XDVMP
eXclusive Diffractive Vector Meson Production

Tobias Toll

Status Update

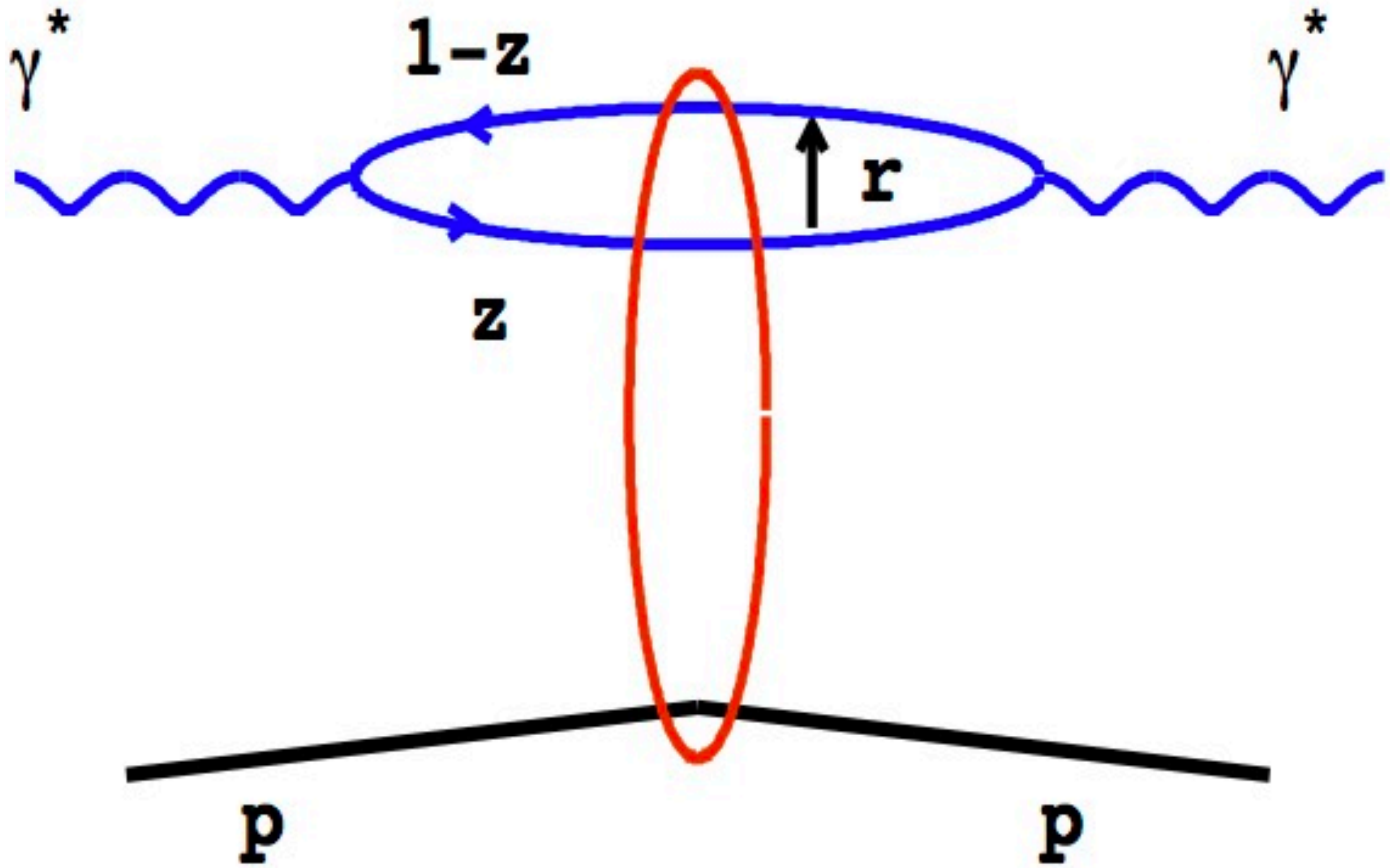
Theory background

What has been done in the last months

Some results

Present Problems

The Dipole Model

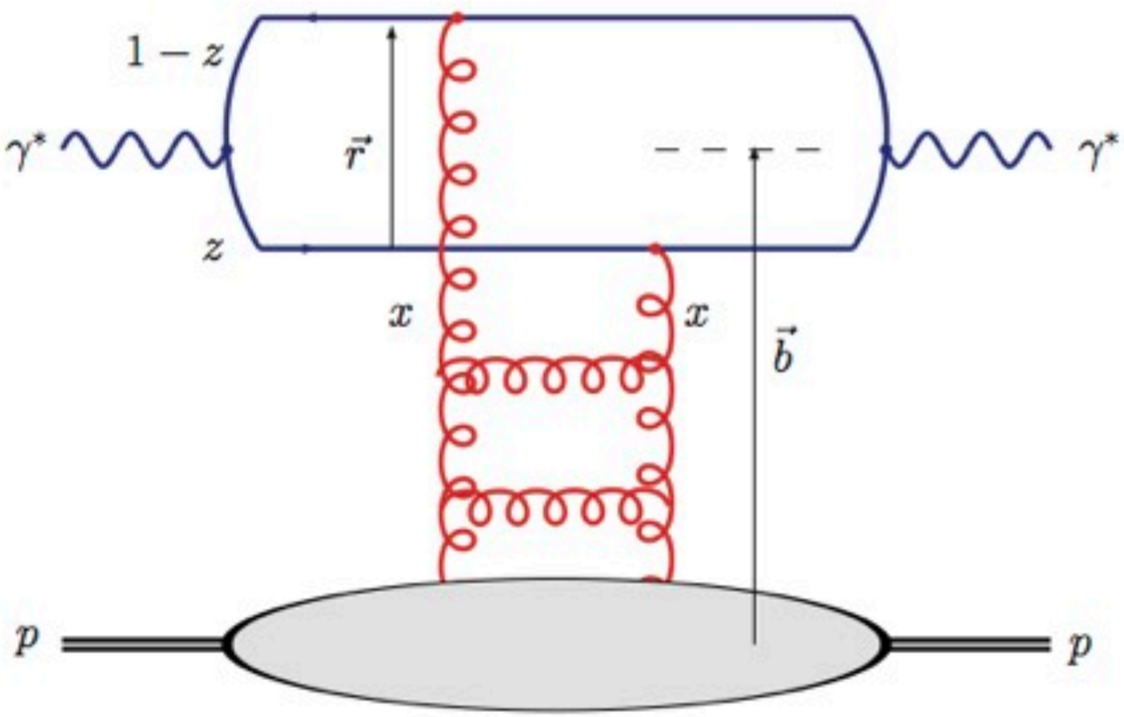


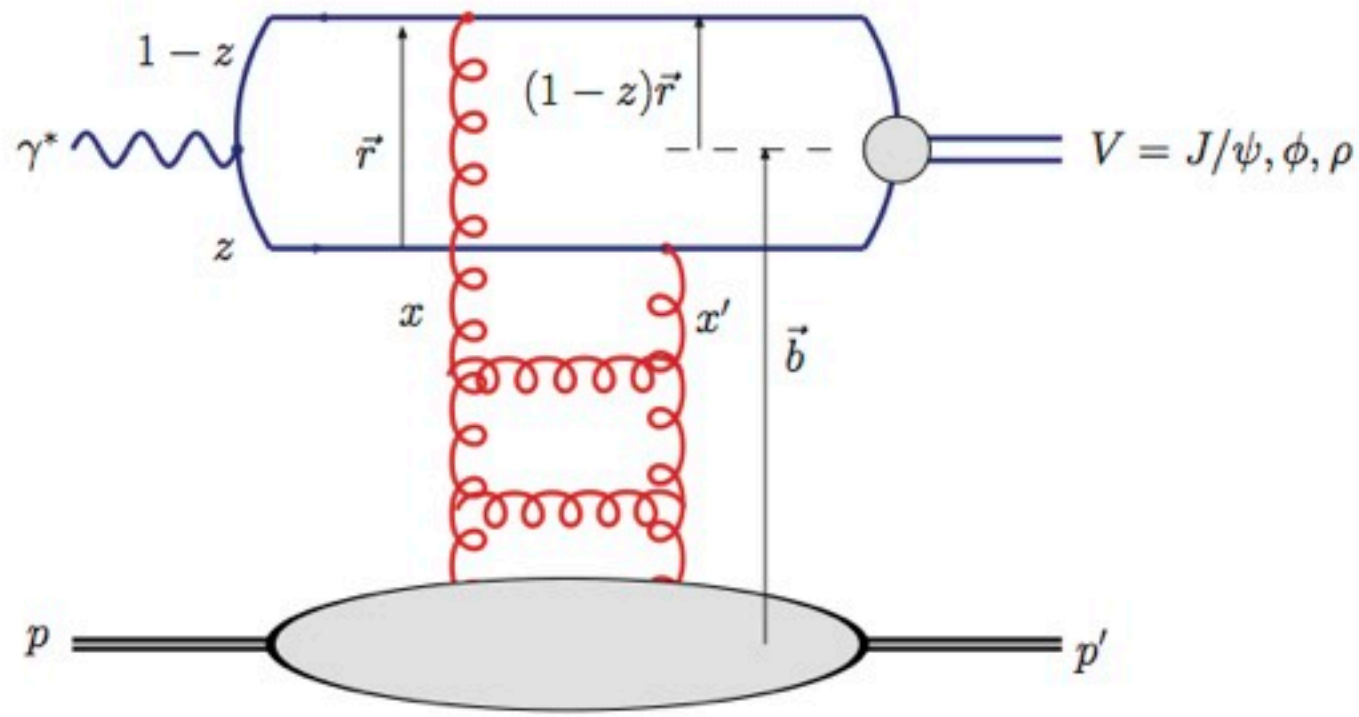
Elastic photon-proton scattering

$$\mathcal{A}^{\gamma^* p}(x, Q, \Delta) = \sum_f \sum_{h,\bar{h}} \int \mathrm{d}^2\mathbf{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} \Psi^*_{h\bar{h}}(r, z, Q) \mathcal{A}_{q\bar{q}}(x, r, \Delta) \Psi_{h\bar{h}}(r, z, Q)$$

Exclusive diffractive processes at HERA within the dipole picture, H. Kowalski, L. Motyka, G. Watt, Phys. Rev. D74, 074016, arXiv:hep-ph/0606272v2

Vector Meson Production





$$\mathcal{A}_{T,L}^{\gamma^* p \to V p}(x, Q, \Delta) =$$

$$i \int \mathrm{d}\mathbf{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b} (\Psi_V^* \Psi)_{T,L} (2\pi r) J_0([1-z] r \Delta)(2\pi b) J_0(b\Delta) \frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}}$$

Known from QED

Needs to be modeled

The Dipole Models

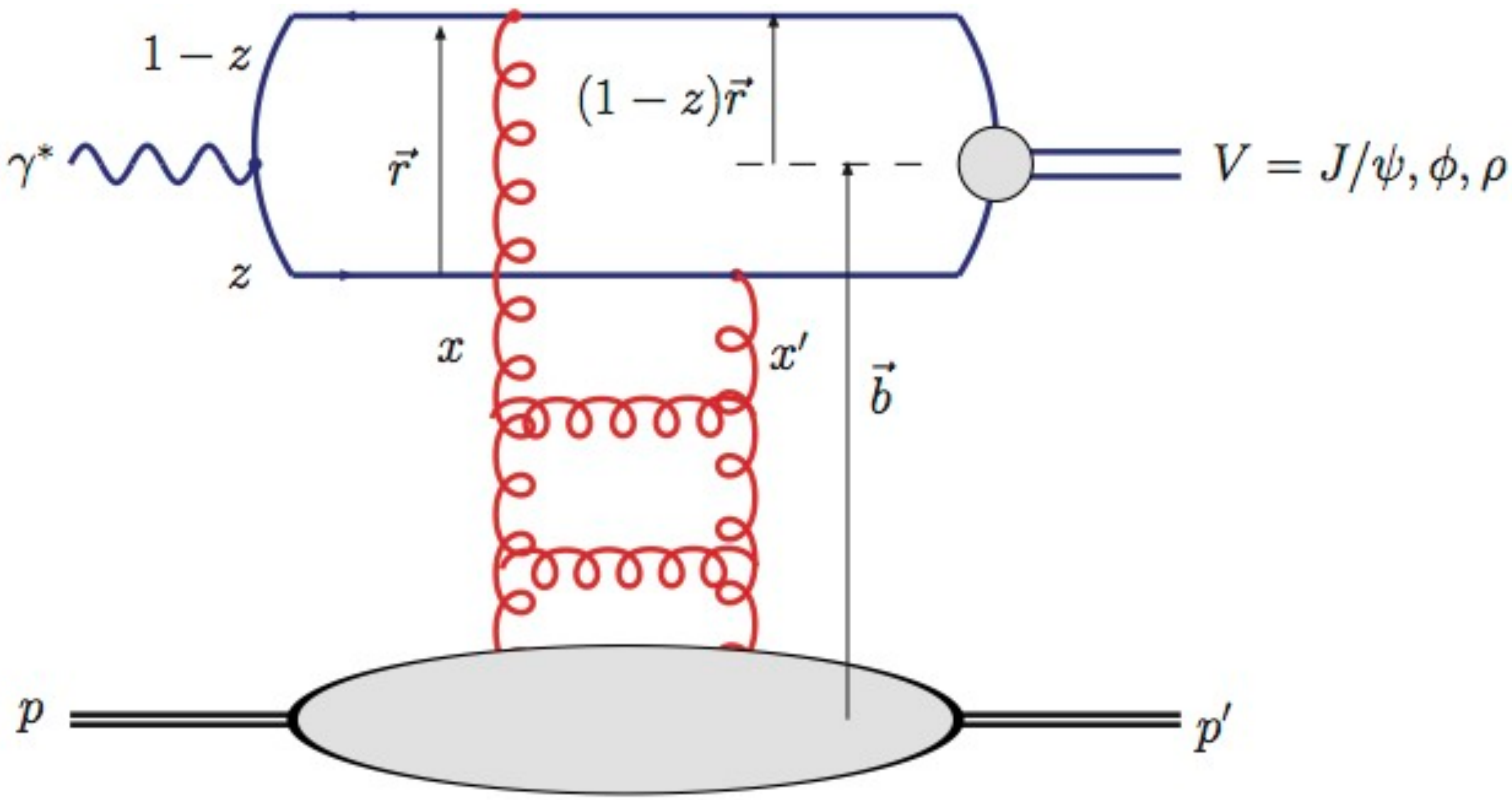
$$\frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}}$$

Two models for the dipole cross-section implemented in XDVMP:

b-Sat

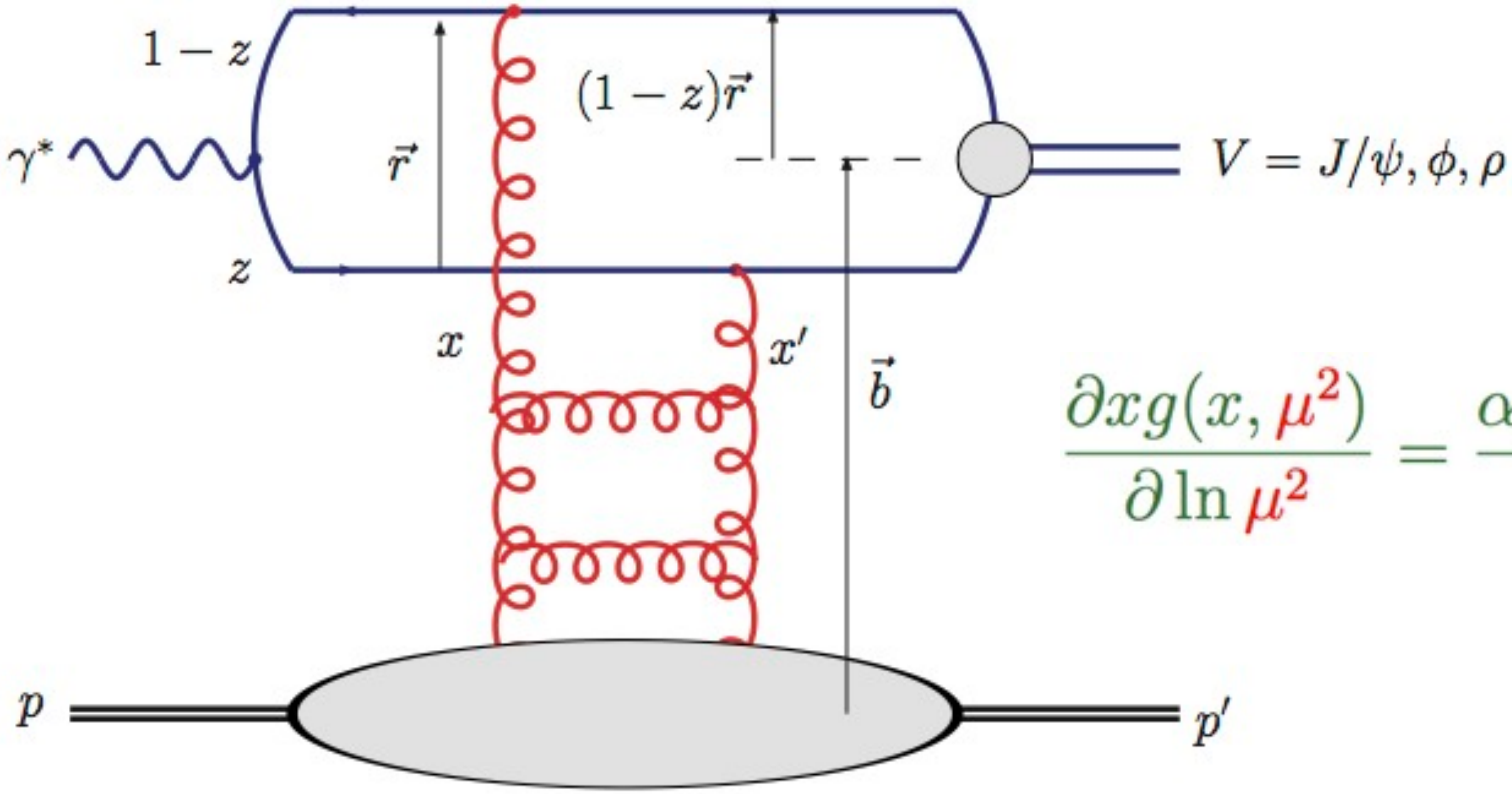
b-CGC

The b-Sat Model



$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_\mathrm{s}(\mu^2) xg(x,\mu^2) T(b)\right)\right]$$

The b-Sat Model

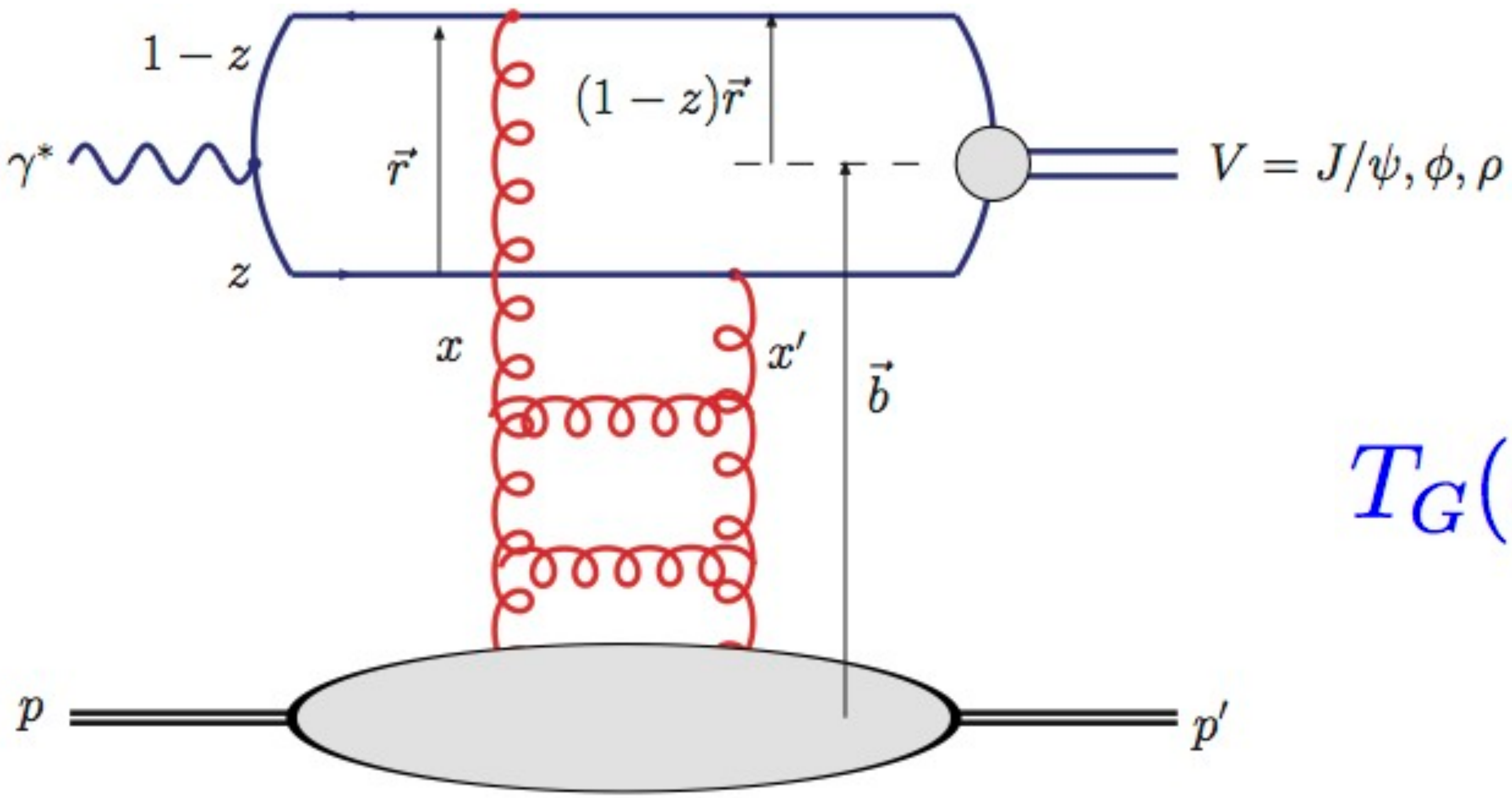


$$\frac{\partial xg(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi}\int_x^1 \mathrm{d}z P_{gg}(z)\frac{x}{z}g\left(\frac{x}{z},\mu^2\right)$$

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c}r^2\alpha_s(\mu^2)xg(x,\mu^2)T(b)\right)\right]$$

$$\mu^2 = \frac{4}{r^2} + \mu_0^2$$

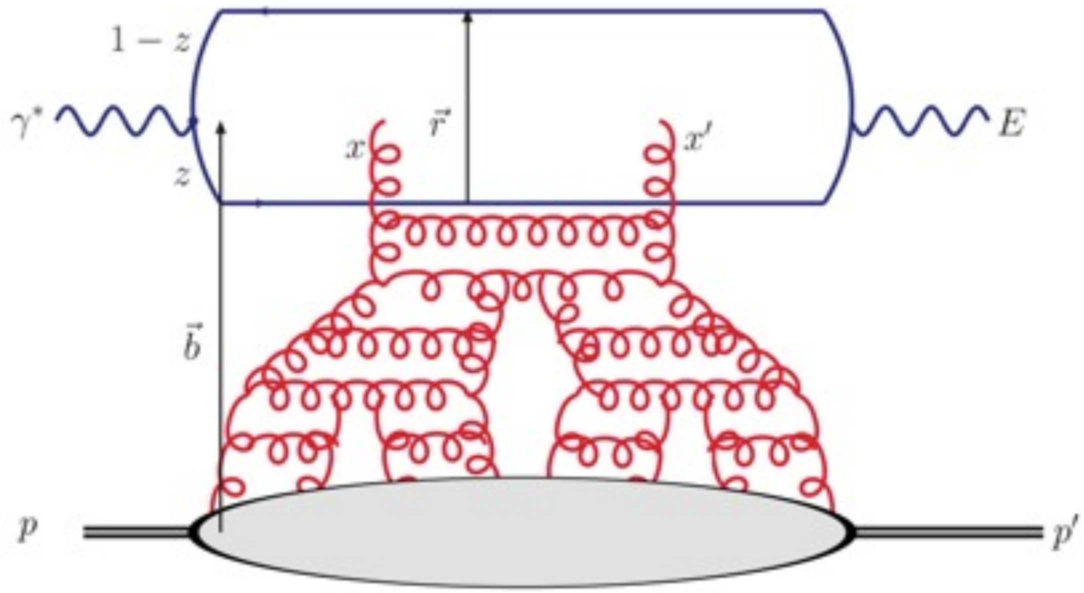
The b-Sat Model



$$T_G(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}}$$

$$\frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) xg(x,\mu^2) T(b)\right)\right]$$

The b-CGC Model



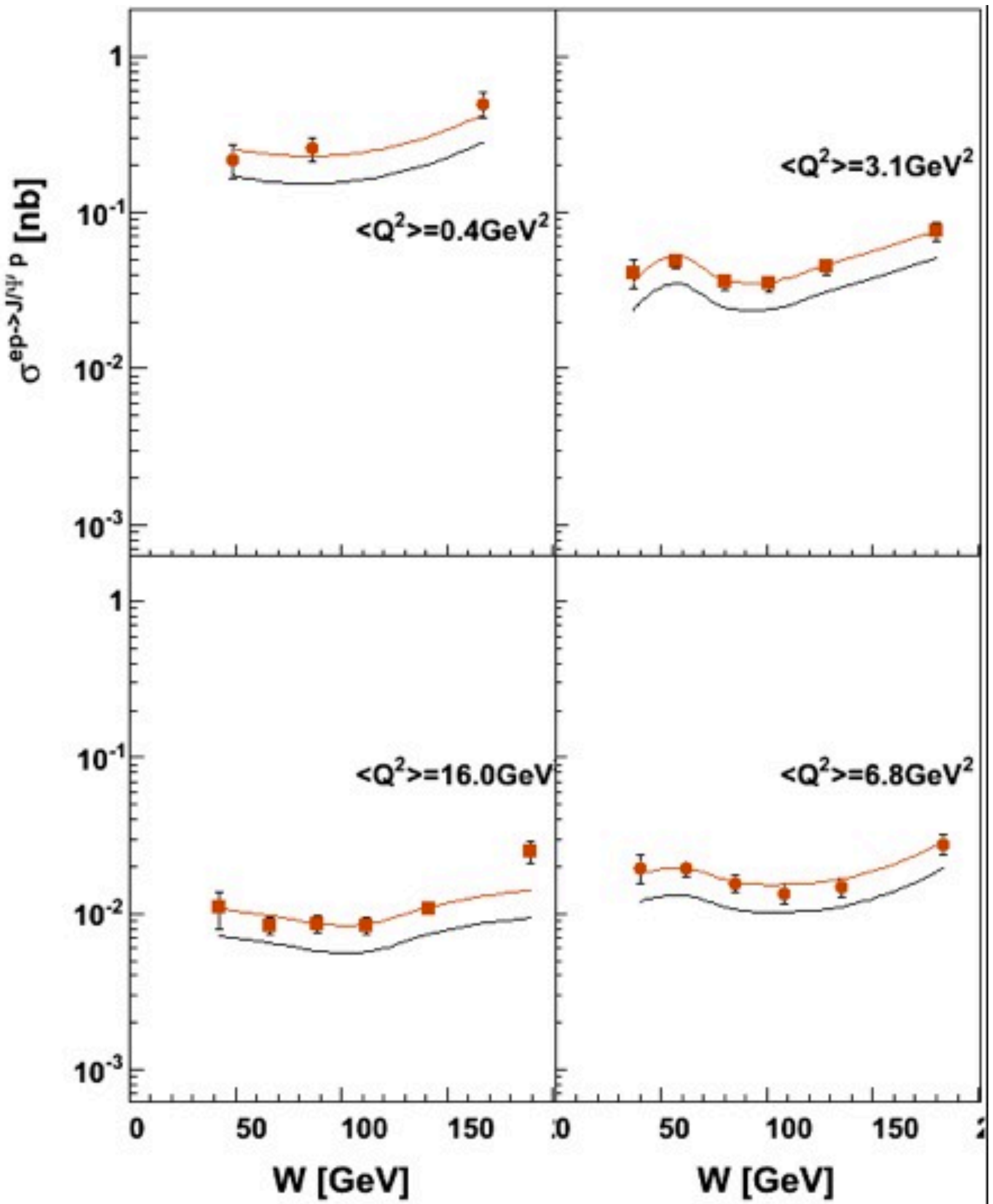
$$Y = \ln(1/x),\ \gamma_s = 0.63,\ \kappa = 9.9$$

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2 \times \begin{cases} \mathcal{N}_0 \left(\frac{rQ_s}{2}\right)^{2\left(\gamma_s + \frac{1}{\kappa\lambda Y}\ln\frac{2}{rQ_s}\right)} & rQ_s \leq 2 \\ 1 - e^{-A\ln^2(BrQ_s)} & rQ_s > 2 \end{cases}$$

$$Q_s \equiv Q_s(x,b) = \left(\frac{x_0}{x}\right)^{\lambda/2} \left[\exp\left(-\frac{b^2}{2B_{\mathrm{CGC}}}\right)\right]^{\frac{1}{2\gamma_s}}$$

First comparison with data

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695



Black Curve: XDVMP b-CGC

Red Curve: Black Curve x 1.5

Something is missing!!

Plots produced by Ramiro Debbe

Real Amplitude Corrections

So far the amplitude has been assumed to be purely imaginary.

To take the Real part of the amplitude into account it can be multiplied by a factor $(1+\beta^2)$

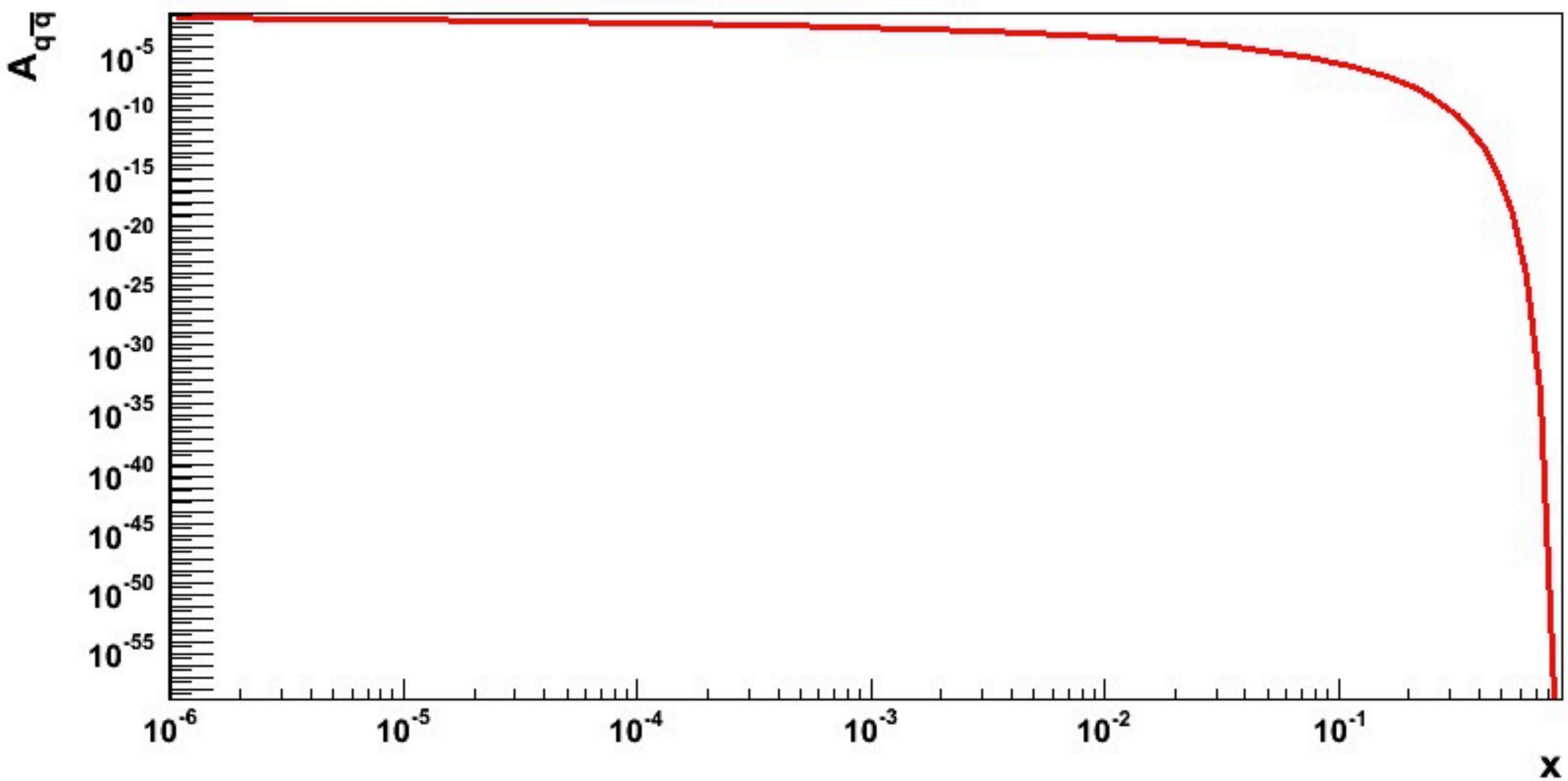
β is the ratio Real/Imaginary parts of the Amplitude:

$$\beta = \tan(\pi\lambda/2) \qquad \lambda \equiv \frac{\partial \ln\left(\mathcal{A}_{T,L}^{\gamma^* p \to Ep}\right)}{\partial \ln(1/x)}$$

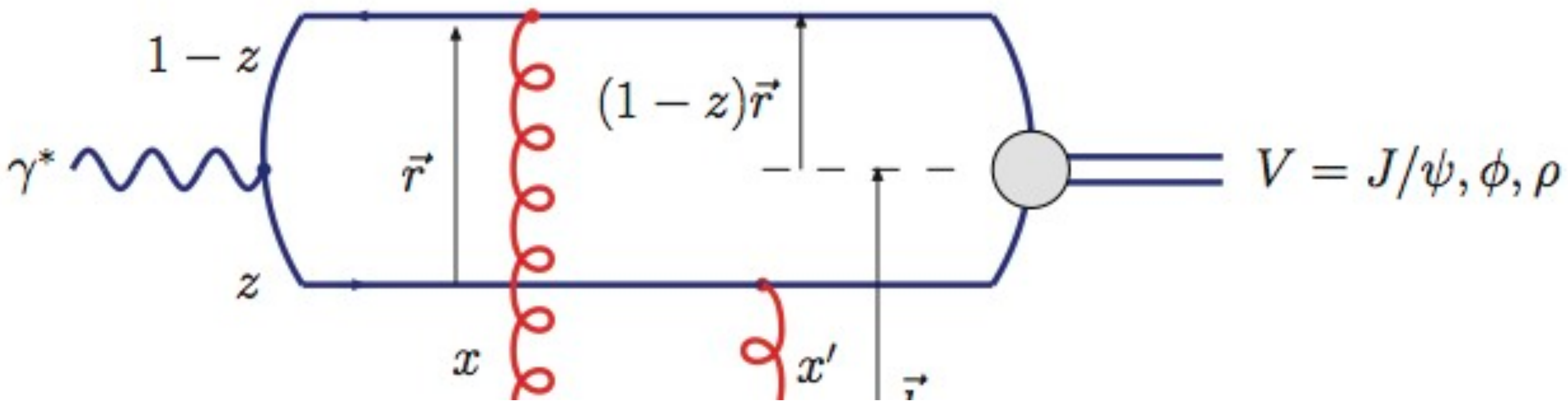
This goes bad for large $x \sim 10^{-2}$

Real Amplitude Corrections

$$\beta = \tan(\pi\lambda/2) \qquad \lambda \equiv \frac{\partial \ln\left(\mathcal{A}_{T,L}^{\gamma^* p \to Ep}\right)}{\partial \ln(1/x)}$$



Skewedness Corrections



The two gluons carry different momentum fractions

This is the Skewed effect

In leading ln(1/x) this effect disappears

It can be accounted for by a factor R_g

$$R_g(\lambda) = \frac{2^{2\lambda+3}}{\sqrt{\pi}} \frac{\Gamma(\lambda + 5/2)}{\Gamma(\lambda + 4)} \qquad \lambda \equiv \begin{cases} \dfrac{\partial[xg(x,\mu^2)]}{\partial \ln(1/x)} & \text{bSat} \\ \dfrac{\partial \ln(\mathcal{A}_{T,L}^{\gamma^* p \to Ep})}{\partial \ln(1/x)} & \text{bCGC} \end{cases}$$

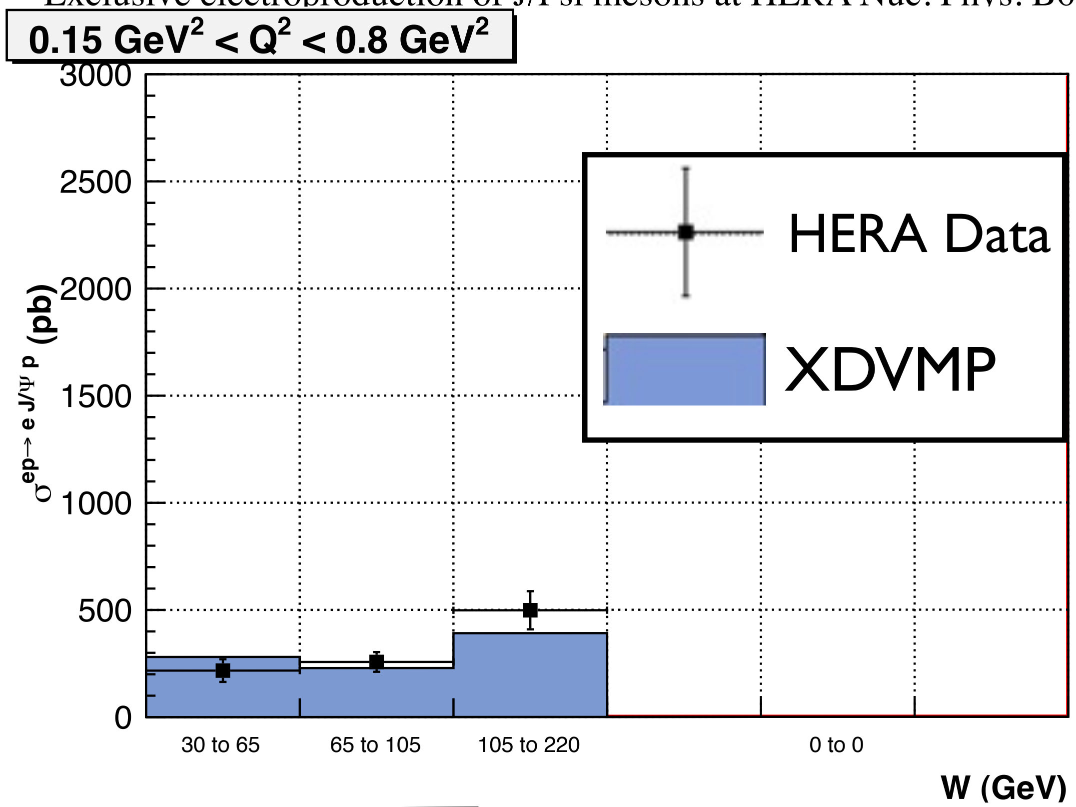
Again, this goes bad for large $x \sim 10^{-2}$!

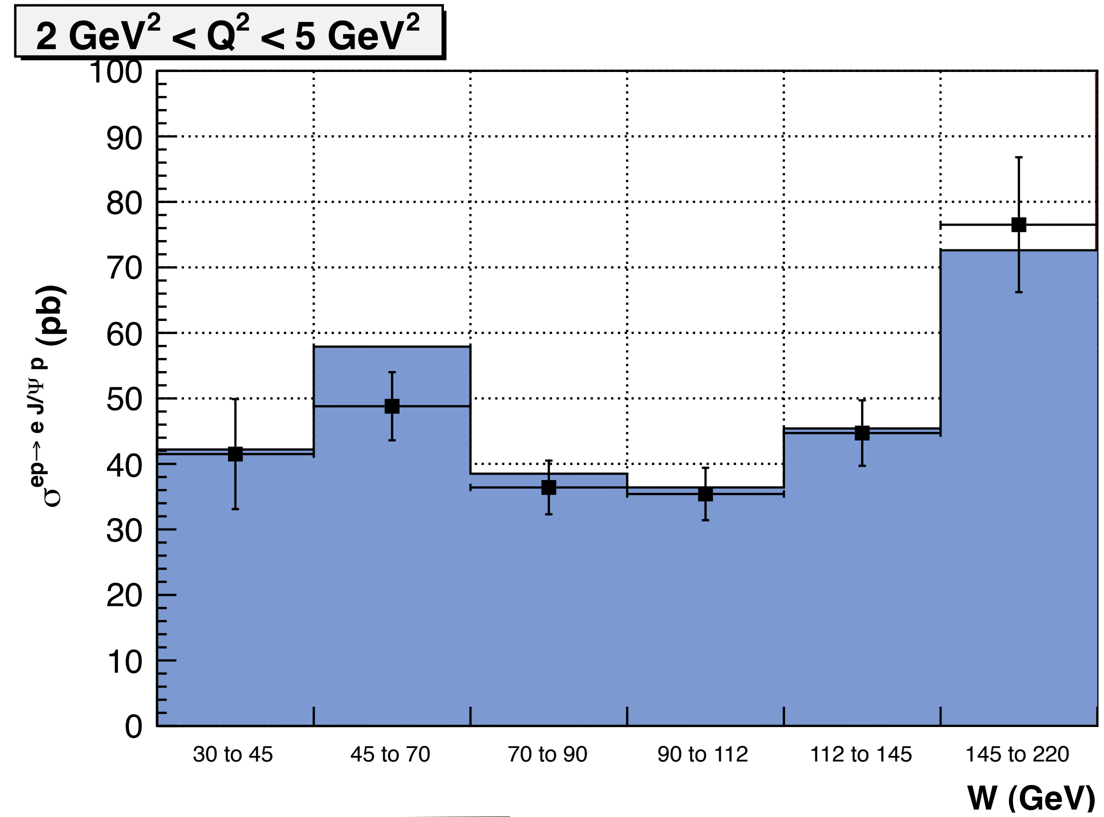
Implemented with exponential damping to control this.

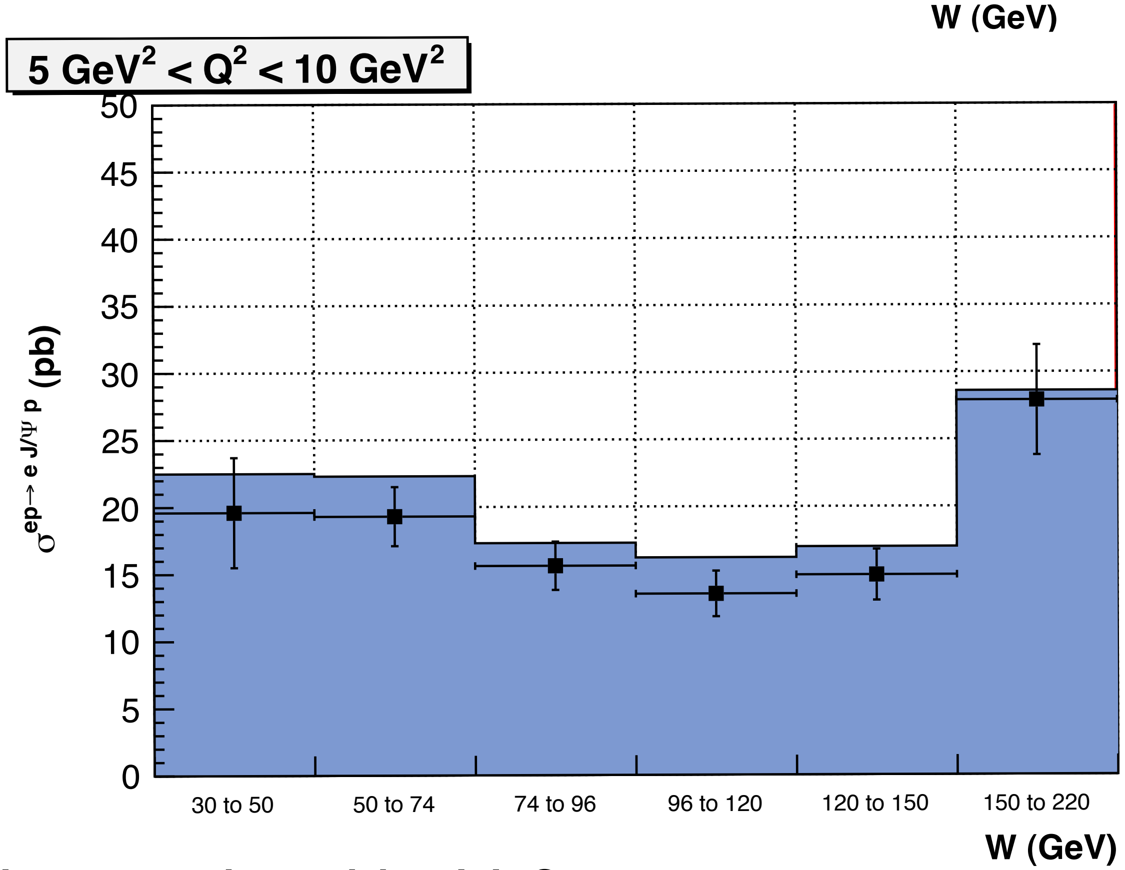
J/Psi at HERA vs. b-CGC

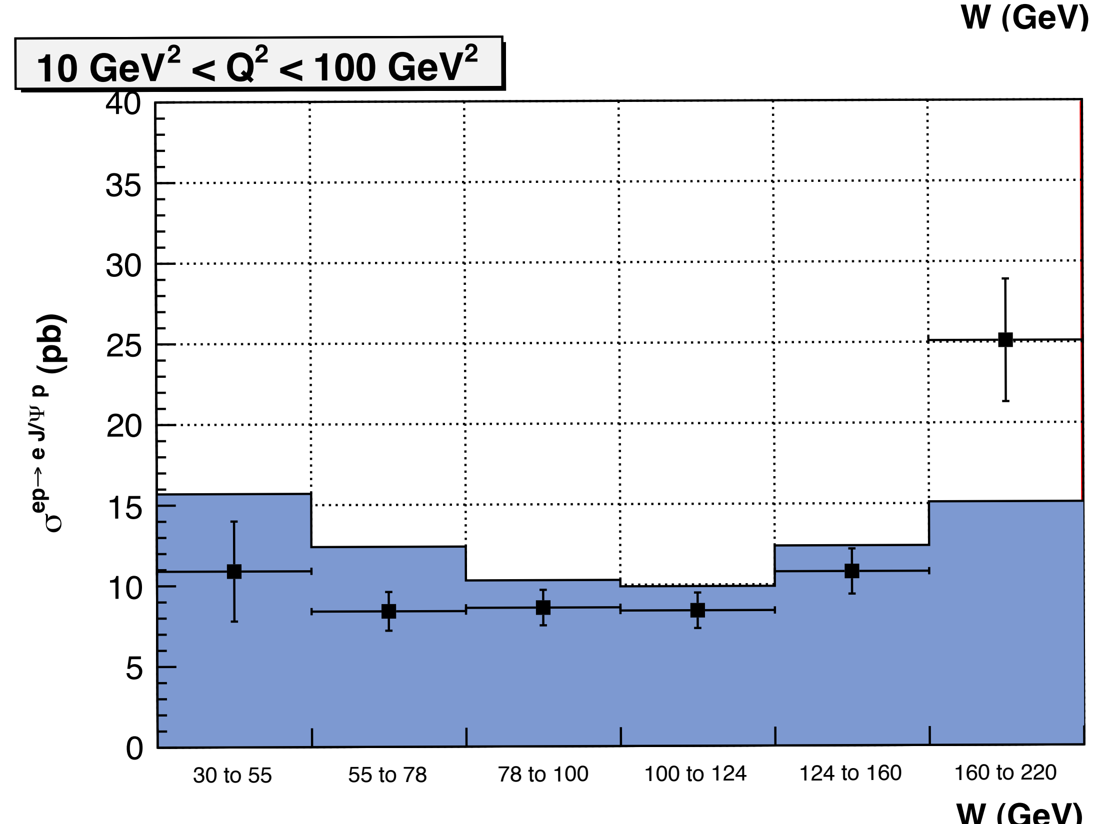
With all correction!!

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695







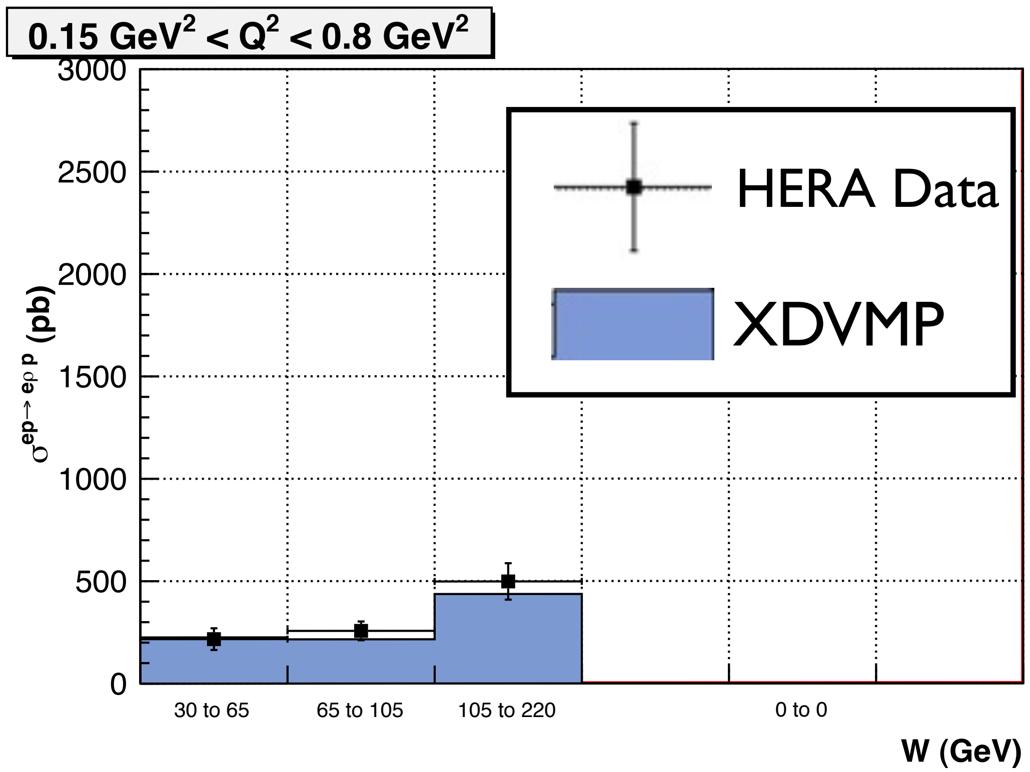


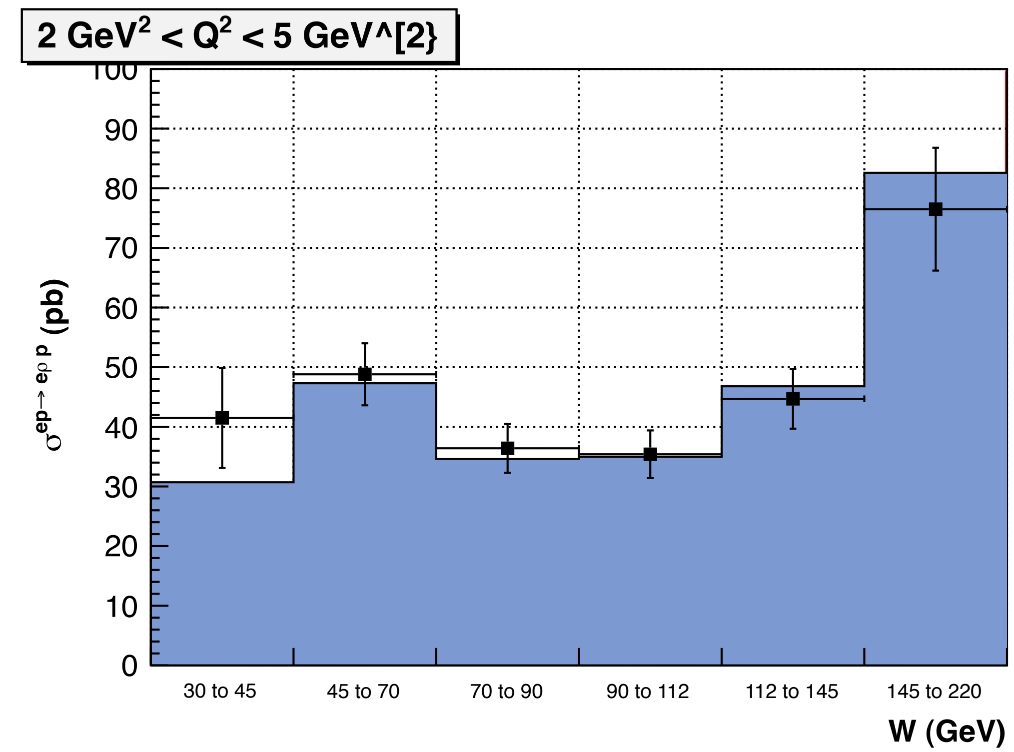
Plots produced by M. Savastio

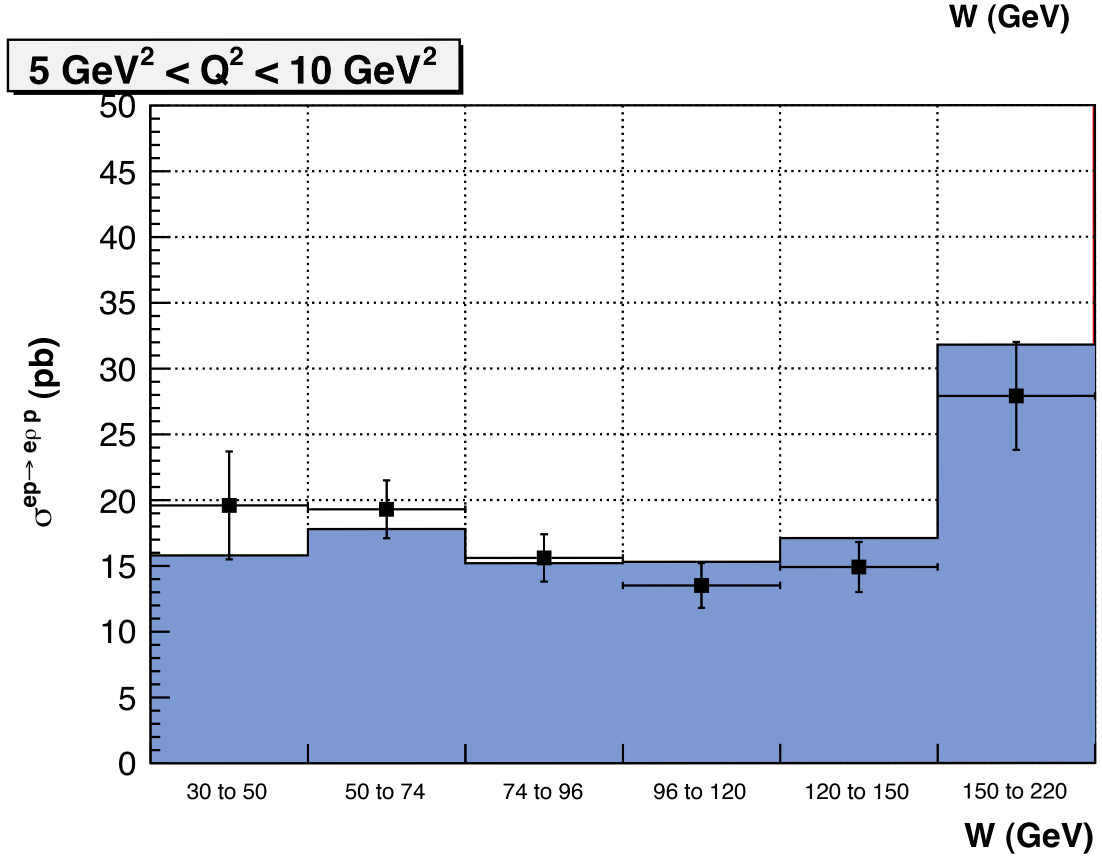
J/Psi at HERA vs. b-Sat

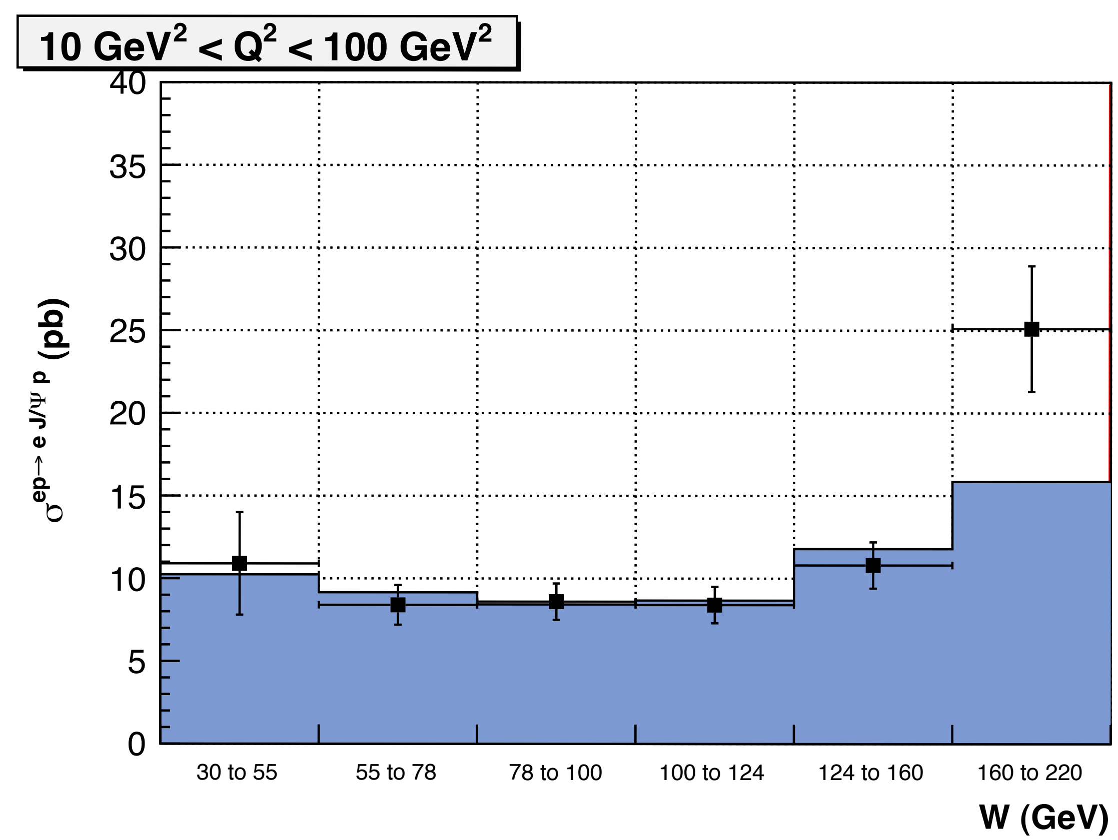
With all correction!!

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695









Plots produced by M. Savastio

Going from ep to eA

b-Sat ep:

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) T(b)\right)\right]$$

T(b) is the proton shape function

b-Sat eA:

$$\frac{\mathrm{d}\sigma^A_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) \sum_{i=1}^{A} T_p(\mathbf{b} - \mathbf{b}_i)\right)\right]$$

Should follow the Wood-Saxon distribution

Nuclear enhancement of universal dynamics of high parton densities. H. Kowalski, T. Lappi, and R. Venugopalan
s **Phys.Rev.Lett.100:022303,2008**.

Going from ep to eA

b-CGC ep:

$$Q_s \equiv Q_s(x,b) = \left(\frac{x_0}{x}\right)^{\lambda/2} \left[\exp\left(-\frac{b^2}{2B_{\rm CGC}}\right)\right]^{\frac{1}{2\gamma_s}}$$

b-CGC eA:

$$Q_s(x,b) = \left(\frac{x_0}{x}\right)^{\lambda/2} \sum_{i=1}^{A} \left[\exp\left(-\frac{(\mathbf{b}_\perp - \mathbf{b}_{i\perp})^2}{2B_{CGC}}\right)\right]^{\frac{1}{2\gamma_s}}$$

Should follow the Wood-Saxon distribution

Generating a Nucleus

The Algorithm:

Generate radii according to Wood-Saxon and store in array

Sort the radius array to make distance comparisons faster

Generate angles

cos(theta) uniform in [-1:1]

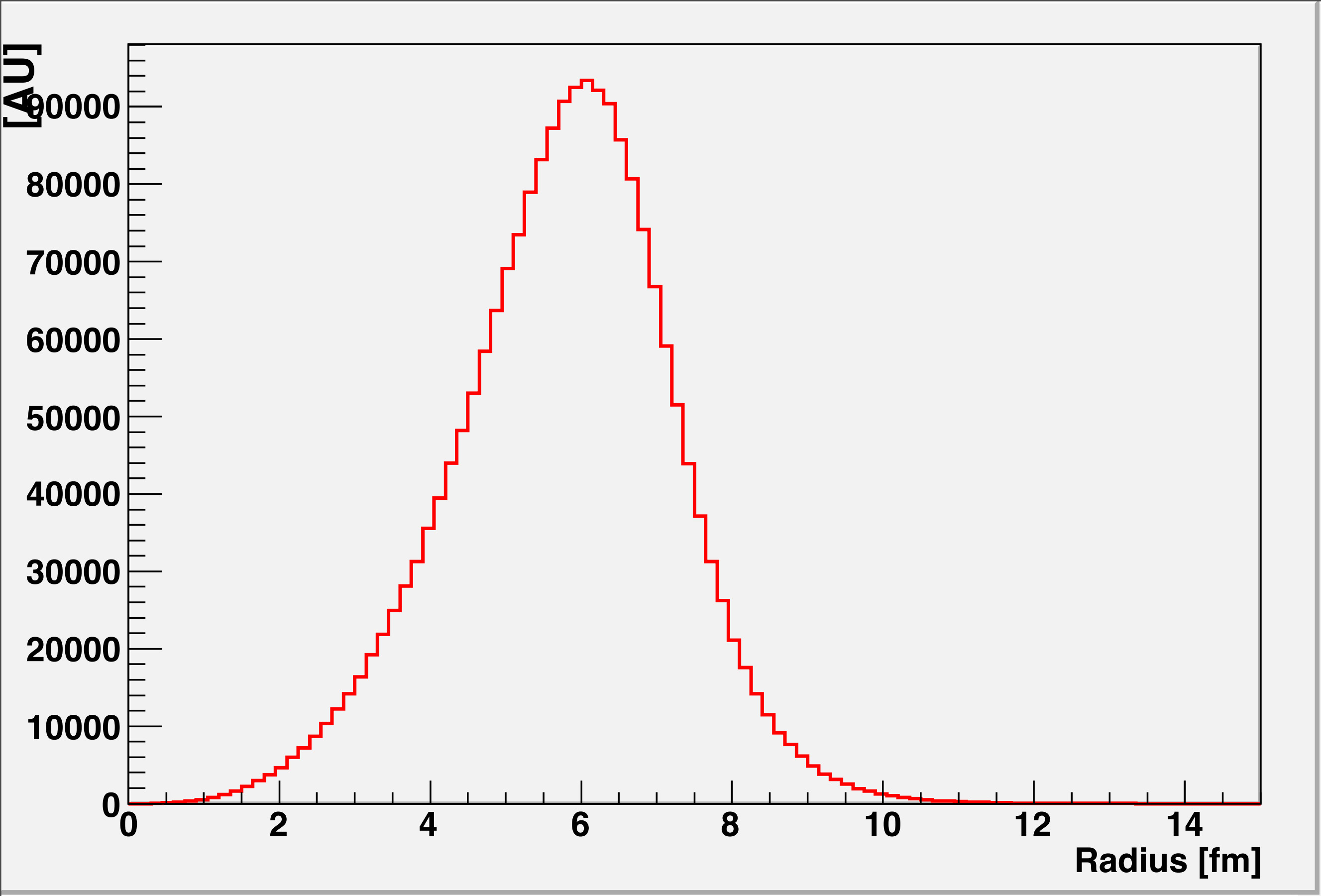
phi uniform in [0:2pi]

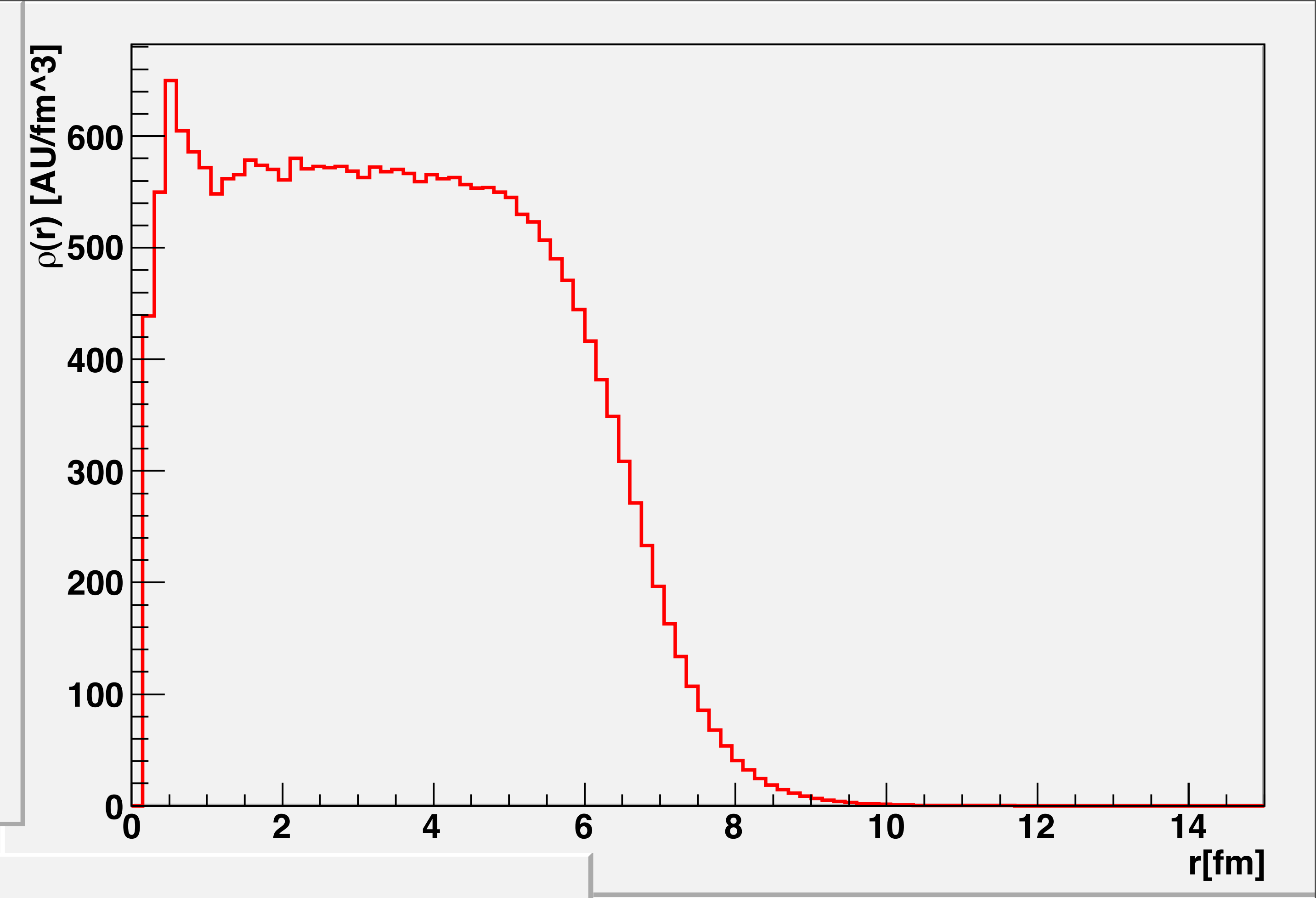
Check if the new nucleon is within distance dcore from any previous nucleon

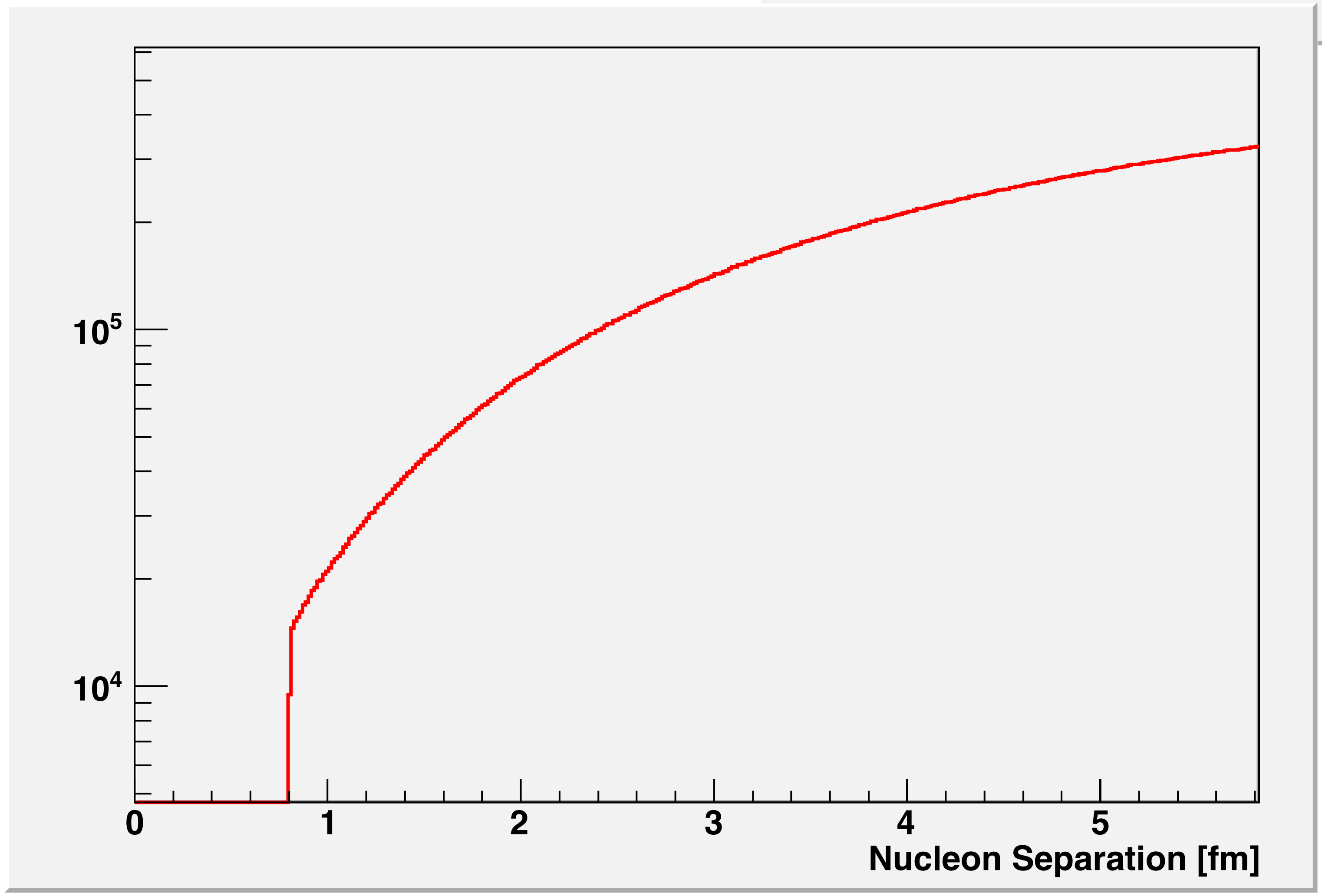
If not -> keep it

else -> regenerate angles

If this fails 1000 times discard nucleus and restart


[AU]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
2
4
6
8
10
12
14
Radius [fm]


ρ(r) [AU/fm^3]
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
r[fm]


10^5
10^4
0
1
2
3
4
5
Nucleon Separation [fm]

Problems!

Technical:

MC has the same cross-section formula all the time
Our's fluctuate a lot event by event!!!
This makes the code unreliable in present form...

Theoretical:

$$\mathcal{A}_{T,L}^{\gamma^* p \rightarrow Vp}(x, Q, \Delta) = i \int \mathrm{d}\mathbf{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b} (\Psi_V^* \Psi)_{T,L} e^{-i[\mathbf{b}-(1-z)\mathbf{r}]\cdot\Delta} \frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}}$$

Angular Symmetry

$$= i \int \mathrm{d}\mathbf{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b} (\Psi_V^* \Psi)_{T,L} (2\pi r) J_0([1-z]r\Delta)(2\pi b) J_0(b\Delta) \frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}}$$

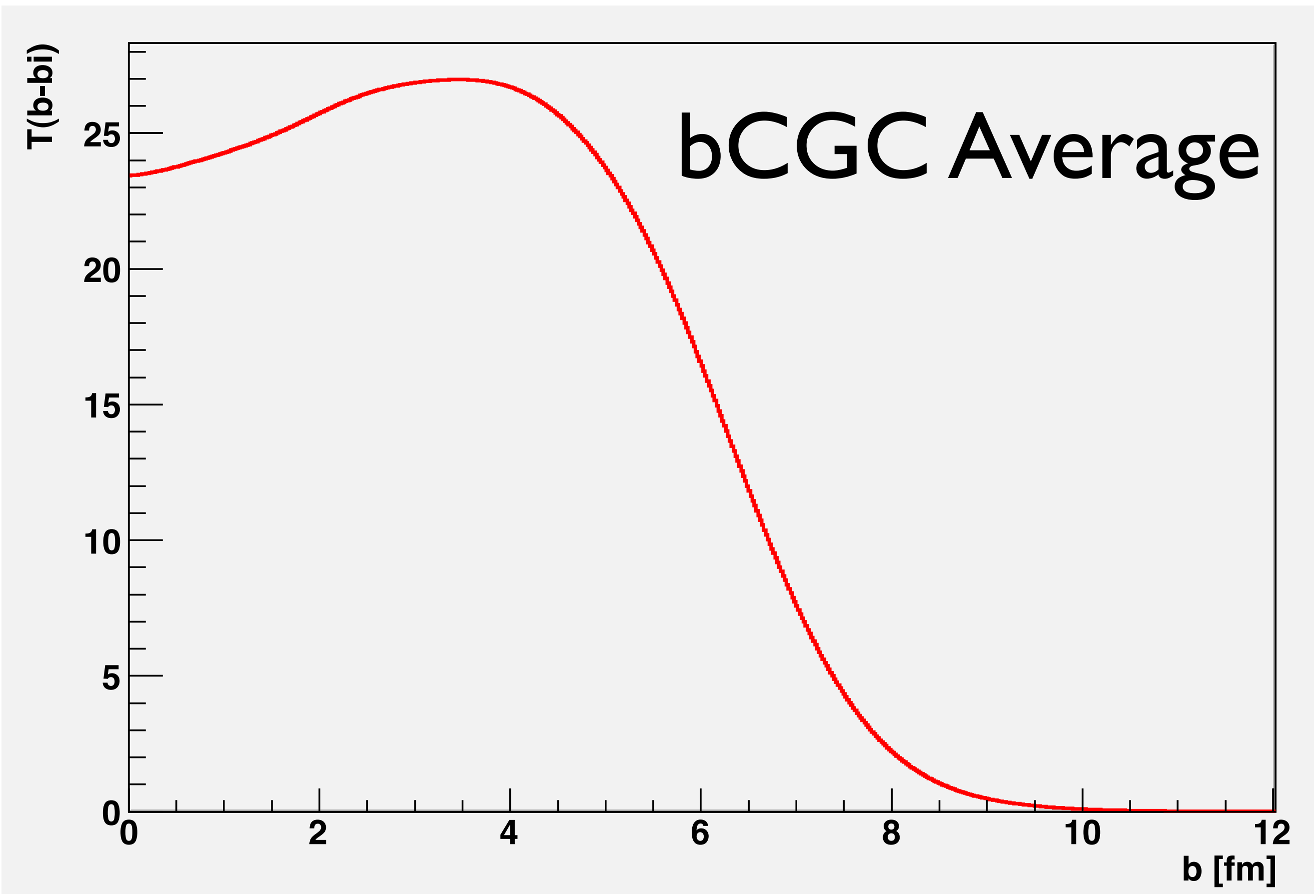
Present Solution (yesterday)

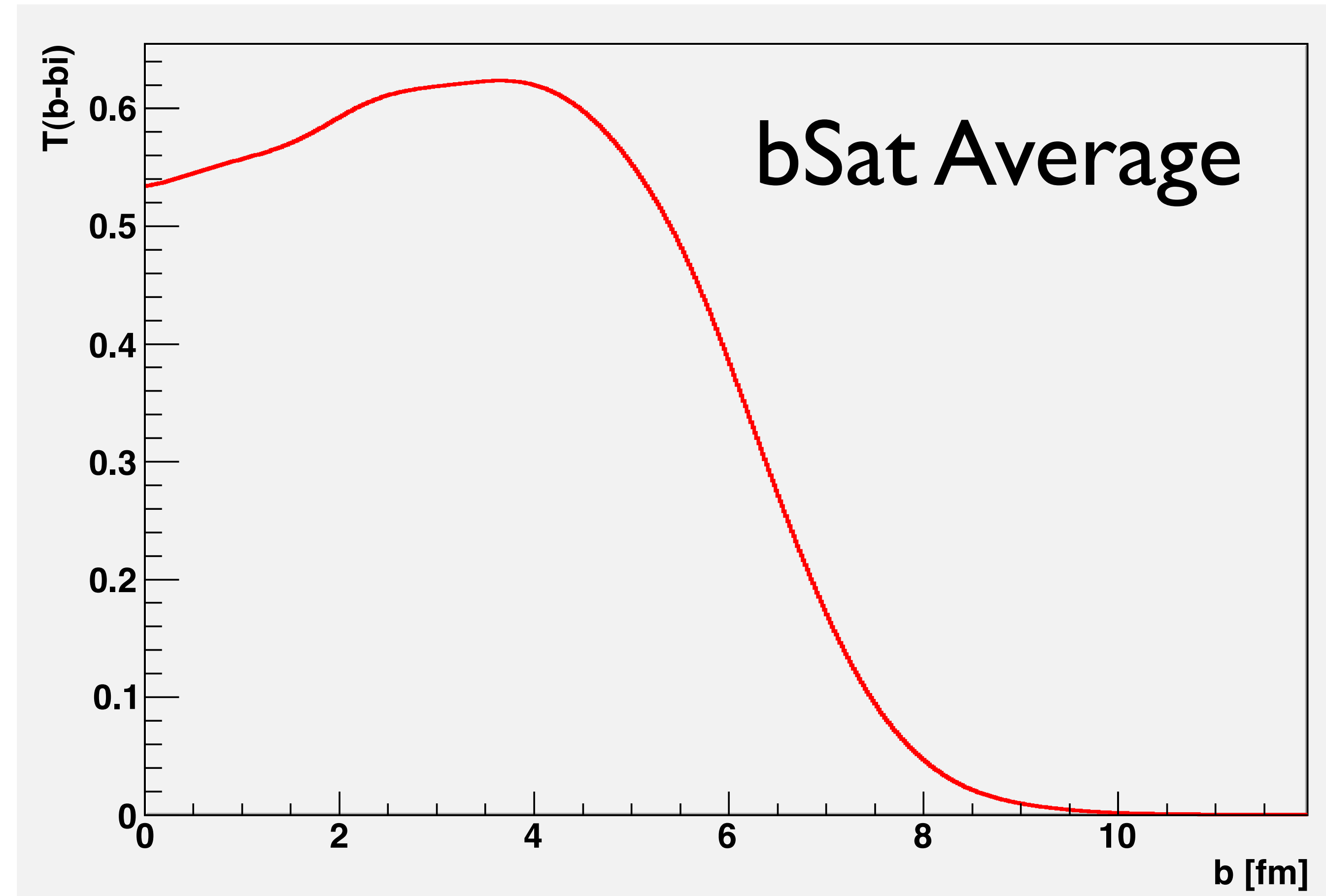
- At the beginning of the program, create a b-dependency function which:
  - includes the average of many nuclei.
  - is averaged over angle.
- Use the same function in all events.

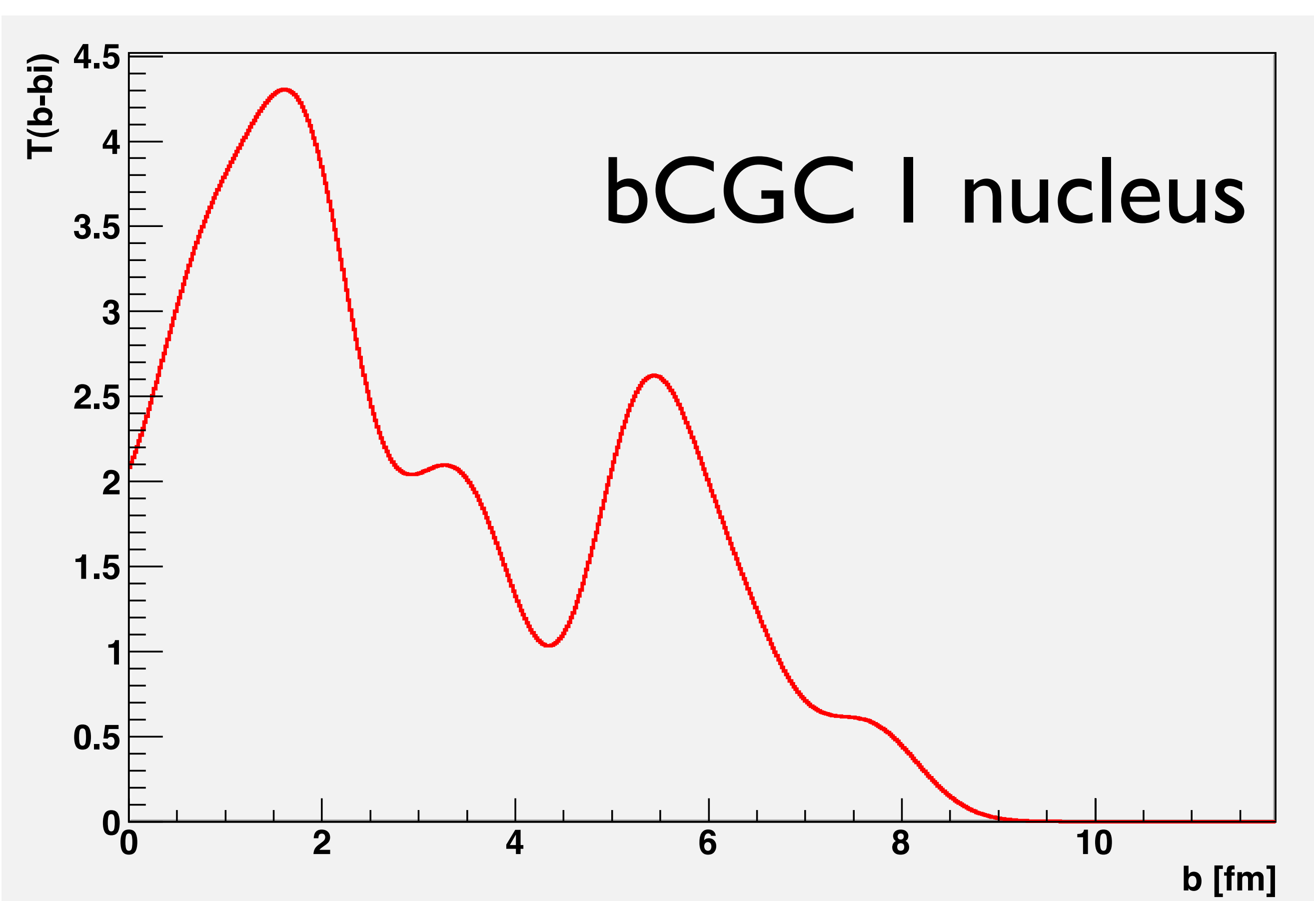
Time:

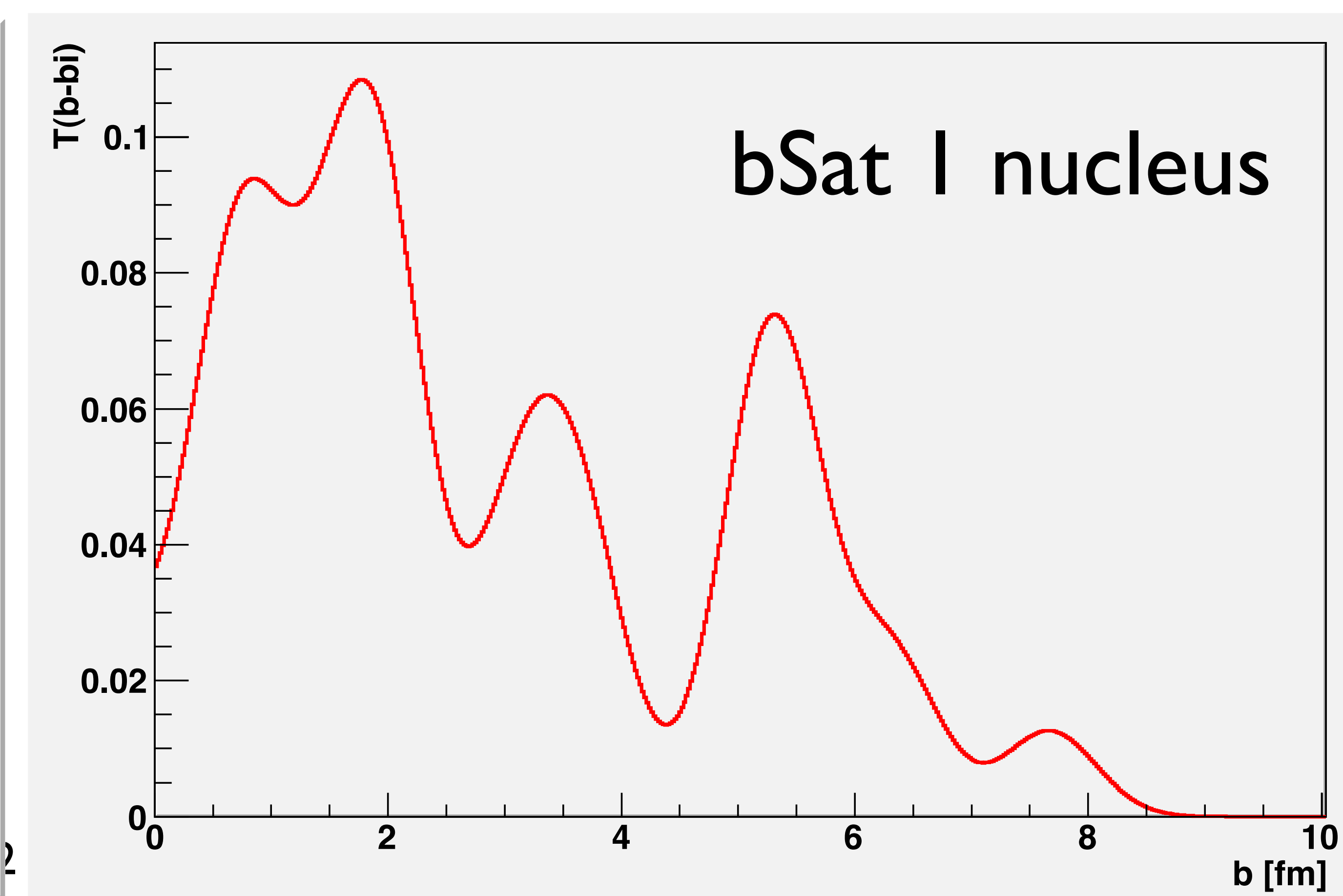
bCGC 10k events takes 7.5h, bSat longer!

Pb 208

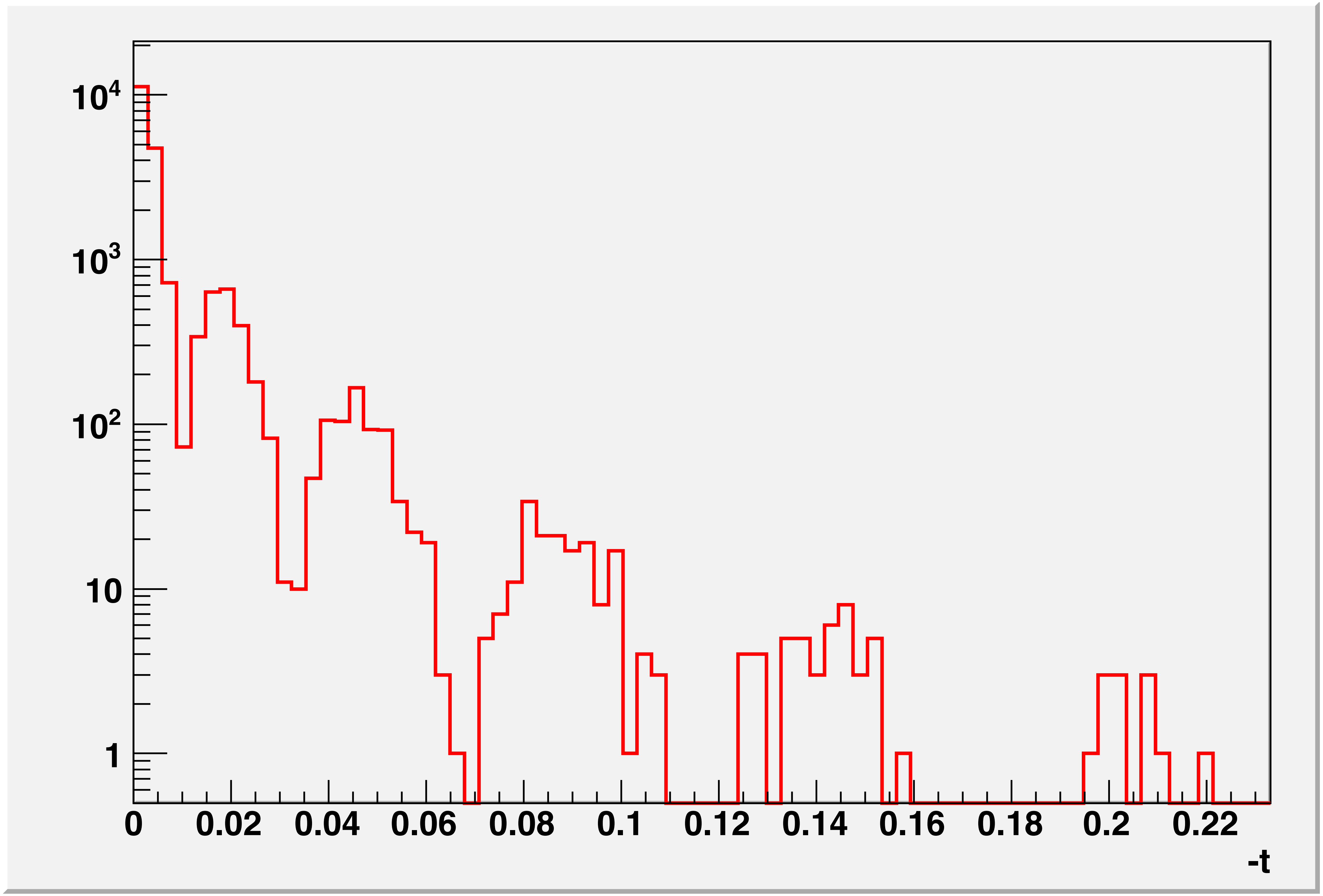

bCGC Average
T(b-bi)
25
20
15
10
5
0
0
2
4
6
8
10
12
b [fm]


bSat Average
T(b-bi)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
b [fm]

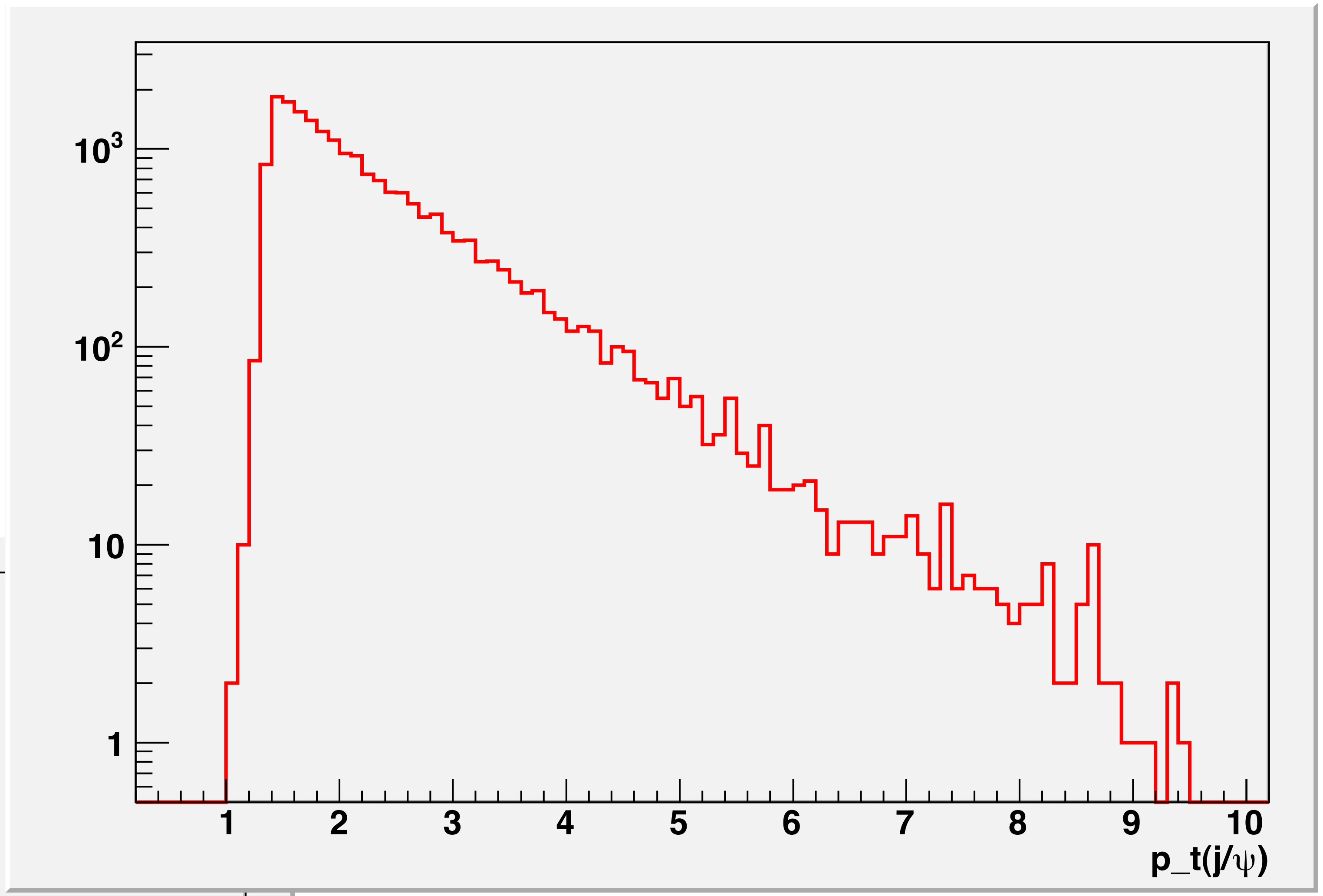

bCGC 1 nucleus
T(b-bi)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
b [fm]

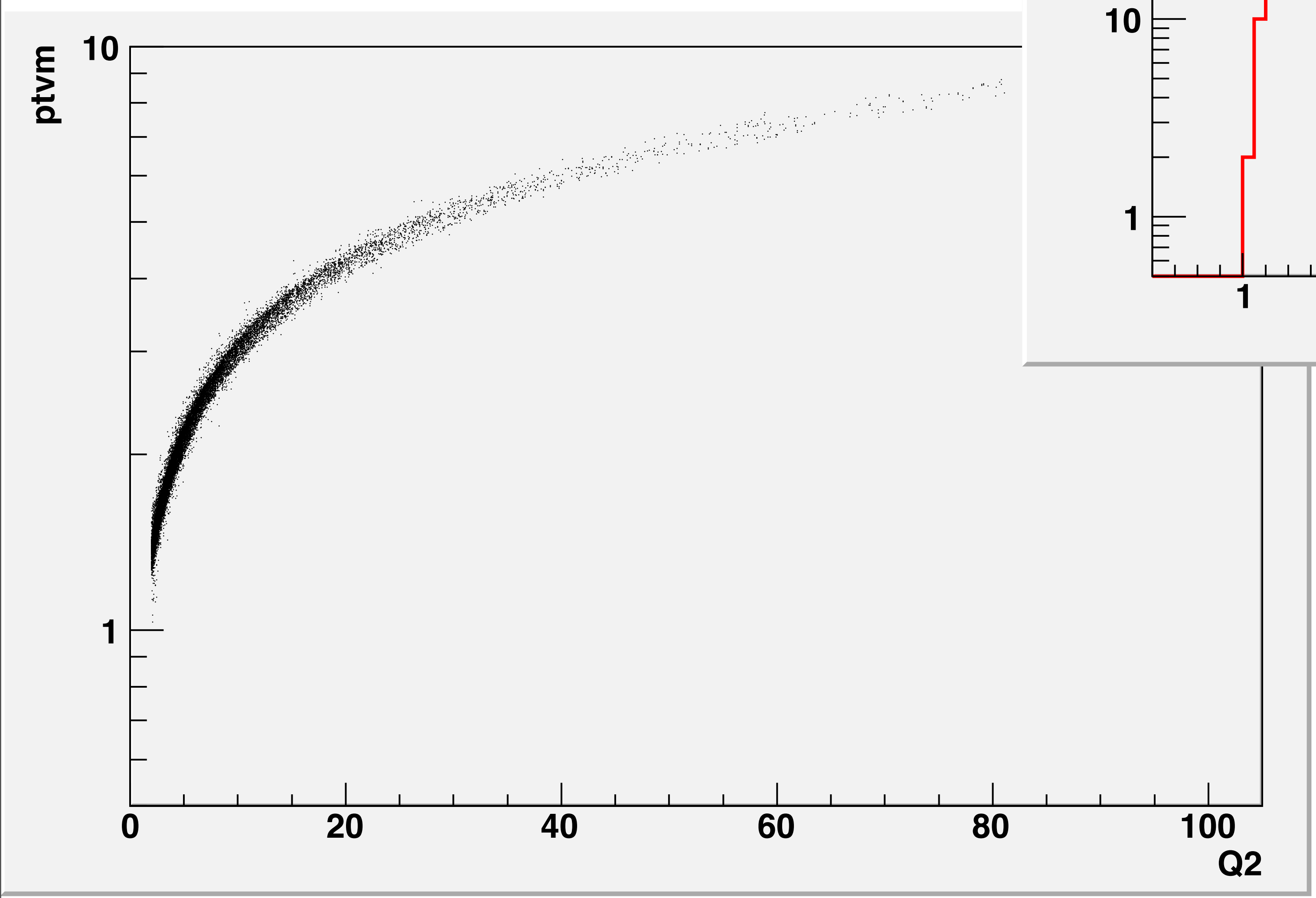

bSat 1 nucleus
T(b-bi)
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
b [fm]

Results bCGC 20k Events



Results bCGC 20k Events





Also in Progress

- DVCS
  Has been partly implemented.
  Not tested, no results

- Photoproduction

What has been done

- Real part of Amplitude corrections (done)
- Skewedness Corrections (done)
- Nucleus Generation and Implementation (ongoing)
- DVCS amplitude (ongoing/todo)
- Photoproduction (todo?)