Few more TMD generators

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Outline

- From Naïve generator to single-particle generator.
- Gagik Gavalians and Haruts generator.
- NJL-jet generator
- Conclusions/discussions

Cross section

$$
\begin{aligned}
&\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \\
&\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
&\quad+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
&\quad+S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] \\
&\quad+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right] \\
&\quad+|\boldsymbol{S}_\perp|\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) \\
&\qquad+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
&\qquad+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Bigg] \\
&\quad+|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
&\qquad+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},
\end{aligned}
$$

(

Naïve generator

Instead of

$$\frac{d\sigma}{dxdydzdP_T d\phi_h} = K\left(F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}F_{UU}^{\cos(\phi_h)}\cos(\phi_h) + ...\right)$$

generate

$$\frac{d\sigma}{dxdydzdP_T d\phi_h} = KF_{UU,T}\left(1 + \varepsilon\frac{F_{UU,L}}{F_{UU,T}} + \sqrt{2\varepsilon(1+\varepsilon)}\frac{F_{UU}^{\cos(\phi_h)}}{F_{UU,T}}\cos(\phi_h) + ...\right)$$

Or even simple

$$\frac{d\sigma}{dxdydzdP_T d\phi_h} = KF_{UU,T}\left(1 + A\cos(\phi_h) + B\cos(2\phi_h) + C\sin(\phi_h)\right)$$

Check if you do really generate it! Check do you really get as output your functions.

What do I have in Naïve Generator

Distribution functions.

- MSTW (with Q2 evolution)
- Haruts equations.

Fragmentation functions

- DSS (Phys Rev D 76, 074033 (2007), Phys Rev D 75, 114010 (2007)) .
- D(z) from J. Binnewies and collaborators (hep-ph/9503464).

Random generators

Up to above simple generations one can use:

- TRandom from root
- TRandom3 from root

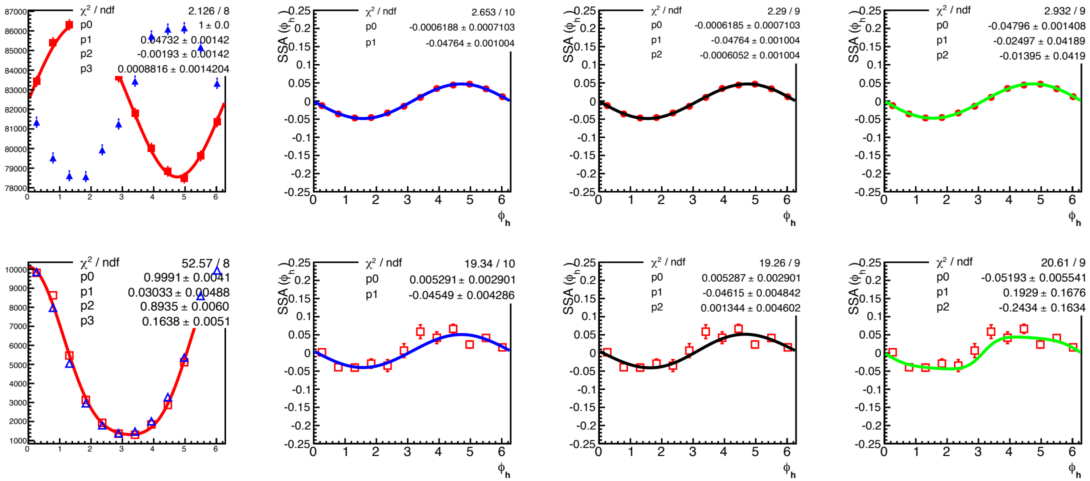
While if one will use FOAM will see the difference

- http://jadach.home.cern.ch/jadach/Foam/Index.html
- http://root.cern.ch/root/html/TFoam.html

TFoam

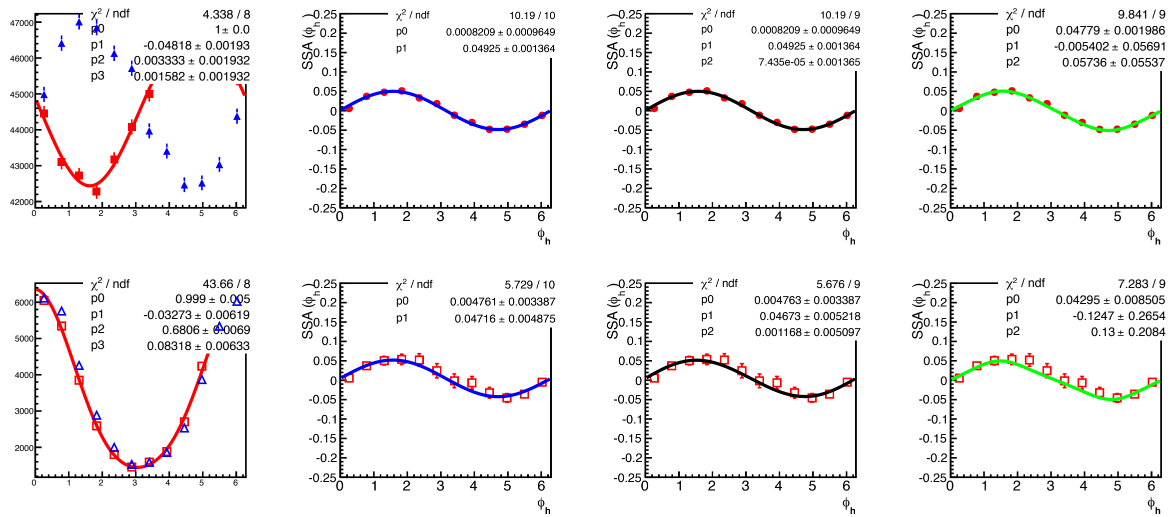
```
*****   Demonstration Program for Foam version 1.02M    *****
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
F                                                          F
F               ****************************************                F
F                ******      TFoam::Initialize    ******                F
F               ****************************************                F
F                                       FoamX               F
F    Version =          1.02M    =                Release date:  2005.04.10 F
F      kDim =          8 =  Dimension of the hyper-cubical space              F
F     nCells =       5000 =  Requested number of Cells (half of them active)   F
F     nSampl =       5000 =  No of MC events in exploration of a cell          F
F       nBin =        500 =  No of bins in histograms, MC exploration of cell  F
F   EvPerBin =       1000 =  Maximum No effective_events/bin, MC exploration   F
F   OptDrive =          2 =  Type of Driver   =1,2 for Sigma,WtMax             F
F     OptRej =          1 =  MC rejection on/off for OptRej=0,1                F
F   MaxWtRej =             2   =      Maximum wt in rejection for wt=1 evts F
F                                                          F
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
```

Step function on z for sin(x) moment



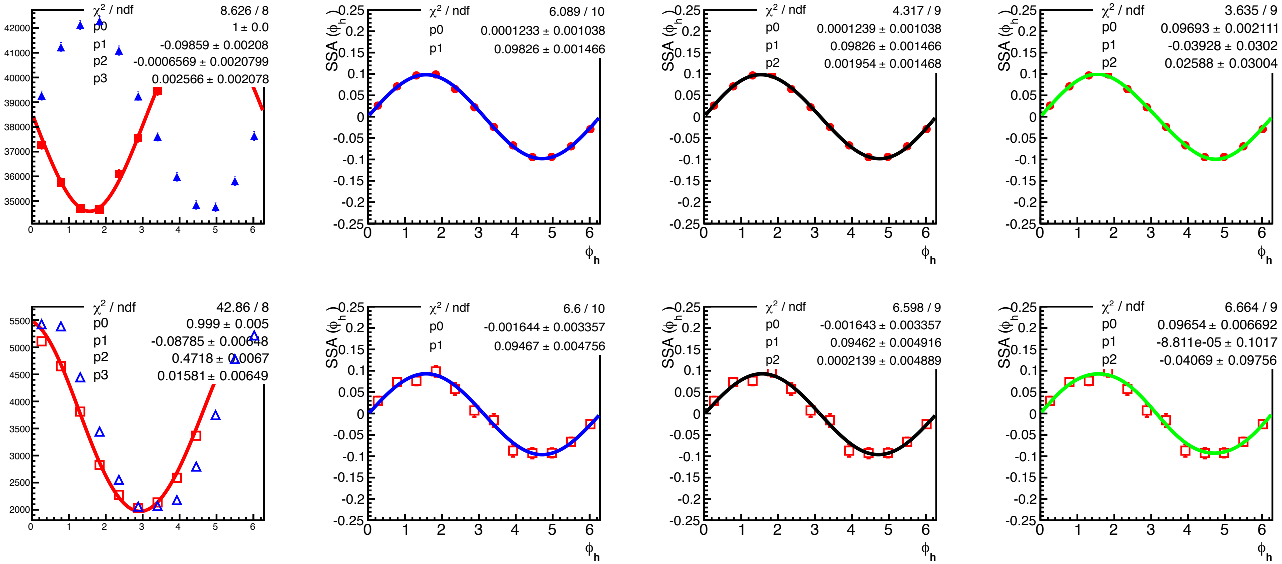
Generated asymmetry Reconstructed within the error bars.

$$f = \frac{p0\sin(x)}{1 + p1\cos(x) + p2\sin(2x)}$$

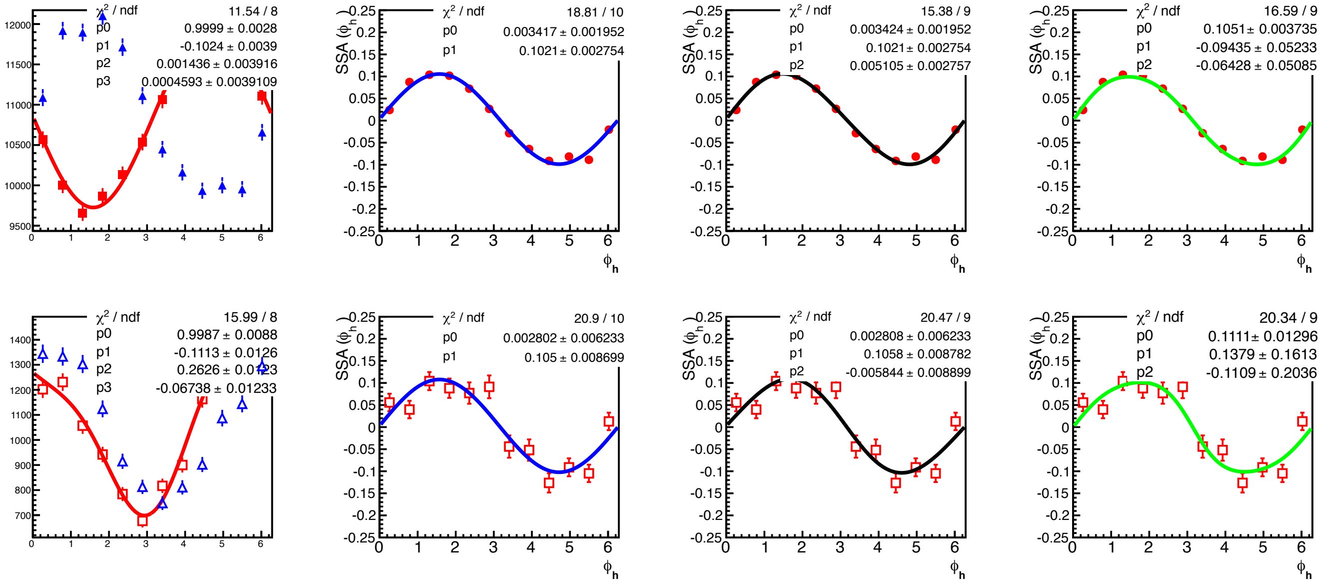


$$f = p0 + p1\sin(x) \qquad f = p0\sin(x) + p1\sin(2x)$$

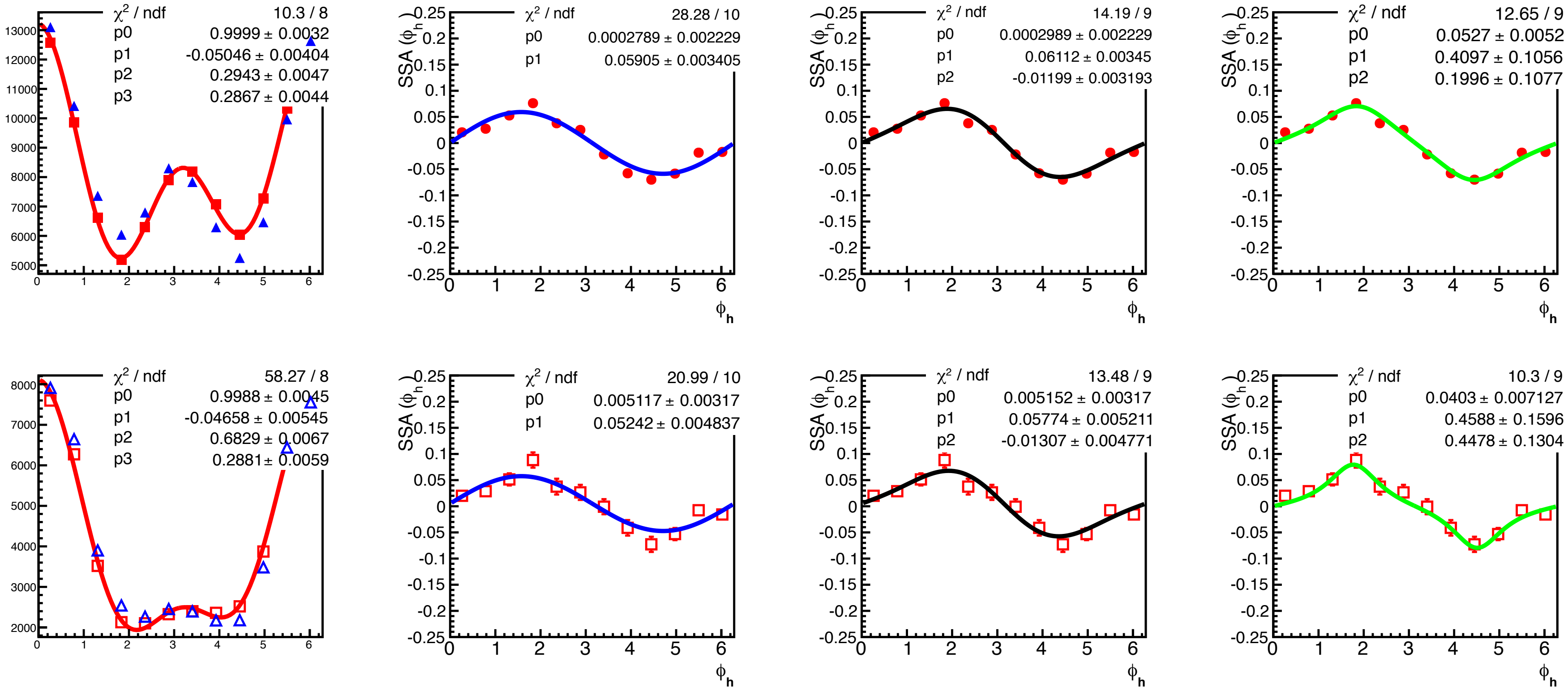
Step function on z for sin(x) moment



Generated asymmetry Reconstructed within the error bars.



Important checks



So how we would like to generate?

$$\frac{d\sigma}{dxdydzdP_T d\phi_h} = f(x, y, z, P_T, \phi_h, \phi_s, P_B, P_T)$$

We need to choose

$$\frac{d\sigma}{dQ^2 dxdzdP_T d\phi_h} = f(x, Q^2, z, P_T, \phi_h, \phi_s, P_B, P_T)$$

And guess for initial stage would be better to have our outputs in one of above formats
Then each group can create its favorite output format from above variables

Problems up to here:

- Positivity bound
- Compatibility of different models …
- If one would like to include also RC, then he needs to check generation limits also.

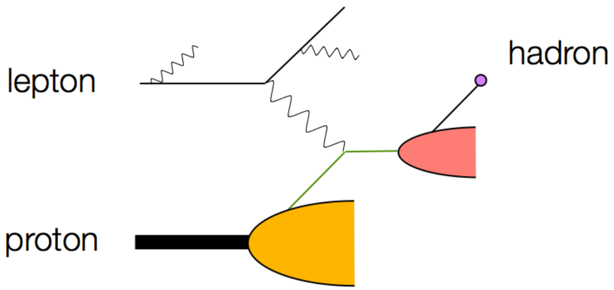
Gagik Gavalians and Haruts generator

- Based on full FOAM
- Can include structure functions and cross section even in fortran
- General interface
- Does not include CERN LIB.

NJL-jet generator

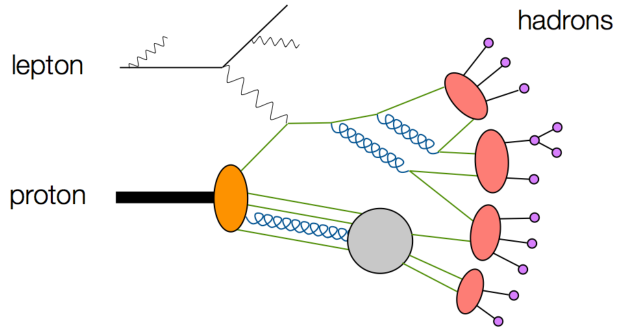
Transverse Momentum Dependent Fragmentation and Quark Distribution Functions from the NJL-jet Model.
Hrayr H. Matevosyan, Wolfgang Bentz, Ian C. Clo¨et and Anthony W. Thomas. **arXiv:1111.1740** [hep-ph]

Single-particle or 2 particle DIS gen



NJL-jet

Full event generator

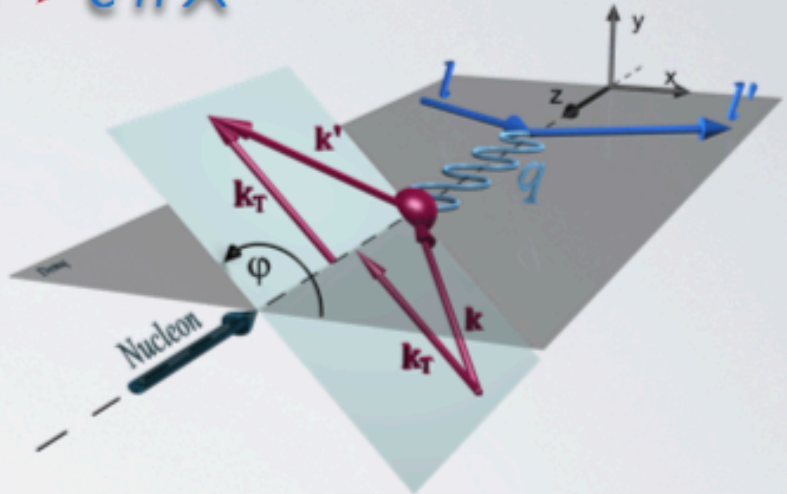


Plots from A. Bacchetta

The JET-MC is a Monte Carlo event generatoing framework developed for SIDIS, which is a intermediary between the two types of generatros Alessandro described yesterday: Full Event Generators (Pythia, etc) and the generators for single particle inclusive SIDIS. It assumes the TMD factorization picture to probe the transverse quark structure of the nucleon, but employs the quark-jet model for hadronization.

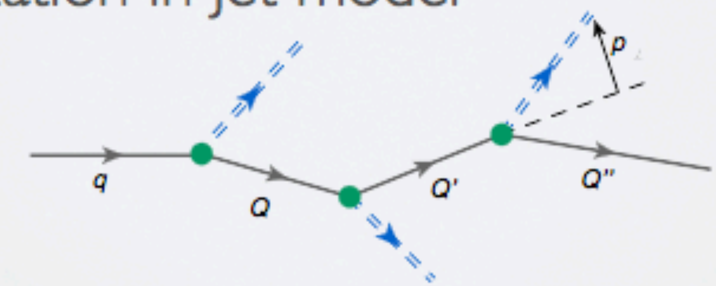
JET-MC FRAMEWORK

- Event Generator for SIDIS : e N → e h X
- Cross-section factorizes:



$$\frac{d^5\sigma^{lN\to l'hX}}{dx\ dQ^2\ dz\ dP_T^2\ d\phi_h} = \sum_q \frac{\pi\alpha^2 e_q^2}{Q^4} \int d^2\boldsymbol{k_T}\ q(x,k_T^2)\ D_q^h(z,P_\perp^2)$$

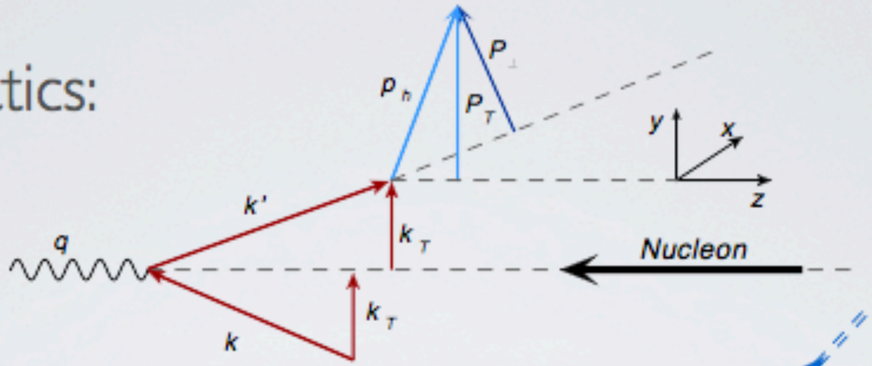
- Quark Hadronization in Jet model



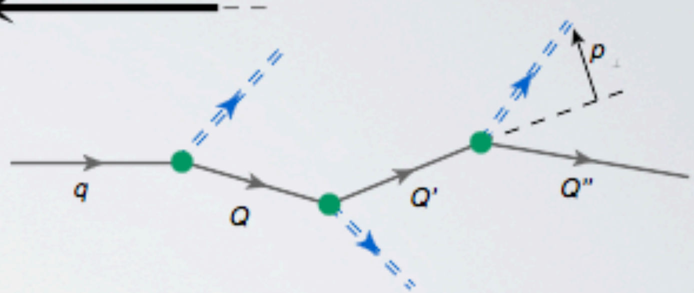
Slides from H. Matevosyan
arXiv:1111.1740 [hep-ph]

JET-MC FRAMEWORK

- SIDIS Kinematics:



- Quark Hadronization in Jet model



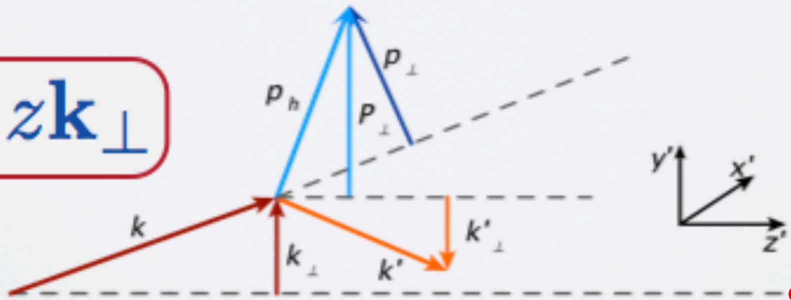
  - TMD splittings:
  - Conserve transverse momenta at each link.

  Calculate the Number Density

$$\mathbf{k}_\perp = \mathbf{P}_\perp + \mathbf{k}'_\perp$$

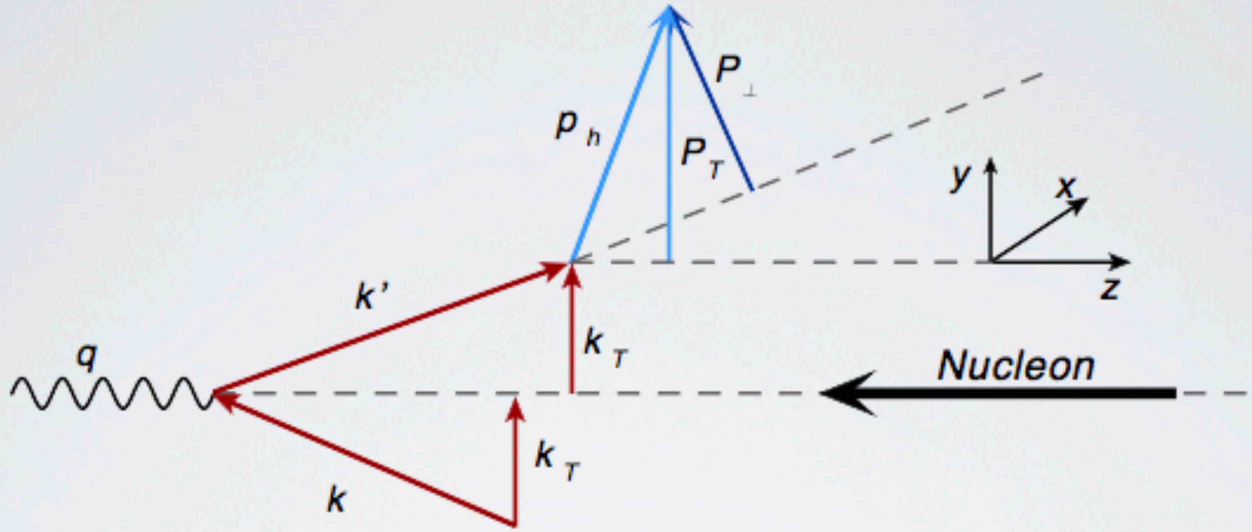
- Keep track of transverse momenta at each hadroniz. vertex

$$\mathbf{P}_\perp = \mathbf{p}_\perp + z\mathbf{k}_\perp$$



Slides from H. Matevosyan

THE TRANSVERSE MOMENTA OF HADRONS IN SIDIS

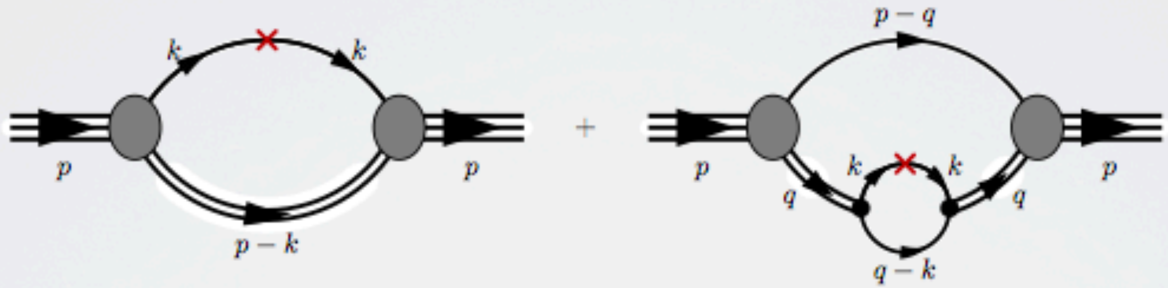


- Use TMD quark distribution functions calculated in the NJL model .
- Transfer of the transverse momentum: $\mathbf{P_T} = \mathbf{P}_{\perp} + z\mathbf{k_T}$
- Evaluate $\langle P_T^2 \rangle$ using MC simulations to calculate the number densities

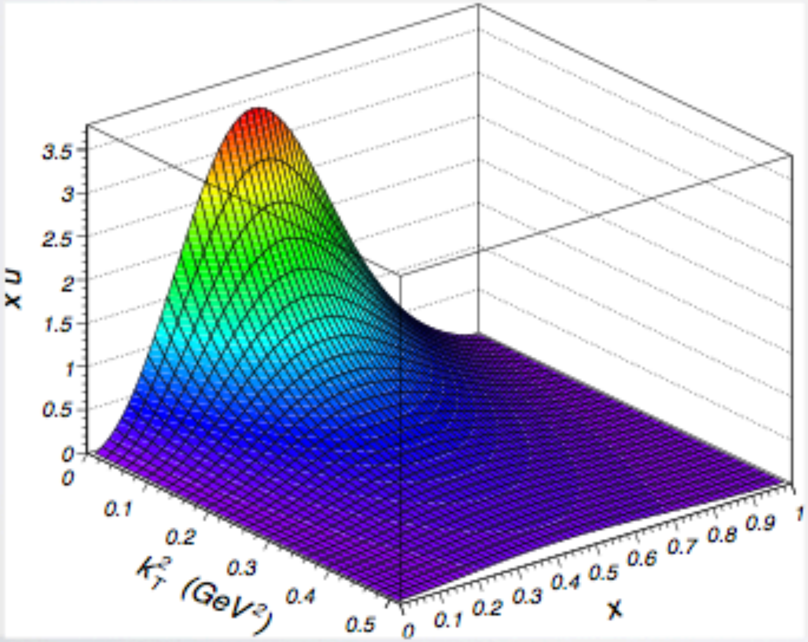
Slides from H. Matevosyan

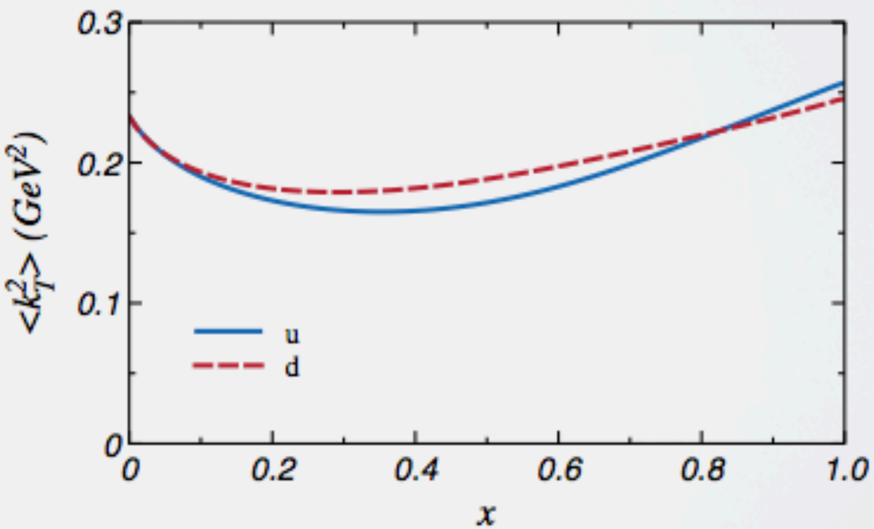
NJL-JET: TMD PDFS

- Quark-diquark picture: Nucleon from Faddeev Eq.



- TMD - quark flavor dependent, x - dependent!

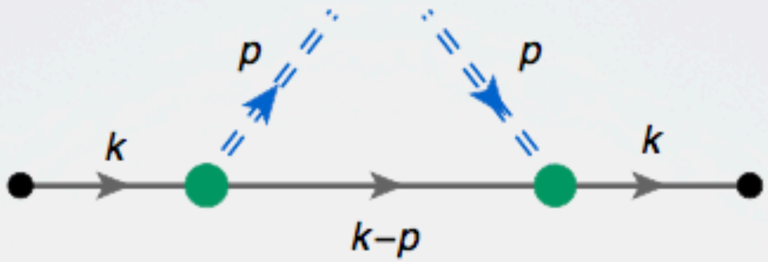




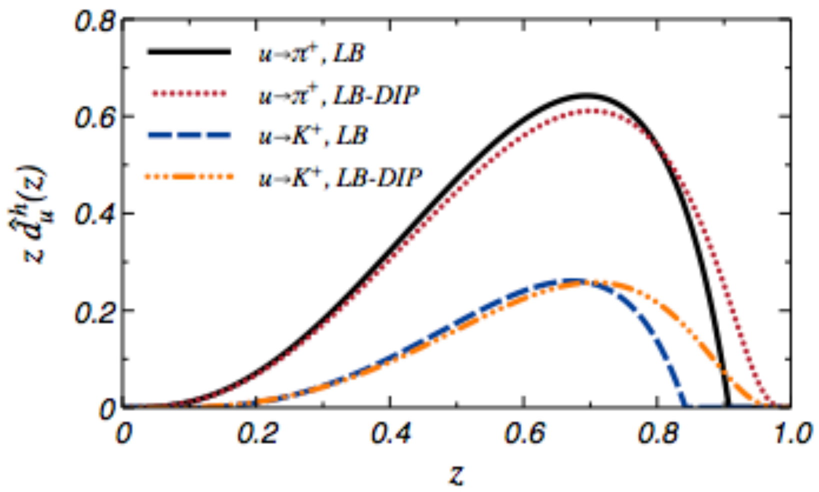
Slides from H. Matevosyan

NJL-JET: TMD SPLITTINGS

- One-quark truncation of the wavefunction:



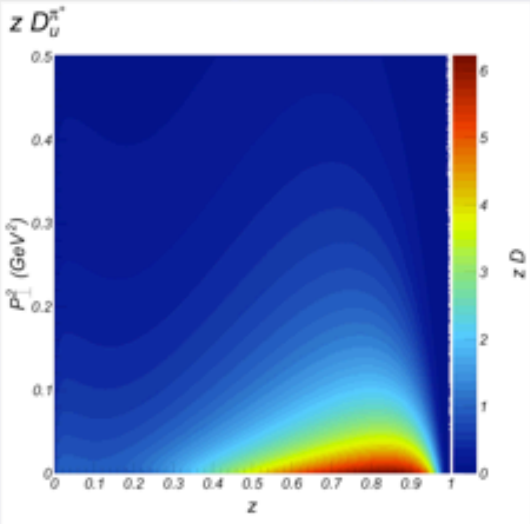
- Improving LB regularization with dipole cut-off (no new pars)

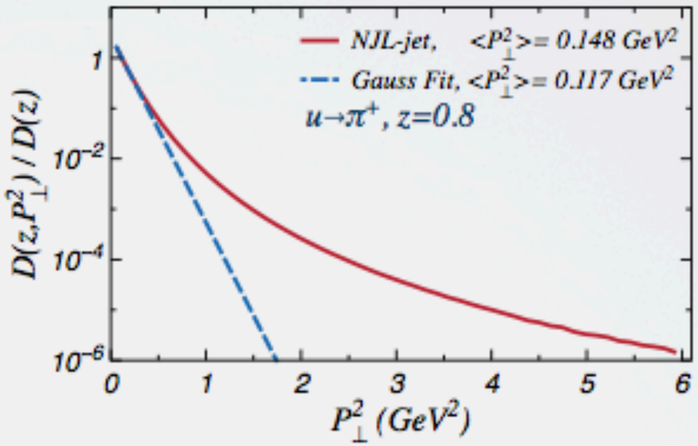


Slides from H. Matevosyan

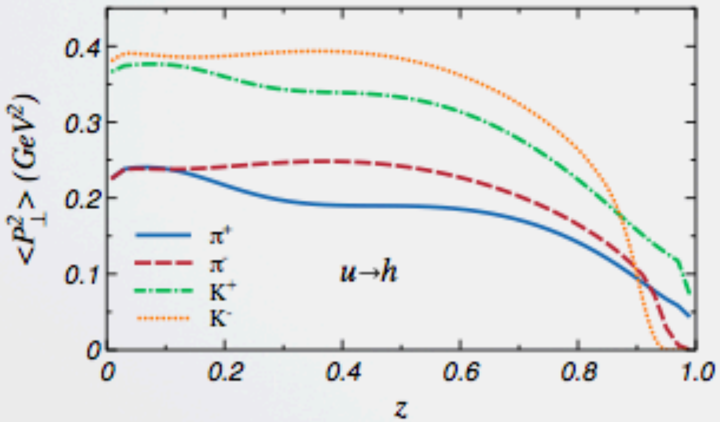
NJL-JET: TMD SPLITTINGS II

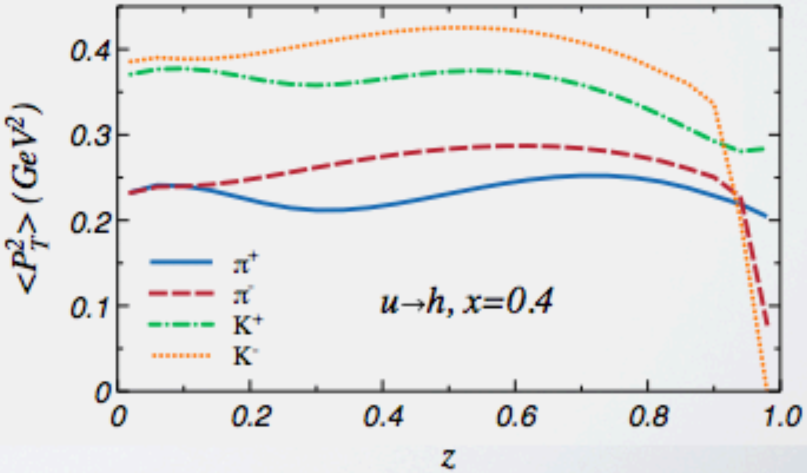
- Gaussian ansatz for a FIXED Z gives reasonable fit.





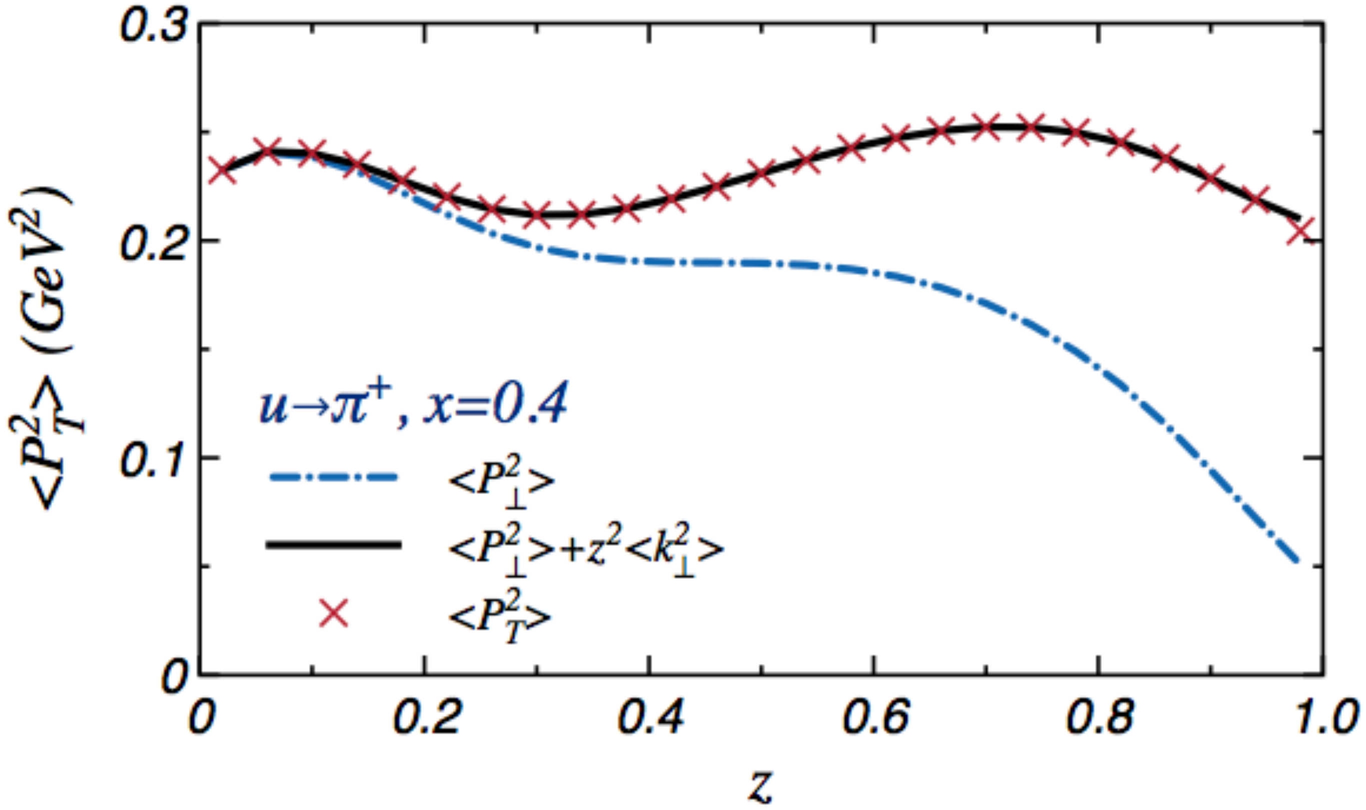
- Moderate z - dependence of TM, strong flavor and hadron type





AVERAGE TRANSVERSE MOMENTA

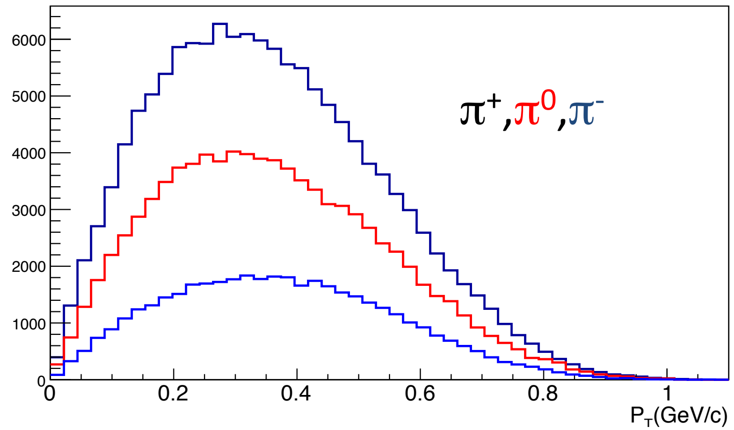
Slides from H. Matevosyan
arXiv:1111.1740 [hep-ph]

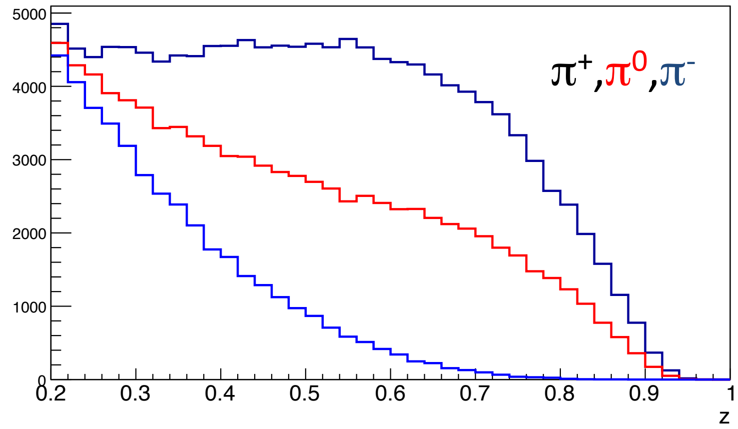


Input: $\mathbf{P_T} = \mathbf{P_\perp} + z\mathbf{k_T}$

Output: $\langle P_T^2\rangle(z,x) = \langle P_\perp^2\rangle(z) + z^2\langle k_T^2\rangle(x)$

Example for 6 GeV





Pions P_T and z distributions for CLASS 6 kinematics from NJL-jet MC

Conclusions/Outlook NJL-jet

- b) It accommodates PDFs and FFs with arbitrary transverse momentum dependence. Allows for quark flavor and produced hadron type dependence of TMDs.

- b2) Models the decay of the produced hadrons (for now only 2-body decays of rho, K* and phi).

- c) Can (and in the near future will) be extended to accommodate the angular momentum effects, TMD evolution, etc.

- d) Can be easily switched to become "generators for a single particle inclusive SIDIS" by setting the number of emitted hadrons to 1 and using the full FFs for the hadron emission vertex.

Conclusions/Outlook

- We need simple TMD event generator for single hadron production.
- We need string fragmentation (which will produce not only pions and kaons, also rho, K*, phi …). **arXiv:1111.1740 ?**
- We need consistent model/s which we can apply for all our experiments (Q2 evolution ?).
- We need to have standard as an input and output.