Using the spent beam at the ILC in order to understand strong field physics at the IP

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DESY

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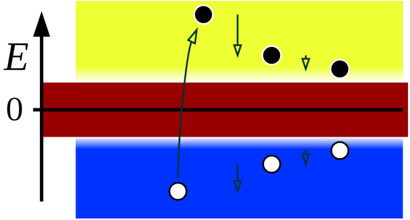
The strong field regime



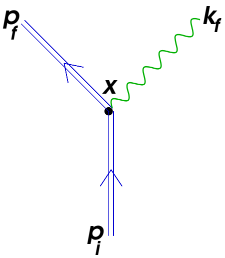
Υ sets the strong field scale.

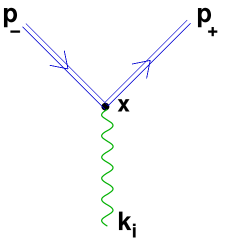
At $\Upsilon = 1$,

- the incoming charged particle sees a field strong enough to promote virtual particles to real particles
- Nonlinear effects dominate

Machine	LEP2	SLC	ILC	CLIC
E (GeV)	94.5	46.6	500	1500
$N(\times 10^{10})$	334	4	2	0.37
σ_x, σ_y (μm)	190, 3	2.1, 0.9	0.49, 0.002	0.045, 0.001
σ_z (mm)	20	1.1	0.15	0.044
Υ_{av}	0.00015	0.001	0.24	4.9

Strong field effects at LCs - 1st order processes





CURRENTLY

- Beamstrahlung & coherent pair production calculated via quasi-classical approximation (QCA)
- Incoherent pairs calculated with beamstrahlung photon and equivalent photon approximation (EPA)

UNCERTAINTIES

- crossing/radiation angle (classical theory assumed)
- integration over final states - QCA requires fermions on-axis
- the rate of spin flip/IP depolarisation

MORE PRECISELY

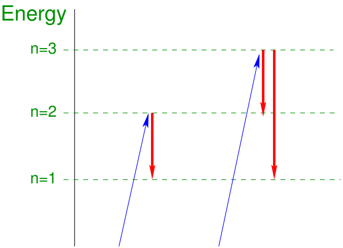
- Intense field QFT (Furry picture) calculations
- effects due to two strong fields
- Simulation via IPstrong
- Experimental tests

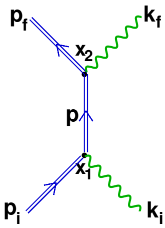
Strong field effects - New physics

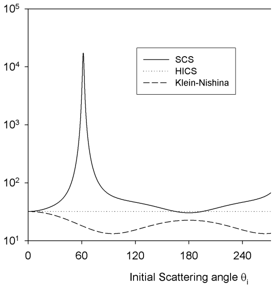
Resonant transition between
Zel'dovich energy levels in 2nd order processes

$$(q + nk)^2 = m_*^2$$

q = effective electron momentum
n = nth energy level
m_* = effective electron mass
k = LASER 4-momentum

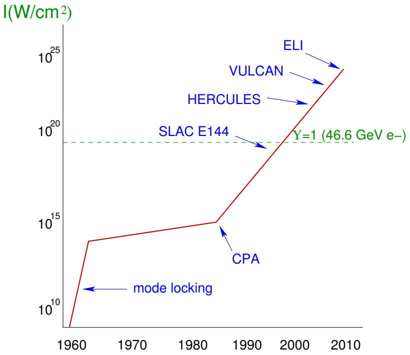






Where else to find Strong fields?

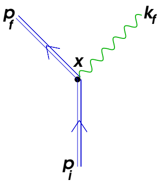
- $E_{\text{crit}} = 1.32 \times 10^{16}$ V/m, $\Upsilon = E/E_{\text{crit}}$
- Magnetic field at surface of neutron star, $B \to B_{\text{crit}}$
- heavy ion collisions, $E \to 2Z\alpha E_{\text{crit}}$ (positron production spectrum not understood)
- Earths magnetic field in boosted frame of cosmic rays
- Electric field of a charge bunch at a future linear collider (in boosted frame)
- ultra-intense LASERS

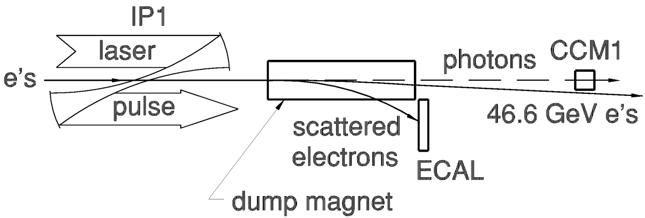


$$\Upsilon = \frac{2\gamma E_{\text{lab}}}{E_{\text{crit}}} \quad , \quad I = \frac{E_{\text{lab}}^2}{377\Omega} = \frac{E_{\text{crit}}^2}{4508\gamma^2}$$

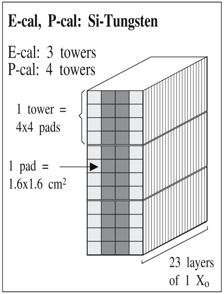
so $\Upsilon = 1$ for $I = 1.4 \times 10^{19}$ W/cm^2 and 46.6 GeV electrons

SLAC E144 experimental setup

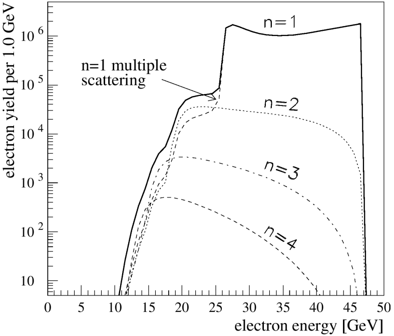


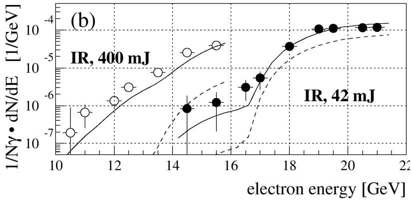


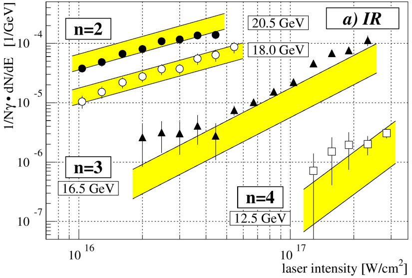
- 46.6 GeV e- beam collides with focussed ND:YAG laser at $\theta = 17^o$
- measurements made of pulse width, spot size and laser energy to get Intensity $\approx 10^{18}$ W/cm^2
- electrons with $E \leq 30$ GeV detected by Si-Tungsten ECAL, $\frac{\sigma}{E} \approx \frac{0.25}{\sqrt{E(\text{GeV})}}$
- photons converted in Al and detected in gas Cherenkov, $\Delta N_\gamma = 10\%$



SLAC E144 results



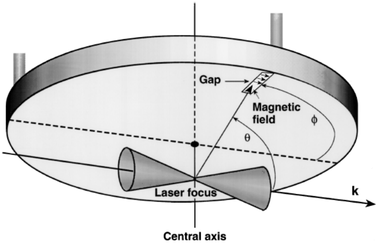


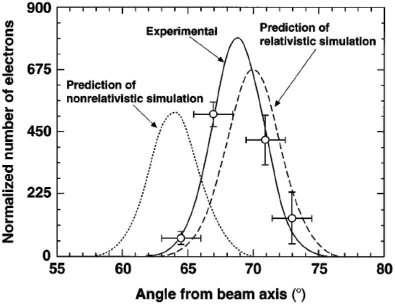


- Compton edge shifted by multiphoton effects
- Multiple Compton scattering vs nonlinear Compton scattering
- n=1 edge should also be mass shifted $m \to \sqrt{m^2 + e^2 a^2}$
- yellow band - uncertainty in I, N_γ

Rochester experiment - strong field mass shift

(Meyerhofer et al, J Opt Soc Am B 13(1) 113 (1996))





(b)

- high intensity LASER ionizes Ne,Kr→80,175 keV electrons
- 1.5ps CPA laser, $I \approx 10^{18}$ W/cm^2
- magnetic spectrometer, energy and angular distribution (1.5^o resolution)
- nonlinear mass shift detected

A strong field experiment at the ILC

The actual proposal:

That we use some part of the extraction line to interact a terawatt LASER with the spent electron beam to do strong field physics

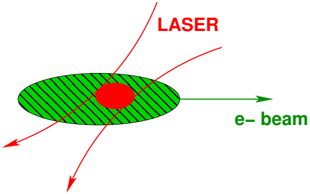
What we would like to measure/discover

- The mass shift, multiphoton effects to higher precision
- dependence of nonlinear effects on polarisation
- draw conclusions with expected primary IP effects
- New physics - Zel'dovich resonances, new solutions in two fields, higher orders

Issues/benefits

- Ideally be at a post IP beam focus
- We will have to think about possible backgrounds - situating of detectors
- Should be no interference with current extraction line diagnostics
- Dont need primary IP collisions
- Data collection time at the level of days for basic strong field phenomena

Reaching the critical field with the ILC beam



Experiment	$\lambda(\mu m)$	E_{laser}	focus	pulse	I(W/cm^2)	E_{e^-} (GeV)	Υ
E144 (SLAC)	1	2 J	60 μm^2	1.5 ps	$\approx 10^{18}$	46.6	0.27
ILC (E144 laser)	1	2 J	60 μm^2	1.5 ps	$\approx 10^{18}$	125-500	0.72-2.9
ILC (PL 9000)	1	3 J	40 μm^2	0.5 ps	6.75×10^{18}	125-500	1.87-7.54

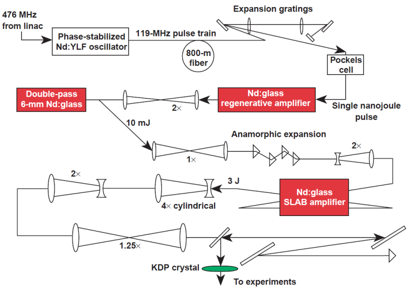
$$I = \frac{E_{\text{laser}}}{\text{spot} \times \text{pulse}}$$

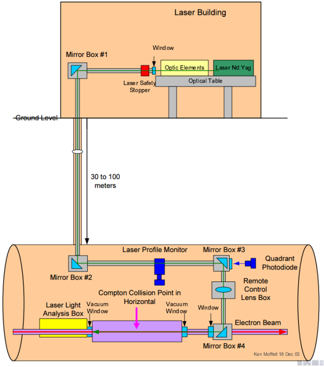
$$E_{\text{lab}}(\text{V/m})=19.4\sqrt{I(W/cm^2)}$$

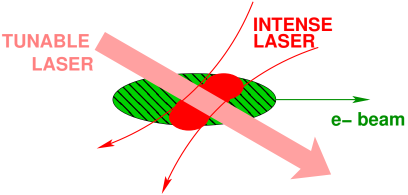
$$\Upsilon = \frac{2\gamma E_{\text{lab}}}{1.32 \times 10^{16}}$$

- can investigate high Υ due to boost from ILC beam and modern laser
- multiphoton effects dominate at $\Upsilon \approx 1$
- new QFT tests possible

LASER system and IP

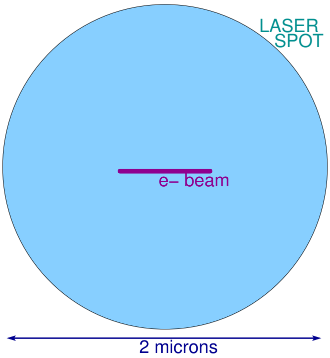


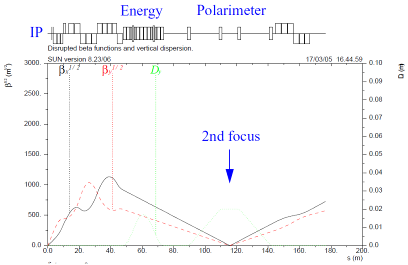




- Intense LASER produced via chirping
- Compression stage at end to avoid damaging optical elements
- A second tunable average intensity LASER allows us to scan for resonances

Location in the extraction line





- laser spot size much bigger than nominal e- beam profile
- doesnt need to be at second focus, but analysing magnets required
- minimize backgrounds - situation of ECAL, PCAL, GCAL
- make sure no interference with other diagnostics

Summary

- Future LC will involve strong fields at IP $\rightarrow$ nonlinear effects
- past experimental tests confirm strong field QFT in a limited way
- Interaction of terawatt laser with spent beam + ECAL,PCAL,GCAL $\rightarrow$ ready made strong field experiment
- The boost provided by spent beam energy means $\Upsilon \rightarrow 10$
- Can run parasitically, need stable beam energy, beam size not so important
- Confirm mass shift, multiphoton effects $\rightarrow$ cross-checks to IP effects
- New strong field QFT tests: resonances, solutions in two fields
- a more detailed study of feasibility can be made