Exclusive Production

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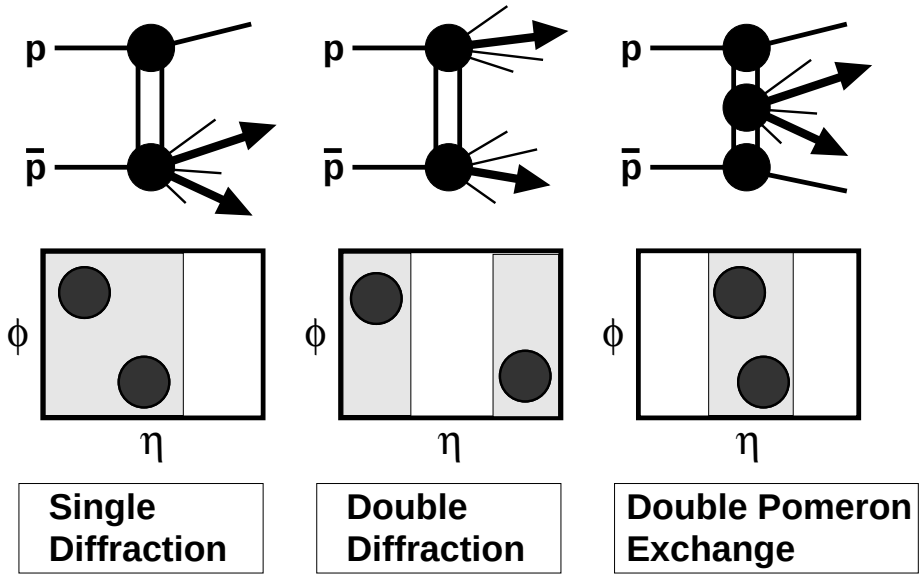
for the CDF Collaboration

Workshop :
Future of QCD at the Tevatron
May 20-22, 2004

- Introduction
- Results
- Run II Prospects

Run II Diffractive Program



Single Diffraction

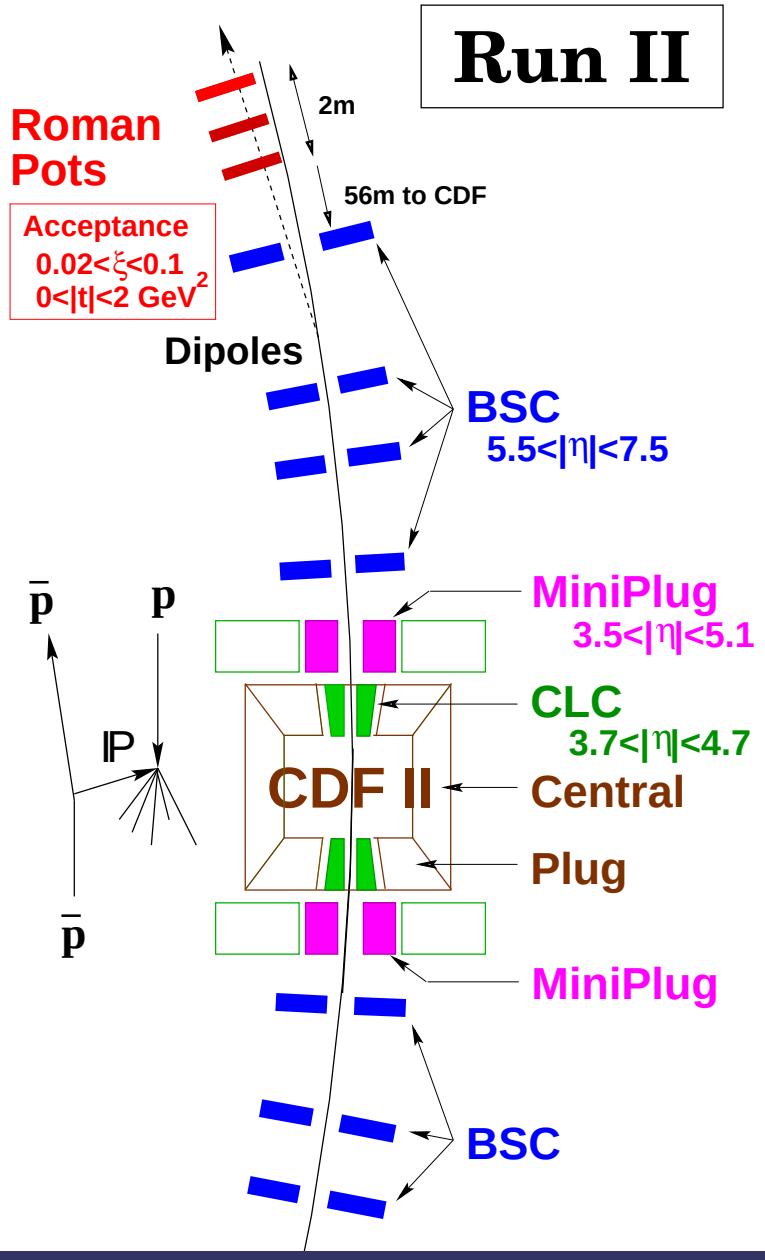
- Q^2 and ξ dependence of F_{jj}^{D}
- process dependence of F^{D}

Double Diffraction

- jet-gap-jet at large $\Delta\eta$ (with MiniPlugs)

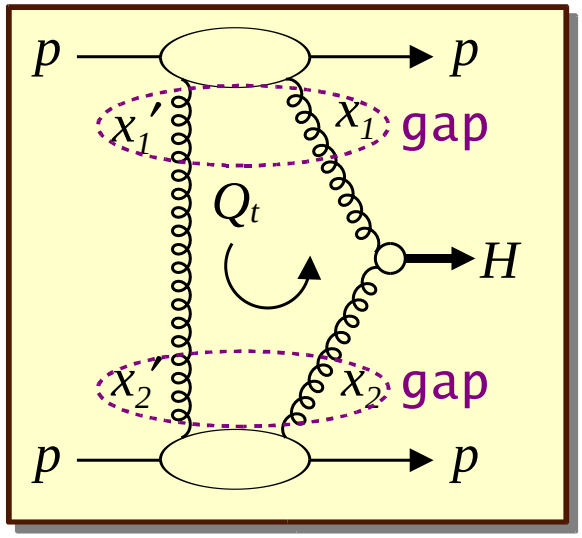
Double Pomeron Exchange

- F_{jj}^{D} vs gap width on the other side
- exclusive dijet/$b\bar{b}$ production
- low mass exclusive states



Exclusive Higgs Production in DPE(?)

Exclusive



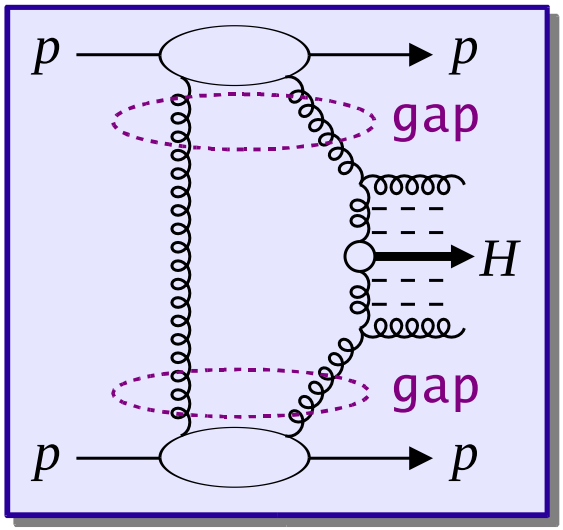
$gg^{PP} \rightarrow H$

Bialas, Landshoff
Phys. Lett. B256, 540 (1991)

Khoze, Martin, Ryskin
Eur. Phys. J. C23, 311 (2002)

Boonekamp, Peschanski, Royon
Nucl. Phys. B669, 277 (2003)

Inclusive



$gg^{PP} \rightarrow H + X$

Standard Model light Higgs (M_H~120 GeV) :

- $gg \rightarrow H$ via t-quark loop + soft g exchange → color neutral
- $p + p \rightarrow p + H(\rightarrow b\bar{b}) + p$: "exclusive" channel → clean signal
- $M_H = M_{miss} = (s \cdot \xi_p \cdot \xi_{\bar{p}})^{1/2}$

Khoze, Martin, Ryskin : σ_H^{excl} ~ 3 fb, S/B ~ 3 @ LHC (if $\Delta M_{miss} \approx 1$ GeV)

→ Attractive Higgs discovery channel at LHC !

Calibrating Diffractive Higgs Predictions using Exclusive Dijet/χ_c^0/$\gamma\gamma$ Production

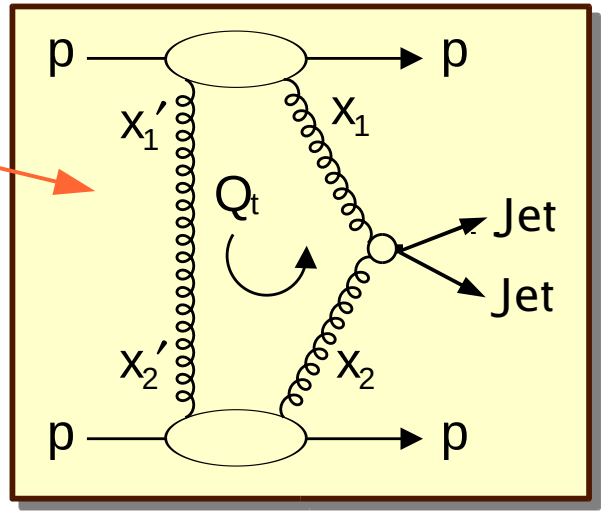
Exclusive Dijets : $gg^{PP} \rightarrow gg$

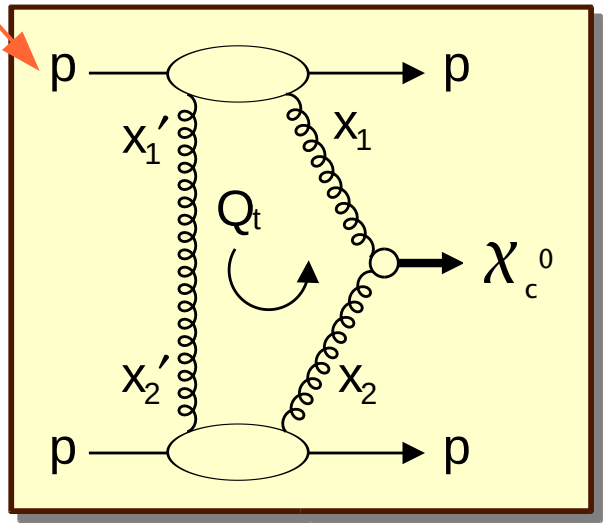
- large cross section
- exclusive $gg^{PP} \rightarrow q\bar{q}$ suppressed

Exclusive χ_c^0 : $gg^{PP} \rightarrow \chi_c^0$ (c-loop)

Exclusive $\gamma\gamma$: $gg^{PP} \rightarrow \gamma\gamma$ (u-loop)

- small cross section but clean signal

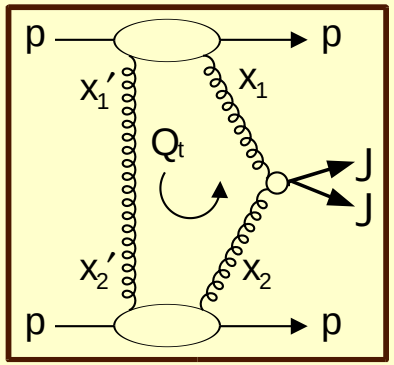




- Establish exclusive processes experimentally (if exists)
- Calibrate Higgs sensitivity at Tevatron/LHC using cross sections or limits for exclusive processes

Predictions for Exclusive Dijets in DPE

Exclusive

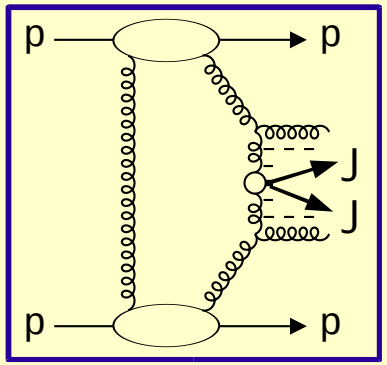


$gg^{PP} \rightarrow gg$

Khoze, Martin, Ryskin

Eur. Phys. J. C23, 311 (2002), C25, 391 (2002), C26, 229 (2002)

Inclusive



$gg^{PP} \rightarrow gg + X$

Run I : PRL 85, 4215 (2000)

Dijet Mass Fraction:

$$R_{jj} = \frac{M_{jj}^{cone}}{M_X}$$

Exclusive Dijet : $gg^{PP} \rightarrow gg$

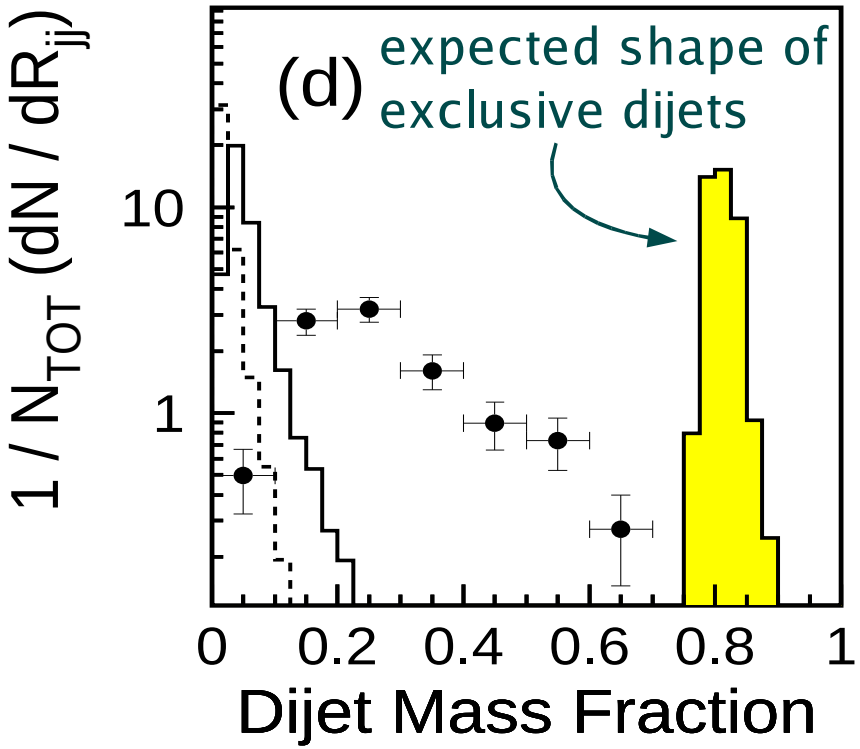
Run I : ~130 inclusive DPE dijets

→ σ_{excl} < 3.7 nb (95% C.L.)

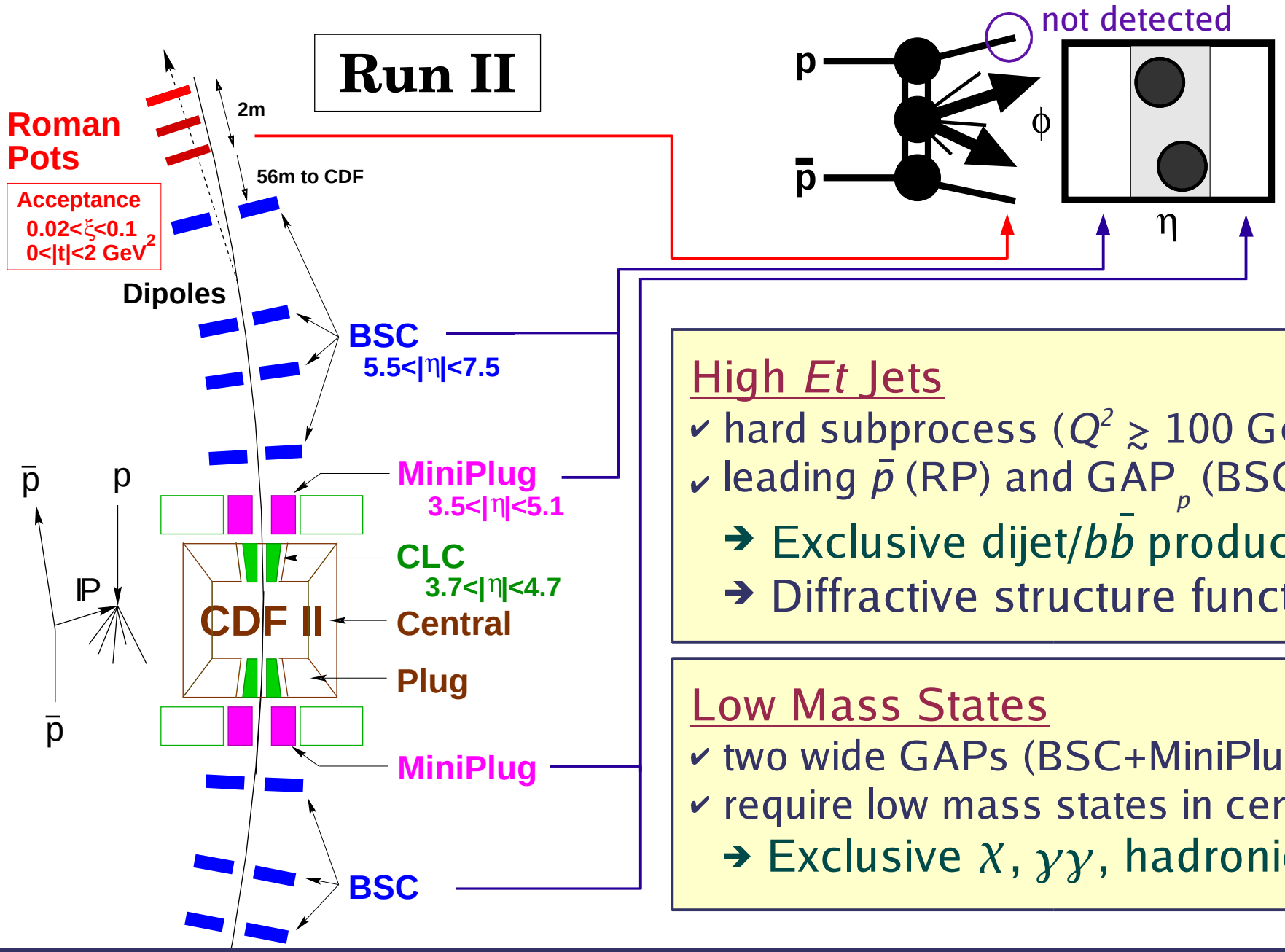
KMR Prediction :

~1 nb (factor 2 uncertainty)

@ Run I Kinematic Region



Run II DPE Physics



High *Et* Jets

- ✔ hard subprocess ($Q^2 \gtrsim 100$ GeV^2)
- ✔ leading $\bar{p}$ (RP) and GAP$_p$ (BSC, MP)
  - ➔ Exclusive dijet/$b\bar{b}$ production
  - ➔ Diffractive structure function

Low Mass States

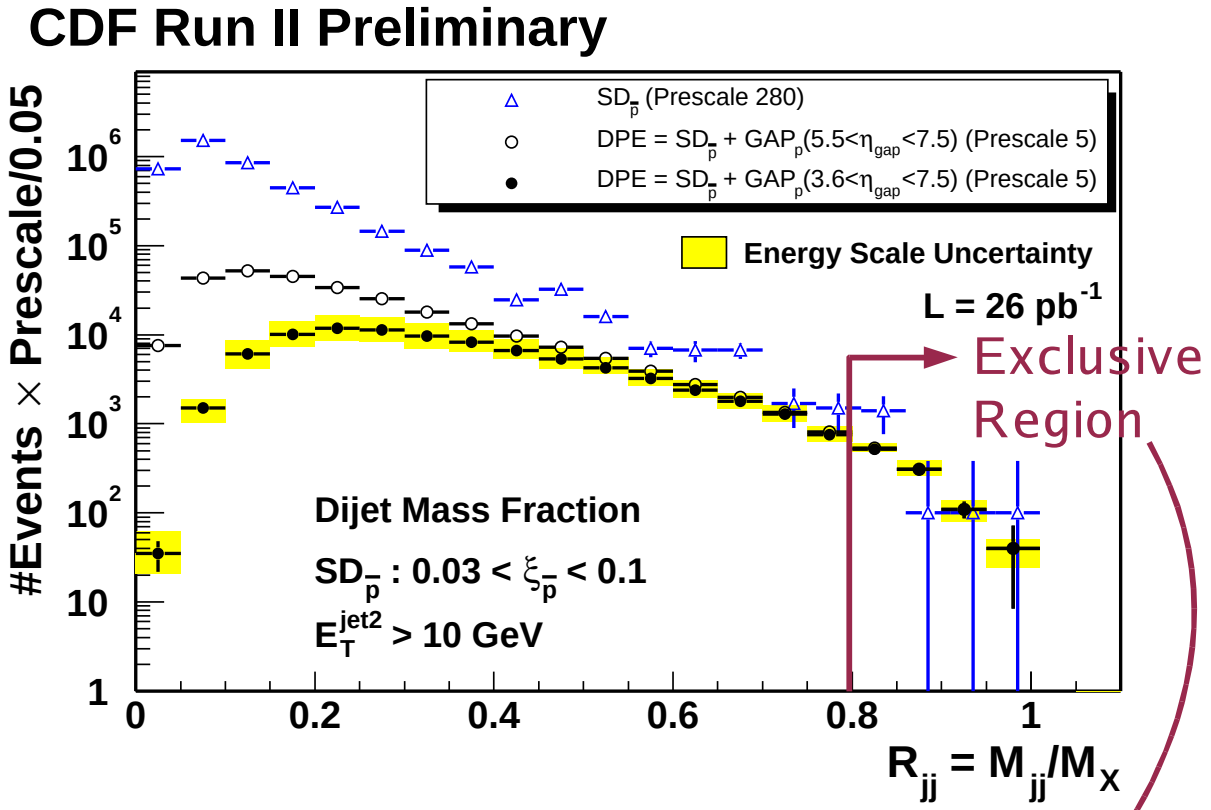
- ✔ two wide GAPs (BSC+MiniPlug)
- ✔ require low mass states in central
  - ➔ Exclusive χ, $\gamma\gamma$, hadronic state

Exclusive Dijet Cross Section Limit

Dedicated DPE Trigger :
RP + J5 + GAP_p^{BSC}

26 pb^{-1} data (Sep-Dec 2002)

- R_{jj} falls smoothly as $R_{jj} \rightarrow 1$
- No significant excess at high R_{jj}



$|\eta^{jet1,2}|<2.5$, $0.03<\xi_{\bar{p}}<0.1$, $3.6<\eta_{gap}<7.5$, $R_{cone}=0.7$

$\sigma_{DPE}(R_{jj}>0.8) = 970 \pm 65(stat) \pm 272(syst)$ pb $(E_T^{jet1} > 10$ GeV$)$

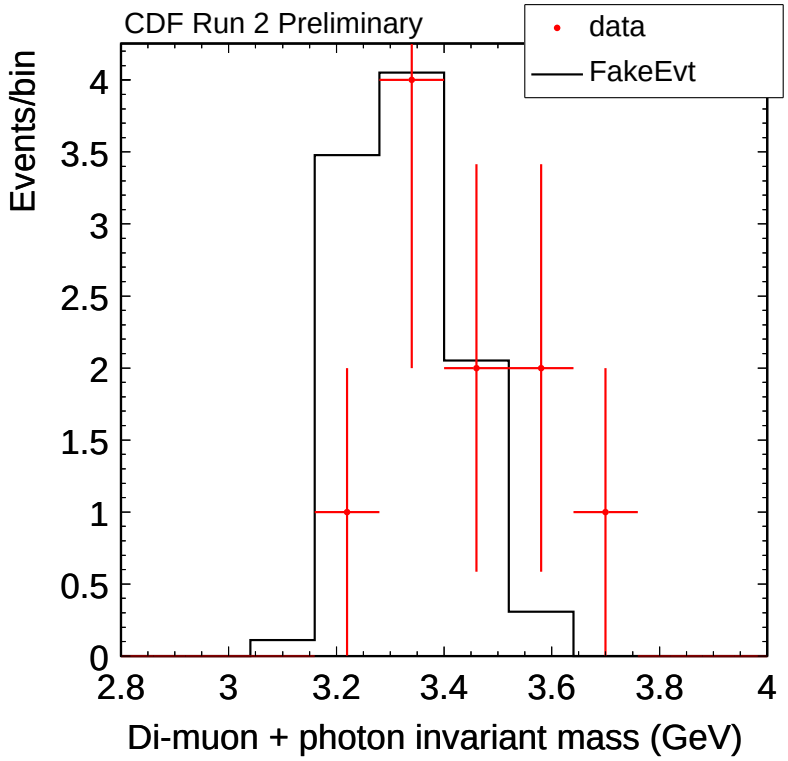
$34 \pm 5(stat) \pm 10(syst)$ pb $(E_T^{jet1} > 25$ GeV$)$

KMR prediction → 60 pb (factor 2 uncertainty)
Eur. Phys. J. C23, 311 (2002)
@ $25<E_T^{jet}<35$ GeV, $|\eta^{jet1}-\eta^{jet2}|<2$

Exclusive χ_c^0 Cross Section Limit

$$\bar{p} + p \rightarrow \bar{p} + \chi_c^0 (\rightarrow J/\Psi + \gamma) + p$$

- Di-muon trigger (muons with p_T>1.5 GeV, $|\eta|$<0.6)
- Reject cosmic rays with time of flight information
- Select J/Ψ mass window
- Require large gaps on both p and $\bar{p}$ sides



10 events:

Exclusive $\chi_c^0(\rightarrow J/\Psi+\gamma)$ candidates

Assume 10 events are all $J/\Psi+\gamma$

$|y^{J/\Psi}|$<0.6, $p_T^{J/\Psi}$>2 GeV

$\sigma(\bar{p}p \rightarrow \bar{p}+J/\Psi+\gamma+p)$ = 49 ± 18(stat) ± 39(syst) pb

KMR Prediction → $\sigma(\bar{p}p \rightarrow \bar{p}+\chi_c^0(\rightarrow J/\Psi+\gamma)+p)$

Eur. Phys. J. C19, 477 (2001)

≈ 70 pb at $|y^{J/\Psi}|$<0.6 (factor 2-5 uncertainty)

Extracting Exclusive Dijets in DPE

Bialas, Landshoff
Berera, Collins
Khoze, Martin, Ryskin

Theory

Color-singlet $q\bar{q}$ production cross section :

$\sigma^{excl}(gg^{PP} \to q\bar{q}) \propto \rho(1-\rho)$ where $\rho = 4m_q^2/M_{JJ}^2$

$\to 0$ as $m_q \to 0$

➔ Consequence of "$J_Z = 0$" selection rule for gluon polarization

Exclusive dijets : $gg^{PP} \to gg$ only at $M_{JJ} \gg m_q$

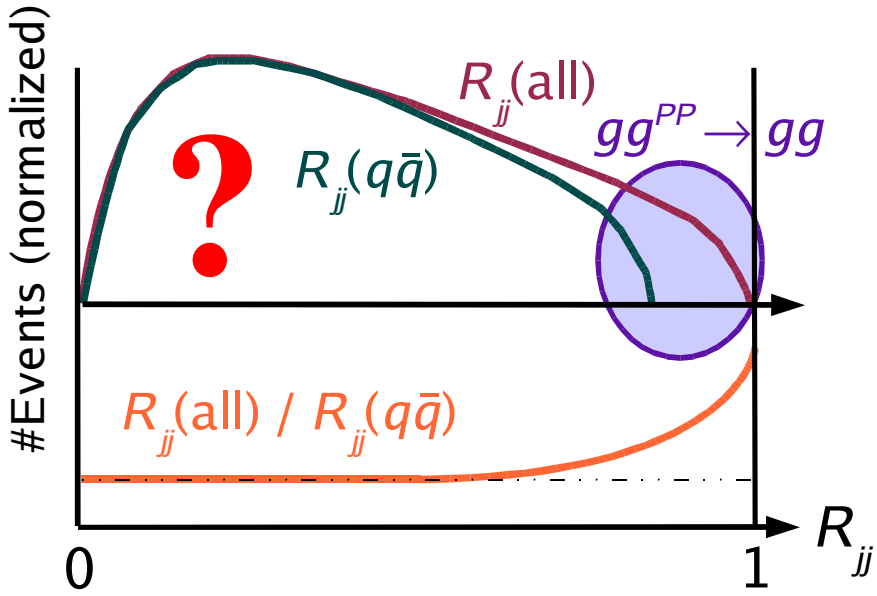
⇩

Use exclusive $q\bar{q}$ suppression

Exclusive $gg^{PP} \to gg$ contribution might manifest itself as an excess over inclusive $q\bar{q}$ at high $R_{jj} \sim 1$

Exclusive Dijets/$b\bar{b}$ in DPE : Prospects - I

Experiment



Direct search for $q\bar{q}$ suppression :

Heavy Flavor Quark Jets

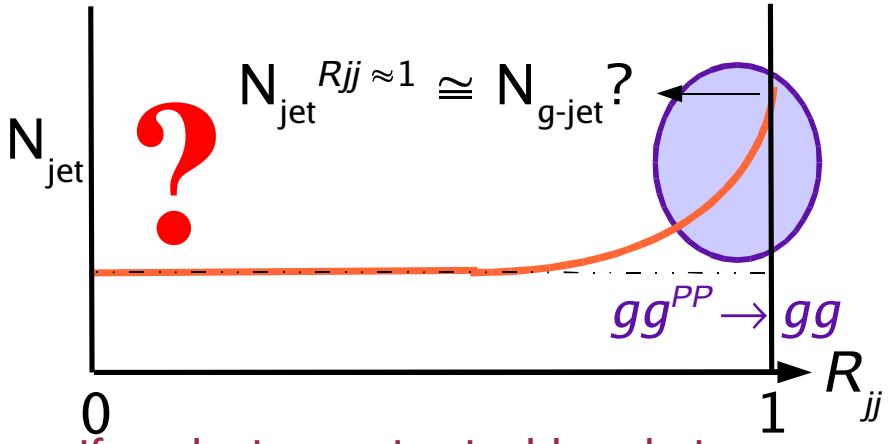
- look for excess in R_{jj}(all)/$R_{jj}(Q\bar{Q})$ as $R_{jj} \rightarrow 1$

☺ many exp. systematics canceled out

☺ HF quarks identified well : g mistag @ O(1%)

☹ heavy quark mass

→ contribution from exclusive b/c process



if exclusive gg is sizable relative to "inclusive tail" background at high R_{jj}

Indirect search for $q\bar{q}$ suppression :

Difference of Quark and Gluon Jets

charged particle multiplicity in jet : N_{jet}

$N_{g\text{-jet}} \cong 1.6\ N_{q\text{-jet}}$ (CDF Run I)

- look into how N_{jet} behaves as $R_{jj} \rightarrow 1$

☺ light quark mass → exclusive uds suppressed

☹ light q/g jets not well separated

Exclusive Dijets/$b\bar{b}$ in DPE : Prospects - II

SMALL # of DPE HF-jets from *prescaled* RP+J5+GAP$_p^{BSC}$ data

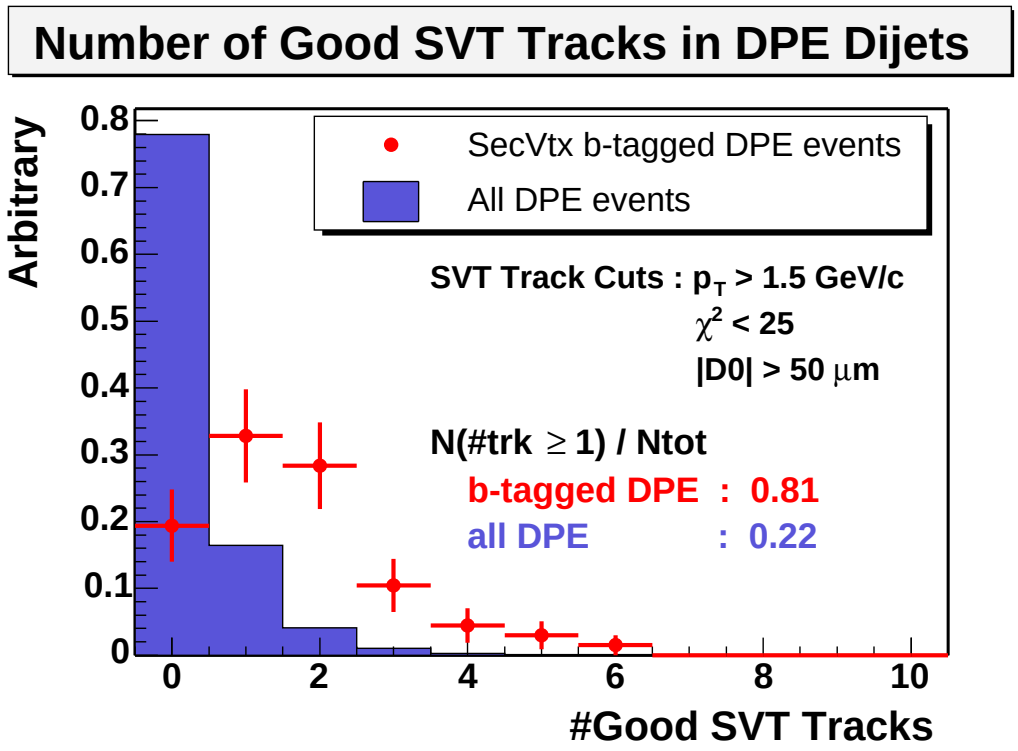
➔ Need unprescaled (high efficient) *b*-jet trigger!

DPE *b*-jet trigger (under study)

- ✔ L1 : RP + J5 + GAP$_p^{BSC}$
- ✔ L2 : ≥1 Silicon Vertex Trigger (SVT) track with |d0| >50 μm
- ✔ L3 : none

➔ ~20% of RP+J5+GAP$_p^{BSC}$ rate

➔ high efficiency (~80%) for $b\bar{b}$ at L2 looks achievable



Will be proposed to CDF as a new trigger soon

Exclusive Dijets/$b\bar{b}$ in DPE : Prospects - III

From studies of DPE HF-jets from RP+J5+GAP$_p^{BSC}$ data

Assume 80% efficiency for $b\bar{b}$ jets at L2

Instantaneous Lum (E31)	1.0-1.5	3.0-3.5	6.0-6.5
Integrated Lum (pb^{-1})	300	300	300
Expected #HF dijets :			
➢ single *b*-tag	~ 1200	~ 900	~ 300
➢ exclusive region R_{jj}>0.8*	~ 50	~ 25	~10
➢ double *b*-tag	~ 70	~ 50	~ 20
➢ exclusive region R_{jj}>0.8*	~ 3	~ 1.5	~ 0.6

* if HF-jet is not suppressed at R_{jj}>0.8

- Good amount of DPE HF-jet sample expected in 1-2 years
  → studies of background/efficiency, HF contents (beauty, charm)
- Double *b*-tag events help enhance $b\bar{b}$ due to flavor creation

Exclusive χ_c^0 in DPE : Prospects

New DPE-χ_c^0 trigger will start taking data soon!!

DPE-$\chi_c^0 \rightarrow J/\Psi(\rightarrow\mu\mu)$ + γ trigger

- ✔ L1 : ≥1 Central Muon p_T>1.5 GeV + GAP_p^{BSC} + $GAP_{\bar{p}}^{BSC}$
- ✔ L2 : none
- ✔ L3 : 1 Muon + 1 Track with J/Ψ mass cut

More statistics will help better understanding of background/multiplicity

- Event yield of the DPE-χ_c^0 trigger suffers from small branching fractions of $\chi_c^0 \rightarrow J/\Psi+\gamma$ (0.7%) and $J/\Psi \rightarrow \mu\mu$ (6%)
- Investigating trigger for $\chi_c^0 \rightarrow h^+h^-$ with much larger branching fraction

Exclusive $\gamma\gamma$ in DPE : Prospects

New DPE-$\gamma\gamma$ trigger will start taking data soon!!

DPE-$\gamma\gamma$ trigger

- ✔ L1 : ≥2 EM tower E_T>4 GeV + GAP_p^{BSC} + $GAP_{\bar{p}}^{BSC}$
- ✔ L2 : none
- ✔ L3 : diphoton E_T>4 GeV

Study inclusive/exclusive diphoton in DPE

lower statistics but fewer uncertainties

- Exclusive : $gg \rightarrow$ (u-loop) $\rightarrow \gamma\gamma$ process is dominant
  similar to exclusive Higgs: $gg \rightarrow$ (t-loop) $\rightarrow$ H
- Maybe possible to measure $R_{\gamma\gamma}/R_{jj}$ to look for exclusive $\gamma\gamma$ peak at high $R_{\gamma\gamma}$

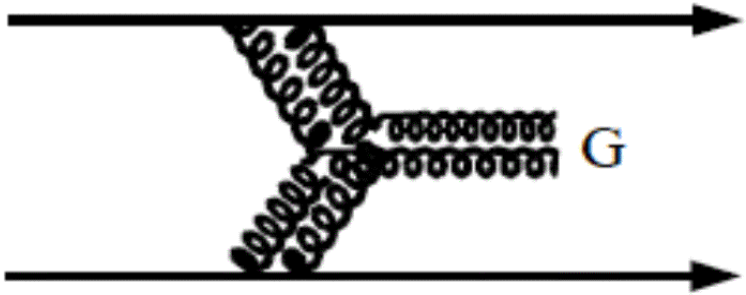
Exclusive Low Mass States in DPE

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

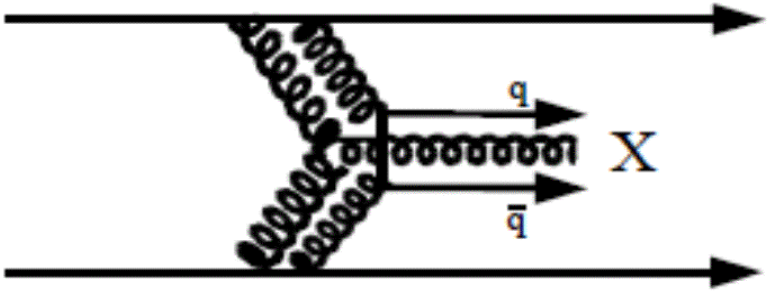
Rapidity Gaps

Central system with

- low mass (< 4 GeV)
- low multiplicity (2-6 charged particles)



GlueBall States



Hybrid States

Look for Hyperons, Glueballs, Hybrids and other interesting states

Status: trigger under study

Exclusive Final States : Run II Prospects

Goal :

- Investigate existence/properties of exclusive final states : dijets, $\chi_{c(b?)}{}^{0}$, $\gamma\gamma$ and other exotic states
- Derive the cross sections or limits of exclusive processes

Exclusive Dijets :

- ✔ R_{jj}(all) / R_{jj}(*b*-quark) for R_{jj} > 0.75 → extract exclusive dijets
- ✔ quark/gluon composition vs R_{jj} → complementary analysis
- ✔ DPE *b*-jet trigger under development

Exclusive Low Mass States :

- ✔ $\chi_c{}^0$: DPE-J/Ψ trigger in DAQ soon, $\chi_c{}^0 \rightarrow h^+h^-$ trigger under study
- ✔ $\gamma\gamma$: DPE-$\gamma\gamma$ trigger in DAQ soon
- ✔ Hadronic states : trigger under study

Towards Run II Goal

Integrated Luminosity Needs :

- Exclusive Dijets/$b\bar{b}$ → Limits on exclusive process
- Diffractive W and J/Ψ → process dependence
- Diffractive QCD Evolution → Q^2 dependence

Trigger Needs :

- Exclusive DPE-$b\bar{b}$, $\chi_c{}^0$, $\gamma\gamma$ and Hadronic states
- Jet-Gap-Jet with jets in MiniPlugs (test BFKL)

High inst. luminosity spoils diffractive signal due to pileup

Special Running Conditions?

Low Luminosity Run (~1E30)

- RP-ξ vs Calorimeter-ξ calibration
- background subtraction shape in SD
- low-ξ gap data shape
- jet-gap-jet with jets in MiniPlugs

Summary

Studies of Run II diffractive physics in good progress

CDF is actively pursuing exclusive production physics

Run II Preliminary Results:

- Improved upper limit on exclusive dijet production
- Obtained upper limit on exclusive χ_c^0 production

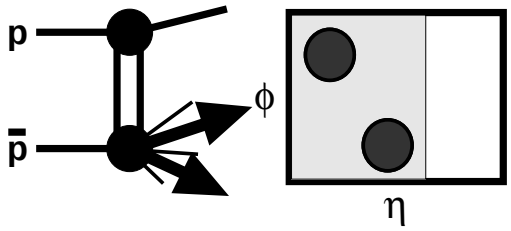
Towards Run II Goals:

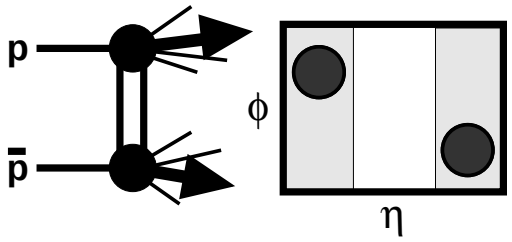
number of new DPE triggers will allow us to study exclusive physics in detail

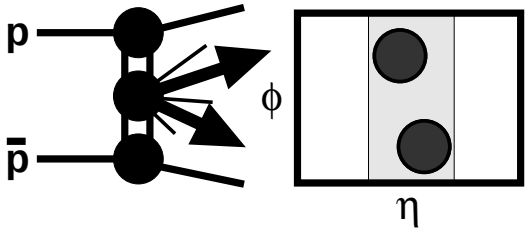
- b-jet
- χ_c^0 ⇨ Exclusive Higgs?
- $\gamma\gamma$
- hadronic states ⇨ Hadron Spectroscopy

Backup

Diffractive Measurements in Run I







Soft Diffraction

Single Diffraction	Double Diffraction	Double Pomeron Exchange
PRD 50, 5535 (1994)	87, 141802 (2001)	PRL submitted

Hard Diffraction

Rapidity Gap Tag

- *W* 78, 2698 (1997)
- Dijets 79, 2636 (1997)
- *b*-quark 84, 232 (2000)
- J/Ψ 87, 241802 (2001)

- Jet-Gap-Jet :
  - 1.8TeV 74, 855 (1995)
  - 1.8TeV 80, 1156 (1998)
  - 630GeV 81, 5278 (1998)

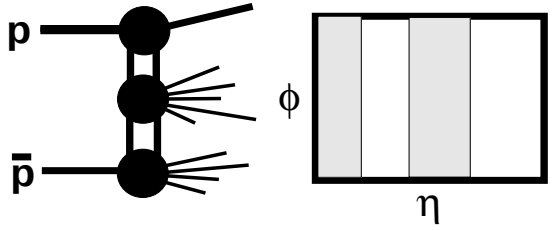
Roman Pot Tag

- Dijets :
  - 1.8TeV 84, 5043 (2000)
  - 630GeV 88, 151802 (2002)

- Dijets 1.8TeV
  85, 4217 (2000)

Multi-Gap Diffraction

91, 011802 (2003)



* PRL references

Data Selection : DPE Dijet Analysis

Cuts	DPE PS5/26 pb^{-1}	SD PS*[1]280/26 pb^{-1}	ND PS6K/6 pb^{-1}
Triggered Events	397K	356K	278K
Single Vertex	365K	205K	196K
$\lvert Z_{vertex} \rvert < 60$ cm	347K	195K	186K
# Jets (R=0.7) ≥ 2	204K	158K	160K
|detector $\eta^{jet1,2}$| < 2.5	163K	122K	123K
$E_T^{jet1,2} > 10$ GeV*[2]	116,473	93,567	85,038
$0.01 < \xi_{\bar{p}}^{X} < 0.1$	54,552	14,956	N/A
$GAP_{\bar{p}}$ (MiniPlug)	17,101	N/A	N/A

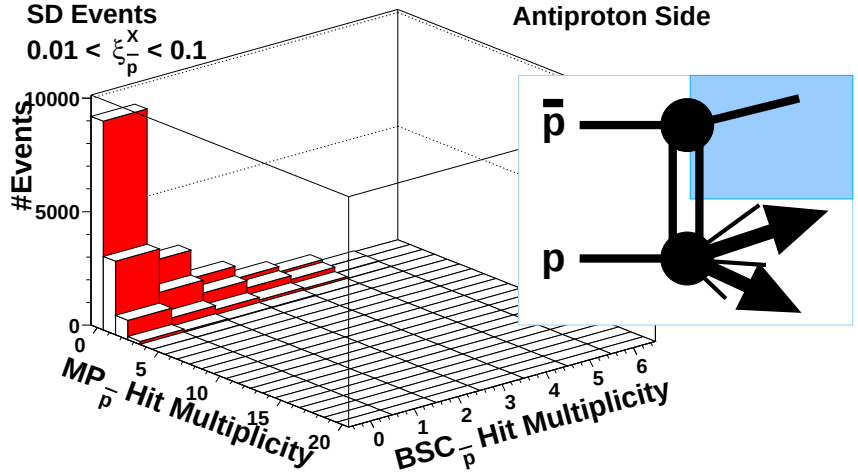
*[1] Effective prescale factors in total sample

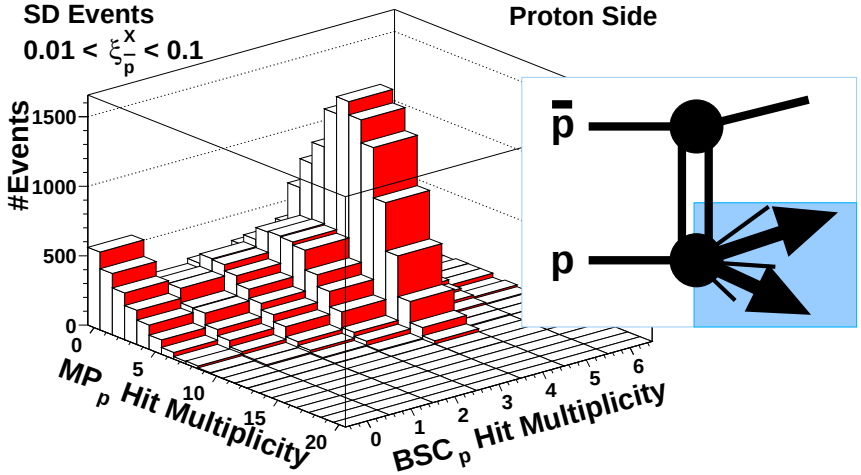
*[2] Jet energy corrected to the parton level, Run I UE energy subtracted

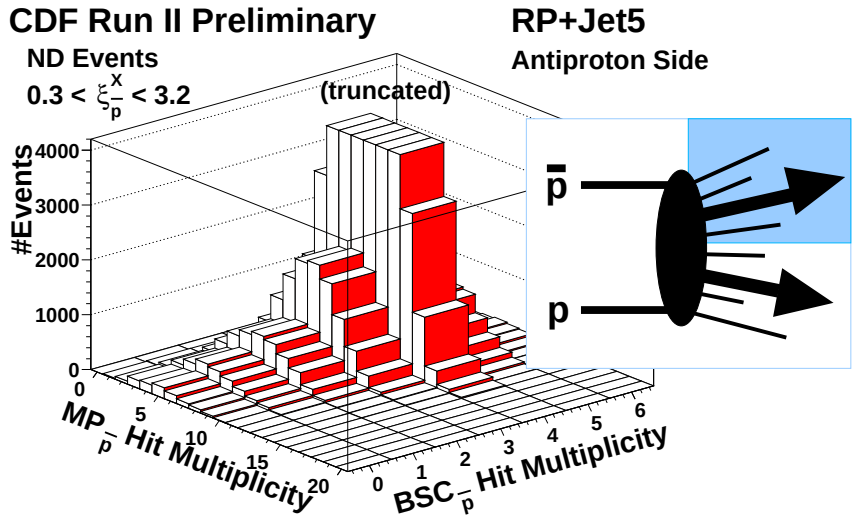
DPE Signal in SD Trigger Data

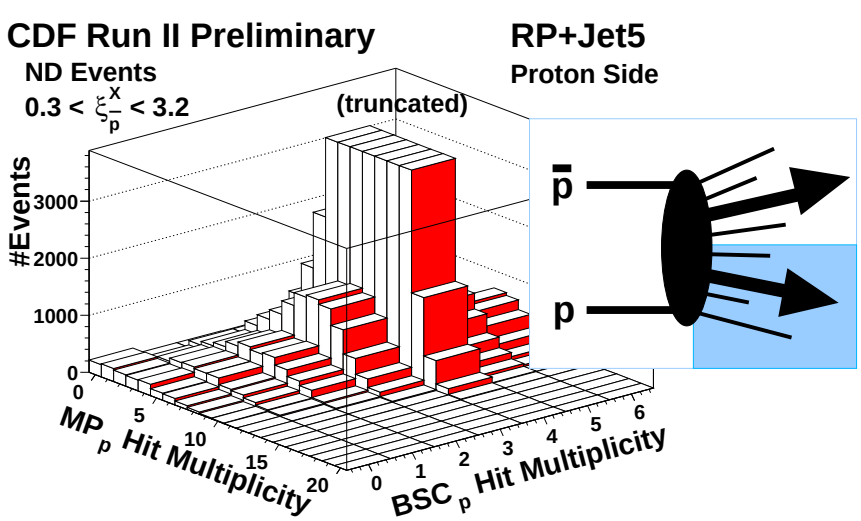
SD

ND





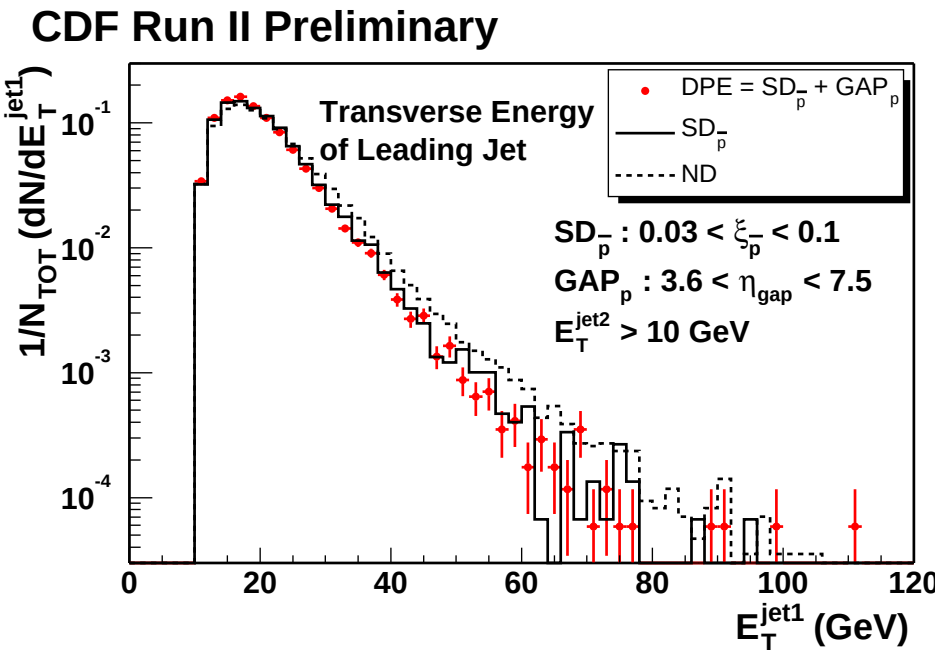


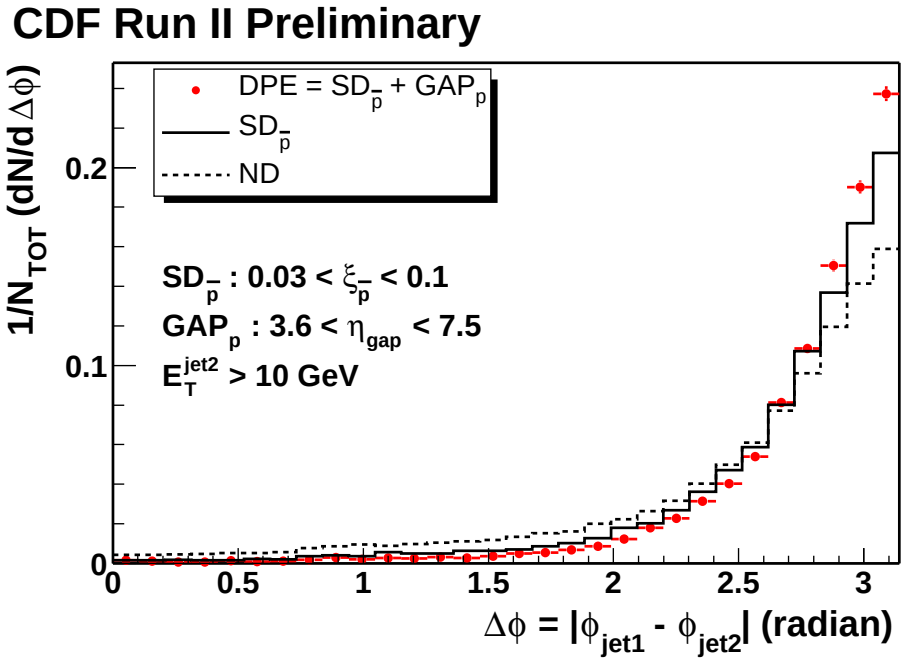


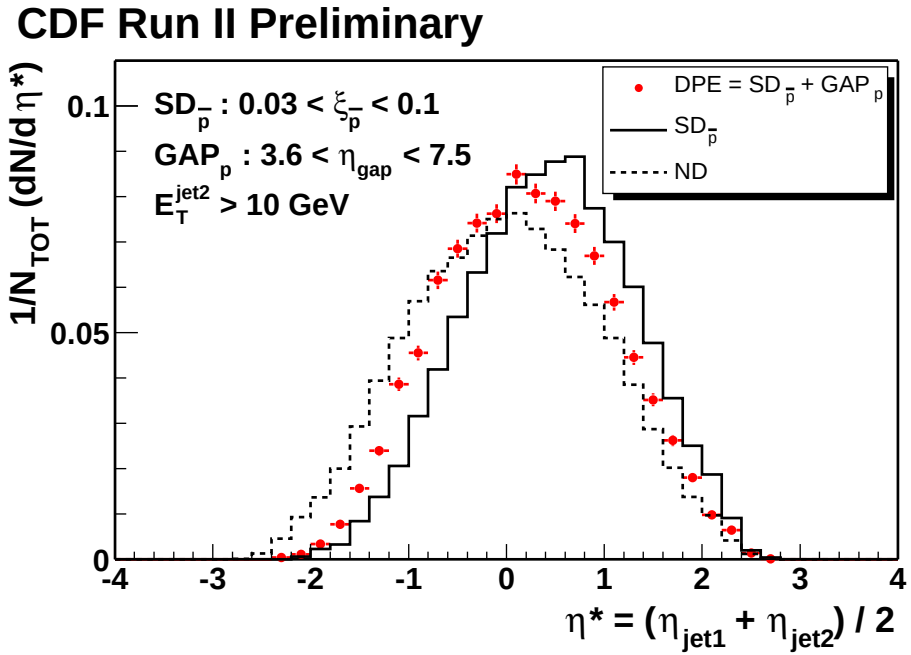
Antiproton Side

Proton Side

Kinematic Distributions

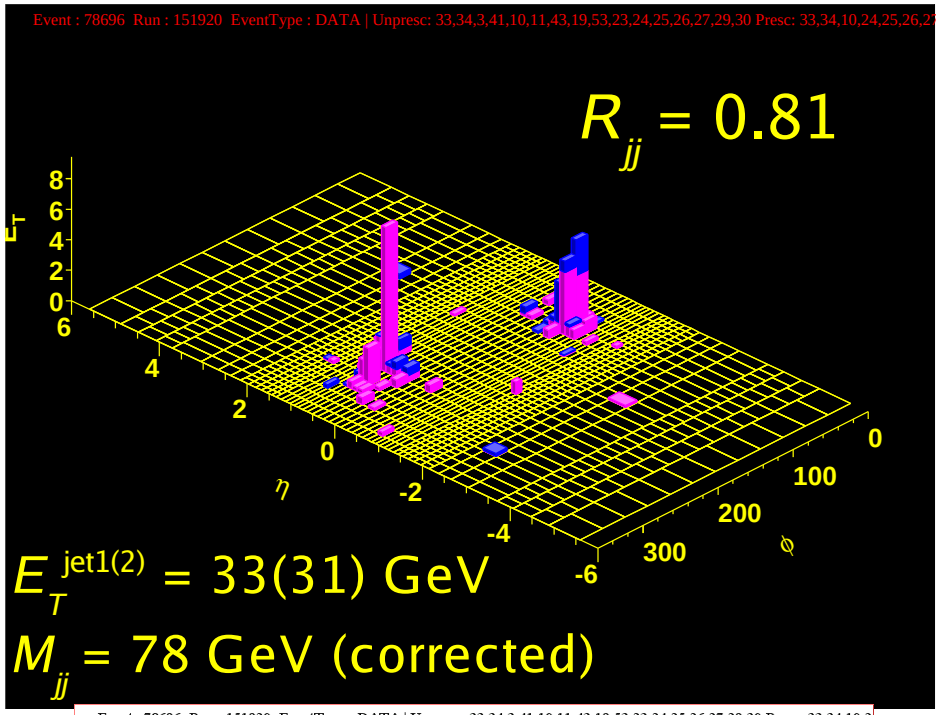


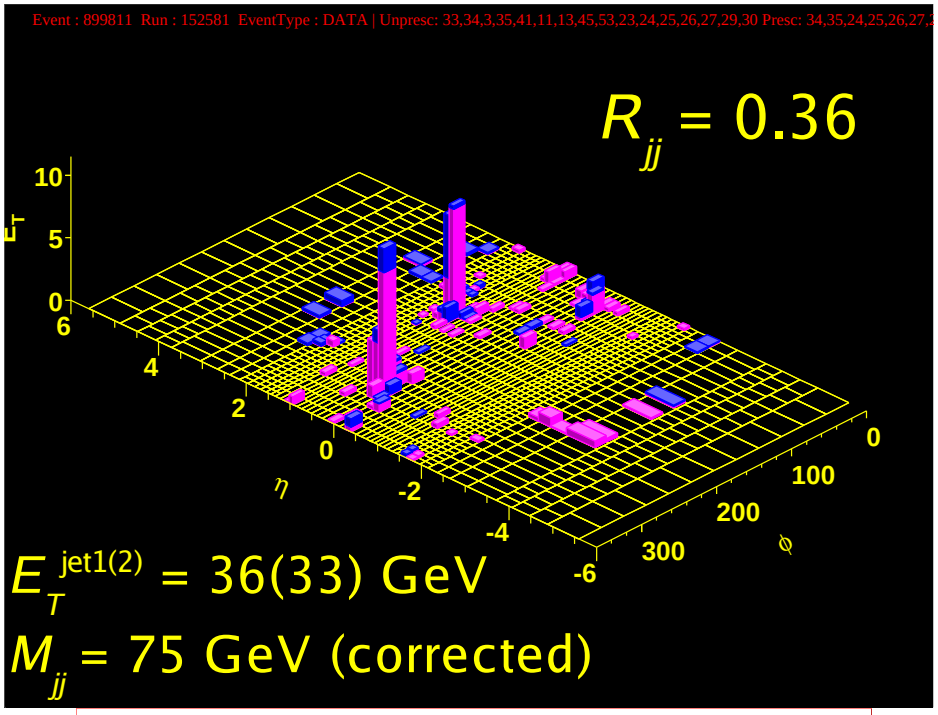


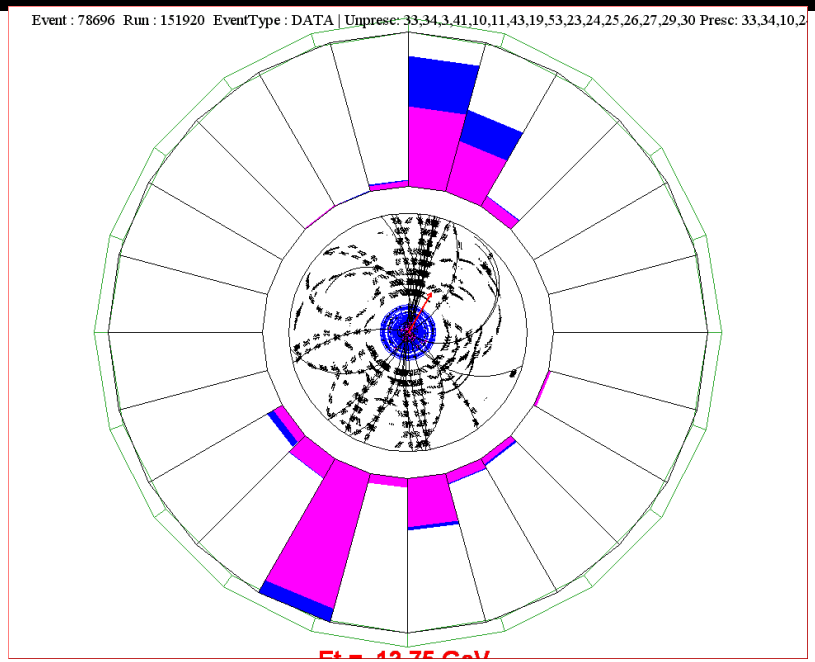


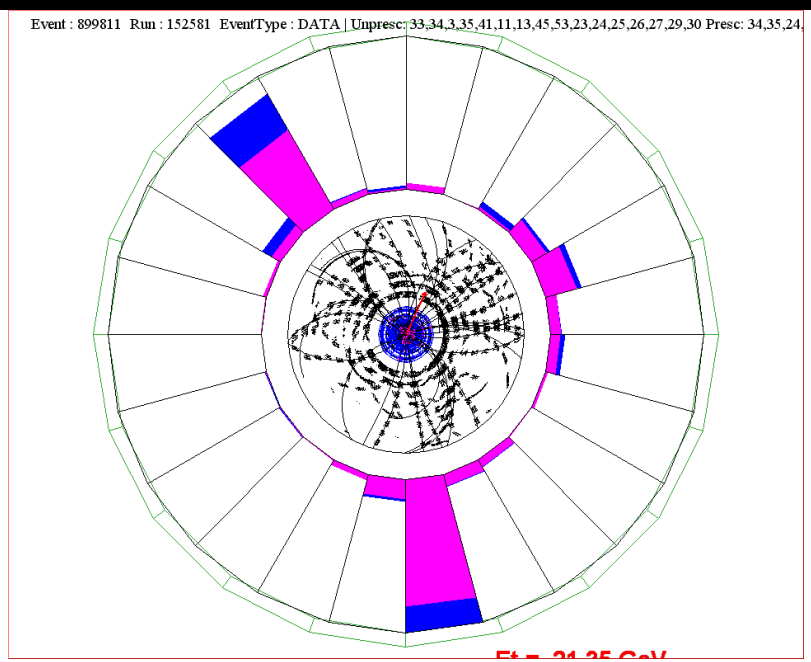
- DPE\SD jet E_T steeper than ND
- SD jets boosted away from $\bar{p}$
- $\overline{\Delta\Phi}_{DPE} > \overline{\Delta\Phi}_{SD} > \overline{\Delta\Phi}_{ND}$

DPE Dijet Event Displays

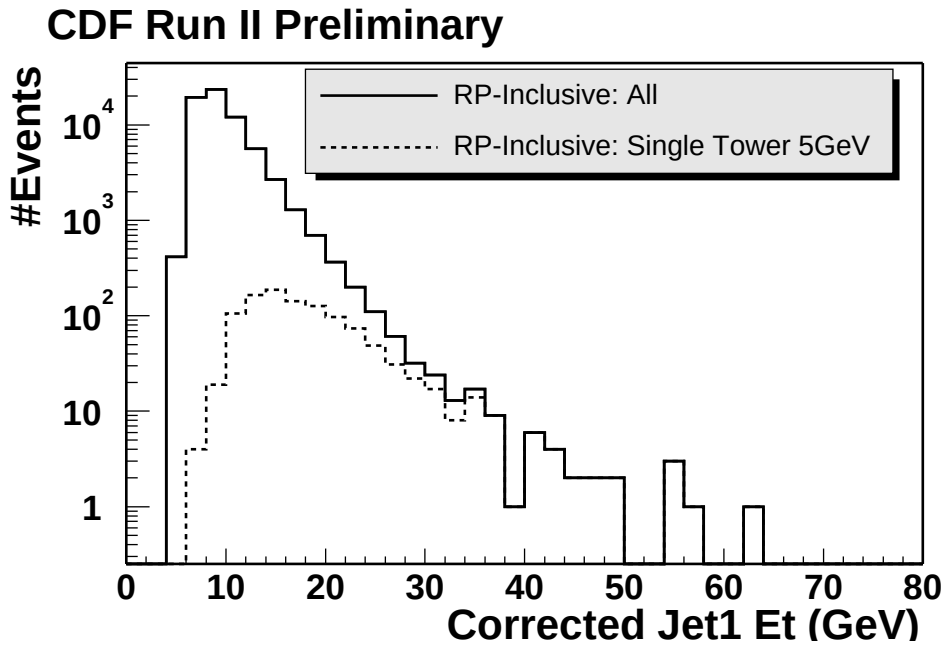


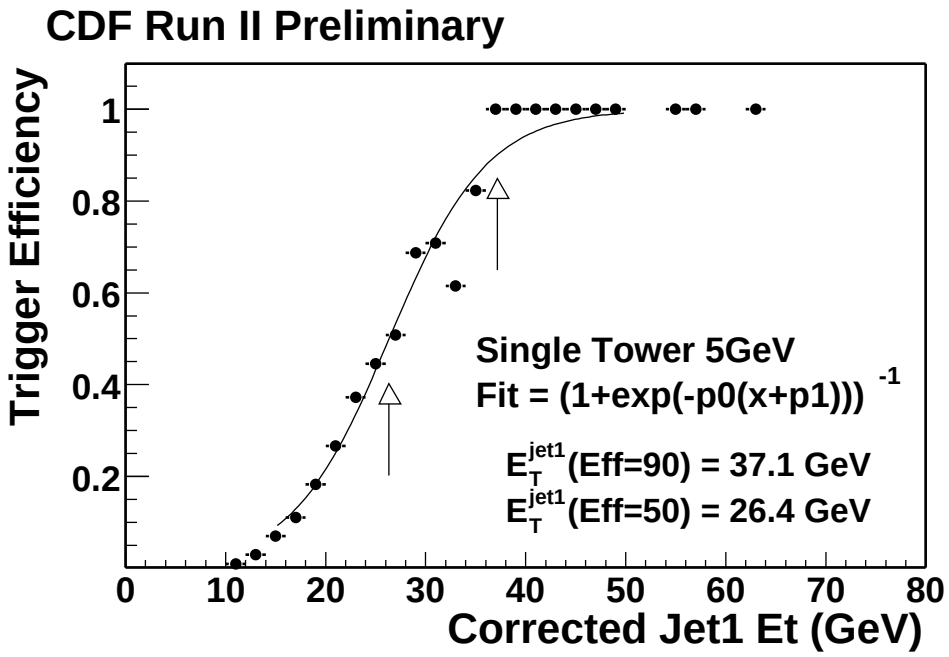






Jet Trigger Efficiency



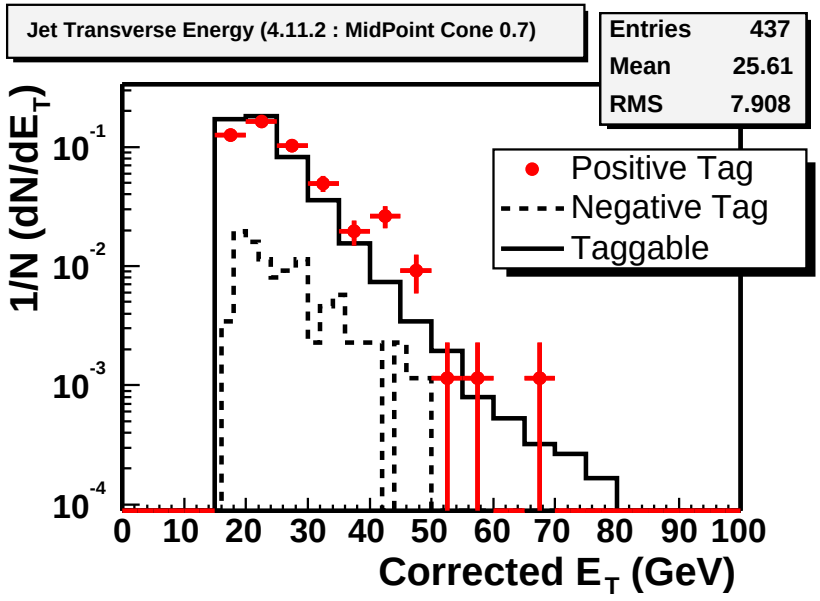


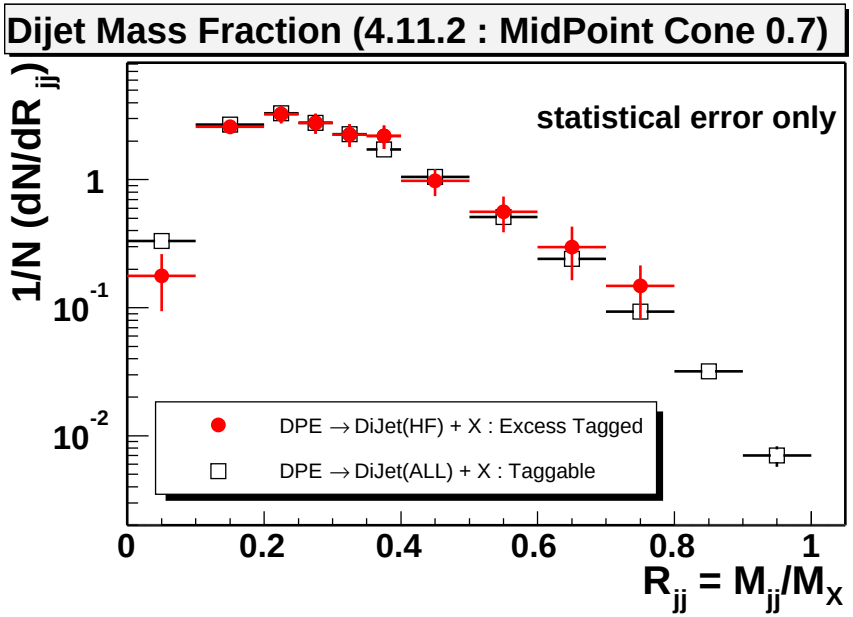
Trigger Efficiency vs Leading Jet E_T intervals

E_{T1}^{min}	E_{T1}^{max}	$\epsilon(\Delta E_{T1})$
10	15	5.77 ± 0.29 %
15	20	14.4 ± 0.7 %
20	25	31.6 ± 1.6 %
25	35	66.6 ± 3.3 %
35	50	95.1 ± 4.8 %
50	110	$100\ ^{+0}_{-5}$ %

±5% error assigned

Heavy Flavor Jets in DPE





SecVtx/JetProb algorithms applied to all available DPE data (before Fall '03 shutdown)

~350 excess tagged in 38K taggable jets

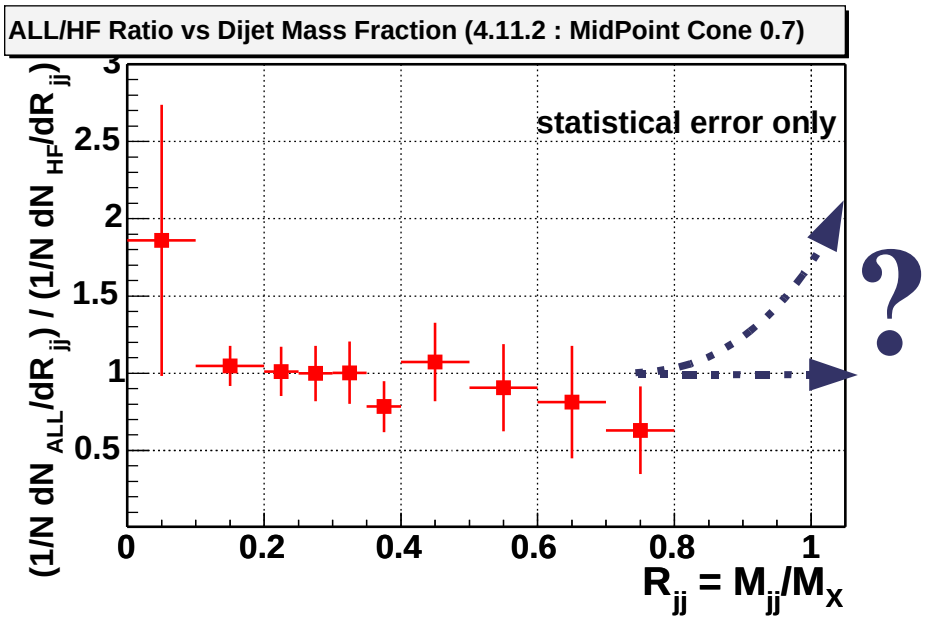
R_{jj} shapes agree well at $R_{jj} < 0.8$

HF dijets at $R_{jj} > 0.8$:

0 events observed

~2 events expected if $R_{jj}(\mathrm{HF}) \approx R_{jj}(\mathrm{all})$

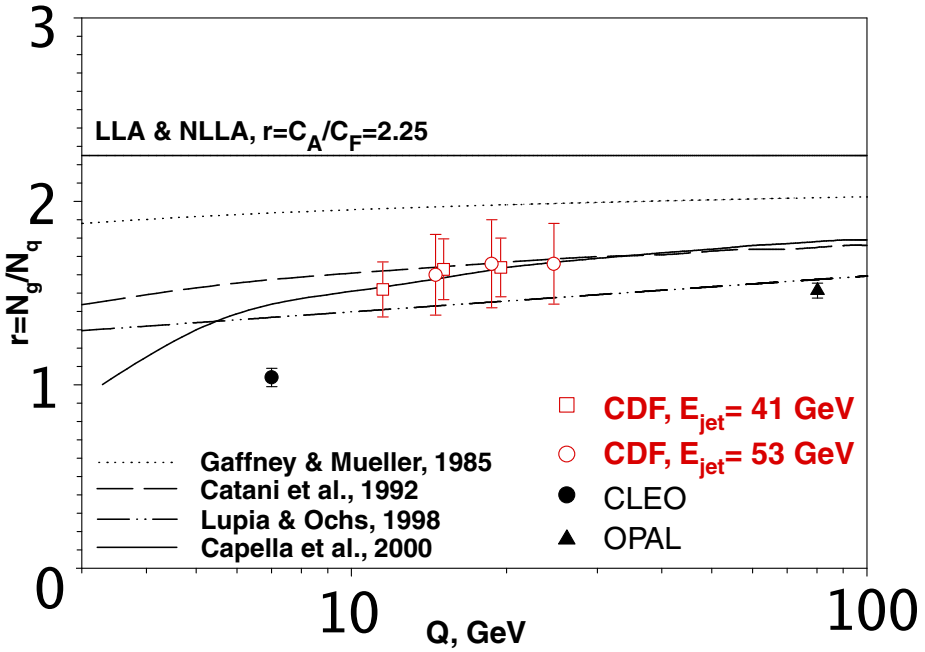
➔ need more data



Quark/Gluon Jets in DPE

A. Korytov, A. Pronko, A. Safonov

Run I CDF Results:
ratio of charged particle multiplicities in gluon and quark jets



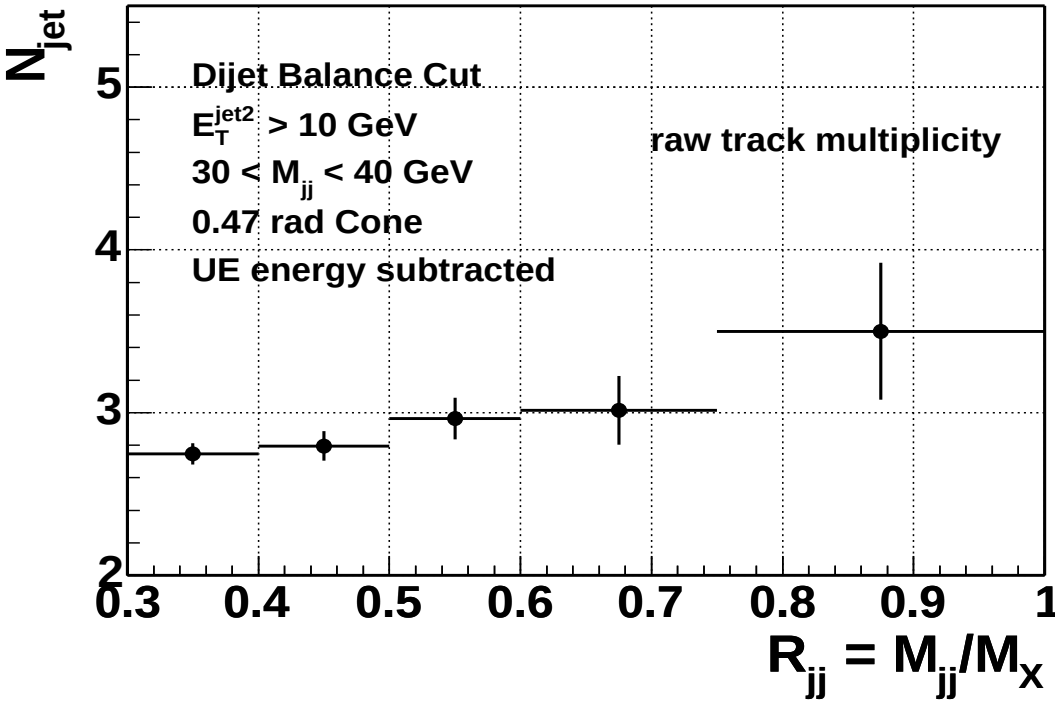
Theory curves for Λ_{QCD}=230 MeV

Energy scale : Q = E_{jet} sinθ_C (CDF)

= 2E_{jet} (CLEO, OPAL)

θ_C = opening angle of cone w.r.t. Jet axis

Charged Track Multiplicity in a Jet vs Dijet Mass Fraction



Preliminary analysis of charged track multiplicity (N_{jet}) in a jet of DPE data :

- increasing trend of N_{jet} with R_{jj} in 30<M_{jj}<40 GeV range
- need more data & study....