Scaling & Assumptions for MDI, Collimation & Shielding

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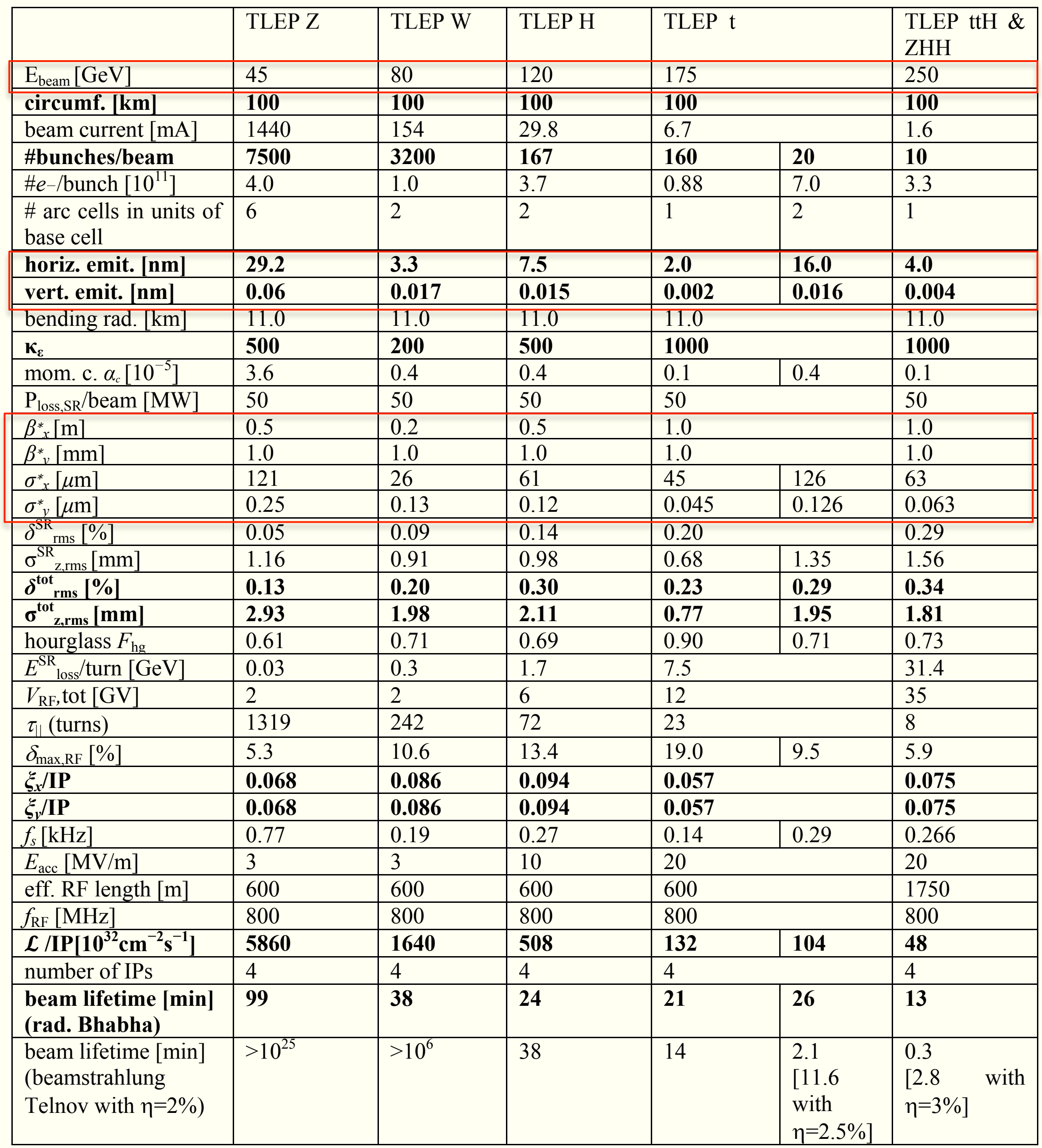
Outline

- Starting beam key parameters
- IR Design *i.e. crossing angle?*
- Detector constraints
- Background sources
- Tools to handle these effects
- Conclusions: plans of the work

Parameter Table

[from B. Holzer, Oct.4]



	TLEP Z	TLEP W	TLEP H	TLEP t		TLEP ttH & ZHH
E_{beam} [GeV]	45	80	120	175		250
circumf. [km]	**100**	**100**	**100**	**100**		**100**
beam current [mA]	1440	154	29.8	6.7		1.6
#bunches/beam	**7500**	**3200**	**167**	**160**	**20**	**10**
$\#e-$/bunch $[10^{11}]$	4.0	1.0	3.7	0.88	7.0	3.3
# arc cells in units of base cell	6	2	2	1	2	1
horiz. emit. [nm]	**29.2**	**3.3**	**7.5**	**2.0**	**16.0**	**4.0**
vert. emit. [nm]	**0.06**	**0.017**	**0.015**	**0.002**	**0.016**	**0.004**
bending rad. [km]	11.0	11.0	11.0	11.0		11.0
κ_ε	**500**	**200**	**500**	**1000**		**1000**
mom. c. α_c $[10^{-5}]$	3.6	0.4	0.4	0.1	0.4	0.1
$P_{loss,SR}$/beam [MW]	50	50	50	50		50
β^*_x [m]	0.5	0.2	0.5	1.0		1.0
β^*_y [mm]	1.0	1.0	1.0	1.0		1.0
σ^*_x [μm]	121	26	61	45	126	63
σ^*_y [μm]	0.25	0.13	0.12	0.045	0.126	0.063
δ^{SR}_{rms} [%]	0.05	0.09	0.14	0.20		0.29
$\sigma^{SR}_{z,rms}$ [mm]	1.16	0.91	0.98	0.68	1.35	1.56
$\boldsymbol{\delta^{tot}_{rms}}$ **[%]**	**0.13**	**0.20**	**0.30**	**0.23**	**0.29**	**0.34**
$\boldsymbol{\sigma^{tot}_{z,rms}}$ **[mm]**	**2.93**	**1.98**	**2.11**	**0.77**	**1.95**	**1.81**
hourglass F_{hg}	0.61	0.71	0.69	0.90	0.71	0.73
E^{SR}_{loss}/turn [GeV]	0.03	0.3	1.7	7.5		31.4
V_{RF},tot [GV]	2	2	6	12		35
$\tau_{\|\|}$ (turns)	1319	242	72	23		8
$\delta_{max,RF}$ [%]	5.3	10.6	13.4	19.0	9.5	5.9
$\boldsymbol{\xi_x}$**/IP**	**0.068**	**0.086**	**0.094**	**0.057**		**0.075**
$\boldsymbol{\xi_y}$**/IP**	**0.068**	**0.086**	**0.094**	**0.057**		**0.075**
f_s [kHz]	0.77	0.19	0.27	0.14	0.29	0.266
E_{acc} [MV/m]	3	3	10	20		20
eff. RF length [m]	600	600	600	600		1750
f_{RF} [MHz]	800	800	800	800		800
$\boldsymbol{\mathcal{L}}$ **/IP**$\boldsymbol{[10^{32}cm^{-2}s^{-1}]}$	**5860**	**1640**	**508**	**132**	**104**	**48**
number of IPs	4	4	4	4		4
beam lifetime [min] (rad. Bhabha)	**99**	**38**	**24**	**21**	**26**	**13**
beam lifetime [min] (beamstrahlung Telnov with η=2%)	$>10^{25}$	$>10^{6}$	38	14	2.1 [11.6 with η=2.5%]	0.3 [2.8 with η=3%]

IPAC'13 Shanghai

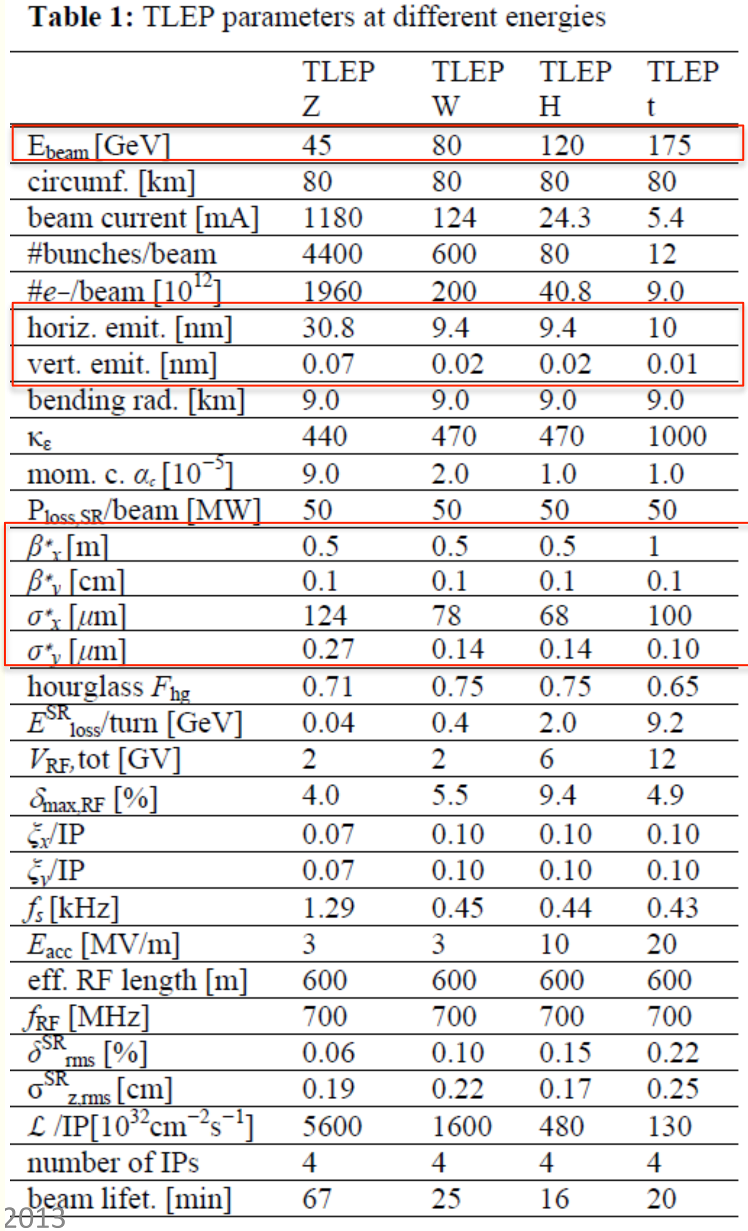


Table 1: TLEP parameters at different energies

	TLEP Z	TLEP W	TLEP H	TLEP t
E_{beam} [GeV]	45	80	120	175
circumf. [km]	80	80	80	80
beam current [mA]	1180	124	24.3	5.4
#bunches/beam	4400	600	80	12
$\#e-$/beam $[10^{12}]$	1960	200	40.8	9.0
horiz. emit. [nm]	30.8	9.4	9.4	10
vert. emit. [nm]	0.07	0.02	0.02	0.01
bending rad. [km]	9.0	9.0	9.0	9.0
κ_ε	440	470	470	1000
mom. c. α_c $[10^{-5}]$	9.0	2.0	1.0	1.0
$P_{loss,SR}$/beam [MW]	50	50	50	50
β^*_x [m]	0.5	0.5	0.5	1
β^*_y [cm]	0.1	0.1	0.1	0.1
σ^*_x [μm]	124	78	68	100
σ^*_y [μm]	0.27	0.14	0.14	0.10
hourglass F_{hg}	0.71	0.75	0.75	0.65
E^{SR}_{loss}/turn [GeV]	0.04	0.4	2.0	9.2
V_{RF},tot [GV]	2	2	6	12
$\delta_{max,RF}$ [%]	4.0	5.5	9.4	4.9
ξ_x/IP	0.07	0.10	0.10	0.10
ξ_y/IP	0.07	0.10	0.10	0.10
f_s [kHz]	1.29	0.45	0.44	0.43
E_{acc} [MV/m]	3	3	10	20
eff. RF length [m]	600	600	600	600
f_{RF} [MHz]	700	700	700	700
δ^{SR}_{rms} [%]	0.06	0.10	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	0.19	0.22	0.17	0.25
$\mathcal{L}$ /IP$[10^{32}cm^{-2}s^{-1}]$	5600	1600	480	130
number of IPs	4	4	4	4
beam lifet. [min]	67	25	16	20

Boundary Conditions

- **Ideal case:**
  - – high luminosity
  - – Full (4π) detector acceptance
  - – Low background conditions

clarify extra-contraints:
injection, proton ring,
1 or 2 rings, crossing angle

- **Real life:**
  - – Achievable Luminosity

    high enough as required by physics program
  - – Good detector acceptance

    in forward/rear direction
  - – Tolerable background rates

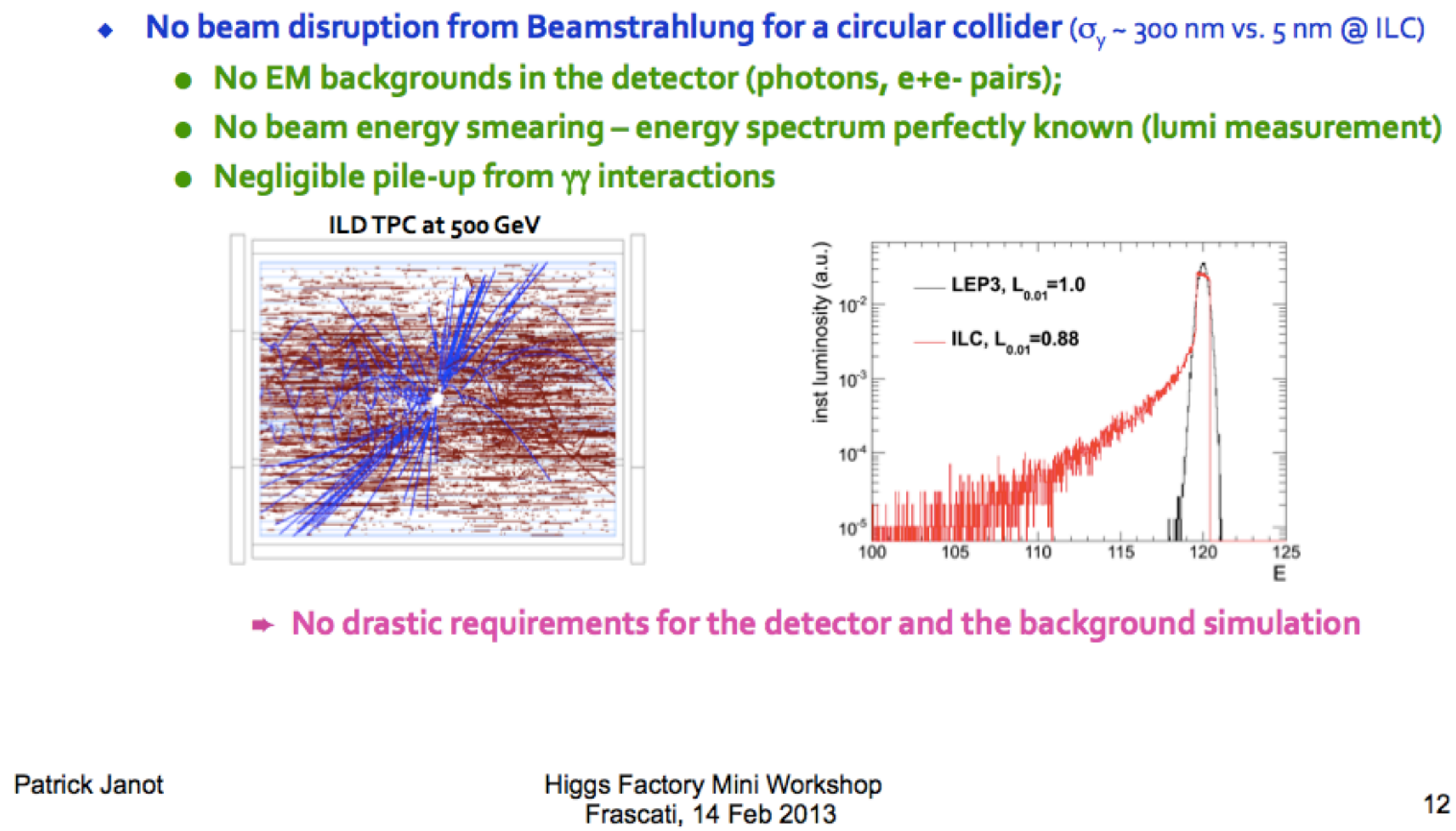
L and acceptance requirements depend very much on physics program

Detector Constraints

- Physics acceptance from the nominal beam axis
- Smallest possible beam pipe radius
- Thinnest possible beam pipe wall
- Solenoidal detector
- Separation scheme
- L* (IP to first quad) key parameter: 4m

Remedies:

- Low SR backgrounds — first bends far from IP, to minimize quads rate: orbit at center of quads
- Low Beam-gas backgrounds — good pumping
- Low radiative Bhabha backgrounds — proper shielding



- **No beam disruption from Beamstrahlung for a circular collider** (σ_y ~ 300 nm vs. 5 nm @ ILC)
  - **No EM backgrounds in the detector (photons, e+e- pairs);**
  - **No beam energy smearing – energy spectrum perfectly known (lumi measurement)**
  - **Negligible pile-up from $\gamma\gamma$ interactions**

➨ **No drastic requirements for the detector and the background simulation**

Patrick Janot

Higgs Factory Mini Workshop
Frascati, 14 Feb 2013

12

much better environment wrt linear collider but beam is recirculated ➡
relevant effects for lifetime

Background Considerations

- background processes
- approximations used
- implementation needed

The tools:

- for the beams: Geant4/FLUKA for SR, BDSIM, GUINEA-PIG, BBBrem, HTGEN, MCGAS, PLACET,…
- for the detector: Geant4/FLUKA, BDSIM,…

There should be collaboration/synergy between interaction region and detector design

General Approach

Collection of background generators

primaries

Transport inside a Geant4 (or equivalent) beamline description (magnetic fields and material)

shielding

Propagation in a Geant4 (or equivalent) detector description

hit collections

Background impact determination in the subsystems

Background Sources- / Rates to be evaluated

- **Luminosity sources**
  - Beamstrahlung
  - Bhabha (Radiative)
  - Pair production $e^+e^- \to e^+e^- e^+e^-$
  - Muon production $e^+e^- \to e^+e^- \mu^+\mu^-$
  - beam-beam (Halo)
- **Linear with Currents**
  - Synchrotron radiation
  - Beam-gas Coulomb/ Bremsstrahlung
- **Other sources**
  - thermal outgassing due to HOM losses
  - injection background
  - High order modes
  - Compton thermal photons
  - ion or electron cloud
  - intrabeam scattering

Beamstrahlung

- Dominant effect on lifetime
- Dedicated studies already performed
  - theoretical [Yokoya, Telnov, …]
  - numerical with GUINEA-PIG [D. Schulte]
- Effect on luminosity studied by Ohmi

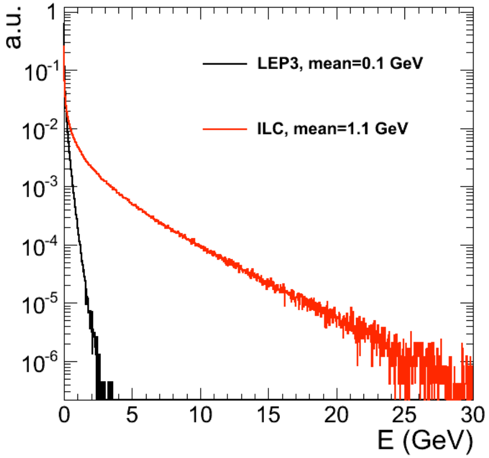
- More investigation as a background source

Beamstrahlung

- Beamstrahlung dependencies:

$$\Upsilon \propto \frac{N\gamma}{\sigma_z(\sigma_x + \sigma_y)}$$

- 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



BS γ spectrum

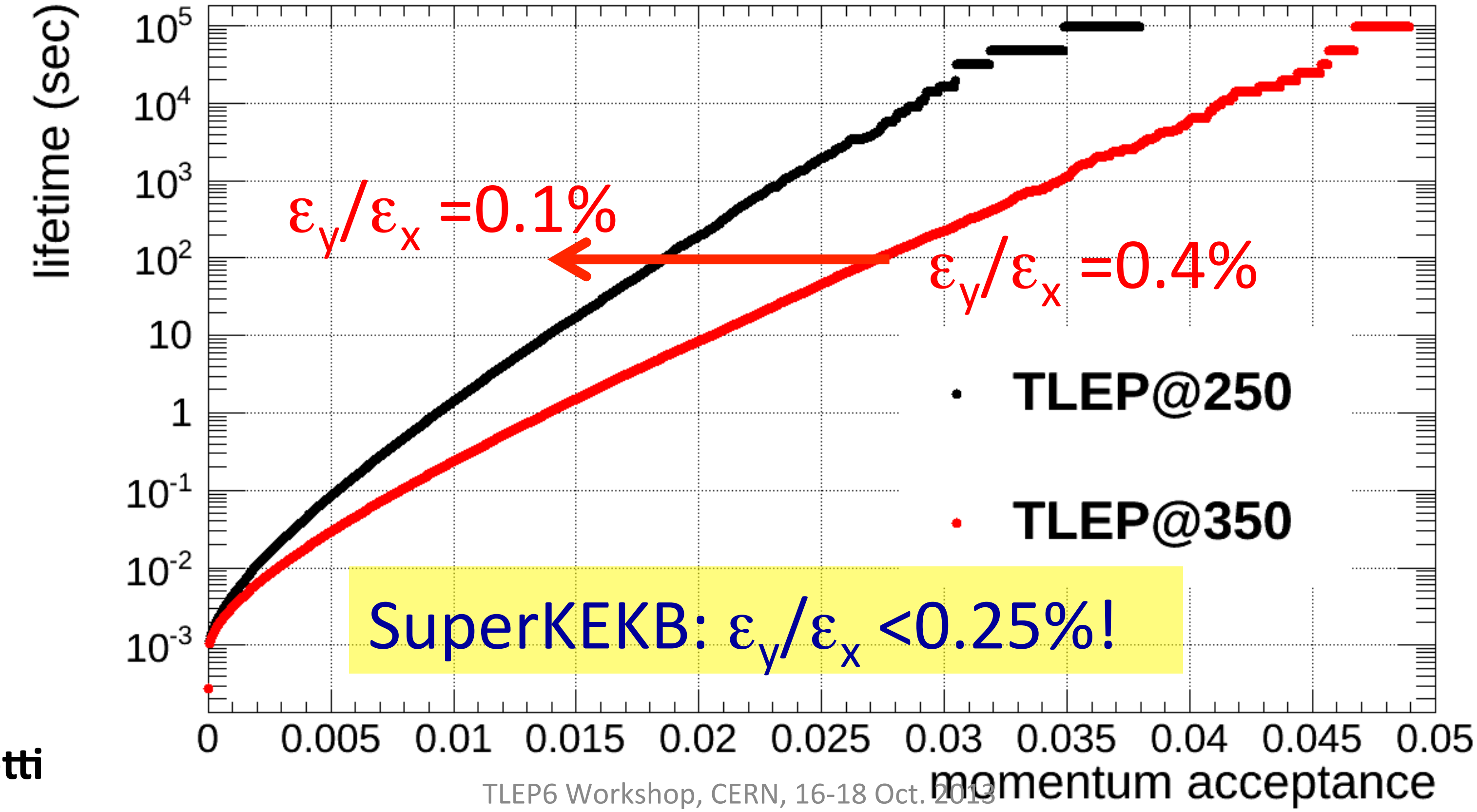
M. Zanetti

beamstrahlung lifetime

$$\Upsilon \propto \frac{N\gamma}{\sigma_z(\sigma_x + \sigma_y)}$$

- simulation w 360M macroparticles
- τ varies exponentially w energy acceptance η
- post-collision *E* tail → lifetime τ

beam lifetime versus acceptance δ_{max} for 4 IPs:



$\varepsilon_y/\varepsilon_x$ =0.1%

$\varepsilon_y/\varepsilon_x$ =0.4%

SuperKEKB: $\varepsilon_y/\varepsilon_x$ <0.25%!

M. Zanetti

Radiative Bhabhas

- Bremsstrahlung process in the forward direction in BhaBha scattering: $e^+e^- \to e^+e^- \gamma$
- Simulation with the BBBrem generator (R. Kleiss and H. Burkhardt) and fully propagate in the Geant-4 description
- The outgoing particles are not the direct responsible for detector backgrounds but they generate potentially dangerous showers and backscattered particles in the downstream beamline elements
- Beamline and shielding design is very important

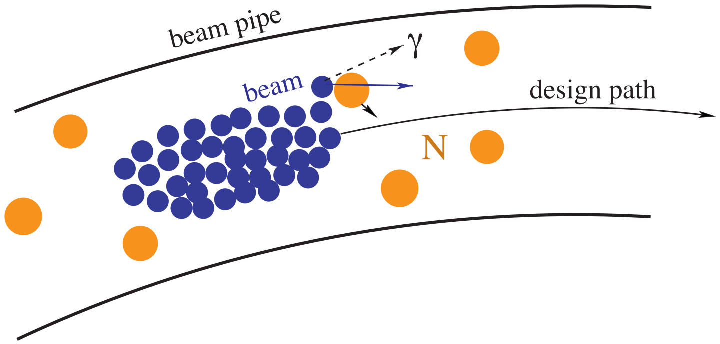
Low angle Bhabhas also very important at such high luminosity (showers in various materials)

Pair production (e^+e^-)

- $e^+e^- \to e^+e^- \, e^+e^-$
- can be studied with GUINEA-PIG generator (D. Schulte)
- can be high production rate but particles have low energy and loop in the solenoid field
- relevant for which sub-system?
  - typically low energy curling e^+e^- relevant for vertex detector and first layers of tracking devices
- first guess at generator level (with magnetic fields)
- full simulation with Geant4 needed for detailed study

Same statements are valid for $\mu^+\mu^-$ production to be checked at these energies

Beam-gas

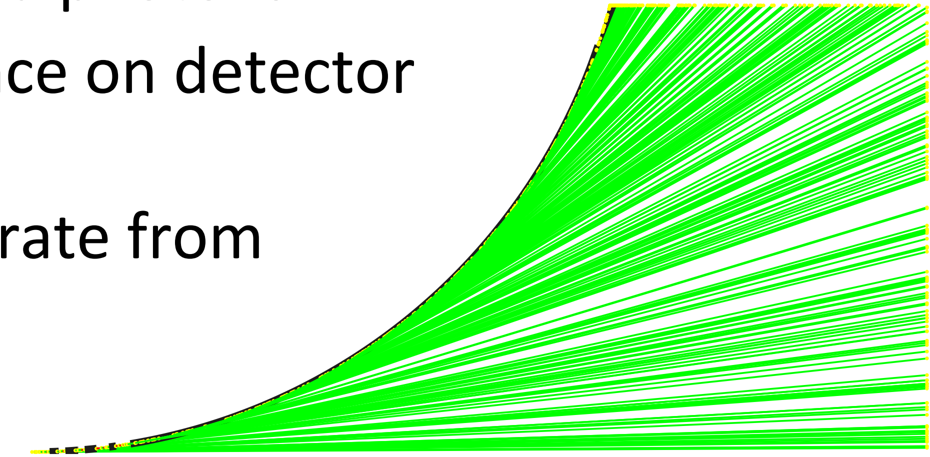


- Mainly Coulomb/Bremsstrahlung interactions with residual gas molecules in the beampipe
- As a start: the estimate based on LEP2 rates and rescale for beam currents.

- For a more quantitative and accurate estimate, the lattice description is needed.
- TOOL:
  - PLACET, HTGEN (Helmut)
  - MCGAS Monte Carlo developed for SuperB (Manuela)

Synchrotron Radiation

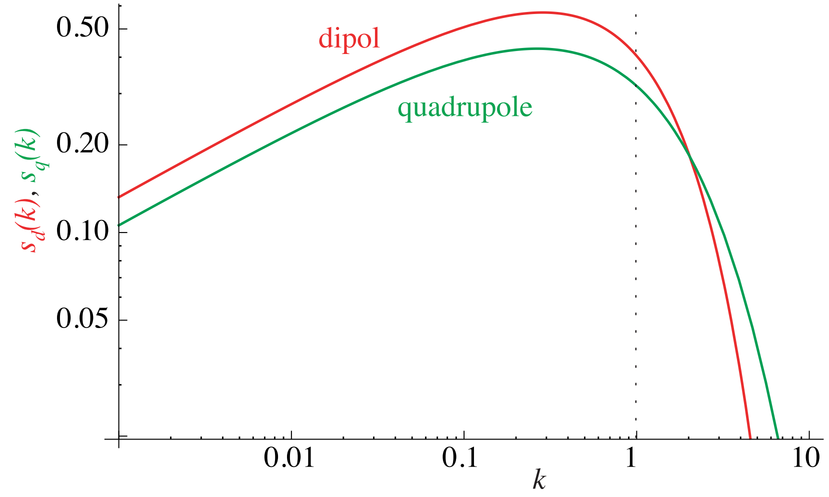
- SR Power (dipoles, quads, ..)
- calculate the rate of photons through the detector beam pipe
- add in calculation the compensating solenoids and detector field
- calculation of backscattered photons
- scattering rate and incidence on detector beam pipe
- forward scattered photon rate from upstream bend magnets



Geant4 bend example

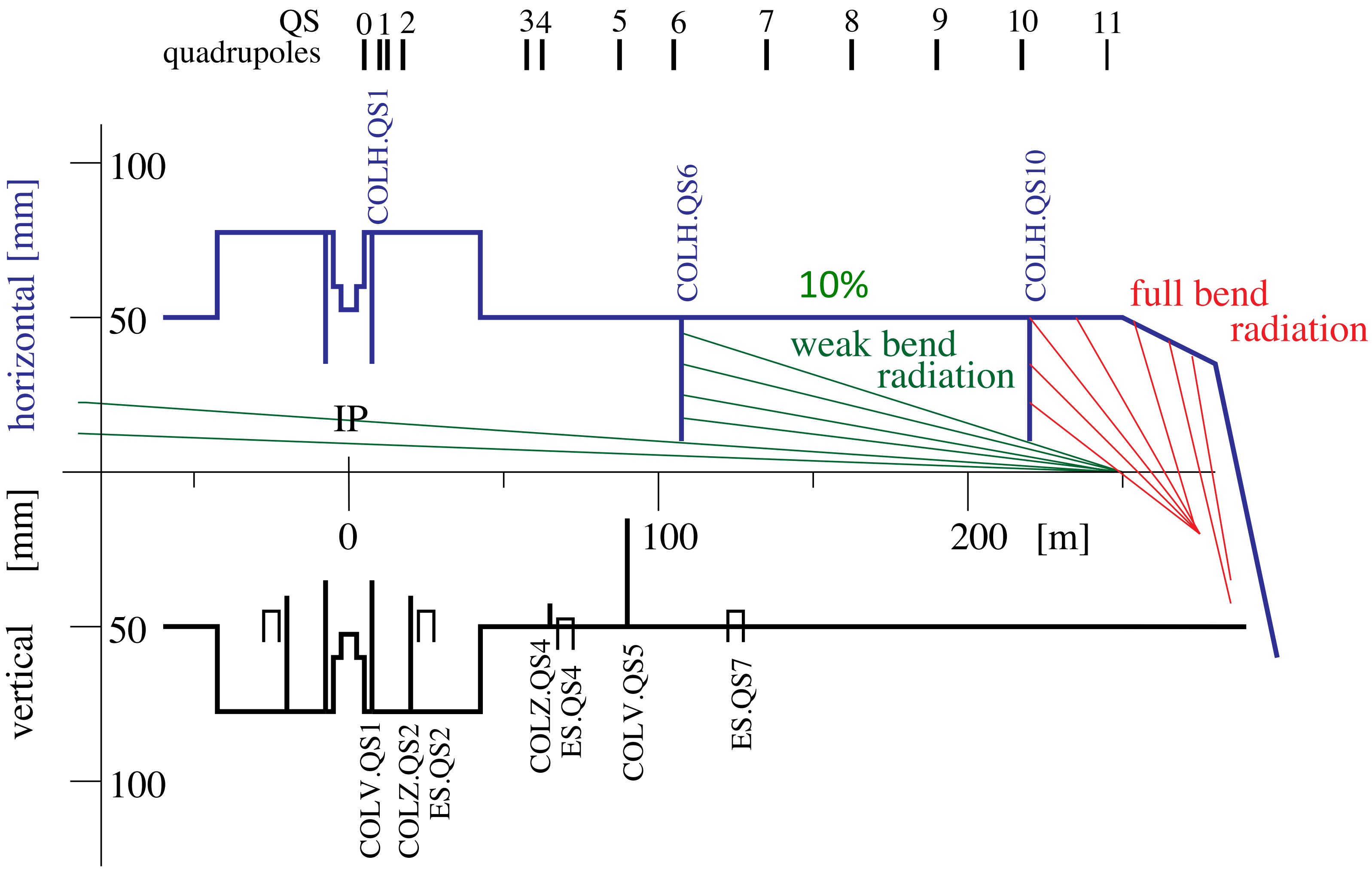
SR scaling

- Power
- Critical energy
- spectrum



The Interaction Region has to be designed to reduce the bending of incoming beam trajectories and offset in quadrupoles – work together with the IR design group.

LEP IR


QS
quadrupoles
0 1 2
34
5
6
7
8
9
10
11
COLH.QS1
COLH.QS6
COLH.QS10
10%
full bend
radiation
weak bend
radiation
IP
horizontal [mm]
100
50
0
100
200
[m]
vertical [mm]
50
100
COLV.QS1
COLZ.QS2
ES.QS2
COLZ.QS4
ES.QS4
COLV.QS5
ES.QS7

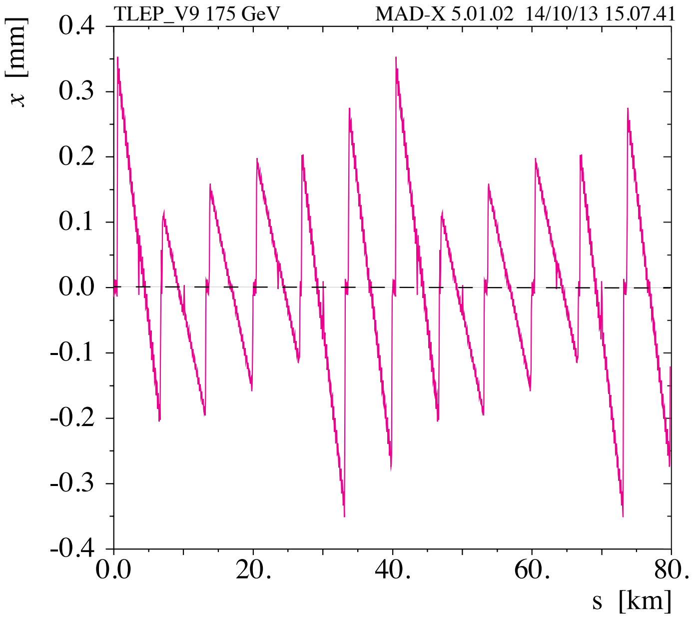
Synchrotron radiation, dipoles and quadrupoles

watch out for quads SR radiation: keep beam offset in quads small
at present, assuming no crossing angle, TLEP quads SR is smaller than in LEP -thanks to 12 RF stations and smaller emittance

LEP 100 GeV energy loss by syn. rad. U0 = 2.92 GeV/turn
Eγ mean = 0.222 MeV, 7.76 γ in 11.55 m long bend
Increased by 0.2% from quads by sawtooth and
by 0.5% from beam size of which 22% from insertion quads

TLEP 175 GeV
12 straight sections, all with RF
Sawtooth +/- 0.4 mm -->small

Prelim **TLEP** 175 GeV, U0 = 8.6 GeV
Eγ mean = 0.388 MeV, 8.13γ per 21.3 m long bend
~ 0.2% from quads by sawtooth
increase by beam size small due to small emittance



Typical Fields

	LEP	TLEP
Energy	100 GeV	175 GeV
Bending fields	0.1 T	0.06 T
Mean γ energy	0.2 MeV	0.4 MeV

circular HFs: synchroton-radiation heat load

	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

TLEP has >10 times less SR heat load per meter than PEP-II or SPEAR! (though higher photon energy)

N. Kurita, U. Wienands, SLAC

synchrotron radiation - activation

NEUTRON PRODUCTION BY LEP SYNCHROTRON RADIATION USING EGS

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

A. Fasso
3rd TLEP3 Day

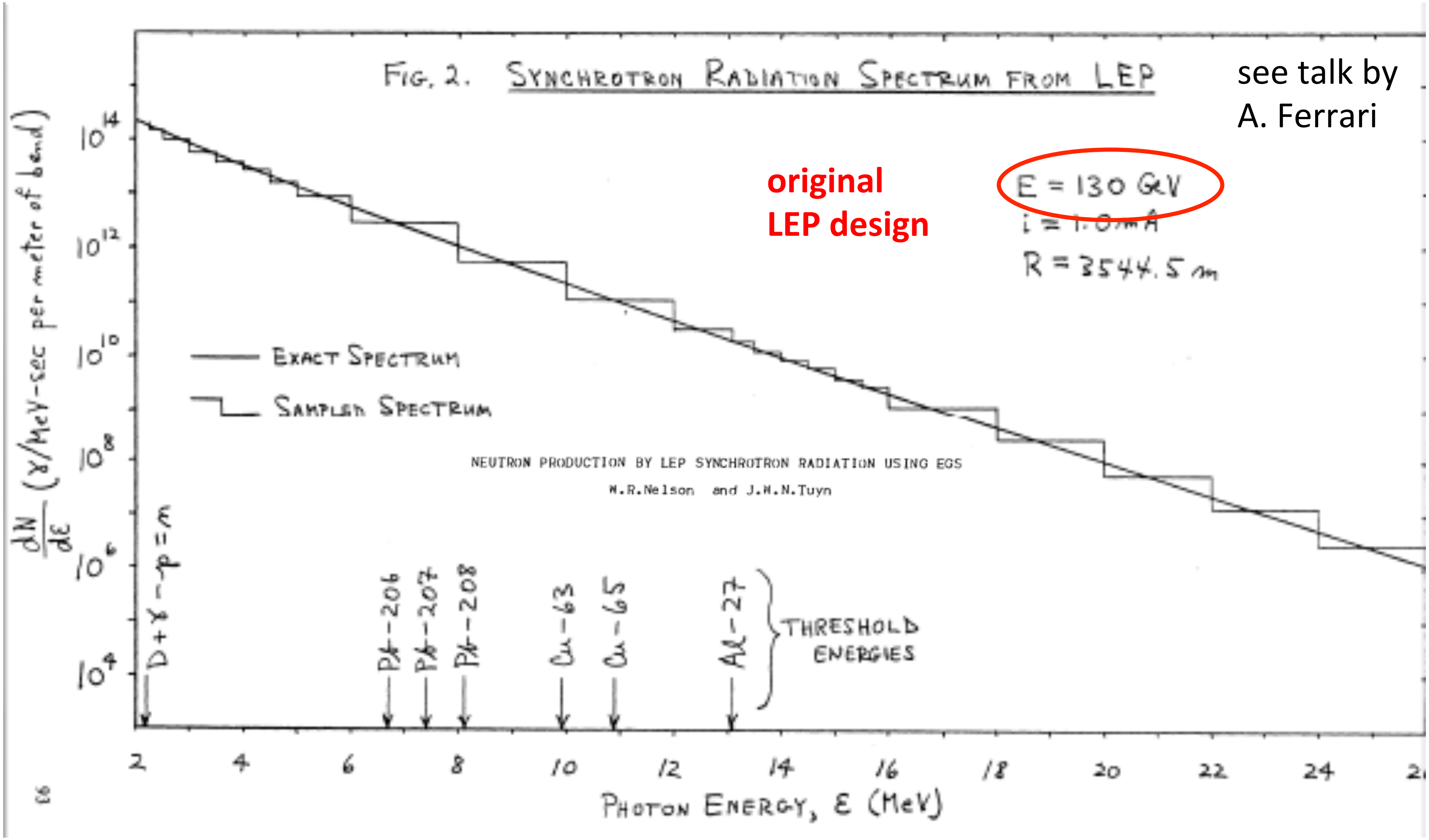


FIG. 2. SYNCHROTRON RADIATION SPECTRUM FROM LEP

NEUTRON PRODUCTION BY LEP SYNCHROTRON RADIATION USING EGS

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

see talk by
A. Ferrari

original
LEP design

High Order Modes

Last step, temporally:

- Need an engineering design:
- need location of joints and bellows
- beam pipe cross sections
- mask locations
- detector beam pipe

Simulation results may bring to re-design some part, procedure will be iterated

SuperKEKB / TLEP

parameters	unit	TLEP t	TLEP Z	SUPERKEKB	
				LER	HER
L/IP	10^{34} cm^{-2}s^{-1}	1.3	56	80	
E_{beam}	GeV	175	45	4	7
β_x*	m	1	0.5	0.032	0.025
β_y*	cm	0.1	0.1	2.7	3.0
ε_x	nm	10	30.8	3.2	4.6
ε_y	pm	10	0.07	8.6	12.9
I_{beam}	A	0.0054	1.18	3.6	2.6
$\kappa = \varepsilon_y / \varepsilon_x$	%	0.1	4.4	0.27	0.28
I_{bunch}	mA	0.45	0.27	1.44	1.04
N_{part}/beam	10^{12}	9	1960		
N_{part}/bunch	10^{11}	7.5	4.45		
n bunches	#	12	4400	2500	
σ_x*	μm	100	124	10	11
σ_y*	μm	0.1	0.27	0.048	0.062
beam lifetime	min	20	67	5	

Starting parameters (IPAC13)

- E_{beam}= 175 GeV (max energy)
- β_x*= 1m
- β_y*= 1 mm
- ε_x = 10 nm
- ε_y = 10 pm $\varepsilon_y/\varepsilon_x$=0.1%
- I_{beam} = 5.4 mA
- N_{part} = 9 10^{12}/beam – 7.5 10^{11} /bunch (12 bunches)
- σ_x* = 100 μm
- σ_y* = 0.1 μm

SuperKEKB
β_y*=300 μm
$\varepsilon_y/\varepsilon_x$=0.25%
lifetime 5 min (TLEP: ~15 min)

But, SuperKEKB is so lower in energy that lifetime/backgrounds dominated by different processes- similarity in the energy acceptance

Conclusions

- **Plans:**
  - need detailed IR design
    (L*, crossing angle, #beam pipes,..)
  - detailed study of backgrounds

- **Organization:**
  - Background optimization integrated in IR design
  - Backgrounds should not be intended to determine simply if a certain detector is feasible, but should be used to optimize the machine and the detector design