# Workshop Summary

Stefan Hesselbach
IPPP, Durham University

Advanced QED methods for future accelerators
Cockcroft Institute, 04 March 2009

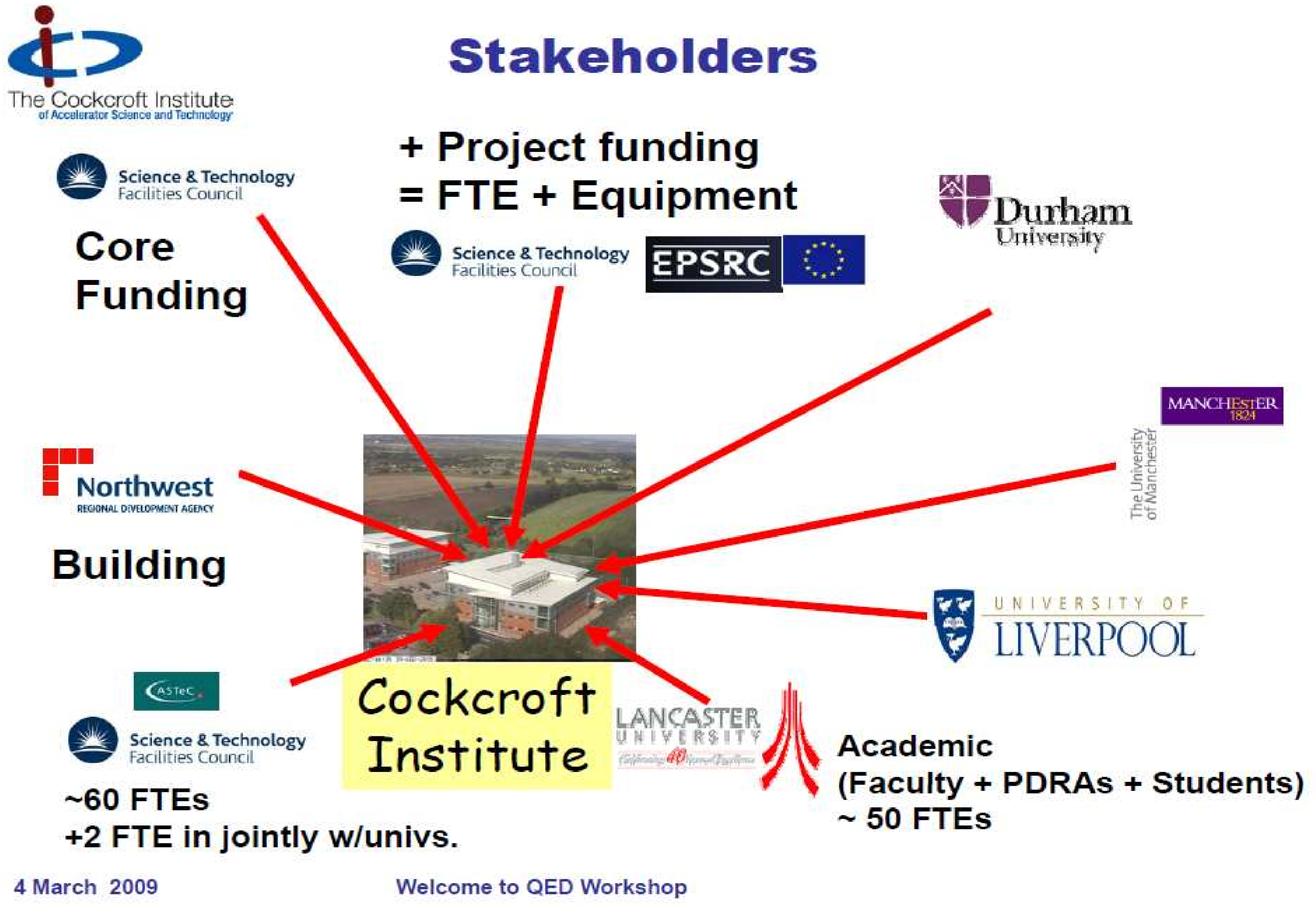
# Overview

- Introduction
- Intense Field QED (IFQED) methods
  - Operator quasiclassical method
  - Method of Nikishov/Ritus (Furry representation)
- IFQED calculations
- Simulations
- Applications

# Introduction session

- J. Dainton: Workshop welcome and Overview
- I. Bailey: Scope of the Workshop
- G. Moortgat-Pick: The Furry representation

J. Dainton: Workshop welcome and overview



I. Bailey: Scope of the Workshop

# Origin and aims of Workshop

- This workshop follows on from a small workshop on "Models of Depolarisaton in Linear Colliders" held at the CI last year
- The goal of that workshop was to evaluate models of depolarisation at the interaction point of future linear colliders and identify any further theoretical work required.
- The aim of this workshop is to gain a firmer understanding of the QED techniques available and applicable to processes in the intense fields expected at future accelerators.

## Conclusion

- Furry representation: intermediate between Heisenberg and Dirac representation
- eigenstates of bound system instead of free-particle system
- effects of external field adapted in Dirac function of electron
- due to this bound state, adaption/inclusion of
  - commutation relations
  - gauge transformations
  - charge conjugation operation
  - contribution of self-closed diagrams in vacuum polarization
  - electron propagator $\mathcal{G}(x,x') \neq \mathcal{G}(x-x')$

# Session 1
# Intense Field QED (IFQED) methods

- V.N. Baier: Recent development of quasiclassical operator method

- A. Hartin: The method of Nikishov and Ritus (using the Furry representation)

# Recent development of quasiclassical operator method


## V. N. Baier and V. M. Katkov

Budker Institute of Nuclear Physics, Novosibirsk, Russia



The quasiclassical operator method is described. Application of the method for series of problems are discussed. These are processes in the superposition of plane wave and constant field, radiation in linear colliders, radiation in inhomogeneous field, theory of radiation in oriented crystals, radiation spectra taking into account energy loss.



"Advanced QED methods for future accelerators",
Cockcroft Institute, Daresbury, UK
March 3-4, 2009

V.N. Baier: Recent development of quasiclassical operator method

• Transition probability for ultrarelativistic case

the radiation probability

$$dw_\gamma =< i|M^+M|i > d^3k \qquad (7)$$

The next step of calculation is series of transformation of operators ("disentanglement") in Eqs.(7), (6). As a result one obtains

$$M = \frac{e}{2\pi\sqrt{\hbar\omega}}\int_{-\infty}^{\infty} R(t)\exp\left[i\frac{kx(t)}{\varepsilon - \hbar\omega}\right]dt = \frac{e}{2\pi\sqrt{\hbar\omega}}\int_{-\infty}^{\infty} R(t)\exp\left[i\int_0^t \frac{kp(t')}{\varepsilon - \hbar\omega}dt'\right]dt, \qquad (8)$$

- Application for (selection)
  - Processes in Plane Wave and Constant Field
  - Radiation in Linear Colliders
  - Radiation in Oriented Crystal

# Synopsis

- Methodology
  - Use Furry picture to include the external field
  - Volkov Solution
  - Dressed momentum and mass shift
  - Propagator in the external field
  - Modified Feynman rules
- Beamstrahlung example
  - Tree level with respect to the Furry Picture
  - Only consider unpolarised fermions
  - Specific Volkov representation for constant crossed field
  - Fourier Transform of the Volkov solutions
  - Phase Integral calculation
  - The Beamstrahlung Transition Rate
  - Comparison with Operator method

# Summary

- Work in the Furry picture
- Use Volkov solutions for fermions in an external field
- Write the propagator in terms of Volkov E functions
- Use usual Feynman rules with a modified vertex
- Take Fourier Transform to simplify the dependence on space-time variables
- For constant crossed field, no mass shift, dressed momentum
  - no mass shift
  - no dressed momentum
  - no interpretation in terms of external field photons
- Method applied to Beamstrahlung process
- I want the most effecient simplification to apply to higher orders
- Expressions simplified to functions of single Airy functions
- Comparison of Transition Rates between Operator and Nikishov-Ritus show agreement for ultra-relativistic fermions

# Session 2
# IFQED calculations

- A. Di Piazza: Vacuum polarization effects in intense laser fields

- T. Heinzl: Compton Scattering at High Intensities

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# Vacuum polarization effects in intense laser fields

A. Di Piazza, K. Z. Hatsagortsyan, E. Loetstedt,
U. D. Jentschura, A. I. Milstein and C. H. Keitel

# CONCLUSIONS

- Quantum vacuum is an interesting object to study
- Strong laser fields can be used to probe QED vacuum (light-by-light diffraction)
- Connection between testing QED vacuum and QED at high fields (laser photons merging in laser-proton collisions, photon splitting in a laser field, Delbrueck scattering in combined Coulomb and laser fields, laser-assisted bremsstrahlung and channeling of electron-positron pairs in a laser field)

# COMPTON SCATTERING AT HIGH INTENSITIES

TOM HEINZL

ADVANCED QED METHODS FOR FUTURE ACCELERATORS

COCKCROFT INSTITUTE

03/03/2009

with: C. Harvey (UoP), A. Ilderton (Dublin), K. Ledingham (Strathclyde), H. Schwoerer (Stellenbosch), R. Sauerbrey and U. Schramm (FZD)

# Basic intensity effect

- Consider charged particle in plane e.m. wave ( $k^\mu$ )
- calculate average 4-momentum $q^\mu \equiv \langle p^\mu(\tau) \rangle$

  where $p^\mu(\tau)$ is solution of *classical* EoM
- Result: 'quasi-momentum' (longitudinal addition)

$$q^\mu \equiv p^\mu + \frac{a_0^2\, m^2}{2\, k \cdot p}\, k^\mu \equiv p^\mu + q_L^\mu$$

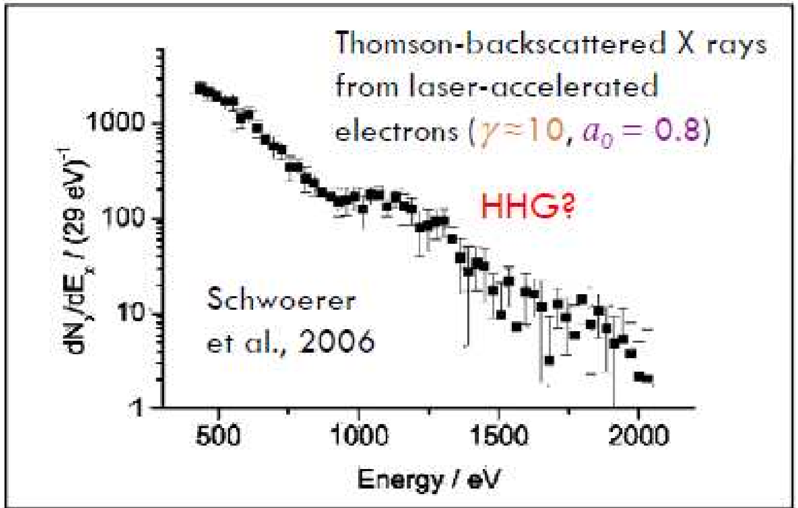
with $$q^2 = m^2(1 + a_0^2) \equiv m_*^2$$

$\rightarrow$ **mass shift** due to 'quiver' motion

(Sengupta 1951, Kibble 1964)

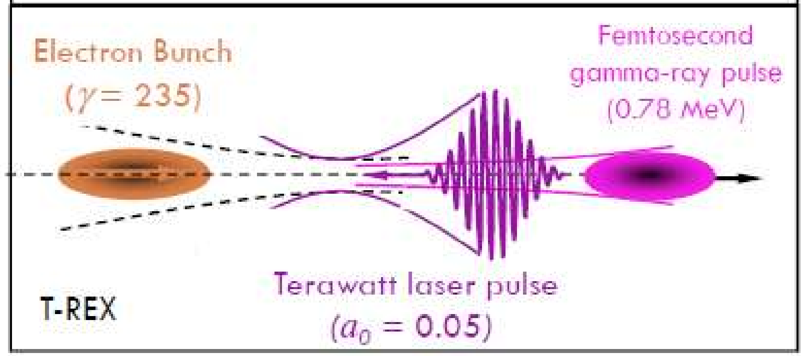
# NLC: Outlook

- Theory requires testing:
  - Establish Furry picture
  - Quasi-momentum?
  - Mass shift?




- Applications include:
  - X-ray generation

    e.g. T-REX @ Livermore
  - Polarized gamma beams
  - Utilise for probing vacuum birefringence?



# Session 3
## Simulation of IFQED processes in colliders

- C. Rimbault: Guinea-Pig++ Update
- A. Hartin: IFQED processes in CAIN

# Implementation and study of depolarizing effects in GUINEA-PIG++ beam-beam interaction simulation

- Depolarization effect overview
- Depolarization & beam-beam simulations
- GP++/CAIN Comparison for beam state after interaction
- GP++/CAIN Comparison at the luminosity contribution time

People involved: P. Bambade, F. Blampuy (summer intern),G. Le Meur, C. Rimbault

# Luminosity weighted depolarization

| Lumi Depolarization in **GP++** | Nominal | LowN | LargeY | LowP |
|---|---|---|---|---|
| T-BMT only (%) | 0.17 | 0.08 | 0.41 | 0.28 |
| **T-BMT+spin-flip (%)** | **0.23±0.01** | **0.13±0.01** | **0.46±0.01** | **0.41±0.01** |
| $\Delta P_{lw}/\Delta P$ for T-BMT | 0.270 | 0.276 | 0.295 | 0.269 |

| Lumi Depolarization in **CAIN** | Nominal | LowN | LargeY | LowP |
|---|---|---|---|---|
| T-BMT only (%) | 0.19 | 0.09 | 0.48 | 0.30 |
| **T-BMT+spin-flip (%)** | **0.24** | **0.13** | **0.57** | **0.50** |
| $\Delta P_{lw}/\Delta P$ for T-BMT | 0.297 | 0.310 | 0.329 | 0.278 |

| | | | | |
|---|---|---|---|---|
| **(SpinFlip)/tot (%)** *withGP++* | 26 | 38 | 11 | 32 |

| | | | | |
|---|---|---|---|---|
| **(GP-CAIN)/CAIN (%)** | -4 | ~0 | -19 | -18 |

- Problem with LargeY and LowP (20% diff CAIN/GP)?
- SpinFlip represents about 10 to 40% of the total depolarisation

# Summary

- Discussed what CAIN simulates
- Pointed out where IFQED processes enter into CAIN
- 1st order beamstrahlung and coherent pair production
- anomalous magnetic moment in external field included into T-BMT equation
- The IR divergences have not been removed
- 2nd order pair production processes should use Volkov solutions
- Discussed the structure of the matrix element
- Need an analytic solution of the Auxillary functions
- May be able to employ constant crossed approximation $\omega \to 0$
- Discussed dressed propagator poles and the dressed self energy
- Work in progress - expect some numerical results!

# Session 4
# IFQED Applications

- J. Jaeckel: Strong fields and recycled accelerator parts as a laboratory for fundamental physics
- K. Hatsagortsyan: Lepton pair creation in strong laser fields
- U. Uggerhoej: Experiments on strong field QED in crystals
- J. Gratus: Geometric and Ultrarelativistic methods for accelerator physics

# Strong fields and recycled accelerator parts as a laboratory for fundamental physics

Joerg Jaeckel[†]

M. Ahlers*, H. Gies[x],
J. Redondo**, A. Ringwald**

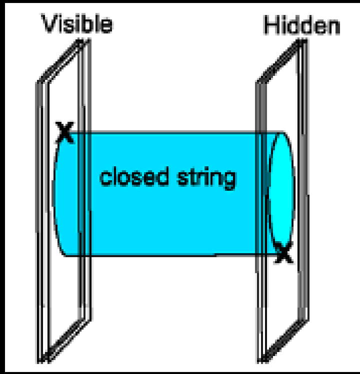
[†]IPPP Durham, [x]ITP Heidelberg, *CTP Oxford,
**DESY

University of Durham

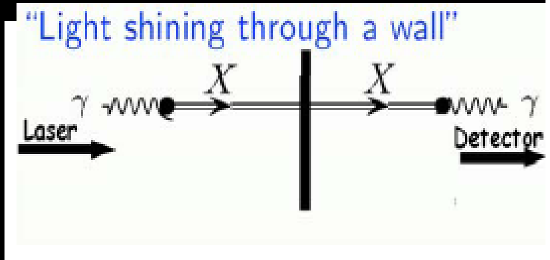
# Searching new particles with recycled tools

University of Durham

- Light particles coupled to photons are "expected" in Extensions of the Standard Model, e.g. string theory




- We can search for them using low energy experiments with photons!! Using recycled accelerator parts!




- These experiments are complementary to the collisions! Test ultrasmall couplings!

- Many more cool experiments possible!

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# Lepton pair creation in strong laser fields

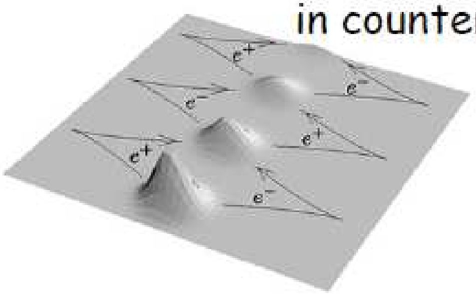
K. Z. Hatsagortsyan, C. Müller, M. Ruf, G. Mocken,

and C. H. Keitel

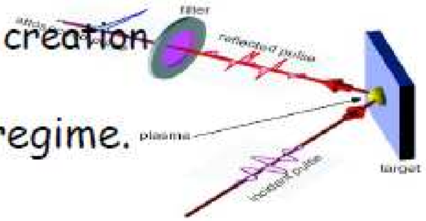

Advanced QED Methods for Future Accelerators, 3rd-4th March, Cockcroft Institute, UK

# Conclusion

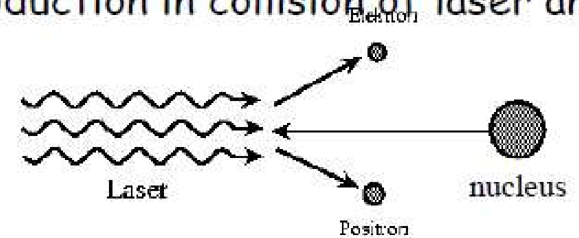
Laser collider: Coherent collisions and muon production in counterpropagating laser pulses via Ps gas



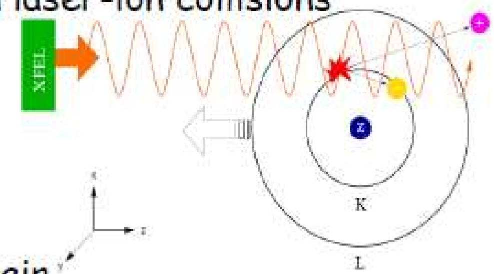
Unusual application of attosecond lasers: with CERN-LHC, they represent most promising tool for experimental realization of multiphoton pair creation



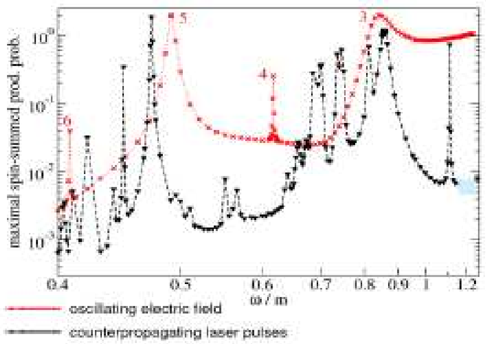

Pair production in collision of laser and ion beam in the multiphoton regime.

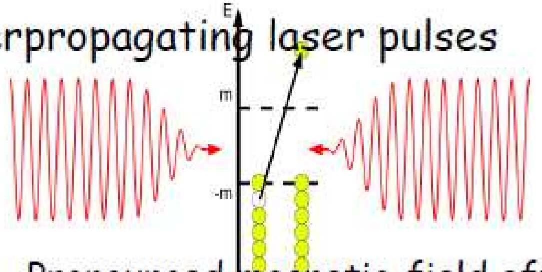



At high Z values, bound-free pair creation can compete with free pair creation in laser-ion collisions




Pair production in counterpropagating laser pulses




Pronounced magnetic-field effects exist in pair creation in a standing wave of high frequency: spliting and shift of resonance lines

# Experiments on strong field QED in crystals (CERN NA43 and NA63)

J.U. Andersen, H. Knudsen, S.P. Møller, A.H. Sørensen, E. Uggerhøj, U.I. Uggerhøj
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# Geometric and ultrarelativistic methods for accelerator physics

Jonathan Gratus

Physics Department Lancaster University and The Cockcroft Institute

Advanced QED methods for future accelerators 03-04 March 2009

# Outlook

- Tom Heinzl proposed 2nd workshop in January 2010 at DESY or CERN
  - Including laser community (ELI, …)
  - Results expected from Daresbury, Dresden
- Thanks to
  - Cockcroft Institute
  - IPPP Durham
  - Prof. Baier
  - Sue Waller