Super B Factory: The Machine* and Physics Capabilities

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Frascati Υ-Workshop on B Factories

October 5, 2004

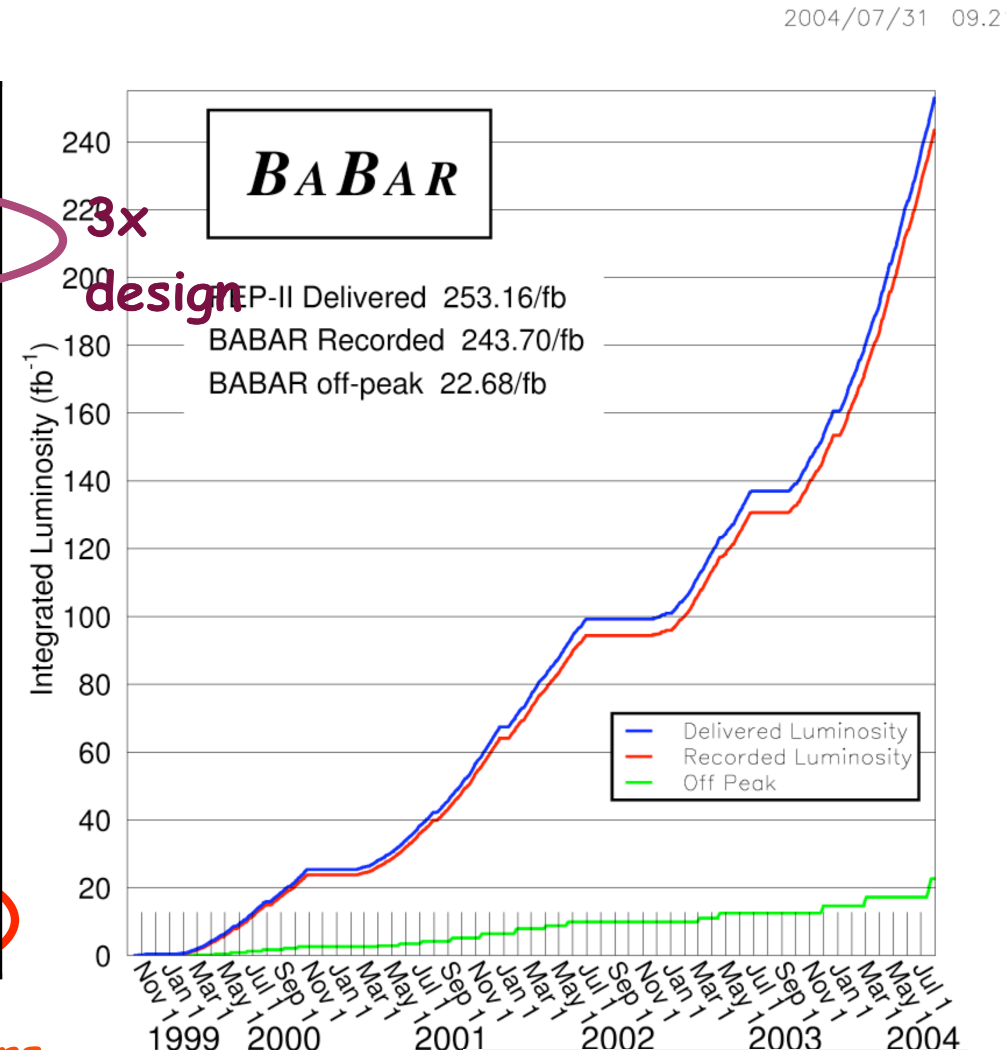
*Warning: Not a machine expert!

PEP-II integrated luminosity

PEP-II Records	
Peak luminosity	0.923×10^{34} cm^{-2} s^{-1}
Best shift	246.3 pb^{-1}
Best day	710.5 pb^{-1}
Best 7 days	4.464 fb^{-1}
Best week	4.464 fb^{-1}
Best month	16.72 fb^{-1}
Best 30 days	17.04 fb^{-1}
BABAR logged	246.4 fb^{-1}

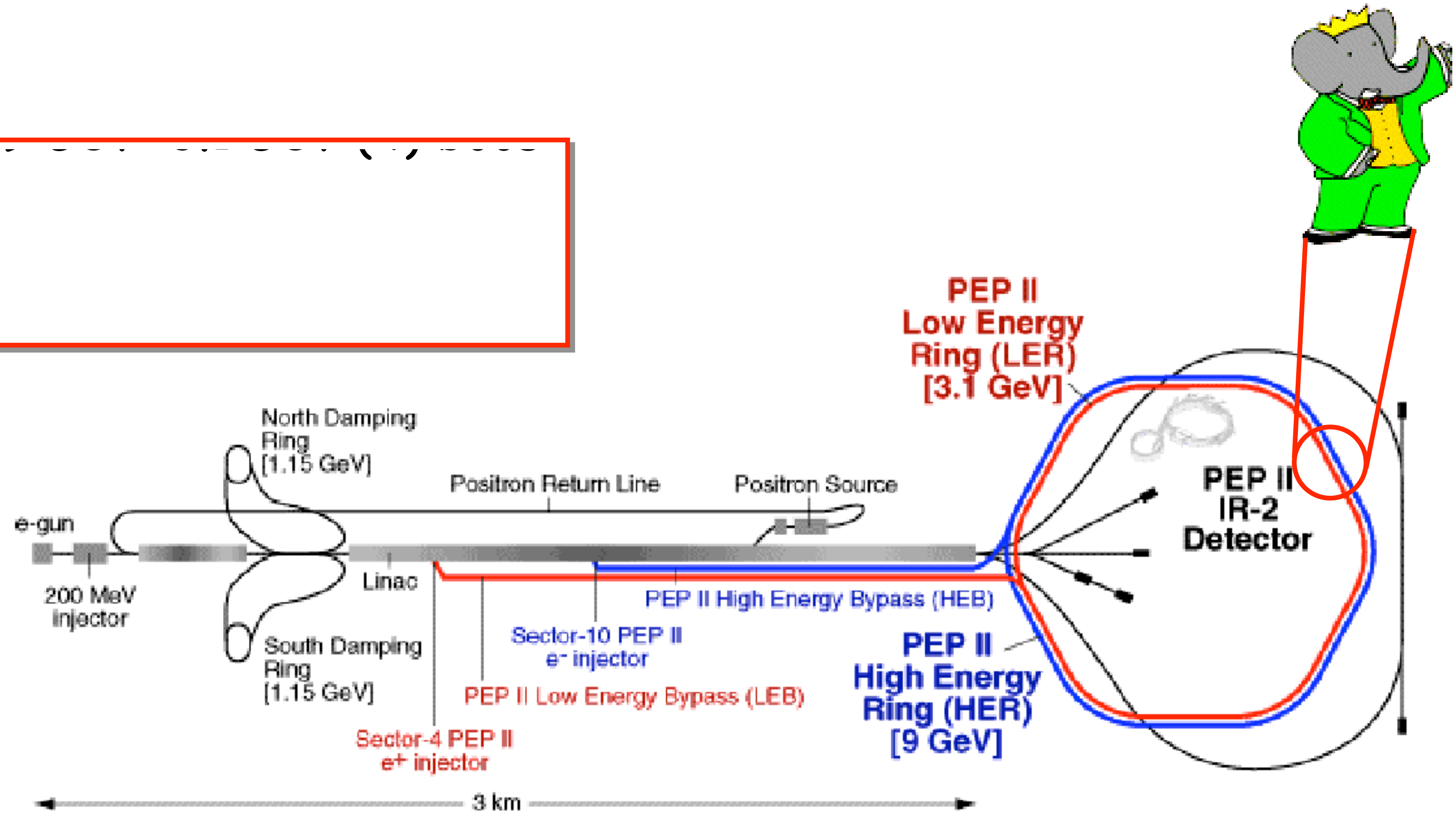
3x design

~245 million $B\bar{B}$ pairs



(as of July 31, 2004)

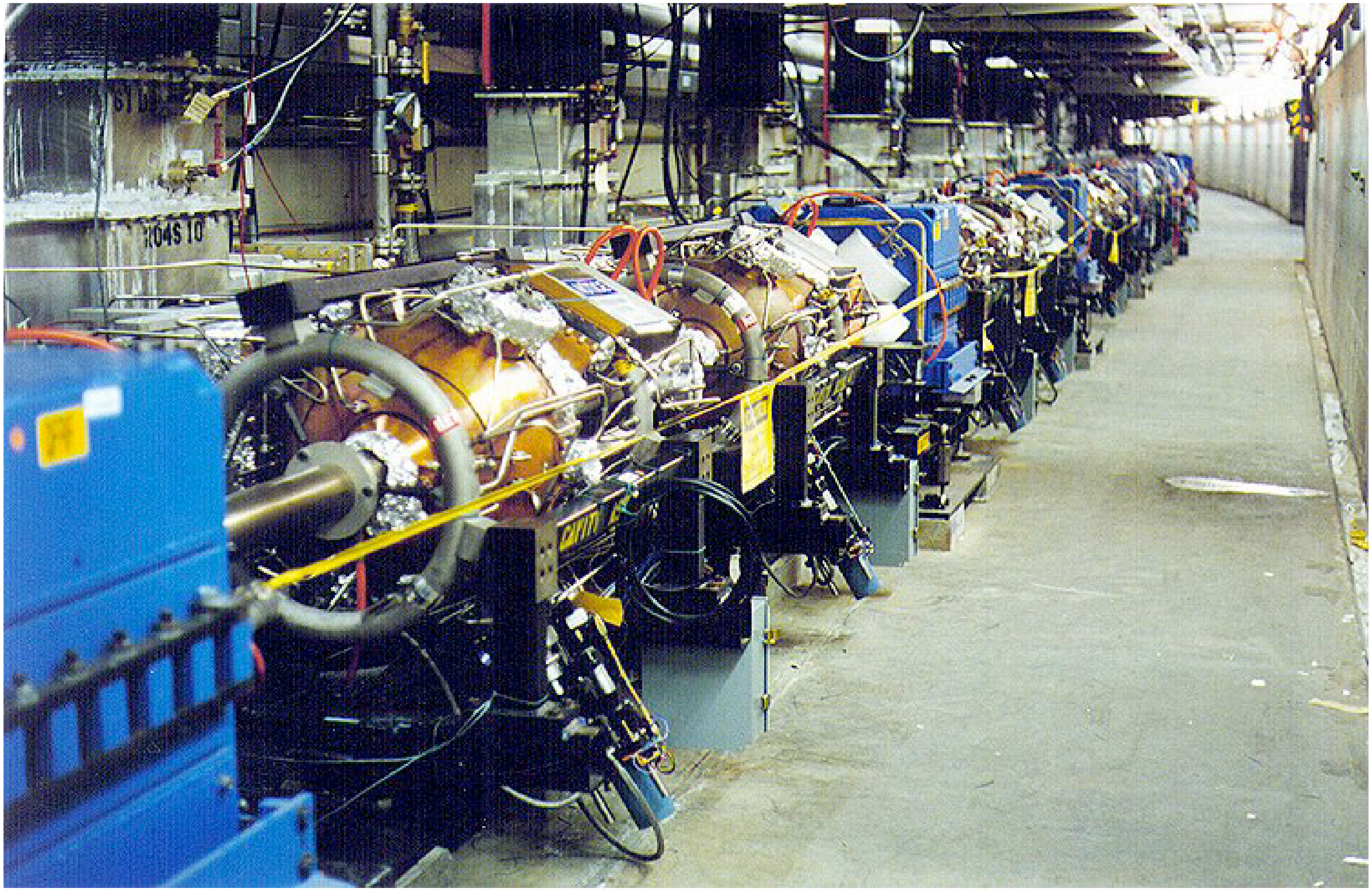
PEP-II schematic layout



PEP-II tunnel: 2.2km
in circumference

PEP-II arc section

PEP-II HER RF cavities



BR_049 HER Cavities Region 12 8-19-97

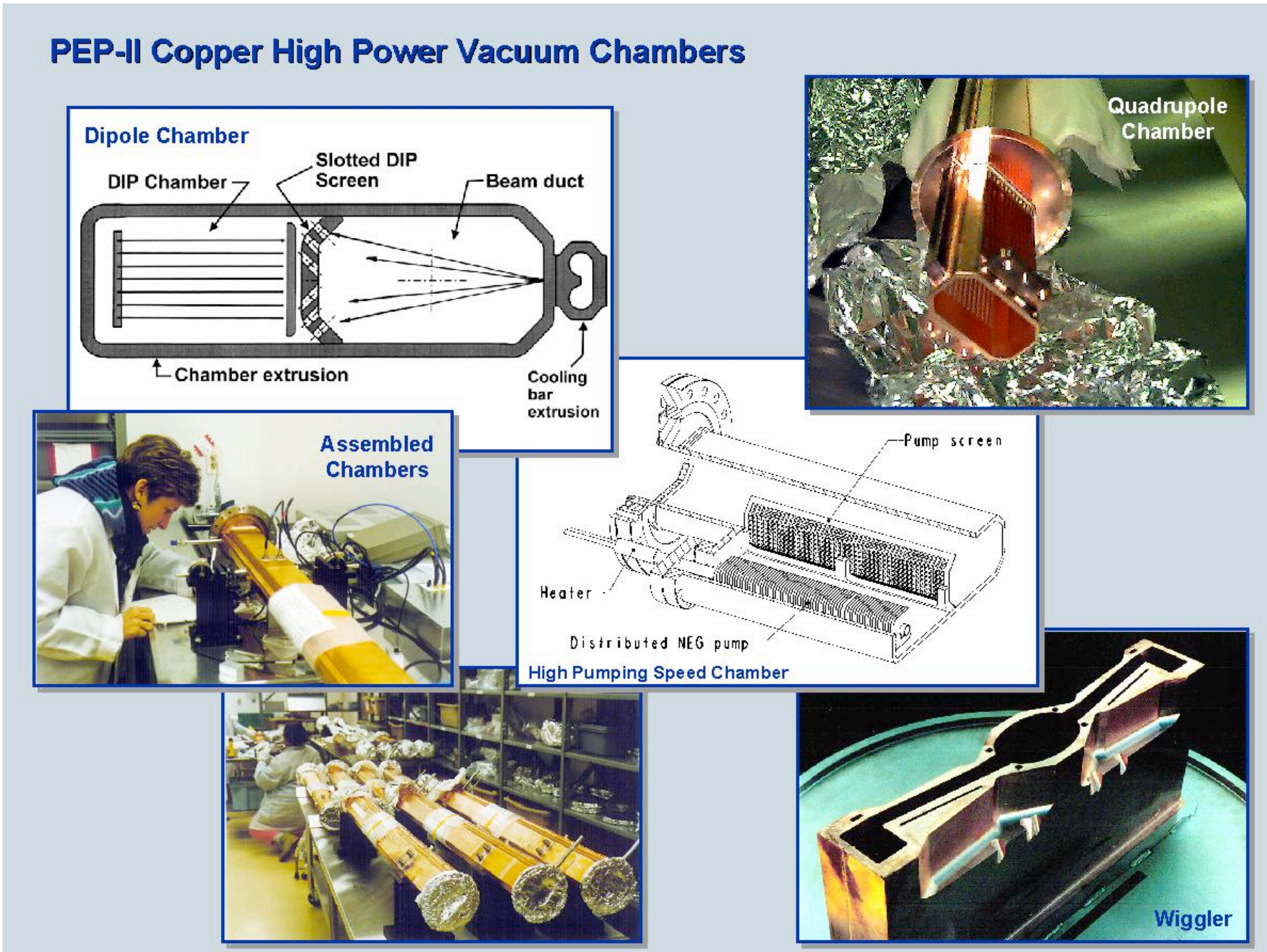
HER copper vacuum system: limit at 3A

Photon Stop limits

3.0 A at 9 GeV
4.8 A at 8 GeV
6.2A at 7.5 GeV

Cu chambers absorbing 100 W/cm of synchrotron radiation

Total HER SR power = 5 MW

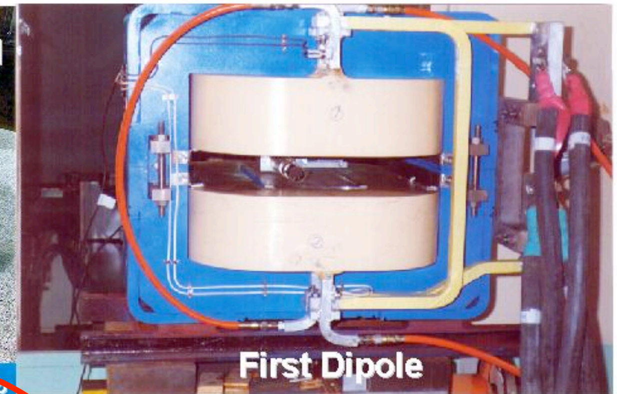


LER aluminum vacuum system: limit at 4.5A

Photon Stop limits

4.5 A at 3.1 GeV

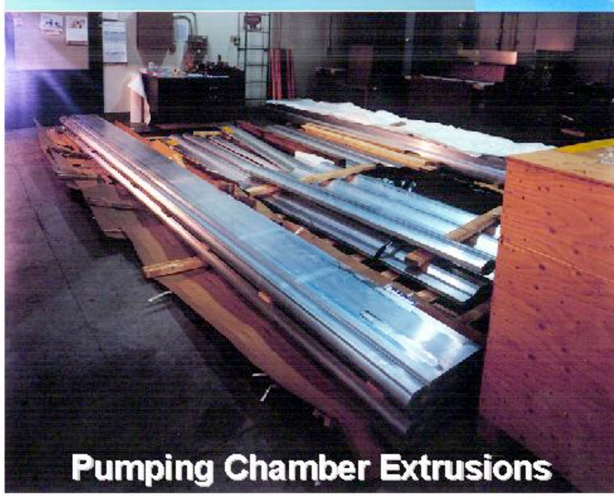
Antechambers Reduce Electron-Cloud-Instability



Low Energy Ring

High power photon stops

Total LER SR power = 2 MW

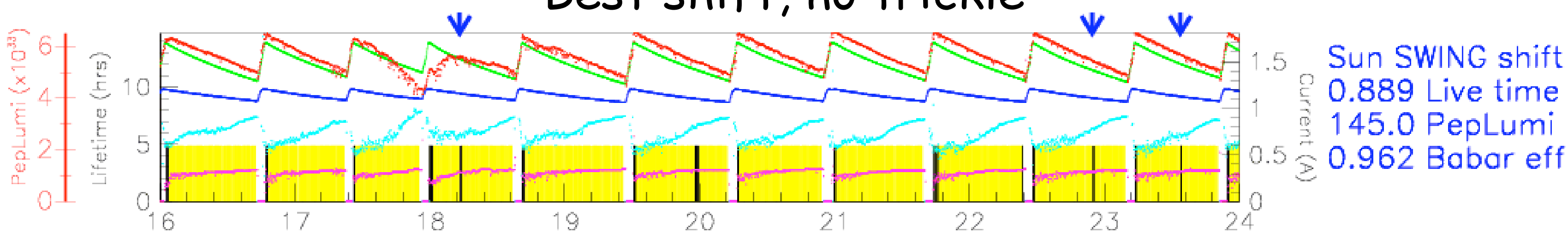


Lessons learned from PEP-II & KEKB

- *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 (1 A x 2 A).*
- *Bunch-by-bunch feedbacks work (4 ns spacing).*
- *Beam-beam tune shifts reach 0.08 (v) to 0.10 (h).*
- *Injection rates good; continuous injection feasible.*
- *Electron Cloud Instability (ECI) ameliorated for now!*

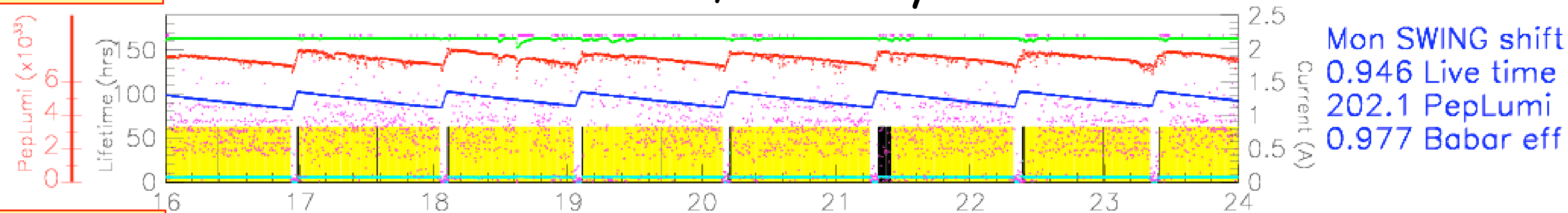
Trickle injection at the B Factories

Best shift, no trickle



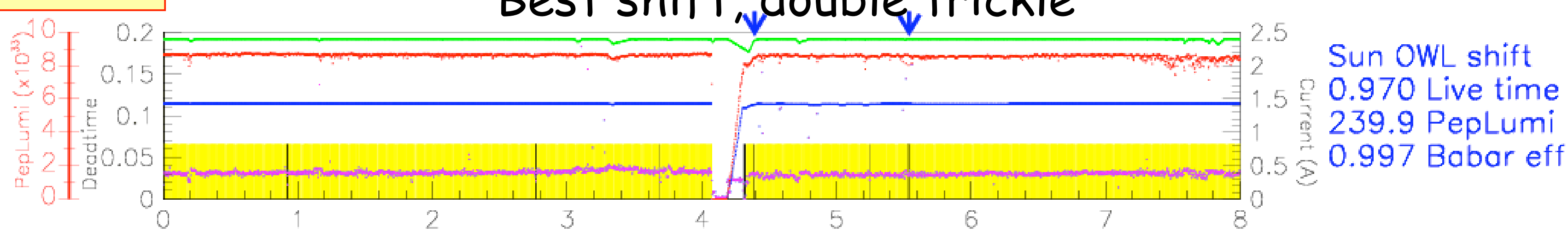
Nov 2003

Best shift, LER only trickle



Mar 2004

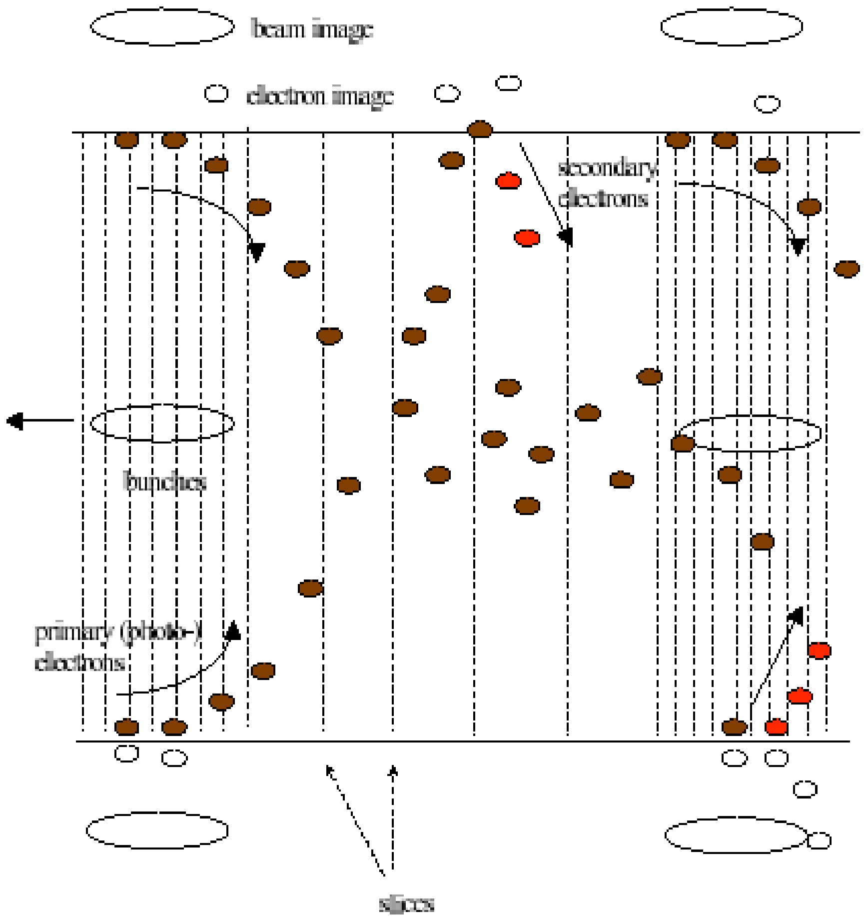
Best shift, double trickle

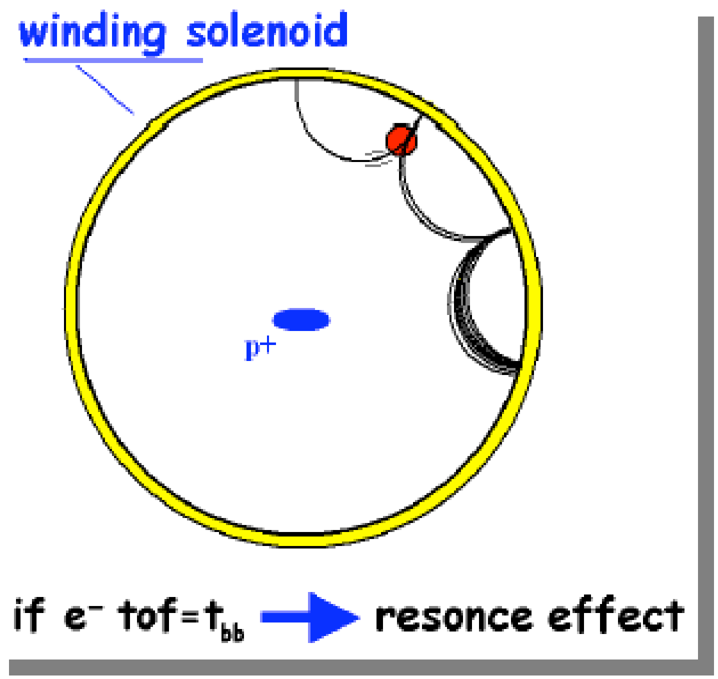


PEP-II: ~5 Hz continuous
KEKB: at ~5-10 min intervals

PEP-II Lumi
HER current
LER current

Electron Cloud Instability & multipacting





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

Windings added for ECI reduction

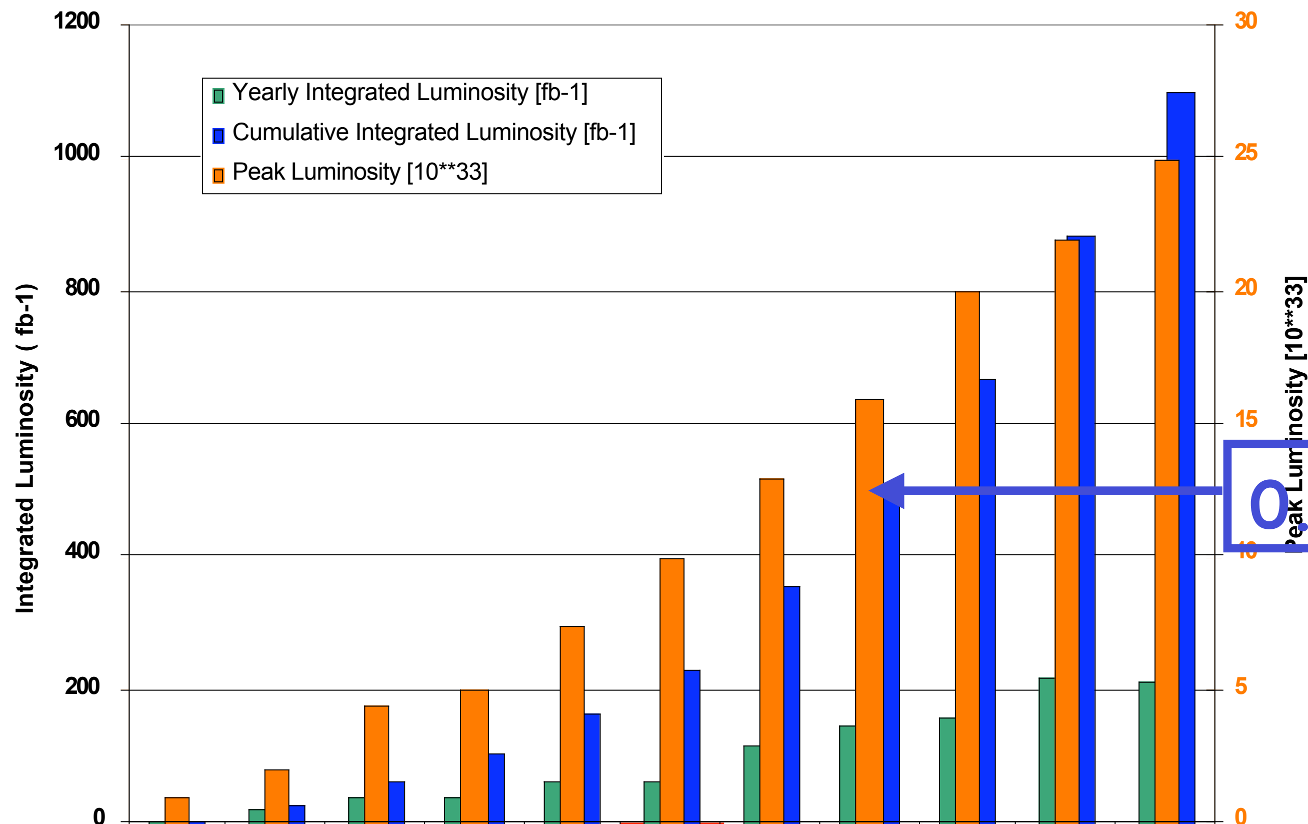
Projected performance of PEP-II

Luminosity (x10^{34})	0.9	2.4	Units
e^+	3.1	3.1	GeV
e^-	9.0	9.0	GeV
I^+	2.45	4.5	A
I^-	1.55	2.2	A
□(y*)	11	8	mm
□(x*)	30	30	cm
Bunch length	10	7.5	mm
# bunches	1588	1700	
Crossing angle	0	0	mrad
Tune shifts (x/y)	4.5/7	8/8	x100
rf frequency	476	476	MHz
Site power	40	40	MW
	Jul 04	Jul 07	

LER photon stop limit

For 05 & 06 shutdowns: Additional LER and HER rf stations, vacuum chamber upgrades, stronger B1 separation field,…

PEP II Luminosity Projections

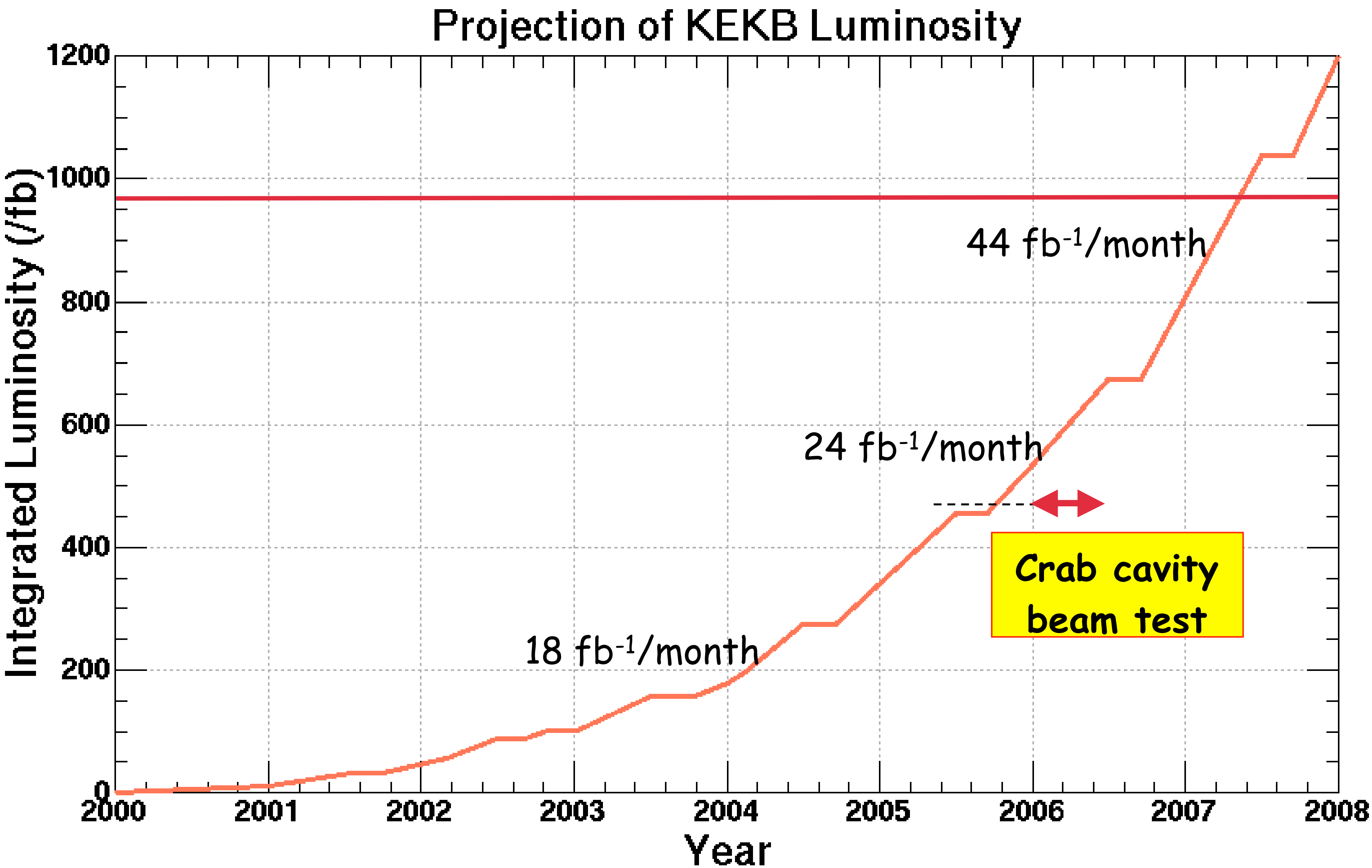


	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Yearly Integrated Luminosity [fb-1]	3	23	41	39	62.6	66.1	120.1	151	160.1	217	216
Cumulative Integrated Luminosity [fb-1]	3	26	67	106	168.6	234.7	354.8	505.8	665.9	882.9	1098.9
Peak Luminosity [10**33]	1	2	4.4	5	7.5	10	13	16	20	22	25

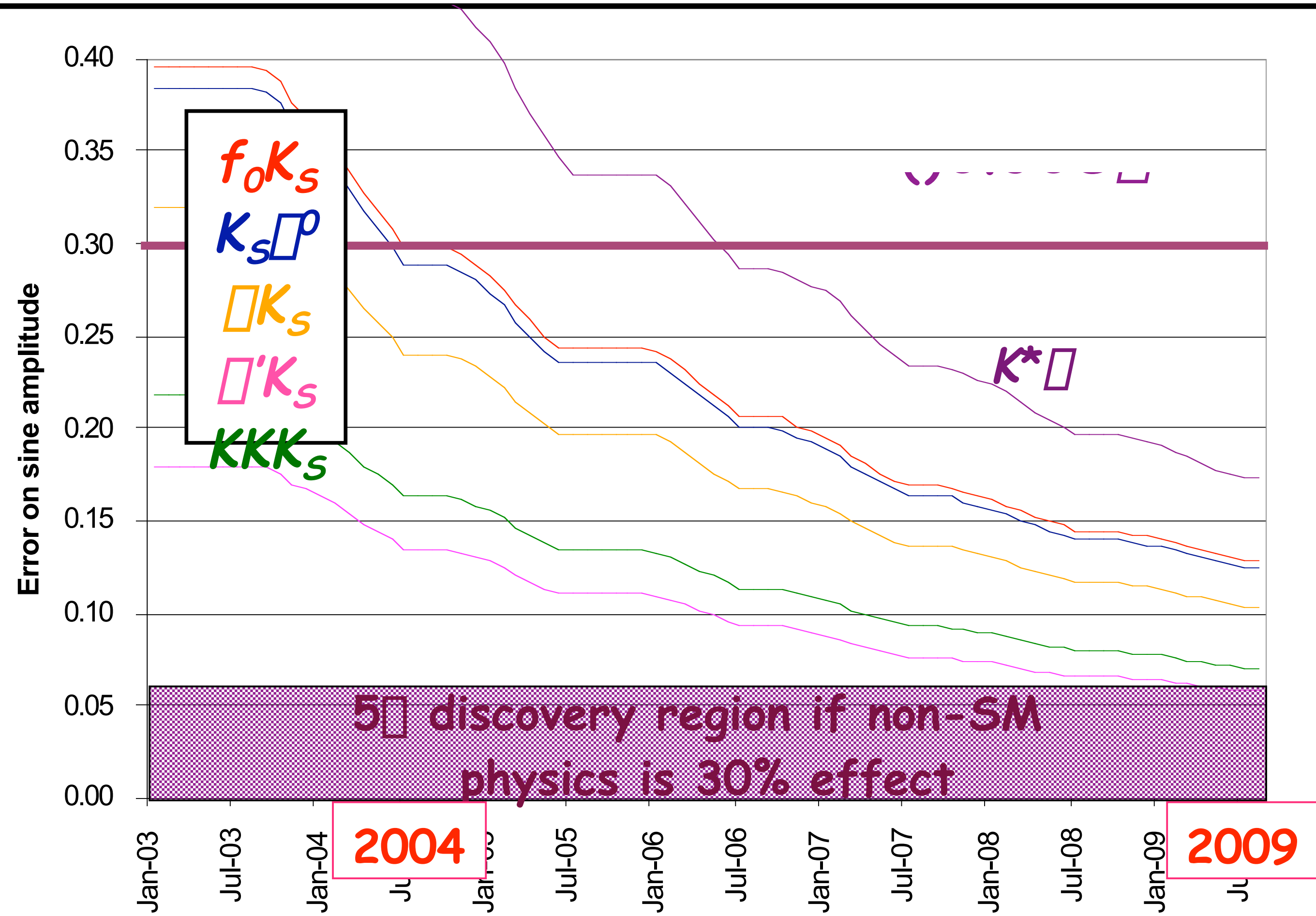
Year

2004 2006 ← 1.6×10^{34}

Projections at KEKB



Projections for Penguin Modes



Luminosity expectations:

2004=240 fb^{-1}
2009=1.5 ab^{-1}

Similar projections for Belle as well

Projections are statistical errors only;
but systematic errors at few percent level

BABAR Roadmap Study: Jan – July 04

- **Defining physics case for Super B Factory**
  - Emphasis on sensitivity to new physics in *CP* violation & rare decays
  - Emphasis on need & capability for precision SM measurements
- **Requirements of viable project plans**
  - Estimates for duration of approval and funding process
  - Collider options and upgrade capabilities
  - Detector capabilities & requirements in light of projected backgrounds
  - Integrated scenarios for collider and detector construction, with implications for time to first data
- **Projections of physics reach in light of competition & other opportunities**
  - Projections of samples and sensitivities; analysis of physics reach

Luminosity Equation

- ξ_y is the beam-beam tune shift parameter (~0.065)
- I_b is the bunch current (1 to 3 mA)
- n is the number of bunches (~1600)
- β_y^* is the IP lattice optics function (vertical beta) (10 mm)
- E is the beam energy (3.1 and 9 GeV)
- L is luminosity in units of 10^{33} cm^{-2} s^{-1}

Achieving Super B Luminosities

Higher Currents:

- More rf power, cooling, injector
- More HOM heating (more bunches)
- Beam instabilities
- Electron clouds, fast ions

Smaller β_y^*:

- Smaller physical/dynamic aperture
- Shorter lifetime, more background

Shorter σ_z:

- More HOM heating
- Coherent synchrotron radiation
- Shorter lifetime, more background

Higher tune shifts:

- Head-on collisions replaced by angled crossing
- Degrades maximum tune shift unless crabbing cavities used

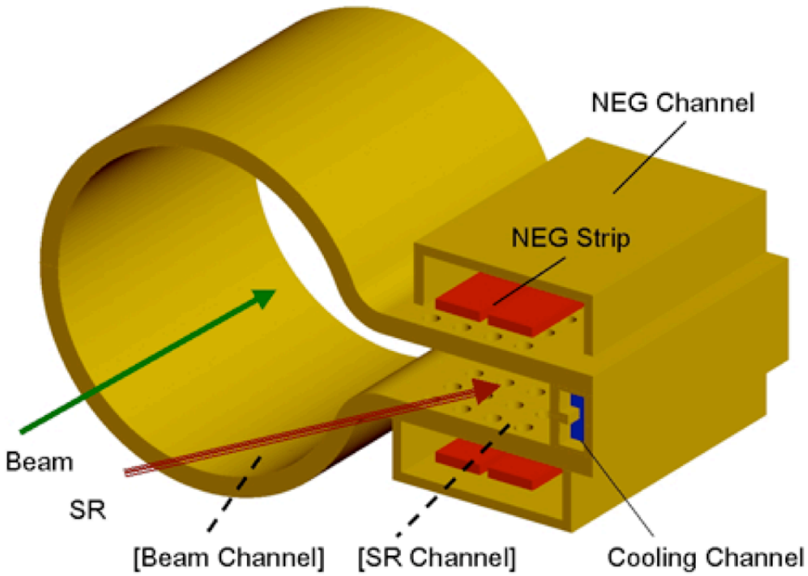
Parameters for High-Luminosity B Factory

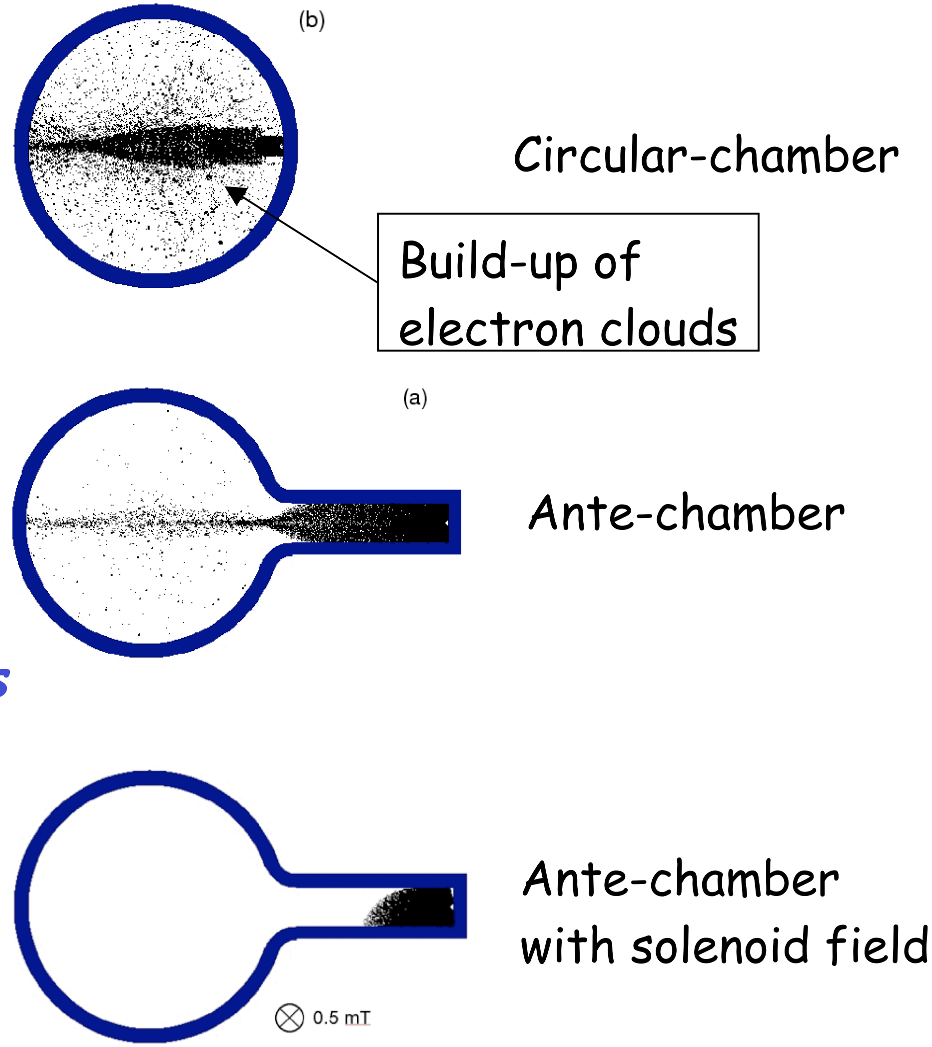
Luminosity ($\times 10^{34}$)	0.9	2.4	15	25	70	Units
e^+	3.1	3.1	3.1	3.5	8.0	GeV
e^-	9.0	9.0	9.0	8.0	3.5	GeV
I^+	2.45	4.5	8.7	11.0	6.8	A
I^-	1.55	2.2	3.0	4.8	15.5	A
$\beta(y^*)$	11	8	3.6	3.0	1.5	mm
$\beta(x^*)$	30	30	30	25	15	cm
Bunch length	10	7.5	4	3.4	1.7	mm
# bunches	1588	1700	1700	3450	6900	
Crossing angle	0	0	0	±11	±15	mrad
Tune shifts (x/y)	4.5/7	8/8	11/11	11/11	11/11	x100
rf frequency	476	476	476	476	952	MHz
Site power	40	40	75	85	100	MW
J.Seeman	Jul 04	Jul 07	LER vacuum	+IR	+HER vacuum, 952MHz rf	

New techniques for Super B-Factory

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

Vacuum system for Super B Factory



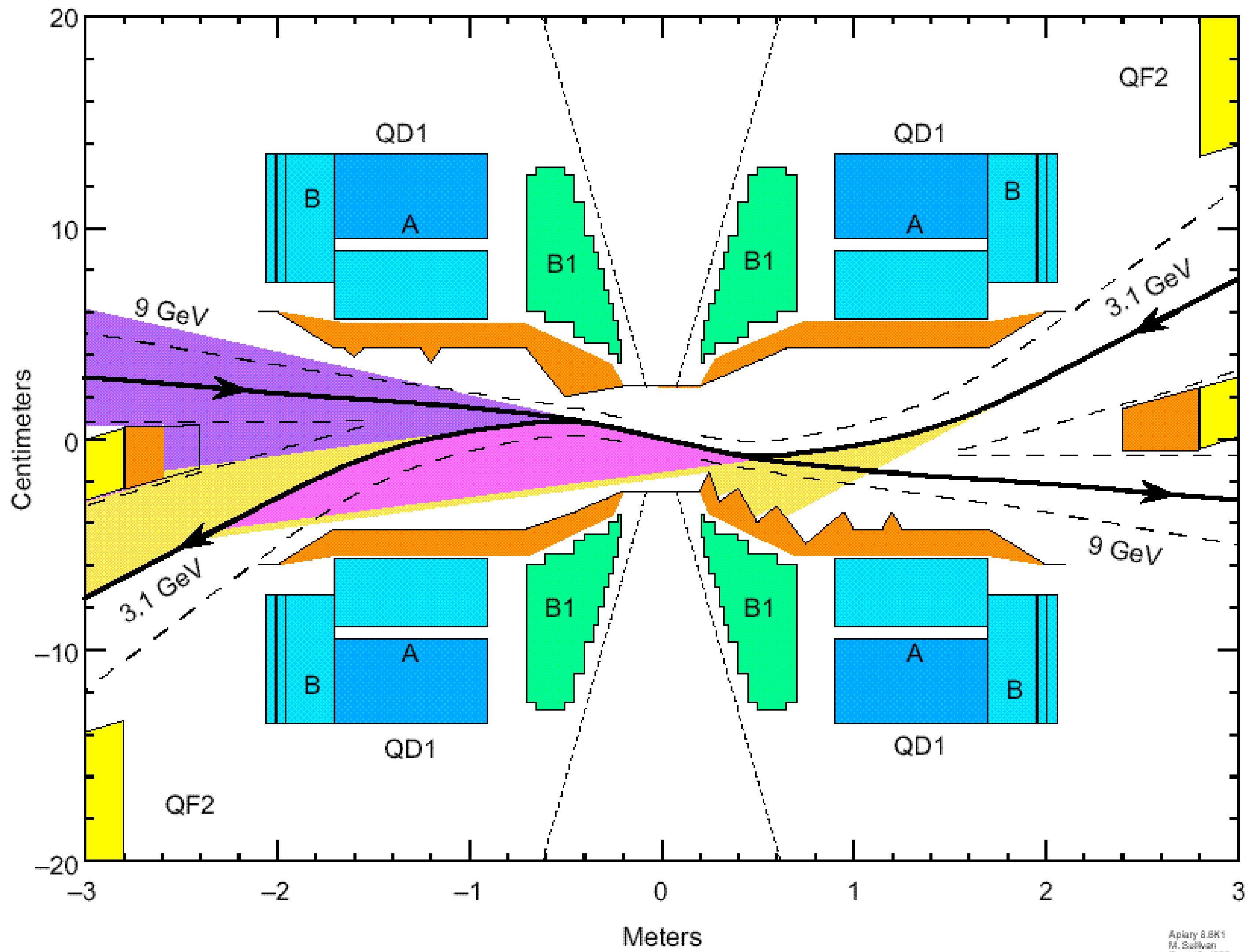


- *Antechamber and solenoid coils in both rings.*
- *Absorb intense synchrotron radiation.*
- *Reduce effects of electron clouds.*

Interaction region design

PEP-II
Head-On IR
Layout

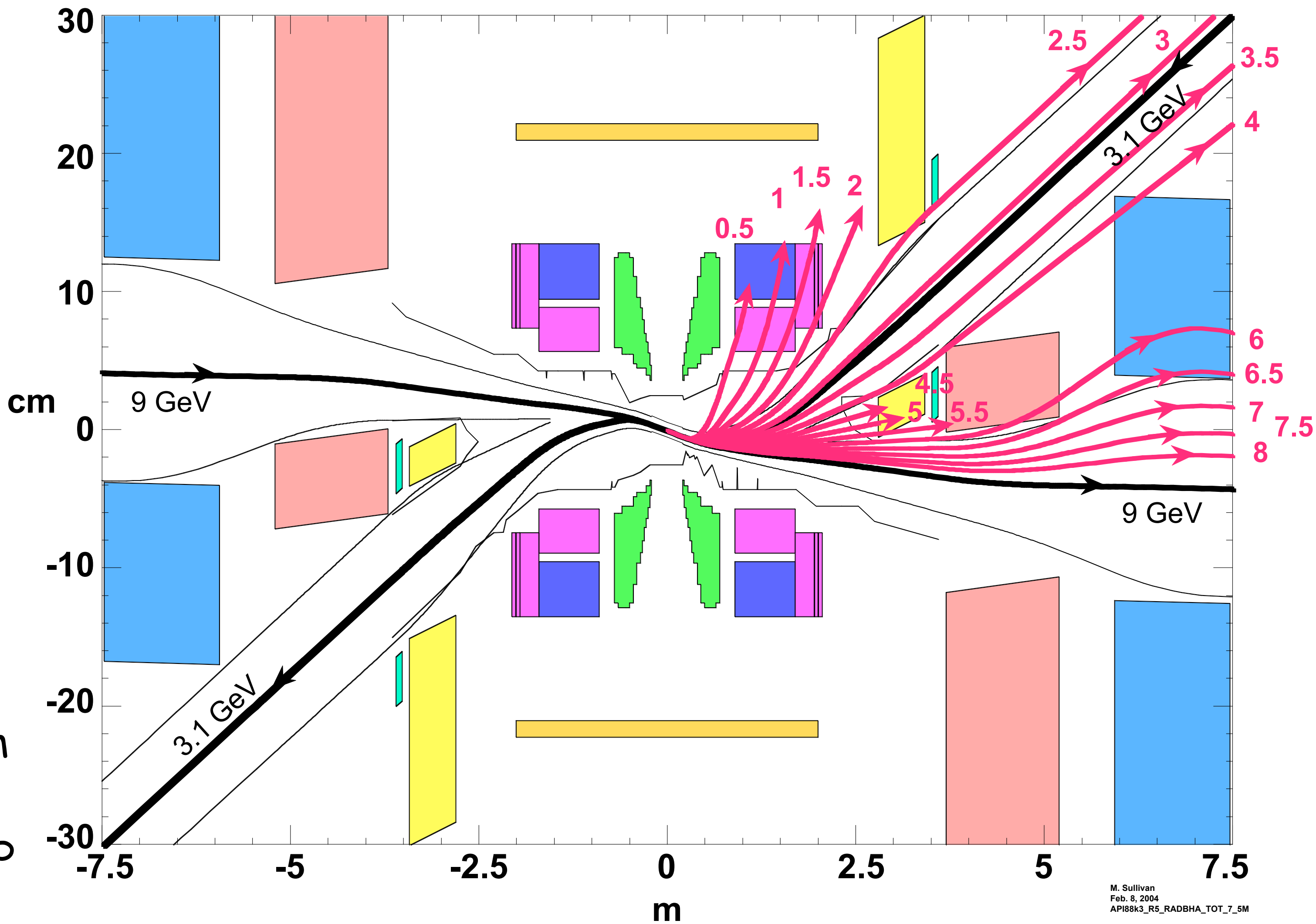
- SR in bend & quadrupole magnets
- Current dependent terms due to residual vacuum



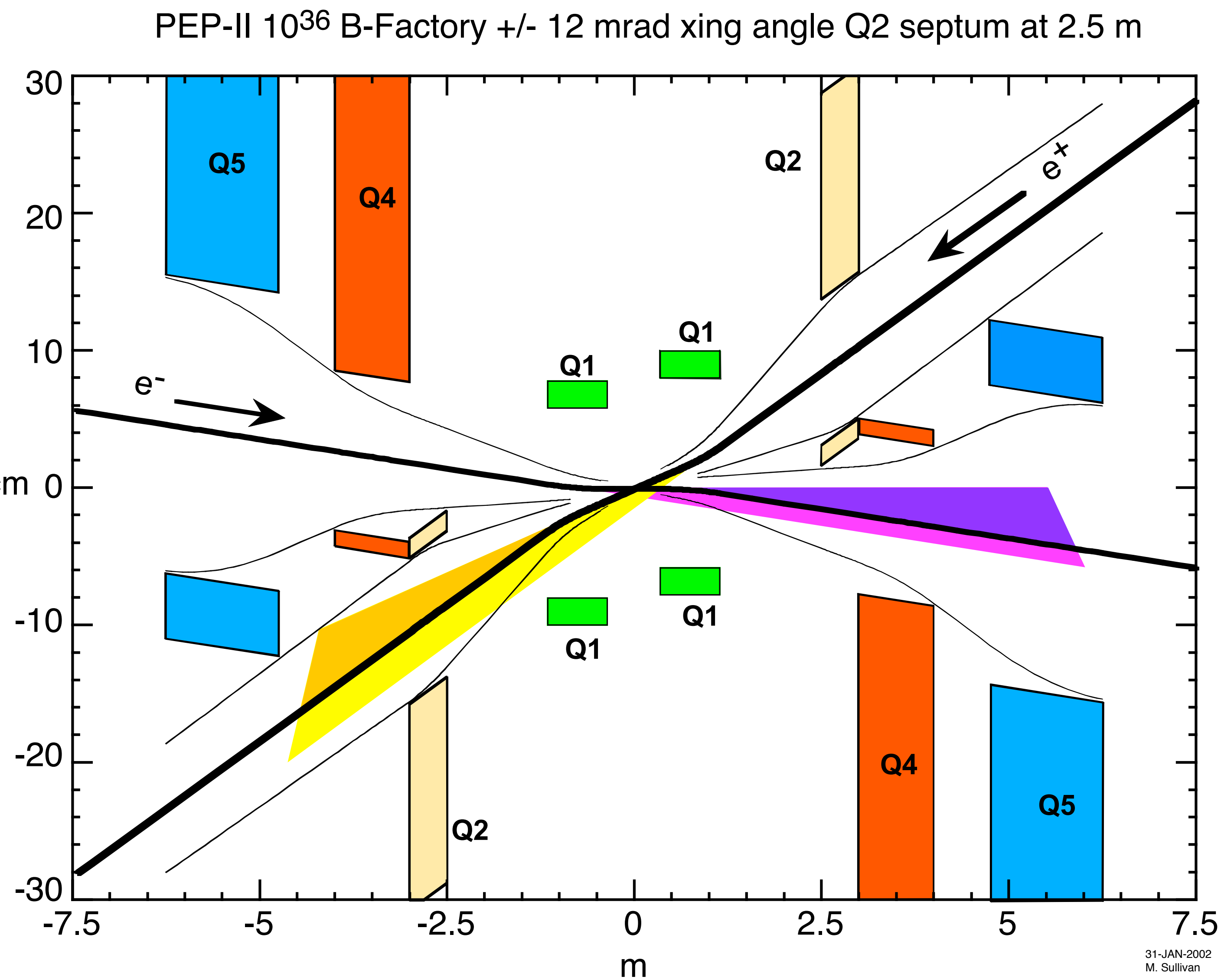
Luminosity-dependent backgrounds

PEP-II Head-On IR Layout

- SR in bend & quadrupole magnets
- Current dependent terms due to residual vacuum
- Bhabha scattering at IP



IR concept for a Super B-Factory



±12 mr crossing angle

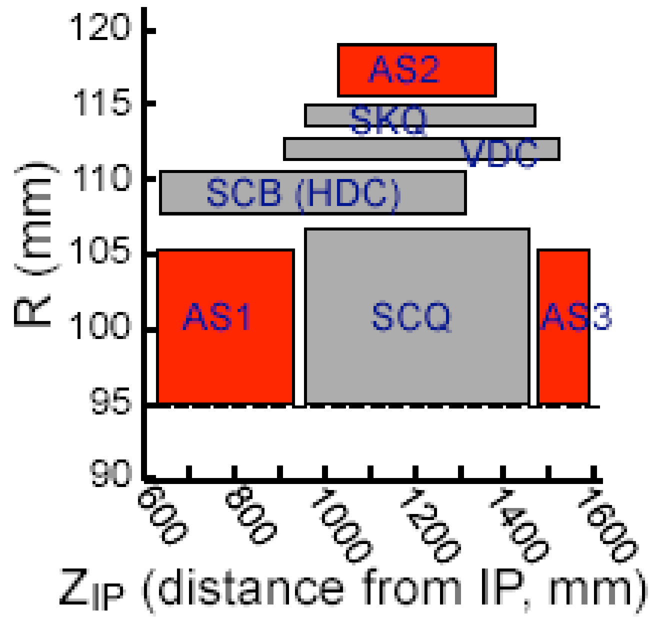
- No background calculations yet

Can luminosity component be reduced?

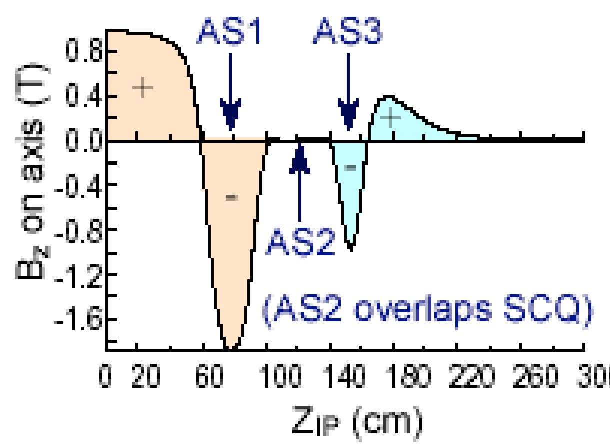
M.Sullivan

New IR magnet design

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

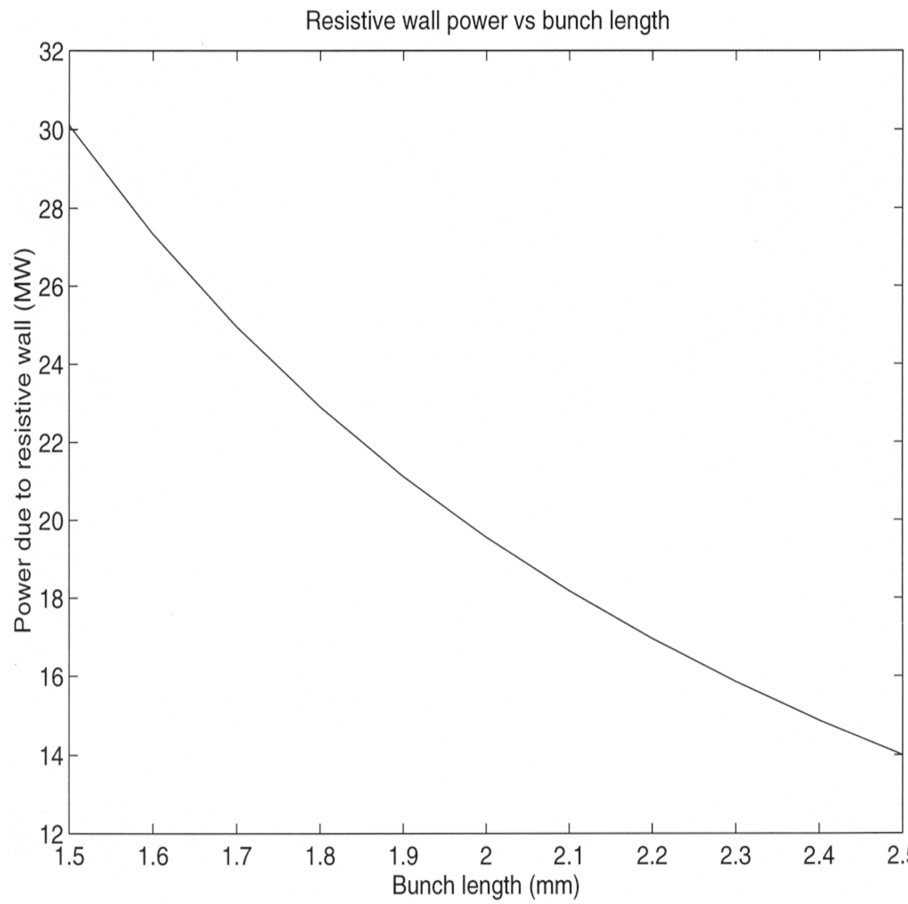


All coils numerically wound on a bobbin.

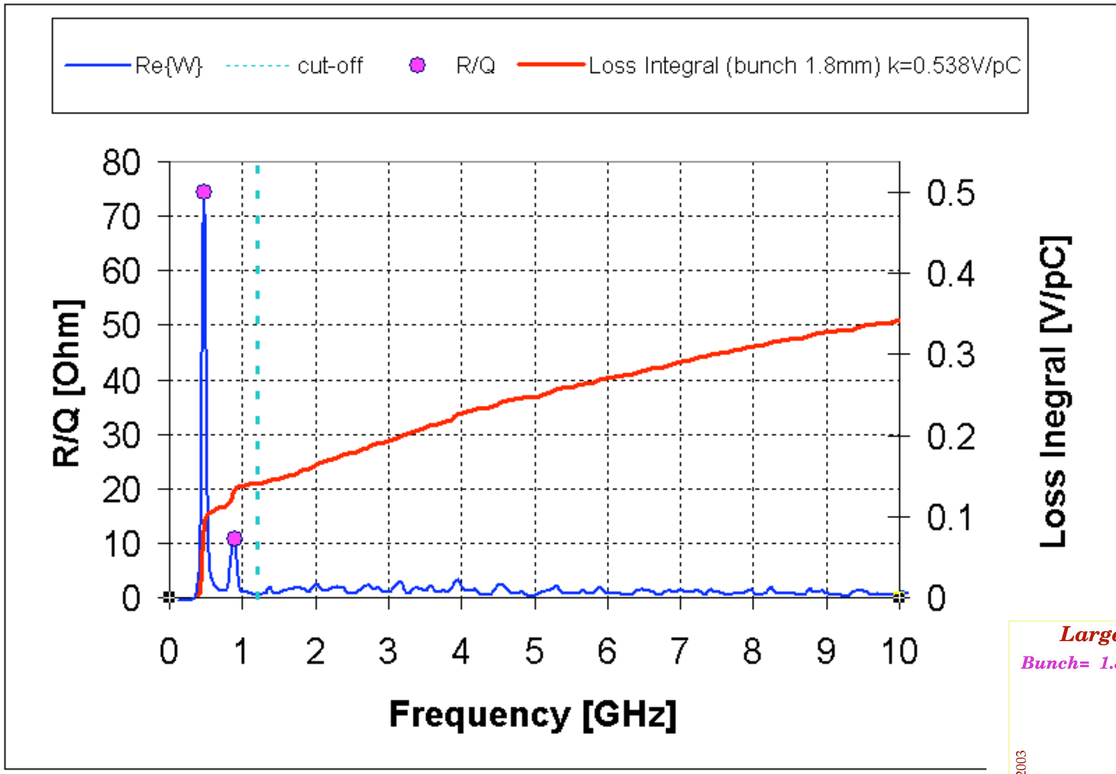


Power scaling equations

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



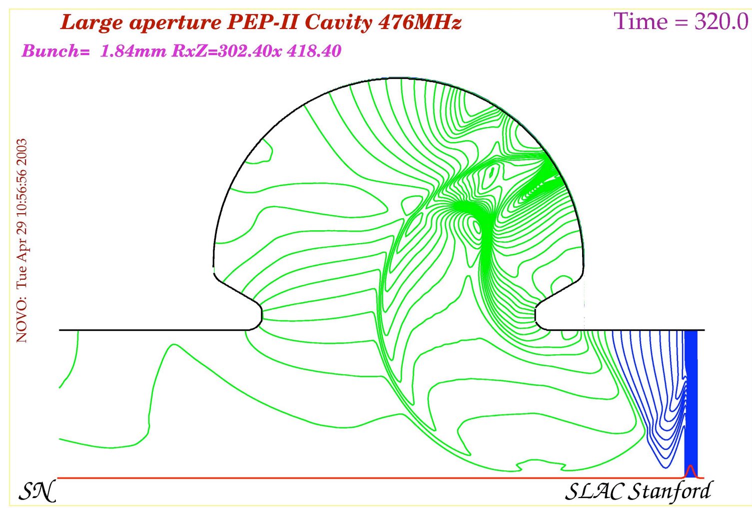
HOM calculations: 476 MHz cavity



S.Novokhotski

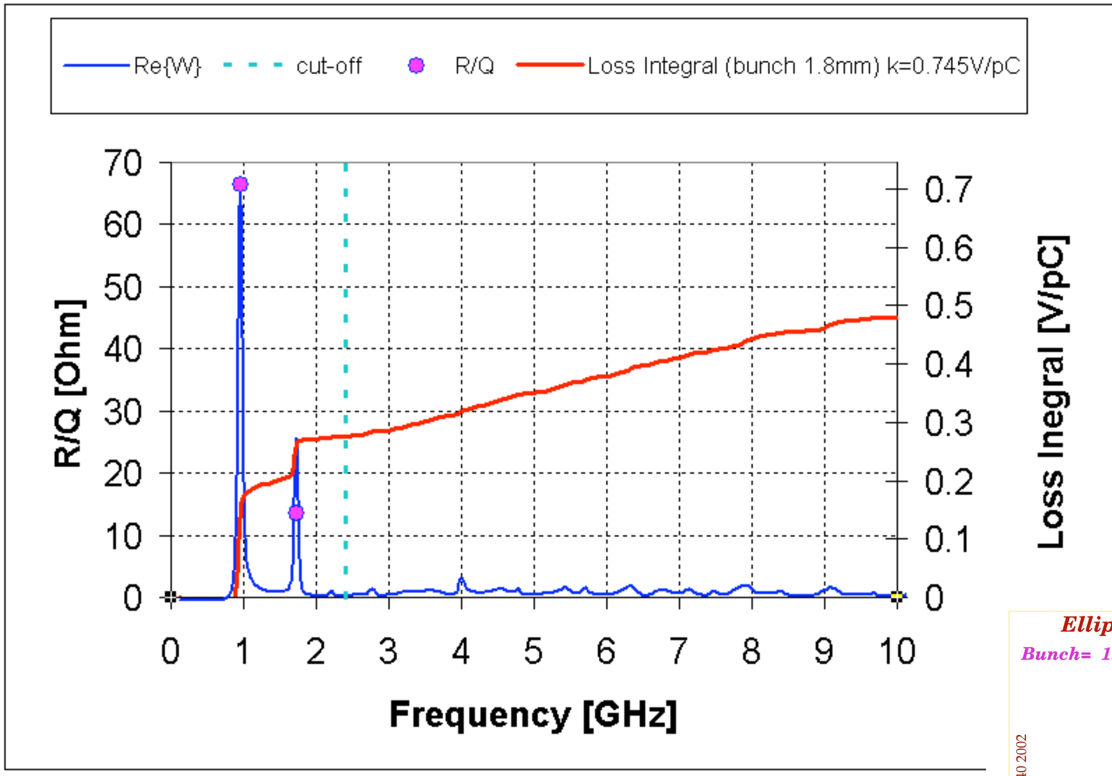
R_{beam} = 95.25 mm
Total loss = 0.538 V/pC
Loss integral above cutoff = 0.397 V/pC

HOM Power = 203 kW @ 15.5A



476 MHz cavity with a larger beam opening

HOM calculations: 952 MHz cavity



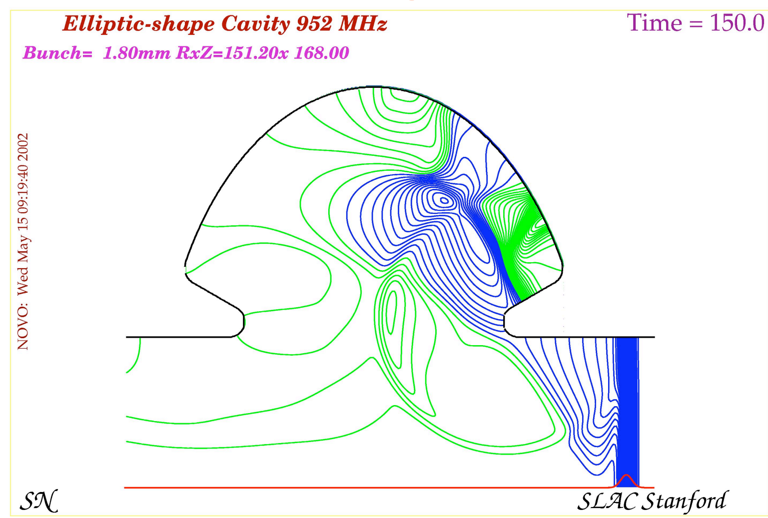
S.Novokhotski

R_{beam} = 47.6 mm

Total loss = 0.748 V/pC

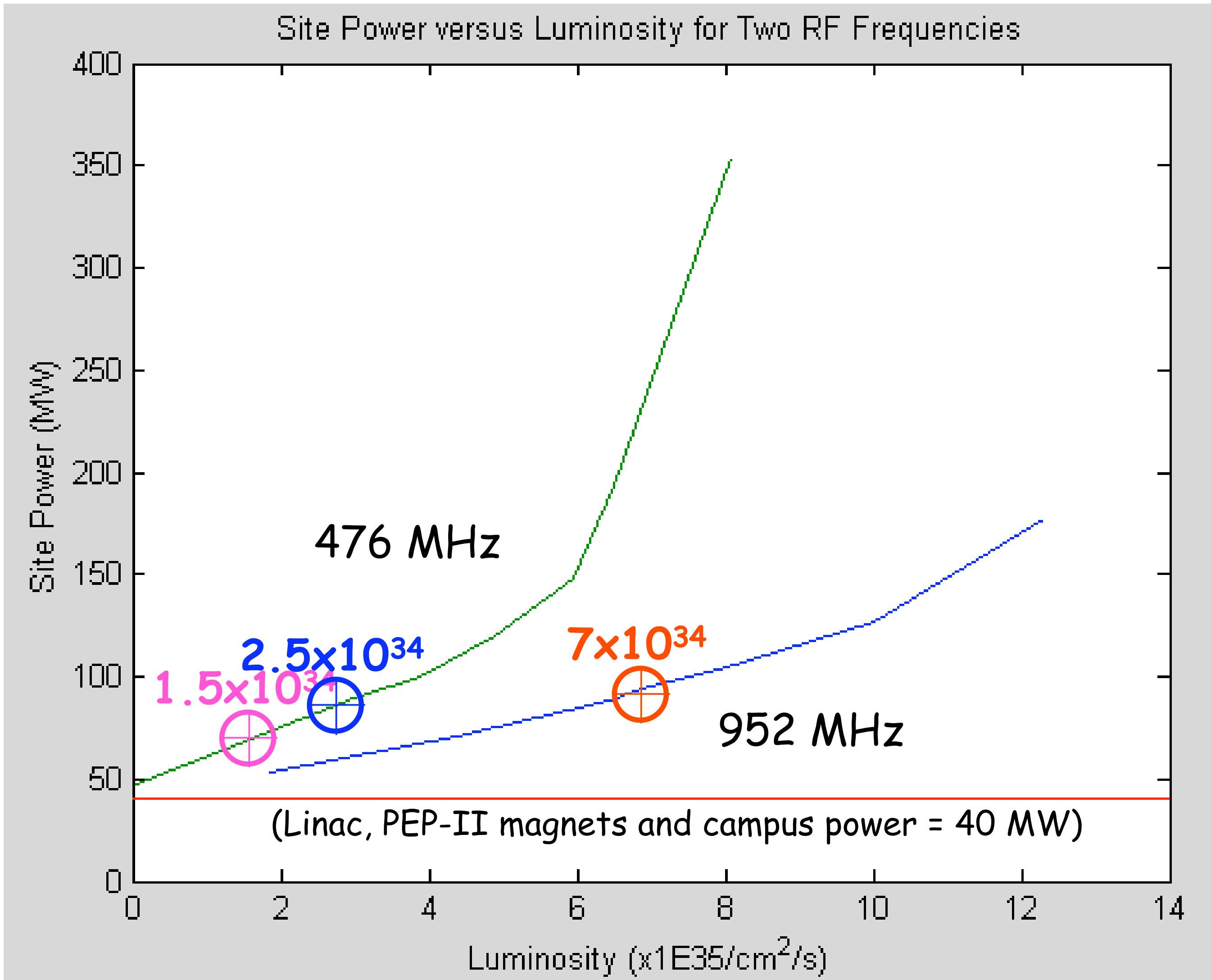
Loss integral above cutoff = 0.472 V/pC

HOM Power = 121 kW @ 15.5A



952 MHz cavity with a larger beam opening

Site power limits



J.Seeman

PEP-II upgrades schemes

Luminosity ($\times 10^{35}$)	1.5	2.5	7	5□ 7
RF frequency (MHz)	476	476	952	476□ 952
Site power (MW)	75	85	100	70□ 100
Crossing angle	No	Yes	Yes	Yes
Crab cavities	No	Yes	Yes	Yes
Replace LER	Yes	Yes	Yes	Yes
Replace HER	No	Yes	Yes	Yes
Upgradeable	No	Yes (to 952MHz)	Yes	Yes

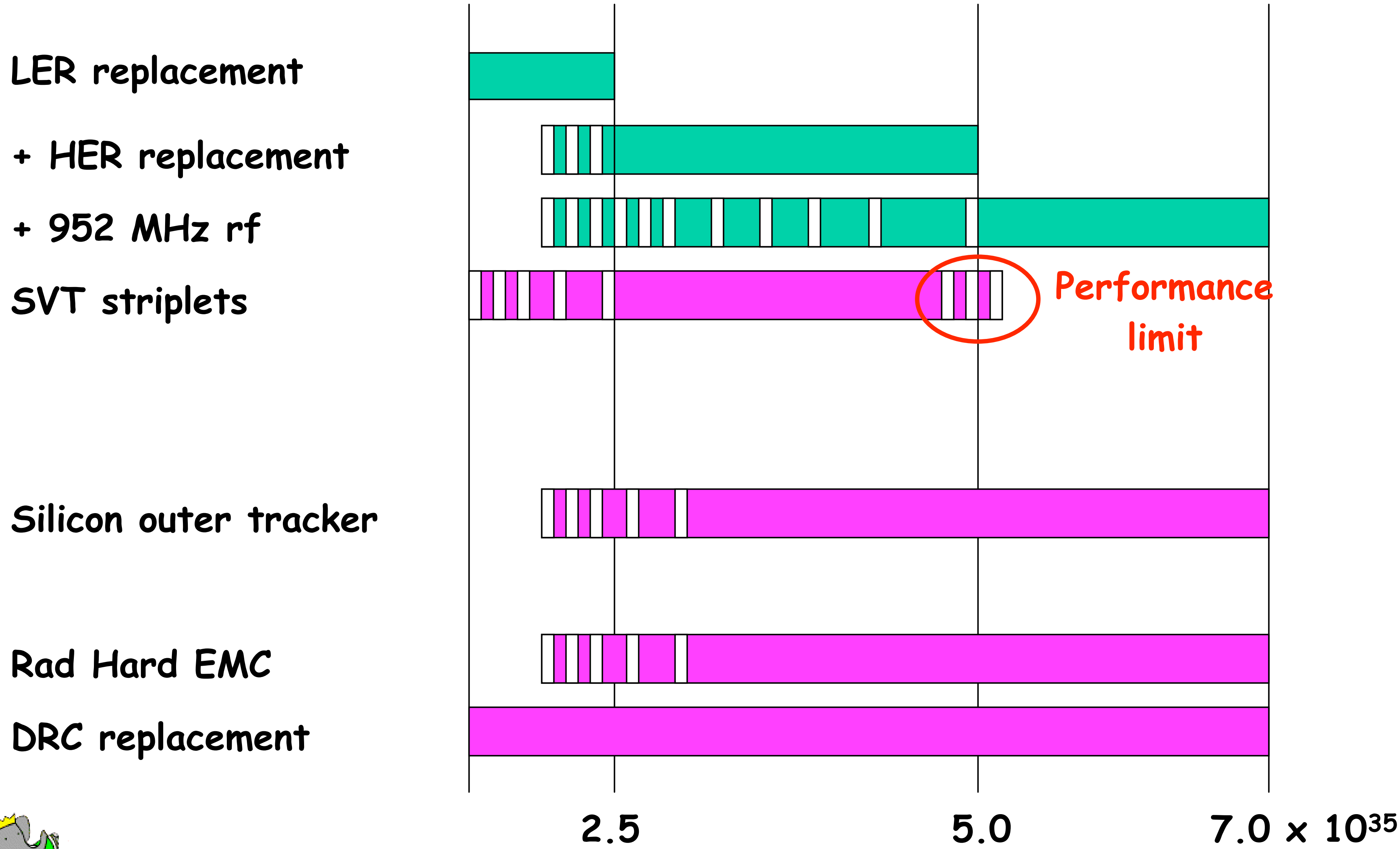
Recommended

Detector requirements depend on projecting backgrounds for luminosities that are >20 times larger than at present

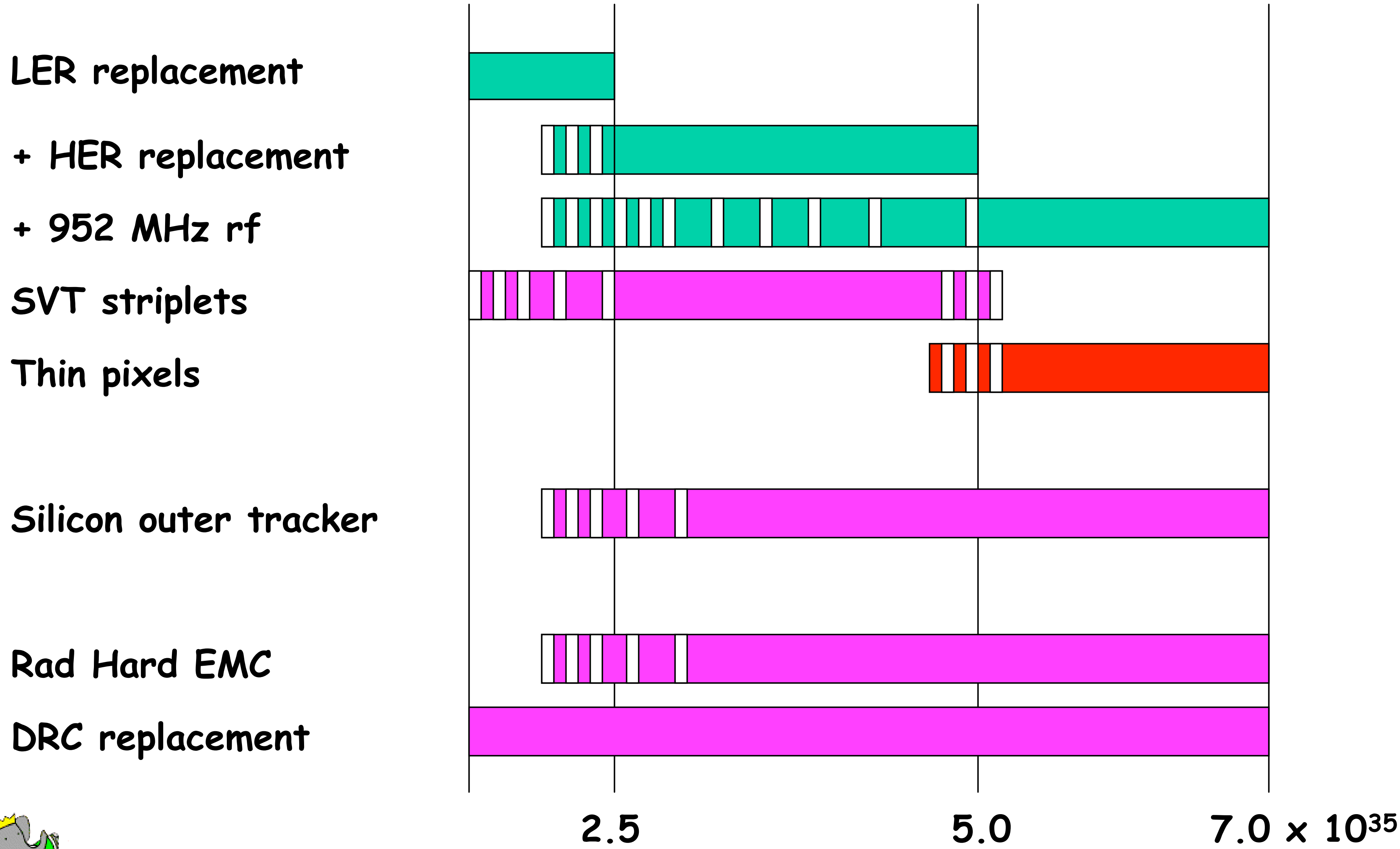
Recommended scenario: 5 to 7 x 10^{35}

- *Replace present RF with 952 MHz frequency over period of time.*
- *Use 8 x 3.5 GeV with up to 15.5 A x 6.8 A.*
- *New LER and HER vacuum chambers with antechambers for higher power (x 4).*
- *Keep present LER arc magnets but add magnets to soften losses; replace HER magnets as well.*
- *New bunch-by-bunch feedback for 6900 bunches (every bucket) at 1 nsec spacing. (Presently designing feedback system being 0.6-0.8 nsec spacing.)*
- *Push β_y^* to 1.5 mm: need new IR (SC quadrupoles) with 15 mrad crossing angle and crab cavities*

Upgrade Plan: Initial 5x10^{35} Project



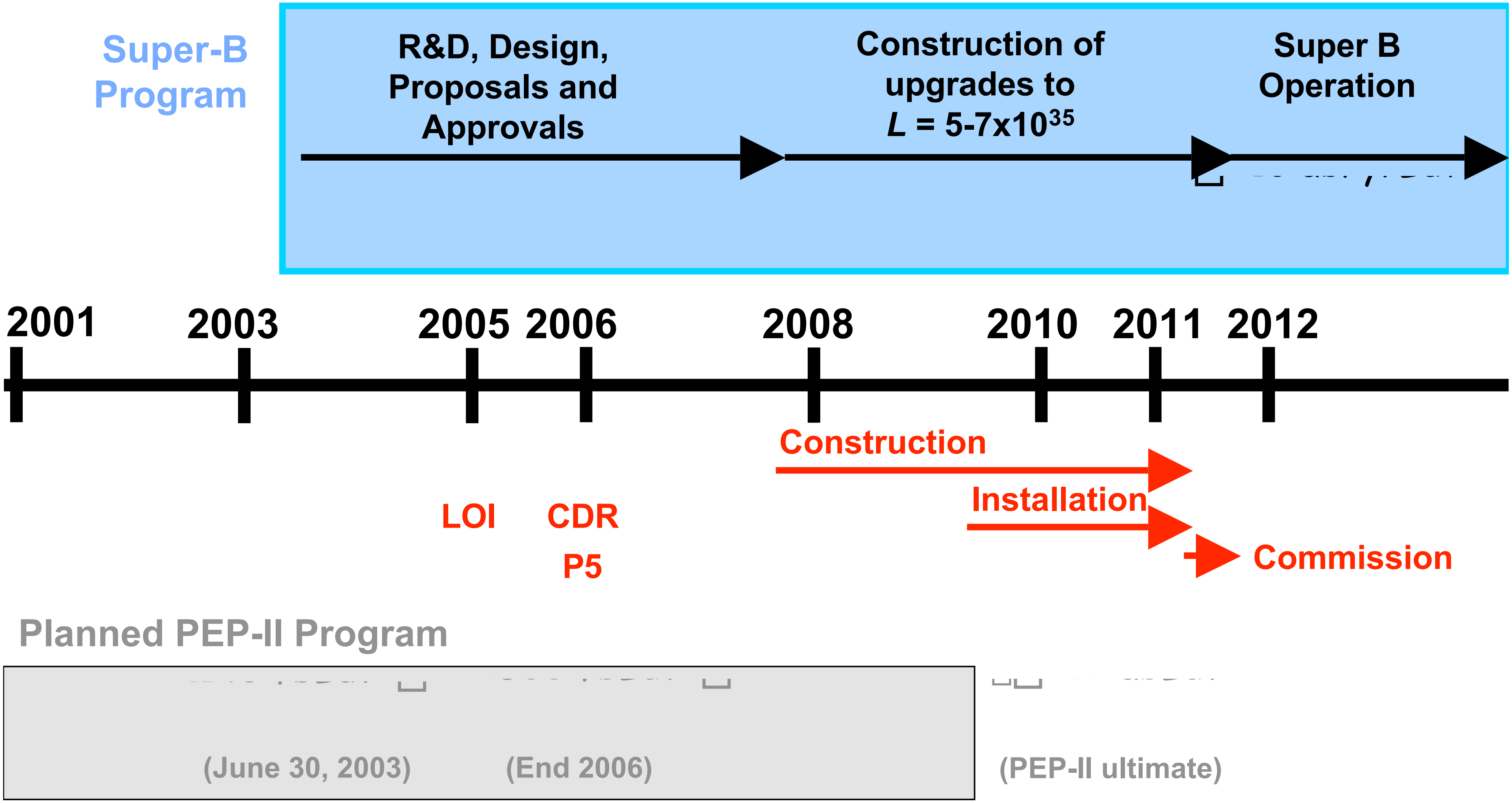
Upgrade Plan: Ultimate Reach



Important Factors in Upgrade Direction

- ***Project is "tunable"***
  - Can react to physics developments
  - Can react to changing geopolitical situation
    - Project anti-commutes with linear collider
    - Will emerge from *BABAR* and Belle, but could be attractive to wider community in context of other opportunities
  - As we learn more about machine and detector requirements and design, can fine tune goals and plans within this framework
- ***Project has headroom***
  - Major upgrades to detector and machine, but none contingent upon completing fundamental R&D
  - Headroom for detector up to 5×10^{35}; with thin pixels beyond
  - Headroom for machine up to 8.5×10^{35}; requires additional rf, which can be staged into machine over time

Possible Timeline for Super B Program



LOI: Super B Factory at KEK

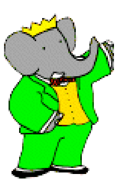
- Machine Parameters
- Beam-Beam Interactions
- Lattice Design
- Interaction Region
- Magnet System
- Impedance and Collective Effects
- RF System
- Vacuum System
- Beam Instrumentation
- Injector Linac
- Damping Ring
- Construction Scenario

SuperKEKB LOI:
KEK Report 04-4
http://belle.kek.jp/superb/

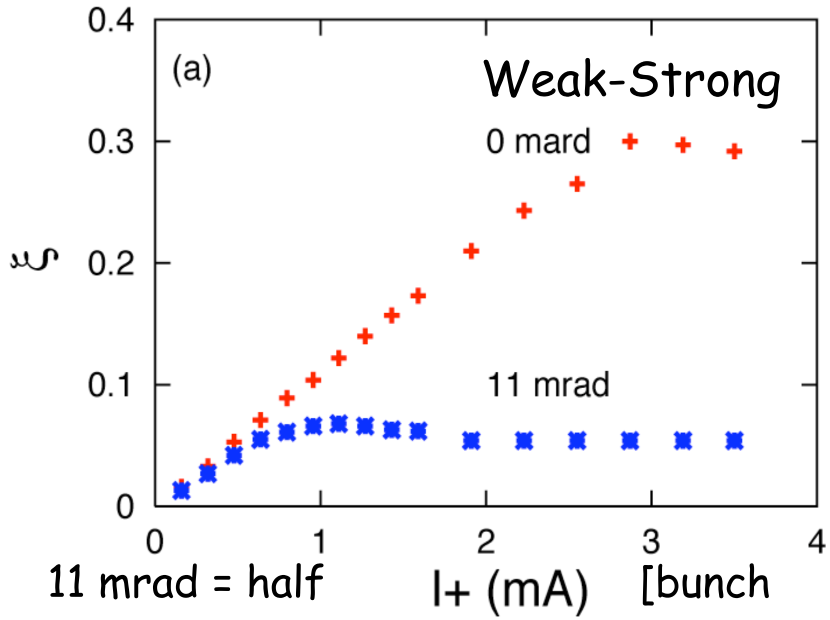
Super KEKB machine parameters

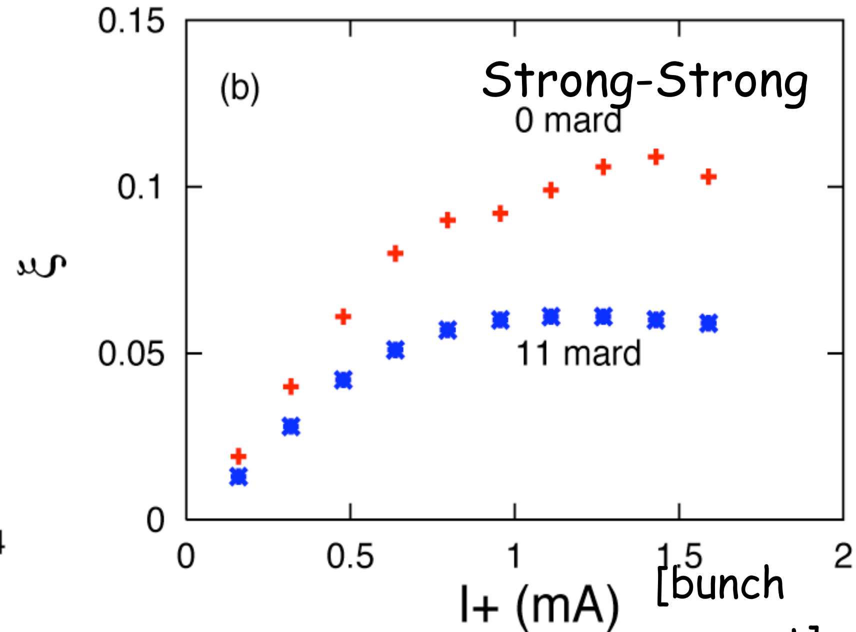
Parameter		LER	HER	Unit
Beam currrent	I	9.4	4.1	A
Number of bunches	n_b	5018		
Horizontal beta at IP	□$_x$	20		cm
Vertical beta at IP	□$_y$	3		mm
Bunch length	□$_z$	3		mm
Emittance	□$_x$	24		nm
Coupling	□	0.75		%
Crossing angle	□$_x$	30 (crab-crossing)		mrad
Momentum compaction	□$_p$	2.7×10^{-4}	1.8×10^{-4}	
RF voltage	V_c	15	20	MV
Synchrotron tune	□$_s$	0.031	0.019	
Vertical beam-beam	□$_y$	0.14 (0.28)		
Luminosity	L	2.5 (5)		$\times 10^{35}$ cm^{-2} s^{-1}

Beam-beam parameter is obtained from simulations: strong-strong (weak-strong)



Simulation: head-on vs finite-crossing





11 mrad = half crossing angle

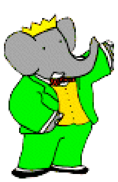
[bunch current]

[bunch current]

- *Beam-beam limit is ~0.05 for finite-crossing collision from the both simulations. (Not much difference between 11 & 15 mrad)*
- *Head-on collision much improves beam-beam parameter.*
- *Discrepancy between Weak-Strong and Strong-Strong simulation is a factor of 2 for head-on collisions.*

Opportunities for Super B Factory

- *Current program of PEP-II/BABAR and KEKB/Belle could attain ~1-2 ab^{-1} by end of the decade*
  - Data samples will be almost 10x larger than now and 100-200x times larger than CLEO
    - **With such a large increase in sensitivity to rare decays, expect that there is a significant discovery potential**
    - **Rich program of flavor physics/CP violation to be pursued**
- *Even larger samples may offer opportunity to search for new physics in CP violation and rare decays*
  - High-luminosity asymmetric e^+e^- colliders with luminosities 10^{35}-10^{36} $cm^{-2}s^{-1}$ and up to 10 ab^{-1}/year – "Super *B* Factory"
    - **Emphasis on discovery potential and complementarity in an era when LHC is operating, along with LHCb and BTeV (?)**
    - **Complementary flavor physics if LHC discovers SUSY, etc; discovery window if no new physics seen?**

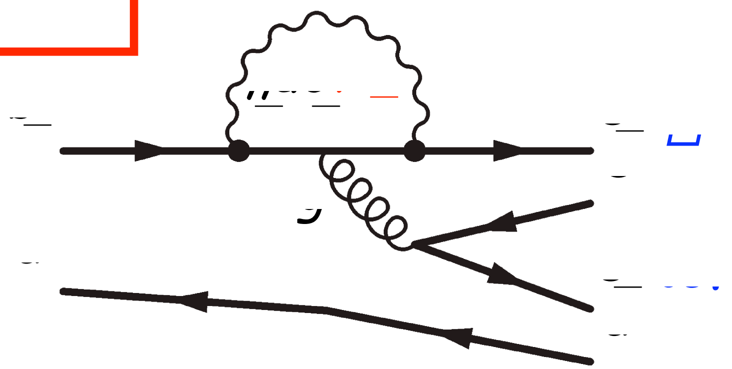


Physics Capabilities: Angle Projections

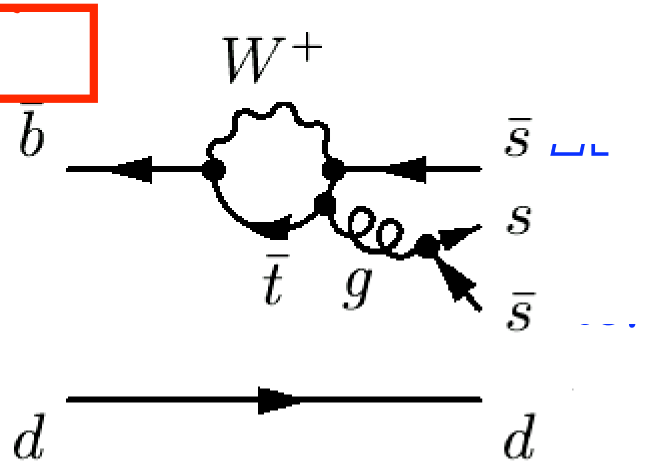
Unitarity Triangle Angles [degrees]	e^+e^- [ab^{-1}]			Hadronic b [1yr]	
Measurement	3	10	50	LHCb	BTeV
□(□□) ($S_{□□}$, B□ □□ BR's+ isospin)	6.7	3.9	2.1	-	-
□(□□) (Isospin, Dalitz) (syst ≥3°)	3, 2.3	1.6, 1.3	1, 0.6	2.5 -5	4
□ (□□) (penguin, isospin, stat+syst)	2.9	1.5	0.72		
□(J/□K_S) (all modes)	0.3	0.17	0.09	0.57	0.49
□(B□ $D^{(*)}$K) (ADS)		2-3		~10	<13
□(all methods)		1.2-2			

Theory: □ ~ 5%, □ ~ 1%, □ ~ 0.1%

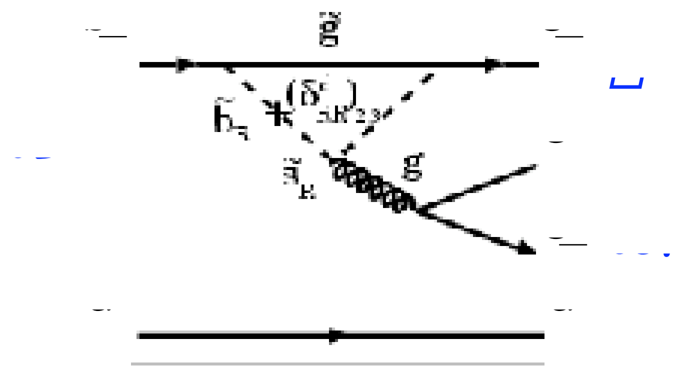
Potential New Physics contributions



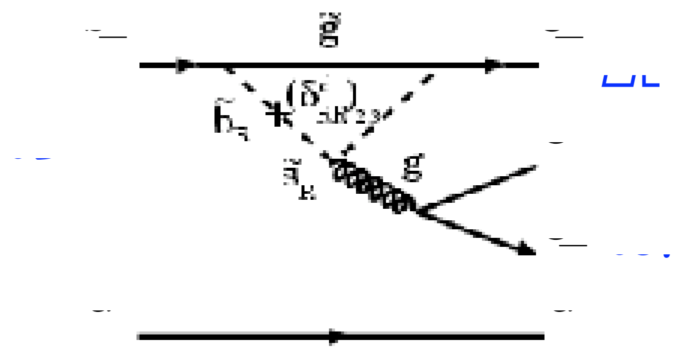
"Internal Penguin"



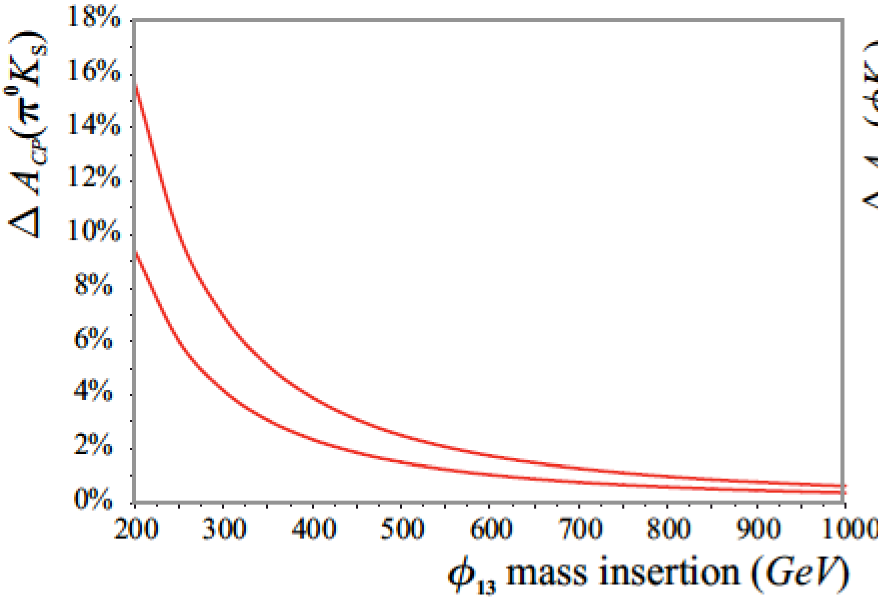
New physics in loops?

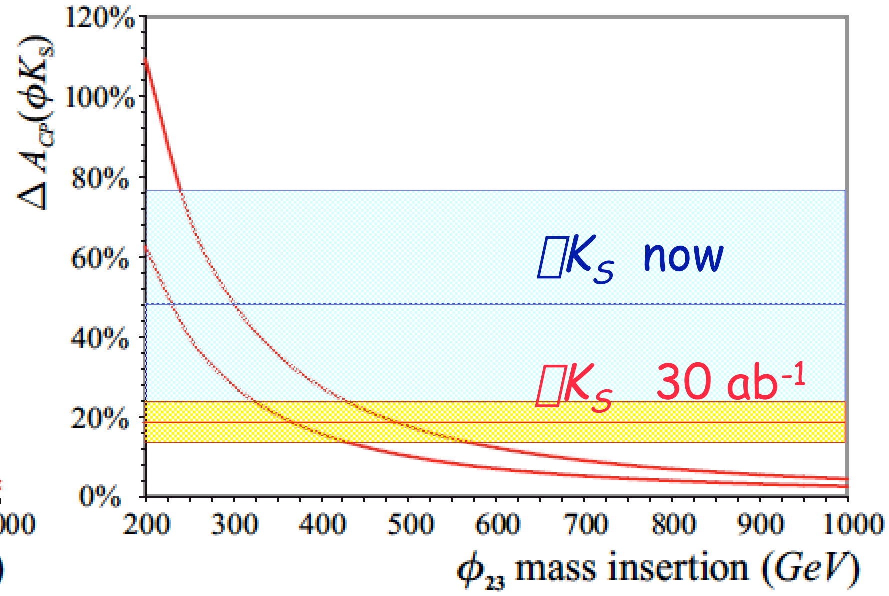


SUSY contribution with new phases



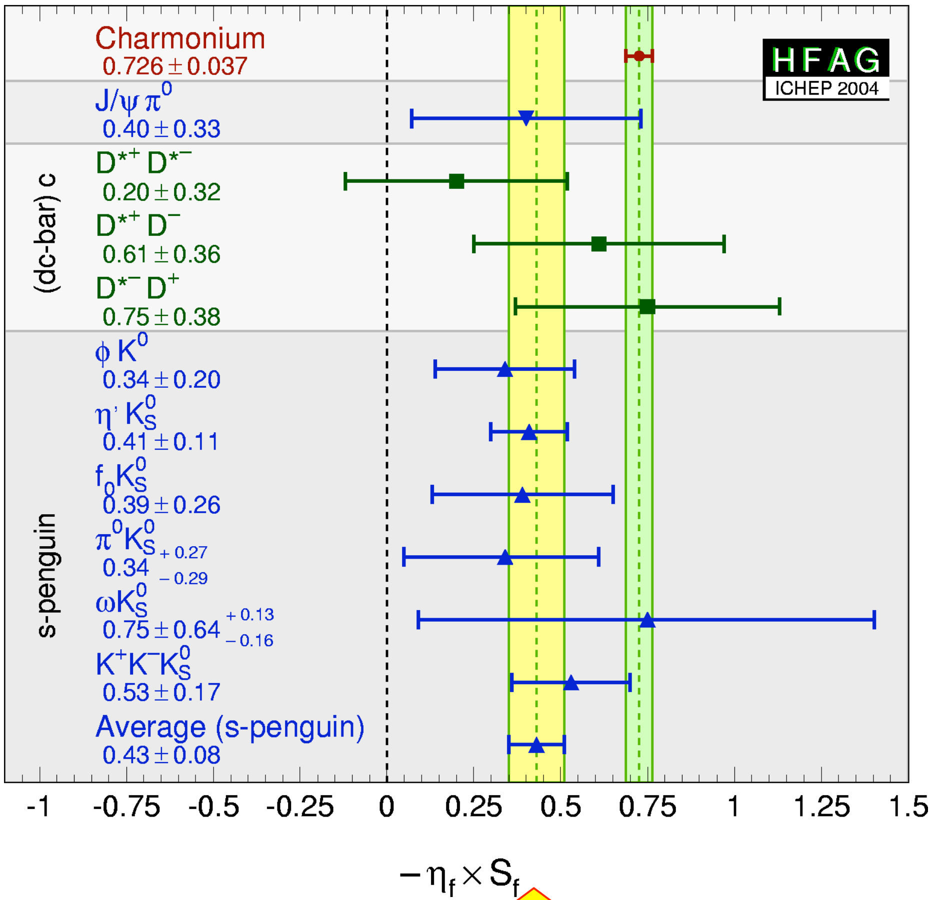
New Physics Sensitivity

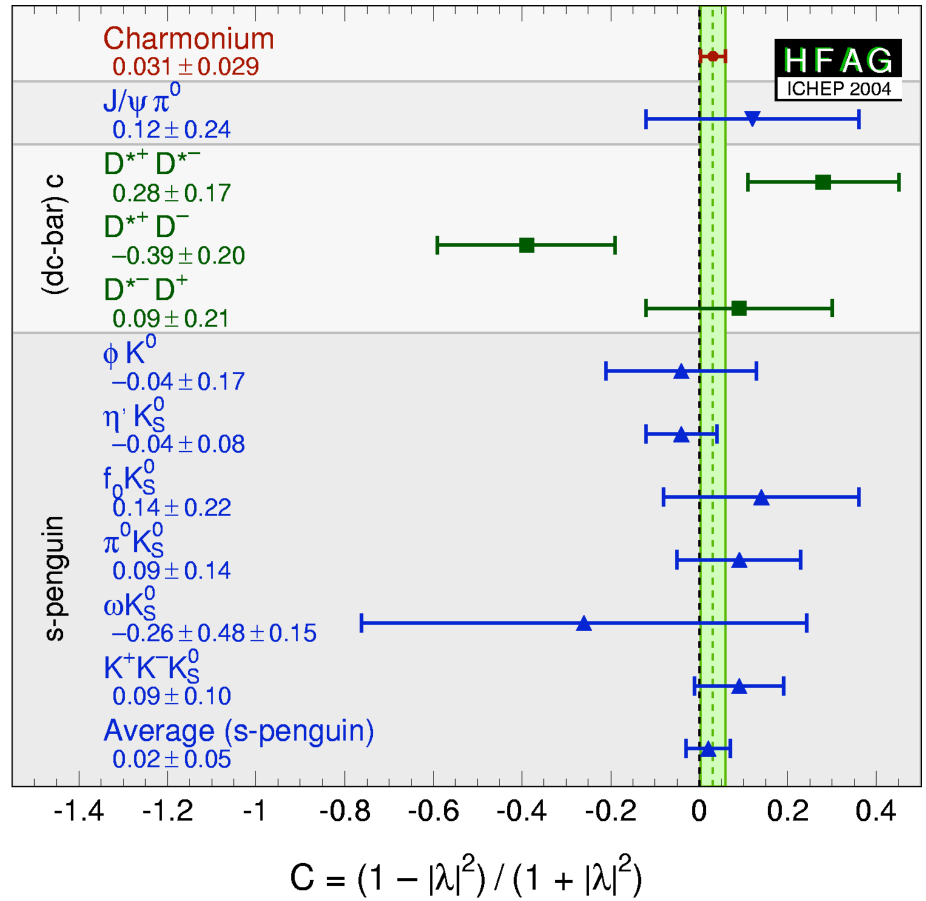




Ciuchini, Franco, Martinelli, Masiero, & Silvestrini

Averages for sin2 and s-penguin modes





3.6s from s-penguin to sin2b (cc)

No sign of Direct *CP* in averages

CP Violation in b→s penguins

Rare Decays, New Physics, CPV [%]		e^+e^- [ab^{-1}]			Hadronic b [1yr]	
Measurement	Goal	3	10	50	LHCb	BTeV
S(B^0□ □K_S)	SM: <5	16	8.7	3.9	16 (?)	7 (?)
S(B^0□ □K_S+□K_L)	SM: <5					
S(B□ □'K_s)	SM: <5	5.7	3	1		
S(B□ K_s□^{0})	SM: <5	8.2	5	4		
S(B□ K_s□^{0}□)	SM: <2	11.4	6	4		
A_{CP} (b□ s□)	SM: <0.5	2.4	1	0.5		
A_{CP}(B□ K*□)	SM: <0.5	0.59	0.32	0.14	-	-
CPV in mixing (|q/p|)		<0.6			-	-

CP Violation in b→s penguins

Rare Decays, New Physics, CPV [%]		e^+e^- [ab^{-1}]			Hadronic b [1yr]	
Measurement	**Goal**	**3**	**10**	**50**	**LHCb**	**BTeV**
$S(B^0$□ □$K_S)$	SM: <0.25	16	8.7	3.9	16 (?)	7 (?)
$S(B^0$□ □K_S+□$K_L)$	SM: <0.25					
$S(B$□ □$'K_s)$	SM: <0.3	5.7	3	1		
$S(B$□ K_S□$^0)$	SM: <0.2	8.2	5	4		
$S(B$□ K_S□□ □$)$	[illegible]	[illegible]	[illegible]	4		
A_{CP} (b□ s□)	SM: <0.5	2.4	1	0.5		
A_{CP}(B□ K*□)	SM: <0.5	0.59	0.32	0.14	-	-
CPV in mixing (|q/p|)		<0.6			-	-

Discovery potential at Super *B* for non-SM physics

More Rare decays precision

Rare Decays – New Physics		e^+e^- [ab^{-1}]			Hadronic b [1 yr]	
Measurement	Goal	3	10	50	LHCb	BTeV
□(b□ d□) / □(b□ s□)					-	-
□(B□ D$^{(*)}$□□)	SM:8x10^{-3}	10.2%	5.6%	2.5%	-	-
□(B□ s□□) (K$^{-,0}$,K*$^{-,0}$)	SM: ~5% 1 excl: 4x10^{-6}			~3□	-	-
□(B□ invisible)		<2x10^{-6}	<1x10^{-6}	<4x10^{-7}	-	-
□(B$_d$ □ □□)		-	-		1-2 evts	1-2 evts
□(B$_d$ □ □□)		-	-		-	-
□(□□ □□)			<10^{-8}		-	-

More Rare decays precision

Rare Decays – New Physics		e^+e^- [ab^{-1}]			Hadronic b [1 yr]	
Measurement	Goal	3	10	50	LHCb	BTeV
□(b□ d□) / □(b□ s□)					-	-
□(B□ $D^{(*)}$□□)	SM: 8×10^{-3}	10.2%	5.6%	2.5%	-	-
□(B□ s□□) ($K^{-,0}$, $K^{*-,0}$)	SM: ~5% [illegible] 4×10^{-6}			~3□	-	-
□(B□ invisible)		$<2\times10^{-6}$	$<1\times10^{-6}$	$<4\times10^{-7}$	-	-
□(B_d □ □□)		-	-		1-2 evts	1-2 evts
□(B_d □ □□)		-	-		-	-
□(□□□□)			[illegible]			-

Discovery potential at Super *B* for non-SM physics

Discovery potential at Super *B* for non-SM physics

$b \to s l^+ l^-$ precision

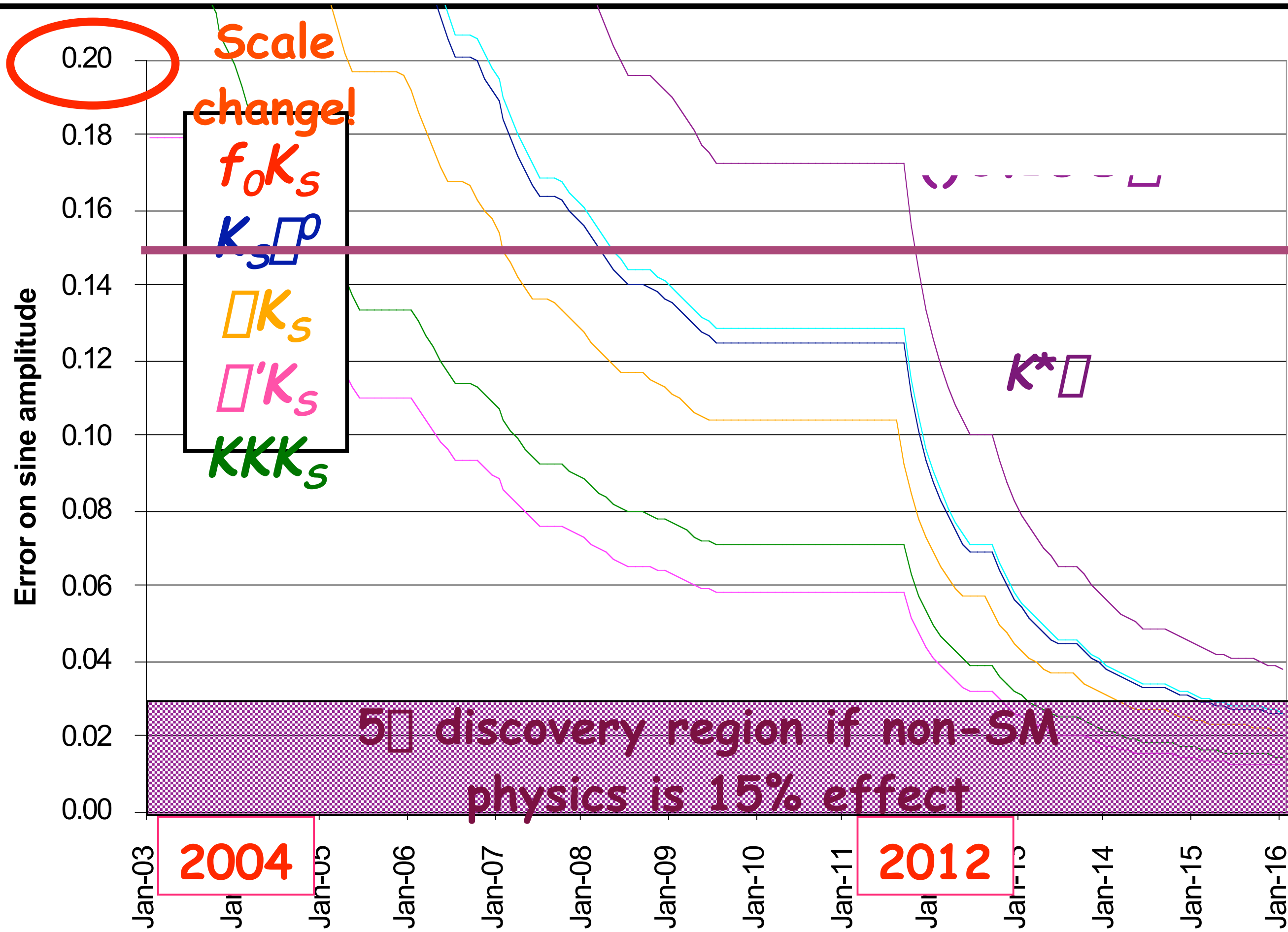
New Physics – Kl^+l^-, sl^+l^- [%]		e^+e^- [ab^{-1}]			Hadronic b [1 yr]	
Measurement	**Goal**	**3**	**10**	**50**	**LHCb**	**BTeV**
$\Gamma(B\to K\mu^+\mu^-)/\Gamma(B\to Ke^+e^-)$	SM: 1	~8	~4	~2	-	-
$A_{CP}(B\to K^*\mu^+\mu^-)$: all	SM: <5	~6	~3	~1.5	~1.5	~2
$A_{CP}(B\to K^*\mu^+\mu^-)$: high mass	SM: <5	~12	~6	~3	~3	~4
$A^{FB}(B\to K^*\mu^+\mu^-)$: s_0 $A^{FB}(B\to K^*\mu^+\mu^-)$: A_{CP}	SM: ±5	~20	~9	9	~12	
$A^{FB}(B\to s\mu^+\mu^-)$: $\hat{s}_0$		27	15	6.7		
$A_{FB}(B\to s\mu^+\mu^-)$: C_9, C_{10}		36-55	20-30	9-13		

$b \to s l^+ l^-$ precision

New Physics – Kl^+l^-, sl^+l^- [%]		e^+e^- [ab^{-1}]			Hadronic b [1 yr]	
Measurement	**Goal**	**3**	**10**	**50**	**LHCb**	**BTeV**
$R(B\to K\mu^+\mu^-)/R(B\to Ke^+e^-)$	SM: 1	~8	~4	~2	-	-
$A_{CP}(B\to K^*\ell^+\ell^-)$: all	SM: <5	~6	~3	~1.5	~1.5	~2
$A_{CP}(B\to K^*\ell^+\ell^-)$: high mass	SM: <5	~12	~6	~3	~3	~4
$A^{FB}(B\to K^*\ell^+\ell^-)$: s_0 $A^{FB}(B\to K^*\ell^+\ell^-)$: A_{CP}	SM: ±5	~20	~9	9	~12	
$A^{FB}(B\to s\ell^+\ell^-)$: $\hat{s}_0$		27	15	6.7		
$A_{FB}(B\to s\ell^+\ell^-)$: C_9, C_{10}		36-55	20-30	9-13		

Discovery potential at Super B for non-SM physics

Projections for Super B Factory



Luminosity expectations

Super B Factory
$5\text{-}7 \times 10^{35}\ cm^{-2}s^{-1}$

Projections are statistical errors only; but systematic errors at few percent level

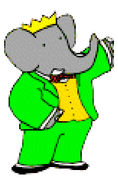
Conclusions

- ***Strong physics case for Super B Factory***
  - Program rests on ability to explore of new physics through flavor couplings and phases
    - Complementary to LHC collider experiments
    - Complementary to hadron *b* experiments; could even be viewed as natural successor
  - Precision Standard Model physics a second fundamental pillar of program
- ***Arguments will evolve with time and data***
  - Perhaps our data is already hinting at new physics, which will motivate further precision studies of flavor physics
  - couplings and phases

Physics case may very well continue to strengthen with time

Conclusions

- *Next Steps*
  - Working to find common ground with Belle and to engage wider community in exploring physics capabilities
  - Focusing on critical issues and necessary detector R&D; will need support from DOE and national funding agencies
  - Intend to develop a site specific conceptual and technical designs for a Super *B* Project on appropriate time scale, including better understanding of expected backgrounds
    - Builds on proven track record of high-luminosity storage rings and general purpose e^+e^- detectors
    - Builds on our present knowledge of *CP* violation and rare *B* decays; expect that case will only strengthen as we explore ever increasing data samples over the next few years
  - Aim to gain a better understanding of detector requirements and limitations imposed by backgrounds



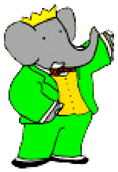
References

- EOI and LOI (Jan 04) for SuperKEKB [http://belle.kek.jp/superb/]
- Super B Workshop in Hawaii (Jan 04) [http://www.phys.hawaii.edu/~superb04/]
- BABAR Roadmap Report (Jul 04)
- 10^{36} Workshop (available shortly)

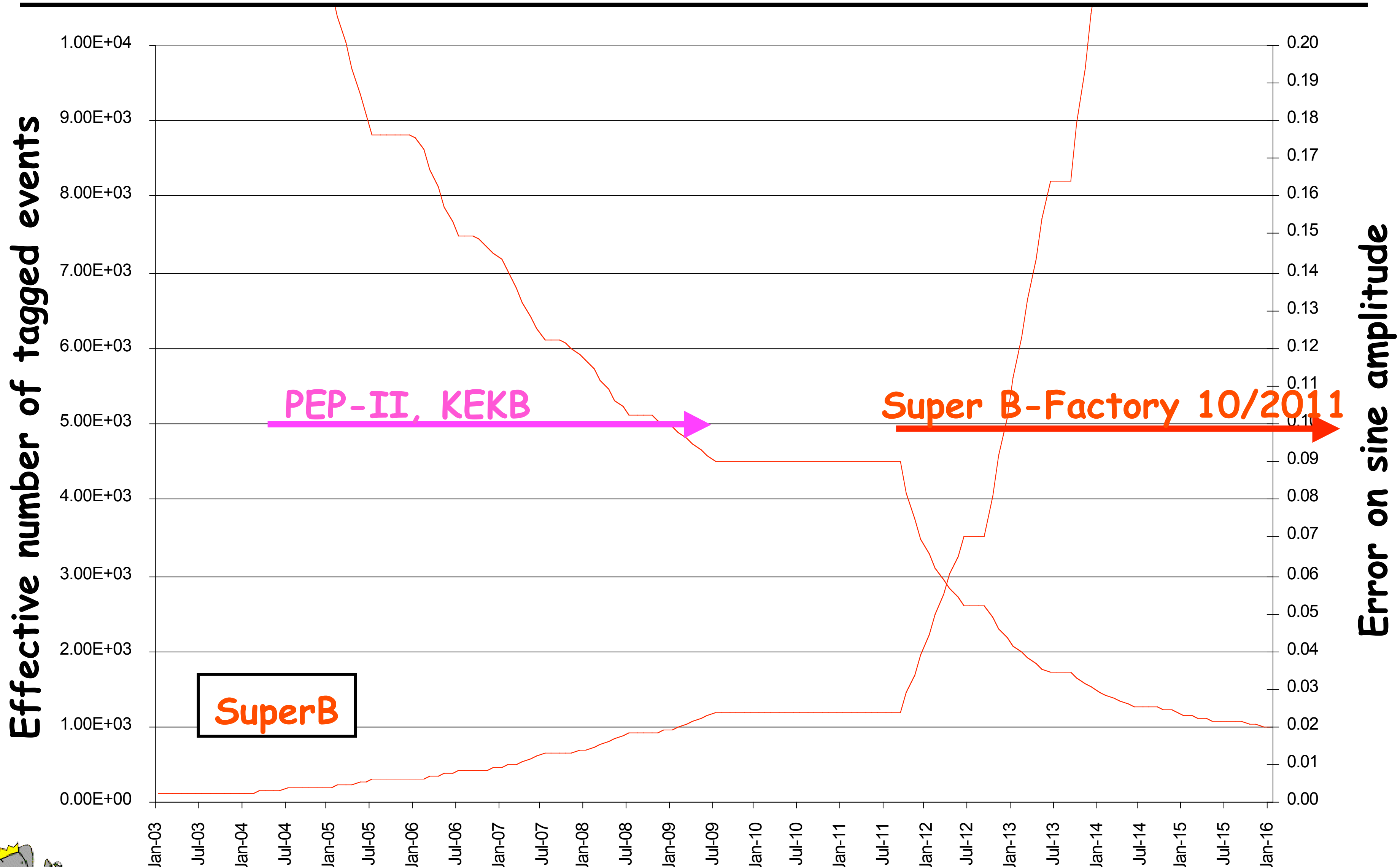
Backup Slides

Projecting Physics Reach

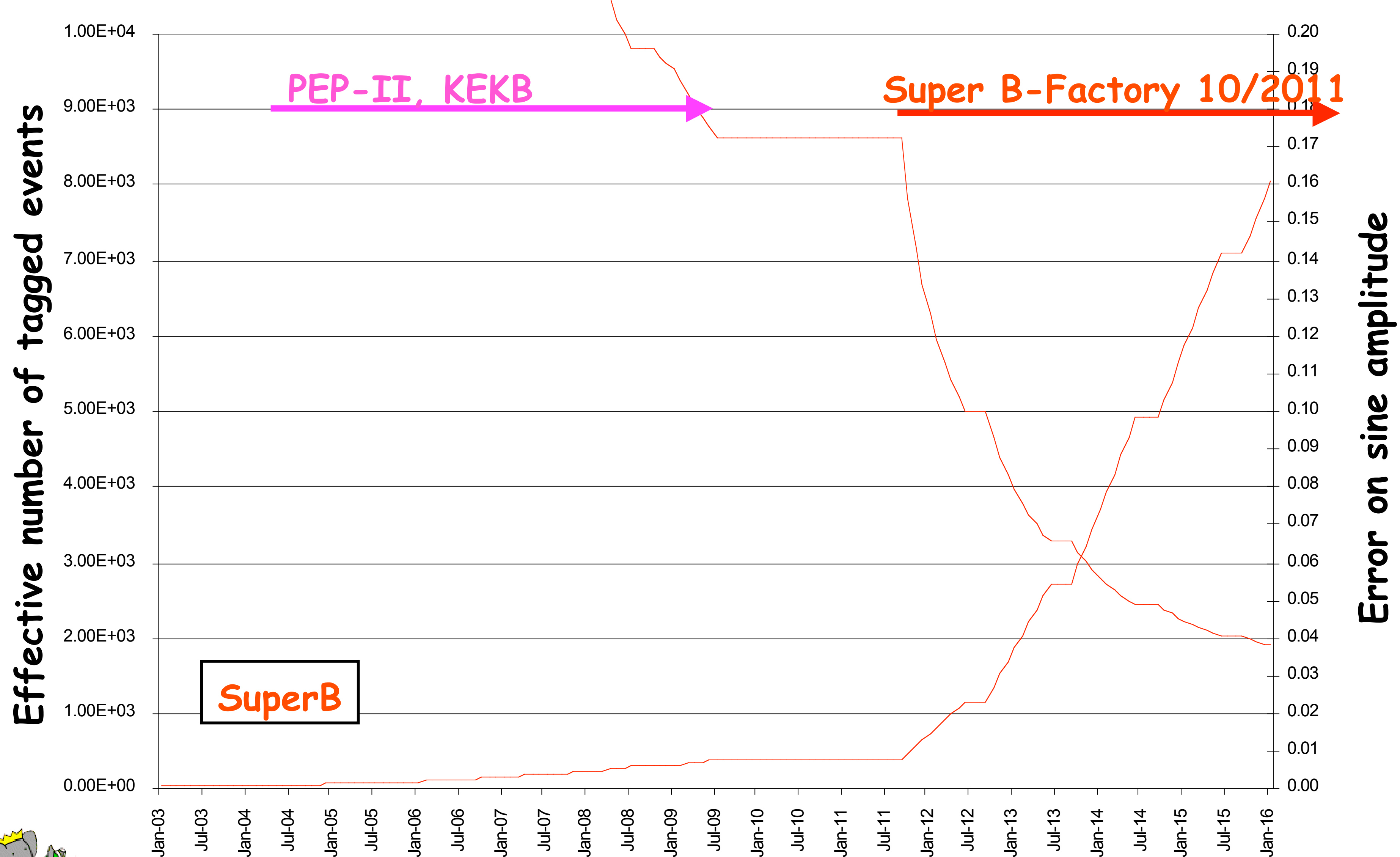
- ***Working assumptions for projections***
  - LHCb:
    - Start in Jan 2008 with 50% of design for 2 years
  - BTEV:
    - Start in Jan 2010 with 50% of design for 2 years
  - Rolling start for Super *B* Factory:
    - Oct 2011 = 2.5×10^{35}
    - Oct 2012 = 5×10^{35}
    - Oct 2013 = 7×10^{35} with replacement of inner SVT by thin pixel device



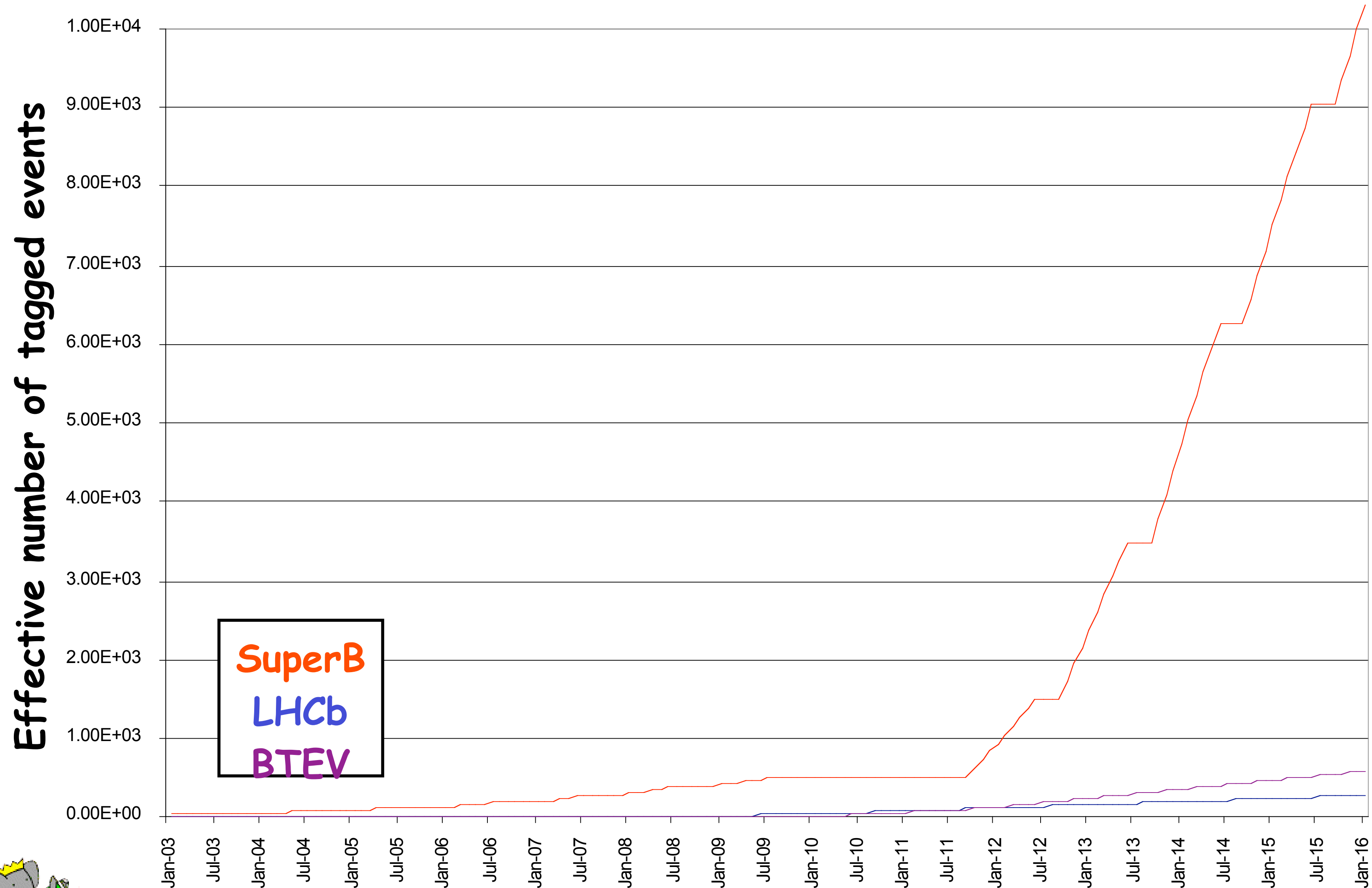
Projections for □+□-



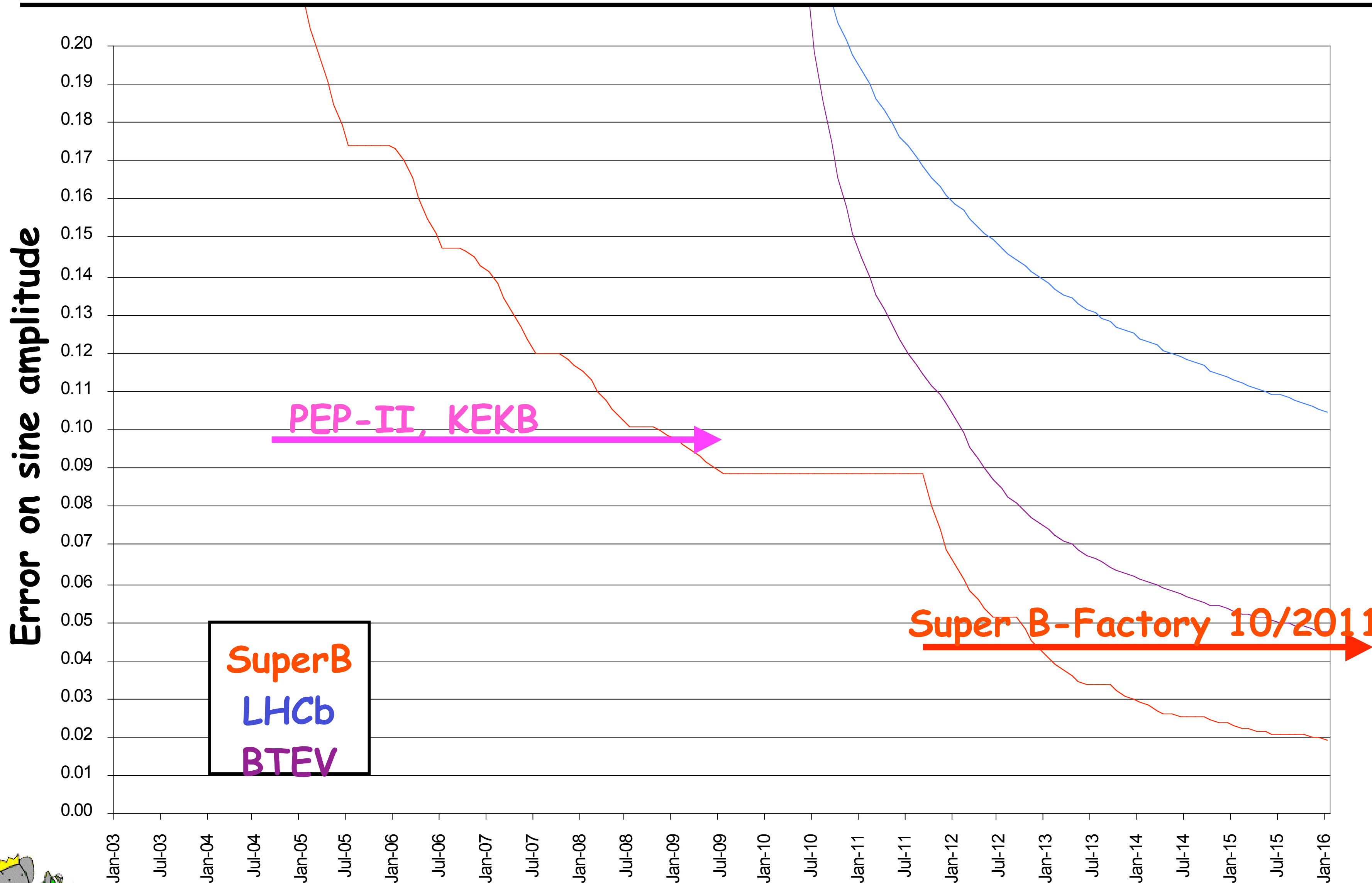
Projections for $K^*\gamma$



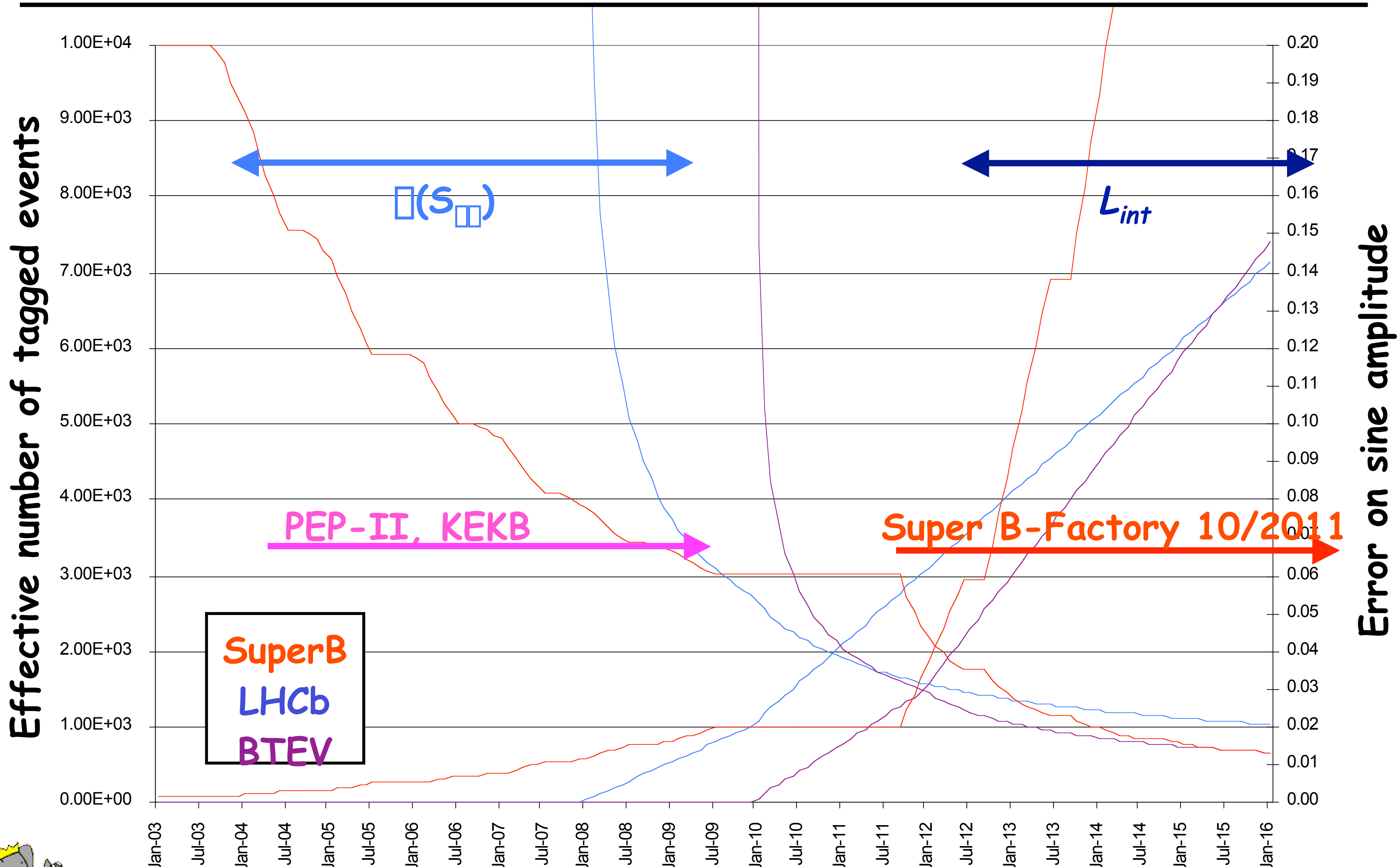
Tagged Sample Projections for K^0



Error Projections for □K^0



Projections for [?]+[?]-



Projections for 2-Body Isospin Analysis