# Probing Strong-field QED at FACET-II (SLAC E-320)

**Snowmass Community Planning Meeting**

**October 5-8, 2020**

Sebastian Meuren

(representing the E-320 collaboration)

U.S. DEPARTMENT OF ENERGY Office of Science

Stanford PULSE Institute

SLAC NATIONAL ACCELERATOR LABORATORY

# E-320 Collaboration (SLAC/FACET-II)

| | |
|---|---|
| Carleton University, Ottawa, Ontario, Canada | Thomas Koffas |
| Aarhus University, Aarhus, Denmark | Christian Nielsen, Allan Sørensen, Ulrik Uggerhøj |
| École Polytechnique, Paris, France | Sébastien Corde, Pablo San Miguel Clave |
| Max-Planck-Institut für Kernphysik, Heidelberg, Germany | Antonino Di Piazza, Christoph H. Keitel, Matteo Tamburini, Tobias Wistisen |
| Helmholtz-Institut Jena and University of Jena, Germany | Harsh, Christian Rödel, Felipe Salgado, Jannes Wulff, Matt Zepf |
| Universidade de Lisboa, Portugal | Thomas Grismayer, Luis Silva, Marija Vranic |
| Imperial College London, UK | Stuart Mangles |
| Queen's University Belfast, UK | Niall Cavanagh, Gianluca Sarri, Matthew Streeter |
| California Polytechnic State University, CA USA | Robert Holtzapple |
| Lawrence Livermore National Laboratory, CA USA | Félicie Albert |
| SLAC National Accelerator Laboratory and Stanford PULSE Institute, Menlo Park, CA USA | **Phil Bucksbaum**, **Zhijiang Chen**, Angelo Dragone, Frederico Fiuza, Alan Fry, **Elias Gerstmayr**, Siegfried Glenzer, Tais Gorkhover, Carsten Hast, Mark Hogan, Chris Kenney, Stephan Kuschel, **Sebastian Meuren (PI)**, Brendan O'Shea, **David Reis**, Douglas Storey, Glen White, Vitaly Yakimenko |
| University of California Los Angeles, CA USA | Chan Joshi, Warren Mori, Brian Naranjo, James Rosenzweig, Oliver Williams, Monika Yadav |
| University of Colorado Boulder, CO USA | Robert Ariniello, Michael Litos |
| University of Nebraska - Lincoln, NE USA | Ozgur Culfa, Matthias Fuchs, Kyle Jensen, Ethan Welch |

**International collaboration (16 institutions, 7 countries)**:
*SFQED theory & simulations, SFQED experiments (E-144, recent LWFA & crystal-based), strong-field AMO/x-ray science, HEDP/plasma physics, accelerator science, high-intensity laser & detector experts*

# E-320: collide 30 TW laser pulses with 13 GeV electrons

## QED scales

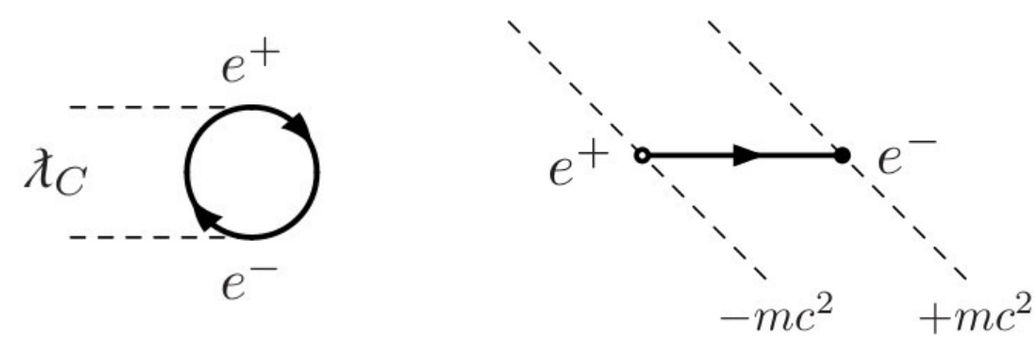
- *Energy*: $\mathscr{E} = mc^2 \approx 1$ MeV (electron/positron rest mass)
- *Length*: Compton wavelength $\lambda\!\!\!^{-}_C = \hbar/(mc)$ (vacuum fluctuations due to uncertainty)
- *Field*: $E_{cr} = m^2c^3/(e\hbar) \sim 10^{18}$ V/m
  Laser intensity: $I_{cr} = c\varepsilon_0 E_{cr}^2 \sim 10^{29}$ W/cm²

**Quantum/beamstrahlung parameter:** $\chi = E^*/E_{cr}$

measures rest-frame electric field $E^*$ in units of $E_{cr} = m^2c^3/(e\hbar)$

## QED critical field:

$E_{cr} = mc^2/(e\lambda\!\!\!^{-}_C)$: can transfer rest energy ($\sim mc^2$) over Compton length $\lambda\!\!\!^{-}_C = \hbar/(mc)$



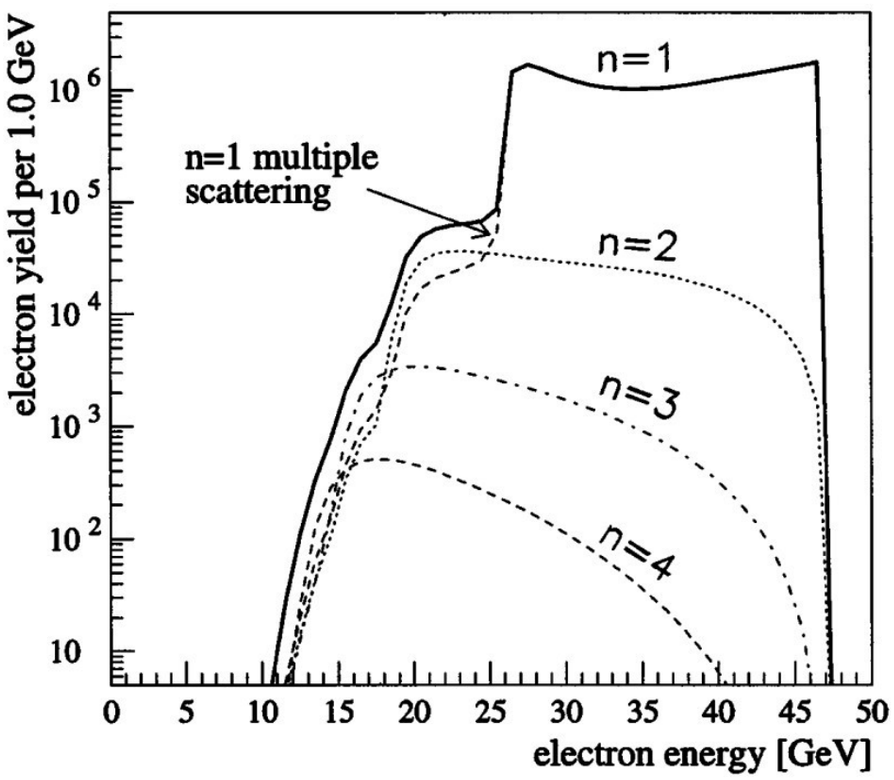

→ **QED vacuum becomes unstable**

FACET-II: Yakimenko et al., PRAB 22, 101301 (2019)

# E-320: observing nonperturbative photon emission

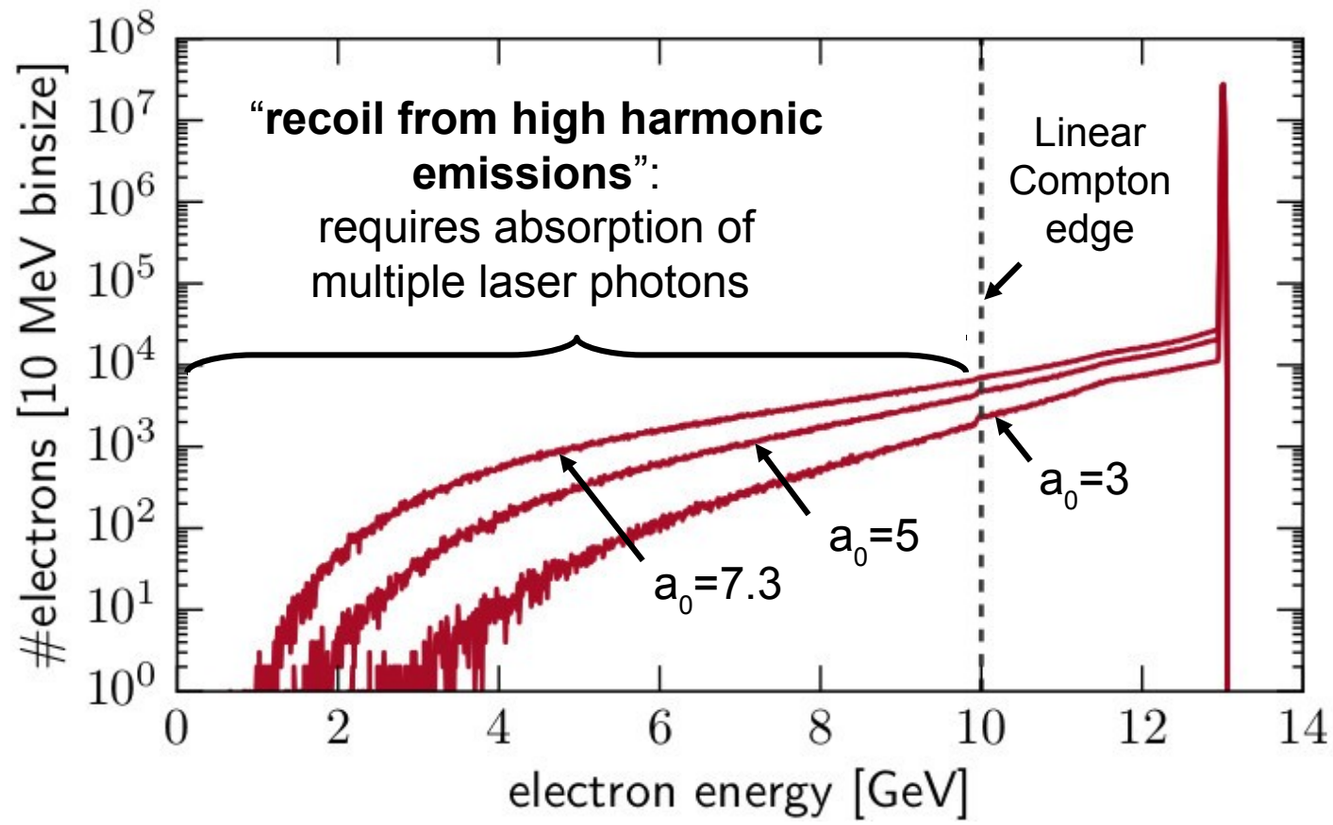
SLAC

## E-144: perturbative multi-photon regime
($a_0 \lesssim 1$, $\chi \lesssim 1$:1990s)




E-144 PRL 76, 3116 (1996)
perturbative scaling: $\sim a_0^{2n}$

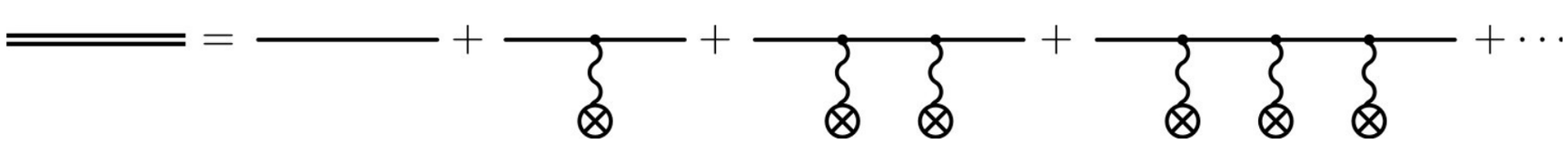
## E-320: nonperturbative quantum regime
($a_0 \gg 1, \chi \gtrsim 1$: 2021)




Simulations: M. Tamburini & M. Vranic

Interaction with n~100 laser photons

**Interaction with multiple laser photons** (e.g., Brown & Kibble, Phys. Rev. 133,1964):

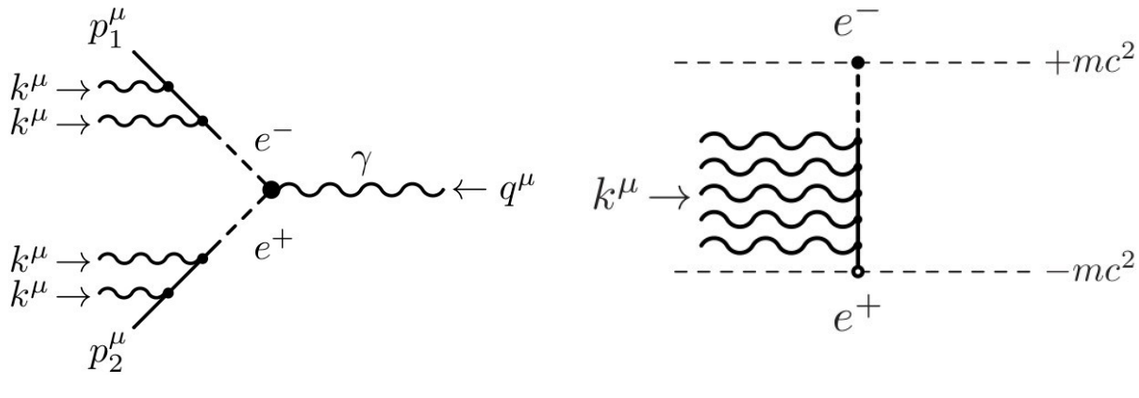


Breakdown of both classical synchrotron radiation and single-photon Compton scattering

$$a_0 = \frac{|e|E}{mc\omega} \approx 0.75\,\frac{\mathrm{eV}}{\hbar\omega}\sqrt{\frac{I}{10^{18}\,\mathrm{W/cm^2}}}$$

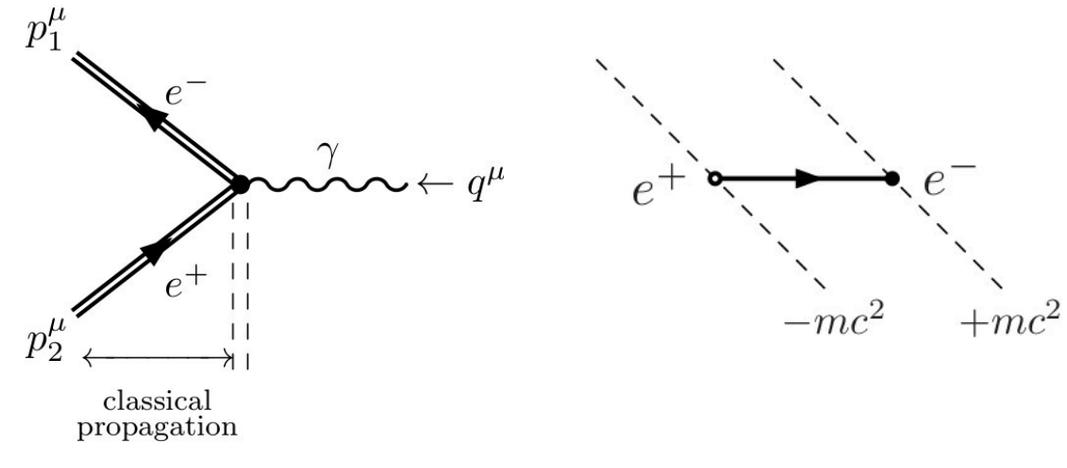
# E-320: observing photon-induced vacuum decay

## E-144: multi-photon pair production



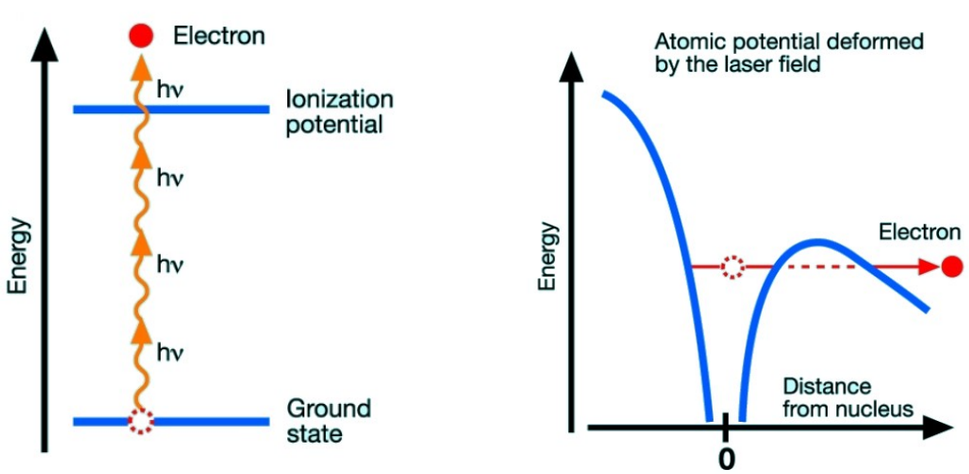

"Positron Production in Multiphoton Light-by-Light Scattering" E-144 PRL 79, 1626 (1997)

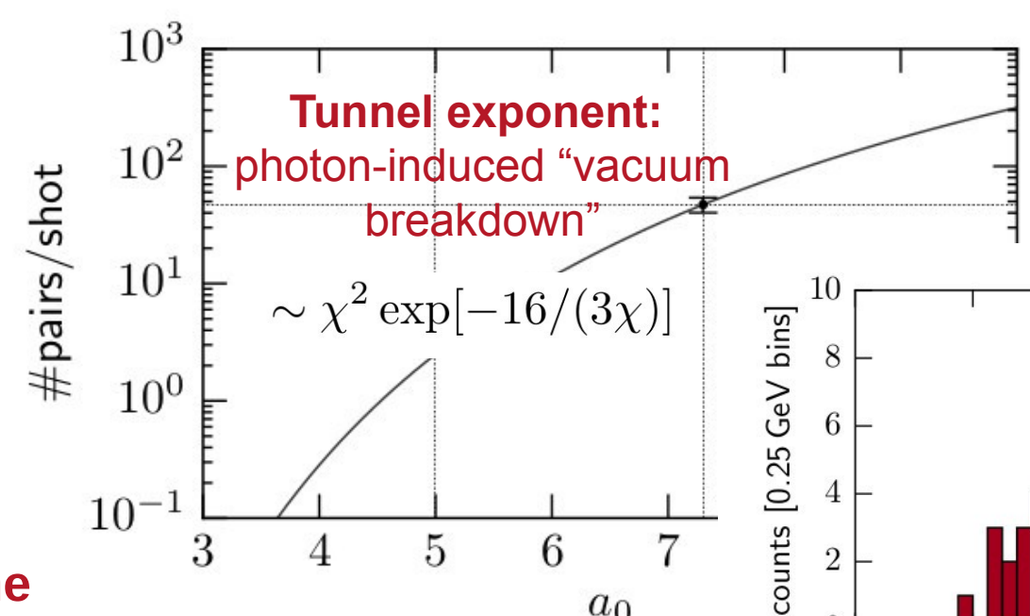
## E-320: tunneling pair production



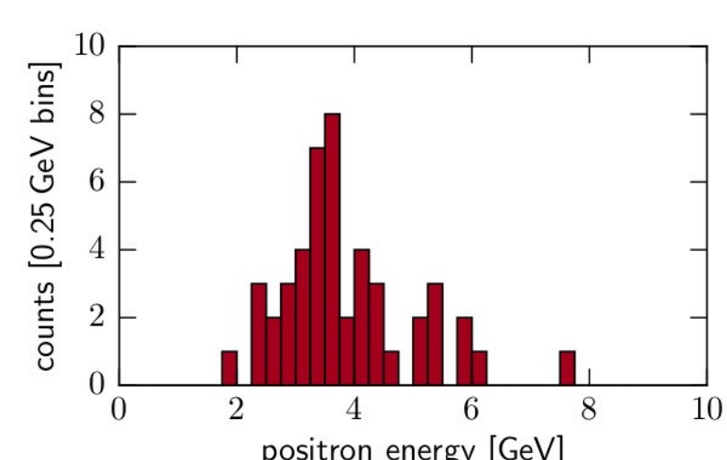

Photon → virtual pair → tunneling → real pair
(local constant field approximation)

## Completely analogous to tunnel ionization



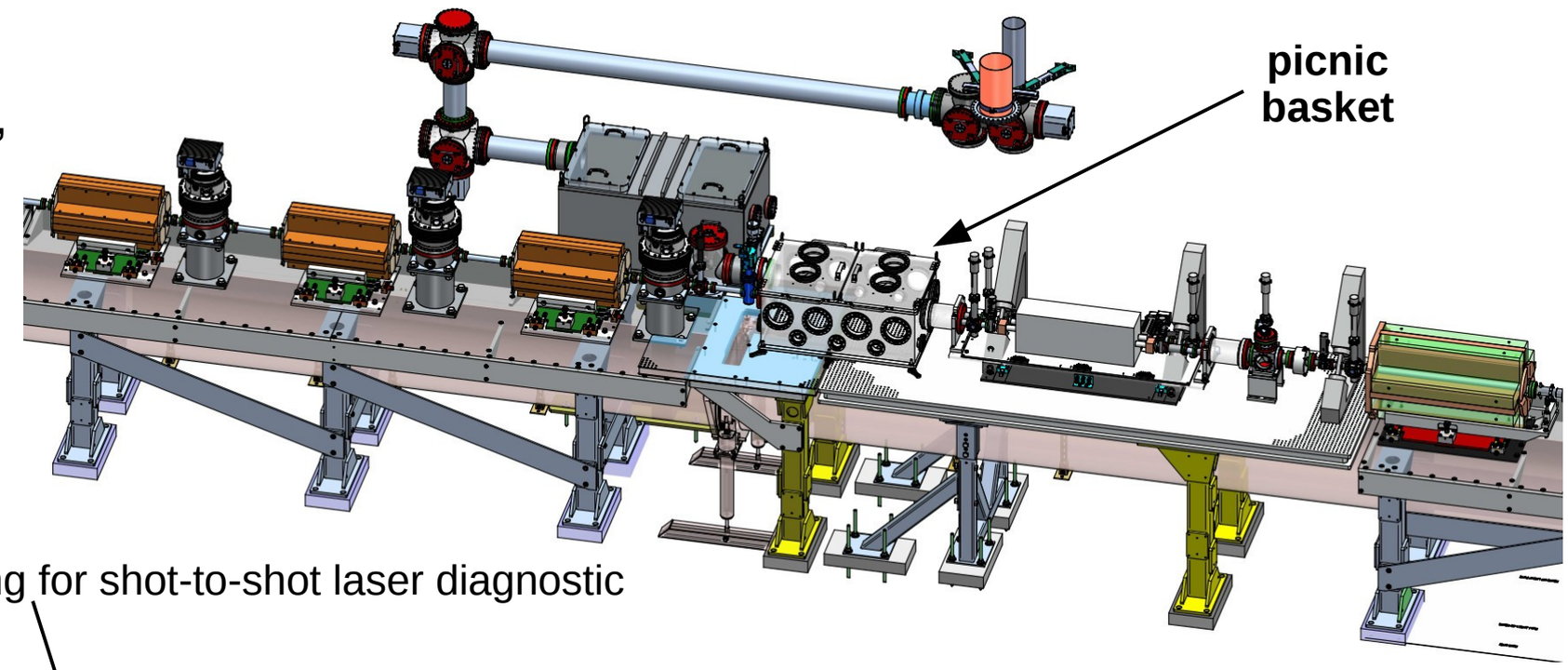

**Positron Production**

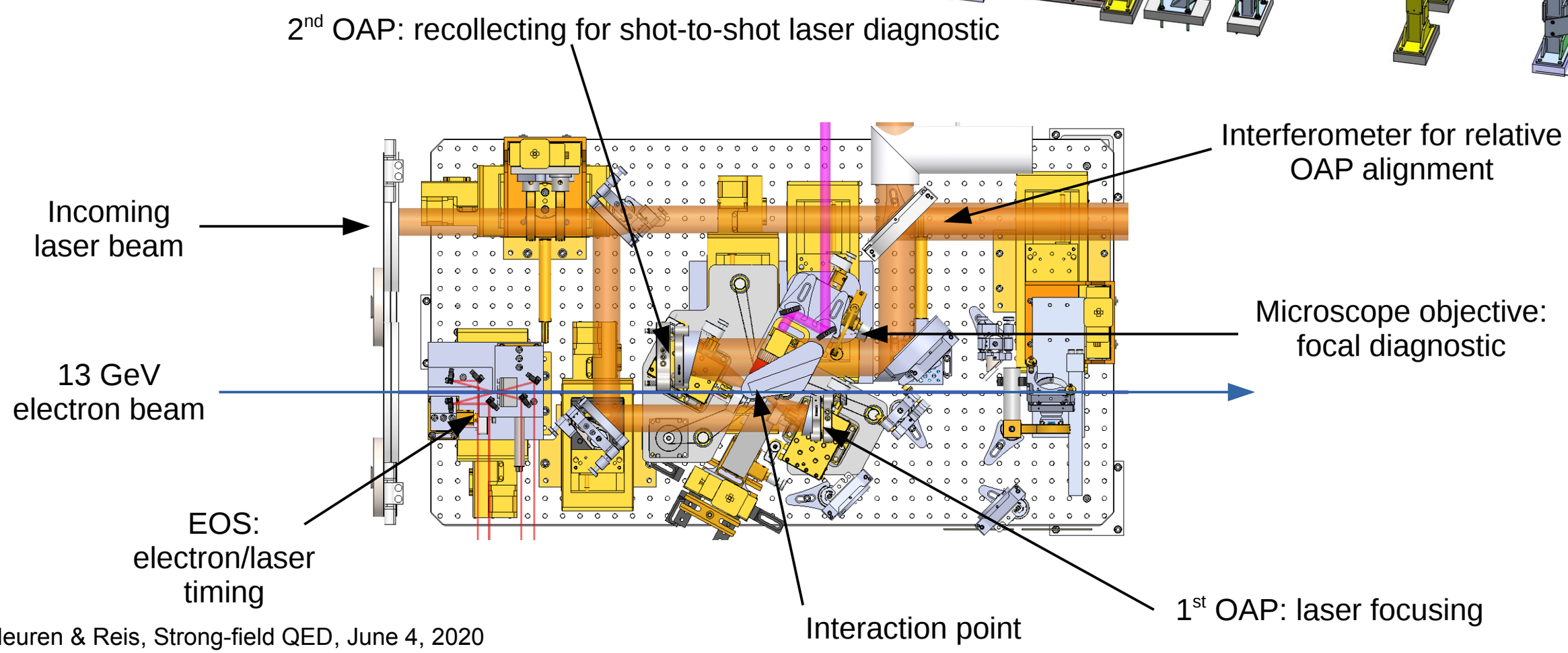



**E-320 will probe a qualitatively new regime of light-matter interaction**

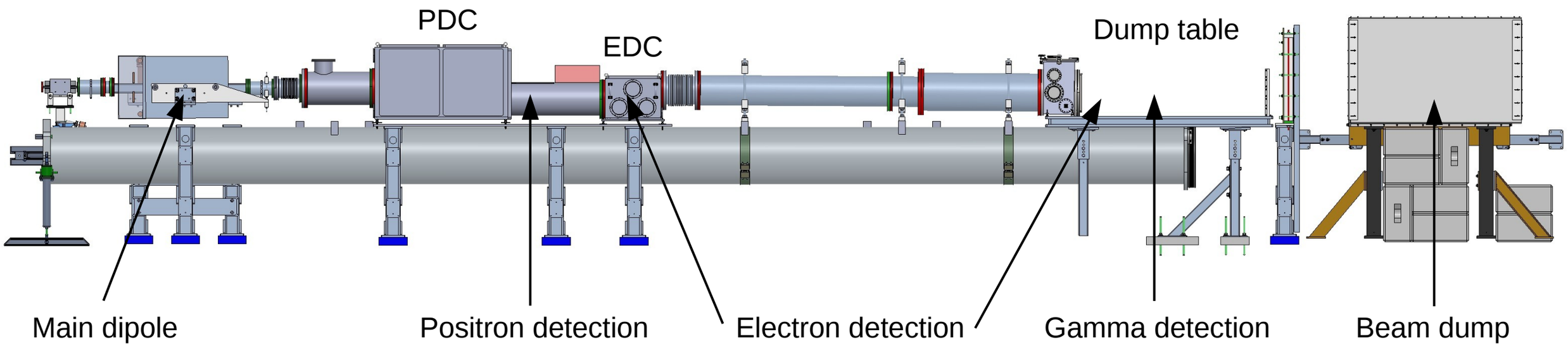
# FACET-II IP area

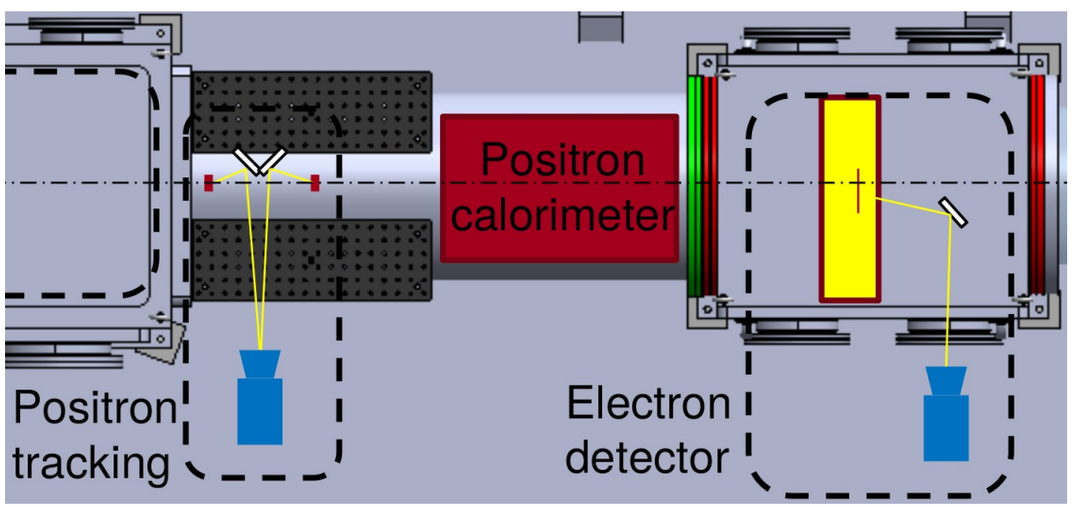
- Experiment will be installed in the FACET-II “picnic basket”
- Challenge: ~ 10 experiments will run “simultaneously”
- After LCLS-II is online: limited access 8 hours in 2 weeks



# FACET-II spectrometer beamline

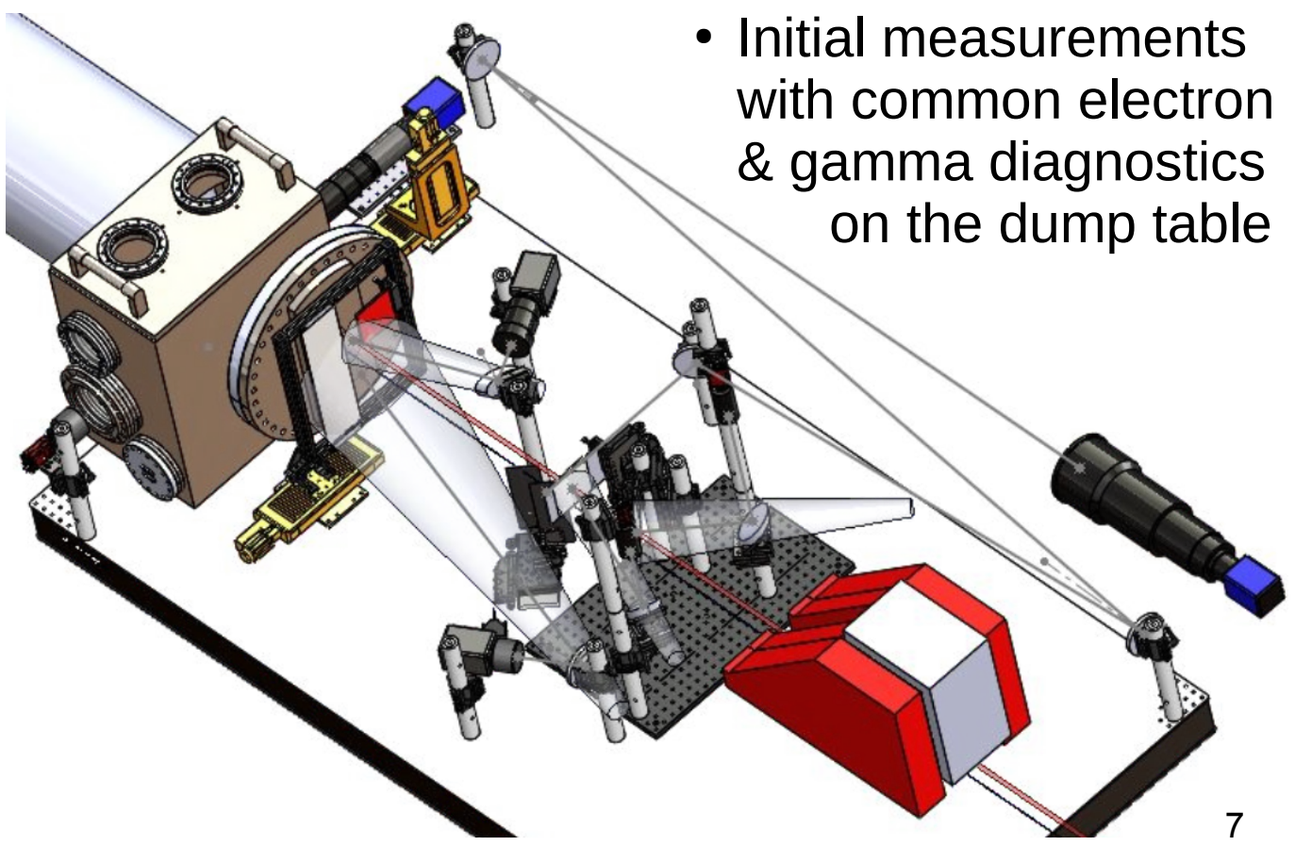



New beamline (D. Storey): detect single positrons and low-energy electrons with low background

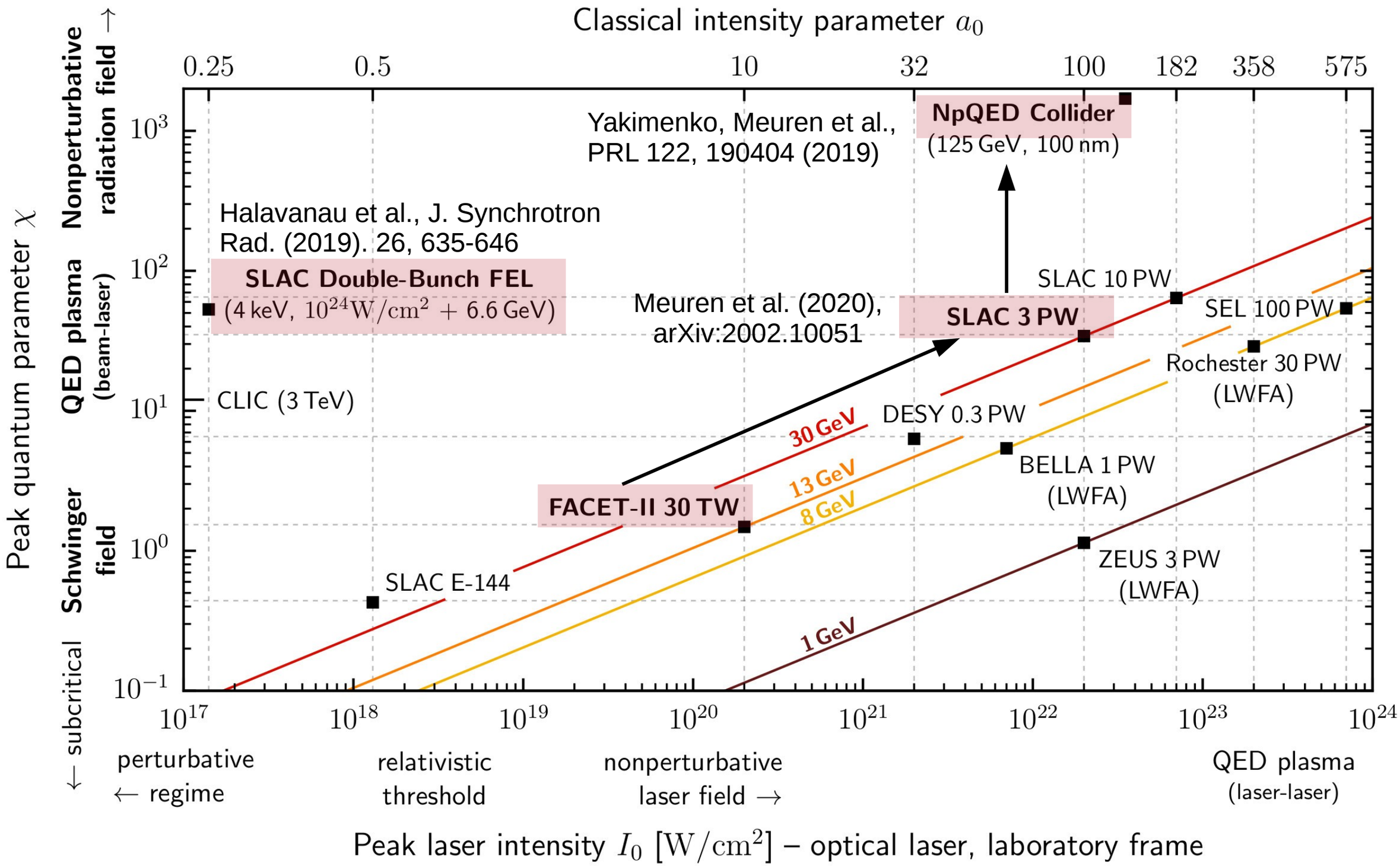
## Dump table diagnostics

- Initial measurements with common electron & gamma diagnostics on the dump table



**Next update: FACET-II PAC Meeting, 26-29 October 2020**
https://facet.slac.stanford.edu/proposals/pac2020

# Beyond E-320

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# Thank you for your attention