Electron Lenses : New Versatile Accelerator “Swiss Knife”

Vladimir SHILTSEV (Fermilab)

2019 International Particle Accelerator Conference

23 May 2019 – Melbourne, Australia

Tetsuji NISHIKAWA (1926-2010)

- 1964-66 BNL linac
- 1969 Japan National Lab for High Energy Physics
  - 12 GeV proton synchrotron
  - Neutron facility (→ J-PARC)
  - 500 MeV cancer treatment synchrotron
  - KEK Photon Factory
  - TRISTAN collider

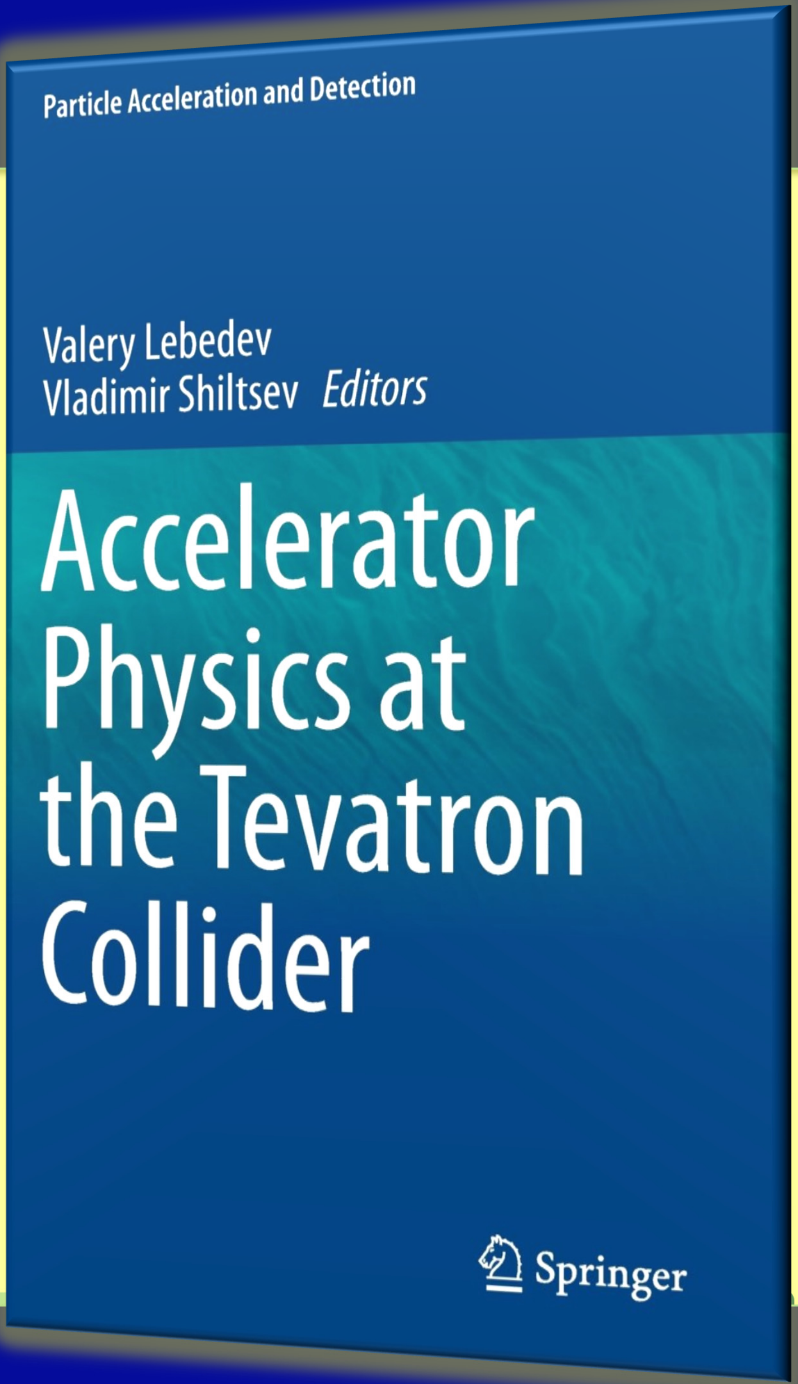

William Wallenmeyer
James Leiss
Kohei Shinozawa
Tetsuji Nishikawa
THE FIRST MEETING OF THE US-JAPAN COMMITTEE ON
HIGH ENERGY PHYSICS
SLAC - 1979


Shin-Ichi KUROKAWA
Chair of IPAC19Prize Committee
2011 IPAC ROLF WIDEROE PRIZE

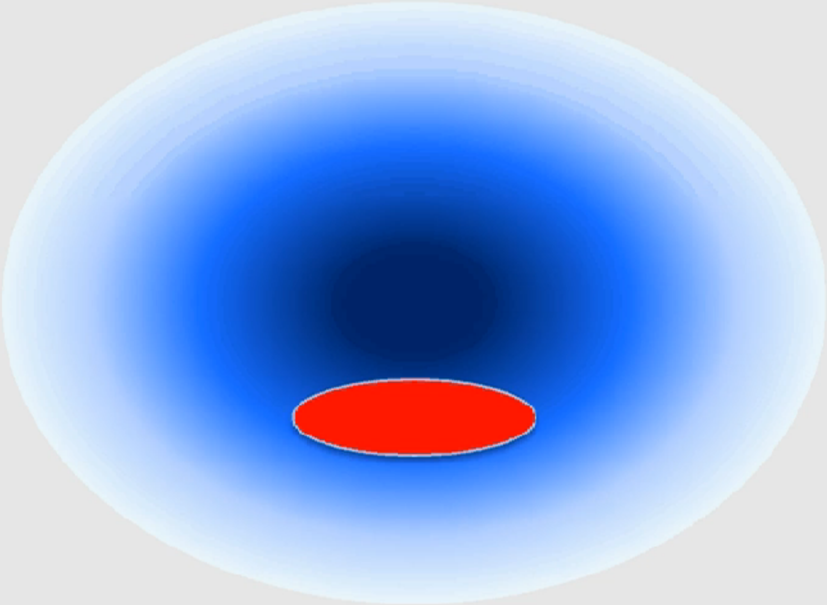
Many thanks to those who nominated me and to many colleagues I had fortune to work with over many years on the electron lenses, the Tevatron collider and many interesting and important topics from beam-beam effects to bent crystal collimation, ground motion and orbit stabilization, head-tail instability and super-fast HV pulsers, future collider designs and construction of IOTA ring, beam commissioning of the worlds' best ILC CryoModule and very fast cycling HTS magnet.

Book (2014)

- A lot of illuminating material on the beam physics of supercolliders can be found in our 2014 book (with Valery Lebedev, eds.)
- Below, I mostly concentrate on the electron lenses and their applications

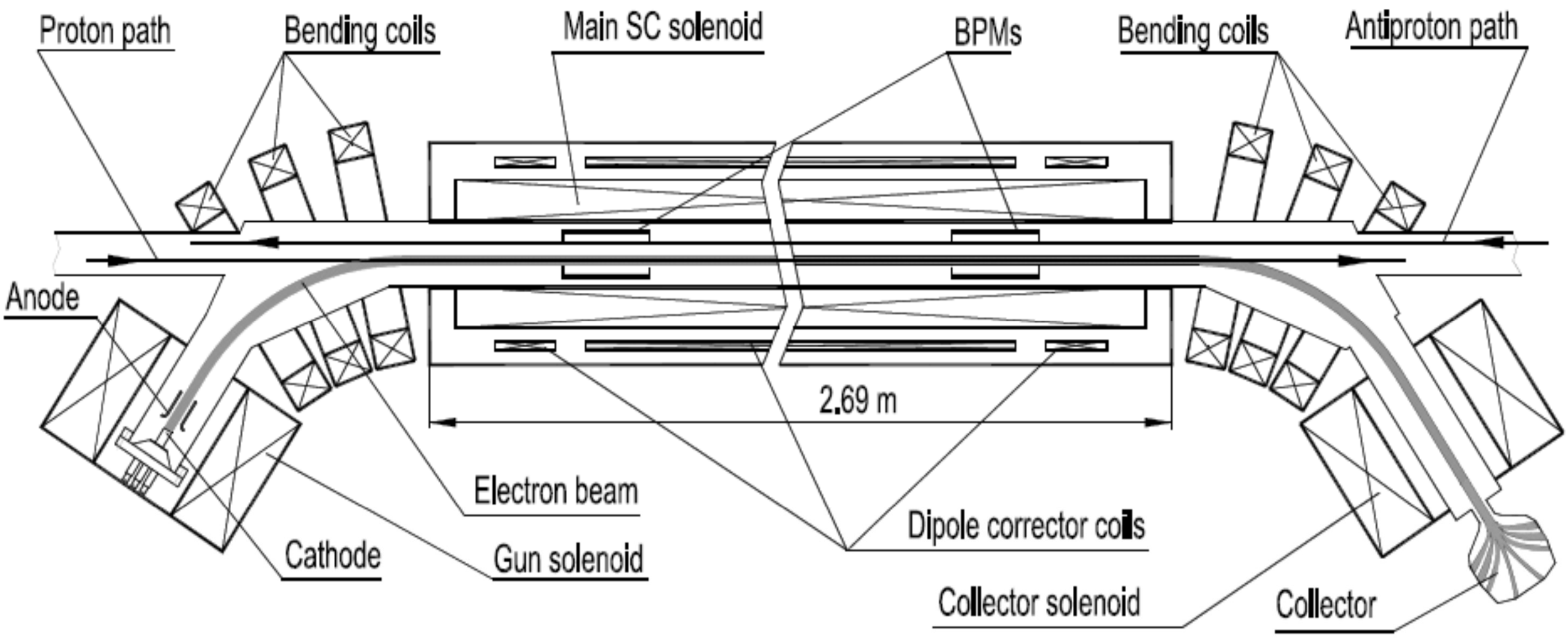


What Can Be Done With Electron Space Charge



Electron Lens

~4 mm dia 2 m long in 3T solenoid beam of ~10kV ~1A electrons ($\sim10^{12}$) can turn on/off in 0.5 usec



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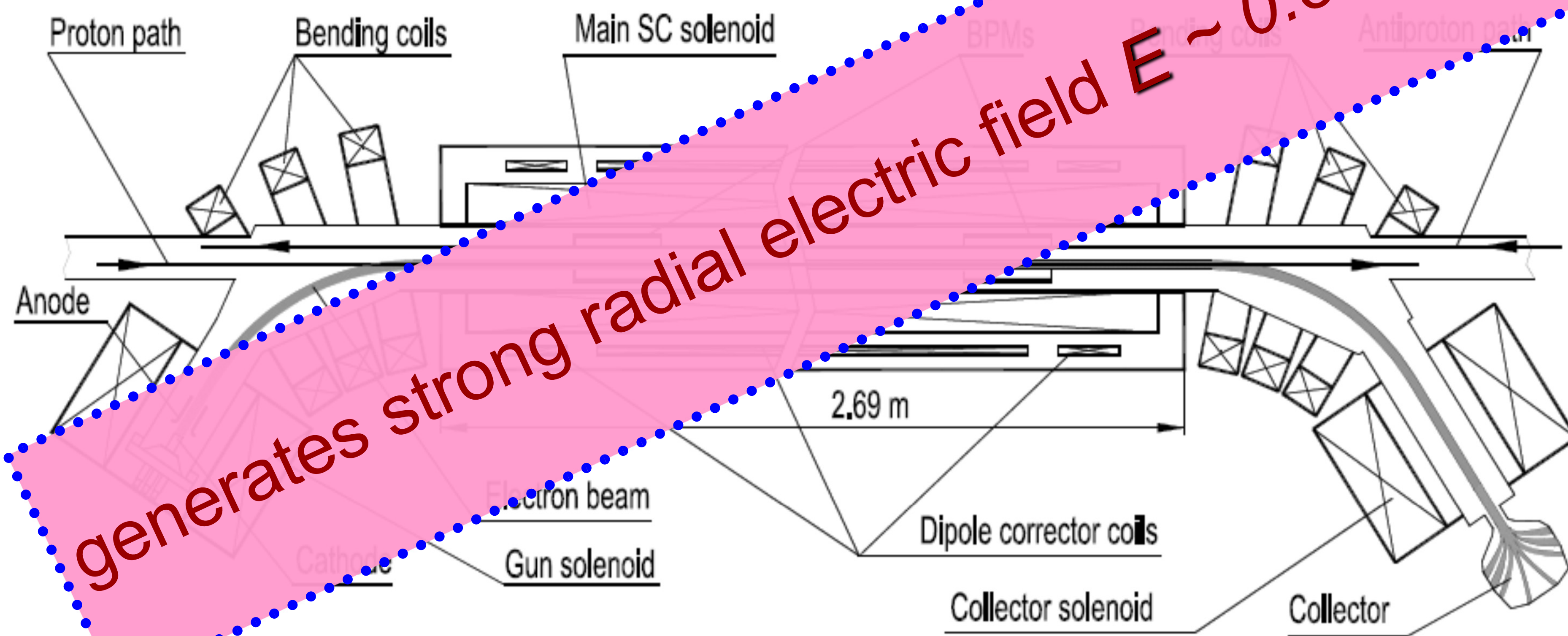
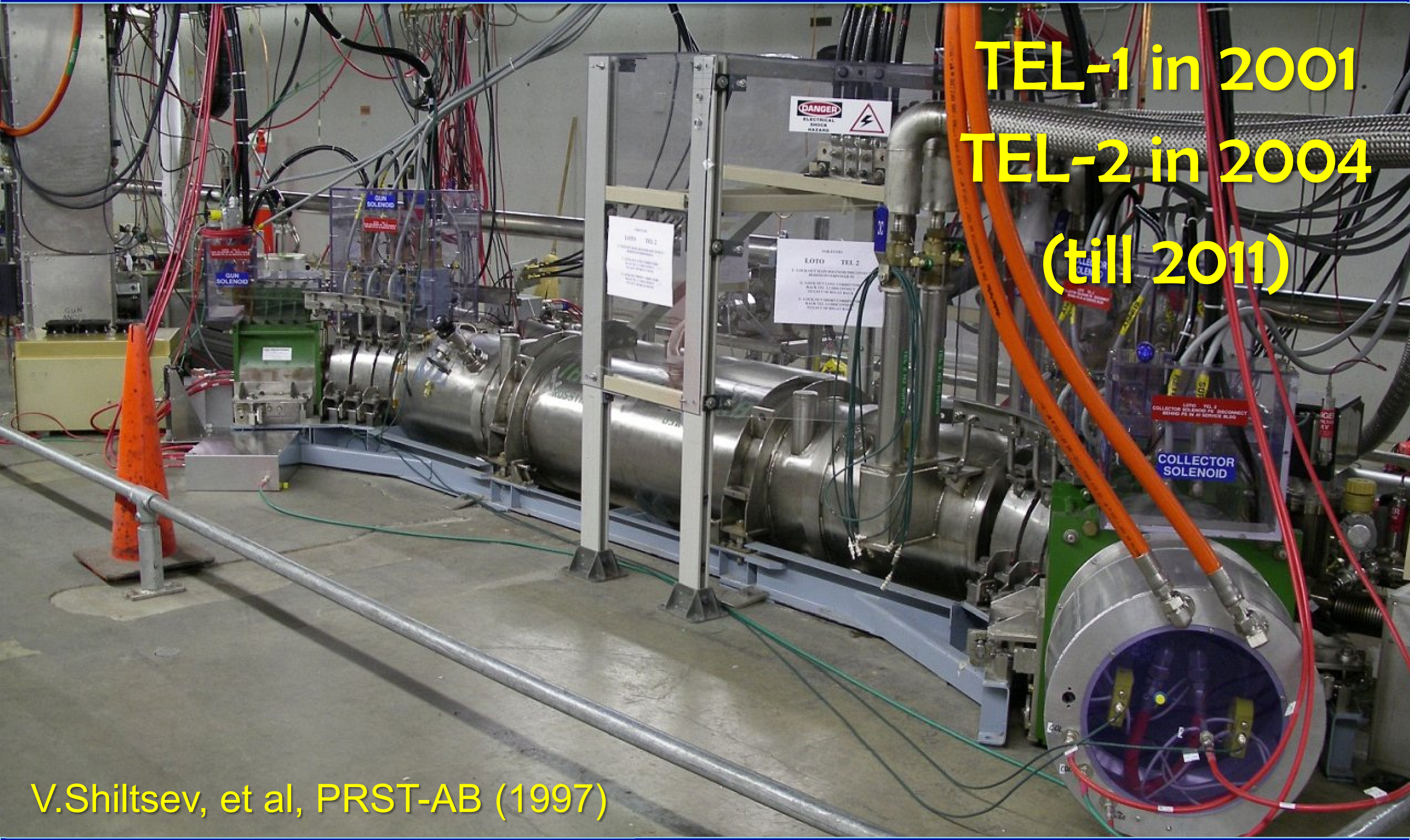


generates strong radial electric field E ~ 0.3MV/m

Two Electron Lenses Were Installed in Tevatron



TEL-1 in 2001
TEL-2 in 2004
(till 2011)

V.Shiltsev, et al, PRST-AB (1997)

What Electron Lenses Are Good For (1)

In the Fermilab Tevatron Collider:

PAST

- ❖**long-range beam-beam** compensation (varied tune shift of individual 1 TeV bunches by 0.003-0.01);

  Shiltsev et al., Phys. Rev. Lett. ***99****, 244801 (2007)*
- ❖**abort gap collimation** (for 10 years in regular operation);

  Zhang et al., Phys. Rev. ST Accel. Beams ***11****, 051002 (2008)*
- ❖studies of **head-on beam-beam** compensation;

  Shiltsev et al, NJP (2008); Stancari et al., PRL 107, 084802 (2011)
- ❖demonstration of **halo scraping with hollow electron beams**;

  Shiltsev (2006); Stancari et al., Phys. Rev. Lett. 107, 084802 (2011)

What Electron Lenses Are Good For (2)

Presently used in RHIC at BNL for **head-on beam-beam compensation** with significant luminosity gain ~x2

Fischer et al., Phys. Rev. Lett. 115, 264801 (2015)

PRESENT

Current areas of research:

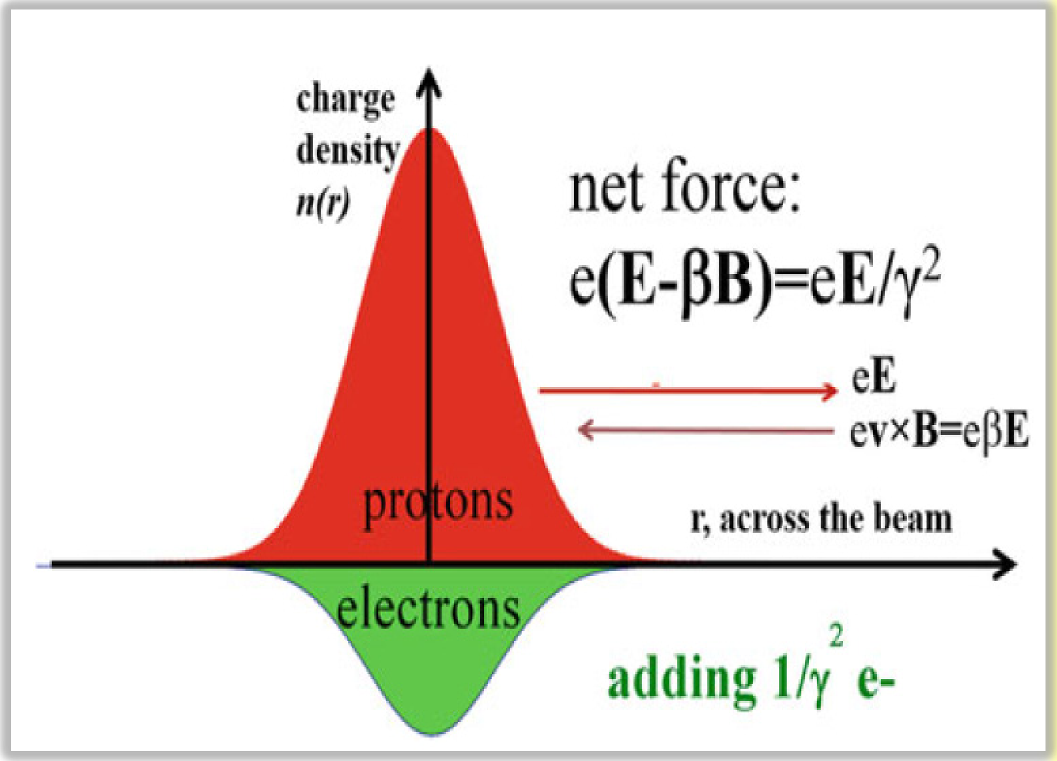
- **hollow electron beam collimation** of protons in the HL-LHC;
  Conceptional Design Report, CERN-ACC-2014-0248 (2014)
- **long-range beam-beam compensation** as current-bearing "wires" in the HL-LHC
  *Valishev,Stancari, arXiv:1312.5006; Fartoukh et al., PRSTAB **18**, 121001 (2015)*
- generation of **nonlinear integrable lattices,** eg in IOTA
  Shiltsev et al, PRSTAB(1997), Nagaitsev, et al., IPAC'12; Stancari et al., IPA
- to generate tune spread for **Landau damping** of coherent instabilities in the LHC, FCC-hh (better than 10,000 octupoles), FNAL Recycler
  Shiltsev (2006), Shiltsev, Alexahin, Burov, Valishev PRL (2018)
- to **compensate space-charge effects** in modern RCSs
  Burov, Foster, Shiltsev (2000), Stern et al, IPAC'18

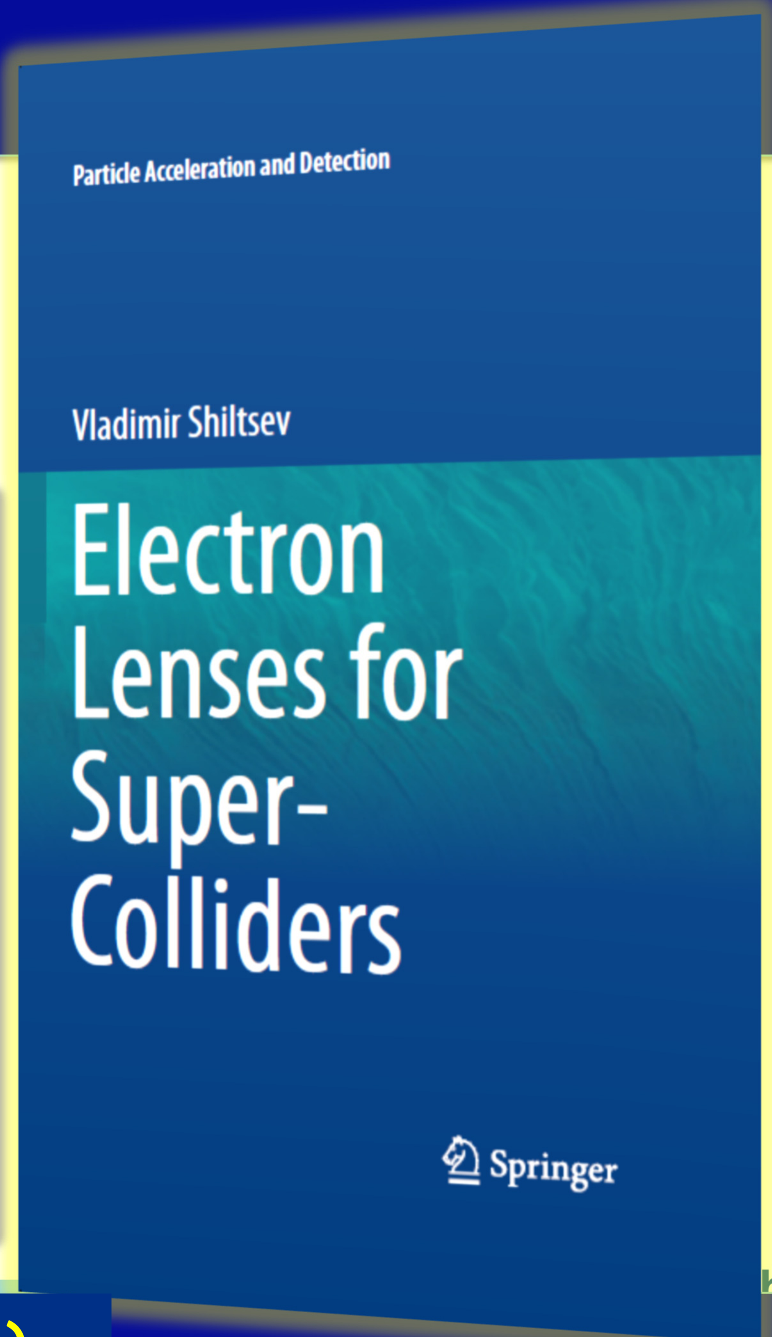
FUTURE

versatile applications depending on e-beam profile + pulsing

Book (2017)

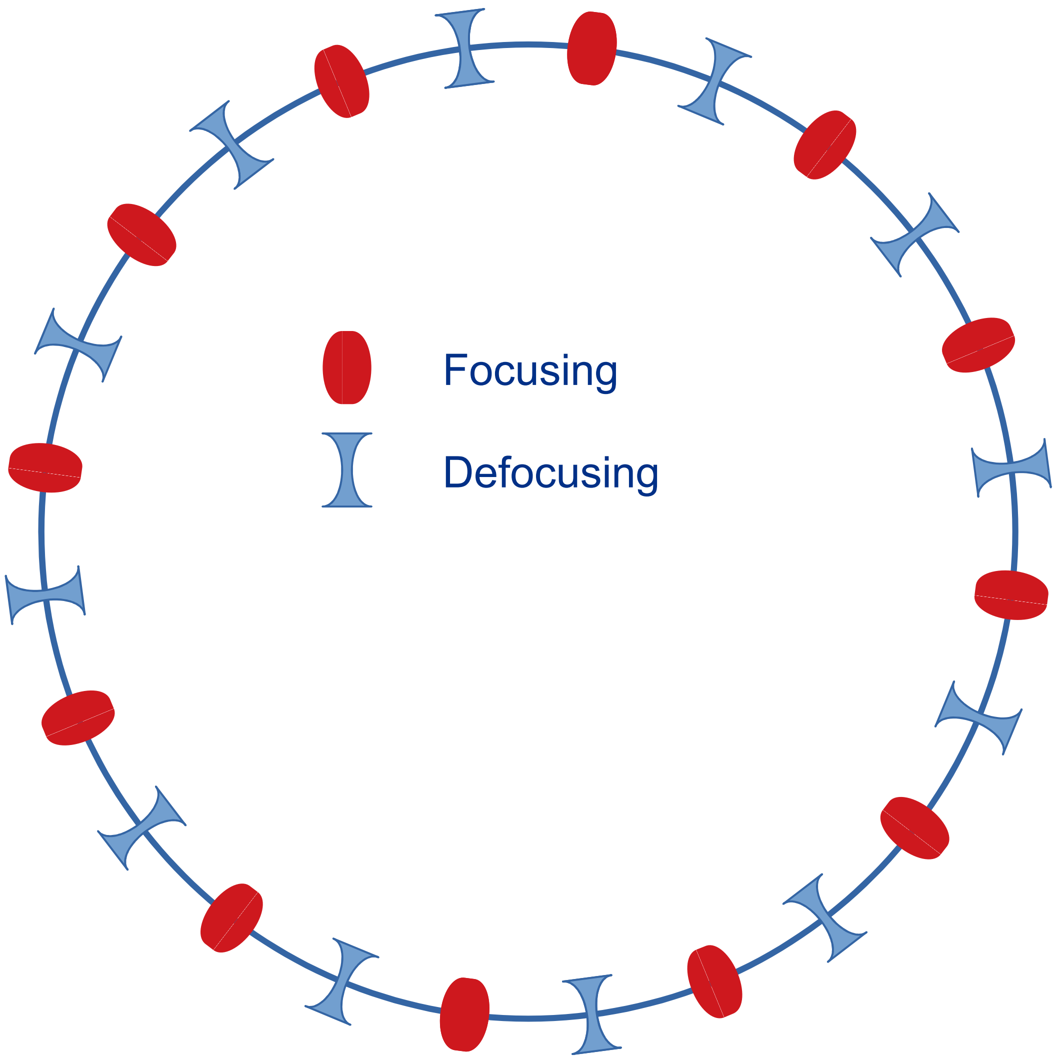
Let me discuss here just one example: compensation of space-charge effects by electron lenses





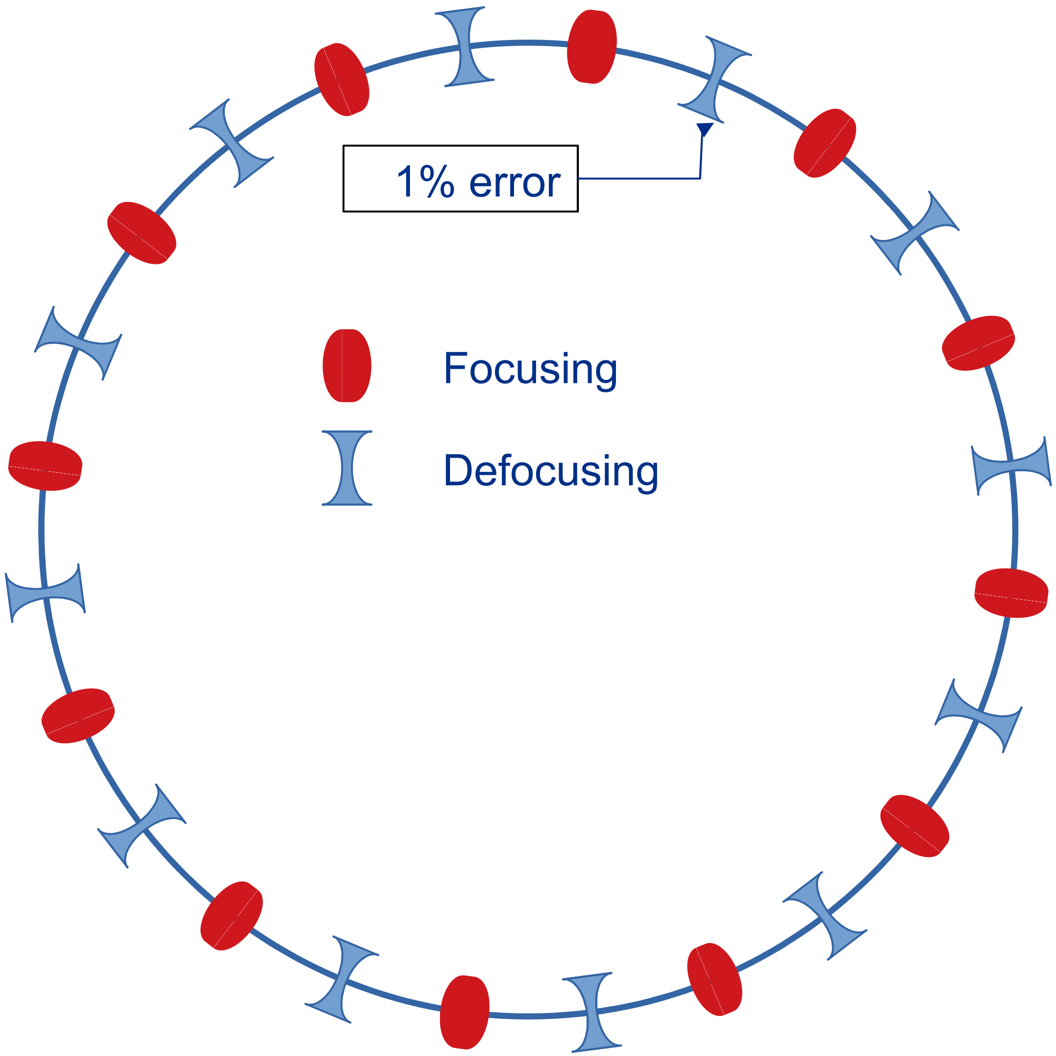
PIC simulations by E.Stern, et al (FNAL)

1000 Turns in a Ring with dQ_{SC}=-0.9



Case #1

1000 Turns in a Ring with dQ_{SC}=-0.9

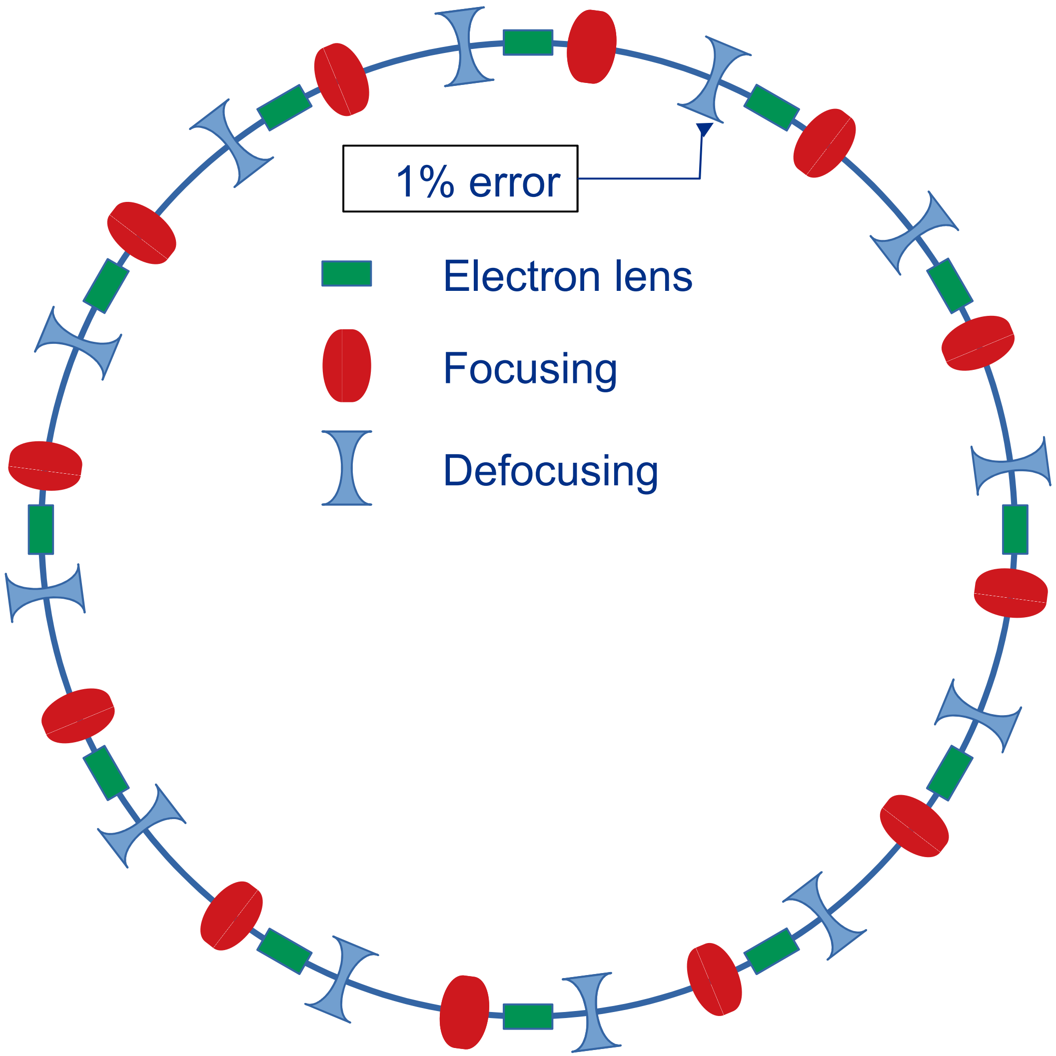


Case #2

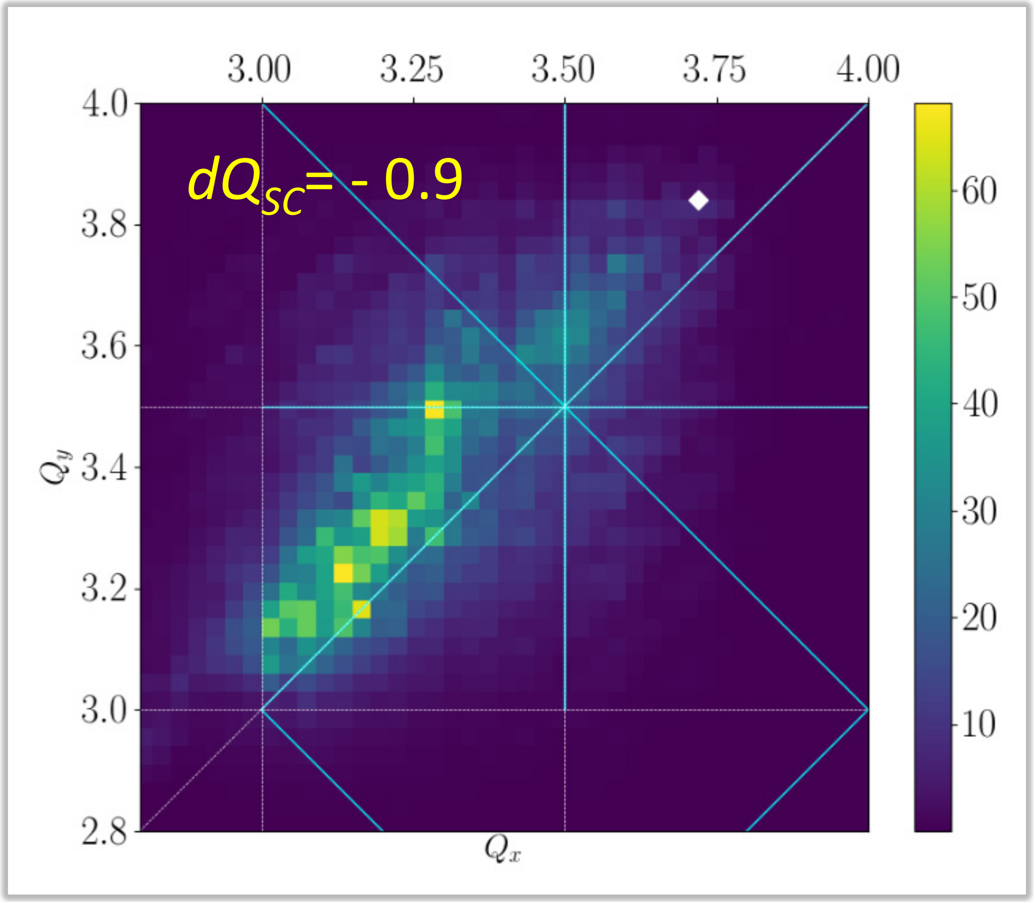
Fermilab

1000 Turns in a Ring with dQ_{SC}=-0.9

Case #3



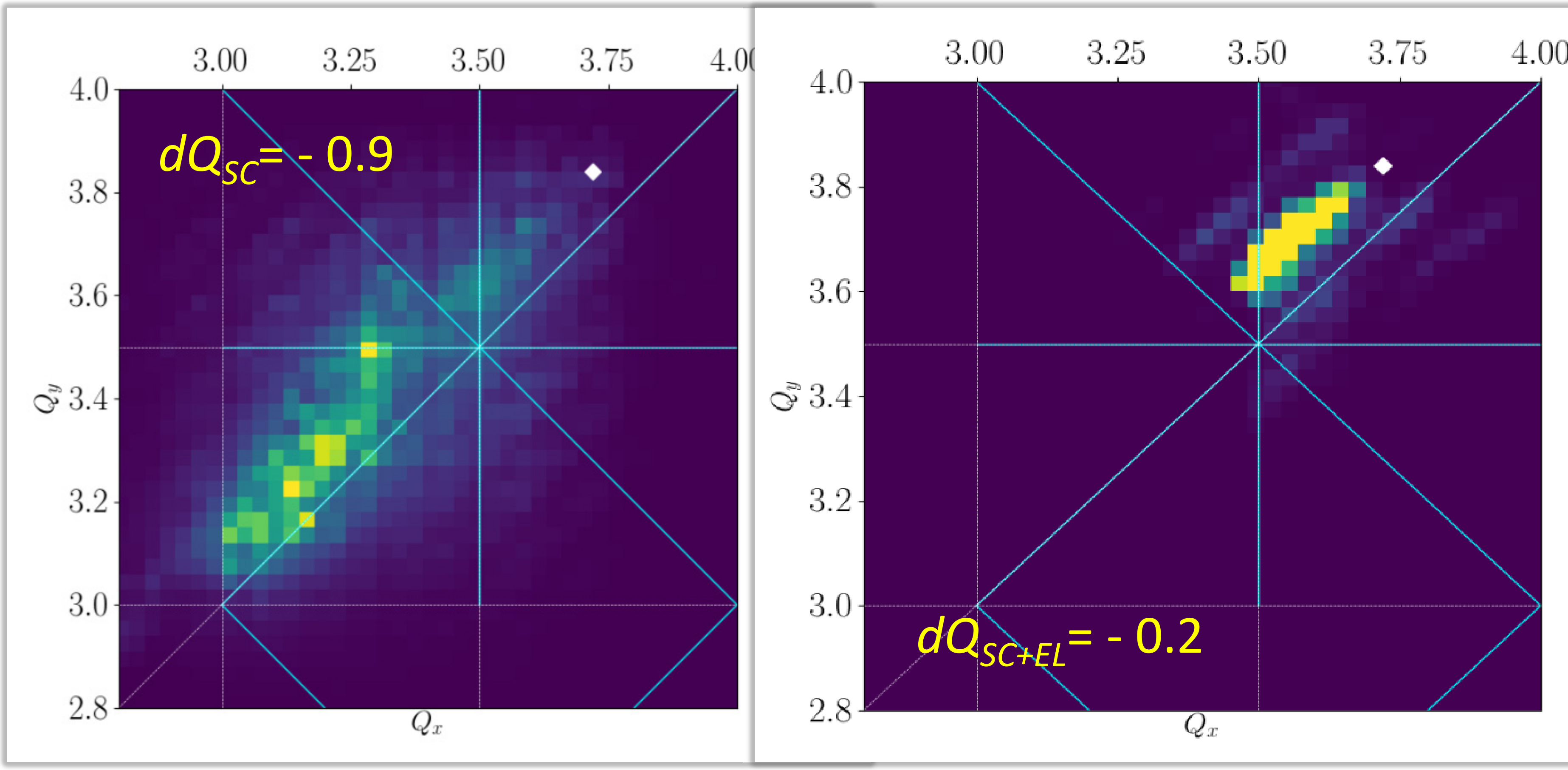
Tune Footprint dQ_{SC}=-0.9



no e-lenses

Stern et al, THPAF075, IPAC18, Beams Document 6790-v1 FNAL (2019)

Tune Footprint dQ_{SC}=-0.9

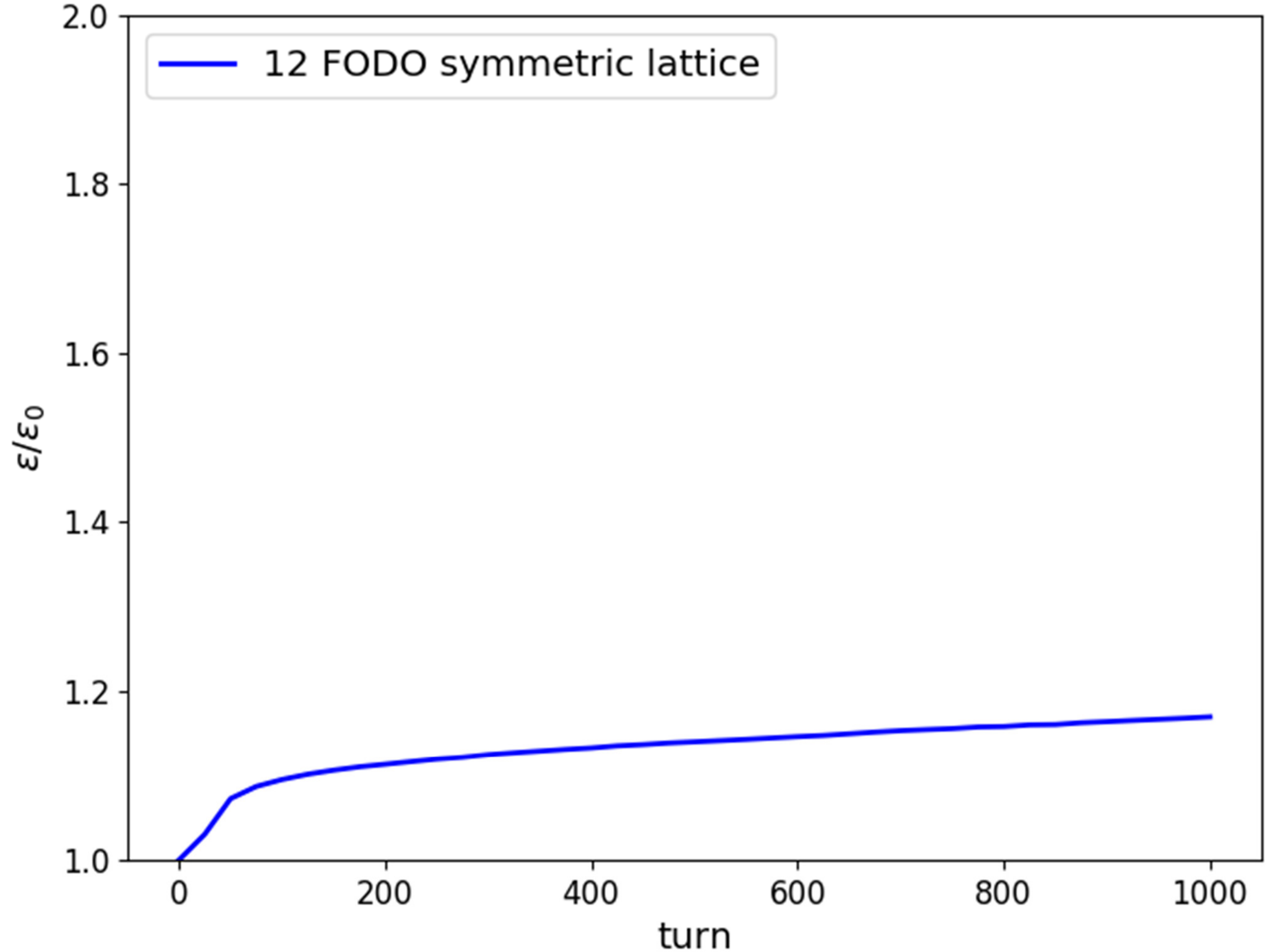


no e-lenses **~75% e-lens compensation**

Stern et al, THPAF075, IPAC18, Beams Document 6790-v1 FNAL (2019)

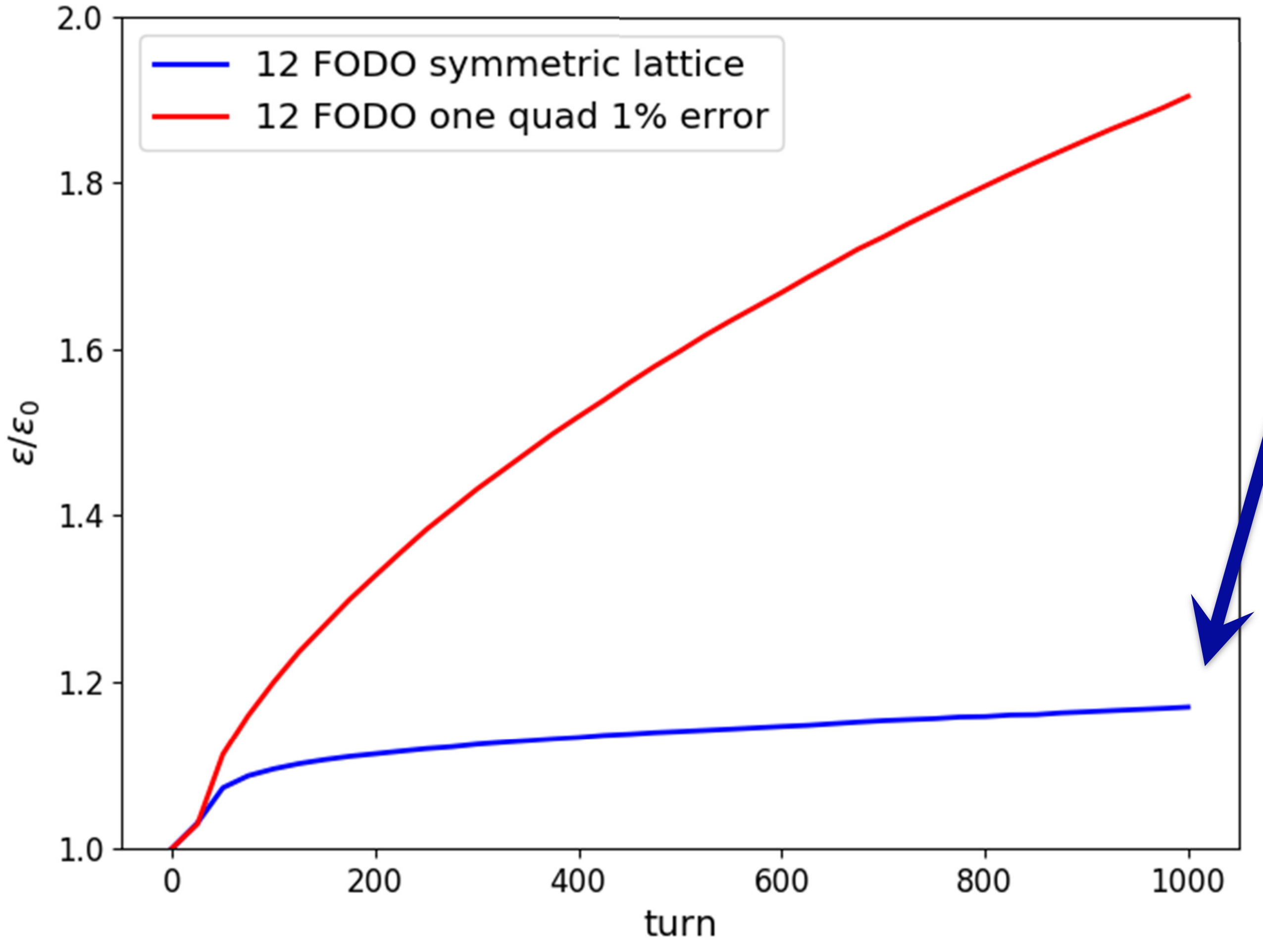
Emittance Growth – Case #1

no error, no e-lenses



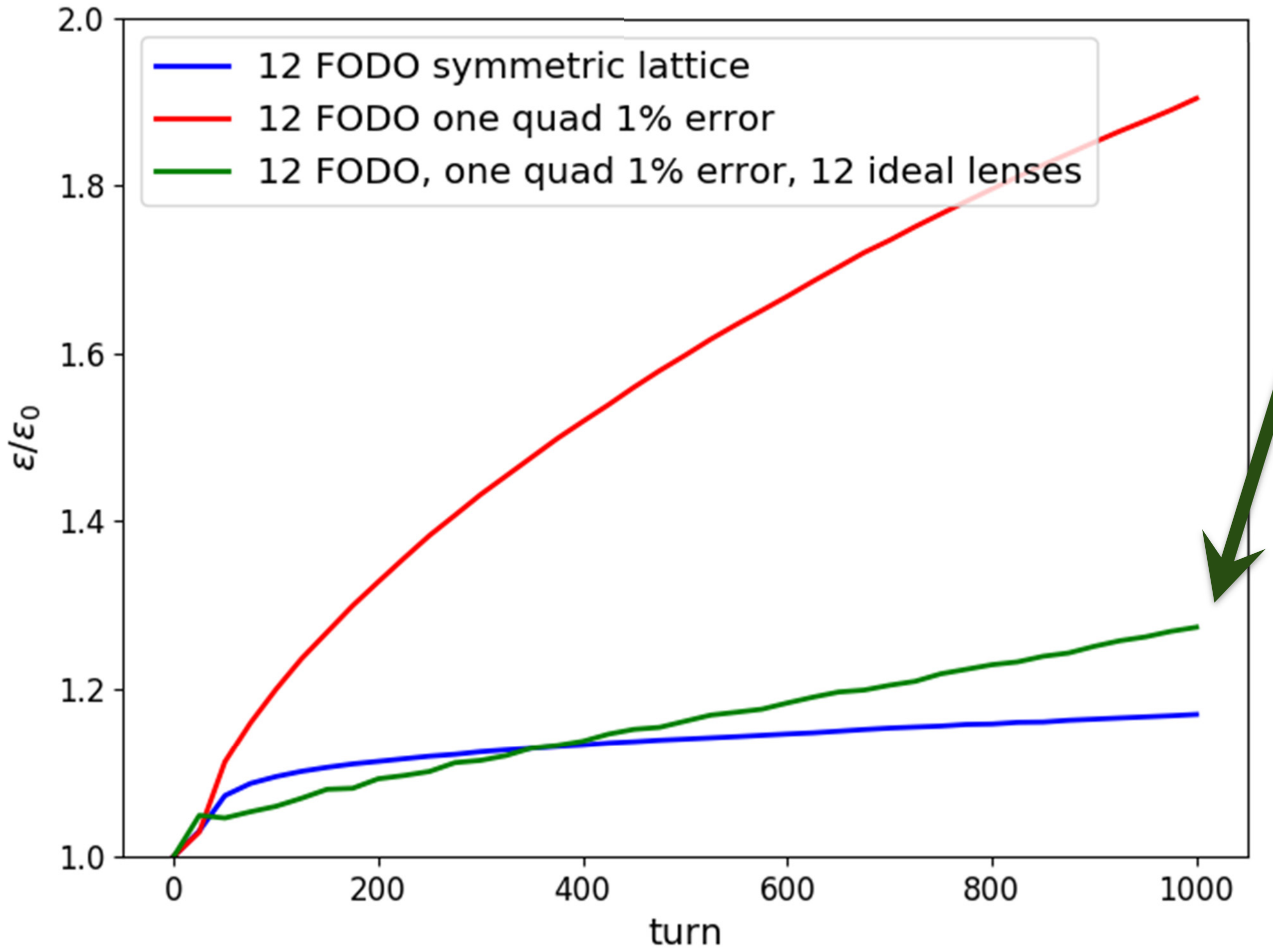
Emittance Growth – Case #2

1% error, no e-lenses

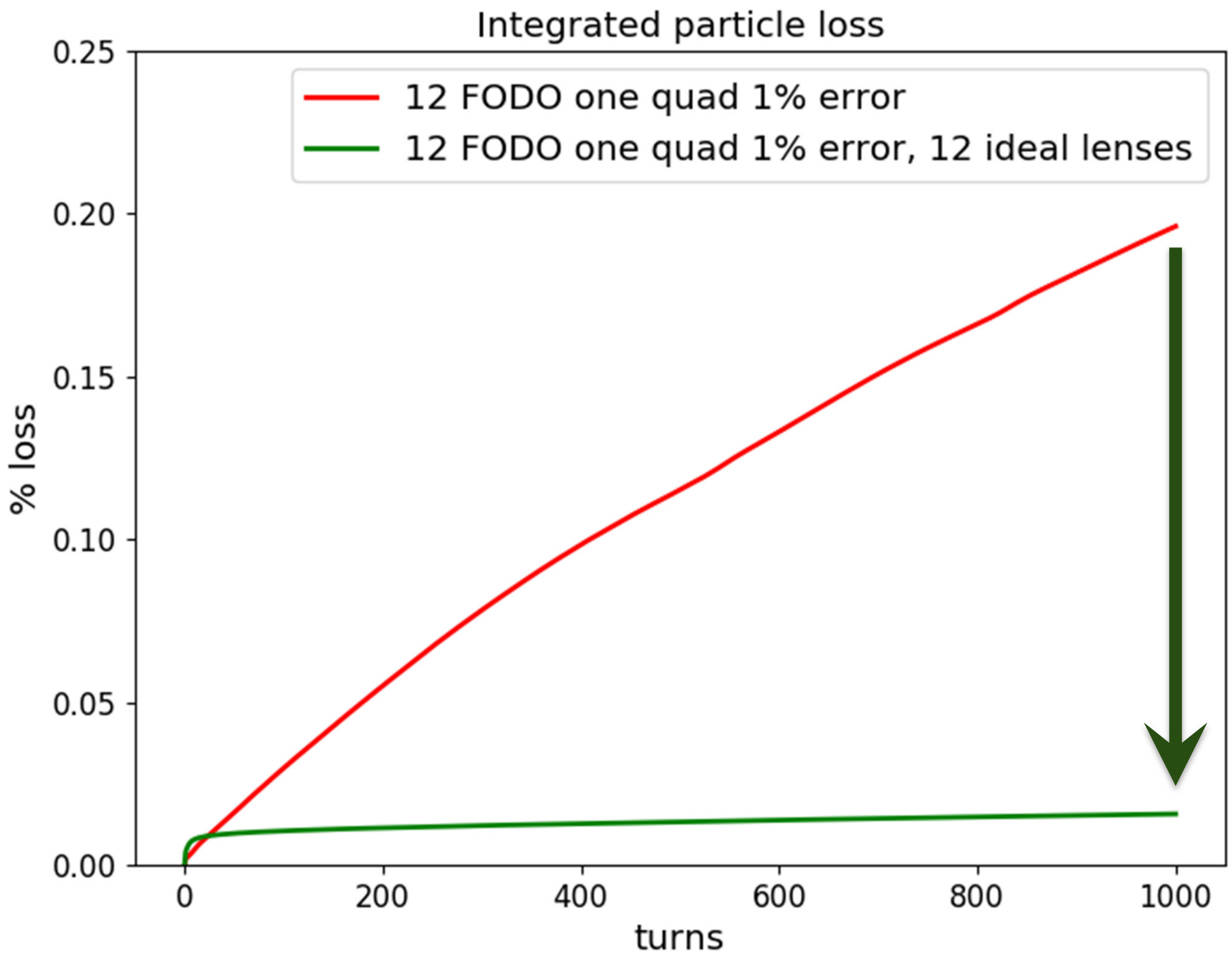


Emittance Growth – Case #3

1% error, 12 e-lenses

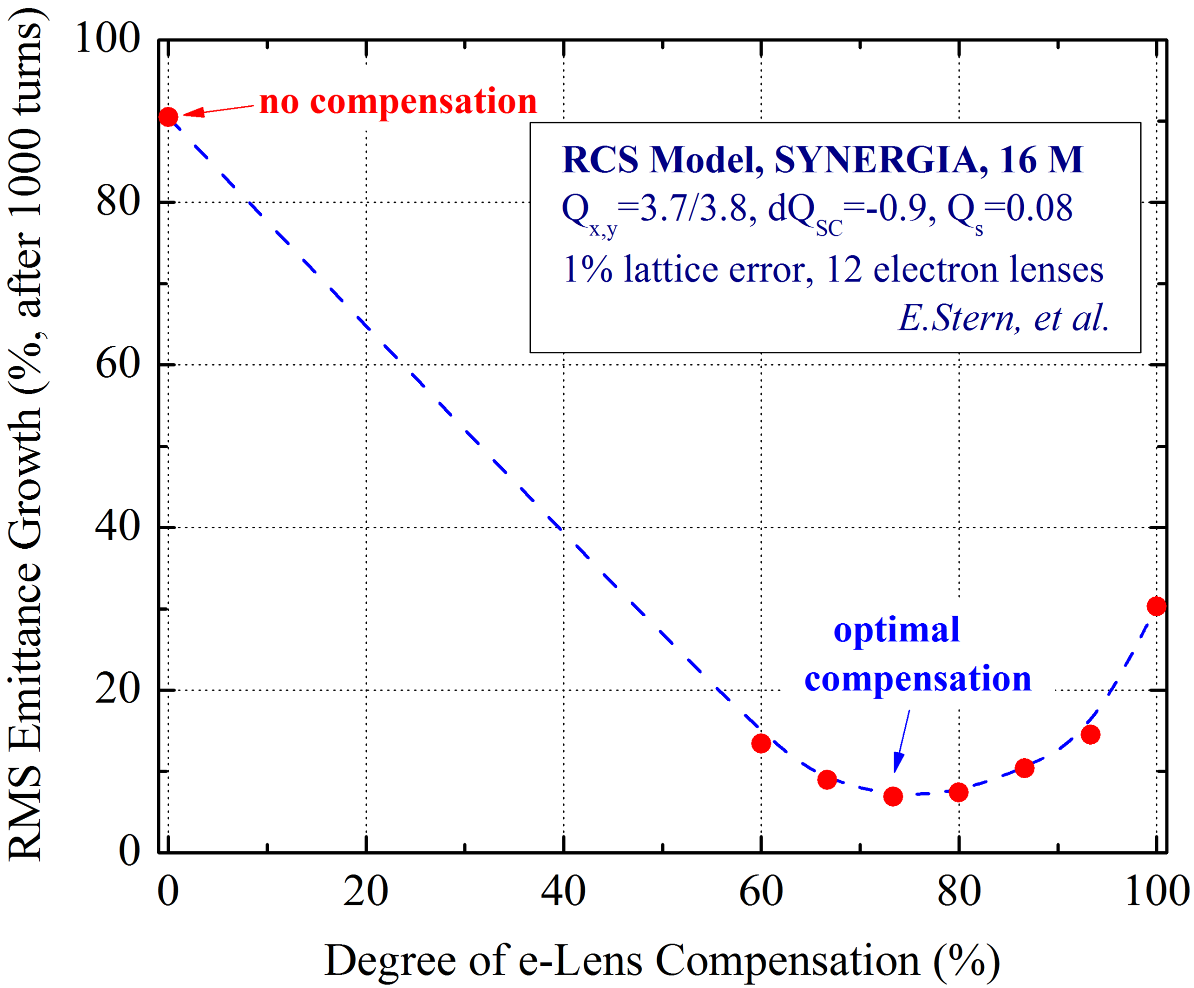


Particle Losses at 4σ – Case #2 and #3

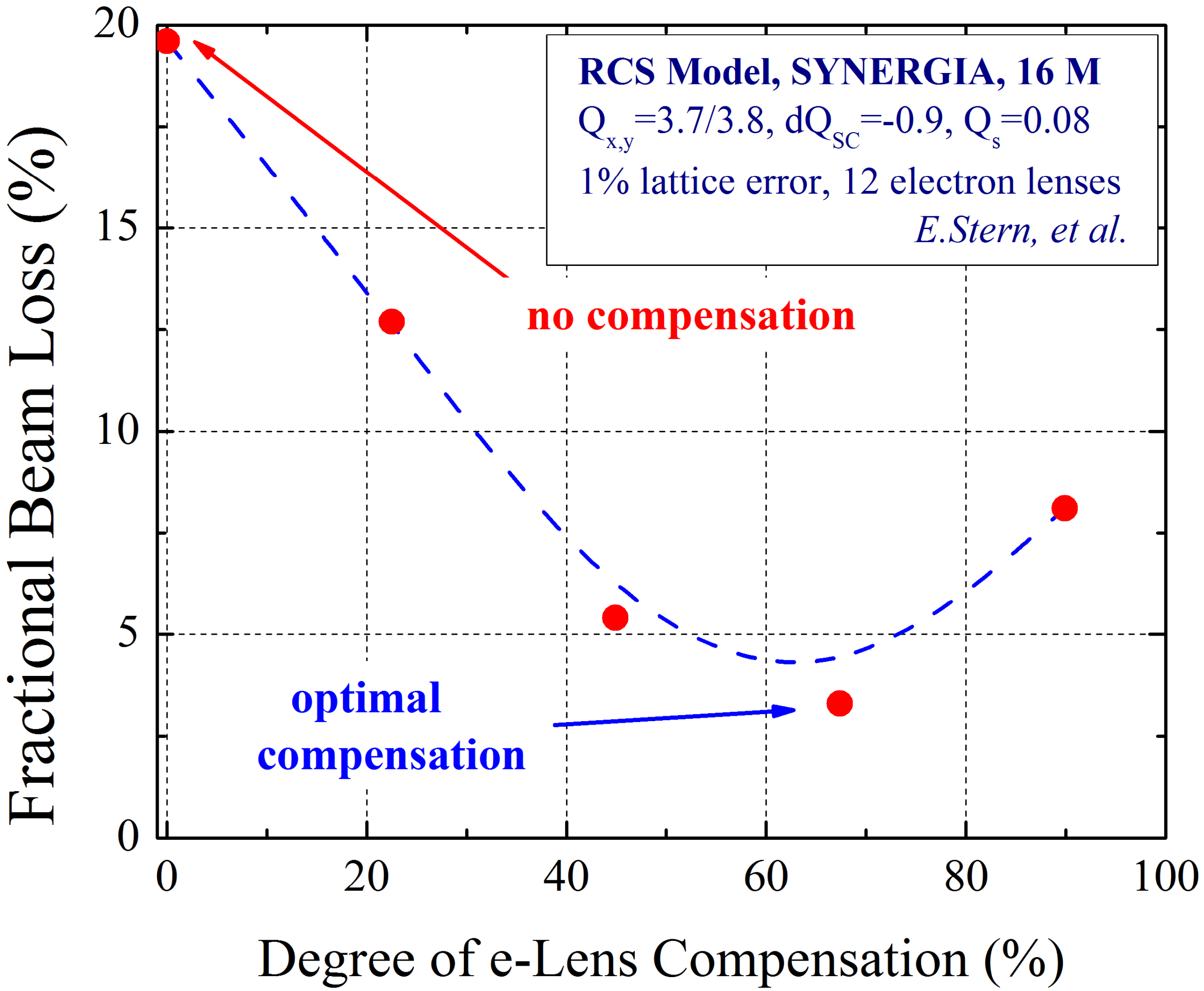


e-lenses reduce losses ~6 fold !

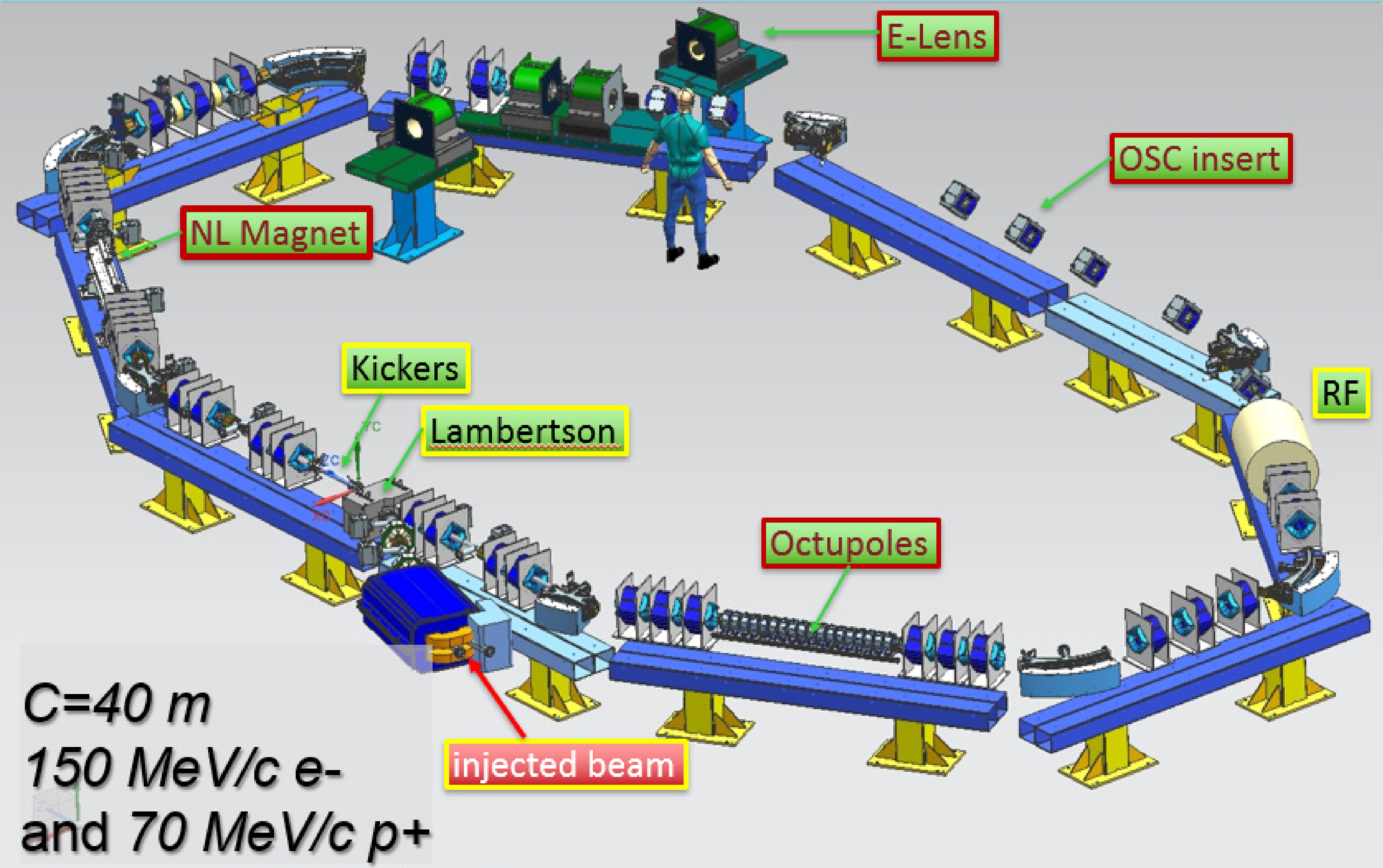
Optimal Compensation ~75% (emitt. growth)



Optimal Compensation ~70% (beam losses)



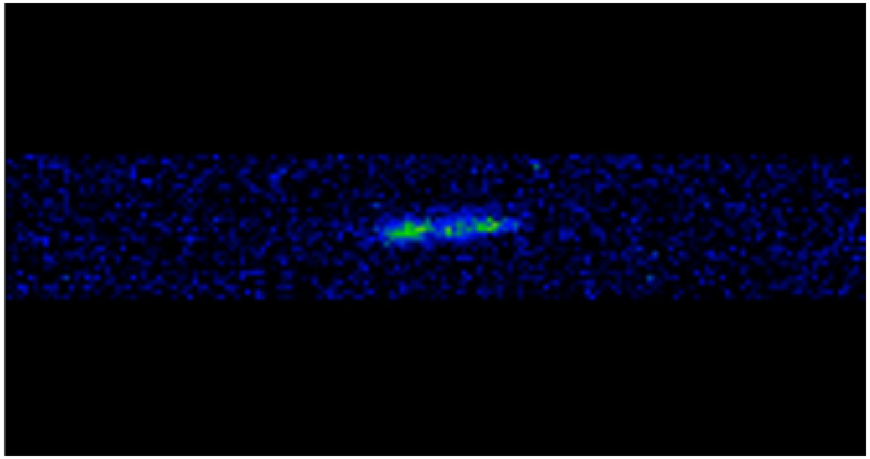
IOTA: *Integrable Optics Test Accelerator*



C=40 m
150 MeV/c e-
and *70 MeV/c p+*

IOTA: *Integrable Optics Test Accelerator*

IOTA/FAST 2018/2019 Research Run



Real-time image of radiation of a single electron in the IOTA ring, courtesy A.Romanov

https://fast.fnal.gov/

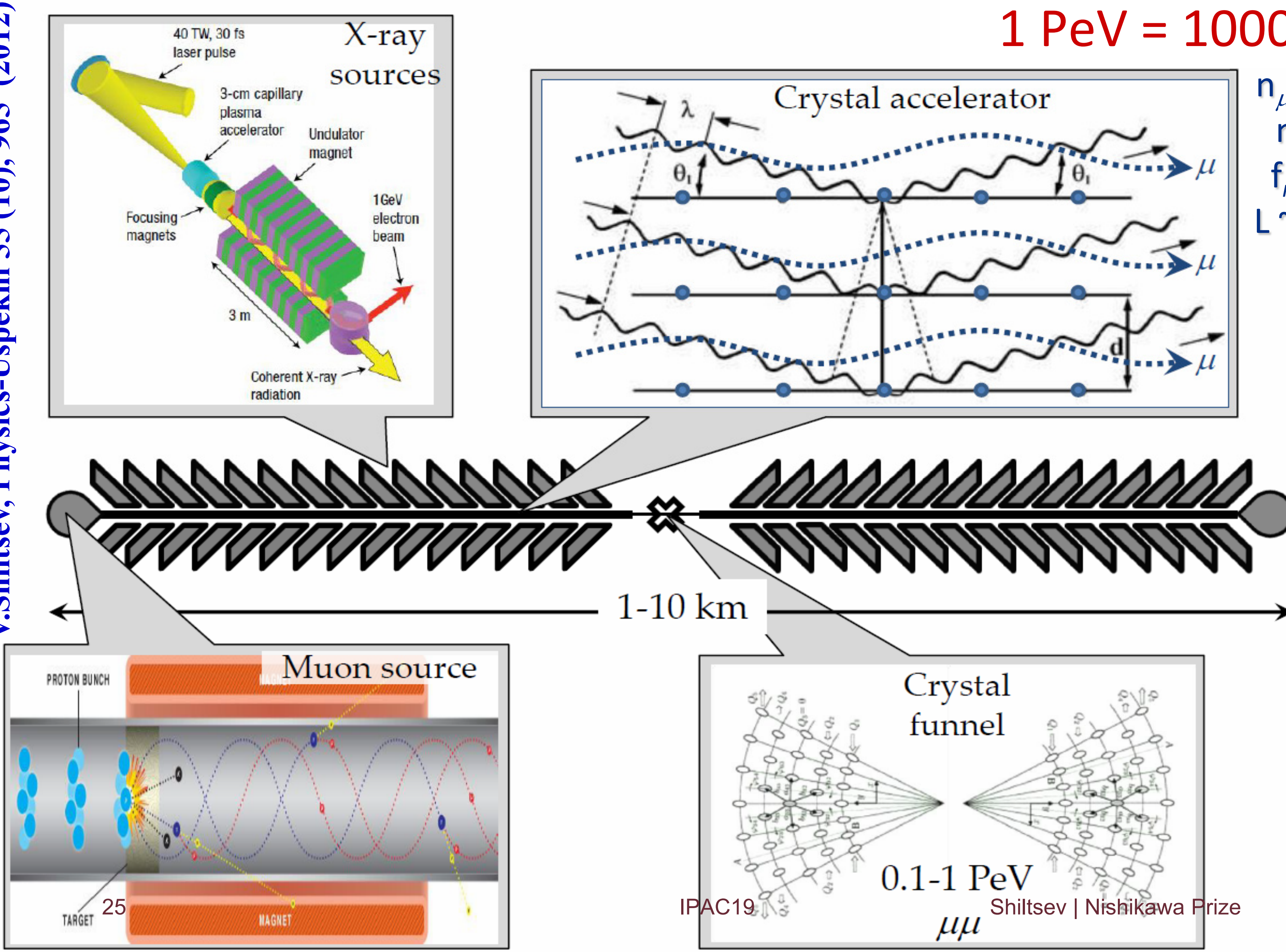
- Nonlinear Integrable Optics
- Single-electron tomography
- Initial experiments towards Optical Stochastic Cooling, Quantum Science
- Higher-Order Mode Measurements in the ILC SRF Cryomodule
- Magnetized beam manipulation technique (for the EIC project)
- Short-range wakefields studies
- **IPAC19: Invited talk T.Zolkin** (FRXPLS1)+17 posters: MOPGW113, MOPRB088, MOPGW107 , MOPGW127, MOPRB089, MOPTS115 , WEPTS068, WEPTS070, WEPTS074, WEPTS078, WEPTS073, MOPGW109, WEPGW100, WEPGW163, MOPGW108, THPRB106 ,TUPRB089

Linear $\mu+\mu-$ Crystal X-ray Collider

V.Shiltsev, Physics-Uspekhi 55 (10), 965 (2012)

1 PeV = 1000 TeV

n_{μ} ~1000
n_B ~100
f_{rep} ~10^6
L ~10^{30-32}



ilab

Li… er

V.Shiltsev, Physics-Uspekhi 55 (10), 965 (2012)

TeV
~1000
~100
~10^6
$10^{30\text{-}32}$

Fermilab, June 24-26, 2019

Workshop on Beam Acceleration in Crystals and Nanostructures

https://indico.fnal.gov/event/19478/

Organized by T. Tajima (UCI) and V. Shiltsev (FNAL)
Proceedings Editors: G. Mourou, V. Shiltsev, T. Tajima

Endorsed by: APS GPAP, APS DPB, ICFA ANA, ICUIL

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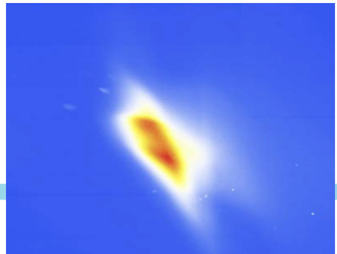
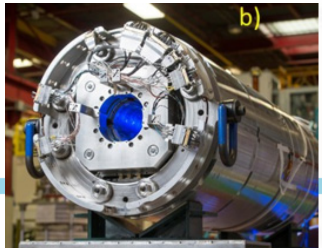
https://www.aps.org/units/dpb/



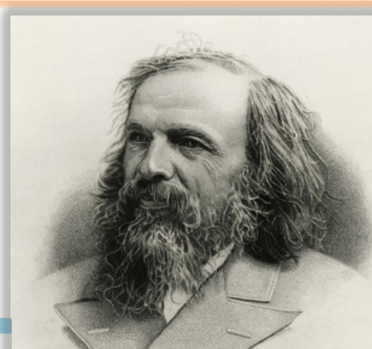



Celebrate Science! – 2019 is UNESCO's

Int'l Year of Periodic Table (150 yrs)

1869

Series	Zero Group	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
0	x								
1	y	Hydrogen H=1·008							
2	Helium He=4·0	Lithium Li=7·03	Beryllium Be=9·1	Boron B=11·0	Carbon C=12·0	Nitrogen N=14·04	Oxygen O=16·00	Fluorine F=19·0	
3	Neon Ne=19·9	Sodium Na=23·05	Magnesium Mg=24·1	Aluminium Al=27·0	Silicon Si=28·4	Phosphorus P=31·0	Sulphur S=32·06	Chlorine Cl=35·45	
4	Argon Ar=38	Potassium K=39·1	Calcium Ca=40·1	Scandium Sc=44·1	Titanium Ti=48·1	Vanadium V=51·4	Chromium Cr=52·1	Manganese Ma=55·0	Iron Fe=55·9 Cobalt Co=59 Nickel Ni=59 (Cu)
5		Copper Cu=63·6	Zinc Zn=65·4	Gallium Ga=70·0	Germanium Ge=72·3	Arsenic As=75·0	Selenium Se=79	Bromine Br=79·95	
6	Krypton Kr=81·8	Rubidium Rb=85·4	Strontium Sr=87·6	Yttrium Y=89·0	Zirconium Zr=90·6	Niobium Nb=94·0	Molybdenum Mo=96·0	—	Ruthenium Ru=101·7 Rhodium Rh=103·0 Palladium Pd=106·5 (Ag)
7		Silver Ag=107·9	Cadmium Cd=112·4	Indium In=114·0	Tin Sn=119·0	Antimony Sb=120·0	Tellurium Te=127	Iodine I=127	
8	Xenon Xe=128	Cæsium Cs=132·9	Barium Ba=137·4	Lanthanum La=139	Cerium Ce=140	—	—		— — — (—)
9		—	—		—	—	—	—	
10	—	—	—	Ytterbium Yb=173	—	Tantalum Ta=183	Tungsten W=184	—	Osmium Os=191 Iridium Ir=193 Platinum Pt=194·9 (Au)
11		Gold Au=197·2	Mercury Hg=200·0	Thallium Tl=204·1	Lead Pb=206·9	Bismuth Bi=208	—	—	
12	—	—	Radium Rd=224	—	Thorium Th=232	—	Uranium U=239		



Dmitri Mendeleev

https://www.iypt2019.org/

Thank You for Your Attention!