Parasitic particle physics at the high intensity frontier: Tests of non-linear QED in the collision of electron beams with laser beams

Andreas Ringwald

in collaboration with

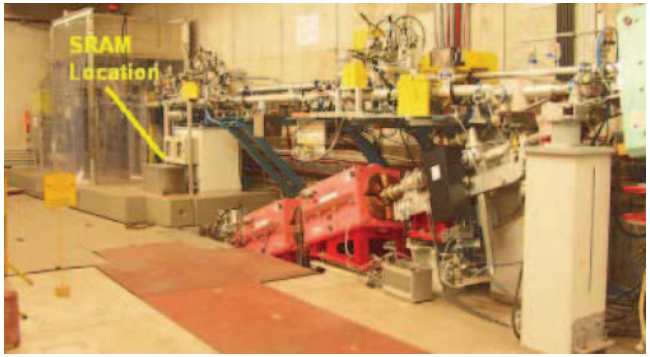
Paola Arias, Holger Gies (Jena), Axel Lindner, Gerhard Paulus (Jena), Javier Redondo (Munich), Andreas Wipf (Jena)

Beschleuniger-Ideenmarkt

June 16-17, 2010, DESY, HH, Germany

Introduction

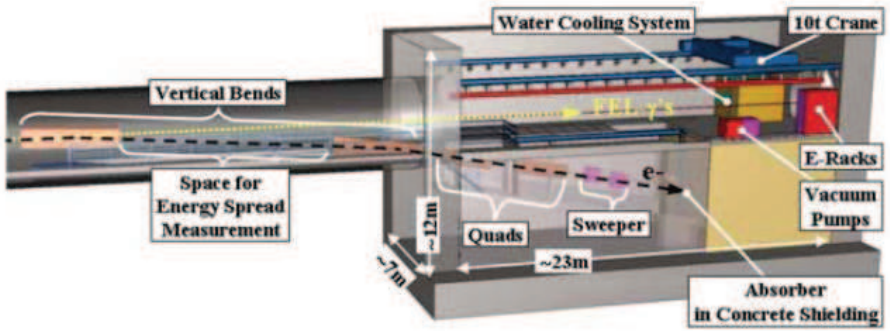
- Since the shutdown of HERA, there are no active particle physics experiments exploiting the accelerators at DESY, apart from
  - detector tests exploiting test beam lines at DESY II
  - the upcoming OLYMPUS experiment exploiting DORIS
  - accelerator tests exploiting the FLASH linac
- Unique intense electron beams of FLASH (XFEL) just dumped



- **Missing unique parasitic particle physics opportunities!**

Introduction

- Since the shutdown of HERA, there are no active particle physics experiments exploiting the accelerators at DESY, apart from
  - detector tests exploiting test beam lines at DESY II
  - the upcoming OLYMPUS experiment exploiting DORIS
  - accelerator tests exploiting the FLASH linac
- Unique intense electron beams of FLASH (XFEL) just dumped

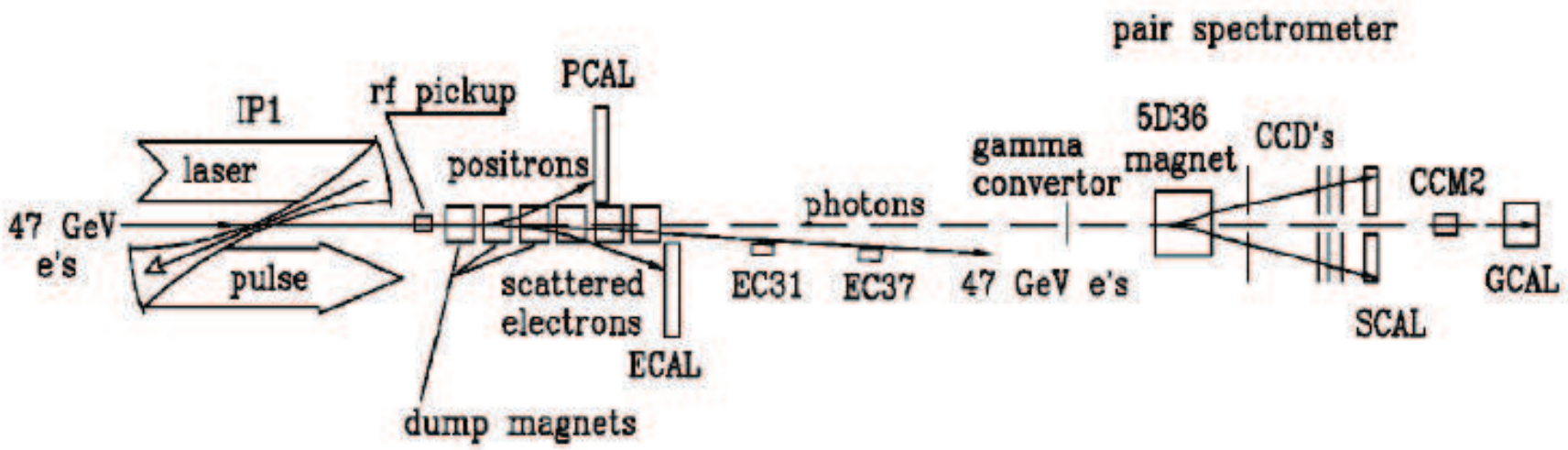


- **Missing unique parasitic particle physics opportunities!**

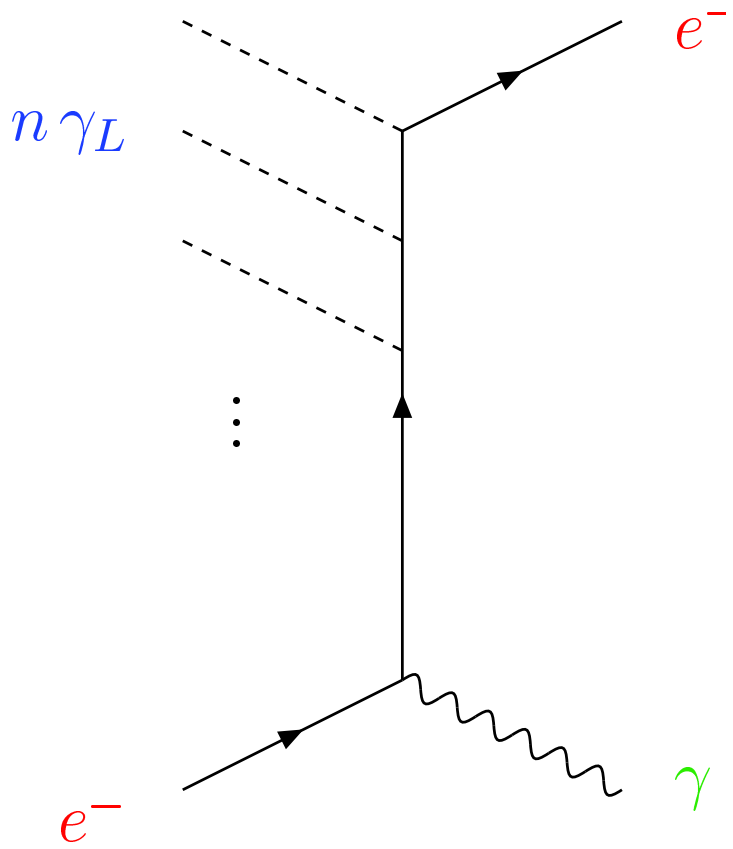
- **Parasitic particle physics opportunities exploiting electron beams colliding with intense laser beams:**
  - **Non-linear QED in collision of e^- beam with intense laser beam**
  - **Plasma wakefield experiments**
  - **Beam laser-beam interactions to modulate longitudinal bunch**

Non-linear QED in collision of e^- beam with intense laser beam

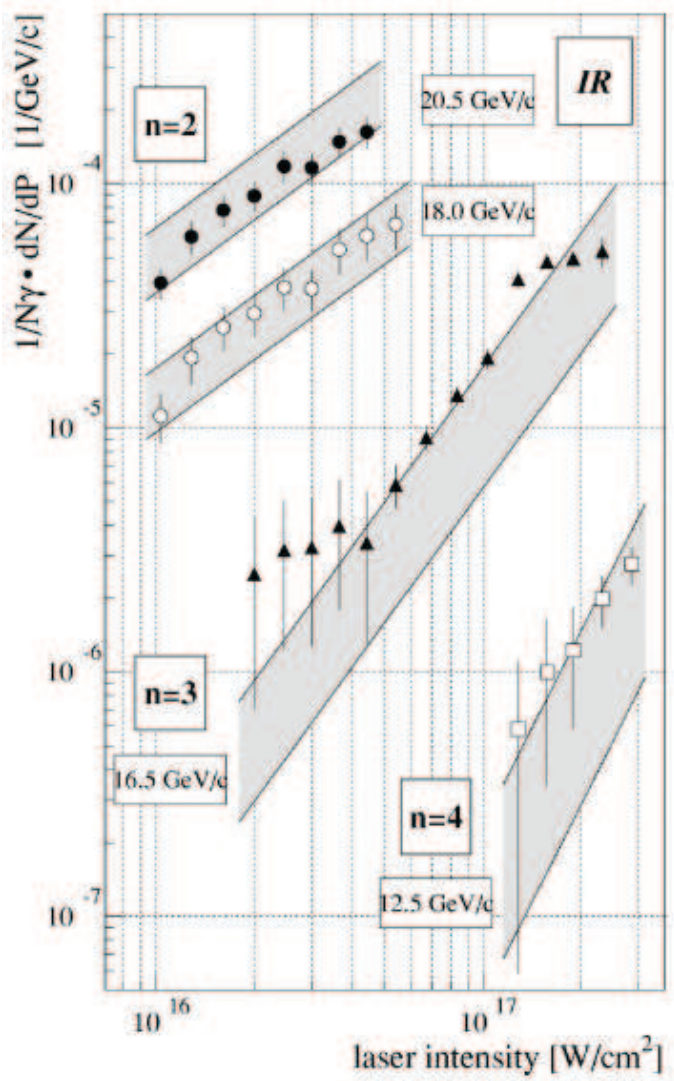
- SLAC E144 studied non-linear QED in the collision of a 46.6 GeV electron beam (the Final Focus Test Beam) with Terawatt pulses from a Nd:glass laser [Bula et al., PRL 76 (1996) 3116; Burke et al., PRL 79 (1997) 1626; Bamber et al., PRD 60 (1999) 092004]



- **Non-linear QED**
  multi-photon param. $\eta = \frac{e\mathcal{E}_{\rm L}}{\omega_{\rm L} m_e}$
  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$

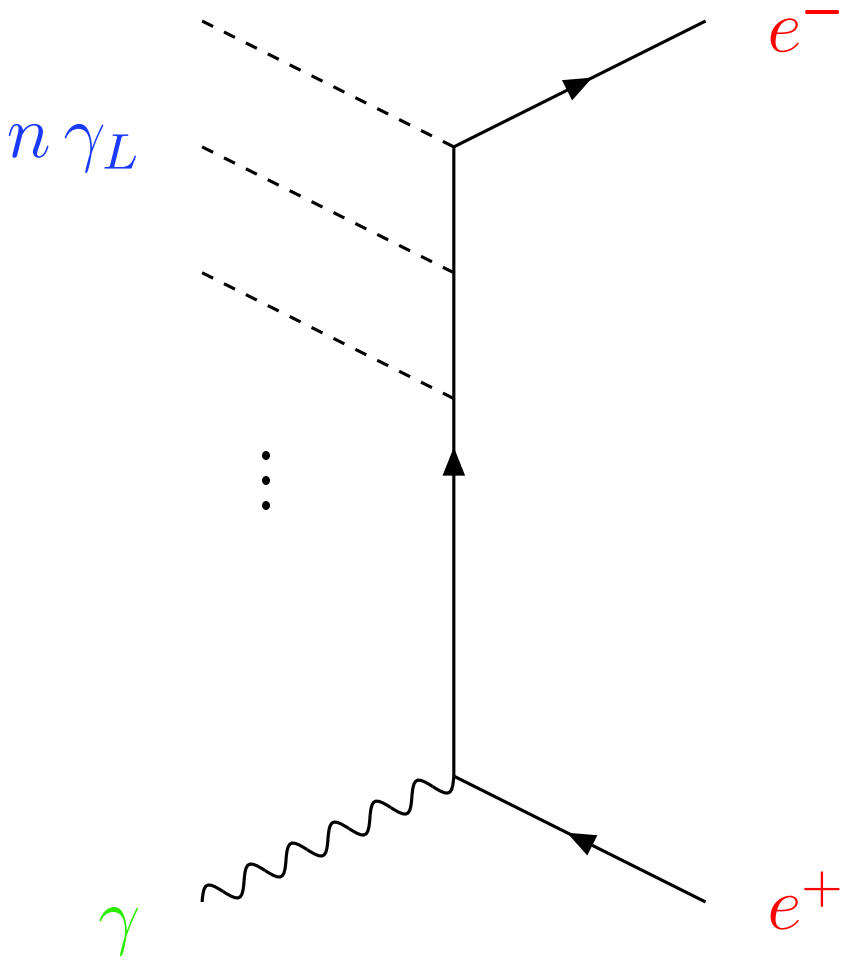


- **Non-linear QED**
  multi-photon param. $\eta = \frac{e\mathcal{E}_{\rm L}}{\omega_{\rm L} m_e}$
  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$
    Electron yield,
    $Y_e \propto \eta^{2(n-1)} \propto I^{n-1}$



[SLAC E144]

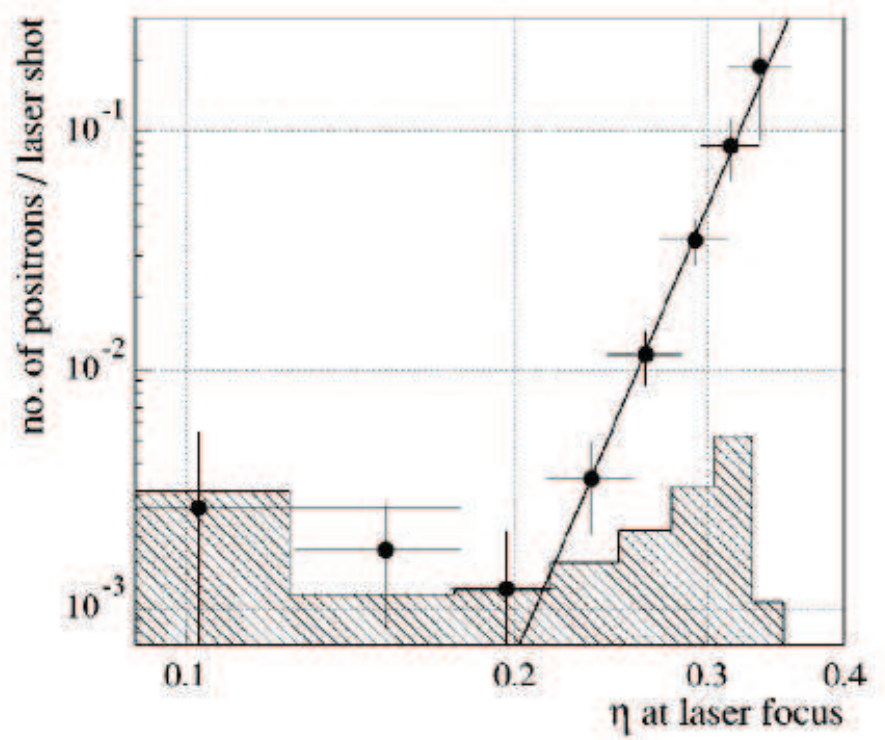
- **Non-linear QED**
  multi-photon param. $\eta = \frac{e\mathcal{E}_{\rm L}}{\omega_{\rm L} m_e}$
  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$
    Electron yield,
    $Y_e \propto \eta^{2(n-1)} \propto I^{n-1}$
  - **Pair production:**
    * Stimulated process ($\eta \ll 1$)
      $\gamma + n\,\gamma_{\rm L} \to e^+e^-$
      Positron rate,
      $R_{e^+} \propto \eta^{2n} \propto I^n$



- SLAC E144: $\eta \ll 1$, $\kappa \ll 1$

- **Non-linear QED**
  multi-photon param. $\eta = \frac{e\mathcal{E}_{\rm L}}{\omega_{\rm L} m_e}$

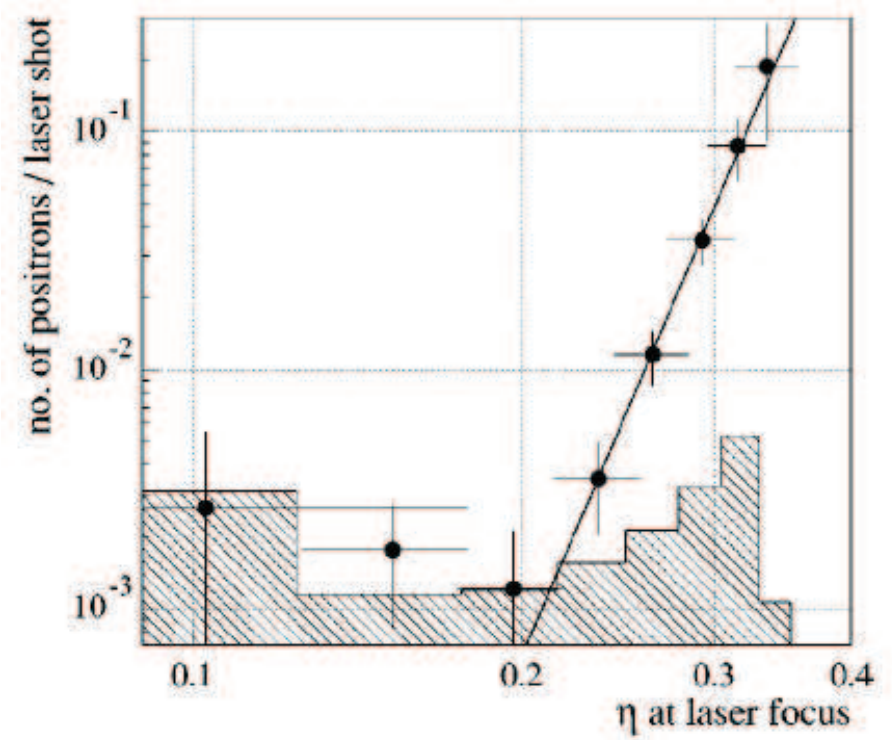
  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$
    Electron yield,
    $Y_e \propto \eta^{2(n-1)} \propto I^{n-1}$
  - **Pair production:**
    * Stimulated process ($\eta \ll 1$)
      $\gamma + n\,\gamma_{\rm L} \to e^+e^-$
      Positron rate,
      $R_{e^+} \propto \eta^{2n} \propto I^n$



[SLAC E144]

- SLAC E144: $\eta \ll 1$, $\kappa \ll 1$

- **Non-linear QED**
  multi-photon param. $\eta = \frac{e\mathcal{E}_{\rm L}}{\omega_{\rm L} m_e}$
  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$
    Electron yield,
    $Y_e \propto \eta^{2(n-1)} \propto I^{n-1}$
  - **Pair production:**
    * Stimulated process ($\eta \ll 1$)
      $\gamma + n\,\gamma_{\rm L} \to e^+e^-$
      Positron rate,
      $R_{e^+} \propto \eta^{2n} \propto I^n$
    * Spontaneous tunneling process ($\eta \gg 1$)
      $R_{e^+} \propto \exp(-8/3\kappa)$ where
      $\kappa = 2\frac{E_\gamma}{m_e}\frac{\mathcal{E}_{\rm L}}{\mathcal{E}_{\rm crit}}$



[SLAC E144]

- SLAC E144: $\eta \ll 1$, $\kappa \ll 1$

- **XFEL electron beam plus petawatt laser will allow to probe the non-perturbative tunneling regime,**

$$\eta \gg 1,$$

for the first time in the laboratory

– laser at SLAC E144:

$$I \approx 0.5 \times 10^{18}\ \mathrm{W/cm^2}\ \text{at}\ 1035(527)\ \mathrm{nm}$$

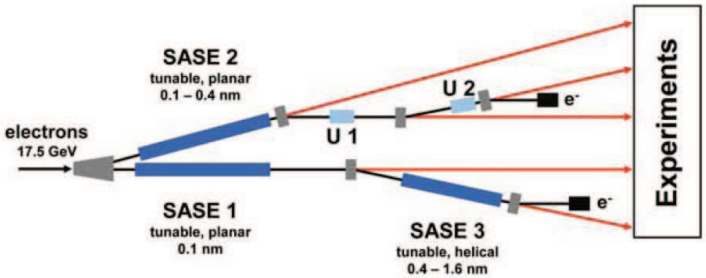
– laser such as **POLARIS** currently set up in Jena reach easily

$$I \sim 10^{21}\ \mathrm{W/cm^2}\ \text{at}\ 1035(527)\ \mathrm{nm}$$

and thus more than one order of magnitude larger values of $\eta \propto I^{1/2}$

- Development of ideas:
  - Gianni Carugno (Padova) asked me whether I see any chance to repeat and improve the SLAC E144 experiment at DESY (15.04.08)
  - Discussion of this idea over lunch in Trento (26.06.08). Partipants: Dunne, Kämpfer, AR, Sauerbrey
  - Meeting at DESY (20.11.08). Participants: Carugno, Ruoso (Padova); Lindner, Redondo, AR, ... (DESY)
  - Meeting in Jena (18.09.09). Participants: Gies, Paulus, Wipf (Jena); Lindner, Redondo, AR (DESY)

- **Window of opportunity:** Empty beamlines/tunnels at XFEL



Conclusions

- Strong physics motivation for installing a petawatt laser at XFEL
  - Non-linear QED in collision of e^- beam with intense laser beam
    - non-linear Compton scattering
    - e^+e^- pair production from perturbative multi-photon absorption regime to non-perturbative tunneling (Schwinger) regime
  - Plasma wakefield experiments
  - Beam laser-beam interactions to modulate longitudinal bunch

- **Need access to the electron beam before it is dumped!!!!**