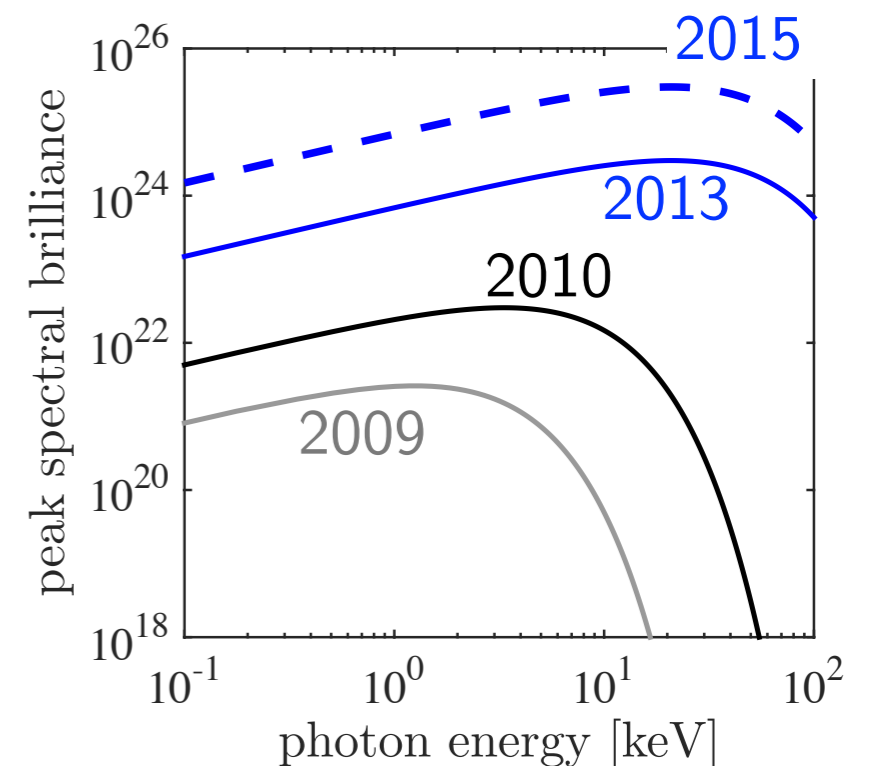
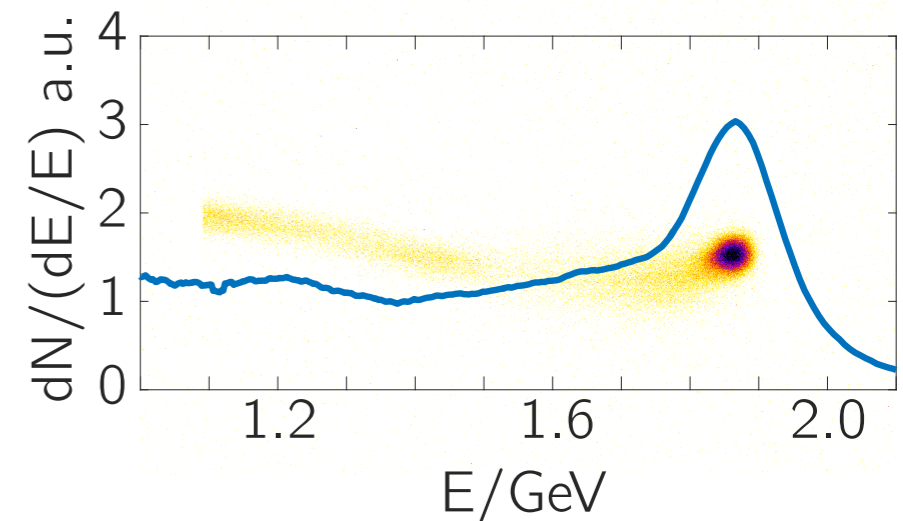


**HEDP physics experiments using an
XFEL plus a Laser wakefield accelerator**

Stuart Mangles

Laser Wakefield Accelerators

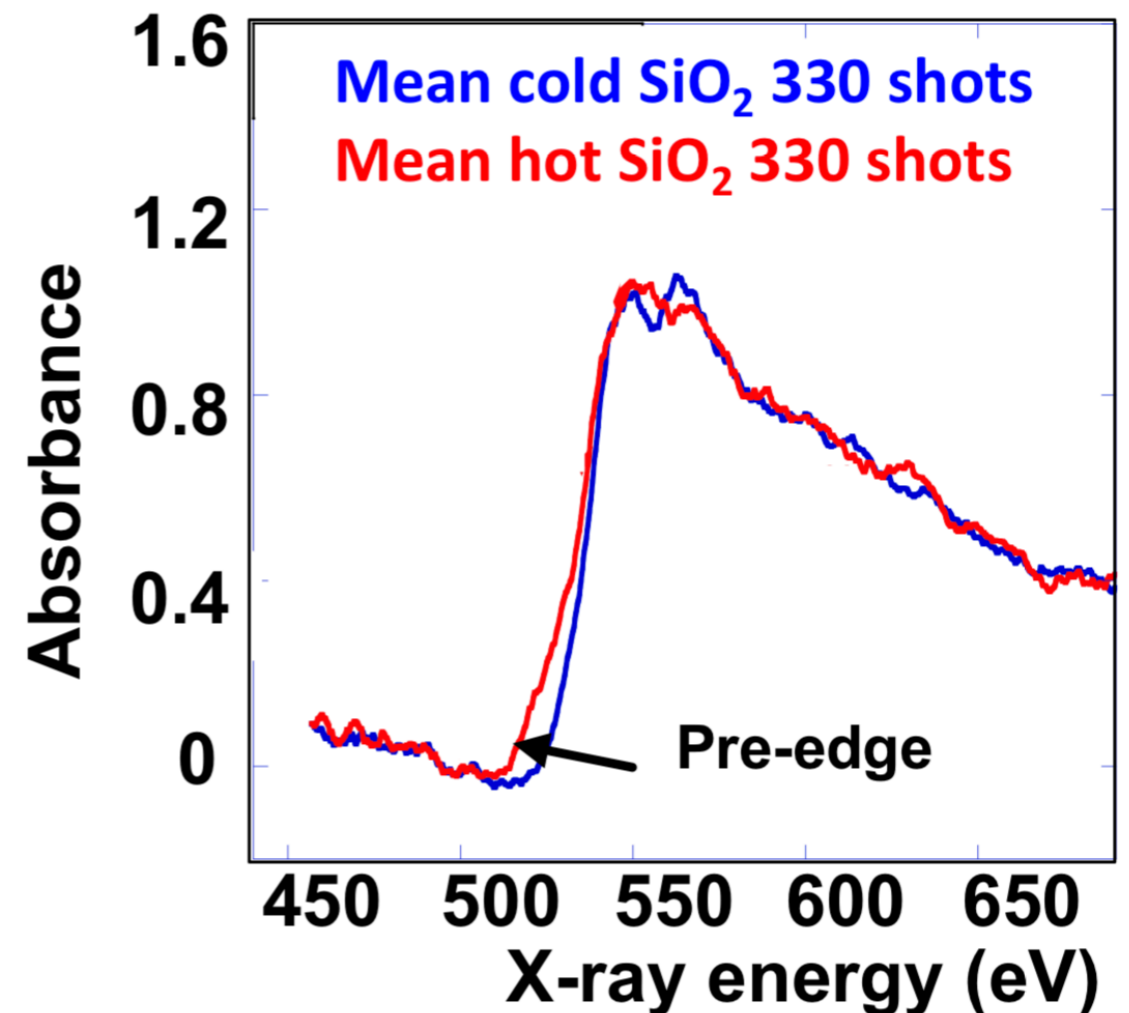
- LWFAs: compact source of high-energy electrons (1 - 2 GeV*)
 - betatron radiation: broadband, femtosecond X-rays (10 keV*)
 - bremsstrahlung: broadband, femtosecond γ -rays (up to 1.5 GeV*)
- If we had a LWFA at a UK XFEL what sort of experiments could we do?



* with a 200 TW laser: parameters can go up or down depending on laser power.

Betatron radiation for femtosecond X-ray absorption spectroscopy

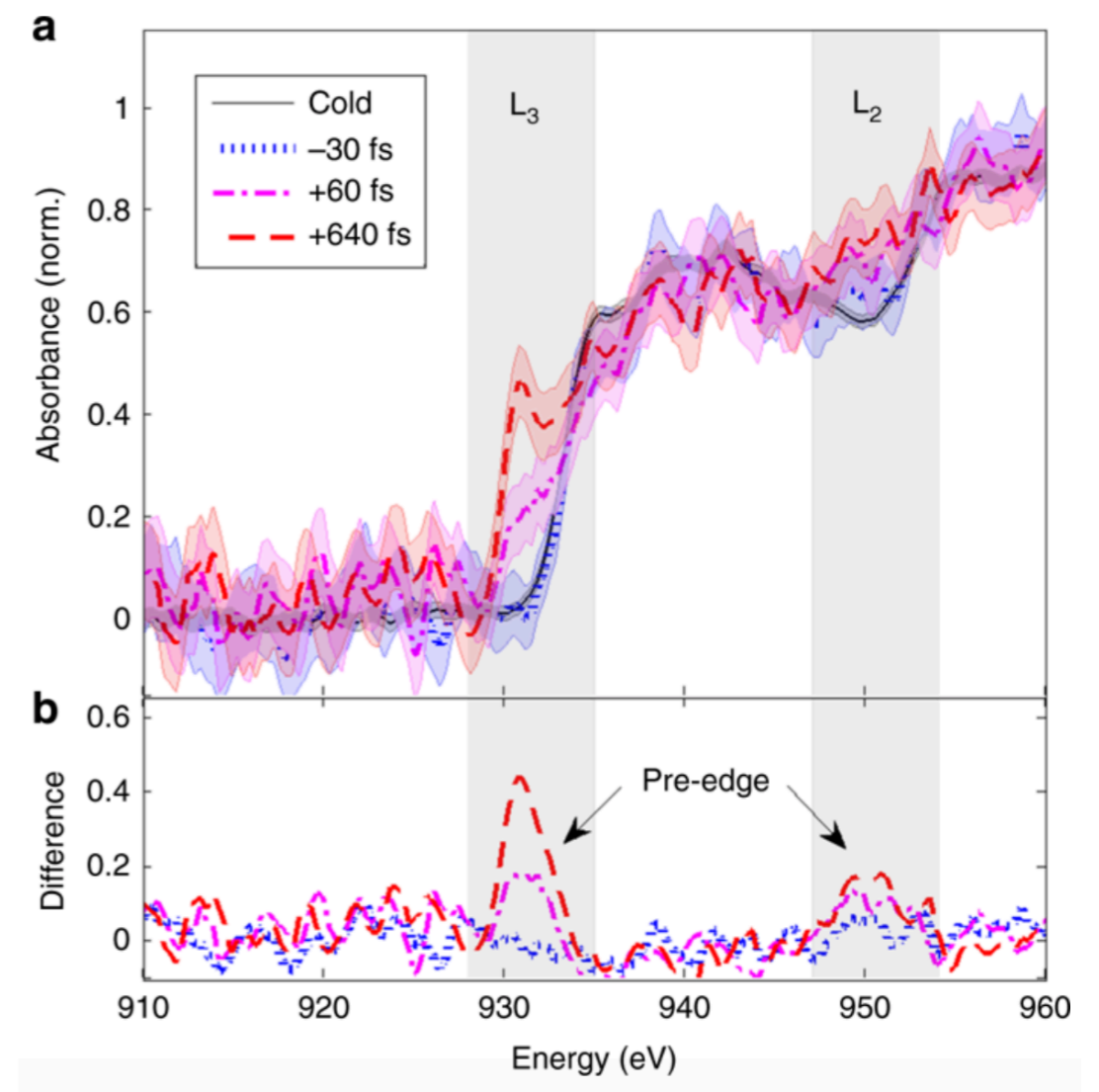
- Betatron probe (XANES)
 - L-edge XANES (F Albert et al @MEC LCLS)
 - $P < 100$ TW laser
 - » low energy x-rays
 - » low flux: many shots



Albert, Felicie, "Applications of light sources driven by laser wakefield acceleration" IPAC 2018

Betatron radiation for femtosecond X-ray absorption spectroscopy

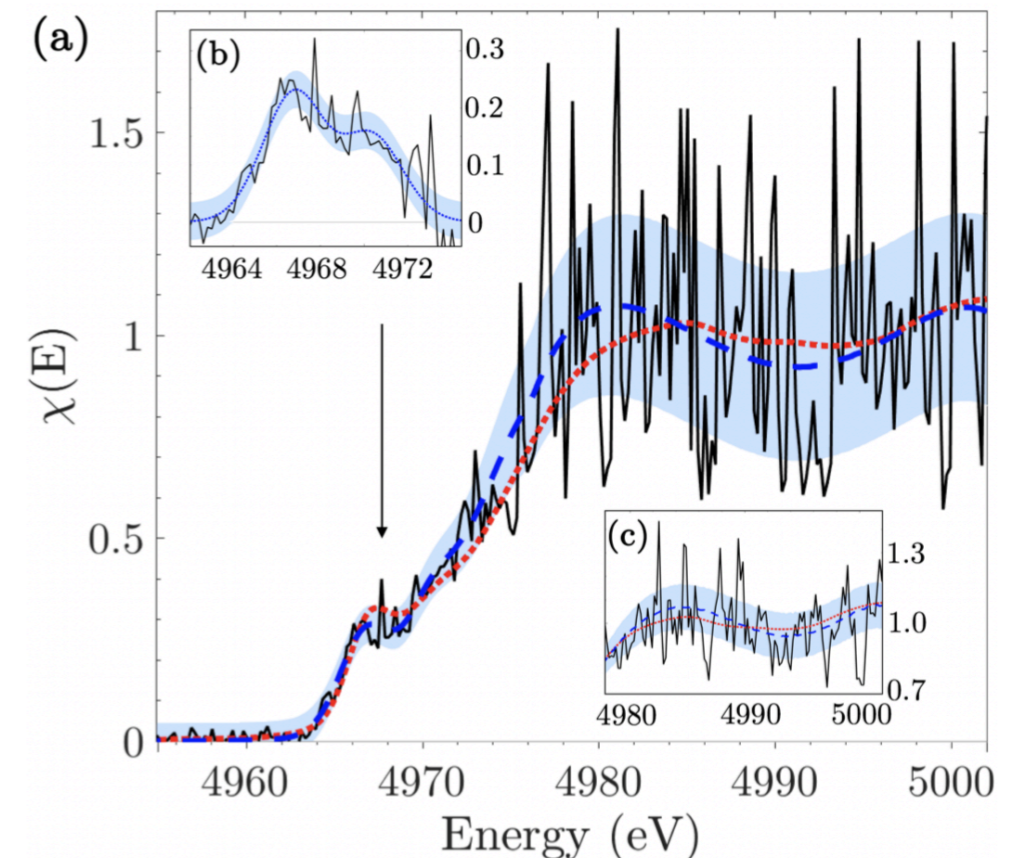
- Betatron probe (XANES)
- Laser pump
 - L-edge XANES (Mahieu et al @LOA)
 - sub 100 fs electron heating of warm dense matter observed
 - $P < 100$ TW laser
 - » low energy x-rays
 - » low flux



Mahieu et al *Nature Communications* 9, 3276 (2018)

Betatron radiation for femtosecond X-ray absorption spectroscopy

- Betatron probe (XANES)
 - K-edge XANES (Kettle et al @Gemini)
 - $P > 200$ TW laser
 - » high energy x-rays
 - » high flux
 - » XANES in single laser shot

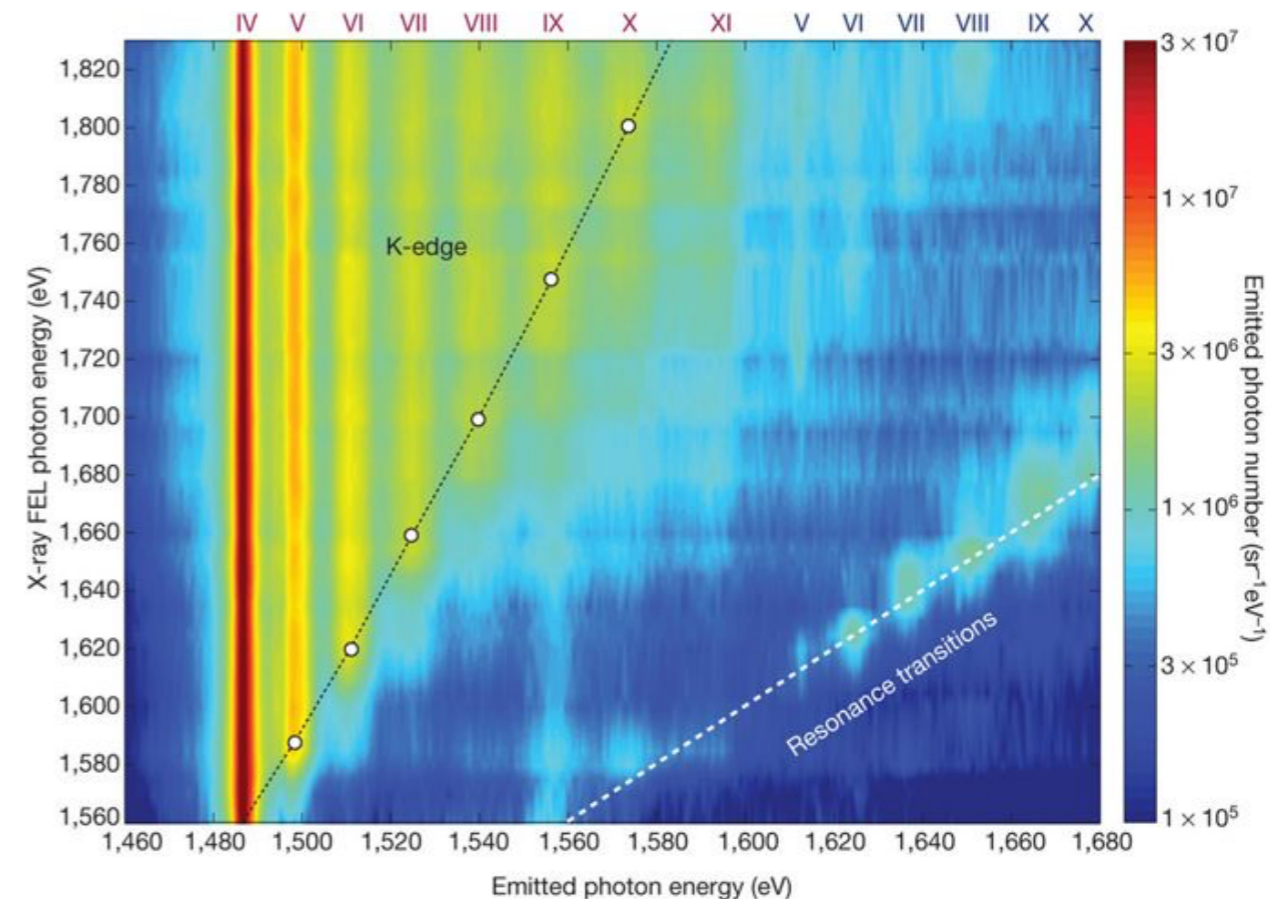


B Kettle et al [arXiv:1907.10167](https://arxiv.org/abs/1907.10167) [physics.plasm-ph]

XFEL pump + betatron probe

- XFEL pump can create warm dense matter, far from equilibrium
 - e.g. Vinko et al Nature 2012 (@LCLS), but diagnosis limited to emission
 - betatron probe could measure time-resolved absorption
 - » study dynamics and pathways to equilibrium

Vinko et al. Nature, 482, 59–62(2012)



Photon-photon-physics

- Photon-photon physics

- fundamental prediction of QED
- untested with real photons

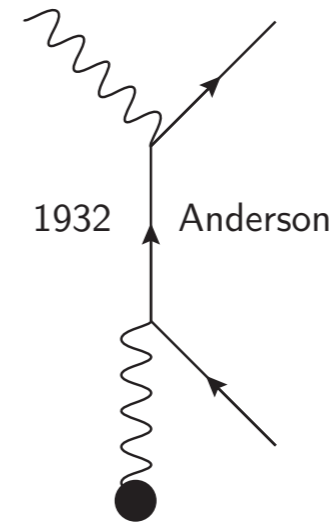
- inelastic scattering:

 - » photon + photon > electron + positron

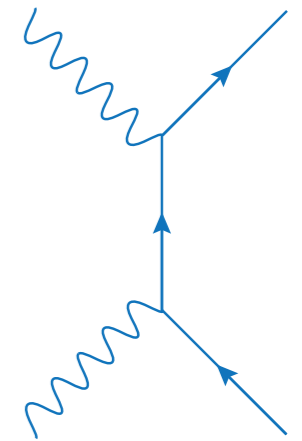
- elastic scattering:

 - » photon + photon > photon + photon

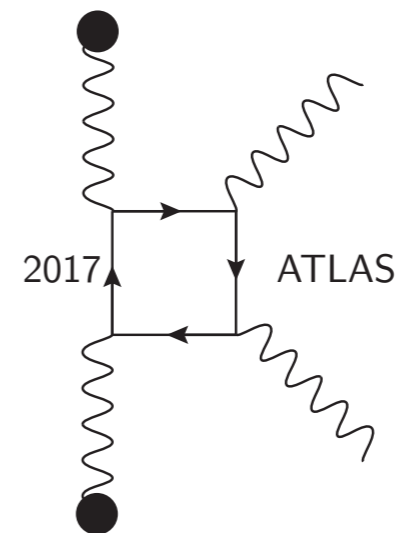
Bethe-Heitler pair production



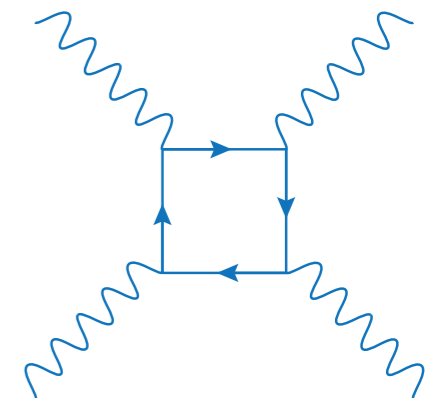
Breit-Wheeler pair production



photon-photon scattering



photon-photon scattering

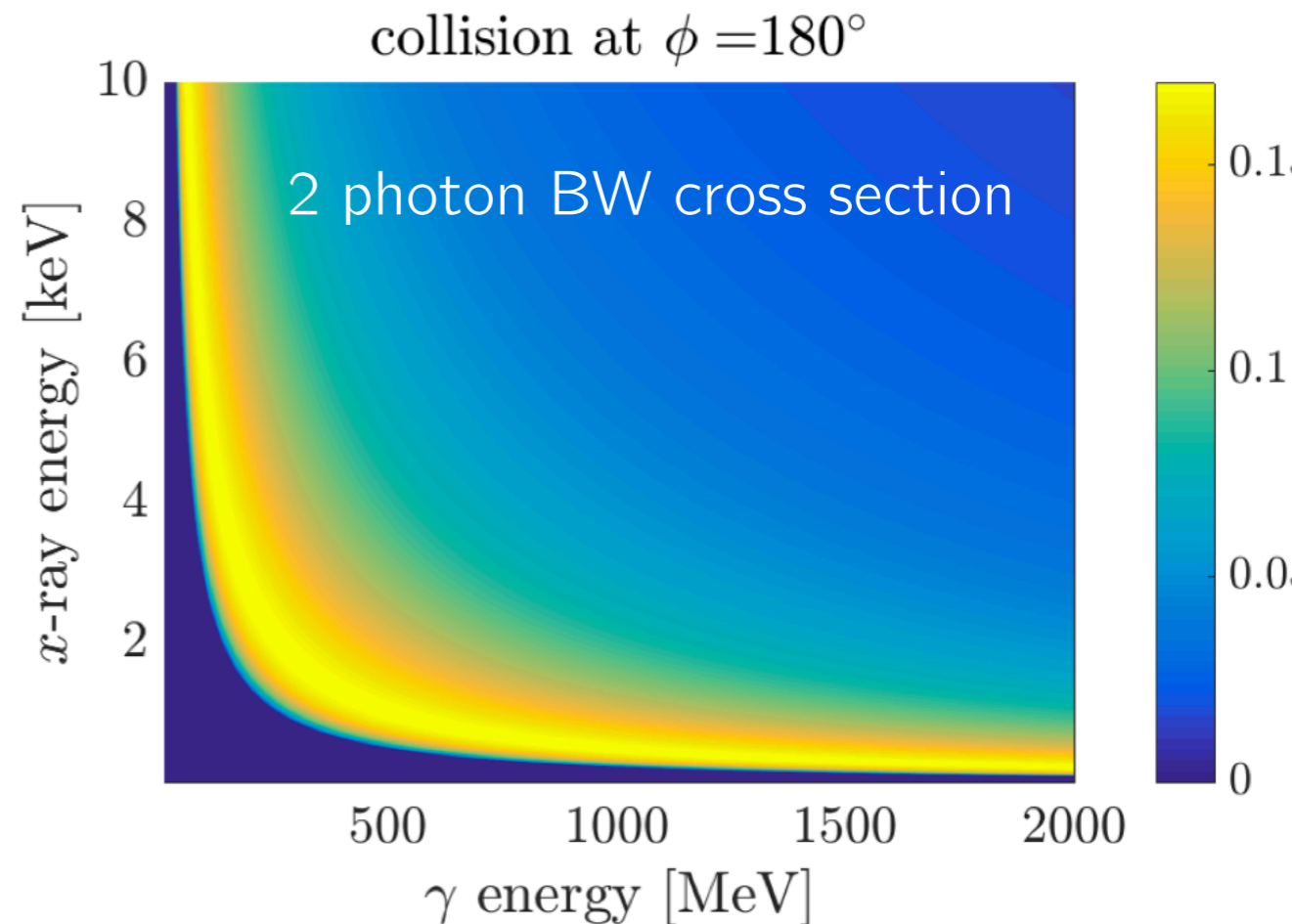


ATLAS Collaboration, Nature Phys. 13, 852 (2017)

Photon-photon-physics

$$s = \frac{E_1 E_2 (1 - \cos \phi)}{2m_e^2 c^4}$$

- Invariant mass of collision determines cross section
 - inelastic threshold at $s = 1$
 - photon-photon physics in astrophysics important at $s \approx 1$

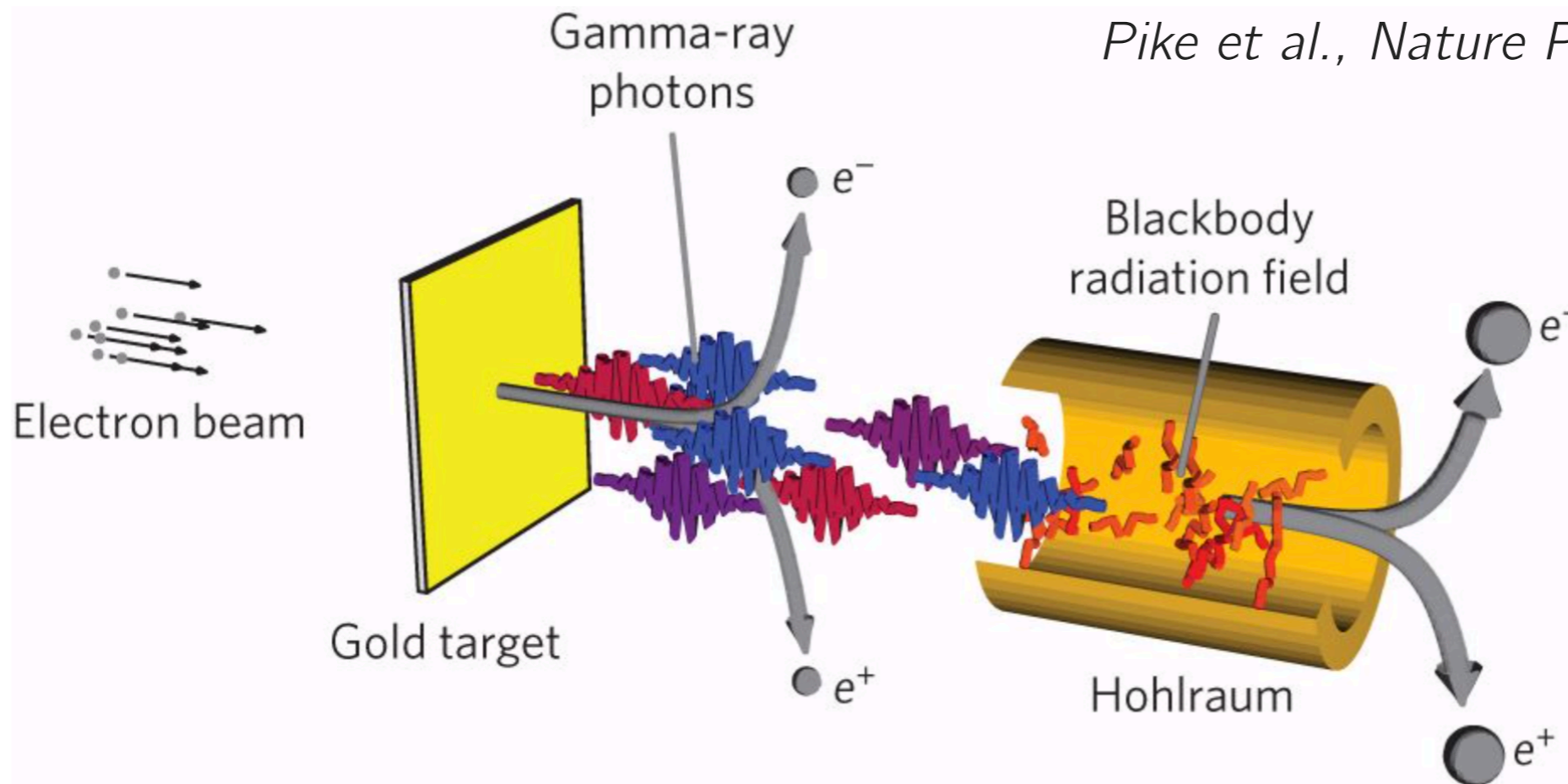


Photon-photon-physics

- gamma rays interact with cosmic microwave background
 - limit on energy of gamma rays reaching Earth from distant sources
 - some tension between the number of observed TeV gamma-rays (e.g Meyer et al Phys Rev D 87, 035027 (2013))
- elastic scattering important in early universe
 - R. Svensson A Zdziarski, Astrophys. J. 349 415 (1990)

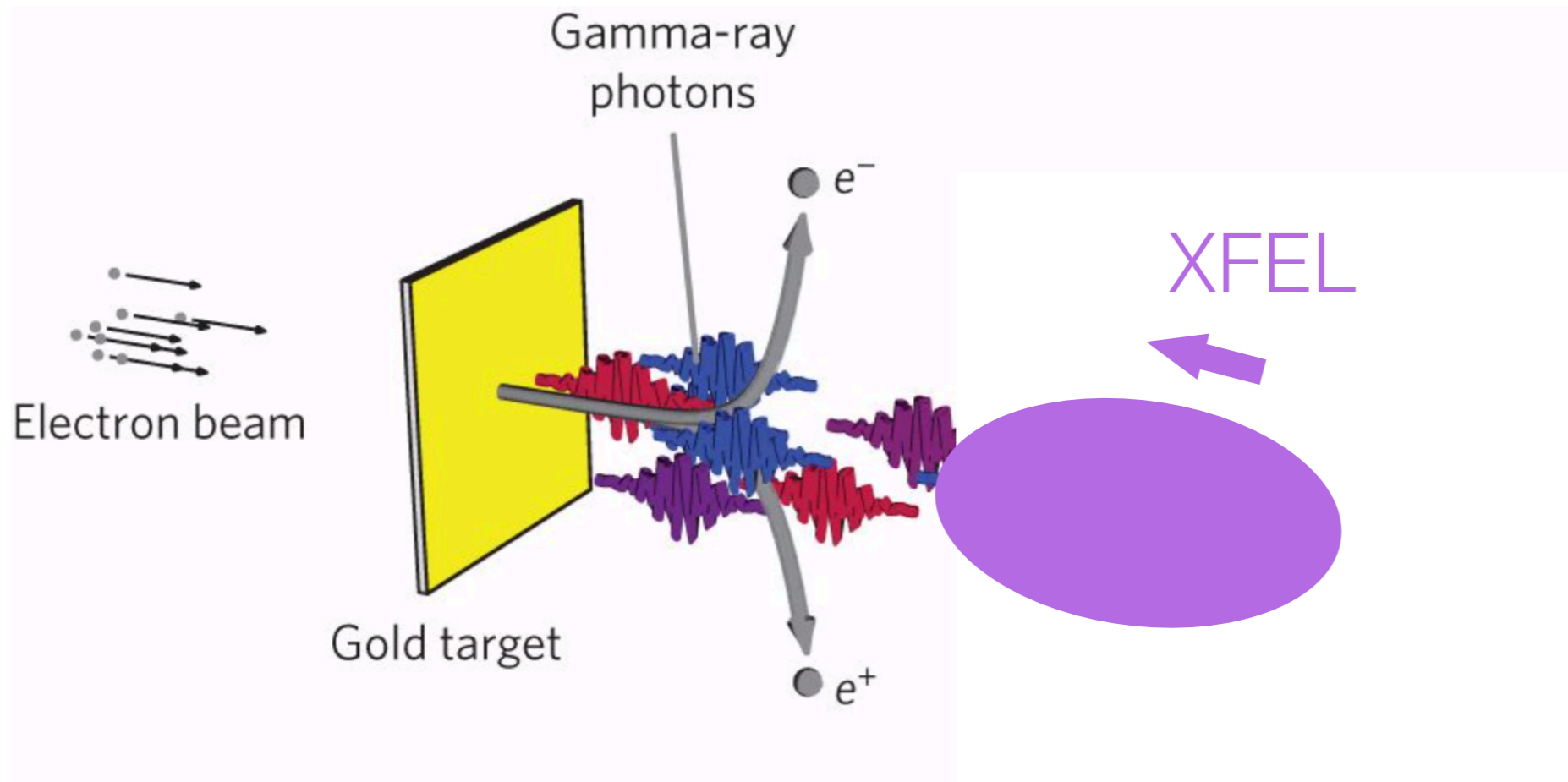
Pike et al Photon-Photon collider proposal

Pike et al., Nature Photonics, 8, 434–436 (2014)



- High-energy 100s MeV photons (LWFA + bremsstrahlung)
- Dense keV photons (MJ laser driven hohlraum)
 - » 10,000 e^+e^- per laser shot
 - » only few shots possible

Pike et al Photon-Photon collider proposal: use an XFEL



- High-energy 100s MeV photons (LWFA + bremsstrahlung)
- Dense keV photons from XFEL
 - » many e^+e^- pairs per shot
 - » a few elastic scattering events per shot

Summary

- Ability to combine a LWFA + XFEL could open new opportunities
- Two examples:
 - Betatron radiation as probe of high energy density matter far from equilibrium
 - photon-photon physics with real photons