Compton Parameters Optimization

Some considerations @ the interaction point

Alessandro Variola
IN2P3 LAL - ORSAY
Posipol Workshop @ CERN

@ Snowmass

Alternative solution for the polarised positron source :

The main subjects were :

- Laser power is not enough for a single γ-e^- collision.
  We can increase the repetition frequency (there are 200 msec for injection and cooling)
- Multiple injections in the damping ring (or in a separated accumulation ring).
- f_{rep}= 325 MHz. Low Duty Cycle (1 % ->100 µs/10ms)
- Large use of the optical cavity technology to enhance the photon pulse intensity
- 2 solutions explored : Yag and CO_2 Lasers – complex scheme for lasers and cavity stacking but…….

It makes sense!!!!

Where we can improve (R&D):

Laser Power !!
Cavity Finesse !!

but optimization can be performed on :
Crossing angle, f_{rep}, interaction point parameters, collection system, multiple re-injection, charge per bunch..etc etc

,

Compton Simulations (CAIN)

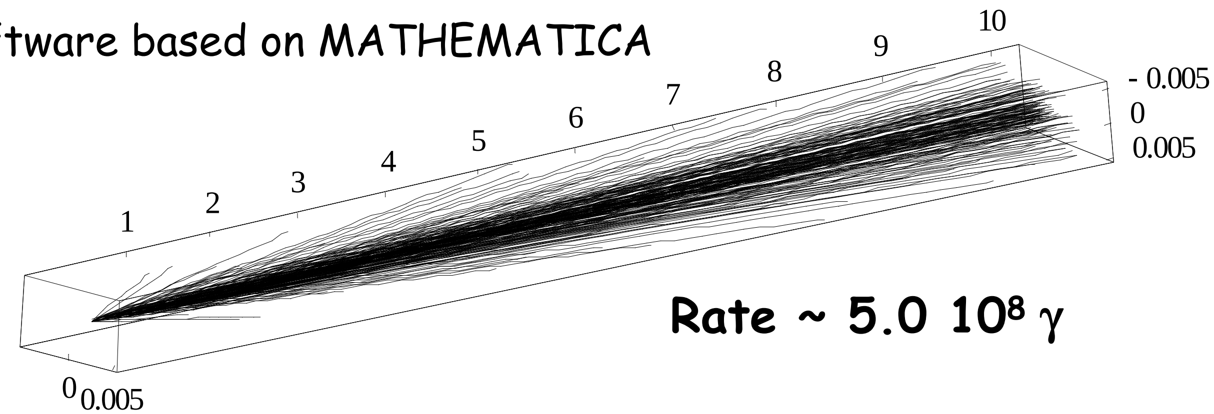
Realistic baseline for the laser & electrons beams parameters
(we have to start from some baseline, not try to look for a final scheme but only for a parameter space study …….then scaling is easier).

Electrons: 1.3 GeV, 10nC, σ_x= 30µm, σ_y= 5µm, σ_z= 6mm,
ε_x = 4.5nm, ε_y = 25pm,
β_y = 1m, β_x = 20cm, Collision Angle = 0, Crab = 0,

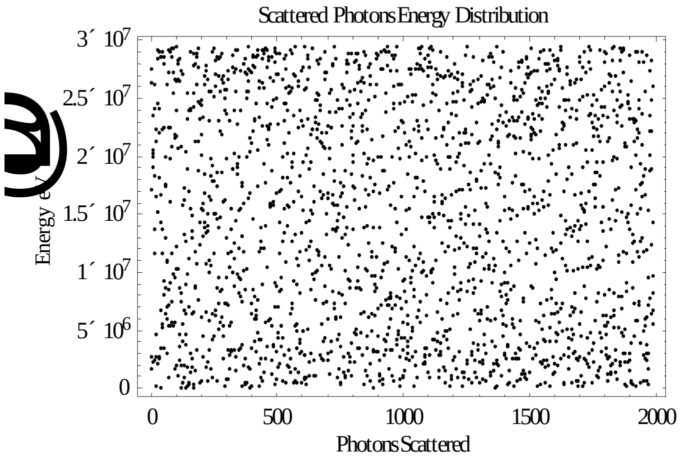
Photons (LASER): λ = 1.06µm, ω_0 = 20µm, z_R ~ 1.18 mm,
Energy/Pulse = 0.1J
(5 10^4 gain with 2 µJ or 5 cavities*10^4 gain @ Several MHz – or ATF laser)

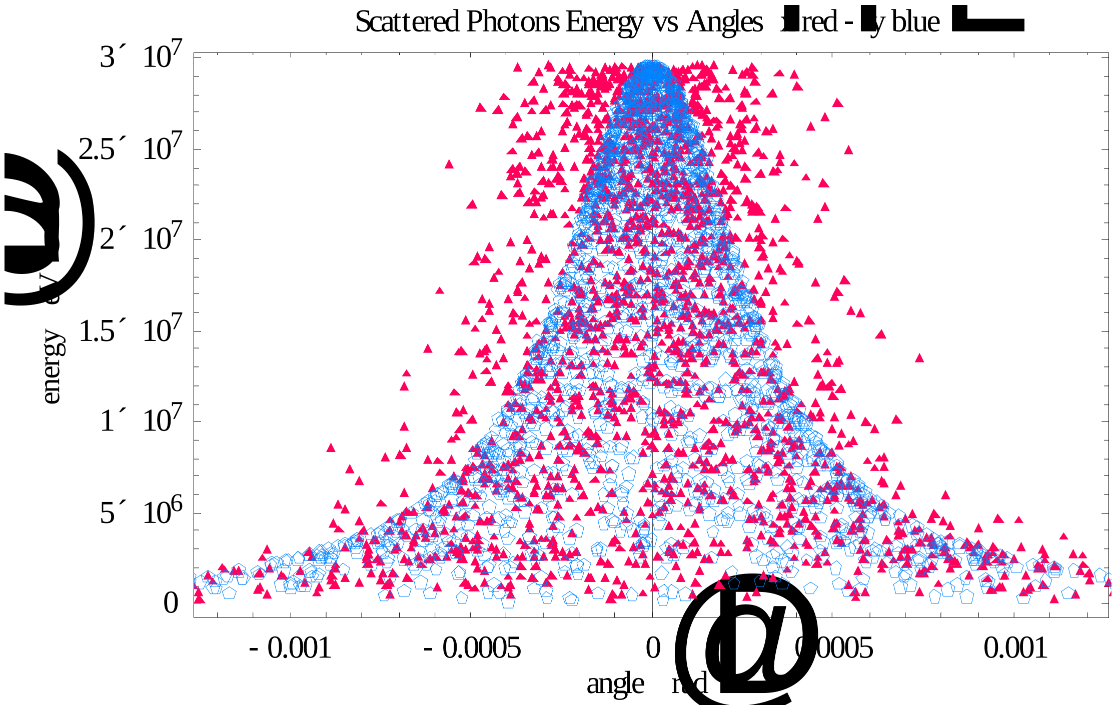
~ 5 10^8 γ

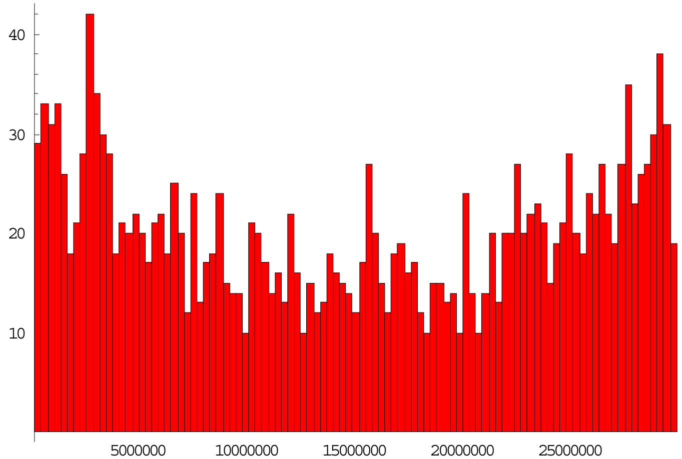
Analysis software based on MATHEMATICA



Rate ~ 5.0 10^8 γ







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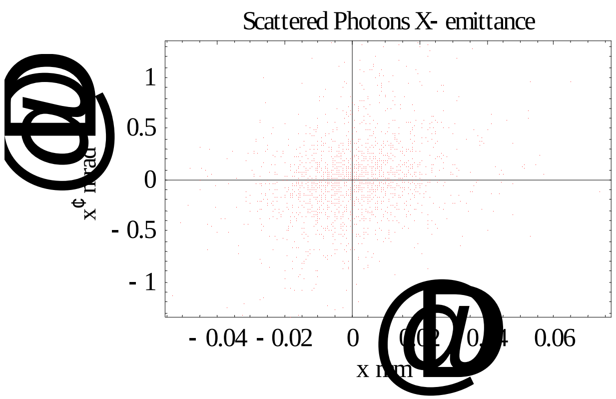
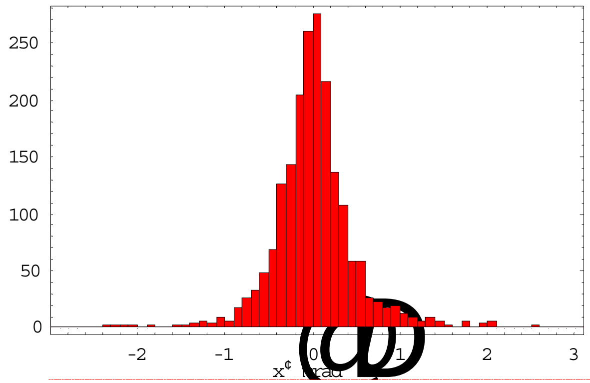
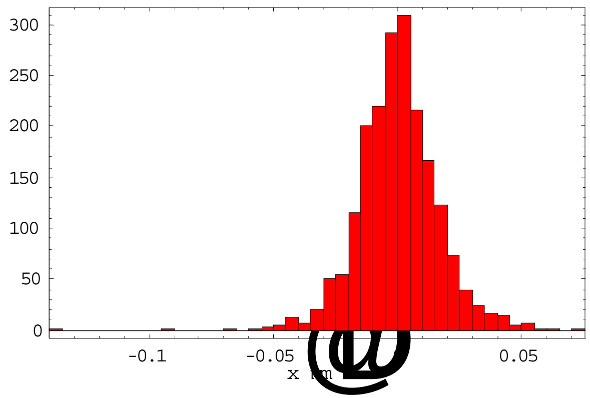
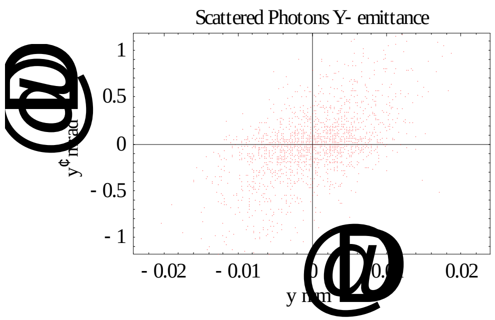
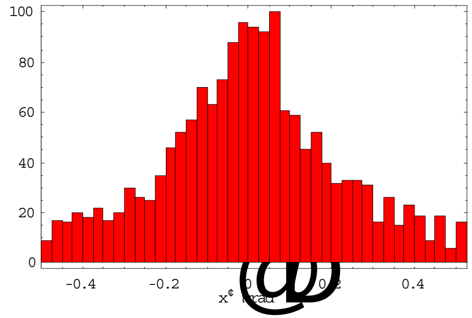
γ-Emittances

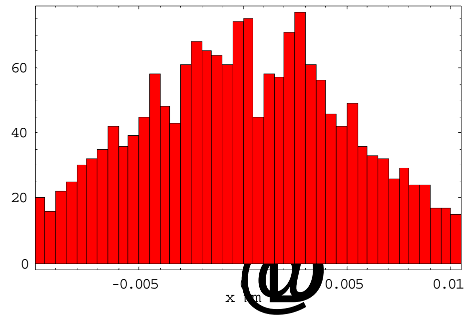












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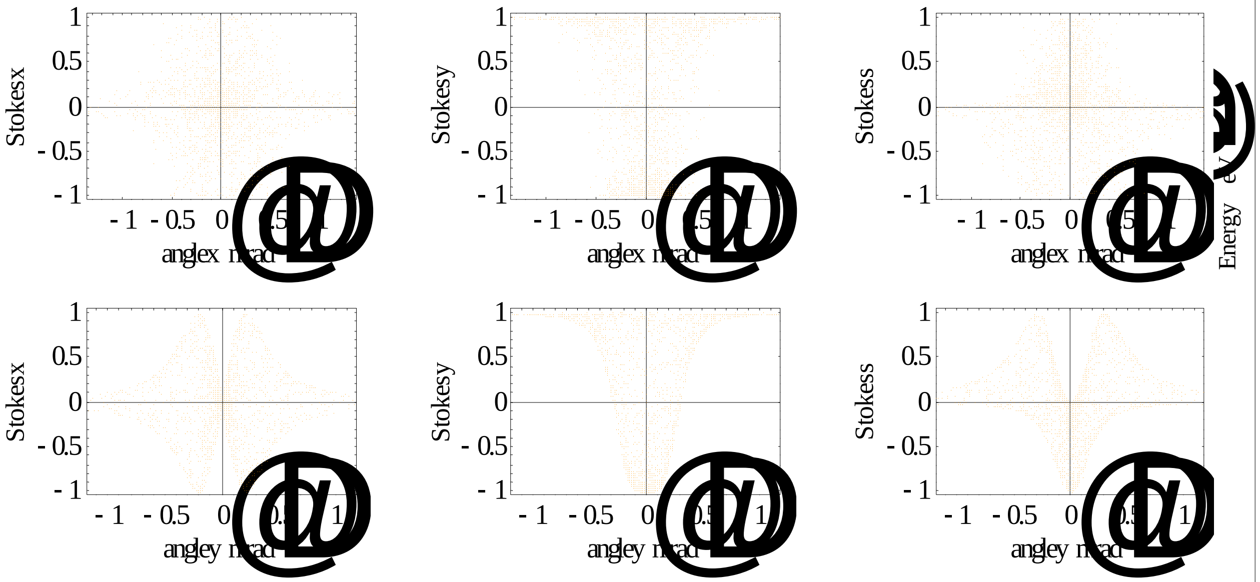
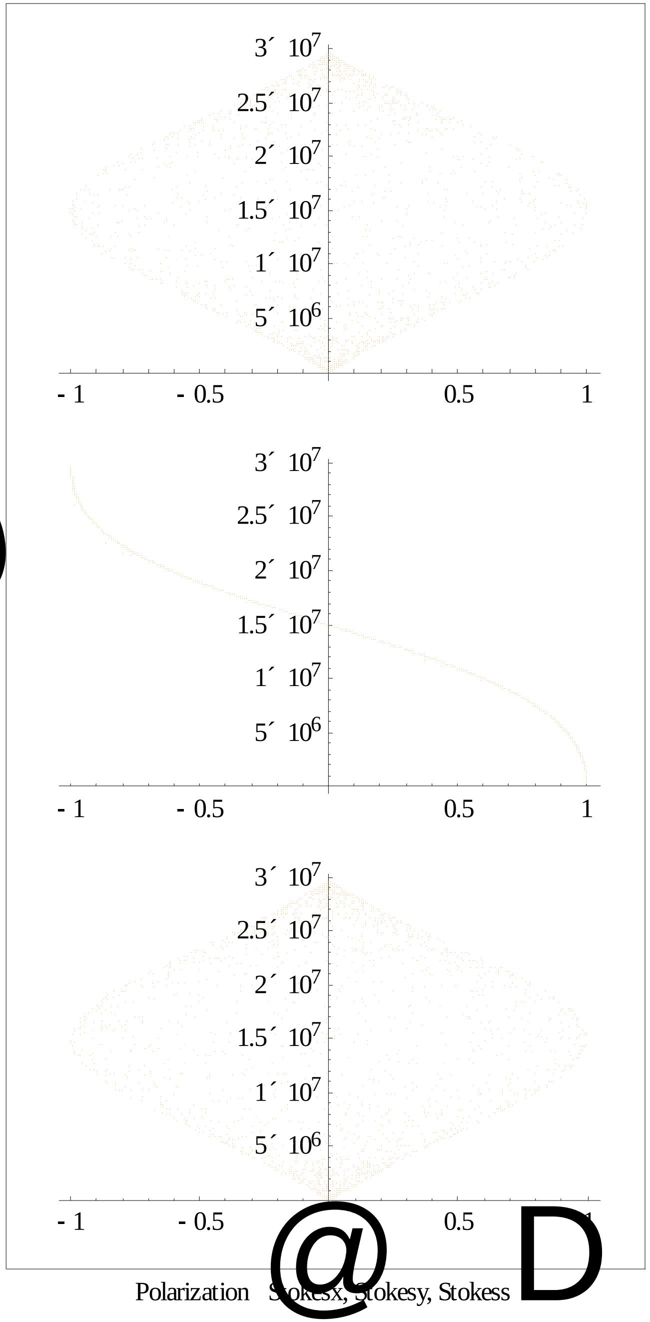
Polarization





03/05/2006

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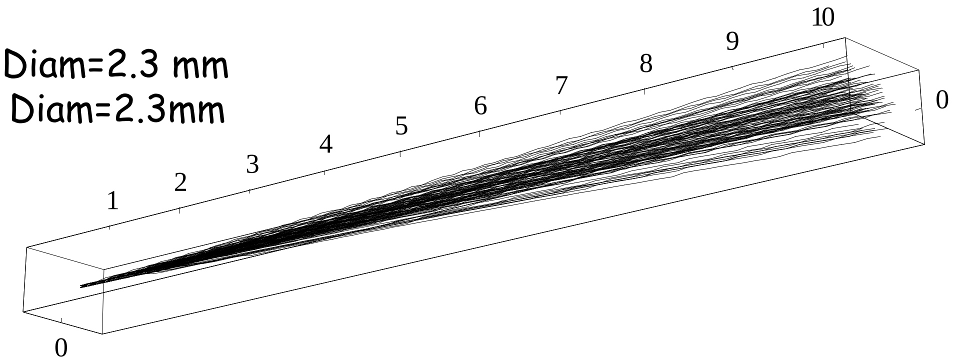
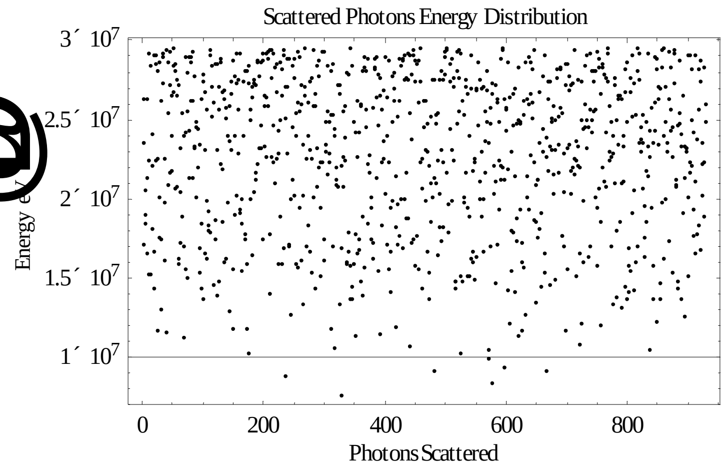
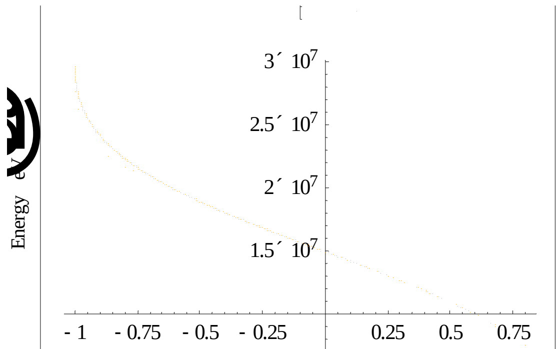
Diaphragm

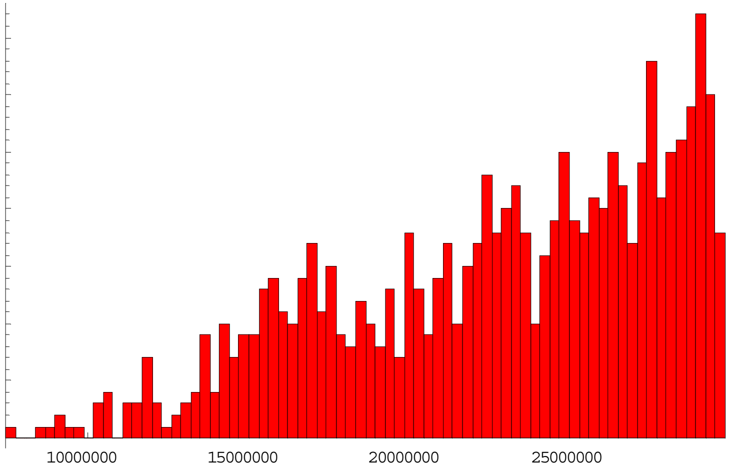
Two diaphragms: 1st Dist=3m Diam=2.3 mm
2nd Dist=6m Diam=2.3mm

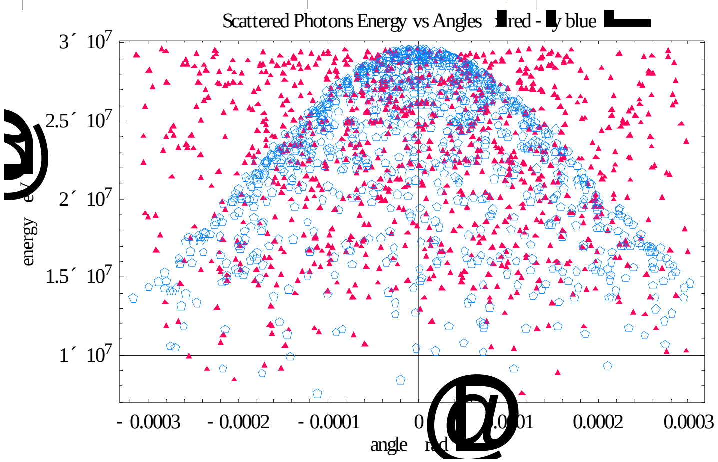




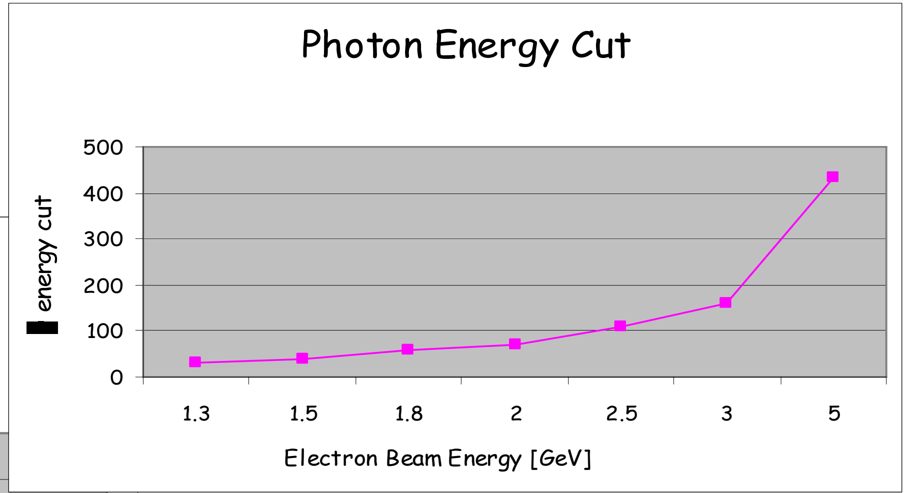


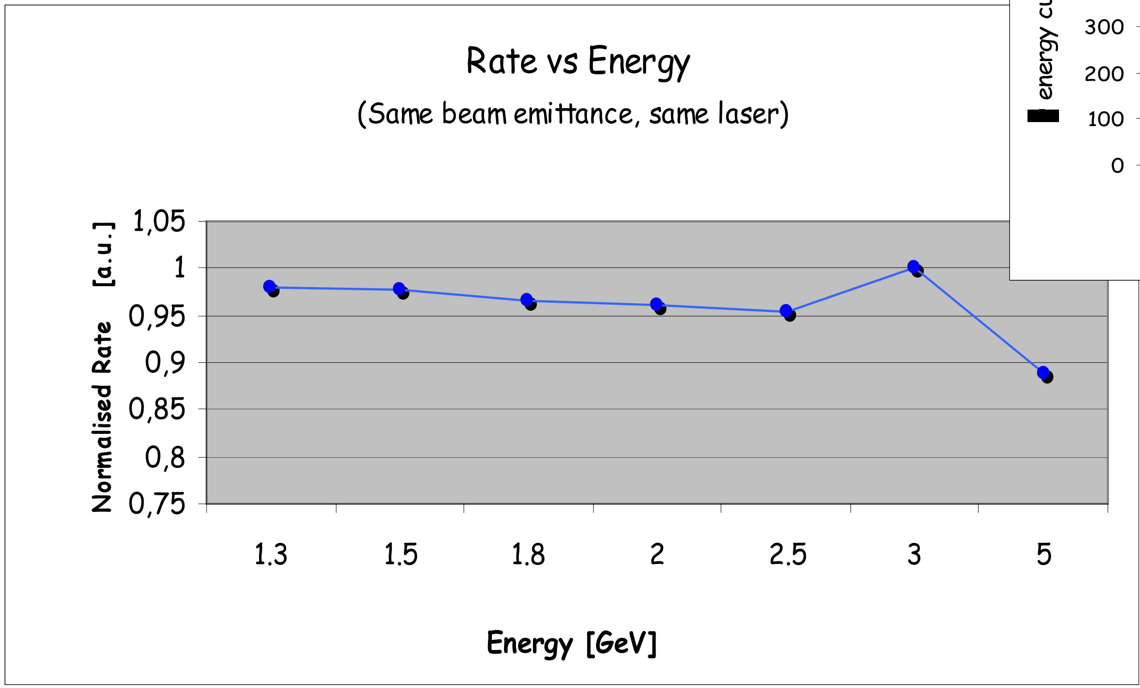
For S_{av}~-0.68 ->losses:
Diaph ~2.74 10^8 ~ 55%





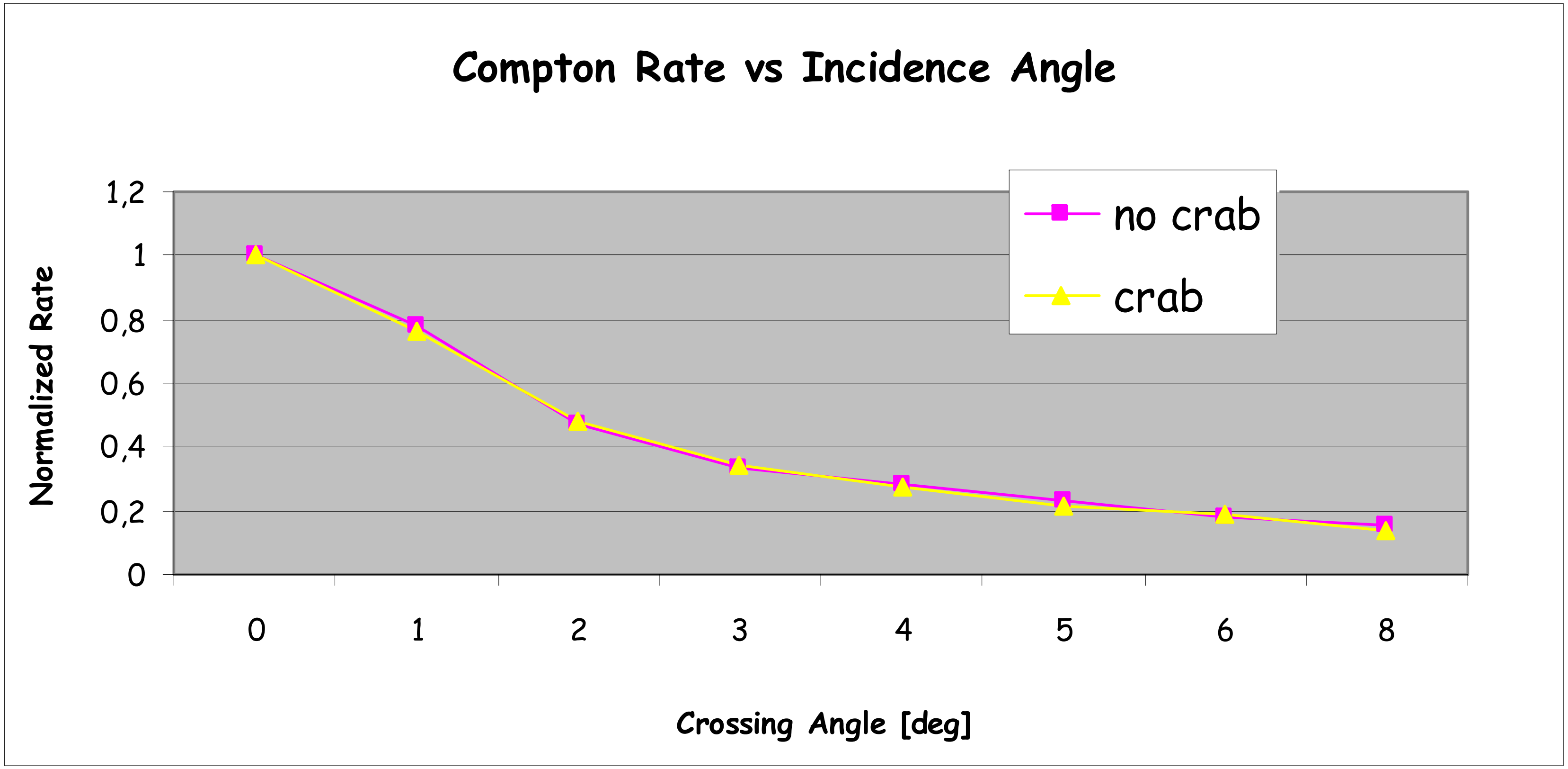
Parameters : Energy & Cutoff





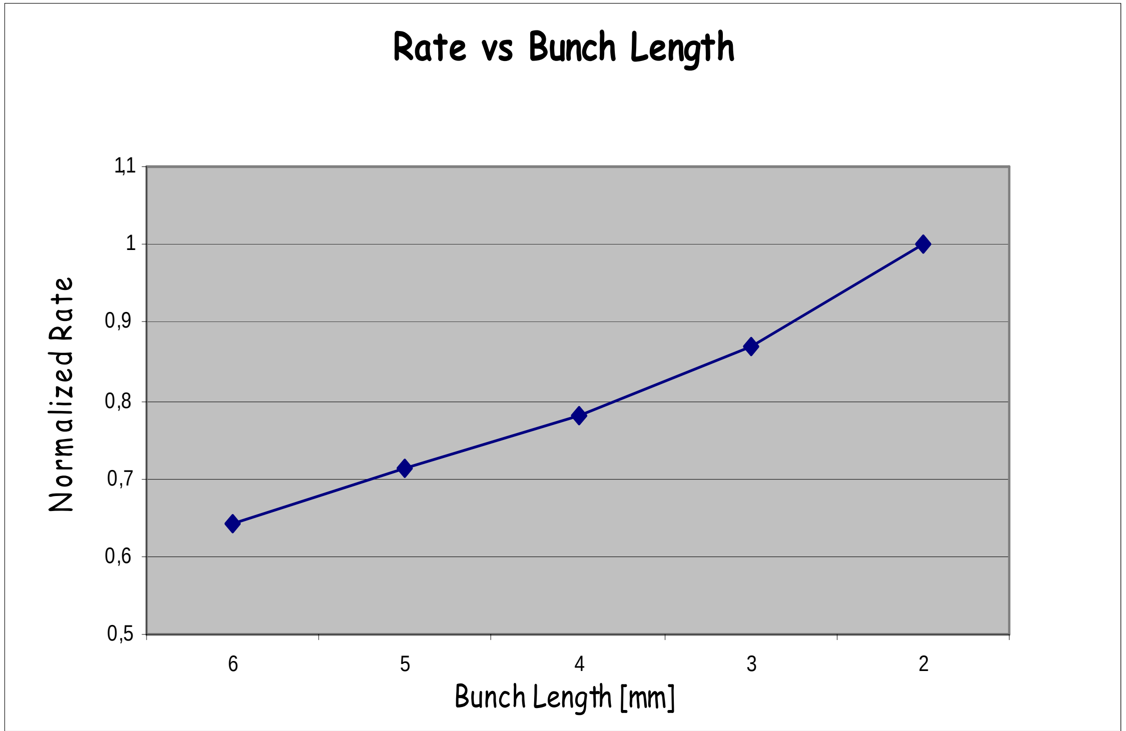
a) No gain increasing the beam energy
b) Photon energy cut increases and so does the energy spread of the produced positrons

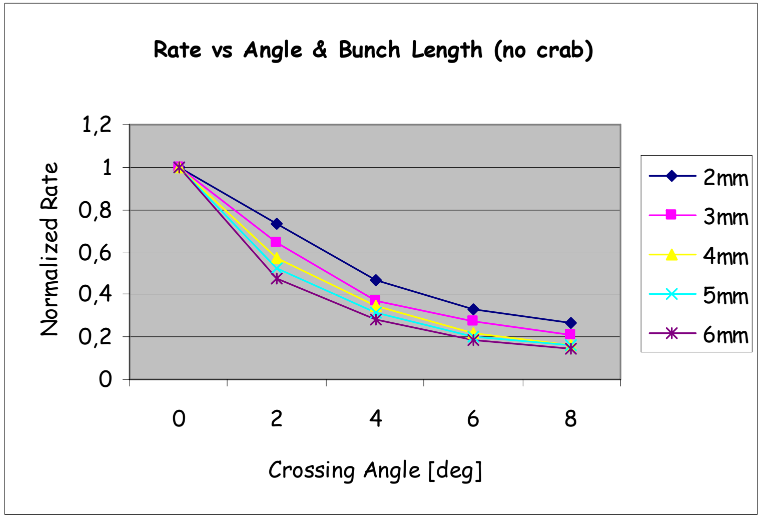
Crossing Angle

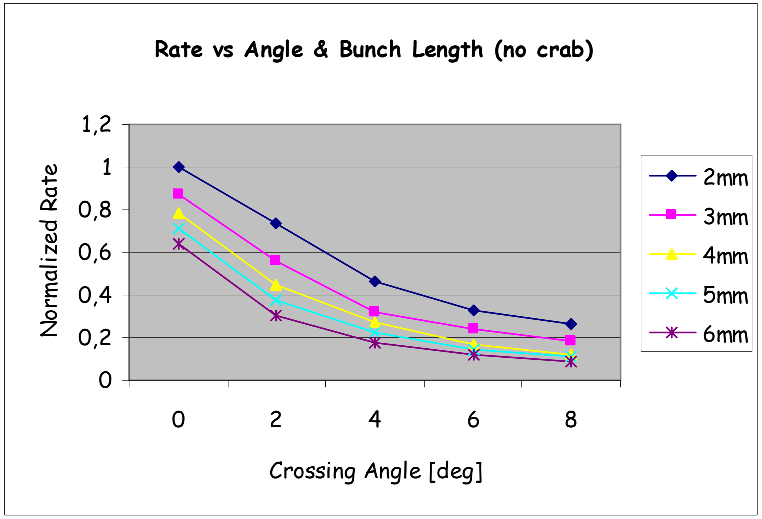


c) Without crabbing the loss is noticeable (time overlap)
d) Crabbing @ θ_{crab}=-ϕ does not help

Bunch Length & Angle

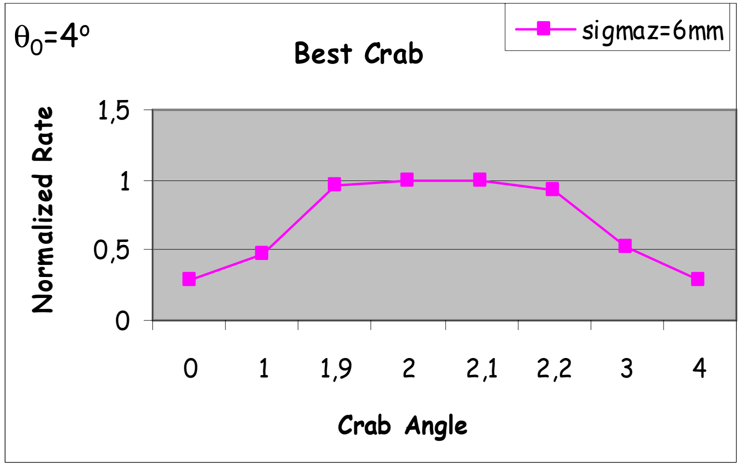


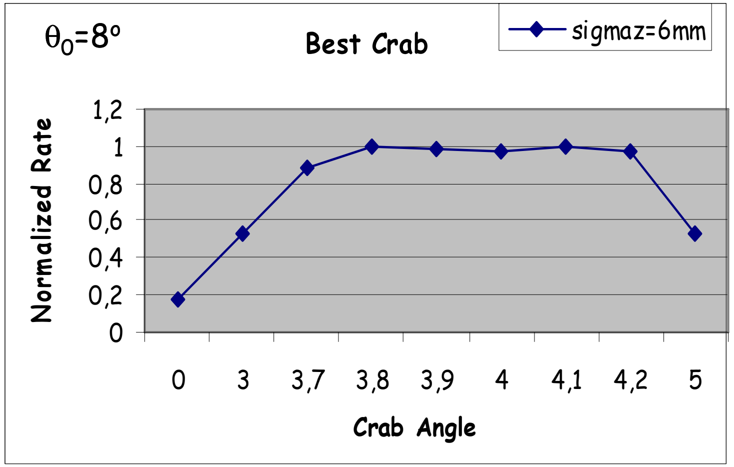


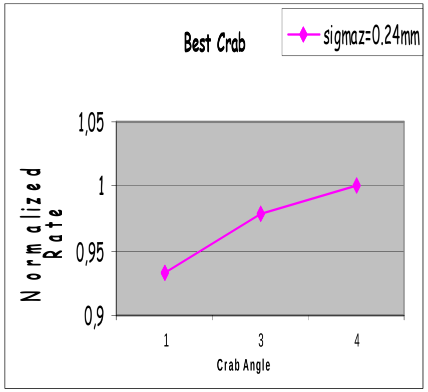


e) Reducing the bunch length gives an important gain (~ linear)
f) The shorter the bunch length the less sensitive to the angle loss effect

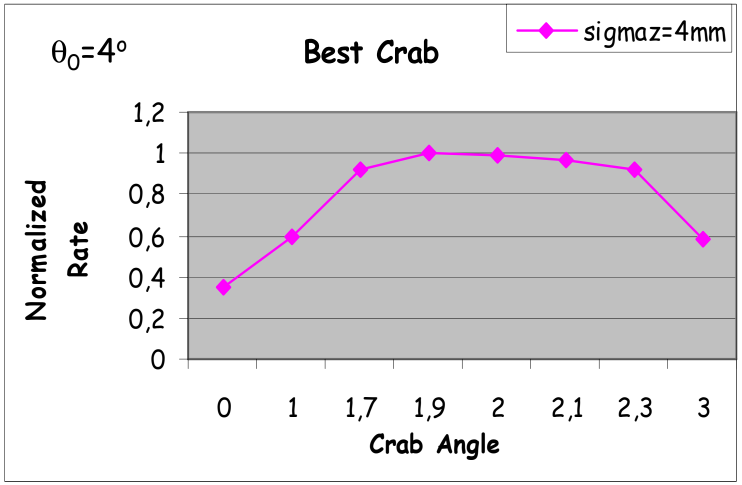
BUT…….Crab Angle Optimisation

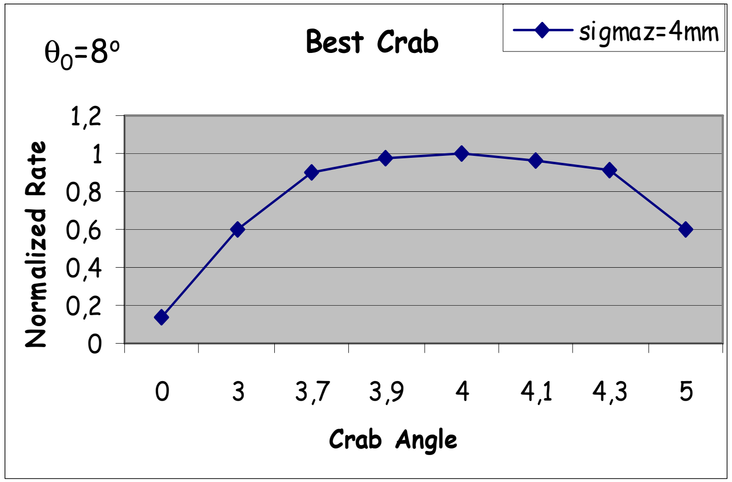




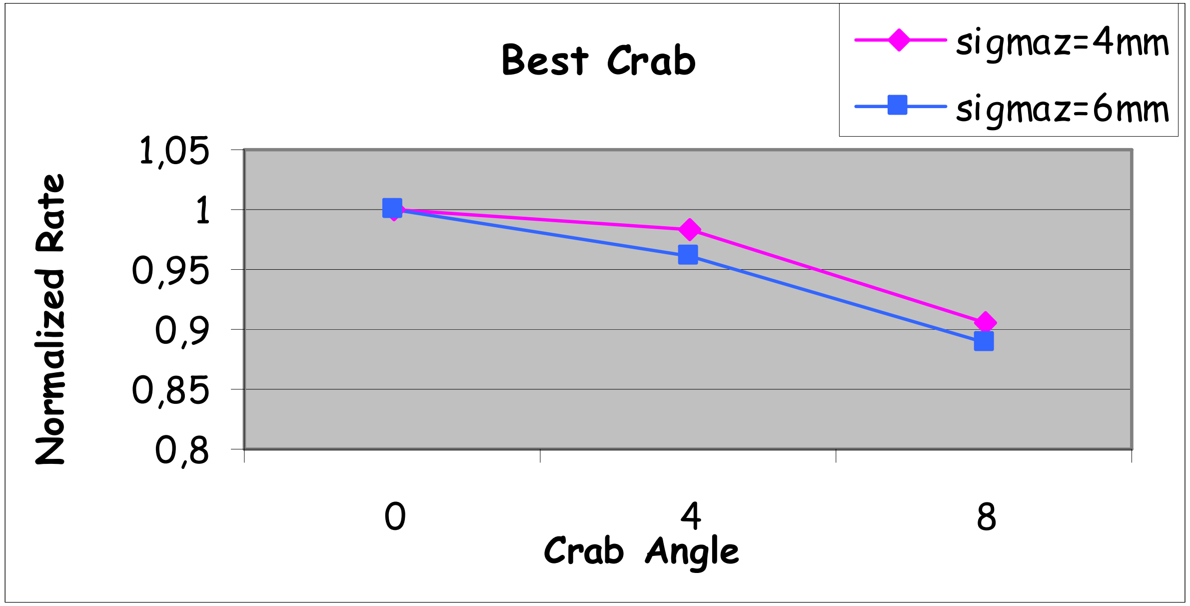


very short bunch





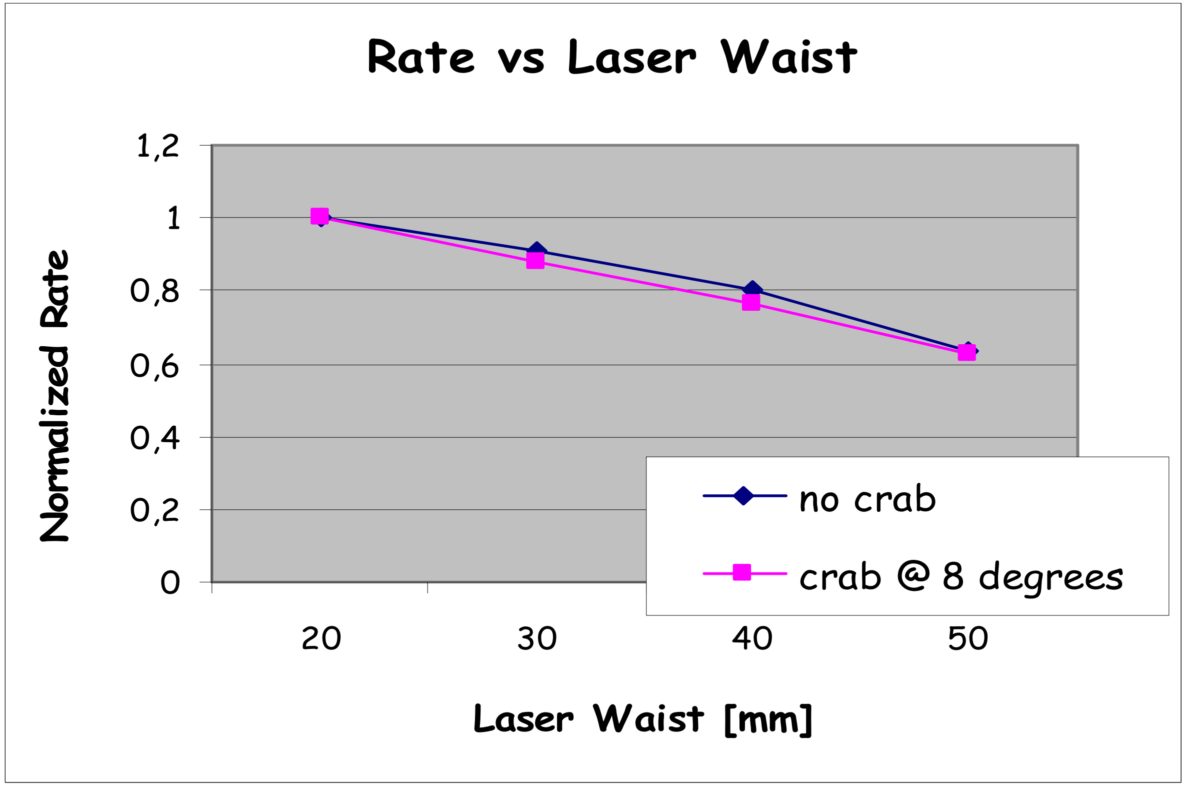
Best Crab



Taking into account the 8 deg case it is already a gain factor ~ 4.5

g) Crabbing is important
h) Best crab is at ~ crossing angle/2
i) Shorter bunches are less sensitive to crab

Long Electron Beam – Short Laser Pulse: effect on laser waist (hourglass)



I) Increasing the laser waist does not entail a dramatic loss

Round Beam – Flat Beam

The reference for the flat beam
is always the case illustrated before (5 and 20 μm)

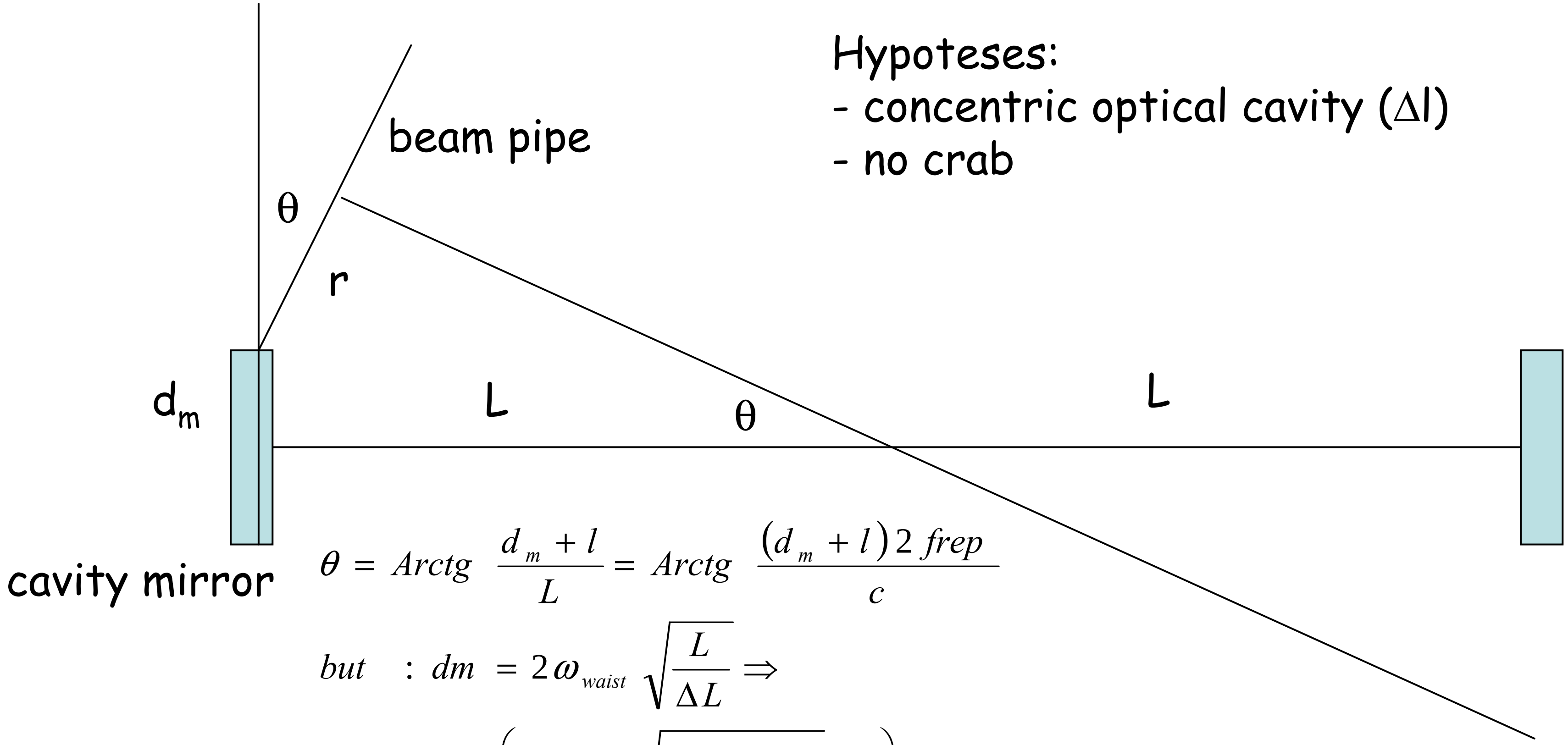
If we vary the beta functions at the collision point to make the electron beam round we have that:

Round beam σ		Rate round / Rate flat
20 μm		0.73
18 μm		0.81
16 μm		0.93
15 μm		0.99

m) No evident need for a round beam

Parameters Considerations : f_{rep}, collision angle, Δl

Hypoteses:
- concentric optical cavity (Δl)
- no crab



$$\theta = Arctg\ \frac{d_m + l}{L} = Arctg\ \frac{(d_m + l)\,2\ frep}{c}$$

$$but\ :\ dm = 2\,\omega_{waist}\sqrt{\frac{L}{\Delta L}} \Rightarrow$$

$$\theta = Arctg\ \frac{\left(2\,\omega_{waist}\sqrt{\frac{c}{2\ frep\ \Delta L}} + l\right)2\ frep}{c}$$

Alessandro Variola
IN2P3 LAL - ORSAY
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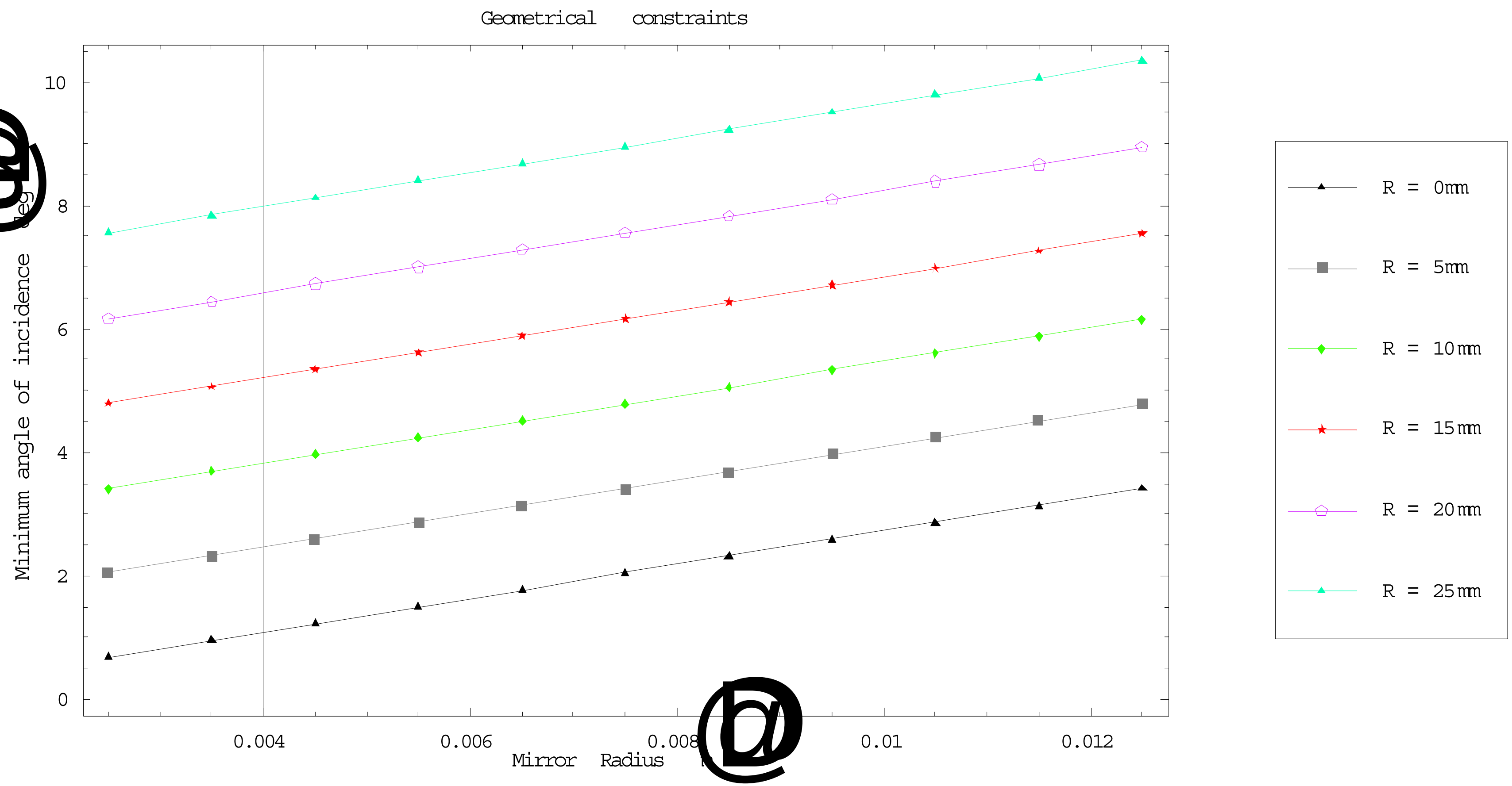
Crossing Angle vs Mirror Radius & Beam Sizes



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the rate does not increase linearly with the repetition frequency (angle effect)

$$R = N_{\gamma} N_{e^-} g; \qquad g = \frac{f_{rep} Cos\frac{\theta}{2}}{2\pi} \frac{1}{\sqrt{\sigma_{ye^-}^2 + \sigma_{y\gamma}^2}\sqrt{\left(\sigma_{xe^-}^2 + \sigma_{x\gamma}^2\right) Cos^2\frac{\theta}{2} + \left(\sigma_{ze^-}^2 + \sigma_{z\gamma}^2\right) Sin^2\frac{\theta}{2}}}$$

$$where: \theta = Arctg\left(\frac{4 f_{rep}}{c}\left(\frac{3}{2}\sqrt{\frac{c\lambda_L}{\pi\, f_{rep}}\sqrt{\frac{c}{2 f_{rep}\Delta L}}} + sp + 2\sqrt{\varepsilon\left(\beta^* + \frac{\left(\frac{c}{4 f_{rep}}\right)^2}{\beta^*}\right)}\right)\right)$$

$$where: \omega_{\text{waist}}^2 \approx \frac{L\lambda_L}{\pi}\sqrt{\frac{\Delta L}{4L}} \qquad \text{and} \qquad \frac{\omega_{\text{waist}}^2}{\omega_{\text{mirror}}^2} = \frac{\Delta L}{4L}$$

MECHANICAL STABILITY:

Remember that in a concentric cavity (small waists)
a laser pointing error (equivalent to a cavity mirror displacement)
couple the cavity power to a Hermite-Gauss mode (10) :

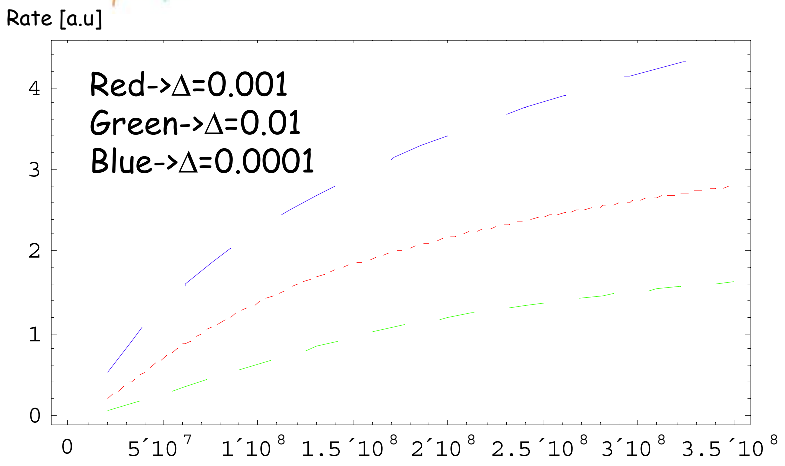
$$coupling = \left(\frac{\theta \, \pi \, \omega_0}{\lambda} \right)^2$$

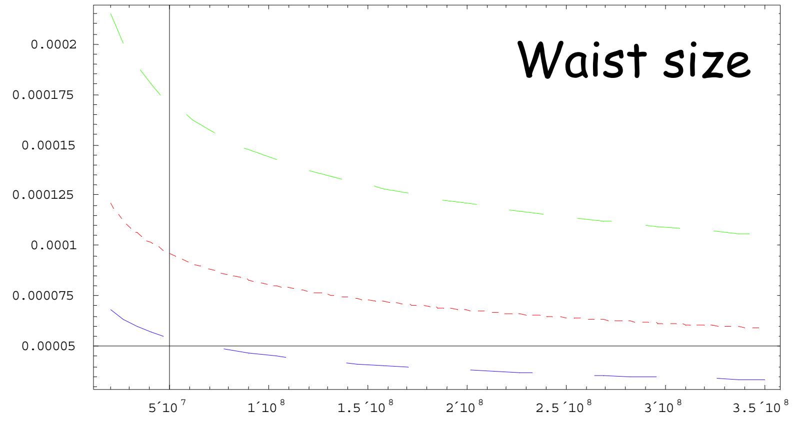
$$where \quad \theta = \frac{\Delta \mathrm{r}}{\Delta \mathrm{l}} \quad ; \qquad \Delta \mathrm{r} = \text{pointing error}$$

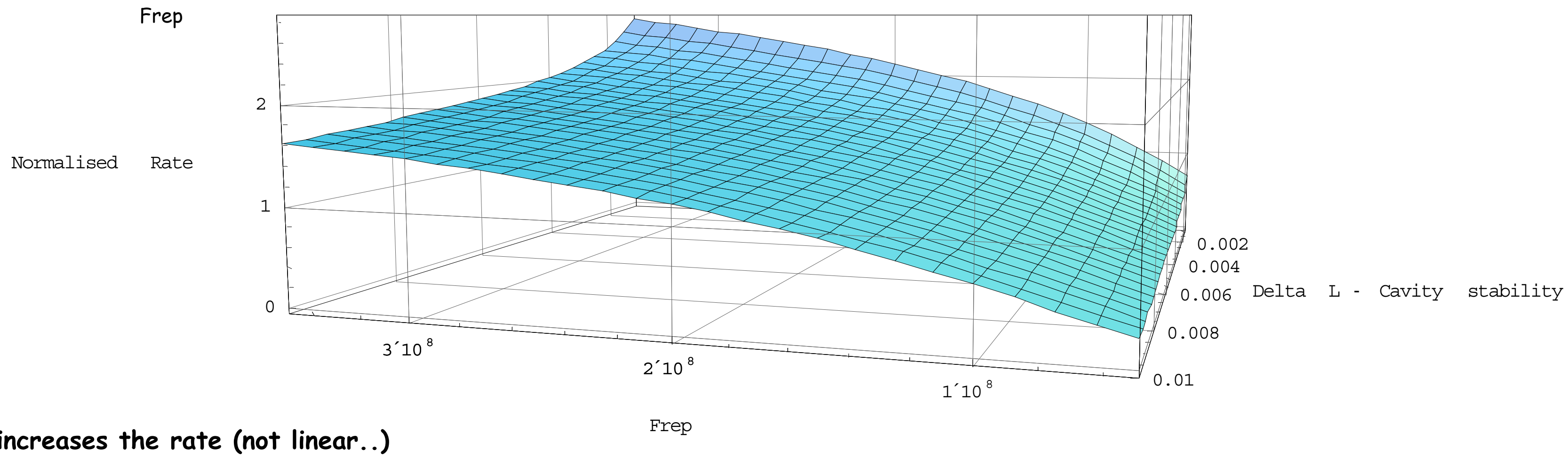
$$\text{So Power Loss} \propto \Delta \mathrm{l}^{-2}$$

Need for a (maybe too much) stable cavity
For a CO_2 laser..@#%^&^^^&!!!!

$\varepsilon = 10^{-10}$
bunch length = 6mm
β = 10cm

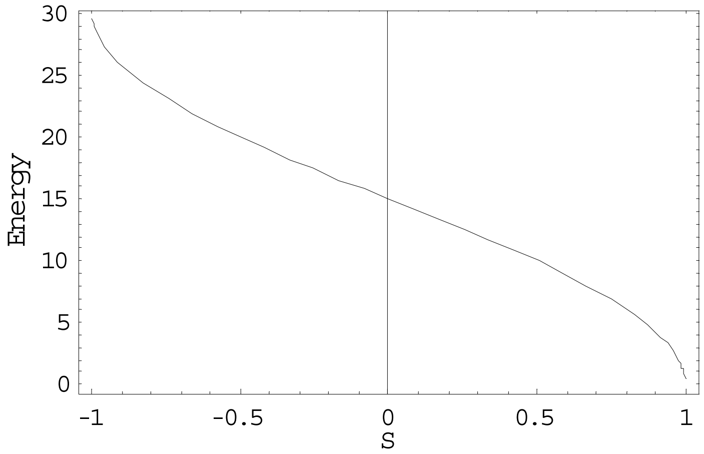


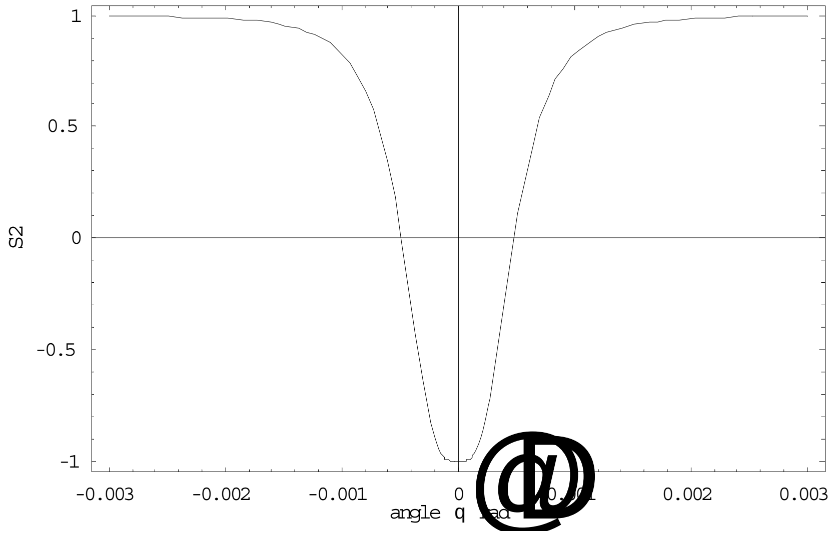




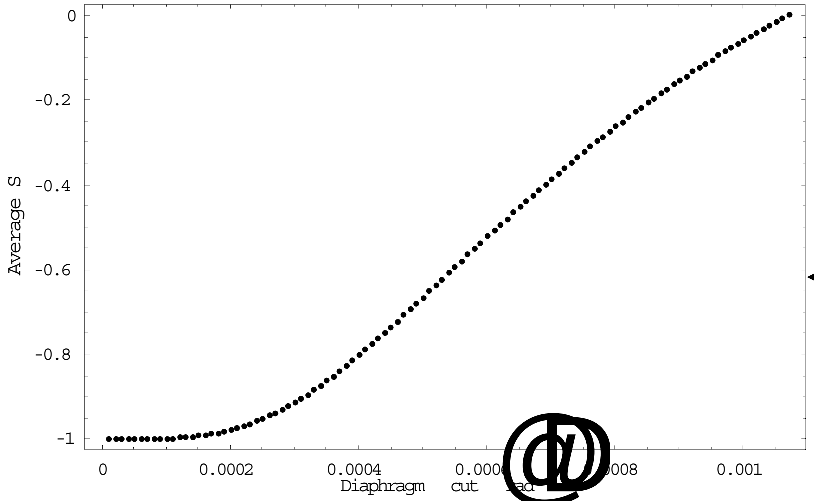
n) f_{rep} increases the rate (not linear..)
o) Cavity mechanical stability is a function of f_{rep} for a given waist.
To attain a small waist: increase f_{rep} (slow), decrease Δl (difficult) => It is necessary to look for 4 mirror cavity.
There is more interest in increasing f_{rep} up to~100MHz

Polarization Limitations





$$S = Cos\left[\pi \frac{8\gamma^2 \lambda_{cut}}{\lambda_{Laser}(2+\gamma^2\theta^2)}\right]$$

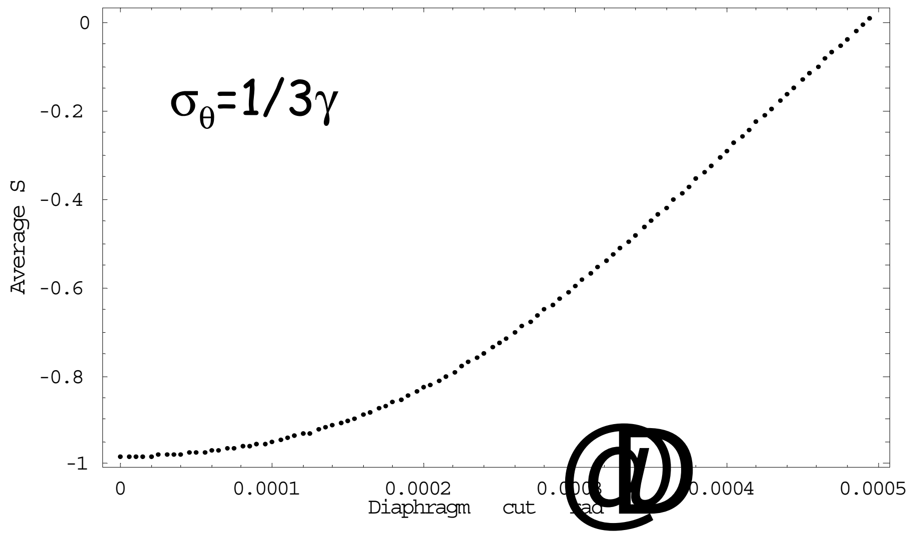


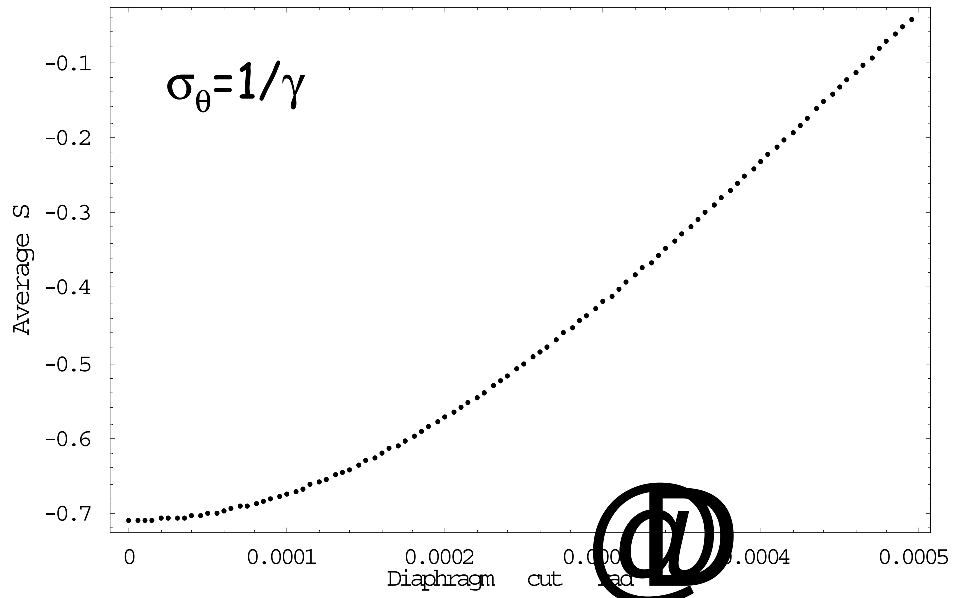
Diaphragm in the angular range gives a variation in average polarization

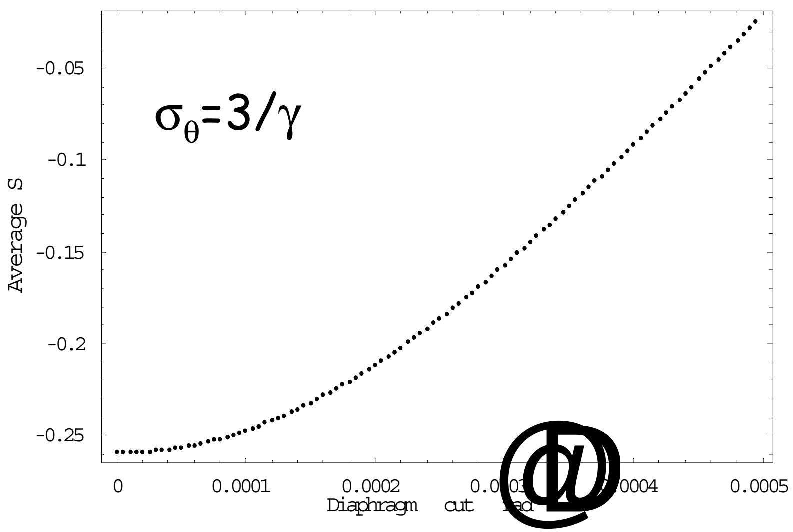
$$S_{av} = \frac{\int_{-\theta_1}^{\theta_1} S(\lambda,\theta)d\theta}{\Delta\theta}$$

Real Beam

For a real beam we need to convolute with a Gaussian angular distribution







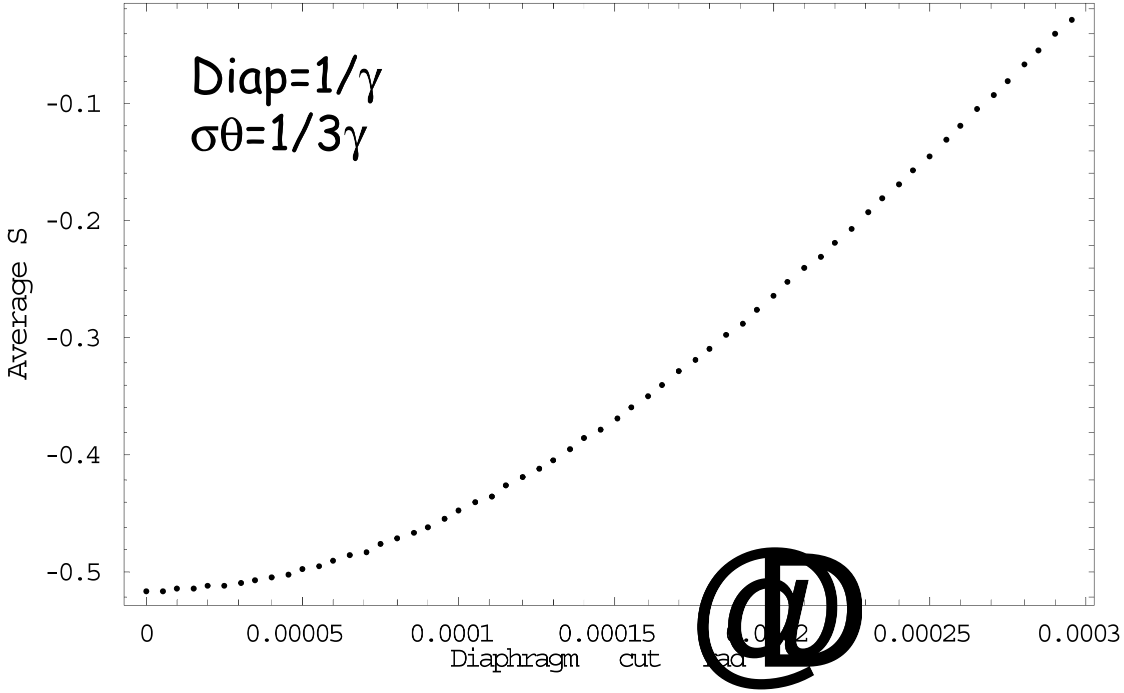
p) In a waist, as a rule of thumb for the angular spread, we have that for acceptable polarization

$\sigma_\theta<1/2\gamma \Rightarrow \sqrt{\frac{\varepsilon}{\beta^*}} < \frac{1}{2\gamma}$

$$\sigma > 2\gamma\varepsilon$$

*)We cannot have very low beta!!!!

En=1.8 GeV



It also depends on the energy:

increasing the energy there are no more tails to cut.....!!!

*) We cannot have high energy if the angular spread (so emittance) does not scale...!!
POLARIZATION IS A SERIOUS CONSTRAINT ON THE ENERGY AND THE β*

So, in the optimization process, to increase the cross section we have to reduce the laser and the beam sizes but:

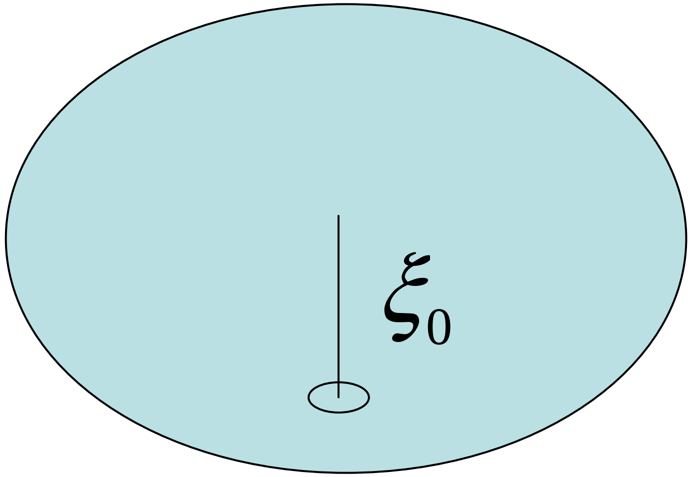
At a given emittance and energy we should not look for too tight parameters!!!

1) Beam => Loss in polarization
2) f_{rep} => No linear gain as D.C and problem in the Compton ring (less f_{rep} => less crossing angle).
More important: cavity locking @ high D.C is easier!!!
3) Laser waist => Mechanical stability for 2 mirrors cavity &
.....see F.Zomer Talk. We do not have a "squared" loss....

High Duty Cycle & Multiple Re-Injection

If the solution is to go for lower f_{rep} we can compensate increasing the Duty Cycle…

Some basic considerations:



$$N_{tot/bunch} = \frac{\Delta T\ D.C\ f_{rep}}{N_{bunch}} N_\gamma \varepsilon_{syst} \varepsilon_{acc} \quad ;\ \Delta T = 0.2s$$

$$\varepsilon_{acc} = \frac{\Delta\xi_{ring}}{\Delta\xi_{iniz}}$$

$$\Delta\xi_{ring} = \frac{\xi_0}{\tau} T \quad ; T = \frac{N_{bunch}}{f_{rep}}$$

where:

$\xi_0 = inj\ position\ in\ the\ bucket,\quad \tau = cooling\ \ Time,$

$T\ period\ between\ re\text{-}injection\ \ in\ the\ same\ bucket$

$$so:\ N_{tot/bunch} = \frac{\xi_0}{\Delta\xi_{iniz}} \frac{0.2\ D.C}{\tau} N_\gamma \varepsilon_{syst}$$

N_{tot} is indipendent of f_{rep}

A final example:

Fiber laser + Fabry Perot cavity……
10 cavity 2 10^4 gain
2.5 microjoule pulse @ 100 MHz

Laser pulse Energy [Joule]
pulseE= 5.00000000D-01
Laser pulse length [m]
sigt= 2.40000000D-04
Laser pulse wavelength [m]
laserwl= 1.06000000D-06
Laser waist size [m]
xw= 2.00000000D-05
Laser Rayleigh length [m]
zr= 1.18550666D-03

Beam Energy [eV]
ee= 1.30000000D+09
Particles per bunch
realParticles= 6.25000000D+10
Collision beta function x
betax= 2.00000000D-01
Collision beta function y
betay= 1.00000000D+00
Beam size sigma x [m]
sigx= 2.00000000D-05
Beam size sigma y [m]
sigy= 5.00000000D-06
Beam length sigma z [m]
sigz= 4.00000000D-03
Emittance x
emitx= 2.00000000D-09
Emittance y
emity= 2.50000000D-11
Crabangle [rad]
crabAngle=-5.23598776D-02
Collision angle [rad]
LaserAngle= 1.04719755D-01

****
****

Beam STATISTICS
+++Right-going photon 14975 macro particles 3.743D+09 real
Average (t,x,y,s) 1.000D-02-3.805D-07-8.883D-08 9.996D-03 m
R.m.s. (t,x,y,s) 3.020D-15 1.505D-04 1.021D-05 2.861D-03 m
Min (t,x,y,s) 1.000D-02-7.591D-04-5.906D-04-4.697D-03 m
Max (t,x,y,s) 1.000D-02 7.461D-04 2.463D-04 2.402D-02 m
Average (En,Px,Py,Ps) 1.464D+07-3.022D+01-1.580D+01 1.464D+07 eV
R.m.s. (En,Px,Py,Ps) 9.332D+06 2.995D+03 2.425D+03 9.332D+06 eV
Min (En,Px,Py,Ps) 5.701D+02-1.190D+04-4.551D+03 5.687D+02 eV
Max (En,Px,Py,Ps) 2.952D+07 1.022D+04 4.594D+03 2.952D+07 eV

So if Capture Eff is ~ 2. %
And polariz. diaph. ~ 65% => Ne+ ~ 5 10^7

We need 400 re injection =>@ 100MHz =>
~ 11 msec
D.C ~ 10% (in 100 msec)

If 50% =>1 cavity !!!!

Is it possible?

Alessandro Variola
IN2P3 LAL - ORSAY
Posipol Workshop @ CERN

CONCLUSIONS

1) An increase in the Compton Ring energy must be carefully
Evaluated (@ a fixed laser wavelength)…..the only advantage
is the pair production (but increasing the En Spread and limited by polarization!).
2) Realistic case: we have to foresee a factor two in gamma's number
for the polarization diaphragm
3) Reducing the bunch length -> important rate increase
4) Crabbing -> important rate increase from optimisation
5) No visible advantages in using round beams
6) Increasing waist size: no drastic loss
7) 2 mirror cavity => rate is not linear with f_{rep} (mech. stability)
8) Diaphragming for polarization gives the constraint for beta* and γ
9) Multiple re-injection and high duty cycle: is it a possibility to be explored?
10) A lot of optimization work is still required……..

but we can try to relax the beam (laser & electrons) parameters and
the repetition frequency looking for more Tech R&D (laser & cavity)
and for more D.C

Directions………………


43
3
High Duty Cycle
Low Repetition Frequency
No Low Beta
Short Bunches
5
5
CRAB
Low Energy
(Polarization)
3
43
No Small
Waist
3
130

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