DØ QCD: Past, Present, and Future

Andrew Brandt, University of Texas at Arlington

DØ Run II preliminary

DØ data, Cone R=0.7
- |y| < 0.5
- 1.5 < |y| < 2.0
- 2.0 < |y| < 2.4
NLO (JETRAD) CTEQ6M
R_{soft}=1.3, \mu_F = \mu_R = 0.5 p_T^{max}
\sqrt{s}=1.96\text{TeV}
L_{int} = 143 \text{ pb}^{-1}

Physics Seminar
May 7, 2004
Jefferson Lab
Tevatron at Fermilab

Batavia, Illinois

$\sqrt{s} = 1.8$ TeV

Run II (2001 - ?):
$\sqrt{s} = 1.96$ TeV

Chicago

CDF

DØ

Main Injector & Recycler

Booster
Upgraded Run II DØ Detector

- New Silicon and Fiber Trackers in 2 T magnetic field
- New forward muon system with \(|\eta|<2\) and good shielding
- New trigger electronics to deal with 396 ns bunch spacing
DØ Status

- Important milestone: reprocessed full dataset in Fall 2003
  - Greatly improved tracking performance
  - Good fraction processed off-site
  - Current analyses use up to 250 pb\(^{-1}\)
  - Used primarily for Heavy flavor (t,b) physics, new particle searches (Higgs, SUSY, etc.), EW
  - But I’m not going to talk about that at all!

- Excellent performance of Accelerator Division in 2004
  - DØ recorded 70 pb\(^{-1}\) in 2004
Strong Nuclear Force: Quantum Chromodynamics
Gluon Exchange, also holds the nucleus together.
All quarks carry a color charge
Gluons carry two color charges

Different from other Forces:
Gluons can interact with other gluons.
Quarks and gluons are free at small distances (asymptotic freedom), but not at large distances (confinement) ⇒ cannot observe bare color

Always observe quarks in multiplets:
Baryons $qqq$ (Proton neutron) and Mesons (quark antiquark pair)

Proton: $uud$
Also contains gluons and quark-antiquark pairs in a sea.

Neutron: $udd$

Pion: $ud$
**Typical QCD Event**

In a pp collision, a gluon or quark may be exchanged:

```
q       q
\bar{q} \bar{q}   q
\bar{q} q g q g
```

Due to the color flow in the event, particles are produced throughout phase space, and concentrated in regions around the struck partons (jets).

---

**Diffraction**

- **Elastic Scattering**

- **Single Diffraction**

If exchanged particle had color:

```
p
```

The event is no longer diffractive!

The exchanged particle must be colorless for diffractive event!
Lots of Run I QCD


Jets+Subjets
Hard Diffraction
Color Coherence and Energy Flow
Photons etc.
Parton-Parton Scattering

- Described by QCD.

\[
\sqrt{s} = \text{proton c.o.m. energy} = 1.96 \text{ TeV}
\]

\[
\hat{s} = \text{parton c.o.m. energy squared} = x_1x_2s
\]
Perturbative QCD and Jet Production

\[ \hat{\sigma} \sim \alpha_s^2 \text{ (LO)} \]

Parton distribution (PDF)

Hard scatter (pQCD)

Observable jet of particles in detector

Fragmentation into hadrons

\[ \hat{\sigma} \sim \alpha_s^3 \text{ (NLO)} \]

Includes radiative corrections and gluon emission - much of current QCD is a study of this additional radiation
In a Two Jet event the following is measured:

Jet: $E_T, \eta, \phi$  (pseudorapidity $\eta = -\ln[\tan \theta / 2]$)

$$M^2 = 2E_{T,1}E_{T,2}[\cosh(|\eta_1 - \eta_2|) - \cos(|\phi_1 - \phi_2|)] \text{(massless)}$$

Jet 1:
$E_{T,1}^1, \eta_1, \phi_1$

Jet 2:
$E_{T,2}^2, \eta_2, \phi_2$

$E_T = \text{Energy} \times \sin \theta$
Jet Production and Reconstruction

Highest $E_T$ dijet event in Run I at DØ

- $E_T^1 = 475$ GeV, $\eta^1 = -0.69$
- $E_T^2 = 472$ GeV, $\eta^2 = +0.69$

- Fixed cone-size jets
- Add up towers
- Iterative algorithm
- Jet quantities: $E_T, \eta, \phi$
High Energy Art
The Run I DØ Central Inclusive Jet Cross Section

- How well do we know proton structure (PDF)?
- Is NLO ($\alpha_s^3$) QCD “sufficient”?
- Are quarks composite (preons)?

$\frac{1}{\Delta \eta \Delta E_T} \int \frac{d^2 \sigma}{d E_T d \eta} (\text{fb/GeV})$

'$\text{DØ Run 1B} \left( \int L dt = 92 \text{ pb}^{-1} \right)$

$\bullet 0.0 \leq |\eta| < 0.5$

$\bullet$ JETRAD

DO and CDF data in good agreement. NLO QCD describes the data well. No evidence for compositeness (yet).
Run II datasets have better discrimination of PDFs – for *gluons* at high $x$

reliable test of accuracy of parton-level NLO calculation and pQCD matrix elements

place to search for new physics, traditionally

- **central region** $\Rightarrow$ the largest transverse energy $\Rightarrow$ sensitive to PDFs and potential new physics
- **forward regions** $\Rightarrow$ still sensitive to PDFs but less “sensitive” to new physics
The highest $p_T$ & di-jet mass

3-dim plot (azimuth-)

<table>
<thead>
<tr>
<th></th>
<th>1st jet</th>
<th>2nd jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T$ [GeV/c]</td>
<td>616</td>
<td>557</td>
</tr>
<tr>
<td>$\eta$</td>
<td>-0.19</td>
<td>0.25</td>
</tr>
<tr>
<td>$\varphi$ [rad]</td>
<td>0.65</td>
<td>3.78</td>
</tr>
</tbody>
</table>
Conclusions

We measured inclusive cross section in the central and forward calorimeter regions.

Run II – higher $p_T$ than Run I ($p_T \sim 350$ GeV)

All presented results are preliminary – more luminosity is being collected.

Our measurement is well described by the next-to-leading order perturbative QCD throughout the whole kinematic region – theory is in good agreement with measured data, given the uncertainties.
Diffraction/Color singlet exchange

- Exchange of quantum numbers of the vacuum (no charge or color), often referred to as **Pomeron** exchange

- Experimental signatures:
  - **rapidity gap** - absence of particles or energy above threshold in some region of rapidity in the detector
  - **intact proton** - p or \( \bar{p} \) scattered at small angle from the beam

- **Single Diffraction**
  - either p or \( \bar{p} \) intact
  - search for rapidity gap in forward regions of DØ
    - **Luminosity Monitor**
    - **Calorimeter**
  - Hard Diffraction (UA8), SD+high \( P_T \)

- **Elastic Scattering**
  - p and \( \bar{p} \) intact, with no momentum loss
  - no other particles produced
  - search for intact protons in beam pipe
    - **Forward Proton Detector**
Learning about the Pomeran

• **QCD** is theory of strong interactions, but **40%** of total cross section is attributable to **Pomeran** exchange -- not calculable and poorly understood

• Does it have partonic structure? **Soft? Hard? Super-hard? Quark? Gluon?** Is it universal -- same in **ep** and **p pbar**? Is it the same with and without **jet** production?

• Answer questions in HEP tradition -- collide it with something that you understand to learn its structure

• Note: variables of diffraction are **t** (momentum transfer) and **ξ ~ M^2** (fractional momentum loss) with FPD measure \( \frac{d^2\sigma}{dt d\xi} \) without FPD just measure **σ**
Luminosity Monitor

Luminosity Monitor (LM)

- Scintillating detector
- $2.7 < |\eta| < 4.4$
- Charge from wedges on one side are summed:
  Detector is **on/off** on each side, North and South

(Run I $n_{l0} = \#$ tiles in L0 detector with signal $2.3 < |\eta| < 4.3$)
Cells arranged in layers:
- electromagnetic (EM)
- fine hadronic (FH)
- coarse hadronic (CH)

- Sum E of Cells in EM and FH layers above threshold:
  \[ E_{EM} > 100 \text{ MeV} \]
  \[ E_{FH} > 200 \text{ MeV} \]

\( n_{\text{cal}} = \# \text{ cal towers with energy above threshold} \)
DØ Dijet Events: $\eta-\phi$ Legos

**Typical Event:**

**HSD topology:**

**HDPE topology:**
Hard Color-Singlet Exchange (central gap)

Count tracks and EM Calorimeter Towers in $|\eta| < 1.0$

($E_T > 30$ GeV, $\sqrt{s} = 1800$ GeV)

Measured fraction ($\sim 1\%$) rises with initial quark content:
- Consistent with a soft color rearrangement model preferring initial quark states
- Inconsistent with two-gluon, photon, or U(1) models

Why study Diffractive W Boson?

The pomeron (IP) structure is not yet understood which motivates a study that will better clarify the quark/gluon composition involved. This is found in the diffractive W, which to leading order can only happen based on a quark component in the pomeron.¹

\[ \begin{align*}
\text{a)} & \quad \text{LO: } q\bar{q} \rightarrow W \\
\text{b)} & \quad \text{NLO: } qg \rightarrow q + W
\end{align*} \]

Diffractive process (a) probes the quark content of the pomeron.

¹(Bruni & Ingelman, Phys. Lett. B311(1993)318)
Observation of Diffractive W/Z

- Observed clear diffractively produced W and Z boson signals
- Events have typical W/Z characteristics
- Background from fake W/Z gives negligible change in gap fractions

<table>
<thead>
<tr>
<th>Sample</th>
<th>Diffractive / All</th>
<th>Probability Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central W</td>
<td>(1.08 + 0.19 - 0.17)%</td>
<td>7.7σ</td>
</tr>
<tr>
<td>Forward W</td>
<td>(0.64 + 0.18 - 0.16)%</td>
<td>5.3σ</td>
</tr>
<tr>
<td>All W</td>
<td>(0.89 + 0.19 – 0.17)%</td>
<td>7.5σ</td>
</tr>
<tr>
<td>All Z</td>
<td>(1.44 + 0.61 - 0.52)%</td>
<td>4.4σ</td>
</tr>
</tbody>
</table>

Sample Diffractive                  Probability Background
All                  Fluctuates to Data
Central W (1.08 + 0.19 - 0.17)% 7.7σ
Forward W (0.64 + 0.18 - 0.16)% 5.3σ
All W (0.89 + 0.19 – 0.17)% 7.5σ
All Z (1.44 + 0.61 - 0.52)% 4.4σ

Run II Improvements

• Larger luminosity allows search for rare processes

• Integrated FPD allows accumulation of large hard diffractive data samples

• Measure $\xi, t$ over large kinematic range

• Higher $E_T$ jets allow smaller systematic errors

• Comparing measurements of HSD with track tag vs. gap tag yields new insight into process
DØ Run II Diffractive Topics

**Soft Diffraction and Elastic Scattering:**
- Inclusive Single Diffraction
- Elastic scattering (t dependence)
- Total Cross Section
- Centauro Search
- Inclusive double pomeron
- Search for glueballs/exotics

**Hard Diffraction:**
- **Diffractive jet**
- Diffractive b,c,t, Higgs
- **Diffractive W/Z**
- Diffractive photon
- Other hard diffractive topics
- **Double Pomeron + jets**
- Other Hard Double Pomeron topics

**Rapidity Gaps:**
- **Central gaps+jets**
- Double pomeron with gaps
- Gap tags vs. proton tags

Topics in **RED** were studied with gaps only in Run I

<100 W boson events in Run I, >1000 tagged events expected in Run II
Calorimeter Energy Sum

• Use energy sum to distinguish proton break-up from empty calorimeter:

Log(energy sum) on North side:

Areas are normalised to 1

• Esum cut of 10GeV was chosen for current study

• Final value will be optimised using full data sample

• Compare 'empty event' sample with physics samples:

  • Empty event sample: random trigger. Veto LM signals and primary vertex, i.e. mostly empty bunch crossings
  • Physics samples: minimum bias (coincidence in LM), jet and $Z \rightarrow \mu\mu$ events
Search for diffractive $Z \rightarrow \mu\mu$

Nine single diffractive $Z \rightarrow e^+e^-$ events. No result in muon channel.

- RunII: first search for forward rapidity gaps in $Z \rightarrow \mu^+\mu^-$ events

- Inclusive $Z \rightarrow \mu\mu$ sample well understood:
  - 2 muons, $p_T > 15$GeV, opposite charge
  - at least one muon isolated in tracker and calorimeter
  - anti-cosmics cuts based on tracks:
    - displacement wrt beam
    - acolinearity of two tracks
First step towards gap: LM only

- Separate the Z sample into four groups according to LM on/off:
  - Expect worst cosmic ray contamination in sample with both sides of LM off
  - no evidence of overwhelming cosmics background in LM off samples

- cosmics shape expected from inclusive sample
**Z Mass of rapidity gap candidates**

- Add Esum requirement:
  - Invariant mass confirms that these are all Drell-Yann/Z events
  - Will be able to compare Z boson kinematics ($p_T$, $p_z$, rapidity)

```
89.8 ± 0.1 GeV
89.6 ± 1.0 GeV
89.3 ± 2.0 GeV
90.2 ± 1.3 GeV
```
Diffractive $Z \rightarrow \mu \mu$ candidate
Z→μμ with rapidity gaps: Summary

• Preliminary definition of rapidity gap at DØ Run II

• Study of Z→μ+μ- events with a rapidity gap signature (little or no energy detected in the forward direction)

• Current status:
  • Evidence of Z events with a rapidity gap signature
  • Quantitative studies of gap definition, backgrounds, efficiency in progress (effects could be large)
  • No interpretation in terms of diffractive physics possible yet

• Plans:
  • Measurement of the fraction of diffractively produced Z events
  • Diffractive W→μν, W/Z→electrons, jets and other channels
  • Use tracks from Forward Proton Detector
Forward Proton Detector (FPD)

- a series of momentum spectrometers that make use of accelerator magnets in conjunction with position detectors along the beam line

- Quadrupole Spectrometers
  - surround the beam: up, down, in, out
  - use quadrupole magnets (focus beam)
  - also shown here: separators (bring beams together for collisions)

A total of 9 spectrometers composed of 18 Roman Pots
Acceptance

Quadrupole ($p$ or $\bar{p}$)

Dipole (only)

$\xi$ Geometric (φ) Acceptance

Dipole acceptance better at low $|t|$, large $\xi$

Cross section dominated by low $|t|$

Combination of Q+D gives double tagged events, elastics, better alignment, complementary acceptance

$M_{X}(\text{GeV})$ vs $|t| (\text{GeV}^2)$

Dipole acceptance

Combination of Q+D gives double tagged events, elastics, better alignment, complementary acceptance
All 6 castles with 18 Roman pots comprising the FPD were constructed in Brazil, installed in the Tevatron in fall of 2000, and have been functioning as designed.
FPD Detector Design

- 6 planes per detector in 3 frames and a trigger scintillator
- U and V at 45 degrees to X, 90 degrees to each other
- U and V planes have 20 fibers, X planes have 16 fibers
- Planes in a frame offset by ~2/3 fiber
- Each channel filled with four fibers
- 2 detectors in a spectrometer
Detector Construction

At the University of Texas, Arlington (UTA), scintillating and optical fibers were spliced and inserted into the detector frames.

The cartridge bottom containing the detector is installed in the Roman pot and then the cartridge top with PMT’s is attached.
Detector Status

• 20 detectors built over a 2+ year period at UTA.

• In 2001-2002, 10 of the 18 Roman pots were instrumented with detectors.

• Funds to add detectors to the remainder of the pots have recently been obtained from NSF (should acknowledge funding from UTA REP, Texas ARP, DOE, and Fermilab as well).

• During the shutdown (Sep-Nov. 2003), the final eight detectors and associated readout electronics were installed. All 18 pots are routinely inserted near the beam.

[Image: A2 Quadrupole castle with all four detectors installed]
Elastic Scattering

- Elastic scattering: $\xi = 0$

- Quadrupole acceptance:
  - $t > 0.8 \text{ GeV}^2$ (requires sufficient scattering angle to leave beam)
  - all $\xi$ (no longitudinal momentum loss necessary)

- Measure $dN/dt$ for elastic scattering using incomplete FPD:

- **antiproton side:**
  - quadrupole ‘up’ spectrometer
  - trigger only

- **proton side:**
  - quadrupole ‘down’ spectrometer
  - full detector read-out
Elastic Data Distributions

After alignment and multiplicity cuts (to remove background from halo spray):

\[ \xi = \Delta \frac{p}{p} \]

Events are peaked at zero, as expected, with a resolution of \( \sigma_{\xi} = 0.019 \)

The fit shows the bins that will be considered for corrected \( dN/dt \).
Preliminary Elastic Scattering Results

• The $d\sigma/dt$ data collected by different experiments at different energies

• A factor of $10^{-2}$ must be applied to each curve

• New DØ $dN/dt$ distribution has been normalized by E710 data

Dipole TDC Resolution

- Can see bunch structure of both proton and antiproton beam
- Can reject proton halo at dipoles using TDC timing
Summary and Future Plans

- Early FPD stand-alone analysis shows that detectors work, will result in elastic dN/dt publication (already 1 Ph.D.)
- FPD now integrated into DØ readout (detectors still work)
- Commissioning of FPD and trigger in progress
- Tune in next year for first integrated FPD physics results

BUT Wait, There’s More!
GTeV: Gluon Physics at the Tevatron

- A future experiment at the Tevatron
- 2009: CDF & D0 complete data taking
  - BTeV to run 2009-~2013
- Primary Goal of GTeV: QCD (perturbative & non-perturbative)
- Uses CDF or D0 detector as “core”
- Add precision forward and very forward tracking

thanks to Mike Albrow for his slides
Primary Goal: Understand Strong Interactions

Foci:

Gluon density $g(x, Q^2)$ at very low $x$
- saturation, unitarity, gluodynamics, non-perturbative frontier

Pure Gluon jets
- profiles, content, color connection, $gg$ compared to $q\bar{q}$ jets

Determine glueball spectrum
- Relates to pomeron trajectories, strings, lattice ...

Measure exclusive $\chi^0_c, \chi^0_b$
- Relates to SM Higgs study at LHC

Discover new exotic hadrons
- Hybrids, 4-quark, pentaquarks, ...

Search for exotic fundamentals
- CP-odd H, Radions, gluinoballs ...

Andrew Brandt
GTeV
Jefferson Lab
Use Tevatron as Tagged Gluon-Gluon Collider

\[ \sqrt{s_{gg}} = \sim 1-100 \text{ GeV} \]

\[ \sigma_{\sqrt{s}} \sim 100 \text{ MeV} \]  
(Stretch Goal)

Glueballs and Hybrids
New Exotic Hadrons
chi_c and chi_b states
Hunting strange exotic animals (radions, ...?)

Everywhere: Gluodynamics, perturbative and non-perturbative issues

Like \( \gamma \gamma \) collider in LC
The REAL Strong Interaction

extended, strong coupling non-perturbative
point-like, weak coupling perturbative

Many approaches, none complete:

→ Lattice Gauge Theory
  Small volume, hadron size

→ Regge Theory: Analyticity +
  Unitarity + Crossing Symmetry
  + Complex angular momenta

→ String models

Want a complete understanding of S.I. \( Q^2 = 0 \rightarrow \infty \)

Non-perturbative – perturbative transition
Some of proposed program could be done now, except:

1) Do not have 2-arm forward p-taggers (dipole spectrometer)
2) Small angle (< 3 deg) region trackless
3) Limit on number of triggers
4) Bandwidth allocated small

60 Hz → 250 Hz → > 1 KHz for 2009 [10^{10}/year]

CDF, D0: NP QCD <~ 10%, other ~ 90%
GTeV: NP QCD ~ 90%, other <~ 10%

& upgrade of forward and very forward detectors
**Probing Very Small x Gluons**

High parton densities  
New phenomena (gluon saturation)  
HERA measures \( q(x) \) to \(~ 10^{-5} \)  
g(\( x \)) by evolution, charm  
GTeV : measure \( g(x) \) to \(~ 10^{-4} \)  
(also \( x >~ 0.5 \)) more directly

\[
x_1 = \frac{p_T}{\sqrt{s}}\left(e^{y_1} + e^{y_2}\right) ; \quad x_2 = \frac{p_T}{\sqrt{s}}\left(e^{-y_1} + e^{-y_2}\right)
\]

e.g. \( \sqrt{s}=1960 \text{ GeV} \), \( p_T = 5 \text{ GeV} \), \( y_1 = y_2 = 4 (2.1^0) \)  
\( \Rightarrow \) \( x_1 = 0.56 \), \( x_2 = 10^{-4} \)

Instrument \( 0.5^0 < \theta < 3^0 \) region with tracking, calorimetry (em+had), muons, \( J/\psi \) jets, photons ...

& \( Q^2 < \sim 2 \text{ GeV}^2 \) ? (HERA)
Gluon Jets

LEP(Z) ... \( \sim 10^7 \) q-jets, detailed studies

“Pure” g-jet sample: 439 events (OPAL), Delphi more but 80% “pure”

\[ e^+e^- \rightarrow Z \rightarrow b\bar{b}\ g \]

g-jet contaminated at low-x

In \( pp \rightarrow p\ JJ \bar{p} \) with \( M_{MM} \approx M_{JJ} \)

(2 jets and \( \sim \) nothing else)

\( \sim 99\% \) pure g-jets

q-jets suppressed by \( J_z = 0 \) rule

\[ \sim 10^5 \) pure g-jets

Fragmentation, scaling
color singlet back-to-back gg jets: DPE unique
Gluonia and Glueballs

Gluons (G) are hadrons without valence quarks
Allowed in QCD – or, if not, why not?
Some can mix with q\overline{q} mesons
Some have exotic quantum numbers and cannot
J^{PC} = 0^{--}, even^{+-}, odd^{--}
Glue-glue collider ideal for production (allowed states singly, others in association GG', G + mesons.)
Forward p\overline{p} selects exclusive state, kinematics filters Q.Nos:

Forward protons: J^p = 2^+ exclusive state cannot be non-relativistic q\overline{q} (J_z =0 rule)

Exclusive central states e.g.
\phi\phi \rightarrow 4K, \pi\pi KK, DD^*, \Lambda\Lambda, etc

Other processes:
\pi p \rightarrow [\phi\phi] + n
J / \psi \rightarrow \gamma + G
e^+e^- \rightarrow J / \psi, \Upsilon + G
pp (low \sqrt{s}) \rightarrow G + anything

This one \rightarrow gg \rightarrow G, GG, G+anything
**Central Exclusive Production**

**gg fusion**: main channel for H production.

Another g-exchange can cancel color, even leave p intact.

\[
p p \rightarrow p + H + p
\]

Theoretical uncertainties in cross section, involving skewed gluon distributions, gluon k_T, gluon radiation, Sudakov form factors → Probably \( \sigma(SMH) \sim 0.2 \) fb at Tevatron, not detectable, but may be possible at LHC (higher L and \( \sigma \sim 3 \) fb?)

Theory can be tested, low x gluonic features of proton measured with exclusive \( \chi_c^0 \) and \( \chi_b^0 \) production.

Khoze, Martin, Ryskin hep-ph/0111078

Lonnblad & Sjodahl hep-ph/0311252

and many others
Exclusive $\chi_c$ search in CDF: $p \bar{p} \rightarrow p \chi_c \bar{p}$

Predictions for Tevatron: Khoze, Martin, Ryskin $\sim 600$ nb
Feng Yuan $\sim 735$ nb (20 Hz at Tevatron!)

In reality: $\text{BR}(\chi_c^0 \rightarrow J/\psi \gamma) \sim 10^{-2}$; $\text{BR}(J/\psi \rightarrow \mu^+\mu^-) \sim 6.10^{-2}$
No other interaction $\sim 0.25$; acceptance(trig) $\sim 10^{-2}$
$\Rightarrow$ few pb (1000's in 1 fb$^{-1}$)

$\sigma(p p \rightarrow p \chi_b \ p) \sim 120$ pb (KMR)
$\times(\text{BR} \rightarrow \Upsilon\gamma) \times(\text{BR} \rightarrow \mu\mu\gamma) \Rightarrow \sim 500$/fb$^{-1}$

Measuring forward $p \rightarrow$ central quantum numbers
$J^P=0^+ ; \ 2^{++}$ suppressed at $t=0$ for $q\bar{q}$ state

(Khoze,Martin,Ryskin hep-ph/0011393; F.Yuan hep-ph/0103213)

If MM resolution $\sim 100$ MeV, exclusive test, resolve states
Beyond the Standard Model

**CP-odd Higgs**: allowed $20 < M < 60$ GeV
Don’t couple to $W,Z \ldots$ produced by $gg \rightarrow t$-loop $\rightarrow h$
But $b$-$\overline{b}$ too ... Mass resolution critical

Low $\beta \Rightarrow$ Medium $\beta$  $\sigma_{\text{MM}} \approx 100$ MeV
($z,t$) correction $\approx ?$

**Radions**: Quantum fluctuations in 5th dimension: tensor + scalar
$20$ GeV and up allowed if parameters right. Like $h$ but gg coupling high
Width $\sim$ keV, Decay $\rightarrow b \overline{b}$

**Light Gluinos and Gluinoballs**
Gluino $g-$ could be lightest SUSY particle
LSP Does not decay in detector --- forms heavy hadrons. Can form bound states “gluinoballs”

$\sigma(p\overline{p} \rightarrow p + G(60\text{GeV}) + b\overline{b} \approx 20\text{fb (Tevatron)}$
**BFKL and Mueller-Navelet Jets**

Color singlet (IP) exchange between quarks  
Enhancement over 1g exchange – multiRegge gluon ladder  
Jets with large y separation  
n minijets in between (inelastic case)  
large gap in between (elastic case)

Cross section enhanced \( \left( \frac{s}{t} \right)^{\omega} \)

\[ \omega_{\text{BFKL}} = \frac{4N_c \ln 2}{\pi} \alpha_s \approx 0.5 \text{ for } \alpha_s = 0.19 \]

\[ \bar{n} \sim \omega \ln \left( \frac{s}{t} \right) \sim 3 - 4 \]

**Measure \( f_n(\eta, p_T, \sqrt{s}, \Delta\eta) \)**

Fundamental empirical probe of new regime: non-perturbative QCD at short distances.
Hadron Spectroscopy: an example

X(3872) discovered by Belle (2003)
Seen soon after by BaBar, CDF, and DØ
Relatively narrow

\[ M_{X(3872)} - M_{J/\psi} - 2M_{\pi} = 495 \text{ MeV} \]
\[ \Gamma < 3.5 \text{ MeV} \]

What are its quantum numbers?
Why so narrow? What is it?

\[ D\bar{D}^* \text{ "molecule"? or } \{\{cd\} \Leftrightarrow \{\bar{c}\bar{d}\}\} \text{ state?} \]

If we see in exclusive DPE:

\[ I^G J^{PC} \text{ (DPE)} \]
\[ 0^+0^{++} \Rightarrow \text{favored} \]
\[ 0^+0^{--}, 0^+1^{--}, 0^+1^{++} \Rightarrow \text{not at } 0^\circ \]
\[ 0^+2^{++} \Rightarrow \text{not } q\bar{q} \]

Also, cross-section depends on “size/structure” of state.
Add:
New pots very forward: through quadrupoles + near (55m) + far (~160m?)
Other forward detectors (tracking, upgrade calorimetry e.g.) \( \rightarrow \) "Cone Spectrometers"
New DAQ and trigger system \( \rightarrow \) kHz
Silicon (certainly want it) ... hope it’s still good (COT also)

Andrew Brandt  
GTeV  
Jefferson Lab
Very Forward: Roman Pots

**D0** has 8+8 quadrupole spectrometer pots + 2 dipole spectrometer pots
Scintillating fiber hodoscopes (~ 1mm)

CDF has 3 dipole spectrometer pots
0.8 mm x-y fibers

**GTeV:** Quads + near + far dipoles
Silicon ustrip, pixels, trig scint
Quartz Cerenkov for ~ 30 ps TOF
Re-using D0 detector?

Add:
New/upgrade pots very forward: quad + near (55 m) + far (160 m?)

Forward ("cone") region probably not instrumentable
Spaces for pots and their position: quad, near dipole, far dipole

**Replace 3 dipoles with 2 High Field dipole(s) → ~ 4 m spaces**

- 6.5 Tesla, same current, temperature! (Tech.Div or outside)
- critical path, ~ 4 years

Momentum and Missing mass resolution Limits? Medium-beta?

- p-z correlation? stability, drifts

**Instrumentation:** precision (~ 10 um?) BPMs at pots

**Co-existence with BTeV:** Luminosity (~2-4 e31 also high?),
- Beam-beam tune shift, Long-range tune shift,
- Electrostatic separators, Luminosity lifetime, ...
Many Subjects not Covered

Just a few:

The cosmic ray connection: very forward particle production data needed

Jet – gap - X – gap - Jet (low mass X) different from p—X---p ?

Very soft photons < 100 MeV, via conversions

p → 3 jet fragmentation: 3 very forward jets, with & without gaps

Bose-Einstein correlations: directional, event type, high statistics

Many other studies will be done, as happens in CDF & D0 now.
> To present and discuss QCD issues that remain to be addressed by the CDF and DØ detectors at the Tevatron.
> To evaluate physics, especially non-perturbative QCD and the non-perturbative/perturbative interface, that may require upgrades to an existing detector and/or running beyond the present high-pT/high mass program.
> To review the QCD and other physics potential of the Tevatron beyond 2009 in the context of BTeV and the LHC.

http://conferences.fnal.gov/qcdws/

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Andrew Brandt

GTev

Jefferson Lab
GTeV plans

- LOI for Spring 2005 PAC
- Convenors:
  Physics: Fred Olness (SMU)+Mark Strikman (Penn St.)
  MC: Brian Cox (Manchester)
  Tevatron: Mike Martens (FNAL)+Yuri Alexahin (FNAL)
  Forward Detectors: Rick Tesarek (FNAL) + Helio da Motta (CBPF) + Risto Orava (Helsinki)

Studying technical issues (critical path is high field dipole to create warm space) + can we build a collaboration?
My Opinion

• Solid physics program, needs refinement
• Makes sense to have a second experiment
• Need U.S. HEP experimental alternatives to LHC
• Training of new GTeV experts will help offset LHC drain in 2007-2009
• Need 5-10% of CDF/ DØ + people from HERA, fixed target, Jlab, etc. to be viable

Come to workshop, send me e-mail w/questions/commnts