SSC and VLHC What (Acc.-Physics-) Lessons are Applicable to HE-LHC?

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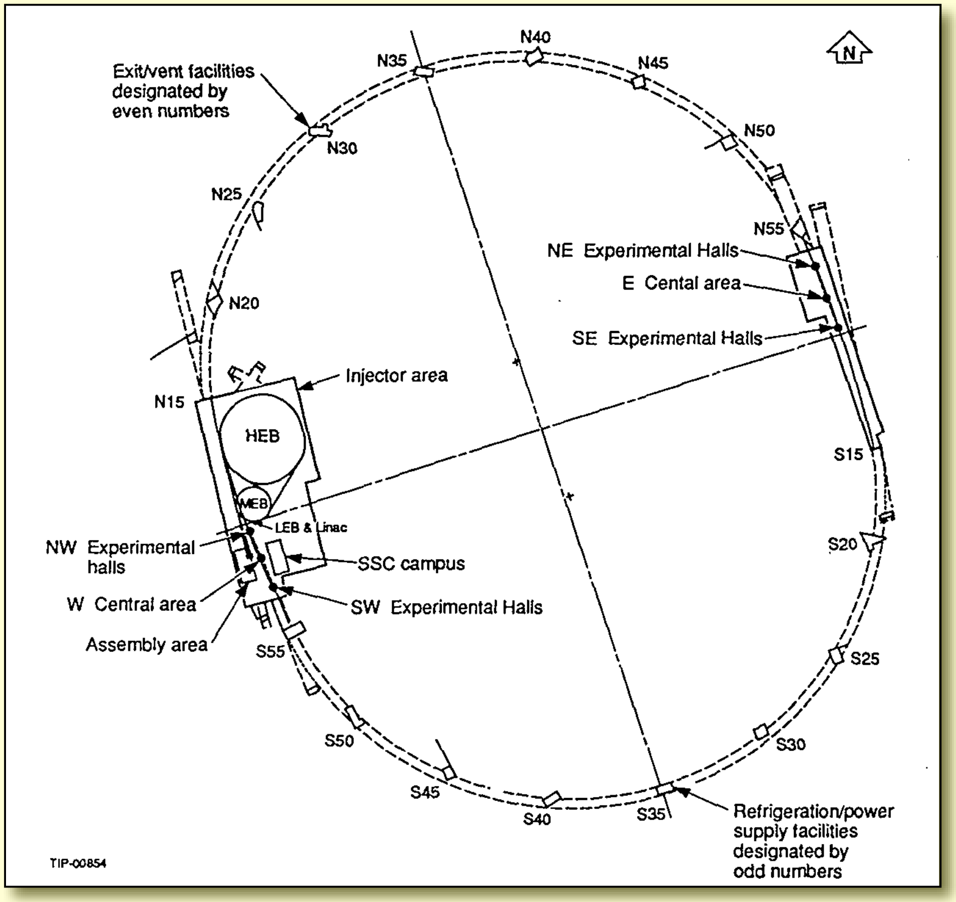
Outline

- Introduction
  - SSC
  - VLHC
- Relevant Issues
  - Magnet apertures
  - Synchrotron radiation handling
  - *e*-Cloud
- Summary

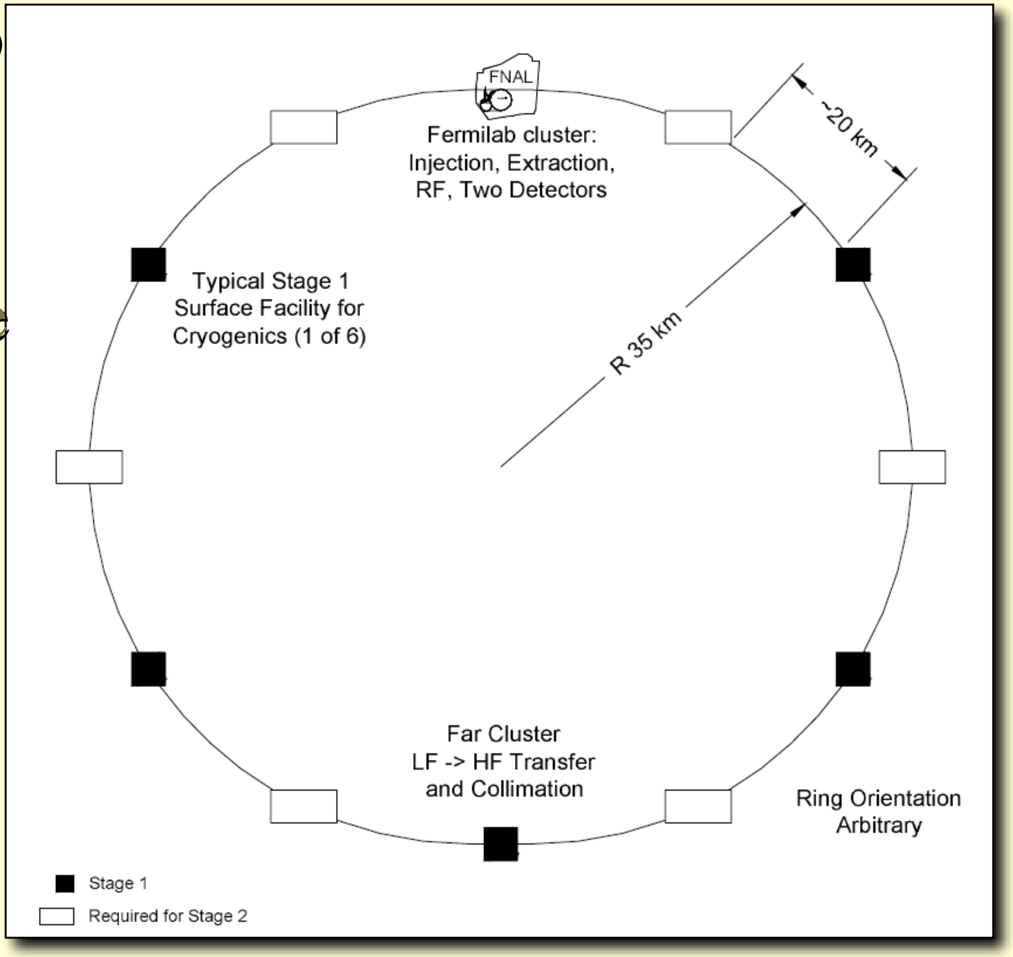
SSC Layout & Parameters

- 87 km circumference
- 20 on 20 TeV p on p
- 10^{33} $cm^{-2}s^{-1}$ lumi
- 0.75 10^{10} ppb
- 1 μmr norm emittance
- 16.7 ns bunch spacing
  - up to 15 kb/ring
  - 360 MHz rf system
- 400 MJ stored energy/beam
- 2 TeV inj. energy
- 6.7 T dipole field

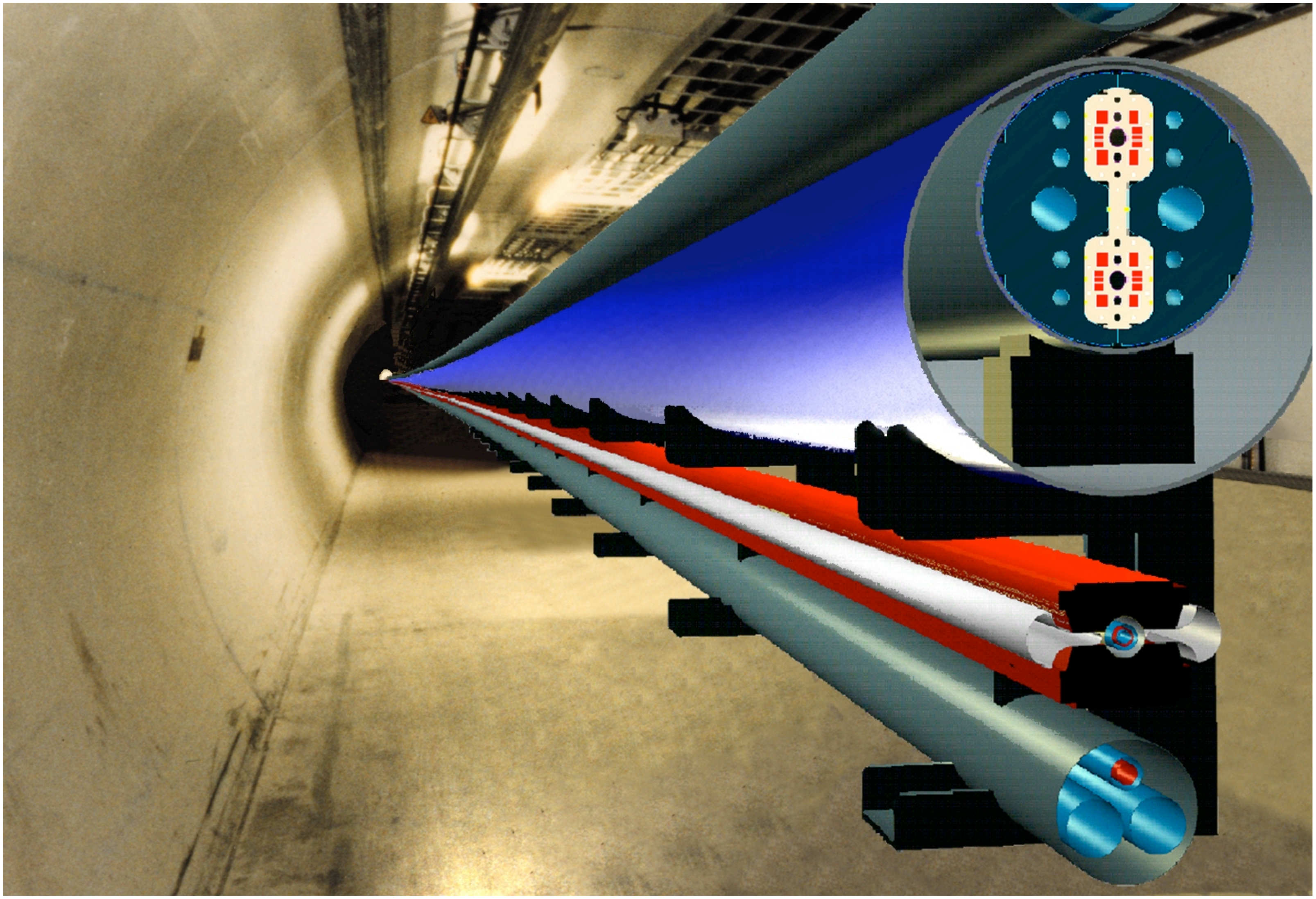


VLHC Parameters & Layout

- 233 km circumference
- 20 on 20 (87.5 on 87.5) TeV p on p
- 10^{34} ($2*10^{34}$) $cm^{-2}s^{-1}$ lumi
- 2.6 (0.9) 10^{10} ppb
- 1.5 (0.04[0.2]) μmr norm emittance
- 18.8 ns bunch spacing
  - up to 37 kb/ring
  - 478 MHz rf system
- 3.0 (3.9) GJ stored energy/beam
- 0.9 (10) TeV inj. energy
- 2 (9.8) T dipole field



VLHC Tunnel Concept

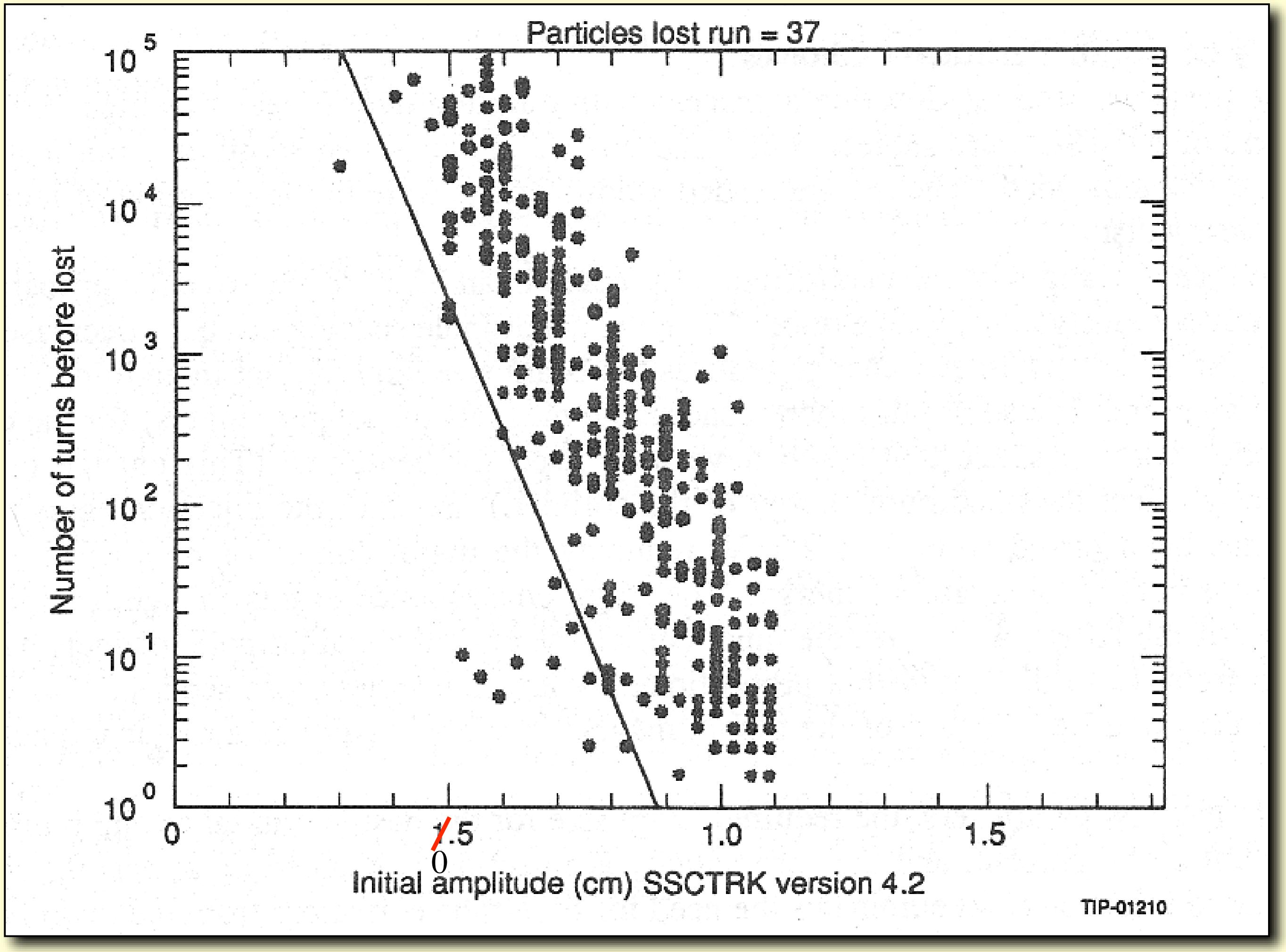


Magnet Apertures

- SSC: 40 mm initially
  - increased to 50 mm for dipoles first
  - then for quadrupoles as well
  - significant cost driver
- VLHC II:
  - 40 mm
  - at 10 TeV injection energy this may actually be ok
    - despite the liner, which costs aperture

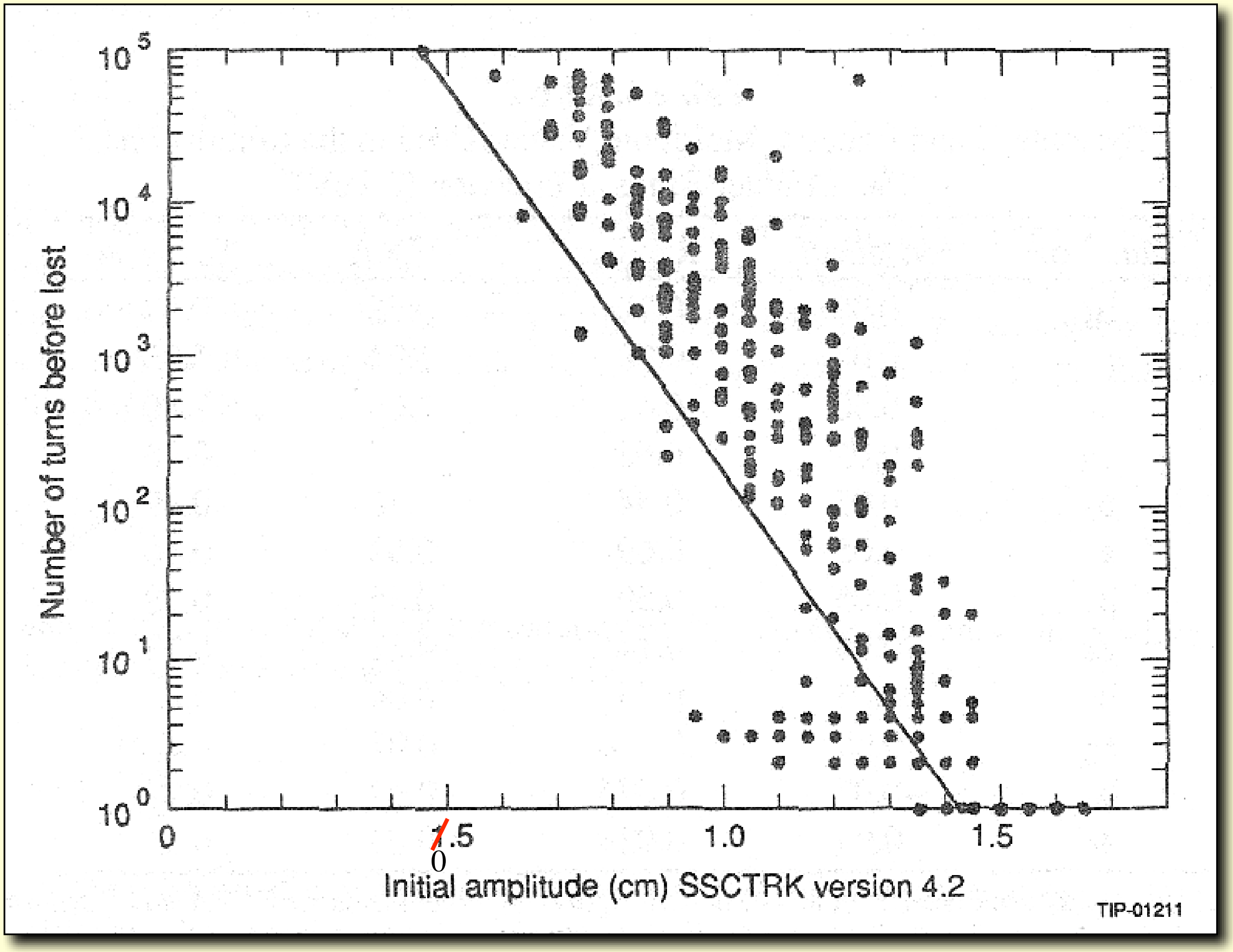
SSC Survival Plot 40-mm Dipole

SSCL-SR-1056



SSC Survival Plot 50-mm Dipole

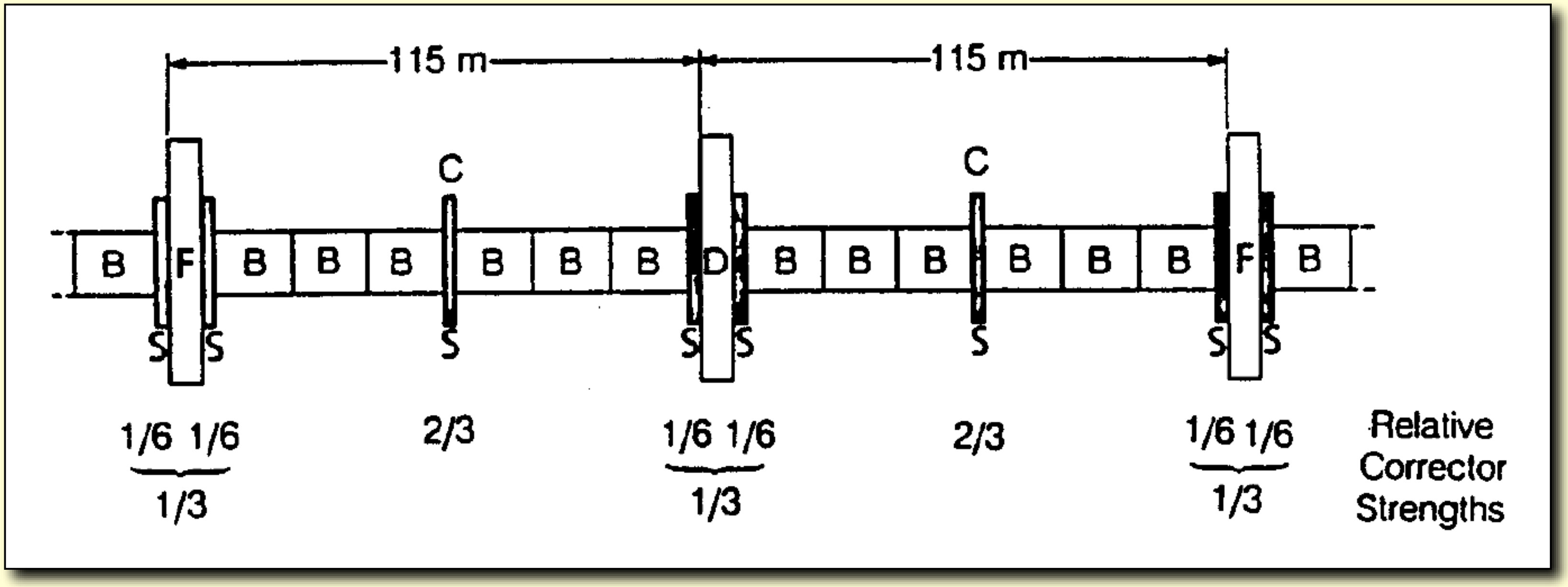
SSCL-SR-1056



Correction of Field-harmonics Errors

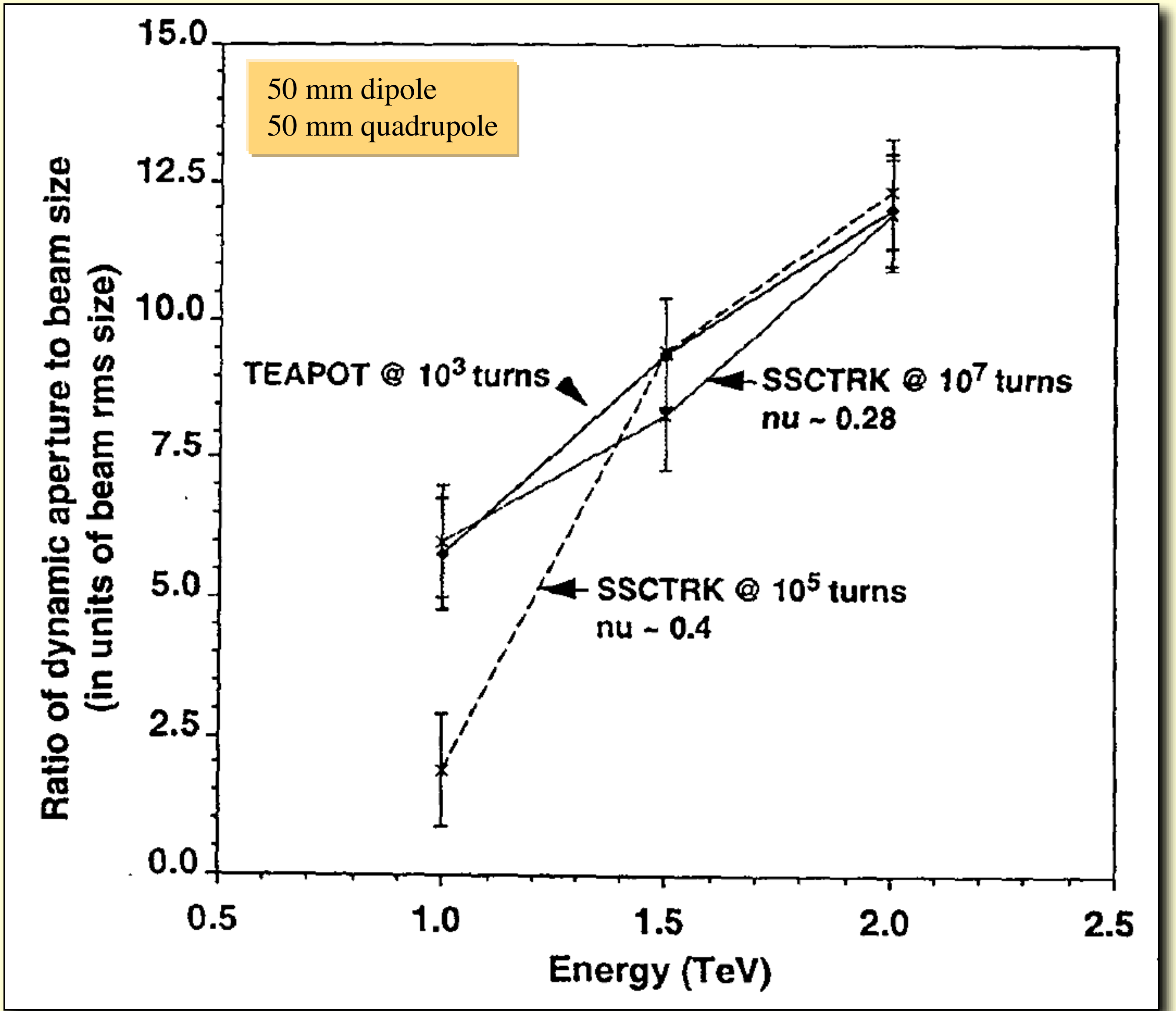
D. Neiffer, SSC-N-525

- SSC considered mid-cell (Neuffer-Simpson) correction of multipoles:
  - good correction of sextupole errors
    - octupoles in F,D and C used to cancel remaining oct. terms
    - simpler technically than bore-tube correctors
  - considered necessary for SSC @ 1 TeV injection (50/40 mm [D/Q]).

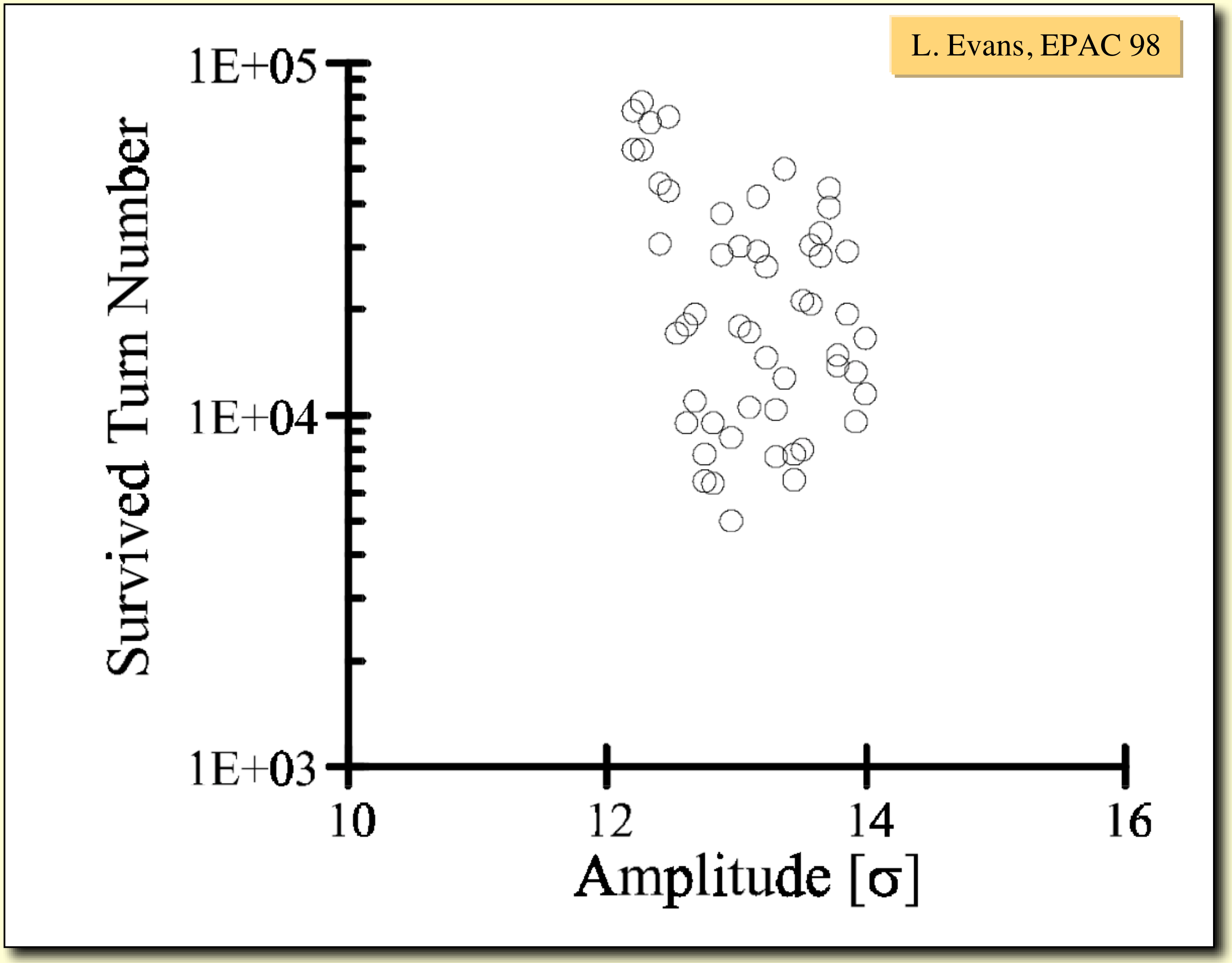


Acceptance vs Injection Energy

SSCL-SR-1235



Comparison: LHC Survival Plot



Synchrotron Radiation

Parameter	Unit	LHC	SSC	VLHC II	HE-LHC
Energy/ring	TeV	7	20	87.5	16.5
Energy loss/turn	MeV	0.010	0.053	15.3	0.2
Power(tot/beam)	kW	5.8	9	1050	255
Dipole power density/beam	W/m	≈ 0.3	≈0.15	4.7	2.8
crit. Energy	keV	0.044	0.284	8.03	0.575
damping time (⊥)	h	26	≈30	2.5	2

Synch. Rad. (cont'd)

- Power density: HE-LHC ≈ 1/2 VLHC, 20 SSC
  - Heat load on cryo system
    - basically a question of $$ (and maybe reliability) and liners
  - Photon desorption of gas from the walls
    - more than just $$:
      - any irradiated surface will outgass
      - need sufficient capacity of (cryo-) pumping
      - local pressure limited to avoid scattering loss
        - » to say nothing of e-cloud etc.

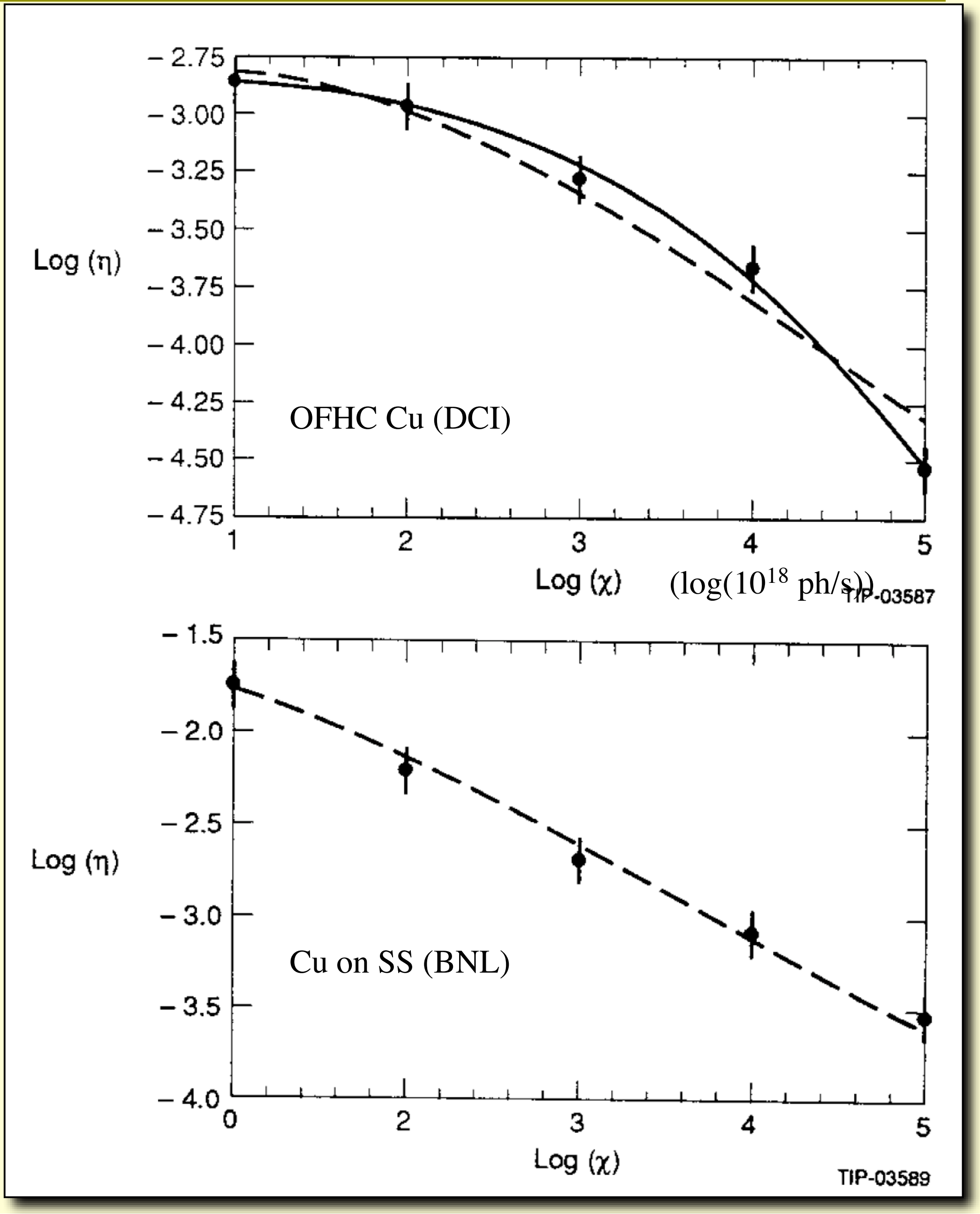
S.R. Mitigation

- SSC (no liner in baseline)
  - issue under study at project termination
    - Establish a diffusion model using photo-desorption data then available form BNL, DCI and BINP on various Cu surfaces
      - varying conditions and exposure times
- VLHC: liner with optimized holes

SSC Diffusion Model

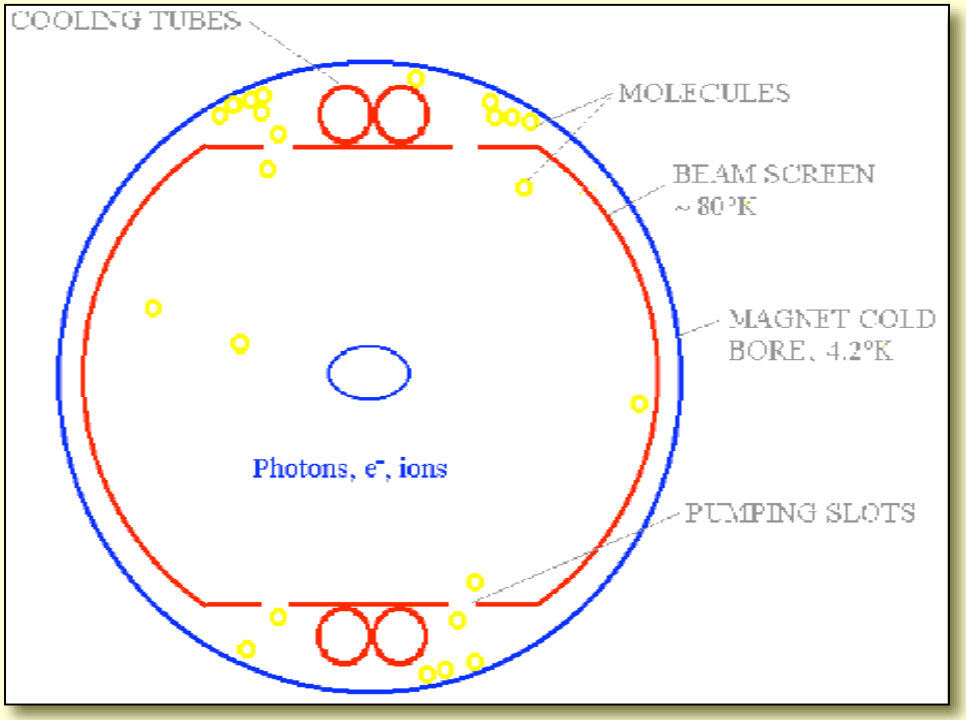
G. Dugan, SSCL-SR-610

- Photo desorption data
- Model establishes material properties
  - η, diffusion rates
  - fit to 8 diff. samples
- Then estimate behaviour in SSC
  - time to form monolayer of H_2
    - OFHC is longest
    - none of them clearly longer than the required 4000 h



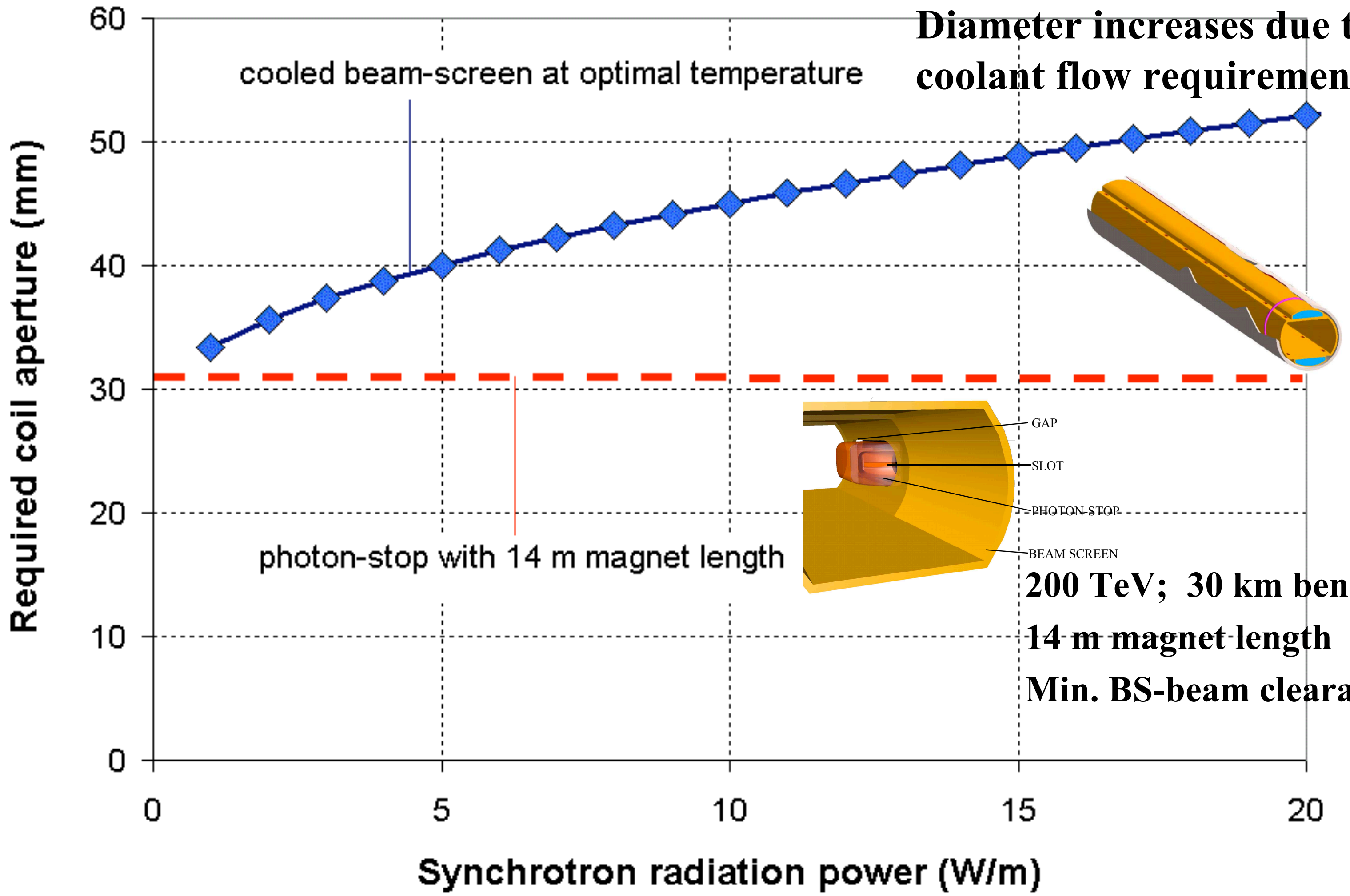
VLHC Liner

- Basically like LHC liner
  - Claim is that <0.1% slot area is sufficient for pumping
  - 80 K to absorb ≈ 4 W/m
  - Consider a getter on wall



VHLC Magnet Aperture Required

Limon,
VLHC WS 2003



Diameter increases due to increased coolant flow requirements

200 TeV; 30 km bend radius

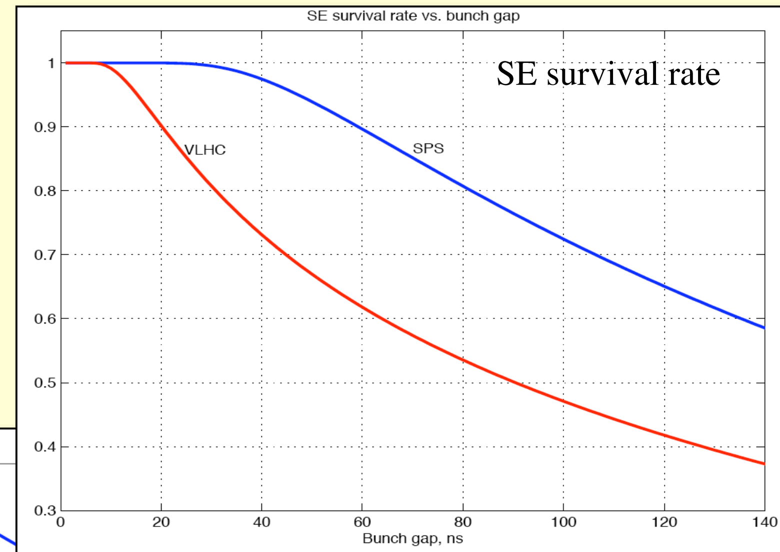
14 m magnet length

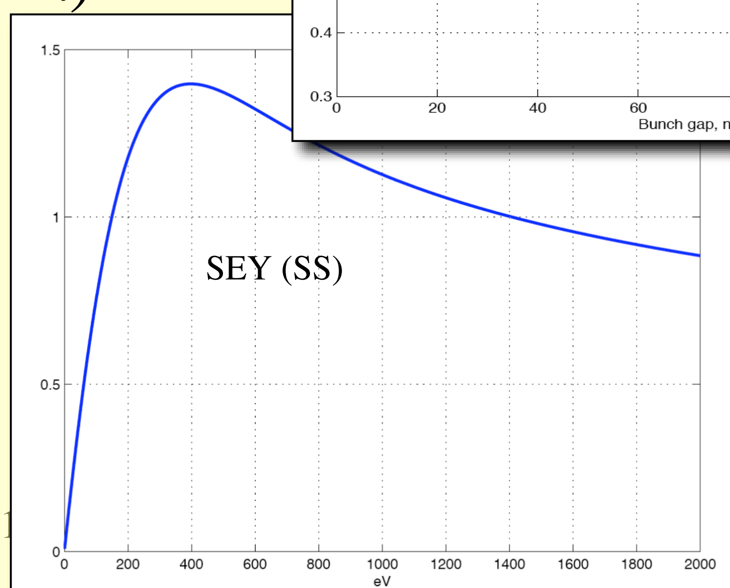
Min. BS-beam clearance=4 mm

e-Cloud

FNAL TN-2158

- For VLHC: the issue was studied:
  - threshold of 3.5×10^{10} ppb estimated for 18.8 ns spacing
    - comparing to ≈ 1999 SPS exp. data
    - possibly oly 2×10^{10}
  - less survival because in part of small vacuum chamber (not signif.)
  - SEY ≈ 1.3
  - 0.9×10^{10}/bunch seems safe…

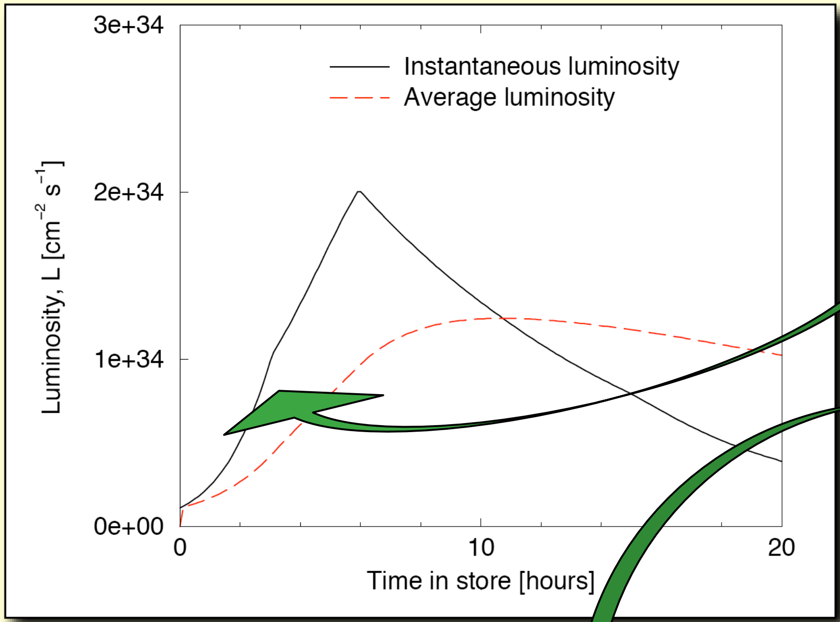




VLHC: Luminosity profile

FNAL TN-2158

flat-beam scenario

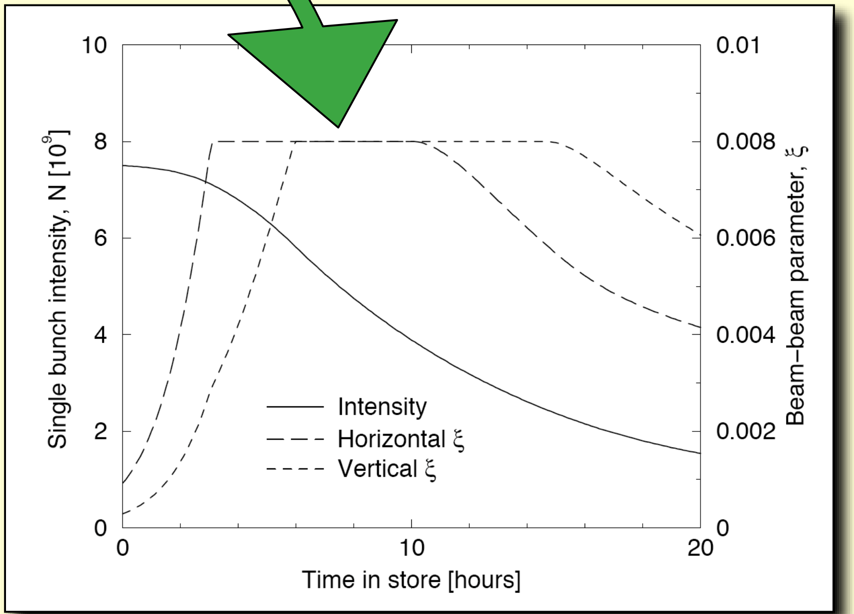


Start @ low L: large (relative) injected beam

Prevent horiz. emittance from shrinking too much

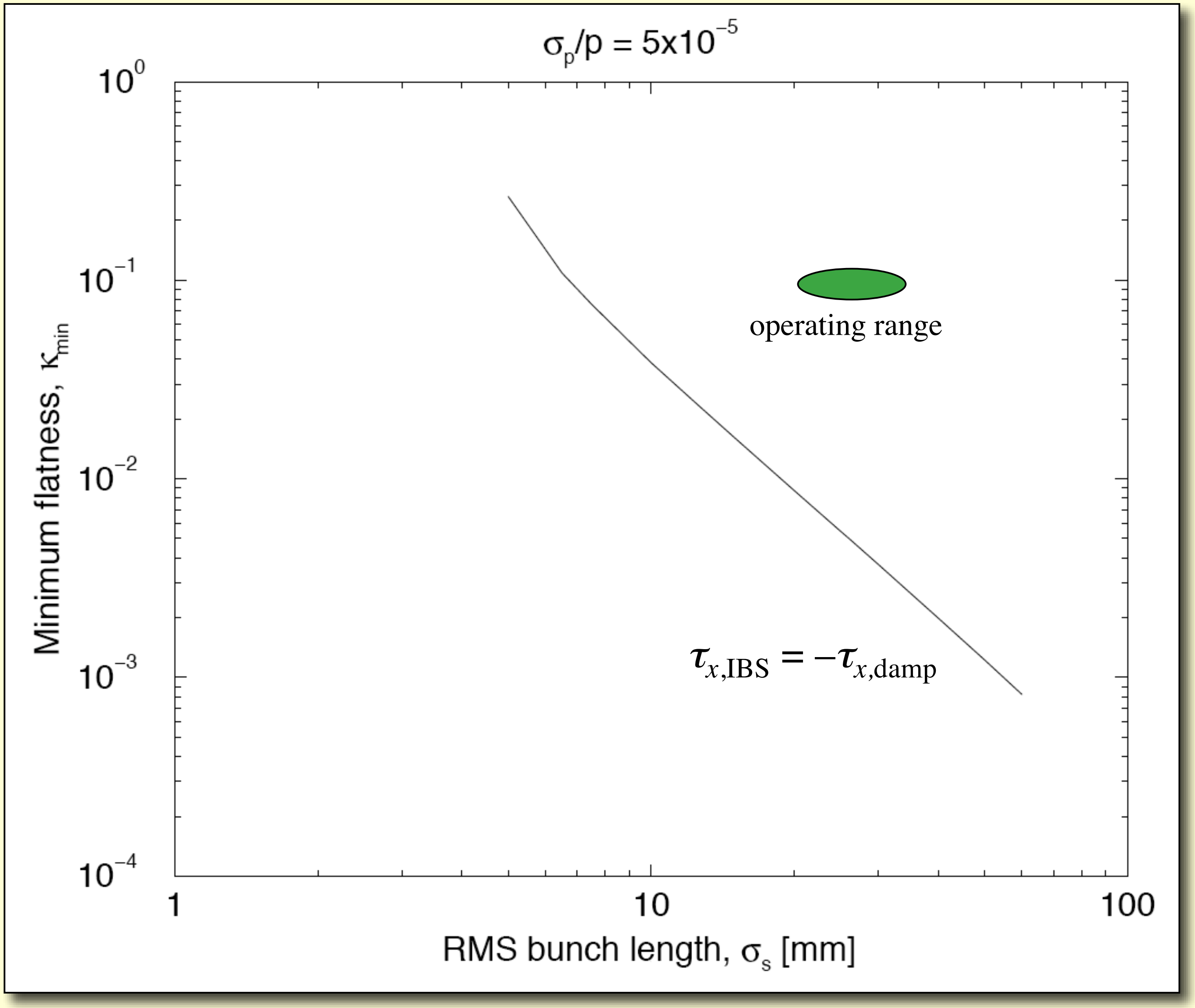
After peak, burn-off reduces L.

use crossing angle (in presence of damping) to maintain constant ξ until intensity becomes too low.



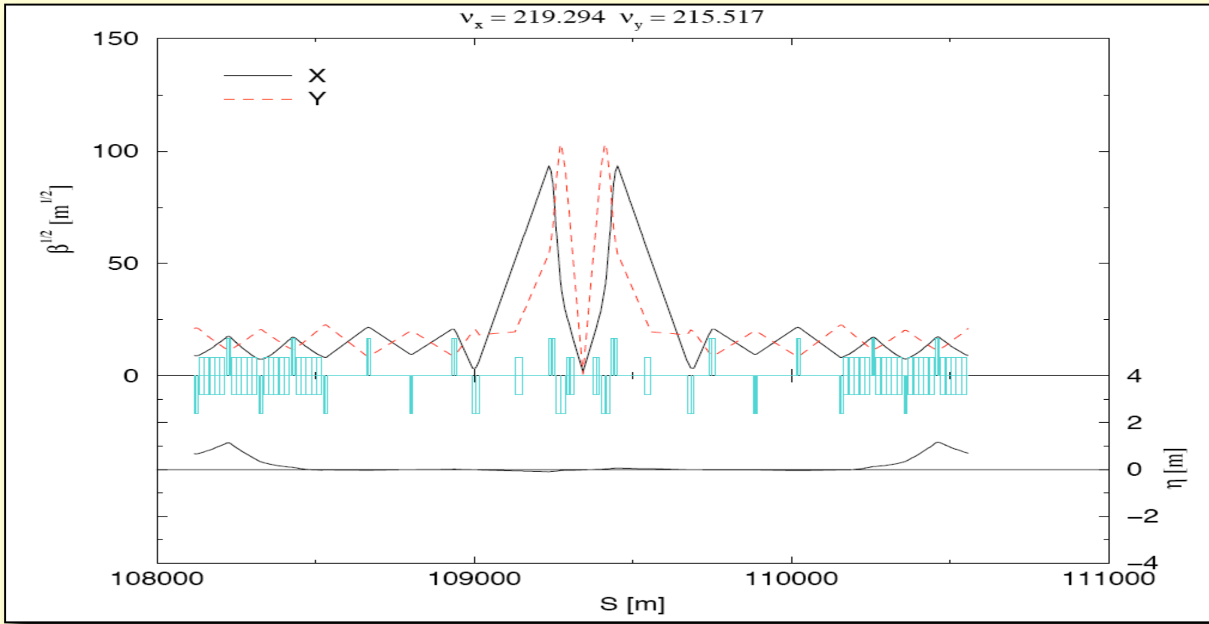
VLHC min. Flatness

Balance damping vs IBS in x plane

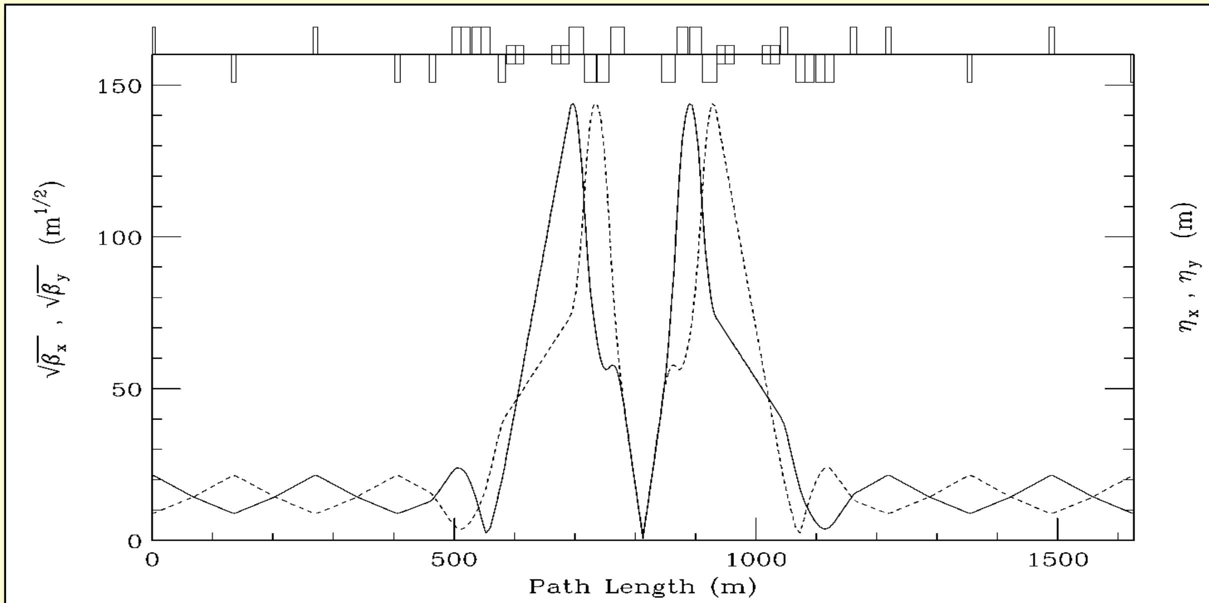


VLHC IR Designs

- Flat beam:
  - $\beta_x{}^* = 0.37$ m
  - $\beta_y{}^* = 3.7$ m
  - $\beta\wedge \approx 10$ km
  - $L_{sep} = 30$ m



- Round beam
  - $\beta^* = 0.5$ m
  - $\beta\wedge \approx 20$km
  - $L_{sep} = 120$ m



U. Wienands, SLAC-LARP
HE-LHC ws, Malta, 14-Oct-10

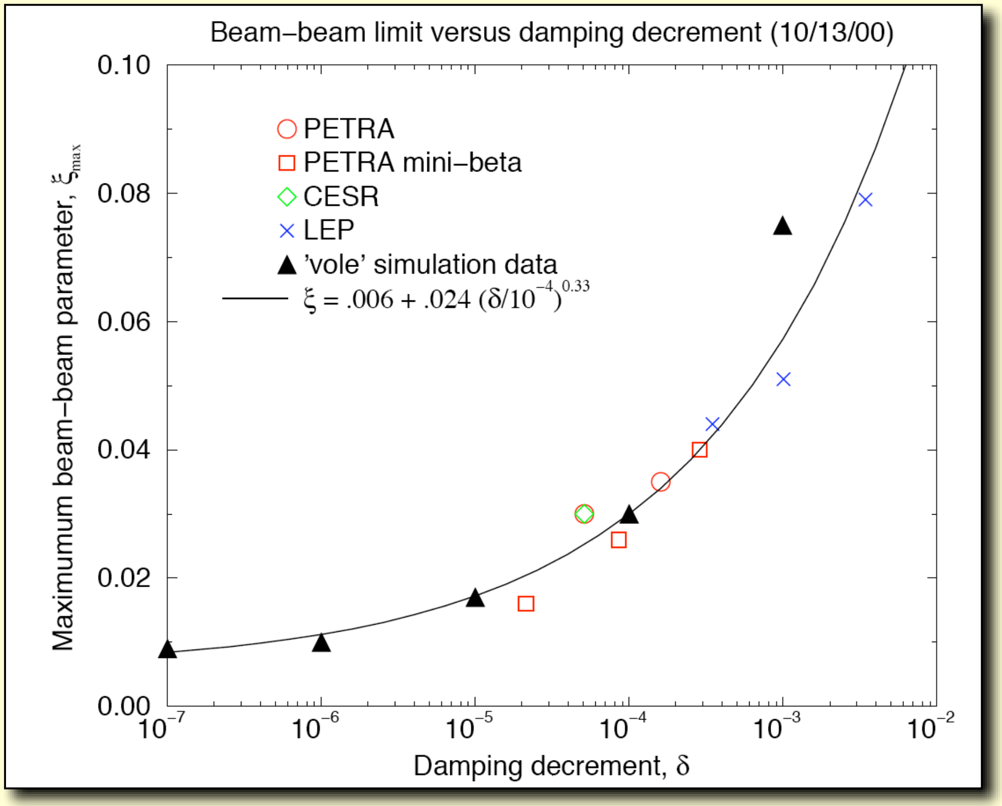
VLHC flat-round beam comparison

- Advantage of flat:
  - lower β^
  - earlier separation
    - less parasitic xings
- But…
  - QD0 is tough!
    - large aperture, or
    - not enough room,
    - radiation

(at peak L in previous plot)	FLAT	ROUND
Flatness parameter, κ	0.1	1
Beam-beam parameter $\xi_x = \xi_y$	.008	.008
Peak luminosity L (10^{34} cm^{-2}s^{-1})	2.0	2.0
Average luminosity, 20 hr L_{ave} (10^{34} cm^{-2}s^{-1})	1.02	0.98
Initial bunch intensity N (10^9)	7.5	7.5
Collision beta horz β_x^* (m)	3.7	0.71
Collision beta vert β_y^* (m)	0.37	0.71
Maximum beta horz $\widehat{\beta_x}$ (km)	7.84	14.58
Maximum beta vert $\widehat{\beta_y}$ (km)	10.75	14.58
Horizontal emittance ϵ_x (μm)	.161	.082
Vertical emittance ϵ_y (μm)	.016	.082
Collision beam size horz σ_x^* (μm)	2.53	0.79
Collision beam size vert σ_y^* (μm)	0.25	0.79
Maximum beam size horz $\widehat{\sigma}_x$ (μm)	116	113
Maximum beam size vert $\widehat{\sigma}_y$ (μm)	43	113
Angular beam size horz σ_x' (μr)	0.68	1.11
Angular beam size vert σ_y' (μr)	0.68	1.11
Total crossing angle α (μr)	10.0	10.0
Separation distance, L_{sep} (m)	30	120
Number of long range collisions per IR	20	84
Long range tune shift per IR, horz $\|\Delta Q_x\|$	.0008	.0166
Long range tune shift per IR, vert $\|\Delta Q_y\|$	.0081	.0166

Beam-Beam (VLHC)

- $\xi \propto \delta^{(1/3)}$(Chao ...)
  - for VLHC, HE-LHC $\delta \approx 10^{-7}$
  - > 0.0025 effect



Impedance

Machine	$R\,(\mathrm{m})$	$b\,(\mathrm{mm})$	$\frac{Z_{\parallel}}{n}\,(\Omega)$	$Z_{\perp}^{BB}\,(\frac{\mathrm{M}\Omega}{\mathrm{m}})$ Broadband	$Z_{\perp}^{LH}\,(\frac{\mathrm{M}\Omega}{\mathrm{m}})$ Liner holes	$Z_{\perp}^{RW}\,(\frac{\mathrm{M}\Omega}{\mathrm{m}})$ Resis. wall
MI	529	25.4	1.6	2.2	-	26
LHC	4243	18.0	0.66	28	1.5	124
SSC	13866	16.5	0.68	54	21	4200
VLHC						
Stage 1	36924	9	0.6	490	-	65000 (?)
Stage 2	36924	10	0.6	390	90	55000

Table 1: Impedance budgets for various hadron rings. The resistive wall transverse impedance is quoted for the lowest frequency mode, at $(n-\nu_\beta)\omega_0$.

To convert to thresholds, watch bunch length and dE/E

Longitudinal Parameters

Parameter	Unit	LHC	SSC	VLHC II	HE-LHC
Bunch length	mm	75	≈60 @ injection	26 (≈30)	65
$\delta E/E$ (1σ)	1	1.1×10^{-4}		0.5×10^{-4}	0.4×10^{-4}
Bunch charge	ppb	1.1×10^{11}	0.75×10^{10}	0.9×10^{10}	1.3×10^{11}
Bunch frequency	MHz	40	60	55	40

- Short, intense bunches => significant power leakage beyond screen possible
  - also deposits power in screen itself
- Affects instability thresholds
  - HE-LHC ≈ factor 3…4 beyond LHC (σ_l, $\delta E/E$, Q_{bunch})
  - assumes heating in the longitudinal plane

VLHC Study Items

3.14 Fundamental Problems, and Future Research Fronts

Four major issues could severely alter HF ring performance estimates, given our present knowledge of Accelerator Physics and the preliminary state of the HF design:

1. **Energy deposition.** The power of debris products exiting the collision point goes far beyond current experience. Is there an acceptable engineering solution?

2. **Operational aperture.** The physical beam sizes are so small that the operational aperture is probably more important than the dynamic aperture. How far can the closed orbit move before the beam is lost? Is operational feedback necessary on closed orbits, tunes, and chromaticities in order to accelerate beam to top energy?

3. **Instabilities.** Although the HF ring is in general an order of magnitude more immune to instability issues than the LF ring (due to its higher rigidity), there is still room for considerable concern. For example, the electron cloud heat load in the cryogenic beam environment could be unacceptable.

4. **Diffusion.** The operational scenario assumes that the beam emittances decrease by an order of magnitude or more, with a damping time of order 2.5 hours (10^7 turns). Our basic understanding of slow diffusion mechanisms does not preclude the possibility that this is fundamentally impossible. Can we reliably extrapolate from other colliders?

Synopsis

- Magnet aperture
  - SSC with 50 mm magnets @ 2 TeV ≈ same dyn. ap. as LHC (??)
  - mid-cell correctors can help
- Injection energy
  - For 40-mm SSC, 1 TeV considered too low.
  - For 50-mm SSC, 2 TeV considered possibly unnecessary (–> 1.5 TeV)
- Synch. radiation
  - SSC diffusion model may be useful in estimating gas loads
  - VLHC photon stops likely not applicable to HE-LHC (geometry)
  - Damping may raise ξ, but not a whole lot
  - VLHC would need to heat up beams (bunch length, stability!)
- Flat-beam collider
  - Doublet IR likely easier (except QD0!) than triplet IR
    - β^ lower, or longer L^*, or smaller β^*
- e-cloud, radiation, bunch length
  - not much beyond LHC

Note: SSC $\beta\gamma\varepsilon = 1\ \mu$m

Some References

- Website with list of SSC info:
  - http://lss.fnal.gov/archive/other/ssc/
- SSC SCDR, SSCL-SR-1056
  - (not on the web)
- SSC Retrospective
  - SSCL-SR-1235, http://ccdb4fs.kek.jp/cgi-bin/img_index?199407001
- VLHC Design Report
  - FNAL Report TN-2149, http://tdserver1.fnal.gov/tddoc/DesignStudyReport/upload/PDF/
- VLHC Accelerator Physics Report
  - FNAL Report TN 2158, http://vlhc.org/AP.pdf
- VLHC Instability Workshop
  - SLAC-PUB-8800, http://vlhc.org/SLAC-PUB-8800.pdf

End of Presentation