The dimuon physics continuum
An update

The contributions to the dimuon spectrum above 1.5 GeV are open charm, Drell-Yan and open beauty.

Goal : Extract all contributions from the dimuon experimental spectra.

Means : Use the shape (slope) of their mass distribution as a discriminating variable.

June 21, 2004, Sébastien Gadrat for the LPC, Clermont-Ferrand.

Outline

Five sections for this talk:

- ✓ *Preliminary Study: first simulation estimate* of the slope of open charm and Drell-Yan and *discrepancy* between these slopes and those extracted from data.
- ✓ *Study* of open charm, Drell-Yan and open beauty *production* with *PYTHIA*. Comparison to data and/or theoretical expectations.
- ✓ *Higher statistics simulations* and improvement of the *shape functions*.
- ✓ The *response functions* of the muon arms to Drell-Yan and open charm signals.
- ✓ Conclusions and outlook.

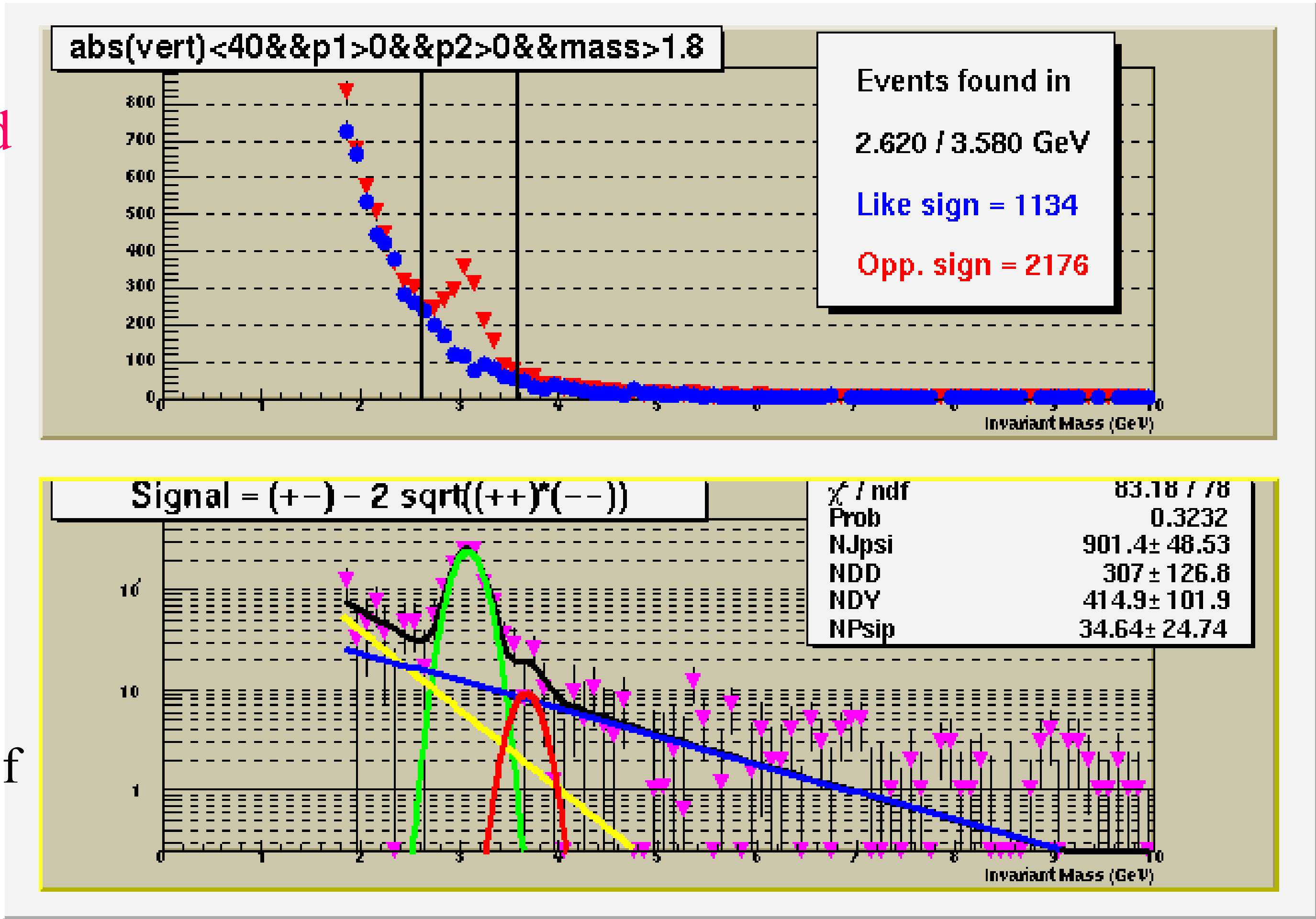
Fitting the dimuon spectrum (I)

The reconstruction (with preco and pro.35) of small PYTHIA-PISA samples of open charm and Drell-Yan (~10k events each) gave us MWG.root files. The slopes obtained from the fit (with one exponential) have been used to fit north arm d-Au dimuon data (december 2003).

J/Ψ and Ψ ' contributions are fitted with a gaussian.

Open charm (yellow)
Slope = (1.82 ± 0.07) GeV^{-1}
Drell-Yan (blue)
Slope = (0.64 ± 0.02) GeV^{-1}

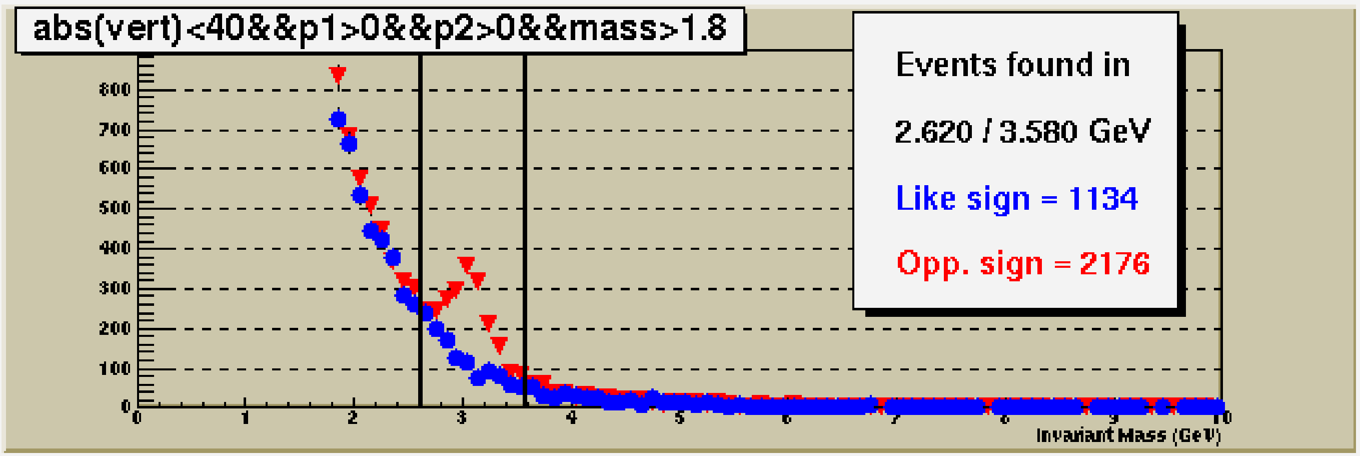
The free parameters of the fit give the number of dimuons from each contribution.

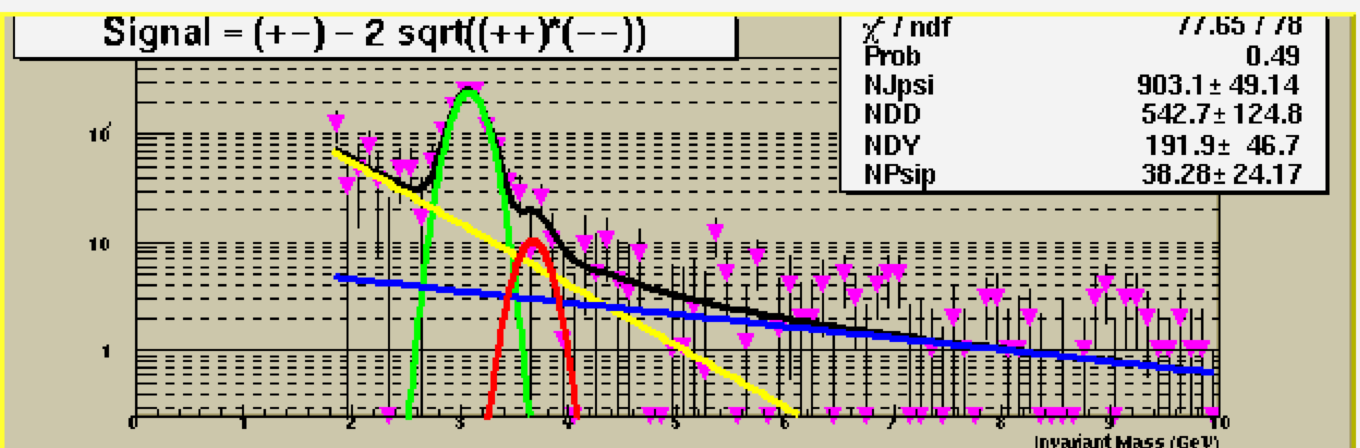


Fitting the dimuon spectrum (II)

The slopes are now obtained from the data. For the Drell-Yan, it is obtained by assuming that for high mass (> 6 GeV) we only have Drell-Yan contribution. Then we can deduce the Open charm slope from the low mass region .

⇒ These slopes appear to be less steep than the simulated ones (previous slide).





For Open charm :
Slope = (1.3 ± 0.1) GeV^{-1}
(previous was 1.82)
For Drell-Yan :
Slope = (0.25 ± 0.02) GeV^{-1}
(previous was 0.64)

The Drell-Yan number is about half than for the previous slide and the DD number become here almost twice.

Conclusion from this prelimianry study

- ✓ Discrepancy between simulated slopes and those extracted from data not understood:
  - Need to check the PYTHIA simulation for open charm and Drell-Yan versus data and/or theoretical predictions (this study will also give systematics errors for the slopes).
  - Possibly some open beauty contribution above ~3 GeV.
- ✓ Need to get higher statistics samples for both open charm and Drell-Yan:
  - Improvement of the fit functions and their parameters.
  - Since Drell-Yan exhibits a tail at high mass, Drell-Yan production will be done in two parts (first part for mass < 4.3 GeV and the second one for mass above).

Open charm production with PYTHIA

- ***Start point***: the set of parameters that was used in the single electron paper (*PRL 89, 082301*), already tuned to low energy data.

- ***Comparison to higher energy open charm data*** from Fermilab (*The CDF Collaboration, FERMILAB-PUB/03/217-E*):
  - ✓ production of the charmed mesons is underestimated by about a factor of 2;
  - ✓ the shapes in p_t distributions are consistent within about 20 to 30 %.

- ***Systematic study of the most relevant open charm production parameters:***
  - ✓ width of the k_t (gaussian) distribution from 1 to 3 GeV;
  - ✓ comparison to NLO PDF (CTEQ5M1);
  - ✓ addition of some NLO processes (flavor excitation, gluon splitting and parton showers);
  - ✓ the c quark mass.

    ⇒ Only the c quark mass had an effect on the slope of the mass distribution, beyond the statistical accuracy.

⇒ *Thus we kept all the parameters values of the single electron paper (including the c quark mass).*

Drell-Yan Production compared to theoritical expectation

Theoritical DY $d\sigma/dm$ distributions in pp collisions @200 GeV C.M. (using NLO PDF CTEQ 6M) were provided by Ramona Vogt.

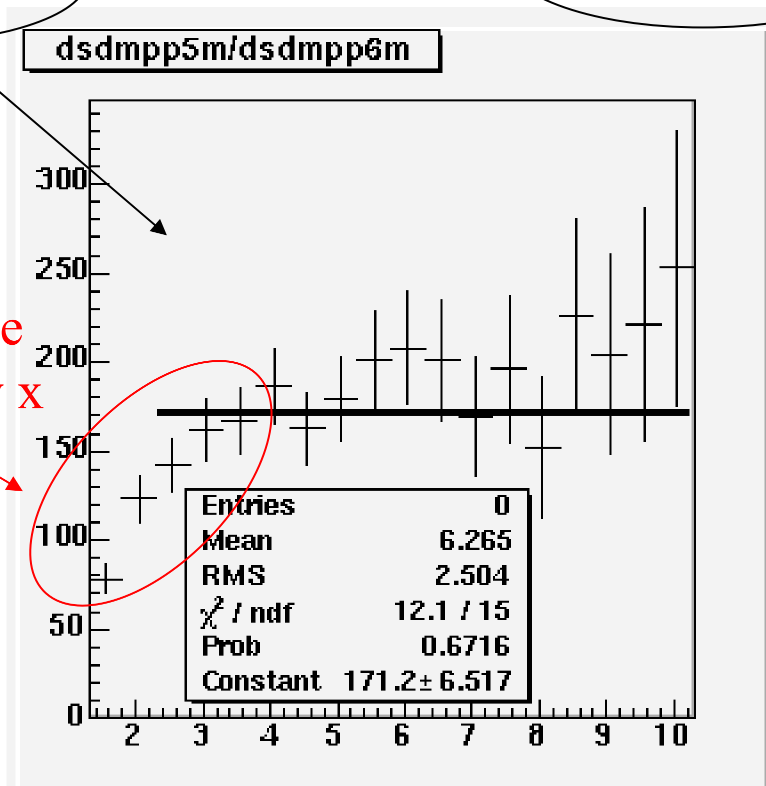
We compared this distribution to PYTHIA output with k_t = 2 GeV, $Q^2 = \hat{s}$ and CTEQ 5M1. This comparison has been done bin by bin for two ranges of mass :

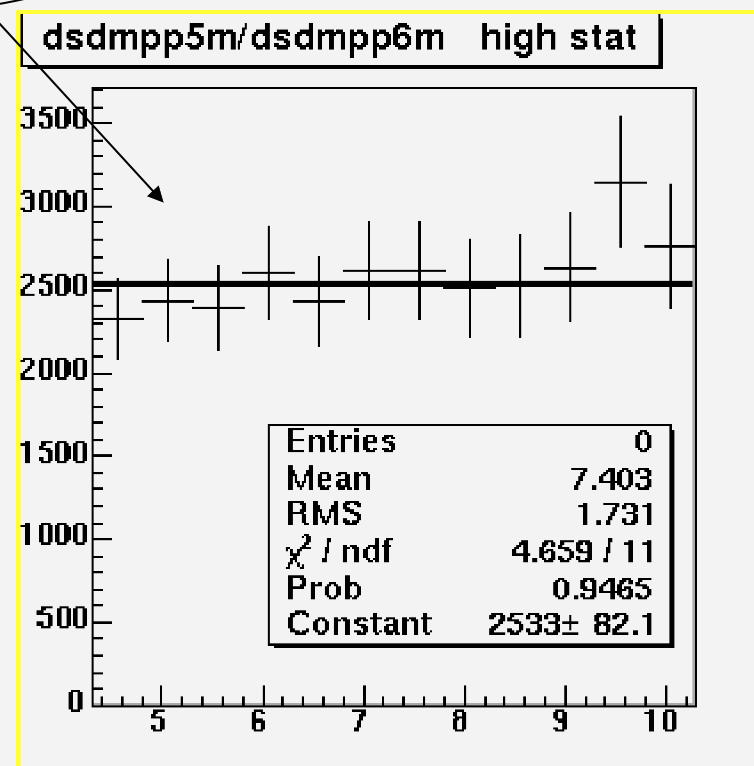
1.3 to 10.3 GeV

4.3 to 10.3 GeV

$\Rightarrow$ Good agreement

This is due to a different behaviour of the two pdfs at low x (R. Vogt).

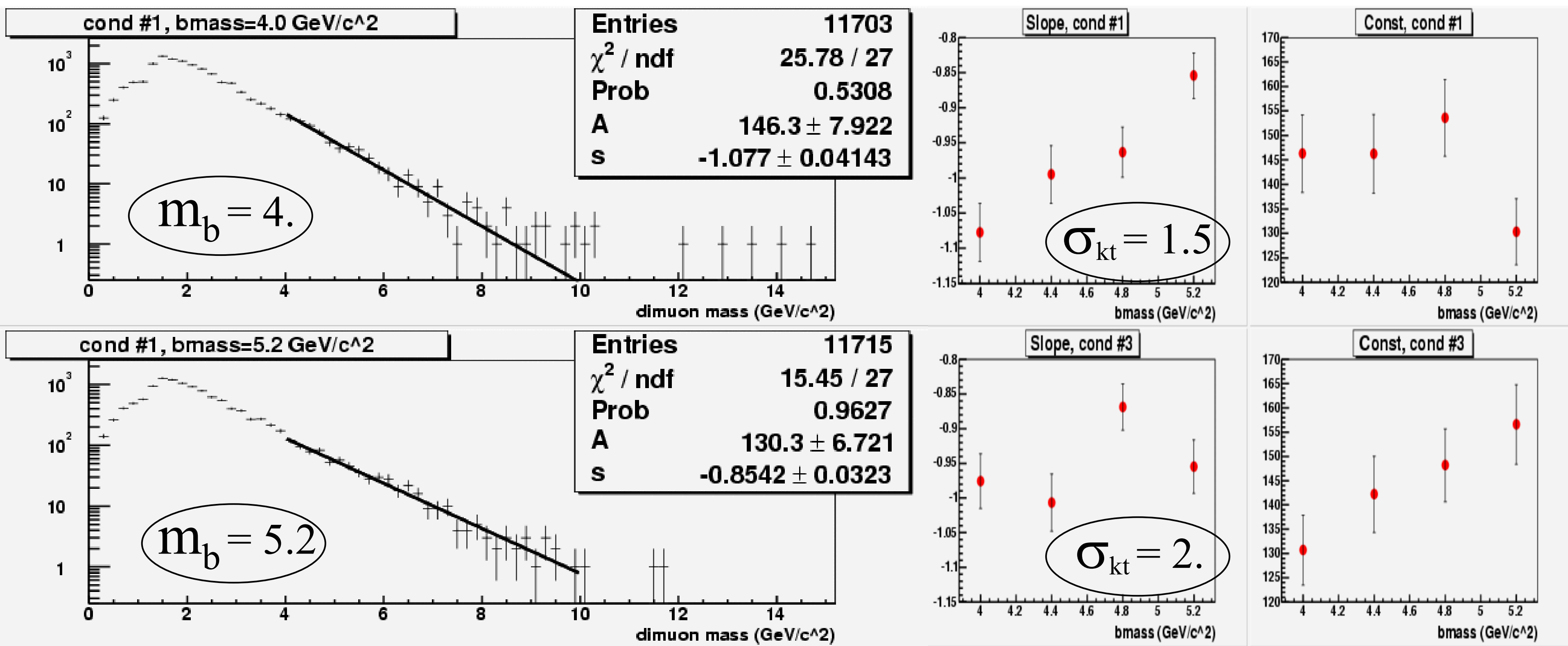




First study of Open beauty with PYTHIA

A systematic study of relevant PYTHIA parameters for open beauty production has been started. Studied parameters are k_t width (k_t distribution being gaussian), cut off for this distribution, Q^2 and b quark mass.

The b quark mass seems to be the only parameter changing the slope (fit with one exponential). The slope becoming less steep when the mass increases. This effect seems to be more important when the k_t gaussian becomes narrower.



High statistics production

- PYTHIA settings used have been described in previous slides; The following cuts are used:
  - ✓ $P_\mu \geq 1$ GeV
  - ✓ $M_{\mu\mu} \geq 1.3$ GeV
- PISA vertex distribution is gaussian with $z_{rms} = 30$ cm.
- Reconstruction made @RCF with Fun4All and pro.50.
- *Drell-Yan* production:
  - ✓ In South, we have 2 * 95 uncorreleted PYTHIA samples of 10k events each which gives a total of ~ 460k dimuons in picoDSTs.
  - ✓ In North, we have 2 * 88 uncorreleted PYTHIA samples of 10k events each which gives a total of ~ 520k dimuons in picoDSTs.
- *Open charm* production:
  - ✓ In South, we have 98 uncorreleted PYTHIA samples of 10k events each which gives a total of ~ 71k dimuons in picoDSTs.
  - ✓ For North, production is still running, 94 PYTHIA files have already been reconstructed.

Fitting the picoDST shape

- For the fit as well as for the response function we currently use four cuts:
  - ✓ $| Z_{BBC} | \leq 150$ cm and trigger 2D
  - ✓ $| Z_{BBC} | \leq 150$ cm and trigger 1D1S
  - ✓ $| Z_{BBC} | \leq 40$ cm and trigger 2D
  - ✓ $| Z_{BBC} | \leq 40$ cm and trigger 1D1S
- Plots are for *opposite sign dimuons*, *like sign* being *substracted*.
- The fit functions are sums of exponentials, *three* for Drell-Yan and *two* for open charm:
  - ✓ Drell-Yan fit function:

$$F_{DY}(x) = c0 * \{ c1*s1*\exp[-s1*(x-2.2)] + s2*\exp[-s2*(x-2.2)] + c3*s3*\exp[-s3*(x-2.2)] \}$$

  - ✓ Open charm fit function:

$$F_{DD}(x) = c0 * \{ \exp[-s1*(x-1.3)] + c1*\exp[-s2*(x-1.3)] \}$$

The first parameter (c0) is a normalization constant (from which one can compute the number of dimuons under the fit).

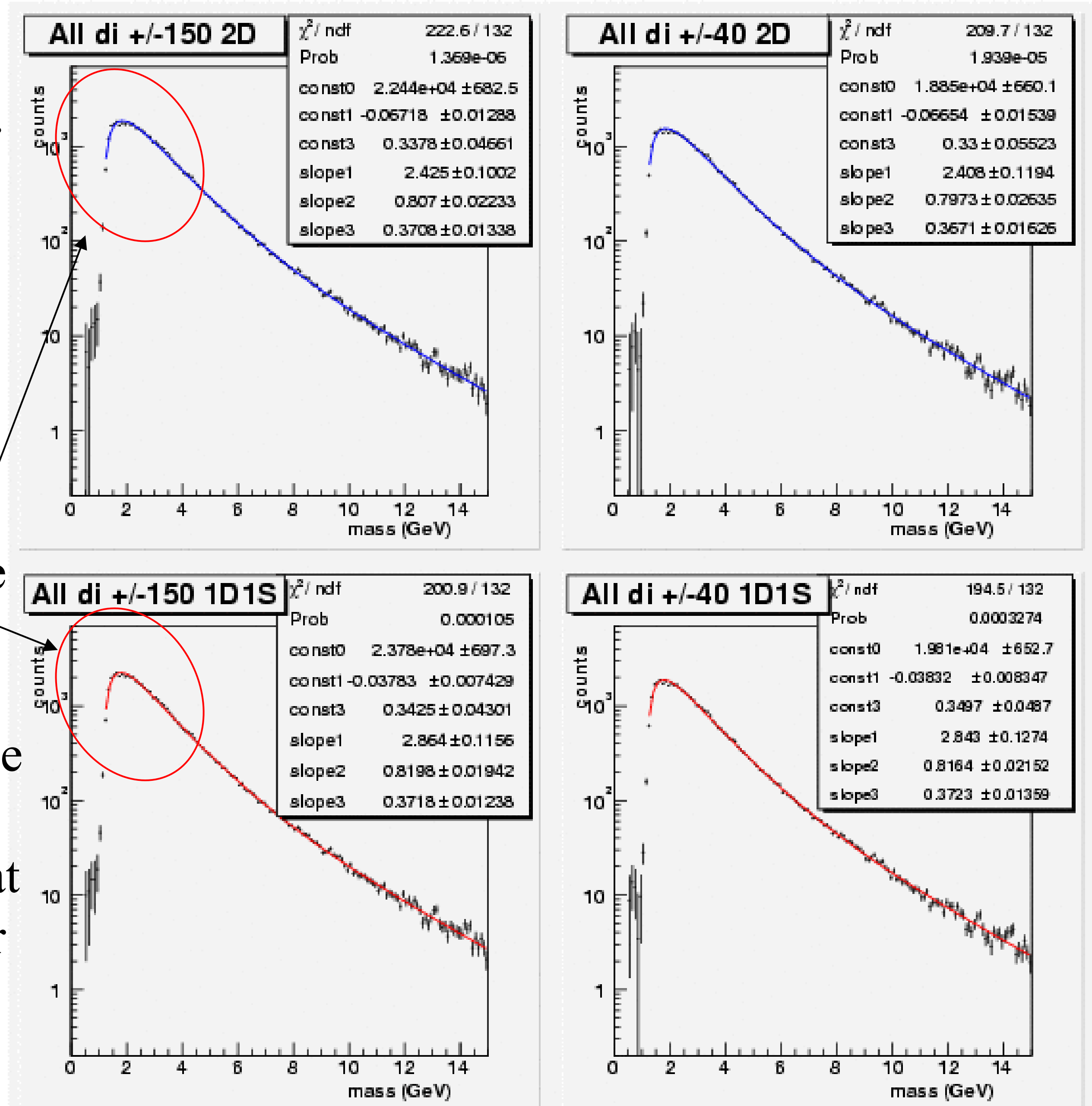
Drell-Yan mass distribution in South arm

Fit of Drell-Yan mass distributions for south arm.

Upper plots are for 2D trigger, below are 1D1S trigger (see histos title).

⇒ No change upon BBC vertex cut.

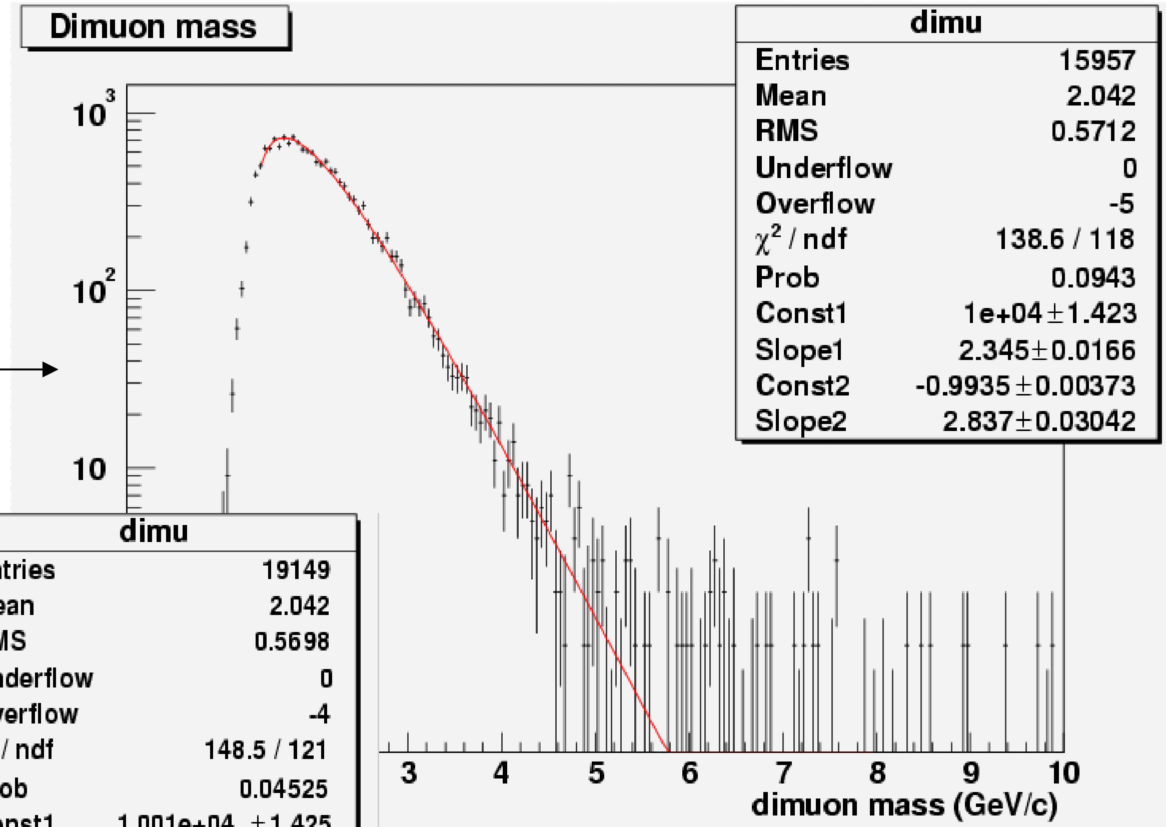
⇒ A *small change* (change oustide error bars) can be seen for the slope of the turn over (slope 1). Because lower masses are better accepted due to the fact that 1D1S trigger accepts lower momentum muons.



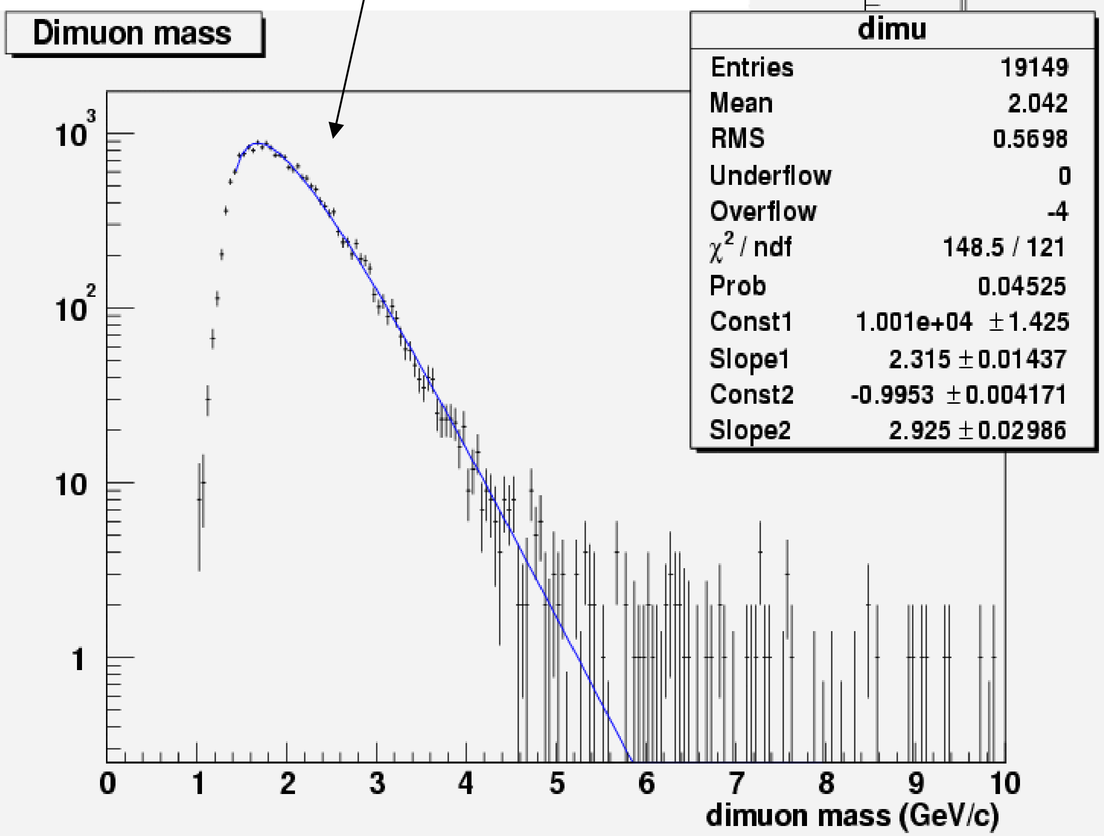
Open charm fit for South arm

Open charm fit for South arm and 2D trigger.

$|Z_{BBC}| \leq 40$ cm



$|Z_{BBC}| \leq 150$ cm

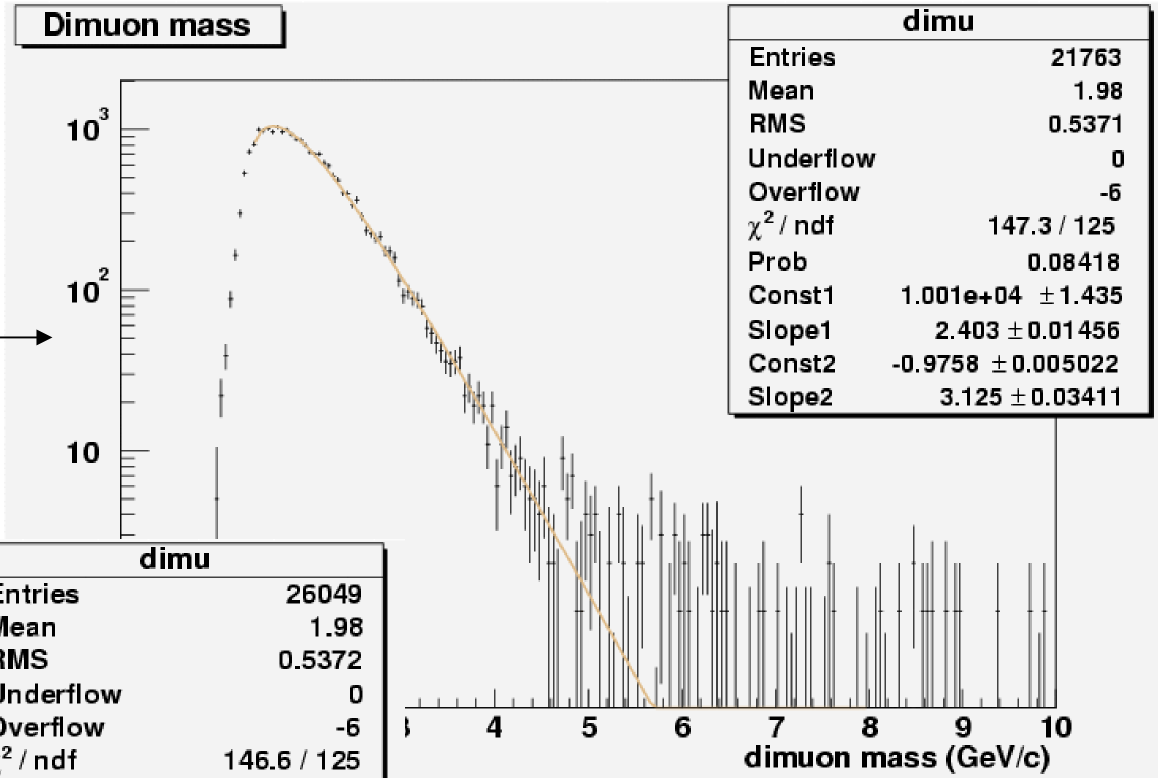


As seen previously for Drell-Yan, there is *no change* upon vertex cut.

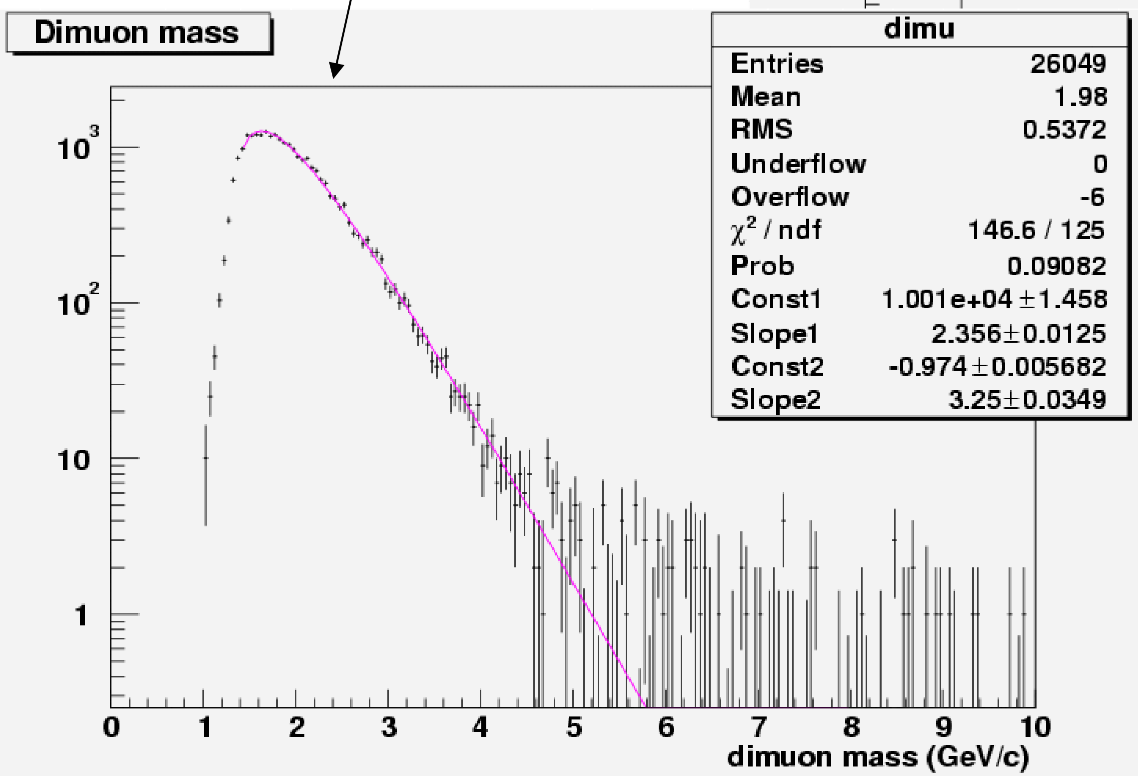
Open charm mass distribution in South arm

Open charm fit for South arm and 1D1S trigger.

$|Z_{BBC}| \leq 40$ cm



$|Z_{BBC}| \leq 150$ cm



No change upon vertex cut but a *small change for the slope of the turn over* .

⇒ same behaviour of the shapes as for DY.

Response function

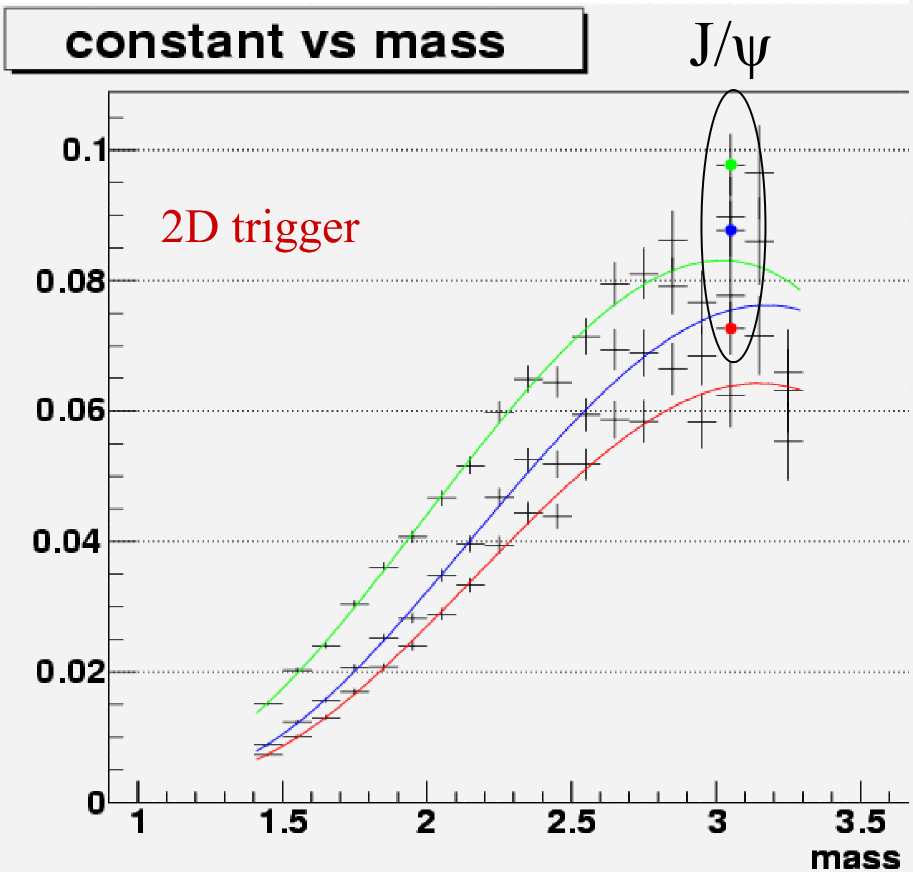
- ✓ The response function analysis has been done event-by-event, making a slice in the PYTHIA mass distribution and fitting the corresponding picoDST mass distribution with a gaussian.
- ✓ Practically, we used the ROOT TH2::FitSlicesY() method.
- ✓ We show the results of these slice fits along the PYTHIA mass range. The plots are for the constant, mean and RMS of the gaussian fits.
- ✓ The constant is given as the probability for a PYTHIA event to be reconstructed.
- ✓ We also show on the plots the response function for J/Ψ computed in the south muon arm as a reference.

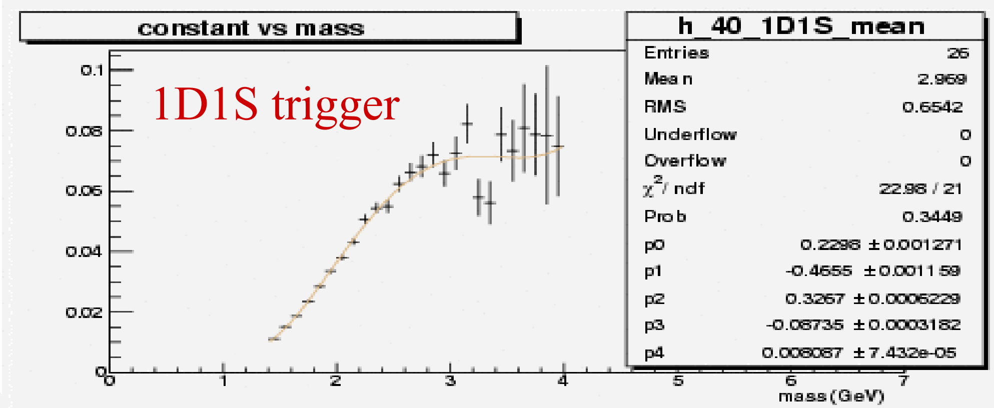
Open charm response function for South arm

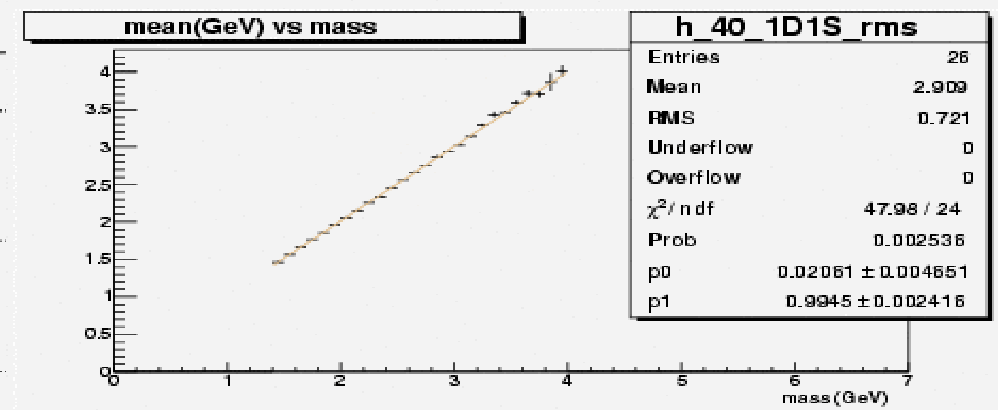
Upper curve: $|Z_{BBC}| \leq 150$ cm

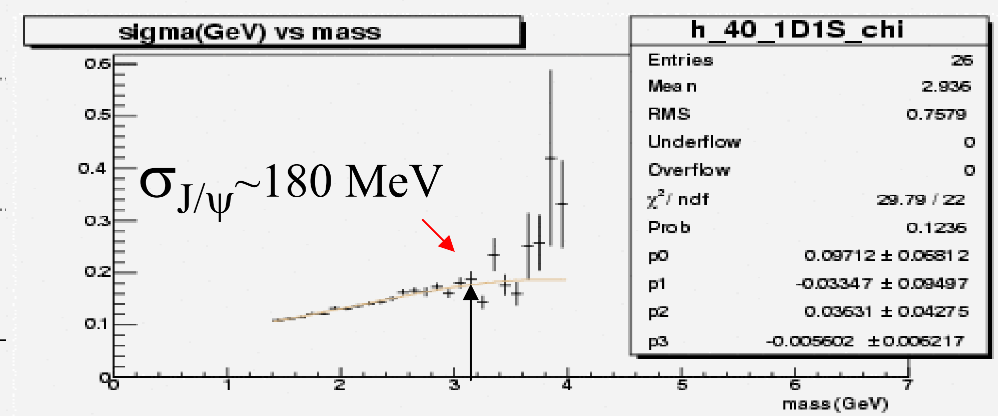
Middle curve: $|Z_{BBC}| \leq 150$ cm & 2D

Lower curve: $|Z_{BBC}| \leq 40$ cm & 2D

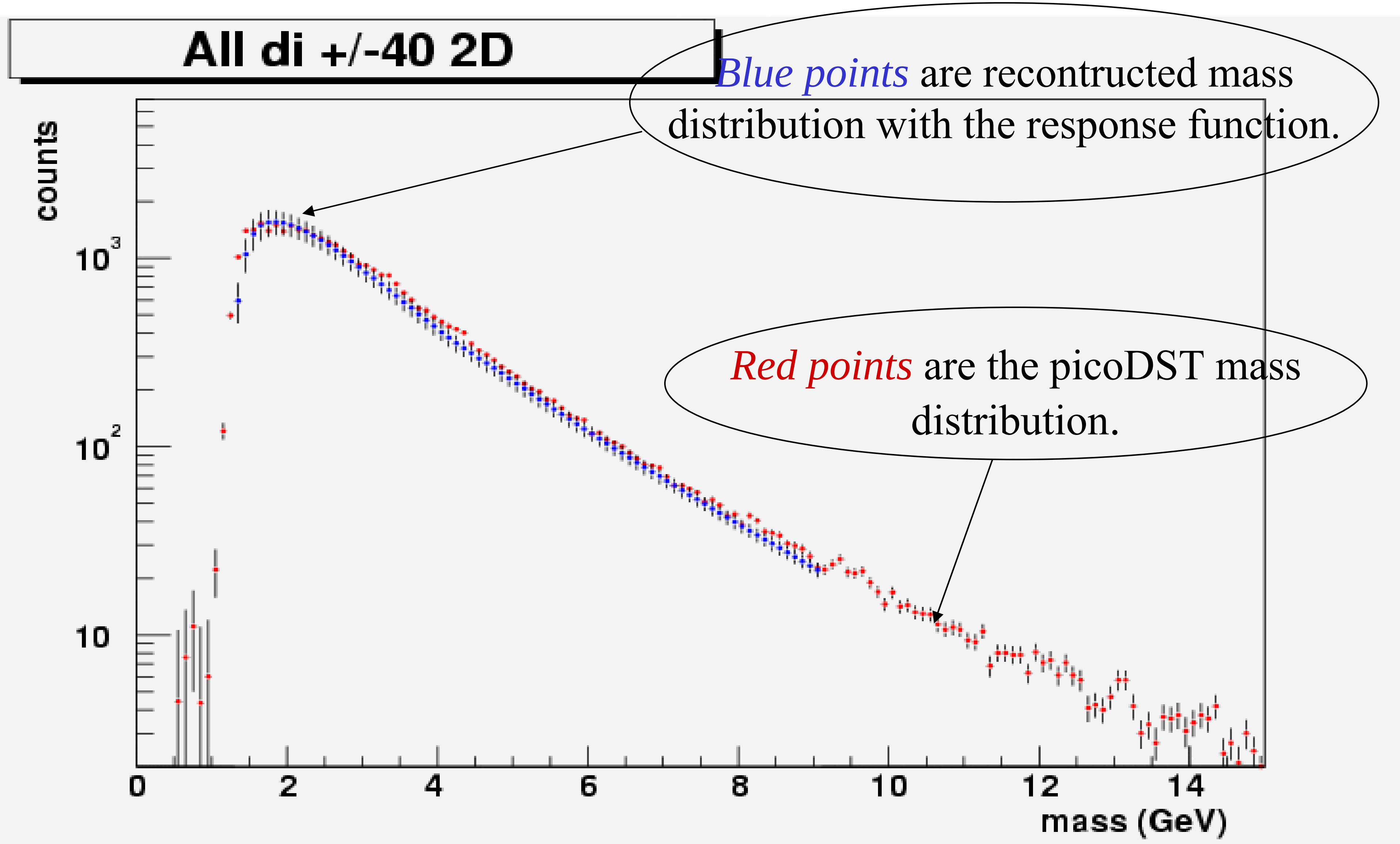








Systematic study with the response function (Drell-Yan example)



Conclusion about the response function

- The response function is qualitatively understood but need more checks.
- The response function can be used to optimize spectral shapes (especially below lower threshold for simulation).
- It can also be used to do a systematic study, instead of processing the whole reconstruction chain $\Rightarrow$ huge gain of computing time !!!

Final conclusion

- ✓ Presently enough statistics for Drell-Yan and open charm in both North and South arm.
- ✓ Software tools are *completed*.
- ✓ Shape and response functions are qualitatively understood but need more quantitative study.

Outlook and timescale…

- We are planning to do a first fit of the latest picoDSTs of run 3 (for both p-p and d-Au)

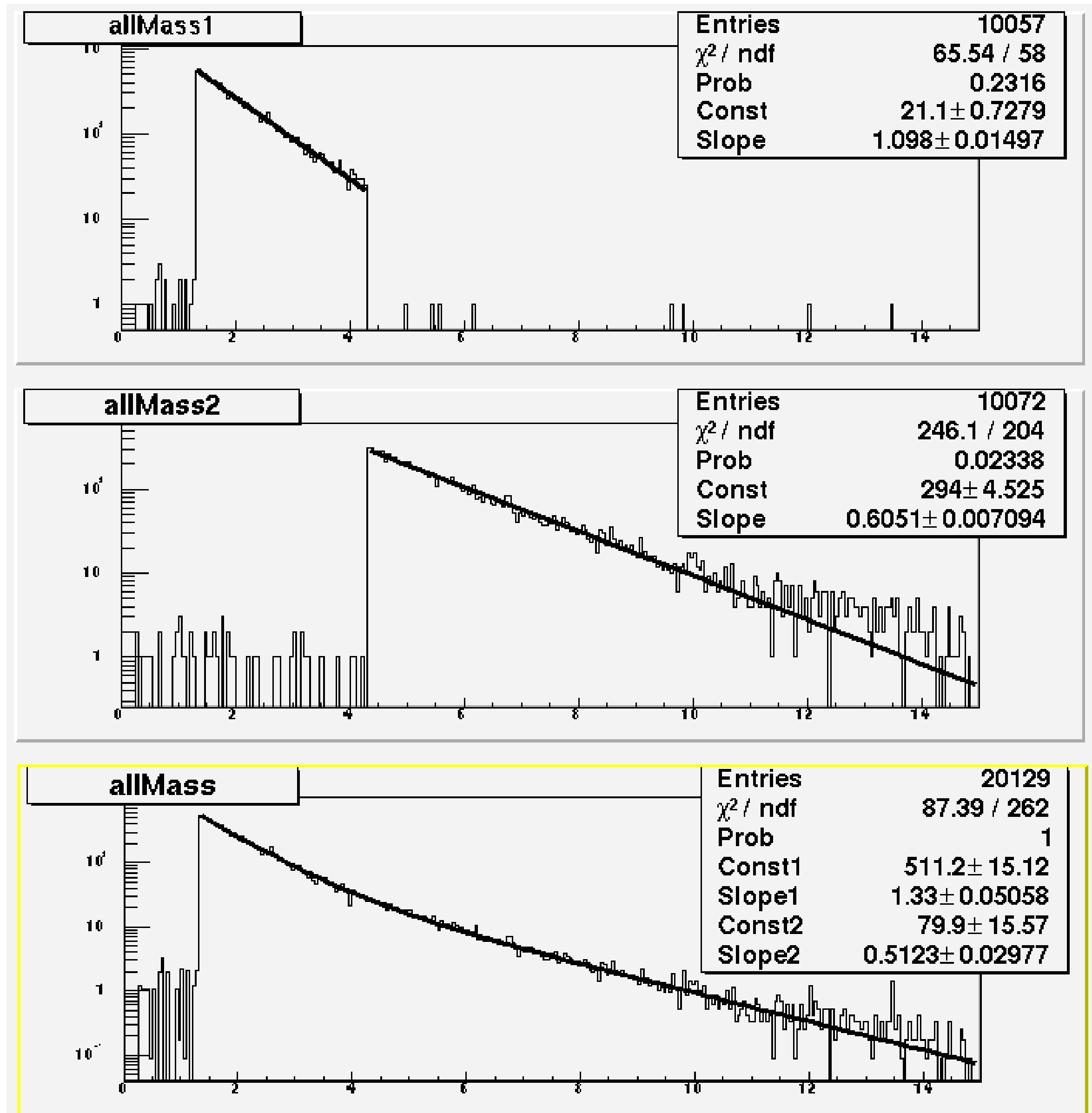
  →*should be done in July*.
- Shape of Drell-Yan in n-n collisions will be checked, at least in one arm.
- A check with CTEQ 6M will also be done, at least for Drell-Yan.
- *We expect some level of completion of the full study by the end of the summer*.

Back up slides

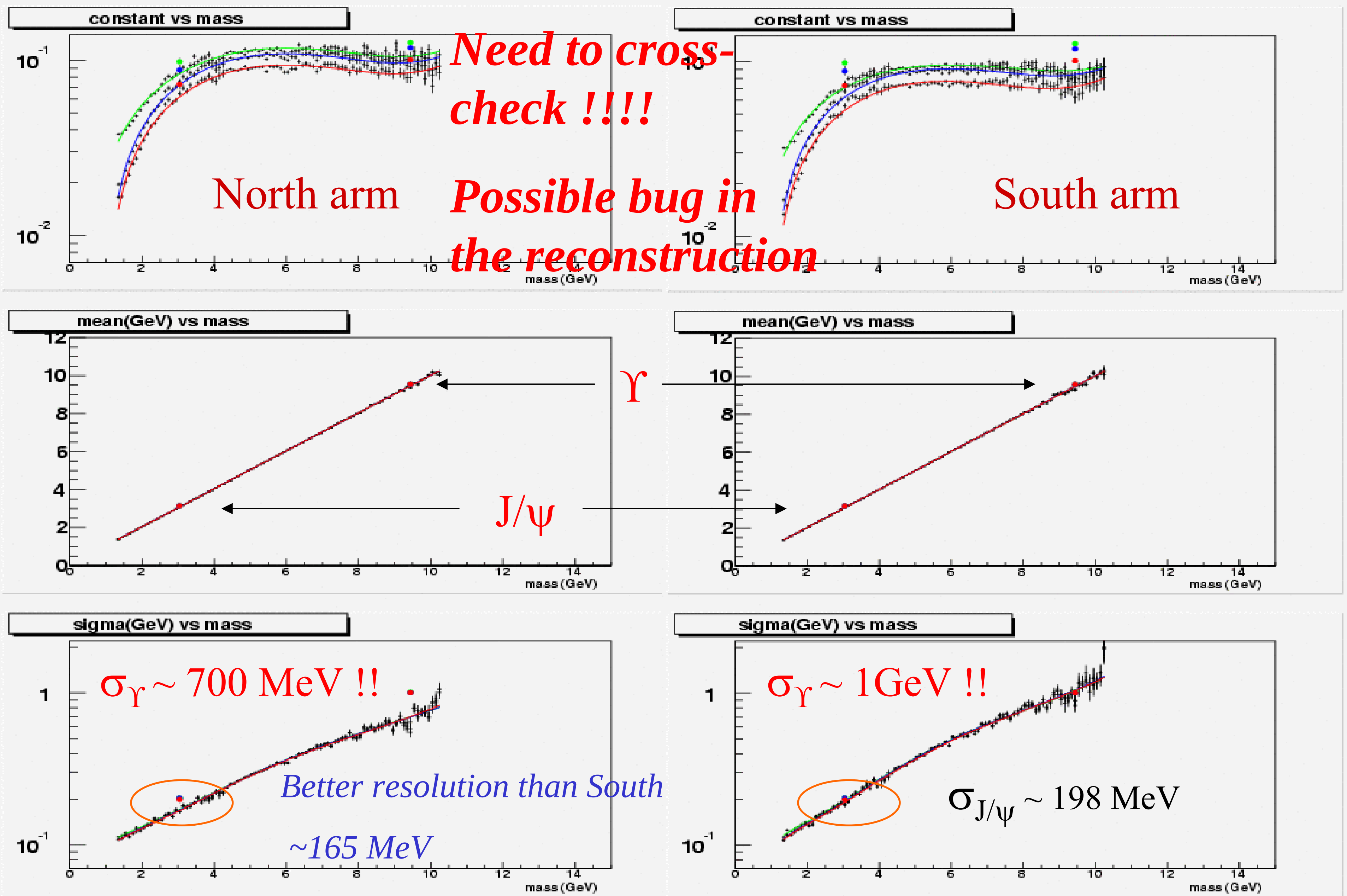
Generating high mass statistics for Drell-Yan

In order to improve statistics at high mass, the full mass spectrum is done in two pieces :
(a) m = 1.3 to 4.3 GeV
(b) m > 4.3 GeV
Piece (b) is then matched to piece (a) using the calibration factor : $(\sigma_b/\sigma_a)*(n_a/n_b)$ where σ and n are the cross-section and number of generated events.

Top plot : piece (a) from pythia.
Middle plot : piece (b) from pythia.
Bottom plot : sum of the two plots using the calibration factor (here, it is 0.0853).



Drell-Yan response function and some strange results



Muon arm response function to Drell-Yan, J/ψ and Υ signals.

The concept of response function.

Physics signal defined over n kinematical variables, $i = 1, n$. Input signal : $S(X_i)$. Output (measured) signal : $s(x_i)$. Response function $R(x_i, X_i)$ with

$$s(x_i)\, dx_i = \int_{-\infty}^{+\infty} \dots \int_{-\infty}^{+\infty} R(x_i, X_i)\, S(X_i)\, dX_i\, dx_i\ .$$

Integrating over all x_i variables but one (here the kept variable is mass), the corresponding integrated response function $R(x, X)$ is now defined with

$$s(x)\, dx = \int_{-\infty}^{+\infty} R(x, X)\, S(X)\, dX\, dx\ .$$

Experimentally, the only way to determine the response function is to use a known line shaped signal (*e.g.*, J/ψ, Υ). With the line located at $X = A$, $S(X)$ being replaced with $S(X)\, \delta(X - A)$, one gets

$$s(x)\, dx = R(x, A)\, S(A)\, dx\ , \qquad \text{and thus} \qquad R(x, A) = \frac{s(x)}{S(A)}\ .$$

If the signal is a continuum, the only way to determine the response function is to do simulation, so we know both the input and ouput signals, $S(X)$ and $s(x)$. Defining

$$s_X(x)\, dX\, dx = R(x, X)\, S(X)\, dX\, dx\ ,$$

we can approach the response function by making a finite but small slice ΔX in the input distribution $S(X)$ at $X = A$, with, as above,

$$R(x, A) \simeq \frac{s_A(x)}{S(A)}\ .$$

The practical method.

Analysis of the Pythia and picodst root files **event-by-event**, making a slice in the Pythia mass distribution, and fitting the corresponding picodst mass distribution.

The fitting is done in ROOT using the TH2::FitSlicesY(...) method. Firstly, the picodst mass and Pythia mass are stored into a 2D histo along Y and X, respectively (notice X is the same here and in our mathematical presentation, but Y is actually x). Secondly, the FitSlicesY method makes a slice of width ΔX for each $X = A$ bin, the slice being projected and fitted along Y (or x). Under the cut conditions we are using now, the fit function is a single gaussian.

With the fit parameters C, m and σ, and the fit function written in the form

$$f(x) = S(A)\, \frac{C\, \Delta x}{\sqrt{2\pi}\, \sigma}\, exp\left(-\frac{1}{2}\left(\frac{x - m}{\sigma}\right)^2\right)\ ,$$

the fit constant C is the probability for a Drell-Yan dimuon, generated by Pythia in the mass bin $X = A$, to be reconstructed through the simulation chain and pass specific picodst cuts.

The above parameters values are themselves fitted with Nth degree polynomials over the Pythia X mass range : N = 4 for the constant C, N = 2 for the mean m, and N = 5 for σ. Those polynomials and the expression

$$R(x, X) \simeq \frac{f(x)}{S(A)}$$

define the approached response function for a Drell-Yan signal and for a given set of conditions, especially picodst cuts.

Vertex distributions

Open charm picoDST   picoDST_pp_03S_GoodRuns_pro50.root   Drell-Yan pDSTs