International workshop on Linear Colliders (LCWS99)
Sitges 29/4 - 5/5/1999, working group D2, friday 30 th of April

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# Machine Backgrounds common to all machines

largely based on experience with LEP

- Introduction
- off momentum
  beam-gas
  Compton scattering on black body radiation
- beam-tails
- muons
- synchrotron radiation

# Introduction

Advantage of $e^+e^-$ machines used to be:
- low background,
- well defined initial state (quantum numbers and energy)

still true ?

- Energy less well defined because of Beamstrahlung

- Clean ?
  not getting easier - higher energies and luminosities, lower $\beta$
  needs major attention : Bkg. should be understood as one
  of the main challenges and design constraints in future Linacs

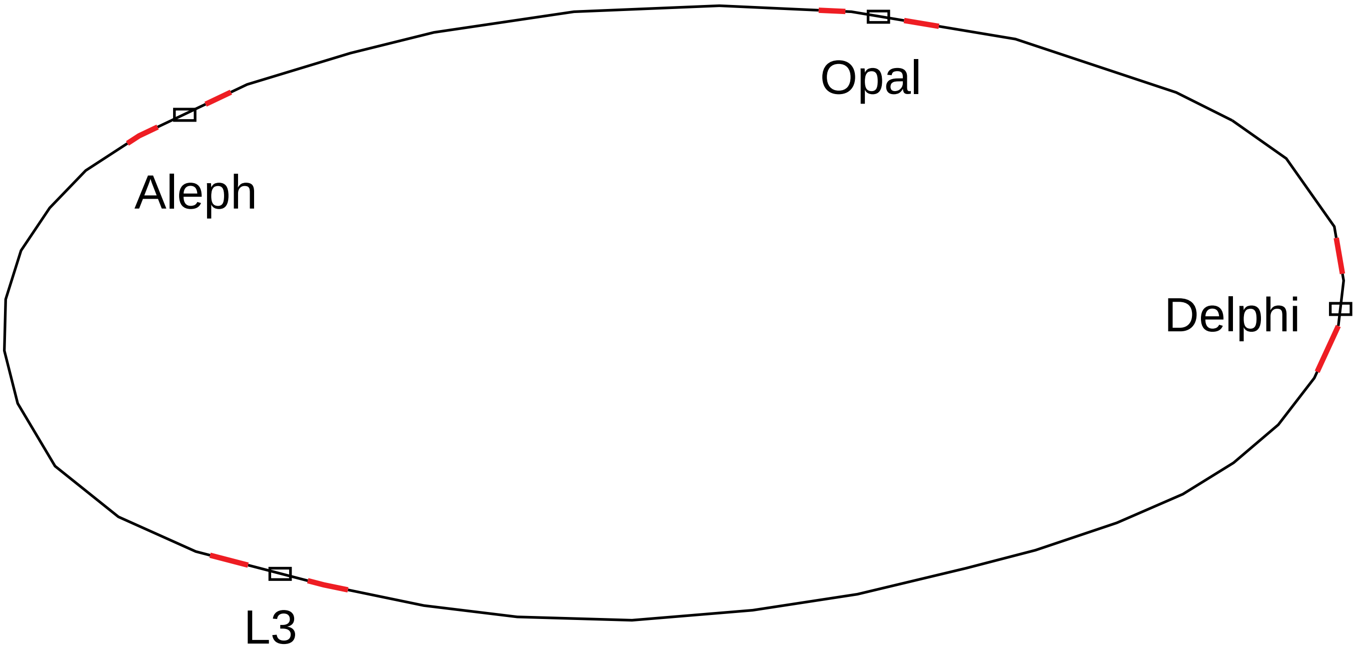
Circular machines / Linac :
- advantage of Linac:
  absence of bends and strong synchrotron radiation

  not quite true with beam delivery system (BDS)
  bending magnets used to produce dispersion in
  chromatic correction / collimation section
  --> BDS system several km long

  more difficult than in circular machines:
  Beamstrahlung and beam disruption,
  high intensity (beam power) and very small spotsize
  (how to make collimators that survive beam loss).

LEP 1999 $E_b \approx$ 100 GeV,

Loss from Synchrotron Radiation, nearly 3 GeV / turn



cavities 1999 ( 352 MHz )

| Type | No | gradient | total MV |
|---|---|---|---|
| Cu | 48 | | 100 |
| Solid Nb | 16 | 5 MV | 136 |
| Cu / Nb | 272 | 6.9 MV | 3197 |
| | | | 3.4 GV |

# **Off momentum,** observation in LEP :

particle scattering processes account for beam lifetime
(lost when outside Rf-bucket $\Delta p/p \sim 1.3$ %) and on a very low level halo/tails
typical loss rates for 6 mA beam $n=3.3 \cdot 10^{12}$ part. ($4 \cdot 10^{11}$ /bunch)

beam-beam Bremsstrahlung $\tau \approx 10$ h, $dn/dt = 9.2 \cdot 10^{7}$ /sec
Compton-thermal photon $\tau \approx 50$ h, $dn/dt = 1.8 \cdot 10^{7}$ /sec
beam -gas .5 nTorr CO $\tau \approx 100$ h, $dn/dt = 0.9 \cdot 10^{7}$ /sec

## Background:

- beam-beam Bremsstr. detailed generation with dist. cutoff
  Kleiss,Burkhardt, Comp.Phys.Comm 81:372 (1994), leaving IR, no problem
- Compton-thermal - close to beam energy, major background
  in very forward region up to 0.7 / bunch passage
  to LEP lumi monitors
- Beam Gas:
  into Experiments (> 40 mrad, $\Delta p/p > 10$ %)
  ~ .005 / bunch pass. in good conditions
  > few nTorr in straights considered as vacuum problem

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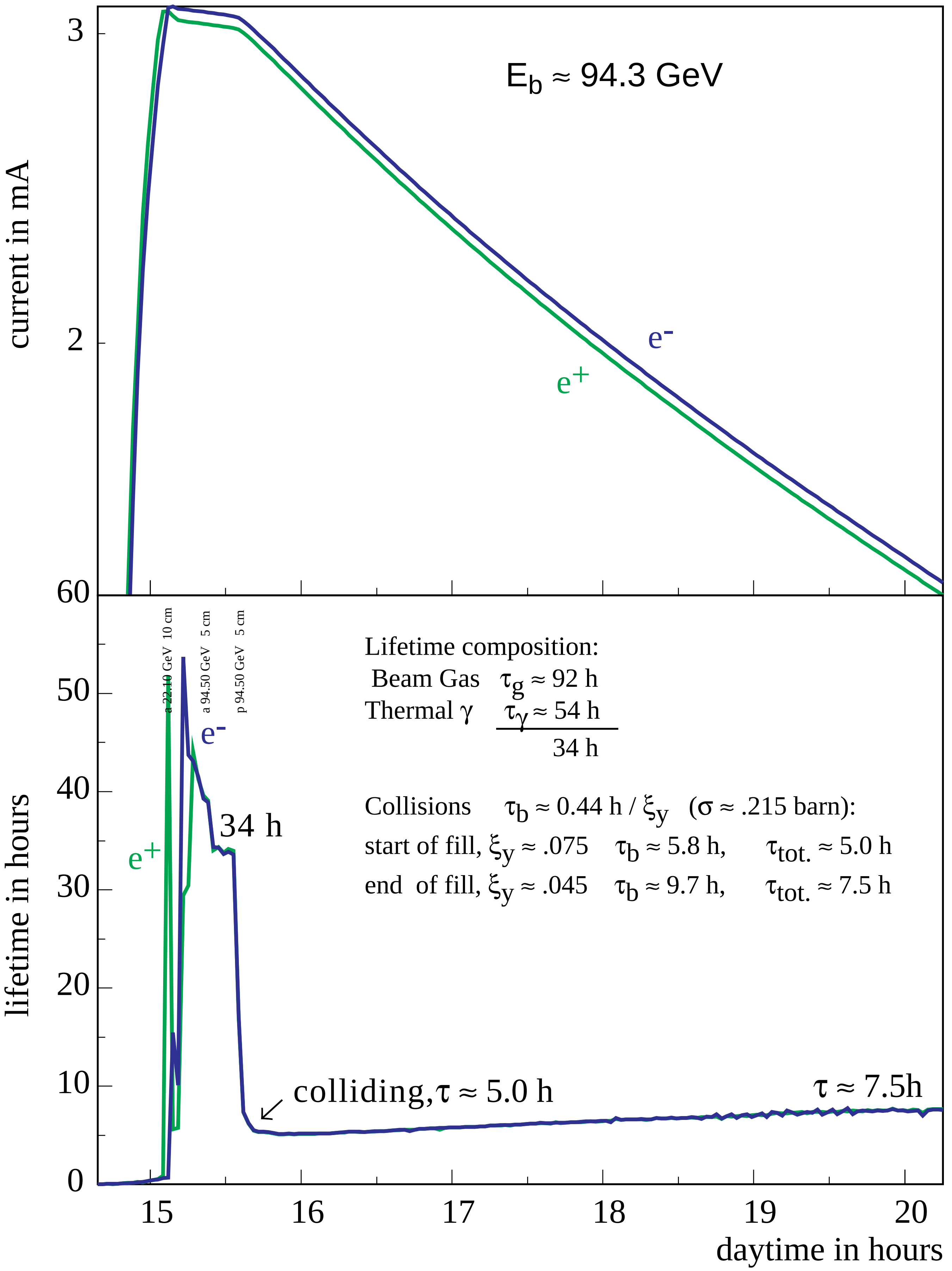
Still: LEP1 (2 • 45.6 GeV, Z production) Background limited
running at beam-beam limit - beam size growing with intensity
at some point unstable, extra tails (beam-beam resonances)
background spikes tripping experiments, lifetime drops
to some extend cured by tune, lower chromaticity, emit. increase
opening collimators
→ avoid scraping into in beam-halo close to experiments

LEP2 with lots of high gradient (7 MV/m) superconducting RF
less spikes, not Bkg. limited,
in LEP no evidence for RF induced tails

Currents and Lifetime for Fill 5259 on 4-10-1998



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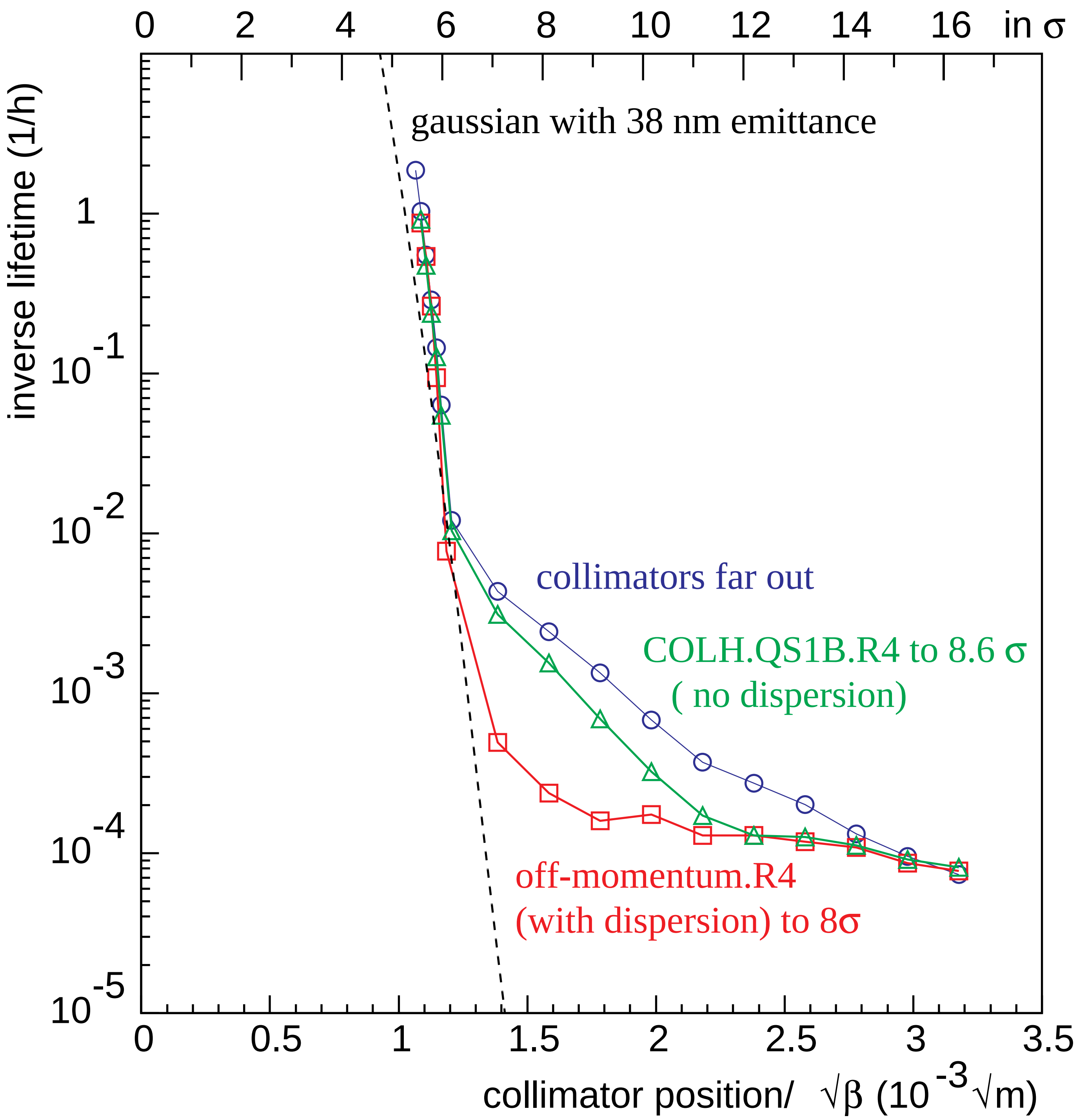
# Measured beam halo/tails at LEP2, 80.5 GeV, using movable scrapers



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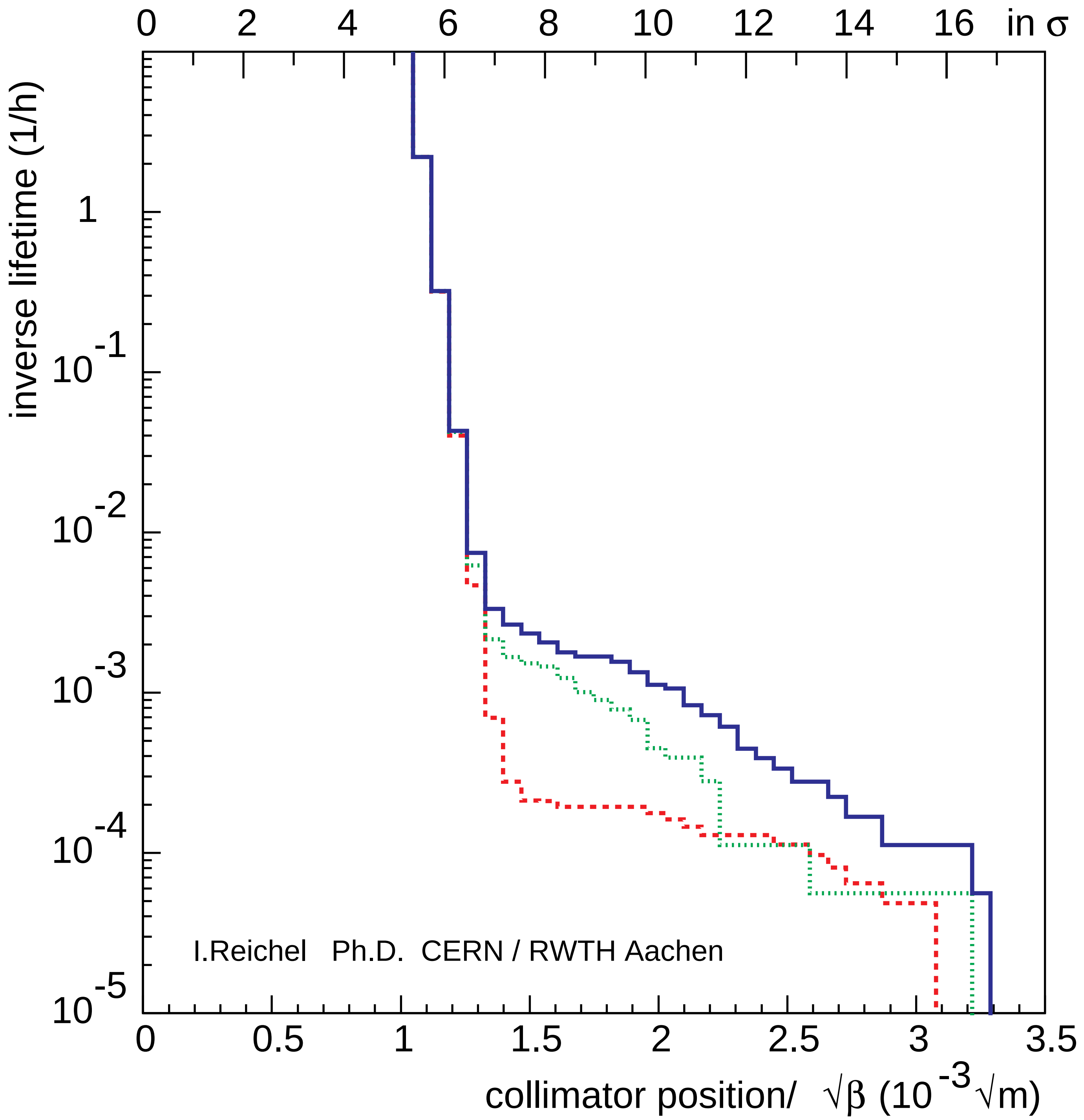
# LEP2 Beam/Halo Simulation



using thermal photon Monte Carlo + DIMAD tracking through LEP lattice

"TRANSVERSE BEAM TAILS DUE TO INELASTIC SCATTERING"

by H.Burkhardt, I.Reichel, G.Roy to be published

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# Beam Gas scattering

energy spectrum

$$\frac{d\sigma}{dk} = \frac{A}{N_A X_0}\,\frac{1}{k}\left(\frac{4}{3} - \frac{4}{3}k + k^2\right)$$

$k = E_\gamma / E_b$

| $k_{min}$ | $\int_{k_{min}}^{1} \frac{1}{k}\left(\frac{4}{3} - \frac{4}{3}k + k^2\right)\, dk$ |
|---|---|
| 1 % | 5.3 |
| 2 % | 4.4 |
| 3% | 3.9 |
| 10 % | 2.3 |

rad. length $X_0 \sim A / Z(Z+1)$, $\sigma \sim Z(Z+1)$ or roughly $\sigma \sim Z^2$

$CO \approx N_2 \approx 50 \bullet H_2$

for $N_2$ (≈CO) : $\frac{A}{N_A X_0}$ = 1.224 barn

σ = 6.5 barn for 1% loss ( 4.7 barn for 3%, 2.9 barn for 10 %)

Gas Pressure and Density:

T = 23 °C = 296.15 K, $P_{gas}$ = 1n Torr = 1.33 $10^{-7}$ Pa

$\rho = P_{gas} / kT = 3.26\ 10^{13}$ molecules / $m^3$

scattering probability with over 1 % eloss = $\rho \bullet \sigma = 2.1 \bullet 10^{-14}$ / m

generic collider:

$10^{10}$ particles, 1000 m : 0.21 off. mom. electrons/bunch (1 % loss)

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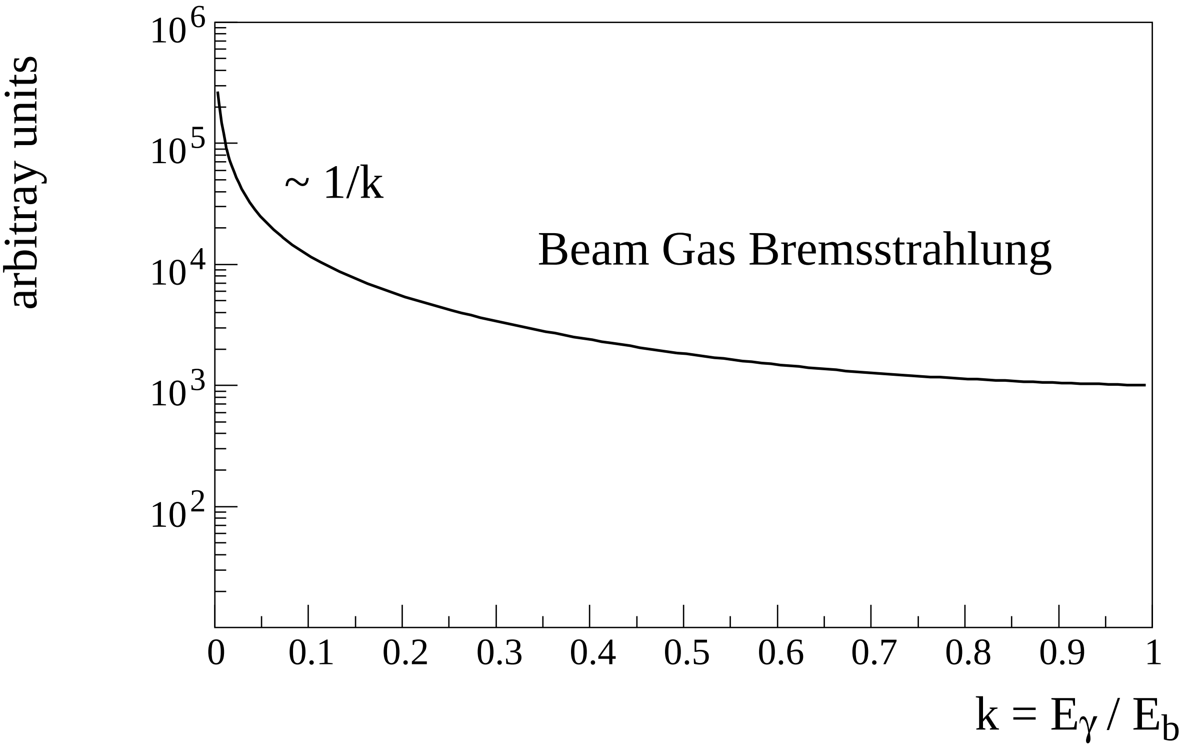

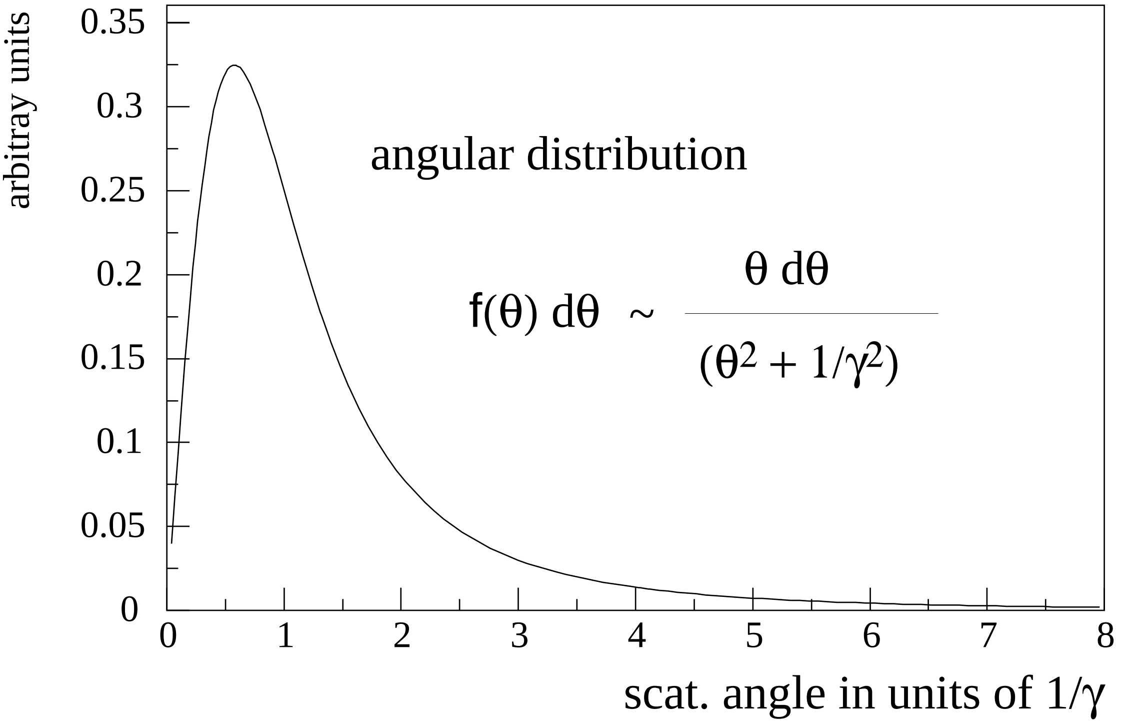

peaked at $1/\gamma$ or 2 µrad at 250 GeV, ~ negligible

# Compton Scattering on Black Body Radiation

LEP:
Observed single beam lifetime (40-70 h) dominated by
Compton scattering off thermal photons

Beam pipe at room temperature ~ 24°C
Photon density from Planck black body radiation:

$$\rho_\gamma = 8\pi \left(\frac{kT}{hc}\right)^3 \cdot \underbrace{\int_0^\infty \frac{x^2}{e^x - 1} dx}_{2\,\xi(3) \approx 2.404} \;=\; 5.3 \bullet 10^{14} \ / \ m^3$$

V.I. Telnov, NIM A260 (1987) 304-308
idea inspired by γγ-collider, known prev. in astrophysics
Compton Scattering on light from Stars, Feenberg, Primakoff Phys.Rev. 73 (1948) 449
3 K radiation, J.Felten, Phys.Rev. Lett. 15 (1965) 1003

First direct observation of thermal-photon scattered electrons and measurement of energy spectrum in LEP: A.C.Melissinos:
Dehning et al. Phys.Rev.Lett. B 249 (1990) 145.

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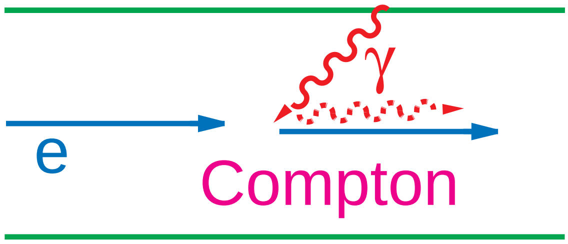
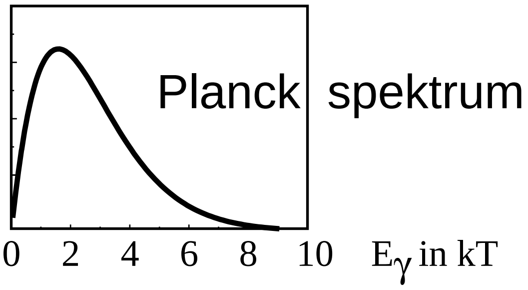
# Compton Scattering on Thermal Photons

$24^{o}$C beam Pipe black body radiator



$\gamma_{LEP2}$ = 180 000 ~ (2 • $10^5$ )

$\gamma_{250\ GeV}$ = 490 000 ~ (5 • $10^5$ )



mean energies:

initial : $E_\gamma^i$ = 2.7 kT = 0.07 eV

e-rest: $E_\gamma = \gamma E_\gamma^i$ = 6.2 keV << $m_e$ Compton

$\cong E^{*'}_{\gamma\,\mathrm{scat.}}$ ~ elastic, Thomson, .67 barn

Lab: $E_\gamma' = \gamma E_\gamma^{*'} \cong \gamma^2 E_\gamma^i$

~ 2.2 % $E_b$ 90 GeV (LEP2)

~ 5.3 % $E_b$ 250 GeV

effect in LEP:
particles with more than ~ 1% Δp/p get lost (Rf-bucket)
up to 3% Δp/p travelling through arcs, halo / tails
major Background source at low angles
( ~ 3 • $10^4$ el./ sec hitting LEP-lumi calorimeters)

detailed Monte Carlo Simulation, event-generator Planck+Compton (H.B. SL/Note 93-73)
+ tracking through LEP lattice, tail simulation (PAC 1997)

see my homepage http://wwwcn.cern.ch/~hbu/

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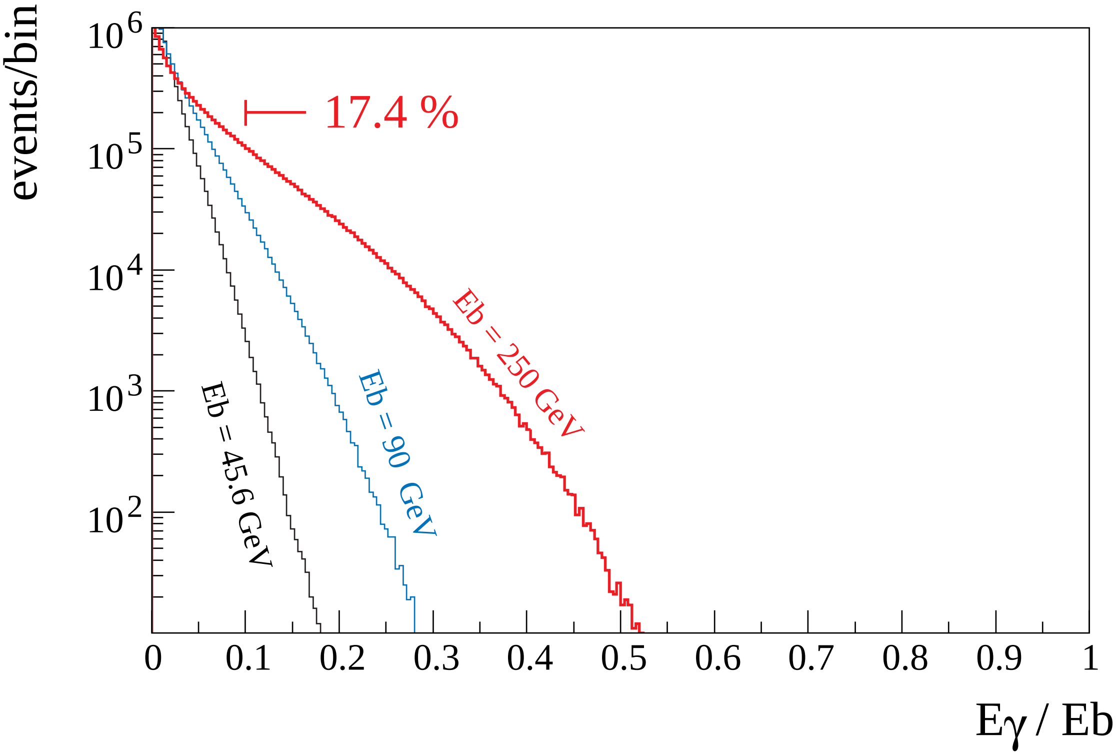
# Spectra and Normalization



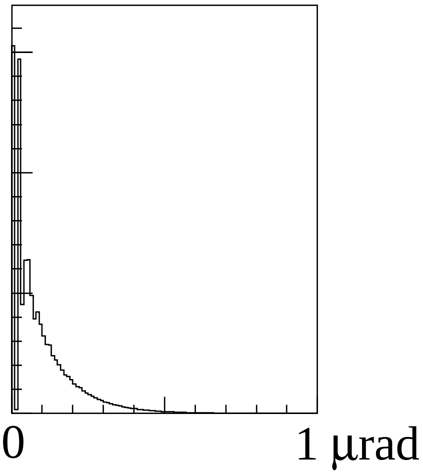
beam lifetime if all scattered particles were lost

$$\tau_{min} = \frac{1}{\rho_\gamma \ c \ \sigma_T} = 26.17 \text{ hours}$$

LEP2 90 GeV, Δp/p accept (RF-bucket) ~1.2 %, half of scatt. lost -> $\tau$ = 55 hour

electron scattering angle
in Lab:

~negligible (~independent of $E_b$)



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# Bkg from thermal photons

cross section:

$\sigma_T = 8\pi/3\ r_e^2 = 0.6652$ barn

at 250 GeV $\sigma = 0.89 \cdot \sigma_T = 0.59$ barn

Phot. density, room temp. (24°C) $\rho\gamma = 5.32 \cdot 10^{14}$ /m3

scat. prob = $3.14 \cdot 10^{-14}$ / m

for bunch of $10^{10}$, 1000m : 0.314 Compt. scatt. / bunch

| $\Delta p/p$ | fraction | |
|---|---|---|
| 0 - 1 % | 26 % | ( or 74.3 % > 1 %) loss |
| 1 - 2 % | 14 % | tail particles |
| 2 - 5 % | 24 % | |
| 5 - 10 % | 19 % | more locally lost |
| > 10 % | 17 % | |

generic linear collider, $10^{10}$ particles/bunch, over 1000 m

number of Compt scatt. per bunch with eloss of:

0.23 with $\Delta p/p >$ 1 %

0.16 with $\Delta p/p >$ 3 %

0.05 with $\Delta p/p >$ 10 %

similar to Bremsstrahlung on 1 nTorr

# Off Momentum Bkg, Linear Collider

wanted ( number of off. particle hits / bunch ):

< 0.01 in detector ( > 30 mrad, to allow veto for searches and
good lumi meas.)

and not much more hitting within ~100 m around IP ($\gamma$'s from shower)

simulations give rather comparable numbers for different machines,
expectations roughly
bunch of $10^{10}$ particles, production over 1000 m:

Beam Gas Bremsstr.:
1 nTorr CO : 0.21 / bunch with >1% loss (.1 for >10%)

~ 1/5 hitting last 200 m 0.04 / bunch
~ 1/10 hitting detector 0.005 / bunch

+ about the same from Compton scattering on thermal Photons
or together about 0.01 / bunch

aim for vacuum of 1 nTorr

# Muon Background

~ negligible in LEP

production: stopping beam particles - cleaning tails
~ $4 \bullet 10^{-4}$ μ per primary electron

generic Linear collider: $10^{10}$ el./bunch
if $10^{-3}$ in tail, cleaning by collimator : 4000 μ's /bunch

several 100 μ's /bunch can reach the IP unless:

collimation done as far as possible from IP
magnetic fields (toroids) to sweep away the μ's

LEP experience:
only fundamental reason for halo are scattering processes

for good vacuum 1nTorr : scat. Prob 2.1 $10^{-14}$/m
- 10 km Linac : $2 \bullet 10^{-10}$ or only 2 part./ bunch in tails
  now fundamental reason to have problems with tails / μ's

--> Invest in understanding / eliminating the halo
- collimation sections with movable scraper/loss detector
- good vacuum everywhere, low residual dispersion

several stages of toroids as fallback solution

# Synchrotron Radiation

strongly dependent on BDS layout and collimators,

some comments, based on

- LEP experience: Synchr. Rad enormous
  LEP2 6•$10^{20}$ $\gamma$/sec , Ecrit = 630 keV, P ≈ 18 MW,
  every electron radiates on $\gamma$ every ~ 1.6 m
  experiments very well screened

main arc radiation: well kept away from experiments,
10 % dipoles + horiz. coll. at beginning of straight section
surprise - background from multiple reflection
specular reflection of X-rays at very small angles

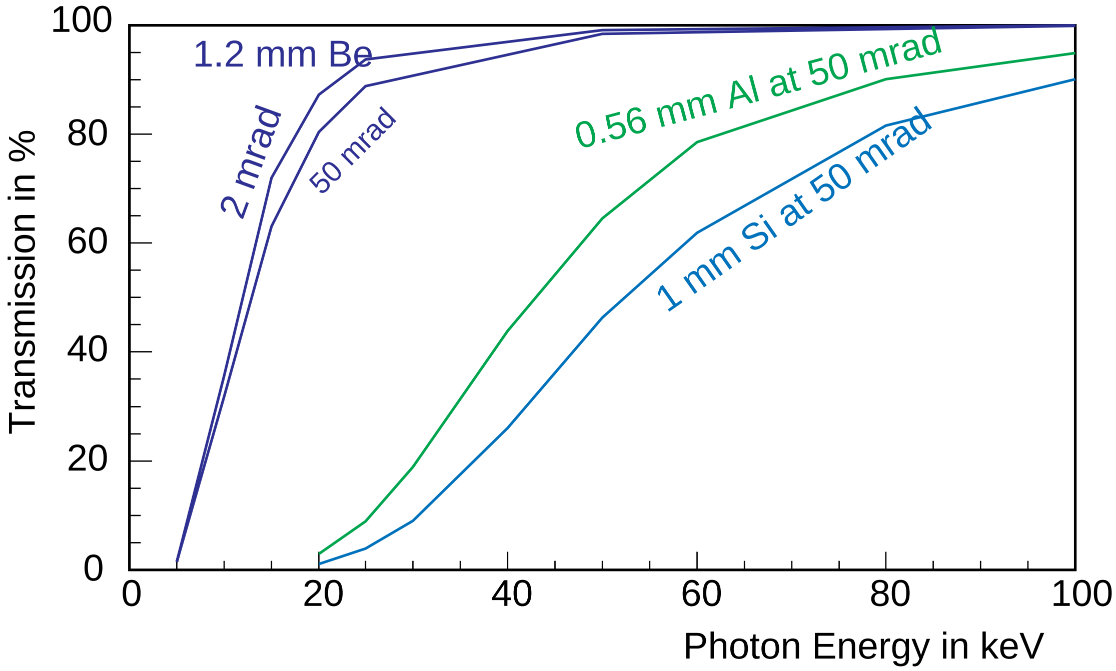
radiation from quads ~ 2.5 $\gamma$ per electron in straight section :
2 pairs of V-coll, 2 pairs of H-coll. and mask at each Expt
no direct, only scattered synchrotron light can reach experiments
seen mainly: ~ backscattered synchr. light from quads
few $\gamma$'s detected (TPC) / crossing (45 kHz cross. rate)
no problem with occupancy
however current drawn by gas-chambers (~50nA) not far from tolerable limit

Bkg spikes: unstable with halo producing showers and hard synchr. rad. in quads

LEP1 -> LEP2 (improved coll. and masks in LEP2)
overall level increased, more stable, less BKG spikes

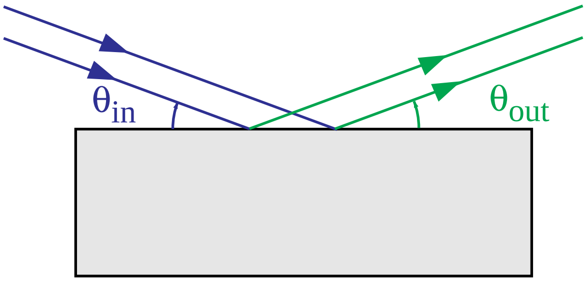
# X-Ray Transmission

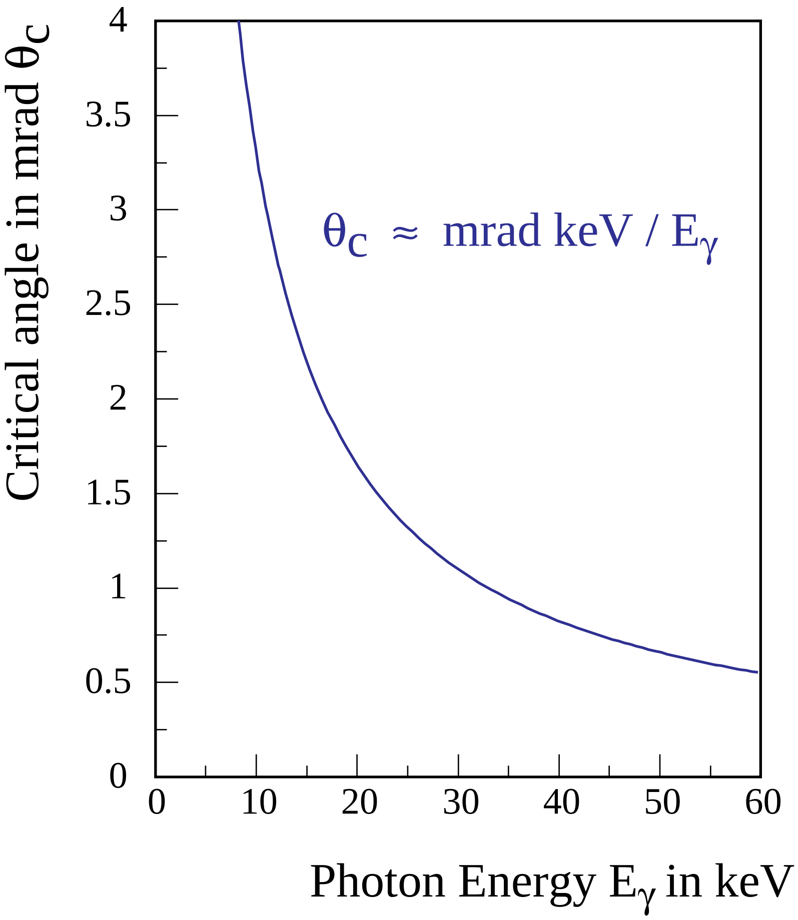
**already rather soft x-rays ( ~ 30 keV) have to be considered:**



## they can undergo (multiple) X-Ray Specular Reflection

specular reflection





reflectivity for
specular reflection:

below $\theta_c$ : nearly 100 %
very quickly dropping above
i.e. :
at 1 mrad up to 33 keV
at 100 µrad (1cm in 100m) up to 330 keV

see : Batterman and Bilderback in Handbook on Synchrotron Radiation Vol.3 Eds G.S.Brown, D.E.Moncton, Amsterdam: North Holland, 1991, pp 120-124,

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from G.von Holtey, A.H.Ball et al., NIM A 403 (1998) 205-246

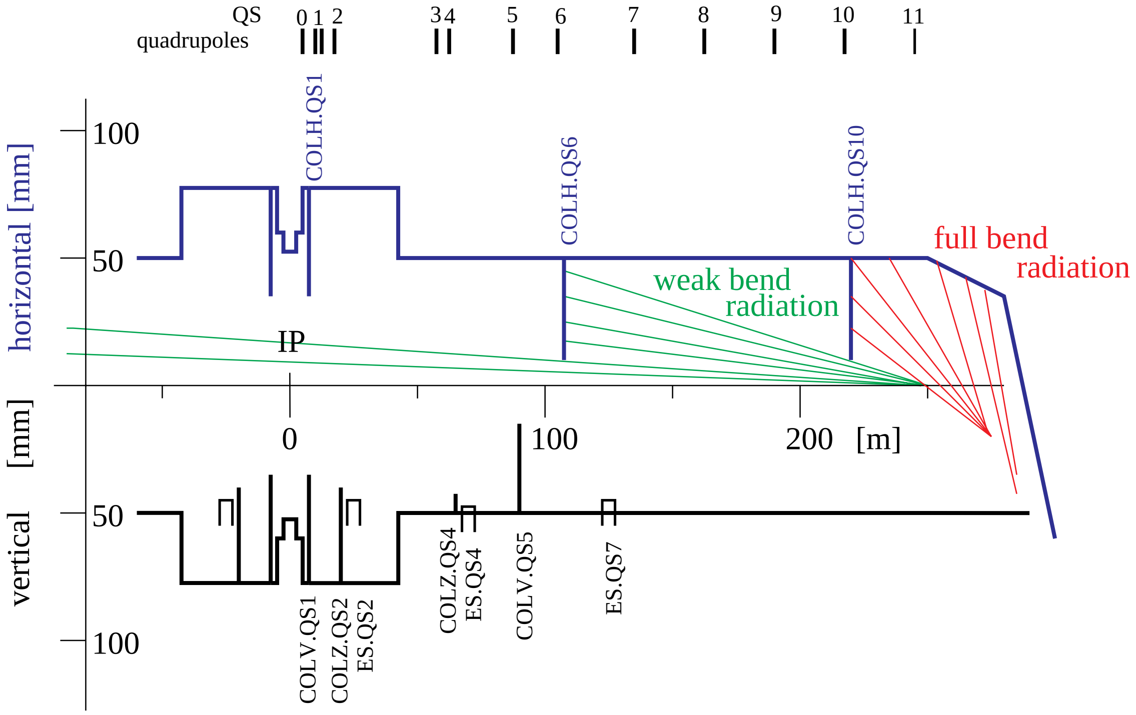

Fig. 2. Layout of the straight section around IP4 or IP8 in the horizontal and vertical planes. Shown are the locations of quadrupoles (QS) , electrostatic separators (ES) and collimators (COLH, COLV, COLZ). The solid lines mark the inner vacuum chamber radii for the LEP1 layout.

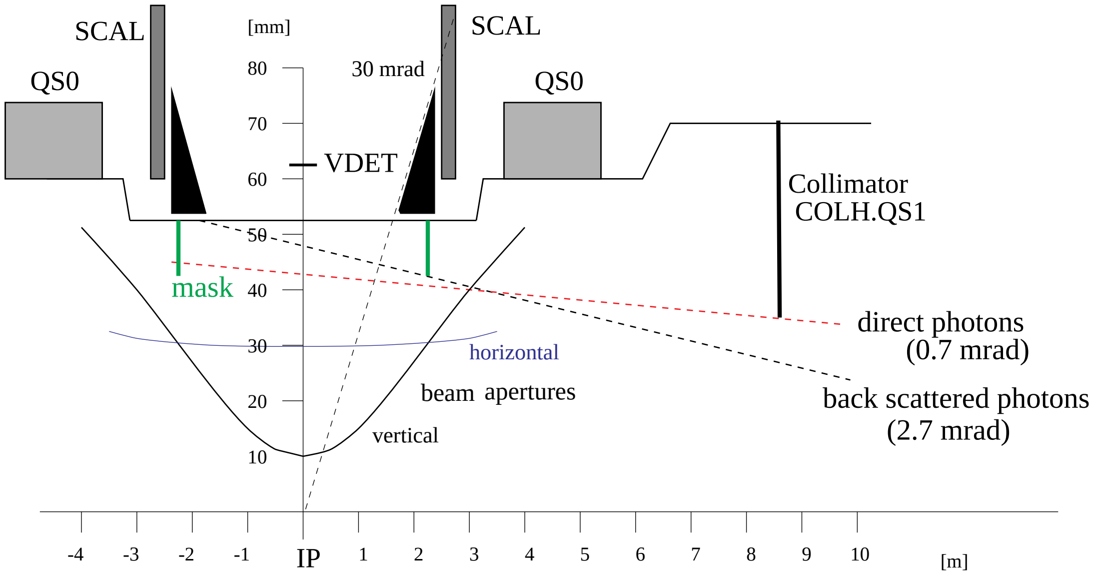

Fig. 9. Schematic layout of synchrotron radiation masks around a LEP IP, indicating the boundary conditions for a mask solution: (i) to stay outside the required LEP aperture (solid lines, marked horizontal and vertical), (ii) to cast a shadow over the entire unshielded IP beampipe length for small angle backscattered photons (dashed line), (iii) to stay outside the very intense beam of direct photons collimated by the near (8.5 m) synchrotron radiation collimator, when closed to 12 beam standard deviations (dashed line).

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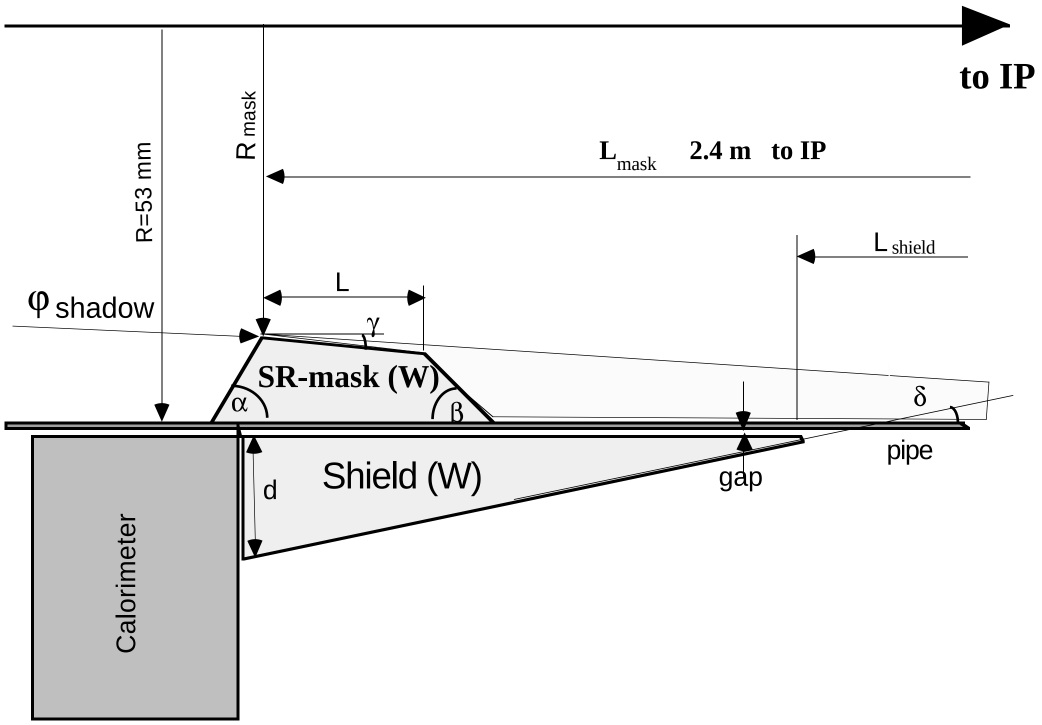
# Mask and Collimator Design Some ideas

- Collimators/Masks are there to stop particles
  at the same time source of scattered particles.

for collimators/mask closest to IP:

--- optimize material and surface angle ---

material:
Reduce Fluorescence photons from surface by coating
LEP collimators made of tungsten, the closest ones
to the IP are W coated with Ag/Cu layers



LEP IR. region. Cut through cylindrical mask and outer shield

# Summary

Good experimental (Background) conditions:
one of the main challenges and design constraints
of future $e^+e^-$ Linacs

Vacuum : aim for $10^{-9}$ Torr

Synchrotron radiation:
collimators also source of scattered particles
collimate close to background sources
careful design for collimators/mask close to IP

no fundamental reason to have substantial amount of halo

- avoid scraping in high energy beams
- monitor / clean in all stages
  after damping rings, compressors, Linac
- good vacuum everywhere