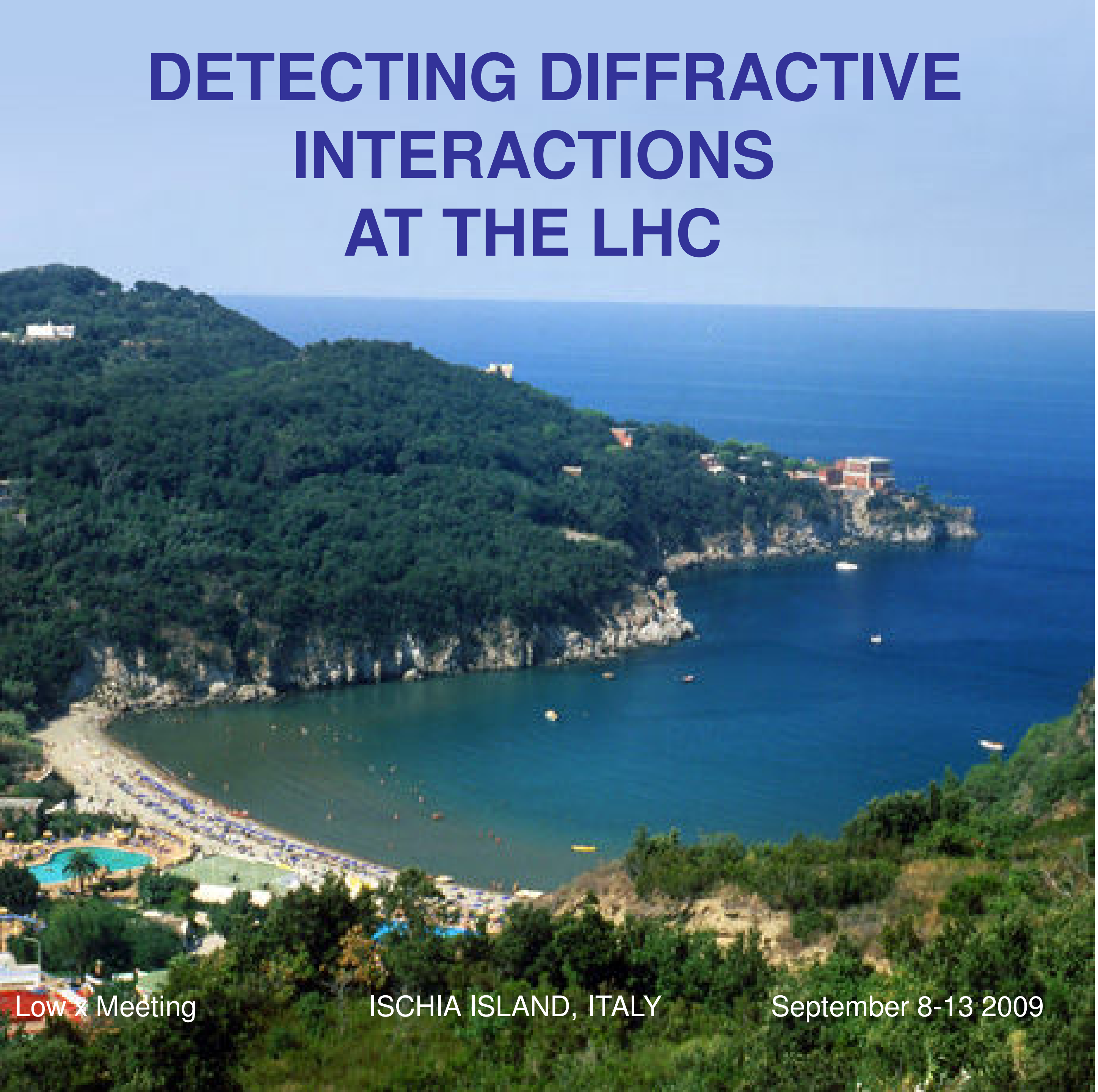

DETECTING DIFFRACTIVE INTERACTIONS AT THE LHC

(1) Multivariate classification of diffractive and non-diffractive events at low lumi LHC.

(2) Low mass central diffraction at LHCb.

Risto Orava

University of Helsinki,
Helsinki Institute of Physics
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Low x Meeting ISCHIA ISLAND, ITALY September 8-13 2009

(1)The event classification studies by

The Helsinki Group members:
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in Association with the Adaptive Informatics Research
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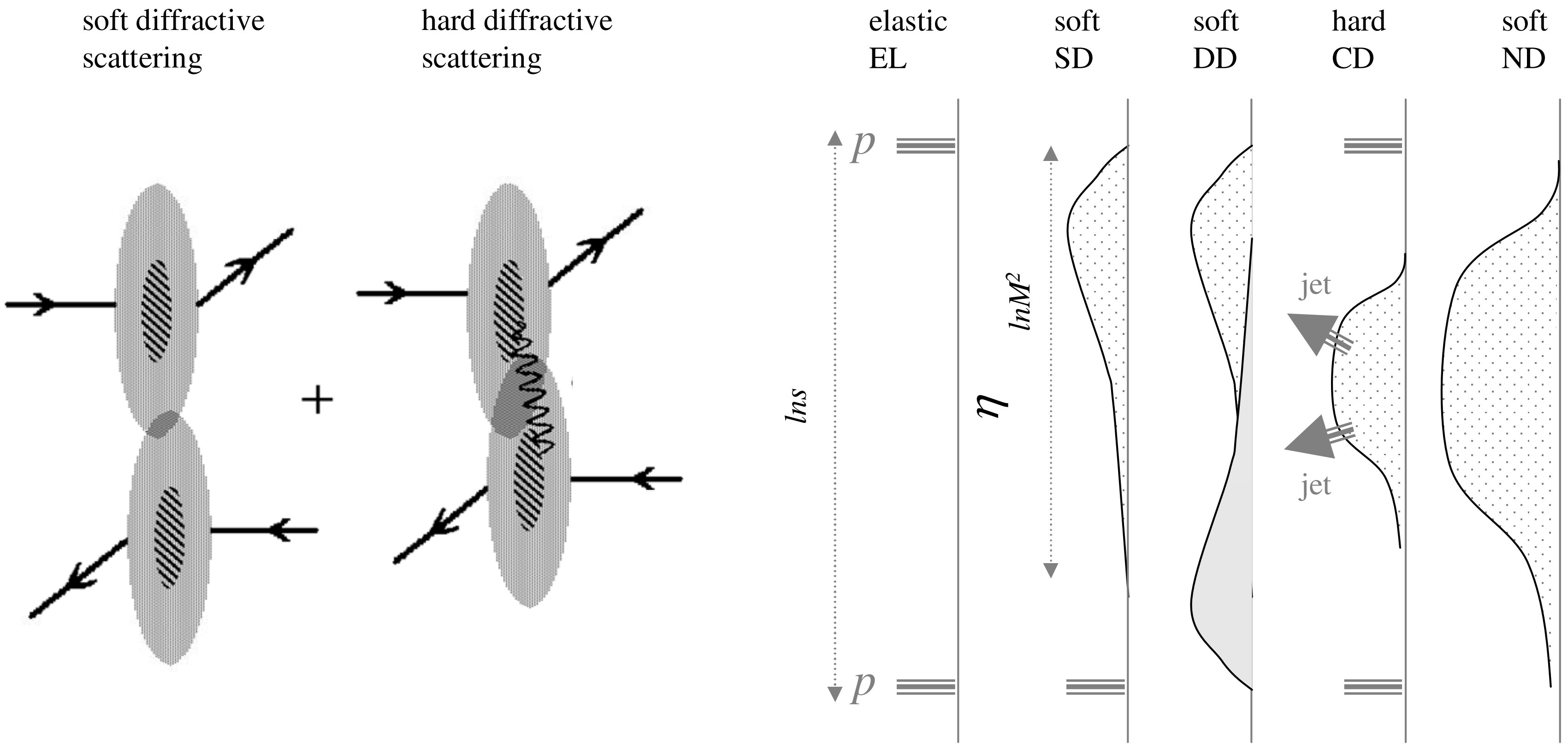
SPACE-TIME STRUCTURE OF DIFFRACTIVE EVENTS

$$\sigma_{TOT} \equiv \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD} + \sigma_{ND}$$



HOW TO CLASSIFY INELASTIC LHC EVENTS AS SD, DD, CD or ND IN AN EXPERIMENT?

PREDICTIONS FOR THE DIFFRACTIVE CROSS SECTIONS VARY…

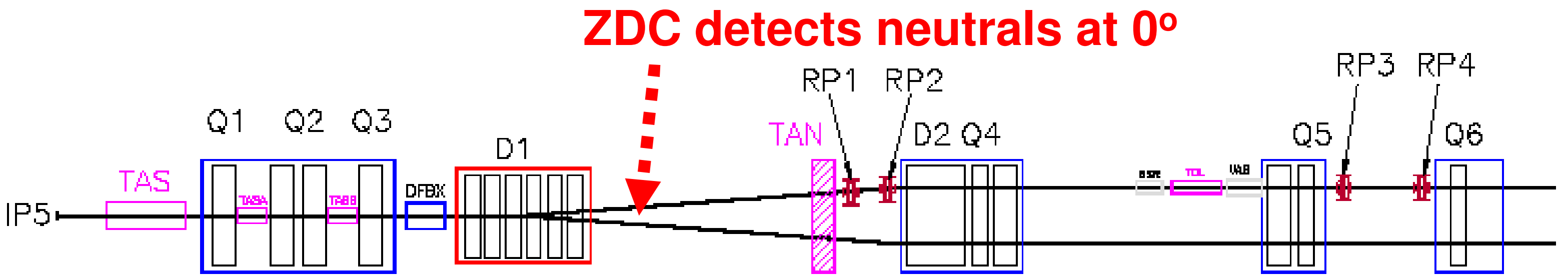
Cross Section (mb)	GLMM (mb)	KMR (mb)	PYTHIA6.205	PHOJET1.12	"GW"(mb)
σ_{TOT}	92.10	88.00	101.50	119.00	90.00
σ_{EL}	20.90	20.10	22.20	34.40	20.00
σ_{SD}	11.80	13.30	14.30	11.00	10.00
σ_{DD}	6.10	13.40	9.80	4.06	5.00
$(\sigma_{EL} + \sigma_{DIFF})/\sigma_{TOT}$	0.42	0.53	0.46	0.42	0.39

σ_{CD} anywhere between a few μb's to a few mb's.

Predictions for the proton-proton cross sections at the LHC ($\sqrt{s}$ = 14 TeV), GLMM and KMR PYTHIA6.205 and PHOJET1.12., "GW" refers to a Good and Walker based toy model.

LOW MASS DIFFRACTION IS NOT UNDERSTOOD – WINDOW OF OPPORTUNITY FOR EARLY LHC.

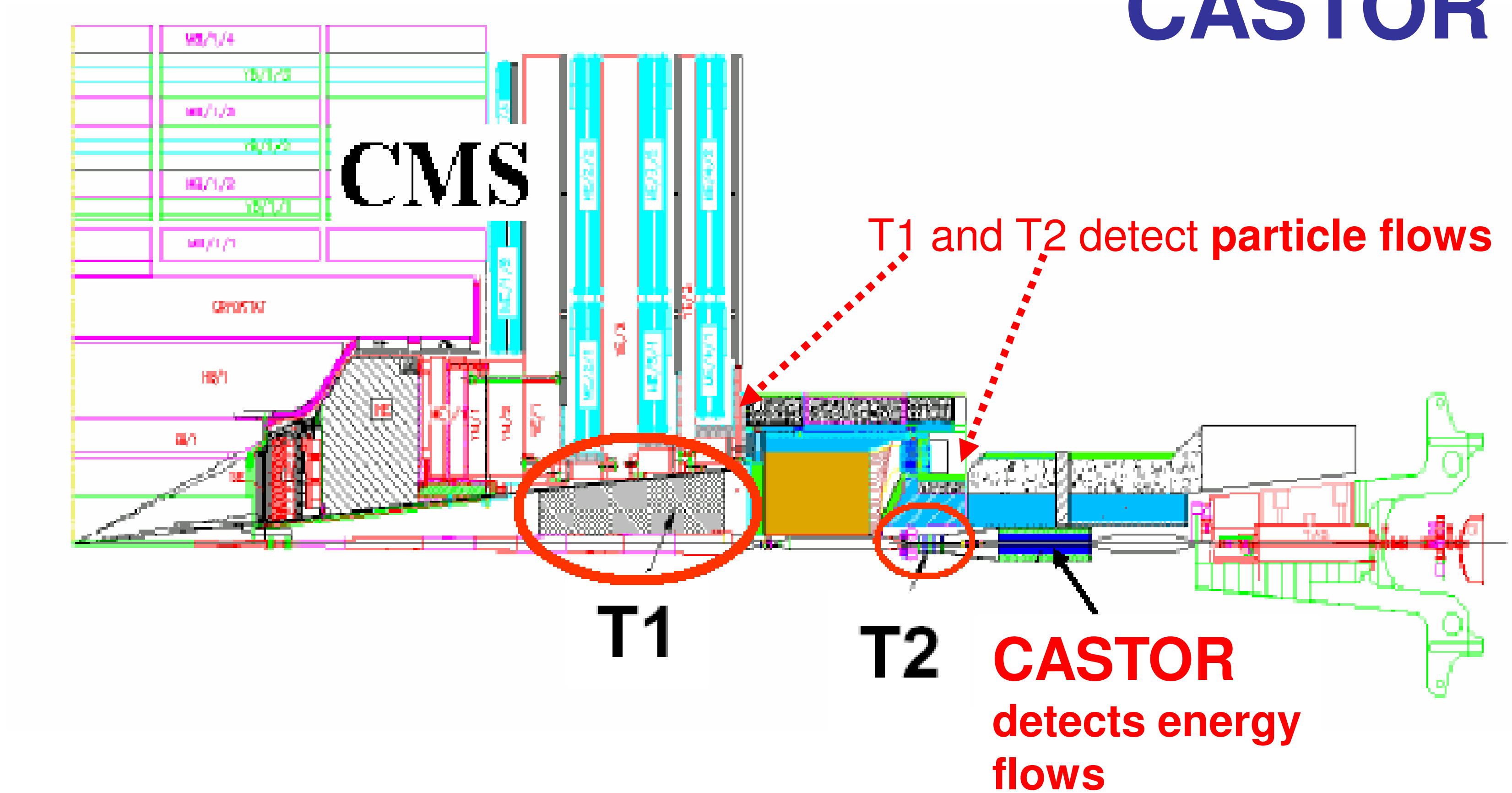
FORWARD DETECTORS (1): THE ROMAN POTS AND ZDC



The *TOTEM lay-out of leading proton detectors (Roman Pots). The detector locations at ±147m (RP1) and at ±220 m (RP3) are shown .*

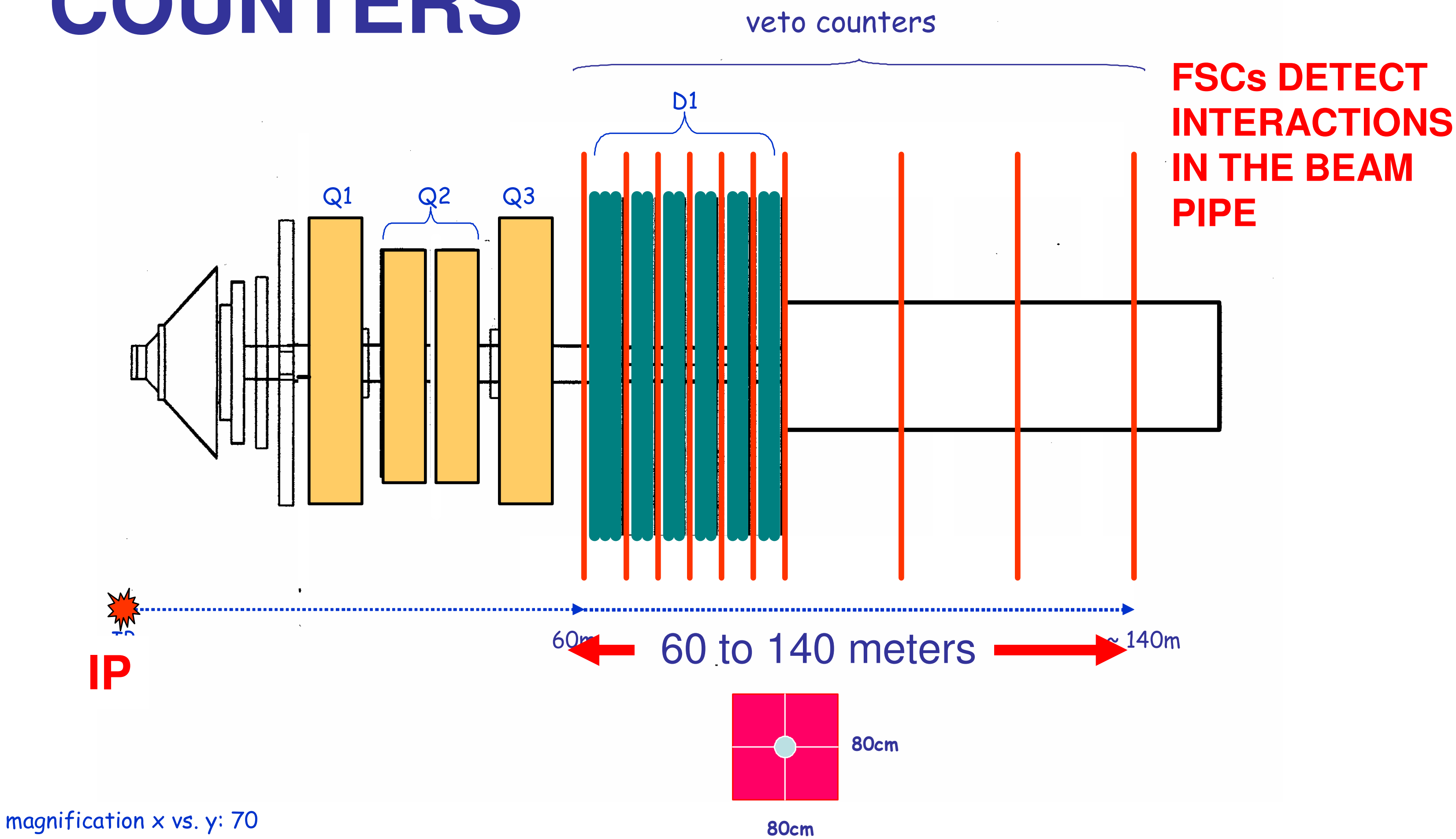
IN THIS ANALYSIS, THE ROMAN POTS ARE NOT USED IN CLASSIFYING THE LHC EVENTS.

(2) T1, T2 SPECTROMETERS, AND CASTOR



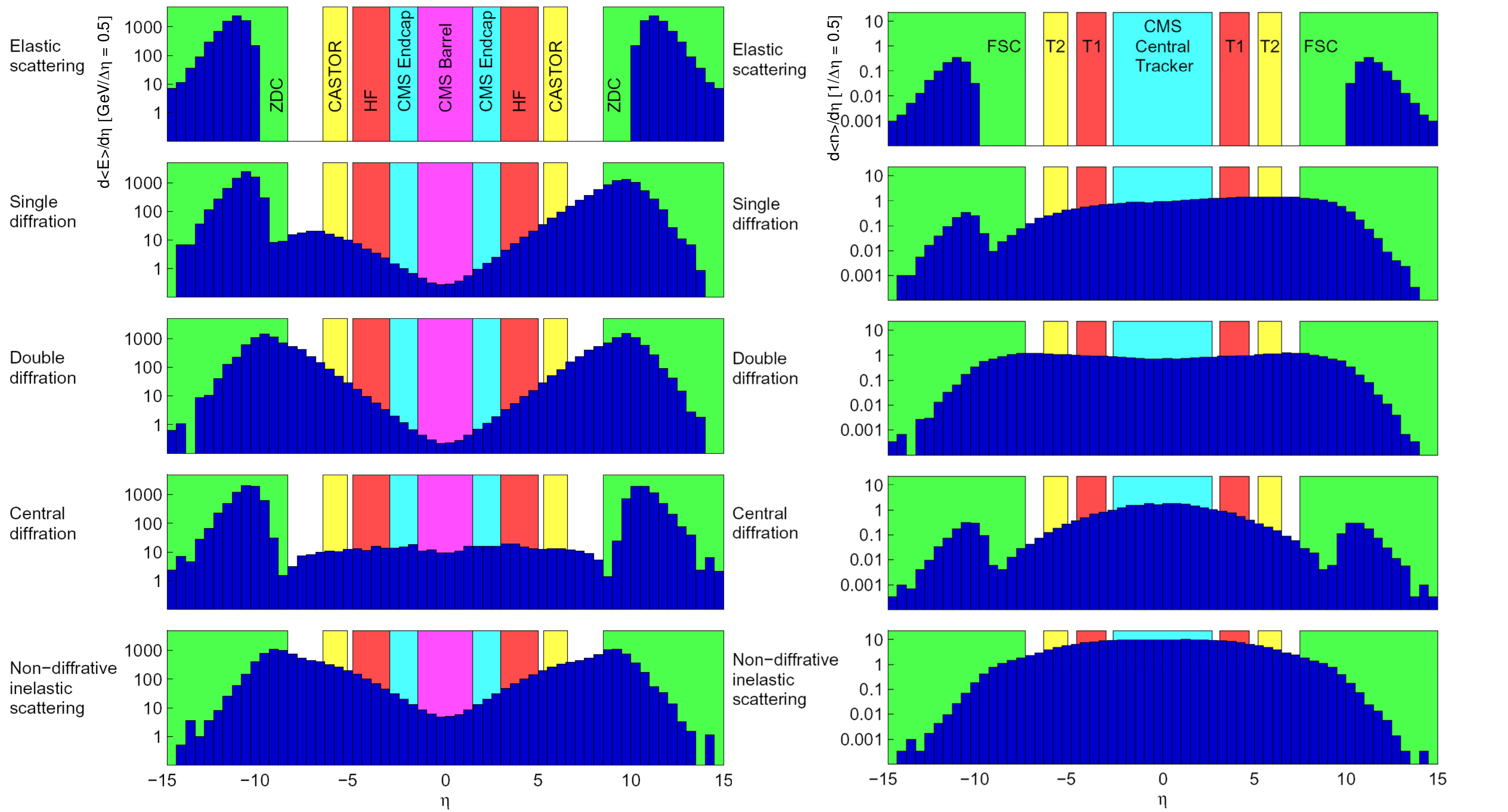
The lay-out of TOTEM inelastic spectrometers, T1 based on Cathode Strip Counters (CSC), and T2 based on Gas Electron Multipliers (GEMs).

(3) PROPOSED FORWARD SHOWER COUNTERS



The proposed upgrade of Forward Shower Counters, FSCs, to the CMS forward detector lay-out at ±60 to ±140 meters from the IP, the 10 vertical lines from ±60 m on indicate the locations of the proposed veto counters.

ENERGIES MULTIPLICITIES



23 INPUTS FOR EVENT CLASSIFICATION

INPUT INFORMATION FOR EVENT CLASSIFICATION

- *particle flows* by TOTEM $T1_{R/L}$, $T2_{R/L}$ spectrometers and CMS $FSC_{R/L}$ counters at ±60 to ±140 m from IP5 [5],
- *transverse energy detection* by the CMS Barrel and End Cap Calorimetry, $HF_{R/L}$, and $CASTOR_{R/L}$ calorimeters
- *neutral particle detection* by the CMS $ZDC_{R/L}$ calorimeters.

AIM AT A PROBABILISTIC APPROACH: EACH EVENT TO BELONG *TO EVERY ONE* OF THE EVENT CLASSES WITH A WEIGHT ≠ 0.

Variable	Comments
E_zdcl	ZDC energy left
E_casl	CASTOR energy left
E_hfl	HF energy left
t2ml	T2 multiplicity left
t1ml	T1 multiplicity left
fwdm1l	FSC multiplicity left plates 1-2
fwdm2l	FSC multiplicity left plates 3-8
fwdm3l	FSC multiplicity left plates 9-10
fwd1stl	1st FSC plane hit left
fwdmaxl	FSC plane with the maximum amount of hits left
E_zdcr	ZDC energy right
E_casr	CASTOR energy right
E_hfr	HF energy right
t2mr	T2 multiplicity right
t1mr	T1 multiplicity right
fwdm1r	FSC multiplicity right plates 1-2
fwdm2r	FSC multiplicity right plates 3-8
fwdm3r	FSC multiplicity right plates 9-10
fwd1str	1st FSC plane hit right
fwdmaxr	FSC plane with the maximum amount of hits right
endc_l	CMS endcap energy left
endc_r	CMS endcap energy right
barrel	CMS barrel energy

INPUT FOR EVENT CLASSIFICATION

LEADING PROTONS ARE NOT USED

Datasets

- *12,000* events of each category (SD, DD, CD, and ND), were generated using either PYTHIA or PHOJET and GEANT.

- To improve the classification accuracy and to facilitate learning of the data, the SD events were divided into two classes: SD1 and SD2, in which either the beam-1 proton (circulating anti-clockwise in the LHC ring) or the beam-2 proton (circulating clockwise in the LHC ring).

- Each dataset was further sub-divided into a training data of *10,000* events and a test data of *2,000* events.

- The algorithms were trained using the training data and their performance was validated using the test data.

- The test data is presented to the algorithms only after the training phase is completed and can thus be used to verify the generalization capability of the classifiers.

NOTE: LUMINOSITIES OF THE ORDER OF 10^{30} $cm^{-2}s^{-1}$ ASSUMED
$\Rightarrow$ NO PILE-UP

MULTIVARIATE TECHNIQUES

Gene expression programming (GEP):

A recently introduced evolutionary algorithm (Ferrara) that is used to evolve *expression trees* (Figure).

GEP is distinguished from other evolutionary algorithms by having separate representations and structures for the genotype (the chromosome) and the phenotype (the expression tree) of an individual.

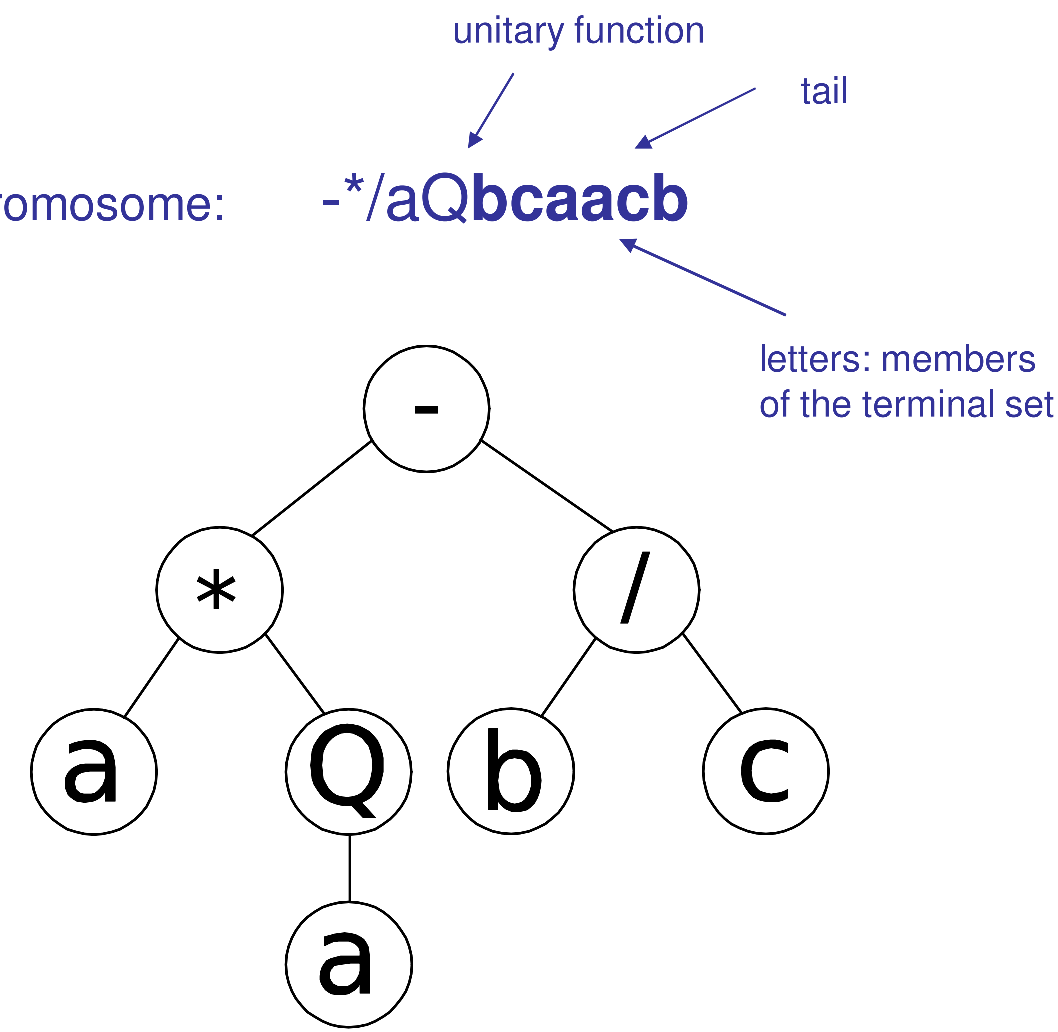
The algorithm is used to evolve simple, easy to manipulate, linear chromosomes represented as text strings, which in turn encode the more complex expression trees of various shapes and sizes.

GEP can be seen as a combination of genetic algorithms and genetic programming; the former evolves binary strings while the latter is used to optimize the tree-like entities.

Karva expression of a chromosome: -*/aQ**bcaacb**

Translated into an *expression tree; read from left to right.*

Note: Some of the tail section is not used!



Evolve the expression tree, encoded by the *Karva* expression, so that the output of the tree maximizes a predefined performance criterion, **the fitness function**.

The expression trees evolved by GEP are here used as classifiers (the objective is to maximize the classification accuracy of the output of the tree given a set of input vectors).

Each tree is here used for binary classification (*signal/background* separation) only, by introducing a threshold (*= 0.5*) for the output of the tree. When the output is equal to, or greater than the threshold, the input vector is classified as *signal* and below the threshold as *background*.

Neural Networks

Neural networks (NN) are adaptive data modelling tools inspired by the functional model of the human brain.

Since about a decade, the neural networks are widely used in high-energy physics data analysis.

Here a particular type of feed-forward neural networks, called the multi-layer perceptron (MLP) network is used. The MLP network consists of an input layer, output layer and one or more hidden layers of neurons.

When information propagates through the network in the forward direction, the weighted sum of the activation levels of the input neurons is fed into a hidden layer of N_{hid} neurons.

The activation level of the hidden neurons is determined by a transfer function f whose output is, in turn, fed into the output layer.

Support Vector Machines

Support Vector Machines (SVMs) have become a popular multivariate analysis tool in high energy physics.

SVMs are mostly used for classification tasks, but they can also be applied to e.g. regression.

The main idea in SVMs is to find a hyperplane that separates two different data samples, representing different classes, with the largest possible margin. The margin is defined as the distance from the hyperplane to the closest data points.

It is not always possible to find such a plane and, therefore, the data points are usually projected nonlinearly into a higher dimensional space before finding the optimal hyperplane.

Multi-class classification

The classification algorithms are usually designed for binary problems, where the goal is to distinguish two classes

$\Rightarrow$ multi-class classification tasks are often reduced into several binary problems.

Several different techniques for the reduction exist:
one-against-all, *one-against-one* and *ordered binarization* etc.

Self-organizing maps

The self-organizing map (SOM) is an artificial neural network algorithm which is here used for dimensionality reduction and data visualization.

With a SOM, a non-linear mapping of the analysed *23*-dimensional space to a two dimensional map is achieved.

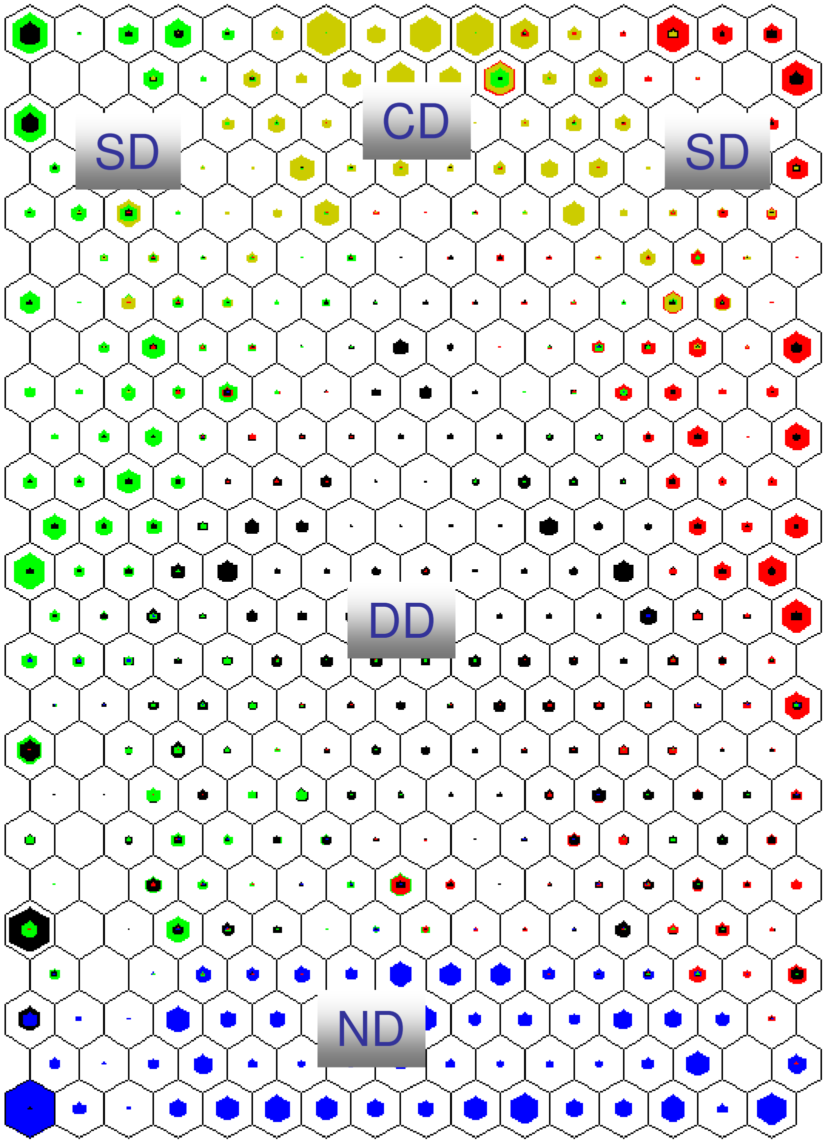
The map consists of *n* by *m* nodes which all contain a model vector.

The nodes are arranged on a hexagonal grid.

The mapping of an input vector is conducted by going through all nodes and calculating Euclidean distances between model vectors and the input vector.

The node with the smallest distance to the input vector is called the best matching unit (BMU) and the input vector is mapped to this node.

red=SD1, green=SD2, blue=ND, black=DD, yellow=CD



SOM ALGORITHM

How well the different event categories are separated in the multivariate analysis?

A SOM is trained with *60,000* PYTHIA or PHOJET simulated events (*12,000* of each type).

The different event categories are mapped on the SOM (Figure), with colour codes to identify the event categories: red for the SD1, green for the SD2, blue for the ND, black for the DD and yellow for the CD events.

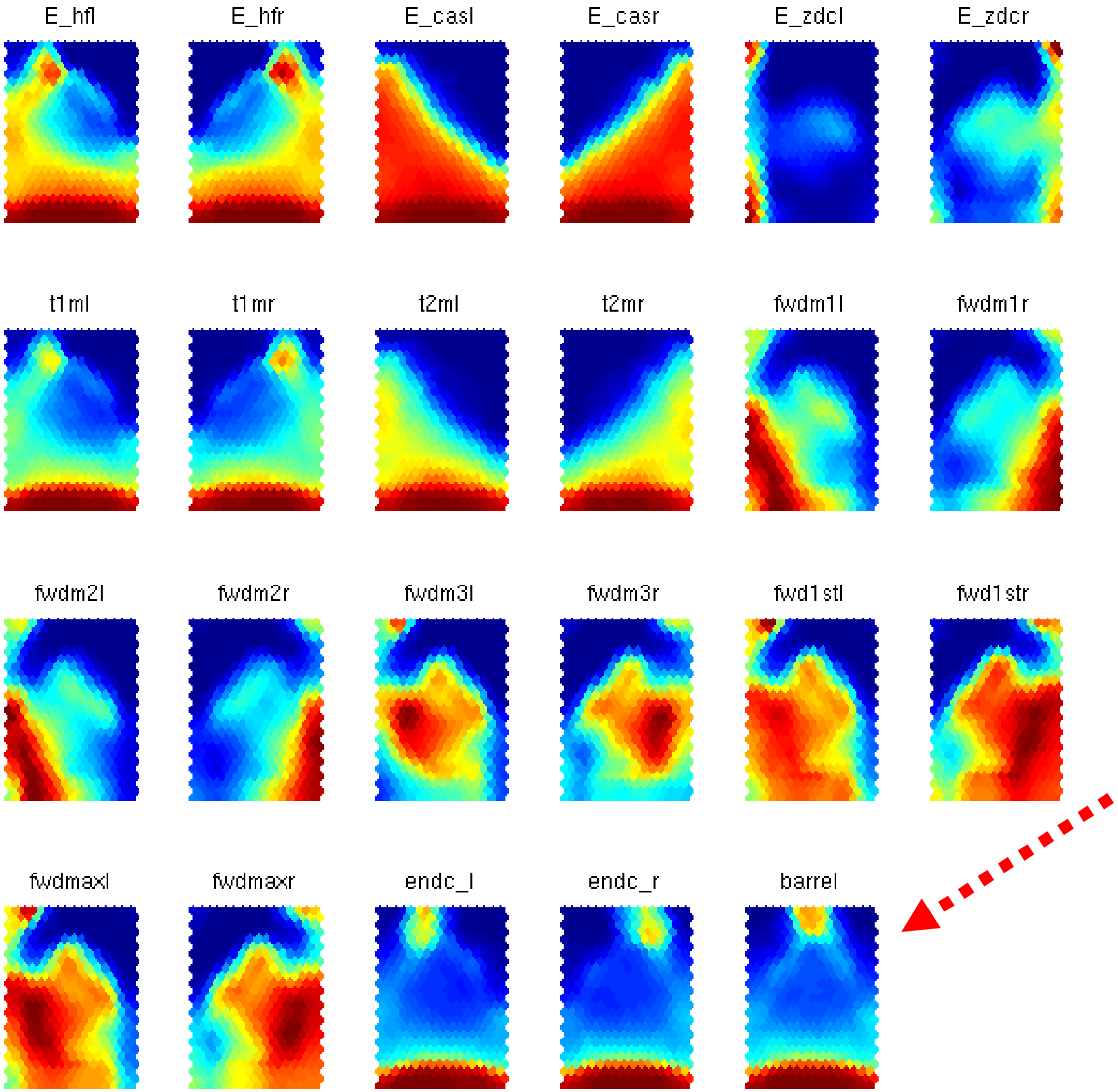
The larger the colour patch on a node the more events are mapped to the node.

The map clearly demonstrates that the non-diffractive events are easily identified; they are basically all clustered at the bottom of the map.

Similarly, the CD events are rather well separated from the other diffractive event categories.

The most significant overlap occurs between the SD and DD events.

THE 23 SOM MAP NODES



Each input dimension is shown in a separate component plane.

Red colour on a node of a component plane indicates that the variable usually receives large values among the events mapped to that node.

The CMS barrel calorimeter values, indicate that it usually detects large energy depositions from the events that are mapped to the ***bottom*** and to the ***top-centre*** of the map.
These regions mainly contain ND events and CD events $\Rightarrow$ the ND and CD events tend to release large amounts of energy within the CMS barrel.

EVENT CLASSIFICATION EFFICIENCIES

Method	**Efficiency**
GEP ordered binarization	92.49
GEP one-against-all	88.54
SVM ordered binarization	94.21
SVM one-against-one	94.38
NN ordered binarization	94.54
NN 5 outputs	94.42

The efficiencies represent the probability of correctly classifying an event belonging to a randomly selected class.

EVENT CLASSIFICATION PURITIES

Method	**DD**	**SD**	**CD**	**ND**
GEP ordered binarization	96.72	83.45	93.12	97.81
GEP one-against-all	83.85	82.78	91.01	97.18
SVM ordered binarization	97.75	84.40	96.37	99.97
SVM one-against-one	97.61	84.89	96.61	99.90
NN ordered binarization	97.44	85.19	97.04	99.92
NN 5 outputs	97.70	84.96	96.66	99.92

The purities represent the probability that an event classified to a given class in fact belongs to that particular class.

CONCLUSIONS – PART 1

The ND background is easily rejected by all three multivariate techniques; the single diffractive (SD), double diffractive (DD) and central diffractive (CD) event categories are well separated.

When either CMS or TOTEM detectors are dropped out; significant decline in efficiencies/purities is obtained, i.e. ***both*** sets of detectors are required for a decent analysis outcome.

The event classification results depend on the particular Monte Carlo model used to train and test the algorithms; As long as the models correctly reflect the kinematical constraints (energy-momentum conservation) and the cross features of different event categories, the results should reliably reflect the efficiencies and purities of a real event analysis at the LHC.

CONCLUSIONS – PART 1...

Further development is being carried out by the authors:

(1) to combine the best features of the three techniques into a unified probabilistic approach for event-by-event analysis, and

(2) to develop an unsupervised scenario that is less dependent on a particular Monte Carlo model in use.

The aim of the ongoing work is to develop an algorithm that can be used to evaluate relative rates of different diffractive event categories and, finally, to optimize the analysis of central diffractive production of $J^{PC} = 0^{++}$ states, such as heavy quarkonia, glueballs, Higgs boson, etc.

CENTRAL DIFFRACTION AT THE LHCb

LHCb IS IDEAL FOR DETECTING AND ANALYSING LOW MASS CENTRAL DIFFRACTIVE PRODUCTION OF EXCLUSIVE $\pi^+\pi^-/K^+K^-$ STATES IN:

$$pp \to p + M + p$$

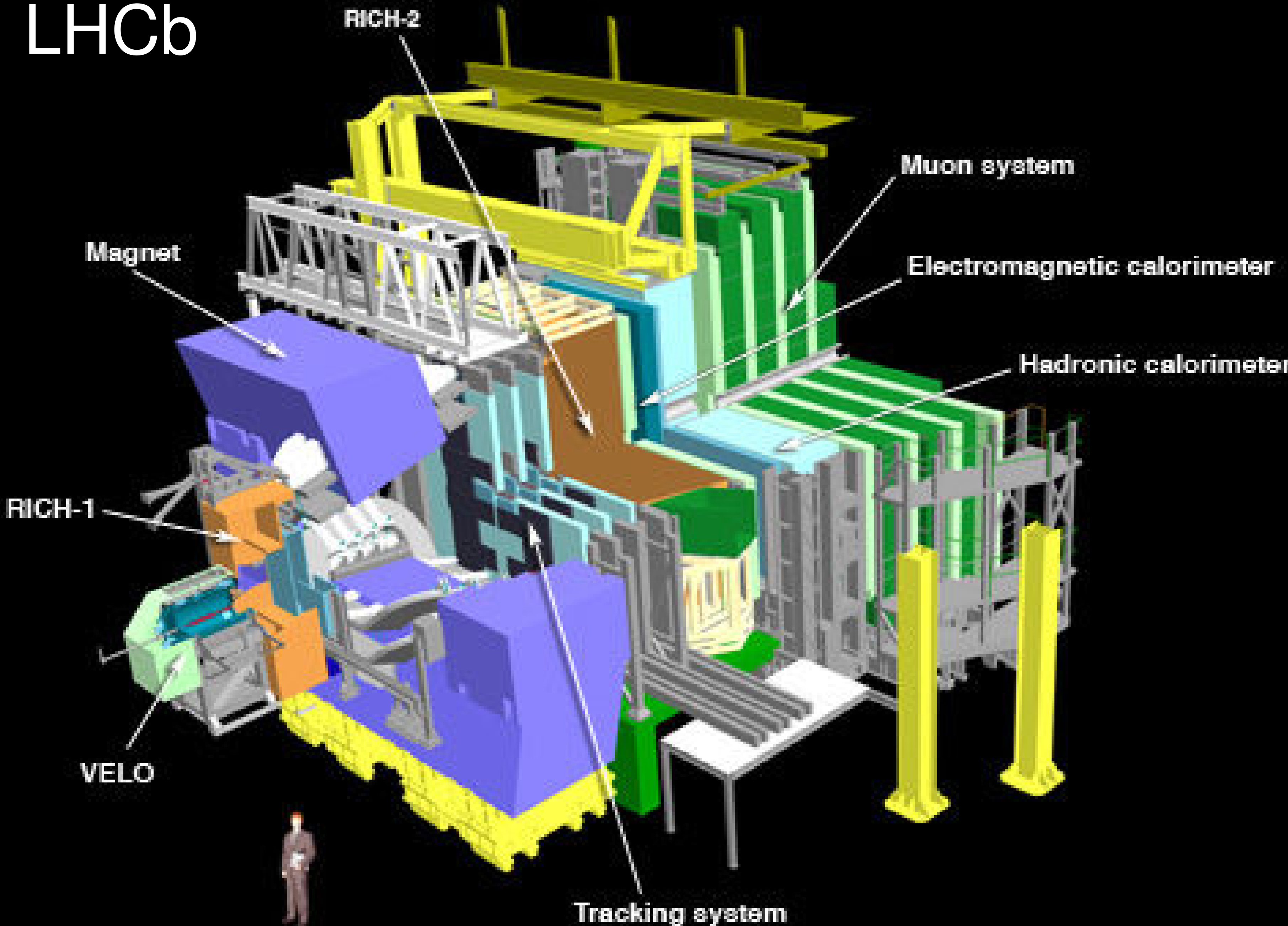
glueballs, hybrids, heavy quarkonia: χ_c, χ_b

$\pi^+\pi^-/K^+K^-$ STATES AS SPIN-PARITY ANALYZERs.

HOW TO FACILITATE THIS?

Jerry W. Lämsä and RO

LHCb


RICH-2
Muon system
Electromagnetic calorimeter
Hadronic calorimeter
Magnet
RICH-1
VELO
Tracking system

THE PROPOSED LHCb FSC LAY-OUT

ADD FSCs AT **20 – 100 METERS** ON BOTH SIDES OF IP8 – THE FSCs DETECT SHOWERS FROM THE VERY FORWARD PARTICLES.

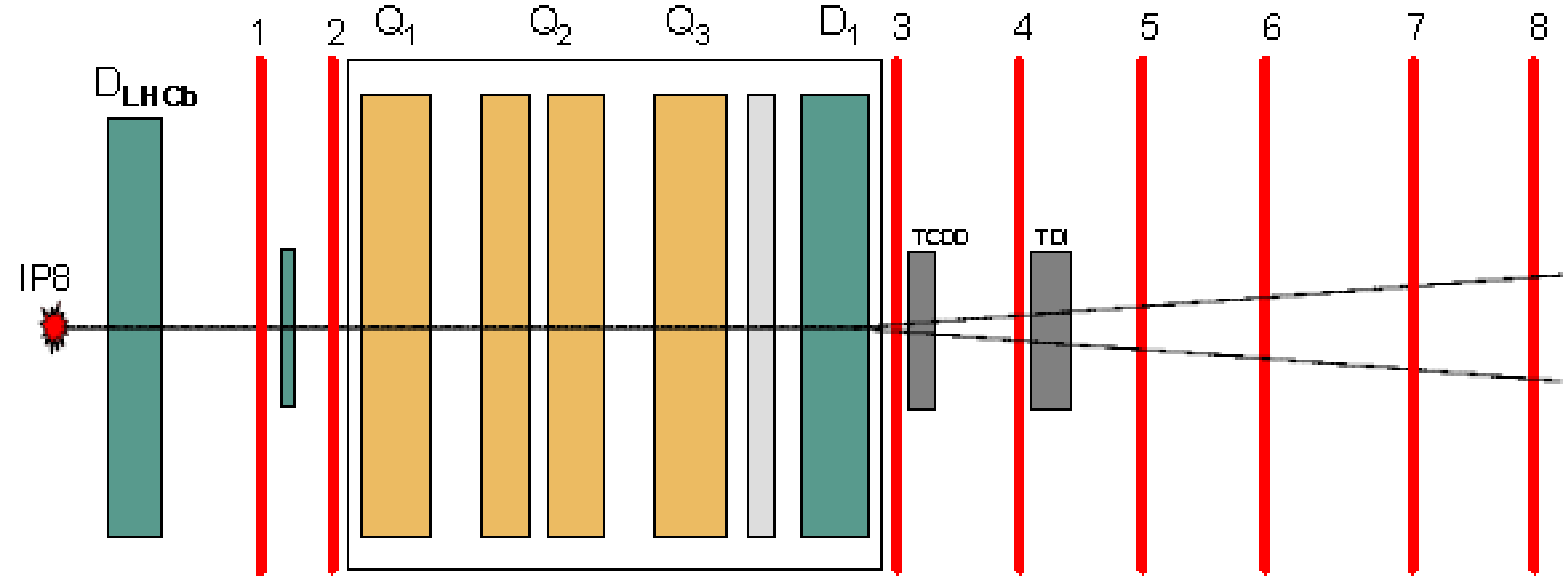


Figure 1. *The layout of LHCb detectors at the LHC Interaction Point (IP8). The proposed Forward Shower Counters (FSCs) are shown as vertical lines (1 to 8). The locations of the dipole (D) and quadrupole (Q) magnet elements are shown as green (dark) and yellow (light) boxes.*

TRIGGER FOR LOW CHARGED MULTIPLICITIES IN THE SPD, RESTRICT NO. OF CHARGED TRACKS IN VELO AND ABSENCE OF A SIGNAL IN FSCs

- TO DETECT A LOW MULTIPLICITY DECAY, A SMALL NUMBER OF CHARGED TRACKS ARE REQUIRED TO STRIKE THE SCINTILLATOR PAD DETECTOR (SPD).

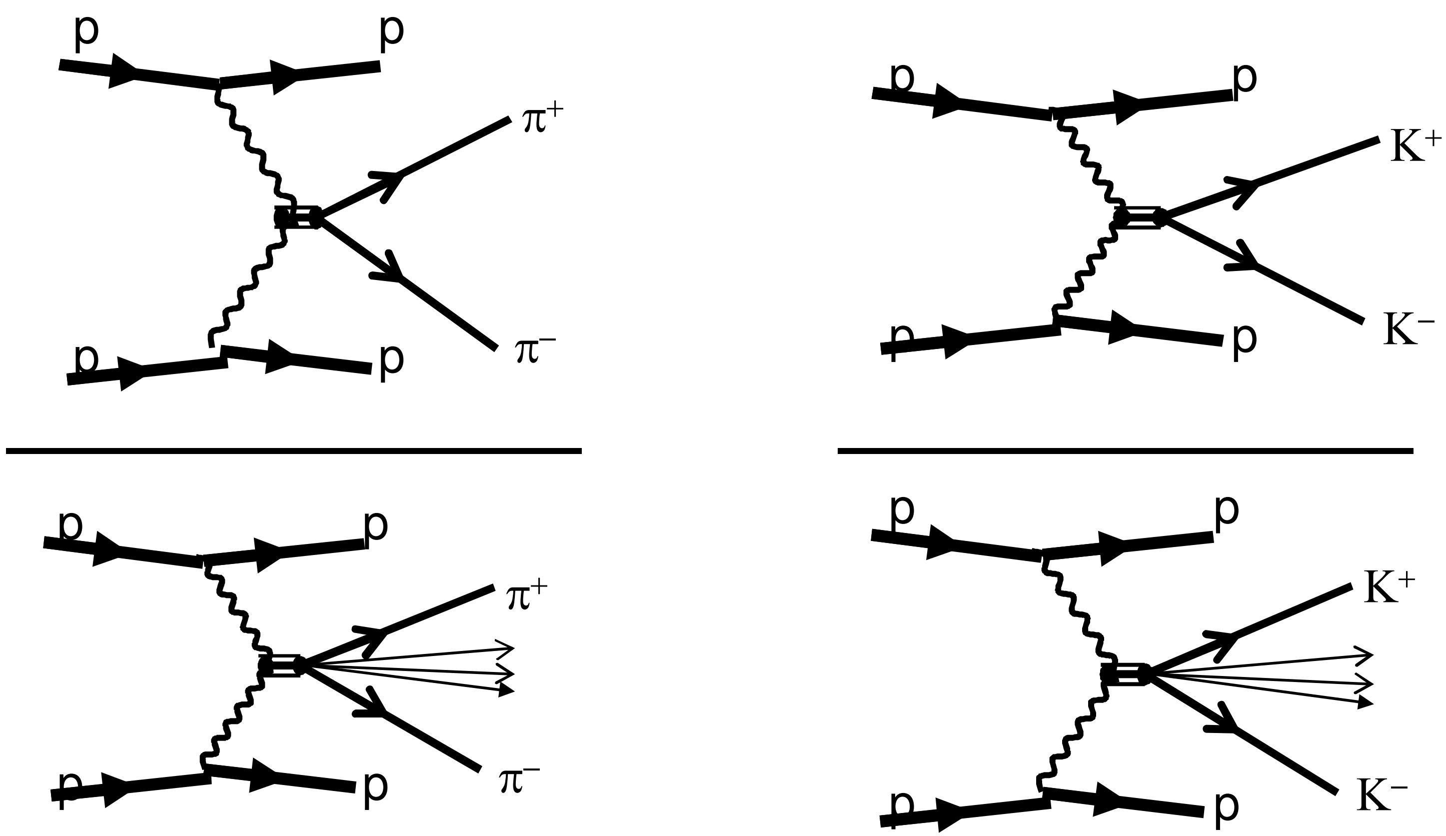
- THE LHCb VErtex LOcator (VELO) IS REQUIRED TO HAVE NO CHARGED TRACKS (CENTRAL ANGLE VETO) WITHIN 10 – 170 deg.

- SIMULATION USES A COMBINATION OF PHOJET+PYTHIA & GEANT.

- ANGULAR ACCEPTANCE OF THE SPECTROMETER: < 250 mrad (vertical), < 300 mrad (horizontal)

- NOTE: IN LOW LUMINOSITY LHCb RUNS, ONLY A SINGLE INTERACTION PER BX IS EXPECTED.

PURITIES FOR EXCLUSIVE STATES



$\Delta M \approx 20$ MeV

CENTRAL DIFFRACTION ACCEPTANCE

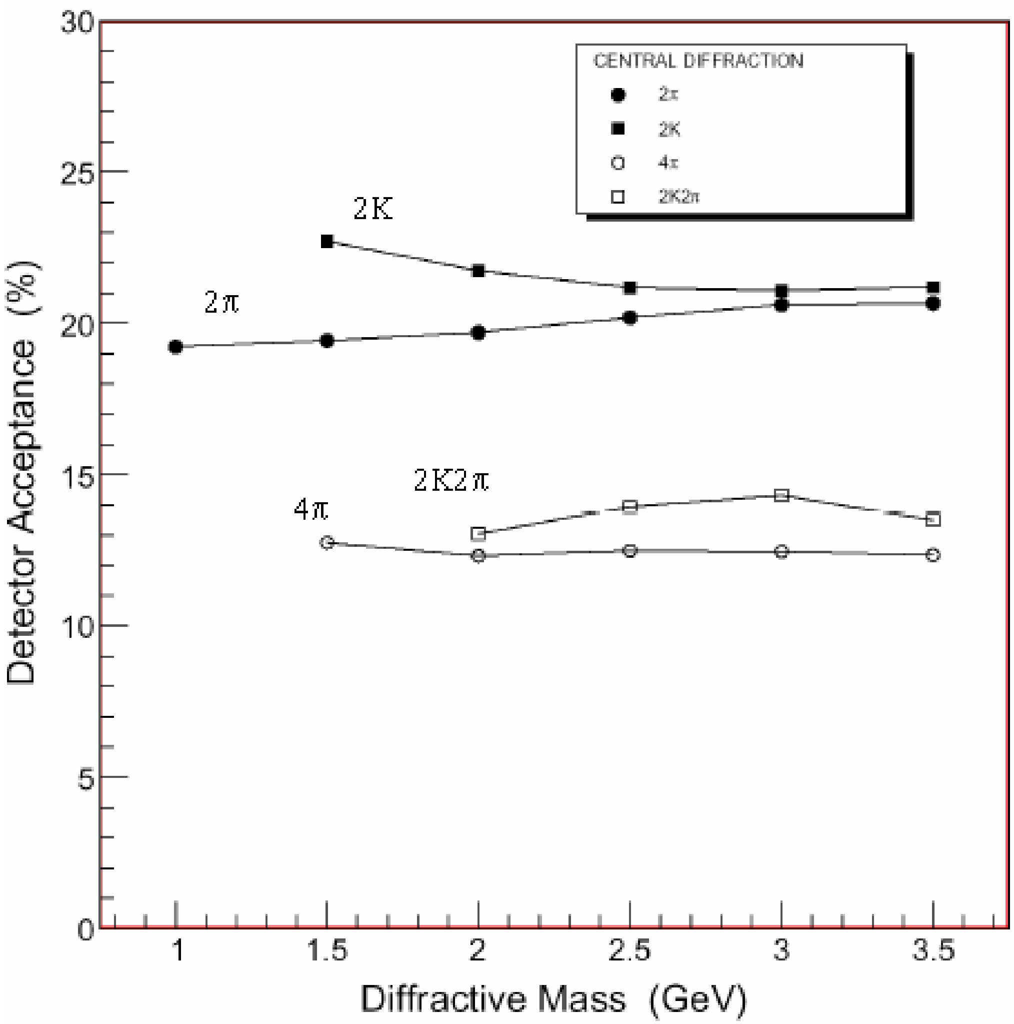


Figure 2. *The detector acceptance as a function of the central diffractive mass for $\pi^+\pi$, K^+K, $2\pi^+2\pi$ and $K^+K\pi^+\pi$ decay channels.*

CENTRAL DIFFRACTION PURITY

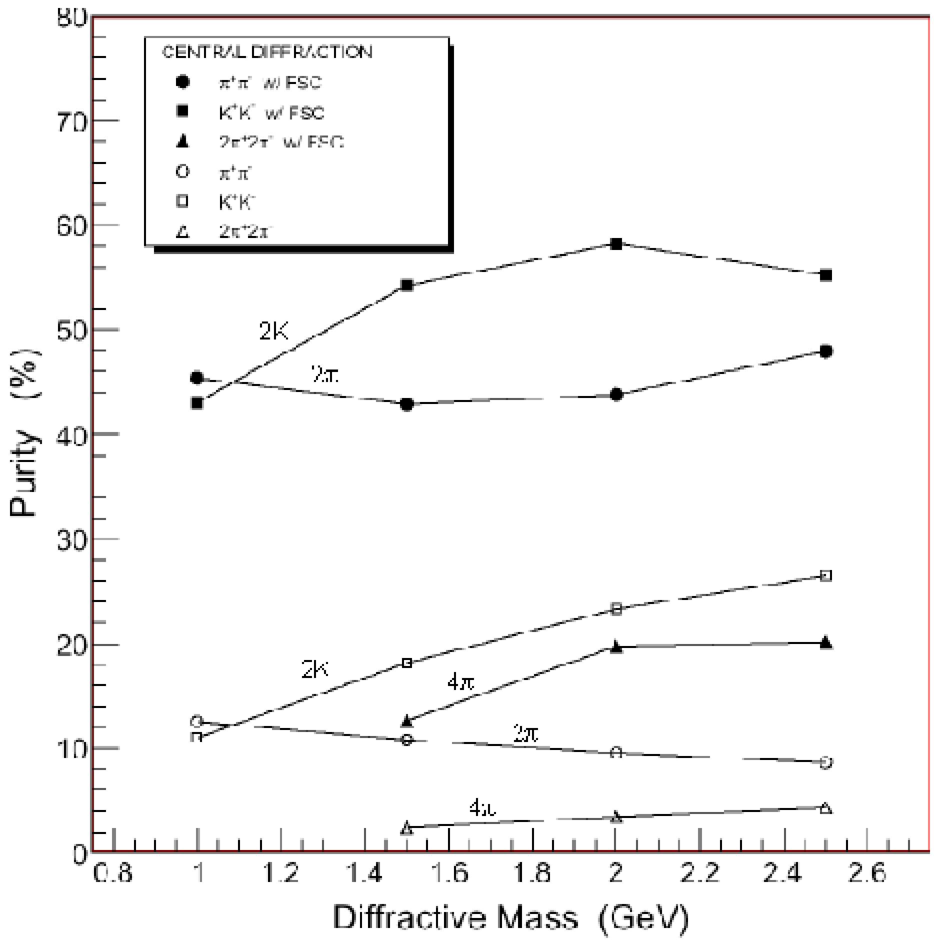


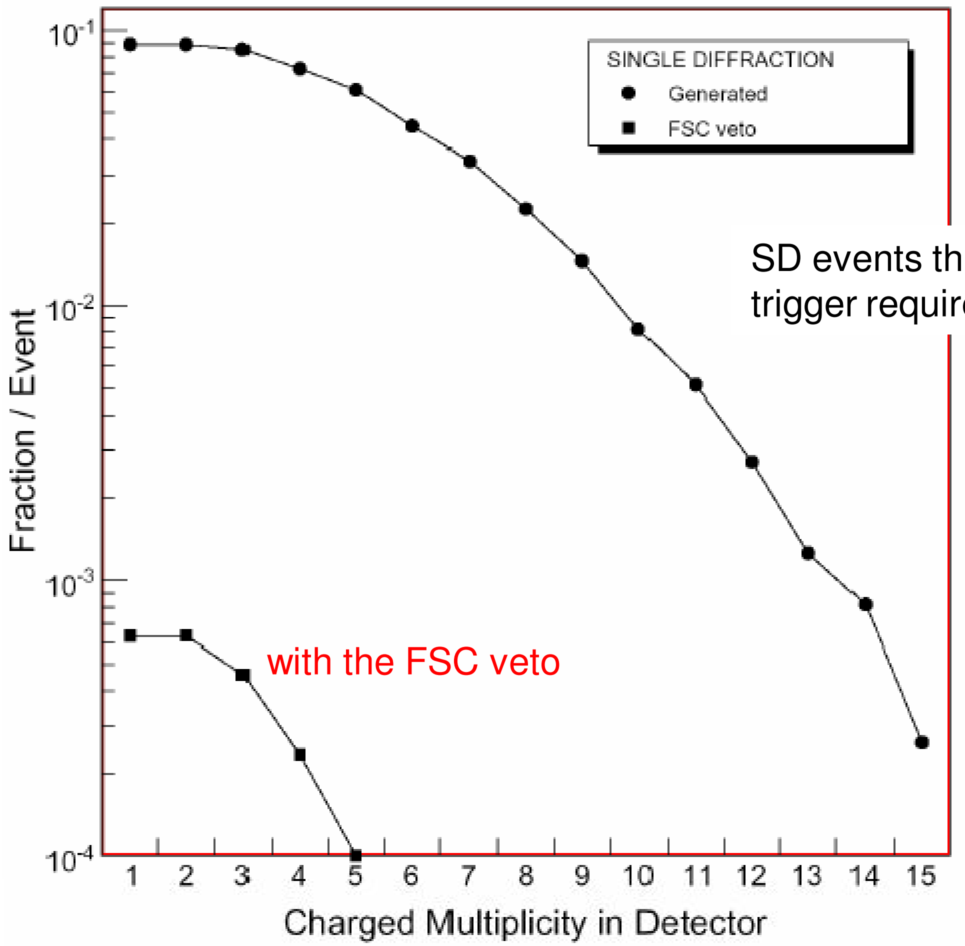
Figure 8. *The purities, i.e. the fractions of cases where a particle combination, $\pi^+\pi^-$, K^+K^-, $2\pi^+2\pi^-$, (within the acceptance) originates from the exclusive decay of the central system M rather than from feed-down of higher mass states, as a function of the effective mass of the particle combination..*

CONCLUSIONS – PART 2

Feasibility studies of the exclusive diffractive processes for the LHCb experiment have been carried out.

With a simple addition of Forward Shower Counters (FSCs), the experiment is shown to be ideally suited for detailed QCD studies and searches for exotic mesons states, such as glueballs, hybrids, and heavy quarkonia.

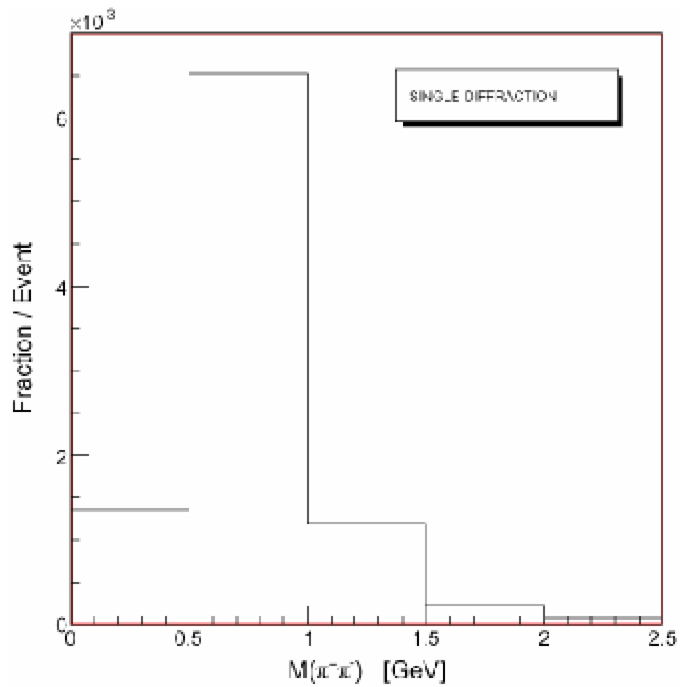
SINGLE DIFFRACTION BACKGROUND

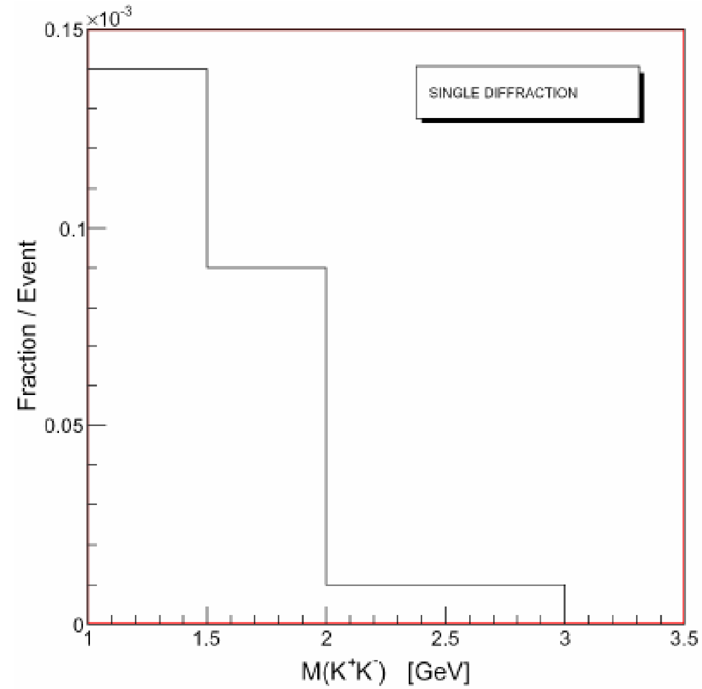


SD events that satisfy the SPD trigger requirement ~9%

Figure 3. *The probability per event for a given number of charged particles to be emitted within the spectrometer detector acceptance region is given by the upper curve (filled circles), the lower curve (filled squares) gives the acceptance with deployment of the FSCs.*

SINGLE DIFFRACTION BACKGROUND





The contributions from single diffractive events that produce a unique $\pi^+\pi^-/K^+K^-$ pair within the detector acceptance vs. mass of the pair.

FSC EFFICIENCY vs. DIFFRACTIVE MASS

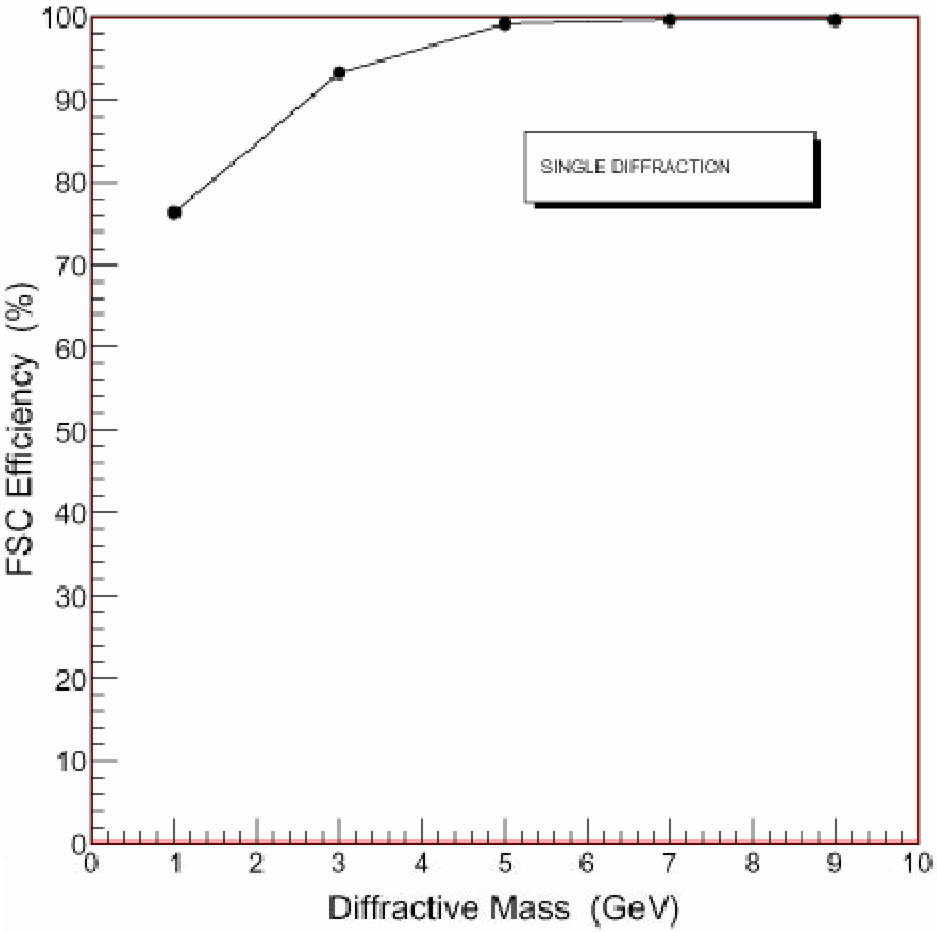


Figure 6. *The efficiency to detect single diffractive events (SD) by the Forward Shower Counters (FSCs) as a function of the diffractive mass.*

NON-DIFFRACTIVE BACKGROUND

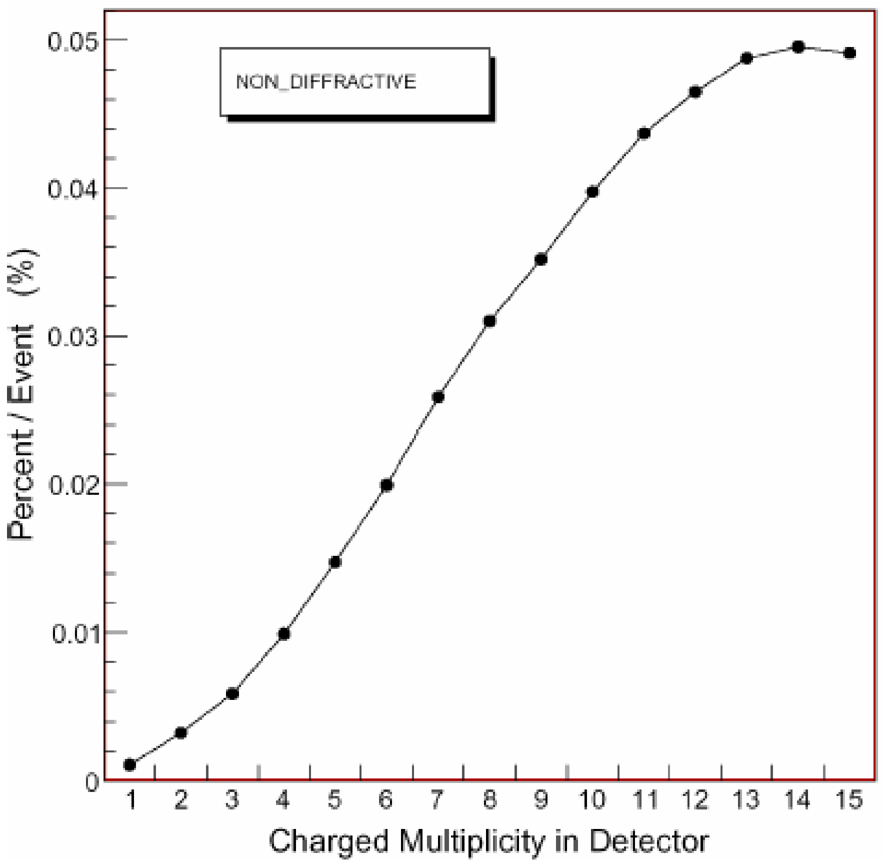


Figure 7. *The efficiency to detect non-diffractive events (ND) by the Forward Shower Counters (FSCs) as a function of the charged multiplicity in the detector.*