# Tests of non-linear QED in the collision of electron beams with laser beams

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in collaboration with

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**2. Beschleuniger-Ideenmarkt**

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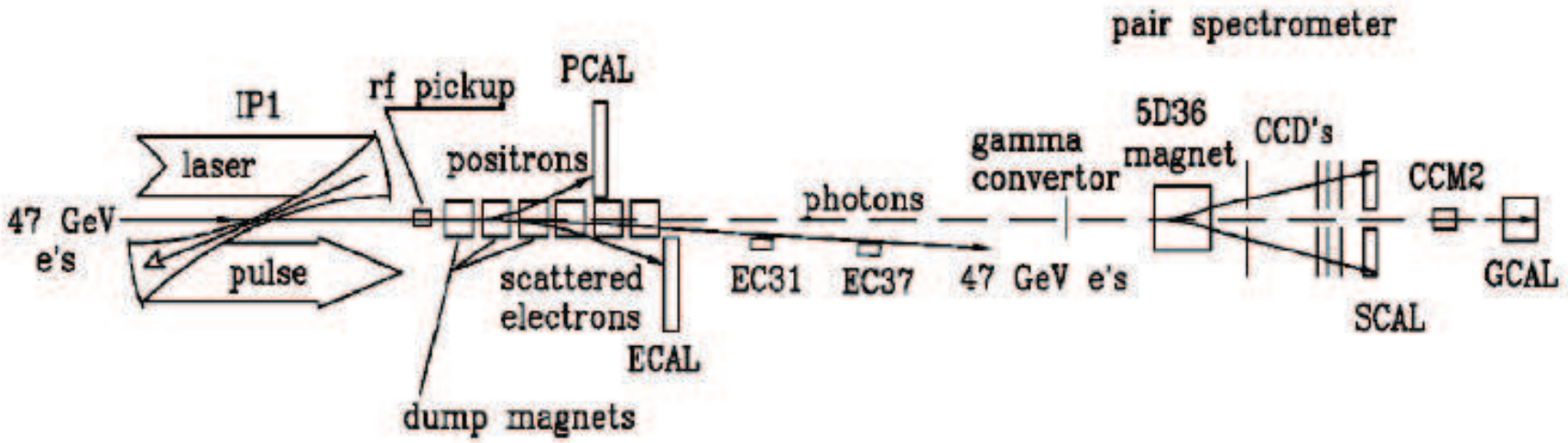
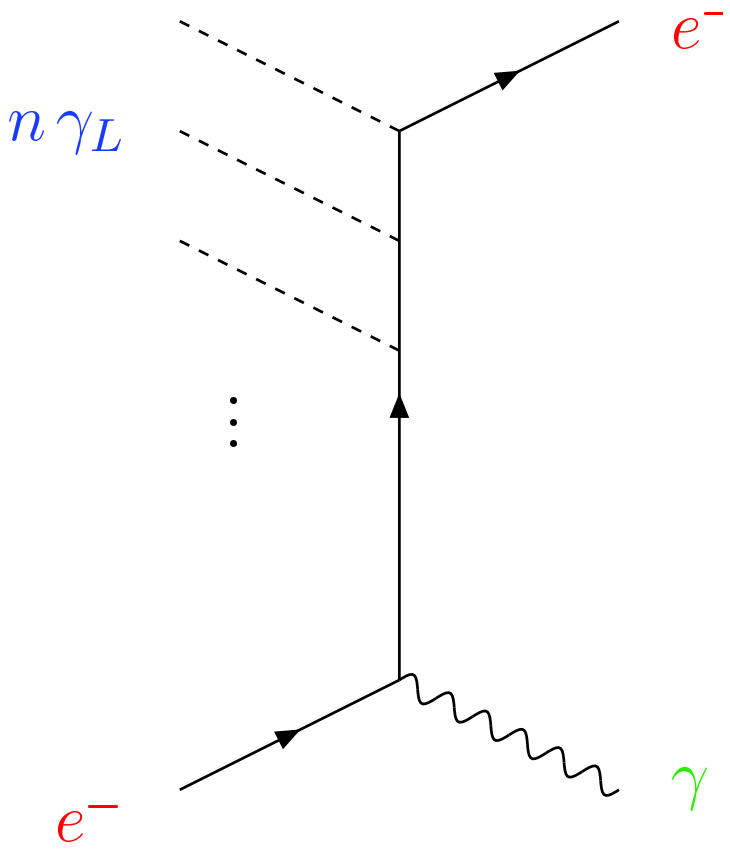
- SLAC E144 studied non-linear QED in the collision of a 46.6 GeV electron beam (the Final Focus Test Beam) with photon pulses from a terawatt class Nd:glass laser

[Bula et al., PRL 76 (1996) 3116; Burke et al., PRL 79 (1997) 1626; Bamber et al., PRD 60 (1999) 092004]



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

  - **Non-linear Compton**
    $e + n\,\gamma_{\rm L} \to e + \gamma$



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  Electron yield,
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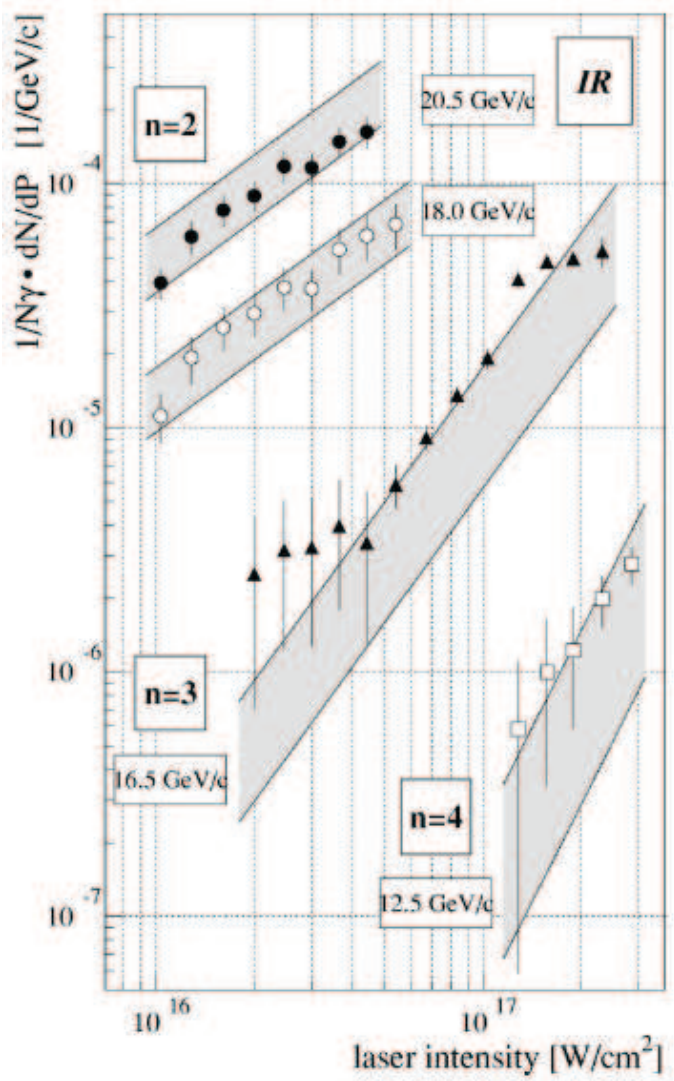


[SLAC E144]

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  - **Pair production:**
    * Stimulated process ($\eta \ll 1$)
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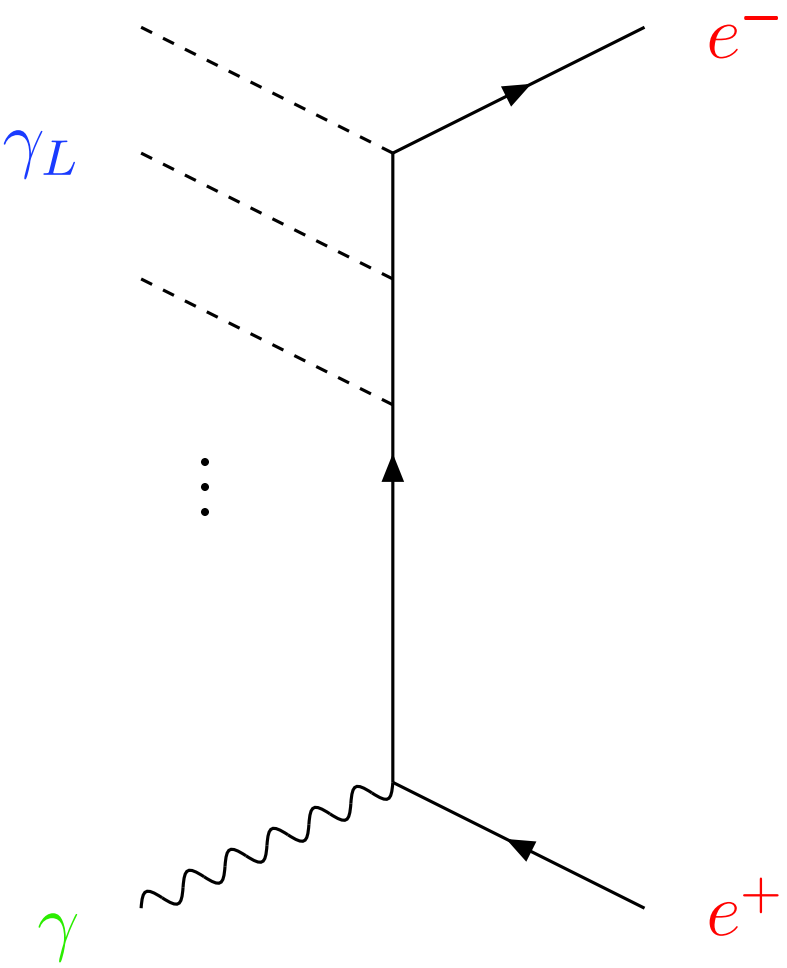
      Positron rate,
      $R_{e^+} \propto \eta^{2n} \propto I^n$



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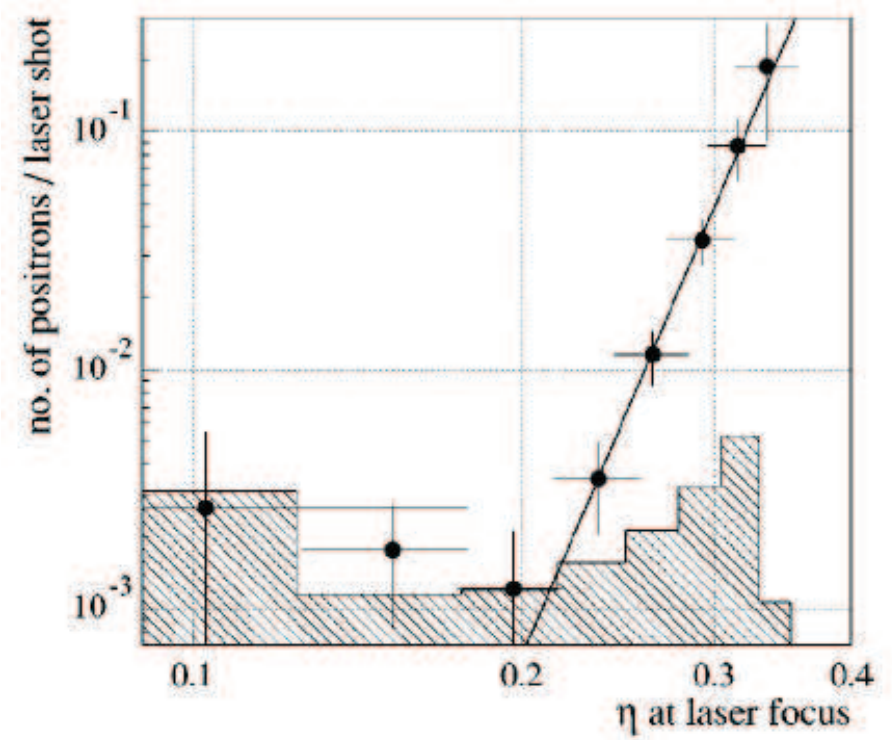


[SLAC E144]

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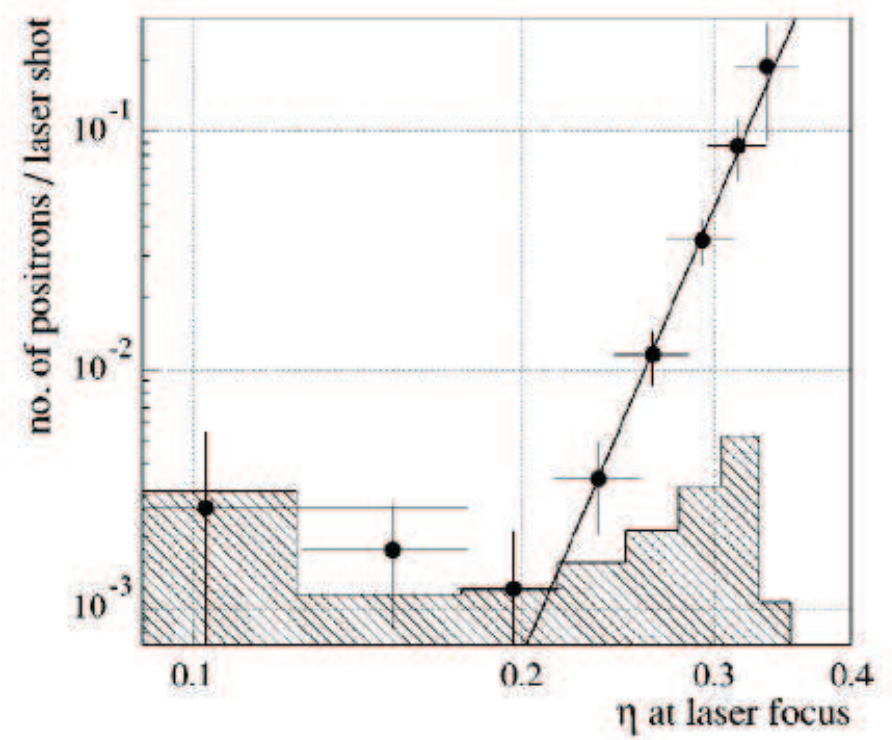
      $\gamma + n\,\gamma_{\rm L} \to e^+e^-$
      Positron rate,
      $R_{e^+} \propto \eta^{2n} \propto I^n$
    * Spontaneous tunneling process ($\eta \gg 1$)
      $R_{e^+} \propto \exp(-8/3\kappa)$ where
      $\kappa = 2\frac{E_\gamma}{m_e}\frac{\mathcal{E}_{\rm L}}{\mathcal{E}_{\rm crit}}$

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




[SLAC E144]

Improvements over SLAC 144: Petawatt class laser to probe $\eta \gg 1$, $\kappa \lesssim 1$:

$$\eta = 7.6 \left[\frac{I}{10^{21}\ \mathrm{W/cm^2}}\right]^{1/2} \left[\frac{\lambda_\mathrm{L}}{0.4\ \mu\mathrm{m}}\right]$$

| LASER | SLAC 144 | Required e.g. |
|---|---|---|
| Energy per pulse | 0.32 J (Green) | 1 J |
| Wavelength | 527-1064 nm | 800 nm |
| Pulse Duration | 1.5 ps FWHM | few $\times$ ps FWHM |
| Focus radius | $\sim \mu$m | few $\times$ $\mu$m |
| Intensity on target | $10^{18}$ W/cm$^2$ | $10^{21}$ W/cm$^2$ |
| $\eta$ (maximum) | 0.32 | 15.38 |

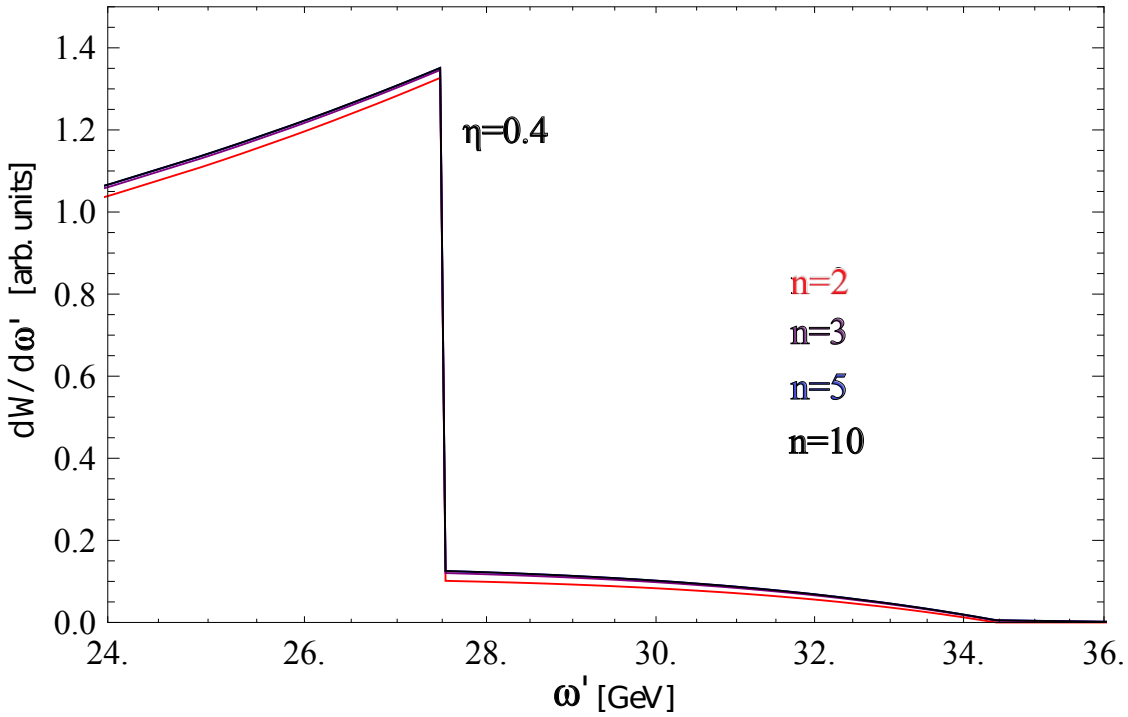
Improvements over SLAC 144: Petawatt class laser to probe $\eta \gg 1$, $\kappa \lesssim 1$:

$$\kappa = 0.94 \left[\frac{I}{10^{21}\mathrm{W/cm}^2}\right]^{1/2} \left[\frac{\omega'}{5\ \mathrm{GeV}}\right]$$

| Experiment | $\omega'$ [GeV] | $I$ [W/cm$^2$] | $\kappa$ |
|---|---|---|---|
| SLAC | 29 | $10^{18}$ | 0.17 |
| FLASH | 0.2 | $10^{21}$ | 0.03 |
| XFEL | 5 | $10^{21}$ | 0.94 |

- Rate for non-linear Compton as function of energy of hard photon $\omega'$

SLAC:




[Arias,Redondo,AR]

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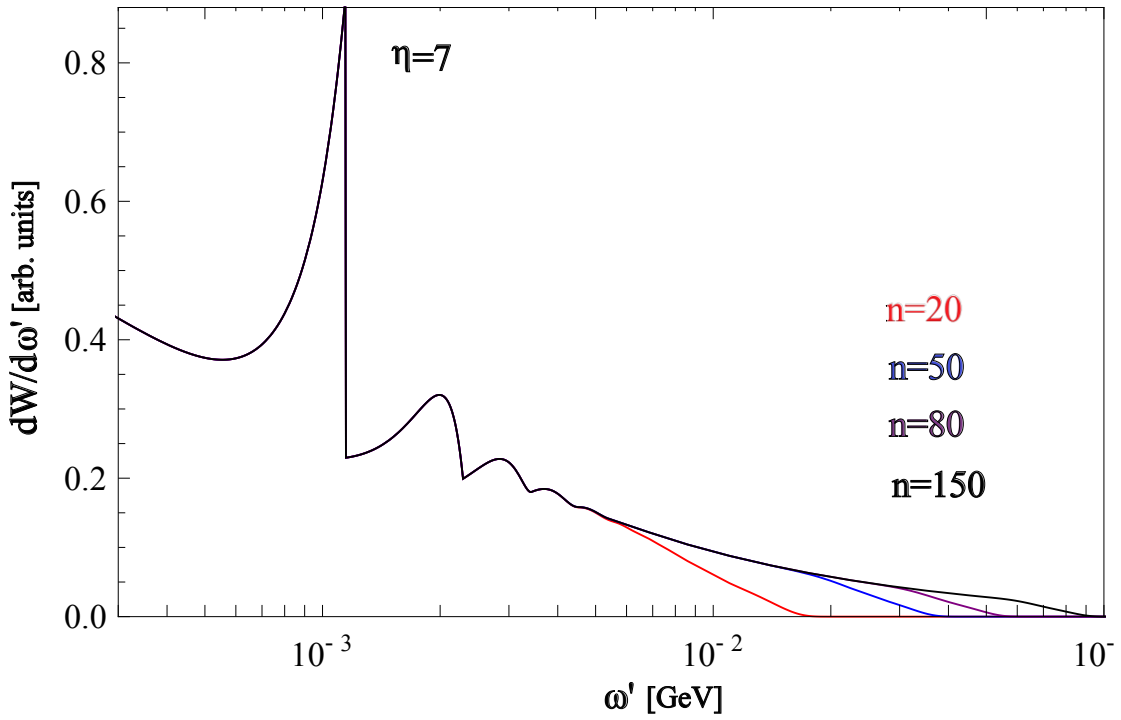


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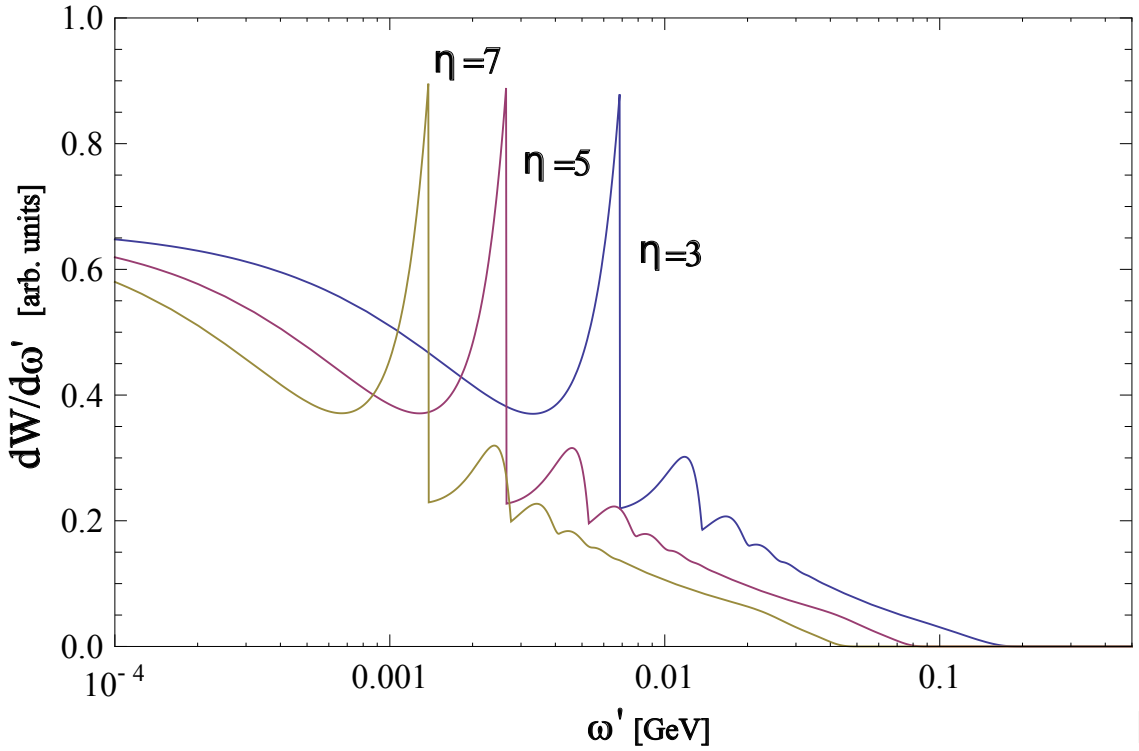


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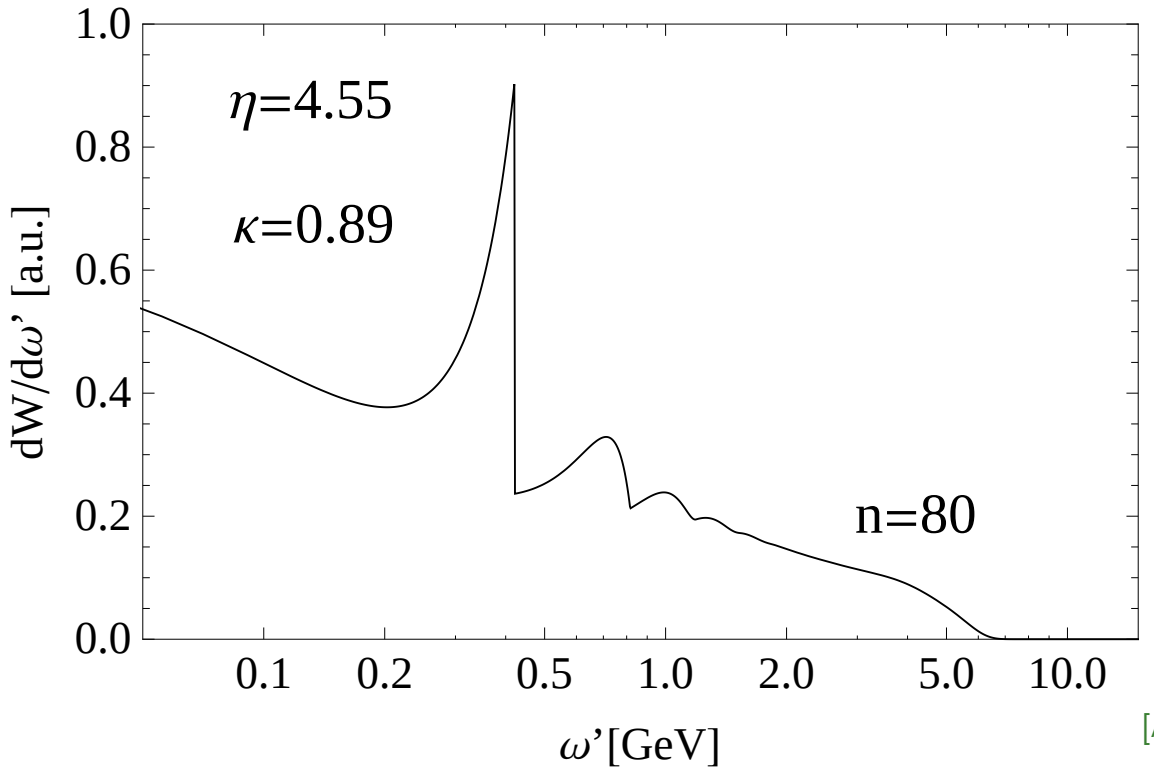
XFEL:




[Arias,Redondo,AR]

# Conclusions

- Colliding the FLASH and later XFEL electron beams with intense photon beams from a laser would allow unique studies of non-linear QED:
  - nonlinear Compton scattering (FLASH)
  - non-perturbative spontaneous pair production (XFEL)

- Requirements very similar to the ones of the project "10 GeV Laser-Plasma-Booster Stufe für FLASH":
  - an extra beam-line at FLASH II (and later at XFEL) which can deliver dedicated single bunches at few Hz repetition rate
  - installation of a petawatt laser system