GTeV: Gluon Physics at the Tevatron

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

Primary Goal: Understand Strong Interactions

Foci:

Gluon density g(x, Q2) at very low x

saturation, unitarity, gluodynamics, non-perturbative frontier

Pure Gluon jets

profiles, content, color connection, gg compared to q-qbar jets

Determine glueball spectrum

Relates to pomeron trajectories, strings, lattice ...

Measure exclusive χ_c^0, χ_b^0

Relates to SM Higgs study at LHC

Discover new exotic hadrons

Hybrids, 4-quark, pentaquarks, ...

Search for exotic fundamentals

CP-odd H, Radions, gluinoballs $\tilde{g}\tilde{g}$ ...

Use Tevatron as Tagged Gluon-Gluon Collider

$$\sqrt{s_{gg}} = \sim 1\,\text{GeV} \Rightarrow \sim 100\,\text{GeV}$$

$$\boxed{\sigma_{\sqrt{s}} \sim 100\,\text{MeV}} \longleftarrow \text{(Stretch Goal)}$$

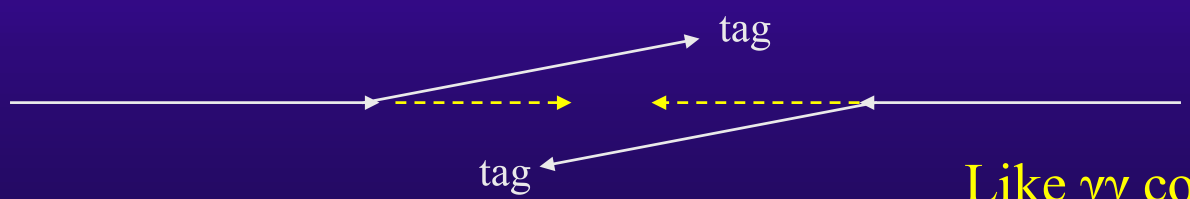
Glueballs and Hybrids

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

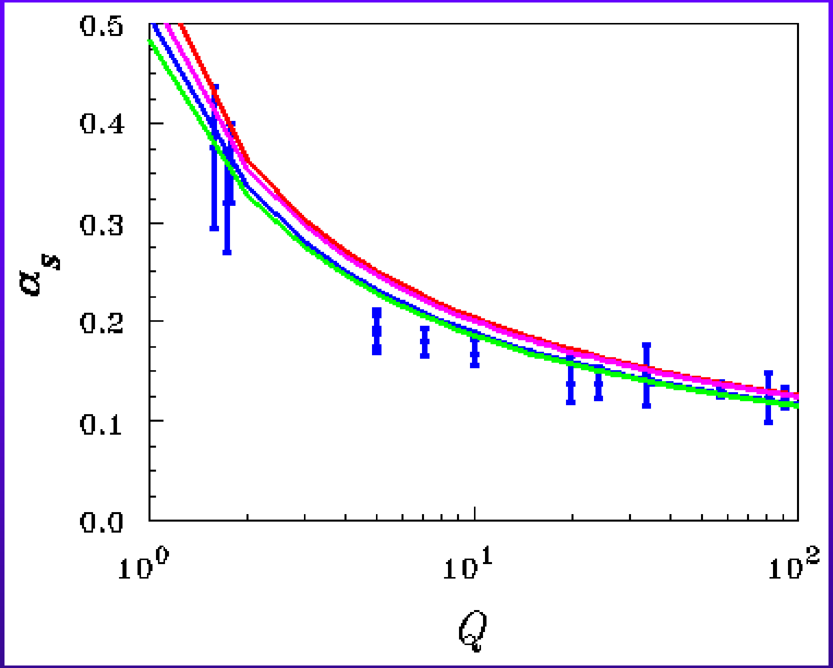
point-like, weak coupling
perturbative

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]

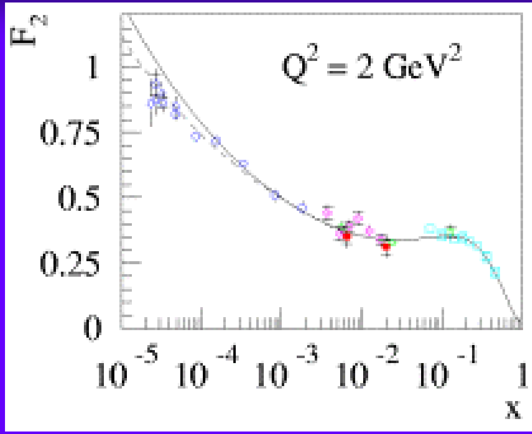
CDF, D0: NP QCD <~ 10%, other ~ 90%

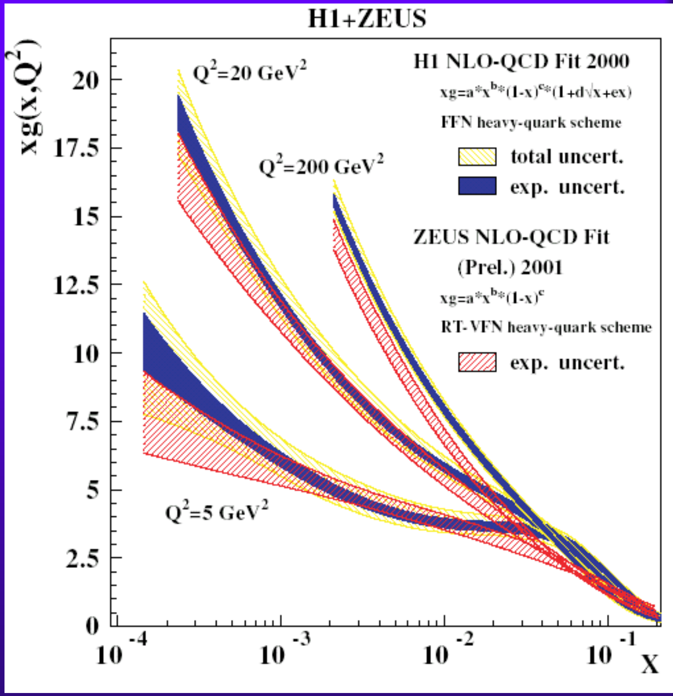
GTeV: NP QCD ~ 90%, other <~ 10%

& 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





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

e.g. $\sqrt{s}$=1960 GeV, p_T = 5 GeV, $y_1 = y_2$=4 (2.1^0)

$$\Rightarrow \qquad x_1 = 0.56, \; x_2 = 10^{-4}$$

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

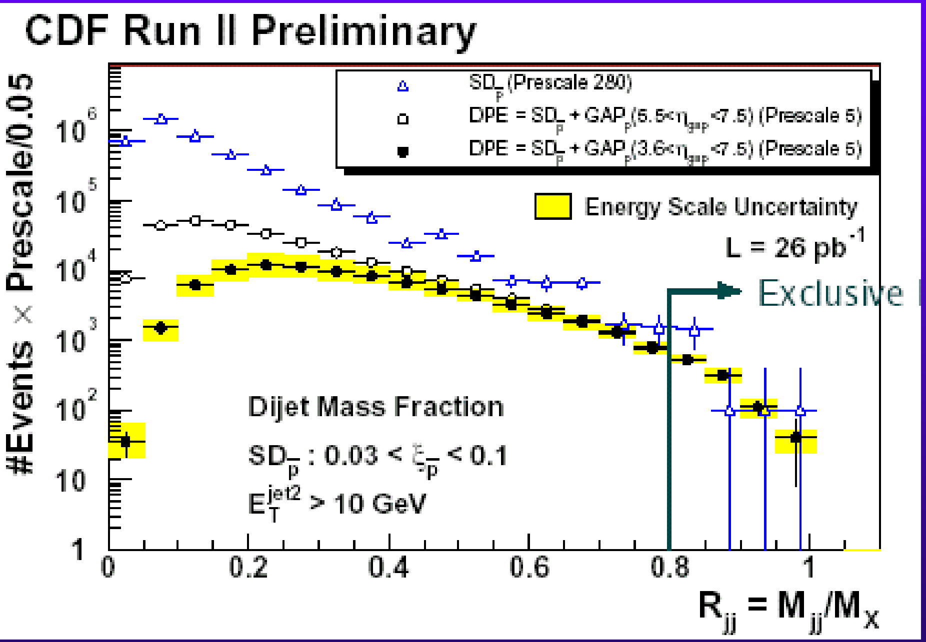
Gluon Jets

LEP(Z) ... ~ 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 $pp \rightarrow p \quad JJ \quad \bar{p}$ with $M_{MM} \approx M_{JJ}$

(2 jets and ~ nothing else)
> ~ 99% pure g-jets
q-jets suppressed by Jz = 0 rule



$\boxed{\sim 10^5 \text{ pure g-jets}}$

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

Central Exclusive Production

... or, diffractive excitation of the vacuum

> "IT IS CONTRARY TO REASON TO SAY THAT THERE IS A VACUUM OR A SPACE IN WHICH THERE IS ABSOLUTELY NOTHING."
>
> DESCARTES

→ Virtual states in the vacuum can be promoted to real states by the glancing passage of two particles.

Charged lepton (or q) pairs : 2-photon exchange
Hadronic states : 2-pomeron exchange (DPE) dominates

Vacuum quantum number exchange.
Central states' quantum numbers restricted.
Measure forward p,pbar → missing mass, Q-nos.

Ideal for Glueball, Hybrid spectroscopy

I^G	J^{PC} (DPE)	
0^+	0^{++}	←
0^+	0^{-+}	
0^+	1^{-+}	Not at 0^0
0^+	1^{++}	
0^+	2^{++}	←

Gluonia and Glueballs

Hadrons G without valence quarks
Allowed in QCD – or, if not, why not ?
Some can mix with $q\bar{q}$ 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 $p\bar{p}$ selects exclusive state, kinematics filters Q.Nos :

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

Exclusive central states e.g. $\phi\phi \rightarrow 4K$, $\pi\pi KK$, $D\bar{D}^*$, $\Lambda\bar{\Lambda}$, etc

Other processes:

$\pi^- p \rightarrow [\phi\phi] + n$
$J/\psi \rightarrow \gamma + G$ $\quad$ $e^+e^- \rightarrow J/\psi, \Upsilon + G$
$p\bar{p}$ (low $\sqrt{s}$) $\rightarrow$ G + anything
This one → $gg \rightarrow$ G, GG, G+anything

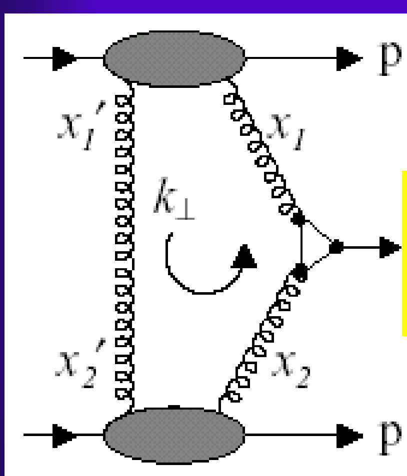
Central Exclusive Production

gg fusion: main channel for H production.

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

$$p\,p \rightarrow p \quad + \quad H \quad + \quad p$$

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?)



u-loop : $\gamma\gamma$	c-loop : χ_c^0
b-loop : χ_b^0	t-loop: H

Theory can be tested, low x gluonic features of proton measured with exclusive χ_c^0 and χ_b^0 production.

Khoze,Martin,Ryskin hep-ph/0111078
Lonnblad & Sjodahl hep-ph/0311252
and many others

Exclusive χ_c search in CDF : $p\,\bar{p} \to p \quad \chi_c \quad \bar{p}$

(Angela Wyatt)

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

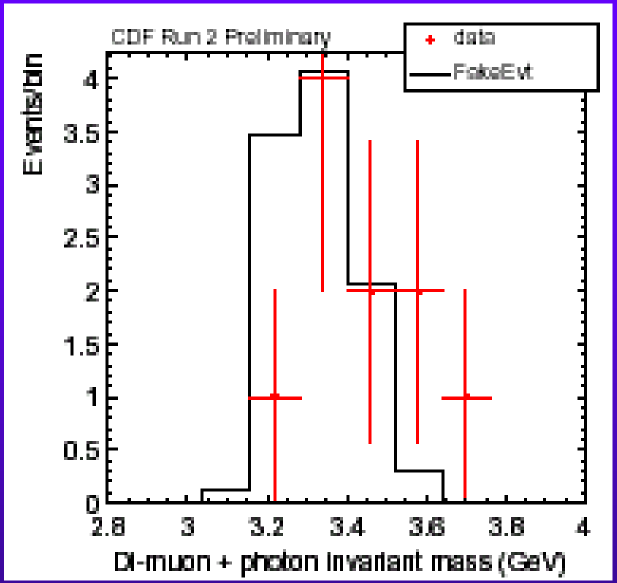
In reality: $BR(\chi_c^o \to J/\psi\,\gamma) \sim 10^{-2}$; $BR(J/\psi \to \mu^+\mu^-) \sim 6.10^{-2}$

No other interaction ~ 0.25; acceptance(trig) ~ 10^{-2}

$\Rightarrow$ few pb (1000's in 1 fb^{-1})

$\sigma(p\,p \to p \quad \chi_b \quad p) \sim 120$ pb (KMR)

$\times(BR \to \Upsilon\gamma)\times(BR \to \mu\mu\gamma) \Rightarrow \sim 500/fb^{-1}$



Measuring forward p → 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)

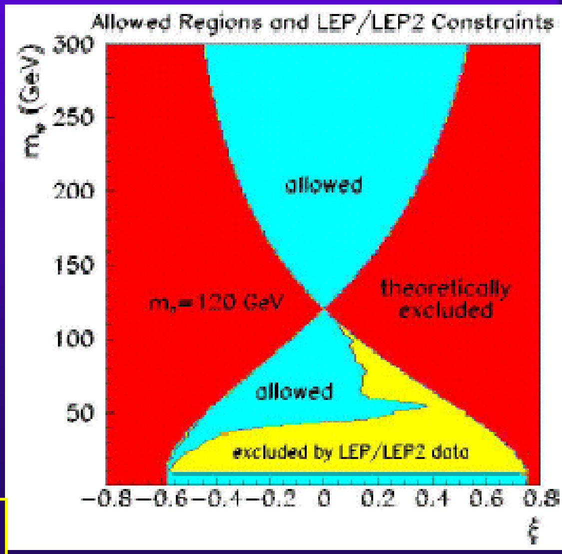
If MM resolution <~ 100 MeV, exclusive test, resolve states

Beyond the Standard Model

CP-odd Higgs : allowed 20 < M < 60 GeV
Don't couple to W,Z ... produced by gg → t-loop → h
But b-bbar b/g large too ... Mass resolution critical

Low $\beta \Rightarrow$ Medium β $\sigma_{MM} \approx 100$ 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 ~ keV, Decay → b bbar



Light Gluinos and Gluinoballs

Gluino $\tilde{g}$ could be lightest SUSY particle LSP
Does not decay in detector --- forms heavy hadrons. Can form $\tilde{g}\tilde{g}$ bound states "gluinoballs"

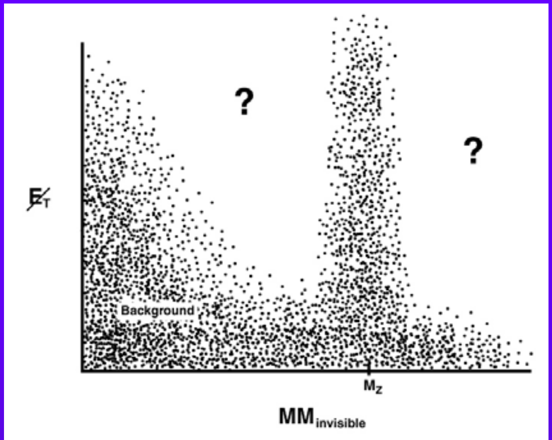
$\boxed{\sigma(p\bar{p} \to p + \tilde{G}(60\text{GeV}) + \bar{p}) \approx 20\text{fb (Tevatron)}}$

Missing Mass!

$$MM^2_{central} = (p_1 + p_2 - p_3 - p_4)^2 \quad (4 - \text{vectors})$$

$$MM^2_{invisible} = (p_1 + p_2 - p_3 - p_4 - \Sigma_{rest} p_i)^2$$

Peak at M_Z for $Z \to \nu\bar{\nu}$



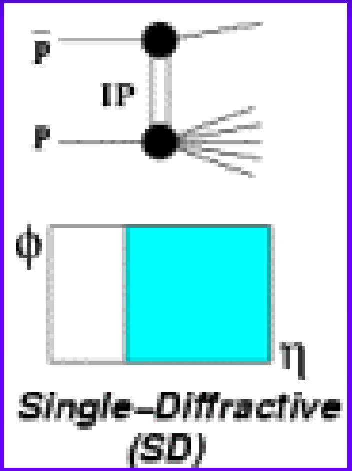
ET as 3rd axis?

Extreme case of rest of detector completely empty
No MM peaks "expected"
But threshold bump → pair production of e.g. LSPs
Needs measurement of all forward particles
Tracking + dipoles (?)
Background from double beam halo:
Timing (<~30 ps) on pots, Luminosity dependence

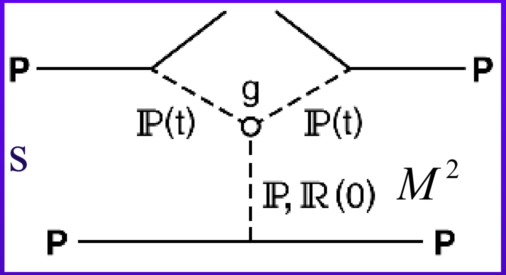
Single Diffractive Excitation

$$\sigma_{inv} = \frac{m_0^2}{16\pi^2}\frac{1}{s}\sum_{iij} G_{iij}(t)\left(\frac{s}{M^2}\right)^{2\alpha_i(t)}\left(\frac{M^2}{m_0^2}\right)^{\alpha_j(0)} + \ldots$$

s-dependence at various fixed t, $M^2 \Rightarrow \alpha_i(t)$



System X can be soft (all low pT)
or hard (jets, W, Z).
HERA-Tevatron difference – universal screening?
Pomeron trajectory probably different for
hard and soft systems. Similar seen at HERA in

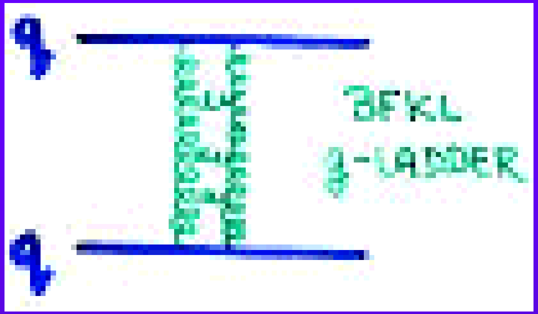


$\gamma^* p \to \rho \quad p$ (soft) and $\gamma^* p \to \psi/\Upsilon \quad p$ (hard)

Systematic study of trajectories, needs s-dependence
→run at sqrt{s} = 630, 900, 1300, 1960 GeV
(~ log spacing, modest runs at lower sqrt{s})

BFKL and Mueller-Navelet Jets

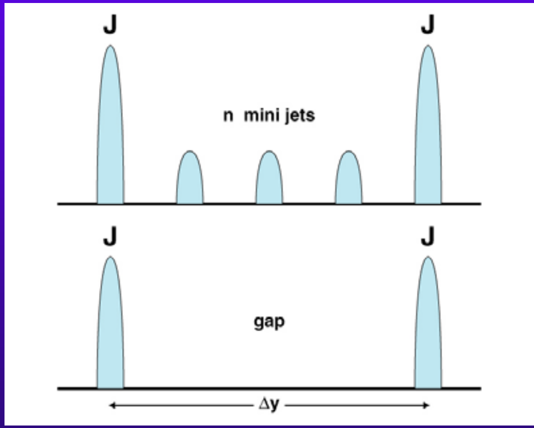
Color singlet (IP) exchange between quarks
Enhancement over 1g exchange – multiRegge gluon ladder
Jets with large y separation
n minijets in between (inelastic case)
large gap in between (elastic case)



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

$$\omega_{BFKL} = \frac{4N_c \ln 2}{\pi}\alpha_S \approx 0.5 \text{ for } \alpha_S = 0.19$$

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



Measure fn(η, p_T, $\sqrt{s}$, $\Delta\eta$)

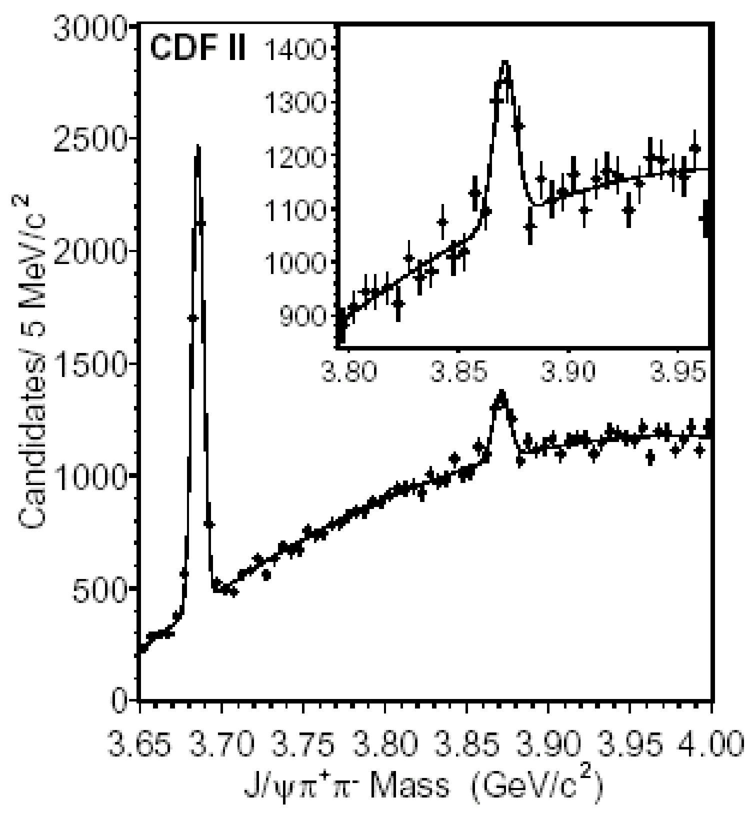
Fundamental empirical probe of new regime:
non-perturbative QCD at short distances.

Hadron Spectroscopy: an example

X(3872) discovered by Belle (2003)
Seen soon after by BaBar and CDF
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?

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

If we see in exclusive DPE:

$$I^G J^{PC} \text{ (DPE)} \quad \begin{array}{l} 0^+0^{++} \Rightarrow \text{favored} \\ 0^+0^{-+}, 0^+1^{-+}, 0^+1^{++} \Rightarrow \text{not at } 0^\circ \\ 0^+2^{++} \Rightarrow \text{not } q\bar{q} \end{array}$$

Also, cross-section depends on "size/structure" of state.

Bjorken: Low pT is the frontier of QCD

As pT drops from **200 → 100 → 50 MeV** what happens?
Larger distances: 1 f → 4 fm
How do gluon fields in protons "cut off" ?

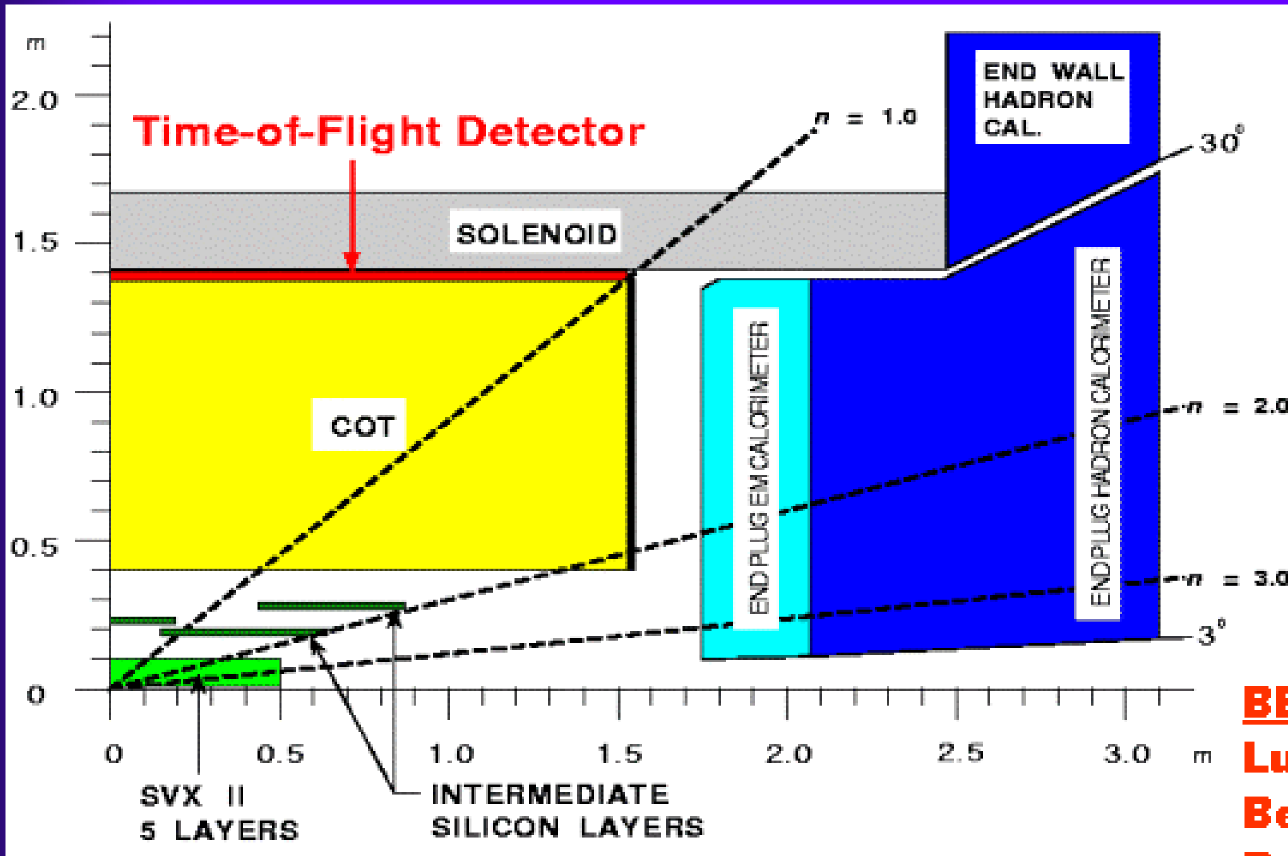
Multiplicity distributions of very low pT particles, correlations, ...
Low-pT cloud in special events

[Runs with reduced field, Si-only tracking, etc
..................absorption and multiple scattering is limit]

Large impact parameter, b, collisions

RHIC AA can measure b, how can we? Diffraction at small t

Detectors

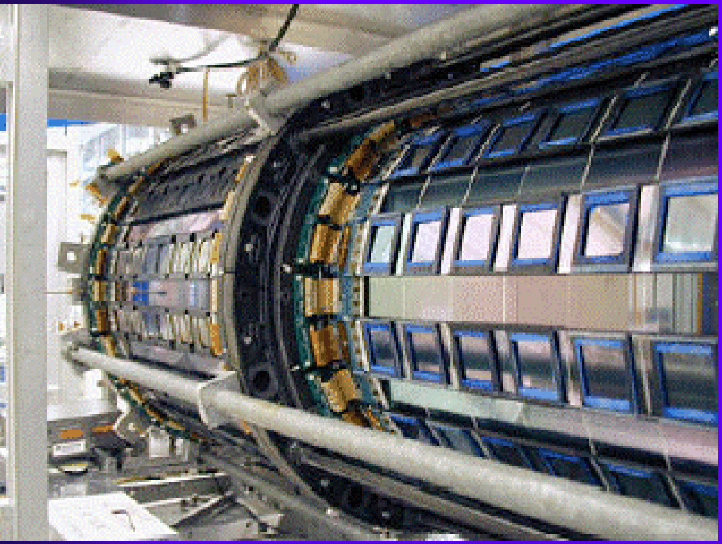


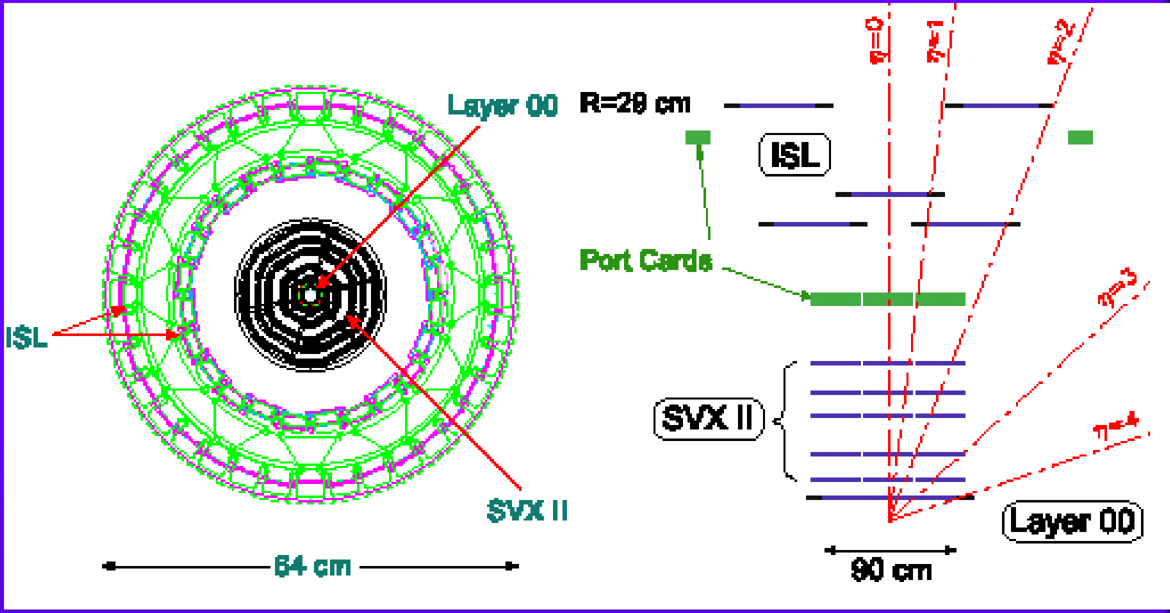
D0 an option.
I focus on CDF
(tracking, hadron ID
dE/dx, TOF)

BEYOND 3 deg :
Luminosity Counters
Beam Shower Counters
Roman Pots
MiniPlugs

Add:
New pots very forward E&W: through quadrupoles + near (55m) + far (~160m?)
Other forward detectors (tracking, upgrade calorimetry e.g.) → **"Cone Spectrometers"**
New DAQ and trigger system → kHz
Silicon (certainly want it) ... hope it's still good (COT also)

CDF Silicon VerteX Detector SVX



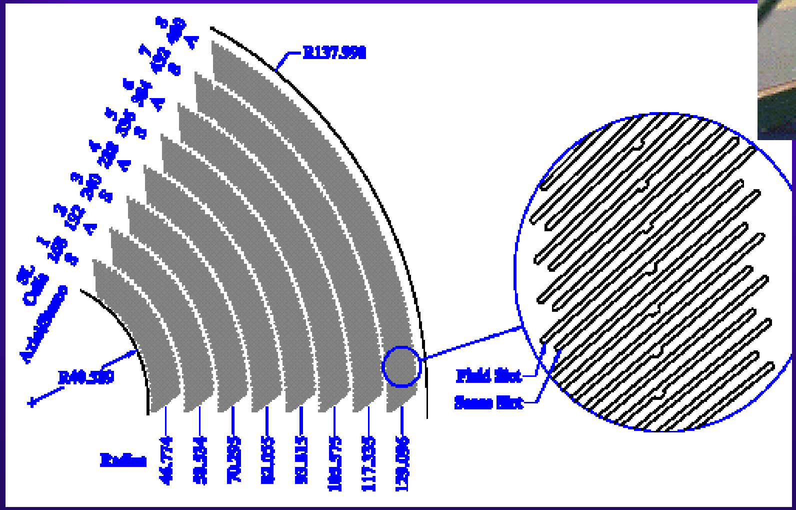


For beauty, charm, tau identification and measurement.
~ 720,000 strips, 25um with 50um readout
L00 : ~ 1.5 cm from x, R-phi view
SVXII: 3 double 90 deg layers + 2 double 1.2 deg layers
ISL : 1 or 2 double 1.2 deg layers.
Impact parameter resolution ~ 30 um @ 1 GeV/c

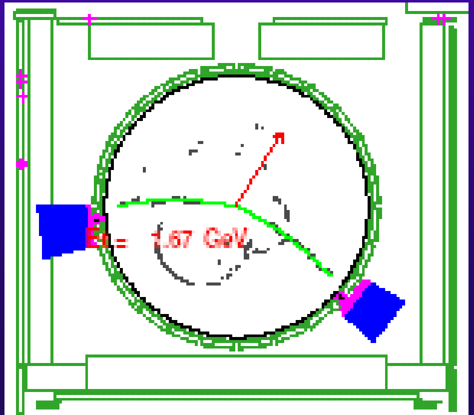
CDF Central Outer Tracker (COT)

Drift chamber
3.1m in z, 0.34-1.32m in R
96 layers → 30,240 s.wires
40 um gold-plated tungsten
ADC & TDC each end
6 um Au-mylar field sheets

Resolution ~ 150 um/wire

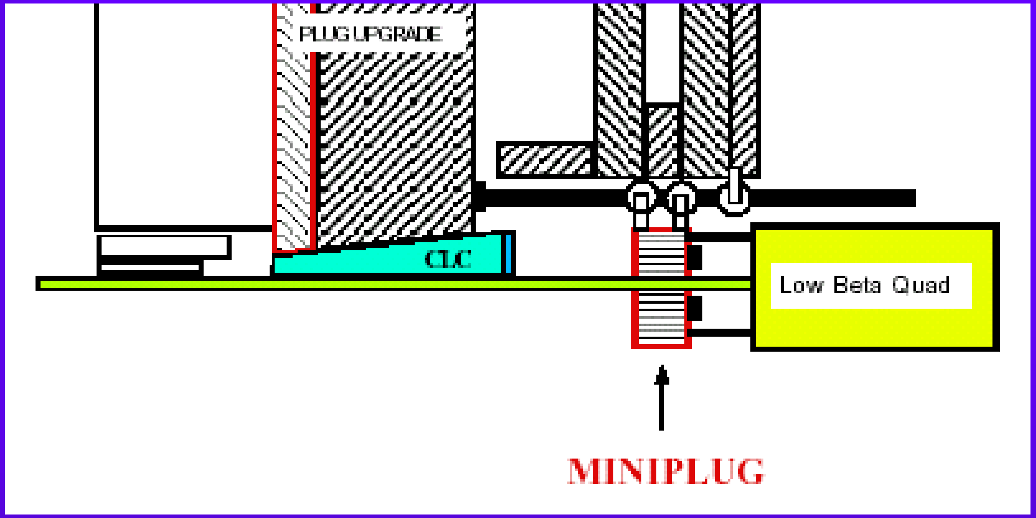


J/ψ γ
(*probably* χ_c)



New Forward Region (0.5-3.0 deg): Cone Spectrometer?

Now: 48 CLC counters + MiniPlugs



Can (remove Q1 and) push back ~ 2 m low-beta quads

Tracking e.g. GEM layers (50 um, 15 ns) over large area

Deeper Calorimeter (~8 int. lengths) high granularity, em/had

Possibility of forward dipoles (?) or toroid fields on calo iron

Upgrade motivation: Low-x with v.forward jets, J/psi

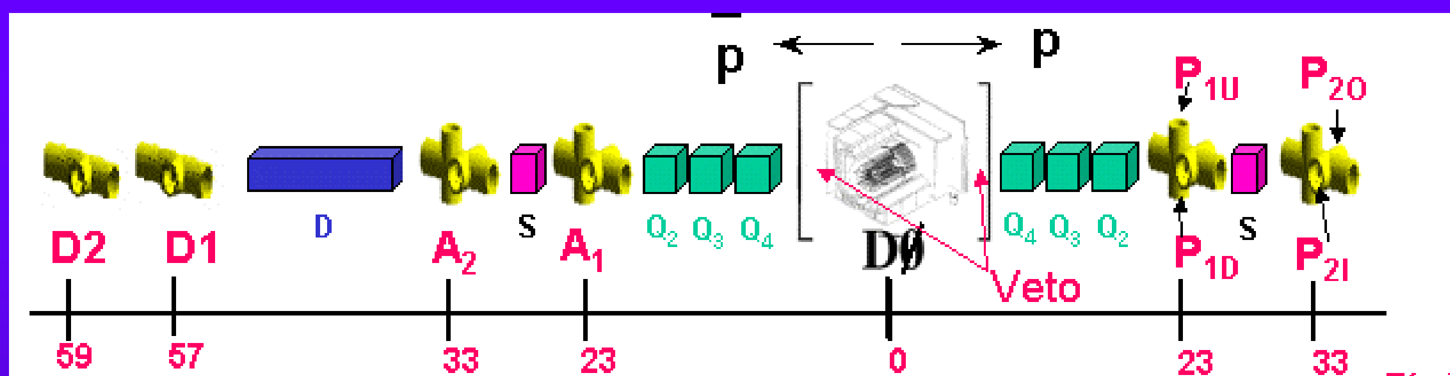
(BFKL) J - minijets - J, J – gap – J and J + X + J ... etc

"Cone Spectrometers"

Jets, μ, e, J/ψ, γ ?

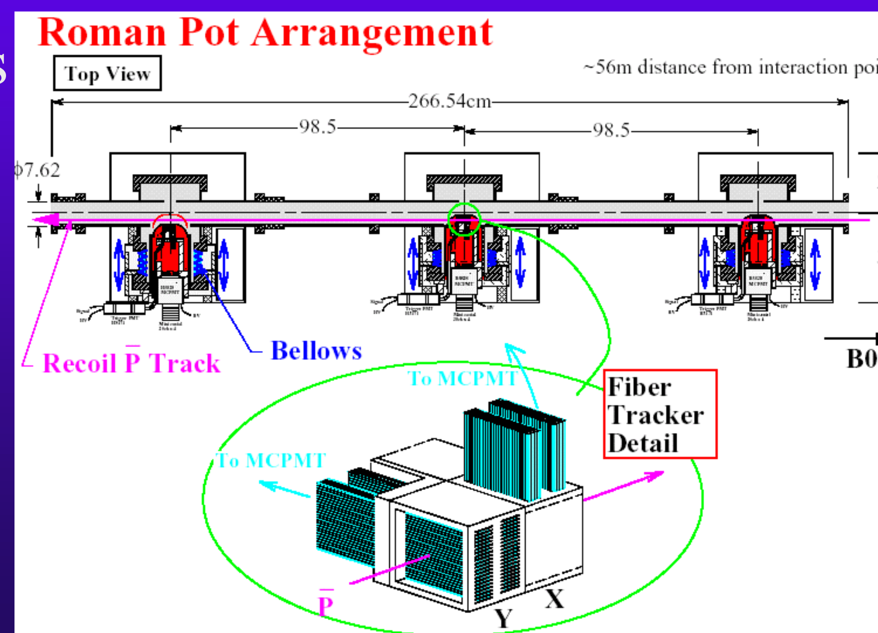
Very Forward: Roman Pots

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

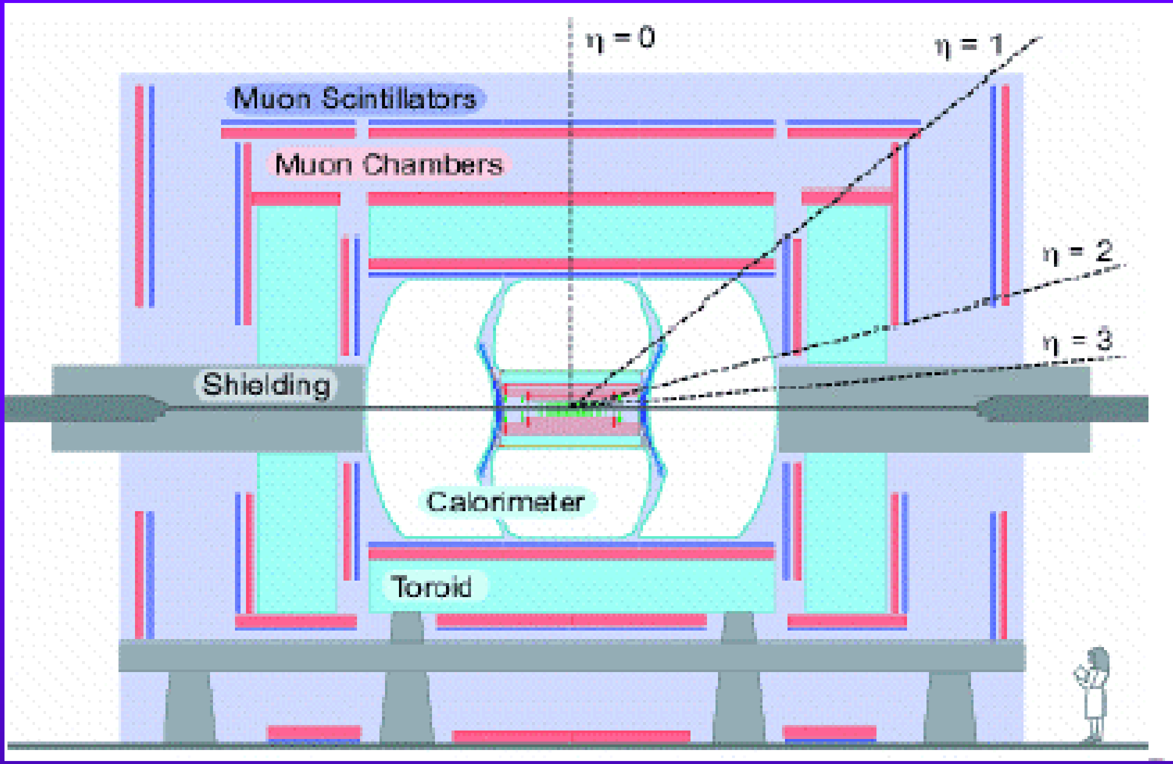


CDF has 3 dipole spectrometer pots
0.8 mm x-y fibers

GTeV: Quads + near + far dipoles
Silicon ustrips, pixels, trig scint
Quartz Cerenkov for ~ 30 ps TOF



Re-using D0 detector?



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

Forward ("cone") region probably not instrumentable

Tevatron Issues

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.

GTeV plan

Forming Working Groups, conveners.
Workshop at Fermilab May 20-22 :

The Future of QCD at the Tevatron

CDF & D0 now → 2009
HERA, BNL, JLab, etc
BTeV, LHC beyond 2007
What is unique for GTeV beyond 2009?

Please come!

Proposal to PAC Spring 2005 (?)

Working Groups	Topics
Physics	Low Mass Double Pomeron
	High Mass DPE & Higgs
	Jet-Gap-Jet Studies+BFKL
	Small-x g and g-jets
	Hadron spectroscopy
	Single Diffractive Excitation
	Exotics
	Cosmic Ray issues
	Event Generators
Detectors	Simulations with Detectors
	Cone Spectrometers
	Roman pots ("v.forward")
	Central detector
(DAQ & Trigger)	Triggers L1 L2 L3
	kHz DAQ
	Computing on/off line, GRID
Tevatron	High Field Dipoles
	Orbit issues, beta, ES seps
	Roman Pot insertions
	BTeV-GTeV interaction

Concluding Remarks

There will be a vast amount of QCD physics still
to be done in 2009. Here I have only scratched the surface.
Unknown territory: discoveries likely.

The CDF and D0 detectors are great central detectors for this
program, suitably upgraded at modest cost:
DAQ, trigger, forward (few deg) and very forward (pots)
Not all ~1500 physicists on CDF and D0 want to go to LHC
We hope physicists come from DESY, BNL, JLab etc expts.

Tevatron running anyway for BTeV, so it's great value.

Let's do it!