Event generator for exclusive reactions at high and low virtuality with adaptations for Hall C

1) Reactions and specific options

2) Framework

3) Running the generator independently and with simc

4) Examples

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Temple University
Hall C collaboration meeting, June 29, 2019

Reactions

High virtuality exclusive reactions ($Q^2 > 1$ GeV^2)

→Generalized Parton Distributions physics

Deeply Virtual Compton Scattering (DVCS): e P →e' P' γ (high Q^2)

Timelike Compton Scattering (TCS) = γ P →e^+e^- P'

Double Deeply Virtual Compton Scattering (DDVCS): e P →e' P' $\mu^+\mu^-$

Low virtuality exclusive reactions ($Q^2 < 1$ GeV^2)

→Proton polarizabilities, meson Form Factors

Virtual Compton Scattering (VCS): e P →e' P' γ (low Q^2)

Exclusive electro-production of π°: e P →e' P' π°

Exclusive electro-production of π^+: e P →e' N' π^+

Standard reactions

→PDF, Form Factors, and basis for experimental studies

Deep Inelastic Scattering (DIS): e P →e' X

Elastic Scattering: e P → e' P'

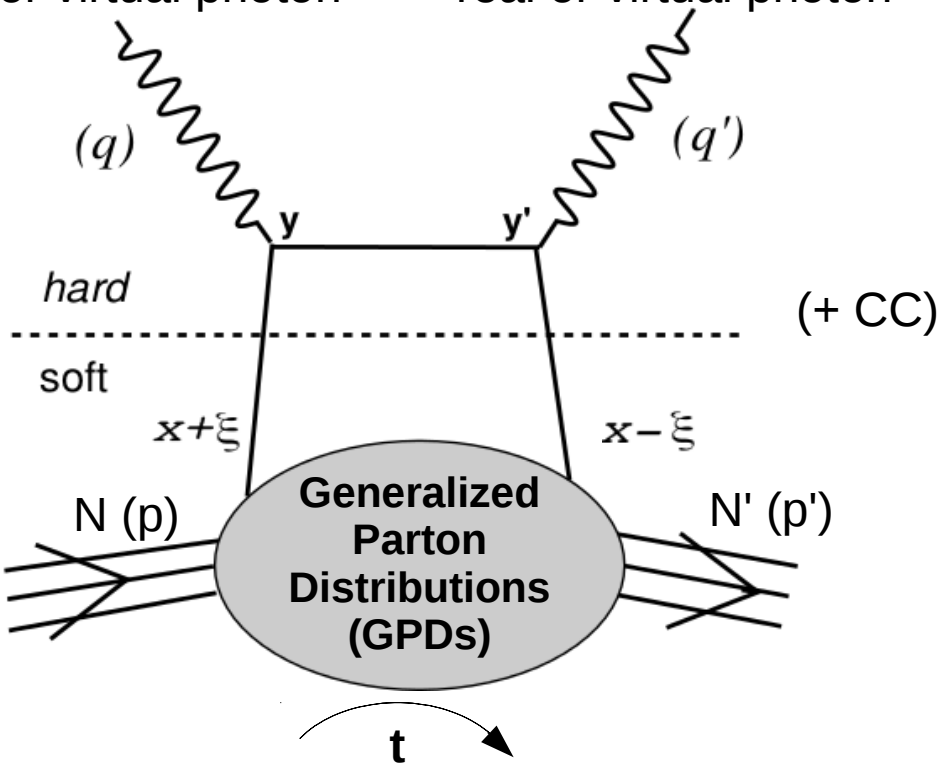
Hard exclusive Compton-like reactions

γ(*) N → N' γ(*)

access Generalized Parton Distributions, parametrization of generator based on VGG model

Compton part

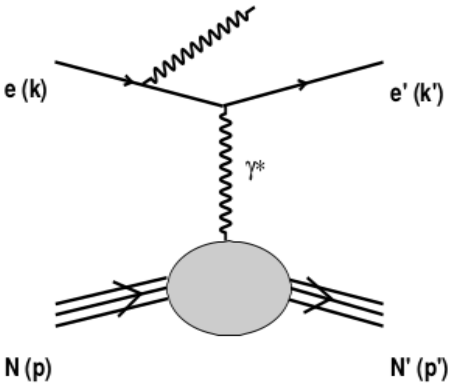
real or virtual photon real or virtual photon



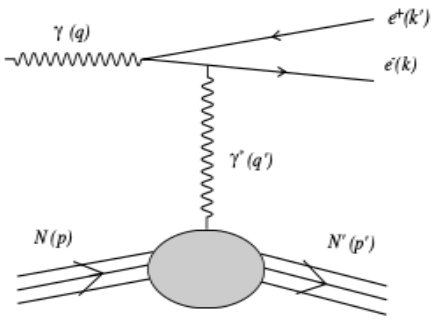
(+ CC)

Interference with Bethe-Heitler

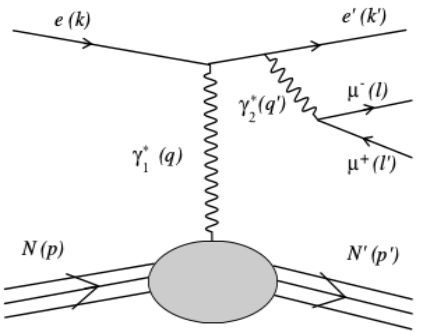
BH with DVCS

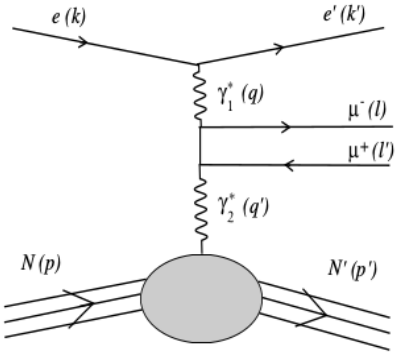


BH with TCS



BH with DDVCS





Generator modules:

DVCS: polarized electron beam, polarized P or N target (L or ⊥)

TCS: circularly or linearly polarized photon beam, polarized P or N target (L or ⊥). γ or e^- beam

DDVCS: polarized electron beam, unpolarized P or N target

Hard exclusive meson production: unweighted only in current version (need model)

→ use of LO and leading twist amplitudes, GPD H only in current version (previously also H̃)

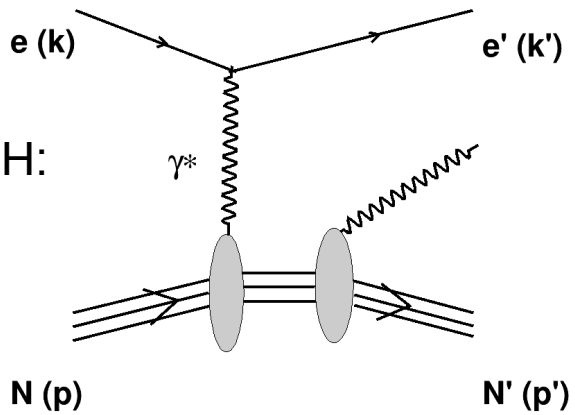
Low virtuality exclusive reactions

γ* P → P' γ or M

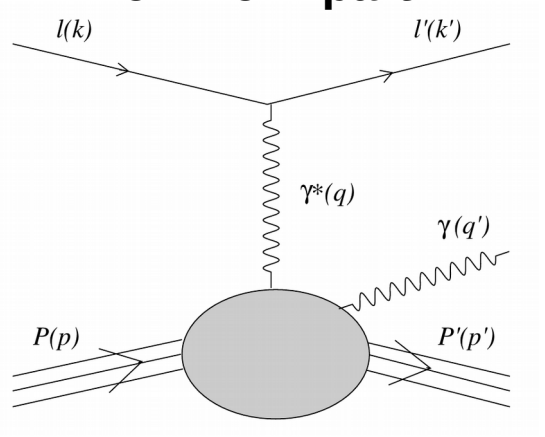
access form factors and polarizabilities, paramerization in generator based on MAID model

VCS+BH:

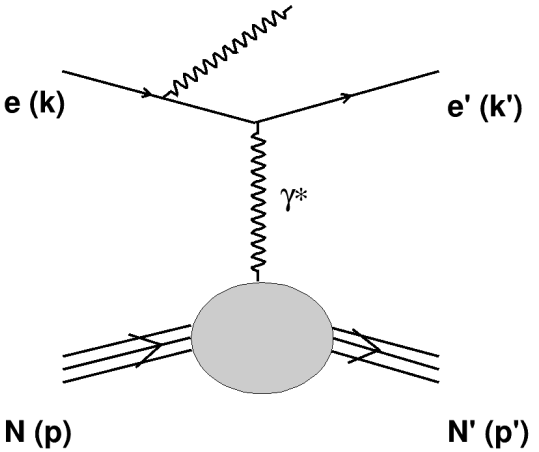
Compton Born



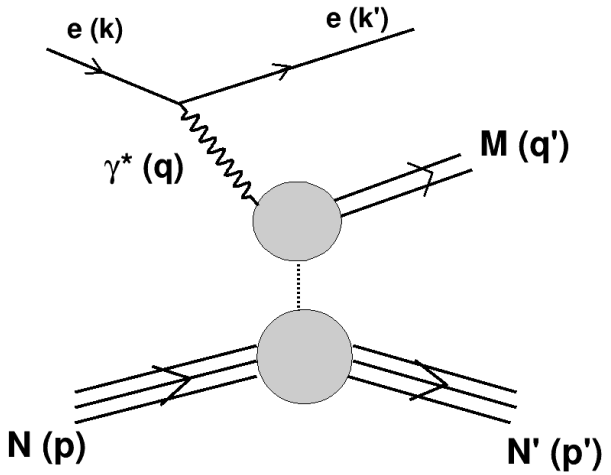
non-Born part



Bethe-Heitler



Exclusive π° or π+ production:



Generator modules:

VCS: unpolarized off P, VCS+BH
decomposed into 5 sub-processes
(B. Pasquini MAID 2007)

π°: unpolarized off P (MAID 2003)

π+: unpolarized off P (MAID 2003)

Specific options

• **Generation of weighted events:**
- standard, generated flat within a set of variables: counting rates and unpolarized cross sections

• **4π generation of events as a function of kinematic invariants:**
- phase-space studies and scans
- can be used with extensions for any fix target or collider experiment, narrow or 4π acceptance

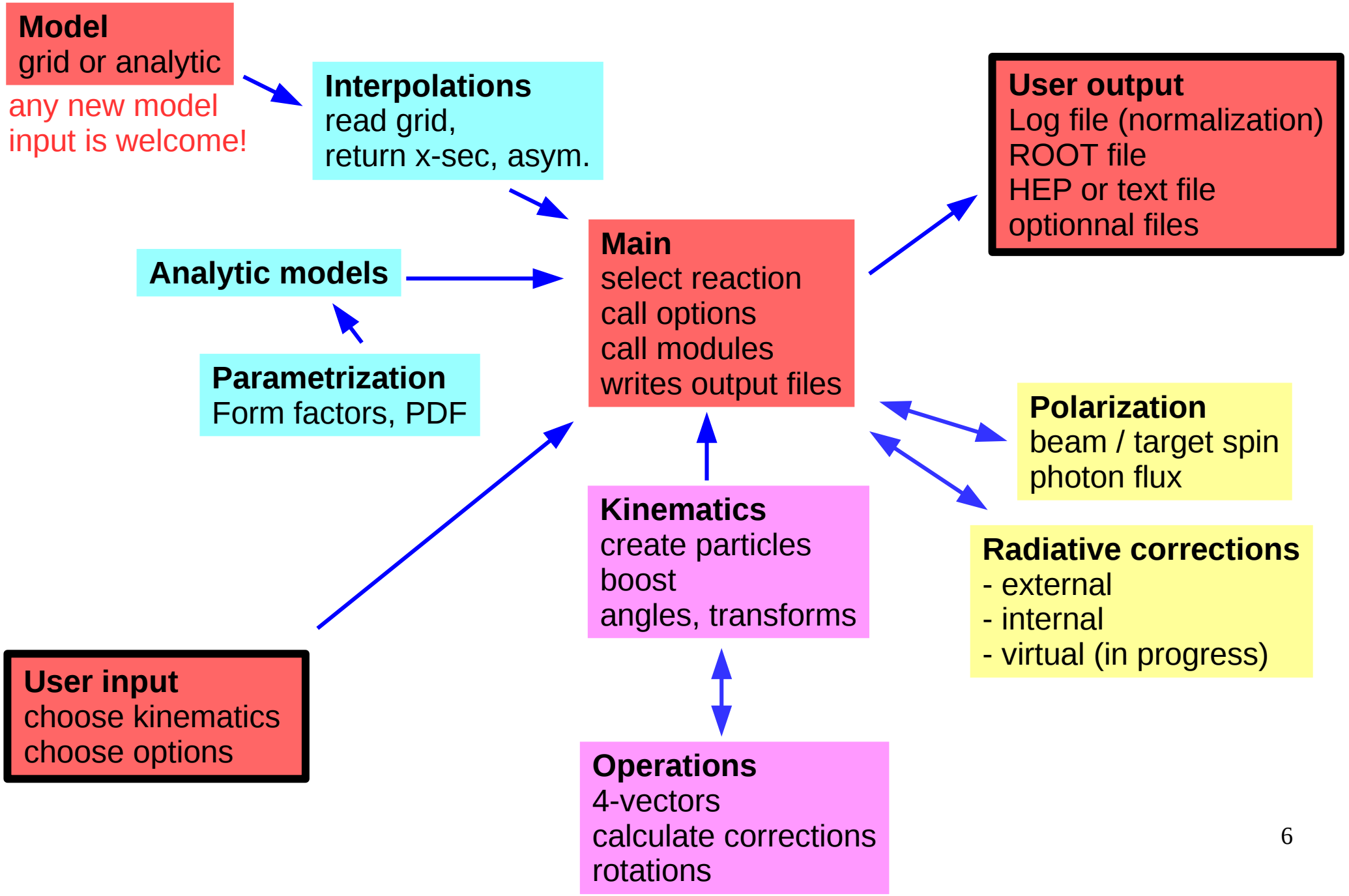
• **Beam and target spin, events weighted according to polarization**
→ for high virtuality reactions only
- prediction of realistic single and double spin asymmetries, fits of polarized cross sections
- target: L or ⊥, electron beam: linear, photon beam: circular or linear

• **Sub-processes simultaneous event weighting**
→ for Compton-like processes studies, generally dominated by Bethe-Heitler
- interpretation of data, F.O.M.
- BH as less model dependent for counting rates estimation in some reactions
- phase-space scan to avoid specific regions

• **Electron or photon beam**
→for Timelike Compton Scattering
- realistic prediction in case of quasi-real photons with angle and virtuality corrections

• **Radiative corrections**
- external and real corrections: all reactions, virtual corrections: not yet
- adjustable target lenght and material

Framework


Model
grid or analytic
any new model
input is welcome!
Interpolations
read grid,
return x-sec, asym.
User output
Log file (normalization)
ROOT file
HEP or text file
optionnal files
Analytic models
Main
select reaction
call options
call modules
writes output files
Parametrization
Form factors, PDF
Polarization
beam / target spin
photon flux
Kinematics
create particles
boost
angles, transforms
Radiative corrections
- external
- internal
- virtual (in progress)
User input
choose kinematics
choose options
Operations
4-vectors
calculate corrections
rotations

User input file

Variable name	usage	limits (grid)	default value	other recommandations
Number of events to generate	limit size of output file	10000		limit to 50000 for memory
Beam type	real photon (0) initial electron (1)	0 or 1	0 or 1	
Photon energy range	cross section	[5, 11.5] GeV	11	less than electron if quasi-real
Beam energy (if electron beam)	for photon flux	[$\sim$ 5, 11.5] GeV	11	$>$ max(E_γ)
$\theta_\gamma(max)$	bremsstrahlung angle max	-	0	photon cone for bremsstrahlung flux
lepton type	electron (1) muon (2)	1 or 2	1	kinematic only, no muons in cross sections
Target lenght	bremsstrahlung	-	15 cm	only electron mode
Target composition (A,Z)	bremsstrahlung and EPA	material	(1,1) or 1001	only electron mode
Target = p (1) or n (2)	cross section	1, 2	1	
Beam polarization dilution factor	pol. cross sections	[0, 1]	0.8	electron polarization or linearly pol. photon
Beam pol. vector direction	polarized cross sections	0 (circular) 1 (x-axis) 2 (y-axis) or 3 (45°)	0	set 0 if unpolarized
Target polarization direction	polarized cross sections	0 (unpolarized), 1 (x-axis), 2 (y-axis), 3 (z-axis)	3	set 0 if unpolarized
Target dilution factor	polarized cross section	0 to 1	0.7	
-t	Mandelstam variable	cross section	[.04, 2.04]	
Q'^2	outgoing photon virtuality	cross section	[.09, 9.2] GeV^2	
θ_{CM}	azimuthal angle of decay leptons	[30°, 150°]	[30°, 130°]	
Q^2_{max}	quasi-real photons max.	0 to 0.3	0.3	low Q^2 dominate
Output	(0) ROOT, (2) HEP, (1) both	0, 1, 2	0	recommend only ROOT

Table 2: User's input file parameters for TCS-type events generation. All units are GeV.

Example: TCS input file
(past version, more options in v5)

beam and photon flux options

choice of final state

target choice
radiative corrections options here

polarization options

kinematic limits

output format
acceptance limits can be set here

Output files

ROOT file:

note: content depends on the reaction

SIM_Tree: (all events)

1) 4-vectors array for all incoming and outgoing particles (E, px, py, z)
2) Kinematics (Q^2...)
3) Spin direction, ε, dilution factors
4) total and subprocesses weights, asymmetries
5) Normalization: flux, number of events

Dump_Tree: (one entry)

1) input file options
2) normalization informations

HEP file:

standard HEP file + associated text file to print various weights and options

TEXT file:

to be used with simc modified version

HMS particle (-y, x, z, E), SHMS particle (-y, x, z, E), weights and event information

LOG file:

to be used with simc modified version

1) total and saved number of events, phase-space, run index
2) options
3) input file

Generating data and plugging to simc

1) Copy full directory: /work/halla/solid/mboer/public/Generator_publicversion/version5.0

2) Set environment from the new directory
set.csh && source /apps/root/6.10.02/setroot_CUE.csh

3) Modify user's input file

4) Run:
./DEEPGen (reaction) (run index) (seed in batch mode)

Reaction list:

1. tcs (weighted)
2. ddvcs
3. dvcs
4. vcs
5. pi 0
7. pi+
30. dis
31. elastic
32. elastic_lab
11. ps_eephoto_fix (phase-space)
12. ps_eeel_fix
13. ps_vcs_fix
15. ps_pi0_fix
17. ps_pin_fix

5) SIMC: download version with doc. (Sylvester's page): https://gitlab.com/jpsi007/simc-file-input

5) Recompile simc with modified libraries on: /work/halla/solid/mboer/public/mod_simc

6) Running generated events with this version of simc:
- needs name of log file after the name of data file in command line
- simc input file: switch off beam radiations and request external data input file

Modified simc output file

Additions to simc output root file, name of new entries for each reaction in ROOT tree:

	VCS	π°	π+	TCS	DDVCS	DVCS	elastic
Weight	σ^{tot}	σ^{tot}	σ^{tot}	σ^{BH}	σ^{BH}	σ^{BH}	σ^{tot}
Wgt2	σ^{BH}	φ_{CM}	-	σ^{TCS}	σ^{DDVCS}	σ^{DVCS}	-
Wgt3	$\sigma^{VCSborn}$	θ_{CM}	-	σ^{tot}	σ^{tot}	σ^{tot}	-
vara	$\sigma^{tot\ born}$	-y (γ_1)	-y (N')	BSA	-y (P')	BSA	-
varb	$\sigma^{vcs\ NB}$	x (γ_1)	x (N')	TSA	x (P')	TSA	-
varc	L/R asym	z (γ_1)	z (N')	BTSA	z (P')	BTSA	Q^2
vard	y*flux corr.	y*flux corr	y*flux corr	y flux	BSA	y*flux corr	y*flux corr.
vare	Ebeam	Ebeam	Ebeam	Ebeam	Ebeam	Ebeam	Ebeam
loga	run index						
logb	total number of events generated "T (file)"						
logc	generation total phase-space "PS"						

Normalization:

weights = differential cross sections in invariants Q^2, Q'^2, xb, t, φ, θ, E(γ)... (see note)

σ(bin) and N(bin)=σ(bin)*L such as: $\sigma^{bin} = \frac{\sum_i^N W_i * PS}{\sum_j^{\text{files}}(T)}$

Examples: asymmetries out of generator (from note January)

DVCS: BSA, TSA (L), BTSA (L)

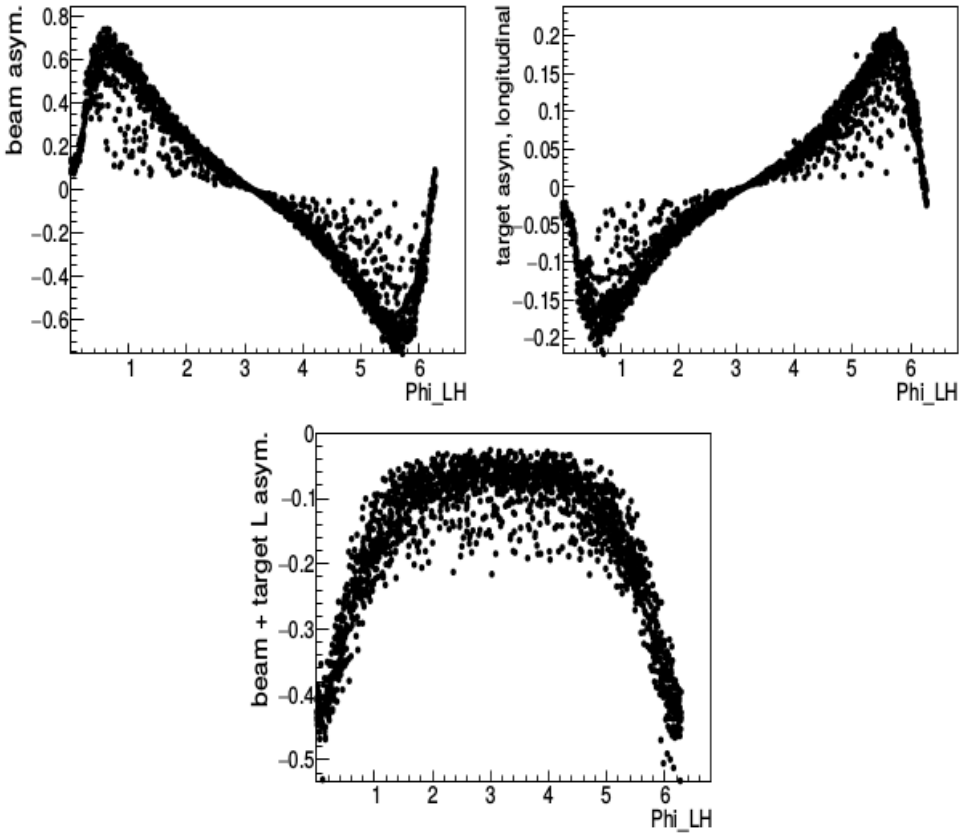


Figure 14: DVCS+BH generated spin asymmetries from a polarized electron beam (top left panel), longitudinally polarized target (top right panel), polarized beam+longitudinally polarized target (bottom panel). The beam energy is set at 11 GeV and $0.2 < x_{bj} < 0.25$, $4 < Q^2 < 5$ GeV^2, $-0.6 < t < -0.5$ GeV^2. Asymmetries are displayed as a function of ϕ_{LH} (rad.).

TCS: BSA

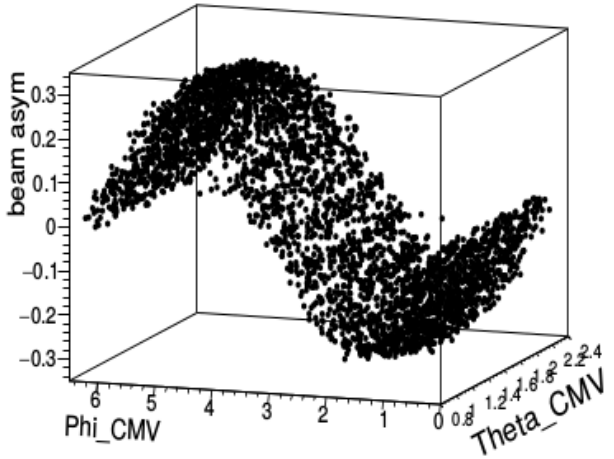


Figure 16: TCS+BH beam spin asymmetry as a function of ϕ, for 5<E$_\gamma$<11.4 GeV, $6.5 < Q'^2 < 7$ GeV^2 and 0.6<-t<0.7 GeV^2.

DDVCS: BSA

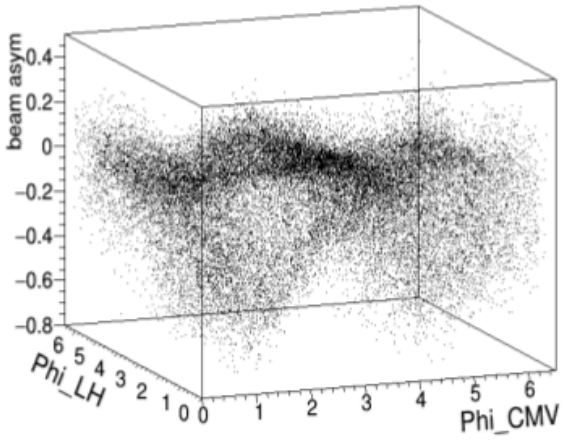
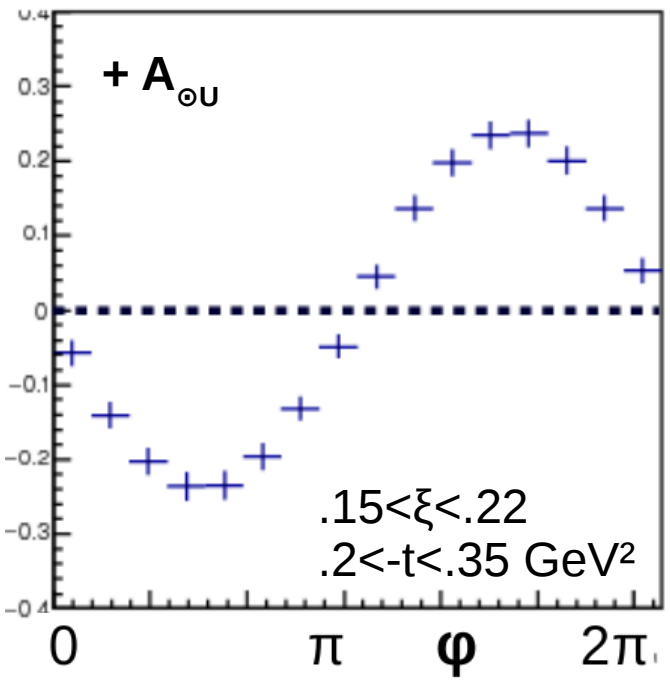


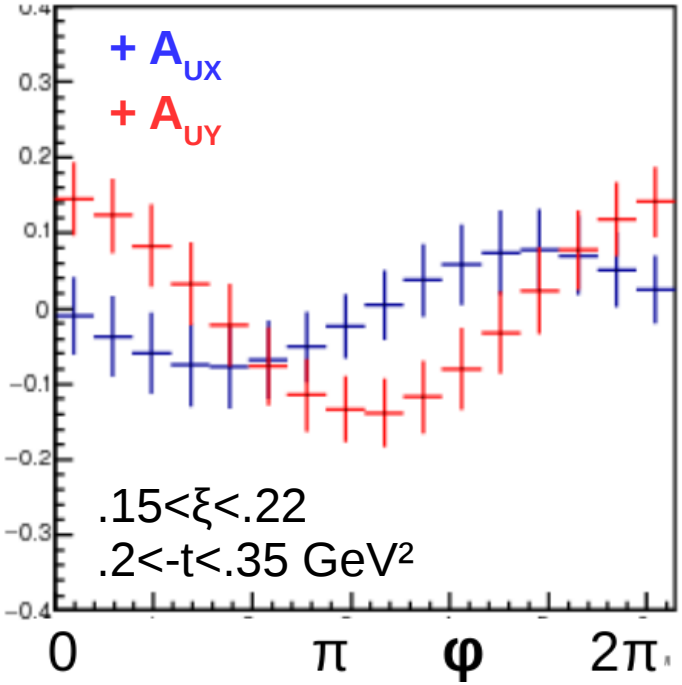
Figure 18: DDVCS+BH beam spin asymmetry as a function of ϕ_{CM} and ϕ_{LH} (units are radians).

2-dim distributions: asymmetries vs "physics" φ
just an example, use polarized σ for predictions

Examples of applications: TCS projections with various options

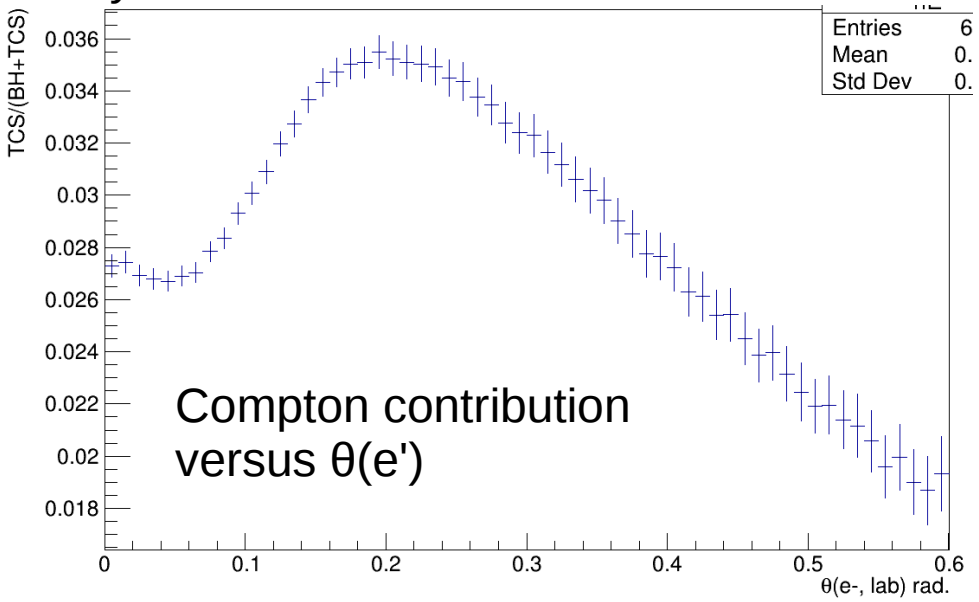
• asymmetries: beam & ⊥ target, version 4, 2018 (E12-18-005)





⇒ advantage:
asymmetries are integrated over bin width,
this is not a "theory" projection

• for BH measurement in Hall D, Compton contribution to systematic uncertainties, version 4, 2018



⇒ advantage: phase-space scan and F.O.M. to identify fast regions to enhance various contributions

N.B.: I added this slide because Julie "requested" twice that I show something on TCS

Summary

• **Event generator for physics studies and JLab simulations**
- hard exclusive processes
- low virtuality processes
- standard reactions

• **Adaptations to run with simc and other software**

• **Documentation and binaries:**

- Note on version 4 (January 2019): in Hall C data base, index #1000
https://hallcweb.jlab.org/doc-public/ShowDocument?docid=1000

- Wiki page:
https://hallaweb.jlab.org/wiki/index.php/DEEPGen_event_generator (2018)

- New version binaries: /work/halla/solid/mboer/public/Generator_publicversion/version5.0
(few options disabled until complete check performed)

- questions: mboer@jlab.org

• **Updated full documentation and code coming soon**