TCS and DDVCS event generator
New public version

1) Notations and principle
2) User's parameters: input and output files
3) Tests on TCS generation
4) Tests on DDVCS generation
5) Where to find a public version, status

Marie Boër, June 29, 2017, JLab ee meeting.

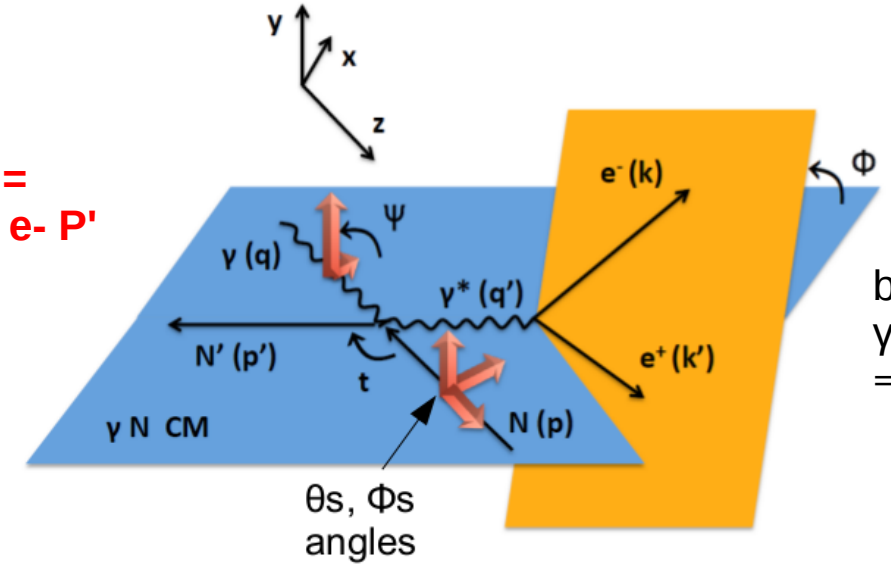
Notations for Bethe-Heitler + TCS reaction

• 5 independent variables for unpolarized cross section.
Choice for the generator: Q'^2, t, Eγ, φ, θ

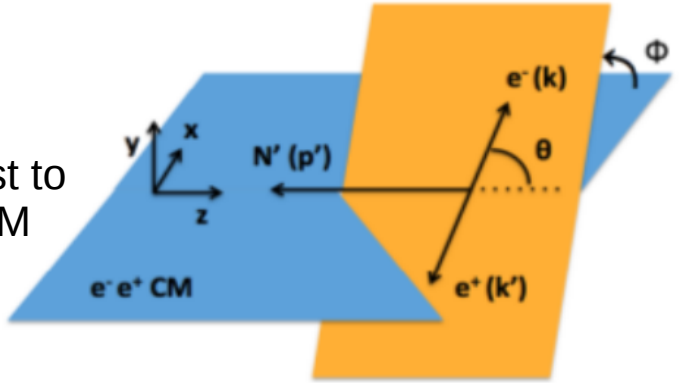
• Linearly polarized beam: also depend on Ψ_s,Θ_s (photon polarization angle vs lab. axis. $\Theta_s = 90°$)

• Polarized target: depend on φ_s, θ_s (target polarization angle vs lab. axis)
longitudinal: (θ_s=0°), along x: (φ_s=0° θ_s=90°), along y: (φ_s=90°, θ_s=90°). Any transverse direction possible.

BH+TCS =
γ P → e+ e- P'



boost to
γ* CM
⇒



Ψ: (reaction plane, γ spin)
φ: (hadronic plane, e^+e^- pair)
θ: (γ*, e^-)
θs, Φs: (target spin vector orientation)

• Electron beam induced TCS (quasi-real photon) ⇒ see scheme for DDVCS
additional angles are: φ_{beam}, θ_{beam}, θ_γ

Polarization angles for TCS and polarized cross sections

New in this version of the generator

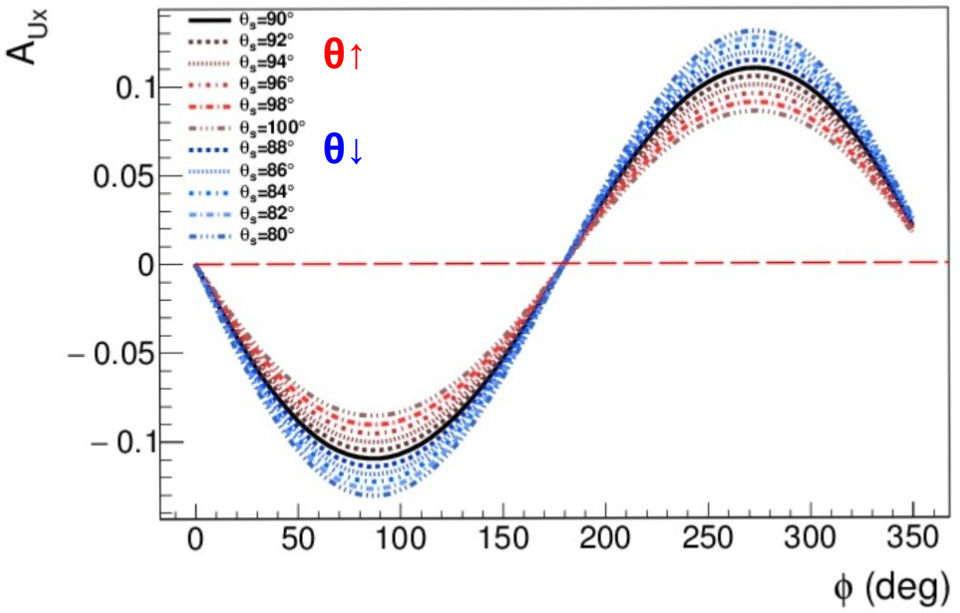
- polarized cross section: random spin direction for beam and target
- dilution factor: fixed for the target, fixed in case of linearly polarized beam (plan to calculate for next version), energy dependent for circularly polarized beam
- asymmetry at the given event kinematic for phase-space scan
- any target spin direction is possible

Beam:
circularly polarized or linearly polarized

Target:
linearly polarized →correction for $\theta_s \neq 0°$ in version 3.0, not in 3.1 (% level)
transversely polarized →corrections for $\theta_s \neq 90°$ in version 3.0, not in 3.1 (% level)

Asym vs Φ, here: $\Phi_s = 0°$, different θ_s integrated over θ [45°, 135°].

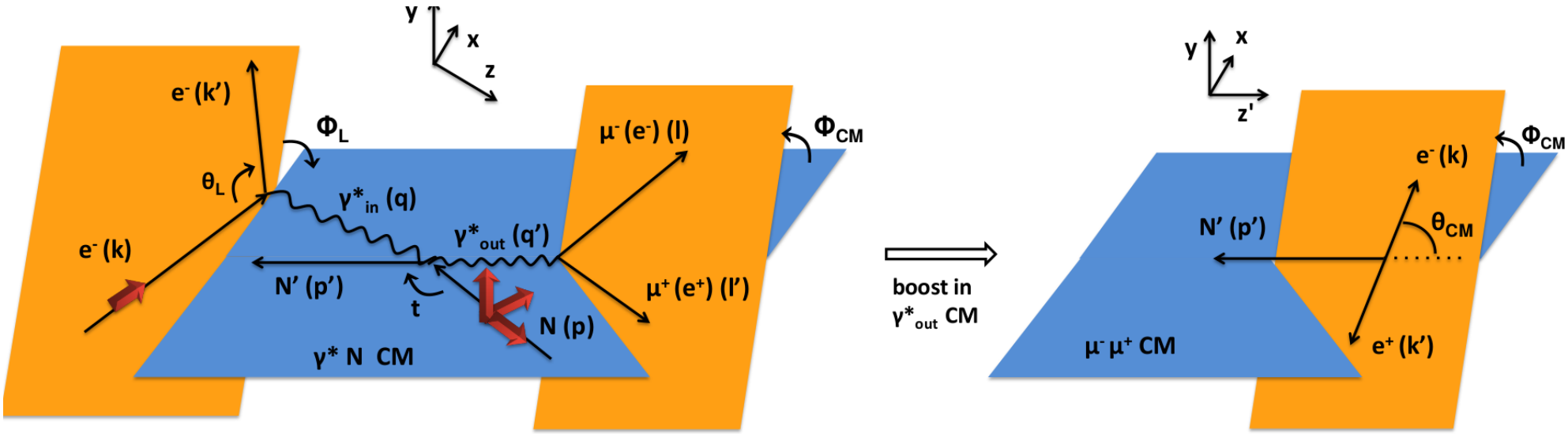
~1% or less deviation expected for θs=1°



Notations for Bethe-Heitler + DDVCS reaction

BH+DDVCS = e P → e' μ+ μ- P'

• 7 independent variables for unpolarized cross section.
Choice for the generator: Q^2, Q'^2, t, x_{bj}, φ_L, φ_{CM}, θ_{CM}



With the generator:
unpolarized cross section, beam polarized cross section, asymmetry.

Notation of the angles in generator files:
φ_{CM}= Phi_CMV
θ_{CM} = Theta_CMV
φ_L = Phi_LH
φ_{beam}, θ_{beam} = theta_beam, phi_beam

Principle

1) User input file: TCS or DDVCS

2) Random generation of kinematics (linear in all dimensions), calculations of 4-vectors...

3) Event weighting by cross sections:

- unpolarized cross sections for BH+TCS or BH+DDVCS, "only BH", "only TCS or DDVCS" (can be switch on/off)

- polarized cross sections with dilution factor, beam and/or target

- asymmetries beam and/or target

- for TCS with quasi-real photon: equivalent flux

- version 3.0: calculations done for each event. Precise but slow. No checks of edge of phase space → cuts on acceptance maybe needed

corrections for $\theta s \neq 0°$ or 90° included for polarized targets

- version 3.1: grid of cross sections with linear interpolation/extrapolations. % level accuracy vs "direct calculations". Faster, checks of edges of phase space. No θs corrections.

4) Output file: ROOT TTree

Input files

TCS

Variable name	usage	limits (grid)	default value
Experimental configuration	Beam and target parameters		
Beam type	real photon (0) initial electron (1)	0 or 1	0 or 1
Beam energy (if electron beam)	used to calculate the photon flux	$[\sim 6, 12]$ GeV	11
Luminosity	used for normalization	-	10^{35} cm^{-2}
out leptons	electron (1) or muon (2)	1 or 2	2
Target lenght	luminosity	-	15 cm
Target composition (A,Z)	luminosity	single atoms	(1,1) or 1001
	only LH2 in v3.0, other targets in v3.1		
Target = p (1) or n (2)	weight	1, 2	1
	Polarization options		
Beam polarization dilution factor	polarized cross sections	$[0, 1]$	0.8
Beam pol. vector direction	case linearly polarized	1 (x-axis), 2 (y-axis) or 3 (45°)	1
Target polarization direction	polarized targets	0 (unpolarized), 1 (x-axis), 2 (y-axis), 3 (z-axis)	3
Target dilution factor	polarized targets	0 to 1	0.7
Kinematics	Kinematic range		
Photon energy	photon	$[4.5, 11.5]$	$[5, 10.5]$
-t	Mandelstam variable	xx	$[.05, .7]$
Q'^2	final photon virtuality	xx	$[.09, .3]$
θ_{CM}	azimuthal angle of decay leptons	$[40°, 140°]$	$[40°, 140°]$
Q^2_{max}	quasi-real photons maximal virtuality	0 to ~ 0.5	0.3

DDVCS

Variable name	usage	limits (grid)	default value
Experimental configuration	Beam and target parameters		
out leptons	electron (1) or muon (2)	1 or 2	2
Target lenght	luminosity	-	15 cm
Target composition (A,Z)	luminosity	single atoms	(1,1)
Target = p (1) or n (2)	weight	1, 2	1
Beam polarization dilution factor	polarized cross sections	$[0, 1]$	0.8
Kinematics	Kinematic range		
-t	Mandelstam variable	xx	$[.05, .7]$
x_{bj}	Bjorken variable	xx	$[.09, .3]$
Q^2	initial photon virtuality	xx	$[1, 7]$
Q'^2	final photon virtuality	xx	$[.09, .3]$
θ_{CM}	azimuthal angle of decay leptons	$[40°, 140°]$	$[40°, 140°]$
Misc. options	Switch on/off weighting options		
Process	BH only unpol. (1), BH+DDVCS but not unpol. BH or DDVCS (2), BH+DDVCS and BH and DDVCS unpol. (3)	-	3

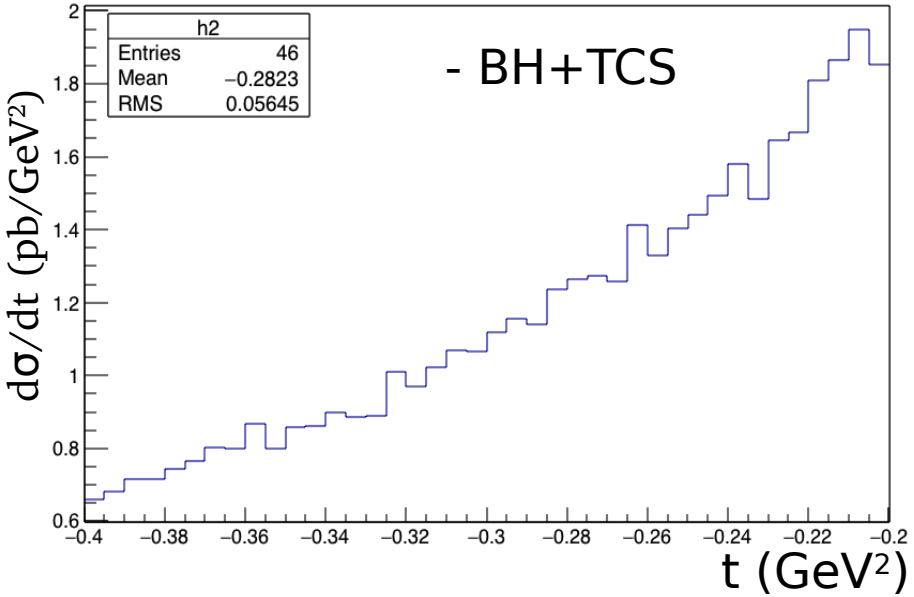
Output files

- TCS_Tree: if TCS is generated
- DDVCS_Tree: if DDVCS is generated
- Debug_Tree: 500 first events, contains 4-vectors in various frames

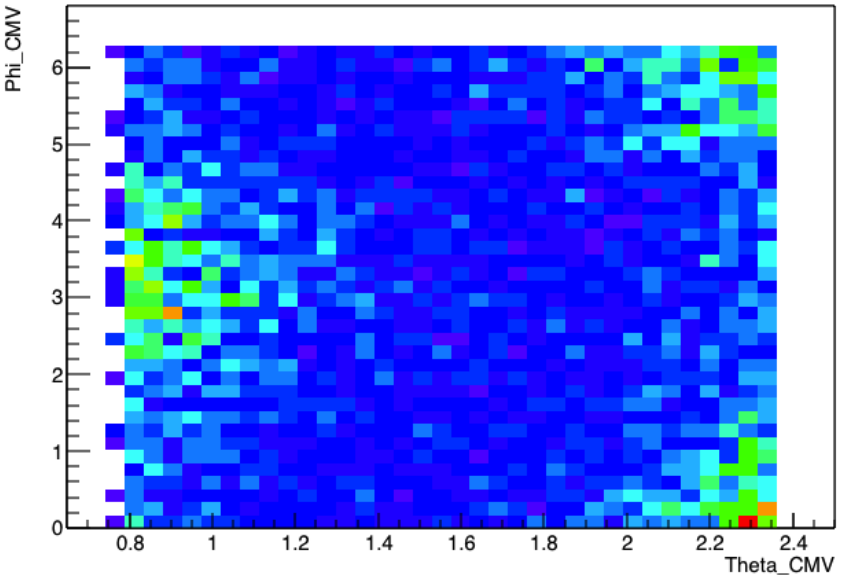
Basic contain

- 4-vectors in lab frame for incoming and outgoing particles
- invariants and other kinematic variables
- polarization vectors and spin directions
- event weights (polarized, unpolarized, asymmetries).
- For TCS with quasi-real beam: "real photon" cross sections + actual cross sections including photon flux factor. Flux factor provided and additional angles.
- event number...

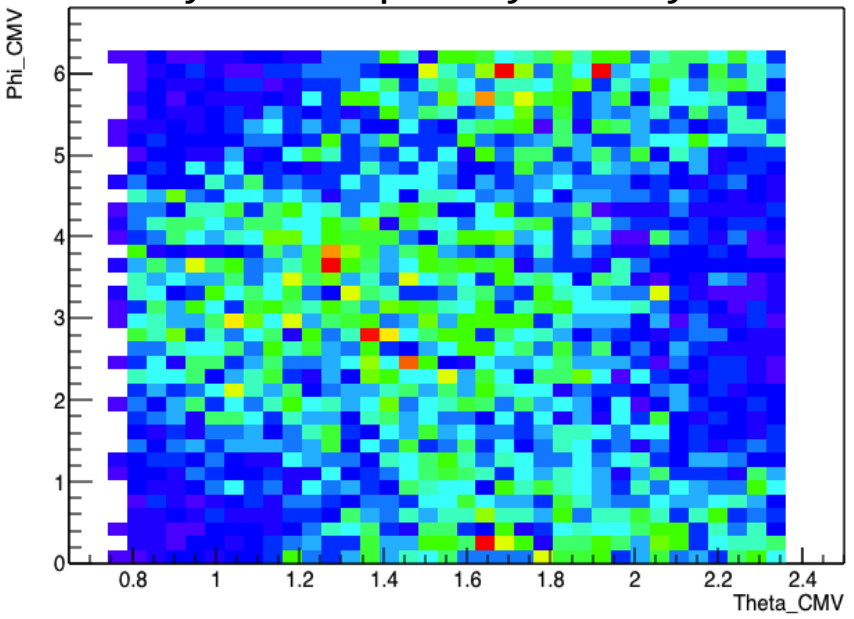
Tests on TCS: kinematics



Weighted φ vs θ
by unpol. cross section



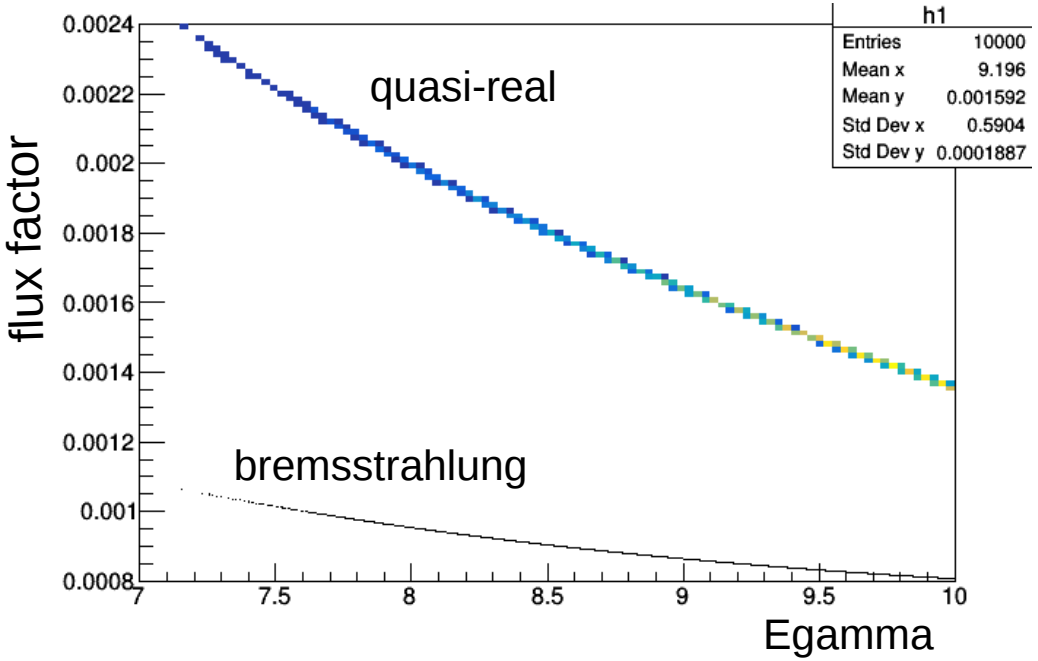
by beam spin asymmetry



⇒ all distributions follow expectations.
⇒ more checks and figures on my wiki page or on demand

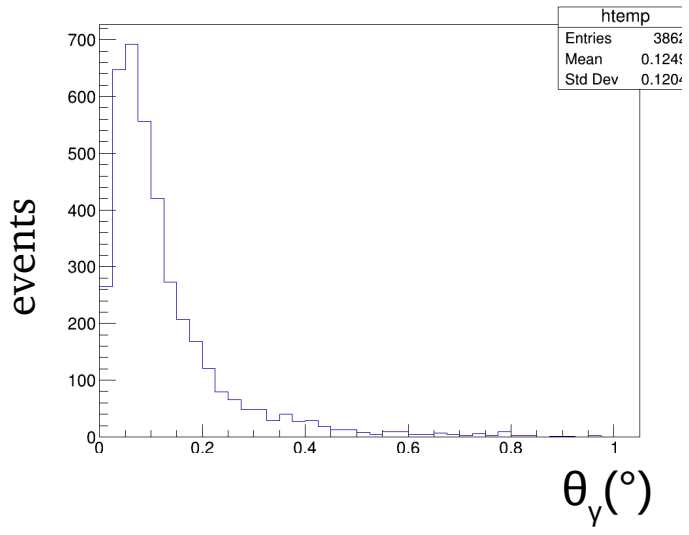
Tests on TCS: quasi-real

Photons Flux factor

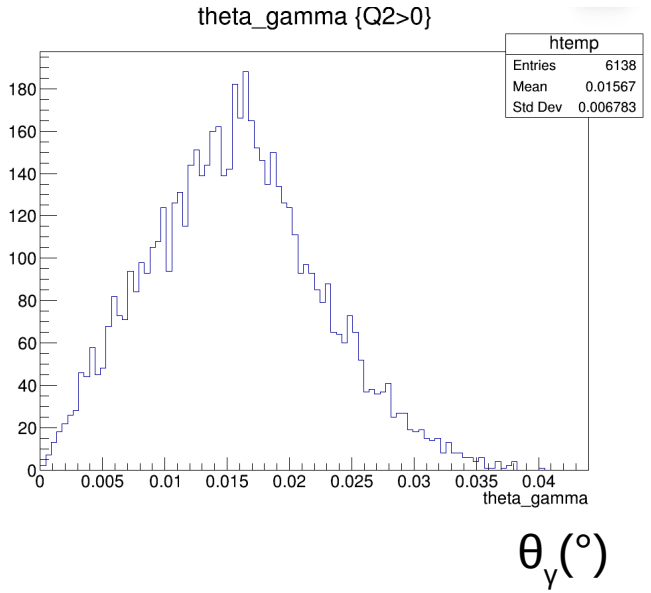


Polar angle distributions

real photon (from sampling method egs5) (needs validation)

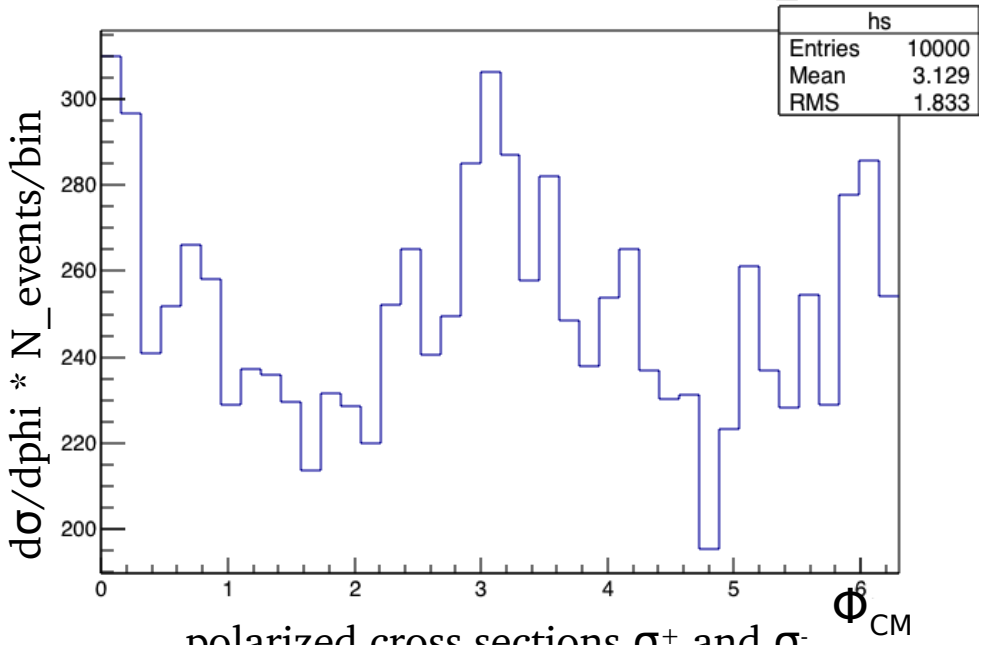


quasi-real gamma distrib

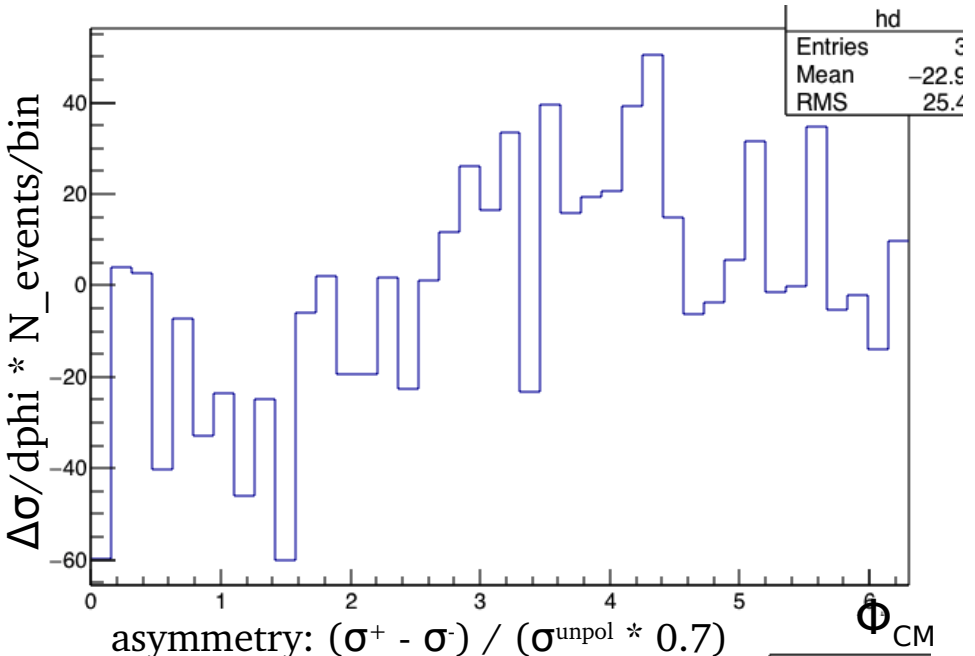


Tests on TCS: get generated target spin asymmetry (//) from polarized cross sections

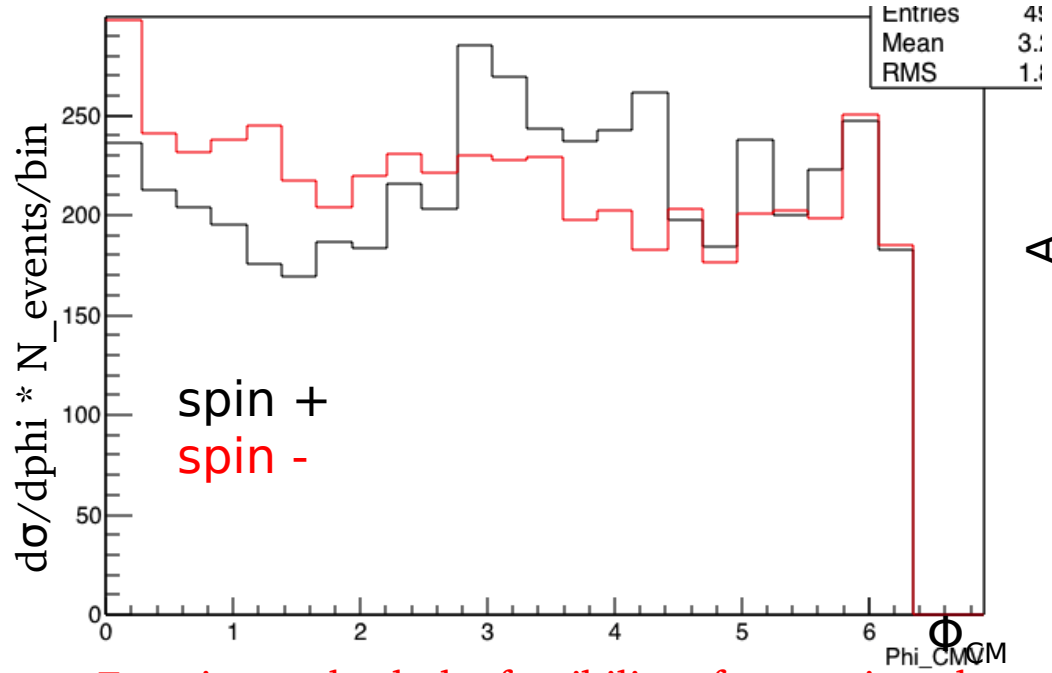
unpolarized cross section vs phi_CM



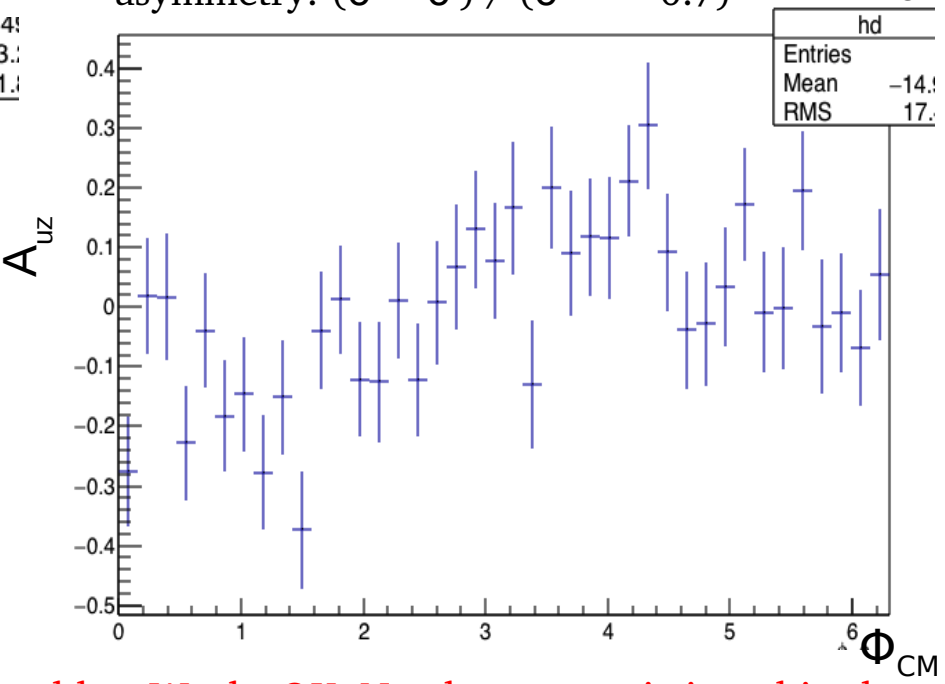
cross section difference ($\sigma^+ - \sigma^-$) vs phi_CM



polarized cross sections σ^+ and σ^-



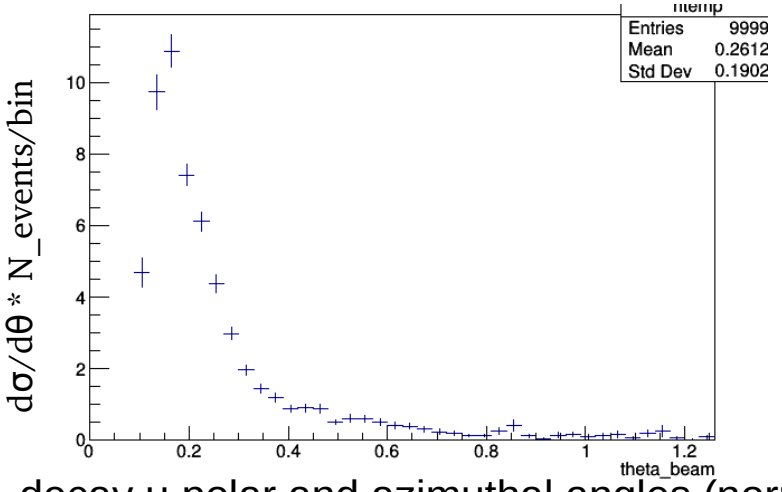
asymmetry: $(\sigma^+ - \sigma^-) / (\sigma^{unpol} * 0.7)$

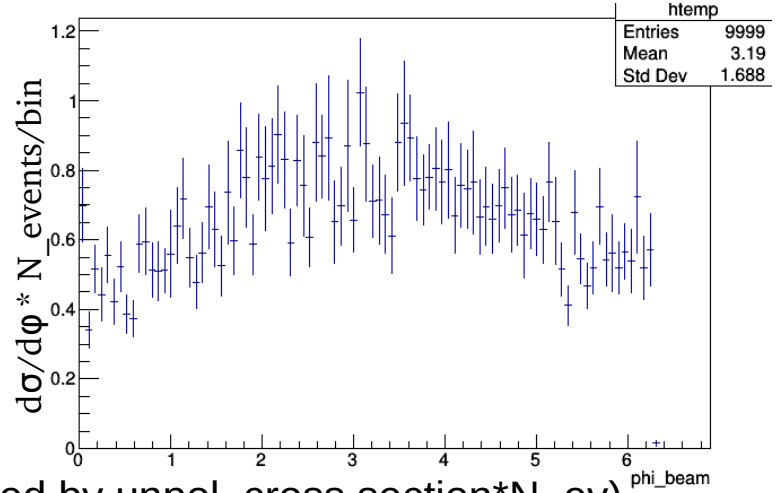


⇒ Exercise to check the feasibility of extracting observables. Works OK. Need more statistic to bin the sample and compare to the generated actual asymmetries.

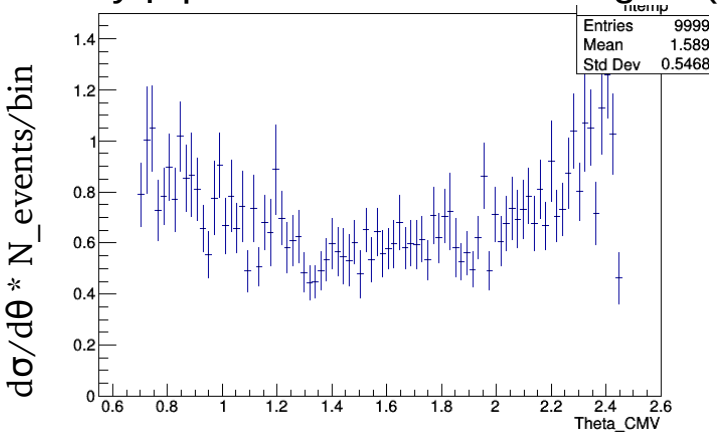
Tests for DDVCS: Angular distributions

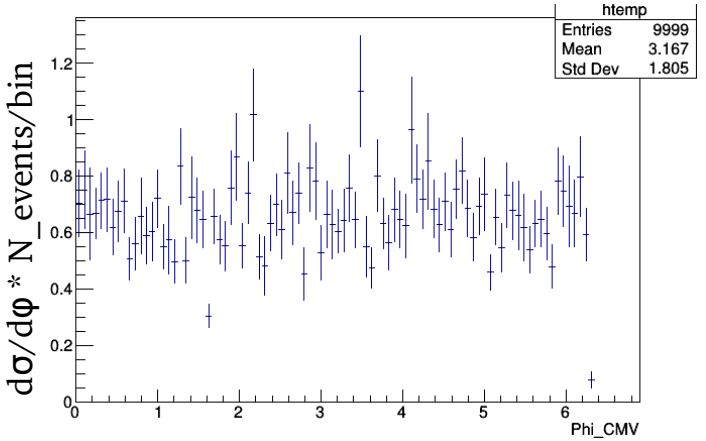
beam polar and azimuthal angles (normalized by unpol. cross section*N_ev)



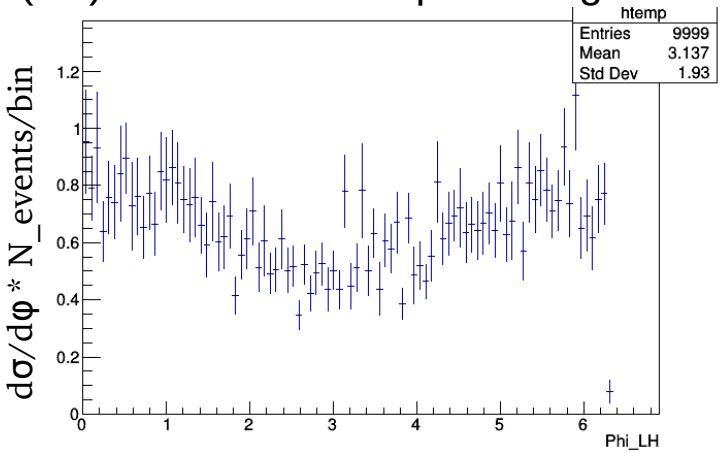


decay μ polar and azimuthal angles (normalized by unpol. cross section*N_ev)





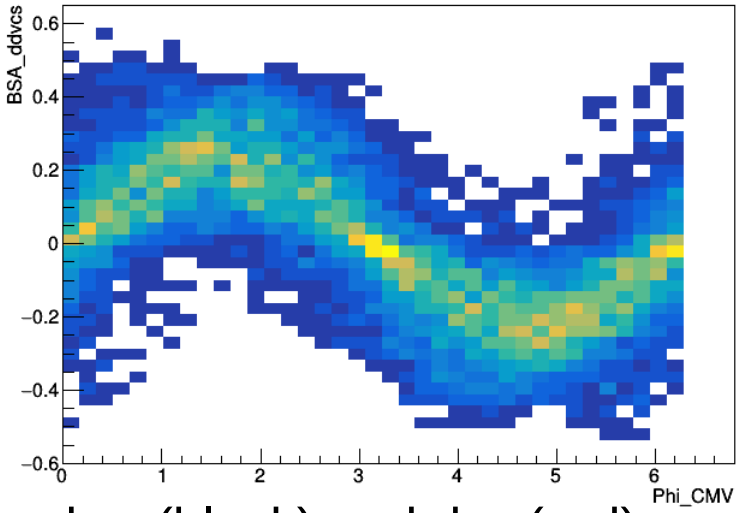
(ee') versus reaction plane angle

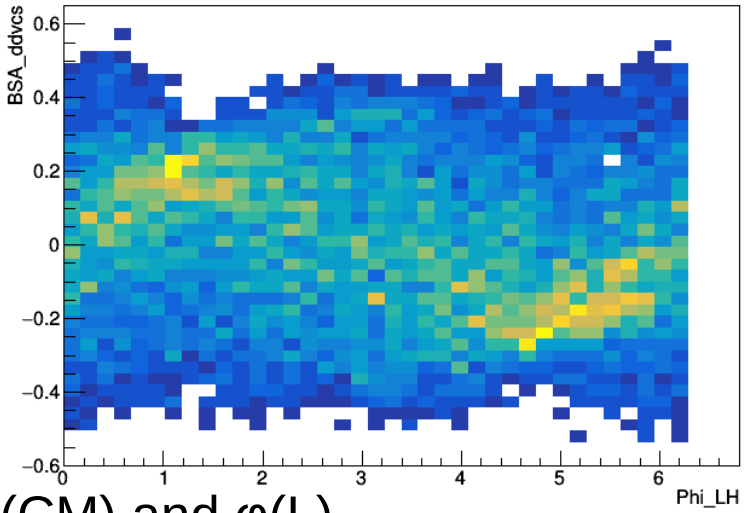


⇒ Distributions follow expectations for DDVCS+BH

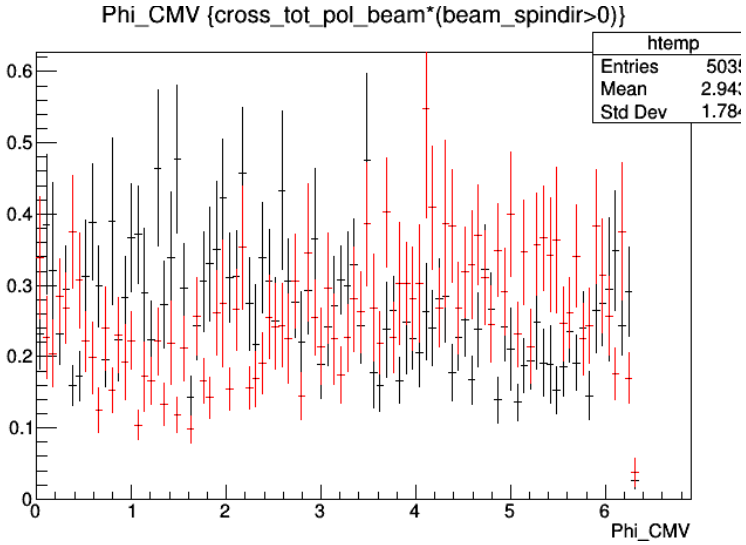
Cross sections and asymmetries for DDVCS

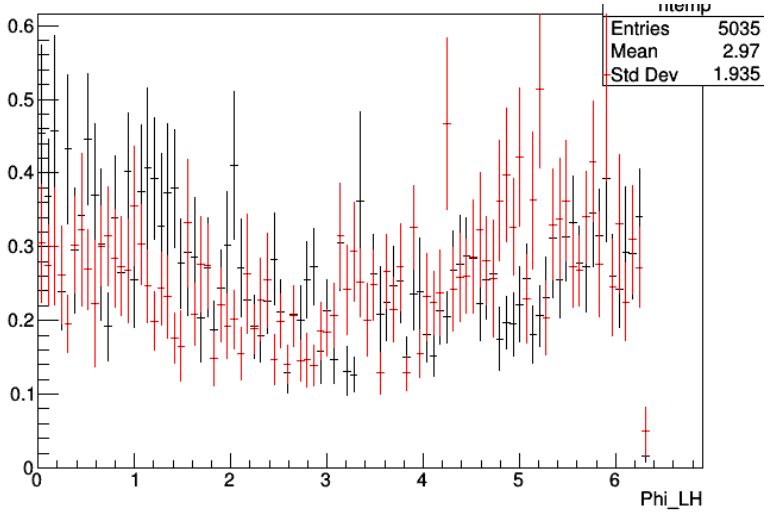
Beam spin asym. vs φ(CM) and φ(L)





dσ+ (black) and dσ- (red) vs φ(CM) and φ(L)





⇒expected for this kinematic, polarized cross sections for ↑ and ↓ reproduce the asymmetry

Where to find the generator, status and summary

"**slow version**" **3.0:** for testing the generator, not appropriated for large data set

- public version available:
/work/halla/solid/mboer/public/Generator_publicversion/version3.0_slow

- All information about this version are in:
/work/halla/solid/mboer/public/Generator_publicversion/version3.0_slow/README

"**fast version**" **3.1:** build ongoing. Wait for comments on version 3.0 before making it public.

- Generator wiki page (for reference, documents and explanations):
https://hallaweb.jlab.org/wiki/index.php/DDVCS_and_TCS_event_generator

- Note written with all directives, I will circulate it with version 3.1

Status / Summary:

- generate BH+TCS and BH+DDVCS events

- new: polarization/spin included, different targets, polarized cross sections, corrections angles...

- checks on kinematic and results OK

- slow version public and can be used, fast version in build, note ready

- need improvement on linearly polarized TCS. Wait comments for other improvements coming with v3.1

Please send your comments if you test the version 3.0. I can still modify version 3.1.

Backup

History of past versions of this generator

Version 1: spring 2015

- counting rates for TCS and DDVCS LOI/proposal in 2015
- use grids for unpolarized cross sections: discretization effects visible, some approximations
- real and quasi-real photon beam for TCS

Version 2: 2015-2016

- interpolations / extrapolations to avoid discretization effects (% level accuracy),
- runs faster (several versions), several technical improvements,
- flags and calculations at various points to prevent "finding" points where divergencies may occur when calculating BH close to kinematic edges or specific phi+theta combinations
- asymmetries
- circulated to few persons to make some predictions, but it was a relatively slow version

New version (3.0): last updates

Warning: it is the "slow" version for checking the needs. Fast version upcoming after first comments (needs few weeks for building on the farm + some coding).

What is new for TCS

- polarization vectors for beam and for target: phi_s, theta_s (target) and Psi_s (linearly polarized beam) dependences
- transversally and linearly polarized targets included
- corrections in cross sections calculations for spin not aligned along beam or target axis
- spin asymmetries (raw) and polarized cross sections (corrected for dilutions factor (s) of beam and/or target)
- circular polarization rate vs energy
- non zero polar angle from sampling for bremsstrahlung photons in case of e- beam

What is new for DDVCS

- beam polarized cross section

New in general:

- faster than last "slow" version
- new options in input files
- option to run only BH or only BH+TCS (DDVCS) without BH or TCS (DDVCS) "alone" to go faster