

New Physics Searches with Bhabha Scattering and Positron Source Characterization

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LEEPP

JLab, Newport News, VA

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Version 7:

Slide 24 – I added some missing references.

Slide 28 - See new comment about achieving T polarization at beam energies other than 110 MeV.

Forward

My long term goal is to see high priority, multi-year, POLARIZED e+ beam experiment in the end-stations.

In Hall C, among other things, such experiments might search for new physics in small PC asymmetries.

In the bigger picture, positron beams in the JLab end-stations at 1-11 GeV would:

- Continue to serve the 1000+ member JLab (fixed target) user community,
- Expand the science program into qualitatively new regimes,
- Do great new science cost effectively,
- Provide JLab with at least another decade of mission, with scheduling interleaving e- and e+ running.

It cannot be overstated that polarized positron beams of the planned intensity in nuclear/particle scattering experiments would be **ABSOLUTELY UNPRECEDENTED**. None of the high energy e+e- colliders had reversible e+ polarization, hence none of them had the capability to do potentially profound comparisons of polarized e- versus polarized e+ interactions.

But how do we get to there from here? Are lower energy measurements merely a stepping stone, or a parallel physics program with its own merits? Out of respect for the wisdom and initiative of the LEEPP organizers, I describe here a program of measurements near the e+ beam energy of 110 MeV.

Outline

- Quick motivation and overview
- Introduction to e^+ at JLab
- Bhabha scattering ($e^+ e^- \rightarrow e^+ e^-$)
- Parity conserving, transverse asymmetries as a BSM laboratory
- Possible LERF measurements
- Summary

Quick Motivation and Overview

There is evidence for matter with weak couplings to the SM: dark matter.

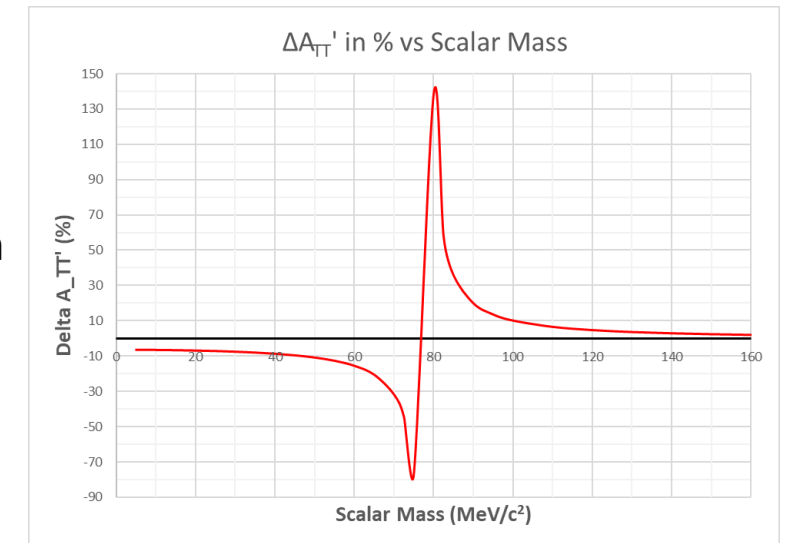
Light dark matter is being searched for at JLab. Eg, the ongoing A' -strahlung program.

Once we have an e^+ beam, we can exploit the enhancement of sensitivity from the s -channel $e^+e^- \rightarrow X$, making JLab highly competitive in the mass range of 3-100 MeV/c^2

But rather than try to search for BSM physics by detecting all possible final states, my focus is measuring small PC asymmetries to search for interference terms between SM gamma exchange and BSM amplitudes.

So far, I've found two interesting transverse asymmetries in Bhabha scattering ($e^+e^- \rightarrow e^+e^-$). The Mainz group has found another.

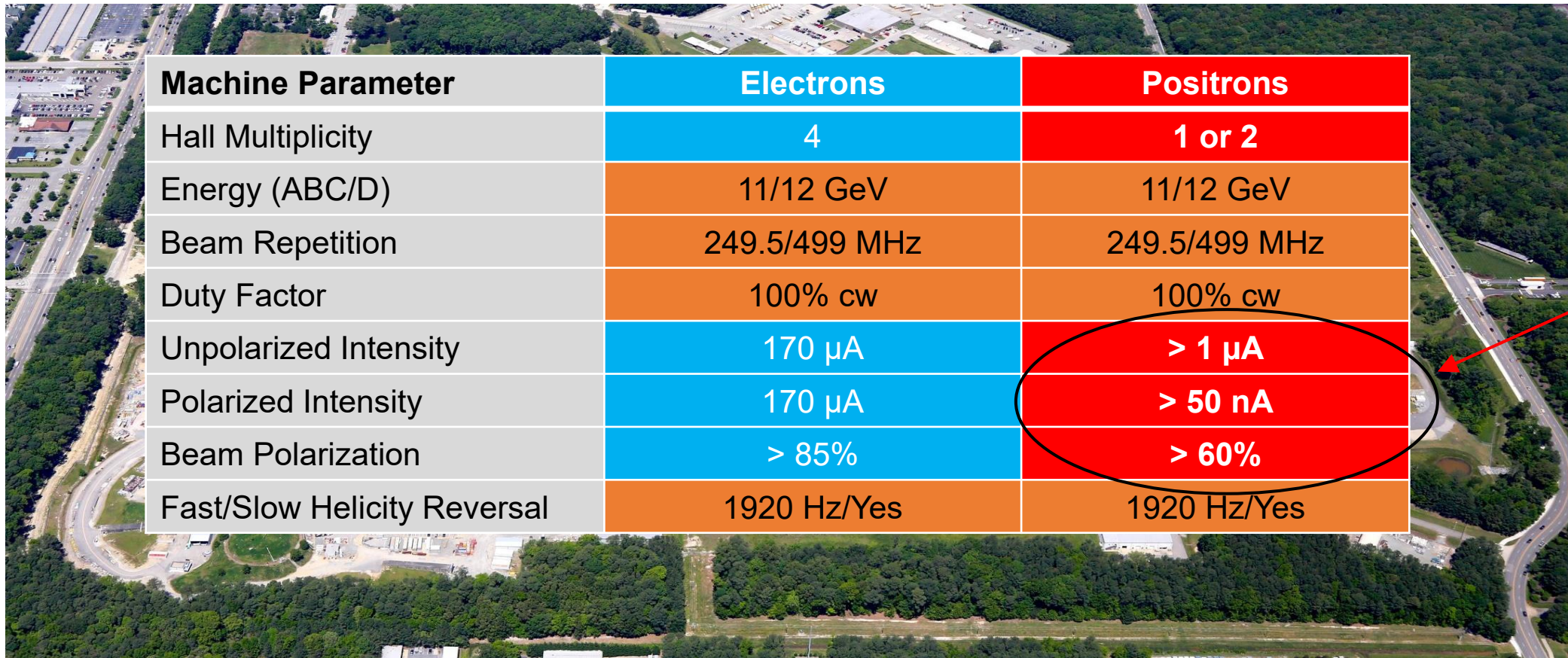
Such PC BSM searches may be extendable to other highly interpretable reactions like $e^+e^- \rightarrow 2\gamma$ and Moller scattering ($e^-e^- \rightarrow e^-e^-$).



JLab Site



Projected Capability of a Positron Injector

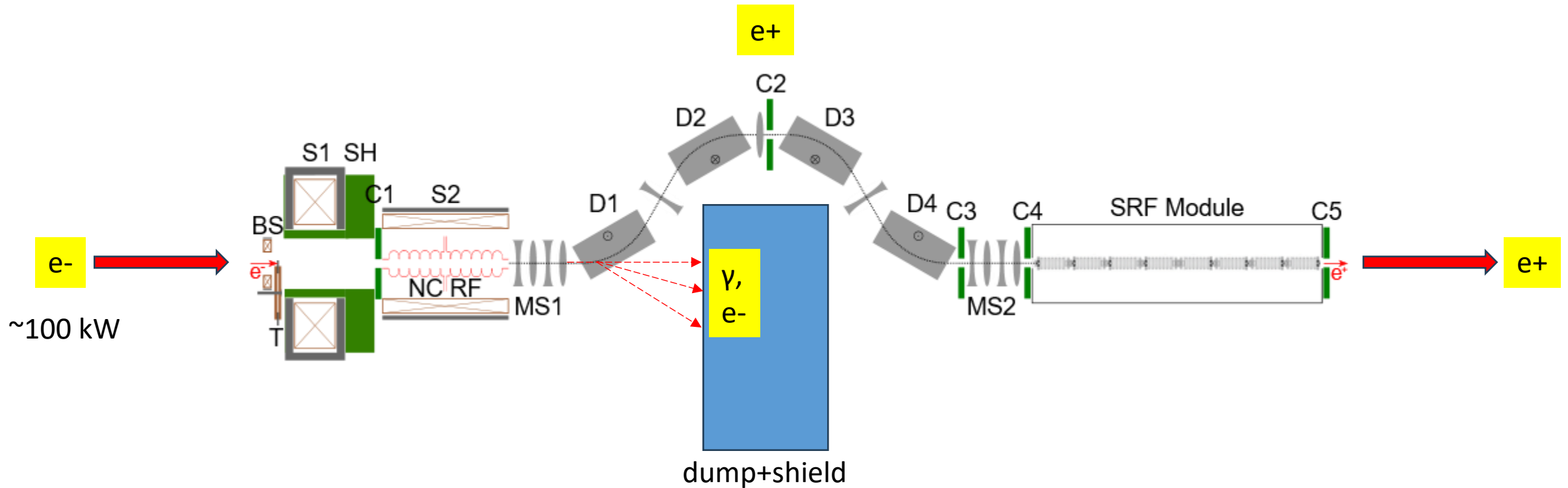


Machine Parameter	Electrons	Positrons
Hall Multiplicity	4	1 or 2
Energy (ABC/D)	11/12 GeV	11/12 GeV
Beam Repetition	249.5/499 MHz	249.5/499 MHz
Duty Factor	100% cw	100% cw
Unpolarized Intensity	170 μA	> 1 μA
Polarized Intensity	170 μA	> 50 nA
Beam Polarization	> 85%	> 60%
Fast/Slow Helicity Reversal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

A red arrow points from a yellow box containing an exclamation mark to the Positrons column of the table, specifically highlighting the intensity and polarization values.

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.

Proposed e⁺ Injector Design



The e^+ polarization increases with the fraction E_{e^+}/E_{beam} .

For more information on the polarized e^+ source, see the link at [Positron beams at Ce+BAF](#)

A Growing, Conditionally Approved 12 GeV Program:

Physics Theme:	Abbreviated Proposal Titles	Contact Person	Observable
GPDs: 3D structure of the nucleon	“Beam Charge Asymmetries for DVCS on the Proton”	Voutier	Charge asymmetry in DVCS with L polarized beam
	“DVCS using an e+ beam”	Munoz Camacho	Charge asymmetry in DVCS
Beyond the Standard Model	“A Dark Photon Search with a Jlab e+ Beam”	Wojtsekhowski	Bump hunt in e+e- → 2gamma
Improving the Precision of Electron Scattering Experiments:			
2-photon exchange	“Direct Measurement of Hard 2-Photon Exchange with e- and e+”	Schmidt	Charge asymmetry
	“Measurement of 2-photon Exchange in Unpolarized positron-proton and electron-proton Scattering”	Nycz	“ “
	“Measurement of the 2-Photon Exchange Contribution in electron-Neutron and Positron-Neutron Elastic Scattering”	Fuchey	“ “
multi-photon exchange	“Measurement of DIS from Nuclei with e- and e+ beams to Constrain the Impact of Coulomb Corrections in DIS”	Gaskell	“ “
	“Multi-Photon Effects in Inclusive and Semi-Inclusive DIS”	Hague	“ “

Where this talk might evolve to in 1-2 years:
expanding the need for beam polarization.

Additionally Approved 12 GeV Program:

Physics Theme:	Abbreviated Proposal Titles	Contact Person	Observable
GPDs: 3D structure of the nucleon	“Beam Charge Asymmetries for DVCS on the Proton”	Voutier	Charge asymmetry in DVCS with L polarized beam
	“DVCS using an e+ beam”	Munoz Camacho	Charge asymmetry in DVCS
Beyond the Standard Model	“A Dark Photon Search with a Jlab e+ Beam”	Wojtsekhowski	Bump hunt in e+e- → 2gamma
	??Precision transverse asymmetries in Bhabha scattering??	Mack	Transverse asymmetries in Bhabha scattering
Improving the Precision of Electron Scattering Experiments:			
2-photon exchange	“Direct Measurement of Hard 2-Photon Exchange with e- and e+”	Schmidt	Charge asymmetry
	“Measurement of 2-photon Exchange in Unpolarized positron-proton and electron-proton Scattering”	Nycz	“ “
	“Measurement of the 2-Photon Exchange Contribution in electron-Neutron and Positron-Neutron Elastic Scattering”	Fuchey	“ “
multi-photon exchange	“Measurement of DIS from Nuclei with e- and e+ beams to Constrain the Impact of Coulomb Corrections in DIS”	Gaskell	“ “
	“Multi-Photon Effects in Inclusive and Semi-Inclusive DIS”	Hague	“ “

Bhabha scattering
($e^+ e^- \rightarrow e^+ e^-$)

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

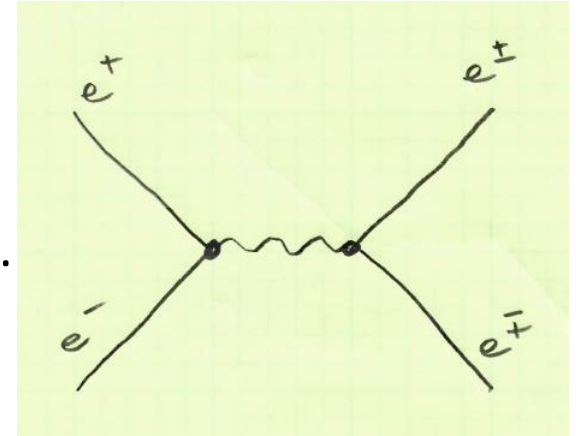
The s-channel amplitudes are constrained by the spin of the exchanged particle:

- In the Standard Model (SM), the neutral boson is effectively* a γ or Z^0 (ie, spin = 1).
- Beyond the SM, other neutral particles can be exchanged (eg, spin = 0, 2). Any observation of spin 0 or 2 exchanges would require BSM physics.

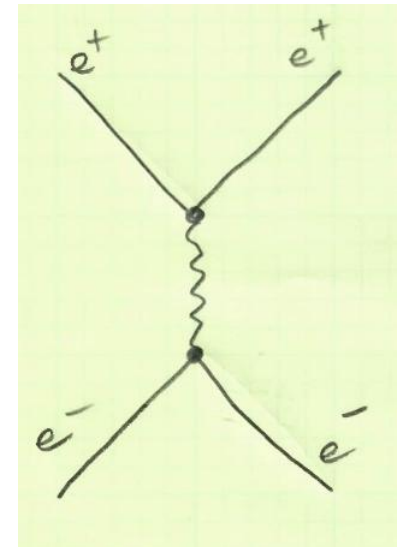
Bhabha scattering is a purely leptonic reaction, and is therefore highly interpretable. It has the potential to interfere a strong t-channel SM amplitude with an unsuppressed, s-channel BSM amplitude.

*Because the spin = 0 Higgs and the spin = 2 graviton couple to mass and the energy-momentum tensor, respectively, their contributions are completely negligible in JLab Bhabha experiments.

s-channel



t-channel



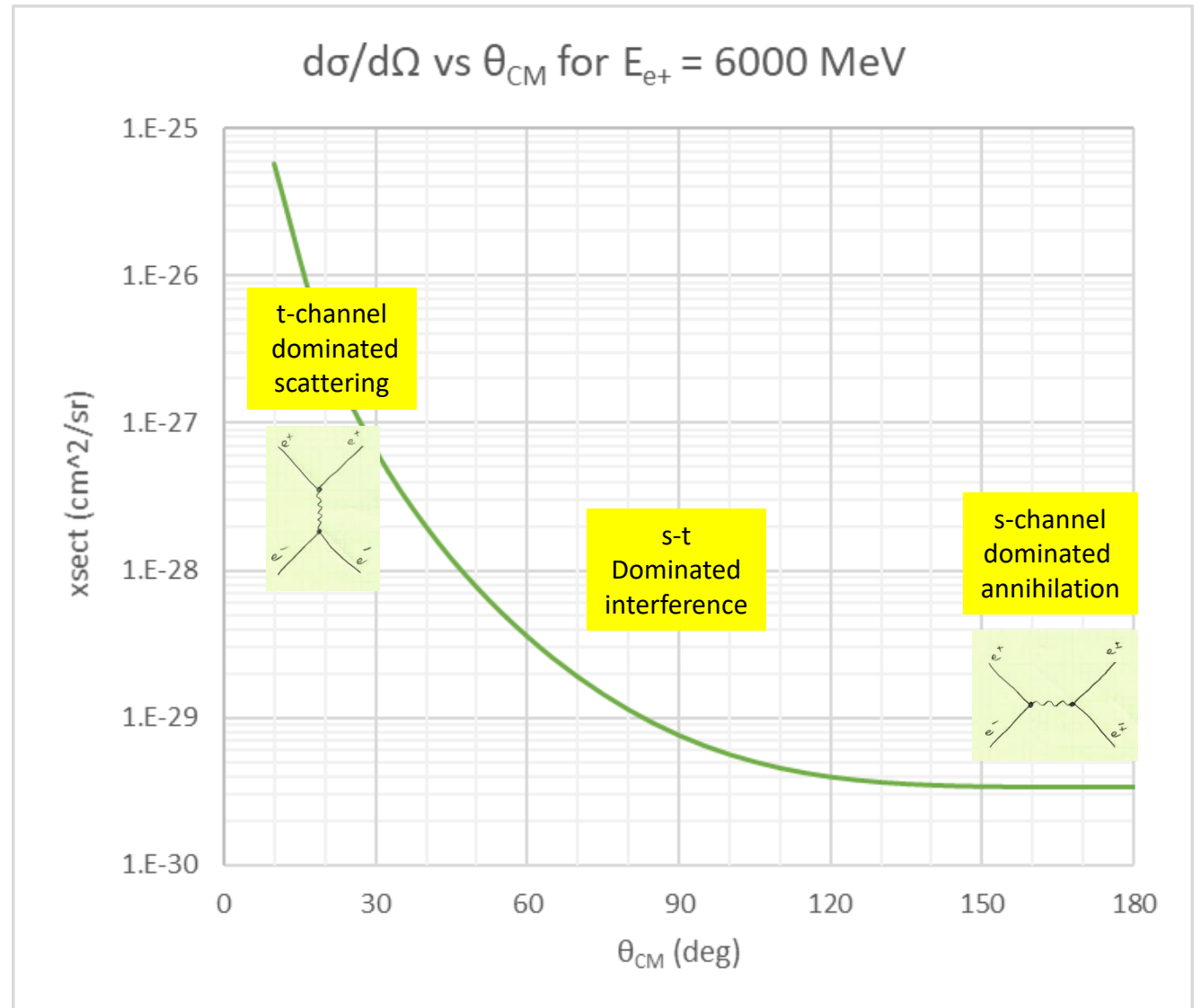
Bhabha $d\sigma/d\Omega$ vs θ_{CM}

The differential xsect has 2 regions:

- The forward, t-channel dominated regime provides very large xsects.
- The backward regime accesses s-channel annihilation, as well as interference of s- and t-channel exchange.

There is a distinct flattening for $\theta_{cm} > 90\text{deg}$.

The backward xsects are still quite large by Jlab standards: several $\mu\text{B}/\text{sr}$ in this 6 GeV example.



Parity Conserving, Transverse Asymmetries as an Interpretable BSM laboratory



Detour: Helicity Amplitudes Notation

F_{ij}^{kl} represents the amplitude for transition between initial state “ij” and final state “kl”, namely

$$F_{e^+e^-}^{e^+e^-} = F_{\text{initial}}^{\text{final}}$$

The indices are “L” or “R”, so the helicity matrix has $2 \times 2 \times 2 \times 2 = 16$ entries.

For example: F_{LR}^{LR} represents a LR \rightarrow LR scattering.

Since the final polarizations are usually impractical to measure, you will often see the shorthand $F_{i,j}$ representing only the initial e^+e^- state.

Such shorthand implies a summation of nondistinguishable contributions to the final helicity states (LR, RL, LL, and RR).

Helicity Amplitudes in Bhabha Scattering

$$\begin{aligned}
 4|M|^2 = & \quad + |F_{LR}|^2 + |F_{RL}|^2 + |F_{LL}|^2 + |F_{RR}|^2 \quad \leftarrow \text{Unpolarized xsect} \\
 & + \mathbf{P}_{e^-}^L (+ |F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 - |F_{LL}|^2) \quad \leftarrow \text{Longitudinal polarization only} \\
 & + \mathbf{P}_{e^+}^L (- |F_{RL}|^2 + |F_{RR}|^2 + |F_{LR}|^2 - |F_{LL}|^2) \quad \leftarrow \text{Longitudinal polarization only} \\
 & + \mathbf{P}_{e^-}^L \mathbf{P}_{e^+}^L (- |F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 + |F_{LL}|^2) \quad \leftarrow \text{Longitudinal polarization only} \\
 & + \mathbf{P}_{e^-}^T (+ 2\text{Re}(F_{RL}F_{LL}^* + F_{RR}F_{LR}^*) \cos(\phi_m - \phi) \\
 & \quad - 2\text{Im}(F_{RL}^*F_{LL} - F_{RR}^*F_{LR}) \sin(\phi_m - \phi)) \\
 & + \mathbf{P}_{e^+}^T (- 2\text{Re}(F_{LR}F_{LL}^* + F_{RR}F_{RL}^*) \cos(\phi_p - \phi) \\
 & \quad - 2\text{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL}) \sin(\phi_p - \phi)) \\
 & + \mathbf{P}_{e^-}^T \mathbf{P}_{e^+}^T (- 2\text{Re}(F_{RR}F_{LL}^*) \cos(\phi_m - \phi_p) \\
 & \quad - 2\text{Im}(F_{RR}^*F_{LL}) \sin(\phi_m - \phi_p) \\
 & \quad - 2\text{Re}(F_{LR}F_{RL}^*) \cos(\phi_m + \phi_p - 2\phi) \\
 & \quad + 2\text{Im}(F_{LR}^*F_{RL}) \sin(\phi_m + \phi_p - 2\phi)) \\
 & + \mathbf{P}_{e^+}^L \mathbf{P}_{e^-}^T (- 2\text{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*) \cos(\phi_m - \phi) \\
 & \quad + 2\text{Im}(F_{RL}^*F_{LL} + F_{RR}^*F_{LR}) \sin(\phi_m - \phi)) \\
 & + \mathbf{P}_{e^+}^T \mathbf{P}_{e^-}^L (+ 2\text{Re}(F_{LR}F_{LL}^* - F_{RR}F_{RL}^*) \cos(\phi_p - \phi) \\
 & \quad + 2\text{Im}(F_{LR}^*F_{LL} + F_{RR}^*F_{RL}) \sin(\phi_p - \phi))
 \end{aligned}$$

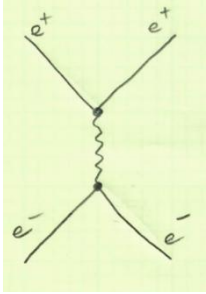
Transverse polarization introduces the interference of helicity amplitudes, making Bhabha scattering a rich BSM laboratory.

None of the 6 PC and 6 PV transverse asymmetries implied here has been published.

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

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>

Bhabha t-channel Helicity Amplitudes

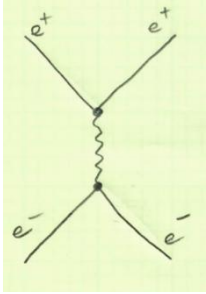


In the t-channel, helicity is largely conserved at each vertex, with flip probabilities suppressed by $1/\gamma = 2m_e/E_{cm}$.

Unsuppressed scatterings are diagonal (in red).

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

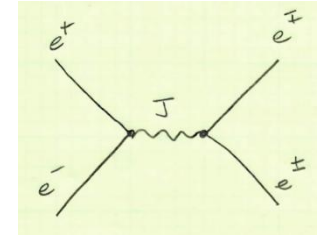
Bhabha t- and s-channel Helicity Amplitudes



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

Unsuppressed scatterings are diagonal (in red).

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

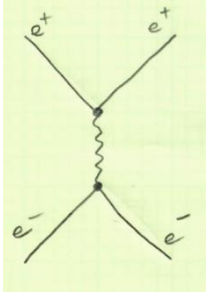


In the s-channel, only scatterings consistent with the exchange of a spin = 1 gamma or Z are allowed, with violations proportional to $1/\gamma = 2m_e/E_{cm}$.

Unsuppressed scatterings link only RL and LR (in red)

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

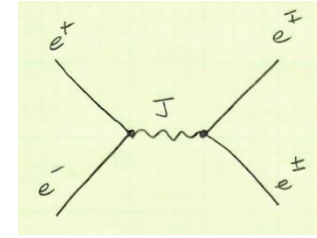
Bhabha and Scalar Exchange Helicity Amplitudes



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

Unsuppressed scatterings are diagonal (in red).

		Final e ⁺ e ⁻ helicity			
		LR	RL	LL	RR
Initial e ⁺ e ⁻ helicity	LR	$F_{LR}^{LR,t}$			
	RL		$F_{RL}^{RL,t}$		
	LL			$F_{LL}^{LL,t}$	
	RR				$F_{RR}^{RR,t}$



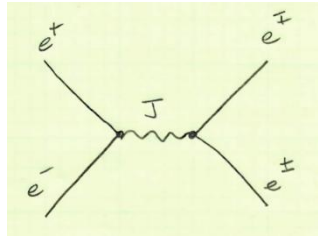
In the s-channel, only scatterings consistent with the exchange of a spin = 1 gamma or Z are allowed, with violations proportional to $1/\gamma = 2m_e/E_{cm}$.

Unsuppressed scatterings link only RL and LR (in red)

		Final e ⁺ e ⁻ helicity			
		LR	RL	LL	RR
Initial e ⁺ e ⁻ helicity	LR	$F_{LR}^{LR,s}$	$F_{LR}^{RL,s}$		
	RL	$F_{RL}^{LR,s}$	$F_{RL}^{RL,s}$		
	LL			Scalar	Scalar
	RR			Scalar	Scalar

BSM scalar contributions would not be suppressed here.

Bhabha s-channel Photon and Scalar Helicity Amplitudes



What if we look for a transverse asymmetry that interferes s-channel exchanges of a photon and a scalar?

Eg, in a purely s-channel reaction like $e^+e^- \rightarrow \mu^+\mu^-$.

But to first order:

- Photon exchange couples only to LR and RL.
- Scalar exchange couples only to LL and RR.

They cannot reach the same final state, so there's no transverse asymmetry with an interference term potentially sensitive to scalars (except for small crumbs at the level of $1/\gamma$).

This gives rise to the over-broad statement I see once per year in the literature:

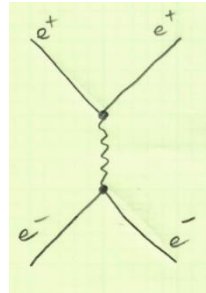
“Scalar and vector exchange amplitudes do not interfere”.

		Final e+e- helicity			
		LR	RL	LL	RR
Initial e+e- helicity	LR	$F_{LR}^{LR,S}$	$F_{LR}^{RL,S}$		
	RL	$F_{RL}^{LR,S}$	$F_{RL}^{RL,S}$		
	LL			Scalar	Scalar
	RR			Scalar	Scalar

Note: In the original image, the LR and RL final helicity columns are circled in orange, and the LL and RR final helicity columns are circled in yellow. Red arrows point from the LR and RL rows to their respective columns, and from the LL and RR rows to their respective columns.

Bhabha t-channel Photon and s-channel Scalar Helicity Amplitudes

What if we look for a transverse asymmetry that interferes t-channel photon exchange and s-channel scalar exchange?



Bingo! Both couple $LL \rightarrow LL$ and $RR \rightarrow RR$.

The transverse asymmetry we want is the one I call A_{TT}' which is proportional to

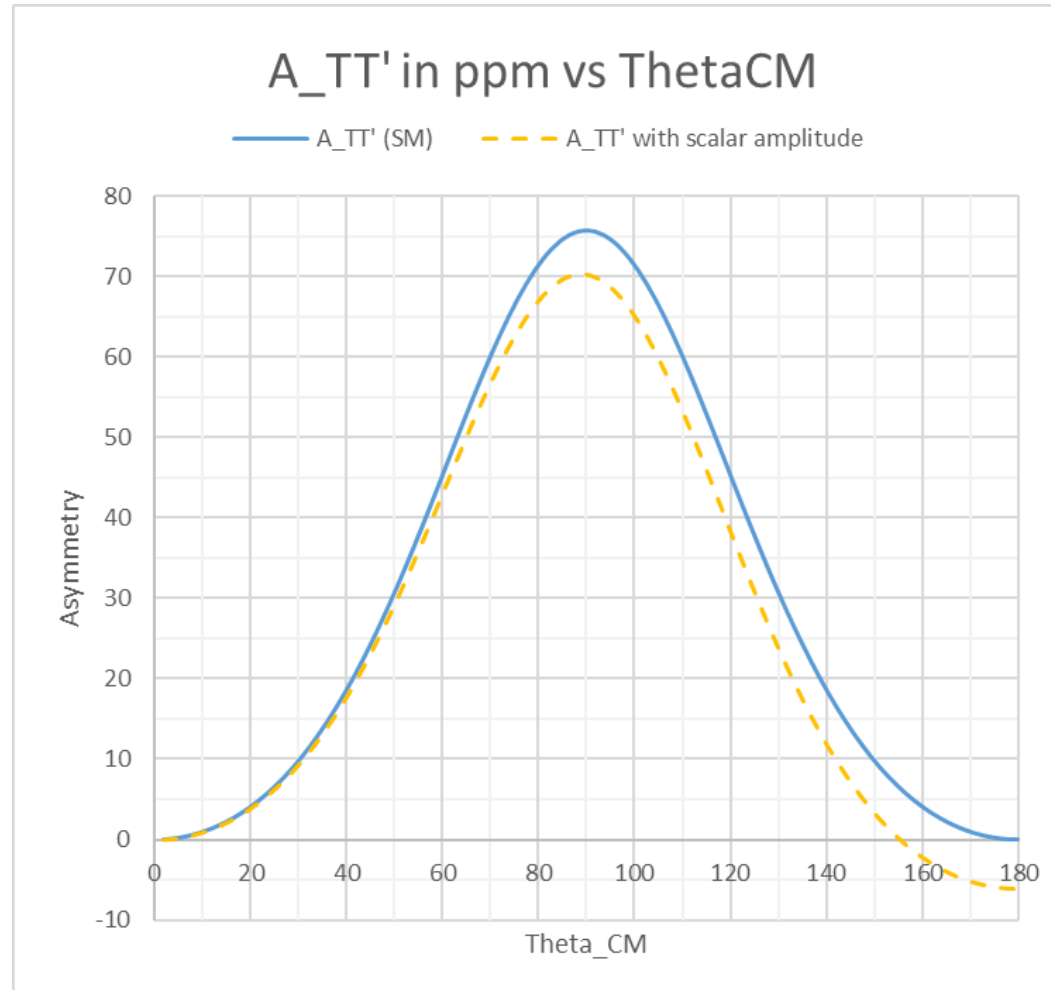
$$-2\text{Re}(F_{RR}F_{LL}^*)\cos(\phi_m - \phi_p)$$

So ... one can interfere scalar and vectors, just not in exclusively s-channel reactions. This existence proof requires a t-channel carrier wave is, so it only works for Bhabha scattering (or the muon collider equivalent).

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

A_{TT}' vs θ_{CM}

For $E = 6$ GeV, corresponding to $E_{cm} = 78.3$ MeV/c²,
a scalar mass of 25 MeV/c², and a coupling $g_s = 1E-3$:



The peak magnitude is ~ 75 ppm.

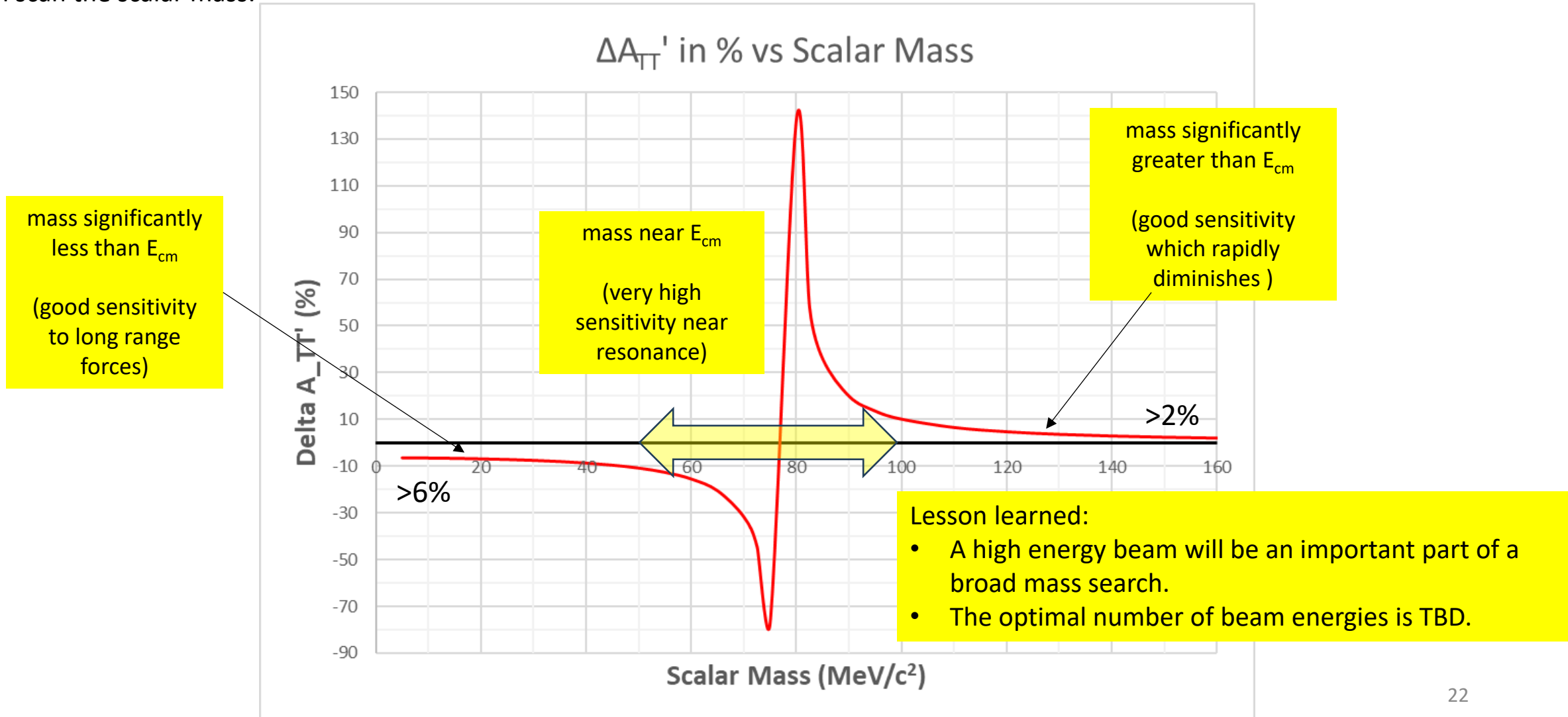
For this beam energy, the sensitivity seen here is similar for all masses from 0 to 50 MeV/c² (i.e., well below E_{cm}).

However, the sensitivity can be much larger near resonance, and much smaller far above resonance.

On the next slide, I'll fix θ_{CM} and vary the mass.

$\Delta A_{\pi\pi}'$ vs Scalar Mass

For $E = 6$ GeV, corresponding to $E_{\text{cm}} = 78.3$ MeV/c²,
Fix the angle at $\theta_{\text{CM}} = 90$ deg, set the coupling $g_s = 1E-3$,
then scan the scalar mass:



Mainz Calculations for a Different But Fascinating Transverse Asymmetry: A_{TU} in Hall C Kinematics

New Physics Searches via Beam Normal Spin Asymmetry in Bhabha Scattering

New Physics Searches via Beam Normal Spin Asymmetry in Bhabha Scattering

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(Dated: December 1, 2025)

We examine the sensitivity of the beam normal spin asymmetry in Bhabha scattering to beyond the Standard Model (BSM) mediators, in the context of the JLab polarized positron program. A key property of this observable is that the Standard Model contribution exhibits a zero crossing at a fixed scattering angle, providing a clean, effectively background-free point for these searches. We consider scalar, vector and axial-vector mediators and present projected bounds, finding scalar and vector scenarios allowing to extend their search ranges significantly beyond existing constraints.

The search for light dark sector particles in the MeV to GeV mass range has intensified over the past decade [1–6], with a particular focus on axion-like particles (ALPs) [7–23] and dark photons [24–36]. The coverage across this mass range is primarily provided by e^+e^- colliders, beam-dump, and fixed-target experiments, mostly relying on “bump hunt” and missing energy searches. These have proven powerful but are not exhaustive. In particular, the few MeV to few hundred MeV mediator-mass range remains relatively underexplored [15, 18, 22]. The detection of low-energy final states is challenged by large QED backgrounds and detector-threshold effects which complicate reconstruction [11, 19, 23], motivating complementary low-energy precision programs such as PADME [37], the MAGIX@MESA facility [38], and the Jefferson Lab (JLab) polarized positron program [39].

In this work, we consider the Bhabha scattering process

$$e^-(p_1, s_1) + e^+(p_2, s_2) \rightarrow e^-(p_3, s_3) + e^+(p_4, s_4), \quad (1)$$

where p_1 and p_2 (p_3 and p_4) denote the initial (final) electron and positron four-momenta, and the s_i denote the corresponding helicities.

Imposing parity (P), time-reversal (T), and charge-conjugation (C) invariance leads to five independent helicity amplitudes for this process [40]. For the purpose of exploring the contribution of P, T, and C conserving dark messenger particles to this process it is convenient to parameterize the amplitude \mathcal{T} through the following covariants:

$$\mathcal{T} = S \bar{u}_3 u_1 \bar{v}_2 v_4 + P \bar{u}_3 \gamma^5 u_1 \bar{v}_2 \gamma^5 v_4$$

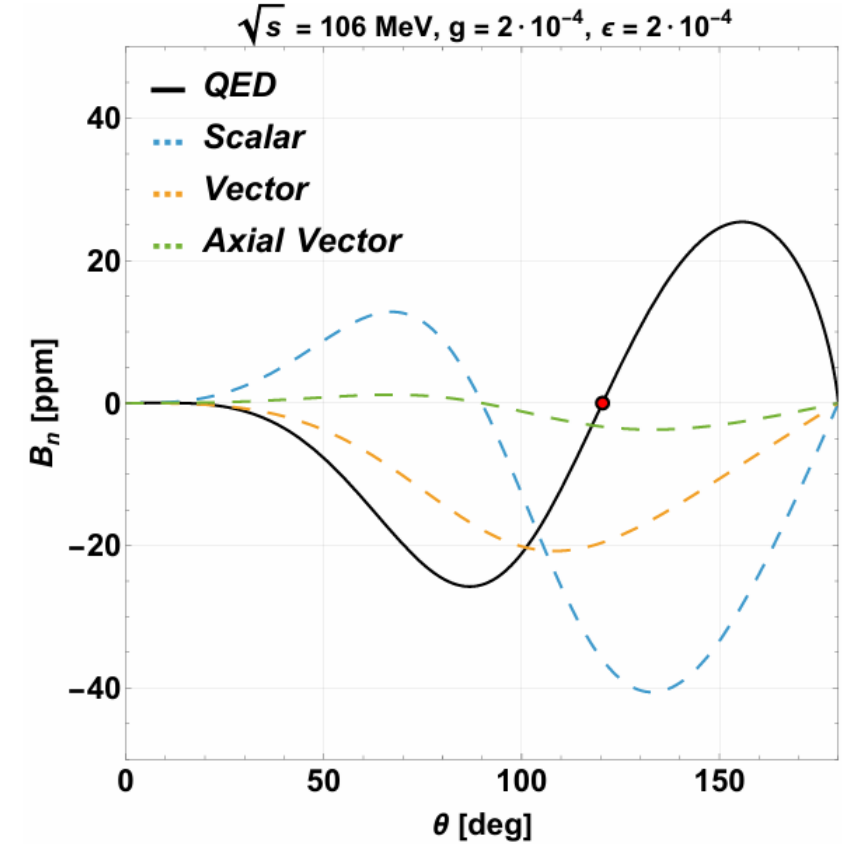


FIG. 2. Comparison of the angular dependence of the QED and BSM contributions to the Bhabha beam normal spin asymmetry B_n for indicated values of BSM coupling strengths, for an 11 GeV e^+ beam at JLab. The QED zero-crossing point is marked with a red dot.

Summary Table of Must-Do Bhabha PC Transverse Asymmetries

Transverse Asymmetry	Proportional to These Helicity Amplitudes	ϕ Dependence	Suppression in SM	BSM Sensitivity	References and Comments
A_{TT}'	$-2\text{Re}(F_{RR}F_{LL}^*)$	$\cos(\phi_m - \phi_p)$	$1/\gamma^2$	Spin 0	Me (unpublished, simply following breadcrumbs in the critical paper by Hikasa, PRD, 33 , 3203 (1986).)
A_{TT}	$-2\text{Re}(F_{LR}F_{RL}^*)$	$\cos(\phi_m + \phi_p - 2\phi)$	Unsuppressed.	Spin 2 (signal is a small fwd-bkwd asymmetry)	Me (unpublished, repurposing the helicity amplitudes for spin 2 from the graviton work by Rizzo, https://iopscience.iop.org/journal/1126-6708 A_{TT} is also ideal for T polarimetry
A_{LT}	$-2\text{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*)$	$\cos(\phi_m - \phi)$	$1/\gamma$	Dipole operators?	Wen et al, PRL 131, 241801 (2023) BSM case presently unclear. A must-do cuz never measured.
A_{TU}	$-2\text{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL})$ More interesting if Initial State Radiation is employed	$\sin(\phi_p - \phi)$	α/γ (two-photon)	Spin 0 (scalars only), Spin 1, also dipole operators?	The previous speaker!!! [2511.22568] New Physics Searches via Beam Normal Spin Asymmetry in Bhabha Scattering See also same Wen et al work, PRL 131, 241801 (2023).

Summary Table of Much More Speculative Extensions

Transverse Asymmetry	Proportional to These Helicity Amplitudes	ϕ Dependence	BSM Sensitivity	Comments
Bhabha:				
A_{LT} vs A_{TL}	$-2\text{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*)$	$\cos(\phi_m - \phi)$	Matter-antimatter asymmetry?	Expt'l headaches: best candidate for keeping the Fe target dilution constant, but getting L polarization in Fe target is awkward and seemingly introduces asymmetry.
A_{TU} vs A_{UT}	$-2\text{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL})$	$\sin(\phi_p - \phi)$	Matter-antimatter asymmetry?	Expt'l headaches: this is a seemingly poor candidate for a precision test due to the radically different dilution factors for A_{TU} vs A_{UT} . But perhaps they can be cross-normalized at a boring θ_{cm} .
$e+e- \rightarrow 2\gamma$??	??	Spin 0 or 2 decaying to 2γ , or heavy electron	Eric Voutier got me interested in this. I have to hunt for the BSM amplitudes.
$e-e- \rightarrow e-e-$??	??	Doubly charged scalar or fermion	The BSM scalar amplitudes are trivial. I have to hunt for the BSM fermion amplitudes.

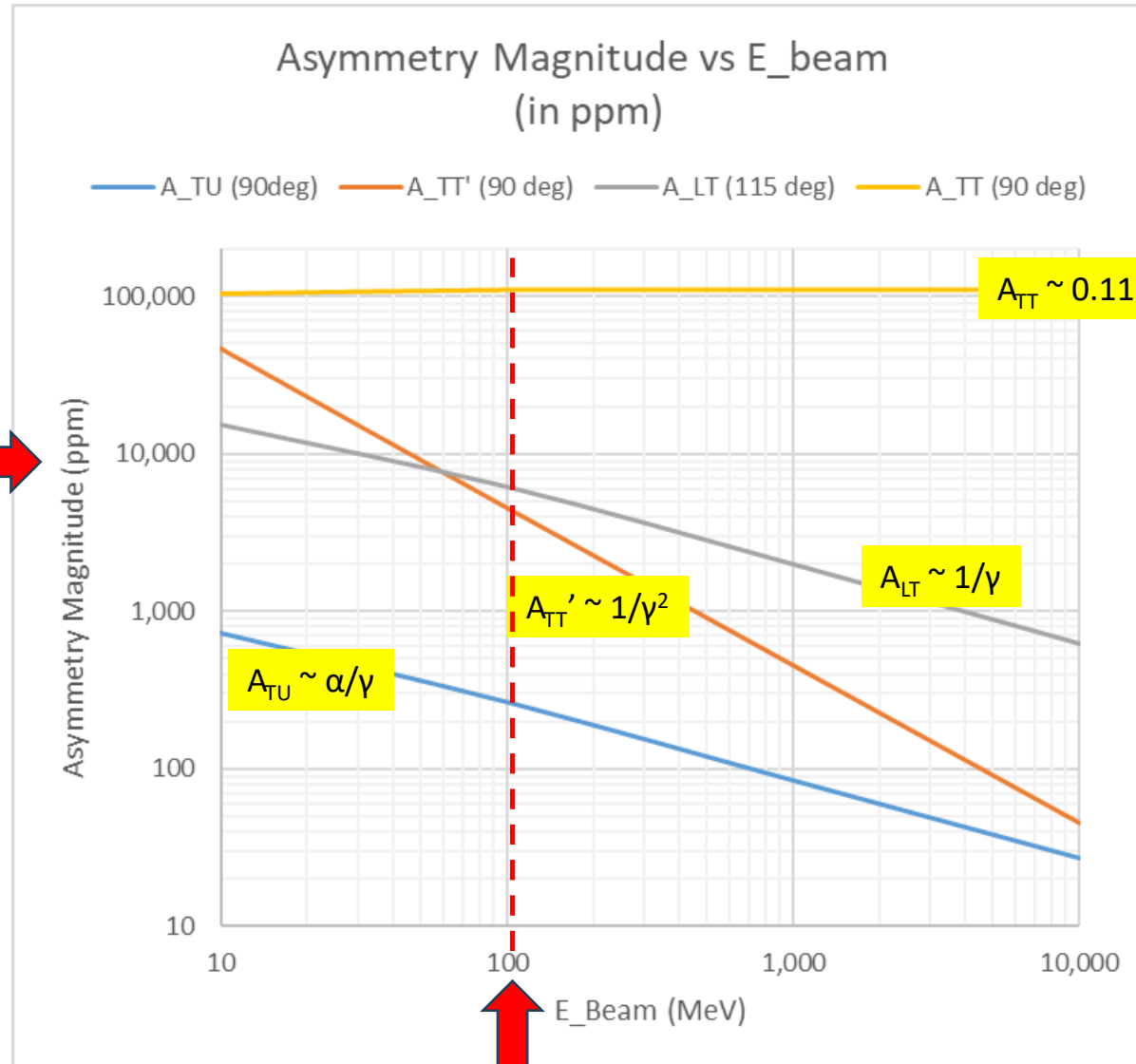
Possible LERF Measurements

(just the present list of Bhabha must-do's)

Transverse Bhabha Asymmetry Magnitudes vs E_{beam}

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

10,000 ppm is 1%



110 MeV

Near $E_{\text{beam}} = 110$ MeV,
 $A_{\text{TT}'}$ and A_{LT}
are approaching 1%.

We may make the first
measurements of these
asymmetries in the future e^+
injector, years before GeV-scale
positrons are available in Hall C.

Getting Transverse Polarization for 5-10 MeV e^+ is Awkward!

Last year, Joe G sent me some notes on the facts of life about getting transverse polarization. It was much more traumatic for me than those other facts of life.

Electrons produced by the photocathode are L polarized, and spin precession is proportional to $\gamma\Delta\theta(g-2)/2$, but

- $(g-2)/2$ is ~ 0.001
- γ is at most a few x 100 in LERF,

hence spin precession is balky in LERF. At 5-10 MeV, it would take many revolutions to precess L to T (ie, by 90°).

But what about that Wien filter trick (ie, drift thru crossed E and B fields)? That works great for the low energy electrons, produced near room temp off a photocathode, then accelerated a bit.

For positrons produced highly relativistically, fuhgeddaboutit; the HV's would be too high.

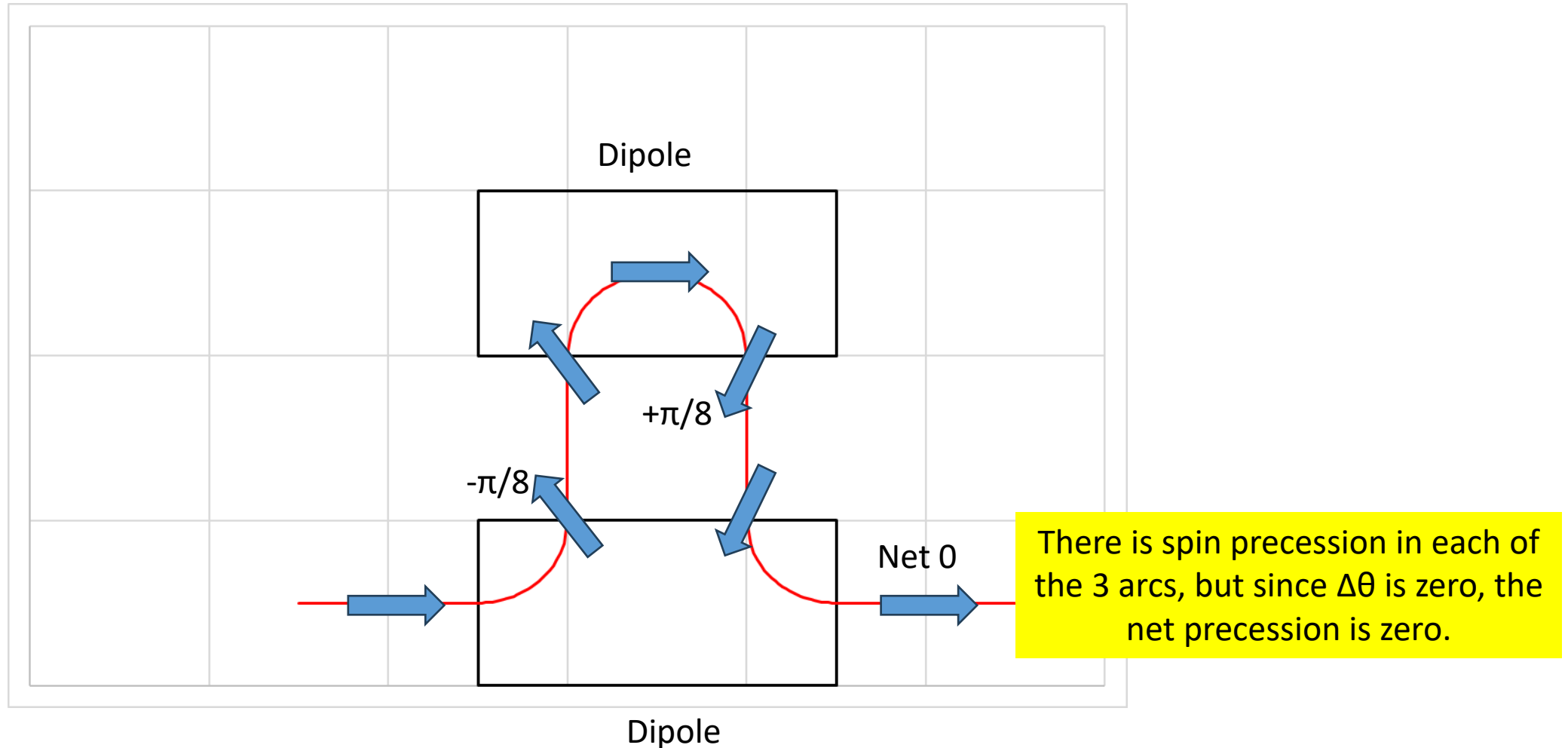
So for brute force, cost-effective, precession from L to T, an arguable magic minimum energy to keep in mind is **110.2 MeV where a single 360° bend does the trick.**

Note added after the discussion session led by Joe G:

By running fully T polarized positrons thru a linac out of phase (ie, ERL mode), it is possible to lower their beam energy while preserving their polarization. **See Fanglei Lin's slide 13.** Getting these lower energy e^+ to where there is space for experiments, while preserving polarization, needs some thought.

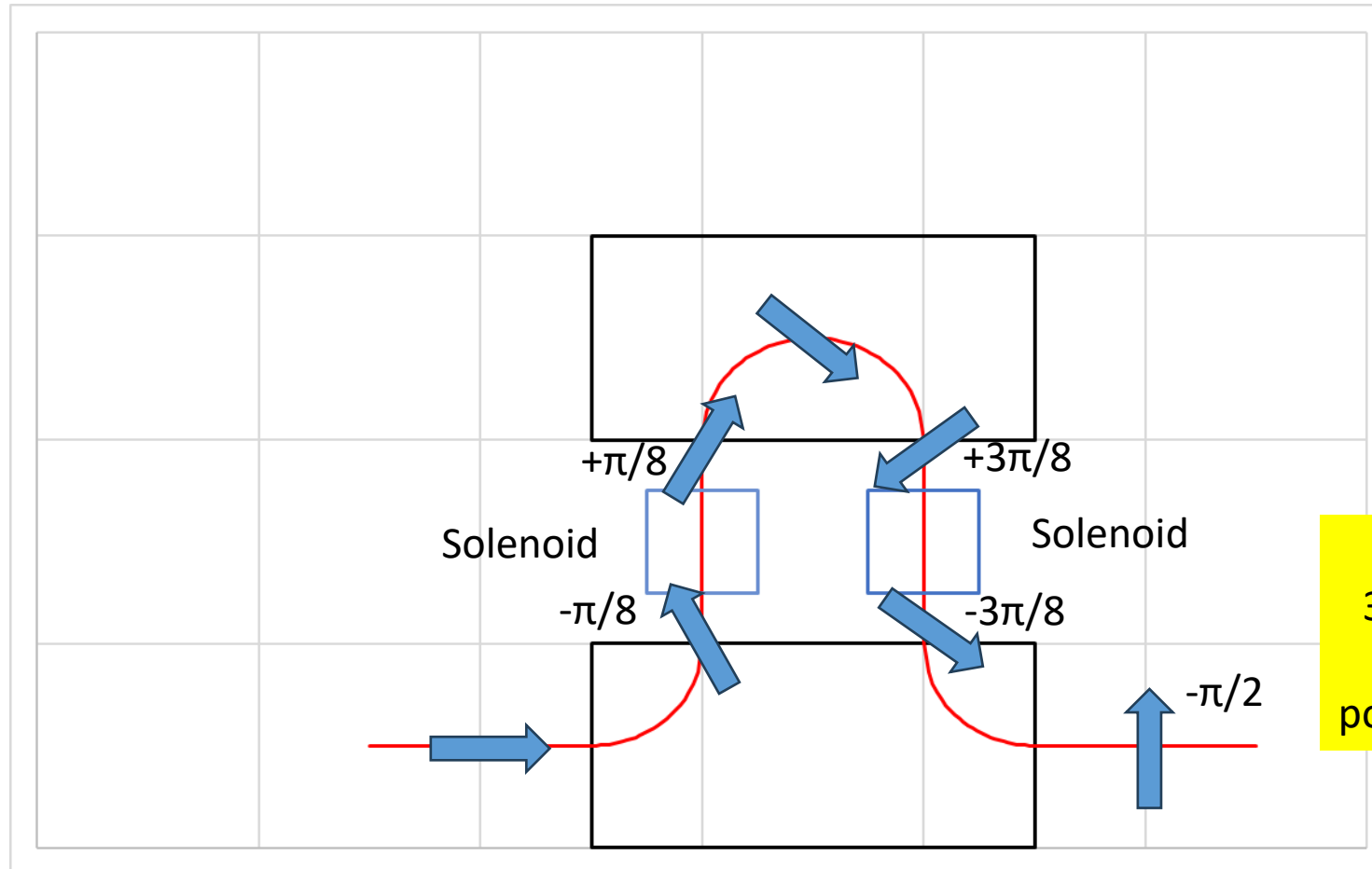
How Not to Achieve Transverse Polarization at 110 MeV

Adapting from Joe G's notes and Fanglei Lin's detailed email, here's the spin precession when you let the e+ take a dumb detour:



Scheme to Achieve Transverse Polarization at 110 MeV

When they add solenoids, the detour becomes brilliant! :



Adding solenoids allows the 3 dipole spin precessions to add coherently, achieving full T polarization near 110 MeV in LERF.

Draft LOI for 110 MeV e+ Beam

e+ beam properties:

L or T polarization (note that T polarization requires a non-trivial 360 degree bend)
KE = 110 MeV, implying an e- driver beam of higher energy

Target:

magnetized Fe foil 5 microns thick, tiltable

The nuclear experimentalists would

- i. build the target and its reversal schemes,
- ii. design a magnetic spectrometer and even the spectrometer magnets if they are small enough,
- iii. provide the focal plane detectors,
- iv. provide a data acquisition,
- v. provide a Faraday cup and readout

Goals:

- Do essentially the full transverse Bhabha program: the helicity suppressed transverse asymmetries A_{LT} , A_{TT}' , and A_{TU} , and possibly the redundant – or extremely interesting - A_{TL} and A_{UT} .
- With T beam polarization available, Eric V might like to add Mott scattering measurements.
- Characterize the L beam polarization via A_{LL} , and the T beam polarization via A_{TT} .
- Characterize the e+ beam intensity

Draft LOI for 110 MeV e+ Beam

e+ beam properties:

L or T polarization (note that T polarization requires a non-trivial 360 degree bend)
KE = 110 MeV, implying an e- driver beam of higher energy

Target:

magnetized Fe foil 5 microns thick, tiltable

The nuclear e

- i. build the
- ii. design a
- iii. provide t
- iv. provide a
- v. provide a Faraday cup and readout

Joe G said to make the best physics case.
For Bhabha scattering, that requires high T polarization imho.
So I dropped plans for a 5-10 MeV measurement,
but there's a slide on it in the backups.

Goals:

- Do essentially the full transverse Bhabha program: the helicity suppressed transverse asymmetries A_{LT} , A_{TT} , and A_{TU} , as well as either redundant – or extremely interesting - A_{TL} and A_{UT} .
- With T beam polarization available, Eric V would like to add Mott scattering measurements.
- Characterize the L beam polarization via A_{LL} , and the T beam polarization via A_{TT} .
- Characterize the e+ beam intensity

Detector Requirements

Must have:

- An unusually large momentum acceptance.
- The ability to distinguish whether a particle is e^+ or e^- .
- A high degree of azimuthal symmetry.
- Coincidence detection of e^+e^- over as large a CM angle range as possible.
- Coincidence timing resolution better than 10 nsec.
- The ability to determine whether the e^+e^- is a typical Bhabha event.
- The ability to reconstruct θ_{CM} and ϕ for a typical Bhabha event.
- For physics: the acceptance must include CM angle range of 90° - 135° .
- For polarimetry: the acceptance must include a large CM angle bite centered on 90° .
- High suppression of the obvious hard background suspects: Mott scattering singles, photoproduced pairs, accidental coincidences, back-streaming from the beam dump, beamline and scattering chamber rescattering, cosmic rays.
- High suppression of soft backgrounds

Very nice to have:

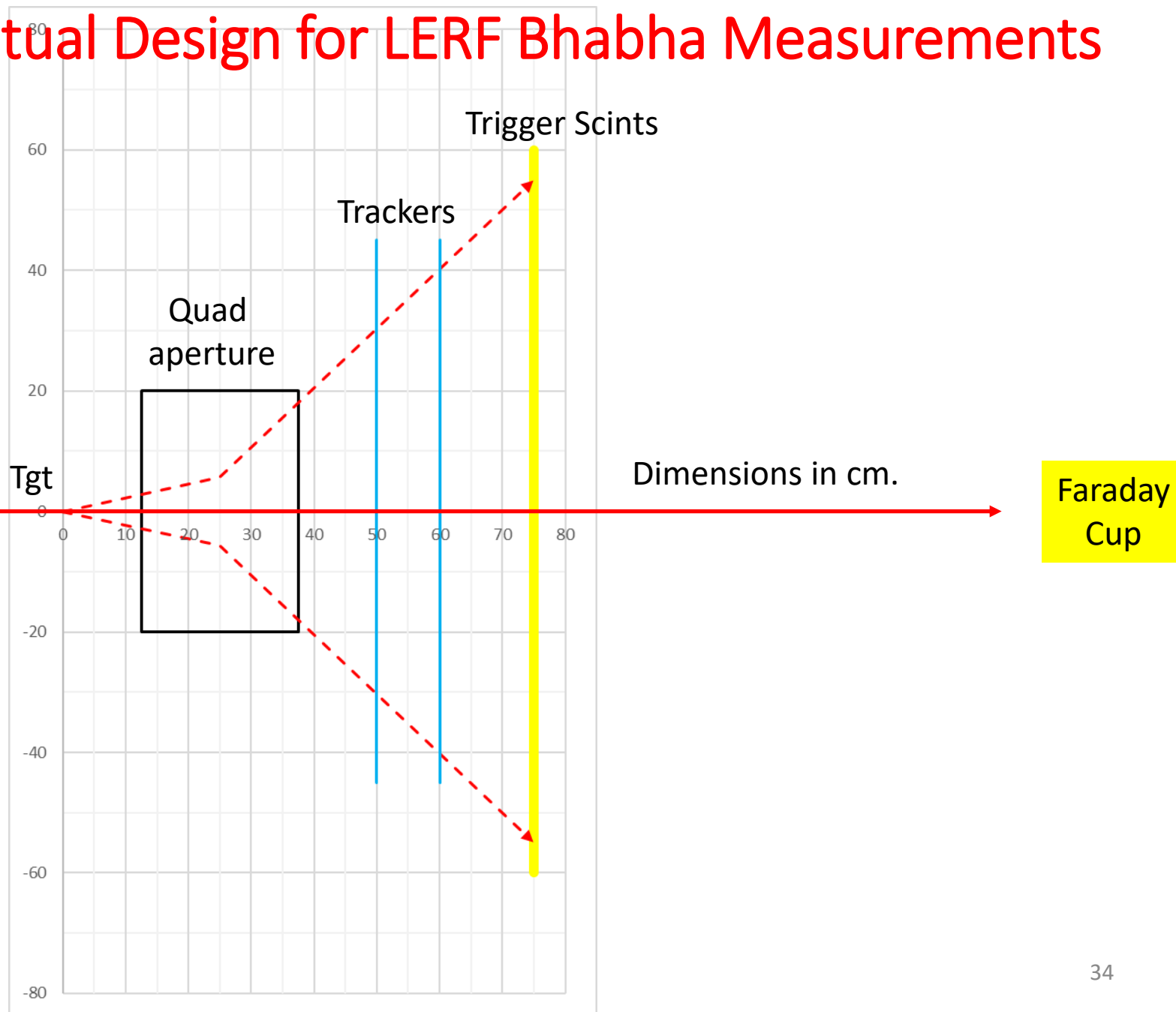
- The ability to determine whether the e^+e^- is consistent with ISI, then correctly reconstruct θ_{CM} and ϕ_+ .
- Works for the Moeller scattering reaction.
- Doesn't block large scattering angles for A_{TU} measurements on nuclei (ie, the beam normal single spin asymmetry in Mott scattering).
- Doesn't block coincidence photons from $e^+e^- \rightarrow 2\gamma$ near the CM angle of 90° .

A Promising Conceptual Design for LERF Bhabha Measurements

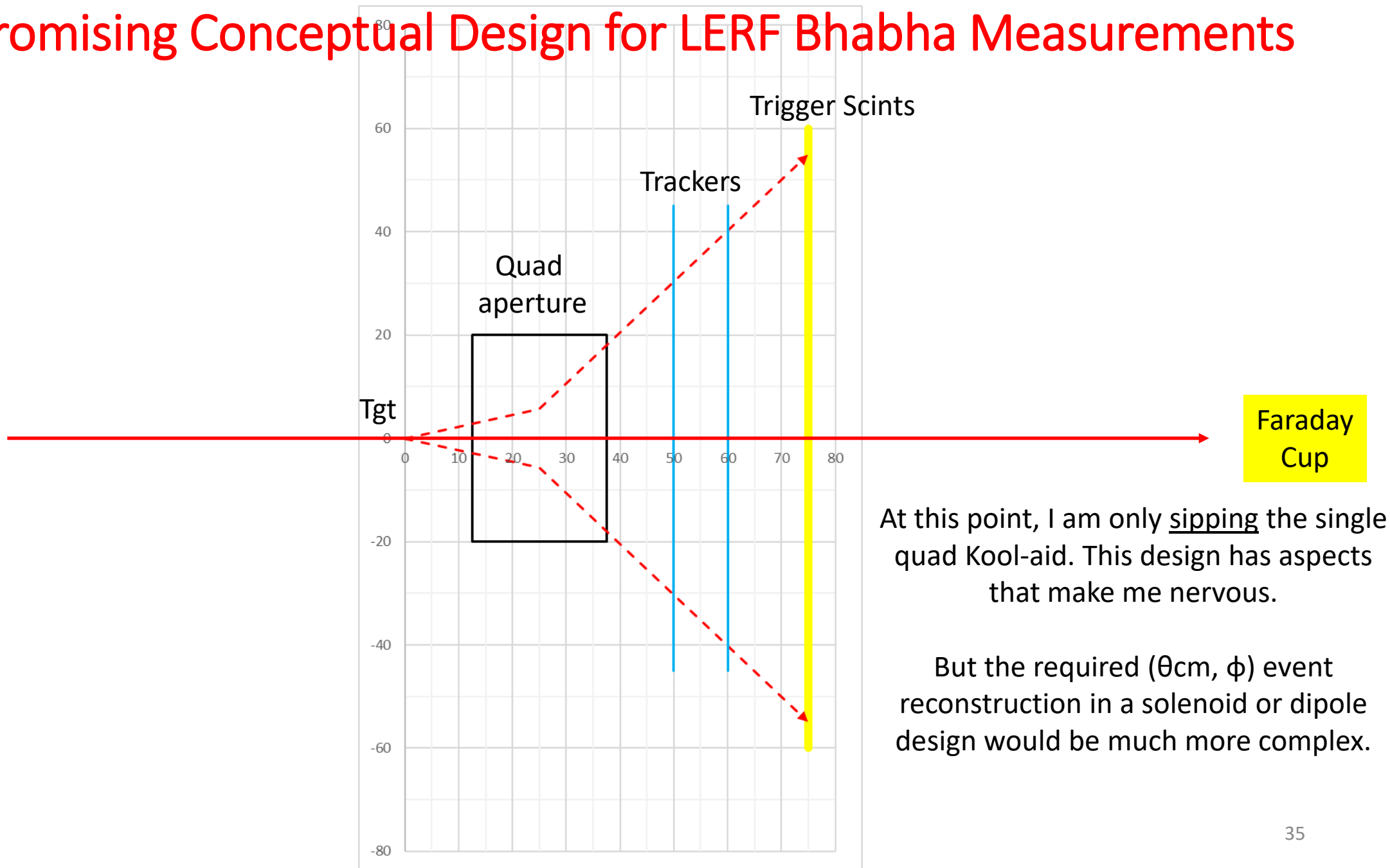
For θ_{cm} of 135° , the low energy e^+e^- bend a lot.

A large lab angle acceptance is required.

A magnetic field is needed to distinguish e^+e^- .
But since Bhabha is a 2-body reaction, we may be able to isolate it with an unconventional spectrometer.

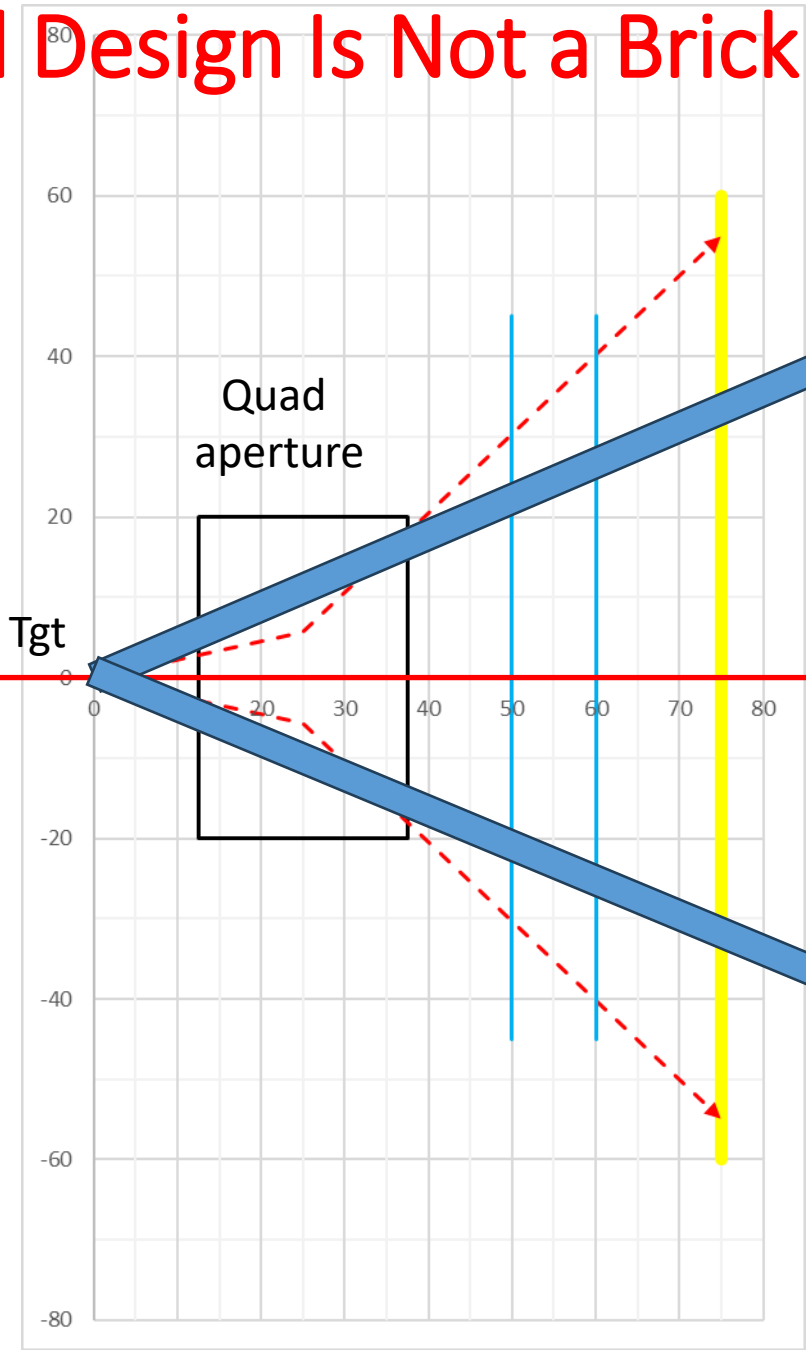


A Promising Conceptual Design for LERF Bhabha Measurements



This Conceptual Design Is Not a Brick in the Beamline

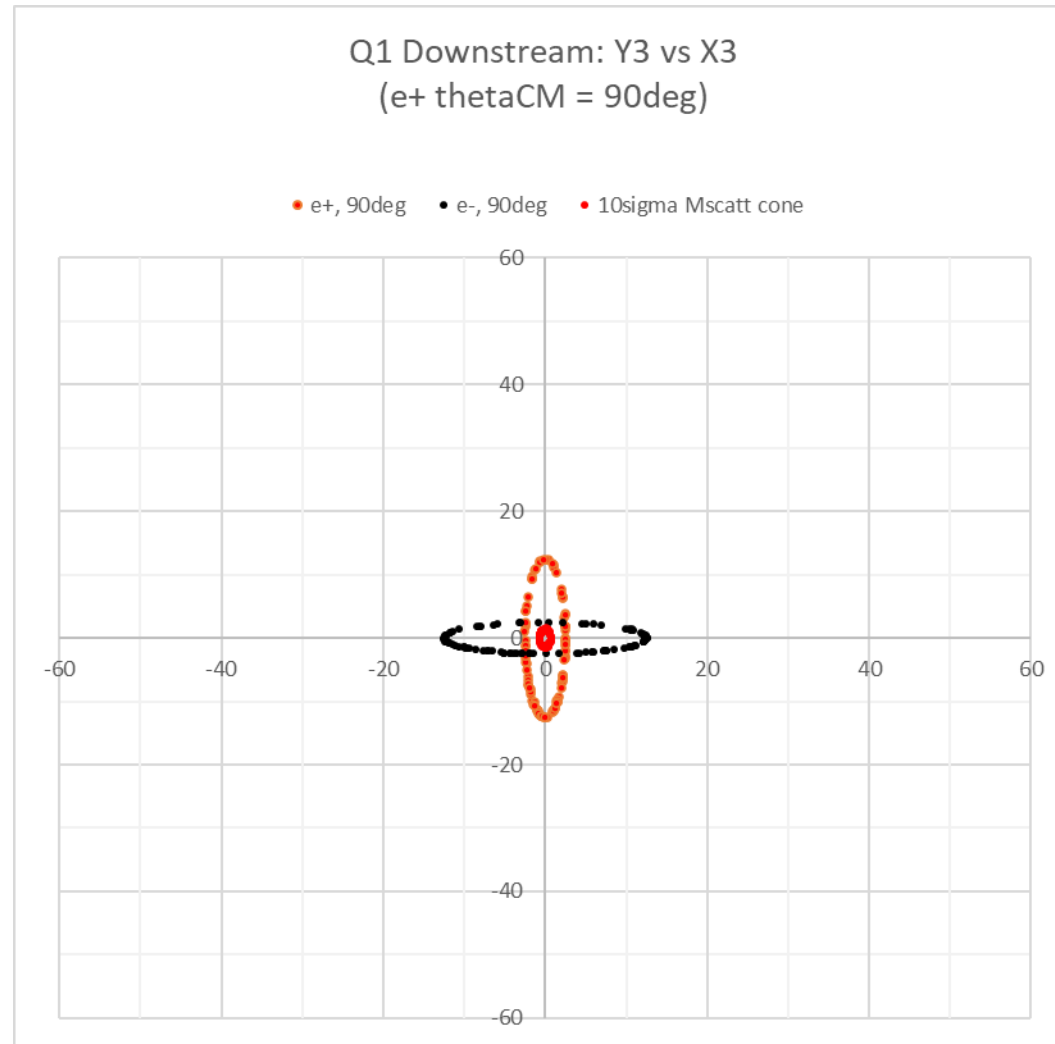
Large angle acceptance available for BNSSA in Mott (also called the Sherman function).



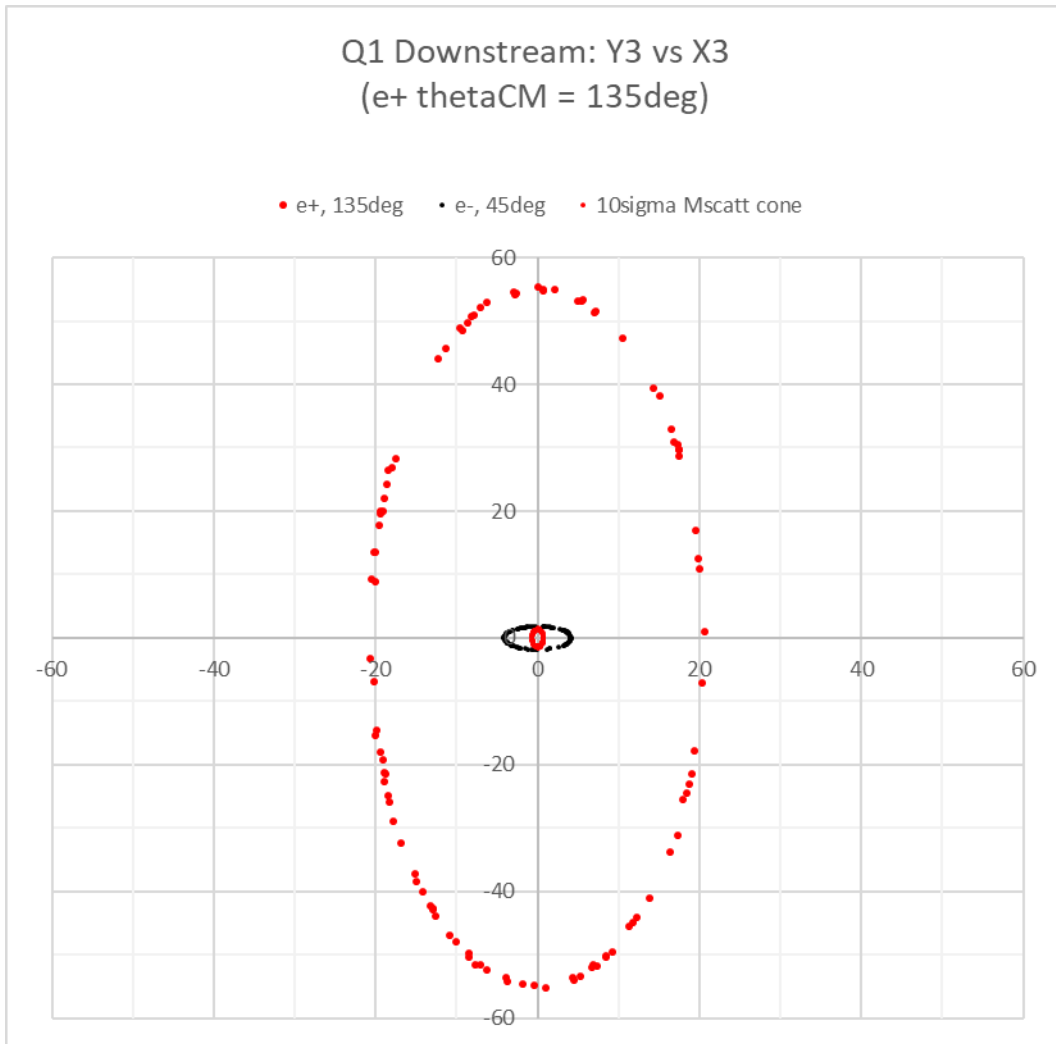
Appreciable forward angle acceptance for $e^+e^- \rightarrow 2\gamma$, including significant coincidence acceptance useful for T polarimetry near $\theta_{cm} \sim 90^\circ$.

Floor?
36

Detector Plane Shape and Size (all on same scale)

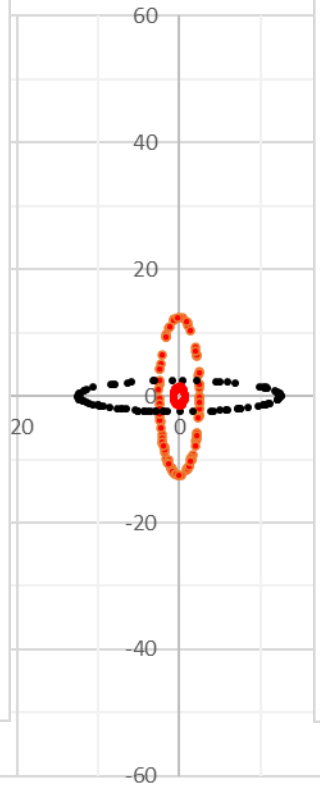


Detector Plane Shape and Size (all on same scale)



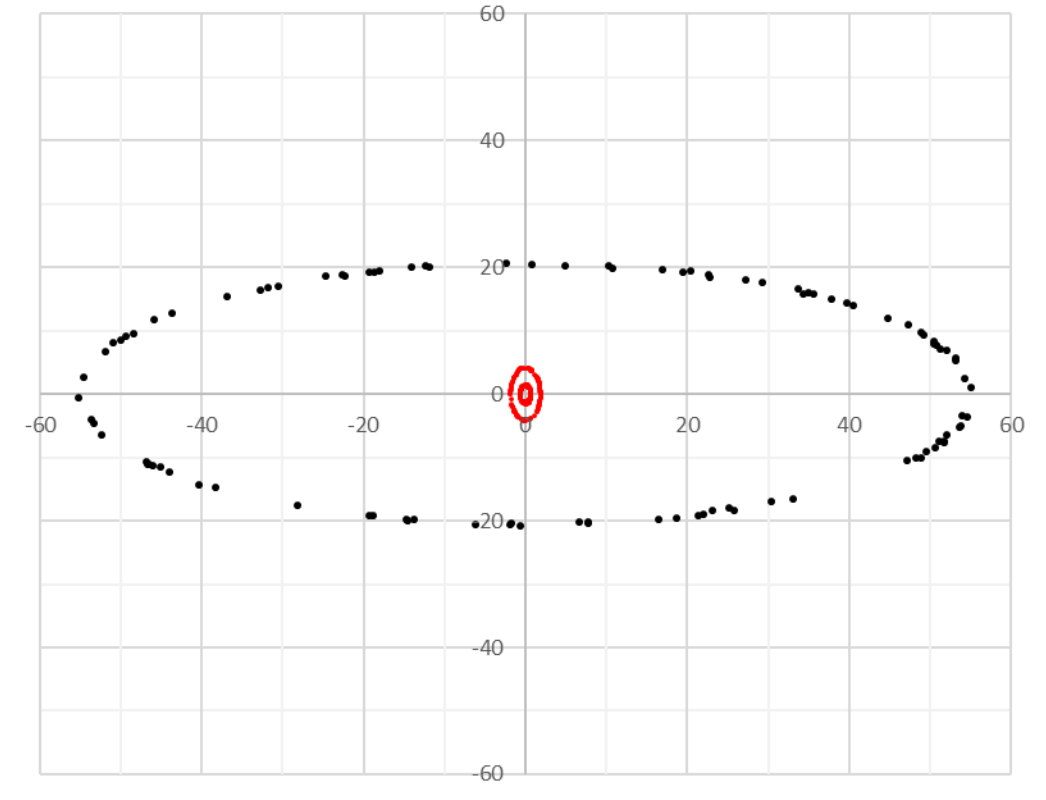
Q1 Downstream: Y3 vs X3
(e^+ theta_{CM} = 90deg)

• e^- , 90deg • 10sigma Mscatt cone

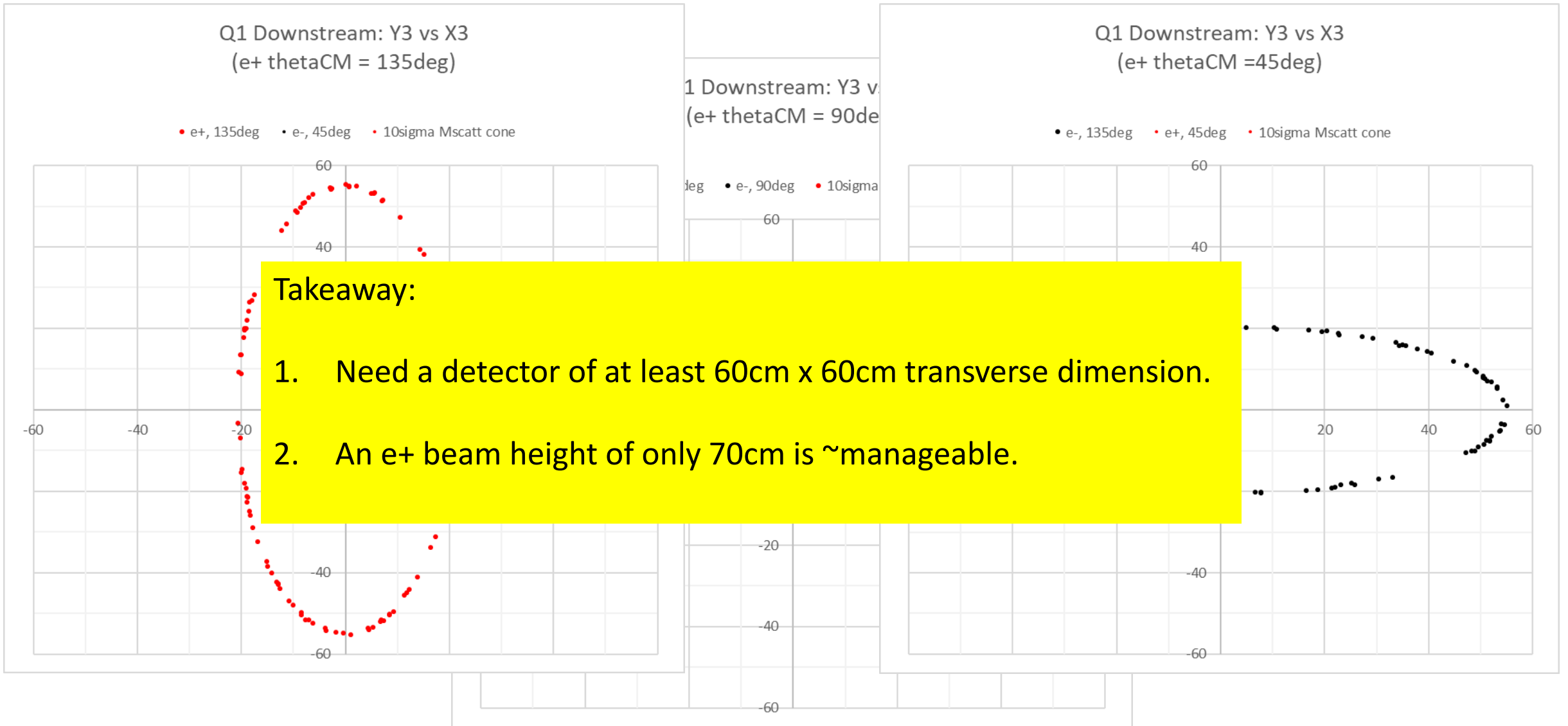


Q1 Downstream: Y3 vs X3
(e^+ theta_{CM} = 45deg)

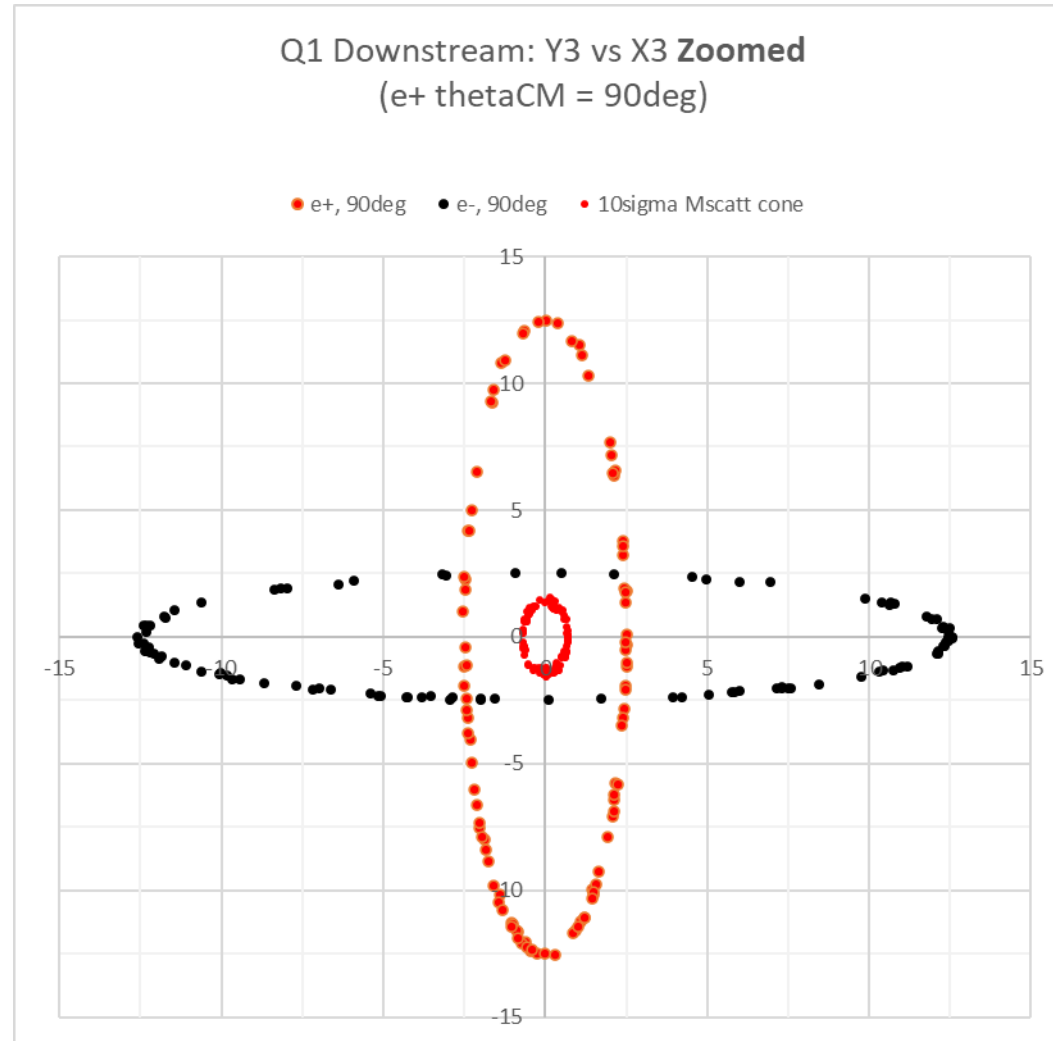
• e^- , 135deg • e^+ , 45deg • 10sigma Mscatt cone



Detector Plane Shape and Size (all on same scale)

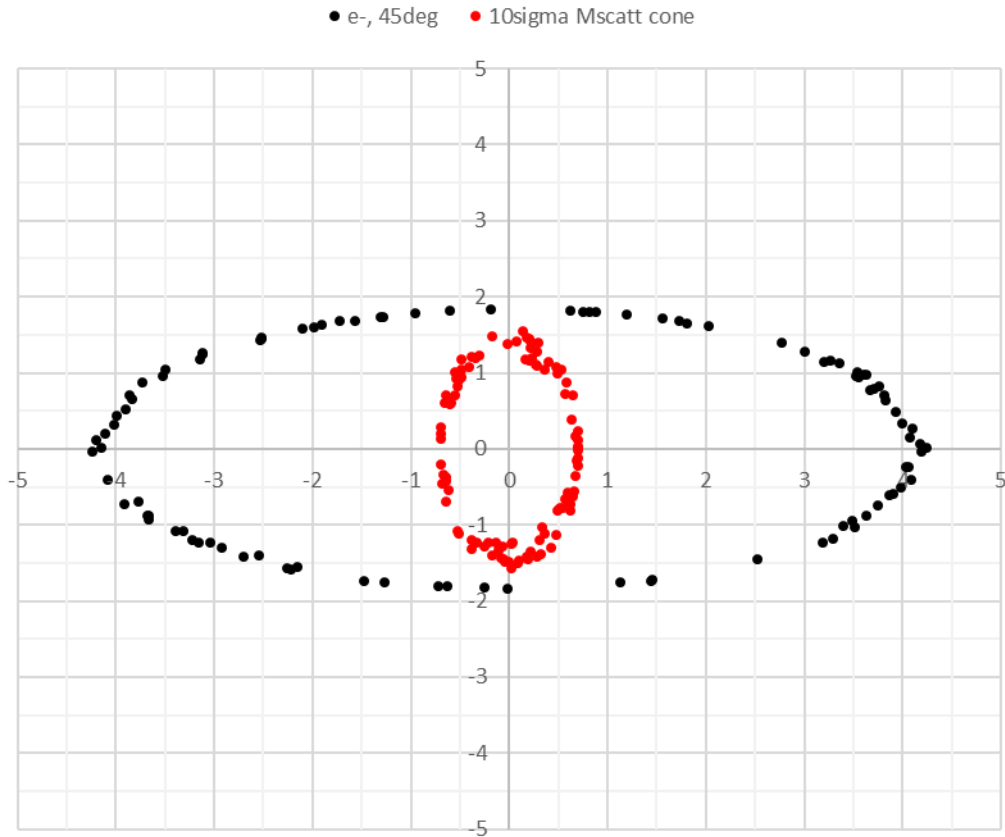


Detector Plane Shape and Size (zoomed to inner ellipse, not same scale)

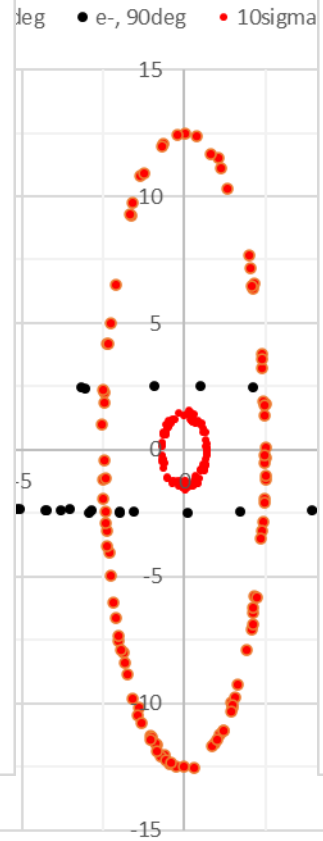


Detector Plane Shape and Size (zoomed to inner ellipse, not same scale)

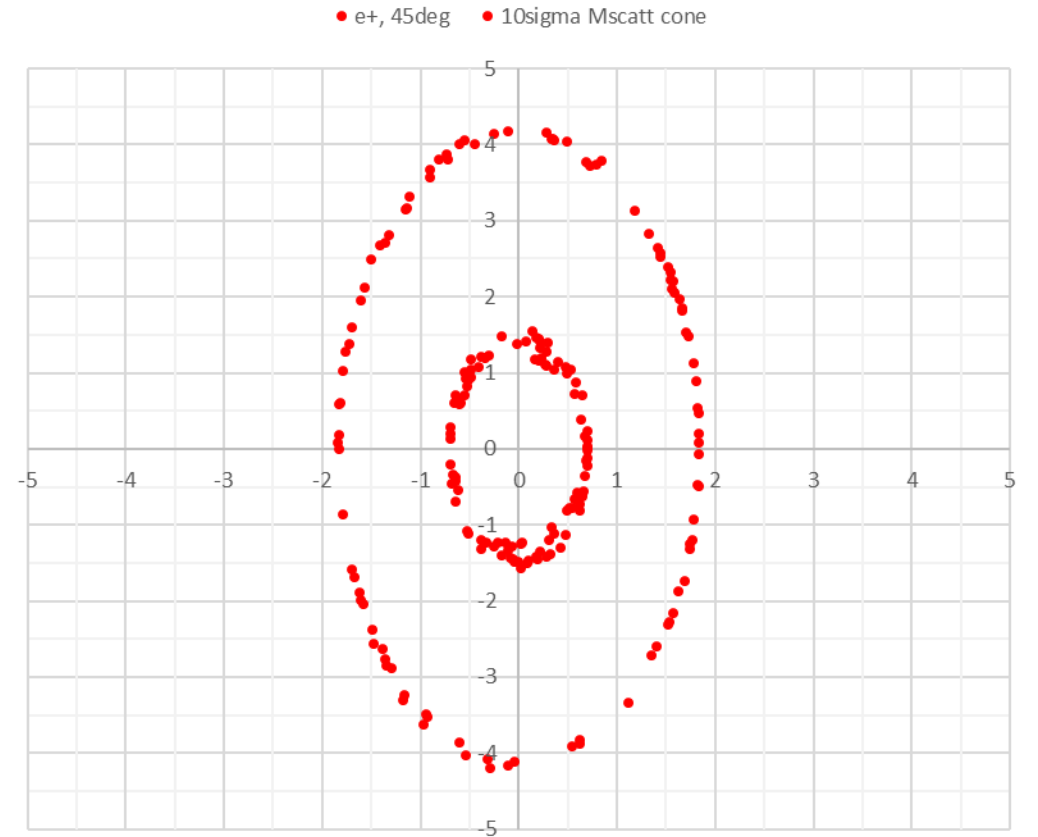
Q1 Downstream: Y3 vs X3 Zoomed
(e+ thetaCM = 135deg)



Q1 Downstream: Y3 vs X3
(e+ thetaCM = 90deg)



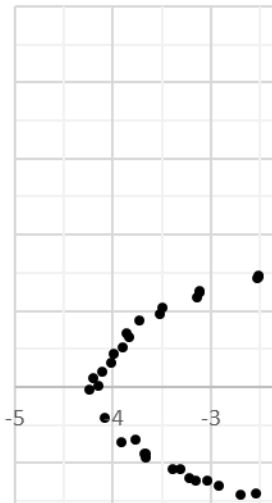
Q1 Downstream: Y3 vs X3 Zoomed
(e+ thetaCM = 45deg)



Detector Plane Shape and Size (zoomed to inner ellipse, not same scale)

Q1 Downstream: Y3 vs X3 Zoomed
(e+ thetaCM = 135deg)

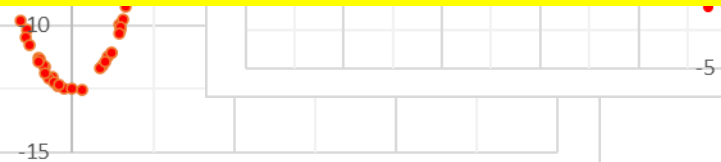
• e-, 45deg • 10sigma Mscatt cone



Q1 Downstream: Y3 vs X3 Zoomed
(e+ thetaCM = 45deg)

• e+, 45deg • 10sigma Mscatt cone

Q1 Downstream: Y3 vs X3
(e+ thetaCM = 90deg)



Takeaway:

For $\theta_{cm}^{e+} = 135^\circ$, the coincident e- are getting close to the beamline.

Given that 1 nA of e+ beam is only $6.3E9$ e+/second,
I expect the m-scattered rate in the active acceptance of the tracker to be low.

(But Mott scattering – which is e+ scattering from the Fe nuclei –
will dominate the rates by an order of magnitude.)

Detector Requirements

Must have:

- An unusually large momentum acceptance.
- The ability to distinguish whether a particle is e+ or e-.
- A high degree of azimuthal symmetry.
- Coincidence detection of e+e- over as large a CM angle range as possible
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Very nice to have:

- The ability to determine whether the e+e- is consistent with ISI, then correctly reconstruct θ_{CM} and ϕ_+ .
- Works for the Moeller scattering reaction.
- Doesn't block large scattering angles for A_{TU} measurements on nuclei (ie, the beam normal single spin asymmetry in Mott scattering).
- Doesn't block coincidence photons from e+e- \rightarrow 2gamma near the CM angle of 90°.

I won't know for sure without another half year of work, but most of the requirements for a LERF Bhabha program appear to be addressable with the simple quad design.

This one will be tough though:

Polarimetry Using Bhabha

A_{TT} to determine T beam polarization:

- It comes for free inside the acceptance.
- Undiluted analyzing power is ~ 0.12 . (dilution from Fe target is $\sim 2/26 = 0.077$)
- 1% statistics every 10 hours.

A_{LL} to determine L beam polarization:

- Requires a dedicated run tilting the Fe target.
- Undiluted analyzing power is ~ 0.78 .
- 1% statistics in less than 10 minutes.

Summary

- A positron beam facility at Jlab would enable a detailed study of transverse asymmetries in Bhabha scattering ($e^+ e^- \rightarrow e^+ e^-$), providing sensitivity to new e^+e^- interactions between the mass scales probed by positronium and e^+e^- colliders.
- I have outlined measurements near an e^+ beam energy of 110 MeV in LERF. This would be the first measurements of these transverse asymmetries. Although the helicity suppression is modest at this low e^+ beam energy, we will constrain various BSM physics at the mass scale of 3-10 MeV/c².
- An LOI will be submitted to this PAC. Let me know if you're interested, if you have a better idea for the detectors, or want to see if you can squeeze your 110 MeV idea onto the floor at the same time.
- The Bhabha transverse asymmetry program is extendable to 30-100 MeV/c² in Hall C by employing GeV-scale e^+ beams.

Acknowledgments

We would like to acknowledge members of the **Ce⁺BAF Working Group**, the **Jefferson Lab Positron Working Group**, the **DOE industry partner Xelera**, members of the **DOE US-Japan HEP Collaboration**, and collaborators at **Universities and National Labs** which contribute to the positron R&D effort.

T. Abe, Z. Alam, J. Benesch, A. Bogacz, M. Bruker, L. Cardman, J. Conway, S. Covrig, P. Degtiarenko, Y. Enomoto, A. Flanneri, S. Gessner, P. Ghoshal, S. Gopinath, J. Grames, J. Gubeli, C. Gulliford, S. Habet, G. Hays, C. Hernandez-Garcia, D. Higinbotham, R. Kazimi, M. Kohl, M. Kostin, V. Kostroun, F. Lin, V. Lizarraga-Rubio, D. Mack, K. Mahler, Y. Morikawa, S. Nagaitsev, E. Nanni, S. Ogur, N. Raut, B. Rimmer, Y. Roblin, A. Seryi, K. Smolenski, M. Spata, M. Stutzman, R. Suleiman, A. Sy, N. Taylor, D. Turner, A. Ushakov, C. Valerio-Lizarraga, E. Voutier, H. Wang, S. Wang, M. Yamamoto, S. Zhang, Y. Zhang, V. Ziemann



I routinely communicate about e⁺ matters with a dozen of these people.
They're a great bunch!



Additional Thanks To:

W&M (with a shout out to Professor Justin Stevens, as well as to their IT department)

CNU (with a shout out to Professor William Phelps, as well as to the opulent-yet-scholarly Tribble library)

Marc Vanderhaegen and his group (with a shout out to Cornelis Mommers, my cafeteria lunch partner from QNP2024, for enthusiastically carrying the positron virus to Mainz)

Bogdan Wojtsekhowski, who has quietly encouraged the physics potential of polarized positrons.

extras

Straw Man LOI for 5 MeV e^+ Beam

e^+ beam properties:

L polarized beam only, since getting T polarization is extremely impractical at this energy
KE = 5 MeV (give or take a factor of 2), implying an e^- driver beam of higher energy

Target:

magnetized Fe foil 1 micron thick, tiltable

The nuclear experimentalists would

- i. build the target and its reversal schemes,
- ii. design a magnetic spectrometer, and even the spectrometer magnets if they are small enough,
- iii. provide the focal plane detectors,
- iv. provide a data acquisition,
- v. provide a Faraday cup and readout

Goals:

- Do what physics we can with Bhabha scattering: the first ever measurements of the helicity suppressed transverse asymmetries A_{LT} (physics case TBD) and A_{UT} (lots of dilution)
- Characterize the L beam polarization via A_{LL} .
- Characterize the e^+ beam intensity

Afterward

We have to crawl before we can walk.

The PC transverse asymmetry experiments in Hall C, with precision at the ppm level, will require somewhat different apparatus and skills than the current PV longitudinal asymmetry measurements with precision at the ppb level.

(Q-weak was successful, but it was a 3rd generation PV experiment and we still made some bad-but-recoverable mistakes.)

LERF experiments would allow:

- Great positron science early
- Help out with e⁺ source characterization (polarimetry, current)
- Develop an early version of the transverse Fe target (which will need to be much more ϕ -agile in Hall C)
- Time for the theory community to help with BSM sensitivity estimates, higher order QED backgrounds, and provide guidance
- Train the workforce needed to measure PC transverse asymmetries with ppm level precision

I'm a fan of a modest LERF program as a stepping stone to much more difficult, multi-year end-station experiments.

Summary of Bhabha Physics Measurements at 110 MeV

Highlighting the target and possibly overlapping beam time estimates.

Transverse Asymmetry	Proportional to These Helicity Amplitudes	ϕ Dependence	Target	BSM Sensitivity	Beam Time
A_{TT}'	$-2\text{Re}(F_{RR}F_{LL}^*)$	$\cos(\phi_m - \phi_p)$	Fe	Spin 0	?? hours with T beam
A_{TT}	$-2\text{Re}(F_{LR}F_{RL}^*)$	$\cos(\phi_m + \phi_p - 2\phi)$	Fe	Spin 2 (big SM background, but there is small fwd-backward asymmetry)	In parallel with above beamtime
A_{LT}	$-2\text{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*)$	$\cos(\phi_m - \phi)$	Fe	BSM sources of unsuppressed single helicity flip (such as dipole operators)	?? Hours with L beam
A_{TU}	$-2\text{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL})$	$\sin(\phi_p - \phi)$	Be	Spin 0 (scalars only), Spin 1	I'm not even close to an estimate. Imaginary amplitudes, so not business as usual: Benefits from Initial State Radiation reconstruction, possibly several beam energies

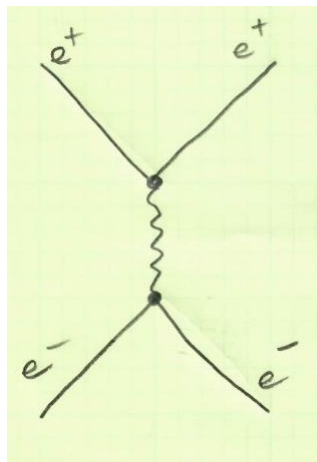
A_{TT}' Calculation in the SM

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

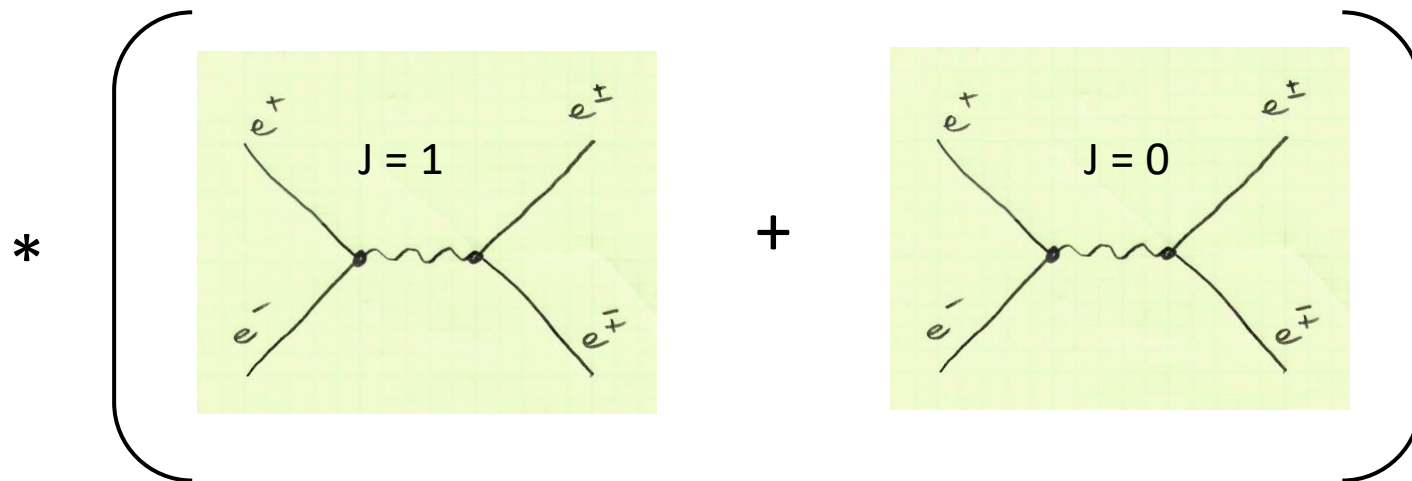
$$"F_{RR}F_{LL}" = F_{RR}^{LR}F_{LL}^{LR} + F_{RR}^{RL}F_{LL}^{RL} + F_{RR}^{LL}F_{LL}^{LL} + F_{RR}^{RR}F_{LL}^{RR}$$

Due to sign cancellations in $F_{RR}^{LR}F_{LL}^{LR} + F_{RR}^{RL}F_{LL}^{RL}$, the dominant SM contribution is from $F_{RR}^{LL}F_{LL}^{LL} + F_{RR}^{RR}F_{LL}^{RR}$.

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



t-channel
(unsuppressed for
 F_{LL}^{LL} and F_{RR}^{RR})

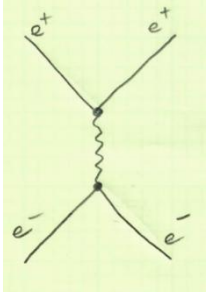


SM s-channel
(suppressed by $1/\gamma^2$ for
 F_{LL}^{RR} and F_{RR}^{LL})

BSM s-channel
(unsuppressed for
 F_{LL}^{RR} and F_{RR}^{LL})

This is pretty much the optimal scenario for searching for BSM scalars using a precision measurement of a PC asymmetry!!!

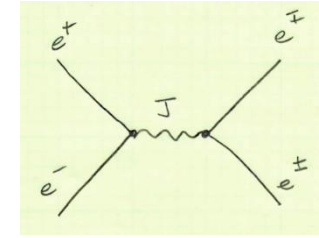
Bhabha t- and s-channel Helicity Amplitudes



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

Unsuppressed scatterings are diagonal (in red).

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



In the s-channel, only scatterings consistent with the exchange of a spin = 1 gamma or Z are allowed, with violations proportional to $1/\gamma = 2m_e/E_{cm}$.

Unsuppressed scatterings link only RL and LR (in red)

		Final e+e- helicity			
		LR	RL	LL	RR
Initial e+e- helicity	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	$\sim 1/\gamma$	$\sim 1/\gamma$	$\sim 1/\gamma^2$	$\sim 1/\gamma^2$

BSM scalar contributions would not be suppressed here.

Is there an observable we can exploit to search for them?

Helicity Amplitudes in Bhabha Scattering (PC only)

$$\begin{aligned}
 4|M|^2 = & \quad + |F_{LR}|^2 + |F_{RL}|^2 + |F_{LL}|^2 + |F_{RR}|^2 \\
 & + P_{e^-}^L (+ |F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 - |F_{LL}|^2) \\
 & + P_{e^+}^L (- |F_{RL}|^2 + |F_{RR}|^2 + |F_{LR}|^2 - |F_{LL}|^2) \\
 & + P_{e^-}^L P_{e^+}^L (- |F_{RL}|^2 + |F_{RR}|^2 - |F_{LR}|^2 + |F_{LL}|^2) \\
 & + P_{e^-}^T (+ 2\text{Re}(F_{RL}F_{LL}^* + F_{RR}F_{LR}^*) \cos(\phi_m - \phi) \\
 & \quad - 2\text{Im}(F_{RL}^*F_{LL} - F_{RR}^*F_{LR}) \sin(\phi_m - \phi)) \\
 & + P_{e^+}^T (- 2\text{Re}(F_{LR}F_{LL}^* + F_{RR}F_{RL}^*) \cos(\phi_p - \phi) \\
 & \quad - 2\text{Im}(F_{LR}^*F_{LL} - F_{RR}^*F_{RL}) \sin(\phi_p - \phi)) \\
 & + P_{e^-}^T P_{e^+}^T (- 2\text{Re}(F_{RR}F_{LL}^*) \cos(\phi_m - \phi_p) \\
 & \quad - 2\text{Im}(F_{RR}^*F_{LL}) \sin(\phi_m - \phi_p) \\
 & \quad - 2\text{Re}(F_{LR}F_{RL}^*) \cos(\phi_m + \phi_p - 2\phi) \\
 & \quad + 2\text{Im}(F_{LR}^*F_{RL}) \sin(\phi_m + \phi_p - 2\phi)) \\
 & + P_{e^+}^L P_{e^-}^T (- 2\text{Re}(+F_{RL}F_{LL}^* - F_{RR}F_{LR}^*) \cos(\phi_m - \phi) \\
 & \quad + 2\text{Im}(F_{RL}^*F_{LL} + F_{RR}^*F_{LR}) \sin(\phi_m - \phi)) \\
 & + P_{e^+}^T P_{e^-}^L (+ 2\text{Re}(F_{LR}F_{LL}^* - F_{RR}F_{RL}^*) \cos(\phi_p - \phi) \\
 & \quad + 2\text{Im}(F_{LR}^*F_{LL} + F_{RR}^*F_{RL}) \sin(\phi_p - \phi))
 \end{aligned}$$

Unpolarized xsect

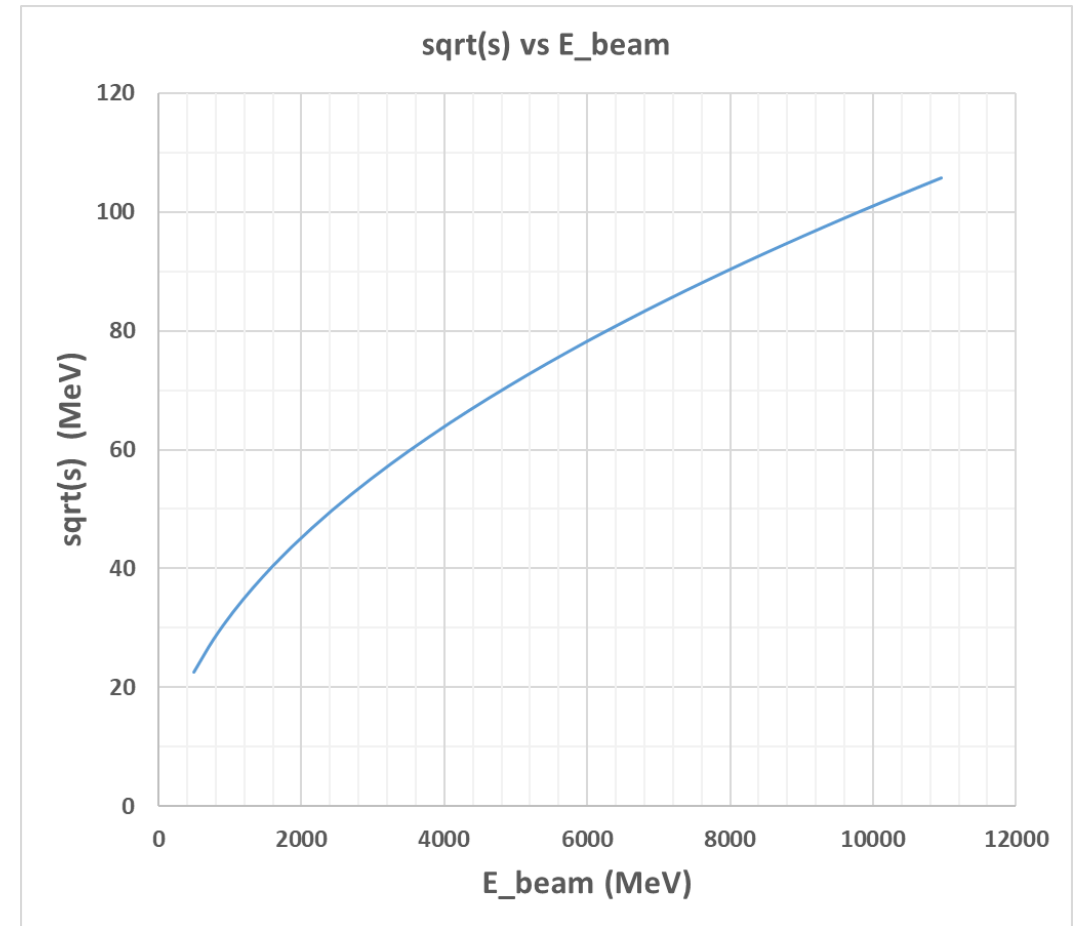
Longitudinal polarization only

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

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

At a 12 GeV CEBAF, the CM energy range will be $\sim 20\text{-}105 \text{ MeV}/c^2$.

$$\begin{aligned} E_{\text{cm}} &= \sqrt{s} \\ &= \sqrt{2m_e^2 + 2E_{\text{beam}}m_e} \\ &\sim \sqrt{2E_{\text{beam}}m_e} \end{aligned}$$



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

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

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

A_{TT} and $A_{\text{TT}'}$

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

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

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



The relatively large A_{TT} signal oscillates like $\cos(2\phi)$.

A_{TT} and $A_{\text{TT}'}$

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



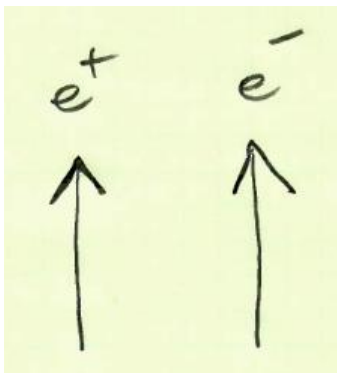
The much, much smaller $A_{\text{TT}'}$ signal is a monopole, ie, independent of the ϕ_{e^+} .

A_{TT} and $A_{\text{TT}'}$

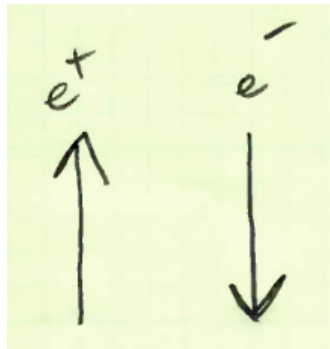
$$\text{Yield}_{\text{TT}}(\theta, \phi) \sim A_{\text{TT}'} \cos(\phi_p) + A_{\text{TT}} \cos(\phi_p - 2\phi)$$

$A_{\text{TT}'}$ 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.

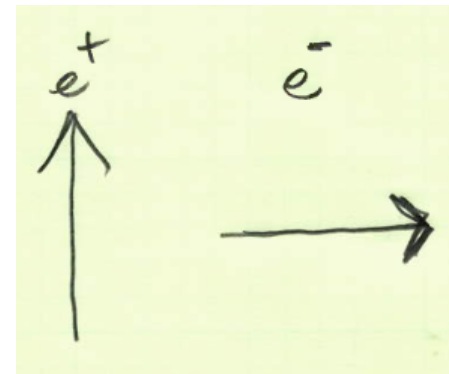
This signal reverses when ϕ_m or ϕ_p is reversed. (below)



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



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



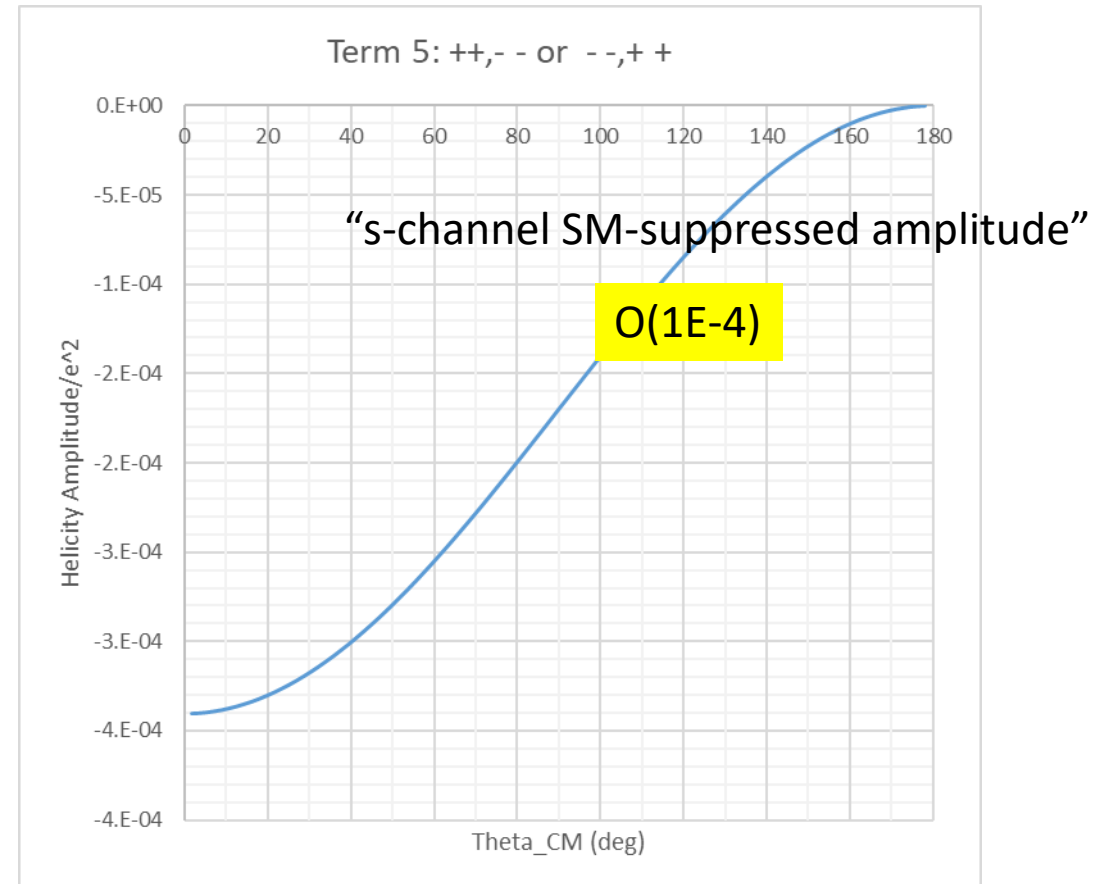
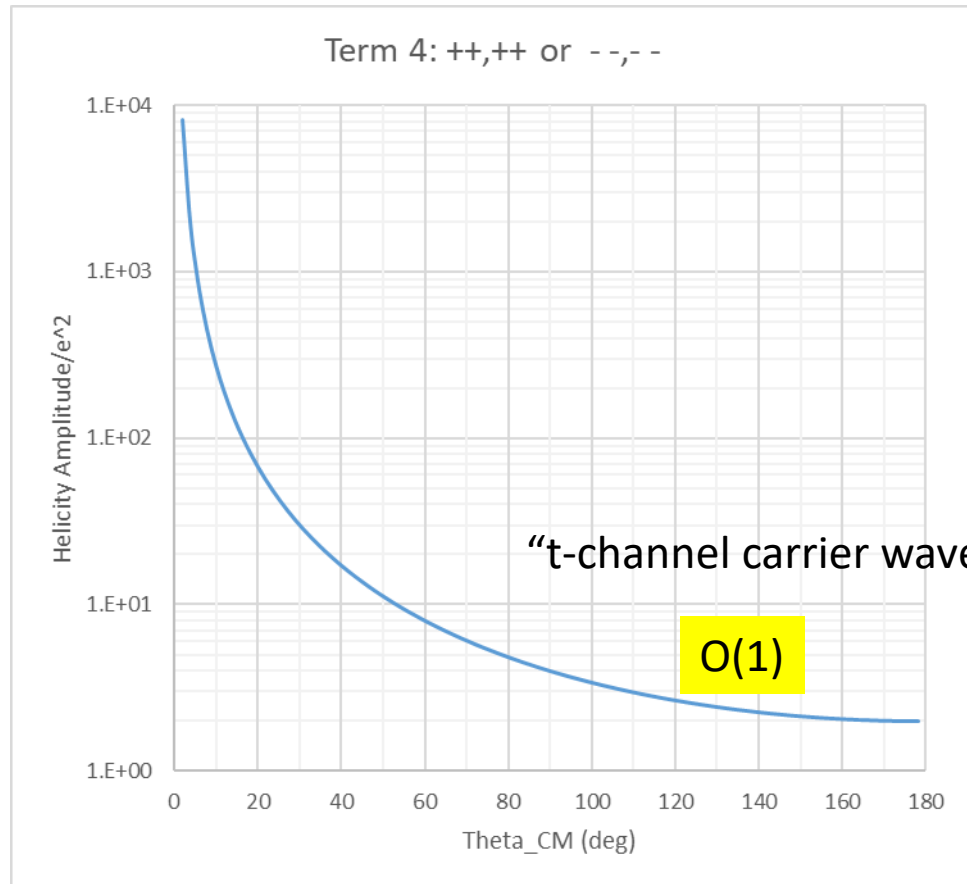
$$\cos(\phi_m - \phi_p) = 0$$

Magnitudes of Terms 4 and 5 at Backward Angles

A_{TT}' is proportional to the product Term4*Term5.

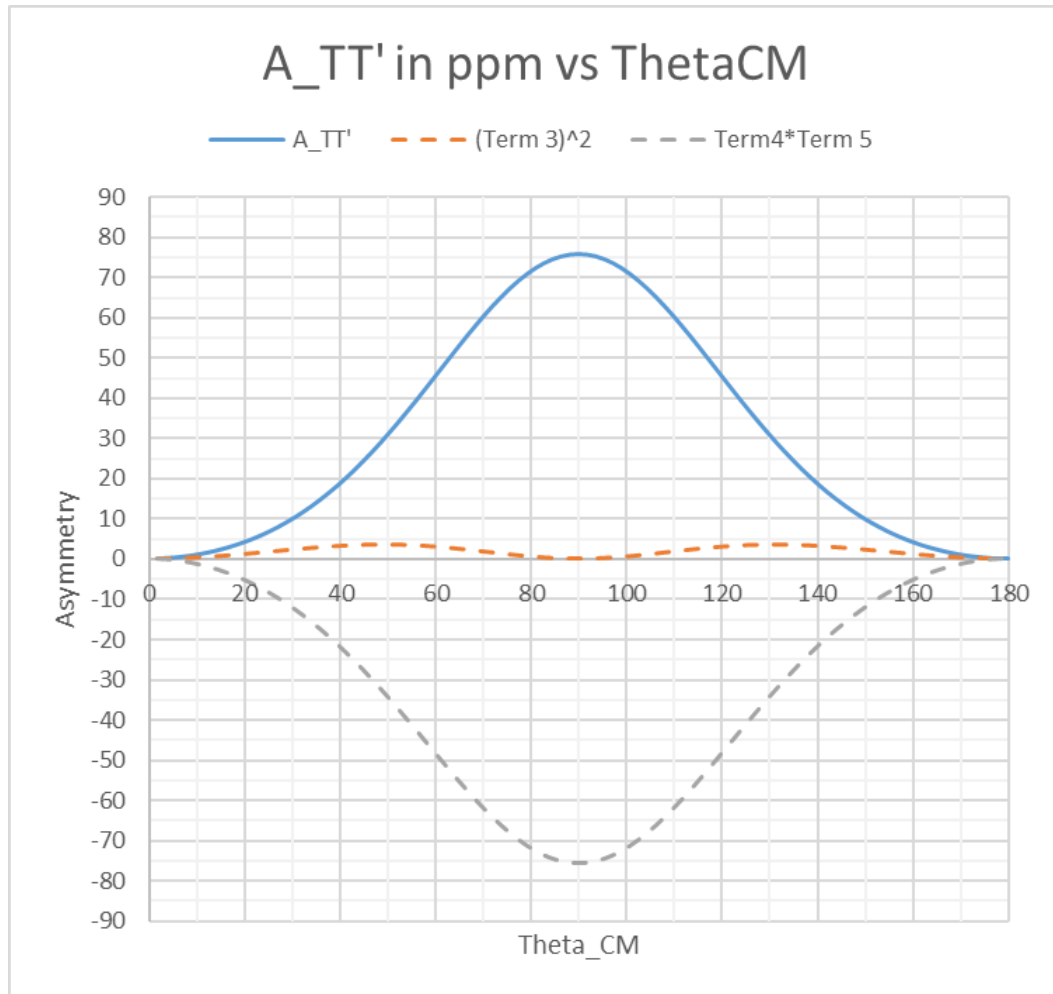
Term 5 is highly helicity suppressed if $J = 1$ particles like photons are exchanged.

Term 5 is not helicity suppressed when $J = 0$ particles are exchanged.



A_{TT}' Result in the SM

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



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

There is no zero crossing.

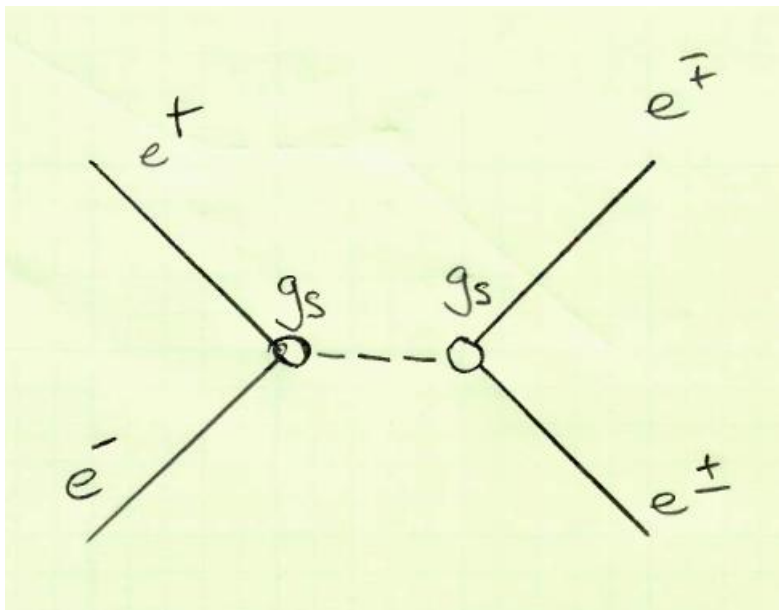
(For what it's worth, I note that $1/\gamma^2$ is 167 ppm.)

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

Adding a BSM Scalar to A_{TT}'

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

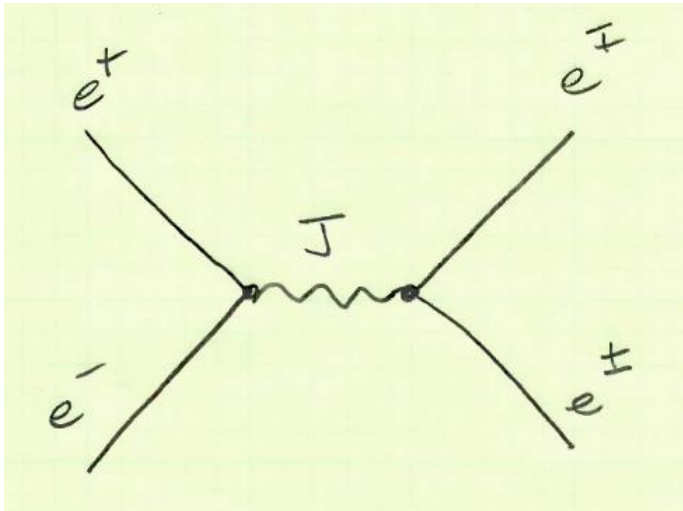
$A_{TT}' \sim F_{RR}^{LL}F_{LL}^{LL} + F_{RR}^{RR}F_{LL}^{RR}$ would be approximately

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

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

s-channel Constraints on Exchanged J

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



$J_z = -+1$
(SM vectors)

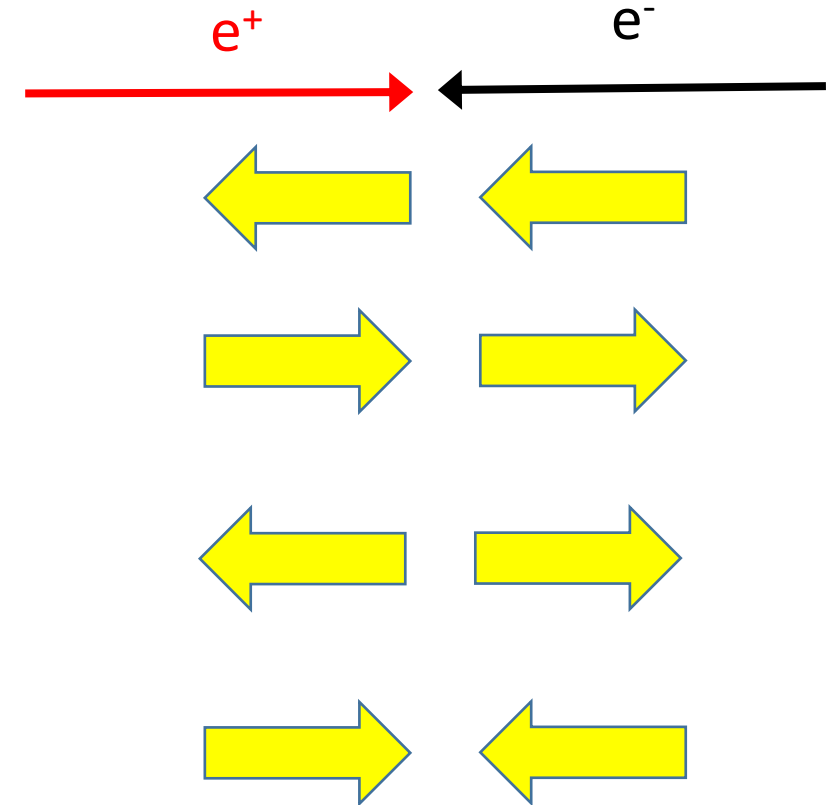
$J_z = 0$
(SM Higgs,
BSM scalars)

LR

RL

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

Transversely Polarized e⁺ Beam on Transversely Polarized e⁻Target*

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

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.


*Credit to:
“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>

Transversely Polarized e^+ Beam on Transversely Polarized e^- Target

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

The two PC asymmetries implied above are:

\mathbf{A}_{TT} : The term $\text{Re}(F_{\text{LR}}F_{\text{RL}}^*)\cos(\phi_m + \phi_p - 2\phi)$ has no helicity suppression, hence the asymmetry is relatively large. We will use it as a SM candle to tell us the product of polarizations $\mathbf{P}_{e^-}^T \mathbf{P}_{e^+}^T$.

 \mathbf{A}'_{TT} : The term $\text{Re}(F_{\text{RR}}F_{\text{LL}}^*)\cos(\phi_m - \phi_p)$ is doubly helicity suppressed.

How big is \mathbf{A}'_{TT} , and how sensitive is it to a BSM scalar?