Photon Collider

Higgs Physics at Future Colliders

A.F.Żarnecki

Warsaw University

Thanks to:

- A. Stahl (LCWS 2002 in Korea)
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Introduction

Why do we need Photon Collider ?

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Photon-photon collisions:

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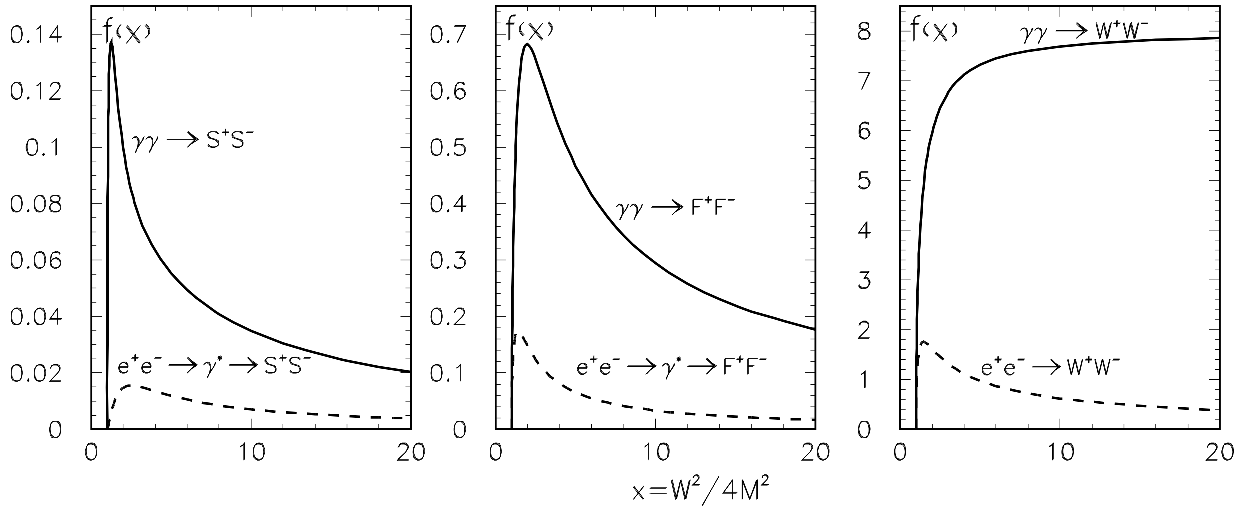

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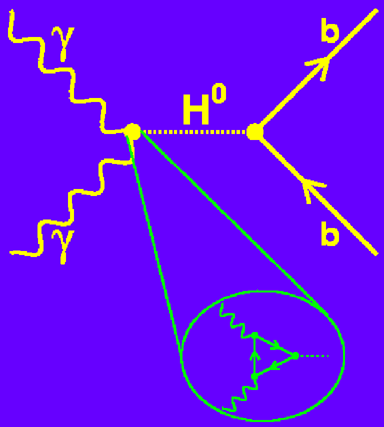
  resonant Higgs production   similar to Z° in e^+e^-

Physics Highlights

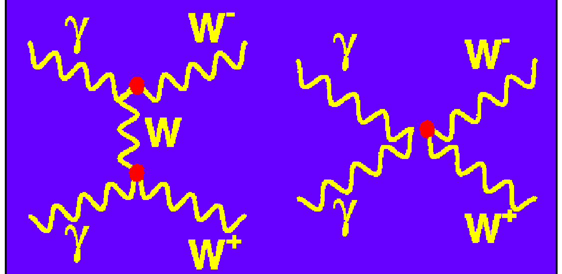
Higgs



Realistic Photon Spec.
More realistic Detector
More accurate Bgd.

⇒Some Improvement

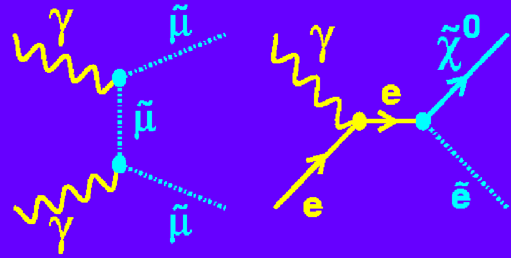
TGC / QGC



High Cross Section
Direct Access to Pol.

⇒Similar Resolution compared to e+e-

SUSY



High Cross Section
High Reach for selectrons

⇒Just Starting

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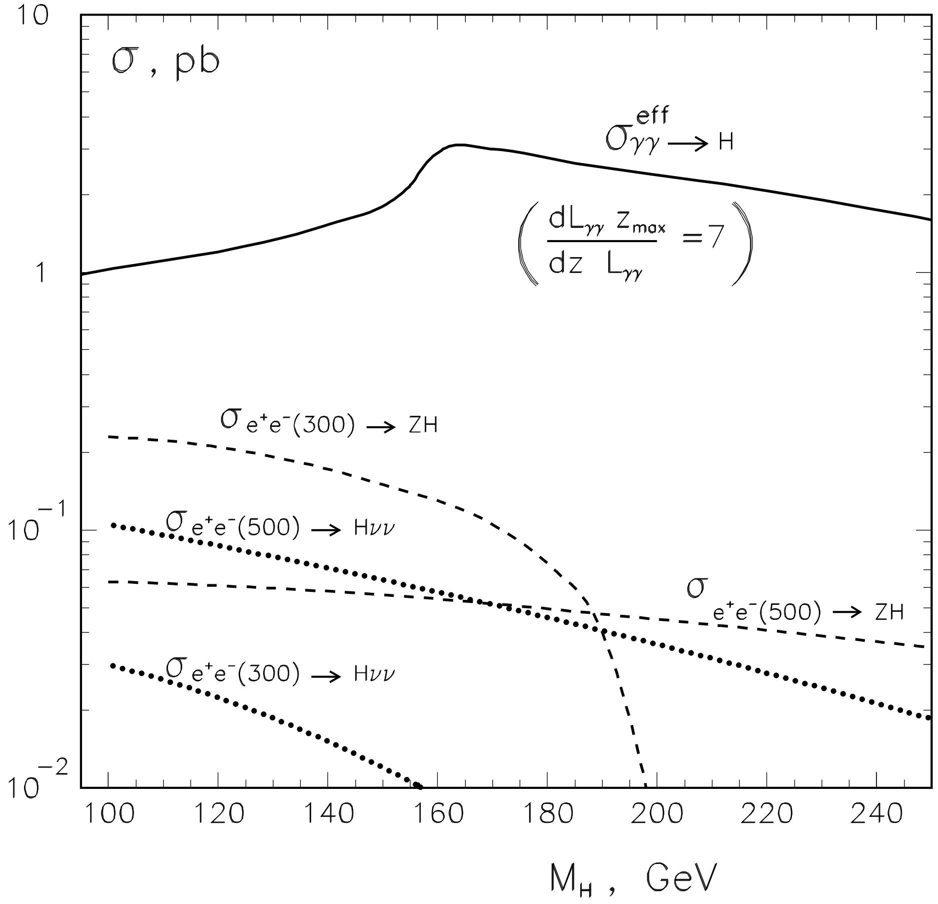
Comparison of SM Higgs boson production cross sections:



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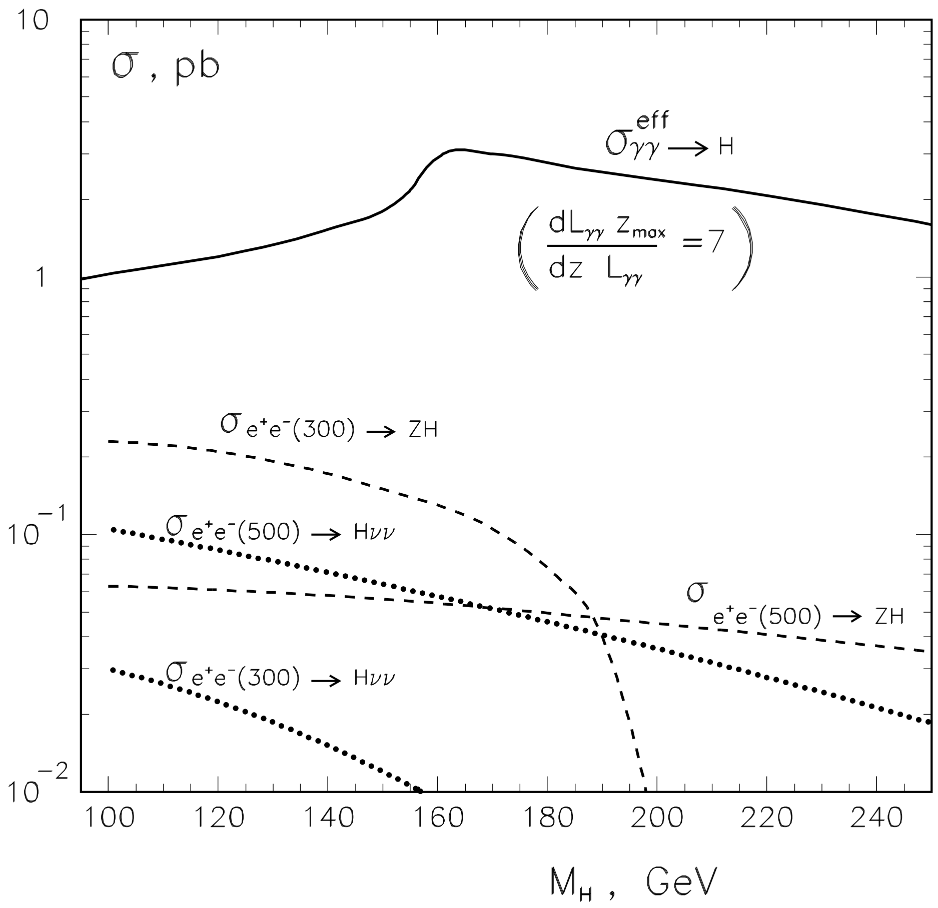

$\gamma\gamma$ cross section order of magnitude higher

$$\sigma = \frac{1}{\mathcal{L}_{\gamma\gamma}} \frac{d\mathcal{L}^{J_z=0}_{\gamma\gamma}}{dW_{\gamma\gamma}} \cdot \frac{4\pi^2\ \Gamma_{\gamma\gamma}}{M_h^2}$$

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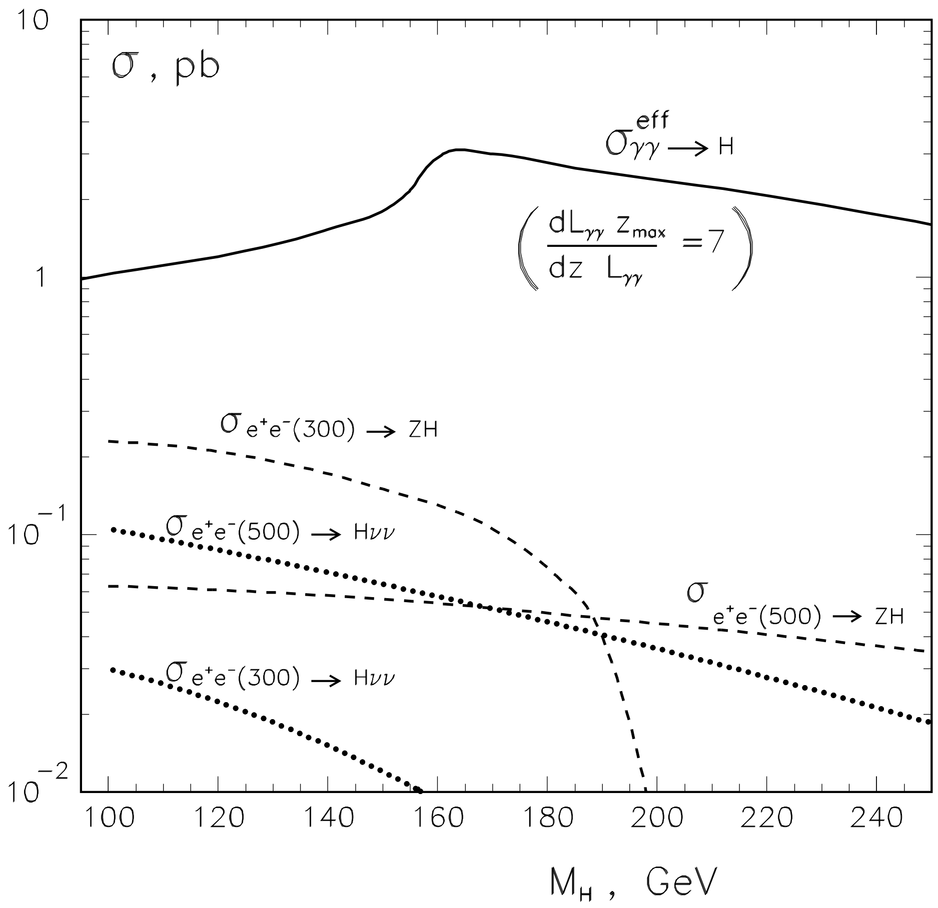

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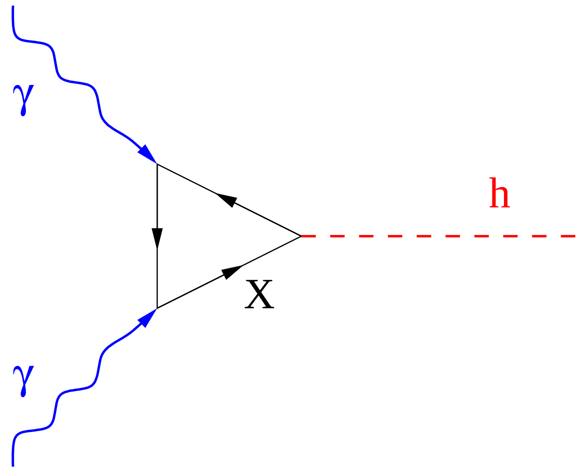
expected $\gamma\gamma$ luminosity similar to e^+e^-

Higgs boson at PC

Two-photon width of the Higgs boson $\Gamma_{\gamma\gamma}$ is sensitive to all massive and charged particles in the loop:

$$\Gamma(h \to \gamma\gamma) = \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\,\pi^3} \cdot |\mathcal{A}|^2$$



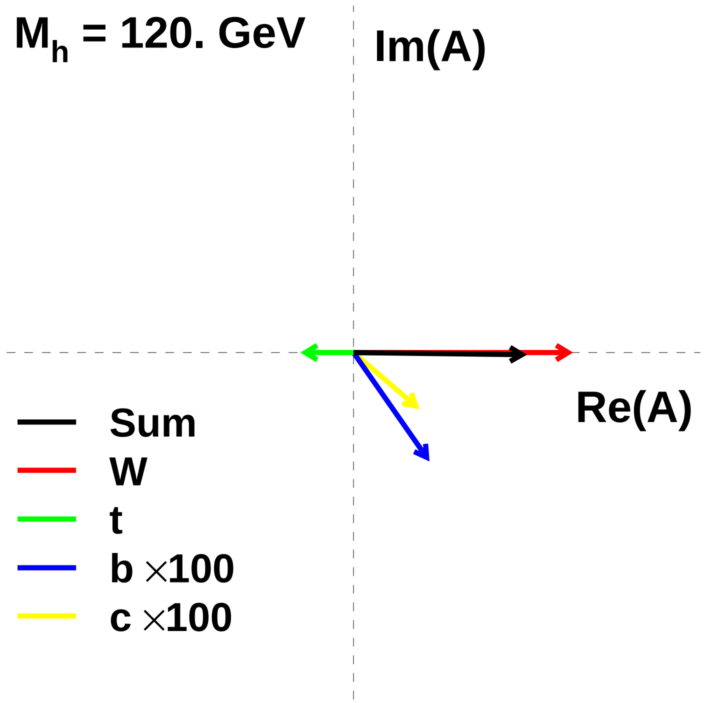
where:

$$\mathcal{A} = A_W(M_W) + \sum_f N_c Q_f^2 A_f(M_f) + \ldots$$

two-photon amplitude

Phase

amplitude $\mathcal{A}$ is real
imaginary contribution from light fermions - very tiny



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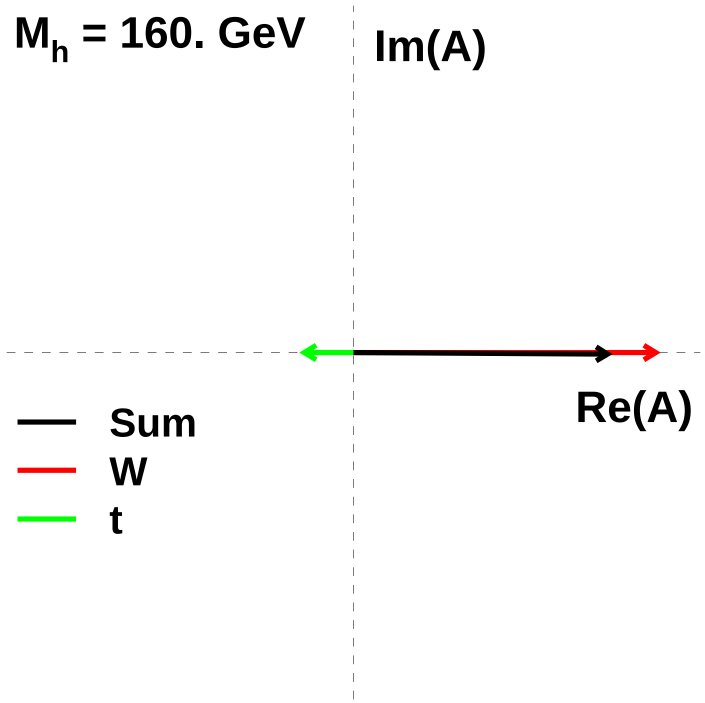

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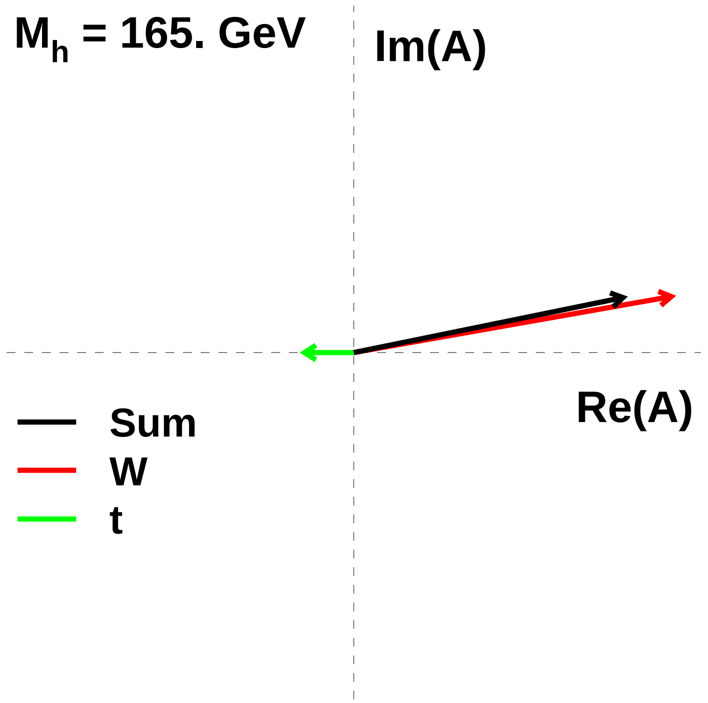
W contribution is complex



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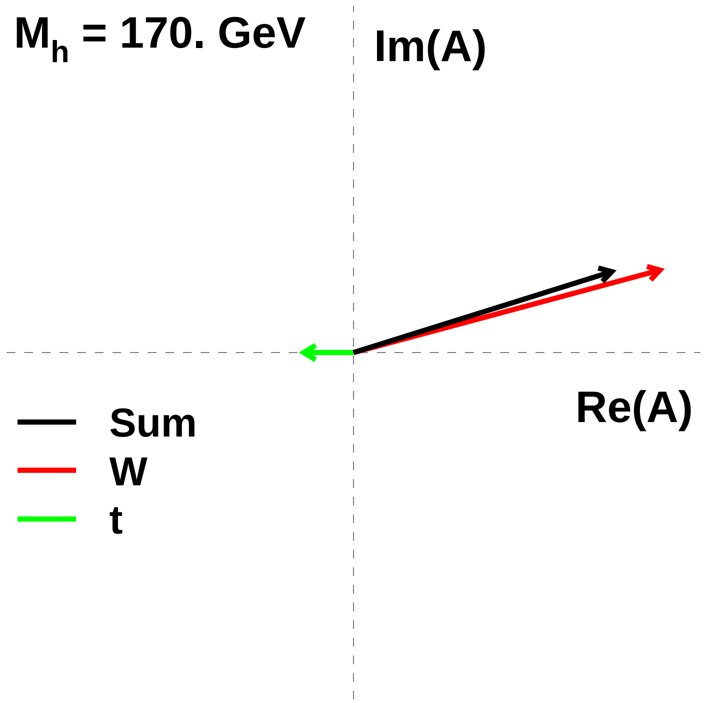

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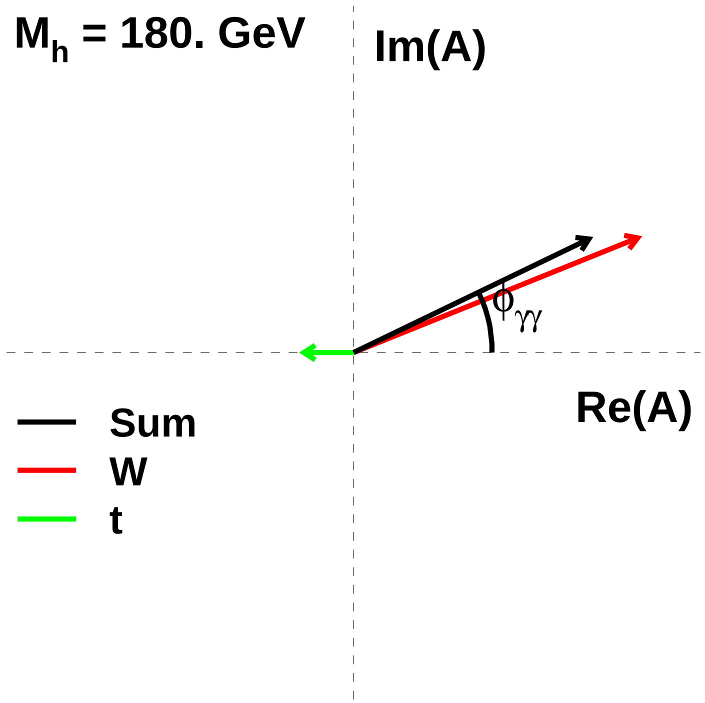
$\mathcal{A} = |\mathcal{A}| \cdot e^{i\phi}$ - phase $\phi_{\gamma\gamma} \neq 0$

$\Gamma_{\gamma\gamma} \sim Im(\mathcal{A})^2 + Re(\mathcal{A})^2$



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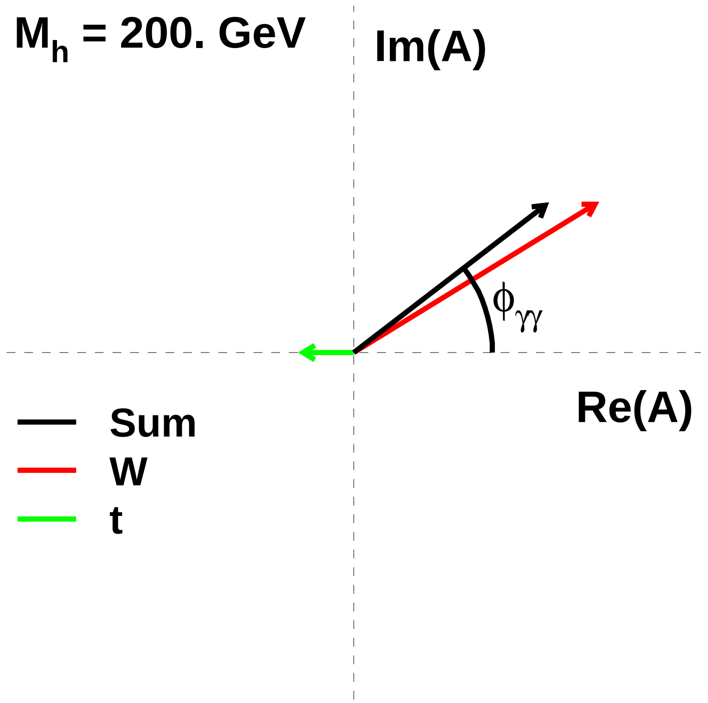

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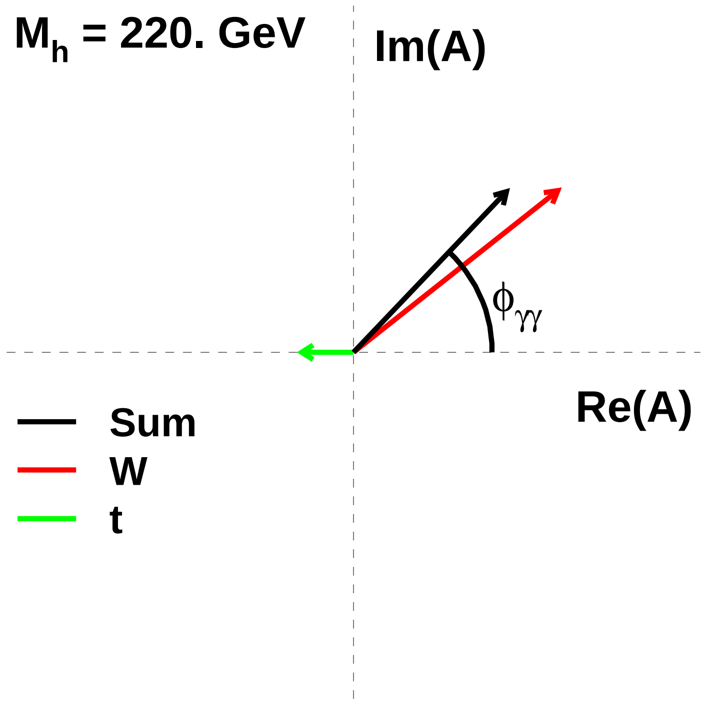

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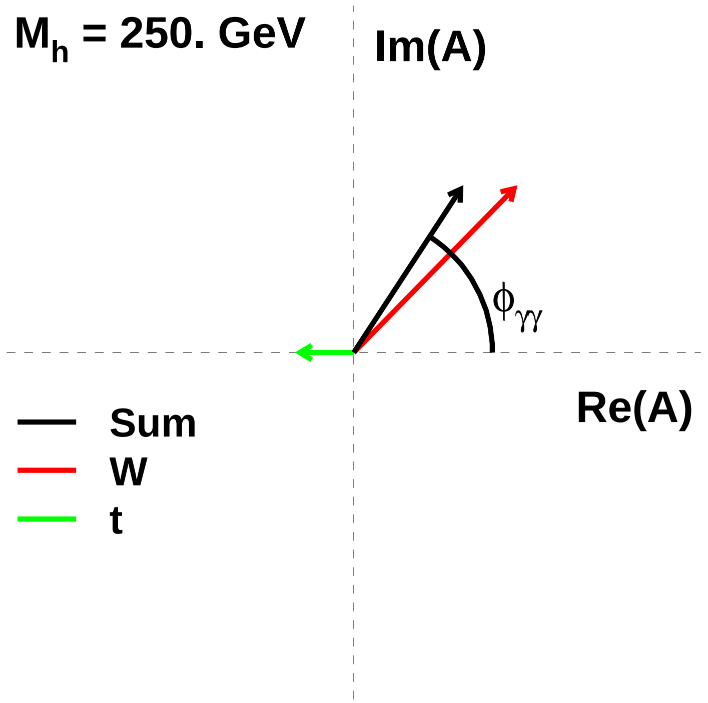

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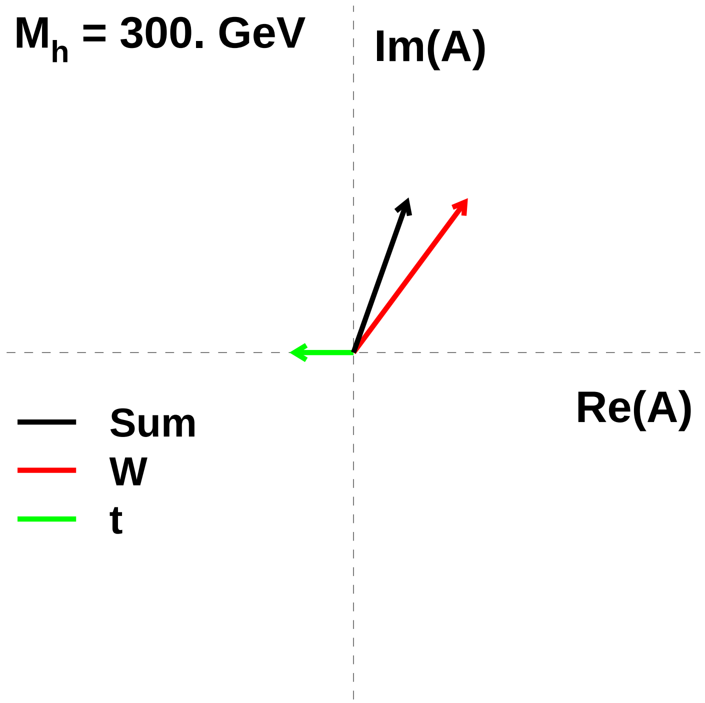

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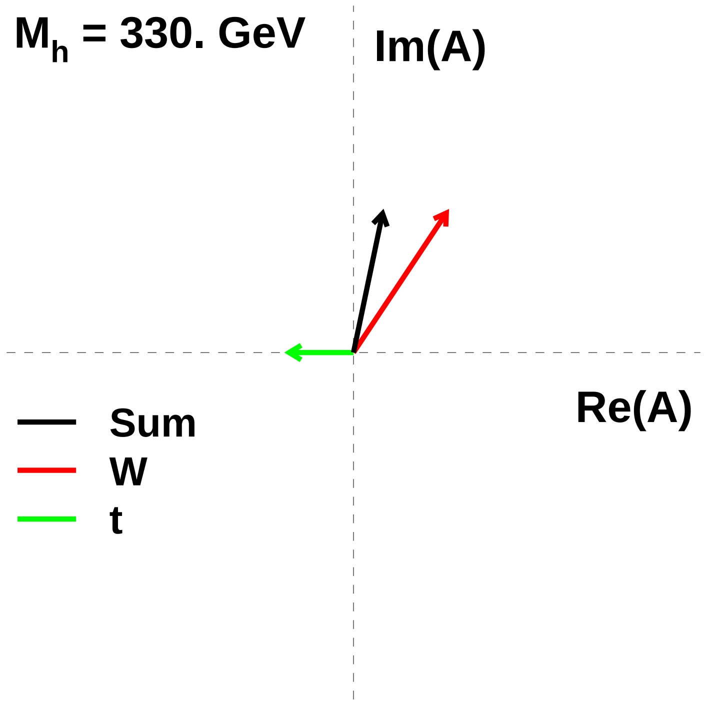

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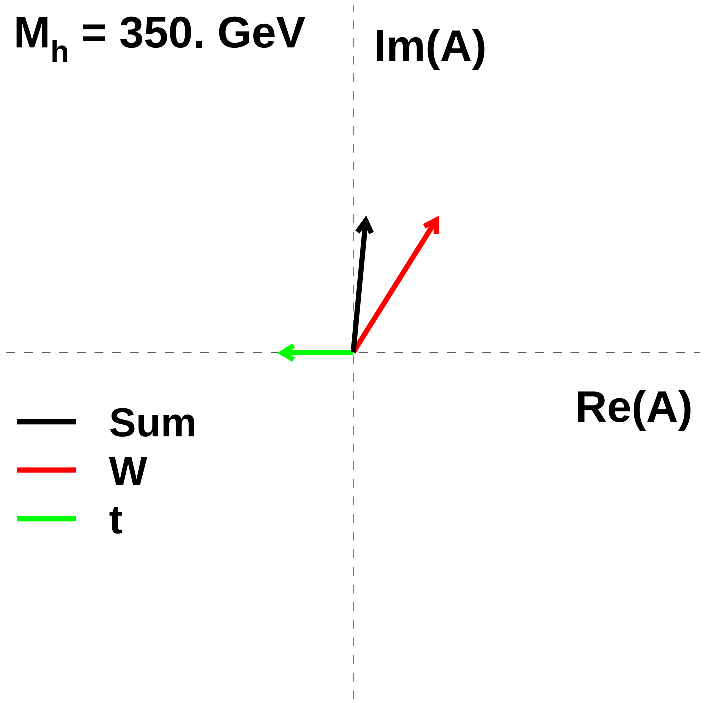

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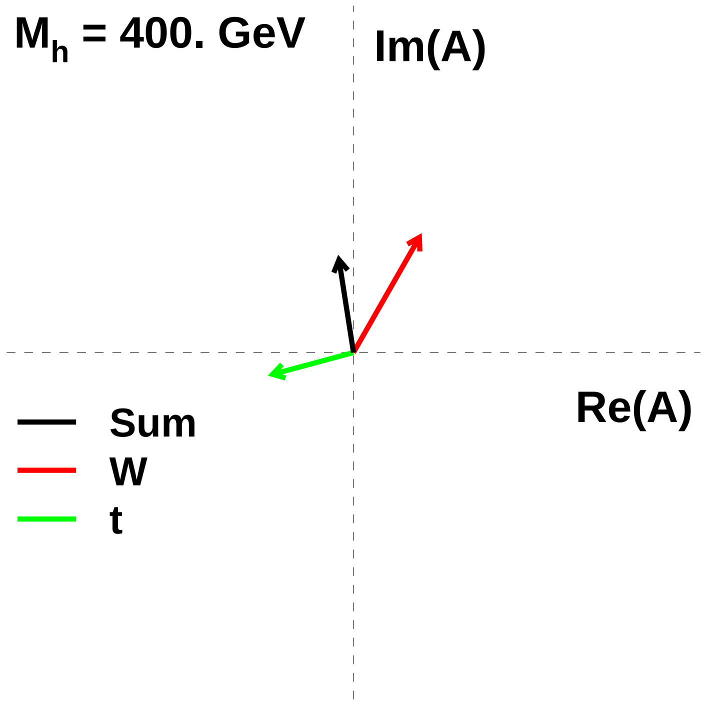

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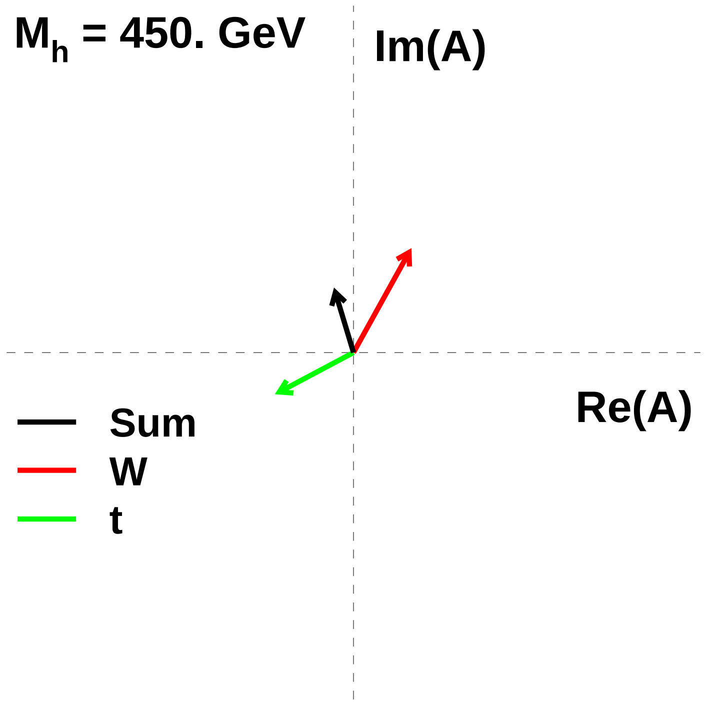

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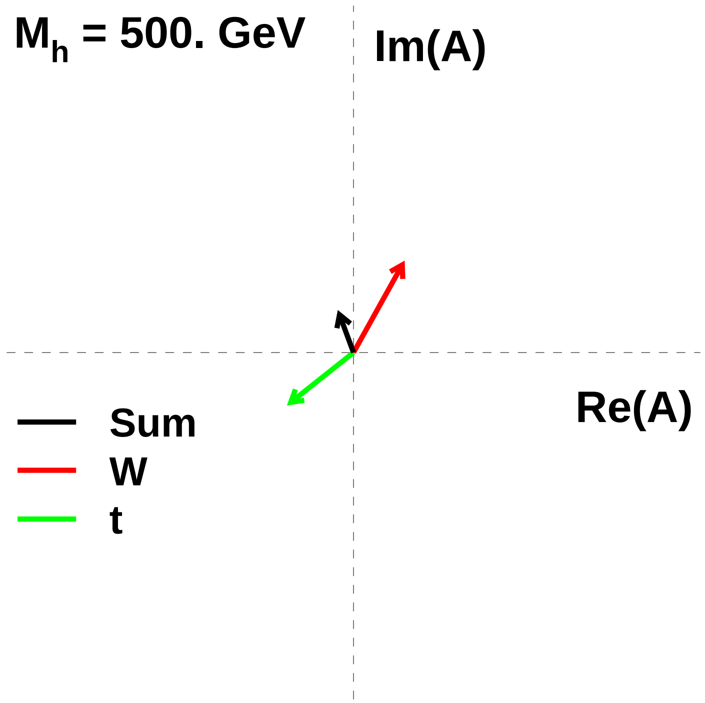
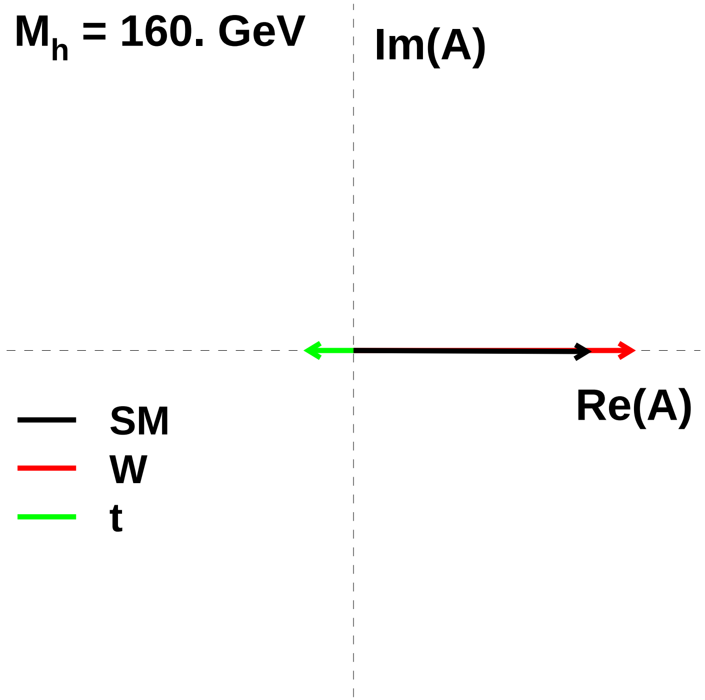


New particles

Expected contribution from new heavy particle - real



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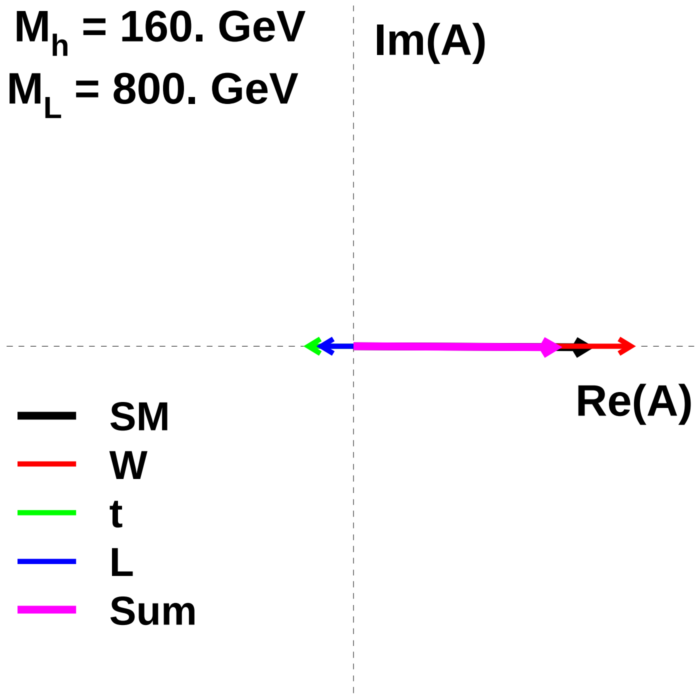

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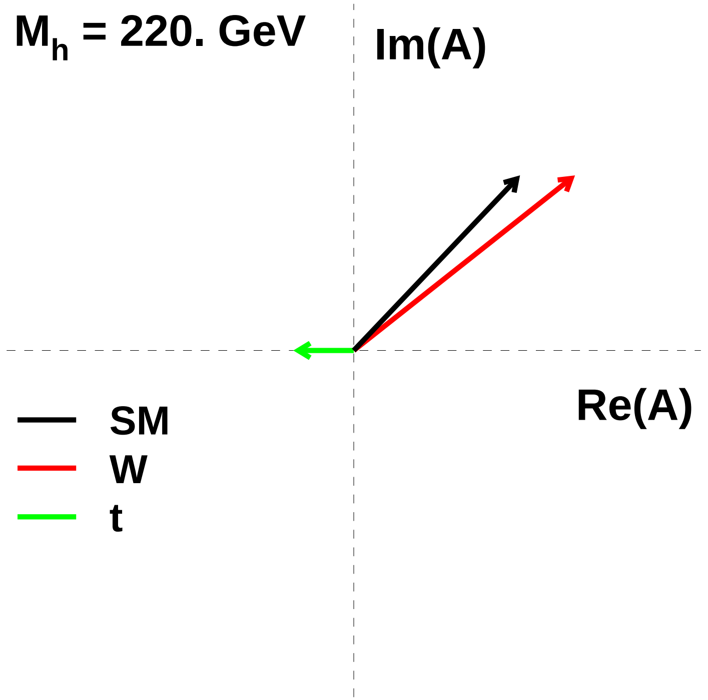

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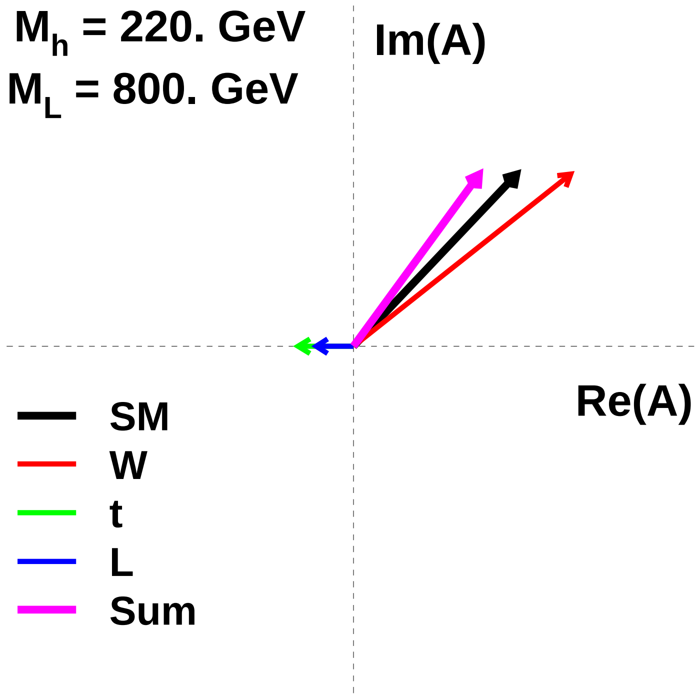

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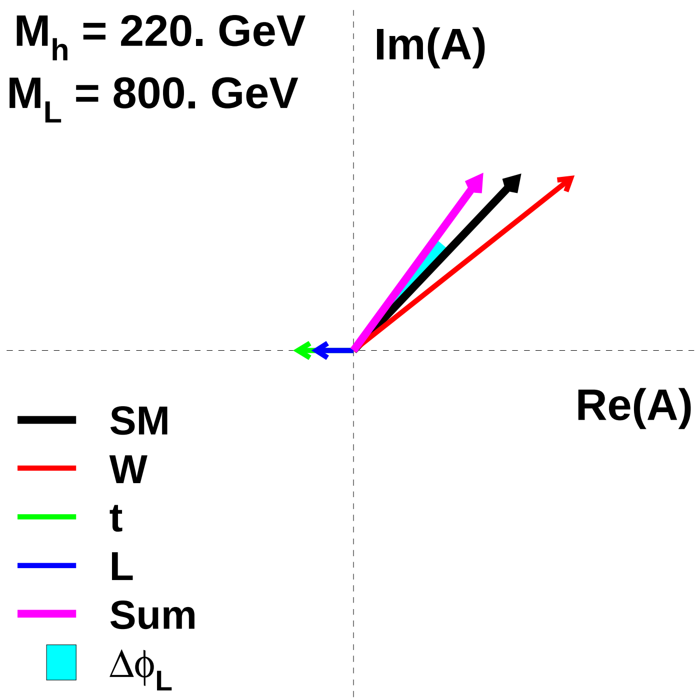

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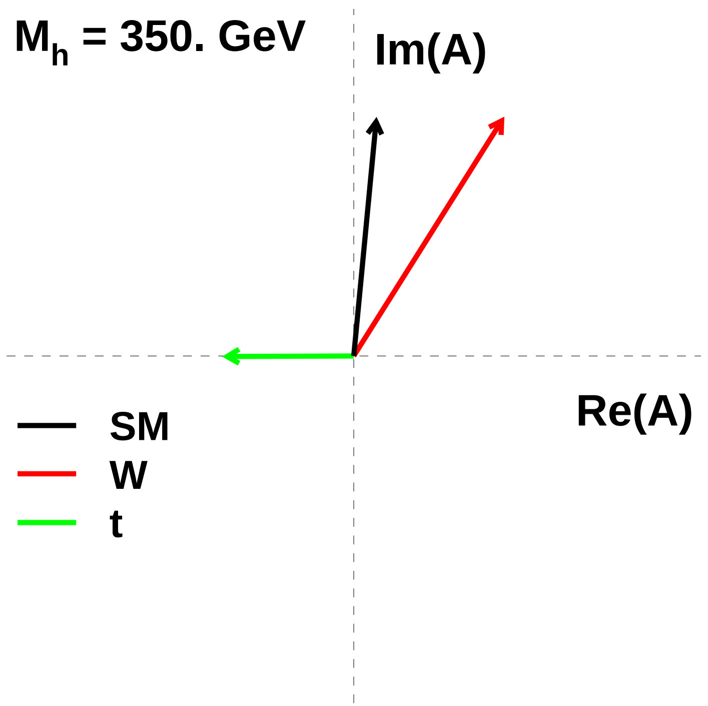

for M_h ~350 GeV
amplitude mostly imaginary:

$$Re(\mathcal{A}) \sim 0$$

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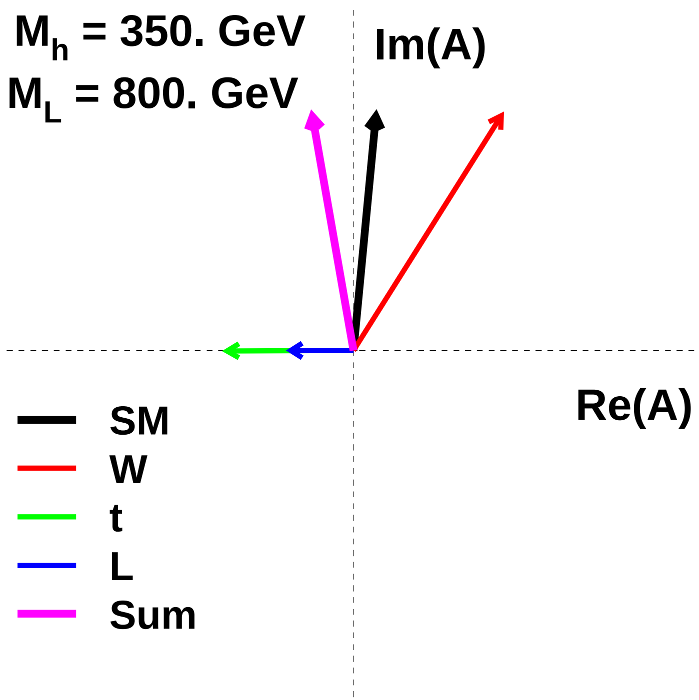

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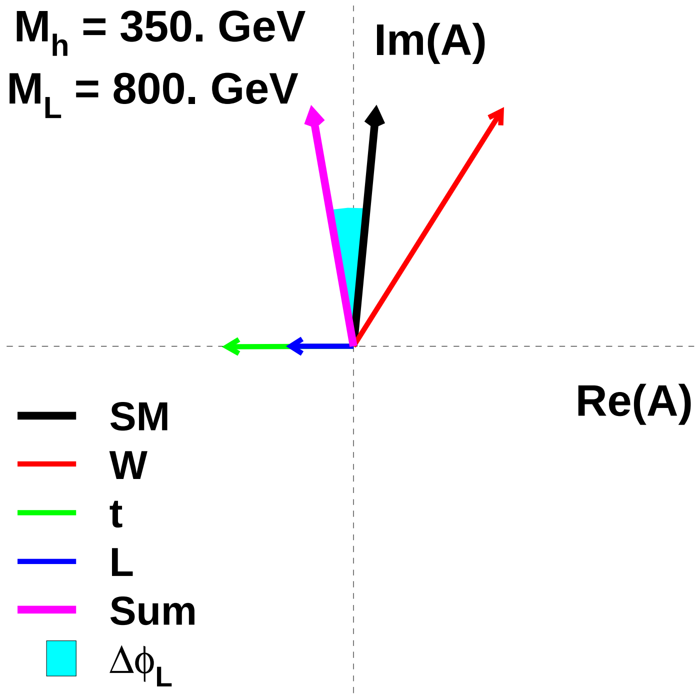

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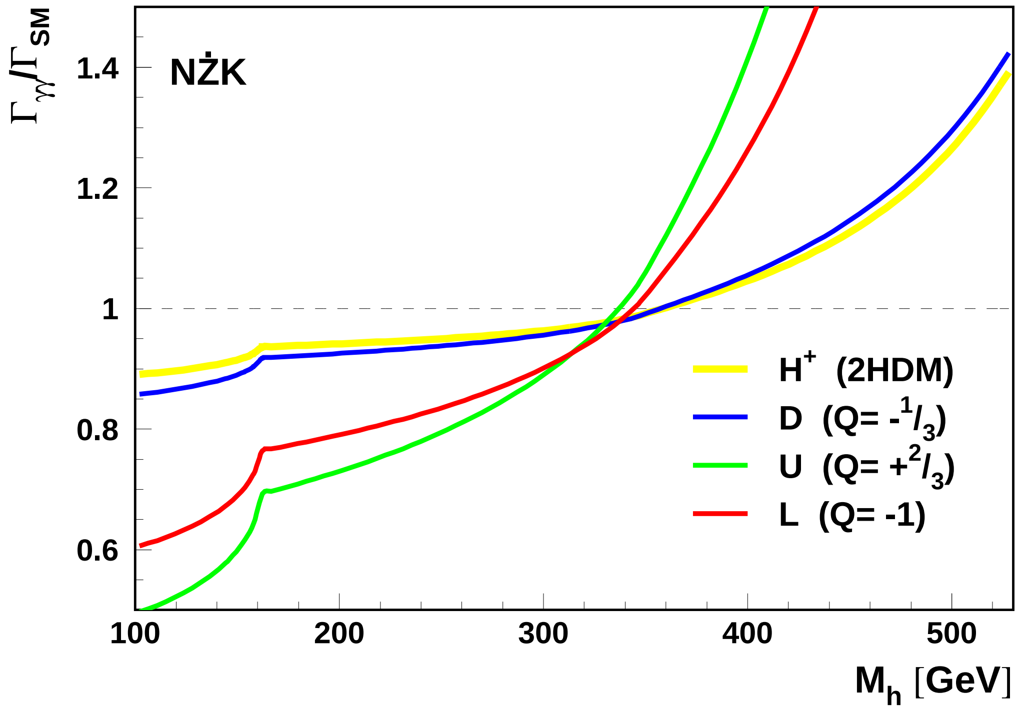
$\Rightarrow$ measure $\phi_{\gamma\gamma}$?

New particles

Contribution to $\Gamma_{\gamma\gamma}$ from new heavy charged particles with mass $\sim$800 GeV

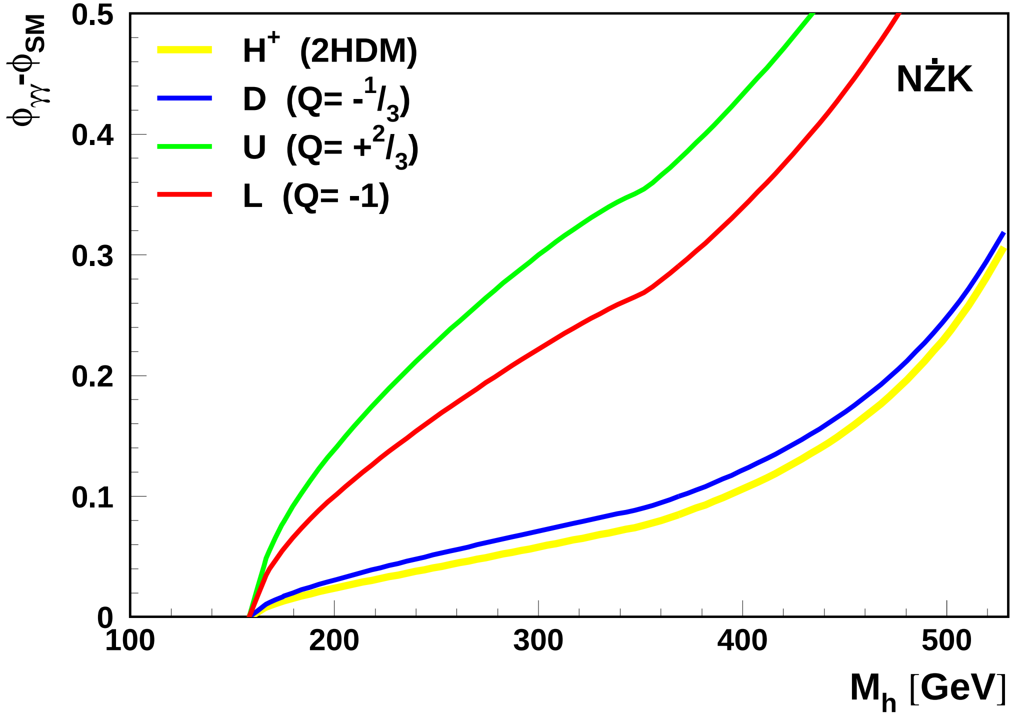


Significant deviations in $\Gamma_{\gamma\gamma}$ for small M_h

Small effects for $M_h \sim 350$ GeV

New particles

Contribution to $\phi_{\gamma\gamma}$ from new heavy charged particles with mass $\sim$800 GeV



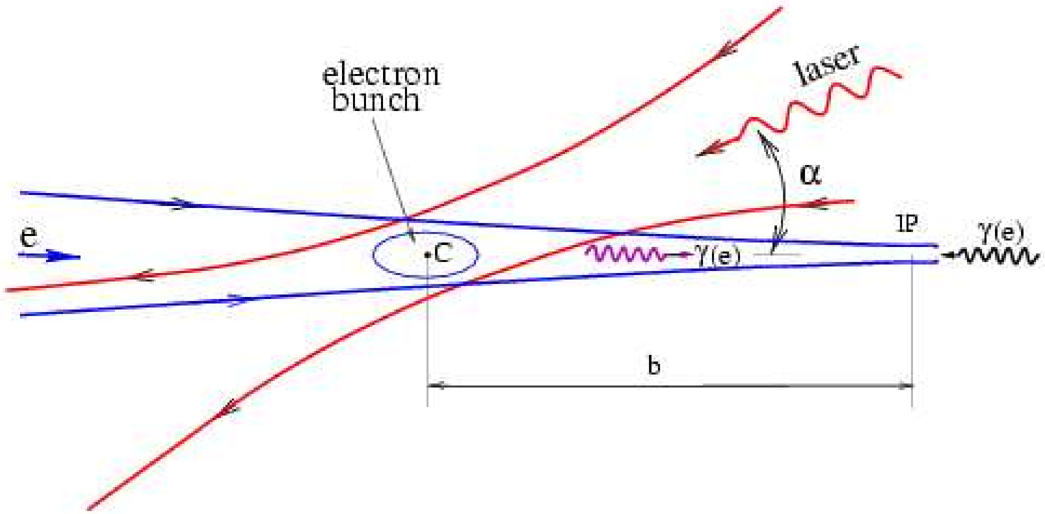
No deviations in $\phi_{\gamma\gamma}$ for light Higgs
$M_h < 160$ GeV.

Large effects expected for heavy Higgs

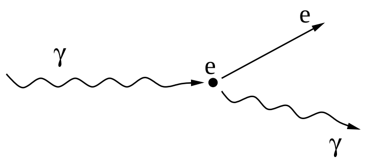
How can we measure it?

Photon Collider

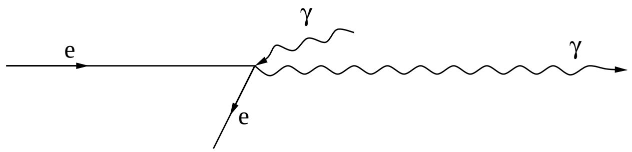
High energy, high intensity photon beam can be obtained using Compton backscattering of laser light off the high energy electrons



Compton scattering:



backscattering:



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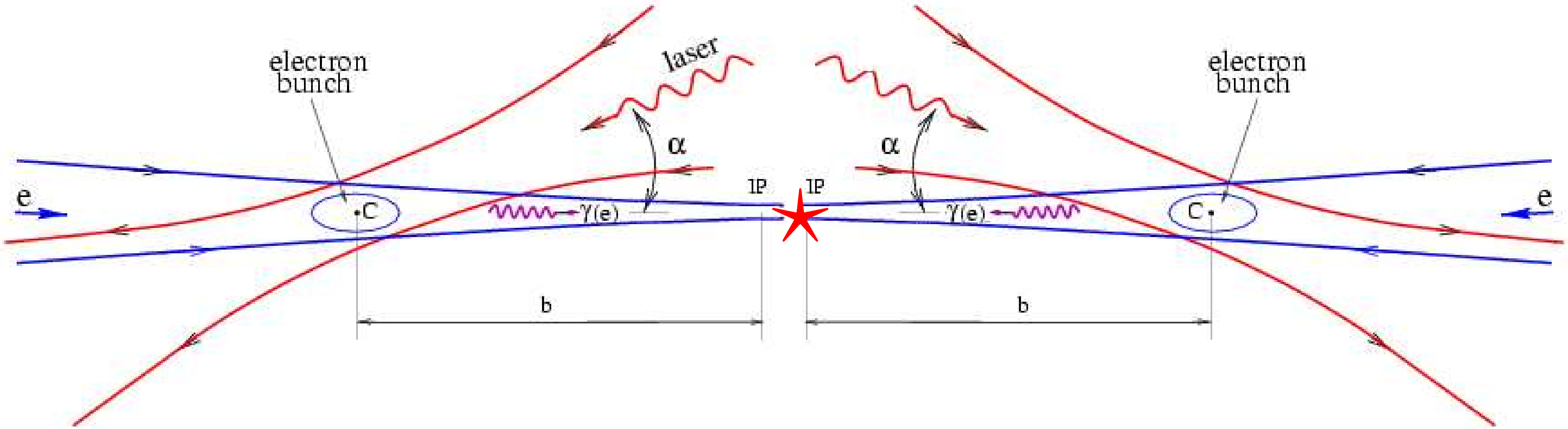
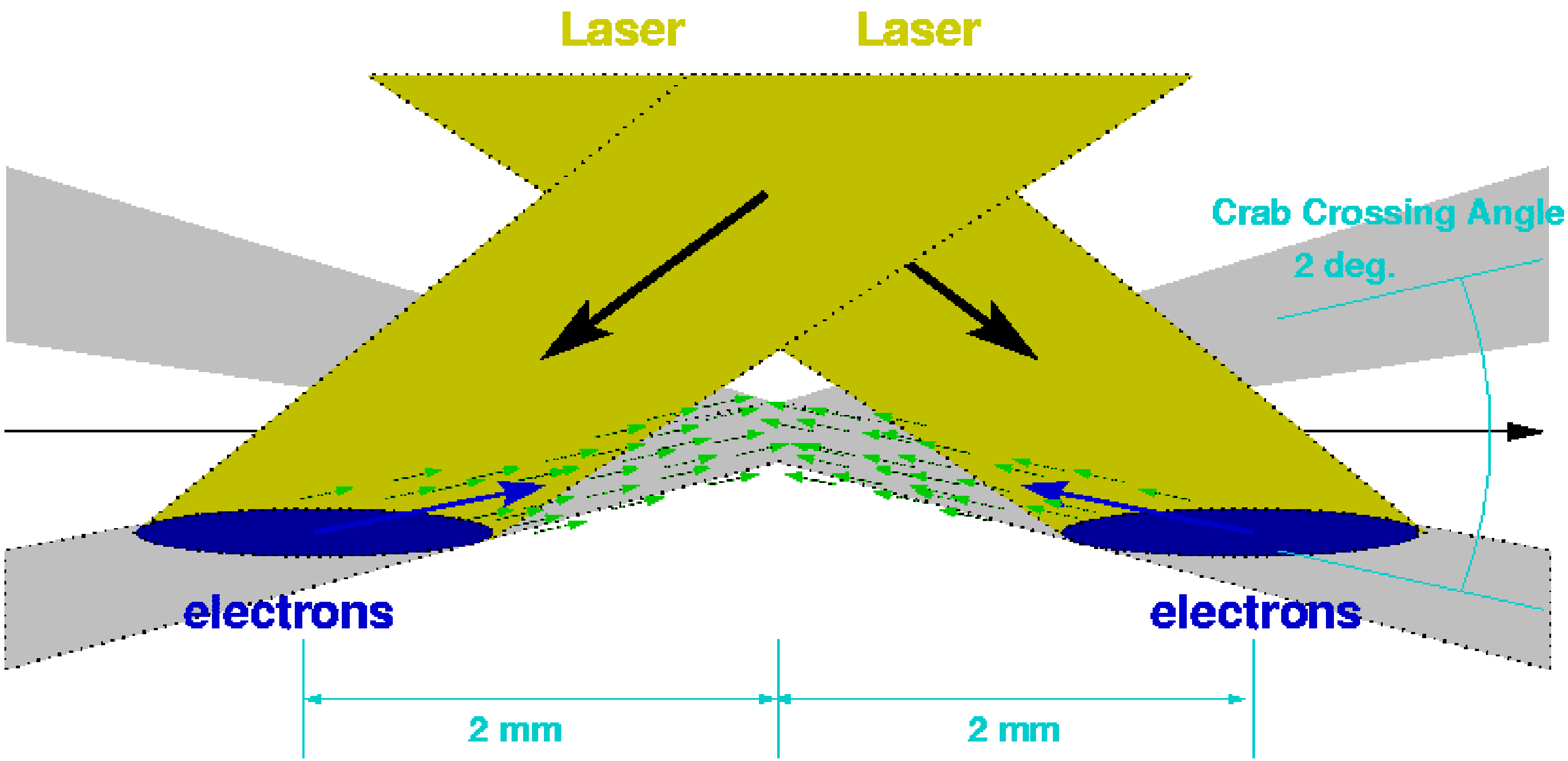
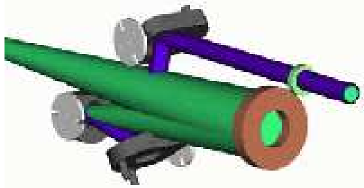


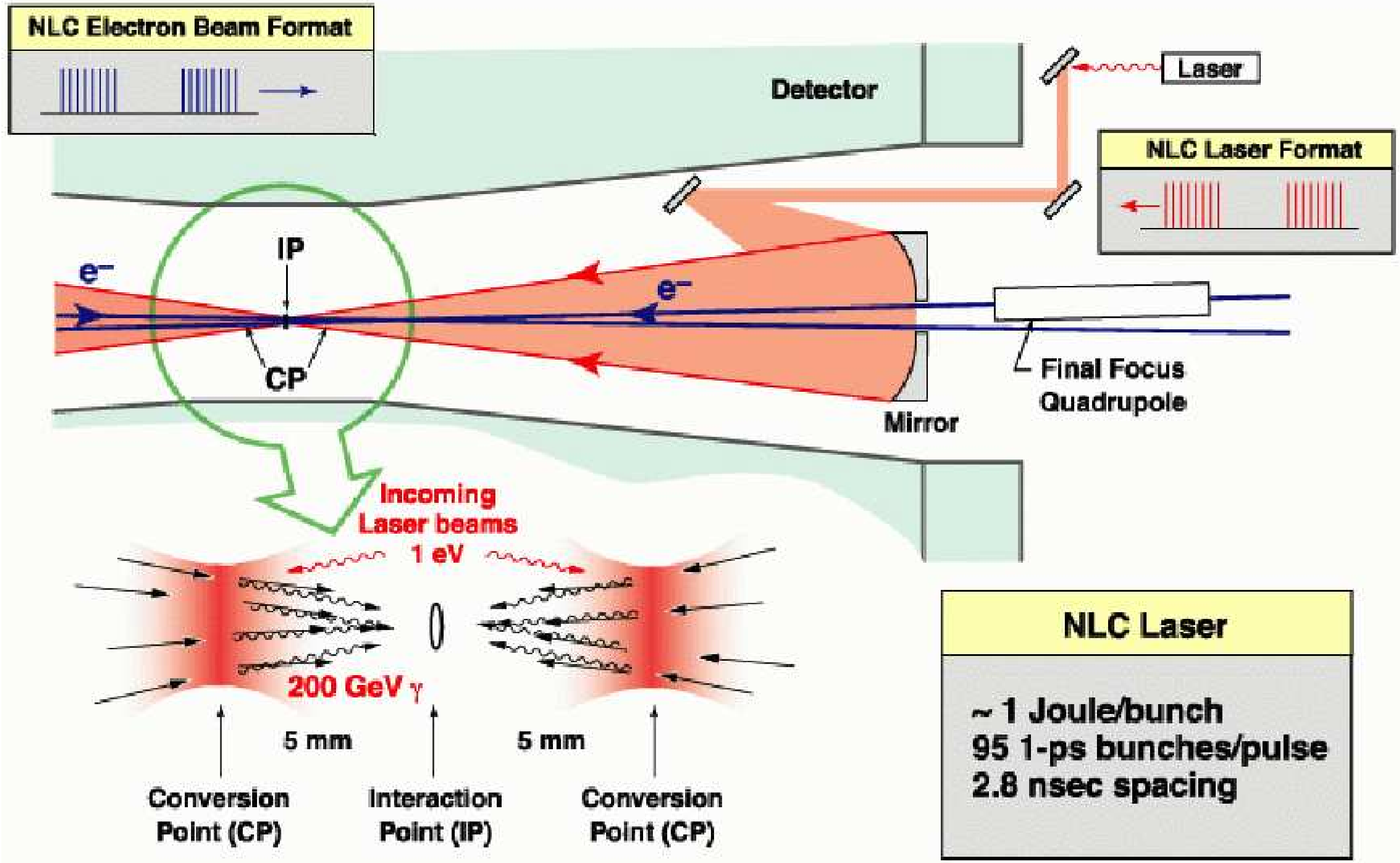
PC: natural extension of all e^+e^- linear collider projects including TESLA

Basic Idea


Laser
Laser
Crab Crossing Angle
2 deg.
electrons
electrons
2 mm
2 mm



Photon Colliders – The marriage of lasers and electron linear colliders

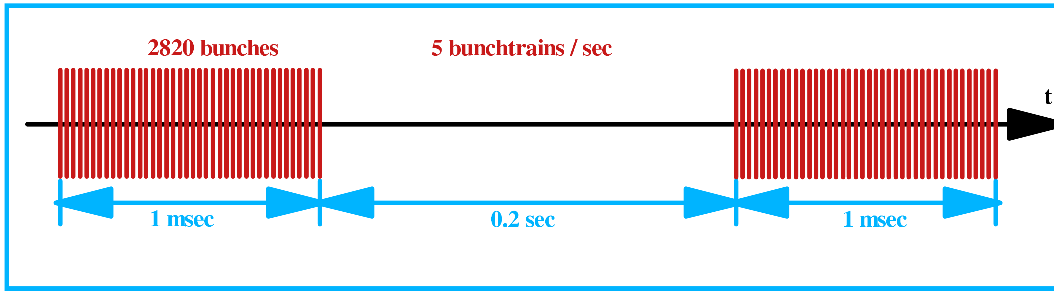


Laser requirements

- **Laser pulses of**

$\approx 5\,\mathrm{J}$	pulse energie
$\approx 1\text{-}3\,\mathrm{ps}$	pulse duration (FWHM)
$\approx 14\,\mu\mathrm{m}$	spotsize $(1/e^2)$
$\approx 1\,\mu\mathrm{m}$	wavelength
$2.5^\circ - 4^\circ$	e^- - IR crossing angle

- **have to match the TESLA bunch-structure**
  - 2820 bunches/train
  - 337 ns spacing
  - 5 Hz repetition rate



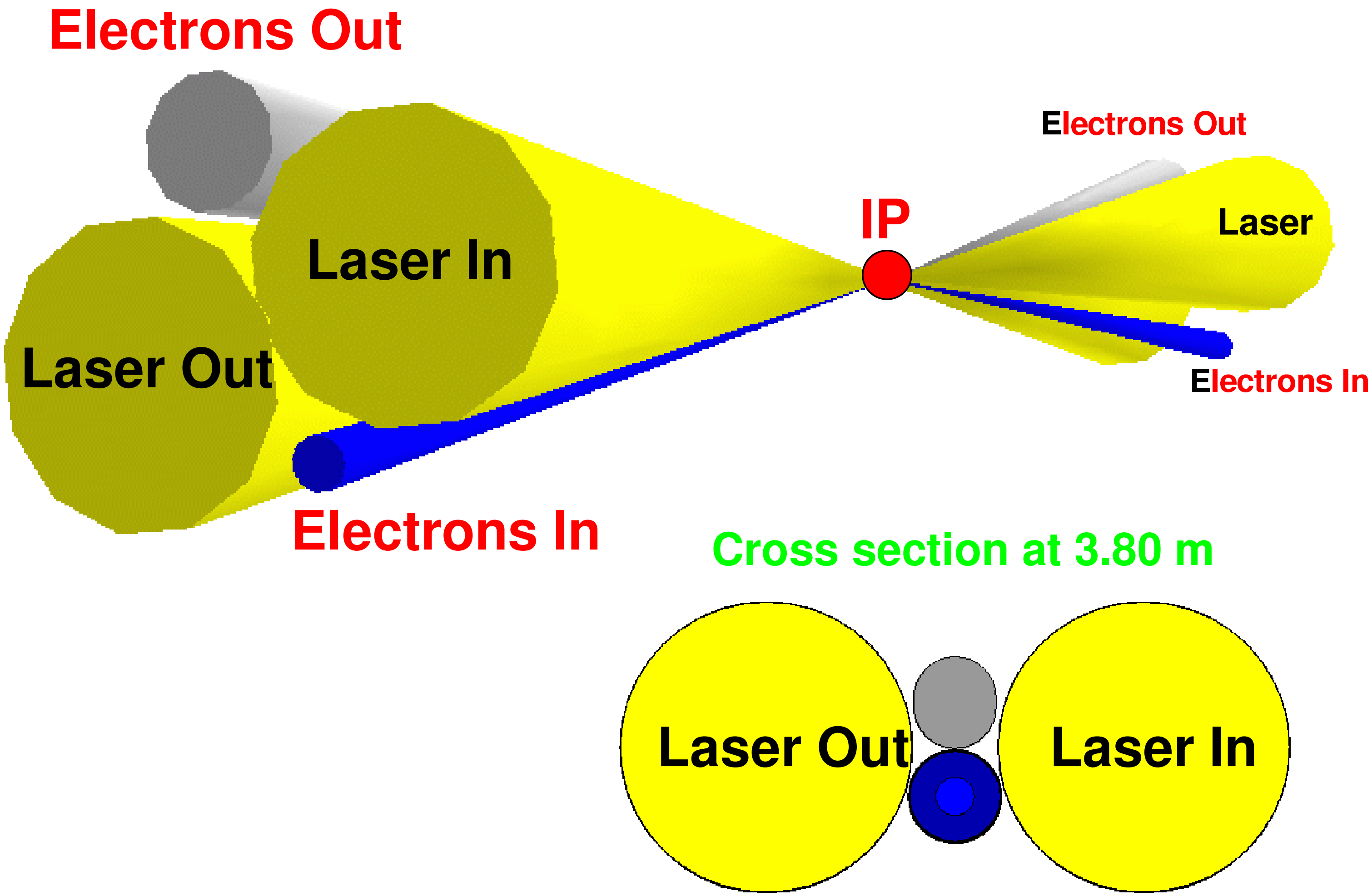
Requires:

- high peak power ($\approx$ 2 TW)
- high average power ($\approx$ 70 kW)
- precise timing, low jitter (1 ps)

One solution:

- **Pulsed laser with the correct timestructure and relaxed power requirements feeds a resonant cavity for enhancement of power**
- **telescopic active or passive ring resonator**

Layout of the Beams

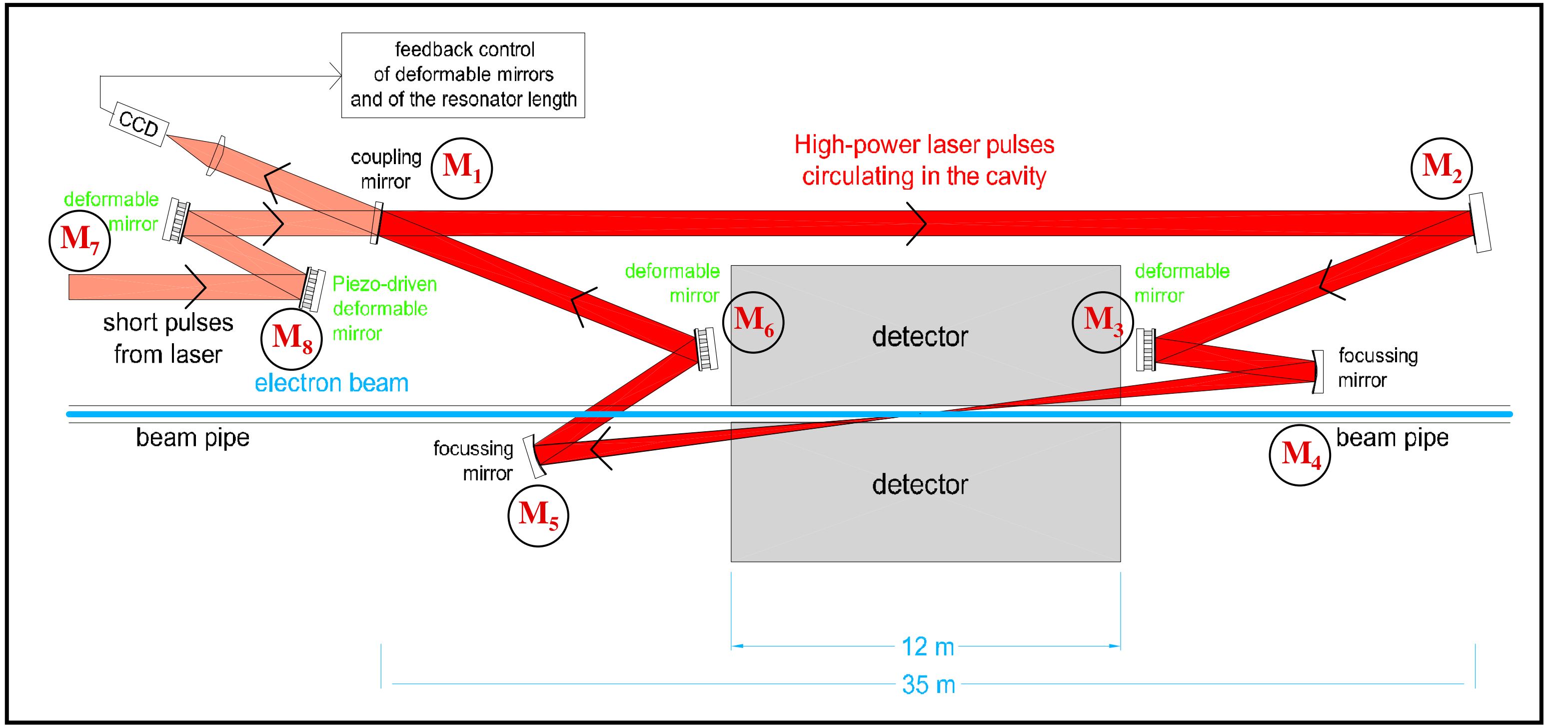


How to meet the length control requirement

Use of 2 lasers:

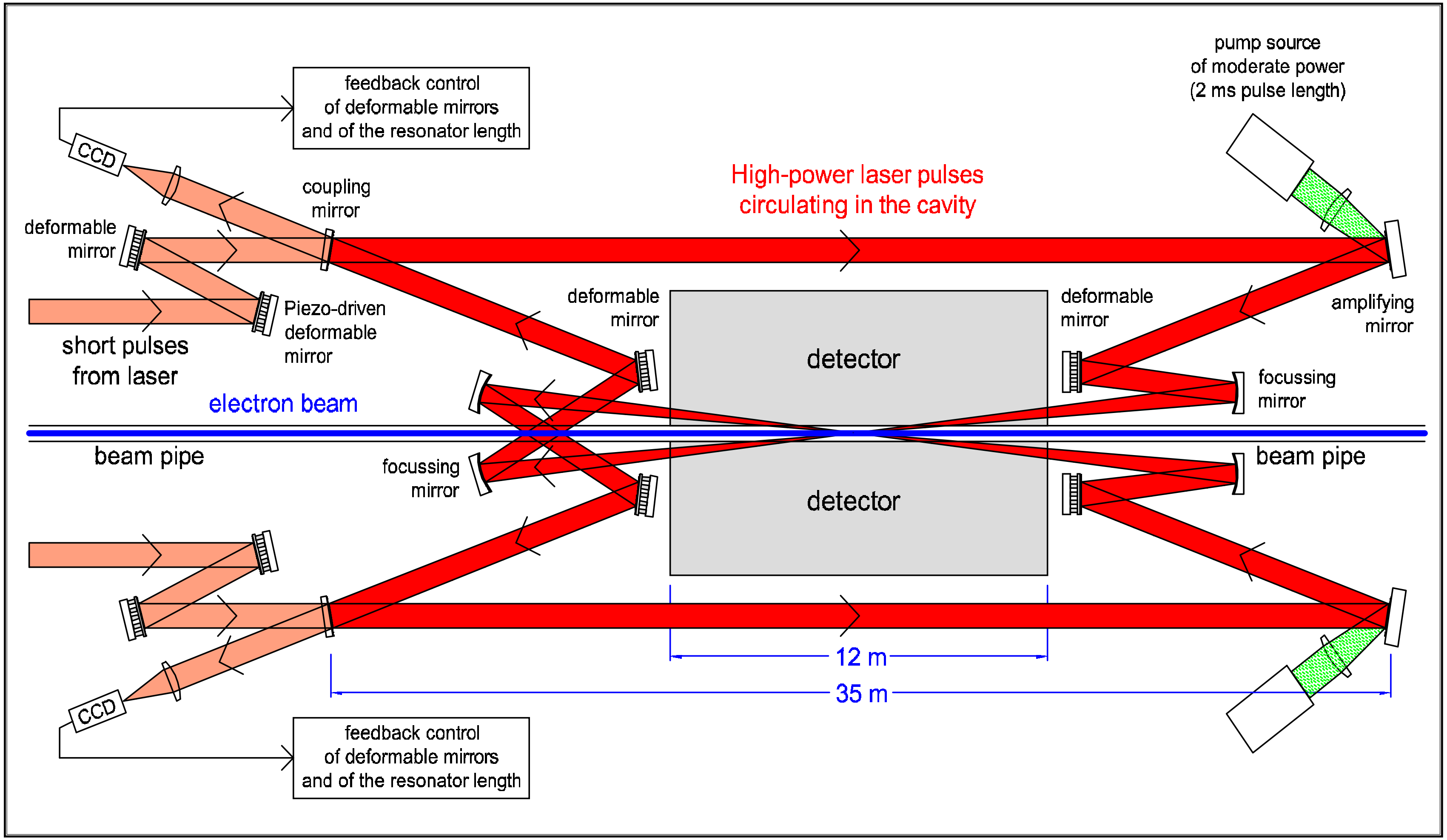
- **weak cw-laser for prealignement of the cavity - length control (Pound-Drever-Hall scheme: frequency side-bands)**
- **mode-locked high-power laser for compton process (deformable mirrors controlled by wavefront sensor)**

principle scheme of a passive cavity with deformable mirrors:

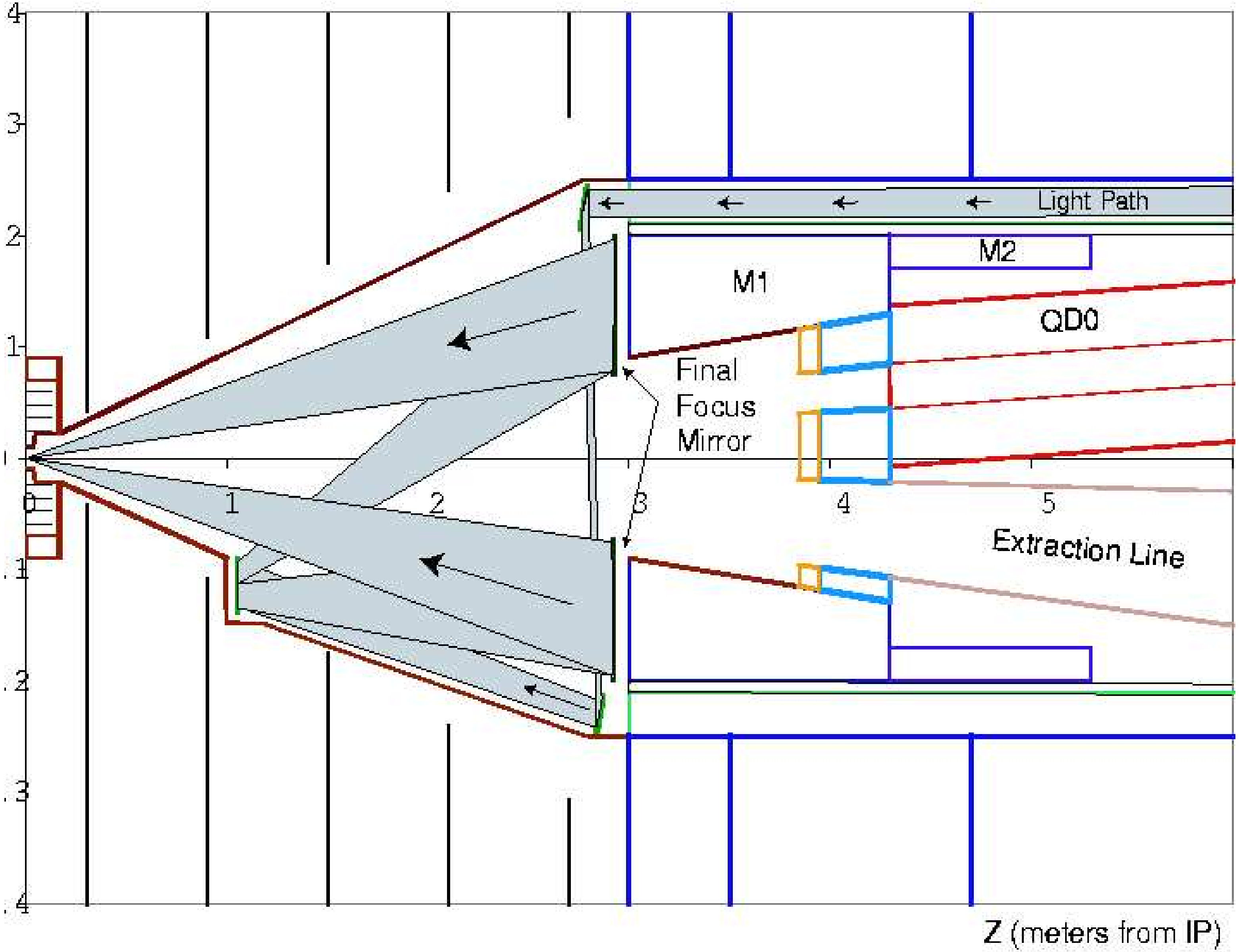


final focus: M4, M5: off-axis paraboloid ⟹ no beam magnification (V=1)

Laser: Ring Resonator



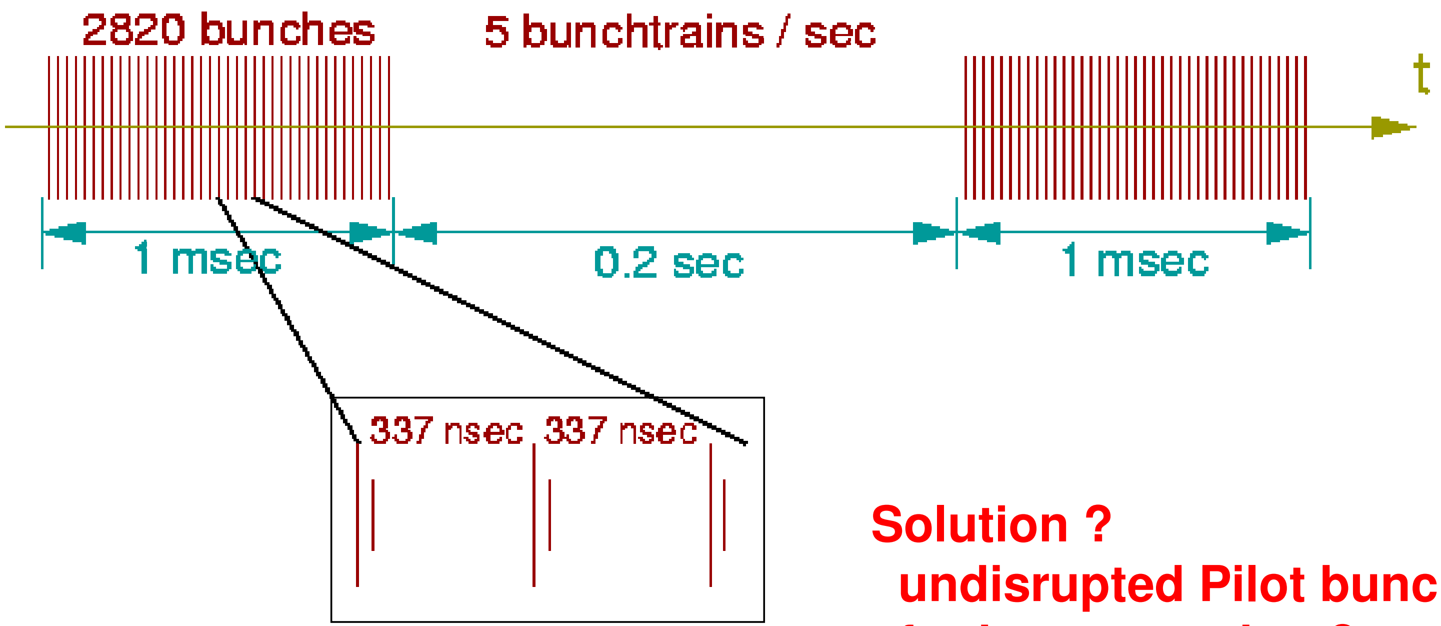
IR design… Gronberg et.al



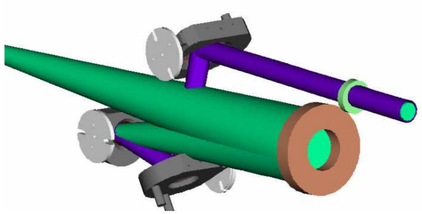
Beam Steering: e-e- IP

fast feed-back system

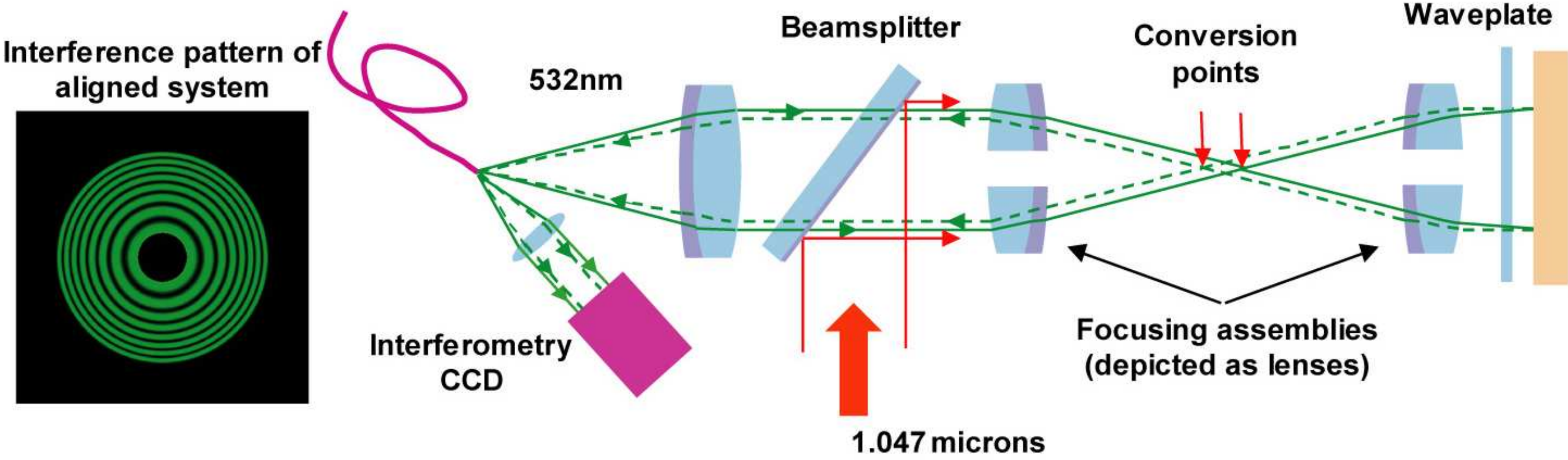
Problems:
- disrupted beam has large tails
- large apperture of BPMs



Solution ?
undisrupted Pilot bunches
for beam steering ?

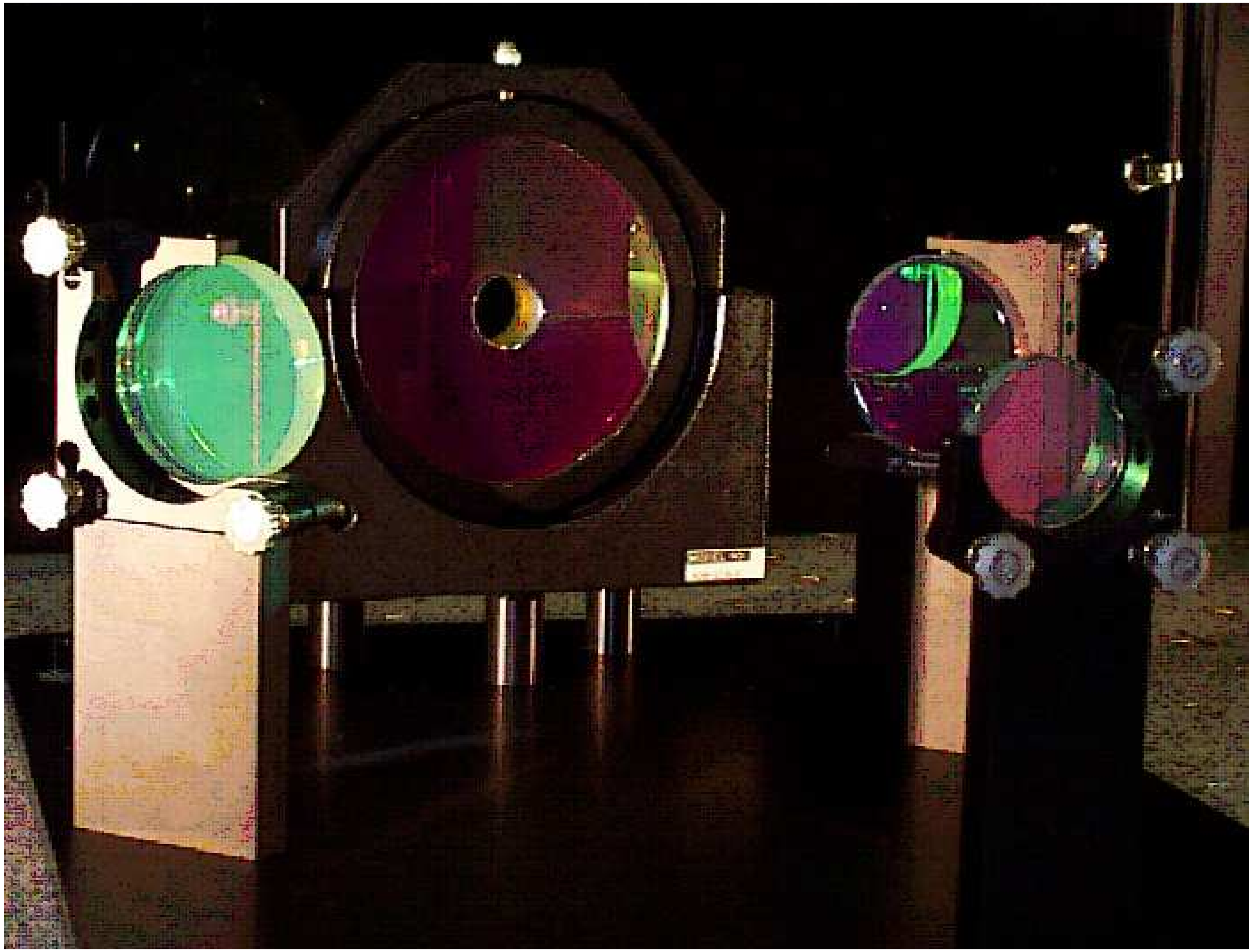


Interferometric Alignment System Testbed Under Construction



- Half-scale prototype of optics / alignment system is currently under construction
  - Optics fabricated, currently being coated
  - Alignment system being assembled
  - Operation in September 2002

Test optical cavity



Photon Collider

To get very high $\gamma\gamma$ luminosity we need very powerful lasers and strongly focused electron beams.

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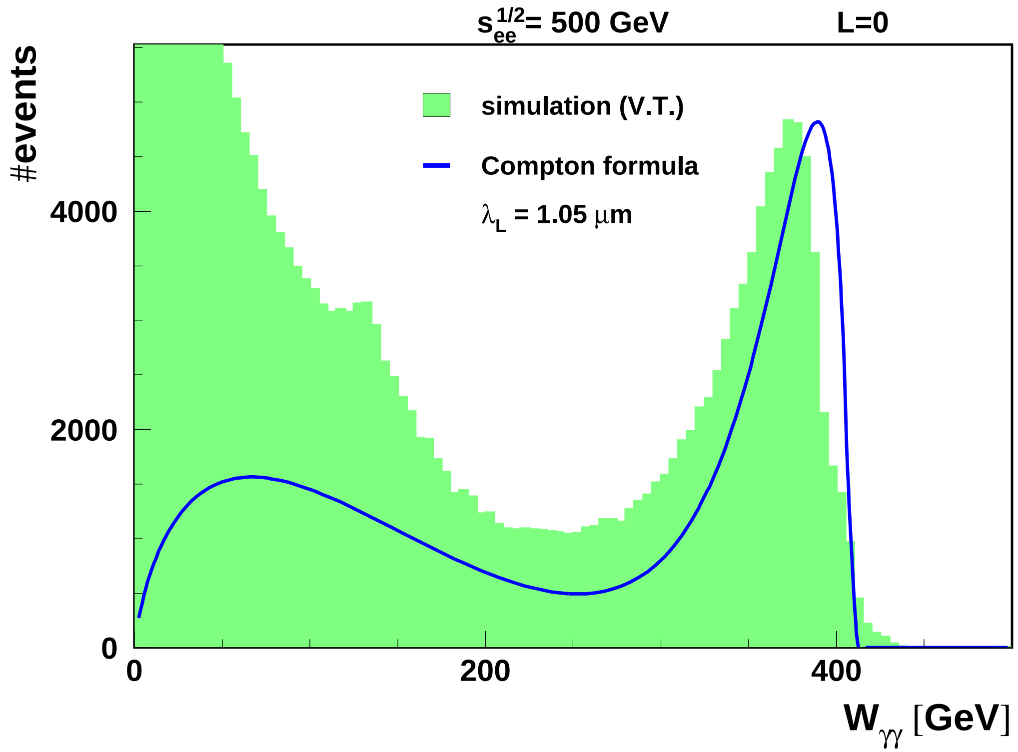
Higher order processes become important.

Compton formula fails to describe the luminosity spectrum

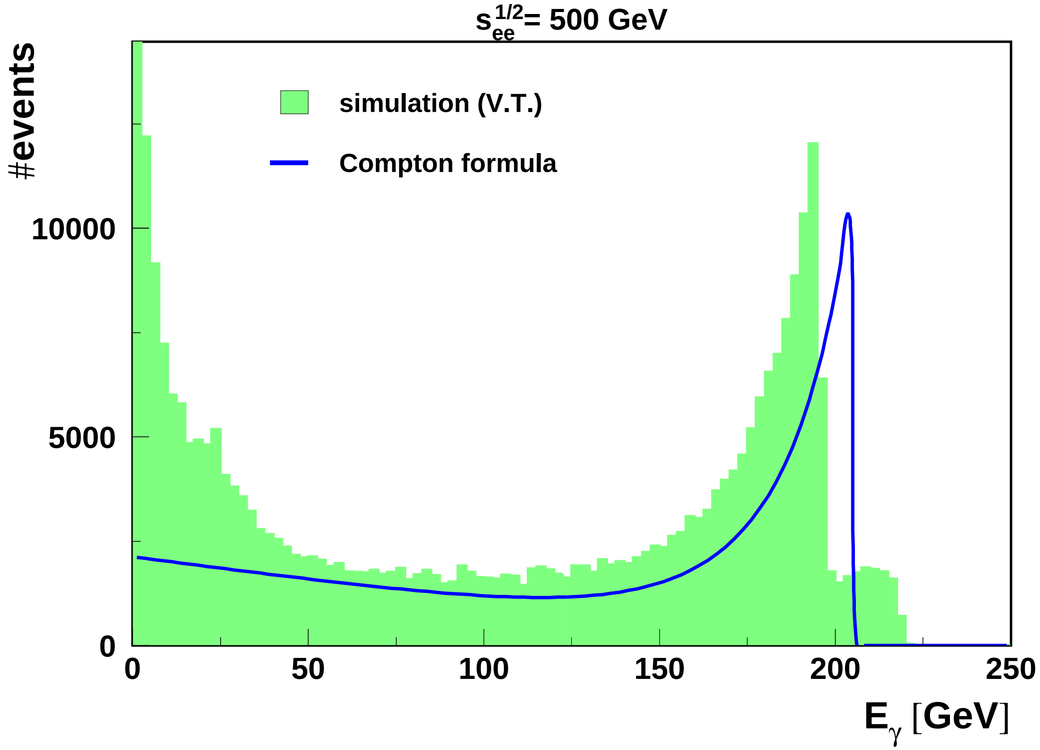


CompAZ

Parametrization of the photon energy spectrum

Compton formula

corrected for:



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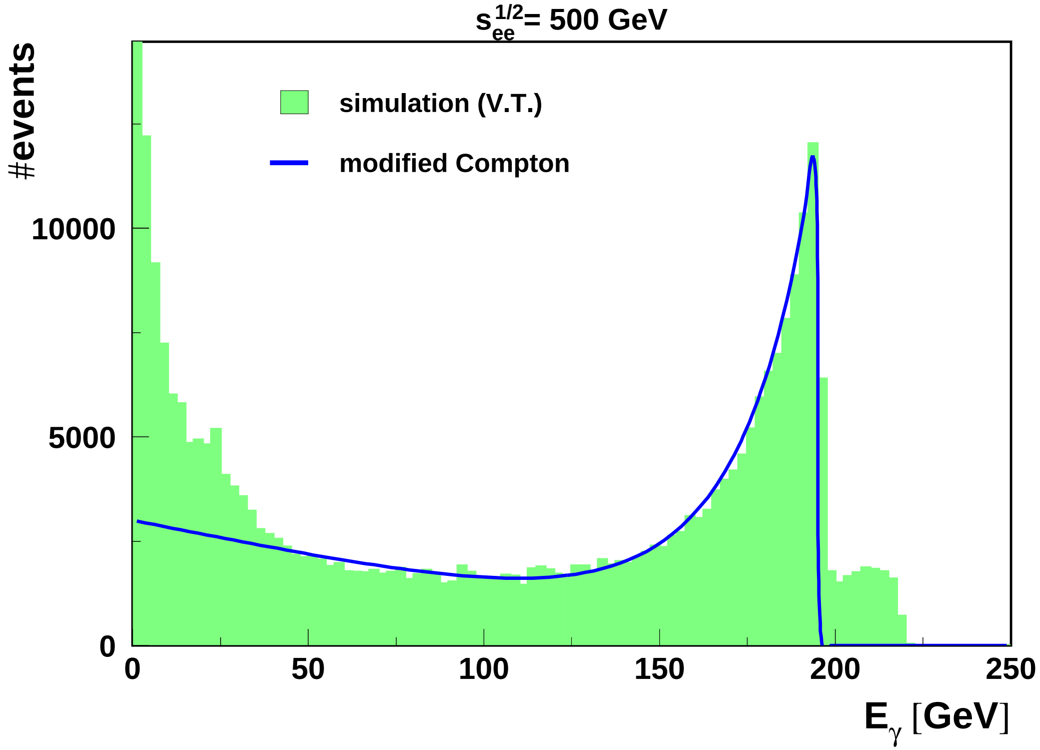

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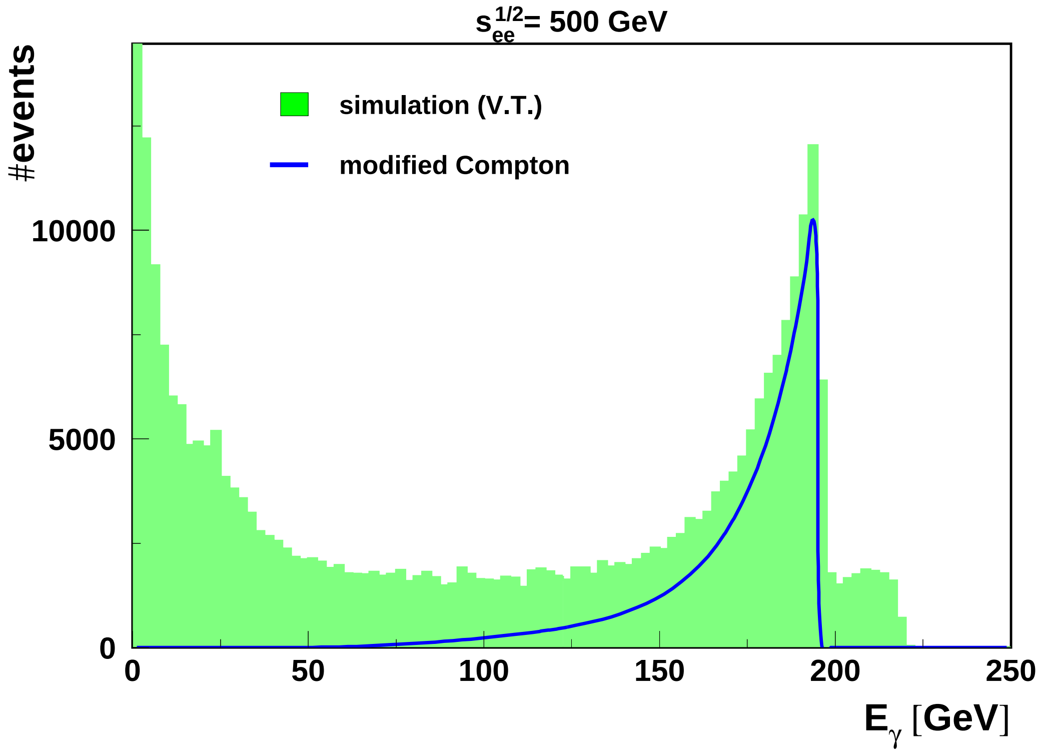


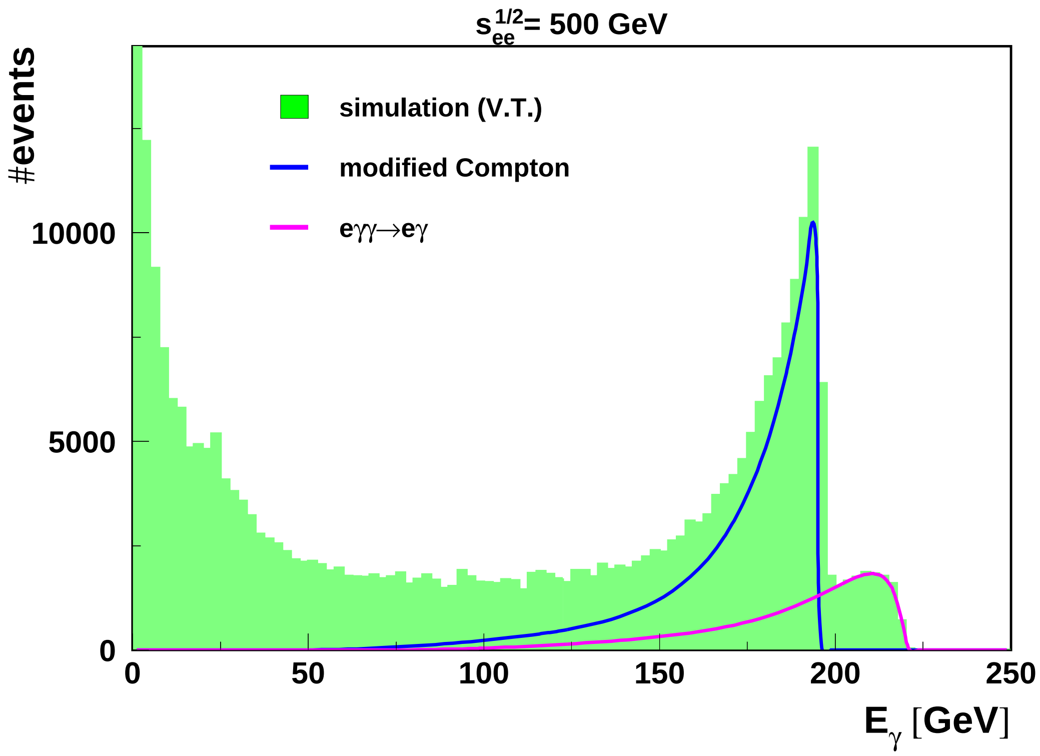
CompAZ

Parametrization of the photon energy spectrum

Compton formula

corrected for:

- nonlinear effects
- angular correlations
- two photon scattering



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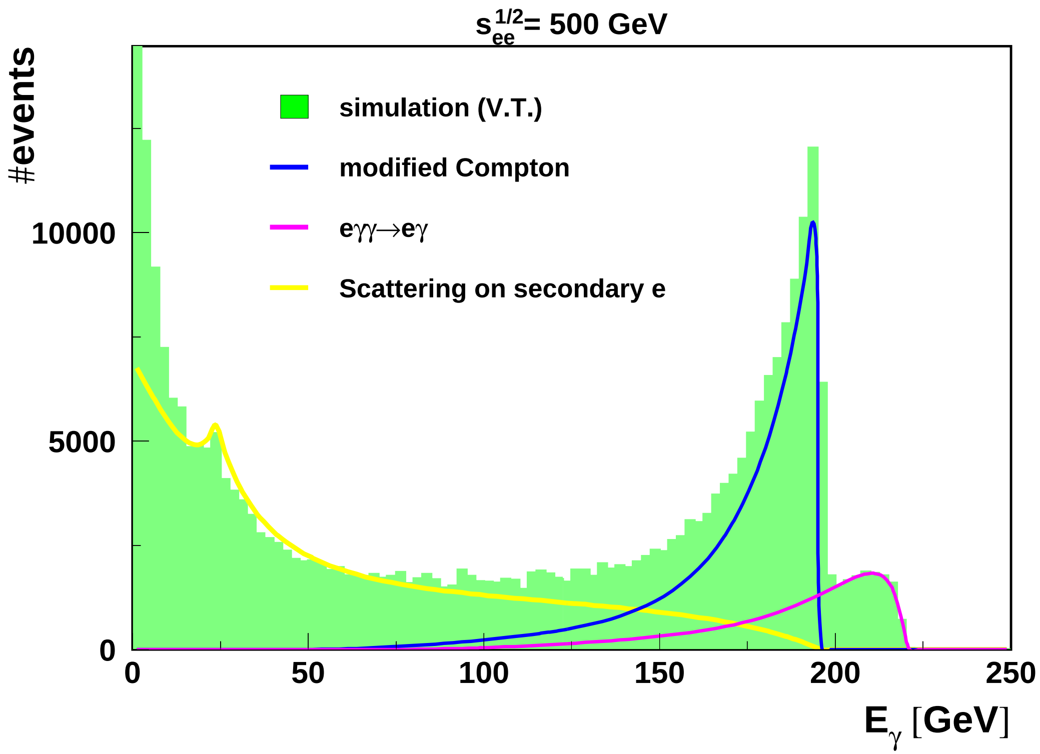

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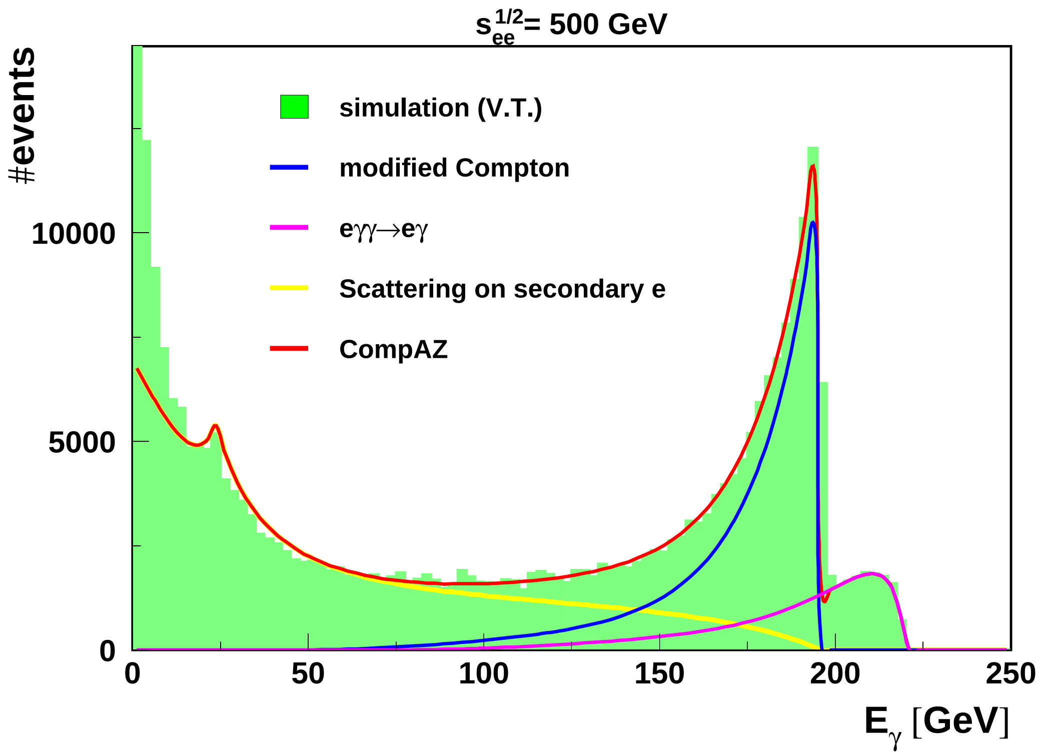
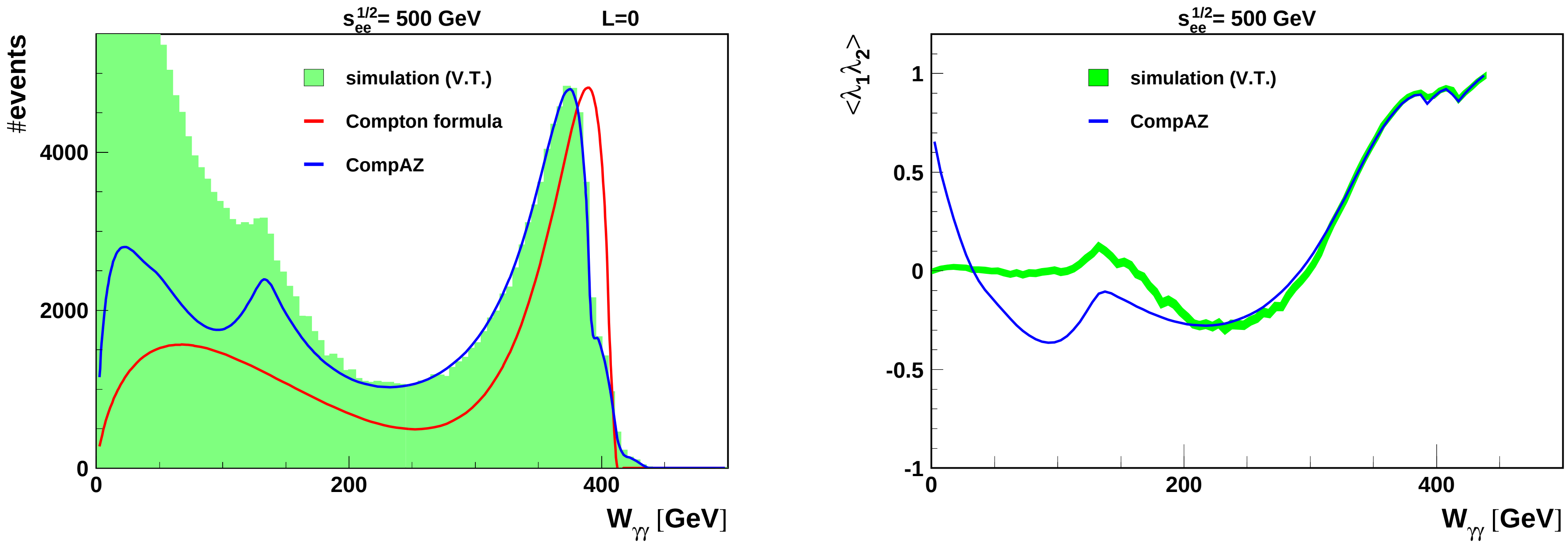


⇒ CompAZ

CompAZ

TESLA Photon Collider luminosity spectra parametrization
Very good description of the high energy part

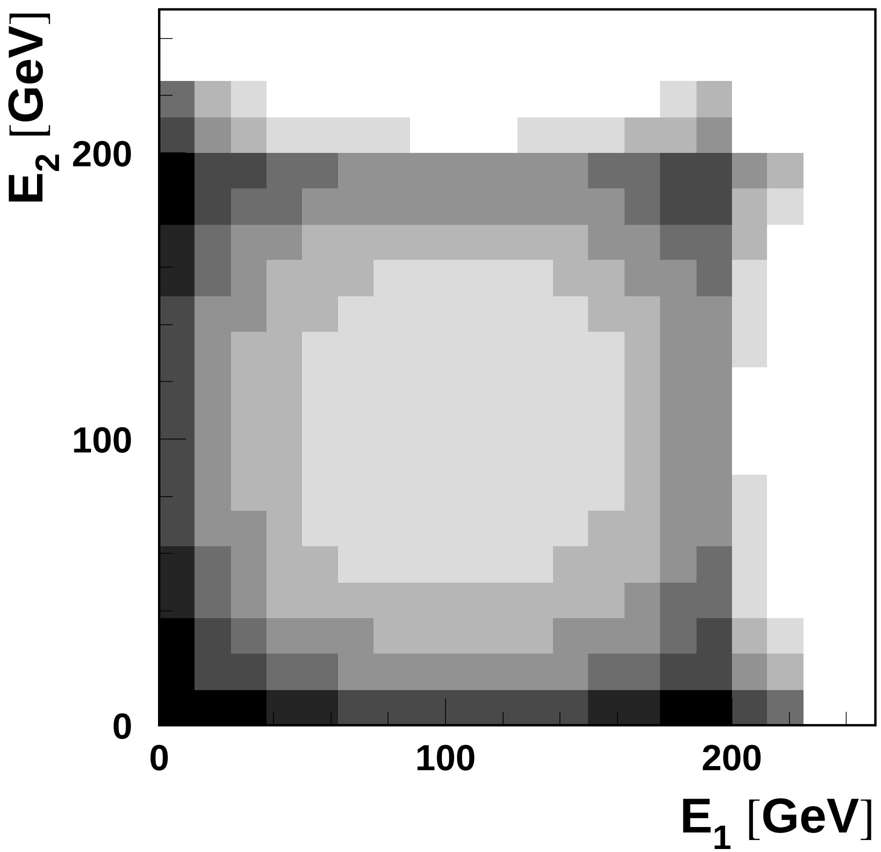
$\gamma\gamma$ invariant mass   polarization



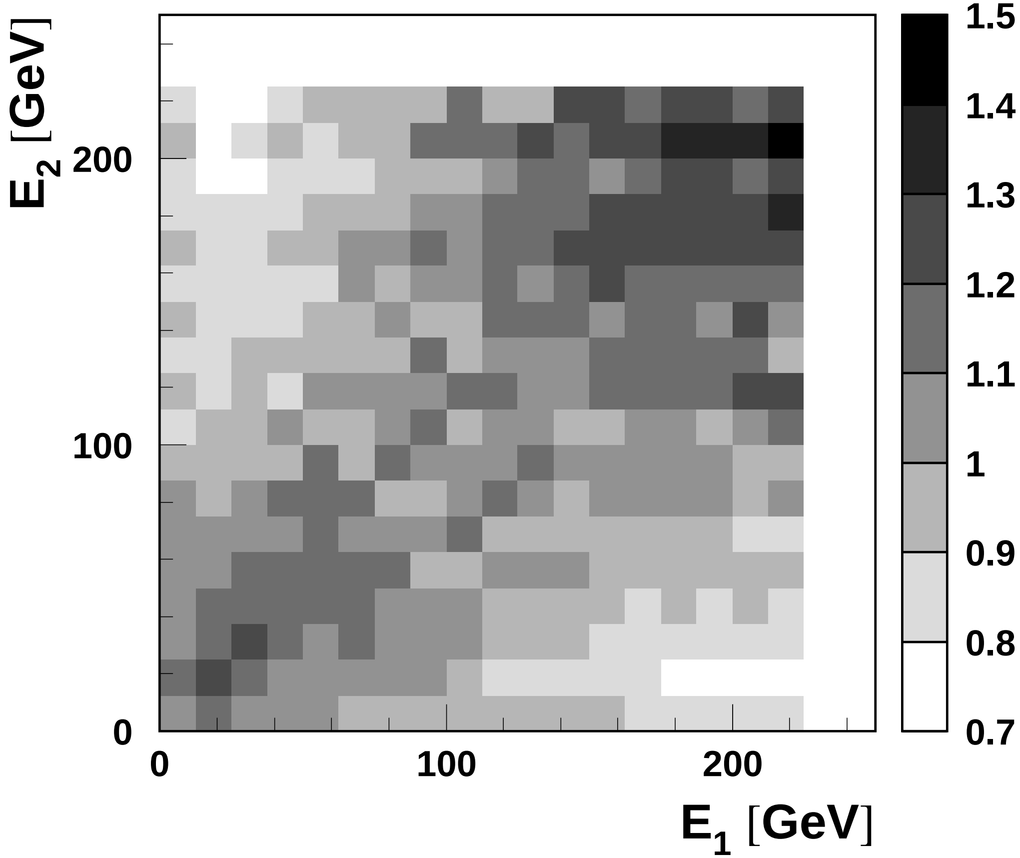
Beam energy correlations

There are large correlations between energies of two beams

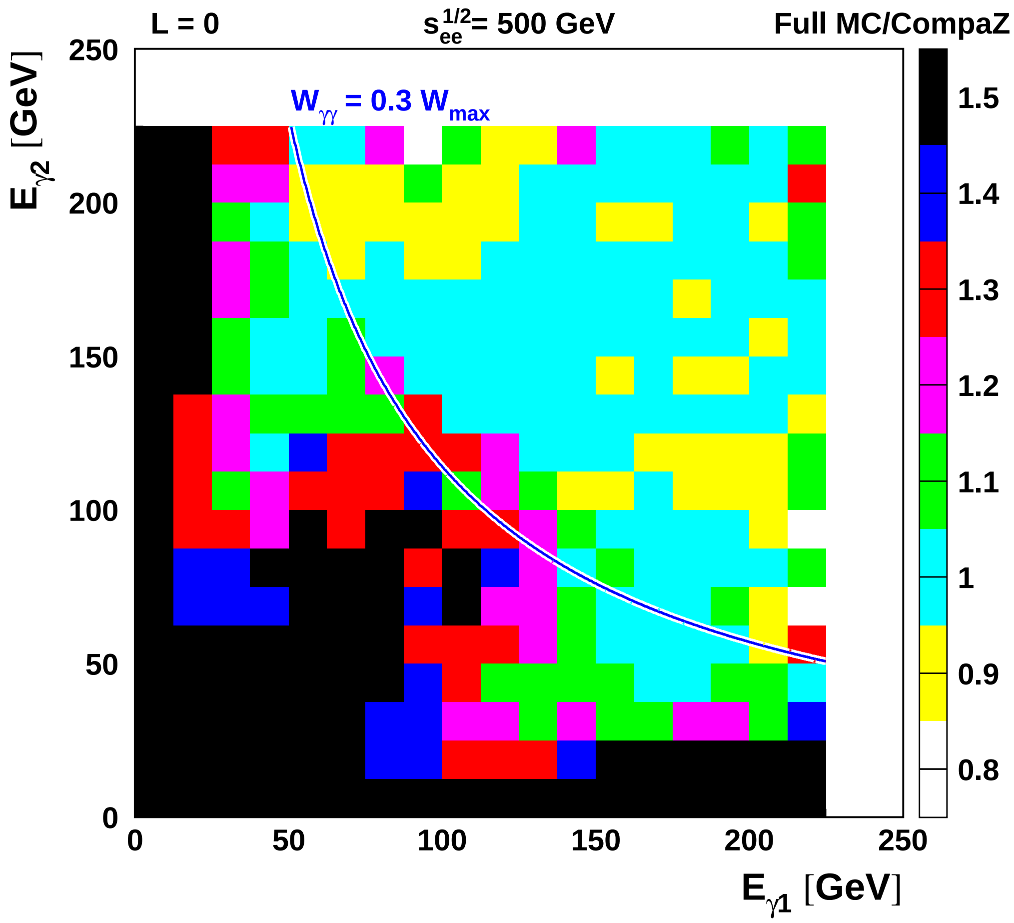
energies



normalized to uncorrelated supperposition

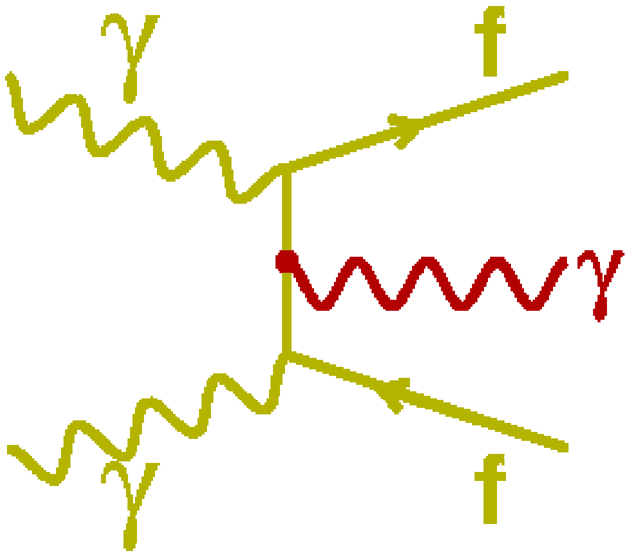


Beam energy correlations

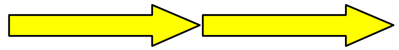


CompAZ describes well correlations in high energy part of the spectra

Luminosity and Polarization

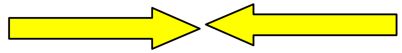


J = 2



$$\sigma = \frac{0.72\ \text{pb}}{s_{\gamma\gamma}\ [\text{TeV}]}$$

J = 0



$$\sigma = \frac{0.86\ \text{pb}}{s_{\gamma\gamma}\ [\text{TeV}]}\ \frac{8\, m_f^2}{s_{\gamma\gamma}}$$

Tagged Photons

$$\gamma\gamma \to f\,\bar{f}\,\gamma$$

$\sigma \neq 0$ **for** $J = 0, 2$

Luminosity Measurement

- Proposals
  - ee → ee (μμ) / not for J=0
  - ee → eeγ (μμγ)
  - ee → 4 leptons
- Precision ~0.1% (stat)
- For Higgs (J=0) e.g. ee → eeγ

TESLA luminosity:

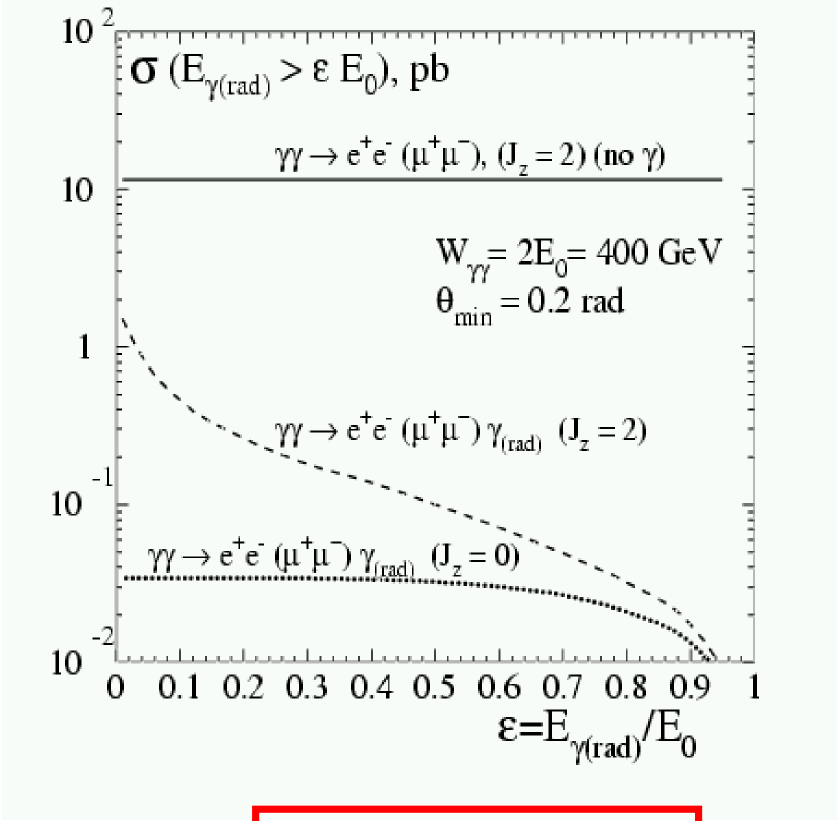
$$\mathcal{L}(\sqrt{s'} > 0.8\sqrt{s'_{\max}}) = 5.3 \cdot 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\mathcal{L}(m_{\mathrm{H}} \pm 1\,\mathrm{GeV}) = 3.8 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

with $\mathcal{P} \approx 90\%$

⇒ in a 2 years run ($2 \cdot 10^7$s):

$$\frac{\Delta\mathcal{L}}{\mathcal{L}}(\sqrt{s'} > 0.8\sqrt{s'_{\max}}) = 0.35\%$$
$$\frac{\Delta\mathcal{L}}{\mathcal{L}}(m_{\mathrm{H}} \pm 1\,\mathrm{GeV}) = 1.3\%$$

Moenig,Marfin,Telnov



For eγ collisions
- eγ → eγ
- eγ → eee

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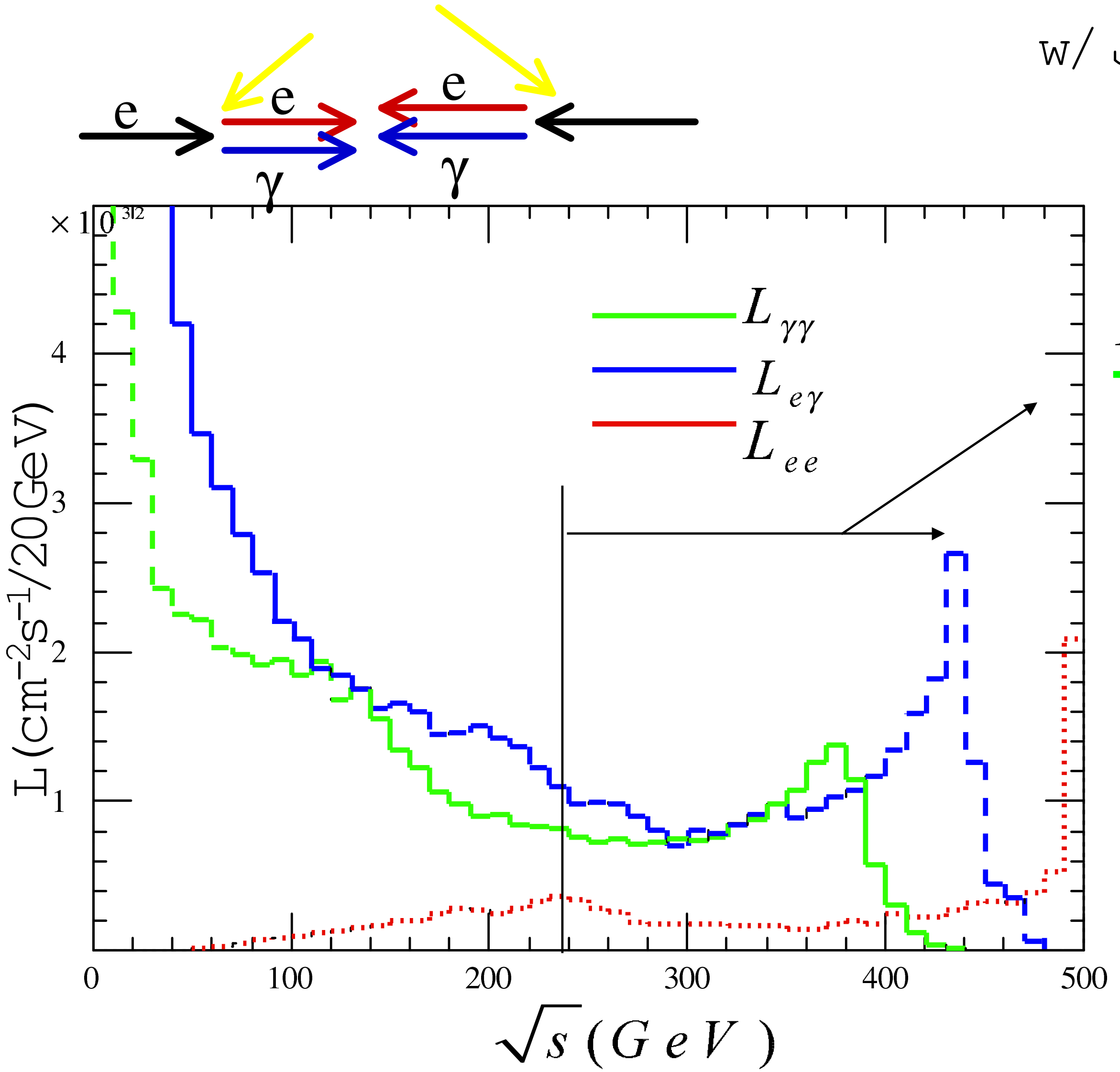
Luminosity Simulation (CAIN)

w/ JLC $\gamma\gamma$ parameter



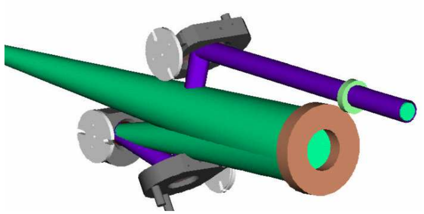
$L_{\gamma\gamma}^{eff}$: 1.37×10^{33}

$L_{e\gamma}^{eff}$: 2.4×10^{33}

L_{ee}^{eff} : 0.7×10^{33}

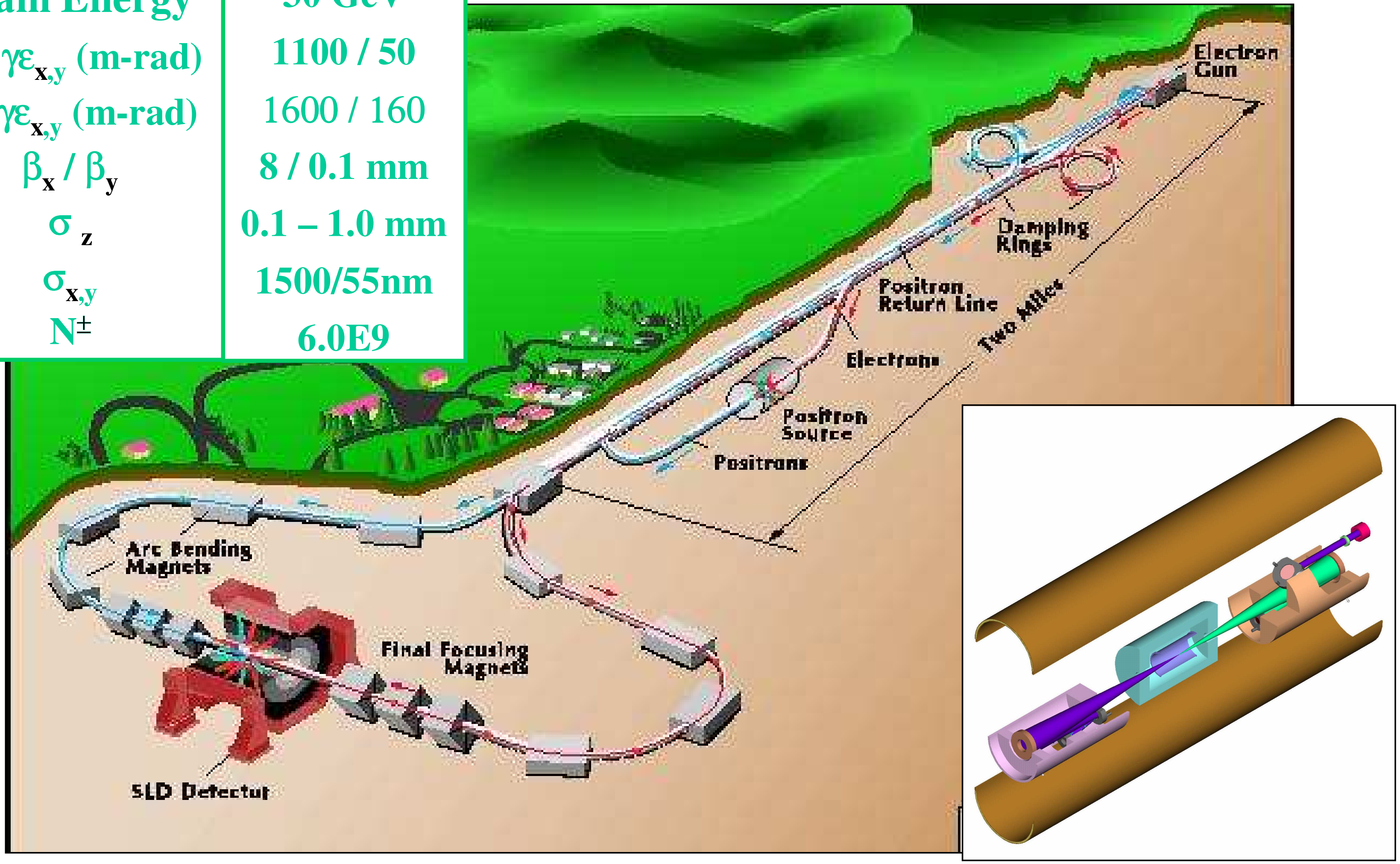
L_{ee}^{geo} : 1.18×10^{34}

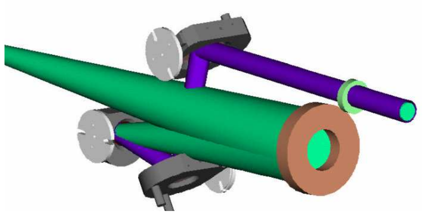
$cm^{-2} s^{-1}$



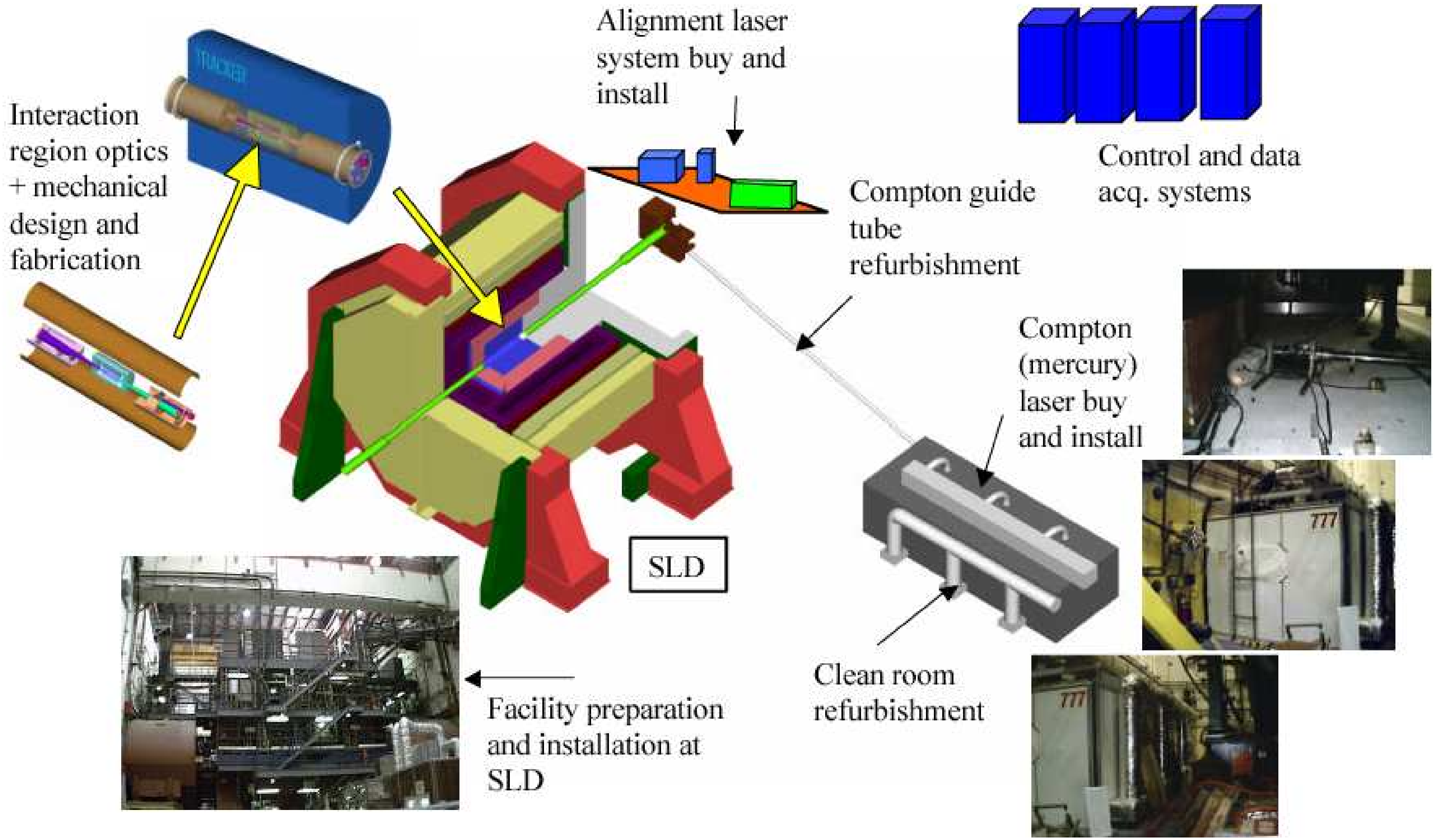
$\gamma\gamma$ Engineering Test Facility at SLC
Revive SLC and install beampipe with optics to produce $\gamma\gamma$ luminosity

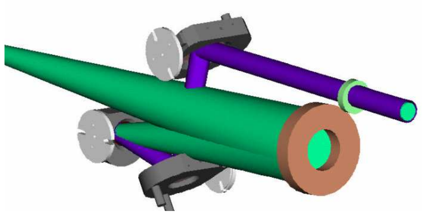
Beam Energy	**30 GeV**
DR $\gamma\epsilon_{x,y}$ (m-rad)	**1100 / 50**
FF $\gamma\epsilon_{x,y}$ (m-rad)	1600 / 160
β_x / β_y	**8 / 0.1 mm**
σ_z	**0.1 – 1.0 mm**
$\sigma_{x,y}$	**1500/55nm**
$N^{\pm}$	**6.0E9**





SLC Photon collider requires upgrade of beam pipe and installation of optics, laser and alignment system

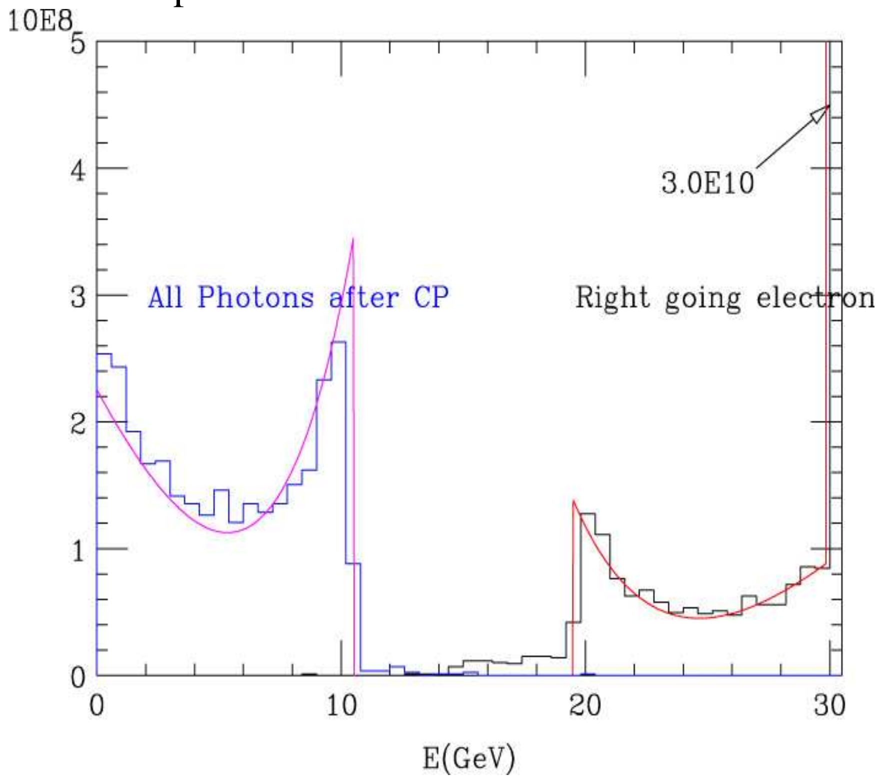




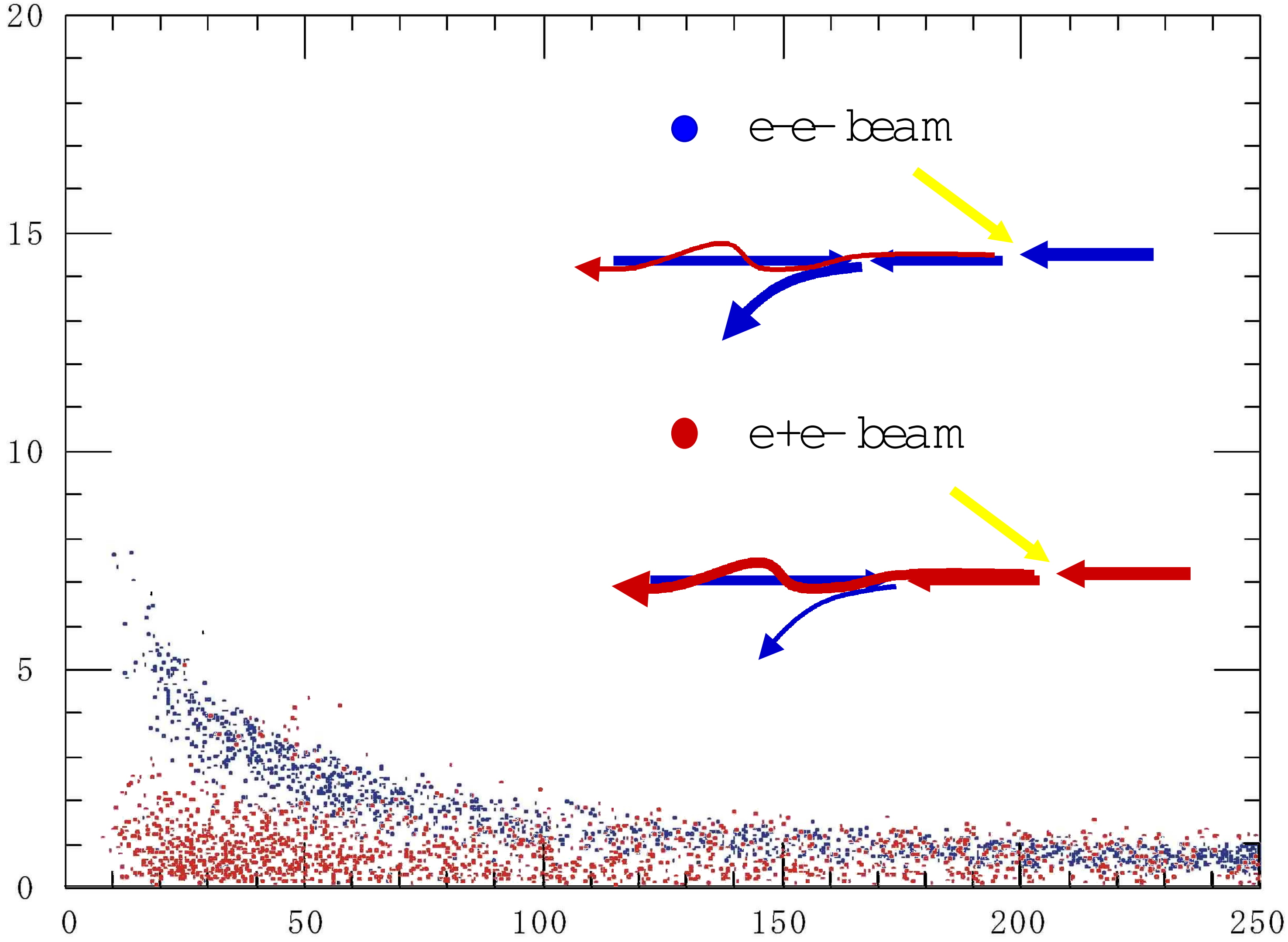
Compton backscattering at 30 GeV with a low power laser

- 0.1 Joule laser pulses produce measurable $\gamma\gamma$ luminosity
  - 25% of incoming electrons Compton scatter
  - Maximum photon energy 1/3 of incoming electron energy
  - Electron energy cuts off at 20 GeV
    - Low energy tail from multiple scatters
- The $\gamma\gamma$, $e\gamma$ and ee events can be separated solely with their kinematic information
  - Identify two hit events in the calorimeter
  - No tracking required
  - Run ~1 day for a spectrum

Comparison of CAIN with a simple PANDORA parameterization. Laser pulse of 0.1 Joule

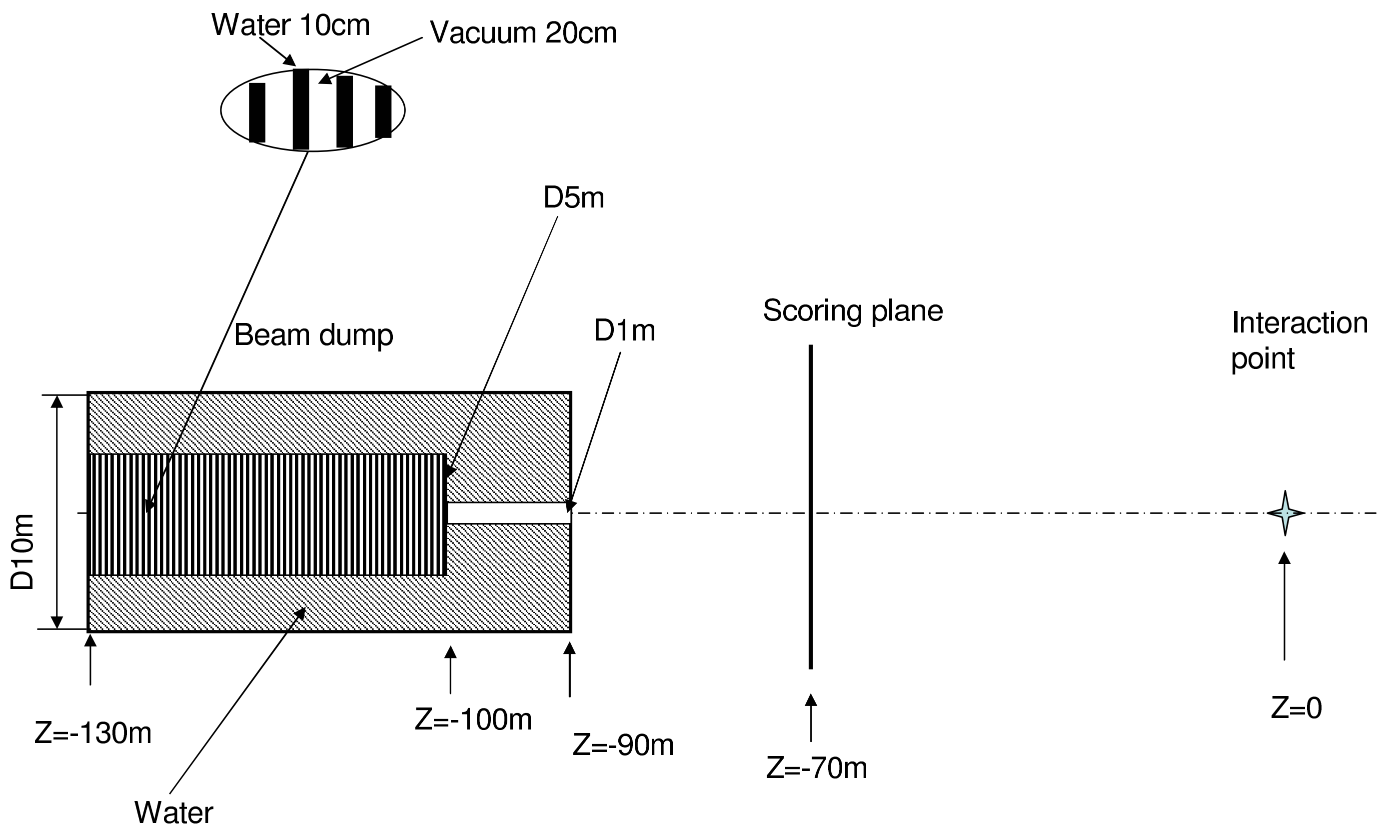


Disruption of Spent Electrons



Neutron background: mask design

Option 3: “hybrid” cylinder with tunnel and sandwich absorber”



Conclusions

- Strongly motivated option for Future Linear Collider
  many issues will be discussed at future meetings...

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- Strongly motivated option for Future Linear Collider
  many issues will be discussed at future meetings...
- Seems feasible, promissing results of first studies.
- Many technical details still to be studied
  for all projects (TESLA, NLC, GLC):
  - Powerfull and very “precise” laser
  - Optical cavity
  - Influence on detector design
  - Background reduction
  - Luminosity and polarisation measurement