Minimizing the uncertainty due to parton distribution and production mechanism in the determination of the W mass

Arnaud Lucotte[(1)] thanks to Ian Adam[(2)]
DØexperiment

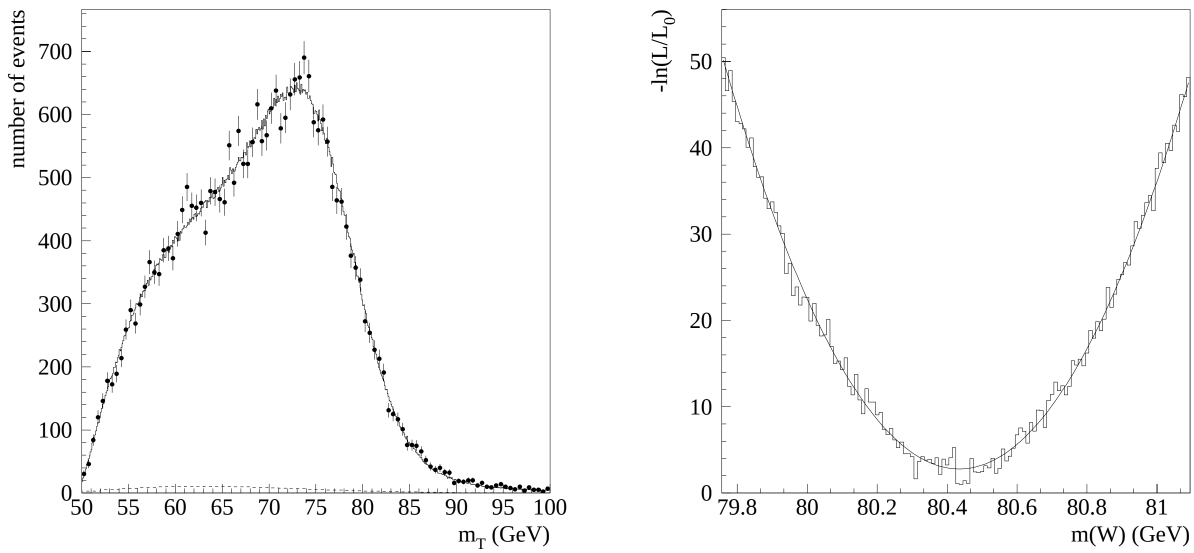
[(1)] New York University at Stony Brook
[(2)] Columbia University

1. Theoretical limitations on the W mass determination at $p\bar{p}$
2. The theoretical framework of the W production cross-section
   - parametrization of the W-mass resonance
   - resummed cross-section and $\mathrm{d}^2\sigma/\mathrm{dydP_T}$
   - non-perturbative contribution in $\mathrm{d}^2\sigma/\mathrm{dydP_T}$
3. The experimental constraints on the modelisation at DØ
   - error in W-mass distribution: the parton luminosity effects
   - constraint on $\mathrm{d}^2\sigma/\mathrm{dydP_T}$ spectrum: the choice of the pdf
   - constraint on $\mathrm{d}^2\sigma/\mathrm{dydP_T}$ spectrum: non-perturbative paramaters
4. Conclusion

Theoretical limitations on the W mass determination

Sources of errors in W-mass determination

- W-mass from maximum likelihood fit to M_T or E_T^e



Sources of error (MeV)	M_T^W	E_T^e
Statistical	70	90
Energy Scale	75	75
Detector Syst.	91	55
Theoretical Syst.	33	61

$\Rightarrow$ Uncertainty on theoretical models becomes a limiting factor:

- For measurements with higher statistics (run II)
- For determination using E_T^e distributions

The theoretical framework of the W-production cross-section

Specify W cross-section in terms of:

- m - Mass
- y - Rapidity
- $\mathrm{P_T}$ - Transverse momentum

$$\frac{\partial^3\sigma}{\partial P_T \partial y \partial m}$$

$$\swarrow \qquad\qquad \searrow$$

$$\left|\frac{\partial^2\sigma}{\partial P_T \partial y}\right| \times \frac{d\sigma}{dm}$$

Collins-Soper-Sterman [CSS]
Davies-Stirling-Weber [DSW]
Arnold & Kauffman [AK]
Ladinsky-Yuan [LY]

$$\times \frac{e^{-\beta m}}{m} \frac{m^2}{\left(m^2 - M_W^2\right)^2 + m^4\Gamma_W^2/M_W^2}$$

the parametrization of the W-mass resonance

Dependance of the W-mass distribution

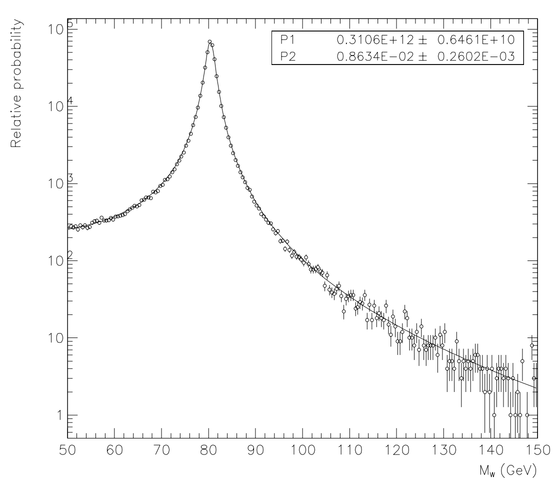
$$\frac{d\sigma}{dm} = \frac{e^{-\beta m}}{m} \times \frac{m^4\Gamma_W^2/M_W^2}{(m^2 - M_W^2)^2 + m^4\Gamma_W^2/M_W^2}$$

→ Relativistic Breit-Wigner: Dependence in Γ_W

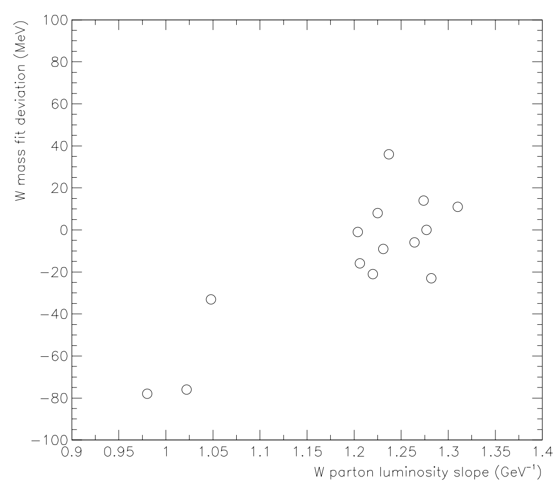
→ Parton Luminosity factor:

$$\frac{e^{-\beta m}}{m} \equiv \sum_{i,j} f_i\left(\frac{m}{\sqrt{s}}e^{y}, m^2\right) f_j\left(\frac{m}{\sqrt{s}}e^{-y}, m^2\right)$$

- f_i: is the pdf for the parton i/proton. β is the slope
- parton with momentum fraction $me^y/\sqrt{s}$ at m^2



M_W distribution (MRSA)



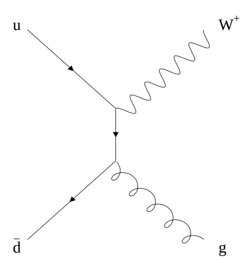
M_W vs β_W

The resummed cross-section and $d\sigma/dydP_T$

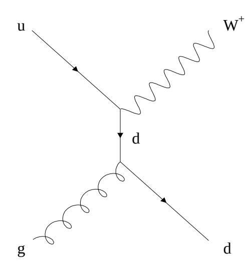
W-Production cross-section

- Drell-Yan processus : $P_T^V \approx 0$ wrt $p\bar{p}$ axis

$\Rightarrow$ Higher order QCD-corrections $\Rightarrow P_T^V \neq 0$



Gluon ISR



Compton q-g

$\Rightarrow$ Divergence at low P_T of $\alpha_s \log\left(Q^2/P_T^2\right)$ terms at Q scale

The Collins-Sopper-Sterman framework

- Re-summation of LO and NLO terms:

$$\frac{d\sigma_{ij}}{dP_T dy} \propto \int d^2b \times e^{i\bar{b}\bar{P}_T} W(b, Q, \ldots)$$

$W(b, Q\ldots)$ depends on [AK]:

- parameters: b (impact par.), s, m (mass), $\frac{Q}{\sqrt{s}}e^y$ (x_1), $\frac{Q}{\sqrt{s}}e^{-y}$ (x_2)
- pdfs : $f_i(\ldots)$ and $f_j(\ldots)$
- the re-summed terms in exponential form
- a Non-Perturbative Term, important for $P_T \leq 10$ GeV

The non-perturbative contribution in $d\sigma/dydP_T$

Non-pertubative correction to the resummed cross-section

- S_{NP} controls the shape of W for low $P_T < P_T^{min}$ ($b > b_{max}$)

$$W(b, Q...) \rightarrow W(b^*, Q...)e^{-S_{NP}(b^*)}, \qquad b^* = \frac{b}{\sqrt{1 + b^2/b_{max}^2}}$$

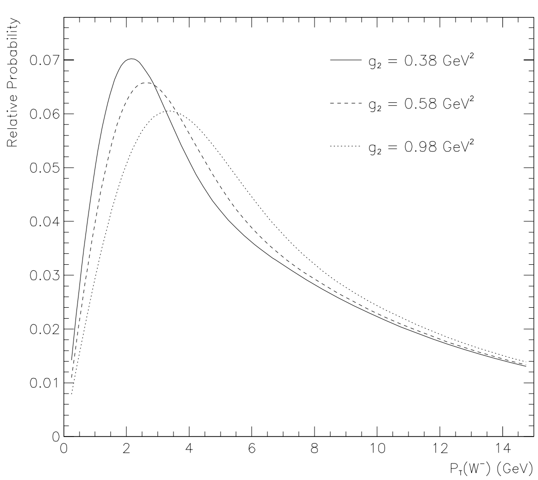
Parametrization of the non-perturbative function S_{NP}

- constrained by low P_T Drell-Yan data fit

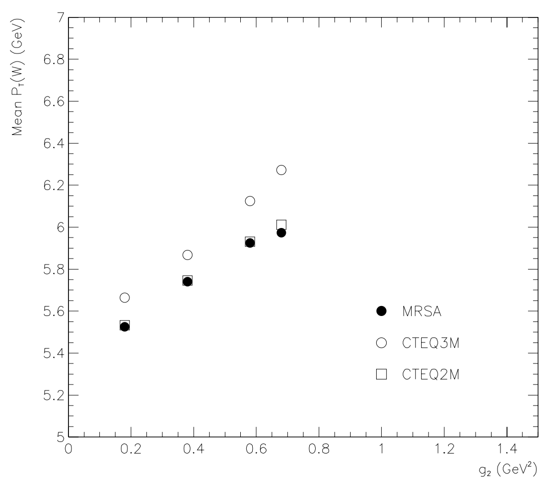
$\Rightarrow$ Modelisation of [DSW] improved by [LY]:

$$S_{NP}(b) = b^2 \left(g_1 + g_2 \ln \left(\frac{Q}{2Q_0} \right) \right) + b g_1 g_3 \ln(100 x_1 x_2)$$

$\rightarrow$ need strong constraint on g_2



P_T^W vs g_2



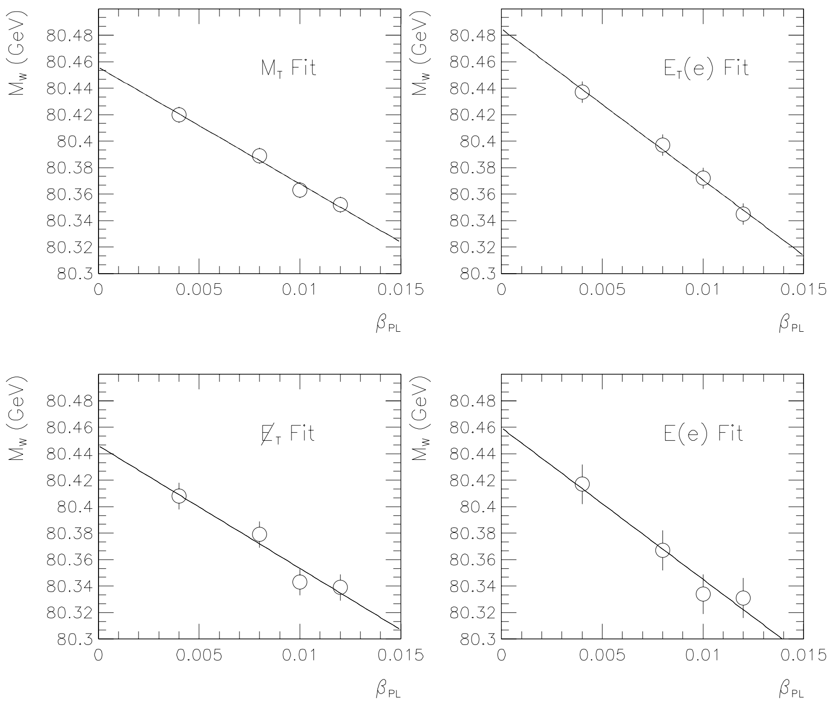
$< P_T^W >$ vs g_2

Errors in the W-Mass distribution: the parton luminosity

Uncertainty from the parton luminosity

→ compute β for pdfs MRSA/CTEQ2M/CTEQ3M/MRSD-'

→ for each β generate MC and perform fit to data



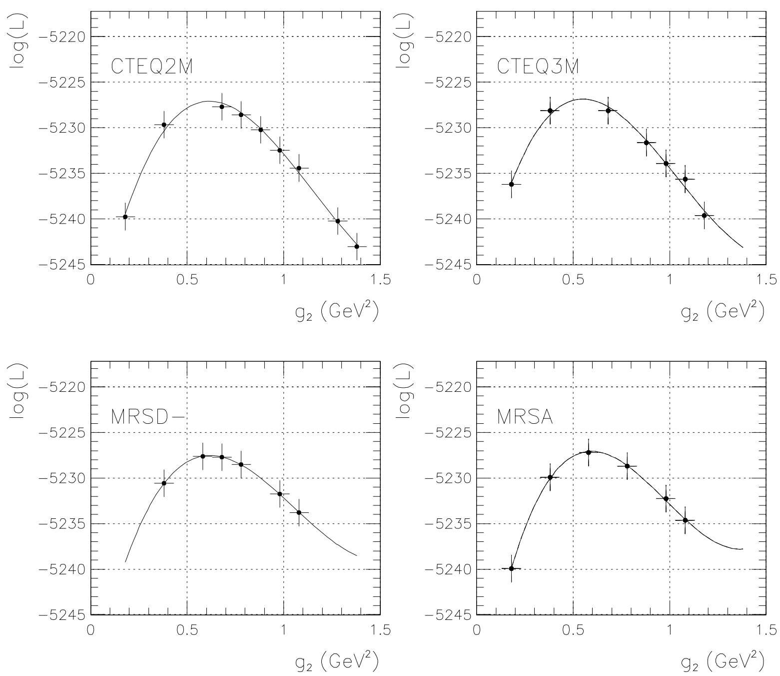
Translated error on fitted W-mass for $\Delta\beta = 0.001\ \mathrm{GeV}^{-1}$

Observables	M_T^W Fit	E_T^e Fit
ΔM_W (MeV)	-8.8 ± 1.0	-11.4± 1.3

Errors in $d^2\sigma/dydP_T$ spectrum: the choice of the pdf

Constraints from the P_T^Z measurement

→ fixe g_1, g_3 from [LY] fit
→ fit g_2 from $P_T(ee)$ distribution in $Z \to e^-e^+$
→ enter g_2 as input in P_T^W



→ compute $\text{Max}\{M_W(\text{pdf}) - M_W(\texttt{MRSA})\}$ as systematics

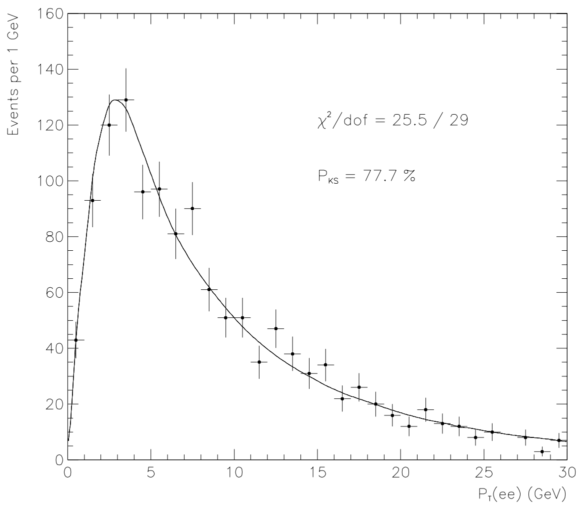
Translated errors on fitted W-mass

Observables	M_T^W Fit	E_T^e Fit
ΔM_W (MeV)	21	48

Errors in $d^2\sigma/dydP_T$ from the non-perturbative contribution

The g_2 determination from P_T^Z measurements

→ fixe g_1 and g_3 from [LY] fit
→ for **MRSA** pdf , fit g_2 from $P_T(ee)$ in $Z \to e^- e^+$
→ enter g_2 as input to P_T^W , compute systematics and changes in pdf



Results for **MRSA** :

$$g_2 = 0.587 \pm 0.095 \pm 0.052 \pm 0.043 \ \mathrm{GeV}^2$$

stat. syst. pdfs

Theoretical Predictions:

$$g_2 = 0.59 \pm 0.12 \ \mathrm{GeV}^2 \quad \text{[LY]}$$

Translated error in the fitted W-mass

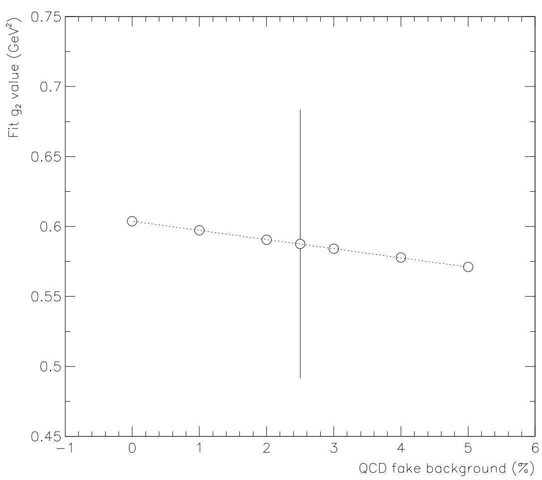
- Main limitation: statistics at run I (systematics at run II)

Observables	M_T^W Fit	E_T^e Fit
ΔM_W (MeV)	5	28

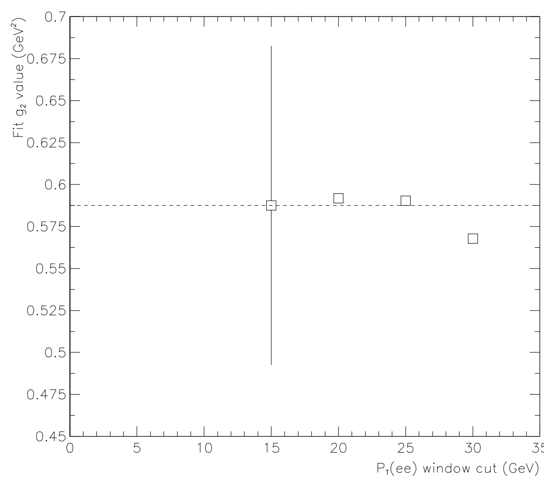
Errors in $d^2\sigma/dydP_T$ from the non-perturbative contribution

Systematic errors in g_2 (GeV^2) determination

Background	0.018
e^- energy resolution	0.02
e^- energy scale	0.02
$u_{//}$ efficiency	0.02
Φ acceptance	0.01
Radiative decays	0.03
Systematical	0.052
TOTAL	0.108



g_2 vs background



g_2 vs P_T-window

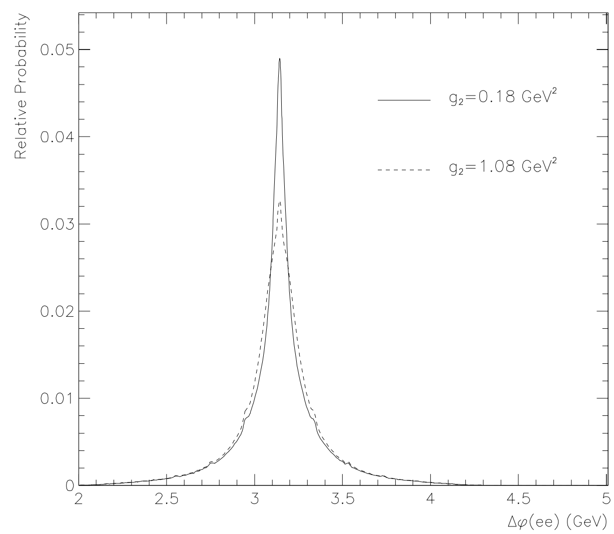
Errors in $d^2\sigma/dydP_T$ **from the non-perturbative contribution**

The determination of g_2 from $\Delta\phi(ee)$

- use of the correpondance $\Delta\Phi(ee)$ versus P_T^Z for electrons in $Z \to e^+e^-$

Higher $< P_T^Z >$ values

$\Rightarrow$ wider $\Delta\Phi(ee)$



$\Delta\Phi(ee)$ vs g_2

The determination of g_2 from $\Delta\phi(ee)$:

− carries less informations than $P_T(ee)$: $\Rightarrow$ statistically limited

+ is less sensitive to reconstruction biases in:
e^- energy scale and resolution

$\Rightarrow$ important at run II

Conclusions

Theoretical errors for production models become a limiting factor:

1. for a high statistics run II at $p\bar{p}$ collider
2. for all measurements based on a fit to E_T^e spectrum (lower systematics wrt M_T^W fit)

Theoretical errors in production model originate from:

Sources	$\mathrm{M_T^W}$ Fit	$\mathrm{E_T^e}$ Fit	$\not{E}_T$ Fit
$\Delta\Gamma_\mathrm{W}$	9	7	6
Parton luminosity	10	10	10
$\mathrm{d^2}\sigma/\mathrm{dP_T dy}$: pdf	21	48	30
$\mathrm{d^2}\sigma/\mathrm{dP_T dy}$: $\mathrm{g_2}$	5	28	9
TOTAL	25	57	33

→ dominated by errors in the non-resonant part to $\mathrm{d^2}\sigma/\mathrm{dP_T dy}$

Theoretical error can be experimentally constrained by both :

1. a precise determination of g_2 from $\mathrm{P_T(ee)}$ (run I) or from $\Delta\Phi(\mathrm{ee})$ (run II)
2. stringent constraints on the pdf (asymmetry measurement)