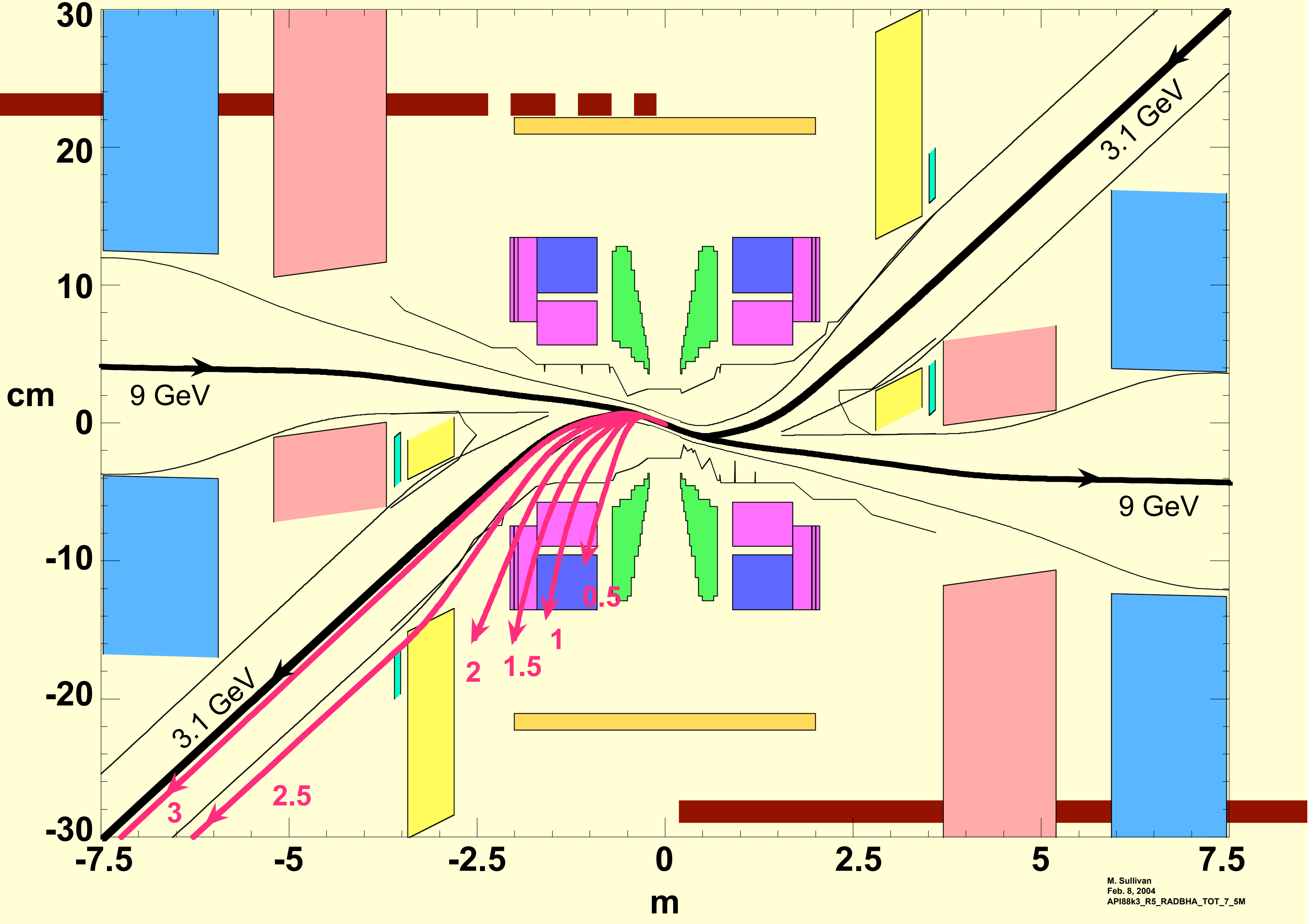
Sullivan



M. Sullivan
Feb. 8, 2004
API88k3_R5_RADBHA_TOT_7_5M

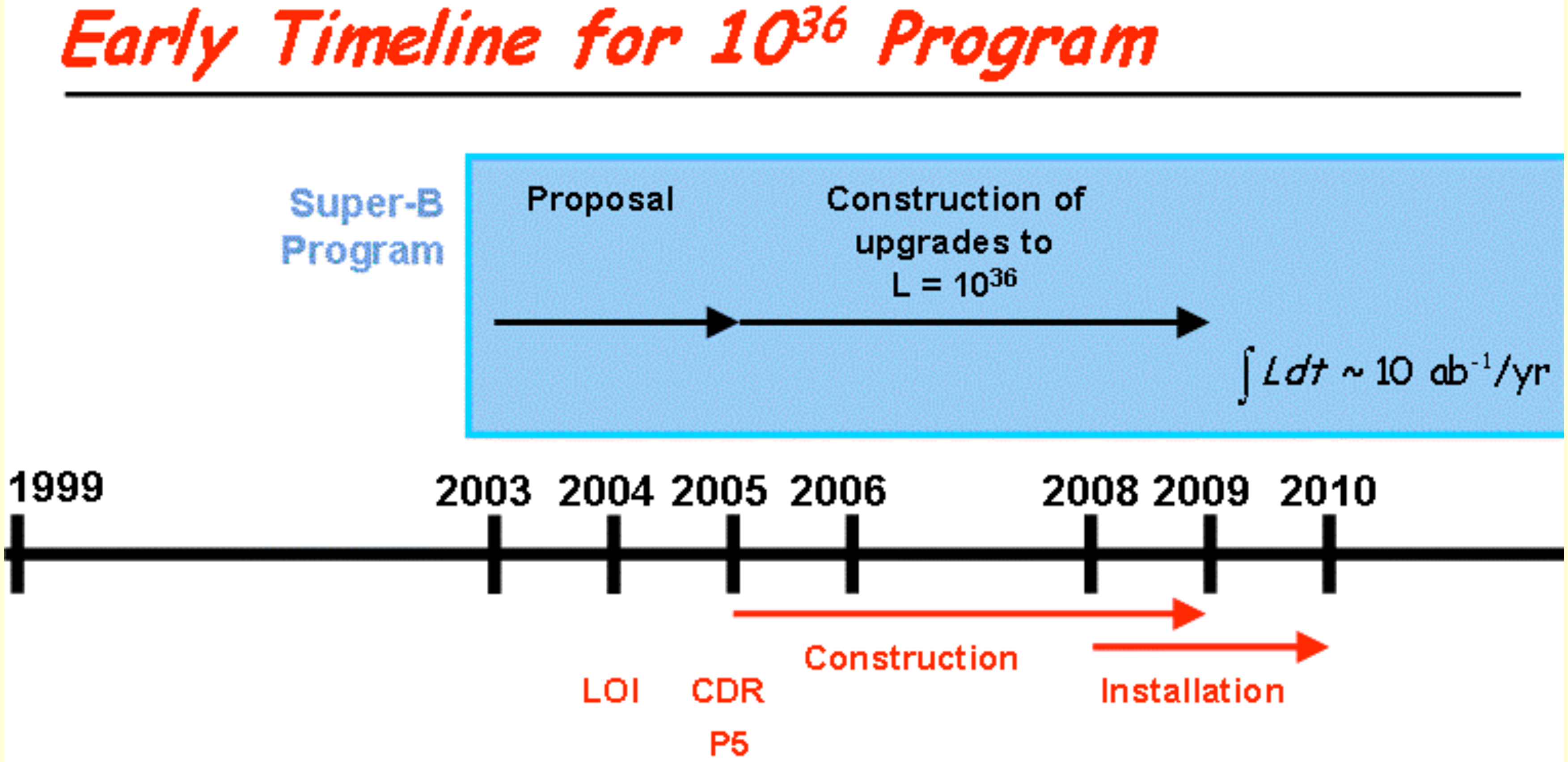
LER Radiative Bhabhas

Sullivan



M. Sullivan
Feb. 8, 2004
API88k3_R5_RADBHA_TOT_7_5M

Possible Super-PEP-II Timeline



Early Timeline for 10^{36} Program

Super-B Program

Proposal

Construction of upgrades to $L = 10^{36}$

$\int L dt \sim 10 \ ab^{-1}/yr$

Construction

Installation

LOI

CDR

P5

Conclusions

- PEP-II has reached a luminosity of 8.0 x 10^{33}. It has integrated 520/pb in one day with LER trickle injection. HER trickle tested. Near term upgrades are going well.
- Total delivered about 180 fb^{-1}. (BaBar ~165 fb^{-1})
- The parameters of a Super-PEP-II were studied with RF frequencies of 476 MHz and 952 MHz.
- At the present, for 80 to 120 MW of total power, linac and campus included, 476 MHz provides a luminosity of about 2 to 4 x 10^{35} and 952 MHz provides about 0.7 to 1.0 x 10^{36}. Vertical beam-beam parameters are 0.11.