An Electron-Electron Collider for JLab?

Charles Hyde
Old Dominion University

My Context

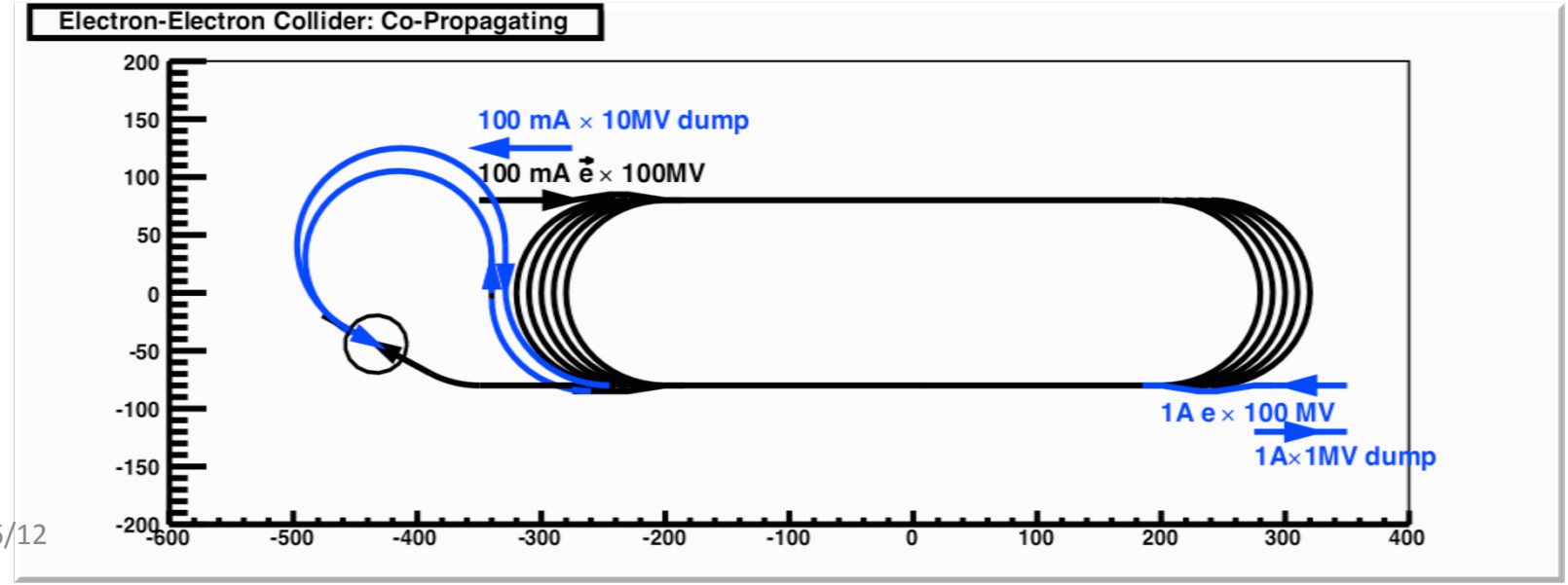
- Starting ~2015, we have at least 10 years of exciting physics to do with the 12 GeV upgrade.
- I personally am convinced that the most exciting project for QCD physics in the U.S. beyond 2020 is an Electron-Ion Collider
  - Construction start 2020, Physics start 2025
  - Luminosity, polarization, hermetic detectors are the critical parameters (in decreasing order).
  - Maximum CM energy is not the critical parameter.
- If an EIC is built elsewhere, or delayed by >5 years, is there a future for QCD physics at JLab that will still appear new and exciting in 2020++?

A Polarized Electron-Electron Collider @ JLab

- Is it exciting?
- Is it unique?
  - What is the advantage/distinction *vis à vis* e^+e^- colliders
- Is it (relatively) inexpensive?
  - ≤ 12 GeV upgrade.
- Is it the only (or best) option?
  - I am just trying to present an option.
- I have only initial, tentative, and partial answers to these questions
  - Invitation to dialog.

A Straw-Man Design

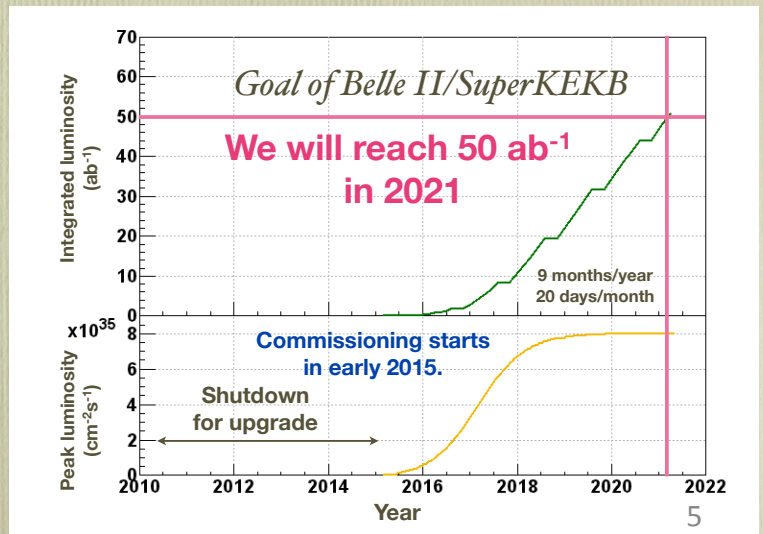
- Double Energy Recirculation
  - [100 mA x 6 GeV $\vec{e}^-$] × [1A x 0.59 GeV e^-] ➔ $\sqrt{s}$ = 3.8 GeV
    - 100mA polarized is 10x current achievements
    - 2MW RF power ➔ 600:1 ERL is 15x current achievements
- e^-e^- Luminosity $2 \cdot 10^{35}/cm^2/s$ ➔ 500 fb^{-1}/month
  - Normalized transverse emittance 10^{-6} meter•radian
  - $\beta^*_{x,y}$ = (10,0.25) mm ➔ Beam spot at IP = (3,0.5)μm
  - Quasi-real $\gamma\gamma$ luminosity > $(10^{31}/cm^2/s)$ (ds_γ/s_γ)



Accelerator Context

- B-factories $\sqrt{s} \approx 10$ GeV
- BaBar
  - Final Luminosity $10^{34}/cm^2/sec$
  - integrated luminosity $\geq 500\ fb^{-1}$
- Belle
  - 5 years to reach $10^{34}/cm^2/sec$
  - Luminosity record $2 \cdot 10^{34}/cm^2/s$
  - Integrated luminosity $1000\ fb^{-1}$
- Belle-II/SuperKEKB
  - Ground breaking 11/11
  - Design $8 \cdot 10^{35}/cm^2/sec$
- SuperB
  - Italy, France, SLAC…
  - Design $10^{36}/cm^2/sec$
    - $(3\ A)^2$
    - $\beta_y^* \approx 0.3$ mm
    - RF power ~10MW

SuperKEKB luminosity projection



Physics Program

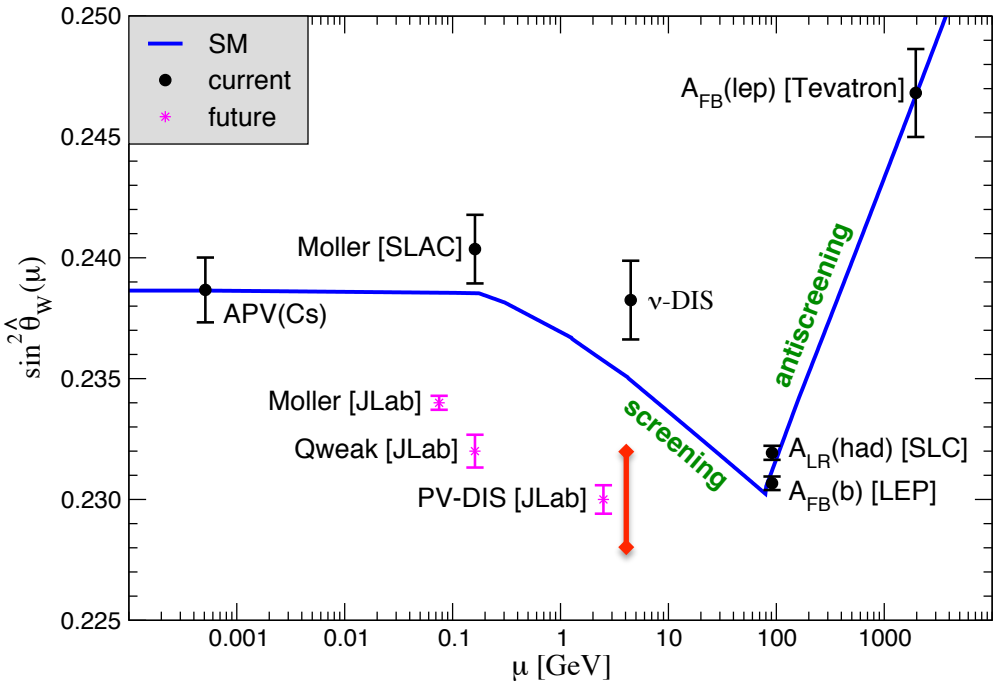
- Parity Violating Møller Scattering
  - ee → ee, free of nuclear background
  - B-factories are not polarized
- Two photon QCD physics
  - Transition Form Factors
    - $\gamma^*\gamma \rightarrow \pi^0, \eta$, or $\eta' \ldots \eta_C$
    - $\gamma^*\gamma^* \rightarrow \pi^0, \eta$, or $\eta' \ldots$
  - t-channel Compton scattering
    - $\gamma\gamma \rightarrow \pi^+\pi^-, \pi^0\pi^0, K^+K^-$, *or* K^0K^0
    - $\gamma^*\gamma \rightarrow \pi^+\pi^-, \ldots$

Parity Violating Møller Scattering

- Møller Figure of Merit (FOM)
  - PV asymmetry
    $A_y \sim [Q^2/M_Z^2]\,(¼ – \sin^2\theta_W) \sim [s/M_Z^2]\,(¼ – \sin^2\theta_W)$
  - Møller cross section $\sigma \sim 1/Q^2 \sim 1/s$
  - FOM = $\sigma A_y^2 \sim s$

	ee Collider	12 Gev Møller
s (GeV^2)	14	0.011
L ($cm^{-2}s^{-1}$)	$2\bullet10^{35}$	$3\bullet10^{39}$
$L\bullet FOM$	2.8	33
$\delta\sin^2\theta_W$	**0.002***	0.0003

*1 PAC yr ~ 3 yrs



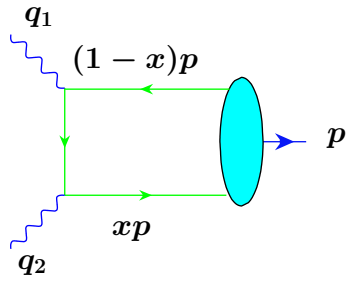
Two Photon Physics

- Projected e^-e^- luminosity =$2 \cdot 10^{35}$ at $\sqrt{s}$~4 GeV
- Previous e^+e^- *B*-factory luminosity = 10^{34} at $\sqrt{s}$~10 GeV
- Projected SuperKEK and/or SuperB luminosity 10^{36}
- B-factory detectors and triggers are not optimized for two-photon physics
  - Belle measured $\gamma\gamma \rightarrow \pi\pi$
  - BaBar measured $\gamma^*\gamma \rightarrow \pi^0, \eta, \eta'$ and $\gamma^* \rightarrow$ p p-bar

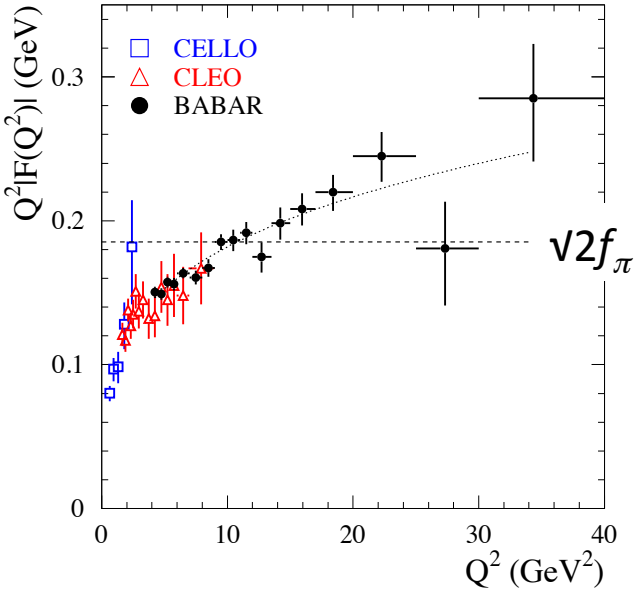
Two-Photon Physics: Scalars

- $\gamma\gamma \rightarrow$ scalars
  - Possible contribution to muon *g–2* anomaly
  - Search for new physics is limited by hadronic corrections
- Scalar-Isoscalar spectrum
  - $\sigma(600)$
  - $f_0(980)$
  - $f_0(1370)$
  - …

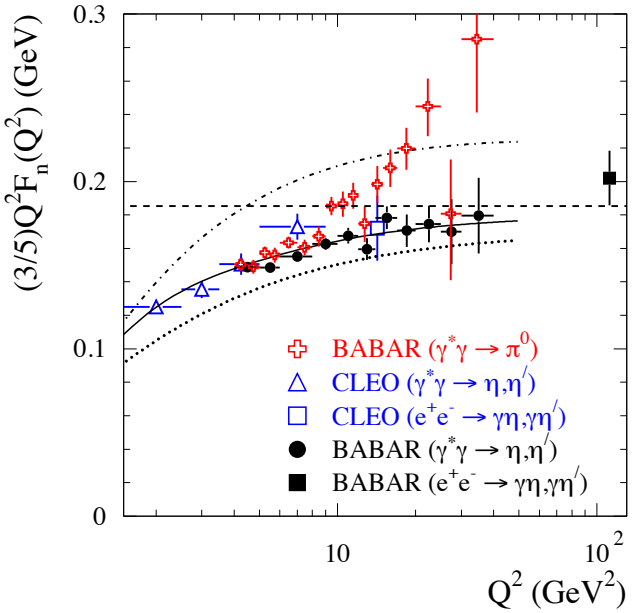
$\gamma^*\gamma \rightarrow \pi^0$ Transition Form Factor



- Rosetta Stone of pQCD
  - until BaBar spoiled the party [Phys Rev D**80** 05002].
- Strong intrinsic k_T corrections?
  - e.g. A. Radyushkin PRD**80** 094009
- Universal scaling for $\gamma^*\gamma^* \rightarrow \pi^0$
  - $[Q_1^2+Q_2^2]\,F(Q_1^2,Q_2^2) = f(\omega)$
    - $Q^2_{1,2} = Q^2(1\pm\omega)/2$
  - Violated by strong k_T corrections?
- $\gamma^*\gamma^* \rightarrow \pi^0$
  - Rough projection of error bars in e^-e^- collisions $\delta F(2\text{GeV}^2,Q^2) \sim 0.025/Q^2$ for $\Delta Q^2=4\text{GeV}^2$, $Q^2<14\ \text{GeV}^2$

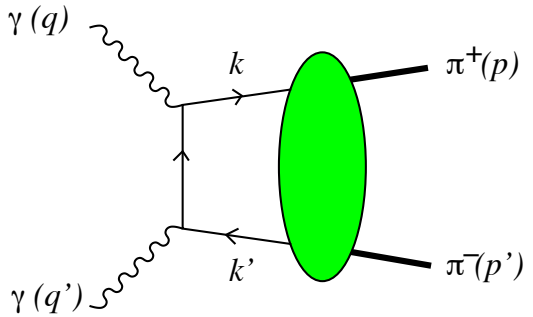


BaBar Anomaly in $\gamma^*\gamma \rightarrow \pi^0$ TFF



- No anomaly seen in $\gamma^*\gamma \rightarrow \eta, \eta'$
- Maybe BaBar $\gamma^*\gamma \rightarrow \pi^0$ data are wrong
  - Update with future super B-factories
  - Expect to observe scaling in $\gamma^*\gamma^* \rightarrow \pi^0$
    - Map out pion DA from 'inversion' $\omega = (Q_1^2 - Q_2^2)/Q^2$ dependence
- Maybe BaBar $\gamma^*\gamma \rightarrow \pi^0$ data are correct
  - We understand the pion even less than we thought
  - Violations of scaling in $\gamma^*\gamma^* \rightarrow \pi^0$ are possible signatures of k_T effects or $q\bar{q}g$ higher twist correlations.

t-channel Compton: γγ → ππ,…



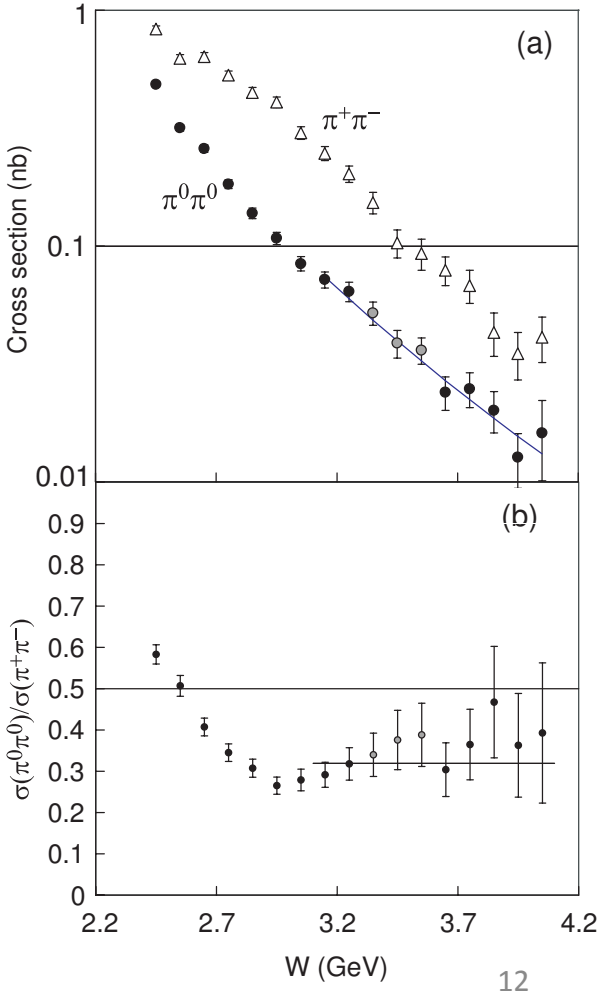
- Asymptotic pQCD ←high mass(ππ)
  - gluon exchange to balance momenta
    - Brodsky Lepage, Phys. Rev. D **24**, 1808 (1981)

$$\frac{\sigma(\gamma\gamma \to \pi^0\pi^0)}{\sigma(\gamma\gamma \to \pi^+\pi^-)} \approx 0.05$$

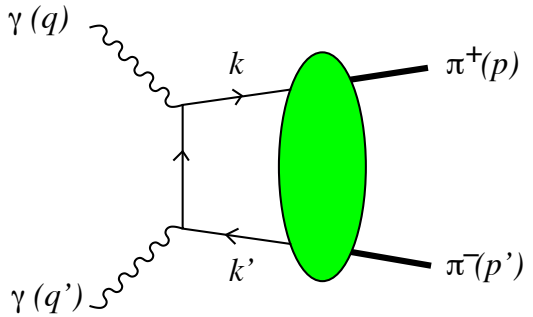
- 'Feynman' Mechanism
  - Soft interactions generate high momentum quarks
    - Diehl, Kroll, & Vogt PL B**532** (2002) 99

$$\frac{\sigma(\gamma\gamma \to \pi^0\pi^0)}{\sigma(\gamma\gamma \to \pi^+\pi^-)} \approx 0.5$$

- Belle Data (200 fb^{-1})
  - Phys Rev D**79** 052009 (2009).

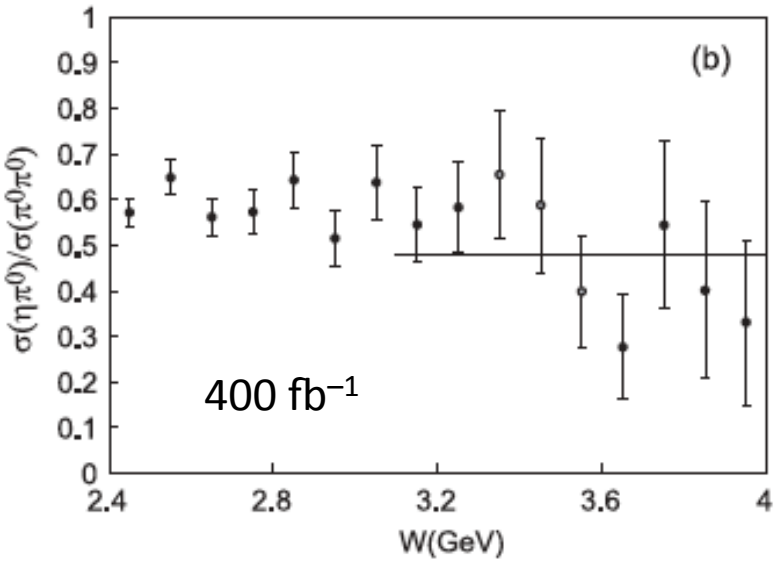


'DVCS' in $e^-e^- \rightarrow e^-e^-\pi\pi$,…

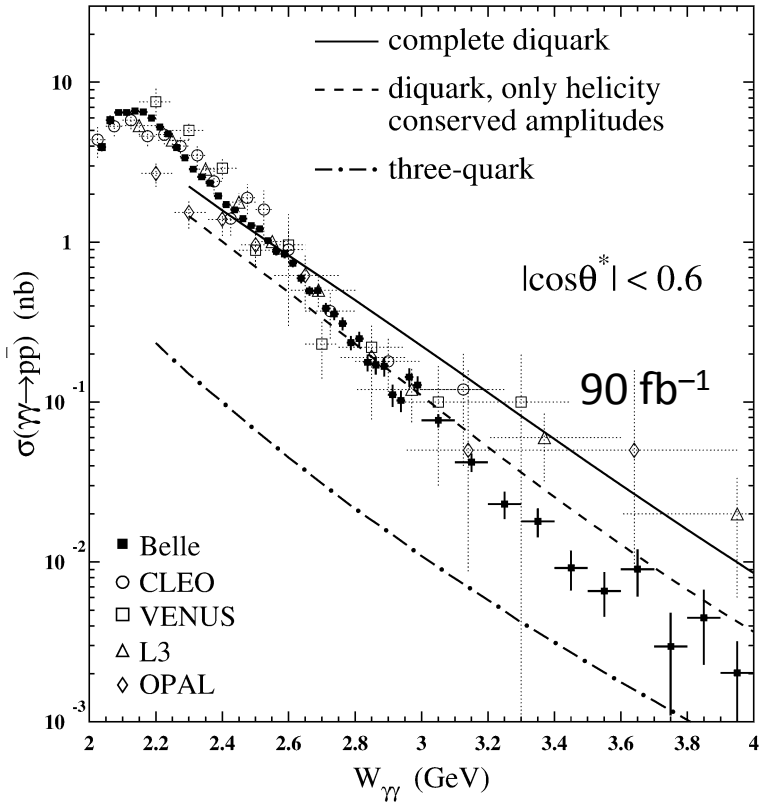


- Time-like GPDs
  - $\gamma^* \gamma \rightarrow \pi\pi,\ldots p\bar{p}$
- Single and double γ^* polarization observables
  - Dynamics of super-fast quarks

[Belle] PRD **80,** 032001 (2009)



Belle Collaboration / Physics Letters B 621 (2005) 41–55



Energy and/or Polarization Upgrade

- As described, one Hall e^-e^- collisions could be compatible with fixed target running in other Halls
- Use 500 MHz or 750 MHz separator to divide full energy 6 (or 11 GeV) beam for full energy double polarized collisions:
  - Full polarization study of $\gamma^*\gamma \rightarrow \pi^+\pi^-$,…
  - 10×10 GeV^2 extends physics reach to b-threshold
  - Luminosity ≥ $2 \cdot 10^{34}/cm^2/s$

~~Conclusions~~ Points for further discussion

- Novel and exciting QCD and EW physics opportunities with a dedicated ee Collider
- More discussion required to establish range of conservative to aggressive-but-possible machine parameters.
  - What is a reasonable cost estimate?
- How does detector design, triggering, polarization affect the comparison with beauty- or charm-factories?