DIFFRACTIVE PARTICLE INTERACTIONS

Konstantin Goulianos
The Rockefeller University

Physics Colloquium

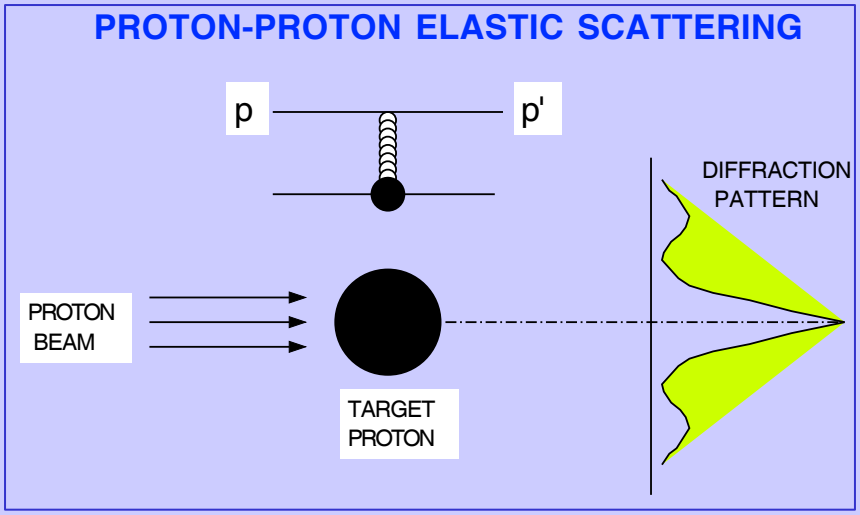


Brown University
11 April 2005

http://physics.rockefeller.edu/dino/my.html

What is Particle Diffraction?

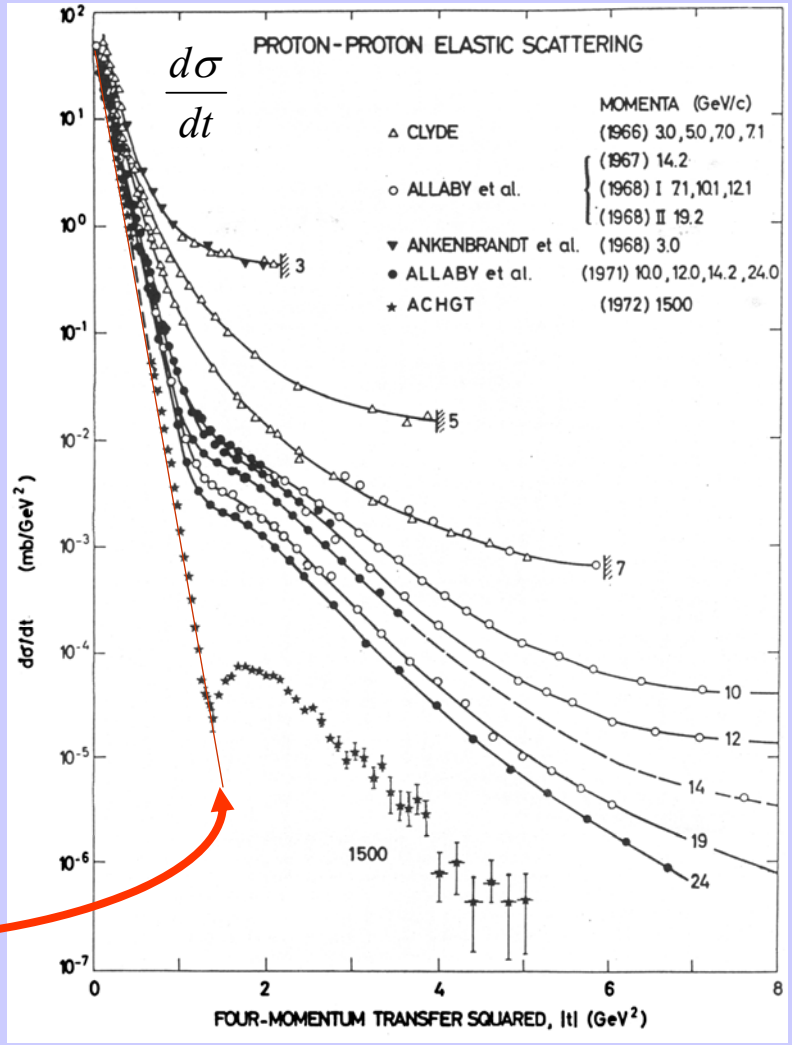
Elastic Scattering



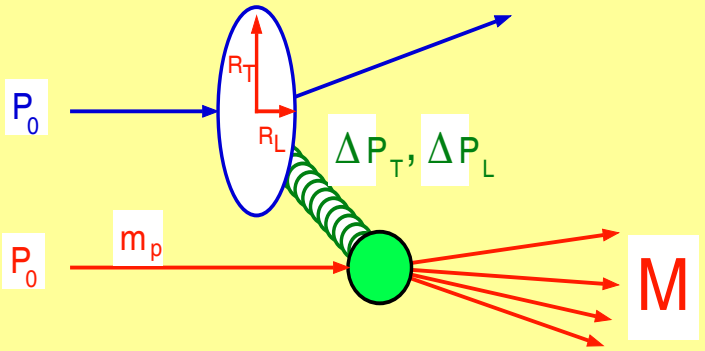
COHERENCE $\Delta p_T \sim \frac{1}{\lambda}$

$$\frac{d\sigma}{dt} \sim e^{bt} \sim e^{-\frac{R^2}{4}(p\theta)^2}$$

$$R = \frac{1}{m_\pi} \Rightarrow b \approx 13 \left(\frac{GeV}{c}\right)^{-2}$$

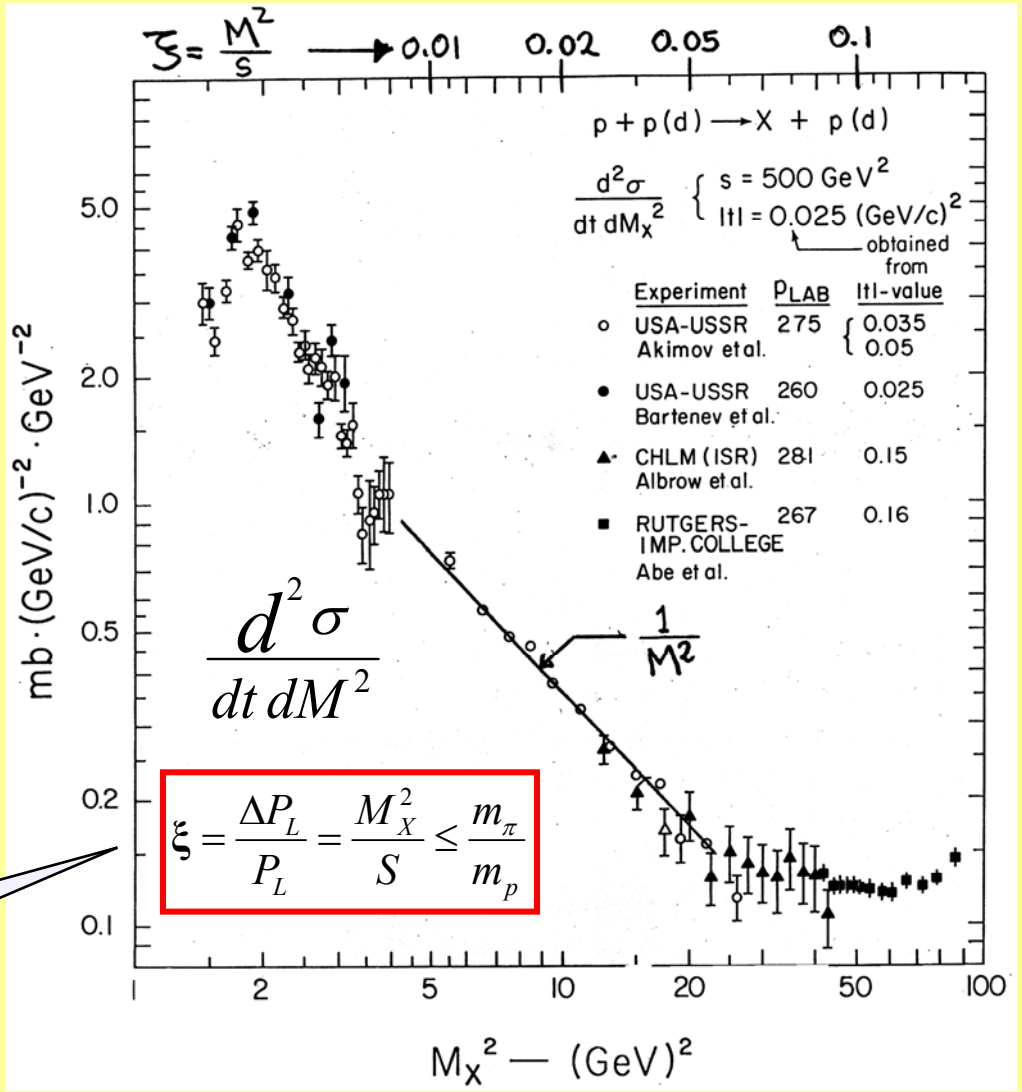


Diffraction Dissociation

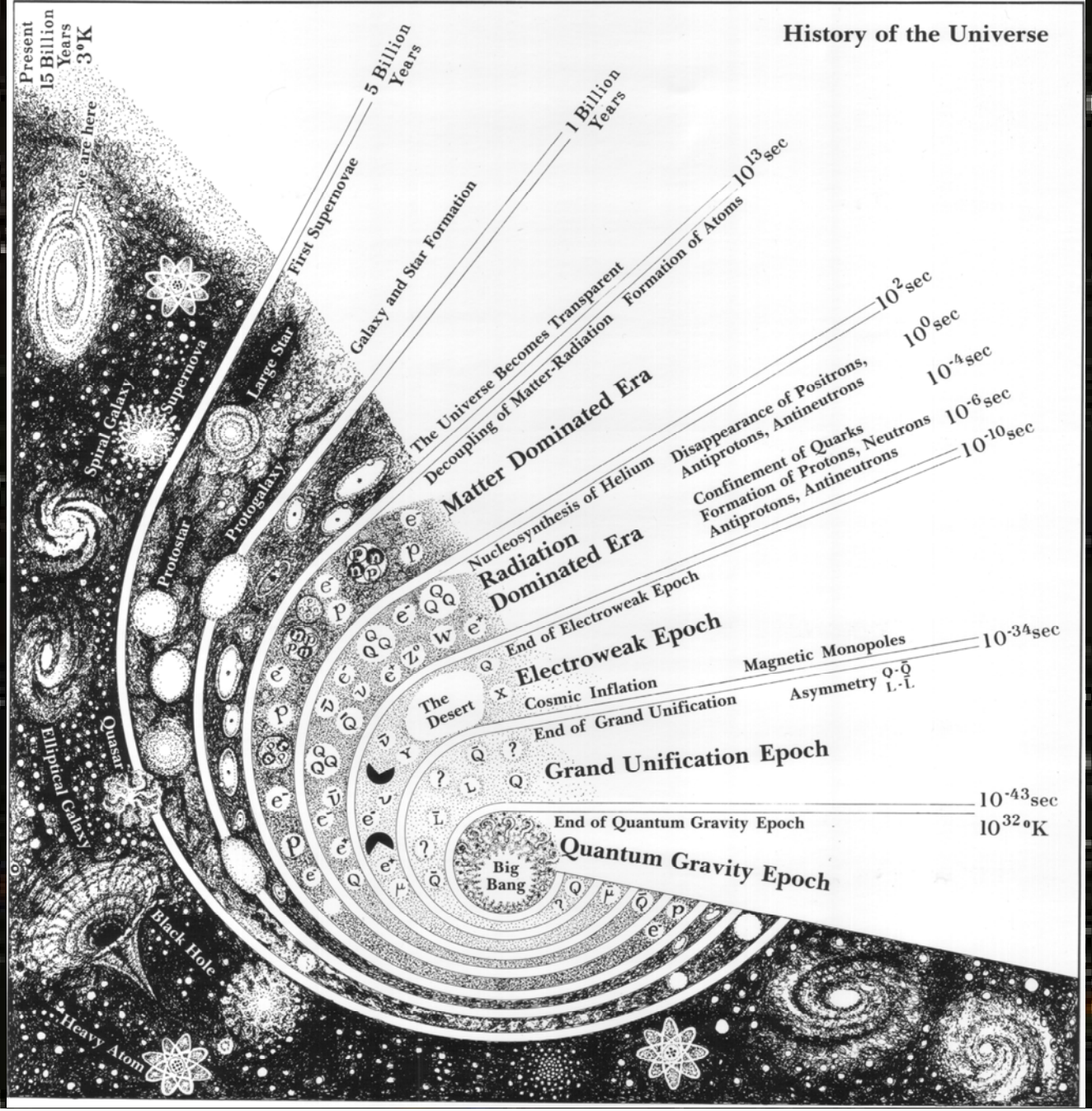


$$\Delta p_L \sim \frac{1}{\lambda}$$

COHERENCE CONDITION



Why Study Particle Diffraction?


History of the Universe
Present
15 Billion Years
3°K
we are here
5 Billion Years
1 Billion Years
10^{13}sec
First Supernovae
Galaxy and Star Formation
The Universe Becomes Transparent
Decoupling of Matter-Radiation
Formation of Atoms
Spiral Galaxy
Supernova
Large Star
Protostar
Protogalaxy
Matter Dominated Era
10^{2}sec
10^{0}sec
10^{-4}sec
10^{-6}sec
10^{-10}sec
Nucleosynthesis of Helium
Disappearance of Positrons, Antiprotons, Antineutrons
Confinement of Quarks
Formation of Protons, Neutrons
Antiprotons, Antineutrons
Radiation Dominated Era
End of Electroweak Epoch
Electroweak Epoch
10^{-34}sec
The Desert
Cosmic Inflation
Magnetic Monopoles
End of Grand Unification
Asymmetry $Q\text{-}\bar{Q}$ $L\text{-}\bar{L}$
Grand Unification Epoch
10^{-43}sec
End of Quantum Gravity Epoch
10^{32}°K
Big Bang
Quantum Gravity Epoch
Quasar
Elliptical Galaxy
Black Hole
Heavy Atom

Black Hole Eats Star!

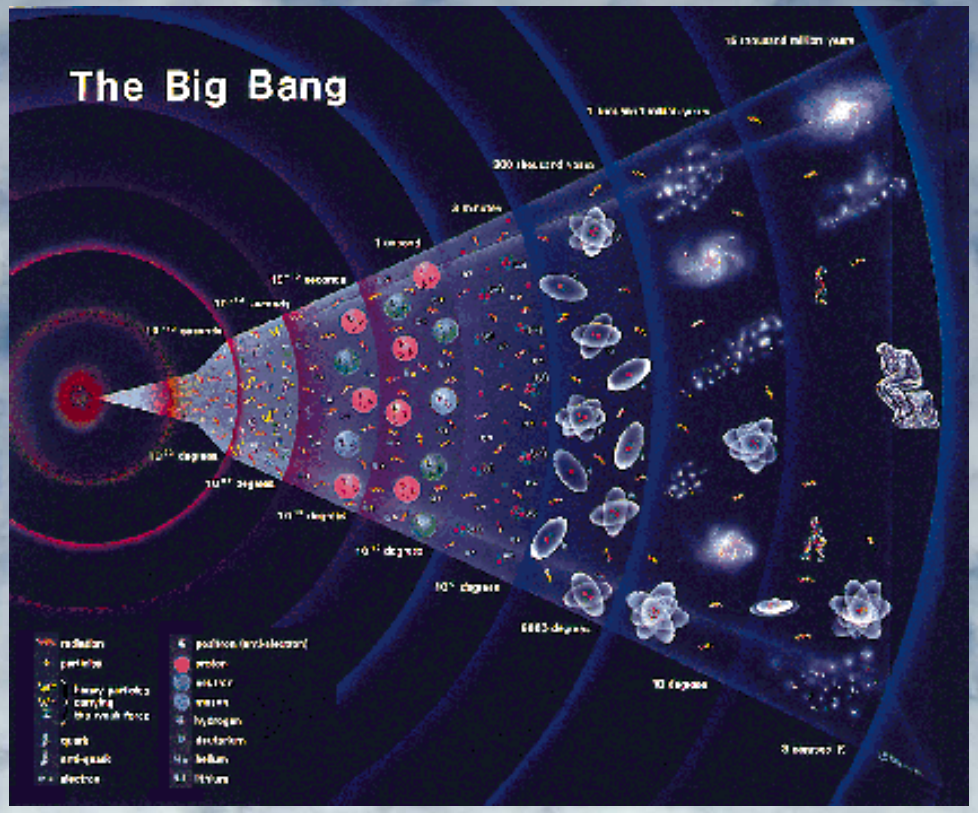


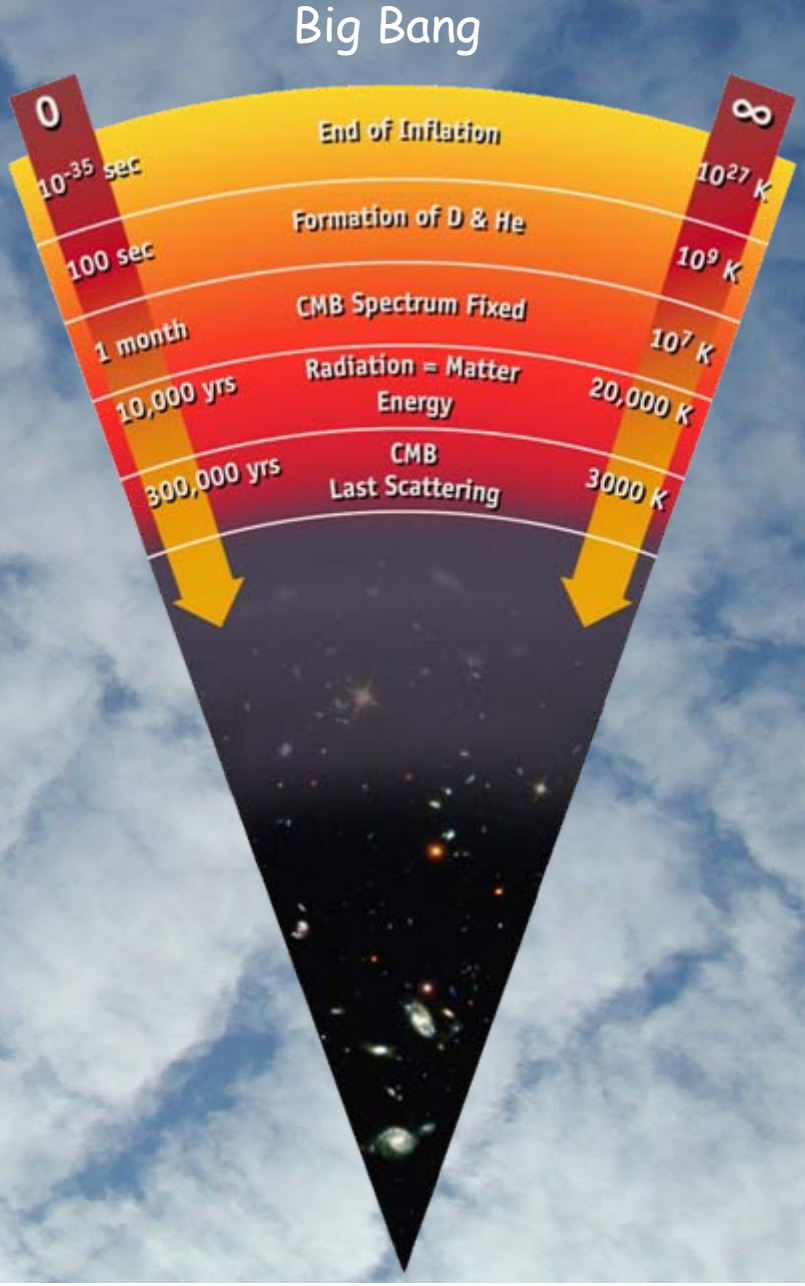
AP Photo

In this illustration, an arrow points to the doomed star. Part of its mass, shown by the white stream, was swallowed by the black hole.

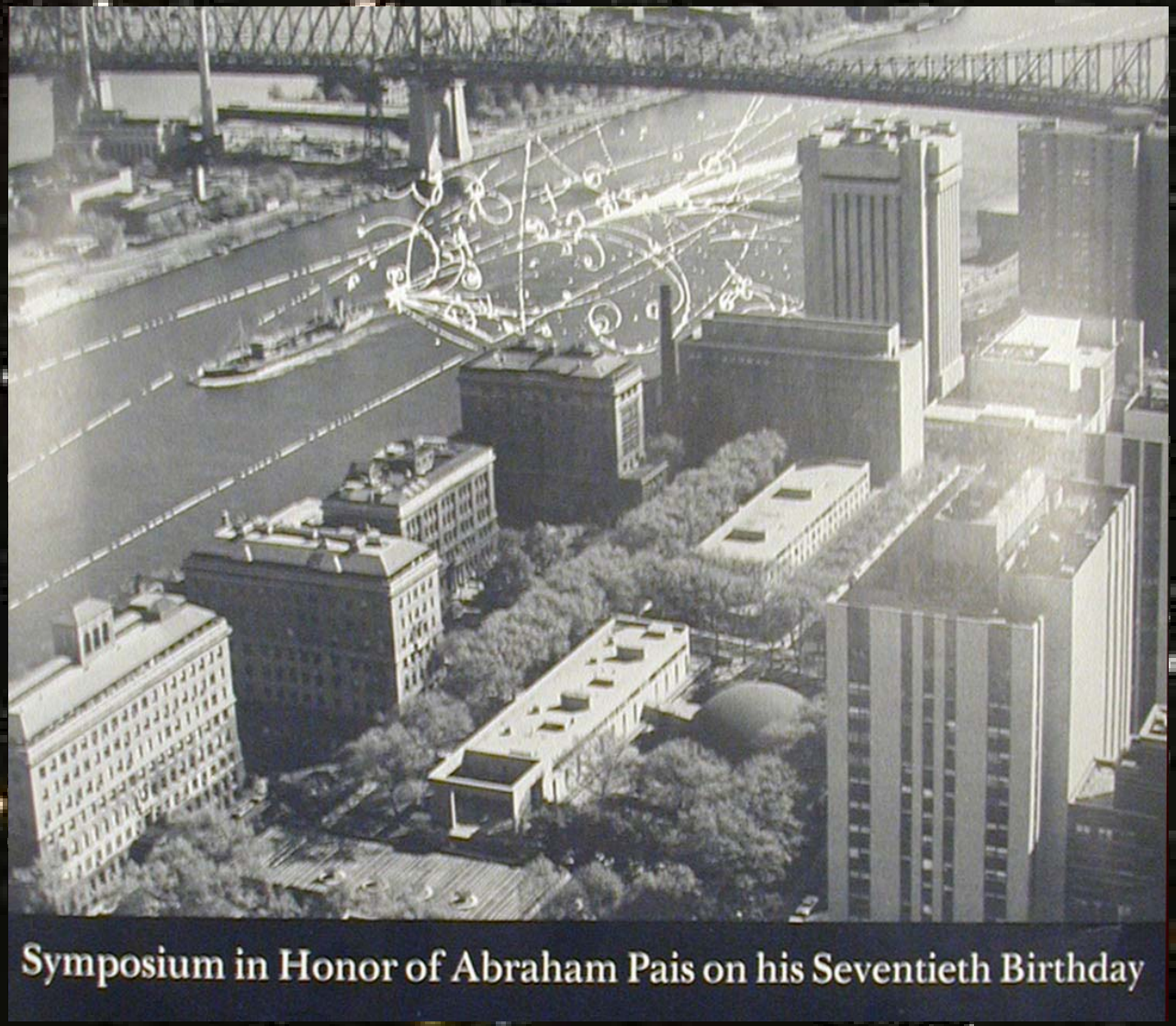
Star No Match for Black Hole

Big bang!

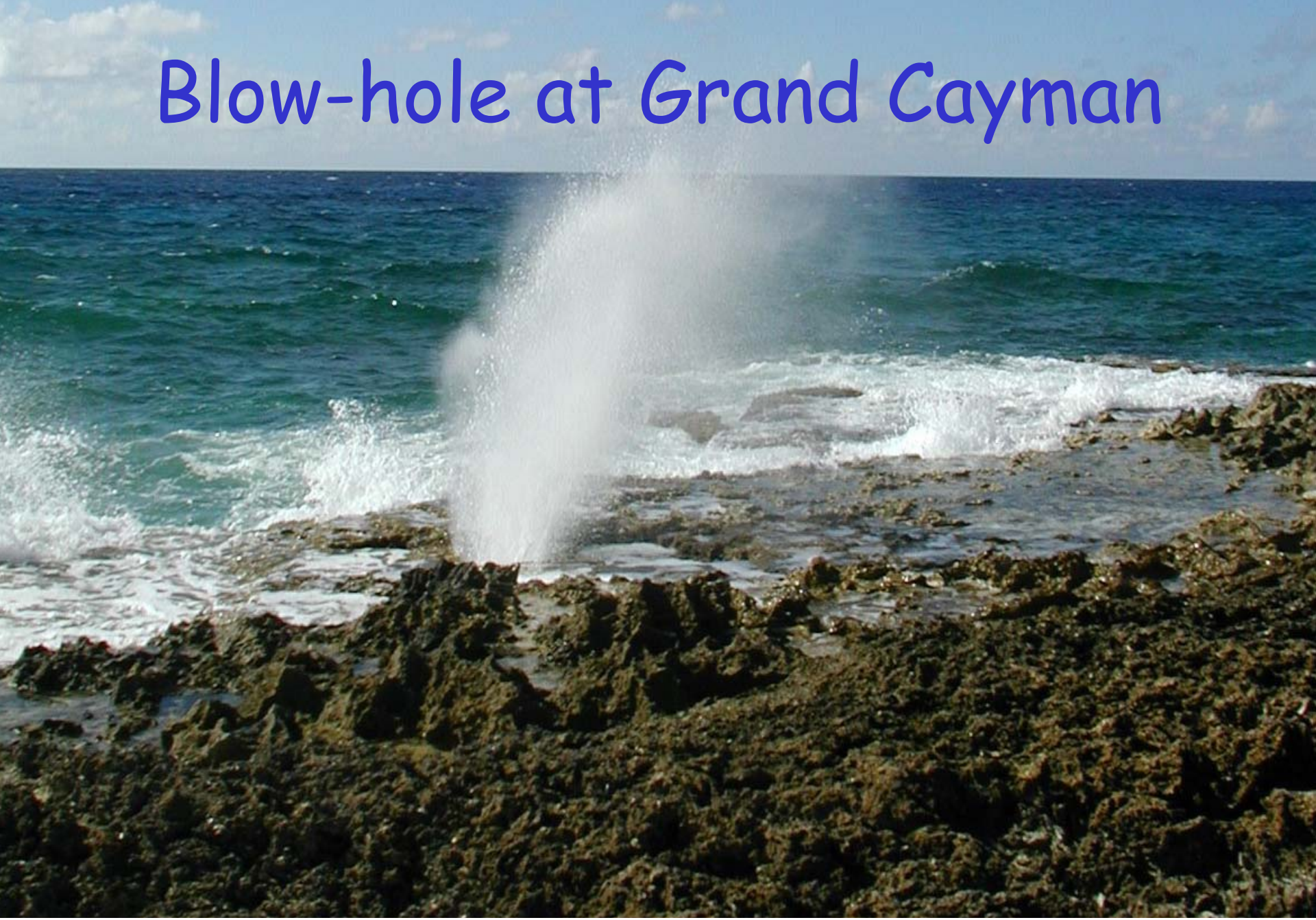

The Big Bang


Big Bang
0
∞
End of Inflation
10^-35 sec
10^27 K
Formation of D & He
100 sec
10^9 K
CMB Spectrum Fixed
1 month
10^7 K
Radiation = Matter
Energy
10,000 yrs
20,000 K
CMB
Last Scattering
300,000 yrs
3000 K

Big Bang on the East River!

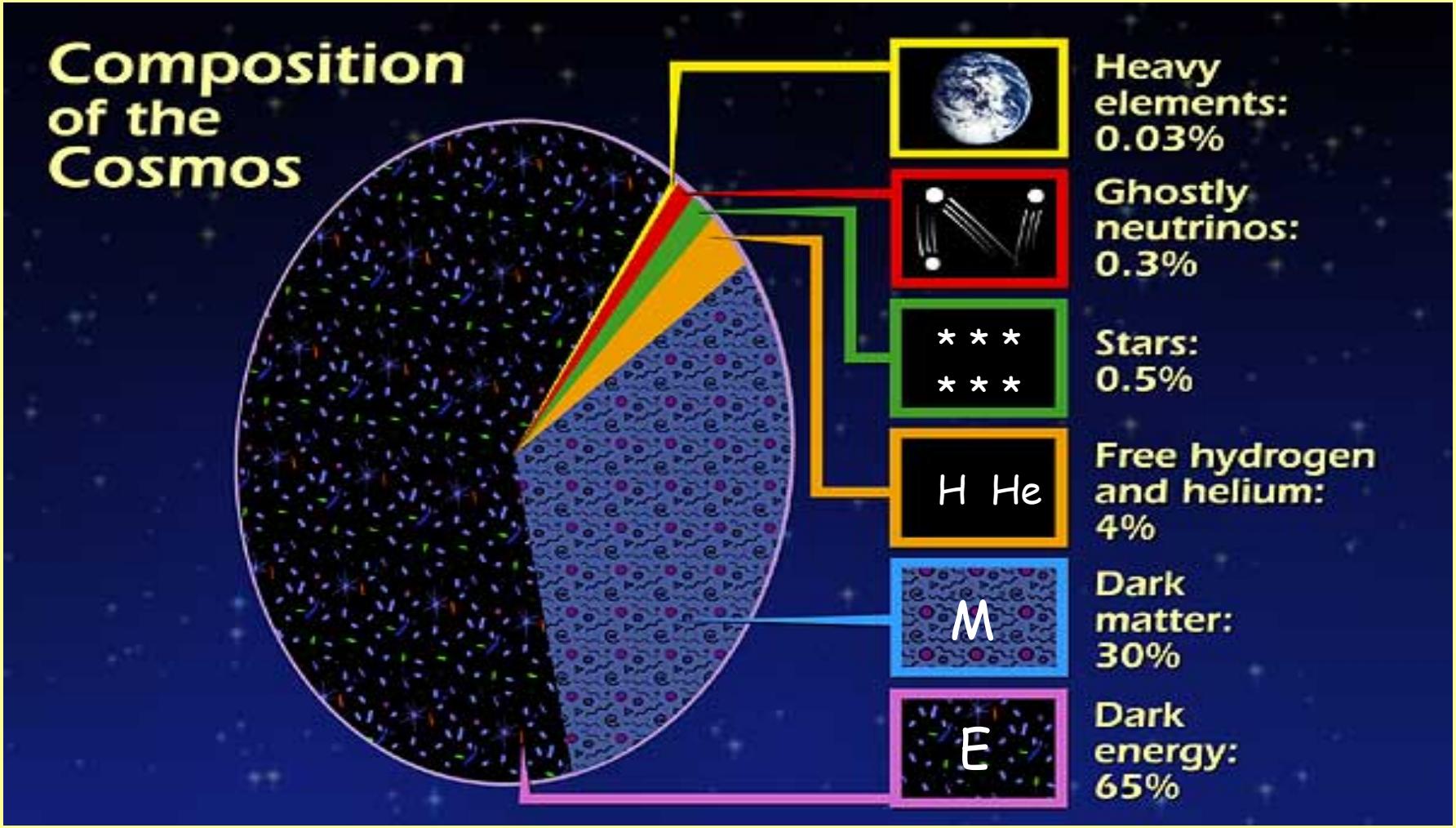


Blow-hole at Grand Cayman



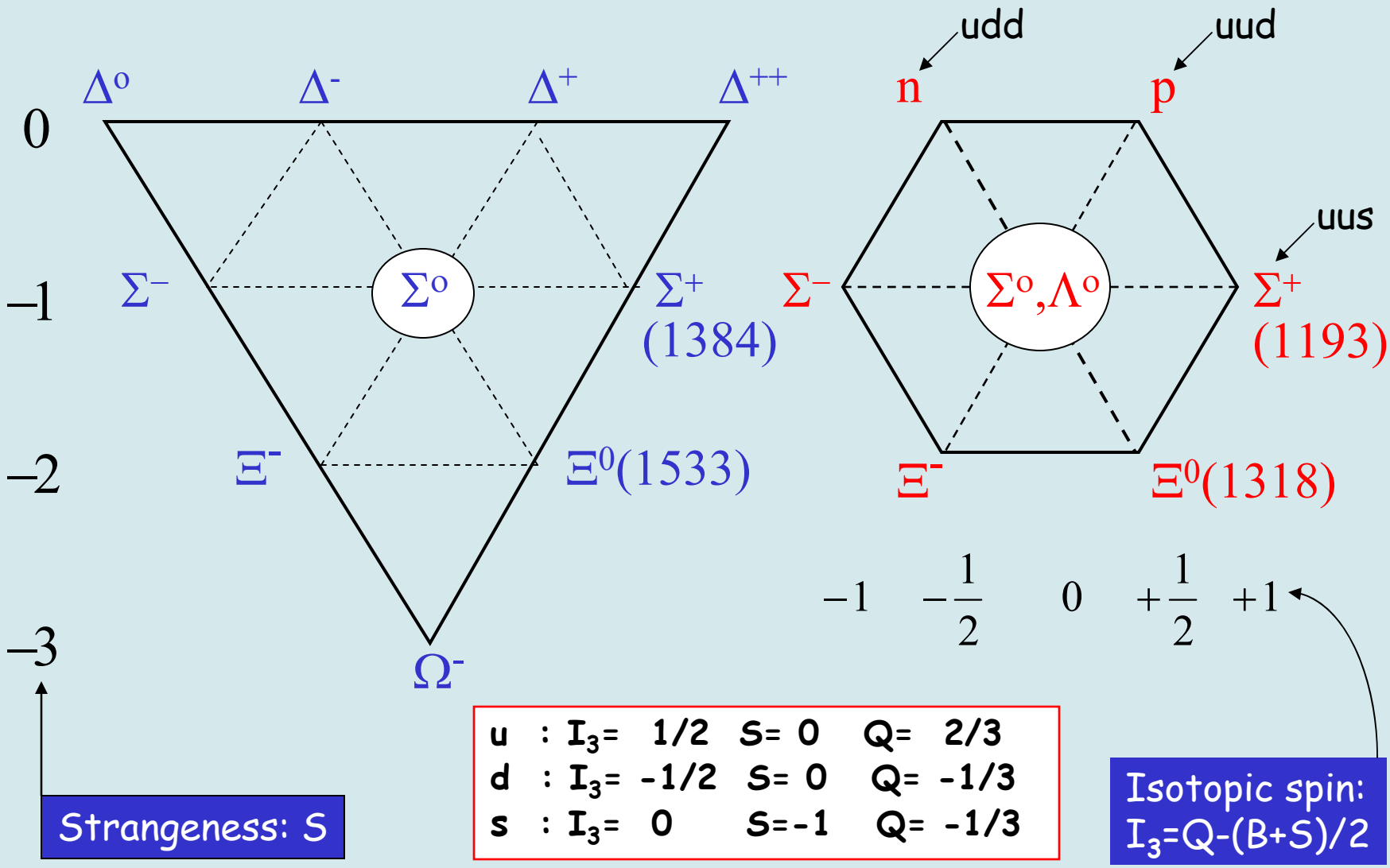
Why should I care about Particle Diffraction?

What is Dark Energy?



SU3
The Standard Model
String theory
QCD

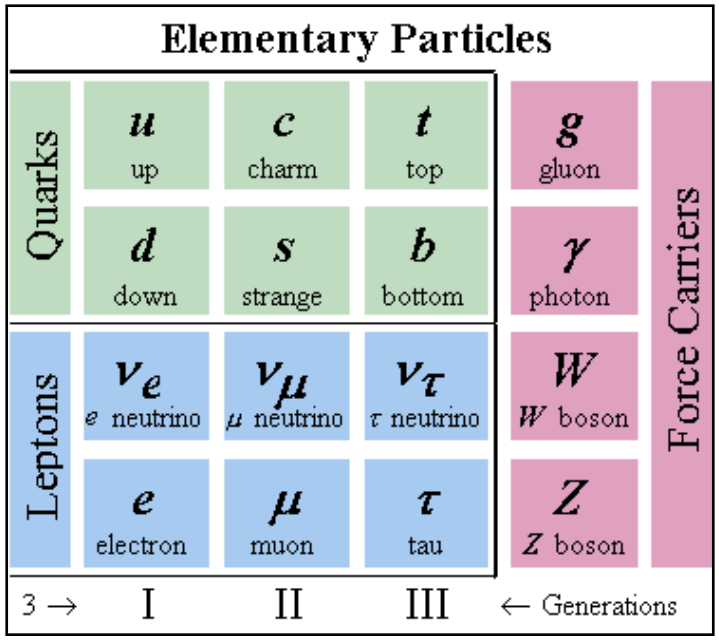
SU3: Law and Order in the Particle Zoo





The Standard Model

Glashow, Salam, and Weinberg



$$L = -\frac{1}{4}W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

$$+\bar{L}\gamma^{\mu}\left(i\partial_{\mu} - g\frac{1}{2}\tau.W_{\mu} - g'\frac{Y}{2}B_{\mu}\right)L$$

$$+\bar{R}\gamma^{\mu}\left(i\partial_{\mu} - g'\frac{Y}{2}B_{\mu}\right)R$$

$$+\left|\left(i\partial_{\mu} - g\frac{1}{2}\tau.W_{\mu} - g'\frac{Y}{2}B_{\mu}\right)\phi\right|^2 - V(\phi)$$

$$-\left(G_1\bar{L}\phi R + G_2\bar{L}\phi_c R + \text{hermitian conjugate}\right)$$

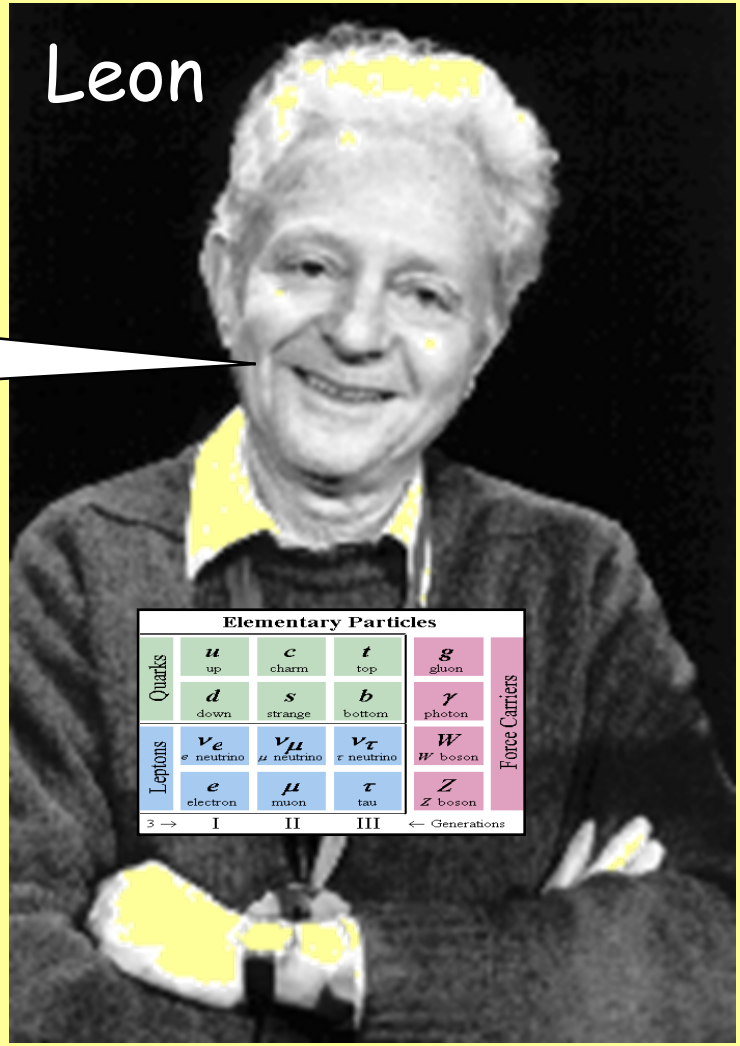
$M\gamma, g = 0$ $M_{W,Z} \sim 80\, M_p$ $M_{top} \sim M_{gold}$

Higgs field generates Mass !

	Force	Strength
g	→ strong	1
γ	→ electromagnetic	10^{-2}
W, Z	→ weak	10^{-14}

Leon & the SM

A good theory should fit on a T-shirt!



But what about interactions?

$$L = -\frac{1}{4}\mathrm{W}_{\mu\nu}\mathrm{W}^{\mu\nu} - \frac{1}{4}\mathrm{B}_{\mu\nu}\mathrm{B}^{\mu\nu}$$

$$+\bar{\mathrm{L}}\gamma^{\mu}\left(i\partial_{\mu} - g\frac{1}{2}\tau.\mathrm{W}_{\mu} - g'\frac{\mathrm{Y}}{2}\mathrm{B}_{\mu}\right)\mathrm{L}$$

$$+\bar{\mathrm{R}}\gamma^{\mu}\left(i\partial_{\mu} - g'\frac{\mathrm{Y}}{2}\mathrm{B}_{\mu}\right)\mathrm{R}$$

$$+\left|\left(i\partial_{\mu} - g\frac{1}{2}\tau.\mathrm{W}_{\mu} - g'\frac{\mathrm{Y}}{2}\mathrm{B}_{\mu}\right)\phi\right|^{2} - \mathrm{V}(\phi)$$

The Peon

$$-\left(\mathrm{G}_1\bar{\mathrm{L}}\phi\mathrm{R} + \mathrm{G}_2\bar{\mathrm{L}}\phi_c\mathrm{R} + \text{hermitian conjugate}\right)$$

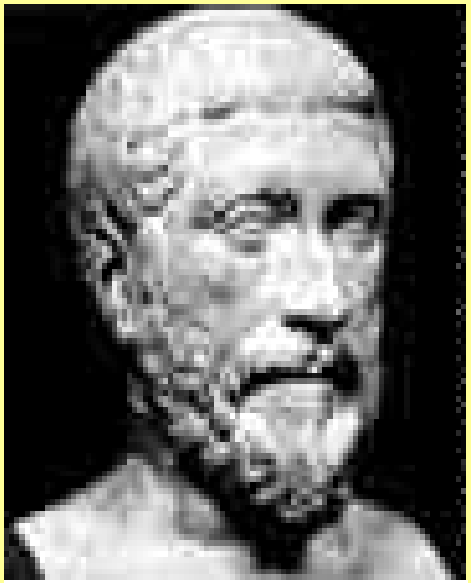
AND WHAT ABOUT GRAVITY?

String Theory, then?

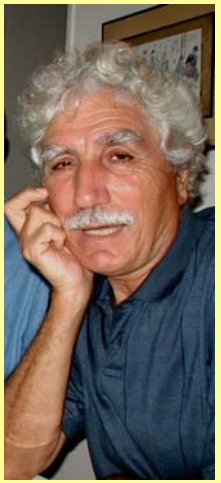
Particles correspond to the vibration modes of a string in 10 dimensions

Gravity is included!

Pythagoras applied it to music in 400 BC:
1+2+3+4=10







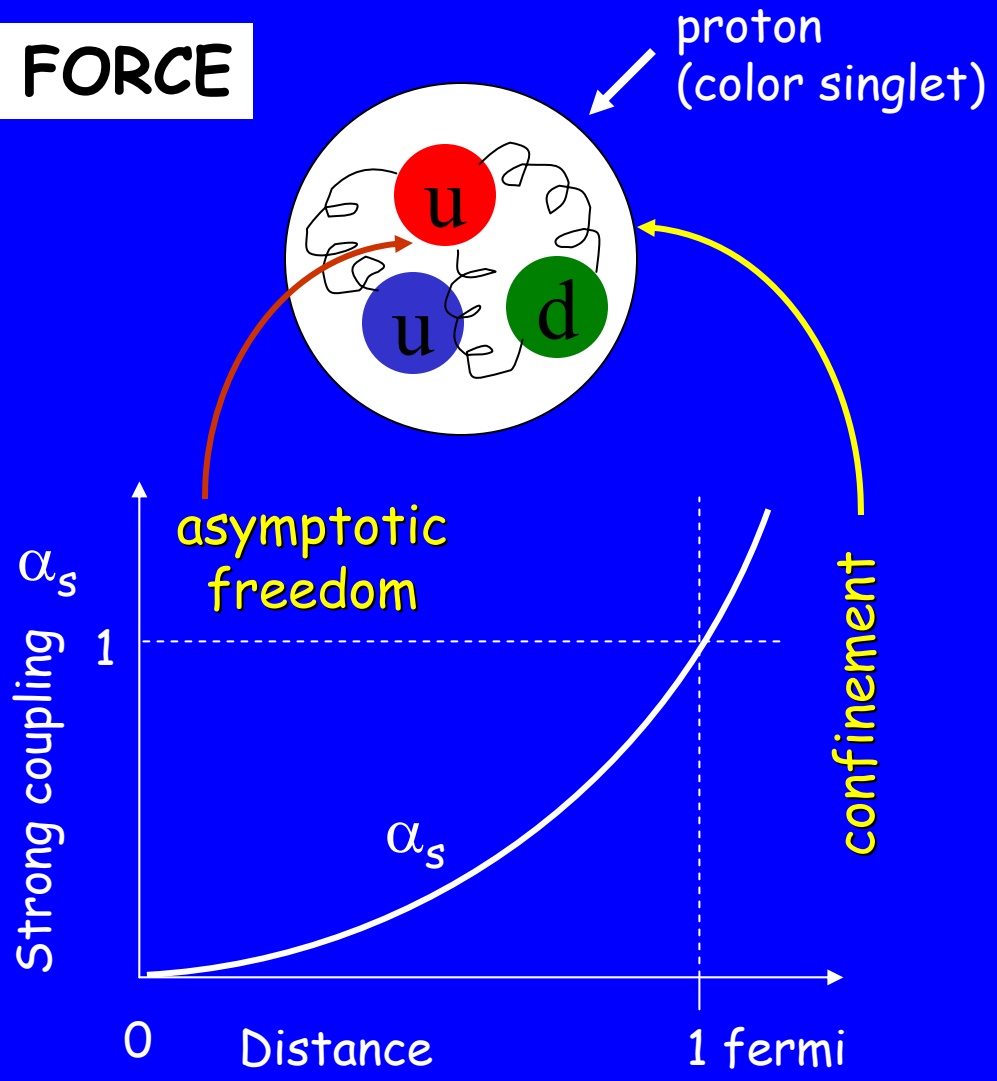
And it surely makes an interesting T-shirt!

QCD – Quantum Chromo-Dynamics

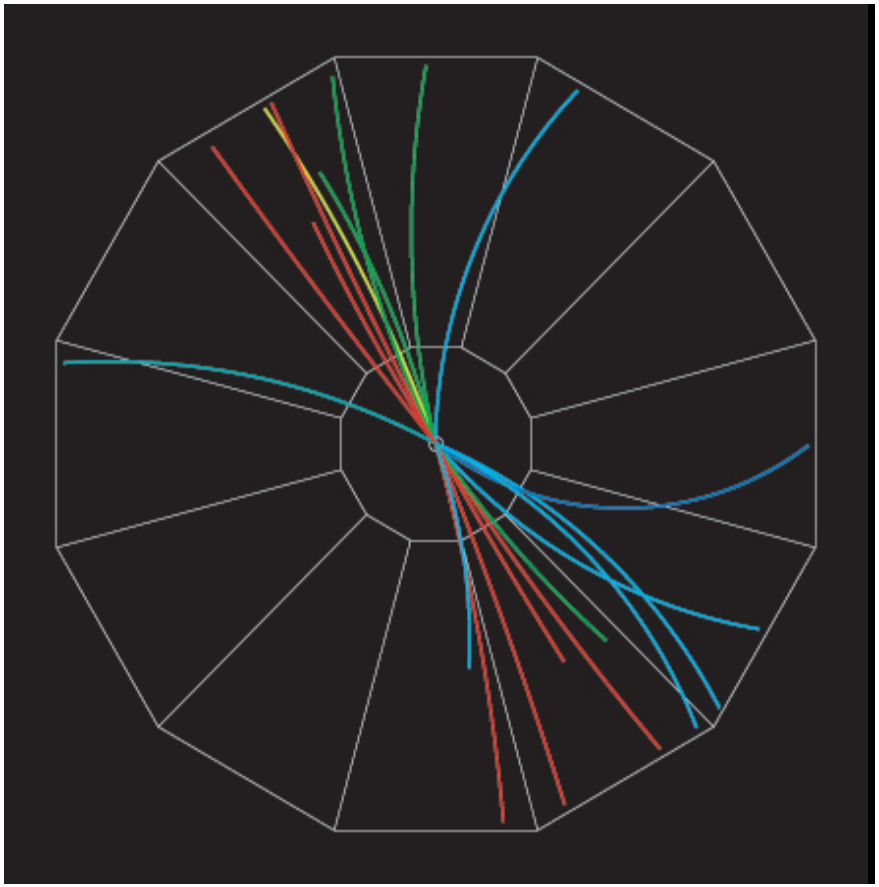
The Theory of Strong Interactions

COLOR FORCE





Collisions and Explosions





Diffractive Interactions



Suren Bagdasarov



Andrei Solodsky



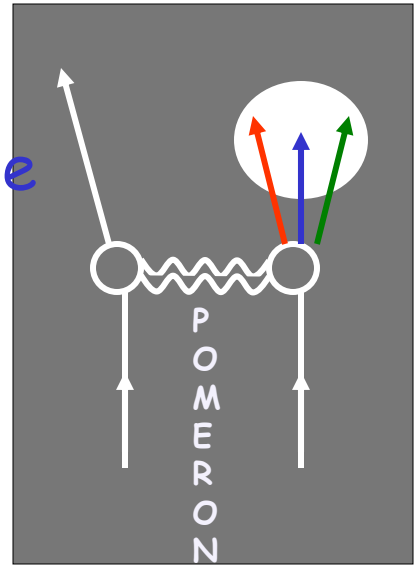
Kenichi Hatakeyama

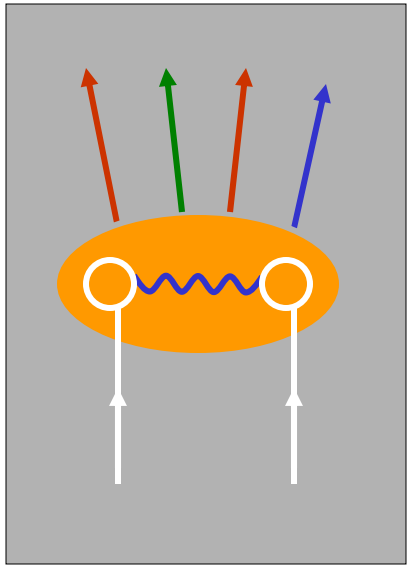
Diffractive:

colorless exchange

Protons retain their quantum numbers

ENERGY ESCAPES





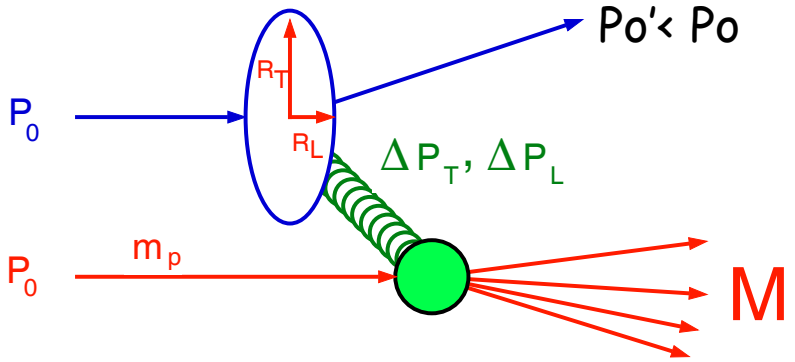
Non-diffractive:

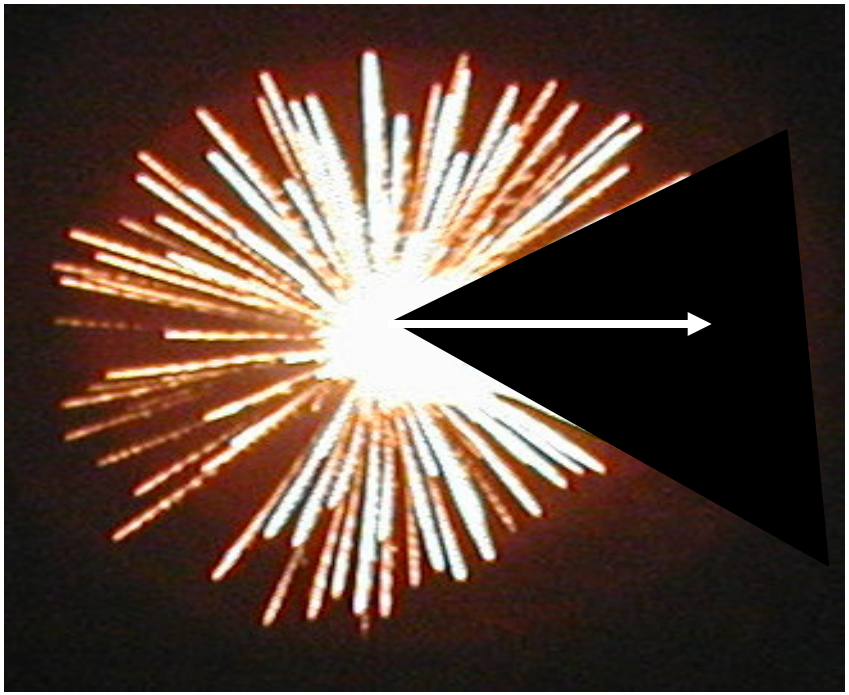
color exchange

Protons acquire color and break apart

CONFINEMENT

Asymmetric explosion





Rapidity

p_T -limited transverse momentum



p_L

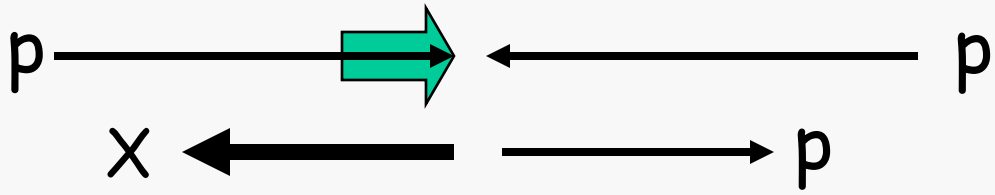


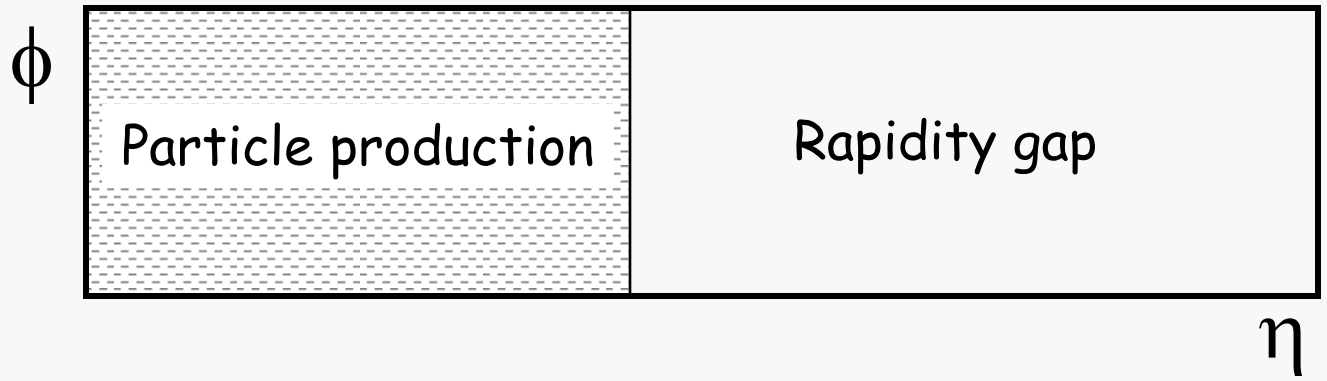
$$\text{rapidity}: \quad y = \frac{1}{2}\ln\frac{E + p_L}{E - p_L} = \frac{E + p_L}{\sqrt{p_T^2 + m^2}}$$

$$\text{pseudorapidity}: \quad (m = 0) \quad \eta = -\ln\tan\frac{\theta}{2}$$

Rapidity Gaps

Bj, PRD 47 (1993) 101: regions of (pseudo)rapidity devoid of particles





$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{conctant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2}$$

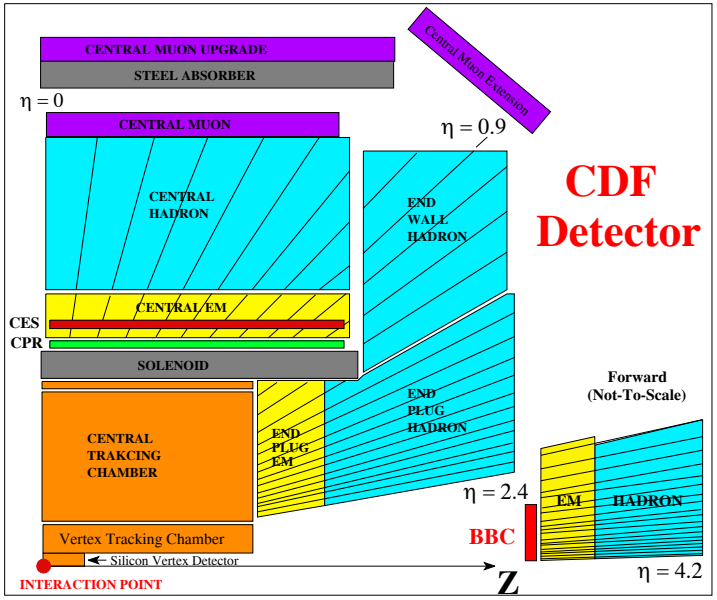
Forty Years of Diffraction

http://physics.rockefeller.edu/dino/my.html

- 1960's BNL: first observation of pp -> pX
- 1970's Fermilab fixed target, ISR, SPS
  → Regge theory & factorization

  Review: KG, Phys. Rep. 101 (1983) 169
- 1980's UA8: diffractive dijets ⇨ hard diffraction
- 1990's Tev Run-I: Regge factorization breakdown
  Tev/ HERA: QCD factorization breakdown
- 21st C Multigap diffraction: restoration of factorization
  Ideal for diffractive studies @ LHC

Run-I A,B: Rapidity Gap Studies



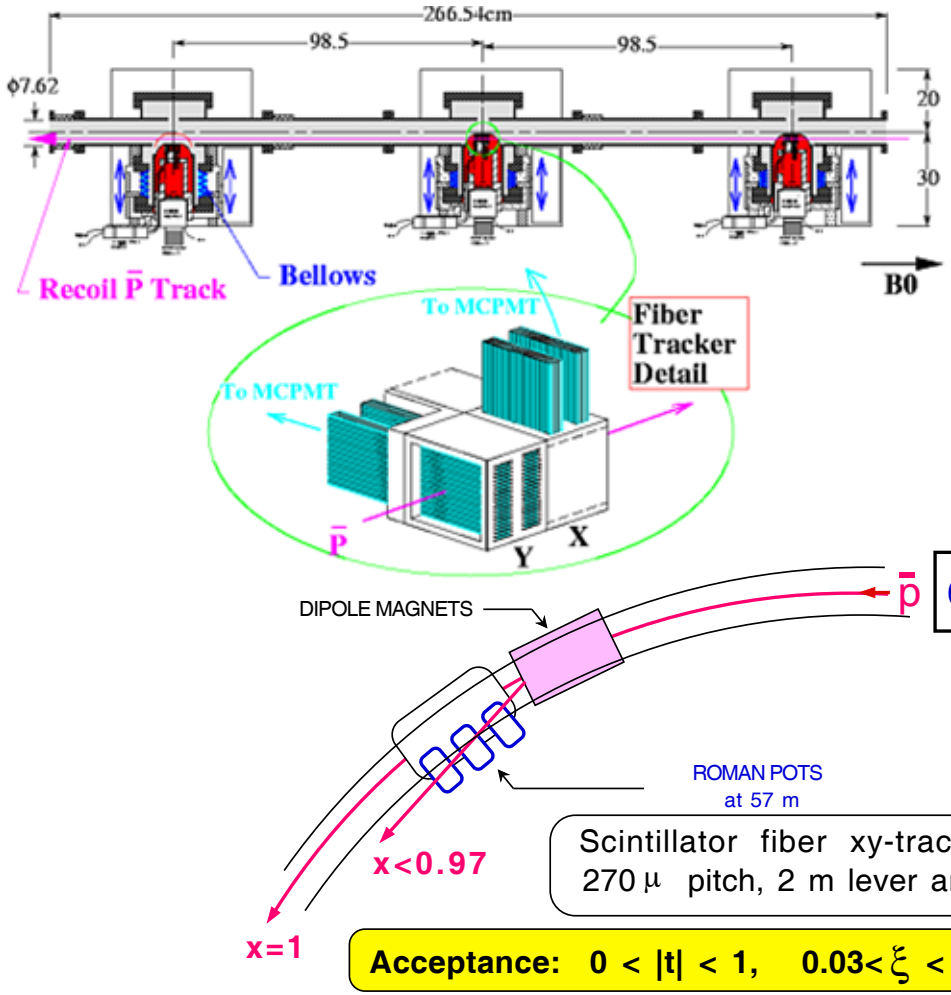
Forward Detectors

BBC $3.2<\eta<5.9$

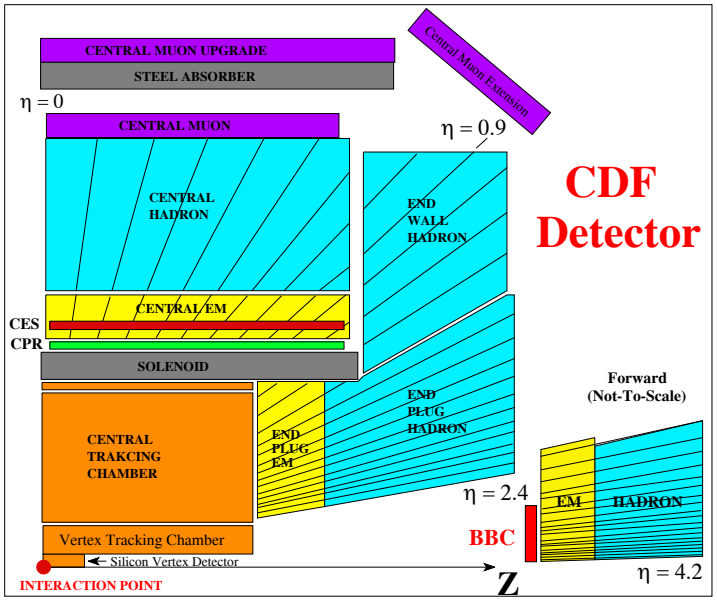
FCAL $2.4<\eta<4.2$

CDF-IC

Run-IC



Run-IA,B

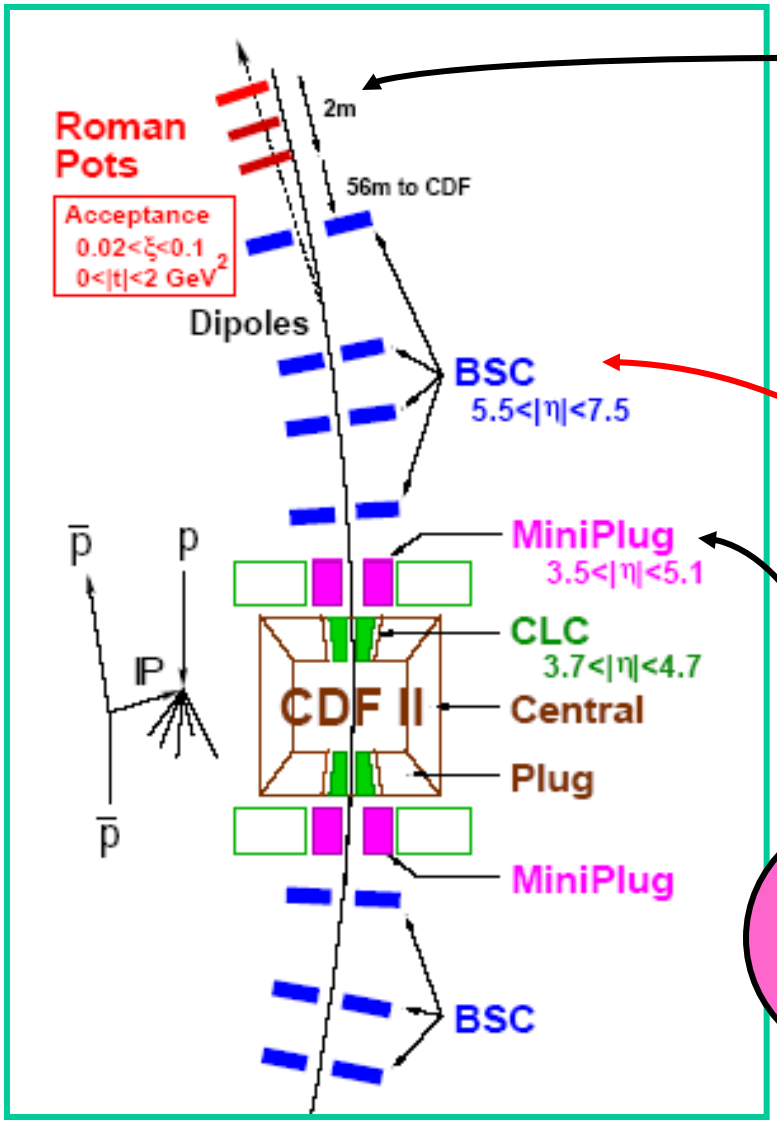


Forward Detectors

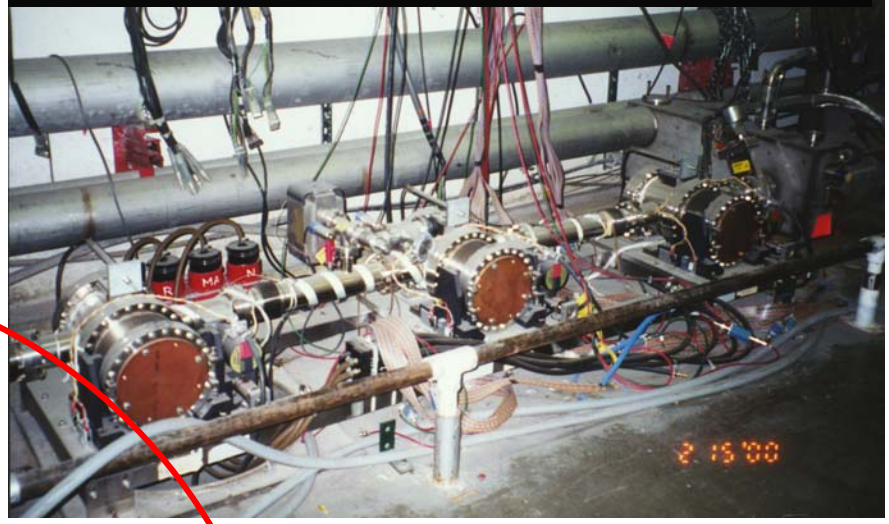
BBC 3.2<η<5.9

FCAL 2.4<η<4.2

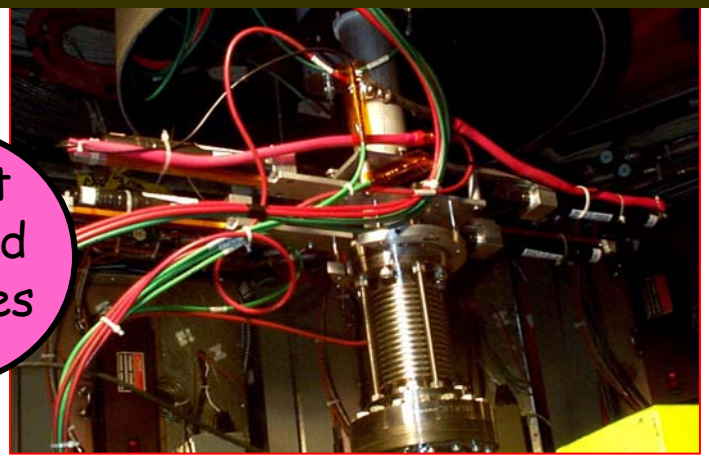
CDF-II



Tag leading p-bar @ 0.02 < ξ< 0.1

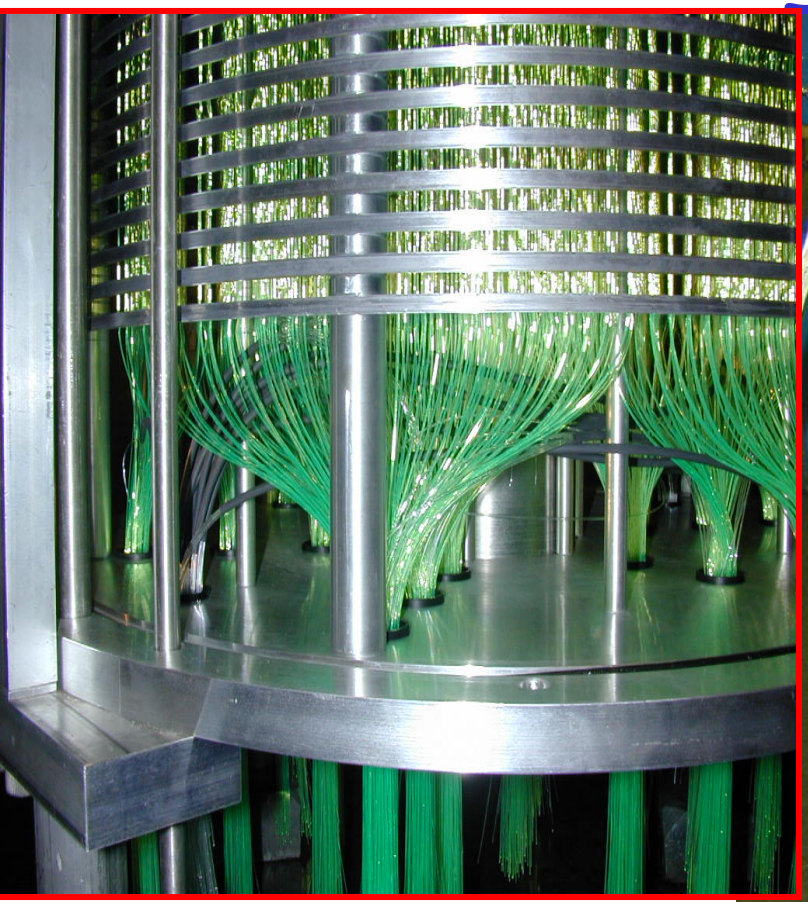


Reject (retain) 95% of ND (SD)events



detect forward particles

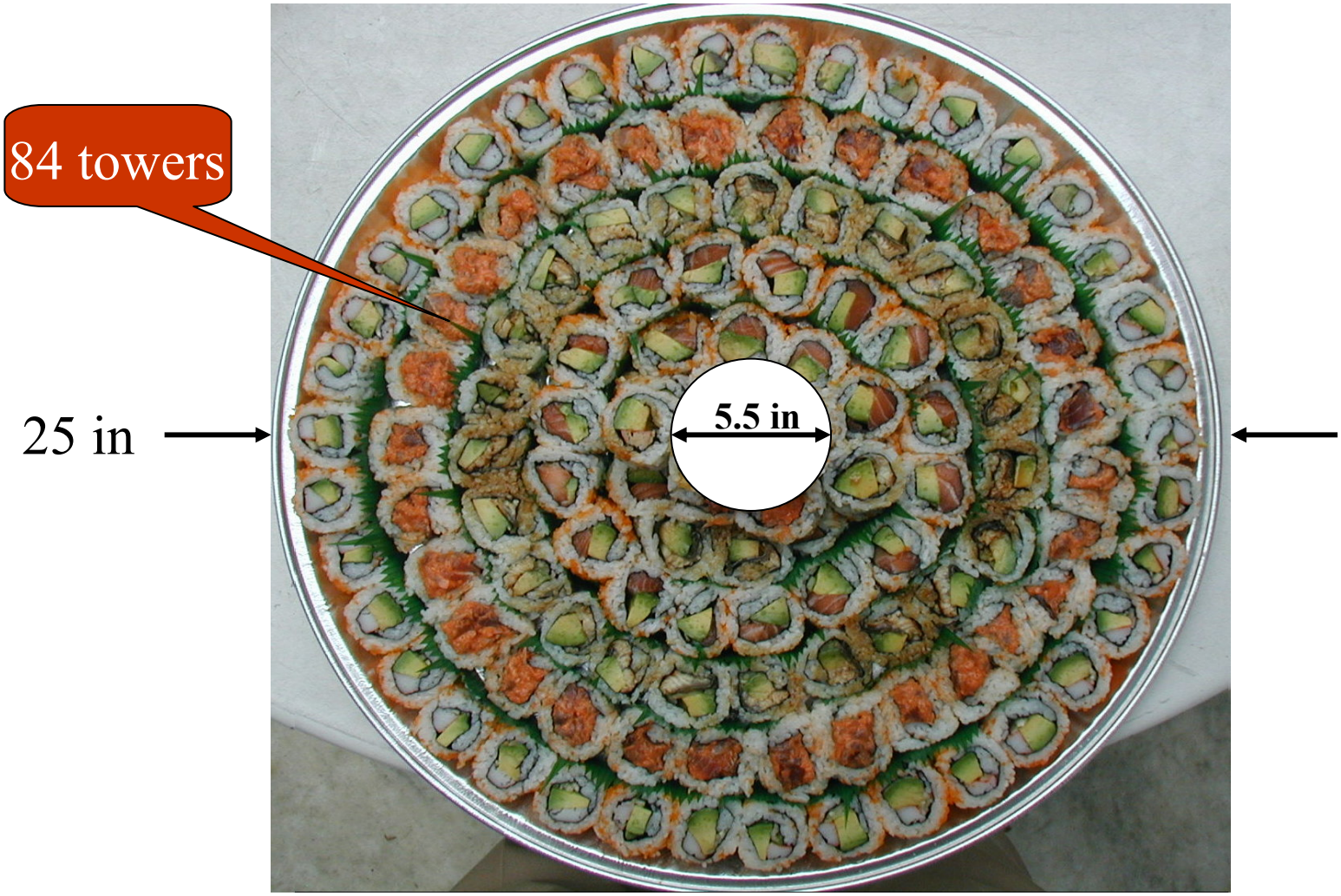
MiniPlug Calorimeter





About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in 36x$\frac{1}{4}$" lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.

Artist's View of MiniPlug

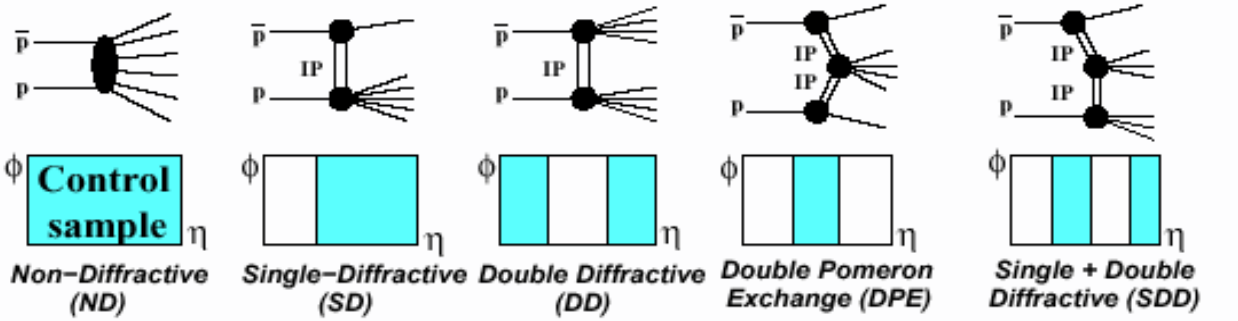


Diffraction@CDF in Run I

16 papers

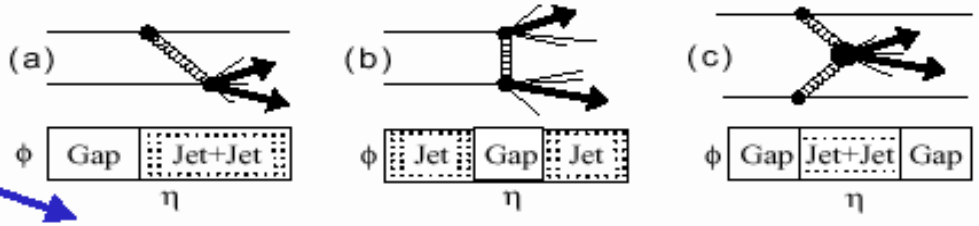
- Elastic scattering PRD 50 (1994) 5518
- Total cross section PRD 50 (1994) 5550
- Diffraction

SOFT diffraction



PRD 50 (1994) 5535 | PRL 87 (2001)141802 | PRL 93(2004)141601 | PRL 91(2003)011802

HARD diffraction



PRL references

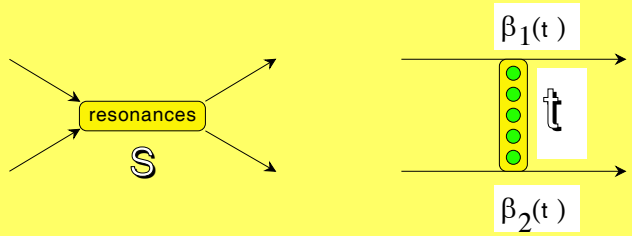
with roman pots

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

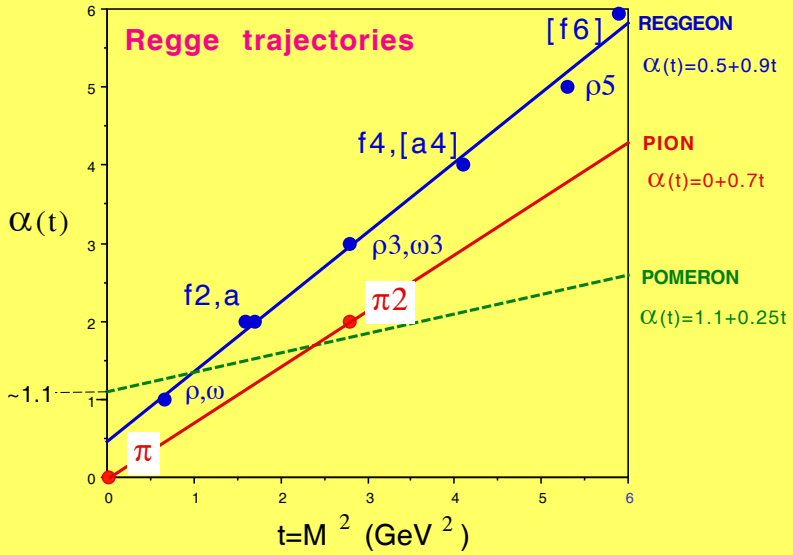
W 78 (1997) 2698	JJ 74 (1995) 855	JJ 85 (2000) 4217
JJ 79 (1997) 2636	JJ 80 (1998) 1156	
b-quark 84 (2000) 232	JJ 81 (1998) 5278	
J/ψ 87 (2001) 241802		

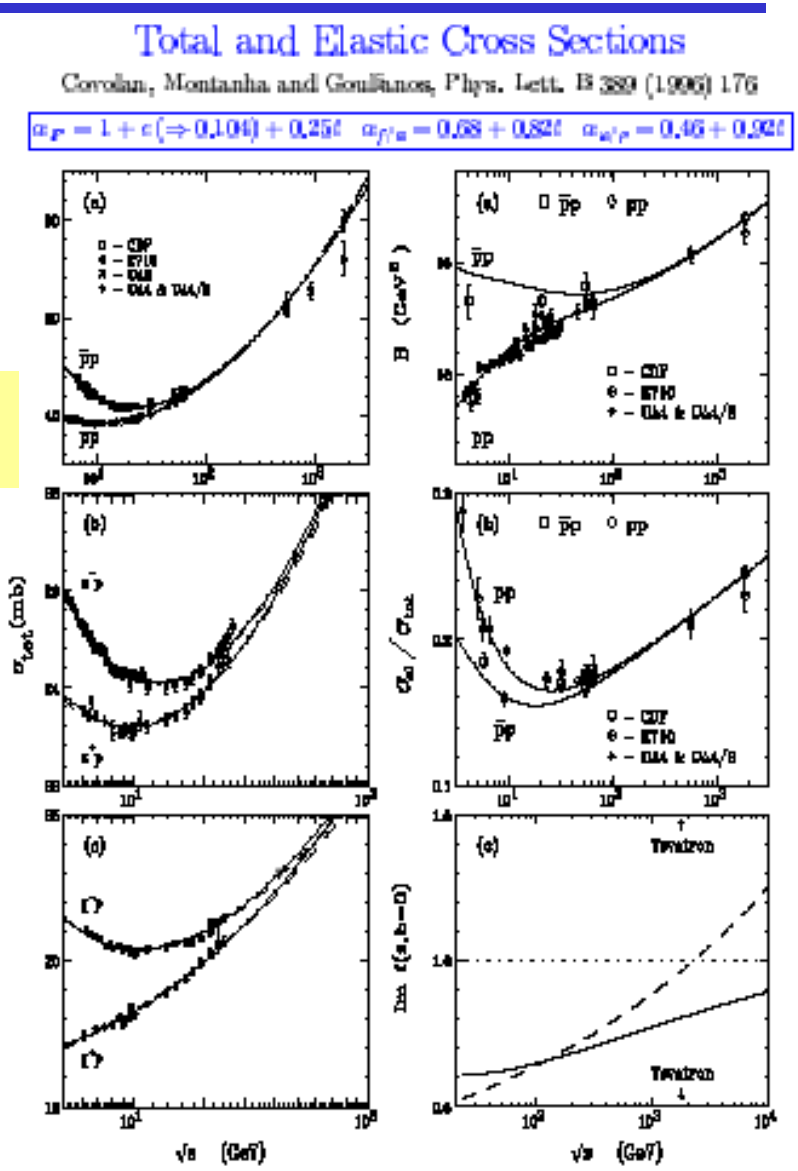
Elastic & Total Cross Sections

REGGE THEORY

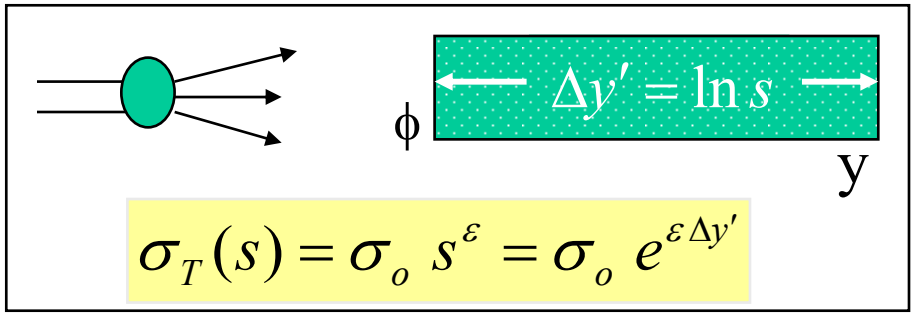


$$T(s,t) = \frac{1}{s}\beta_1(t)\,\beta_2(t)\,s^{\alpha(t)}\,\phi_{a(t)} \qquad \sigma_T = \beta^2(0)\,s^{\alpha(0)-1} \sim s^{\varepsilon}$$





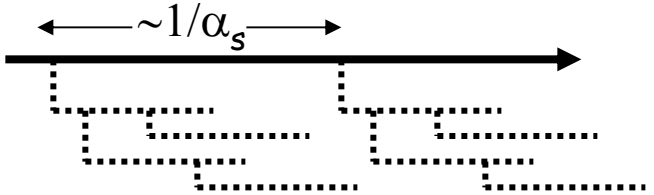
The QCD Connection

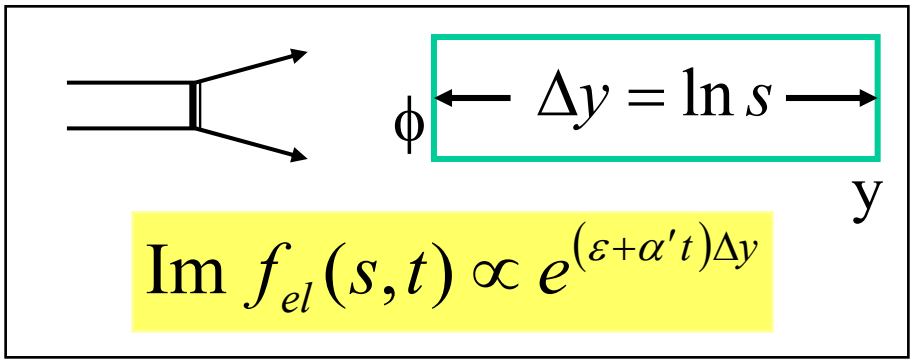


The exponential rise of $\sigma_T(\Delta y')$ is due to the increase of wee partons with $\Delta y'$

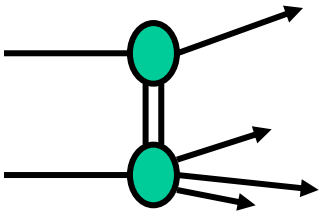
(see E. Levin, An Introduction to Pomerons,Preprint DESY 98-120)

Total cross section:
power law rise with energy





Elastic cross section
forward scattering amplitude



Single Diffraction

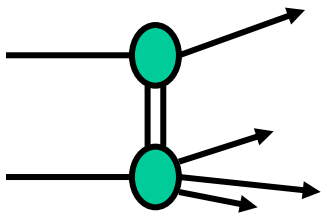
$$\frac{d^2\sigma_{SD}}{dtd\xi} = f_{IP/p}(t,\xi) \bullet \sigma_{IP-\bar{p}}(M_X^2)$$

Pomeron flux

Pomeron-proton total x-section

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

Grows faster than $\sigma_T \sim s^{\varepsilon}$



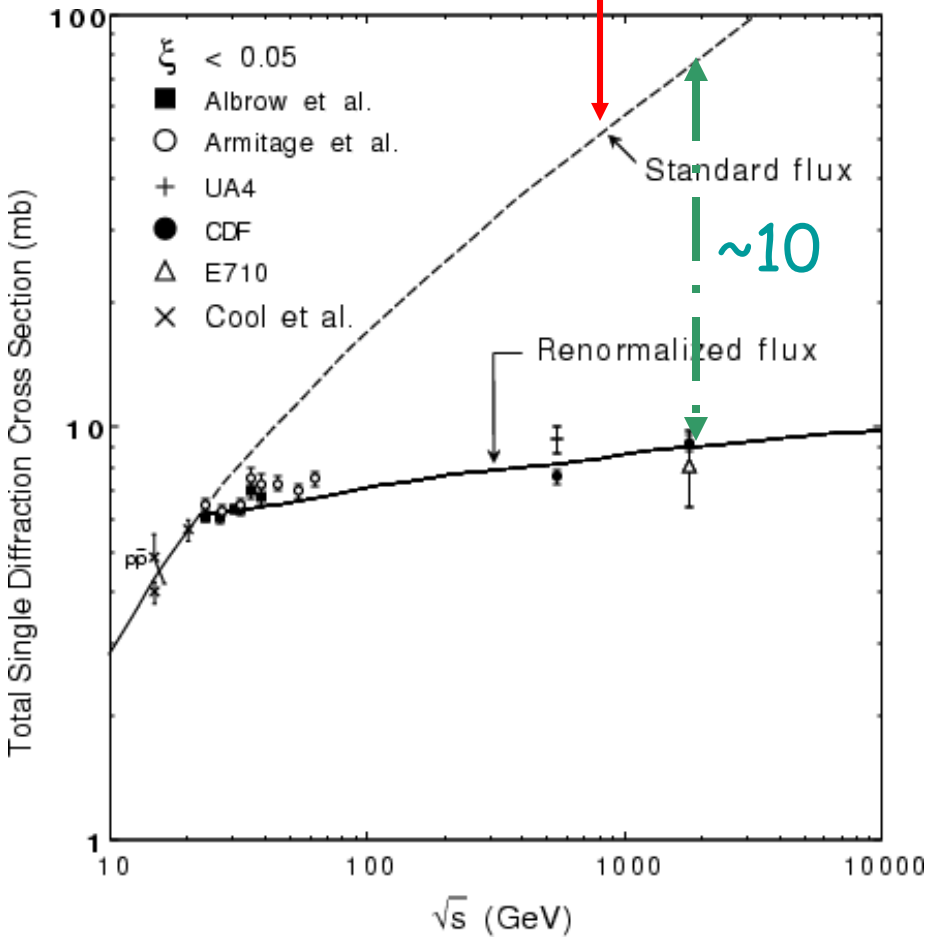
Renormalization

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

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

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

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



KG, PLB 358 (1995) 379

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

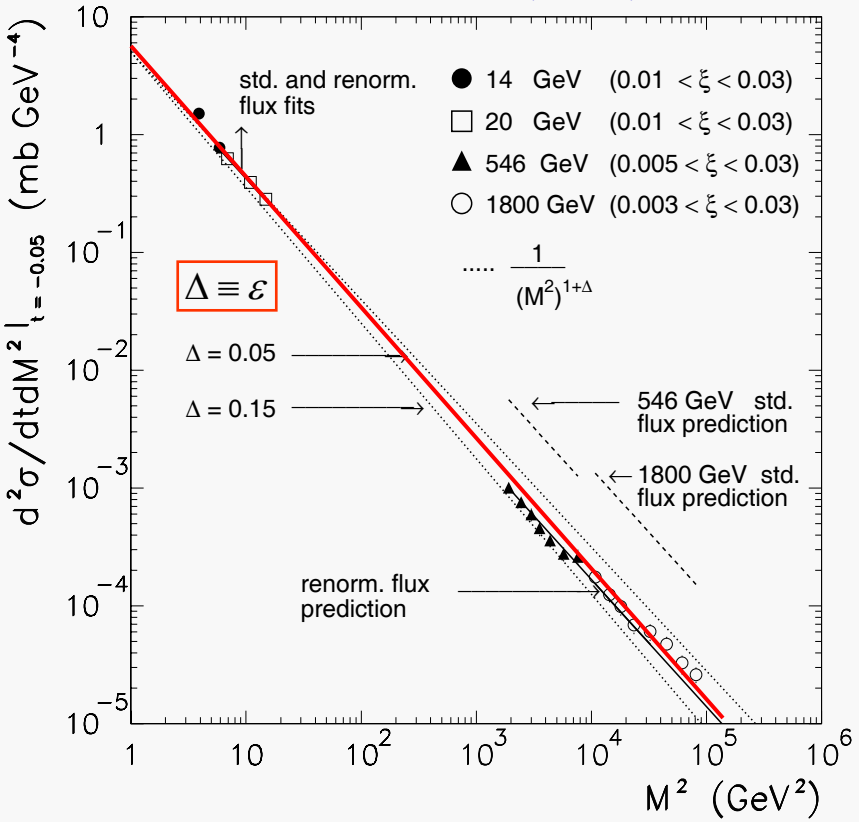
A Scaling Law in Diffraction

Factorization breaks down in favor of M^2-scaling

renormalization

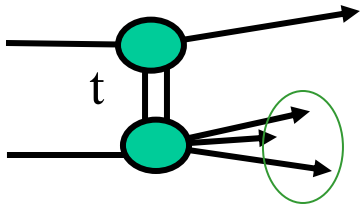
$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon} \to 1}{(M^2)^{1+\varepsilon}}$$

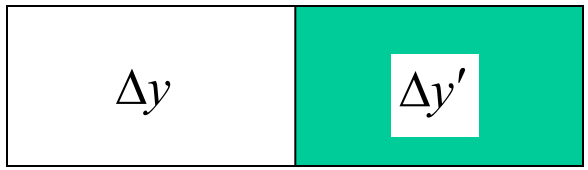
KG&JM, PRD 59 (1999) 114017



QCD Basis of Renormalization

(KG, hep-ph/0205141)





2 independent variables: $t, \Delta y$

color factor

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

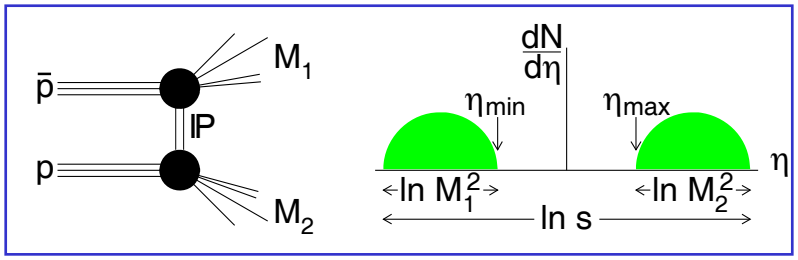
$$\frac{d^2\sigma}{dt\, d\Delta y} = C \bullet F_p^2(t) \bullet \left\{ e^{(\varepsilon + \alpha' t)\Delta y} \right\}^2 \bullet \kappa \bullet \left\{ \sigma_o\, e^{\varepsilon\, \Delta y'} \right\}$$

Gap probability

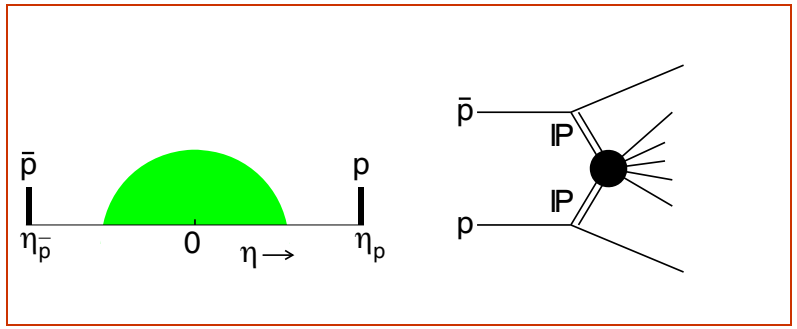
$$\sim e^{2\varepsilon \Delta y} \longrightarrow \int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\, \Delta y} \approx s^{2\varepsilon}$$

Renormalization removes the s-dependence → SCALING

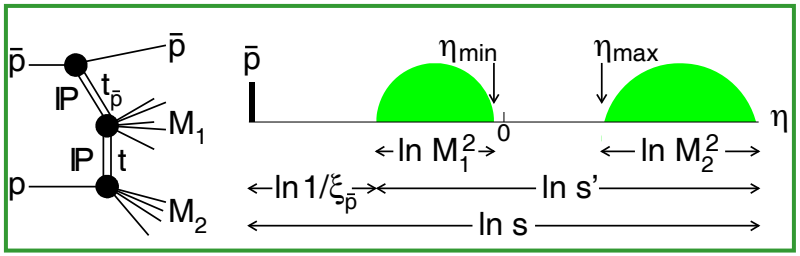
Central and Double Gaps



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



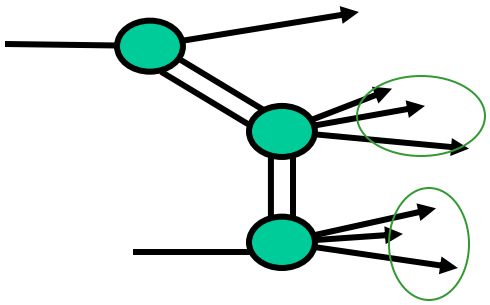
- **Double Pomeron Exchange**
  - Two forward gaps

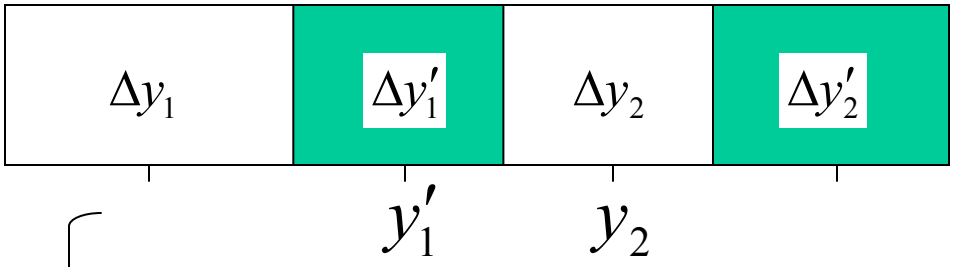


- **SDD: Single+Double Diffraction**
  - One forward + one central gap

Multigap Renormalization

(KG, hep-ph/0205141)





5 independent variables $\{ t_1, \Delta y = \Delta y_1 + \Delta y_2, t_2 \}$

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

Sub-energy cross section (for regions with particles)

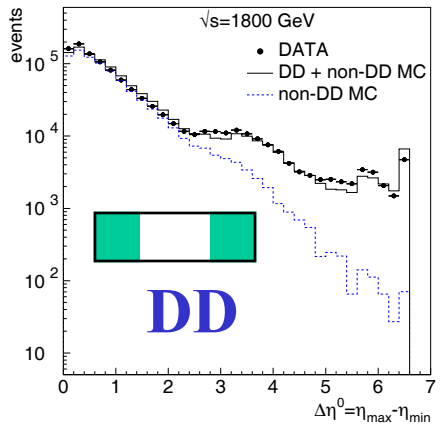
$$\sim e^{2\varepsilon \Delta y}$$

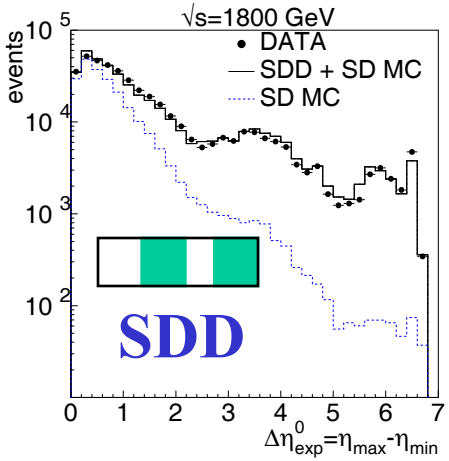
$$\int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\,\Delta y} \approx s^{2\varepsilon}$$

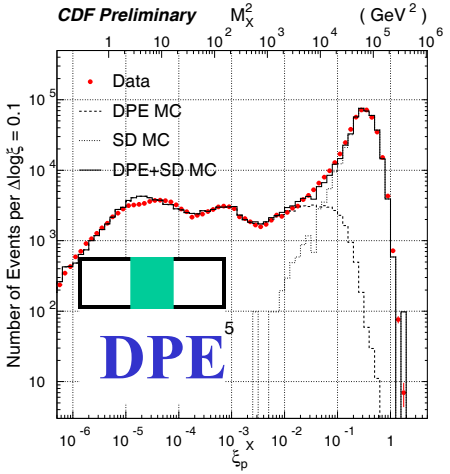
Same suppression as for single gap!

Central & Double-Gap CDF Results

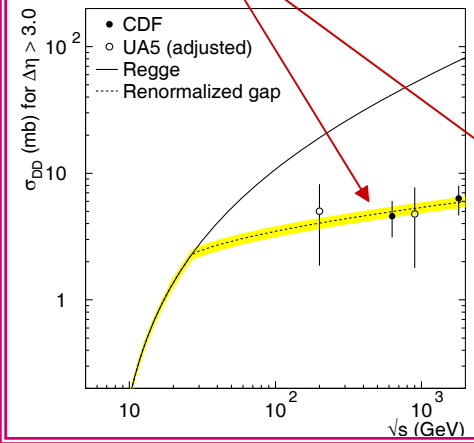
Differential shapes agree with Regge predictions

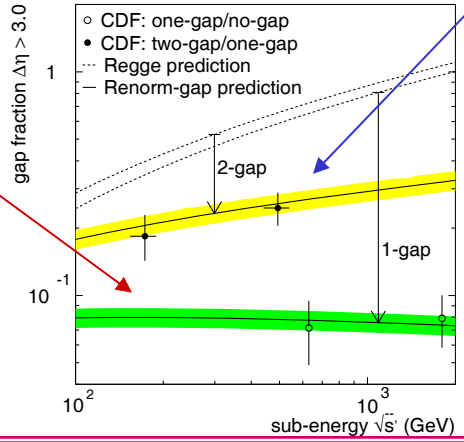


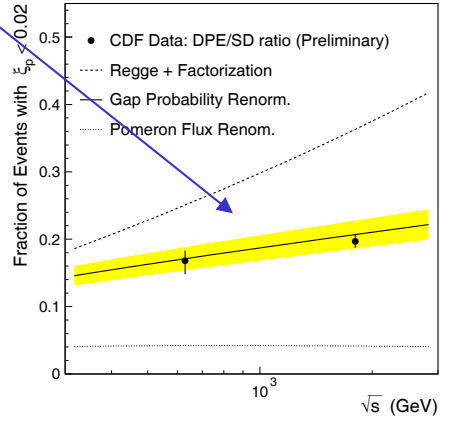




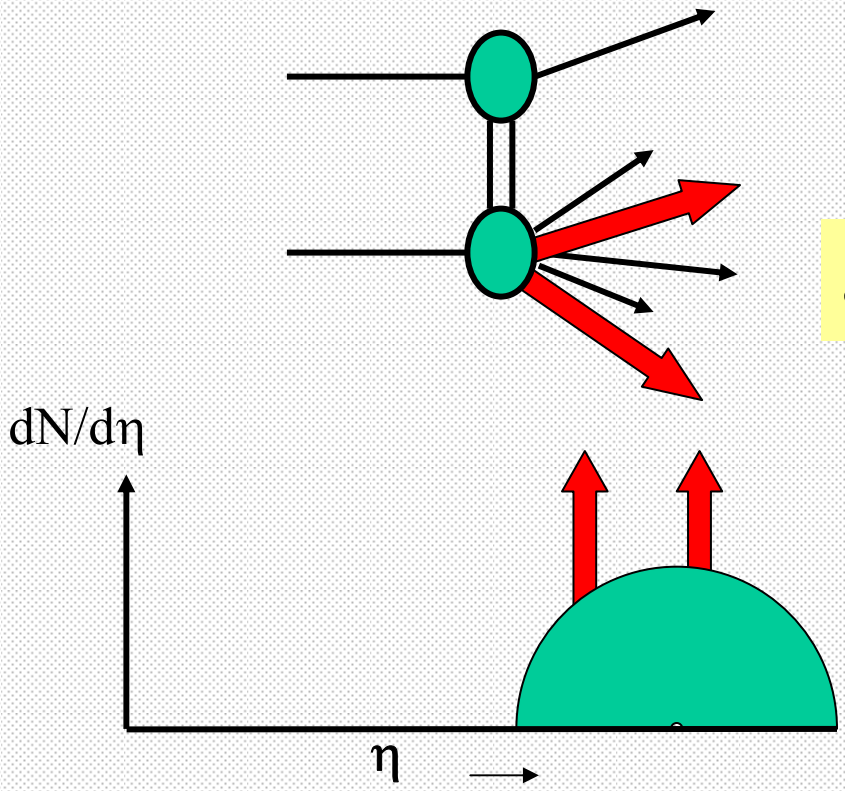
- **One-gap cross sections are suppressed**
- **Two-gap/one-gap ratios are** $\approx \kappa = 0.17$







Hard Diffraction @ CDF



JJ, W, b, J/ψ

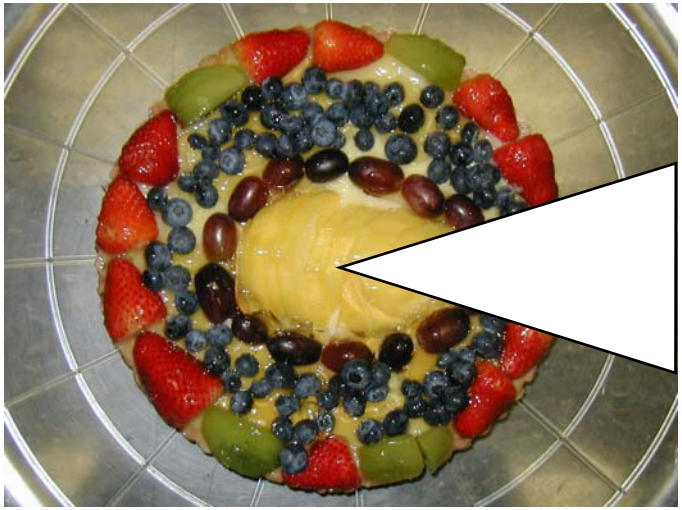
Diffractive Fractions @ CDF

$$\bar{p}p \rightarrow (Hd + X) + \text{gap}$$

SD/ND ratio at 1800 GeV

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

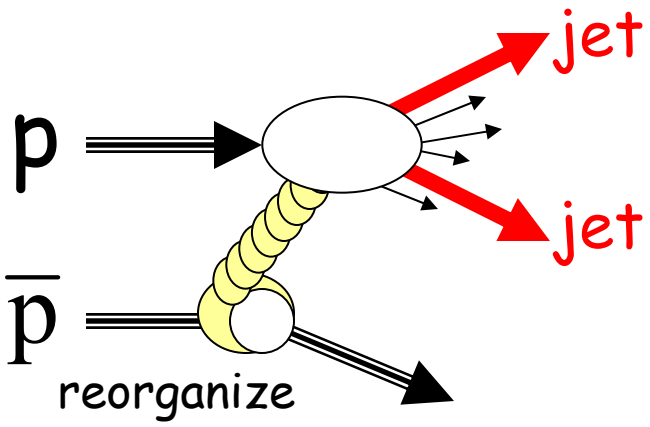
All ratios ~ 1%
➔~ uniform suppression
~ FACTORIZATION



Did the person who ate the missing piece of pie remove any fruit from the rest of the pie!

Diffractive Dijets @ Tevatron

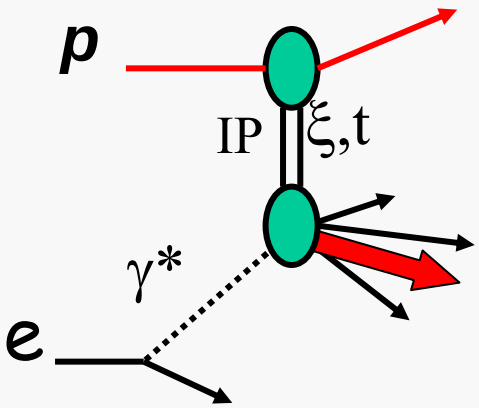
Factorization breaks down: but how?



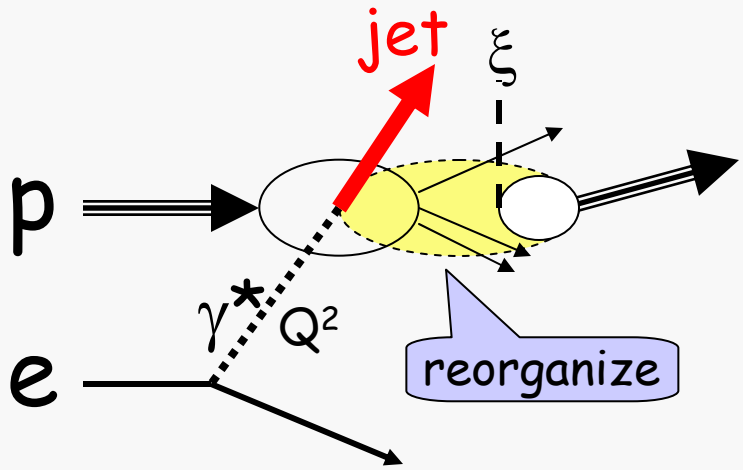
$$F^D(\xi, x, Q^2) \propto \frac{1}{\xi^{1+2\varepsilon}} \cdot F(x/\xi, Q^2)$$

Diffractive DIS @ HERA

Pomeron exchange



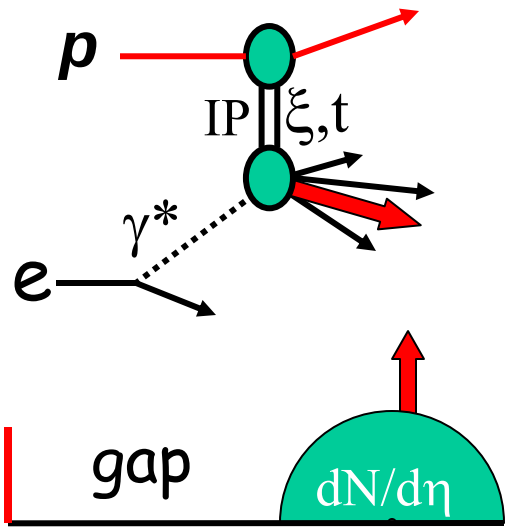
Color reorganization

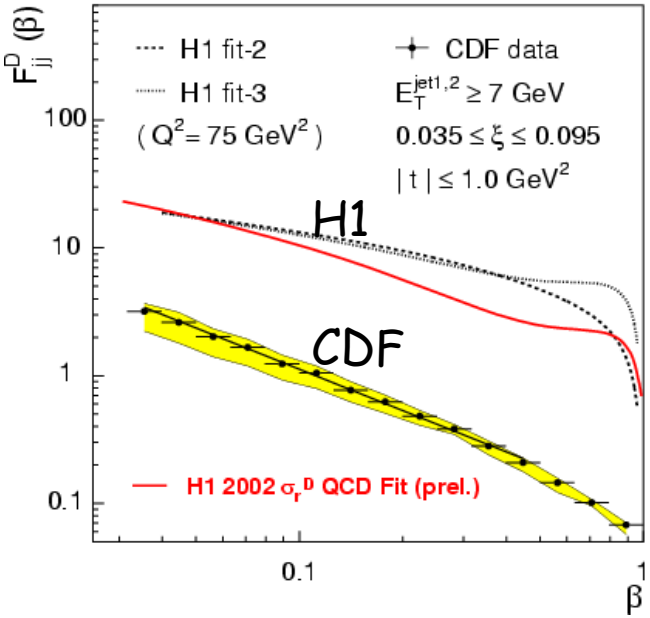


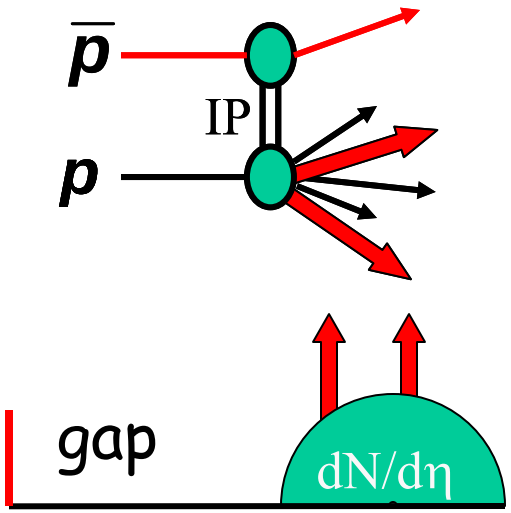
Factorization holds
(John Collins)

Tevatron vs HERA: Factorization Breakdown

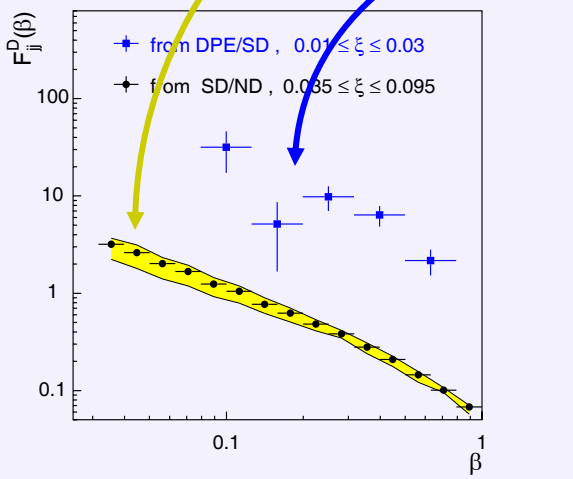
Predicted in KG, PLB 358 (1995) 379

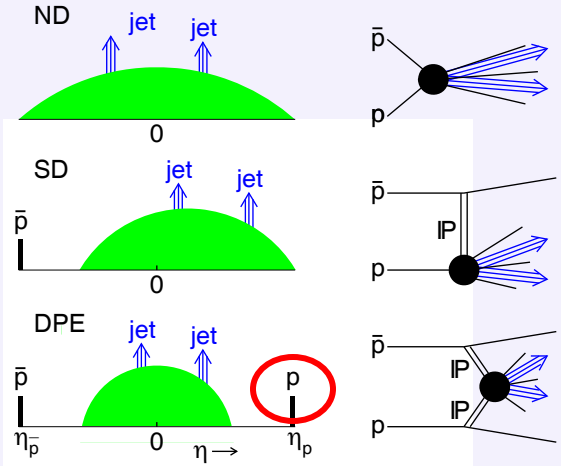






Restoring Factorization

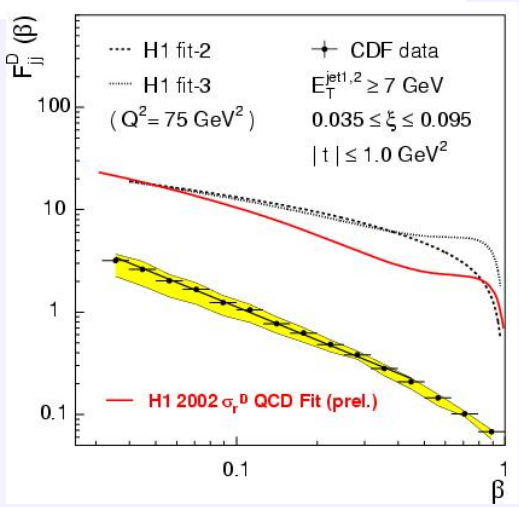


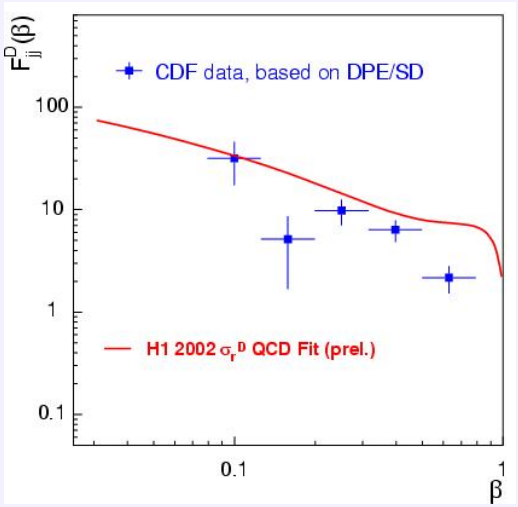


R(SD/ND)

R(DPE/SD)

DSF from two/one gap: factorization restored!



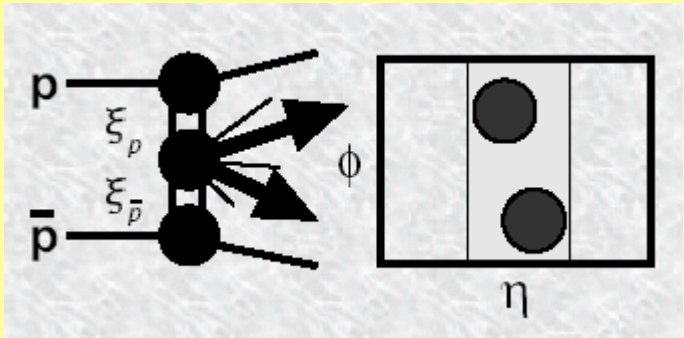


Diffractive Higgs Production

Interest in diffractive Higgs production

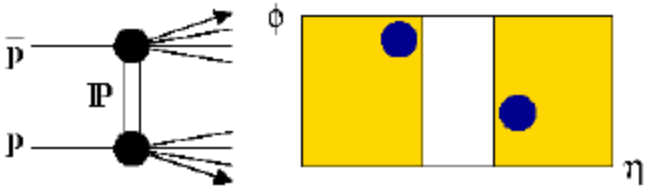


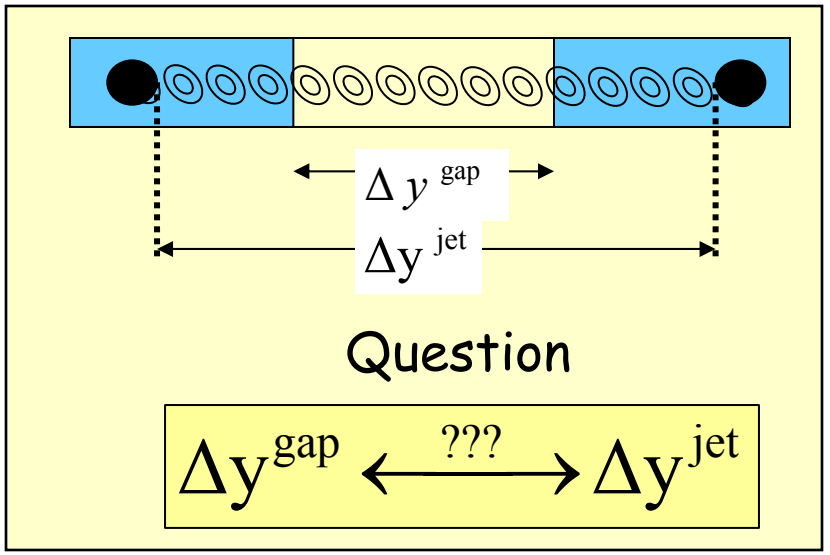
Calibrate on exclusive dijets

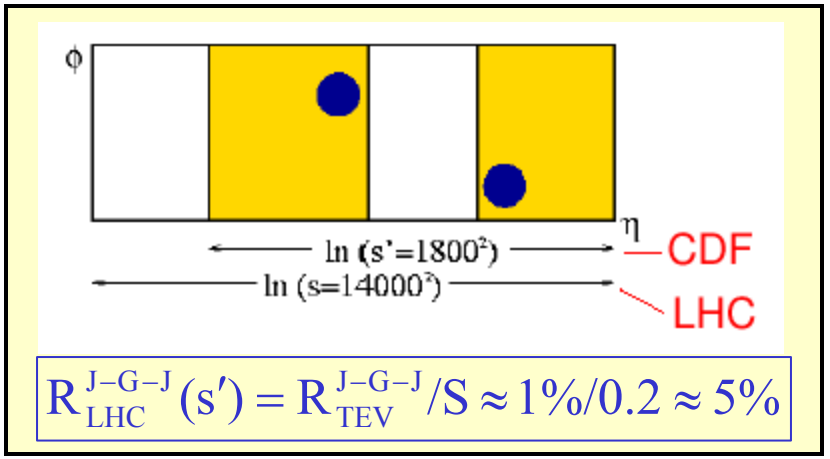


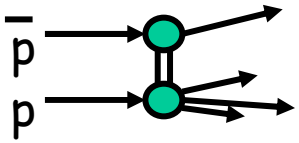
Gap Between Jets

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



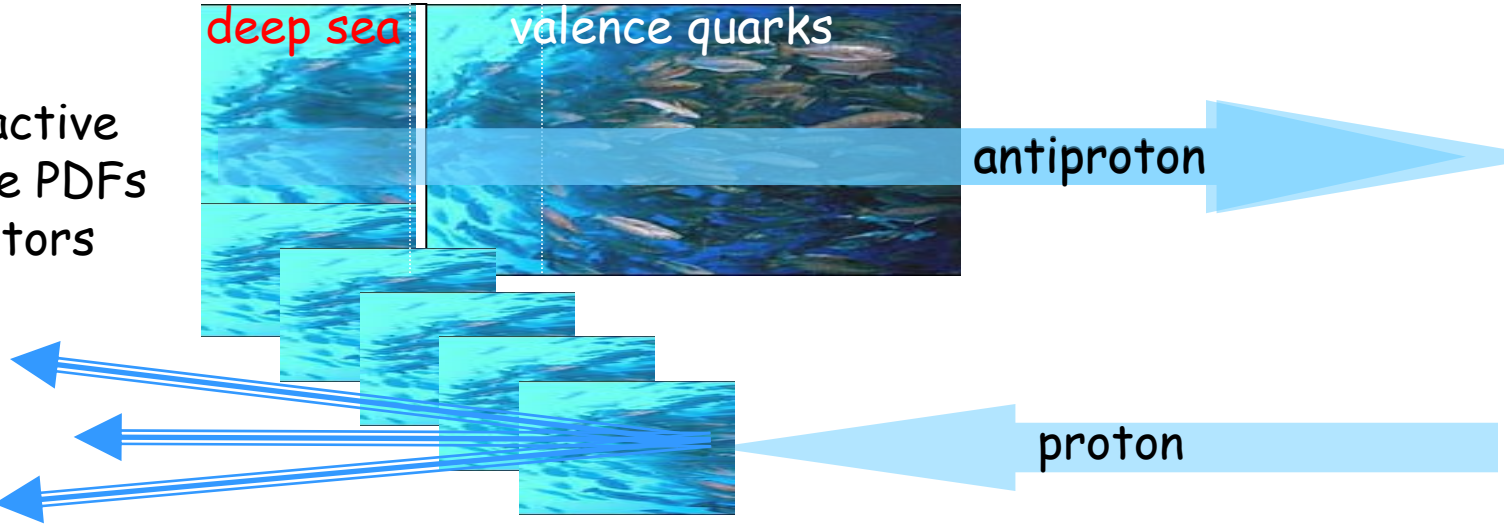


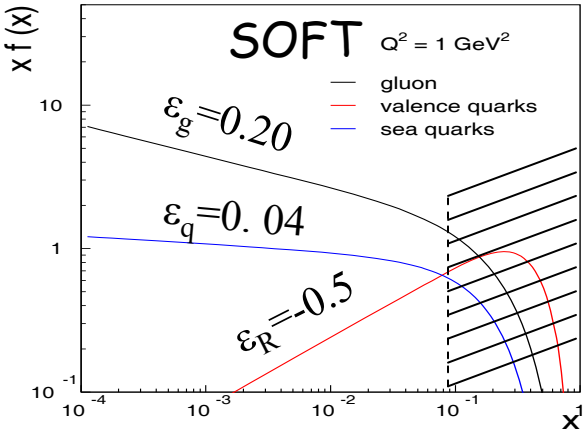




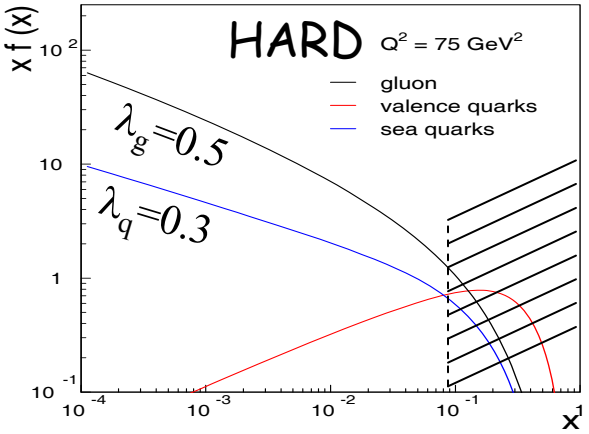
Diffraction in QCD

Derive diffractive from inclusive PDFs and color factors

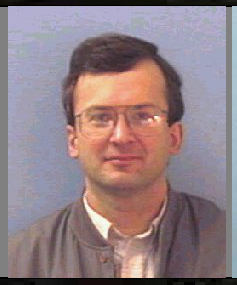




$$x \cdot f(x) = \frac{1}{x^{\varepsilon\,(\text{or}\,\lambda)}}$$



The Rockefeller Experimental HEP Group

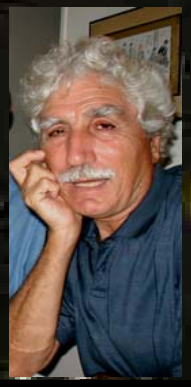










Anwar Luc Stefano Michele Mary Koji Christina Andrea Ken





It surely makes an interesting T-shirt!

BACKUP

Summary

SOFT DIFFRACTION

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

HARD DIFFRACTION

- Flavor-independent SD/ND ratio
- Little or no Q^2-dependence in SD/ND ratio

✓Universality of gap prob. across soft and hard diffraction
✓ Pomeron evolves similarly to proton

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

$F^D_{JJ}(\xi,\beta,Q^2)$ @ Tevatron

$$F^D(\xi,\beta,Q^2) \propto \frac{1}{\xi^{1+2\varepsilon}} \cdot \frac{C(Q^2)}{(x/\xi)^{\lambda(Q^2)}} \propto \frac{1}{(\beta s)^{2\varepsilon}} \cdot \frac{1}{\xi^{1+2\varepsilon}} \cdot \frac{C}{\beta^{\lambda}}$$

$$N^{-1}_{\text{renorm}} = \int_{\xi_{\min}}^{1} \frac{d\xi}{\xi^{1+2\varepsilon}} \xrightarrow{\xi_{\min} = \frac{x_{\min}}{\beta} \sim \frac{1}{\beta s}} (\beta s)^{2\varepsilon}$$

$$\text{RENORM} \quad \Rightarrow \quad R^{SD}_{ND}(x) \sim \frac{1}{s^{2\varepsilon}} \frac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-(2\varepsilon)}$$

$$\varepsilon_g = 0.2 \rightarrow x^{-0.4}$$

Soft Diffraction Summary

Experiment:

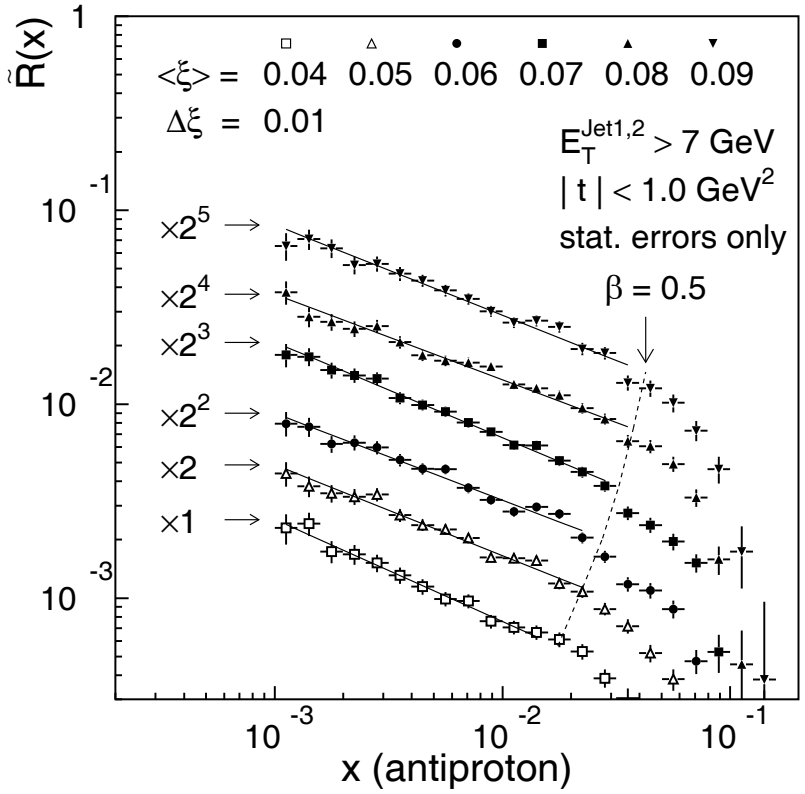
- M^2 – scaling
- Non-suppressed double-gap to single-gap ratios

Phenomenology:

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

SD/ND Dijet Ratio vs x_{Bj}@ CDF

$$R(x) = \frac{F_{jj}^{SD}(x)}{F_{jj}^{ND}(x)}$$



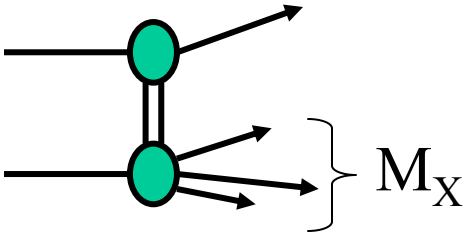
0.035 < ξ < 0.095

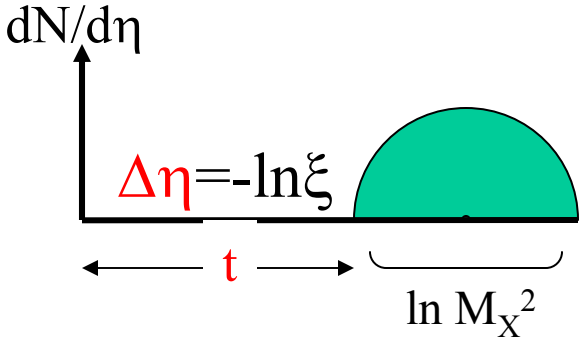
Flat ξ dependence

$$R(x) = x^{-0.45}$$

Hard Diffraction @ CDF

- SOFT DIFFRACTION



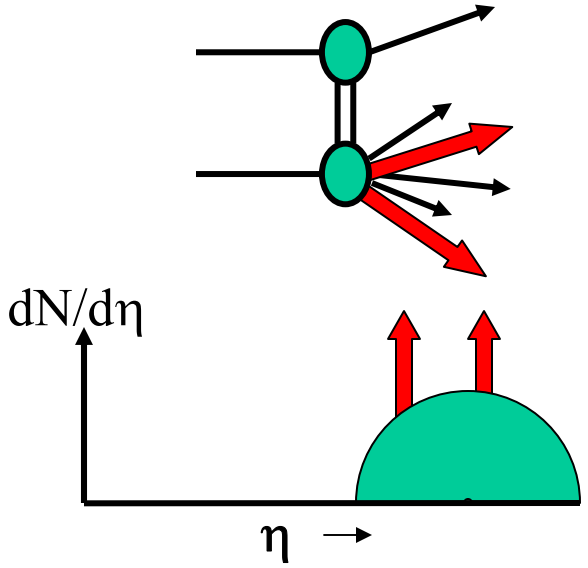


$\xi=\Delta P_L/P_L$

ξ=fractional momentum loss of scattered (anti)proton

Variables: (ξ, t) or ($\Delta\eta$, t)

- HARD DIFFRACTION



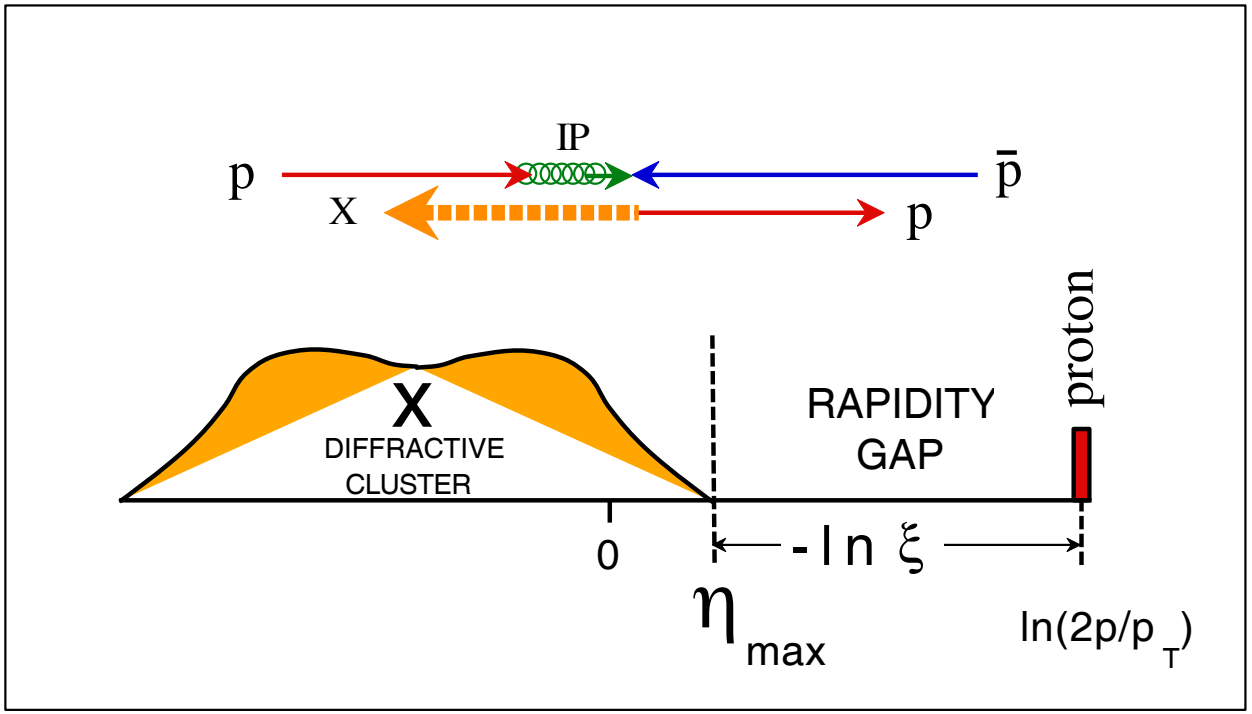
Additional variables: (x, Q^2)

$$x_{Bj} = \sum E_T^{jet} e^{-\eta^{jet}} / \sqrt{s}$$

$$x = \beta\,\xi, \quad Q^2 = (E_T^{jet})^2$$

Rapidity Gaps

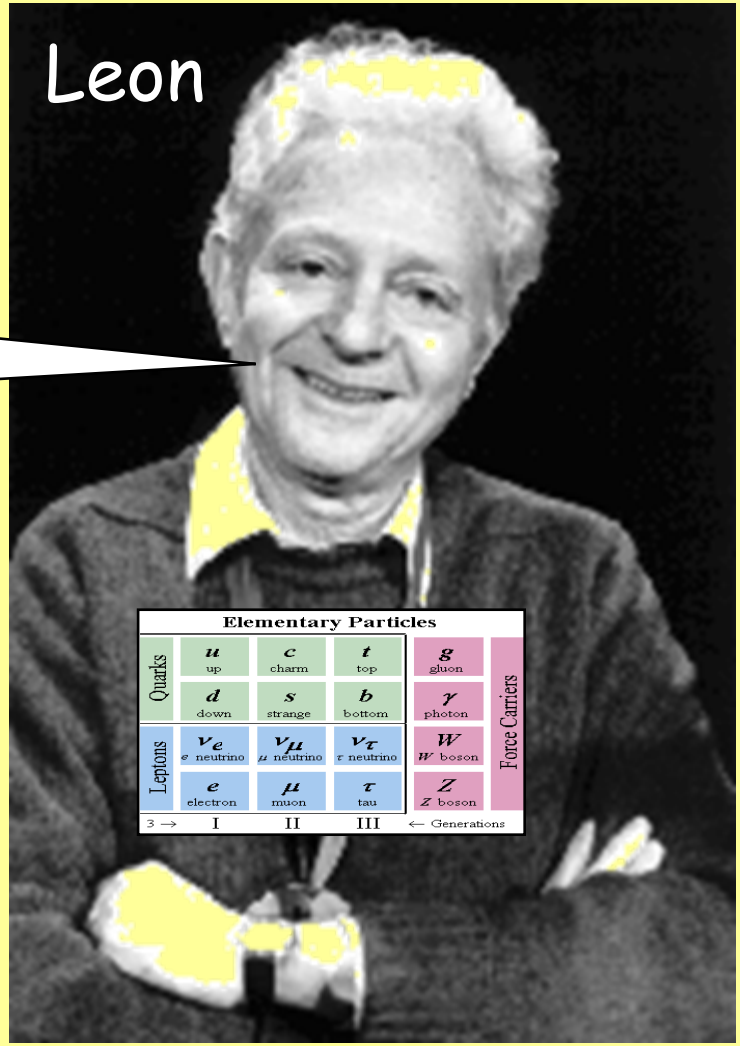
Bj, PRD 47 (1993) 101: regions of (pseudo)rapidity devoid of particles



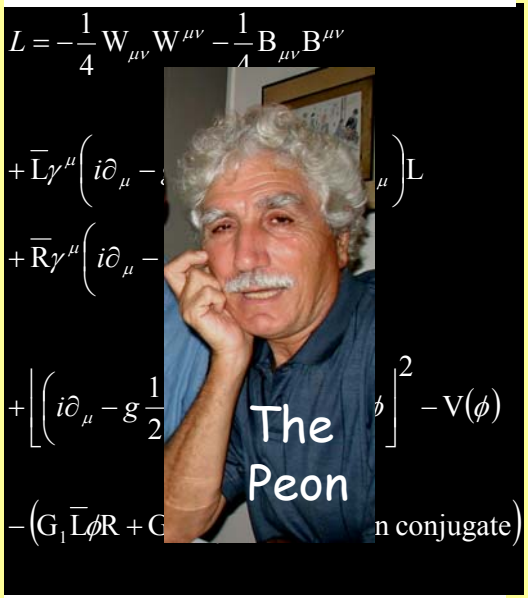
$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{conctant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2}$$

Leon and the Peon

A good theory should fit on a T-shirt!



But what about interactions?

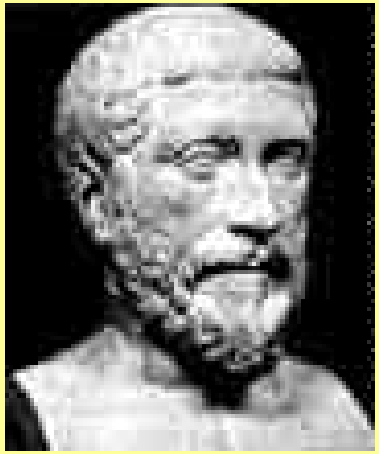


AND WHAT ABOUT GRAVITY?

String Theory, then?

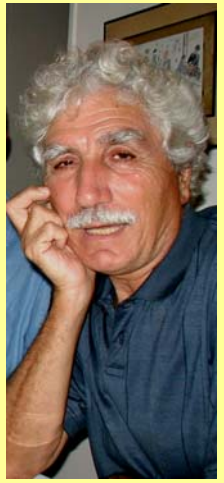
Particles correspond to the vibration modes of a string in 10 dimensions

Pythagoras applied it to music: 1+2+3+4=10





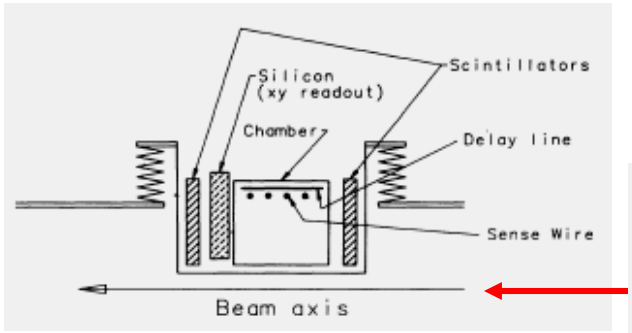
Gravity is included!



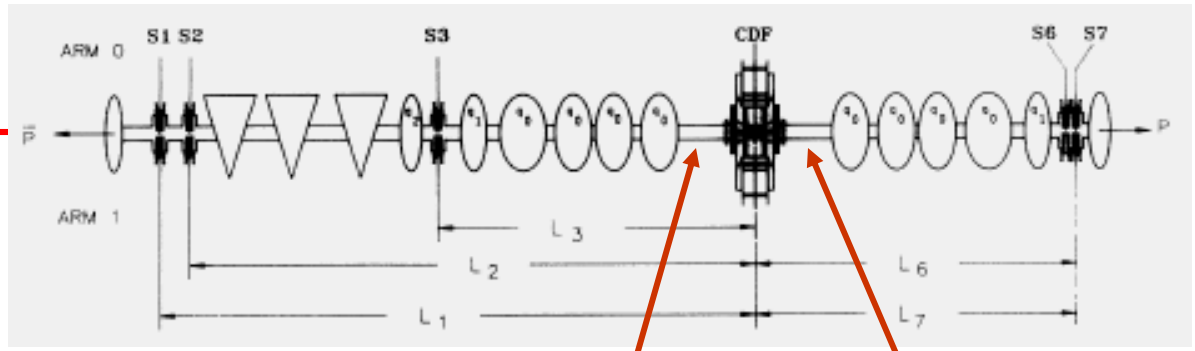
And it surely makes a good looking T-shirt!

CDF in Run I-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

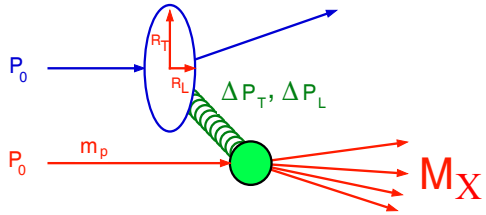
Additional Detectors

Trackers up to $|\eta| = 7$

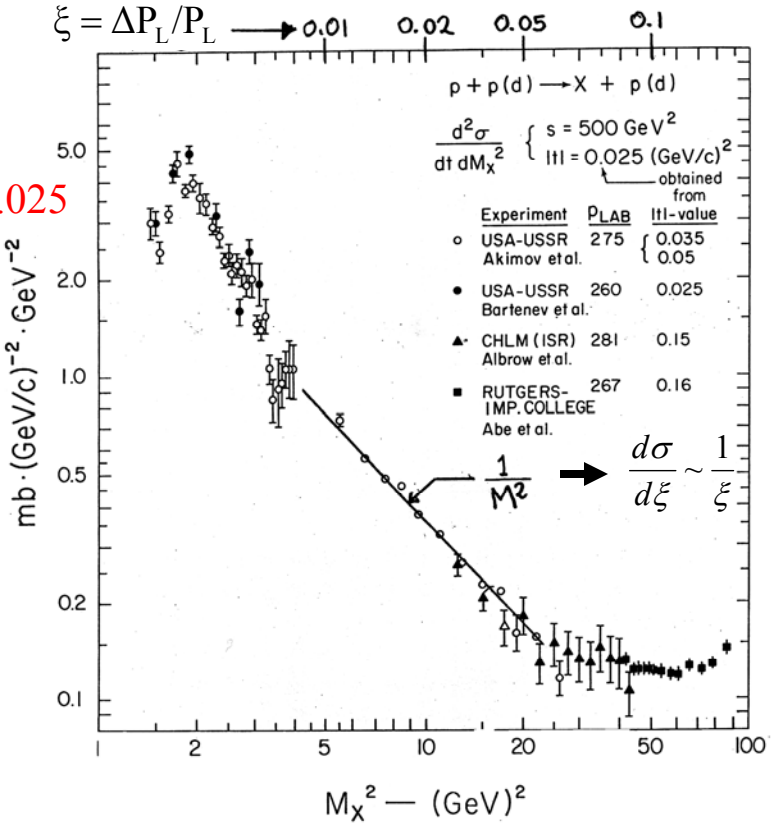
Results

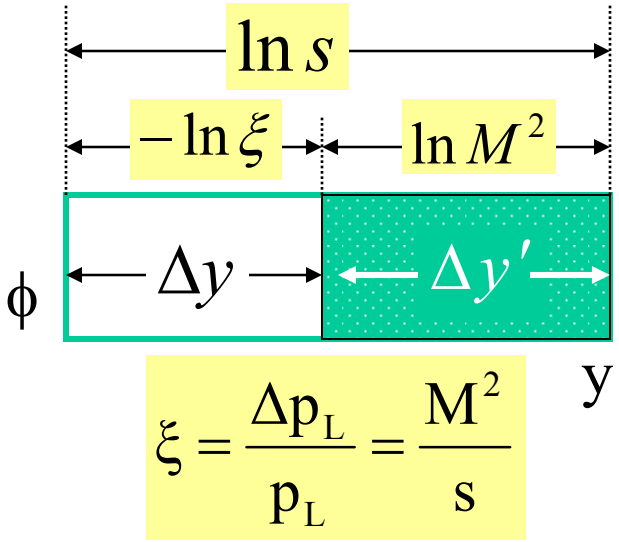
- Total cross section $\sigma^{tot} \sim s^{\varepsilon}$
- Elastic cross section $d\sigma/dt \sim \exp[2\alpha' \ln s]$ → shrinking forward peak
- Single diffraction Breakdown of Regge factorization

First 20 Years



$$\left.\frac{d^2\sigma}{dt\,dM^2}\right|_{t=0.025}$$





$$\xi = \frac{\Delta p_L}{p_L} = \frac{M^2}{s}$$

$$\frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \quad \Leftrightarrow \quad \frac{d\sigma}{d\Delta y} \propto \text{constant}$$

KG, Phys. Rep. 101 (1983) 171

POMERON: color singlet
w/vacuum quantum numbers

Rapidity Gaps

Bj, PRD 47 (1993) 101: regions of (pseudo)rapidity devoid of particles

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations.

From Poisson statistics:

$$P(\Delta y) = e^{-\rho \Delta y} \quad \left(\rho = \frac{dn}{dy} \right)$$

(ρ=particle density in rapidity space)

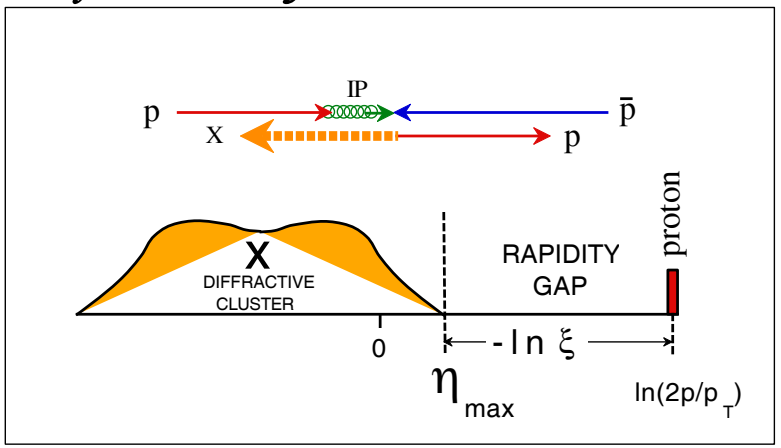
Gaps are exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy.

$$\xi \equiv \Delta p / p$$

$$\Delta y \approx -\ln \xi = \ln s - \ln M^2$$

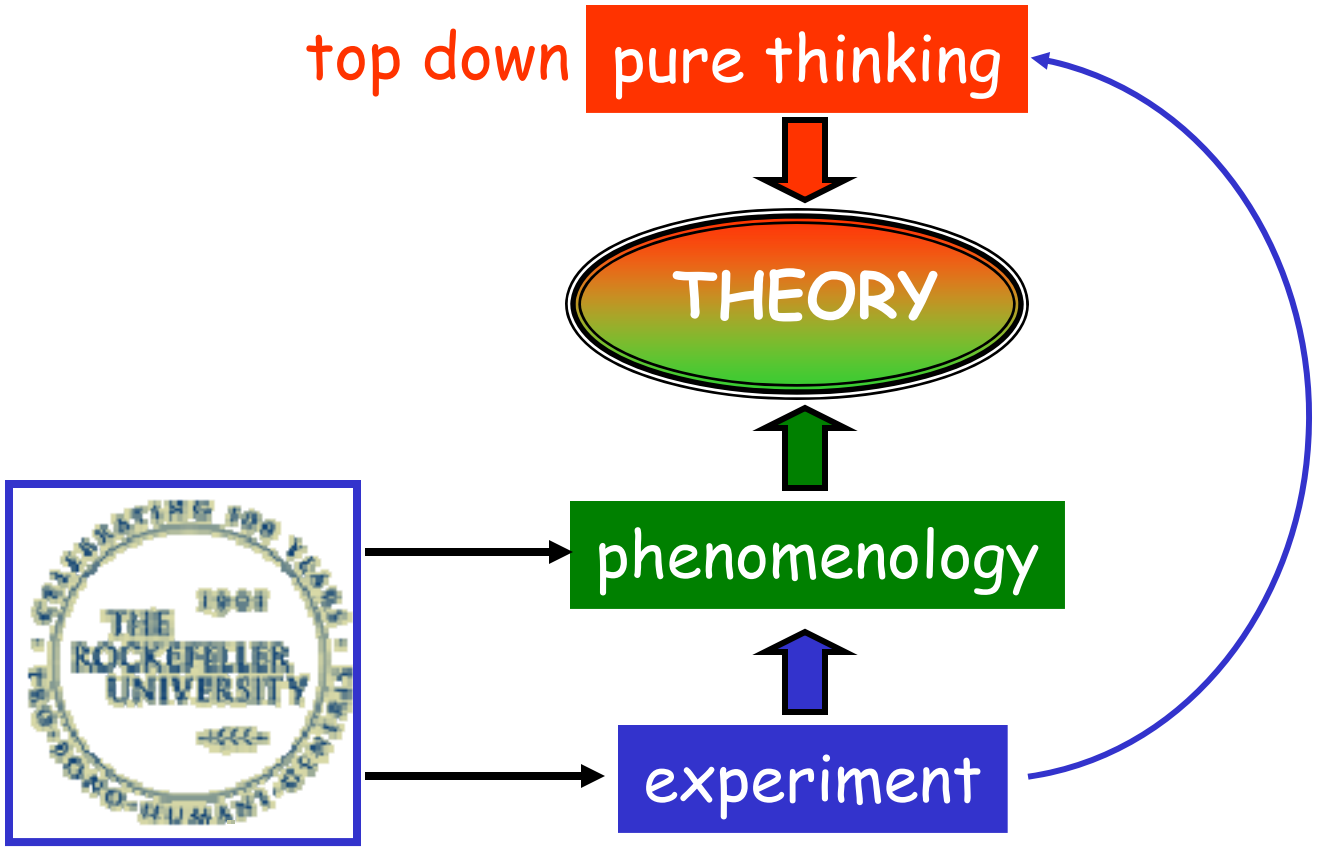


$$\left(\frac{d\sigma}{d\Delta y} \right)_{t=0} \sim e^{2\varepsilon \Delta y} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{\left(M^2\right)^{1+\varepsilon}}$$

2ε: negative particle density!

Theory of Diffraction

- Important for understanding hadron structure and quark confinement.
- QCD can only be solved perturbatively for cases in which $\alpha_s << 1$.
- Need to develop new mathematical methods to deal with diffraction.

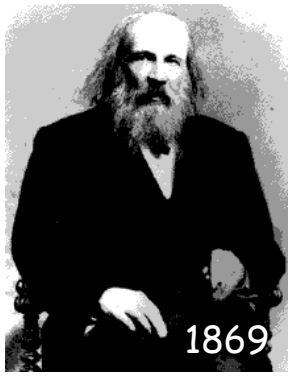


Elementary Particles

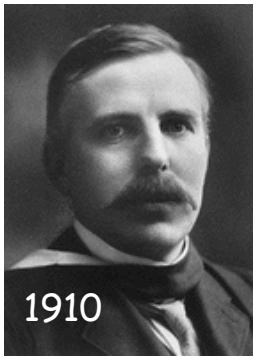


450 BC







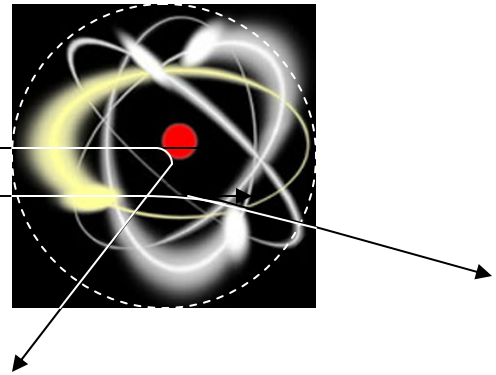




Aristotle	Demokritos	Mendeleyev	Thomson	Rutherford	Gell-Mann
earth water air fire	atom	periodic table	electron	nucleus	quarks

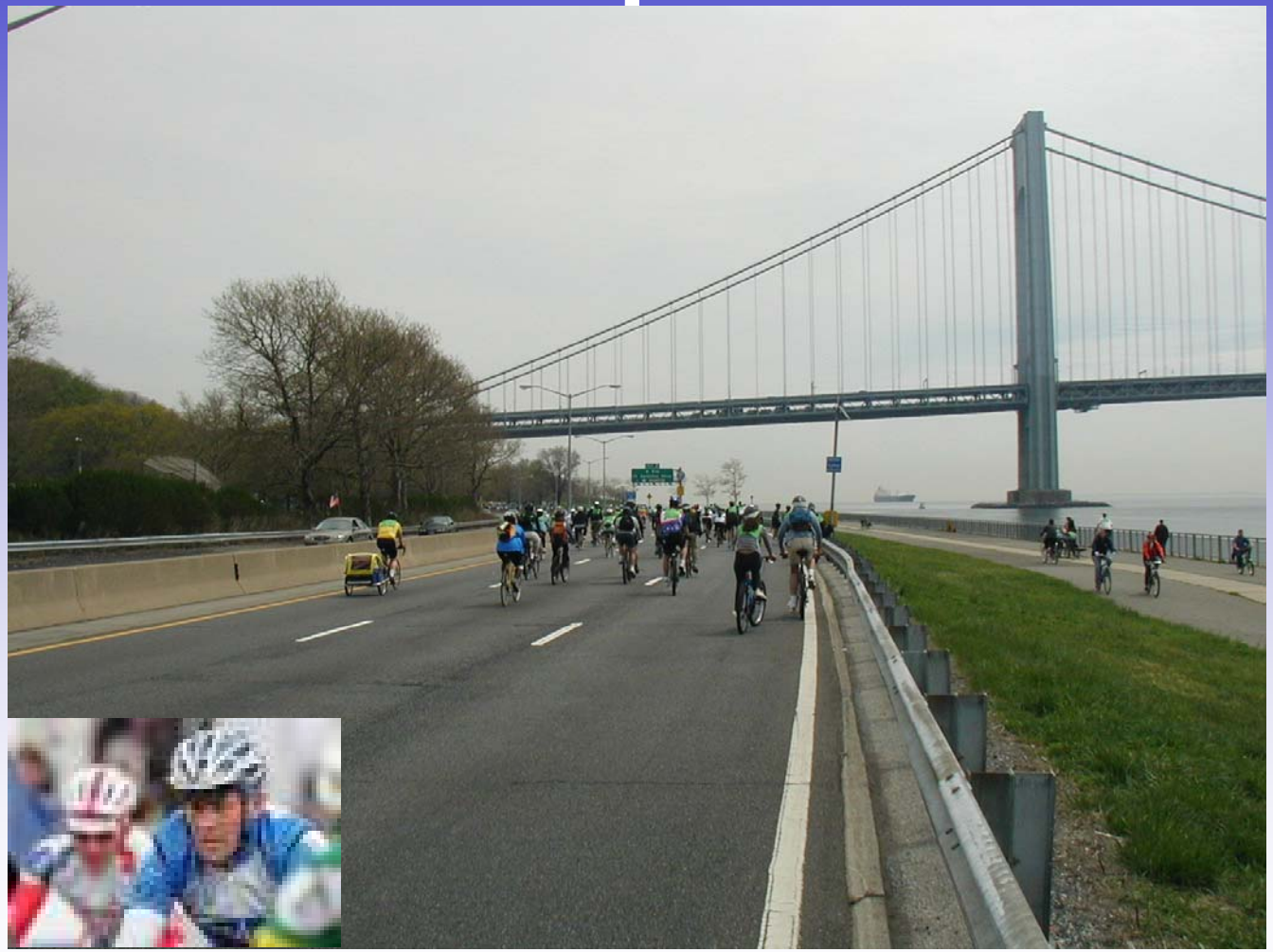
Rutherford Experiment

Source → α-particles



Large angle scattering → atoms have nuclei

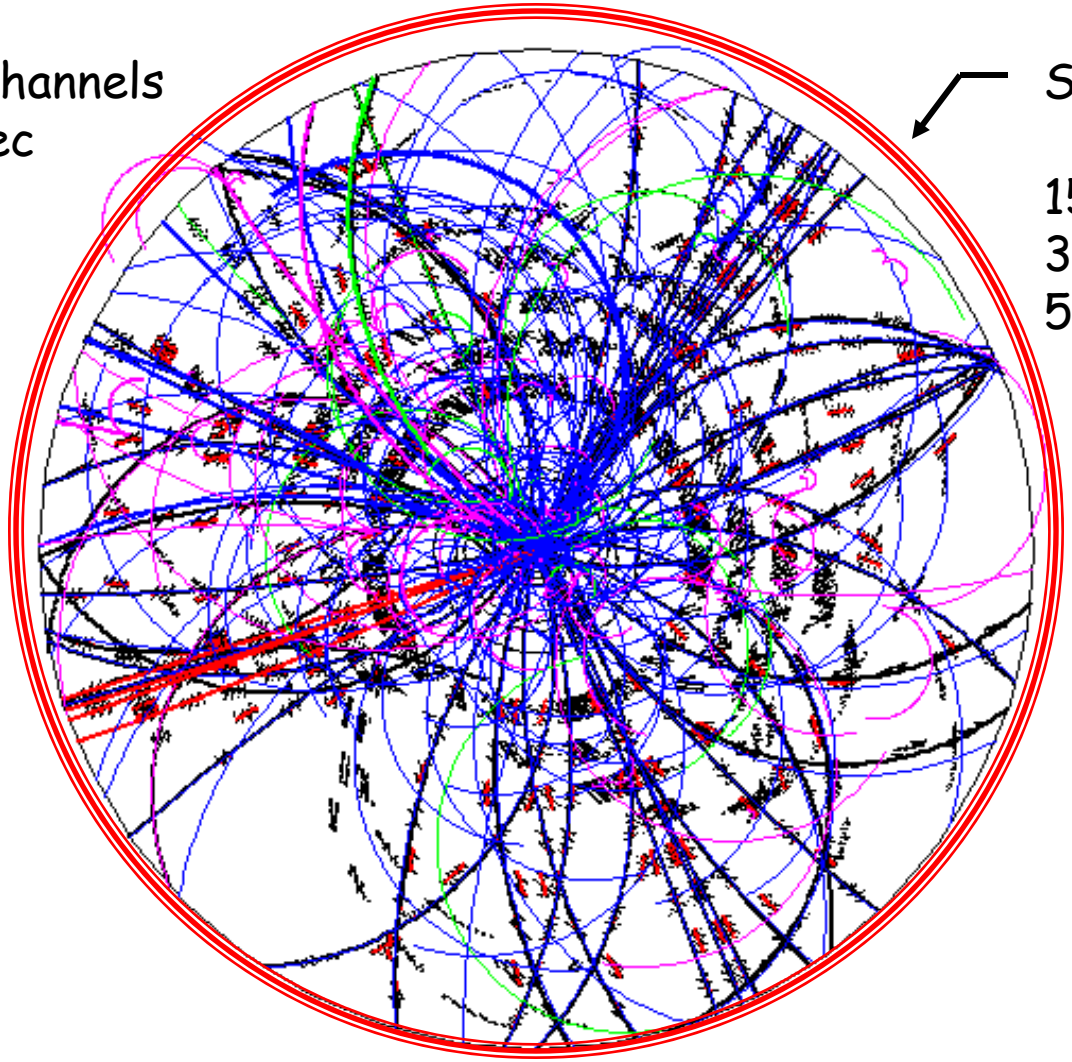
Tour de particule



CDF event in central tracker

10^6 electronic channels
10^6 collisions/sec

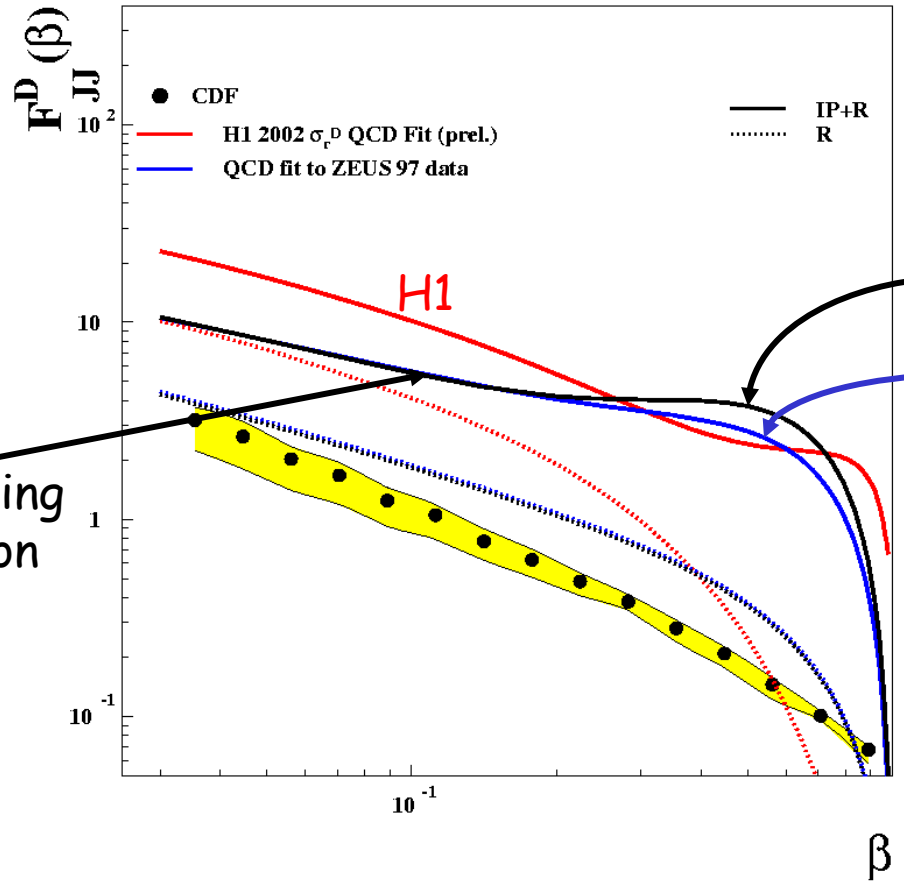
Trigger:
L1: 100 K/sec
L2: 1 K/sec
L3: 100/sec



Superconducting solenoid
15 Kgauss
3 m diameter
5 m long

New: $F^{D}_{JJ}(\beta)$ from ZEUS-LPS Data

M. Arneodo, HERA/LHC workshop, CERN, 11-13 Oct 2004

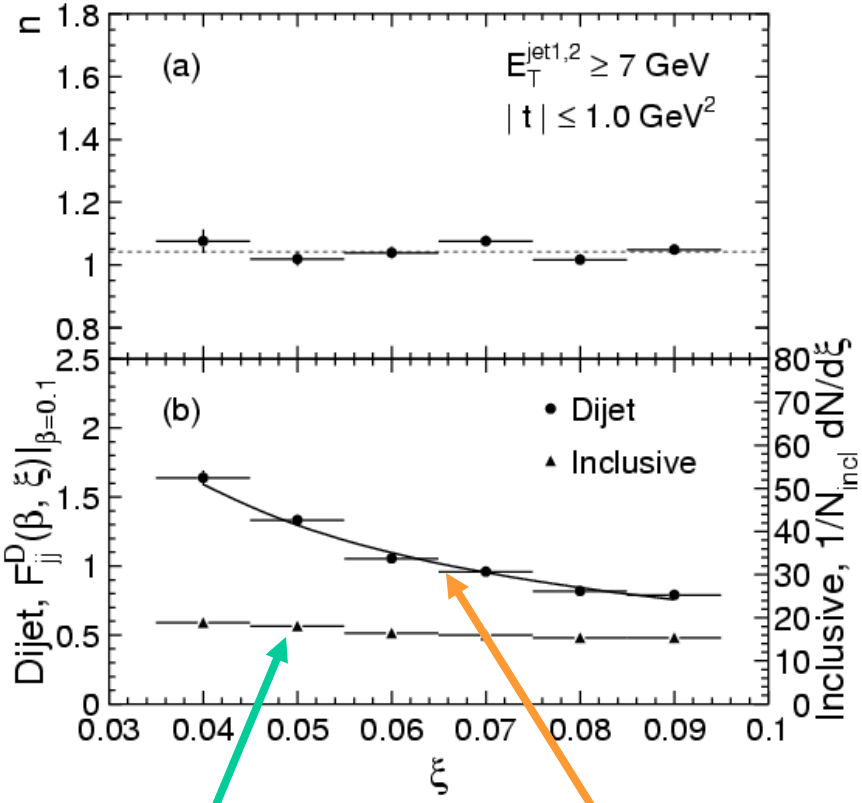


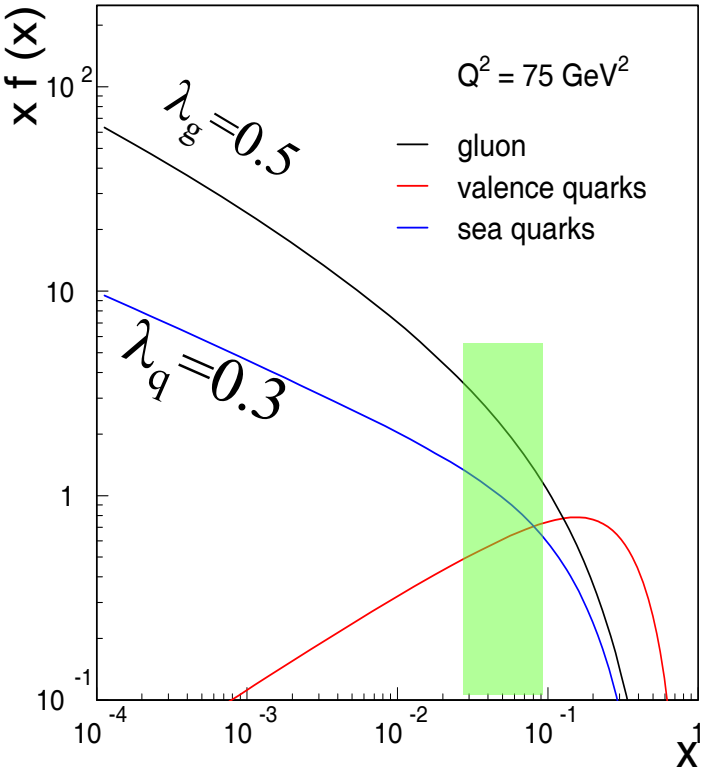
ZEUS Fit including charm data

Fit without charm data

Flat after subtracting Reggeon contribution

ξ-dependence: Inclusive vs Dijets





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

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

Pomeron dominated

The Factors κ and ε

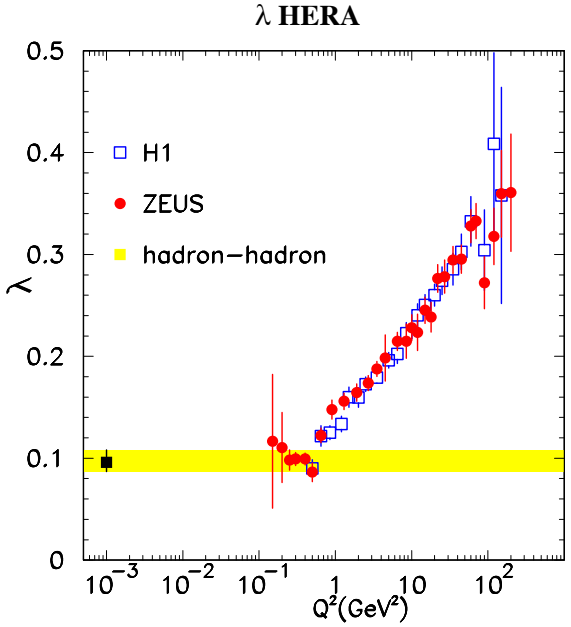
Experimentally:

KG&JM, PRD 59 (114017) 1999

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

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

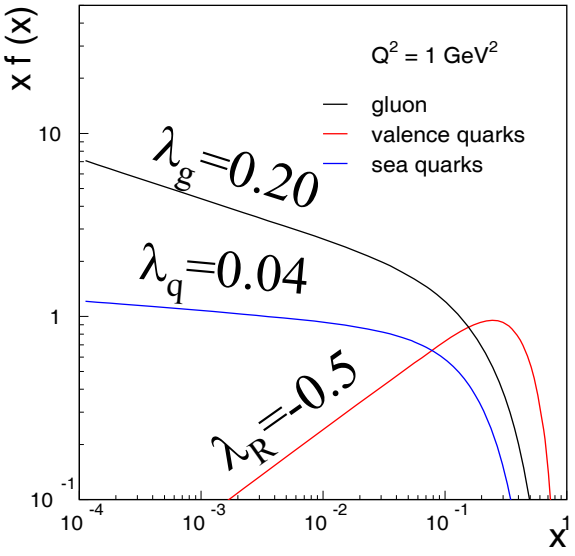


$$x \cdot f(x) = \frac{1}{x^{\lambda}}$$

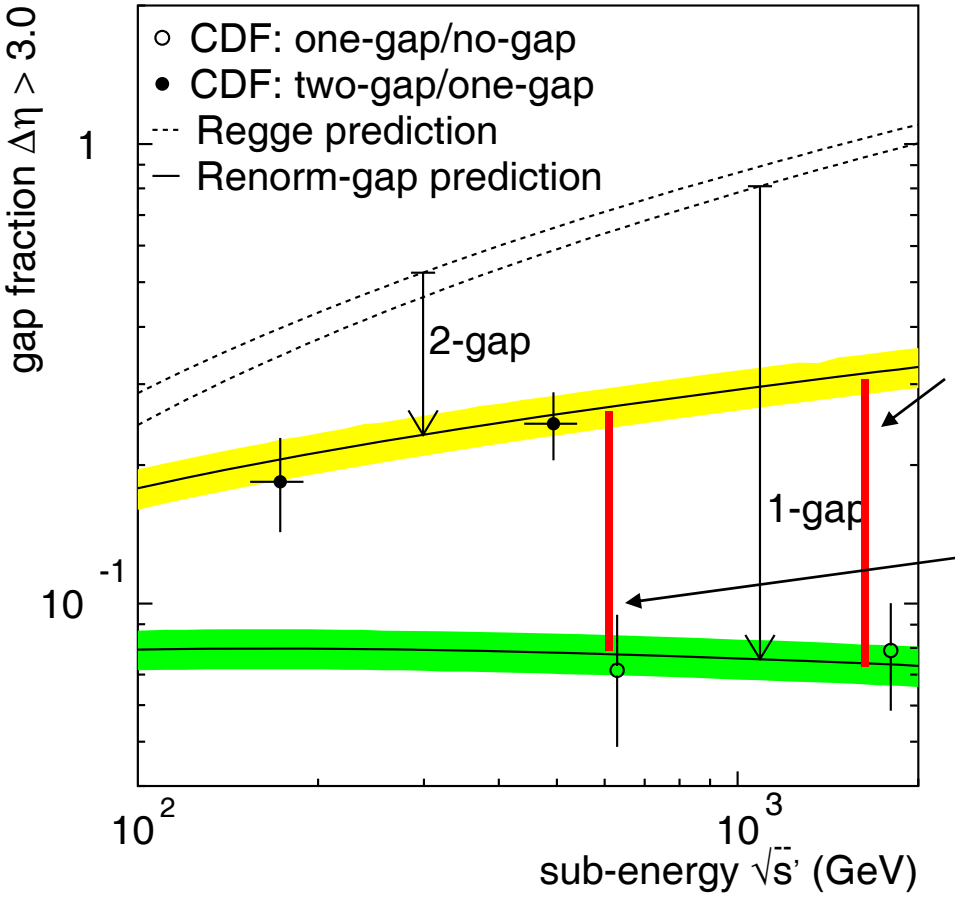
f_g=gluon fraction
f_q=quark fraction

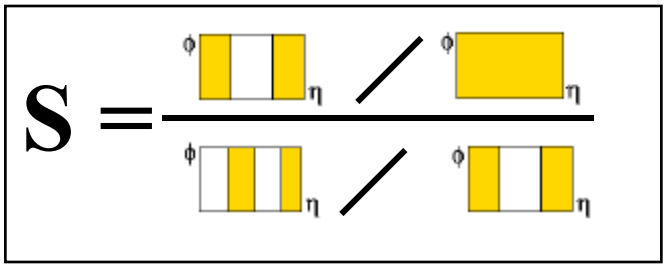
$$\int_{x=1/s}^{1} f(x)\,dx \sim s^{\lambda}$$

CTEQ5L



Gap Survival Probability





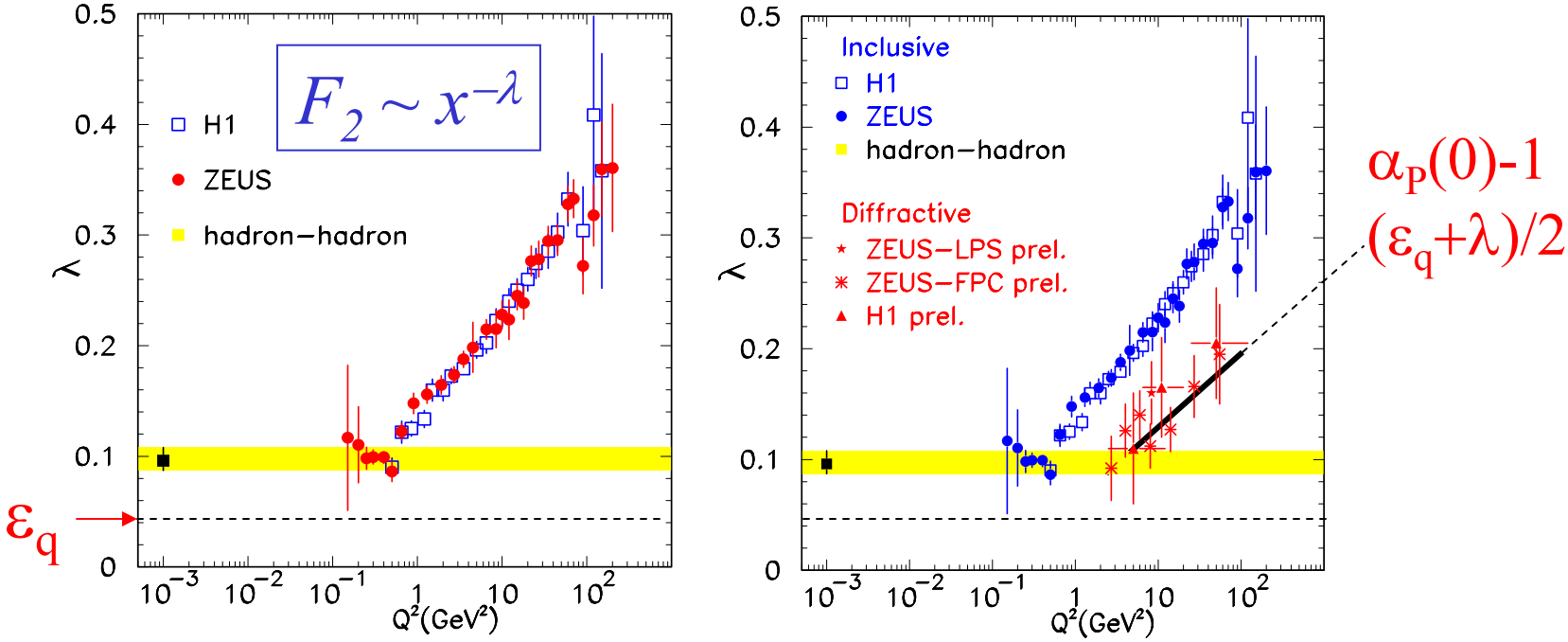
$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \text{GeV}) \approx 0.23$$

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

Results similar to predictions by:
Gotsman-Levin-Maor
Kaidalov-Khoze-Martin-Ryskin
Soft color interactions

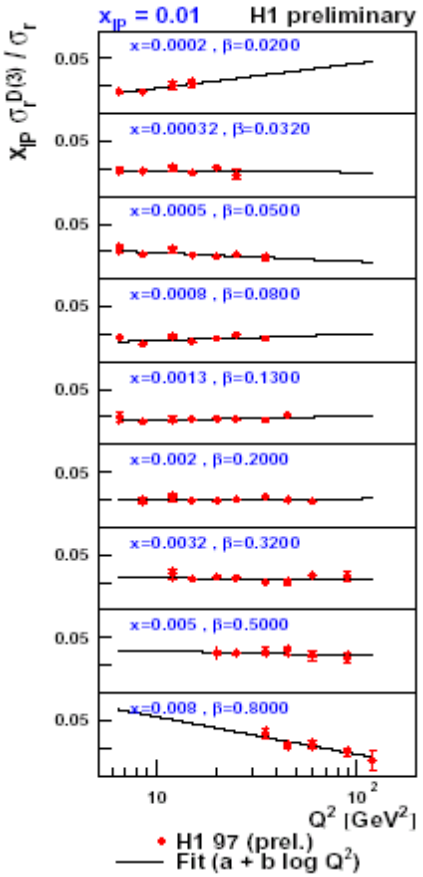
Inclusive vs Diffractive DIS

KG, "Diffraction: a New Approach," J.Phys.G26:716-720,2000 e-Print Archive: **hep-ph/0001092**



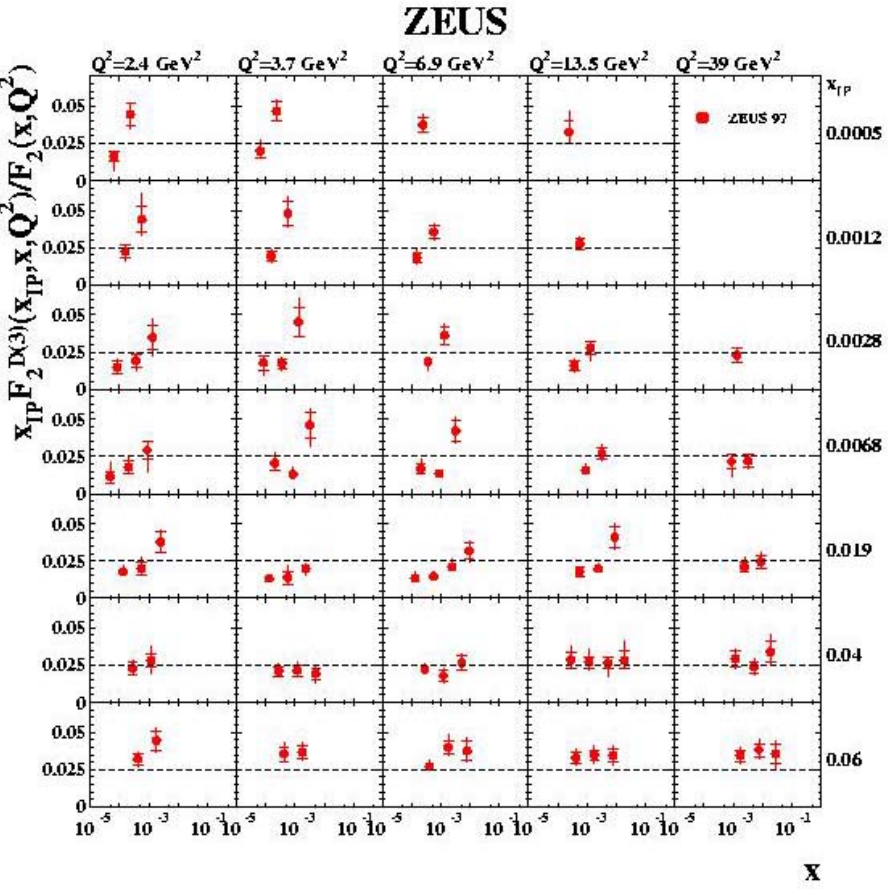
$$F_2^{D(3)}(\xi,\beta,Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \propto \frac{1}{\xi^{1+\varepsilon+\lambda}} \cdot \frac{C}{\beta^{\lambda}}$$

$\sigma^{diff}/\sigma^{incl}$ DIS at HERA

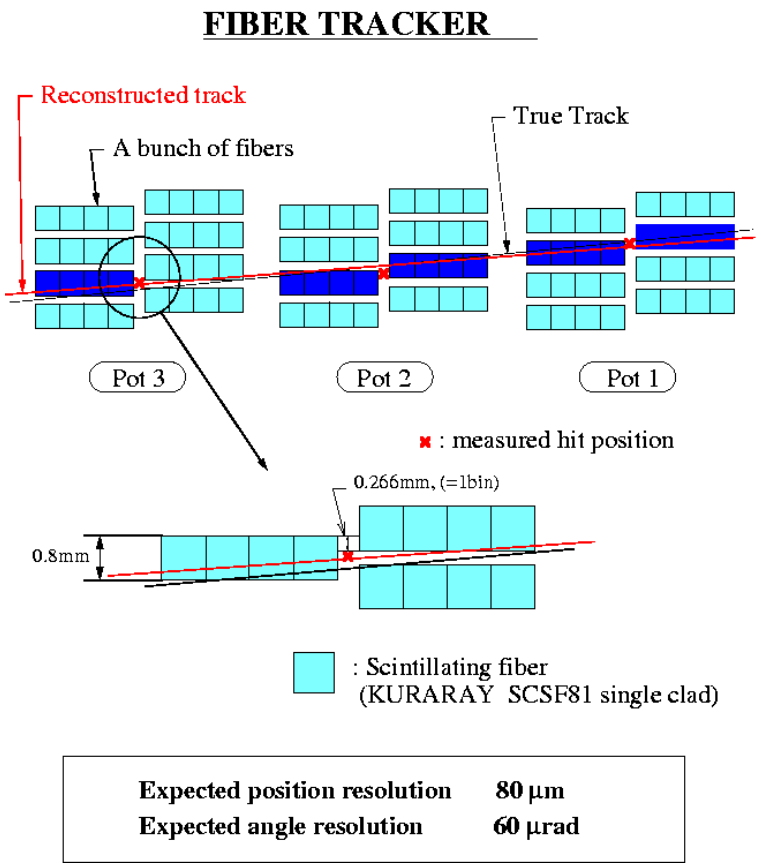


At fixed x:
flat Q^2-dependence

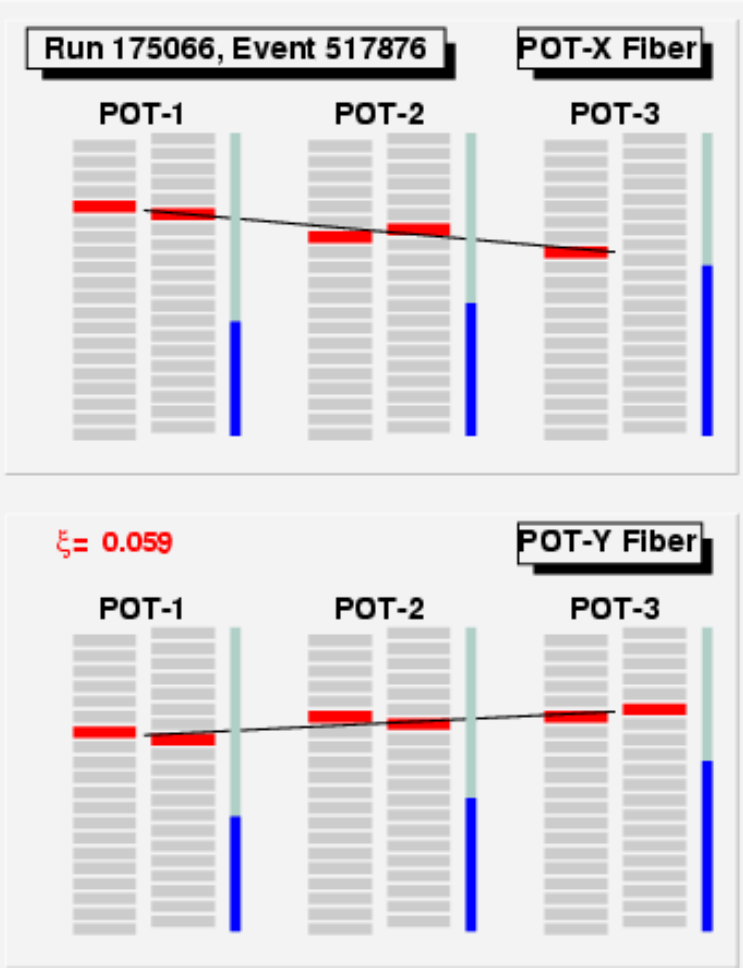
At fixed Q^2:
flat x-dependence



Roman Pot tracking



Expected position resolution	**80 μm**
Expected angle resolution	**60 μrad**



Diffractive Structure F'n @CDF

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

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

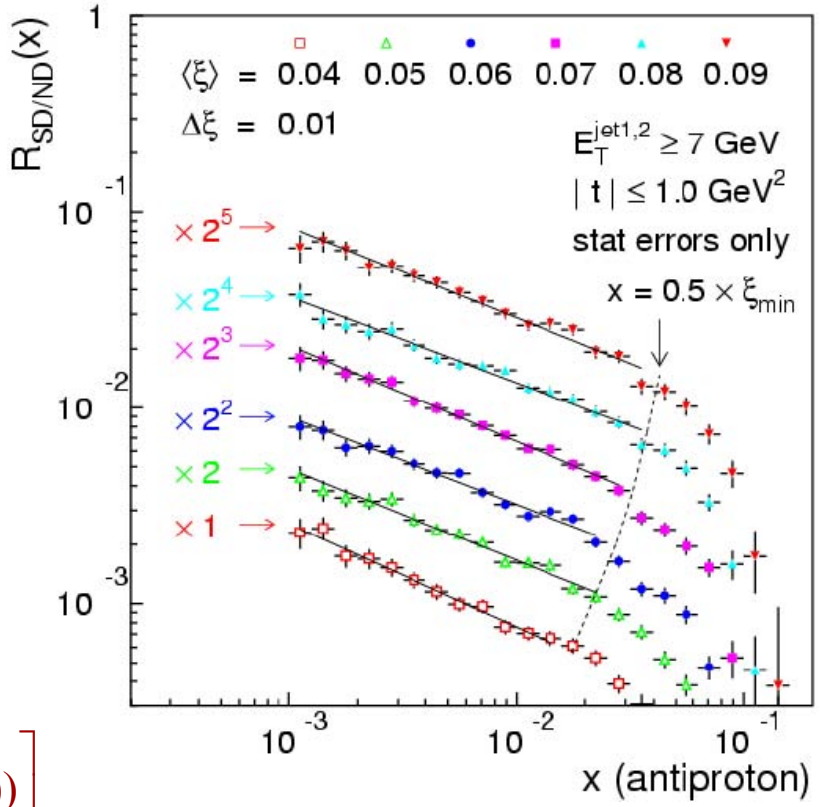
$$x_{\bar{p}} \equiv p_{g,q}/p_{\bar{p}} = \frac{\sum_{i=1}^{2(3)} E_T^i \cdot e^{-\eta^i}}{\sqrt{s}}$$

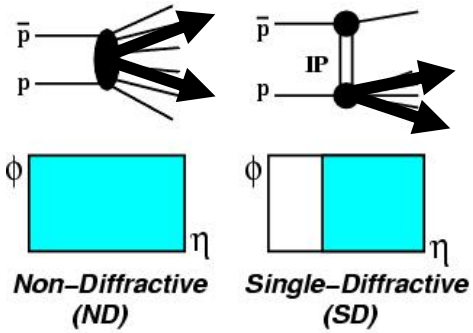
$$R_{\frac{SD}{ND}}(x_{\bar{p}}) \approx R_0 \cdot x_{\bar{p}}^{-0.45}$$

- 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 $x_{\bar{p}}$

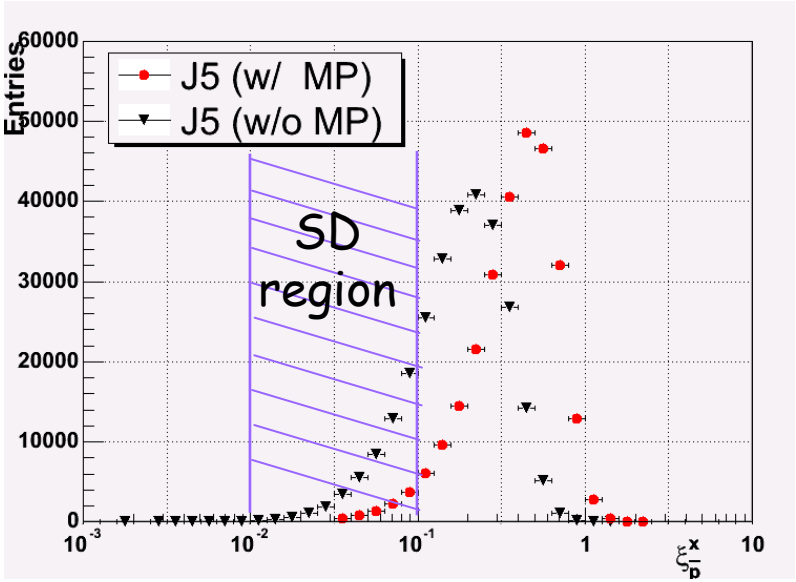


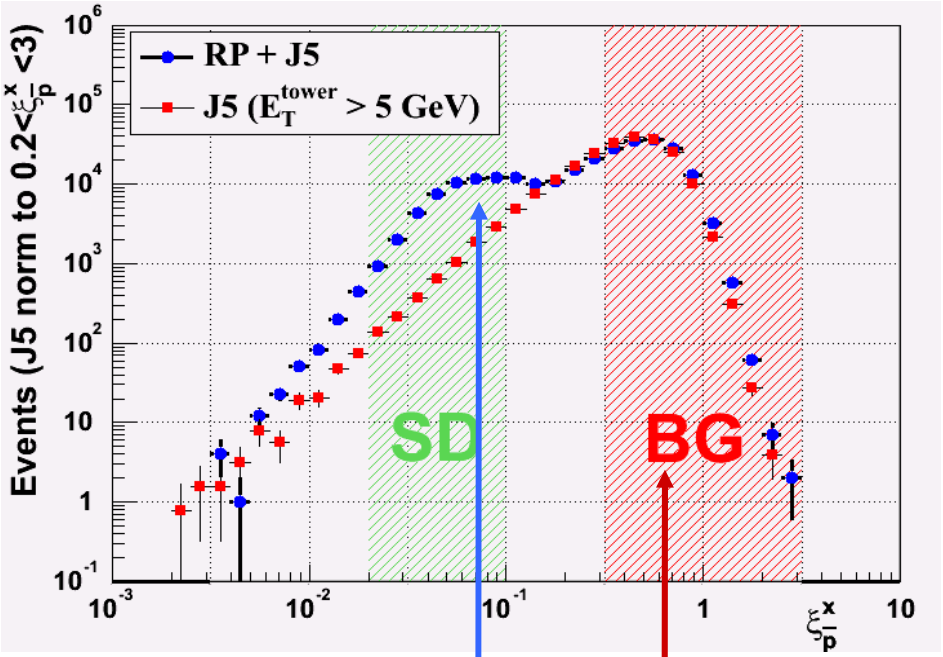


Diffractive dijets

ξ : momentum loss fraction of pbar

$$\xi = \frac{\Sigma_{(\text{all towers})} E_T\, e^{-\eta}}{\sqrt{s}}$$





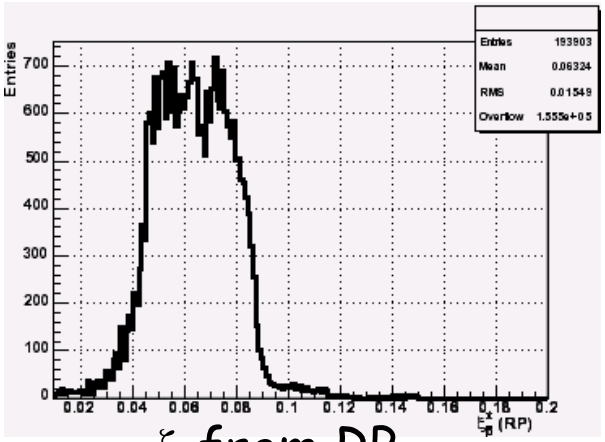
Approx. flat at ξ<0.1

$$\frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \rightarrow \frac{d\sigma}{d(\log\xi)} = \text{const}$$

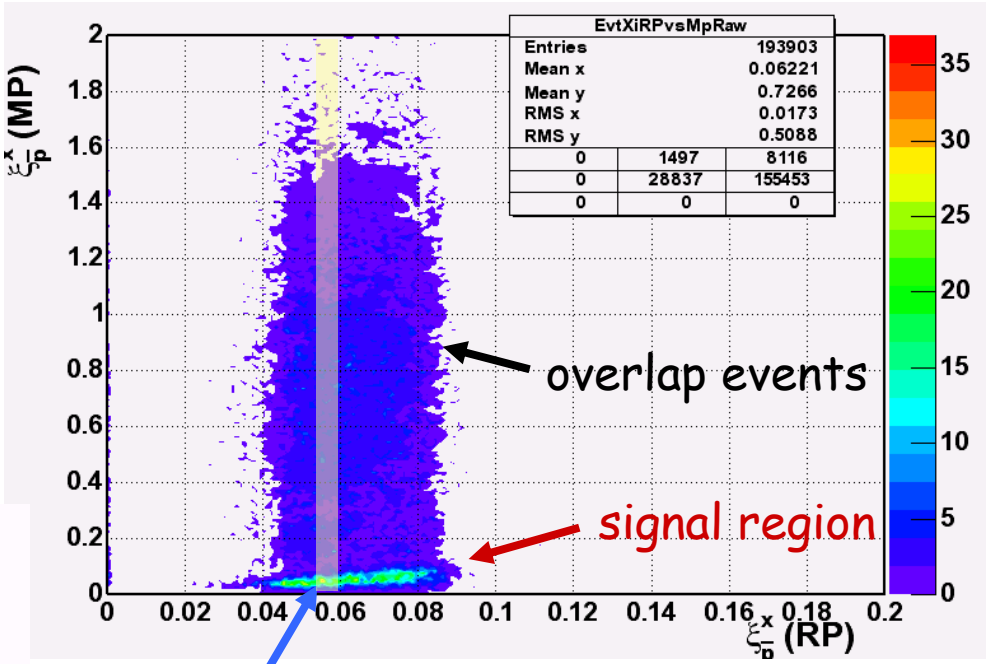
overlap events

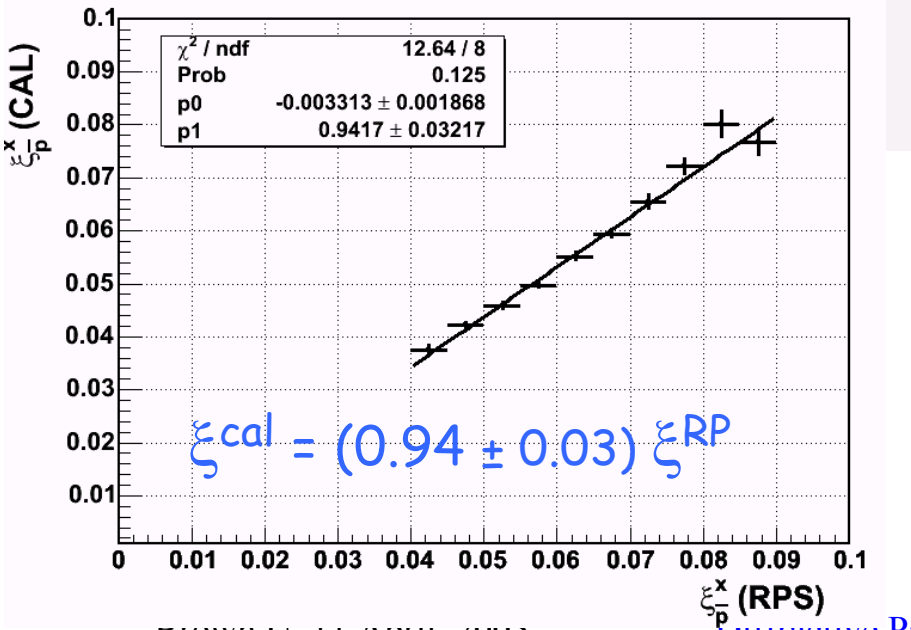
MP energy scale: ±25% →Δlogξ = ±0.1
RP acceptance (0.03<ξ< 0.1) ~ 80% (Run I)

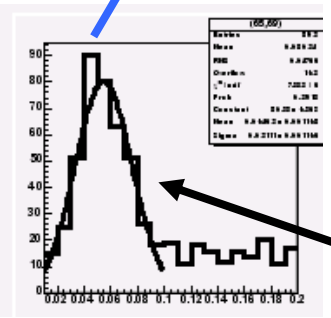
ξ: RP vs calorimeter



ξ from RP



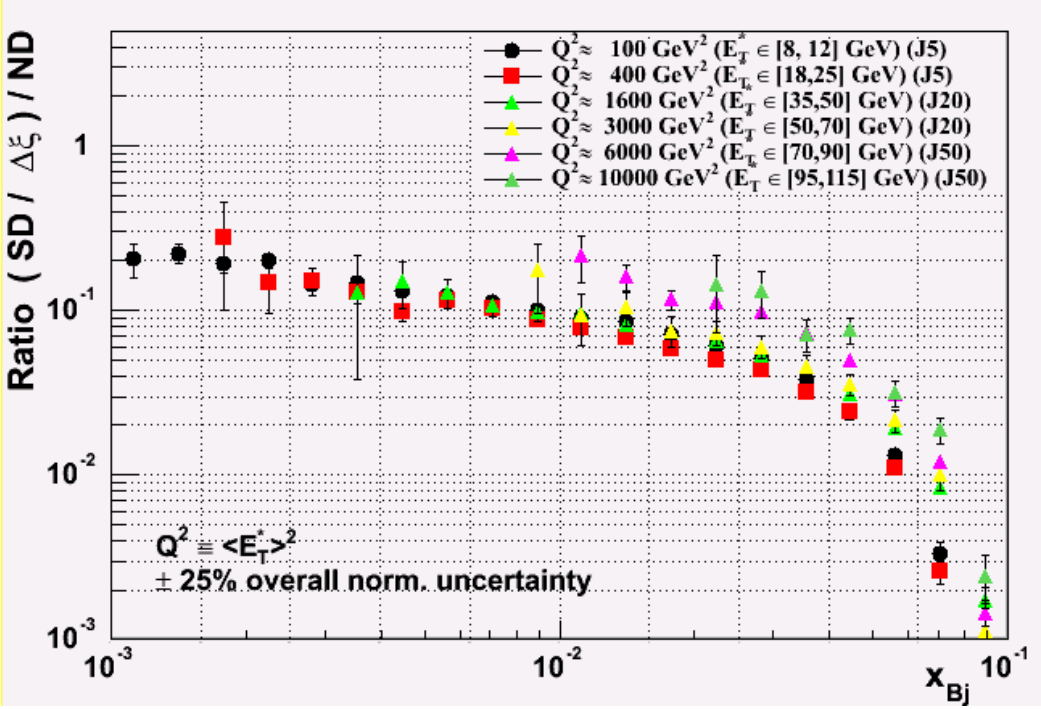




ξ^{cal} distribution for slice of ξ^{RP}

σ/mean ~ 30%

Q^2-dependence of SD/ND ratio

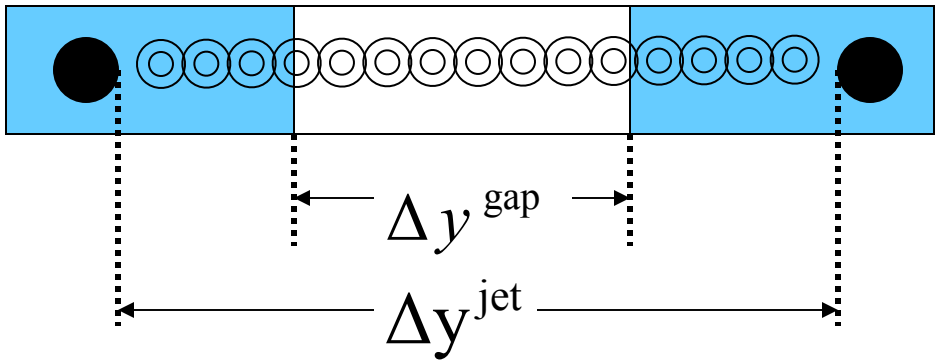


- No appreciable Q^2 dependence within $100 < Q^2 < 10{,}000\ GeV^2$

⇨ Pomeron evolves similarly to proton

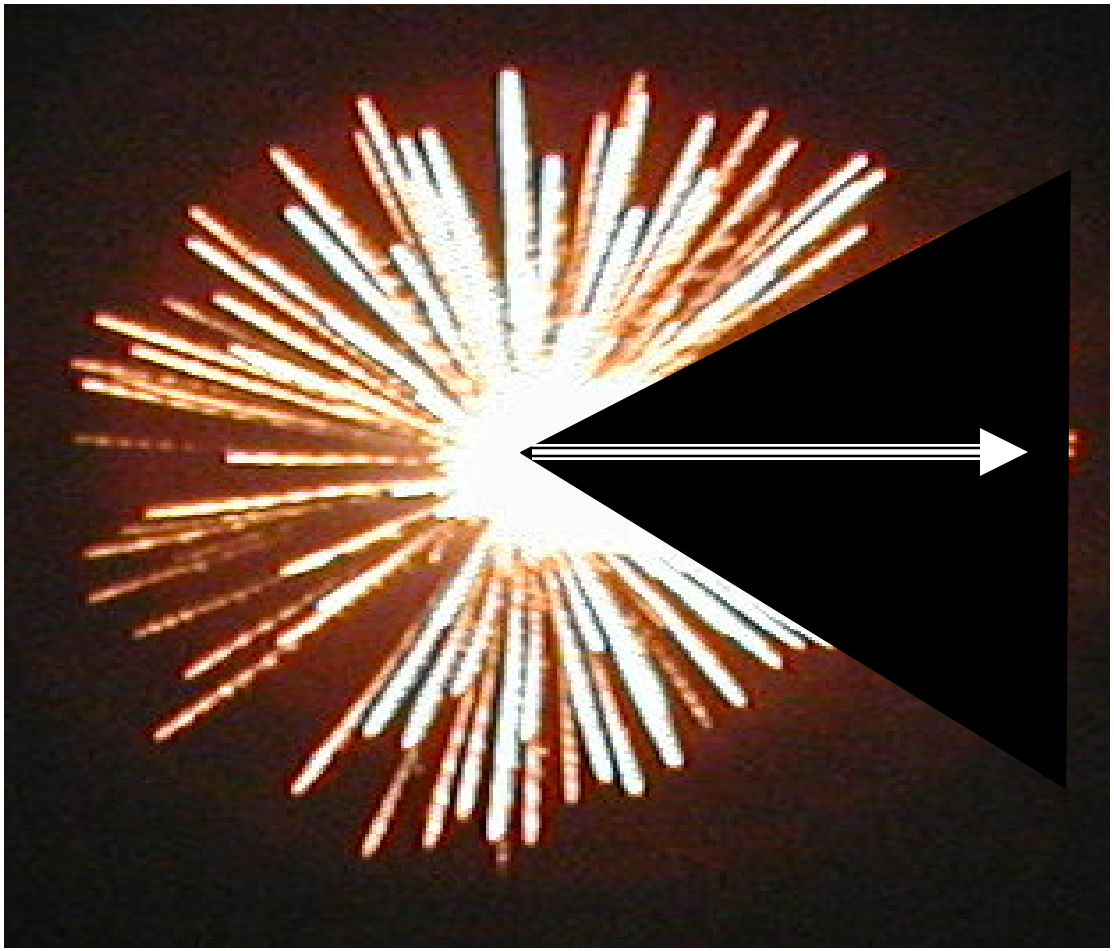
CDF2LHC

TOPIC	STATUS
➢ (Q^2, t) dependence of DSF	close to ready
➢ Exclusive χ_c production	close to ready
➢ Low mass states in DPE	need good trigger
➢ Exclusive b-bbar production in DPE	need b-trigger
➢ ξ -dependence of DSF	need low lum run
➢ Jet-gap-Jet ^{W}/jets in miniplugs	need low lum run



$$\Delta y^{gap} = \Delta y^{jet} \Rightarrow \text{BFKL}$$
$$\Delta y^{gap} \neq \Delta y^{jet} \Rightarrow \text{composite}$$

Gaps in fireworks?



Rapidity Gaps

Bj, PRD 47 (1993) 101: regions of (pdeudo)rapidity devoid of particles

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations.

From Poisson statistics:

$$P(\Delta y) = e^{-\rho \Delta y} \quad \left(\rho = \frac{dn}{dy} \right)$$

(ρ=particle density in rapidity space)

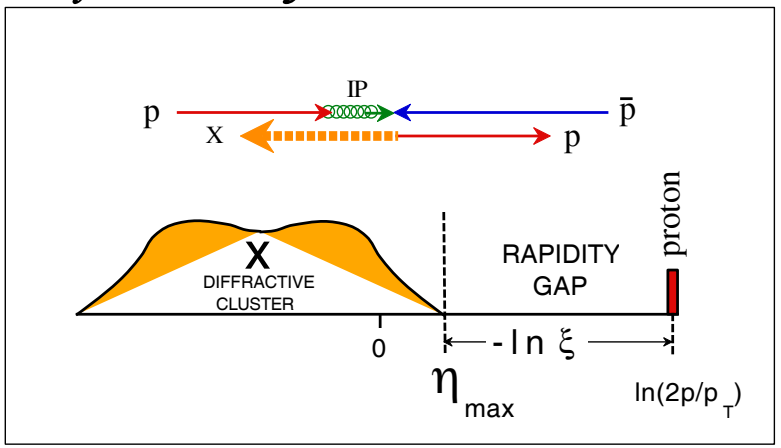
Gaps are exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy.

$$\xi \equiv \Delta p / p$$

$$\Delta y \approx -\ln \xi = \ln s - \ln M^2$$



$$\left.\frac{d\sigma}{d\Delta y}\right|_{s,t=0} \sim \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2}$$