Exploration of a Tevatron-Sized Ultimate Light Source

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Outline

- Concept
- Nonlinear dynamics optimization
- Analysis of microwave instability
- Performance predictions
- Potential APS upgrade
- Conclusion and questions

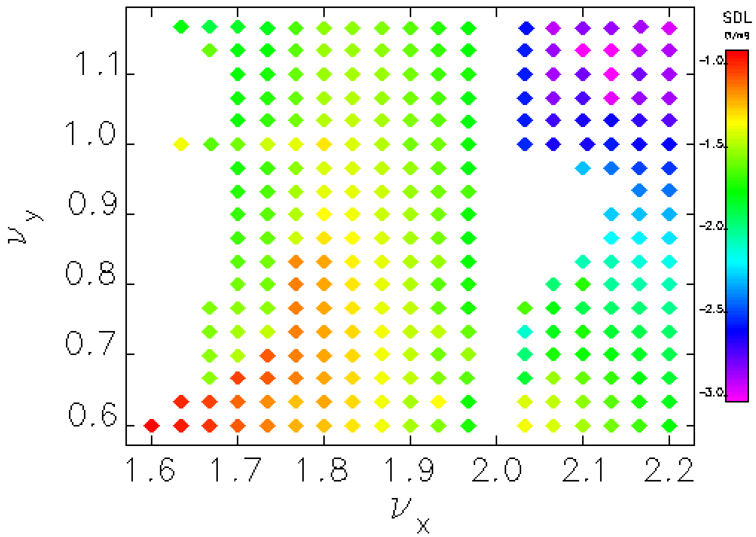
Exploratory "τUSR" Lattice

- Roughly match Tevatron geometry
  - 6-fold symmetry
  - 6.21 km circumference (vs 6.28 for Tevatron)
- All lattice modules are adapted from the PEP-X design[1,2,3]
  - 30 MBA cells in each of six arcs
    - Larger bending radius
    - 180 ID straight sections (!)
  - Long straight sections use FODO cell
  - Six matching quads between arcs and FODO cells
- For cell tunes, started with Y. Cai's suggestion of ν_x=2.166, ν_y=1.166

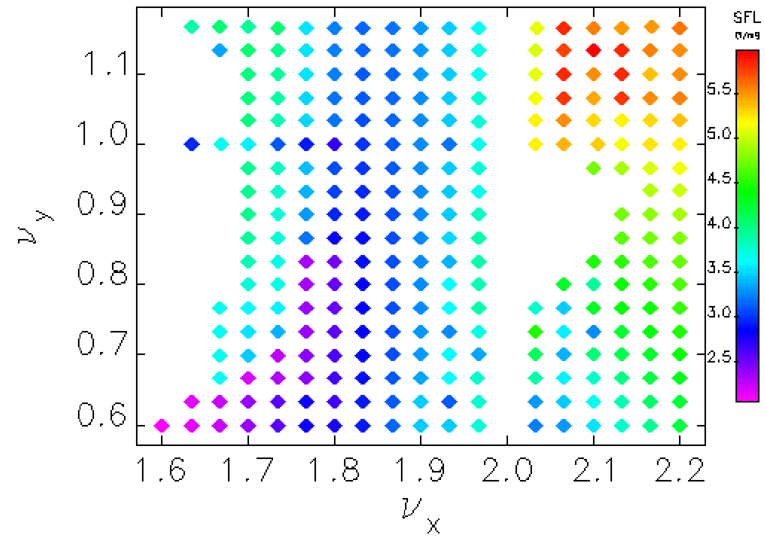
[1]M.-H. Wang *et al*., Proc IPAC11, THPC074.
[2]Y. Nosochkov *et al*., Proc. IPAC11, THPC075.
[3]Y. Cai, NIM A 645:168-174 (2011).

Scan of Cell Tunes (9 GeV)

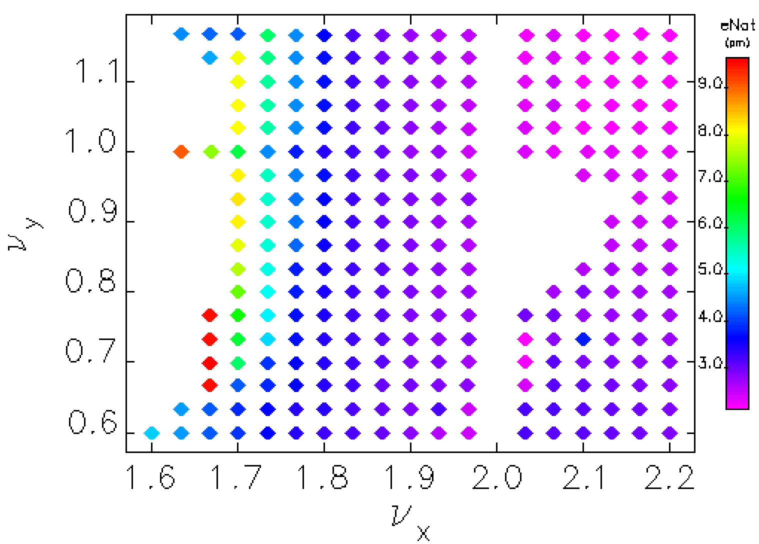
Integrated SD strength



Integrated SF strength



Natural emittance



- Original tunes per cell were x=2.17, y=1.17
- Lower to 1.90, 0.90
  - 2.9 pm emittance
  - Sextupoles 40~50% weaker

Nonlinear Dynamics Optimization[1]

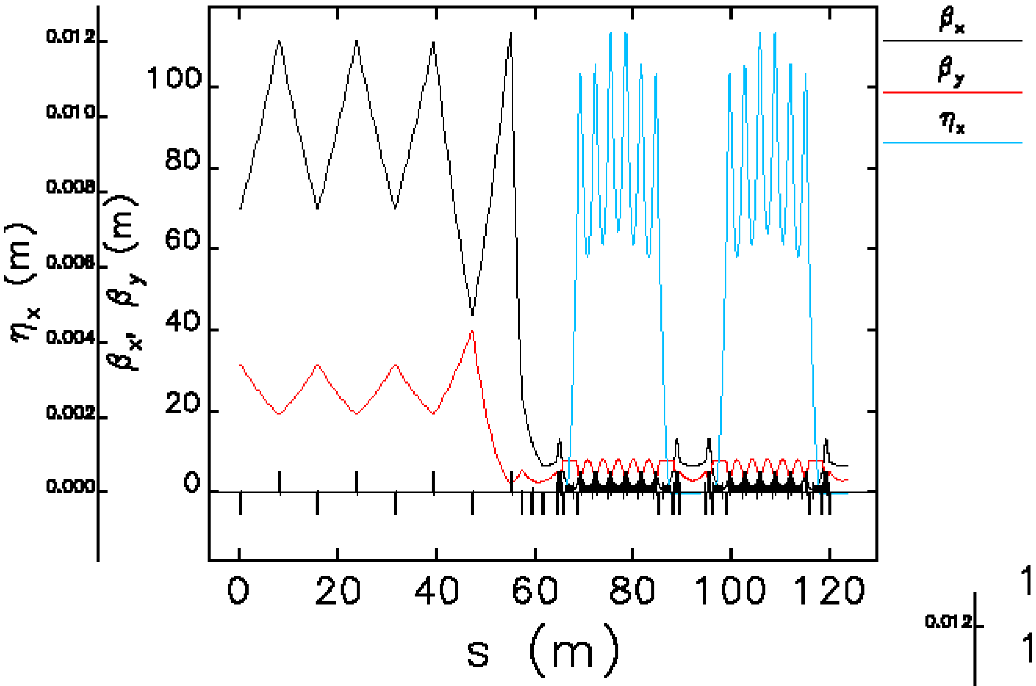
- Use tracking-based Multi-objective Genetic Algorithm (MOGA) to directly improve
  - Dynamic acceptance area
  - Touschek lifetime computed from local momentum acceptance for first arc cell
- Variables
  - Integer tunes
  - Fractional tunes
  - Three SF families
  - Five SD families
  - Three harmonic sextupole families
- Add quad strength and tilt errors to give ~1% lattice function beats, $\kappa \sim 0.2$
- ID chambers with ±18mm by ±3mm gaps
- Chromaticities corrected to +1 in both planes

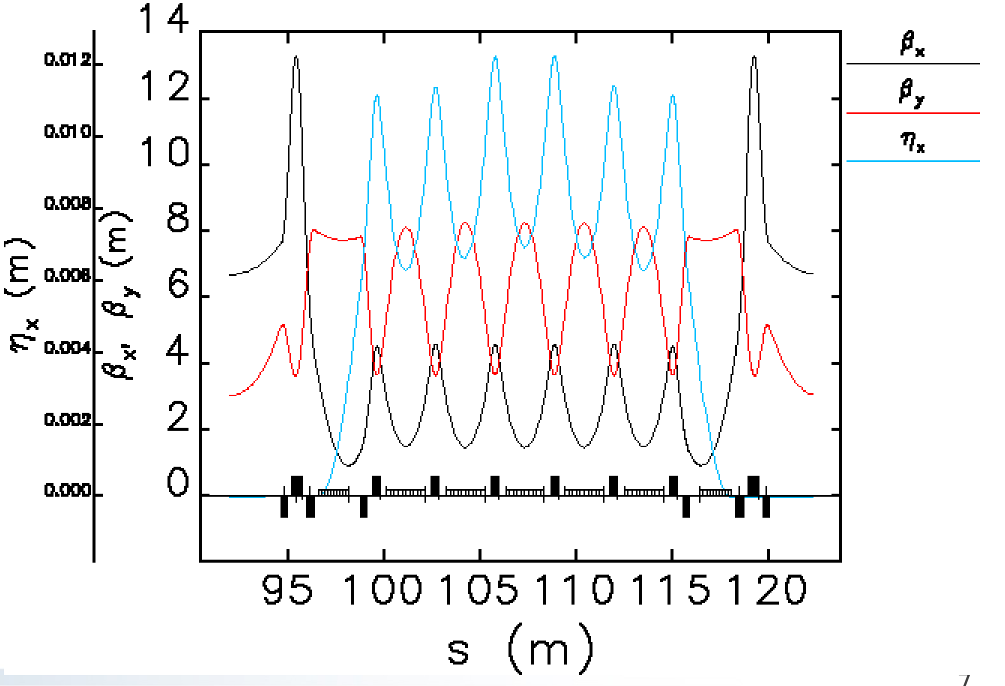
1: M. Borland *et al.*, APS LS-319, 2010.

Typical lattice parameters

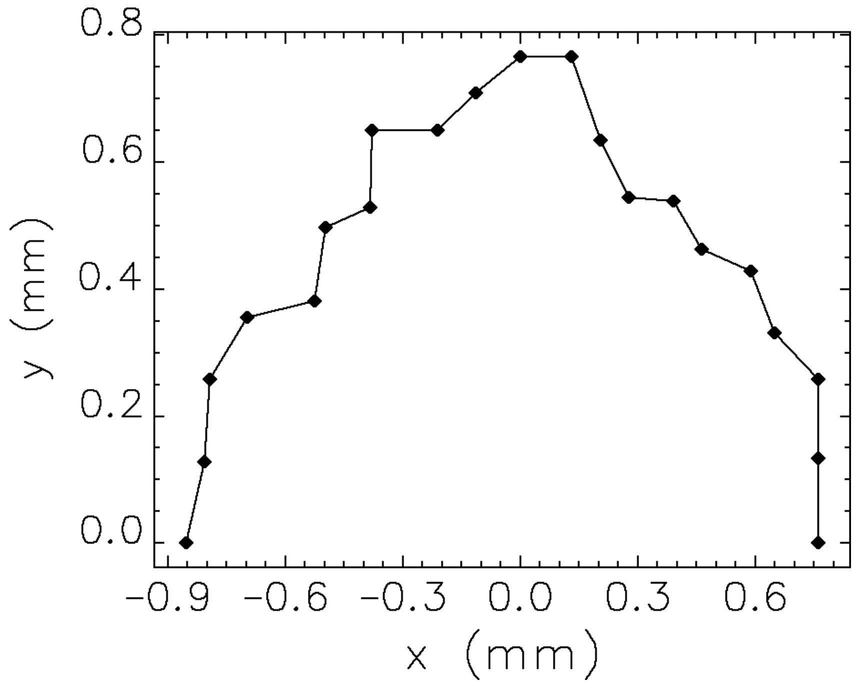
Betatron Tunes		
Horizontal	344.100	
Vertical	171.164	
Natural Chromaticities		
Horizontal	-476.675	
Vertical	-274.241	
Lattice functions		
Maximum β_x	113.354	m
Maximum β_y	39.925	m
Maximum η_x	0.012	m
Average β_x	13.542	m
Average β_y	7.555	m
Average η_x	0.007	m
Radiation-integral-related quantities at 9 GeV		
Natural emittance	2.918	pm
Energy spread	0.096	%
Horizontal damping time	91.382	ms
Vertical damping time	243.007	ms
Longitudinal damping time	713.162	ms
Energy loss per turn	1.535	MeV
Miscellaneous parameters		
Momentum compaction	5.979×10^{-6}	
Damping partition J_x	2.659	
Damping partition J_y	1.000	
Damping partition J_δ	0.341	

Lattice functions





Dynamic acceptance

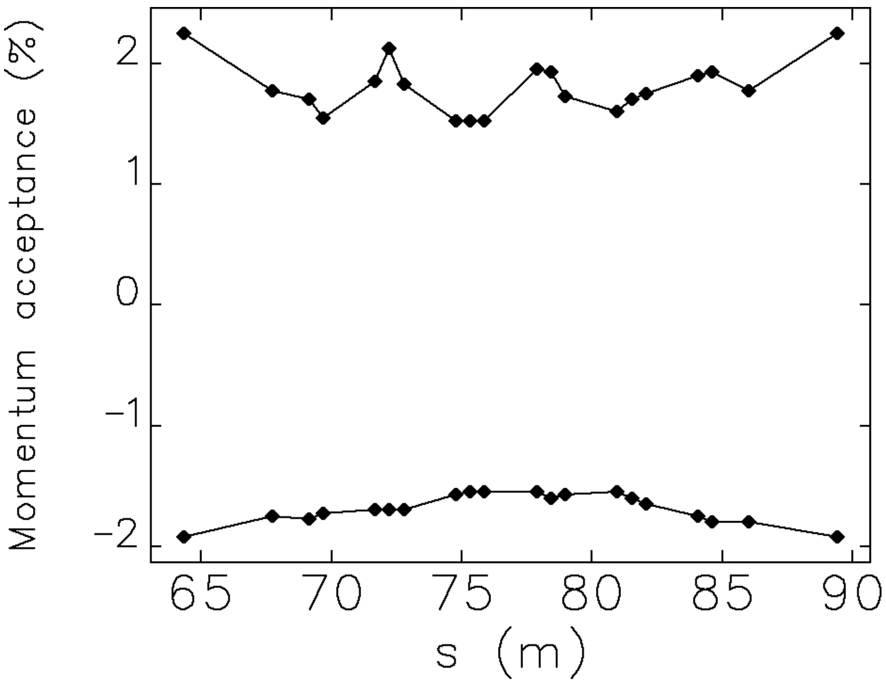


Optimization explored less than 500 configurations so far, so this may improve with more running time

- Adequate for on-axis injection if $\varepsilon_{inj} < 2$ nm
- Impacts gas scattering lifetime
  - Assume 0.5 nT and same partial pressures as APS
  - Predict 4.2 hour gas scattering lifetime[1]

1: Computed using TAPAs, available from the Google play store (search for “Michael Borland”).

Local momentum acceptance



- This is lower than the ±2% target
- Predicted Touschek lifetime is ~4 hours for 0.5 nC bunches and κ~1
  - Combined lifetime with gas scattering is ~2 hours

Magnet Strengths

- PEP-X design has combined function quadrupoles and sextupoles
- Here, we just look at strengths separately
- Sextupoles require ~12mm bore radius (using L=0.35m)

Name	Length	Gradient
		T/m
QD1	0.15	-53.79
QD2	0.17	-51.48
QD3	0.15	-59.37
QDS1	0.15	-13.00
QDS2	0.15	-39.93
QDS3	0.15	-15.29
QDSE	0.15	-6.61
QF1	0.28	62.62
QF2	0.20	93.26
QF3	0.20	71.71
QFC	0.20	72.04
QFS1	0.15	-6.15
QFS2	0.15	30.22
QFS3	0.15	7.58
QFSE	0.15	5.43

Name	Integrated Strength
	T/m^2
SD1	-4139.60
SD2	-4066.24
SD3	-4014.99
SD4	-4140.59
SF1	6650.50
SF2	6730.27
SF3	6618.28
SH1	-9.43
SH2	2.02
SH3	25.70
SH4	-21.24
SH5	-3.77
SH6	10.65

Running with Round Beams

- There are various ways to make "round beams", i.e., κ~1
  - Run on the ν_x-ν_y=N resonance:
    - Pro: $\epsilon_x=\epsilon_y=\epsilon_0/2$
    - Con: hard to control
  - Add a vertically-deflecting damping wiggler
    - Pro: wiggler will provide damping
    - Con: strong, long-period wiggler will impact energy spread, no sharing of ϵ_0 between planes
  - Add x-y emittance-exchange insertions outside of arcs
    - Pro: simple implementation, doesn't mess up cancellation of driving terms inside arcs
    - Con: $\epsilon_x=\epsilon_y=\epsilon_0/\sqrt{2}$
- Of these, the EEX insertion seems preferable
  - Need to explore beam dynamics effects, however
  - Is it actually different from running on ν_x-ν_y=N?

Collective Effects Estimation

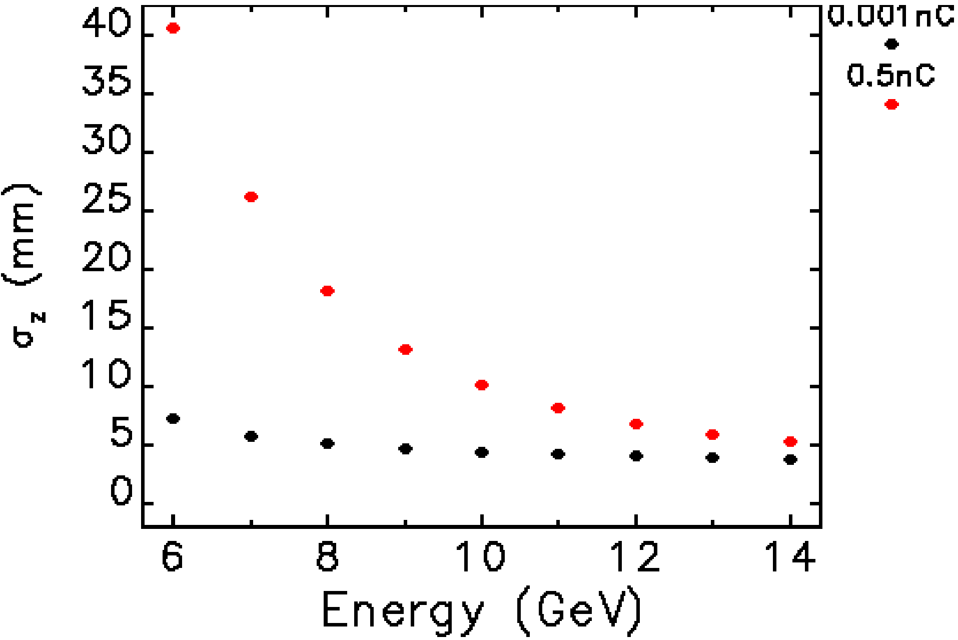
- To estimate collective effects, we use some programs that come with **elegant**
  - **haissinki**[1]: potential well distortion
  - **ibsEmittance**[2]: intrabeam scattering
  - **touschekLifetime**[2]: Touschek lifetime
  - Assume κ=1
- We use |Z/n|=0.28Ω (APS model)
  - Too optimistic if beam pipe is very small
- Microwave threshold is

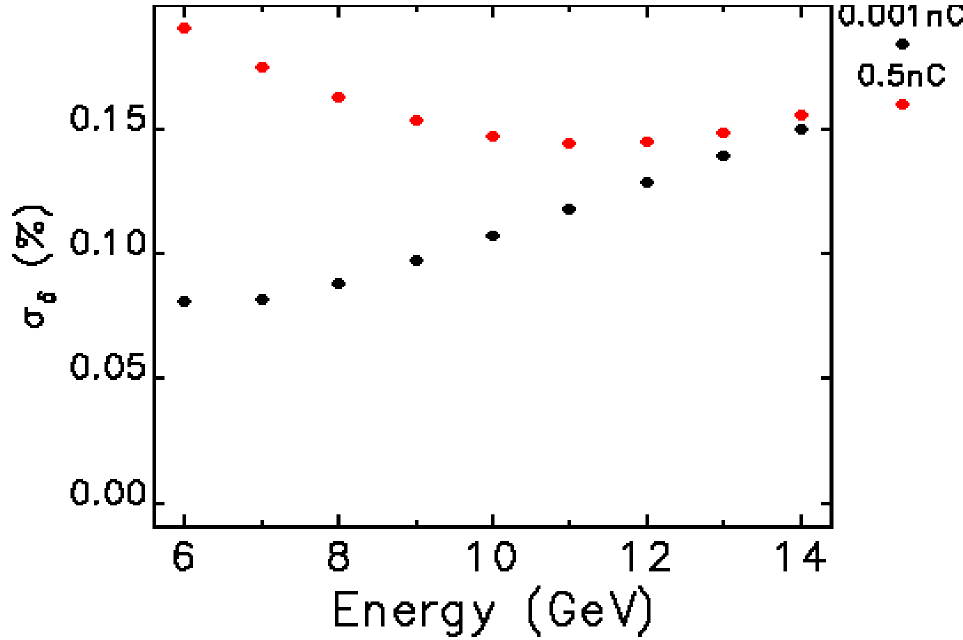
$$I_{mw} = \frac{\sqrt{2\pi}\alpha_c E \sigma_l \sigma_\delta^2}{R|Z/n|}$$

  - Known to be conservative (factor of 5 for APS)
    - Add 5x fudge factor

1: L. Emery *et al.* 2: A. Xiao *et al.*

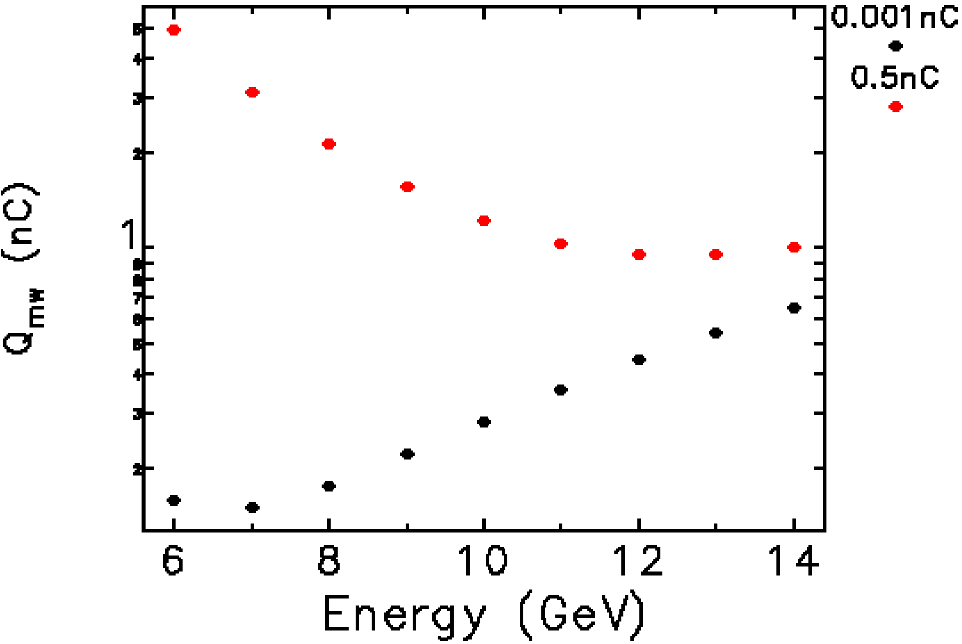
Trends in longitudinal parameters

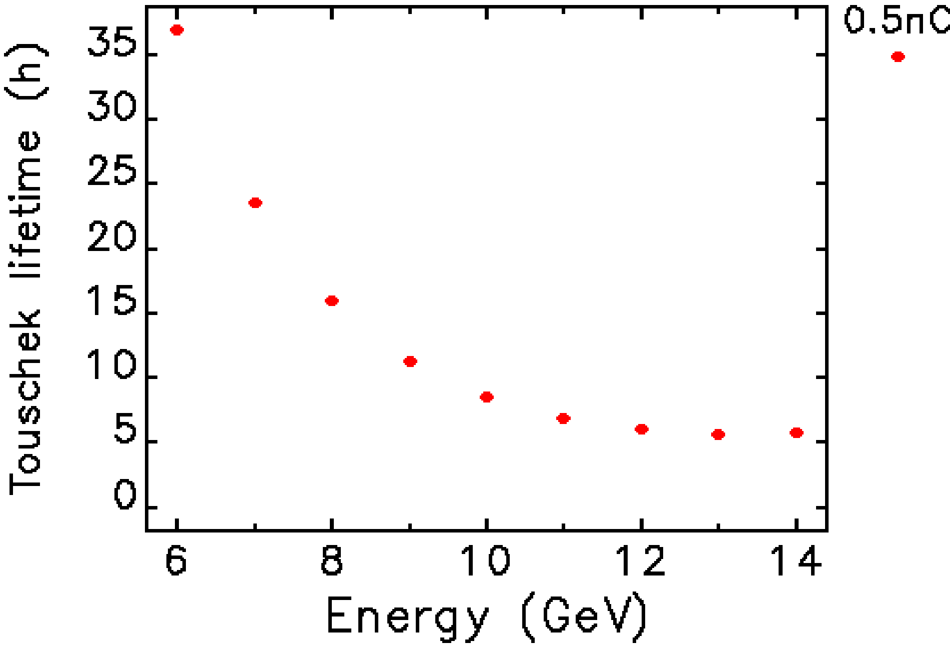




- For 0.5 nC case, trends are promising
- E.g., for 9 GeV
  - Energy spread increases by 50%
  - Bunch lengthens nearly three-fold
- Suggests an advantage to *lower* energy

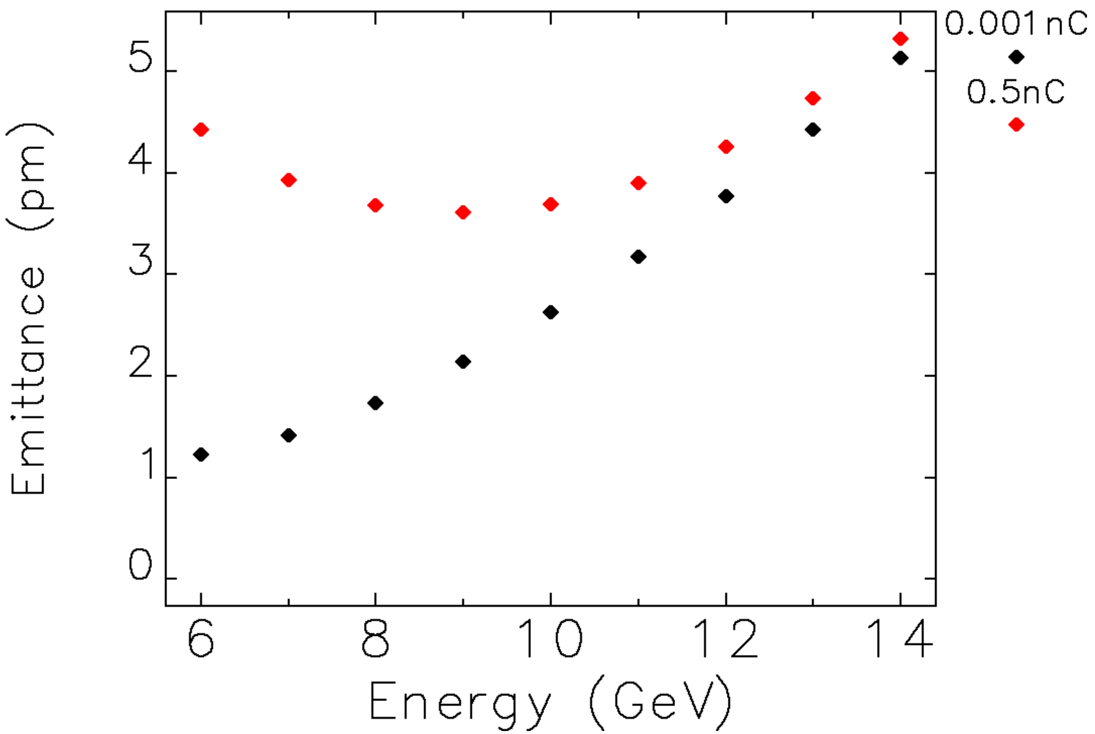
Surprising trends in MWI and Touschek





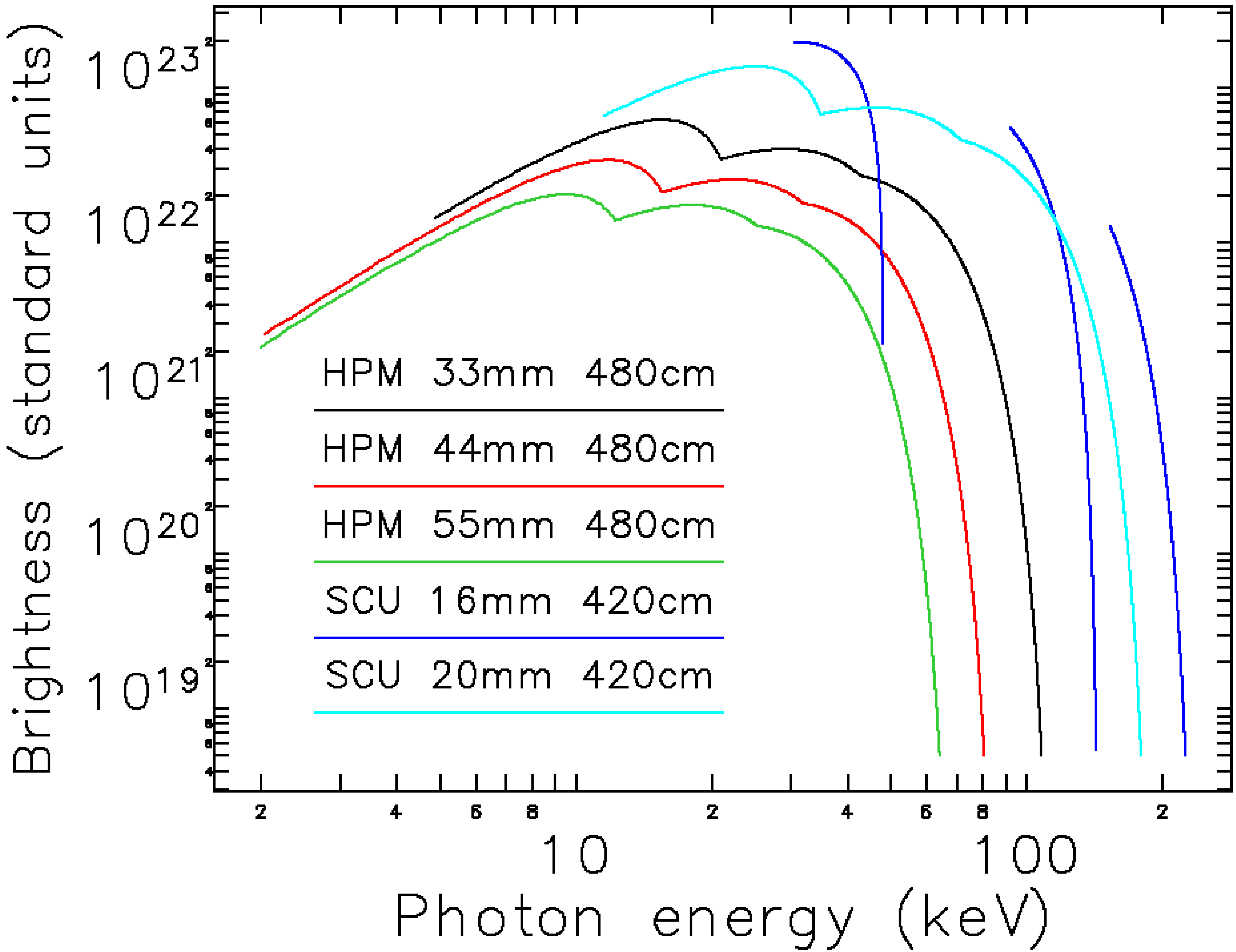
- MWI threshold is >0.9 nC throughout range
- Threshold generally *increases* with decreasing energy
  - Completely contrary to scaling results
  - Due to PWD and IBS, ignored before
- Touschek lifetime calculation assumes ±2% momentum acceptance
  - Touschek lifetime increases at lower energy!

Trend for Emittance



- For 0.5 nC, broad minimum centered on 9 GeV
  - <4 pm in both planes is very good
- Appears that increased Touschek lifetime *does not* result from transversely colder beam at low energy
- We'll take 9 GeV as our working energy

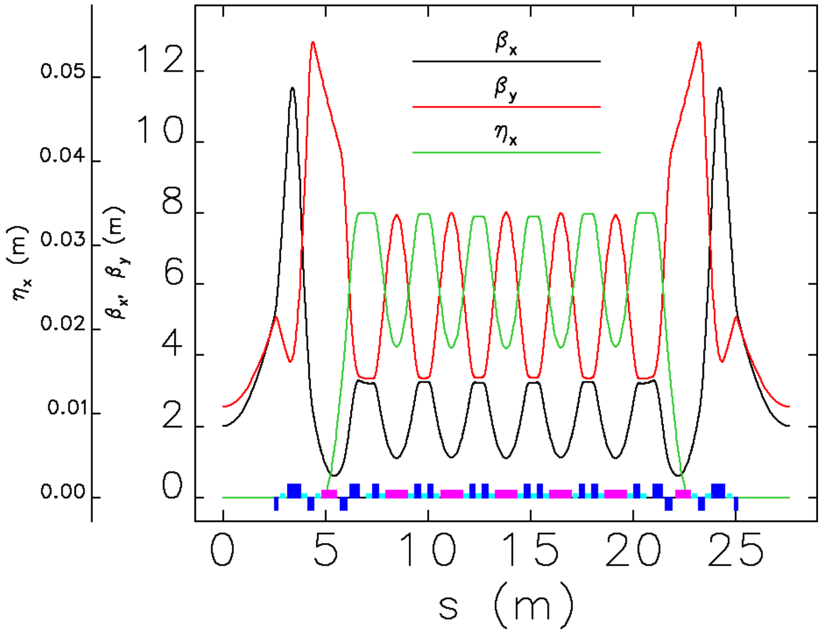
Brightness



Brightness (standard units)
10^23
10^22
10^21
10^20
10^19
HPM 33mm 480cm
HPM 44mm 480cm
HPM 55mm 480cm
SCU 16mm 420cm
SCU 20mm 420cm
2 4 6 8 2 4 6 8 2
10
100
Photon energy (keV)

MBA Lattice for APS (Very Preliminary)

- Drop energy to 6 GeV
  - Reduces magnet strengths
  - Allows larger vacuum bore
  - Implications for ID choices
- Intensive 2-year R&D program just funded
  - Lattice and dynamics
  - Gradual installation
  - Collective effects
  - Magnet and vacuum design
  - Postdoc opportunity



Very similar to MAX IV design

	Present	MBA Lattice
Lattice type	DB	7BA
Electron energy	7 GeV	6 GeV
Current	100 mA	300 mA
Emittance	3.4 nm	147 pm

Conclusion and Questions

- Summarized exploratory work on a Tevatron-sized USR
  - So far, no show-stoppers found
  - Extremely high brightness promised from a 9 GeV ring
- Much work still needed
  - More detailed analysis of collective instabilities
    - Need impedance model consistent with small beam pipe
  - Given that IBS inflates emittance nearly 2-fold, should we relax the lattice to double ϵ_0?
  - Continue error studies and nonlinear dynamics optimization
  - Need to study approaches to and effects of running with $\kappa=1$
  - Are combined-function quad/sext magnets workable?
  - Beta functions at straights are too large (optimum is L/π). What's the trade-off between this and low emittance?
  - What's optimum beam energy for brightness-hungry science applications?
  - What's tolerable in terms of insertion devices (beam dynamics, emittance)?
  - Need injector design with <2nm emittance
  - ...

Acknowledgements

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  - K. Bane, Y. Cai, R. Hettel, Y. Nosochkov, M.-H. Wang
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