The TMDGen Monte Carlo Generator

S. Gliske

Argonne National Lab
(Formerly of the U. of Michigan)
HERMES and STAR Collaborations

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Guiding Principles

- Depend on as few other libraries as possible
- Allow for future expansion and modification (C++ polymorphism)
- Allow for a variety of basic physics
  - I.e. allow for *pp*, *ep* collider, *ep* fixed target, all polarizations, etc.
  - Also allow for SIDIS single hadron, SIDIS dihadron, exclusive production, etc.
- Allow for different end users
  - Output must have interface to HERMES software framework
  - Allow expansion for other experimental software frameworks.
  - Must be able usable for theorists with no experimental software framework
- Allow for any model for the cross section
  - For factorized cross section, allow any model for distribution and fragmentation functions
  - Also can allow non-factorized models, i.e. models for the structure functions instead.
- Allow full modeling of intrinsic k_T and p_T distributions:
  - Every event has a given value of k_T and p_T

General Structure

- Basic algorithm is
  1. Throw cross section variables
  2. Evaluate the cross section
  3. Apply acceptance/rejection
     - Can also just use the computed weight of the event.
  4. Convert cross section variables to lab variables
  5. Save the output (in some fashion)
- Note: TMDGen began as a port of GMC_Trans from FORTRAN to C++
- Although TMDGen has outgrown its beginings, many thanks to Gunar Schnell, Dehlia Hasch, and others who worked on GMC_Trans

What is currently tested in TMDGen?

- All input options given via a human readable text file
  - Reminiscent of a KUMAC, but it is not
- Basic physics:
  - SIDIS single hadron, unpolarized and transverse target moments
  - SIDIS dihadrons, unpolarized and transverse target moments
- Output
  - HERMES DAD/ADAMO tables
  - Root TFile
- Variety of models (listed later)

How would one add...

- Other SIDIS polarization states
  - Just need to finish testing the cross section terms
- A new model for distribution or fragmentation functions
  - Create a new child of the right abstract base class
  - Construct the object in the right place
- A new term in the cross section
  - Create a new child of the right abstract base class
  - Construct the object in the right place
- A new cross section (such as exclusive production or *pp*)
  - Define the cross section term classes and follow the pattern already existent
- Collider *ep* instead of fixed target *ep*
  - Add a new conversion function from cross section to lab variables
- A target other than a proton
  - Ensure the distribution functions support the desired target
  - Add possibly missing distribution functions

Intrinsic Transverse Momentum

- Every event has a value of intrinsic k_T and p_T.
- Not all models necessary use the values given
- The observable $P_{h\perp}$ and the quark distribution intrinsic transverse momentum k_T are chosen as the independent variables.
- The fragmentation p_T is then set by momentum conservation (satisfying the usual delta function).
- TMDGen allows for addition TMD functions to multiply models of distribution and fragmentation functions without explicit TMD.
- One can also create any arbitrary TMD function for distribution and fragmentation functions.
- TMDGen is a full test ground for modeling intrinsic TMD of models!

Implemented Distribution Functions

Distribution Functions	**Model**
f_1	CTEQ
f_1	LHAPDF
f_1	BCR08
f_1	GRV98
g_1	GRSV2000
$f_{1T}, h_{1T}^{\perp}, h_1$	Torino Group
$f_1, g_1, g_{1L}, g_{1T}, f_{1T}, h_1, h_1^{\perp}, h_{1T}^{\perp}$	Pavia Spectator Model

Implemented Fragmentation Functions

Frag. Functions	Final State	Model Identifier
D_1	pseudo-scalar	fDSS
D_1	pseudo-scalar	Kretzer
$D_1, H_1^{\perp}$	dihadron	TMD Spectator Model
$D_1, H_1^{\perp}$	dihadron	Set given partial wave proportional to any other partial wave

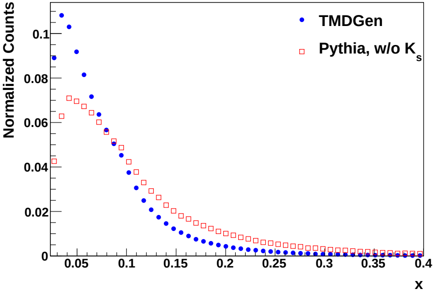
- Dihadron fragmentation functions use the Gliske-partial wave expansion
- The above dihadron D_1 and $H_1^{\perp}$ represent all the partial waves, including the interference fragmentation function $H_{1,sp}^{\sphericalangle}$
- Not all partial waves are necessarily non-zero.

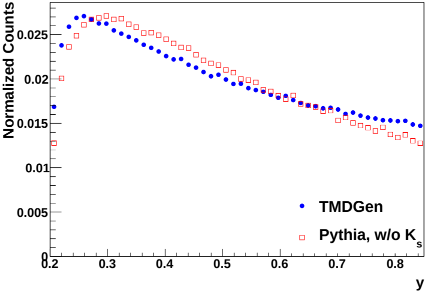
TMDGen Example: SIDIS $\pi^+\pi^0$ production

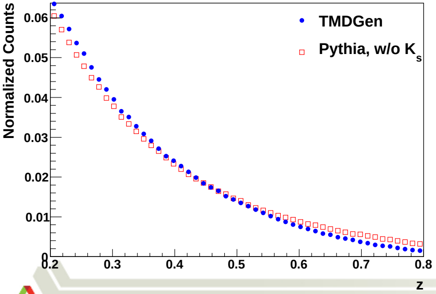
- Dihadron $\pi^+\pi^0$ production includes ρ^+ production
- Final state is $\pi^+\gamma\gamma$
- Distribution function model: GRV98.
- Fragmentation model: my TMD generalization of Bacchetta, *et. al* PRD 74:11 (2006)
- Full details of these plots are in my thesis

  http://www-hermes.desy.de/notes/pub/11-LIB/sgliske.11-003.thesis.pdf
- Following slides will compare data from PYTHIA (tuned to HERMES kinematics) with output of TMDGen.

$\pi^+\pi^0$ Kinematic Distributions, p.1

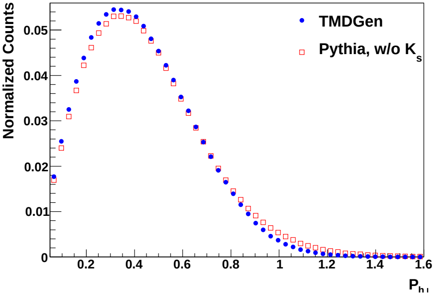






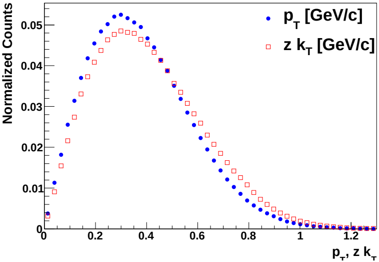
- Close agreement for x, y, z distributions.
- Main discrepancy in x—may be due to imbalance in the flavor contributions, or Q^2 effects.
- Similar results for other $\pi\pi$ and KK dihadrons.

$\pi^+\pi^0$ Kinematic Distributions, p.2



- Fairly good agreement in both $P_{h\perp}$ and M_h distributions.
- Note: some discrepancies in full 5*D* kinematic, but PYTHIA also doesn't match data in full 5*D*

$\pi^+\pi^0$ Kinematic Distributions, Intrinsic Transverse Momentum



- Partonic transverse momentum denoted p_T
- The fragmenting quark's transverse momentum is zk_T
- Model requires $p_T \approx zk_T$ in order to get narrow $P_{h\perp}$ peak
- Model does not require any flavor dependence to k^2, k_T^2 cut-offs
- However, model poorly constrains RMS values $\langle p_T^2 \rangle$, $\langle k_T^2 \rangle$
- No other generator can show p_T, k_T distributions

Conclusion/Outlook

- TMDGen is a flexible framework for all TMD cross sections
- So far, TMDGen tested and used for HERMES Dihadron results
- Many more possible uses for TMDGen
- Main constraint is time/manpower to continue development of TMDGen
- I will gladly share the source code
  - I just need to prepare some installation and use instructions