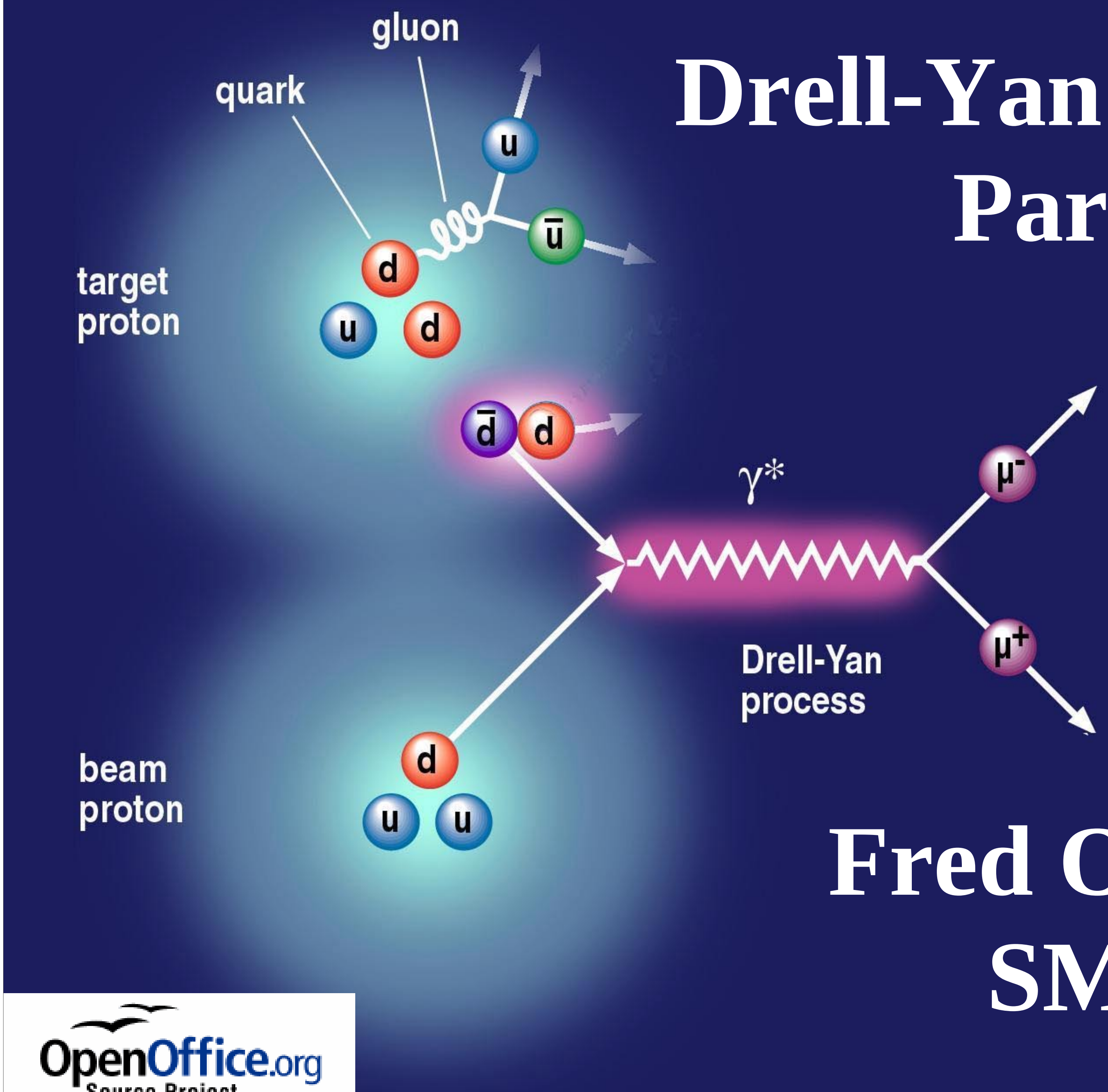
Drell-Yan Process: Part I



Fred Olness

SMU

Part I: Drell-Yan Process

History:

Discovery of J/ψ, Upsilon, W/Z, and “New Physics” ???

Calculation of *q q* $\rightarrow \mu^+\mu^-$ in the Parton Model

Scaling form of the cross section

Rapidity, longitudinal momentum, and x_F

Comparison with data:

NLO QCD corrections essential (the K-factor)

σ(pd)/σ(pp) important for d-bar/ubar

W Rapidity Asymmetry important for slope of d/u at large x

Where are we going?

P_T Distribution

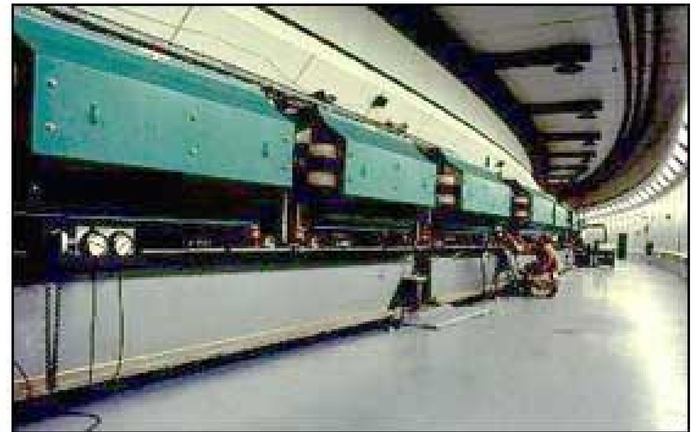
W-mass measurement

Resummation of soft gluons

Historical Background

Our story begins in the late 1960's at CERN

Brookhaven National Lab
Alternating Gradient Synchrotron

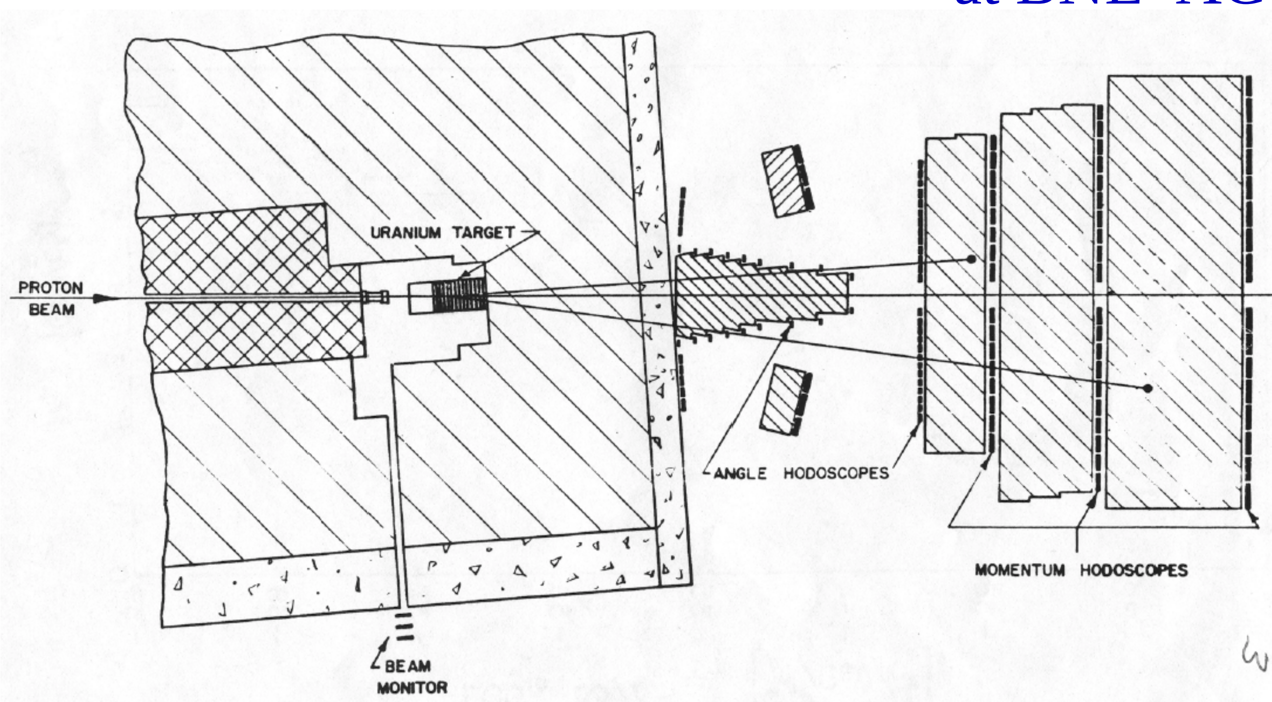


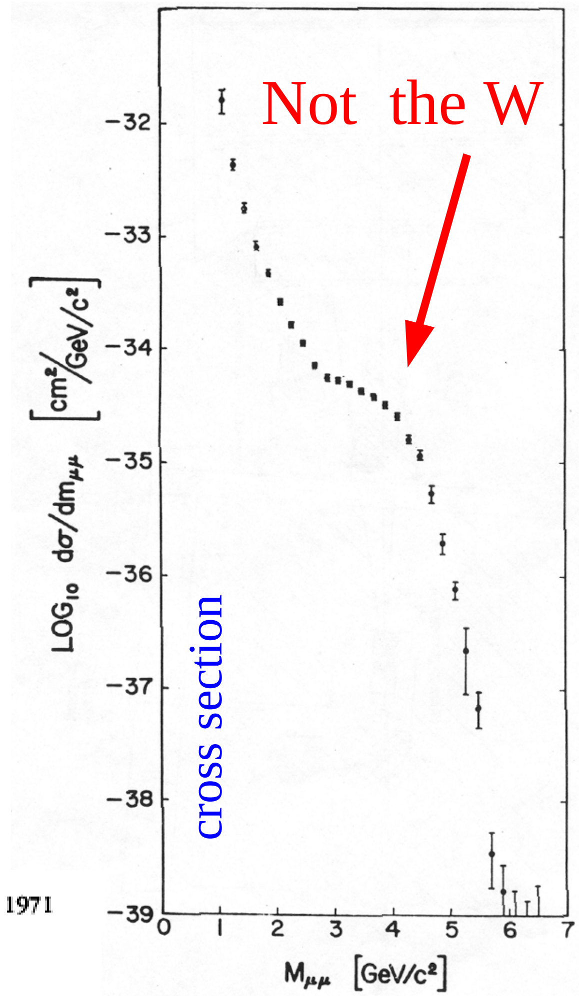
An Early Experiment:

The Goal: $p + N \rightarrow W + X$

They found: $p + N \rightarrow \mu^+ \mu^- + X$

at BNL AGS





$M_{\mu\mu}$ GeV

VOLUME 27, NUMBER 11 PHYSICAL REVIEW LETTERS 13 SEPTEMBER 1971

Production of Intermediate Bosons in Strong Interactions*

L. M. Lederman and B. G. Pope†
Columbia University, New York, New York 10533

(Received 14 June 1971)

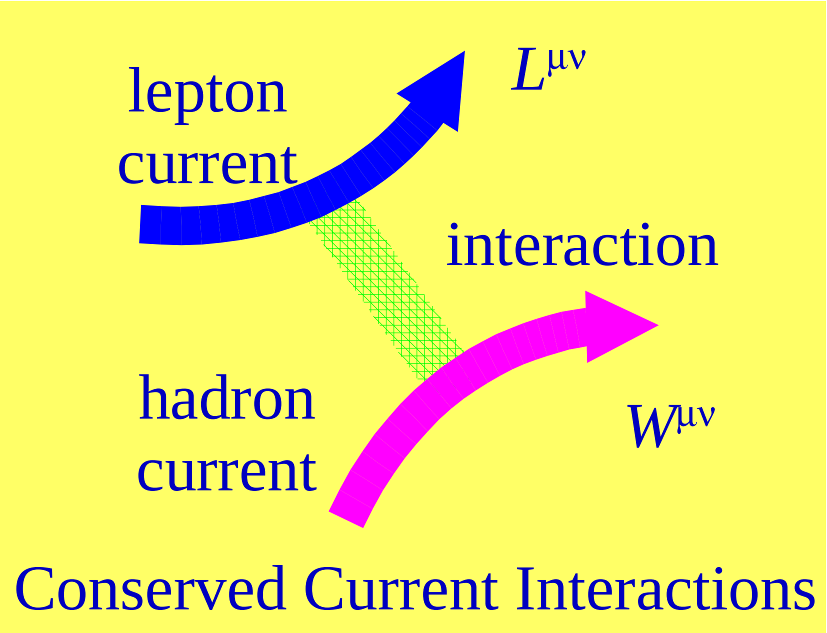
Several searches for the weak intermediate boson (W) have been carried out using the reaction

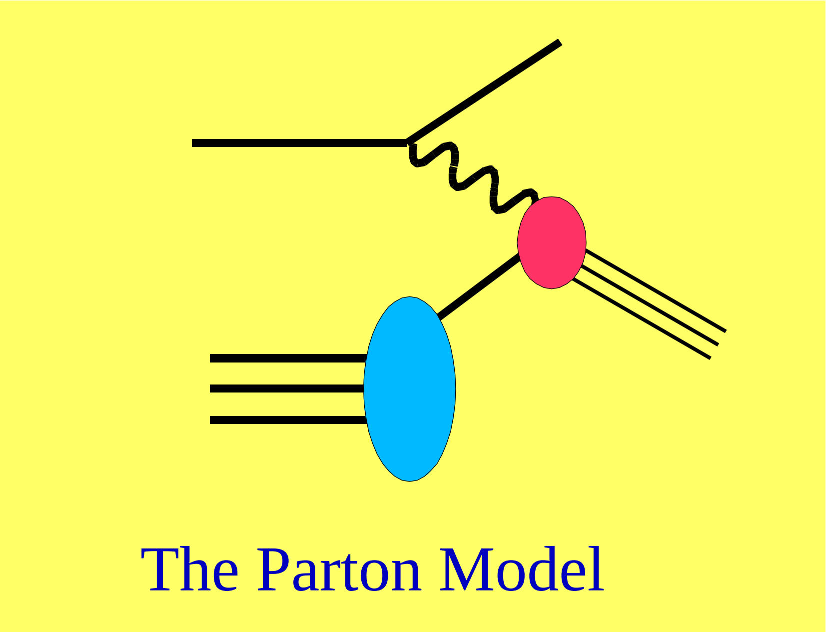
$$p + Z \rightarrow W + \text{anything}, \qquad (1)$$

with the decay of the W into muons as the signature.[1,2] Failure to observe a muon signal from any

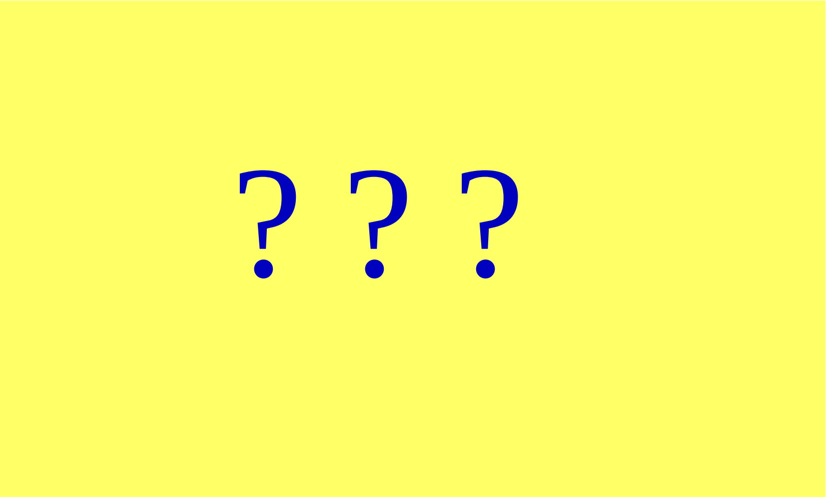
What is the explanation???

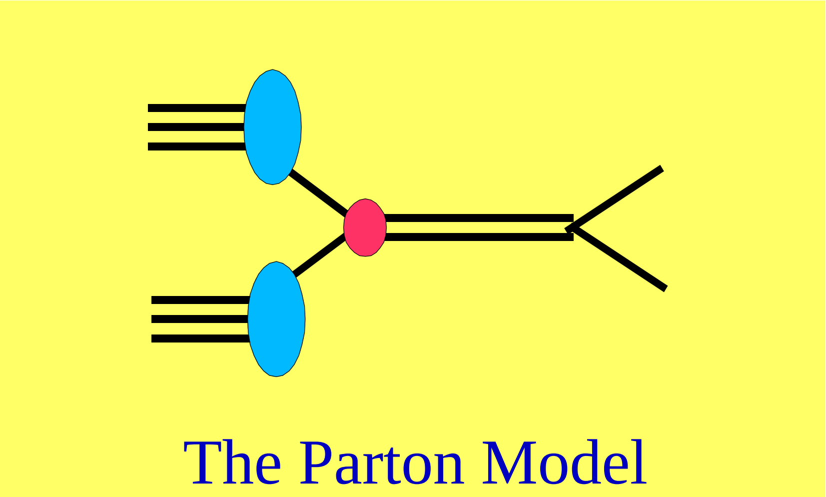
In DIS, we have two choices for an interpretation:





What about Drell-Yan???

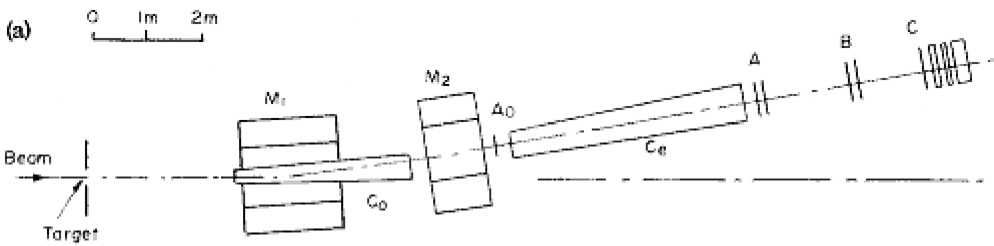




Discovery of the J/Psi Particle

The Process: p + Be $\rightarrow$ $e^+ e^-$ X

very narrow width
$\Rightarrow$ long lifetime



at BNL AGS

VOLUME 33, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECE

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen
J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technolog
Cambridge, Massachusetts 02139

and

Y. Y. Lee
Brookhaven National Laboratory, Upton, New York 11973

(Received 12 November 1974)

We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \mathrm{Be} \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

This experiment is part of a large program to

daily with a thin Al foil. The beam spot

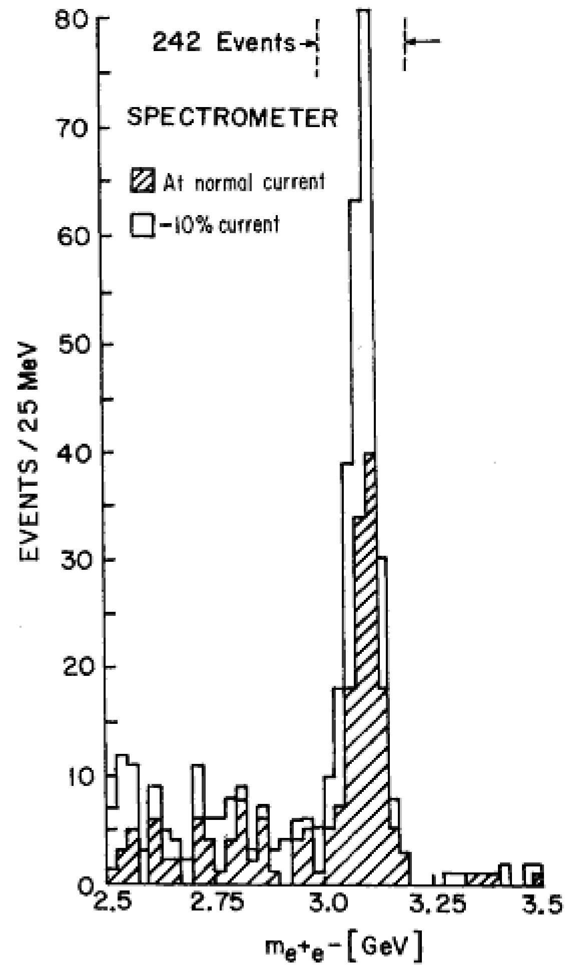
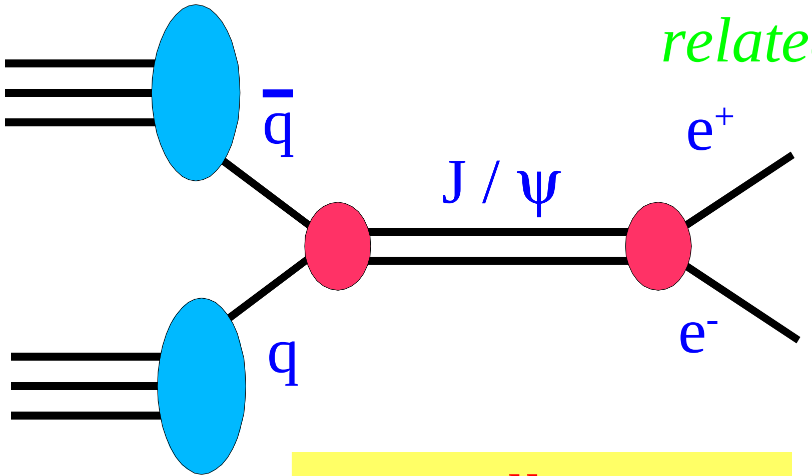
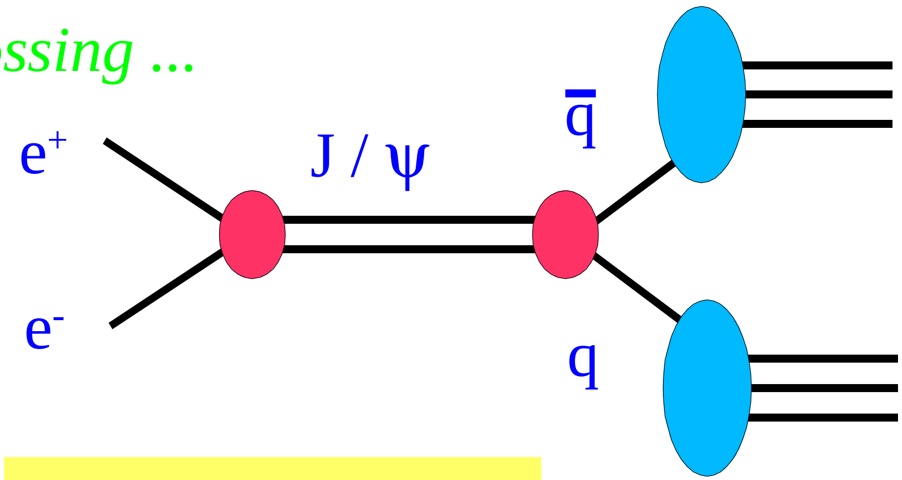


FIG. 2. Mass spectrum showing the existence of J. Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

The November Revolution

related by crossing ...





Drell-Yan
Brookhaven AGS

e^+e^- Production
SLAC SPEAR
Frascati ADONE

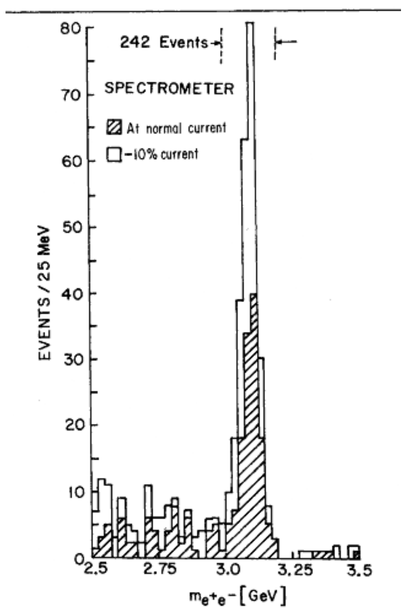
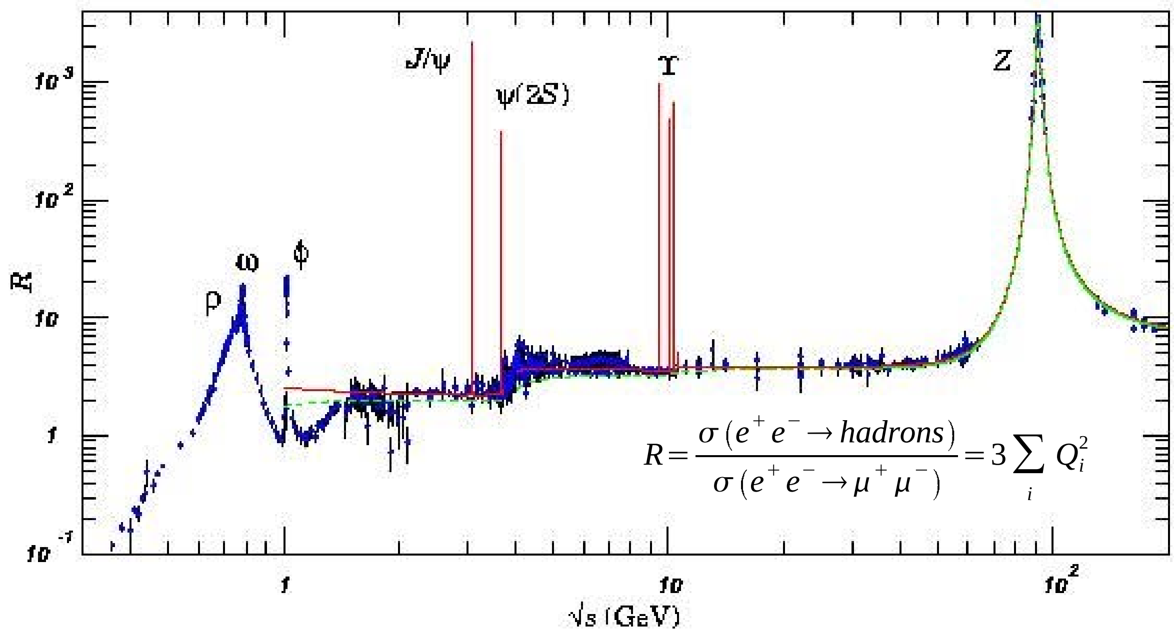


FIG. 2. Mass spectrum showing the existence of *J*. Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.



More Discoveries with Drell-Yan

1974: The J/Psi (charm) discovery

$p+N \to J/\psi$

... *1976 Nobel Prize*

1977: The Upsilon (bottom) discovery

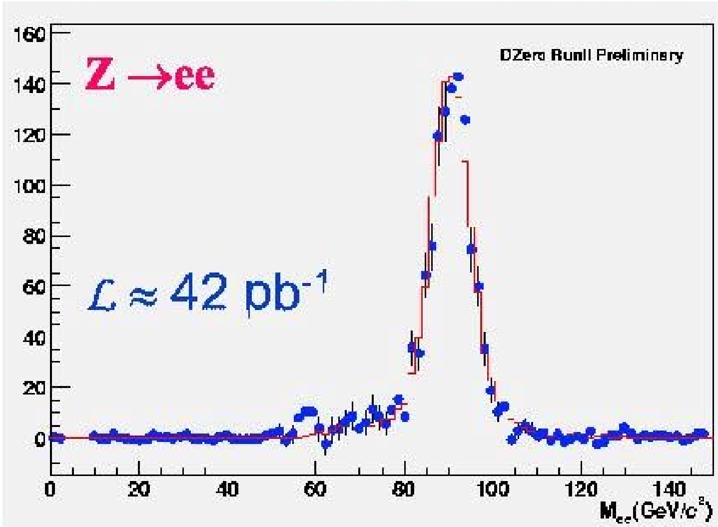
$p+N \to \Upsilon$

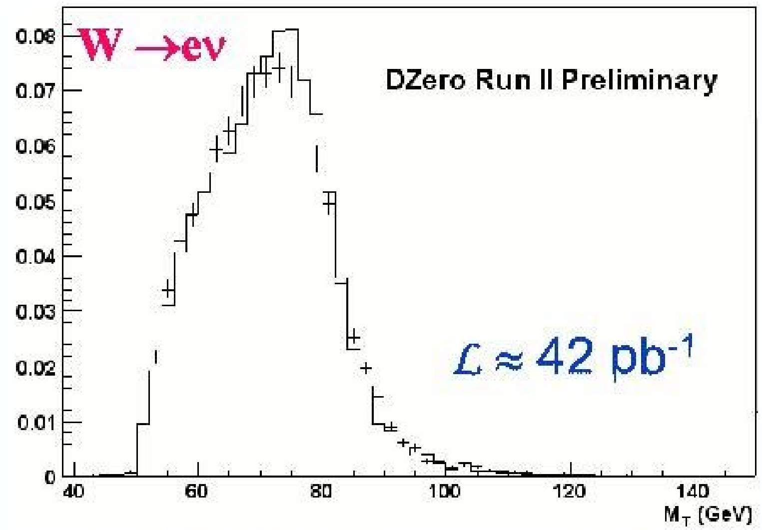
1983: The W and Z discovery

$p + \bar{p} \to W/Z$

... *1984 Nobel Prize*

W/Z in the electron channel





- 1139 Z→ee candidates
  - $|\eta^e|<1.1$, $E_T>25$ GeV, no track match required
- $\varepsilon(Z)\approx 8\%$, bkgd ~ 18%

- 27370 W→eν candidates
  - $|\eta^e|<1.1$, E_T & $\not{E}_T$ >25 GeV
- $\varepsilon(W)\approx 16\%$
- bkgd ~ 3% QCD, ~1.5% τ

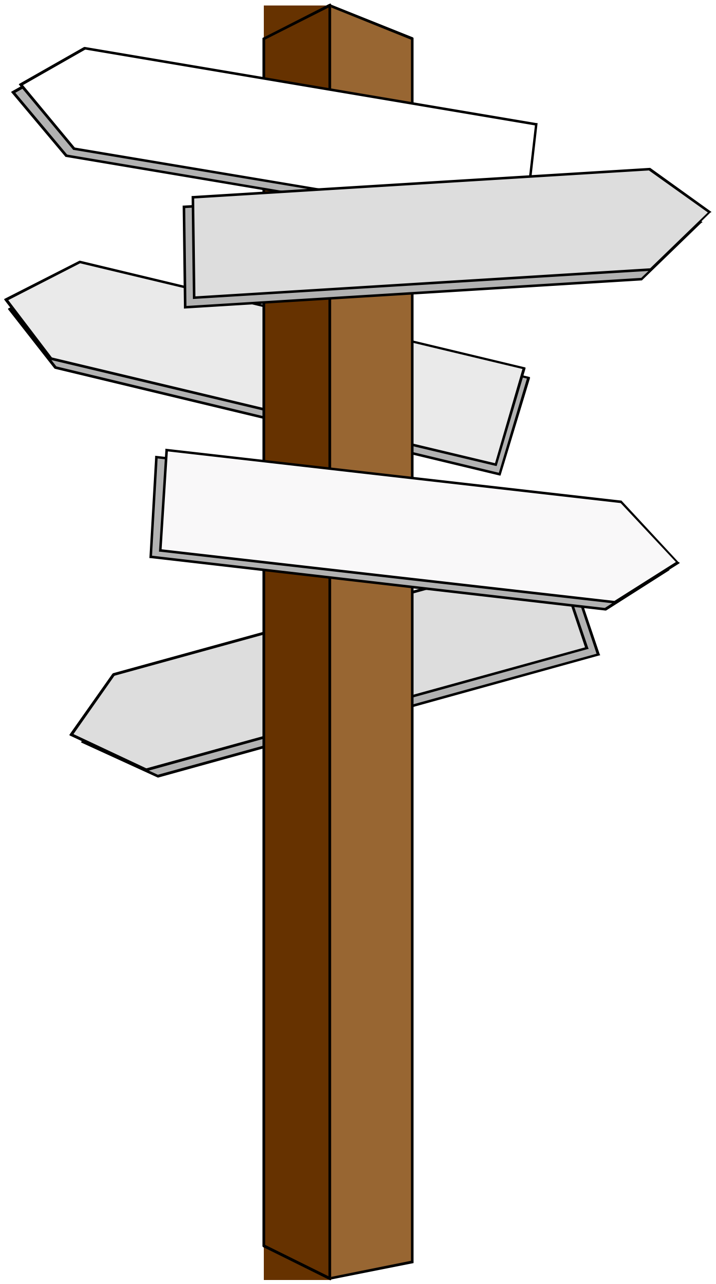
$$\sigma(W)Br(W \rightarrow e\nu) = 3054 \pm 100(N_W) \pm 86(sys) \pm 305(lumi) \quad pb$$

$$\sigma(Z)Br(Z \rightarrow ee) = 294 \pm 11(N_Z) \pm 8(sys) \pm 29(lumi) \quad pb$$

Where do we find

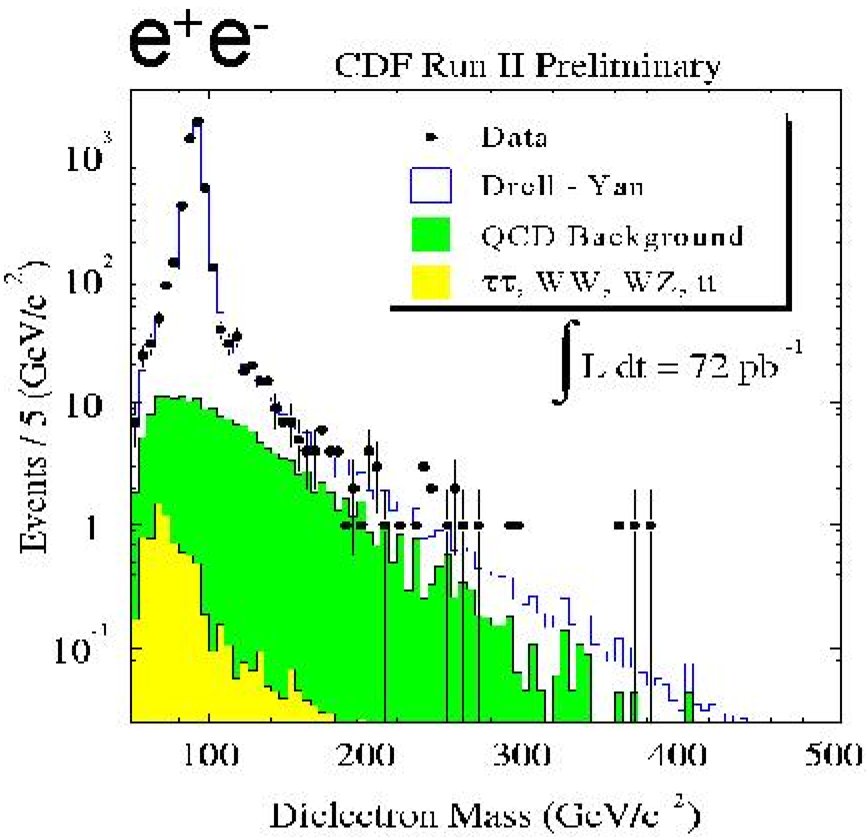
New Physics??

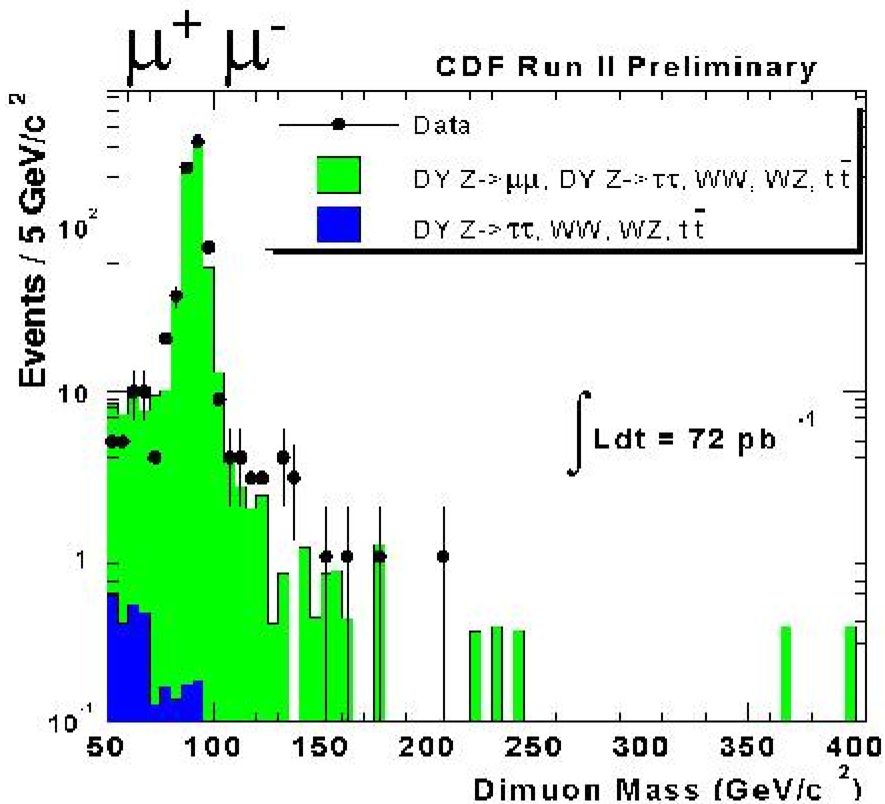
- New Higgs Bosons
- New W' or Z'
- SUSY
- ... unknown...



Search in Drell-Yan Spectrum

- High Mass Dileptons
  - electrons & muons used
- Sensitive to Z' and Randall-Sundrum Graviton
- No excess observed



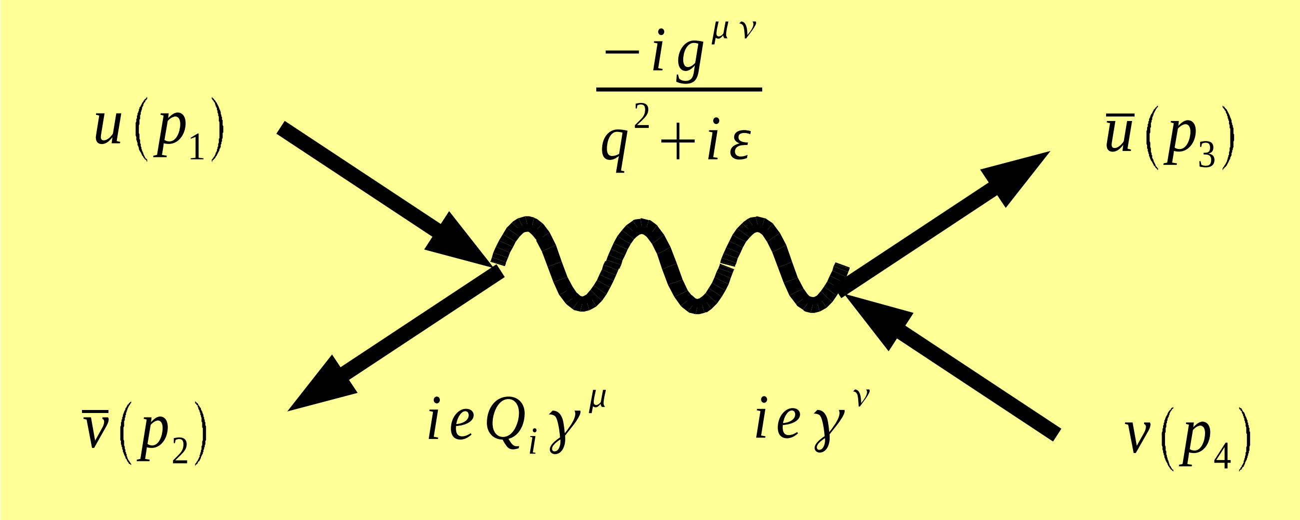


Let's

Calculate

First, we'll compute the partonic $\hat{\sigma}$ in the partonic CMS

Let's compute the Born process: $q+\bar{q}\rightarrow e^{+}+e^{-}$



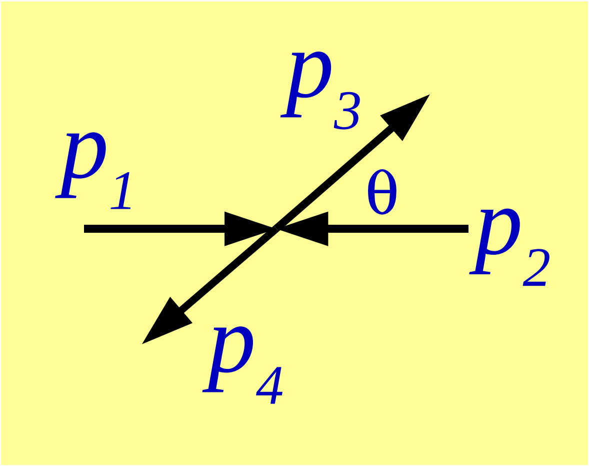
Gathering factors and contracting $g^{\mu\nu}$, we obtain:

$$-i M = i Q_i \frac{e^2}{q^2}\left\{\bar{v}(p_2)\gamma^{\mu} u(p_1)\right\}\ \left\{\bar{u}(p_3)\gamma_{\mu} v(p_4)\right\}$$

Squaring, and averaging over spin and color, ...

$$\overline{|M|^2}=\left(\frac{1}{2}\right)^2 3\left(\frac{1}{3}\right)^2 Q_i^2\,\frac{e^4}{q^4}\,Tr\left[\not{p}_2\gamma^{\mu}\not{p}_1\gamma^{\nu}\right]\ Tr\left[\not{p}_3\gamma_{\mu}\not{p}_4\gamma_{\nu}\right]$$

Let's work out some parton level kinematics



$$p_1^2 = p_2^2 = p_3^2 = p_4^2 = 0$$

$$p_1 = \frac{\sqrt{\hat{s}}}{2}(1,0,0,+1)$$

$$p_2 = \frac{\sqrt{\hat{s}}}{2}(1,0,0,-1)$$

$$p_3 = \frac{\sqrt{\hat{s}}}{2}\left(1,+\sin(\theta),0,+\cos(\theta)\right)$$

$$p_4 = \frac{\sqrt{\hat{s}}}{2}\left(1,-\sin(\theta),0,-\cos(\theta)\right)$$

Defining the Mandelstam variables ...

$$\hat{s} = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

$$\hat{t} = (p_1 - p_3)^2 = (p_2 - p_4)^2$$

$$\hat{u} = (p_1 - p_4)^2 = (p_2 - p_3)^2$$

$$\hat{t} = -\frac{\hat{s}}{2}\left(1 - \cos(\theta)\right)$$

$$\hat{u} = -\frac{\hat{s}}{2}\left(1 + \cos(\theta)\right)$$

We'll now compute the matrix element M

Manipulating the traces, we find ...

$$Tr\left[\not{p}_2\gamma^{\mu}\not{p}_1\gamma^{\nu}\right]\ Tr\left[\not{p}_3\gamma_{\mu}\not{p}_4\gamma_{\nu}\right]$$
$$=4\left[p_1^{\mu}p_2^{\nu}+p_2^{\mu}p_1^{\nu}-g^{\mu\nu}(p_1\cdot p_2)\right]\times 4\left[p_3^{\mu}p_4^{\nu}+p_4^{\mu}p_3^{\nu}-g^{\mu\nu}(p_3\cdot p_4)\right]$$
$$=2^5\left[(p_1\cdot p_3)(p_2\cdot p_4)+(p_1\cdot p_4)(p_2\cdot p_3)\right]$$
$$=2^3\left[\hat{t}^2+\hat{u}^2\right]$$

Where we have used:

$$p_1^2=p_2^2=p_3^2=p_4^2=0$$

$$\hat{s}=2(p_1\cdot p_2)=2(p_3\cdot p_4)$$
$$\hat{t}=2(p_1\cdot p_3)=2(p_2\cdot p_4)$$
$$\hat{u}=2(p_1\cdot p_4)=2(p_2\cdot p_3)$$

Putting all the pieces together, we have:

$$\overline{|M|^2}=Q_i^2\,\alpha^2\,\frac{2^5\pi^2}{3}\left(\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right)$$

with

$$q^2=(p_1+p_2)^2=\hat{s}$$
$$\alpha=\frac{e^2}{4\pi}$$

... and put it together to find the cross section

$$d\hat{\sigma} \simeq \frac{1}{2\hat{s}} \overline{|M|^2} \, d\Gamma$$

In the partonic CMS system

$$d\Gamma = \frac{d^3 p_3}{(2\pi)^3 2E_3} \frac{d^3 p_4}{(2\pi)^3 2E_4} (2\pi)^4 \delta(p_1 + p_2 - p_3 - p_4) = \frac{d\cos(\theta)}{16\pi}$$

Recall,

$$\hat{t} = \frac{-\hat{s}}{2}\left(1 - \cos(\theta)\right) \quad and \quad \hat{u} = \frac{-\hat{s}}{2}\left(1 + \cos(\theta)\right)$$

so, the differential cross section is ...

$$\frac{d\hat{\sigma}}{d\cos(\theta)} = Q_i^2 \alpha^2 \frac{\pi}{6} \frac{1}{\hat{s}} \left(1 + \cos^2(\theta)\right)$$

and the total cross section is ...

$$\hat{\sigma} = Q_i^2 \alpha^2 \frac{\pi}{6} \frac{1}{\hat{s}} \int_{-1}^{1} d\cos(\theta) \left(1 + \cos^2(\theta)\right) = \frac{4\pi\alpha^2}{9\hat{s}} Q_i^2 \equiv \hat{\sigma}_0$$

Some Homework:

#1) Show:

$$\frac{d^3p}{(2\pi)^3 2E} = \frac{d^4p}{(2\pi)^4} (2\pi)\, \delta^+(p^2 - m^2)$$

This relation is often useful as the RHS is manifestly Lorentz invariant

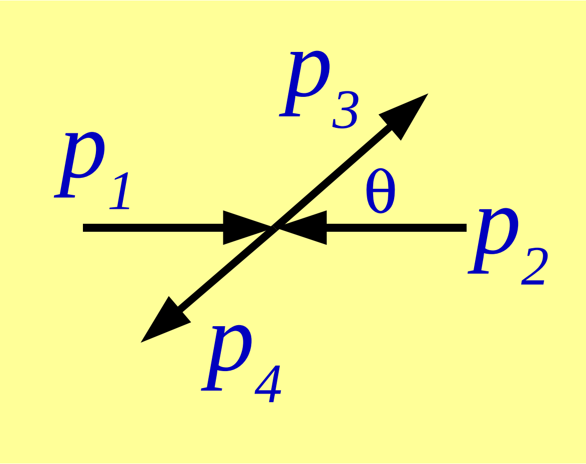
#2) Show that the 2-body phase space can be expressed as:

$$d\Gamma = \frac{d^3p_3}{(2\pi)^3 2E_3} \frac{d^3p_4}{(2\pi)^3 2E_4} (2\pi)^4\, \delta(p_1 + p_2 - p_3 - p_4) = \frac{d\cos(\theta)}{16\pi}$$

Note, we are working with massless partons, and θ *is in the partonic CMS frame*

Some More Homework:

#3) Let's work out the general 2→2 kinematics for general masses.



a) Start with the incoming particles.
Show that these can be written in the general form:

$$p_1 = (E_1, 0, 0, +p) \qquad p_1^2 = m_1^2$$
$$p_2 = (E_2, 0, 0, -p) \qquad p_2^2 = m_2^2$$

... with the following definitions:

$$E_{1,2} = \frac{\hat{s} \pm m_1^2 \mp m_2^2}{2\sqrt{\hat{s}}} \qquad p = \frac{\Delta(\hat{s}, m_1^2, m_2^2)}{2\sqrt{\hat{s}}}$$

$$\Delta(a, b, c) = \sqrt{a^2 + b^2 + c^2 - 2(ab + bc + ca)}$$

Note that Δ(a,b,c) is symmetric with respect to its arguments, and involves the only invariants of the initial state: s, m_1^2, m_2^2.

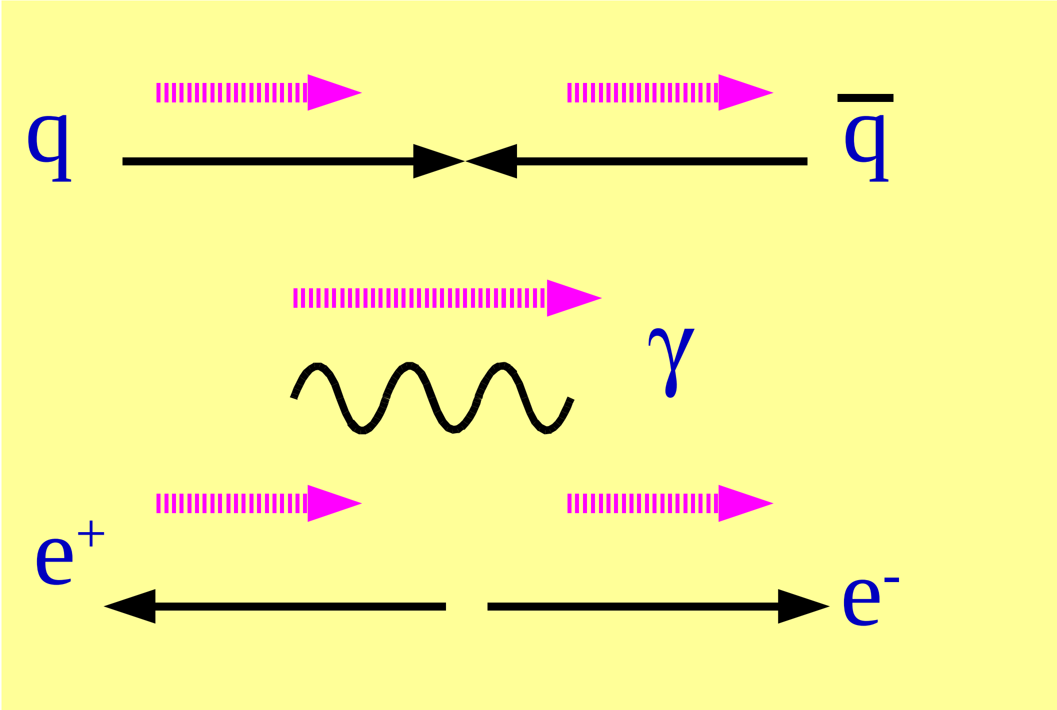
b) Next, compute the general form for the final state particles, p_3 and p_4. Do this by first aligning p_3 and p_4 along the z-axis (as p_1 and p_2 are), and then rotate about the y-axis by angle θ.

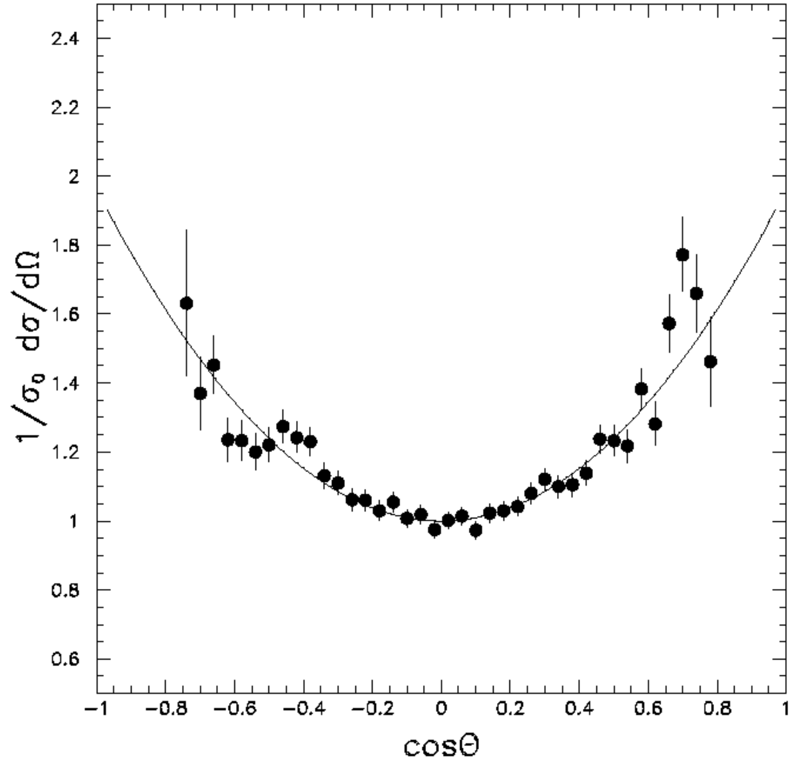
What does the angular dependence tell us?

Observe, the angular dependence: $q + \bar{q} \rightarrow e^+ + e^-$

$$\frac{d\hat{\sigma}}{d\cos(\theta)} = Q_i^2 \alpha^2 \frac{\pi}{6} \frac{1}{\hat{s}} \left(1 + \cos^2(\theta)\right)$$

Characteristic of scattering of spin ½ constitutients by a spin 1 vector



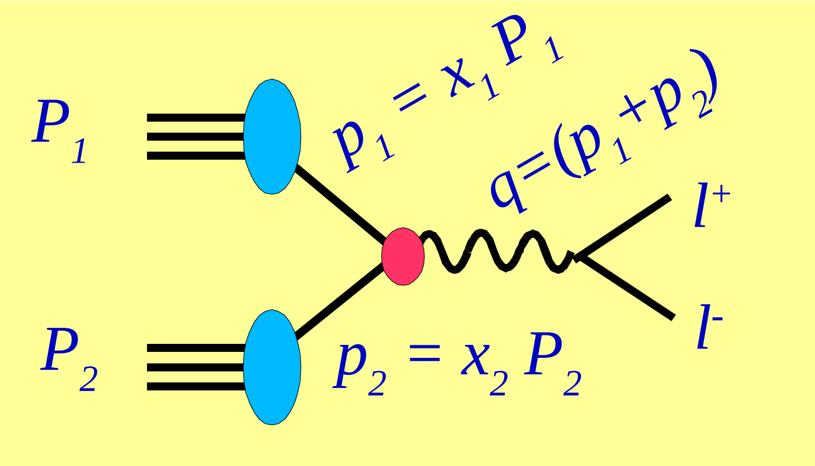


Note, for the photon, the mirror image of the above is also valid; hence the symmetric distribution.

The W has V-A couplings, so we'll find: $(1+\cos\theta)^2$

Next, we'll compute the hadronic CMS

Kinematics in the Hadronic Frame



$$P_1 = \frac{\sqrt{s}}{2}(1,0,0,+1) \qquad P_1^2 = 0$$

$$P_2 = \frac{\sqrt{s}}{2}(1,0,0,-1) \qquad P_2^2 = 0$$

$$s = (P_1 + P_2)^2 = \frac{\hat{s}}{x_1 x_2} = \frac{\hat{s}}{\tau}$$

Therefore

$$\tau = x_1 x_2 = \frac{\hat{s}}{s} \equiv \frac{Q^2}{s}$$

Fractional energy² between partonic and hadronic system

$$\frac{d\sigma}{dQ^2} = \sum_{q,\bar{q}} \int dx_1 \int dx_2 \left\{ q(x_1)\bar{q}(x_2) + \bar{q}(x_1) q(x_2) \right\} \hat{\sigma}_0 \, \delta(Q^2 - \hat{s})$$

Hadronic cross section

Parton distribution functions

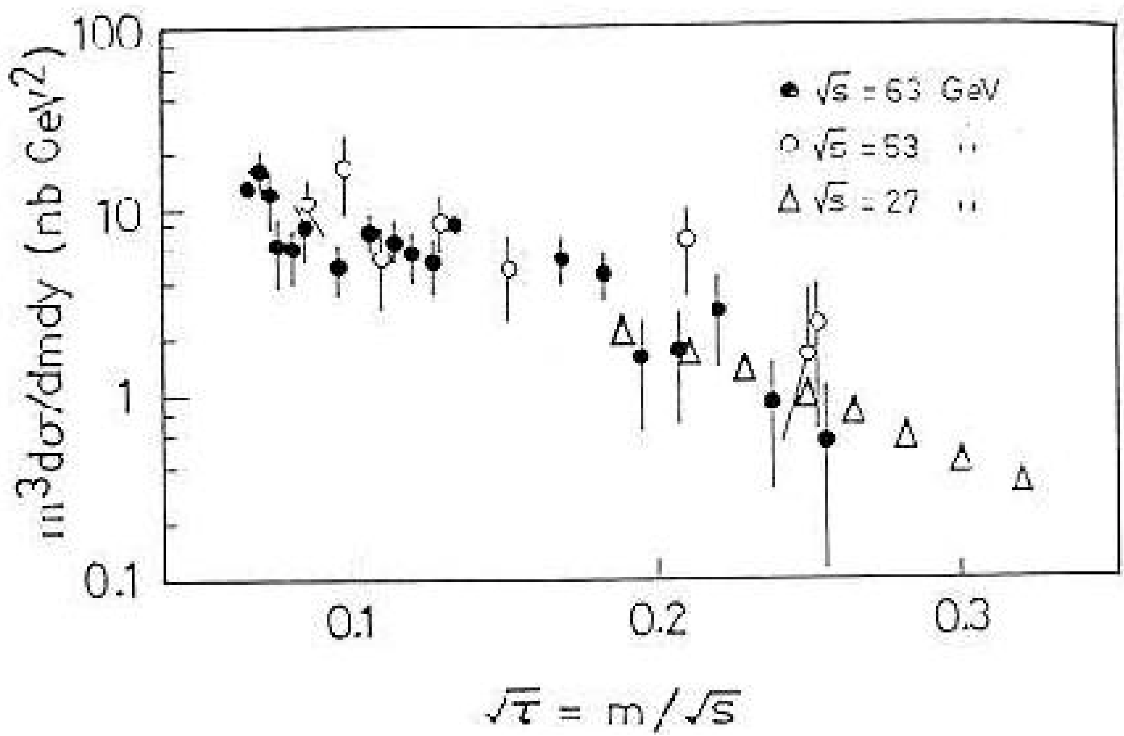
Partonic cross section

Scaling form of the Drell-Yan Cross Section

Using: $\hat{\sigma}_0 = \dfrac{4\pi\alpha^2}{9\hat{s}} Q_i^2$ and $\delta(Q^2 - \hat{s}) = \dfrac{1}{s\,x_1}\,\delta\left(x_2 - \dfrac{\tau}{x_1}\right)$

we can write the cross section in the scaling form:

$$Q^4 \frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2}{9} \sum_{q,\bar{q}} Q_i^2 \int_\tau^1 \frac{dx_1}{x_1}\,\tau\,\{q(x_1)\bar{q}(\tau/x_1) + \bar{q}(x_1)q(\tau/x_1)\}$$



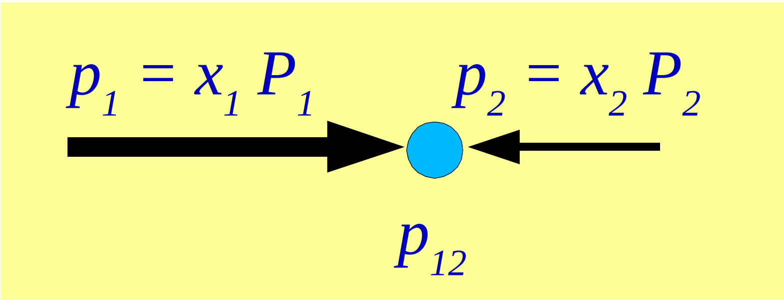
Notice the RHS is a function of only τ, not Q.

This quantity should lie on a universal scaling curve.

Cf., DIS case, & scattering of point-like constituents

Longitudinal Momentum Distributions

Partonic CMS has longitudinal momentum w.r.t. the hadron frame



$$p_{12} = (p_1 + p_2) = (E_{12}, 0, 0, p_L)$$

$$E_{12} = \frac{\sqrt{s}}{2}(x_1 + x_2)$$

$$p_L = \frac{\sqrt{s}}{2}(x_1 - x_2) \equiv \frac{\sqrt{s}}{2} x_F$$

x_F is a measure of the longitudinal momentum

The rapidity is defined as:

$$y = \frac{1}{2}\ln\left\{\frac{E_{12}+p_L}{E_{12}-p_L}\right\} = \frac{1}{2}\ln\left\{\frac{x_1}{x_2}\right\}$$

$$x_{1,2} = \sqrt{\tau}\, e^{\pm y}$$

$$d x_1 d x_2 = d\tau\, dy$$

$$d Q^2 dx_F = dy\, d\tau\; s\; \sqrt{x_F^2 + 4\tau}$$

$$\frac{d\sigma}{dQ^2\, dx_F} = \frac{4\pi\alpha^2}{9Q^4} \frac{1}{\sqrt{x_F^2+4\tau}}\, \tau \sum_{q,\bar{q}} Q_i^2 \left\{ q(x_1)\bar{q}(\tau/x_1) + \bar{q}(x_1) q(\tau/x_1) \right\}$$

So, we're ready to compare with data

(or so we think...)

Let's compare data and theory

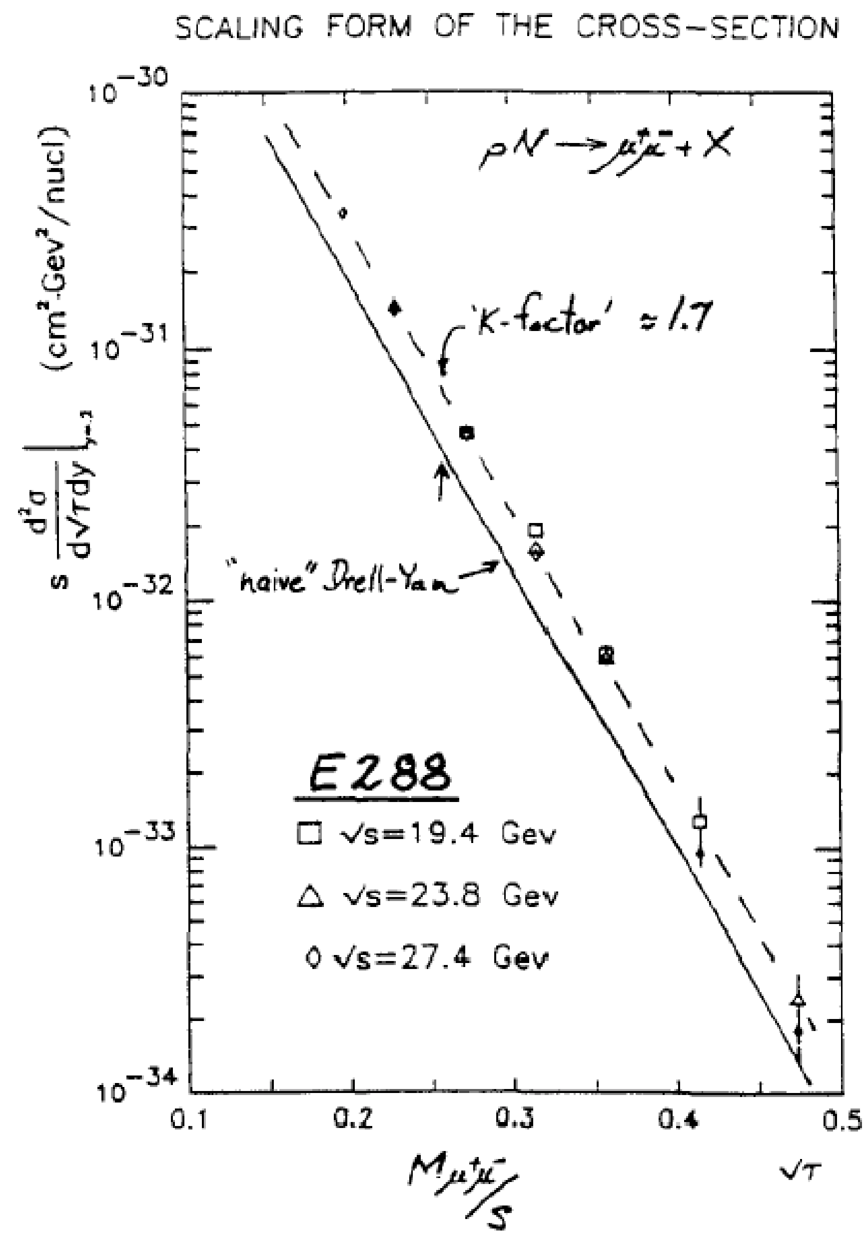


Table 1.2: Experimental K-factors.

Experiment		Interaction	Beam Momentum	$K = \sigma_{\text{meas.}}/\sigma_{\text{DY}}$
E288	[Kap 78]	$p\ Pt$	300/400 GeV	~ 1.7
WA39	[Cor 80]	$\pi^{\pm}\ W$	39.5 GeV	~ 2.5
E439	[Smi 81]	$p\ W$	400 GeV	1.6 ± 0.3
NA3	[Bad 83]	$(\bar{p}$ - $p)Pt$	150 GeV	2.3 ± 0.4
		$p\ Pt$	400 GeV	$3.1 \pm 0.5 \pm 0.3$
		$\pi^{\pm}\ Pt$	200 GeV	2.3 ± 0.5
		$\pi^{-}\ Pt$	150 GeV	2.49 ± 0.37
		$\pi^{-}\ Pt$	280 GeV	2.22 ± 0.33
NA10	[Bet 85]	$\pi^{-}\ W$	194 GeV	$\sim 2.77 \pm 0.12$
E326	[Gre 85]	$\pi^{-}\ W$	225 GeV	$2.70 \pm 0.08 \pm 0.40$
E537	[Ana 88]	$\bar{p}\ W$	125 GeV	$2.45 \pm 0.12 \pm 0.20$
E615	[Con 89]	$\pi^{-}\ W$	252 GeV	1.78 ± 0.06

J. C. Webb, Measurement of continuum dimuon production in 800-GeV/c proton nucleon collisions, arXiv:hep-ex/0301031.

Oooops,

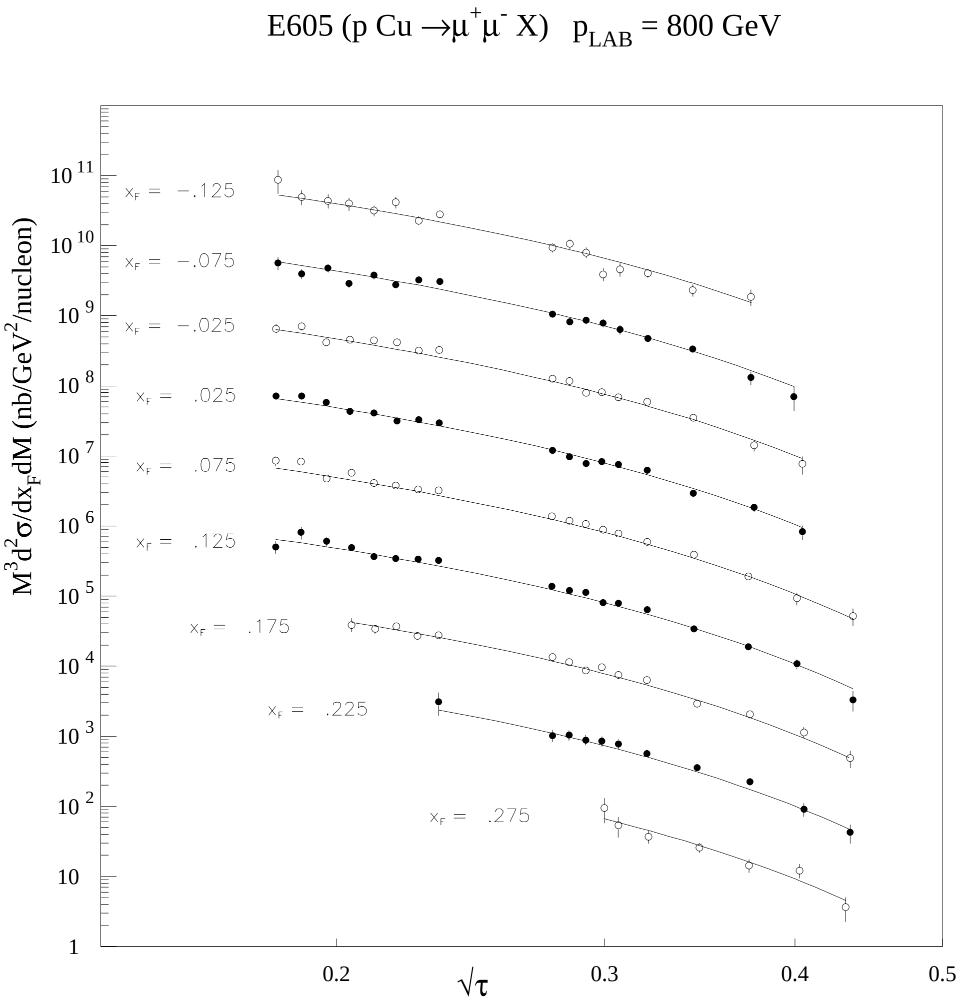
we need the

QCD corrections

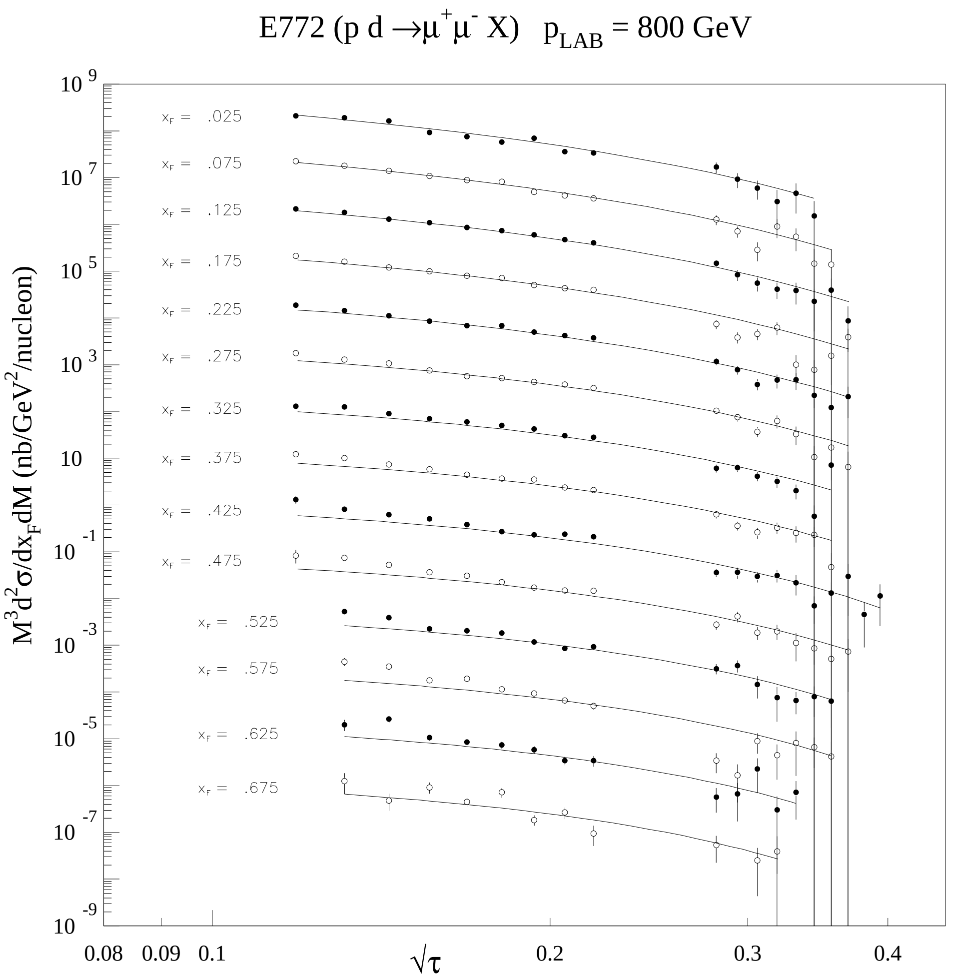
$$K = 1 + \frac{2\pi\alpha_s}{3}(\ldots) + \ldots = ?= e^{2\pi\alpha_s/3}$$

Excellent agreement between data and theory

p + Cu at 800 GeV



p + d at 800 GeV



pp & pN processes sensitive to anti-quark distributions

A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne,
Eur. Phys. J. C23, 73 (2002);
Eur. Phys. J. C14, 133 (2000);
Eur. Phys. J. C4, 463 (1998)

Drell-Yan can give us unique and detailed information about PDF's.

We'll now examine two examples:

1) Ratio of pp/pd cross section

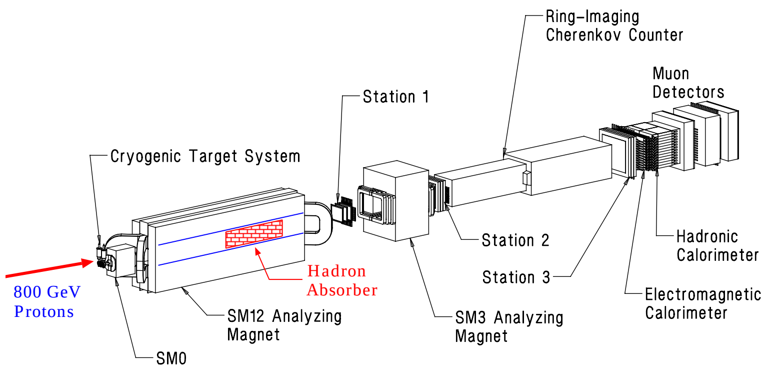
2) W Rapidity Asymmetry

A measurement of $\bar{d}(x)/\bar{u}(x)$

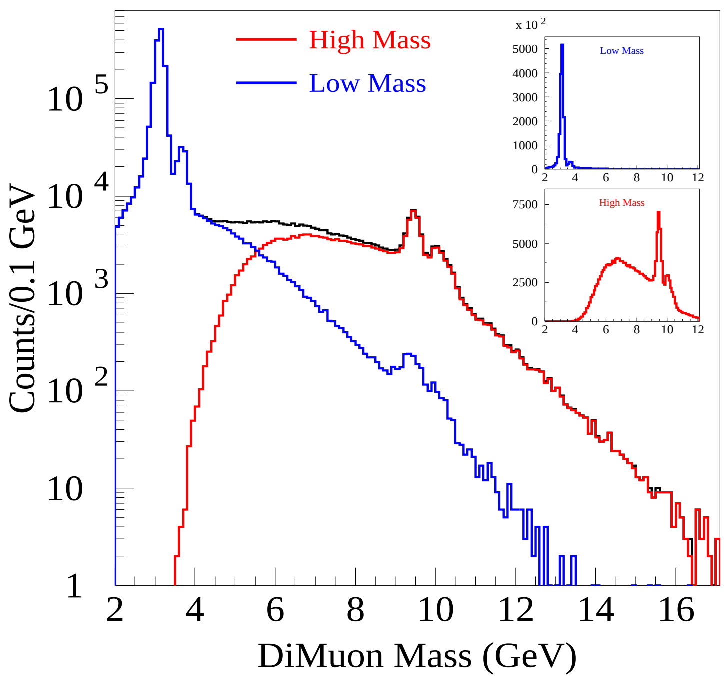
Antiquark asymmetry in the Nucleon Sea

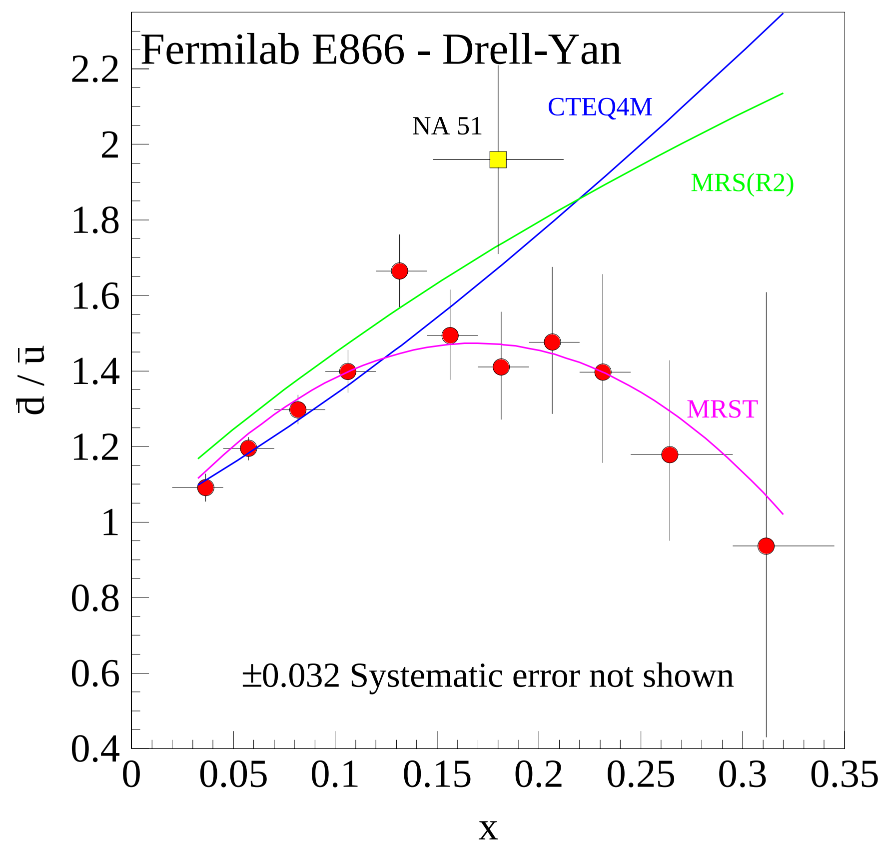
FNAL E866/NuSea

ACU, ANL, FNAL, GSU, IIT, LANL, LSU, NMSU, UNM, ORNL, TAMU, Valpo.



800 GeV $p + p$ and $p + d \rightarrow \mu^+\mu^- X$





Cross section ratio of pp *vs.* pd

Obtain the neutron PDF via isospin symmetry:

$$u \Leftrightarrow d$$
$$\bar{u} \Leftrightarrow \bar{d}$$

In the limit $x_1 >> x_2$:

$$\sigma^{pp} \propto \frac{4}{9} u(x_1)\bar{u}(x_2) + \frac{1}{9} d(x_1)\bar{d}(x_2)$$

$$\sigma^{pn} \propto \frac{4}{9} u(x_1)\bar{d}(x_2) + \frac{1}{9} d(x_1)\bar{u}(x_2)$$

For the ratio we have:

$$\frac{\sigma^{pd}}{2\sigma^{pp}} \approx \frac{1}{2} \frac{\left(1 + \frac{1}{4}\frac{d_1}{u_1}\right)}{\left(1 + \frac{1}{4}\frac{d_1}{u_1}\frac{\bar{d}_2}{\bar{u}_2}\right)} \left(1 + \frac{\bar{d}_2}{\bar{u}_2}\right) \approx \frac{1}{2}\left(1 + \frac{\bar{d}_2}{\bar{u}_2}\right)$$

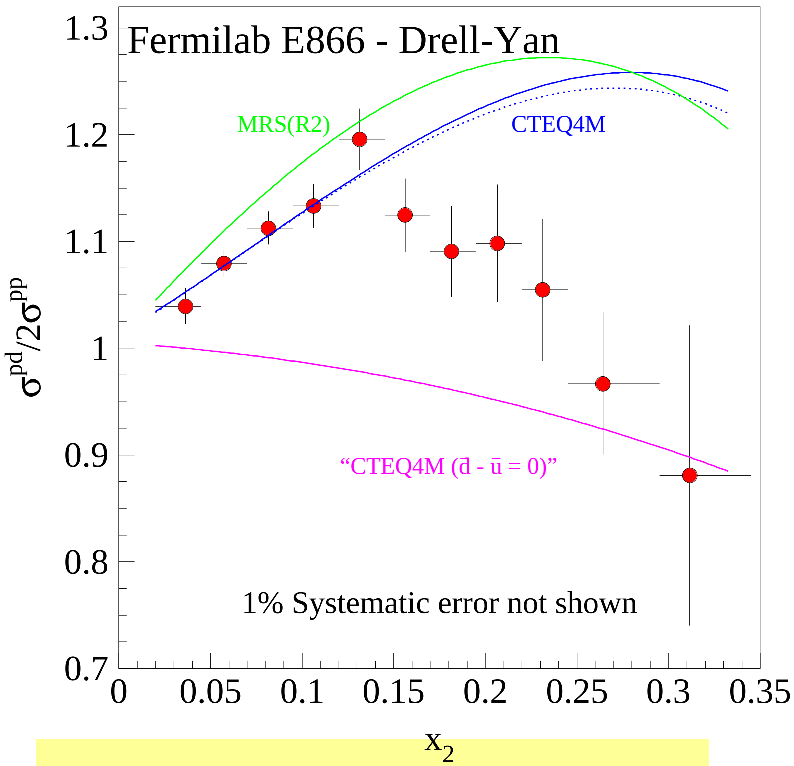
As promised, this provides information about the sea-quark distributions

$$\frac{\sigma^{pd}}{2\sigma^{pp}} \approx \frac{1}{2}\left(1 + \frac{\bar{d}_2}{\bar{u}_2}\right)$$

EXERCISE: Verify the above.

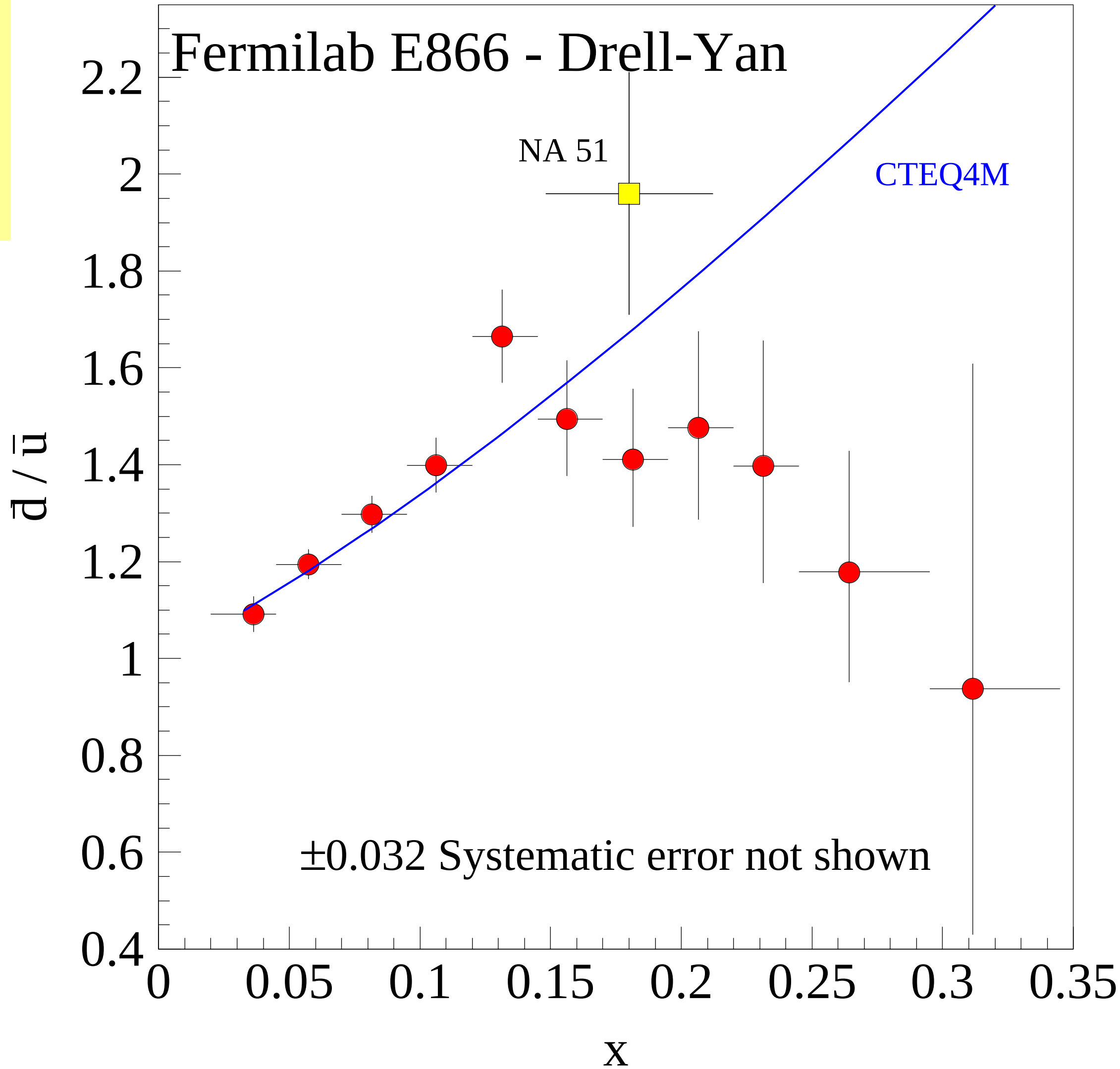
Does the theory match the data???

$$\frac{\sigma^{pd}}{2\sigma^{pp}} \approx \frac{1}{2}\left(1+\frac{\bar{d}_2}{\bar{u}_2}\right)$$



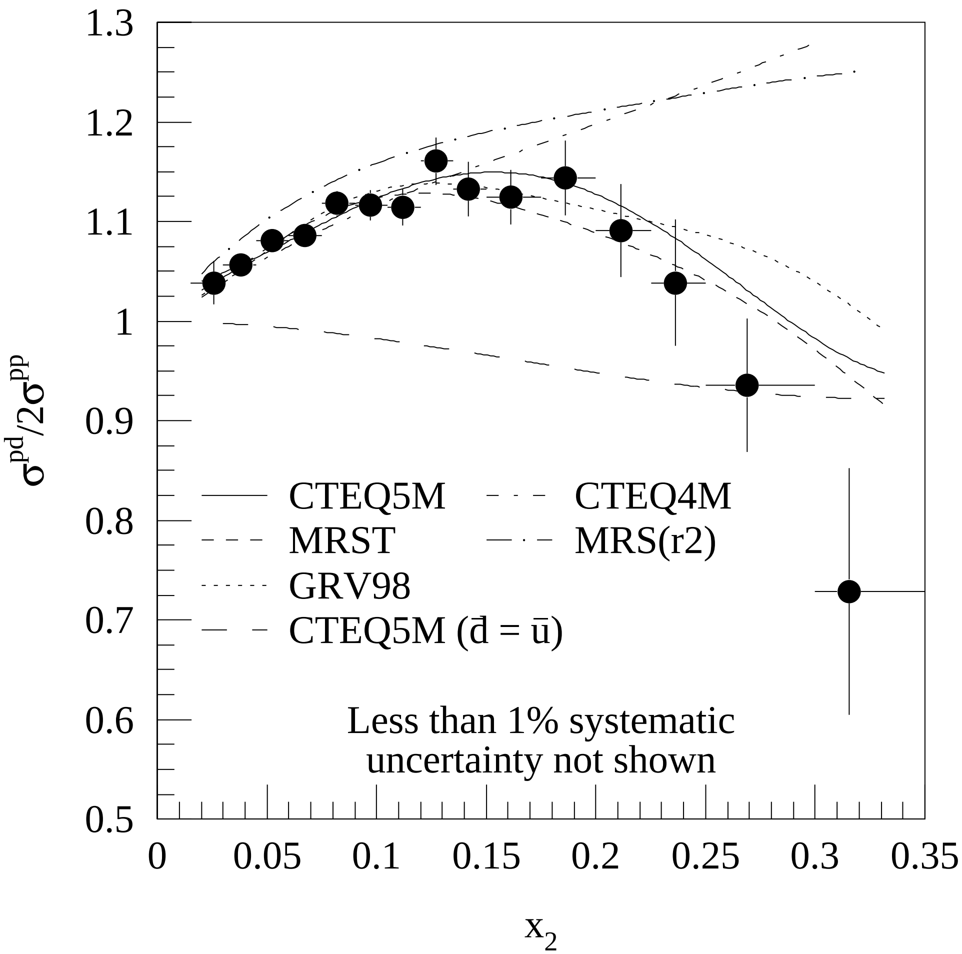
Implies R<1 for large x:

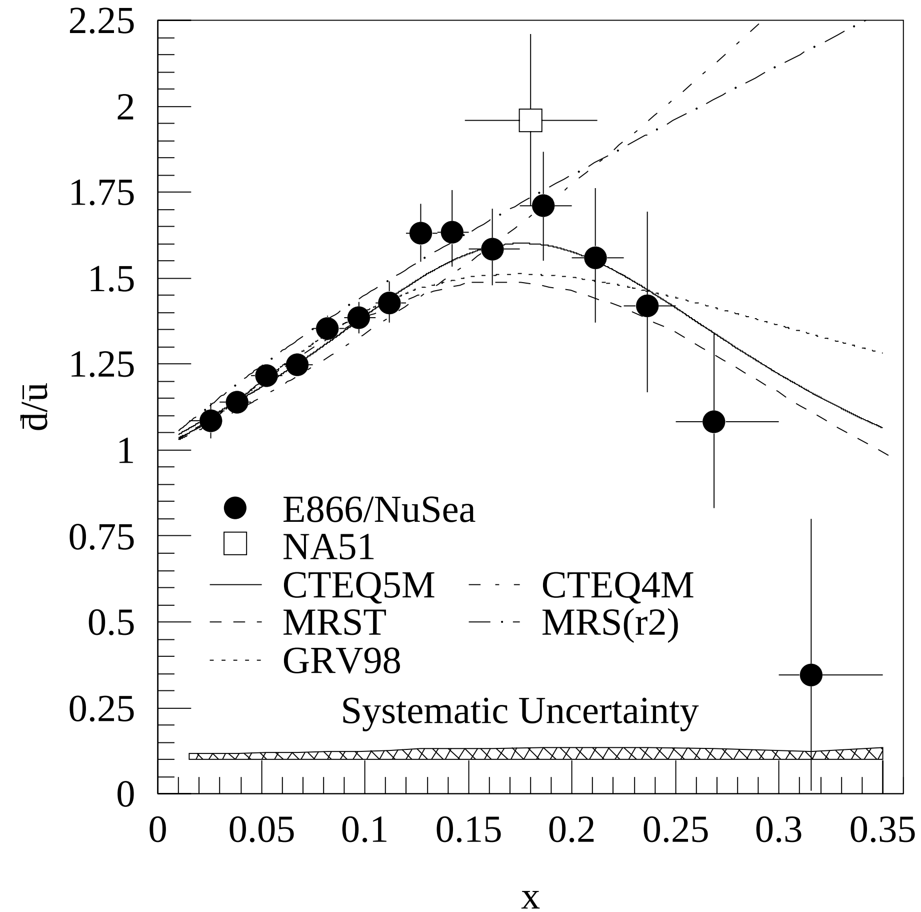
$$\bar{d} \ll \bar{u}$$



E.A. Hawker, et al. [FNAL E866/NuSea Collaboration], Measurement of the light antiquark flavor asymmetry in the nucleon sea, PRL 80, 3715 (1998)

E866 required significant changes in the hi-x sea distributions





With increased flexibility in the parameterization of the sea-quark distributions, good fits are obtained

E.A. Hawker, et al. [FNAL E866/NuSea Collaboration], Measurement of the light antiquark flavor asymmetry in the nucleon sea, PRL 80, 3715 (1998)

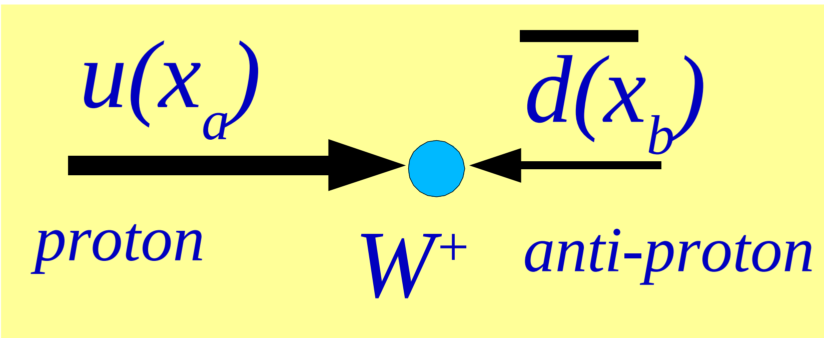
H. L. Lai, et al.} [CTEQ Collaboration], Global {QCD} analysis of parton structure of the nucleon: CTEQ5 parton distributions, EPJ C12, 375 (2000)

Next ...

2) W Rapidity Asymmetry

Where do the W's and Z's come from ???

$$\frac{d\sigma}{dy}(W^{\pm}) = \frac{2\pi}{3}\frac{G_F}{\sqrt{2}}\sum_{q\bar{q}} |V_{q\bar{q}}|^2 \left[q(x_a)\,\bar{q}(x_b) + q(x_b)\,\bar{q}(x_a)\right]$$



For anti-proton:

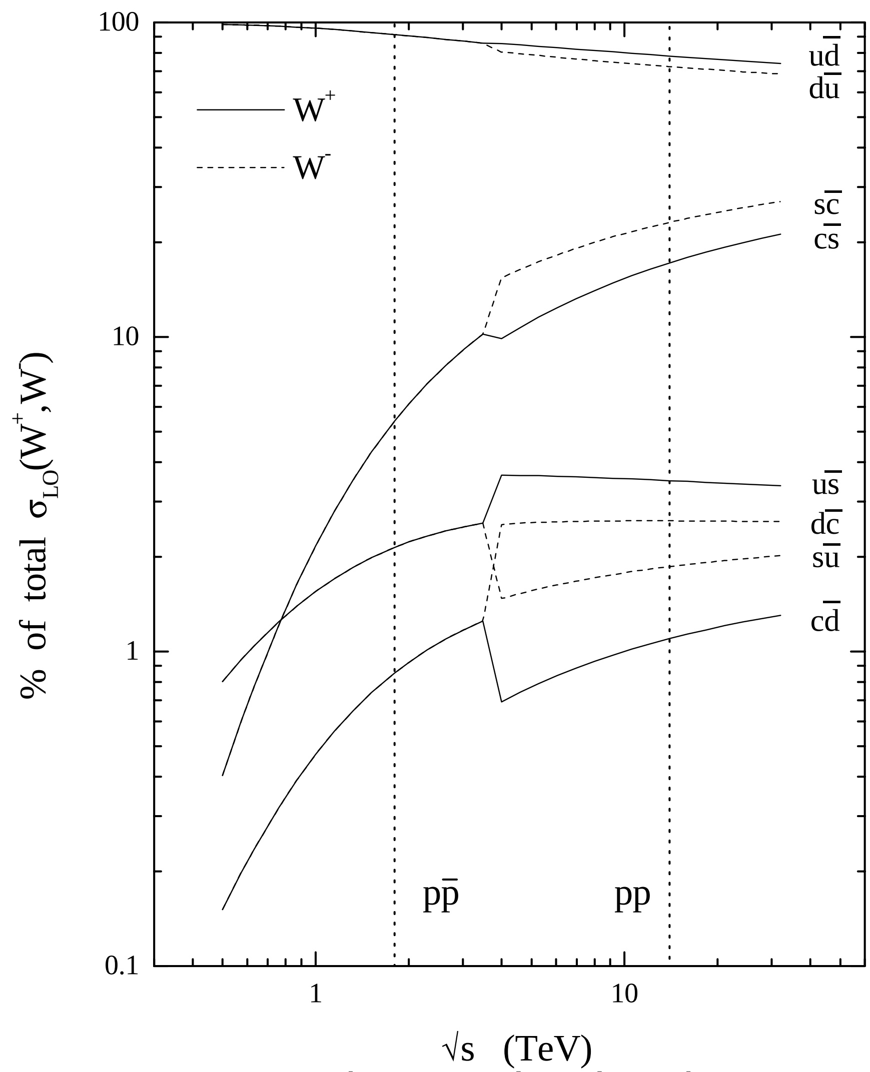
$$u(x) \Leftrightarrow \bar{u}(x) \qquad d(x) \Leftrightarrow \bar{d}(x)$$

Therefore

$$\frac{d\sigma}{dy}(W^{+}) \approx \frac{2\pi}{3}\frac{G_F}{\sqrt{2}}\left[u(x_a)\,d(x_b)\right]$$

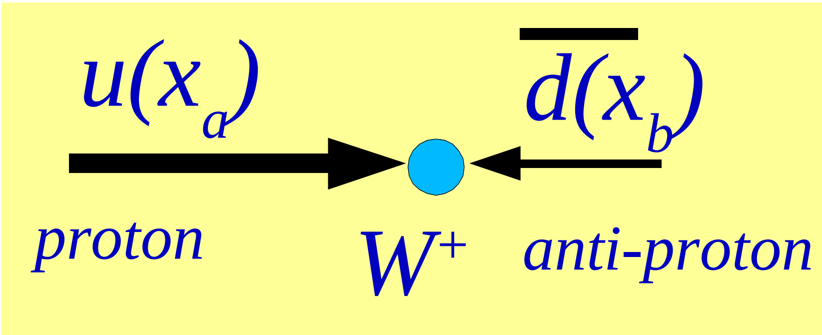
$$\frac{d\sigma}{dy}(W^{-}) \approx \frac{2\pi}{3}\frac{G_F}{\sqrt{2}}\left[d(x_a)\,u(x_b)\right]$$

flavour decomposition of W cross sections



A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C23, 73 (2002); Eur. Phys. J. C4, 463 (1998)

A bit of calculation



$$A(y) = \frac{\frac{d\sigma}{dy}(W^+) - \frac{d\sigma}{dy}(W^-)}{\frac{d\sigma}{dy}(W^+) + \frac{d\sigma}{dy}(W^-)}$$

With the previous approximation,

$$A \approx \frac{u(x_a)d(x_b) - d(x_a)u(x_b)}{u(x_a)d(x_b) + d(x_a)u(x_b)} = \frac{R_{du}(x_b) - R_{du}(x_a)}{R_{du}(x_b) + R_{du}(x_a)}$$

where $R_{du}(x) = \frac{d(x)}{u(x)}$

$$x_{1,2} = x_0 e^{\pm y} \simeq x_0(1 \pm y)$$

We can make Taylor expansions:

$$R_{du}(x_{1,2}) \approx R_{du}(x_0) \pm y\, x_0\, R'_{du}(\sqrt{\tau})$$

Thus, the asymmetry is:

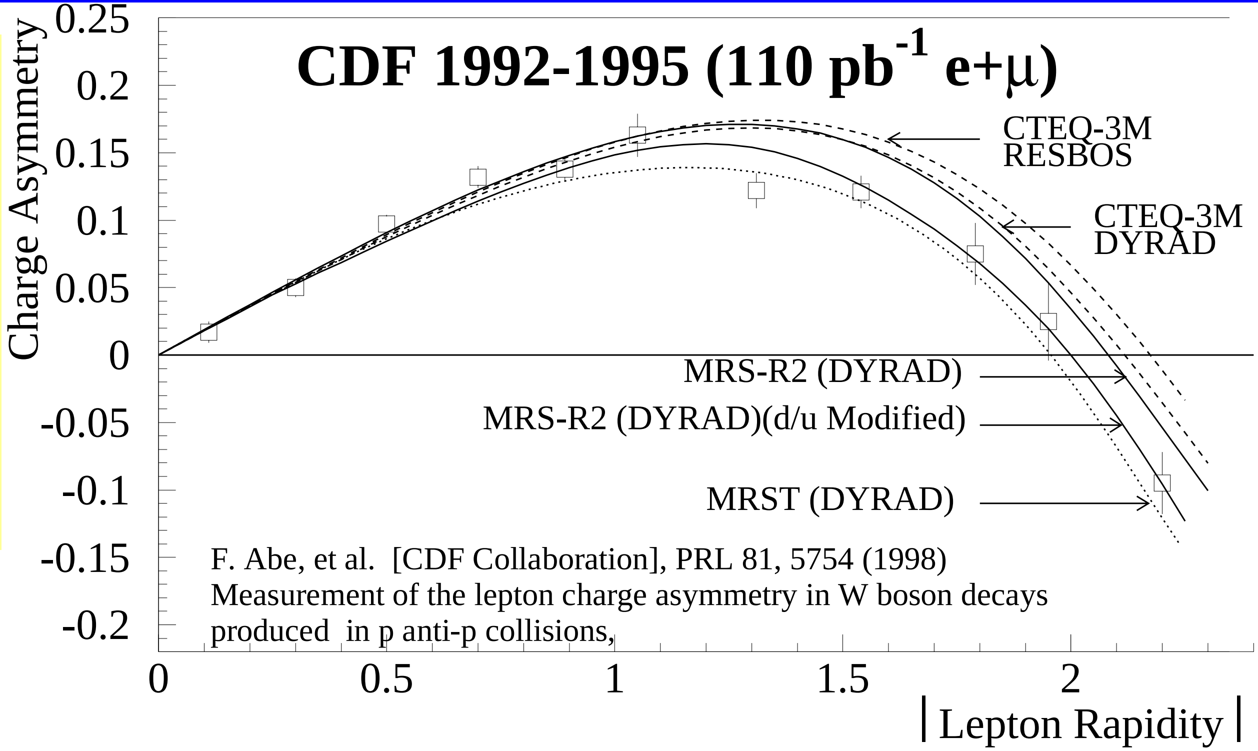
$$A(y) = -y\, x_0 \frac{R'_{du}(x_0)}{R_{du}(x_0)}$$

EXERCISE: Verify the above.

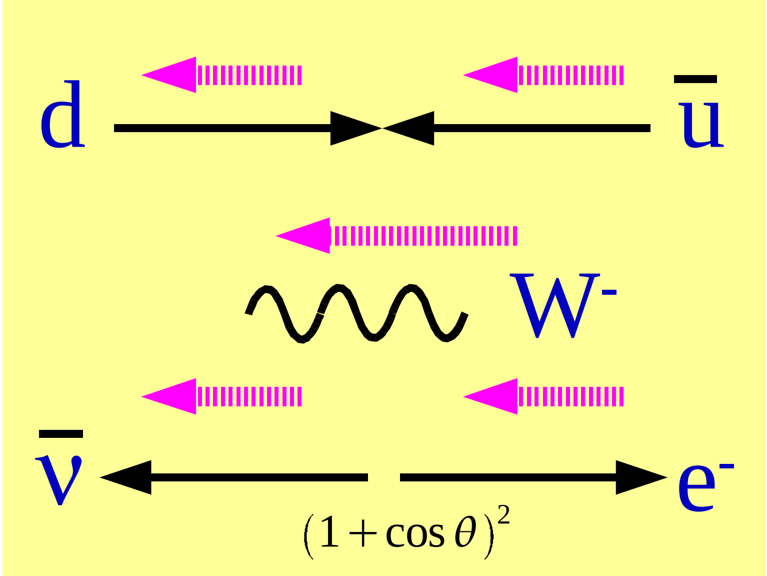
Charged Lepton Asymmetry

Unfortunately,
we don't measure the W
directly since W→eν.

Still the lepton contains
important information



$$A(y) = \frac{\frac{d\sigma}{dy}(l^+) - \frac{d\sigma}{dy}(l^-)}{\frac{d\sigma}{dy}(l^+) + \frac{d\sigma}{dy}(l^-)}$$

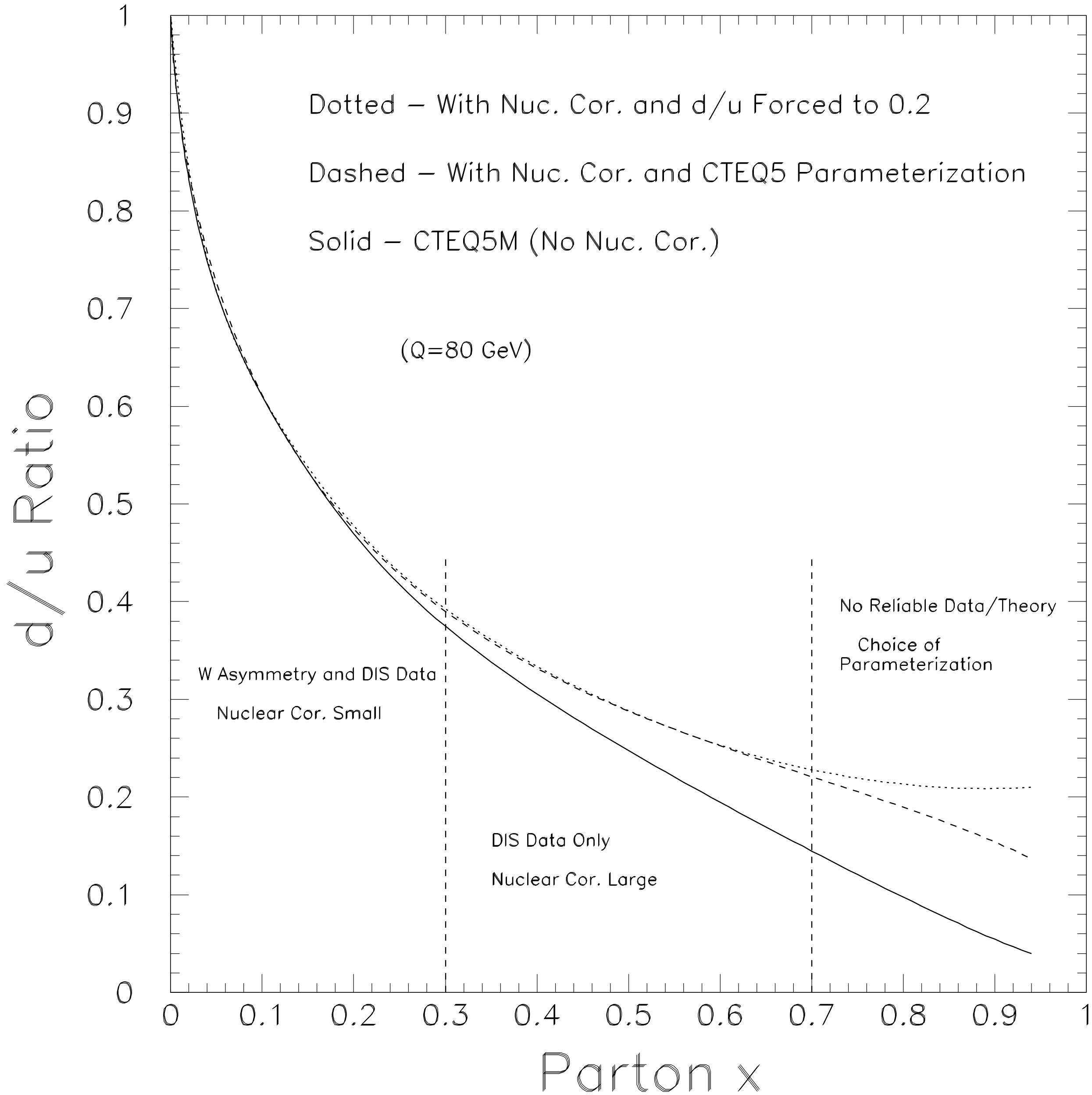


d/u Ratio at High-x

The form of the
d/u ratio at large x
as a function of

1) Parameterization

2) Nuclear Corrections



S. Kuhlmann, et al., Large-x parton distributions, PL B476, 291 (2000)

End of Part I: Where have we been???

History:

Discovery of J/ψ, Upsilon, W/Z, and "New Physics" ???

Calculation of $q\ q \rightarrow \mu^+\mu^-$ in the Parton Model

Scaling form of the cross section

Rapidity, longitudinal momentum, and x_F

Comparison with data:

NLO QCD corrections essential (the K-factor)

σ(pd)/σ(pp) important for d-bar/ubar

W Rapidity Asymmetry important for slope of d/u at large x

Where are we going?

P_T Distribution

W-mass measurement

Resummation of soft gluons