SIMULATIONS: DRELL-YAN AT LOW-INTERMEDIATE ENERGIES

Center of mass energy: some GeV – some tenths GeV

Problems with standard Monte Carlo codes:

Doubtful factorization, mix of different physical pictures

Vector resonances may be important or dominant or the object of the experiment

Fixed nuclear targets (with neutrons and Fermi motion)

Polarization and new structures are easily the center of the experiment

In this presentation my focus are **transverse polarizations** (of hadrons and of quarks) and non-default distribution functions (Transversity, Boer-Mulders).

Relevant general point:

High-energy physics (in borderline sense: LHC Tevatron etc) has created around itself an **economically rich environment** allowing for the specialization of several groups as **professional** “Montecarlers”.

Out of this environment, this is not imaginable.

It is not convenient for a group to spend all of its scientifical life producing and updating a multipurpose code whose main destination is to be used by somebody else.

This mecessarily limits the level and the ambitions of the available generators.

In particular, in the Drell-Yan case it is unthinkable that somebody builds from the scratch a new code that generates both the lepton-antilepton pair and the fragments with TMD and spins.

Two possibilities:

a) An “inclusive” generator: it produces the lepton-antilepton pair, but no fragments.
It may be fully phenomenological, or implement some parton-level physics.

b) An exclusive generator, producing a full event. In this case, an option is readapting an existing code like Pythia.

Acting on a pre-existing model and code (Pythia in the following), the simplest strategy is **not to modify this code at all,** but just print all the particles that Pythia has produced and work on them.

Codes like Pythia allow you to access all the properties of the observable and unobservable particles (quarks, diquarks, gluons, virtual photon, intermediate-state resonances) that have been generated in an event.

Define: "Bare" events: as produced by Pythia
"Dressed" events: after modification / filter

Two strategies: **Filter** and/or **change** events.

1) take a bare event.
2) calculate the **reweight** ratio: **sigma_new / sigma_old**
3a) using the reweight factor to **accept / reject** the event. If accepted, it is a dressed event.
The number of dressed events is smaller than the number of bare events.

Alternative (not to waste bare events):
3a) random-modifying the bare event into an attempt-dressed event
3b) accept/reject the attempt-dressed event only. If accepted, it is a dressed event.
3c) if the attempt-dressed event is rejected, another attempt-dressed event is generated from the same bare event, and so on.
The number of dressed events is equal to the number of bare events.

Let me **assume** that in a generator the phenomenology is **perfectly** implemented.

Apart for scalar particles, **unpolarized particles do not exist**.

Unpolarized target / beam =
50 % spin up
+ 50 % spin down
+ 0 % "no spin"

Assumption: even unpolarized MC events are
50 % events from spin up
+ 50 % events from spin down.

In principle I only need to **separate** events of the two kinds, not to modify them, to obtain events from spin up only.

In the following I stick myself to this principle, but it has two relevant limitations:

1) Phenomenology is far from being perfectly implemented, and this especially regards multi-particle correlations.

2) Parton spins are unobservable. So channels corresponding to different quark spins sum coherently, and often inside quantum loops.

Problem. **Spin assignments in the same or different points of an event must be reciprocally compatible.**

A random local assignment of spins may easily violate angular momentum conservation, or entanglement properties, or Heisenberg principle.

Spin is often “hidden”

The distribution of a group of final particles in an event, or the way parton branchings take place, gives me a partial access to the spin properties of a parent quark.
a) This may conflict with an explicit spin assignment.
b) Combining different such pieces of Information in an artificial event, I may implicitly assign values to the x, y and z components of the spin of the same particle.

An **exclusive multiparticle event** contains much more info than a DF*FF, or DF*DF, or FF*FF, structure.

If I have e.g. 10 final π^+ in a jet, each with FF H(z,kT,S)

Obvious generalization: H(1,2,3,....,10) = H(1)*H(2)*H(3)......*H(10).

If S is the **spin** of a **shared parent** (e.g. the spin of a special quark or hadron), this is **not correct**:

Each H(i) is linear in S, but H(1,2,3,....10) must be linear in S as well.

↓ ↓

H(1) = A + BS, H(1,2,3....) = C(1,2,3,....) + D(1,2,3,.....) S.

Possible exception: $B/A \ll 1$ → negligible nonlinear terms

The generalization H(1) → H(1,2,3,4,.....) requires a MODEL:
How information on a single spin drifts through the sequence of MC steps?

Implementation will use Bayes' theorem

H(1,2) = H(1)*G(2|1) ← first generate 1, and next 2 using 1. And so on for 3, ...

Drell-Yan at Compass or sub-Compass energies: a **simpler problem**.

In Drell-Yan **hard** gluon radiation does not **direcly** affect the hard process.

For S < 400 GeV^2 quark-gluon relevant cascades are rare: even if one is interested in spin effects on the hadron fragment side, the number of involved particles is affordable.

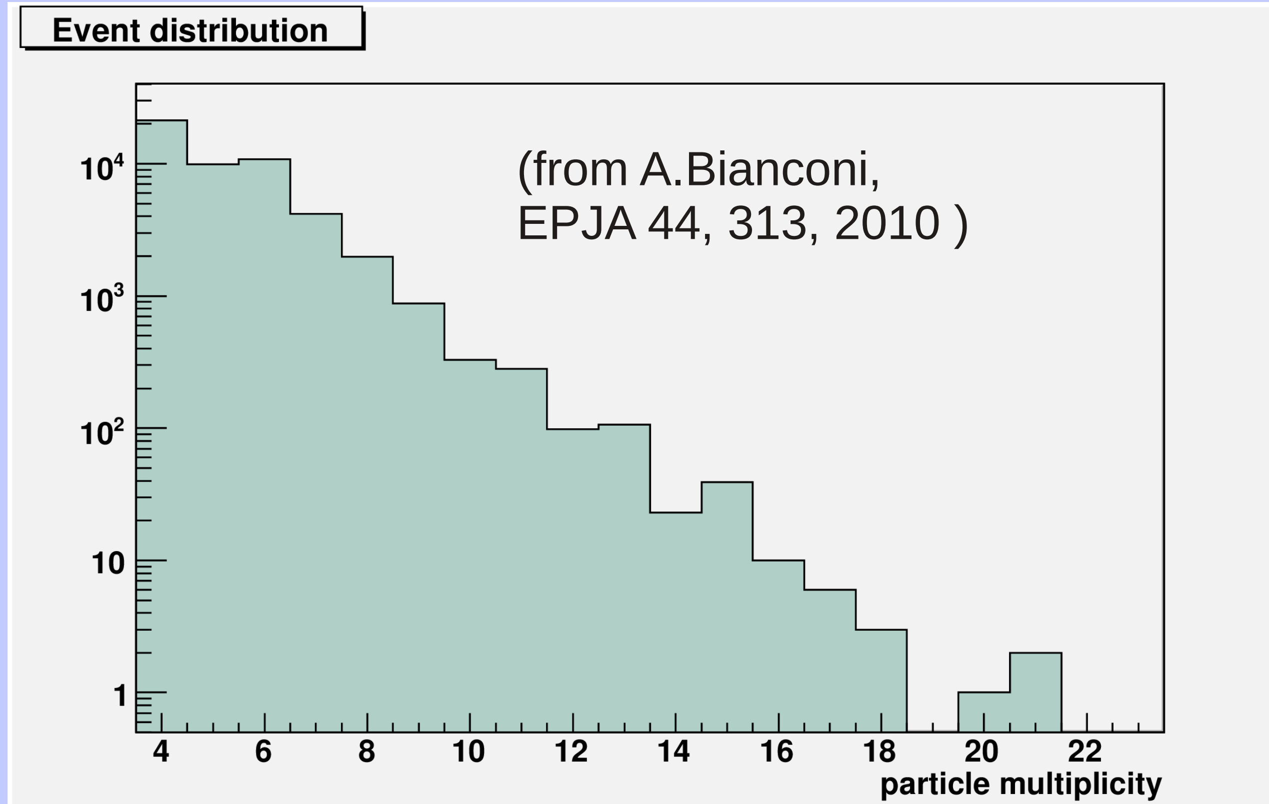
PANDA (s = 30 GeV^2)

Pythia simulation

The number of the fragments
Is very small

An N-Nbar pair is
always present

Almost **half of the events** are **dilepton plus N-Nbar only**



total number	50000
no (anti)baryons	179
1 N-Nbar pair	49805
2 N-Nbar pairs	16
1 p-pbar	21765
1 n-nbar	20078
mixed pair	7993

4 / 1000 of the total

half with no more hadrons
or hard photons

Ratio p-pbar : n-nbar : mixed = 11 : 10 : 4

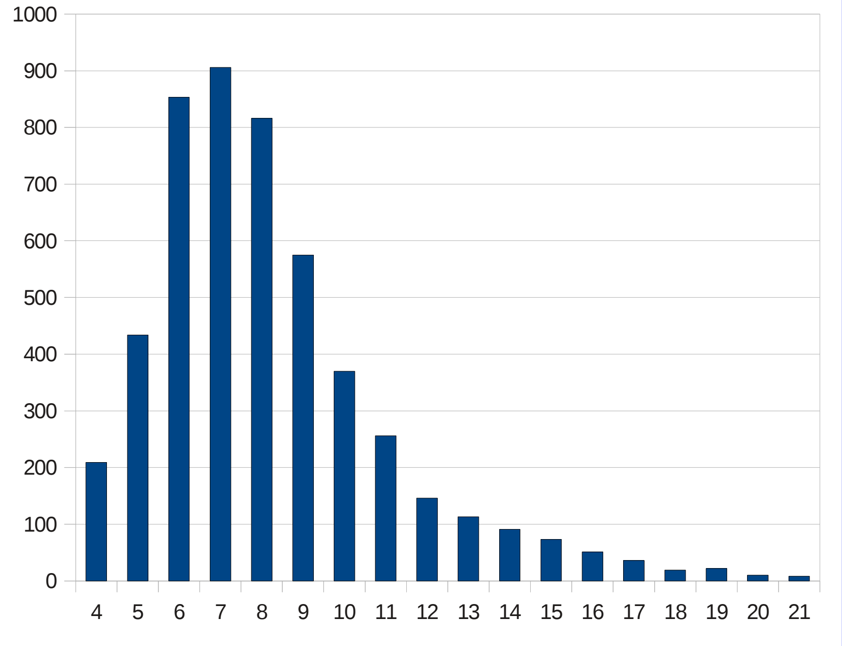
The first ratio means: u-ubar annihilation
+ 50 % / 50 % random creation of u-ubar and d-dbar pairs.

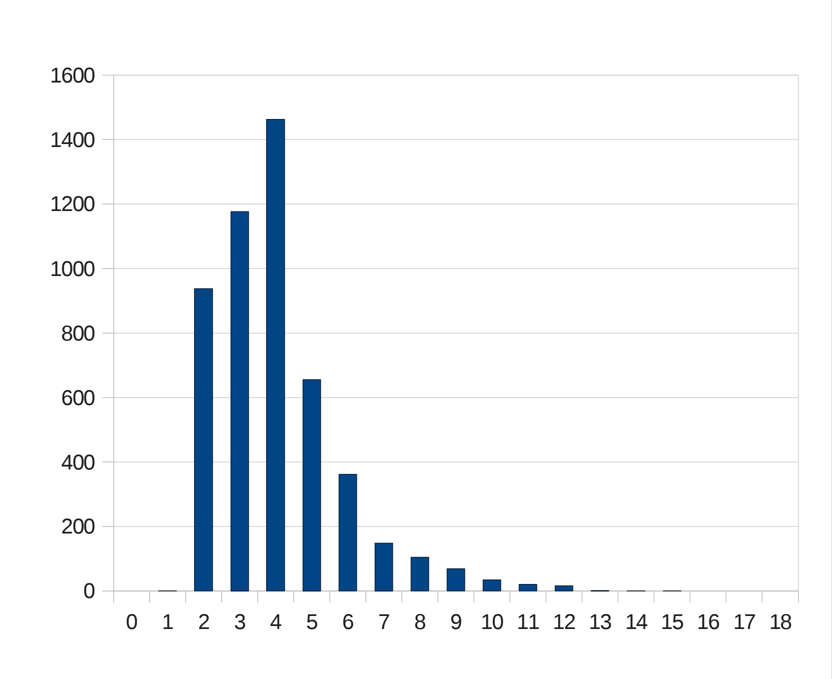
The rather complex Pythia machine in these events becomes very basic:
Quark-diquark splitting,
No gluons,
Final state pair creation with random relative (soft) p.

Antiproton-proton at $s = 100\ GeV^2$

Final multiplicity distribution

Final hadron multiplicity distribution





4	209	0	0
5	434	1	1
6	853	2	938
7	906	3	1177
8	816	4	1463
9	575	5	656
10	370	6	362
11	256	7	149
12	146	8	105
13	113	9	69
14	91	10	35
15	73	11	21
16	51	12	16
17	36	13	2
18	19	14	1
19	22	15	1
20	10	16	0
21	8	17	0

Detailed Pythia event analysis: 3 ranges

PANDA: plain u-ubar + basic recombination: final N-Nbar pair

COMPASS: 2 / 3 primary final hadrons (Baryons and heavy mesons)
decaying into NNbar + pions / photons

S > 400 GeV^2: higher-order Fok states, 1st-order QCD, cascading

For a given S, things simplify at larger Q $\rightarrow$ smaller multiplicity
(total fragment invariant mass $M^2 \approx (1- x_1)\,(1- x_2)\, S$)

My first attempts have regarded home-made MC codes for the low-energy side.
With these I have shown that lepton azimuythal asymmetries correspond to
fragment azimuthal asymmetries. (AB, Eur. Phys. J. A 45, 301-310, 2010)

Present step: spin-filtering Pythia events.

General example: **proton-antiproton, both partially T-polarized**, insertion of **Transversity** and **Lam-Tung-Boer-Mulders** effects, at **CM energy 10 GeV**.
Dilepton mass 4-9 GeV, no more cutoffs.

Basic steps:

a) Read an ordinary Pythia event, without any polarization.

b) On the ground of the proton **average** polarization along an axis, a proton spin +/- ½ is generated along this axis.

c) The hadron-quark splitting event must be associated with a transverse quark spin.
This is generated from the ratio $F(x,p_T,\mathbf{S_P},\mathbf{S_Q})$ / $F(x,p_T)$.
$\mathbf{S_Q}$ is a vector **orthogonal to the quark momentum, with <u>continuous</u> orientation**.
I adopt this policy with unobservable spins.
$F(x,p_T,\mathbf{S_P},\mathbf{S_Q})$ includes Transversity and Boer-Mulders contributions.

d) The same is done for the antiproton.

e) The event is accepted / rejected on the ground of the probability
$\mathbf{P_{hard}}$**(spins) /** $\mathbf{P_{hard}}$**(no-spins)**,
where P_{hard}(spins) and P_{hard}(no-spins) are the **qqbar → e+e-** cross sections calculated with / without specifying polarizations.

This may look simple, but the code doing this is 1054 lines long.

Details.

The **hard-event** cross setion must be used in the **parton cm** (where the virtual photon Is at rest), while the hadron-to-quark **splitting** “natural” frame is the **hadron cm** (the “symmetric collider” frame), and often the laboratory frame is a **target rest frame**.
So, Pythia hadron / parton / lepton momenta must be often boosted on and back.

At the present stage I have not distinguished uubar from ddbar events (the latter are 10 % of the total).

To increase the transversity effect, I have considered polarization 100 % for both proton and antiproton.

In this test phase, the Transversity function and the BM function have a simple form, that does not depend on x and $|\mathbf{P}_T|$.

It is a “soft correlation”: large values of these observables are more likely, but the preference is not very strong.

Transversity: Let Tr be the value of the quark polarization projected along the axis of the proton polarization, and P(Tr) a relative probability for this value, used to implement an Accept / reject procedure.

For $0.5 < Tr < 1$, $P(Tr) = 1$.
For $Tr < -0.2$, $P(Tr) = 0$.
For $-0.2 < Tr < 0.5$, P(Tr) grows linearly from 0 to 1.

Boer-Mulders term: Let BM be the value of $|\mathbf{S}_T \wedge \mathbf{P}_T|$ and P(BM) a relative probability for the accept / reject procedure.

For $0.3 < BM < 1$, $P(BM) = 1$;
For $BM < -0.7$, $P(BM) = 0$;
For $-0.7 < BM < 0.3$, P(BM) grows linearly from 0 to 1.

As an effect, this means a value of Transversity and BM of magnitude 0.1, because a large Tr **and** a large BM are **not compatible** once $\mathbf{P}_T$ and the proton spin have been assigned.
The standard “trade off” event has small $Tr > 0$ and small $BM > 0$.

Fast check of the lepton asymmetries, and matching with fragment asymmetries.

AB has shown (AB, Eur. Phys. J. A 45, 301-310, 2010) that

a) Lepton azimuthal asymmetries may be directly checked in the hadron center of mass frame, without analyzing events in the Collins-Soper frame.

b) In the same hadron c.m. frame, azimuthal fragment asymmetries correspond to lepton asymmetries.

The reason is that if a quark is produced in an “asymmetric” way, the corresponding recoiling diquark is “asymmetric” as well to conserve momentum in the splitting vertex.

BM asymmetry in the HCM:

Asymmetry w.r.t cos(2 phi)   phi = angle between $\mathbf{p}_{1T} - \mathbf{p}_{2T}$ and $\mathbf{q}_T = \mathbf{p}_{1T} + \mathbf{p}_{2T}$

The events where the (transverse component of) the virtual photon momentum and of the difference between the lepton momenta are parallel / antiparallel, are more / less frequent than the events where these 2-vectors are normal.

In my example I get 50,000 events:

26483 events with positive cos(2 phi) and
23554 events with negative cos(2 phi).

In the same event set I have 16,061 events with a proton-antiproton pair in the fragments. In this subset:

8089 ppbar pairs present positive cos(2 phi_p) and
6972 ppbar pairs present negative cos(2 phi_p).

The angle phi_p is calculated as phi, with the proton and antiproton momenta instead of the lepton and antilepton ones.

Transversity effect in the HCM: asymmetry in **cos (2phi – phi$_{S1}$ – phi$_{S2}$)**

If both polarizations are along the y axis, the argument of the cos is 2phi$_y$, the angle between **y** and the transverse vector **p$_{1T}$ – p$_{2T}$** in the HCM.

To be more selective w.r.t this asymmetry, I have restricted the dilepton events to those where **|cos(theta)| < 0.2**, since the effect of Transversity is proportional to **sin^2(theta)**. (theta is the virtual photonpolar angle). I find

3650 events with positive cos(2 phi$_y$)
3984 events with negative cos(2 phiy)

With **no cuts** and analysis on the proton/antiproton pairs, I find

7458 events with positive cos(2 phi$_y$)
7603 events with negative cos(2 phi$_y$)
With no cuts the asymmetry on dileptons is similar. This difference is at the borderline of meaningfullness (with 10000 events 1-sigma is 100 events).

I am studying cuts for ppbar. E.g., imposing |cos(theta$_p$)| < 0.4 I have 1969 vs 2040 events. (theta$_p$ Is the polar angle of the sum of the hadron momenta).

Work in progress. Thank you.