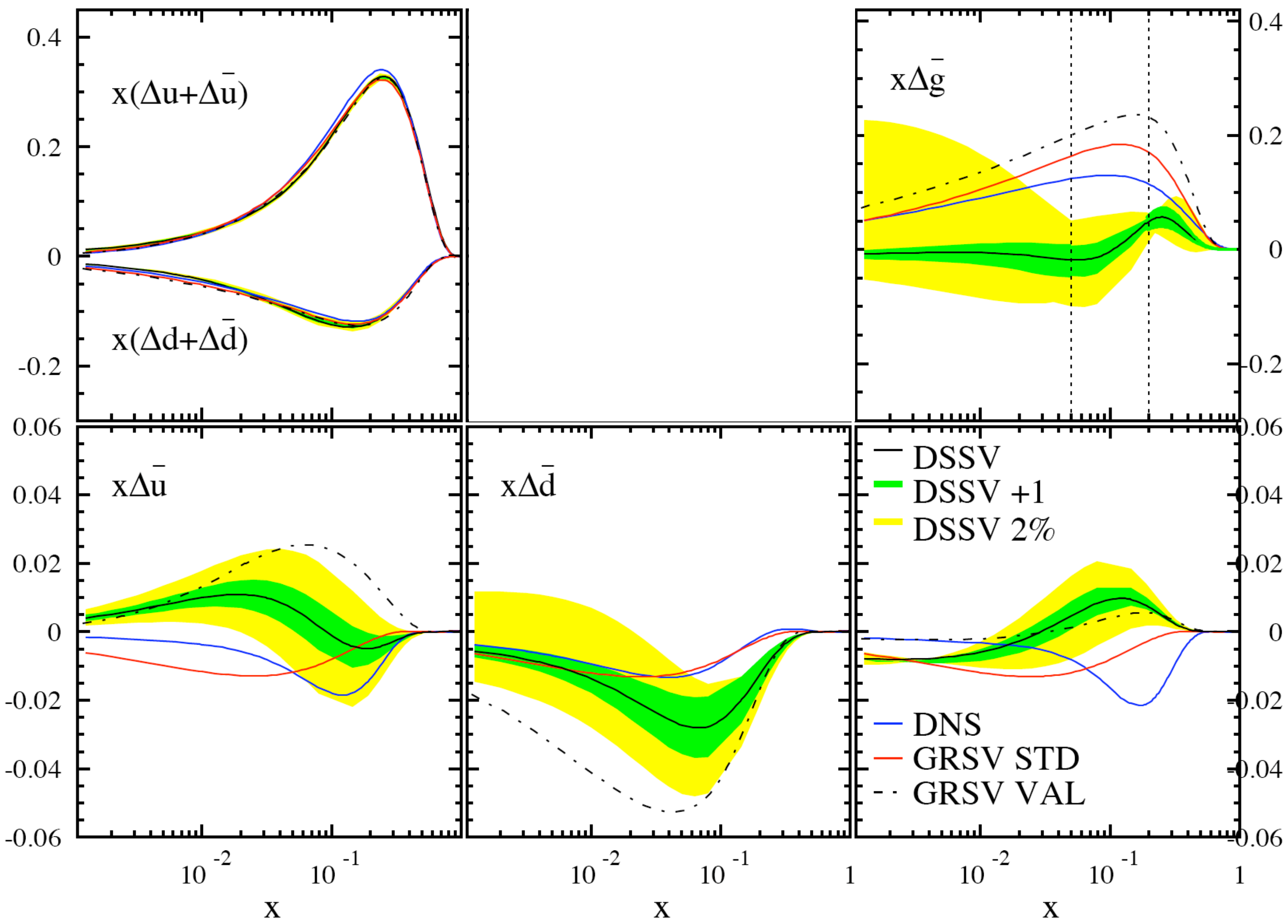
W single-asymmetries at RHIC: a NLO QCD calculation

Daniel de Florian and Werner Vogelsang

Still large uncertainty on antiquark polarized densities

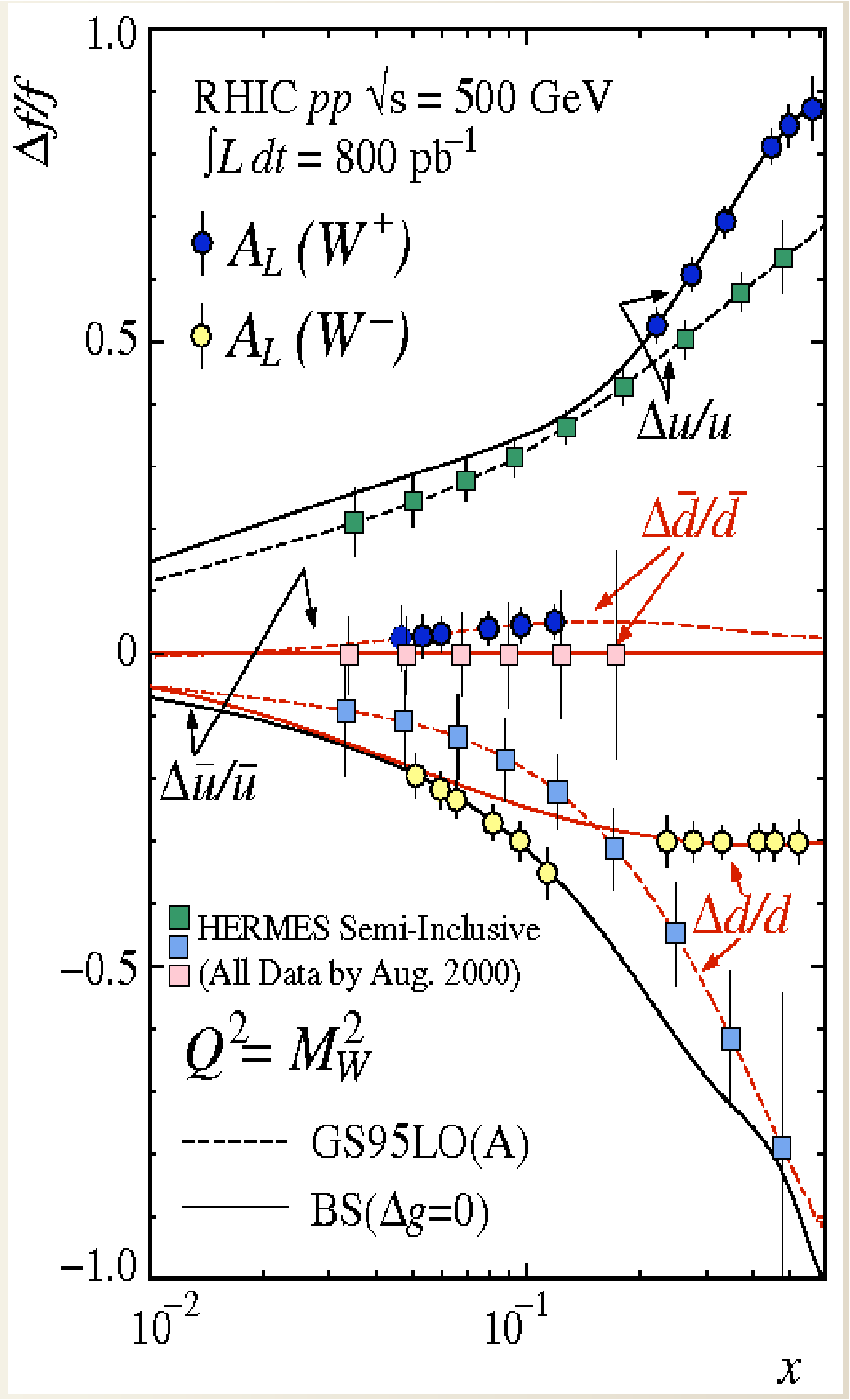
de F. , Sassot, Stratmann, Vogelsang



$Q^2 = 10\ \mathrm{GeV}^2$

(almost) All information comes from SIDIS ...

As W single asymmetries will be measured soon at RHIC



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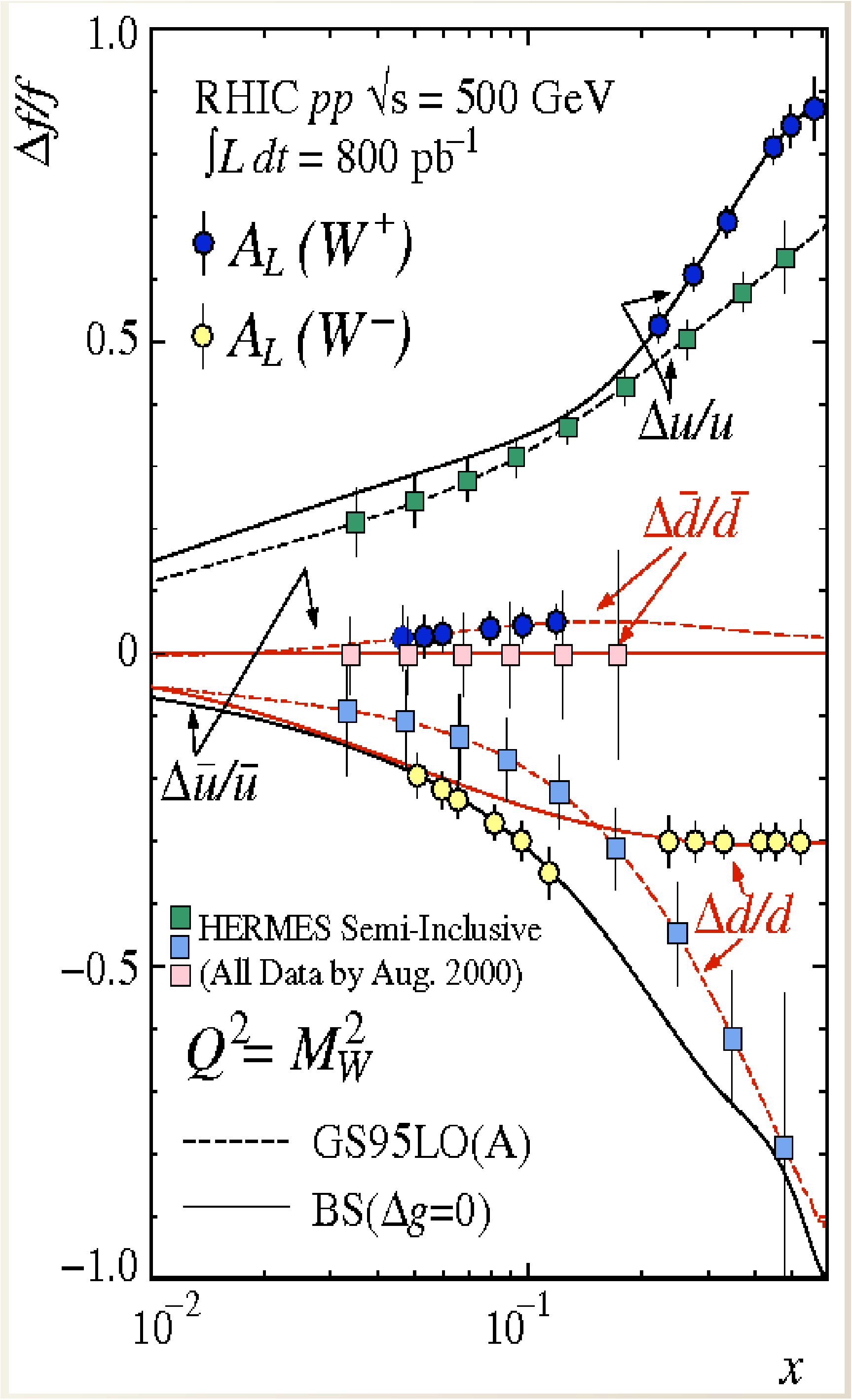

Include W asymmetries in global analysis

Check sensitivity on polarized antiquark distributions

Important : No “full” NLO calculation available yet

RhicBos has several NLO ingredients plus some extra terms (qt-resummation) not needed/not convenient for RHIC

★ Makes technically impossible to include the observable in global fit

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★ Makes technically impossible to include the observable in global fit

Need to count with a new calculation $\sigma(pp \to e\bar{\nu}X)$

- Exclusive to implement experimental cuts
- "Ready/Available" for Mellin implementation
- Full NLO in line with other observables already in fit

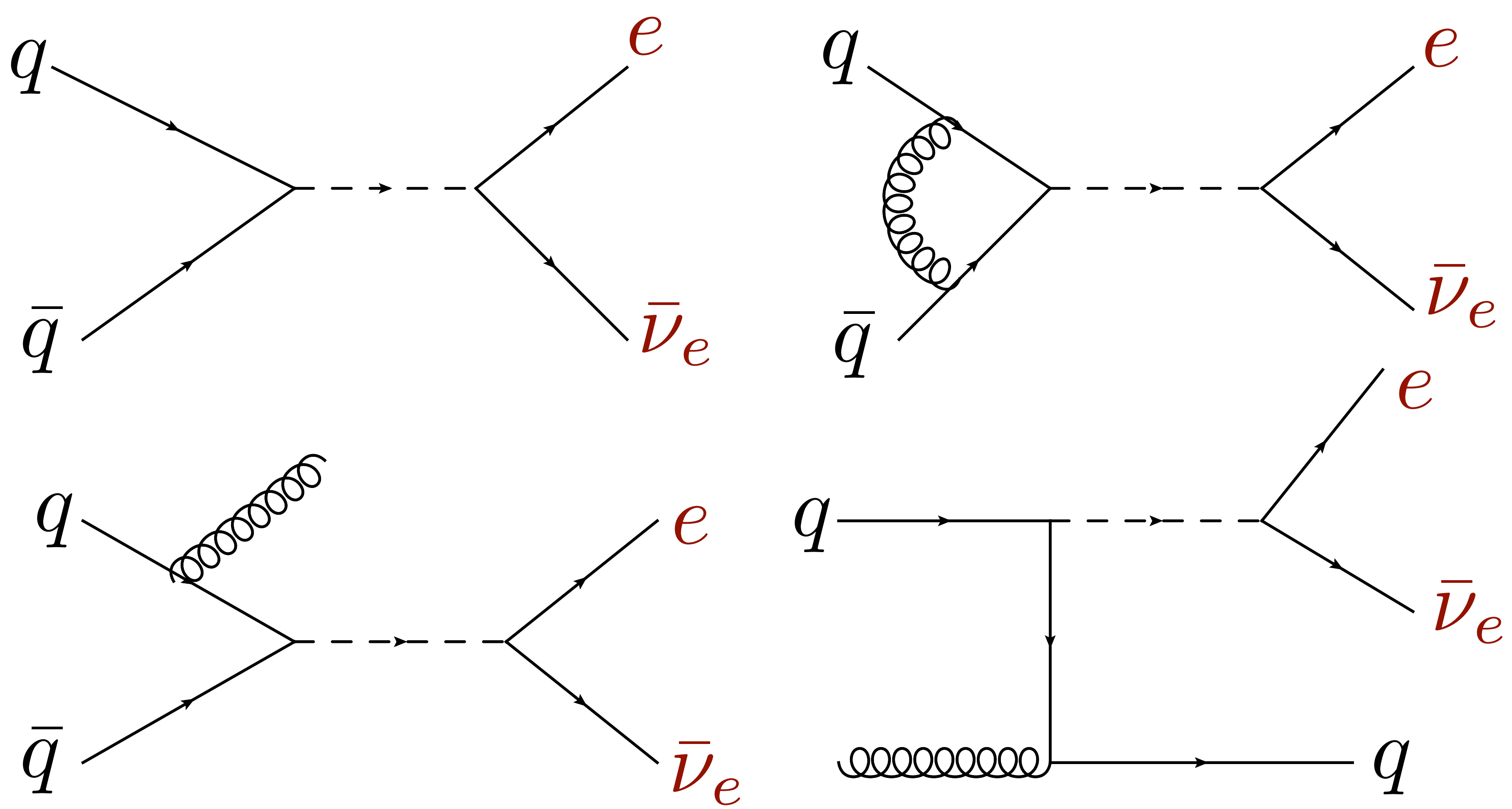
We have just finished the computation and implemented it in a MonteCarlo-like code (in the same line as dijets and h+jet codes)

New channels at NLO

W-

$$\begin{aligned}
\Delta\bar{q}\; q &\rightarrow e\,\bar{\nu}_e \\
\Delta q\; \bar{q} &\rightarrow e\,\bar{\nu}_e \\
\Delta\bar{q}\; g &\rightarrow e\,\bar{\nu}_e\,\bar{q} \\
\Delta g\; \bar{q} &\rightarrow e\,\bar{\nu}_e\,\bar{q} \\
\Delta q\; g &\rightarrow e\,\bar{\nu}_e\,g \\
\Delta g\; q &\rightarrow e\,\bar{\nu}_e\,g
\end{aligned}$$

Some diagrams ..

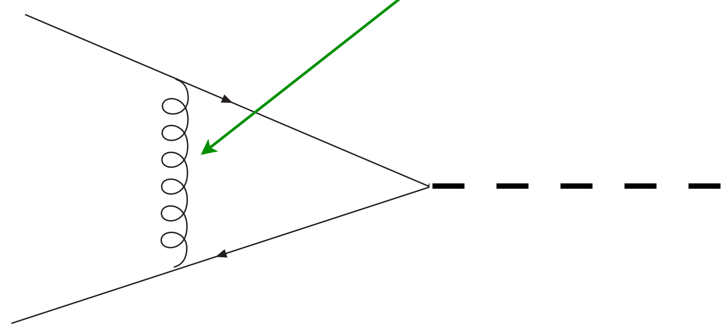


How is the calculation done?

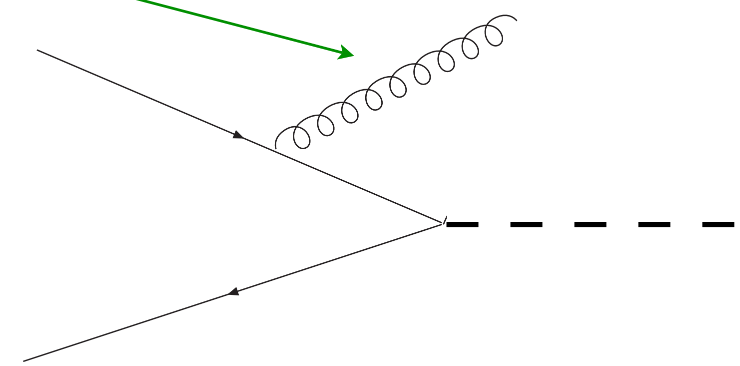
QCD: virtual and real diagrams full of infrared divergencies

soft and collinear gluons

$$\int dPS(e,\bar{\nu}_e)\Big[$$



$$+ \int dp_g$$



$$\Big]$$

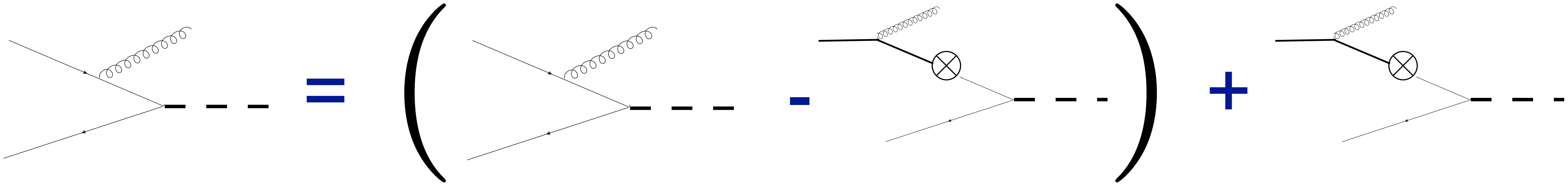
∞ + ∞ + fact/ren. = finite

After gluon integration cancellation between real and virtual contributions

The issue is how to deal with the divergencies in the intermediate steps and obtain the final finite contribution

We implement the subtraction method

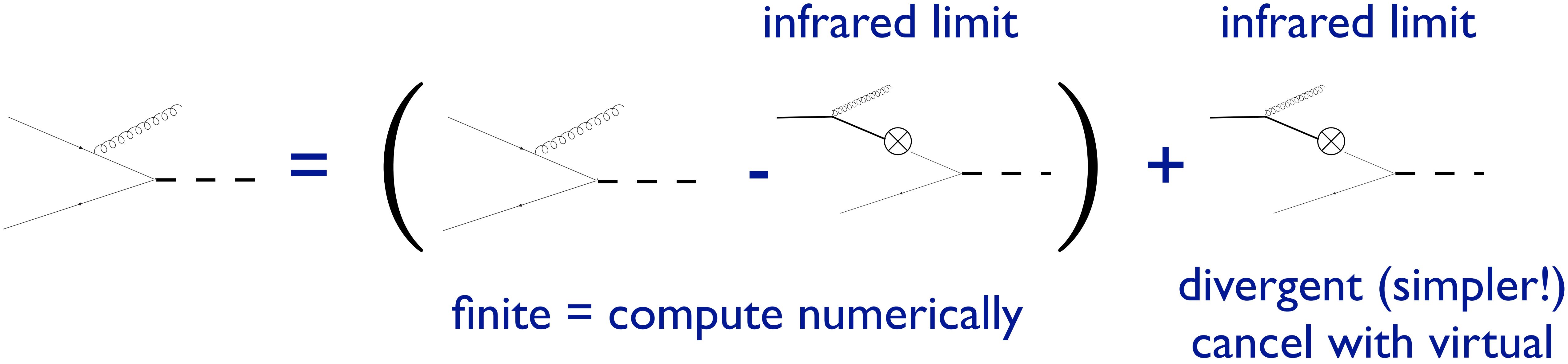
infrared limit infrared limit



finite = compute numerically

divergent (simpler!)
cancel with virtual

Free of any unphysical cutoff



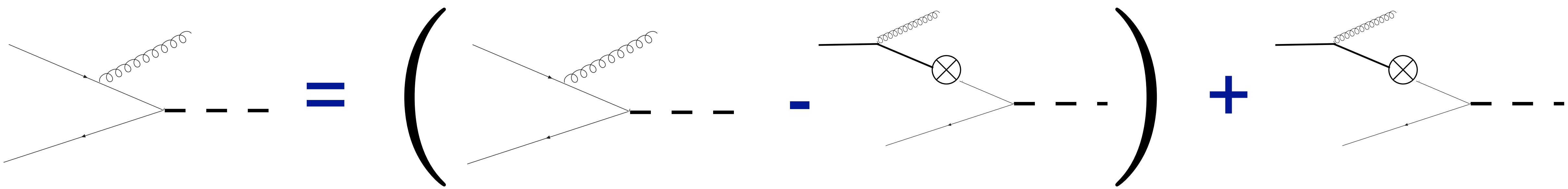
Free of any unphysical cutoff

Phase Space Integration with vegas :

- generate full phase space and x’s
- compute pdfs at corresponding x
- compute weight for the event (matrix element +subtraction)
- bin the results according to observable : cross-section

Full access to final and initial state kinematics :
compute any infrared-safe observable

infrared limit infrared limit



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- Exclusive to implement experimental cuts ✓
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Rather simple to use

```
'test'                  ! prefix for files
 500.d0 1.d0            ! energy,  fact/renorm. scalefactor
  0                     ! polarization   0(unpol)  1(single pol)  2(double pol)
 -1                     ! Charge of the final state W
  1   1                 ! Hadron beams  p=1 pbar=-1
  46                    ! set of pdfs beam 1
  46                    ! set of pdfs beam 2 =1 if Ipol=0 or 2
  -60    -60            ! Number of iterations for vegas (LO, NLO)
  2   2                 ! Vegas parameters: 0 to exclude, 1 for new run, 2 to restart
  250000  1500000       ! Number of calls for vegas
```

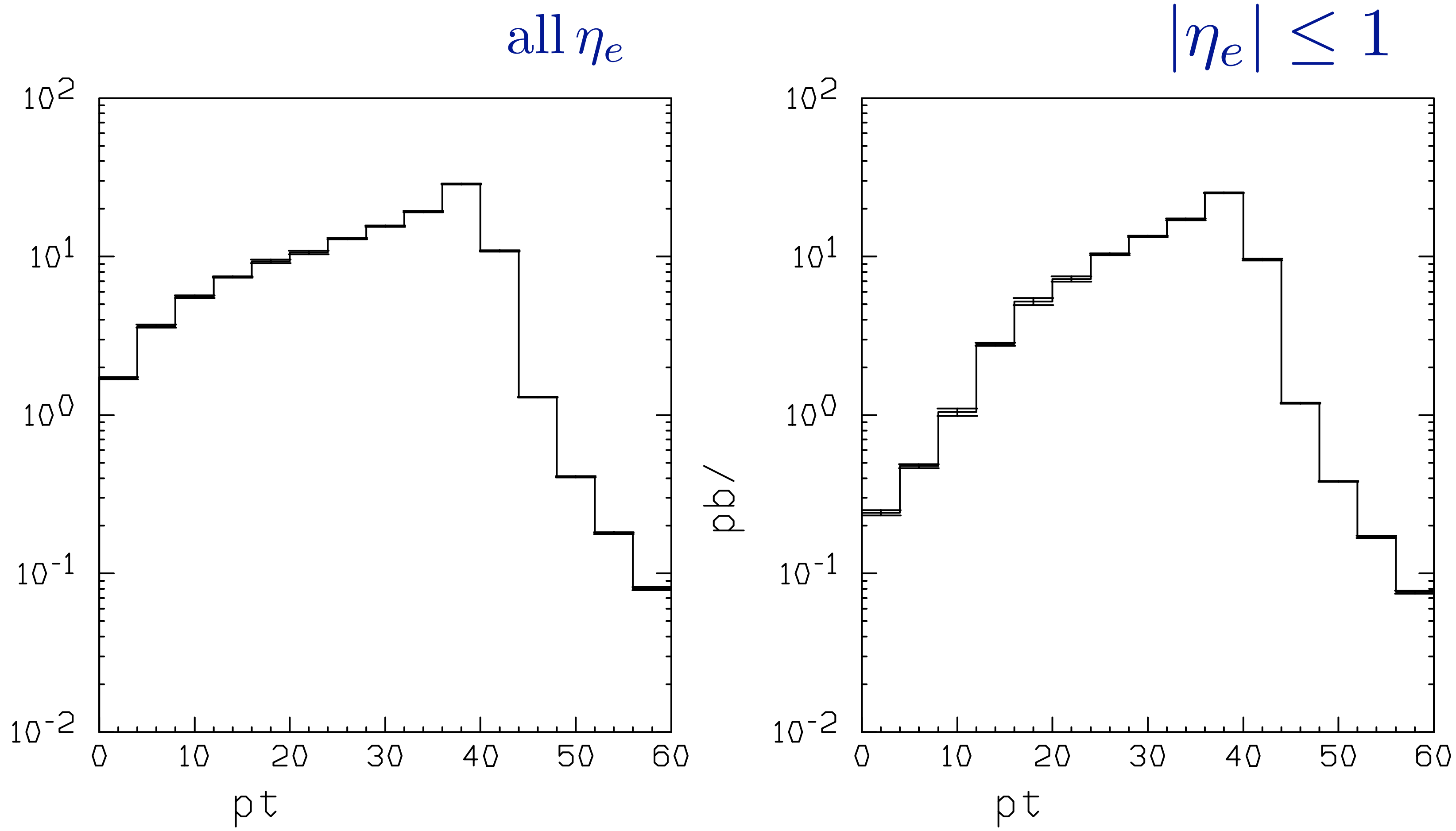
Can use different pdfs, scales, etc

Define observable (bin cross-section) in "user file" : output in topdrawer file

```
      subroutine outfun(www)
c  This is the user analysis routine. It is called for each generated event with the parameter www: weight of the event
c The kinematic of each particle is given by
c      xkt(i)=modulus of the transverse momentum of particle # i  in GeV
c      xeta(i)=pseudorapidity of particle # i
c     xphi(i)=azimuthal angle of particle # i
c     xkt(i),xeta(i),xphi(i) correspond to
c                                    i=1 jet
c                                    i=2 lepton
c                                    i=3 neutrino
c                                   (i=4 W boson as e+nu)
c
c The rapidity is POSITIVE in the direction of beam 1
c
c    To fill the histograms, use
c    topfill(hn,x,weight)
c where:
c    hn = histogram number
c    x = x value
c   weight = weight of the event
```

Available soon ... (manual & paper in preparation)

Transverse momentum of the electron $\sigma(pp \to e\bar{\nu}X)$



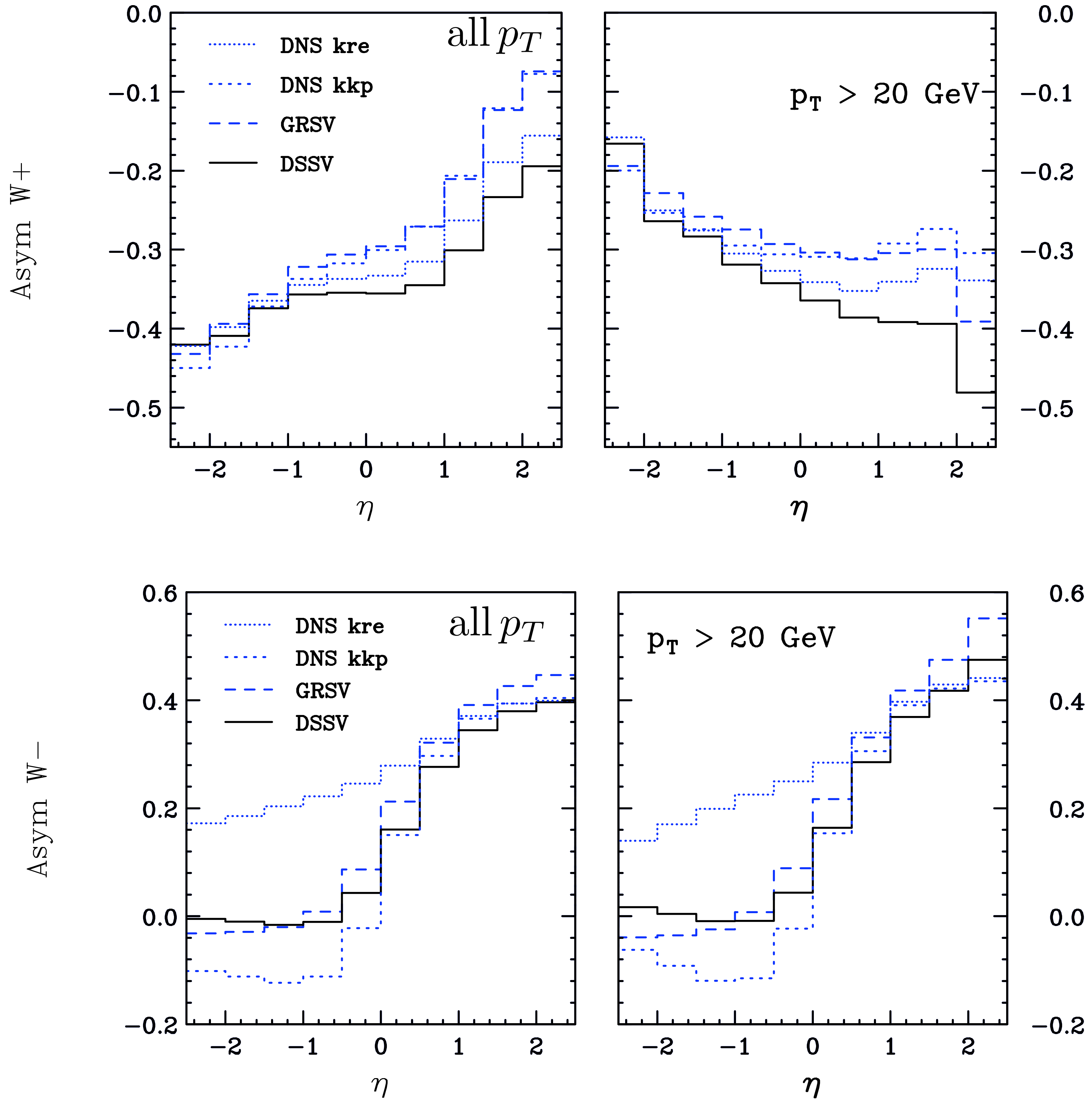
Final state jet available : correlations e-jet, cuts on jet, etc

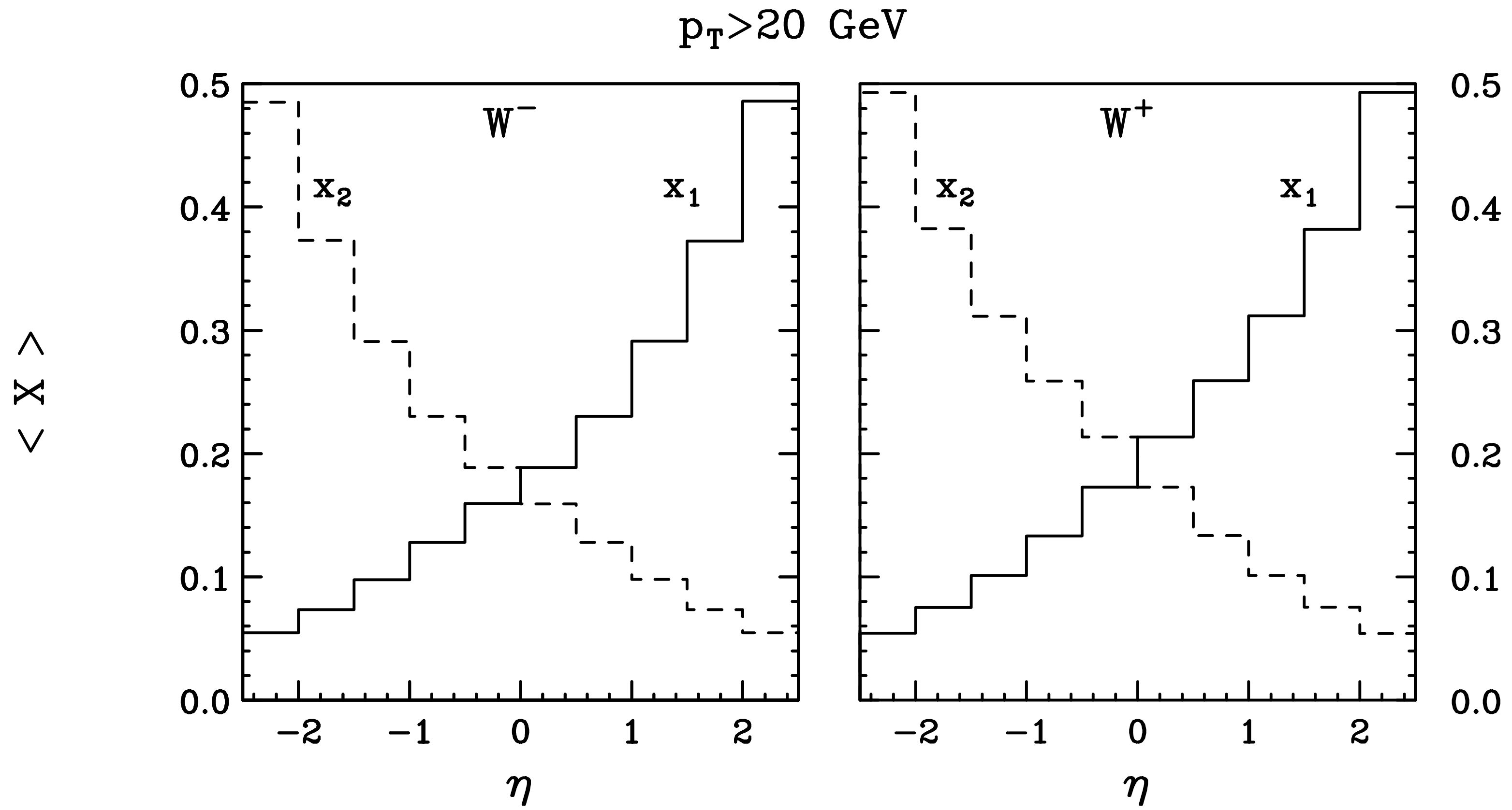
If narrow width

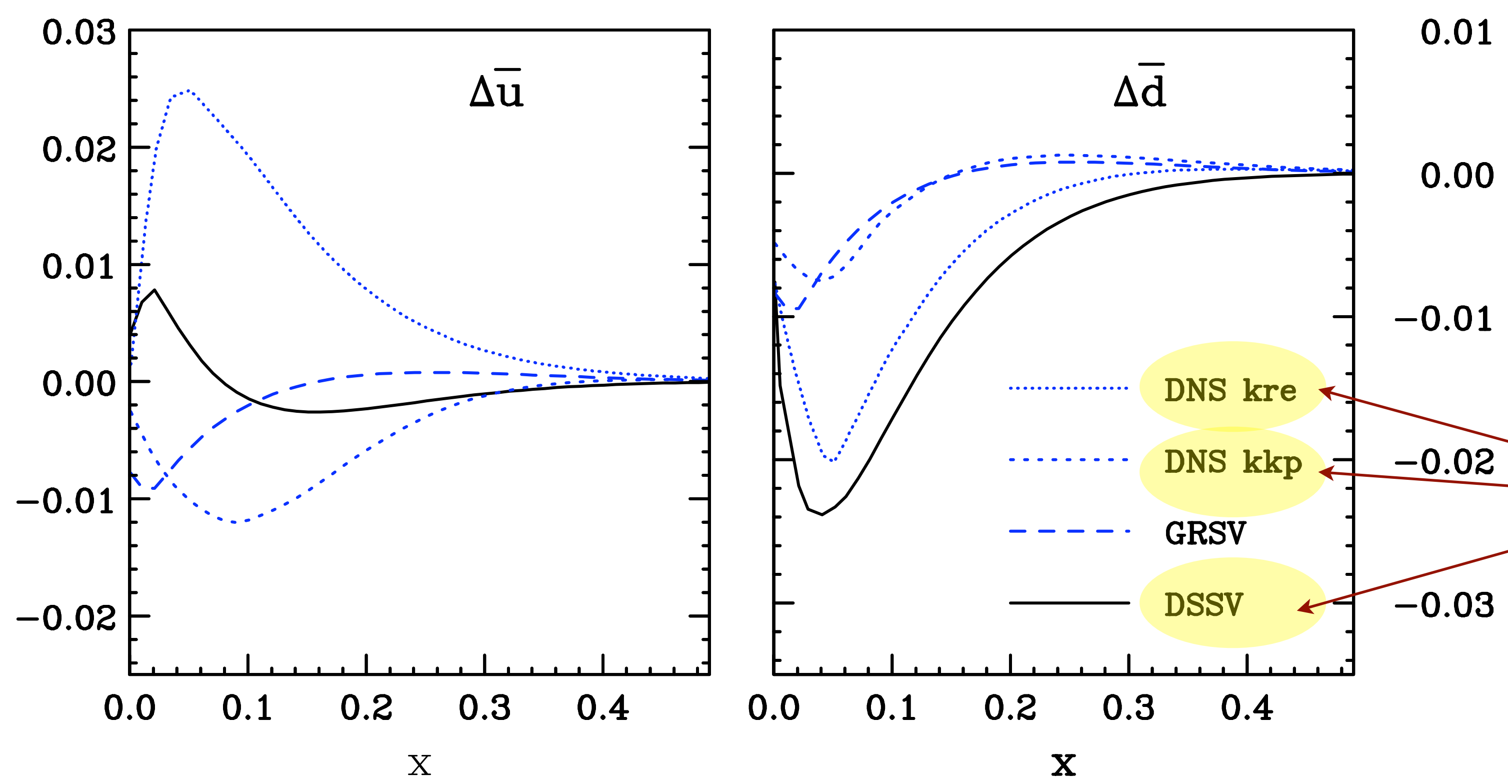
$$\int dPS(e,\bar{\nu})\ d\sigma(pp \to e\bar{\nu}) = \sigma^{NLO}(pp \to W) \times BR(W \to e\bar{\nu}))$$

QCD corrections important K~1.3

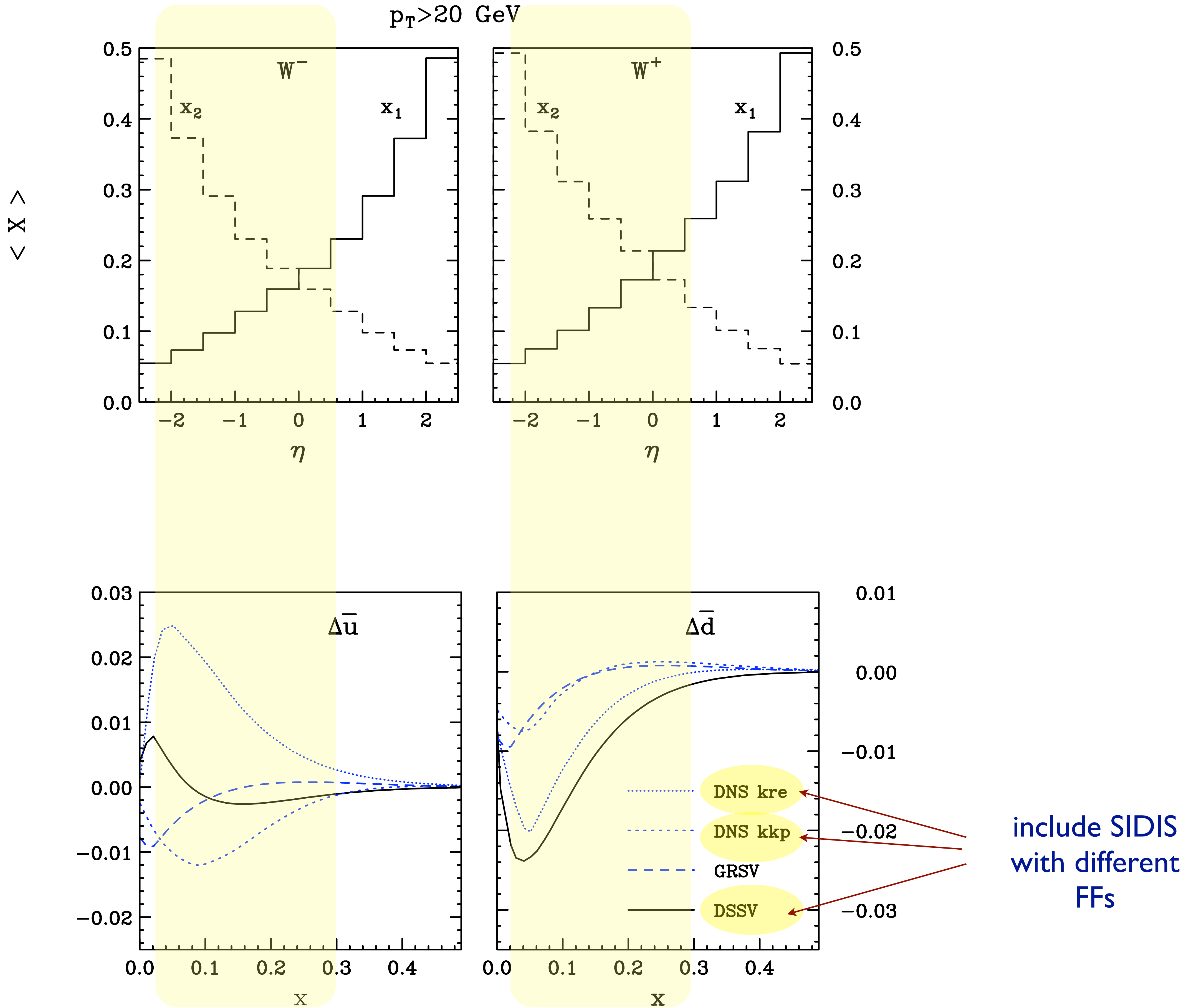
Electron rapidity (without and with pt cut) $\sigma(pp \to e\bar{\nu}X)$





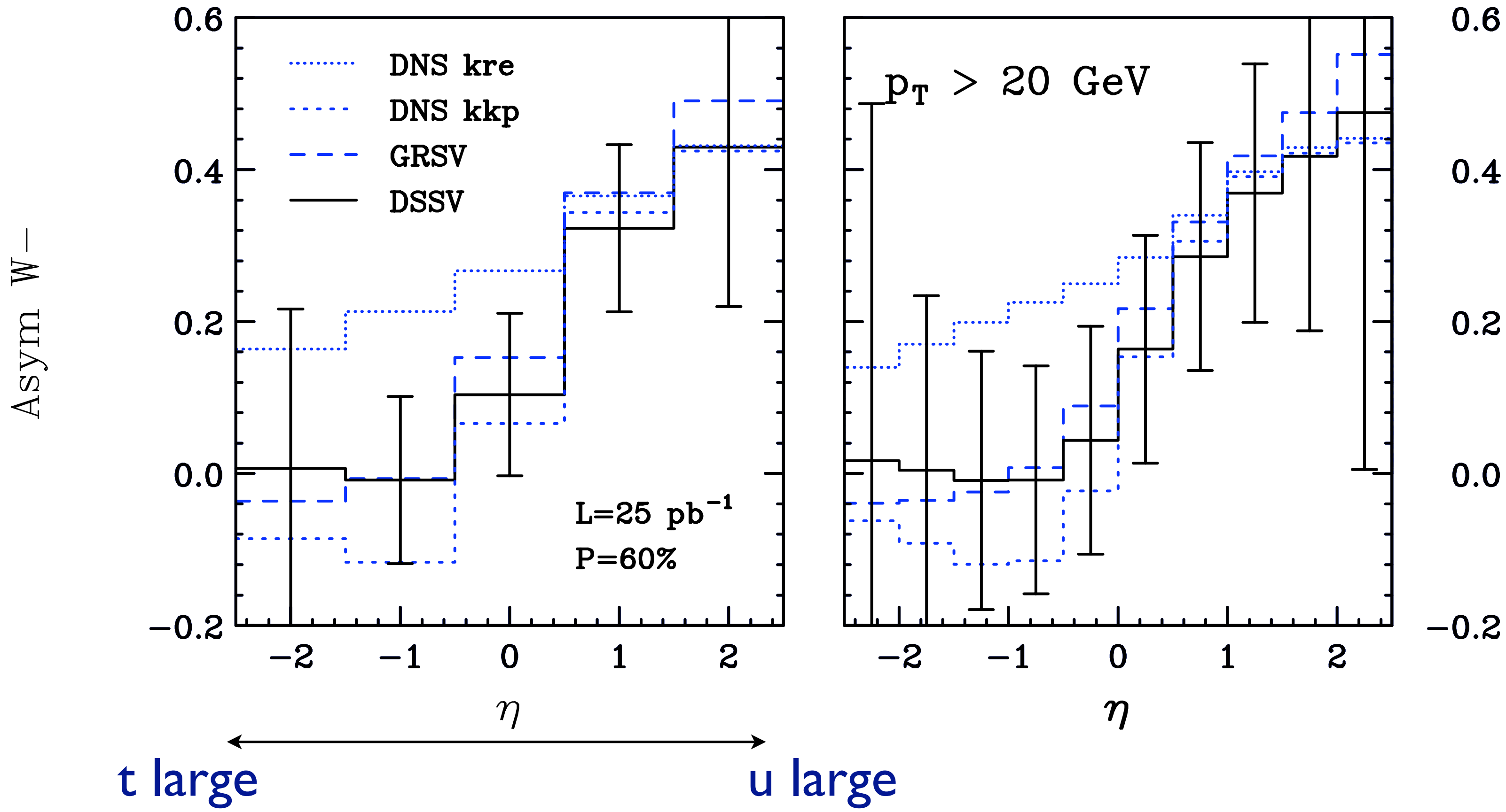


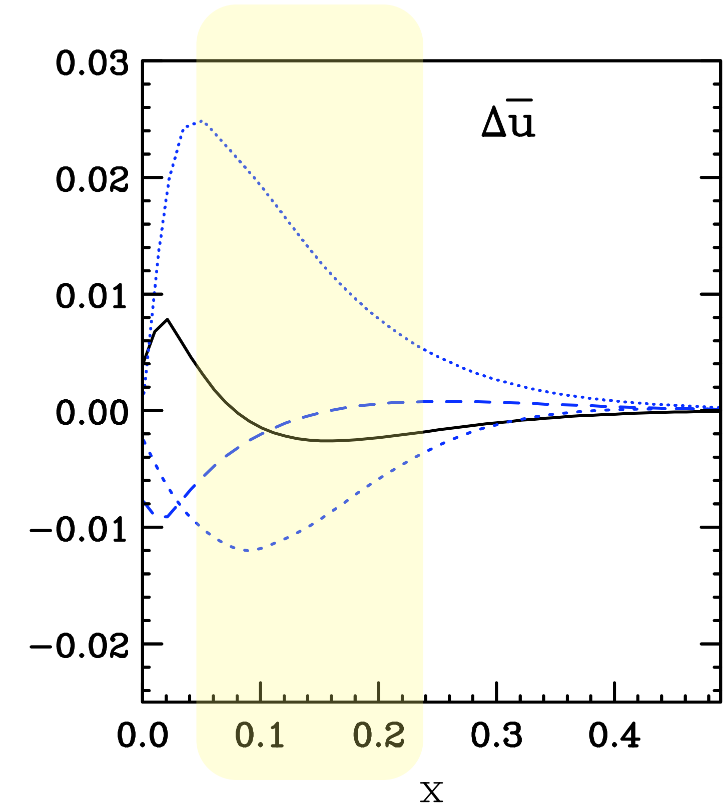
include SIDIS with different FFs



p_T>20 GeV
W^-
W^+
x_2
x_1
< X >
η
$\Delta\bar{u}$
$\Delta\bar{d}$
x
DNS kre
DNS kkp
GRSV
DSSV
include SIDIS with different FFs

W- (electron rapidity)





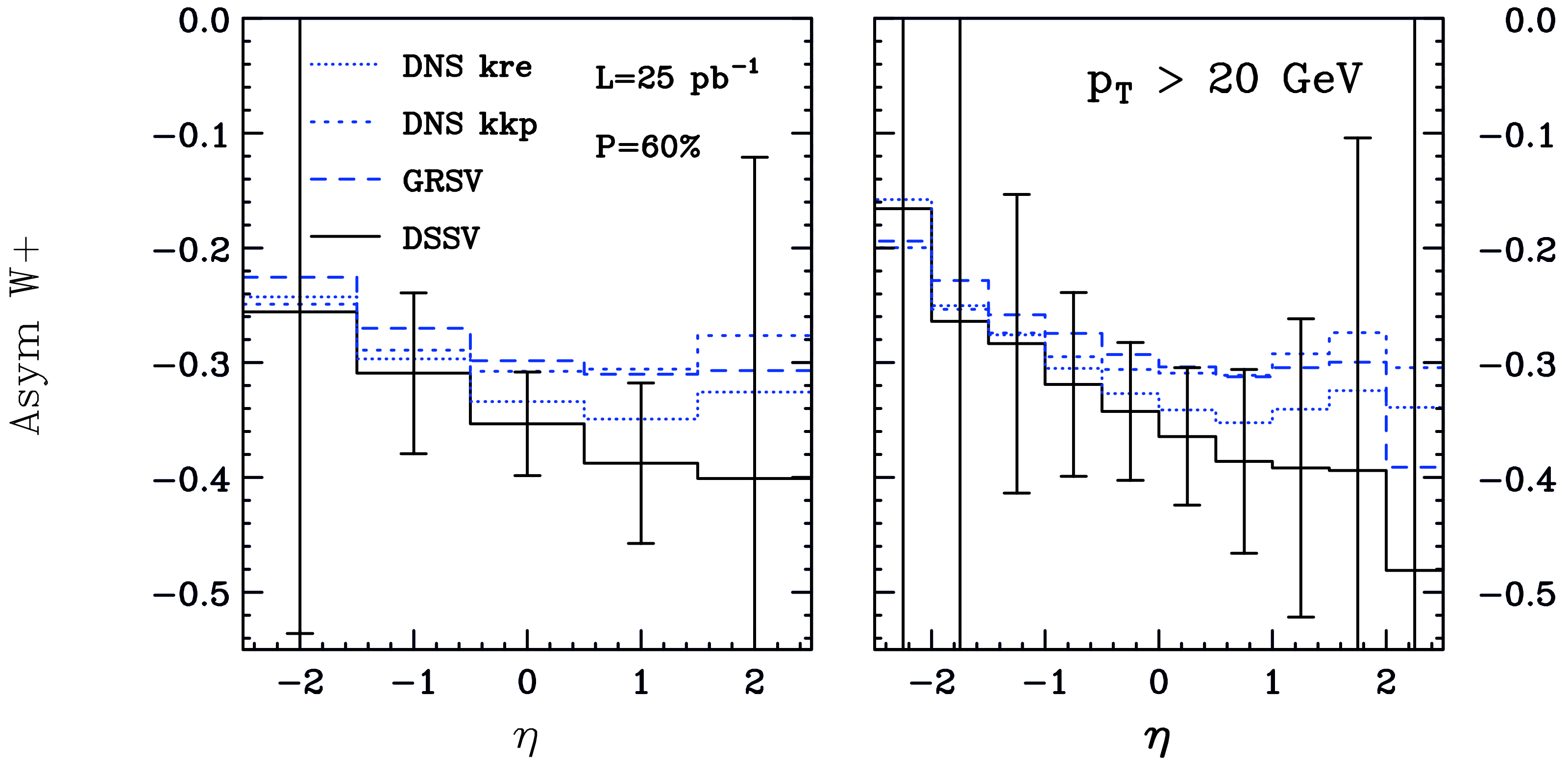
$\Delta\bar{q}_1\, q_2$ $\Delta q_1\, \bar{q}_2$

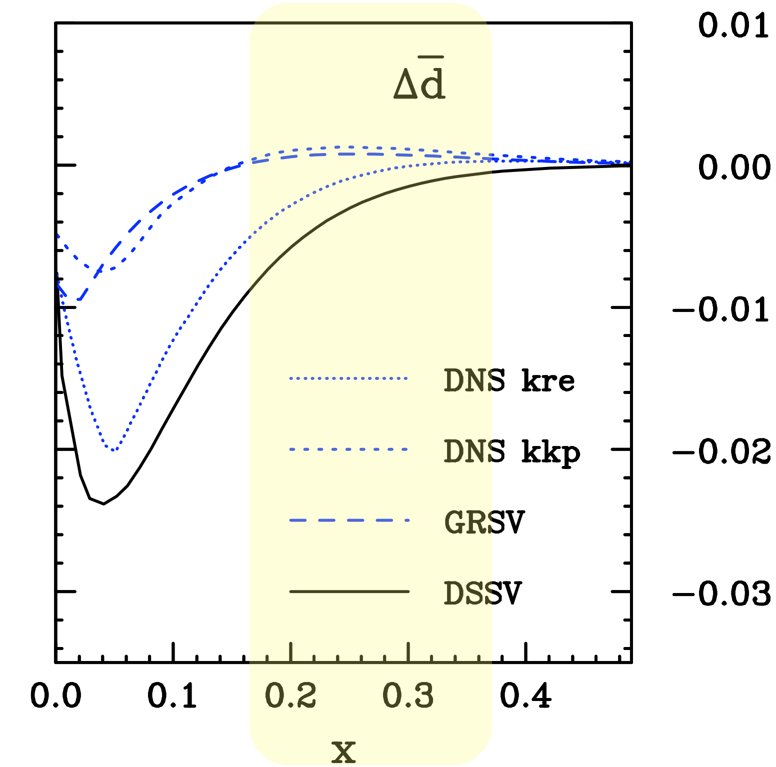
$$\Delta\bar{u}(x_1)d(x_2)(\hat{t}^2) + \Delta d(x_1)\bar{u}(x_2)(-\hat{u}^2)$$

Best scenario: polarized antiquark contribution dominant at central/negative rapidity (small x)

Strong sensitivity on $\Delta\bar{u}$

W+ (electron rapidity)





t large ⟷ u large

$\Delta q_1\, \bar{q}_2$ $\quad$ $\Delta \bar{q}_1\, q_2$

polarized antiquark contribution dominant at central/positive rapidity (larger x)

$$\Delta\bar{d}(x_1)u(x_2)(\hat{u}^2) + \Delta u(x_1)\bar{d}(x_2)(-\hat{t}^2)$$

Not that much sensitivity on $\Delta\bar{d}$ need to look at forward rapidities

To do next: include some "data" in global fit and check impact on distributions

Global fit best in Mellin space : very fast solution of evolution equations and cross-sections (DIS,SIDIS)

$$f^n = \int dz\; z^{n-1}\, f(z)$$

Convolution becomes product!

$$\int f \otimes g \to f^n \times g^n$$

$$d\Delta\sigma \;=\; \sum_{ab} \int dx_a \int dx_b\, \Delta f_a(x_a) f_b(x_b) \times d\Delta\sigma_{ab}$$

Use Mellin inverse for pdfs

$$\frac{1}{2\pi i}\int_{\mathcal{C}_n} dn\; x_a^{-n}\, \Delta f_a^n$$

Obtain a Mellin expression for the pp cross-section

$$\frac{1}{2\pi i}\sum_{ab}\int_{\mathcal{C}_n} dn \quad \Delta f_a^n \quad \int dx_a \int dx_b\, x_a^{-n}\, f_b(x_b)\, d\Delta\sigma_{ab}$$

$$\frac{1}{2\pi i} \sum_{ab} \int_{\mathcal{C}_n} dn \; \Delta f_a^n \; \int dx_a \int dx_b \, x_a^{-n} \, f_b(x_b) \, d\Delta\sigma_{ab}$$

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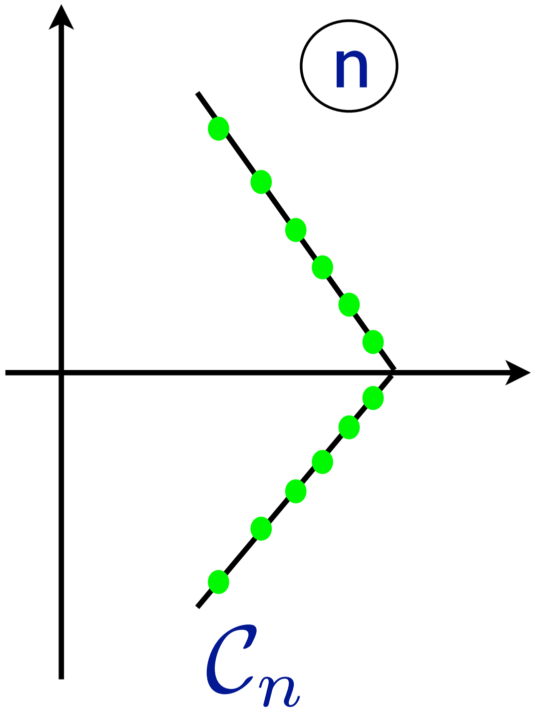
Standard
Mellin
Inverse

Discretize
for Gaussian
Integration
64
support points



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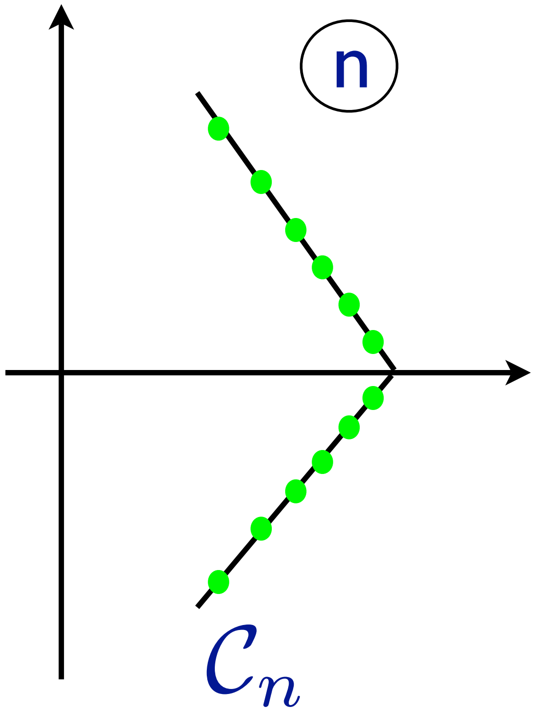
Standard Mellin Inverse

Contains all dependence on polarized pdfs

Discretize for Gaussian Integration 64 support points



$$\frac{1}{2\pi i}\sum_{ab}\int_{\mathcal{C}_n} dn \;\; \Delta f_a^n \;\; \int dx_a \int dx_b \, x_a^{-n} \, f_b(x_b) \, d\Delta\sigma_{ab}$$

Standard Mellin Inverse

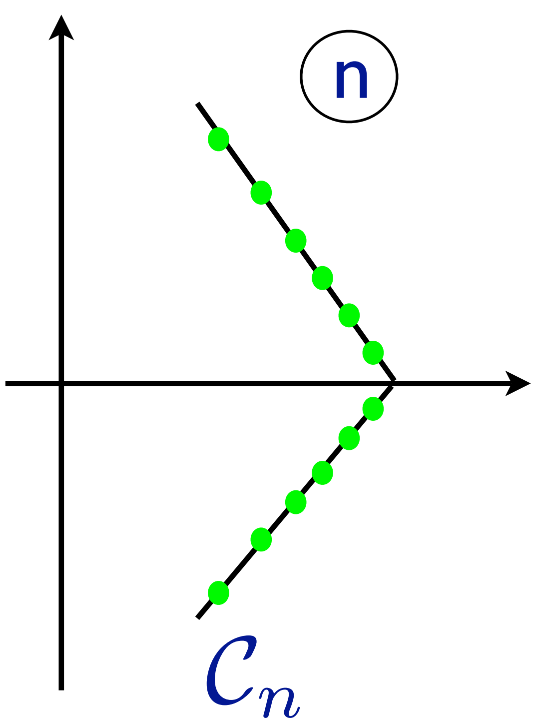
Contains all dependence on polarized pdfs

Completely independent on polarized pdfs : can be "pre-calculated" prior to fit

Evaluate (64 element) grid just once for each subprocess

$$(d\Delta\sigma_{ab})_{n_i}$$

Discretize for Gaussian Integration 64 support points



Once "grids" available fit is cross-section evaluation ~ 0.4 msec

$$(d\Delta\sigma_{ab})_n = \int dx_a \int dx_b \, x_a^{-n} \, f_b(x_b) d\Delta\sigma_{ab}$$

still PS integrals

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still PS integrals

Grid Evaluation complicated (64 x 2 x bins x channels) : profit from Vegas (discrete) integration

Record configuration for each "event": $x_{a,(i)}$ $w_i(x_a)$

grids obtained just by adding

$$(d\Delta\sigma_{ab})_n = \sum_i x_{a,(i)}^{-n} \; w_i(x_a)$$

Vegas sampling helps: calculation of grids in a ~day in single computer

Essential to have access to x's and weights

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If "double polarized": two moments, larger grids efficient method essential

64 → 64 x 64

During the next few weeks/months

Write paper and make code public

Study sensitivity on polarized antiquark distributions by adding some simulated W data to global analysis

But, why a NLO calculation if Rhicbos is available?

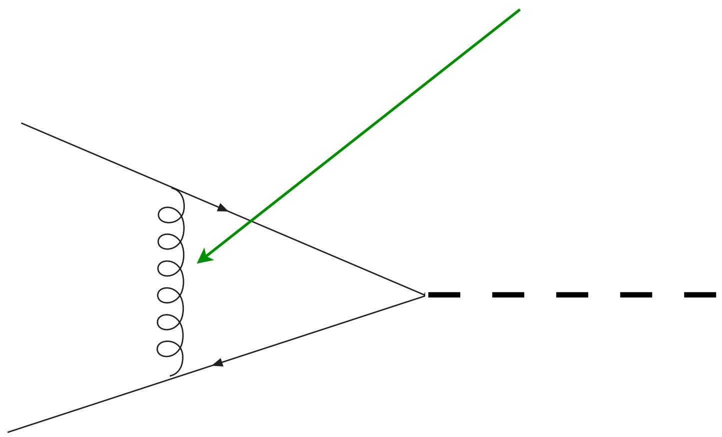
Technical issues : not well suited for Mellin grids preparation, essential for Global fit

Physics “issues” : Rhicbos performs transverse momentum resummation. Not NLO and Not needed/convenient for inclusive observables

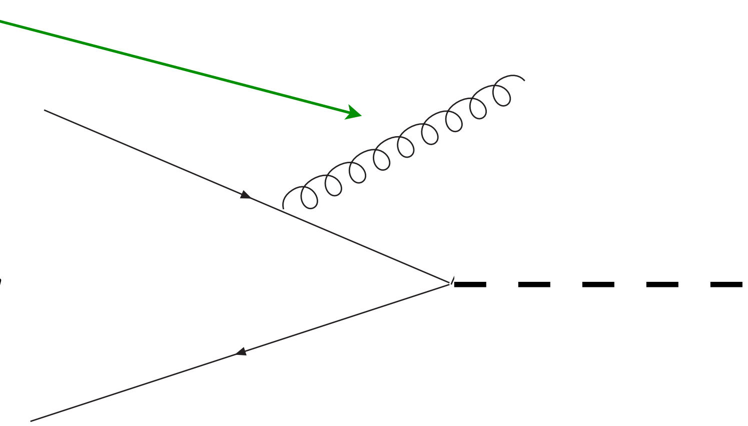
Here “more” doesn’t mean “better” !

QCD: virtual and real diagrams full of infrared divergencies

soft and collinear gluons



$+ \int dp_g$



∞ + ∞ + fact/ren. = finite

Cancellation of singularities guaranteed in inclusive observables

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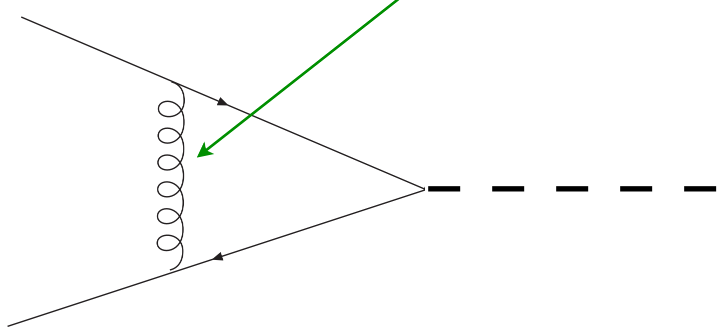

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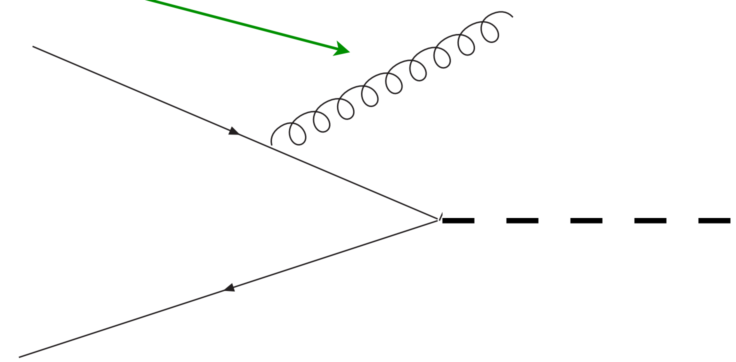
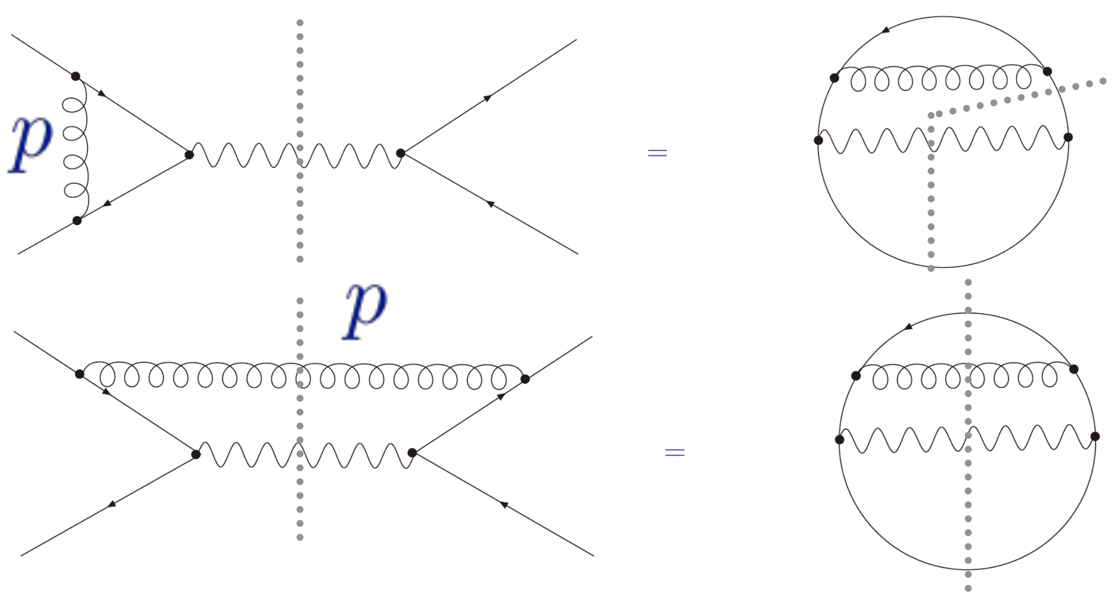


$\infty \quad + \quad \infty \quad$ + fact/ren. = finite

Cancellation of singularities guaranteed in inclusive observables

After gluon integration 1 to 1 relation between real and virtual contributions



virtual $\int d^4p$ full

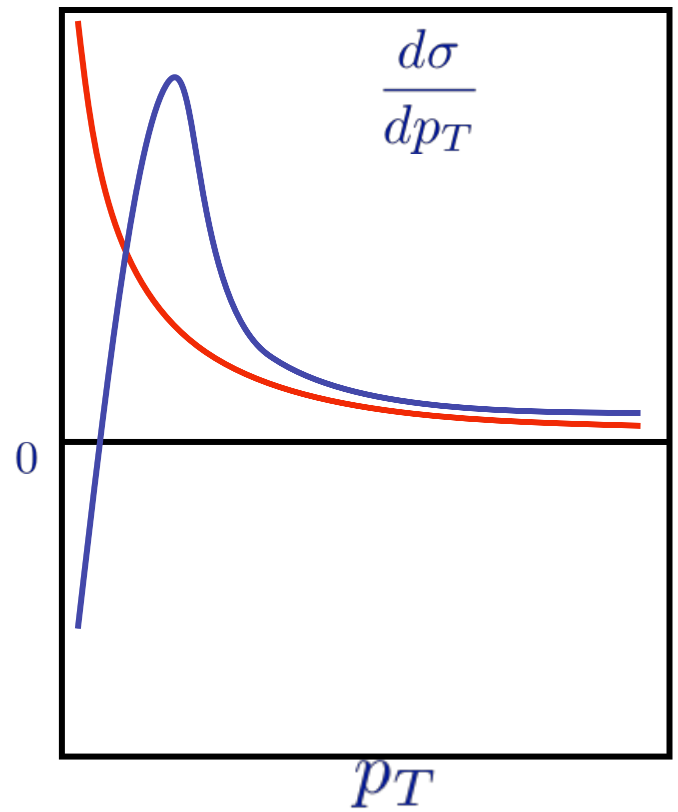
real $\int dPS(p)$ full if no cuts

But not trivial to implement : that makes NLO calculations hard

When is transverse momentum resummation needed?

Production of a heavy mass particle/system with small transverse momentum

Perturbative QCD fails when $p_T \ll M_W$



+ Opposite signs -

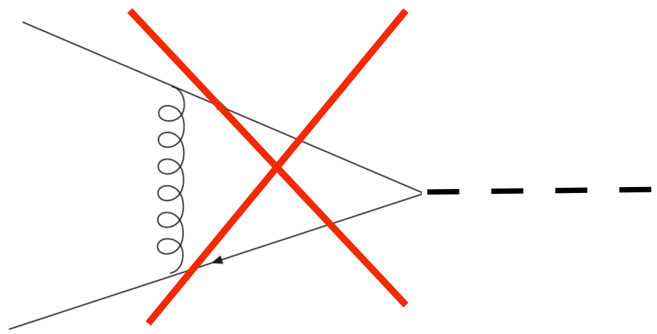
LO cross section diverges to $+\infty$

NLO cross section diverges to $-\infty$

Why?

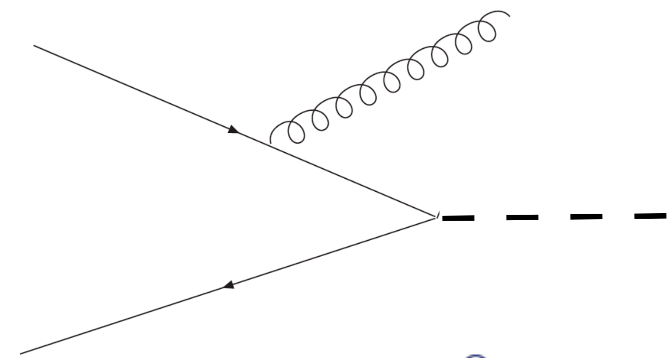
Perturbative QCD reliable when "inclusive" observables are computed

But at small transverse momentum : unbalanced cancellation of infrared singularities



$p_T = 0$

NO virtual



$p_T > 0$

Almost full real

General issue for observable that involves "very constrained "kinematics

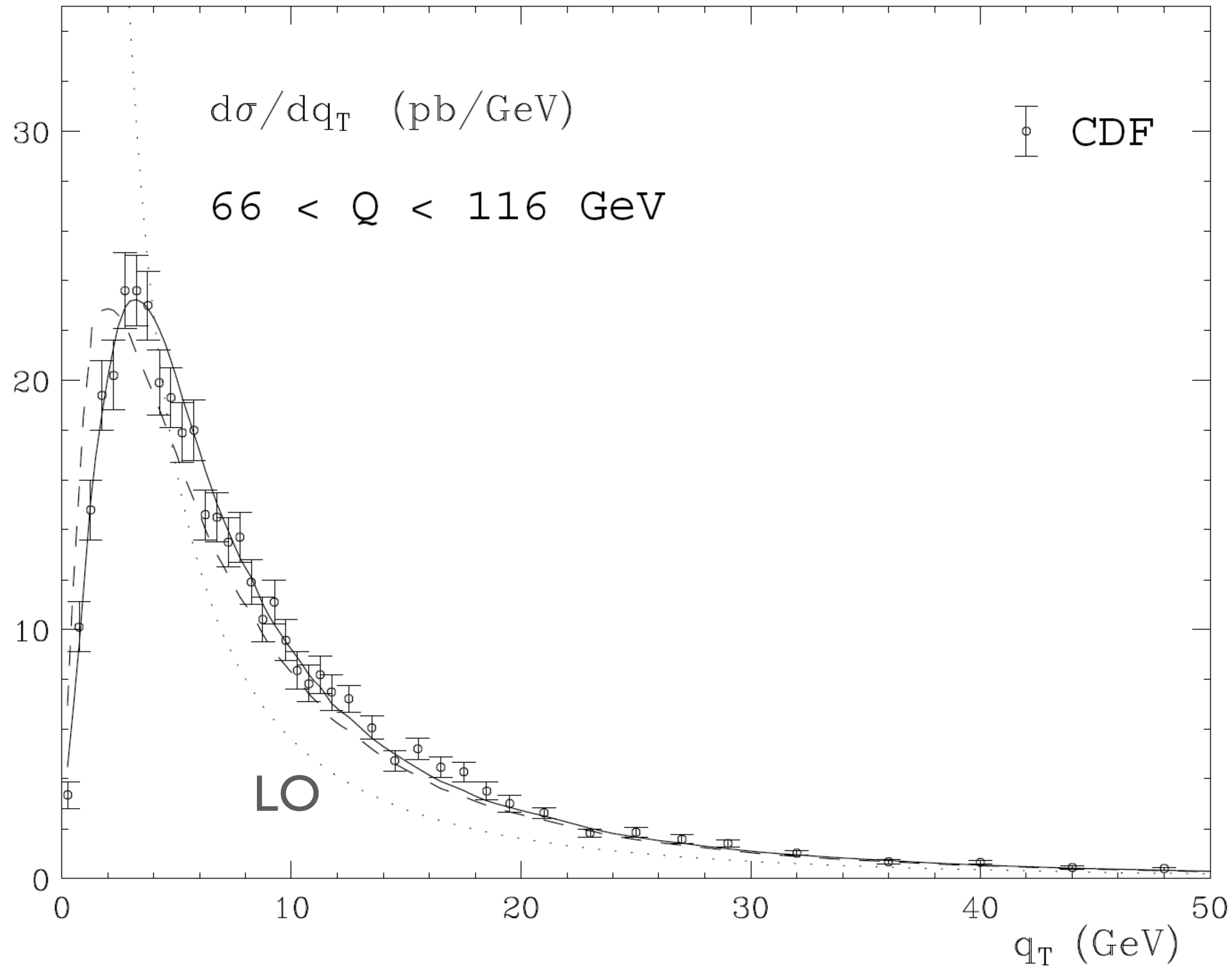
"Failure" shows up in cross section as large logs $\alpha_s^n \log^{2n} \frac{p_T^2}{M_W^2}$ perturbative expansion breaks down

After (re)summing all terms to a given "logarithmic accuracy" pQCD results can be applied to pretty small transverse momentum

Involved technique including Bessel functions and other ugly things like correct matching between resummed and fixed order at larger transverse momentum

Relevant for Tevatron measurement where transverse momentum of the W can be reconstructed : W mass

Example: Z boson

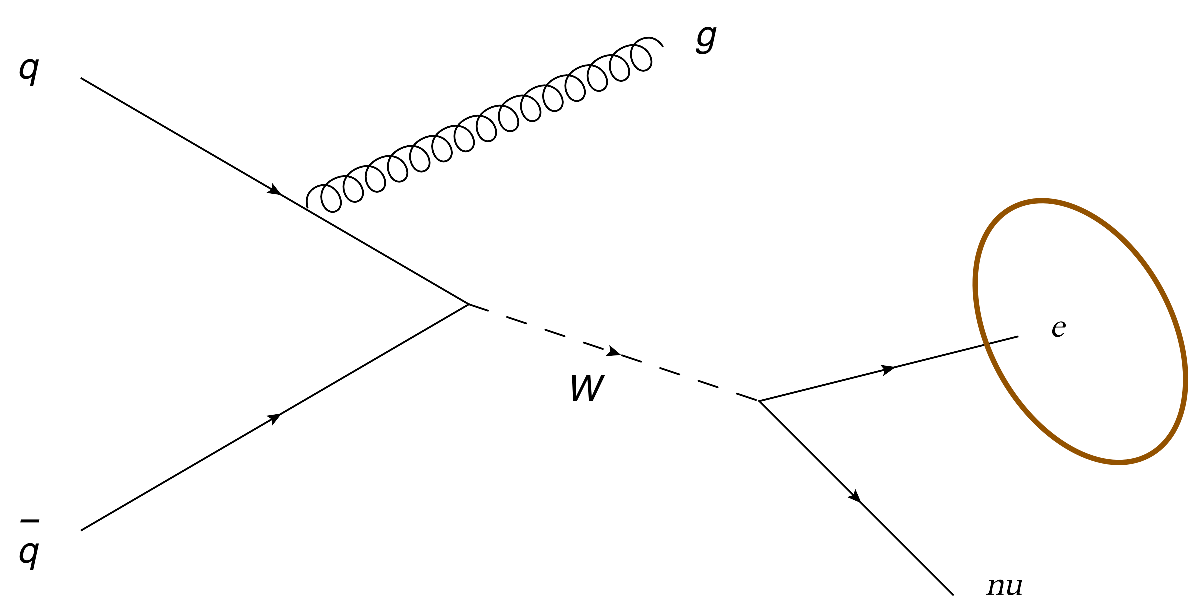


Laenen, Sterman, Vogelsang

But cancellation between virtual and real contributions is "complete" when gluons are integrated out : logs disappear and QCD fixed order calculations are OK : DIS, SIDIS, HQ, jets, etc unless "extreme kinematic regime"

Therefore if one is not interested on the small transverse momentum of the W, using the resummed expression doesn't actually help at all!

cut in lepton is OK for QCD: gluon integrated!



$$dPS \sim d^3 p_g \; d\eta_e \, dp_{Te}$$

In the best scenario : resummation would be the same as fixed order calculation after integration

So, in the best case, this resummation would just introduce many complications

Can not be included in global fit

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Can not be included in global fit

- Implementation in RHICBOS is “old-fashioned”

Matching between resummed and fixed order is not well implemented

Unphysical parameters introduced (like cut-off in Bessel integral)

Total cross-section not recovered $\int dq_T \frac{d\sigma}{dq_T} \neq \sigma^{tot}$ Not the best scenario