Effects of Several Very Long Undulators in the APS ERL Design

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Introduction

- Brightness of photon beam is roughly[1]

$$B \propto \frac{I_e}{E_x E_y \sqrt{4\sigma_\delta^2 + \left(\frac{0.4}{N_u h}\right)^2}}$$

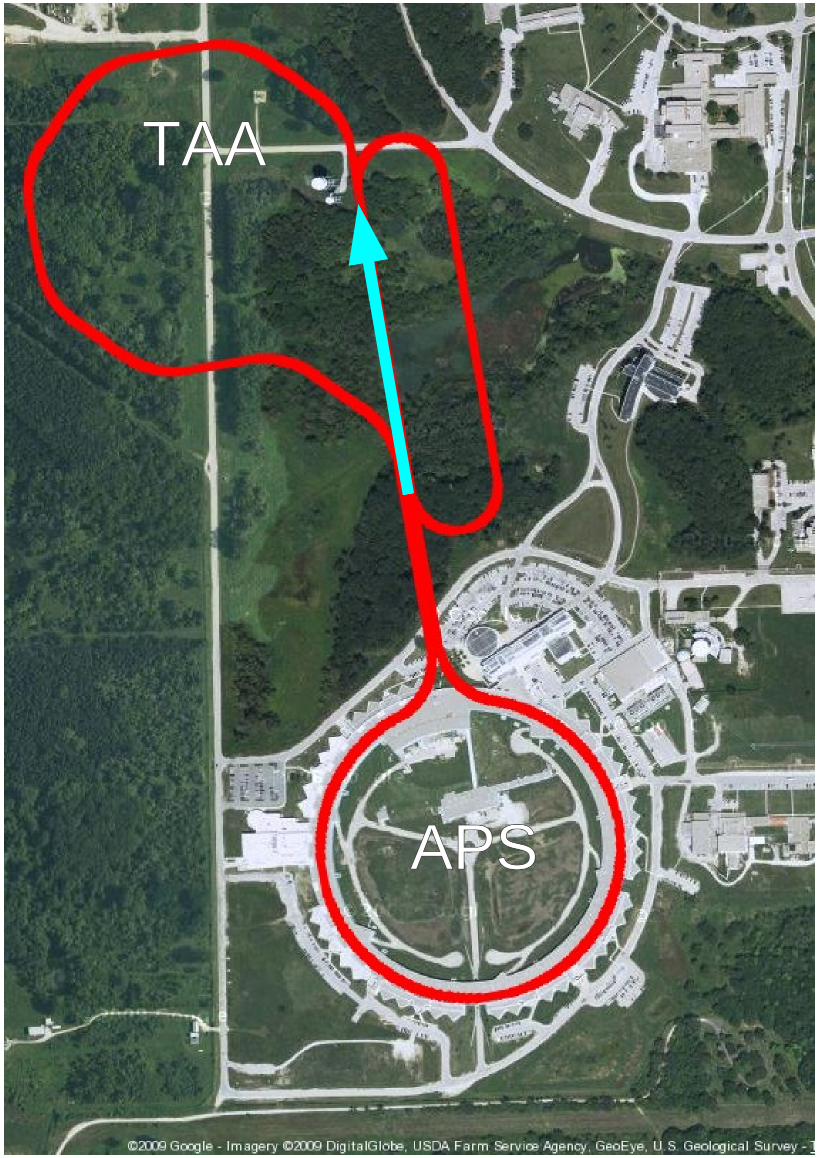
$$E_x = \sqrt{\left(\epsilon_x \beta_x + \frac{\lambda L}{8\pi^2}\right)\left(\frac{\epsilon_x}{\beta_x} + \frac{\lambda}{2L}\right)} \geq \epsilon_x + \frac{\lambda}{4\pi}$$

- ERLs promise three interesting features:
  - Low energy spread (e.g., 0.02%)
  - Diffraction-limited emittance, $\varepsilon \leq \lambda/(4\pi)$
  - Ideal beta functions, $\beta \approx L/(2\pi)$
- Results in
  - Ability to take advantage of long undulators (e.g., >1000 periods)
  - Improved performance for high harmonics
  - Large coherent fraction
- Need to look at impact of long undulators

1:S. Benson *et al.*, NIM A 637 (2011) 1-11.

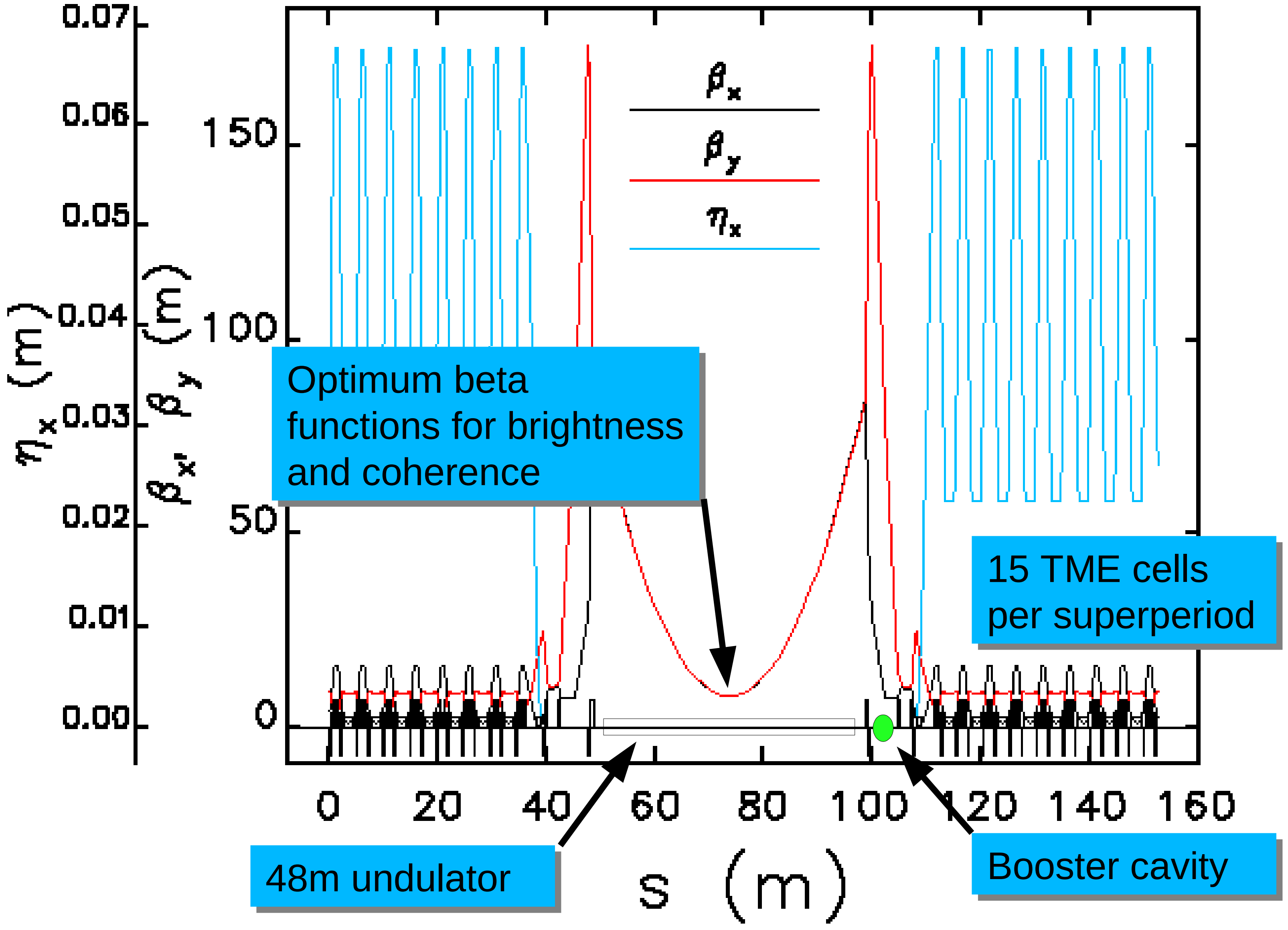
An "Ultimate" ERL@APS Concept

- Two-pass 7 GeV linac with 7 GeV turn-around arc
  - Two-pass linac shown as cost-reducing measure
  - Accelerate away from APS to put highest-quality beam into TAA
- TAA has nine 50-m straight sections
  - Accommodates 48-m undulators to get maximum benefit from beam quality



[1]M.Borland *et al.*, NIM A 582 (2007) 54-56.
[2]M.Borland et al., Proc. PAC09, 44-48.

TAA Optics



0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
η_x (m)
β_x, β_y (m)
150
100
50
0
β_x
β_y
η_x
Optimum beta functions for brightness and coherence
15 TME cells per superperiod
0
20
40
60
80
100
120
140
160
s (m)
48m undulator
Booster cavity

How Does Energy Shift Affect Brightness?

- Beam momentum changes downstream of an undulator as the user changes the gap
- If beam momentum shifts, the photon energy shifts by

$$\left|\frac{\Delta\lambda}{\lambda}\right| = 2\left|\delta\right|$$

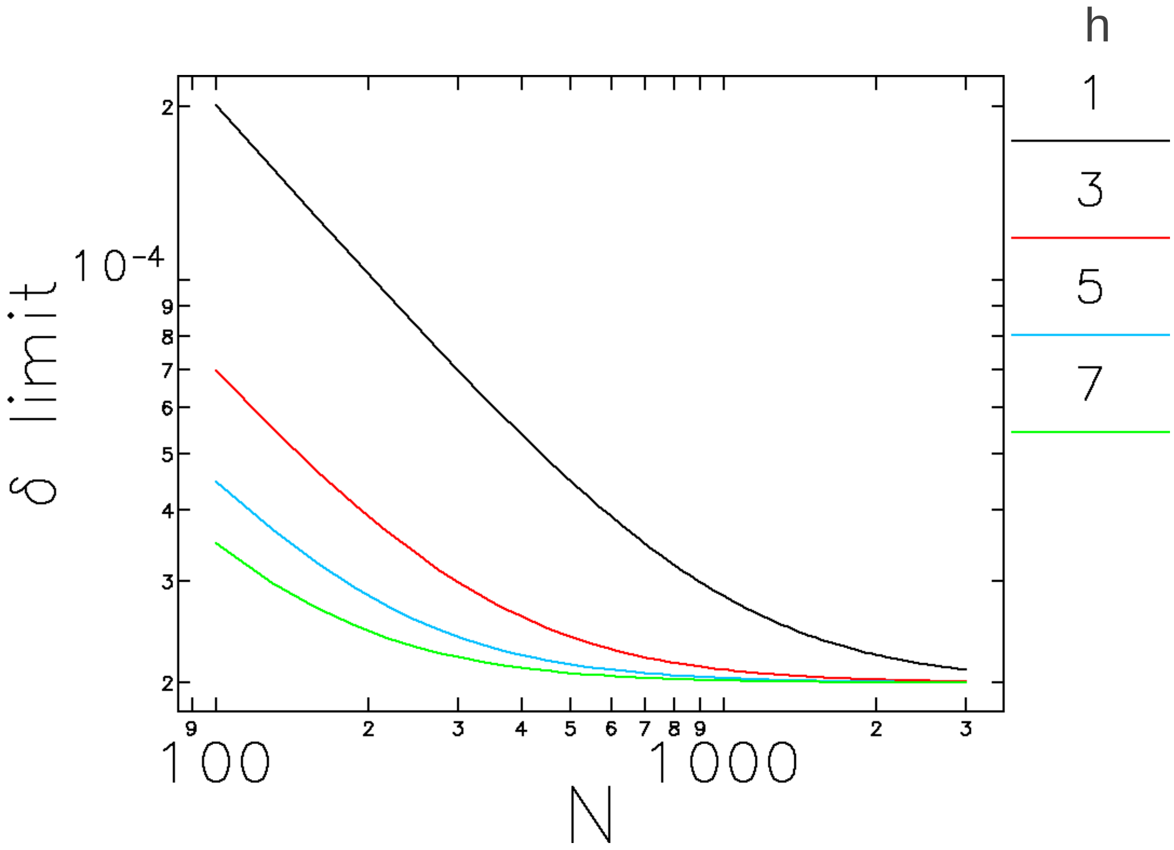
- The effective linewidth of the photon spectrum is

$$\frac{\sigma_\lambda}{\lambda} = \sqrt{(2\sigma_\delta)^2 + \left(\frac{0.4}{Nh}\right)^2}$$

- To avoid moving the spectrum "too much", we require

$$|\delta| \ll \frac{1}{2}\frac{\sigma_\lambda}{\lambda}$$

Energy shift limit for 2×10^{-4} energy spread



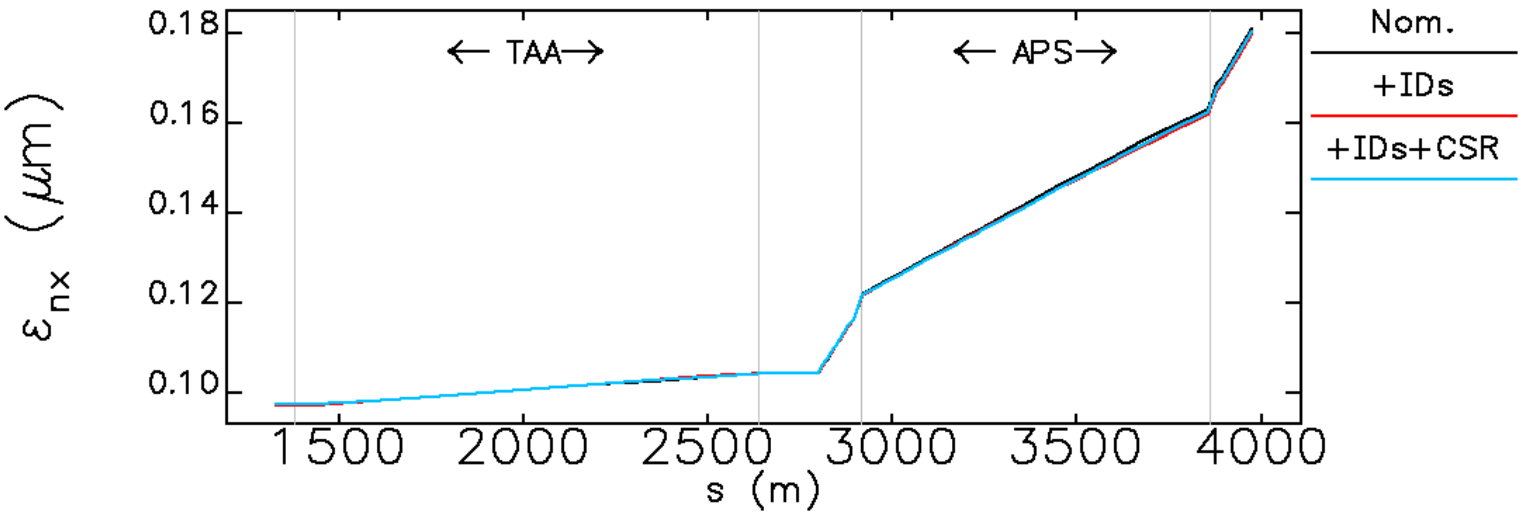
For long undulators, the maximum allowable energy shift is approximately 1/10th the rms energy spread.

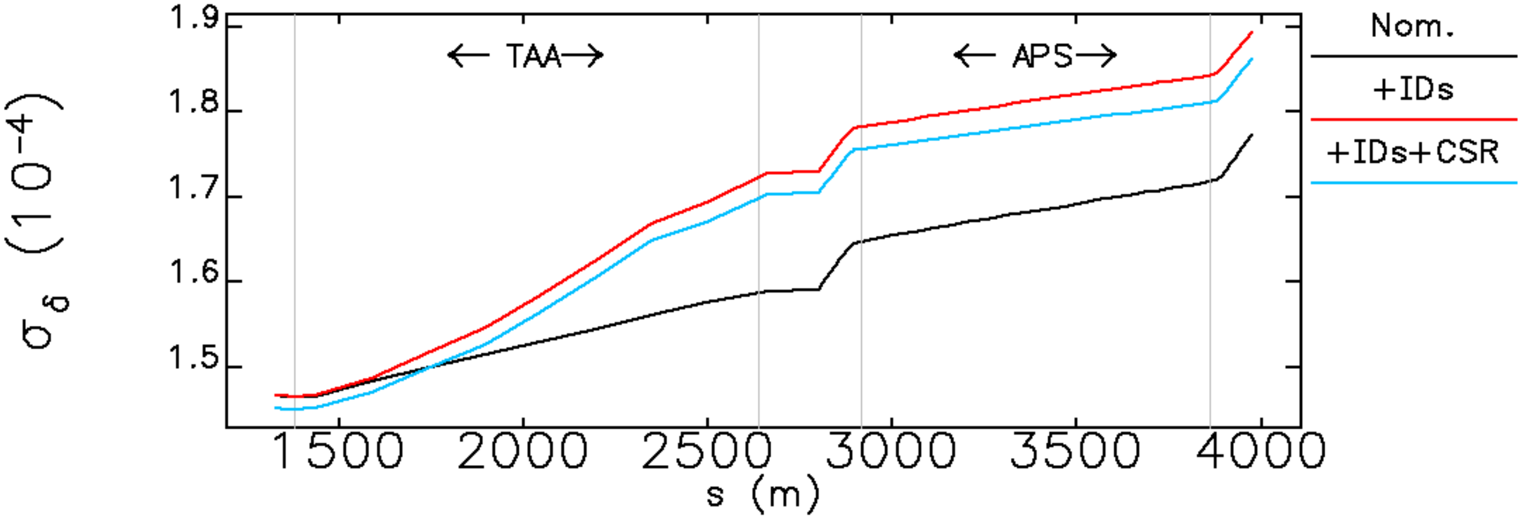
Need for Booster Cavities

- Users must vary undulator gaps, causing energy variation downstream
  - With long devices, variation may exceed the energy spread (1.4 MeV)
  - If uncompensated, will adversely impact downstream users
  - We also need to limit variation in
    - Energy of recovered beam
    - Time of flight through the TAA and APS
    - Energy offset in the 3.5 GeV arcs
- We used a representative set of APS undulator designs
  - Assess impact on beam dynamics
  - Estimate booster cavity parameters
- Booster cavities may be needed in the APS ring portion as well
  - Want to use 8m undulators
  - Could devote every N[th] straight section to a cavity

Undulator		Booster cavity		Number
Period mm	K max.	Voltage MV	Power kW	
18	0.45	0.11	2.7	1
23	1.20	0.46	11.6	1
27	1.78	0.74	18.5	2
30	2.20	0.92	22.9	1
33	2.74	1.18	29.4	2
35	3.08	1.32	33.0	1
55	4.97	1.39	34.8	1

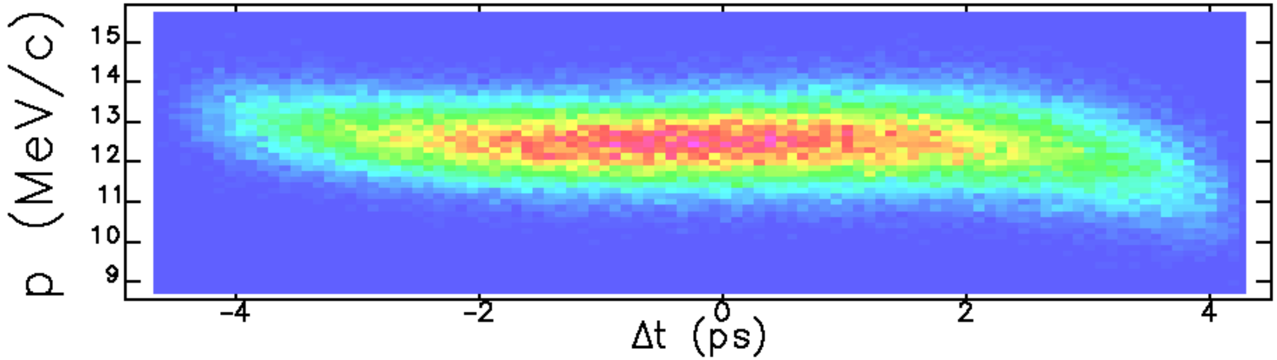
Beam Evolution in 7GeV Portion (19 pC)



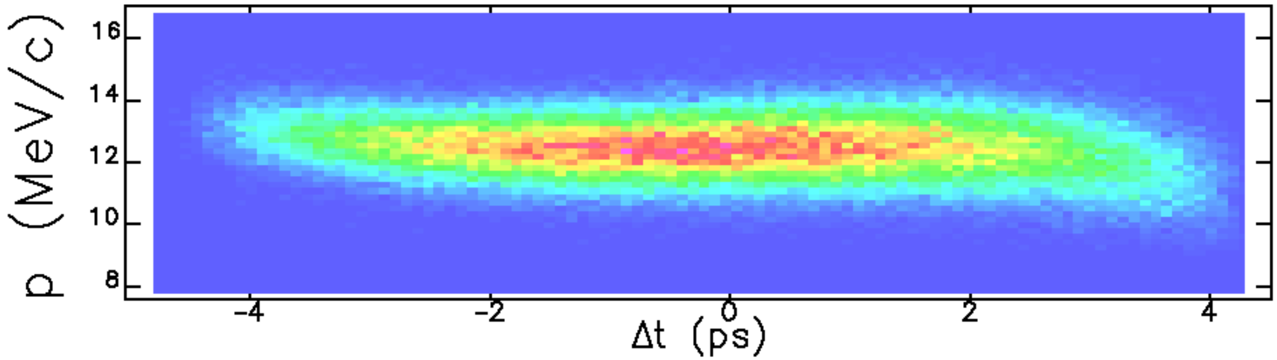


S2E simulation with IMPACT and elegant.

Final Longitudinal Phase Space



Nominal



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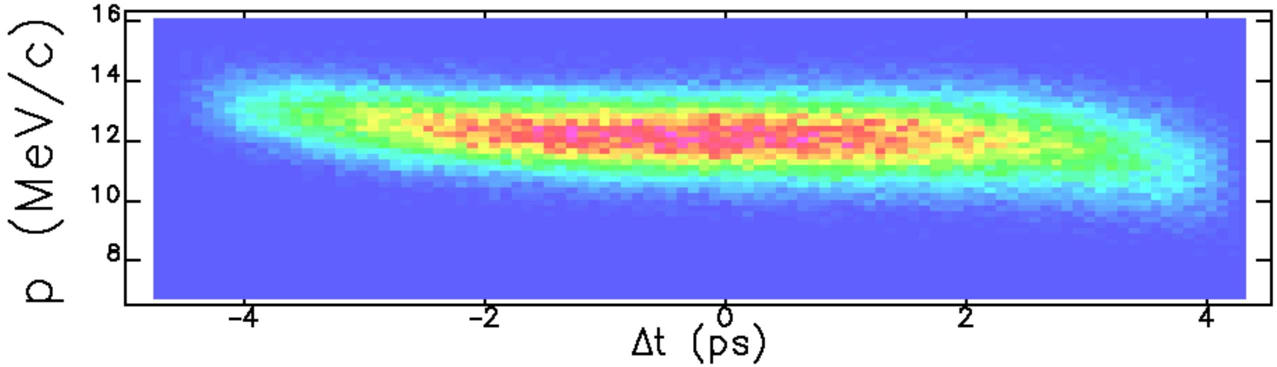

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+CSR

Conclusions

- Even with 9 very long undulators, impact is modest
- Use of booster cavities seems advisable
  - May be necessary only for long-period devices
- Energy spread increase is fairly modest
  - Final energy spread of ~1.3 MeV with all gaps closed
- No emittance growth seen
  - Conclusion should be checked with realistic optics errors (i.e., dispersion leaking into straight sections)
- More detail available in
  - M. Borland, G. Decker, X. Dong, L. Emery, A. Nassiri, Proc. PAC09, 44-48 (2009).