QED radiative effects in NC event generators

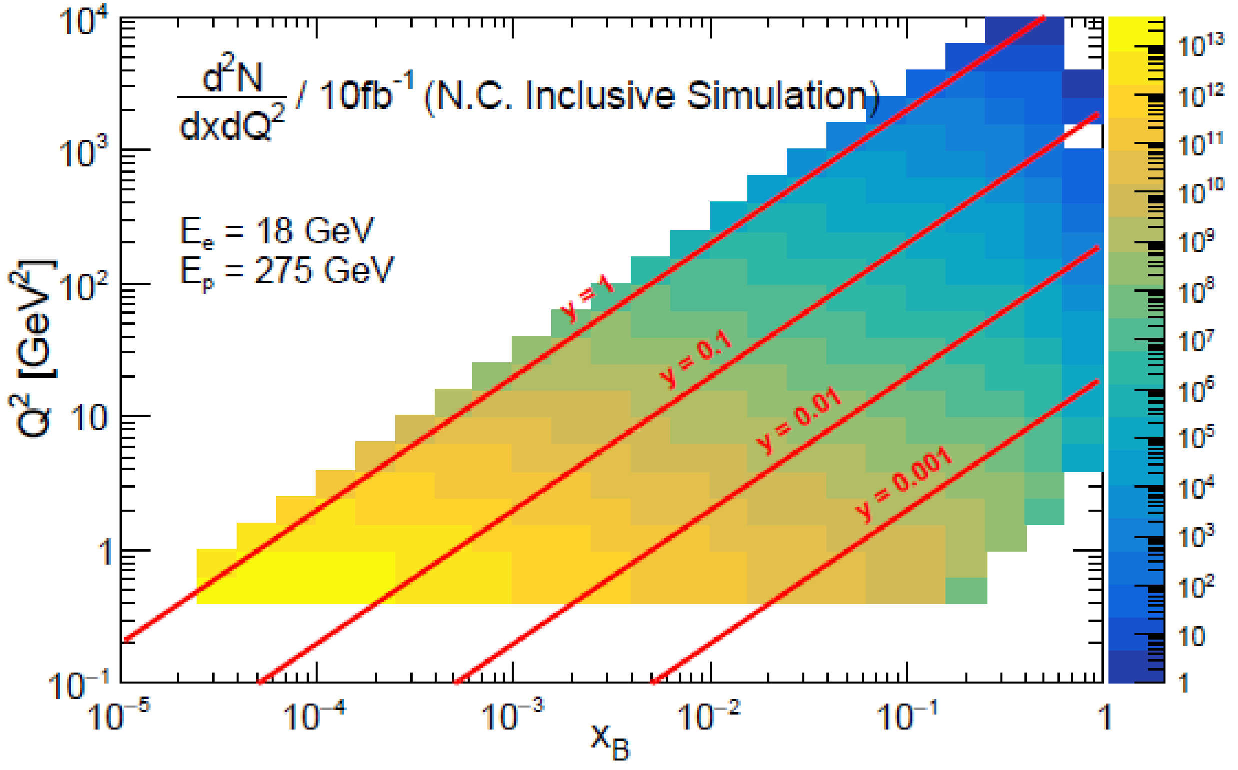
Barak Schmookler

Outline

- I'll show comparisons of the inclusive NC cross section at the Born level from *Pythia6*, *Djangoh*, and *Pythia8* with calculations using the input PDF.
- Next, I'll discuss the results of *Djangoh* and *Pythia6* NC simulations when including QED radiative effects.

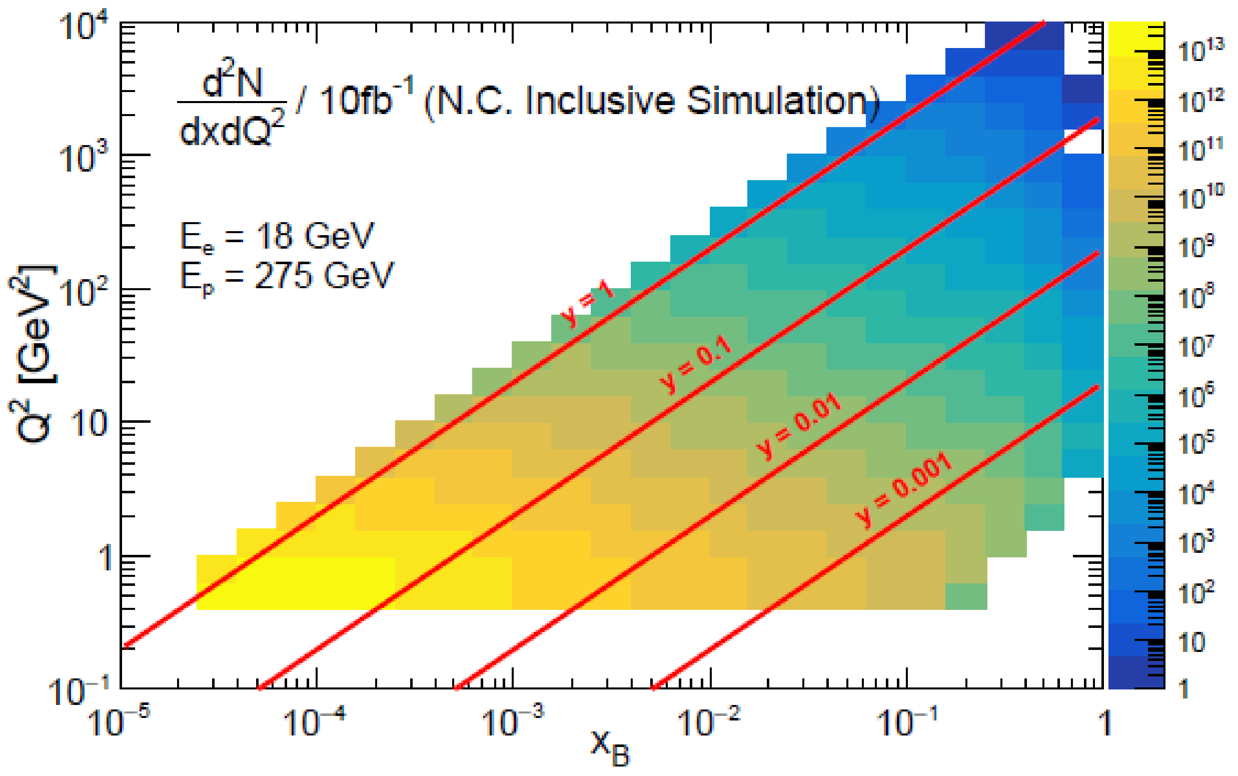
NC cross section extraction

- Inclusive NC events are generated at the Born level for the 3 simulation programs using the *cteq6l1* (10042) – LO fit w/ LO α_s – and the cross section is extracted using the binning shown.
- The average cross section in each bin for the simulation programs is compared to a calculation using the PDFs directly.

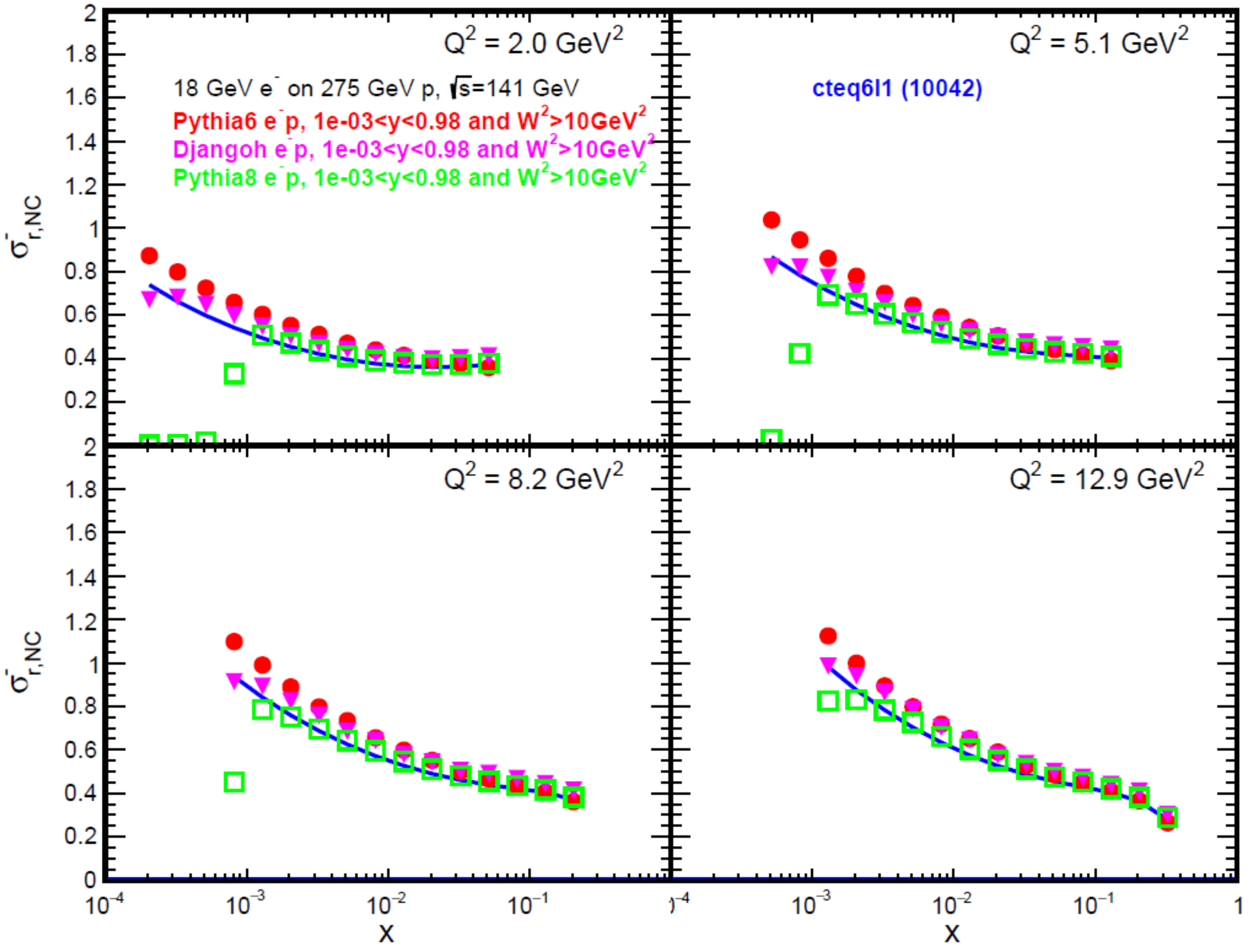


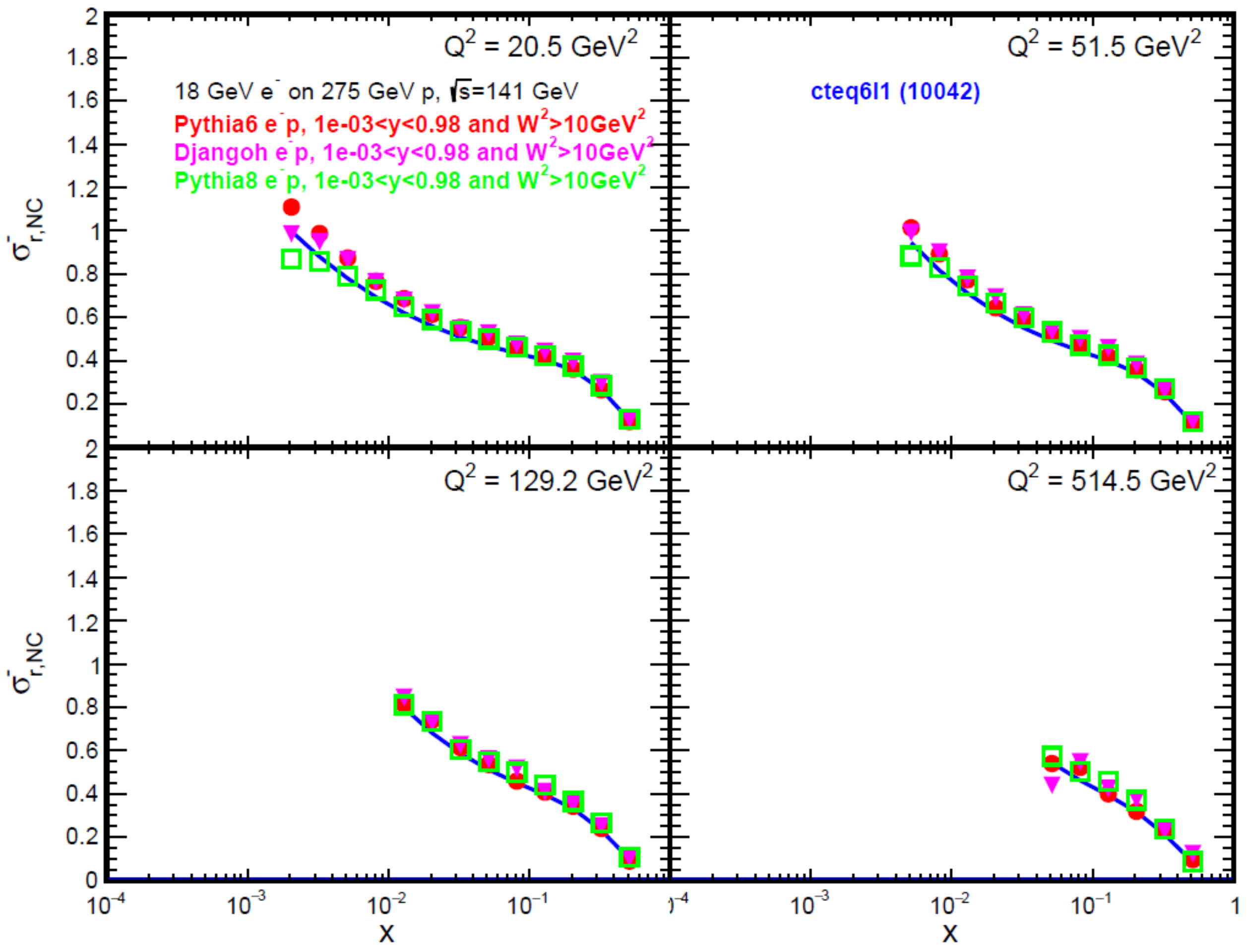
NC cross section extraction

$$\sigma_{r,NC}^{e^{\pm}p\rightarrow e^{\pm}X} = \frac{Q^4 x}{2\pi\alpha^2 Y_+} \times \frac{d^2\sigma_{NC}^{e^{\pm}p\rightarrow e^{\pm}X}}{dxdQ^2} = F_2 + \frac{Y_-}{Y_+}xF_3 - \frac{y^2}{Y_+}F_L$$

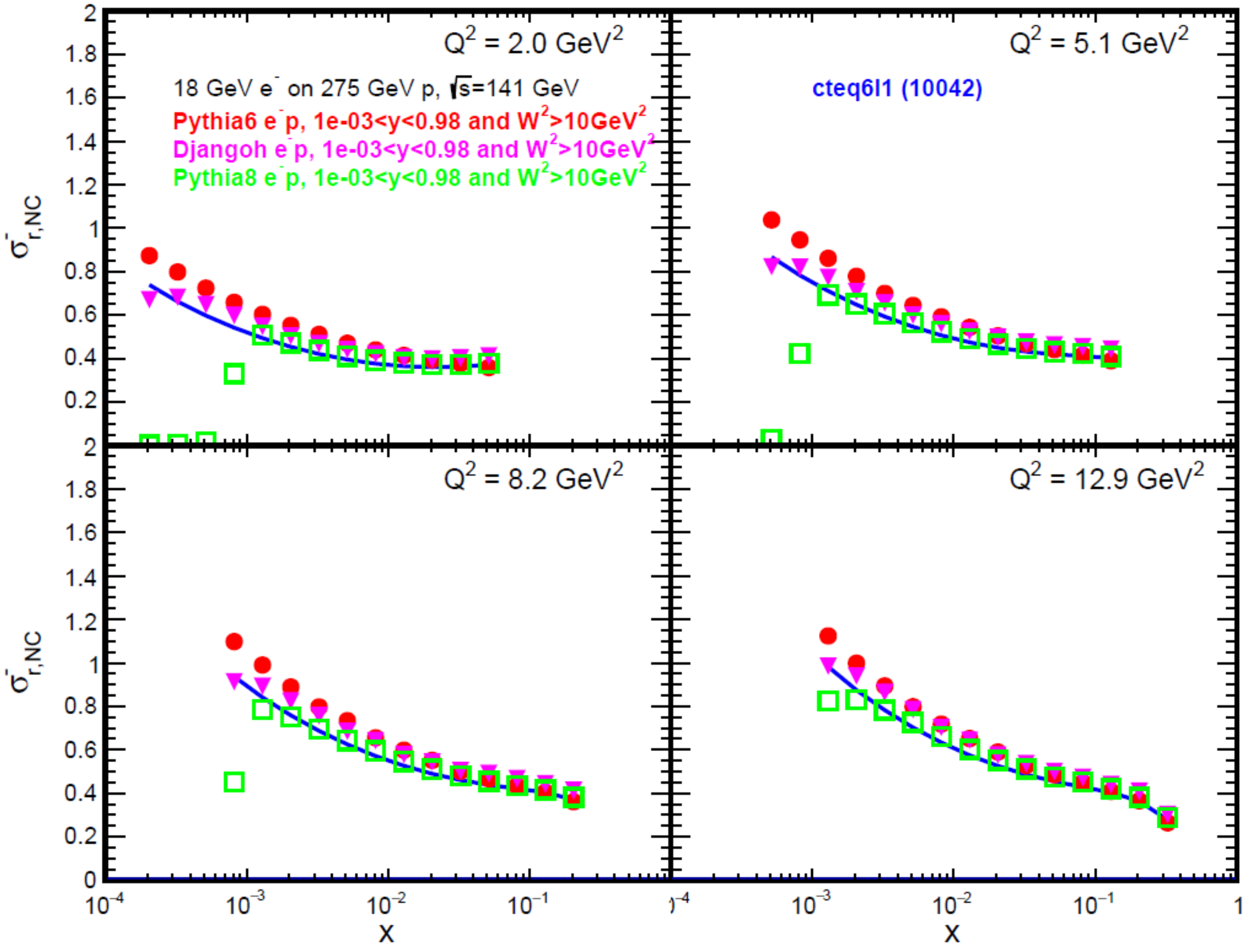


Cross section comparison – simulation and calculation





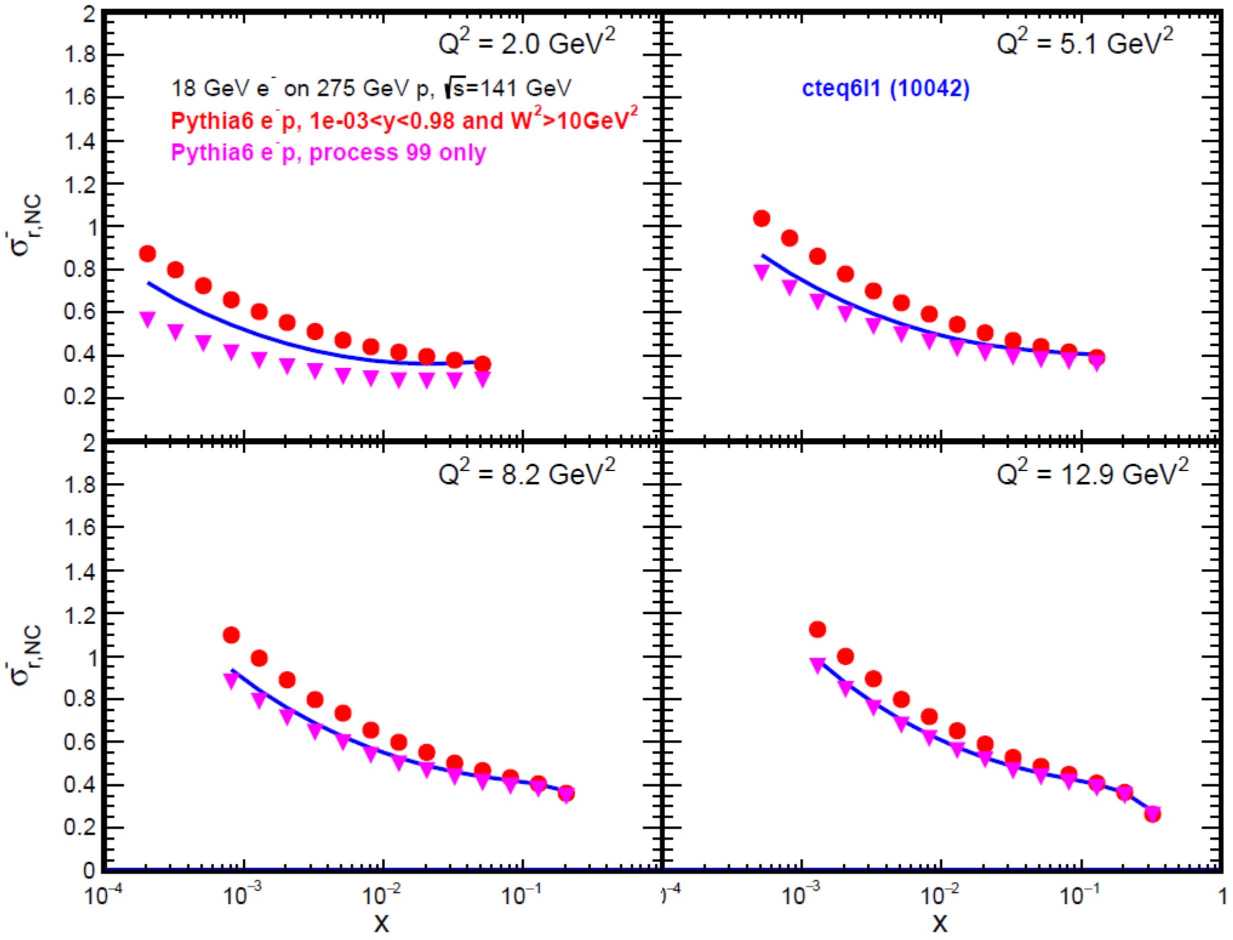
Cross section comparison – simulation and calculation

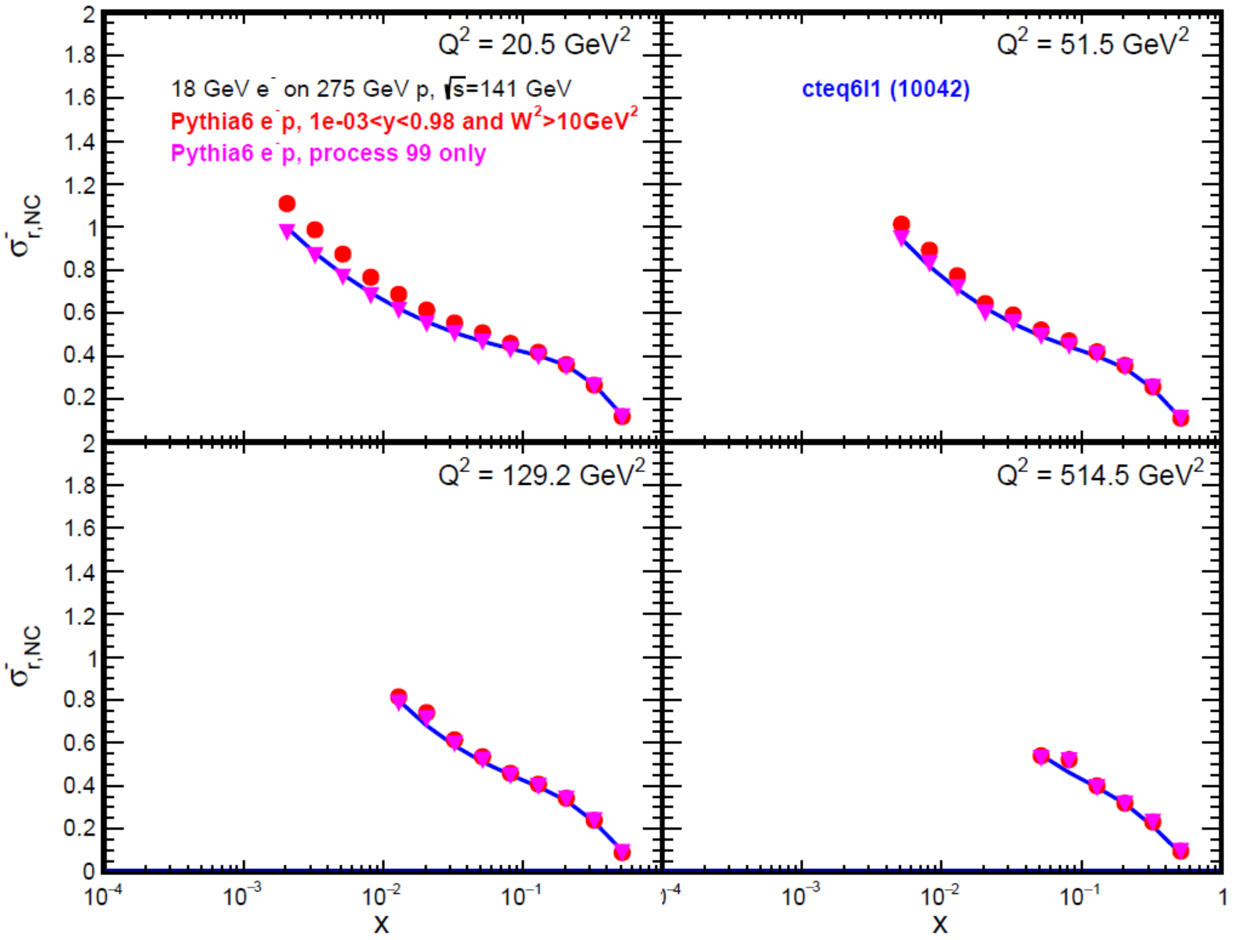


Some comments:

- The calculation (blue curve) shows the result of calculating at LO the average reduced cross section in each bin using the equation on the previous slide.
- *Pythia6* is higher than *Djangoh* at low x. This is probably due to *Pythia6* including additional processes.
- *Pythia8* (at least the input file I am using) has strange behavior at low-x.
- *Pythia6* will agree with the calculation at higher Q^2 if only LO process events are selected (see next slide).

Cross section comparison – *Pythia6* process selection

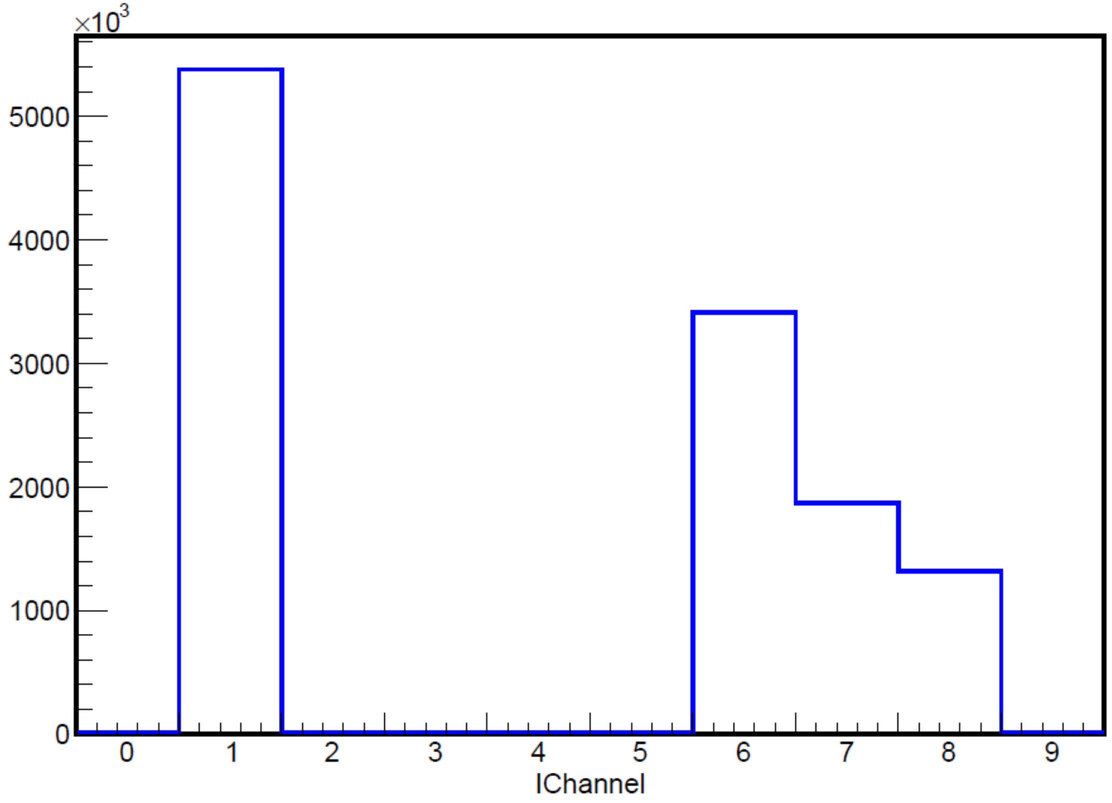




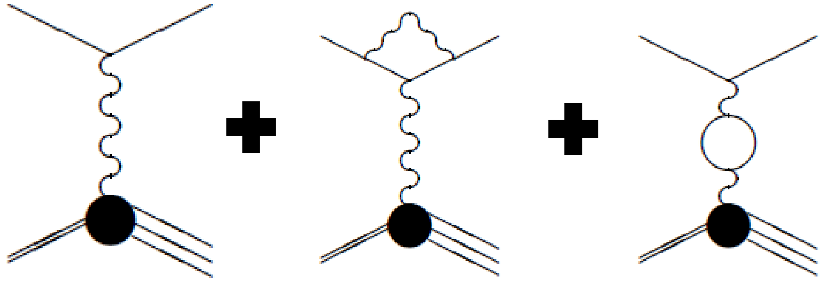
Radiative effects in the simulation programs

- *Djangoh* includes QED radiation based on the *HERACLES* program.
- The BNL version of *Pythia6* includes QED radiation based on the *RADGEN* program.
- I’ll focus mostly on *Djangoh* today.

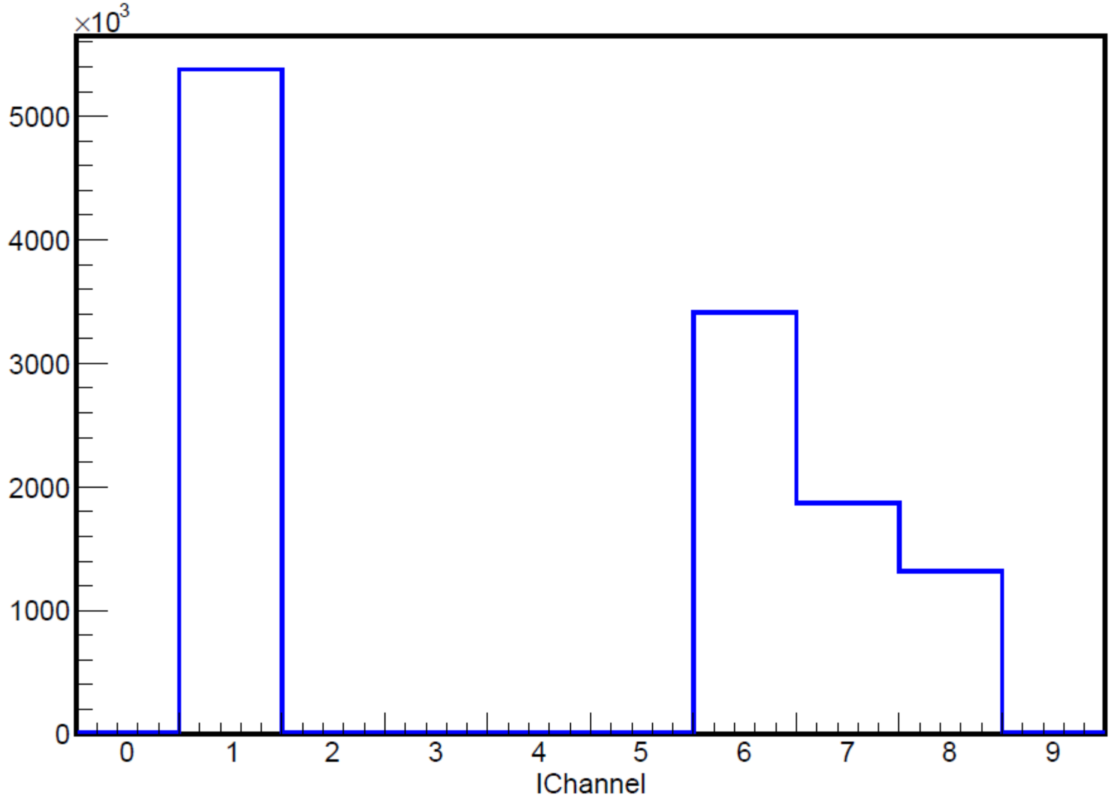
Radiative effects channels in *Djangoh*



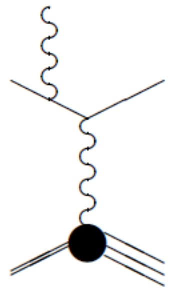
Channel 1



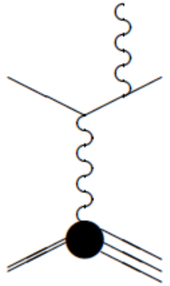
Radiative effects channels in *Djangoh*



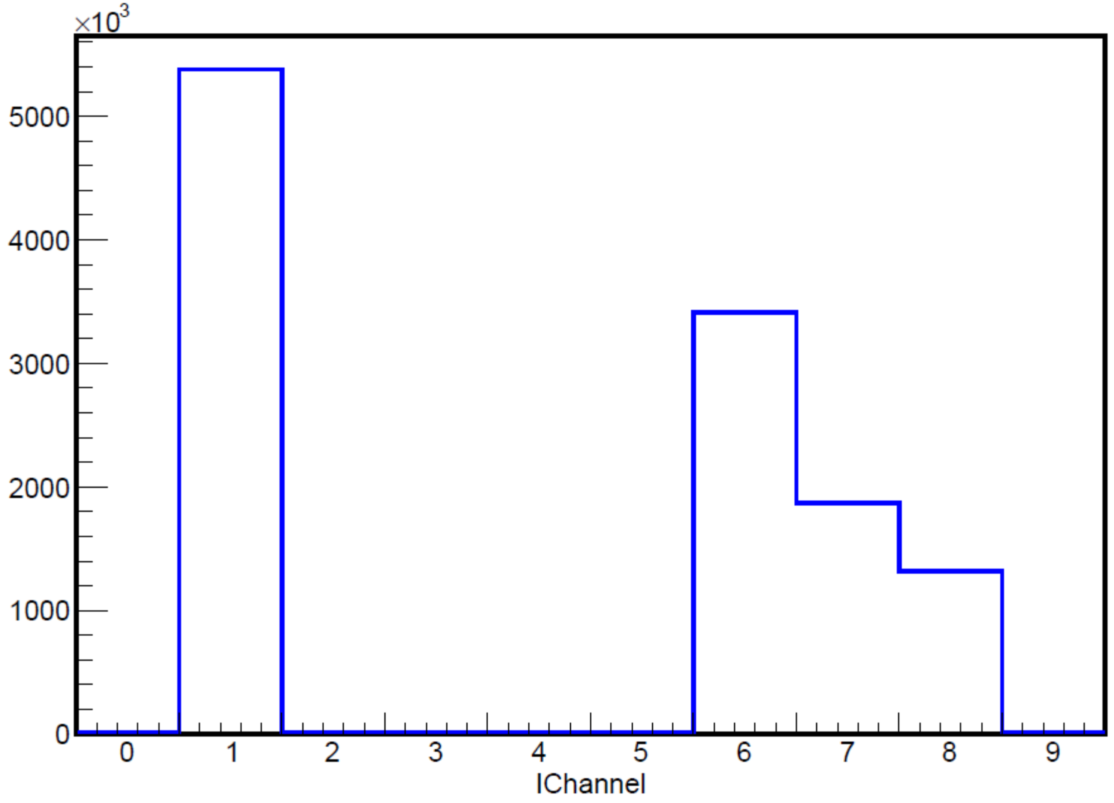
Channel 6



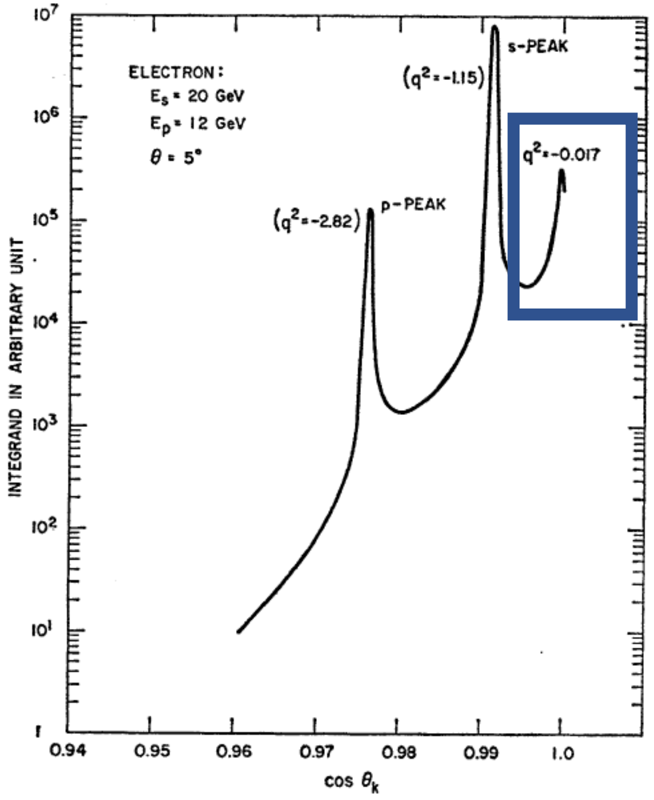
Channel 7



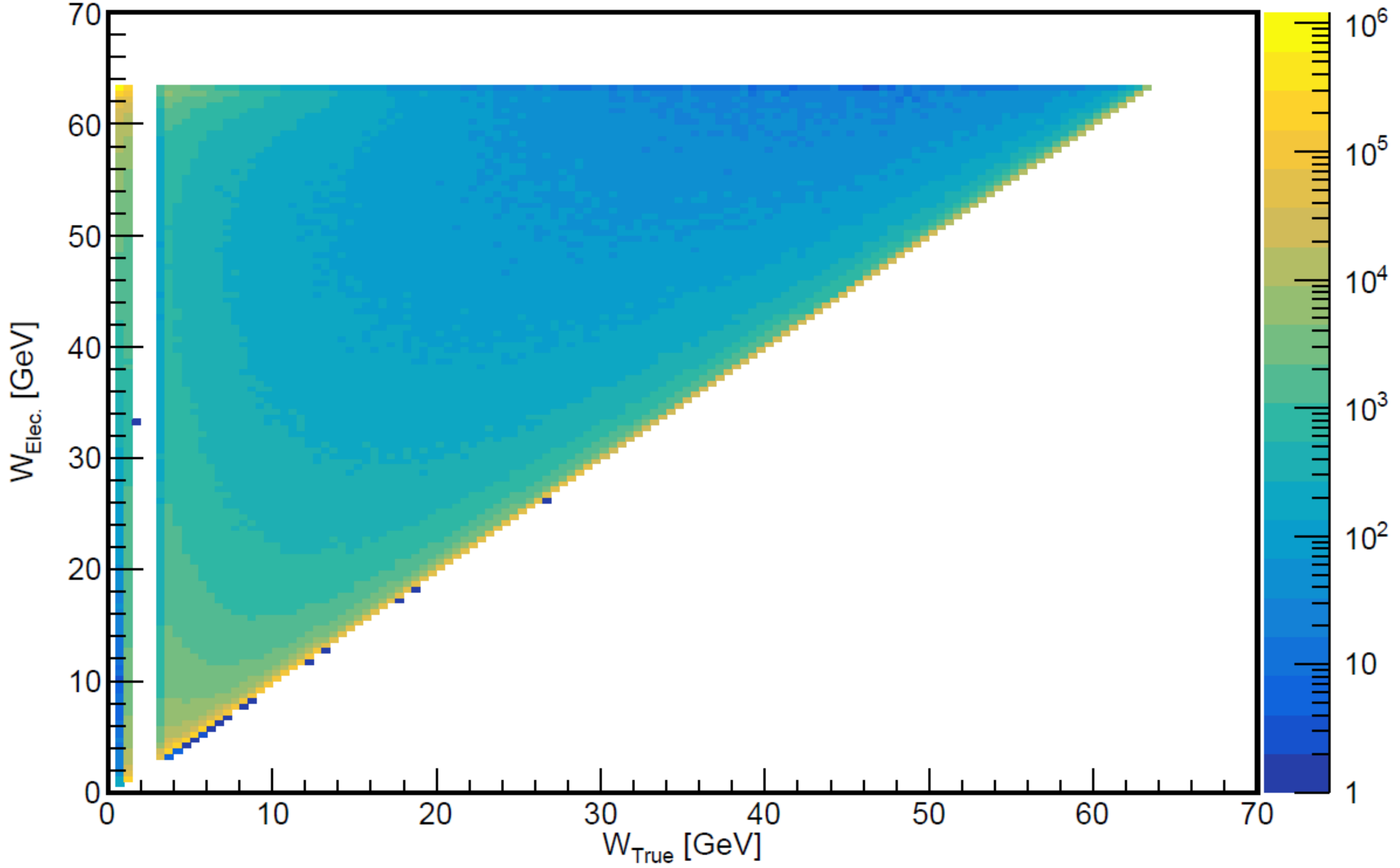
Radiative effects channels in *Djangoh*



Channel 8 ???



Kinematic distribution – scattered electron vs. true



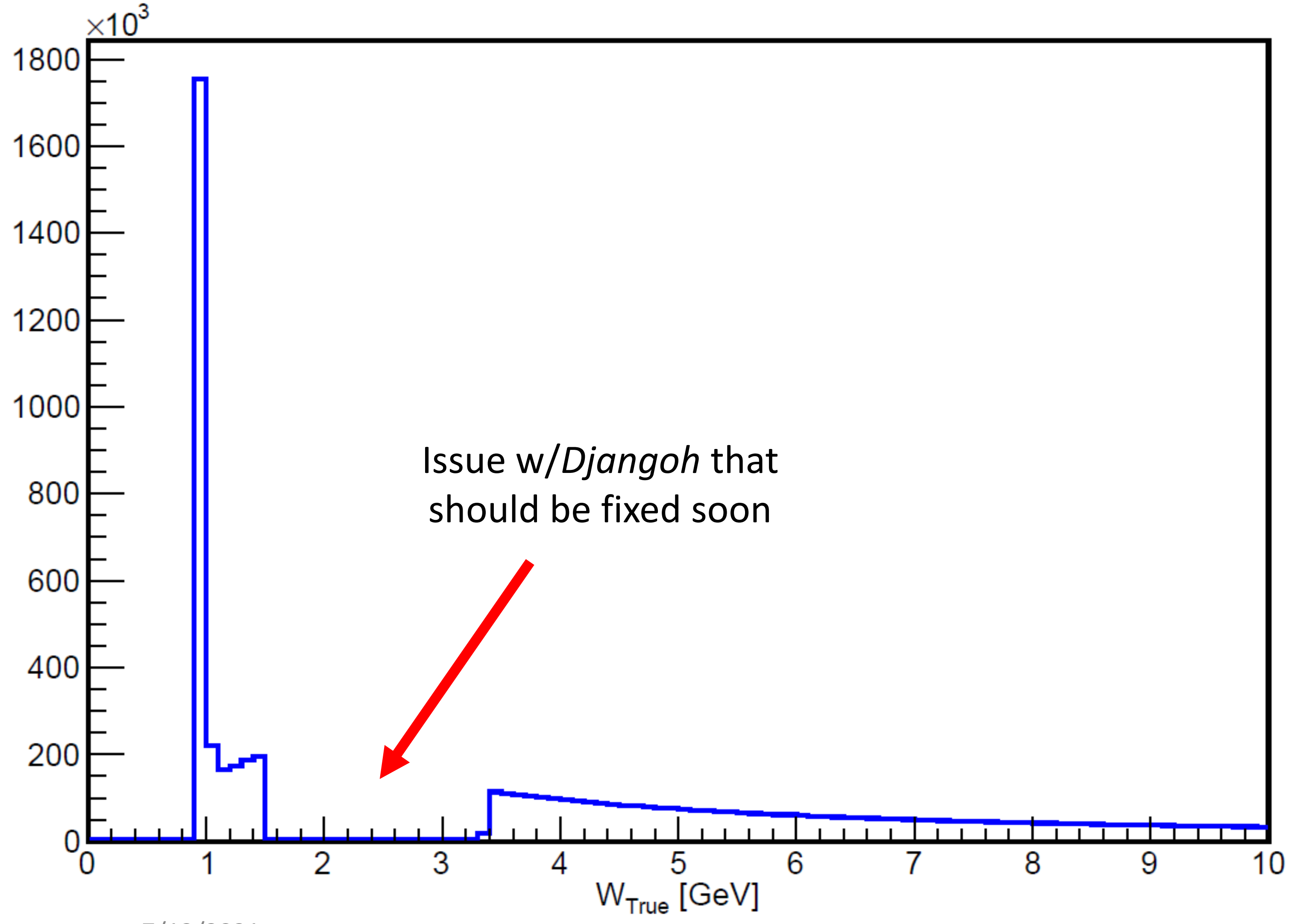
$$q \to q - k$$

In incoming proton rest frame:

$$W_{true}^2 = W^2 - 2E_\gamma(\nu + M - \sqrt{\nu^2 + Q^2}\cos\theta_\gamma).$$

$$W^2 = Q^2(1/x - 1) + M^2$$

Kinematic distribution – scattered electron vs. true



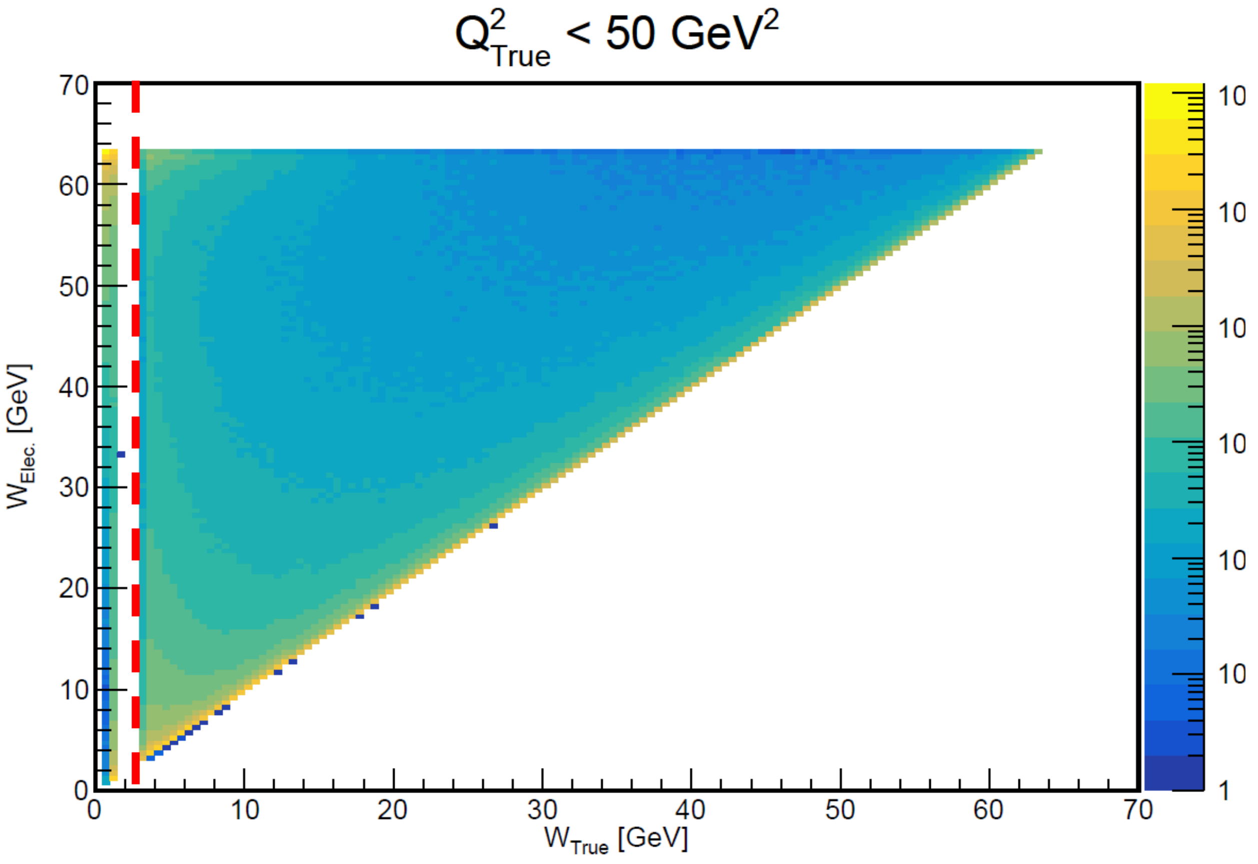
$$q \to q - k$$

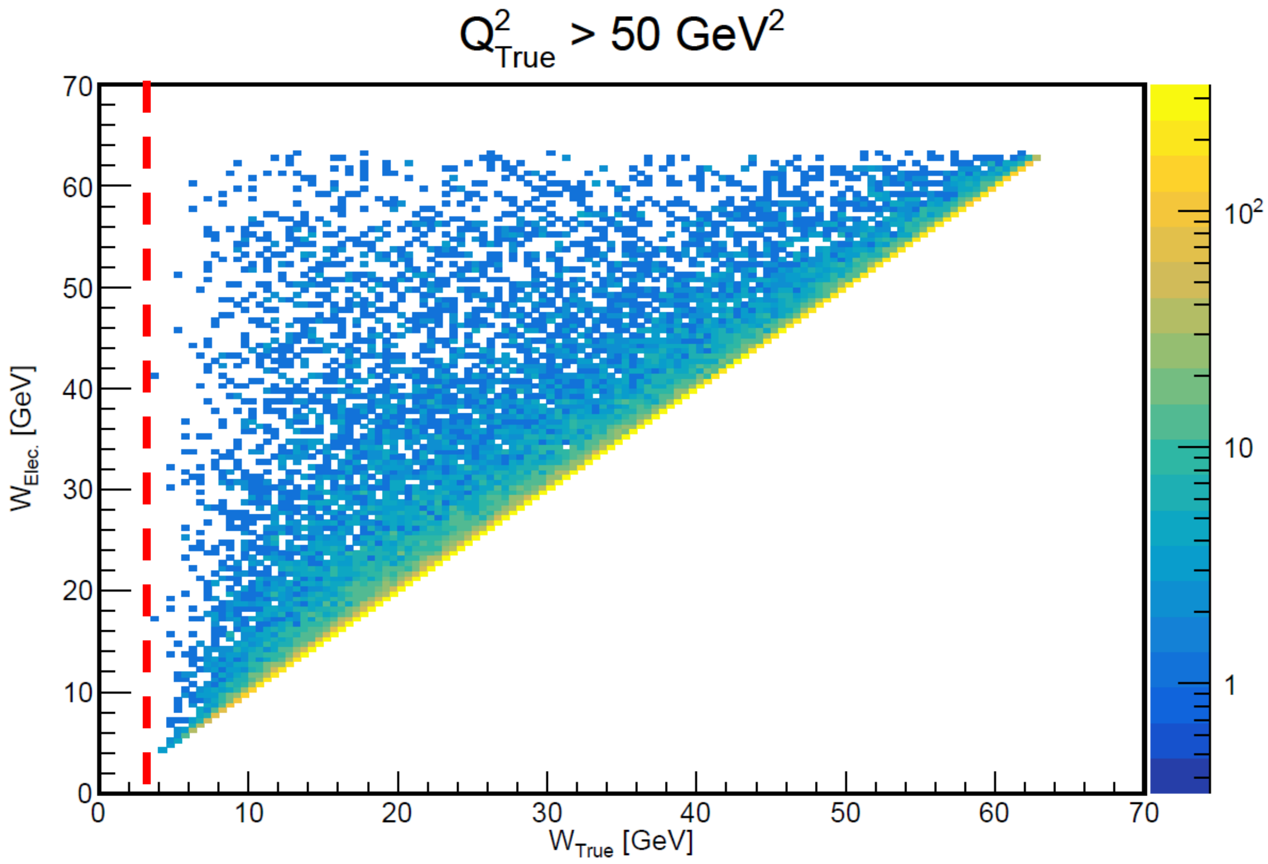
In incoming proton rest frame:

$$W_{true}^2 = W^2 - 2E_\gamma(\nu + M - \sqrt{\nu^2 + Q^2}\cos\theta_\gamma).$$

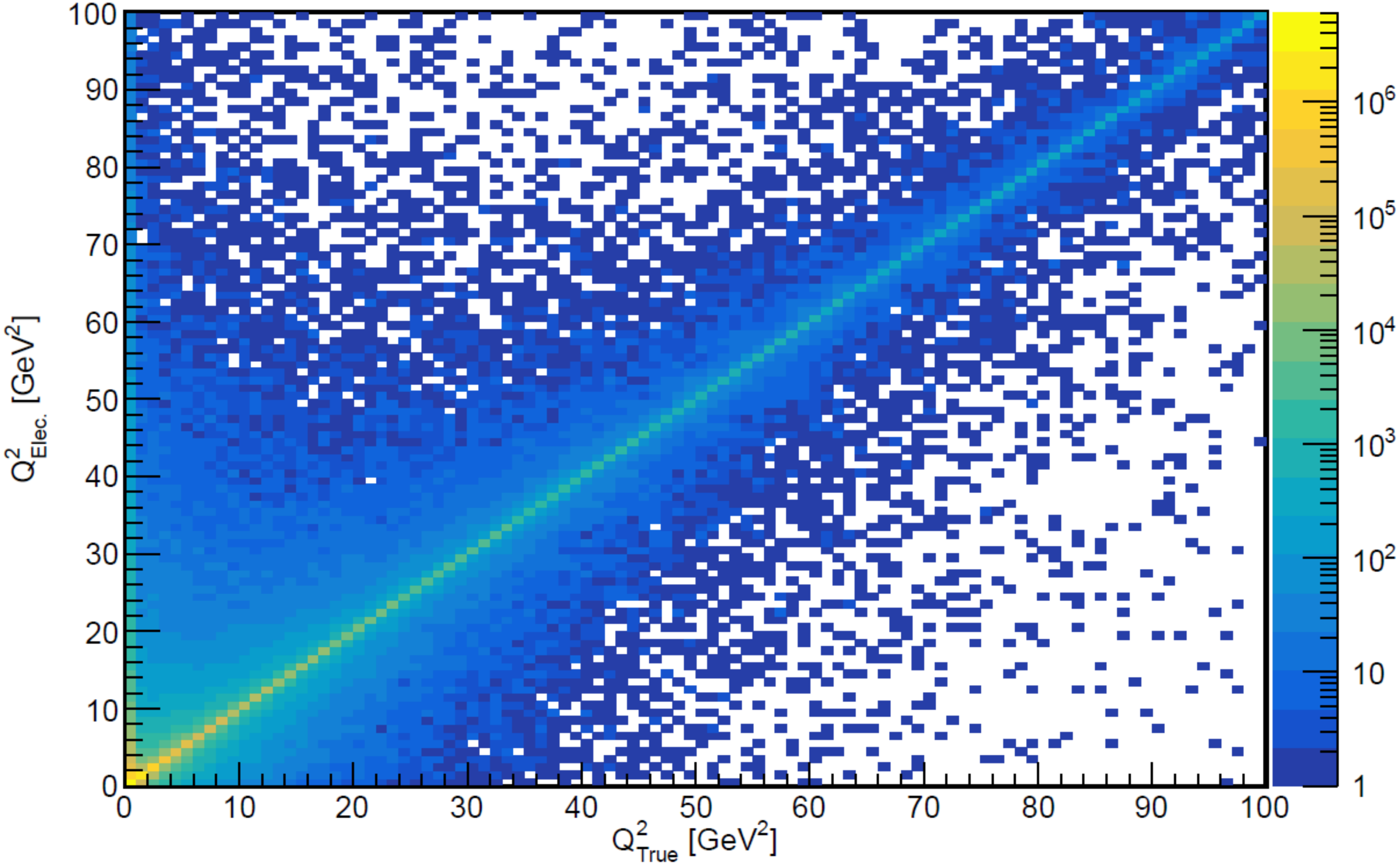
$$W^2 = Q^2(1/x - 1) + M^2$$

This issue is only important at lower Q^2





Kinematic distribution – scattered electron vs. true



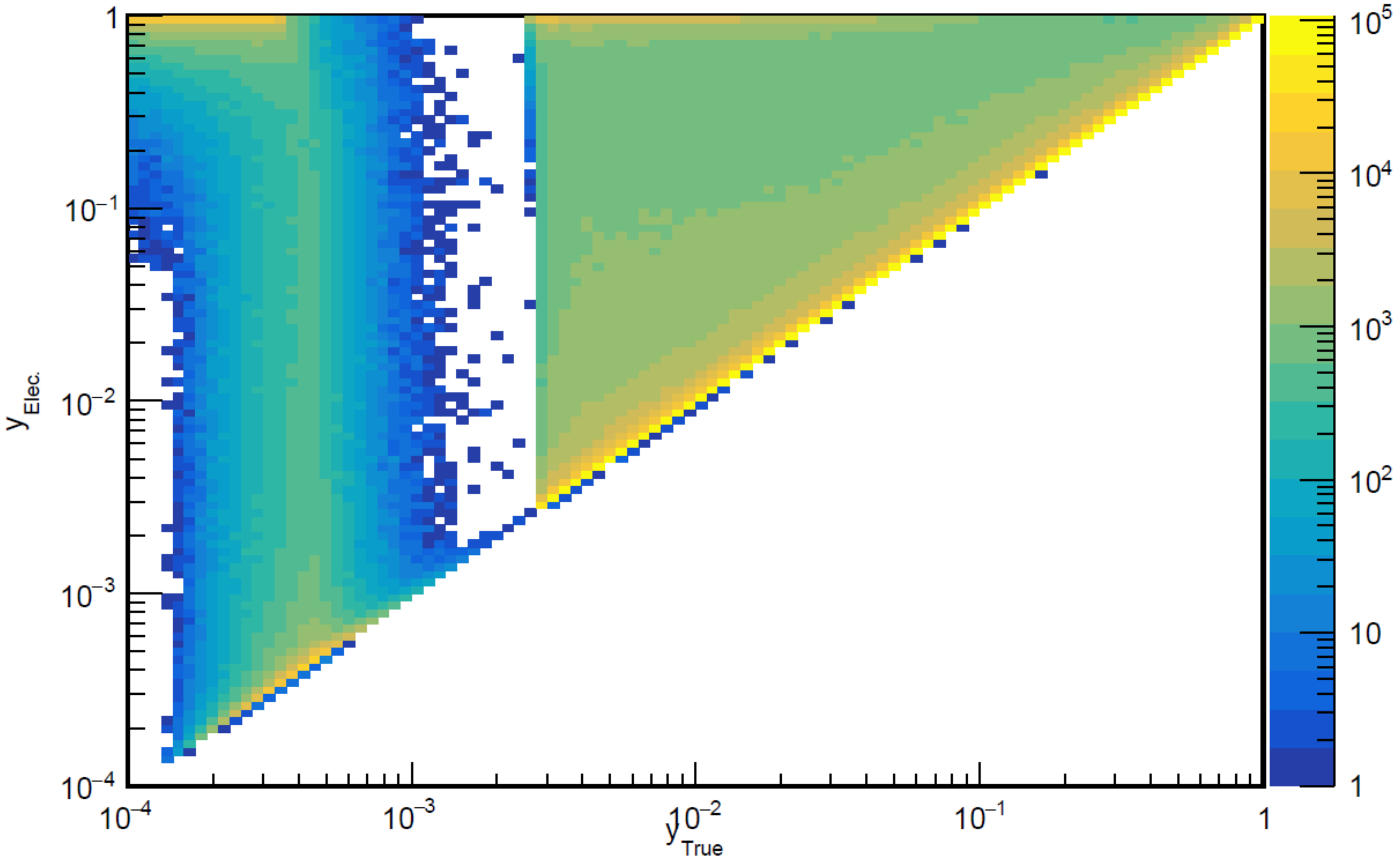
$$q \to q - k$$

In incoming proton rest frame:

$$Q^2_{true} = Q^2 + 2E_\gamma(\nu - \sqrt{\nu^2 + Q^2}\cos\theta_\gamma)$$

$$Q^2 = 4EE' \sin^2\frac{\theta}{2}$$

Kinematic distribution – scattered electron vs. true



$$q \to q - k$$

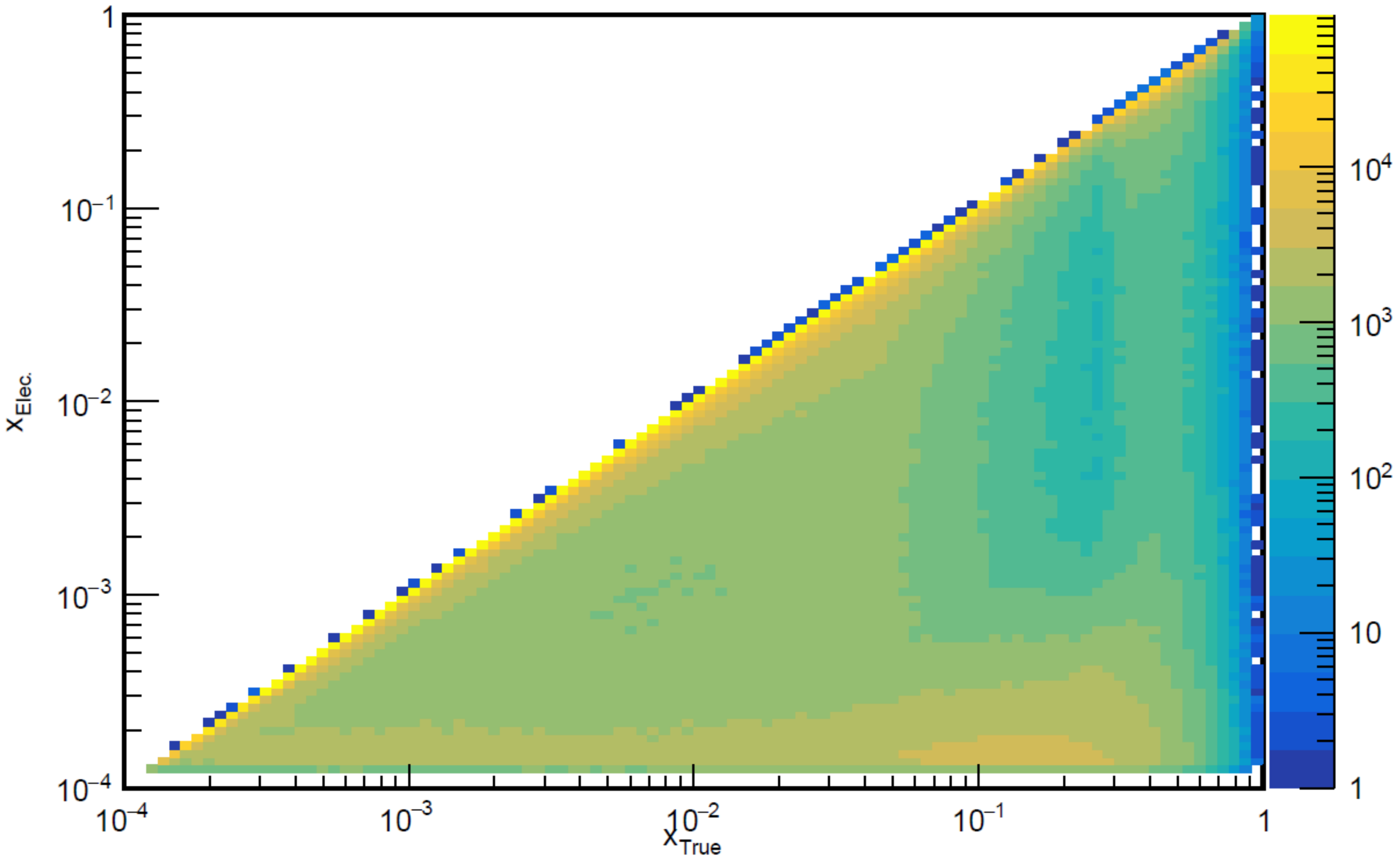
In incoming proton rest frame:

$$y = \frac{\upsilon_{true}}{E}$$

$$y = \frac{\nu}{E}$$

$$\nu_{true} = \nu - E_\gamma \qquad \nu = E - E'$$

Kinematic distribution – scattered electron vs. true



$$q \to q - k$$

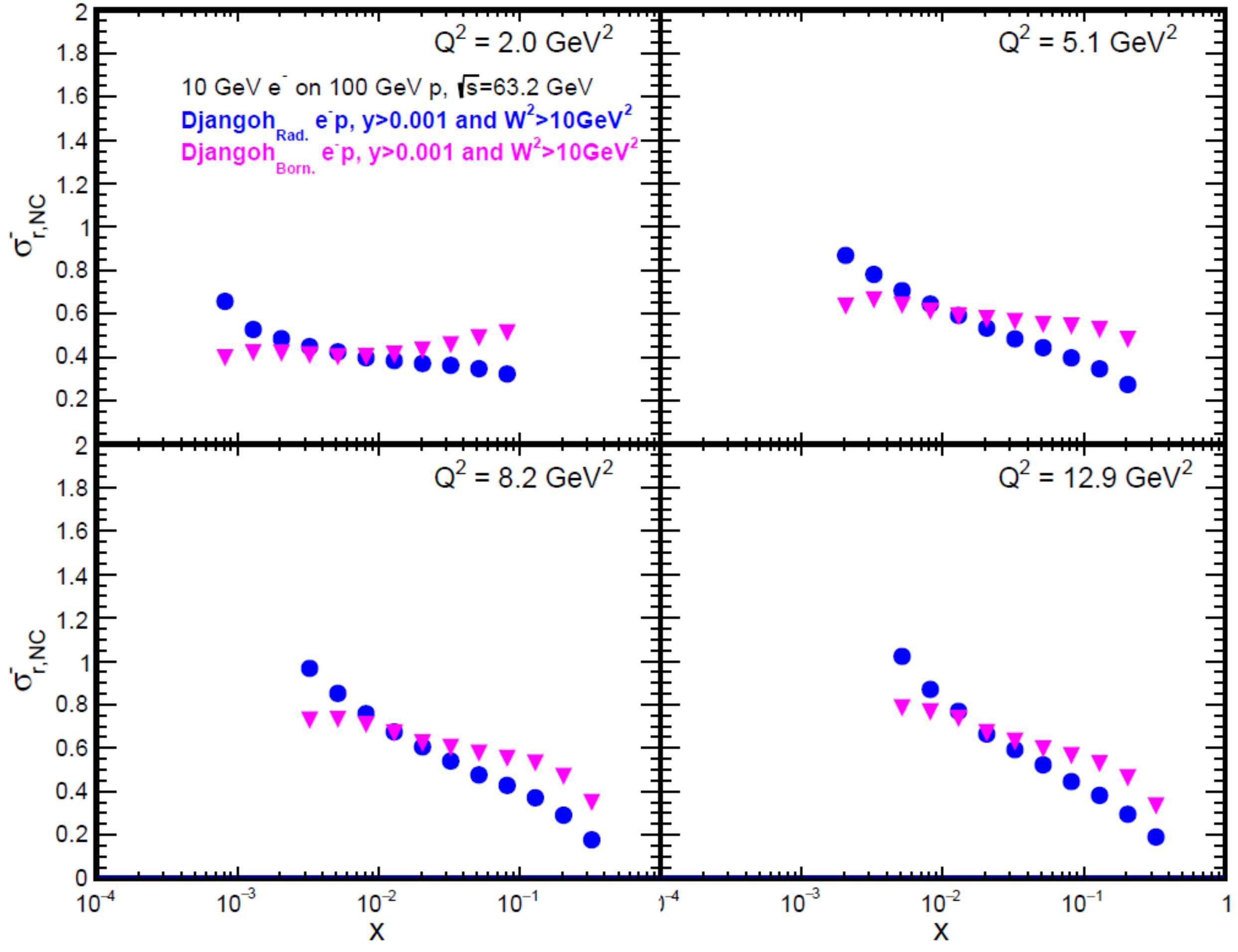
In incoming proton rest frame:

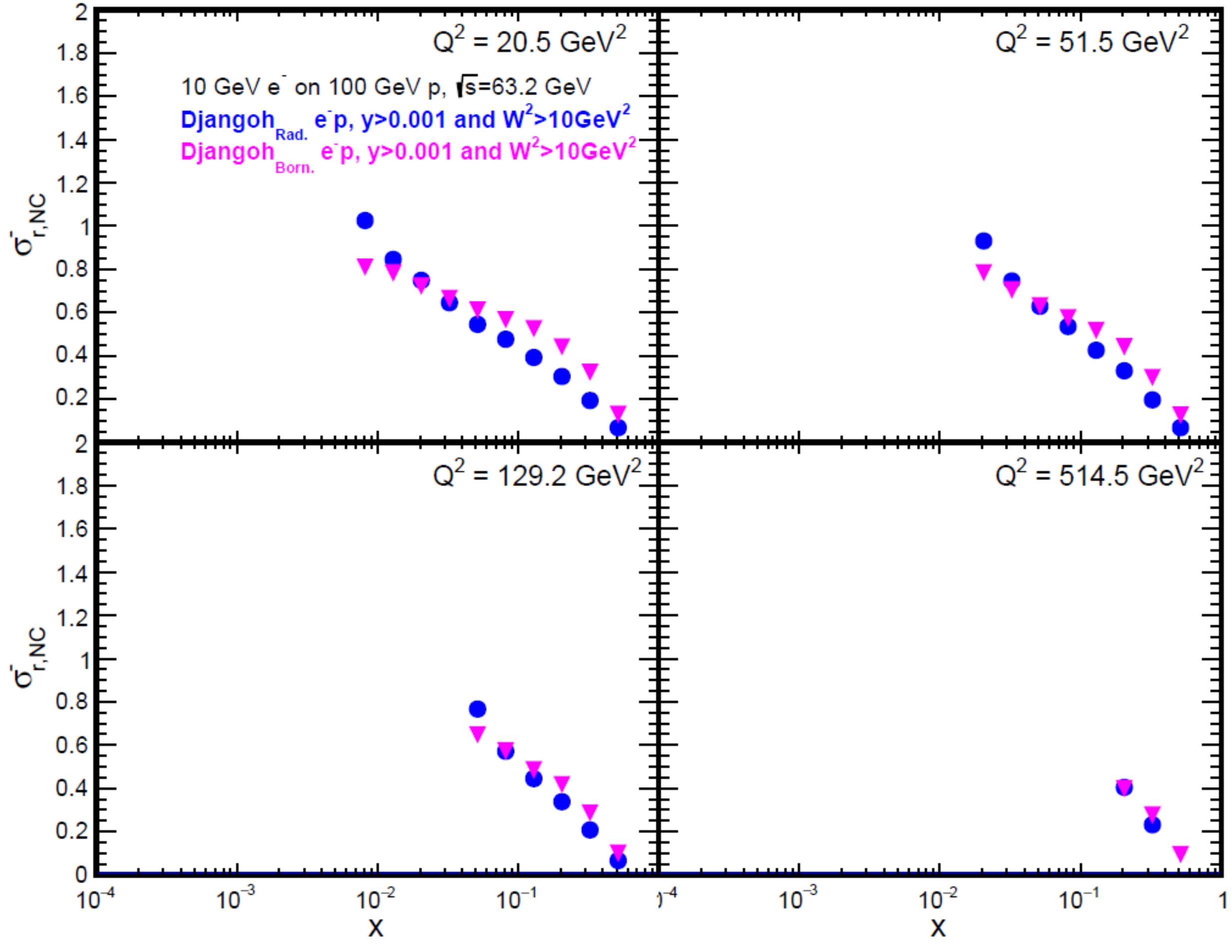
$$x_{true} = \frac{Q^2_{true}}{2M\nu_{true}}$$

$$x = \frac{Q^2}{2M\nu}$$

$$\nu_{true} = \nu - E_\gamma \qquad \nu = E - E'$$

Radiative correction factor – scattered electron method





One event in *PythiaeRHIC/RADGEN*

```
 1     21         11      0       3     4      0.000000     0.000000   -10.000000    10.000000     0.000510
0.000000        0.000000        0.000000
 2     21       2212      0       5     0     -0.000000     0.000000   100.000000   100.004402     0.938270
0.000000        0.000000        0.000000
 3     21         11      1       0     0      0.535189    -0.903093    -9.537248     9.594848     0.000510
0.000000        0.000000        0.000000
 4     21         22      1       0     0     -0.535189     0.903093    -0.462752     0.405152    -1.073310
0.000000        0.000000        0.000000
 5     21       2212      2       0     0     -0.000000     0.000000   100.000000   100.004402     0.938270
0.000000        0.000000        0.000000
 6     21    9900220      4       0     0     -0.816422     0.988845     7.281930     8.148995     3.425677
0.000000        0.000000        0.000000
 7     21       2212      5       0     0      0.281233    -0.085752    92.255319    92.260558     0.938270
0.000000        0.000000        0.000000
 8     12          2      6      13    15     -0.829264     0.986121     0.600349     1.459258     0.330000
0.000000        0.000000        0.000000
 9     11         -2      6      13    15      0.012842     0.002724     6.681581     6.689738     0.330000
0.000000        0.000000        0.000000
10      1       2212      7       0     0      0.281233    -0.085752    92.255319    92.260558     0.938270
0.000000        0.000000        0.000000
11      1         11      3       0     0      0.535189    -0.903093    -9.537248     9.594848     0.000510
0.000000        0.000000        0.000000
```

```
25     55         22      1       0     0      0.000511     0.000526    -0.003713     0.003785     0.000000
0.000000        0.000000        0.000000
```

One event in *PythiaeRHIC/RADGEN*

1	21	11	0	3	4	0.000000	0.000000	-10.000000	10.000000	0.000510	0.000000	0.000000	0.000000
2	21	2212	0	5	0	-0.000000	0.000000	100.000000	100.004402	0.938270	0.000000	0.000000	0.000000
3	21	11	1	0	0	0.535189	-0.903093	-9.537248	9.594848	0.000510	0.000000	0.000000	0.000000
4	21	22	1	0	0	-0.535189	0.903093	-0.462752	0.405152	-1.073310	0.000000	0.000000	0.000000
5	21	2212	2	0	0	-0.000000	0.000000	100.000000	100.004402	0.938270	0.000000	0.000000	0.000000
6	21	9900220	4	0	0	-0.816422	0.988845	7.281930			0.000000	0.000000	0.000000
7	21	2212	5	0	0	0.281233	-0.085752	92.255319			0.000000	0.000000	0.000000
8	12	2	6	13	15	-0.829264	0.986121	0.600349			0.000000	0.000000	0.000000
9	11	-2	6	13	15	0.012842	0.002724	6.681581	6.689738	0.330000	0.000000	0.000000	0.000000
10	1	2212	7	0	0	0.281233	-0.085752	92.255319	92.260558	0.938270	0.000000	0.000000	0.000000
11	1	11	3	0	0	0.535189	-0.903093	-9.537248	9.594848	0.000510	0.000000	0.000000	0.000000
25	55	22	1	0	0	0.000511	0.000526	-0.003713	0.003785	0.000000	0.000000	0.000000	0.000000

But q is given an e-e' – not as e-e'-k. So, I don't know how to interpret the event output.

See the radiated photon in the final state

Conclusions

- Generators seem to work well (with some small caveats) at Born level at calculating inclusive NC cross section. Cross section analysis code is working well.
- Radiative effects need some work in both programs.