Multiple Parton Interaction Studies at DØ

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on behalf of the DØ Collaboration

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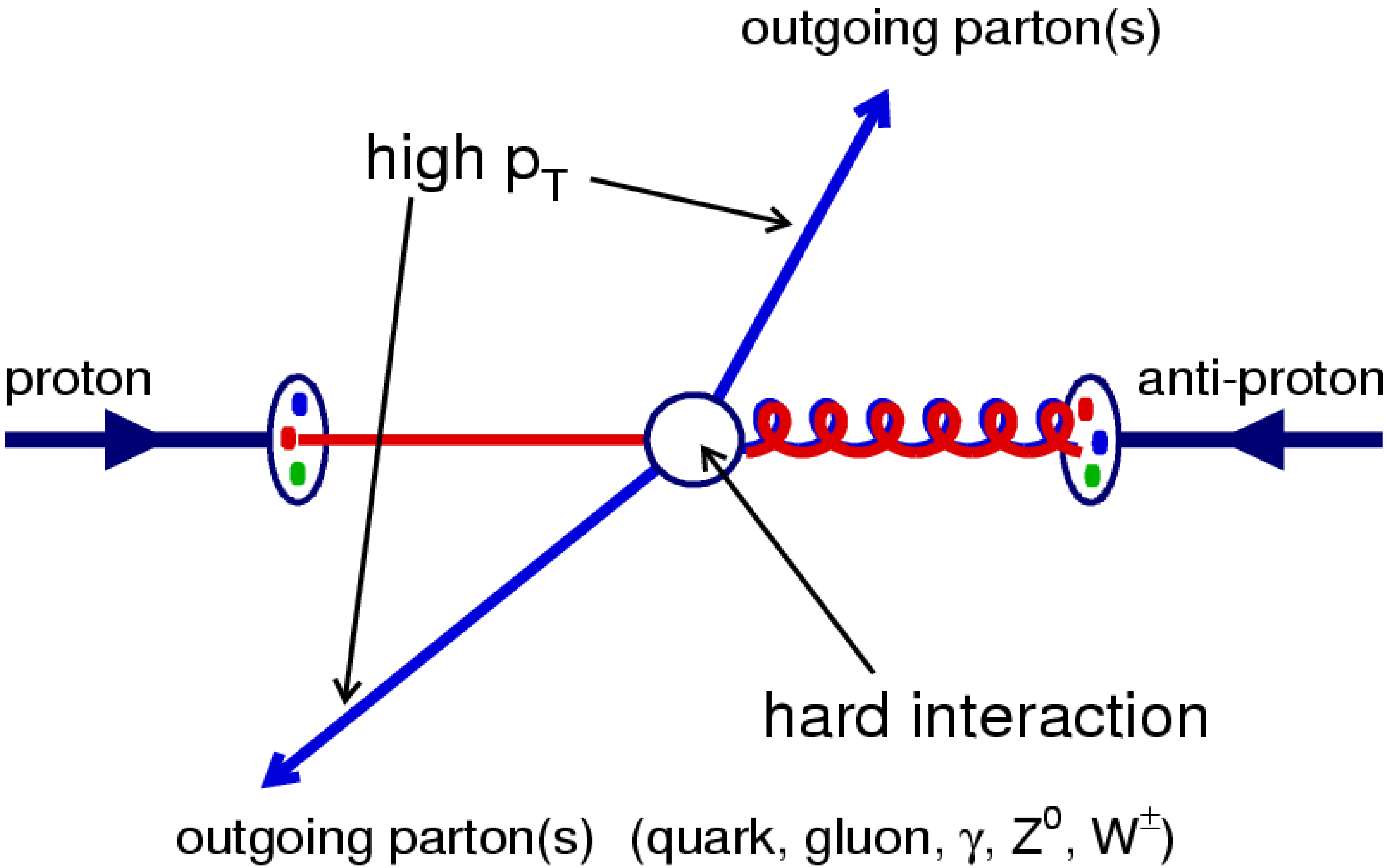
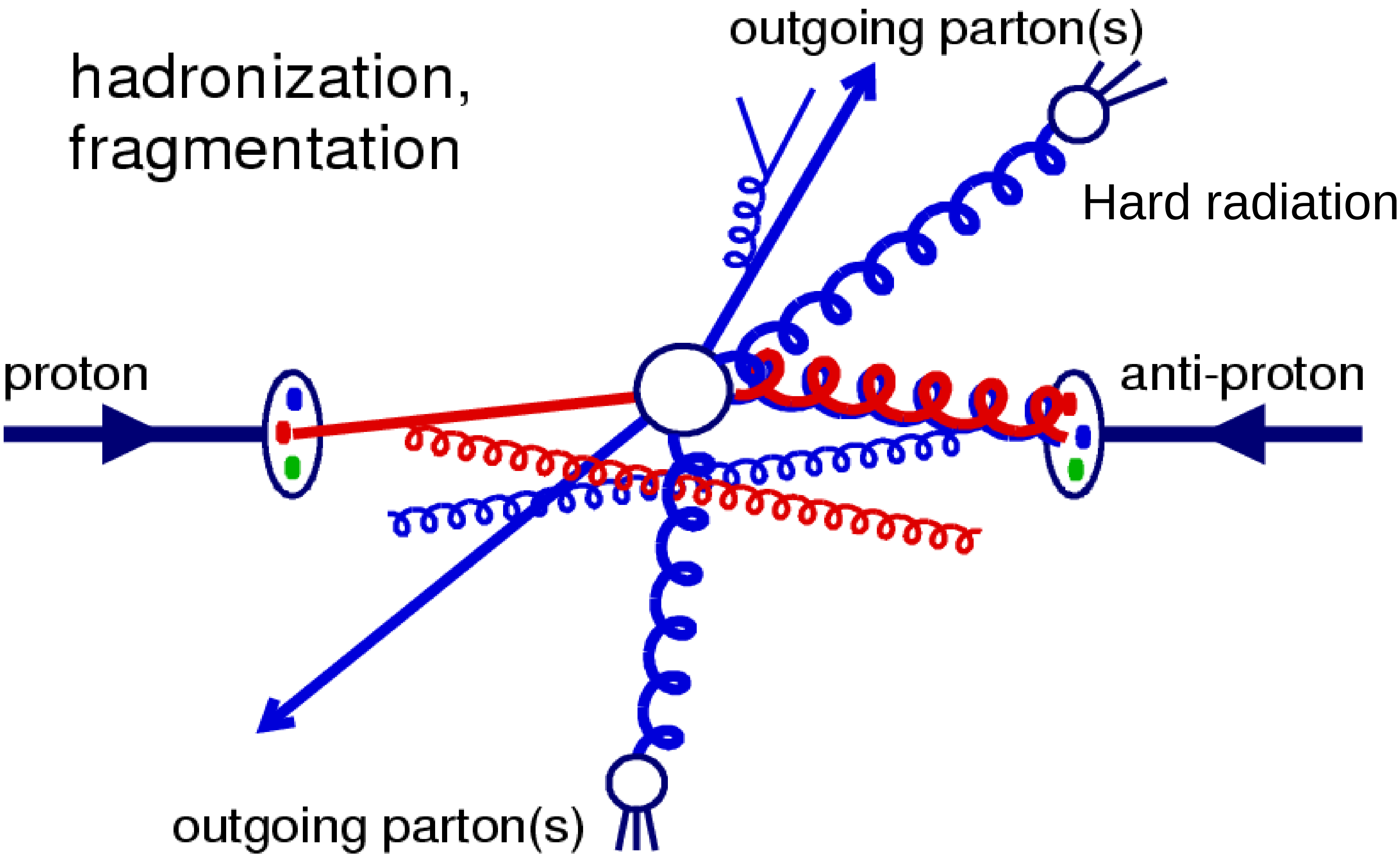
Outline

- Big ideas and history
- Double Parton interactions in $\gamma\gamma$ + dijet
- Double Parton interaction in $J/\psi + \Upsilon$ events
- Summary / interpretation

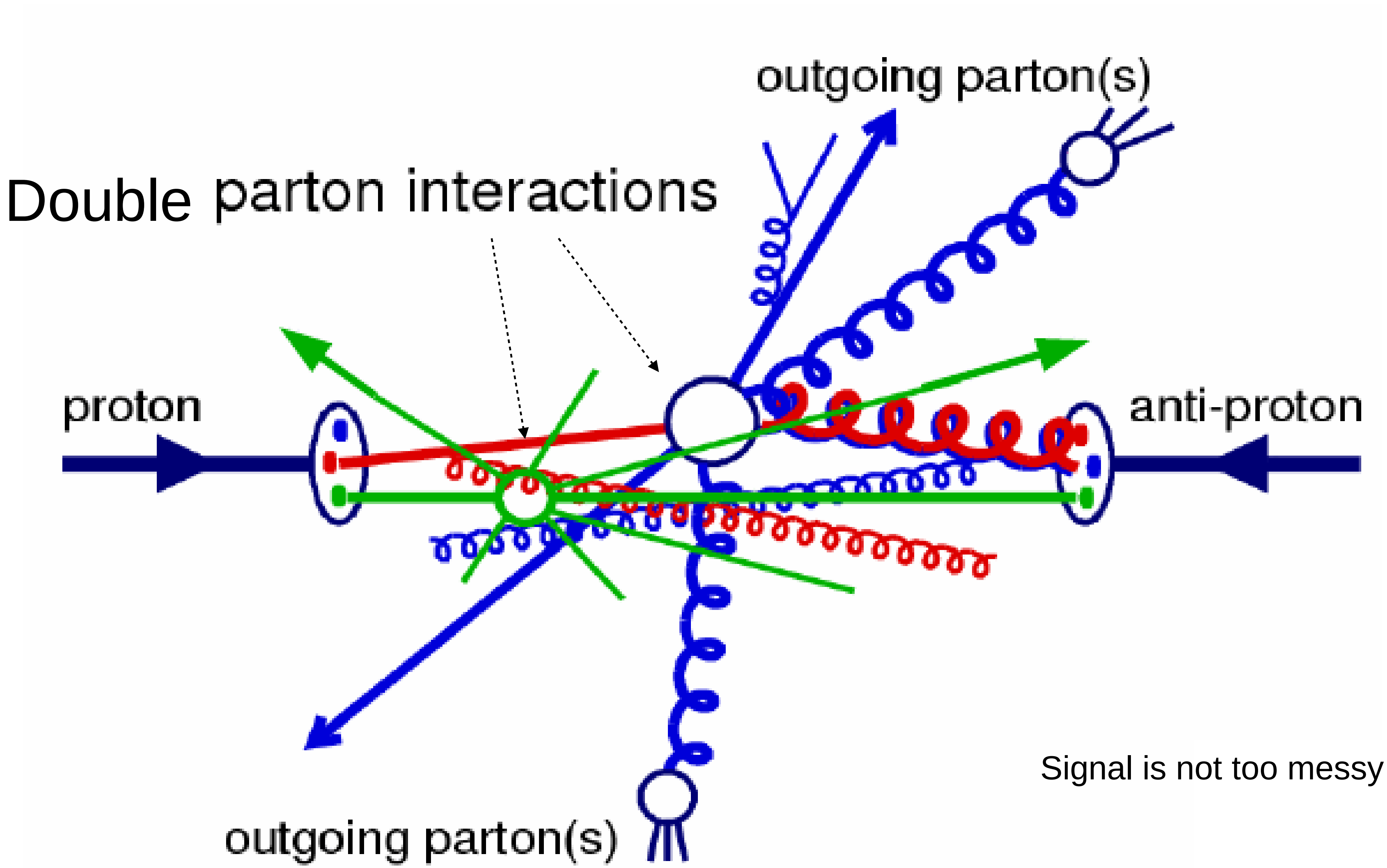
Hadron-Hadron collision: simplified



Hadron-Hadron collision: traditional



Hadron-Hadron Collision: Double parton interactions



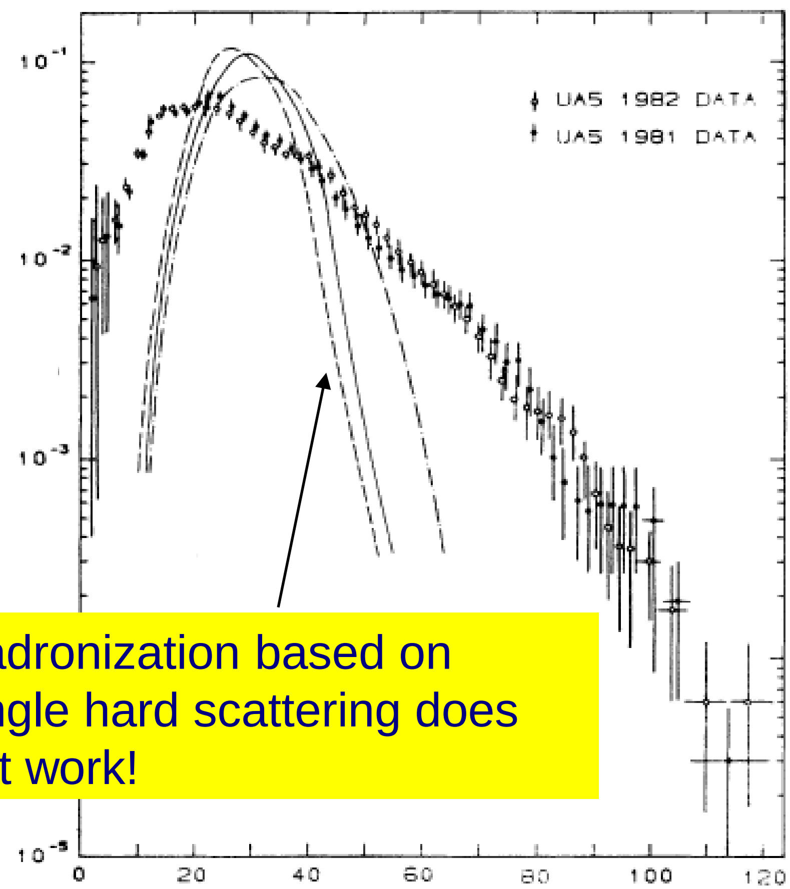
Signal is not too messy

Historical data #1

Charged particle multiplicity

UA5, 540 GeV, ppbar

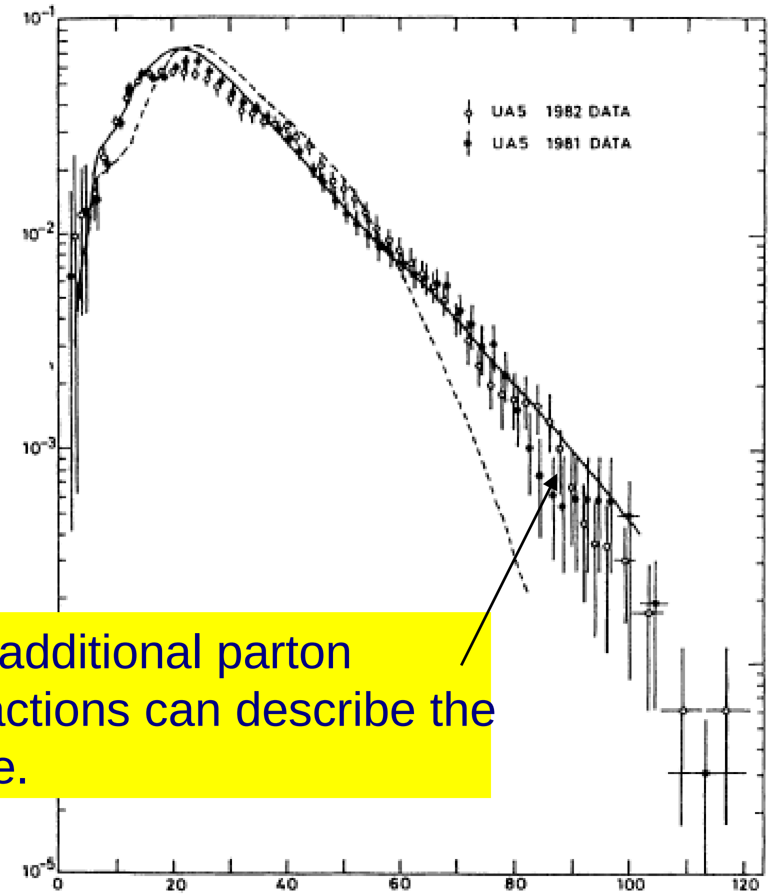
Hard scattering only; +ISR/FSR



Hadronization based on single hard scattering does not work!

Nch

Multiple Parton Interaction models



Only additional parton interactions can describe the shape.

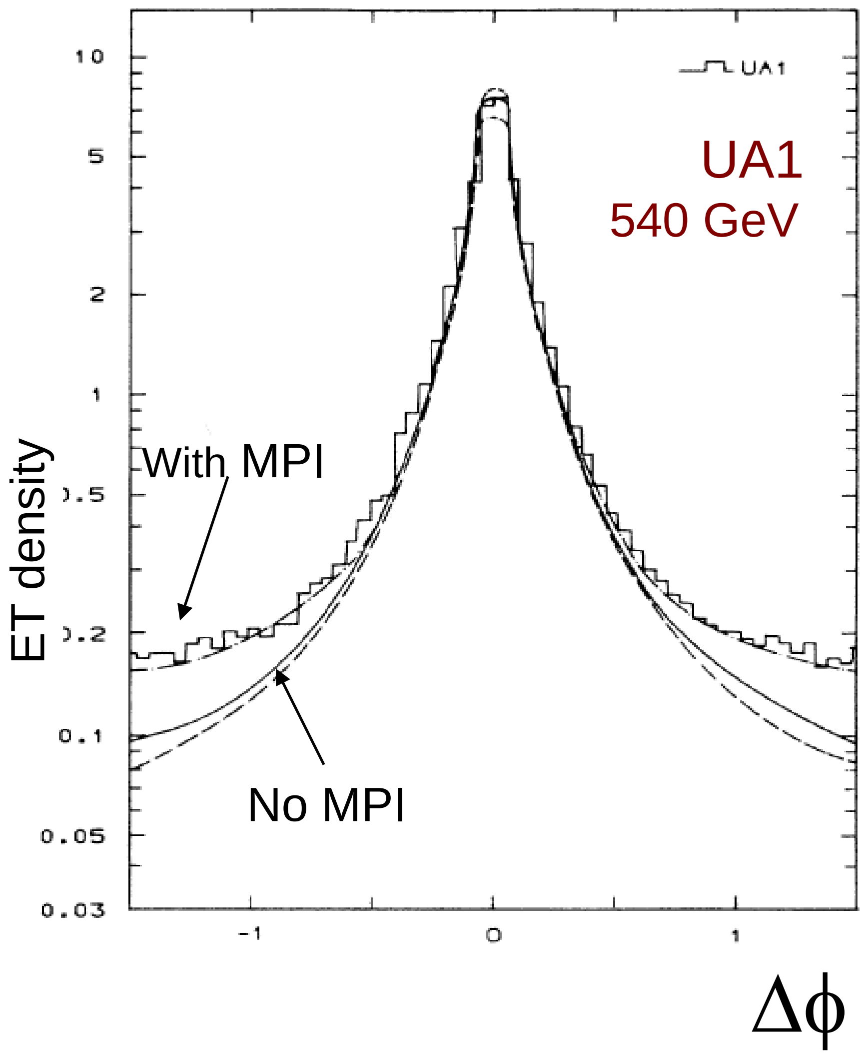
Nch

σ_n is a cross section to produce a final state with *n* tracks (Nch).

Historical data #2

Jet pedestal effect

Jet pT>35 GeV



ET density distribution inside and around jet can only be described if MPI contribution is taken into account.

ET density and charge particle multiplicities allowed T.Sjostrand and M.van Zijl to build first real, software-implemented MPI model (aka “Tune A”) and describe many “puzzling features” in jet productions in UA1-UA5: PRD36 (1987) 2019

Motivation

Most MPI processes are non-perturbative

implemented in models of hadron structure and fragmentation.

Being phenomenological, experimental input crucial. [mainly minbias]

Tevatron (0.63, 1.8, 1.96 TeV; + recent 0.3, 0.9 runs)
SPS (0.2, 0.54, 0.9 TeV),
LHC (7 & 8 TeV data)
Tevatron DY and similar LHC data.

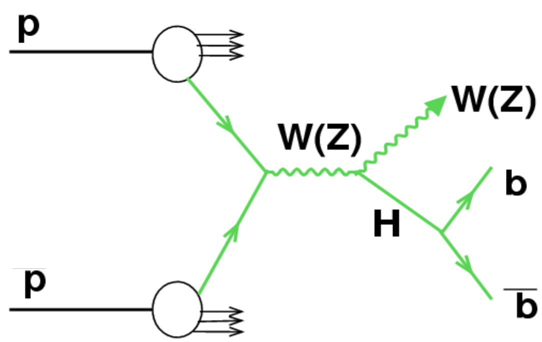
MPI can be tested in higher pT regime [e.g. pT(jet) > 15 GeV]

In the energy regime of perturbative QCD!
MPI events can mimic a signature of a new physics processes

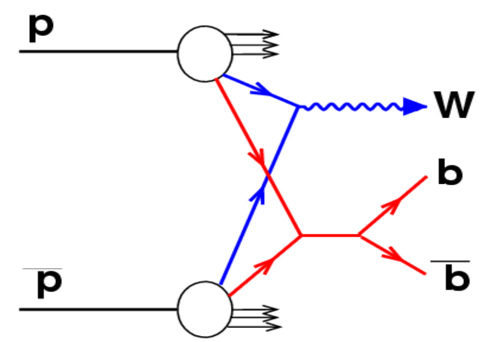
Having measured MPI observable and reliably calculable partonic cross section, one can limit MPI phenomenological models.

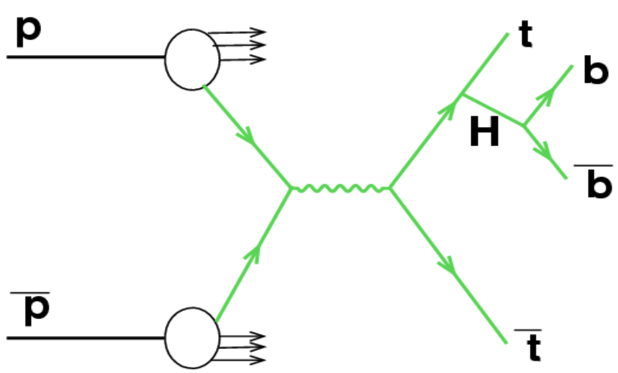
Double Parton events: Higgs production background

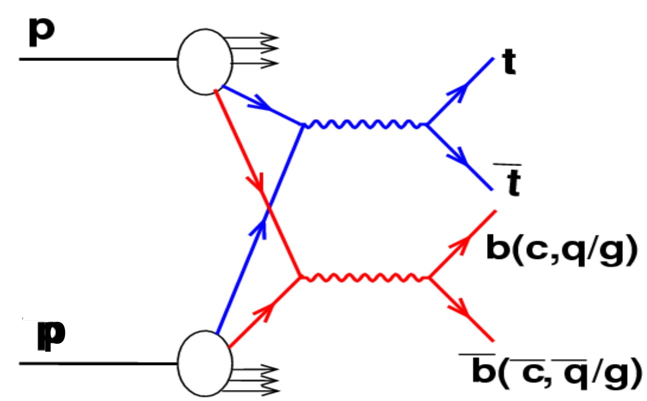
SP Signal



DP background







- ➢ Many Higgs production channels can be mimicked by a Double Parton event!
- ➢ Same is true for many other rare (especially multijet) processes

Double parton and effective cross sections

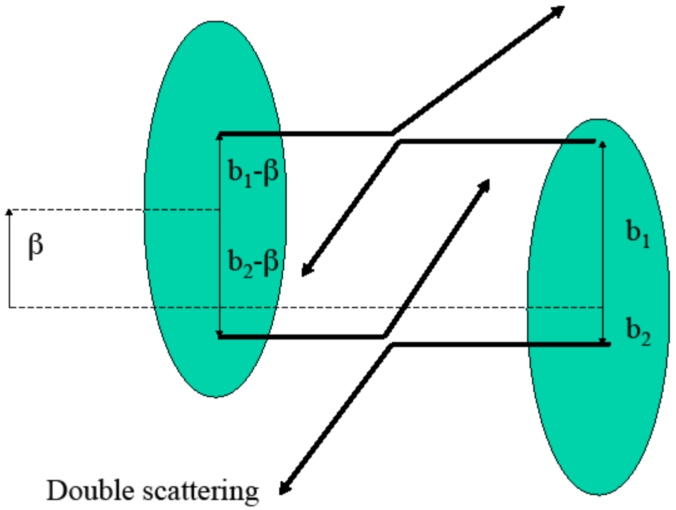
σ_{DP} - double parton cross section for processes A and B

σ_{eff} - characterizes size of effective interaction region

→ information on the spatial distribution of partons.

Uniform: σ_{eff} is large and σ_{DP} is small

Compact: σ_{eff} is small and σ_{DP} is large



→ σ_{eff} is phenomenological parameter
=> should be measured in experiment !

$$\sigma_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{\mathrm{eff}}}$$

Effective cross section σ_{eff} is directly related with parton spatial density:

$$\sigma_{\mathrm{eff}} = [\int d^2\beta [F(\beta)]^2]^{-1}$$

$$F(\beta) = \int f(b) f(1-b) d^2 b$$

where f(b) is the density of partons in transverse space.

=> Having σ_{eff} measured we can estimate f(b)

β is impact parameter

Double Parton Interactions in $\gamma\,\gamma$ + dijet events:

New!!!

- Extraction of DP events
- Measurement of effective cross section

- Basic approach:
  - Determine photon purity
  - Determine photon + jet acceptance
  - Determine double parton fractions

  - Count events, divide by luminosity
    - Calculate DP cross-section
    - Calculate σ_{eff}.
    - The usual.

Kinematic cuts:

Diphotons
$P_T^{\gamma 1} > 16$ GeV, $P_T^{\gamma 2} > 15$ GeV
$|y| < 1.0$

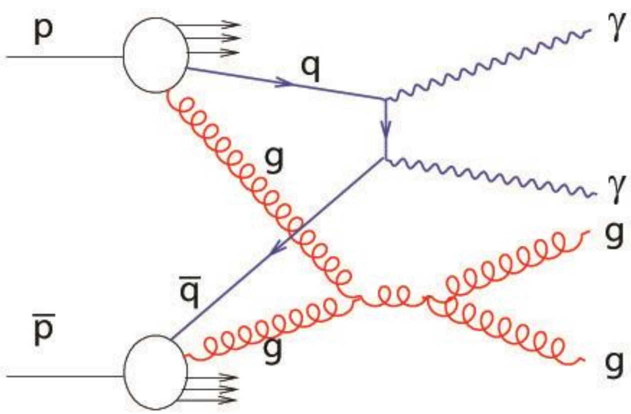
Dijets
$15 < P_T^{jet} < 40$ GeV
$|y| < 3.5$

Number events
$N_{1vtx} = 401$
$N_{2vtx} = 442$

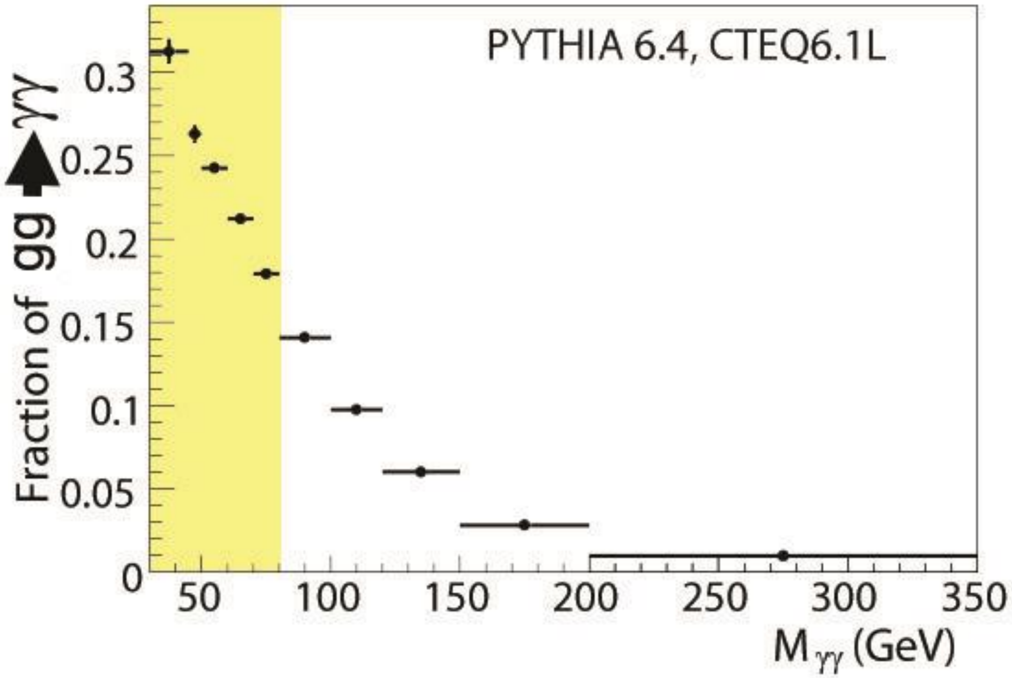
Double Parton Interactions in $\gamma\,\gamma$ + dijet events:

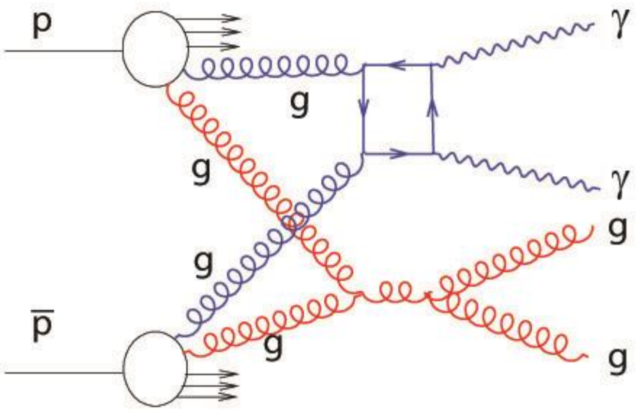
New!!!

- Double parton origins



70 – 80%





20 – 30%

Note that the jet cross section is dominated by $gg \rightarrow gg$ in this kinematic regime.

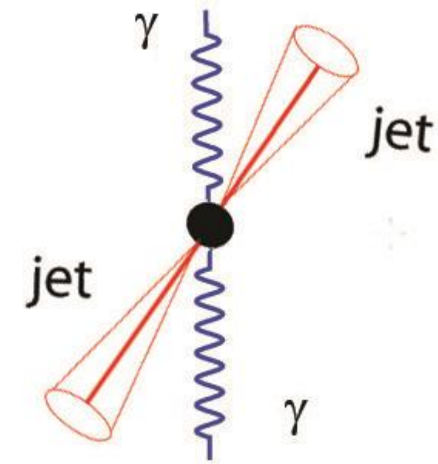
Double Parton Interactions in $\gamma\,\gamma$ + dijet events:

New!!!

- Double parton origins

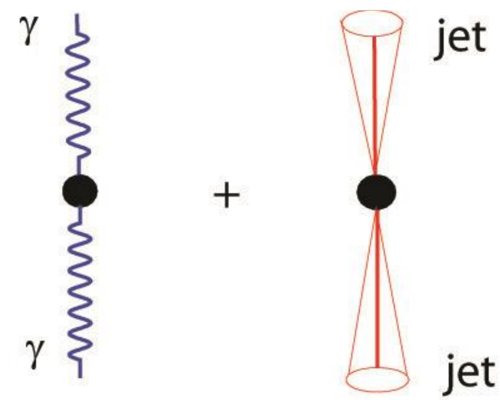
For two hard interactions:
at one pp collision
(Double Parton scattering)

$$P_{DP} = \left(\frac{\sigma^{\gamma\gamma}}{\sigma_{hard}}\right)\left(\frac{\sigma^{jj}}{\sigma_{eff}}\right)$$



For two hard scattering events
at two separate pp collisions
(Double Interaction):

$$P_{DI} = 2\left(\frac{\sigma^{\gamma\gamma}}{\sigma_{hard}}\right)\left(\frac{\sigma^{jj}}{\sigma_{hard}}\right)$$



Same approach as in 1fb^{-1} measurement, PRD81, 052012 (2010)

arXiv:XXXXX

Double Parton Interactions in $\gamma\,\gamma$ + dijet events:

New!!!

$$N_{DP} = P_{DP} \times N_{1int} = \left(\frac{\sigma^{\gamma\gamma}}{\sigma_{hard}}\right)\left(\frac{\sigma^{jj}}{\sigma_{eff}}\right) N_{1col} A_{DP} \epsilon_{DP} \epsilon_{1vtx}$$

$$N_{DI} = P_{DI} \times N_{2int} = 2\left(\frac{\sigma^{\gamma\gamma}}{\sigma_{hard}}\right)\left(\frac{\sigma^{jj}}{\sigma_{hard}}\right) N_{2col} A_{DI} \epsilon_{DI} \epsilon_{2vtx}$$

$$\sigma_{eff} = \frac{1}{2}\frac{N_{DI}}{N_{DP}}\frac{A_{DP}}{A_{DI}}\frac{\epsilon_{DP}}{\epsilon_{DI}}\frac{\epsilon_{1vtx}}{\epsilon_{2vtx}}\frac{N_{1col}}{N_{2col}}\sigma_{hard}$$

Note that

(a) all variables are experimentally derived; or

(b) all variables are in ratios that greatly reduce systematic uncertainties

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Double Parton Interactions in $\gamma\ \gamma$ + dijet events:

New!!!

$\frac{\epsilon_{1vtx}}{\epsilon_{2vtx}}$ 1.021 ± 0.005 Determined in data

$\frac{A_{DP}}{A_{DI}}$ 0.521 ± 0.015 Determined in MC [Pythia and Sherpa]. Difference in acceptance due to variation of energy in jet and photon cones, which vary the chance to pass p_T and η cuts.

$\frac{\epsilon_{DP}}{\epsilon_{DI}}$ 1.372 ± 0.039 Determined in MC [Pythia and Sherpa]. Difference in acceptance due to variation of energy near photons, which affects photon isolation.

Note that

(a) all variables are experimentally derived; or

(b) all variables are in ratios that greatly reduce systematic uncertainties

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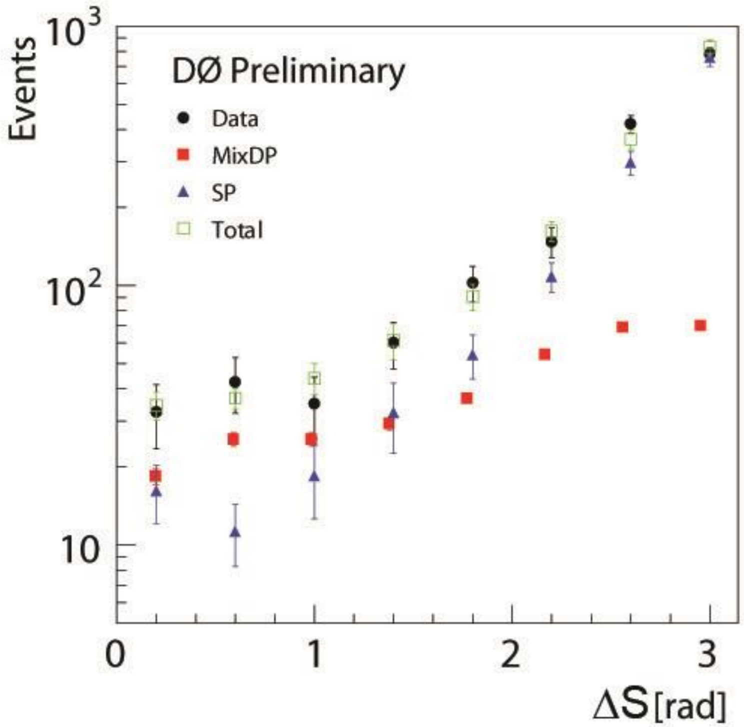
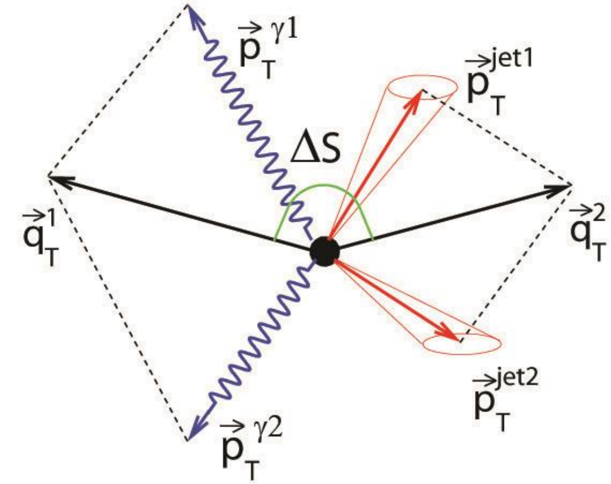
N_{DP}: Single Parton vs Double Parton: ΔS distribution



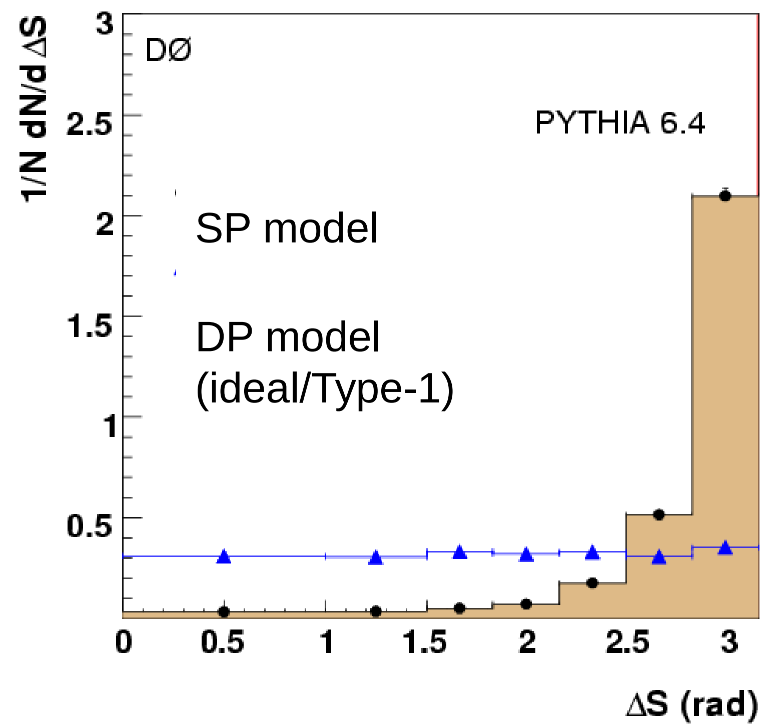
DP events have two uncorrelated scattering centers. ΔS should be flat.

For SP events, ΔS should peak at π.



$$\Delta S = \Delta\phi(p_T^{\gamma,\gamma}, p_T^{jet,jet})$$

In single vertex events, can use ΔS distribution to fit to DS determine $N_{DP} = 401 \times f_{DP}$



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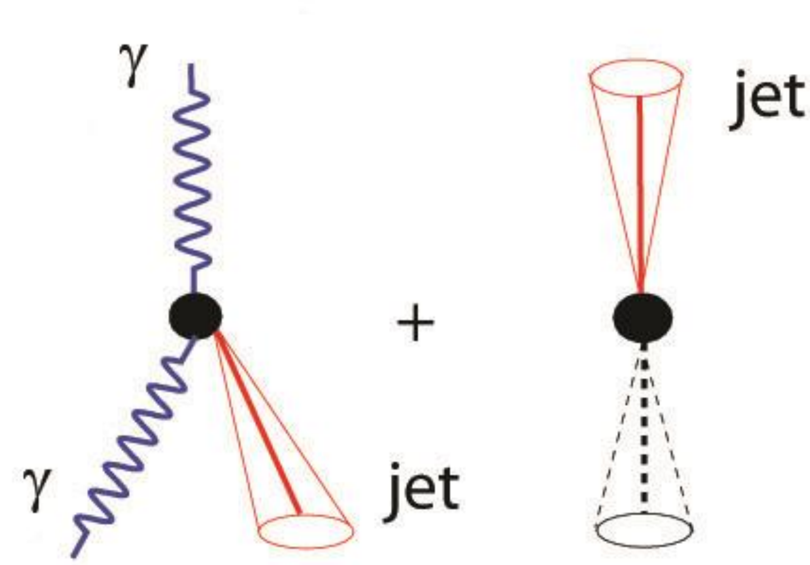
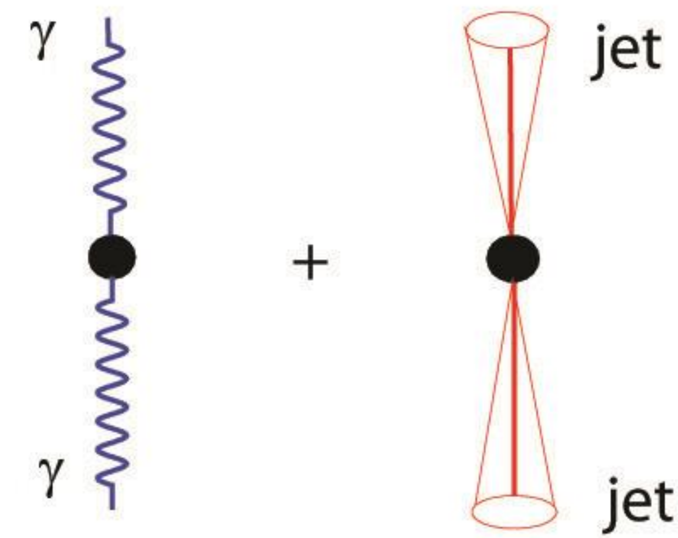
N_{DI}: Number of Double Interaction Events: Vertex pointing

DI $\gamma\gamma$ + dijet events must come from two vertices, one with diphoton and one with dijets.

Look at events with two vertices and use tracks associated with jets to determine their vertex of origin.

$N_{DI} = 442 \times f_{DI}$





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Number of one and two vertex collisions

$$\frac{1}{2}\frac{N_{1col}}{N_{2col}}\sigma_{hard}$$

Determined by world average Tevatron

σ_{hard} = 44.76 ± 2.89 mb

The number of events with one and two collisions determined by integrating σ_{hard} and the known instantaneous luminosity profiles, plus Poissonian statistics.

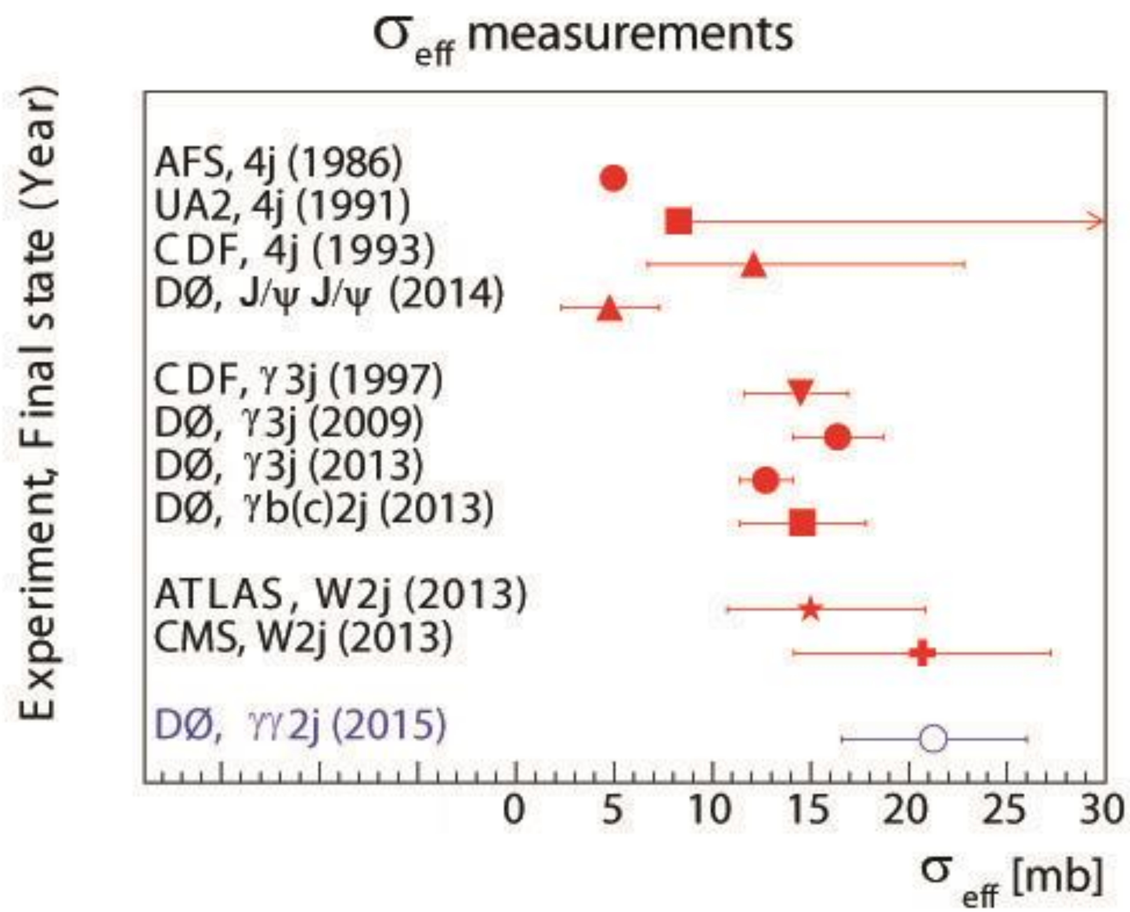
$$\frac{1}{2}\frac{N_{1col}}{N_{2col}}\sigma_{hard} = 18.92 \pm 0.49 \text{ mb}$$

Effective cross section

- Having measured number of DP events and corresponding acceptances and efficiencies one can calculate $\boldsymbol{\sigma_{eff}}$.
- Measured $\boldsymbol{\sigma_{eff}}$ is in agreement with all Tevatron and LHC measurements.

Possible initial state dependence?

	$\gamma\gamma$ + 2 jet
σ_{eff} (mb)	21.3 ± 1.5 (stat) ± 4.5 (syst)
DP Fraction	0.193 ± 0.037



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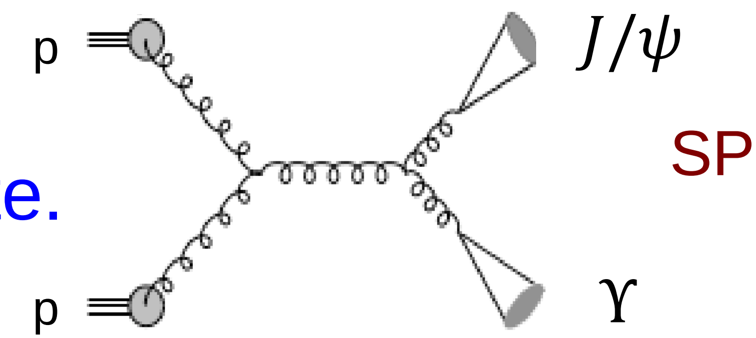
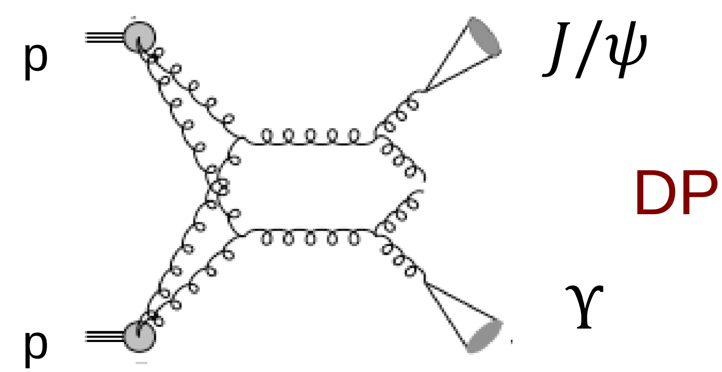
Double Parton Interactions in $J/\psi + \Upsilon$ production

New!!!

- Almost 100% DP
  - 97% [Estimated: arXiv:1504.06531]
  - If highly-DP, excellent laboratory in which to study the phenomenon.
  - However, dominantly gluonic initial state.
  - Study only $J/\psi + \Upsilon \to \mu^+\mu^-$



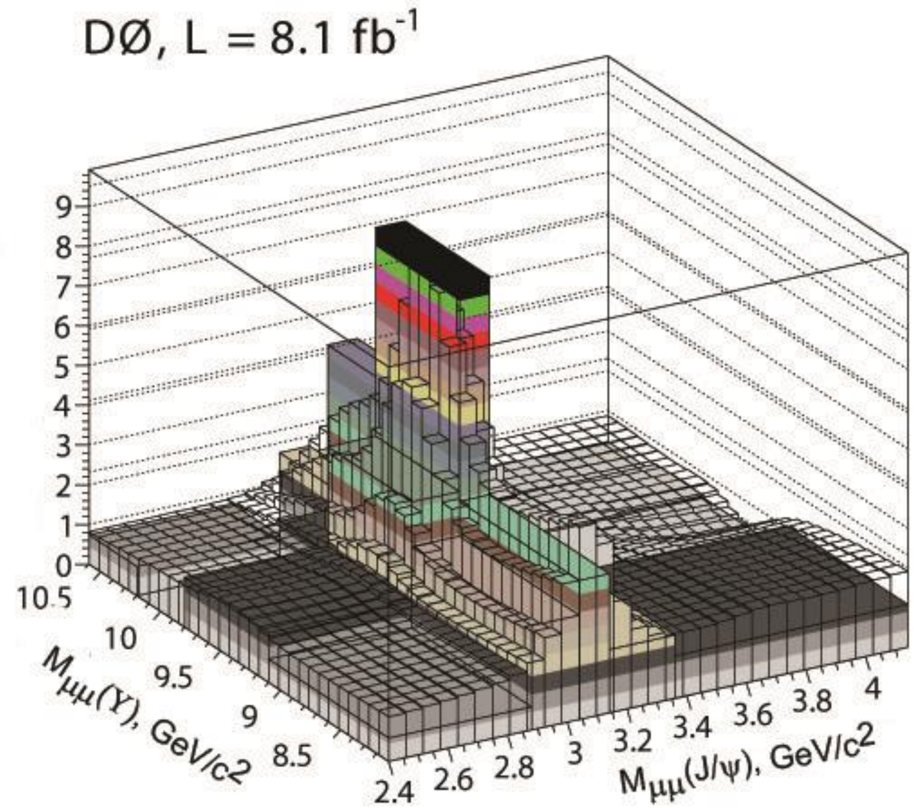


Data selection

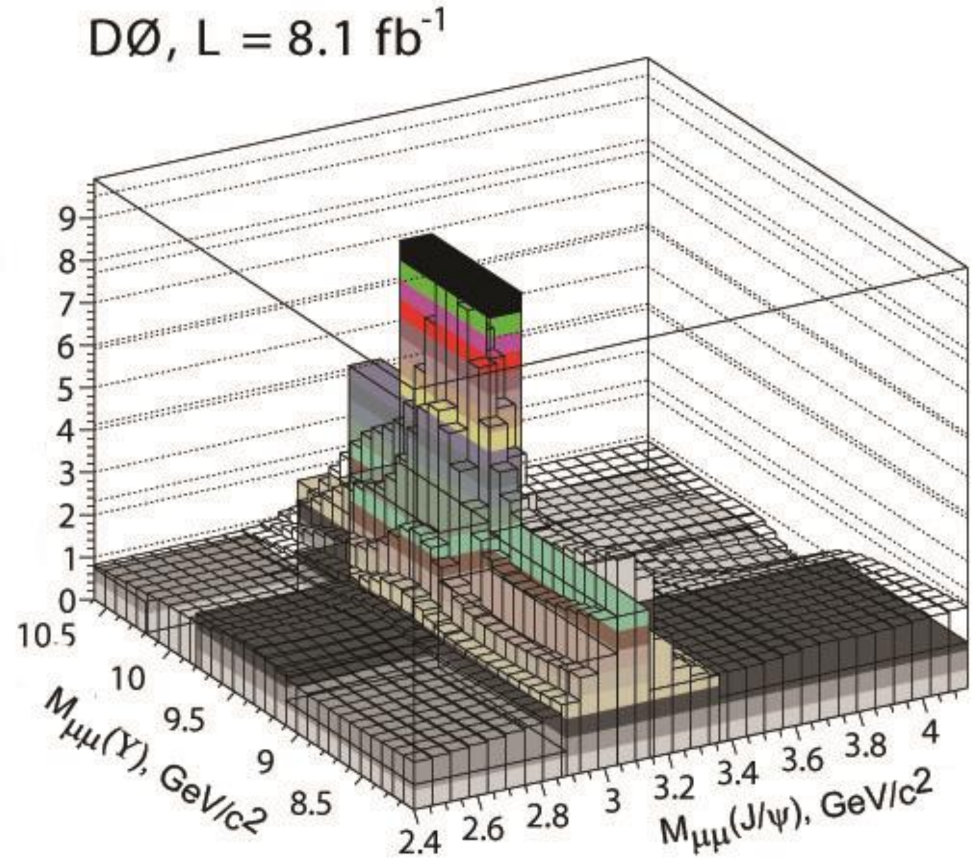
8.1 fb^{-1}

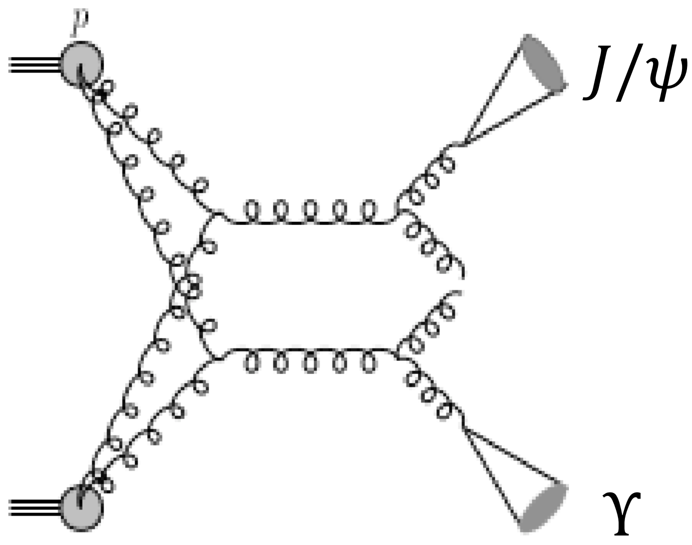
- L = 8.1 fb^{-1} statistics
- Logical OR of low pT unprescaled di-muon triggers
- $pT(\mu) > 2$ GeV if $|\eta| < 2$.
  - exclude muons having hits just outside of toroid
  - veto cosmic muons by timing cut
- muon track segment is matched to the central tracker
- track with at least 3 hits
- opposite charge μ
- r-DCA (transverse distance of closest approach of the track to the primary vertex point) < 0.5 cm; z-DCA < 2 cm
- Muon pair is in
  - $2.88 < M_{\mu\mu} < 3.32$ GeV
  - $9.1 < M_{\mu\mu} < 10.2$ GeV

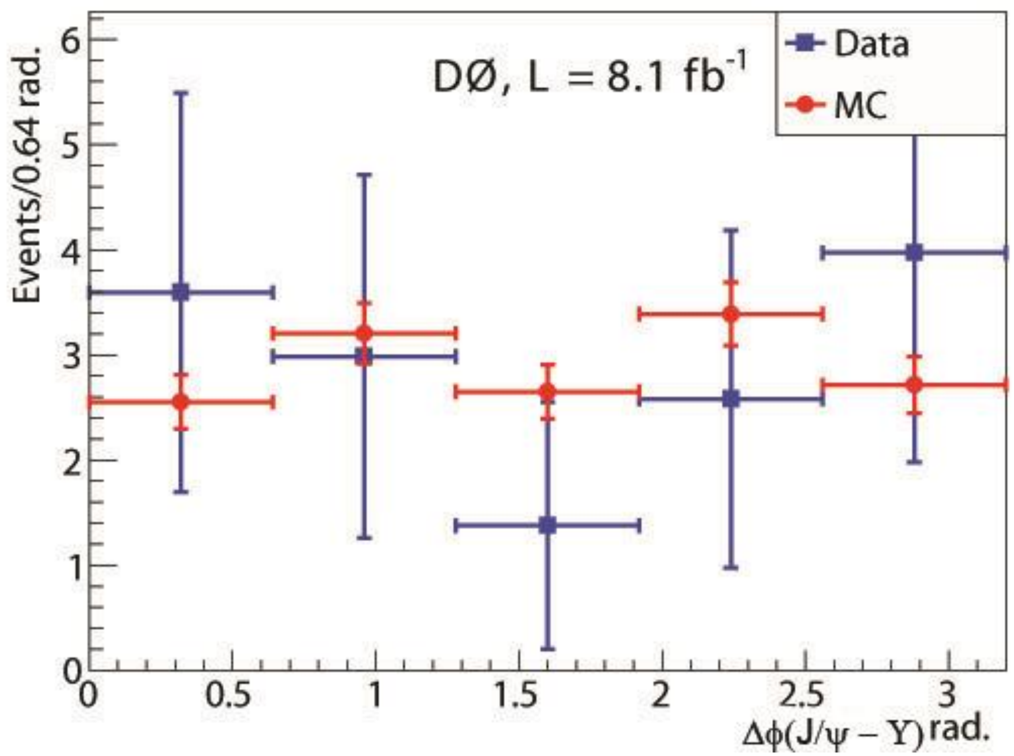
21 events



Results







2D fit. $J/\psi + \Upsilon(1S, 2S, 3S)$

N_{sig} = 14.5 ± 4.6 (stat) ± 3.4 (syst)

P(accidental) = 2.5×10^{-4}

(3.5 σ)

Summary

- Studies of MPI events are important $\rightarrow$ lead to a knowledge of fundamental hadron structure.
- Provide a better description of complex final states in hadron-hadron collisions.
- Double parton production in $\gamma\,\gamma$ + 2-jet final states using (L = 8.1 fb^{-1}):

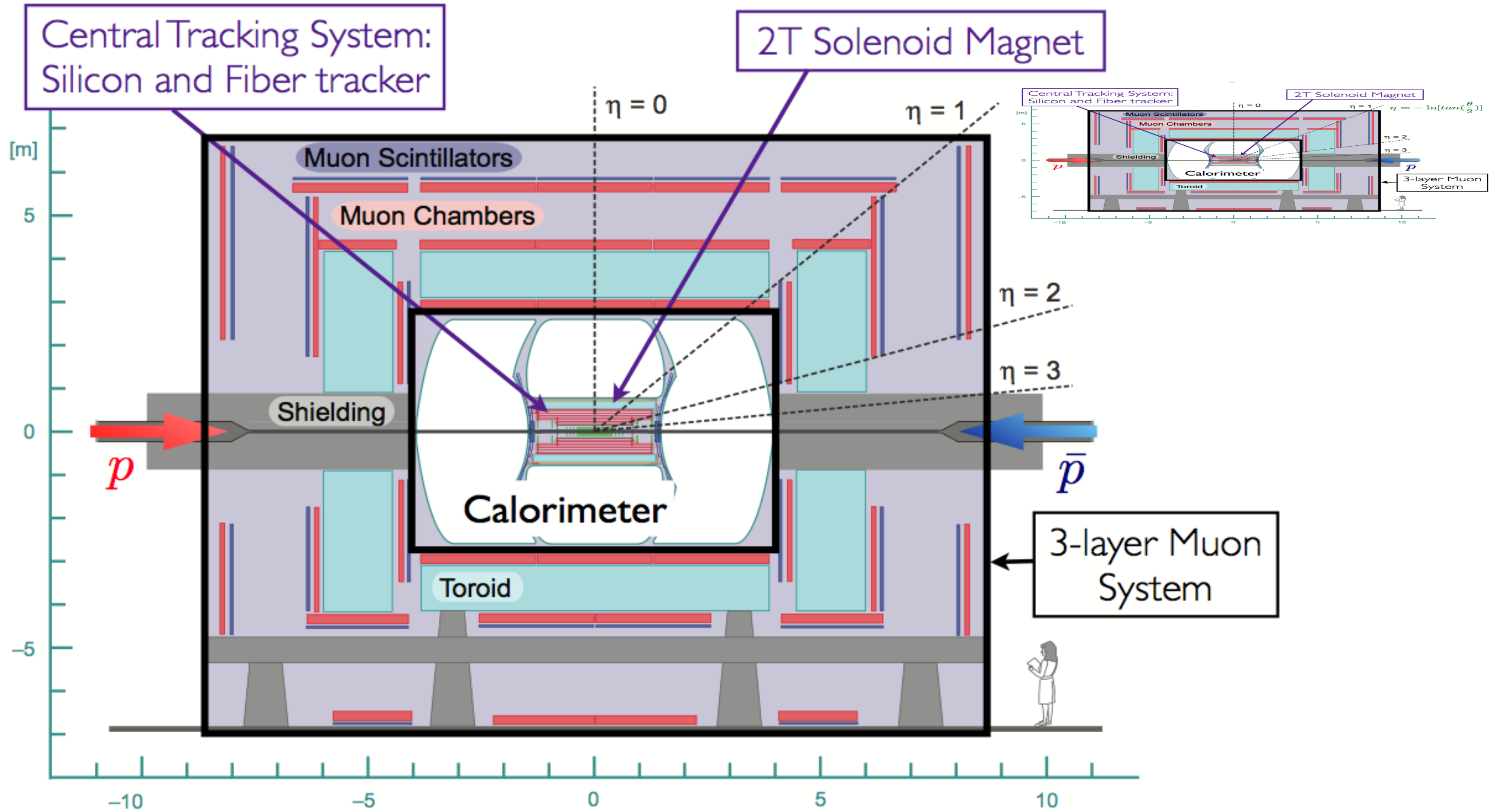
	$\gamma\gamma$ + dijet
Fraction DP events	0.193 ± 0.037
σ_{eff} (mb)	21.3 ± 1.5 (stat) ± 4.5 (syst)

- We have also studied production of $J/\psi + \Upsilon$ production and found that

	$J/\psi + \Upsilon$
Evidence for $J/\psi + \Upsilon$	3.5 σ

- A simple study in $\Delta\varphi(J/\psi, \Upsilon)$ supports DP-dominance claim.
- Studies of the $J/\psi + \Upsilon$ final state are ongoing. Should be available soon, including σ_{eff}.

D0 detector



- Tracking in magnetic field of 2T:
  - Silicon microstrip and central fiber tracker
- Calorimeter: Liquid argon sampling calorimeter
  - Central and Endcap, coverage : |η|<4.2
- Muon system: Drift chambers and scintillation counters,1.8 T toroid
  Wide muon system coverage (|η|<2); thick shielding suppresses background.