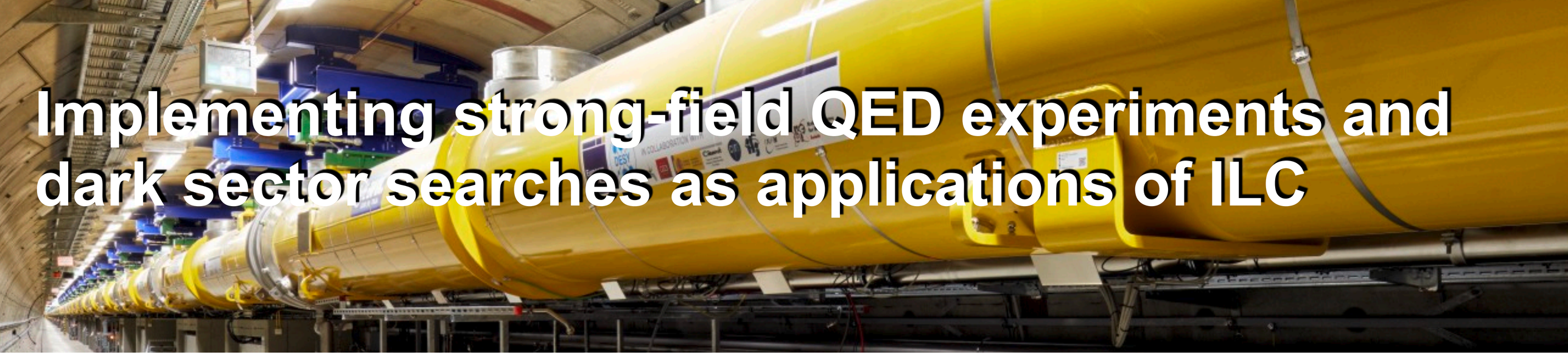
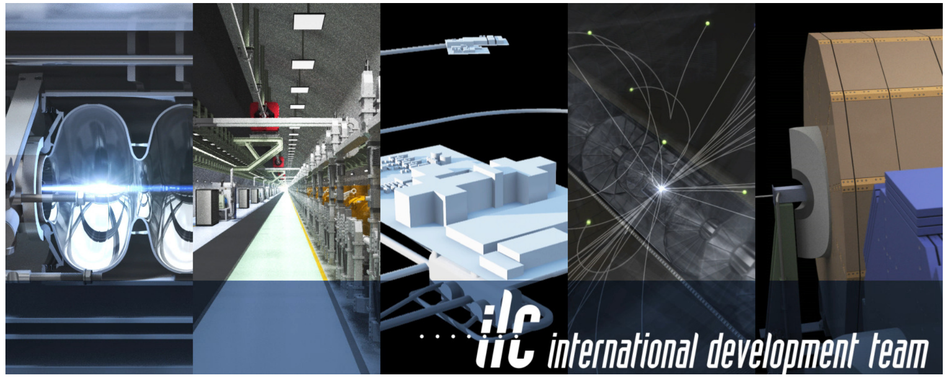


Implementing strong-field QED experiments and dark sector searches as applications of ILC

Jenny List (DESY)
on behalf of LUXE and the IDT
LCWS 2023, SLAC, May 18 2023



Strong-Field QED & Linear Colliders

Why are we talking about this

- dedicated SF-QED experiments can be interesting add-ons to future collider facilities, enriching the physics programme - requires appropriate planning!
  => second part of the talk
  => bonus: ALPS searches a la LUXE-NPOD
- SF-QED is actually the physics governing the beam-beam interaction
  => better knowledge of SF-QED might actually be important for design of future colliders and their precision measurements, eg because:
  - luminosity measurement from low-angle Bhabha scattering limited by knowledge of beam-beam effects
  - beam-beam effects change the effective polarisation

  => first part of the talk

Part I: SF QED for Colliders

Some basic definitions

- QED becomes non-perturbative above Schwinger critical field strength:

$$\mathscr{E}_{\mathrm{crit}} = m_e^2 c^3 / \hbar e = 1.32 \cdot 10^{18}\ \mathrm{V/m}$$

- such an electric field would pull real e+e- pairs out of the ``vacuum'' – analogy: Hawkings radiation
- can reach such fields in lab by
  - shooting highly-intense laser on electron beam
  - by colliding dense e+ e- bunches

  => particle energy helps to reach $\mathscr{E}_{\mathrm{crit}}$ in rest-frame of particle!
- non-linearity / non-perturbativity quantified by
  - $\chi = \gamma \cdot \mathscr{E} / \mathscr{E}_{\mathrm{crit}}$ - in collider context often called Υ, with average

$$\Upsilon = \frac{2}{3}\frac{\langle E_{\mathrm{c}} \rangle}{E_{\mathrm{beam}}} = \frac{5 r_{\mathrm{e}}^2 \gamma N_{\mathrm{e}}}{6 \alpha_{\mathrm{e}} \sigma_{\mathrm{z}} (\sigma_{\mathrm{x}}^* + \sigma_{\mathrm{y}}^*)}$$

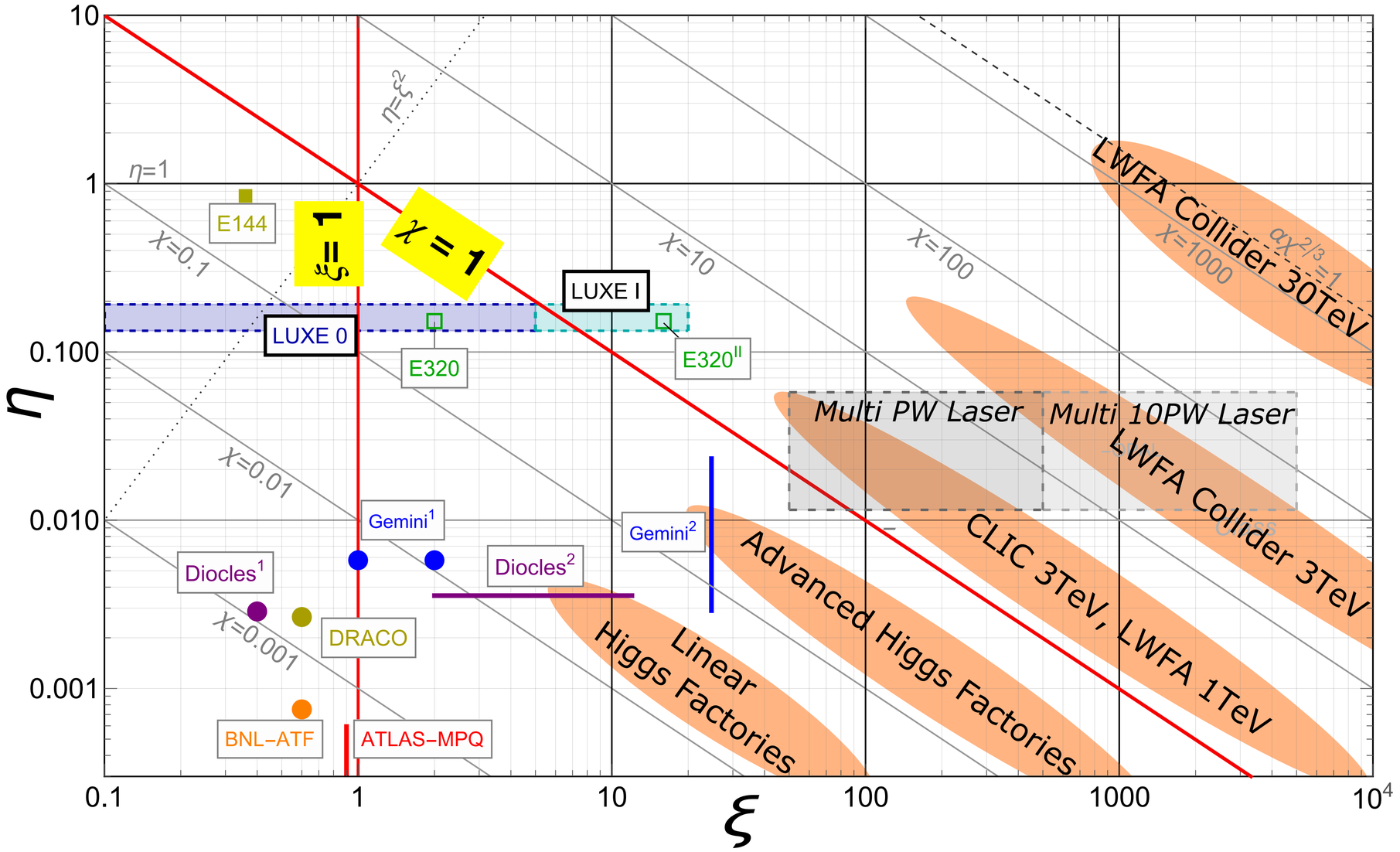
  - "intensity parameter" ξ (often also a0) = work done by background field over a Compton wavelength of the electron in units of the background field's photon energy
    - "obvious" in laser context - less clear how that translates to beam-beam collisions?
    - estimated for **round** beams [arxiv:1807.06968]
      (I don't know a corresponding formula for flat beams
      - if you do, let me know!)

$$a_0 = \sqrt{\frac{2}{\pi^3}} \frac{r_e}{\sigma_0} N$$

Linear Colliders in SF-QED Parameter Space

using the approx. formulae

$$\chi = \eta\xi$$



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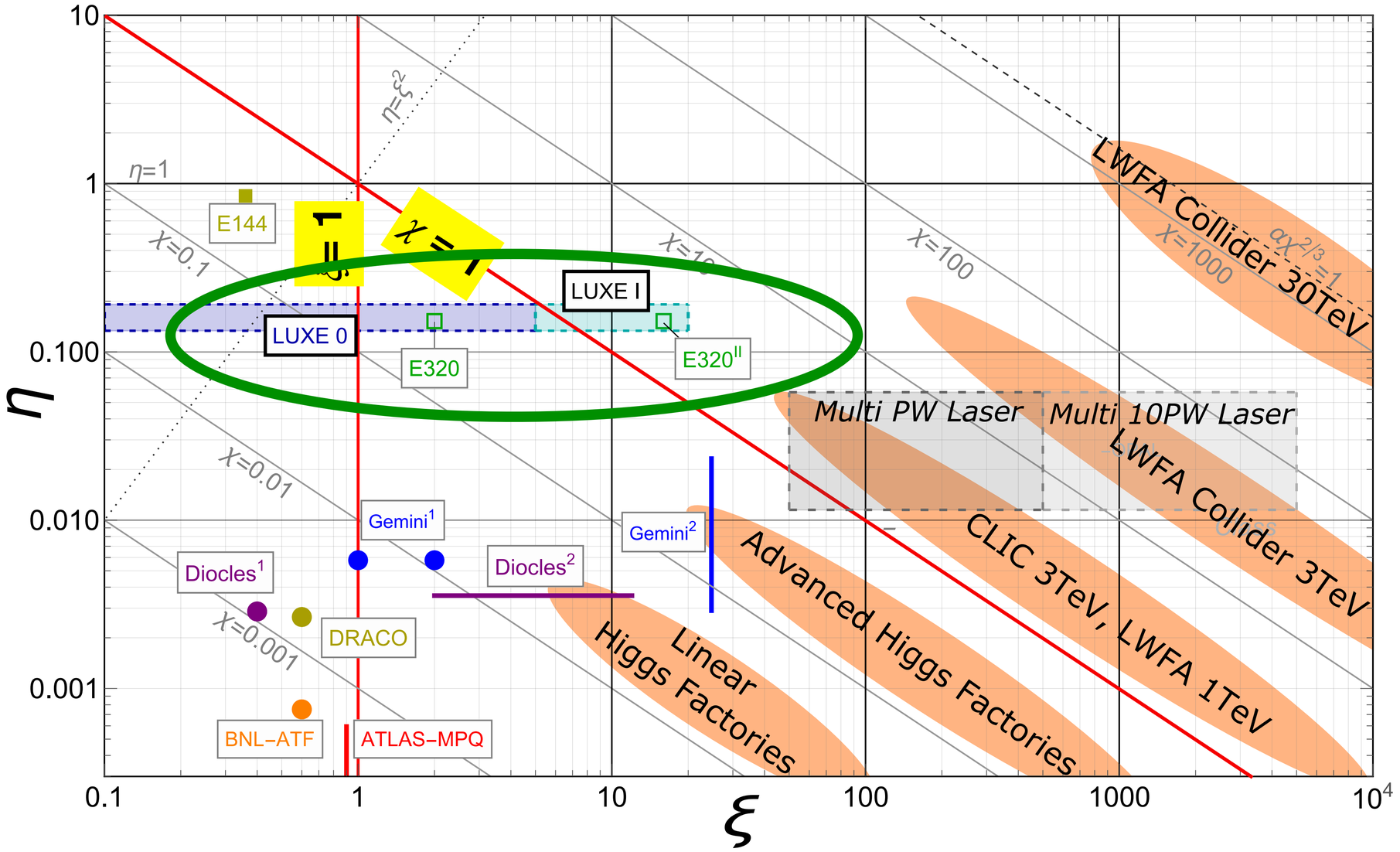

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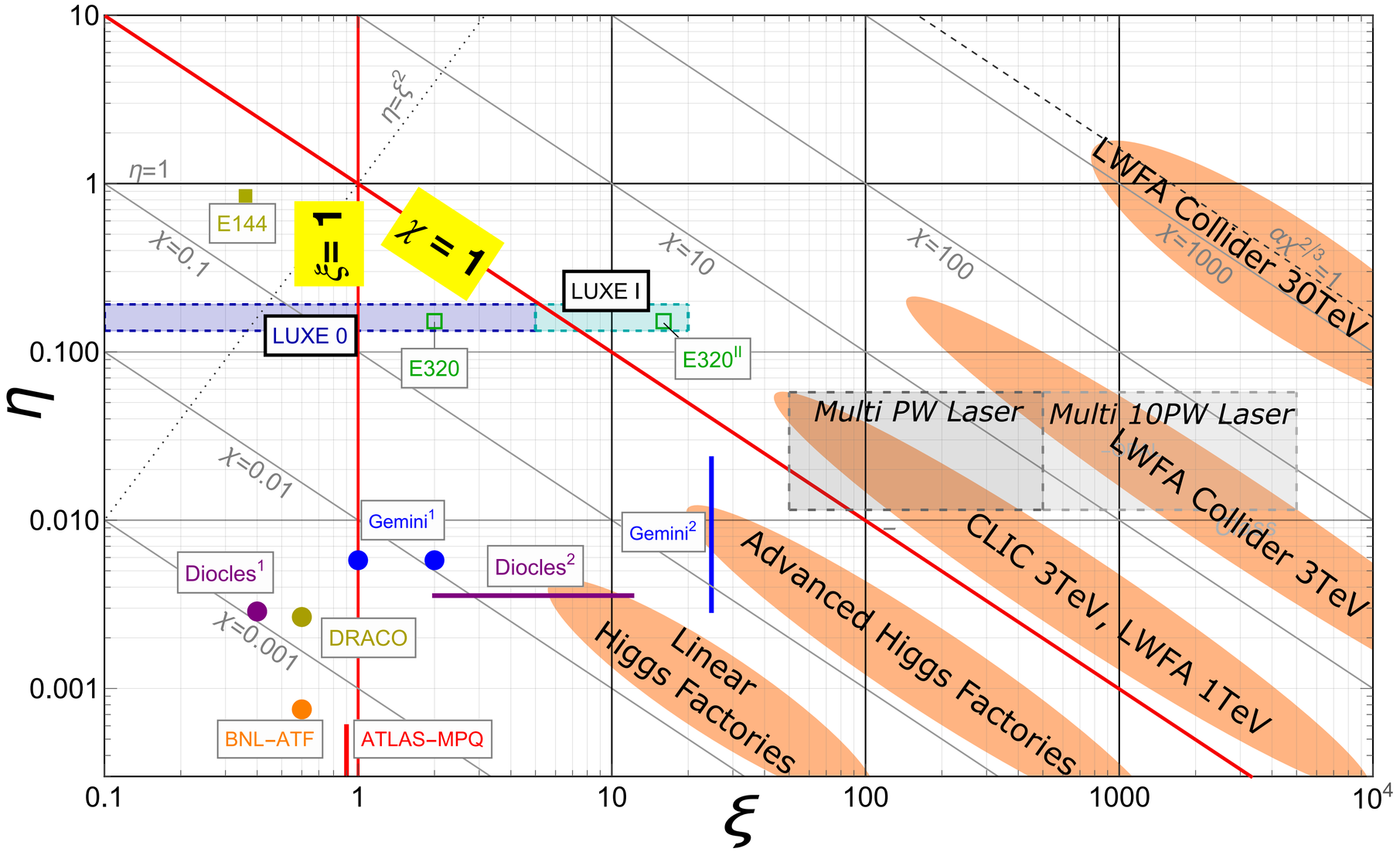

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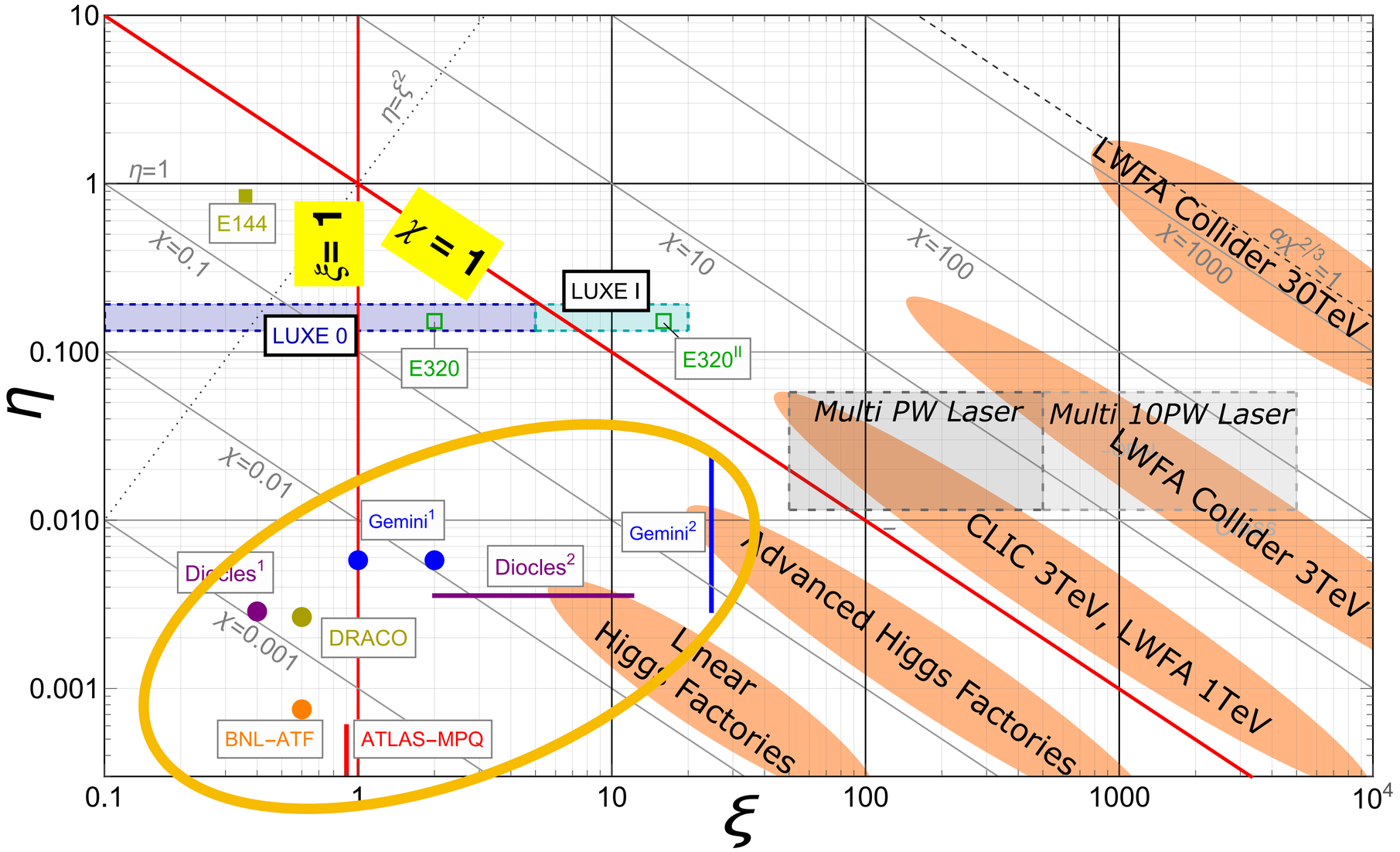

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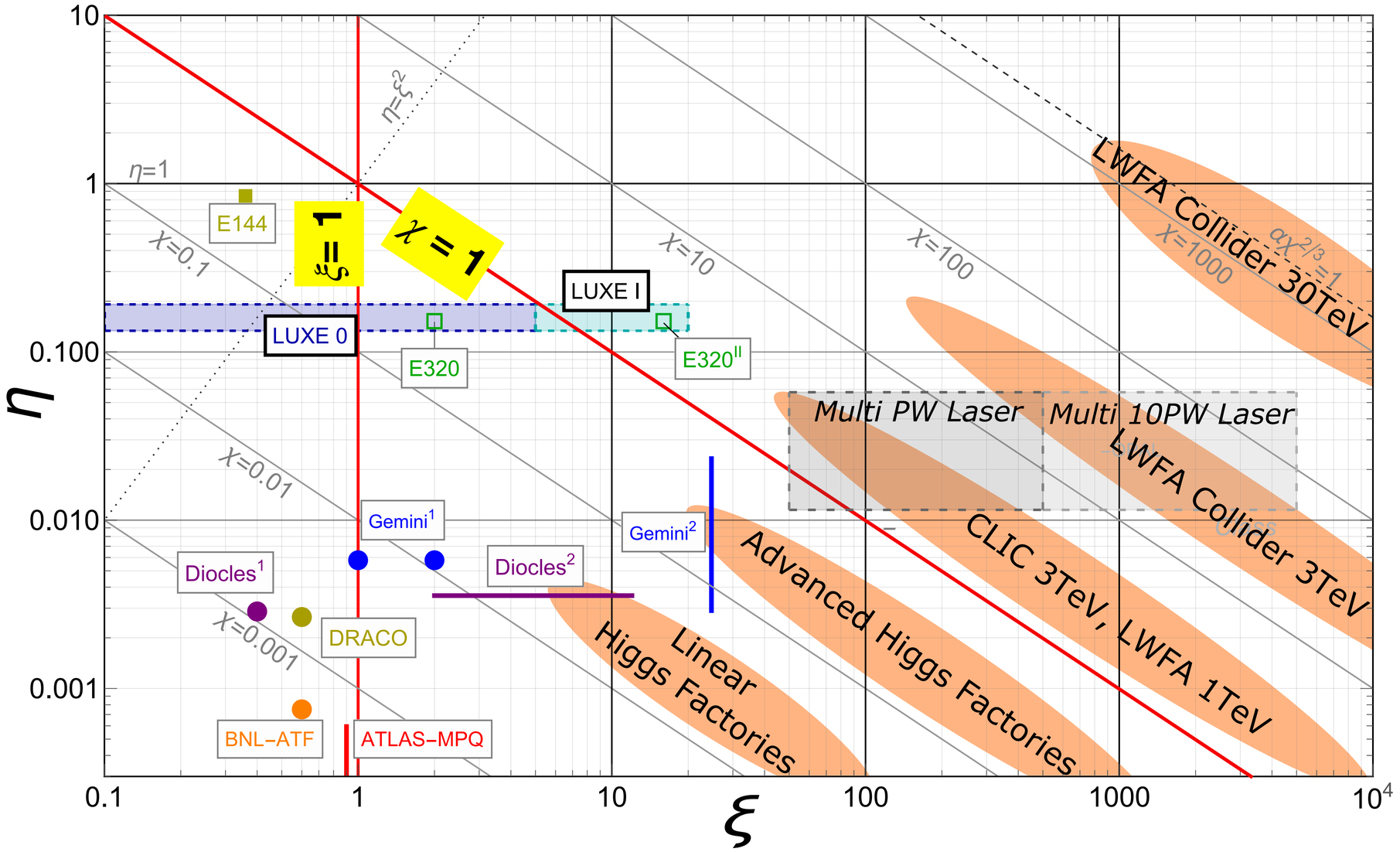

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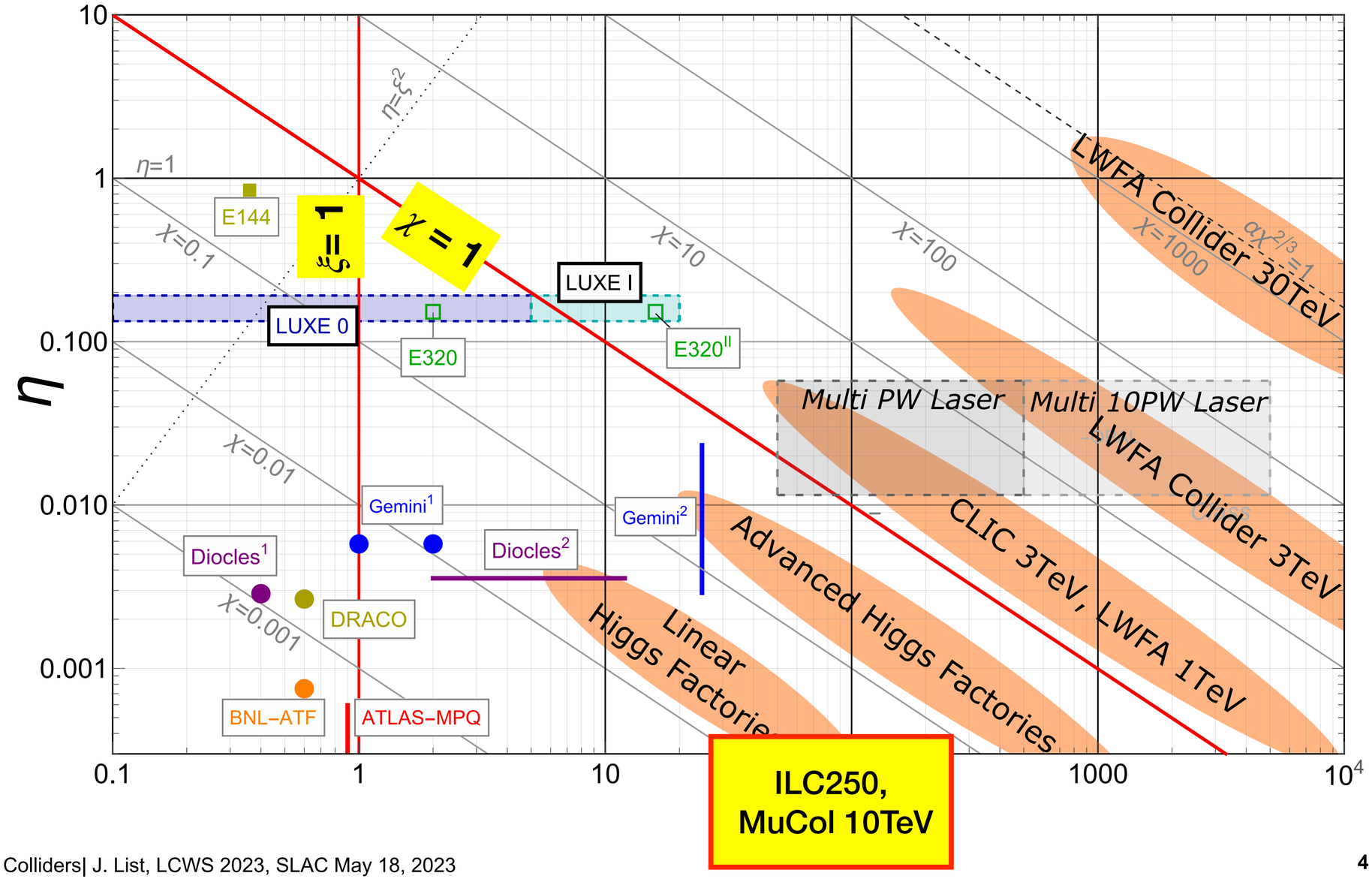

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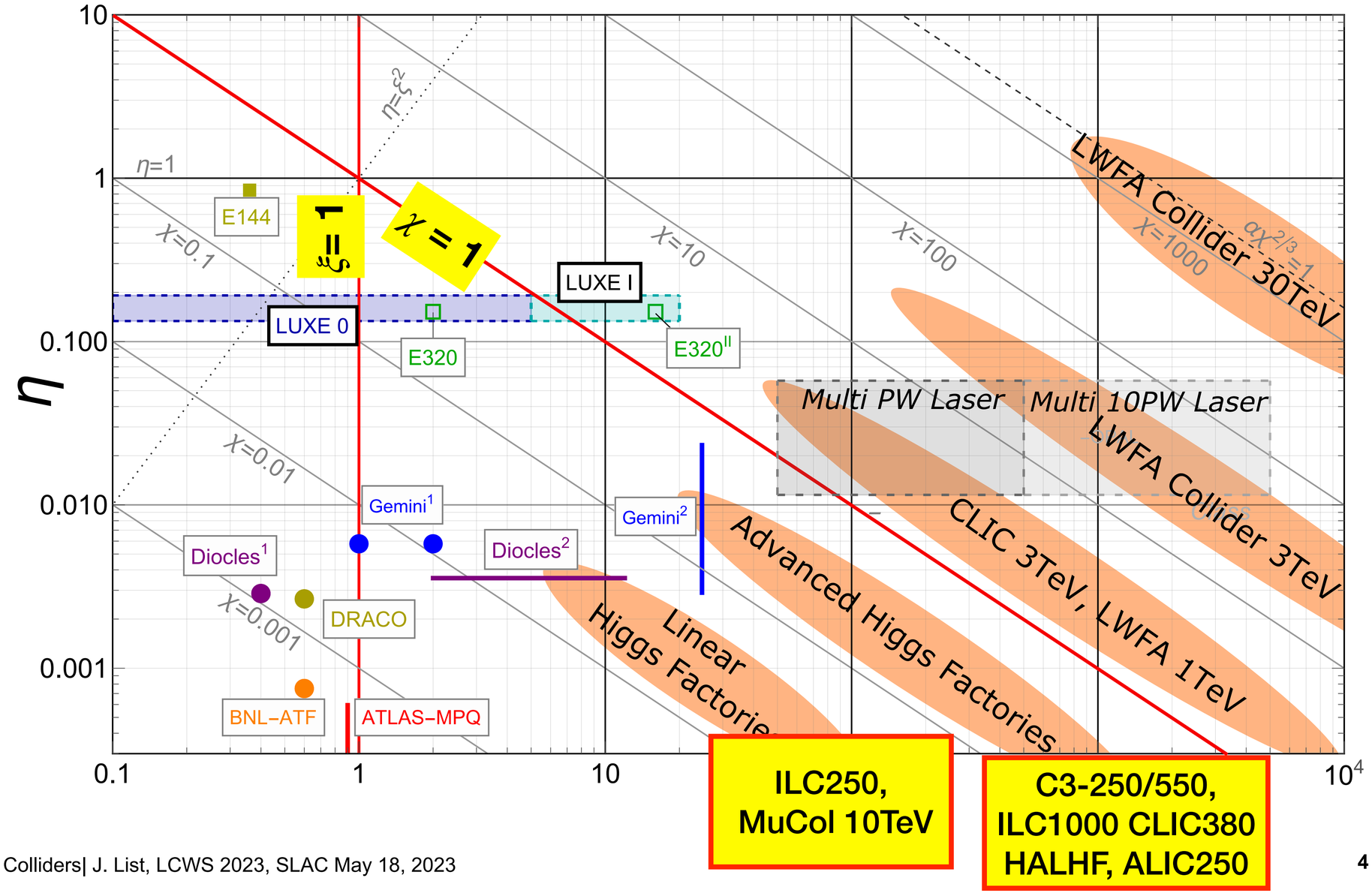

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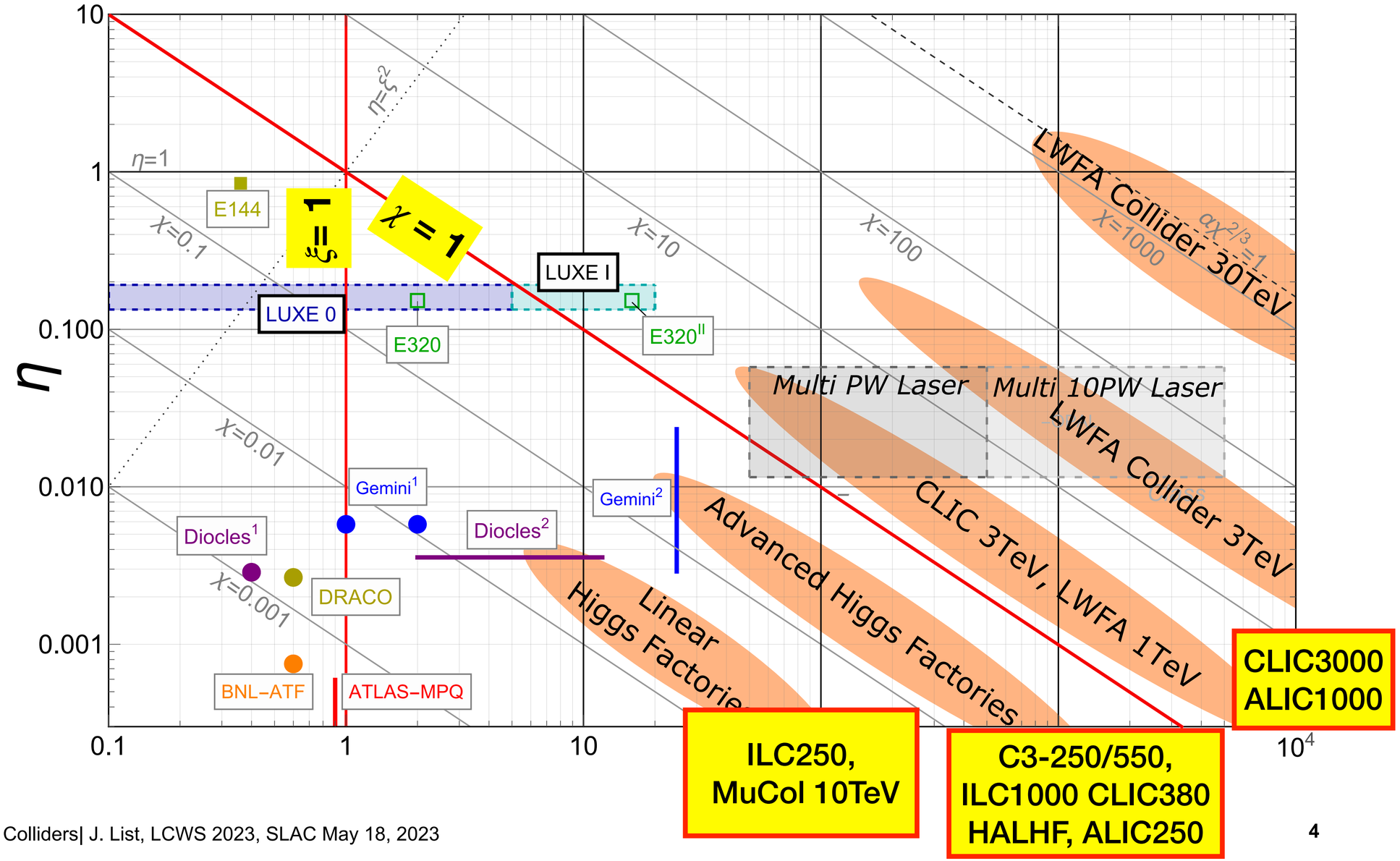

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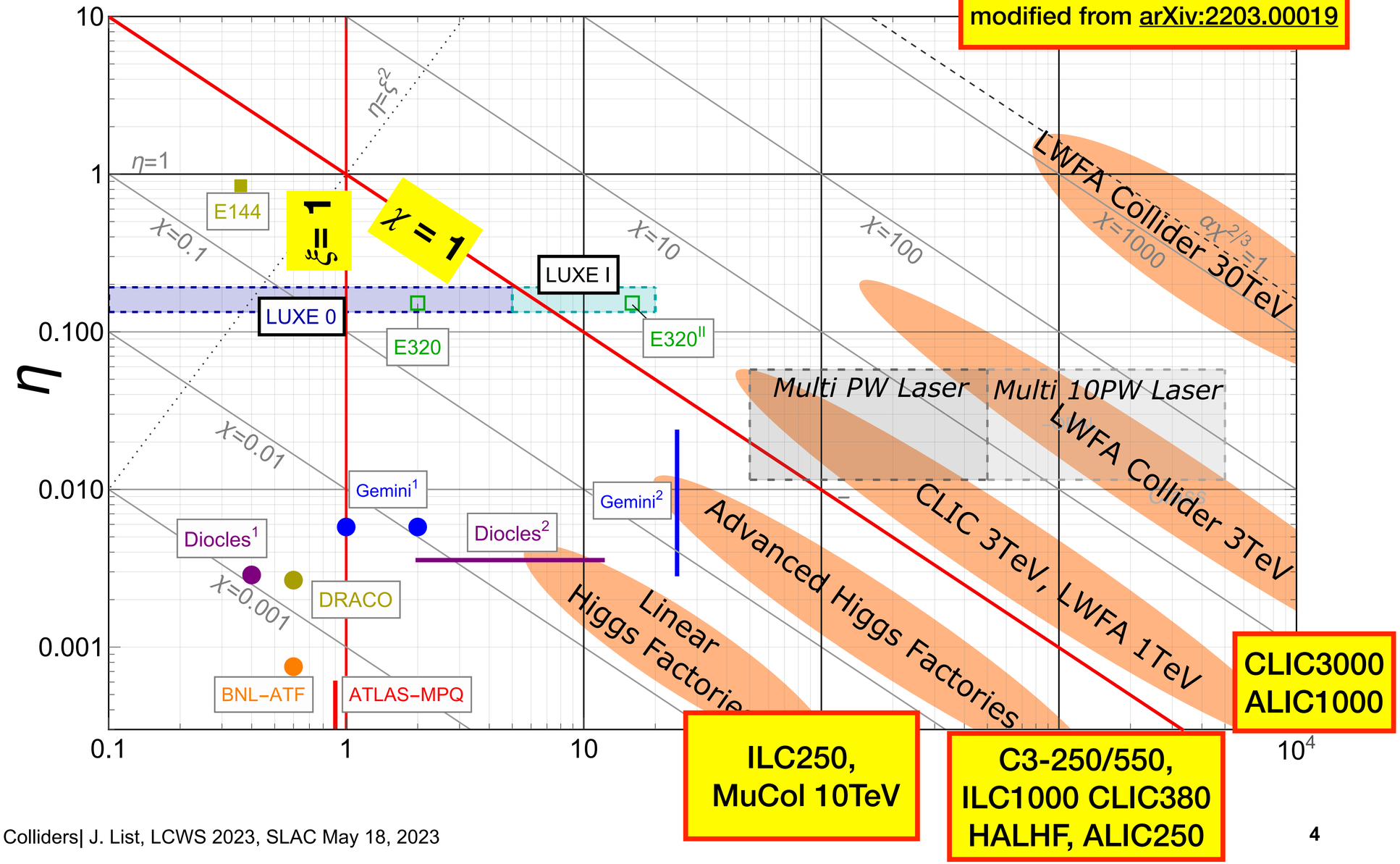

Beyond power-point drawing

Do we know enough?

- electron-laser experiments will probe new regimes in χ, ξ very soon
- significant theory progress in the last decade
  - all formulated from the perspective of strong-field created by a laser pulse
- **=> How do they translate to beam-beam collisions?**
- obviously, this is much more complicated than the simple “average” formulas
  - since many decades, use Particle / Cloud in Cell codes to calculate field strength on grids as beams pass through each other => GuineaPig/GuineaPig++ (D.Schulte) / CAIN (K.Yokoya)
  - have been written in the 1990s (various updates since) and are indispensable for designing e+e- colliders
  - how should they be upgraded to include recent upcoming exp. test?
  - what is the long-term prospects for maintanance and further development of these codes?

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recent review eg
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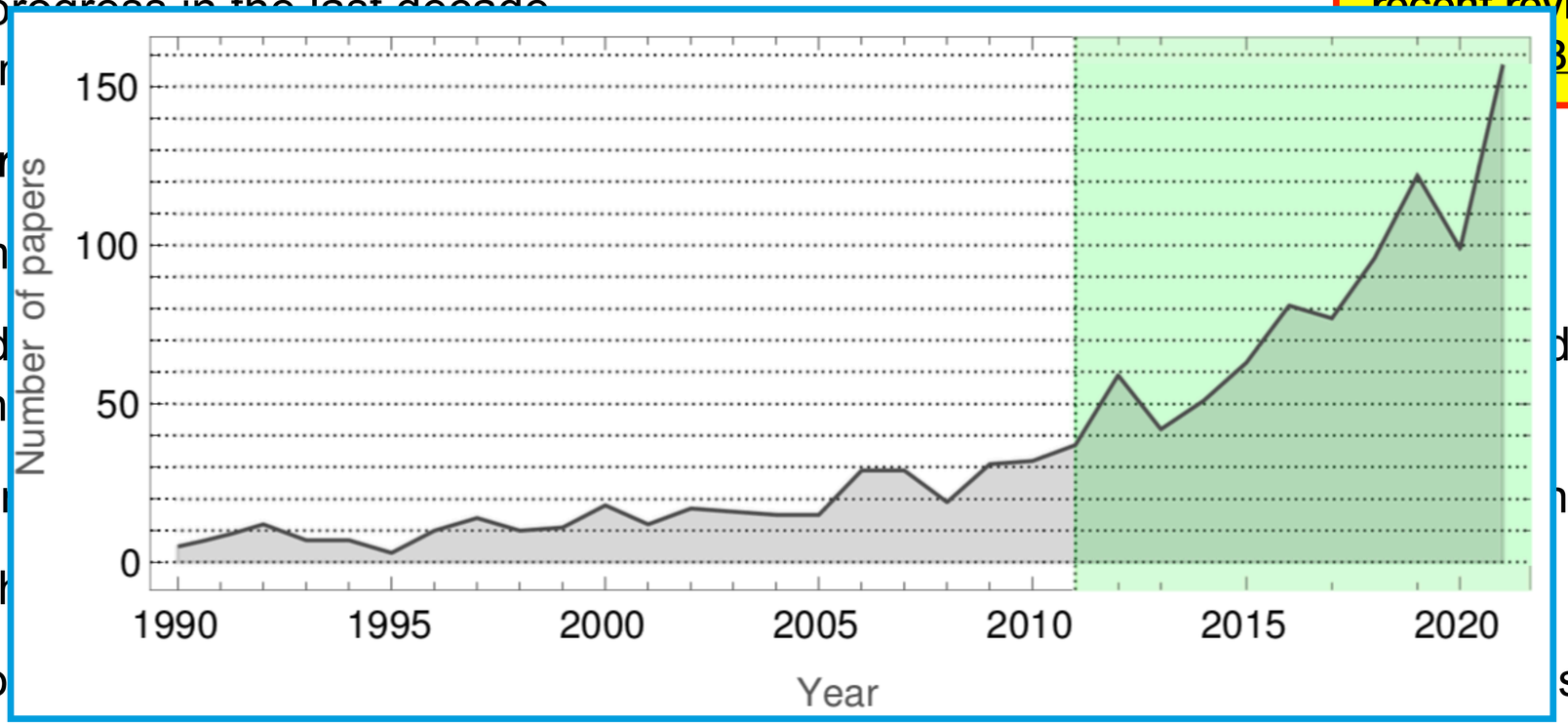

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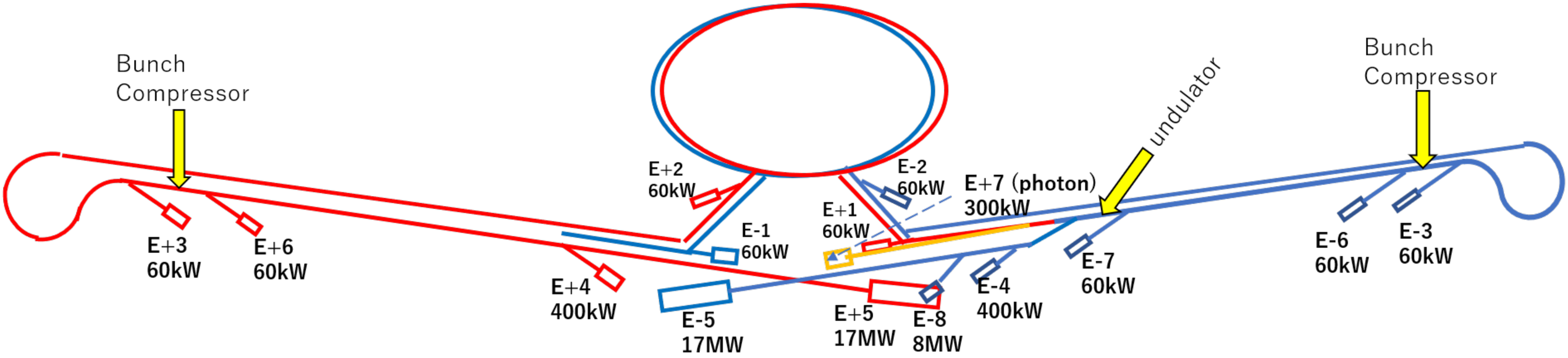
Part II: SF-QED at Colliders - mainly ILC

Overview



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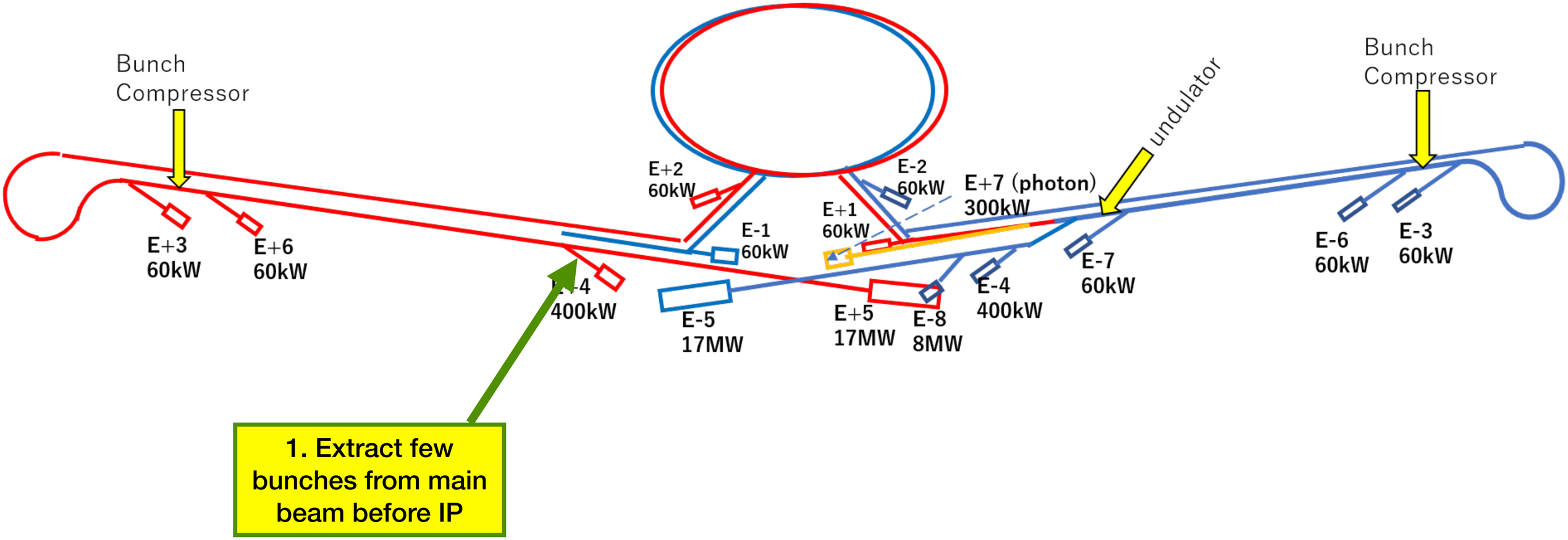

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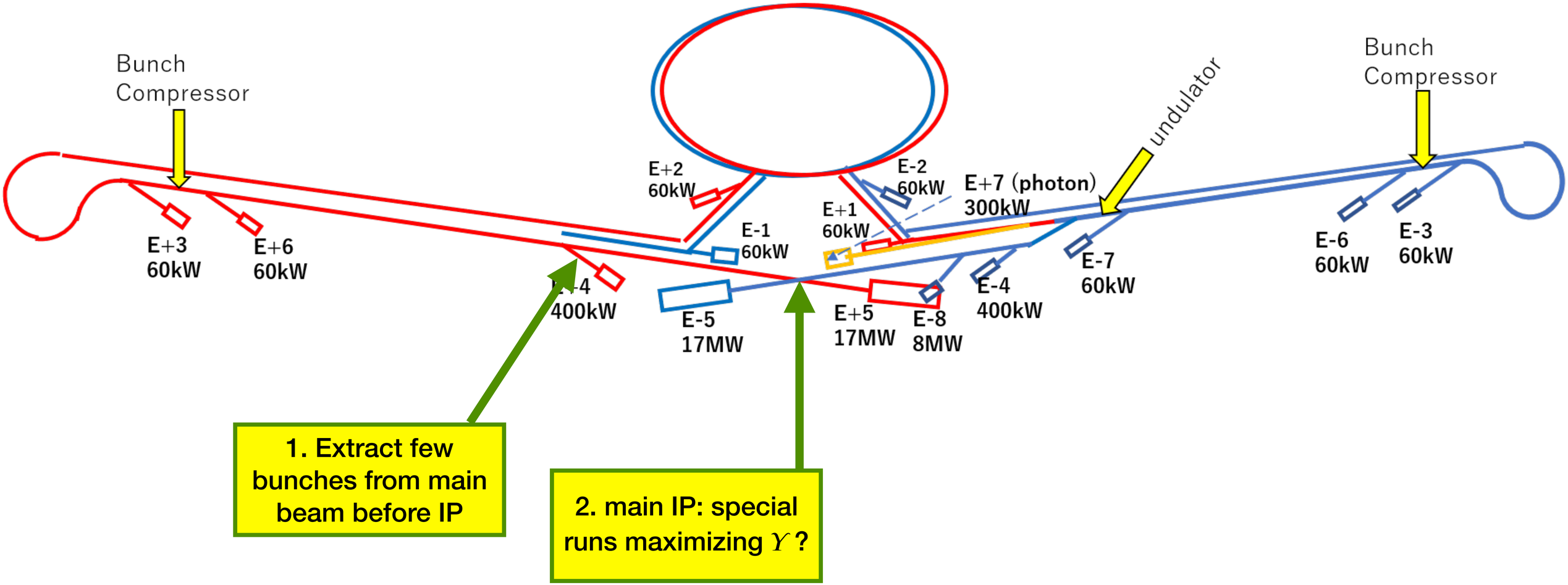

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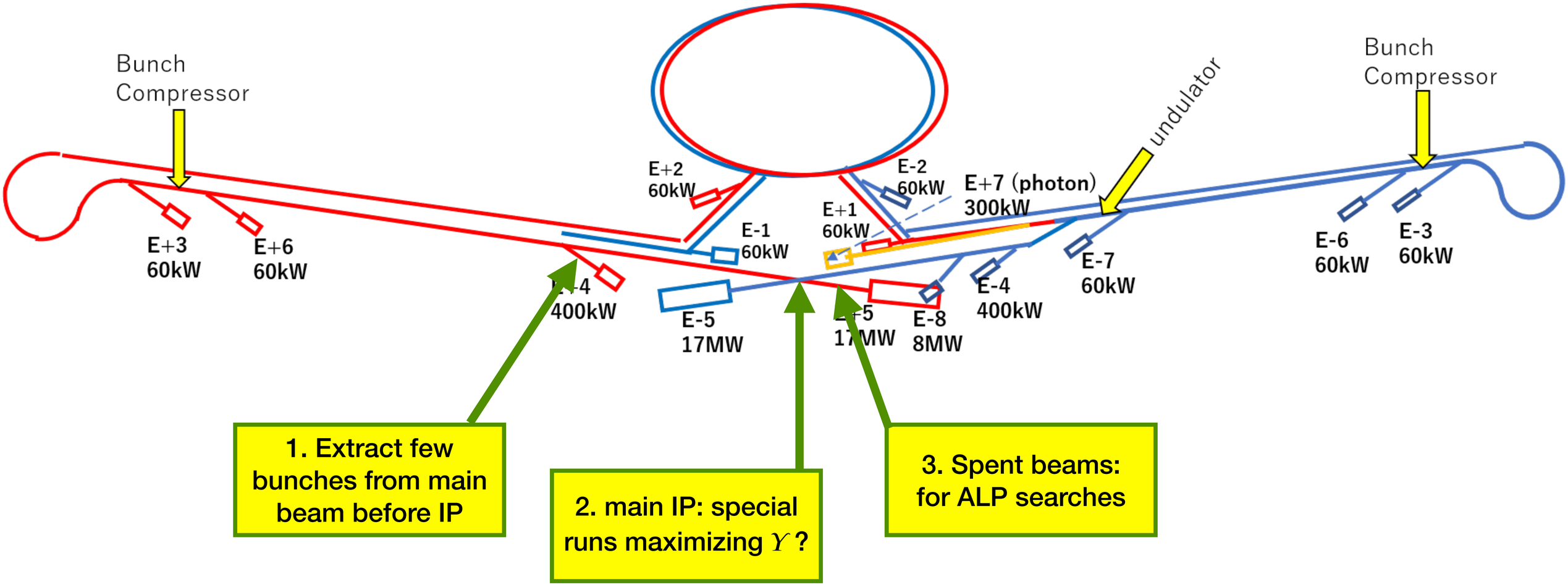
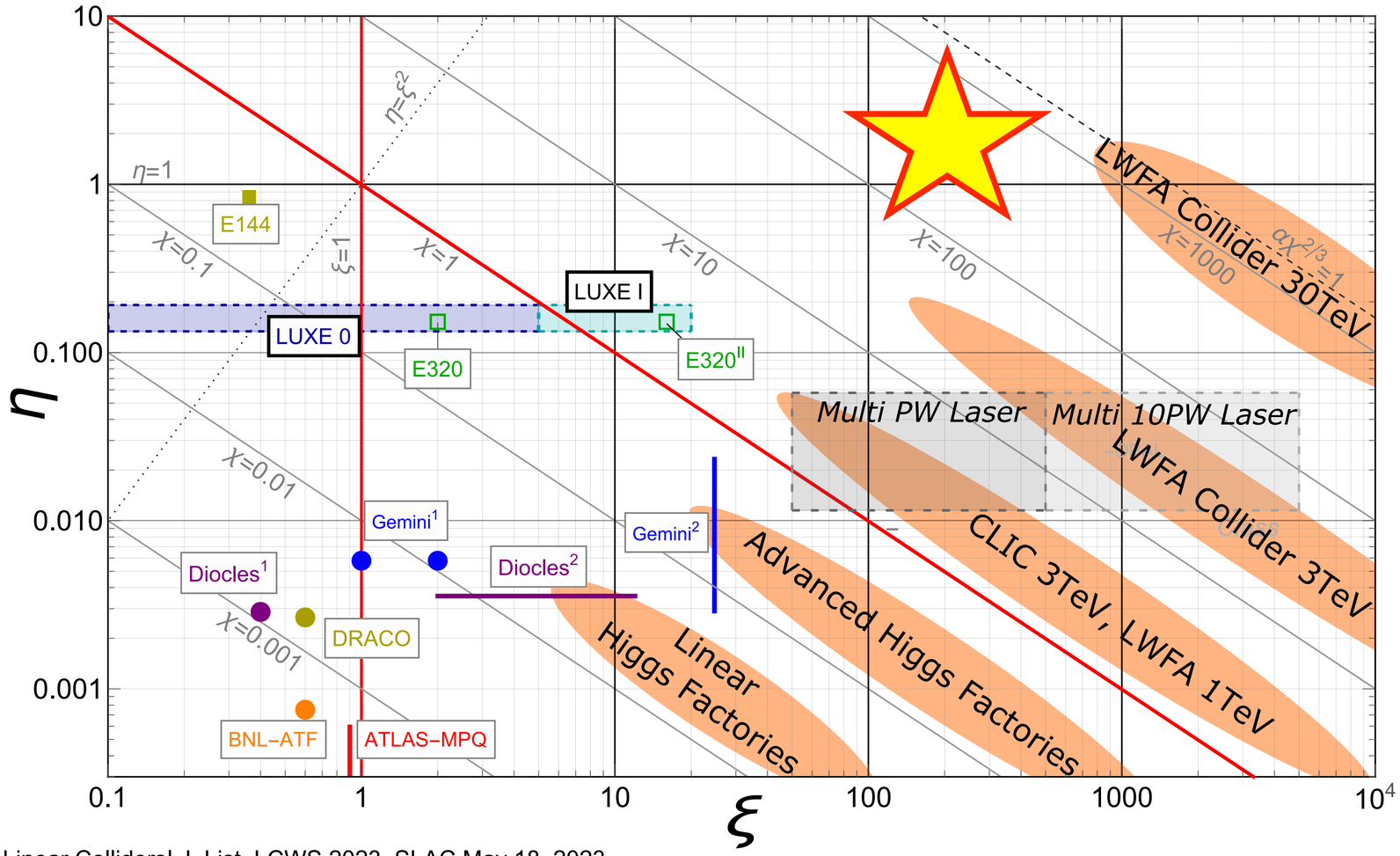


1. LUXE-QED@ ILC

Why are we talking about this

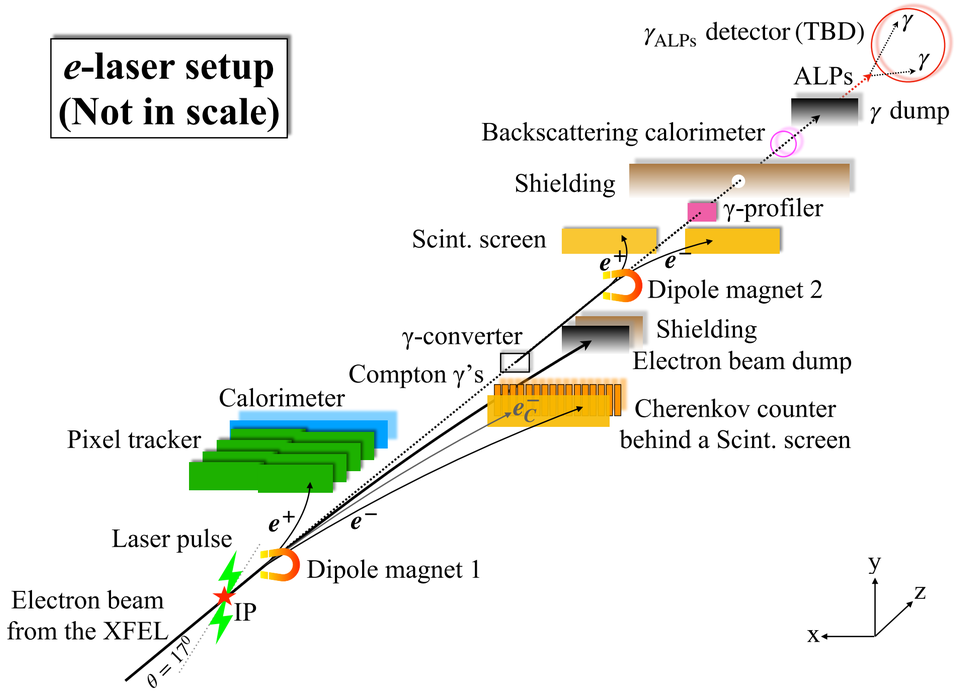
- LUXE (@Eu.XFEL) will probe up to $\xi \simeq 20$, $\chi \simeq 4$
- same laser etc: 17 GeV -> 125 GeV -> 500 GeV=> $\chi \simeq 4$ -> 30 -> 120
- +laser development: another factor 10 on χ

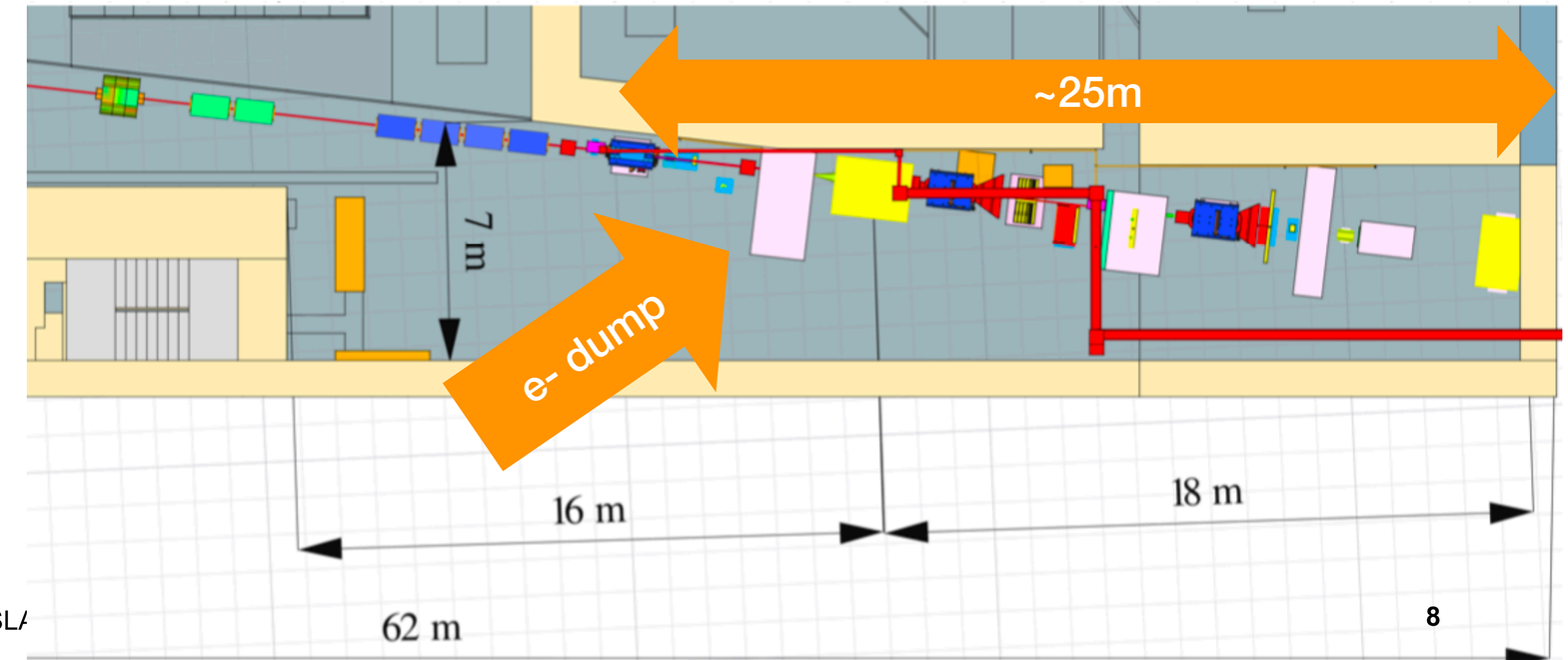


1. LUXE-QED@ ILC

How to

- need well-known beam propertied => tune-up dump
- LUXE:
  - detectors need ~25m after e-laser IP
  - ~5m between e-laser IP and e- dump
- LUXE@ILC:
  - need dipole between e-laser IP and dump
  - higher energy
    - longer drift space for sufficient separation of γ, e-
    - thicker shielding behind dump
    - longer instrumentation?
  - in any case: need significant space ~30m (?) behind dump





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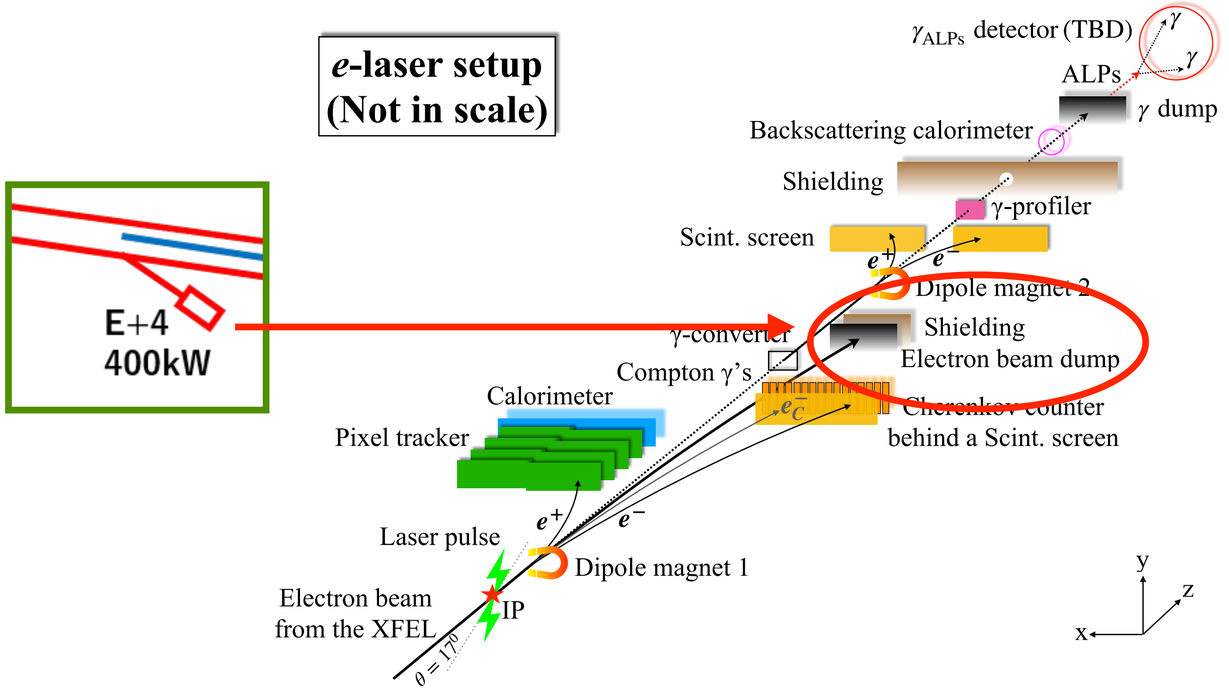
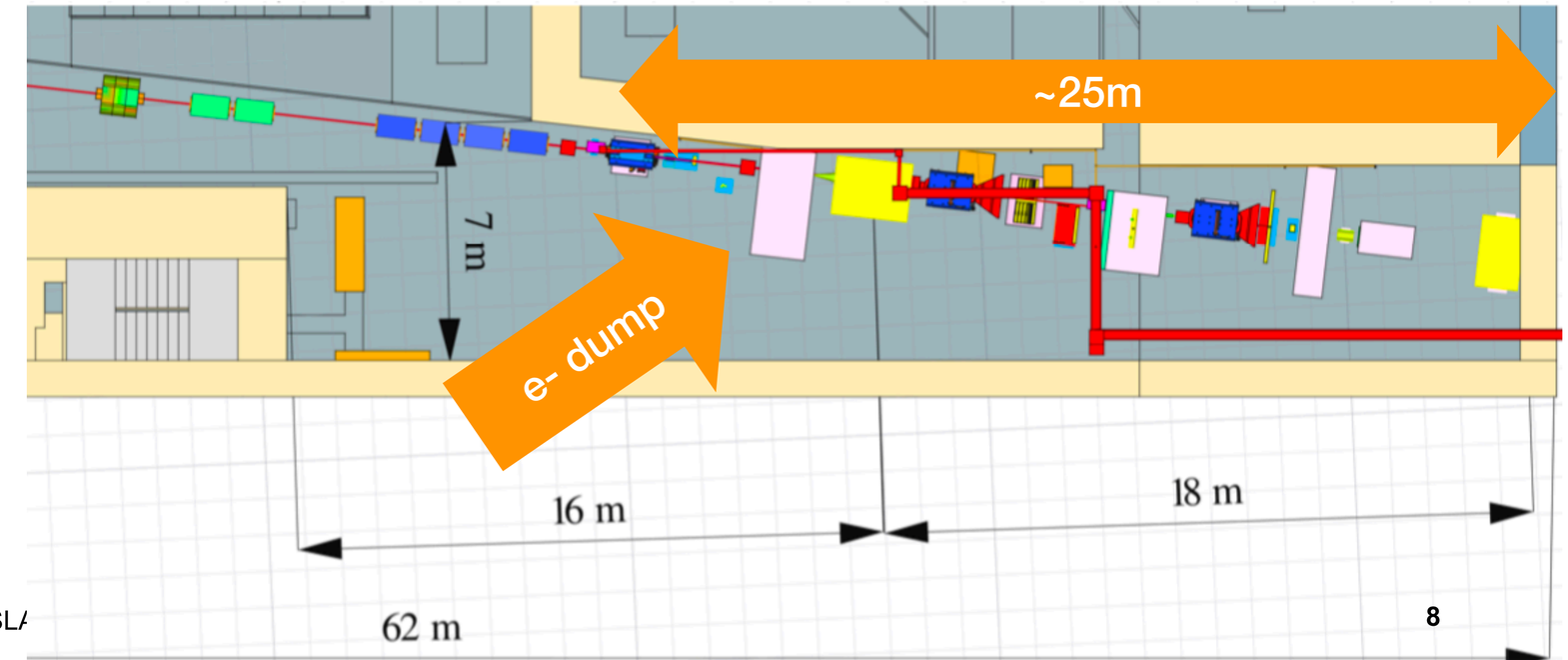




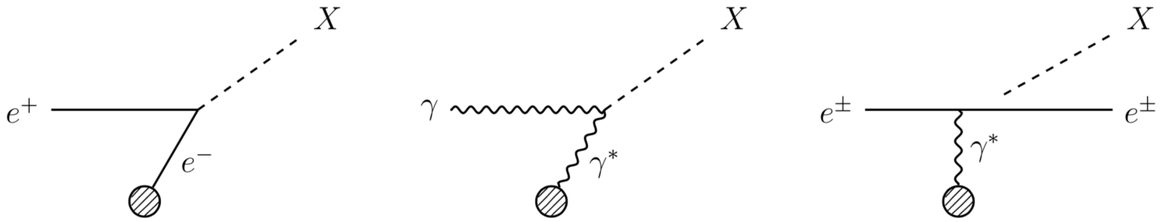
2. SF-QED runs at ILC

Maximise Beamstrahlung

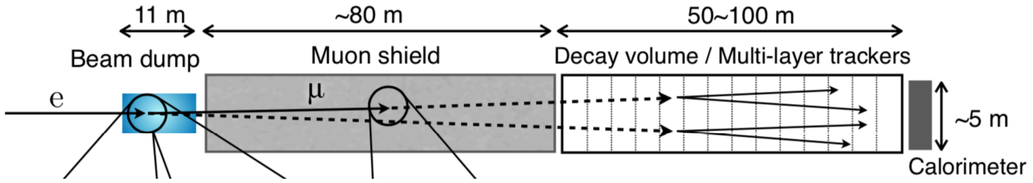
- normally: use flat beams to minimize beamstrahlung
- do dedicated runs to maximize χ ?
  - eg ILC250 with σ_x=σ_y = 50nm instead of σ_x = 500nm, σ_y=7nm => χ = 0.15 instead of 0.03,
    i.e. similar to ILC1TeV
    => could one continuously scan χ over an order of magnitude?
  - could final focus do that?
  - detector fine since also ok at 1TeV?
  - dedicated very-very foward instrumentation (a la GamCal) to measure beamstrahlung photons and pairs?
  - can this help to reduce
    - the uncertainty on modeling beam-beam effects in “normal” collisions, to eg improve luminosity measurement from low-angle Bhabha scattering ?
    - and/or on the depolarisation in collision?

3. LUXE-NPOD at ILC

Axion-like particle search with spent beam

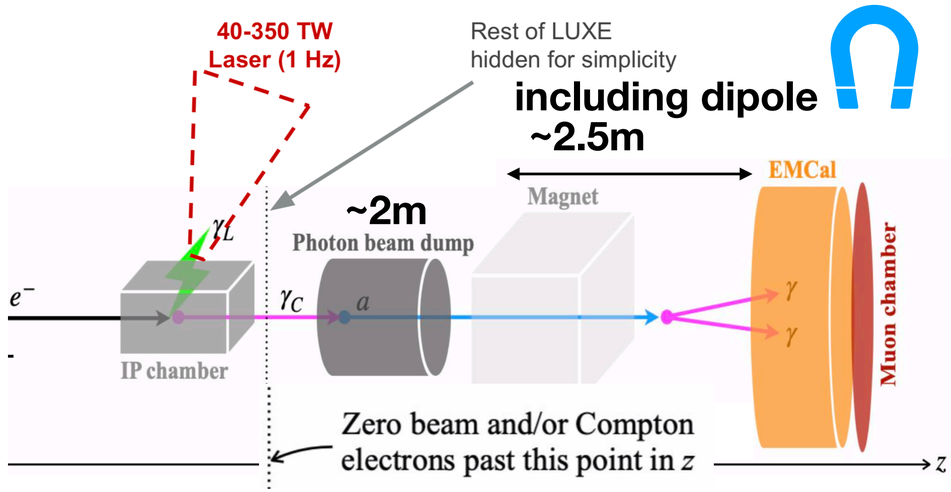


- two possibilities for ALP searches:
  - use ALP production in main beam dump, via pair annihilation, Primakov effect & bremsstrahlung
    => see Sakaki-san's talk in Monday plenary



  - optical dump a la LUXE-NPOD: only Primakoff effect
    - requires e- beam to be deflected by dipole after laser IP
    - photons (and ALPs) go straight to separate dump
    - no charged backgrounds

    => is there a suitable bend in the extraction line?



  - **both seem to have very similar reach**
  - Is there a phenomenological advantage to single out Primakoff / use same coupling for production & decay?
  - NPOD needs laser - but significantly less space?

Summary

A list of questions…

- many interesting questions arising from considering a LUXE-type experiment at a future LC
- SF-QED and future e+e- colliders are intertwined
  - need better understanding of SF-QED for controling beam-beam effects, on lumi, pol and beam energy
  - dedicated high beamstrahlung runs to measure SF-QED?
  - laser-beam experiment in front of tune-up dump?
- need simulation tools to fully profit from upcoming experiments, latest theory developments and growing SF-QED community
  => perspective for long-term support of beam-beam simualtion tools?
- spent beam very competitive in terms of searches for light particles, eg ALPs
  => need to understand better which experimental setup is best, and what this means in terms of civil construction

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Apologies for raising questions instead answering any - happy to take your inputs!

BACKUP

more…

Another view on the chi-xi plane

Why are we talking about this