TLEP

Parameters for e^+e^- circular collider in a 80 km tunnel

Marco Zanetti (MIT)

TLEP

Outline

- Introduction, the physics case
- Beamstrahlung
- Top-up injection
- Synchrotron radiation
- Polarization
- Integration with the experiments
- Summary

TLEP

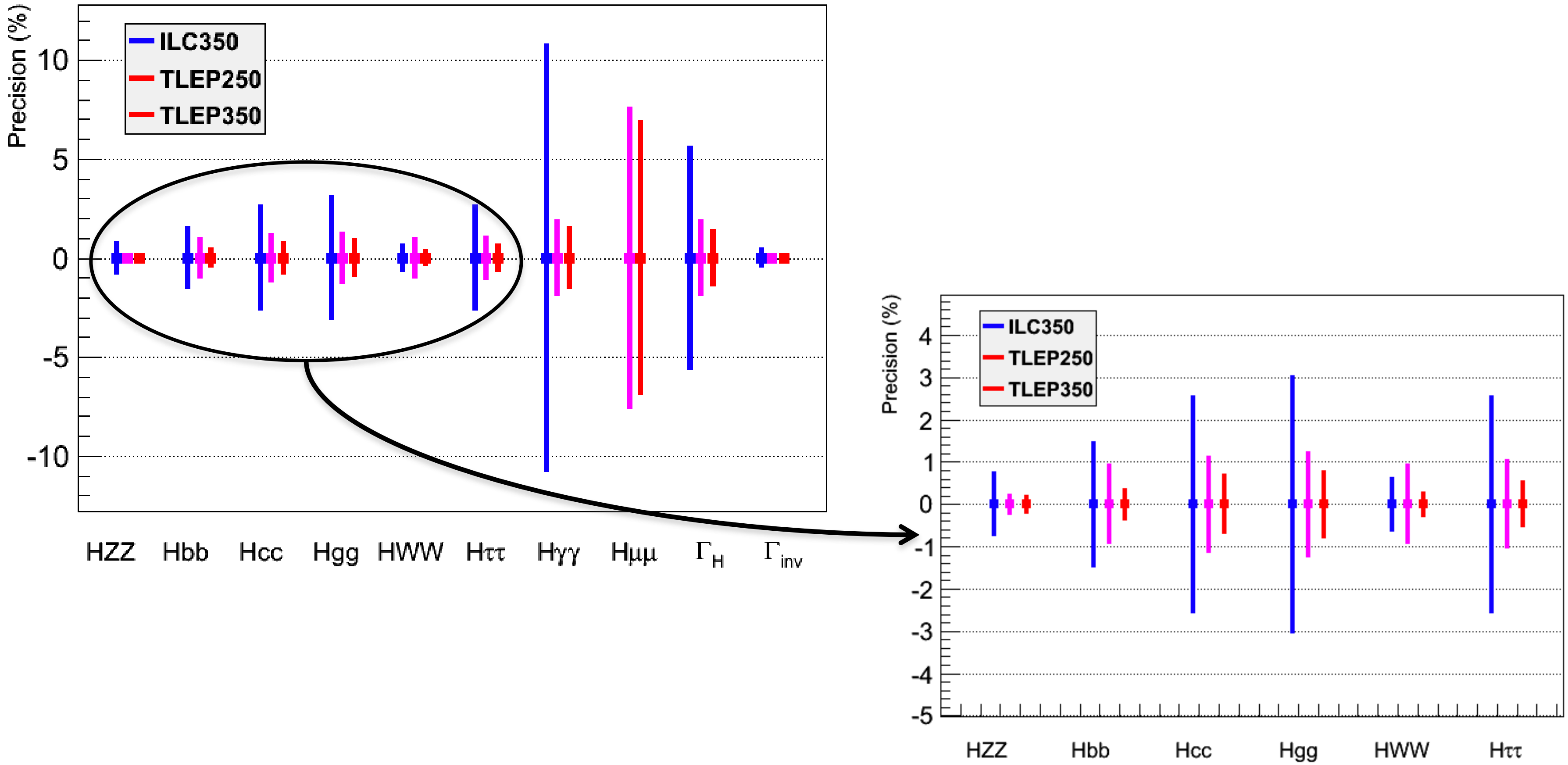
TLEP overview

- Get up to $\sqrt{s}$=350, top-antitop production, L=0.7x10^{34} $cm^{-2}s^{-1}$
- Higgs factory at Z+H threshold $\sqrt{s}$=250, L=5x10^{34} $cm^{-2}s^{-1}$
- GigaZ, L=10^{36} $cm^{-2}s^{-1}$, repeat LEP1 program in 5 min
- Possibility for several interaction points => multiply L, experimental redundancy
- Challenging but well established technology
- Cost-wise in the shadow of the proton-proton program

TLEP

Physics performances: Higgs

- Sub percent precision on the Higgs couplings
- Total width accessible via both ZZ decay and VBF production



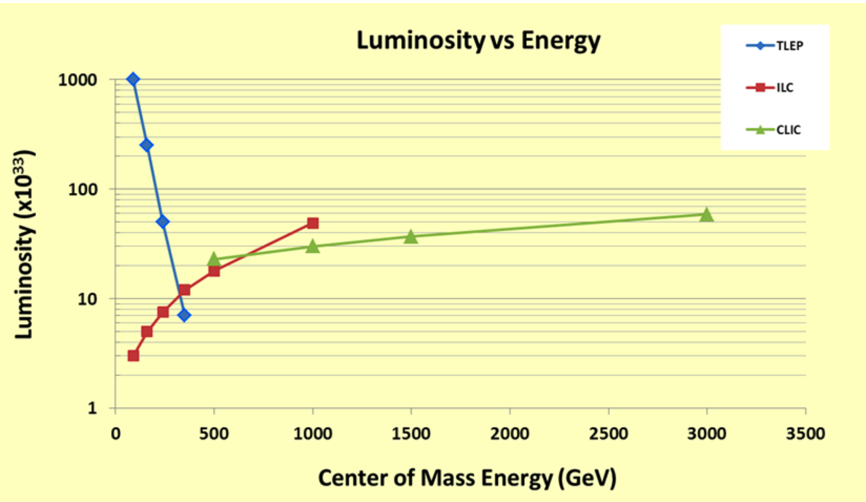
TLEP

Physics performances: Higgs

Accelerator → Physical Quantity ↓	**LHC** 300 fb^{-1} /expt	**HL-LHC** 3000 fb^{-1} /expt	**ILC** 250 GeV 250 fb^{-1} 5 yrs	**Full ILC** 250+350+ 1000 GeV 5yrs each	**CLIC** 350 GeV (500 fb^{-1}) 500 GeV (500 fb^{-1}) 1.4 TeV (2 ab^{-1}) 5 yrs each	**LEP3, 4 IP** 240 GeV 2 ab^{-1} (*) 5 yrs	**TLEP, 4 IP** 240 GeV 10 ab^{-1} 5 yrs (*) 350 GeV 1.4 ab^{-1} 3 yrs (*)
N_H	1.7×10^7	1.7×10^8	6×10^4 ZH	10^5 ZH 1.4×10^5 Hνν		4×10^5 ZH	2×10^6 ZH
m_H (MeV)	100	50	35	35	~70	26	7
$\Delta\Gamma_H / \Gamma_H$	--	--	10%	3%	6%	4%	1.3%
$\Delta\Gamma_{inv} / \Gamma_H$	Indirect (30%?)	Indirect (10% ?)	1.5%	1.0%	--	0.35%	0.15%
$\Delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$	6.5 – 5.1%	5.4 – 1.5%	--	5%	N/A	3.4%	1.4%
$\Delta g_{Hgg} / g_{Hgg}$	11 – 5.7%	7.5 – 2.7%	4.5%	2.5%	N/A	2.2%	0.7%
$\Delta g_{Hww} / g_{Hww}$	5.7 – 2.7%	4.5 – 1.0%	4.3%	1%	1%	1.5%	0.25%
$\Delta g_{HZZ} / g_{HZZ}$	5.7 – 2.7%	4.5 – 1.0%	1.3%	1.5%	1%	0.65%	0.2%
$\Delta g_{HHH} / g_{HHH}$	--	< 30% (2 expts)	--	~30%	~20%	--	--
$\Delta g_{H\mu\mu} / g_{H\mu\mu}$	< 30%	< 10%	--	--	15%	14%	7%
$\Delta g_{H\tau\tau} / g_{H\tau\tau}$	8.5 – 5.1%	5.4 – 2.0%	3.5%	2.5%	3%	1.5%	0.4%
$\Delta g_{Hcc} / g_{Hcc}$	--	--	3.7%	2%	4%	2.0%	0.65%
$\Delta g_{Hbb} / g_{Hbb}$	15 – 6.9%	11 —2.7%	1.4%	1%	2%	0.7%	0.22%
$\Delta g_{Htt} / g_{Htt}$	14 – 8.7%	8.0 – 3.9%	--	15%	3%	--	30%

Physics performances: low √s

- Unprecedented precision on EW observables:
  - $\sigma(m_W)$~0.2 MeV, predict top mass at 100 MeV
- Probe the loop structure, ultimate closure test of SM
- Beam energy assessed by means of resonant depolarization
  - Dedicate one bunch during physics operation, no extrapolation needed

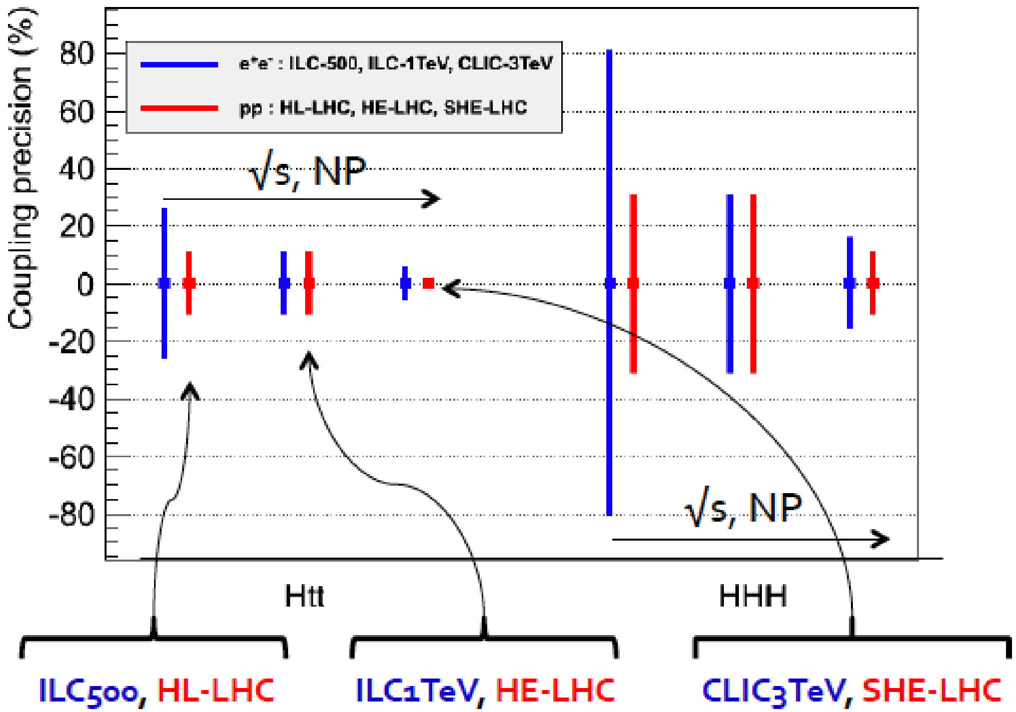


	LEP	ILC	LEP3	TLEP
$\sqrt{s} \sim m_Z$	MegaZ	GigaZ	~TeraZ	TeraZ
Lumi ($cm^{-2}s^{-1}$) #Z / IP / year Polarization vs LEP1	Few 10^{31} $2x10^7$ no 1	Few 10^{33} Few 10^9 easy ~5-10	Few 10^{35} Few 10^{11} maybe ~50	10^{36} 10^{12} maybe ~100
$\sqrt{s} \sim 2m_W$				
Lumi ($cm^{-2}s^{-1}$) Lumi / IP / year Error on m_W	Few 10^{31} 10 pb^{-1} 220 MeV	Few 10^{33} 50 fb^{-1} 7 MeV	$5x10^{34}$ 500 fb^{-1} 0.7 MeV	$2.5x10^{35}$ 2.5 ab^{-1} 0.4 MeV
$\sqrt{s}$ ~ 200-250 GeV				
Lumi ($cm^{-2}s^{-1}$) Lumi / IP / 5 years Error on m_W	10^{32} 500 pb^{-1} 33 MeV	$5x10^{33}$ 250 fb^{-1} 3 MeV	10^{34} 500 fb^{-1} 1 MeV	$5x10^{34}$ 2.5 ab^{-1} 0.4 MeV

TLEP

Upgradeability to higher √s

- People contest the non-upgradeability in √s of a circular e-e+ collider.
- Can a liner collider be upgraded to O(100) pp collider??
- No doubts about the superiority of VLHC+TLEP in terms of physics program.



TLEP

Parameters

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e-/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [μm]	270	30	71	78	43	63
σ^*_y [μm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.67	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

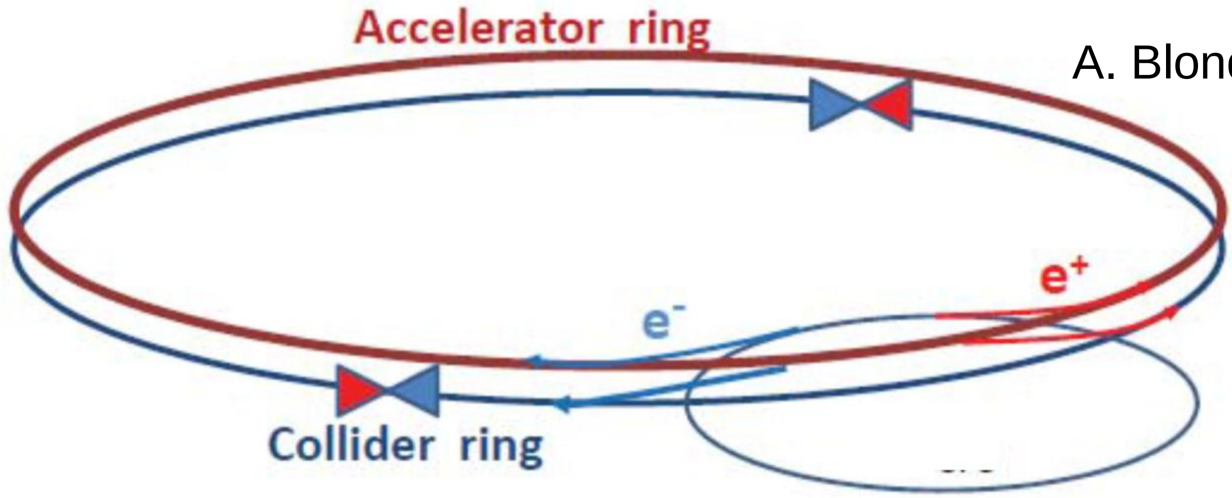
TLEP

Parameters

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
$V_{RF,tot}$ [GV]	3.64	0.5	12.0	2.0	6.0	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	4.2	4.0	9.4	4.9
ξ_x/IP	0.025	N/A	0.09	0.12	0.10	0.05
ξ_y/IP	0.065	N/A	0.08	0.12	0.10	0.05
f_s [kHz]	1.6	0.65	3.91	1.29	0.44	0.43
E_{acc} [MV/m]	7.5	11.9	20	20	20	20
eff. RF length [m]	485	42	600	100	300	600
f_{RF} [MHz]	352	721	1300	700	700	700
δ^{SR}_{rms} [%]	0.22	0.12	0.23	0.06	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.69	0.23	0.19	0.17	0.25
L/IP[$10^{32}cm^{-2}s^{-1}$]	1.25	N/A	107	10335	490	65
number of IPs	4	1	2	2	2	2
Rad.Bhabha b.lifetime [min]	360	N/A	16	74	32	54
Υ_{BS} [10^{-4}]	0.2	0.05	10	4	15	15
n_γ/collision	0.08	0.16	0.60	0.41	0.50	0.51
$\Delta\delta^{BS}$/collision [MeV]	0.1	0.02	33	3.6	42	61
$\Delta\delta^{BS}_{rms}$/collision [MeV]	0.3	0.07	48	6.2	65	95

Beam lifetime

- Bhabha scattering cross section (σ~0.215 barn) implies a burn-off lifetime of ~20 min at 1e34
- Solution: top-up injection
  - Fundamental also for Hubner factor => guarantee high integrated L

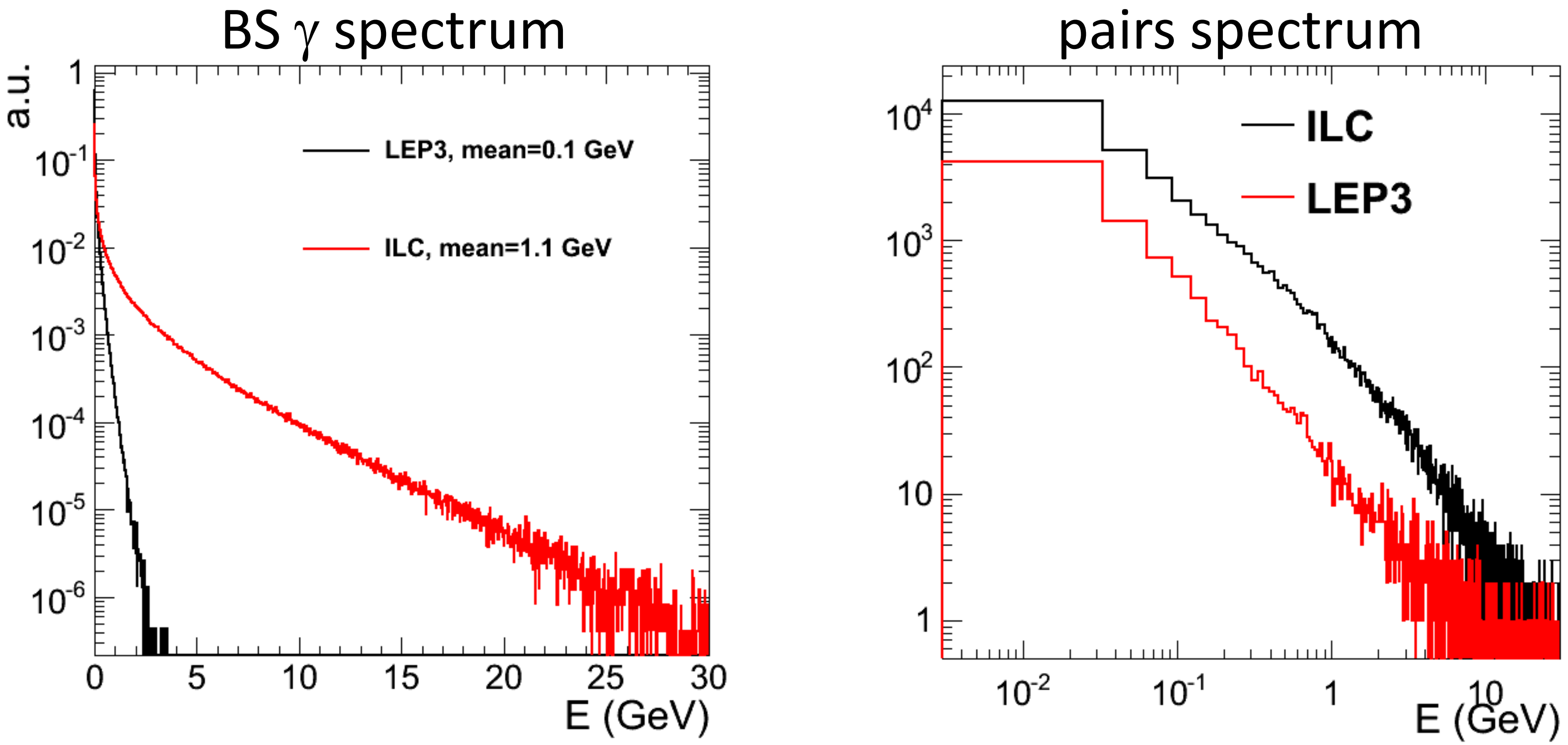


A. Blondel

- High lumi => non-negligible beamstrahlung. Can we keep the beams circulating long enough?

BS Photons

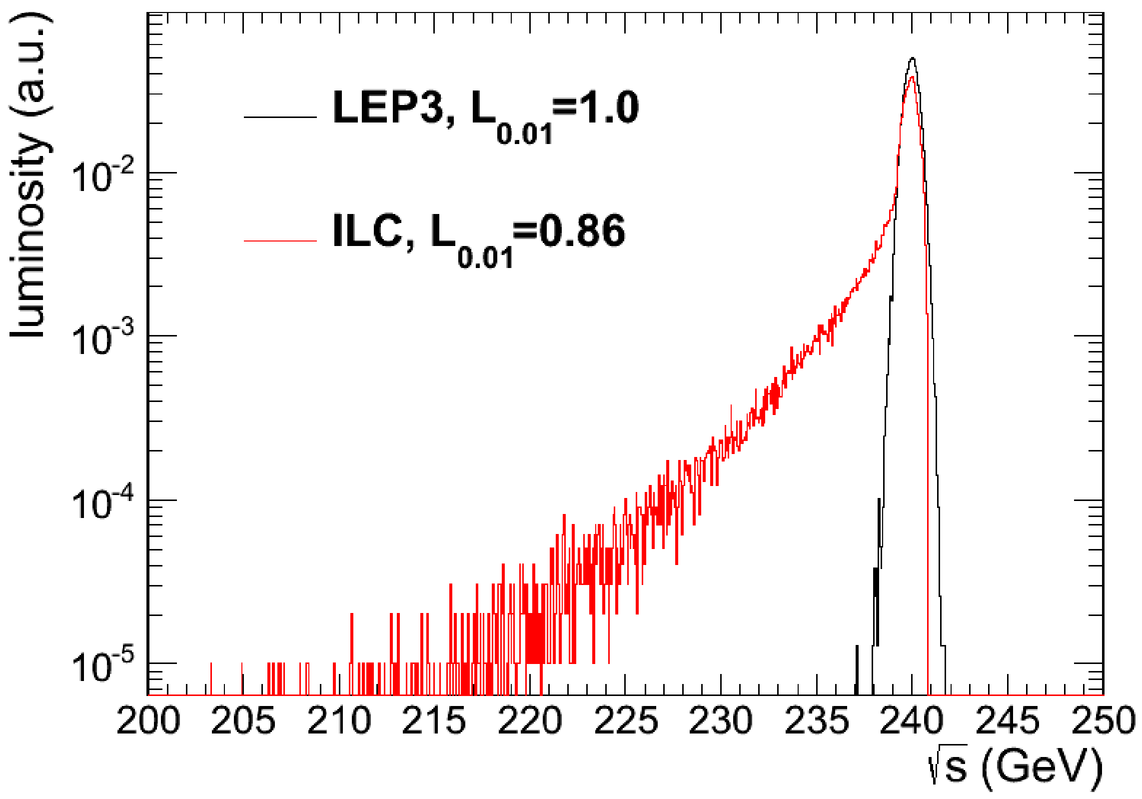
- TLEP(3) BS photon spectrum is much softer than ILC
- Tails up to only a few GeV, compared to tens of GeV for ILC
- As a consequence much reduced pairs background



TLEP

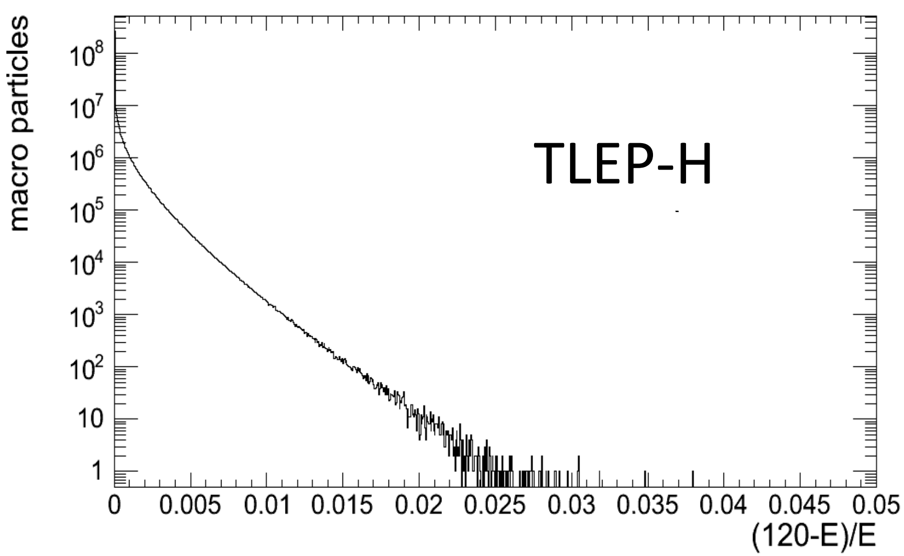
Luminosity profile

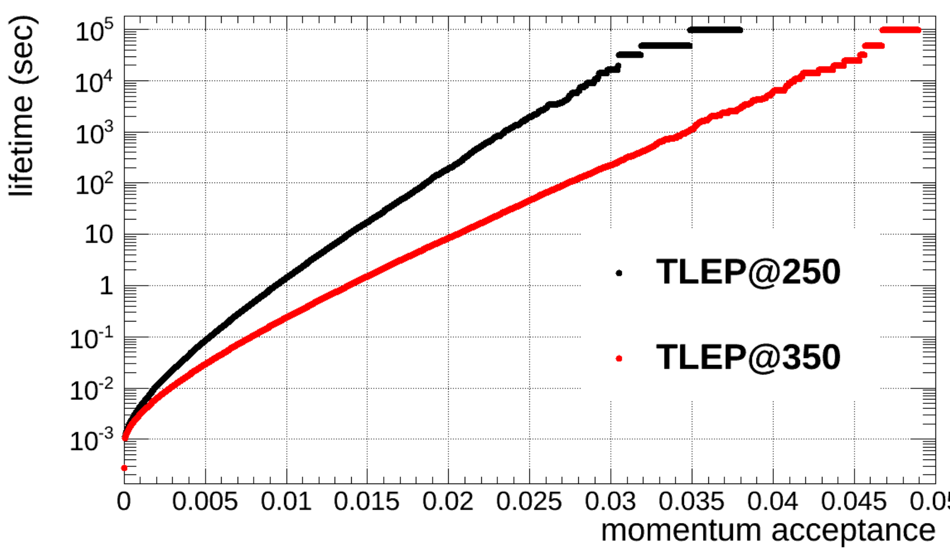
- Softer BS photon spectrum implies much better luminosity profile
- Intrinsic feature of circular high lumi e+e- colliders



BS lifetime

- Simulate and track O(10^8) macroparticles and check the energy spread spectrum (Guinea-Pig)
- Lifetime computed from the fraction of particles beyond a given momentum acceptance (η)
- Exponential dependence on η

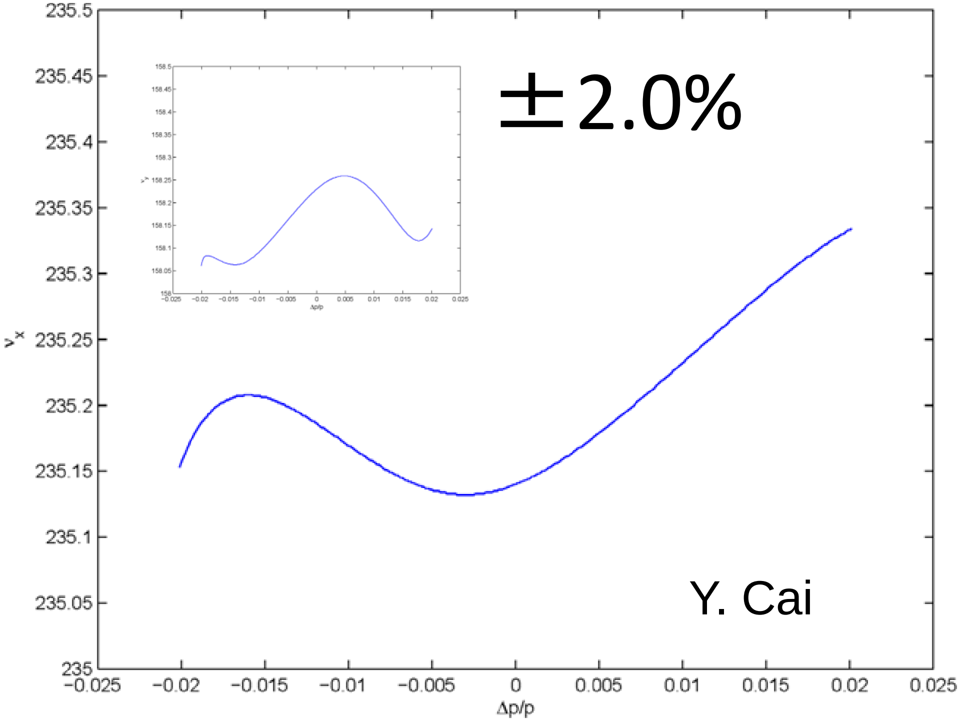


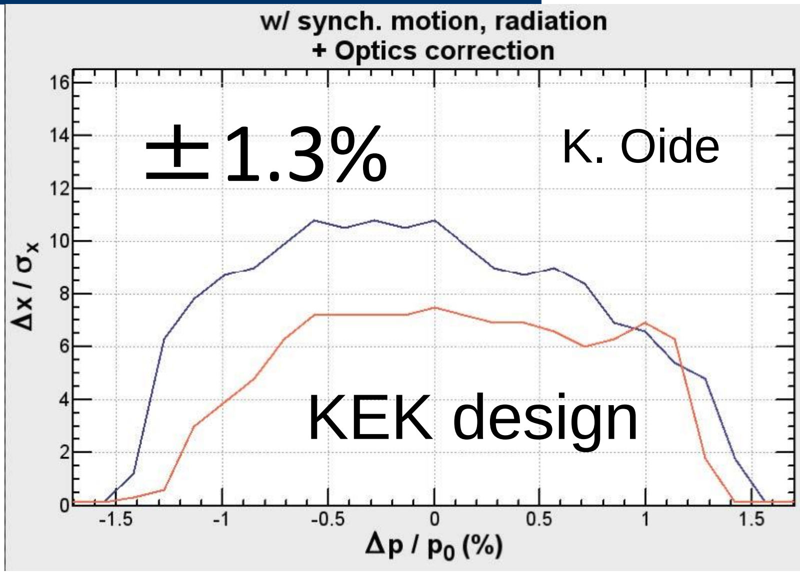


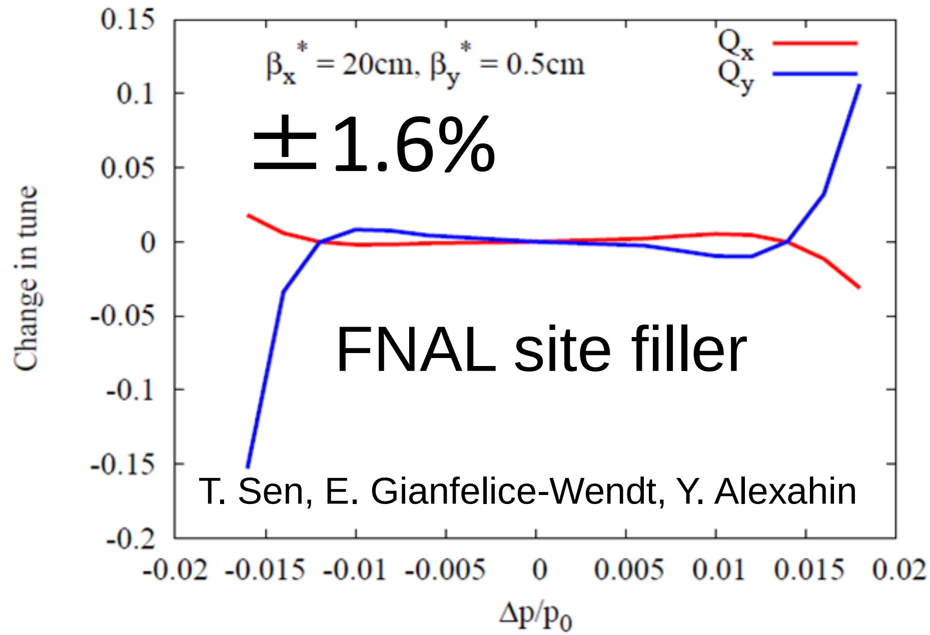
TLEP

Momentum acceptance

SLAC/LBNL design







TLEP

Dealing with BS

- Aiming at more than η=3% could be difficult
- Plenty of room for playing with relevant parameters (σ_x and charges per bunch) maintaining the same luminosity
  - In particular current aspect ratio $\varepsilon_y/\varepsilon_x$ is same as LEP2
  - Look at proposal by Uli Weinand et al. (2^{nd} LEP3 workshop)
- Alternatively a more frequent injection can be envisaged
- Visionary approach: charge compensation:
  - 2 opposite charged bunches per side
  - Null charge, no beamstrahlung
  - Spurios e^+e^+ and e^-e^- collissions
- Bottomline: margin is there to cope with BS
  - TLEP-H is already almost ok!

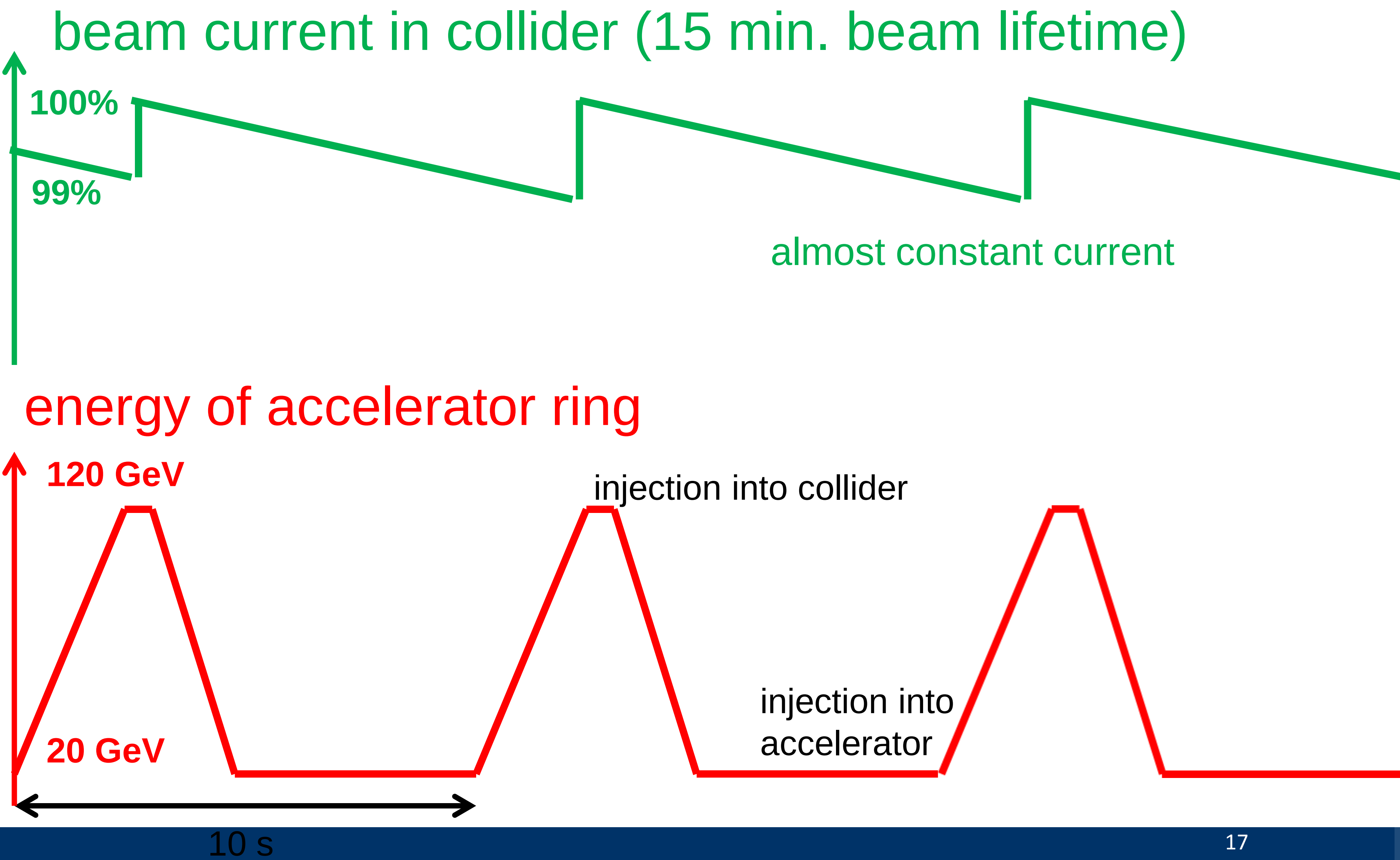
TLEP

Top-up injection

- SPS-LEP experience:
  - $e^{\pm}$ from 3.5 to 20 GeV (later 22 GeV) in 265 ms (~62.26 GeV/s) [K. Cornelis, W. Herr, R. Schmidt]
- Injection sequence [P. Collier, G. Roy]:
  - SPS-> top-up accelerator at 20 GeV
  - Accelerator from 20 to 120 GeV
- Overall acceleration time = 1.6 s
- Total cycle time = 10 s looks conservative (→ refilling ~1% of the LEP3 beam, for tbeam~16 min)

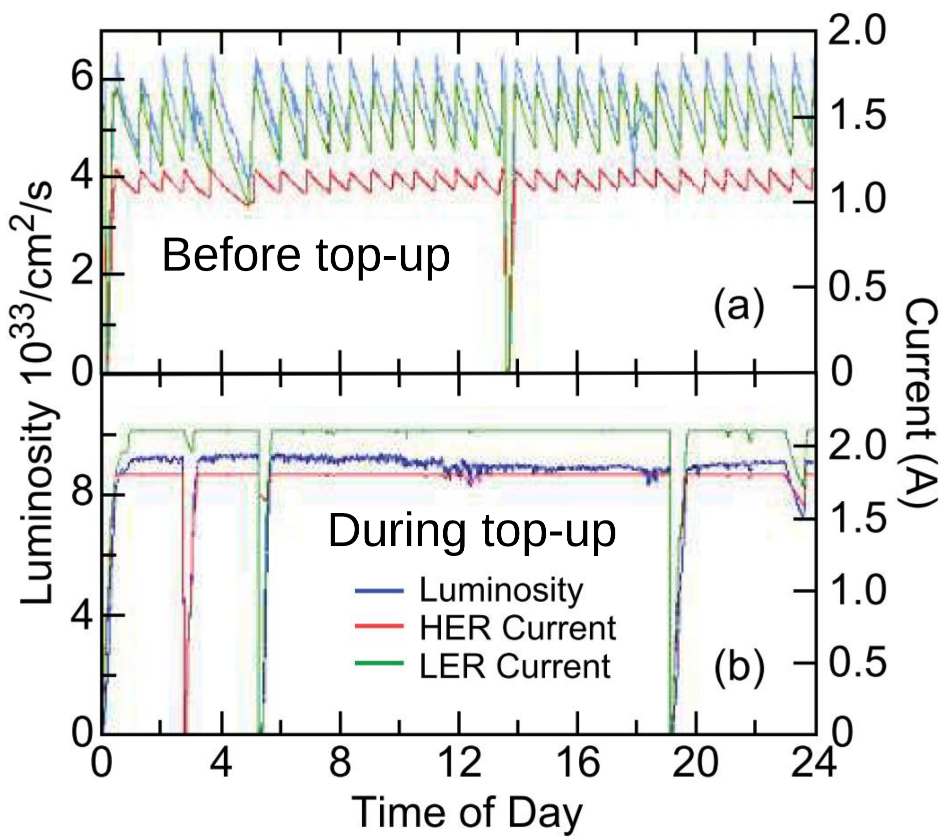
TLEP

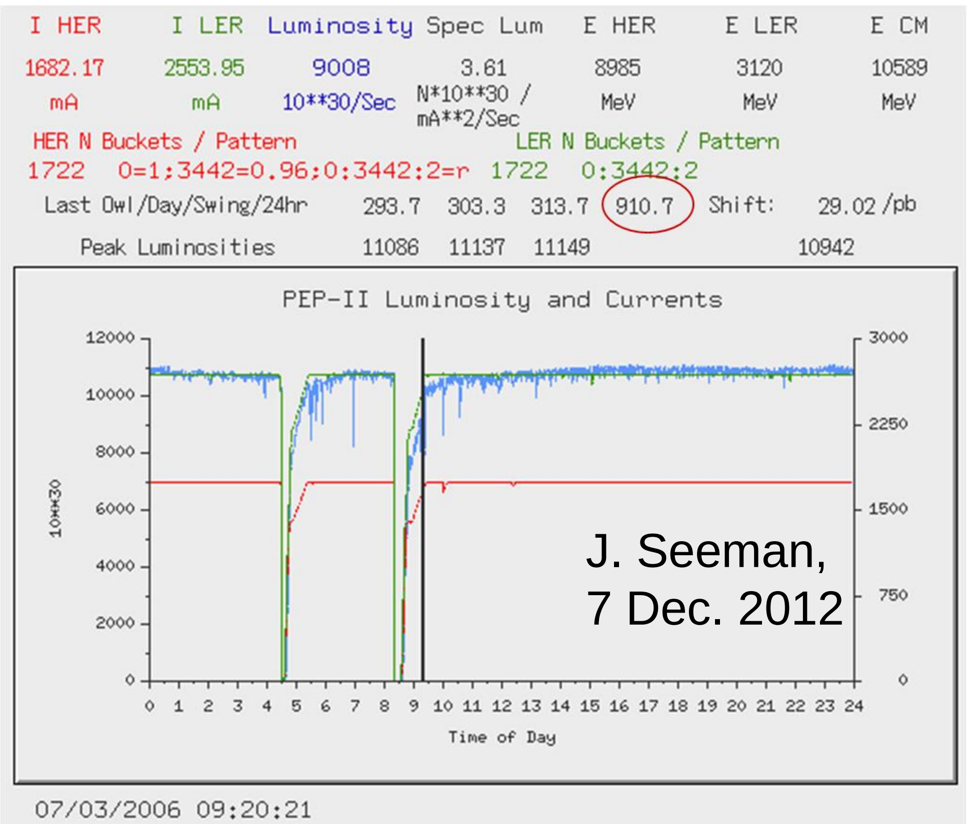
Top-up cycle



Top-up performances

- Super efficient duty cycle achieved at PEPII
- H factor not far from 1:
  - July 3, 2006: $H \approx 0.95$
  - August 2007): H≈0.63





Synchrotron radiation

- 2x100 MW supplied to the beams need to be cooled away, heat load non negligible
- Previous machines (e.g. PEP-II and SPEAR) coped with much higher heat load per meter
- Need to manage higher max photon energy though

	PEPII	SPEAR3	LEP3	TLEP-Z	TLEP-H	TLEP-t
E (GeV)	9	3	120	45.5	120	175
I (A)	3	0.5	0.0072	1.18	0.0243	0.0054
rho (m)	165	7.86	2625	9000	9000	9000
Linear Power (W/cm)	101.8	92.3	30.5	8.8	8.8	8.8

N. Kurita, U. Wienands, SLAC

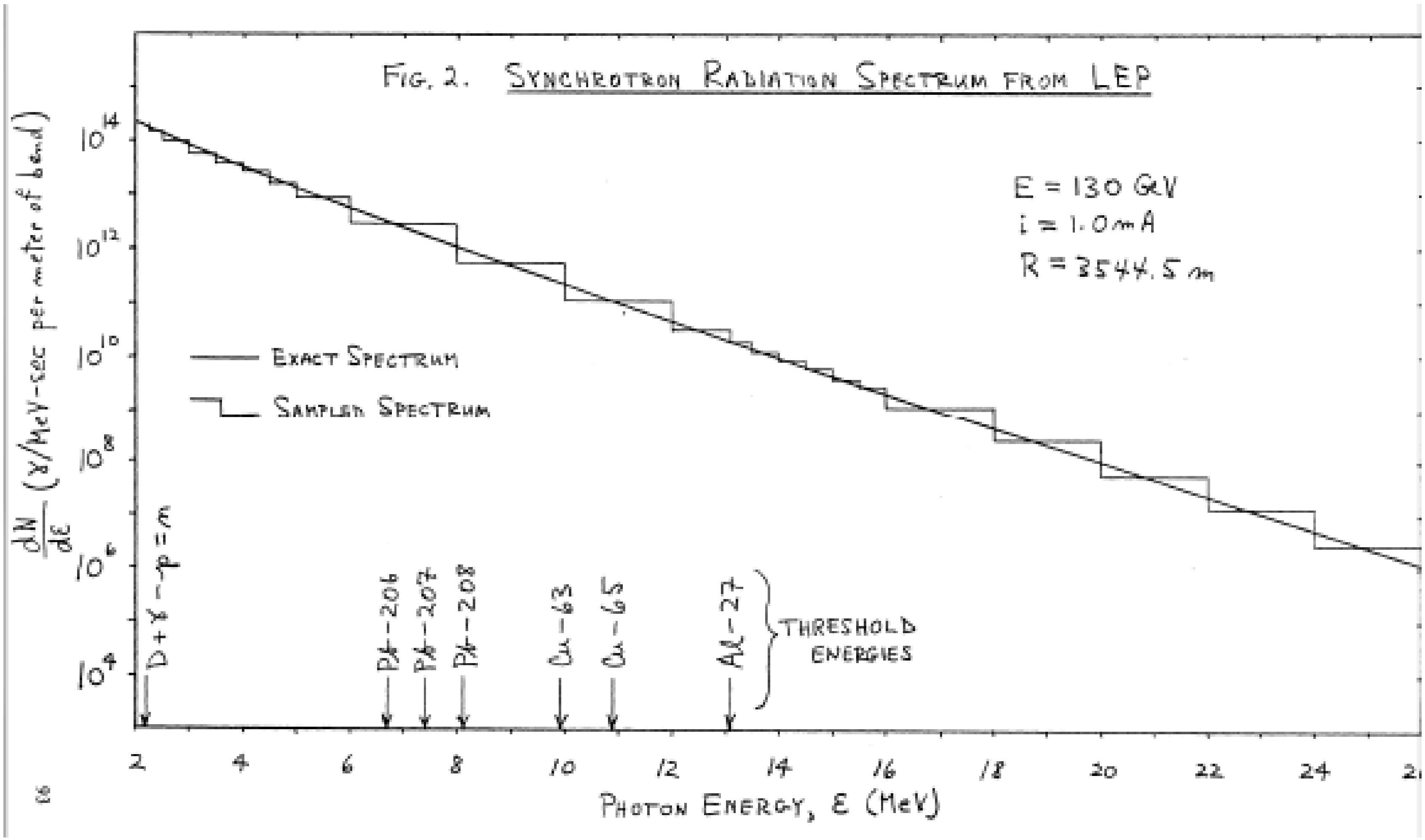
TLEP

Synchrotron radiation

NEUTRON PRODUCTION BY LEP SYNCHROTRON RADIATION USING EGS

N.R.Nelson and J.H.N.Tuyn

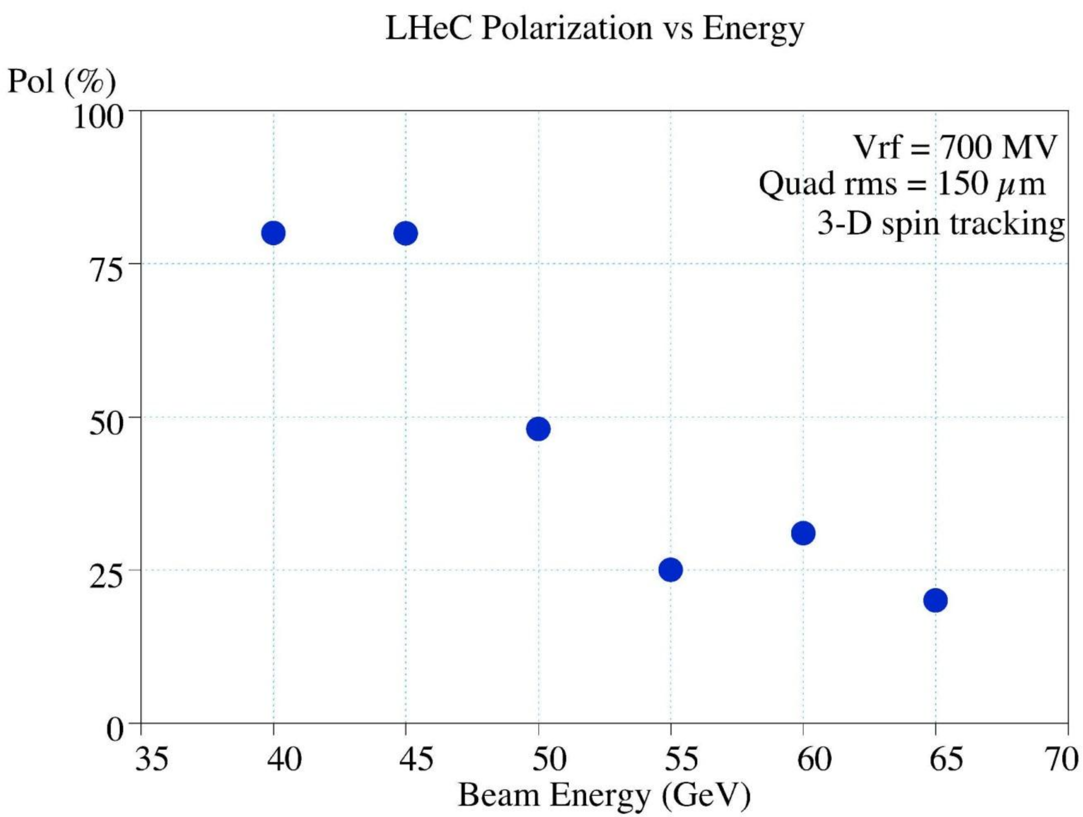
A. Fasso
3rd TLEP3 Day



TLEP

Polarization

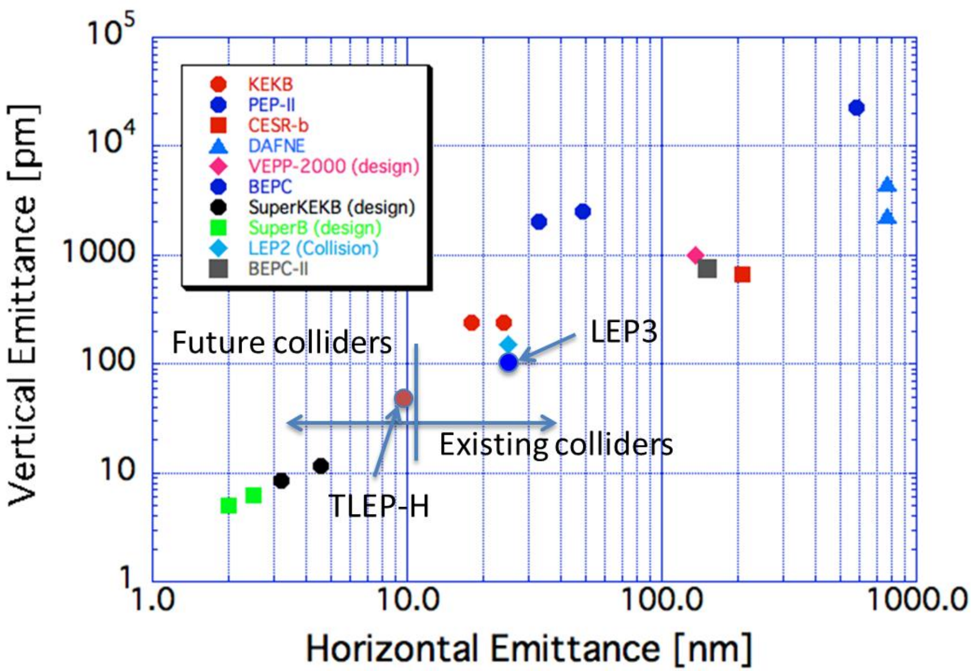
- LHeC equilibrium polarisation vs ring energy, full 3-D spin tracking results [D. Barber, U. Wienands, in LHeC CDR]
- Up to 80% at Z pole

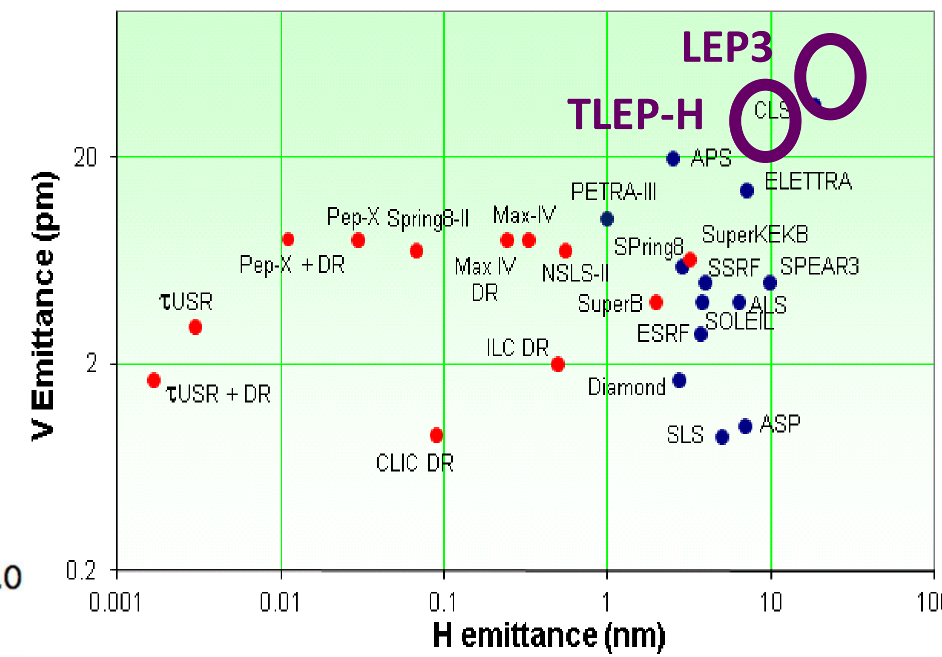


Integration with the Experiments

- Need to arrange the top up accelerator nearby the experiment
- Hole in the detector not acceptable
- Long bypass around the experiments would impact sizably on the overall cost
  - O(10)x4 additional km
- Accelerator and collider intersecting each other at the IP sharing a common beam pipe
- Definitely not straightforward..

Extrapolation





	LEP2→TLEP-H	SLC→ILC 250
peak luminosity	x400	x2500
energy	x1.15	x2.5
vertical geom. emittance	x1/5	x1/400
vert. IP beam size	x1/15	x1/150
e^+ production rate	x1/2 !	x65
commissioning time	<1 year → ?	>10 years →?

BACKUP

luminosity formulae & constraints

$$L = \frac{f_{rev} n_b N_b^2}{4\pi\sigma_x\sigma_y} = (f_{rev} n_b N_b)\left(\frac{N_b}{\varepsilon_x}\right)\frac{1}{4\pi}\frac{1}{\sqrt{\beta_x\beta_y}}\frac{1}{\sqrt{\varepsilon_y/\varepsilon_x}}$$

$$(f_{rev} n_b N_b) = \frac{P_{SR}\,\rho}{8.8575\times10^{-5}\,\frac{\mathrm{m}}{\mathrm{GeV}^{-3}}\,E^4}$$ *SR radiation power limit*

$$\frac{N_b}{\varepsilon_x} = \frac{\xi_x 2\pi\gamma(1+\kappa_\sigma)}{r_e}$$ *beam-beam limit*

$$\frac{N_b}{\sigma_x\sigma_z}\frac{30\,\gamma r_e^2}{\delta_{acc}\,\alpha} < 1$$ *>30 min beamstrahlung lifetime (Telnov) → N_b, β_x*

→minimize $\kappa_\varepsilon=\varepsilon_y/\varepsilon_x$, $\beta_y \sim \beta_x(\varepsilon_y/\varepsilon_x)$ and respect $\beta_y \geq \sigma_z$

LEP3/TLEP parameters -1

soon at SuperKEKB:
β_x*=0.03 m, β_Y*=0.03 cm

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e−/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [µm]	270	30	71	78	43	63
σ^*_y [µm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.59	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

SuperKEKB: $\varepsilon_y/\varepsilon_x$=0.25%

LEP3/TLEP parameters -2

LEP2 was not beam-beam limited

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
$V_{RF,tot}$ [GV]	3.64	0.5	12.0	2.0	6.0	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	5.7	4.0	9.4	4.9
ξ_x/IP	0.025	N/A	0.09	0.12	0.10	0.05
ξ_y/IP	0.065	N/A	0.08	0.12	0.10	0.05
f_s [kHz]	1.6	0.65	2.19	1.29	0.44	0.43
E_{acc} [MV/m]	7.5	11.9	20	20	20	20
eff. RF length [m]	485	42	600	100	300	600
f_{RF} [MHz]	352	721	700	700	700	700
δ^{SR}_{rms} [%]	0.22	0.12	0.23	0.06	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.69	0.31	0.19	0.17	0.25
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	N/A	94	10335	490	65
number of IPs	4	1	2	2	2	2
Rad.Bhabha b.lifetime [min]	360	N/A	18	74	32	54
Υ_{BS} [10^{-4}]	0.2	0.05	9	4	15	15
n_γ/collision	0.08	0.16	0.60	0.41	0.50	0.51
$\Delta\delta^{BS}$/collision [MeV]	0.1	0.02	31	3.6	42	61
$\Delta\delta^{BS}_{rms}$/collision [MeV]	0.3	0.07	44	6.2	65	95
critical SR energy [MeV]	0.81	0.18	1.47	0.02	0.43	1.32

LEP data for 94.5 - 101 GeV consistently suggest a beam-beam limit of ~0.115 (R.Assmann, K. C.)

TLEP

Beamstrahlung

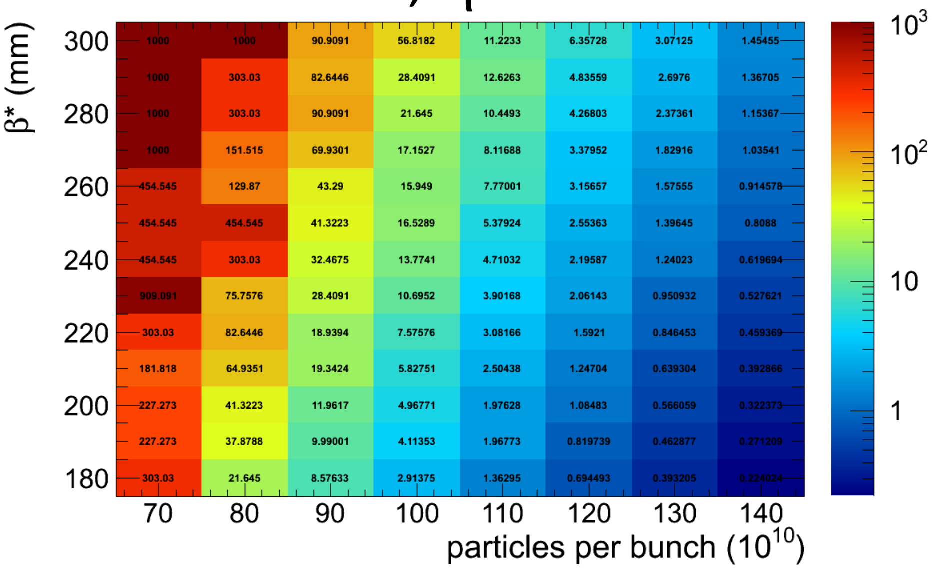
- Beamstrahlung dependencies:
- Flat beams, vertical size affects only luminosity
- For a given bunch length, horizontal size and particles per bunch drive the BS effects
- Same dependencies for the BS photon energy
- Circular collider parameters designed to lead to smaller BS

	N (10^{10})	σ_z (cm)	σ_x (μm)	σ_y (μm)	ε_{Nx} (10^{-6} mrad)	ε_{NY} (10^{-6} mrad)	β_x (m)	β_y (cm)
ILC	2	0.03	0.75	0.008	10	0.035	0.013	0.04
LEP3	100	0.23	71	0.32	6000	28	0.2	0.1
TLEP-H	50	0.23	43	0.22	2200	12	0.2	0.1

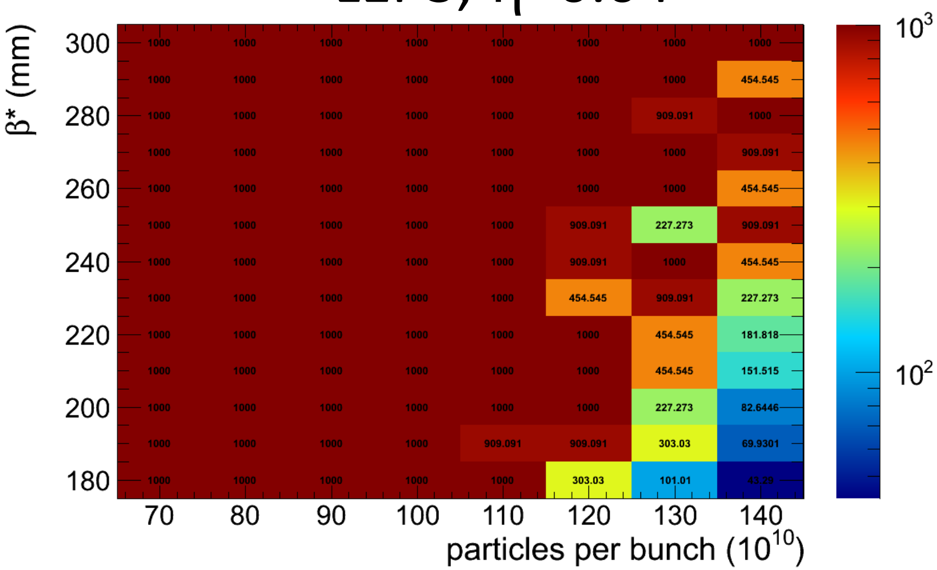
Dealing with BS

- Scan relevant BS parameters:
  - B*x to scale horizontal beam dimension
  - Number of particle per bunch
- BS lifetime for nominal parameters (assuming η=0.04):
  - LEP3: >~ 30 min
  - TLEP-H: ~day
    - >4h for η=0.03, ~4 min for η=0.02

LEP3, η=0.02

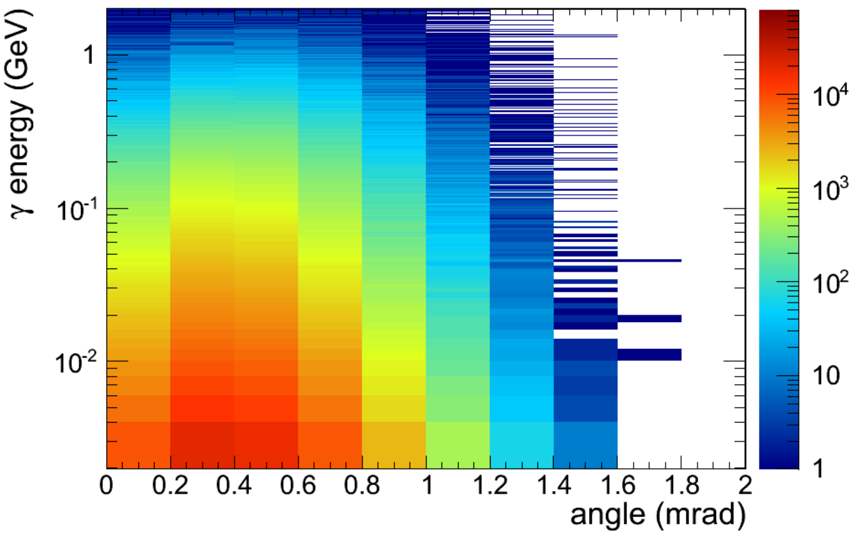


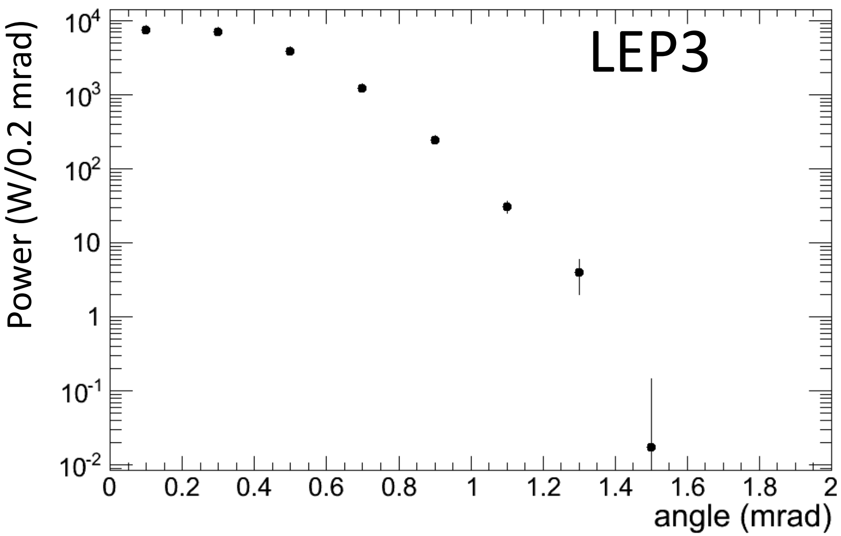
LEP3, η=0.04



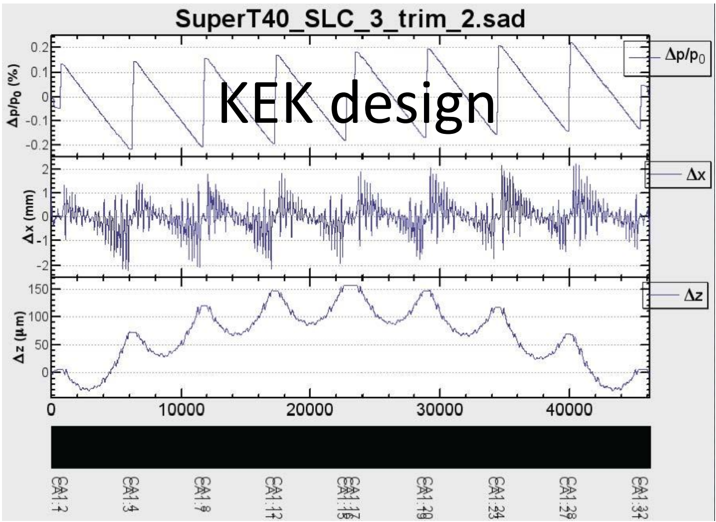
Power

- The spectrum is softer and n_γ is smaller than ILC, but (T)LEP(3) have up to ~x100 more particles per bunch.
- Comparable power dissipation for ILC and circular colliders, O(10) kW
- Most of the power dissipated at very small angle

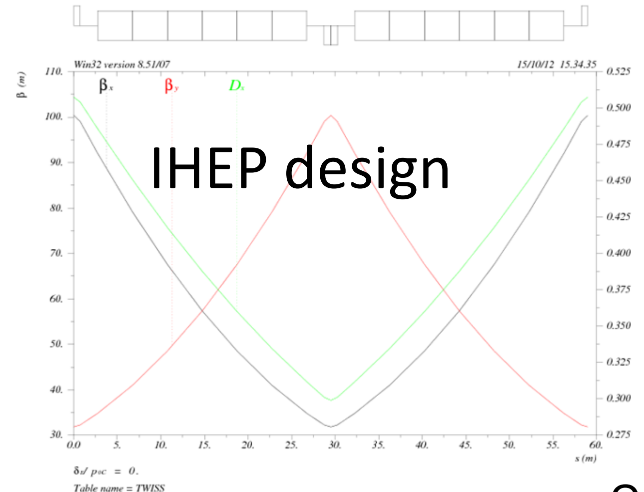




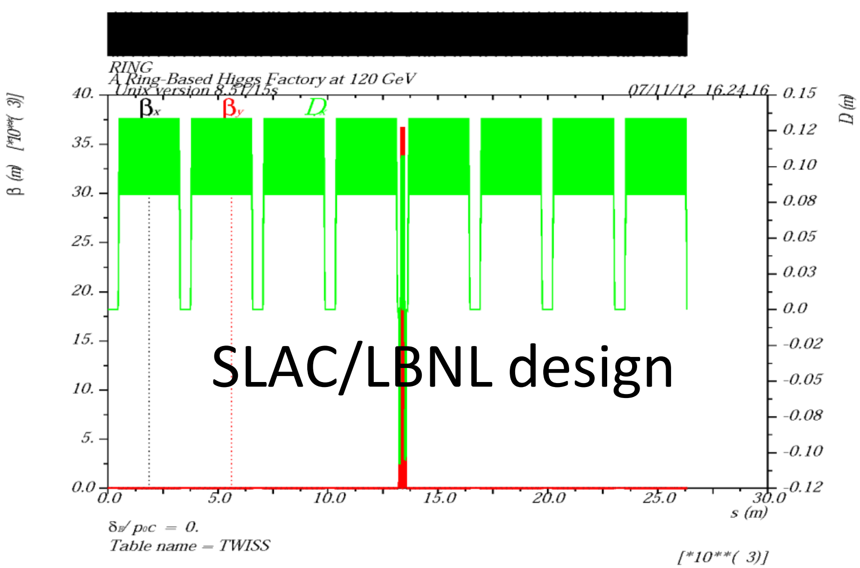
circular HFs – arc lattice



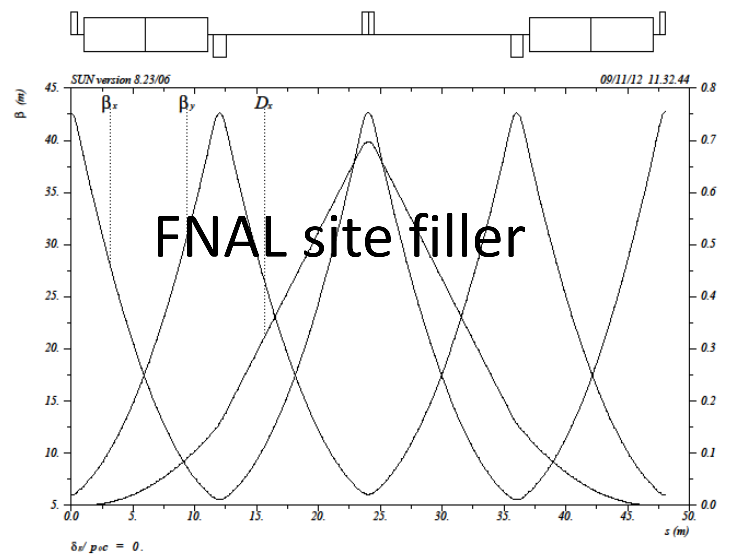
K. Oide



Q. Qin

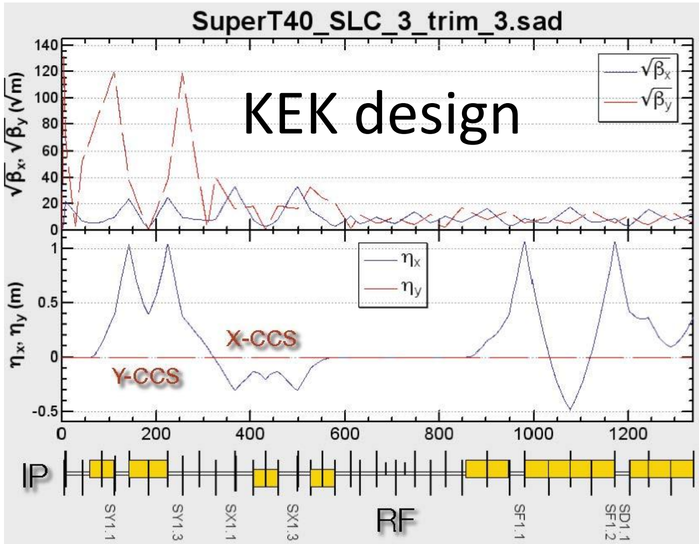


Y. Cai

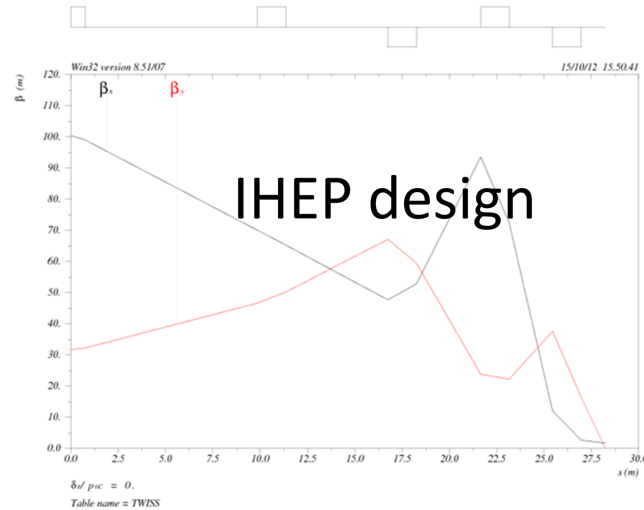


T. Sen, E. Gianfelice-Wendt, Y. Alexahin

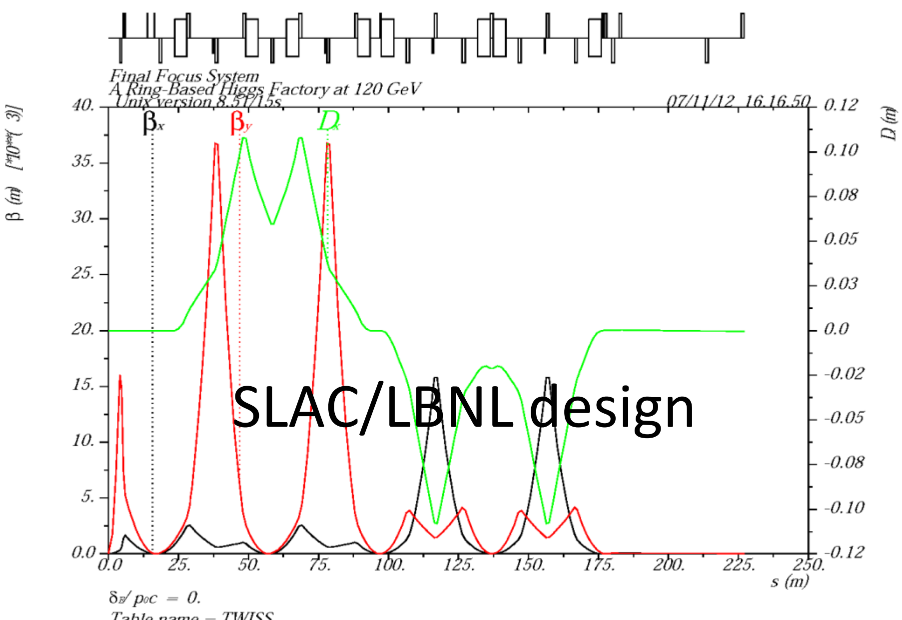
circular HFs – final-focus design



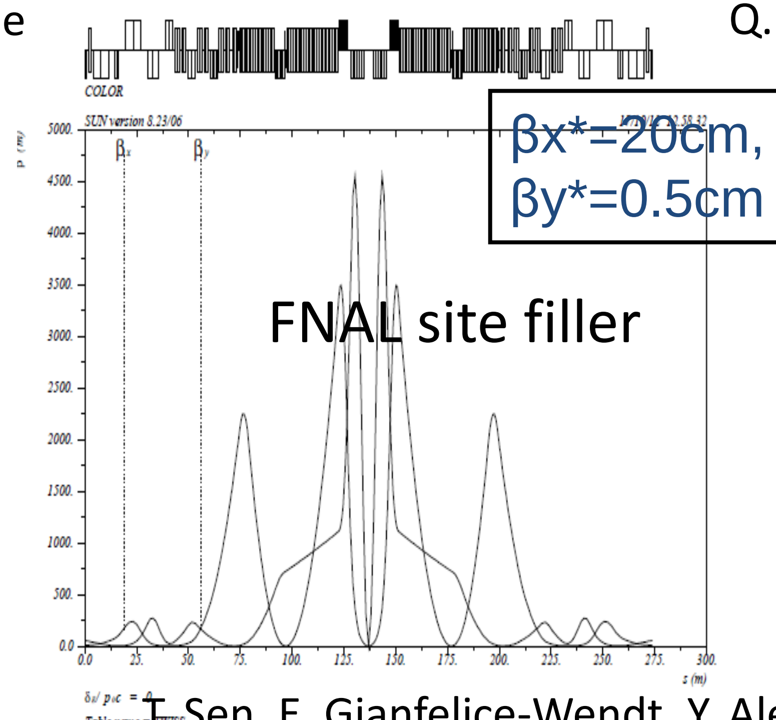
K. Oide



Q. Qin



Y. Cai



T. Sen, E. Gianfelice-Wendt, Y. Alexahin

TLEP

Summary of issues

- SR handling and radiation shielding
- optics effect energy sawtooth [separate arcs?! (K. Oide)]
- beam-beam interaction for large Qs and significant hourglass effect
- IR design with even larger momentum acceptance
- integration in LHC tunnel (LEP3)
- Pretzel scheme for TERA-Z operation?
- impedance effects for high-current running at Z pole