Ring-Linac LHeC

Frank Zimmermann, CERN, BE-ABP

Contributors:

F. Bordry, H.-H. Braun, O.S. Brüning, H. Burkhardt, A. Eide, A. de Roeck, R. Garoby, B. Holzer, J.M. Jowett, T. Linnecar, K.-H. Mess, J. Osborne, L. Rinolfi, D. Schulte, R. Tomas, J. Tückmantel, A. Vivoli, CERN, Geneva, Switzerland; S.Chattopadhyay, J. Dainton, Cockcroft Inst., Warrington; M. Klein, U.Liverpool, United Kingdom; A.K. Ciftci, Ankara U.; H. Aksakal, U. Nigde, Turkey; S. Sultansoy, TOBB ETU, Ankara, Turkey; J. Skrabacz, U. Notre Dame, U.S.A.; T. Omori, J. Urakawa, KEK, Japan; F. Willeke, V. Litvinenko, V. Yakimenko, BNL, New York, U.S.A.; C. Adolphsen, SLAC, U.S.A.

2nd CERN-ECFA-NuPECC Workshop on the LHeC
Divonne, 1 September 2009

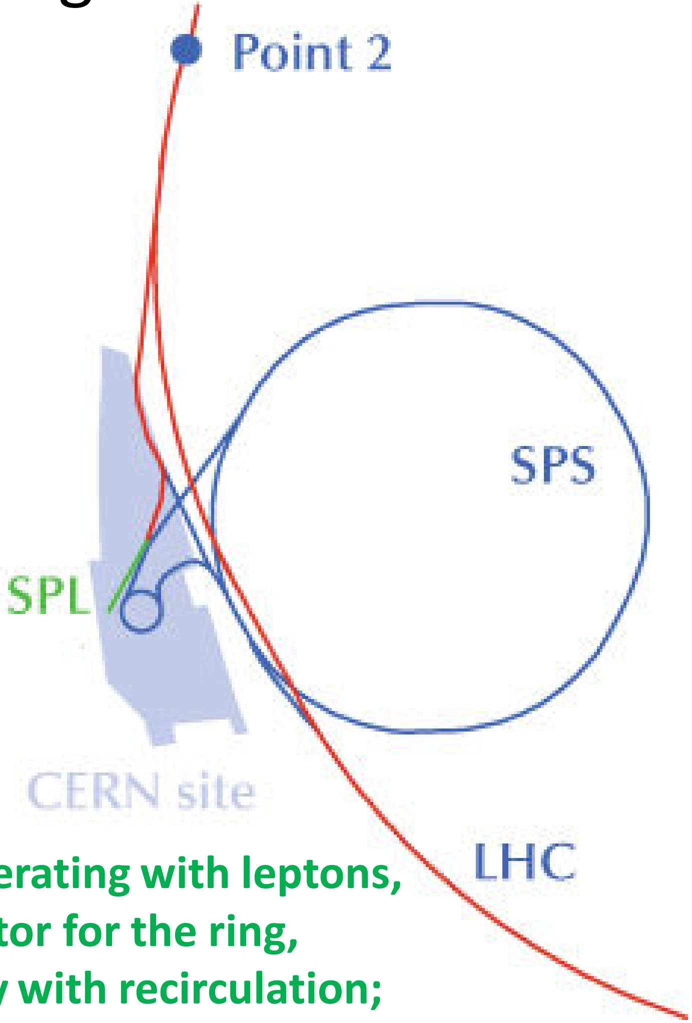
particle-physics requests

(John Dainton, Max Klein)

- lepton energies from 50 to 150 GeV
- peak luminosity ~10^{33} $cm^{-2}s^{-1}$ or higher
- both e- and e+ beams
- polarization

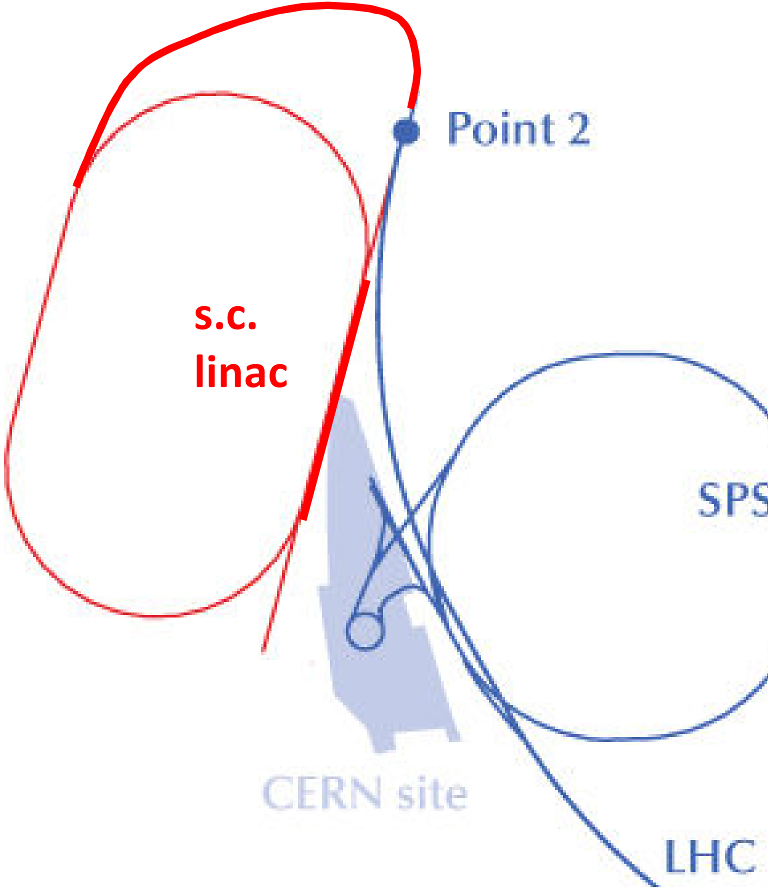
LHeC options including linacs

option 1: “ring-ring” (RR)
e-/e+ ring in LHC tunnel



SPL, operating with leptons, as injector for the ring, possibly with recirculation;

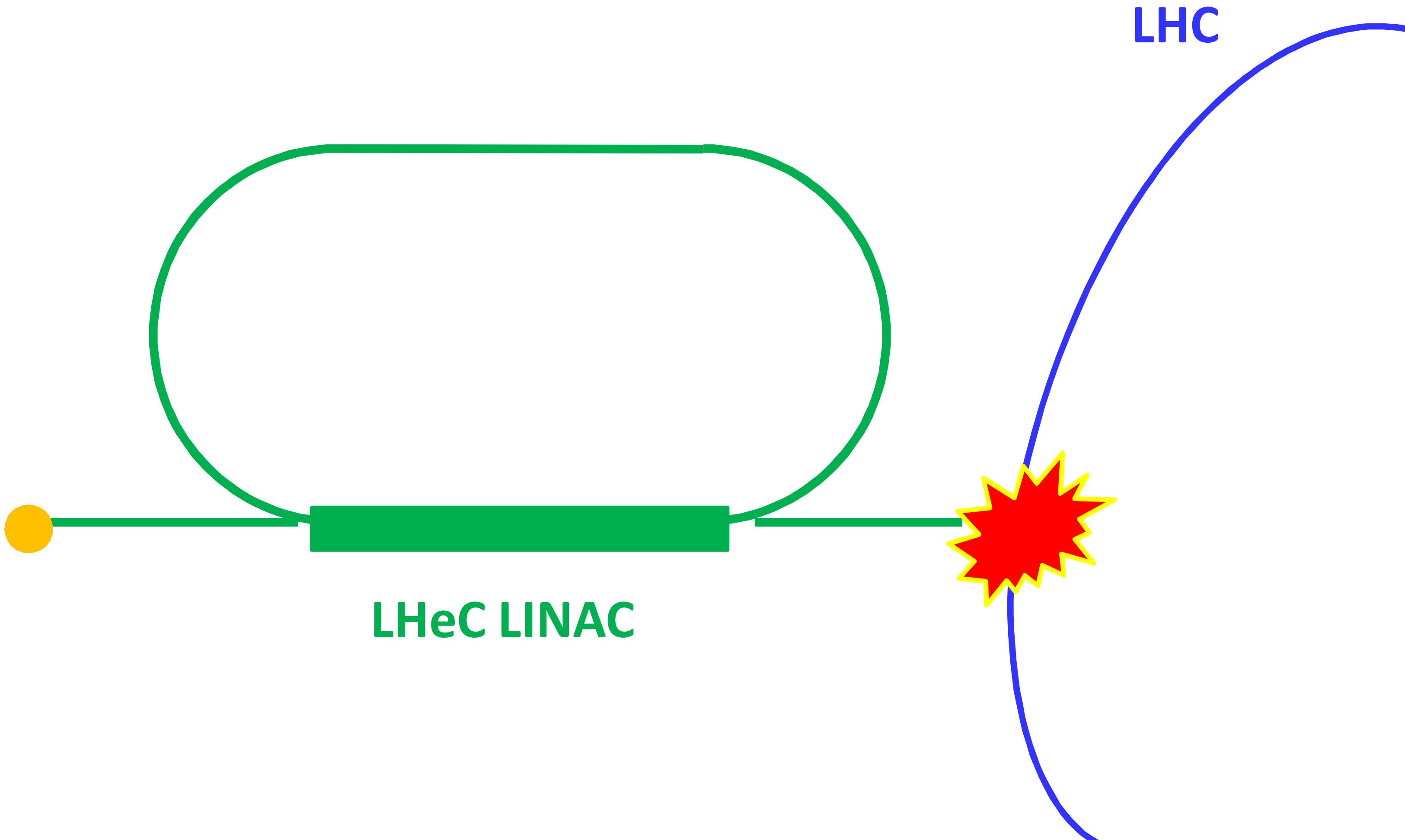
option 2: “ring-linac” (RL)



up to 70 GeV: option for cw operation and recirculation with energy recovery; > 70 GeV: pulsed operation at higher gradient ; γ-hadron option; focus on option 2

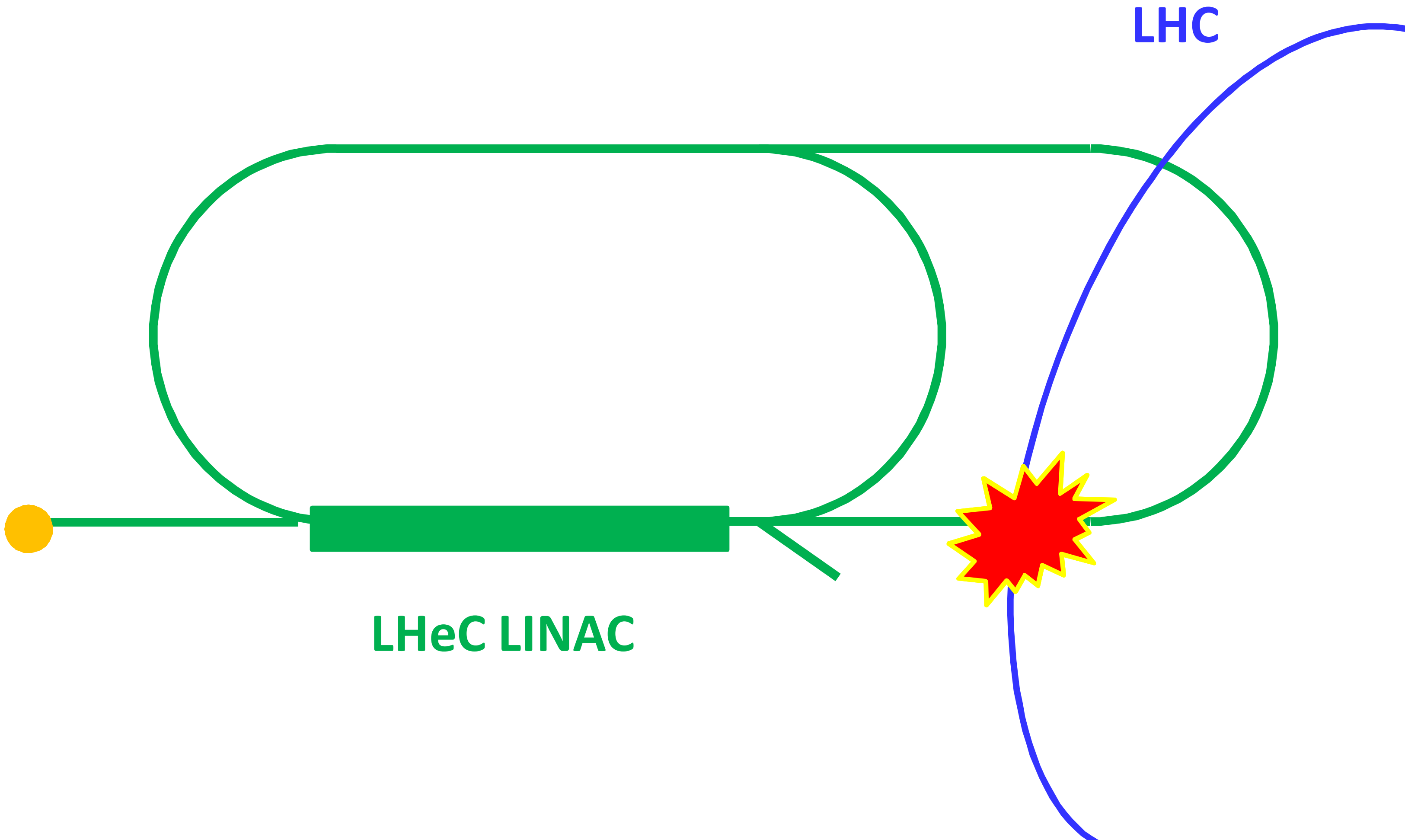
2-pass Recirculating Linear Accelerator

(RLA), 100-140 GeV – *pulsed, high gradient*



4-pass Energy Recover Linac (ERL)

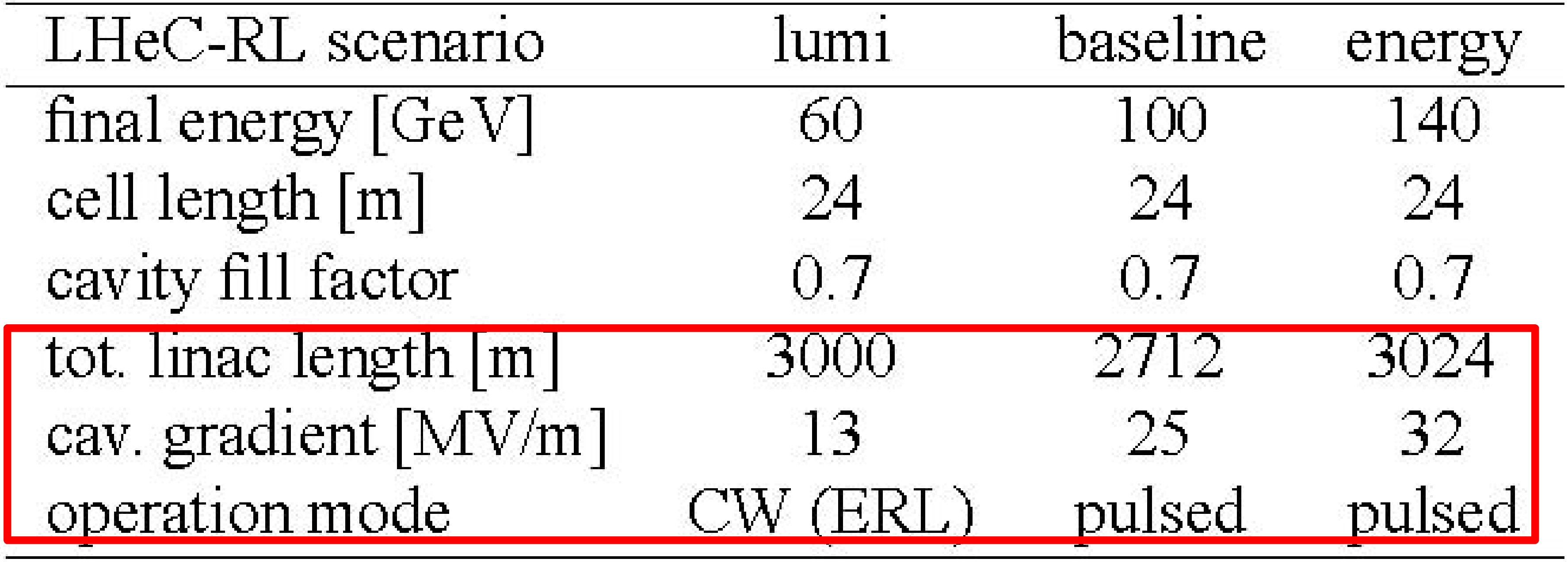
60 GeV – *cw, lower gradient*



3-km long greenfield SC linac

"ILC-like" SC linac parameters

Anders Eide



LHeC-RL scenario	lumi	baseline	energy
final energy [GeV]	60	100	140
cell length [m]	24	24	24
cavity fill factor	0.7	0.7	0.7
tot. linac length [m]	3000	2712	3024
cav. gradient [MV/m]	13	25	32
operation mode	CW (ERL)	pulsed	pulsed

RF frequency: ~700 MHz

4 passes

2 passes

we can use the same linac for all energies!

(different klystrons and modulators for cw and pulsed mode)

can one build a 3-km long linac?

it has been done before (some 50 years ago)

return arc and return drift

choice of **arc radius = 1.5 km**

- dictated by synchrotron radiation
  - ○ energy loss
    - - 140 GeV (70 GeV in arc): 2% energy loss
    - - 100 GeV (50 GeV in arc): 0.7% energy loss
    - - 60 GeV (30 GeV in arc): 0.1% energy loss
  - ○ emittance growth (controlled by the arc-cell length)

return arc length = linac length

total RLA circumference: ~(2x3+2πx1.5)km ~15 km

construction cost assumptions

rough estimate for cost / (unit length) extracted from XFEL, ILC and ELFE designs [w/o escalation]:

✓**linac: 160 k$/m** (assuming 1$~1€)

- with eff. gradient of 11.8 MV/m (XFEL, 20 GV, 1.7 km)

✓**arc section: 50 k$/m**

- 300 M$ per ILC Damping Ring

✓**drift straight: 10 k$/m**

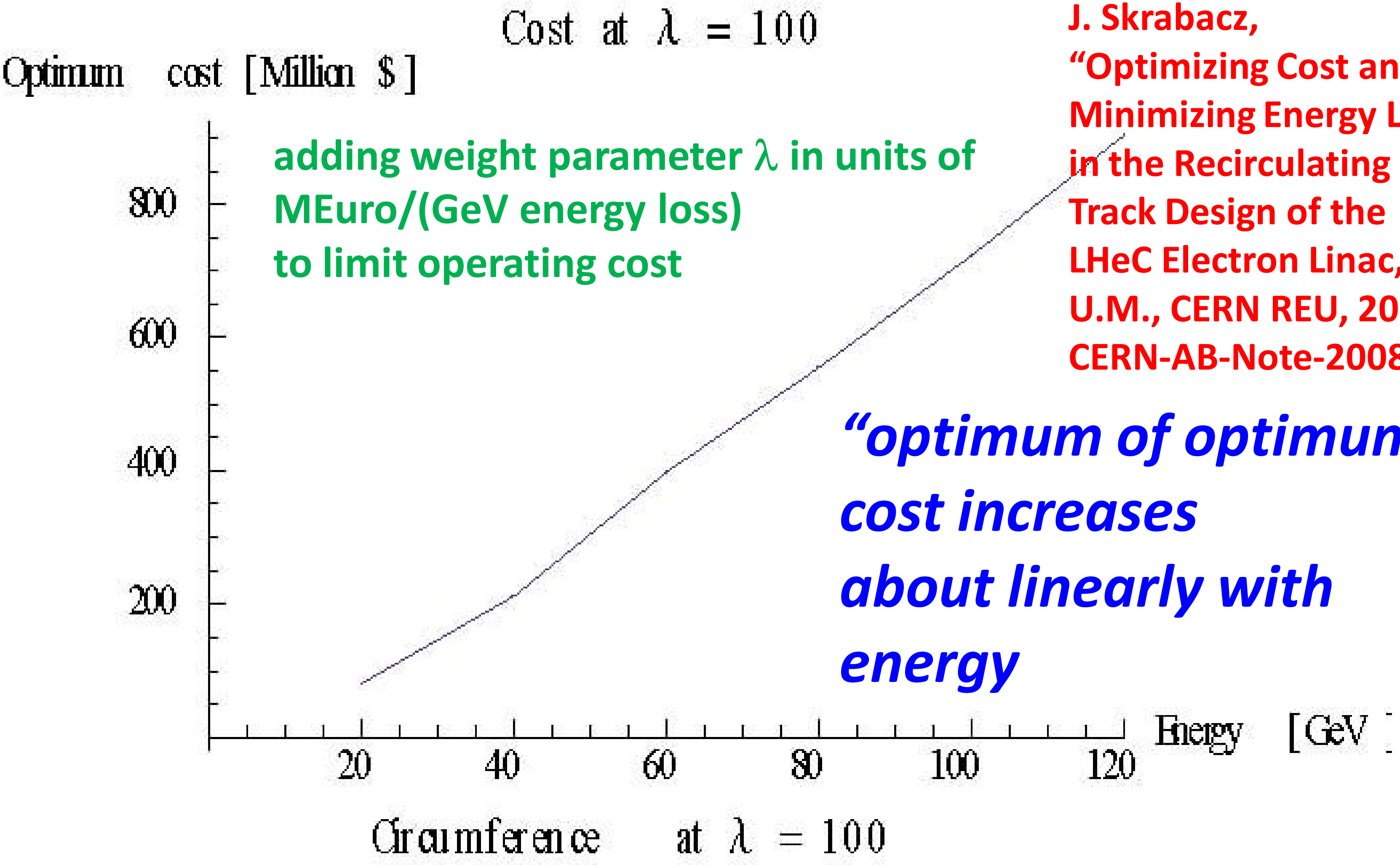
- vacuum + perhaps some diagnostics?, taken as ~20% of cost of arc section from ELFE design

✓**ILC tunnel cost: ~5k $/m**

- already taken to be included in above numbers
- otherwise important only for the straight drifts, potentially raising the drift cost to 15k$/m

optimized cost vs energy

J. Skrabacz



adding weight parameter λ in units of MEuro/(GeV energy loss) to limit operating cost

J. Skrabacz, "Optimizing Cost and Minimizing Energy Loss in the Recirculating Race-Track Design of the LHeC Electron Linac," U.M., CERN REU, 2008; CERN-AB-Note-2008-043

"optimum of optimum" cost increases about linearly with energy

2-pass acceleration is optimum from ~50-140 GeV

R-L construction cost estimate

construction of 140-GeV RLA:
~1 billion €

+ IR, sources, escalation, LHC modifications

→ total cost ~1.5-2.0 billion €

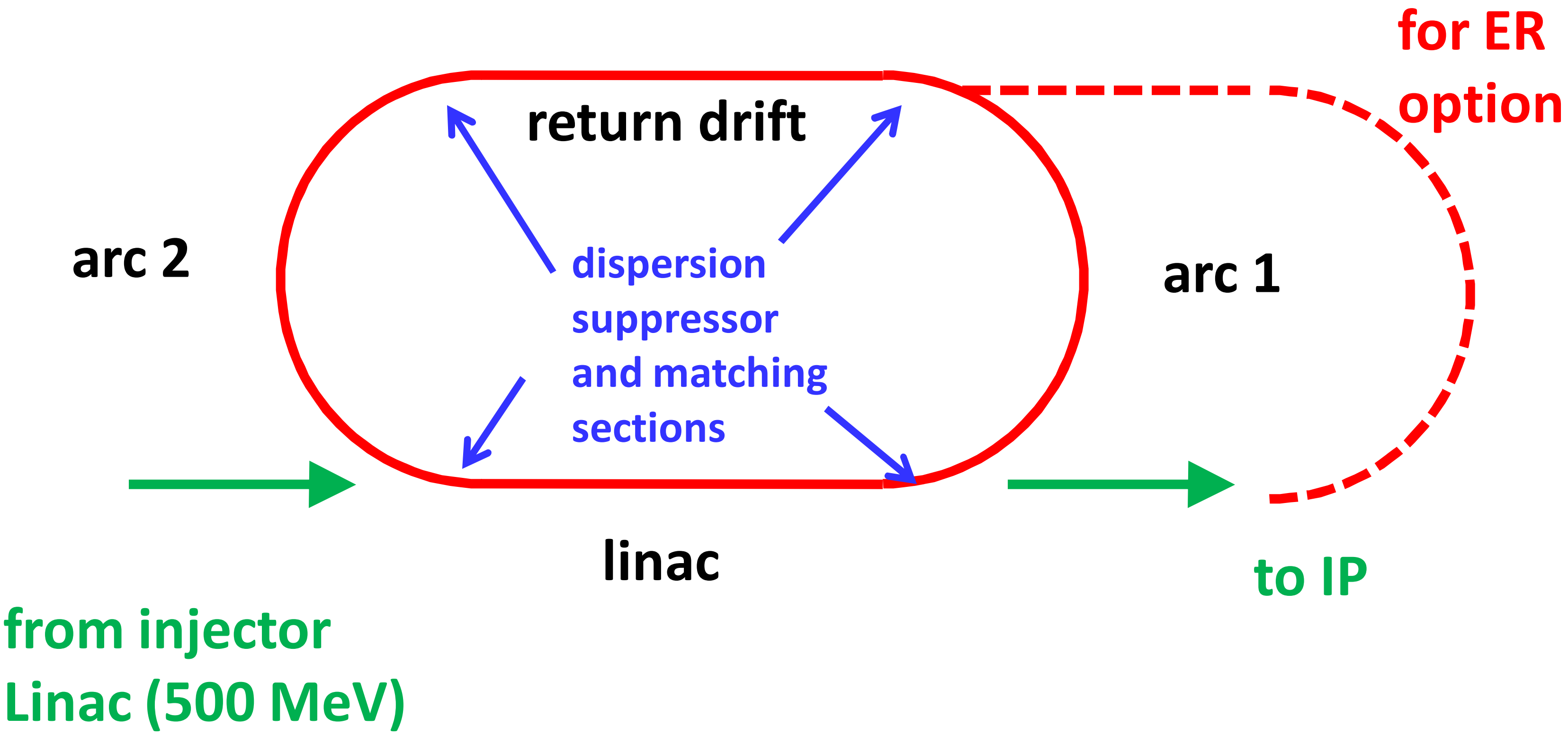
RLA lattice

optics design using PLACET and MAD-X for three scenarios

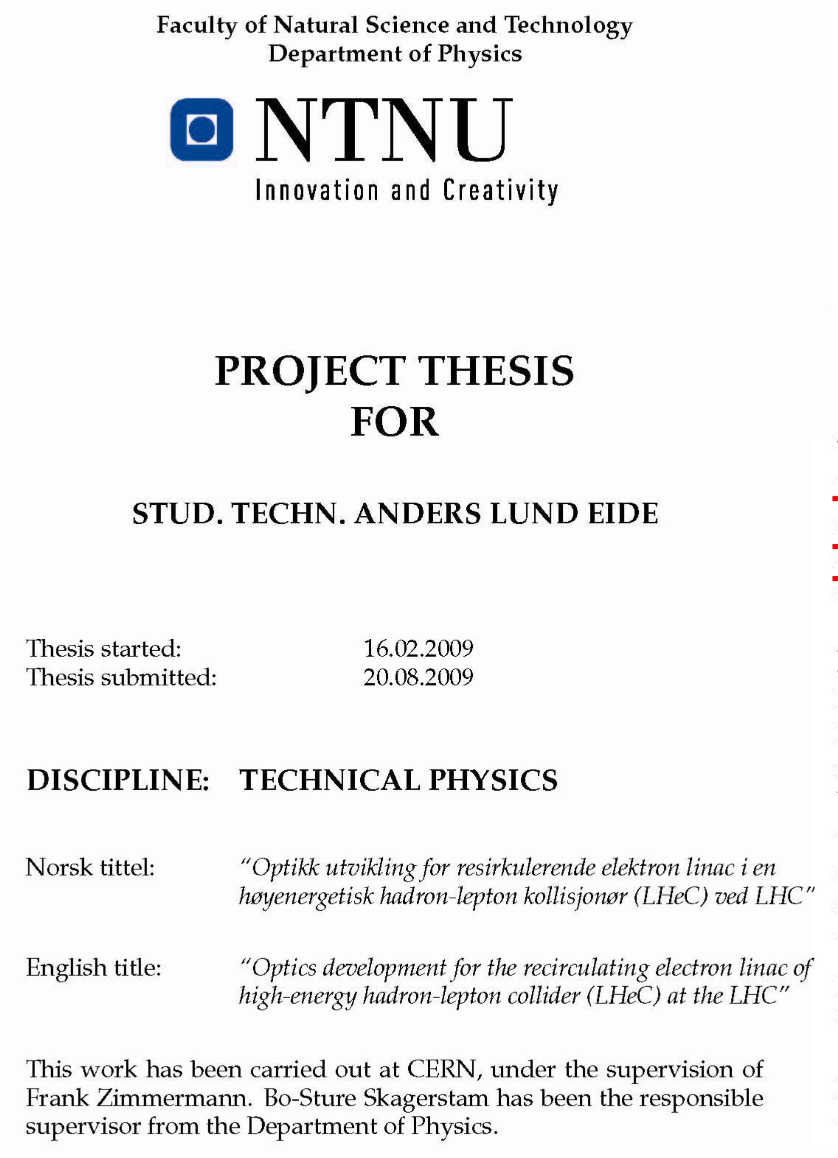
- 60 GeV 4-pass system with deceleration
- 100 GeV 2 passes
- 140 GeV 2 passes

Anders Eide

considered injection energies of 5 GeV and 0.5 GeV (final choice)



master thesis Anders Eide



Faculty of Natural Science and Technology
Department of Physics

NTNU
Innovation and Creativity

PROJECT THESIS
FOR

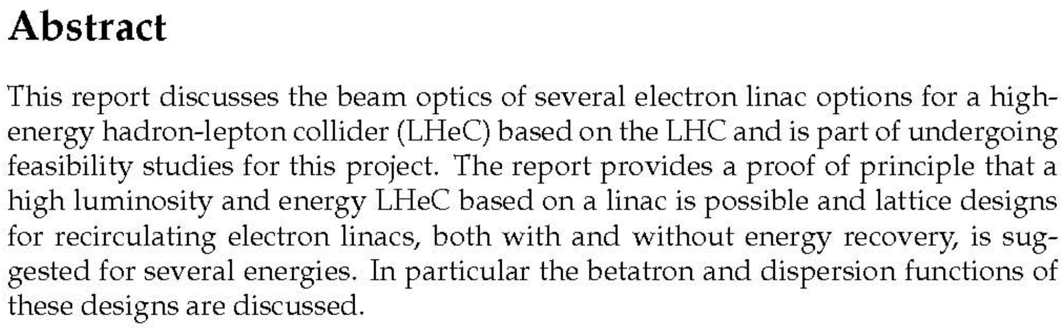
STUD. TECHN. ANDERS LUND EIDE

Thesis started:	16.02.2009
Thesis submitted:	20.08.2009

DISCIPLINE: TECHNICAL PHYSICS

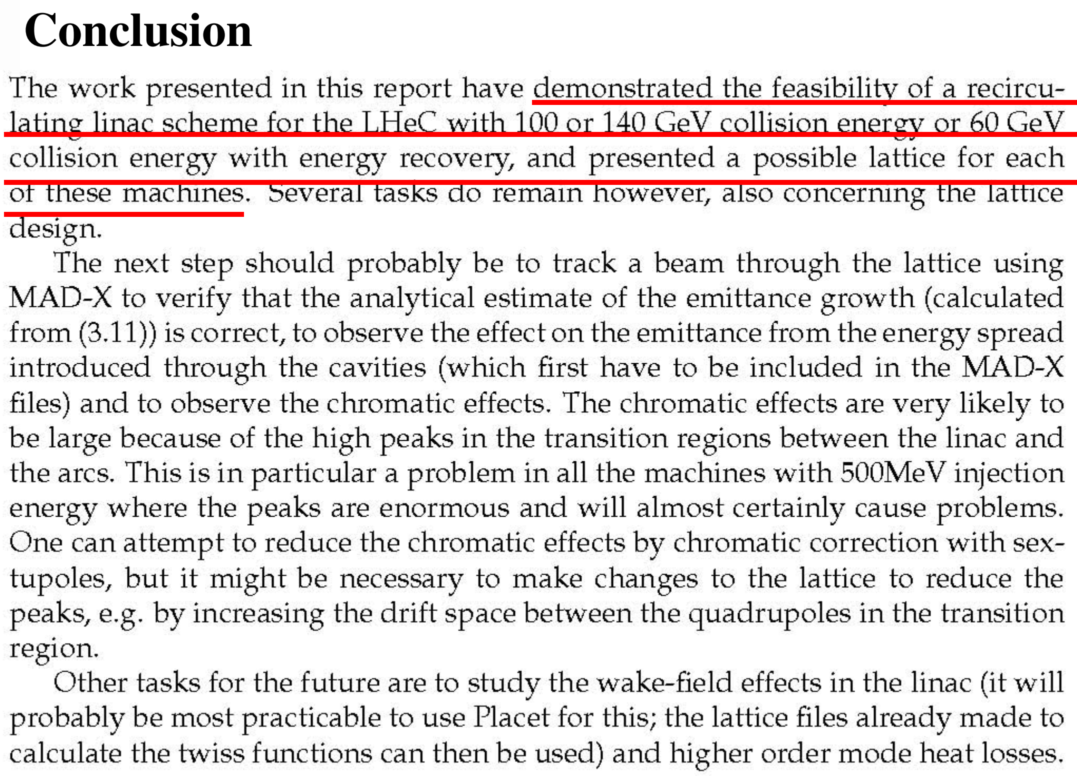
Norsk tittel:	*"Optikk utvikling for resirkulerende elektron linac i en høyenergetisk hadron-lepton kollisjonør (LHeC) ved LHC"*
English title:	*"Optics development for the recirculating electron linac of high-energy hadron-lepton collider (LHeC) at the LHC"*

This work has been carried out at CERN, under the supervision of Frank Zimmermann. Bo-Sture Skagerstam has been the responsible supervisor from the Department of Physics.



Abstract

This report discusses the beam optics of several electron linac options for a high-energy hadron-lepton collider (LHeC) based on the LHC and is part of undergoing feasibility studies for this project. The report provides a proof of principle that a high luminosity and energy LHeC based on a linac is possible and lattice designs for recirculating electron linacs, both with and without energy recovery, is suggested for several energies. In particular the betatron and dispersion functions of these designs are discussed.



Conclusion

The work presented in this report have demonstrated the feasibility of a recirculating linac scheme for the LHeC with 100 or 140 GeV collision energy or 60 GeV collision energy with energy recovery, and presented a possible lattice for each of these machines. Several tasks do remain however, also concerning the lattice design.

The next step should probably be to track a beam through the lattice using MAD-X to verify that the analytical estimate of the emittance growth (calculated from (3.11)) is correct, to observe the effect on the emittance from the energy spread introduced through the cavities (which first have to be included in the MAD-X files) and to observe the chromatic effects. The chromatic effects are very likely to be large because of the high peaks in the transition regions between the linac and the arcs. This is in particular a problem in all the machines with 500MeV injection energy where the peaks are enormous and will almost certainly cause problems. One can attempt to reduce the chromatic effects by chromatic correction with sextupoles, but it might be necessary to make changes to the lattice to reduce the peaks, e.g. by increasing the drift space between the quadrupoles in the transition region.

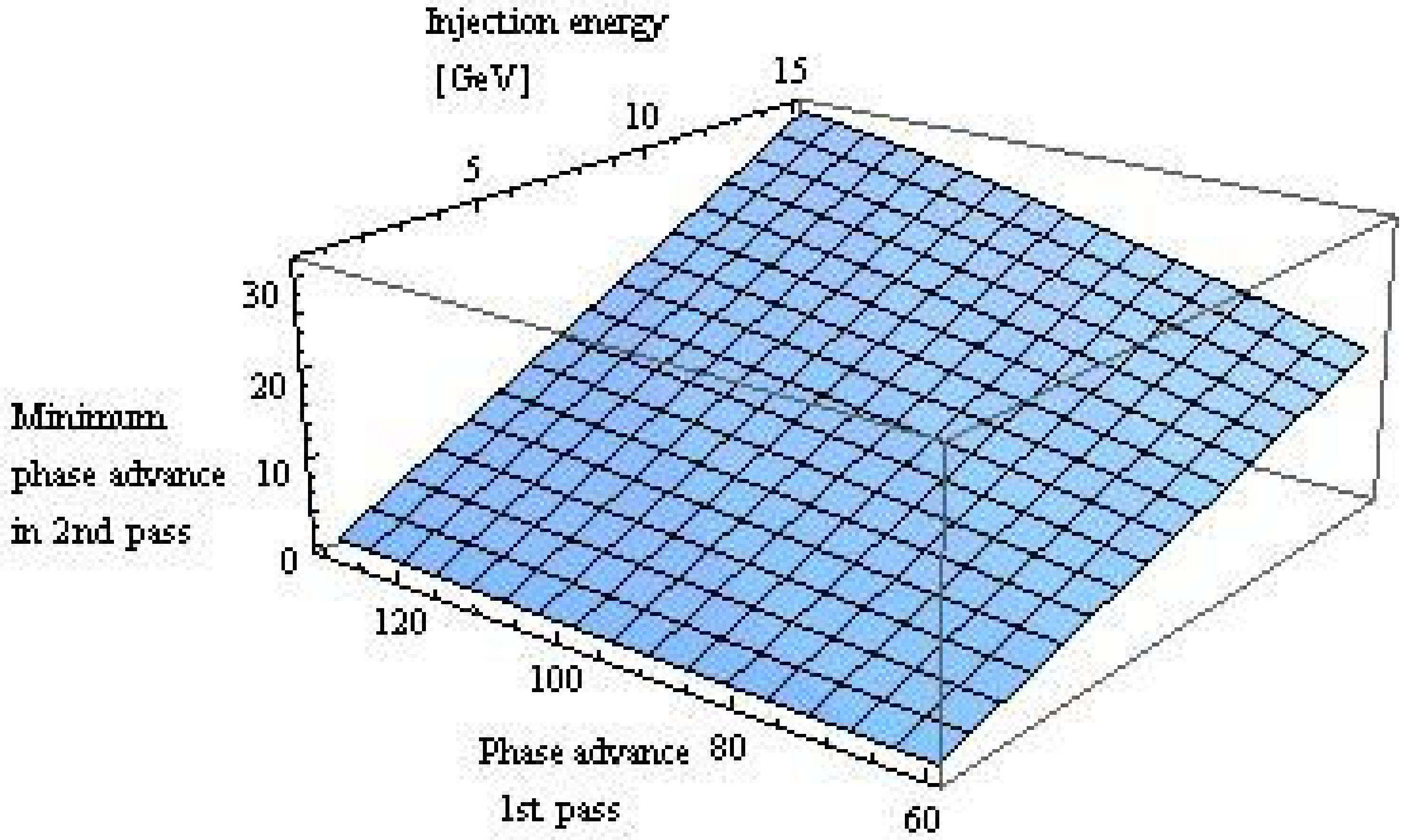
Other tasks for the future are to study the wake-field effects in the linac (it will probably be most practicable to use Placet for this; the lattice files already made to calculate the twiss functions can then be used) and higher order mode heat losses.

http://ab-abp-clic-qcde.web.cern.ch/ab-abp-clic-qcde/Literature/Project_Eide.pdf

RLA optics constraints

same quadrupole magnets determine optics on several passes through the linac at different beam energies → stability constraints

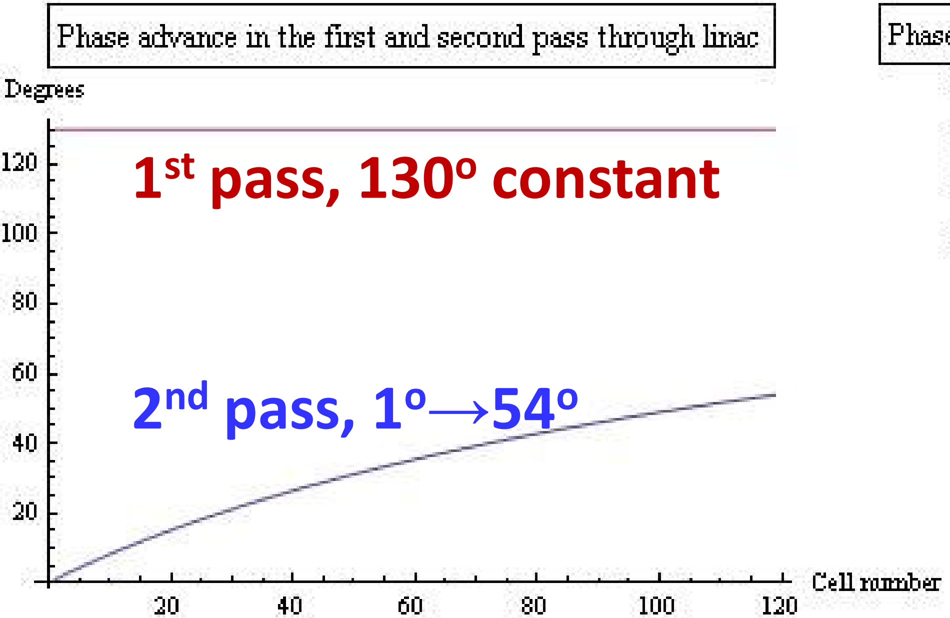
phase adv./cell at start of 2nd linac pass depends on phase adv./cell in 1st pass & injection energy



Anders Eide

linac phase advance

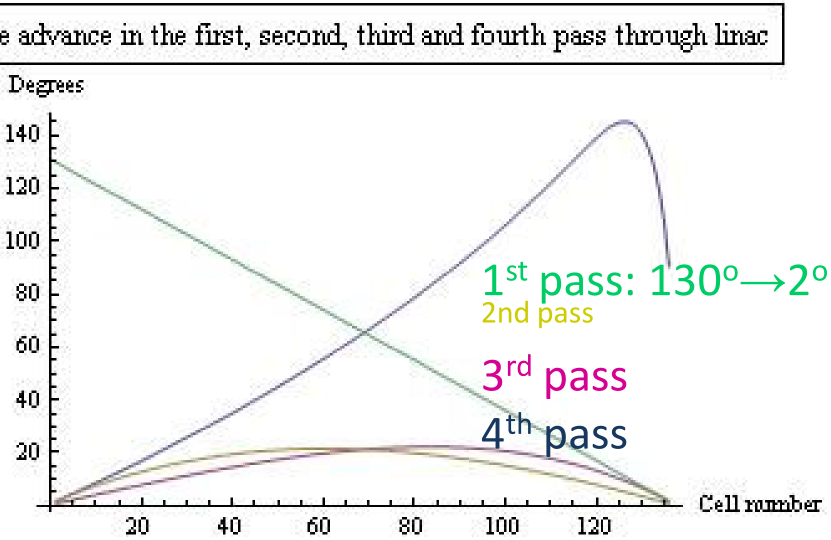
phase adv/cell, 0.5-100 GeV RLA



1st pass, 130° constant

2nd pass, 1°→54°

phase adv/cell, 0.5-60 GeV ERL



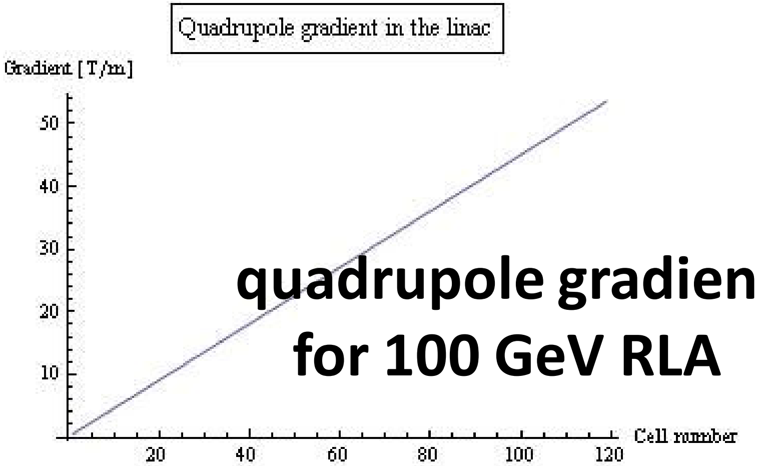
1st pass: 130°→2°

2nd pass

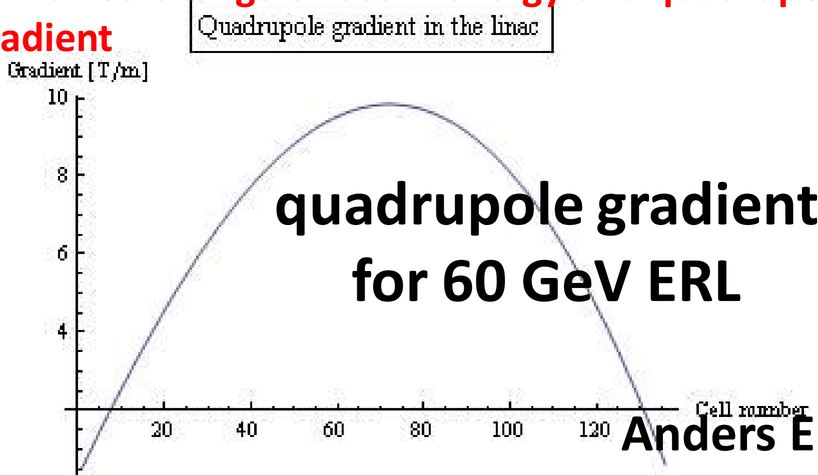
3rd pass

4th pass

local maximum for subsequent passes results from combined change of beam energy and quadrupole gradient



quadrupole gradient for 100 GeV RLA



quadrupole gradient for 60 GeV ERL

Anders Eide

basic cell & magnet parameters

Anders Eide

standard **FODO** cell everywhere

cell length = 24 m

(except 2nd & 5th transition of 60 GeV ERL [48 m])

quadrupole length 470 mm everywhere

maximum quadrupole gradient 78 T/m

(at end of 140 GeV linac)

separation between quadrupoles 11.53 m

to accommodate rf cavities or dipoles,
orbit correctors, BPMs, etc.

dipole length 9.8 m

rf-cavity length 8.4 m

bending radius of dipoles in recirculating arc = **1.5 km**

90° phase advance in the return arcs and return drift

linac injection energy

low energy encouraged by Georg Hoffstaetter

advantages of low (500 MeV) injection:

- for 2-pass recirculating linac [100 or 140 GeV]

  slightly reduced linac length ~2% w.r.t. 5 GeV
- strong impact on energy recovery (ER) efficiency

  η_{max}~$(E_{coll}-E_{inj}-\Delta E_{SR})/E_{coll}$, luminosity~$/(1-\eta_{max})$

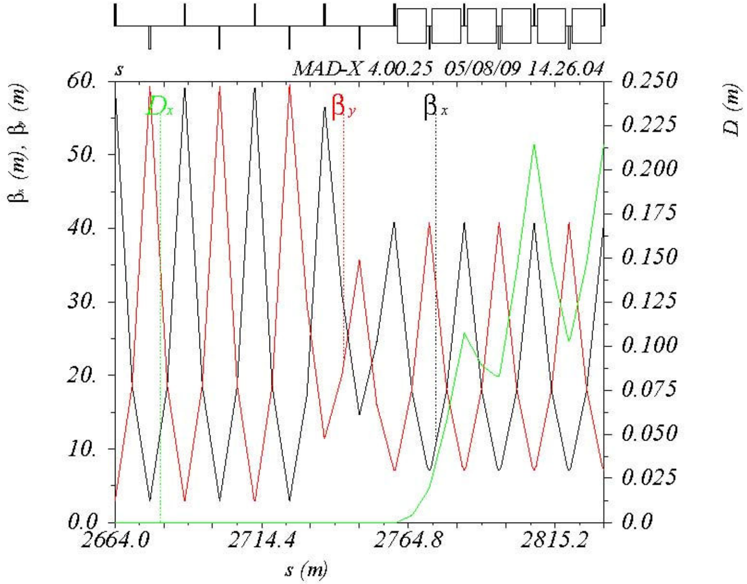
disadvantage:

- large beta functions at transitions & linac ends
- loss of adiabaticity and significant beating

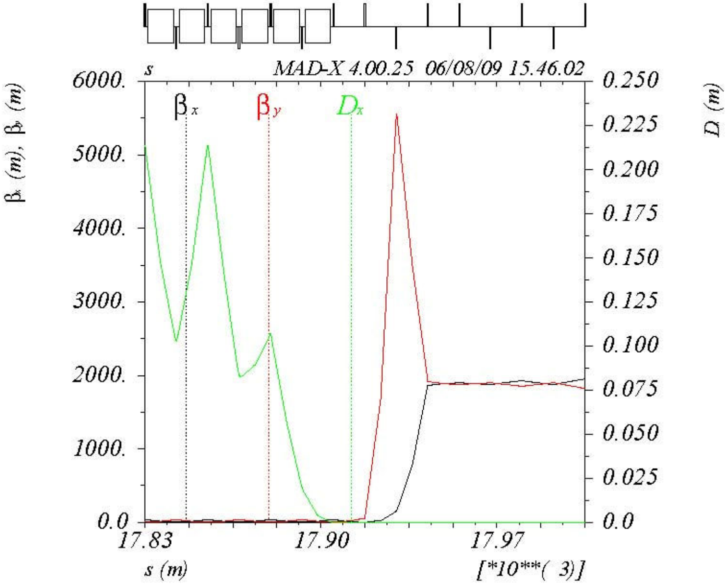
linac-arc transitions

Anders Eide

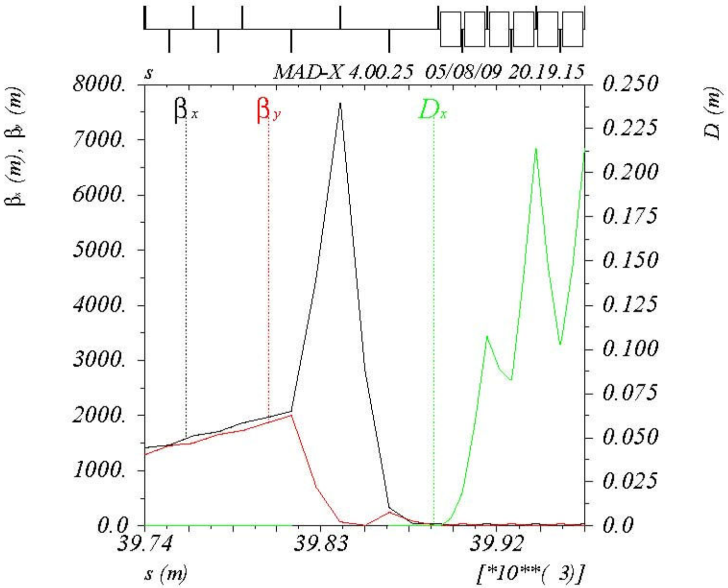
1st of 2 transition in the 100 & 140 GeV RL, similar for all RL, 130° → 90°



2nd of 2 transitions for the 140 GeV RL, 130° → 0.7°

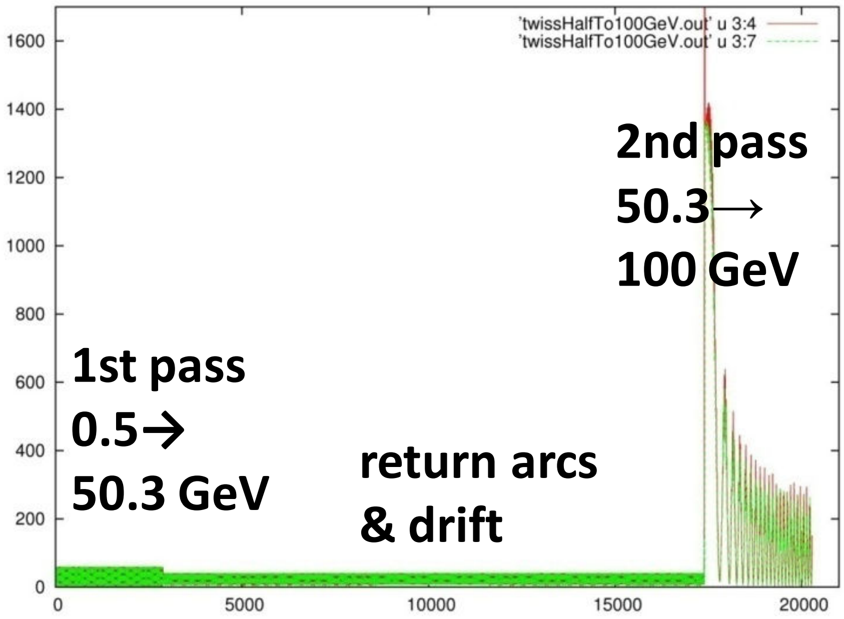


5th of 6 transitions for the 140 GeV RL, 1.9° → 90°



complete optics – 2 passes

100 GeV RLA

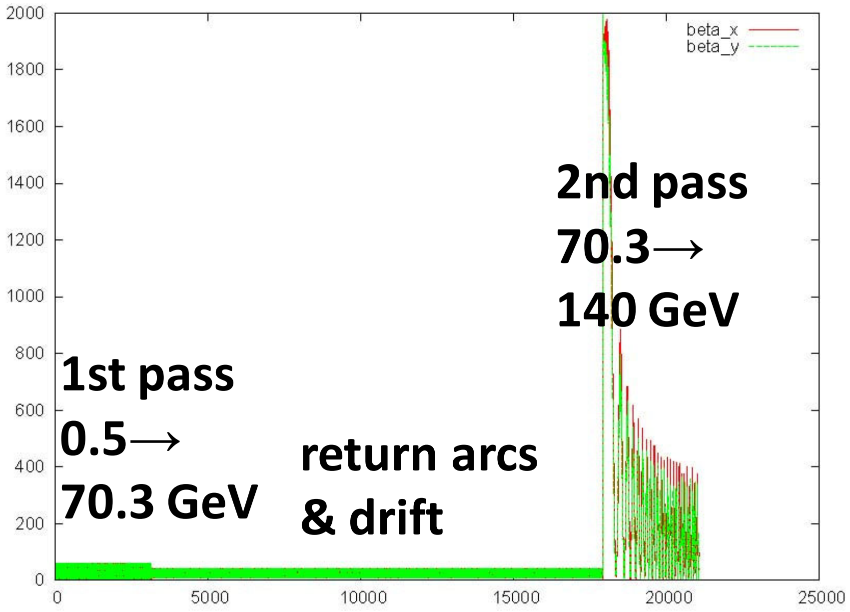


2nd pass
50.3→
100 GeV

1st pass
0.5→
50.3 GeV

return arcs
& drift

140 GeV RLA



2nd pass
70.3→
140 GeV

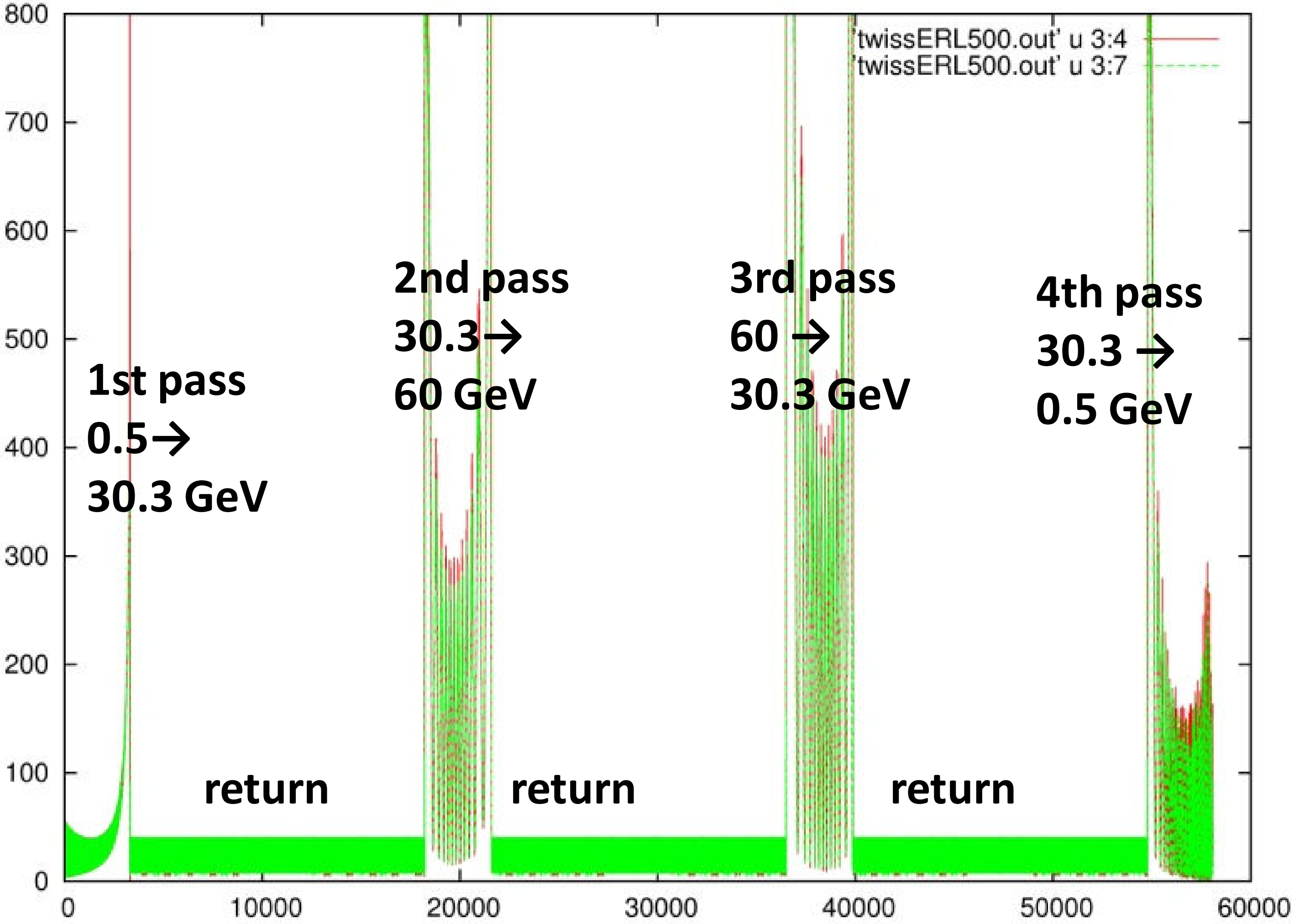
1st pass
0.5→
70.3 GeV

return arcs
& drift

Anders Eide

complete optics – 60 GeV ERL

Anders Eide



1st pass
0.5→
30.3 GeV

2nd pass
30.3→
60 GeV

3rd pass
60 →
30.3 GeV

4th pass
30.3 →
0.5 GeV

return

return

return

RLA & ERL optics performance

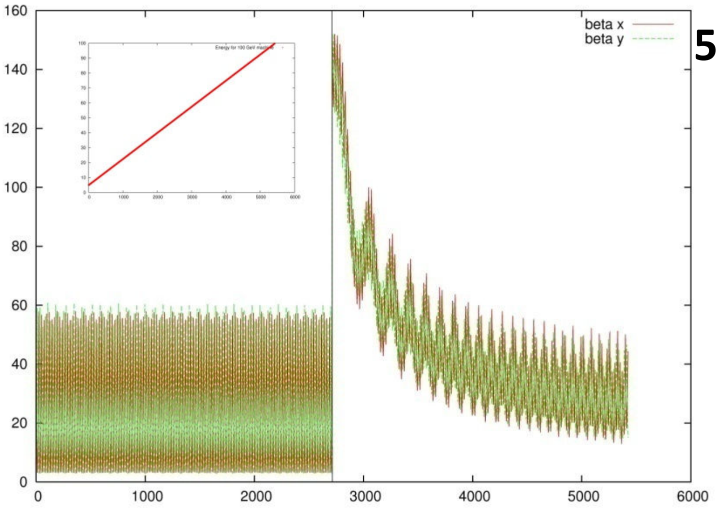
addressed in simulation studies
by ***Yi-Peng Sun (talk tomorrow)***

- MAD-X code modifications for RLAs
- multi-particle tracking with energy spread and synchrotron radiation
- emphasis on emittance

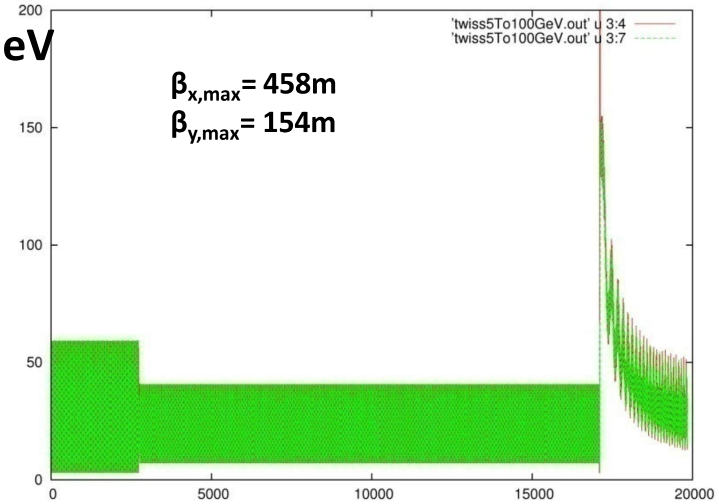
PLACET/MAD-X benchmarks

good agreement between MAD-X and PLACET linacs

Anders Eide



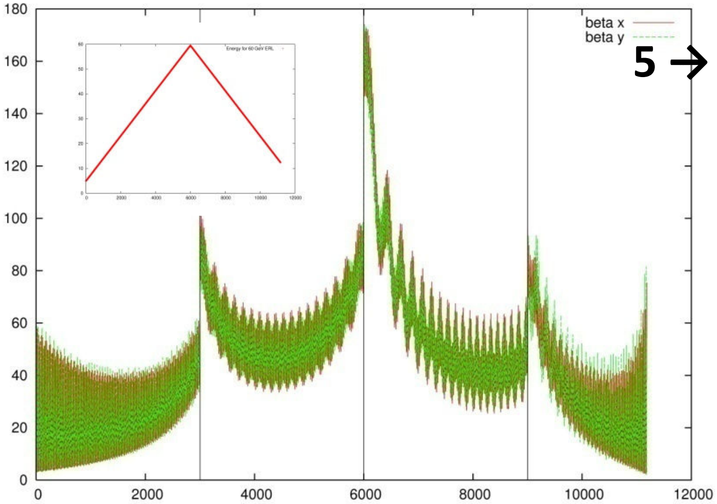
5 → 100 GeV



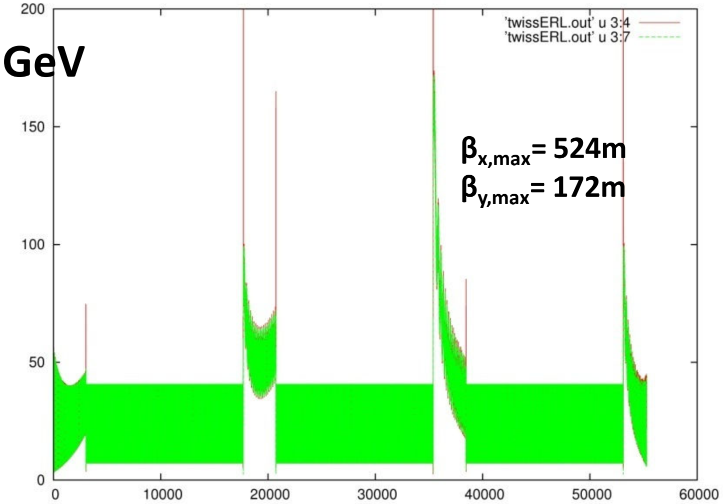
$\beta_{x,max}$= 458m
$\beta_{y,max}$= 154m

Placet (linac only)

MAD-X (with arcs)



5 → 60 → 13 GeV



$\beta_{x,max}$= 524m
$\beta_{y,max}$= 172m

electric power for cryogenics

$$P_{cr} = \underbrace{A\frac{E}{g}}_{\text{static}} + \underbrace{BDEg}_{\text{dynamic}}$$

heat load

$$A \approx 350\ \mathrm{W/m}$$

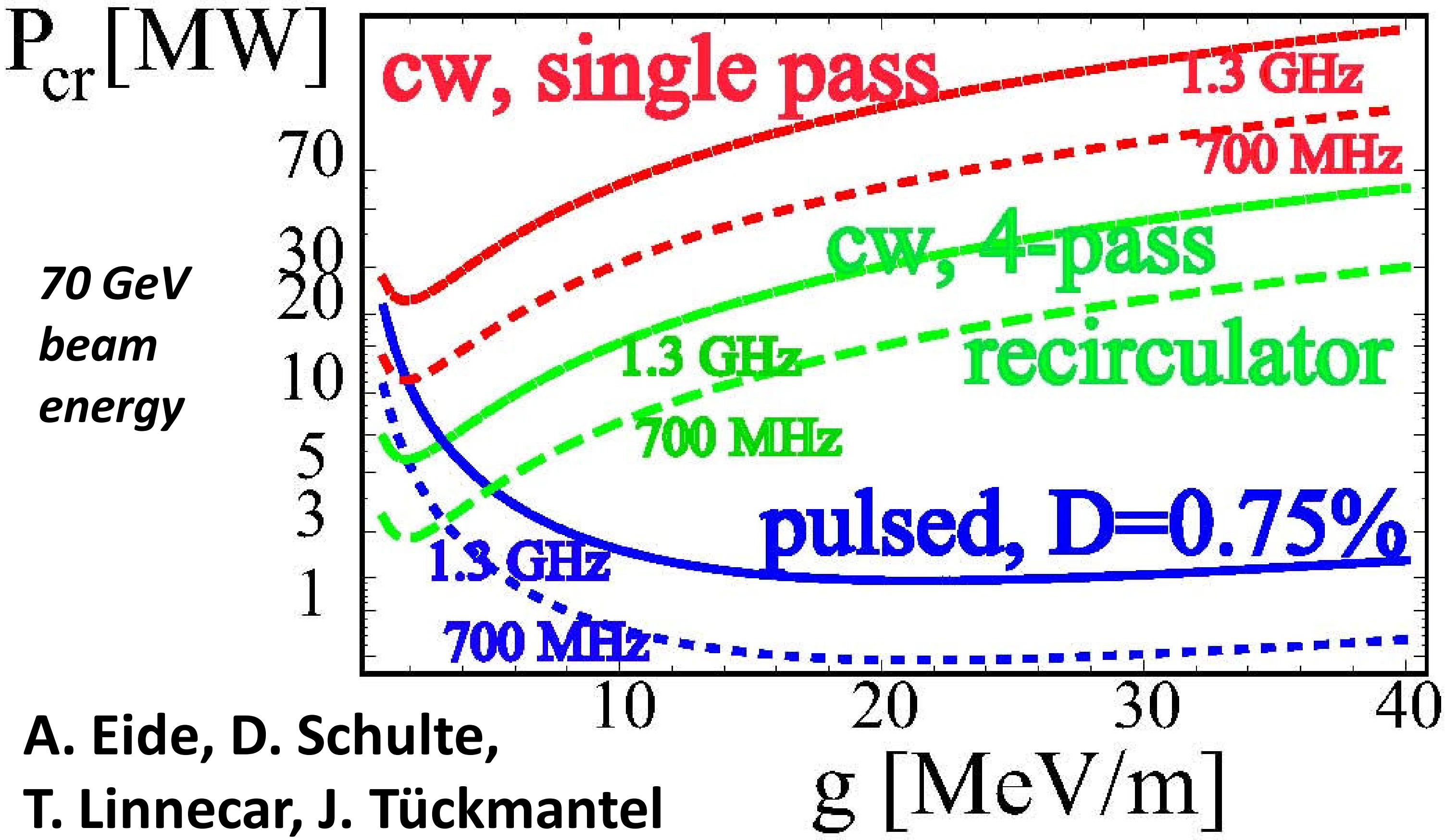
$$B \approx 10^{-10}\ \mathrm{Wm/(eV)^2}$$

$$D \approx \begin{cases} 1 \text{ for cw mode} \\ 0.0075 \text{ for pulsed operation} \end{cases}$$

A. Eide: "Electrical Power of Ring-Linac Options for LHeC,'' T4 Report, 2008

cryogenics electric power vs. acc. gradient:

70 GeV beam energy



cw operation requires low gradient ~10 MV/m

recirculation and 700 MHz frequency further lower cryo-power needs

A. Eide, D. Schulte, T. Linnecar, J. Tückmantel

EPAC'08

RF & total electric power

$$P_{rf} = P_{beam} \frac{1 - \eta_{ER}}{\eta_{rf \to beam} \eta_{wp \to rf}}$$

A. Eide,
H. Braun

$\eta_{wp \to rf}$ ~ 50% for s.c. linacs

$\eta_{rf \to beam}$ ~ 100% in cw mode
$\eta_{rf \to beam}$ ~ $T_b/(T_b+(T_{rf,ref}-T_{b,ref})I_{ref}/I\,)$ in pulsed mode

η_{ERL} ~ 90-98% with ERL option, 0 else

$$P_{total} \approx P_{cr} + P_{rf}$$

total el. power **cryo power** **rf power**

two *p* beam scenarios

	$N_{b,p}$	T_{sep}	$\varepsilon_p\gamma_p$	$\beta^*_{p,min}$
LHC phase-I upgrade “LHC”	**$1.7\text{x}10^{11}$**	**25 ns**	**3.75 μm**	**0.25 m**
LHC phase-II upgrade (“LHC*”)	**$5\text{x}10^{11}$**	**50 ns**	**3.75 μm**	**0.10 m***

* focusing one p beam

in the following consider phase-II upgrade parameters; for phase-I parameters expect ~5 times lower luminosity

(note that SPL and PS2 can deliver ~$4\text{x}10^{11}$ *p*/bunch at 25 ns spacing)

IP parameters

both beams are taken to be round;

e- beam is assumed to be matched to p beam:

$\sigma_p^* = \sigma_e^*$

luminosity:

average e- beam current (limited by available el. power, linac technology & beam dynamics)

$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta_p^*} I_e H_{hg}\left(\frac{\beta_e^*}{\sigma_{z,p}}, \frac{\varepsilon_e}{\varepsilon_p}\right)$$

H. Braun,
C. Adolphsen,
F. Z.

proton brightness
(limited by s.c. in injectors
and LHC pp beam-beam)

p β function limited by
IR layout, chromatic correction,
and also by the e- hourglass reduction factor

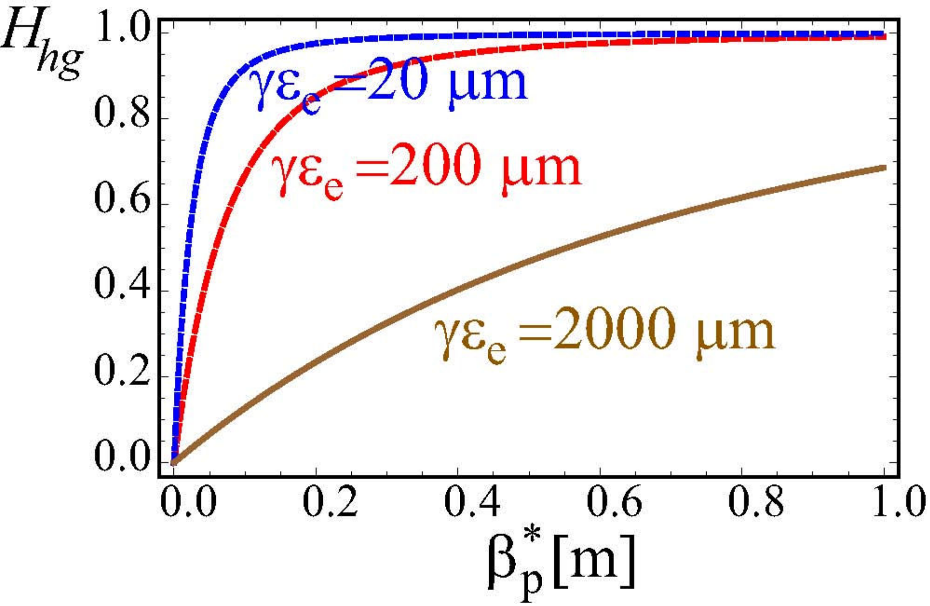
e-p hourglass factor & *p* β^* limit

$$H_{hg}(x,r) = 2\sqrt{\pi}\,\frac{xr}{\sqrt{1+r^2}}\,e^{4z^2r^2/\left(1+r^2\right)}\,\mathrm{erfc}\left(\frac{2xr}{\sqrt{1+r^2}}\right)$$

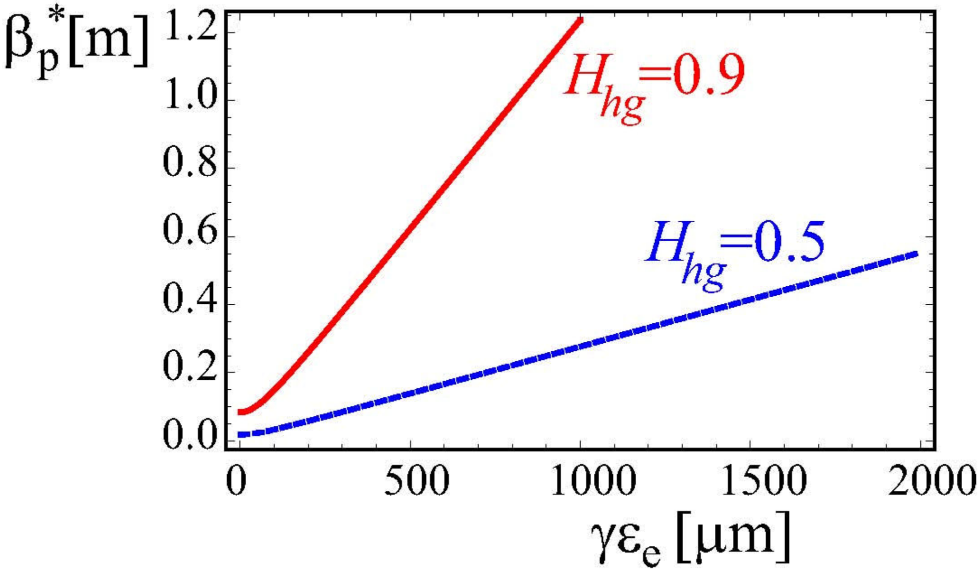
$x=\beta_e^*/\sigma_{z,p}$ $r=\varepsilon_e/\varepsilon_p$

Note: linac $\gamma_e\varepsilon_e$ ~ 10-100 μm
smallest LEP $\gamma_e\varepsilon_e$ ~2 mm at 60 GeV

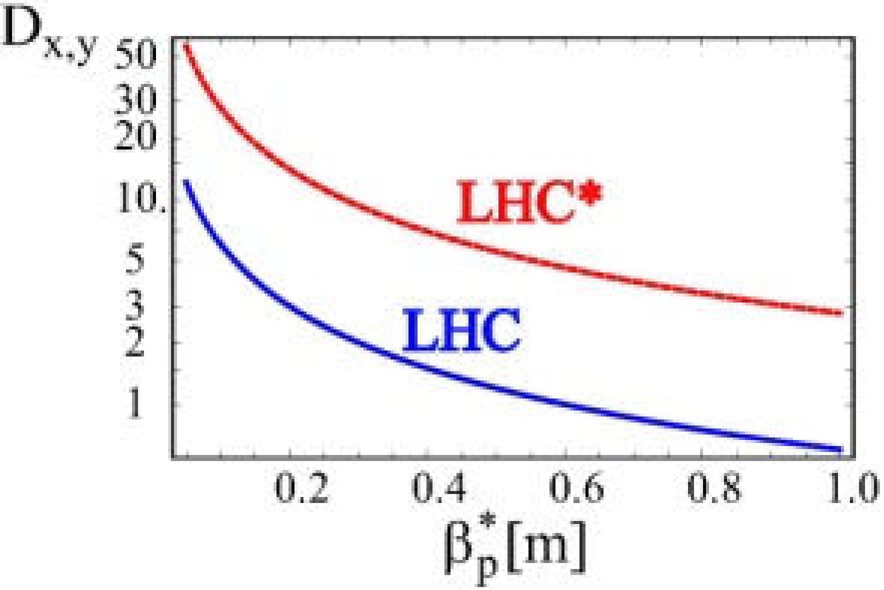
H_{hg} vs. β_p^* for three values of $\gamma_e\varepsilon_e$ assuming E=60 GeV & $\sigma_{z,p}$=7.5 cm



β^*_p vs. $\gamma_e\varepsilon_e$ for two values of H_{hg} assuming E=60 GeV & $\sigma_{z,p}$=7.5 cm



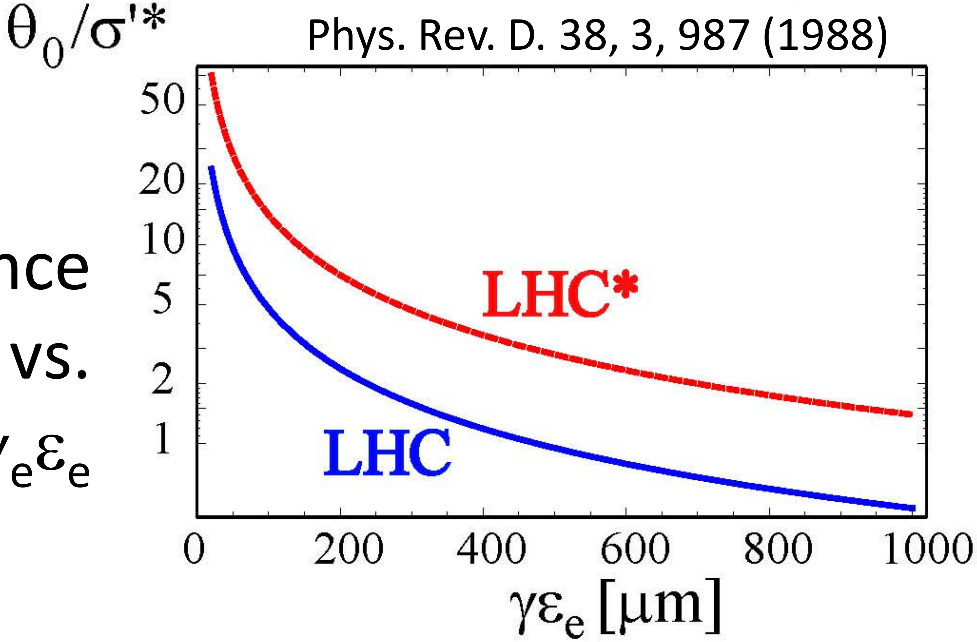
collision effect on e-



e- disruption parameter vs. β^*_p

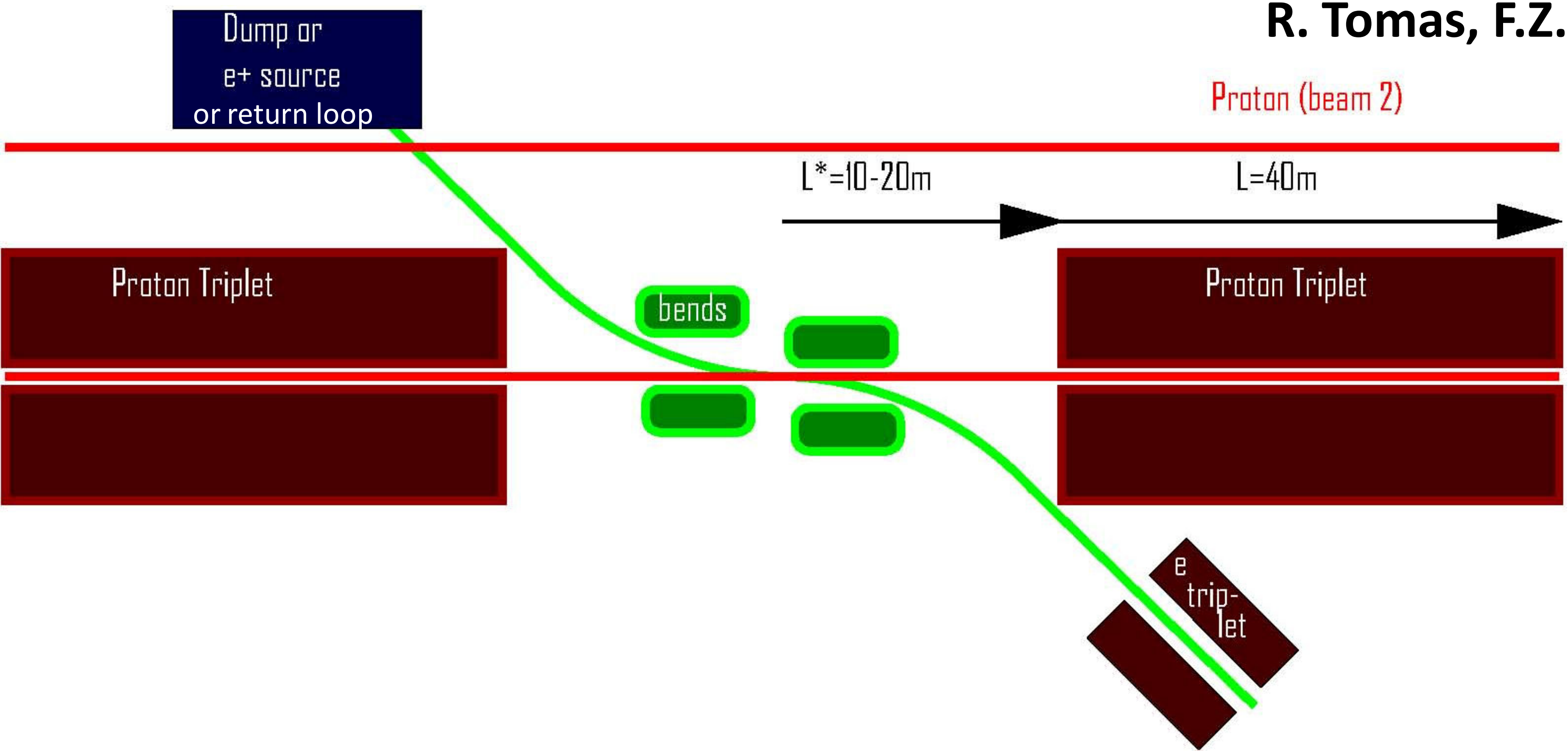
see also: P. Chen, K. Yokoya, Phys. Rev. D. 38, 3, 987 (1988)

relative rms divergence increase in collision vs. initial $\gamma_e\varepsilon_e$



interaction region (2008)

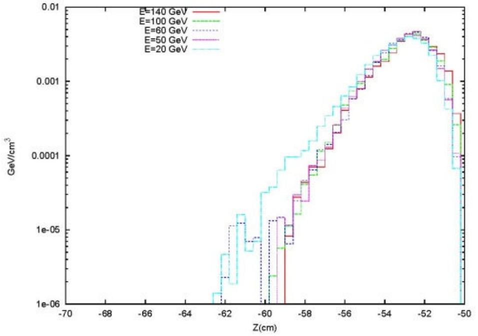
R. Tomas, F.Z.

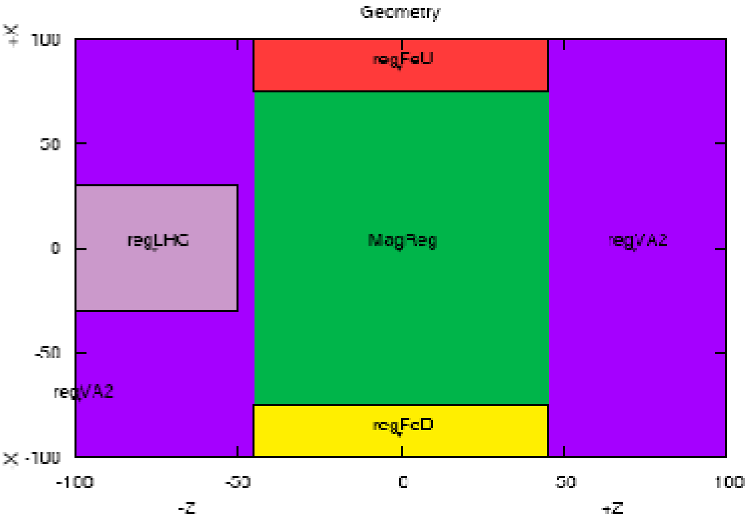


small e- emittance → relaxed β_e^* → $L_e^* > L_p^*$, can&must profit from ↓β_p^*
single pass & low e-divergence → parasitic collisions of little concern;
→ head-on e-p collision may be realized by long separation bends;
→ no crab cavity required up to 50 GeV or higher; later weak cc's

SR shielding FLUKA simulation

beam energy [GeV]	20	50	60	100	140
dipole field [T]	0.6	0.2	0.35	0.5	0.65
offset at LHC triplet [cm]	45	6	8.75	7.5	7
distance IP& p-triplet [m]	10				

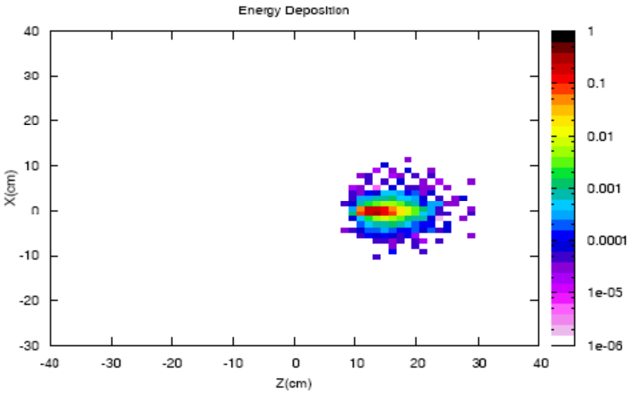




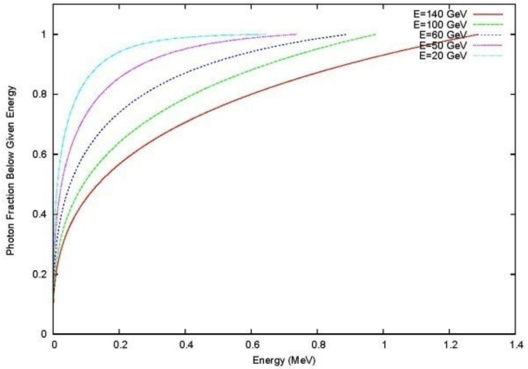
lead shielding in front of triplet

triplet

vacuum



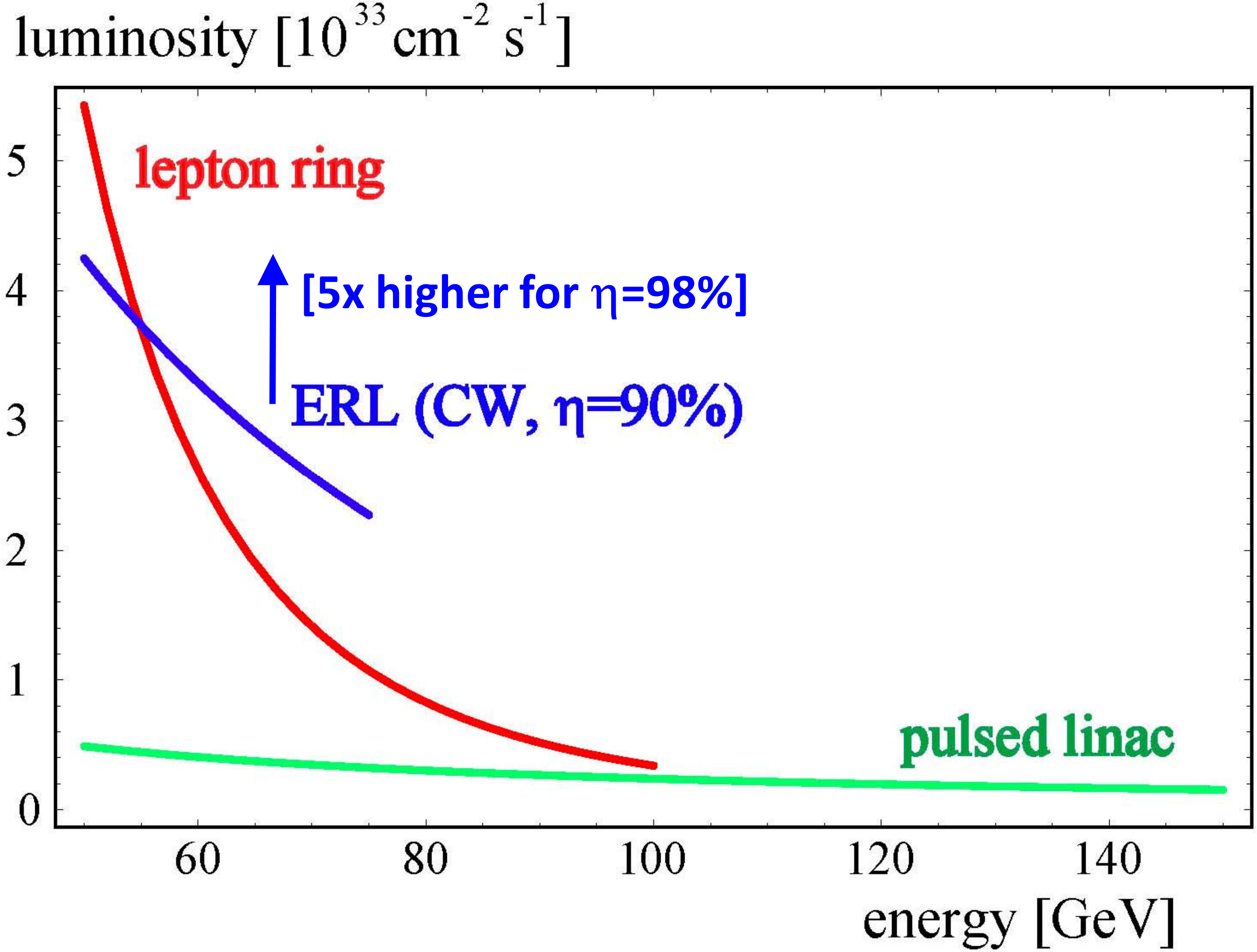
example FLUKA results [GeV/cm³]



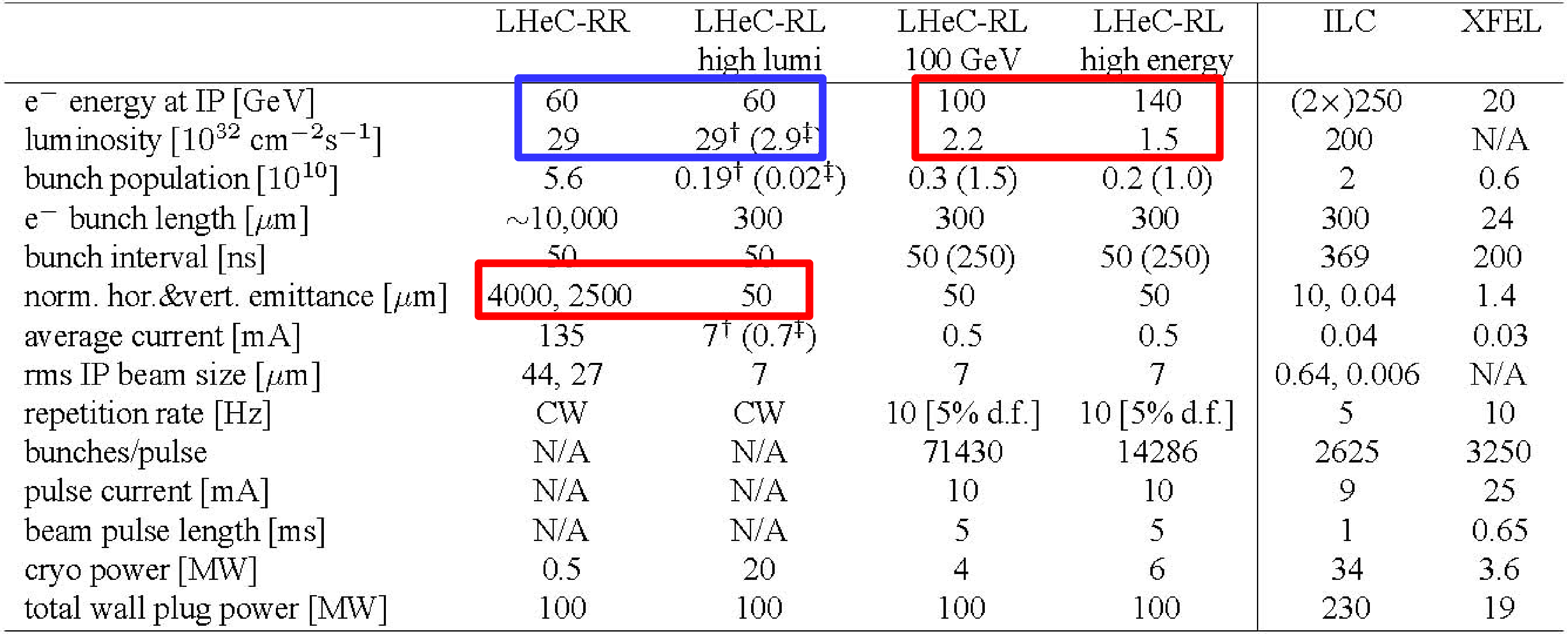
SR code (linked to FLUKA) calculates #SR photos per m, per energy bin

Husnu Aksakal, Nigde U.

LHeC luminosity



example parameters



	LHeC-RR	LHeC-RL high lumi	LHeC-RL 100 GeV	LHeC-RL high energy	ILC	XFEL
e^{-} energy at IP [GeV]	60	60	100	140	(2×)250	20
luminosity [10^{32} cm^{-2}s^{-1}]	29	$29^{\dagger}$ ($2.9^{\ddagger}$)	2.2	1.5	200	N/A
bunch population [10^{10}]	5.6	$0.19^{\dagger}$ ($0.02^{\ddagger}$)	0.3 (1.5)	0.2 (1.0)	2	0.6
e^{-} bunch length [μm]	~10,000	300	300	300	300	24
bunch interval [ns]	50	50	50 (250)	50 (250)	369	200
norm. hor.&vert. emittance [μm]	4000, 2500	50	50	50	10, 0.04	1.4
average current [mA]	135	$7^{\dagger}$ ($0.7^{\ddagger}$)	0.5	0.5	0.04	0.03
rms IP beam size [μm]	44, 27	7	7	7	0.64, 0.006	N/A
repetition rate [Hz]	CW	CW	10 [5% d.f.]	10 [5% d.f.]	5	10
bunches/pulse	N/A	N/A	71430	14286	2625	3250
pulse current [mA]	N/A	N/A	10	10	9	25
beam pulse length [ms]	N/A	N/A	5	5	1	0.65
cryo power [MW]	0.5	20	4	6	34	3.6
total wall plug power [MW]	100	100	100	100	230	19

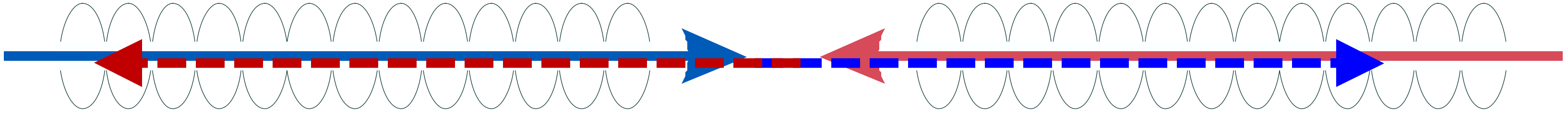
Example LHeC-RR and RL parameters. Numbers for LHeC-RL high-luminosity option marked by `†' assume energy recovery with $\eta_{ER}$=90%; those with `‡' refer to η_{ER}=0%. ILC and XFEL numbers are included for comparison. Note that optimization of the RR luminosity for different LHC beam assumptions leads to similar luminosity values of about 10^{33}cm^{-2}s^{-1}

energy recovery - examples

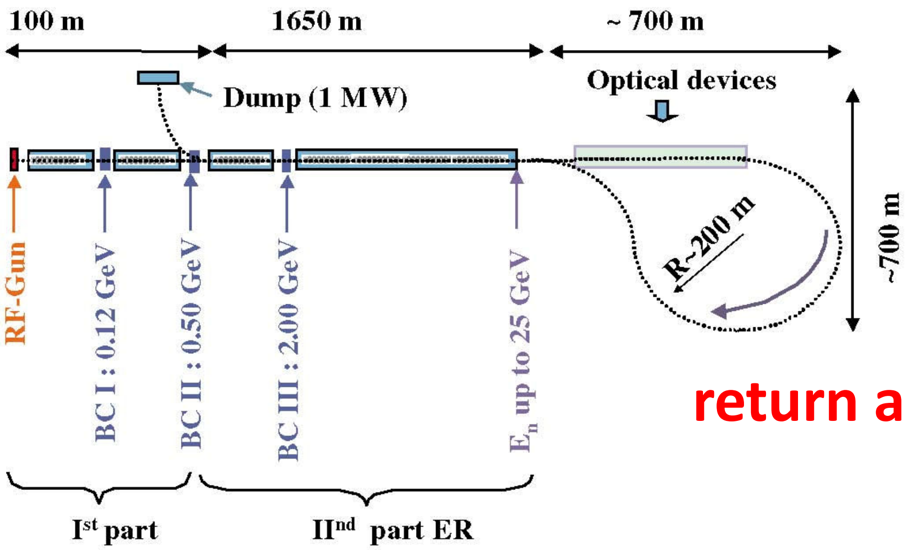
Jlab: **recirculating linac**, 99.5% of energy recovered at 150 MeV and 10 mA, ~98% recovery at 1 GeV and 100 μA with beam swung between 20 MeV to 1 GeV, plans for multi-GeV linacs withcurrents of ~100 mA

S. Chattopadhyay

M. Tigner, "A possible apparatus for electron clashing-beam experiments," Nuovo Cim.37:1228-1231 (1965).

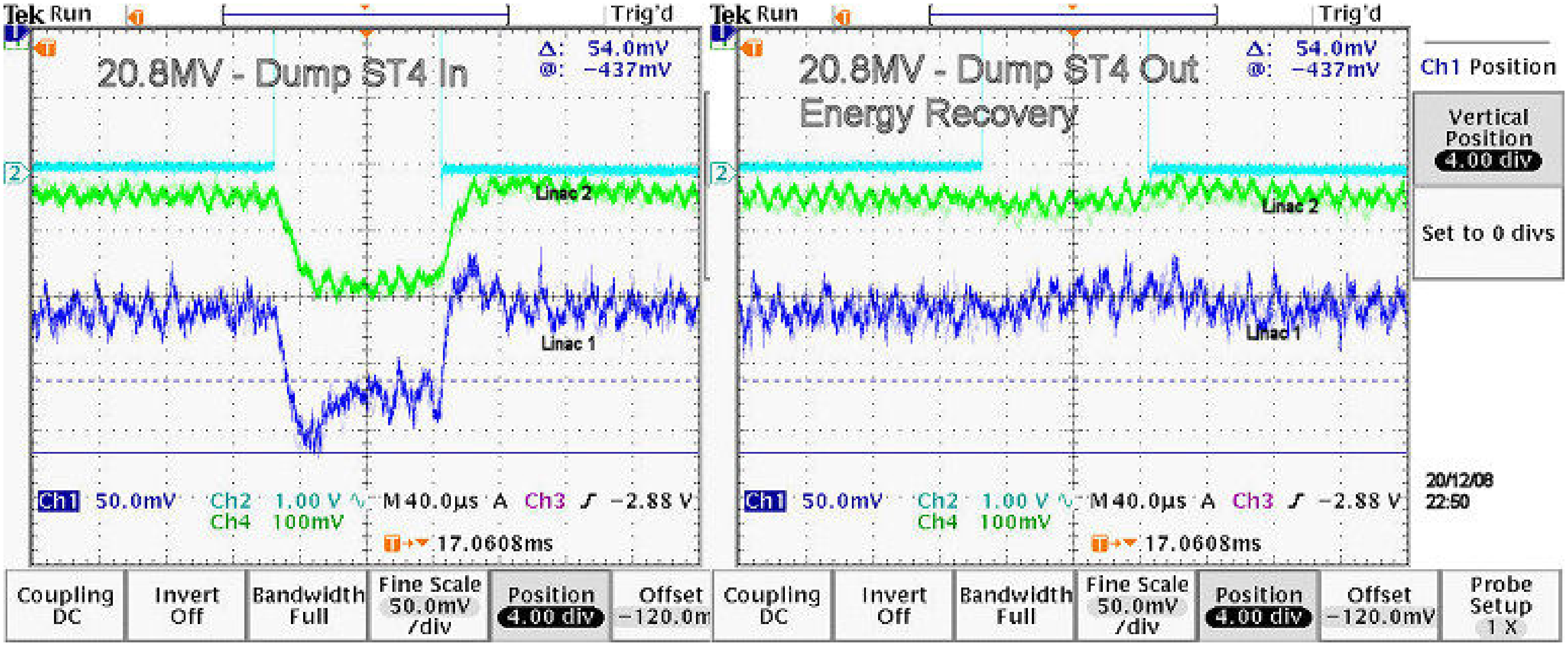


J. Sekutowicz et al, "Proposed continuous wave energy recovery operation of an XFEL," Phys.Rev.ST Accel.Beams 8:010701,2005, up to 98% efficient



return arc

energy recovery in UK’s ALICE



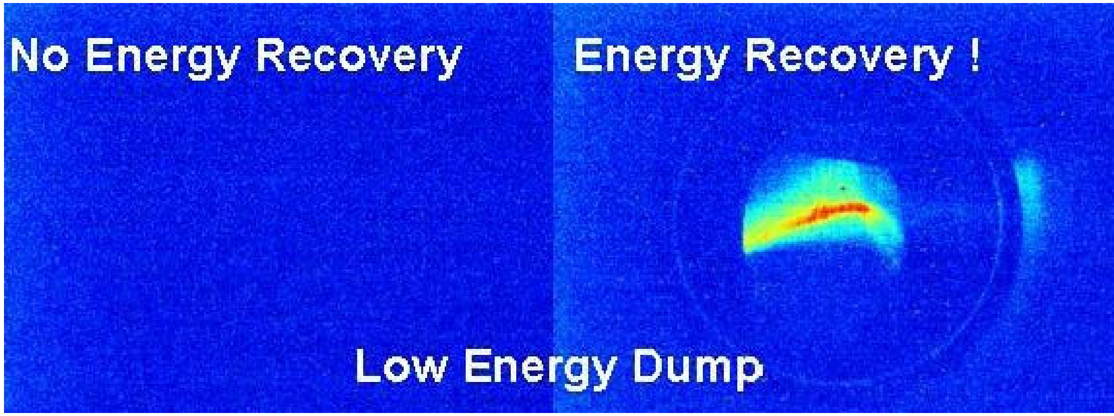
Δ: 54.0mV
@: −437mV

Ch1 50.0mV Ch2 1.00 V M 40.0µs A Ch3 ƒ −2.88 V
Ch4 100mV
17.0608ms

Vertical Position 4.00 div

Coupling DC | Invert Off | Bandwidth Full | Fine Scale 50.0mV /div | Position 4.00 div | Offset −120.0mV | Probe Setup 1 X

ALICE tuned for transport of 20.8 MeV beam, 20 Dec. ’08. Green and dark blue traces show reduction to "zero" in RF demand on both linac cavities when beam is decelerated.



e+ for R-L LHeC

a challenge: **10x more e$^+$ than ILC!**

large # bunches → damping ring difficult

candidate e$^+$ sources under study (*POSIPOL* coll.):

- **spent e- beam impacting on target**
- **crystal hybrid target source**
- **ERL Compton** source for CW operation
  e.g. 100 mA ERL w. 10 optical cavities
- **undulator source using spent e- beam**
- **linac-Compton** source for pulsed operation

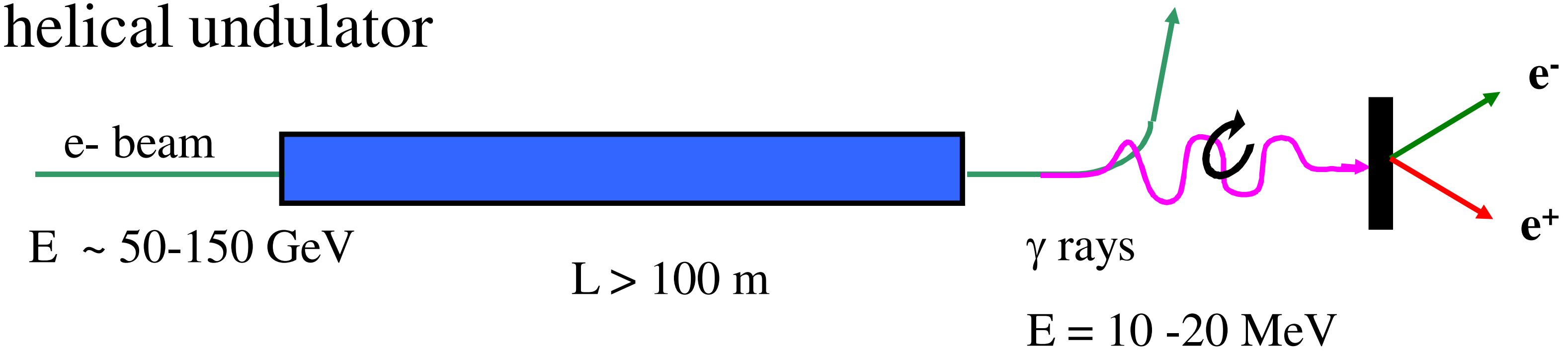
complementary options: collimate to shrink emittance, [extremely fast damping in laser cooling ring?,] **recycle e+ together with recovering their energy?**

T. Omori,
L Rinolfi,
J. Urakawa
et al

talk by Louis Rinolfi tomorrow

some e+ source options

1) helical undulator



e- beam

E ~ 50-150 GeV

L > 100 m

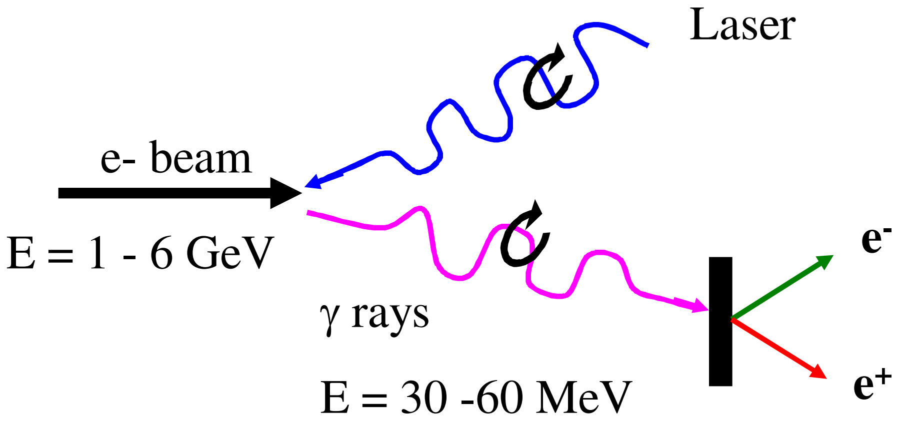
γ rays

E = 10 -20 MeV

e^-

e^+

2) Compton with laser



Laser

e- beam

E = 1 - 6 GeV

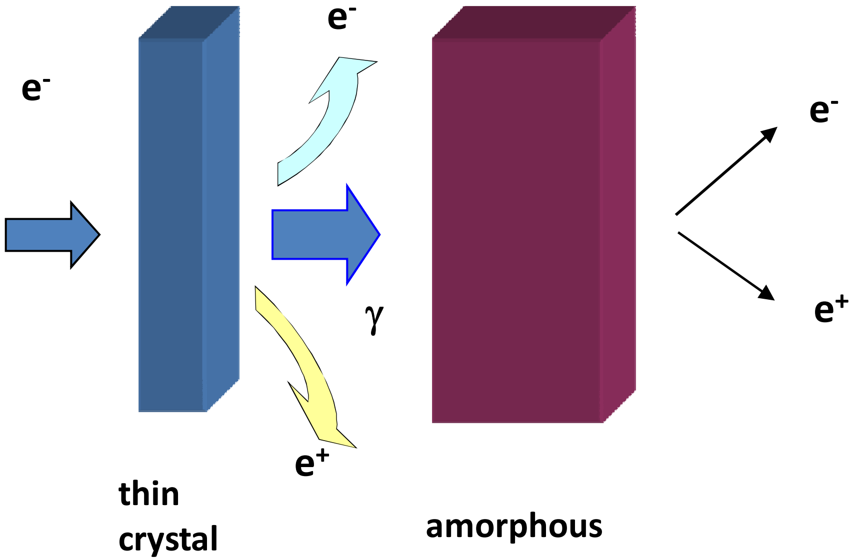
γ rays

E = 30 -60 MeV

e^-

e^+

3) hybrid target (unpolarized)



e^-

e^-

γ

e^+

thin
crystal

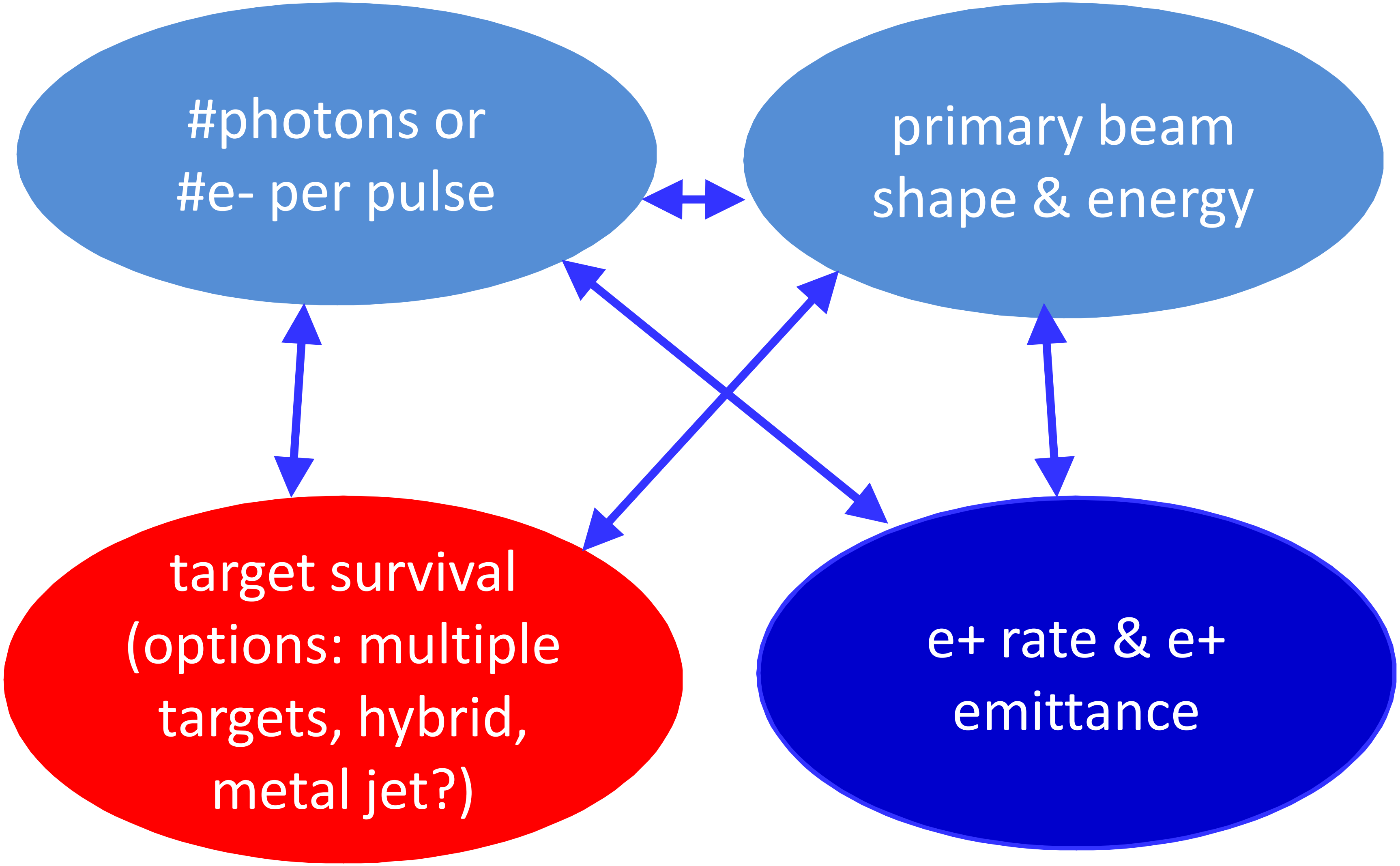
amorphous

e^-

e^+

Louis Rinolfi

e+ source trade offs



#photons or
#e- per pulse

primary beam
shape & energy

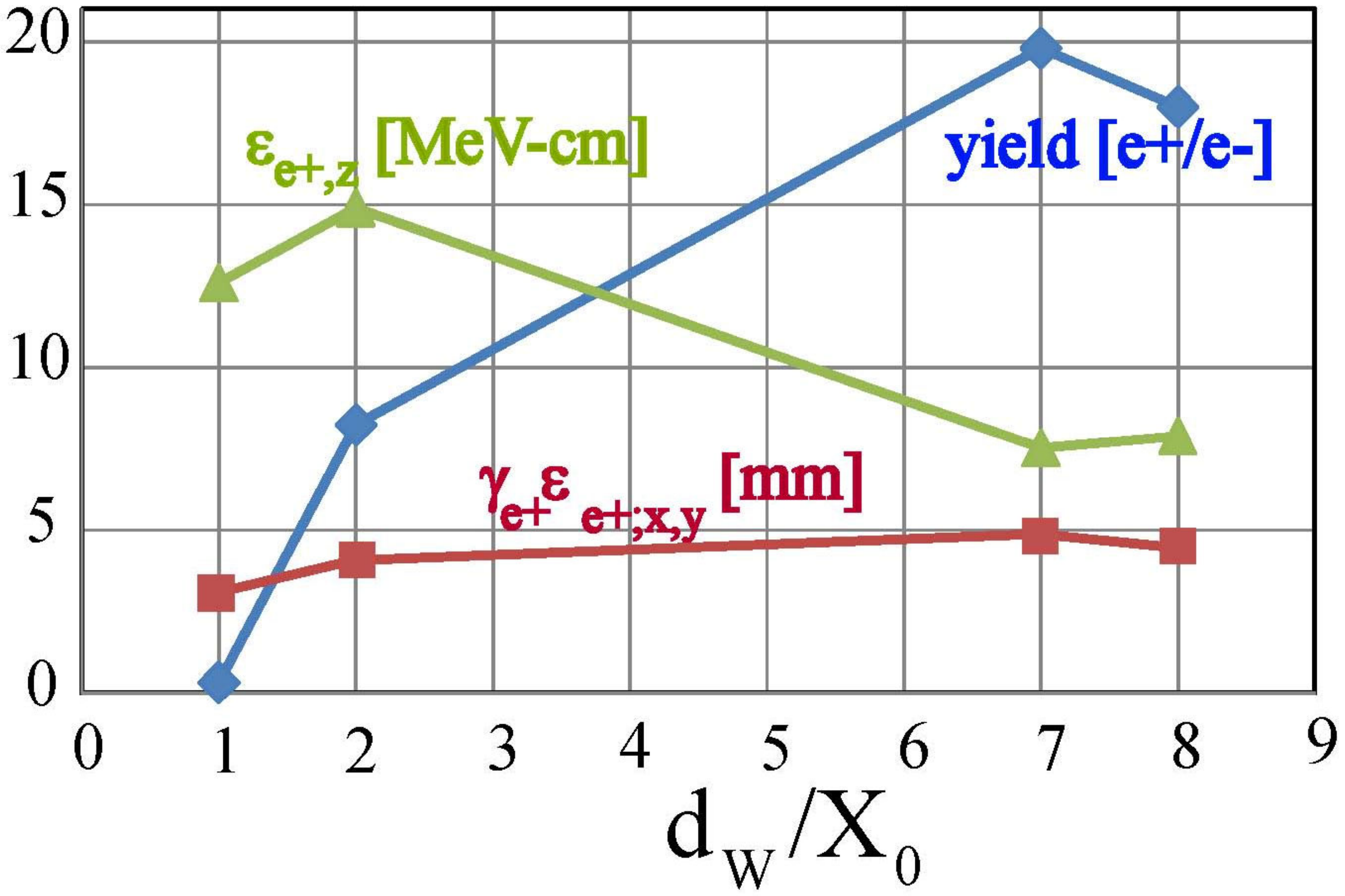
target survival
(options: multiple
targets, hybrid,
metal jet?)

e+ rate & e+
emittance

early L-R e+ source studies

- ✓simulation of e+ production for 60 GeV e-beam hitting target
  (Alessandro Vivoli) – *next slide*
- ✓Compton target heating limits (Alessandro Vivoli)
  - *next next slide*
- ✓Linac Compton source parameters & LHeC optimization
  (Igor Pogorelsky, Vitaly Yakimenko) – *following four slides*
- ✓Compton ERL or Compton ring (Louis Rinolfi)
  talk tomorrow
- ✓spent beam undulator option (Louis Rinolfi)
  talk tomorrow, and one slide
- ✓hybrid target option (Louis Rinolfi) – *talk tomorrow*

e+ from 60-GeV e- on target



Alessandro Vivoli, June 2008

high yield; collimation could yield desired #e+ and sub-mm normalized emittance

simulated e+ yield for amorphous W target of varying thickness hit by a 60-GeV e- beam [$\gamma_e\varepsilon_e$ =20μm, $\sigma_{x,y,e}$=20 μm, β=10 m]

Compton-source target limit

Peak Energy Deposition Density <35 J/g per pulse (W target survival);

each photon (E~27.7 MeV) deposits ~ 2.2×10^{-13} J/g

→ **limit of 1.6e14 photons per pulse** on target;
e+/gamma yield ~ 2%
→ **maximum 3×10^{12} e+ per "pulse"**

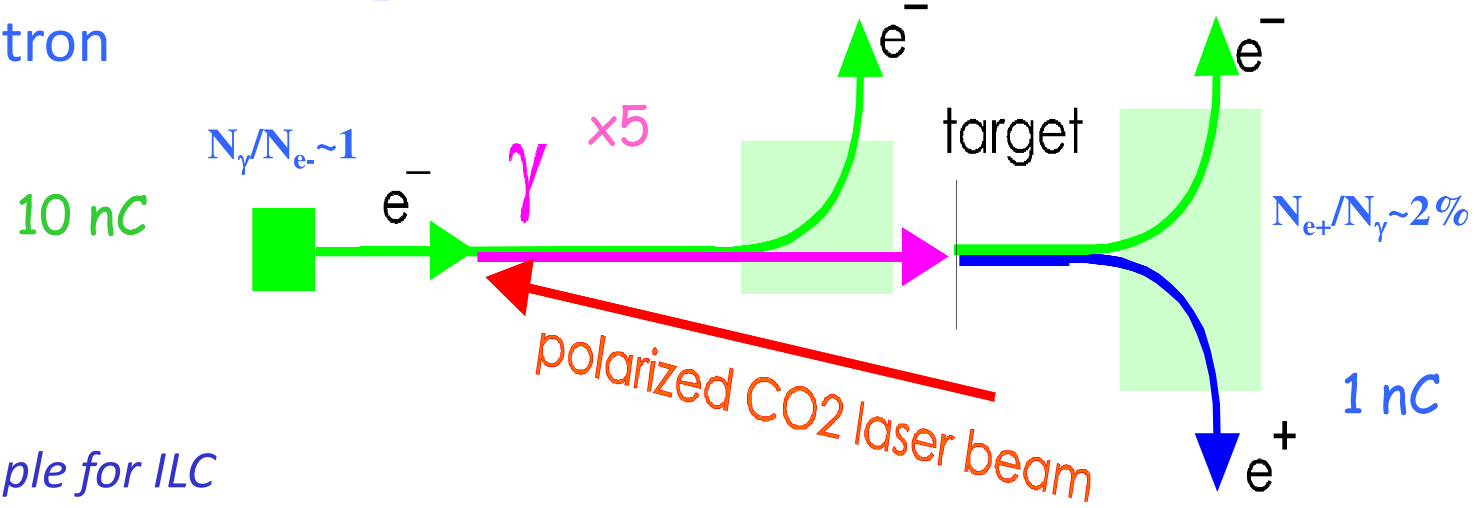
normalized transverse emittance of ILC captured e+ ~6500 micron;
yield proportional to emittance, so that limit =
e.g. 3×10^{9} e+/pulse with $\gamma\varepsilon_{x,y}$=200 μm (***pulse~1 μs***)

Compton e+ source might need stacking or recycling

talk by Louis Rinolfi tomorrow

ILC/CLIC linac Compton source

- ILC and CLIC: order 1 nC charge per e+ bunch.
- Conversion efficiency of polarized γ-photons into polarized e+ about 2%, optimized for 60% polarization. Every e+ requires 50 γ-photons assembled in the same format (bunch length and repetition rate) as collider beams.
- Proposal to accumulate this γ-flux via Compton scattering at several consecutive IPs. In each IP, a 4.75-GeV *e*-beam undergoes a head-on collision with a CO_2-laser pulse that produces one γ-photon per electron



example for ILC

Igor Pogorelsky

linac Compton source linac

e- beam energy	4.75 GeV
e- bunch charge	10 (5) nC
RMS bunch length (laser & e^- beams)	3-5 ps
γ beam peak energy	40 MeV
Number of laser IPs	5 (10)
Total $N\gamma/Ne^-$ yield (in all IPs)	5 (10)
$Ne^+/N\gamma$ capture (@60% polarized)	2%
Ne^+/Ne^- yield	0.1 (0.2)
Total e^+ yield (@60% polarized)	1nC
# of stacking	No stacking

example for ILC

Igor Pogorelsky

ILC/CLIC CO_2 laser parameters

Normalized vector potential	a_0	0.5
Focus size	$2\sigma_L = w_0$	70 μm
Rayleigh length	R_L	1.5 mm
Pulse length	τ_L	5 ps
Pulse energy	E_L	1 J
γ-ray production efficiency	N_γ / N_e	~1

example for ILC

Igor Pogorelsky

LHeC linac Compton source

- **multiple targets/capture (3-5) operating in parallel** needed
- ~30-50 γ's for 1 e+; ~10 γ's per e- (10% of the e-beam power converted to gammas in 10 laser IPs)
- **5 GeV pulsed drive linac with ~ 5-10 nC e- bunches** and 5 times average e+ current [main cost]
- **focus e- and γ beam at target** (not at the Compton IP); e-beam area will be ~4 times at Compton IP, compensated by ~4 times higher circulated laser energy (no showstopper)
- resulting normalized emittance $\varepsilon_N \sim \sigma_{\theta,e+}\,\sigma_{\gamma beam}\,\gamma_{e+}$ where $\sigma_{\theta,e+} \sim 14\ \mathrm{MeV}/E_{e+}\ \mathrm{sqrt}(L_{target}/X_0) \sim 20/\gamma_{e+}$
- **need $\sigma_{\gamma beam}$ <5 μm on target;** easy for 5 GeV e- beam
- **radiation damage** of target material; liquid mercury jet?

V. Yakimenko

undulator e+ source

- using “spent” e- beam of 50-150 GeV energy
- this might produce more photons & small emittance more easily
- option not yet explored, but can learn from CLIC studies (Argonne contribution)
- hoping for help from CI colleagues

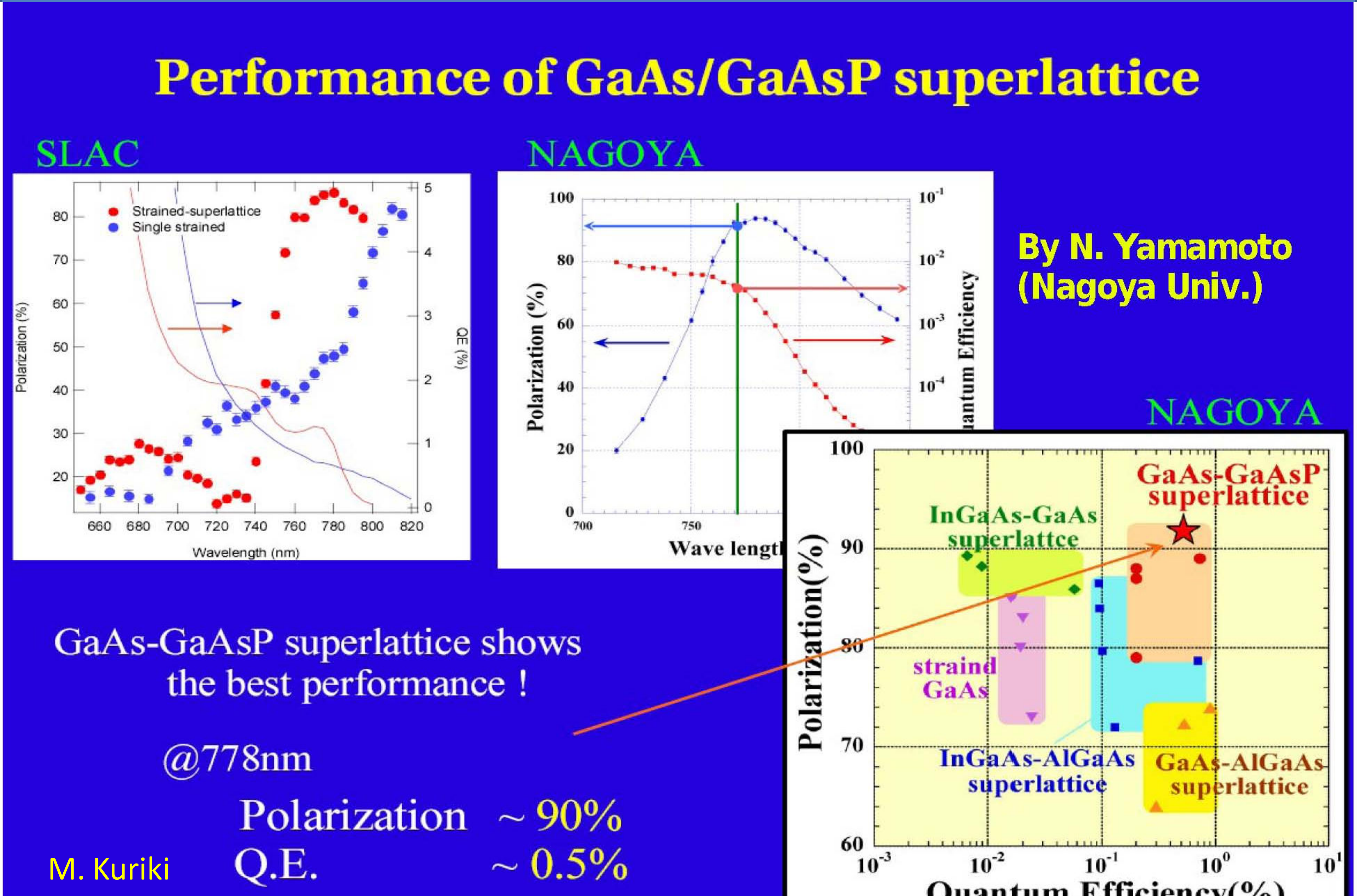
talk by Louis Rinolfi tomorrow

polarized beams

e- : from polarized dc gun
with ~90% polarization,
10-100 μm normalized emittance

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

polarized photo-cathode (e-)



Performance of GaAs/GaAsP superlattice

SLAC

NAGOYA

By N. Yamamoto (Nagoya Univ.)

NAGOYA

GaAs-GaAsP superlattice shows the best performance !

@778nm

Polarization ~ 90%

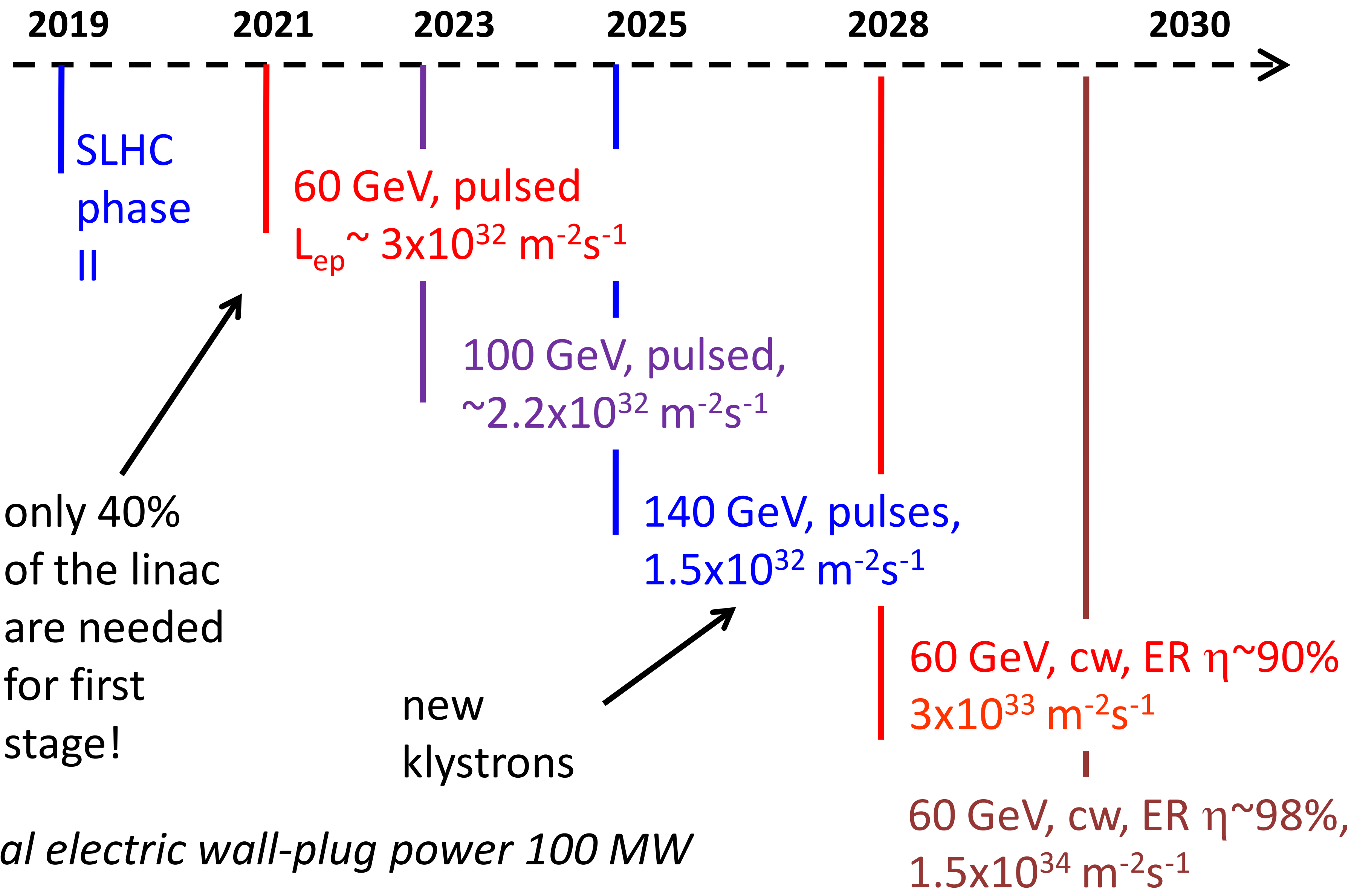
Q.E. ~ 0.5%

M. Kuriki

R-L LHeC physics merits

- no interruption of LHC pp physics program
- ep collisions at much higher energy & luminosity than HERA
- e- beam energy can be increased in stages, w/o any fundamental limit
- possibility of 90% e- and 60% e+ polarization
- potential for large detector acceptance
- additional possibility of γ-p or γ-N collisions via laser Compton back-scattering (this mode is incompatible with energy recovery)

one staged schedule – *E* first



2019

2021

2023

2025

2028

2030

SLHC phase II

60 GeV, pulsed
L_{ep}~ $3\text{x}10^{32}$ $m^{-2}s^{-1}$

100 GeV, pulsed,
~$2.2\text{x}10^{32}$ $m^{-2}s^{-1}$

140 GeV, pulses,
$1.5\text{x}10^{32}$ $m^{-2}s^{-1}$

60 GeV, cw, ER η~90%
$3\text{x}10^{33}$ $m^{-2}s^{-1}$

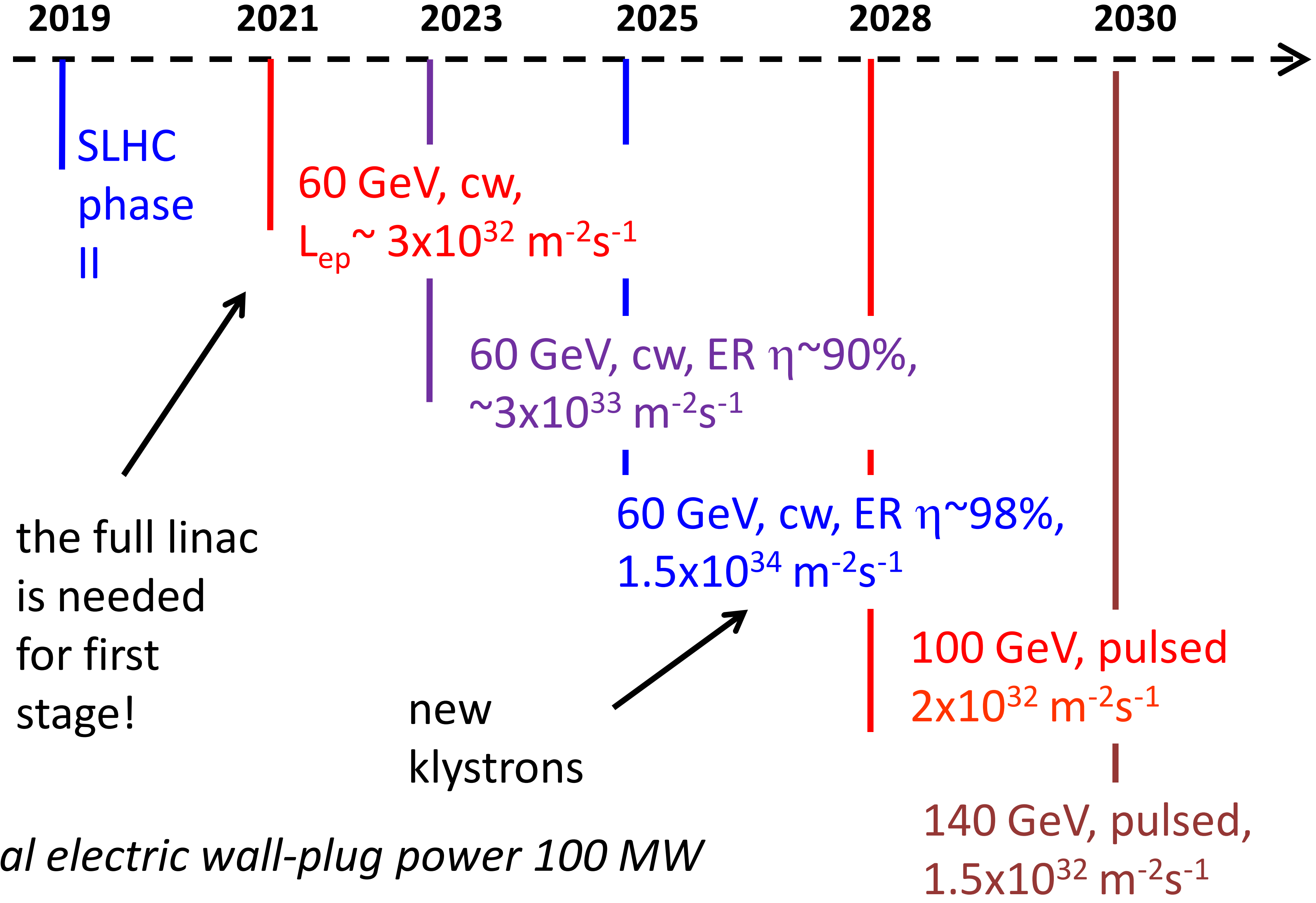
60 GeV, cw, ER η~98%,
$1.5\text{x}10^{34}$ $m^{-2}s^{-1}$

only 40% of the linac are needed for first stage!

new klystrons

total electric wall-plug power 100 MW

2nd staged schedule – *L* first



2019 2021 2023 2025 2028 2030

SLHC
phase
II

60 GeV, cw,
L_{ep}~ 3x10^{32} m^{-2}s^{-1}

60 GeV, cw, ER η~90%,
~3x10^{33} m^{-2}s^{-1}

60 GeV, cw, ER η~98%,
1.5x10^{34} m^{-2}s^{-1}

100 GeV, pulsed
2x10^{32} m^{-2}s^{-1}

140 GeV, pulsed,
1.5x10^{32} m^{-2}s^{-1}

the full linac
is needed
for first
stage!

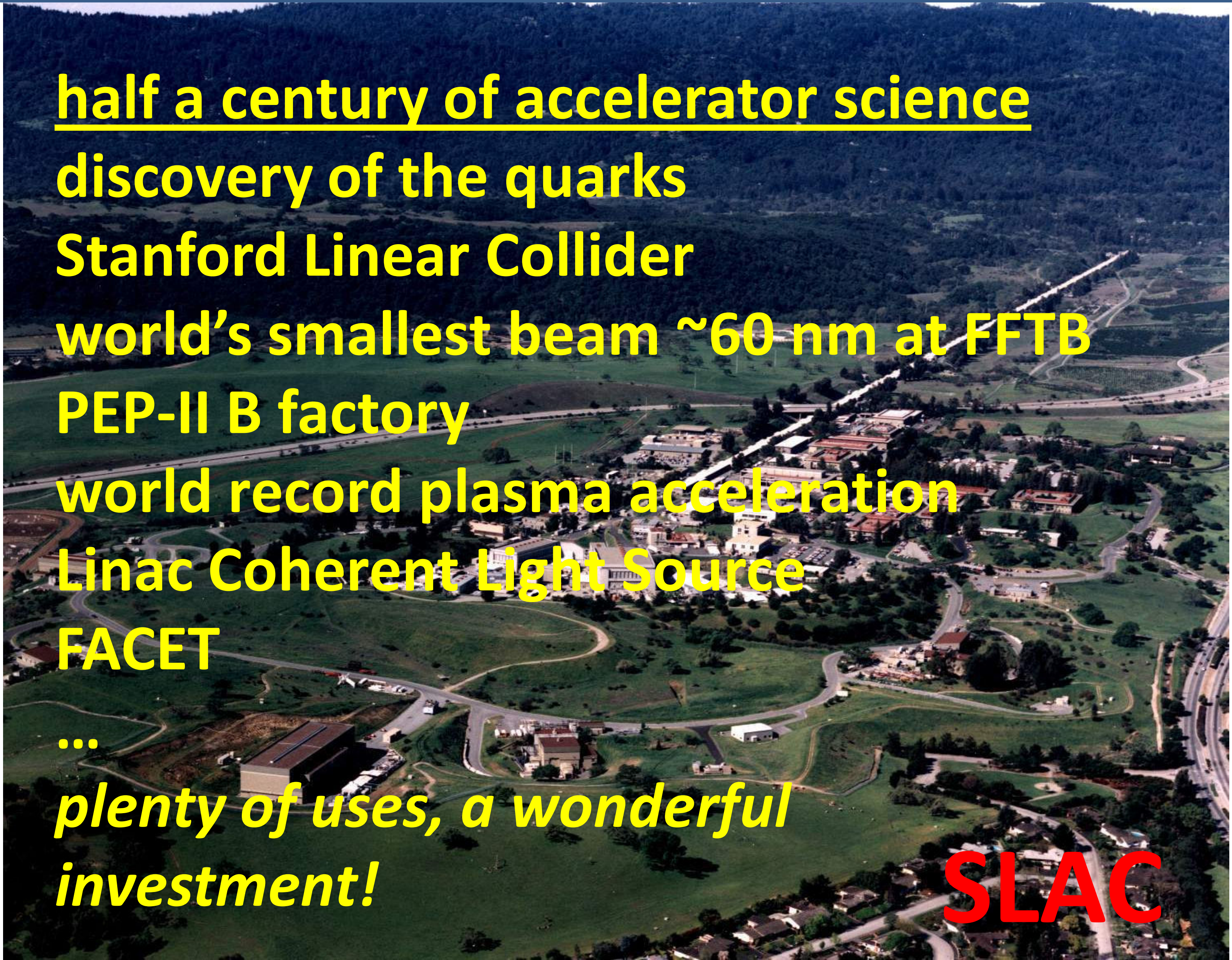
new
klystrons

total electric wall-plug power 100 MW

R-L LHeC accelerator merits

- tunnel construction fully separate from LHC
- low e- emittance allows profiting from smaller β_p^* to boost luminosity; reduced SR from quad's
- energy recovery could raise luminosity 10-50 times
- possibility of simplified IR optics & layout (e- triplet far away, head-on collision, no or weak crab cavities)
- possibility of staged construction & exploitation
- not limited by hourglass or e- beam-beam effects
- 700-MHz SRF synergies with SPL, BNL, ESS
- enabling technology; numerous future linac uses (LC, *p* beams, …); a great investment for CERN

3-km linac built 1962-66



half a century of accelerator science

discovery of the quarks

Stanford Linear Collider

world's smallest beam ~60 nm at FFTB

PEP-II B factory

world record plasma acceleration

Linac Coherent Light Source

FACET

…

plenty of uses, a wonderful investment!

SLAC

conclusions

- peak luminosity up to ~2-3x10^{32} cm^{-2}s^{-1} from 50-150 GeV RLA, limited by el. power (100 MW)
- polarized beams (90% e-, ~60% e+)
- energy recovery can boost the luminosity at 50-70 GeV by a factor 10-50, above 10^{34} cm^{-2}s^{-1}
- construction cost ~1.5-2 ± billion euro for 140 GeV
- construction and operation naturally staged
- e+ production technically possible, but expensive
- primary issues to be further looked at:
    - choice&optimization of e+ generation scheme
    - IR layout, lattice optimization, site layout
- other issues: R-L collisions, energy recovery

related talks at this workshop

Vladimir Litvinenko: e-RHIC
Kenan Ciftcy/Saleh Sultansoy : gamma nucleon collider
Rogelio Tomas: IR design for the linac ring option
Christoph Montag: eRHIC IR design
Rob Appleby: Cockcroft contributions (1 degree option)
Stefan Russenschuck: open sc magnets
John Jowett: ion luminosity
Vladimir Litvinenko: recirculating linacs
Yipeng Sun: emittance growth in recirulating linacs
Louis Rinolfi: e+ / e- sources
Vitaly Yakimenko : linac-Compton sources
Chris Adolphsen: recirculating linacs
Mohammad Eshraqi : SPL as recirculating linac for e+/e-

your help is welcome!

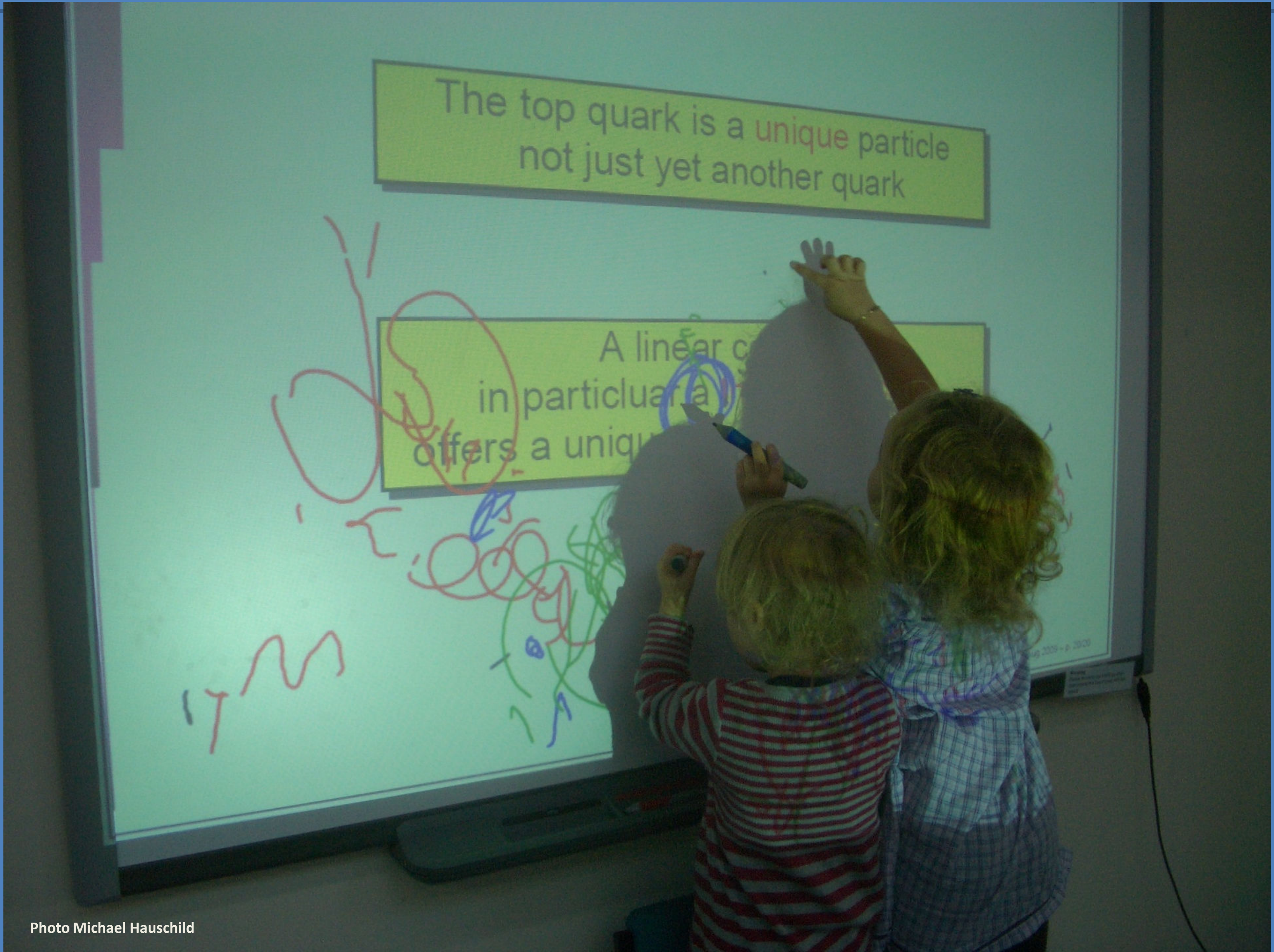


Photo Michael Hauschild