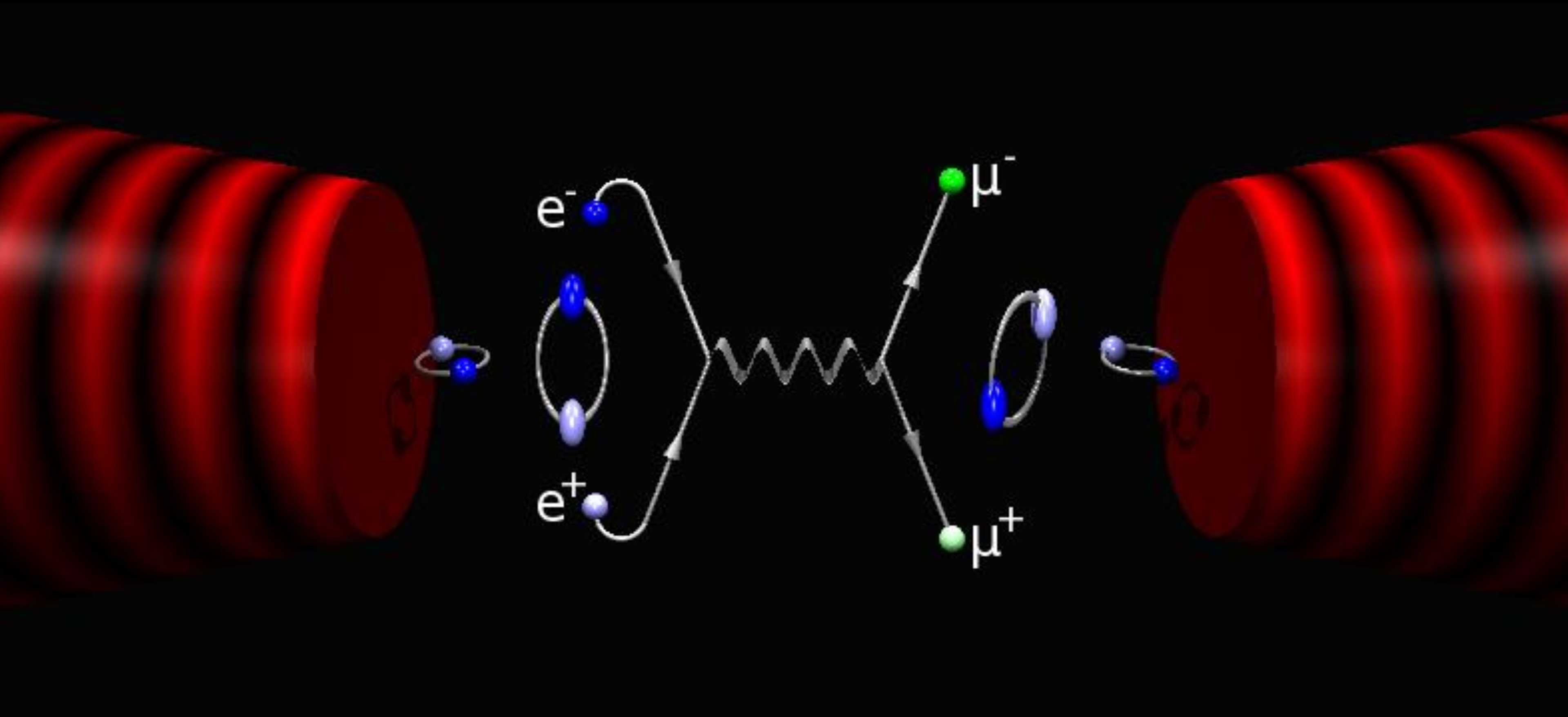
Extremely High-Intensity Laser Interactions With Fundamental Quantum Systems



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Key cooperators for present talk: A. Di Piazza, and K. Z. Hatsagortsyan

Outline

Introduction into Strong-Field QED & Facilities

Laser-Vacuum Interaction:

Laser-enhanced Vacuum Fluctuations and Refractivity

Laser-Particle Interaction:

Relat. Quantum Dynamics, Spin & Radiative Reaction

Pair creation & Recolliders & Cascade Control

Ion Acceleration and Nuclear Quantum Dynamics

Applications:

Extreme laser pulse characterization, GeV particle acceleration & proton therapy, laser colliders, laboratory astrophysics, testing fundamental theories

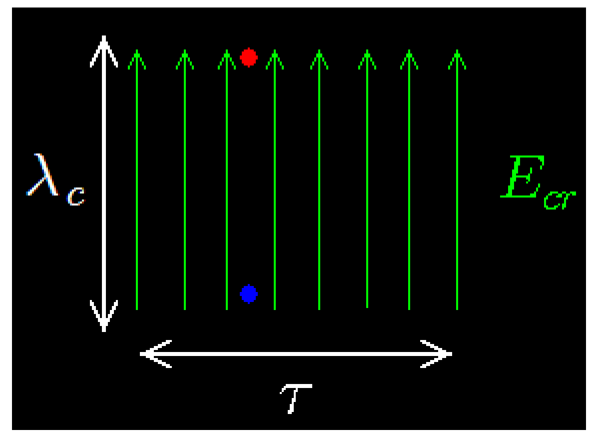
Quantum Vacuum & Critical fields

- Virtual particles are present
- They live for a very short time and cover a very short distance ($\tau = \hbar/mc^2$ and $\lambda_c = \hbar/mc$, respectively). For electrons and positrons: $\lambda_c \approx 10^{-11}$ cm and $\tau \approx 10^{-21}$s.

critical fields: physical meaning

$$\frac{\hbar}{mc} \times eE_{cr} \sim mc^2$$

$$\frac{e\hbar}{mc} \times B_{cr} \sim mc^2$$



Available in highly charged ions but not feasable in near future with laser

$$I_{cr} = \frac{cE_{cr}^2}{8\pi} = 2.3 \times 10^{29} W/mc^2$$

Effects for much smaller fields ?

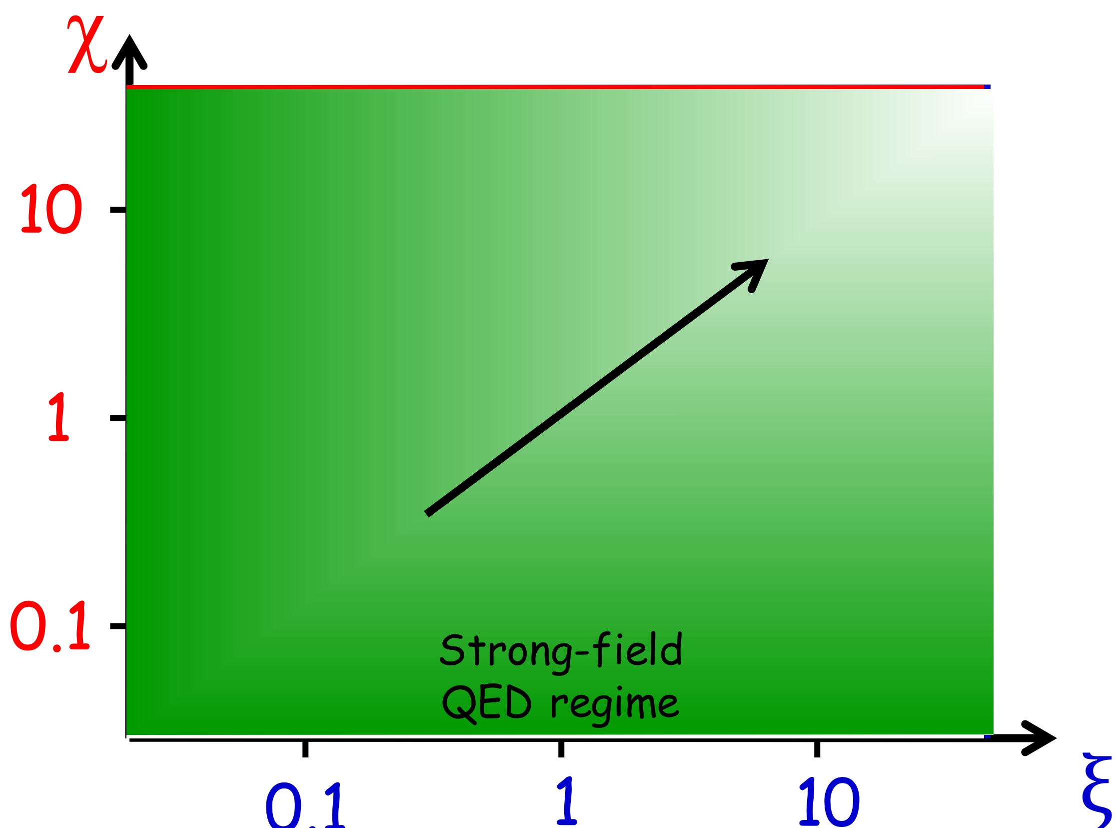
Regimes of QED in a strong laser field

A particle (e^-, e^+ or γ) with energy $\mathcal{E}$ ($\hbar\omega$ for a photon) collides head on with a plane wave with amplitude E_L and angular frequency ω_L (wavelength λ_L)

Relevant parameters
(Di Piazza et al.,
RMP 84, 1177 (2012)):

$$\xi = \frac{1}{2\pi}\frac{|e|E_L\lambda_L}{mc^2} = \frac{|e|E_L\lambda_C}{\hbar\omega_L}$$

$$\chi = 2\frac{\hbar\omega}{mc^2}\frac{E_L}{E_{cr}} = \frac{E_L}{E_{cr}}\Bigg|_{\mathrm{r.\,f.}}$$



Courtesy Di Piazza

Optical laser and electron accelerator technology

Optical laser technology ($\hbar\omega_L = 1$ eV)	Energy (J)	Pulse duration (fs)	Spot radius (μm)	Intensity (W/cm^2)
State-of-art (Yanovsky et al., Opt. Express (2008))	10	30	1	2x10^{22}
Recent/soon (APOLLON, Vulcan, Astra-Gemini, BELLA, CoReLS etc…)	10-100	10-100	1	10^{22}-10^{23}
Near future (2020) (ELI, XCELS)	10^4	10	1	10^{25}-10^{26}

Electron accelerator technology	Energy (GeV)	Beam duration (fs)	Spot radius (μm)	Number of electrons
Conventional accelerators (PDG)	10-50	10^3-10^4	10-100	10^{10}-10^{11}
Laser-plasma accelerators (e.g. Leemans et al., PRL 2013)	0.1-5	50	5	10^9-10^{10}

$$\xi = 7.5 \frac{\sqrt{I_L[10^{20}\mathrm{W/cm^2}]}}{\hbar\omega_L[\mathrm{eV}]}$$

$$\chi = 5.9 \times 10^{-2}\, \mathcal{E}\,[\mathrm{GeV}]\, \sqrt{I_L[10^{20}\,\mathrm{W/cm^2}]}$$

Present technology allows in principle the experimental investigation of strong-field QED and laser particle physics

Courtesy Antonino Di Piazza

Near Future: Extreme power at ELI

***High-Energy Beam Facility**, responsible for development and application of ultra-short pulses of high-energy particles and radiation (ELI-Beamlines, Prague, CZ)*

Nuclear Physics Facility with ultra-intense laser and brilliant gamma beams (up to 19 MeV) enabling novel photonuclear studies (*ELI-NP*, Magurele, RO)

ELI is likely to have this or next year

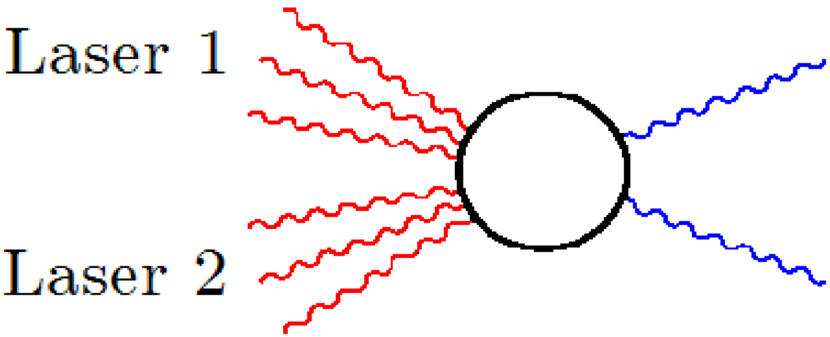
- Two coupled 10PW lasers (ELI-NP)
- One 1-2PW laser @ 10-20Hz (ELI-Beamlines)
- One 1PW laser (OPCPA, <20fs) @ 10Hz (ELI-Beamlines)
- One 10PW laser (1.5kJ, 150fs) (ELI Beamlines)
- One multi-PW laser @ <10Hz (ELI-ALPS)

Each of these exceeds today's state-of-the-art by a factor of ~10

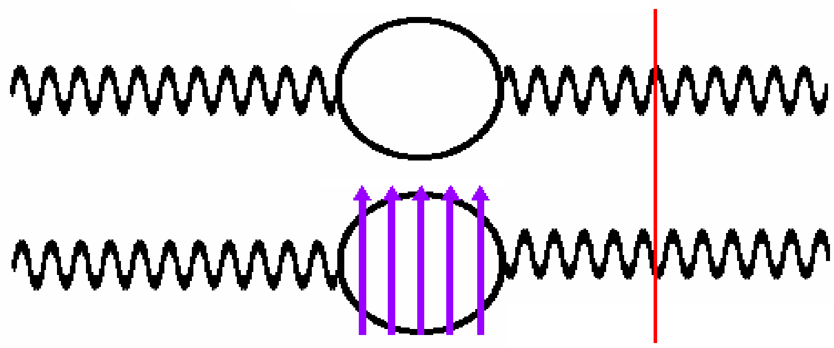
Further XFEL Facilities as DESY and combined sites as HiBef

Effects in plain vacuum to think of e.g. …..

- *Harmonic generation* in vacuum in the collision of two strong laser beams

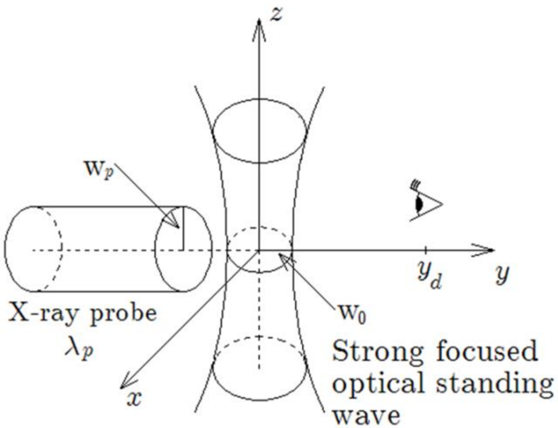


- Vacuum refractive indices with phase shifts in the presence of a strong standing wave



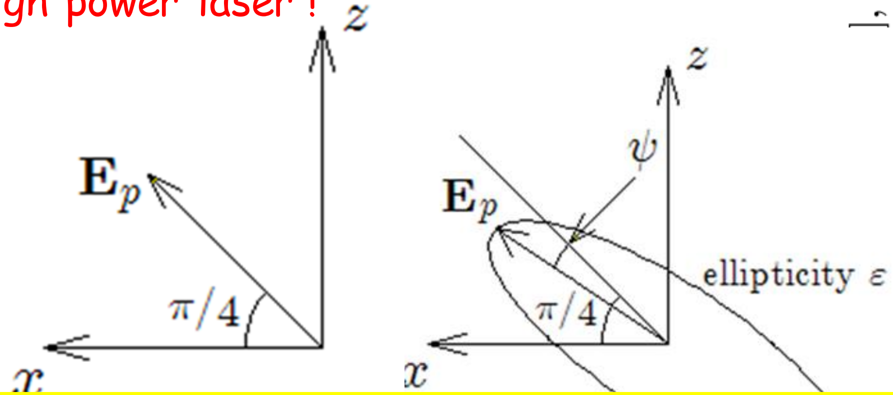
Early investigations of vacuum fluctuations for realistic laser intensities

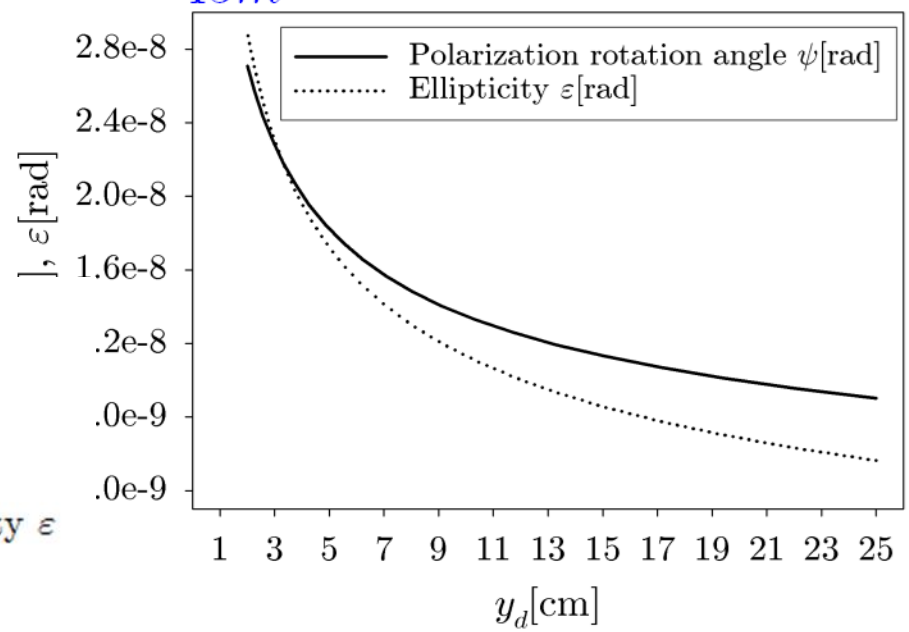
In the presence of strong fields the Maxwell Lagrangian density has to be modified to take into account vacuum fluctuations



$$\mathscr{L} = \frac{1}{2}(E^2 - B^2) + \frac{2\alpha^2}{45m^4}\left[(E^2 - B^2)^2 + 7(\mathbf{E}\cdot\mathbf{B})^2\right]$$

combination XFEL & high power laser !



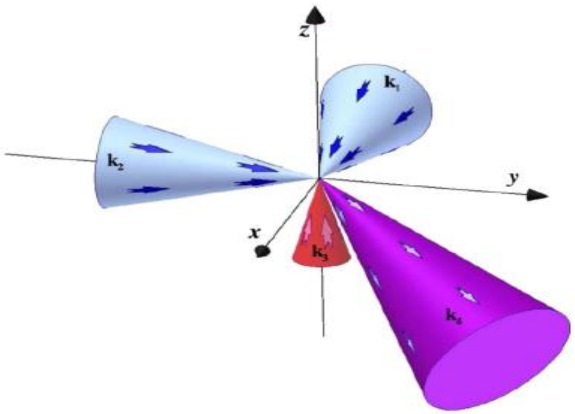


Probe field polarization and elipticity before and after interaction with intense field

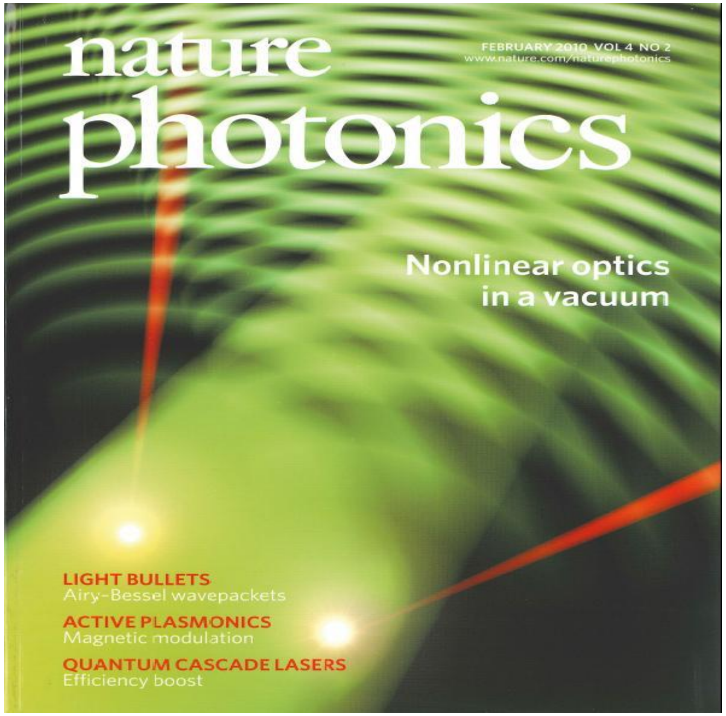
A. Di Piazza et al., PRL 97, 083603 (2006) & see also T. Heinzl et al. Opt. Comm. 267, 318 (2006)

Photon-Photon Scattering

- Electron-positron fluctuations can mediate a pure quantum interaction among laser beams in the vacuum in numerous ways
- Multi PW-class laser systems may open the possibility of observing for the first time direct photon-photon scattering in vacuum (Lundstroem et al. Phys. Rev. Lett. 2006), see also B. King et al. 2018



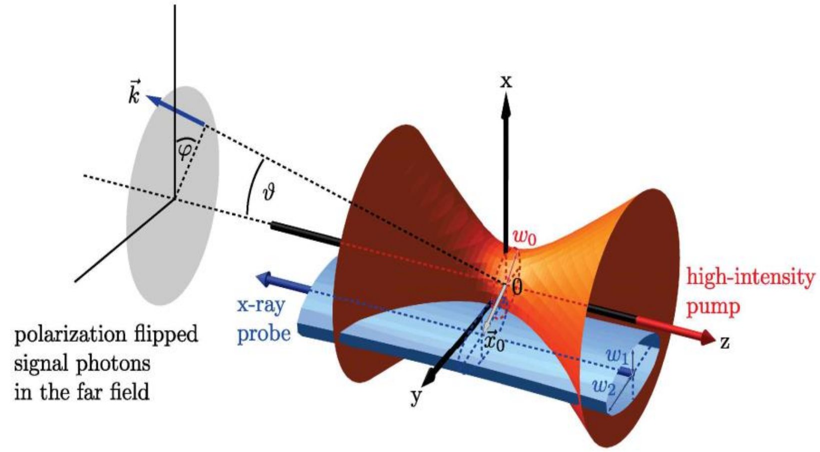
- A matterless double slit setup has been put forward (Ben King et al., Nature Photon. 2010)



Recent most promising proposals

- Two orders more sensitivity for high energy circular polarized photons: S. Bragin et al., PRL (2017): Now doable with ELI Prag or Bukarest

- Employing HiBef scenario: Single-laser setup in the counter propagating configuration can be a promising alternative (Karbstein and Gies, arXiv:1807.03302)



- The number $N_\perp$ of x-ray probe photons undergoing a polarization flip in the interaction of an x-ray beam with N photons, waists w_1 and w_2, interacting with a strong optical beam with waist w_0 (Karbstein, arXiv:1807.03302) … up to factor 3–10 anticipated detectable

w_1/w_0	w_2/w_0	$N_\perp/N$	$N_\perp^{\mathrm{full}}/N$
$1/10$	$1/10$	$2.9 \cdot 10^{-11}$	$3.0 \cdot 10^{-11}$
$1/3$	$1/3$	$2.6 \cdot 10^{-11}$	$2.6 \cdot 10^{-11}$
1	1	$1.2 \cdot 10^{-11}$	$1.1 \cdot 10^{-11}$
3	3	$2.0 \cdot 10^{-12}$	$1.8 \cdot 10^{-12}$
3	$1/10$	$7.8 \cdot 10^{-12}$	$7.4 \cdot 10^{-12}$
3	$1/3$	$7.2 \cdot 10^{-12}$	$6.8 \cdot 10^{-12}$
3	1	$4.9 \cdot 10^{-12}$	$4.4 \cdot 10^{-12}$

Single-particle quantum and many-particle semiclassical dynamics: some basic methods

Single free, bound or vacuum electrons via Dirac Equation

$$i\hbar\partial_t\Psi = \left\{c\boldsymbol{\alpha}\cdot\left[\mathbf{p}+\frac{e}{c}\mathbf{A}\right]+\beta mc^2+V\right\}\Psi$$

Many-Particle Systems/ Plasmas: Semiclassical Methods with classical trajectors but Spin, Radiative Reaction, Gamma Radiation, Pair Production via quantum rates or semiclassical approximations

$$\frac{d}{dt}\vec{p} = m\frac{d}{dt}\frac{\dot{\vec{r}}}{\sqrt{1-(\dot{\vec{r}}/c)^2}} = \vec{F}_{Laser} + \vec{F}_{Coulomb}$$ + Spinforce + Radiative Forces...

Testing Semiclassical Models for Quantum Processes essential

Nonresonant Laser-Particle/Ion Interaction: Dirac Eq. for laser driven atomic systems

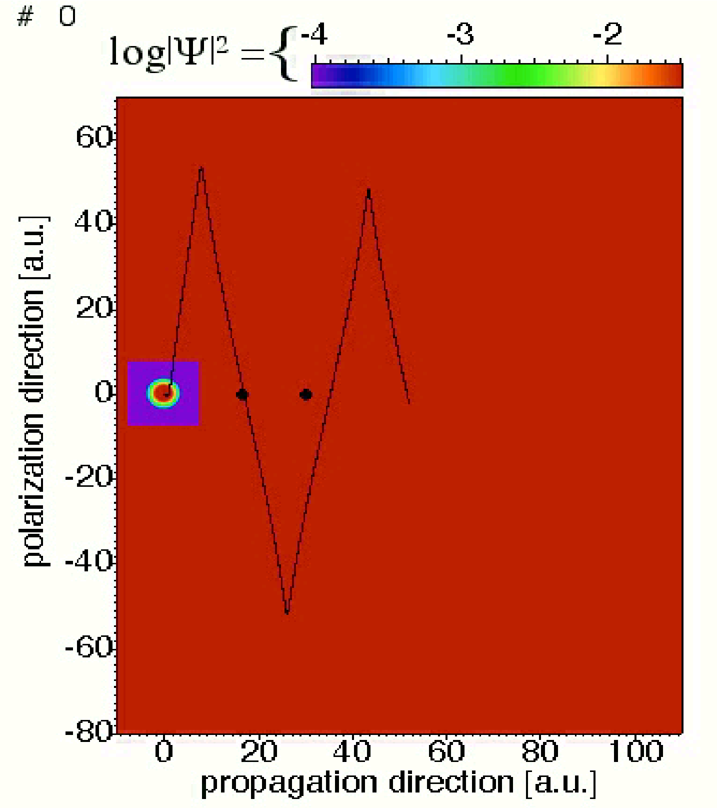
- Problems:

G R Mocken et al., Comp. Phys. Comm. 178, 868 (2008)

- Dirac very similar to Schrödinger, but

$$\Delta t_{\text{Dirac}} \approx 10^{-5}\text{a.u.} \ll \Delta t_{\text{Schrödinger}} \approx 10^{-3}\text{a.u.}$$

- Solutions:
- "Moving position space grid" to keep the grid size small
- "Moving momentum space grid" to keep the position space grid resolution small
- "Variably-sized position space grid" to dynamically adapt the grid size to requirements

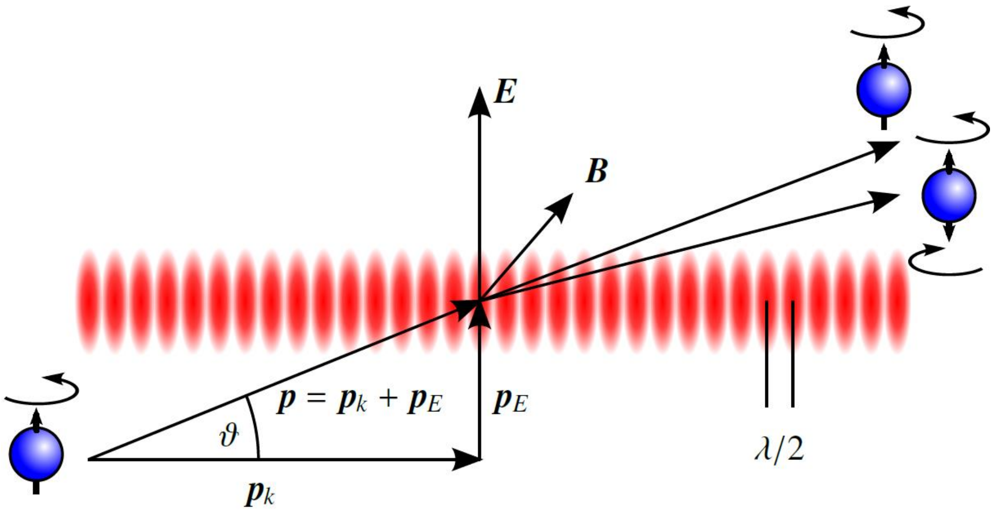


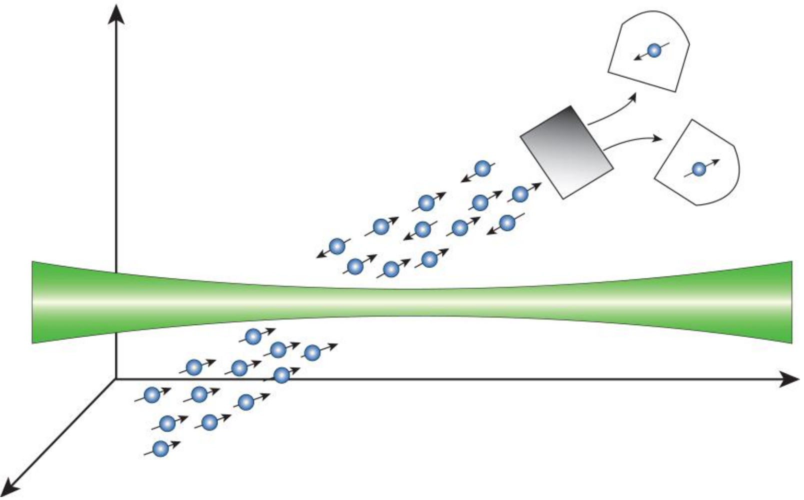
- Drift in laser-propagation direction via magnetic field component
  - problem for recollisions
- Enhanced quantum spreading with increased laser intensity & quantum interference at scattering processes

- Quantum features in various situations of relevance

Intrinsic quantum effects:
Spin dynamics & QED for electron-laser scattering

Scattering of electron at crossed laser fields with spin flip (Kapitza-Dirac effect) via propagation of Dirac equation involving laser fields





A full QED approach reveals quantum nature of the laser field: collapse and revivals for spin oscillations as magnetic coupling weak even for rather intense laser pulses of about 10^{18} W/cm^2

S. Ahrens et al, PRL 109, 043601 (2012) & O. Skoromnik et al, PRA 2013

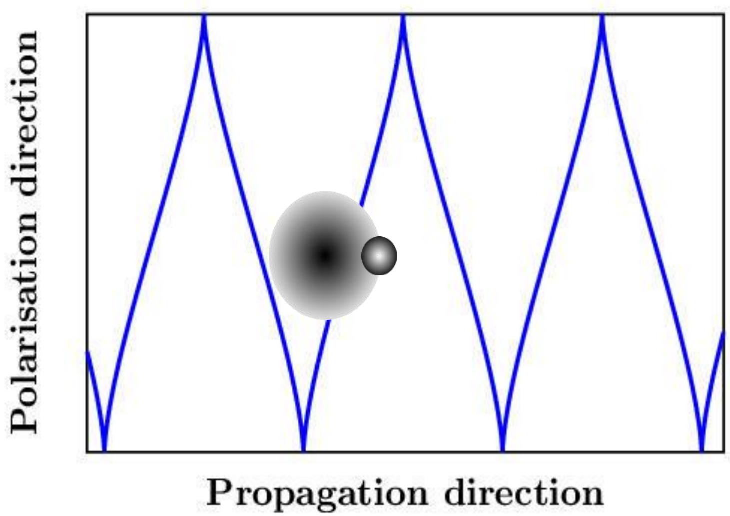
Radiative reaction

$$m_0 \frac{du^\mu}{ds} = -eF_T^{\mu\nu} u_\nu$$

$$\partial_\mu F_T^{\mu\nu} = -e \int ds\delta(x - x(s))u^\nu \longrightarrow F_T^{\mu\nu}(x) = F^{\mu\nu}(x) + F_S^{\mu\nu}(x)$$

Feed-back of modified fields yields Lorentz-Abraham-Dirac equation.

- In the realm of classical electrodynamics, i.e. if quantum effects are negligible, the Lorentz-Abraham-Dirac equation can be approximated by the so-called Landau-Lifshitz equation (Landau and Lifshitz, 1947)

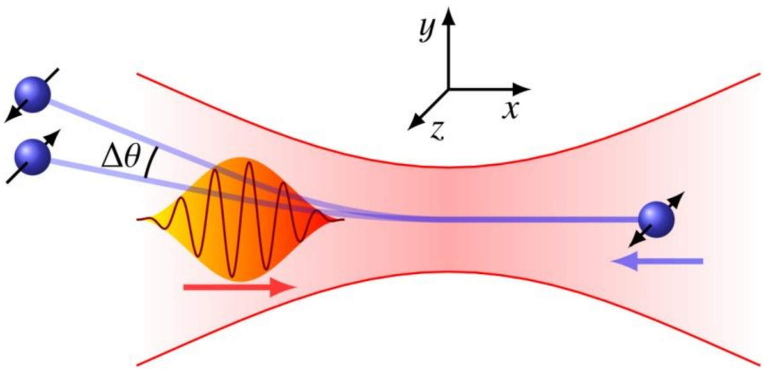


- Damping & reabsorption alters dynamics
- Classical and quantum regimes detectable with extreme lasers
- yields narrowing of energy distribution for plasmas

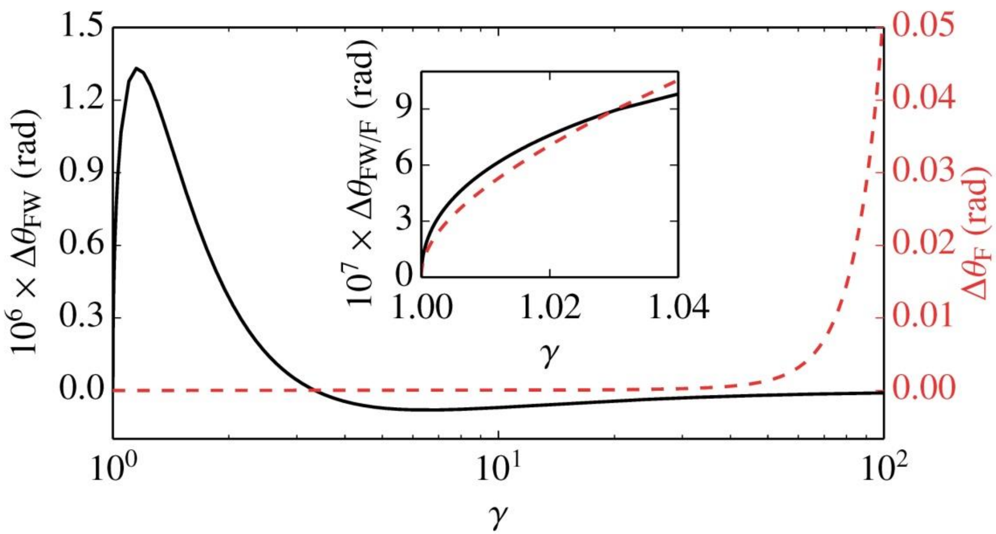
first with lasers: JPB 31, L75 (1998) &

A. Di Piazza et al. PRLs 2009 and 2010

Testing Classical Radiative Reaction and Spin Models via Extreme Lasers



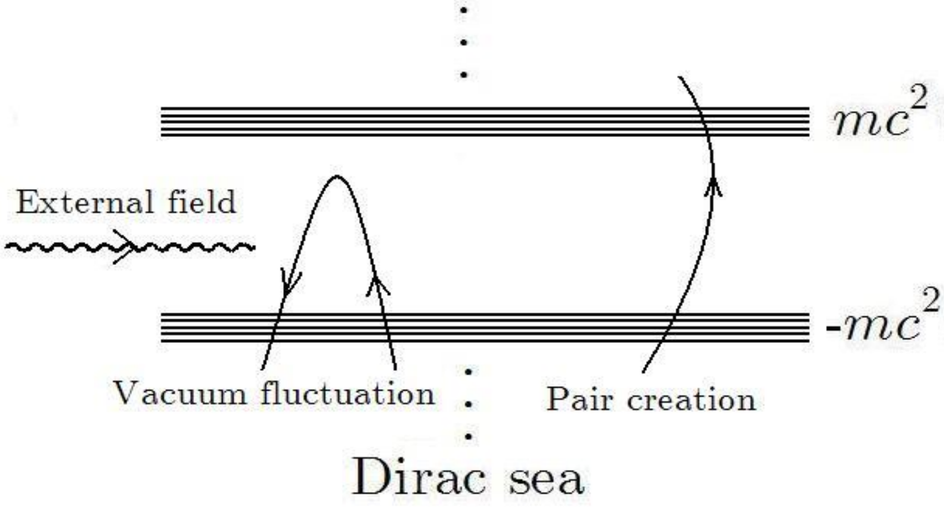
Aberration angle $\Delta\theta$ between spin-up and spin-down electrons as function of initial energy γmc^2 for classical Foldy-Wouthuysen (solid black line, left scale) &Frenkel (dashed light red line, right scale)



counterpropagating laser pulse with initial γ with $E = 4\pi mc^2(\gamma^2 - 1)^{1/2} / (e\lambda)$ (corresponding intensity 8.55 $(\gamma^2 - 1)$ 10^{18} W/cm^2) causing strong acceleration of the electron opposite to its initial velocity. Other laser parameters are λ = 800 nm, n=20 cycles & focus radius $w_0=2\lambda$.

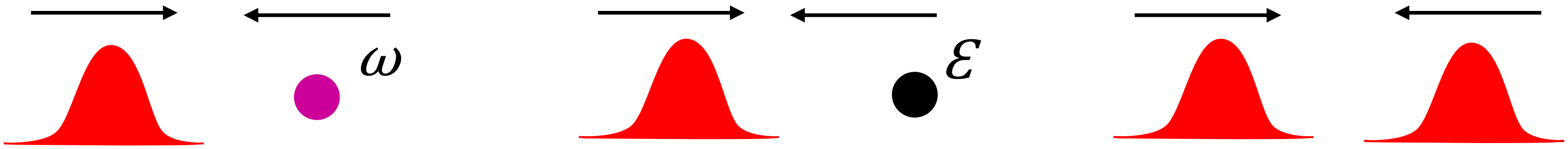
Meng Wen et al, Scientific Reports (2016)

From virtual to real electron-positron pair production



Electron-positron pair production: Mechanisms

Three main classes of pair-production processes have been investigated, including laser fields

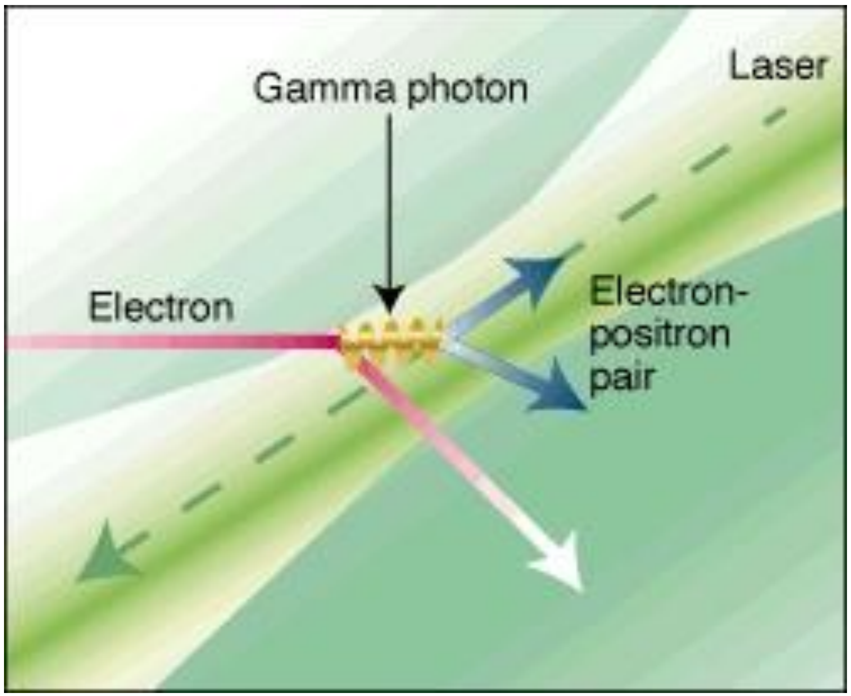


e.g. Schützhold et al PRL 2009 - Hu et al PRL 2010 - Ruf et al PRL 2009 perturbative multiphoton regime at $\xi \gg 1$ and non-perturbative tunneling regime at $\xi \gg 1$– see also Di Piazza et al, RMP 2012

Pair production in strong laser pulses using accelerators

Historical Remark: SLAC Experiment

The first laboratory evidence of multiphoton pair production.



D. Burke et al., Phys. Rev. Lett. 79, 1626 (1997)

- $3.6\times 10^{18} W/cm^2$ optical laser (2.35 eV)
- Electron accelerated to 46.6 GeV
- Energy threshold reached (in center of inertial frame)

Theory: combined treatment of two processes

direct: $e + N\omega \rightarrow e' + e^+e^-$

Bethe-Heitler type

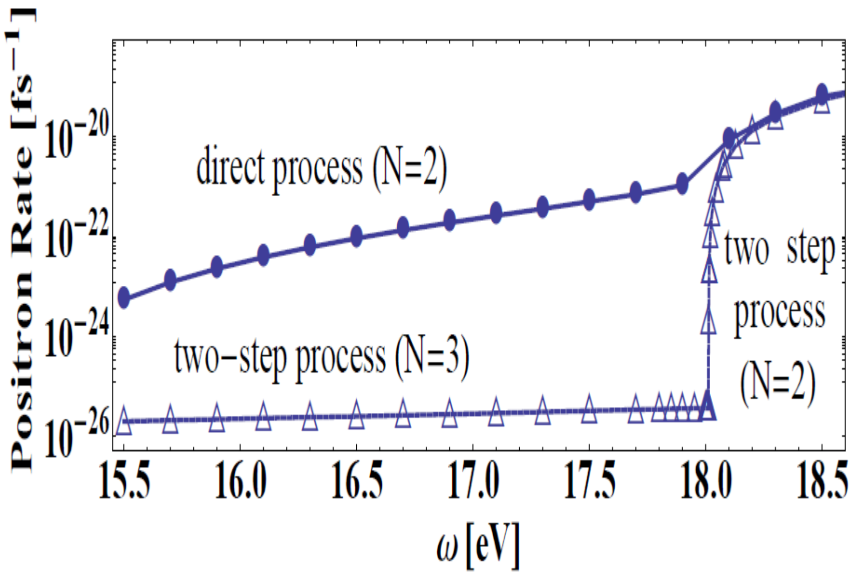
two-step: $e + \omega \rightarrow e' + \gamma$

Compton back scattering &

Multiphoton Breit-Wheeler

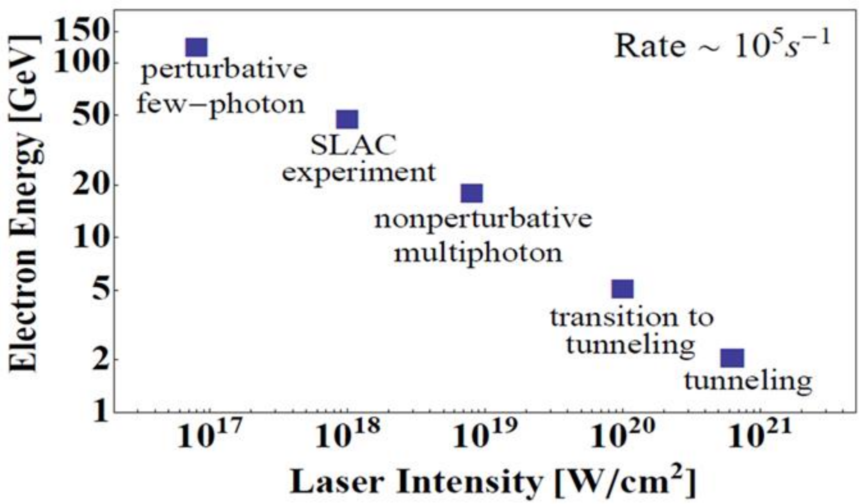
$\gamma + N\omega \rightarrow e^+e^-$

Separate Direct and Two-Step Processes



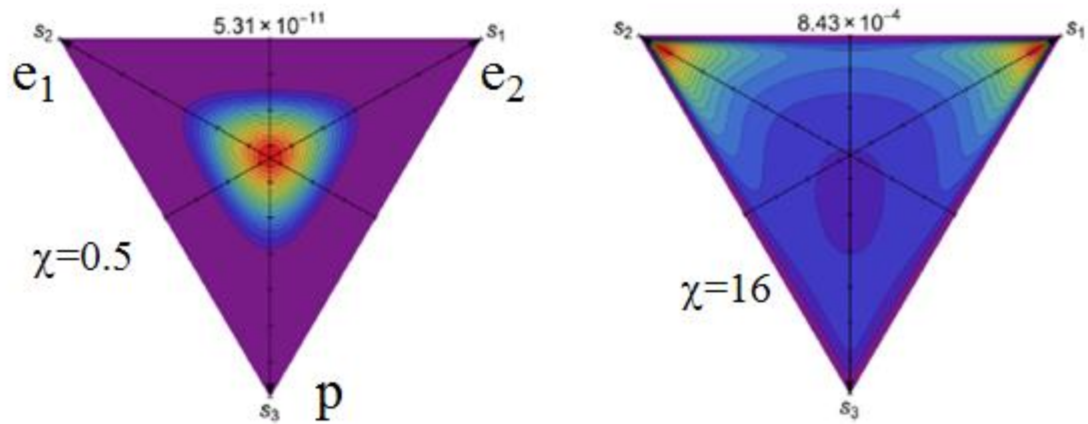
Direct process and two-step process can be separated by kinematic requirements at VUV intensities $10^{13}\,W/cm^2$ with a 17.5 GeV electron from DESY beamline

- Substantial pair production rate in various interaction regimes
- Novel usage of DESY beamline (17.5 GeV) for pair production
- The future of pair production: all-optical setup



Huayu Hu et al., Phys. Rev. Lett. 105, 080401 (2010)

- Technical insight on how to split the trident process into a cascade (two-step) contribution and a direct (one-step) contribution was provided in Ilderton, Phys. Rev. Lett. 2011
- Compact analytical expressions of total trident pair-production and efficient numerical tools via Dinu & Torgrimsson PRD 2018

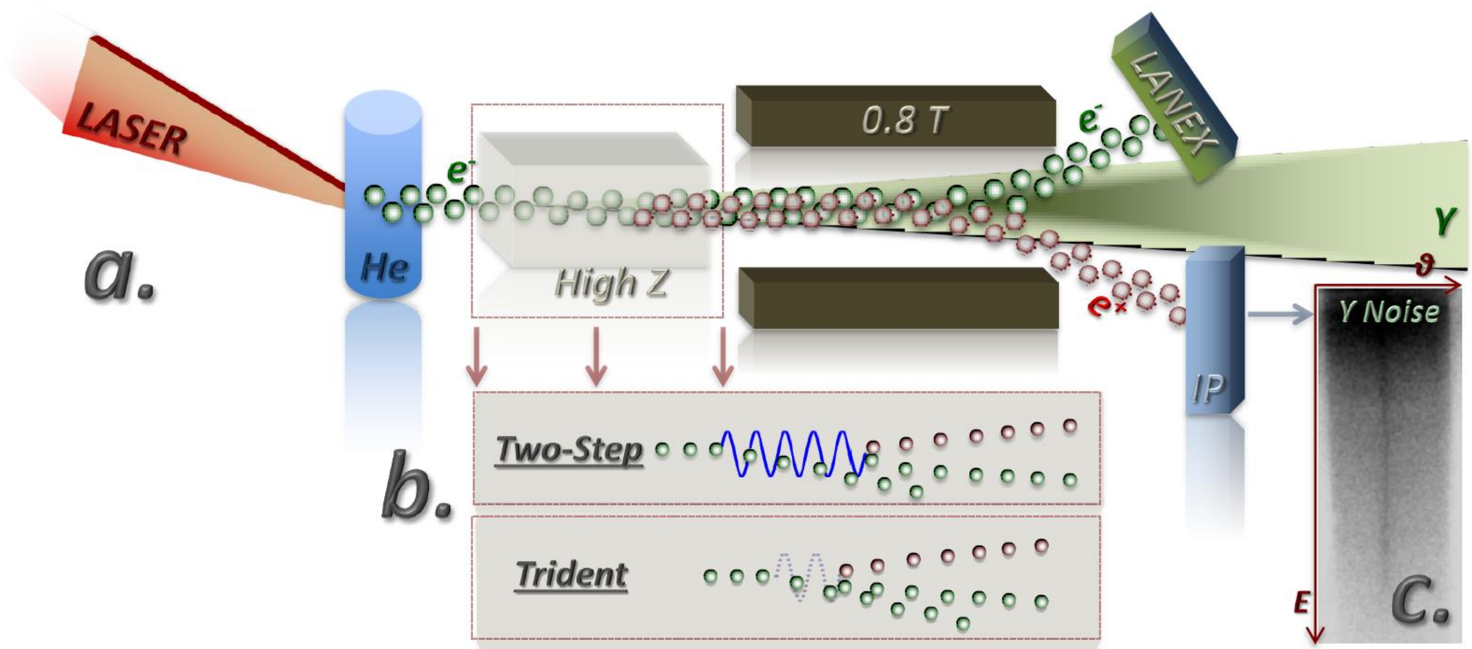


- The way how the energy is distributed among the two final electrons (e_1 and e_2 in the figure) and the positron (p in the figure) depends on χ (the plot shows the results for the cascade channel in the local constant field approximation)

- This and two further studies by King and by Mackenroth and Di Piazza confirm that in the high-field regime ξ>>1 the two-step channel dominates over the one-step channel

Lab. astrophysics: Positron Jets with lasers

Experimental campaign carried out at the HERCULES laser (CUOS, Michigan) with teams around G. Sarri, K. Krushelnick & M. Zepf



(a) Table-top experimental setup for the production of short, narrow, and ultra-relativistic positron beams. (c) 30 fs positron jets as recorded by the image plate.

(b) Theoretical analysis revealed that the scaling with the charge number Z and the thickness d is consistent with a two-step process (Bremsstrahlung+Bethe-Heitler)

Parameters & possible astrophysical significance

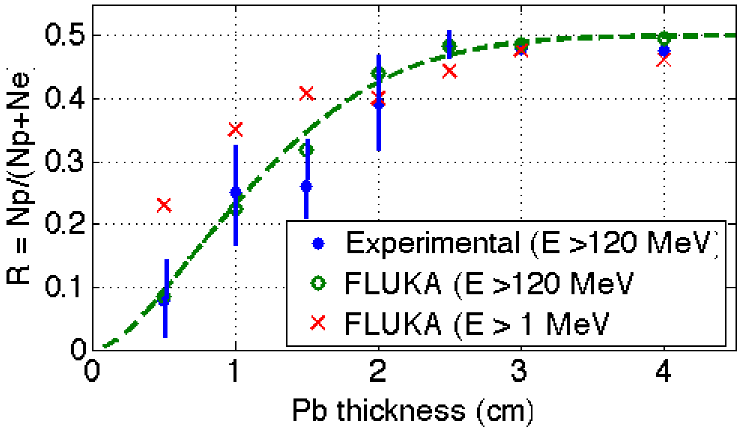
An ultrashort (30fs), ultra-collimated (3mrad) high energy (E_{MAX} = 150 MeV) positron beam generated.

Overall positron yield:	3×10^7
Overall lepton yield:	3×10^8
Positron density:	2×10^{14} cm^{-3}
Lepton density:	2×10^{15} cm^{-3}
Intensity:	10^{19} erg s^{-1} cm

Parameter not as in astrophysical jets but with scaling results may become relevant

G. *et al.*, PRL (2013)

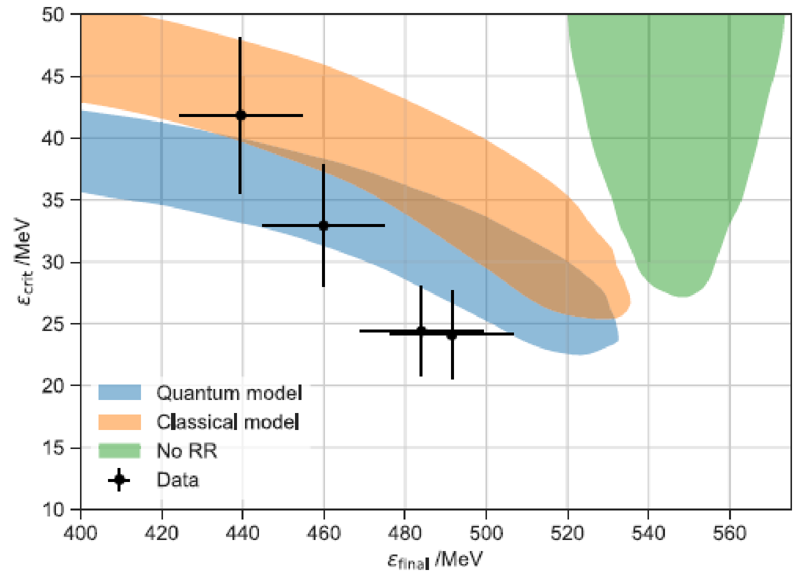
In subsequent experimental campaign at Astra Gemini (Oxford) a-relativistic neutral electron-positron beam generated (G. Sarri et al, Nat. Comm. (2015))

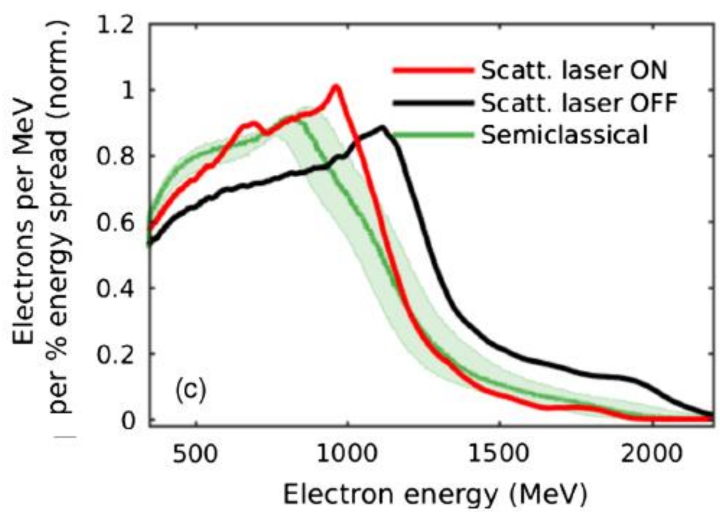


Generation of e^-/e^+ jets with variable % of e^+ from 0 to 50%! Plasma dynamics of those neutral lepton- antilepton jets yet to be studied

- The results of three experimental campaigns on radiation reaction have been reported in the literature this year

- Comparison between different theoretical models and experimental results on the final cut-off electron energy (Cole et al., Phys. Rev. X 2018)

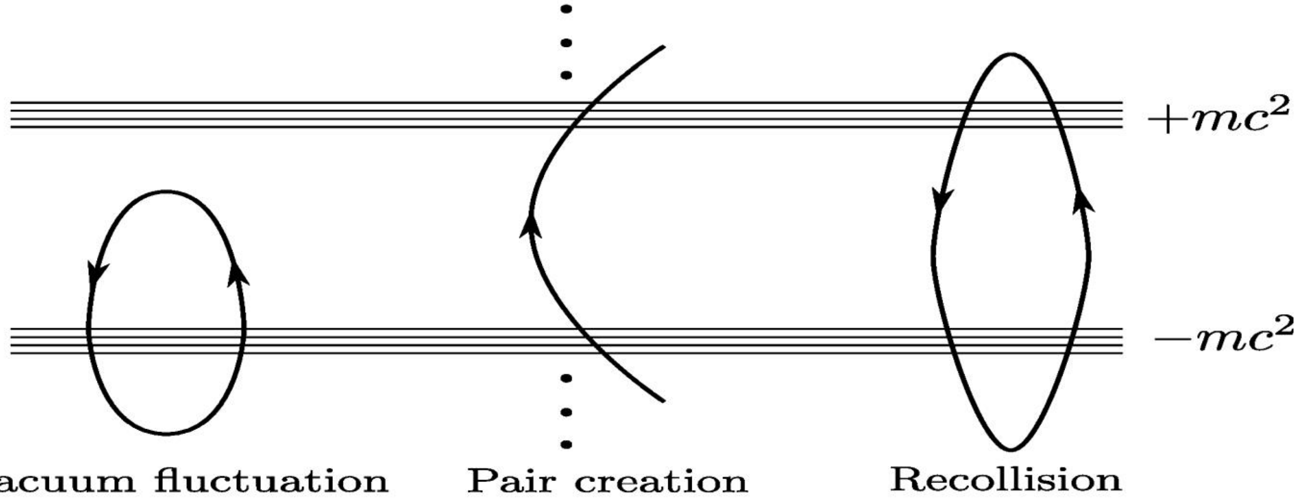




- Experimental (red curve) vs theoretical (green area) final electron energy spectra (Poder et al., Phys Rev. X 2018)

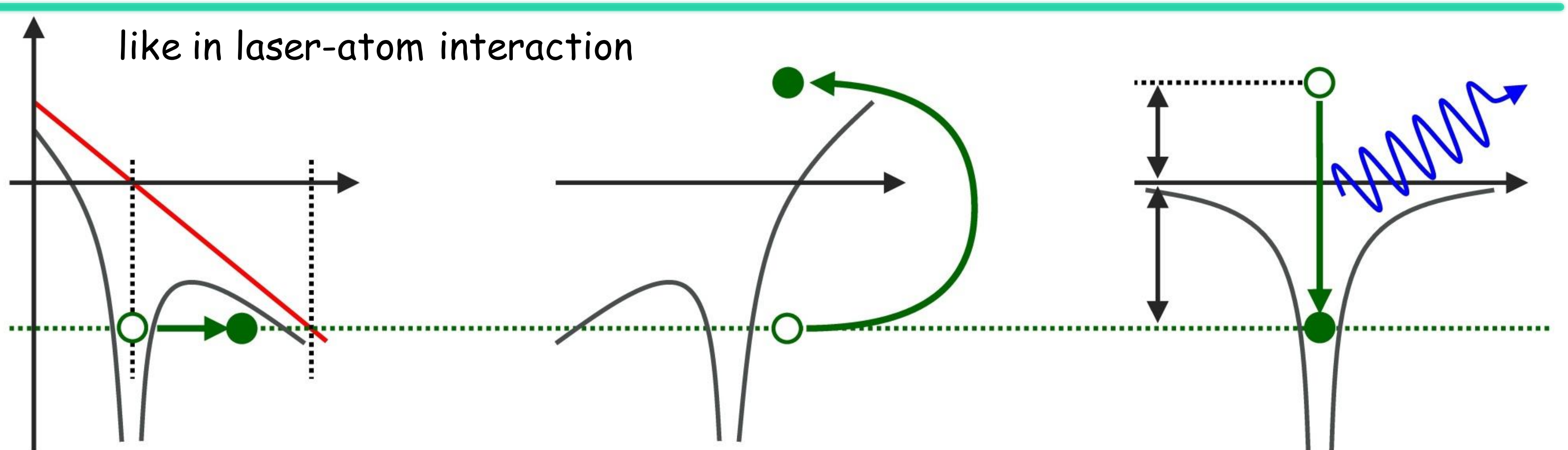
- Quantum radiation-reaction effects in aligned crystals in the photon spectra are reported in Wistisen et al., Nature Commun. 2018

From Collisions to Recollisions in Vacuum



Dirac sea

like in laser-atom interaction



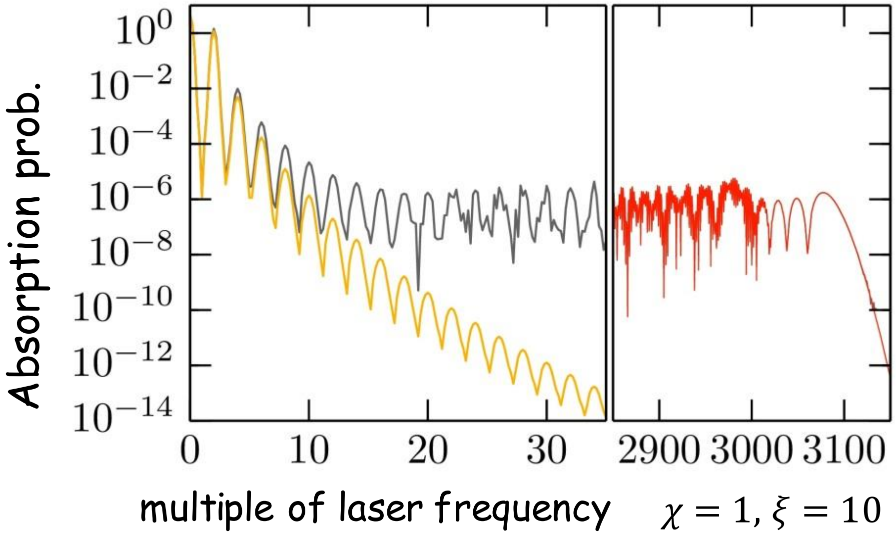
Courtesy of A. Kaldun

a) Tunneling ionization of the atom **b)** Propagation of the free electron inside the laser **c)** Electron-atom recollision

Recollisions in atomic physics: Semi-classical three-step model for High-harmonics generation (HHG)
As the free electron is accelerated by the laser field, a large amount of energy is released during the recollision.

Recollisions of laser-generated electron-positron pairs

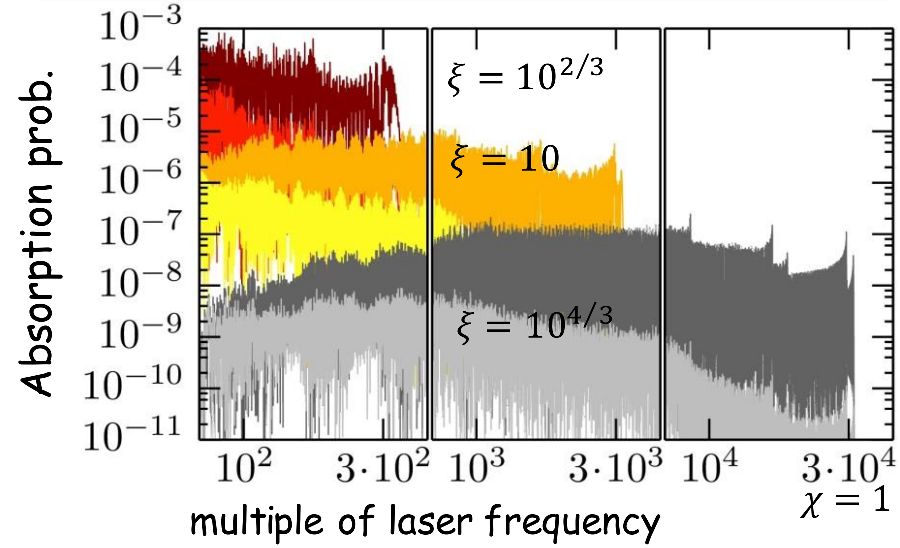
Quasistatic vs. recollision contribution



If real pair creation becomes sizable ($\chi = 1$), also recollision processes contribute (red curve)

They are responsible for the large plateau-region in the photon absorption spectrum

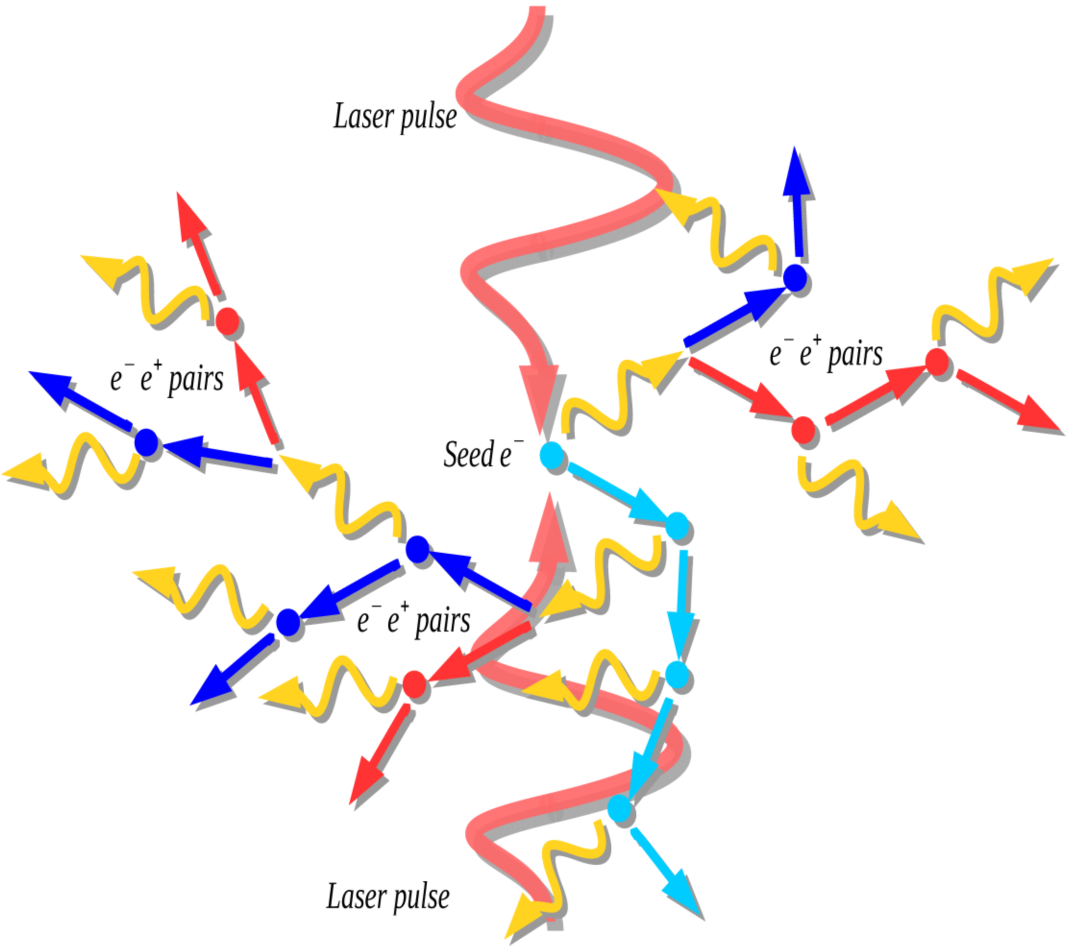
Scaling of the plateau region



- During a recollision many laser photons can be efficiently absorbed from the laser
- The width of the plateau scales as $3.17\xi^3/\chi$
- The height of $\left|\int P_\perp\right|^2$ scales as $\chi^{10/3}/\xi^6$

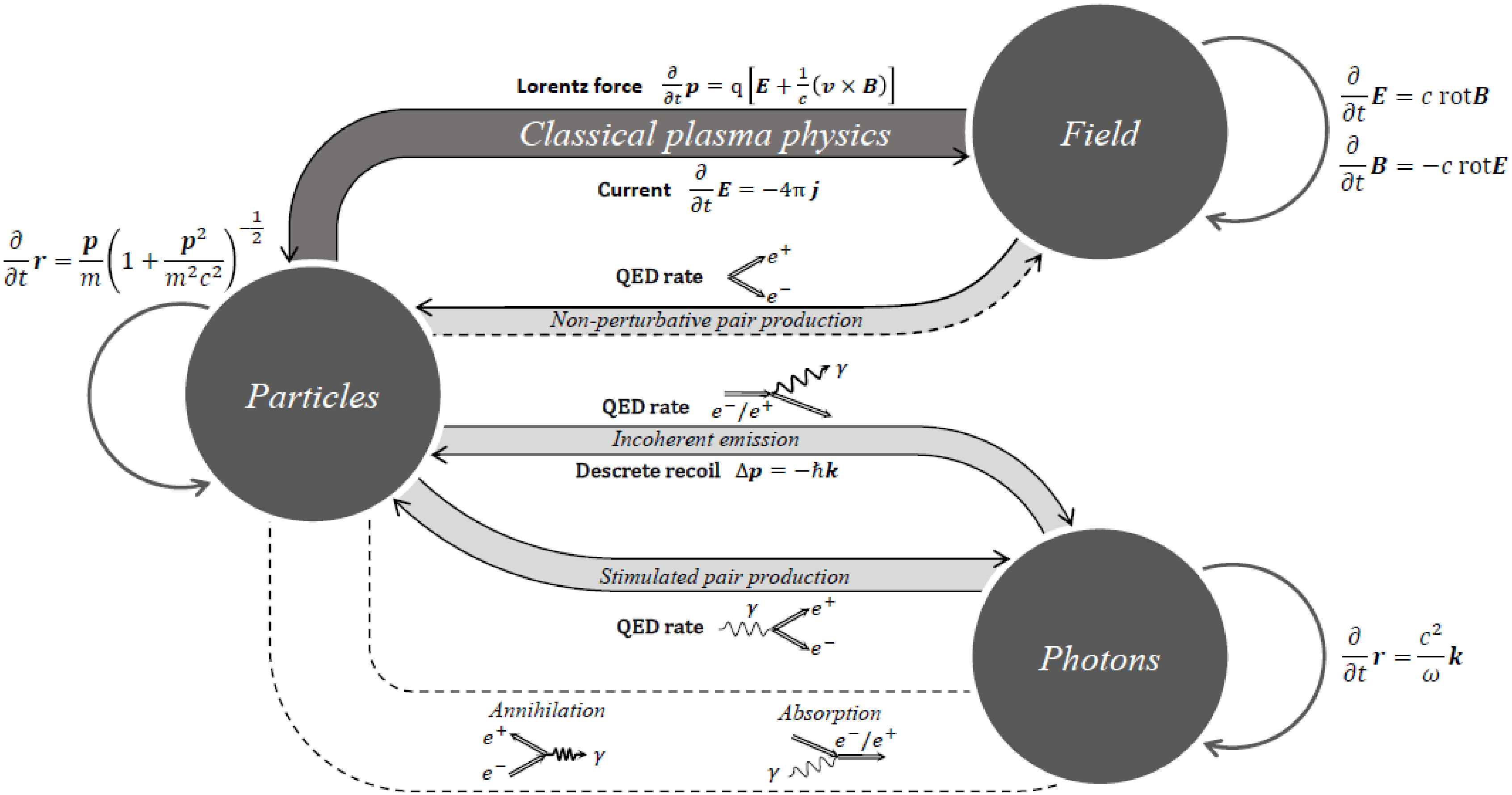
S. Meuren et al, Phys. Rev. Lett. **114**, 143201 (2015)

Laser-driven seeded QED cascades



1) Seed e^- are violently accelerated by the laser fields and emit large amounts of hard photons which, in turn, convert into e^-e^+ pairs.
2) The generated e^-e^+ pairs are then accelerated by the laser fields and originate a new generation of particles.
3) QED cascades were predicted to develop in the collision of two laser pulses each with an intensity around 10^{24} W/cm^2 (Bell PRL 2008, Kirk PPCF 2009, Bulanov PRL 2010, Nerush PRL 2011).
4) Debate on limit of achievable intensity

- Present state: Implemented approach in most PIC codes like EPOCH (see e.g. Ridgers PRL 2012), OSIRIS (see, e.g., Gonoskov et al., PRE 2015), T. Grismayer et al, Phys. Plasm. 2016, M. Tamburini et al., Scient. Rep. 2018



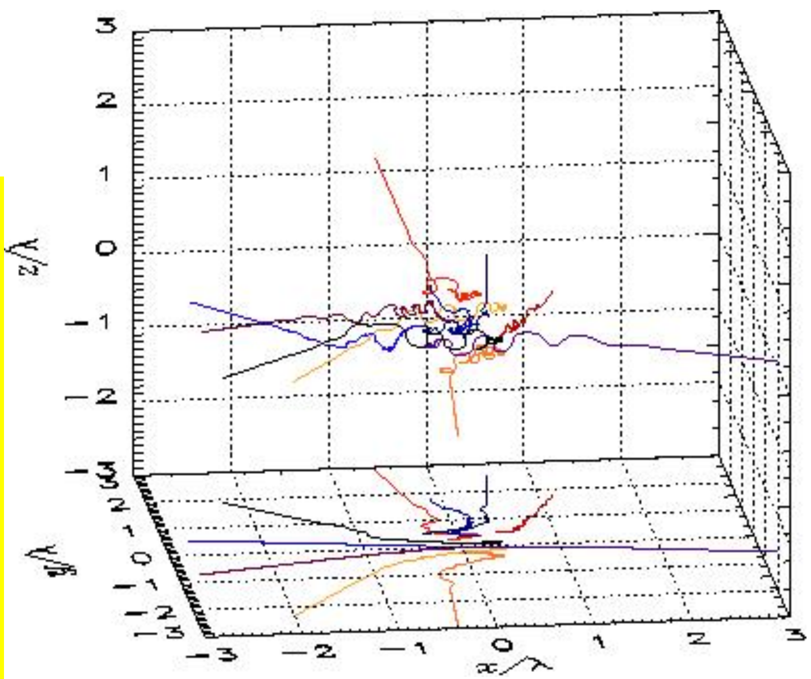
- Only the two basic processes (nonlinear Compton scattering and nonlinear Breit-Wheeler pair production) are implemented

Role of Pulse Shape on Seeded Cascades

- Head-on collison of two laser pulses in background gas
- Monte Carlo Code (Tamburini) similar to that of Nerush/Elkina except including soft photons

Questions:
Role of ponderomotive force expelling seed electrons: can cascades be prevented ?

Can cascades be enhanced with appropriate focussing and suitable seed gases



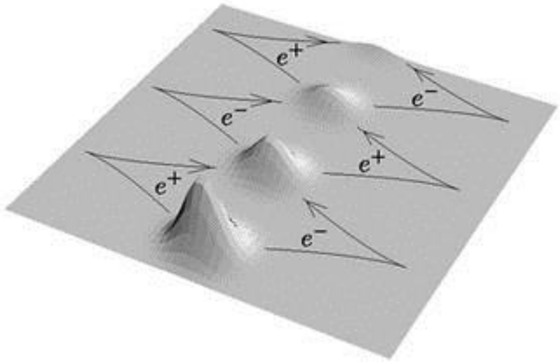
Trajectories for 0 < t < 24 T of ten stray electrons starting at rest from the origin at t=0 and driven by two counterpropagating laser pulses with $I=10^{26}$ W/cm^2 and $w_0=1\,\lambda$. Projection on the focal plane xy.

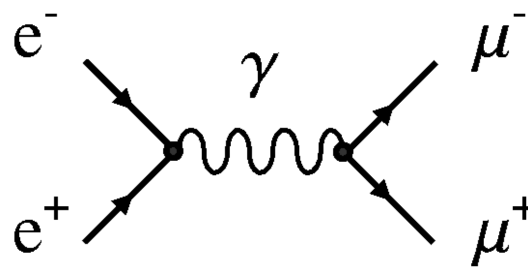
Regimes of seeded e^-e^+ pair creation as function of the laser intensity I and waist radius w_0 (power P) of each laser pulse

I (W/cm^2)	w_0 (λ)	P (PW)	Regime
1×10^{24}	1	10.32	No e^-e^+ pairs
	2	40.47	No e^-e^+ pairs
	3	90.73	Transition region
	4	161.1	e^-e^+ gas
	5	251.6	e^-e^+ cascade
1×10^{25}	1	103.2	No e^-e^+ pairs
	2	404.7	No e^-e^+ pairs
	3	907.3	Transition region
	4	1611	e^-e^+ cascade
1×10^{26}	1	1032	No e^-e^+ pairs
	2	4047	No e^-e^+ pairs
	3	9073	Transition region
	4	16110	e^-e^+ cascade

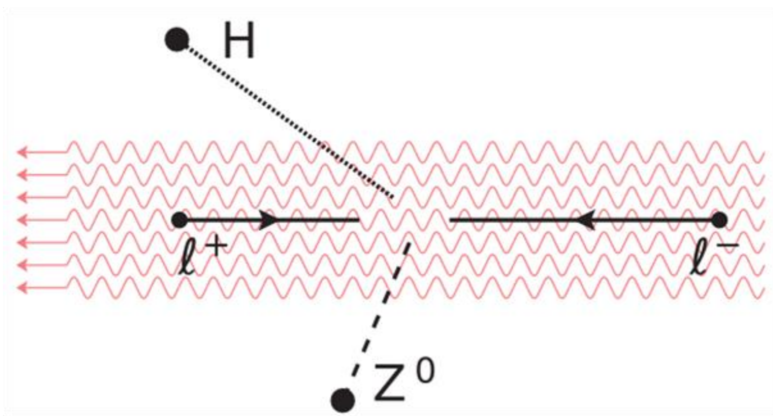
Matteo Tamburini et al., Scientific Rep. (2018)

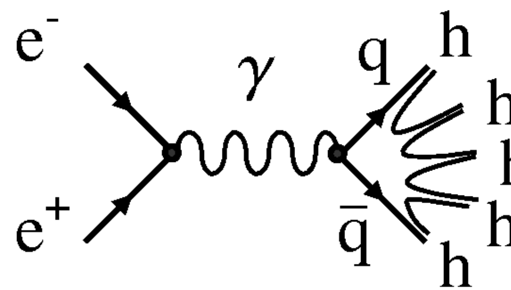
Particle Physics with Laser-driven lepton collisions





muon production
$(m_\mu c^2 = 106\ \mathrm{MeV})$





pion production
$(m_\pi c^2 = 140\ \mathrm{MeV})$

energetic threshold for muon:

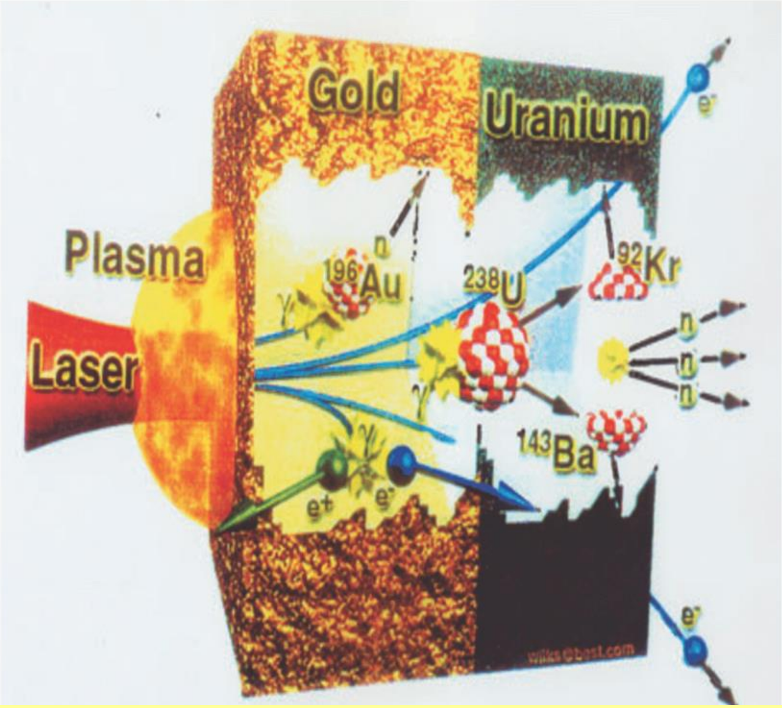
$$2eA \geq 2Mc^2$$

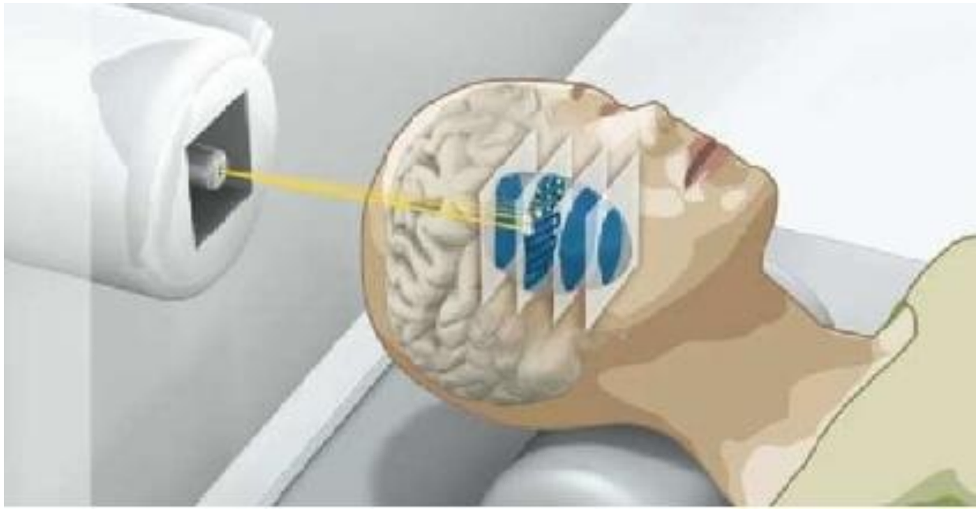
$(I \geq 5\times10^{22}\ \mathrm{W/cm^2}$ at $\lambda = 1\ \mu\mathrm{m})$

K. Z Hatsagortsyan et al., EPL (2006); Higher muon or pion rates via proton FEL collisions: C. Müller et al., PLB (2008), A Dadi & C Müller, PLB (2011), Higgs and Z Boson production S. J. Müller et al., PLB (2014); neutrino photon interactions S. Meuren et al. JHP (2015); probe fundamental processes H Gies EPJ (2009)

Ionic & Nuclear Laser Physics

MeV Acceleration and Nuclear Physics via Laser-Plasma Interaction





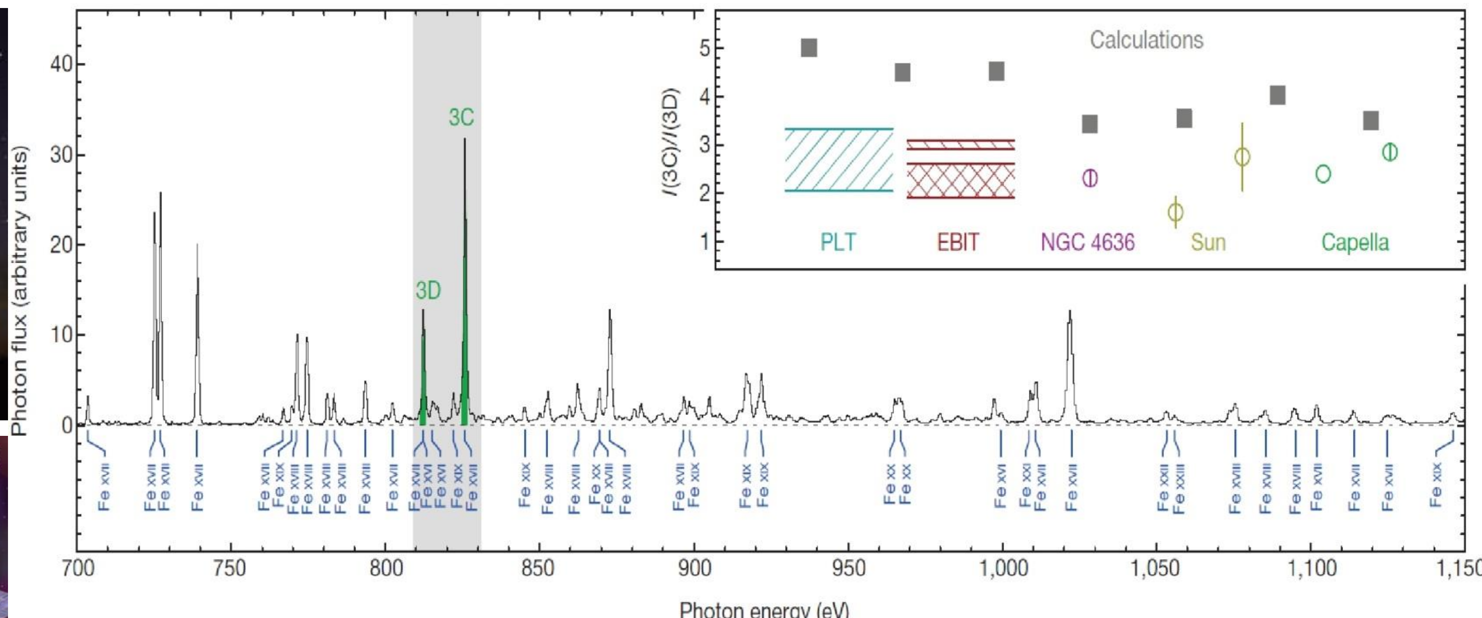
Photonuclear neutrons in G. Pretzler et al., PRE (1998) and K. Ledingham et al., PRL (2000); Deuterium fusion in T. Ditmire et al, Nature (1999); modified alpha decay H Castaneda Cortes et al., PLB (2013); excitation of unexplored instable nuclear states in A. Palffy et al. in PRL (2014)

quasi-monoenergetic protons for cancer therapy: H. Schwoerer et al., Nature (2006);
Current range around 100 MeV per nucleon: J. Schreiber et al., Rev. of Scient. Instr. (2016)
with e.g. 1 GeV carbon ion energies in D. Jung et al., Phys. Plasm. (2013)

Ions interacting with high frequency lasers: laboratory astrophysics

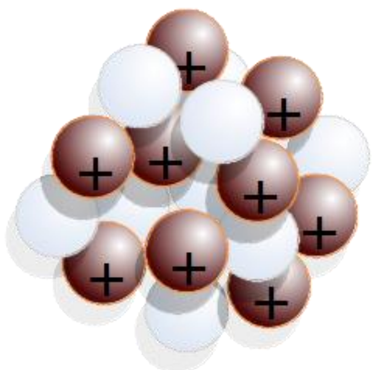
Iron (Fe): the most visible (even if not the most abundant) element of the universe.
Fe ions in stars emit x-ray radiation with characteristic frequencies.

E.g. x-ray spectrum of the star system **Capella** (in the constellation Auriga), recorded by the **Chandra X-ray Observatory** not reproducable with astrotheory



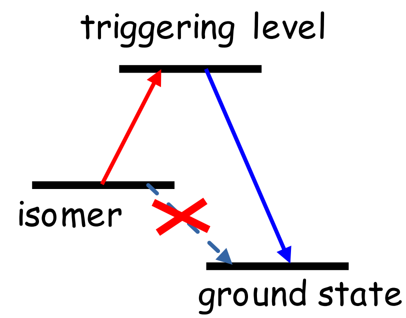
With FELs Experiments S. Bernitt, *et al.,* Nature **492**, 225 (2012) and theory N. S. Oreskina et al, PRL 113, 143001 (2014): discrepancy remains without plasma&correlations effects but nonlinearities may be responsible

Nuclear quantum dynamics and isomer triggering



Triggering = release of stored excitation energy on demand

- clean energy source (nuclear battery)
- insight in nuclear structure
- possibly astrophysical significance



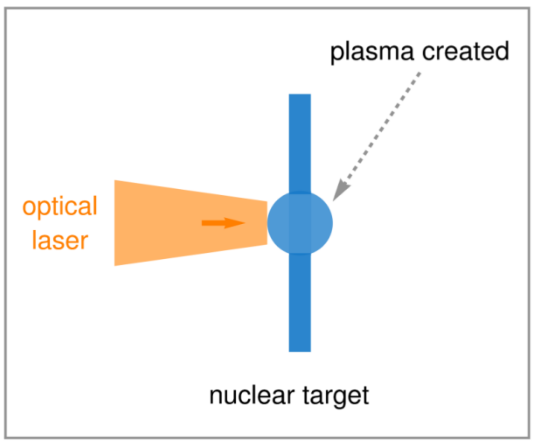
References:
- P. Walker and G. Dracoulis, Nature (London) **399**, 35 (1999),
- A. Pálffy *et al.*, Phys. Rev. Lett. **99**, 172502 (2007)
- Y. Wu et al., Phys. Rev. Lett. 120, 052504 (2018

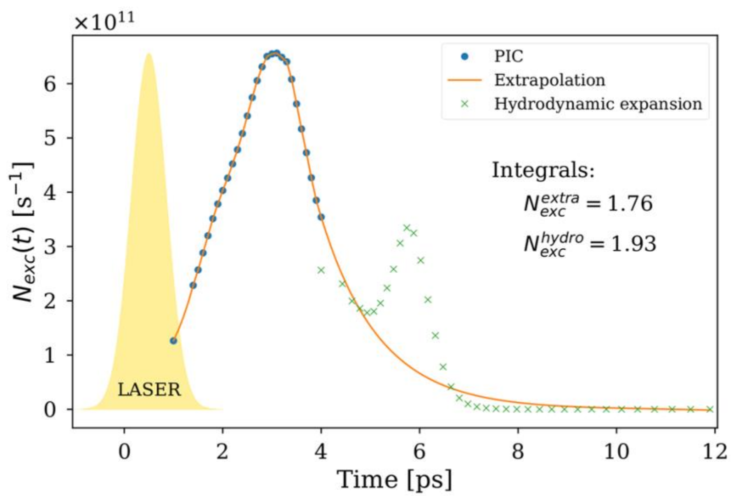
PIC simulation

$$I = 10^{18} W/cm^2;\ \tau_{\text{pulse}} = 500\text{ fs};\ \lambda = 800\text{ nm}$$

$$E_{\text{pulse}} = 100\text{ J}$$

$\Rightarrow$ focal spot area: $\approx 2 \times 10^{-4}\ \text{cm}^{-2}$



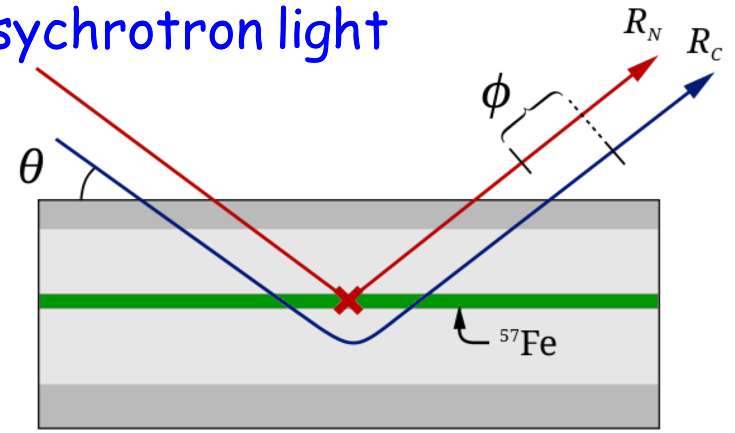


Measurable but not yet useful triggering rates feasible

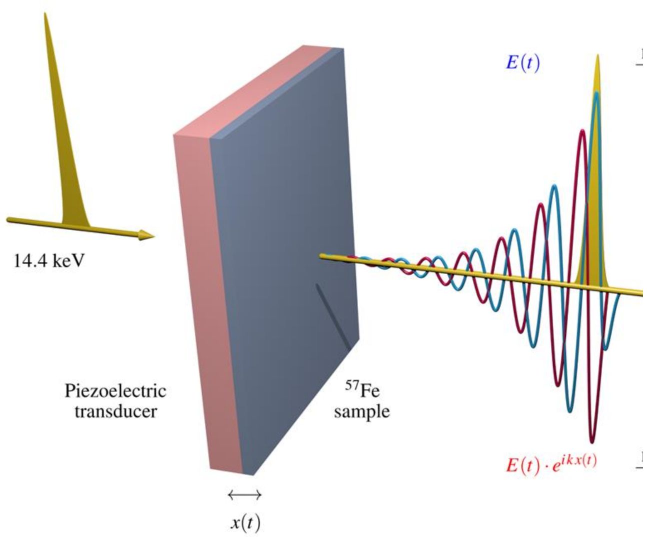
Control with and of Mössbauer nuclei

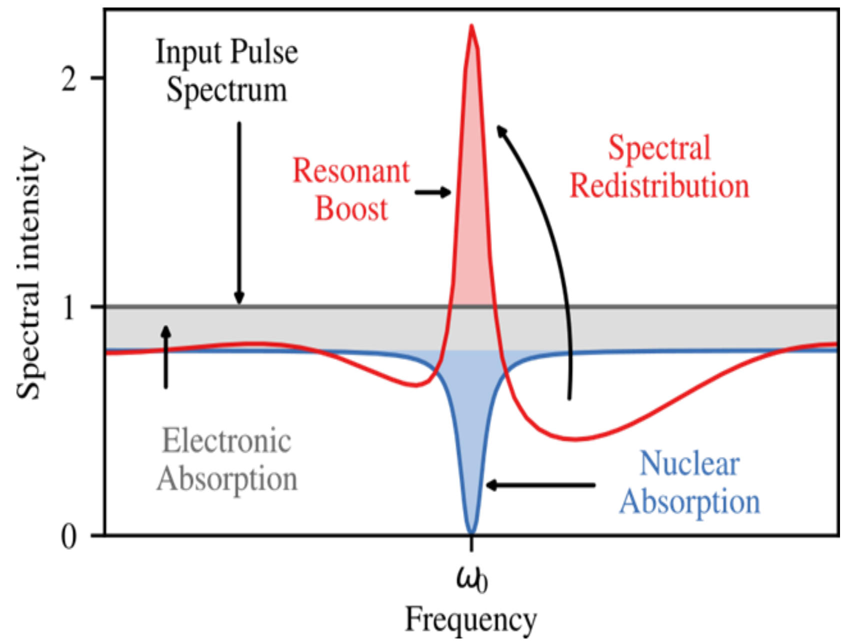
Operate cavity as x-ray interferometry with sychrotron light

- Bound state: narrow nuclear response
- Relative phase controlled by x-ray incidence angle

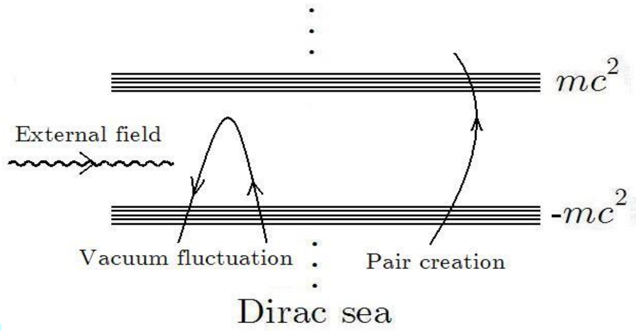


Demonstration of nuclear coherences, interferences and enhanced x-ray Refractivity by K. Heeg et al., PRLs 2013 & twice 2015, see also recent Nature/Science bei Röhlsberger and Kocharovaskaya groups

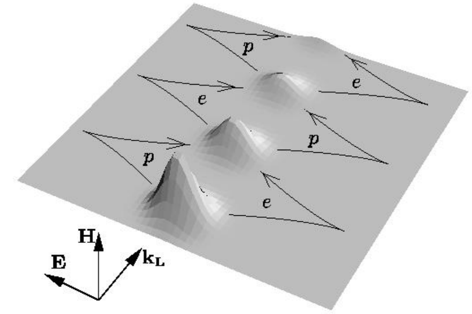




New means of nuclear interactions with shaped radiation sources: K. Heeg et al, Science (2017)



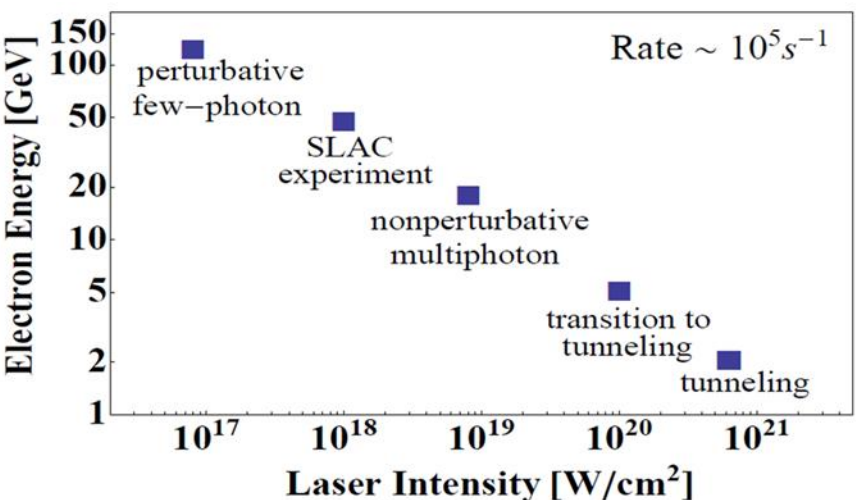
Conclusions

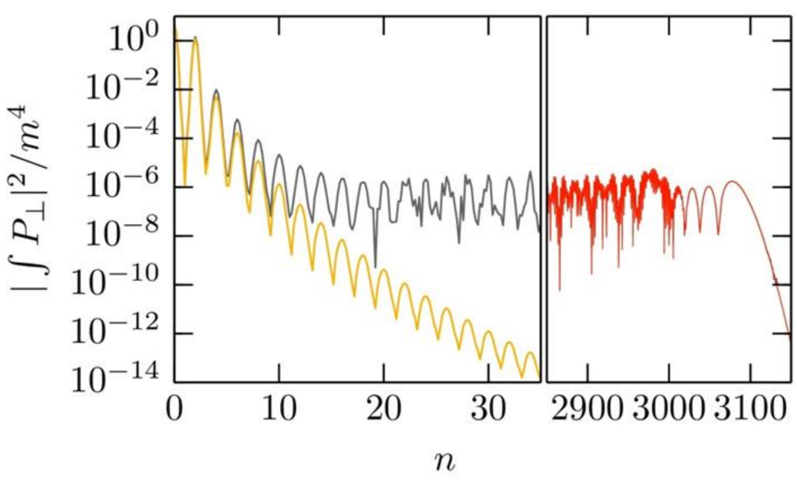


Laser-vacuum interaction: light-light scattering, vacuum refractivity, matterless double slit, ready for implementation

Laser-electron interaction: Dirac & spin dynamics, pair creation with created jets for astrophysics, vacuum collider

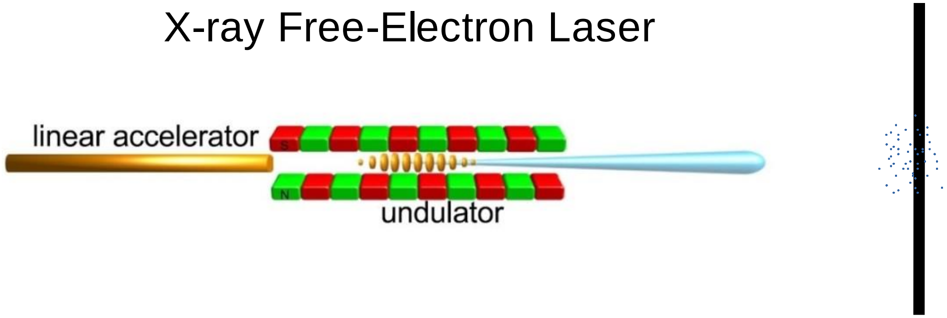
Laser-ion & nuclei interaction: particle acceler., astrophys. iron spectra, nuclear population transfer & x-ray shaping





Mechanisms of laser-nucleus interaction in embedded nuclei

X-ray Free-Electron Laser

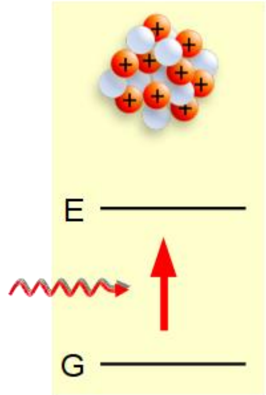


solid-state target

*Driving of **nuclear** transition*

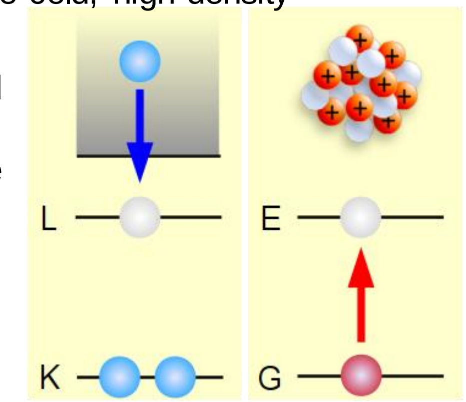
Direct laser-nucleus interaction:

- XFEL provides x-rays (< 25 keV) resonant with nuclear transition
- Obstacles:
  - small nuclear transition widths
  - small size of nuclei
  - screening from electrons



Secondary nuclear processes:

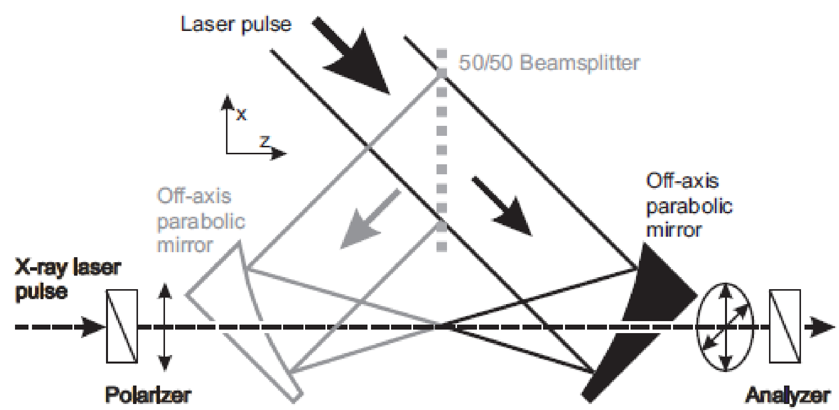
- High intensity XFEL can produce new states of matter, like cold, high-density plasmas
- Processes coupled to the atomic shell, like NEEC become possible
- NEEC is time-reversal of internal conversion

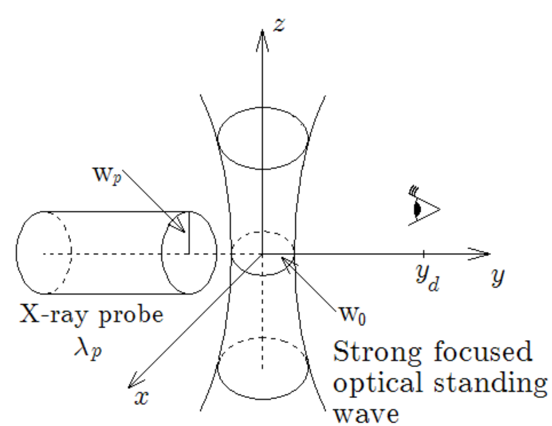


Competition between *direct photoexcitation* and *secondary NEEC*

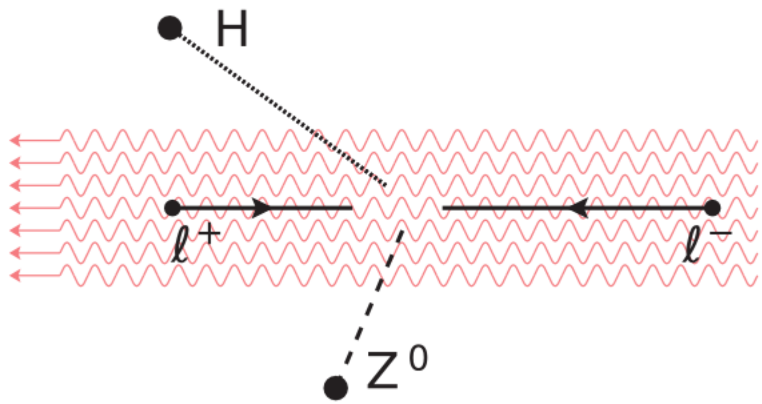
Vacuum polarization

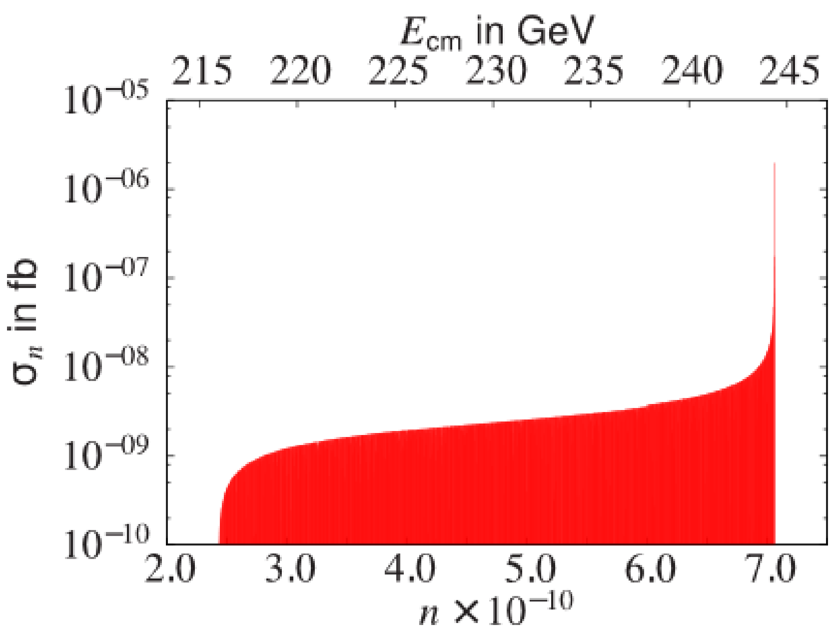
- A promising way of measuring vacuum-polarization effects relies on the interaction between an x-ray photon beam and a strong optical laser field
- Such an experimental setup is expected to be available at DESY (HiBEF project)
- Early calculations (Heinzl et al., Opt. Commun. 2006) have indicated the feasibility of the experiment with multipetawatt lasers (see also King et al., High Power Laser Sci. Eng. 2016)
- Detrimental diffraction effects may decrease the overall effect (Di Piazza et al., Phys. Rev. Lett. 2006)





Higgs boson creation in laser-boosted lepton collisions



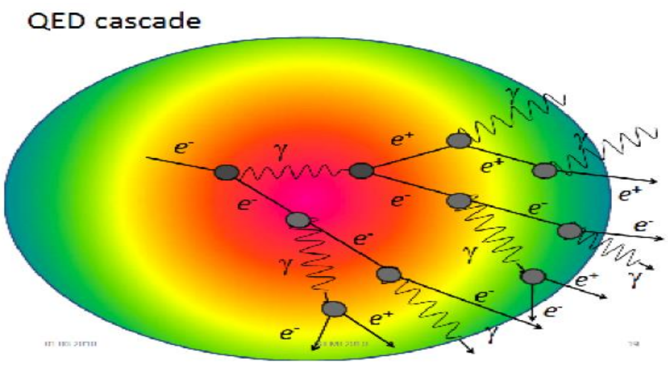


	$\mu^+\mu^-$	e^+e^-
Intensity parameter ξ	1	1
Laser frequency (eV)	1	1
Laser intensity I (W/cm^2)	7.6×10^{22}	1.8×10^{18}
Free lepton energy p^0 (GeV)	71	71
Lorentz factor γ	670	1.4×10^5
Beam waist w_x (mm)	0.8	170
Beam waist w_y (μm)	1.2	1.2
Pulse duration (ns)	11.3	5×10^5
Pulse power (PW)	2.3×10^3	11
Pulse energy (GJ)	26	5.4×10^3
Total cross section (fb)	38	38

S. J. Müller et al., Phys. Lett. B 730 (2014) 161

QED cascades

By an avalanche or cascade process we mean here a process in which even a single electron in a field emits high-energy photons, which can interact with the field itself generating electron-positron pairs, which, in turn, emit photons again and so on (a cascade process may also be initiated by a photon rather than by an electron) - Figure courtesy Elkina



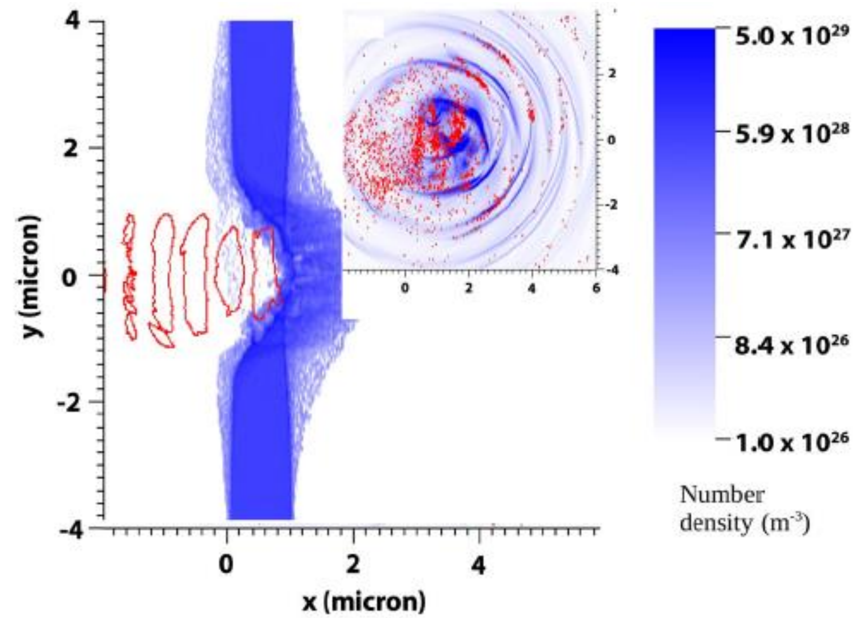
- Kirk and Bell, Phys. Rev. Lett. 2008: first prediction of a cascade production if even a single electron is present in the focus of a standing wave with intensity larger than 10^{24} W/cm^2

- Bulanov et al., Phys. Rev. Lett. 2010: no upper limit is envisaged in the case of linear polarization, due to the reduced electromagnetic emission

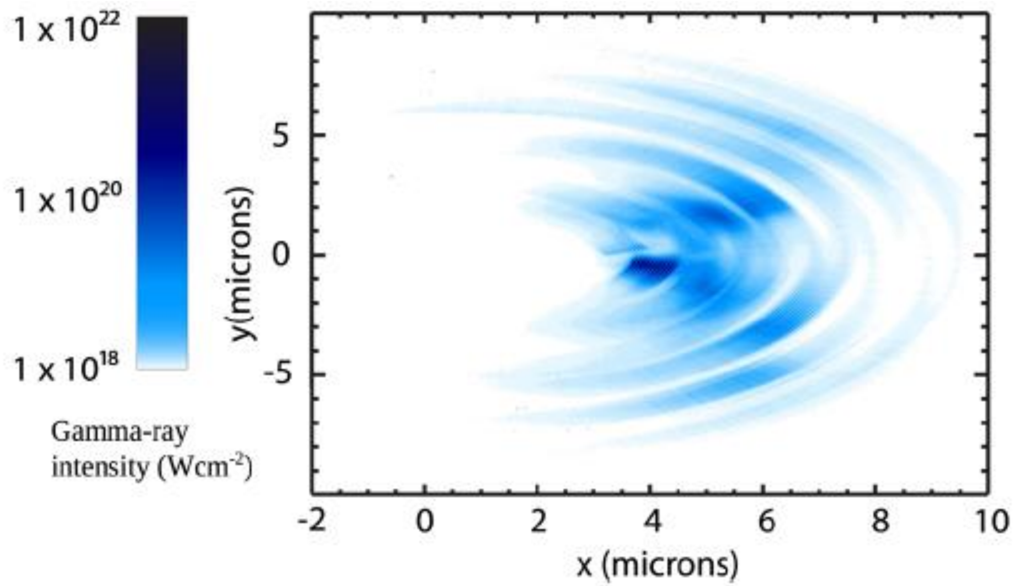
- Nerush et al. Phys. Rev. Lett. 2011: cascades in laser-laser collision occurs independently of the laser polarization at intensities of the order of 10^{24} W/cm^2

(recall: cascade debate only for counterpropagting laser pulses)

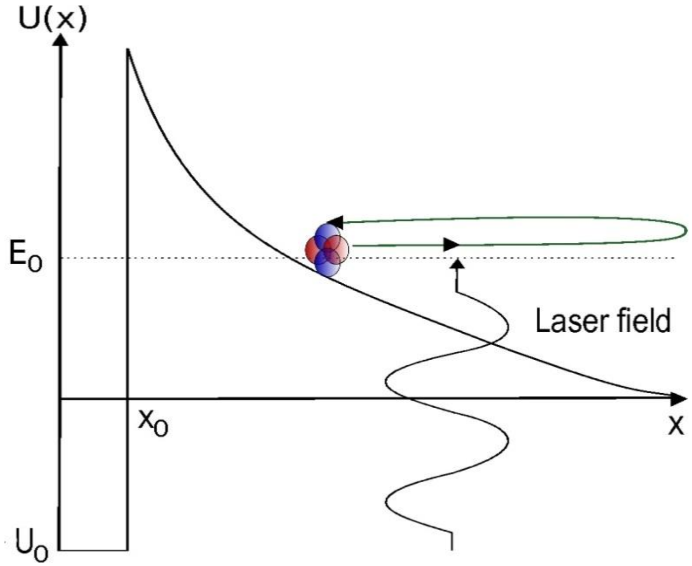
- Numerical simulations have shown the possibility of generating ultra-high density electron-positron plasmas (positron density of $10^{20}\ \mathrm{cm}^3$) by irradiating a solid target with a 10 PW laser beam (Ridgers et al., PRL 2012)



- In addition, 35 % of the incoming laser energy (intensity of 8×10^{23} $\mathrm{W/cm^2}$) is converted into 10^{14} gamma photons with an average energy of 16 MeV: potentially the most intense gamma-ray source available in the laboratory



Nuclear tunneling and recollisions in laser-assisted α decay



Tunneling rate is barely influenced by a strong optical laser (800 nm) but a particle spectrum completely changed by the laser: recollisions with the daughter nucleus occur at intensities of 10^{22}-10^{23} W/cm^2

H Castaneda Cortes et al., PLB (2013)

- Influence for beta decay controversal but broadly believed to be small as well in general
- Fusion with deuterium demonstrated long ago with laser cluster interaction in Ditmire 1998
- Excitation to so far unexplored instable nuclear states in A. Palffy et al. in PRL 2014