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Simulation of events with T-spins and TMD

Focus on a few problems.

1) new observable variables: hadron spins

2) new partially unobservable (and highly non-classical) variables: parton spins

3) new correlations (TMD) necessary to generate the new variables.

Inserting a new **observable** spin is **“easy”**:

1) assume that Pythia events are a complete sum of spin-up + spin-down events

2) separate them, and only use the subset you need

Remark: **“sticking” a spin value** on the proton requires an **accept-reject procedure** performed with the **full probability including TMD.**

Example:

I have a **huge Sivers function > 0**, and I want **proton spin-up 100 %**.

Pythia quarks have axial-symmetric k_T-distribution around the parent proton direction.

If I stick a spin-up to each initial proton, I find 2 subsets of events:

(a) proton spin up and rightward quark k_T
(b) proton spin up and leftward quark k_T

(b)-events must be more frequently discarded than (a)-events.

Internal spins are a much more complex matter.

In principle parton variables are not observable, but within parton model parton momenta behave like almost classical variables.

Example: assigning x does not forbid assigning kT

Spins are neither classical nor almost classical.
Assigning a longitudinal spin would forbid a transverse one and viceversa.

In some sense, along a chain of sub-events (e.g. a branching cascade) spins do not exist. We have tensor indexes that saturate along the chain:

$\mathbf{A}_{ij}\ \mathbf{B}_{jk}\ \mathbf{C}_{klm}\ \mathbf{D}_{ln}\ \mathbf{E}_{m}$ **……** (sequence of density matrixes)

Problem: Interference

Problem: Spin-related observables cannot be simultaneously assigned to all the partons.

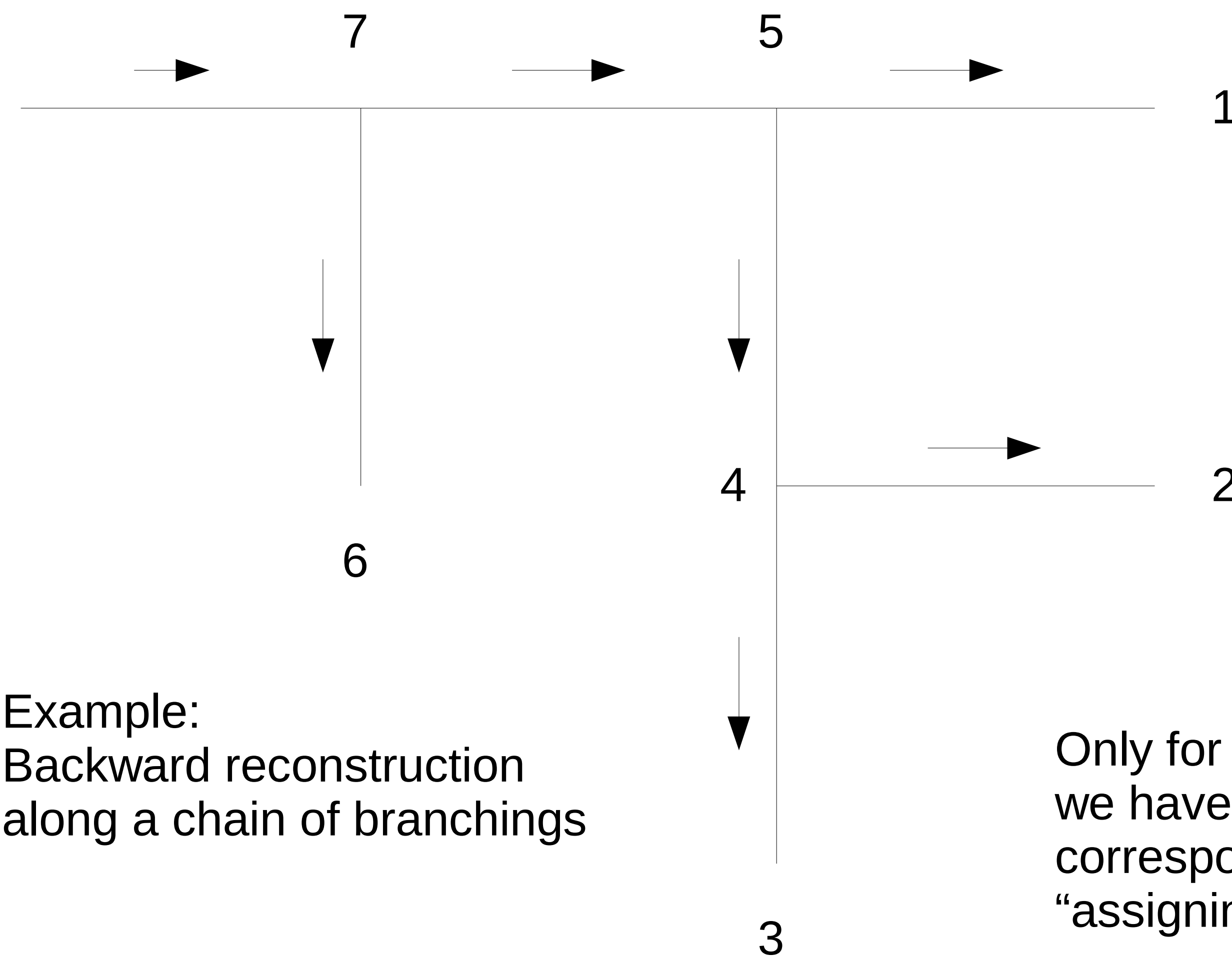
Example: a hadron decays into proton + antiproton + meson.
With some theory I find probability for correlated spins of p and pbar, but:

Observation of p spin changes the distribution of pbar spin.
We have “backward” propagation of a constraint on the probability for pbar spin.

Same but more complex mechanism, in the case of jets of many particles.

If I decide that somewhere a spin assumes a value, all the probability distribution in the rest of the process **including previous steps** and steps **that are not causally consequent to this one**, is affected.

J.Collins, NPB B304 (1988) 794 establishes a rigorous but complex method to work with intermediate state density matrixes. To avoid entanglement problems, density matrixes are backward-modified once some final spin-related observables are generated.



Example:
Backward reconstruction
along a chain of branchings

Only for some final particles
we have something
corresponding to
“assigning a spin”

Several steps in this chain become automatic, with only a part of the final
Initial or final spins random-generated.

Problem: the generation process of an event is much more complex.

Less proper but easier alternative: generating “physical” spins along the chain. This means

$$\mathbf{A_{ij}\ B_{jk}\ C_{klm}\ D_{ln}\ E_{m}\ \ldots\ldots \rightarrow\ A_{ij}\ (j{=}something)\ \ B_{jk}\ \ldots\ldots}$$

In some places along the chain the tensor structures “collapses” into a single random component.

two possibilities:

A) **±1** along a **randomly chosen** direction

B) a **continuous-orientation** classical vector with $\mathbf{|s|^2 = 1}$.

Suggestion by JC: when using this chain of spins, the order of generation must be the same as in the rigorous theoretical framework of NPB-1987.

This does not solve missing interference problems, but avoids entanglement problems.

At each branching A → B + C,
Take spin A from previous step
Generate B with a spin assuming C is not polarized
Complete the chain of decays from B
Backward reconstruct the spin of C
Generate the chain that is daughter of C
Go backward to A

In practics, spin of B is either fixed by conservation
or generated with 50 % probability,
while **for C only the spin probability is nontrivial.**

Rational background: in most cases the spin of a parton is not observable. but its correlations with other spins and momenta are.

Example: Drell-Yan with Lam-Tung violation given by BM*BM

BM is an ST-KT correlation:
for a given Ky, positive and negative Sx are not equally likely.

In an event with given Ky1 and Ky2,
a statistical correlation between the two spins to be generated is present and observable but
for each individual spin the physical probabilities of right or left Sx are equal, as far as we do not know the other spin.

So, when generating both Sx1 and Sx2, we are generating something that will be observed but also something else that nobody will ever be able to confirm or deny on observation ground.

Big problem n.1 for theoreticians:

How spin / tensor properties change along the chain of parton branchings

Related problem: the borderline between evolution and explicit parton branching

Big problem n.2: the spin properties of final hadronization steps.

Big problem n.3: interference: some of the observable are explicit interference functions
2 or more channels must be mixed (example rho-sigma)

Synthesis: **what is still missing are MODELS for the MC pieces. Once they are here, somebody will organize them.**