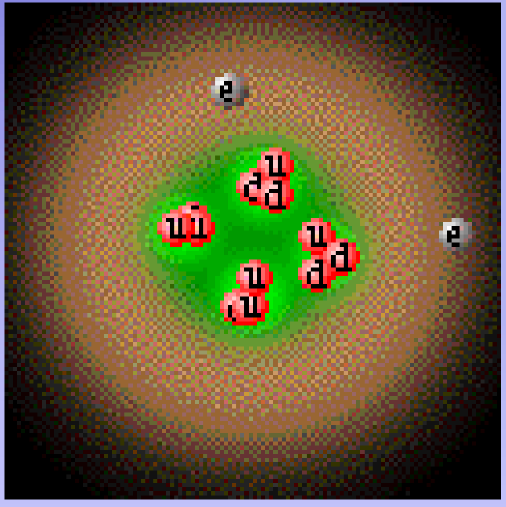
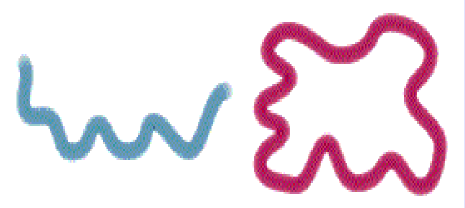
Diffraction, Dark Energy, and Higgs Bosons

Seminar @ NESTOR Institute, PYLOS, GREECE, 20 Aug 07

K. Goulianos

The Rockefeller University





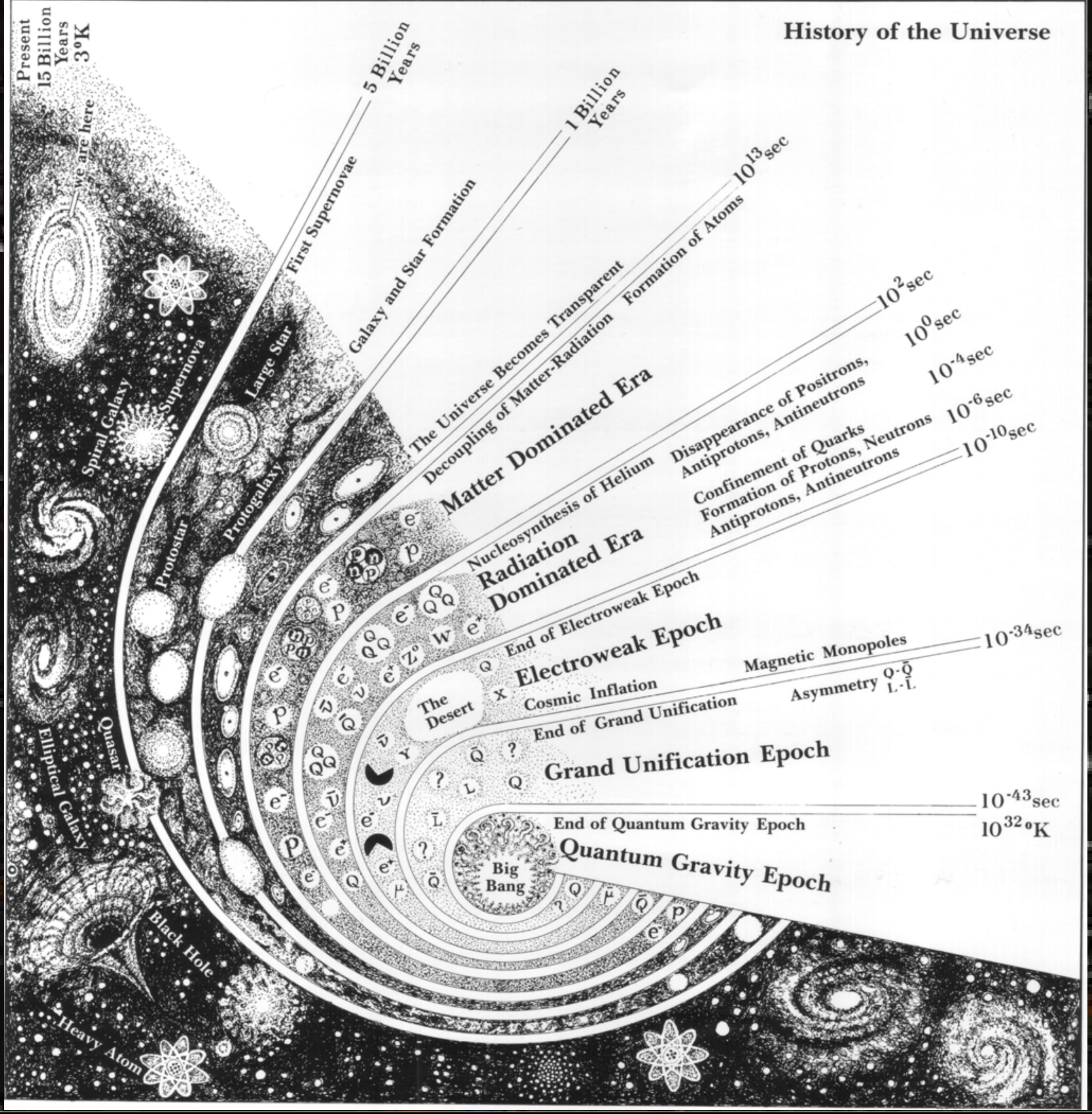
QCD , Strings,

or OTHER?

Contents

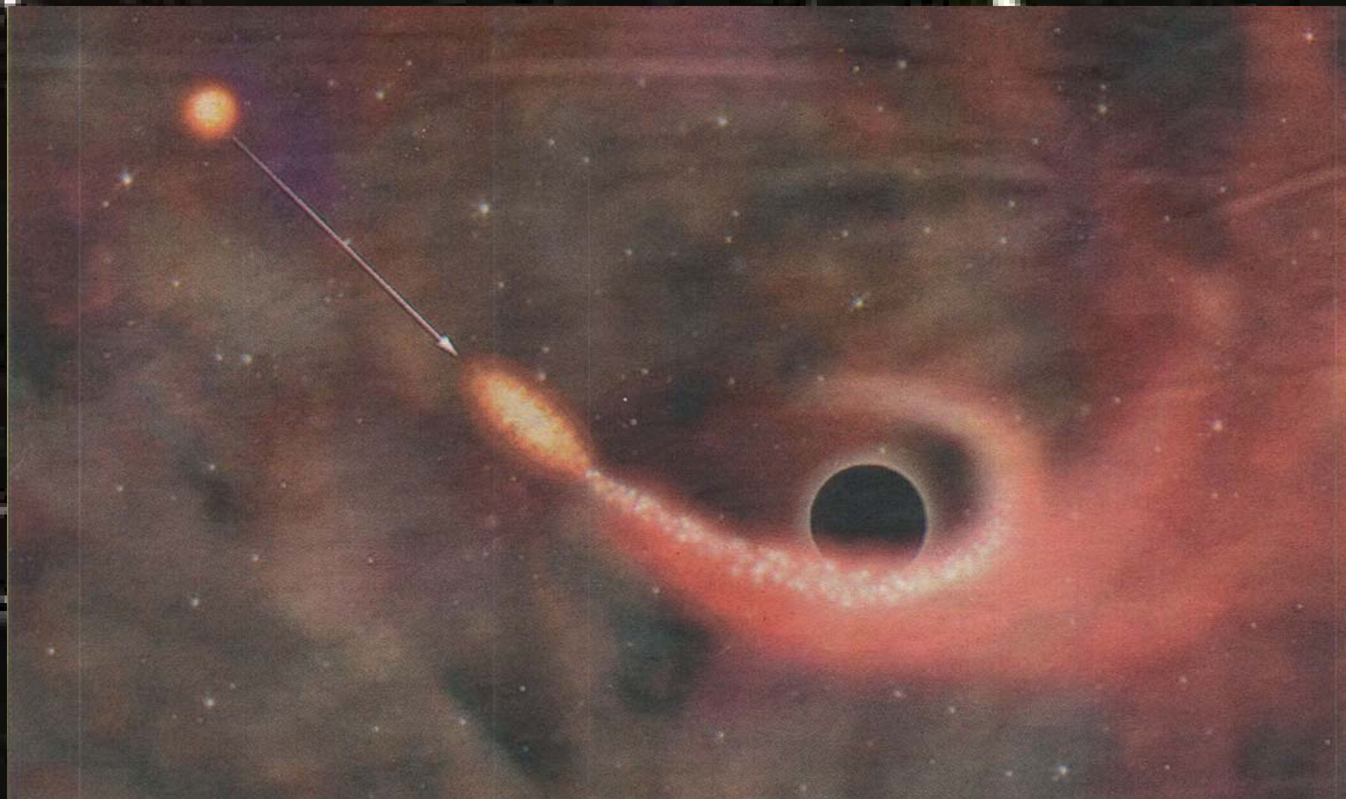
- Introduction
- Diffraction
- Dark Energy
- Higgs Bosons

INTRODUCTION


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

Blow-hole at Grand Cayman

Black Hole Eats Star!

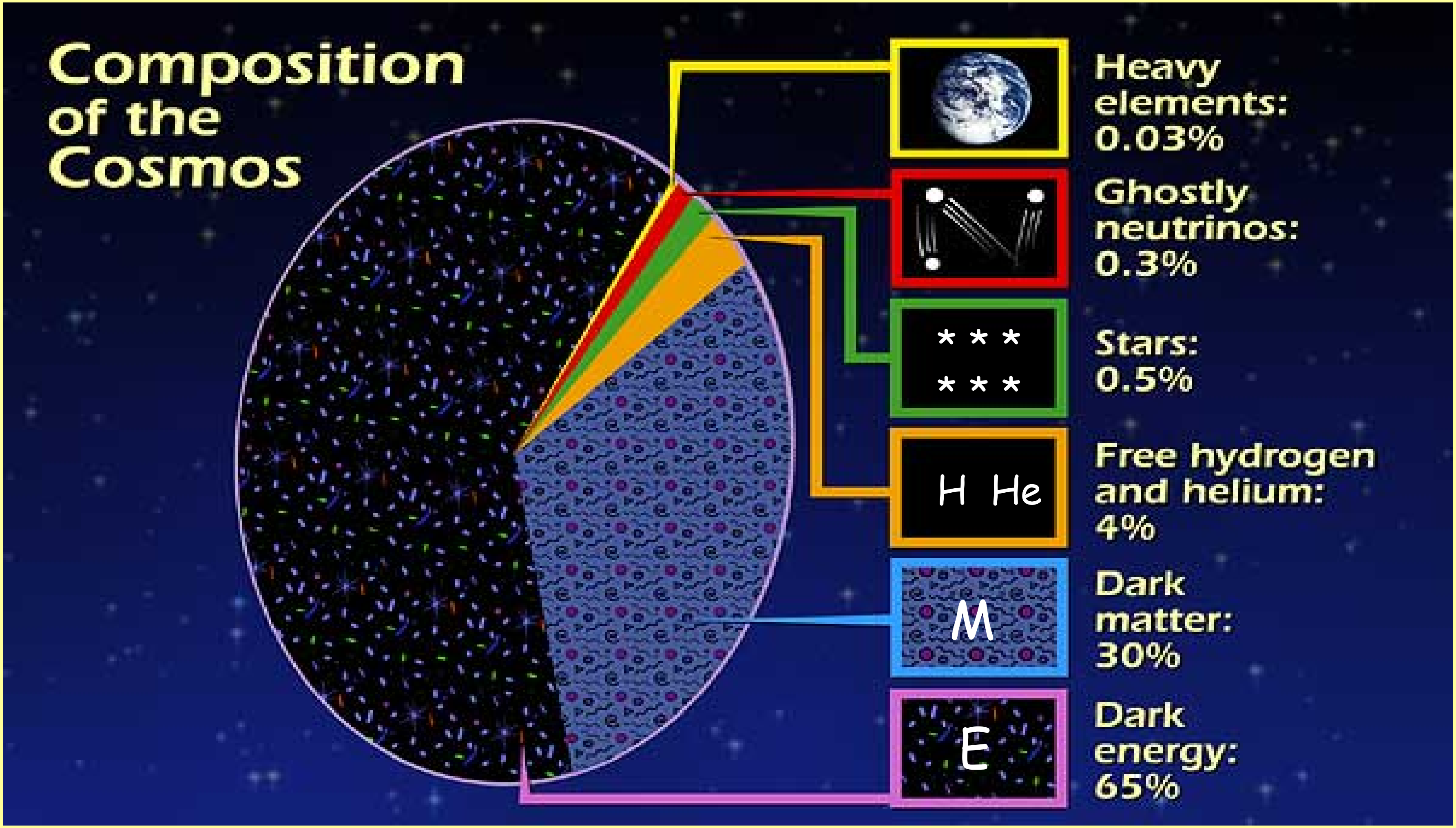


AP Photo

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.

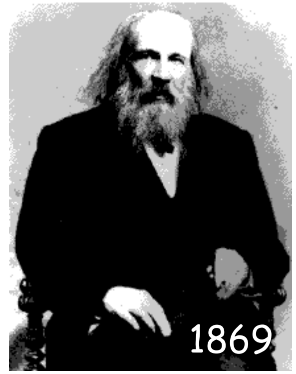
Star No Match for Black Hole

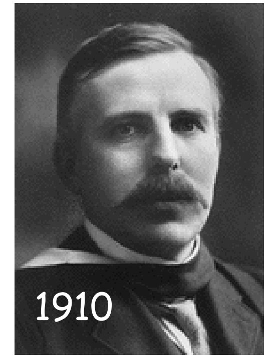
What is Dark Energy?



Elementary Particles

450 BC

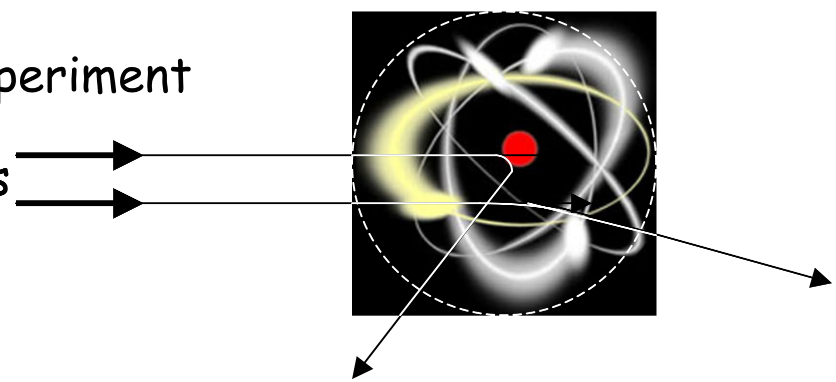




Aristotle	Demokritos	Mendeleyev	Thomson	Rutherford	Gell-Mann
earth water air fire	atom	periodic table	electron	nucleus	quarks

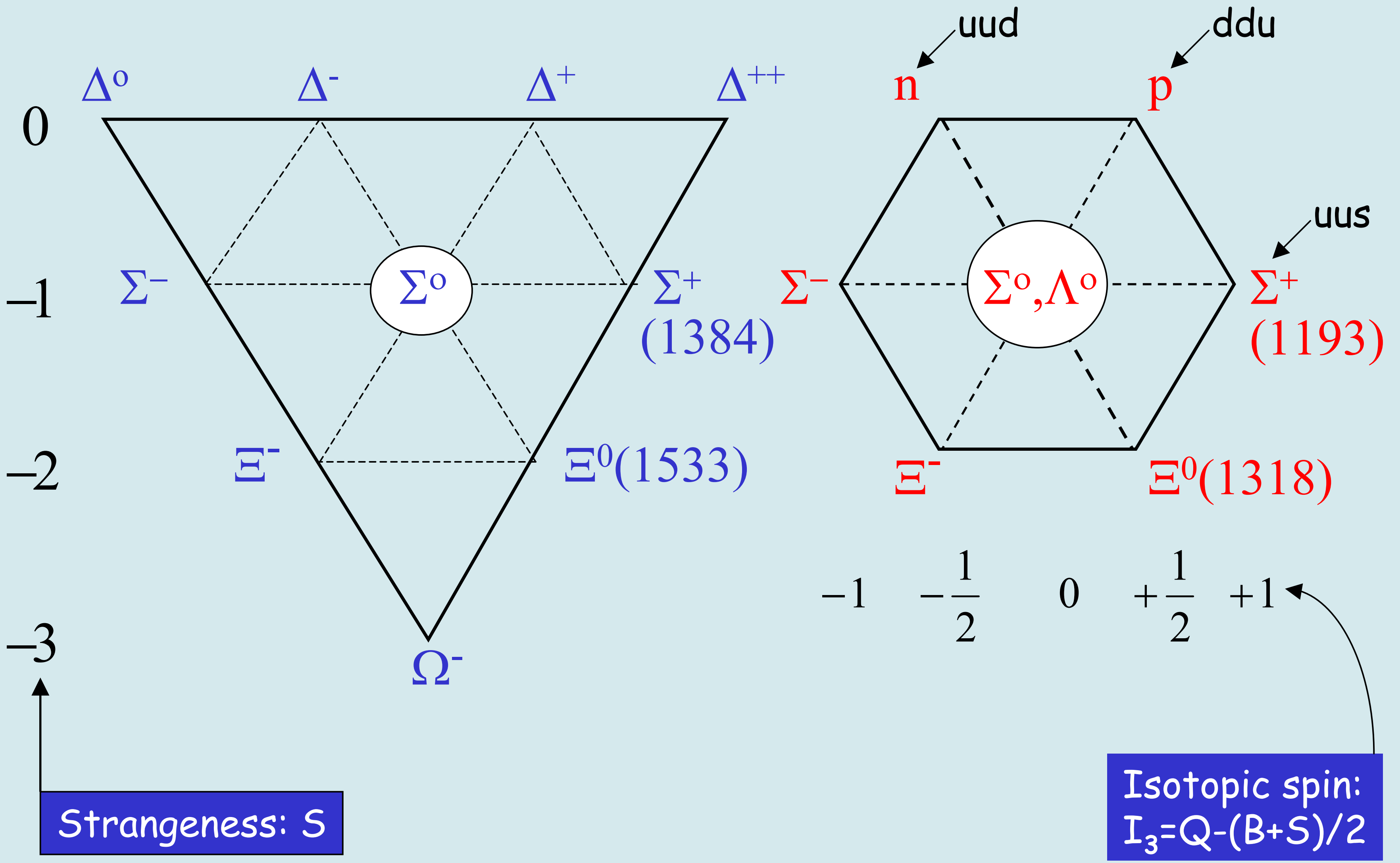
Rutherford Experiment

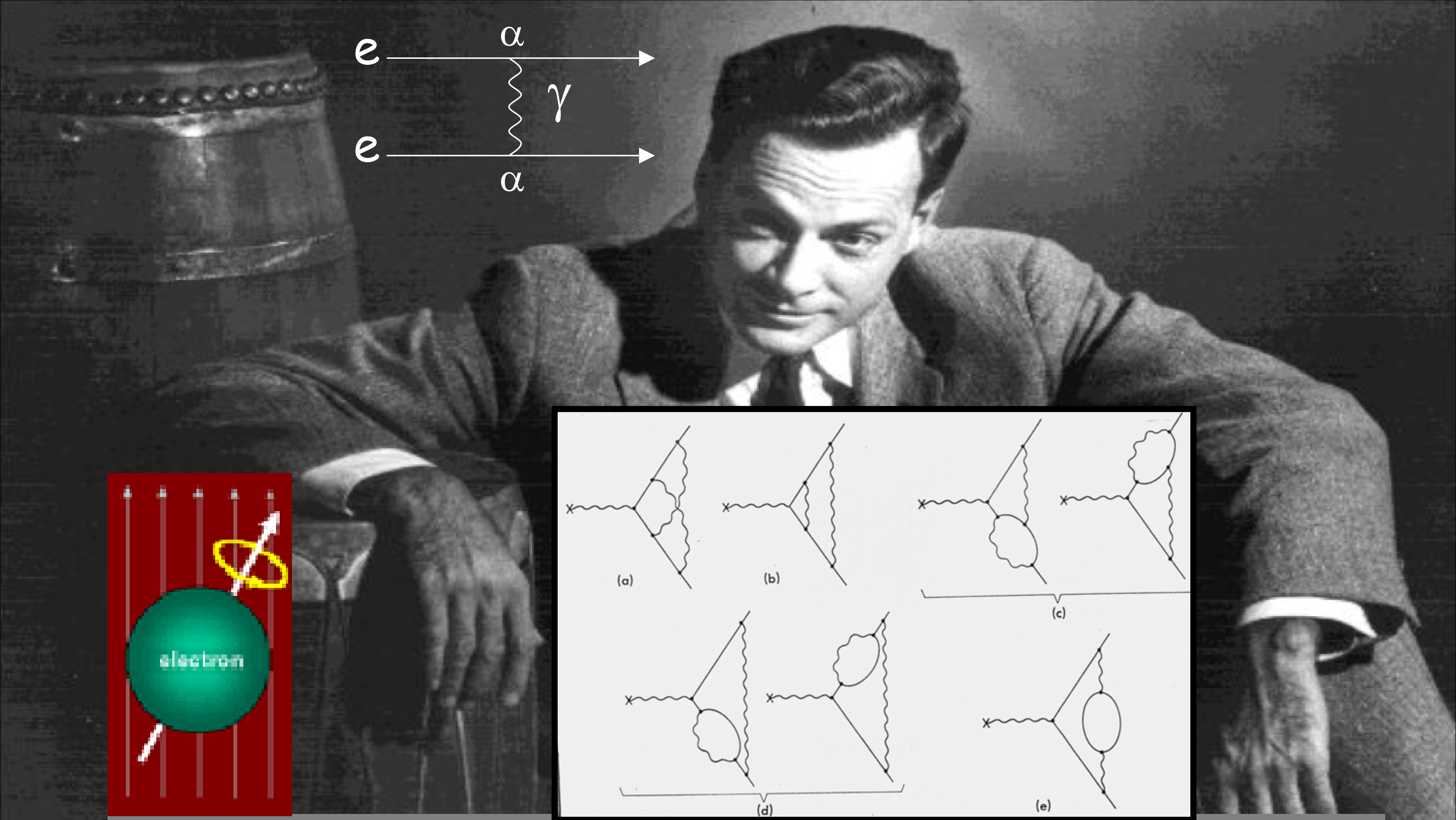
Source → α-particles



Large angle scattering → atoms have nuclei

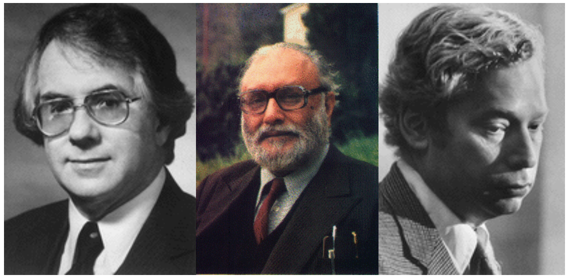
SU3: Law and Order in the Particle Zoo





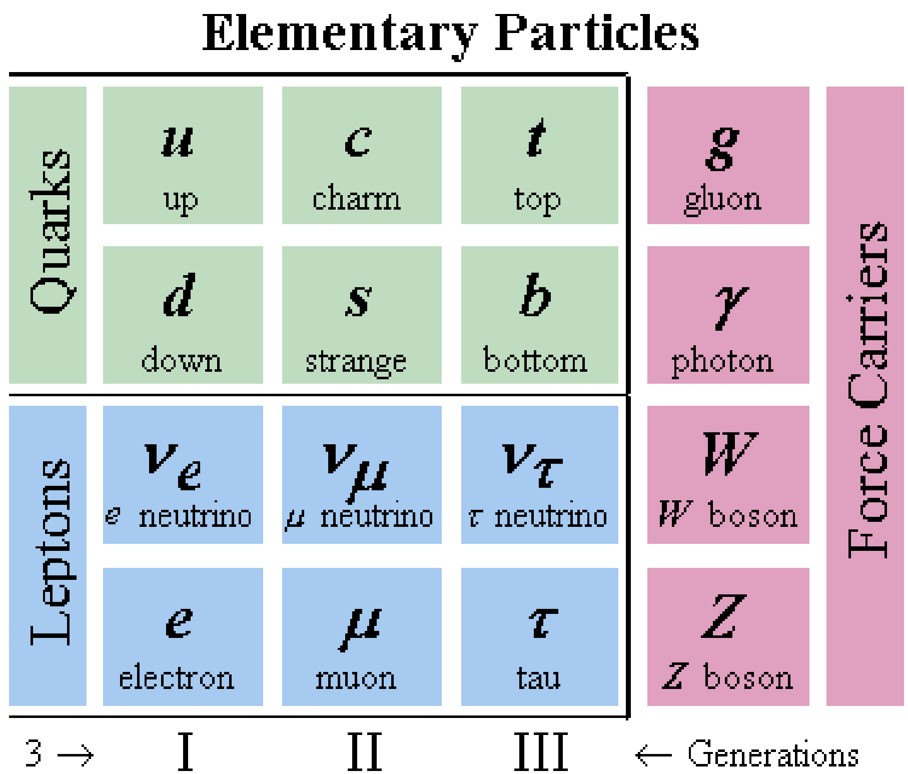
$$\mu = 1.00115965219 \pm 0.00000000001$$

$$\mu = 1.00115965219 \pm 0.00000000003$$



The Standard Model

Glashow, Salam, and Weinberg

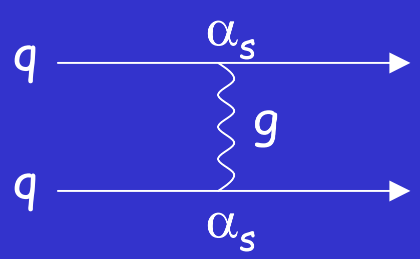


$M_\gamma, g = 0$ $M_{W,Z} \sim 100\ M_p$ $M_{top} \sim M_{gold}$

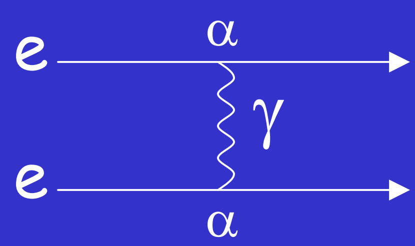
Higgs field generates Mass !

Unification of forces

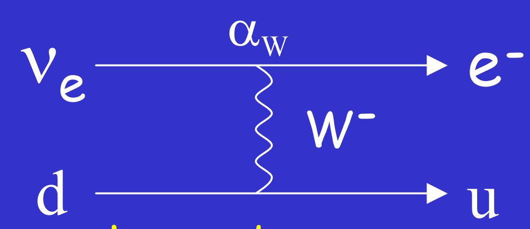
STRONG ~ 1



ELECTROMAGNETIC ~ 10^{-2}

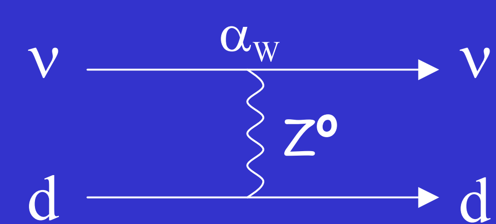


WEAK ~ 10^{-14}



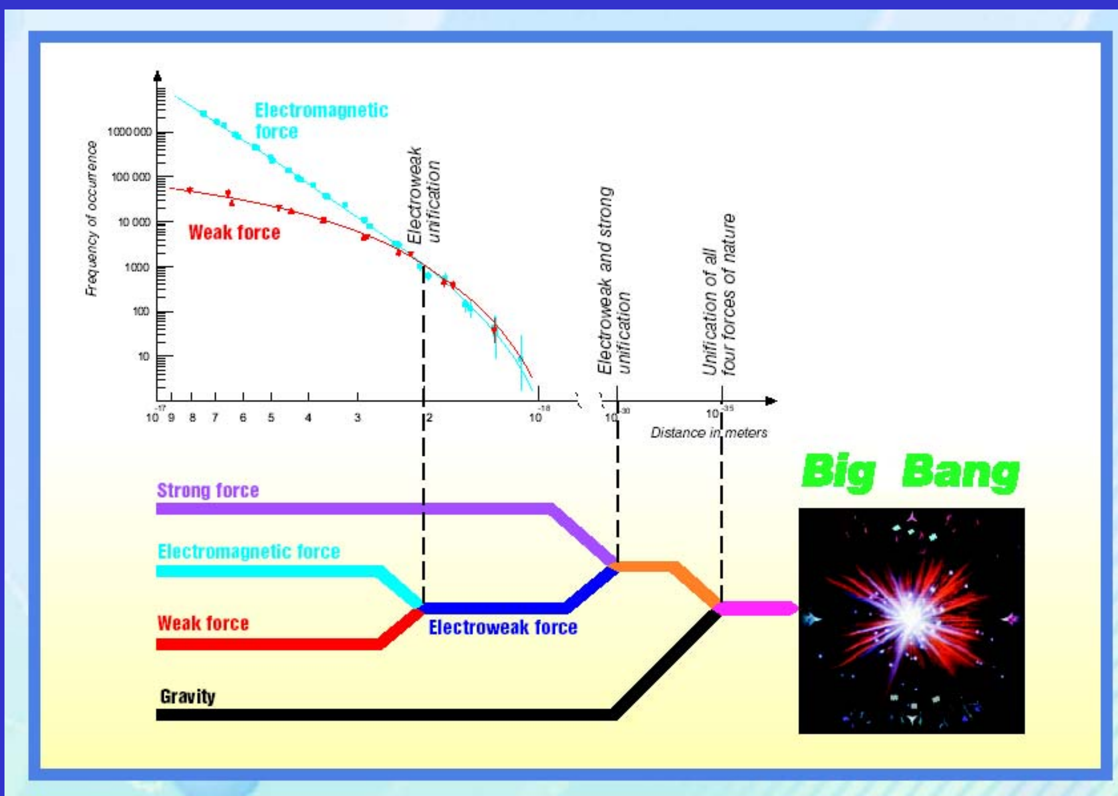
charged current

$\nu_e + n \rightarrow p + e^-$



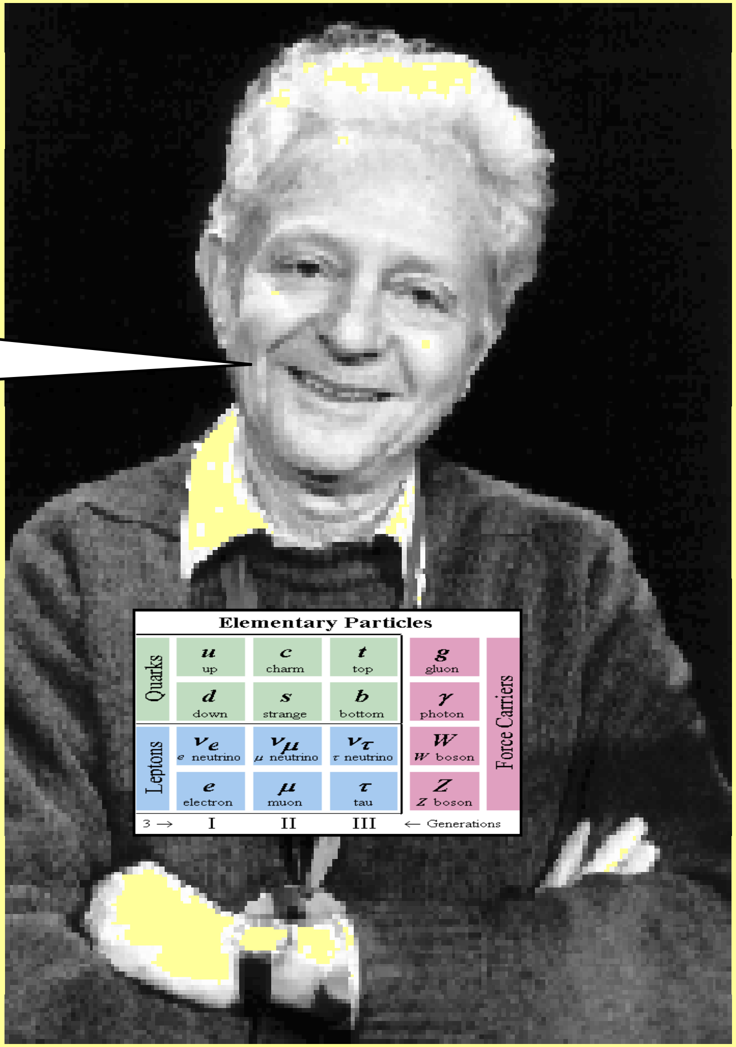
neutral current

$\nu_e + p \rightarrow \nu_e + p$



Leon Lederman & the SM

A good theory should fit on a T-shirt!



But what about interactions?

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

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

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

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

$$-\left(G_{1}\bar{L}\phi R + G_{2}\bar{L}\phi_{c}R + \text{hermitian conjugate}\right)$$

AND WHAT ABOUT GRAVITY?

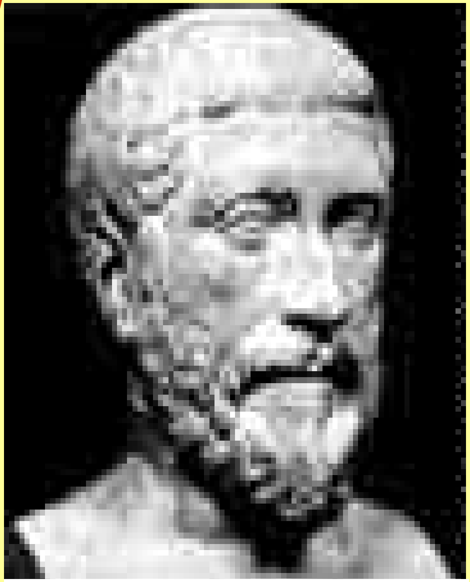
String Theory, then?

http://www.aboutscotland.com/harmony/prop.html

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



It surely makes an interesting T-shirt!

DIFFRACTION

$\bar{p}$-p Interactions

Non-diffractive:

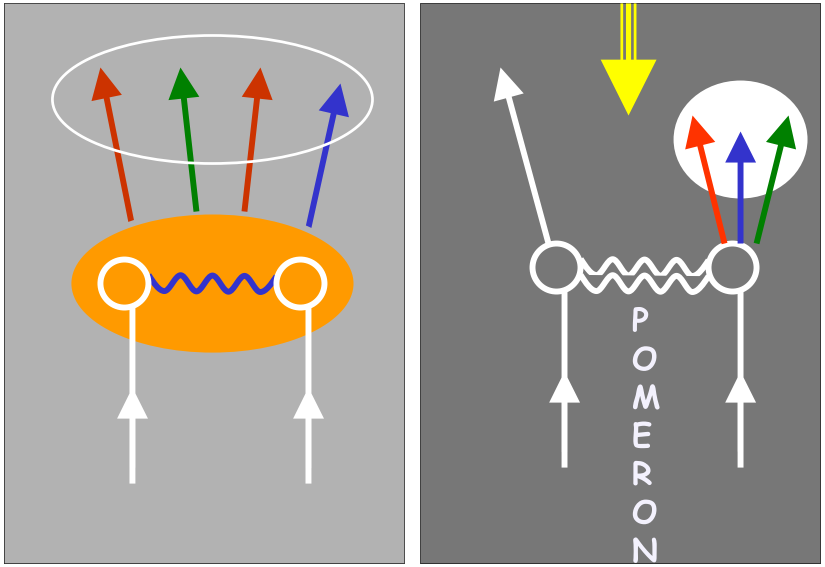
Color-exchange

Diffractive:

Colorless exchange with vacuum quantum numbers

rapidity gap

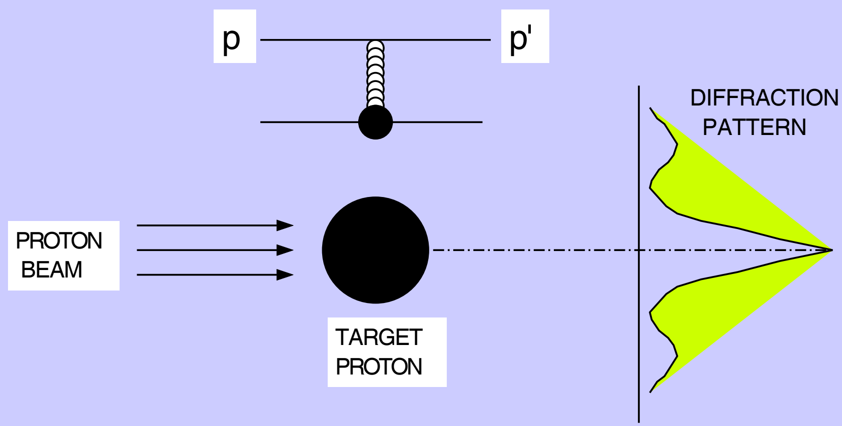
Incident hadrons acquire color and break apart



Incident hadrons retain their quantum numbers remaining colorless

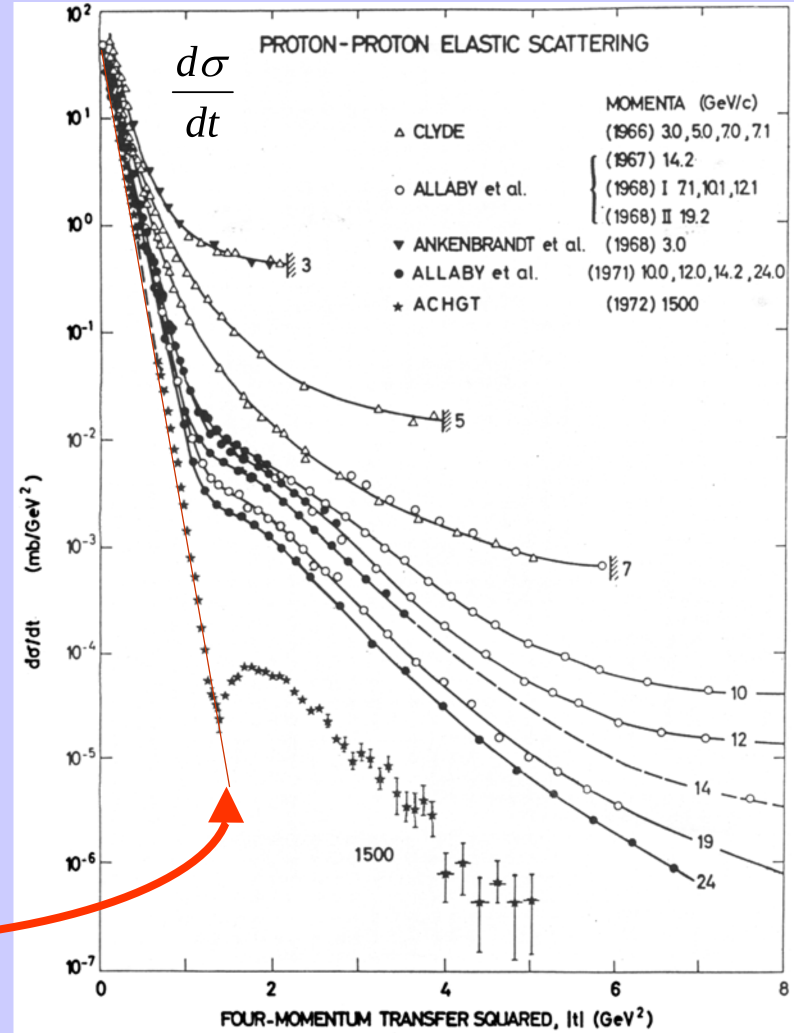
Elastic Scattering

PROTON-PROTON ELASTIC SCATTERING



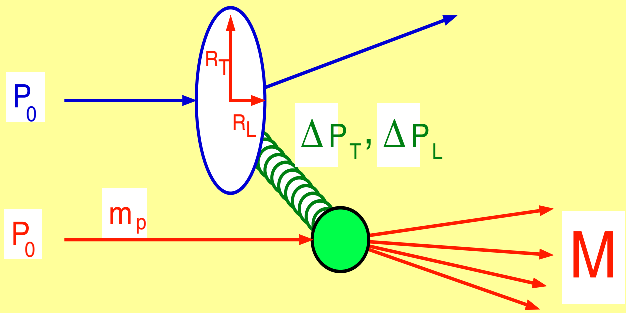
$$\frac{d\sigma}{dt} \sim e^{bt} \sim e^{-\frac{R^2}{4}(p\theta)^2}$$

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



Diffraction Dissociation

KG, Phys. Rep. 101, 169 (1983)



Momentum loss fraction

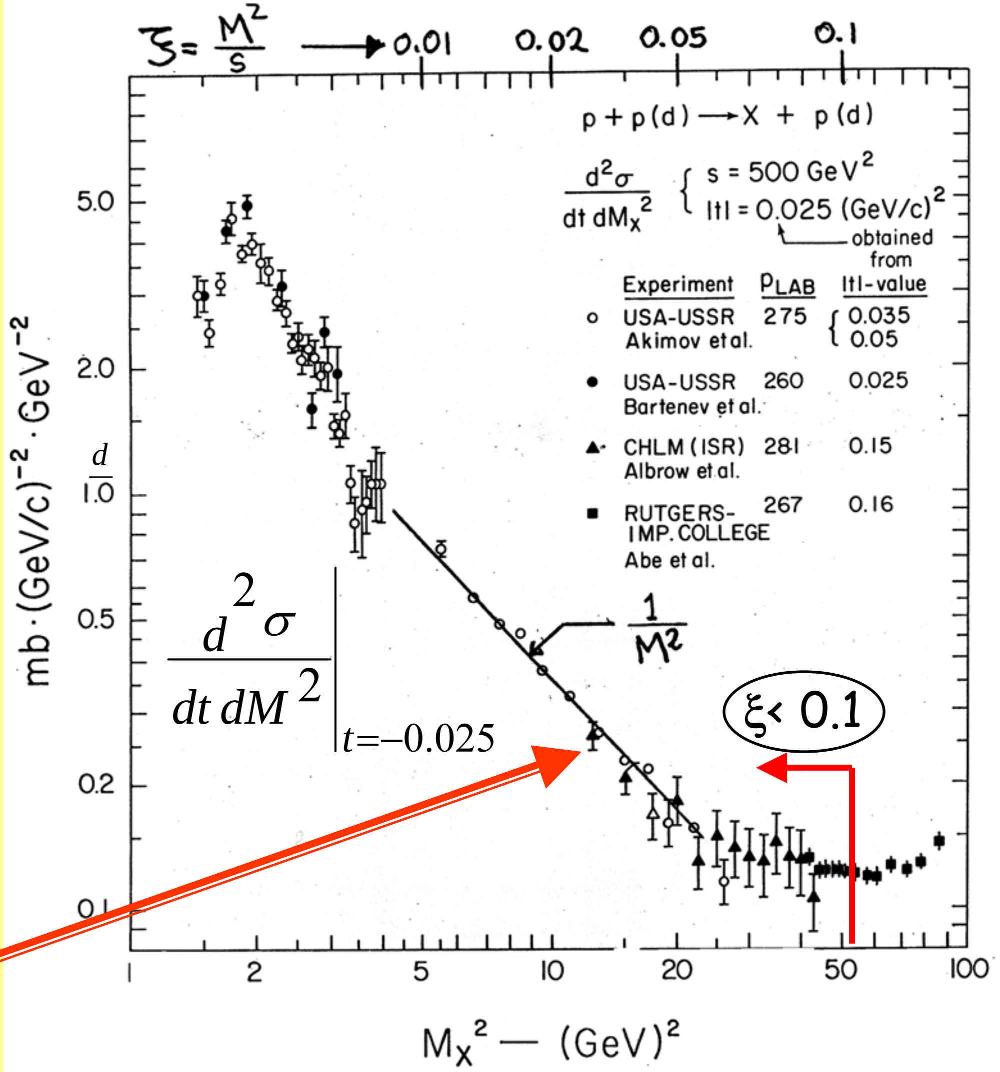
$$\xi = \frac{\Delta P_L}{P_L} = \frac{M^2}{s}$$

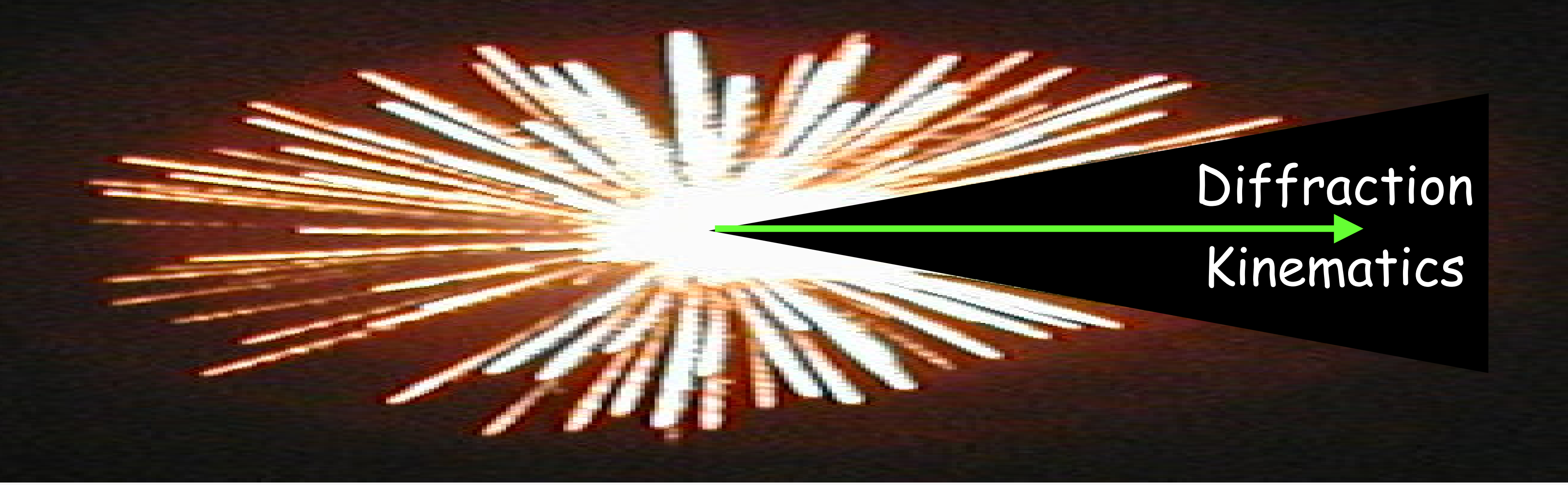
COHERENCE CONDITION

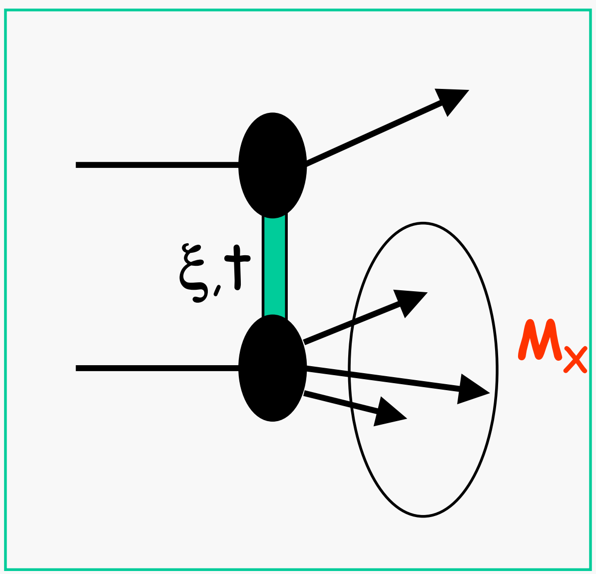
$$\xi < \frac{m_\pi}{m_p} \approx 0.1$$

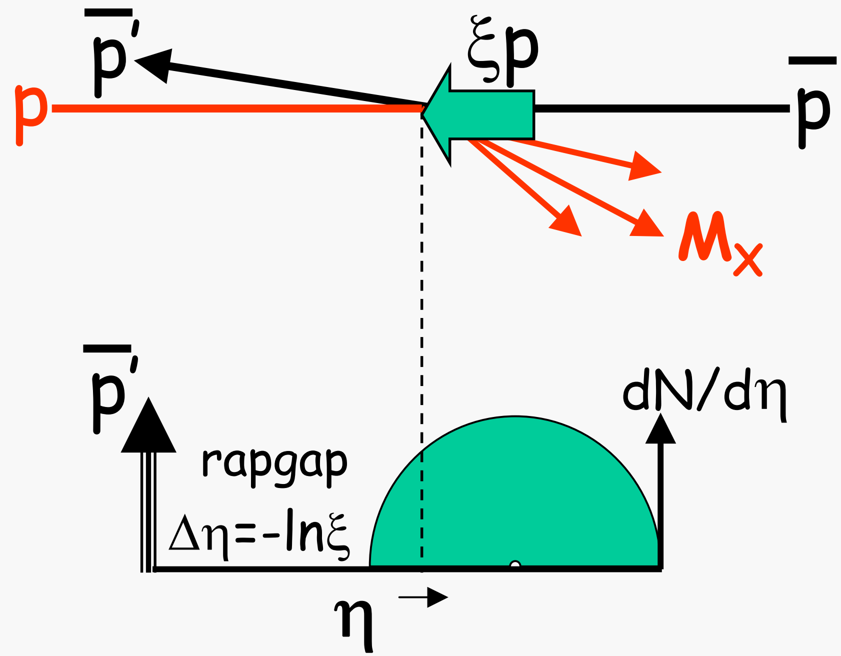
Tevatron	M ➔	0.6 TeV
LHC	➔	4.4 TeV

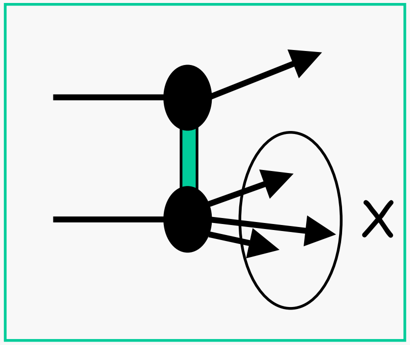
$$\text{Why } \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \text{ ?}$$



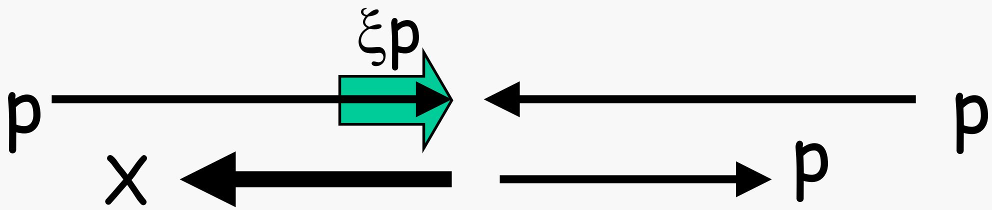

Diffraction
Kinematics

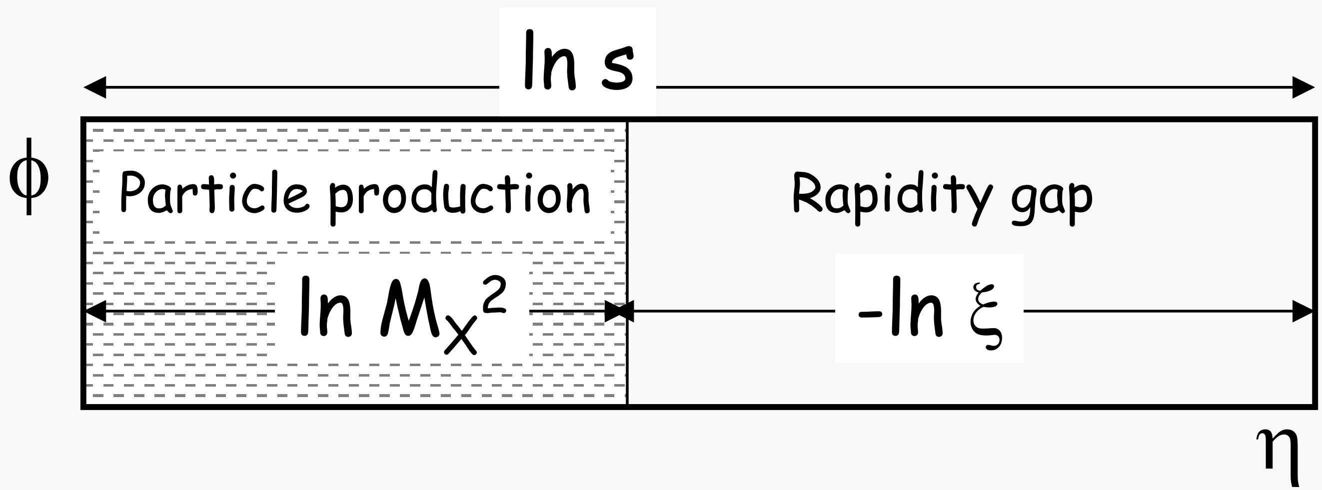

ξ,t
Mx


p̄'
ξp
p
p̄
Mx
p̄'
rapgap
Δη=-lnξ
dN/dη
η



Rapidity Gaps and QCD



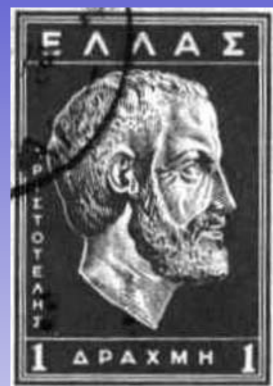


$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

PHENOMENOLOGY

Plato (427-347 B.C)

platonic love



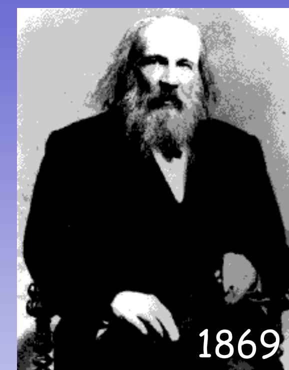
Aristotle

earth
water
air
fire

450 BC

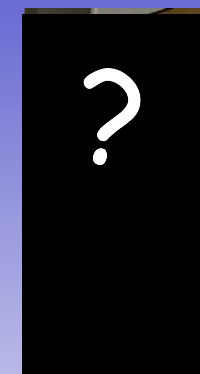
Demokritos

atom



Mendeleyev

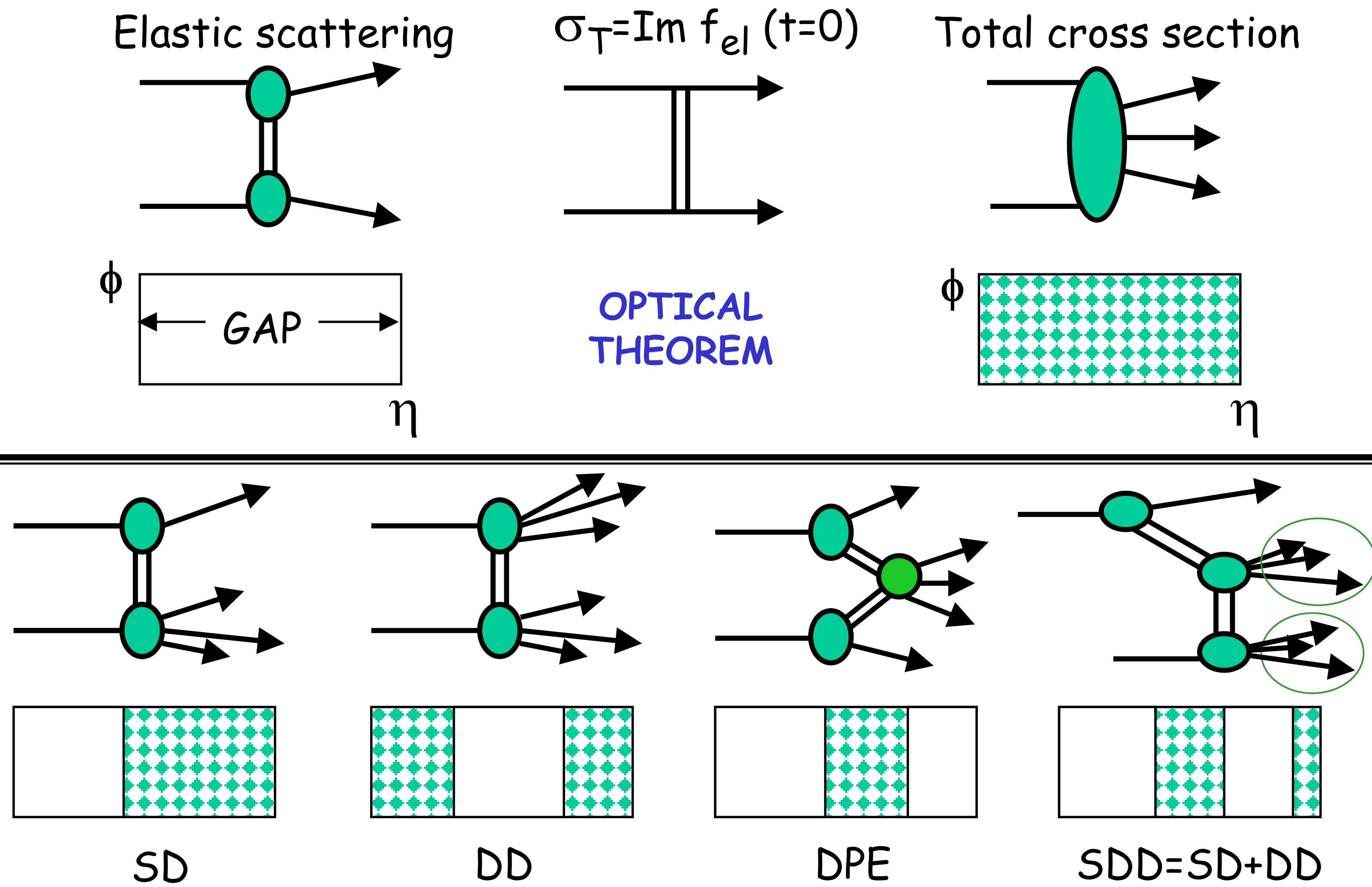
periodic table



2007

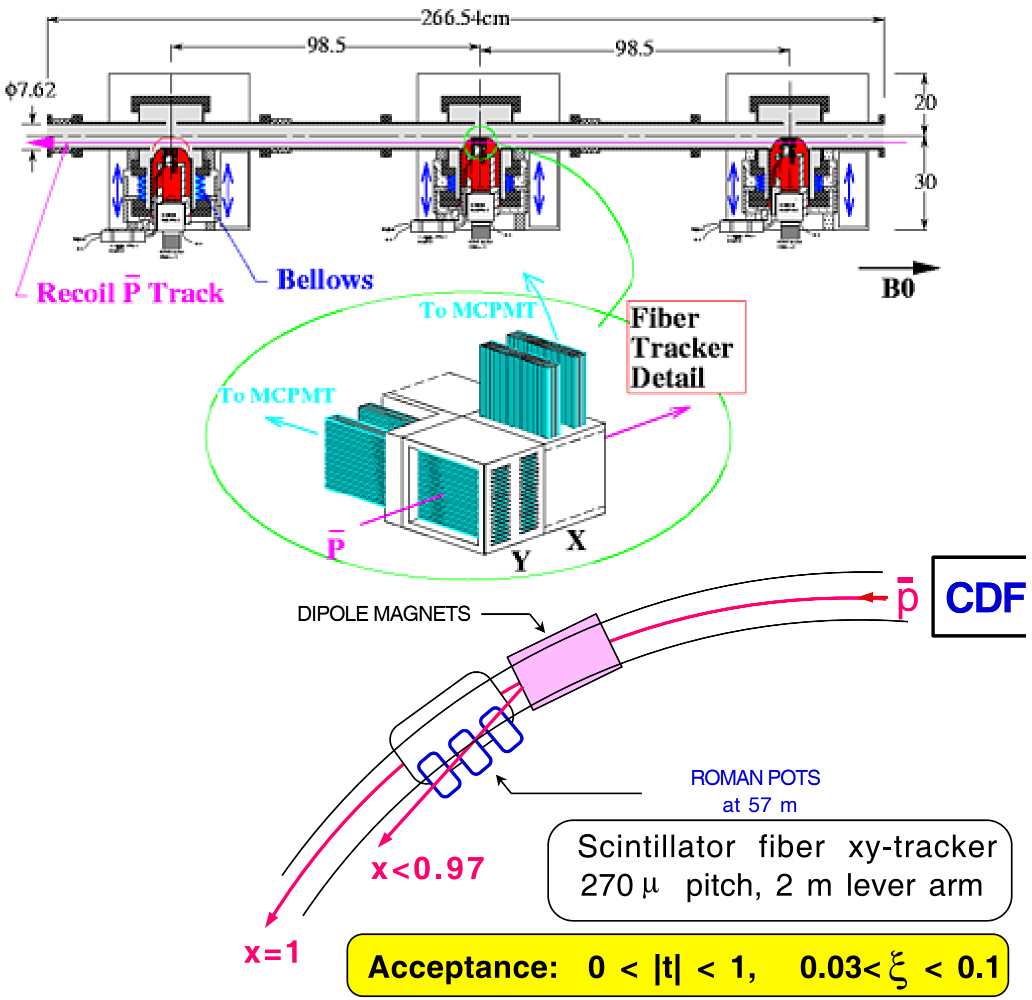
candidates superimposed

Diffraction at CDF

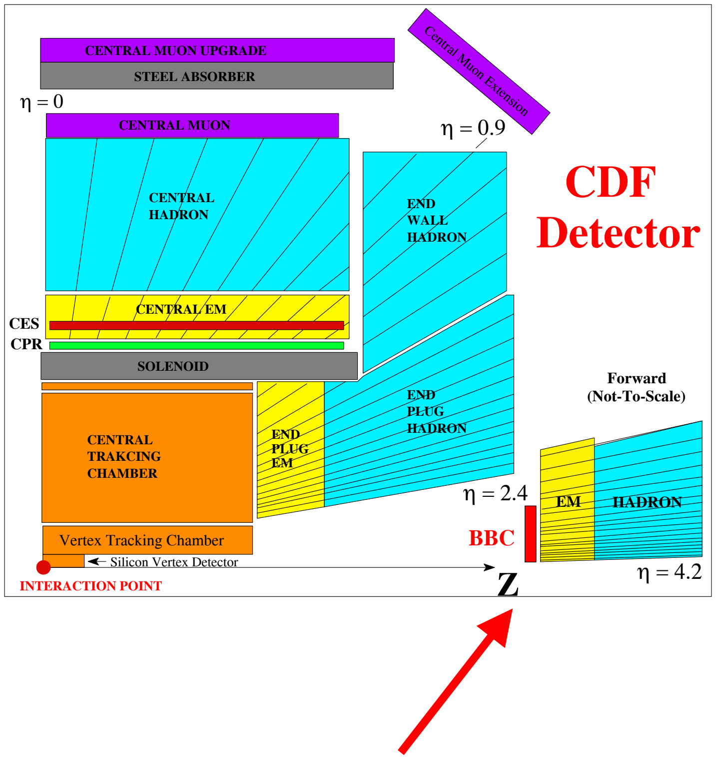


CDF Run 1 (1992-1995)

Run-IC



Run-IA,B

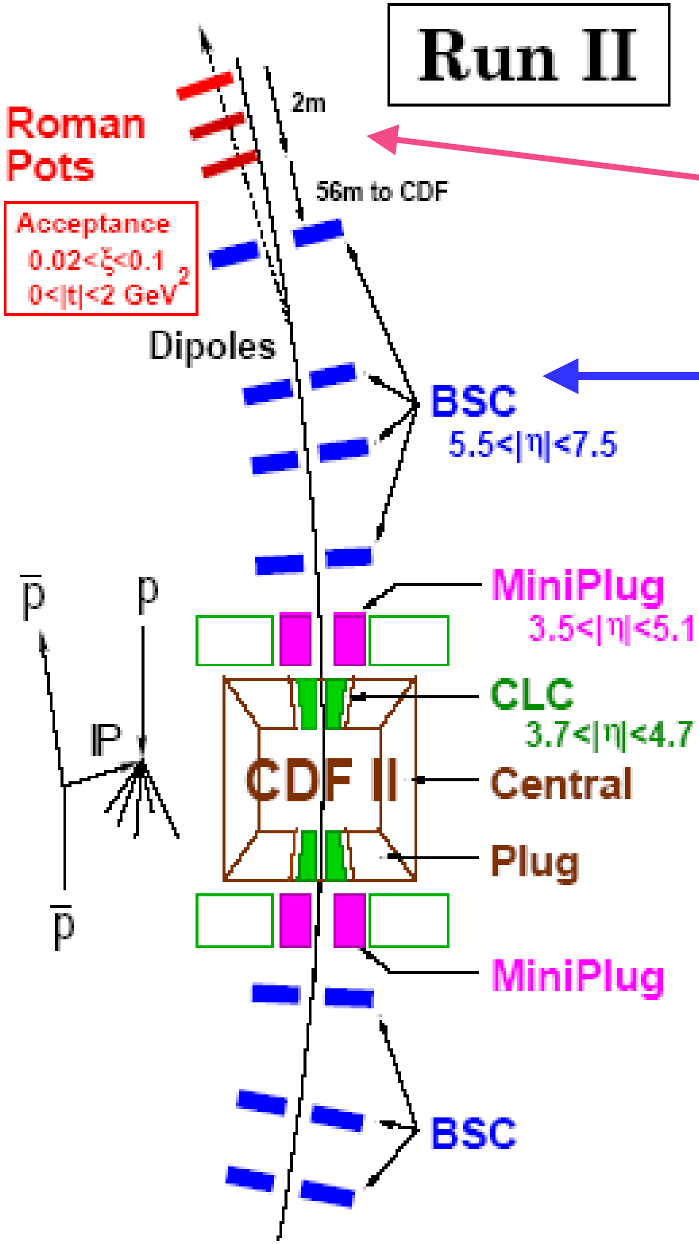


Forward Detectors

BBC 3.2<η<5.9

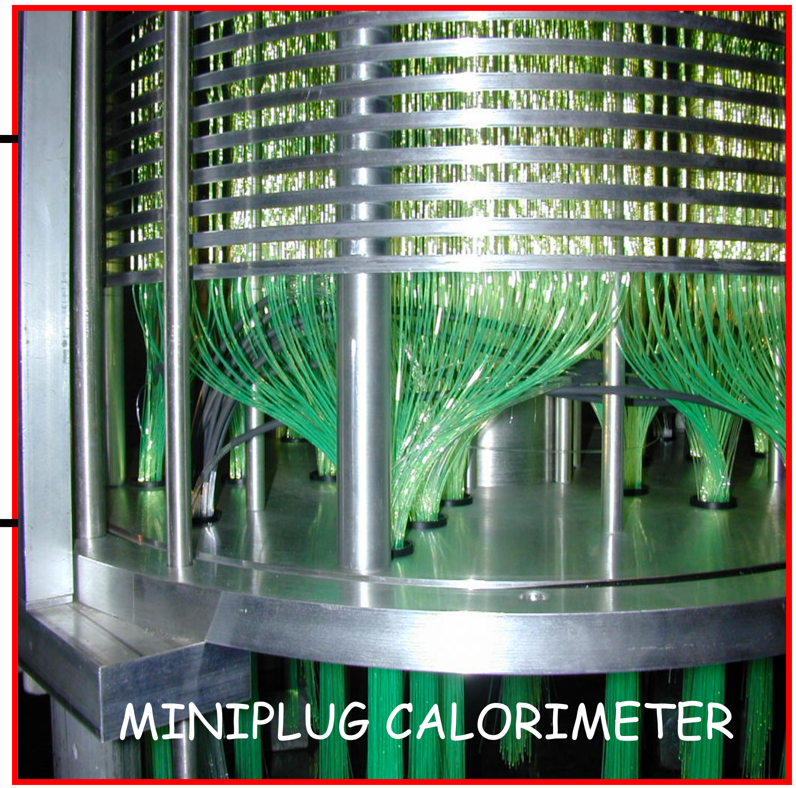
FCAL 2.4<η<4.2

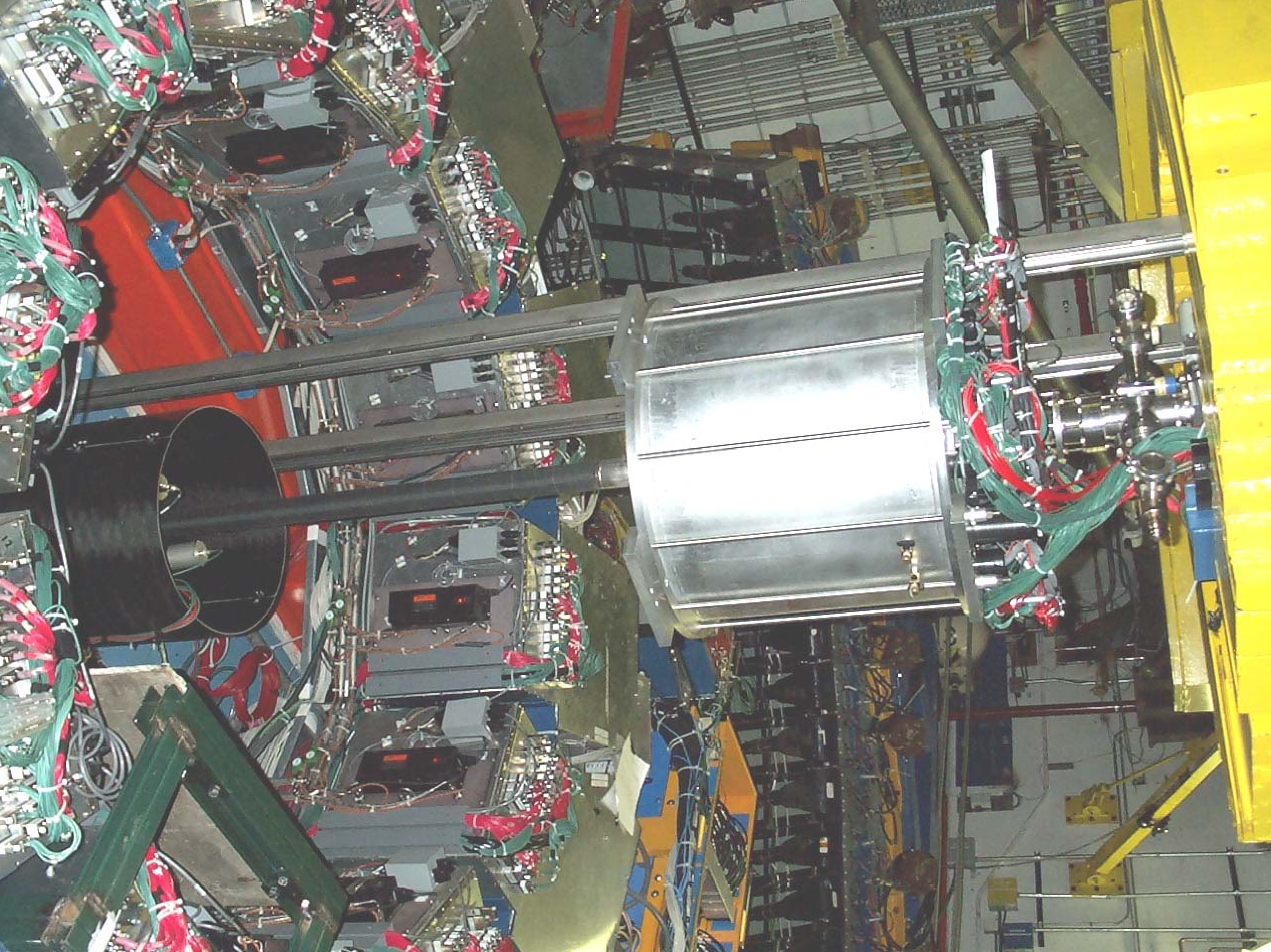
Run II CDF forward detectors



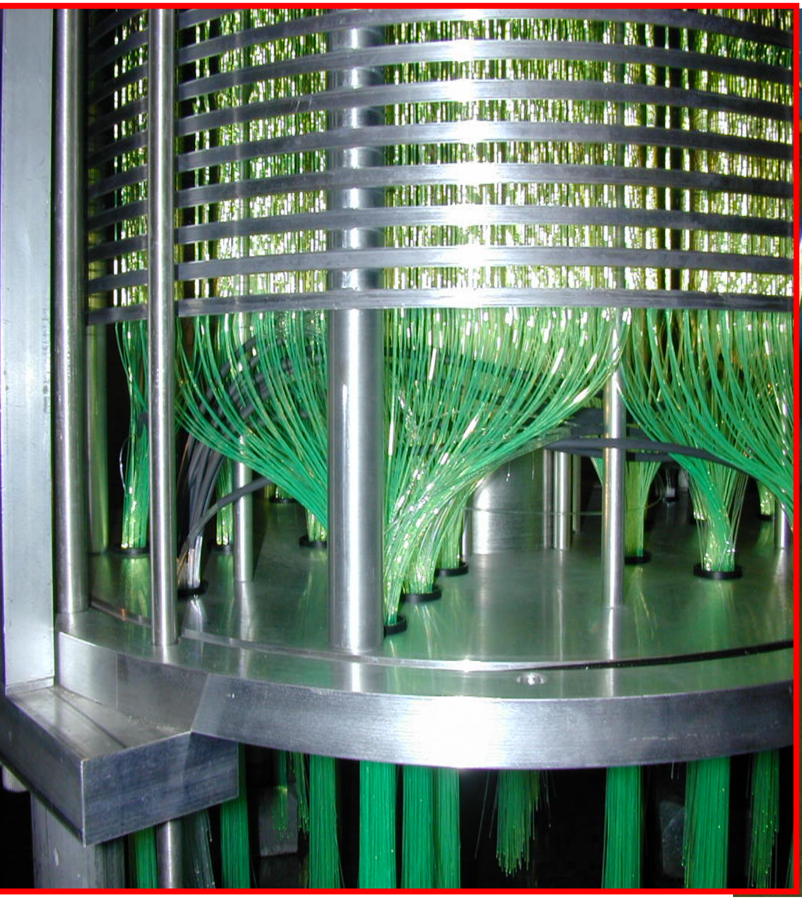
ROMAN POT DETECTORS

BEAM SHOWER COUNTERS: Used to reject ND events





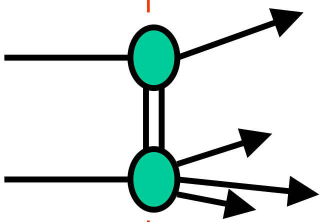
MiniPlug Construction



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.


SOFT DIFFRACTION

Diffraction and Unitarity



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

s^{ε} s^{ε}

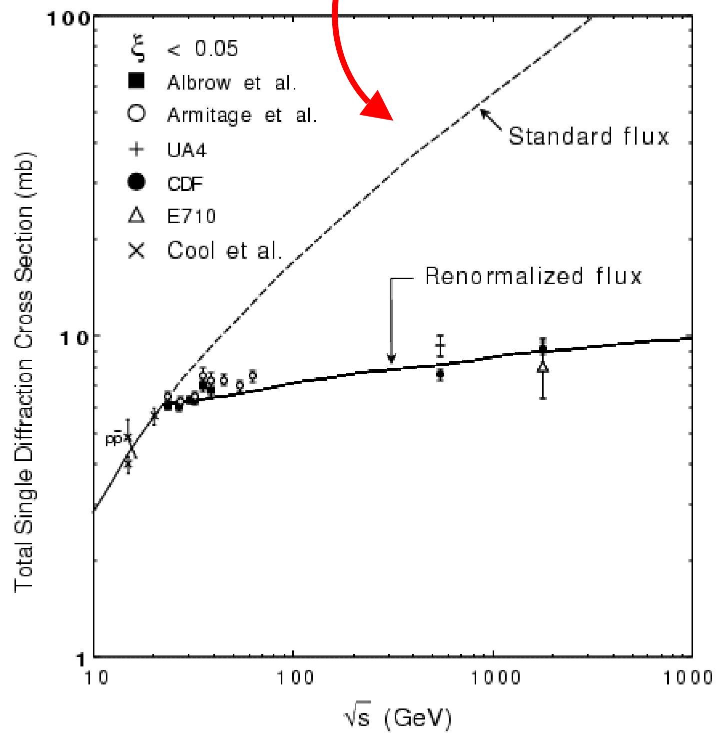
$\sigma_{SD} \sim s^{2\varepsilon}$

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

- **Renormalization:**
  Normalize Pomeron flux to unity
  to eliminate overlapping gaps

KG, PLB 358 (1995) 379

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



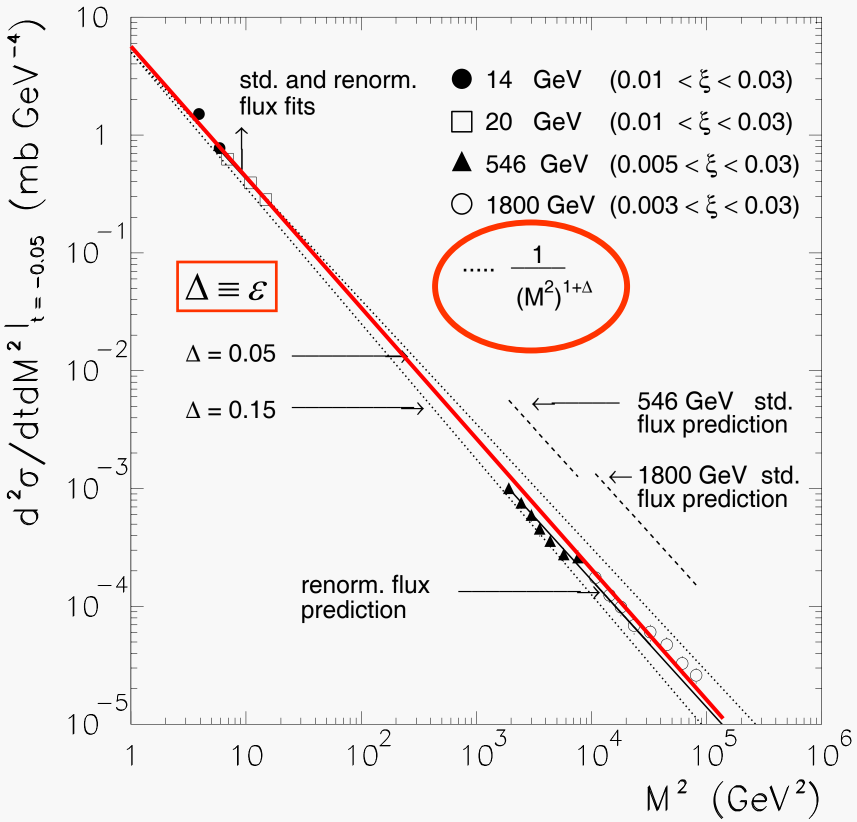
A Scaling Law in Diffraction

renormalization

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

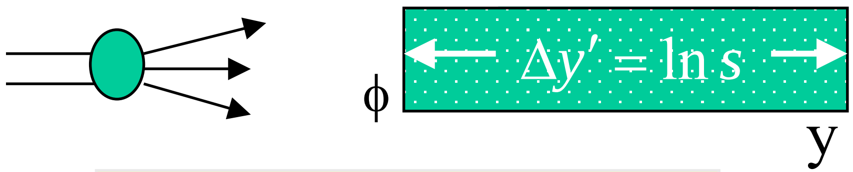
➔ Independent of S over 6 orders of magnitude in M^2!

KG&JM, PRD 59 (1999) 114017

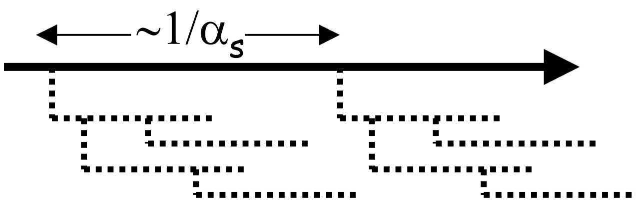


Factorization breaks down so as to ensure M^2-scaling!

The QCD Connection



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



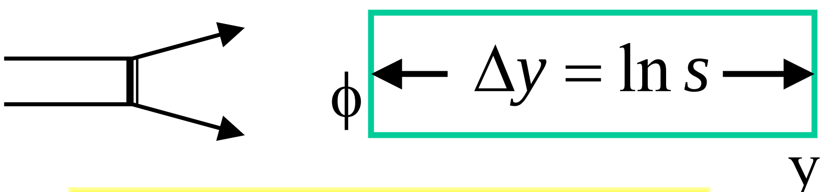
Emission spacing controlled by α-strong

➔ σ_T : power law rise with energy

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

α′ reflects the size of the emitted cluster,

which is controlled by 1 /α_s and thereby is related to ε

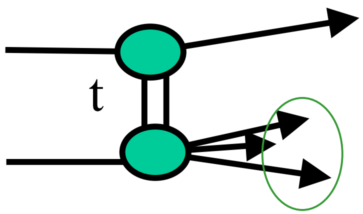


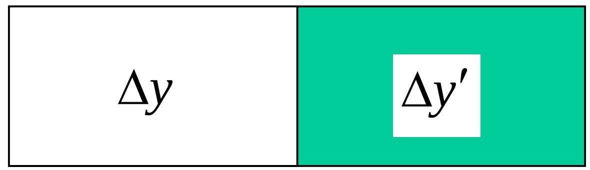
$$\mathrm{Im}\ f_{el}(s,t) \propto e^{(\varepsilon+\alpha' t)\Delta y}$$

← assume linear t-dependence

Forward elastic scattering amplitude

Single Diffraction in QCD





2 independent variables: $t, \Delta y$

color factor

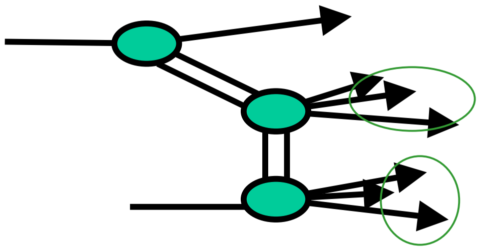
$$\kappa = \frac{g_{IP-IP-IP}(t)}{\beta_{IP-p-p}(0)} \approx 0.17$$

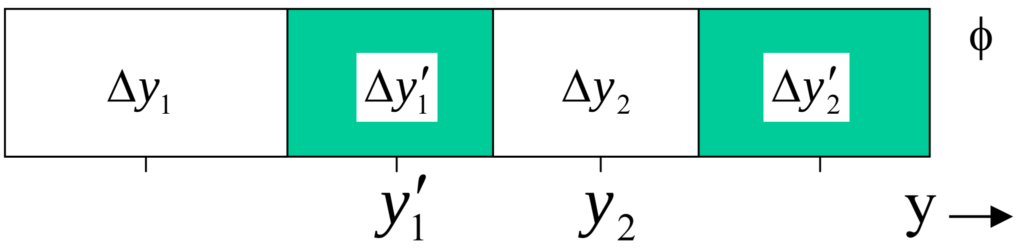
$$\frac{d^2\sigma}{dt\, d\Delta y} = \underbrace{C \cdot F_p^2(t) \cdot \left\{ e^{(\varepsilon + \alpha' t)\Delta y} \right\}^2}_{\text{gap probability}} \cdot \kappa \cdot \underbrace{\left\{ \sigma_o\, e^{\varepsilon\, \Delta y'} \right\}}_{\text{sub-energy x-section}}$$

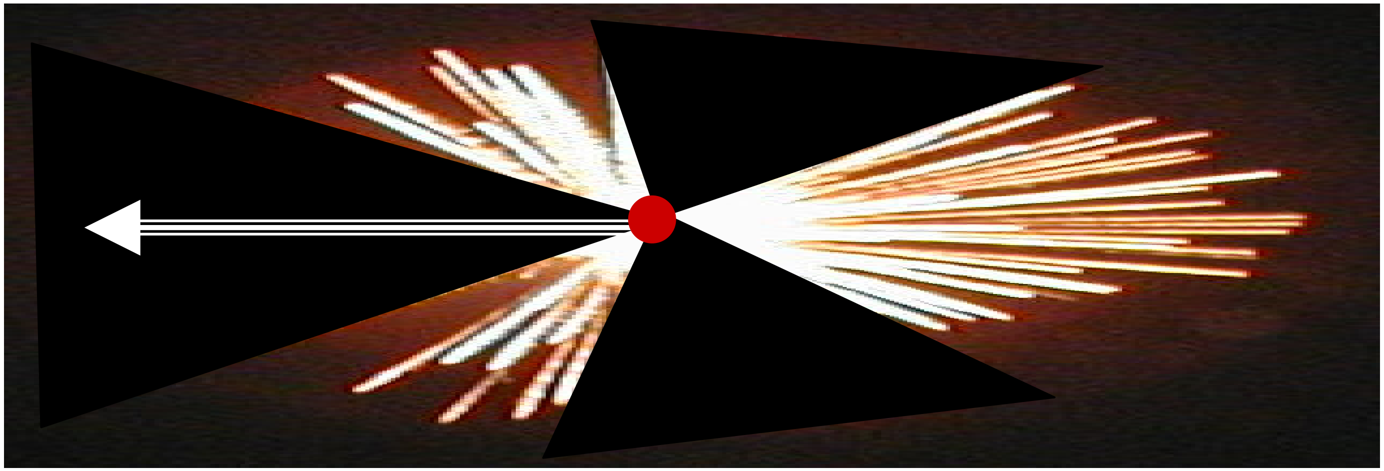
Gap probability MUST be normalized to unity!

Multigap Diffraction

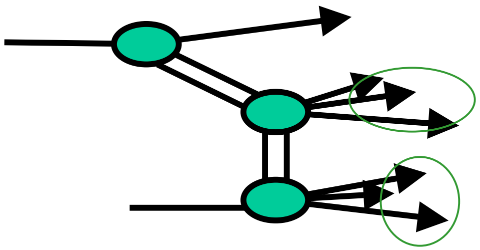
(KG, hep-ph/0205141)

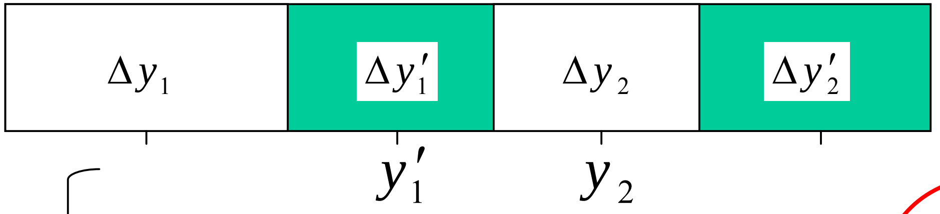






Multigap Cross Sections





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

color factor

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

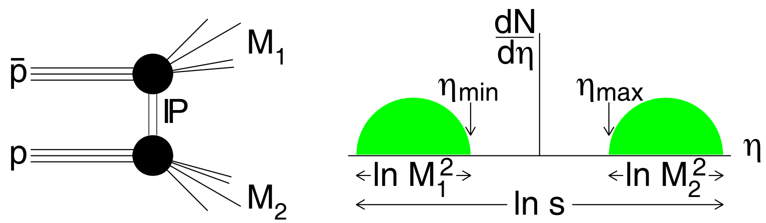
Gap probability

$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

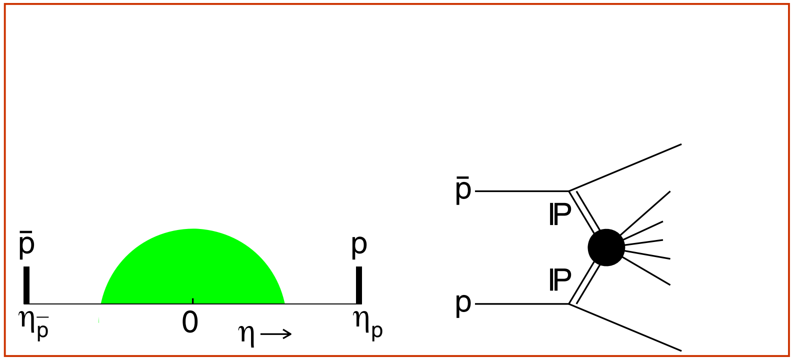
Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

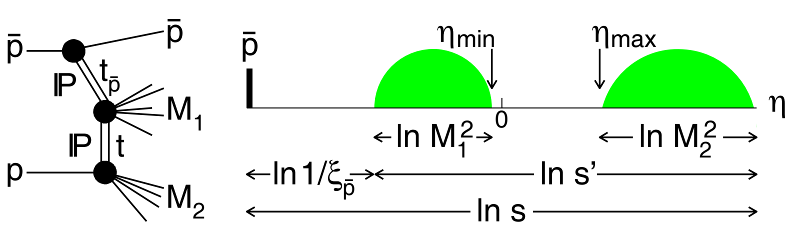
Central and Multigap Diffraction



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



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

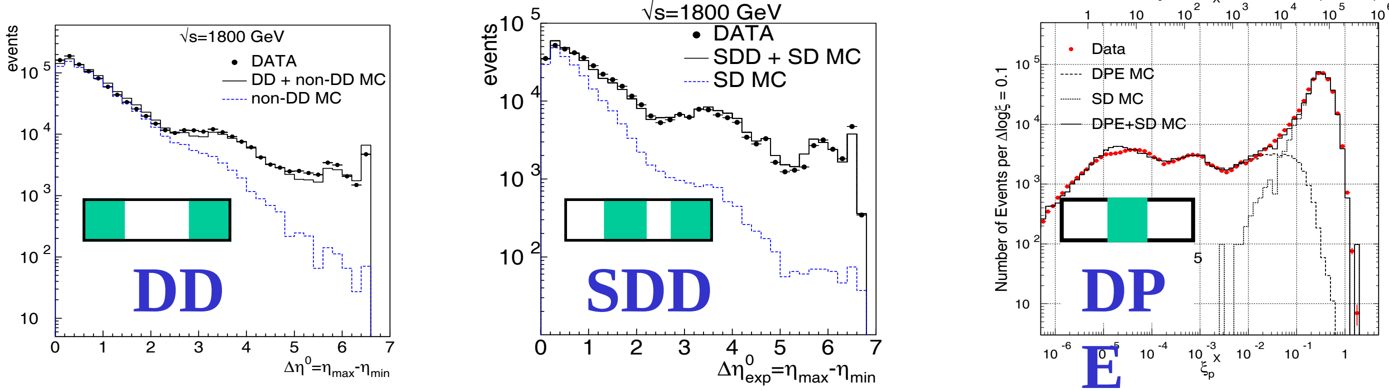


- **SDD: Single+Double Diffraction**
  - **One forward gap+ one central gap**

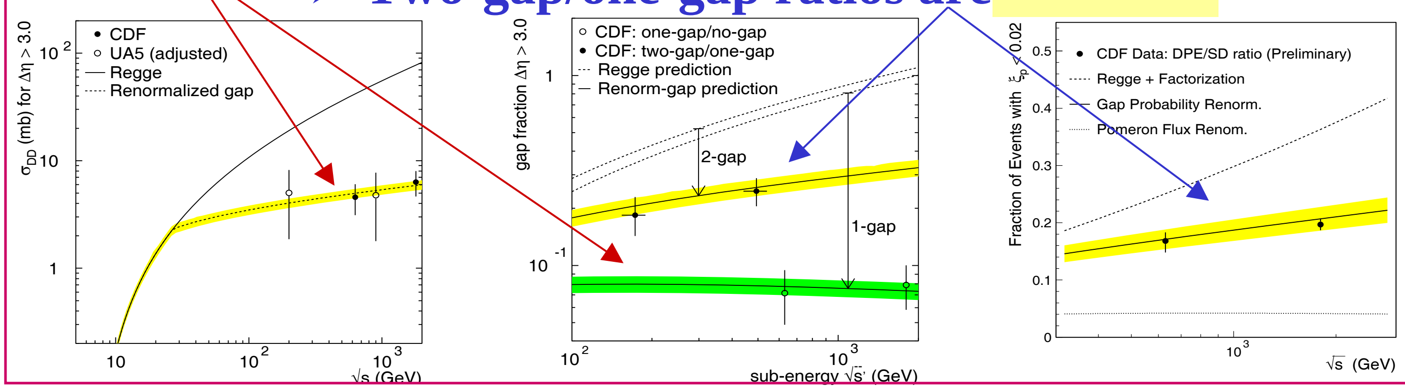
Rate for second diffractive gap is not suppressed!

Central and Two-Gap Results

Agreement with renormalized Regge predictions



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



DARK ENERGY?

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations:

$$P(\Delta y) = e^{-\rho\,\Delta y}, \quad \rho = \frac{dN_{\text{particles}}}{dy}$$

P(Δy) is exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy:

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

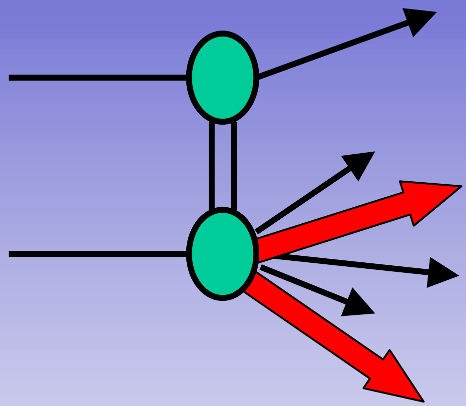
$$P(\Delta y)\Big|_{t=0} \sim e^{2\varepsilon \Delta y}$$

2ε: negative particle density!

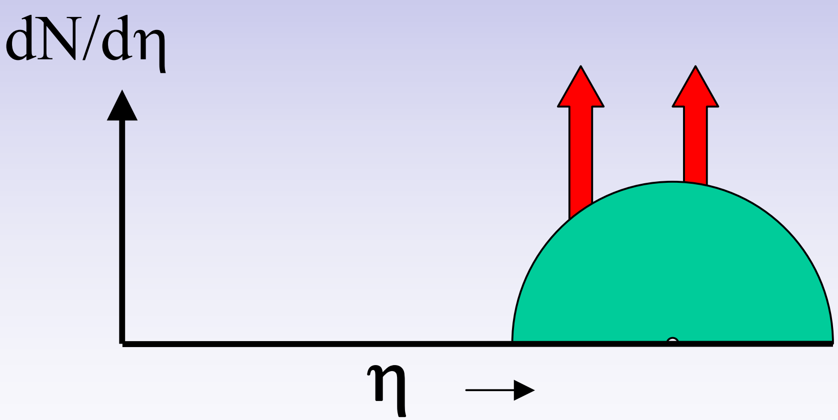
⇓

Gravitational repulsion?

HARD DIFFRACTION



- Diffractive fractions
- Diffractive structure function
  → factorization breakdown
- Restoring factorization
- Q^2 dependence
- t dependence
- Hard diffraction in QCD



JJ, W, b, J/ψ

Hard Diffraction Fractions

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

Fraction:
SD/ND ratio at 1800 GeV

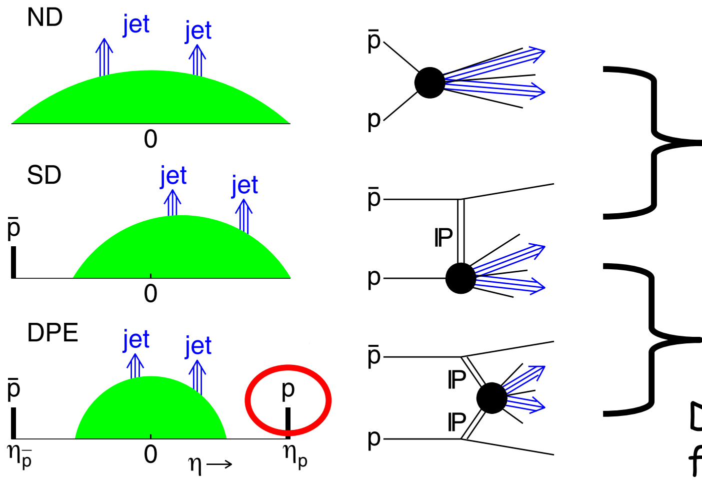
	Fraction(%)
W	1.15 (0.55)
JJ	0.75 (0.10)
b	0.62 (0.25)
J/ψ	1.45 (0.25)

All ratios ~ 1%
➔ ~ uniform suppression
~ FACTORIZATION !

Diffractive ^{non}/Factorization

β=momentum fraction of parton in Pomeron

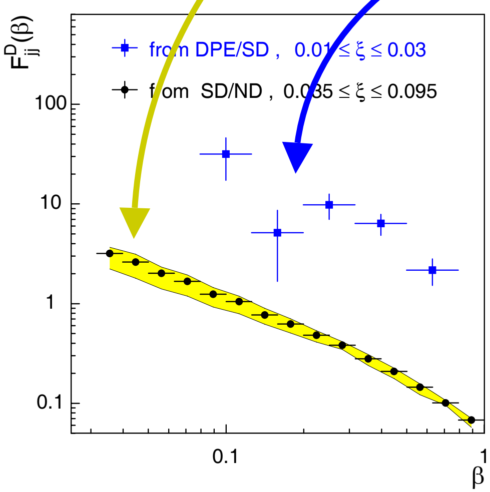
$$\beta = x_{Bj}/\xi$$

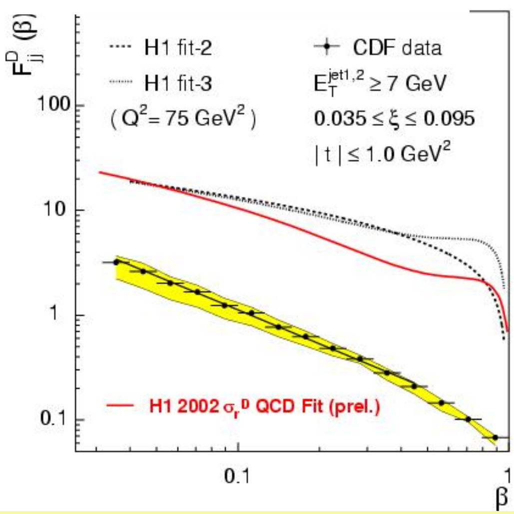


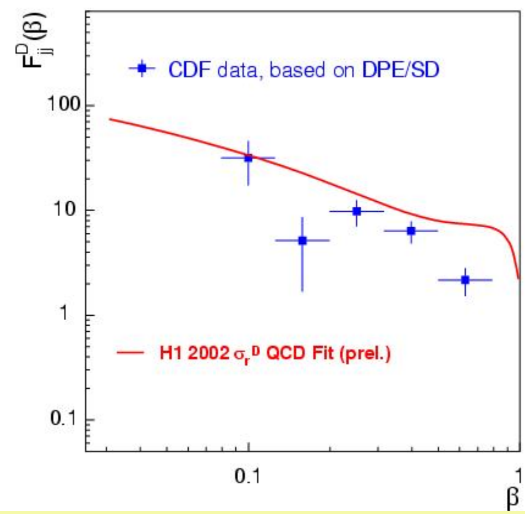
R(SD/ND)

R(DPE/SD)

DSF from two/one gap: factorization restored!

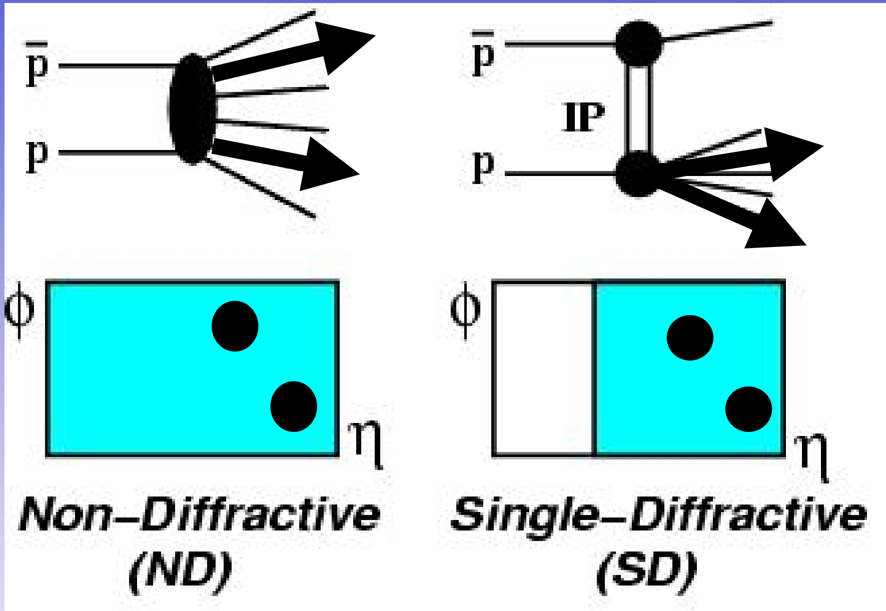






The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS

Diffractive Structure Function

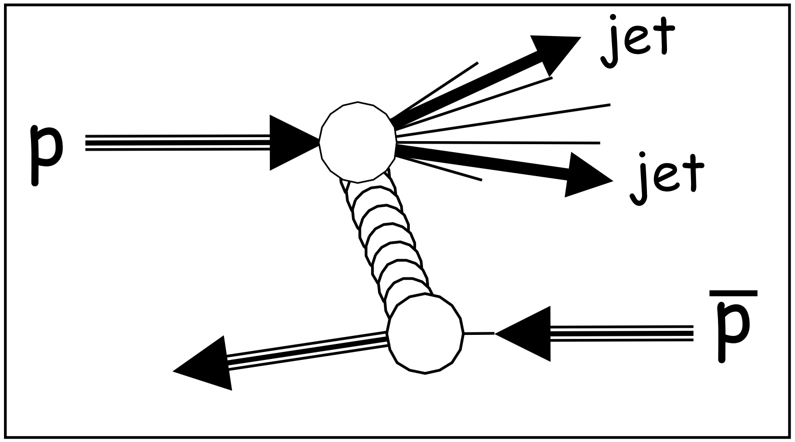


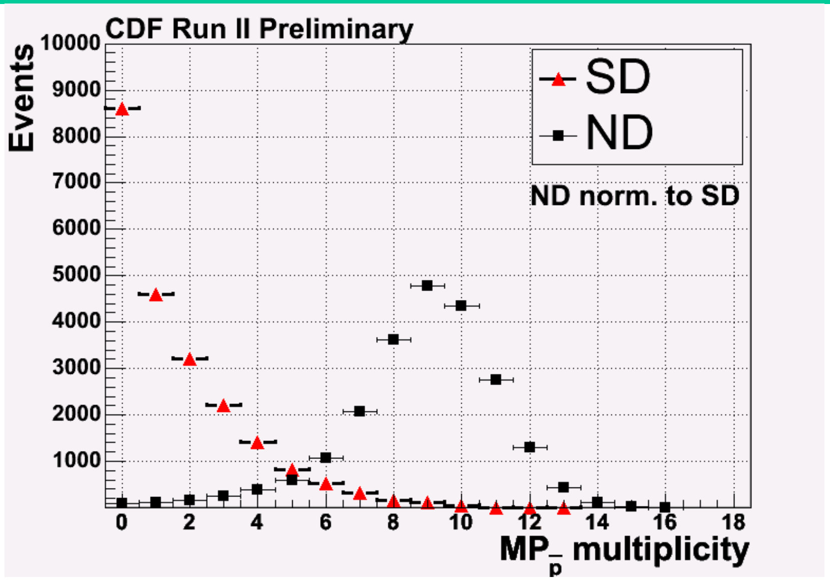
$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}_{jj}^{SD}(x_{Bj})}{\mathrm{Rate}_{jj}^{ND}(x_{Bj})}$$

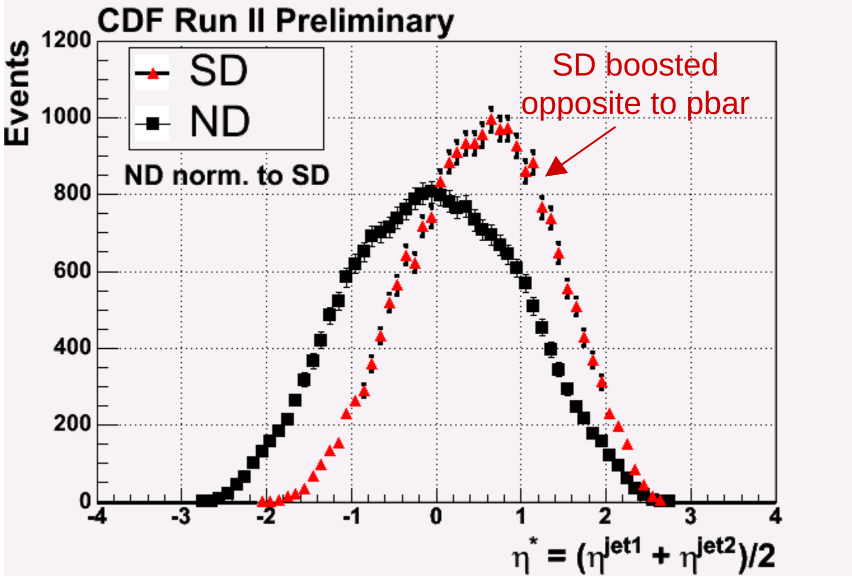
$$\Rightarrow \quad \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$

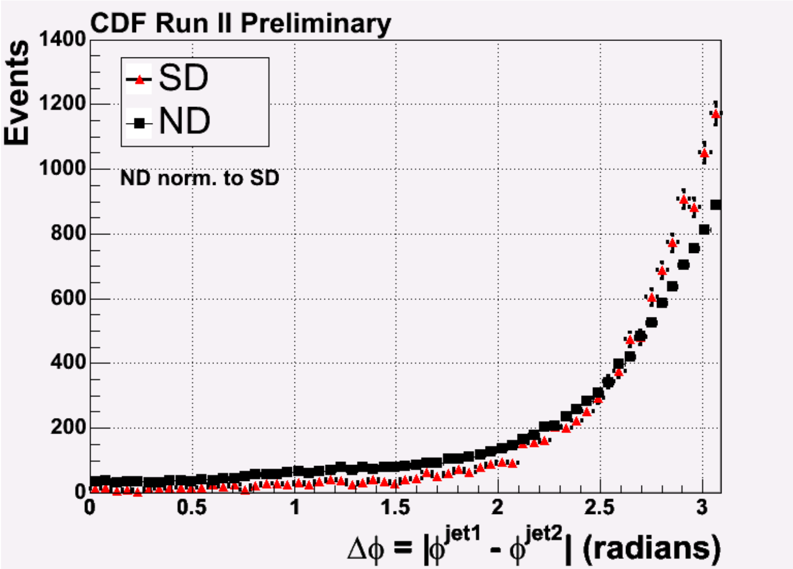
Systematic uncertainties due to energy scale and resolution cancel out in the ratio

Dijet Properties

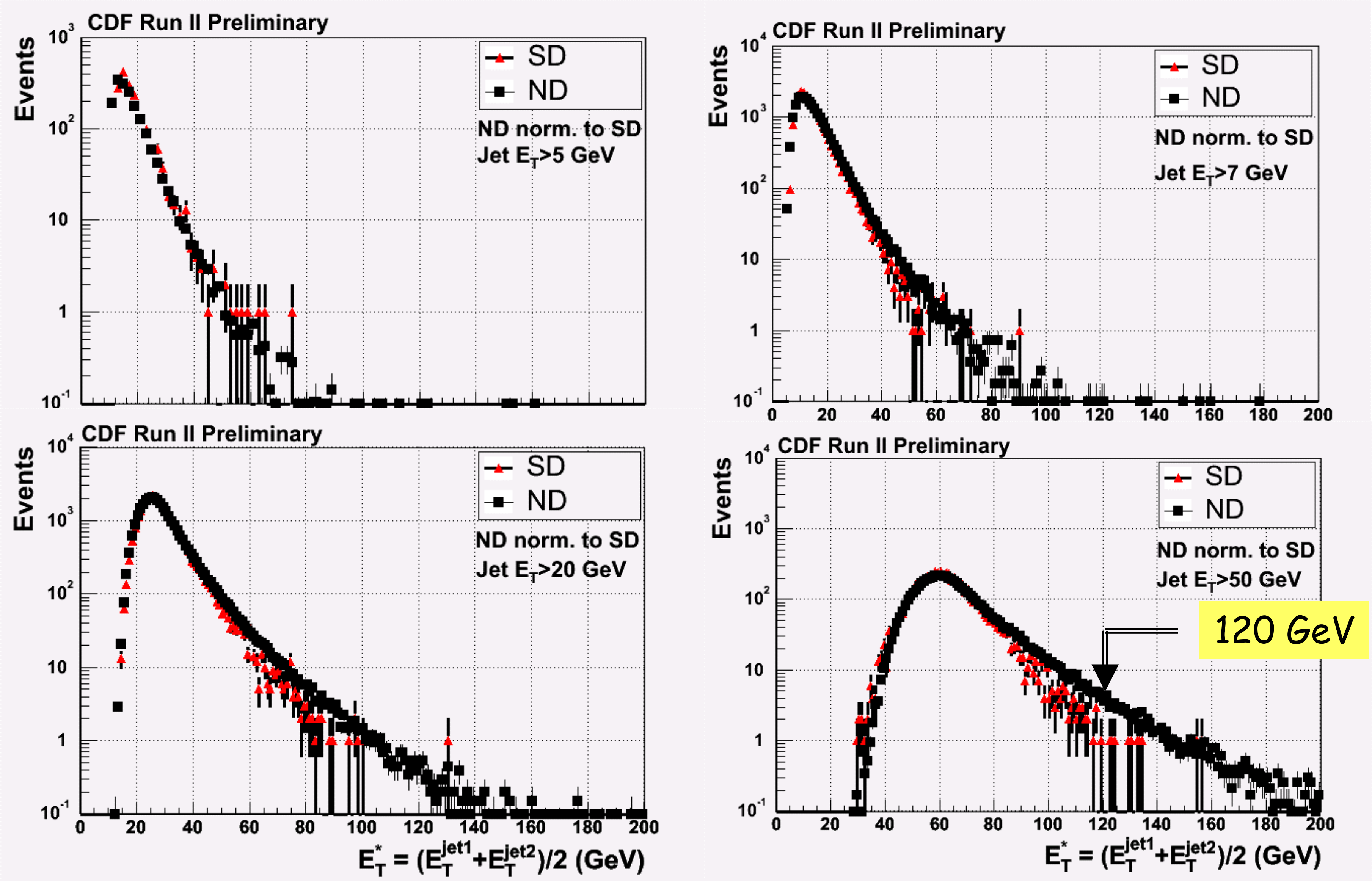




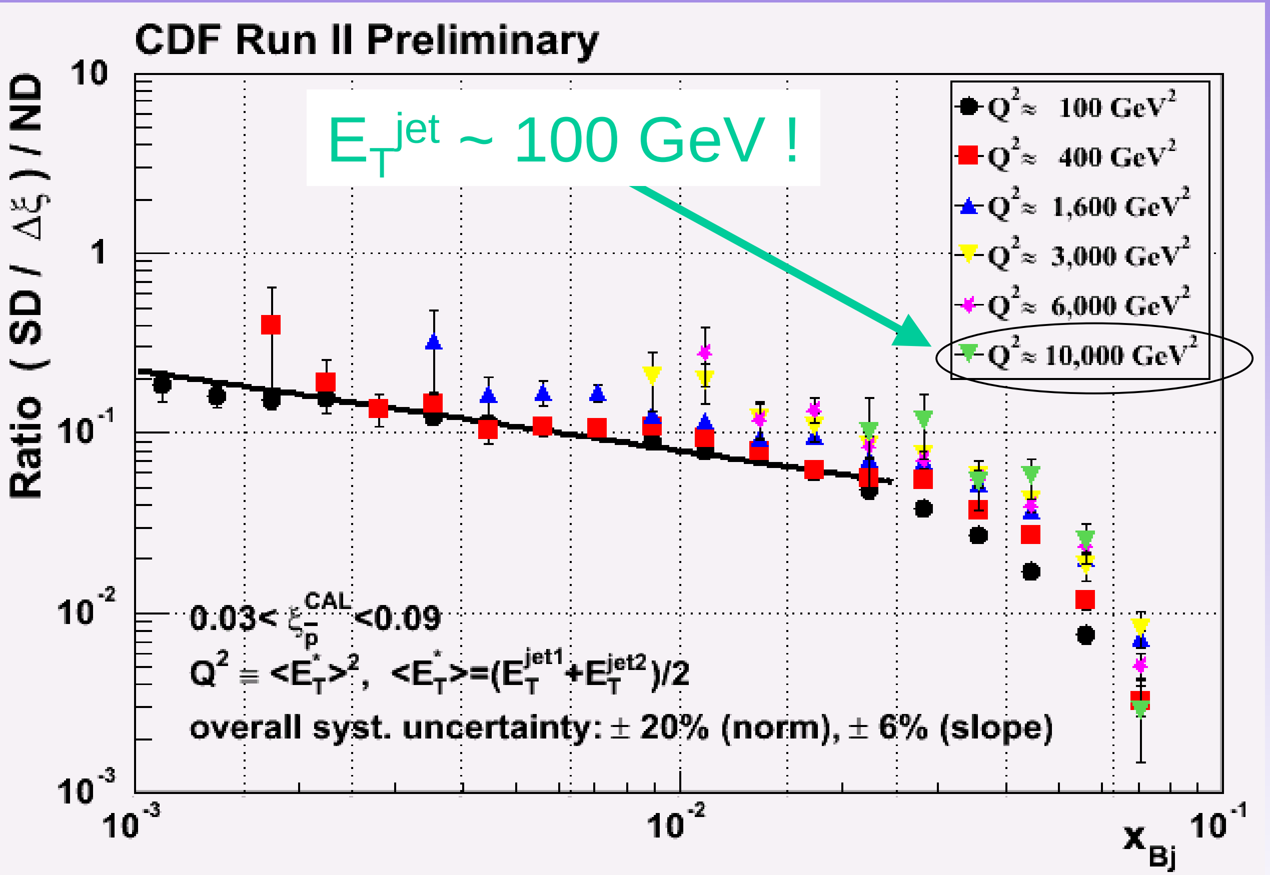




E_T distributions



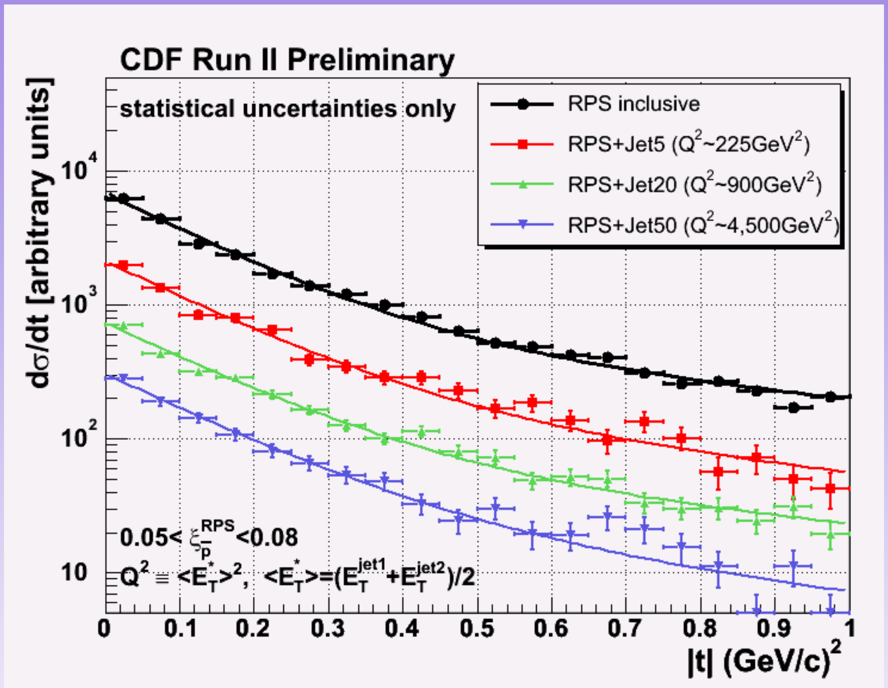
Diffractive Structure Function:
Q^2 dependence

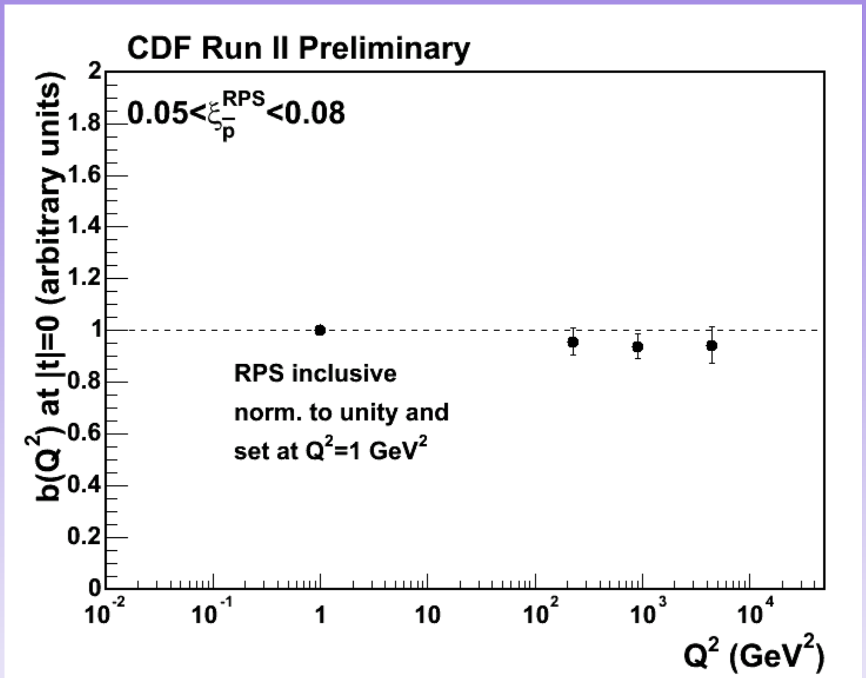


Small Q^2 dependence in region $100 < Q^2 < 10{,}000$ GeV^2

⇨ Pomeron evolves as the proton!

Diffractive Structure Function:
t- dependence





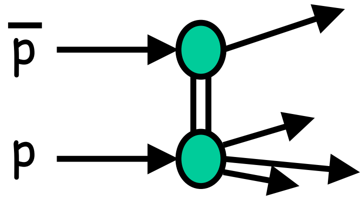
Fit dσ/dt to a double exponential:

$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

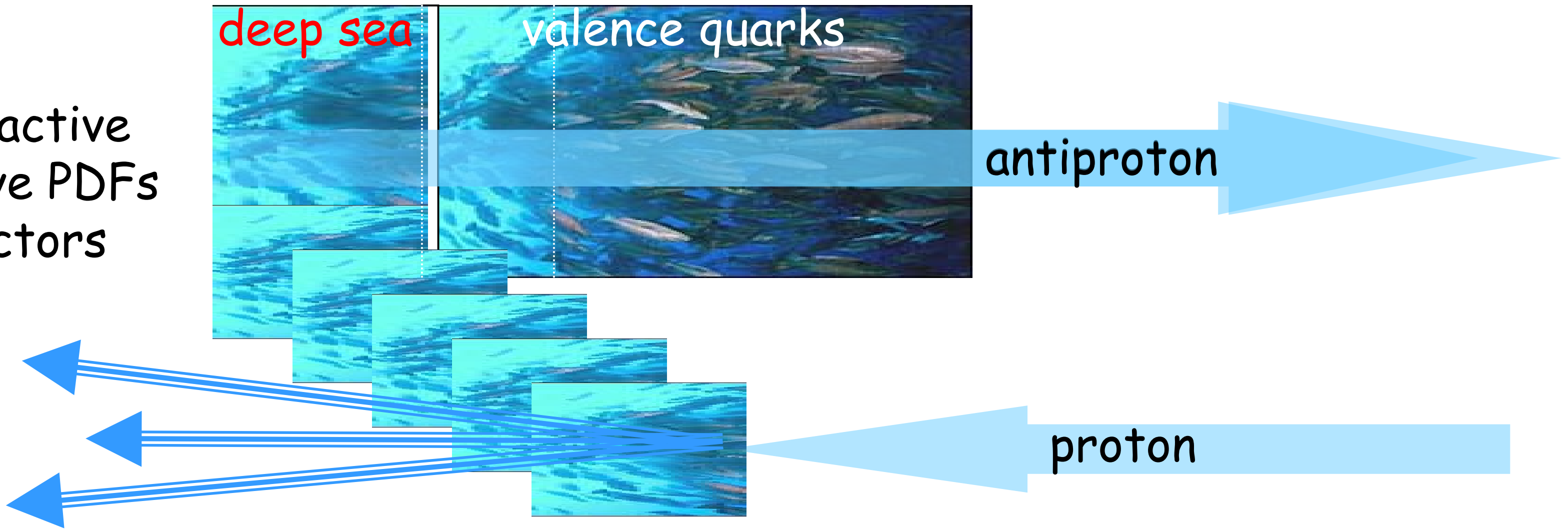
- No diffraction dips
- No Q2 dependence in slope from inclusive to $Q^2 \sim 10^4$ GeV^2

- Same slope over entire region of $0 < Q^2 < 4{,}500$ GeV^2 across soft and hard diffraction!

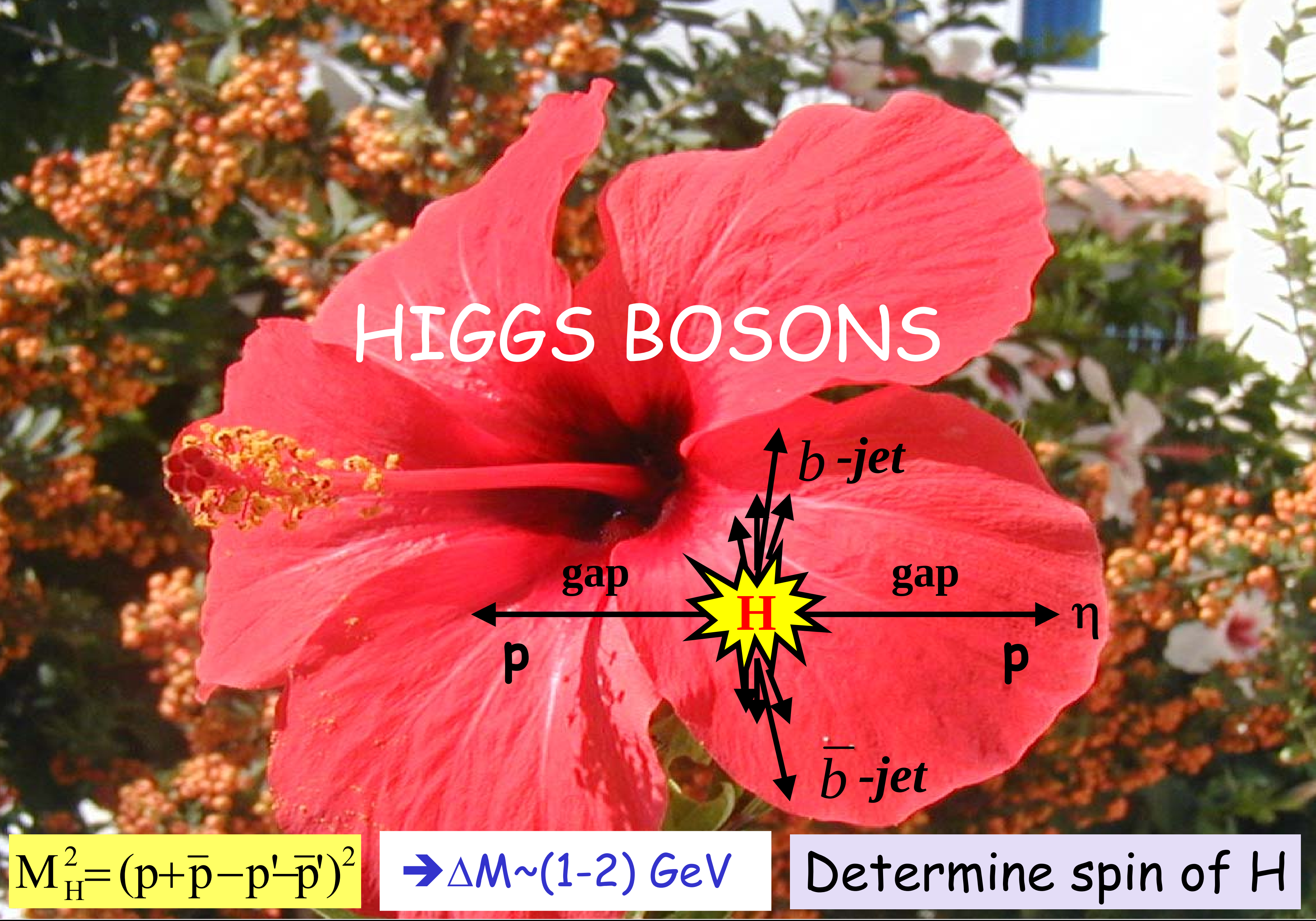
Hard Diffraction in QCD



Derive diffractive from inclusive PDFs and color factors



HIGGS BOSONS



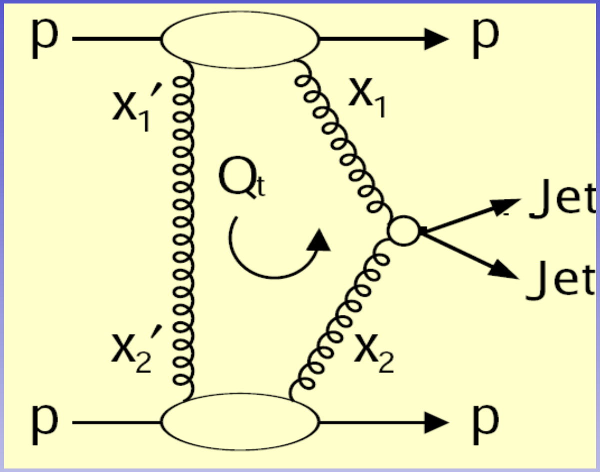
$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$

→ ΔM~(1-2) GeV

Determine spin of H

Exclusive dijets and Higgs bosons

Measure exclusive jj & $\gamma\gamma$ → → → Calibrate predictions for H production rates @ LHC



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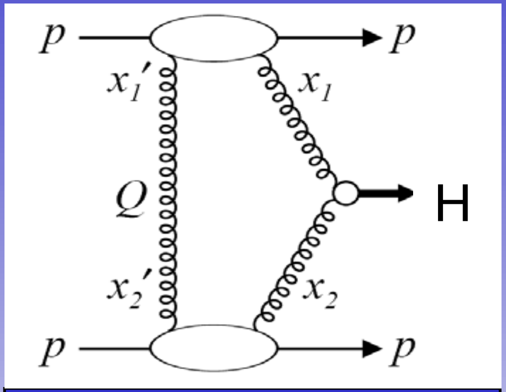
C25,391 (2002);C26,229 (2002)
C. Royon, hep-ph/0308283
B. Cox, A. Pilkington,
PRD 72, 094024 (2005)
OTHER…………………………



KMR: σ_H(LHC) ~ 3 fb
S/B ~ 1 if ΔM ~ 1 GeV

Search for exclusive dijets:
Measure dijet mass fraction

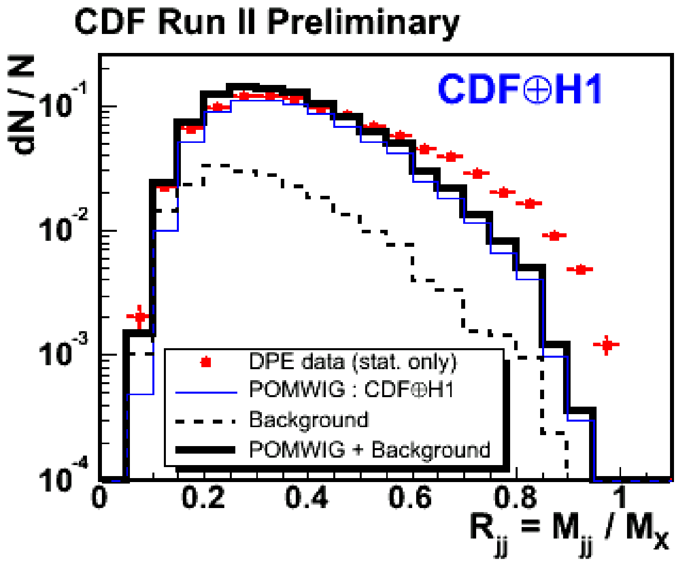
$$R_{jj} = \frac{M_{jj}}{M_X(\text{all calorimeters})}$$

Look for signal as $R_{jj} \rightarrow 1$

Exclusive Dijet Signal

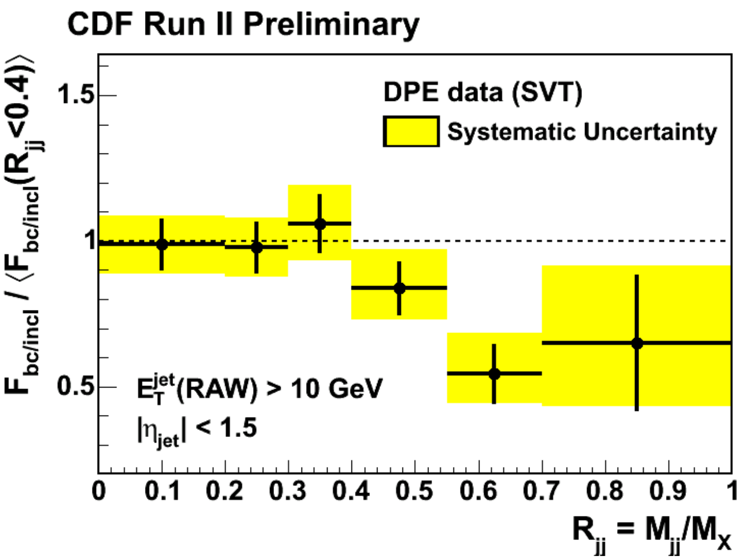
DIJETS

Dijet fraction – all jets



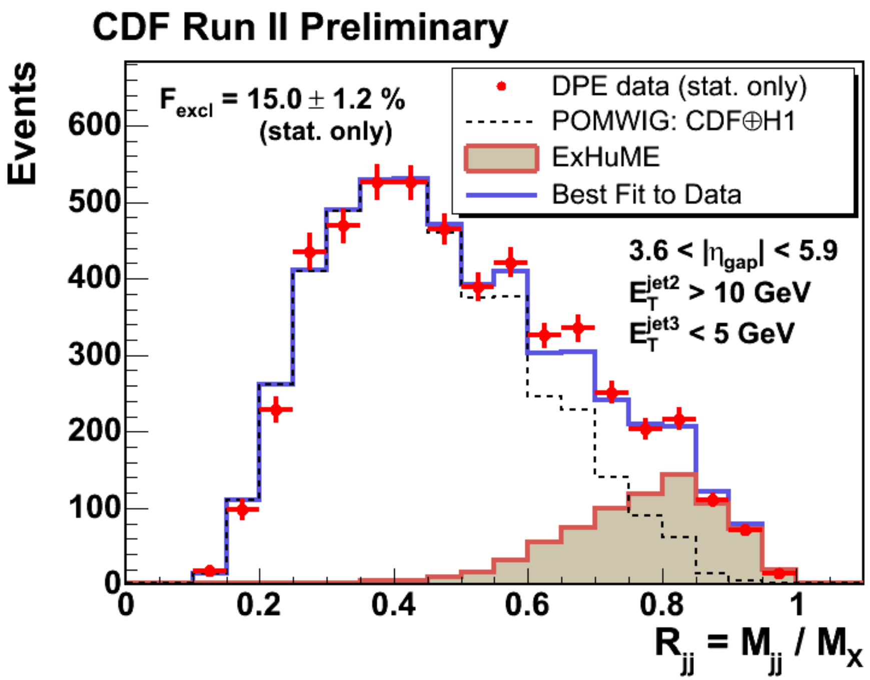
Excess over MC predictions at large dijet mass fraction

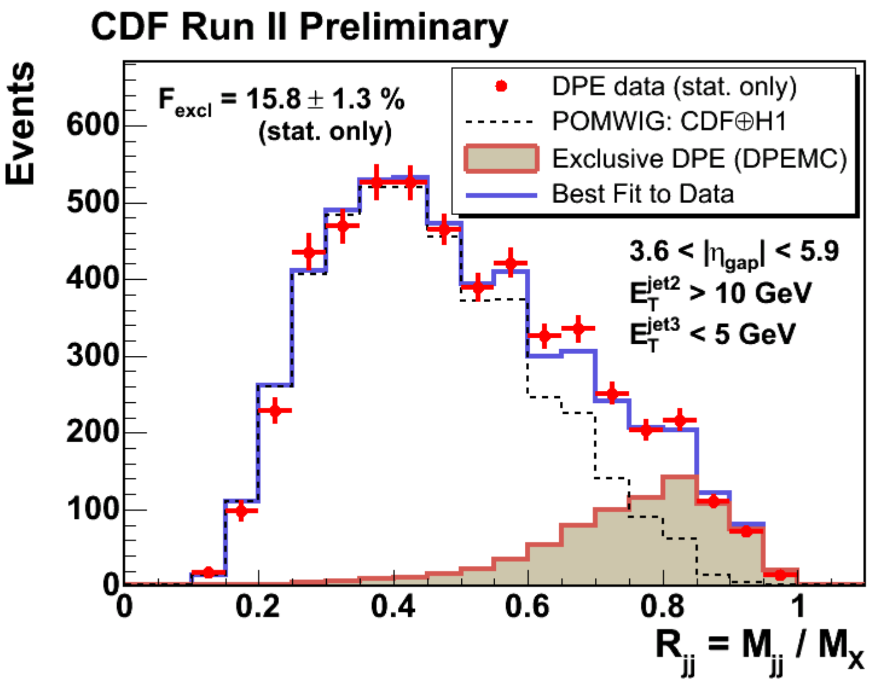
b-tagged dijet fraction



Exclusive b-jets are suppressed by J_Z= 0 selection rule

R_{JJ}(excl): Data vs MC





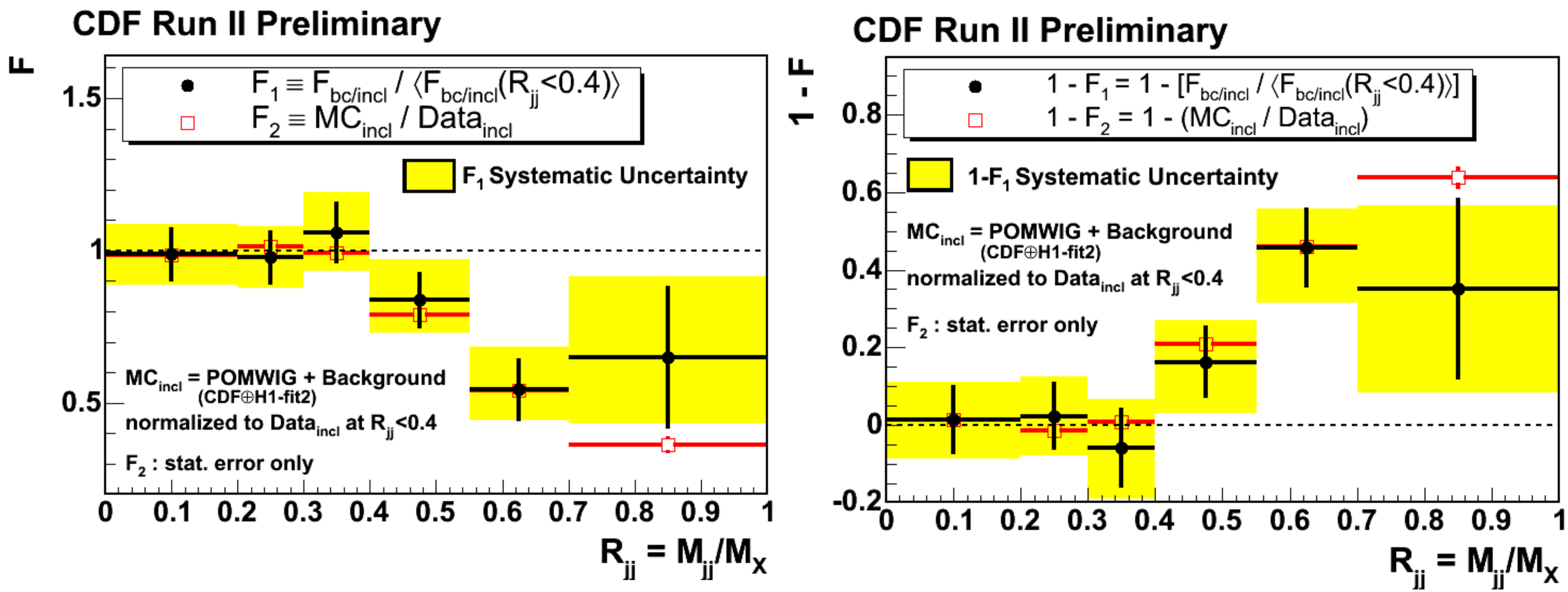
ExHuME (KMR): gg→gg process
➔ uses LO pQCD

Exclusive DPE (DPEMC)
➔ non-pQCD based on Regge theory

Shape of excess of events at high R_{jj}
is well described by both models

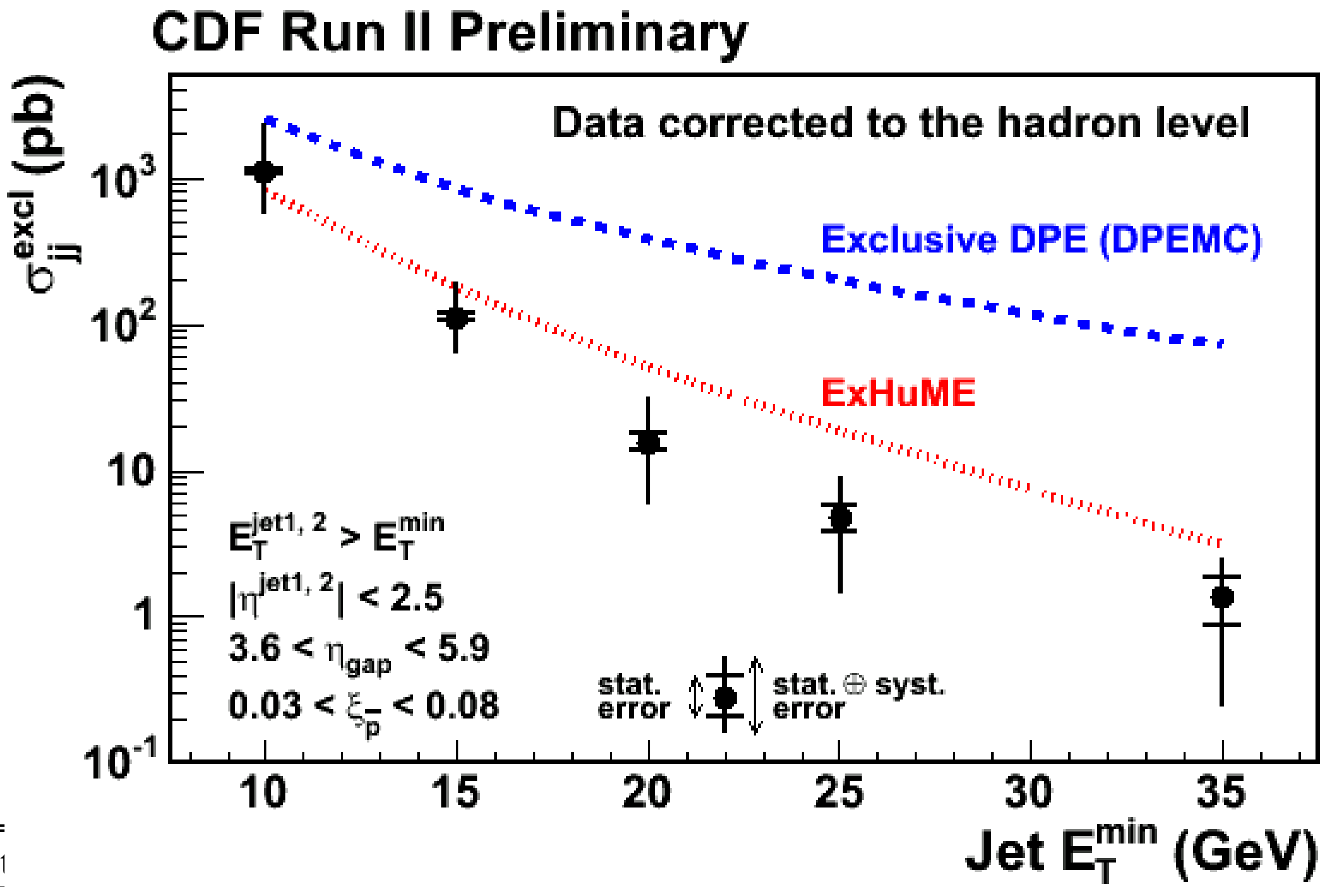
jj_{excl}: Exclusive Dijet Signal

COMPARISON
of
Inclusive data vs MC @ b/c-jet data vs inclusive



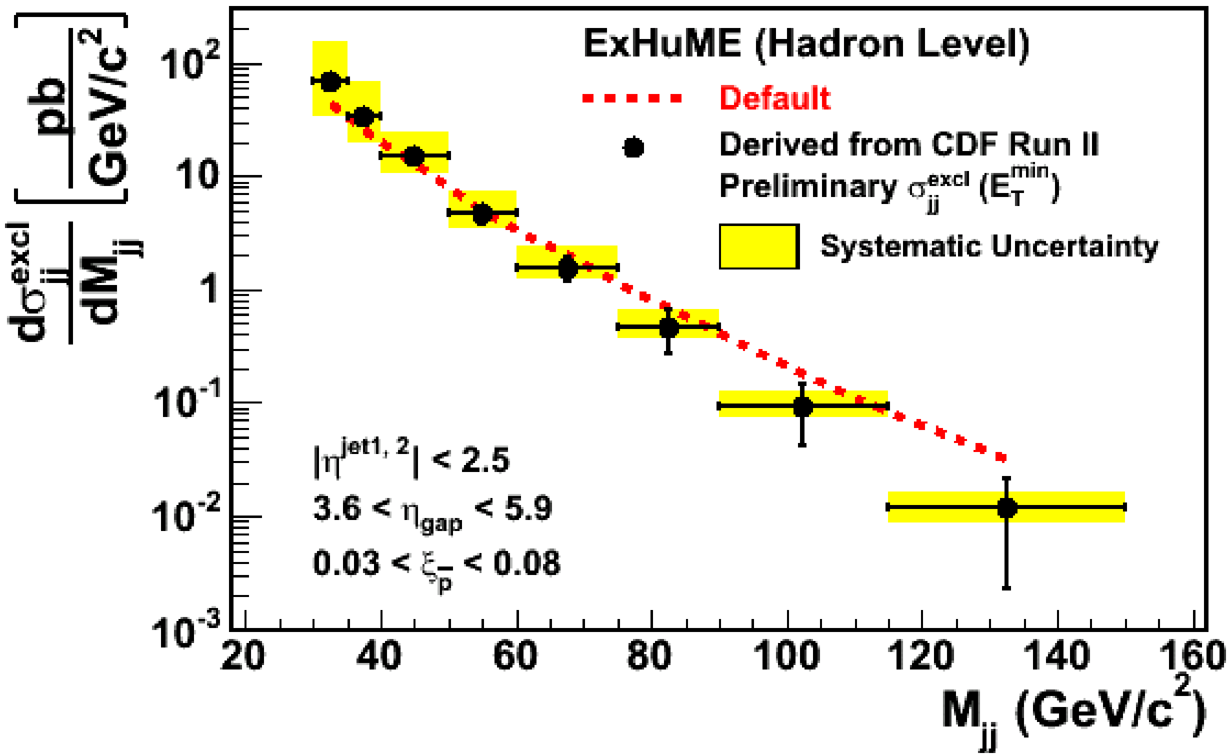
JJ_{excl} : x-section vs E_T(min)

Comparison with hadron level predictions
ExHuME (red)
Exclusive DPE in DPEMC (blue)



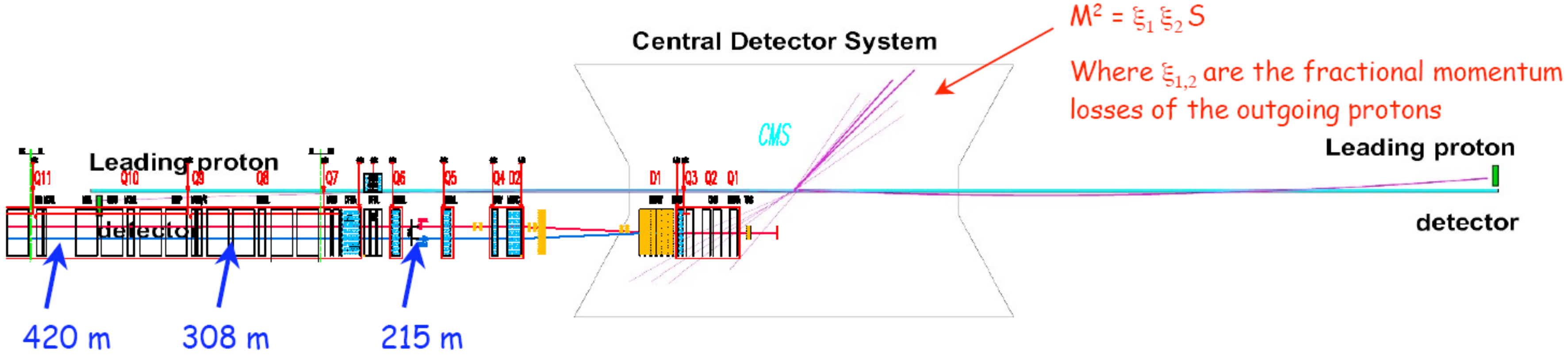
JJ_{excl} : cross section predictions

ExHuME Hadron-Level Differential Exclusive Dijet Cross Section vs Dijet Mass
(dotted/red): Default ExHuME prediction
(points): Derived from CDF Run II Preliminary excl. dijet cross sections



Statistical and systematic errors are propagated from measured cross section uncertainties using ExHuME M_{jj} distribution shapes.

Looking forward @ LHC



TOTEM/CMS
ATLAS

FP420 project: http://www.fp420.com/
Measure protons at 420 m from the IP during normal high luminosity running to be used in conjunction with CMS and ATLAS
Feasibility study and R&D for Roman Pot detector development

- Physics aim :pp $\rightarrow$ p+ X + p (Higgs, New physics, QCD studies)
- Status: Project funded by the UK

Summary

dark energy?

CDF - what we have learnt

- M^2 - scaling ➔ $d\sigma/M^2$ not a function of s
- multigap diffraction ➔restoration of factorization!
- flavor independence of diffractive fractions
- small Q2 dependence of SD/ND x_{BJ}-distributions
- t-distributions independent of Q2
- exclusive dijet cross sections favor the perturbative QCD over the DPE approach

LHC - what to do

- Elastic and total cross sections & ρ-value
- High mass (➔4 TeV) and multi-gap diffraction
- Exclusive production (FP420 project)