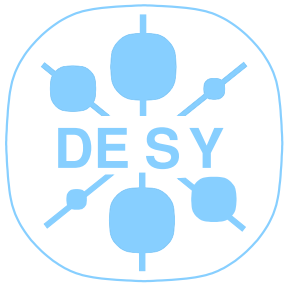
A Photon Collider at TESLA

Klaus Mönig
F. Bechtel, G. Klemz, J. Sekaric, A. Stahl



-Zeuthen

- Introduction
- Laser system
- Luminosity optimisation
- Detector and backgrounds
- Conclusions

Introduction

Physics Motivation:
Want to study $\gamma\gamma \to H \to b\bar{b}$, $\gamma\gamma \to W^+W^-$, $\gamma\gamma \to$ SUSY
$\Rightarrow$ need $\sqrt{s} = 120GeV-$ maximum possible with high luminosity.

TESLA bunch structure: bunch trains with 2800 bunches/train and 337 ns bunch crossing time

➠ laser completely driven by time structure, study only partially valid for warm technology

Detector design:

- Large disruption angle requires crab crossing with $\alpha \approx 35$mrad
- forward part of detector completely driven by laser and crossing angle
- outer part kept identical to e^+e^- TDR-detector

Beam parameters for $\sqrt{s_{ee}} = 500\,\mathrm{GeV}$

	e^+e^-	$\gamma\gamma$	$\gamma\gamma$ (optimistic)
$N/10^{10}$	2	2	2
σ_z [mm]	0.3	0.3	0.3
pulses/train	2820	2820	2820
Repetition rate [Hz]	5	5	5
$\gamma\epsilon_{x/y}/10^{-6}$ [m·rad]	10./0.03	3./0.03	2.5/0.03
$\beta_{x/y}$ [mm] at IP	15/0.4	4/0.4	1.5/0.3
$\sigma_{x/y}$ [nm]	553/5	157/5	88/4.3
$\mathcal{L}(z > 0.8 z_m)$ $[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	3.4	0.6	1.1

The Laser

Wavelength of powerful solid state lasers is in the 1μm range, e.g. Nd:YAG $\lambda = 1.06\mu$m

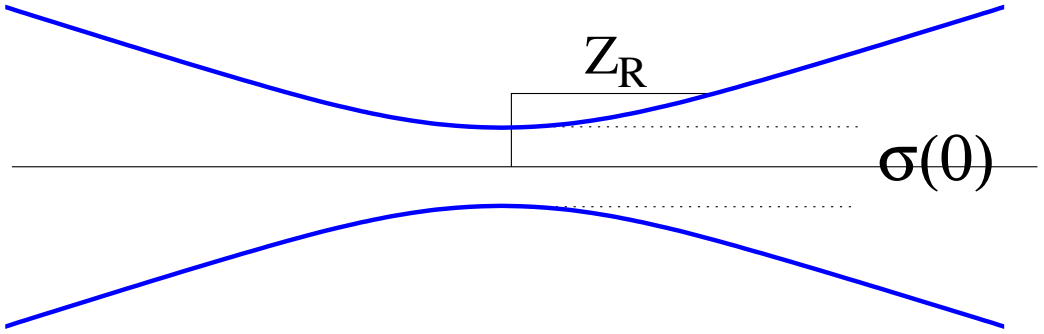
($x = 4.5$ for $\sqrt{s} = 500\,\mathrm{GeV}$)

(If really needed can double or triple frequency)

Laser focusing in diffraction limited region:

$$\sigma_{L,r}(z) = \sigma_{L,r}(0)\sqrt{1 + z^2/Z_R^2} \quad \sigma_{L,r}(0) = \sqrt{\frac{\lambda Z_R}{2\pi}}$$

Z_R: Rayleigh length



$\longrightarrow$ cannot vary length and diameter of laser spot simultaneously

Optimum around $Z_R \approx \sigma_z$ ➠ half opening angle of $\mathcal{O}(1^\circ)$

Fraction of converted electrons:

$$k = N_\gamma / N_e \approx 1 - \exp(-A/A_0)$$

A: pulse energy of laser

For $Z_R \approx \sigma_z$ and head on laser-beam collisions:

$$A_0 \approx \frac{\pi \hbar c \sigma_z}{\sigma_c} \approx 1.5\mathrm{J}$$

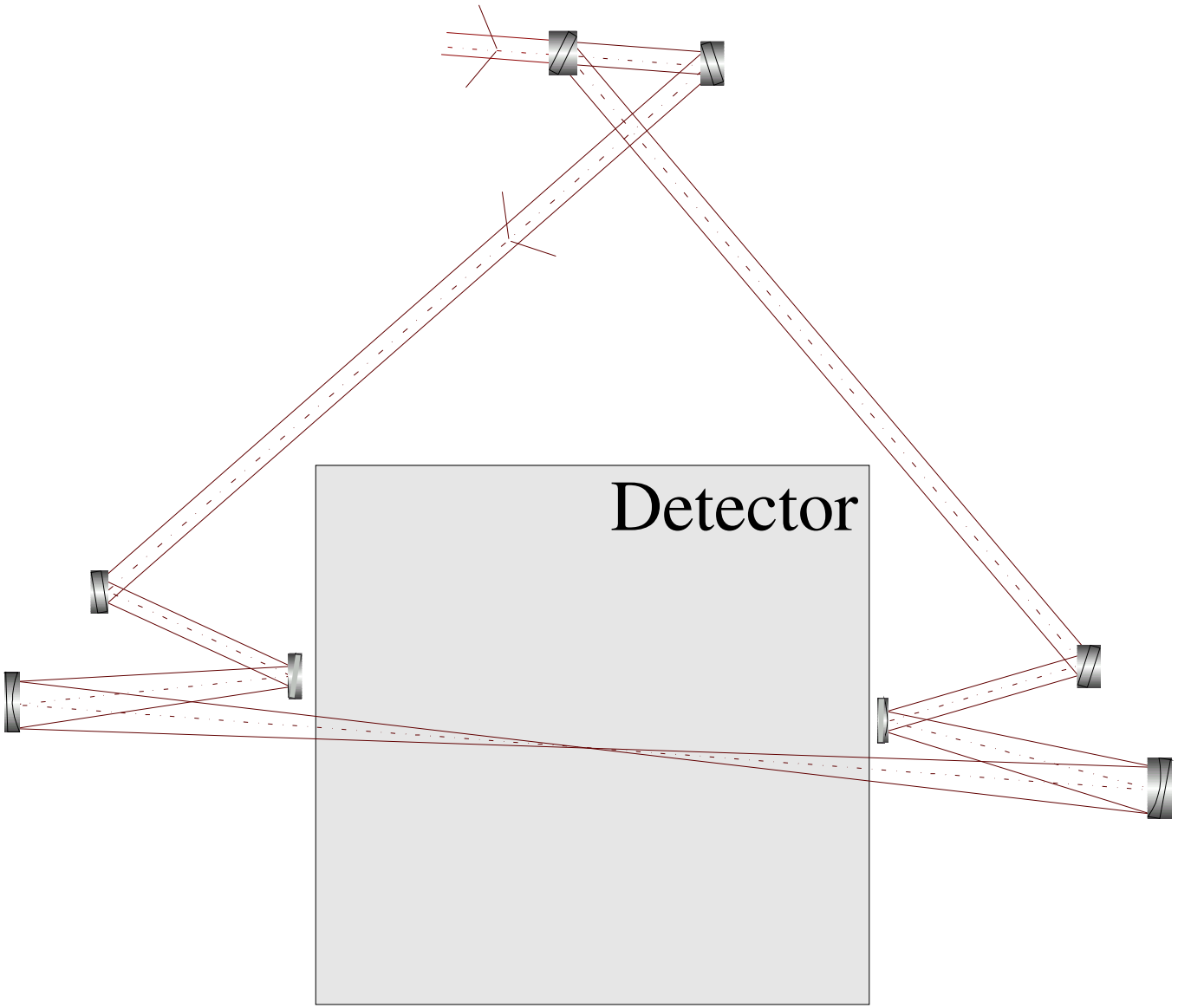
$\Rightarrow$ need $A \approx 2J$ (corresponds to $\xi^2 \approx 0.2$)
(for head on e^--laser collisions)

$\Rightarrow$ total laser power of $\sim 2 \times 30\,\mathrm{kW}$ needed

➠ $\sim$ 60 Mercury lasers from the Livermore fusion program

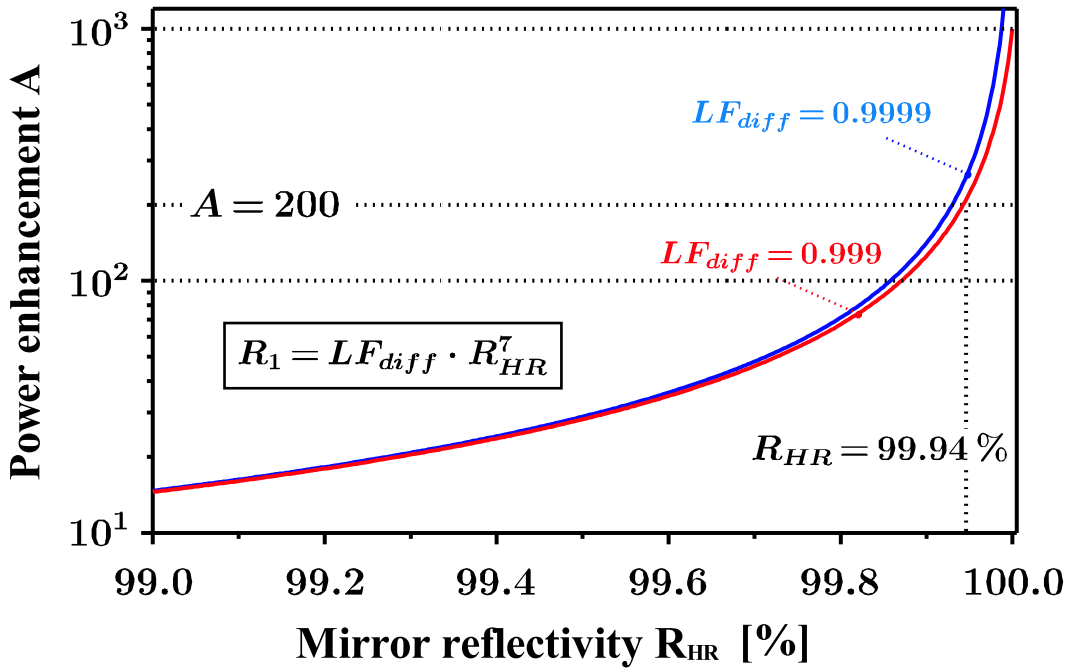
TESLA solution: recycle photons in resonant ring cavity:

- total length: $\sim 100\,\mathrm{m}$
- mounted around the detector
- all mirrors outside detector



Principles of a cavity

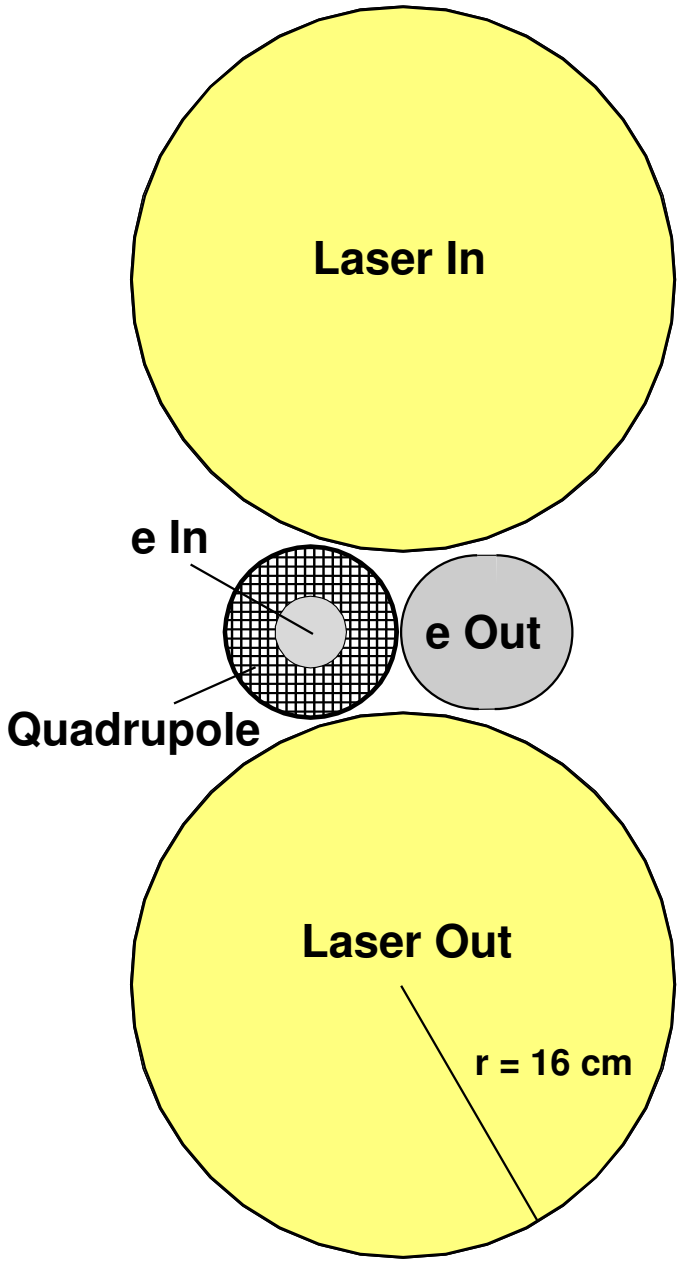
- cavity with N mirrors with reflectivity R_i
- loss per round trip $V = R_2 \cdot R_3 \ldots \cdot R_N \cdot L$ (L = other losses)
- power enhancement of cavity $A = \frac{1-R_1}{\left(1-\sqrt{R_1 V}\right)^2}$ (R_1 =coupling mirror)
- maximal for $R_1 = V$



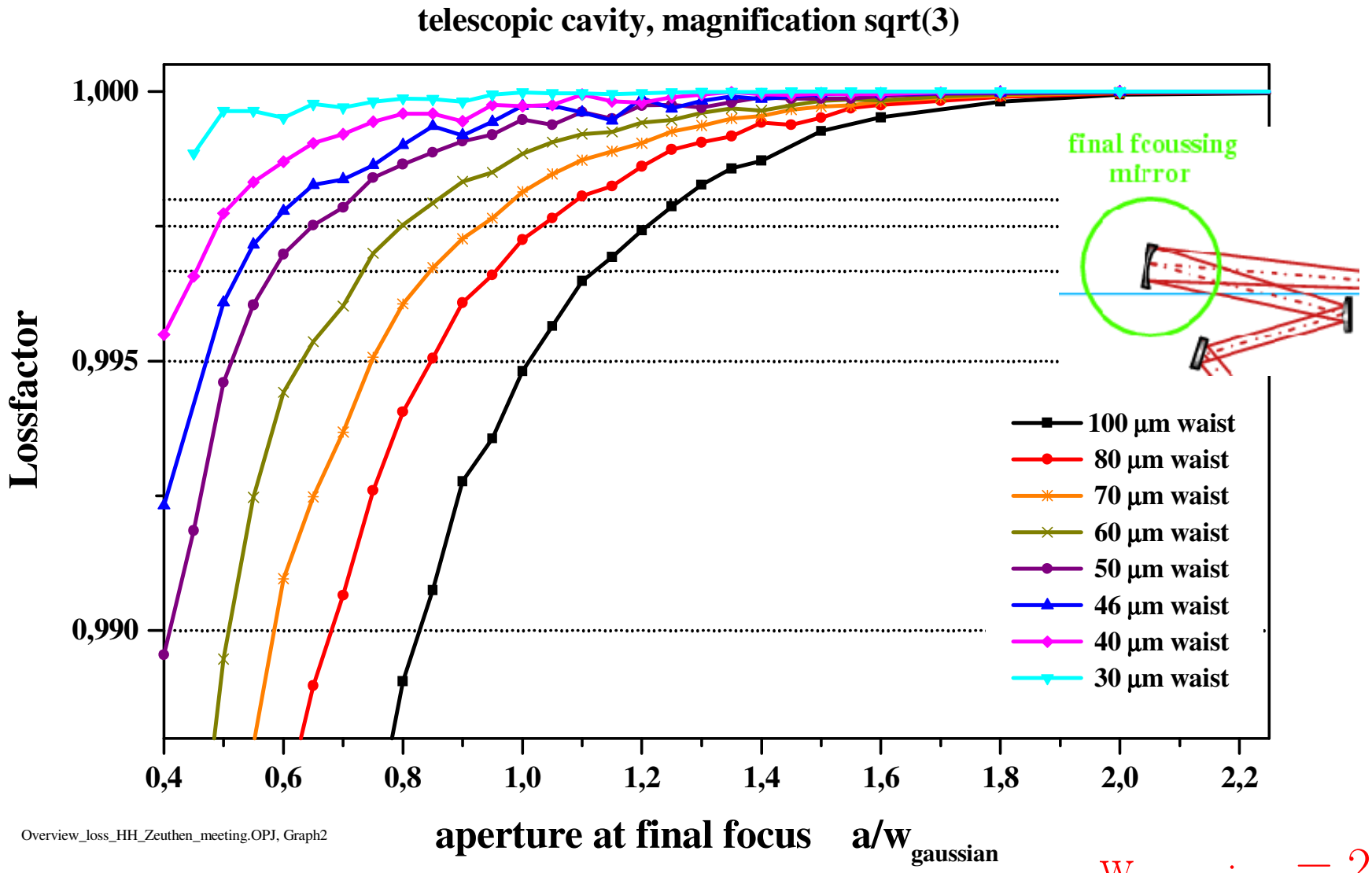
Power enhancement > 100 possible for realistic reflectivities

- To have highly efficient mirrors need crossing angle beam-laser
- crossing angle results in smaller conversion probability
- laser divergence and therefore mirror size depends on Rayleigh length
- finite mirrors result in diffraction losses and broadening of the focus
- have to find optimum crossing angle/Rayleigh length

$\Rightarrow$ even higher laser power needed

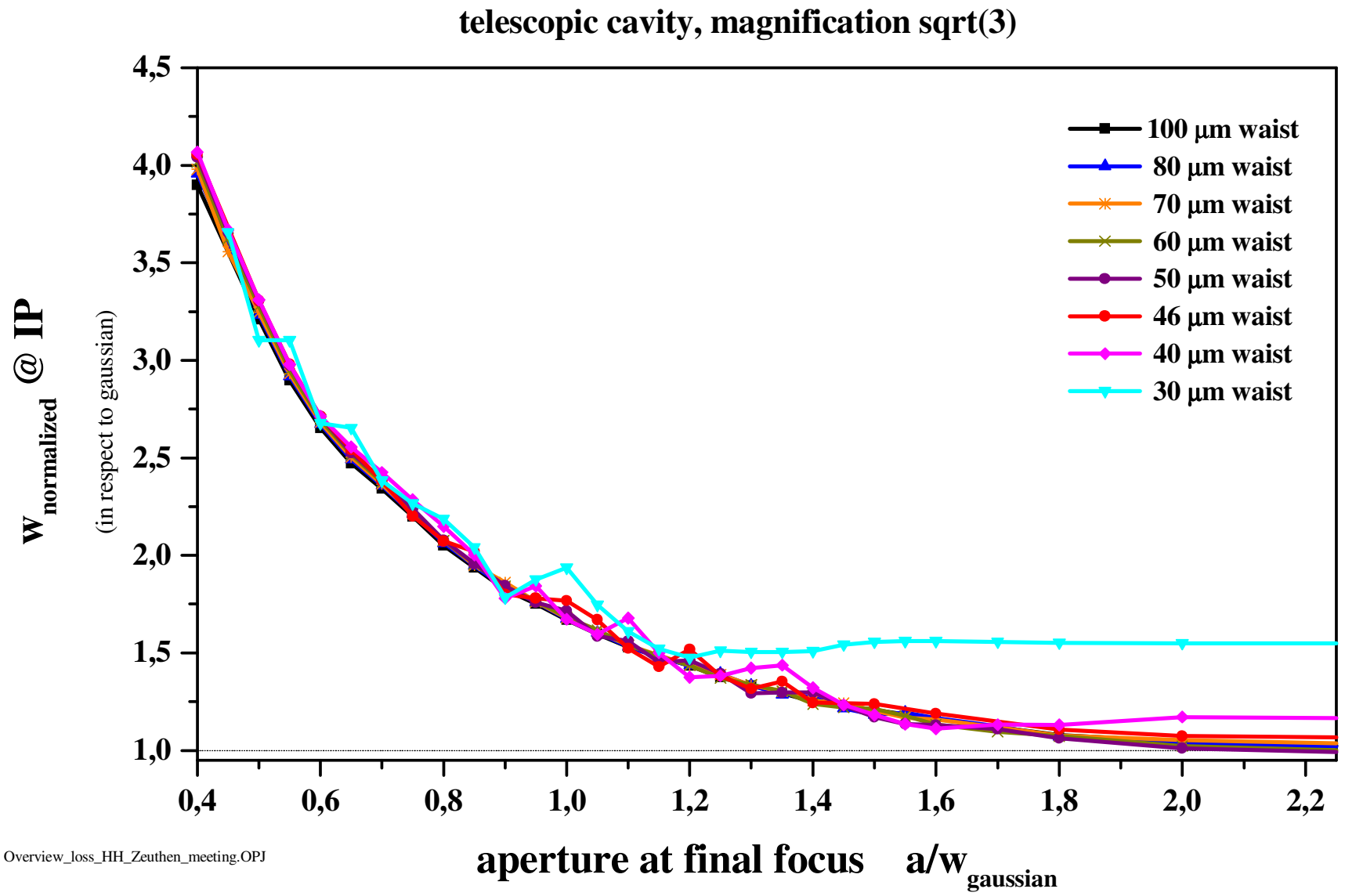


Diffraction losses are small even for small mirrors

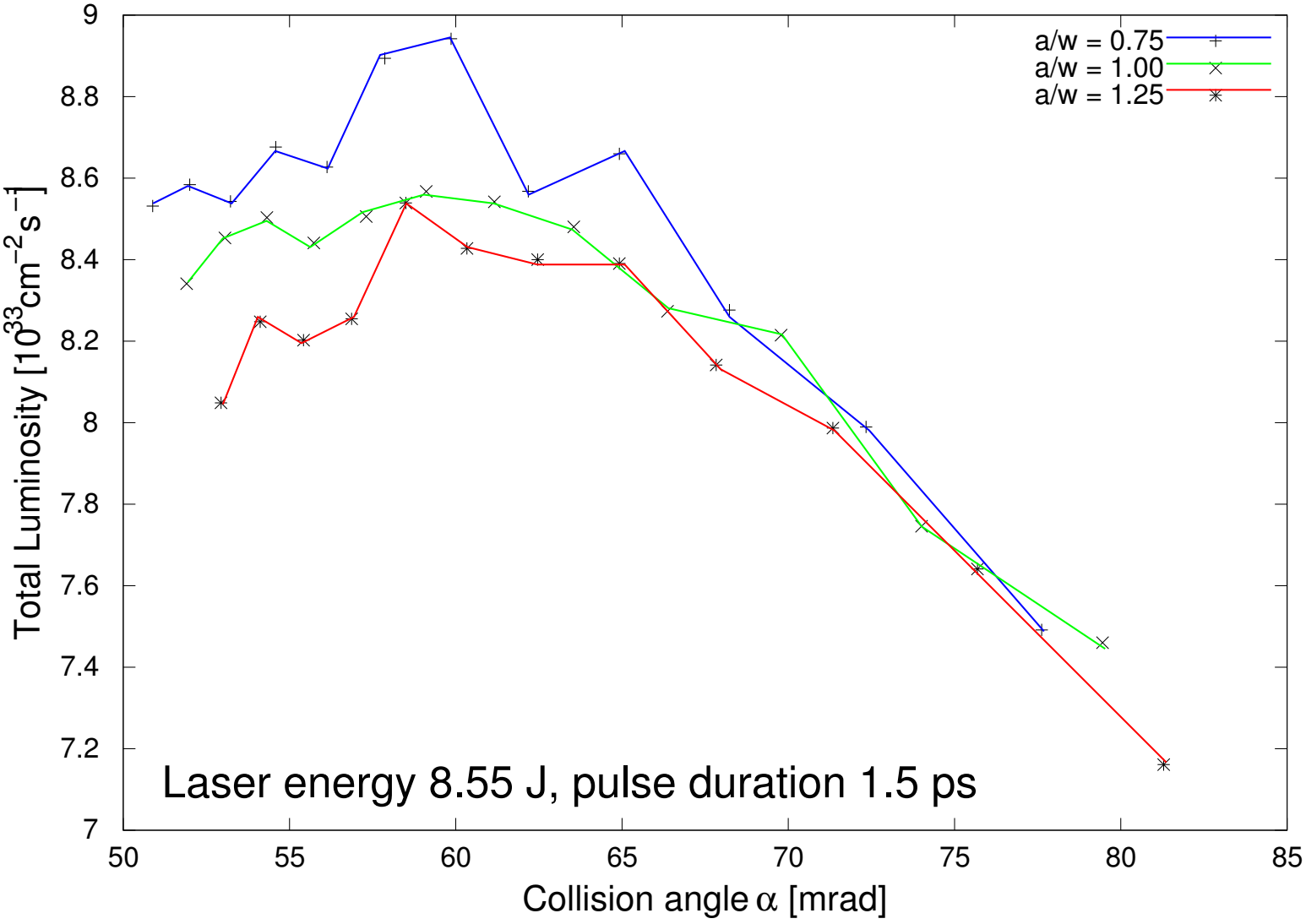


$w_{gaussian} = 2\sigma$

However diffraction broadening is serious



Optimum for relatively small mirrors



Optimum parameters

Laser parameters	TDR pt. VI	This study
Rayleigh length Z_R	0.35 mm	0.63 mm
Collision angle α_0		55.1 mrad
Laser energy A	5 J	9.0 J
pulse duration $\sigma_{L,z}$	1.5 ps	1.5 ps
nonlinearity parameter ξ^2	0.30	0.30
Total Luminosity $[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.10	1.05

TDR parameters can be reproduced

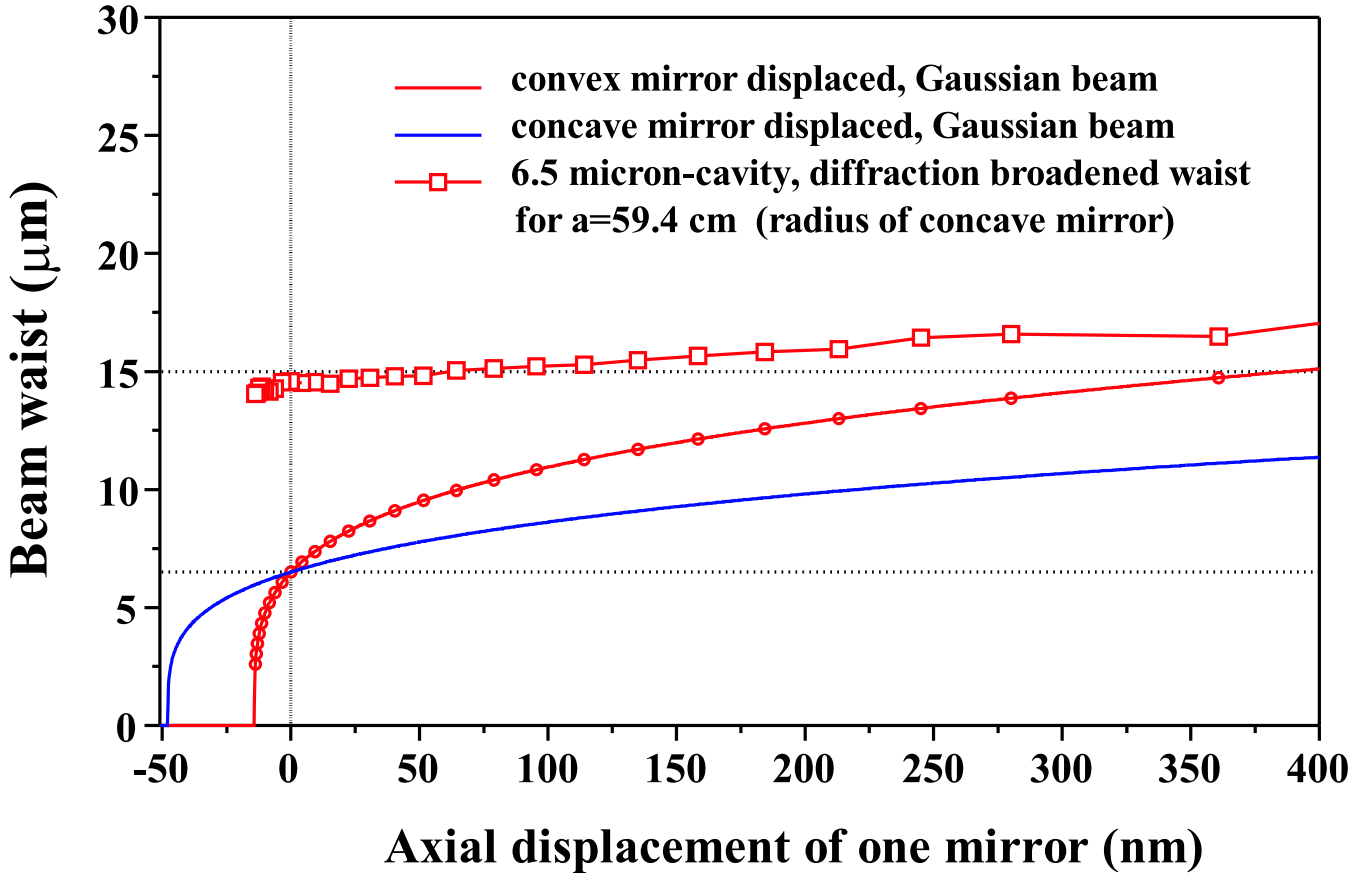
However larger laser pulse-power needed

Alignment tolerances

Total length of cavity: $\Delta L \sim 0.3$nm

Correction procedure understood e.g. from gravitational wave antennas

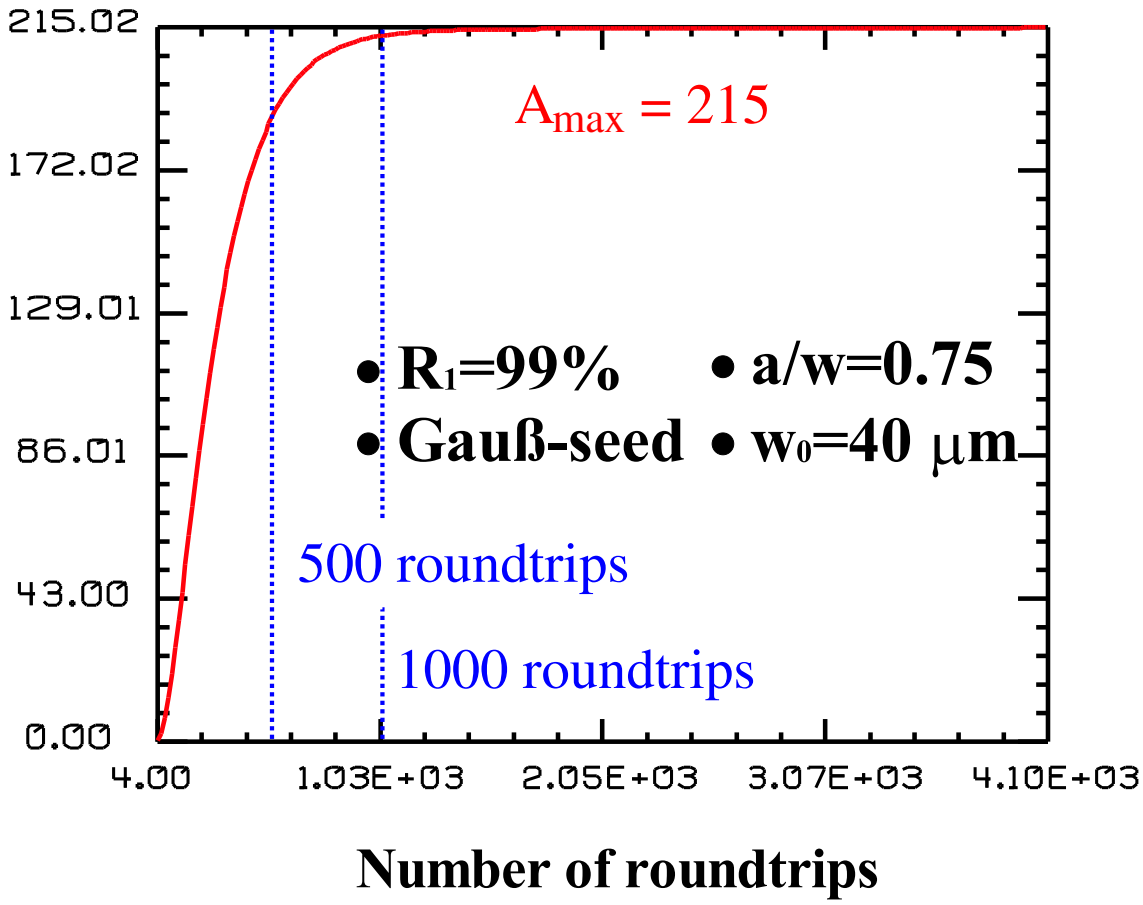
Misalignment of focusing telescope:



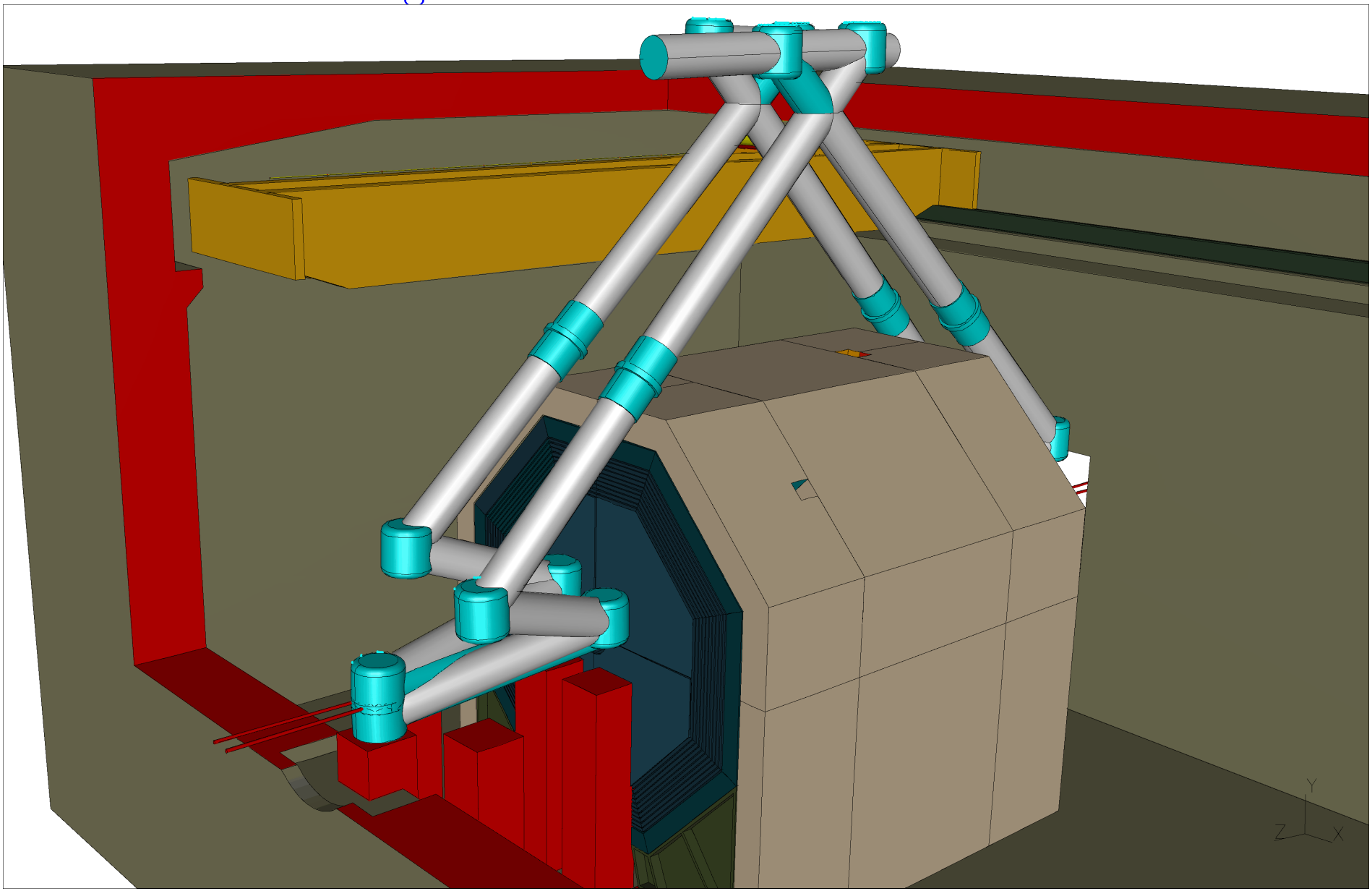
Need precision of
$\sim$ 100nm

Filling of the cavity

- Eigenmode in cavity is non-Gaussian due to diffraction broadening
- However filling of cavity with Gaussian mode works reasonably well
- need ~ 1000 pulses for $A = 215$



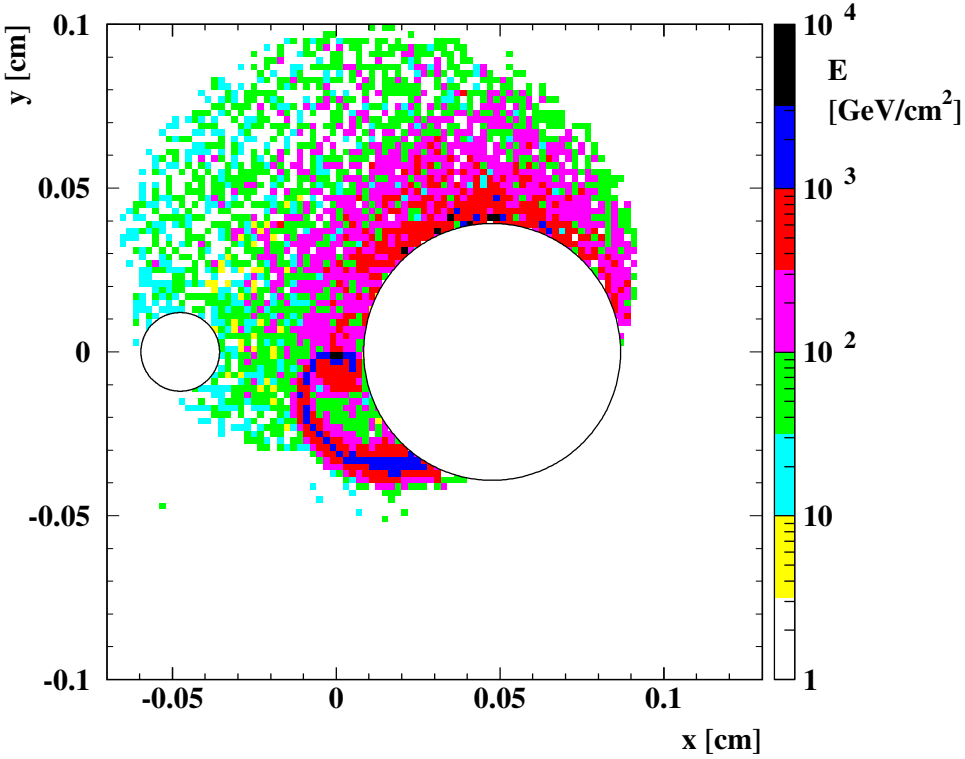
Design of the laser resonator in the hall



Detector and backgrounds

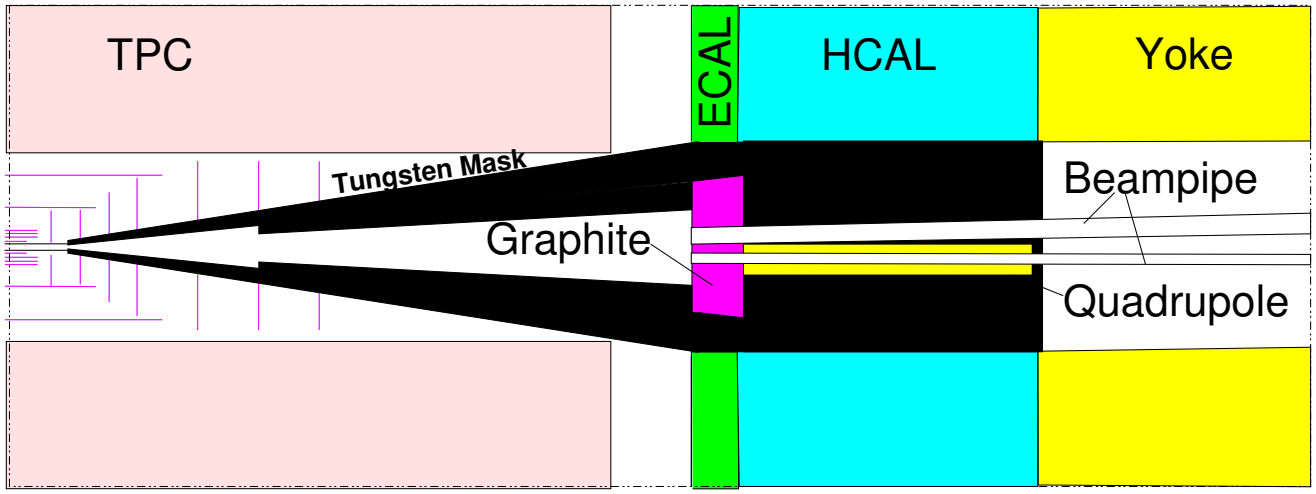
Background in the detector driven by

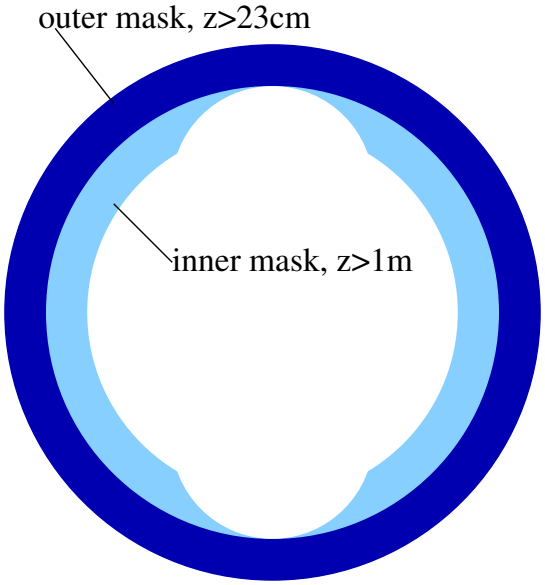
- large disruption angle
- angle between outgoing beam and B-field



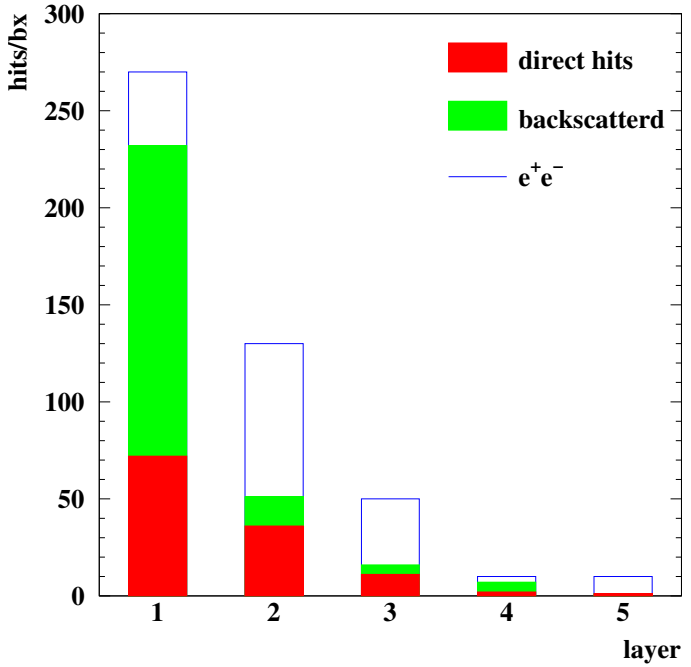
- direct background from pair production smaller than in e^+e^- due to anti-pinch effect
- large potential background from backscattering at detector exit

Background can be suppressed by masks and choice of material





- Backgrounds are similar to e^+e^- and should thus be manageable
- However detector is dead for $\theta < 7.5°$

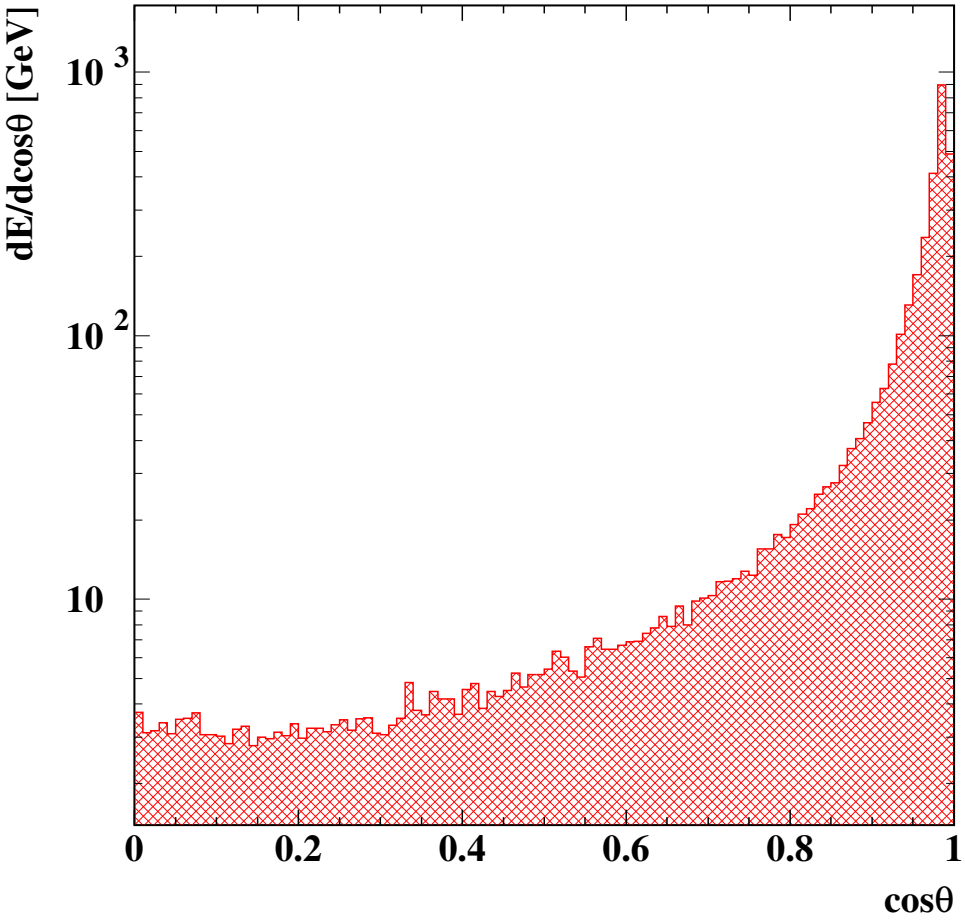


Low energy $q\bar{q}$ background

- Large luminosity and large cross section $\gamma\gamma \to q\bar{q}$ at low $\sqrt{s}$

➡ $\mathcal{O}(1)$event/bx overlaid to physics events (pileup)

- Due to large boost pileup tracks are forward peaked
- Can be largely rejected if physics in not forward peaked (like $\gamma\gamma \to W^+W^-$)



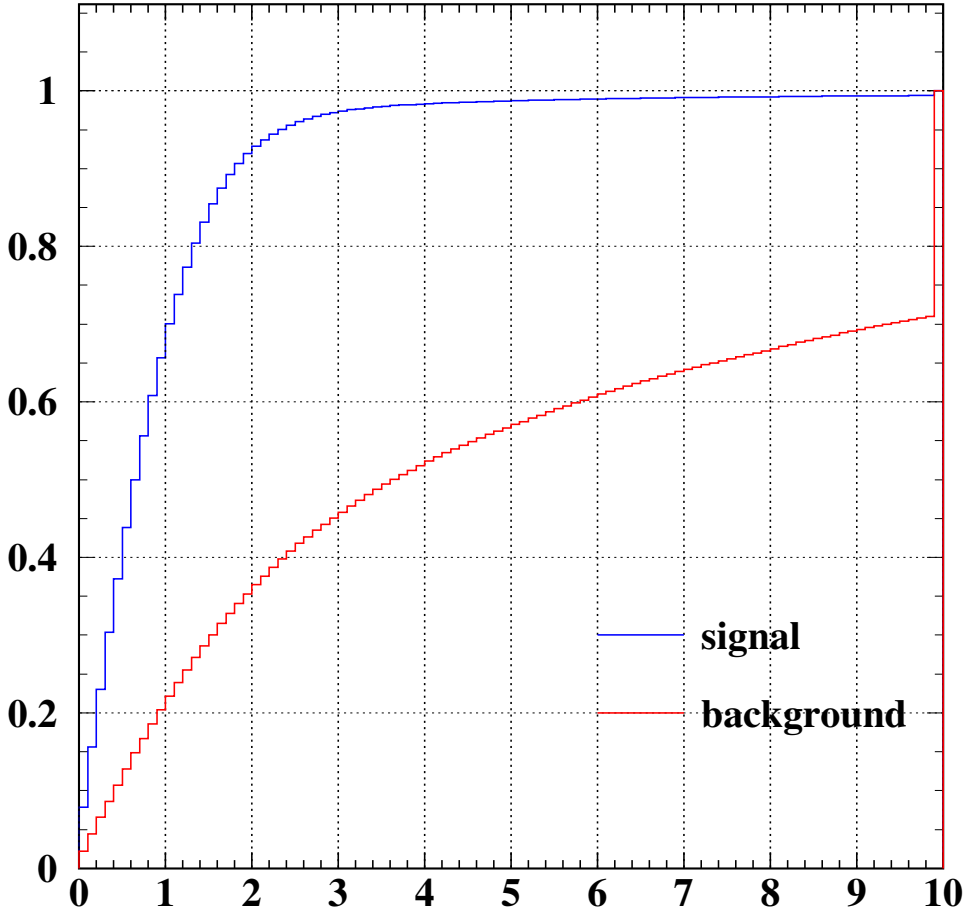
- Additional help/complication: beamspot length $\sim 200\mu$m

$\Rightarrow$ signal and pileup separated in z

  – microvertex detector can help to separate

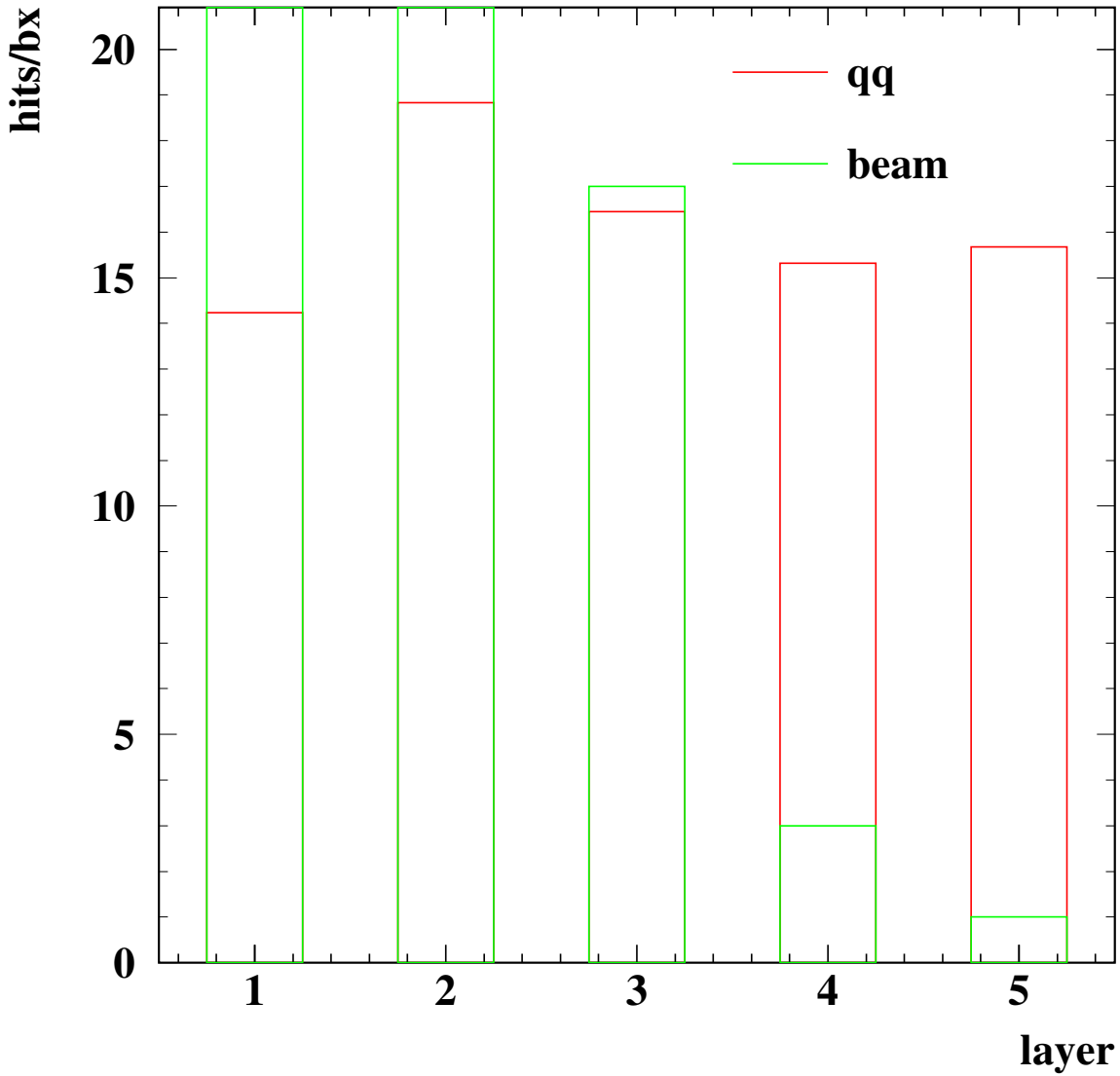
  – can screw up b-tagging, e.g. in Higgs analysis

Integrated Impact Parameter distribution for signal and pileup

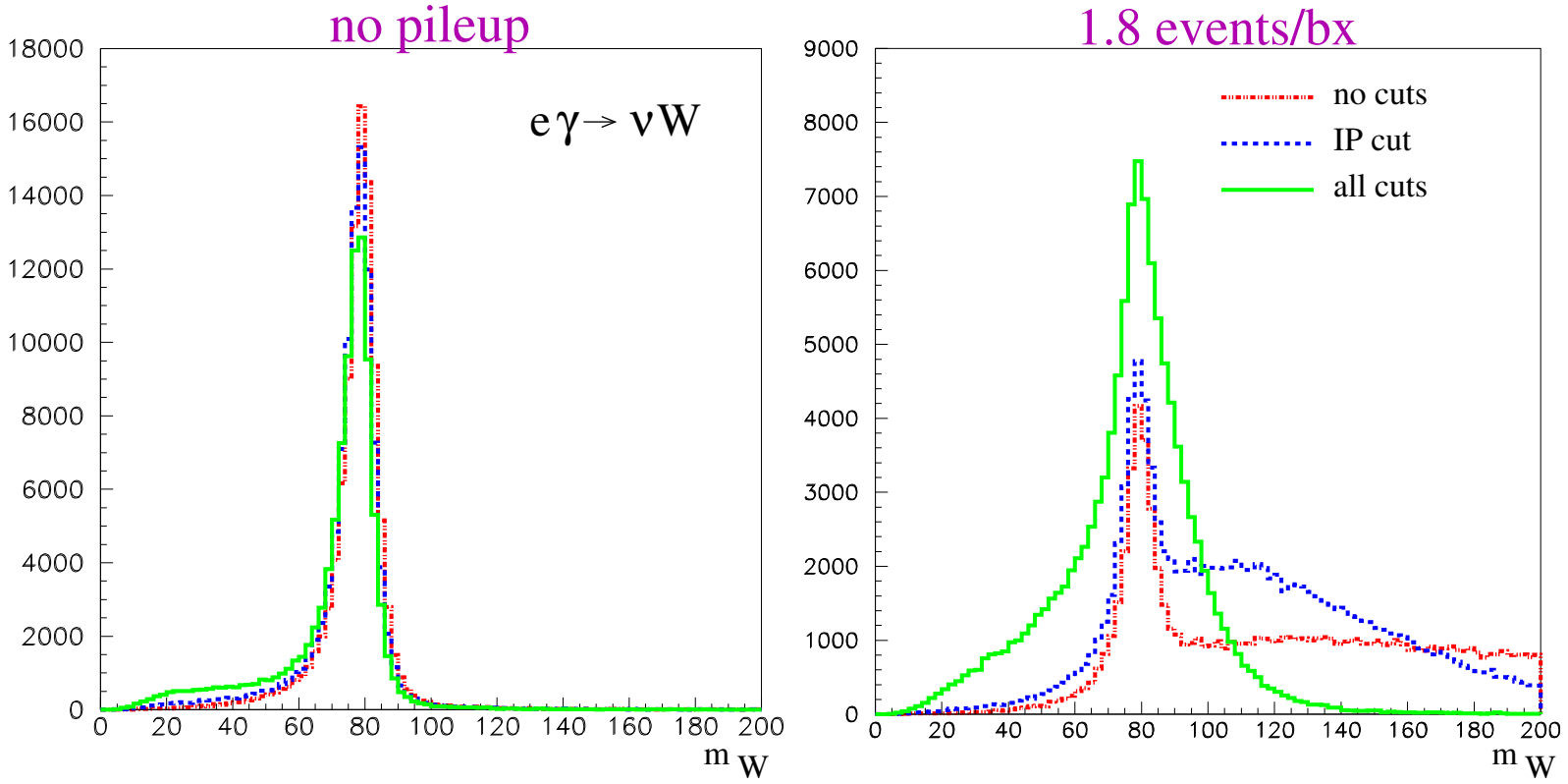


Pileup gives also non negligible background in detector

Hits in vertex detector from beam and pileup



Pileup affects seriously some analyses



Conclusions pileup

- Pileup is a serious issue at a $\gamma\gamma$-collider
- Very good time stamping is a must (no problem at TESLA)
- the long bunches at TESLA help additionally

Conclusions

- no showstoppers found so far
- the laser-cavity seems difficult but possible
- backgrounds are under control
- however the price to pay is a dead detector below 7.5°
- if you want the photon collider to become a reality you have to work on the technical issues