IFQED processes in CAIN

Anthony Hartin

Advanced QED for future colliders Workshop

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  - general features with respect to the matrix element structure

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- **However** Precision physics eg. polarization studies require precise spin tracking (cf. Gudi et al The Power Report)
- Pertinent to look at higher order IFQED and radiative corrections

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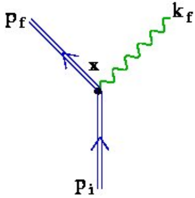

Figure: The beamsstrahlung process.

Spin tracking in CAIN - precession

- Spin precession in the bunch field is given by the T-BMT equation

$$\frac{d\vec{S}}{dt} = -\frac{e}{m\gamma}\left[(\gamma+1)\vec{B}_T + (a+1)\vec{B}_L - \gamma(a+\frac{1}{\gamma+1})\frac{1}{c^2}\vec{\nu}\times\vec{E}\right]\times\vec{S}$$

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- **There is a pole** in the unpolarized part (but not the polarized part) at $u = 0$
- This pole corresponds to the IR divergence $\omega_f \to 0$
- Uncorrected in CAIN/G-P, so uncertainty in the spin-flip rate
- Has to be corrected with the corrected vertex in the external field
- But I wont discuss it further here

CAIN pair production processes

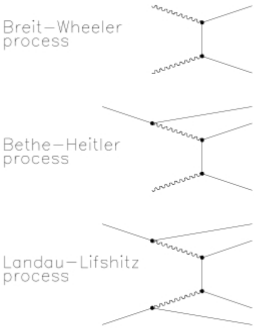

Figure: Beam-Beam pair processes

- Real beamstrahlung photons and/or virtual photons give the three pair production processes
- There is an additional bhabha process of fermion scattering off beamstrahlung photons

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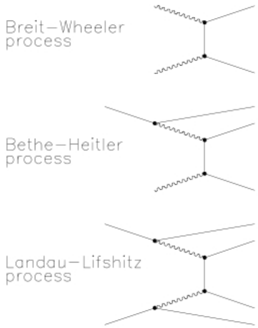

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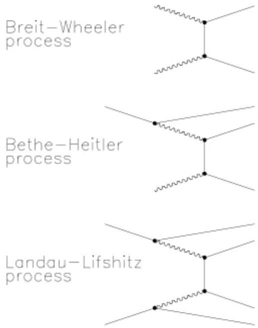

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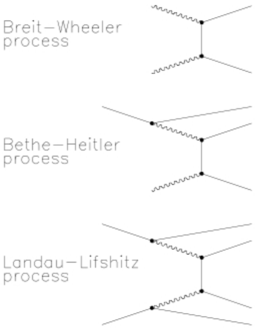

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- The poles of the Dressed propagator are particularly interesting
- Furthermore assume EPA in the external field is still valid
- We need the Second order IFQED processes in the Furry picture

2 vertex pair production in an external field I

- Use the method of Nikishov and Ritus - we need only the modified vertex

$$\Gamma^e_\mu = \int d^4x \bar{E}_{p_-}(x)\gamma_\mu E_{p_+}(x)\exp(-i(k_1 x))$$

$$E_p(x) = \left(1 + \frac{e\not{k}\not{A}}{2(kp)}\right)\exp(iS(x))$$

- We need a product of 4 of these, 2 projection operators and propagator numerators - 2000 terms in the trace!
- We can reduce using the usual rules but still its in our interest to simplify the matrix element as much as possible

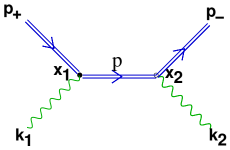

Figure: The 2 vertex IFQED pair production.

2 vertex pair production in an external field II

$$S_{fi} = \int drdsdp\ \bar{u}(p_f)\bar{E}(p_-)\gamma_\mu E(p)\frac{\not{p}+m}{p^2-m^2}\bar{E}(p)\gamma_\nu E(p_+)$$
$$.\delta(p_- - p - k_1 - rk)\delta(p - p_+ - k_2 - sk)$$

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- Try and do the integration over dr before squaring the matrix element

Two vertex Auxillary functions I

- The two vertex auxillary function is an integration of an Airy function product

$$A \equiv \int_{-\infty}^{\infty} \frac{dr}{(p_- k_1) + r(kp)} \mathrm{Ai}(r - Q_1)\mathrm{Ai}(l - r - Q_2) \exp(-irQ_3)$$

- These type of calculations always occur, for circularly polarised field its an infinite summation over Bessel function products

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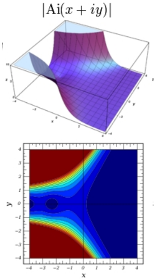
- Result: Airy function product with a complex argument



Two vertex Auxillary functions II

- An alternative for constant crossed field is to use the limit $\omega \to 0$
- Actually this was discussed by Nikishov-Ritus in regards to a decay process (JETP 19,5(1964))

$$\sum_{r=-\infty}^{+\infty} \int dr \ A^2 \delta(p_i + rk - p_f + k_f) \approx \sum_{-r_{eff}}^{+r_{eff}} A^2 \delta(p_i - p_f + k_f)$$

$$\approx \delta(p_i - p_f + k_f)$$

- so in constant crossed field reduces to the field free process
- only for processes which occur also in absence of the external field
- Can I do the same thing for my auxillary function?

$$\frac{1}{(p_- k_1)} \text{Ai}(-l + \frac{\lambda^2}{2}) \exp[i(\frac{\lambda^3}{6} - \frac{\lambda l}{2})]$$

The Volkov propagator poles

- The propagator denominator is a function of r

$$\frac{1}{(p_- k_1) + r(kp_-) - (kk_1))}$$

- The pole can be expressed as

$$r = -\frac{\omega_1}{\omega}\frac{\epsilon_-}{\epsilon_- - \omega_1}$$

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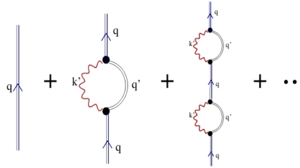
- For bunch collisions we idealised the bunch field
-

Volkov propogator radiative corrections



$$\begin{aligned} G^e_{SE}(x_2,x_1) &= \int d^4p \, E_p(x_2) \frac{1}{\not p - m} \bar{E}_p(x_1) \\ &+ \int d^4p \, E_p(x_2) \frac{1}{\not p - m} \Sigma^e(p) \frac{1}{\not p - m} \bar{E}_p(x_1) \\ &+ \ldots \end{aligned}$$

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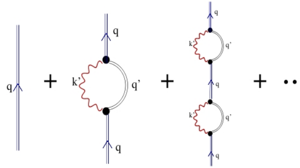

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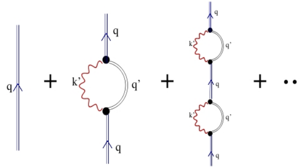

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- Inclusion of electron self energy is straightforward if we consider a self energy sandwiched between E functions
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- Actually we already saw this: since the Optical theorem relates the dressed self energy to beamstrahlung in

$$W \propto \int_0^\infty \frac{du}{(1+u)^2}\left[\int_x^\infty K_{5/3}(y)dy - \frac{u^2}{1+u}K_{2/3}(x)\right]$$

- Its better to say that the IR divergence in the dressed self energy **coincides** with that of the ordinary self energy

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- Work in progress - expect some numerical results!