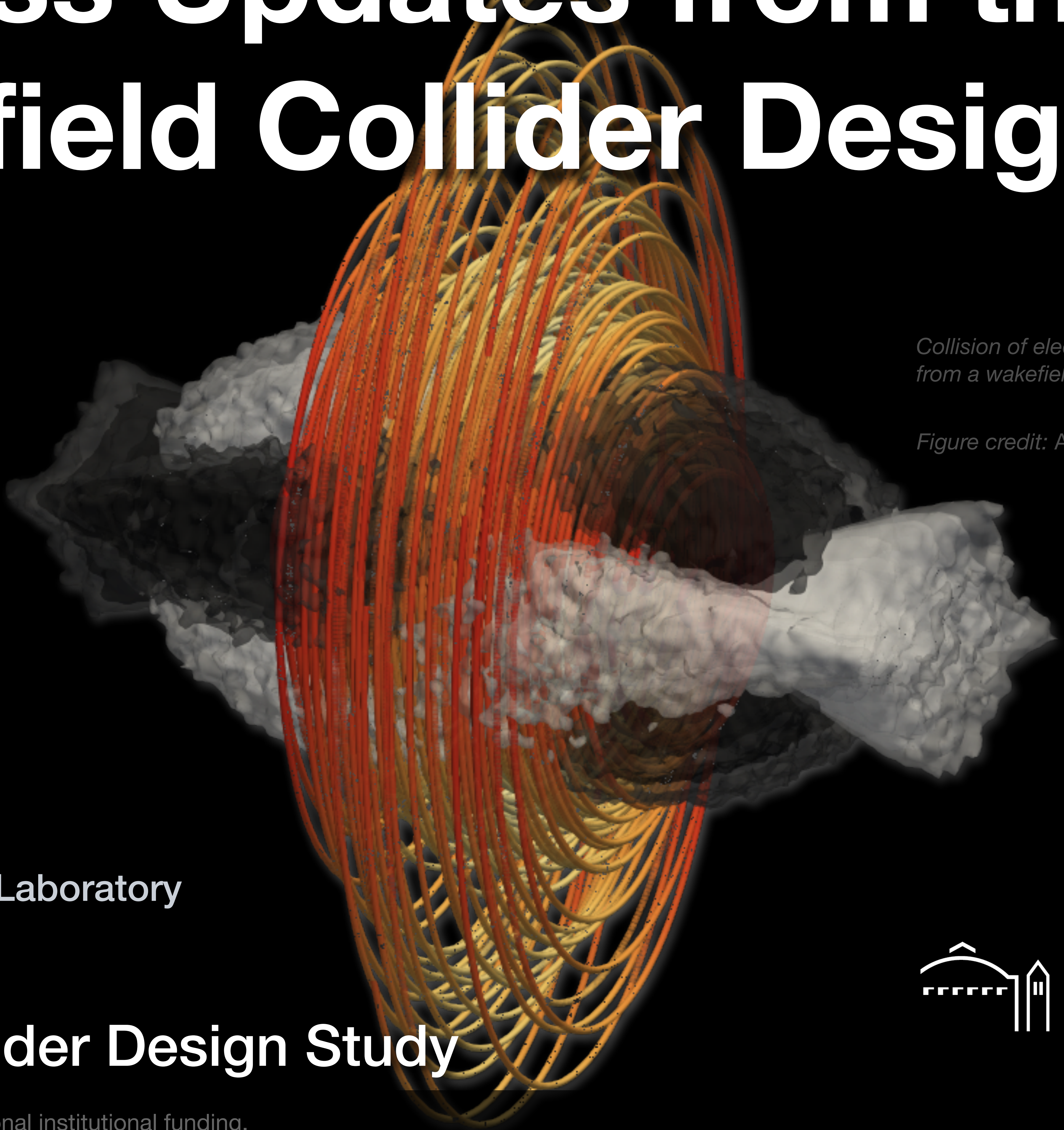
Progress Updates from the 10 TeV Wakefield Collider Design Study



Collision of electron and positron beams from a wakefield collider at 10 TeV pCM

Figure credit: A. Formenti, R. Lehe (LBNL)

Jens Osterhoff

BELLA Center, Lawrence Berkeley National Laboratory

July 28th, 2026
AAC, Los Angeles

on behalf of the

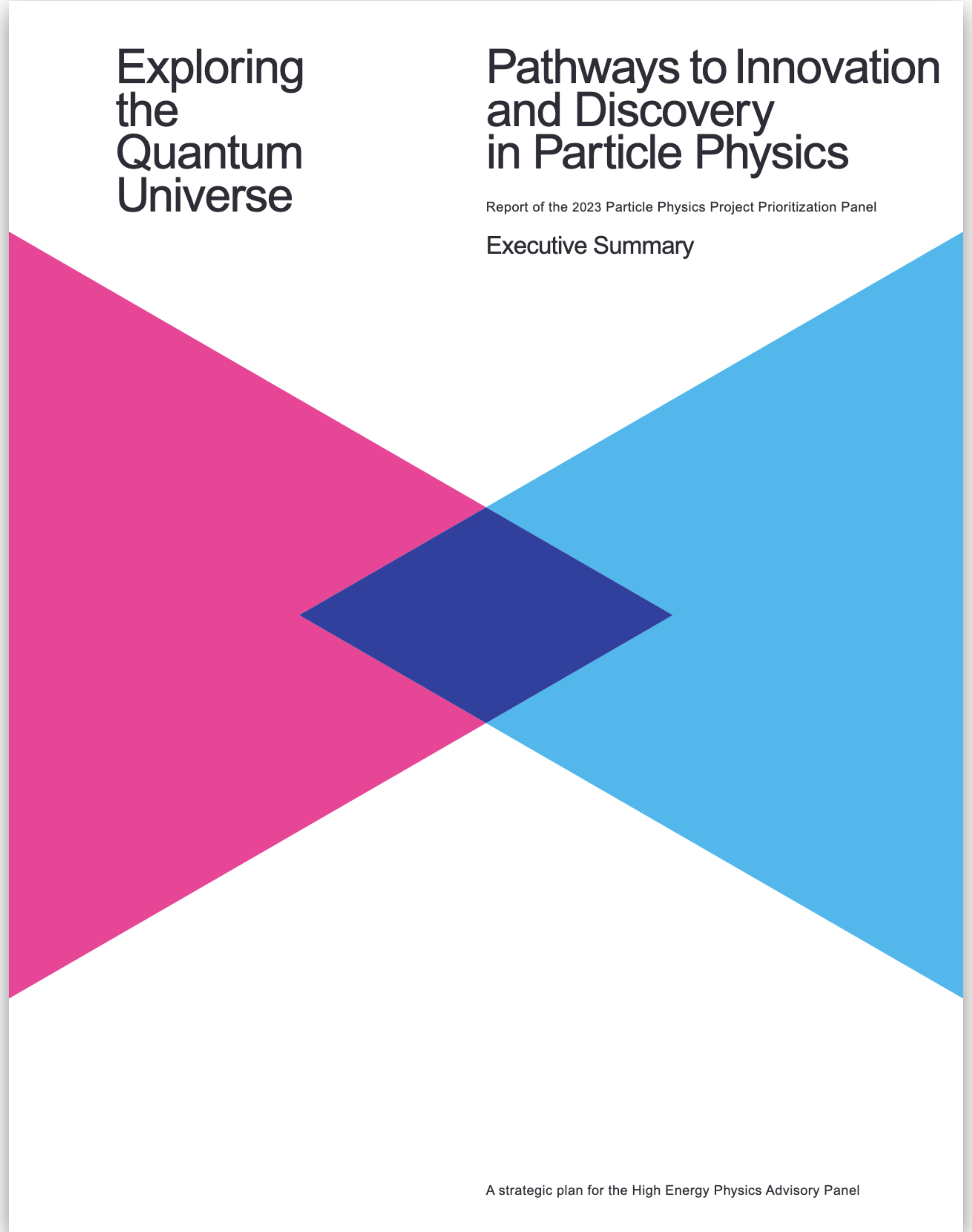
10 TeV Wakefield Collider Design Study

BERKELEY LAB
Bringing Science Solutions to the World

Work supported by LBNL and SLAC LDRDs and miscellaneous international institutional funding.

The 10 TeV Wakefield Collider Design Study was triggered by P5

- The **Snowmass Process** and **P5** (2020-2023) collected input from the global particle physics community to establish priorities for the US HEP Program
- Fed into the **P5 Report (2023)** with Recommendations for particle colliders



Rec. 2c: An **off-shore Higgs factory**… **FCC-ee and ILC** meet our scientific requirements…

Rec. 4a: Support **vigorous R&D** toward a cost-effective 10 TeV pCM collider based on **proton**, **muon**, or possible **wakefield technologies**…

Section 6.4.1: Wakefield concepts for a collider are in the early stage of development. A critical next step is the delivery of an **end-to-end design concept, including cost scales, with self-consistent parameters throughout**.

Three GV/m wakefield accelerator options are under consideration

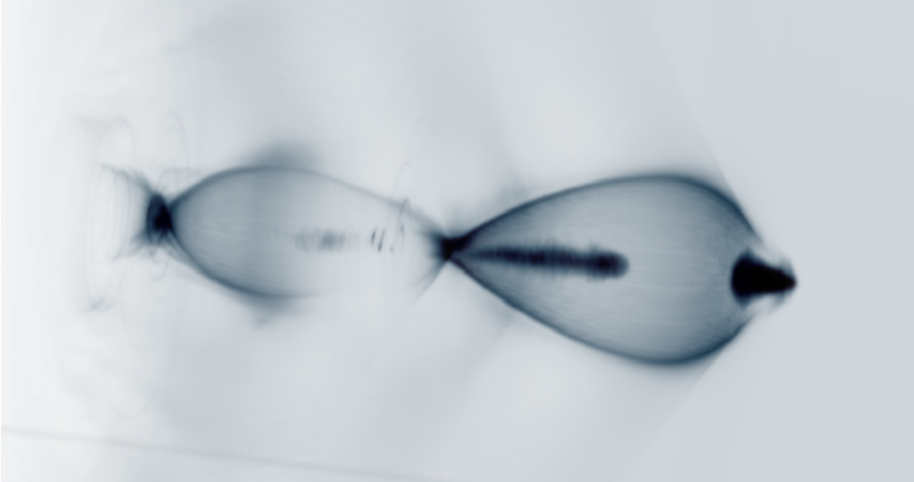
Wakefields in **Plasma**

Laser Driven *(LPA/LWFA)*

BERKELEY LAB

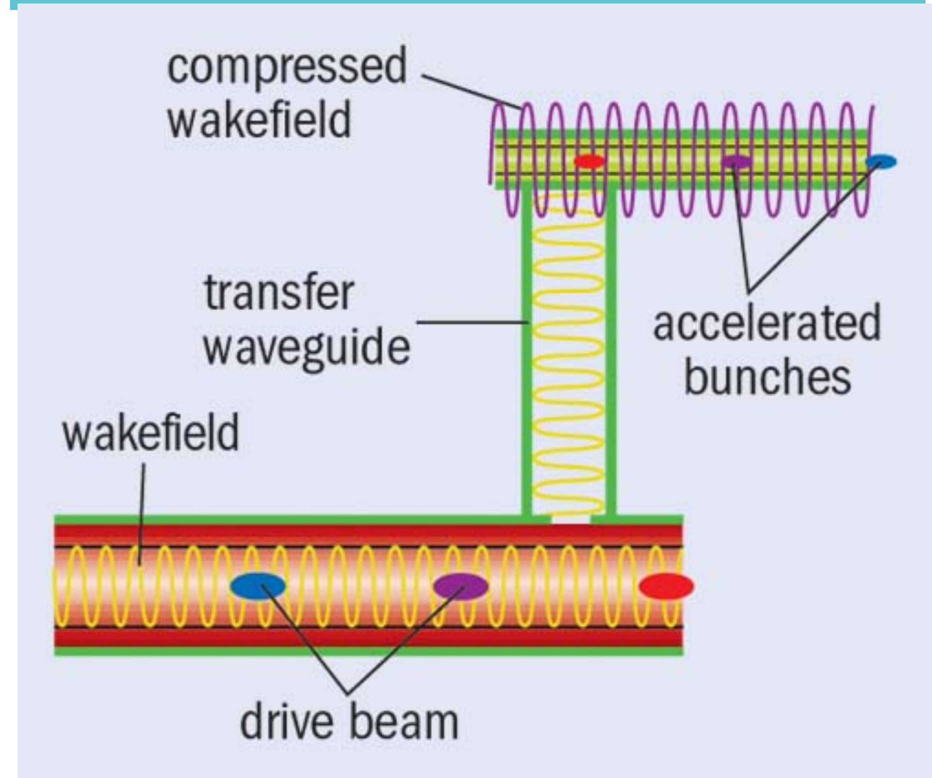
Beam Driven *(PWFA)*

SLAC



Wakefields in **Structures**

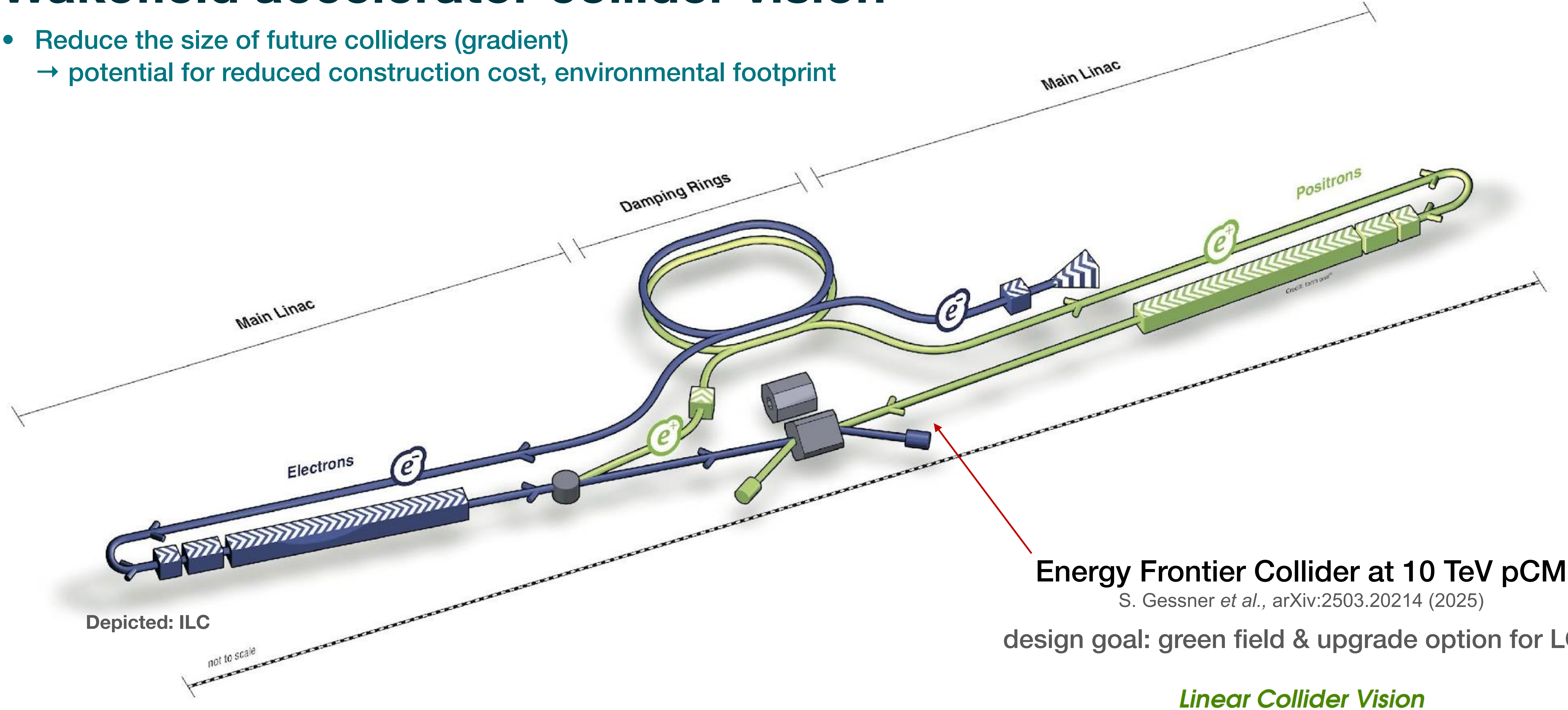
Beam Driven *(SWFA)*



10TeV

Wakefield accelerator collider vision

- Reduce the size of future colliders (gradient)
  → potential for reduced construction cost, environmental footprint



Depicted: ILC

Energy Frontier Collider at 10 TeV pCM

S. Gessner *et al.*, arXiv:2503.20214 (2025)

design goal: green field & upgrade option for LCF

Linear Collider Vision

LCF / up to 550 GeV / 33.5 km

Goal: Produce a *unified* design of a 10 TeV pCM Wakefield Collider by 2028

→ *Interim Design Report by the end of 2026.*
→ *Derive roadmaps and test facility needs.*

The study launched at AAC 2024 as a global, HEP-wide community effort with strong input from

- HEP Theorists,
- Detector Physicists,
- Accelerator Physicists

ALEGRO 2025 WORKSHOP
ADVANCED LINEAR COLLIDER STUDY GROUP

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Leveraging synergies with other collider studies

Linear Collider Vision

HALHF

LiVE

XCC

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HALHF
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XCC

Launched into the *assessment phase:*

- Explore physics and technology options in a self-consistent framework.
- Define metrics.
- Understand tradeoffs.

ALEGRO 2025 @ SLAC

ALEGRO 2026 @ INFN

Are there compelling wakefield collider options at comparatively low cost?

A new paradigm for linear particle collisions at the 10 TeV scale

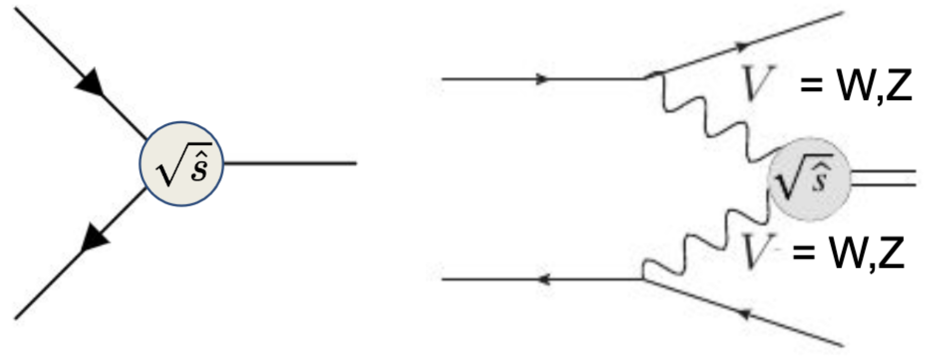
Vector Boson Fusion (VBF) and s-channel annihilation to contribute

Collisions created from the **VBF process at 10 TeV**, in addition to **s-channel annihilation** traditionally associated with electron-positron linear colliders.

Advantageous for luminosity requirements at 10 TeV.

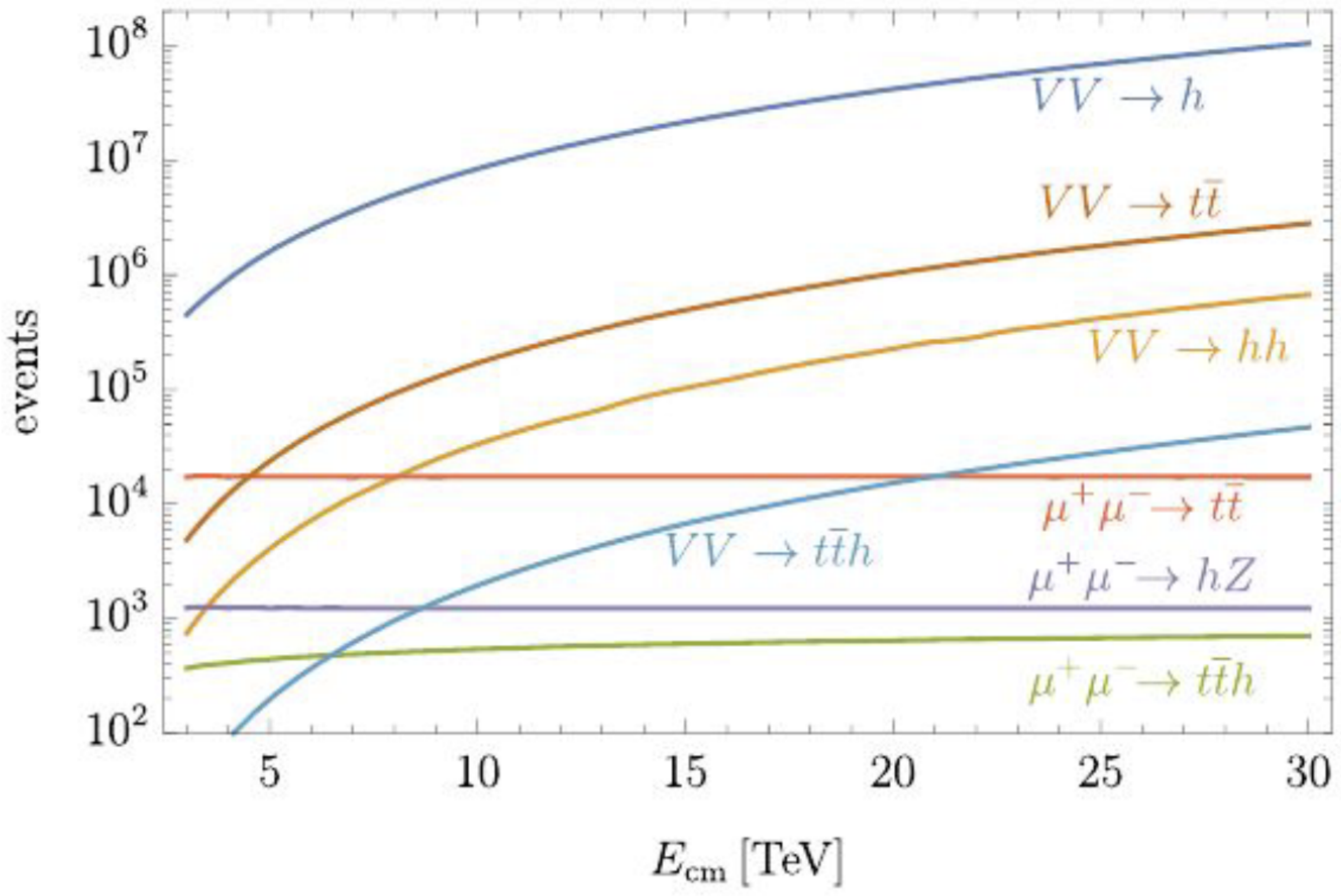
VBF expected to provide production channels for high-energy e^+e^-, e^-e^-, $\gamma\gamma$, and $\mu^+\mu^-$ colliders.

→ **Need to start with a Particle Physics study**



Muon Collider Forum Report
arXiv:2209.01318

$\sigma \sim 1/\hat{s}$ $\sigma \sim \log \hat{s}$



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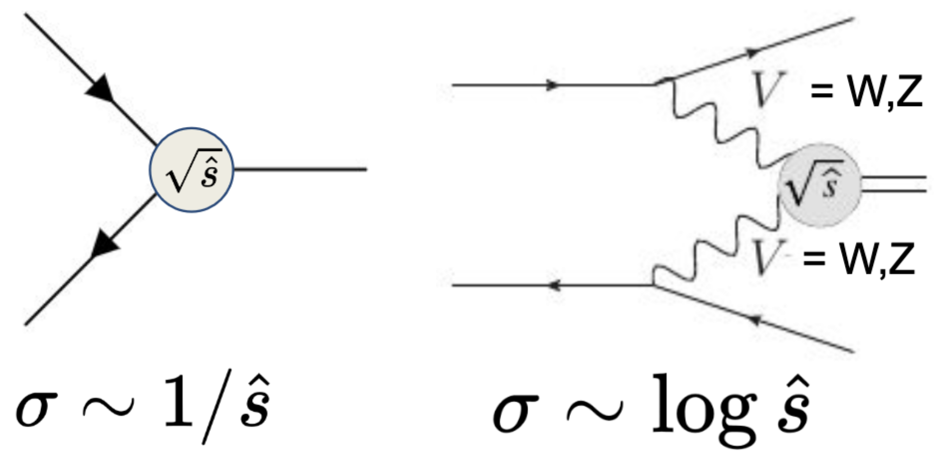

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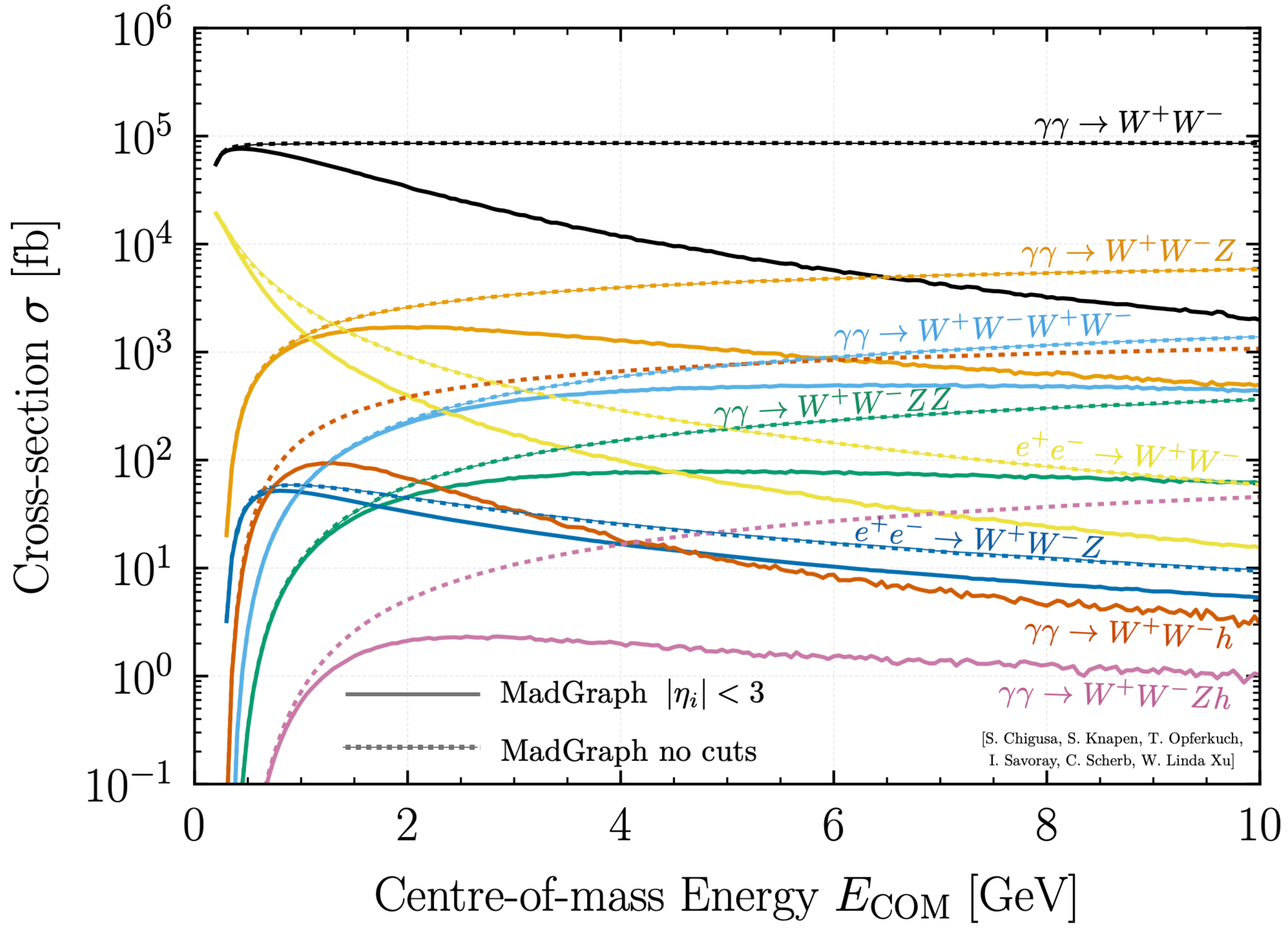
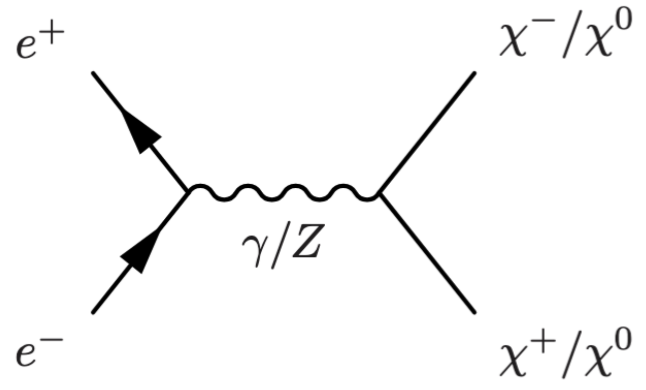


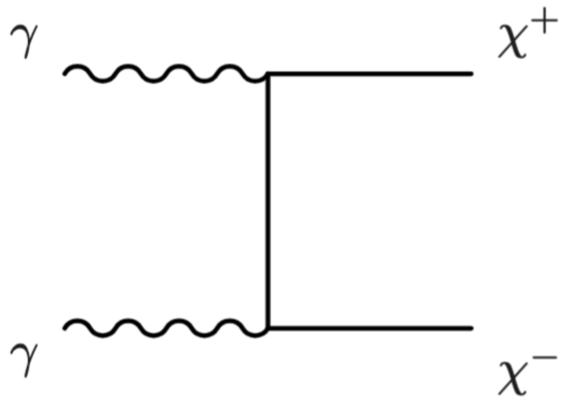
A 10 TeV linear collider may not have to be an electron-positron collider.

We are exploring

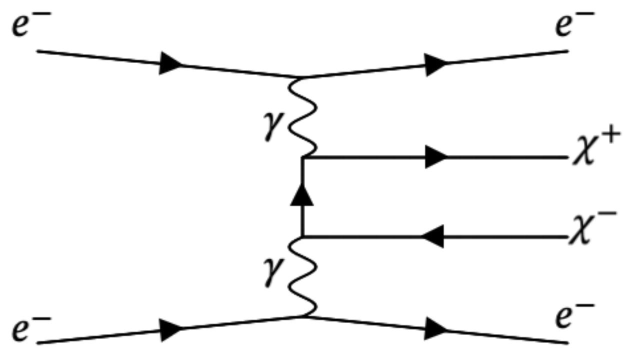
e⁻ / e⁺



γ / γ



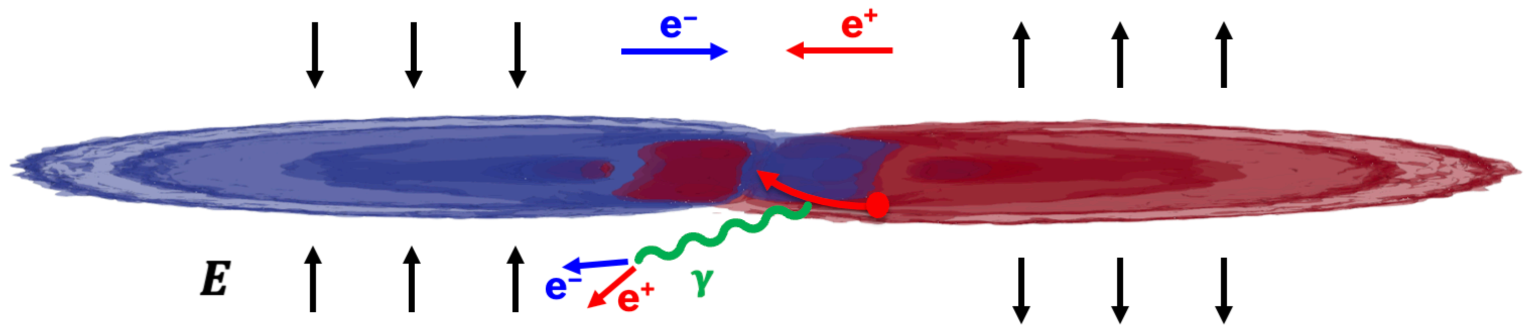
e⁻ / e⁻



Beamstrahlung at 10 TeV must be revisited incl. quantum effects

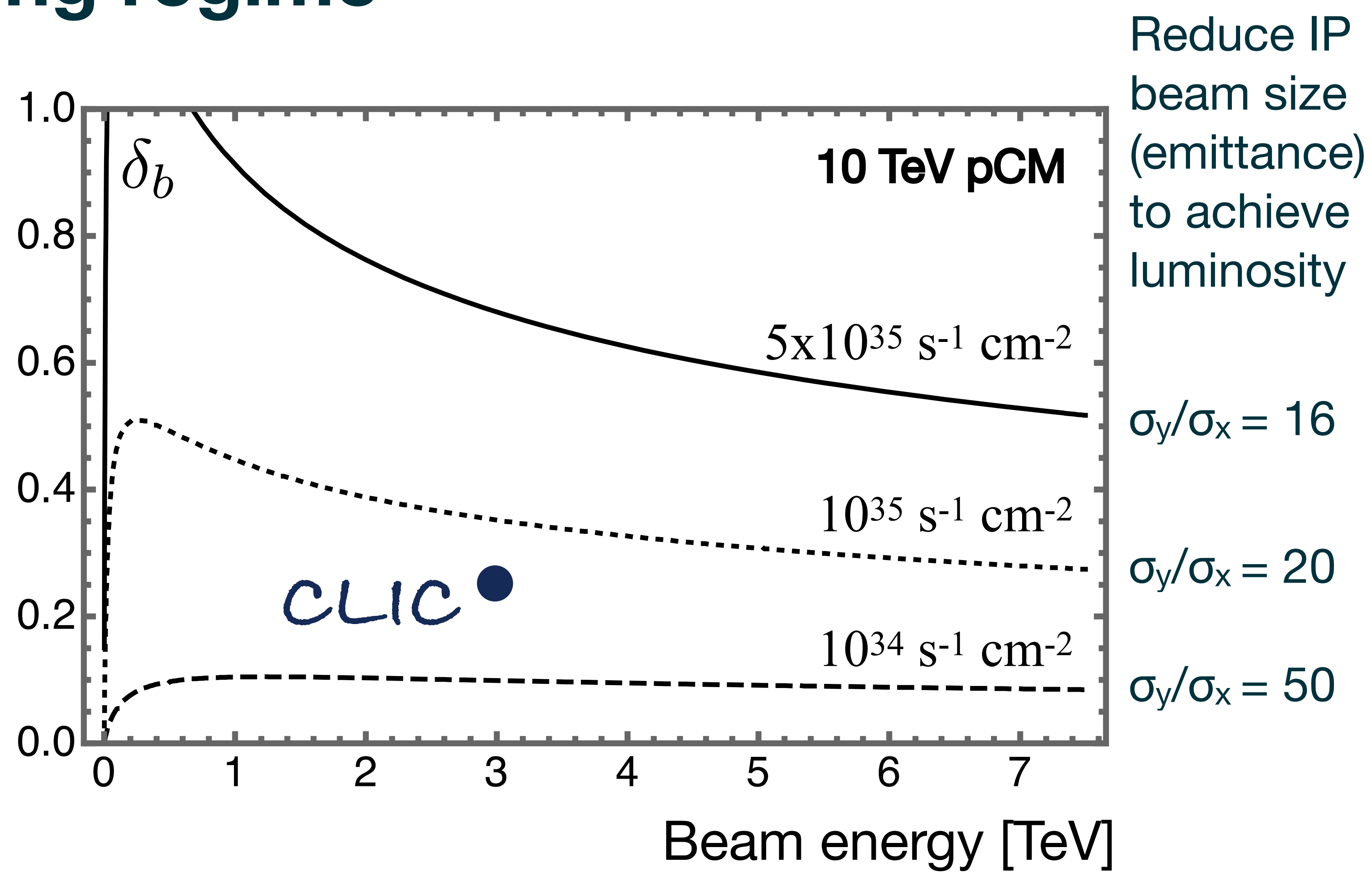
10 TeV linear colliders will operate in the high (quantum) beamstrahlung regime

- Large beamstrahlung effects hard to avoid, can we deal with it?
  IP needs to be studied together with particle and detector physicists



Average fractional particle energy loss: $$\delta_b \propto \frac{N^{2/3}\sigma_z^{1/3}}{(\sigma_x+\sigma_y)^{2/3}\,\gamma^{1/3}}$$

short beams help



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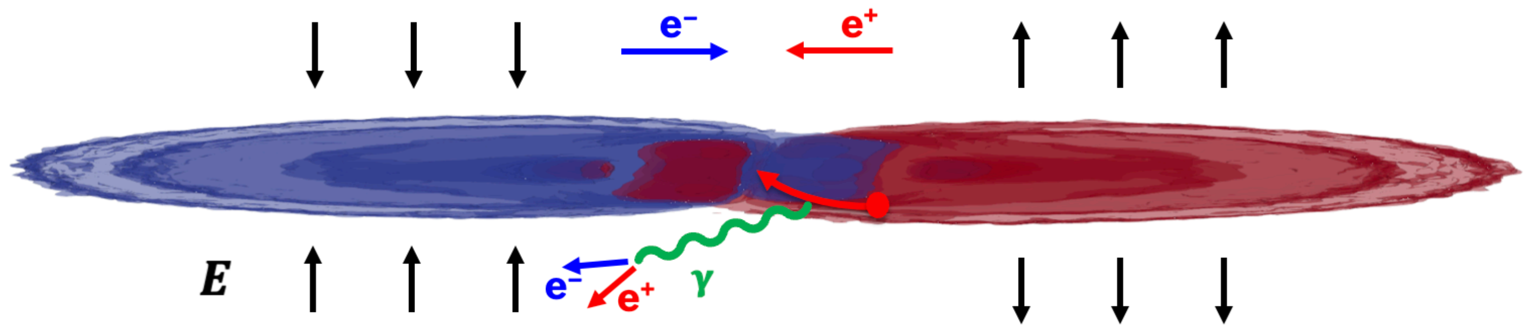

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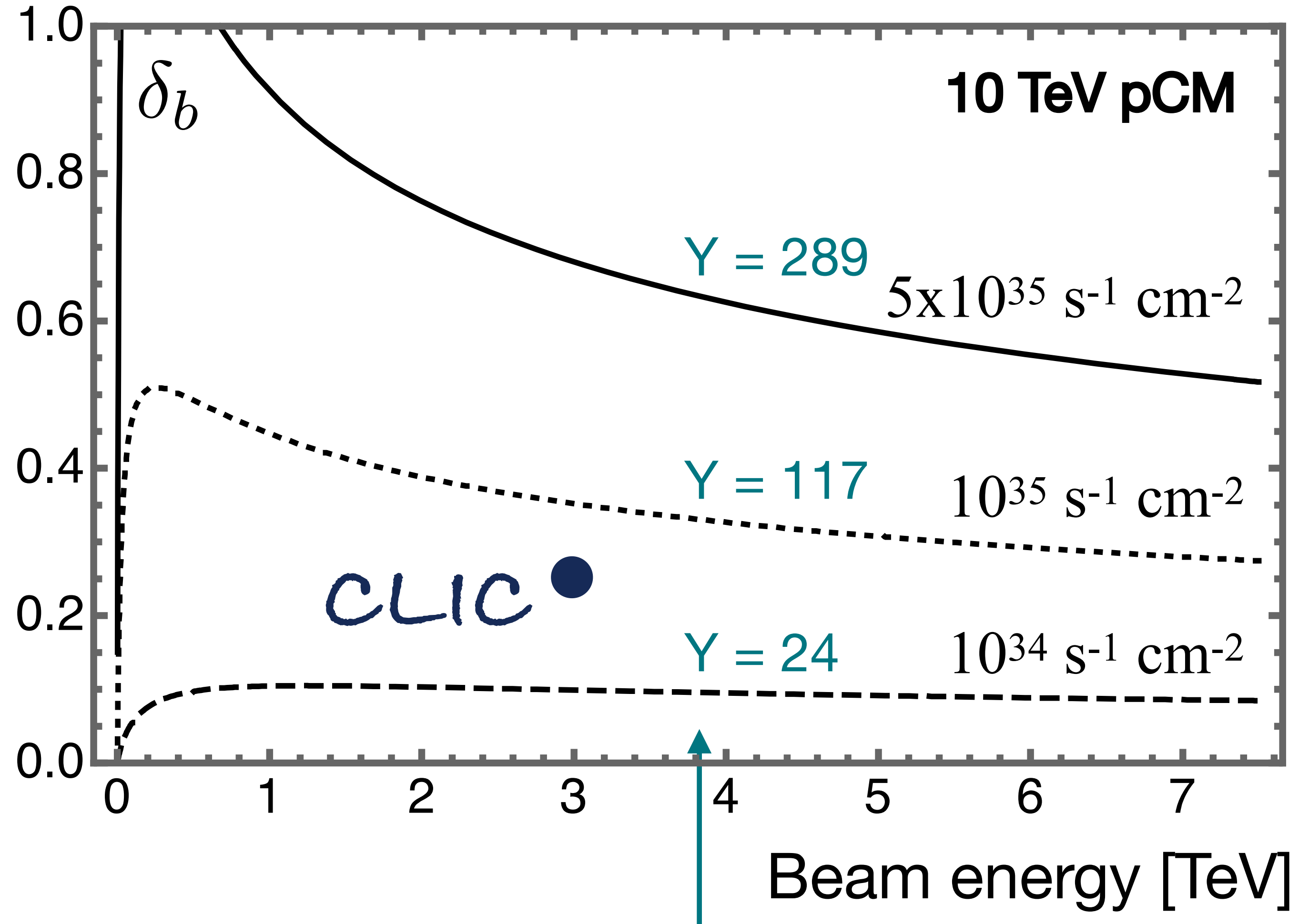
Reduce IP beam size (emittance) to achieve luminosity



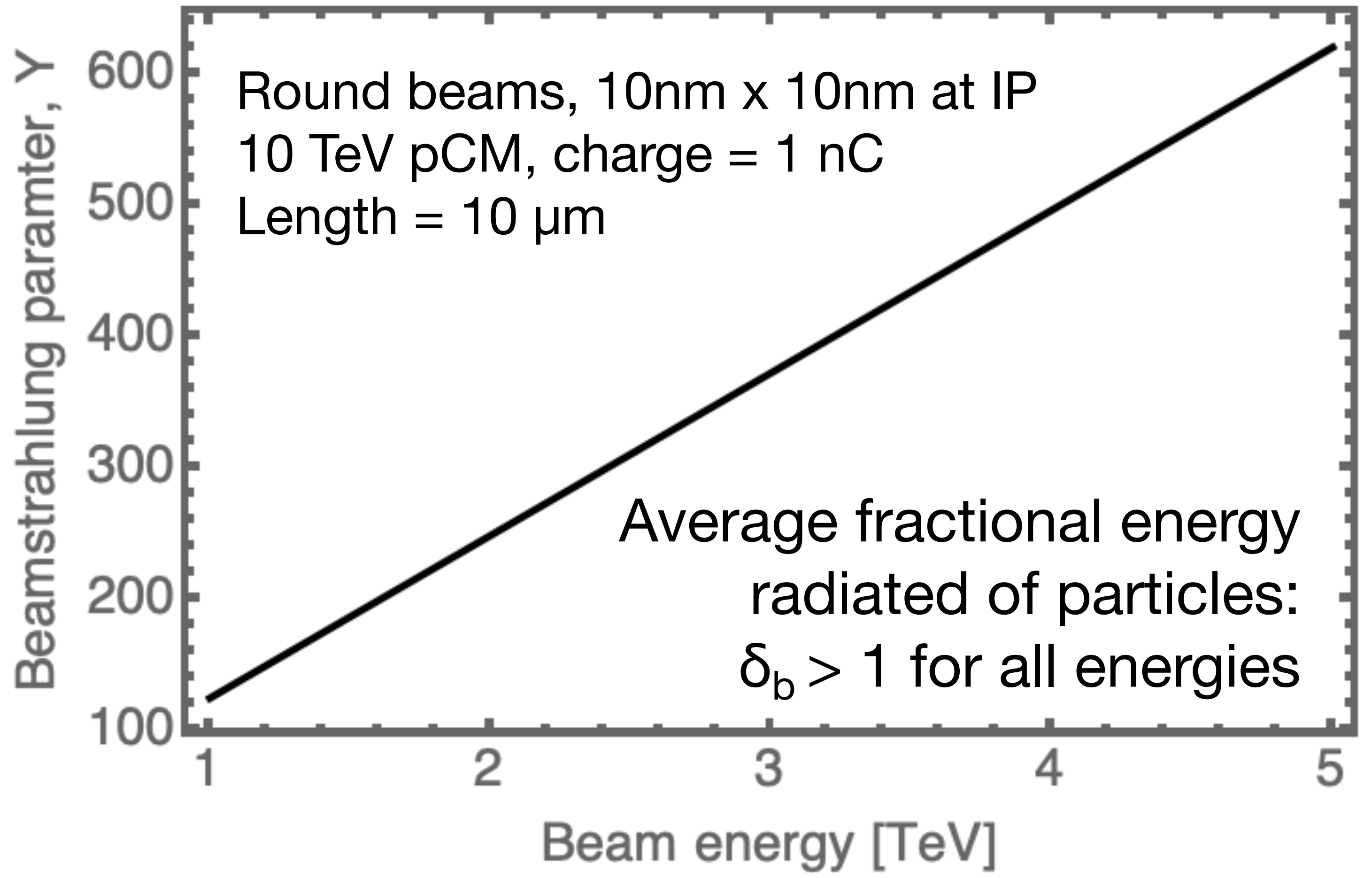
even for flat beams

- Quantum: mean beam field in beam rest frame large compared to Schwinger field

Beamstrahlung parameter (mean field strength of beam normalized to Schwinger field):

$$\Upsilon = \gamma\langle E+B\rangle/E_c \approx \frac{5r_e^2\gamma}{6\alpha(\sigma_x^*+\sigma_y^*)}\frac{N}{\sigma_z}$$

Note: perturbative quantum beamstrahlung theory breaks down for Y > $\alpha^{-3/2}$ ~ 1000



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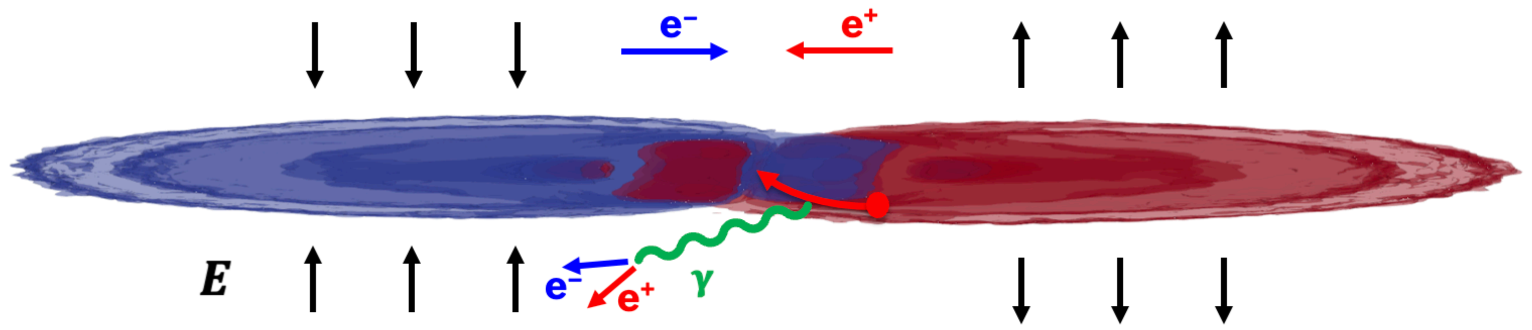

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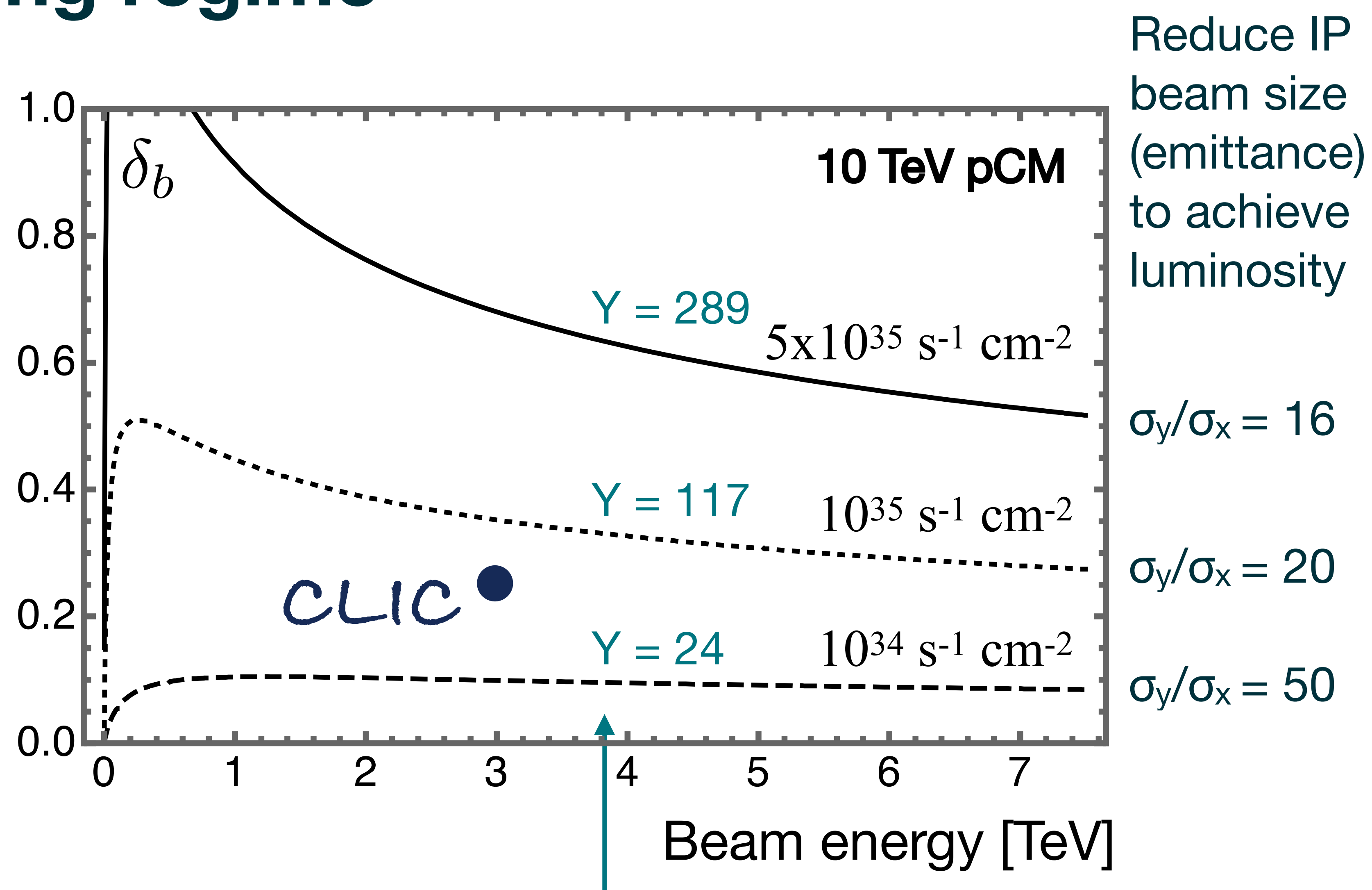

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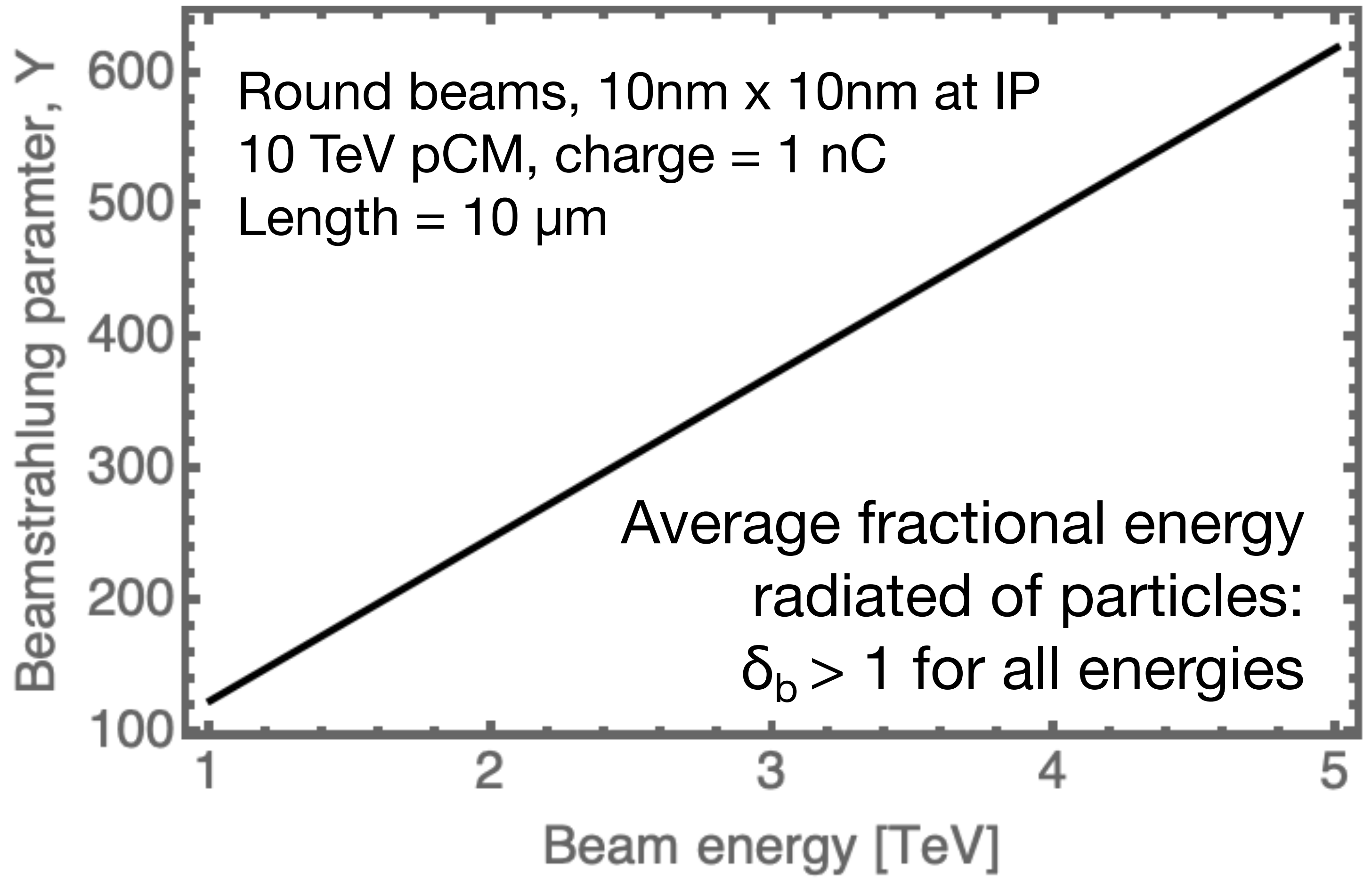
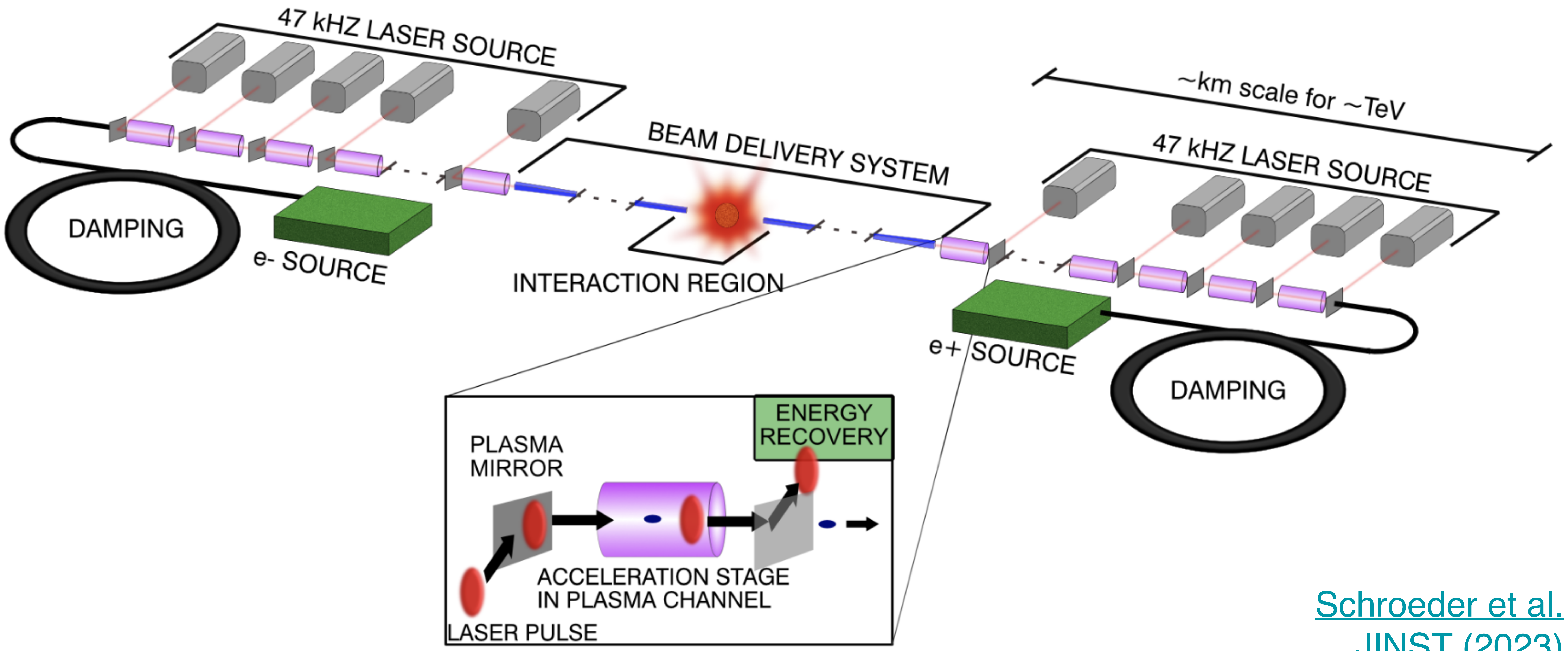


A new regime. We are considering:
- *e⁺e⁻, e⁻e⁻, γγ* collisions
- Round beam collisions in addition to flat beam collisions

Working outwards from the interaction region

Design study approach



[Schroeder et al. JINST (2023)]

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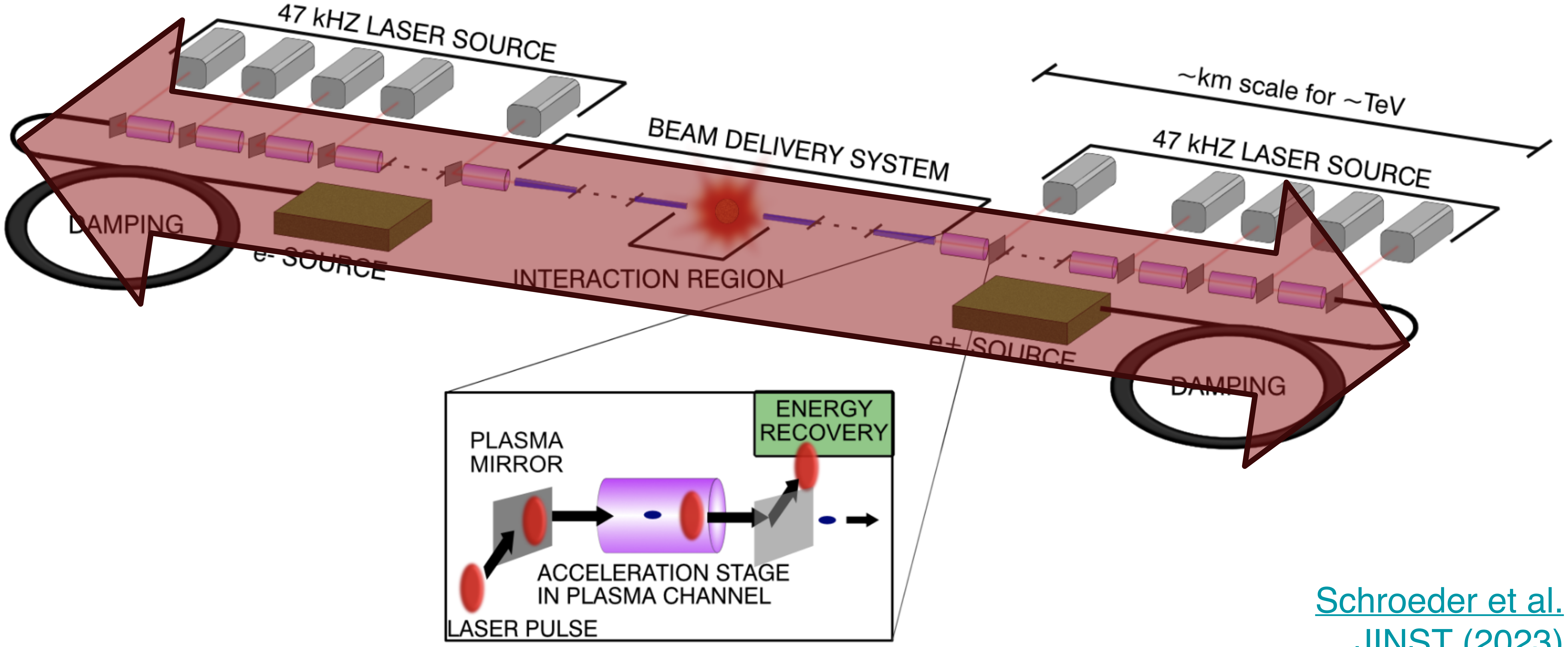
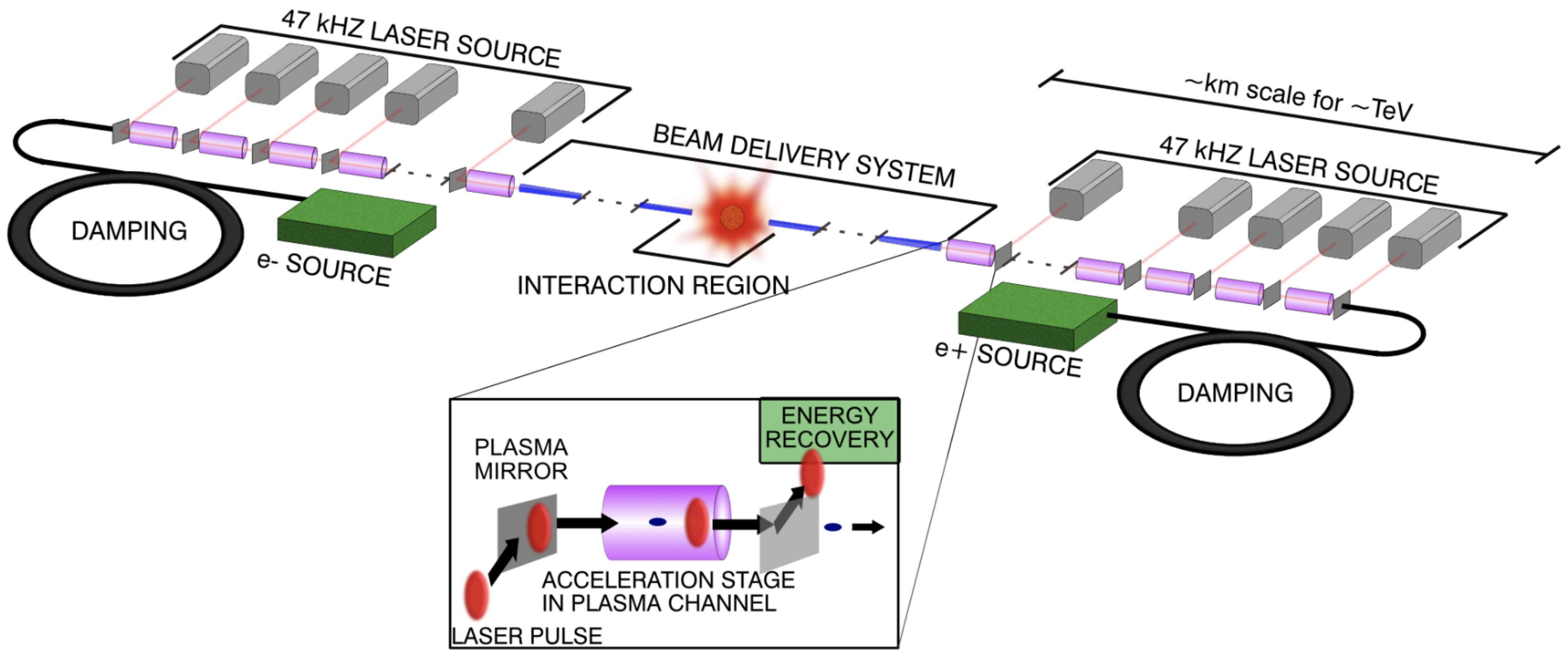


Schroeder et al.
JINST (2023)

Working groups are assessing concepts and are connecting collider components, starting from the IP

- System integration and optimization
- Beam sources (incl. damping rings)
- Drivers
  - Laser
  - Beams - SWFA
  - Beams - PWFA
- Linacs
  - LWFA
  - SWFA
  - PWFA
- Beam delivery system
- Beam-beam interactions
- Beam diagnostics
- Machine-detector interface
- HEP detector
- HEP physics case
- Environmental impact
- Simulations/computing/AI



Green = Broader accelerator community

Orange/blue/purple = AAC specific

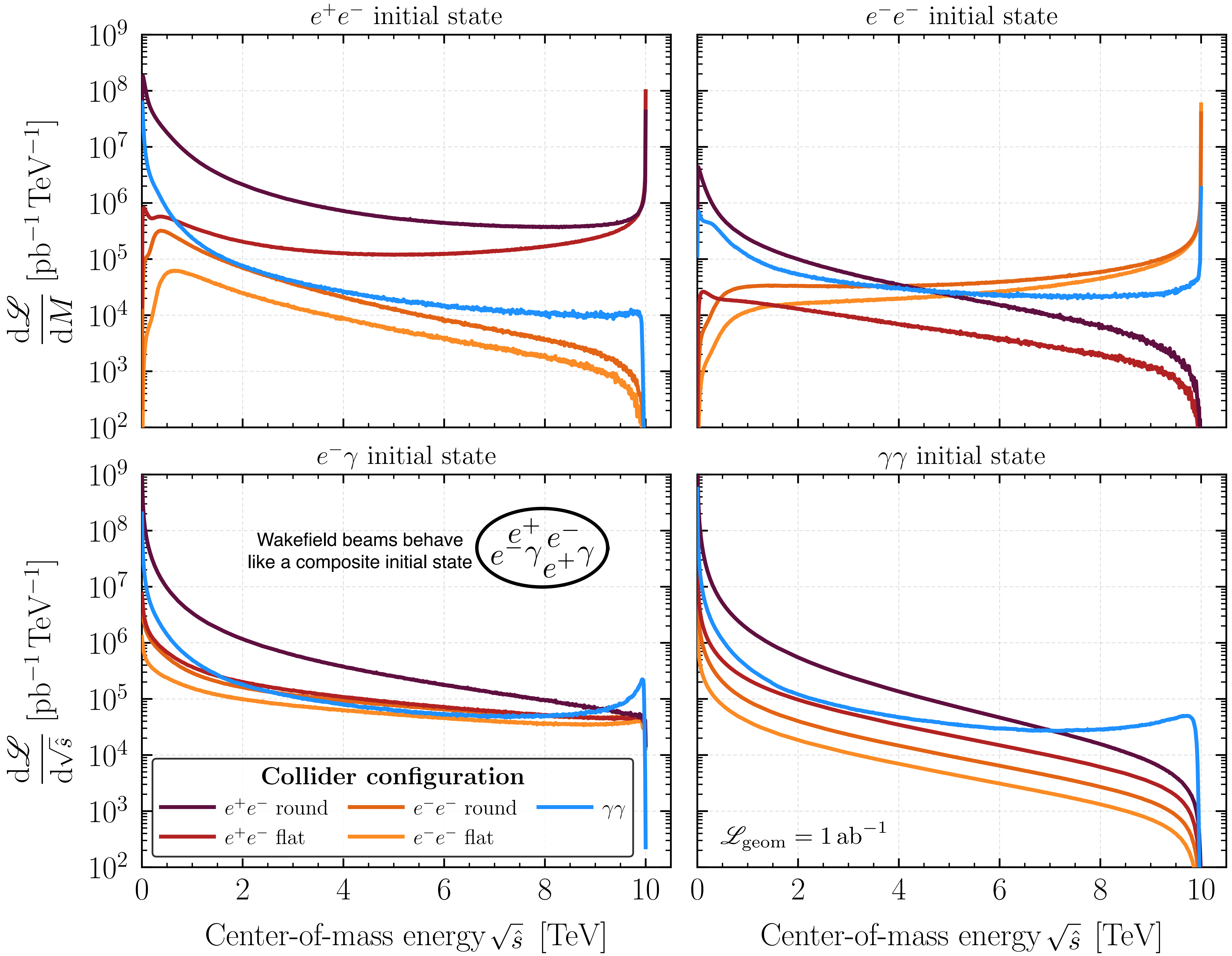
Red = HEP and broader community

Chosen design constraints:

- $E_{z,avg}$ > 500 MeV/m ← LCVision upgrade path
- $\mathcal{L}/P_{tot} > 10^{32}$ cm^{-2}s^{-1} MW^{-1} ← Science per $$$

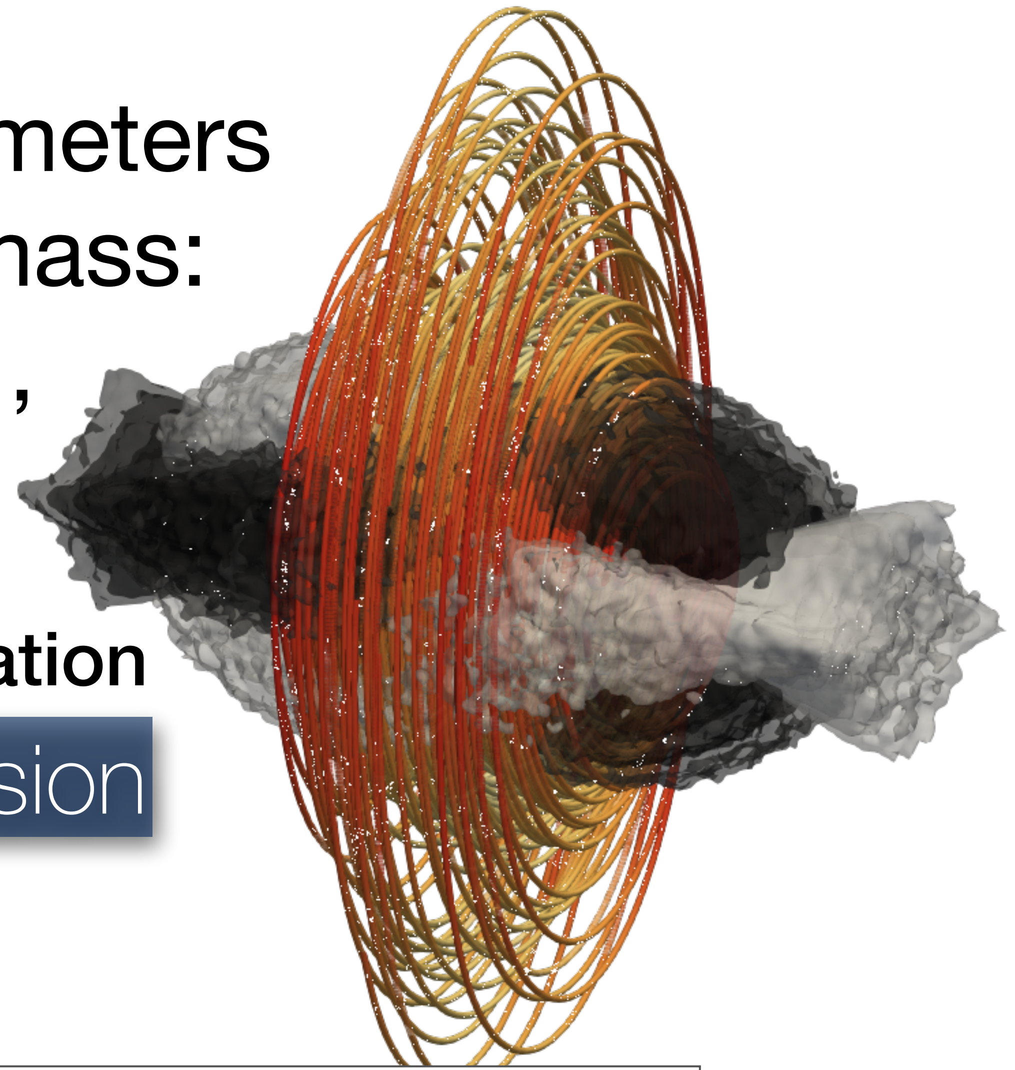
Beam-beam collisions at 10 TeV result in broad lumi spectra

Some highlights from the first two years of 10 TeV Design Study work — Beam-beam simulations



New lepton collider paradigm

- Strong beamstrahlung: broad luminosity spectra
- 10 TeV pCM beams behave like composite initial states
- based on beam parameters developed for Snowmass: C. B. Schroeder *et al.*, JNIST 2023



A. Formenti et al., in preparation

→ talk in this session

arXiv:2511.20912v1

Analytical Approximations for Beamstrahlung at Very High Energy Electron-Positron Colliders

Dongxing He,[1,*] Arianna Formenti,[2,†] Spencer Gessner,[3,‡] and Michael Peskin[3,§]

We study particle productions rates to analyze physics potential

Some highlights from the first two years of 10 TeV Design Study work — Physics case

5 scenarios considered so far

Slide credit: T. Opferkuch (SISSA)

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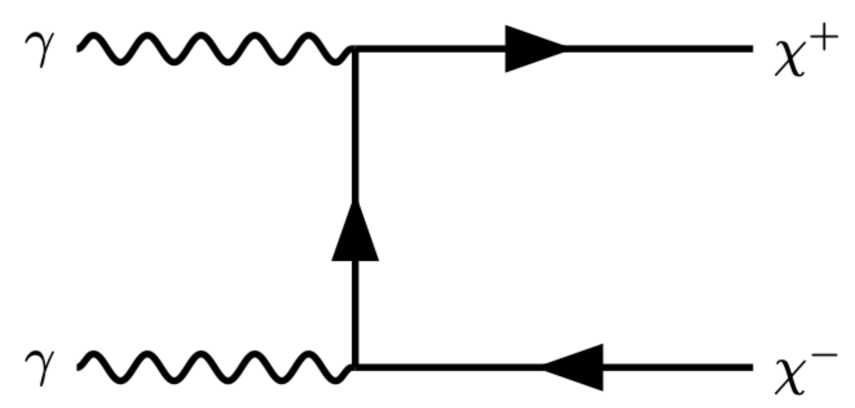
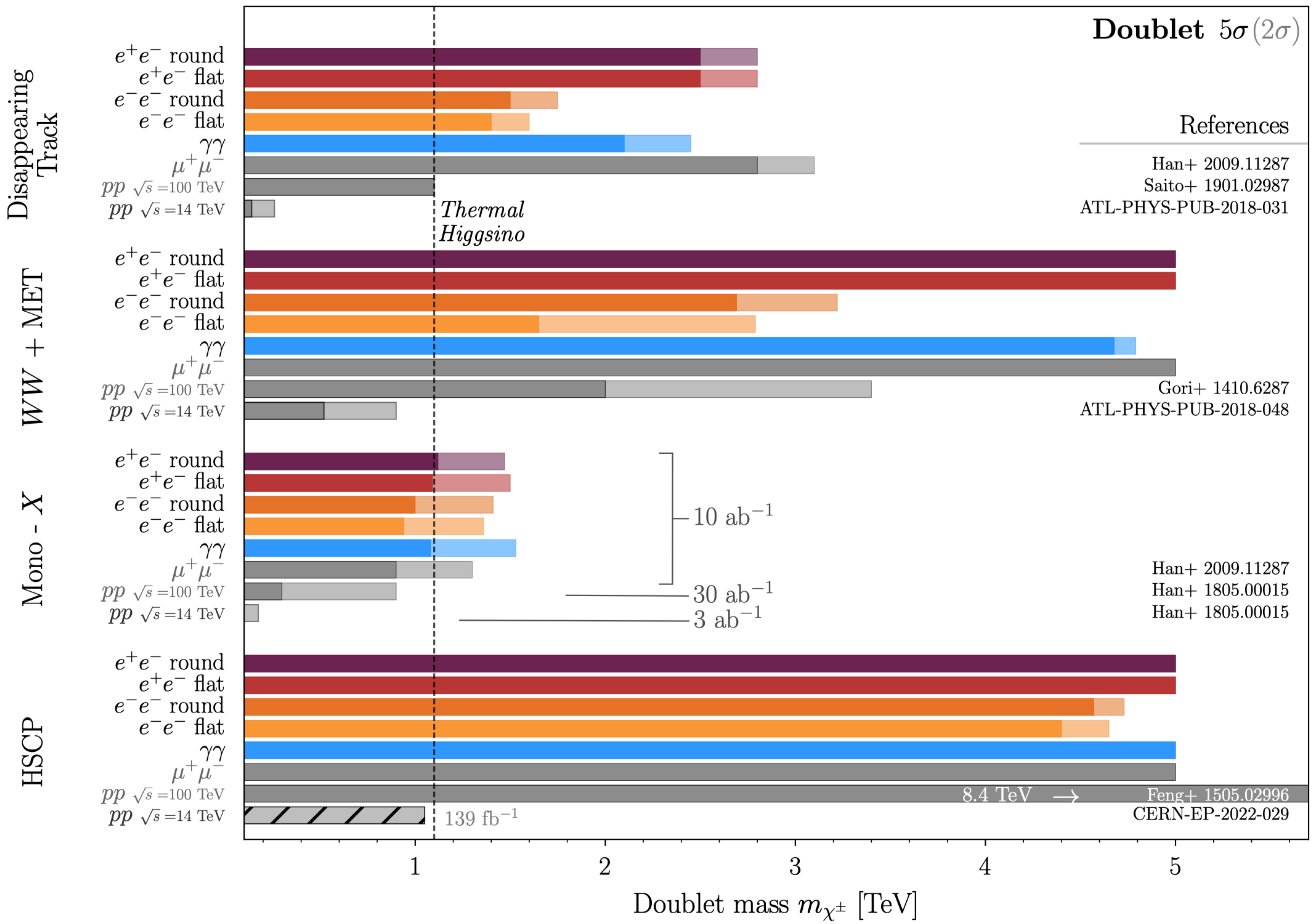
Pair production of electroweak particles (WIMPs)



S. Chigusa, S. Knapen , T. Opferkuch, I. Savoray, C. Scherb, L. Xu; arXiv:2512.09995



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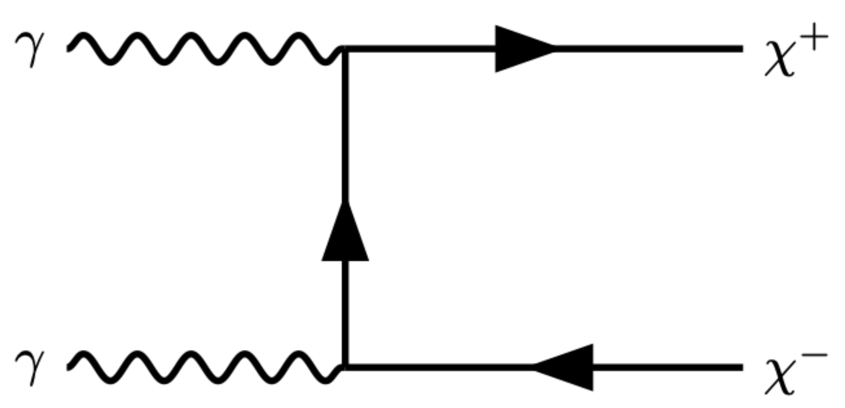

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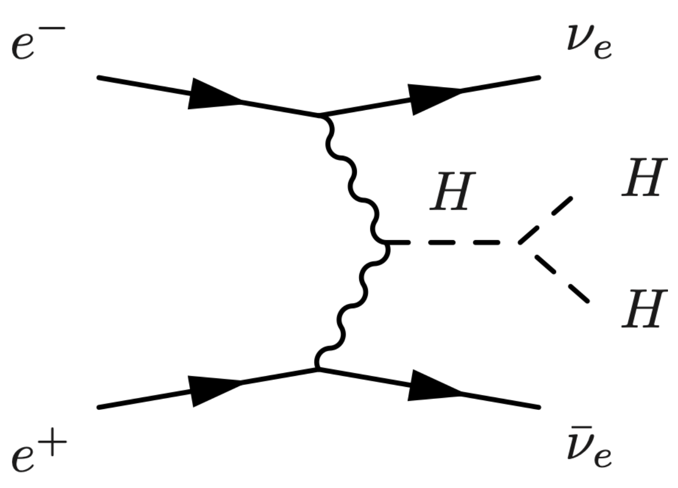
Measure SM triple Higgs coupling



K. Fraser, S. Knapen, K. Langhoff,
R. Szafron; arXiv:2607.19463

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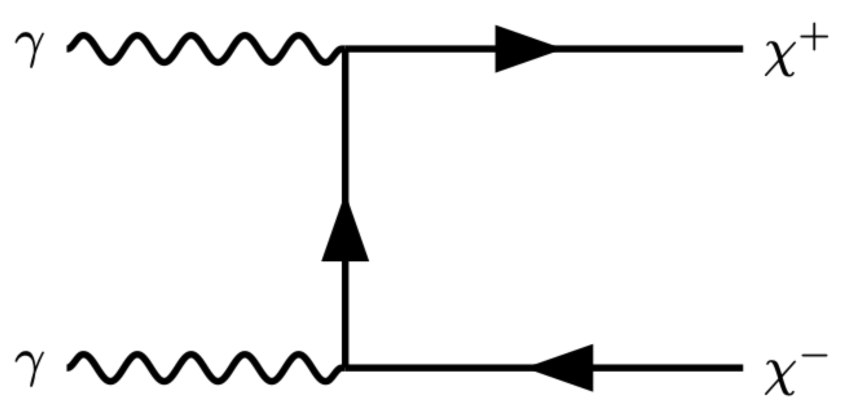

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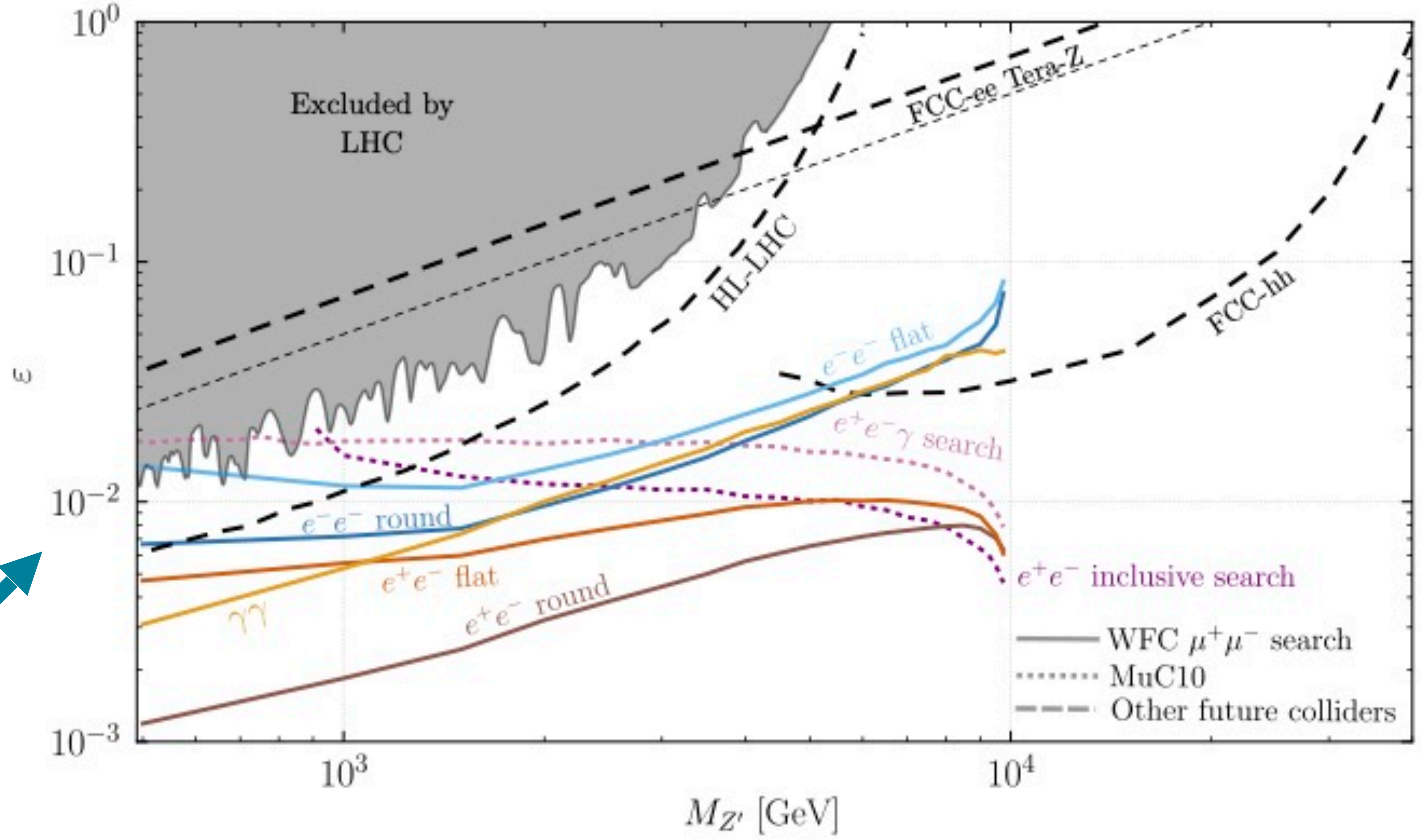

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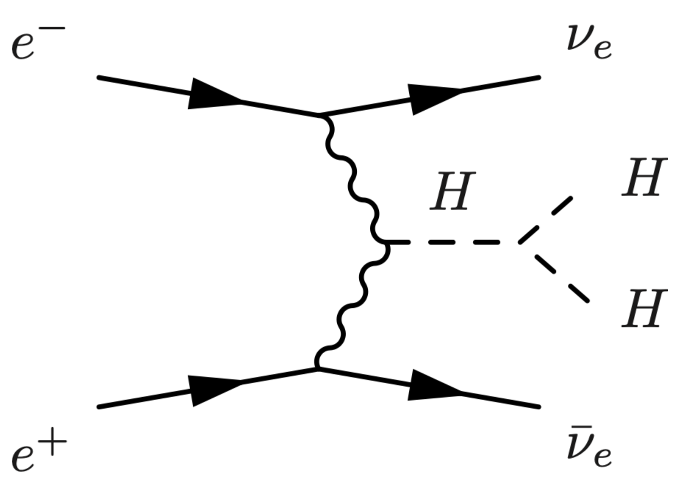

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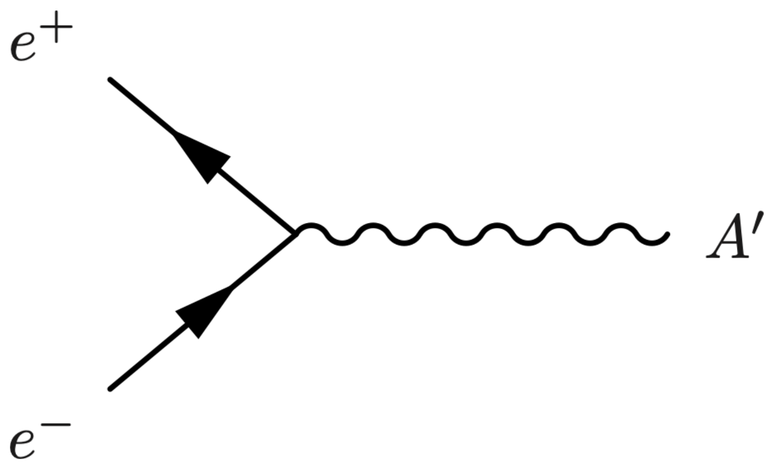
Heavy resonances



M. Cipressi, K. Langhoff, T. Opferkuch; arXiv:2603.18146

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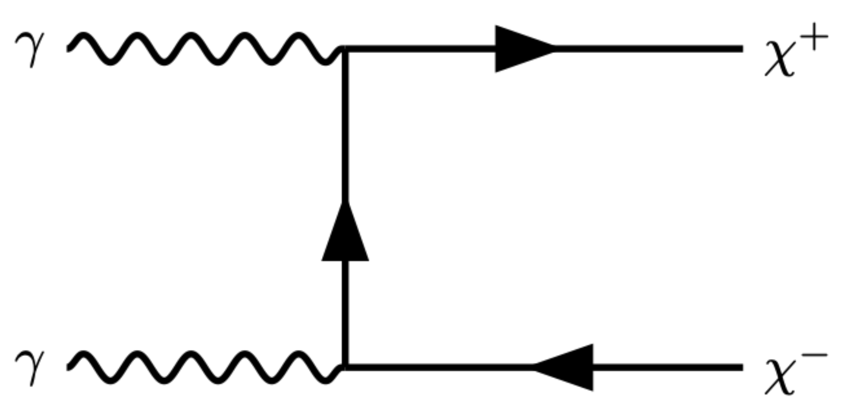

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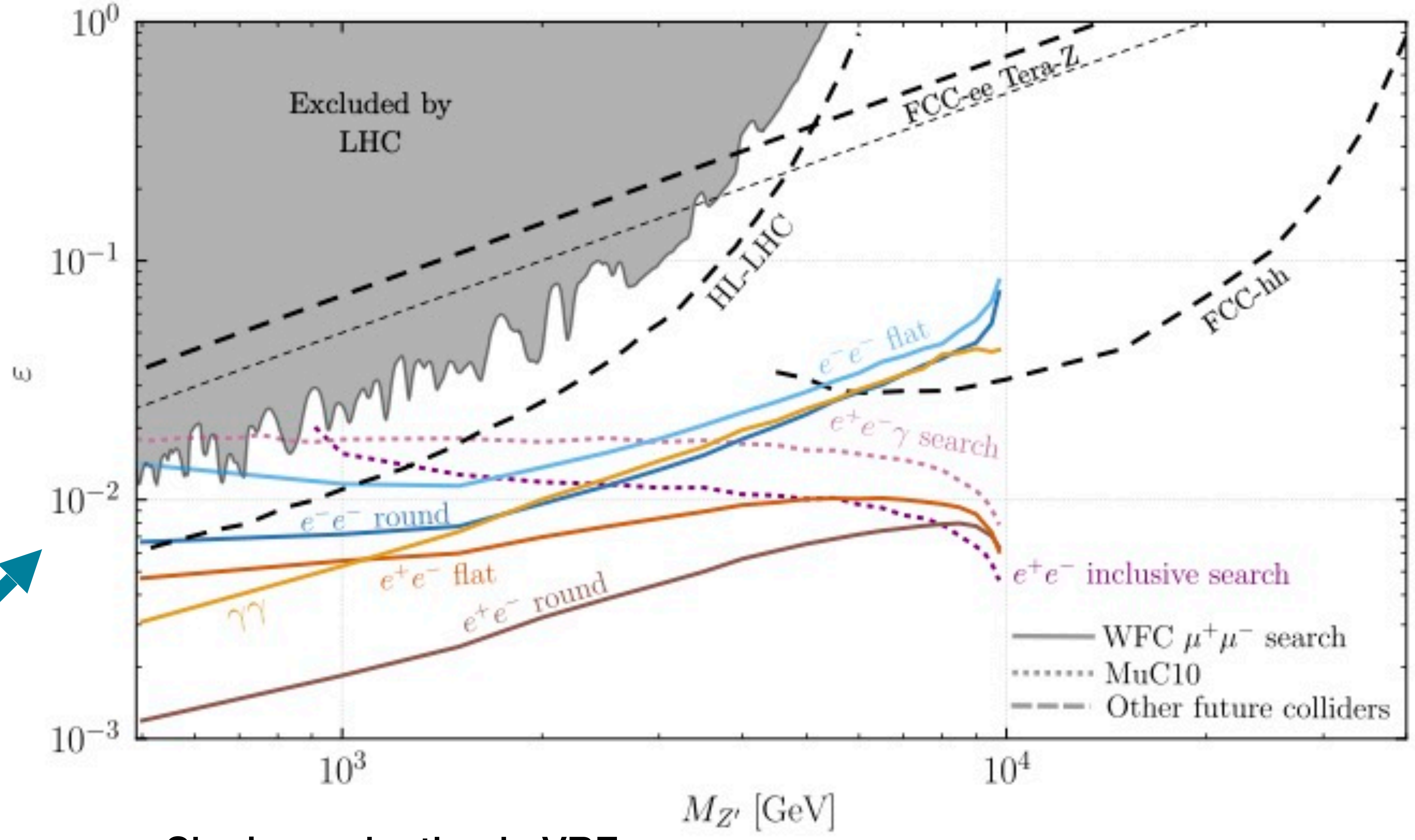

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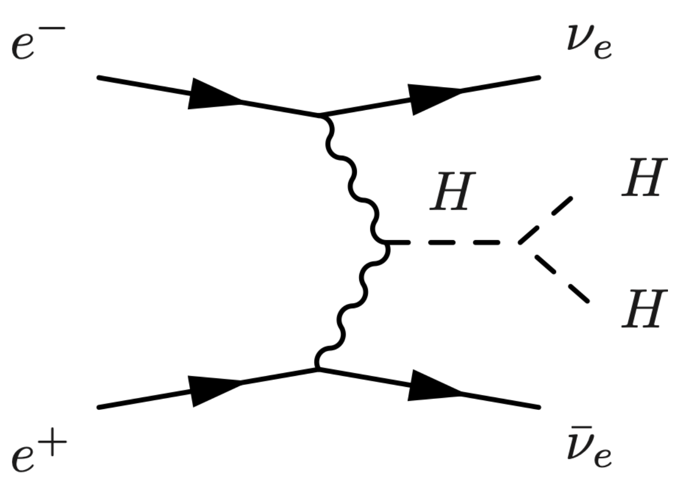

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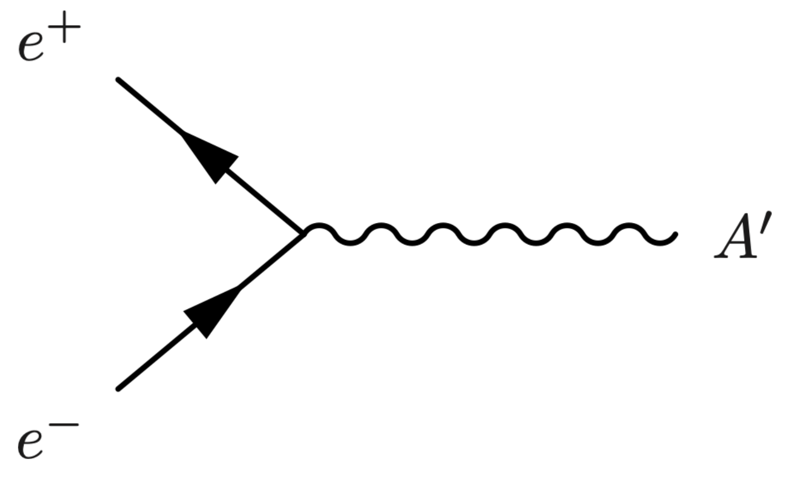

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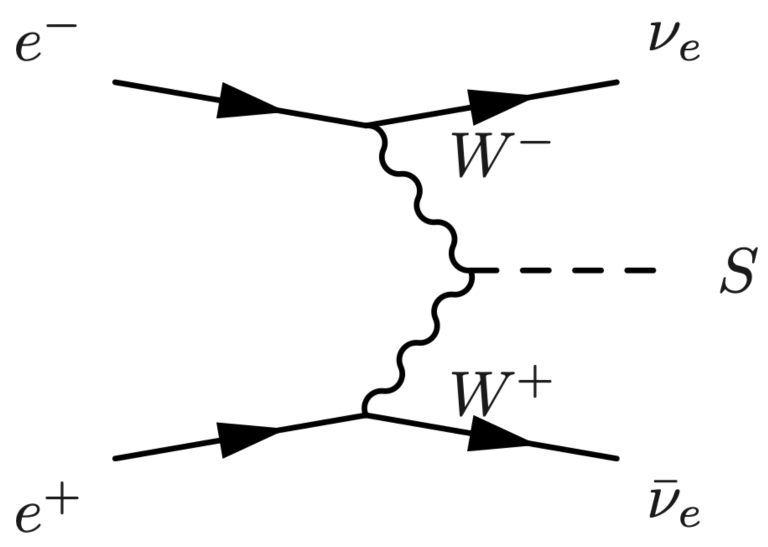
Single production in VBF



S. Chigusa, S. Knapen , T. Opferkuch, I. Savoray, C. Scherb, L. Xu *In progress*

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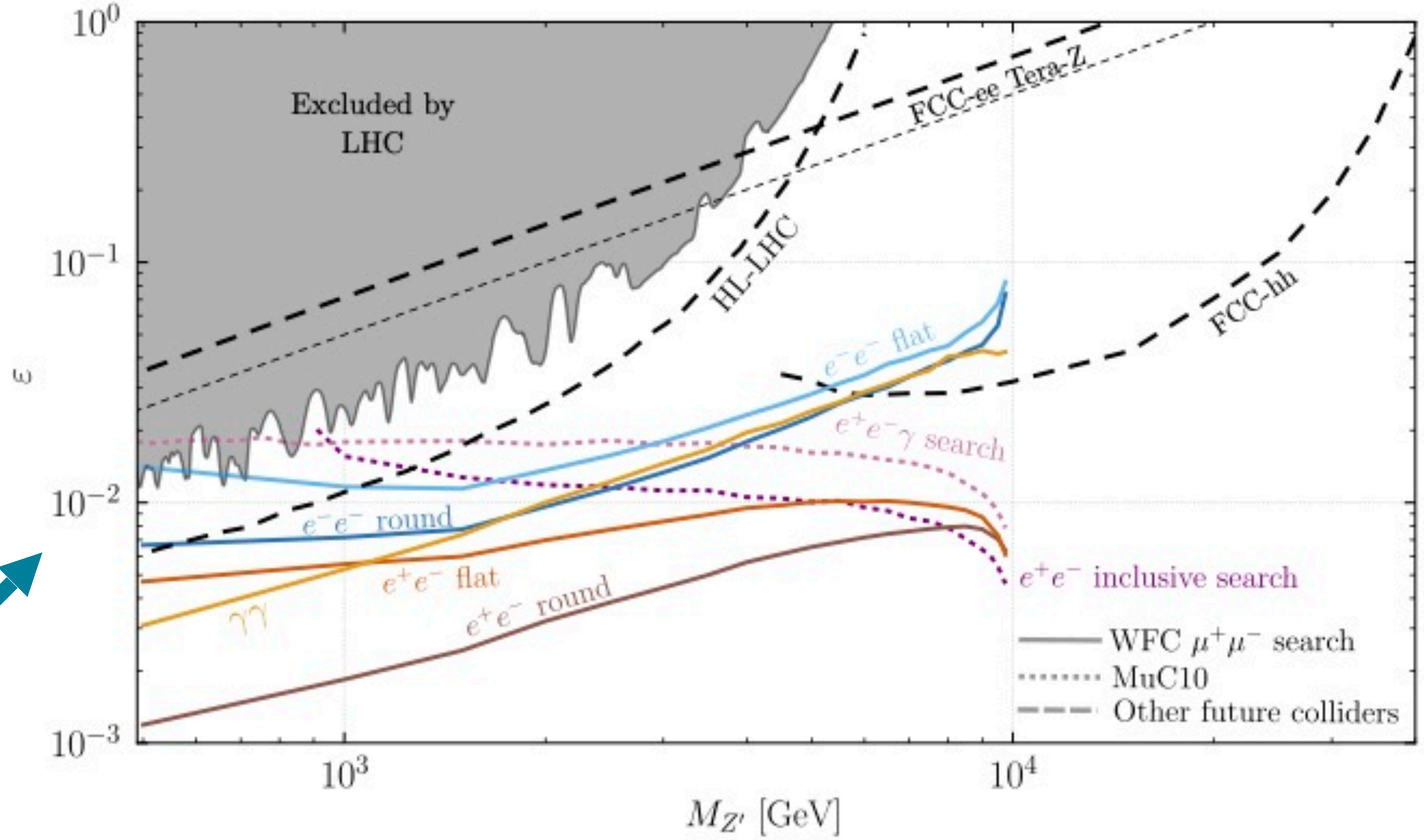

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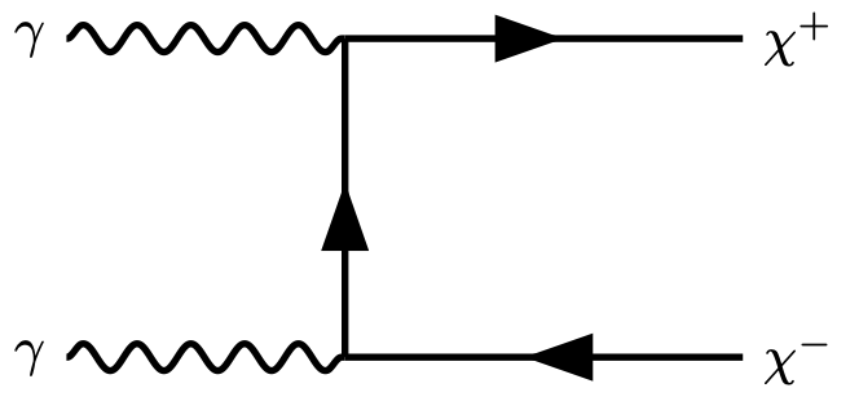

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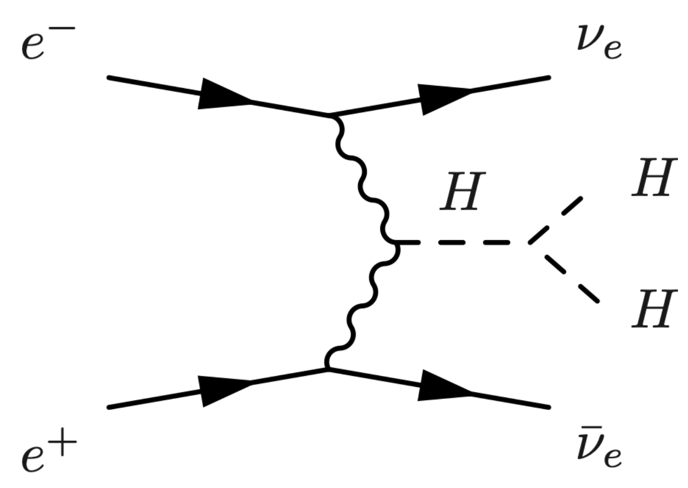

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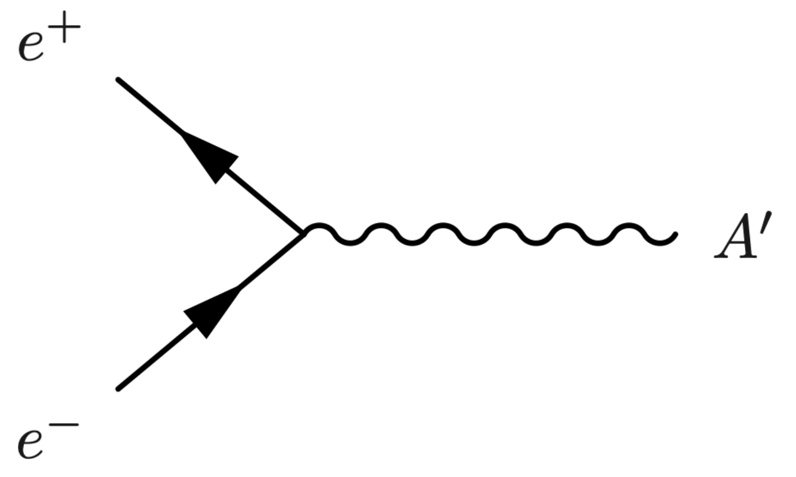
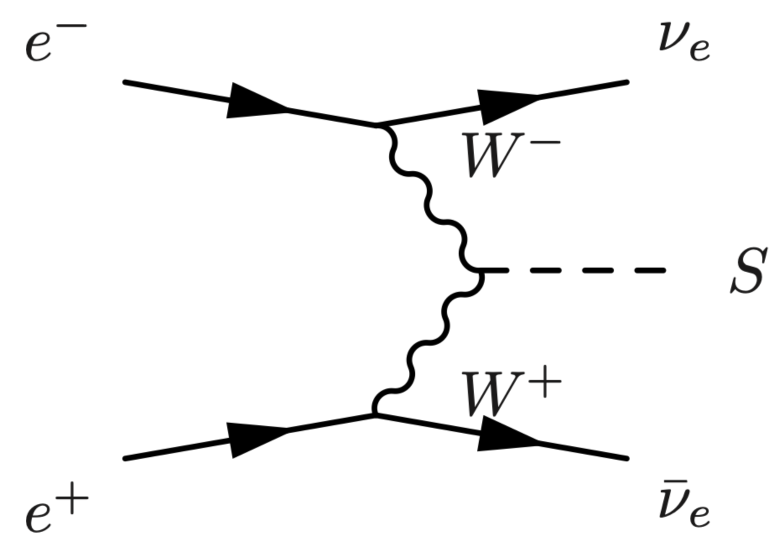


M. Cipressi, K. Langhoff, T. Opferkuch; arXiv:2603.18146

Single production in VBF



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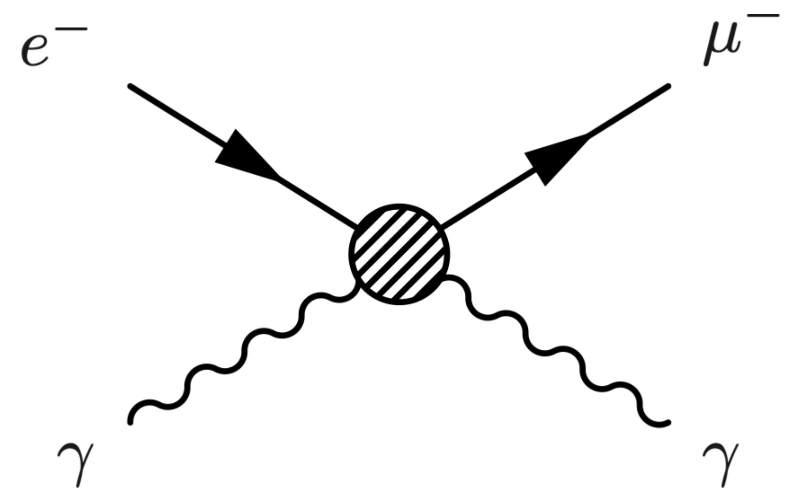
Lepton flavor violation



W. Altmanshofer, I. Bigaran, S. Knapen, P. Munbodh, N. Plešec, and J. Zupan *In progress*

Slide credit: T. Opferkuch (SISSA)

Takeaways from First Physics Studies

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Signal rates often enhanced for round beams

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Backgrounds are also enhanced but analysis methods from the LHC-era can cope

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Implies degraded jet resolution (may hurt Z versus h discrimination)

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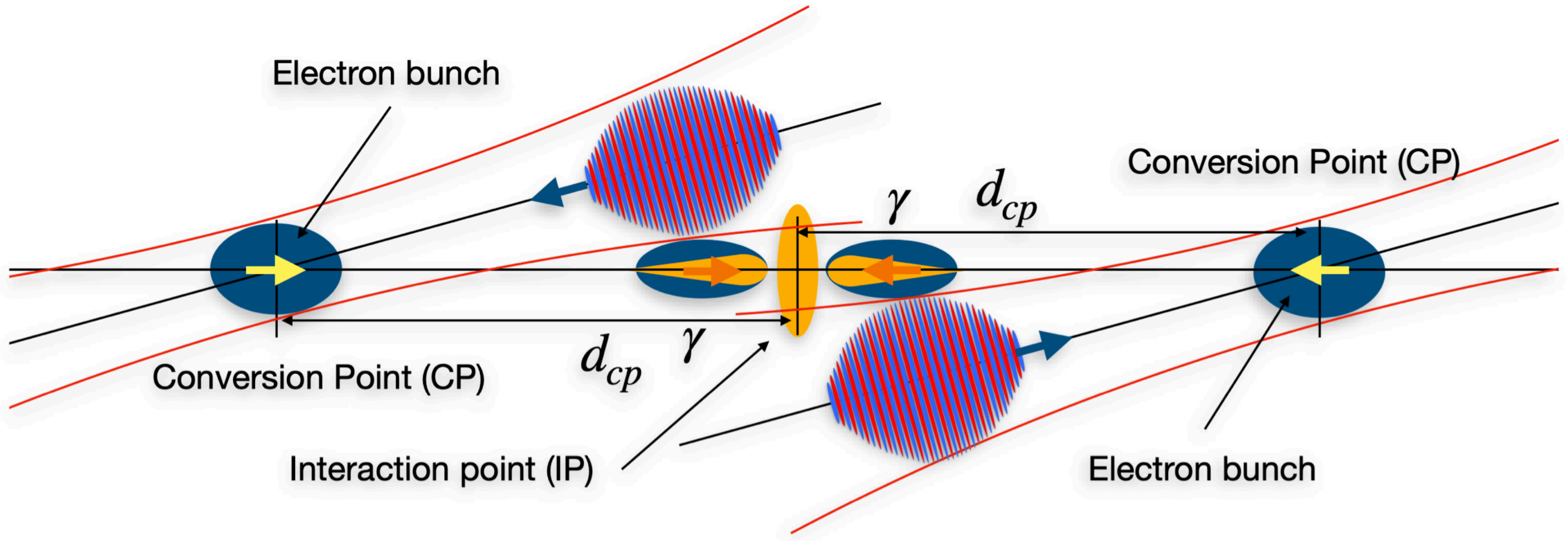
Strong progress in γ/γ CPs & IP, beam delivery system design

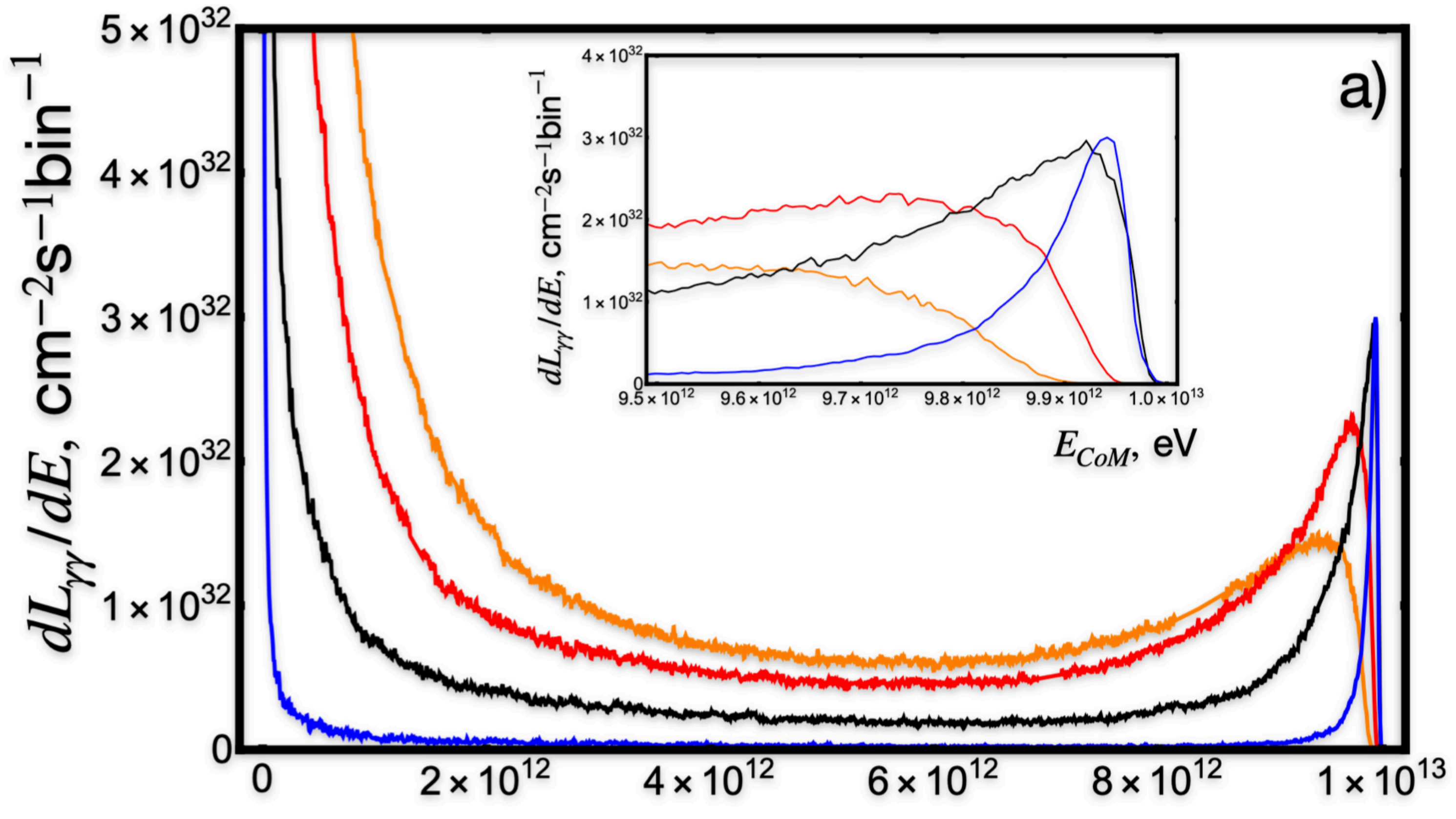
Some highlights from the first two years of 10 TeV Design Study work

Luminosity enhancement and interaction point characterization of a 10 TeV $\gamma\gamma$ collider using variable laser wavelengths.

S. S. Bulanov,* C. Benedetti, A. Formenti, R. Lehe, A. Rastogi, S. Pagan Griso, C. B. Schroeder, and J. Osterhoff
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

T. Barklow, S. Gessner, and A. Schwartzman
SLAC National Accelerator Laboratory, Menlo Park, California, USA





soon on arXiv

→ S. Bulanov, next

New Challenges in Plasma Accelerators: Final Focusing for Wakefield Colliders

Keegan Downham
University of California, Santa Barbara, CA 93106 and
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

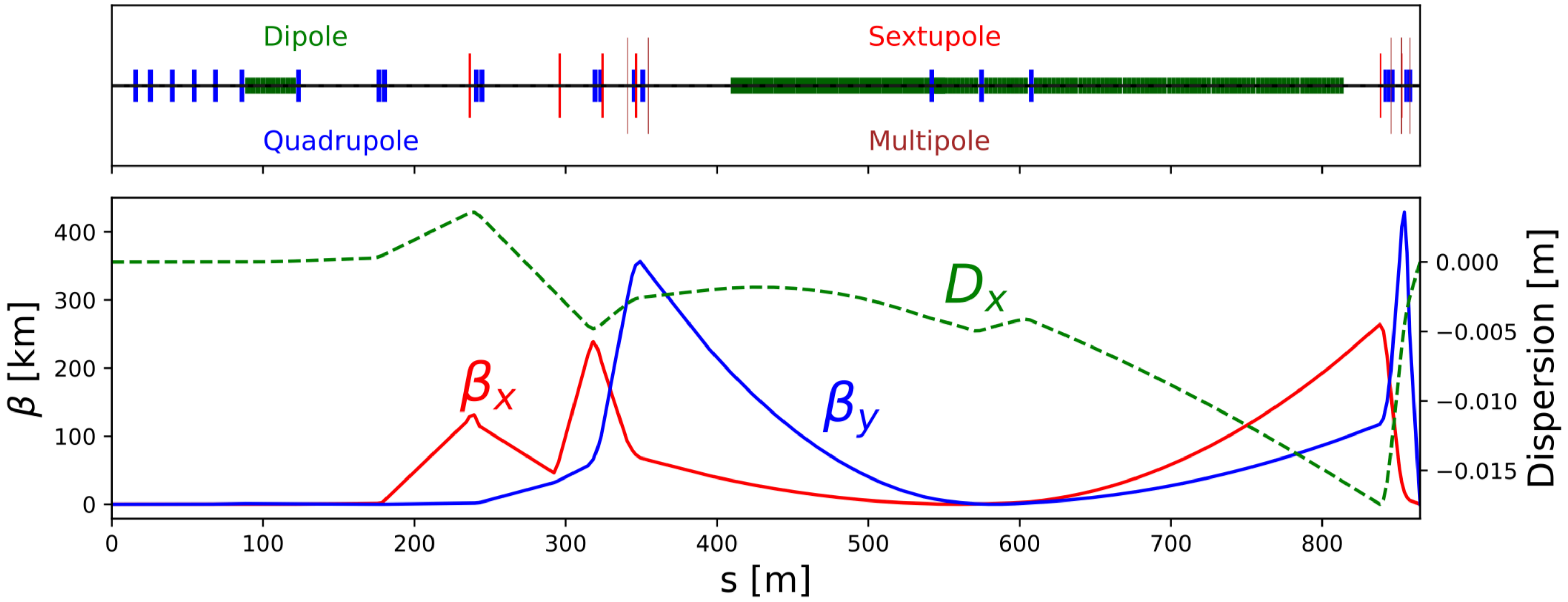
Spencer Gessner
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

Lewis Kennedy and Rogelio Tomás
CERN, Geneva, CH

Andrei Seryi
Old Dominion University, Norfolk, VA 23529

(Dated: January 31, 2026)

arXiv:2602.15777v1



Initial studies provide a final focus design less than 1 km long.

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- Development of near-term applications will open possibilities for very high performance future HEP applications incl. colliders

Conclusion

The 10 TeV Wakefield Collider Design Study has made rapid progress by partnering with HEP theorists, experimentalist, and collider experts

- strong level of engagement from the particle physics community
- new paradigms of 10 TeV colliders are explored and attractive:
  high beamstrahlung, round beam collisions, gamma-gamma

Advanced Accelerator research is undergoing a transition in the US

- focus is turning towards near-term applications
- critical step for increasing TRL towards future colliders

10 TeV Design Study Website

Google Form to Join Study