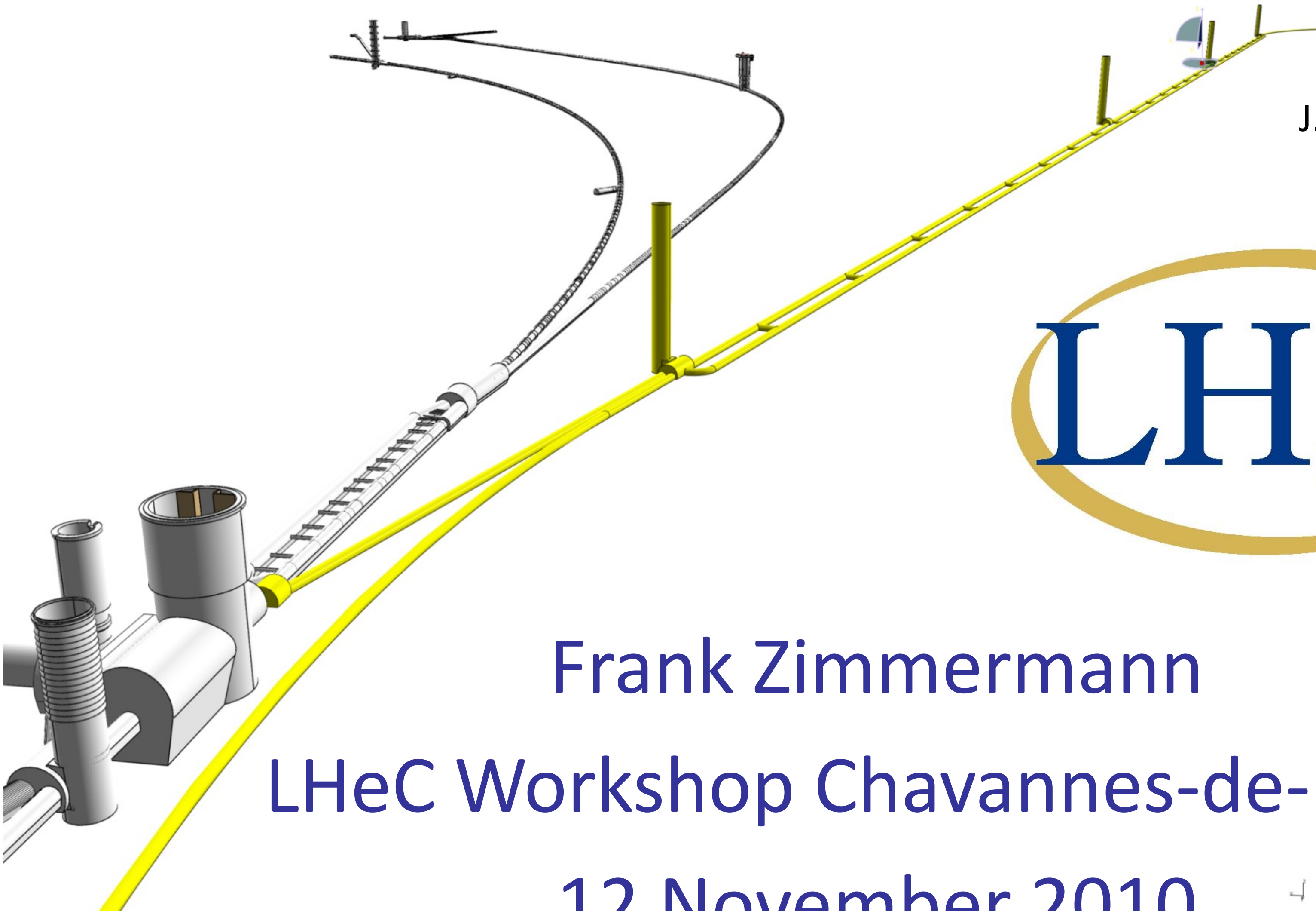
LHeC R-L basic parameters



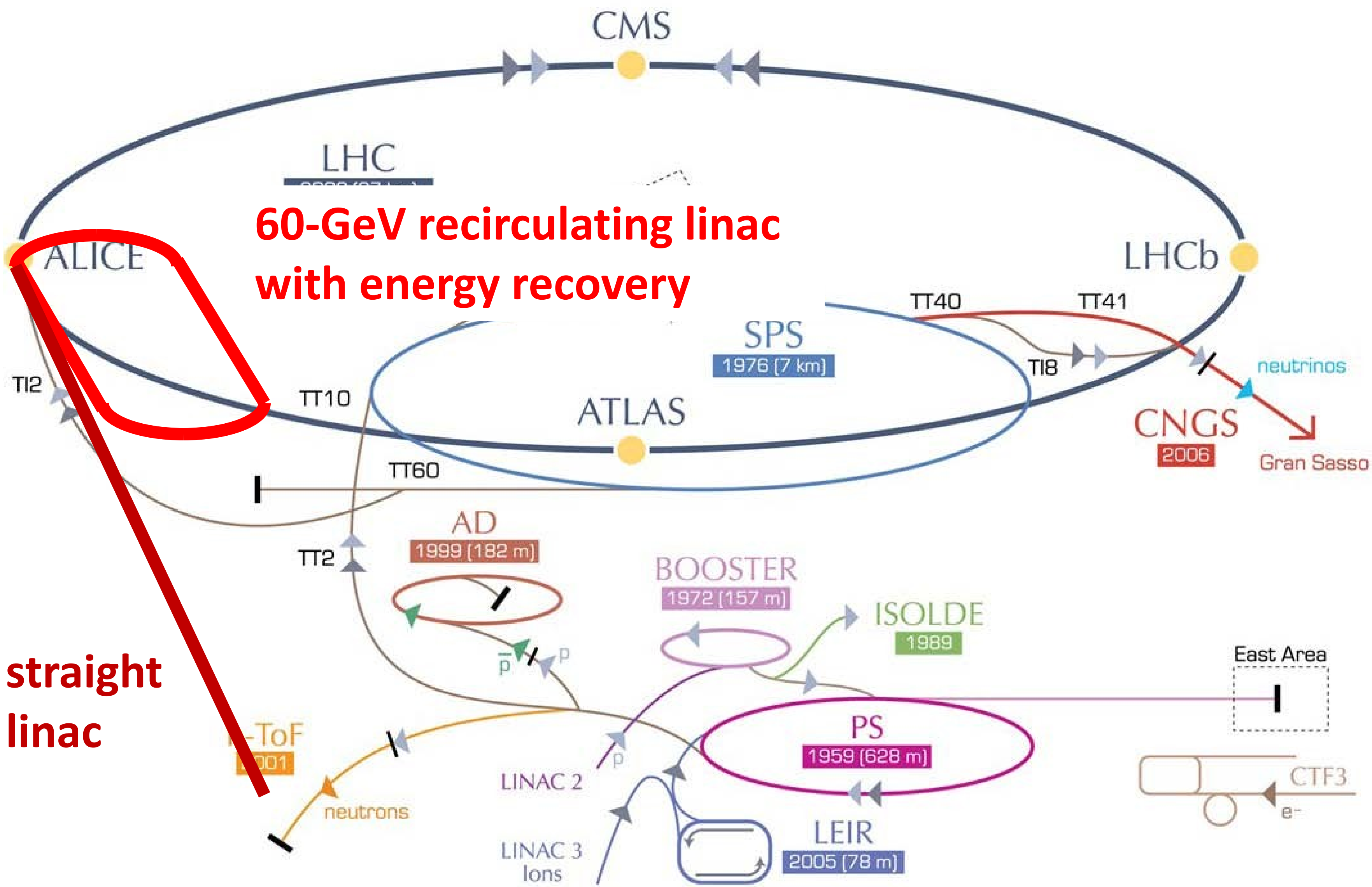
J. Osborne

Frank Zimmermann

LHeC Workshop Chavannes-de-Bogis

12 November 2010

Linac-Ring LHeC – two options



performance targets

e- energy ≥60 GeV

luminosity ~10^{33} $cm^{-2}s^{-1}$

total electrical power for e-: ≤100 MW

e^+p collisions with similar luminosity →***L. Rinolfi***

simultaneous with LHC *pp* physics

e^-/e^+ polarization

detector acceptance down to 1°

getting all this at the same time is very challenging

road map to 10^{33} cm^{-2}s^{-1}

luminosity of LR collider:

(round beams)

$$L = \frac{1}{4\pi e} \frac{N_{b,p}}{\varepsilon_p} \frac{1}{\beta_p^*} I_e H_{hg}$$

highest proton
beam brightness "permitted"
(ultimate LHC values)

$\gamma\varepsilon$=3.75 µm

N_b=1.7x10^{11}

bunch spacing 25 or 50 ns

smallest conceivable
proton β* function:
- reduced *l** (23 m → 10 m)
- squeeze only one *p* beam
- new magnet technology *Nb_3Sn*

β^*=0.1 m

average e^- current !

maximize geometric
overlap factor
- head-on collision
- small e- emittance

θ_c=0

H_{hg}≥0.9

crossing angle

zero crossing angle, head-on collision:

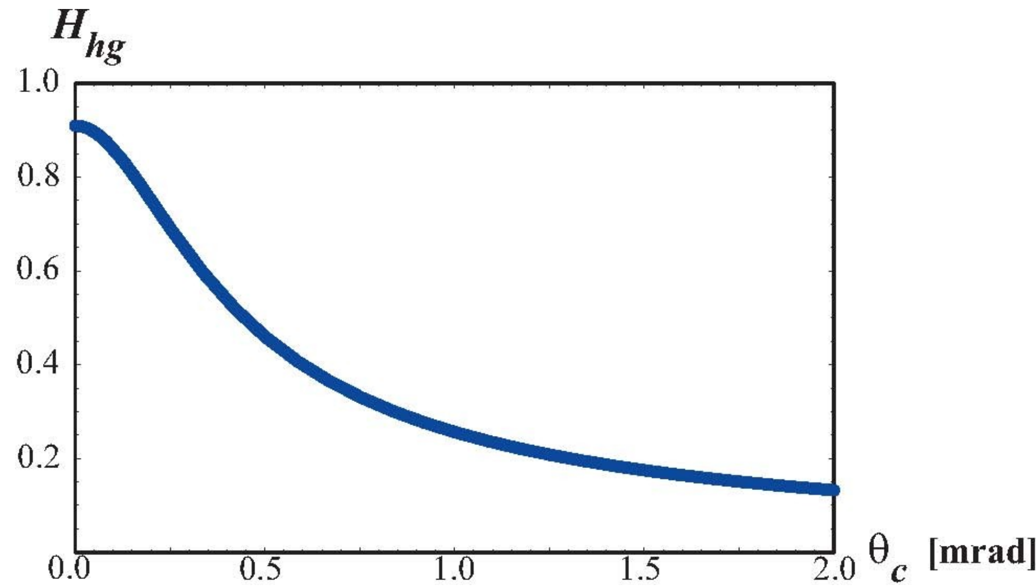
- we need to separate beams by 6-9 cm at 10 m from IP (i.e. 6-9 mrad) [constraint from magnet design]
- crab cavities ruled out [20-30x HL-LHC crab voltage]
- maximum allowed crossing angle for luminosity < 0.5 mrad (see graph)

$$H_{hg} = \frac{\sqrt{\pi}\, z e^{z^2} \operatorname{erfc}(z)}{S}$$

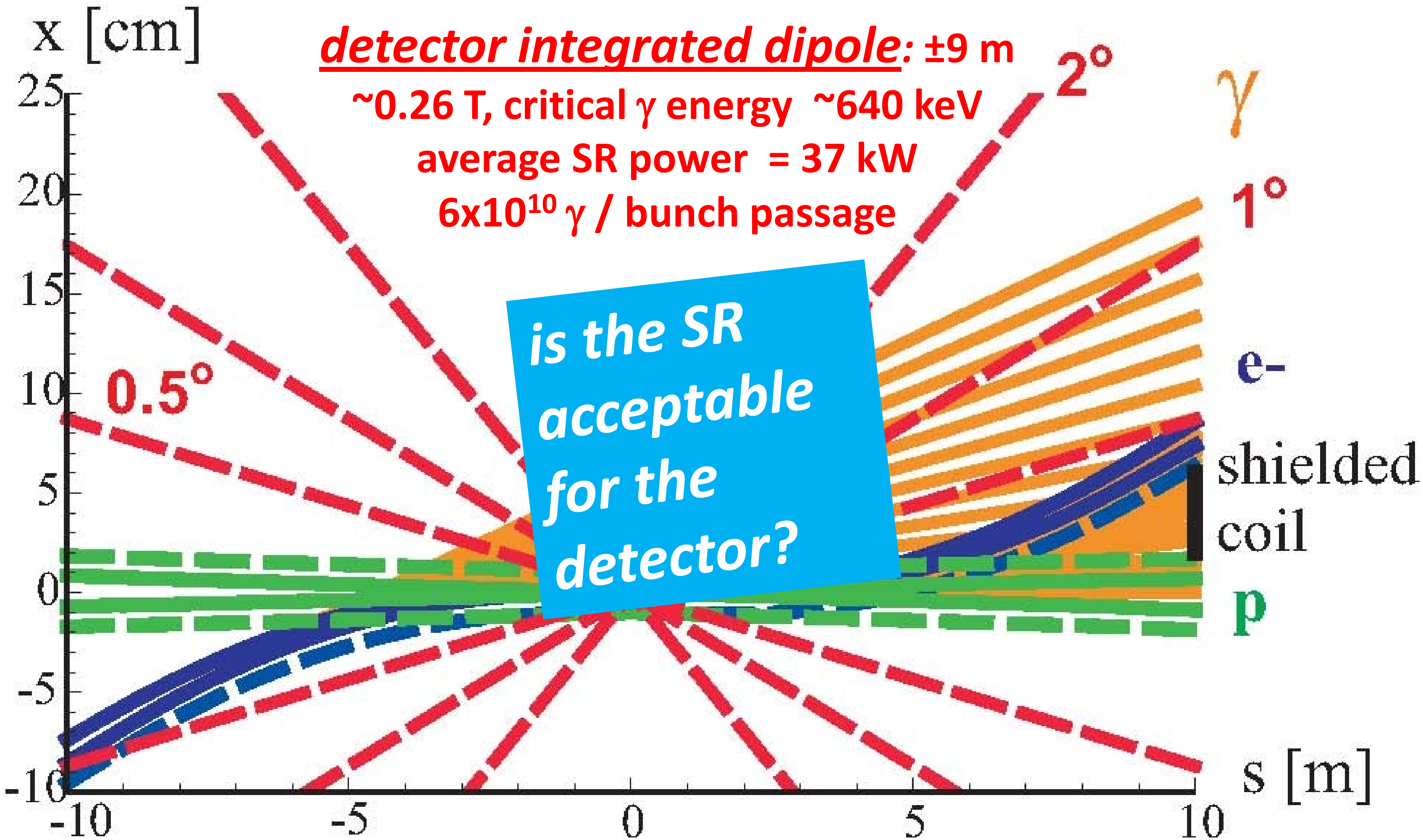
with

$$z \equiv 2 \frac{(\beta_e^* / \sigma_{z,p})(\varepsilon_e / \varepsilon_p)}{\sqrt{1 + (\varepsilon_e / \varepsilon_p)^2}} S$$

$$S \equiv \sqrt{1 + \frac{\sigma_{x,p}^2 \theta_c^2}{8 \sigma^{*2}}}$$

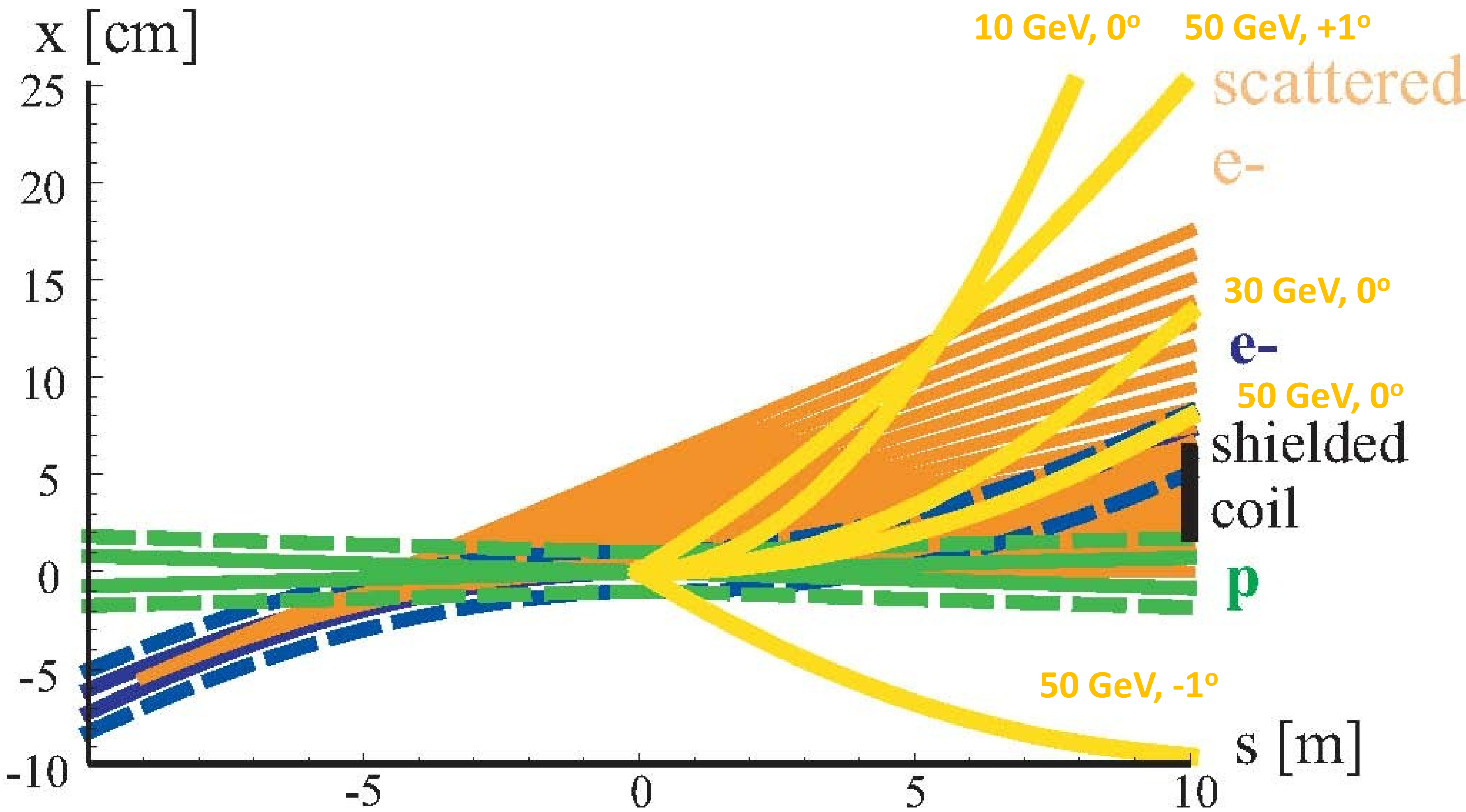


IR layout w. zero crossing angle



beam envelopes of 10σ (electrons) [solid blue] or 11σ (protons) [solid green], the same envelopes with an additional constant margin of 10 mm [dashed], the synchrotron-radiation fan [orange], and the approximate location of the magnet coil between incoming protons and outgoing electron beam [black]

detector acceptance = 0 degree?



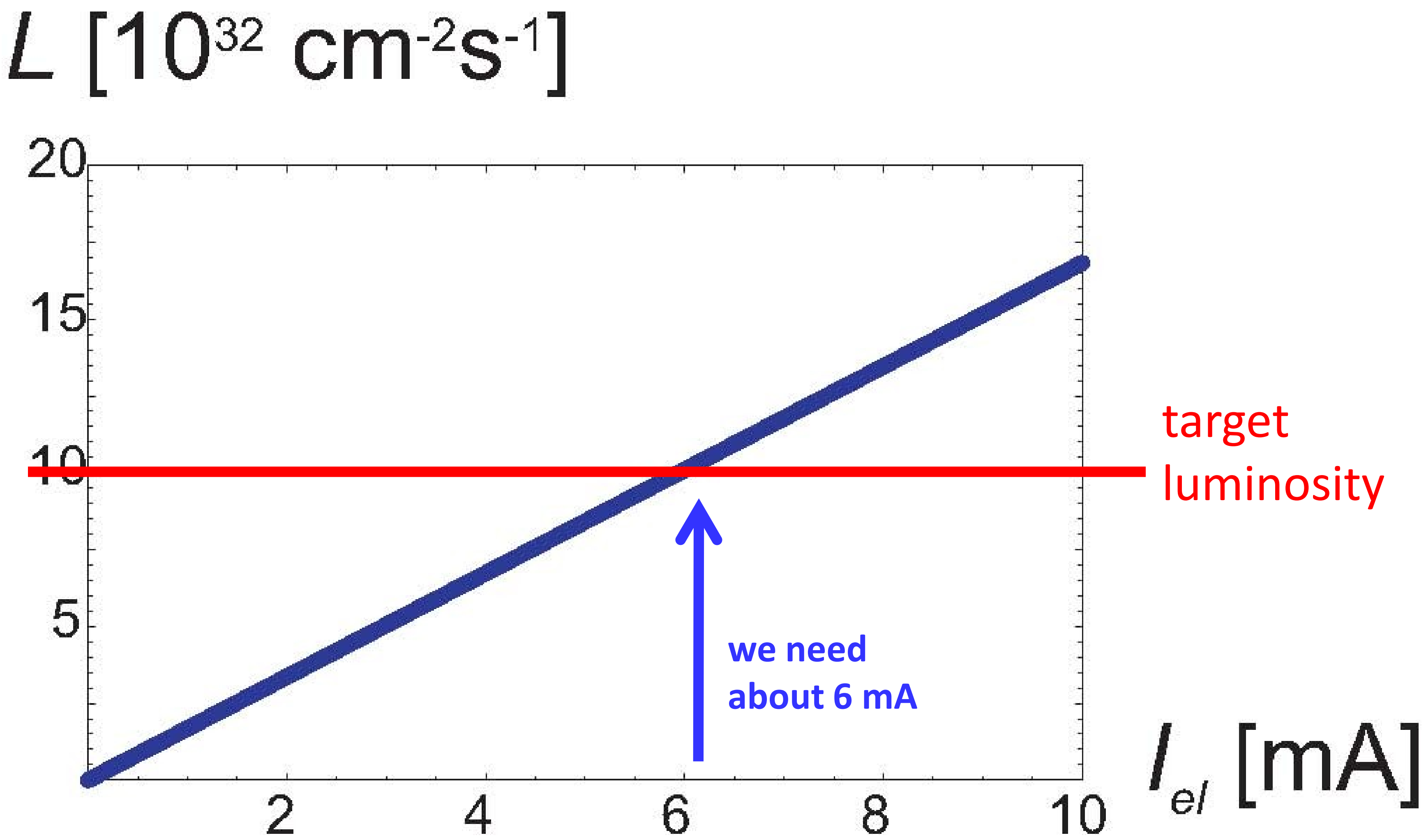
off-energy e^-'s from IP are swept into detector even at 0 degrees; complex acceptance boundary in horizontal-angle/energy space

electron beam

e- emittances and β^* not critical
(protons are big, ~7μm!)

most important parameter:
average beam current

in addition: bunch structure
and polarization



CLIC main beam ~ 0.01 mA (factor 600 missing)

lowering voltage, raise bunch charge & rep rate → 0.06 mA (NIMA 2007)

CLIC drive beam (30 mA, but 2.37 GeV)

ILC design current ~ 0.05 mA (factor ~100 missing)

SC linacs can provide higher average current, e.g. by increasing the duty factor 10-100 times, or even running cw, at lower energy & lower gradient

example design average currents:

CERN HP-SPL: ~2.5 mA (50 Hz)
Cornell ERL ~100 mA (cw)
eRHIC ERL ~ 50 mA at 20 GeV (cw)

LHeC needs ~6 mA at 60 GeV

beam power

6.4 mA at 60 GeV

→ **384 MW beam power !**

→ **~800 MW electrical power !!??**

need for energy recovery!

power reduced by factor $(1-\eta_{ERL})$

→ **LHeC ERL high-luminosity baseline**

one more ingredient

choice of SC linac RF frequency:

~~1.3 GHz (ILC)?~~

~720 MHz!

- requires less cryo-power (~2 times less from BCS theory); true difference ↔ residual resistance, [J. Tückmantel, E. Ciapala]
- better for high-power couplers [O. Napoly]
- synergy with SPL, eRHIC and ESS

ERL electrical site power

cryo power for two 10-GeV SC linacs: 28.9 MW

MV/m cavity gradient, 39 W/m heat at 1.8 K

700 “W per W” cryo efficiency

RF power to control microphonics: 22.2 MW

10 kW/m (eRHIC), 50% RF efficiency

RF for SR energy loss compensation: 24.1 MW

energy loss from SR 13.2 MW, 50% RF efficiency

cryo power for compensating RF: 2.1 MW

1.44 GeV linacs

microphonics control for compensating RF: 1.6 MW

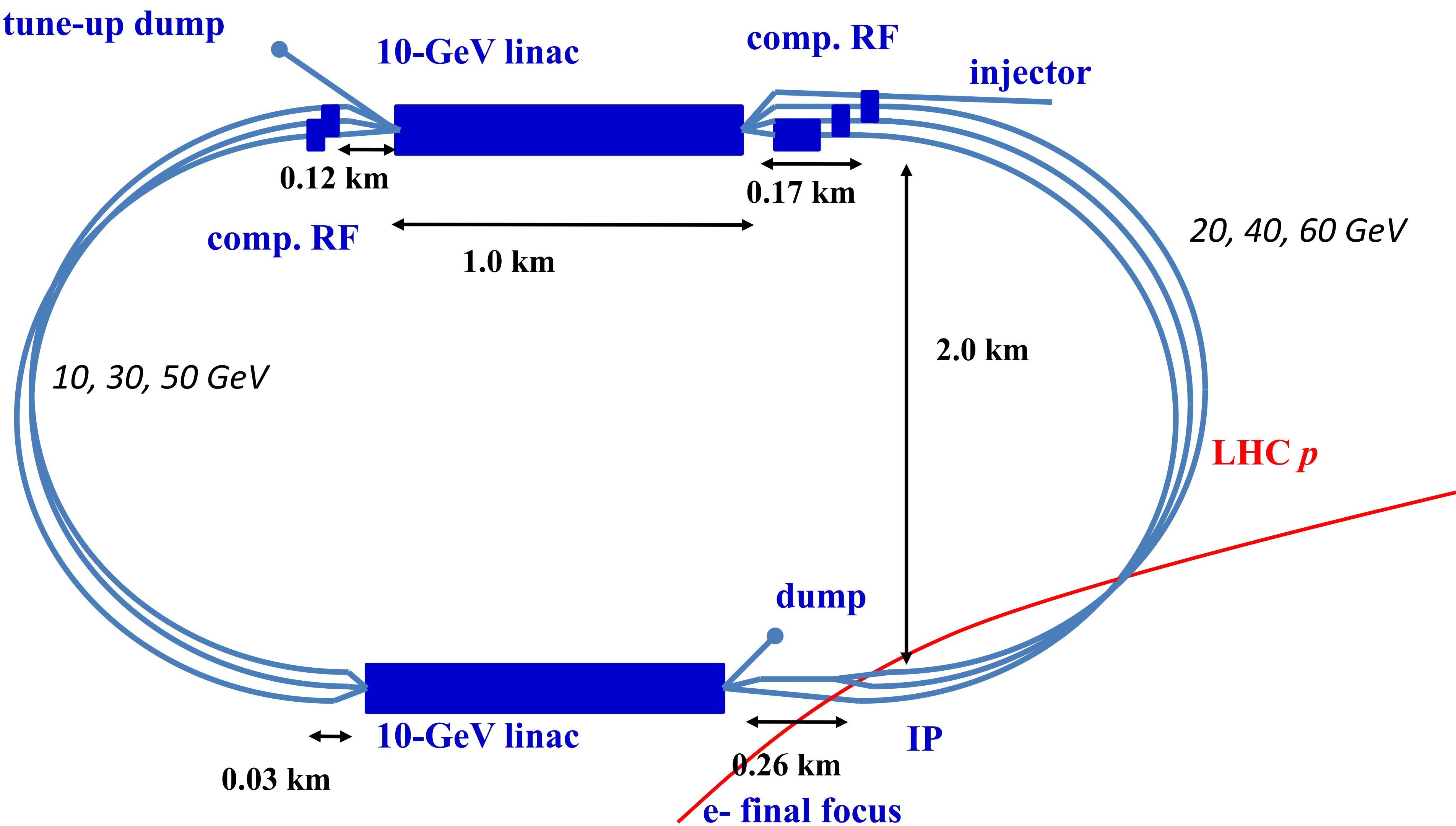
injector RF: 6.4 MW

500 MeV, 6.4 mA, 50% RF efficiency

magnets: 3 MW

grand total = 88.3 MW

ERL configuration



total circumference ~ 8.9 km

ERL components lengths

10-GeV linac length: 1008 m

cavity length 1 m, 56 m long FODO cell with 32 cavities, #cavities/linac = 576, cavity filling factor = 57.1%

effective arc radius = 1000 m

bending radius = 764 m, dipole filling factor = 76.4% (A. Bogacz)

SRF compensation linac: maximum 84 m [at 60 GeV]

combiners & splitters: 20-30 m each

e- final focus: 200-230 m (R. Tomas)

total circumference = LHC circumference / 3 (D. Schulte)

IP parameters (ERL option)

	protons	electrons
beam energy [GeV]	7000	60
Lorentz factor γ	7460	117400
normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	3.75	50
geometric emittance $\varepsilon_{x,y}$ [nm]	0.50	0.43
IP beta function $\beta^*_{x,y}$ [m]	0.10	0.12
rms IP beam size $\sigma^*_{x,y}$ [μm]	7	7
rms IP divergence $\sigma'_{x,y}$ [μrad]	70	58
beam current [mA]	≥430	6.6
bunch spacing [ns]	25 or 50	50
bunch population	1.7×10^{11}	2×10^{9}
crossing angle	0.0	

beam-beam effects

protons

- **head-on tune shift:** $\Delta Q=0.0001$ ***tiny***
- **long-range effect:** ***none***

  36 σ_p separation at s=3.75 m
- **emittance growth** due to **e-beam position jitter**

  p kick 10 nrad (~$10^{-4}\sigma^{*\prime}$) for 1σ offset,

  e- turn-to-turn random orbit jitter ≤ 0.04σ

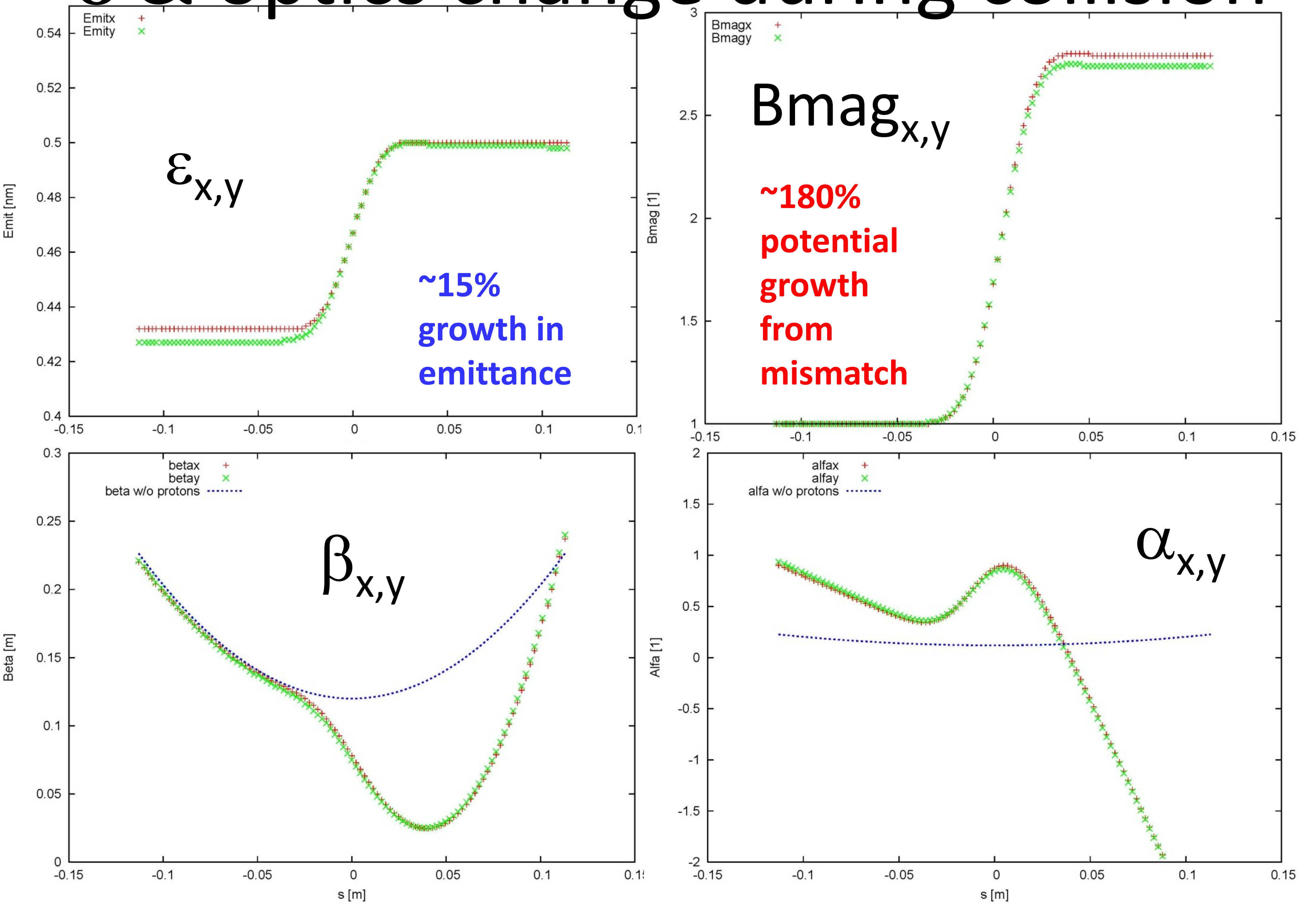
  [scaled from K. Ohmi, PAC'07;
  see also D. Schulte, F. Zimmermann, EPAC2004]

electrons

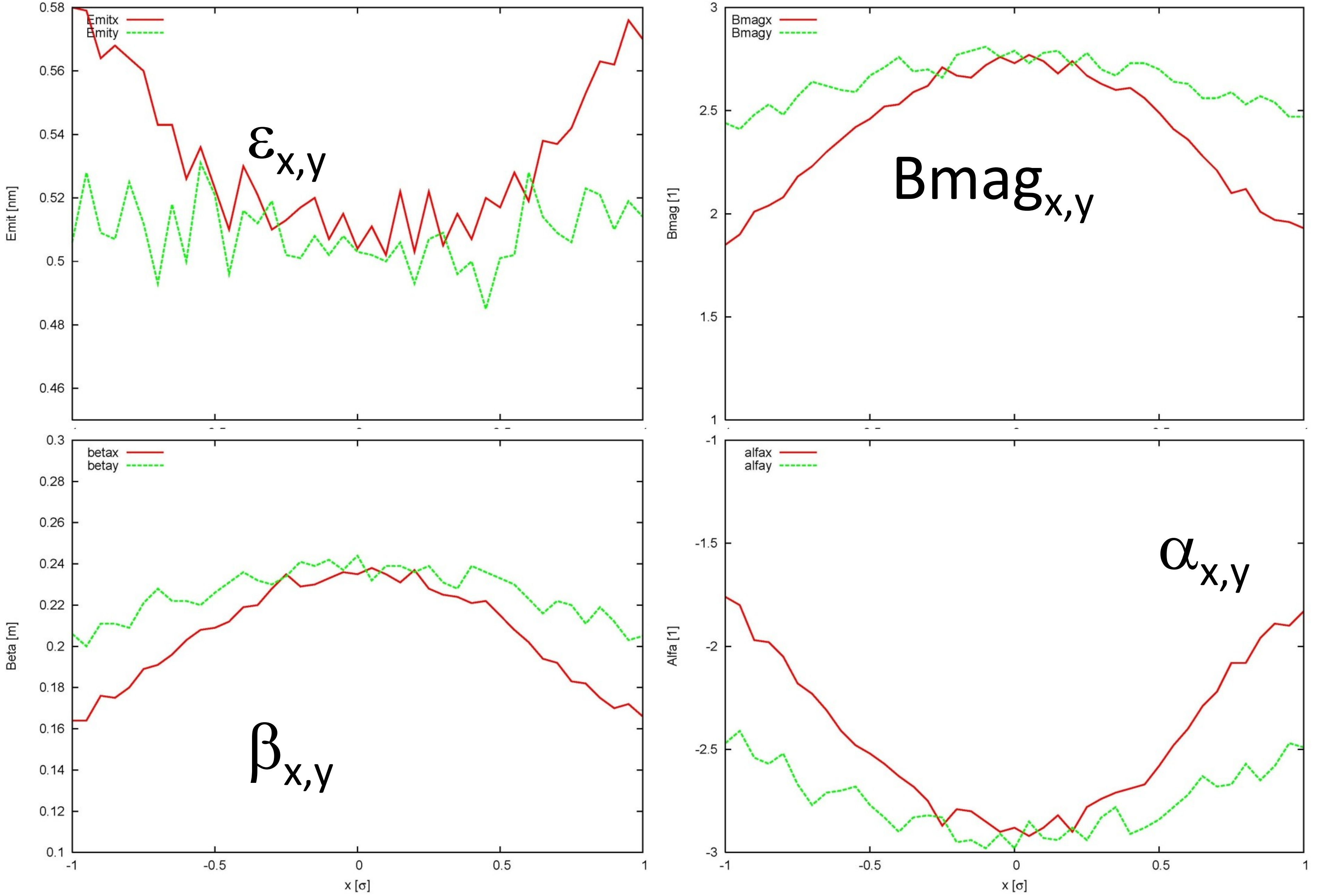
- **disruption**

  $D_{x,y}\approx 6$, $\theta_0\approx 600$ μrad ($\approx 10\sigma^{*\prime}$) ***huge***

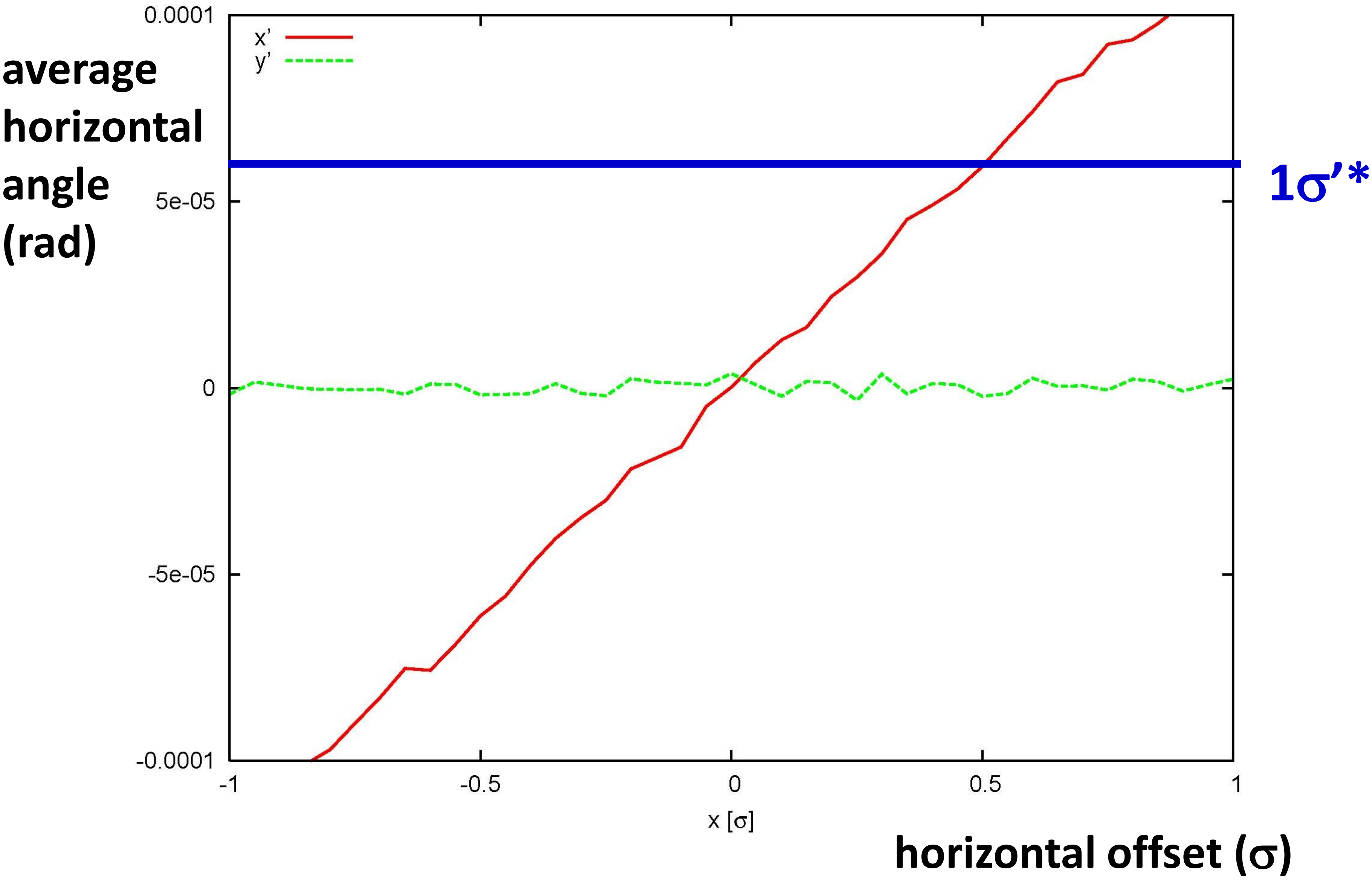
ε & optics change during collision



ε & optics change versus *x* offset



e^- deflection angle



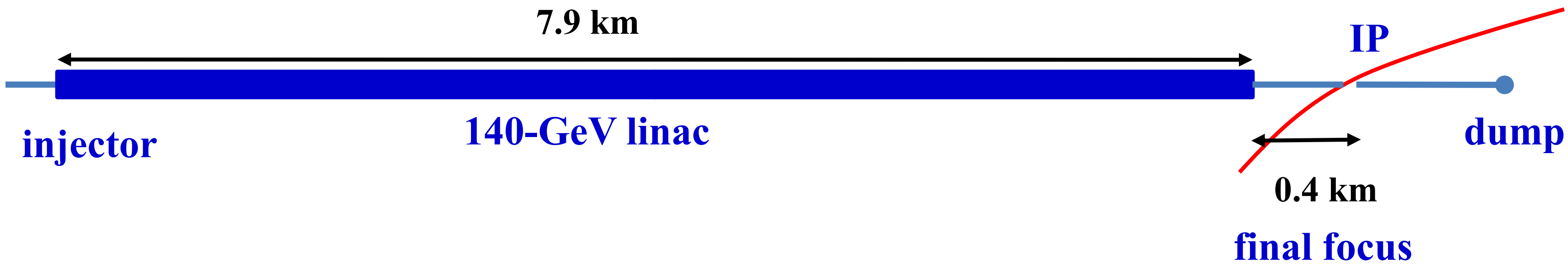
polarization

e- : from polarized dc gun with ~90% polarization, 10-50 μm normalized emittance

spin manipulations / preserving polarization: Wien filter and/or spin rotators, polarimeters to be included in optics design

e+: up to ~60% polarization from undulator or Compton-based source

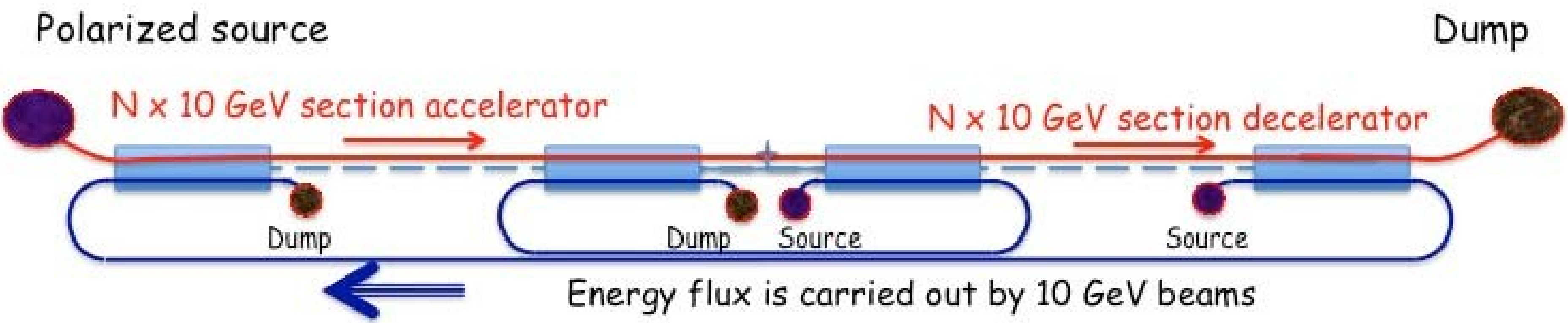
pulsed linac for 140 GeV



- linac could be ILC type (1.3 GHz) or 720 MHz
- cavity gradient: 31.5 MV/m, Q=10^{10}
- extendable to higher beam energies
- no energy recovery
- with 10 Hz, 5 ms pulse, H_g=0.94, N_b=1.5x10^9 : $\langle I_e \rangle$=0.27 mA → $L \approx 4\times10^{31}$ cm^{-2}s^{-1}

highest-energy LHeC ERL option

high energy e- beam is not bent; could be converted into LC?



High luminosity LHeC with nearly 100% energy efficient ERL.
The main high-energy e- beam propagates from left to right.
In the 1st linac it gains ~150 GeV (N=15), collides with the hadron beam and is then decelerated in the second linac.
Such ERL could push LHeC luminosity to 10^{35} $cm^{-2}s^{-1}$ level.

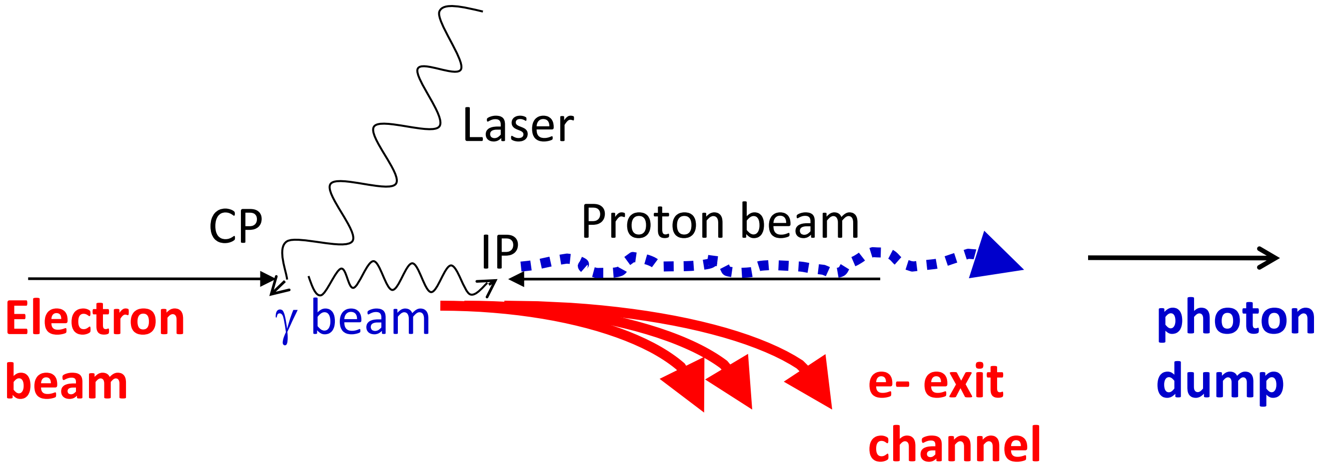
this looks a lot like CLIC 2-beam technology

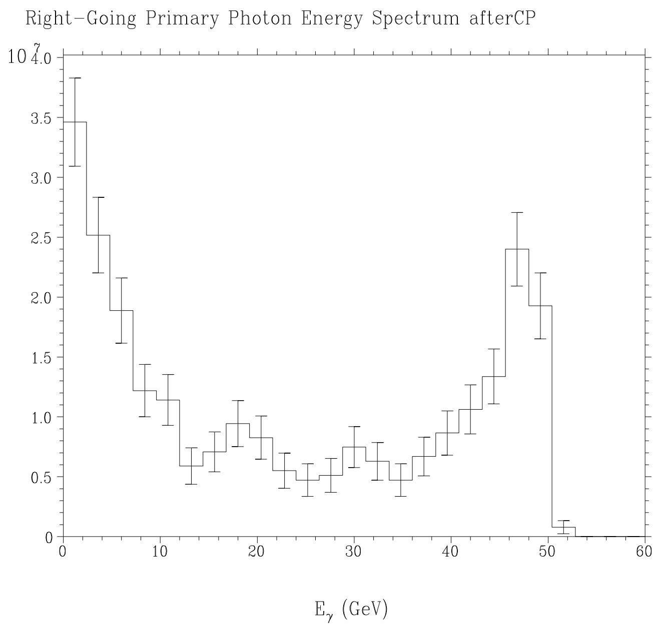
V. Litvinenko,
2nd LHeC workshop
Divonne 2009

γ-p/A option

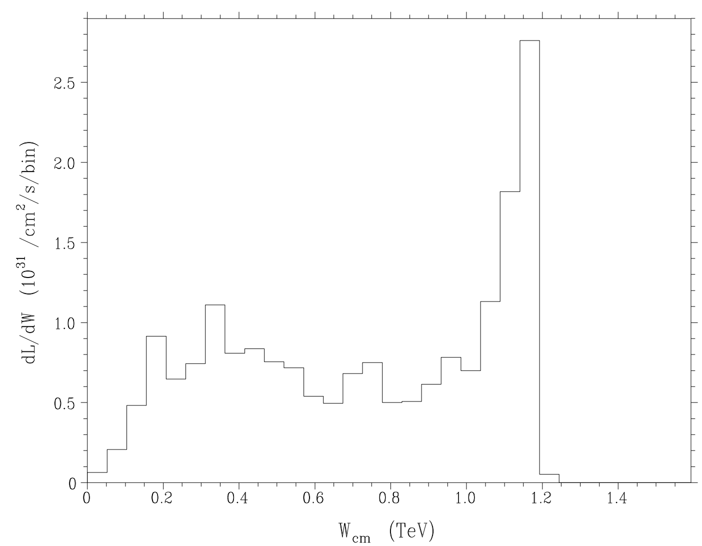
- pulsed linac (60 GeV or 140 GeV)
- photon beam produced by Compton back-scattering off **laser pulse** (λ=240 nm, σ_γ~10 μm, $A_0 \sim h\nu\sigma_\gamma^2/\sigma_c \sim 4$ J); conversion efficiency & **spent e^- energy spread ~10 to 60 GeV**
- stacking external pulses in recirculating cavity; with **e- bunch spacing of e.g. 200 ns** path length could be 60 m; **mirror system**
- conversion point (CP) can be $\Delta s \sim \beta^* \sim$ **0.1 m from IP**
- **extract spent e- beam** (steered by detector dipole);
- **beam dump for neutral photons** in downstream quadrupole channel

γ-p/A option: trajectories & spectra





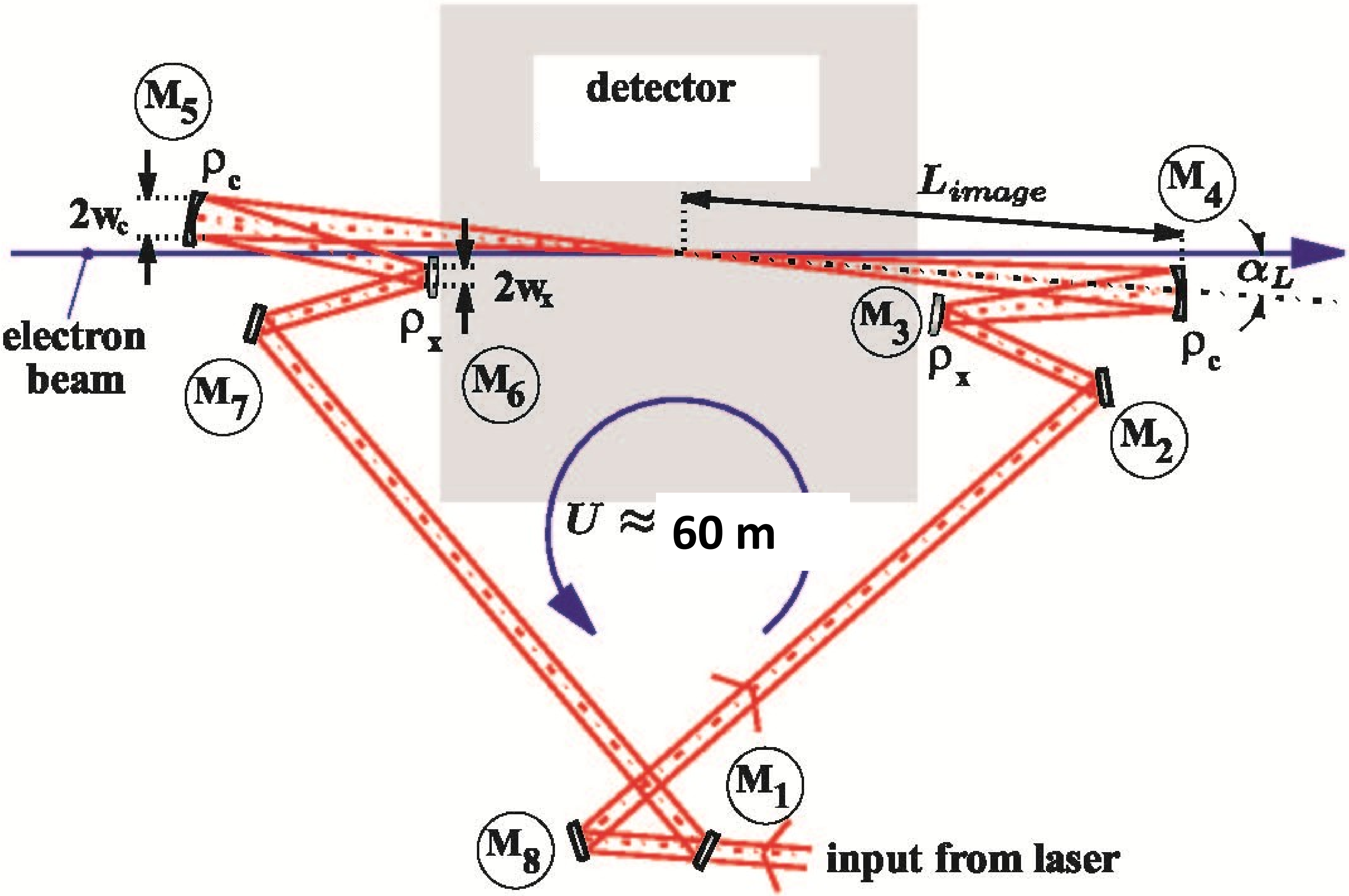
example photon energy spectrum after CP



example luminosity spectrum

H. Aksakal, Z. Nergiz et al

γ-p/A option: recirculating mirrors



G. Klemz, K. Monig. I. Will, et al, NIM A 564 (2006) 212

summary

ERL (60 GeV):
10^{33} $cm^{-2}s^{-1}$, <100 MW, < 9 km circumference,
about 21 GV RF

pulsed linac (140 GeV)
$4x10^{31}$ $cm^{-2}s^{-1}$, <100 MW, < 9 km length,
with γ-p option

high polarization possible, beam-beam benign,
e+ difficult

thank you!

S. Bettoni, C. Bracco, O. Brüning, H. Burkhardt, E. Ciapala, B. Goddard, F. Haug, B. Holzer, B. Jeanneret, M. Jimenez, J. Jowett, K.-H. Mess, J. Osborne, L. Rinolfi, S. Russenschuck, D. Schulte, H. ten Kate, H. Thiesen, R. Tomas, D. Tommasini, F. Zimmermann, *CERN, Switzerland;* C. Adolphsen, M. Sullivan, Y.-P. Sun, *SLAC, USA;* A.K. Ciftci, R. Ciftci, K. Zengin, *Ankara U.,Turkey;* H. Aksakal, E. Arikan, *Nigde U., Turkey;* E. Eroglu, I. Tapan, *Uludag U., Turkey;* T. Omori, J. Urakawa, *KEK, Japan ;* S. Sultansoy, *TOBB, Turkey;* J. Dainton, M. Klein, *Liverpool U., UK;* R. Appleby, S. Chattopadhyay, M. Korostelev, *Cockcroft Inst., UK;* A. Polini, *INFN Bologna, Italy;* E. Paoloni, *INFN Pisa, Italy;* P. Kostka, U. Schneekloth, *DESY, Germany;* R. Calaga, Y. Hao, D. Kayran, V. Litvinenko, V. Ptitsyn, D. Trbojevic, N. Tsoupas, V. Yakimenko , *BNL, USA;* A. Eide, *NTNU, Norway ;* A. Bogacz, *JLAB, USA ;* N. Bernard, *UCLA, USA*

et al