# Single Diffractive Dijets at DØ

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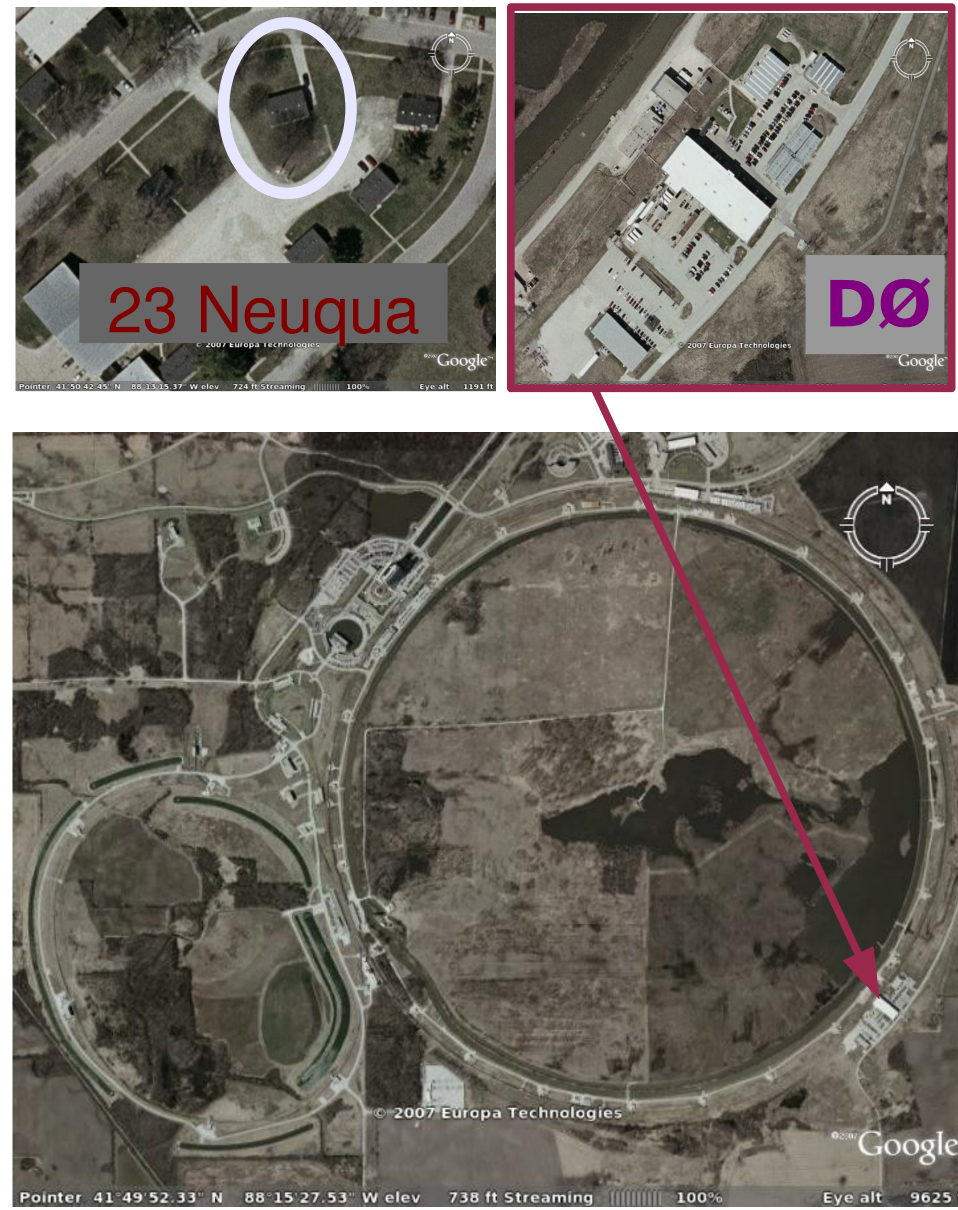
29 of April, 2008

# Outline

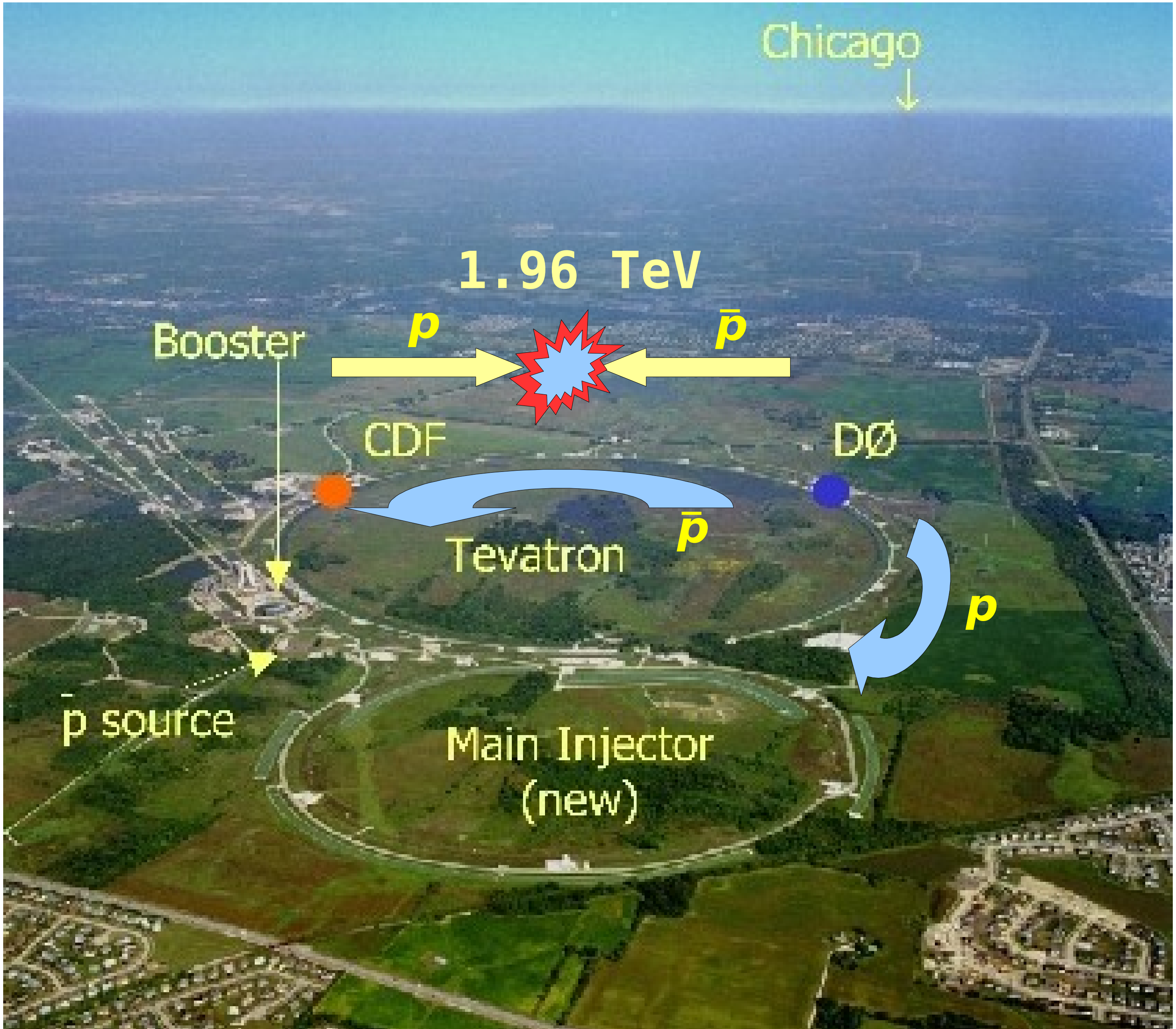
1 – The DØ Experiment
   - The Luminosity Monitor Database
   - The Forward Proton Detector
2 – Phenomenology of Diffraction
3 – Single Diffractive Dijets at DØ
4 - Summary




**Disclaimer**

all the plots presented in this talk are ***work in progress*** and not to be considered as final results, unless stated otherwise.

# The DØ Detector at Fermilab

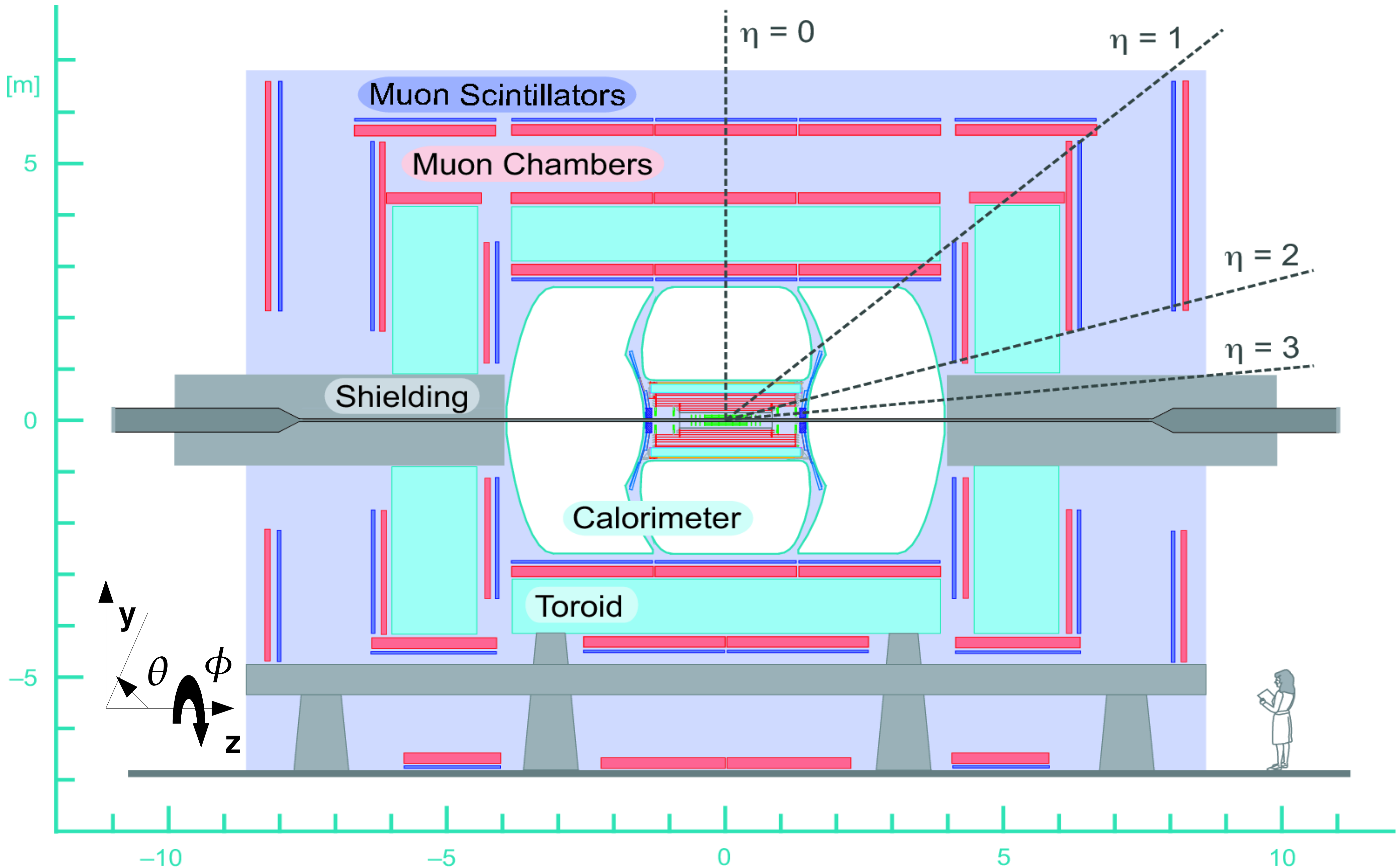


# The DØ Experiment

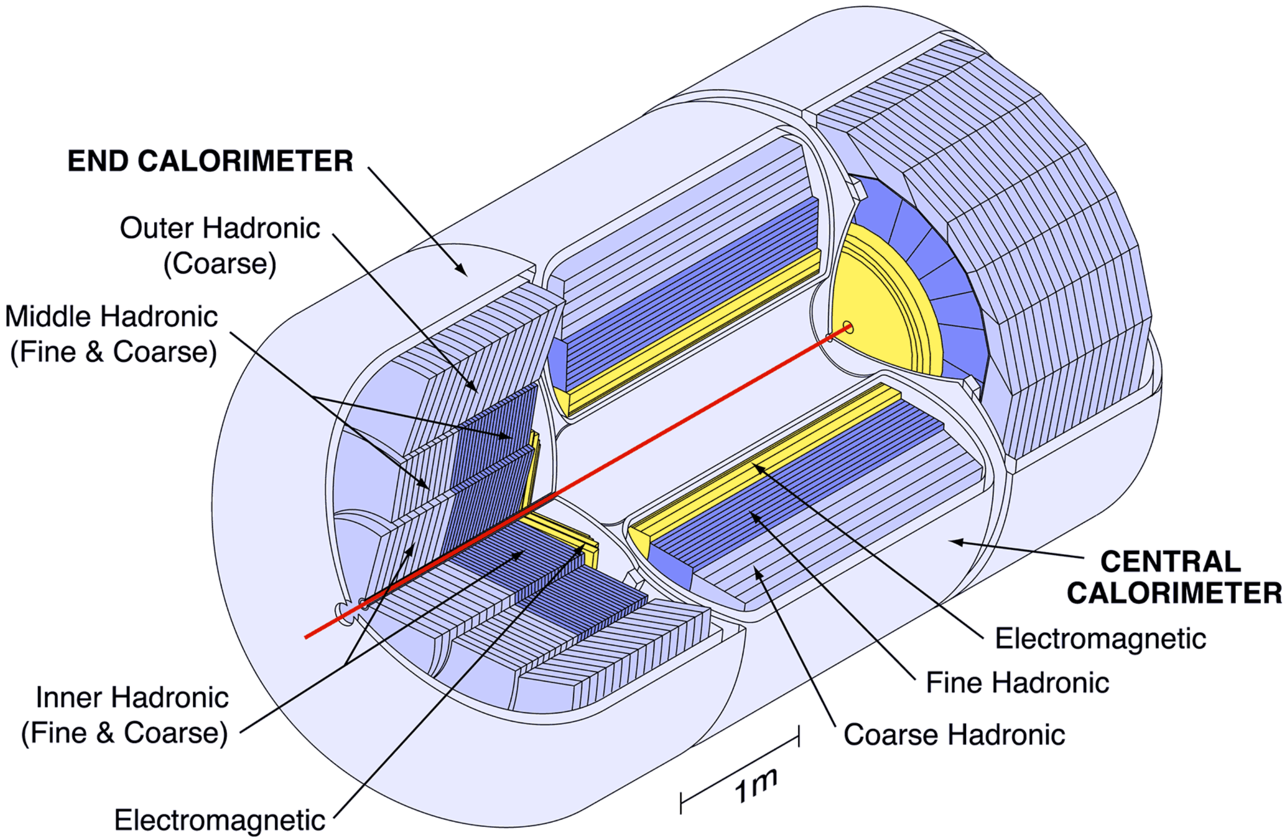
International Collaboration of ~600 members
from more than 80 institutes
and 18 countries


# The DØ Experiment

$$\eta \equiv -\ln[tg(\theta/2)]$$



# The DØ Calorimeter

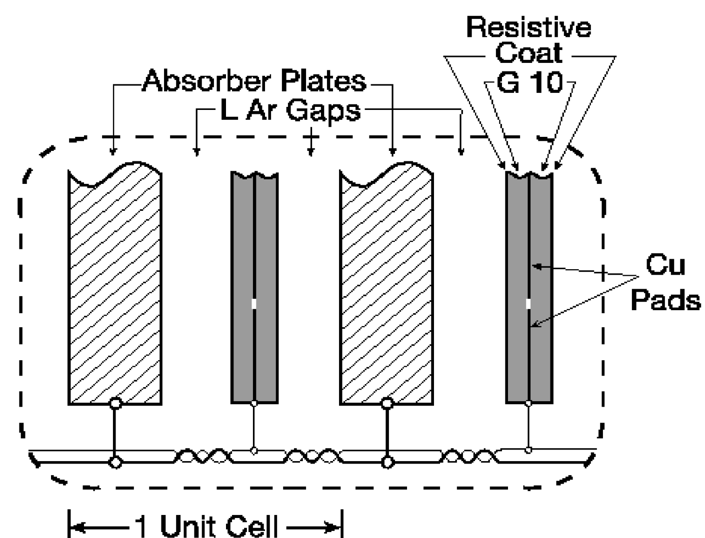



- Uranium/liquid Ar and an intercryostat detector

- stable response, good resolution

- partially compensating (e/h ~1)

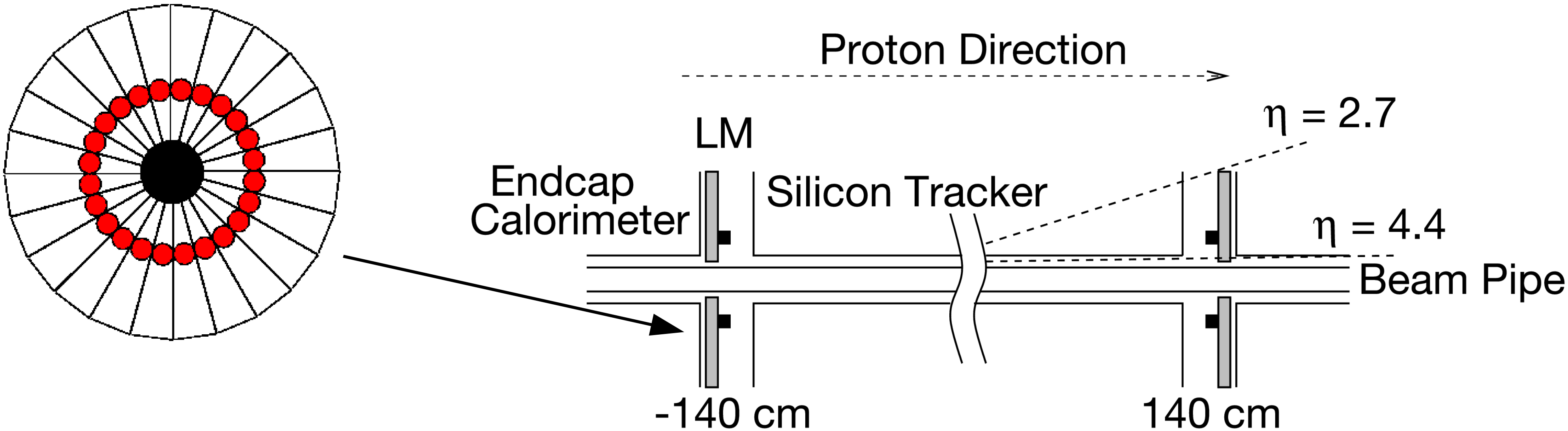
**readout cell:**




- pseudo rapidity coverage: $|\eta| \lesssim 4$

- gaps between cryostats covered with scintillator tiles

# The DØ Luminosity Monitor




- 2 arrays of 24 plastic scintillation counters.

- pseudo rapidity range coverage: $2.7 < |\eta| < 4.4$

<u>Measures the Tevatron luminosity at the DØ interaction region.</u>

$$L = \frac{f \overline{N}_{LM}}{\sigma_{LM}}$$

$\overline{N}_{LM}$ : number of inelastic collisions per beam crossing

$\sigma_{LM}$ : effective cross section for the LM

$f$ : beam crossing frequency

**<u>LBN:</u> fundamental unit of time of the luminosity measurement (~60s)**

**<u>Lum DB:</u> store information by LBN**

# The DØ Luminosity Monitor Database

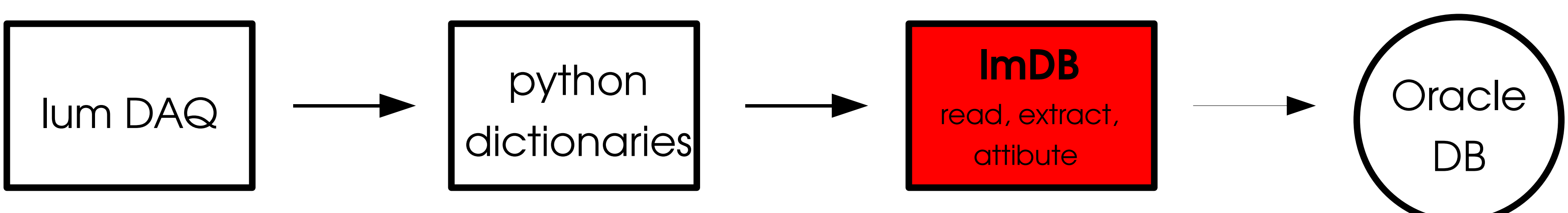
The Luminosity Monitor database is a set of **37 oracle database tables**. Contains information about:

- The Luminosity Monitor Detector;
- The Trigger Framework;
- Fermilab Tevatron Accelerator;
- Offline Data Processing;
-...

All this information comes from **dedicated data acquisition system** (lum DAQ).

From lum DAQ, a special file is created, with all the necessary information for the luminosity database (and much more) stored in **python dictionaries**.

Need a program that is able to **read** these python dictionaries, **extract** the needed information and **attribute** it to the corresponding database table. ==> **lmDB.py**

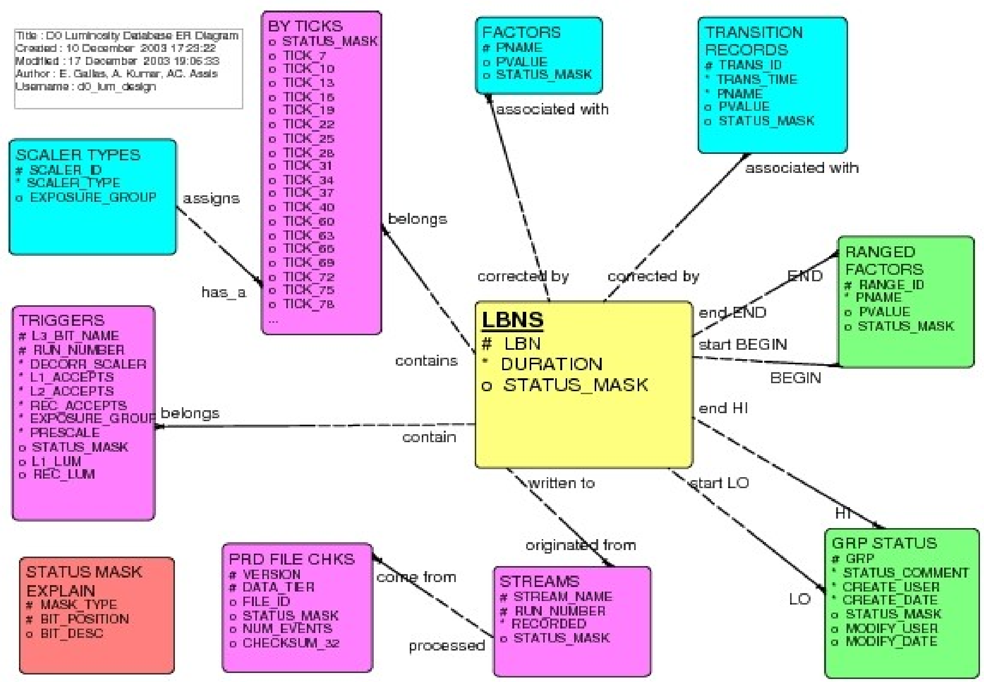


# The DØ Luminosity Monitor Database

**Difficulties:**

- very complex lum DAQ and a huge amount of redundant information in the python dictionaries;
- starting point: very simple database schema that did not reflect all the necessary needs;
- learn about the data and modify the database accordingly, “on the fly”;
- huge amount of data to be loaded (millions and millions of rows) -> How to load it in the database in a reasonable amount of time?

First database “schema”. Only a few tables.



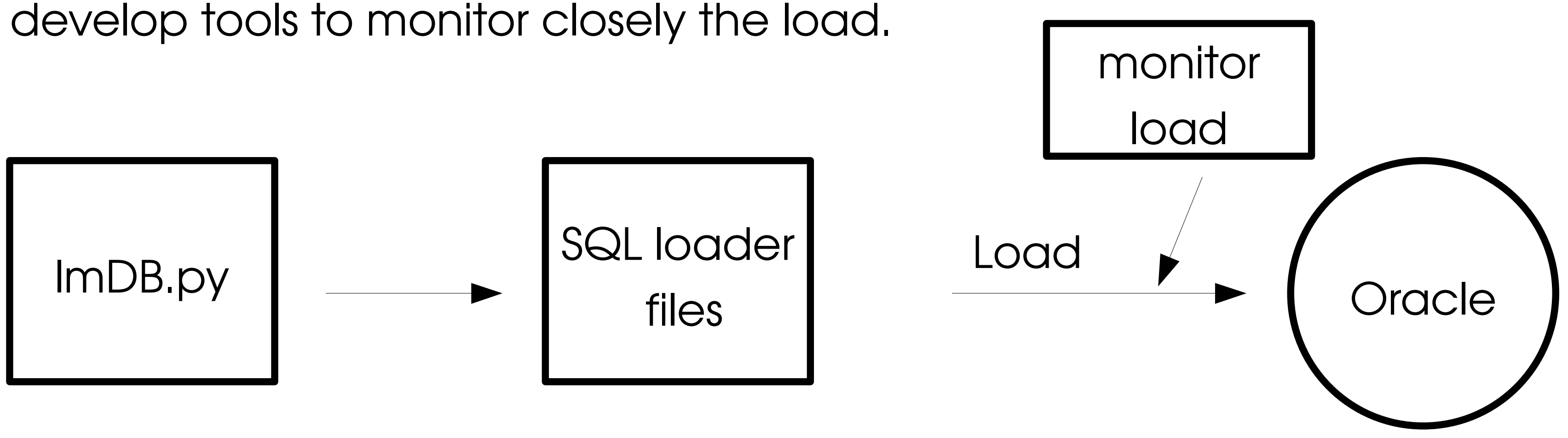
# The DØ Luminosity Monitor Database

**Bulk Load of Data (corresponding to 3 years of data from 2003 to 2005):**

- lmDB.py:
    - uses python methods for each table separately.
    - finds the information in the python dictionaries;
    - extracts it;
    - creates a SQL loader file with pertinent information for each table.

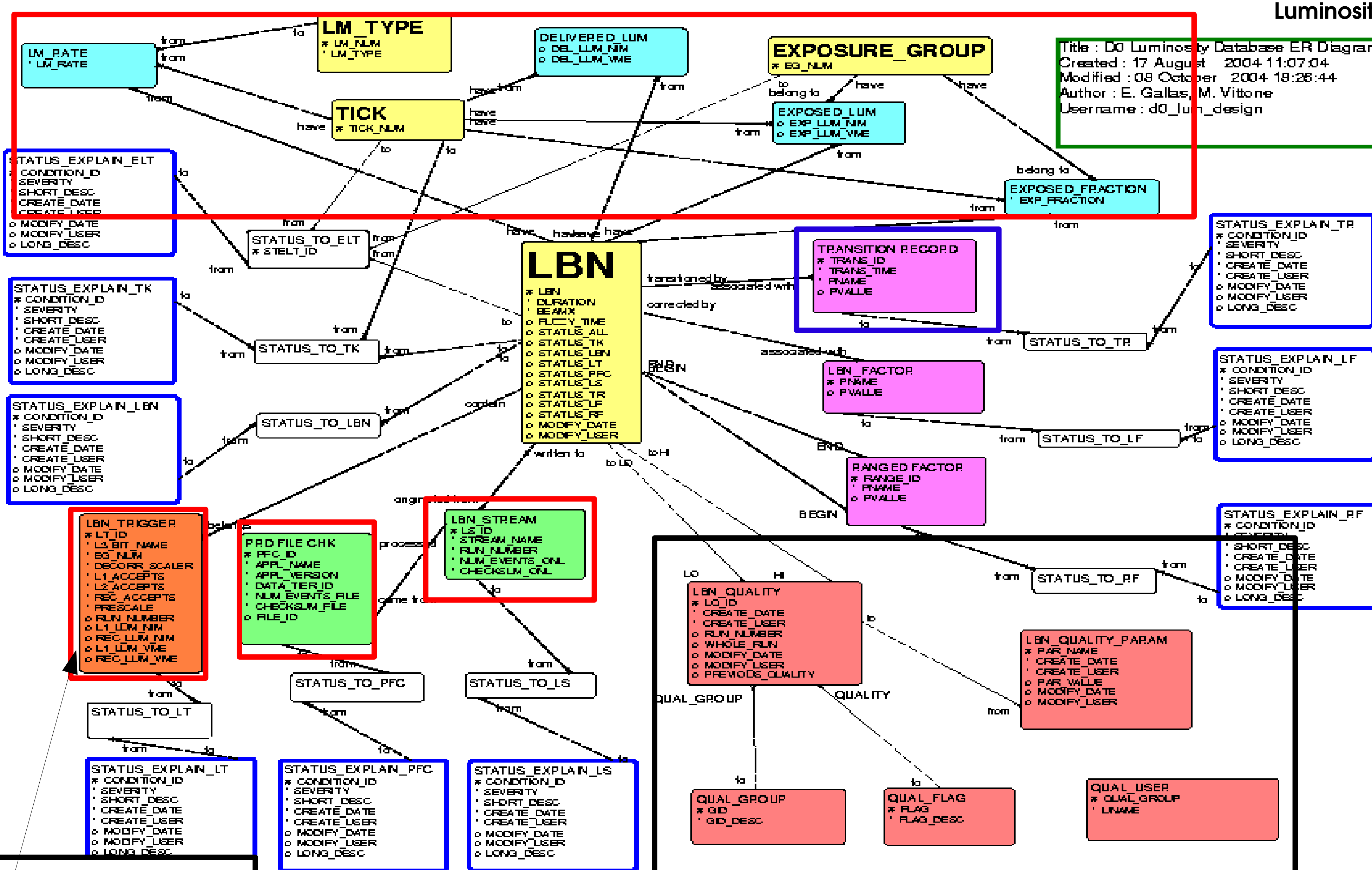
- develop tools to load the SQL loader files created from lmDB.py in database;

- develop tools to monitor closely the load.



# The DØ Luminosity Monitor Database

lm_access
DØ Integrated Luminosity




lm_access
operations reports

LBN quality (not loaded with lmDB.py)

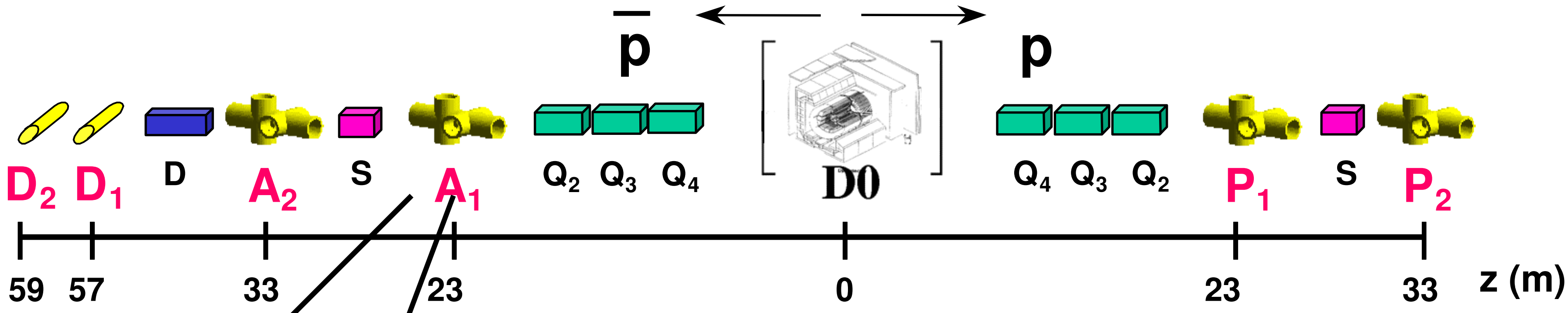
# The DØ Forward Proton Detector

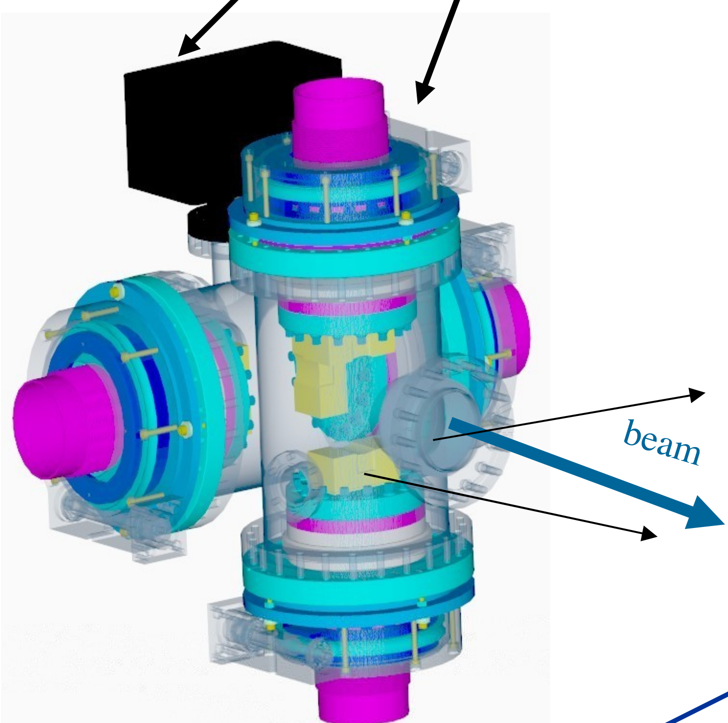
- Detector designed with the purpose of observing Diffractive Physics.

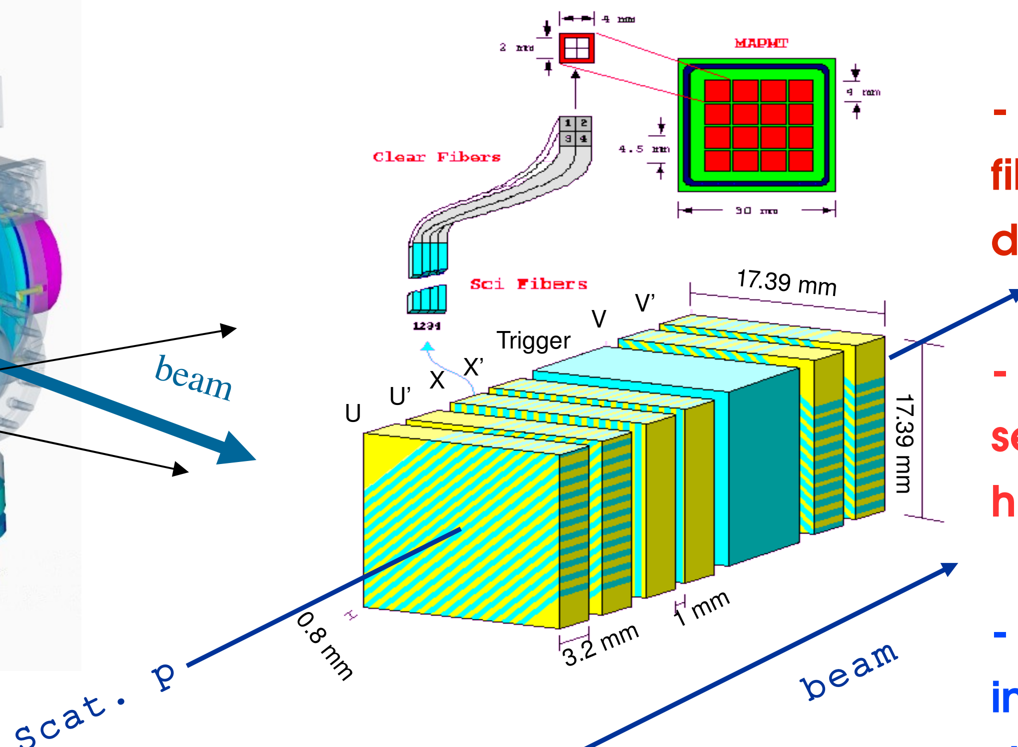
- Consists of 9 independent momentum spectrometers, built to detect scattered protons and antiprotons.

- Was built in Brazil (LNLS), USA (UTA) and the Netherlands (Nikhef).

# The DØ Forward Proton Detector



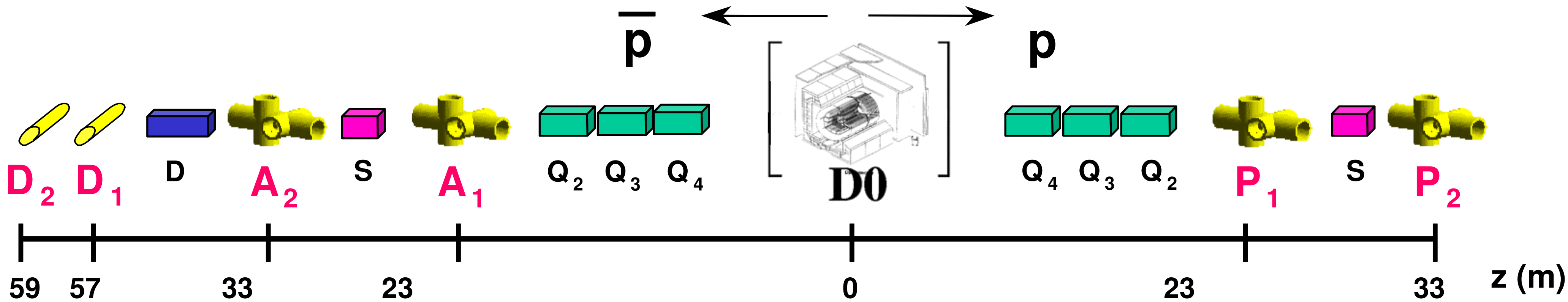

- U and V planes at 45 degrees from X plane and 90 degrees between each other;

- coincidence between 2 fibers in 2 layers of a plane defines a segment;

- coincidence between 2 segments in 2 planes defines a hit;

- coincidence between 2 hits in 2 detectors ( spectrometer ) defines a prototrack;

# 18 Roman pots that form 9 momentum spectrometers



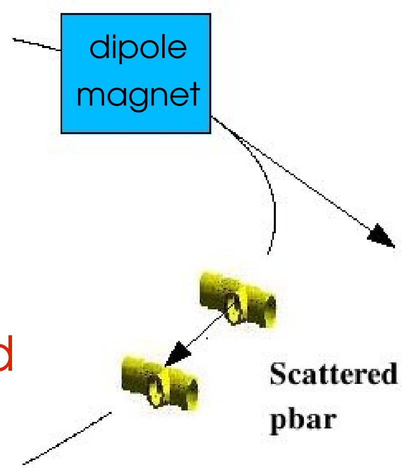

scattered antiprotons side ==> AU, AD, AI, AO and DIPOLES (DI1 and DI2)

scattered protons side ==> PU, PD, PI, PO

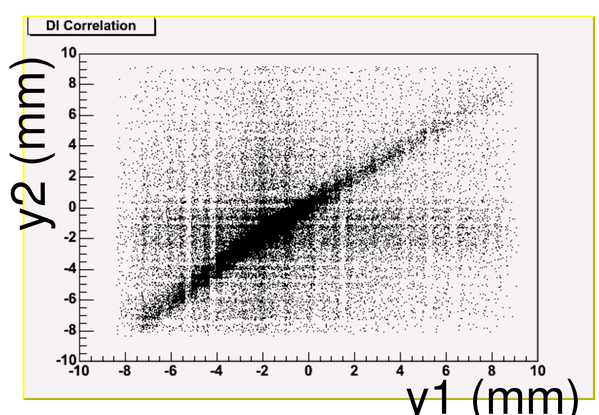
$\xi = 1 - x_p = 1 - \frac{p_f}{p_i}$ **proton mom. frac. loss**

$t = (P_{beam} - P_f)^2$ **4-mom. transfer squared**

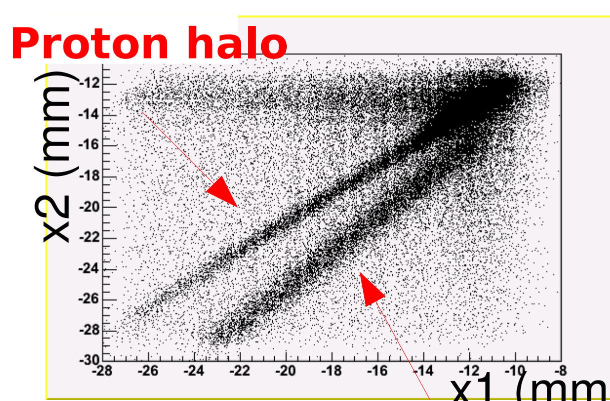
Dipole detectors placed behind the dipole magnet ==> good separation between signal and halo




Vertical Correlation:

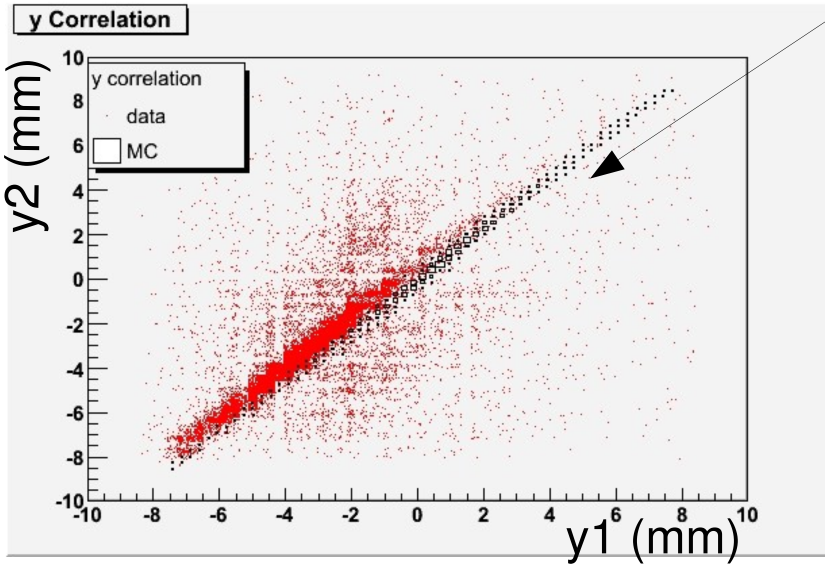



Horizontal Correlation:



# Relative Alignment of Dipole Spectrometer

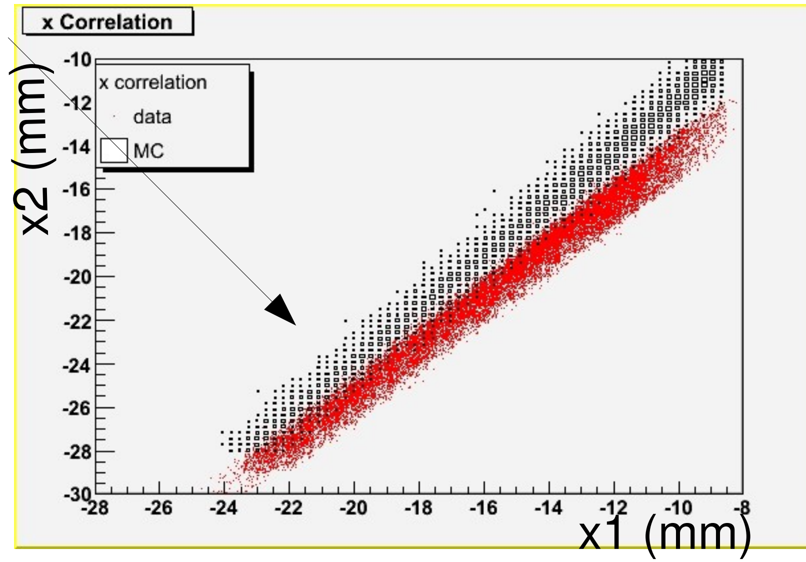
**Vertical Correlation:**




**Signal band**

data vs. MC

**Horizontal Correlation:**



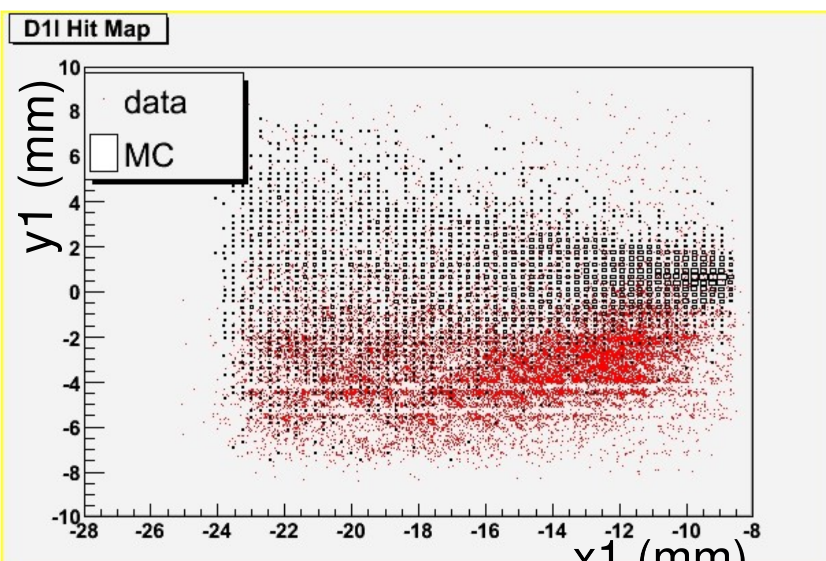

correlation:

hit coordinates x1(DI1) vs. x2(DI2) and y1(DI1) vs. y2(DI2).

hit map:

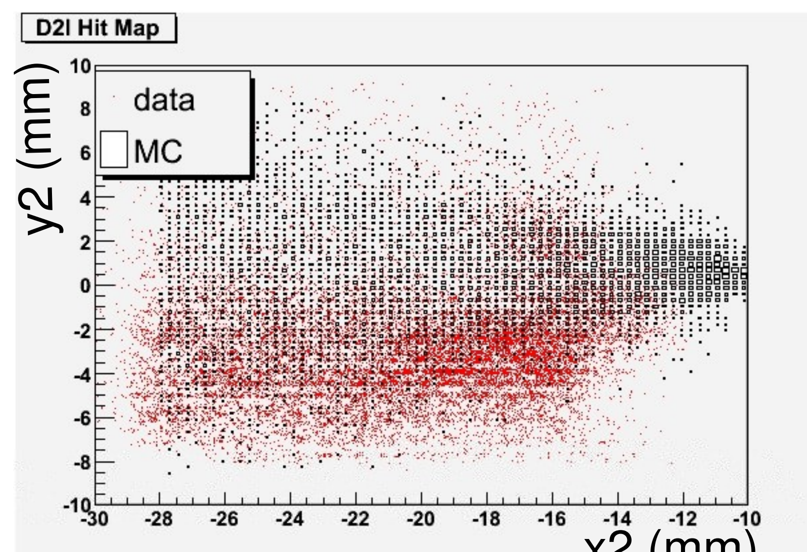
(x,y) hit coordinates.

**hit map for D1I detector:**




**find offset between data and MC and apply it to the data hits.**

**hit map for D2I detector:**



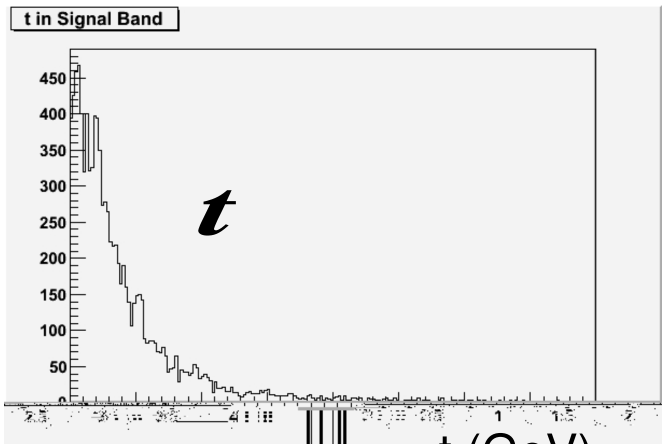

**Data points are shifted in comparison with the Monte Carlo ==> align detectors with respect to each other – relative alignment.**

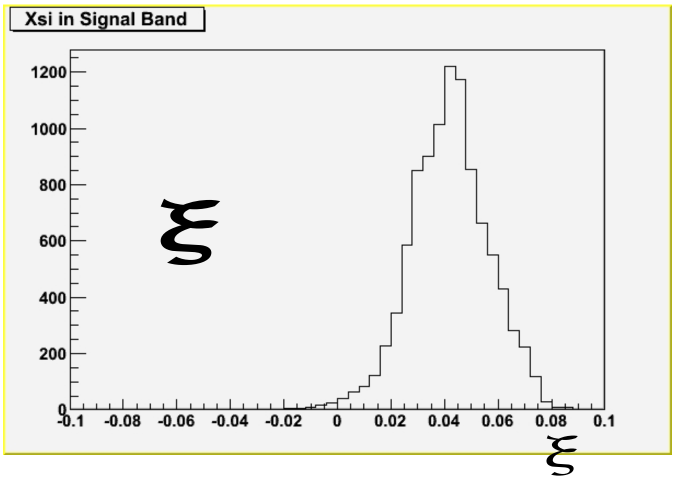
# Track Reconstruction – After alignment

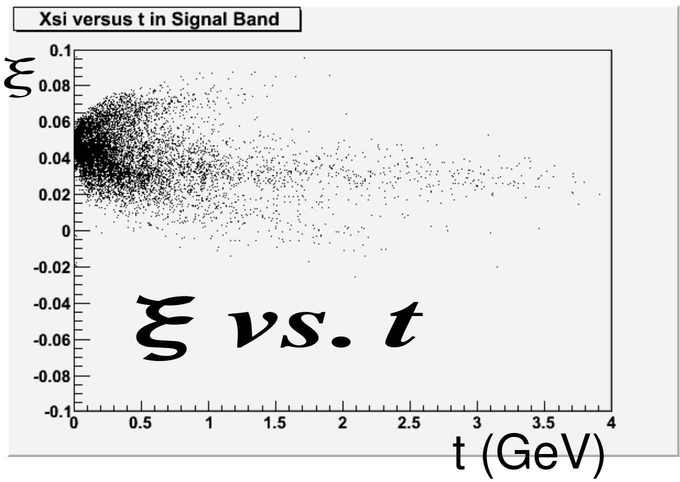
Take correlated hits and reconstruct it back to the Interaction Point, propagating it through the Beam Magnets, Drift Regions and Separators.

Get reconstructed $\xi$ and $|t|$

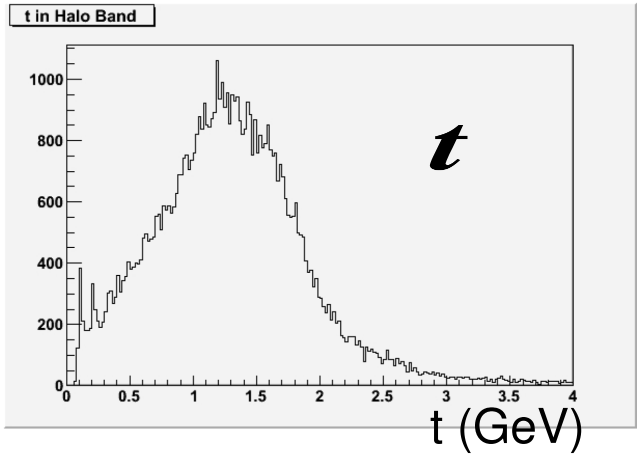
**Signal:**

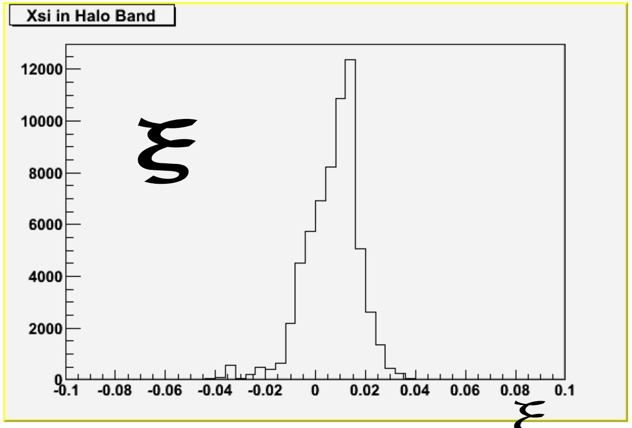


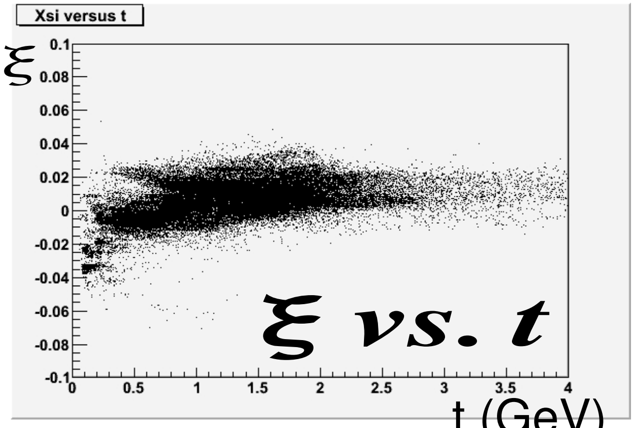




**Proton Halo:**




**Good separation between halo and signal**

**Before alignment tracks were not reconstructed for signal band!**

# Phenomenology of Diffraction

Diffraction in HEP is a reaction in which there are no quantum numbers exchanged between the interacting particles. -> POMERON.

Final state particles have the same quantum numbers as incident particles.

Diffractive Signature: Rapidity Gaps (or low activity region)

Region of the detector devoid of particles (or with very low activity).

two regimes: Soft and Hard Diffraction

soft: distances scale of the order of an atom's radius (~1fm)

hard: distances scale much smaller than the size of a hadron

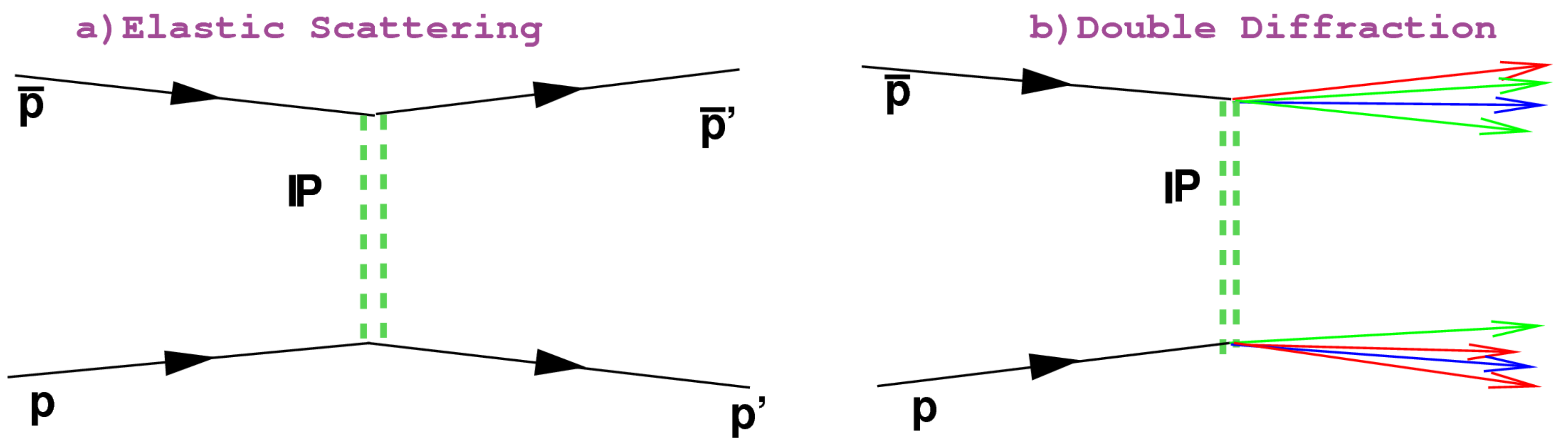
*Main Diffractive Processes*

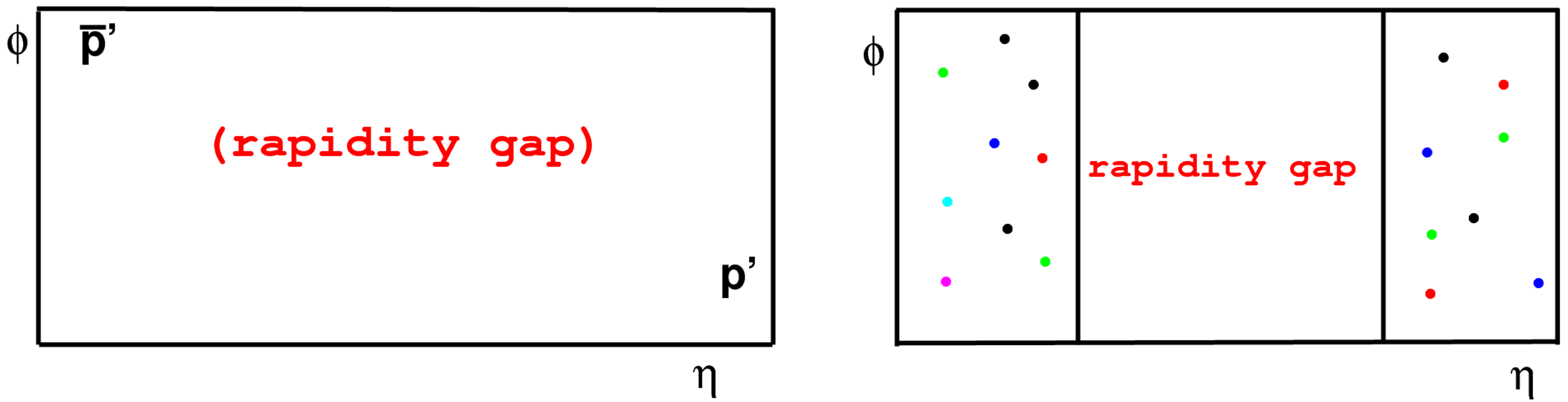
*Elastic Scattering (soft), Single Diffraction (soft and hard),*

*Double Diffraction (soft and hard), Double Pomeron Exchange (soft and hard)*

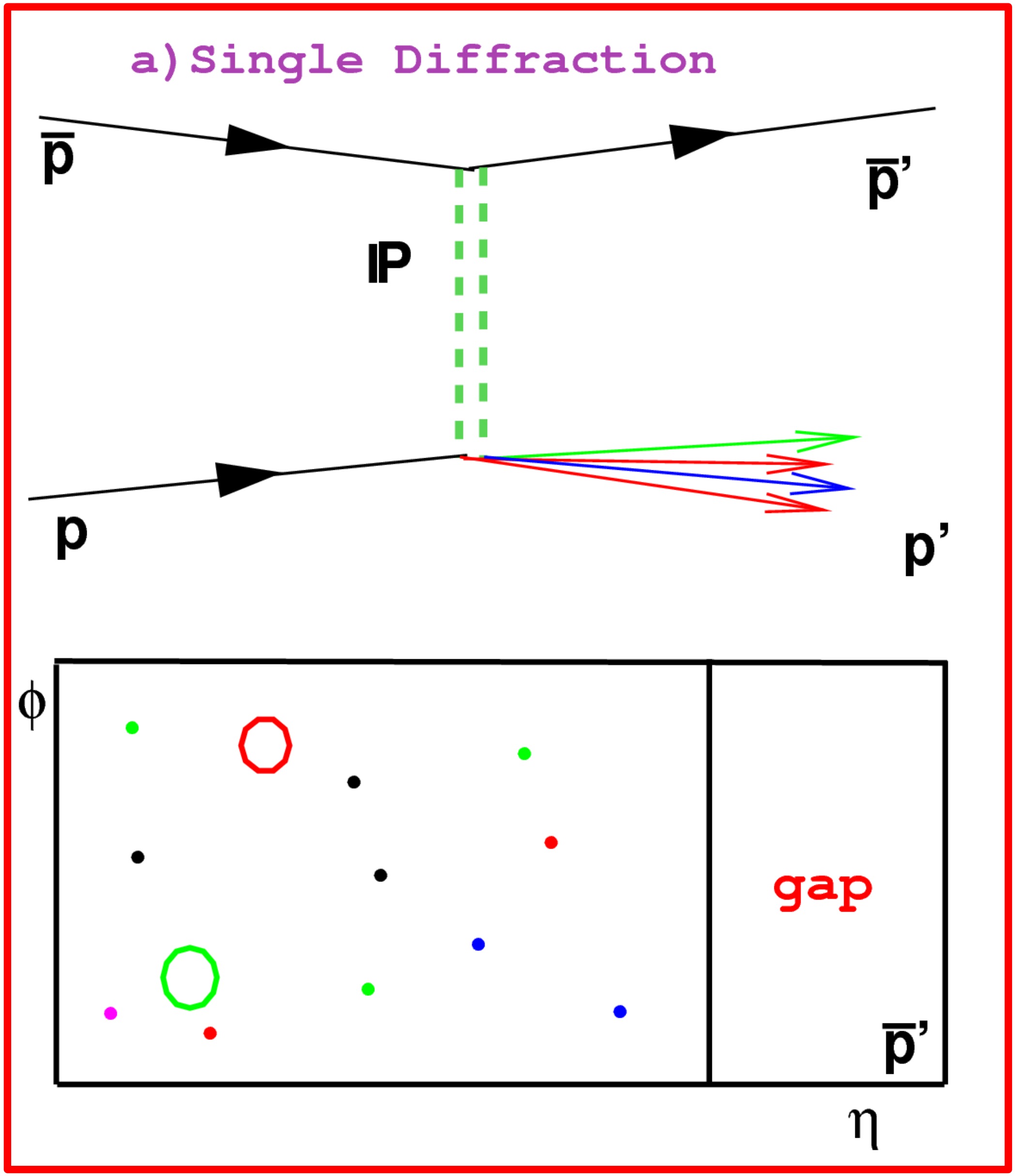
Diffractive processes are vastly studied at the ep collider HERA at DESY, in Germany

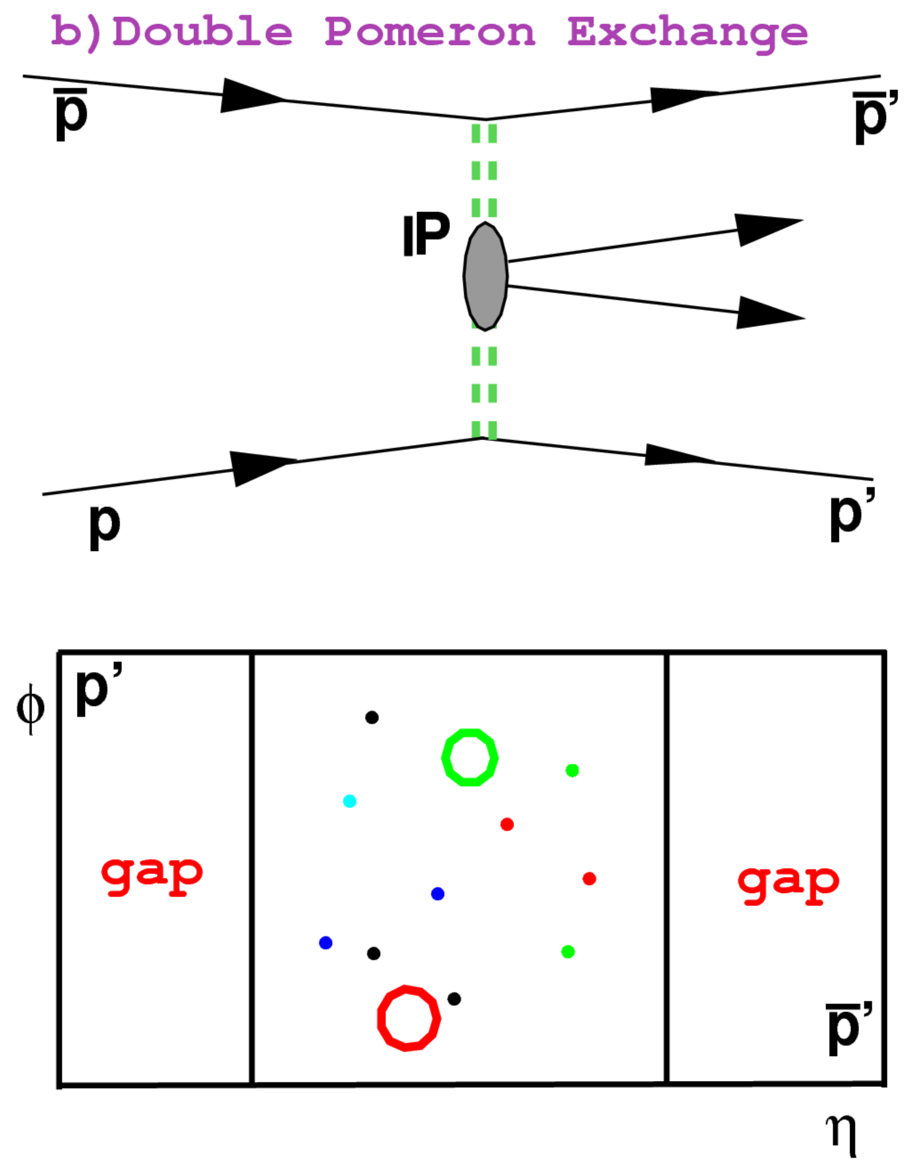
# Elastic Scattering and Double Diffraction



# Single Diffraction and Double Pomeron Exchange

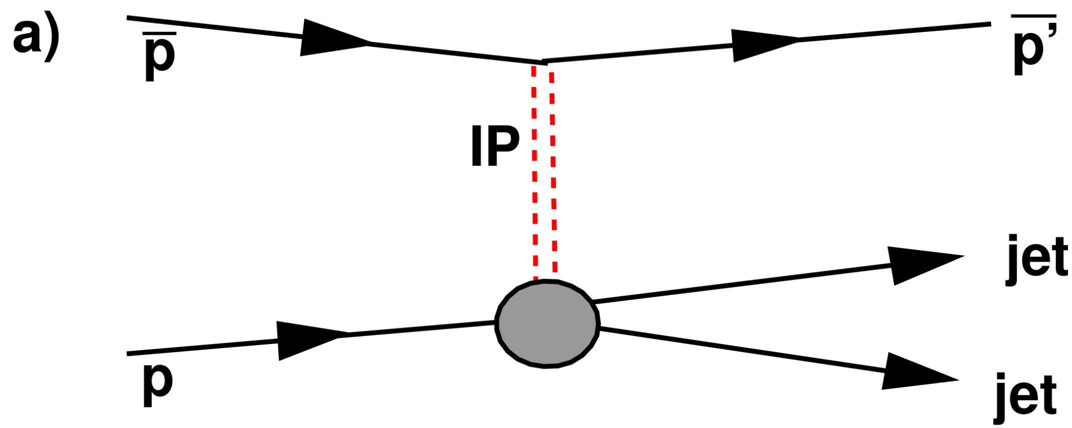


# The Ingelman-Schlein Model

Observation of single diffraction with two jets in the final state of:

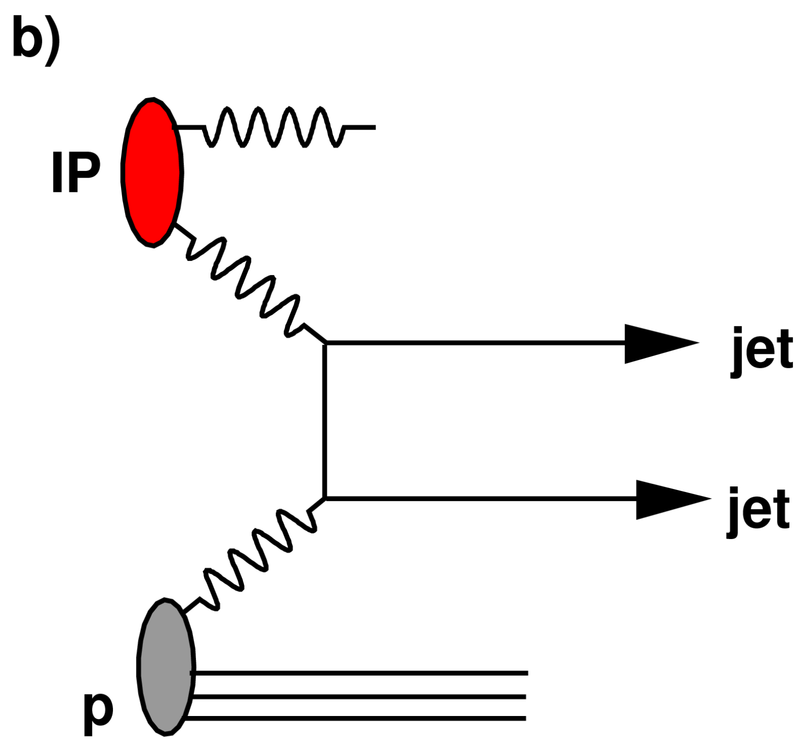
$$p\,\overline{p} \rightarrow \overline{p} + jets$$




Factorizable process that occurs in two distinct steps:

1 – the antiproton emits a pomeron

2 – the proton interacts with the pomeron.



# The Single Diffractive Rate and the Diffractive Structure Function of the Antiproton

**Analysis outline:**

**1 – Select an inclusive dijets sample;**

**2 – Determine the antiproton momentum loss range of the sample (from MC) ==> determination of low activity region size;**

**3 – Determine single diffractive and non diffractive selection cuts to be applied to data (from MC);**

**4 – data vs. MC comparisons;**

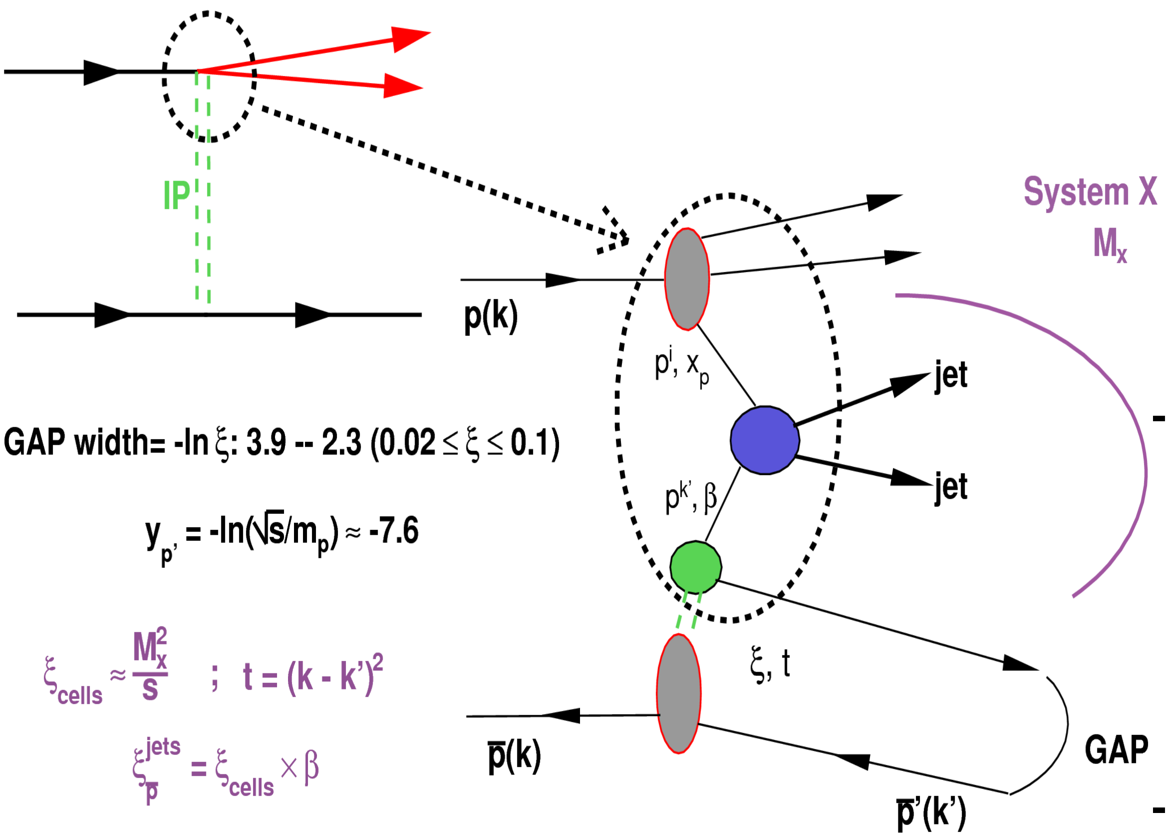
**5 – Estimate corrections to be applied to data** (purity from MC, selection cut efficiency from MC, primary vertex efficiency from data)**;**

**6 – Obtain single diffractive to non diffractive production rate;**

**7 – Extract the diffractive structure function of the antiproton.**

# Single Diffractive Dijets

Single Diffraction




**$\xi$ = antiproton momentum fraction loss;**

$$\xi_{\bar{p}}^{cells} = \frac{\sum_{i=CALO\,Cells} E_{T_i} e^{-\eta_i}}{\sqrt{s}}$$

**- x = antiproton momentum fraction carried by the struck parton;**

$$\xi_{\bar{p}}^{jets} = \frac{\sum_{i=jets} E_{T_i} e^{-\eta_i}}{\sqrt{s}}$$

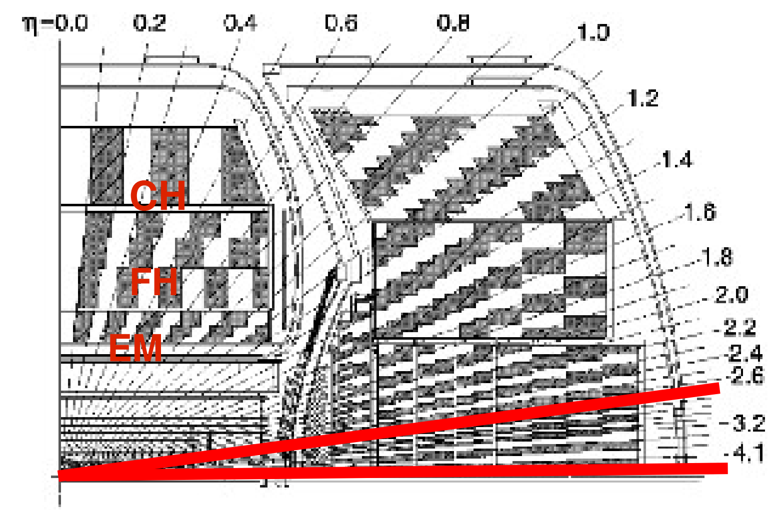
**- $\beta$ = momentum fraction of the Pomeron carried by the struck parton.**

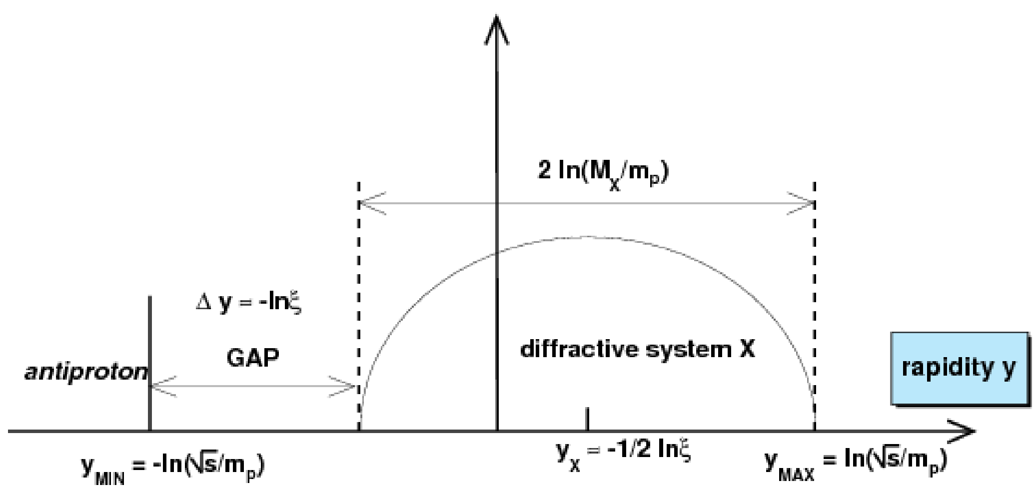
$$\beta \equiv \frac{\xi_{\bar{p}}^{jets}}{\xi_{\bar{p}}^{cells}}$$

# Single Diffractive Dijets

Low Activity Region

- look for a **low activity region** in the (very) **forward** region of the calorimeter;
- **sum up the energy** deposition in the **calorimeter cells** (from the Electromagnetic and Fine Hadronic layers) combined with a cut on the antiproton momentum fraction carried by the struck parton.



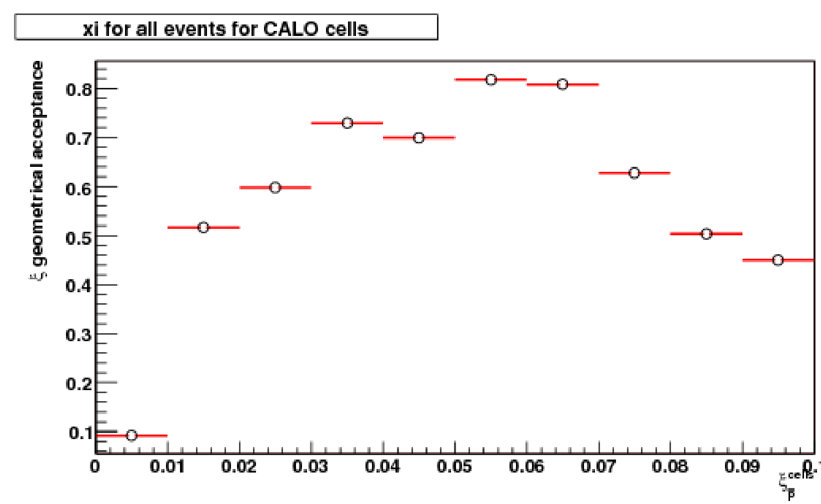




**- GAP width: $\Delta y \sim -\ln\xi$**

**Geometrical Acceptance:**

**$\xi^{reco}/\xi^{gen} > 40\%$**

**$0.02 \leq \xi \leq 0.1$**



# Single Diffractive Dijets

- Data: jets selected with a trigger requirement of minimum pT of 15 GeV. integrated luminosity of 0.1 $pb^{-1}$;

- Diffractive Monte Carlo event generator: POMWIG. Fully reconstructed. Based on the Ingelman-Schlein Model.

- Non Diffractive Monte Carlo event generator: PYTHIA. Fully reconstructed.

- DØ data quality cuts applied.

- Jet Energy Scale applied to jets.

## Dijets Sample

- jets with radius of 0.7;

- at least two good jets according to DØ jet identification criteria;

-two leading jets with $|\eta_{detector}| < 2.4$;

- exclude events with leading jets in $0.8 < \eta_{detector} < 1.4$ ;

- leading jet and second leading jet pT > 20 GeV;

- cut on MET/upT < 0.7 to eliminate calorimeter noise, mainly due to cosmics;

- primary vertex position $|z| < 50$ cm and at least three tracks associated to it. To ensure good quality vertex.

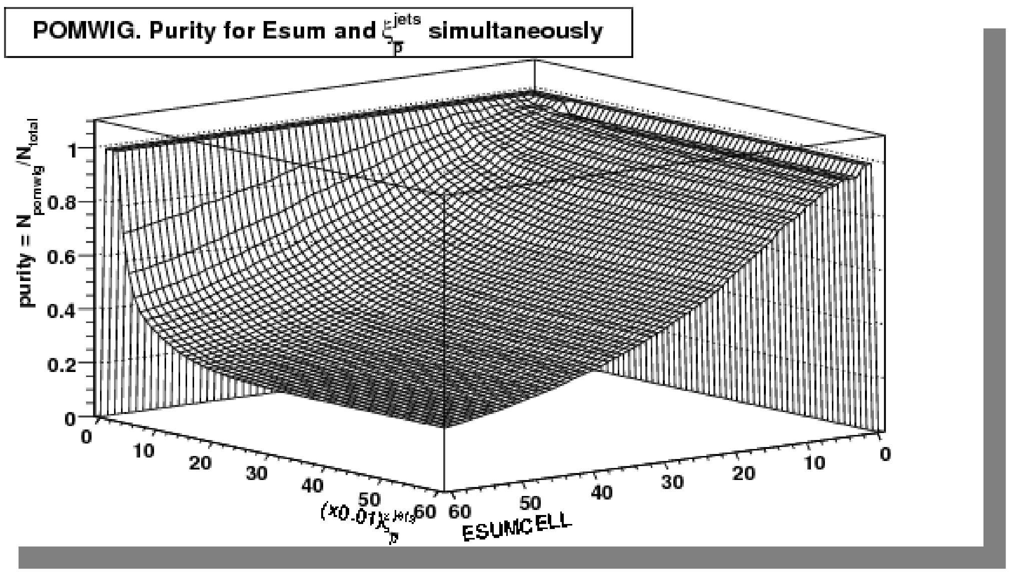
# Single Diffractive Dijets

**Determine the optimal cut on the cells energy sum (Esum)...**

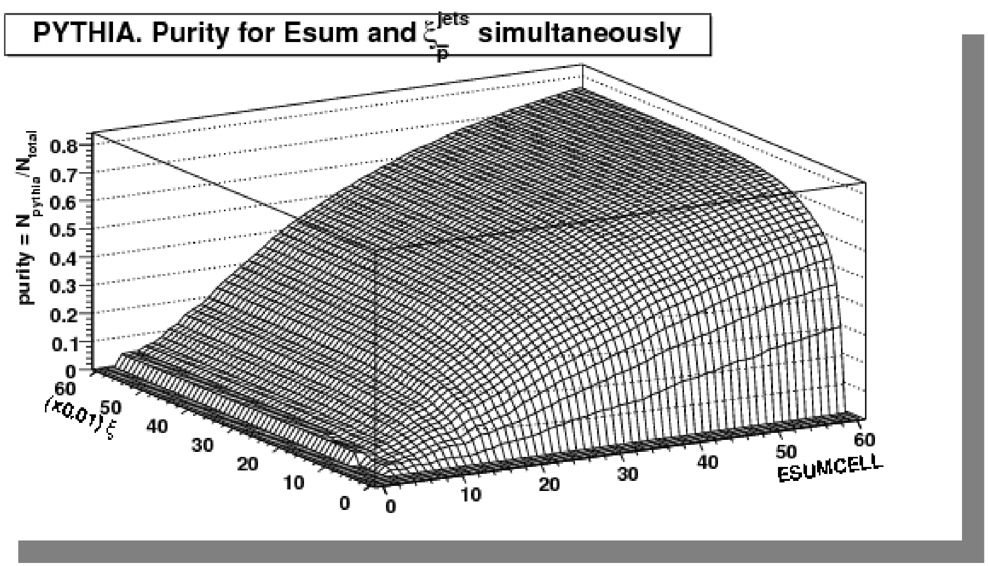
- Using Monte Carlo, compute the purity for several Esum and $\xi^{jets}$ (antiproton momentum fraction loss carried by the struck parton) cuts simultaneously.

purity = fraction of signal from total selected events.

**POMWIG. Purity vs. *Esum* and $\xi^{jets}$**



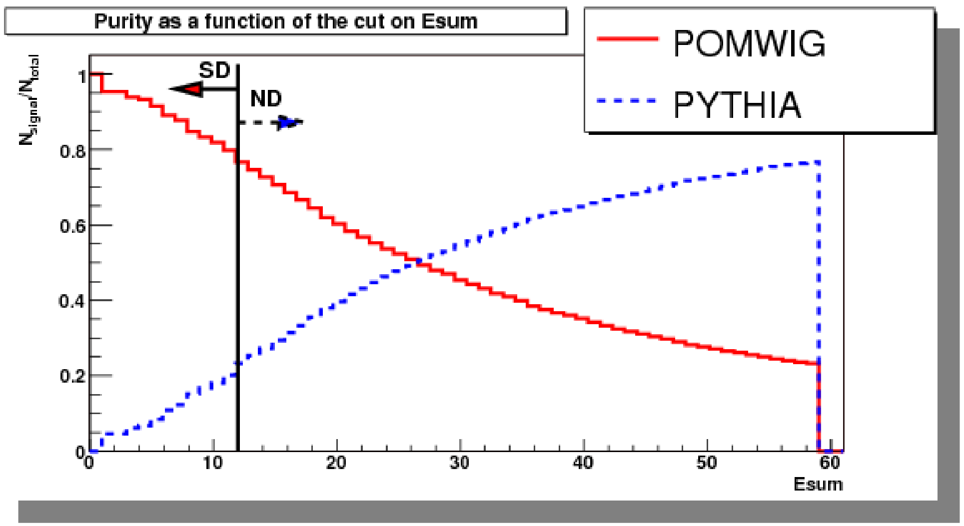

**PYTHIA. Purity vs. *Esum* and $\xi^{jets}$**

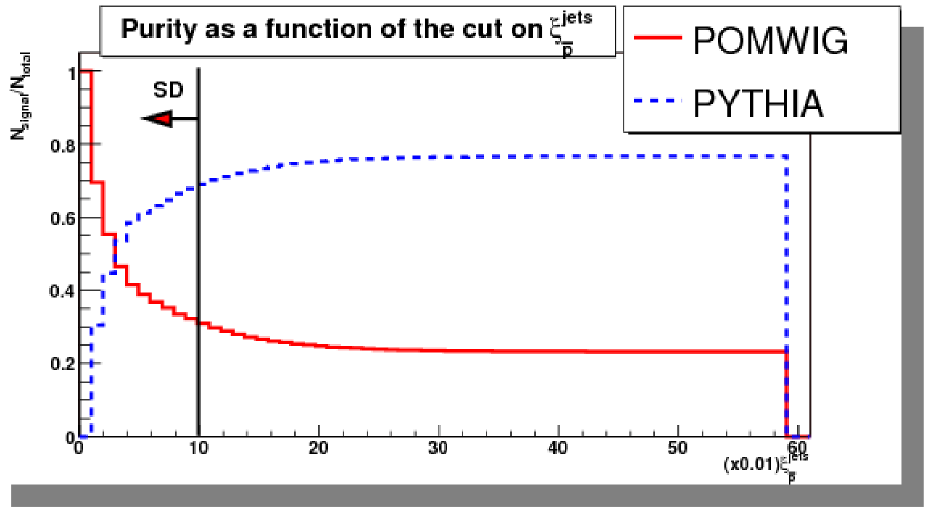


# Single Diffractive Dijets

Selection Cuts

- By taking the projection of the purity on the Esum and $\xi^{jets}$ axis, we determine the optimal cuts for selection of a single diffractive and non diffractive sample.




**- North Single Diffraction (SD). $SD_{NORTH}$:**

**$Esum_{NORTH} \leq 12$ GeV AND $Esum_{SUL} > 12$ GeV AND $\xi^{jets} < 0.1$;**

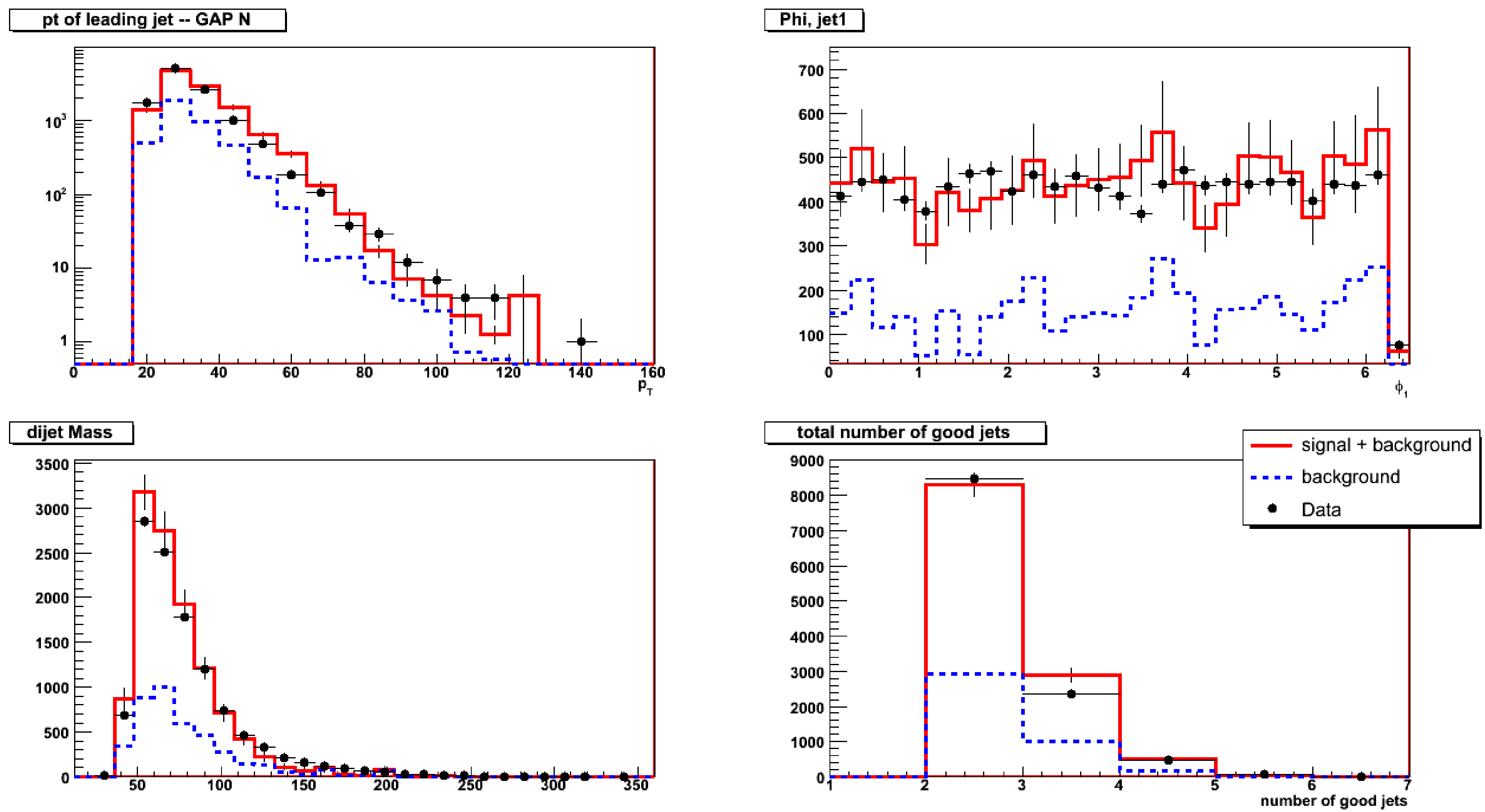
**- Non Diffractive Sample (ND):**

**$Esum_{NORTH} > 12$ GeV && $Esum_{SOUTH} > 12$ GeV.**

# Single Diffractive Dijets

Single Diffractive Sample

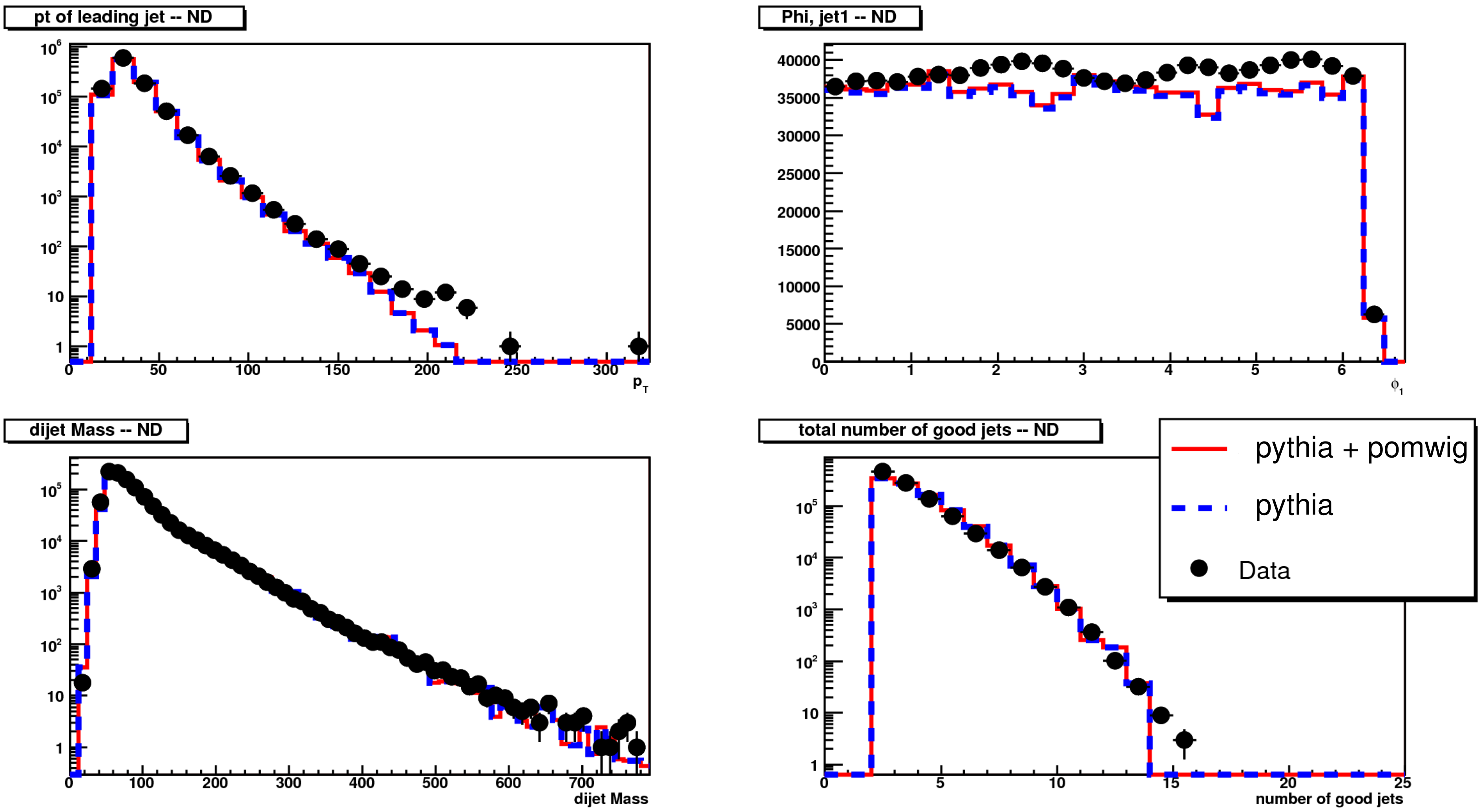
Data Vs. Monte Carlo



# Single Diffractive Dijets

Non Diffractive Selection

Data Vs. Monte Carlo



# Single Diffractive Dijets

- **Purity:** obtained from Monte Carlo.

**SD sample**

$Esum_{NORTH} \leq 12$ GeV AND $Esum_{SOUTH} > 12$ GeV AND $\xi^{jets} < 0.1$;

SD purity = $N_{POM}/N_{TOT}$

**ND sample**

$Esum_{NORTE} > 12$ GeV && $Esum_{SUL} > 12$ GeV

ND purity = $N_{PYT}/N_{TOT}$

- **Selection Efficiency:** obtained from Monte Carlo. Number of events that passed the SD (ND) cuts divided by the number of dijet events.

- **Primary Vertex Efficiency:** obtained from data.
compute it for the SD and ND samples separately.

$$\epsilon_{VTX}^{SD} = \frac{N_{SD}}{N_{SD}^{NOVTX}}$$

$$\epsilon_{VTX}^{ND} = \frac{N_{ND}}{N_{ND}^{NOVTX}}$$

# Single Diffractive to Non Diffractive Production Rate

- The Diffractive Ratio $R_{JJ}$ is obtained as the total number of events selected as Single Diffractive divided by the total number of events selected as Non Diffractive.

- Is corrected for purity, selection efficiency and primary vertex efficiency (all other uncertainties cancel in the ratio).

- We found it to be

$$\boldsymbol{R_{JJ}=[2.09\pm0.05(stats)^{+0.07}_{-0.05}(syst)]\%}$$

- the systematic uncertainty is attributed to Jet Energy Scale only.

# Single Diffractive Dijets

**The Diffractive Structure Function of the antiproton, $F^D_{JJ}$**

- $F^D_{JJ}$ is obtained from the product of the diffractive ratio $R_{JJ}$ with the non diffractive structure function of the proton

$$F^D(\beta) = R_{JJ}(\beta) \times F^{ND}(\beta)$$

1 – Obtain $R_{JJ}$ (ß);

2 – Obtain $F^{ND}$ (ß). From proton parton distributions H1 2000

$$\boldsymbol{F^{ND}(\xi^{jets}, \langle Q^2 \rangle) \equiv \xi^{jets} [\![ f_{g/p}(\xi^{jets}, \langle Q^2 \rangle) + \frac{4}{9} \sum_{q,\bar{q}} [\![ f_{q/p}(\xi^{jets}, \langle Q^2 \rangle) + f_{\bar{q}/p}(\xi^{jets}, \langle Q^2 \rangle) ]\!] ]\!]}$$

$Q^2$: energy scale. $E_T^2$

- obtain $F^{ND}(\xi^{jets}, \langle Q^2 \rangle)$ for each ß bin.
- integrate in $\boldsymbol{\xi^{jets}}$ for each ß bin. -> $F^{ND}$(ß).

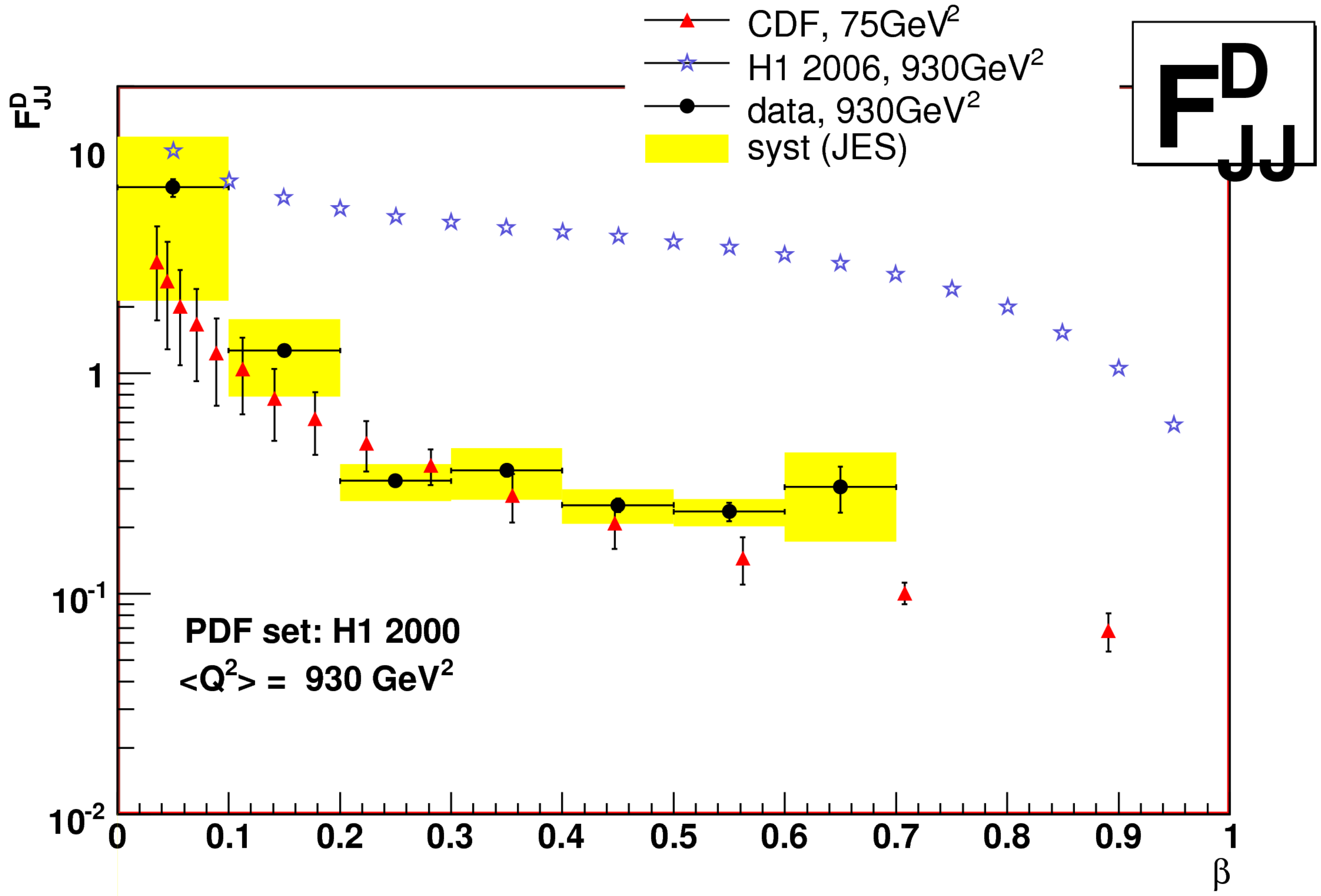
# Single Diffractive Dijets

The Diffractive Structure Function of the antiproton

| | | |
|---|---|---|
| Proton Non Diffractive Structure Function as a function of the momentum fraction of the Pomeron carried by the struck parton.<br><br>Computed with the parton distribution function set H1 2000. | X | Ratio of Single Diffractive to Non Diffractive total number of events as a function of the momentum fraction of the Pomeron carried by the struck parton.<br><br>Corrected for purity and efficiencies. |
| $F^{ND}(\beta)$ | X | $R_{JJ}(\beta)$ |

# Single Diffractive Dijets

The Diffractive Structure Function of the antiproton



# Summary

- The DØ Luminosity Monitor Database;

- The Forward Proton Detector and the relative alignment of the Dipole spectrometer;

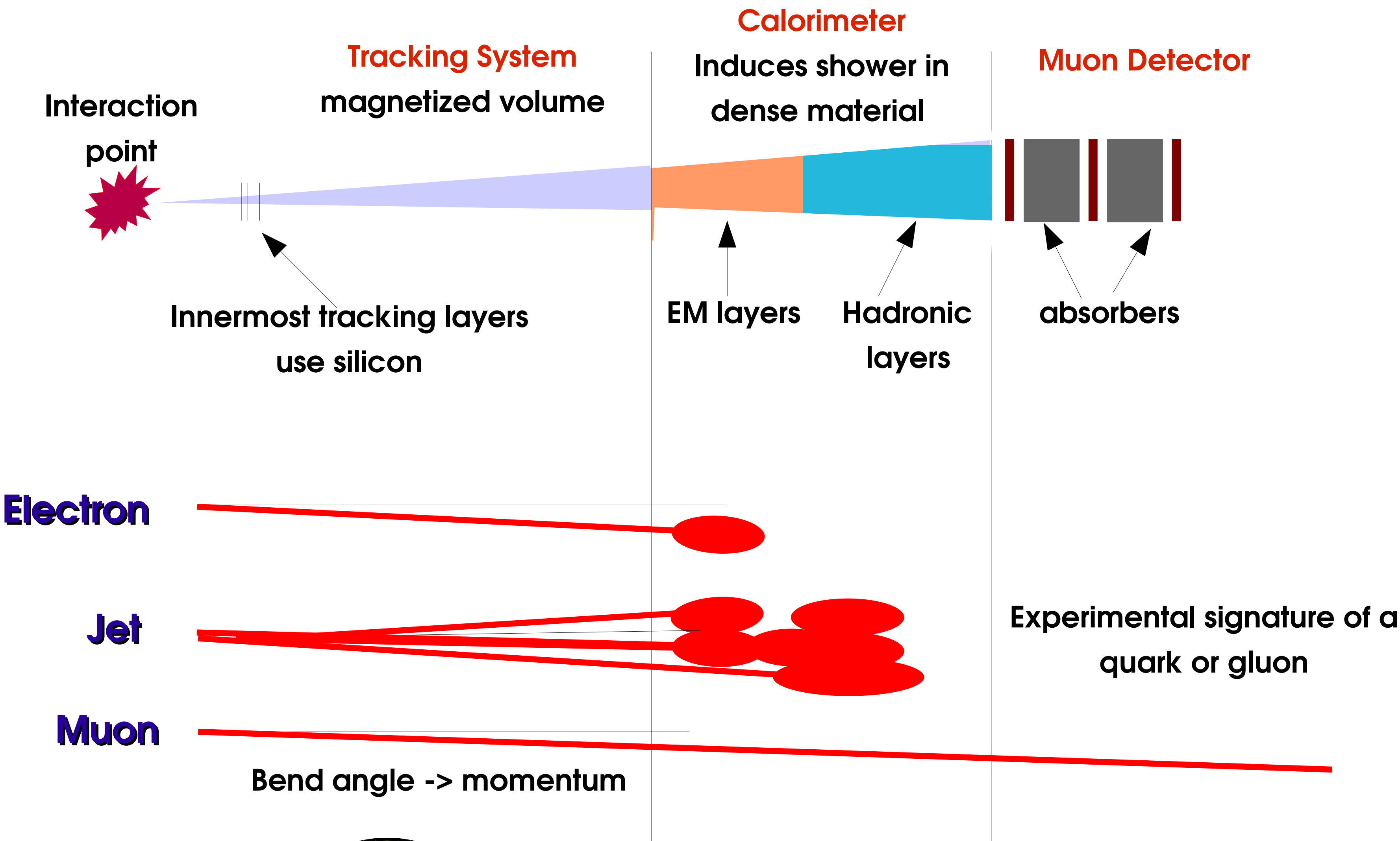
- Single Diffractive Dijets at DØ

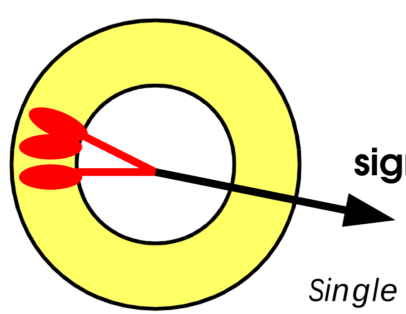
    - measurement of the Single Diffractive to Non Diffractive production rate;

    - first DØ analysis on the extraction of the structure function of the antiproton in single diffractive interactions at \sqrt{s} = 1.96 TeV.

Thank you!

# The DØ Experiment – Typical Detector



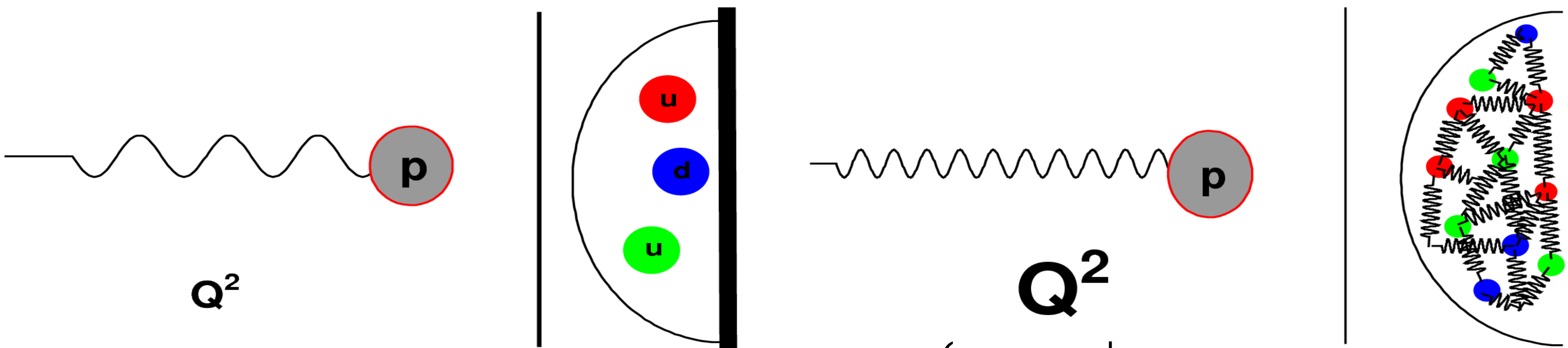



**"Missing Transverse Energy"**

signature of a non-interacting (or weakly interacting) particle, e.g. a neutrino.

# Introduction and Motivation

The Structure of the Proton




**Structure Function:**

- probability of finding parton with momentum fraction x;
- Parameterization of the non perturbative component of the cross section of a given process (**factorization**);
- the structure function is universal. Once it is determined for one type of process it can be used to infer on a different process;
- **PDF: P**arton **D**istribution **F**unction (what the structure function is theoretically made of).

***Does diffractive hard diffraction processes obey QCD factorization, e.g can be described in terms of parton level cross sections convoluted with a universal diffractive antiproton structure function?***

# Introduction and Motivation

- Assuming the universality of the diffractive structure function of the antiproton, one should expect the results obtained from the Tevatron and other experiments (such as ep collider HERA at DESY in Germany) to be the same.

=> Compare the DØ diffractive structure function of the antiproton with H1 (HERA) result: *test of factorization*.

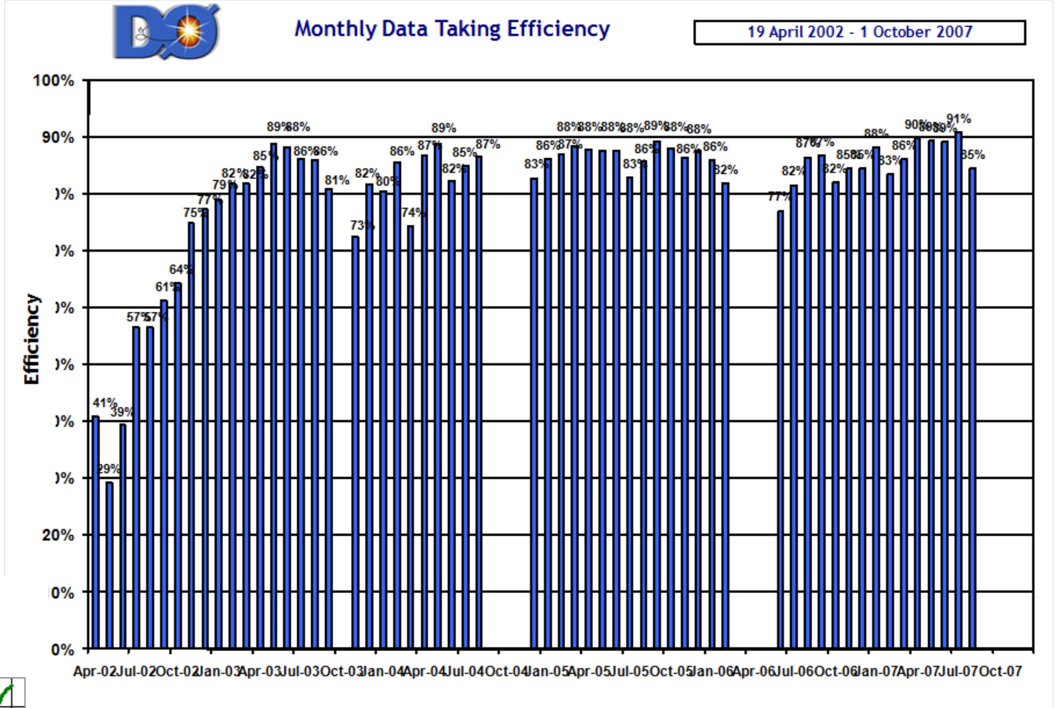
***My personal motivation:***

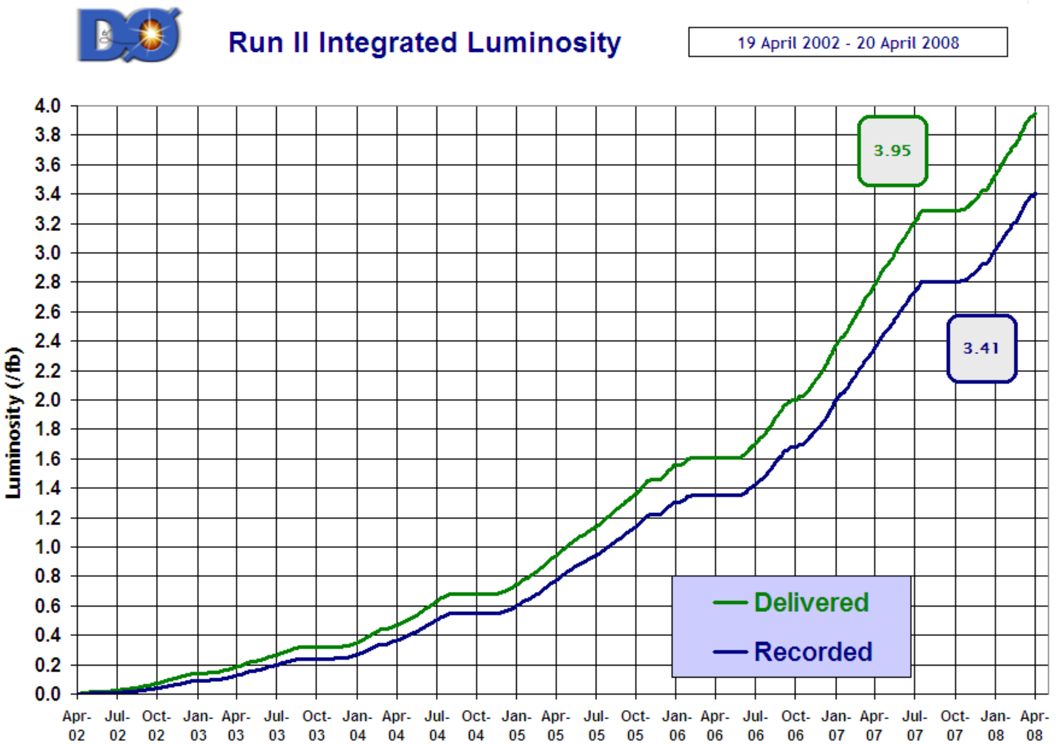
Diffraction is a significant component of strong interaction processes.
=> Understand the strong interactions in all its aspects (the big picture).

Test the most accepted model for hard diffraction, the Ingelman-Schlein model.

# The DØ Detector Performance

- the detector has been running stably, with a data taking efficiency close to 90%

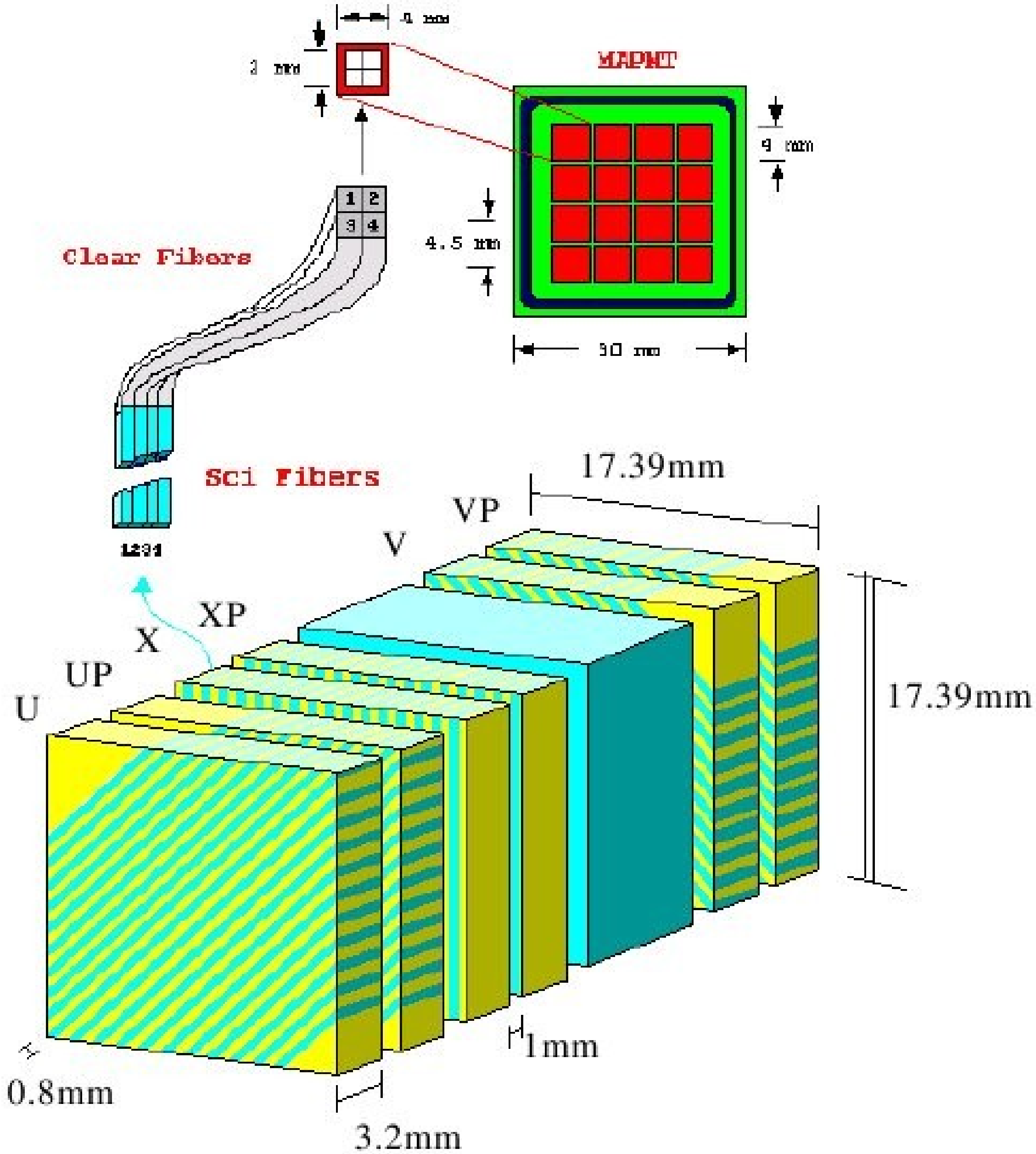



- integrated luminosity of 4.1 $fb^{-1}$

# The DØ Forward Proton Detector

- Scintillating fibers detector.




- U and V planes at 45 degrees from X plane and 90 degrees between each other;

- coincidence between 2 fibers in 2 layers of a plane defines a segment;

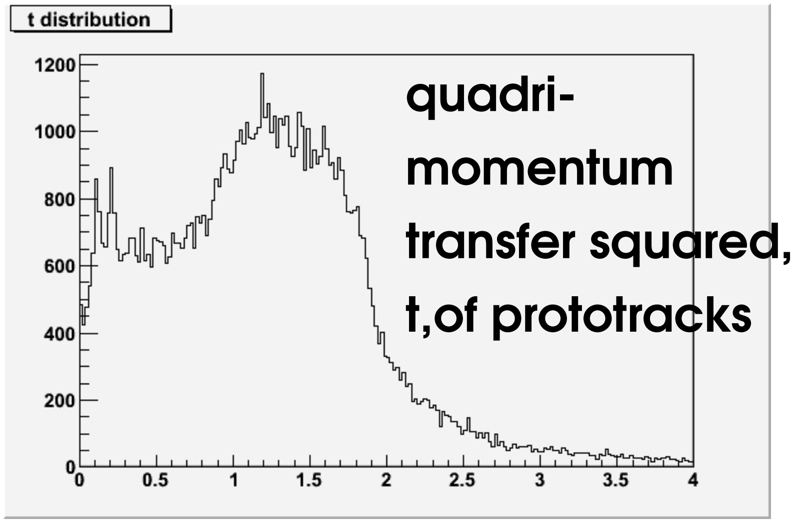
- coincidence between 2 segments in 2 planes defines a hit;

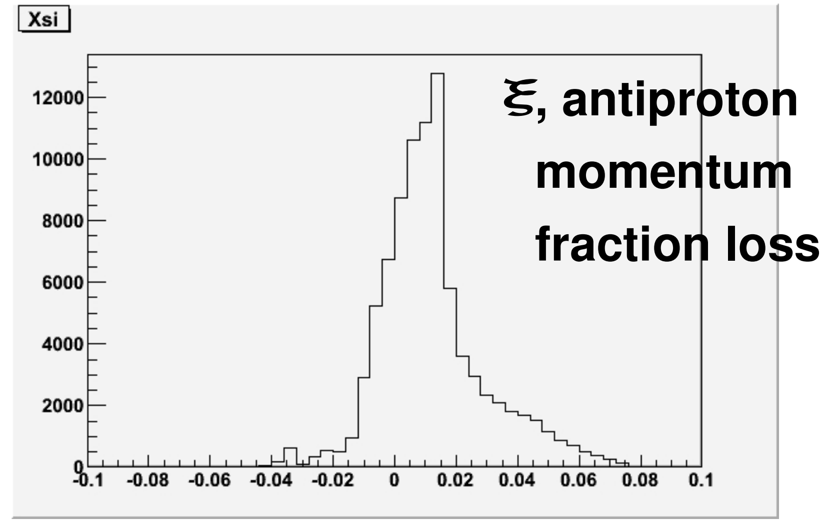
- coincidence between 2 hits in 2 detectors ( spectrometer ) defines a prototrack;

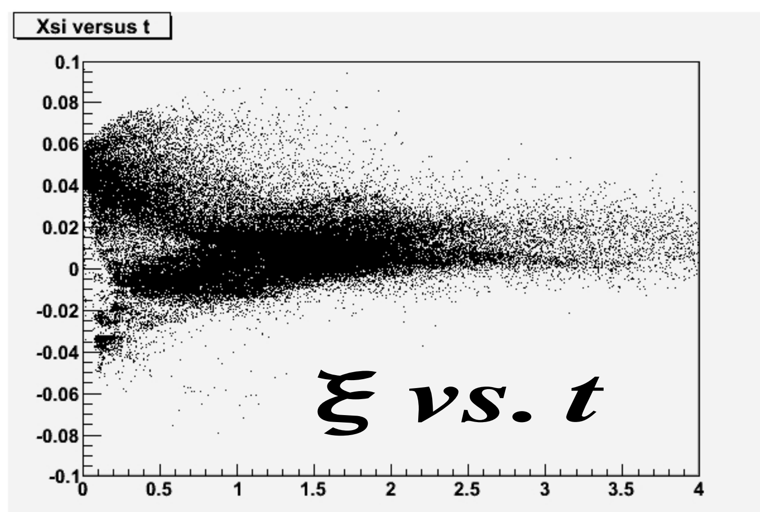
# Track Reconstruction – After Alignment

Take correlated hits and reconstruct it back to the Interaction Point, propagating it through the Beam Magnets, Drift Regions and Separators.

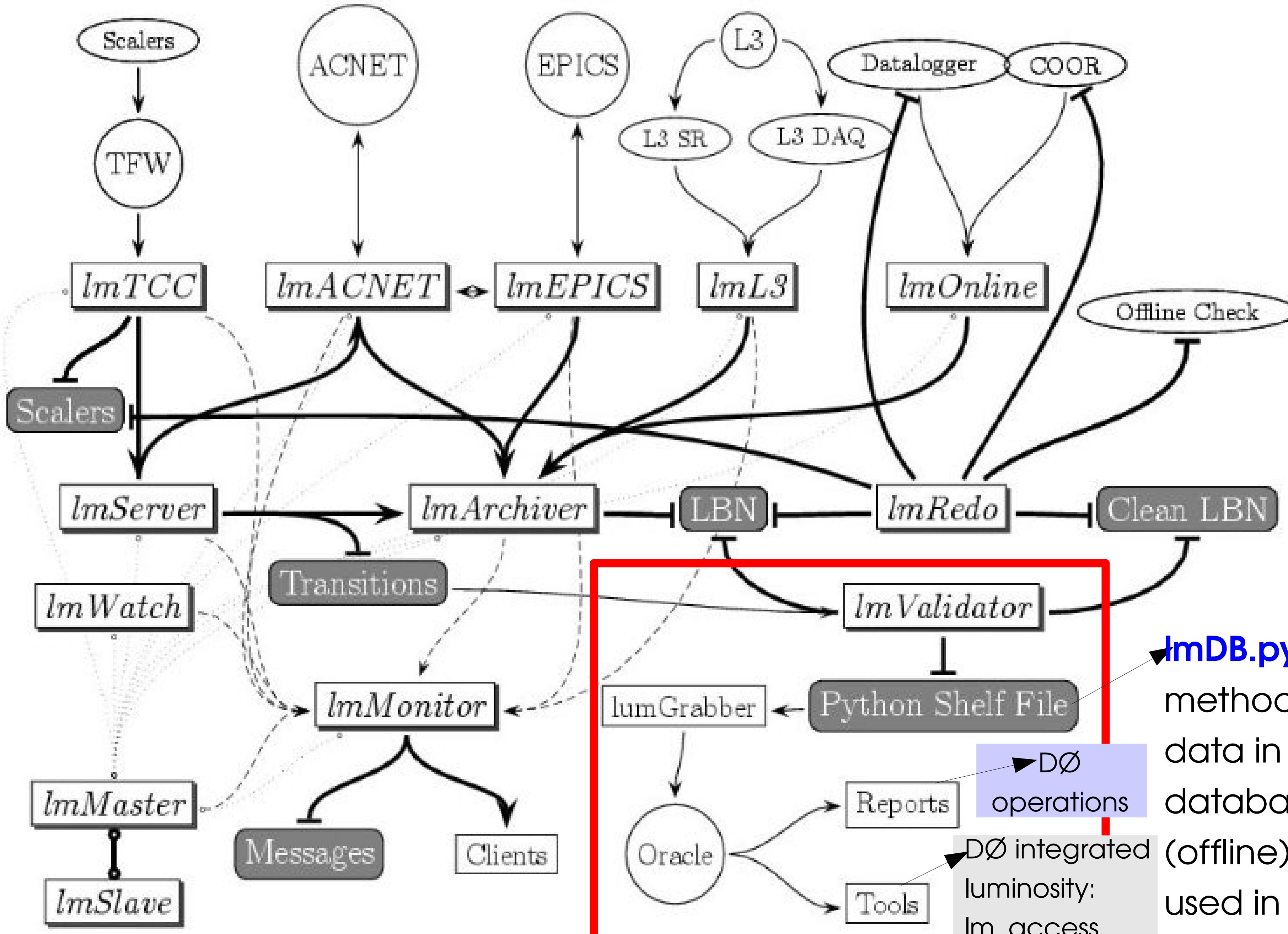
Get reconstructed $\xi$ and $|t|$



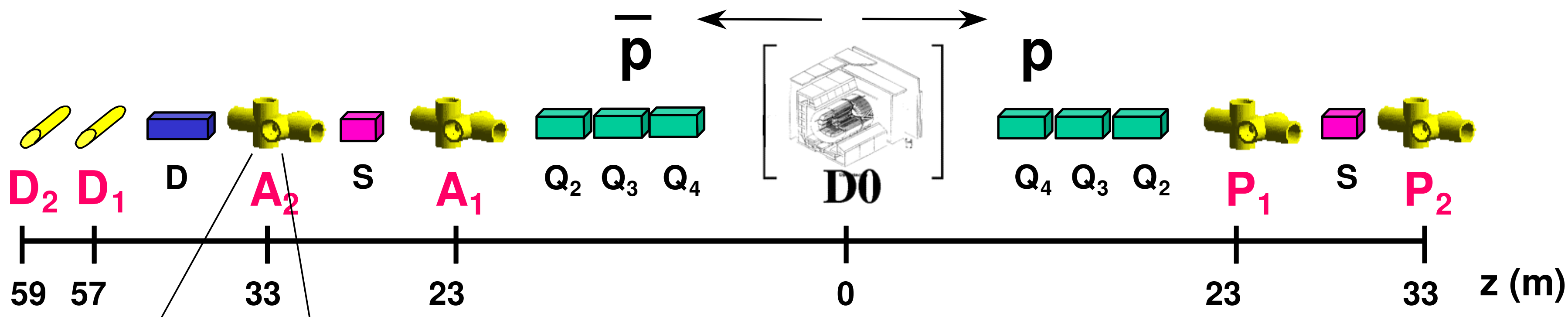



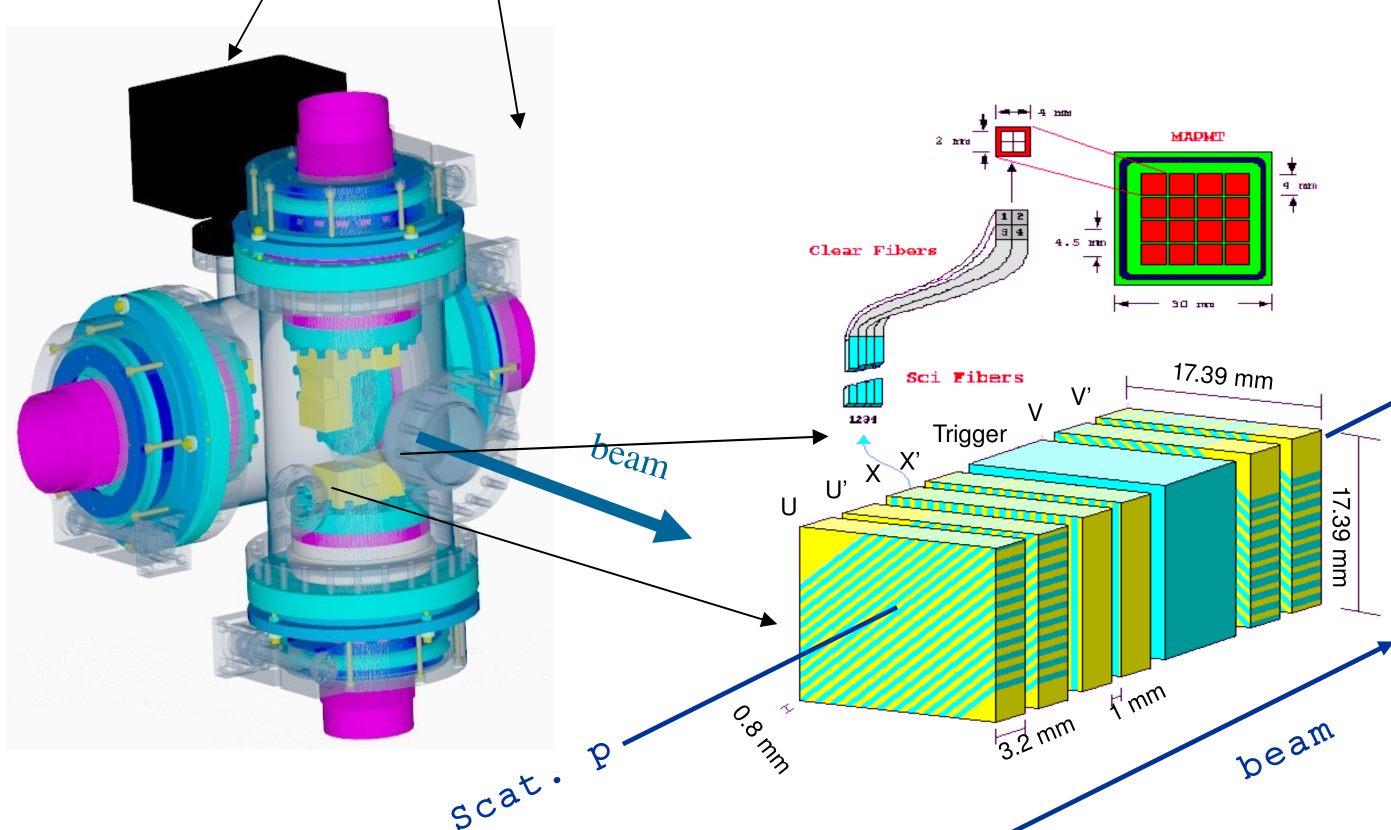
# The DØ Luminosity Monitor Database




**lmDB.py:** python methods to load data in the database (offline). Also used in lumGrabber

# DØ Roman Pots




- Construídos no LNLS
- Desenho original ⇔ minimizar espaço na linha do feixe
- Vácuo de $10^{-11}$ Torr
- Alta precisão ~ 4μm RMS
- Instalado no Fermilab 12/2000
- Funcionando plenamente

# The Ingelman-Schlein Model

starting from the generic hard scattering cross section in which two partons interact to form jets:

$$d\sigma = \sum_{a,b,c,d} f_{a/\bar{p}}(x_a, Q^2)\, dx_a\, f_{b/p}(x_p, Q^2)\, dx_b \times \frac{d\hat{\sigma}_{ab\rightarrow cd}}{d\hat{t}}$$

We assume a parton from the proton interacts with a parton from the pomeron and the antiproton structure function can be replaced by the convolution of the **pomeron structure function** with the pomeron emission rate called the **pomeron flux factor**.

$$x_a f_{a/\bar{p}}(x_a, Q^2) = \int d\xi \int d\beta \int dt\, f_{IP}(\xi, t) \times \beta f_{a/IP}(\beta, Q^2)\, \delta\left(\beta - \frac{x_a}{\xi}\right)$$