



Diffraction and the Forward Proton Detector at DØ

Michael Strang

Physics 5391



What is Diffraction?

- Diffraction encompasses events in which one or both incoming particles undergo diffractive dissociation with any surviving particle having a small angle with respect to the beam axis.
- Basically diffraction in high energy hadron physics encompasses those phenomena in which no quantum number is exchanged between interacting particles
 - Diffracted particles have same quantum numbers as incident particles or in other words quanta of the vacuum are exchanged
- Exchanging quanta of the vacuum is synonymous with the exchanging of a Pomeron (**P**)
 - Named after Russian physicist I.Y. Pomeranchuk
 - Virtual particle carries no charge, isospin, baryon number or color
 - Couples through internal structure
- Can occur in p-pbar and e-p collisions



Types of Diffraction

- Broken into two basic types
 - Soft diffraction
 - Modeled by Regge theory (predates QCD)
 - Analysis of poles in the complex angular momentum plane giving rise to trajectories that describe particle exchange
 - Non-perturbative QCD regime
 - Hard diffraction
 - Modeled by various theories (some building upon Regge Theory)
 - Tries to exploit perturbative QCD regime
 - Allows probing of structure of Pomeron
- Seen in calorimeter through rapidity gaps (regions of the detector with no particles above threshold) and/or tagging the intact final particle
- Diffractive events can account for ~40% of the inclusive cross section of a process

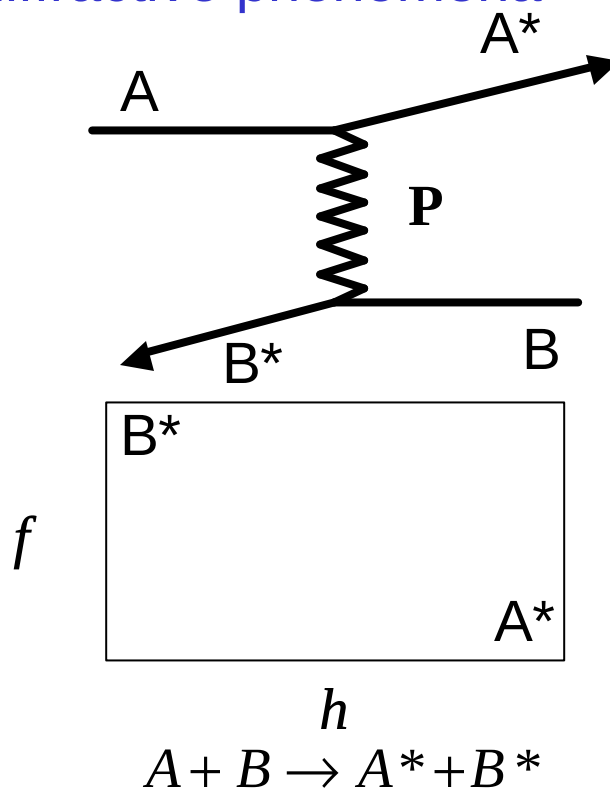


Elastic Scattering

- The particles after diffraction are the same as the incident particles
- The cross section can be written as:

$$\frac{ds/dt}{(ds/dt)_{t=0}} = e^{bt} \cong 1 - b(pq)^2$$

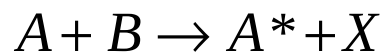
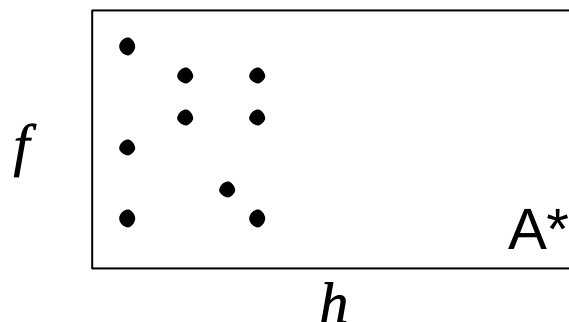
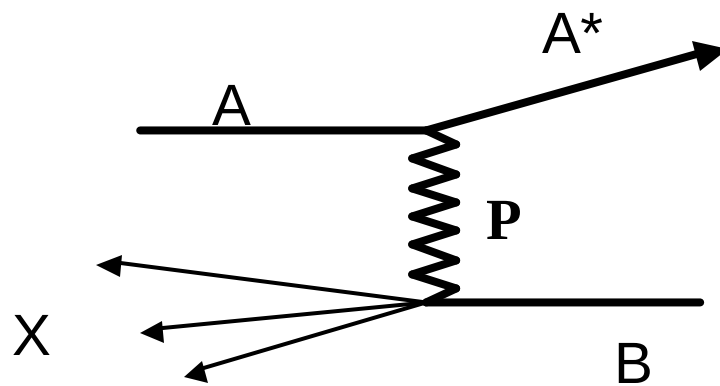
- This has the same form as light diffracting from a small absorbing disk, hence the name diffractive phenomena





Soft Single Diffraction

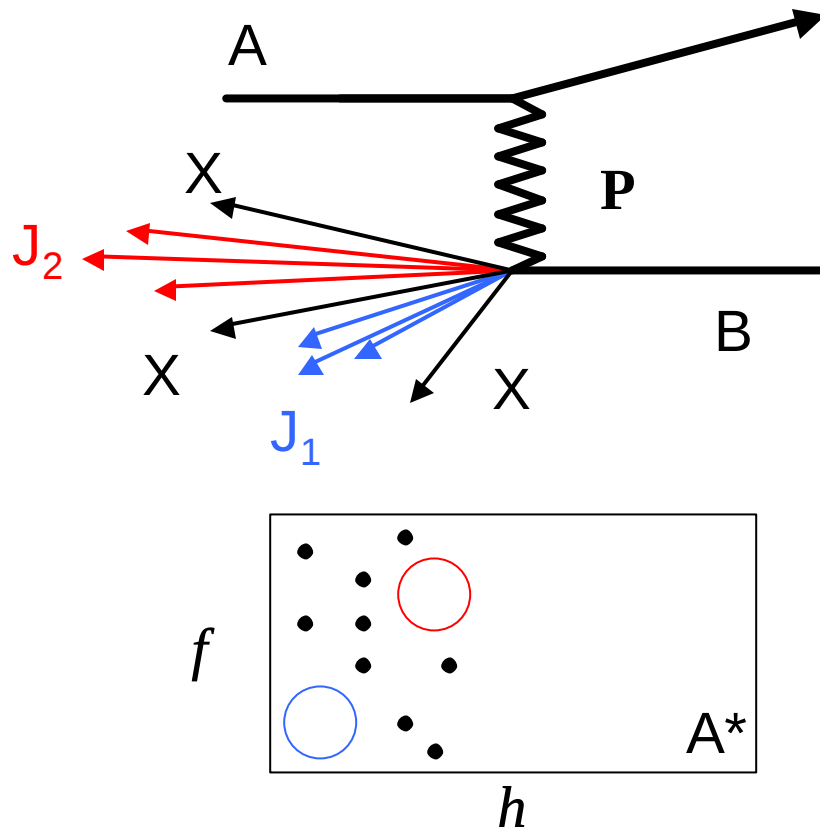
- One particle continues intact while the other becomes excited and breaks apart (diffractive dissociation)





Hard Single Diffraction

- One particle continues intact while the other undergoes inelastic scattering with the Pomeron and breaks apart into a soft underlying event as well as some hard objects (jets, W/Z , J/ψ or massive quarks)



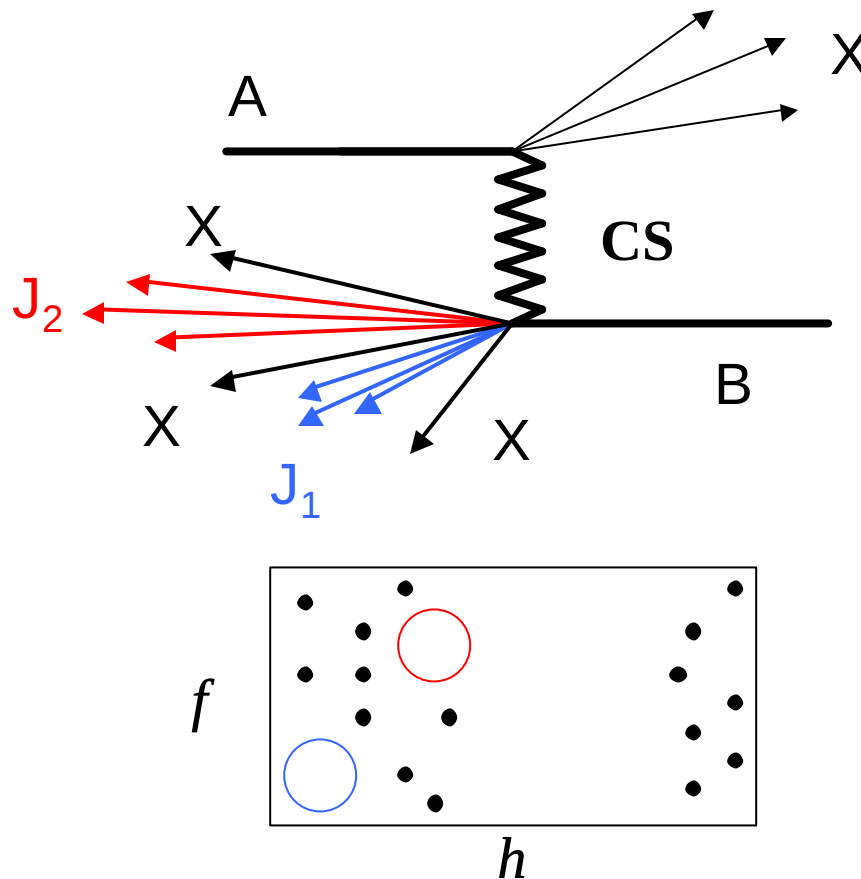
$$A + B \rightarrow A^* + J_1 + J_2 + X$$



Double Diffraction (Color Singlet Exchange)



- Both incoming particles undergo diffractive dissociation (one dissociates by emitting a hard color singlet that then undergoes an inelastic collision with the other particle).
- The diffraction can be hard or soft.

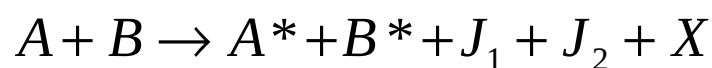
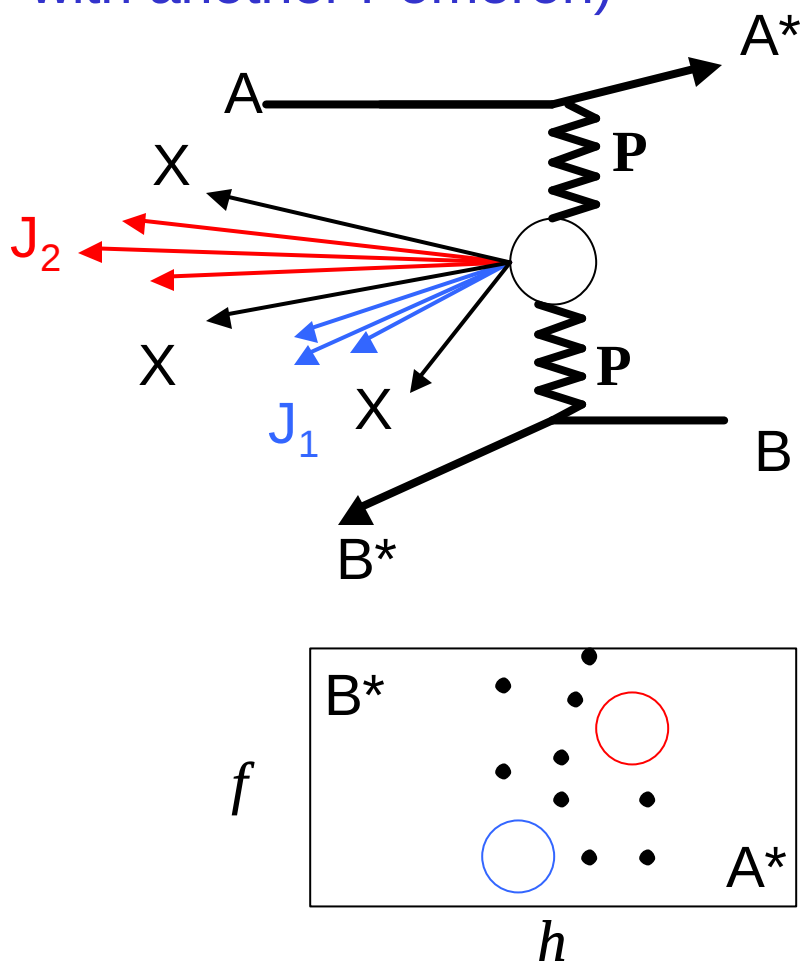


$$A + B \rightarrow J_1 + J_2 + X + \text{gap}$$



Hard Double Pomeron

- Both particles continue intact while hard objects still appear in the detector (Pomeron undergoing inelastic scattering with another Pomeron)





Diffractive Variables

- $x = 1 - p_{A^*} / p_A$
 - the momentum fraction of hadron A taken by the Pomeron (diffraction dominates for $x < 0.05$)

- $t = (p_A - p_{A^*})^2 = -2k^2(1 - \cos q)$
 - Minus the standard momentum transfer squared where k is CM momentum and q is the CM scattering angle

- M_X (diffractive mass) for the resultant system is given by $\sqrt{xs}$
 - s is the total CM energy squared



Ingelman-Schlein Model

- Attempt to blend Regge theory with perturbative QCD

- Factorize the cross section

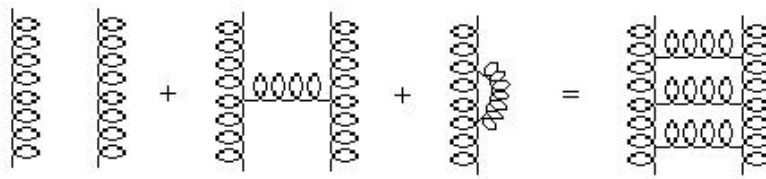
$$\frac{d^2 s (AB \rightarrow AX)}{dx dt} = F_{P/A}(x, t) s (PB \rightarrow X)$$

- Flux factor (structure function for Pomeron content in A) given by a global fit found by Donnachie and Landshoff and remaining part of cross section can be factorized leaving as the only unknown the structure function of the Pomeron (proposed as two quarks or two gluons of flavor similar to proton)
- Hard scattering probes structure of Pomeron (jet production --> gluon structure, W production --> quark structure)



BFKL Theory

- Proposes a more involved gluon structure of the Pomeron
- Add perturbative corrections to two reggeized gluons to form a gluon ladder



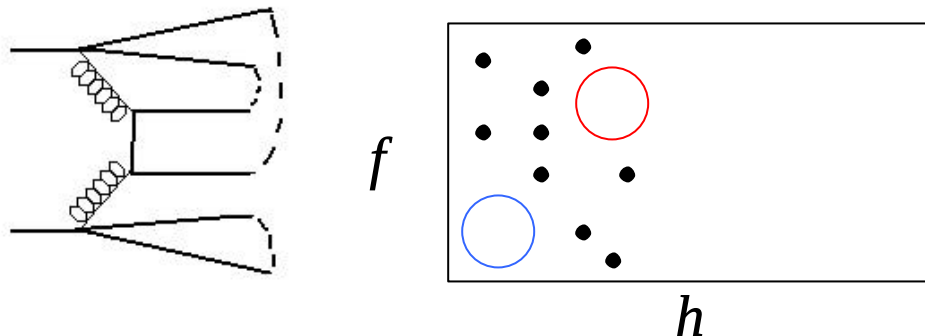
- Use leading logarithmic approximation as the resummation scheme using the BFKL equation
- Resummed amplitude has a cut in the complex angular momentum plane called the BFKL Pomeron
- Causes a different jet topology than F-S



Soft Color Evaporation



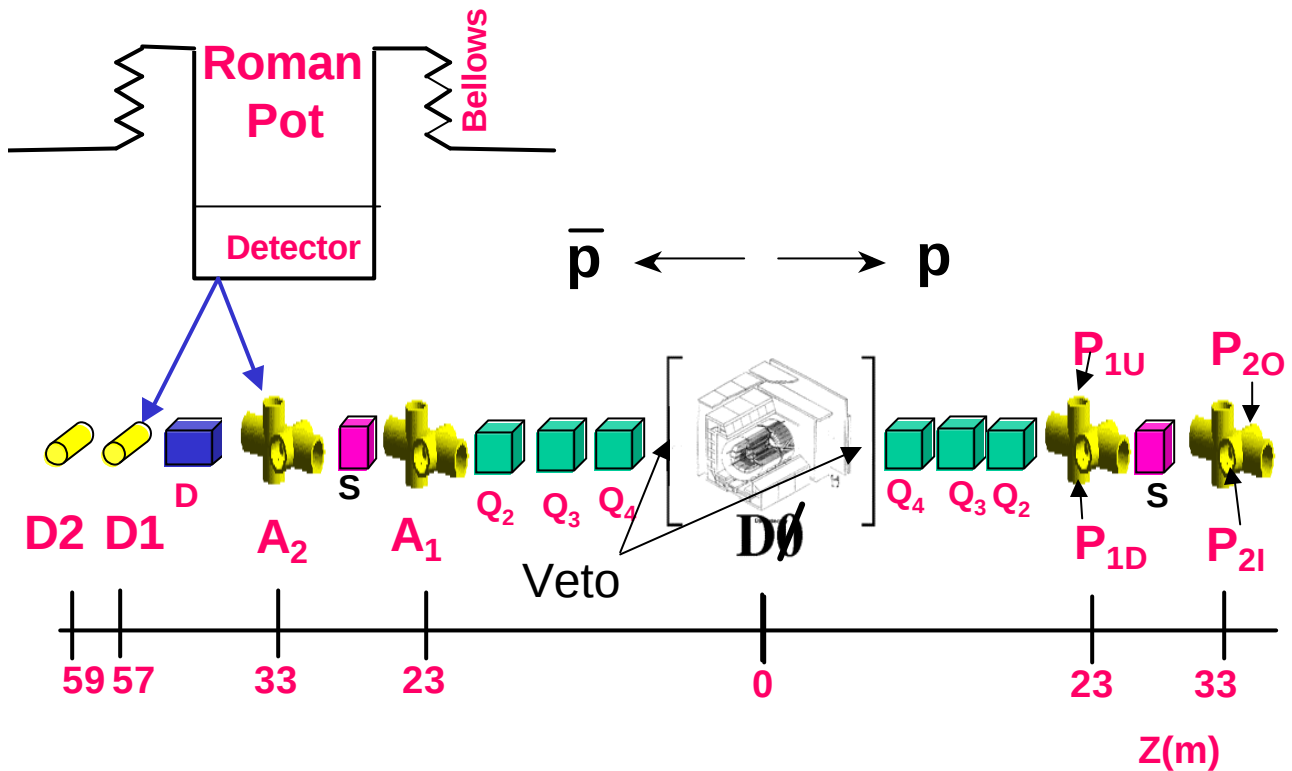
- Account for rapidity gaps without need of a Pomeron
- Allow soft color interactions to change the hadronization process such that color lines are canceled and rapidity gaps appear (non-perturbative, color topology of event changes)



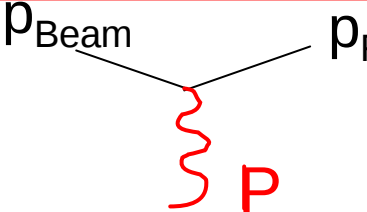
- Look at difference in gap production of gluon processes vs. quark processes to find evidence



Forward Proton Detector



Series of 18 Roman Pots forms 9 independent momentum spectrometers allowing measurement of proton momentum and angle.



$$x = 1 - x_p = \frac{\Delta P}{P} \quad t = (P_{Beam} - P_F)^2$$

1 Dipole Spectrometer ($\bar{p}$) $x > x_{min}$

8 Quadrupole Spectrometers (p or $\bar{p}$, up or down, left or right) $t > t_{min}$

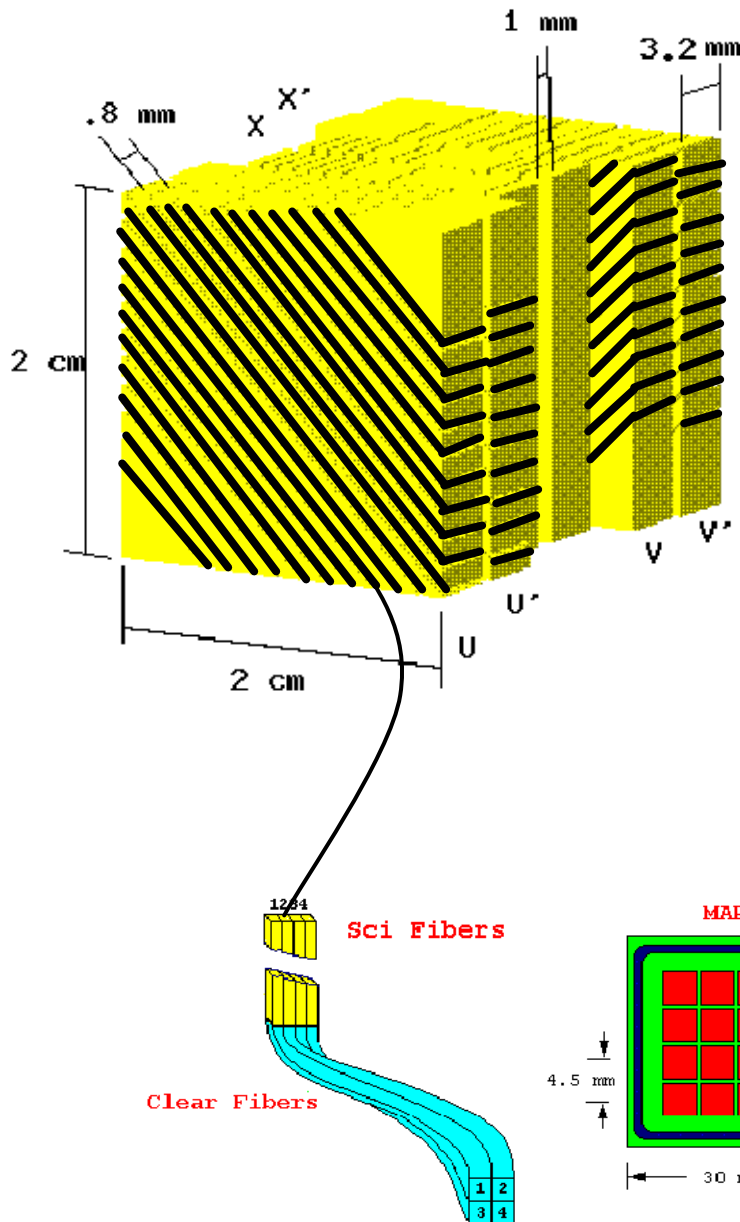


Detector Needs

- Position resolution of $100\mu\text{m}$
 - Beam dispersion and uncertainty in beam position make better resolution unnecessary
- Efficiency close to 100%
- Modest Radiation Hardness
 - Operates at 8σ from beam axis, 0.03 MRad yearly dose expected
- High Rate capability
 - Active at every beam crossing
- Low background rate
 - Insensitive to particles showering along beam pipe
- Small dead area close to the beam
 - Protons are scattered at very low angles, acceptance is very dependent on position relative to beam
- Scintillating Fiber detector spliced with waveguide meets these needs



Detector Layout



6 planes per pot

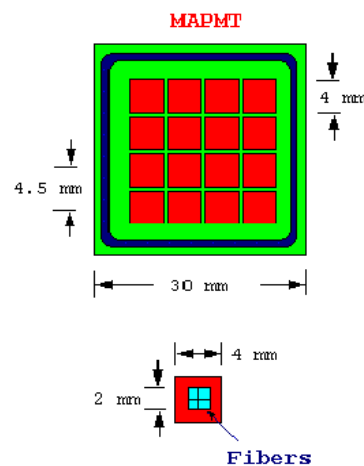
2 planes with same orientation offset by $2/3$

Fibers are separated by $1/3$ in each plane

20 channels U/V, 16 for X

Sci. Trigger in each pot

Read out by MAPMTs

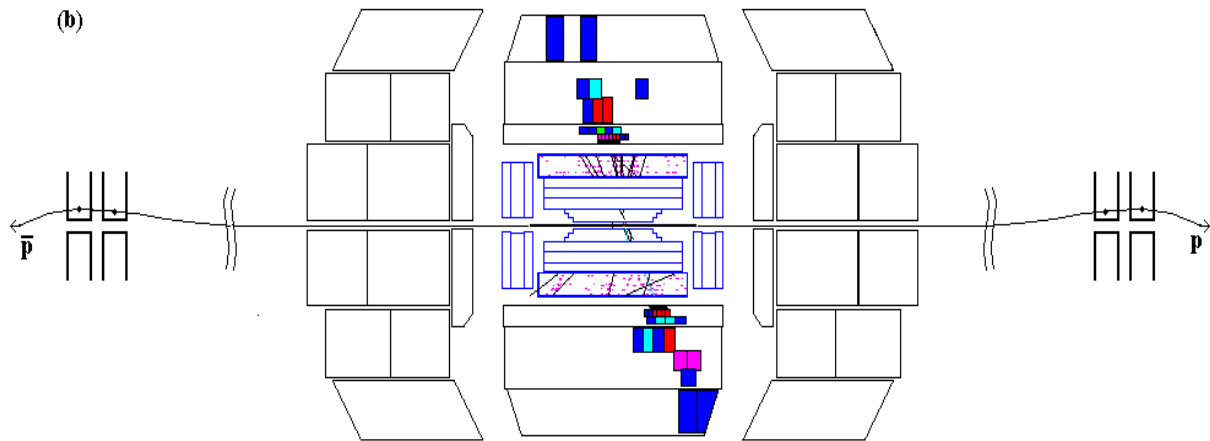
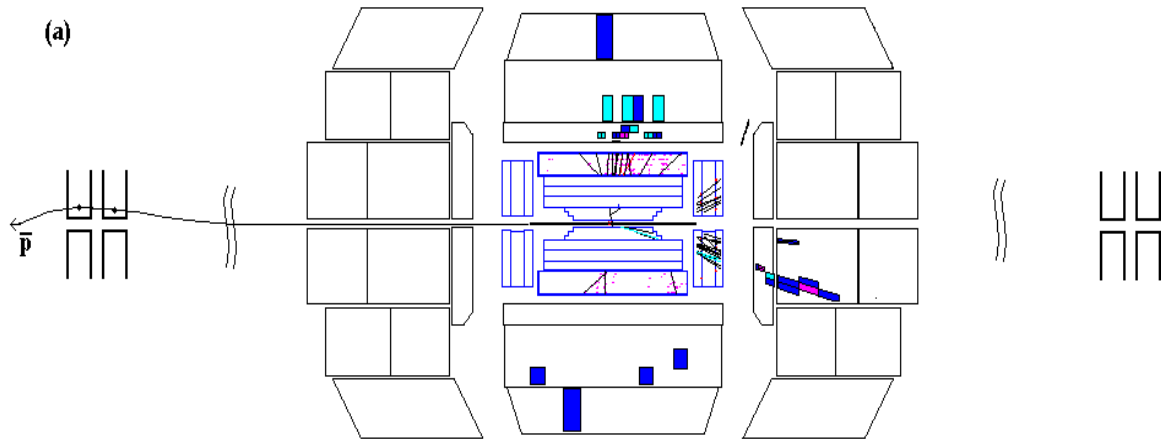




Simulated Diffractive Events



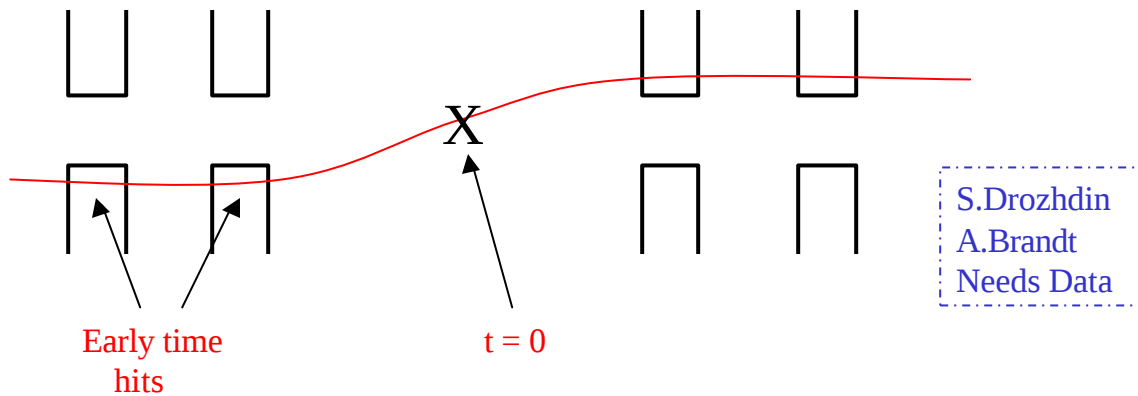
Hard Diffractive Candidate



Hard Double Pomeron Candidate

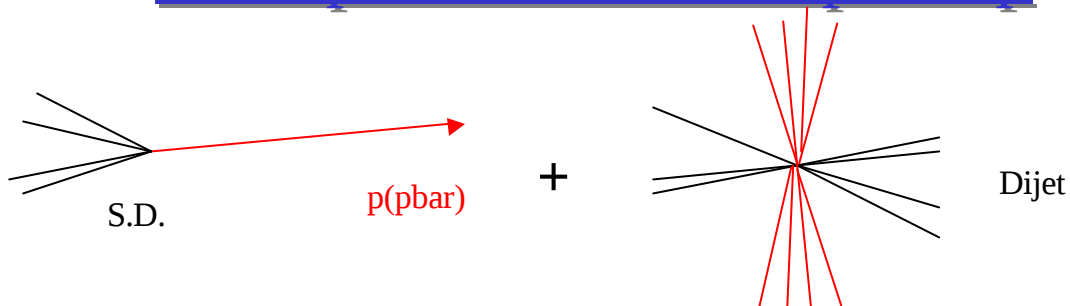


Backgrounds



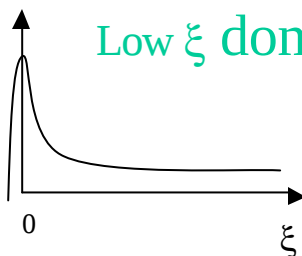
Reject Halo fakes using trigger scint. timing info

Multiple Interactions pile-up



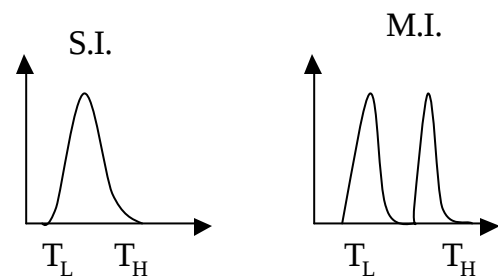
1) Using FPD tracks at L1; cut on $\xi < 0.01$

Low ξ dominates pile-up



M.Martens
Resolution

2) Cut at ΔT on L.M.



L.M.algo C.Miao
FPD W.Carvalho

Michael Strang



Current Status

- FPD appears to be working
- Collecting data independent of rest of DØ (except for Luminosity Monitor signals)
- Studying different spectrometers
- Using data to understand the detectors
 - alignment, efficiencies, resolution, ...
- Working towards optimizing operating positions and parameters
- Working on integration into rest of DØ



Future Measurements Using FPD



- Observation of hard diffractive processes through tagging

- Measure cross sections

$$\frac{d^2s(SD \rightarrow jets)}{dtdM^2} \quad \frac{s(SD \rightarrow jets)}{s(SD \rightarrow all)} \quad \frac{s(SD \rightarrow jets)}{s(p\bar{p} \rightarrow jets)}$$

$$dM = dx / 2x \quad 6\% \text{ for } M_x = 200 \text{ GeV } (x = 0.01)$$

$$dx = 0.0012 \quad 3\% \text{ for } M_x = 280 \text{ GeV } (x = 0.02)$$

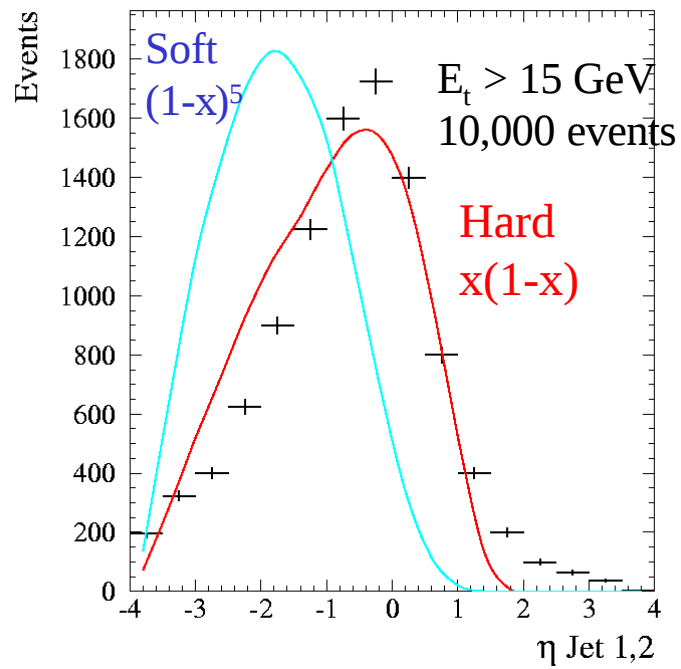
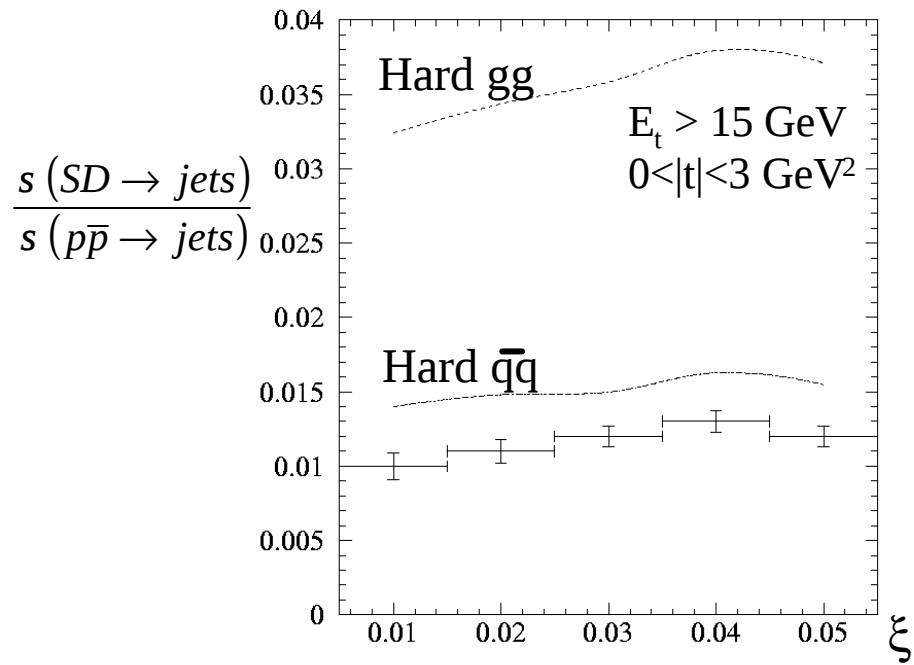
$$dt = 0.12\sqrt{|t|} \quad \text{Dominated by angular dispersion}$$

15% error for $|t| > 0.5 \text{ GeV}^2$ (reduced with unsmearing)

- Measure kinematical variables with sensitivity to pomeron structure (η , E_T , ...) Use Monte Carlo to compare to different pomeron structures and derive pomeron structure
- Combine different processes to extract quark and gluon content.



FPD Measurements (1 fb^{-1})





FPD Measurements (1 fb^{-1})

