Accelerator Physics Issues at the SSC

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A view from Waxahachie...

A List of Issues for VLHC...

- Magnet Aperture
- Lattice Design
- Synchrotron Radiation
- Instabilities/feedback
- Longitudinal Parameters
- Beam-beam Effects
- Emittance Evolution/Control
- Energy Deposition

… all issues present
in SSC, LHC designs

At 50 TeV, mostly just gets a bit harder...

- Synchrotron radiated power into magnets
- Stored beam energy
- Instability thresholds
- Ground motion sensitivity (motion amplitude vs. beam size)
- Etc…

… but, some possible advantages,

especially for high field options:

- Luminosity enhancement
- Simplified IR designs
- Integrated luminosity vs. initial emittances

Magnet Aperture
and
Basic Parameters of the SSC

Beam size vs.
pipe size vs.
coil diameter

- Cell length
- Phase advance
- Correctors
- Alignment

For phase advance

$$\mu = \sin^{-1}(L/2F) = 90°$$

$$\hat{\beta} = 3.41\ L$$

$$\hat{D} = 2.71\frac{L^2}{R}$$

Where

L = ***half cell length,***

R = ***ave. radius of ring***

1986 Blue Book -- L=96m, $\mu = 60^o$, $d_c = 4$cm

1987 ISP Design -- L=114m, $\mu = 90^o$, $d_c = 4$cm

1990 White Book -- L=90m, $\mu = 90^o$, $d_c = 5$cm

Linear Aperture and Dynamic Aperture

Tune Shift
Smear
Stability Limits

Accelerator Experiments (E778)
at the Tevatron

⇒ Gave (some) confidence in
computational abilities

Random field errors were expected to be as *(more?)* important as systematic errors

Tune shift due to systematic multipole, b_n:

n	Tune shift, $\Delta\nu$
1	$<\beta b_1>/2$
2	$<b_2\beta D>\delta$
3	$3<b_3\beta^2>\varepsilon/8 + 3<b_3\beta D^2>\delta^2/2$
4	$3<b_4\beta^2 D>\varepsilon\delta/2 + 2<b_4\beta D^3>\delta^3$

δ = rel. momentum, ε = emittance

Last changes (late 1989) made in direction of increased design conservatism…

reliability, availability, commissioning, …

- L = 114.25 m -----> 90 m
  - reduces beam size
  - increases linear aperture
- E_{inj} = 1 TeV -----> 2 TeV
  - reduces b_2, chromaticity at injection
  - increases dynamic aperture
- d_c = 4 cm -----> 5 cm
  - increases linear/dynamic aperture
  - increases cost...

Considered:

recent experiments

diffusion studies (1989) in Tevatron, SpS
aperture studies (1987-8) in Main Ring

recent tracking studies

Main Ring, SpS simulations
1988-89 SSC tracking (10^5 turns)

Lattice Design

Rings:

Arcs + IR/UT modules; dispersion suppressors

- all lengths in units of bunch spacing (5 m)
- IR/UT/DS lengths multiples of half cell length

Arcs:

standard FODO cells

- standard magnets; occasional short dipoles with space left for cryo-equipment, power feeds, etc.
- dispersion suppressors at ends of arcs

warm/free space

- Added later, to provide space for future upgrades (power/feed points, dampers, instrumentation, spin devices, etc., ??)

*** ***modularity*** ***

Utility Regions:

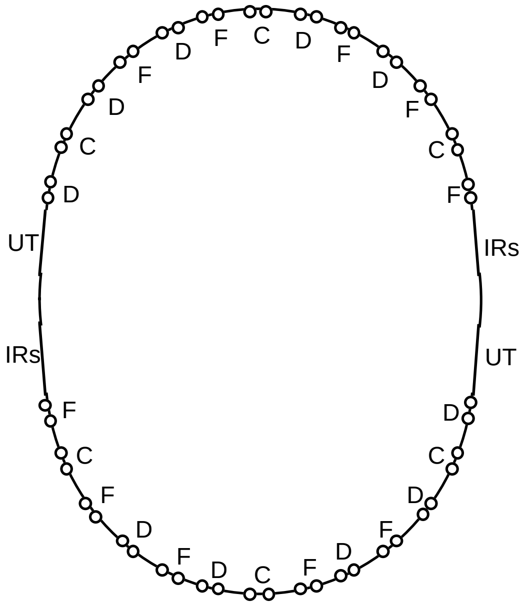
- Injection, extraction, rf, instrumentation

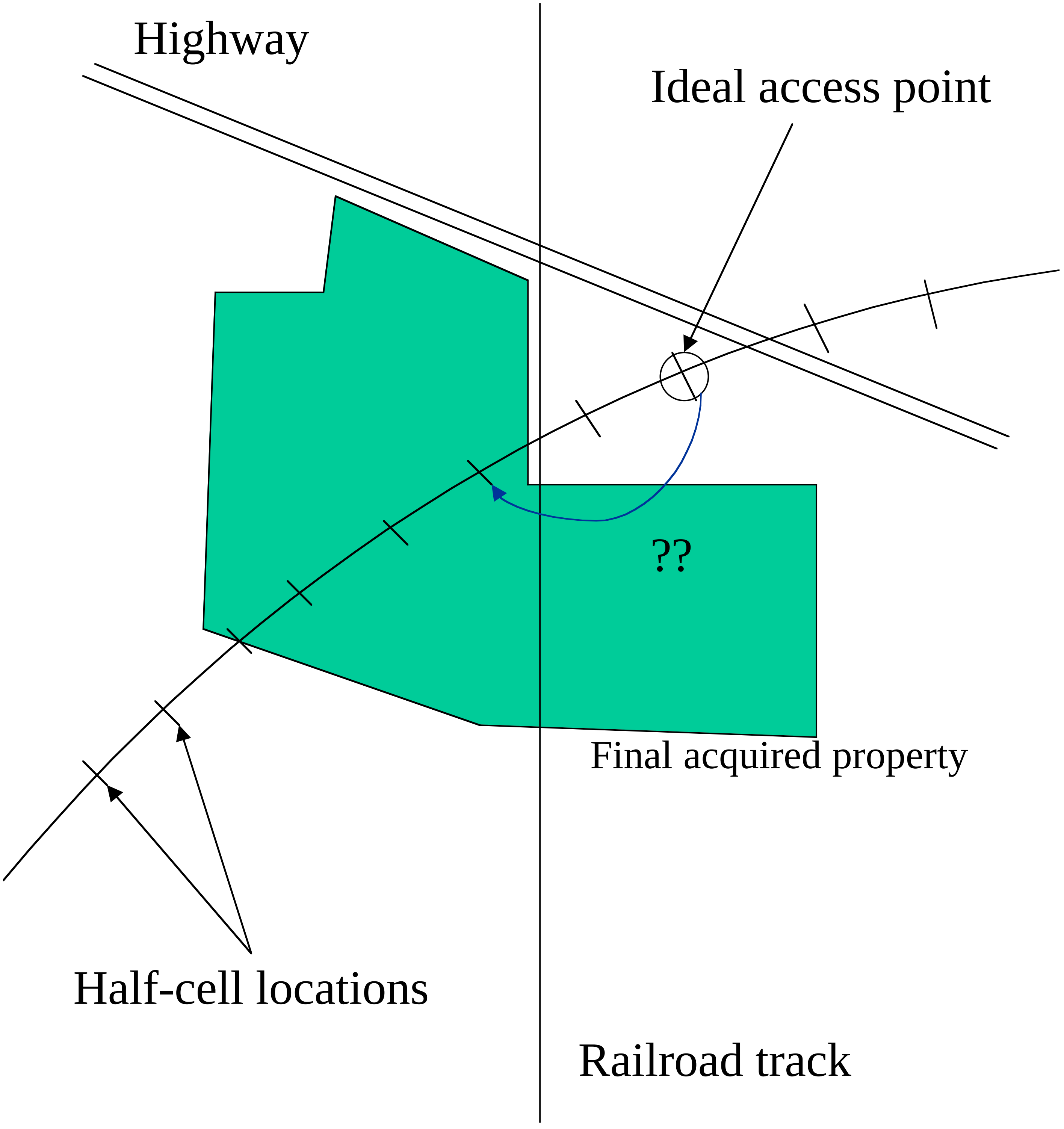
Interaction Regions:

- Low beta, orbit/tune/chromaticity control, dispersion, crossing angle

Generation of “Final” Collider Lattice

- The 10-F lattice left out magnets around the ring to give space for future uses
- “missing magnets” next to F and D quads
- Also, in center locations of half cells
- Positions were massaged to match site conditions





Highway

Ideal access point

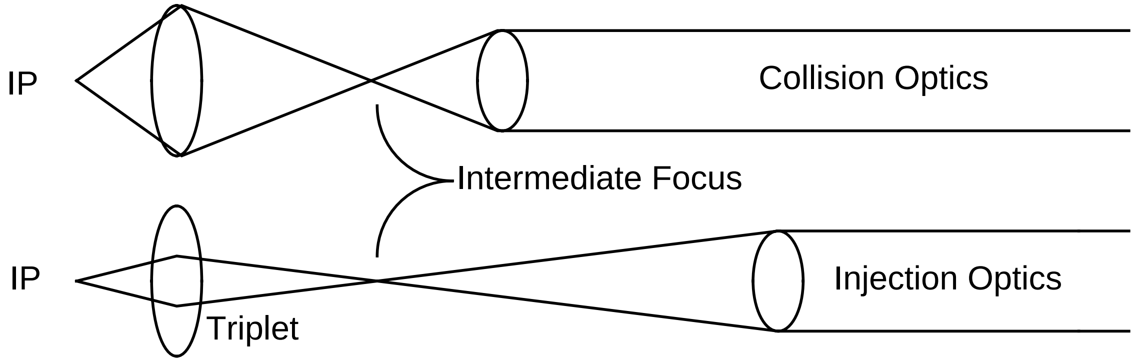
??

Final acquired property

Half-cell locations

Railroad track

Principle of SSC IR Design



- IR design used triplet, not tuned during low-beta squeeze
- Outer quads used to change intermediate focal point
- Thus, could perform squeeze independently on each beam
- M = -I section handled vertical dispersion
- Local steering, sextupoles handled crossing angle, chromatic effects
- IR Working Group met weekly -- optics, correction schemes, hardware, etc.

Other Issues

- Local coupling and its effects
  - Global and local decoupling schemes
- Alignment Issues
  - Accuracy of local smoothing of magnet placement, roll angles, etc.
  - Expected rms quad placement: 0.25 mm
- Ground Motion
  - Long term motion, re-alignment, ATL-law

If $A = 10^{-5}$ $\mu m^2/m/sec$, $L = 90$ m,

then after 1 year,

$$\langle x^2 \rangle = \underset{A}{(10^{-5})}\underset{T}{(\pi\ 10^{7})}\underset{L}{(90)}\ \mu m^2$$

or, $x_{rms} = 0.25$ mm

Synchrotron Radiation

- Impacts on
  - cryo system, vacuum system
  - beam screen/liner design
  - (and hence, magnet design…)
  - At SSC, SR to deliver about 0.1 W/m into dipole magnets
  - Note:
    - Low-field (Snowmass): 0.09 W/m
    - Hi-field (Snowmass): 2.3 W/m
- Enhancement of luminosity
  - Some effect would have been seen at SSC
  - Characteristic damping time about 1 day

Instabilities and Cures

- resistive wall, head-tail, multibunch, etc.
  - Beam pipe requirements: diameter, material, etc.

- ring-wide impedance budget and its control
  - beam pipe AND rf cavities, BPM's, kickers, septa, magnet interconnects, etc.: all monitored very carefully
  - Impedance Committee formed, met weekly

- feedback systems
  - Injection damper systems
  - High energy, bunch-by-bunch damping systems

Beam-beam Effects

- Head-on incoherent tune shift tolerance
  - $\xi \approx 0.002$ per crossing (2-4 per turn)
- Parasitic crossings
  - long range coherent tune shifts, compensation
  - gives total $\Delta\nu \approx 0.01$ for 4 IR's
- Diffusion effects -- small
  - Koga, Tajima, others

Emittance Growth and Control

- injection errors

  e.g., $\Delta x/\sigma_x$ = 1mm/0.5mm ---> 3x emitt. Growth

- ground motion, power supply ripple, RF noise, etc.

- Major impact on injector chain design, specification

- Emittance Committee formed
  - met weekly
  - review designs of various systems

Emittance Budget assigned to each accelerator:

Injector	emittance specification
LINAC	(initial $\varepsilon_n < 0.5\ \pi$ mm-mr)
LEB	0.6 π mm-mr
MEB	0.7 π mm-mr
HEB	0.8 π mm-mr
Collider	**1.0 π mm-mr** *(6 π , 95%)*

Energy Deposition

- Beam induced radiation effects

- Beam Abort Systems

- Beam Halo Scraping Systems

Comparisons:

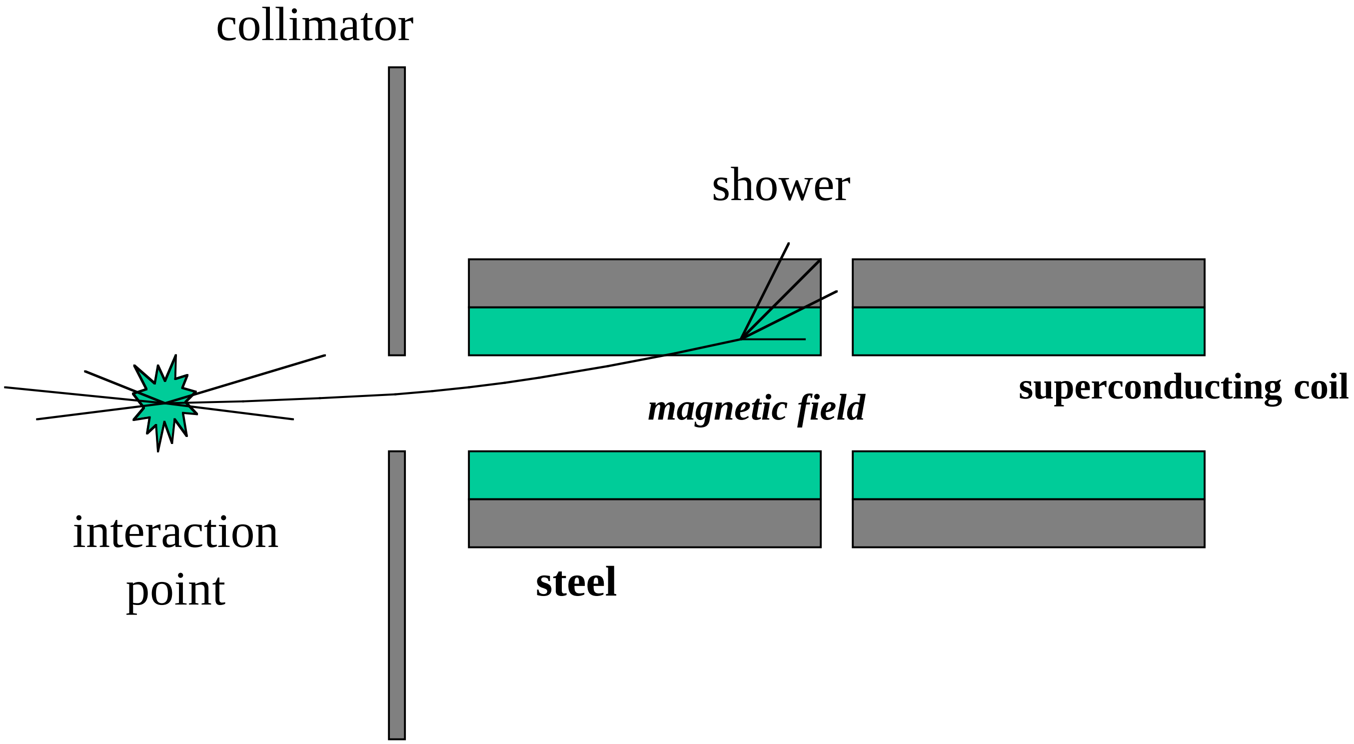
Tevatron:	1 TeV x 2e13 = 0.003 GJ
SSC:	20 TeV x 1e14 = 0.3 GJ
LHC	7 TeV x 5e14 = 0.6 GJ
VLHC (hi)	50 TeV x 1e14 = 0.9 GJ
VLHC (low)	50 TeV x 1e15 = 9.0 GJ

- Interaction Region Element Protection

power delivered into IR quads:

20 TeV x 10^{33} cm^{-2}sec^{-1} x 100 mbarn

320 W *in each direction*



Schematic geometrical configuration used in energy deposition calculations

Table 1: Maximum energy deposition dose rate D' and annual dose D in the superconducting coils of the SSC low-β IR beam elements. Interaction rate is 10^8/sec at $\mathcal{L} = 10^{33}$ cm^{-2} sec^{-1}. Here, the operational year is taken to be 10^7 sec. From Baishev, Drozhdin, Mokhov (SSCL-306).

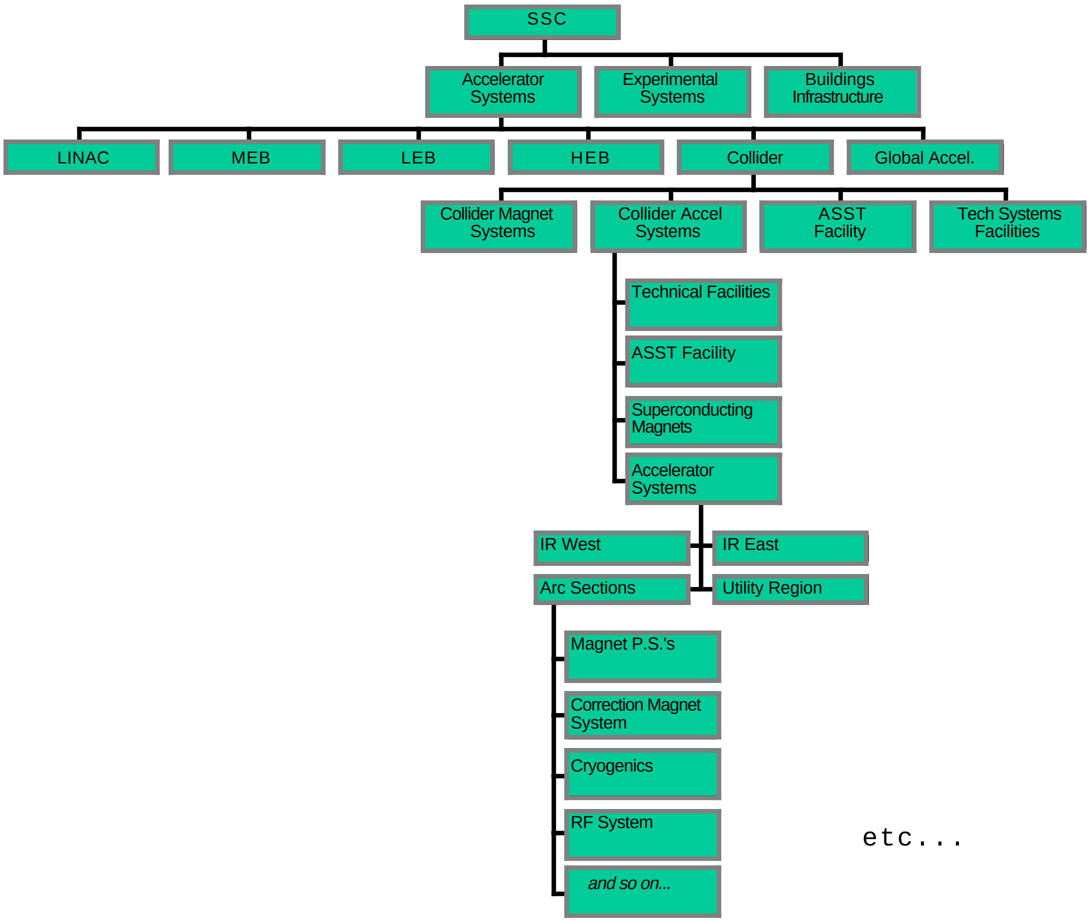
Name	**Distance from IP (m)**	D' **(mW/gm)**	D **(MGy/year)**
IP	0		
QL1	35	0.32	3.20
QL2a	47	0.19	1.92
QL2b	59	0.22	2.22
QL3	73	0.10	0.96
BV1	85	0.01	0.064
BV1	91	0.01	0.11
BV1	97	0.02	0.21

Table 2: Radiation resistance of selected materials. From Baishev, et al.

Material	**Tolerable Dose (MGy)**
Kapton, polyimide Kapton film Carbon-fiber reinforced tube Carbon-fiber-filled epoxy rods	50
G11 CR tube	20
PK102 (epoxy) Crest 7450 epoxy Fiberglass (epoxy impregnated)	10
Fiberglass rein. polyester resin	5
Aluminum mylar	2
Superinsulation	2
Electrical insulation	0.1-10
Tefzel adhesive	0.5
Cerex spunbonded polyester	0.06
Teflon	0.01

Specification Documents

SSC Specification Documents



- SSC
  - Accelerator Systems
    - LINAC
    - MEB
    - LEB
    - HEB
    - Collider
      - Collider Magnet Systems
      - Collider Accel Systems
        - Technical Facilities
        - ASST Facility
        - Superconducting Magnets
        - Accelerator Systems
          - IR West
          - IR East
          - Arc Sections
            - Magnet P.S.'s
            - Correction Magnet System
            - Cryogenics
            - RF System
            - *and so on...*
          - Utility Region
      - ASST Facility
      - Tech Systems Facilities
    - Global Accel.
  - Experimental Systems
  - Buildings Infrastructure

etc...

- “Controlled Documents” maintained to keep track of all element specifications.

- Once “signed off,” then took act of Configuration Management Control Board to make changes.

Future Directions...

- What is minimum beam pipe aperture (include beam screen) which can be tolerated?
- Can *sparse* corrector schemes be achieved?
- Can fault-tolerant correction schemes be achieved, improving reliability?
- Does SR at high field *truly* lessen the field quality requirements at injection?
- Need to look for new and innovative ideas…
  - 4-bore full-range magnet? (Gupta)
  - Low-field injector with high-field storage ring?? (Dugan)
  - ??????