Jets for Atlas

Davison E. Soper
University of Oregon

Argonne National Laboratory, November 2010

Topics

- Programs for jet cross sections.
- Do they give the same cross sections?
- Observable specification in NLO programs.
- The binning problem.
- Theory errors.
- Cross sections to measure.

Programs for jet calculations

- Leading order, with full final state:
  - ✳ Pythia
  - ✳ Herwig
  - ✳ Sherpa
- NLO, but with partonic final state:
  - ✳ Jet (usually "EKS" ; Ellis, Kunszt, Soper)
  - ✳ JETRAD (Giele, Glover, Kosower)
  - ✳ NLOjet++ (Nagy)

The NLO jet programs

- Jetrad (Giele, Glover, Kosower): widely used; cannot set scales to jet P_T.
- Jet (Ellis, Kunszt, Soper): perhaps the fastest, but there are some subtleties to make it faster.
- NLOjet++ (Nagy): the newest, and the only one that can do three-jet observables.

http://vircol.fnal.gov/MCdownload/jetrad.html
http://physics.uoregon.edu/~soper/EKSjets/jet.html
http://nagyz.web.cern.ch/nagyz/Site/NLOjet++/html

Comparison of nlojet++ & "jet" programs

- Do these give the same results?
- Let's see with the one jet inclusive cross section for the Tevatron. (Done with Z. Nagy.)
- Use cone algorithm with R = 0.7, R_{sep} = 1.3 R, rapidity range 0.1 to 0.7, renormalization and factorization scale = 1/2 * P_T.

"jet" result

PJ	Smeared XSECT	Integration error	Unsmearing Correction	Corrected XSECT	Unsmeared Fit XSECT
300.00	0.1618E-03	0.31E-06	0.26E-06	0.1620E-03	0.1615E-03
320.00	0.8679E-04	0.17E-06	0.10E-06	0.8689E-04	0.8714E-04
340.00	0.4682E-04	0.10E-06	0.34E-07	0.4685E-04	0.4706E-04
360.00	0.2536E-04	0.48E-07	0.75E-08	0.2537E-04	0.2541E-04
380.00	0.1371E-04	0.27E-07	-0.15E-08	0.1371E-04	0.1370E-04
400.00	0.7387E-05	0.15E-07	-0.38E-08	0.7384E-05	0.7359E-05
420.00	0.3949E-05	0.80E-08	-0.35E-08	0.3945E-05	0.3933E-05
440.00	0.2093E-05	0.43E-08	-0.27E-08	0.2090E-05	0.2086E-05
460.00	0.1098E-05	0.24E-08	-0.18E-08	0.1096E-05	0.1096E-05
480.00	0.5679E-06	0.16E-08	-0.11E-08	0.5668E-06	0.5684E-06
500.00	0.2880E-06	0.18E-08	-0.67E-09	0.2873E-06	0.2902E-06
520.00	0.1432E-06	0.14E-08	-0.38E-09	0.1428E-06	0.1453E-06
540.00	0.7002E-07	0.57E-09	-0.21E-09	0.6981E-07	0.7112E-07
560.00	0.3353E-07	0.14E-09	-0.11E-09	0.3342E-07	0.3385E-07
580.00	0.1559E-07	0.47E-10	-0.53E-10	0.1554E-07	0.1559E-07
600.00	0.7003E-08	0.22E-10	-0.25E-10	0.6978E-08	0.6899E-08

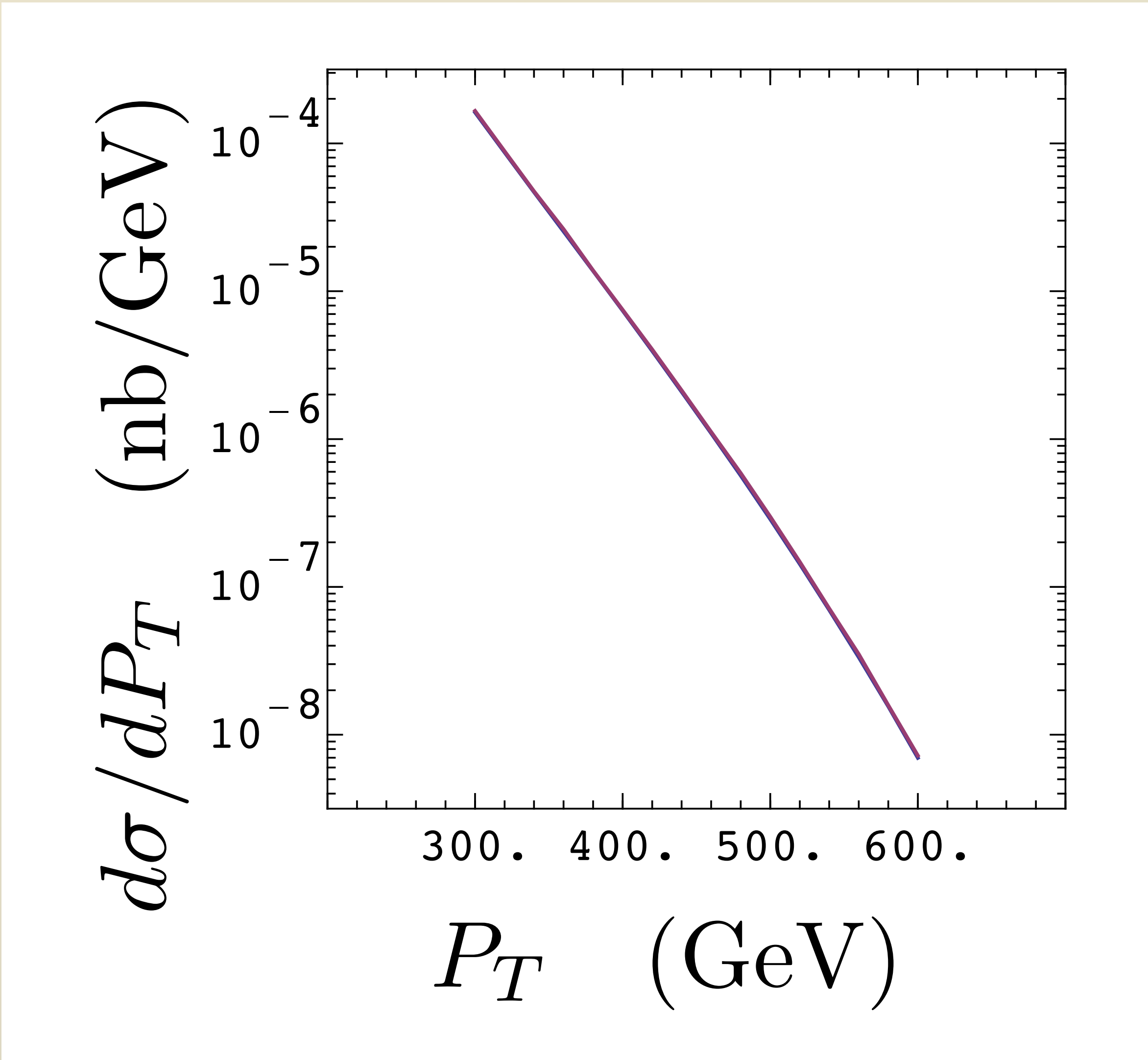
Use these numbers

nlojet++ result

Left bin edge	Bin center	Right bin edge	Average cross section in bin	Integration error
2.900000e+02	3.000000e+02	3.100000e+02	1.656614e-04	1.215310e-06
3.100000e+02	3.200000e+02	3.300000e+02	8.844286e-05	7.198966e-07
3.300000e+02	3.400000e+02	3.500000e+02	4.741659e-05	4.776538e-07
3.500000e+02	3.600000e+02	3.700000e+02	2.630811e-05	2.122814e-07
3.700000e+02	3.800000e+02	3.900000e+02	1.383090e-05	1.442595e-07
3.900000e+02	4.000000e+02	4.100000e+02	7.493720e-06	6.156523e-08
4.100000e+02	4.200000e+02	4.300000e+02	4.033519e-06	3.364019e-08
4.300000e+02	4.400000e+02	4.500000e+02	2.135288e-06	2.300308e-08
4.500000e+02	4.600000e+02	4.700000e+02	1.118295e-06	1.446359e-08
4.700000e+02	4.800000e+02	4.900000e+02	5.881319e-07	8.272902e-09
4.900000e+02	5.000000e+02	5.100000e+02	2.983773e-07	3.333759e-09
5.100000e+02	5.200000e+02	5.300000e+02	1.475190e-07	1.634408e-09
5.300000e+02	5.400000e+02	5.500000e+02	7.149335e-08	1.013526e-09
5.500000e+02	5.600000e+02	5.700000e+02	3.504026e-08	4.864979e-10
5.700000e+02	5.800000e+02	5.900000e+02	1.580191e-08	2.779432e-10
5.900000e+02	6.000000e+02	6.100000e+02	7.232151e-09	1.454653e-10

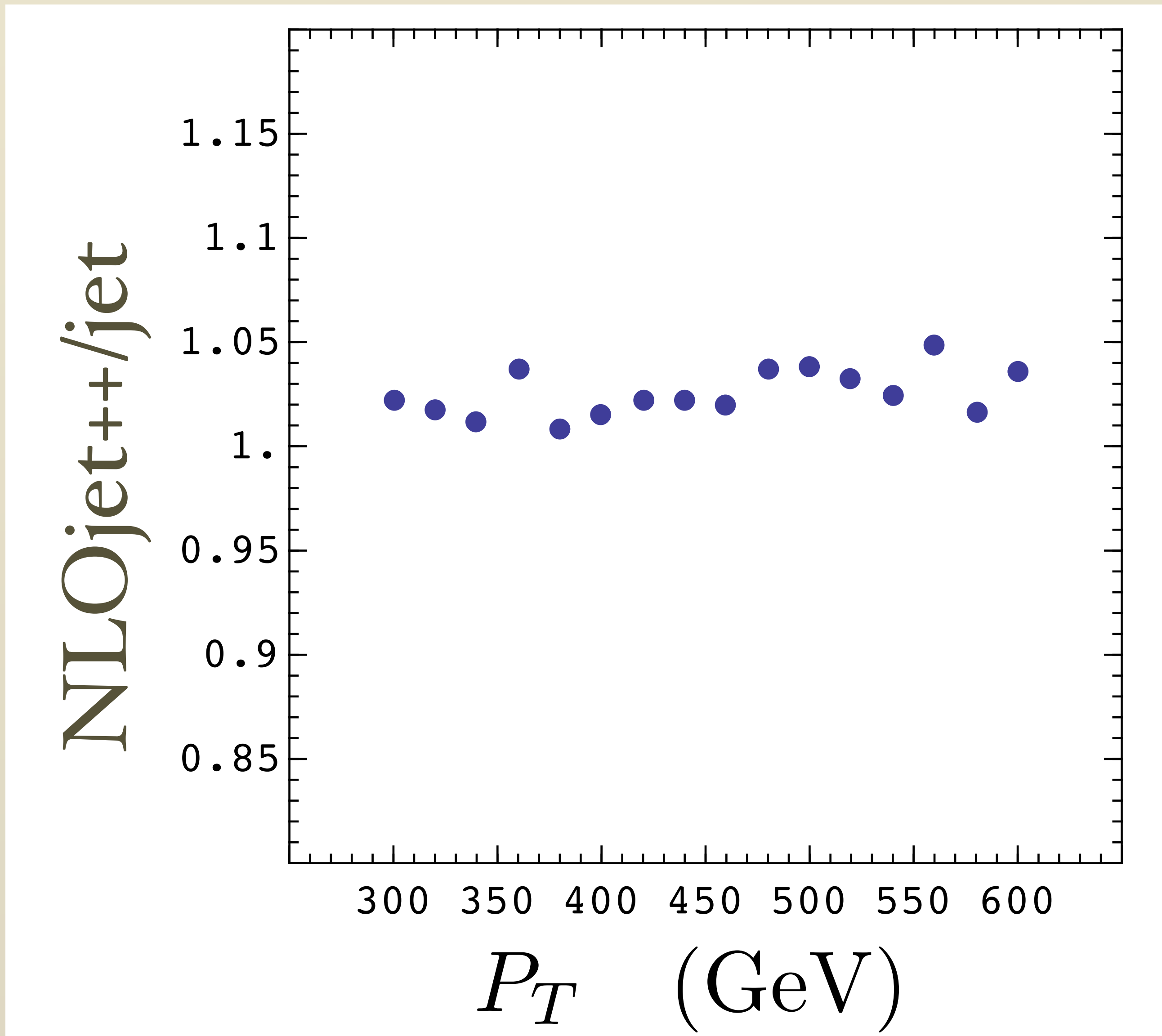
Use these numbers ↗

The result

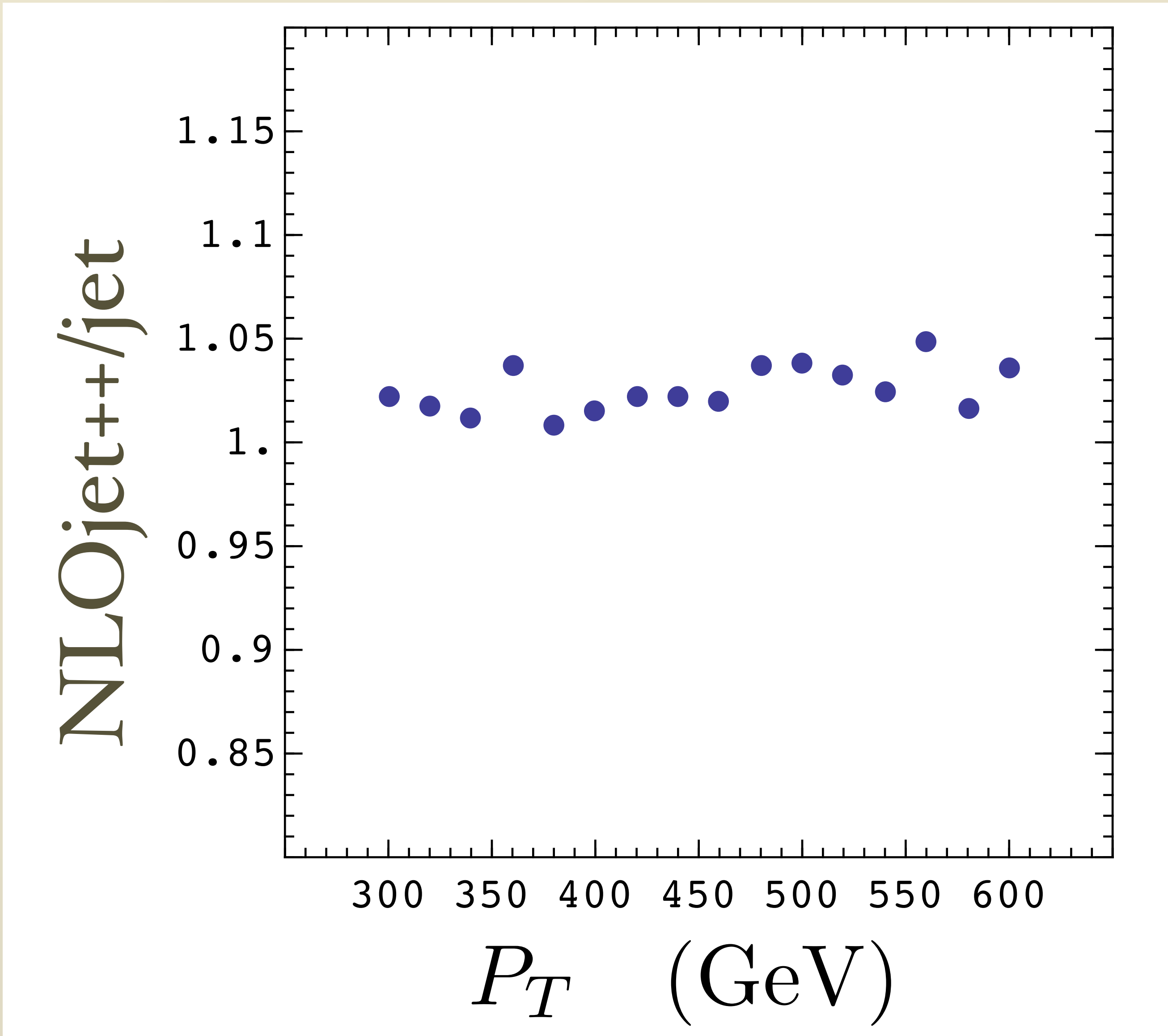


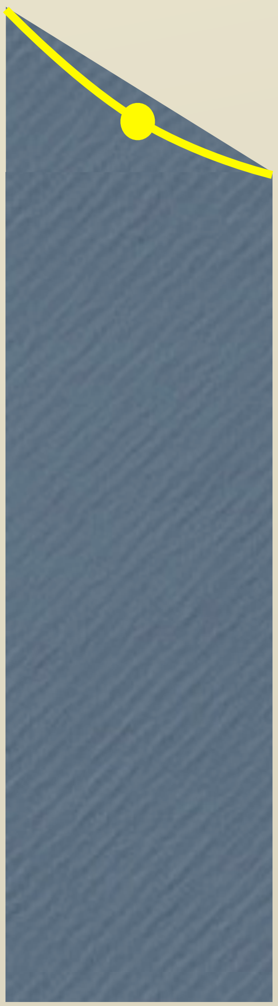
Well, they agree, but maybe we should look at the ratio...

The result for the ratio



This looks like a 2% discrepancy.

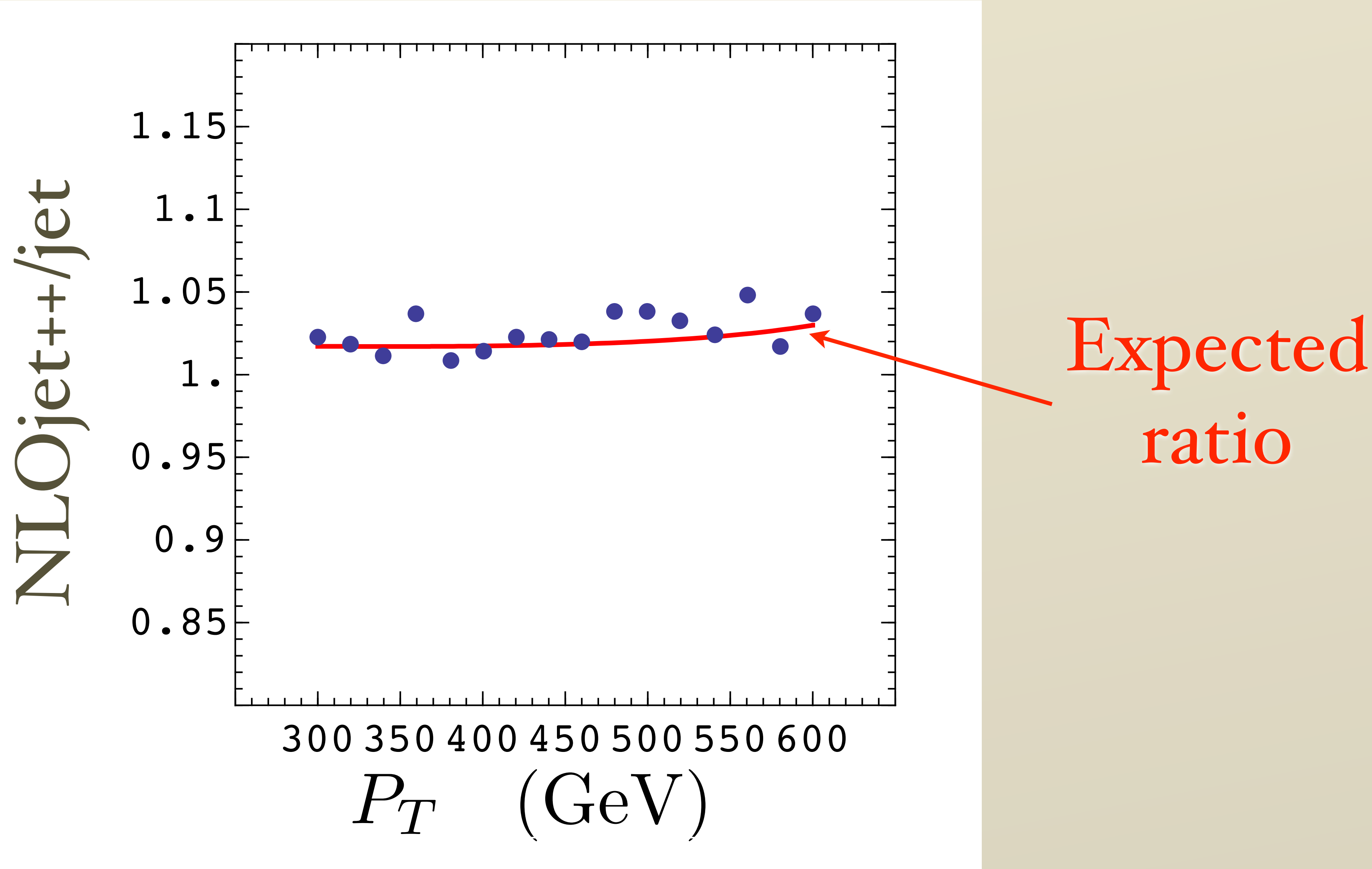




This looks like a 2% discrepancy, but we should plot also the expected ratio, given that the average over a bin and the value at the bin center are not the same.

The result for the ratio

We have agreement within the 2% statistical error of NLOjet++.



- There is also agreement between JETRAD and "jet" (at about the 5% level).

Observable specification

- NLO programs may come predefined to calculate, say

$$\frac{1}{y_{\max} - y_{\min}} \int_{y_{\min}}^{y_{\max}} dy \ \frac{d\sigma}{dP_T dy}$$

- But they can calculate whatever infrared-safe two-jet observable you want. (Or, for nlojet++, also three-jet observables.)

- In Pythia, you get events.
- Then you specify whether it has jets, what transverse momentum, etc.
- In the NLO programs, the specification is typically in a subroutine within the program.
- You can modify the definitions.

The observable definition in program "jet"

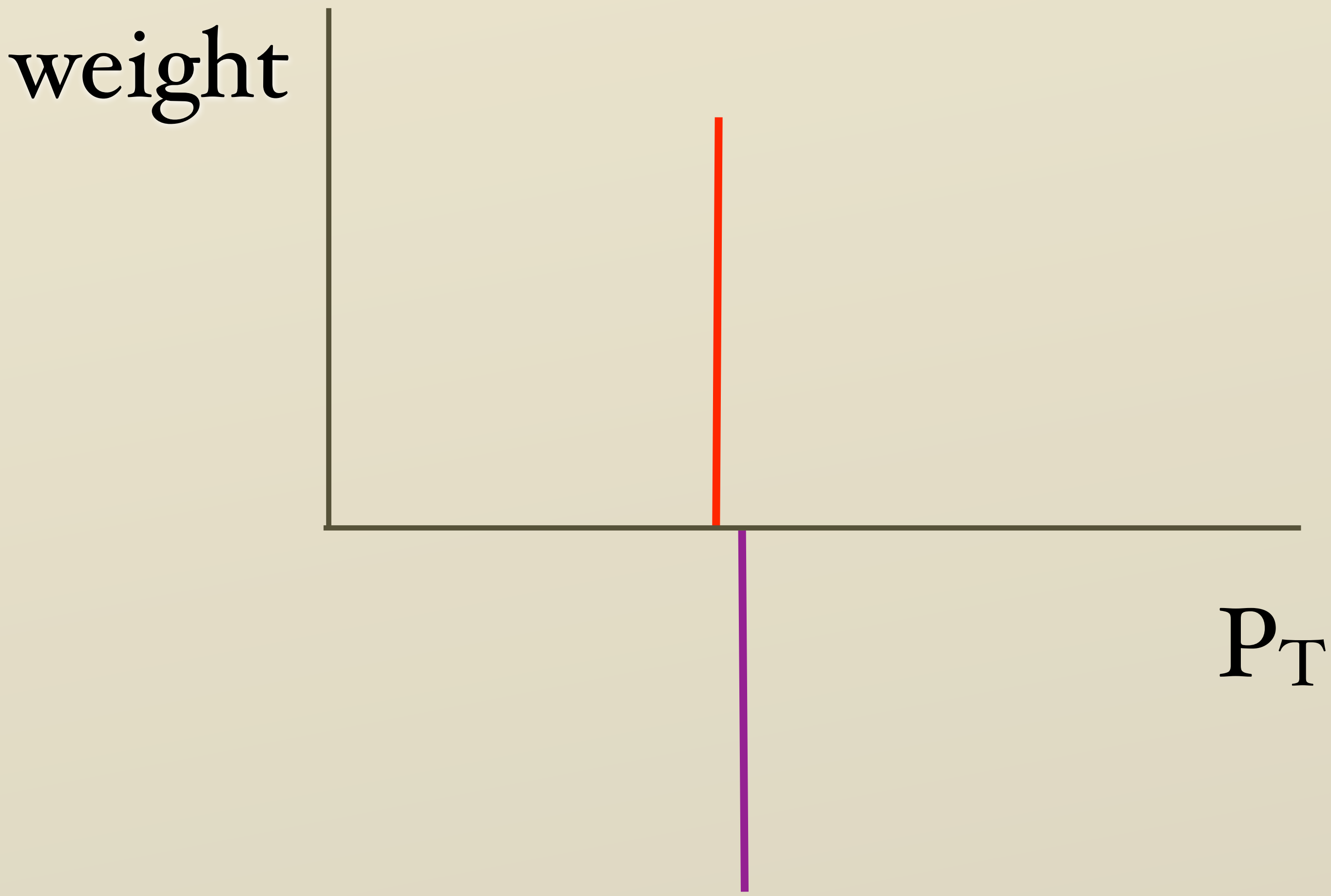
```
     SUBROUTINE
      >    JETDEF(CASE,Y1,P2,Y2,PHI2,P3,Y3,PHI3,OK,PJ,YJ,UNUSED,SVALUE)
...
C
        PHI32 = CONVERT(PHI3 - PHI2)
        RLIMITSQ = MIN( RSEP**2, ( (P2+P3)/P2 * R )**2 )
        DELTASQ = (Y3-Y2)**2 + PHI32**2
...

 C
 C   CASE 1: 2 and 3 are the jet
 C
        IF (CASE.EQ.1) THEN
          IF( DELTASQ.LT.RLIMITSQ ) THEN
             PJ = P2 + P3
             YJ = ( P2*Y2 + P3*Y3 )/PJ
             IF (  INBOUNDS(PJ,YJ) ) THEN
               OK = .TRUE.
             ENDIF
          ENDIF
          RETURN
...
```

The binning problem

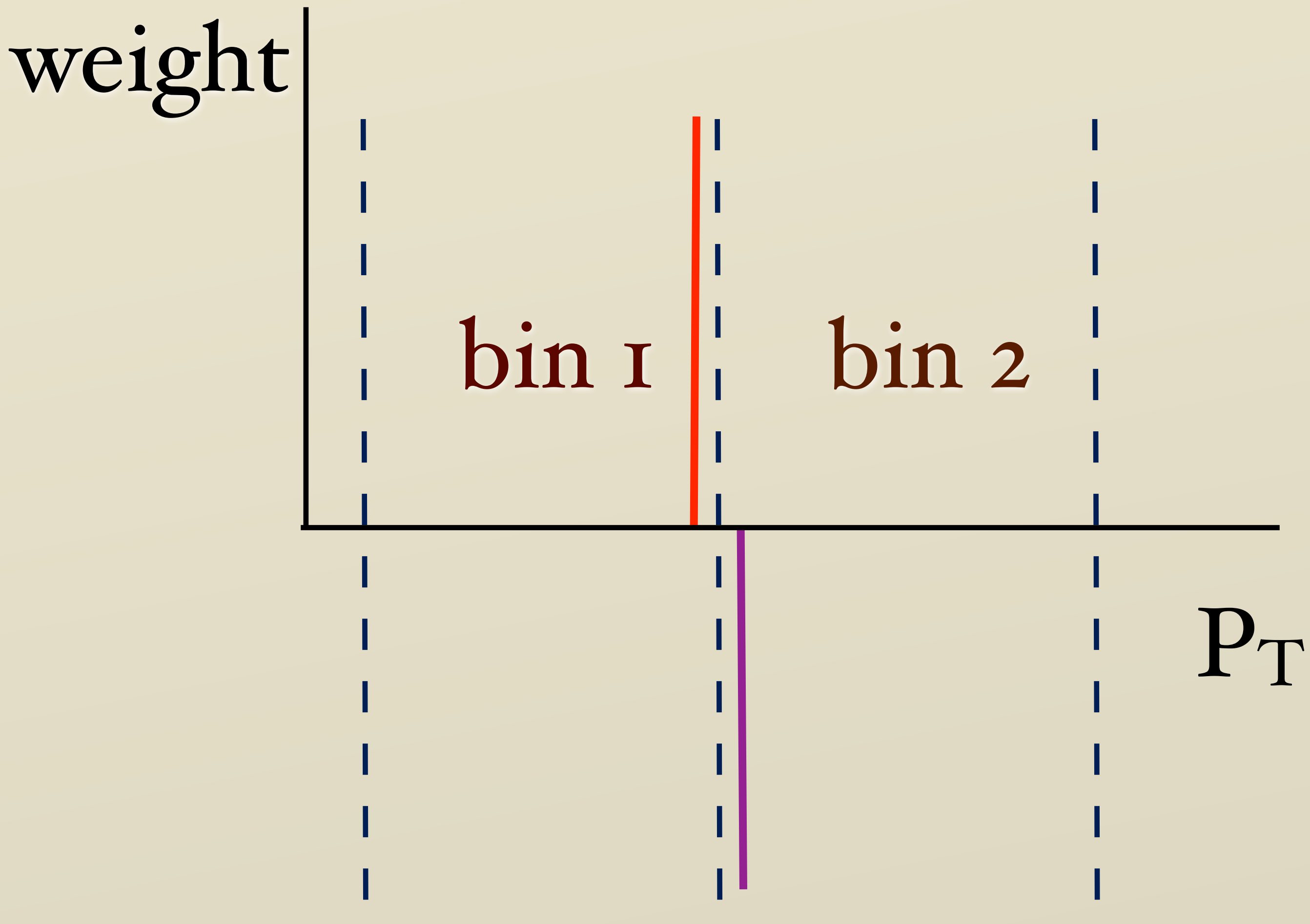
- A NLO program for two jet observables produces
  - a main event with three partons and a (possibly big) positive weight
  - some counter events with two partons and (possibly big) negative weights

- In terms of jet P_T, what you get can look like



- That's OK because if the weights are large then the P_Ts are almost the same, so the weights cancel when we average over P_T.

- But this can happen:



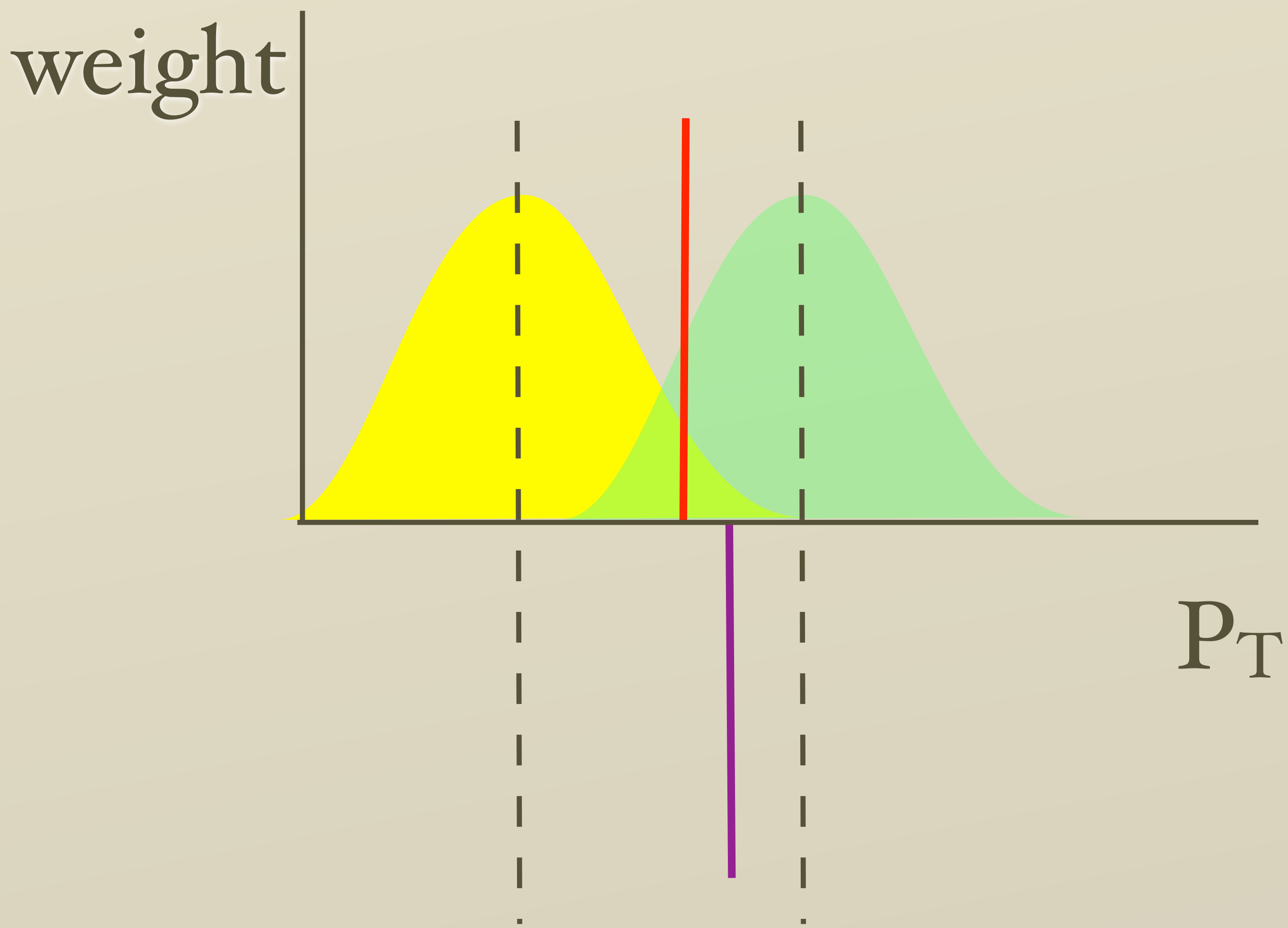
- This can lead to bad fluctuations in the cross section in bins.

- NLOjet++ smears the bin edges a bit.

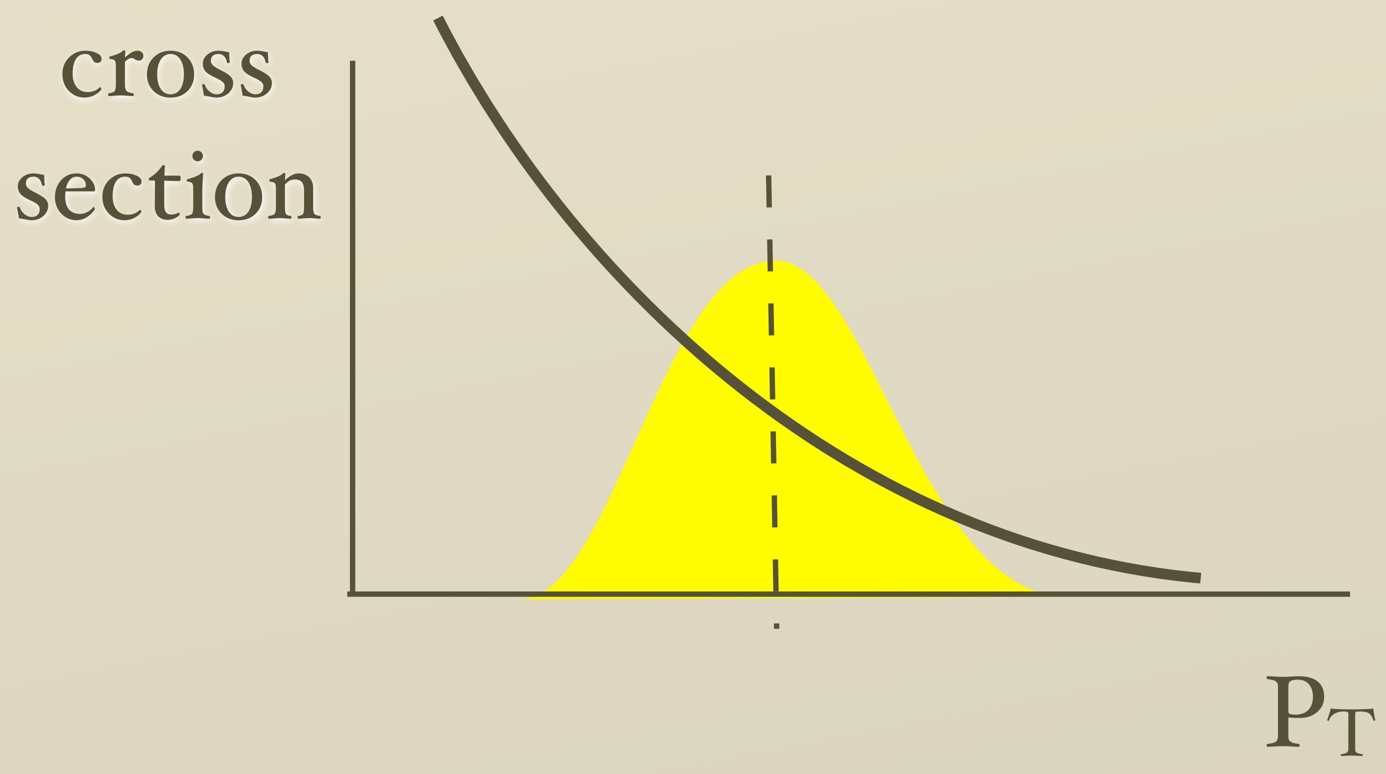
Special tricks in “jet”

- “jet” tries to calculate the cross section at a given P_T, not the cross section in a bin.

- Just smear with a gaussian:



- Unfortunately, the cross section smeared with a gaussian centered at P_T is not the same as the cross section at P_T, more so if the cross section is not flat, or at least linear in P_T.

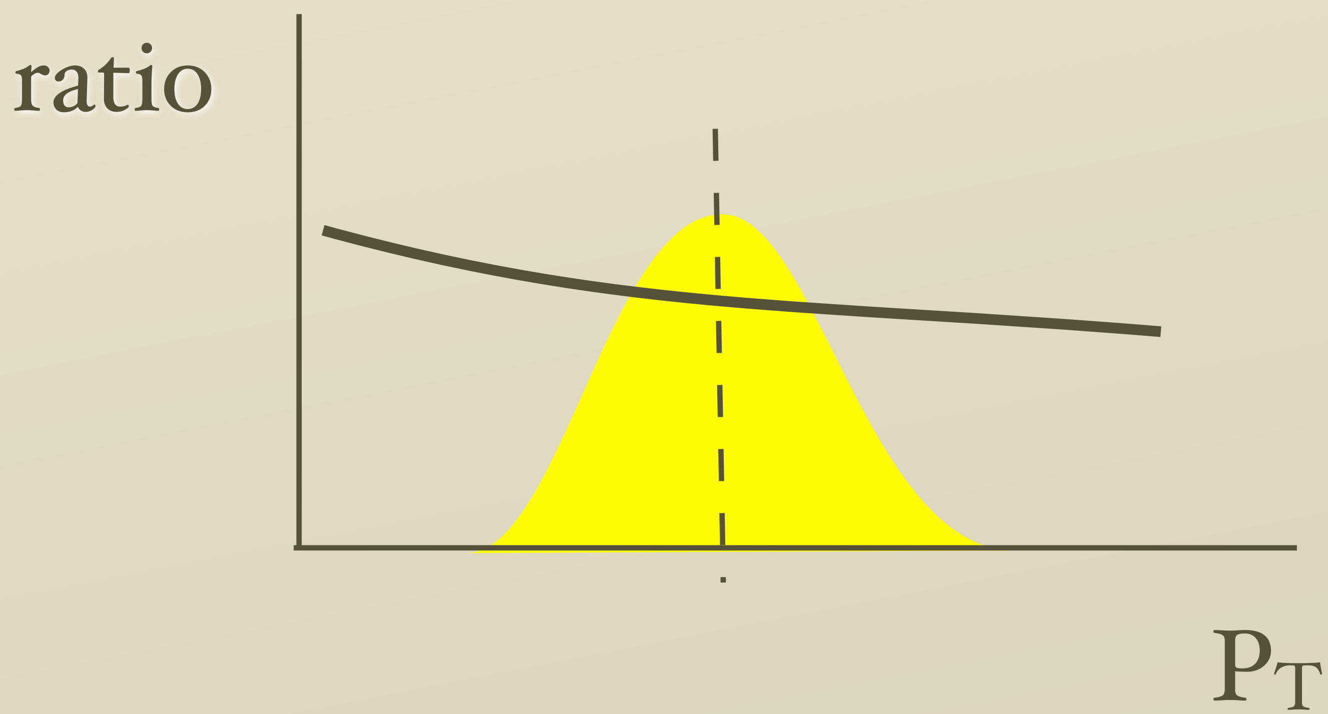


- So we smear the cross section divided by a fit function.

$$\sigma(P_{T,0}) \approx F(P_{T,0}) \int dP_T \; \frac{\sigma(P_T)}{F(P_T)} \times g(P_T - P_{T,0})$$

fit function

gaussian



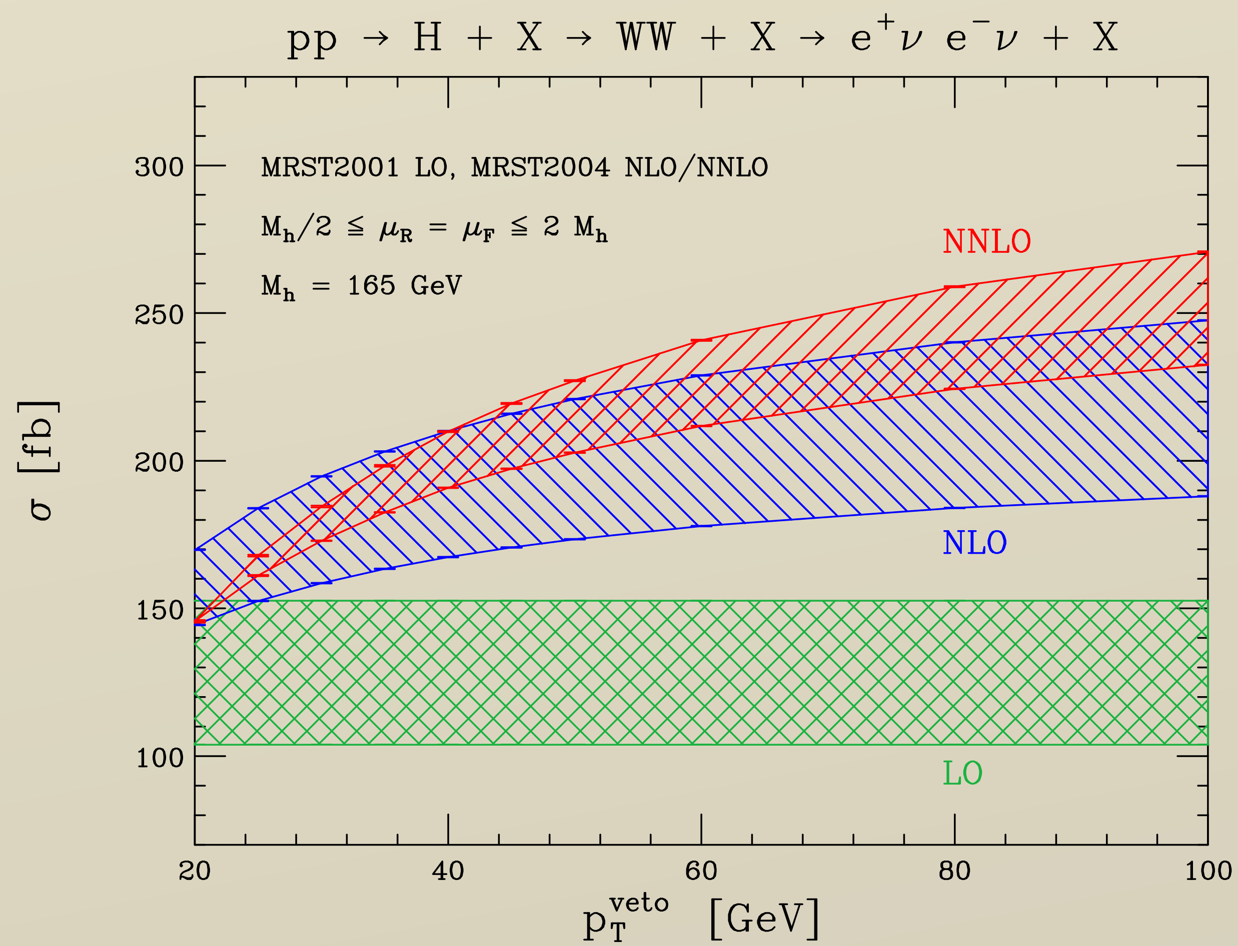
- So we smear the cross section divided by a fit function, then estimate the unsmearing correction.

Theory errors

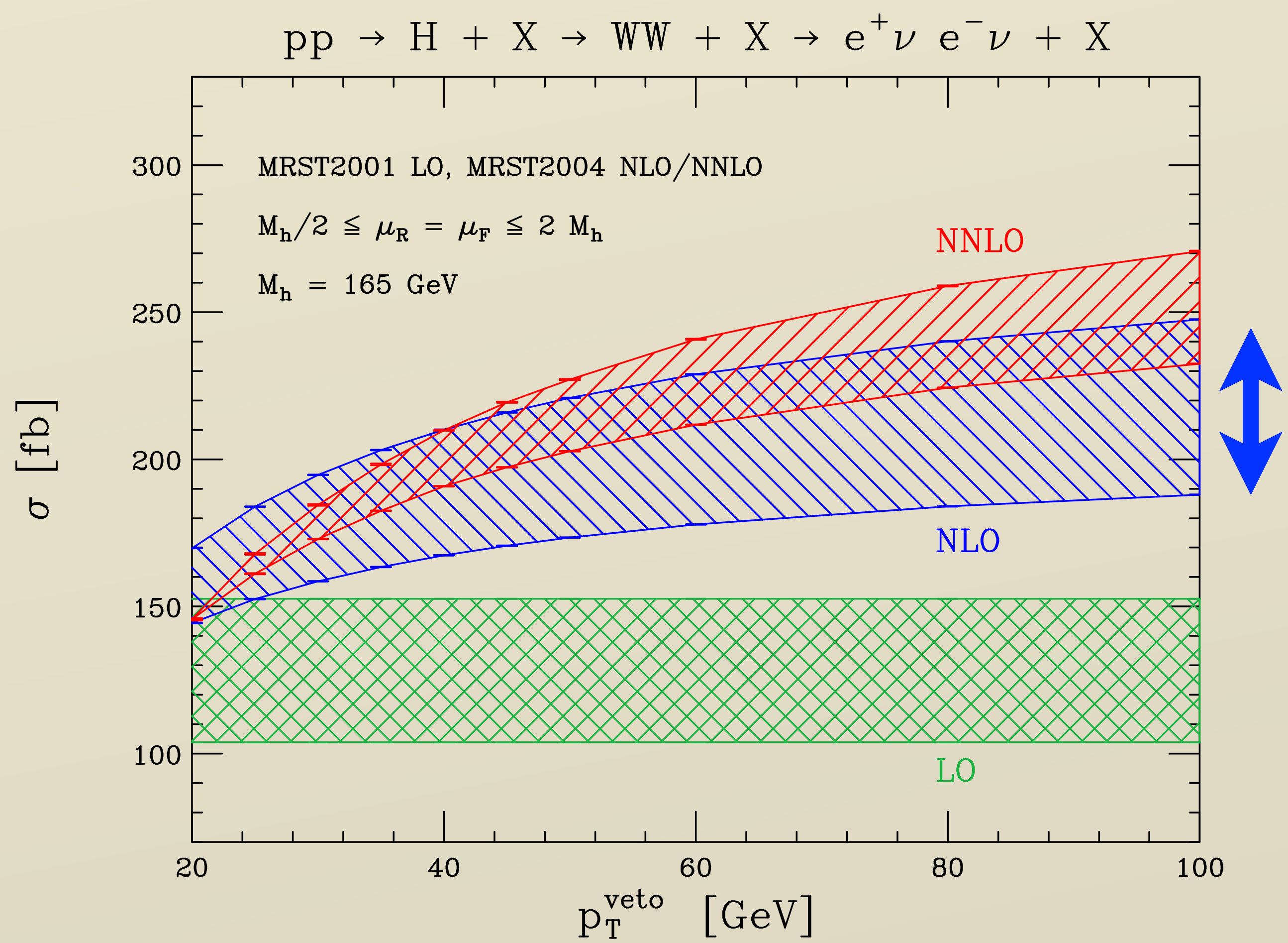
Work with Fred Olness

Motivation

- Perturbative calculations are usually presented with an error estimate.
- For example, Anastasiou, Dissertori, and Stockli, JHEP 0709, 018 (2007):



- Suppose that we have only NLO.



- We hope our NLO error band gives a range where NNLO will fall.

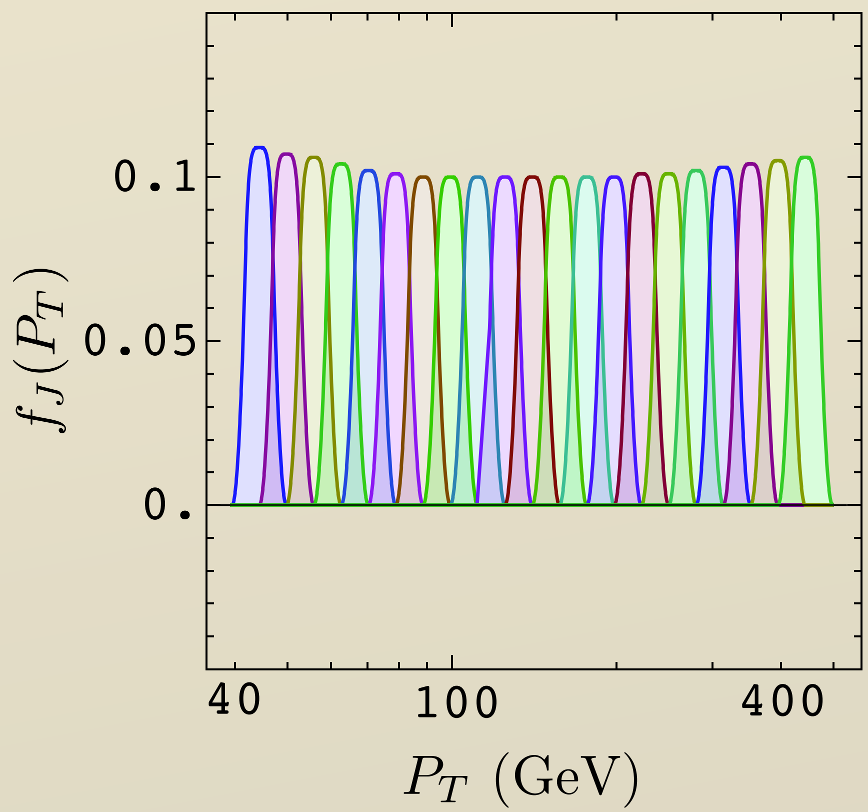
- For cross sections used for parton distributions, we should include the estimated theory error in the fitting procedure.

Format for theory errors

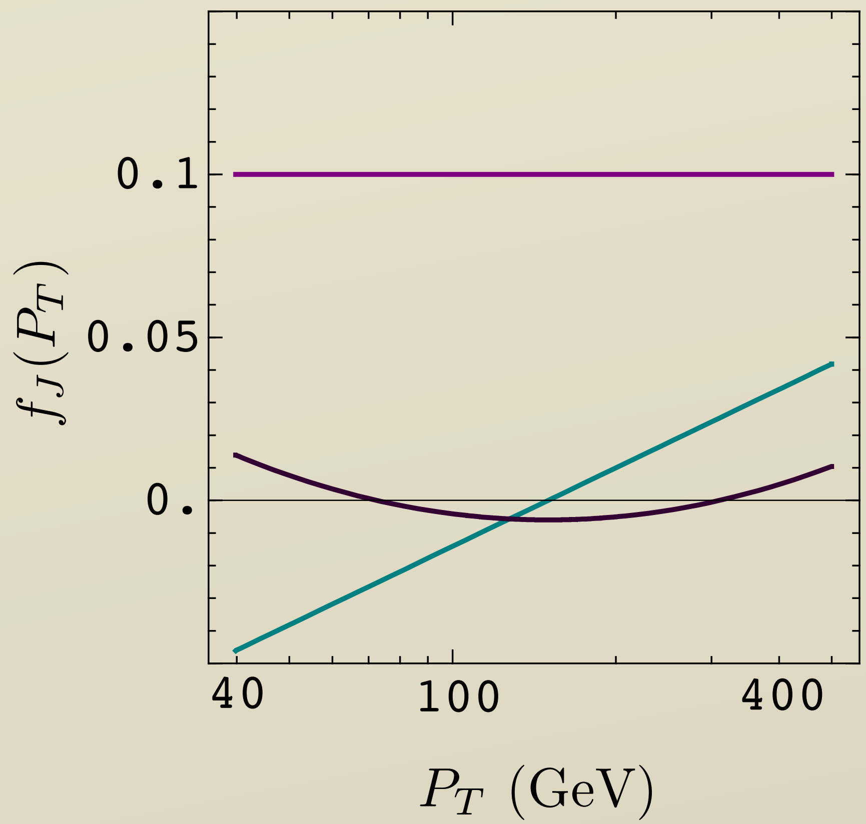
$$\frac{d\sigma}{dP_T dy} = \left[\frac{d\sigma}{dP_T dy}\right]_{\rm NLO} \left\{ 1 + \sum_J \lambda_J f_J(P_T, y) \right\}$$

- $f_J(P_T, y)$ are functions to be specified.
- λ_J are Gaussian random variables with standard deviation 1.
- The size of the functions $f_J(P_T, y)$ gives the size of the errors.
- This gives the complete error matrix as for experimental systematic errors.

$$\frac{d\sigma}{dP_T dy} = \left[\frac{d\sigma}{dP_T dy}\right]_{\mathrm{NLO}} \left\{1 + \sum_J \lambda_J f_J(P_T, y)\right\}$$



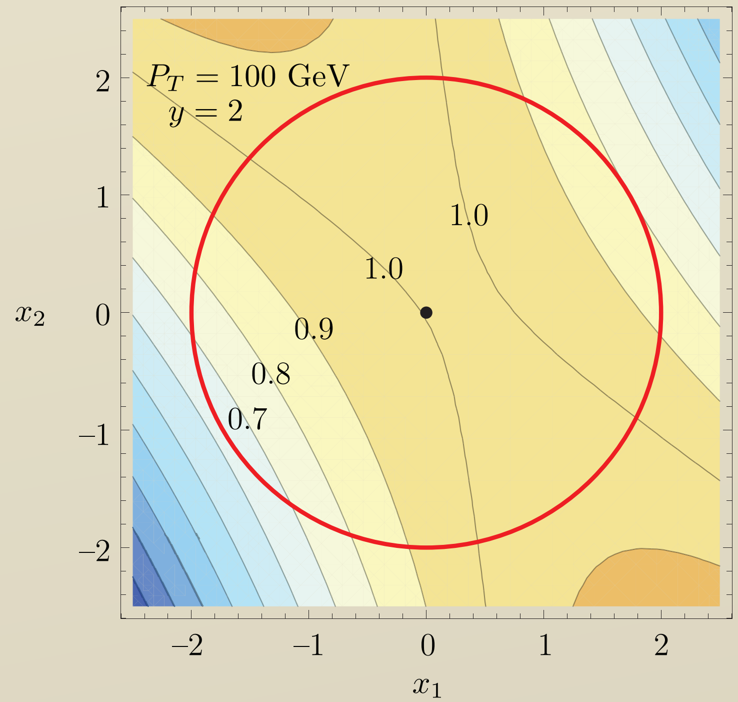
uncorrelated errors



correlated errors

What to include

- Perturbative error estimated from scale dependence.



- Error from power suppressed correction estimated from simple models.

Assembled errors

$$\frac{d\sigma}{dP_T dy} = \left[\frac{d\sigma}{dP_T dy}\right]_{\rm NLO} \left\{1 + \sum_J \lambda_J f_J(P_T, y)\right\}$$

$$f_1(P_T, y) = \frac{4.56 \times 10^{-2}}{\log(M(y)/P_T)}$$

$$M(y) = \sqrt{s}\ e^{-y}$$

$$f_2(P_T, y) = \frac{1.24 \times 10^{-2}\, y^2}{\log(M(y)/P_T)}$$

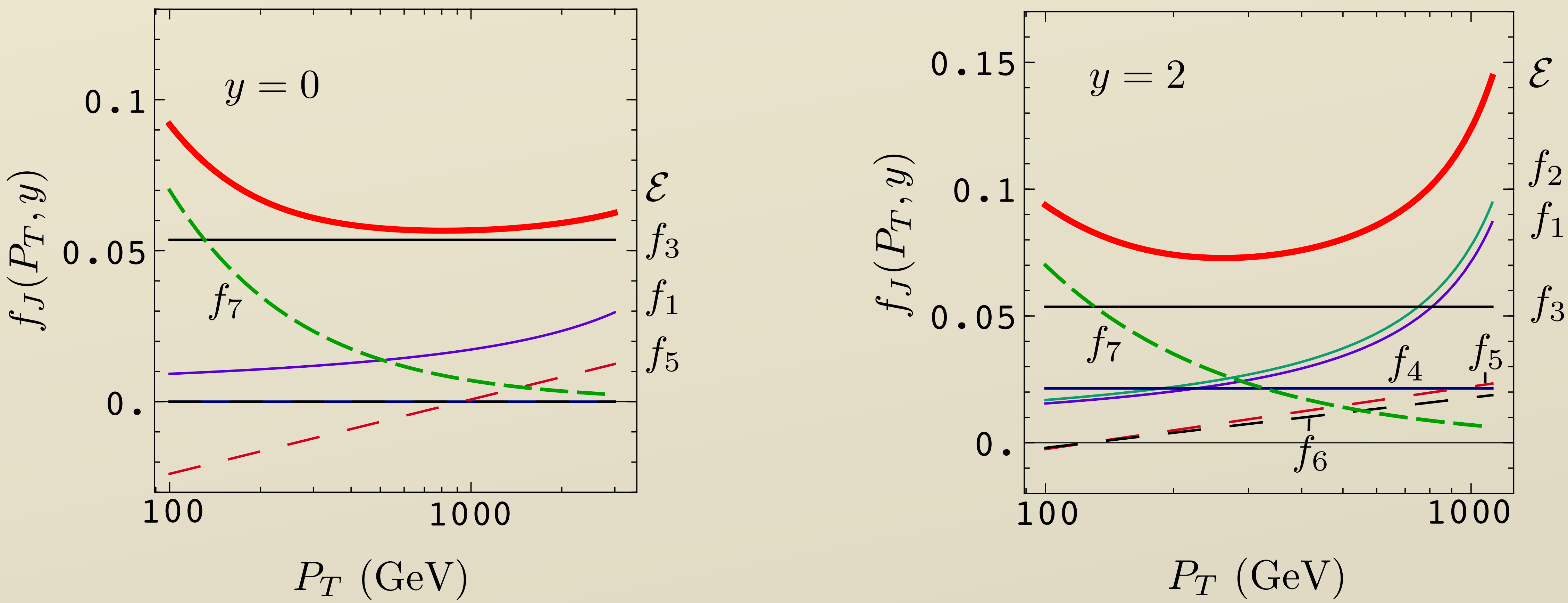
$$f_3(P_T, y) = 5.36 \times 10^{-2}$$

$$f_4(P_T, y) = 0.536 \times 10^{-2}\, y^2$$

$$f_5(P_T, y) = 1.07 \times 10^{-2}\ \log\left(\frac{15\, P_T}{M(y)}\right)$$

$$f_6(P_T, y) = 0.214 \times 10^{-2}\, y^2 \log\left(\frac{15\, P_T}{M(y)}\right)$$

$$f_7(P_T, y) = \frac{7\,\mathrm{GeV}}{P_T}$$



Theory errors for LHC

What to measure?

- One jet inclusive cross section

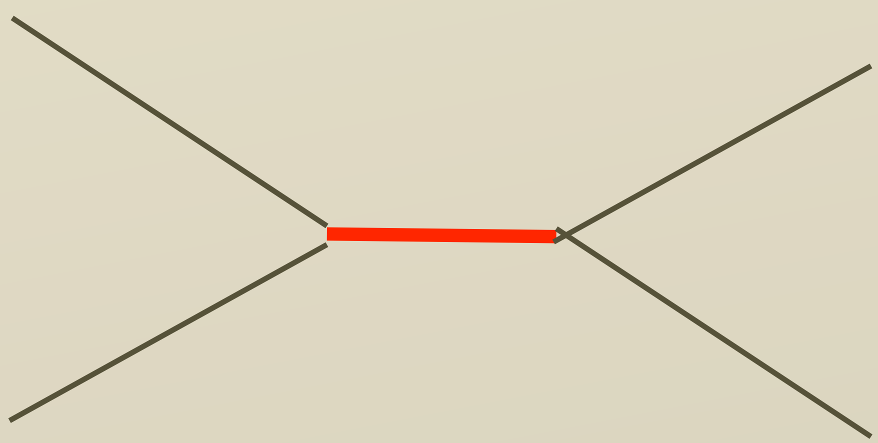
$$\frac{d\sigma}{dP_T\,dy}$$

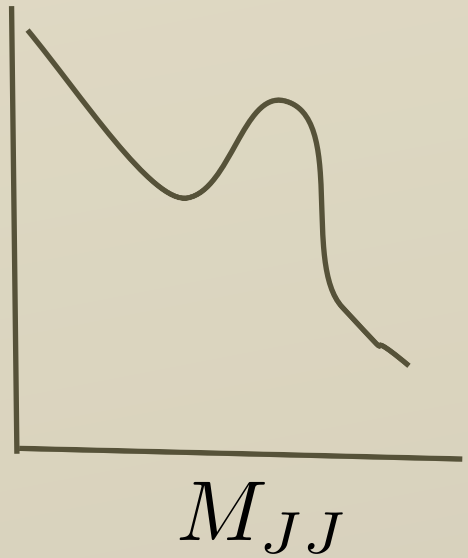
- This is simple.
- The rapidity dependence can help sort out between new physics and deficient partons distributions.

- Two jet cross section

$$\frac{d\sigma}{dM_{JJ}\,dy}$$

- If there is any kind of a resonance that decays to two jets, this will find it.

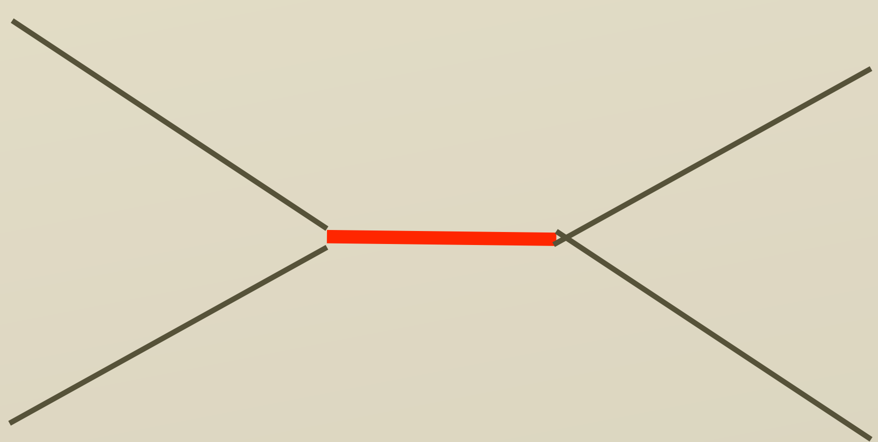


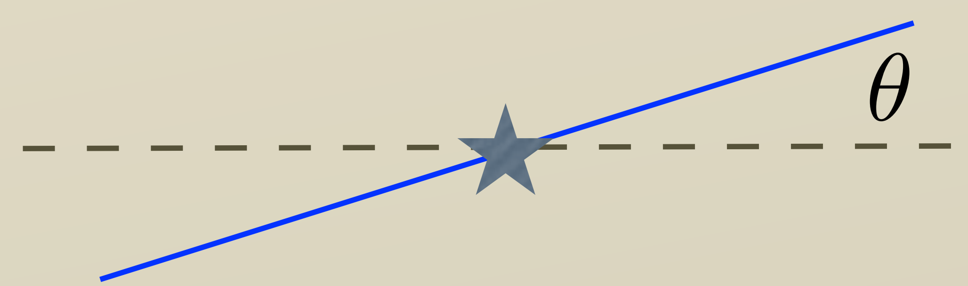


- Two jet angular distribution

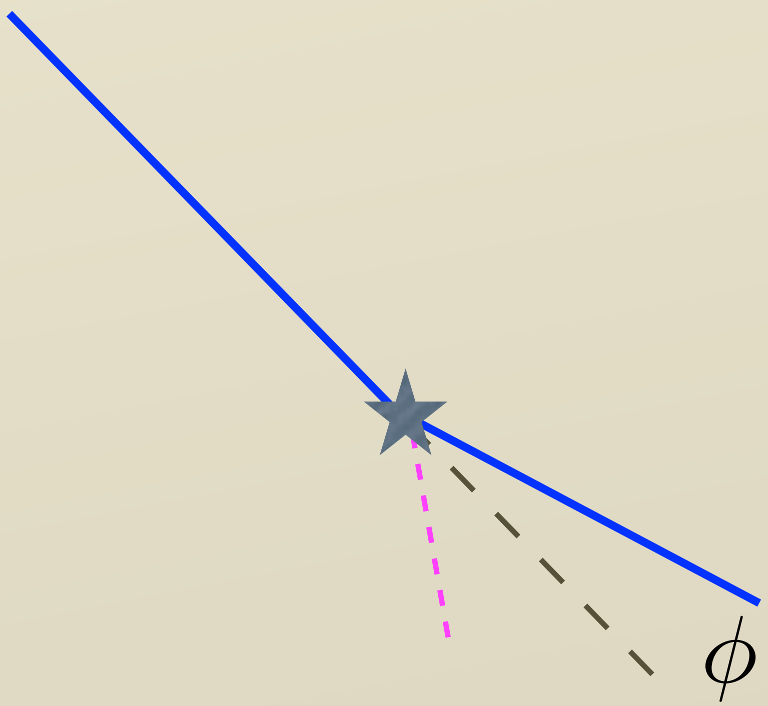
$$\frac{d\sigma}{dM_{JJ}\,dy\,d\cos\theta} \Big/ \frac{d\sigma}{dM_{JJ}\,dy}$$

- New physics signals have a different dependence on angle than does QCD.





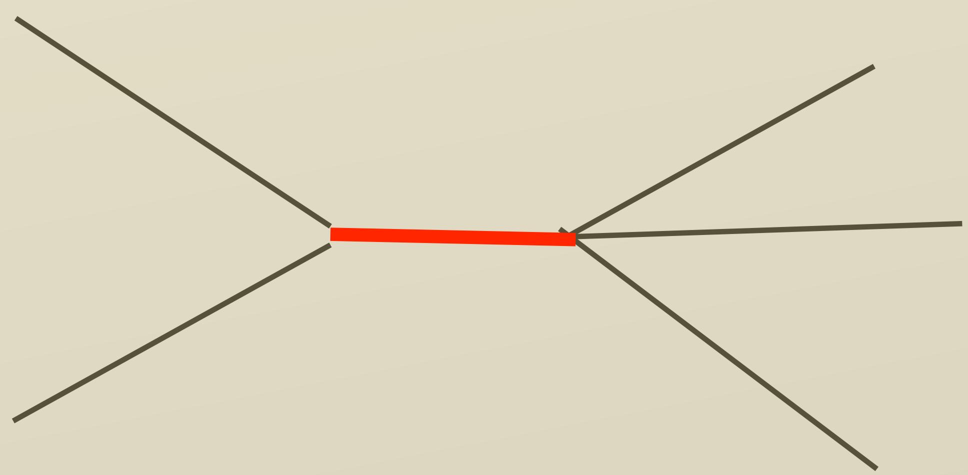
- Two jet azimuthal angular decorrelation

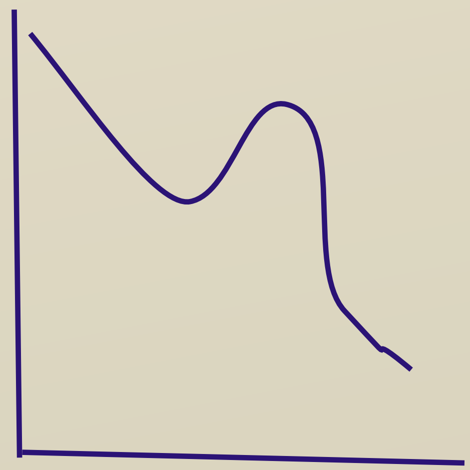


- This is really a three jet observable.

- Three jet invariant mass distribution

$$\frac{d\sigma}{dM_{JJJ}\,dy_{JJJ}}$$





M_{JJJ}

Tuesday, November 16, 2010