Exclusive Di-jet Production at CDF

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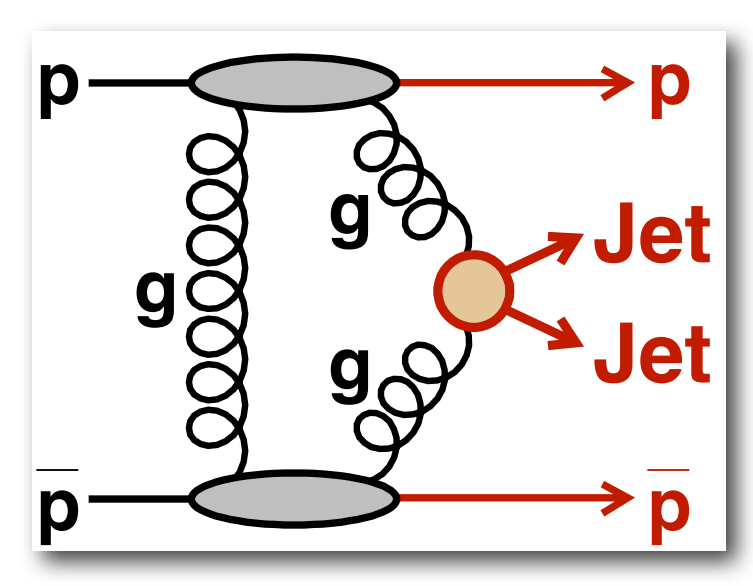
On behalf of the CDF Collaboration

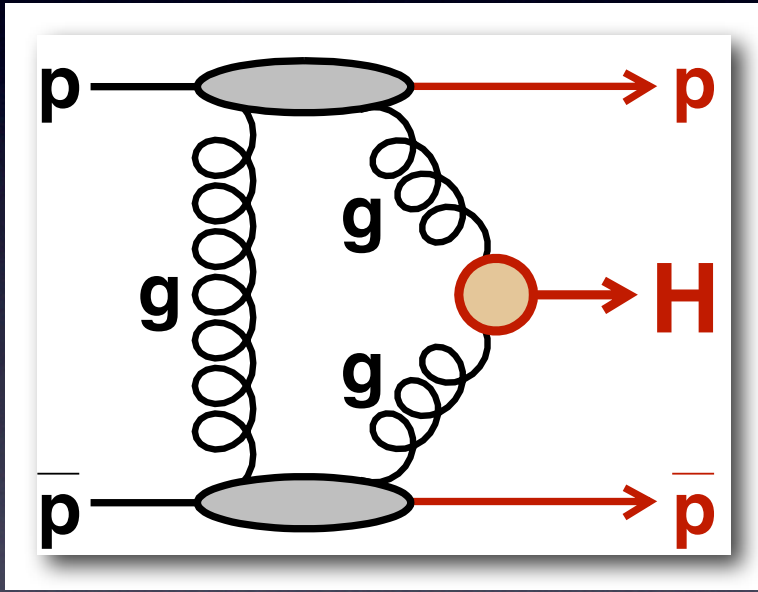
Small-x workshop, Fermilab, March 28-30, 2007

Exclusive Di-jet Production

- Observe exclusive di-jets experimentally
- Test existing exclusive production models

➡ Calibrate predictions for exclusive Higgs at LHC





- $gg \to gg$, $q\bar{q}g$, ...
- $gg \to q\bar{q}$ suppressed ($J_z=0$ rule)
- large cross section

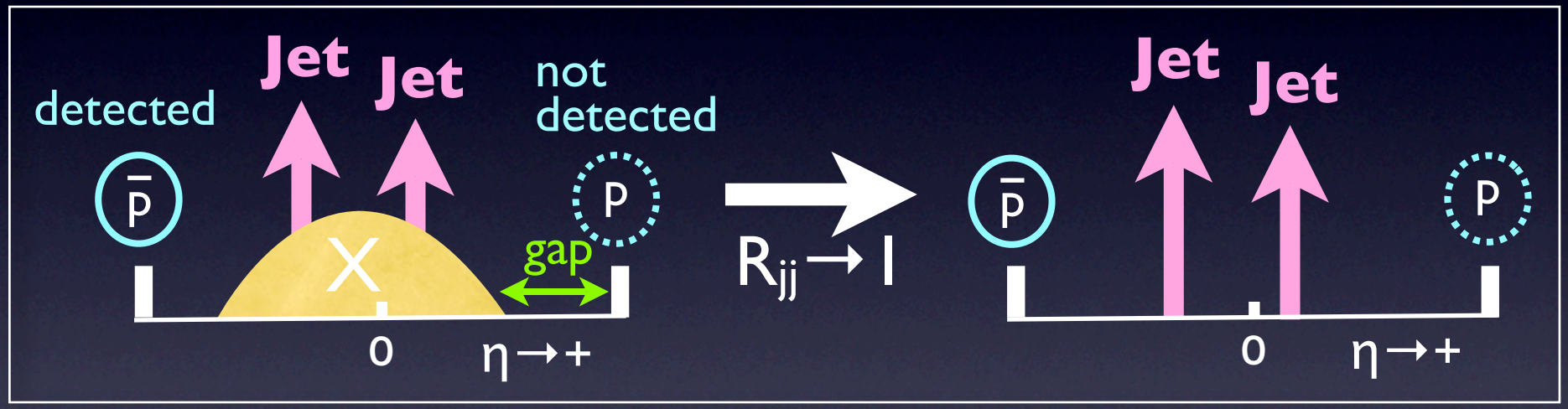
- $gg \to H \to b\bar{b}$ (for light SM Higgs)
- Potential to determine Higgs property at LHC

Outline

- Analysis Strategy
- Search for the Signal
- Results
- Summary

Analysis Strategy

- Select inclusive DPE di-jets : $\bar{p}+p \rightarrow \bar{p}+X(\ni 2\text{jets})+\text{gap}$
- Reconstruct di-jet mass fraction : $R_{jj} = M_{jj}/M_X$
- Look for data excess over DPE di-jet background as $R_{jj} \rightarrow 1$



➡ Signal ($R_{jj}=1$) smeared due to shower/hadronization effects, NLO $gg \rightarrow ggg$, $q\bar{q}g$ contributions, etc.

➡ DPE di-jet background shape from POMWIG MC simulation (⇒ Uncertainty from Pomeron PDF)

POMWIG Monte Carlo Simulation

Use POMWIG v1.3β [Cox and Forshaw, CPC 144,104(2002)] to obtain DPE di-jet background shape

Modified diffractive structure functions to incorporate some of recent experimental measurements

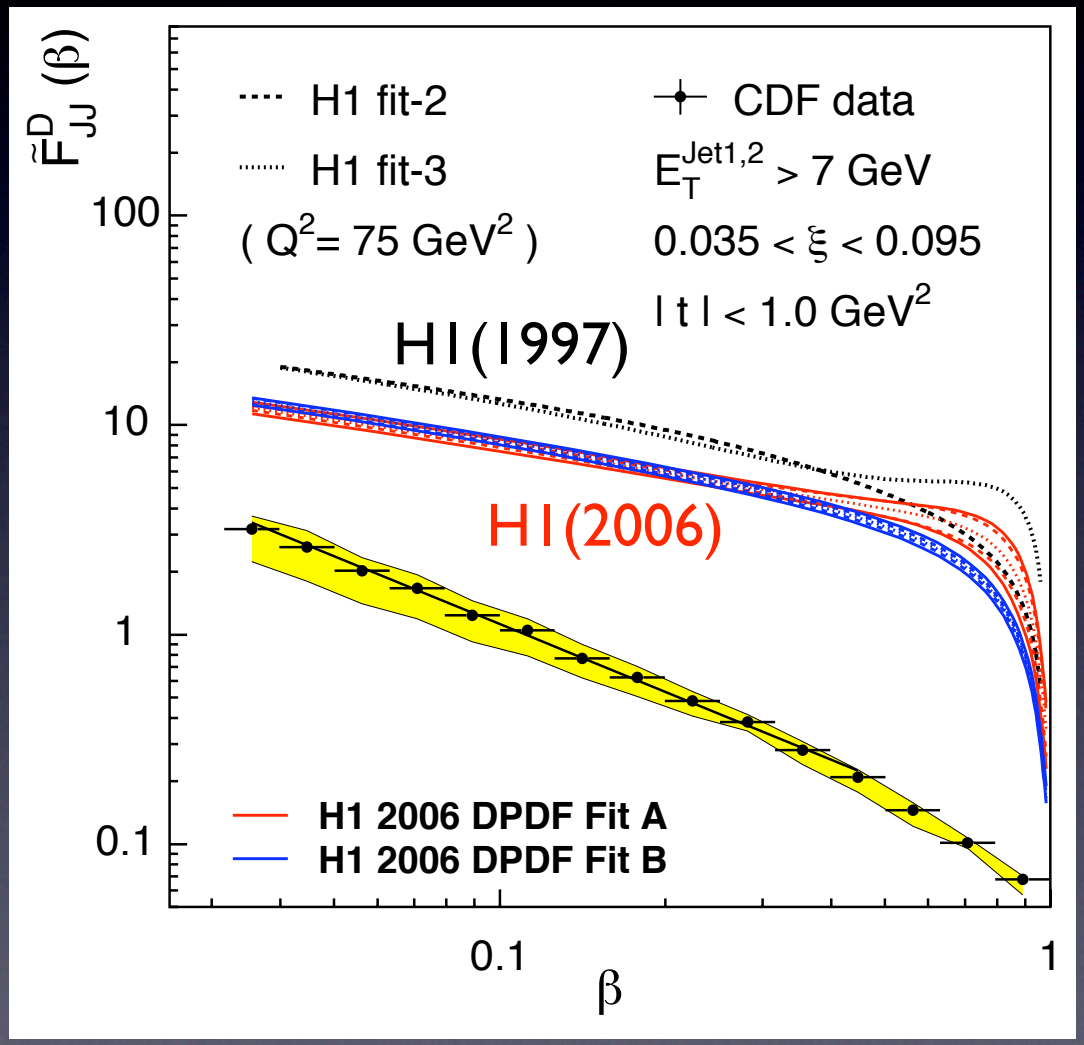
H1-fit2	H1 LO-fit to '94 LRG data
CDF	CDF CDF Run I F_{jj}^D from SD/ND di-jets
CDF⊕H1	CDF Run I F_{jj}^D from DPE/SD di-jets (⇒main PDF)
ZEUS-LPS	ZEUS NLO-fit to '97 LPS data

Also, used

- H1 NLO-fit 3 to '94 LRG data
- Groys, Levy, and Proskuryakov NLO-fit to '98-'99 ZEUS M_X data

New H1 Diffractive PDFs

P. Newman : Hera-LHC workshop, March 2007
(Also, see yesterday's M. Ruspa talk)

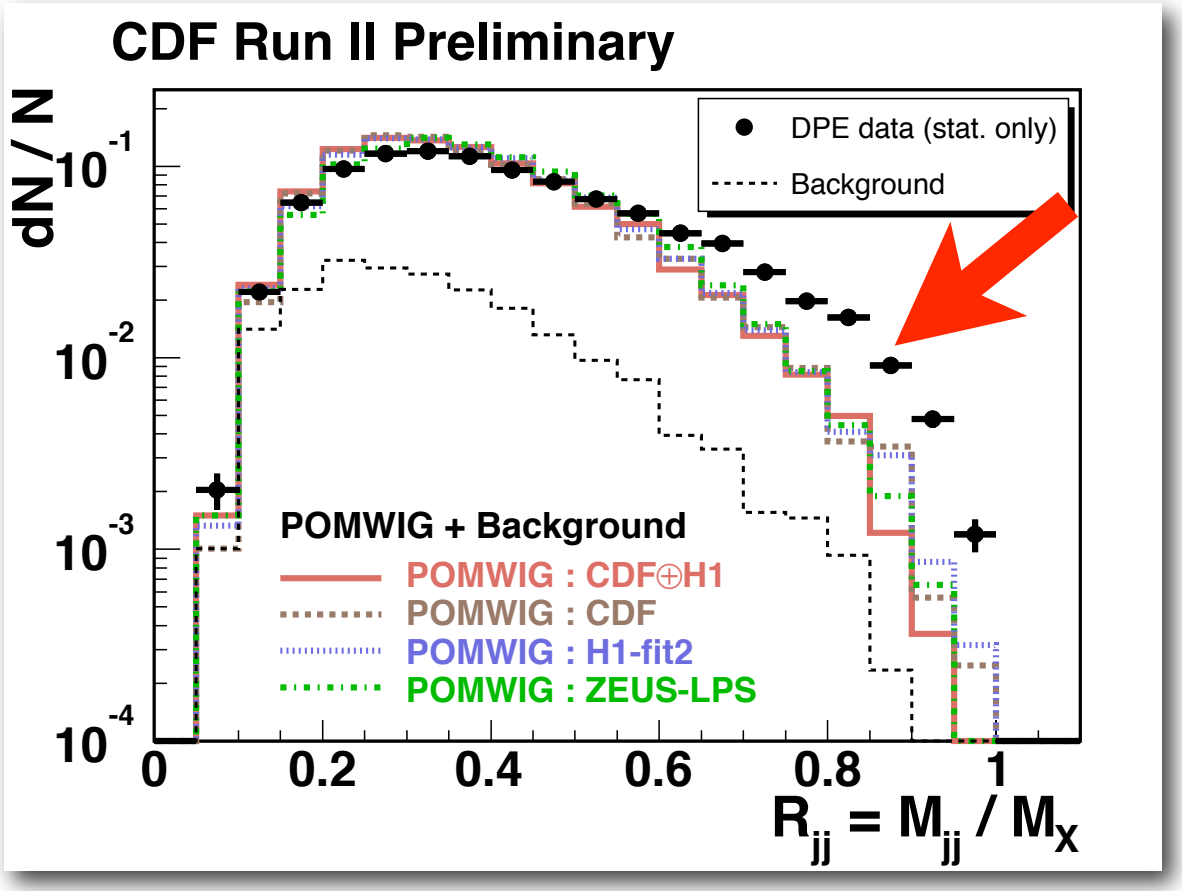


Current analysis uses H1-fit2 (1997)

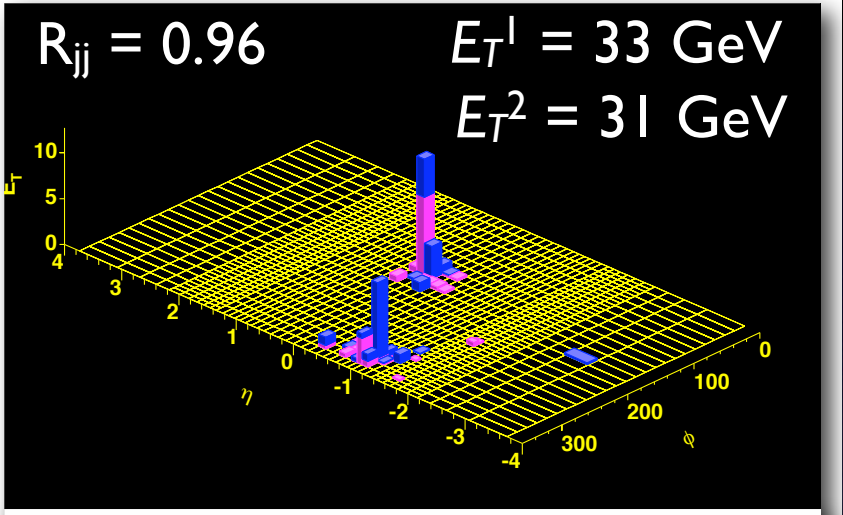
Diffractive PDFs recently updated by H1 (2006)

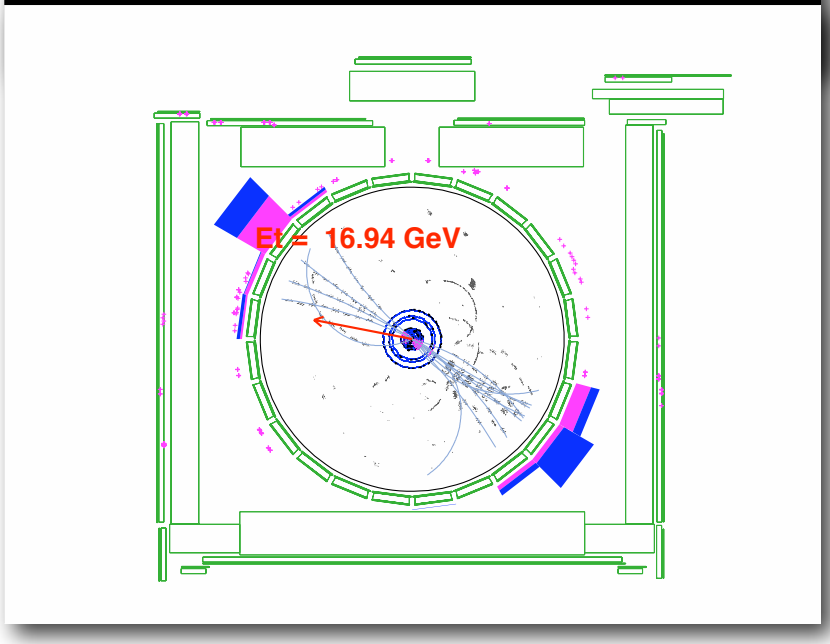
➡ New H1(2006) DPDFs have similar shapes to old DPDFs

Di-jet Mass Fraction



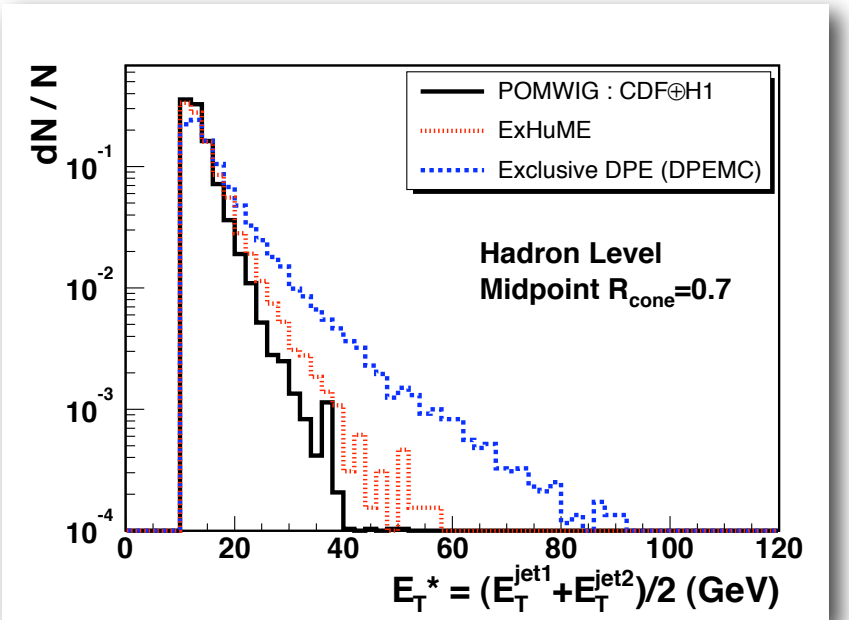
CDF Run II Preliminary





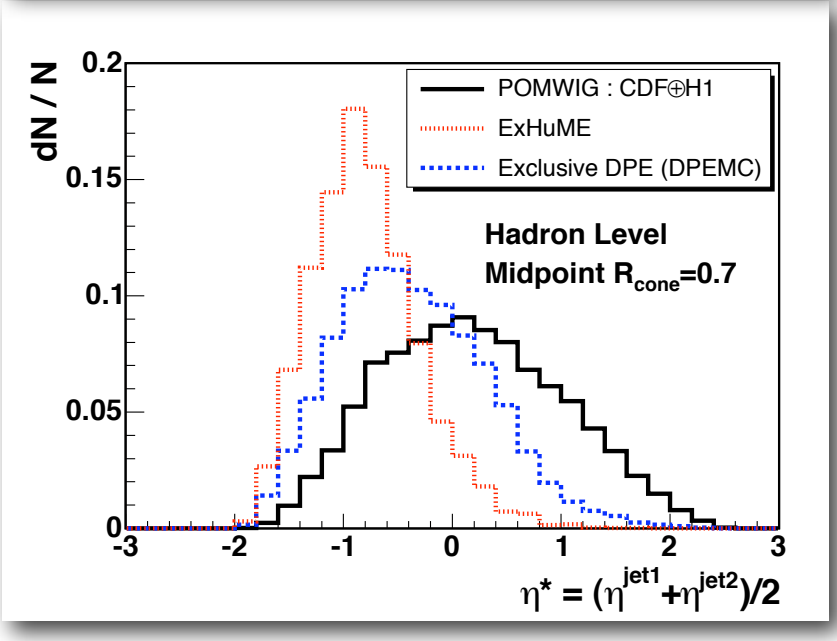
Excess observed over MC simulations with varied PDFs

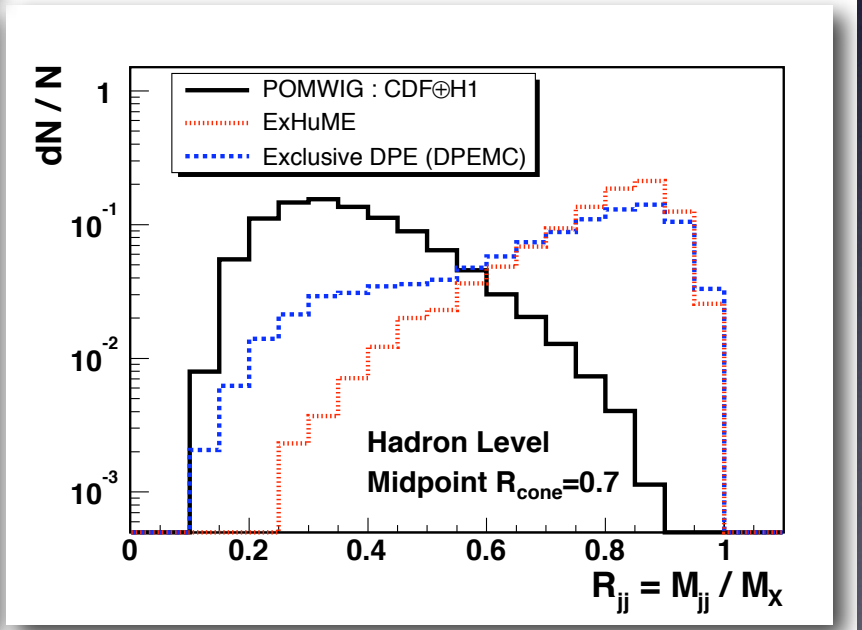
Exclusive Dijet MC Simulations



ExHuME v1.3.1 [CPC 175,232(2006)]
- based on KMR perturbative QCD
- LO matrix element + PYTHIA PS

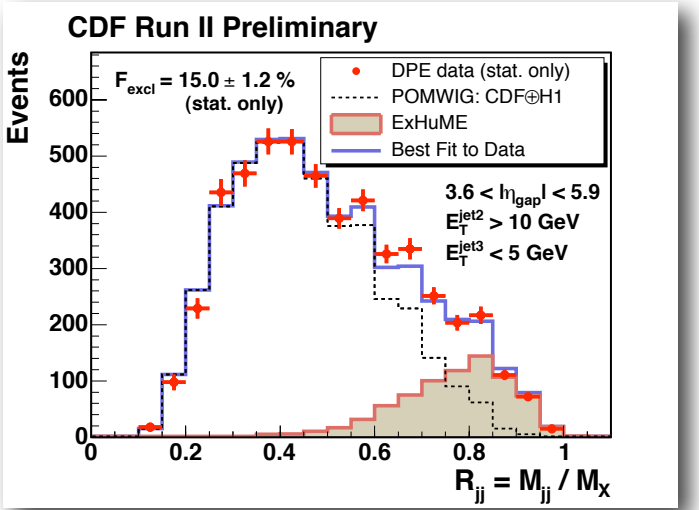
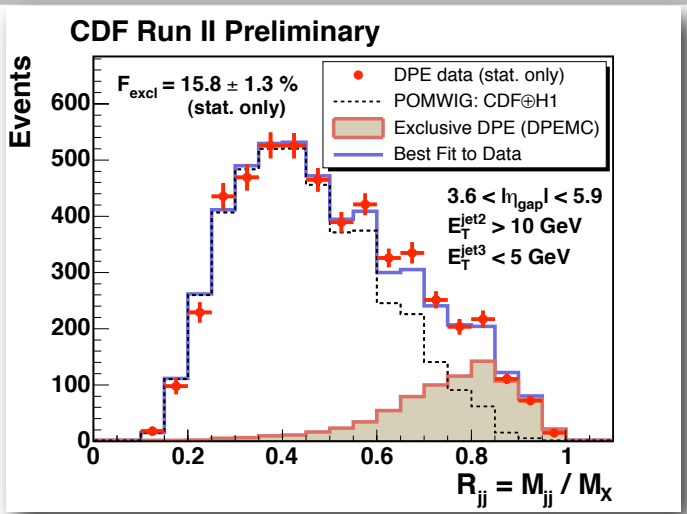
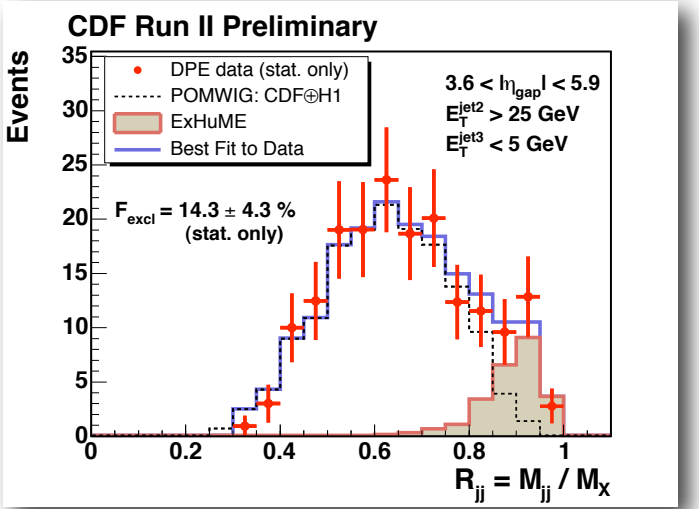
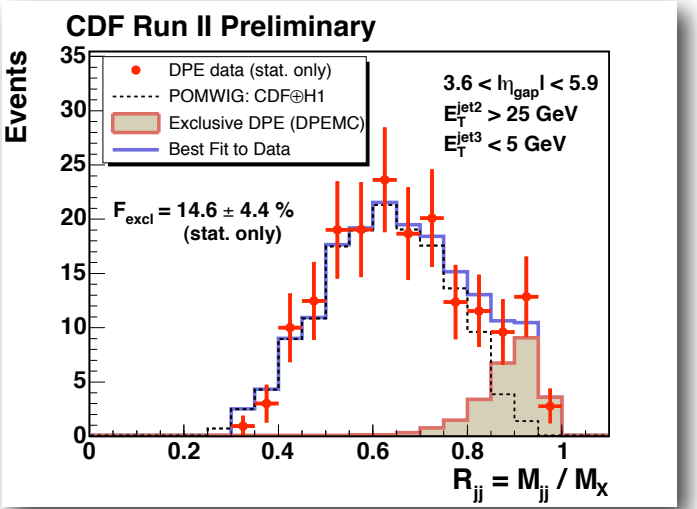
DPEMC v2.5 [CPC 167,217(2005)]
- based on BL non-perturbative Regge inspired model
- LO (HERWIG add-on)





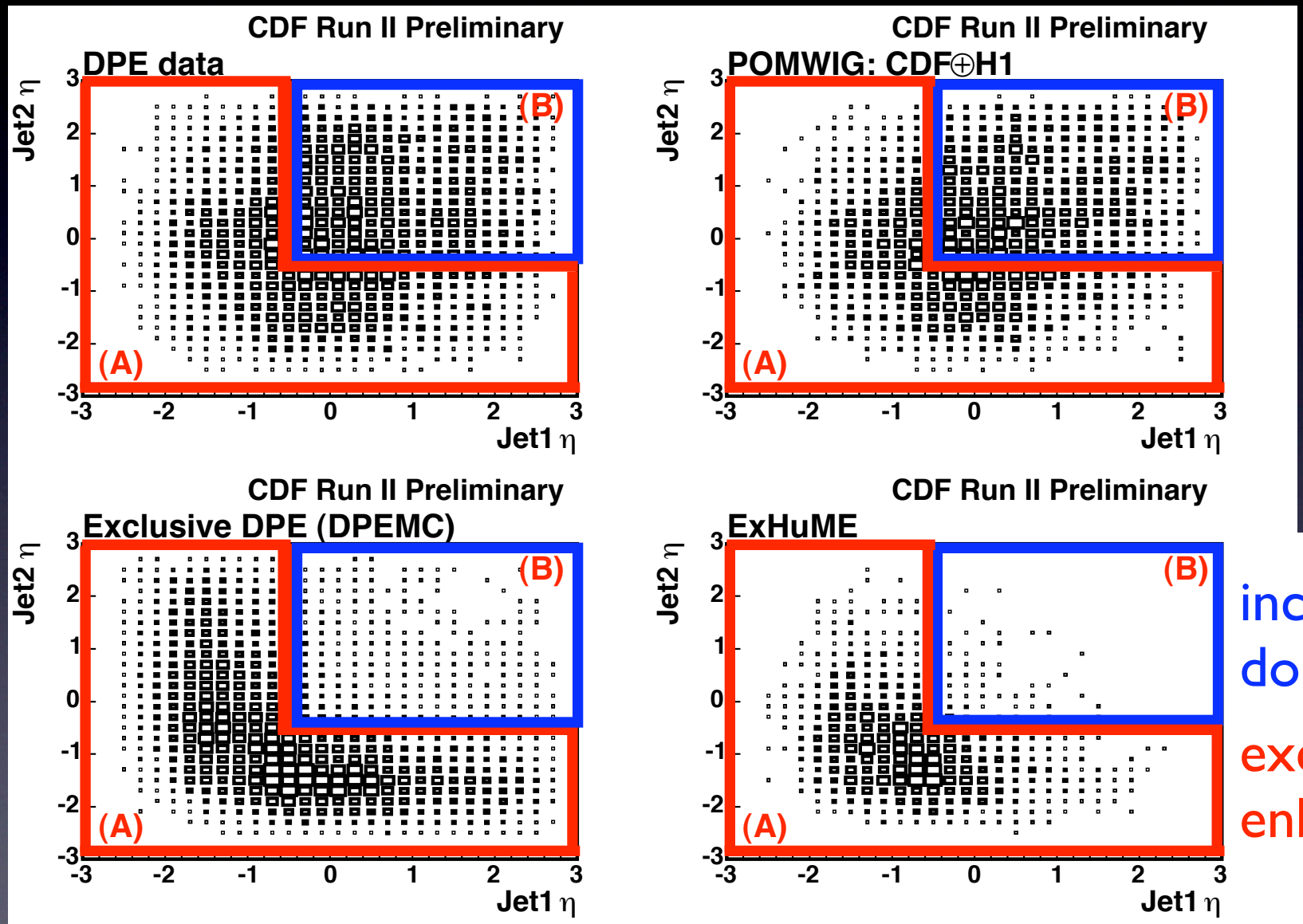
MC Fit to R_{jj} Shape

Binned likelihood fits (MC normalizations as free parameters)

	POMWIG+ExHuME	POMWIG+ExclDPE
$E_T^{jet1,2}>10$GeV $E_T^{jet3}<5$GeV		
$E_T^{jet1,2}>25$GeV $E_T^{jet3}<5$GeV		

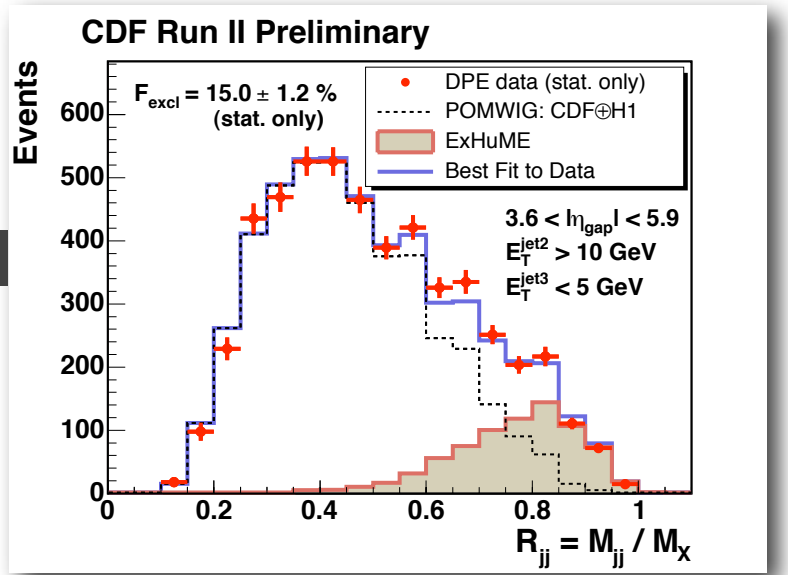
Di-jet Pseudorapidity Distributions

Exclusive djets produced towards outgoing $\bar{p}$ side due to our kinematic acceptance

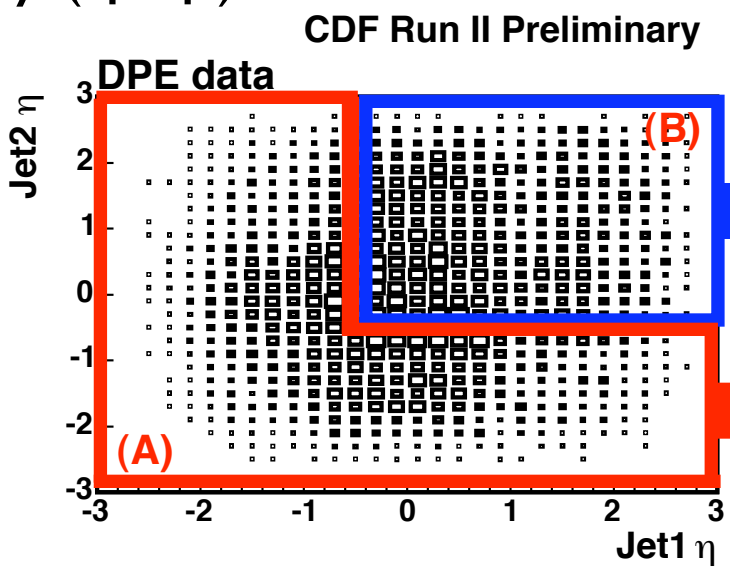


η_{jet}-dependence of the Excess

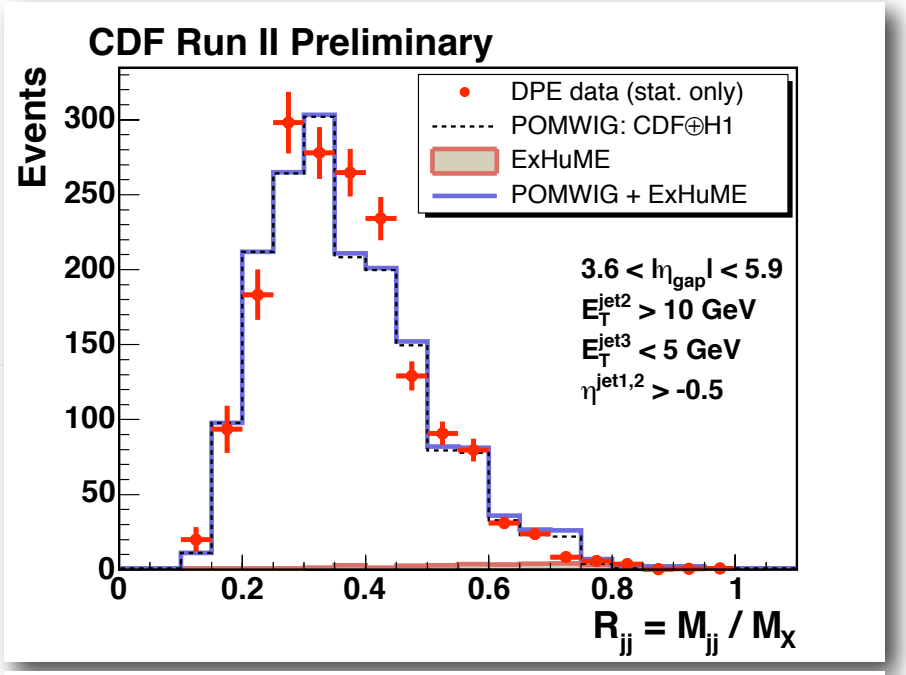
MC normalizations fixed by fits to R_{jj} data shape



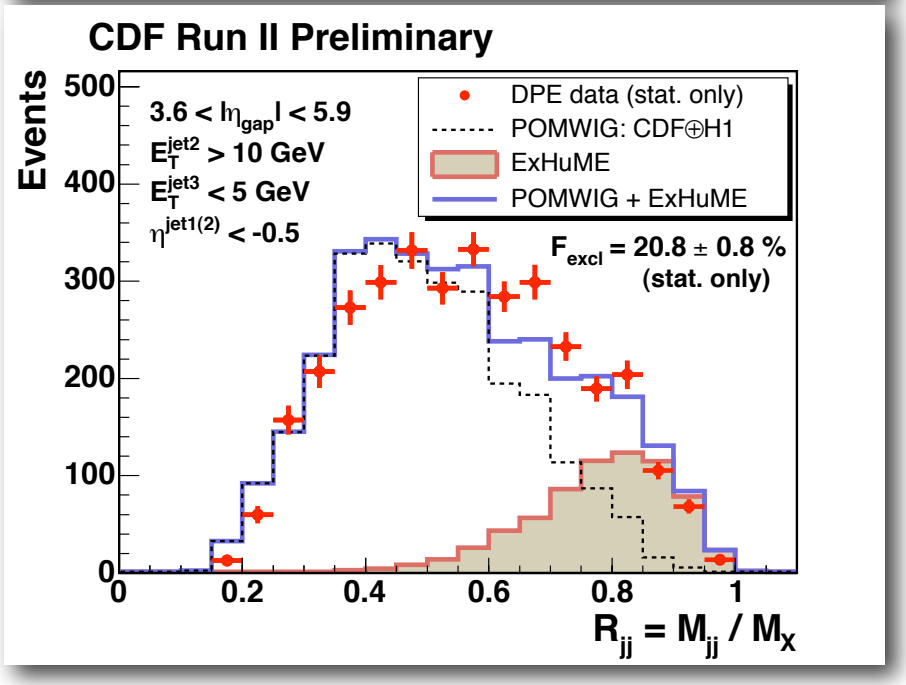
Apply (η_1,η_2) cuts to data and MC



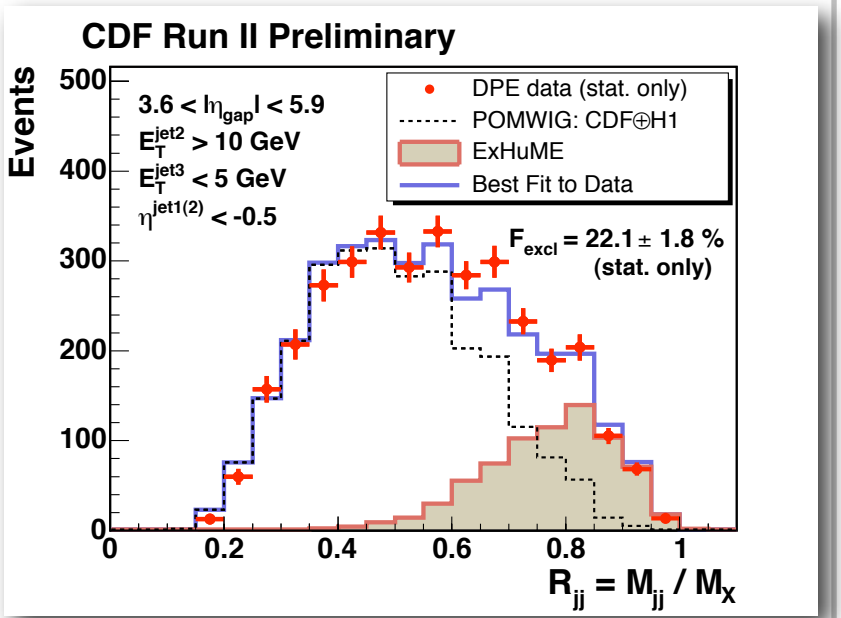
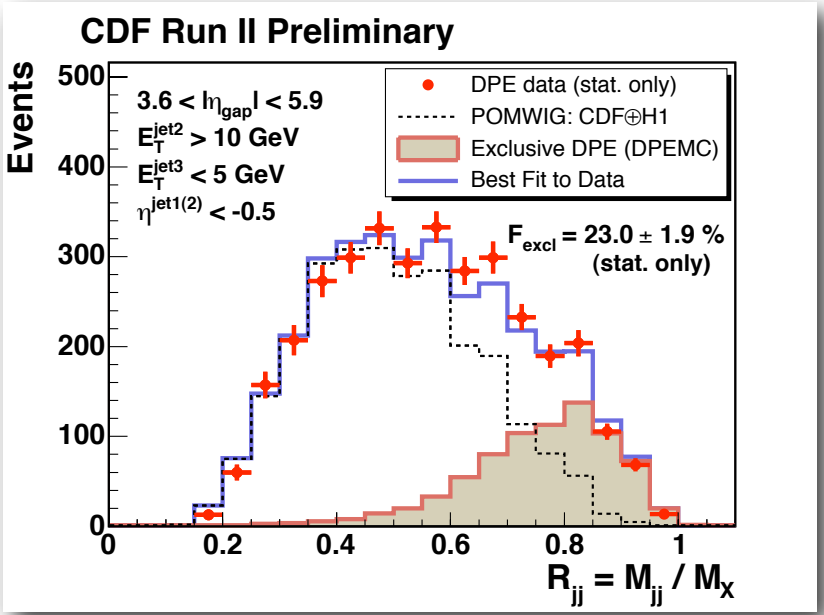
inclusive dominant



exclusive enhanced



MC Fit to R_{jj} Shape

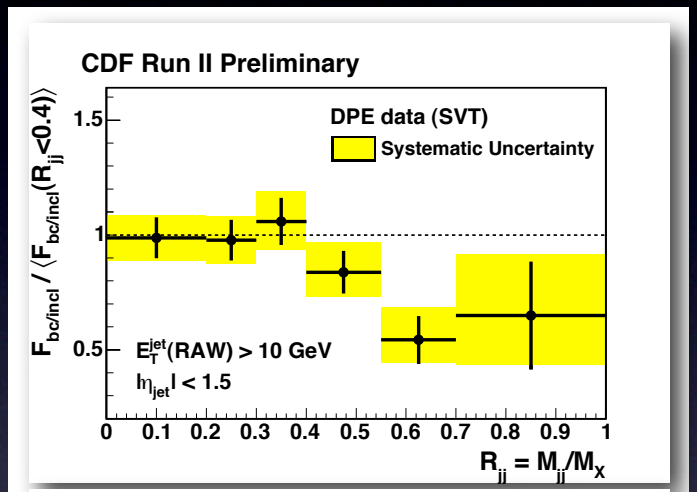
Binned likelihood fits (MC normalizations as free parameters)		
Signal MC	ExHuME	DPEMC Exclusive DPE
data bkgd signal fit		
CDF⊕H1	22.1±1.8 %	23.0±1.9 %
CDF	21.7±1.8 %	22.6±1.9 %
H1-fit2	24.7±2.0 %	26.0±2.1 %
ZEUS-LPS	24.3±2.0 %	25.4±2.1 %

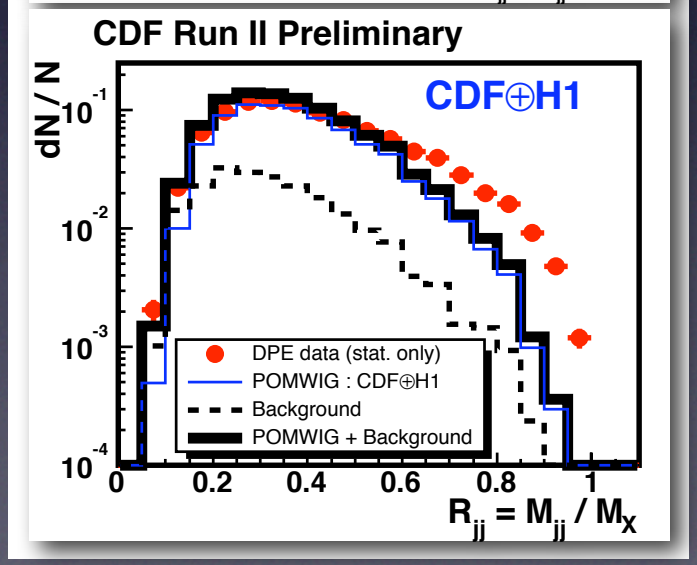
stat. error only

Exclusive Di-jet Signal

LO exclusive $gg \rightarrow q\bar{q}$ suppressed due to Jz=0 rule

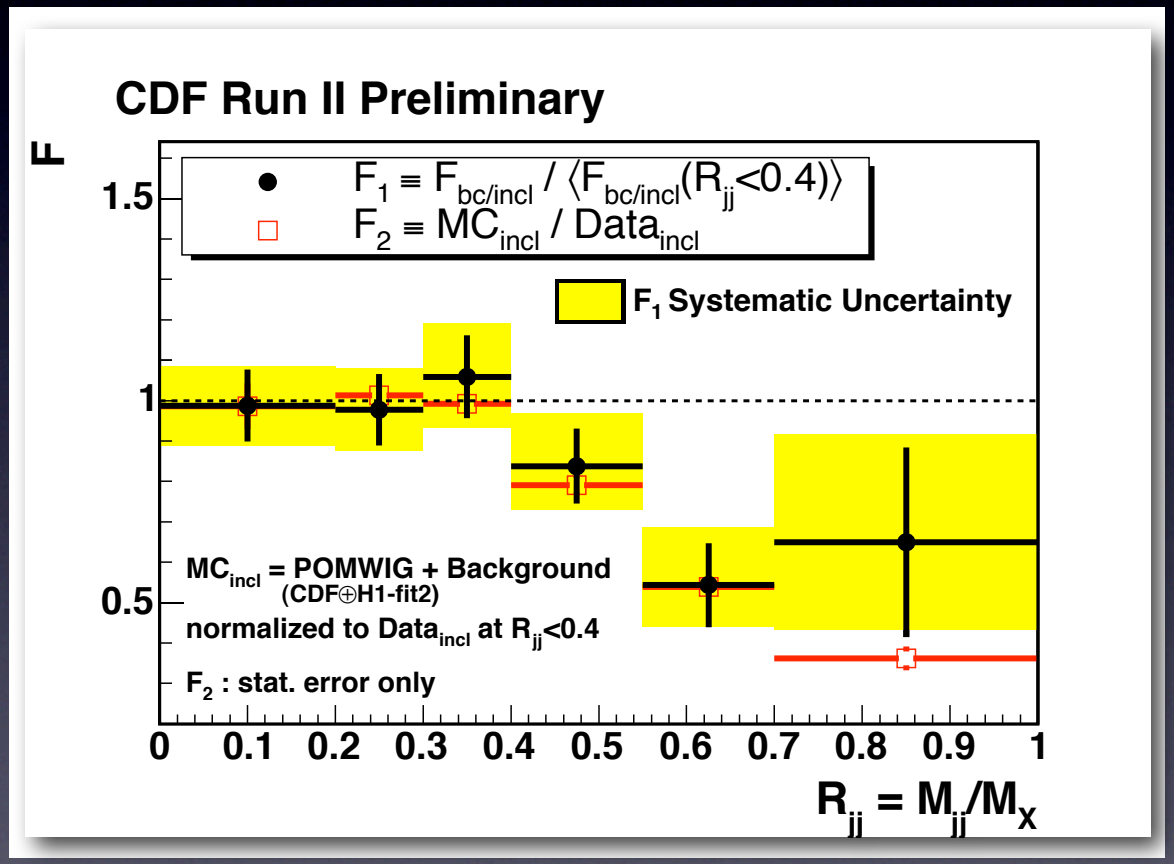
➡ Look for the suppression in heavy flavor jet fraction vs R_{jj}





$$\frac{HF_{data}}{incl_{data}}$$

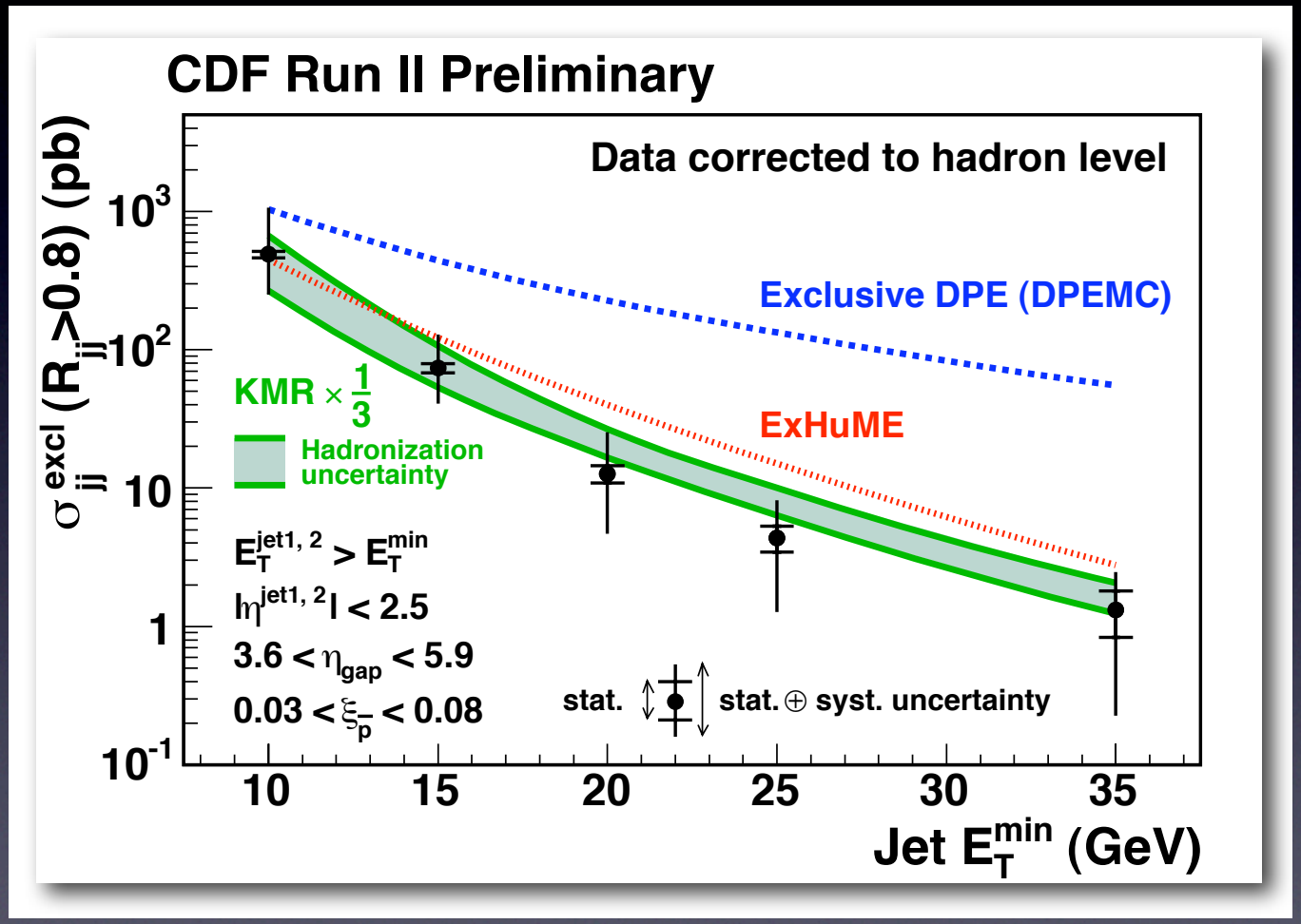
$$\frac{incl_{MC}}{incl_{data}}$$



The two results are consistent with each other

Exclusive Di-jet Cross Section

Integrated Cross Section for R_{jj}>0.8 vs Minimum Jet E_T



DPEMC Exclusive DPE

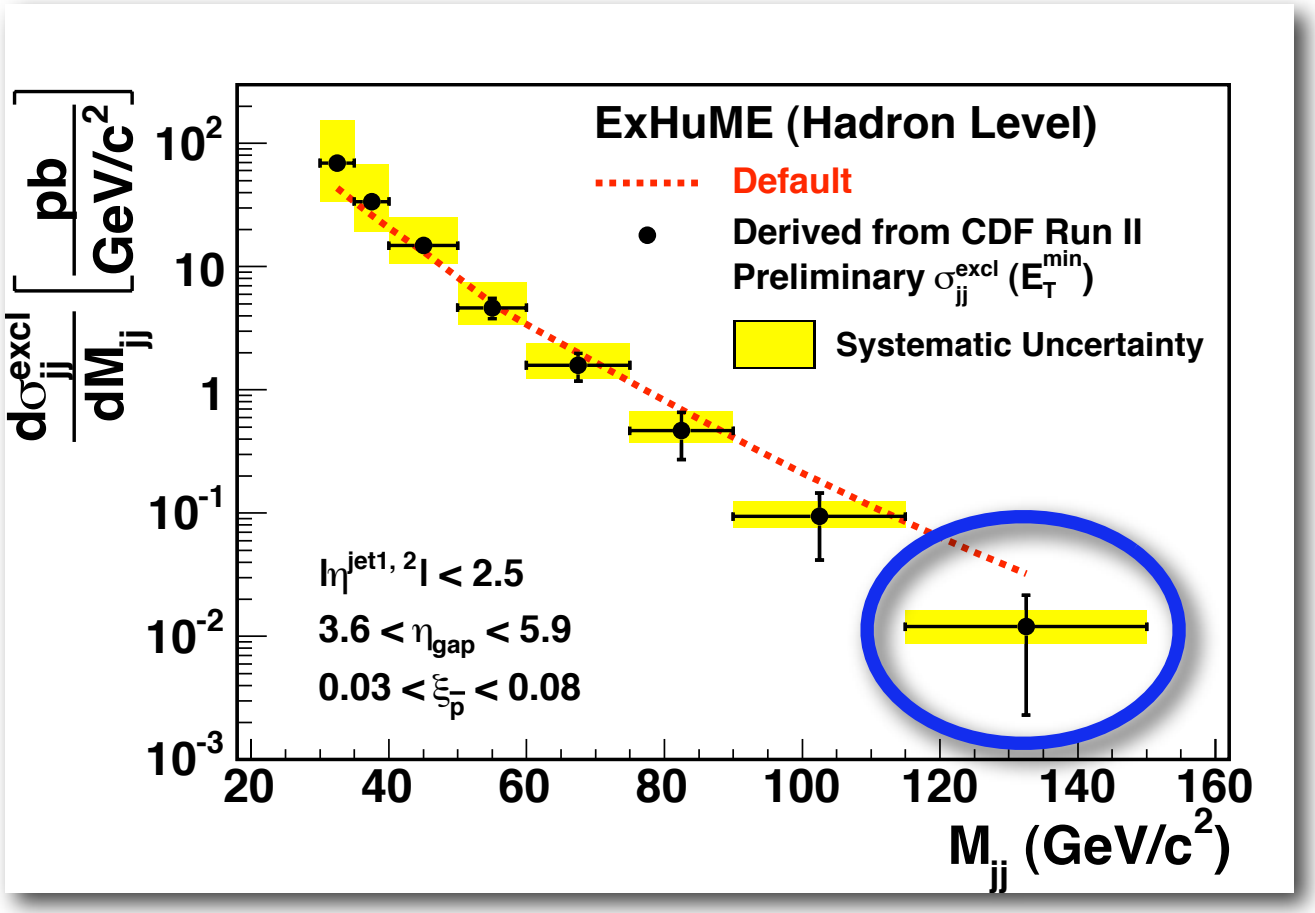
ExHuME

Khoze, Martin, Ryskin
at LO parton-level
(factor 3 uncertainty)
hep-ph/0507040

Measured σ_{jj}^{excl} prefers ExHuME and KMR calculations

Exclusive Di-jet Mass Reach

Unfold measured σ_{jj}^{excl} to $d\sigma_{jj}^{excl}/dM_{jj}$ using ExHuME



CDF $\bar{p}p \rightarrow \bar{p}jjp$ reaches Higgs mass range!!

➡ **pp→pHp** at LHC

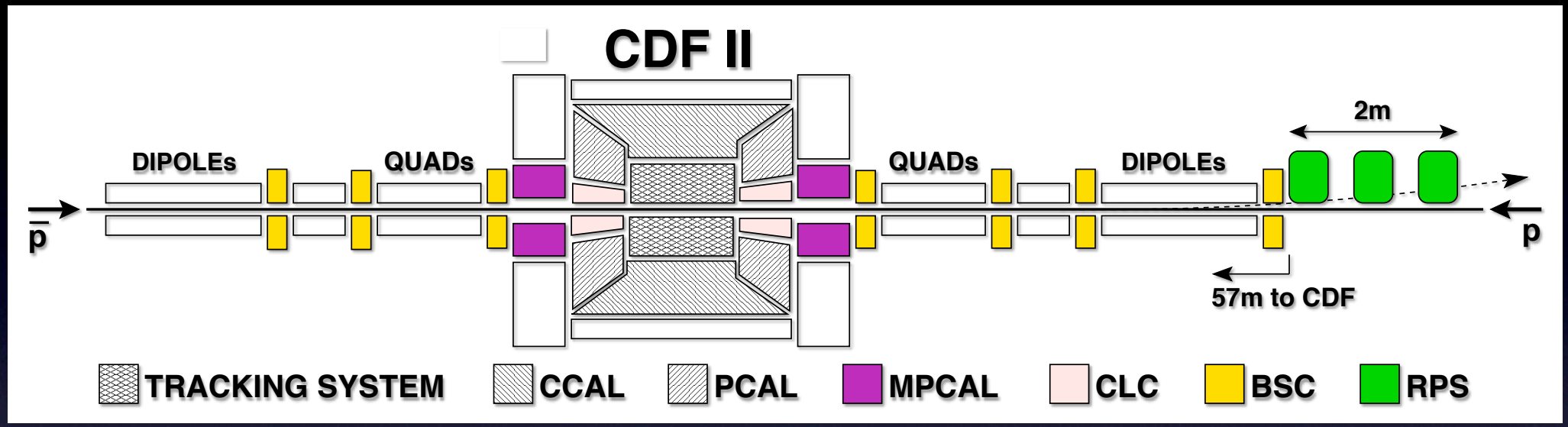
Summary

Observed exclusive di-jet production in $\bar{p}p$ collisions for the first time

- Measured rate consistent with Durham parton-level calculations (factor ~3 uncertainty)
- Data prefer ExHuME over Exclusive DPEMC
- Results encouraging for $pp \rightarrow pHp$ at LHC

Backup

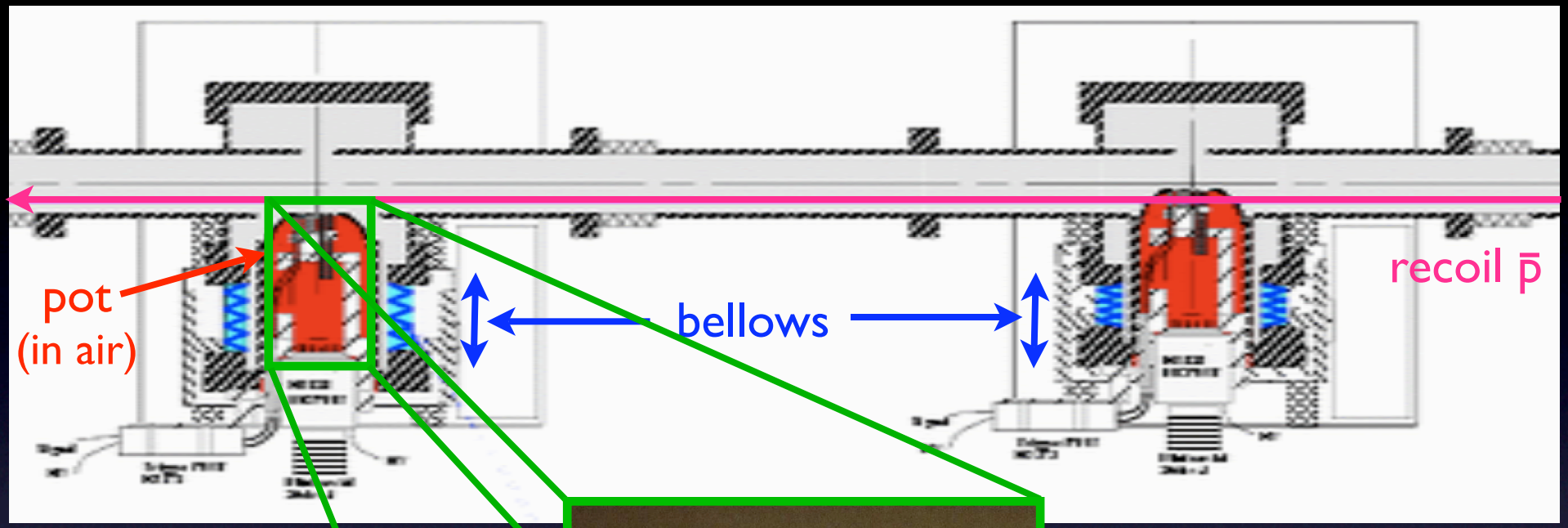
CDF II Detector

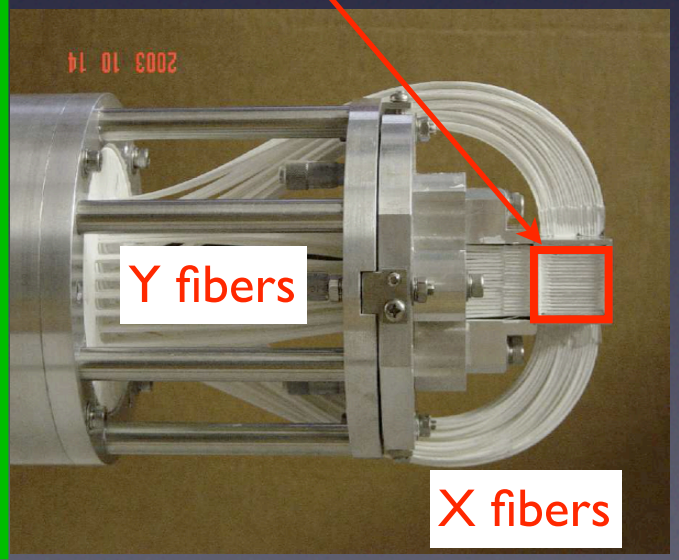


Wide detector coverage helps exclusive measurements

- ➡ Tracking Detectors : $|\eta|<2.0$
- ➡ Calorimeters : $|\eta|<5.2$
- ➡ Veto Counters (BSC) : $5.4<|\eta|<7.4$
- ➡ Leading Antiproton Detectors (RPS)

Roman Pot Spectrometers

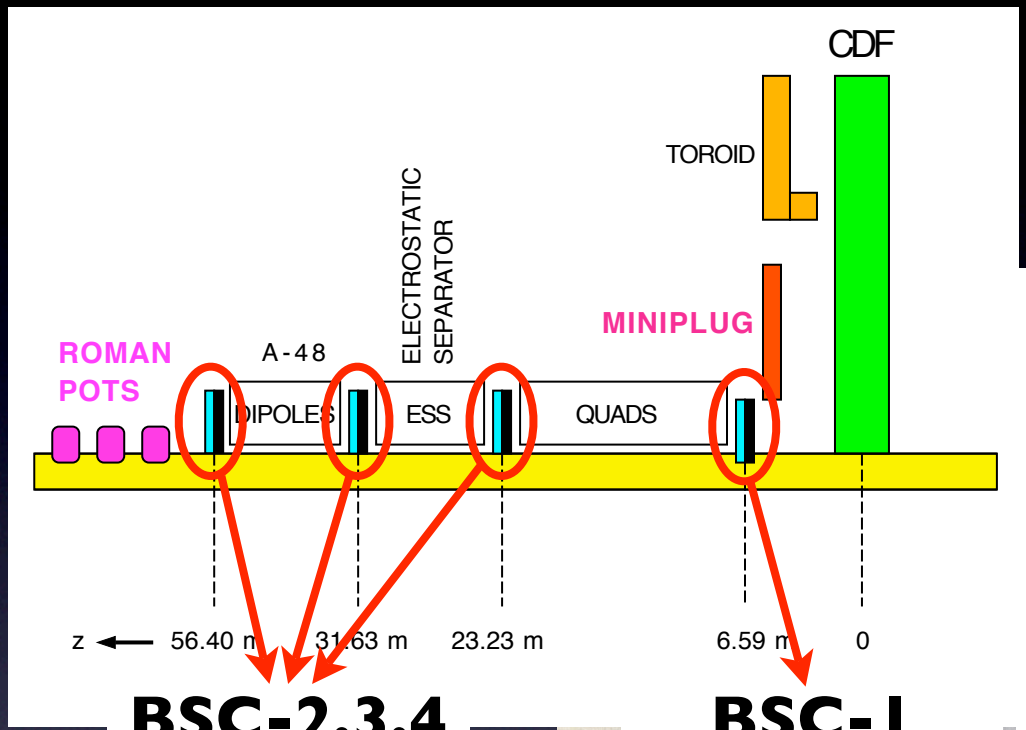




Resolution

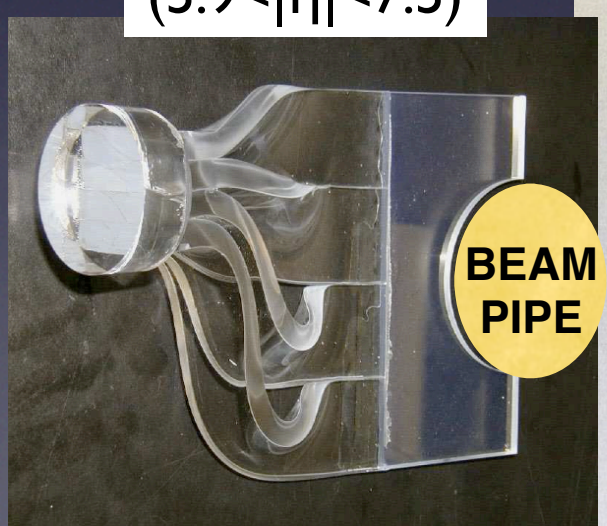
Position	~100μm
Angle	~70μrad

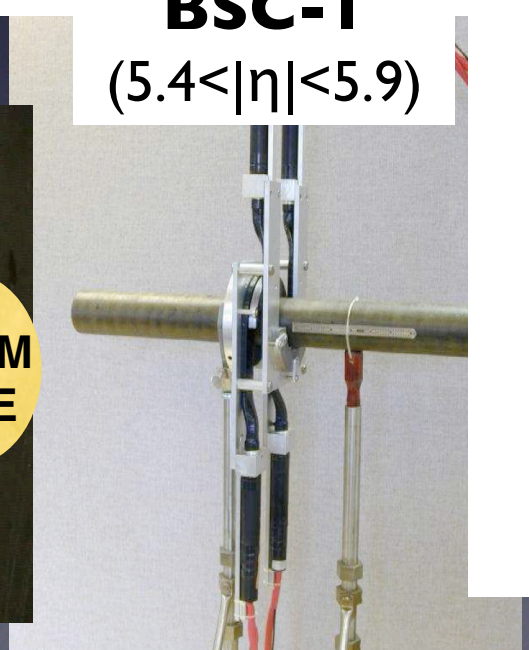
Beam Shower Counters



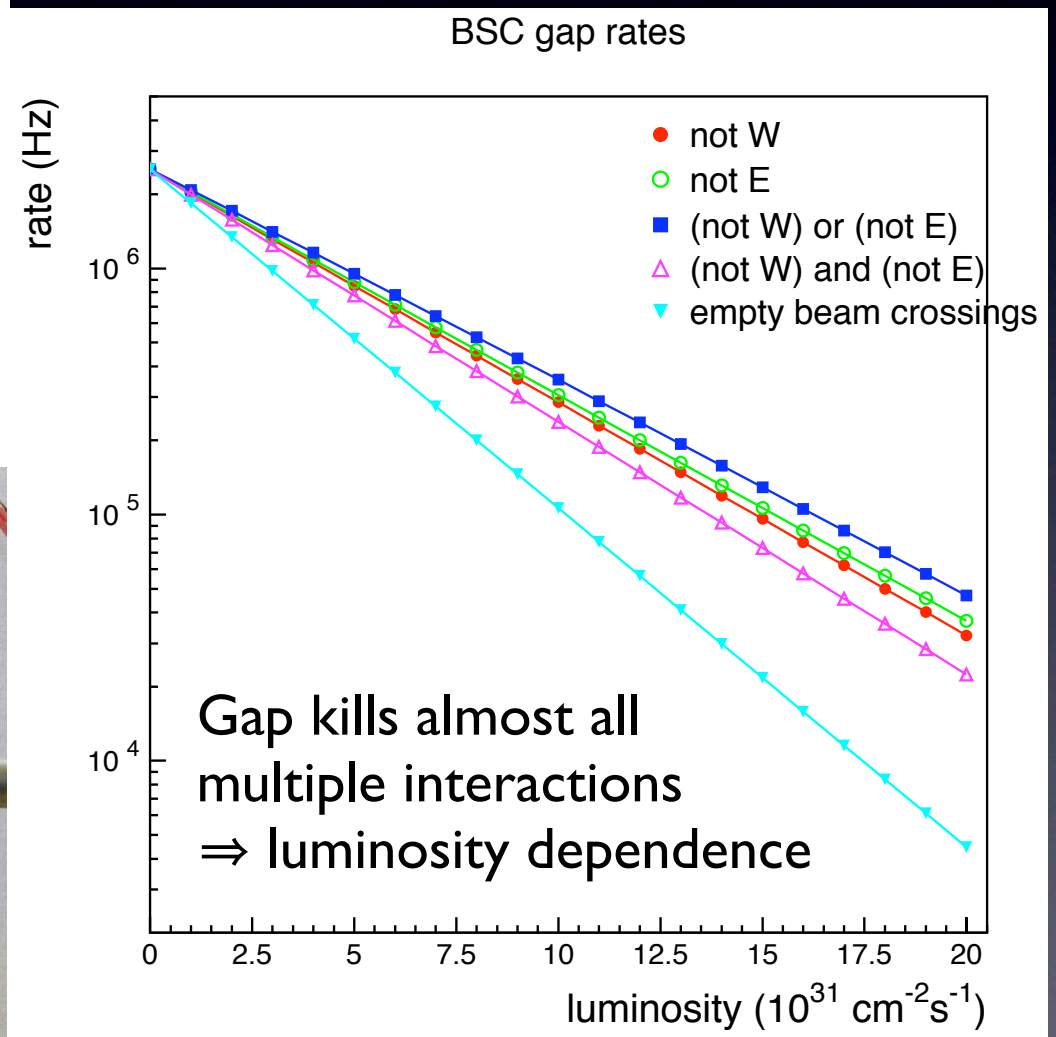
BSC-2,3,4
(5.9<|η|<7.5)

BSC-1
(5.4<|η|<5.9)



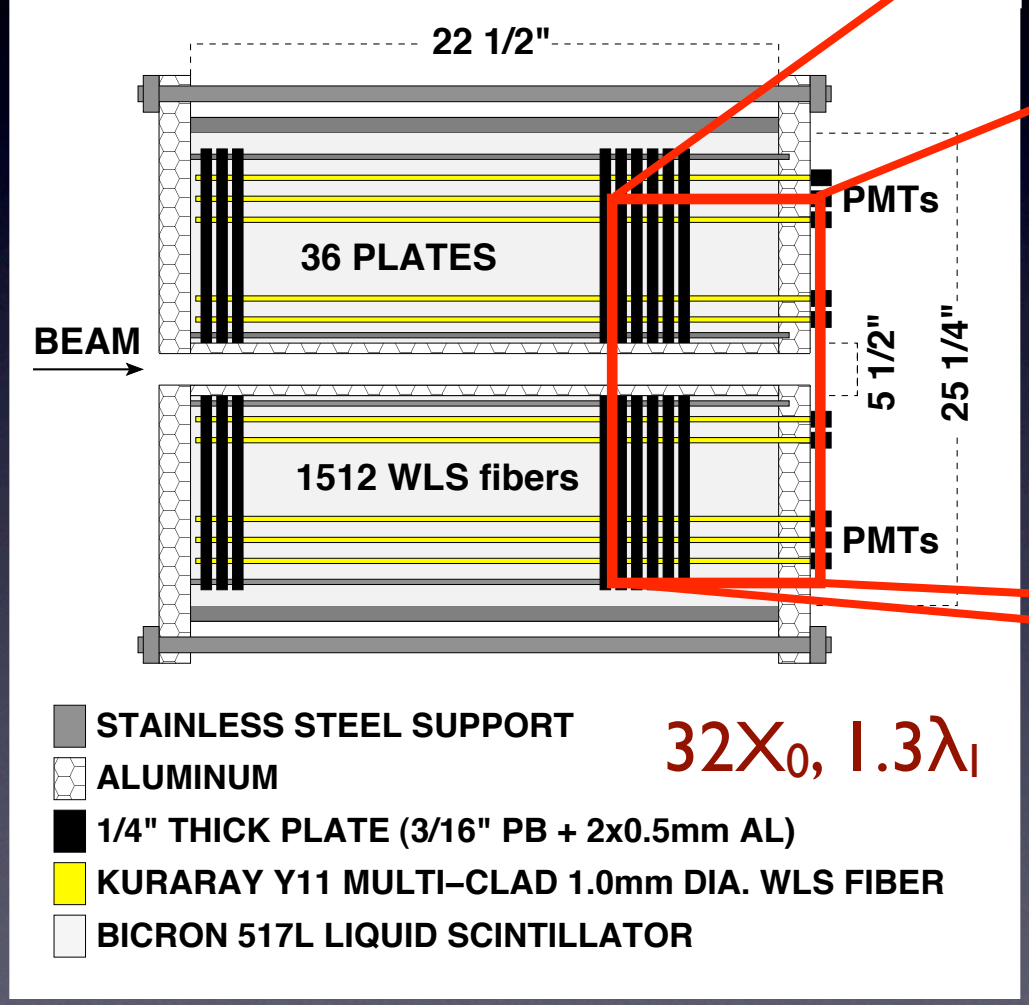


Require BSC veto (gap)
- ➡ Reject >95% of non-diff. events
- ➡ Retain >95% of diff. events with ξ<0.1



MiniPlug Calorimeters

Electromagnetic calorimeter with hadron detection capability

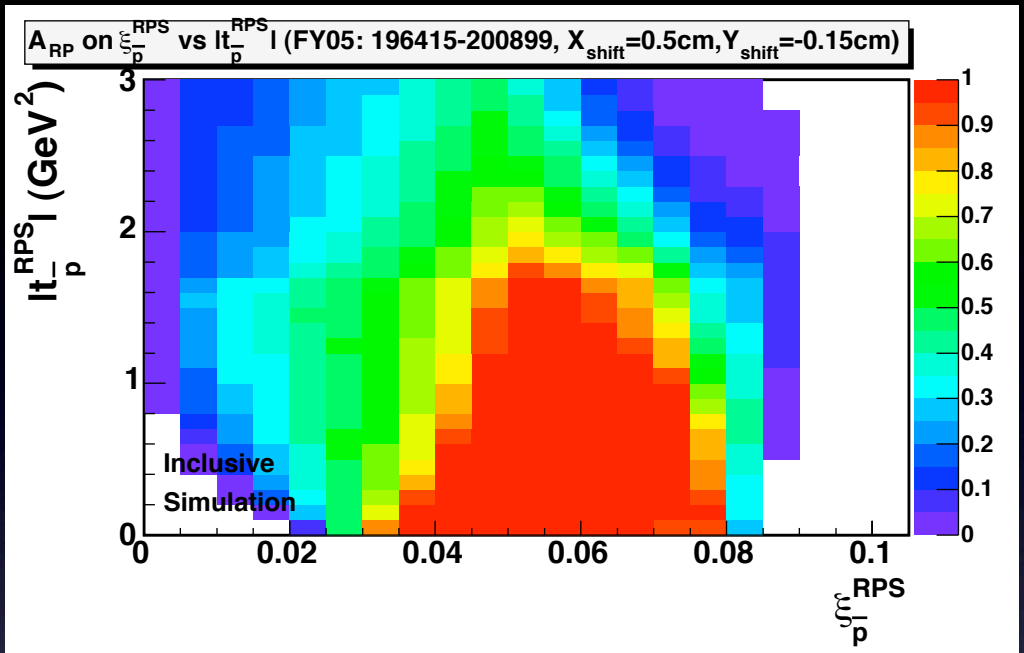


$32X_0$, $1.3\lambda_I$

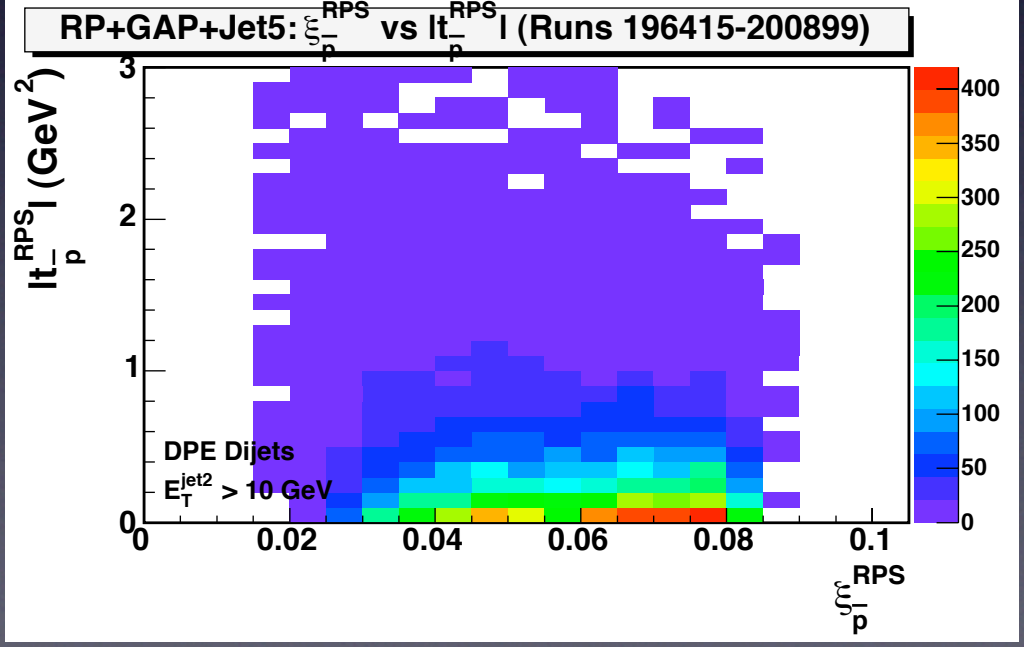
Read out by WLS fibers

- ➡ Good position resolution retained
- ➡ Used to measure particle energy and multiplicity in $3.6<|\eta|<5.2$

RP Spectrometer Acceptance



inclusive (simulation)



DPE di-jets (data)

78.4±0.3(stat) %

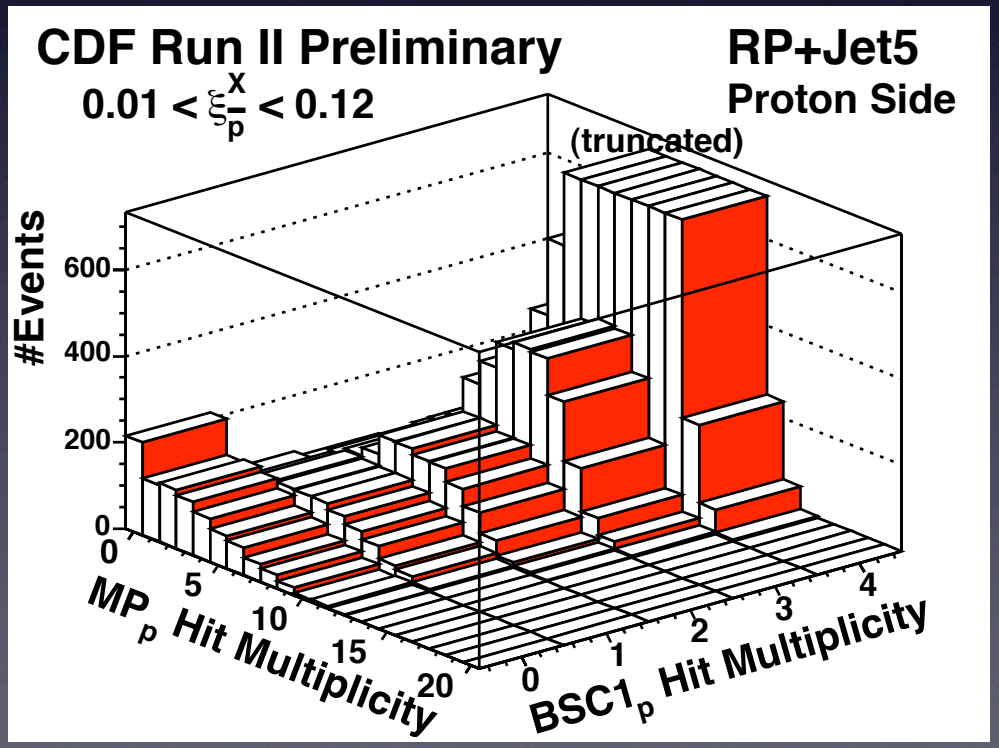
at $0 < \xi < 0.1$, $|t|<3$ GeV^2

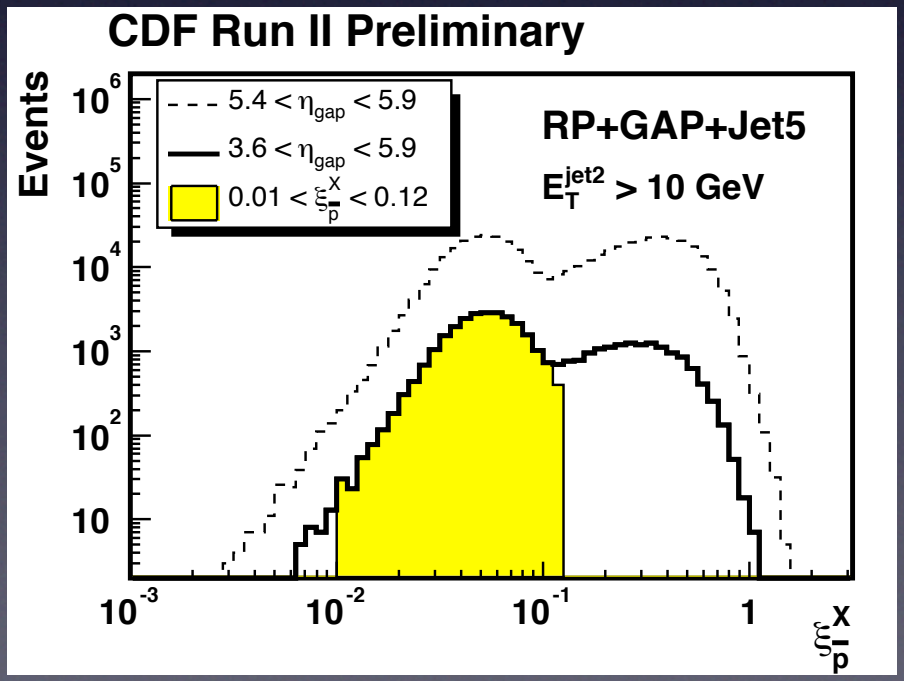
Data Sample and Selections

Data Selection : DPE Jet Trigger (312.5±18.7 pb^{-1})

- Single Vertex
- ≥2 jets with E_T>10 GeV and $|\eta|$<2.5 (corrected to hadron level)
- ZERO hit multiplicity in MP_p and CLC_p
- $0.01 < \xi_{\bar{p}}^{x} < 0.12$ to reject events with multiple $\bar{p}p$ interactions

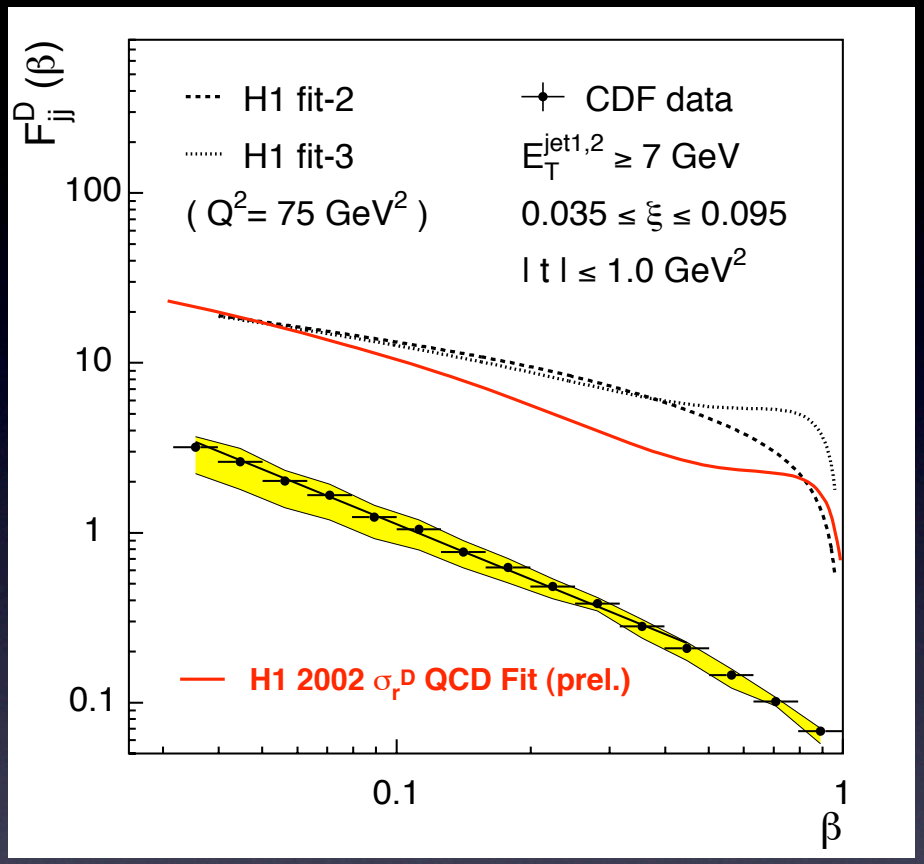
$$\xi_{\bar{p}}^{x} = \frac{\sum_{towers} E_T e^{-\eta}}{\sqrt{s}}$$



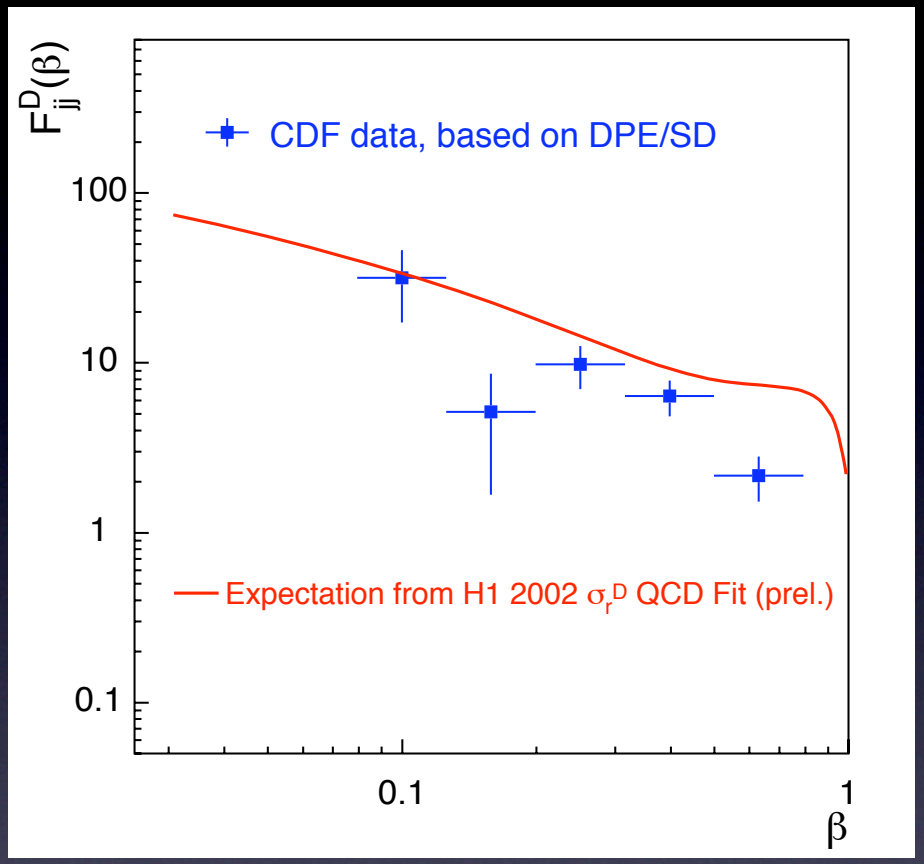


CDF Diffractive Structure Functions

F_{jj}^D from SD dijets



F_{jj}^D from DPE dijets



$$F_{jj}^D(\beta,\xi) = C \cdot \beta^{-n} \cdot \xi^{-m}$$

n = 1.0±0.1

m = 0.9±0.1

⇒ Pomeron exchange

2nd gap less suppressed

⇒ approx. equal to H1 dPDF

$IP_1+IP_2 \rightarrow X$	IP_1	IP_2
CDF	β^{-1}	β^{-1}
CDF⊕H1	β^{-1}	H1-fit2

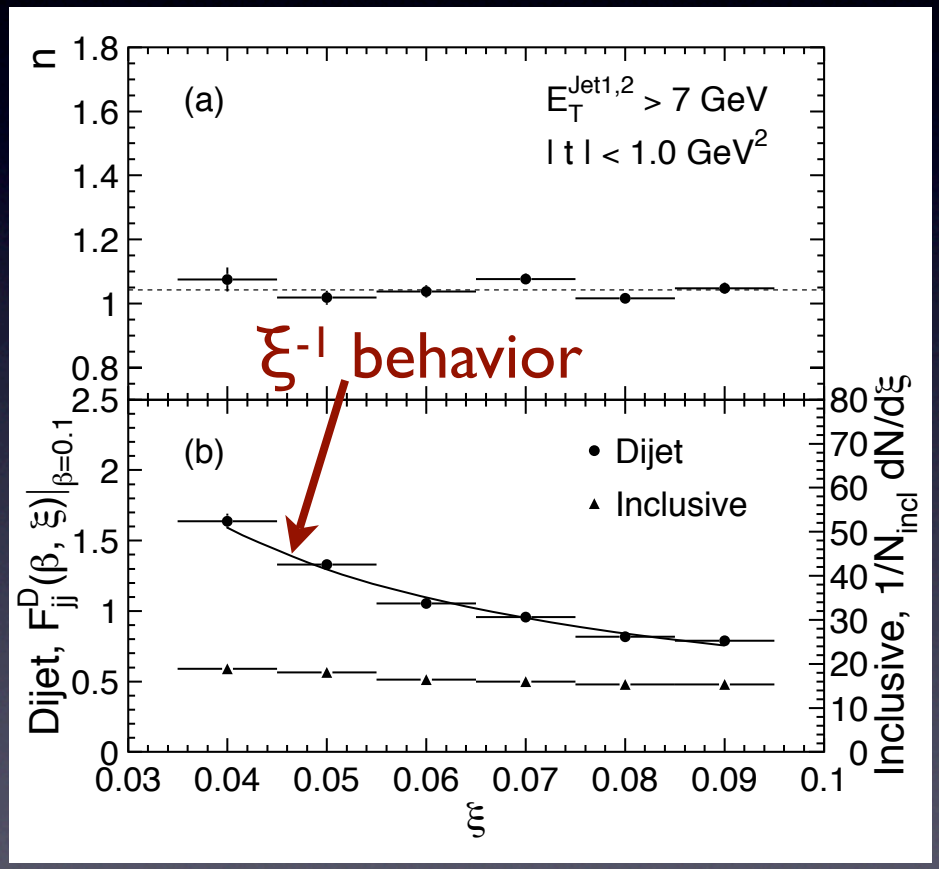
Reggeon Contributions

Pomeron/Reggeon contributions:

$$F_{jj}^{D}(\beta) \sim \Sigma_{i=IP,IR} \int dt \int d\xi\, C_i\, f_{i/p}(\xi,t)\, F_{jj}^{i}(\beta)$$

flux : $f_{i/p}(\xi,t) = e^{b_i t}\, \xi^{1-2\alpha_i(t)}$

	IP	IR
$\alpha_i(t)$	1.20+0.26t	0.57+0.9t
b_i (GeV^{-2})	4.6	2.0
C_i	1	16 (fit 2)



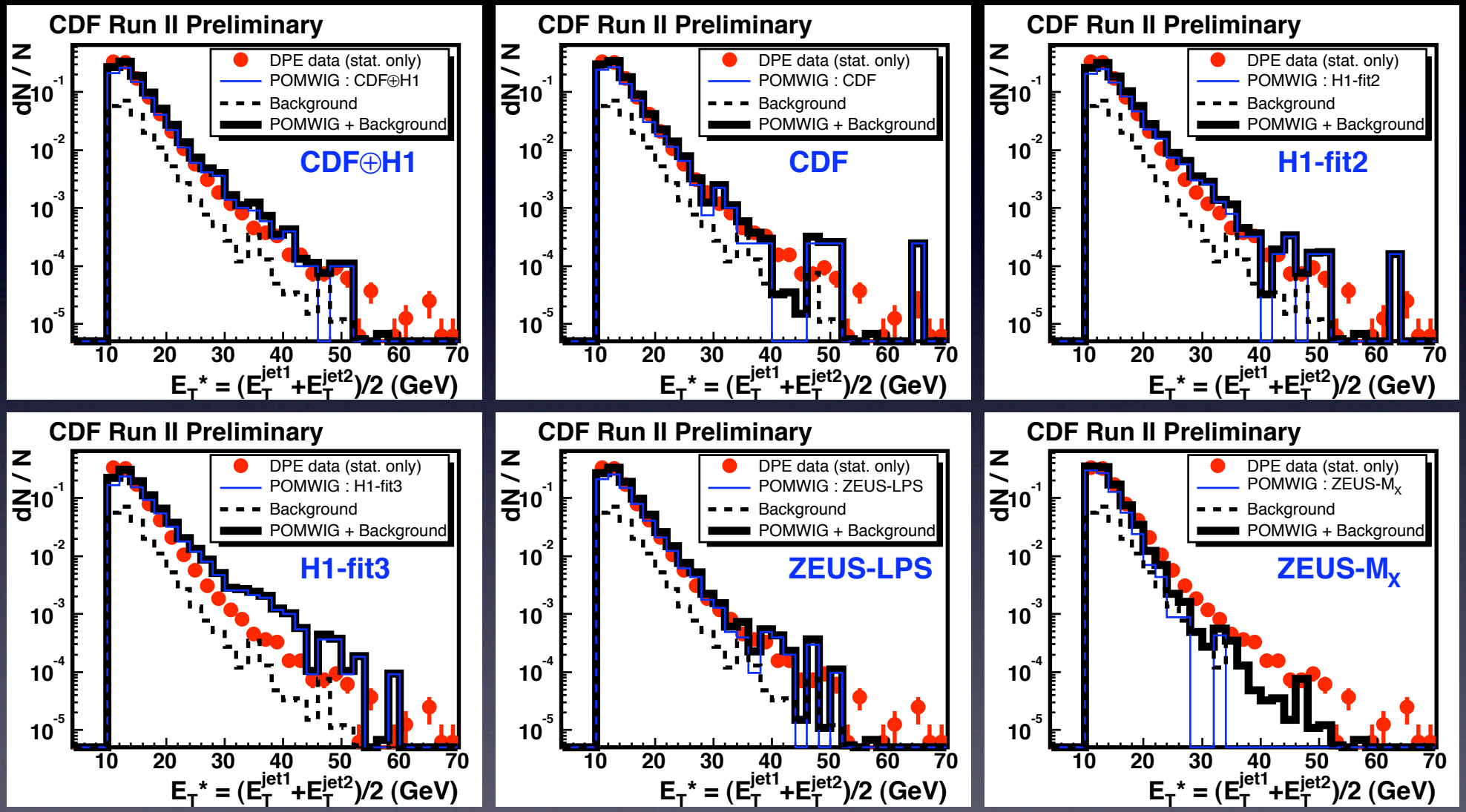
Pomeron/Reggeon flux ratio = 67(19)

at ξ =0.035(0.095), |t|=0.01 GeV^2

⇒ small IR contributions in CDF data

Mean Jet E_T

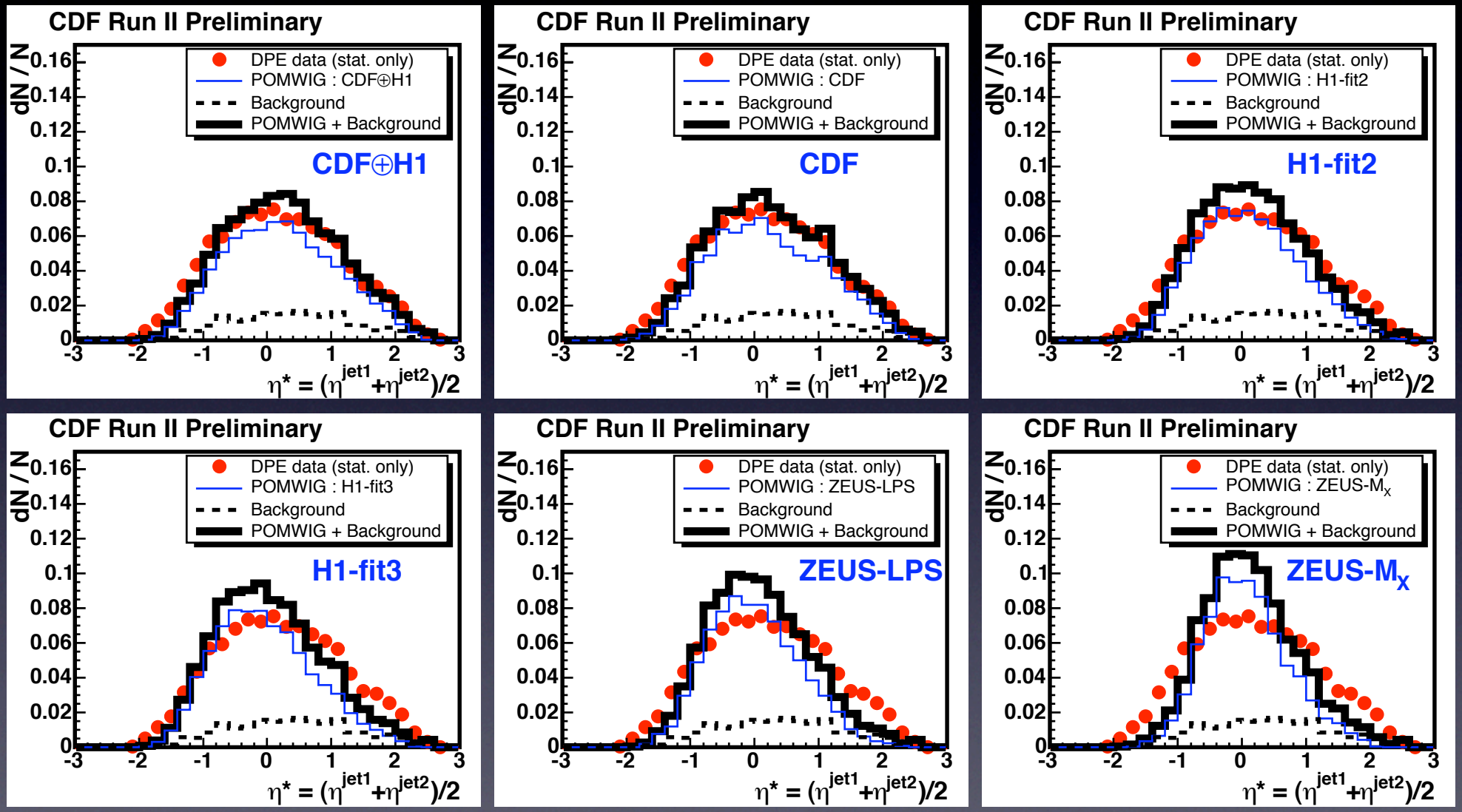
Shape comparison between data and POMWIG MC



POMWIG MC = DPE Signal + ND&SD Background (from data)

Mean Jet Pseudorapidity

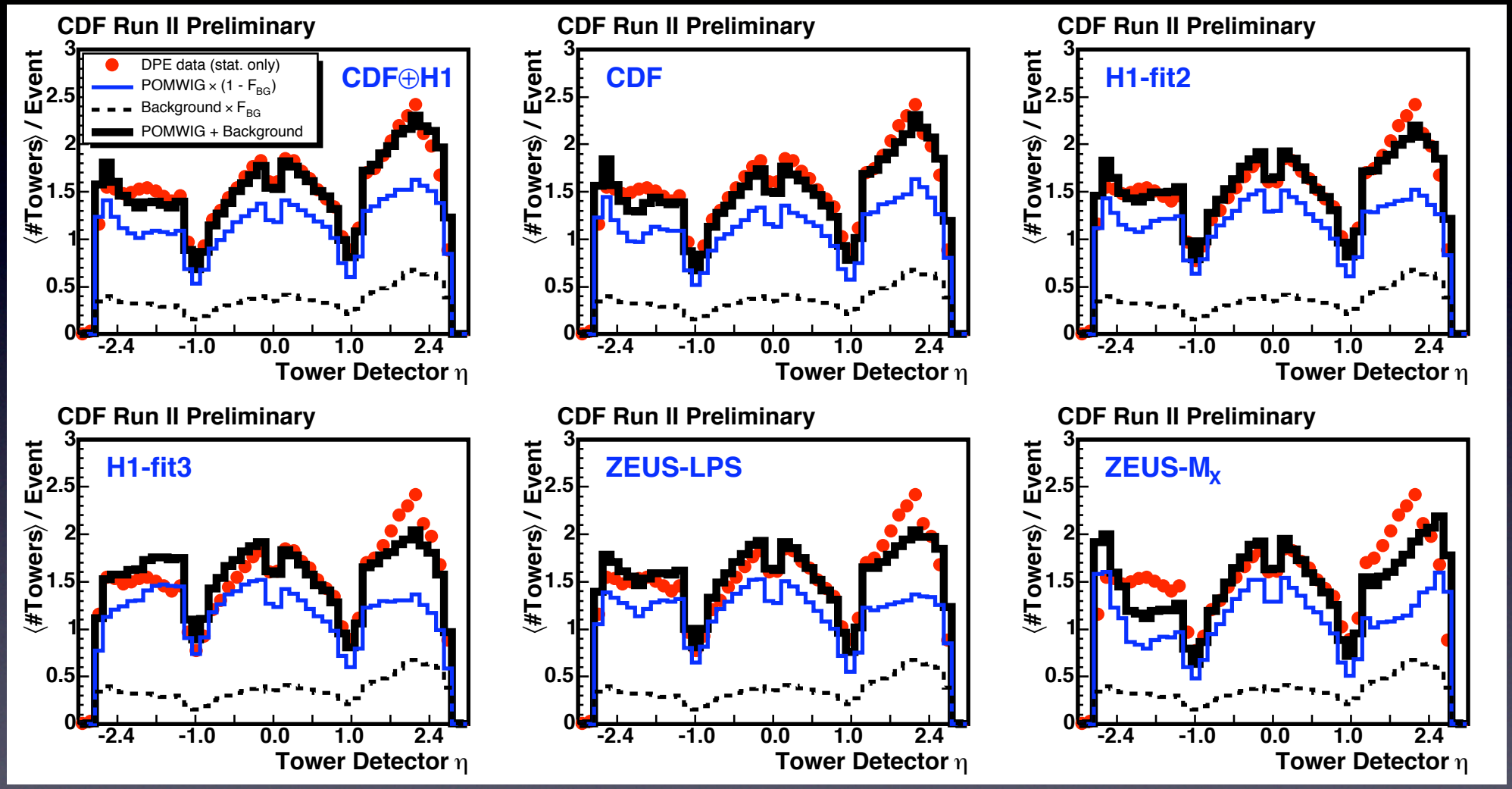
Shape comparison between data and POMWIG MC



POMWIG MC = DPE Signal + ND&SD Background (from data)

Calorimeter Tower Multiplicity

Tower E_T>100 MeV

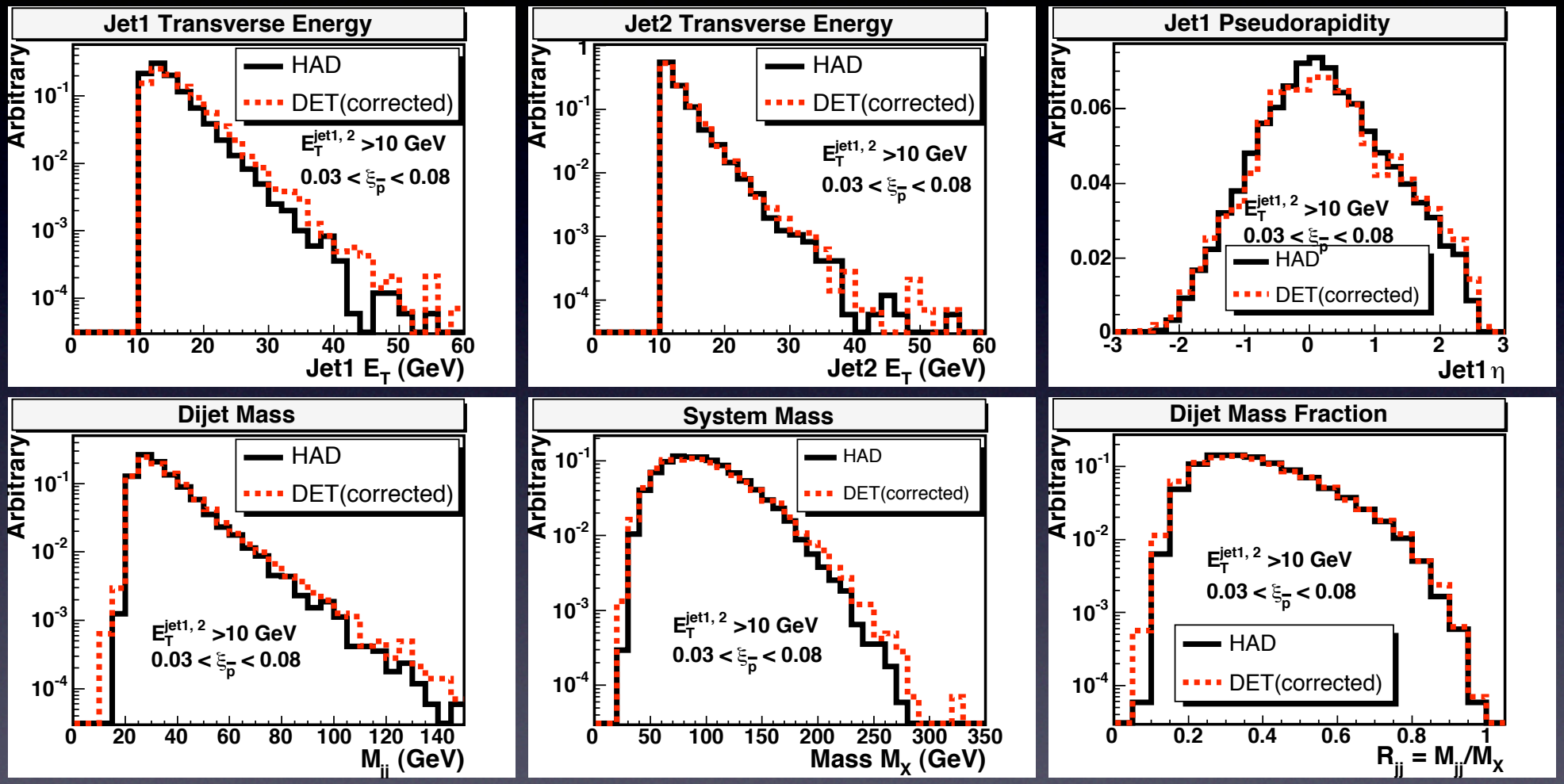


➡ H1-fit3 (ZEUS-MX) looks too hard (soft)

➡ POMWIG with other 4 PDFs reproduces data shapes well

Detector Effects

All distributions are POMWIG DPE signal (CDF⊕H1)



Corrected detector-level distributions agree well with hadron-level distributions

Comparison with KMR

More direct comparison with KMR calculations including hadronization effects preferred

CDF out-of-cone energy measurement (cone R=0.7) :

- 20-25% at E_T^{jet}=10-20 GeV
- 10-15% at E_T^{jet}=25-35 GeV

Good agreement with data found by rescaling parton p_T to hadron jet E_T