A. Bianconi: Simulation of event distributions in Drell-Yan experiments at intermediate energies.

Original aim of this research line:
to understand how many events we really have to collect to get to a certain level of information on some interesting distribution functions. M.Radici in his talk has reported about the development of this program.

Other correlated questions are:

> which ones can be the "best" conditions
> where it is most convenient to look for useful events
> which kinematical cuts can be useful or harmful.

My talk is devoted to these problems. No asymmetry simulations are shown, despite the goal of measuring them is always in the background.

If $H(x)$ or $H(x,kt)$ is the name of the function that we would like to measure, we may individuate different levels of knowledge:

1) To detect effects that are related with H.

2) To certify the existence of H.

3) To establish the magnitude of H.

4) To establish its dependence on x.

Each of these levels of knowledge unavoidably implies different answers to the above questions.
Presently the goal is level (2).
Here I assume that the focus of experiments in the decade 2010-2020 will be level (4), and work accordingly.

The MonteCarlo Event Generator has the general form:

1) **variables are sorted in mixed Collins-Soper frame / Hadron CM frame**

HCM frame random variables:

Tau, x_F (==> x1, x2: Tau = x1*x2, xf = x1-x2)

Pt (dimuon, or photon, transverse momentum)

and CS frame random variables:

Theta, Phi (single muon variables)

Phi_S (spin angles, when necessary)

The above variables form an **event.** They are random sorted, flat.

2) The event is **accepted / rejected** according to the **differential cross section** (described later)

3) **Transformation => muon variables in Hadron CM ("Collider") frame**:

E, Theta, Phi for positive and negative muon

4) **Transformation => muon variables in Fixed Target ("Lab") frame**.

The differential cross section has the factorized form:

$$K(...) * \frac{1}{S} * A(x1,x2) * B(Pt) * C(\Theta,\varphi,\varphi_S)$$

K(...): “k-factor”, i.e. the lager where all the data that do not obey the theory are confined.
B actually also depends on x1, x2 and C on x1, x2 and Pt.

The measurement of C is the goal.
A and B can be taken by available phenomenology, as far as 1/S scaling is really respected.

Event distributions through the available phase space are determined by the product K*A*B / S.
Angular Collins-Soper frame asymmetries by C.

Basic references for the measurement of K, A, B:
J.S.Conway et al, PRD39, 92 (1989)
(DY by 252-GeV negative pions on Tungsten)
E.Anassontzis et al, PRD 38, 1377 (1988)
(DY by 125 negative pions and antiprotons on Tungsten)

They report **systematic and detailed tables of data**, allowing people to reproduce K(...) A(x1,x2) B(Pt) as they measured it .

I must regret that such an extensive presentation of results is not the rule, after experiments.

The $C(\Theta,\varphi,\varphi_S)$ factor is different for the cases of no polarization, single or double polarization, and is taken in part from the previous papers, in part from theoretical models, in part from pure hypotheses. Another talk is centered on it, so I will not discuss related problems anymore.

Problems with the measured differential cross sections:

We have to hope that distributions measured at $S > 250\ GeV^2$ scale in a predictable way at the lower S concerning us presently.

K(...) is assumed to be a function of Tau only and ranges from about 2 (lower and medium Tau, several events) to about 4 (large Tau, scarce events). We don't know what K should be at another S.
We may only HOPE that the value K = 2 is still good at the same Tau but lower S.

The transverse momentum distribution is very different in the two quoted experiments for Pt < 1 GeV/c. This confirms that data at such small Pt originate in soft physics and should not be included in Drell-Yan measurements. We always employ a lower cutoff at 0.5 or 1 GeV/c. But Conway's and Anassontzis' differential cross sections do include all such events, whose weight is more or less 50 % at each value of the x1,x2 pair. Perhaps if a Pt cutoff had been adopted, the reported differential cross sections would be different.

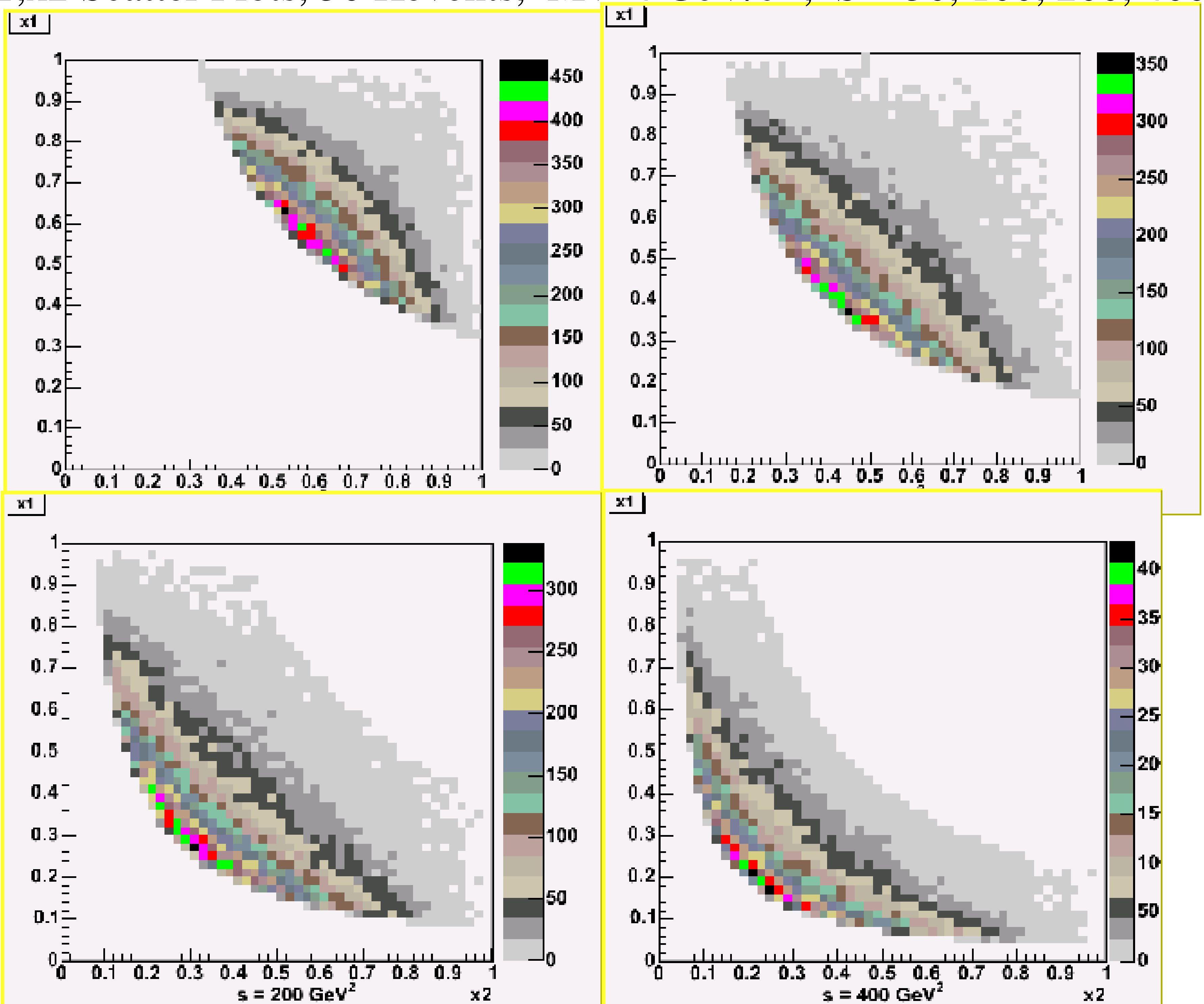
I will show a long series of event scatter plots and distributions.

Normally they have been calculated with the cutoff Pt > 0.5 GeV/c.

The other cutoff is on the dilepton invariant mass M, and is explicitly reported in each figure.

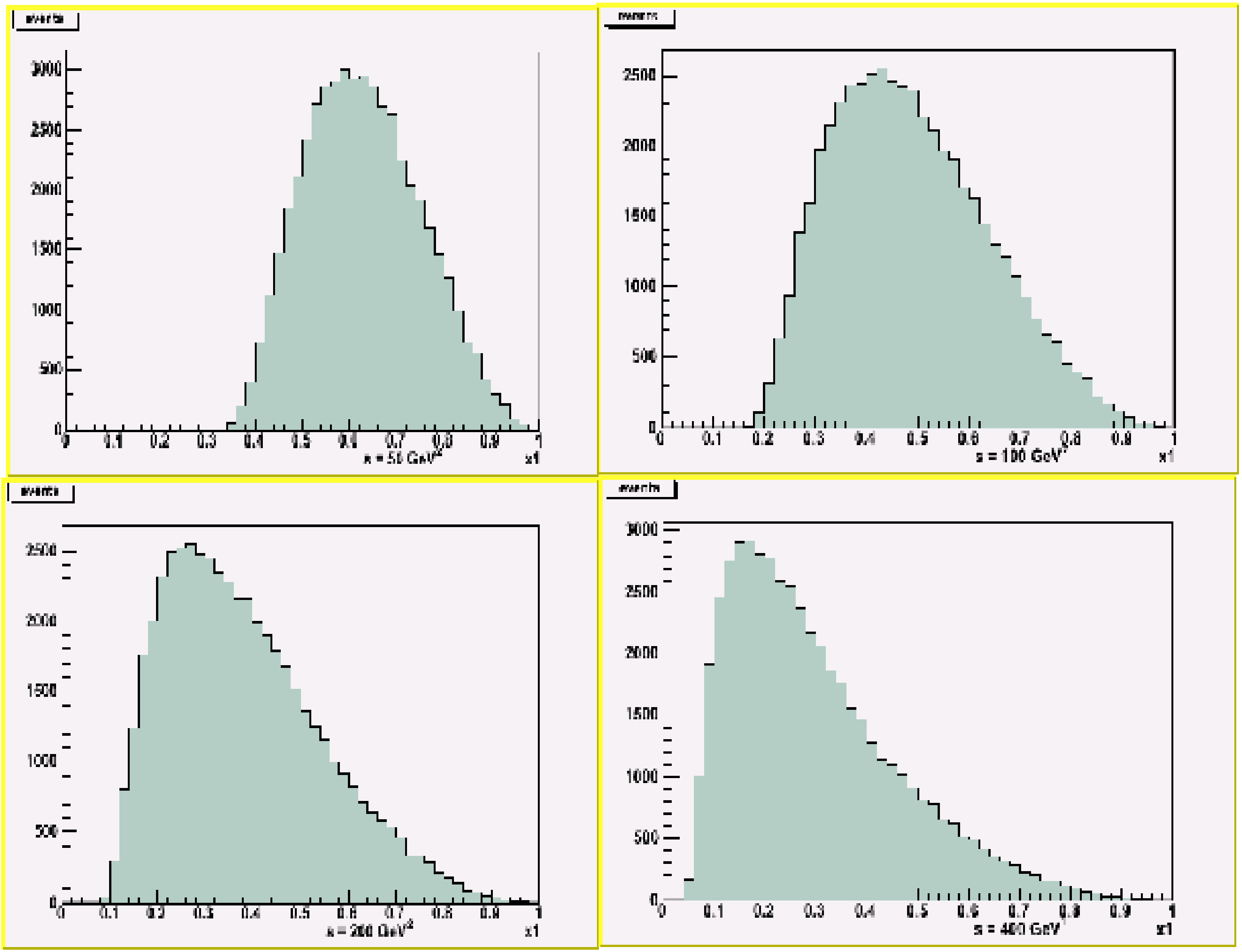
In our asymmetry distributions also some cutoffs on Collins-Soper angles were applied. Such cutoffs are not present in the distributions that I show here.

x1,x2 Scatter Plots, 50 Kevents, M > 4 GeV/c^2 , S = 50, 100, 200, 400 GeV^2



X1 event distributions after X2-integration 50 K events

M > 4 GeV/c^2 S = 50, 100, 200, 400 GeV^2

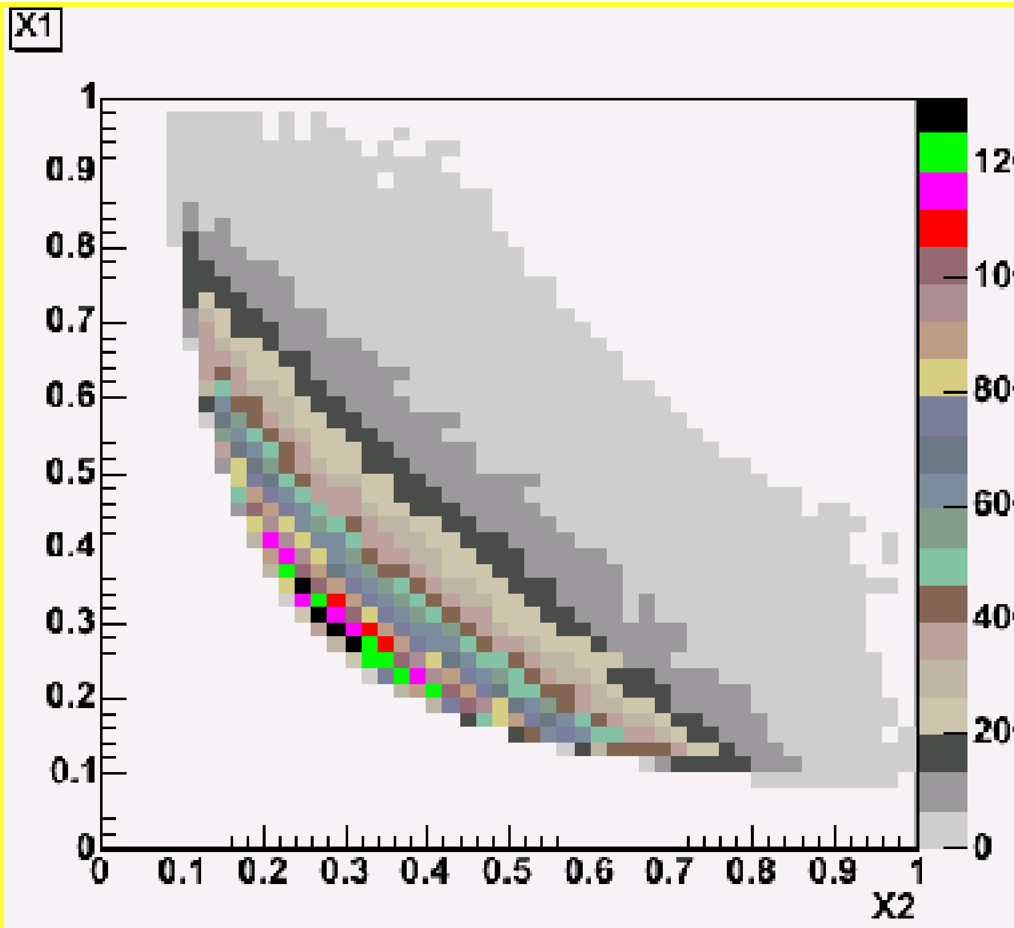


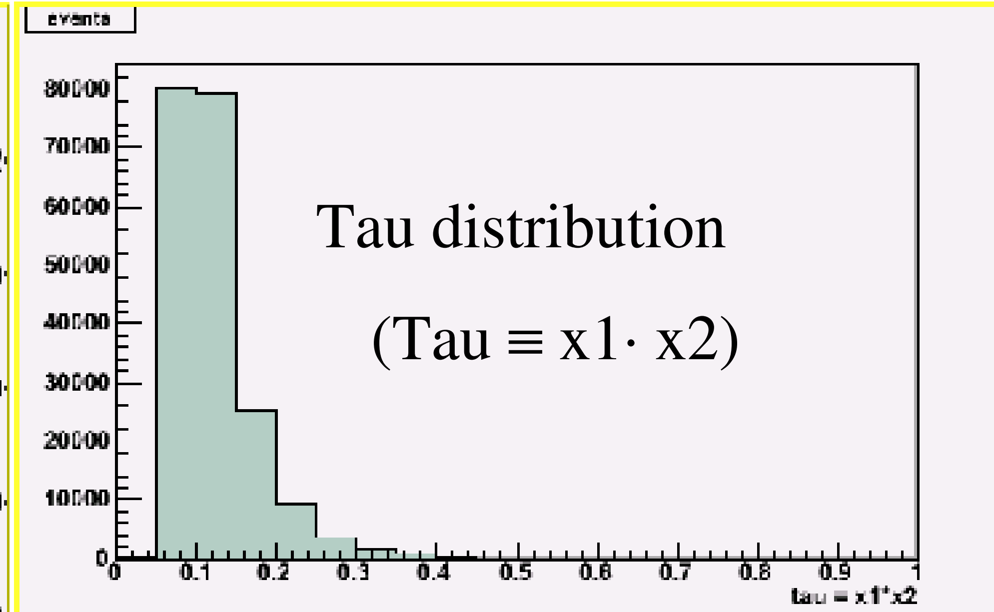
S	Peak X
50	0.45-0.8
100	0.25-0.65
200	0.15-0.5
400	0.08-0.4

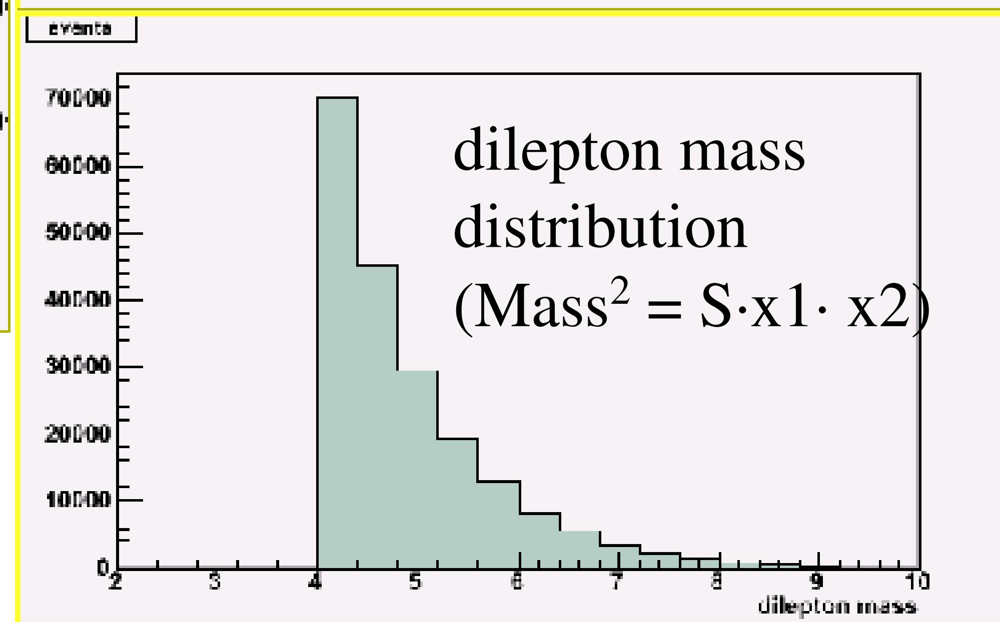
In all cases effective x-ranges **0.3 – 0.4** units

200 K events at S = 200 GeV^2 ; M > 4 GeV/c^2

REMARK: **93 %** events in the x1·x2 range 0.05-0.2 => M range 4-6 GeV/c^2



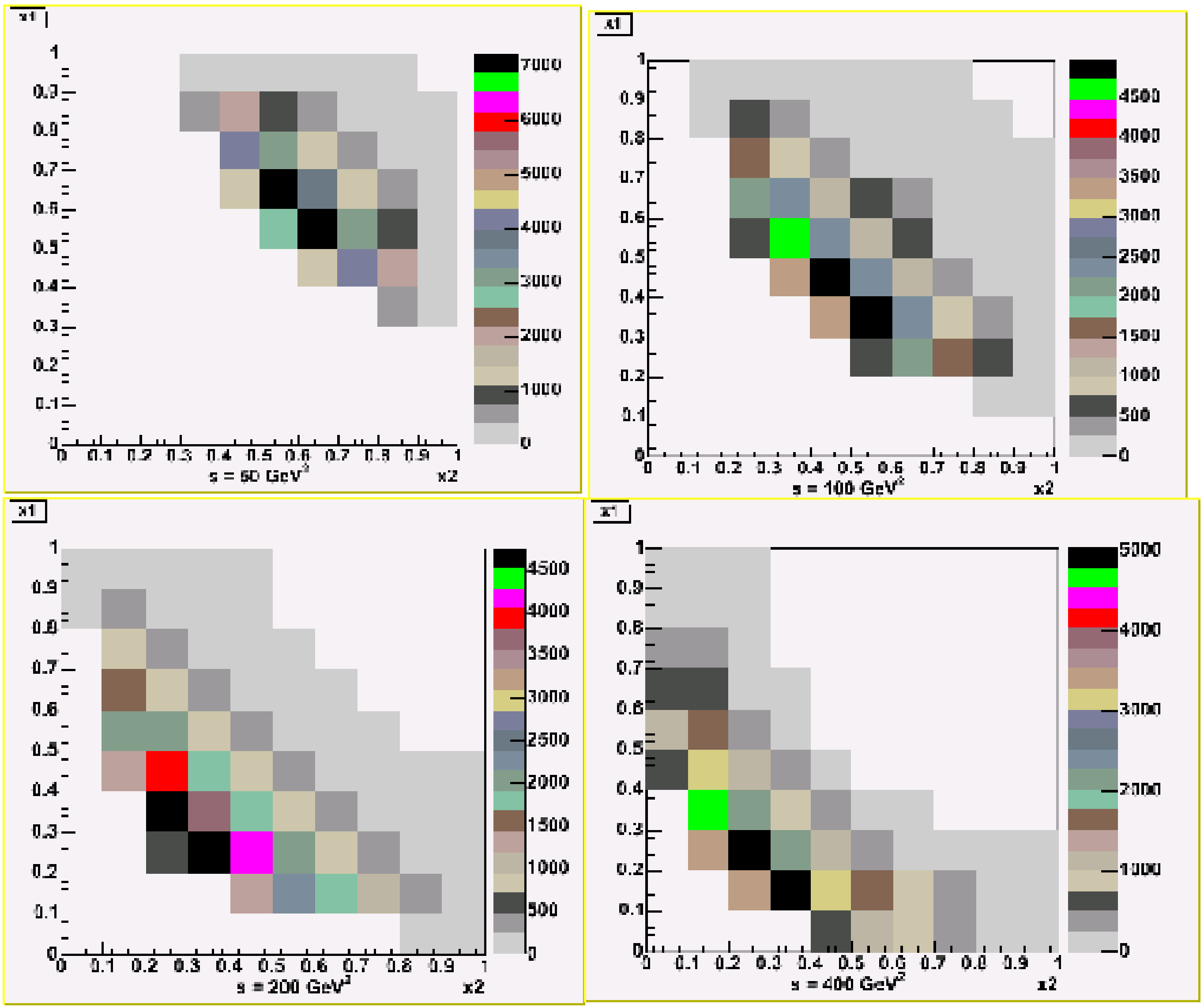




Despite appearances, **effective event space is ≈ one–dimensional**:

x1·x2 ≈ constant ≈ lowest mass / S

Distribution of 50 K events in $(0.1)^2$ x1-x2 ranges. Assuming 10-30 K events survive further cuts, squares with mid-range colors (dark-green / blue) represent a borderline for asymmetry analysis.



Relative **collection times** for events filling the scatter plots:

S	time
400	1
200	2
100	5.6
50	19

for S < 50 this time increases enormously.

Remark 1:

Collection times relative to the **full** phase space may be misleading: as far as scaling is respected, the best option to fill a **single x1x2-range** with small size is the **lowest possible energy that satisfies the condition $\mathbf{M > M_{cutoff}}$**

E.g., for analyzing x1, x2 pairs in a region corresponding to $x1 \cdot x2 \approx 0.25$, with lower mass cutoff 4 GeV/c^2 the condition $M^2 = S \cdot x1 \cdot x2 > 16$ fixes $S > 64\ GeV^2$.

The optimal choice is $S = 70\text{-}80\ GeV^2$.

A smaller S may leave a part of, or all, the requested events below the mass cutoff.

A larger S is worse because of the x1,x2 dependence of the scaling distribution $f(x1)f(x2) / M^2$:

$M^2 \propto x1x2$,

f(x) decreases at increasing x, for $x > 0.3\text{-}0.5$.

Remark 2:

If the goal is **not** to explore a given x1x2 region, but to collect **as many events as possible (no matter where they are) in the shortest possible time** (100 events can be exchanged with 1 liter gasoline) then **the larger S the better**.

Remark 3:

The effective shape $x1 \cdot x2 \approx$ constant of the phase space puts a **serious obstacle on the extraction of a function H(x) from a "diagonal" product of the form H(x1)H(x2)**.
(e.g. H can be transversity in double polarized Drell-Yan).

Example: $H(x) = x^n$, so that $H(x1)H(x2) = x1^n x2^n$

if $x1 \approx \text{constant} / x2$

then $H(x1)H(x2) \approx$ constant.

The choice $H = x^n$ is a extreme case, but the behavior is general and is confirmed by simulation of fixed S experiments: in the (small) region where error bars allow for a clear identification of an asymmetry and of its value, the x-dependence of this asymmetry is small.

Remark 4:
All the previous arguments suggest that measurements at **several S values** are necessary to explore the x-dependence of a function H(x).

How long time is needed?

For S = 60-200 GeV^2 the total cross section has magnitude 0.01-0.1 nb/nucleon with M > 4 GeV/c^2
(the exact values depend on the other cutoffs, like Pt-cutoff).

0.1 nb means 300 events/month with luminosity 10^{30} $cm^{-2}s^{-1}$.

10,000-50,000 events are needed (see M.Radici's talk).

So a **luminosity 10^{31} $cm^{-2}s^{-1}$ is the borderline**: with a smaller luminosity two (or more) generations of scientists are necessary to carry on the experiment.

Also, a comparison with previous experiments (like Conway et al) is misleading:

Most of them used very thick Tungsten targets => several orders of magnitude larger rates than in the experiments we may be interested in here.

Remark 5: The mass problem and the Panda case.

What can we do in a case like Panda where S is 30 GeV^2 ? This means:

1) < x1 > or <x2> have magnitude 0.8 for mass > 4 GeV/c^2.

2) the cross section is 0.0004 nb with the same mass cutoff (although concentrated in a very small phase space).

Possible alternative strategies:

1) begin teaching hadronic physics to my small 11-month old babies;
2) find something important at both x1 and x2 near 1.
3) give up with the mass cutoff 4 GeV/c^2.

Why do we need the M > 4 cutoff?

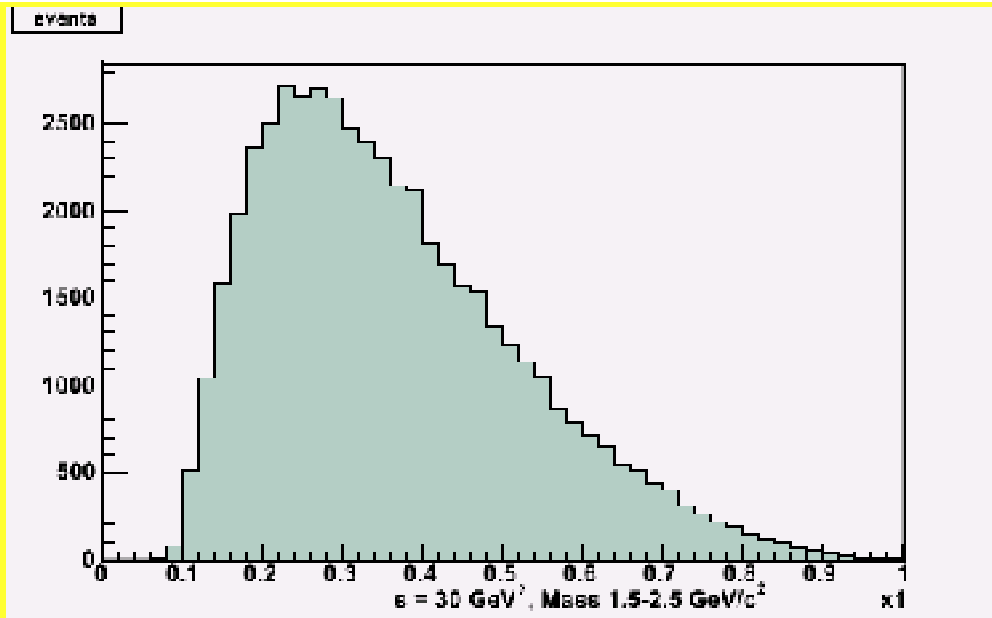
To avoid higher twist effects, and to have a quark-lepton coupling that is flat, smooth and dominated by the virtual photon exchange. But... do we get all this by the M > 4 GeV/c^2 cutoff?

1) The average dilepton mass between 4 and 9 GeV/c^2 is about 5 GeV/c^2. If a typical higher twist term contains the coefficient $M_{nucleon}/M_{dilepton}$ this means 20 % contamination.

2) At S = 100 GeV^2, the mass cutoff 4 GeV/c^2 has the consequence that half of the events have x1 > 0.5. The same is true for x2. Drell-Yan events or hadron annihilations accompanied by production of a few pions?

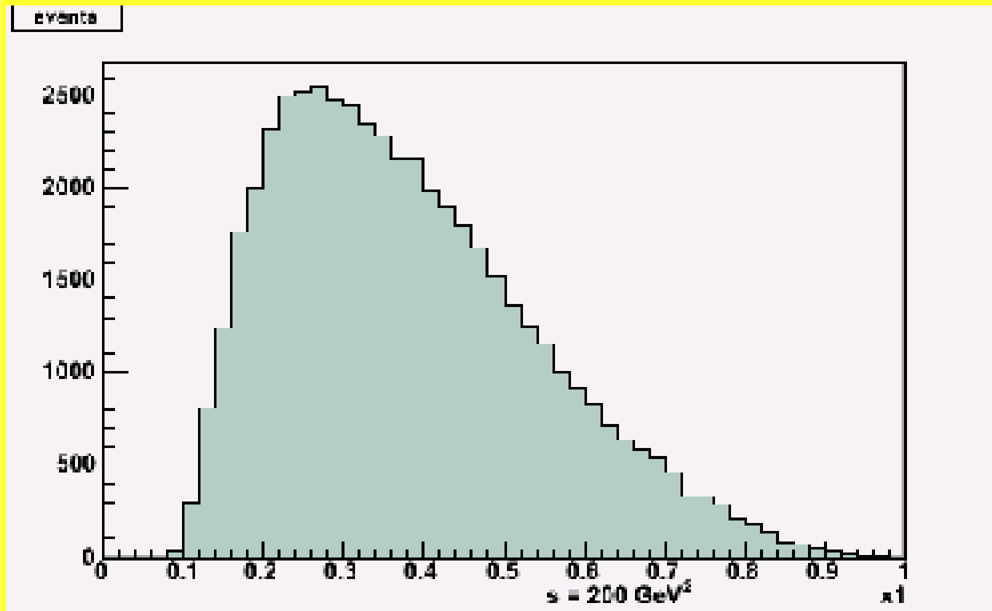
3) The e^+e^{--} --> hadrons cross section between 4 and 9 GeV/c^2 is not flat at all, despite free from narrow peaks or sudden thresholds.

x1 distributions of 50 K events in a low mass range for PANDA compared with a more "ideal" situation



$S = 30\ GeV^2$
$1.5 < Mass < 2.5\ GeV/c^2$

cross section: 1 nb



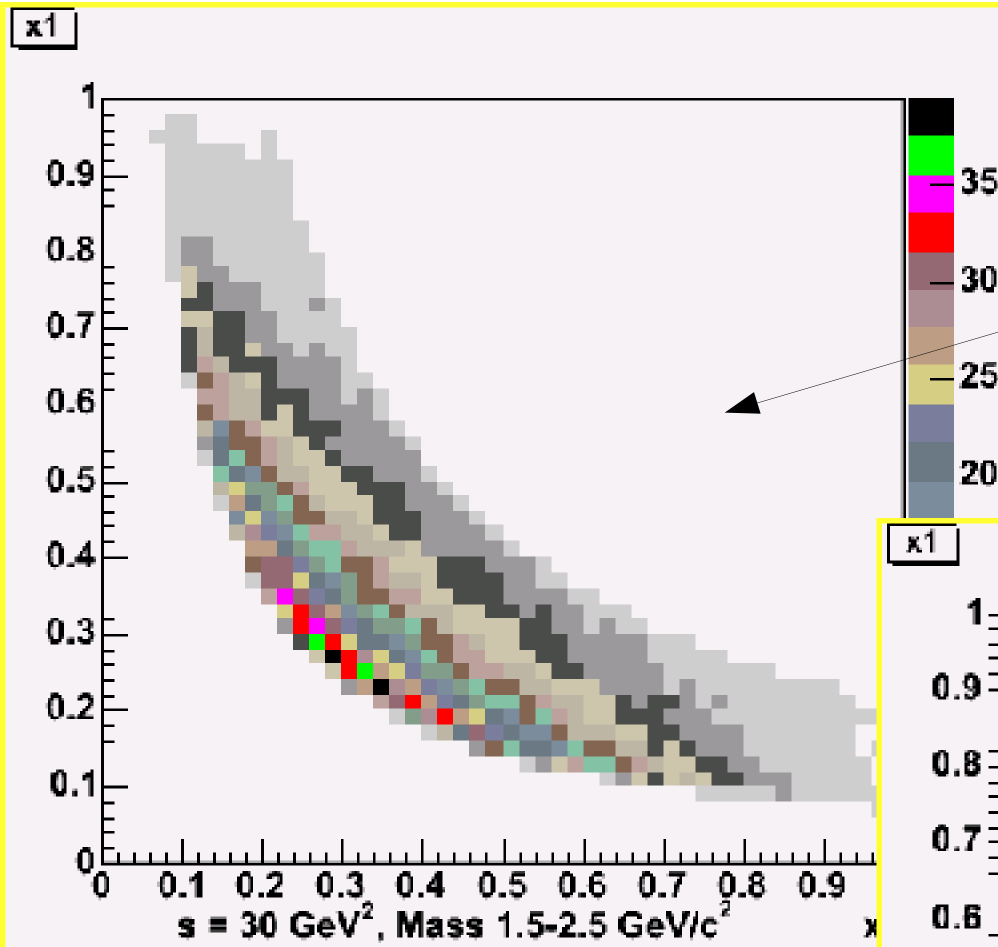
$S = 200\ GeV^2$
$Mass > 4\ GeV/c^2$

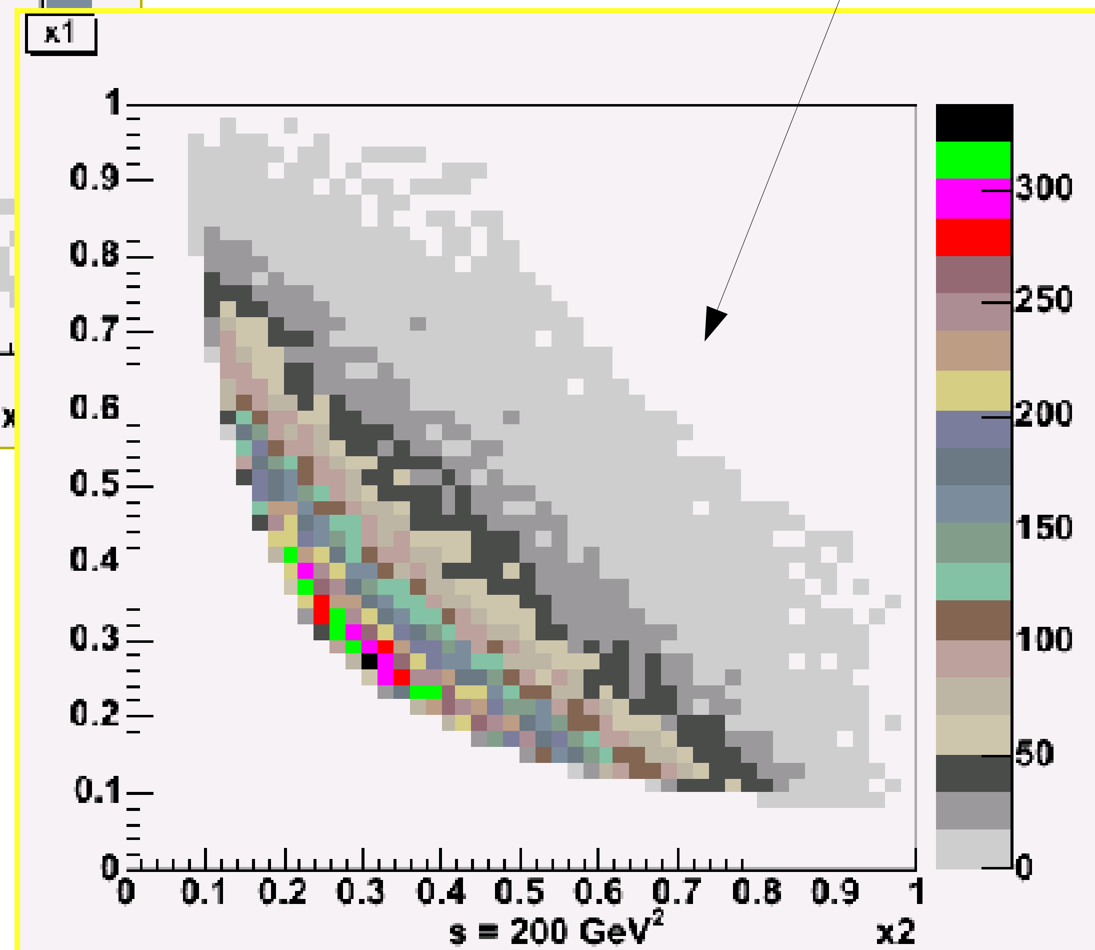
cross section: 0.1 nb

The corresponding x1x2 scatter plots.

S = 30, mass 1.5-2.5

S = 200, mass over 4





What could mean to collect events in the low mass range 1.5-2.5 Ge/c^2 ?

1) From a “pragmatic” point of view, the advantages in terms of cross section are evident: orders of magnitude. Months instead of generations.

2) Higher twist effects associated with small mass are stronger: the nucleon/dilepton mass ratio is 2.5 larger than in the M > 4 case.

3) Higher twist effects related with large x have the same magnitude than in the S = 200, M > 4 case, and are smaller than in all the cases with M > 4, S < 200.

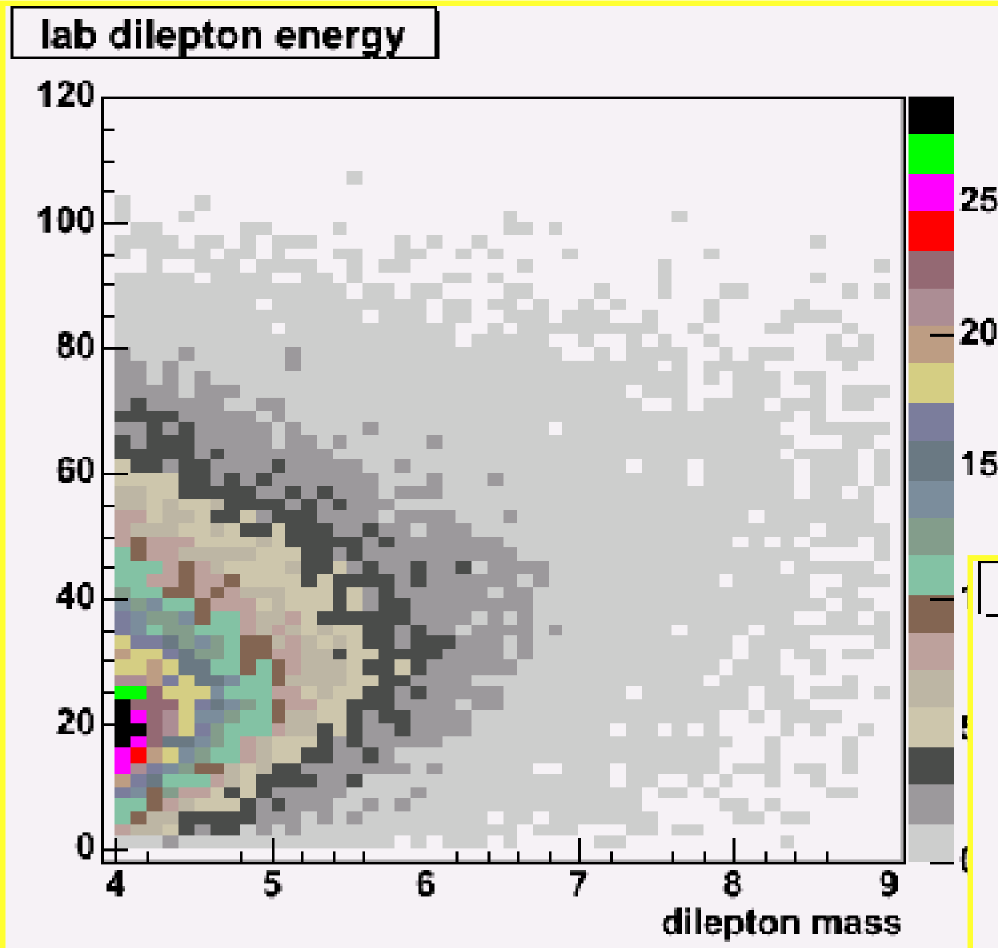
4) The e^+e^{--} --> hadrons cross section is less flat in the 1.5-2.5 than in the 4-9 mass range. Not such a difference, however.
And neither of the two is as flat as the parton model would like.

The conclusion is that **data in the two different mass ranges 1.5-2.5 and 4-9 GeV/c^2 should be compared**, at least for $S < 200$ GeV^2.

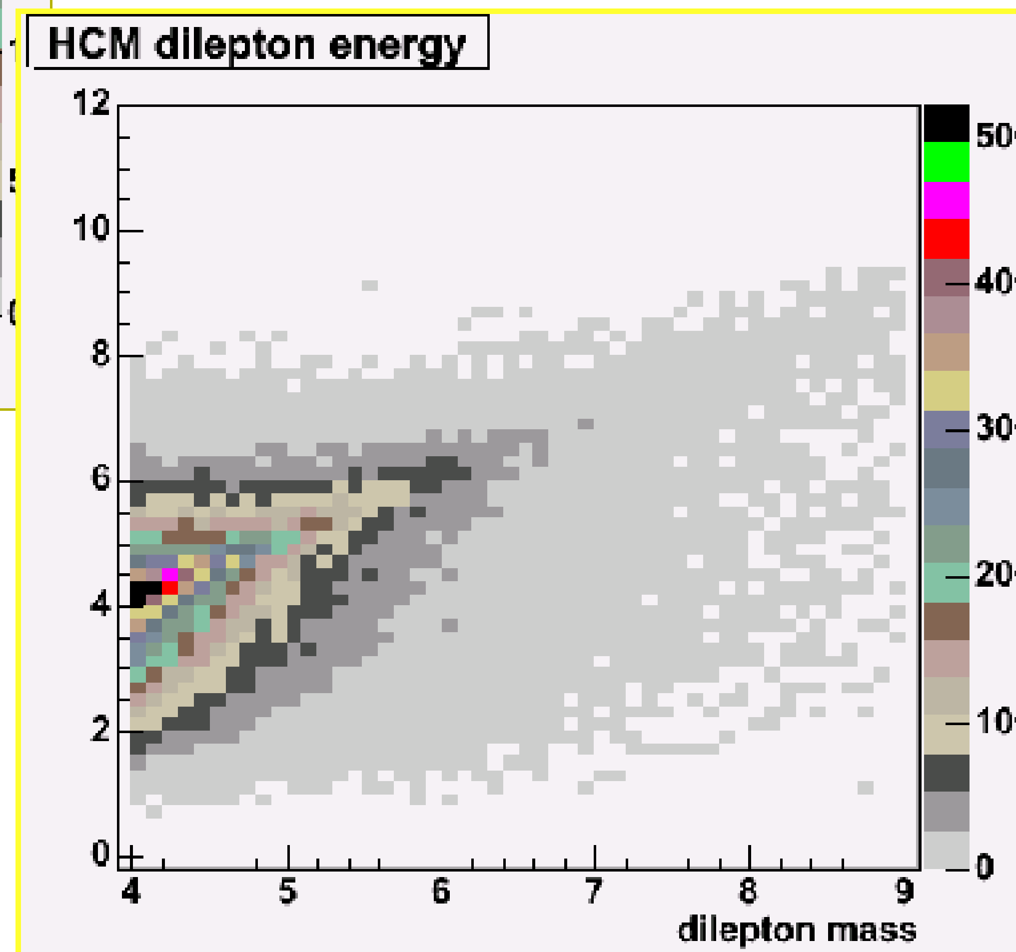
In a case like PANDA there is no alternative to the small mass range choice, apart for a small-rate analysis of the large x1,x2 region.

But where both ranges are accessible, this comparison is **zero-priced**: only later time software may distinguish large and small dilepton masses since the spectrum of the muon energies in the laboratory frame is largely independent from their invariant mass.

Concerning higher twist effects, the main danger is the low mass in one case, the large x1, x2 in the other one. Hopefully a comparison could unveil both.
We remind that the effective mass range of the $M > 4$ region is just 1-2 Ge/c^2 units -> too narrow to separate $1/M^n$ terms with different n.



Correlation between the dilepton mass and its energy for $S = 200\ GeV^2$



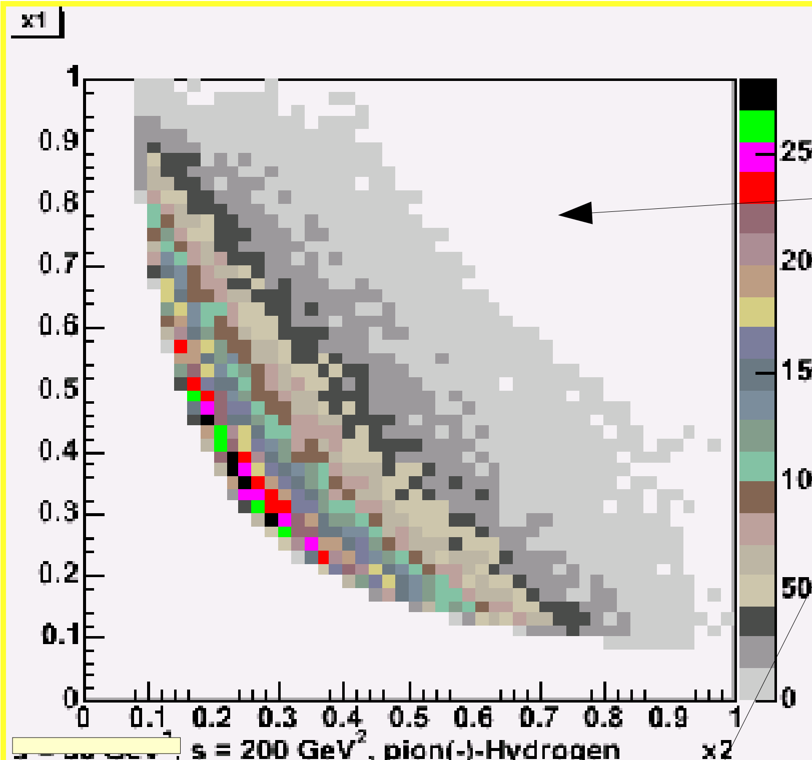
Remark 6: antiprotons or pions?

The rather long time
that the youngest of us have to wait for GSI's Drell-Yan to be operative
caused recently a rising of the quotations of gasoline and of COMPASS
pions.

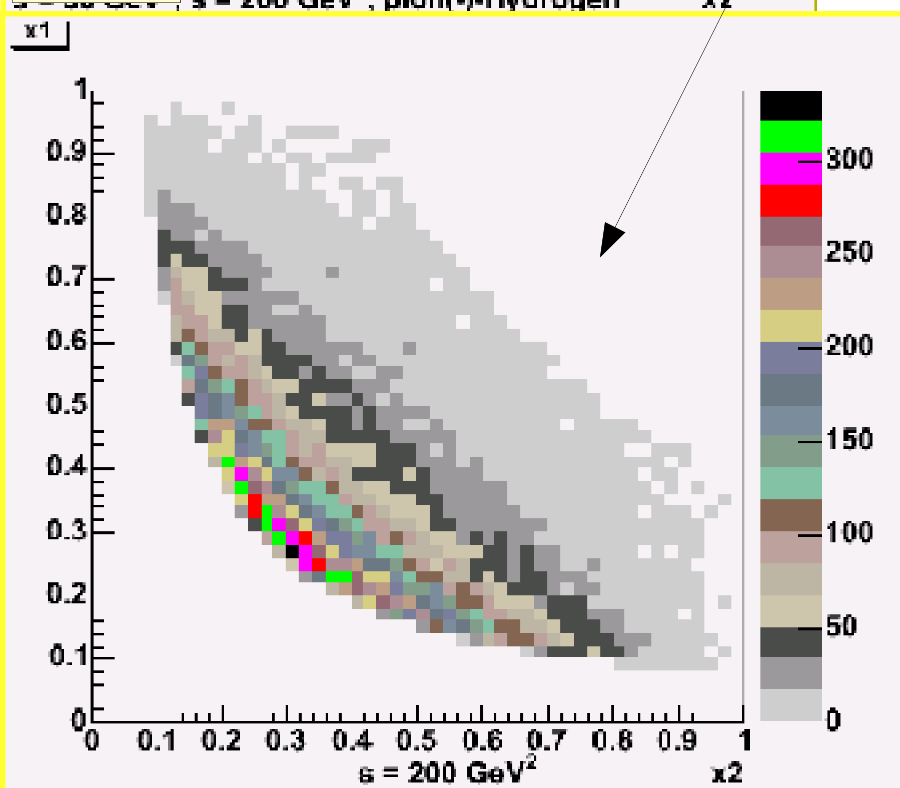
Cross sections: according to the measurements by Anassontzis et al
on negative pions and antiprotons at 125 GeV,
antiproton-nucleus and pion(-)-nucleus total cross sections are almost
the same, with some differences in phase space distribution.

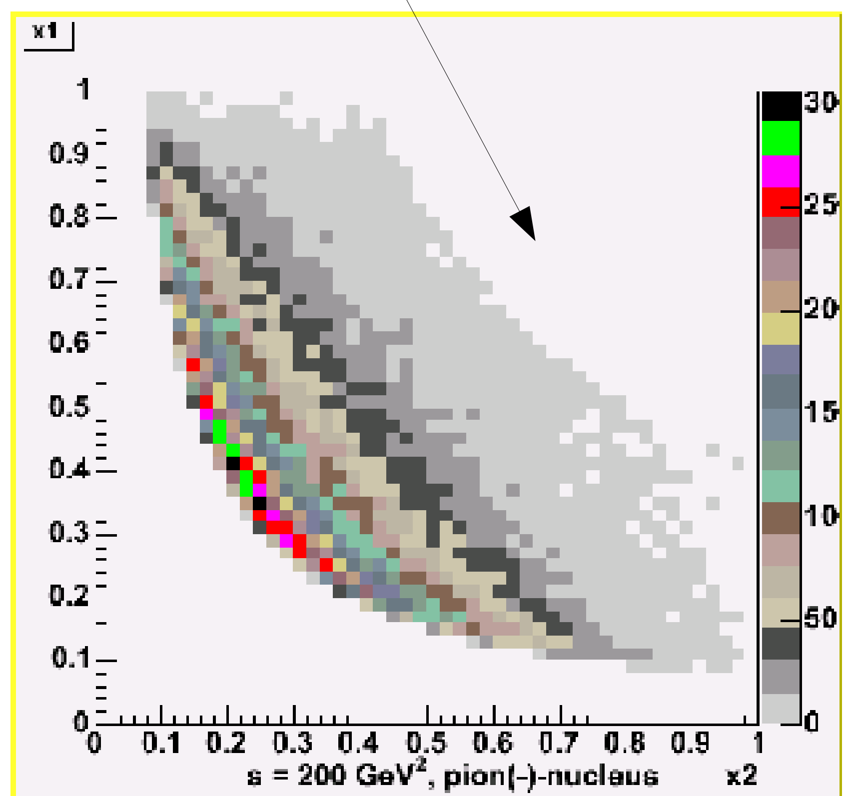
Main disadvantage: a double polarization experiment is impossible.

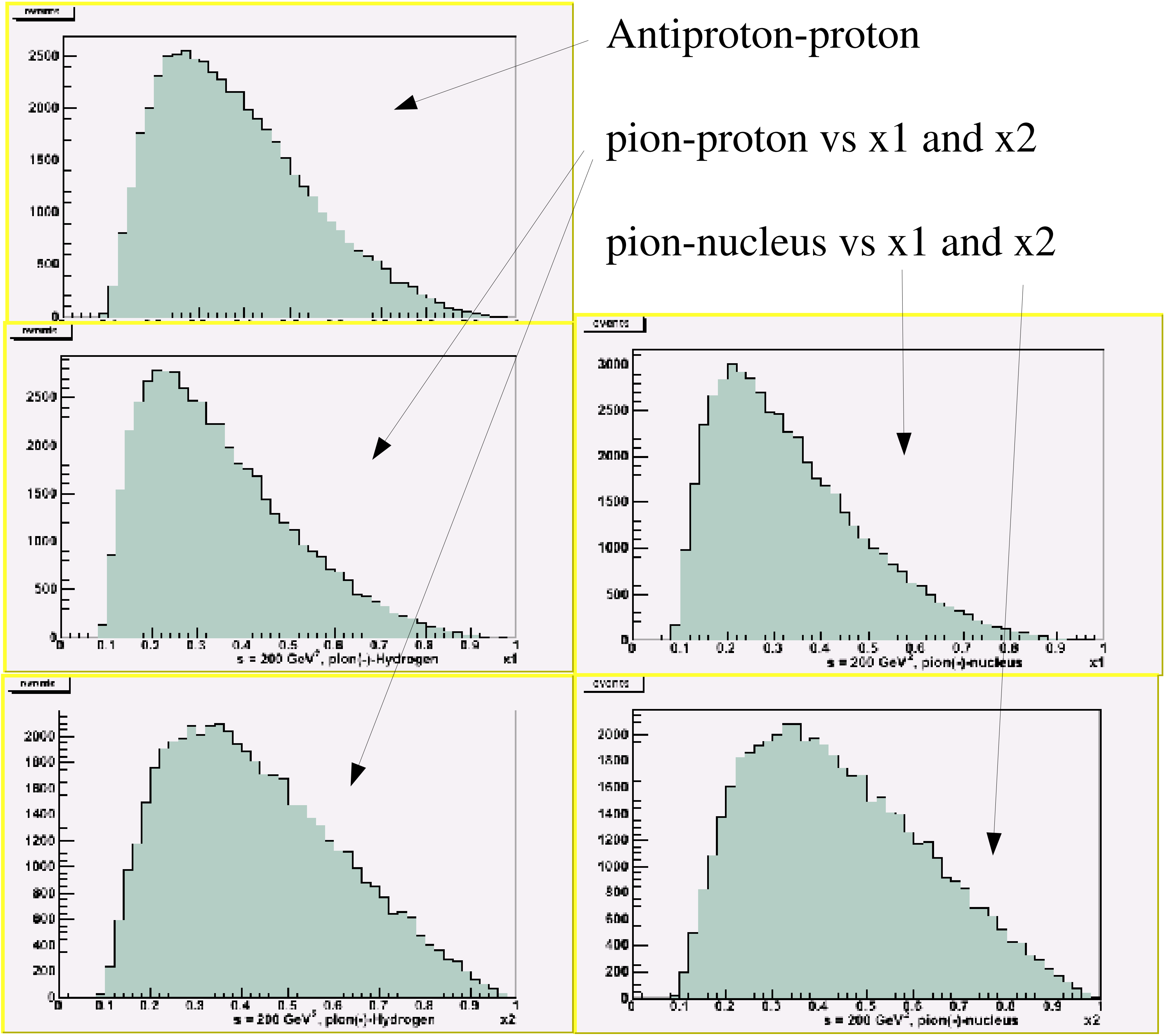
Main advantages:
i) it is a concrete possibility, not a dream.
ii) S may **be changed** up to 200 GeV^2. This permits a wide phase space
exploration.



Pion-proton,
antiproton-proton,
pion-nucleus (Z/A = 0.5)
$S = 200\ GeV^2$,
50 K events each.






Antiproton-proton
pion-proton vs x1 and x2
pion-nucleus vs x1 and x2
x1
x2