Physics with the Helicity-flip Suppressed, Transverse Asymmetries in Bhabha scattering

Dave Mack (Jefferson Lab)

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Introduction

Purely Leptonic Reactions Accessible at JLab

Only one purely leptonic reaction is currently accessible at Jlab: Moeller scattering (**$e^- e^- \rightarrow e^- e^-$**).

With an e^+ injector, two more will become available:

- Bhabha scattering (**$e^+ e^- \rightarrow e^+ e^-$**), and
- Sub-threshold di-muon production (**$e^+ e^- \rightarrow \mu^+ \mu^-$**)*

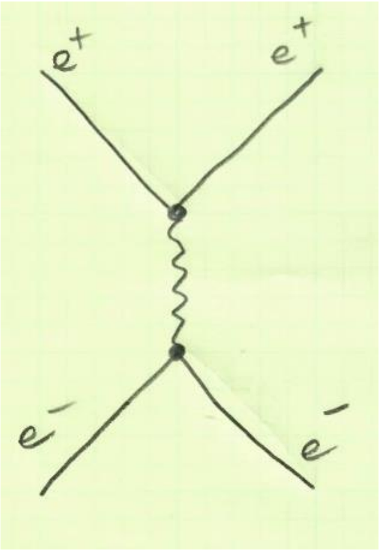
I have chosen to focus on Bhabha scattering since it has advantages including physics reach, feasibility, and flexibility.

(However, we should keep in mind that sub-threshold di-muon production would probe the muon couplings.)

*i.e., only on relativistic electrons in the inner shells of high Z targets. This goes purely through an s-channel annihilation diagram.

Bhabha Scattering: $e^+ e^- \rightarrow e^+ e^-$

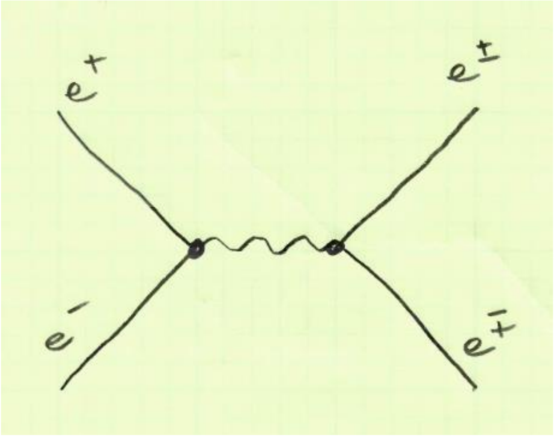
t-channel



The s-channel diagrams are interesting because their contribution to the helicity amplitudes is constrained by the spin of the exchanged particle:

- In the Standard Model (SM), the exchanged boson is effectively a γ or Z^0 (ie, spin = 1).
- Beyond the SM (BSM), other particles can be exchanged (eg, spin = 0).

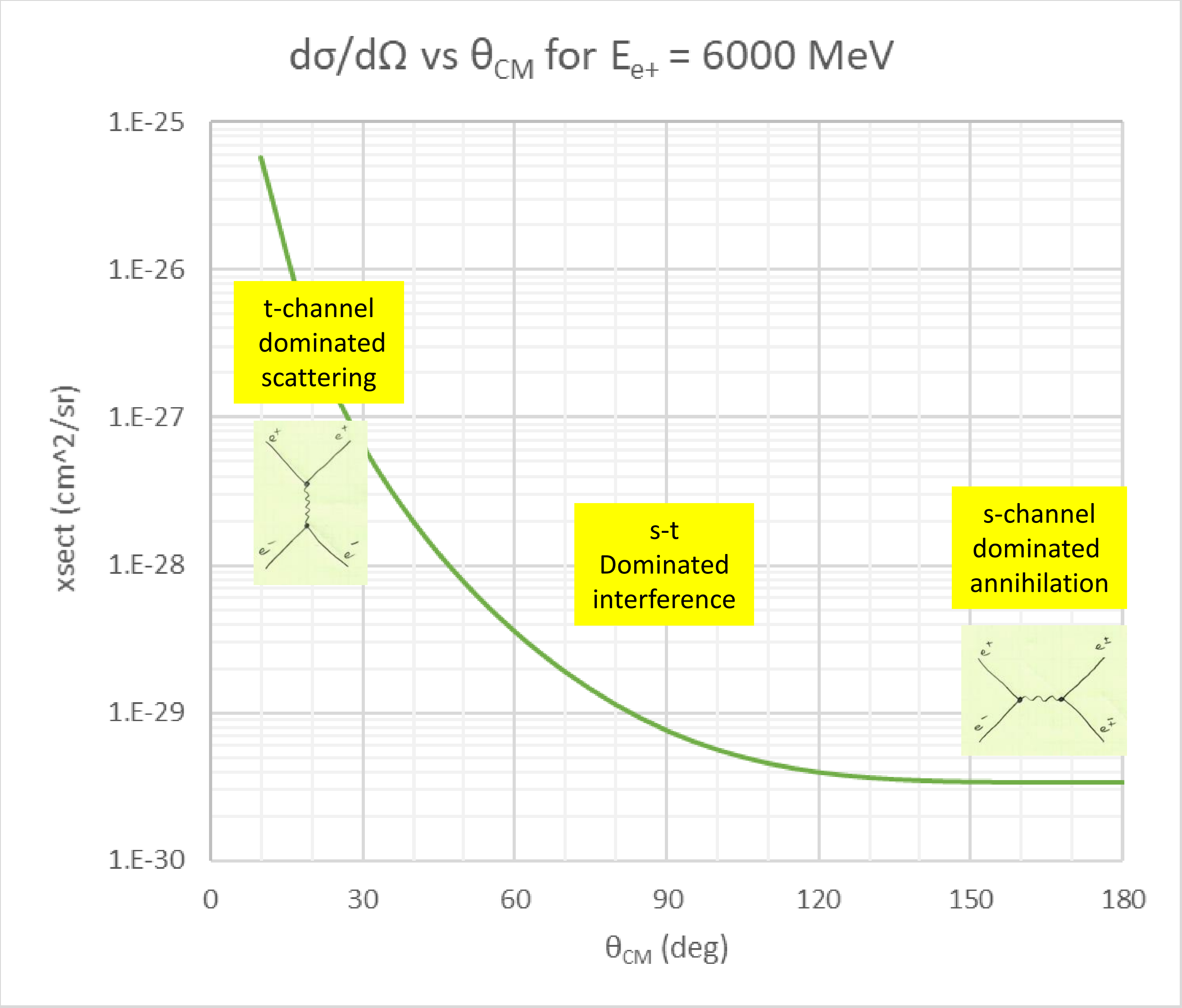
s-channel



Of the 3 reactions I mentioned on the last slide, only Bhabha scattering features interference terms between s- and t-channel, which I'll show below makes Bhabha scattering uniquely sensitive to BSM scalar exchange.

Bhabha dσ/dΩ vs θ_{CM}

- The differential xsect has effectively 3 regions
- The forward, t-channel dominated regime would in principle provide the large xsects needed for PV measurements.
- The two backward regimes access s-channel annihilation, as well as the opportunity to interfere this with t-channel exchange.
- At 6 GeV, the backward xsects are quite large by Jlab standards (a few μB/sr).
- This begs the question of whether we can use this s-t interference region for precision searches for BSM particles.



Helicity Amplitudes Notation

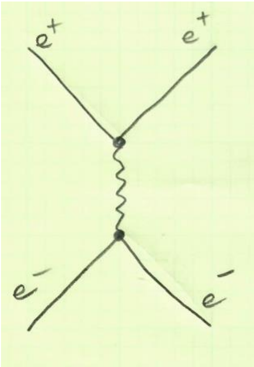
F_{ij}^{kl} represents the amplitude for the transition between initial state "ij" and final state "kl" (ie, $F_{e+e-}^{e+e-} = F_{initial}^{final}$)

The indices are "L" or "R", so there are at most 2x2x2x2 = 16 helicity amplitudes.

You may often see it written as F_{ij} (ie $F_{initial}$) since the final e^+e^- polarizations are generally not measured. This implies a summation over the 4 final helicity states (LR, RL, LL, and RR).

I will write it as F_{ij}^{kl},s to denote the s-channel contribution, or F_{ij}^{kl},t to denote the t-channel contribution.

The t-channel Helicity Amplitudes



In the t-channel, helicity is largely conserved at each vertex, with flip probabilities suppressed by one or two factors of $1/\gamma = 2m_e/E_{cm}$.

Unsuppressed scatterings are LR→LR, RL→RL, LL→LL, and RR→RR.

High energy collider papers typically treat the matrix as if it were purely diagonal (the so-called $m_e \rightarrow 0$ limit). This is reasonable since the effect of SM off-diagonal terms would be smaller than their statistical sensitivity.

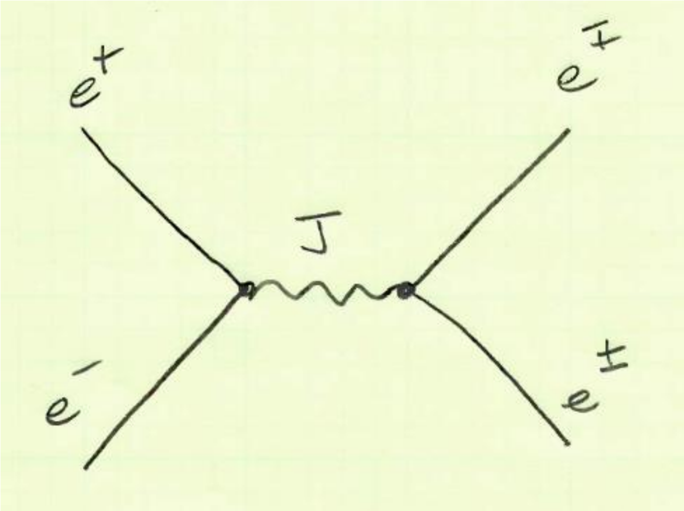
		Final e+e- helicity			
Initial e+e- helicity		LR	RL	LL	RR
	LR	F_{LR}^{LR},t	0	0	0
	RL	0	F_{RL}^{RL},t	0	0
	LL	0	0	F_{LL}^{LL},t	0
	RR	0	0	0	F_{RR}^{RR},t

For fixed target e^+ experiments at Jlab, where our statistical sensitivity may be 1 ppm, the SM off-diagonal terms will be important even at a beam energy of 10 GeV (ie, $\gamma \sim 100$).

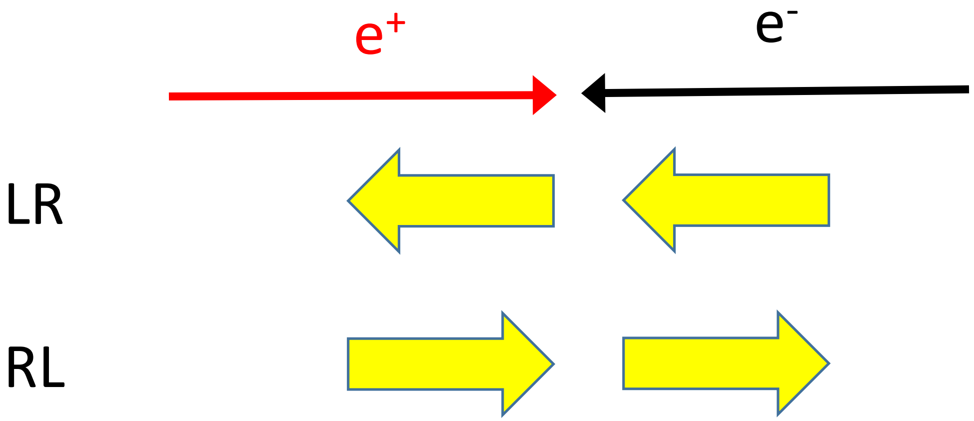
		Final e+e- helicity			
Initial e+e- helicity		LR	RL	LL	RR
	LR	F_{LR}^{LR},t	$\sim 1/\gamma^2$	$\sim 1/\gamma$	$\sim 1/\gamma$
	RL	$\sim 1/\gamma^2$	F_{RL}^{RL},t	$\sim 1/\gamma$	$\sim 1/\gamma$
	LL	$\sim 1/\gamma$	$\sim 1/\gamma$	F_{LL}^{LL},t	$\sim 1/\gamma^2$
	RR	$\sim 1/\gamma$	$\sim 1/\gamma$	$\sim 1/\gamma^2$	F_{RR}^{RR},t

s-channel Constraints on Exchanged J

s-channel annihilation filters the spin of the exchanged boson:



J_z = -+1
(SM vectors)



Adapted from G. Moortgat-Pick et al., Phys. Rept. 460:131-243, 2008

s-channel Constraints on Exchanged J

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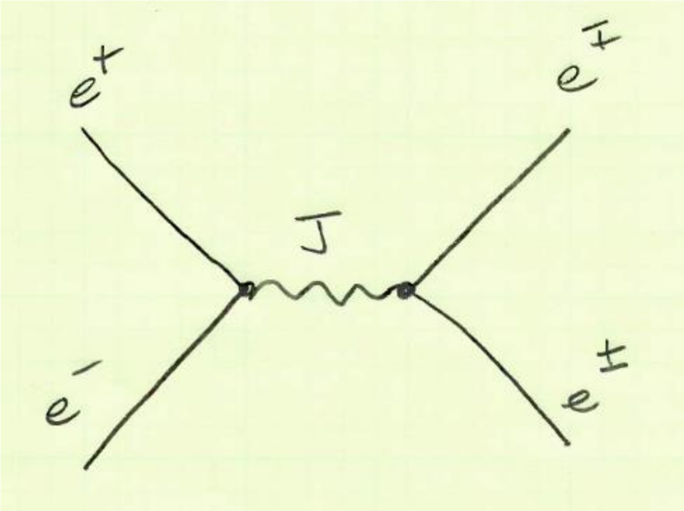
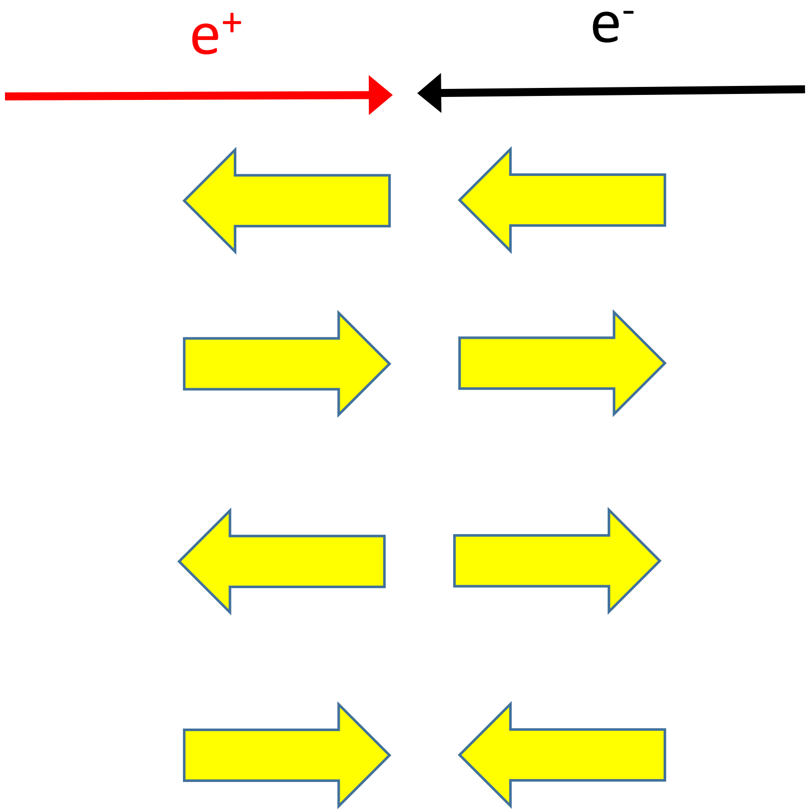




J_z = -+1
(SM vectors)

LR

RL

J_z = 0
(SM Higgs,
BSM scalars)

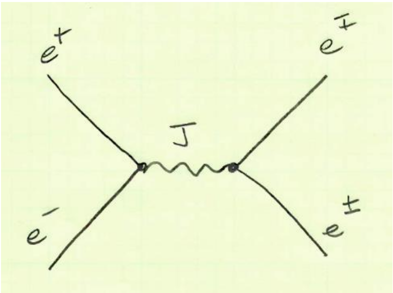
LL

RR

The SM Higgs coupling to the small electron mass is 3E-6, so the amplitude of the above diagram would be 1E-11 hence unmeasureably small.

Adapted from G. Moortgat-Pick et al., Phys. Rept. 460:131-243, 2008

The SM s-channel Helicity Amplitudes



As explained on the previous slide, in the s-channel, only scatterings consistent with the exchange of a spin = 1 gamma or Z are allowed in first order, with exceptions suppressed by one or two factors of $1/\gamma = 2m_e/E_{cm}$.

The only unsuppressed scatterings are the 4 combinations of LR or RL.

In the $m_e \rightarrow 0$ limit, the SM s-channel amplitudes are zero for LL or RR.

	Final e+e- helicity				
Initial e+e- helicity		LR	RL	LL	RR
	LR	F_{LR}^{LR},s	F_{LR}^{RL},s	0	0
	RL	F_{RL}^{LR},s	F_{RL}^{RL},s	0	0
	LL	0	0	0	0
	RR	0	0	0	0

For fixed target e^+ experiments at Jlab, we will of course use the exact 1st order QED helicity amplitudes.
Note the SM amplitudes in the lower right hand corner have high suppression (at least by the standards of PC amplitudes).

	Final e+e- helicity				
Initial e+e- helicity		LR	RL	LL	RR
	LR	F_{LR}^{LR},s	F_{LR}^{RL},s	$\sim 1/\gamma$	$\sim 1/\gamma$
	RL	F_{RL}^{LR},s	F_{RL}^{RL},s	$\sim 1/\gamma$	$\sim 1/\gamma$
	LL	$\sim 1/\gamma$	$\sim 1/\gamma$	$\sim 1/\gamma^2$	$\sim 1/\gamma^2$
	RR	$\sim 1/\gamma$	$\sim 1/\gamma$	$\sim 1/\gamma^2$	$\sim 1/\gamma^2$

The s-channel Helicity Amplitudes with a BSM Scalar

BSM scalars	Final e+e- helicity				
Initial e+e- helicity		LR	RL	LL	RR
	LR	$\sim 1/\gamma^2$	$\sim 1/\gamma^2$	$\sim 1/\gamma$	$\sim 1/\gamma$
	RL	$\sim 1/\gamma^2$	$\sim 1/\gamma^2$	$\sim 1/\gamma$	$\sim 1/\gamma$
	LL	$\sim 1/\gamma$	$\sim 1/\gamma$	F_{LL}^{LL},s	F_{RR}^{RR},s
	RR	$\sim 1/\gamma$	$\sim 1/\gamma$	F_{RR}^{LL},s	F_{RR}^{RR},s

Polarization observables containing the helicity amplitudes F_{LL}^{LL}, F_{LL}^{RR}, F_{RR}^{RR}, or F_{RR}^{LL} seem potentially interesting for BSM scalar searches, because the SM vector exchange backgrounds are suppressed by $1/\gamma^2$.

Let's hunt for an appropriate observable.

Helicity Amplitudes in Bhabha Scattering

$4|M|^2 = \quad + |F_{LR}|^2 + |F_{RL}|^2 + |F_{LL}|^2 + |F_{RR}|^2$ ← Unpolarized xsect

An unpolarized energy scan of the xsect at backward angles could search for scalars. But barring a resonance between E_{cm} = 10-100 MeV/c^2, the sensitivity would be low since the SM vector backgrounds in the s-channel would be large, i.e,

$$|F_{LR}|^2 + |F_{RL}|^2 \gg |F_{LL}|^2 + |F_{RR}|^2$$

These slides are adapted from:
"Polarized positrons and electrons at the linear collider", G. Moortgat-Pick et al., Phys. Rept. 460:131-243,2008, https://arxiv.org/abs/hep-ph/0507011

Helicity Amplitudes in Bhabha Scattering

$$\begin{aligned} 4|M|^2 = \; & +|F_{LR}|^2 + |F_{RL}|^2 + |F_{LL}|^2 + |F_{RR}|^2 \\ & + \mathbf{P}_{e-}^{L}\left(+|F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 - |F_{LL}|^2 \right) \\ & + \mathbf{P}_{e+}^{L}\left(-|F_{RL}|^2 + |F_{RR}|^2 + |F_{LR}|^2 - |F_{LL}|^2 \right) \\ & + \mathbf{P}_{e-}^{L}\,\mathbf{P}_{e+}^{L}\left(-|F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 + |F_{LL}|^2 \right) \end{aligned}$$

Unpolarized xsect

Longitudinal polarization only

Note each polarization dependent line defines a separate asymmetry after dividing by the unpolarized xsect.

Adding L polarization alone would not greatly expand the Bhabha physics program:

- The longitudinal single spin asymmetries A_{LU} or A_{UL} are parity violating, and at tree level are only O(10) ppb. Low energy constraints on BSM sources of parity violation are already excellent thanks to Cs Atomic PV, E158, and Qweak. The Hall A Moeller experiment will improve on this. A competitive PV measurement with few % precision and only 50 nA of polarized e+ beam would require 1000's of years.

- The double spin asymmetry A_{LL} is large, essentially a SM candle that could be used for polarimetry.

Helicity Amplitudes in Bhabha Scattering

$$4|M|^2 = +|F_{LR}|^2 + |F_{RL}|^2 + |F_{LL}|^2 + |F_{RR}|^2$$ ← Unpolarized xsect

$$+ \mathbf{P_{e-}^{L}} (+|F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 - |F_{LL}|^2)$$

$$+ \mathbf{P_{e+}^{L}} (-|F_{RL}|^2 + |F_{RR}|^2 + |F_{LR}|^2 - |F_{LL}|^2)$$

$$+ \mathbf{P_{e-}^{L} P_{e+}^{L}} (- |F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 + |F_{LL}|^2)$$

← Longitudinal polarization only

$$+ \mathbf{P_{e-}^{T}} (+2\mathrm{Re}(F_{RL}F_{LL}^* + F_{RR}F_{LR}^*) \cos(\phi_m - \phi) -2\mathrm{Im}(F_{RL}^*F_{LL} - F_{RR}^*F_{LR}) \sin(\phi_m - \phi))$$

$$+ \mathbf{P_{e+}^{T}} (-2\mathrm{Re}(F_{LR}F_{LL}^* + F_{RR}F_{RL}^*) \cos(\phi_p - \phi) -2\mathrm{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL}) \sin(\phi_p - \phi))$$

$$+ \mathbf{P_{e-}^{T} P_{e+}^{T}} (-2\mathrm{Re}(F_{RR}F_{LL}^*)\cos(\phi_m - \phi_p) -2\mathrm{Im}(F_{RR}^*F_{LL})\sin(\phi_m - \phi_p) \boldsymbol{- 2\mathrm{Re}(F_{LR}F_{RL}^*)\cos(\phi_m+\phi_p-2\phi) +2\mathrm{Im}(F_{LR}^*F_{RL})\sin(\phi_m+\phi_p-2\phi)})$$

$$+ \mathbf{P_{e+}^{L} P_{e-}^{T}} (-2\mathrm{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*)\cos(\phi_m - \phi) +2\mathrm{Im}(F_{RL}^*F_{LL} + F_{RR}^*F_{LR})\sin(\phi_m - \phi))$$

$$+ \mathbf{P_{e+}^{T} P_{e-}^{L}} (+2\mathrm{Re}(F_{LR}F_{LL}^* - F_{RR}F_{RL}^*)\cos(\phi_p - \phi) +2\mathrm{Im}(F_{LR}^*F_{LL} + F_{RR}^*F_{RL})\sin(\phi_p - \phi))$$

↕ Require Transverse polarization (including **L-T** asymmetries)

Transverse polarization introduces the interference of helicity amplitudes, and would be insanely enriching.

As far as I know, none of the asymmetries implied here have ever been deliberately measured.

Only the two asymmetries in **bold** have SM contributions which survive in the $m_e \rightarrow 0$ limit.

Summary Table of the Transverse Asymmetries

Don’t despair, I hate formula-filled slides too!

To make transverse asymmetries less overwhelming, let me reduce those 12 asymmetries to only 4, by dropping the PV ones, and any redundant ones (assuming no CP violation), and giving them easy and obvious names:

Transverse Asymmetry	Proportional to These Helicity Amplitudes	ϕ Dependence	Suppression in SM	Comment
A_{TT}	$-2Re(F_{LR}F_{RL}{}^*)$	$\cos(\phi_m+\phi_p-2\phi)$	Unsuppressed.	SM candle for polarimetry.
A_{TT}'	$-2Re(F_{RR}F_{LL}{}^*)$	$\cos(\phi_m-\phi_p)$	$1/\gamma^2$	BSM scalar/pseudoscalar/tensor search observable. An article is in (slow!) preparation.

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A_{TT}'	$-2\mathrm{Re}(F_{RR}F_{LL}^*)$	$\cos(\phi_m-\phi_p)$	$1/\gamma^2$	BSM scalar/pseudoscalar/tensor search observable. An article is in (slow!) preparation.
A_{TU}	$-2\mathrm{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL})$	$\sin(\phi_p-\phi)$	α/γ (two-photon)	Insensitive to BSM scalars, as I showed at our Oct '24 meeting. Wen et al think they are useful to search for dipole operators, which seems to mean "BSM sources of unsuppressed single helicity flip".*
A_{LT}	$-2\mathrm{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*)$	$\cos(\phi_m-\phi)$	$1/\gamma$	

* X-K Wen et al, PRL 131, 241801 (2023).

The Double Spin Asymmetry, A_{TT}'

(an unusual transverse asymmetry,
seemingly useful for a BSM scalar search)

T Polarized e^+ Beam, T Polarized e^- Target

$$\text{Yield}_{TT}(\theta, \phi) \sim -\text{Re}(F_{RR}F_{LL}^*)\cos(\phi_m - \phi_p) - \text{Im}(F_{RR}^*F_{LL})\sin(\phi_m - \phi_p)$$

$$- \text{Re}(F_{LR}F_{RL}^*)\cos(\phi_m+\phi_p-2\phi) + \text{Im}(F_{LR}^*F_{RL})\sin(\phi_m+\phi_p-2\phi)$$

PC PV

ϕ_p is the azimuthal polarization angle of the e^+ beam.

ϕ_m is the azimuthal polarization angle of the e^- in the target.

For this observable, the cosine terms are PC and therefore dominant. We will ignore the PV terms.

T Polarized e^+ Beam, T Polarized e^- Target

$$\mathrm{Yield}_{TT}(\theta, \phi) \sim -\mathrm{Re}(F_{RR}F_{LL}^*)\cos(\phi_m - \phi_p)$$
$$- \mathrm{Re}(F_{LR}F_{RL}^*)\cos(\phi_m+\phi_p-2\phi)$$

Again, the two asymmetries implied above are:

A_{TT} : The term $\mathrm{Re}(F_{LR}F_{RL}^*)\cos(\phi_m+\phi_p-2\phi)$ has no helicity suppression, hence the asymmetry is relatively large. We will use this observable for polarimetry to tell us the product of polarizations $\mathbf{P_{e-}^T\,P_{e+}^T}$.

A_{TT}' : The term $\mathrm{Re}(F_{RR}F_{LL}^*)\cos(\phi_m - \phi_p)$ is doubly helicity suppressed, and will be the focus of the rest of this section.

A_{TT} and A_{TT}'

$$\text{Yield}_{TT}(\theta, \phi) \sim \; A_{TT}' \cos(\phi_m - \phi_p) \;+\; A_{TT} \cos(\phi_m + \phi_p - 2\phi)$$

To simplify this a bit, use rotational invariance to always define the e- transverse polarization axis as 0:

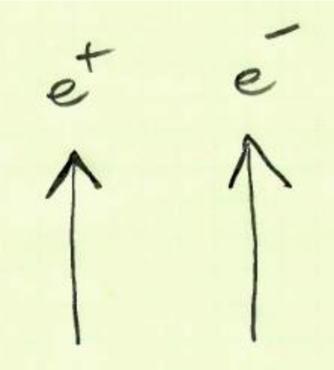
$$\text{Yield}_{TT}(\theta, \phi) \sim \; A_{TT}' \cos(\phi_p) \;+\; A_{TT} \cos(\phi_p - 2\phi)$$

The relatively large A_{TT} signal oscillates like cos(2ϕ).

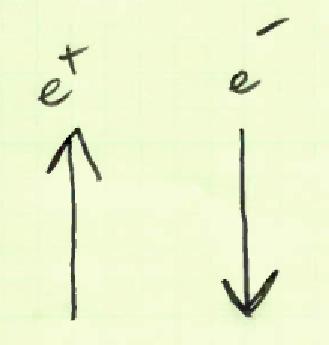
The much smaller A_{TT}' signal is a monopole, ie, independent of the ϕ where the scattered e^+ is detected.

A_{TT}' is unique: it is the only transverse polarization observable which, for fixed $\phi_m - \phi_p$, survives integration over ϕ and thus contributes a tiny amount to the total cross section.

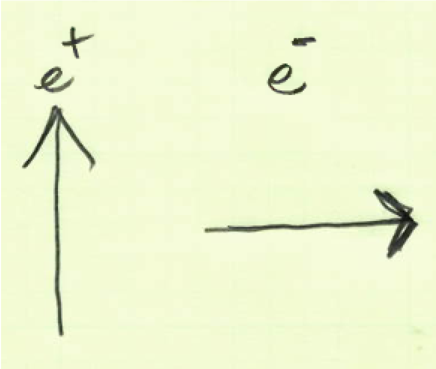
The A_{TT}' monopole signal reverses when ϕ_m or ϕ_p is reversed.



$\cos(\phi_m - \phi_p) = +1$



$\cos(\phi_m - \phi_p) = -1$



$\cos(\phi_m - \phi_p) = 0$

Explicit Bhabha QED Helicity Amplitudes

I could not find any published calculations of A_{TT}' . But Hikasa and others have published the following 1st order helicity amplitudes for non-vanishing electron mass.*

Hikasa Term	Helicity Amplitudes	Approximate Analytic Expression (setting β = 1 for readability)
1	$F_{RL}^{RL} = F_{LR}^{LR} =$	$e^2 [\, 2/(1-\cos\theta)) - 1 \,](1+\cos\theta)$
2	$F_{RL}^{LR} = F_{LR}^{RL} =$	$e^2 [\, 1/\gamma^2 - (1-\cos\theta) \,]$
3	$F_{LL}^{RL} = F_{RR}^{RL} =$ $-F_{LL}^{LR} = -F_{RR}^{LR} =$ $-F_{RL}^{LL} = -F_{RL}^{RR} =$ $F_{LR}^{LL} = F_{LR}^{RR}$	$e^2 (1/\gamma)[\, 1/(1-\cos\theta) - 1 \,]\sin\theta$
4	$F_{RR}^{RR} = F_{LL}^{LL} =$	$e^2 [\, 4/(1-\cos\theta) – (1+\cos\theta)/\gamma^2 \,]$
5	$F_{RR}^{LL} = F_{LL}^{RR} =$	$e^2 (1/\gamma^2)[\, –(1+\cos\theta) \,]$

* K. Hikasa, PRD 33 (1986) 3203
(see Appendix D)

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4	$F_{RR}^{RR} = F_{LL}^{LL} =$	$e^2 [\, 4/(1-\cos\theta) - (1+\cos\theta)/\gamma^2\,]$
5	$F_{RR}^{LL} = F_{LL}^{RR} =$	$e^2 (1/\gamma^2)[\, -(1+\cos\theta)\,]$

* K. Hikasa, PRD 33 (1986) 3203
(see Appendix D)

If BSM scalars exist, the major effect would be a helicity unsuppressed s-channel contribution to Terms 4 and 5.

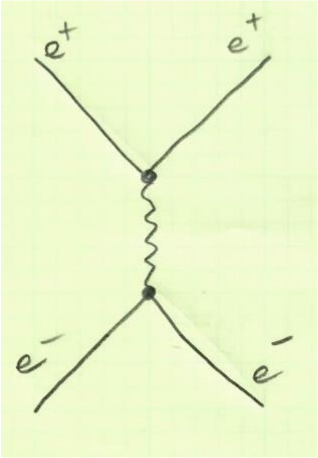
A_{TT}' Calculation in the SM

To calculate A_{TT}', I need to expand the initial-indices-only shorthand of "$F_{RR}F_{LL}$":

$$\text{“}F_{RR}F_{LL}\text{”} = F_{RR}^{LR}F_{LL}^{LR} + F_{RR}^{RL}F_{LL}^{RL} + F_{RR}^{LL}F_{LL}^{LL} + F_{RR}^{RR}F_{LL}^{RR}$$

Because Term 3 is suppressed much more than the factor of $1/\gamma$ naively suggests, the dominant SM contribution is from the latter two Term4*Term5 products, $F_{RR}^{LL}F_{LL}^{LL} + F_{RR}^{RR}F_{LL}^{RR}$. Where

- F_{LL}^{LL} and F_{RR}^{RR} are ~ $e^2\,4/(1 - \cos\theta)$: unsuppressed t-channel exchange
- F_{LL}^{RR} and F_{RR}^{LL} are ~ $-e^2\,(1 + \cos\theta)/\gamma^2$: suppressed s-channel exchange



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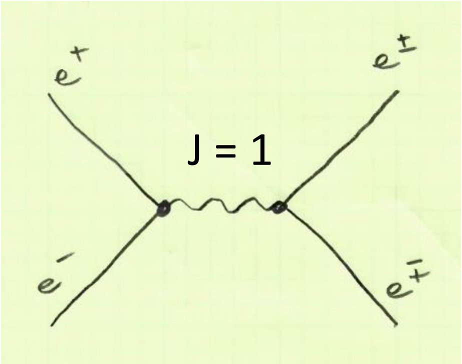
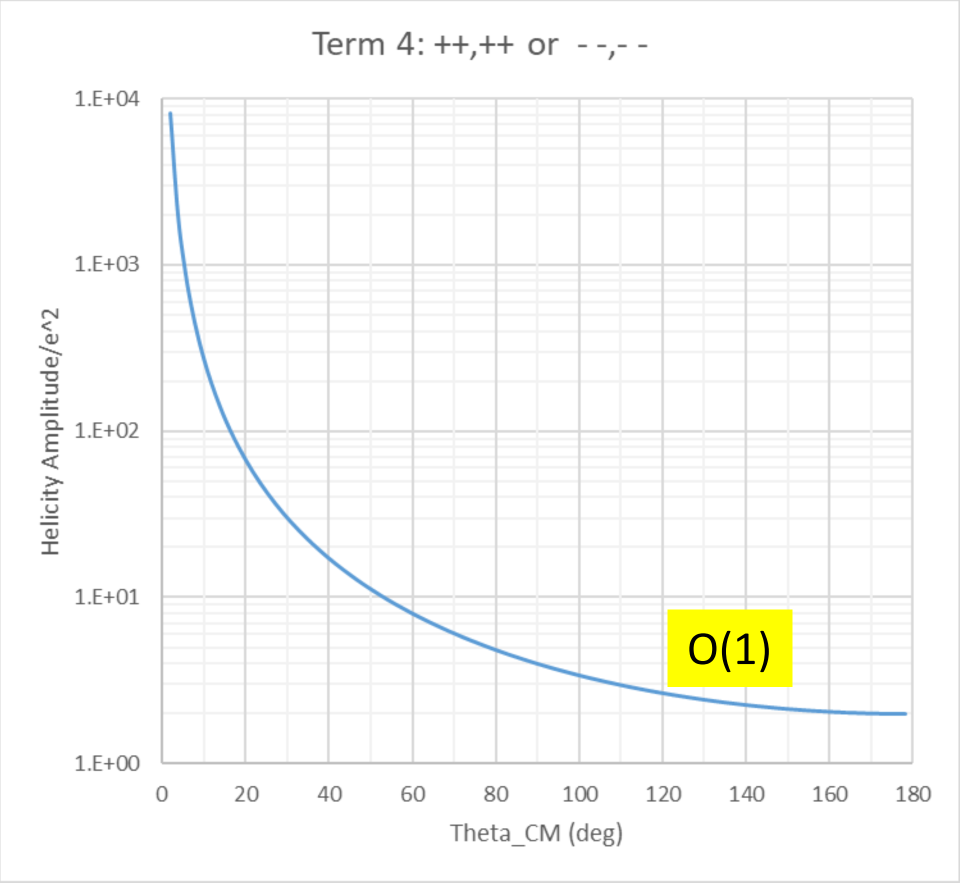
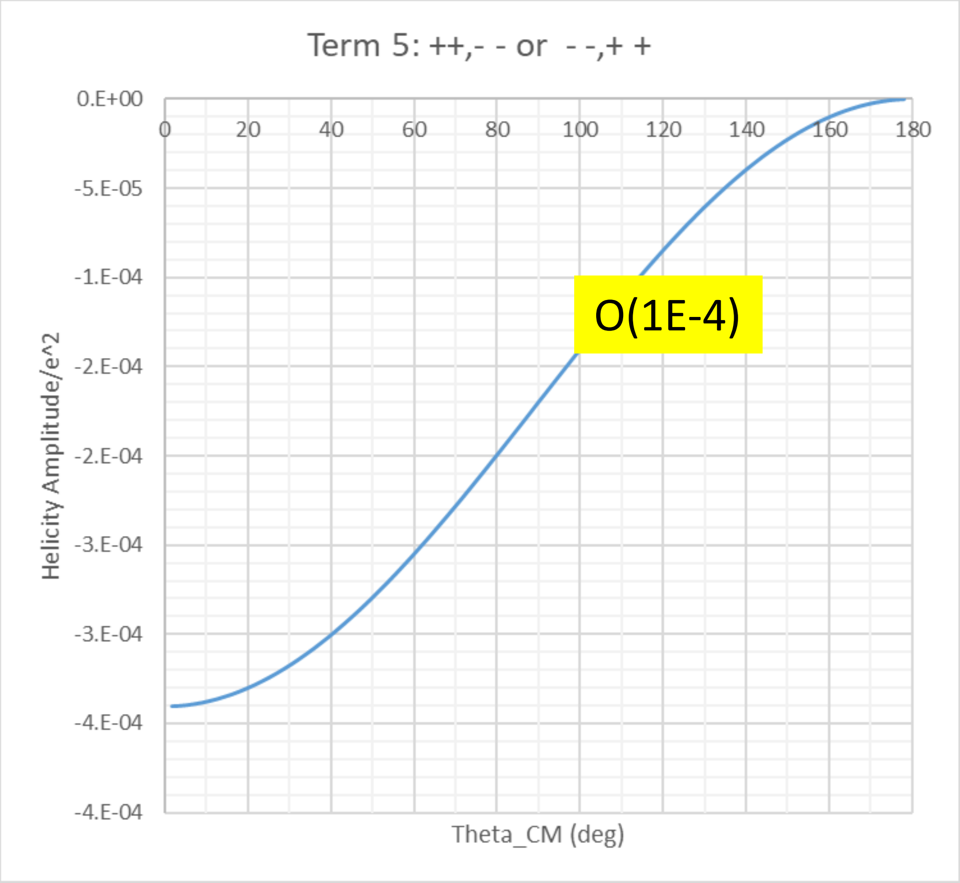


t-channel
(unsuppressed)

s-channel
(suppressed by $1/\gamma^2$ for F_{LL}^{RR} and F_{RR}^{LL})

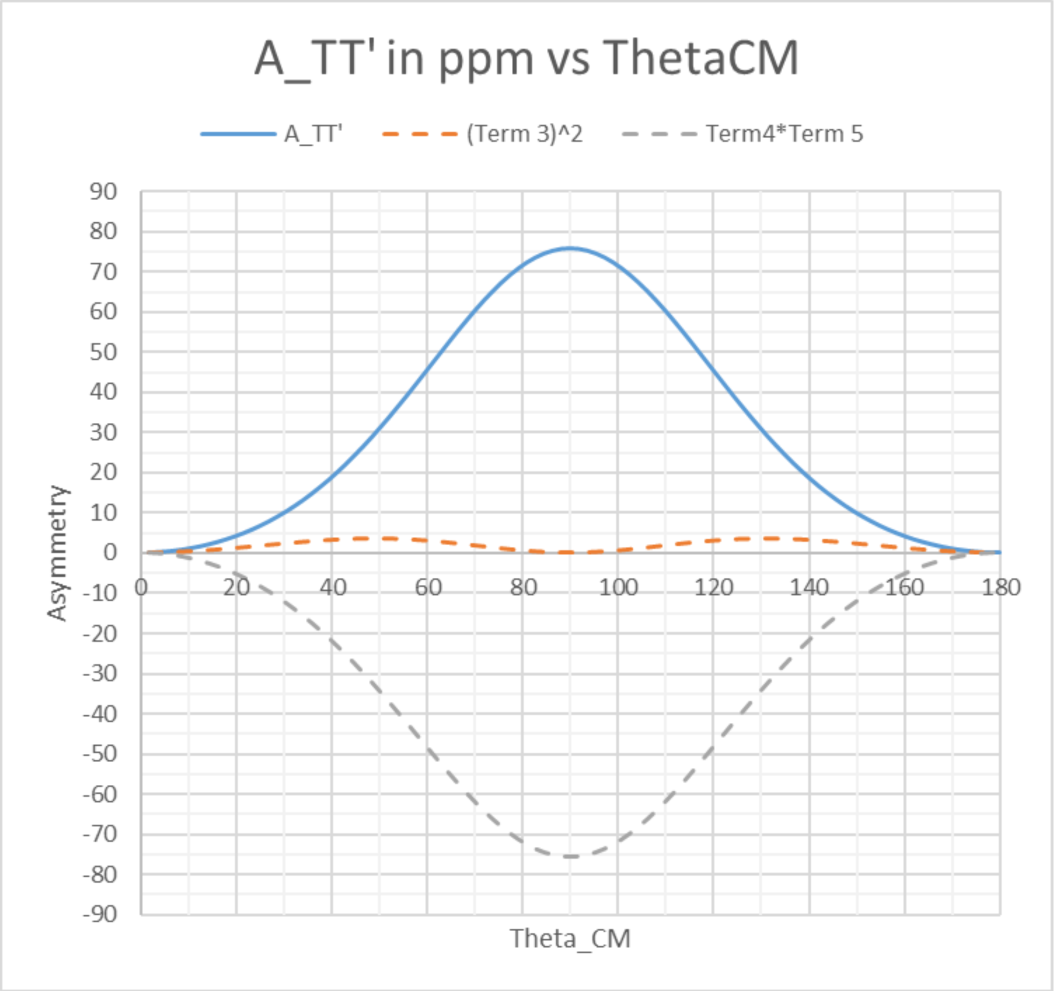
Relative Magnitudes of Terms 4 and 5





A_{TT}' Result in the SM

Here is the asymmetry using the exact 1st order QED helicity amplitudes:



It's never been measured!

The asymmetry is fairly small, ~75 ppm at 6 GeV at 90deg.

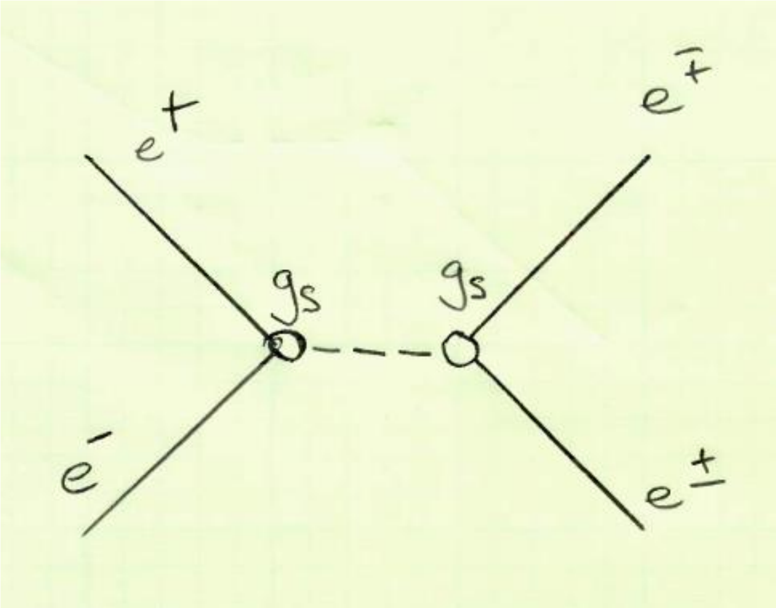
There is no zero crossing.

(For what it's worth, I note that $1/\gamma^2$ is 167 ppm.)

The sign convention for this asymmetry was [Yield(+1,+1) – Yield(-1,+1)]/Sum

Adding a BSM Scalar to A_{TT}'

At our Oct '24 meeting, I added the BSM scalar amplitude in a manner suggested in the old Hikasa reference. However, to eventually publish a plot of projected exclusion in scalar coupling vs mass, and compare to modern papers, I need to incorporate the propagator. This is a work in progress!



The dominant scalar contribution to A_{TT}' will be thru doubly suppressed amplitudes F_{LL}^{RR} and F_{RR}^{LL}

$$F_{RR}^{LL} = F_{LL}^{RR} = -e^2(1 + \cos\theta)/\gamma^2 + g_s^2\text{*propagator}$$

then

$A_{TT}' \sim F_{RR}^{LL}F_{LL}^{LL} + F_{RR}^{RR}F_{LL}^{RR}$ would be approximately

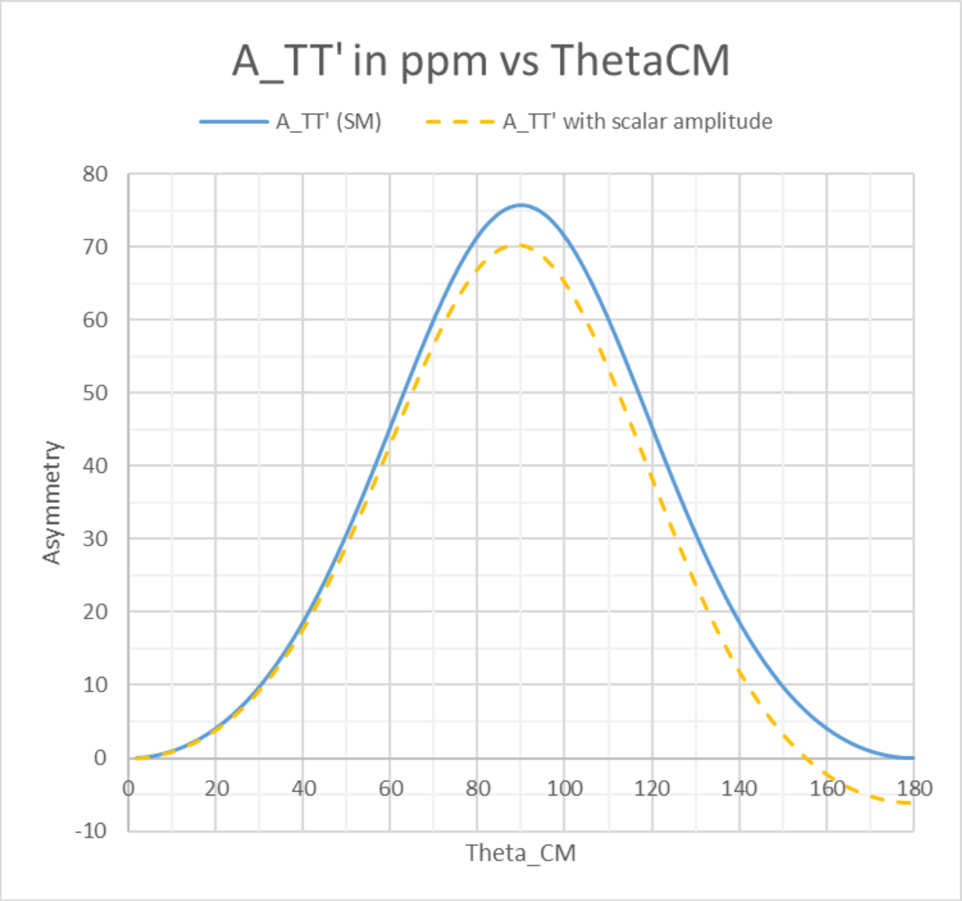
$$2[4e^2/(1 - \cos\theta)] \text{*}[-e^2 (1 + \cos\theta)/\gamma^2 + g_s^2\text{*propagator}]$$

* K. Hikasa, PRD 33 (1986) 3203
(page 3208)

A_{TT}' Including a BSM Scalar Amplitude

Very preliminary.

For E = 6 GeV, which corresponds to E_{cm} ~ 77.5 MeV/c^2.
The scalar mass was set to 25 MeV/c^2, and a coupling g_s = 1E-3.



Comments:

- This plot is representative of the Mass << E_{cm} scenario.

The other two scenarios are:

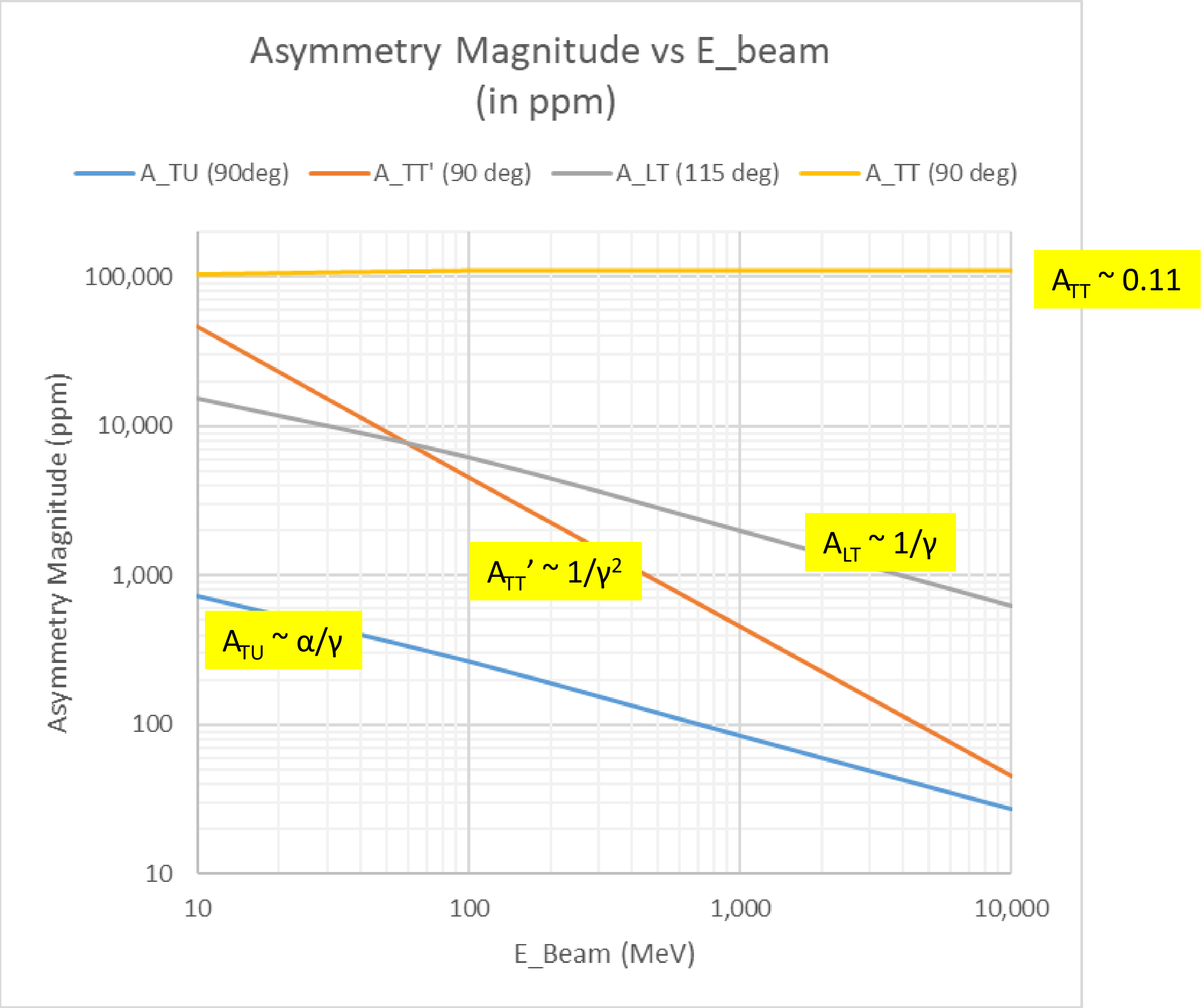
- Mass >> E_{cm} (contact interaction, less sensitive)

and

- Mass ~ E_{cm} (resonance, much more sensitive).

Transverse Asymmetry Magnitudes vs E_{beam}

This plot gives an idea of the magnitude variation expected for these helicity-suppressed asymmetries.



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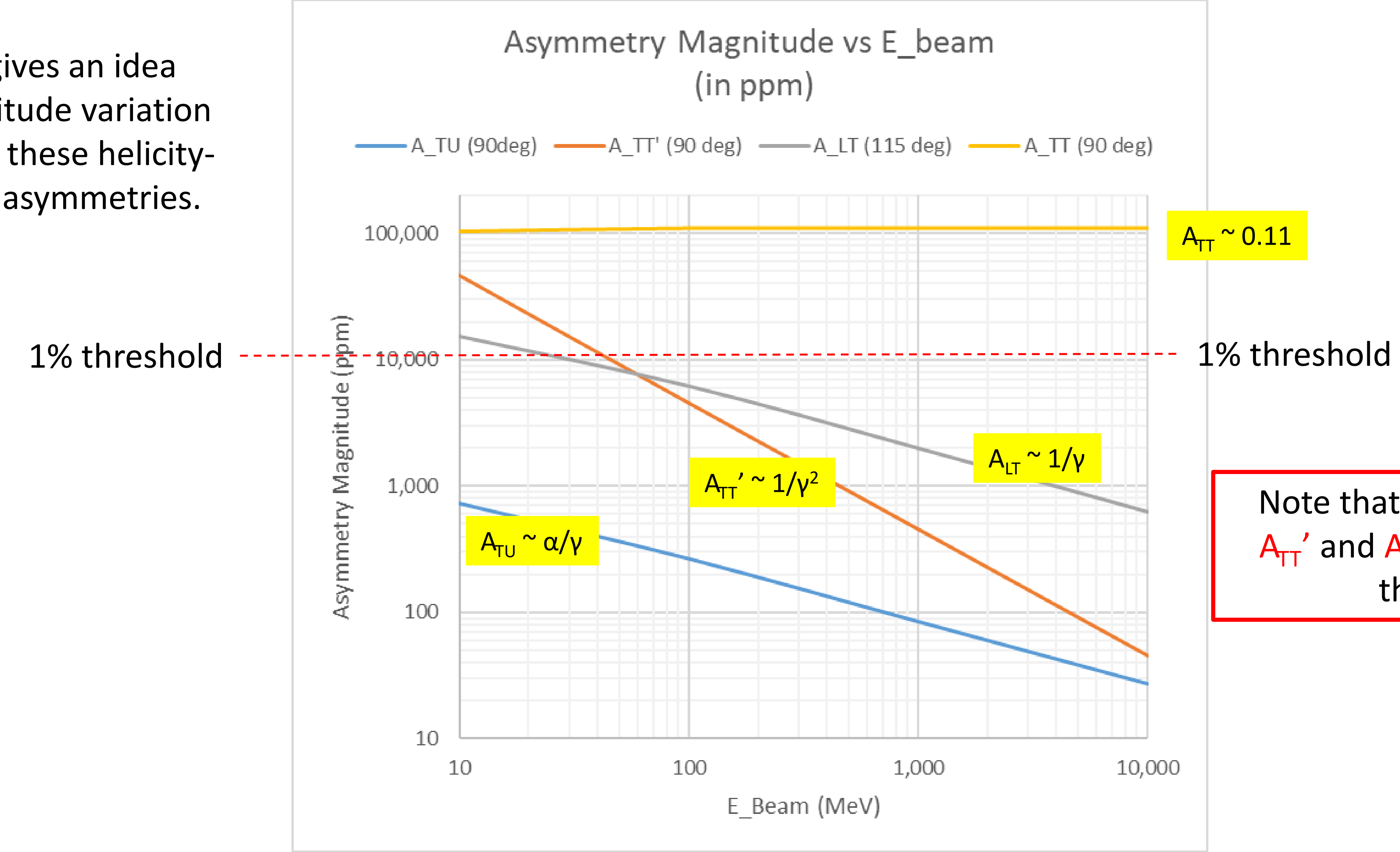


Note that below 100 MeV, A_{TT}' and A_{LT} become larger than 1% !

Plans

- Finish article on A_{TT}' .

- Think hard about what can be done at 10 MeV, then prepare an LOI or proposal for 2026.

While we're waiting for funding for the full e^+ upgrade, we can train the next generation, prototype a transverse target design, help measure the initial e^+ polarization, do some once-in-a-career experiments, excite the community about the e^+ source, and probably have a lot of fun in the process. I respect Eric and Joe's wisdom in pushing low energy experiments at LERF. These are NOT a distraction; they are perhaps the only realistic path forward.

- Continue to develop the science case for a Hall C 12 GeV e^+ proposal based on the 3 helicity-suppressed transverse Bhabha asymmetries (to improve constraints on BSM scalars, pseudo-scalars, tensors, etc.)

Summary

- A positron beam facility at Jlab would enable a detailed study of Bhabha scattering in the relatively unexplored mass range of 10 to 100 MeV/c2 .

- Targets consisting of atomic electrons will permit practical e^+e^- luminosities in Hall C of 10^{35} to 10^{36}. Cross sections are large by Jlab standards due to the small value of s, and the lack of a form factor.

- The resulting high count rates, combined with Jlab's expertise in spin manipulation, would enable Bhabha transverse polarization measurements of unprecedented precision.

Physics foci:

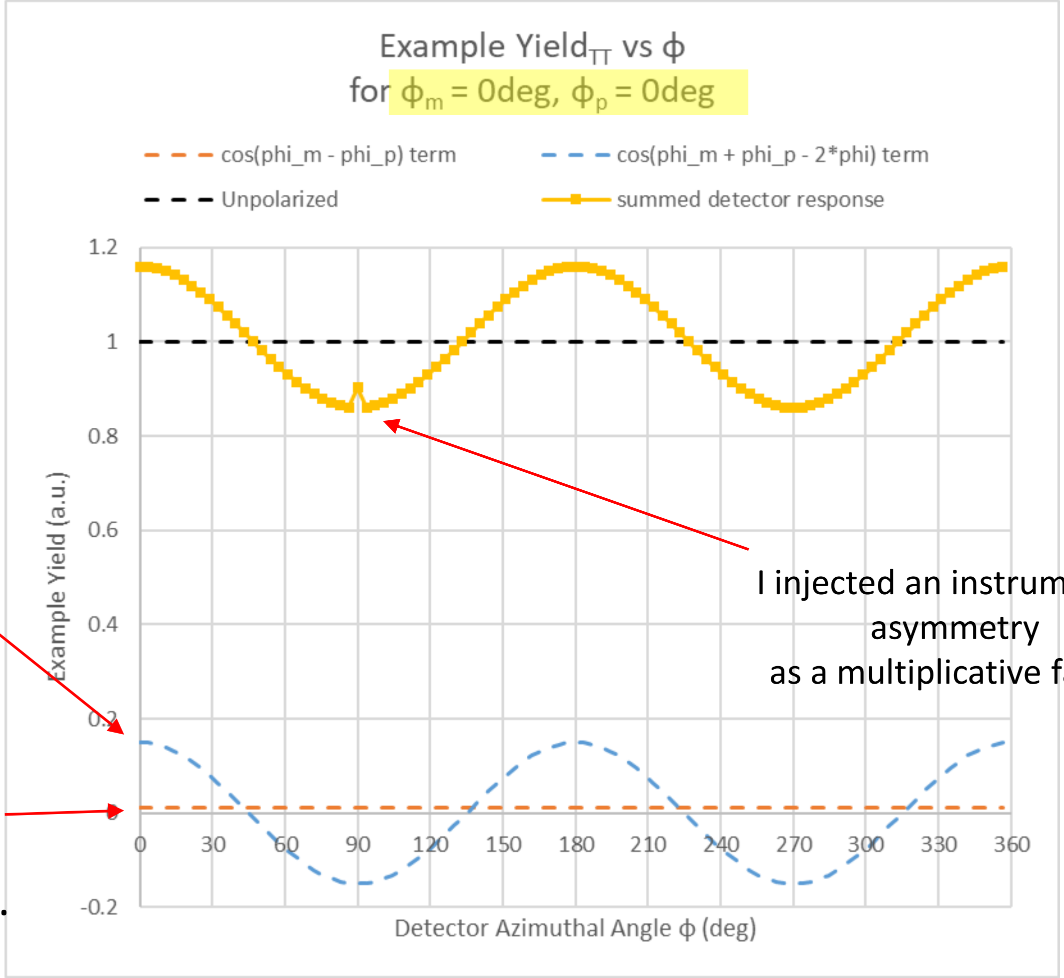
- A_{TT}' : The double spin asymmetry A_{TT}' seems optimally sensitive to the Real part of light scalar or tensor amplitudes.

- A_{LT} and A_{TU} : These are not sensitive to the exchange of J = 0 particles. They are apparently sensitive to the exchange of BSM processes which create unsuppressed single helicity flips, which Wen et al call "dipole interactions" in a SMEFT formalism.

extras

Can We Actually Pull Out the A_{TT}' Signal?

Target e- polarization fixed at 0deg.



A_{TT} represented by big signal.

A_{TT}' represented by small, monopole signal.

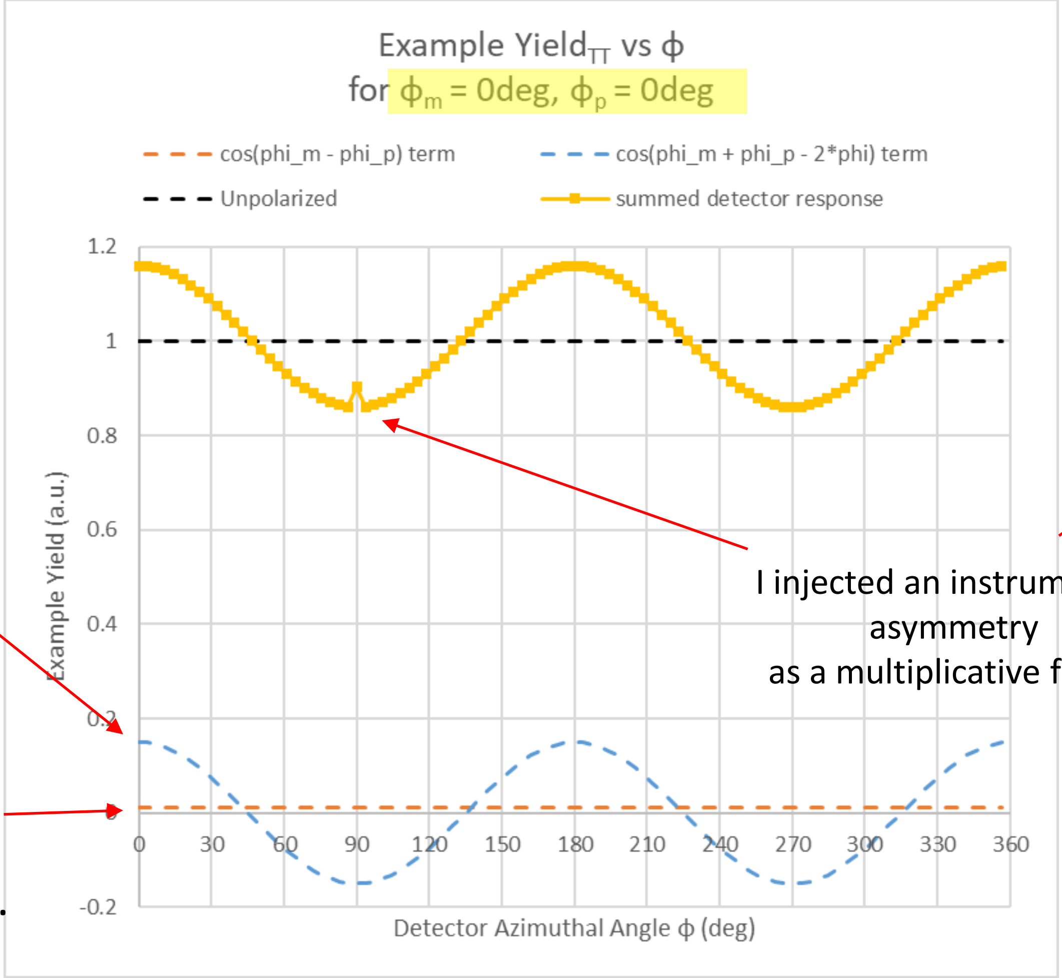
I injected an instrumental asymmetry as a multiplicative factor

Can We Actually Pull Out the A_{TT}' Signal?

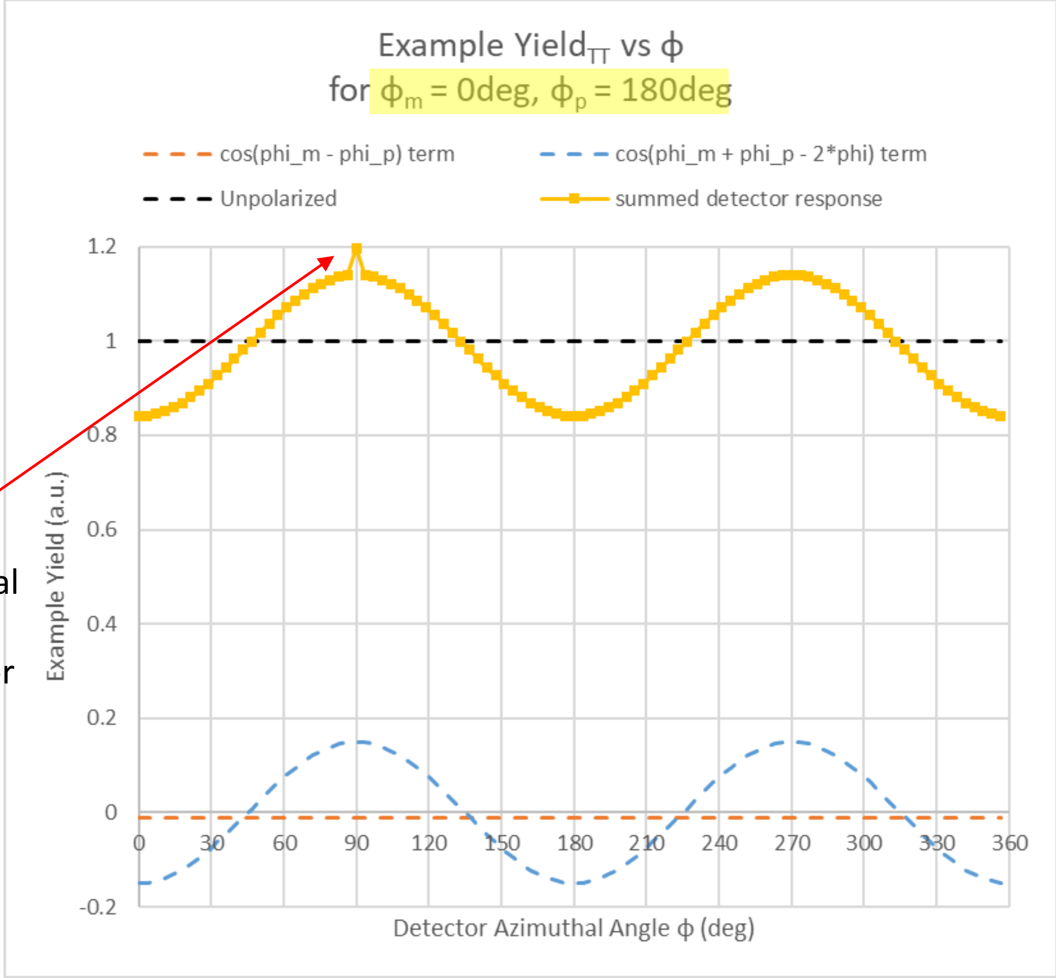
Target e- polarization fixed at 0deg. Reversing the e+ polarization reverses all asymmetries.

A_{TT} represented by big signal.

A_{TT}' represented by small, monopole signal.

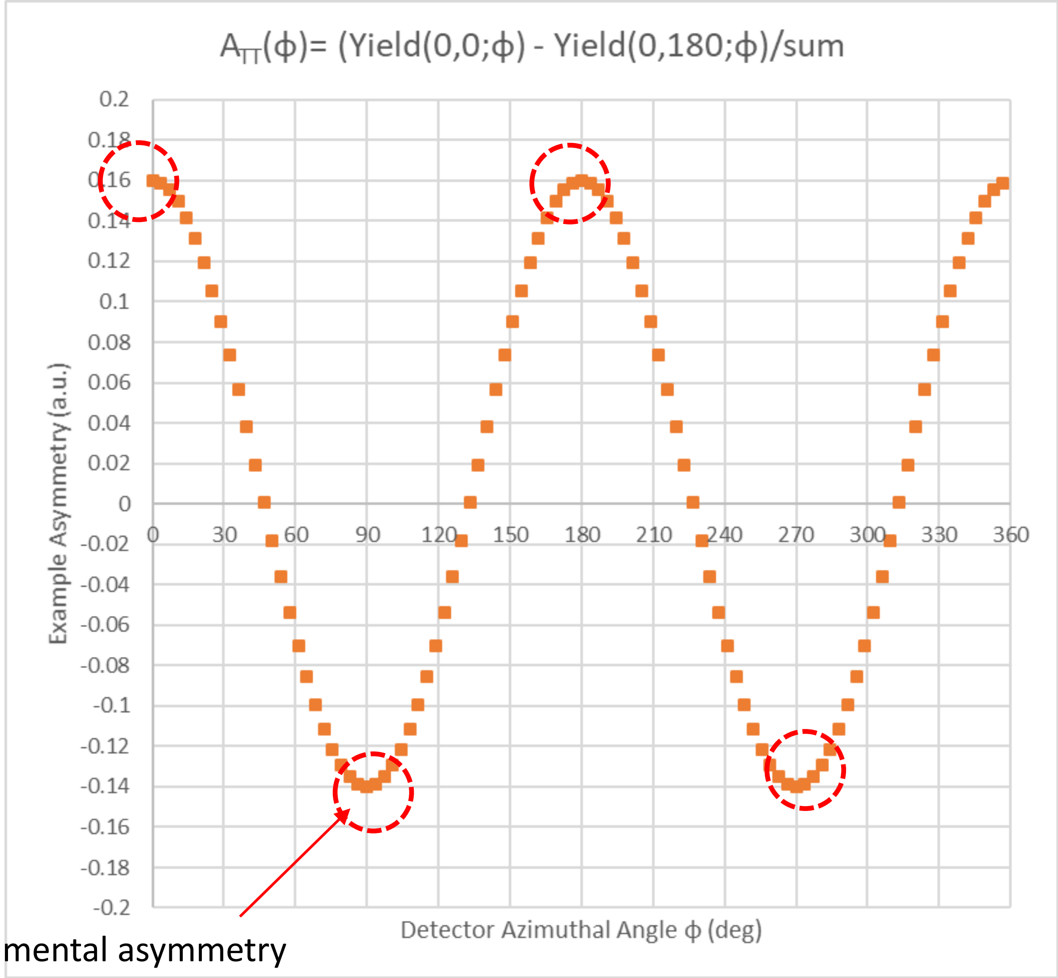


I injected an instrumental asymmetry as a multiplicative factor



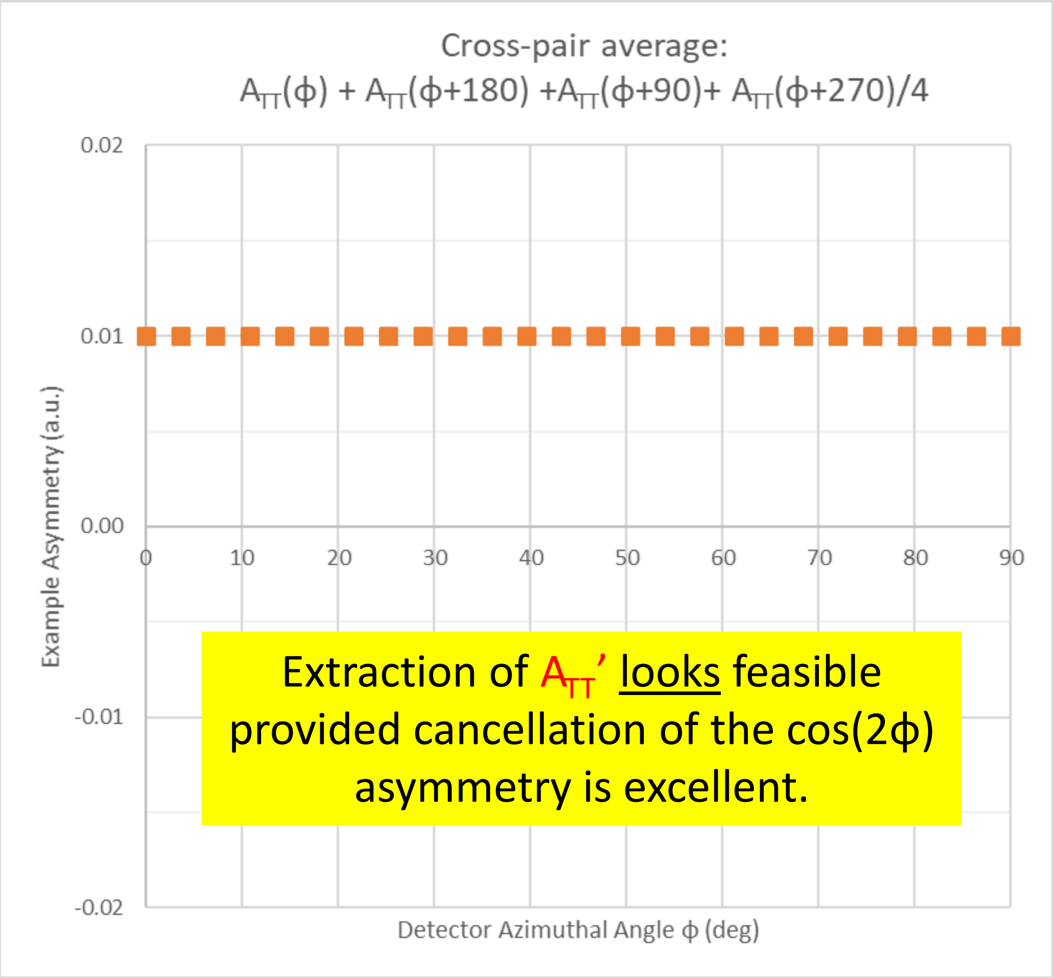
Can We Actually Pull Out the A_{TT}' Signal?

Calculating the asymmetry after reversing the e+ polarization:



Instrumental asymmetry as a multiplicative factor of course cancels exactly: $A = (gN^+ - gN^-)/(gN^+ + gN^-) = (N^+ - N^-)/(N^+ + N^-)$

Averaging over the azimuthal angle in principle cancels the large cos(2ϕ) asymmetry, leaving A_{TT}'.

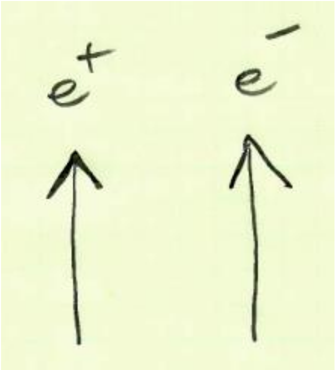


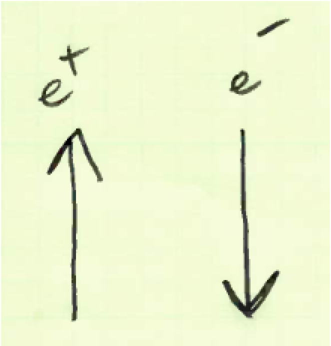
But What About Nonlinearity?

Keep in mind, the cos(2ϕ) term is 4 orders of magnitude larger than the monopole signal of A_{TT}'!

- A quick study suggests nonlinearity as large as 1% would not be a serious issue if it is the same for all detector channels.

- But a differential nonlinearity between detectors at the +-1% level would break the azimuthal asymmetry. This is potentially serious since I find the resulting leakage into the monopole reverses just like the physics signal of interest when ϕ_m or ϕ_p is reversed:

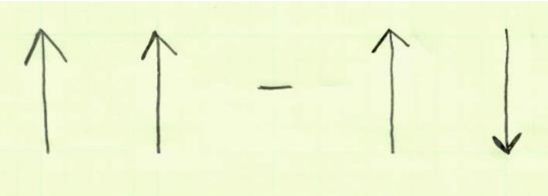




The brute force solution would be to design highly linear detectors, use beam intensity noise to measure the remaining small nonlinearity for each detector ϕ bin, then make corrections.

But What About Nonlinearity?

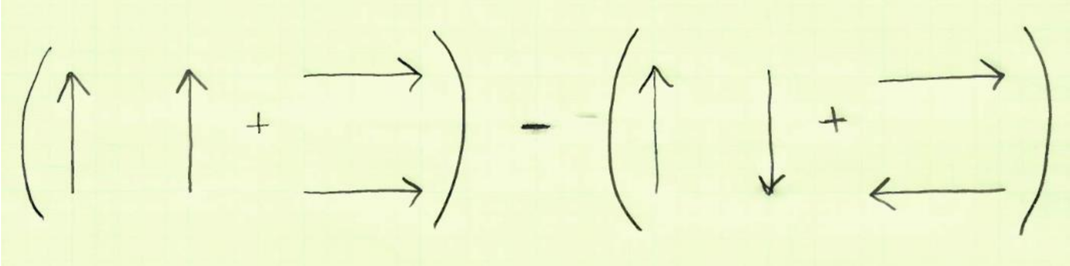
A more elegant and robust solution would be, for half the experiment, to shift the phase of the cos(2ϕ) signal by 90 degrees. Thus, while the A_{TT}' signal is held constant, background peaks in a detector would become troughs in the same detector, and vice versa.



Original A_{TT}' calculation

The following would largely cancel the cos(2ϕ) background, as well as any broken symmetries induced by nonlinearity:

$$A_{TT}' \sim [Y(+0°,+0°) + Y(+90°,+90°)] - [Y(0°,+180°) + Y(+90°,-90°)]$$



Revised A_{TT}' calculation

So we'd need to be able to do slow reversals which alternate between Horizontal and Vertical transverse polarization, while adjusting the target polarization angle by 90° as well.

This needs much more study. But I think I have identified the most serious issue with A_{TT}', and have a tentative solution.

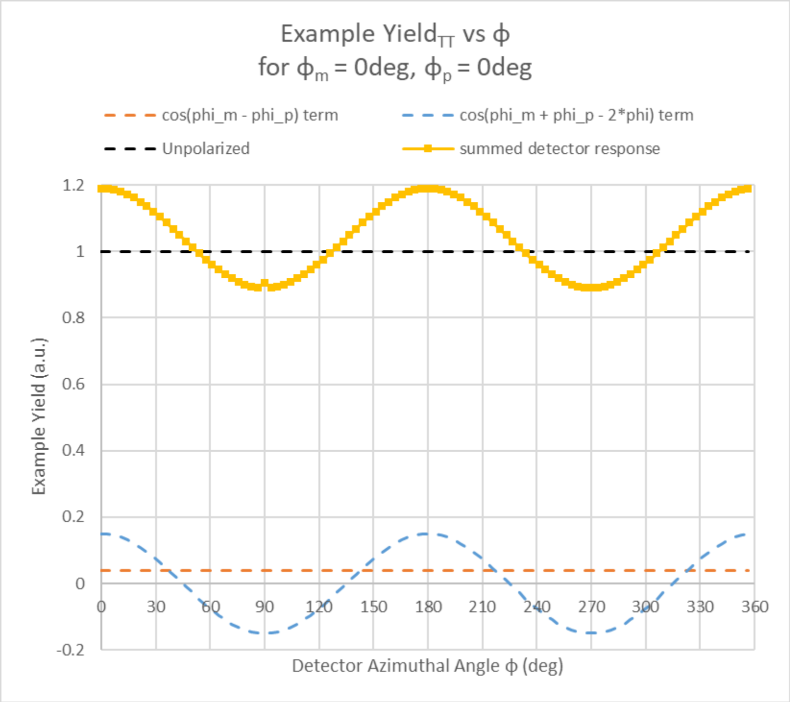
	ϕ_p				
ϕ_m		180	90	0	-90
	180	ϕ_m-ϕ_p = 0 (ϕ_m+ϕ_p = 0)	90 (90)	180 (180)	-90 (90)
	90	-90 (-90)	0 (180)	90 (90)	180 (0)
	0	-180 (180)	-90 (90)	0 (0)	90 (-90)
	-90	90 (90)	-180 (0)	-90 (-90)	0 (-180)

ATT' with excellent cos(2phi) cancellation =
(Yellow+Orange) – (Green+Yellow-green)

The unused "90 (90)" blocks above would be null tests for ATT'.
As can be seen on the right, these null settings do not occur in normal H or V running setups.

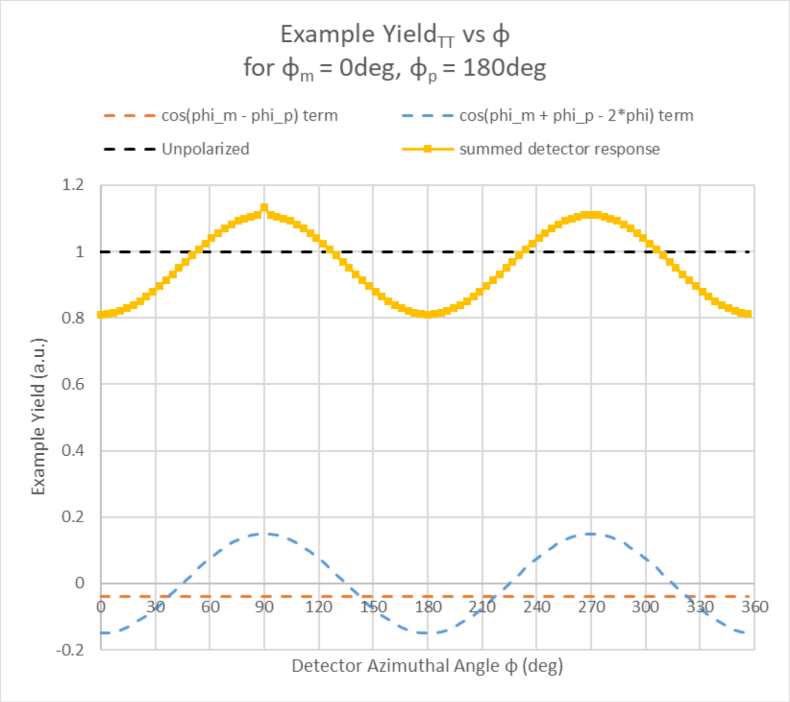
H running (Tgt angle also H)	ϕ_p		
ϕ_m		180	0
	180	ϕ_m-ϕ_p = 0 (ϕ_m+ϕ_p = 0)	180 (180)
	0	-180 (180)	0 (0)

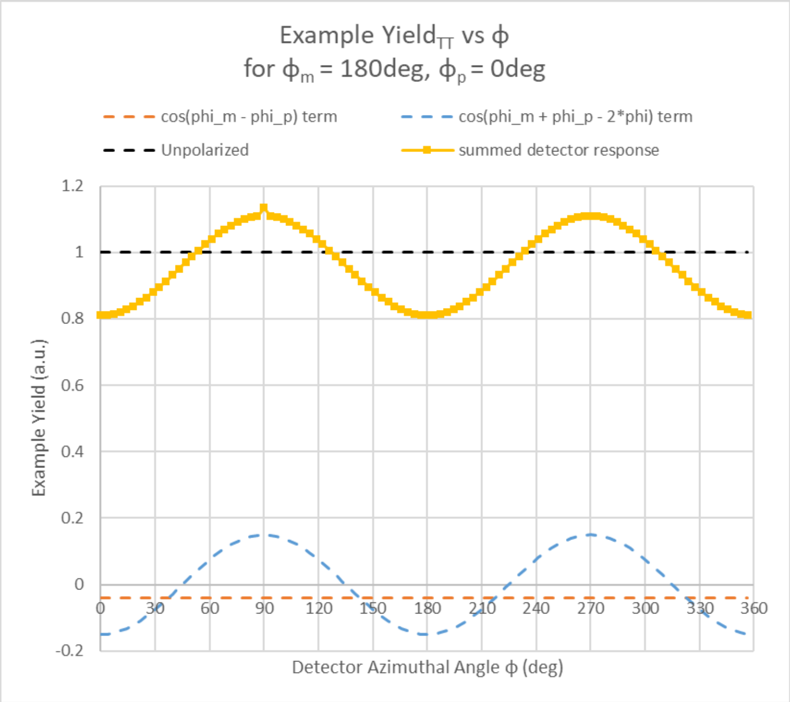
V running (Tgt angle also V)	ϕ_p		
ϕ_m		90	-90
	90	0 (180)	180 (0)
	-90	-180 (0)	0 (-180)



At any fixed ϕ

Flip e+, reverse signal





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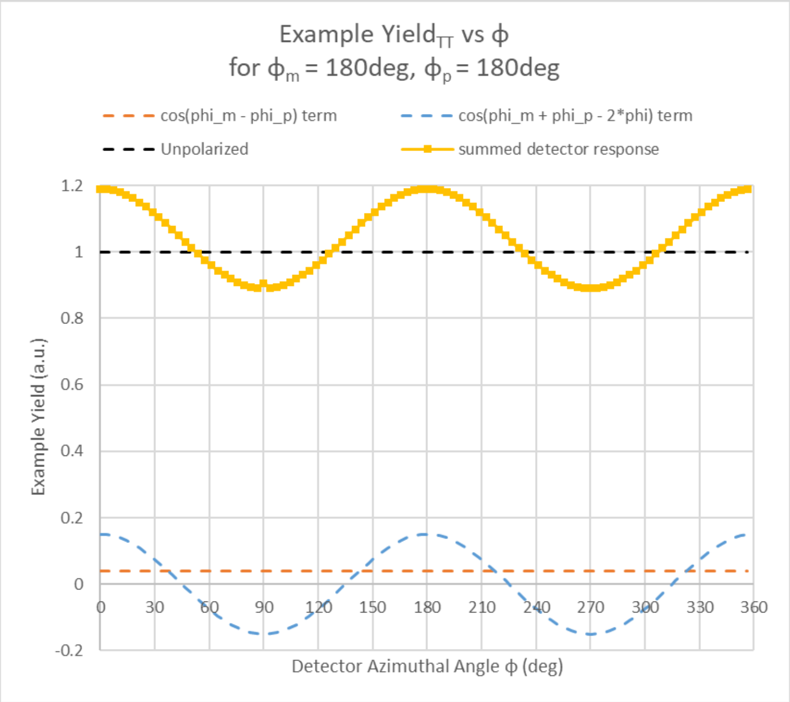
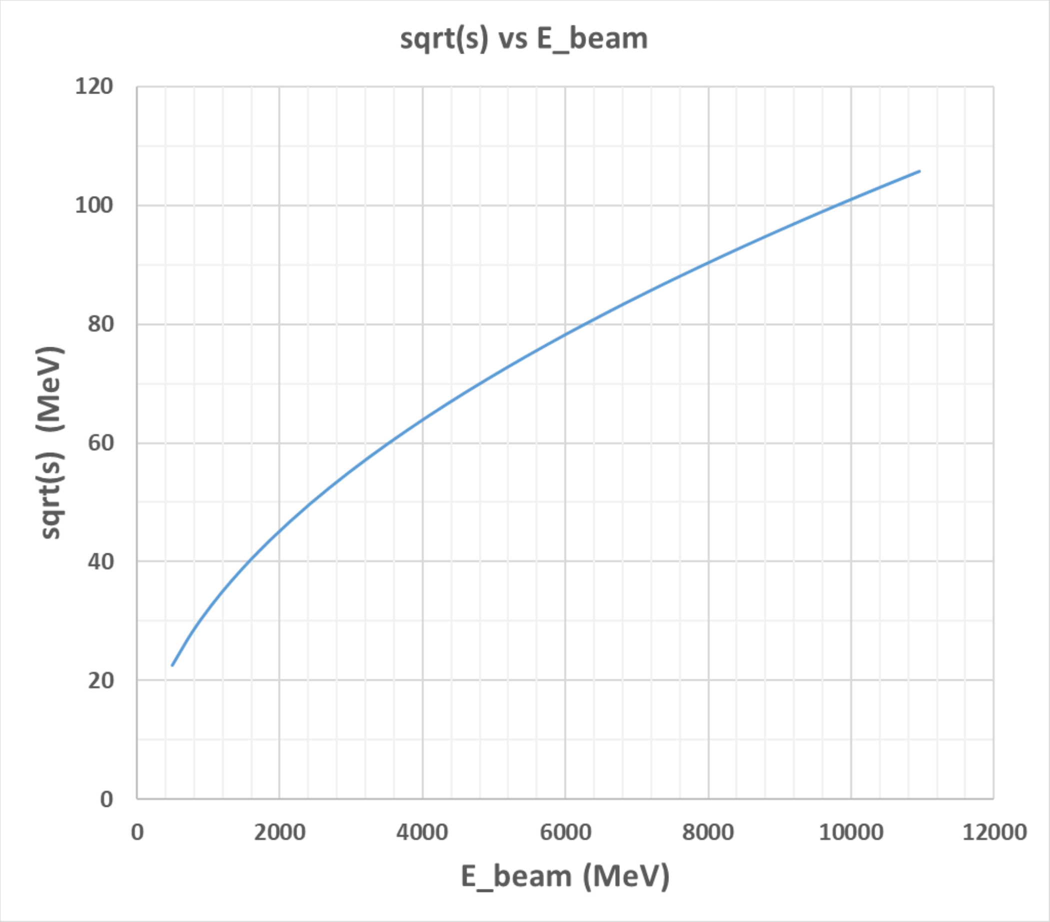


E_{cm} in Bhabha Scattering in Jlab Fixed Target Kinematics

At a 12 GeV CEBAF, the CM energy range will be ~20-105 MeV/c^2.

$$E_{cm} = sqrt(s) = sqrt(2m_e^2 + 2E_{beam}*m_e)$$
$$\sim sqrt(E_{beam})$$



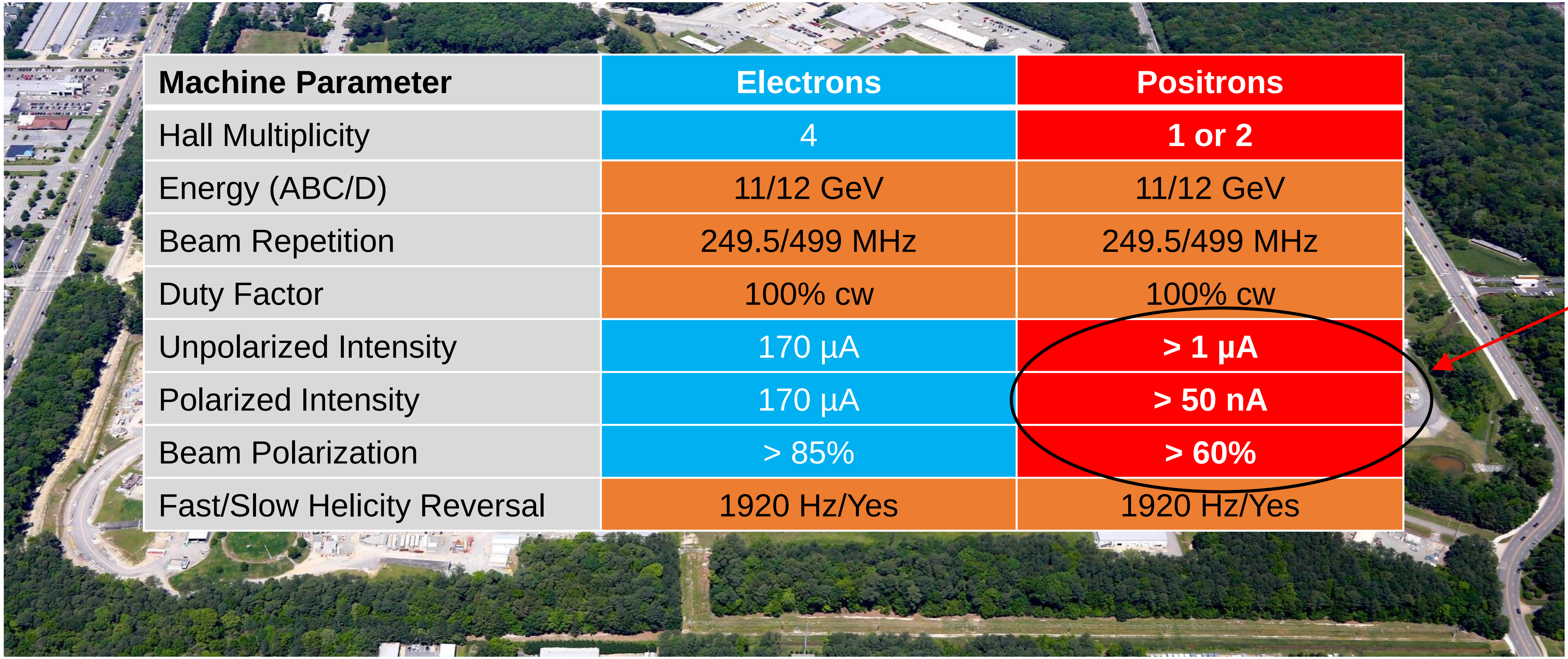
Notes:

- due to the sqrt factor above, it takes a roughly 100 MeV change in E_{beam} to produce a 1 MeV change in E_{cm}.
  (Hold that thought for later!)

- since the differential xsect contains a factor of 1/s, and s is small, the xsect is large by Jlab standards, O(1)-O(100) muB/sr at 90deg CM.

Jlab 12 GeV CW Electron Accelerator

Capability With a Future Positron Injector



Machine Parameter	Electrons	Positrons
Hall Multiplicity	4	**1 or 2**
Energy (ABC/D)	11/12 GeV	11/12 GeV
Beam Repetition	249.5/499 MHz	249.5/499 MHz
Duty Factor	100% cw	100% cw
Unpolarized Intensity	170 μA	**> 1 μA**
Polarized Intensity	170 μA	**> 50 nA**
Beam Polarization	> 85%	**> 60%**
Fast/Slow Helicity Reversal	1920 Hz/Yes	1920 Hz/Yes

!

See talk by Joe Grames at https://indico.jlab.org/event/819/ from the March 2024 PWG Workshop.
There were also many talks on future experiments and related theory calculations.