Background and Machine Detector Interface

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- Luminosity and Spectrum
- Crossing Angle
- Background
- Masks etc.

- Lots of work had been done for the CLIC Physics Report

  need to get dust of different tools

  will put more emphasis on new calculations on demand

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Basic Parameters

- CLIC aims to achieve a luminosity similar to the ILC level at much higher energy

		CLIC	ILC	NLC
E_{cms}	$[TeV]$	3.0	0.5	0.5
f_{rep}	[Hz]	50	5	120
N	$[10^9]$	3.7	20	7.5
ϵ_y	$[nm]$	20	40	40
L_{total}	$10^{34}cm^{-2}s^{-1}$	5.9	2.0	2.0
$L_{0.01}$	$10^{34}cm^{-2}s^{-1}$	2.0	1.45	1.28
n_γ		2.2	1.30	1.26
$\Delta E/E$		0.29	0.024	0.046

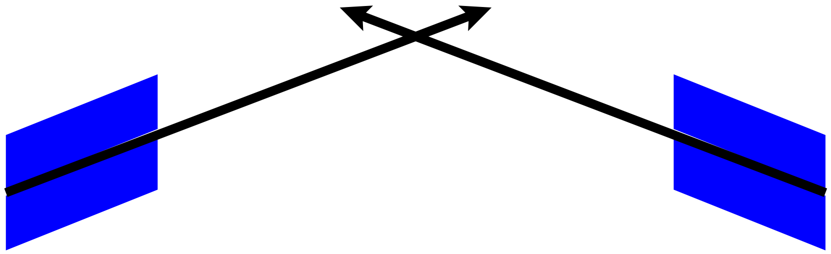
- Luminosity is delivered in 50 pulses per second
- Each pulse lasts about $150\,\mathrm{ns}$, contains 312 bunches spaced by $0.5\,\mathrm{ns}$
- In ILC luminosity is delivery by pulses with 5 Hz
- Each pulse is about $1\,\mathrm{ms}$ long

$\Rightarrow$ Very different regime

  - event reconstruction
  - background conditions

- High energy also affect background level

Interaction Point Layout



- Distance L^* between final quadrupole and interaction point can be chosen
  - below $3.5\,\mathrm{m}$ luminosity is compromised (R. Tomas)
  - $4.3\,\mathrm{m}$ and $3.5\,\mathrm{m}$

  yield similar luminosity

- Design of final doublet is challenging
  - high gradient required
  - support needs to be very stable
    detectors can be quite noisy
  - a permanent magnet design has been done (S. Russenschuck et al.)
  - but energy adjustment of beam delivery system is limited
  - superconducting quadrupoles are very though
    in particular stability
  - but would allow energy adjustment
  - maybe a combined approach is possible

Luminosity and Luminosity Spectrum

- Four main sources of energy spread at the IP

  - initial state radiation

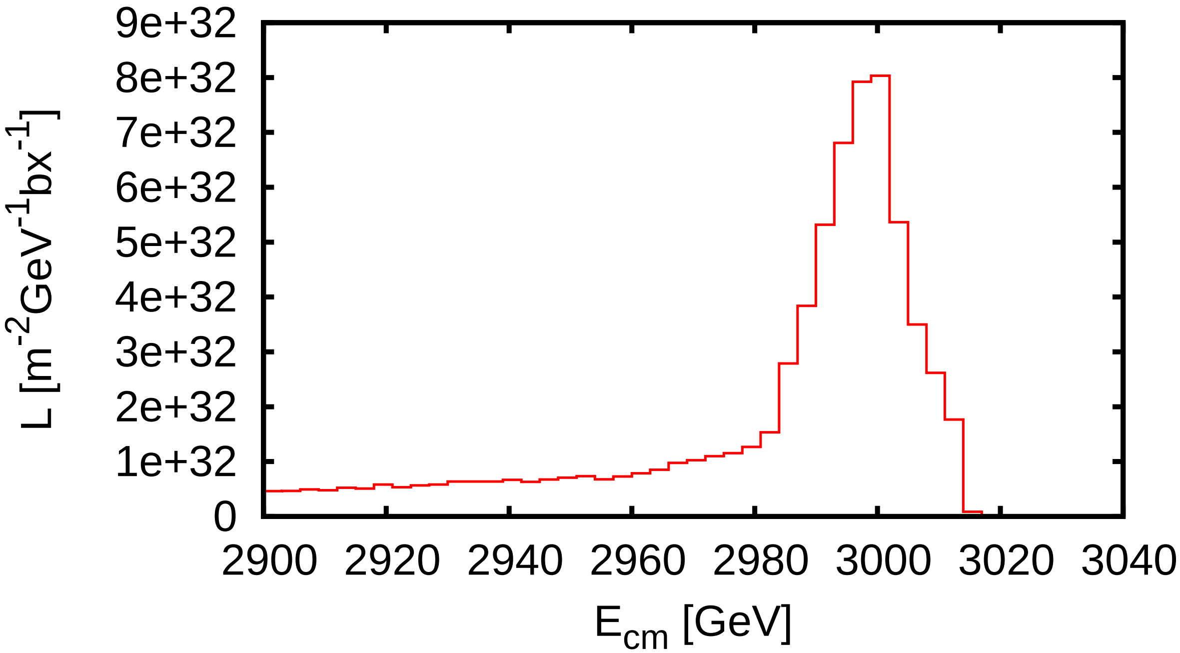
    $\Rightarrow$ unavoidable

    $\Rightarrow$ has sharp peak

  - beamstrahlung

    $\Rightarrow$ similar shape as ISR

    $\Rightarrow$ can be reduced by reducing luminosity



- single bunch energy spread

  due to single-bunch beam loading and RF curvature

  $\Rightarrow$ part cannot be avoided

  $\Rightarrow$ helps in stabilising the linac

  $\Rightarrow$ $\mathcal{O}(1\,\%)$ (better for ILC)

  $\Rightarrow$ now included in simulation

- bunch-to-bunch and pulse-to-pulse variations

  $\Rightarrow$ $\mathcal{O}(0.1\,\%)$

Impact of Luminosity Spectrum

- Reduced production in a resonance

  ⇒ effectively reduced luminosity
- Impact on threshold scans

  ⇒ modified effective cross section, step is less steep
- Two-peak separation

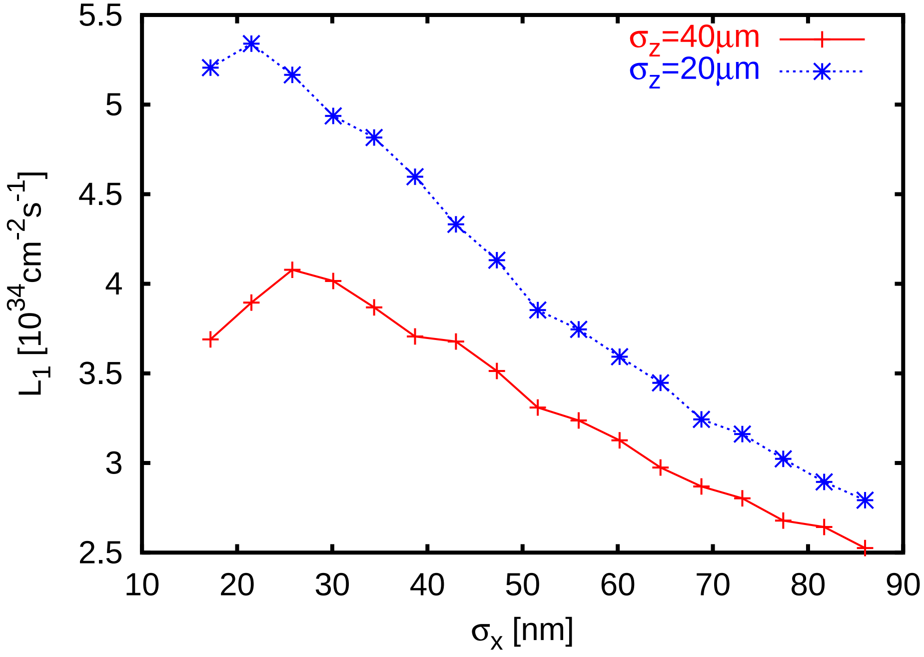
  ⇒ mainly due to single bunch energy spread
- Missing mass analysis

  ⇒ initial conditions are wrong
- Impact on constraint fits

  ⇒ initial conditions are wrong
- Difficulty in spectrum reconstruction

  ⇒ important value not directly measured, correlations are important

Beamstrahlung and Luminosity Optmisation

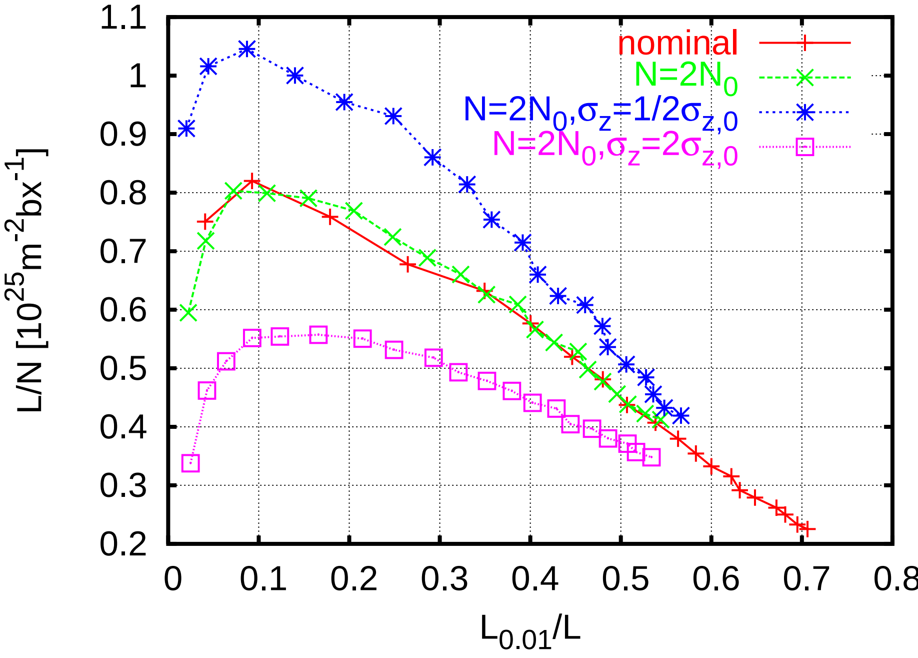


Total luminosity for $\Upsilon \gg 1$

$$\mathcal{L} \propto \frac{N}{\sigma_x}\frac{\eta}{\sigma_y} \propto \frac{n_\gamma^{3/2}}{\sqrt{\sigma_z}}\frac{\eta}{\sigma_y}$$

large n_γ ⇒ higher $\mathcal{L}$ ⇒ degraded spectrum

$$\mathcal{L}_{0.01} \propto \frac{\left(1-\exp\left(-n_\gamma\right)\right)^2}{\sqrt{n_\gamma}}\frac{\eta}{\sqrt{\sigma_z}\sigma_y}$$



chose n_γ, e.g. maximum $L_{0.01}$ or $L_{0.01}/L =$ 0.4 or ...

$$\mathcal{L}_{0.01} \propto \frac{\eta}{\sqrt{\sigma_z}\sigma_y}$$

Reduction of Incoming Energy Spread

- Bunch-to-bunch and pulse-to-pulse variations should be limited to about 0.1% RMS

  ⇒ already difficult to achieve

  ⇒ a reduction would have enormous impact on machine design

- Intra-bunch energy spread can be reduced by reducing the bunch charge

  ⇒ change is always relative to the optimum choice for a given accelerating structure

- Currently optimise for 0.35% RMS energy spread

  ⇒ seem to be able to reach 0.1% with $N = 0.5N_0$

  ⇒ full test of beam stability required

  - luminosity L_1 is reduced to about 30%
  - beamstrahlung is also reduced

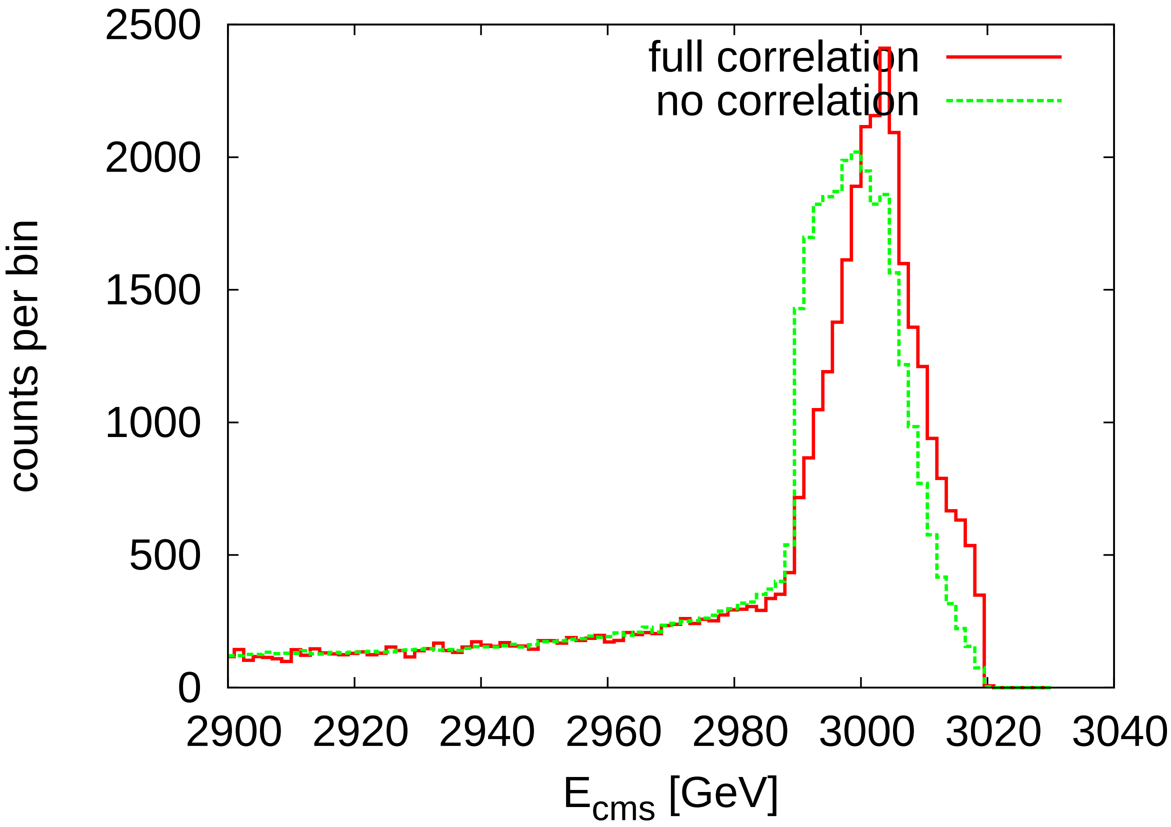
Luminosity Spectrum Reconstruction

- Luminosity Spectrum reconstruction is a challenging task
- One proposed method is to measure Bhabha angles

$$p_{\perp,1} = -p_{\perp,2} \quad \Rightarrow \quad \frac{p_1}{p_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

- Initial transverse momenta could be different
  - is noticeable in ILC

  ⇒ needs to be studied for CLIC



- Need model to seperate the beams
- Simple test remix colliding beam particle energies

  ⇒ different spectrum

  ⇒ correlations are important

⇒ Further study needed

Background Sources

- Machine produced background before IP
    - beam tails from linac
    - synchrotron radiation
    - muons
    - beam-gas, beam-black body radiation scattering (linac+BDS)
- beam-beam background at IP
    - beamstrahlung
    - coherent pair creation
    - incoherent pair creation
    - hadron production
    - neutrons
- spent beam background
    - backscattering of particles
    - especially neutrons

Crossing Angle

- Three main constraints on crossing angle exist
  - extraction of the spent beams without excessive losses
    lower limit
  - multi-bunch kinck instability
    lower limit
  - synchrotron radiation emission in the detector solenoid field
    upper limit
- Simplified simulations of the effect of synchrotron radiation in a detector field of $B_z = 4\,\mathrm{T}$ required (F. Zimmermann)

$$\theta_c \leq 20\,\mathrm{mradian}$$

$\Rightarrow$ this study needs to be repeated with more realistic fields

- The multi-bunch kinck instability is given by

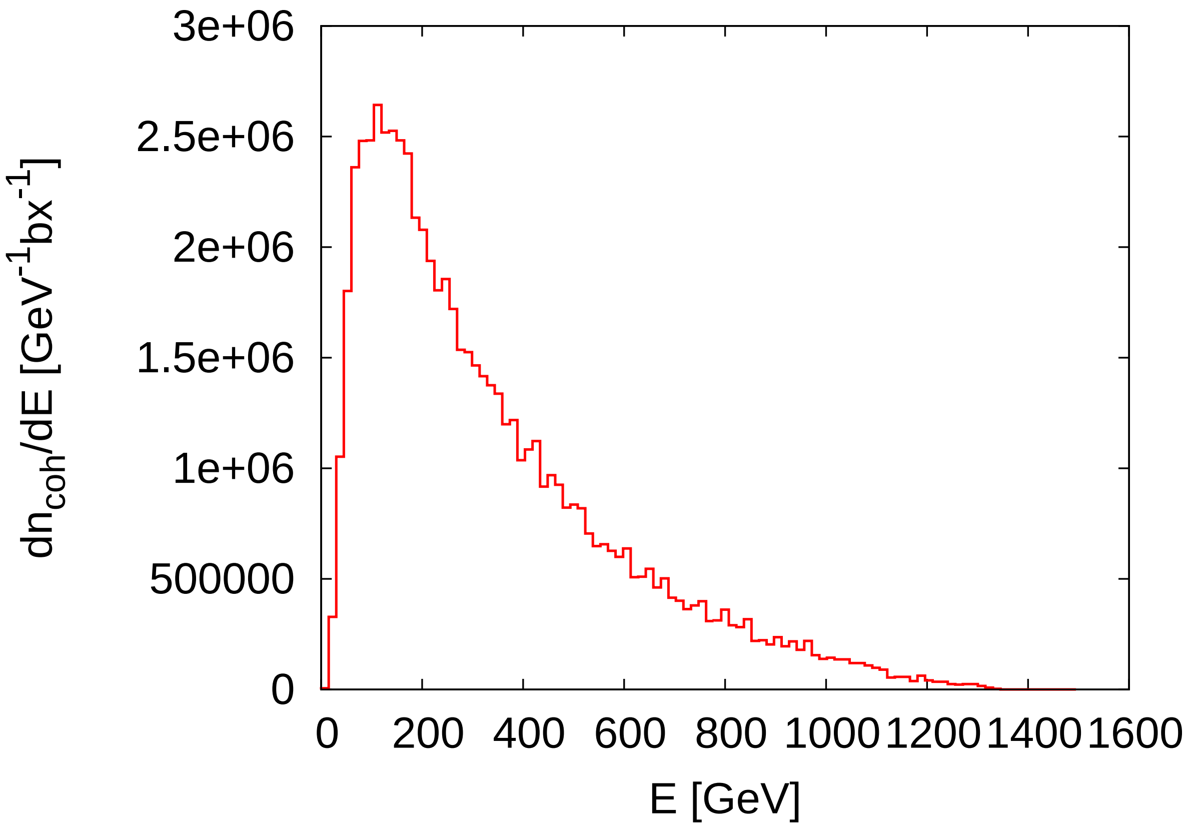
$$\Delta y = \frac{\Delta y_0}{1 - n_c \frac{4Nr_e}{\gamma\theta_c^2}\frac{\delta y'}{\delta \Delta y_0}}$$

Coherent Pairs

- Coherent pairs are generated by a photon in a strong electro-magnetic field
- Cross section depends exponentially on the field

⇒ Rate of pairs is small for centre-of-mass energies below $1\,\mathrm{TeV}$

⇒ In CLIC, rate is substantial



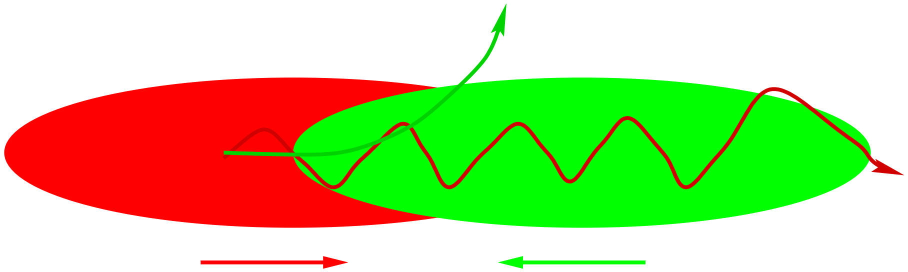
Need to foresee large enough exit hole (about 10mradian)

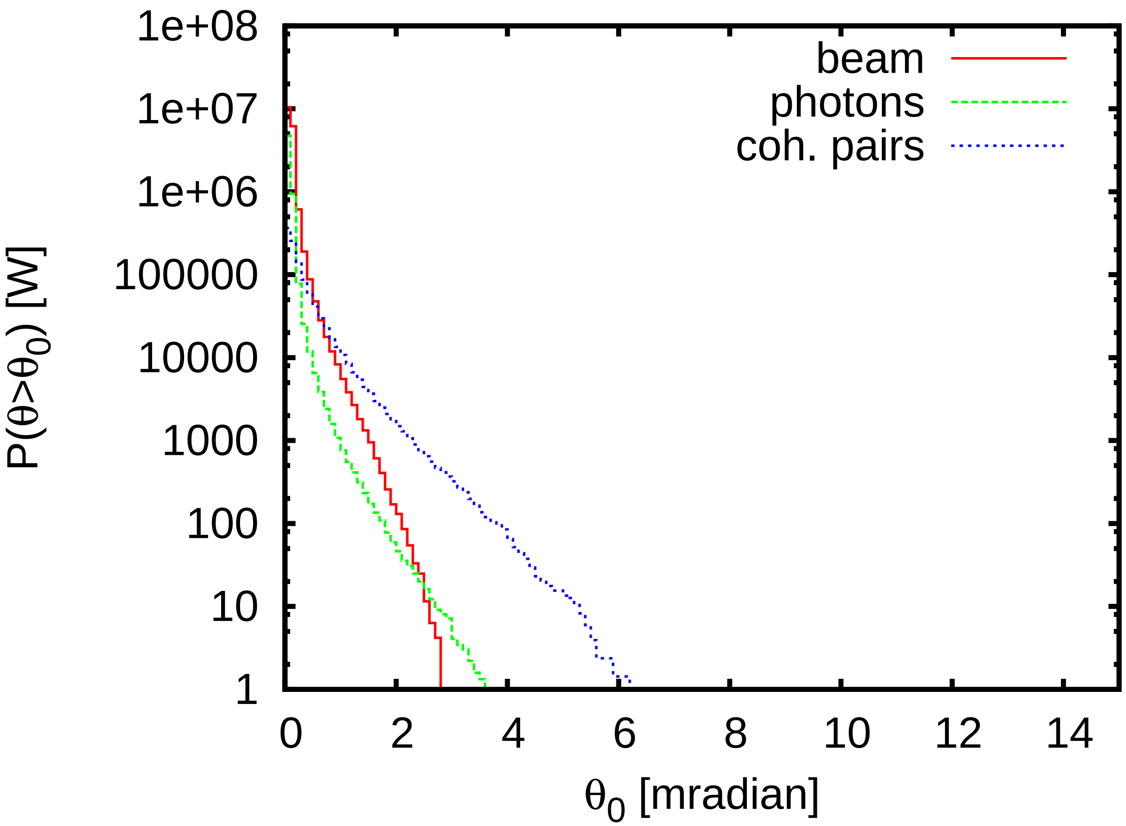
Spent Beam and Crossing Angle

- Crossing angle needs to be large enough to extract spent beam
- For new parameters we need 10mradian angle
  - plus space for quadrupole (2cm in an old design)

⇒ 20 mradian seems OK

- Somewhat smaller angles seem feasible
  - maybe 14 mradian





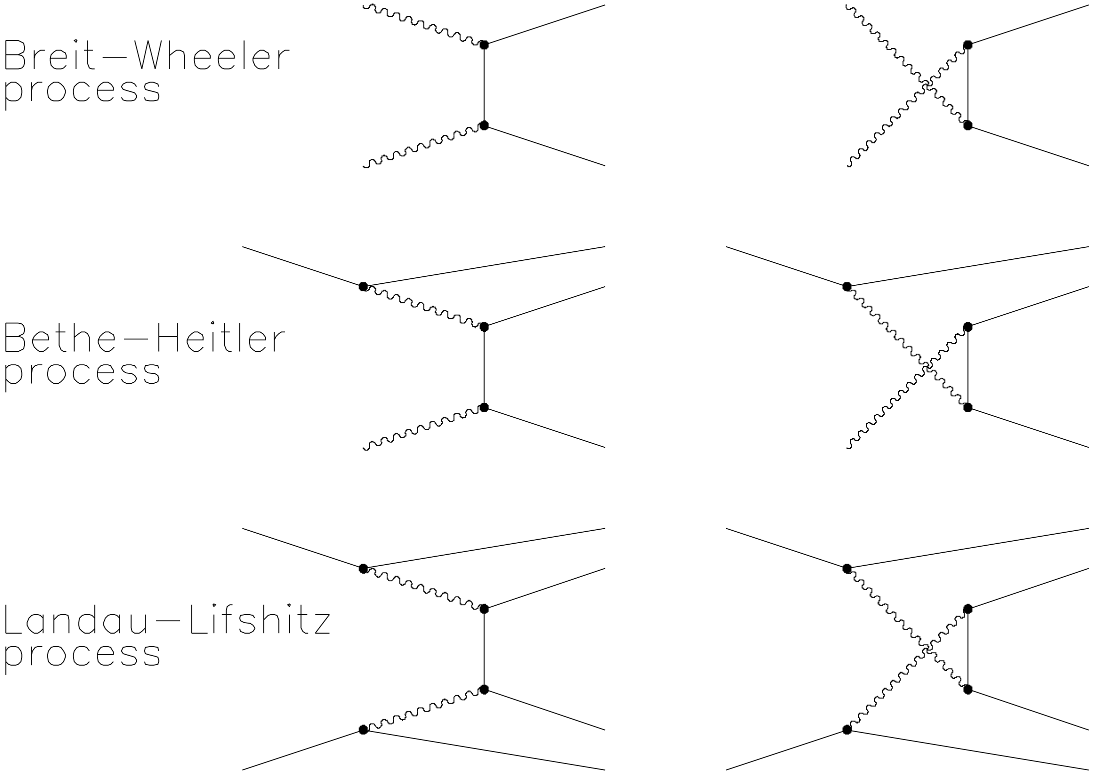
Incoherent Pair Production

Three different processes are important

- Breit-Wheeler
- Bethe-Heitler
- Landau-Lifshitz

The real photons are beamstrahlung photons

The processes with virtual photons can be calculated using the equivalent photon approximation and the Breit-Wheeler cross section



Deflection by the Beams

Most of the produced particles have small angles

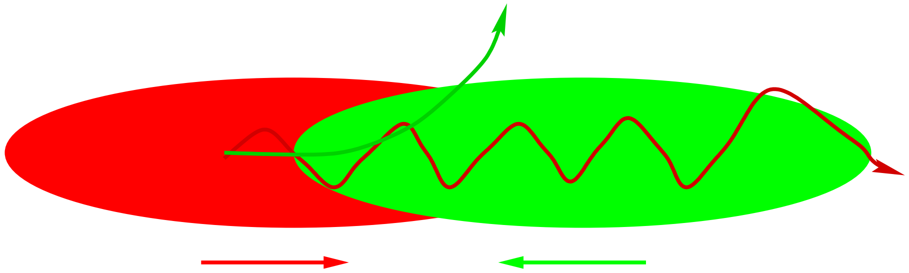
The forward or backward direction is random

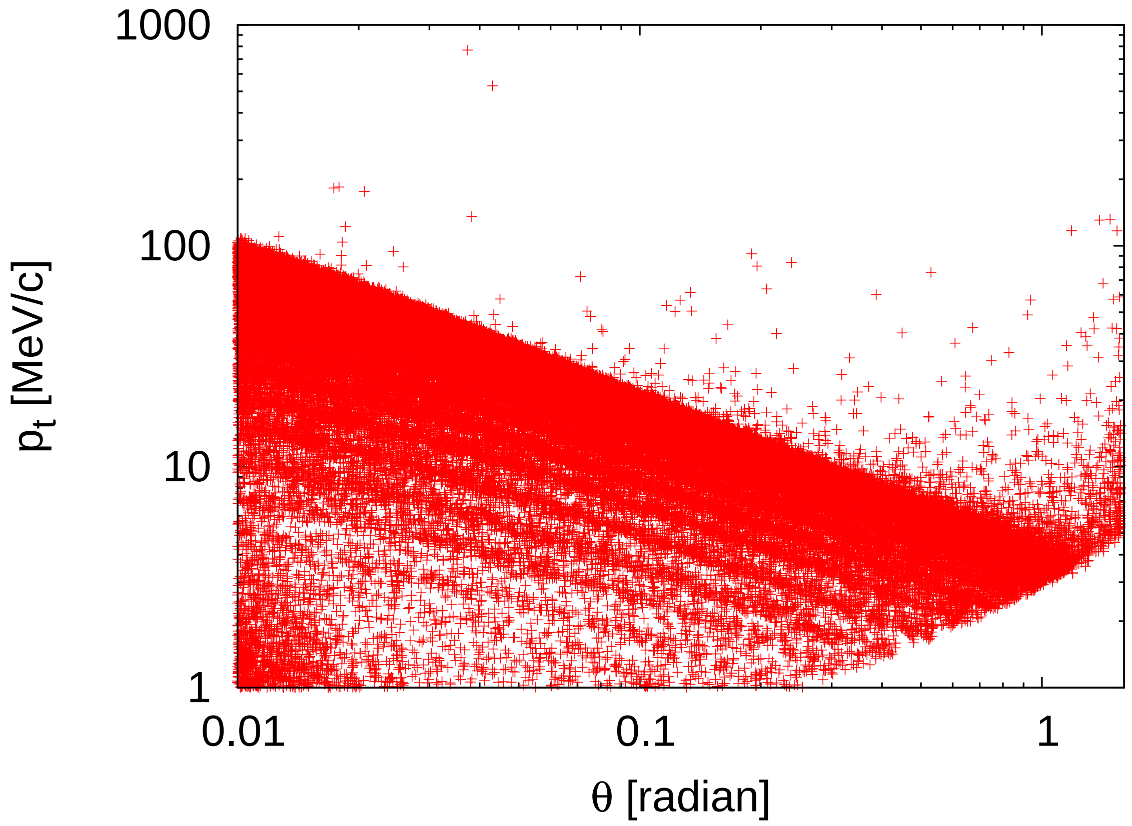
The pairs are affected by the beam

$\Rightarrow$ some are focused some are defocused

Maximum deflection

$$\theta_m = \sqrt{4\frac{\ln\left(\frac{D}{\epsilon}+1\right) D\sigma_x^2}{\sqrt{3}\epsilon\sigma_z^2}}$$





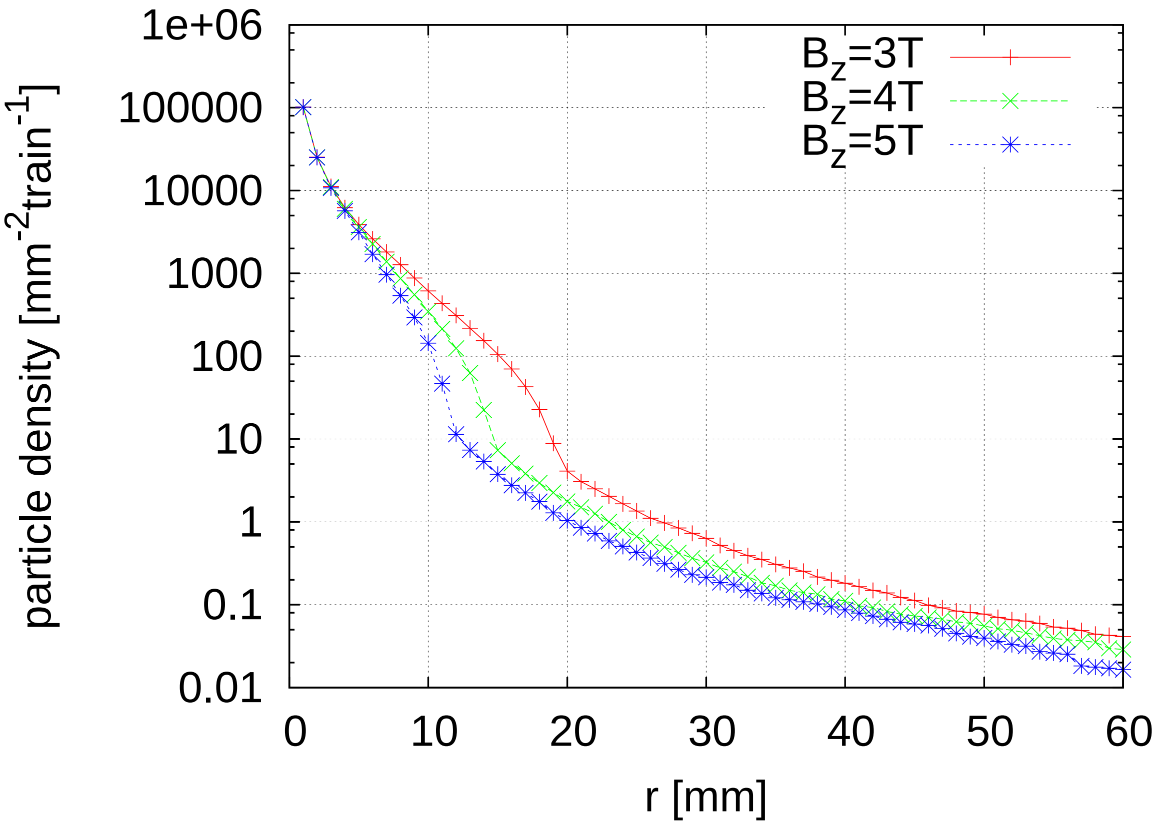
Impact of the Pairs on the Vertex Detector

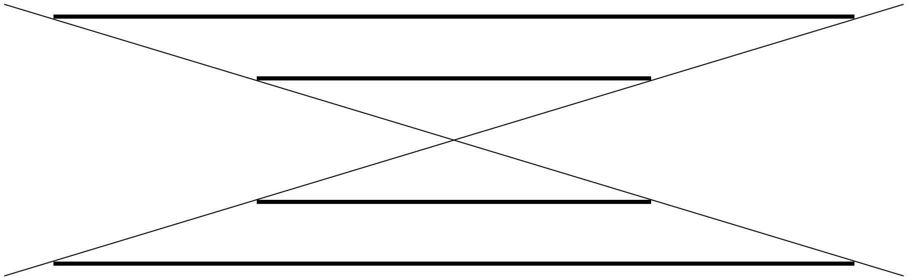
- Simplified study using simple cylinder without mass
  - coverage is down to $200\,\mathrm{mradian}$
- Simulating number of particles that hit at least once
  - experience indicates that number of hits is three per particle
  - but needs to be done with real detector parameters

⇒ At $r_1 \approx 30\,\mathrm{mm}$ expect 1 hit per train and mm^2

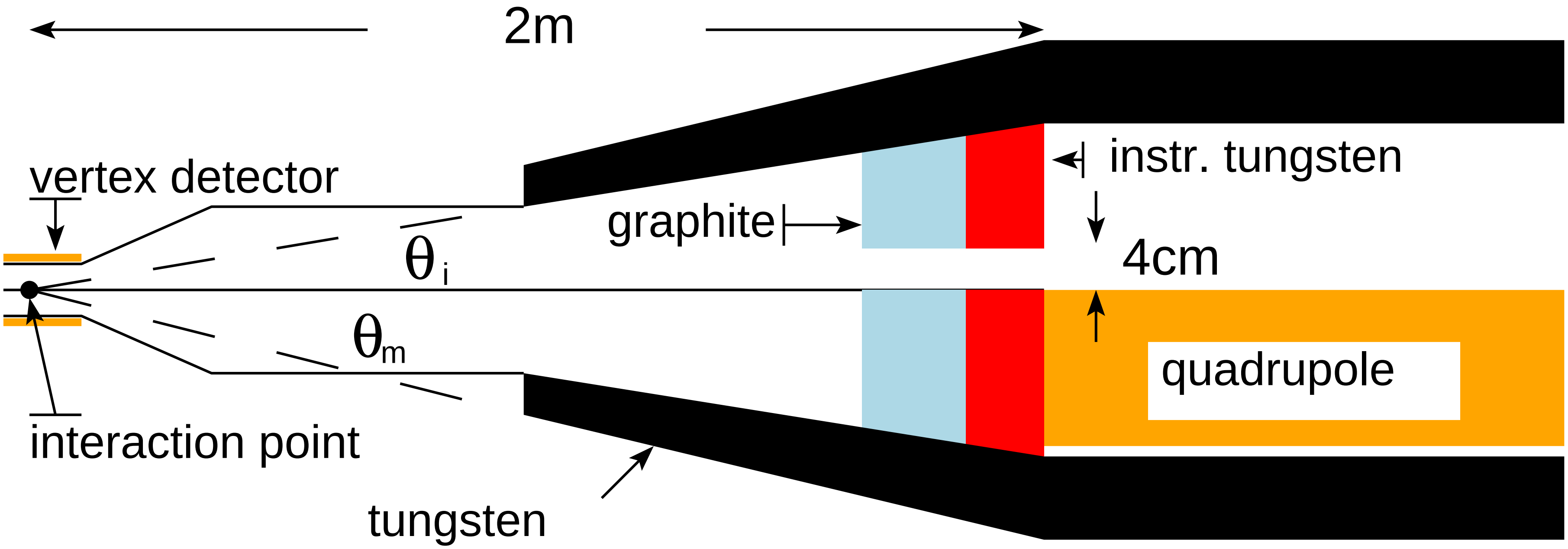
⇒ Detector should be a bit larger

  - but depends on technology





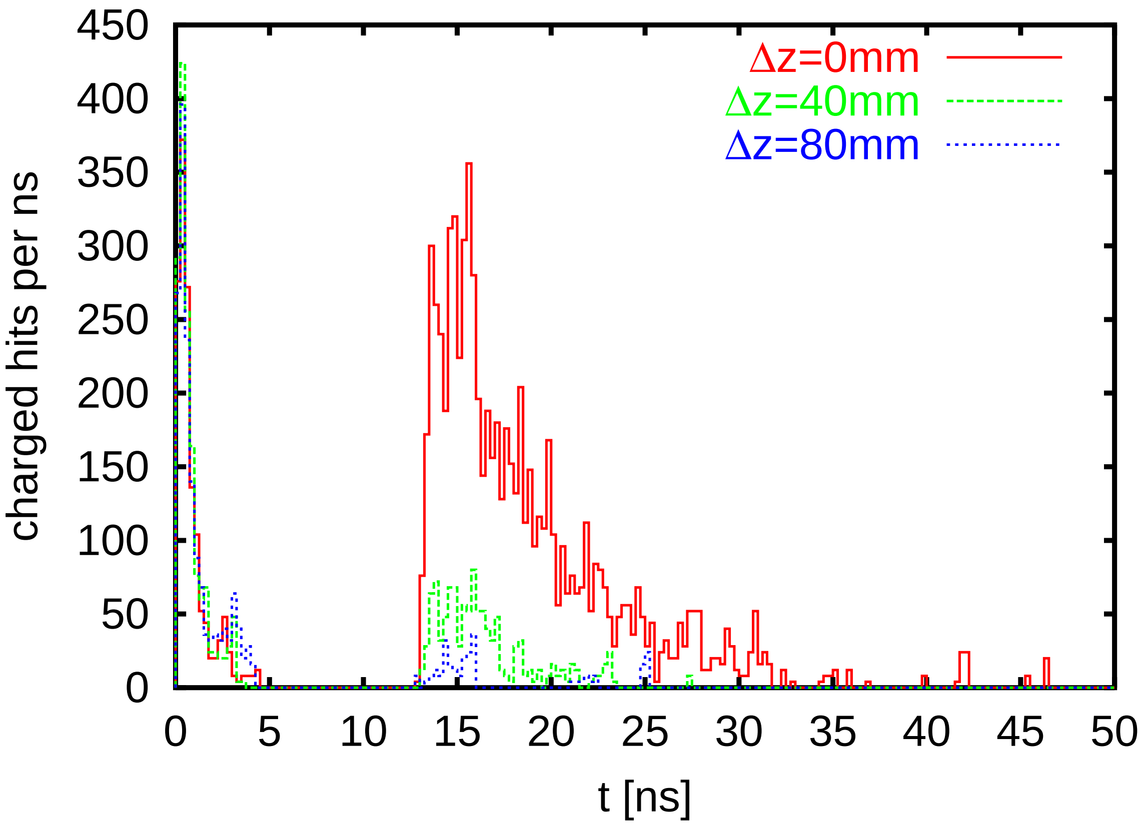
Mask Design



- Current CLIC design corresponds to old TESLA design
  - improvement is possible
  - quadrupole can be further out
- Outer mask suppresses backscattered photons
  - maybe less coverage would be sufficient
- Inner mask prevents backscattering of charged particles
  - distance needs to be small enough that exit hole is smaller than vertex detector

Inner Mask

- Low-Z material reduces backscattering
  - it allows electrons and positrons to penetrate with small probability of scattering
  - it reduces energy of backscattered charged particles via ionisation
- Required thickness is about $10\,\mathrm{cm}$

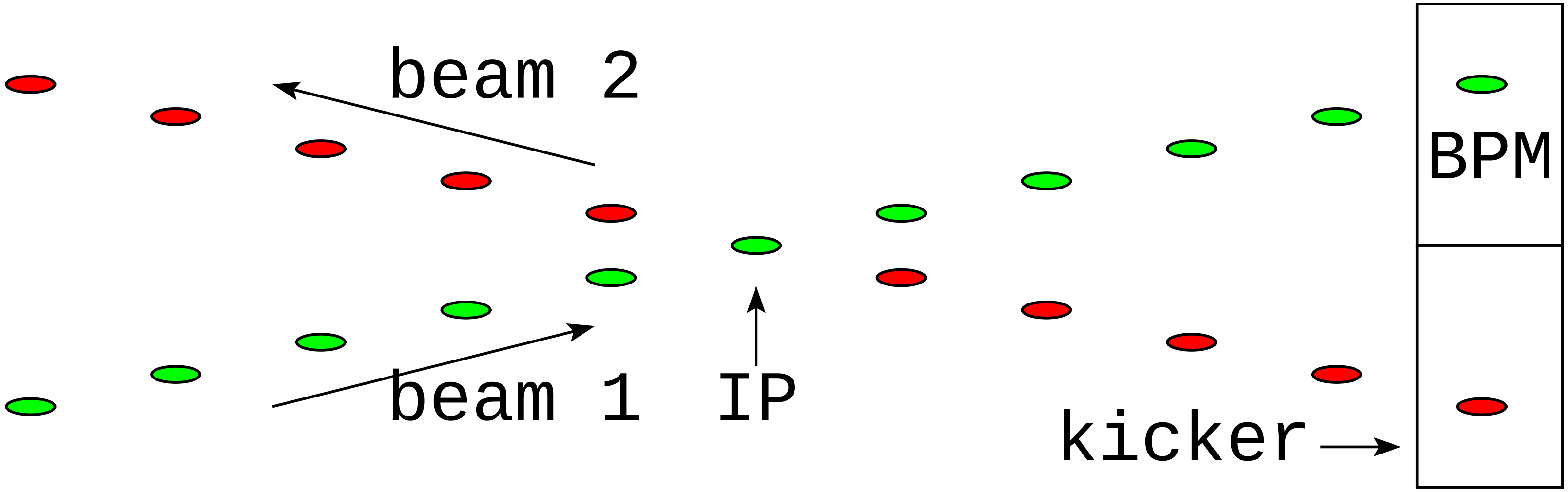


- But hole overlaps with vertex detector

$\Rightarrow$ could have backscattering through the hole, if not careful

Intra-Pulse Interaction Point Feedback

- Reduction of jitter is dominated by feedback latency
  - - IP to BPM
  - - electronics
  - - Kicker to IP
- Assuming 40 ns one can hope for about a factor 2
- Only cures offsets



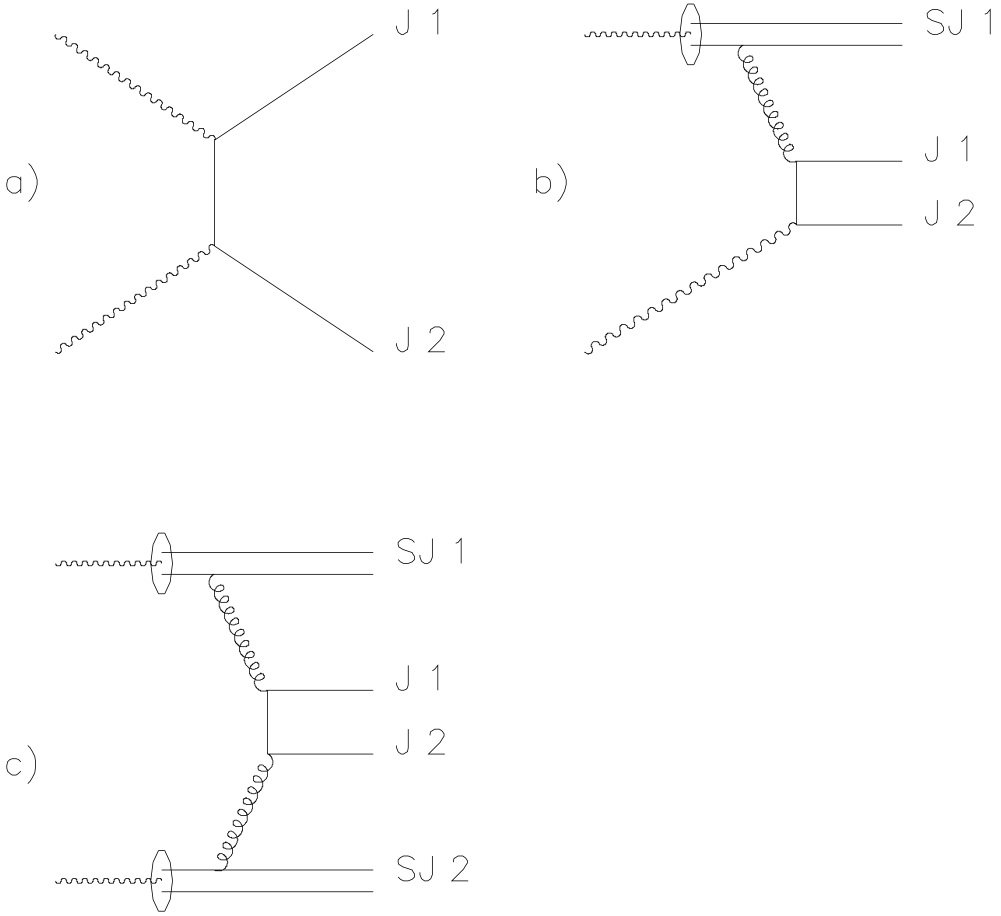
Hadronic Background

A photon can contribute to hadron production in two ways

- direct production, the photon is a real photon
- resolved production, the photon is a bag full of partons

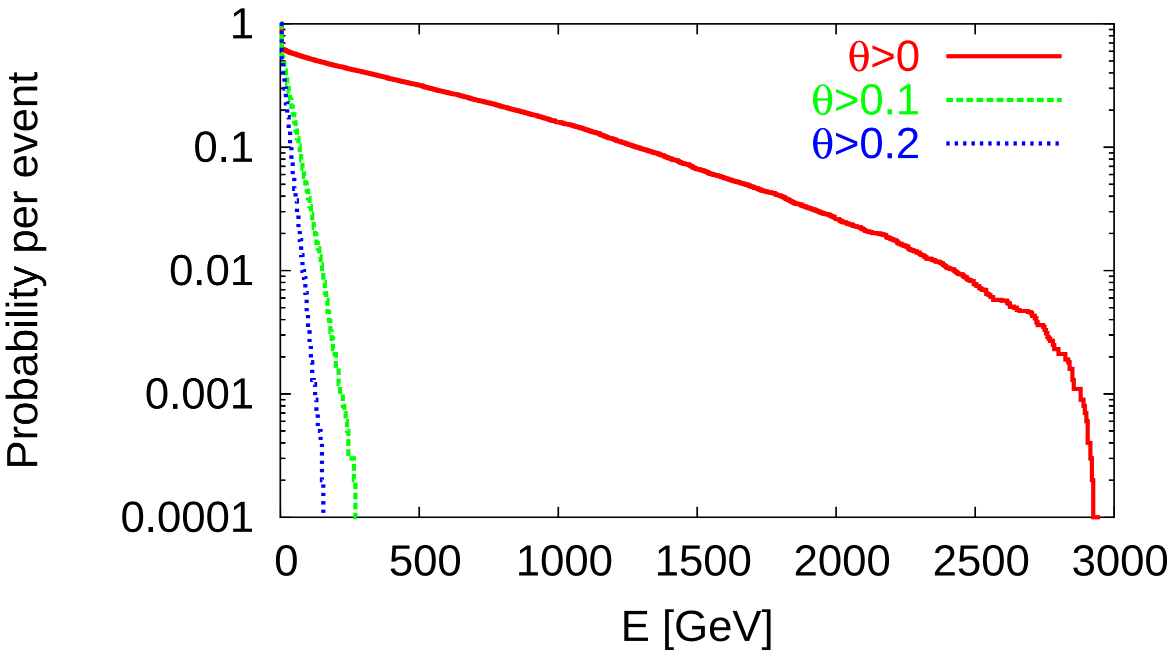
Hard and soft events exist

e.g. “minijets”



Hadronic Events

- Hadronic events with $W_{\gamma\gamma} \geq 5\,\mathrm{GeV}$
- Most energy is in forward/backward direction
  - $E_{vis} \approx 450\,\mathrm{GeV}$ per hadronic event for no cut
  - $E_{vis} \approx 23\,\mathrm{GeV}$ for $\theta > 0.1$
  - $E_{vis} \approx 12\,\mathrm{GeV}$ for $\theta > 0.2$
  - 20% from e^+e^- (cannot be reduced)



- Charged tracks from hadronic events add about 20% to the charged hits in the vertex detector
- Secondary nuetron flux can be noticeable

Low Energy Parameters

- First approach is to use $3\,\mathrm{TeV}$ performance assumptions
  - yields high performance
- Alternative is to assume already demonstrated performaces, where possible
  - more conservative first step
- One could reoptimise for lower energies

  $\Rightarrow$ would yield optimum performance

  $\Rightarrow$ but would need strong motivation by physics case

E_{cms}	$[\,\mathrm{TeV}]$	0.5	0.5	0.5	1.0	1.0	1.0
ϵ_x	$[\,\mu\mathrm{m}]$	4.0	4.0	0.66	4.0	4.0	0.66
ϵ_y	$[\,\mathrm{nm}]$	40	30	20	40	30	20
L_{total}	$[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	0.26	0.305	1.12	0.515	0.62	2.25
$L_{0.01}$	$[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	0.21	0.25	0.68	0.37	0.445	1.08

- Assumed $f_r = 50\,\mathrm{Hz}$

Luminosity and Background Values

		CLIC	CLIC	CLIC	CLIC(vo)	ILC	NLC
E_{cms}	$[TeV]$	0.5	1.0	3.0	3.0	0.5	0.5
f_{rep}	[Hz]	100	50	50	100	5	120
N	$[10^9]$	3.7	3.7	3.7	4.0	20	7.5
ϵ_y	$[nm]$	20	20	20	10	40	40
L_{total}	$10^{34}cm^{-2}s^{-1}$	2.2	2.2	5.9	10.0	2.0	2.0
$L_{0.01}$	$10^{34}cm^{-2}s^{-1}$	1.4	1.1	2.0	3.0	1.45	1.28
n_γ		1.2	1.5	2.2	2.3	1.30	1.26
$\Delta E/E$		0.08	0.15	0.29	0.31	0.024	0.046
N_{coh}	10^5	0.03	37.0	3.8×10^3	$?$	—	—
E_{coh}	$10^3 TeV$	0.5	1080	2.6×10^5	$?$	—	—
n_{incoh}	10^6	0.05	0.12	0.3	?	0.1	n.a.
E_{incoh}	$[10^6 GeV]$	0.28	2.0	22.4	?	0.2	n.a.
$n_\perp$		12.5	17.1	45	60	28	12
n_{had}		0.14	0.56	2.7	4.0	0.12	0.1

- Target is to have about one beamstrahlung photon per beam particle

  - similar effect to initial state radiation

  ⇒ average energy loss is larger in CLIC than ILC

- Note: shorter bunches increase the photon energy but not the number

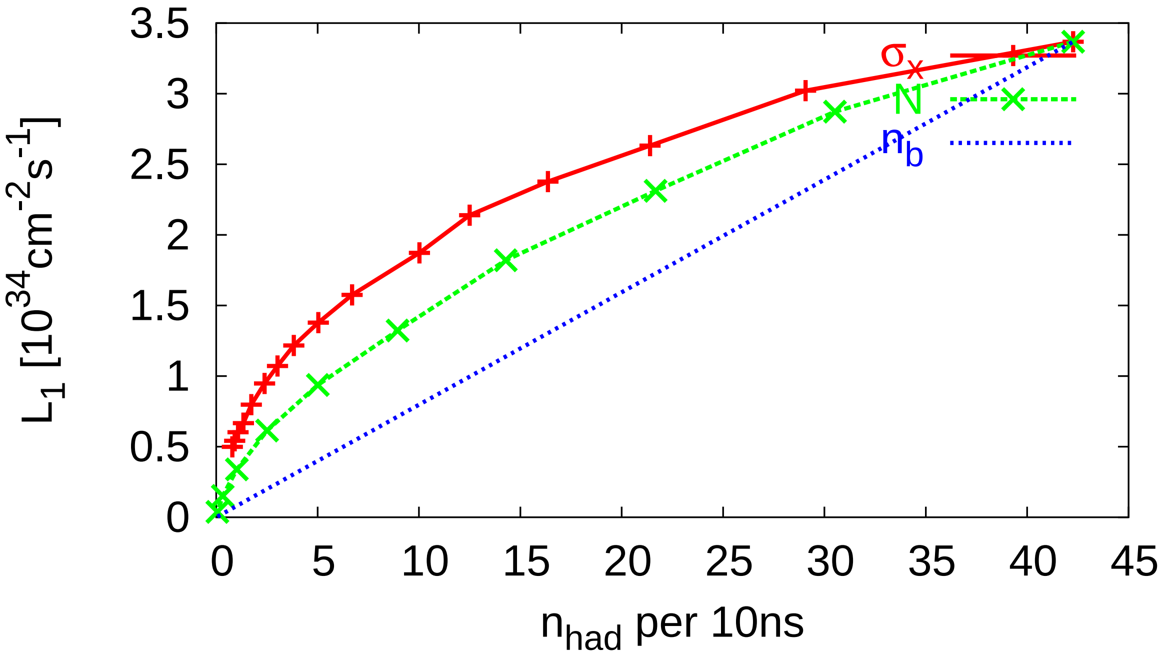
Background Reduction/Spectrum Improvement

- Larger distance Δz between bunches
  - $\Rightarrow L_{0.01} \propto 1/\Delta z \propto B(\delta t)$
  - $\Rightarrow B_{bx}$, $L_{0.01}/L_{total}$ remain constant
- Larger horizontal beam size σ_x
  - $\Rightarrow L_{0.01} \propto 1/\sigma_x$
  - $\Rightarrow B_{bx}$, $L_{0.01}/L_{total}$ improve
  - $\Rightarrow$ may ease focusing, but effect is likely small
- Reduced bunch charge N
  - $\Rightarrow L_{0.01} \propto N^2$
  - $\Rightarrow B_{bx}$, $L_{0.01}/L_{total}$ improve, better coverage
  - $\Rightarrow$ could improve beam dynamics
- Shorter pulse
  - $\Rightarrow L_{0.01} \propto n_b$
  - $\Rightarrow B_{bx}$, $L_{0.01}/L_{total}$ unchanged
  - $\Rightarrow$ reduces background per train

Hadronic Events

- Peak luminosity is shown as fuction of hadronic event rate in $10\,\mathrm{ns}$
- Older parameter set is being used

$\Rightarrow$ Best strategy is to increase horizonal beam size



Machine Background

Beam tails can produce background in the detector/ damage the machine

$\Rightarrow$ use collimation

synchrotron radiation before final doublet

$\Rightarrow$ collimation of photons

synchrotron radiation in final doublet

$\Rightarrow$ collimation of beam tails

muons due to beam loss (collimation)

$\Rightarrow$ distance

$\Rightarrow$ magnetised iron collimators

$\Rightarrow$ detector timing/granularity

beam scattering on black-body radiation

$\Rightarrow$ calculate (seems not a big problem sofar)

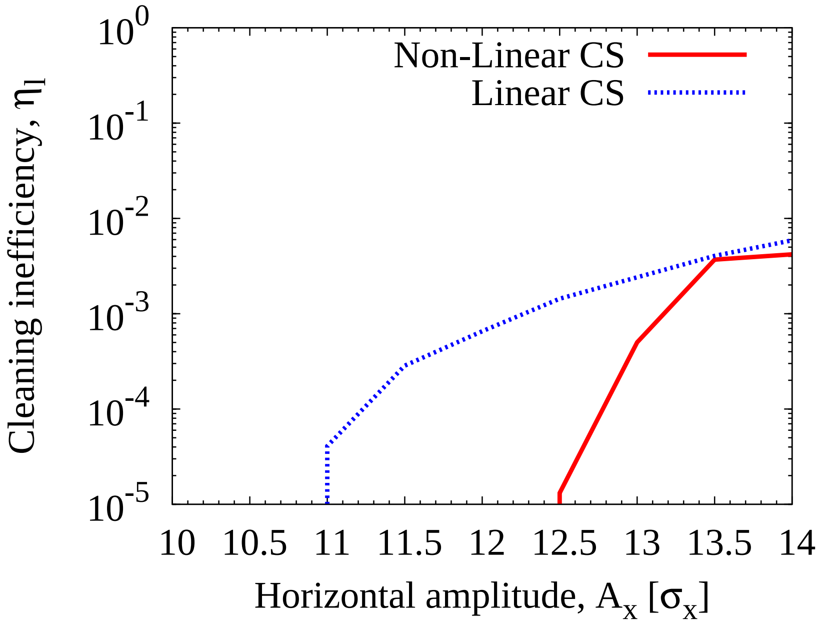
beam-gas scattering

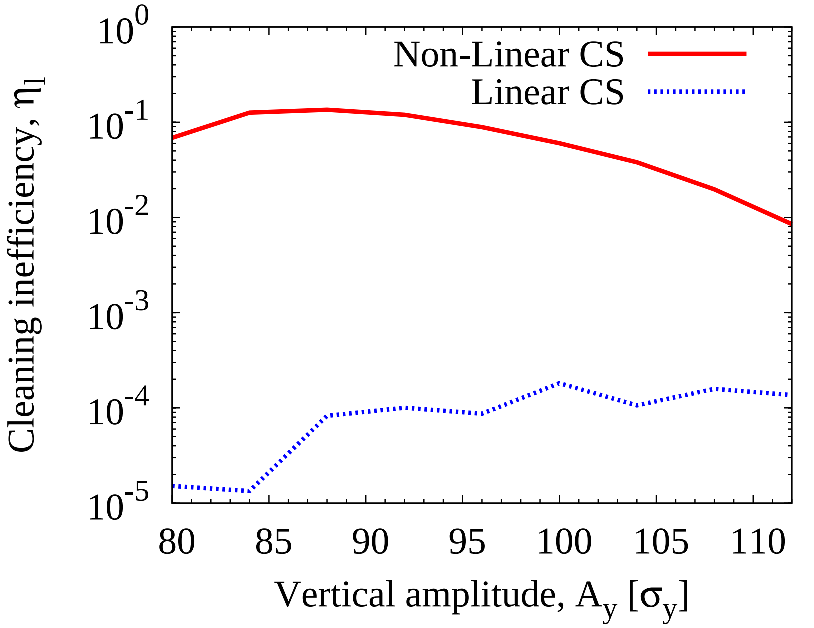
$\Rightarrow$ improve vacuum (H. Burkhardt: $10^{-9}\,\mathrm{torr}$ to equal black body radiation)

Collimation System

- The collimation system removes particles with large transverse amplitudes or large energy errors
- It reduces the background in the detector and protects the machine
- To avoid that collimators are being destroyed a spoiler/absorber system is used
- The transverse collimation is determined by synchrotron radiation emission in the final doublet
- The design strategy has been
  - to make the energy collimation be failsafe
  - but not the betatron collimation
- This is based on the assumption that
  - energy errors can occour from pulse to pulse without a warning
  - betatron oscillations are mainly due to megnet failure which can be interlocked
- Large transverse kicks due to RF breakdowns in the main linac could create a problem

Collimation System Design

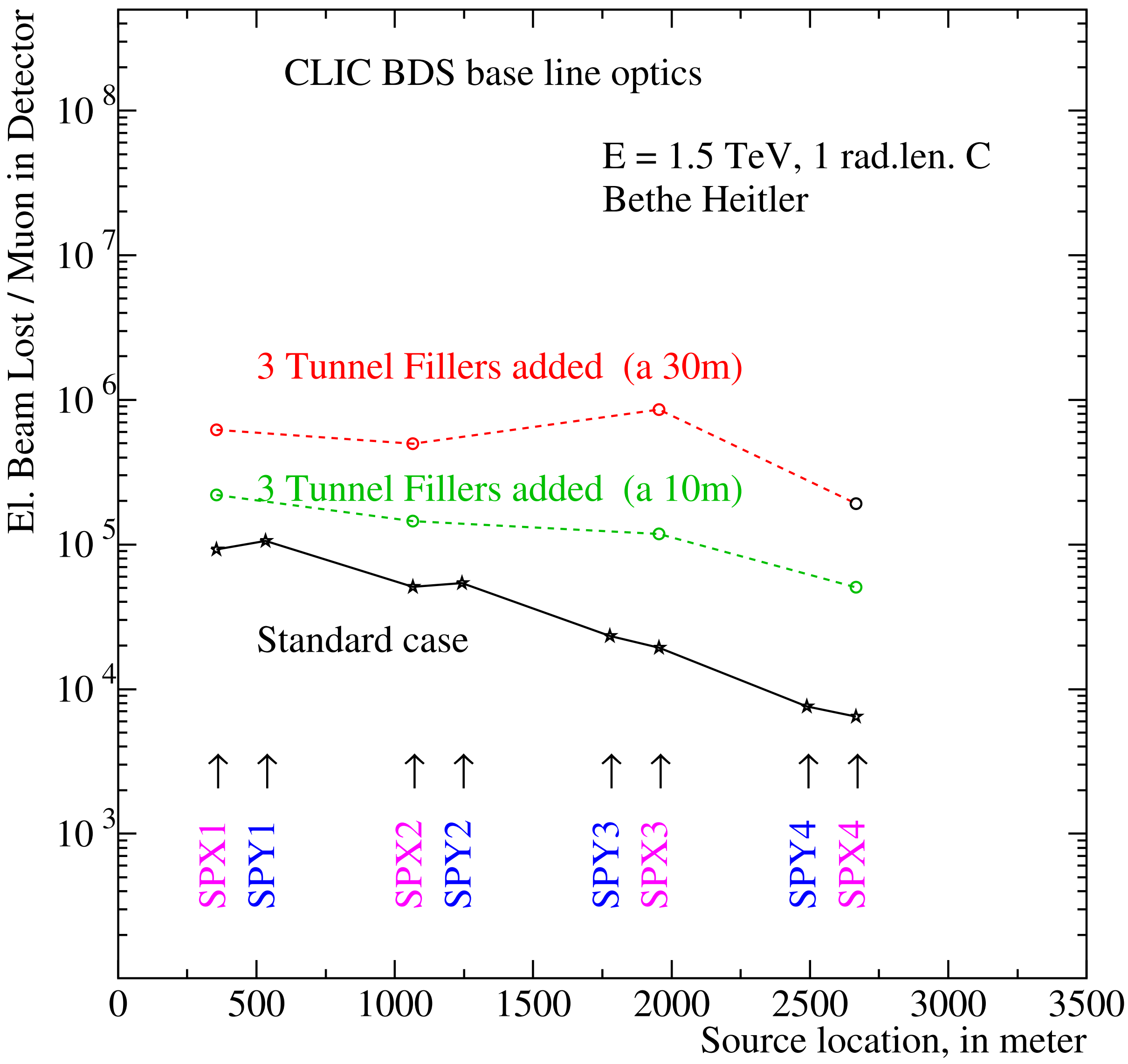




- Two systems have been studied (J. Resta Lopez)
  - a linear one
  - a non-linear one
- Cleaning inefficiency can be quite good
- Linear system could be better than the non-linear one
- More detailed study of performance with imperfections appears useful

Muon Background

- Lost beam particles can generate secondary muons
  - Bethe-Heitler process (simulated)
  - production by photons in the shower
  - by hadronic processes
- Simulations performed with BDSIM (H. Burkhardt)
  - total muon rate expected to be twice larger
- Muons are hard to stop
- Potential means is use of tunnel fillers of magnetised iron
  - problems with tunnel access
  - high cost



Muon Rate

- Rate depends critically on assumption about beam halo
  - expect small values (some 10^{-4} for a vacuum pressure of $10\,\mathrm{ntorr}$, H. Burkhardt, needs more studies)
  - SLC experience has been bad (up to 0.01)
- For a beam halo of 10^{-3} we expect 5×10^4 muons per train in the detector
- Tunnel fillers can reduce this by an order of magnitude
- Better vacuum will help
  - beam stability requires very good vacuum
- But the detector will need to be able to cope with many muons
- Would follow ILC strategy
  - foresee place for tunnel fillers
  - but install them only if necessary

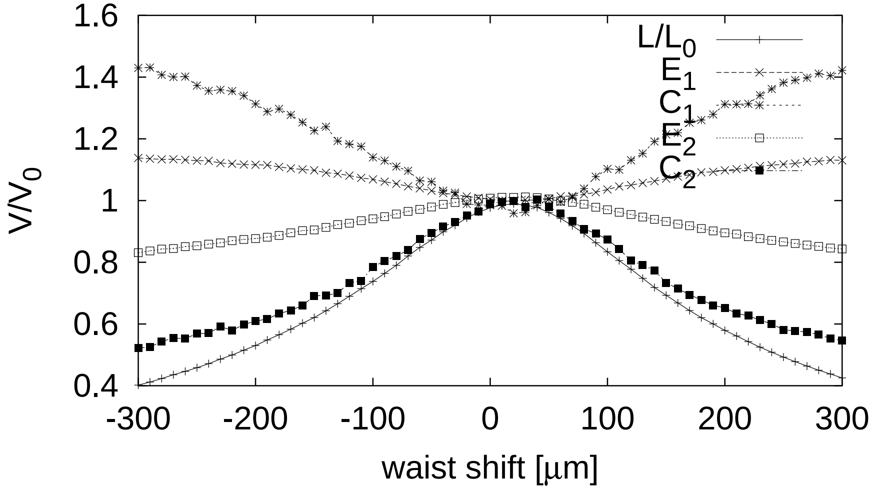
Tools

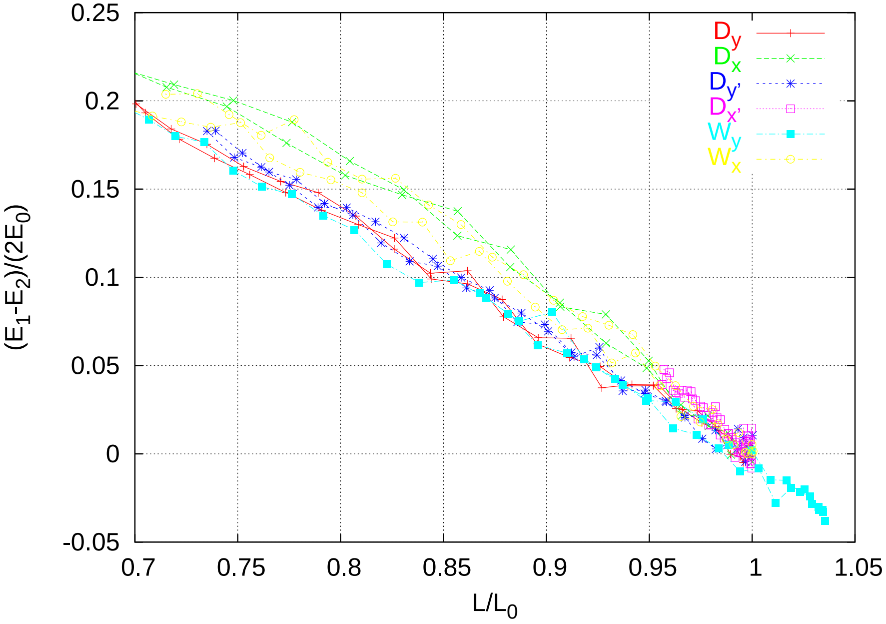
- Simulations
  - GUINEA-PIG: can generate luminosity spectra, electromagnetic and hadronic background, polarization to be included
  - CAIN: no hadronic background, polarization included
  - HTGEN: development of modules to simulate generation of beam halo and tails
  - BDSIM: to track beam halo and tails (GEANT based)
  - PLACET: to simulate realistic beam conditions
- Data bases (need to be updated for latest parameters)
  - CALYPSO: Beam particle collisions with full correlation
  - HADES: Hadronic background events, uses PYTHIA for generation (maybe something to improve)
  - files with pairs

Please Help

- Are the luminosity and background conditions OK?
  - first study has been positive
- Scenarios at lower energies
- Use luminosity and emittance tuning
  - no direct signal for luminosity that is fast
  - use signals to tune knobs (P. Eliasson, D.S.)
  - good candidate is beamstrahlung

  ⇒ instrumentation
- Precision you need for measurements
  - luminosity
  - energy
  - polarisation
- Integration of final quadrupoles





Conclusions

- Machine-detector interface considerations are vital for CLIC
- The luminosity has a pronounced spectrum
  - would aprreciate more feedback on relevance
  - need to investigate the spectrum reconstruction more
- Significant background exists
  - impacts detector design, e.g.
    - vertex detector
    - masking system
- Machine needs components in the detector
  - final quadrupoles
  - instrumentation
- We have a number of tools to study machine detector interface issues
  - we need more people to use them