Diffraction @ CDF

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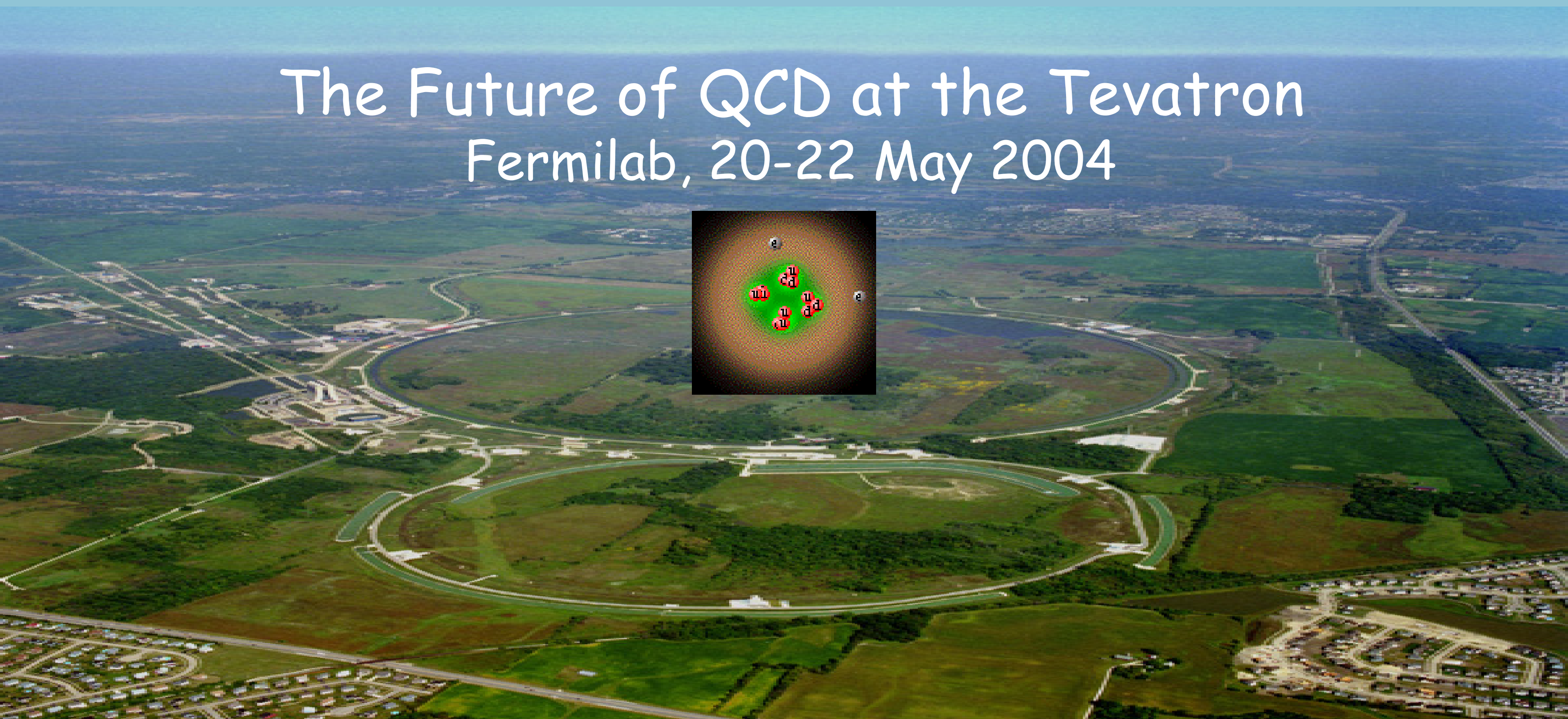
The Rockefeller University



The Future of QCD at the Tevatron

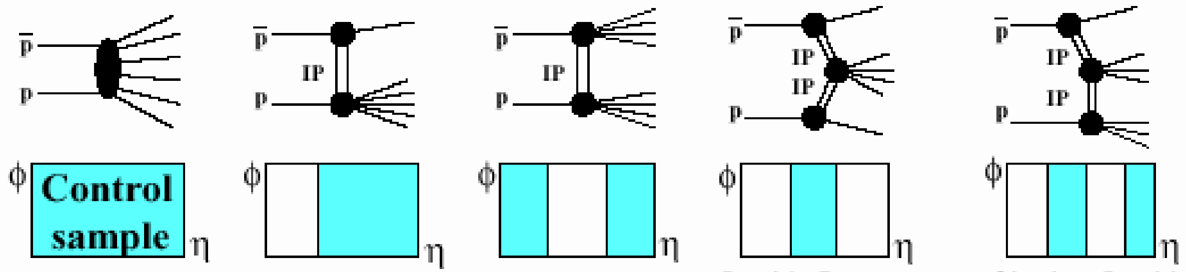
Fermilab, 20-22 May 2004

Diffraction@CDF in Run I

16 papers

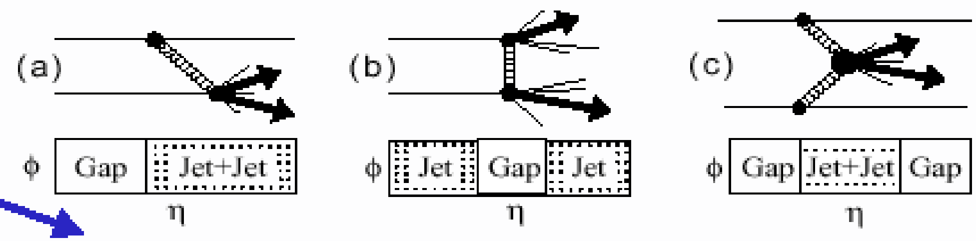
- Elastic scattering PRD 50 (1994) 5518
- Total cross section PRD 50 (1994) 5550
- Diffraction

SOFT diffraction



Non-Diffractive (ND)	Single-Diffractive (SD)	Double Diffractive (DD)	Double Pomeron Exchange (DPE)	Single + Double Diffractive (SDD)
	PRD 50 (1994) 5535	PRL 87 (2001)141802	PRL submitted	PRL 91(2003)011802

HARD diffraction



PRL references

W 78 (1997) 2698	JJ 74 (1995) 855	JJ 85 (2000) 4217
JJ 79 (1997) 2636	JJ 80 (1998) 1156	
b-quark 84 (2000) 232	JJ 81 (1998) 5278	
J/ψ 87 (2001) 241802		

with roman pots

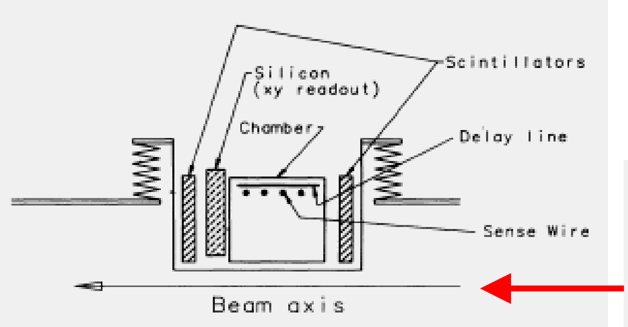
JJ	84 (2000) 5043
JJ	88 (2002) 151802

Run I

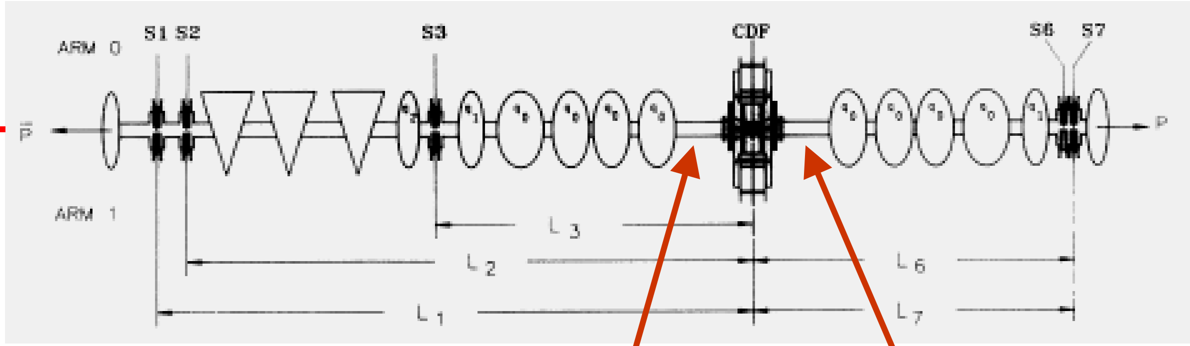
Run #	Dates	pb^{-1}	Physics
1-0	1988-89	~5	Elastic, Diffractive & Total x-sections
1-A,B	1992-95	~120	**Rapidity Gaps**
1-C	1995-96	~10	Roman Pots

Run 1-0 (1988-89)

Elastic, single diffractive, and total cross sections @ 546 and 1800 GeV



Roman Pot Spectrometers



Roman Pot Detectors

- Scintillation trigger counters
- Wire chamber
- Double-sided silicon strip detector

Additional Detectors

Trackers up to $|\eta| = 7$

Results

- Total cross section $\sigma^{tot} \sim s^{\varepsilon}$
- Elastic cross section $d\sigma/dt \sim \exp[2\alpha' \ln s]$ → shrinking forward peak
- Single diffraction Breakdown of Regge factorization

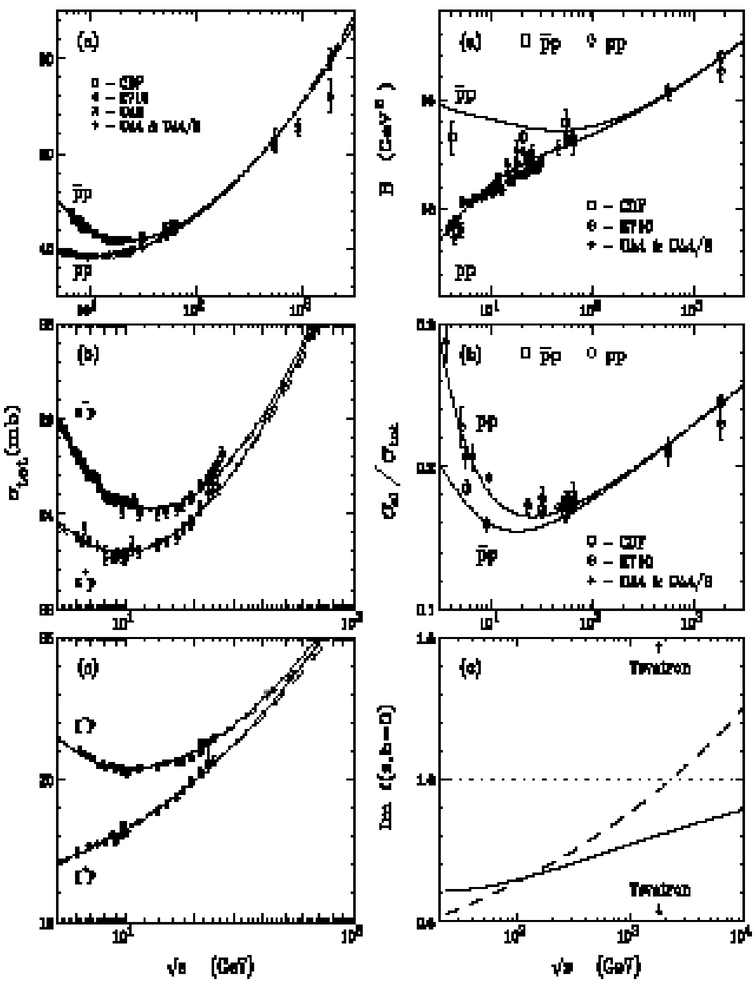
Total & Elastic Cross Sections

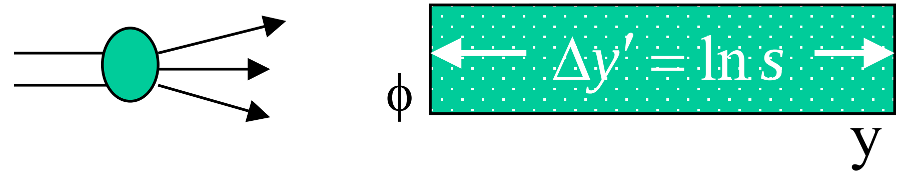
(Run I-0)

Total and Elastic Cross Sections

Covolan, Montanha and Goulianos, Phys. Lett. B 389 (1996) 176

$\alpha_P = 1 + \epsilon (\Rightarrow 0.104) + 0.25t \quad \alpha_{f/\omega} = 0.68 + 0.82t \quad \alpha_{a/\rho} = 0.46 + 0.92t$

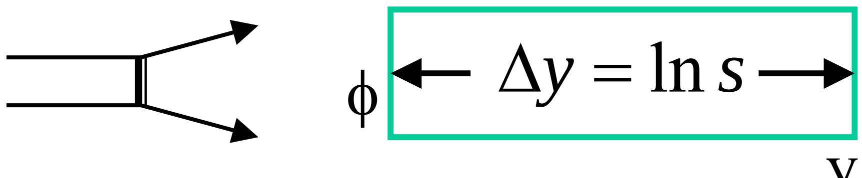




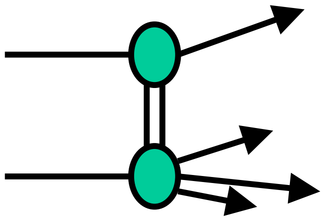
$$\sigma_T(s) = \sigma_o\, s^{\varepsilon} = \sigma_o\, e^{\varepsilon \Delta y'}$$

The exponential rise of σ_T is a QCD aspect expected in the parton model

(see E. Levin, An Introduction to Pomerons,Preprint DESY 98-120)



$$\mathrm{Im}\ f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$



Soft Diffraction (Run I-0)

$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = f_{IP/p}(t,\xi) \bullet \sigma_{IP-\bar{p}}(M_X^2)$$

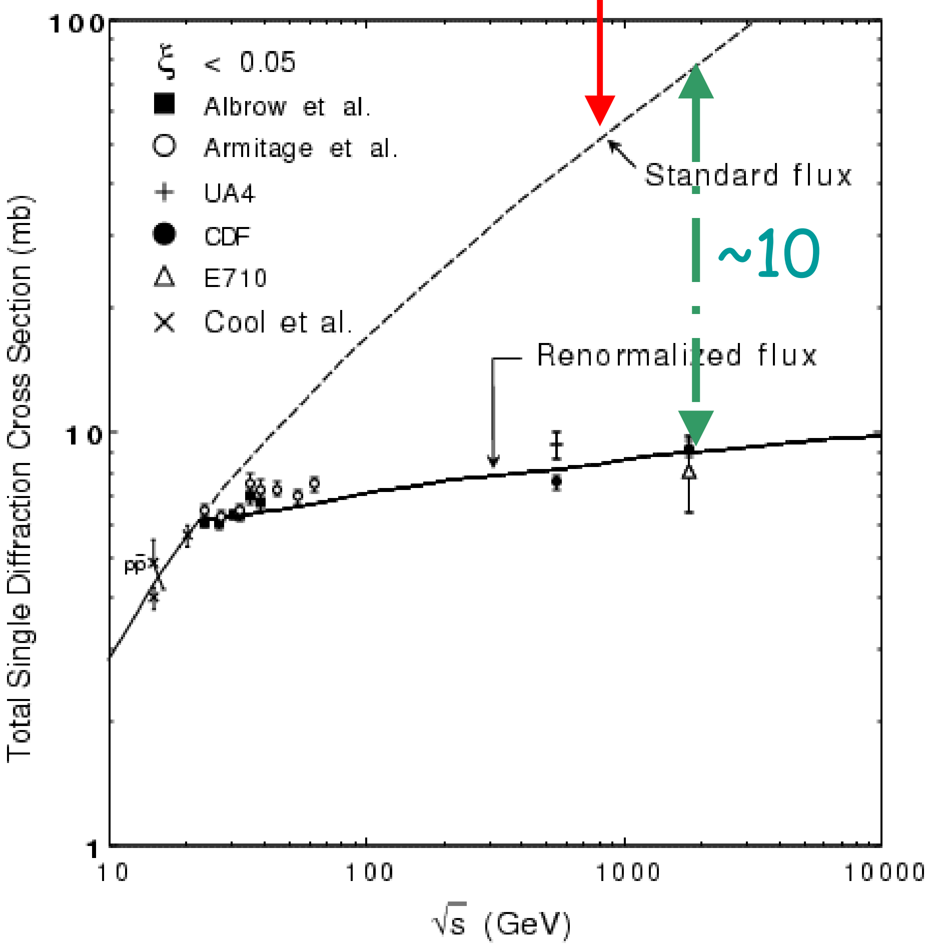
$$\sigma_{SD} \sim s^{2\varepsilon}$$

- **Unitarity problem:**
  With factorization and std pomeron flux σ_{SD} exceeds σ_T at $\sqrt{s} \approx 2\ \text{TeV}$.

- **Renormalization:**
  normalize the pomeron flux to unity

KG, PLB 358 (1995) 379

$$\int_{\xi_{min}}^{0.1} \int_{t=-\infty}^{0} f_{IP/p}(t,\xi)\, d\xi\, dt = 1$$



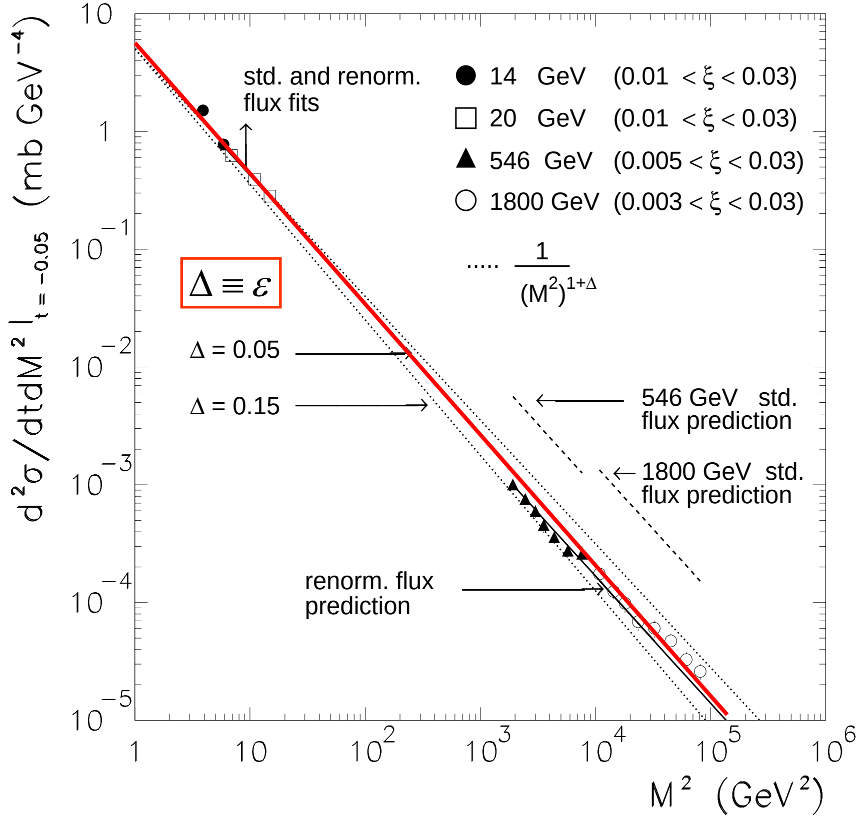
M²-scaling

Factorization breaks down in favor of M^2-scaling

renormalization

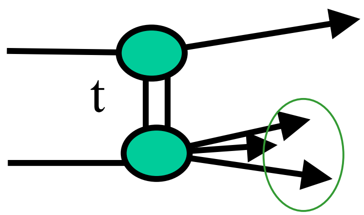
$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon} \rightarrow 1}{(M^2)^{1+\varepsilon}}$$

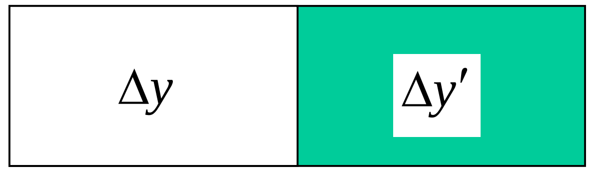
KG&JM, PRD 59 (1999) 114017



QCD Basis for Renormalization

(KG, hep-ph/0205141)





2 independent variables: $t, \Delta y$

color factor

$$\kappa = \frac{g_{IP-IP-IP}(t)}{\beta_{IP-p-p}(0)} \approx 0.17$$

$$\frac{d^2\sigma}{dt\, d\Delta y} = \underbrace{C \bullet F_p^2(t_1) \bullet \left\{ e^{(\varepsilon+\alpha' t)\Delta y} \right\}^2}_{\text{Gap probability}} \bullet \kappa \bullet \underbrace{\left\{ \sigma_o\, e^{\varepsilon\, \Delta y'} \right\}}$$

Gap probability

$$\sim e^{2\varepsilon \Delta y} \longrightarrow \int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\, \Delta y} \approx s^{2\varepsilon}$$

Renormalization removes the s-dependence → M^2-SCALING

κ and ε

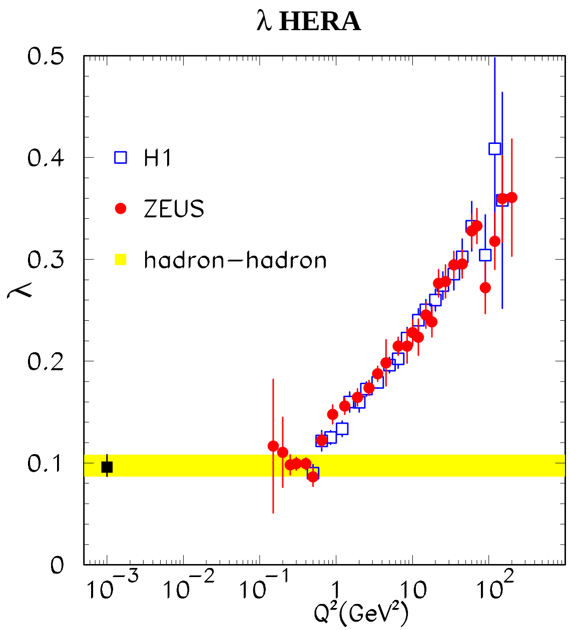
Experimentally:

KG&JM, PRD 59 (114017) 1999

$$\kappa = \frac{g_{IP-IP-IP}}{\beta_{IP-p}} = 0.17 \pm 0.02, \quad \varepsilon = 0.104$$

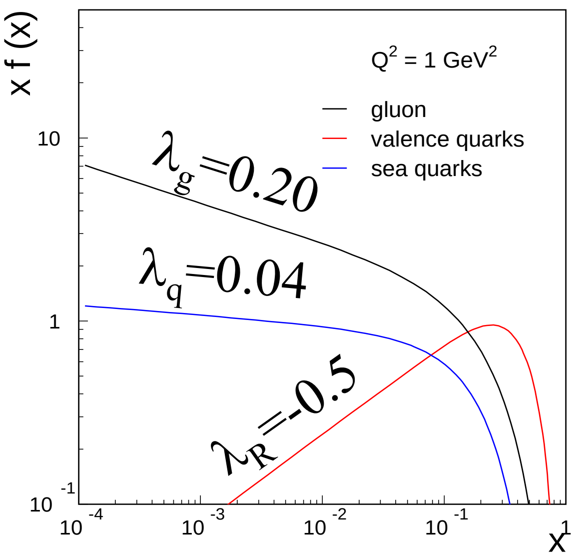
Color factor: $$\kappa = f_g \times \frac{1}{N_c^2 - 1} + f_q \times \frac{1}{N_c} \xrightarrow{Q^2=1} \approx 0.75 \times \frac{1}{8} + 0.25 \times \frac{1}{3} = 0.18$$

Pomeron intercept: $$\varepsilon = \lambda_g \cdot w_g + \lambda_q \cdot w_q = 0.12$$



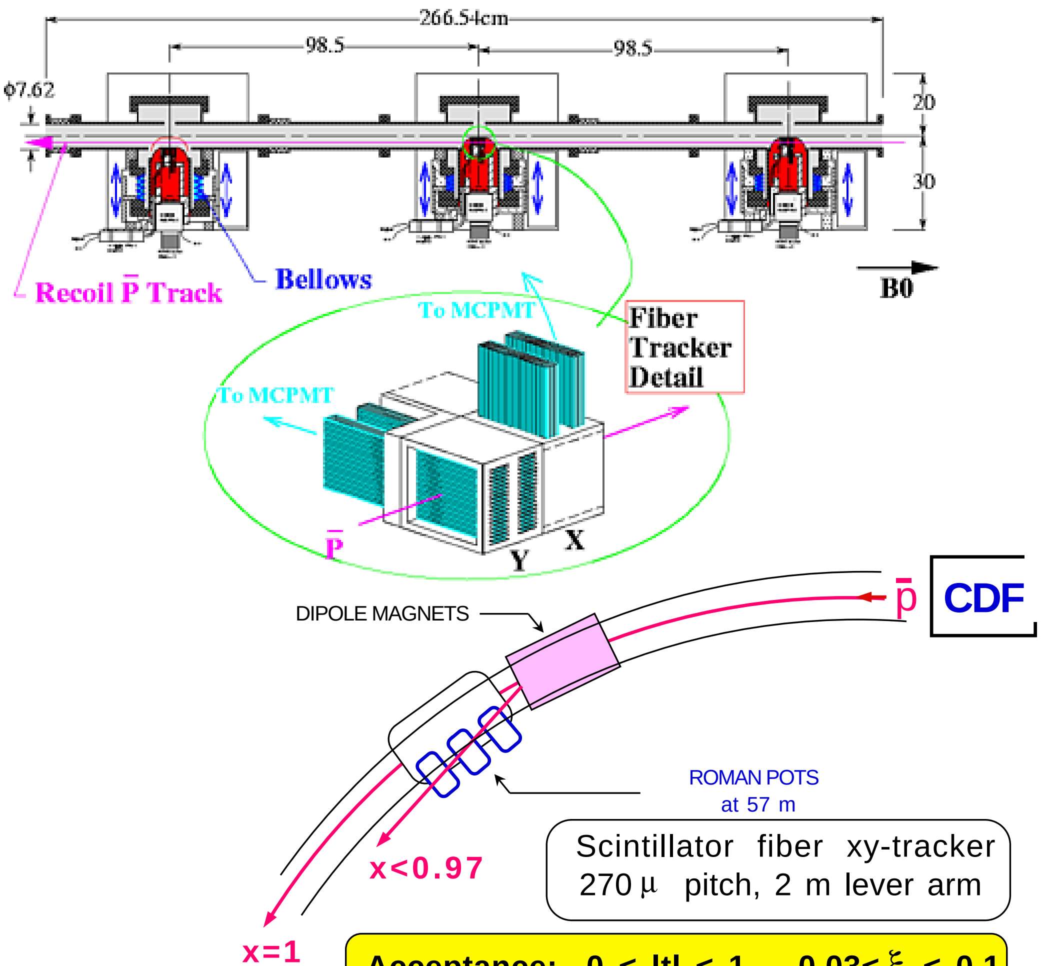
$$x \cdot f(x) = \frac{1}{x^\lambda}$$

f_g=gluon fraction
f_q=quark fraction



CDF-I

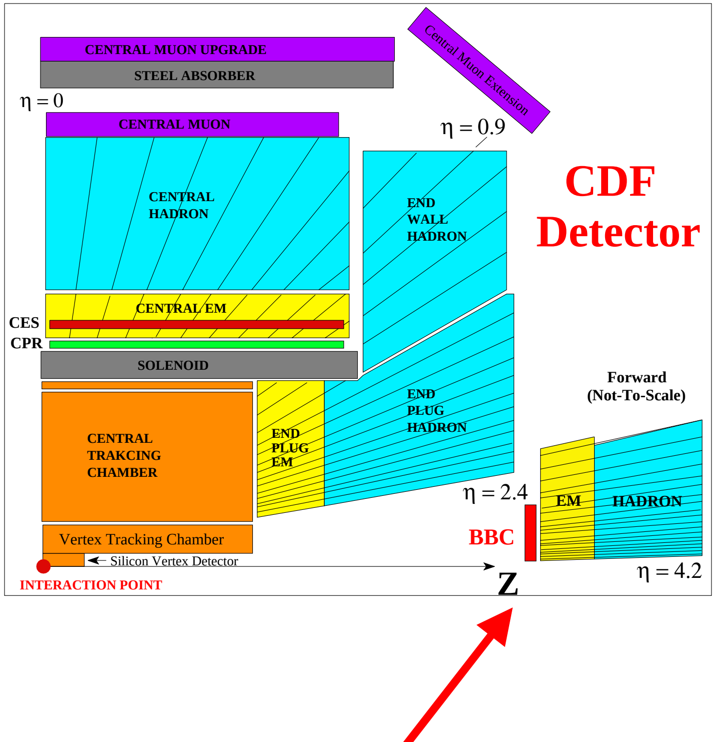
Run-IC



Scintillator fiber xy-tracker
270 μ pitch, 2 m lever arm

Acceptance: 0 < |t| < 1, 0.03< ξ < 0.1

Run-IA,B

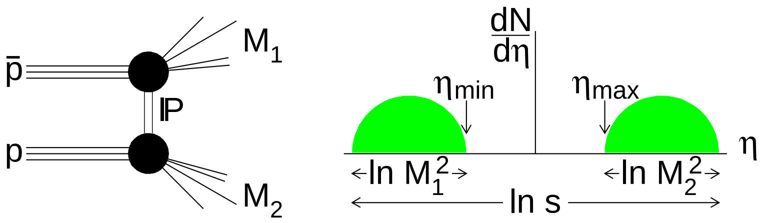


Forward Detectors

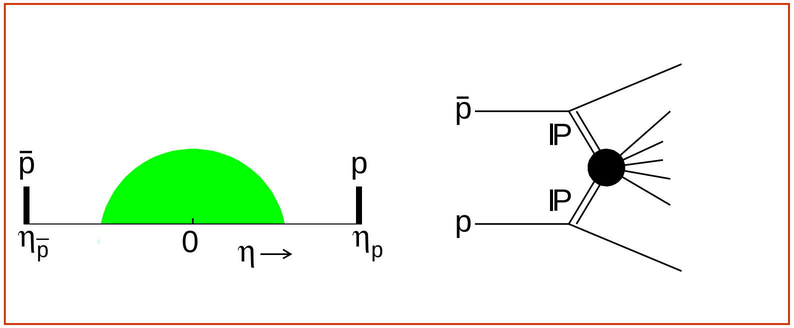
BBC 3.2<η<5.9

FCAL 2.4<η<4.2

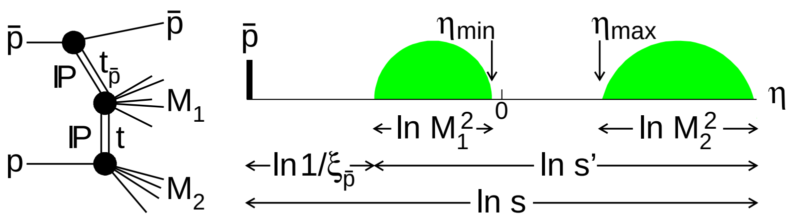
Soft Central and Double Gaps



- **Double Diffraction Dissociation**
  - One central gap



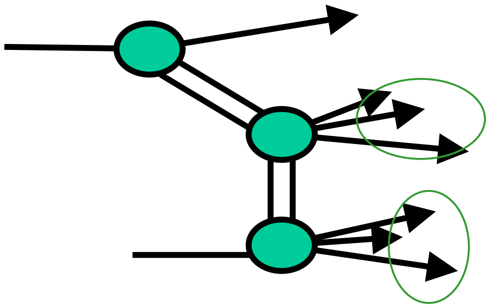
- **Double Pomeron Exchange**
  - Two forward gaps

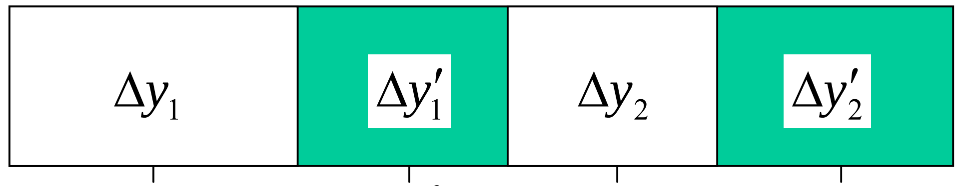


- **SDD: Single+Double Diffraction**
  - One forward + one central gap

Generalized Renormalization

(KG, hep-ph/0205141)





5 independent variables: y'_1, y_2, t_1, $\Delta y = \Delta y_1 + \Delta y_2$, t_2

color factors

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = C \times F_p^2(t_1) \prod_{\text{i=1-2}} \left\{ e^{(\varepsilon+\alpha' t_i)\Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o \, e^{\varepsilon(\Delta y'_1 + \Delta y'_2)} \right\}$$

Gap probability $\sim e^{2\varepsilon \Delta y}$

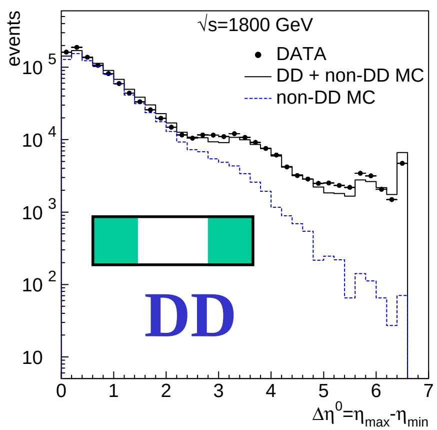
Sub-energy cross section (for regions with particles)

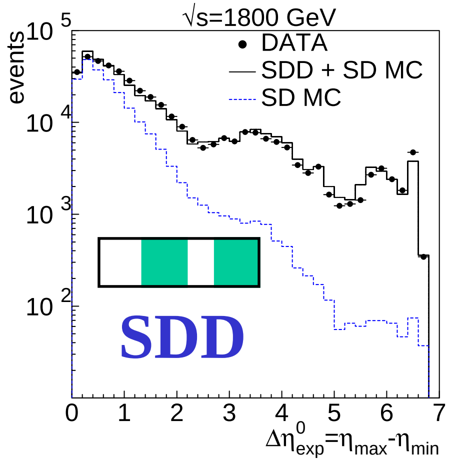
$$\int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\,\Delta y} \approx s^{2\varepsilon}$$

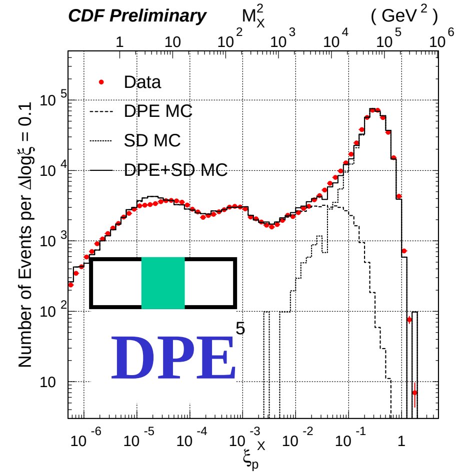
Same suppression as for single gap!

Central & Double-Gap Results

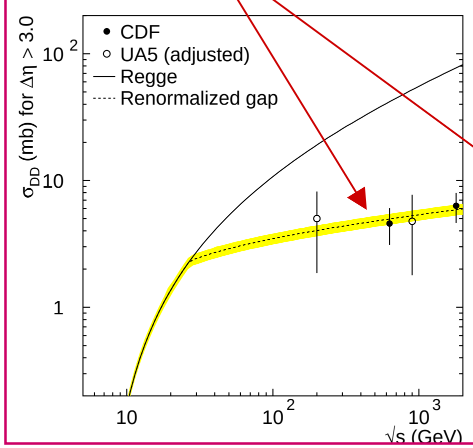
Differential shapes agree with Regge predictions

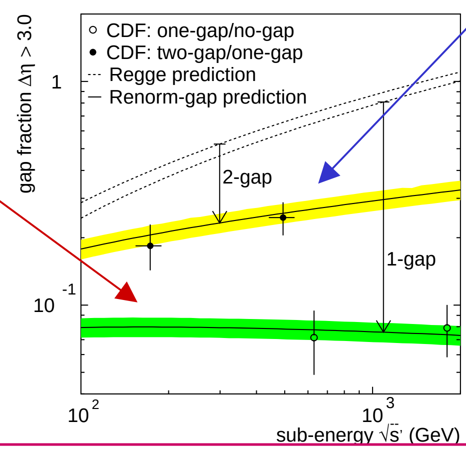


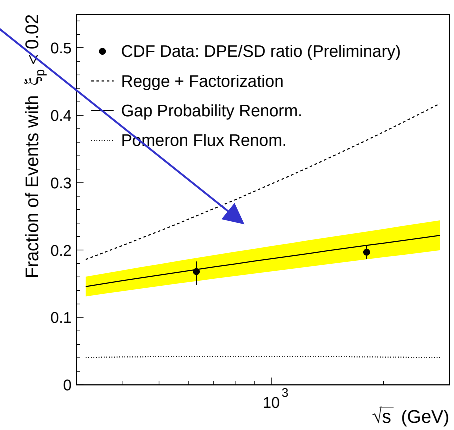




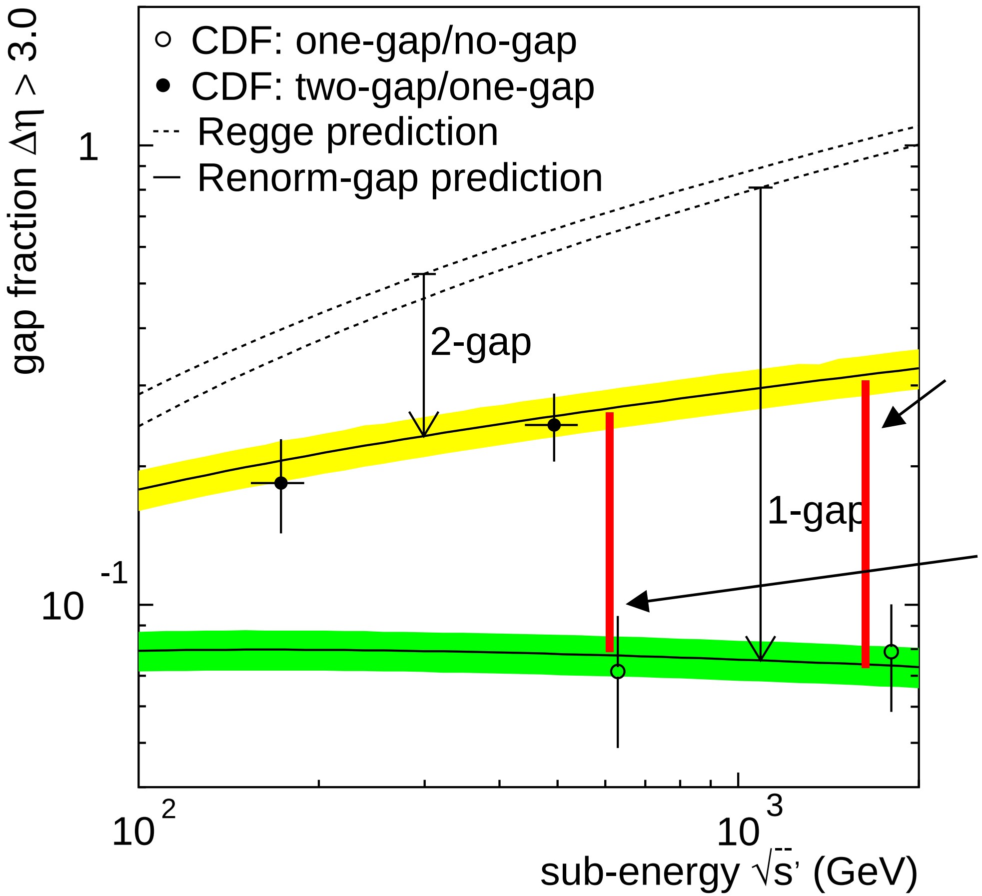
- **One-gap cross sections are suppressed**
  - **Two-gap/one-gap ratios are $\approx \kappa = 0.17$**

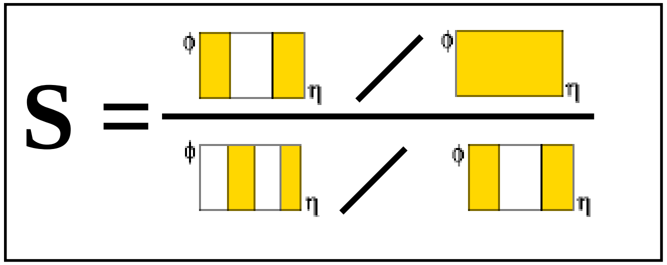






Soft Gap Survival Probability





$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \text{GeV}) \approx 0.23$$

$$S^{1-gap/0-gap}_{2-gap/1-gap}(630\ \text{GeV}) \approx 0.29$$

Soft Diffraction Conclusions

Experiment:

- M^2 - scaling
- Non-suppressed double-gap to single-gap ratios

Phenomenology:

- Generalized renormalization
- Obtain Pomeron intercept and tripe-Pomeron coupling from inclusive PDF's and color factors

Soft diffraction is understood ! (?)

Hard Diffraction

- Diffractive Fractions
- Diffractive Structure Function
- Factorization breakdown and restoration
- DSF from inclusive PDF's
- Hard diffraction conclusions

Diffractive Fractions

$$\bar{p}p \rightarrow X + \text{gap}$$

SD/ND fraction at 1800 GeV

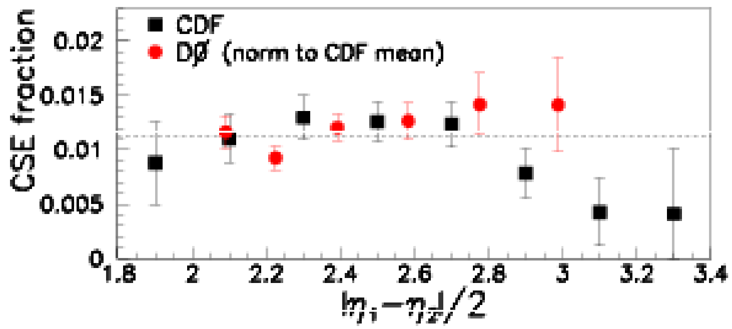
X	Fraction(%)
W	1.15 (0.55)
JJ	0.75 (0.10)
b	0.62 (0.25)
J/ψ	1.45 (0.25)

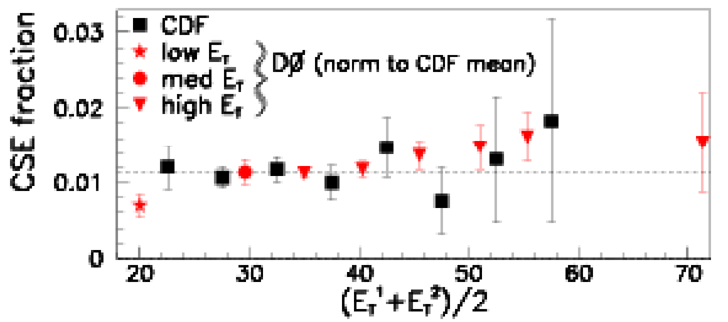
- All SD/ND fractions ~1%
- Gluon fraction $f_g = 0.54 \pm 0.15$
- Suppression by ~5 relative to HERA
  → gap survival probability ~20%

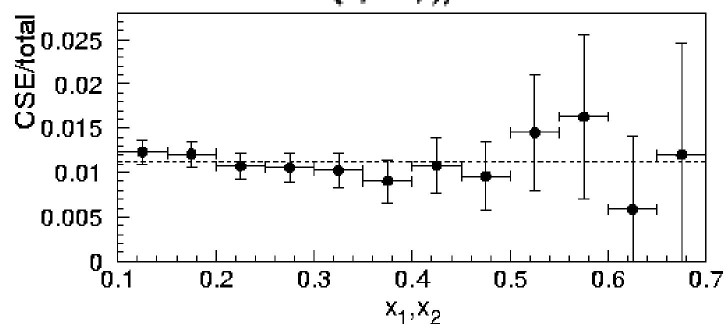
Factorization OK @ Tevatron
at 1800 GeV (single energy)

$$\bar{p}p \rightarrow Jet + \text{gap} + Jet$$

DD/ND gap fraction at 1800 GeV







Diffractive Structure F'n

$$\bar{p} + p \to \bar{p} + Jet + Jet + X$$

- Measure ratio of SD/ND dijet rates as a f'n of $x_{\bar{p}}$

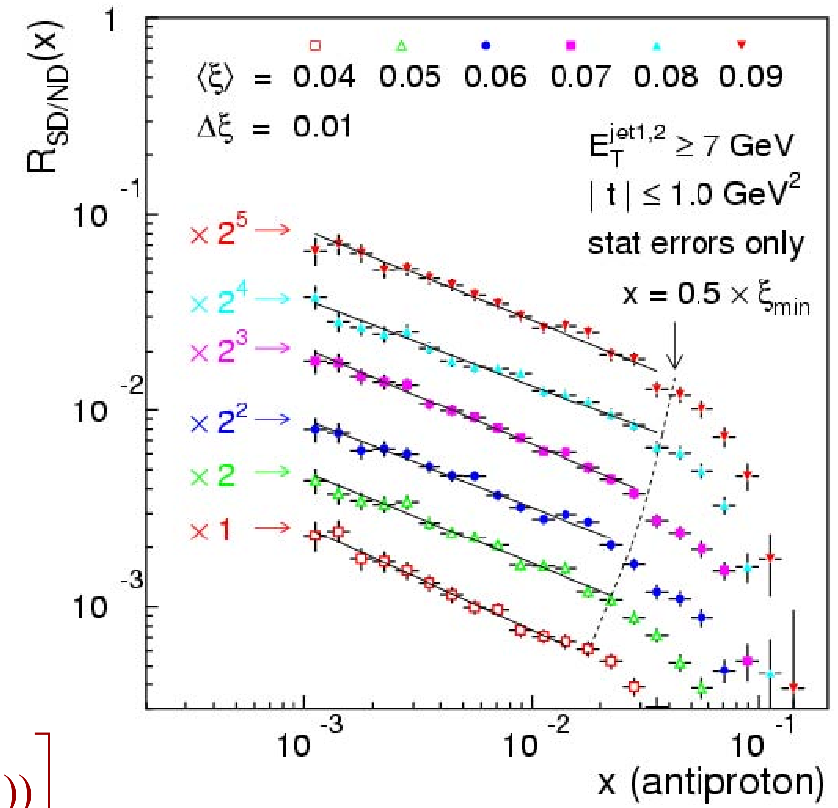
$$x_{\bar{p}} \equiv p_{g,q}/p_{\bar{p}} = \frac{\sum_{i=1}^{2(3)} E_T^i \cdot e^{-\eta^i}}{\sqrt{s}}$$

$$R_{\frac{SD}{ND}}(x_{\bar{p}}) \approx R_0 \cdot x_{\bar{p}}^{-0.45}$$

- In LO-QCD ratio of rates equals ratio of structure fn's

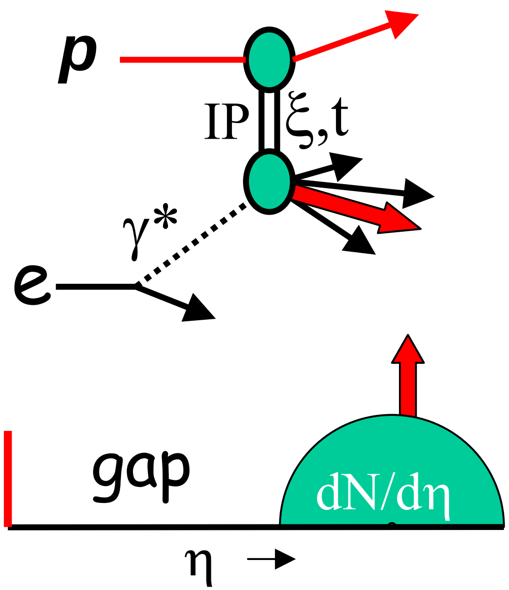
$$F_{jj}(x_{\bar{p}}) = x_{\bar{p}}\left[g(x_{\bar{p}}) + \frac{C_F}{C_A}\sum(q_i(x_{\bar{p}}) + \bar{q}_i(x_{\bar{p}}))\right]$$

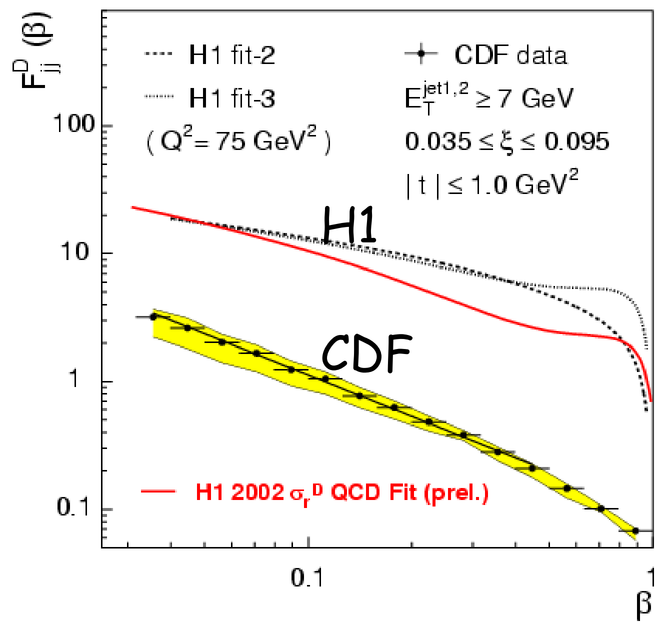
SD/ND Rates vs $x_{\bar{p}}$

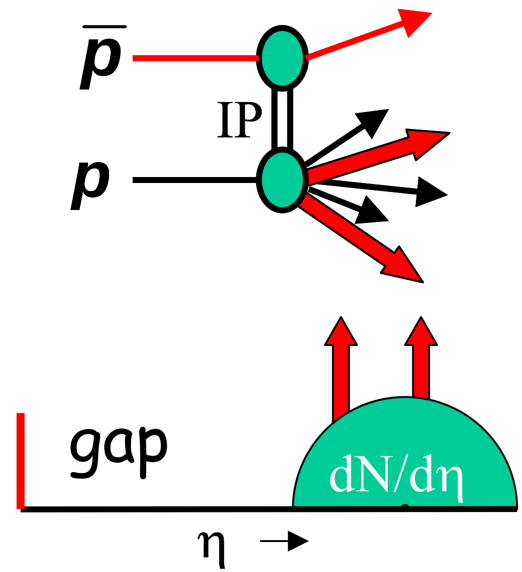


Breakdown of QCD Factorization

HERA —The clue to understanding the Pomeron→ TEVATRON



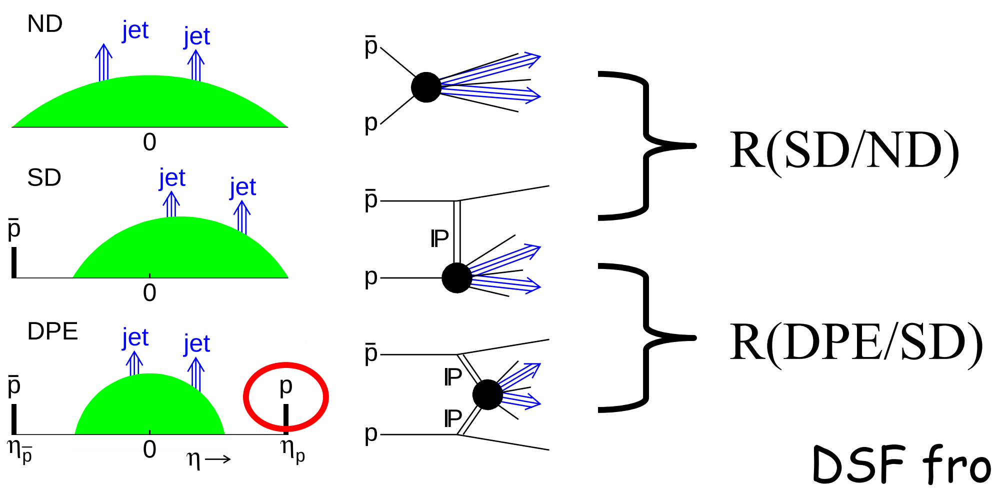


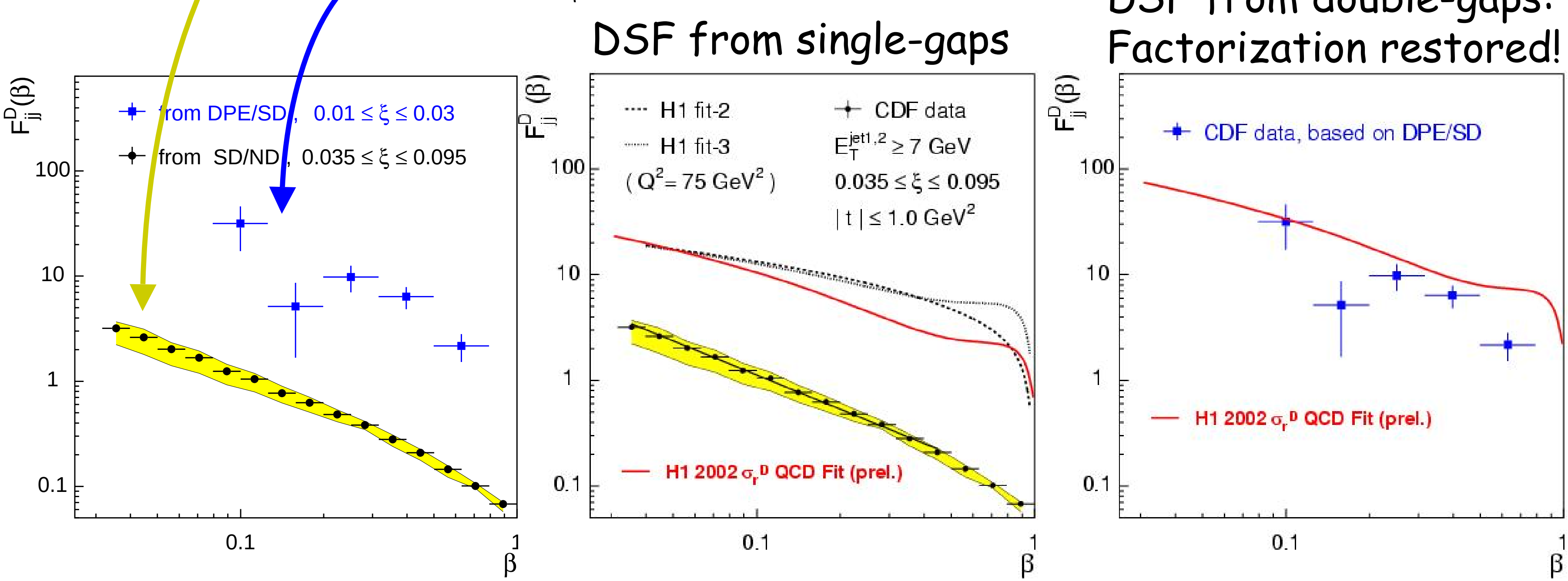


$F_2(Q^2, x)$ ⟶ $F_{JJ}(E_T^{Jet}, x)$

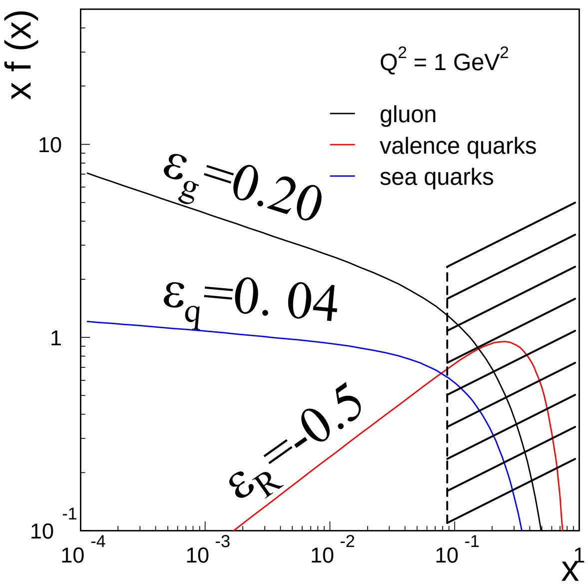
$F_2^D(Q^2, \beta, \xi, t)$ —— ??? ——→ $F_{JJ}^D(E_T^{Jet}, \beta, \xi, t)$

Restoring Diffractive Factorization





DSF from Inclusive pdf's (KG)



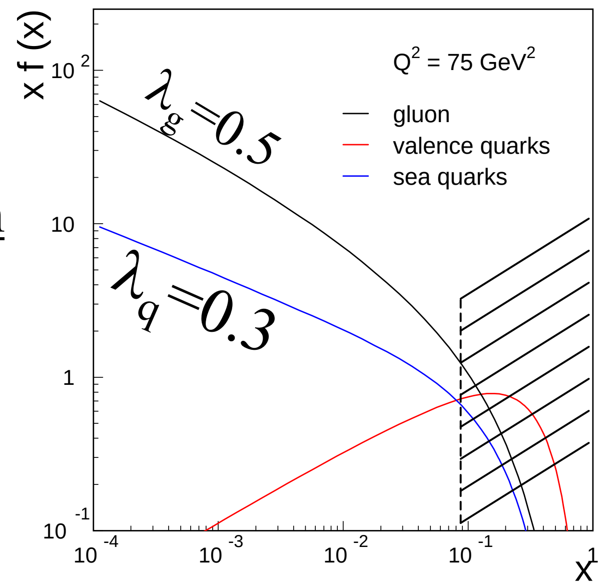
$$x \cdot f(x) = \frac{1}{x^{\varepsilon}}$$

Power-law region

$\xi_{max} = 0.1$

$x_{max} = 0.1$

$\beta < 0.05\xi$



$$F^{D}(Q^2, x, \xi) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F(Q^2, x) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \Rightarrow \frac{A_{NORM}}{\xi^{1+\varepsilon+\lambda}} \cdot \kappa \cdot \frac{C}{\beta^{\lambda}}$$

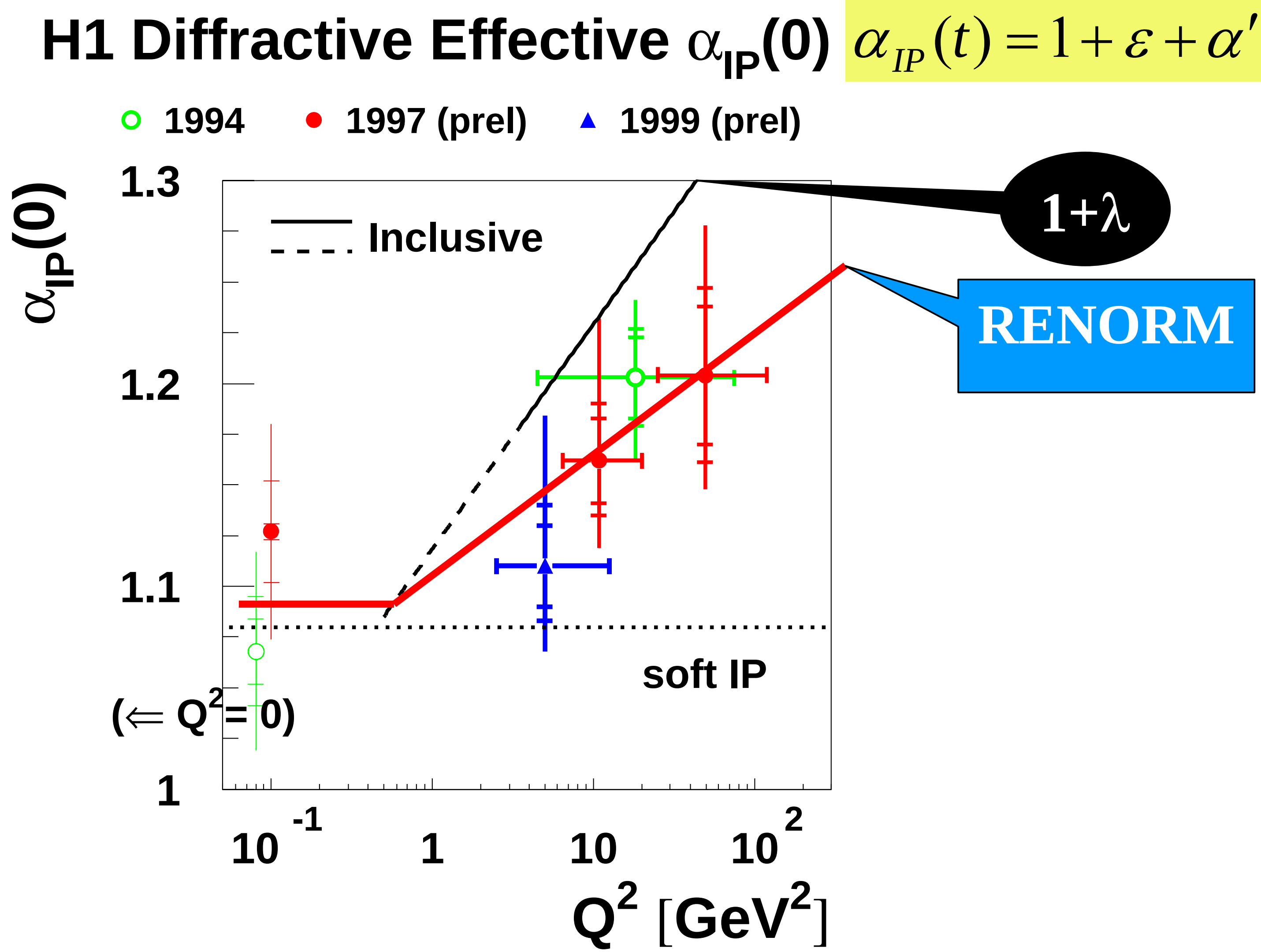
$$\text{HERA(no RENORM)}: \quad R_{DIS}^{DDIS}(x) \xrightarrow{\text{fixed } \xi} \text{constant}$$

$$2\varepsilon_{DDIS} = \varepsilon + \lambda(Q^2)$$

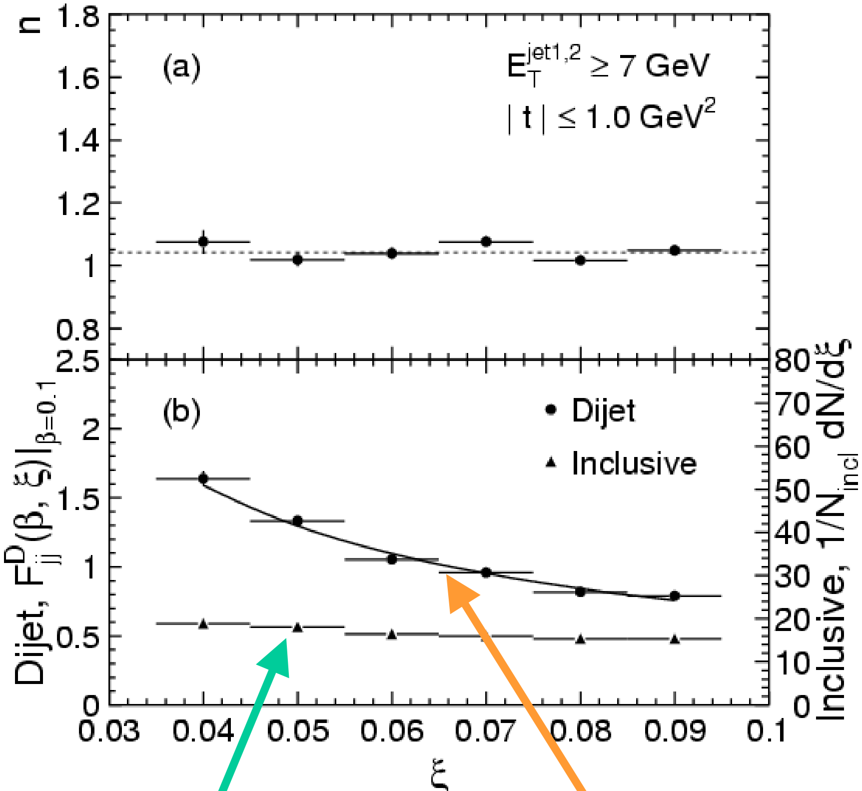
$$\text{TEVATRON} \quad \text{(RENORM)} \quad : R\,\frac{SD}{ND}(x) \propto x^{-(\varepsilon+\lambda)}$$

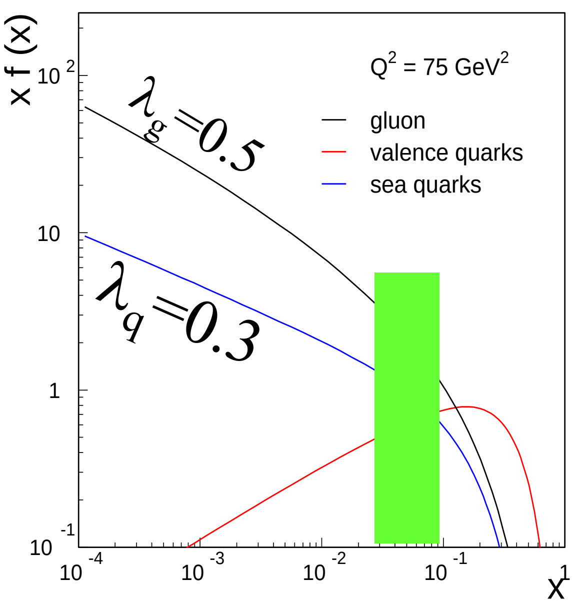
Pomeron Intercept from H1

$\alpha_{IP}(t) = 1 + \varepsilon + \alpha' t$



ξ-dependence: Inclusive vs Dijets





$$F_{jj}(x_{\bar{p}}) = x_{\bar{p}}\left[g(x_{\bar{p}}) + \frac{4}{9}\sum\left(q_i(x_{\bar{p}}) + \bar{q}_i(x_{\bar{p}})\right)\right]$$

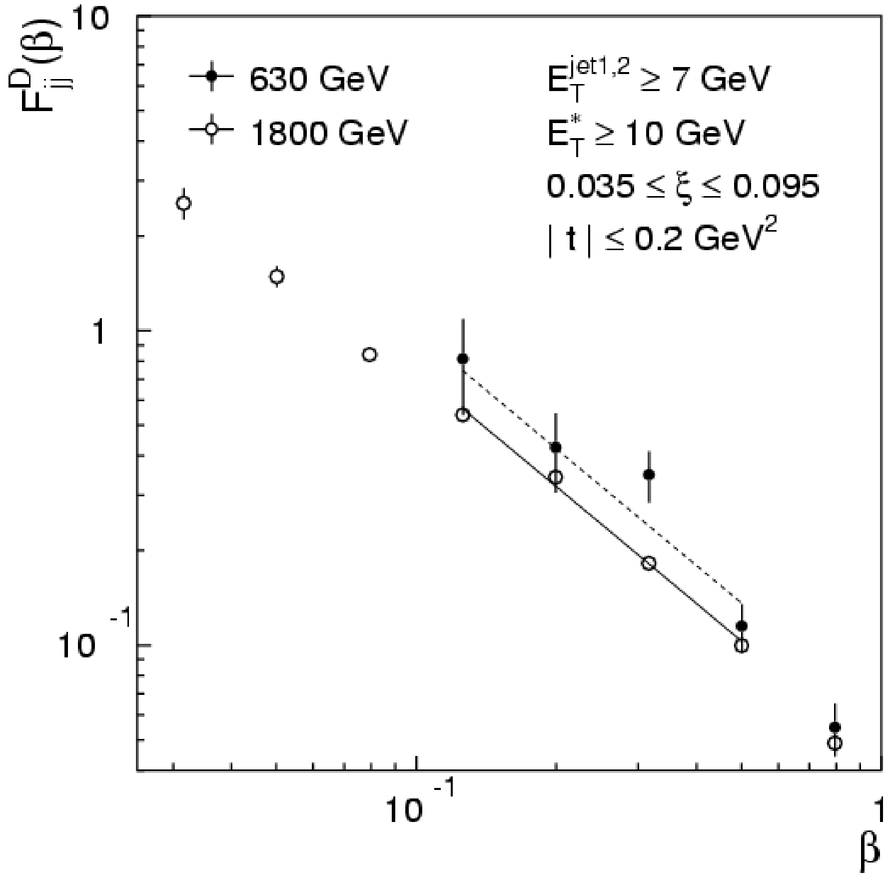
$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

Pomeron+Reggeon

$$F_{jj}^D(\beta,\xi) \propto \frac{1}{\beta^n}\cdot\frac{1}{\xi^m} \quad (n = 1.0 \pm 0.1, \quad m = 0.9 \pm 0.1)$$

Pomeron dominated

Enery Dependence of F_{JJ}^D



Phenomenological Models:

- Renormalization
  Phys. Lett. B 358, 379 (1995).
- Gap survival probability, e.g.
  Eur.Phys. J. C 21, 521 (2001).
- Soft color interactions
  Phys. Rev. D 64, 114015 (2001).

$R_{630/1800}$(predicted) ~ 1.5 - 1.8

$R_{630/1800}$ = 1.3±0.2(stat)+0.4/-0.3(syst)

Hard Diffraction Conclusions

Diffraction appears to be a low-x exchange subject to color constraints

Summary of Run I Results

SOFT DIFFRACTION

- M^2 - scaling
- Non-suppressed double-gap to single-gap ratios

HARD DIFFRACTION

- Flavor-independent SD/ND ratios
- Factorization breakdown and restoration

✓Universality of gap prob. across soft and hard diffraction

Run II Diffractive Program

- Single Diffraction
  - ξ and Q^2 dependence of F_{jj}^D
  - Process dependence of F^D (W, b, J/ψ,...)
- Double Diffraction
  - Jet-Gap-Jet: $\Delta\eta^{gap}$ for large fixed $\Delta\eta^{jet}$
- Double Pomeron Exchange
  - F_{jj}^D on p-side vs ξ-pbar

Also:

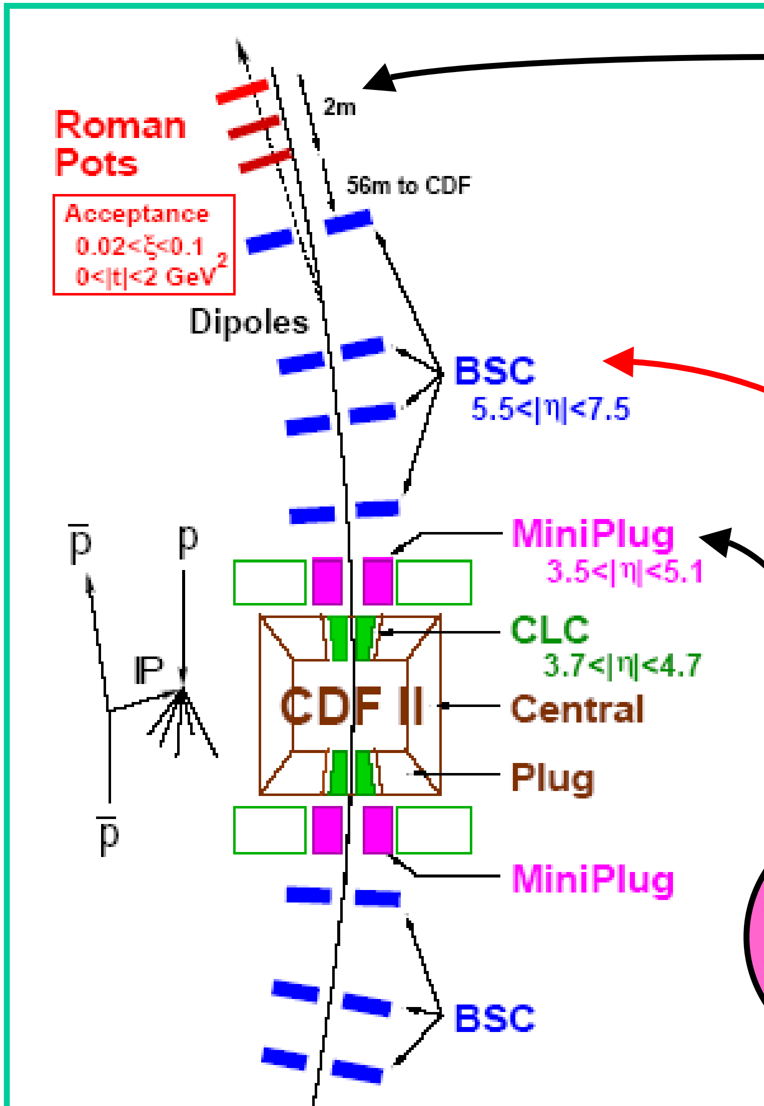
Exclusive central production

- Dijets, χ_c, low mass states, Higgs(!)(?)...

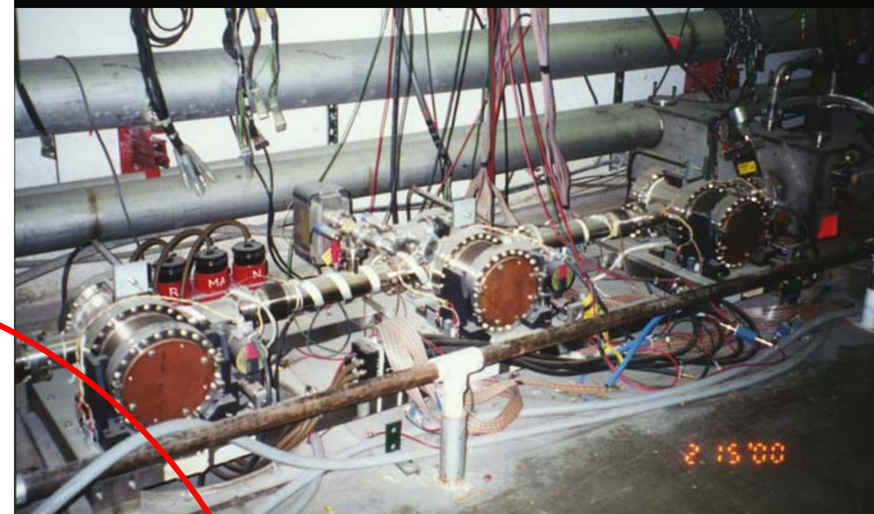
Other

- Open to suggestions

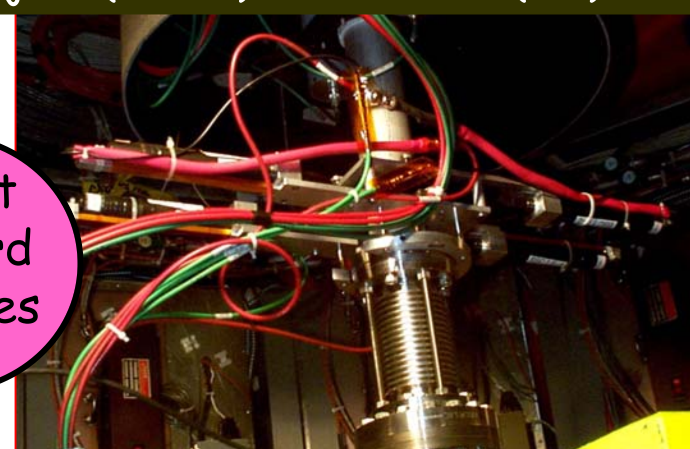
CDF-II



Tag leading p-bar @ 0.02 < ξ< 0.1

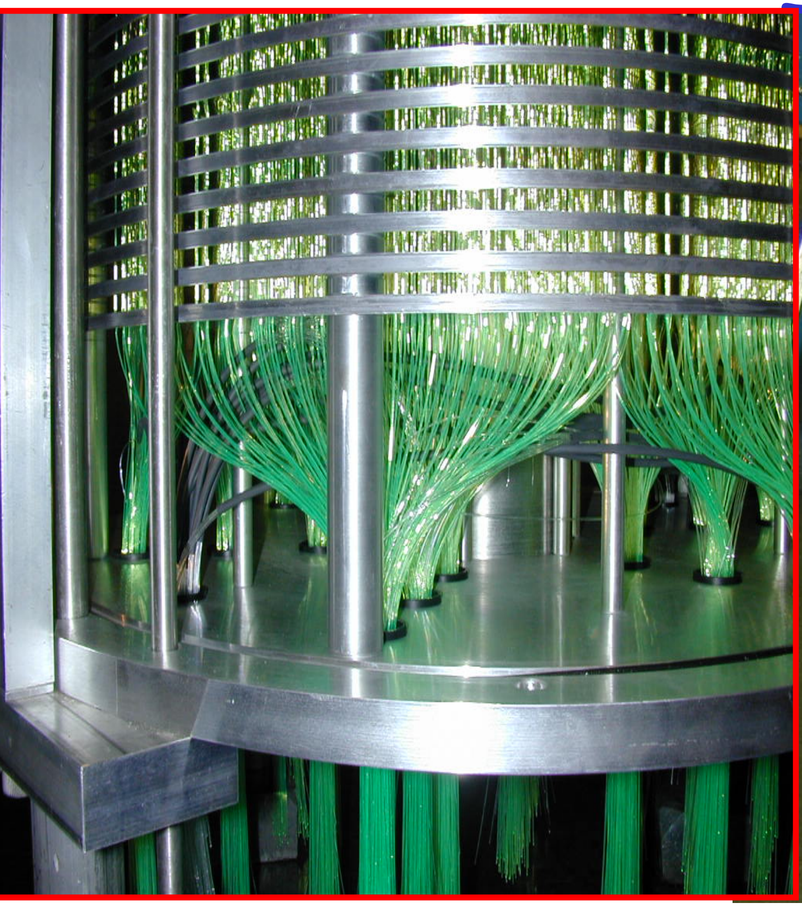


Reject (retain) 95% of ND (SD)events



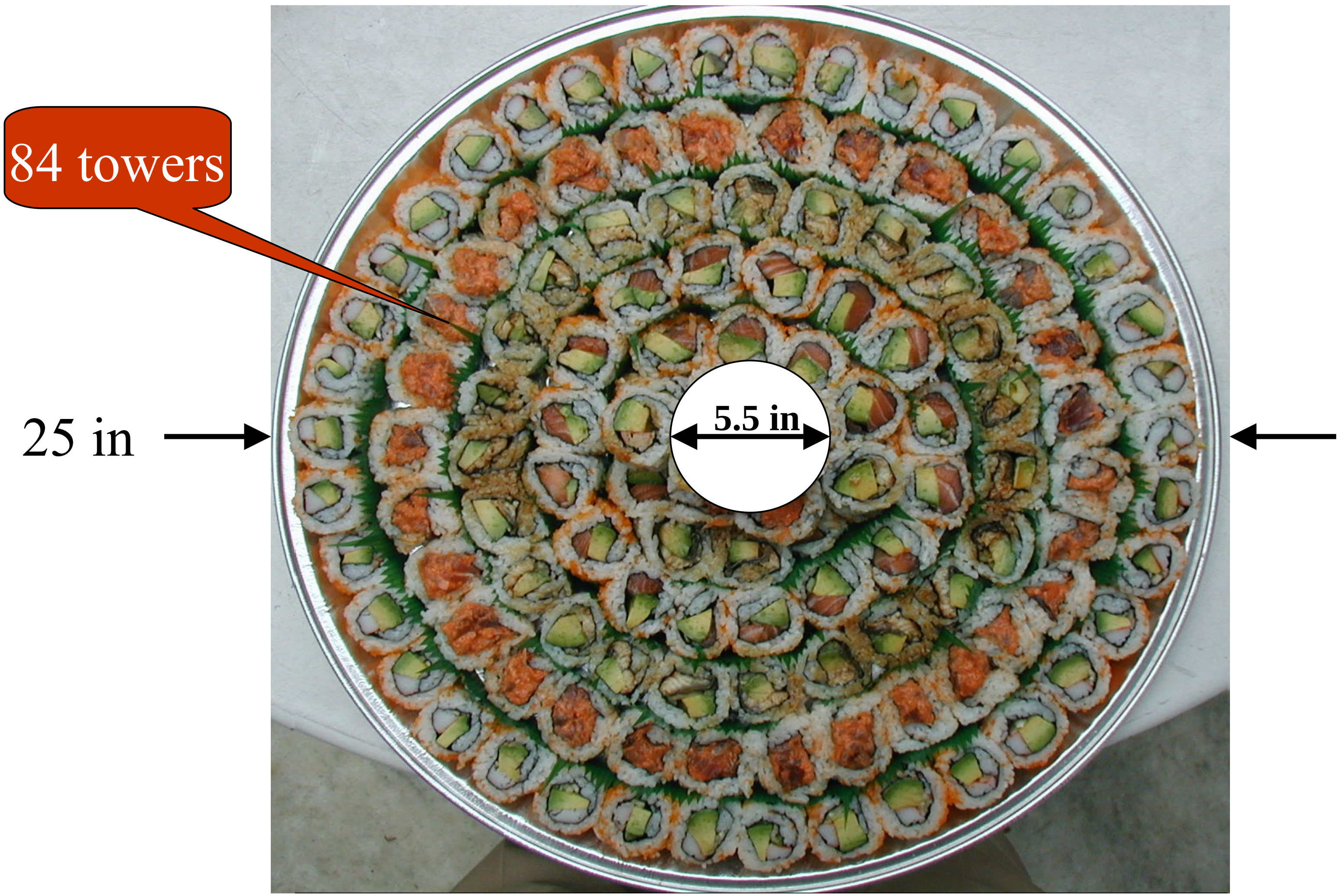
detect forward particles

MiniPlug Calorimeter

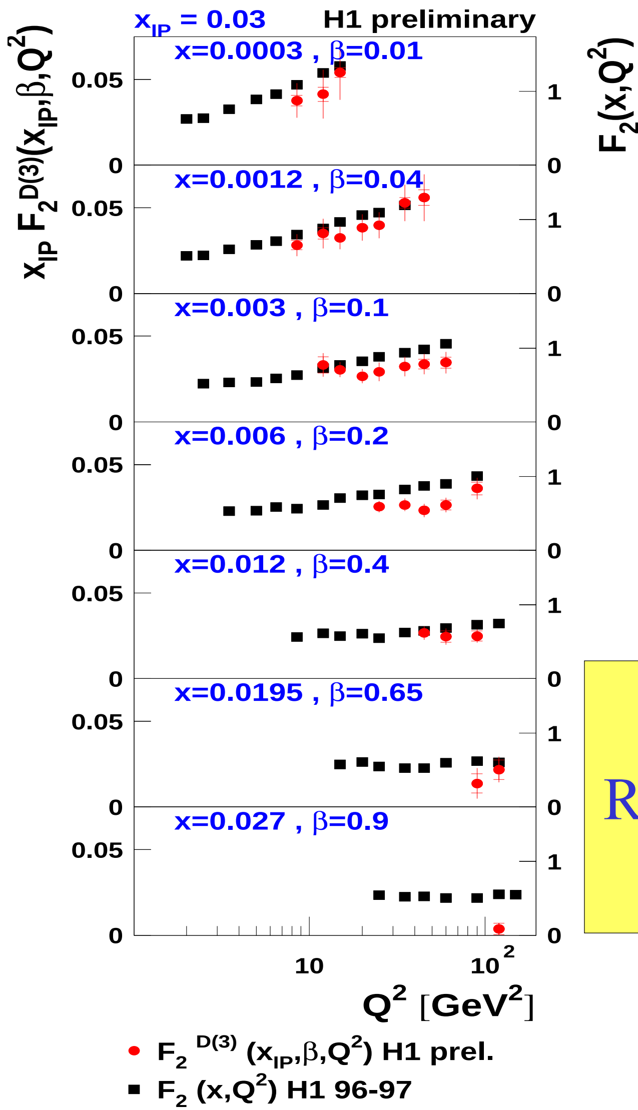


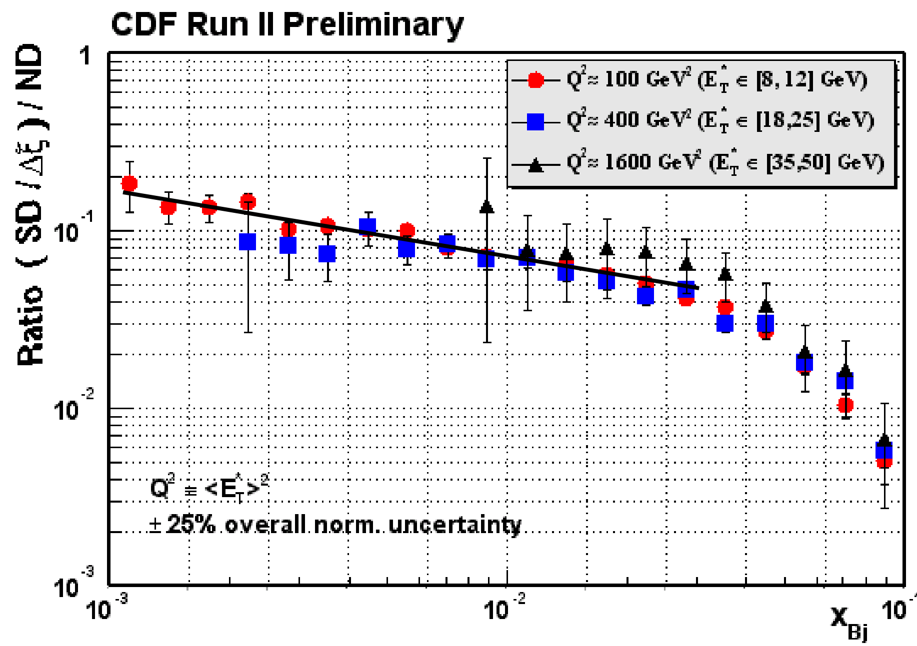
About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in 36x¼" lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.

Artist's View of MiniPlug



Q² dependence of DSF



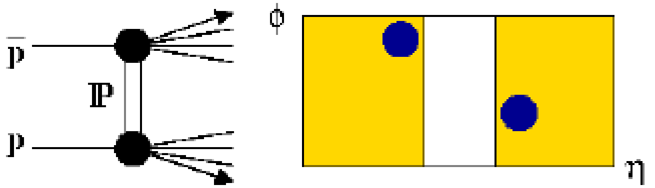


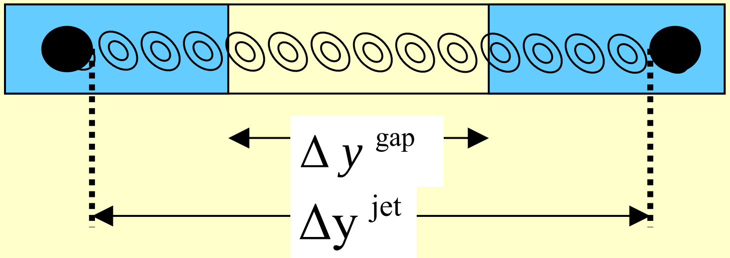
$$R\left(\frac{F^D(Q^2, x, \xi)}{F(Q^2, x)}\right) \Rightarrow \begin{cases} \sim \text{no } Q^2 \text{ dependence} \\ \sim \text{flat at HERA} \\ \sim 1/x^{0.5} \text{ at Tevatron} \end{cases}$$

Pomeron evolves similarly to proton
except for for renormalizartion effects

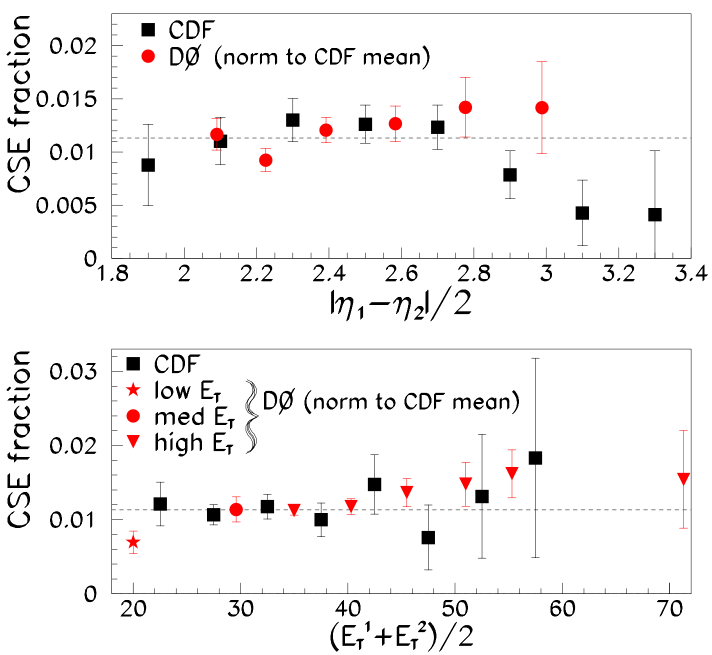
Hard Double Diffraction

$\bar{p} + p \rightarrow \text{Jet} + \text{Gap} + \text{Jet}$



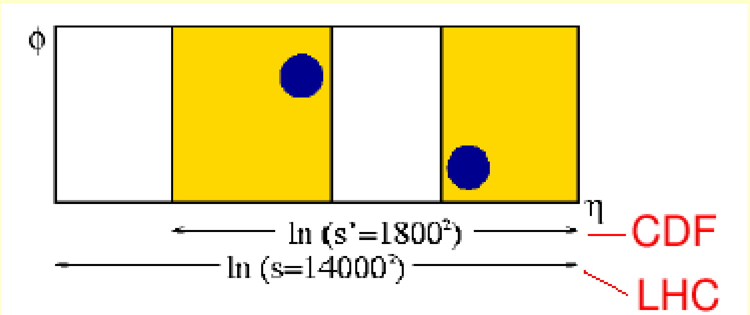


Run I Results



Question

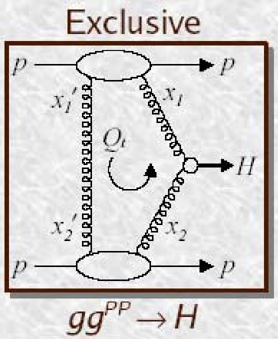
$$\Delta y^{gap} \xleftrightarrow{???} \Delta y^{jet}$$



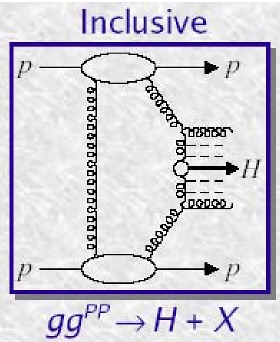
$$R_{LHC}^{J-G-J}(s') = R_{TEV}^{J-G-J}/S \approx 1\%/0.2 \approx 5\%$$

Exclusive Dijets in DPE

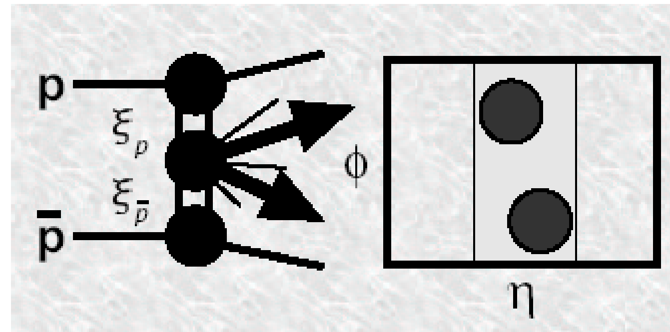
Interest in diffractive Higgs production



Khoze, Martin, Ryskin
Eur. Phys. J.
C23, 311 (2001),
C26, 229 (2002)



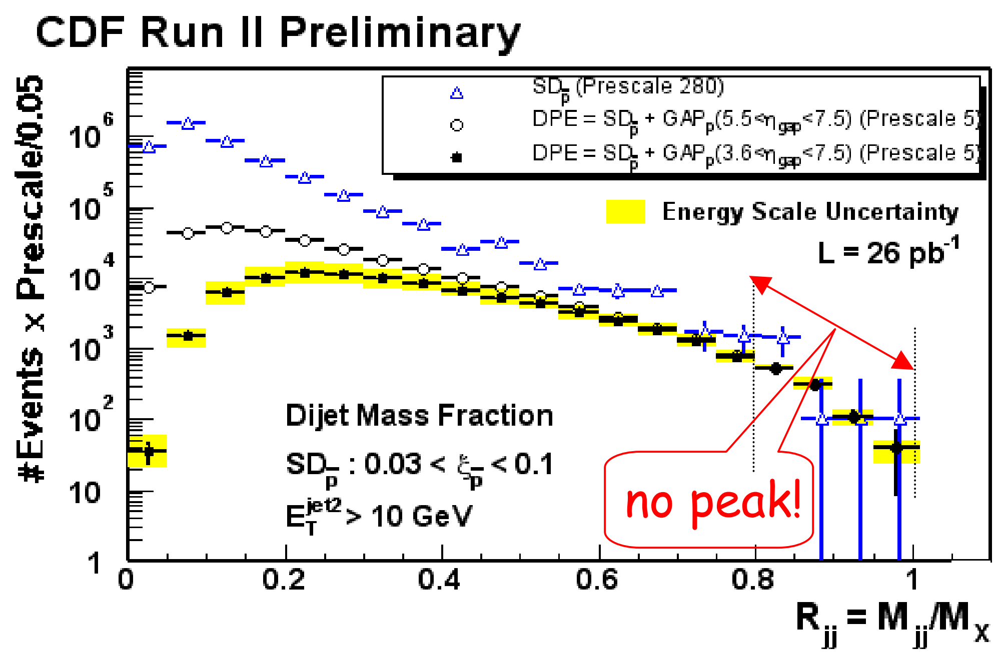
Calibrate on exclusive dijets



Dijet mass fraction

$$R_{jj} = \frac{M_{jj}^{cone}}{M_X}$$

E_T^{jet}	$\sigma_{DPE}^{excl\ jj}(R_{jj} > 0.8)$
10 GeV	$970 \pm 65 \pm 272$ pb
25 GeV	$34 \pm 5 \pm 10$ pb

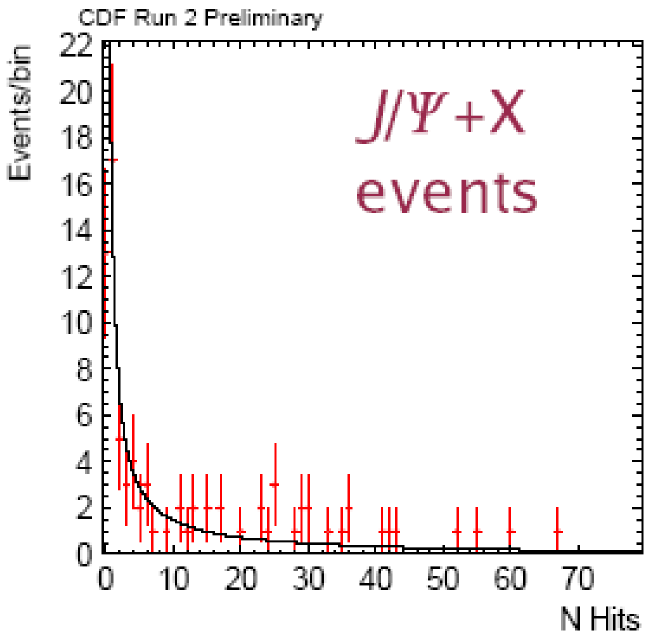


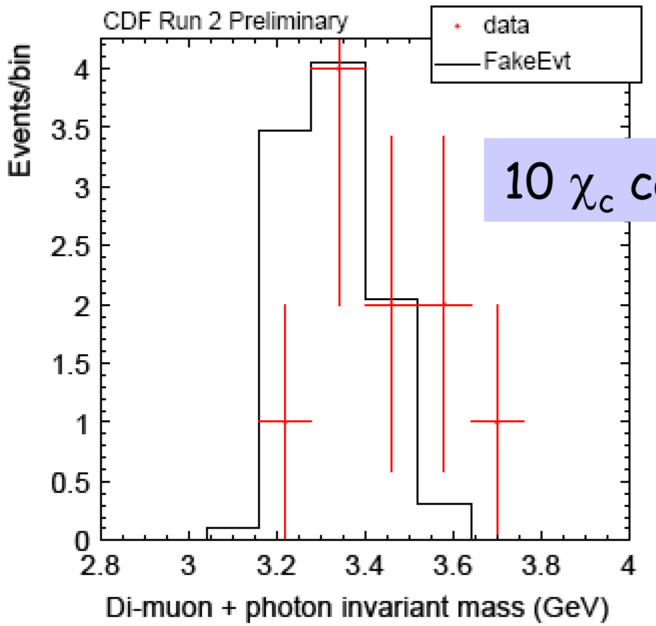
Upper limit for excl DPE-jj consistent with theory

Search for Exclusive χ_c @CDF

$$\bar{p} + p \rightarrow \bar{p} + \chi_c(\rightarrow J/\psi + \gamma) + p$$

- Events are triggered on dimuons
- Select muons with P_T>1.5 GeV, $|\eta|$< 0.6
- Reject cosmic rays using time of flight information
- Select events in J/ψ mass window





10 χ_c candidates

No positive identification of χ_c events
Cross section upper limit comparable to KMR prediction

Merits/Problems/Needs

Merits of CDF Run II diffractive program

- ❑ Measuring ξ **with** calorimeters → full acceptance
  → overlap rejection
- ❑ BSC gap triggers → can take data at high luminosities

But:

- ❑ BSC gap rejects some diffractive events from MP spillover
- ❑ Useful rates too low for many processes, e. g. exclusive b-bbar

Need:

- ❑ Low luminosity runs for calibrations:
  - ➢ ξ-roman pot vs ξ-calorimeter
  - ➢ BSC gap trigger vs roman pot trigger

Also need:

- ❑ $$$ to instrument MPs from current 84 to all 256 channels for EM/hadron discrimination and better jet definition

CONCLUSION

Run II

- CDF has a comprehensive Run II diffractive program
- Modest upgrades & special runs are desirable
  - Full MiniPlug instrumentation
  - Low luminosity ($\sim 10^{30}$) runs for calibrations
  - Data run at 630 GeV

Beyond Run II

- Can think of improvements, but of no compelling diffractive physics that cannot be done in Run II