Possibility of bright, polarized high energy photon sources at the Advanced Photon Source

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Advanced Photon Source, Argonne National Laboratory

Outline

1. Introduction: Existing γ-ray facilities
   APS overview
   Why APS γ-ray?
2. Compton scattering basics
3. Possible performance of the APS γ-ray facility
   Booster
   Storage ring
4. Laser systems
5. Summary

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Existing γ-ray facilities

APS overview 1

APS overview 2

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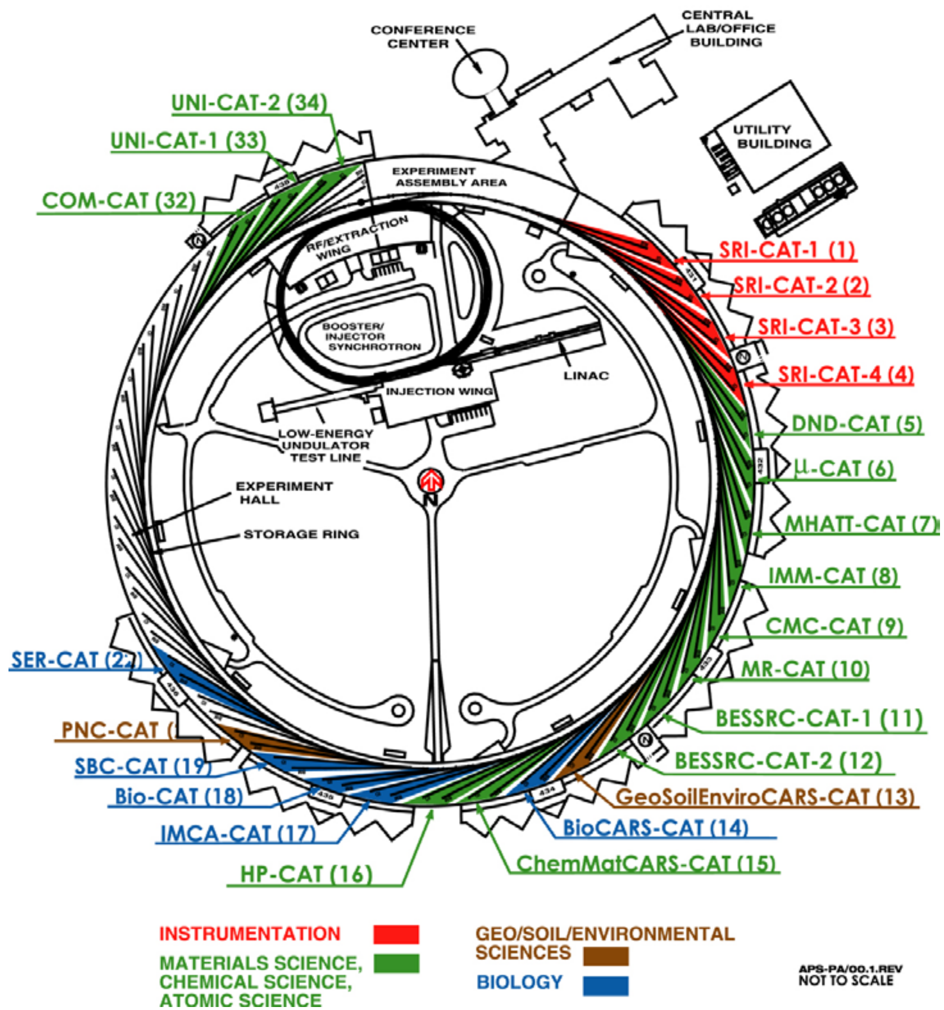
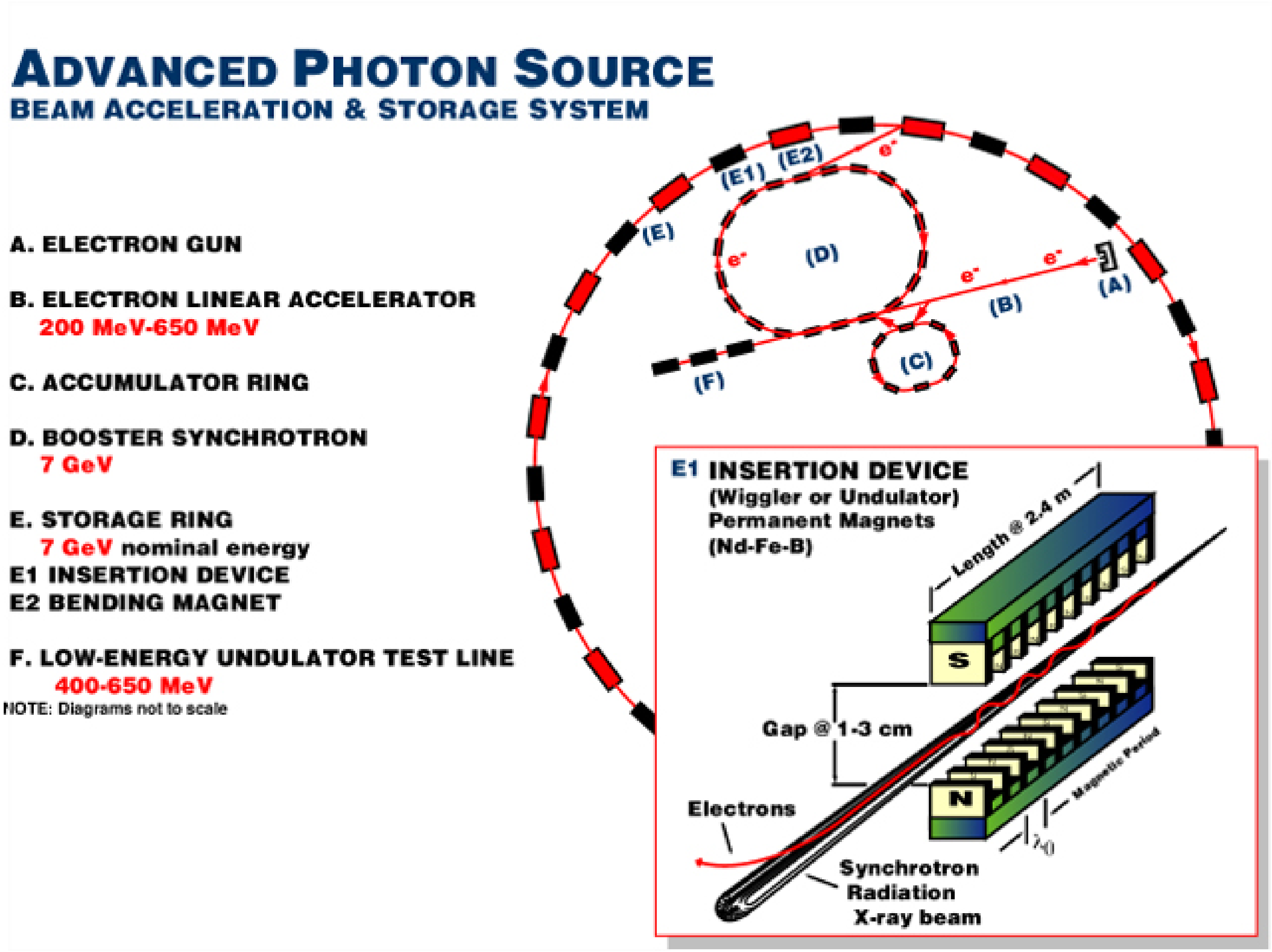
APS Collaborative Access Teams by Sector & Discipline



APS overview 3



Booster Stores .4-4 GeV beam

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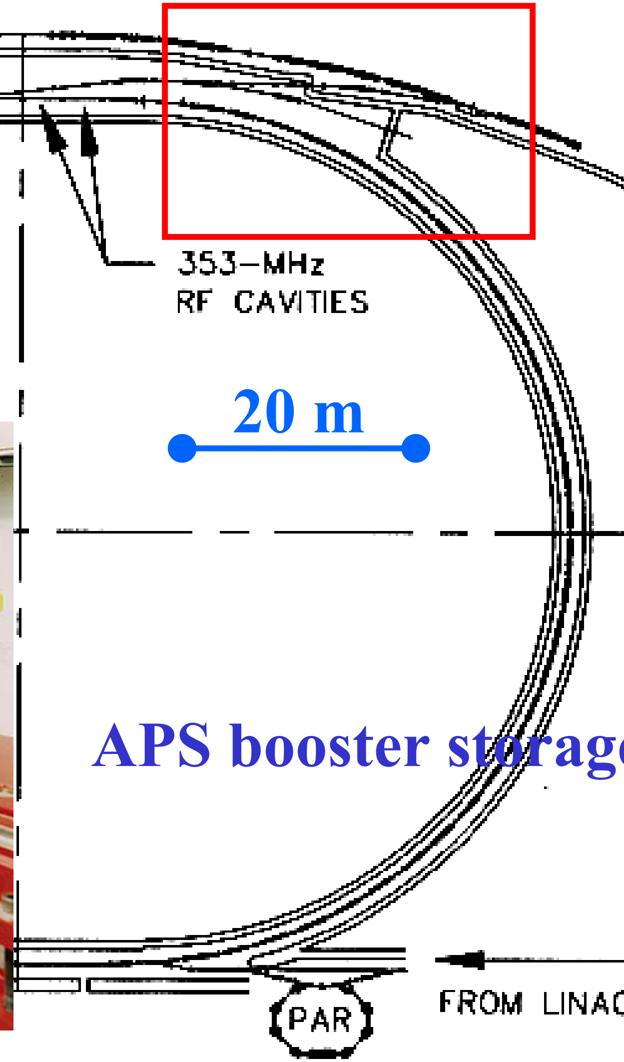
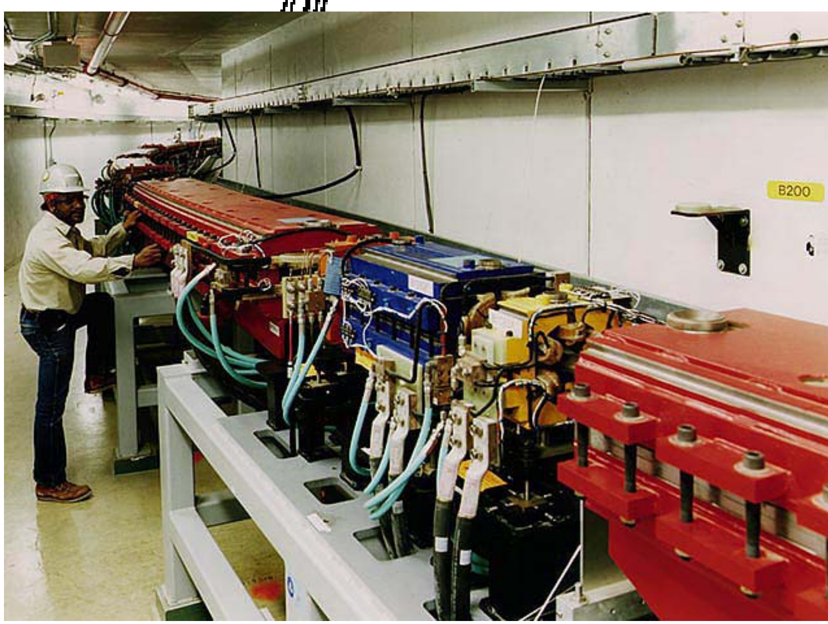
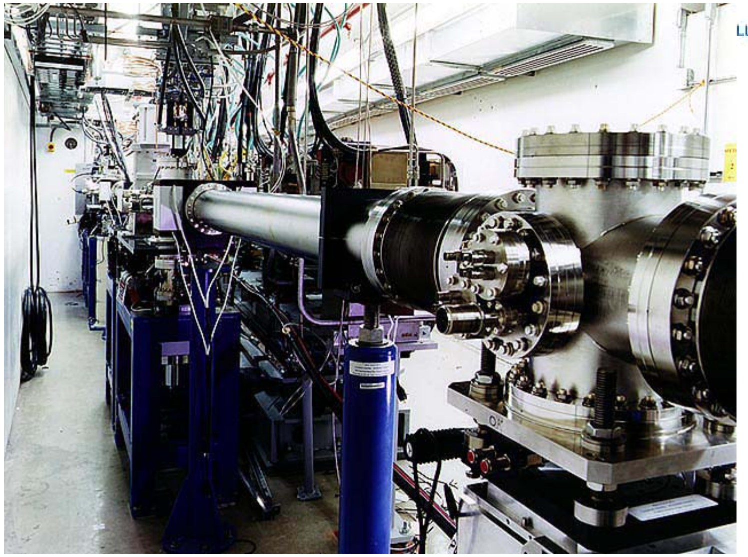




APS booster storage ring

APS SR




INSERTION DEVICE MONO-BEAM STATION
BENDING MAGNET MONO-BEAM STATION
BENDING MAGNET WHITE-BEAM STATION
APS INSERTION DEVICE w/ 5M-LONG VACUUM CHAMBER
BEAMLINE BENDING MAGNET
BENDING MAGNET FIRST OPTICS ENCLOSURE
BENDING MAGNET BEAMLINE
LL FLOOR
EXPE
STORAGE RING BEAM DIRECTION
INSERTION DEVICE WHITE-BEAM STATION
BENDING MAGNET FRONT END
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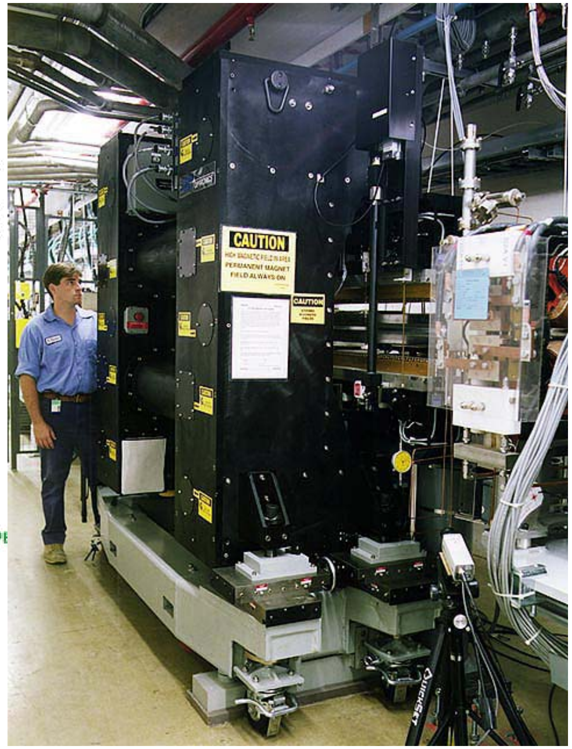
BEAMLINE BENDING MAGNET


CAUTION

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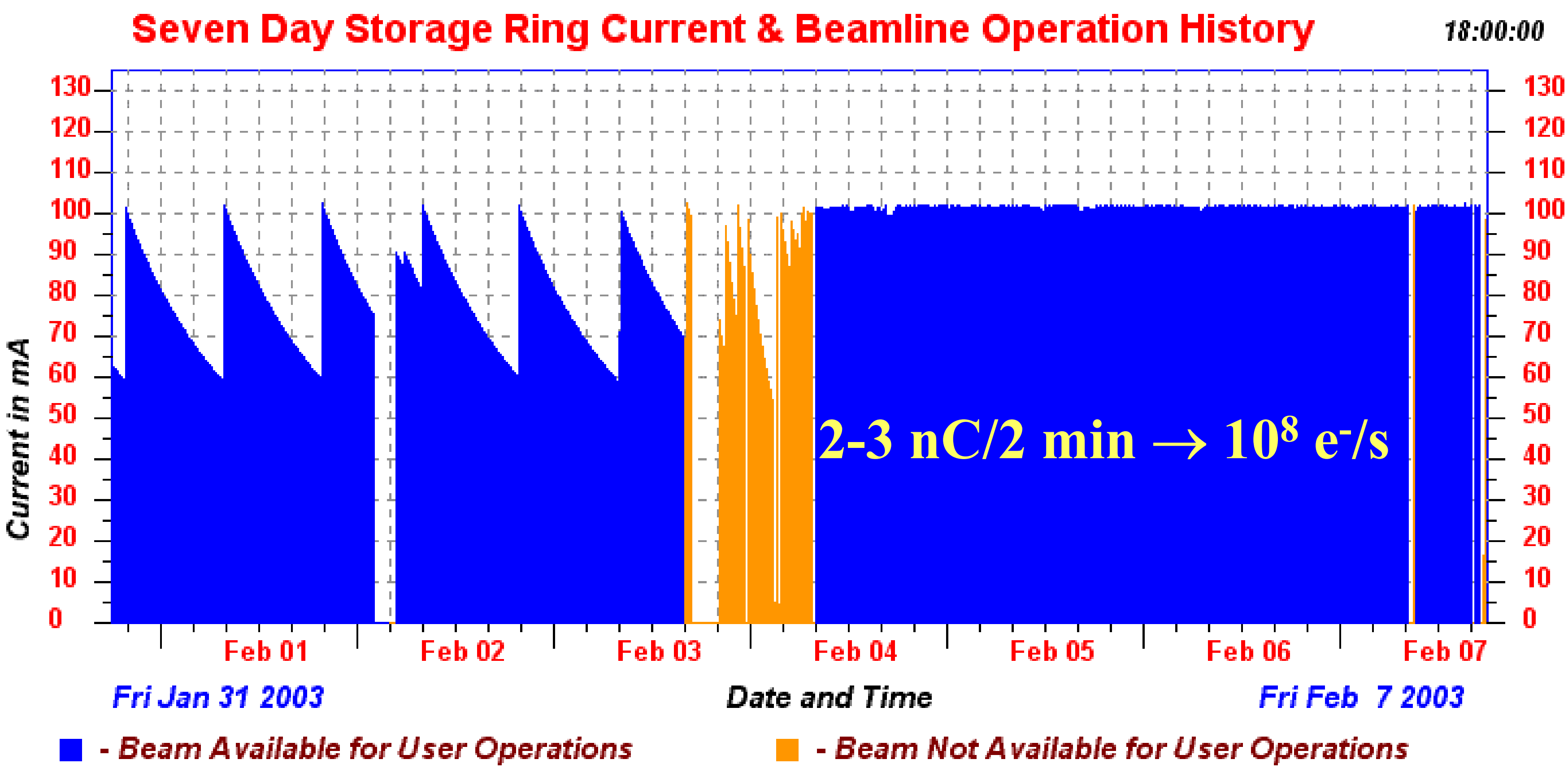
APS parameters

Table 1. APS Booster and storage ring (SR) beam parameters

	Booster	APS SR ID	APS SR BM
Revolution Frequency (kHz)	815	272	
Injection frequency F_i (Hz)	2	0.008	
Nominal energy (GeV)	7	7	
Stored beam energy (GeV)	0.45-4	7	
Energy gain per turn (keV)	32.0	-	
Energy spread, rms @ 7-GeV	0.1%	0.1%	
Emittance ε_0 @ 7 GeV (m-rad)	130×10^{-7} [a]	2.5×10^{-9}	
Coupling factor k	0.1	1-3%	
Electrons per bunch	6.25×10^{10} (10 nC) [b]	10^{11} (15 nC)	
Number of bunches	1	23 [c]	
Bunch repetition rate (kHz)	815	6528	
Bunch length, rms, @ 7 GeV (ps)	77	45	
Beta functions $\beta_{x,y}$ (m)	16, 2.7	19.5, 2.9	2.12, 26.1
Beam size σ_x, σ_y (μm)	786, 102	274, 8.5	91.8, 25.5
Beam divergence $\sigma_{x'}$, $\sigma_{y'}$ (μrad)		11.3, 2.9	56.3, 1.1

a. Recent improvement of the focus of the magnets has improved this down to 93 nm rad [6].
b. This is determined by the safety envelope. The highest ever achieved is 4-5 nC.
c. The typical bunch pattern is 23 bunches spaced evenly at 1/24 of the ring circumference with the 24th bunch missing.

APS: Top-up operation



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Compton scattering basics

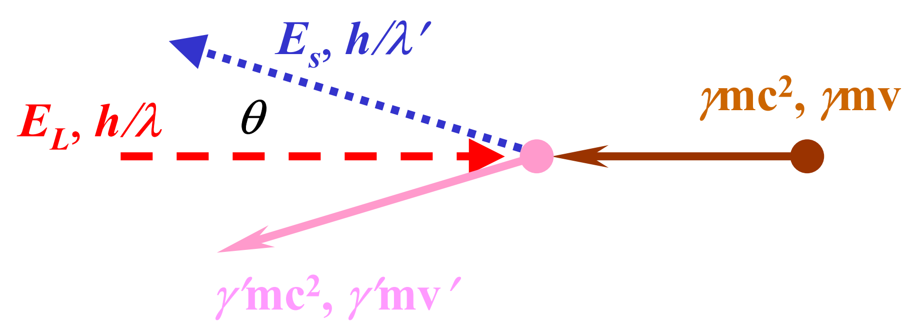
$$E_s = \frac{4\gamma^2 E_L}{1 + \frac{4\gamma E_L}{mc^2} + (\theta\gamma)^2}$$

$$\Sigma = \frac{2\pi r_e^2}{x}\left[\left(1 - \frac{4}{x} - \frac{8}{x^2}\right)\ln(1+x) + \frac{1}{2} + \frac{8}{x} - \frac{1}{2(1+x^2)}\right]$$

$$x = \frac{2\gamma E_L(1 - \beta\cos\phi)}{mc^2} = \frac{4\gamma E_L}{mc^2}$$

$$P_{\gamma\,\max} = P_{Laser}\frac{2}{2 + \frac{(1-a)^2}{a}}$$

a=1/(1+x)

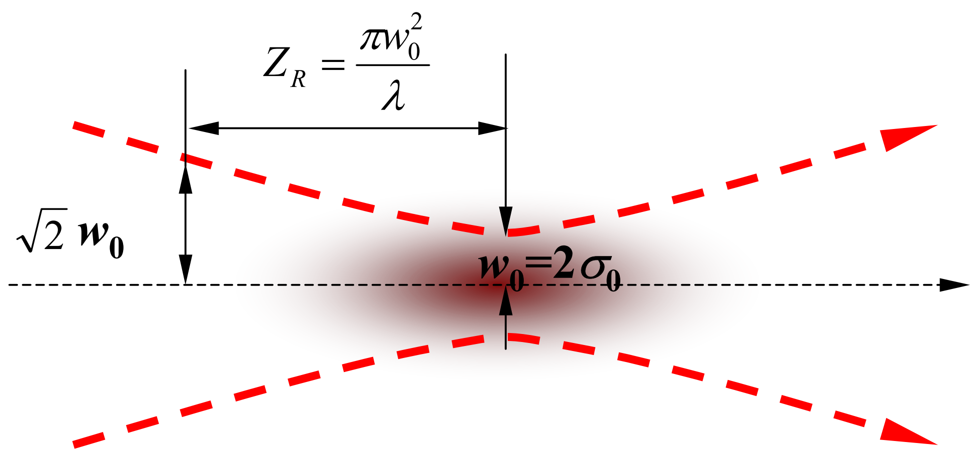


Photon flux calculation

$$f_e = \frac{N_e}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left(-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}-\frac{(z-ct)^2}{2\sigma_z^2}\right)$$

$$f_p = \frac{N_p}{(2\pi)^{3/2}\sigma_0^2\sigma_t}\exp\left(-\frac{x^2+y^2}{2\sigma_0^2}-\frac{(z/c+t)^2}{2\sigma_t^2}\right)$$

$$\sigma_0 \approx \sqrt{\frac{Z_R\lambda}{4\pi}}.$$



Photon flux and bunch lifetime

Photons per scattering

$$N_\gamma = \Sigma \frac{N_e N_p}{2\pi\sqrt{\sigma_0^2+\sigma_x^2}\sqrt{\sigma_0^2+\sigma_y^2}}$$

Flux

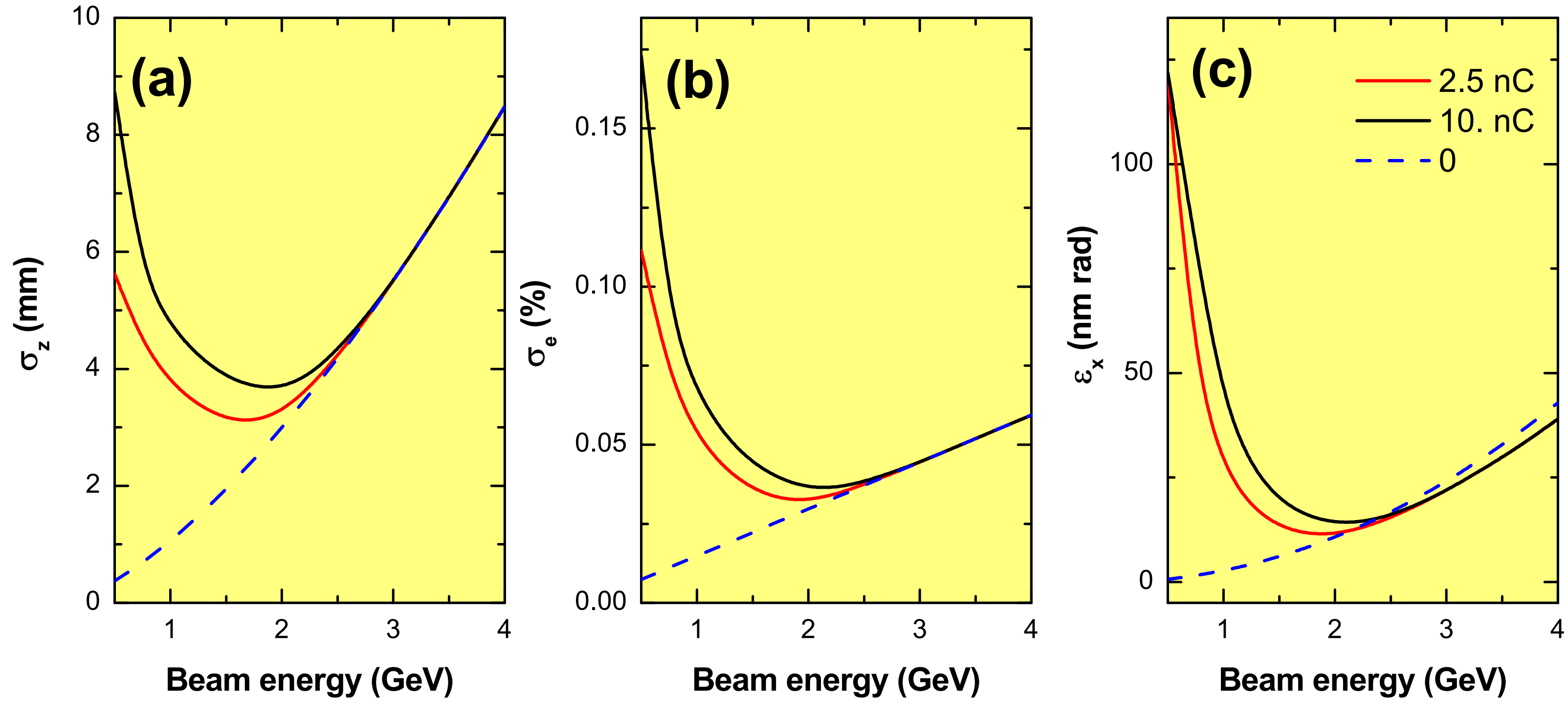
$$F = rN_e \sum_{j=0}^{f-1}(1-r)^j = N_e\left[1-(1-r)^f\right] \approx rfN_e,$$

Lifetime

$$T = -\frac{1}{f}\frac{\ln 2}{\ln(1-r)} \approx \frac{\ln 2}{fr}.$$

$$r = \frac{N_\gamma}{N_e}$$

Booster: Intrabeam scattering



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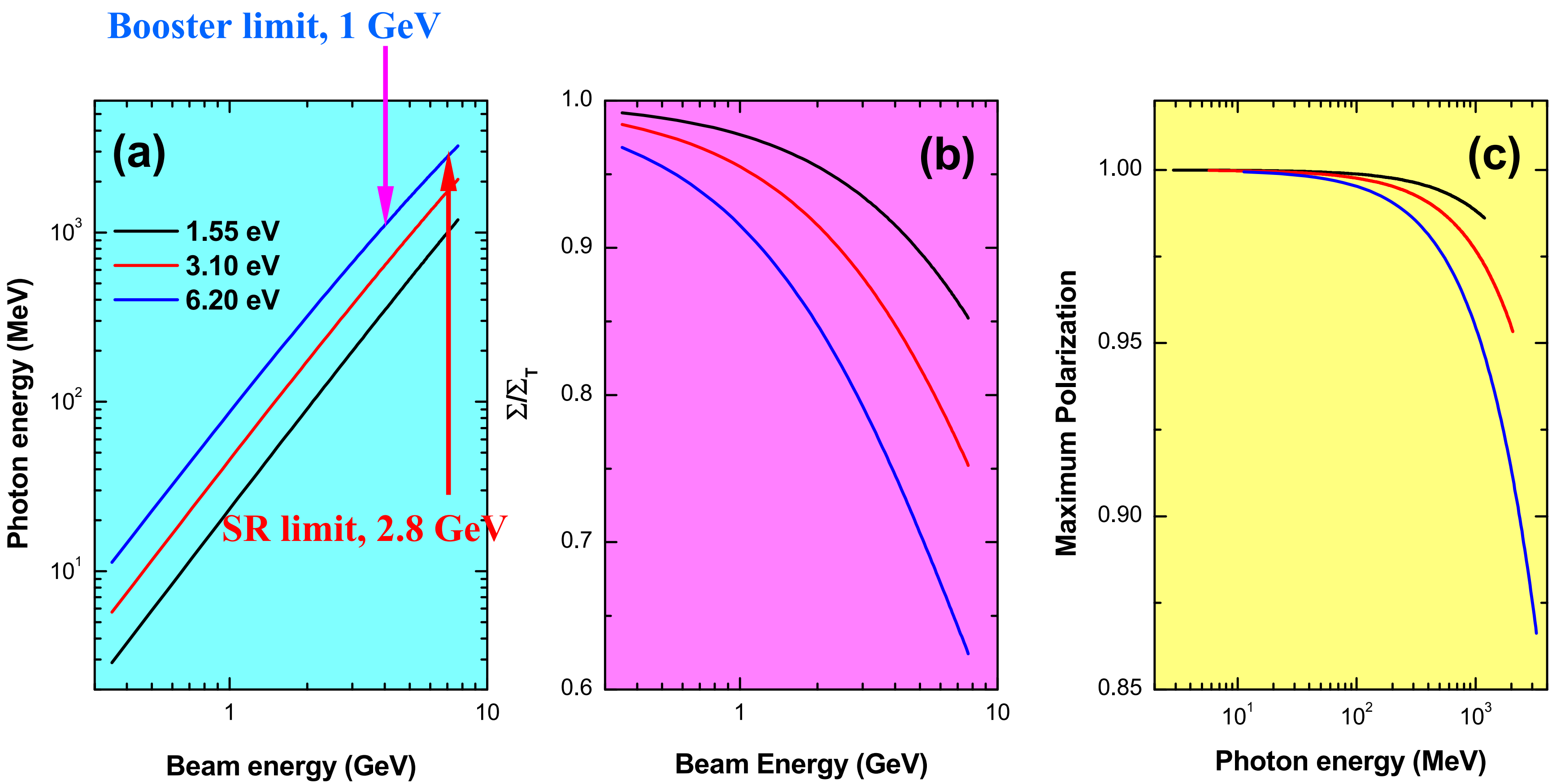
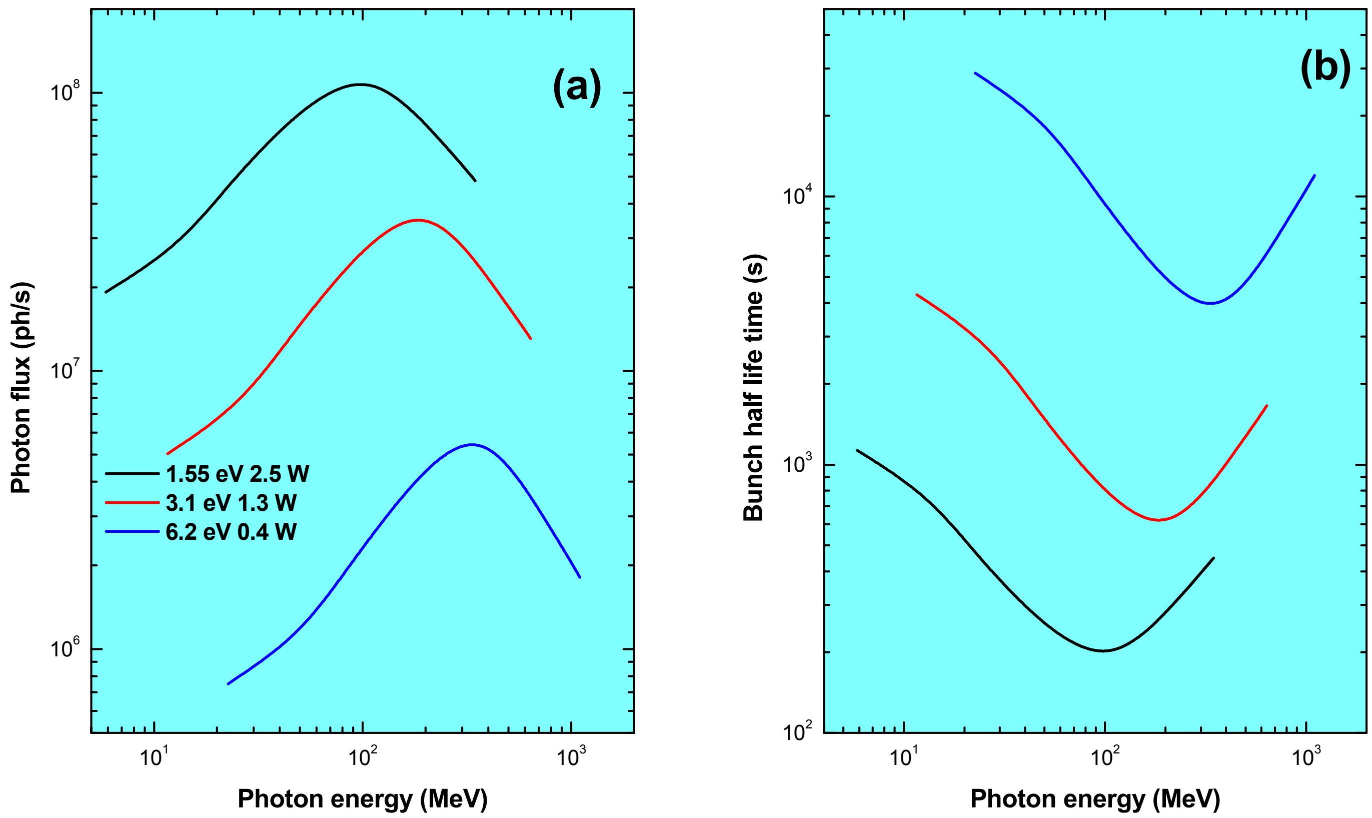
Performance: energy, polarization



Flux and life time: Booster



Coherent Reg A9000, 2.5 W, 250 kHz @ 800 nm
5 nC charge

Reality and Future: booster

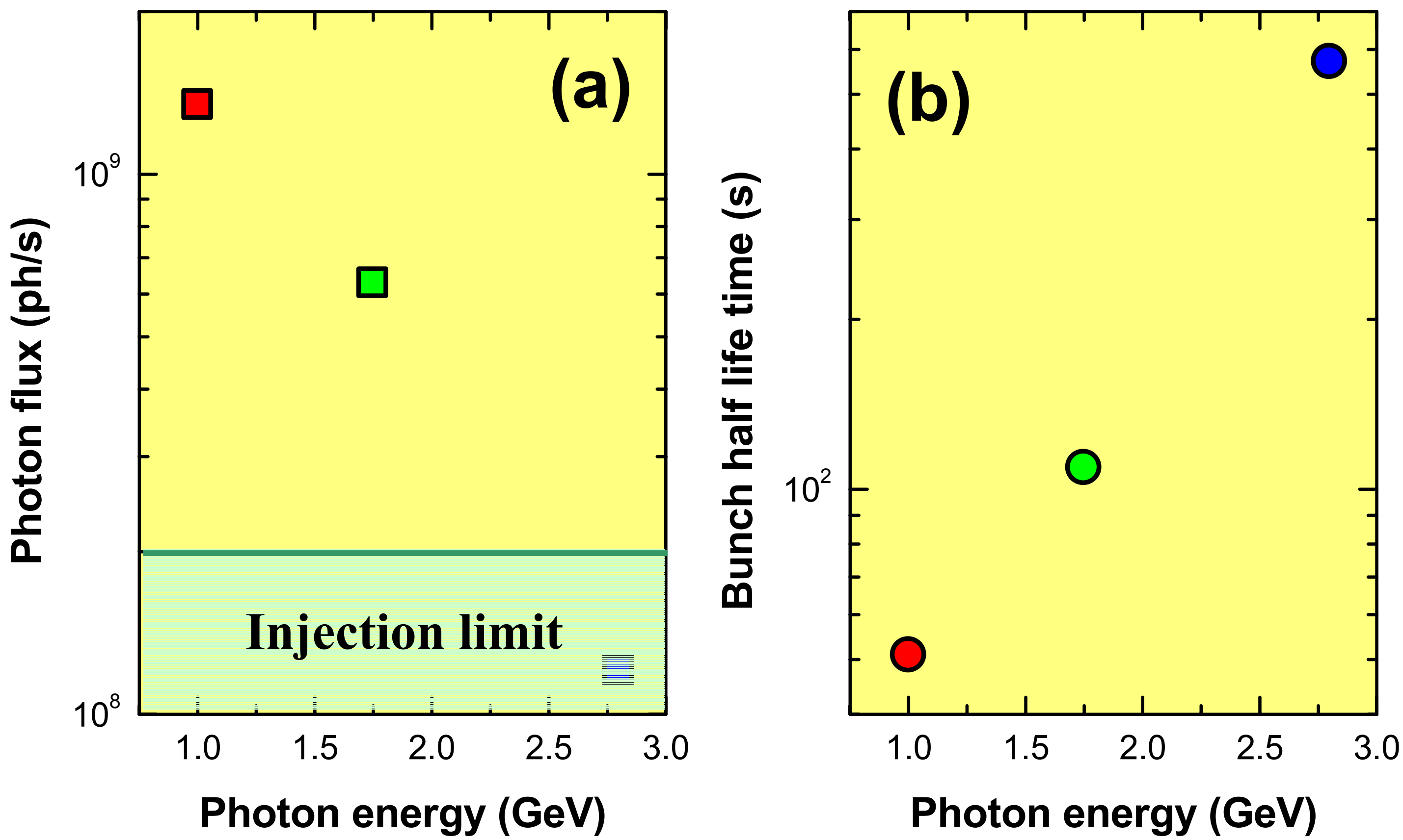
Currently working charge:	2-3 nC
Highest ever achieved:	4-5 nC
Off-the-shelf laser:	2.5 W
Immediately available:	1×10^{8} @ 0.1 GeV 2×10^{6} @ 1 GeV
Repetition rate:	200 photons in 0.1 ns at 815 kHz

To get to higher fluxes

* Need to up grade rf tuner to compensate large beam loading at higher charge
* Replace the magnets for better beam quality
* More powerful laser/intracavity scattering, 10 times or more

Foreseeable:	1×10^{9} @ 0.1 GeV 2×10^{7} @ 1 GeV
Repetition rate:	2000 photons in 0.1 ns at 815 kHz
Machine Limit:	10^{11}

Flux and lifetime: SR



Spectra Physics Tsunami, 3.5 W, 80 MHz @ 800 nm

Reality and Future: SR

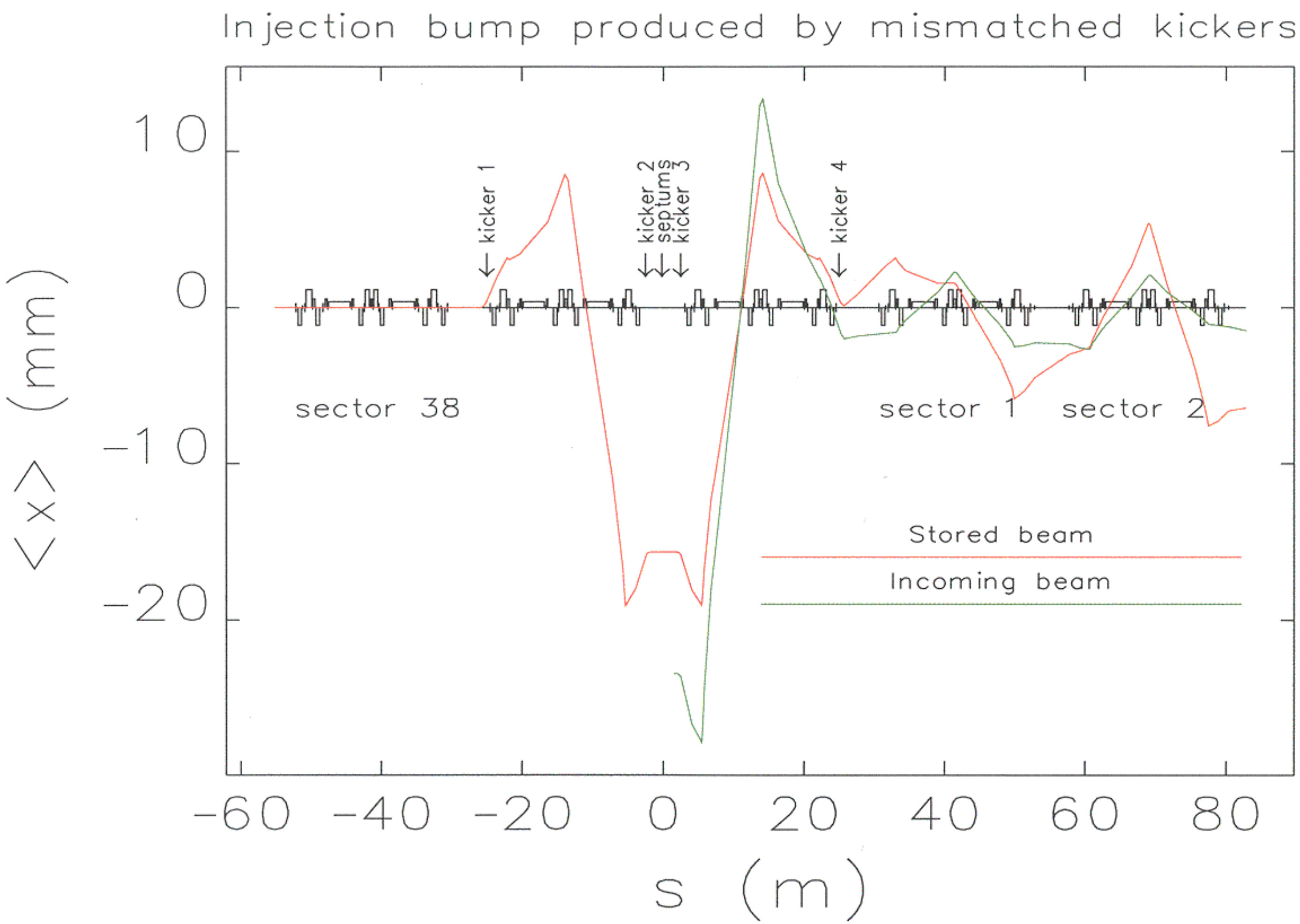
Currently injection charge:	2-3 nC/2 min
	$\rightarrow$1-1.5×10^8 e^-/s loss
Highest ever achieved:	4-5 nC
	$\rightarrow$1-1.5×10^8 e^-/s for depletion
Off the shelf laser:	3.5 W
Immediately available:	1-2×10^8 @ 1, 1.7 GeV
	10^8 @ 2.8 GeV
Repetition rate:	30 photons in 0.1 ns at 6.528 MHz

To get to higher fluxes

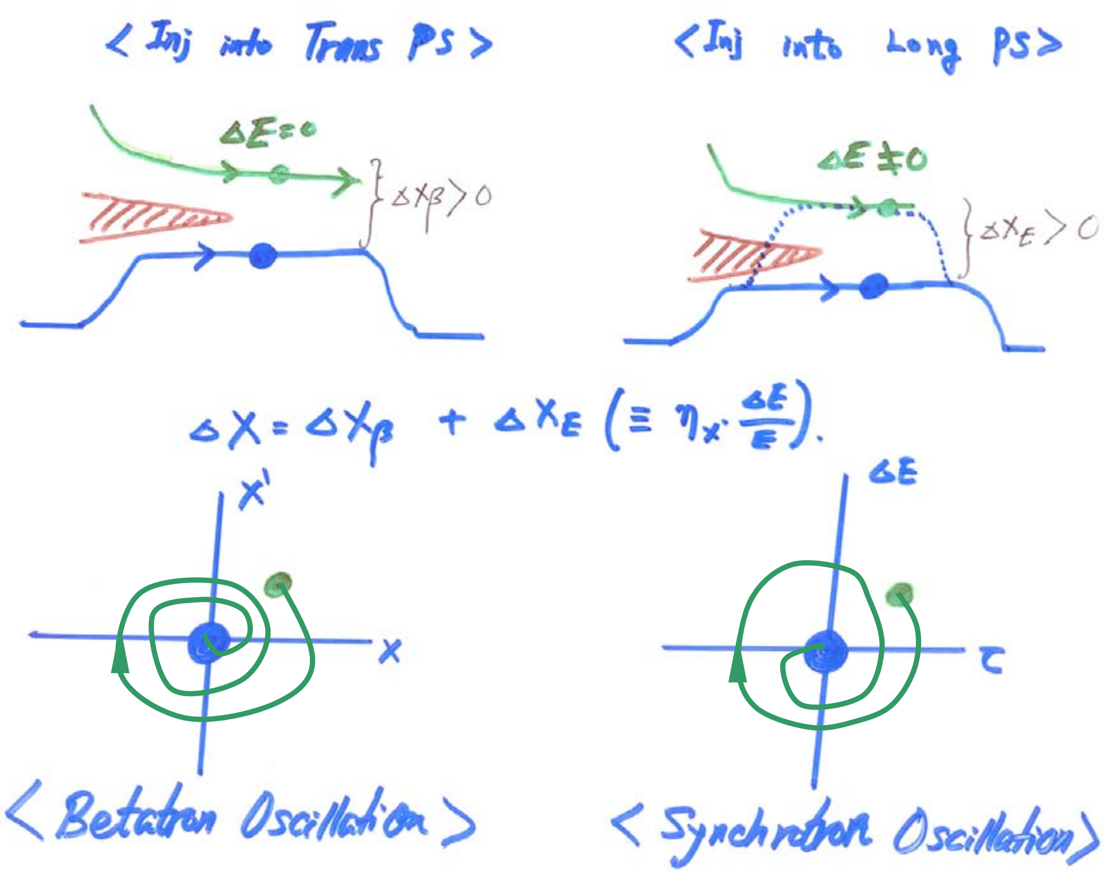
* Booster upgrade for higher charge per shot
* Implement new lattice for quiet injection for more frequent injection up to 2 Hz
* More powerful laser/intracavity scattering: 10 times more

Foreseeable:	1-2×10^9 @ 1, 1.7 GeV
	10^9 @ 2.8 GeV
Repetition rate:	300 photons in 0.1 ns at 6.528 MHz
Machine limit:	10^{11}/s

Transverse injection: orbit disturbance



Longitudinal injection



10 ms **5 ms**

Performance summary

Table 2. Comparison of the Performance of the Proposed APS γ-Ray Source and HIGS

	APS SR	APS booster	ESRF GRAAL [3]	SPring-8 LEPS [3]	HIGS future [3]
Beam energy (GeV)	7	0.4-4	6	8	0.2-1.3
γ-ray energy (GeV)	1, 1.7, 2.8	0.005-1.0	0.55-1.50	1.5-2.4	0.002-0.220
Flux (photons/s)			3×10^6	5×10^6	10^6-10^{10}
Immediate	1-2×10^8	2×10^6 – 10^8			
Foreseeable upgrade	3×10^9-3×10^8	2×10^7 – 10^9			
Machine limit	10^{11}	10^{11}			

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Commercial and custom lasers

Table C1. Performance of the off-the-shelf Ti:Sa lasers

Make and model	Energy per pulse [a]	Rep rate	Average power
Coherent RegA9000	5 μJ compressed 10 μJ uncompressed	250 KHz	2.5 W
Quantronix	>5 mJ compressed 10 mJ uncompressed	1 kHz	10 W
Spectra Physics Tsunami	40 nJ	80 MHz	3.5 W
Coherent Mira	20 nJ	80 MHz	1.4 W

a. In deriving the uncompressed pulse energy, the compressor efficiency is assumed to be 50%.

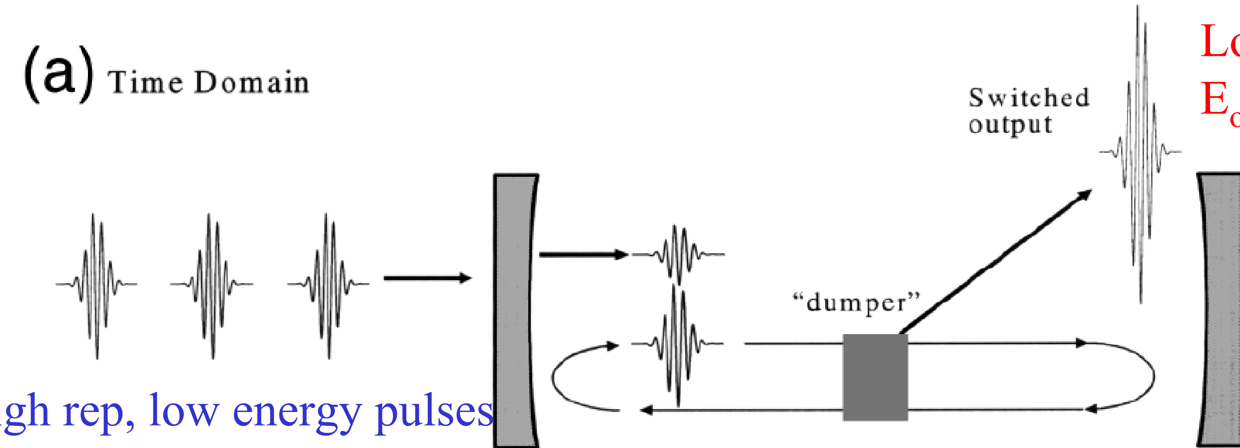
Example of custom laser with higher power:

4 W, 75 MHz at 527, → 8 W @ 1053 nm, operating, J Lab
30 W, 75 MHz at 532, → 60 W @ 1064 nm, under development, J Lab

Laser: external buffer cavity

Purpose: **Laser repetition rate adjustment**
Intracavity scattering?

Low rep output
$E_{out}=nE_s=E_s/loss$



Seed: high rep, low energy pulses
f, E_s

Cavity with length matching
the rep rate of the seed, L=1/f

Jones and Ye, Opt Lett 27, 1848 (2002)

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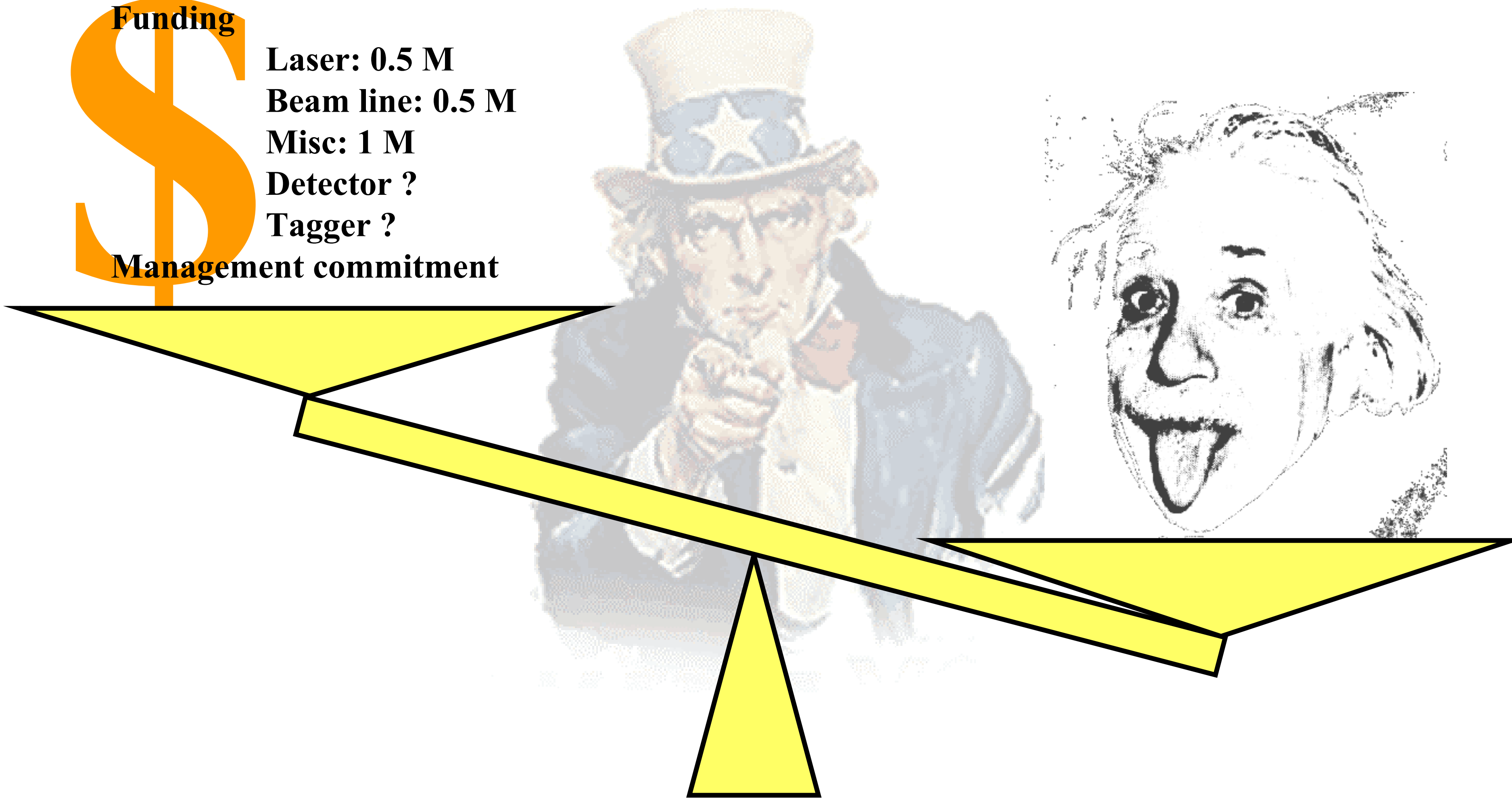
New γ-ray flux distribution map

Challenges

Funding

Laser: 0.5 M
Beam line: 0.5 M
Misc: 1 M
Detector ?
Tagger ?

Management commitment



Announcement

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Discussion

What:	**Technical feasibility** **Physics possibilities**
When:	**8:00 PM on Monday (today)**
Where:	**Ballroom in the Waikiki Terrace Hotel**
Who:	**Anyone interested**
Also:	**Dessert and coffee.**

Acknowledgement

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