Diffractive measurements at the LHC; Elastic scattering

- Measure elastic pp cross section without recording the protons?
- Consistent event classification techniques for solving the problem of ill defined ’rap gaps’ (Gino’s kinematical overlaps, Alan’s rapidity correlations, Asher’s enhanced diagrams, Mario’s radiation between the jets, Gösta’s model perscription, non-exponentially suppressed rap gaps...automatically included in classification) .

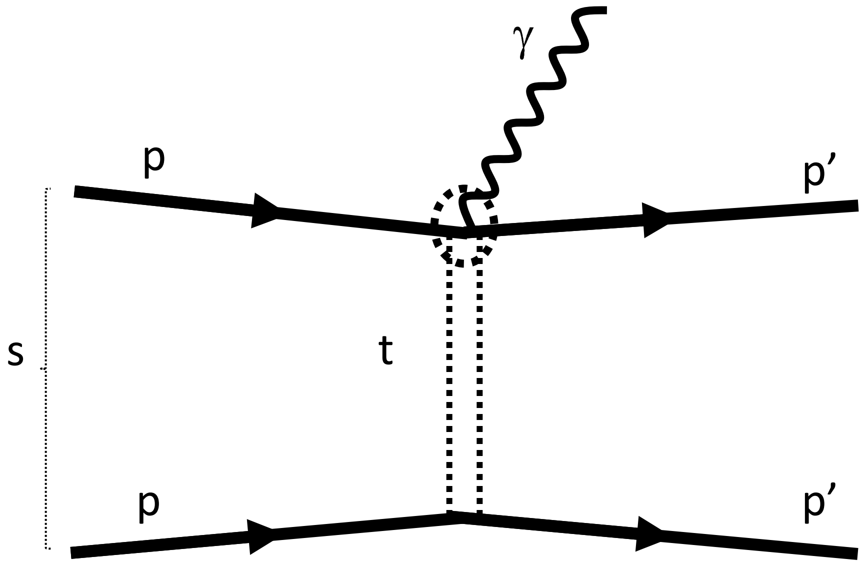
Luminosity and σ_{el}/σ_{tot}

At HERA, bremsstrahlung (from electrons) was succesfully used for luminometry.

We propose to do the same at LHC - bremsstrahlung from protons.

Excluding the extreme models, we know σ_{el} and can measure the luminosity (KMR, Tel-Aviv, PYTHIA differ by 5-7%, only).
or
With a crude luminosity measurement can exclude a range of extreme models on σ_{el} .

BREMSSTRAHLUNG FROM PROTONS



- Due to very small momentum transfer in forward radiation, theoretical uncertainties are minimized $\Rightarrow$ direct relation between the photon spectra and σ_{el}

- Bremsstrahlung cross section is large enough $\sim 0.18 \times 10^{-3}$ of σ_{el}

Work in progress: Jerry Lämsä, KMR group, Michael Murray, Grzegorz Brona, and RO

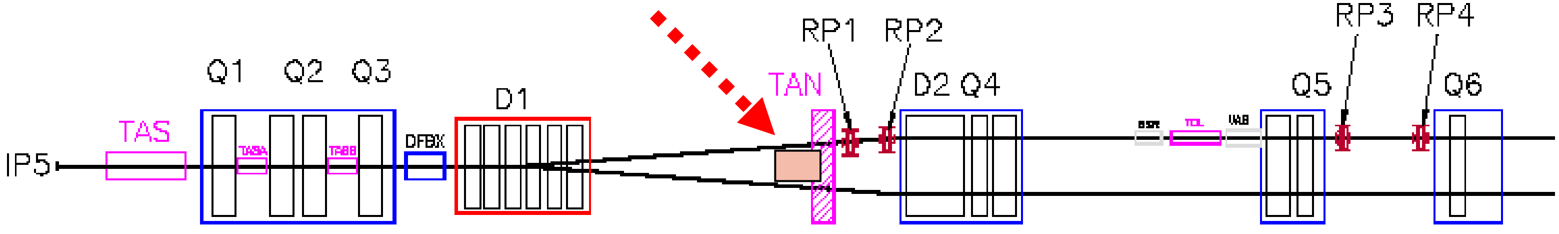
- Use luminosity from the W/Z standard candle measurements or from the beam scan (Van der Meer) $\Rightarrow$ model-independent way to measure σ_{el}

- The ZeroDegreeCalorimeter (ZDC) for detecting the bremsstrahlung gammas - the Forward Shower Counters (FSC) to veto backgrounds.

- The set-up of the proposed measurement with k=50-500 GeV and for 3.5 x 3.5 TeV and/or 5 x 5 TeV.

FORWARD DETECTORS:
THE ROMAN POTS AND ZDC

ZDC detects neutrals at 0º

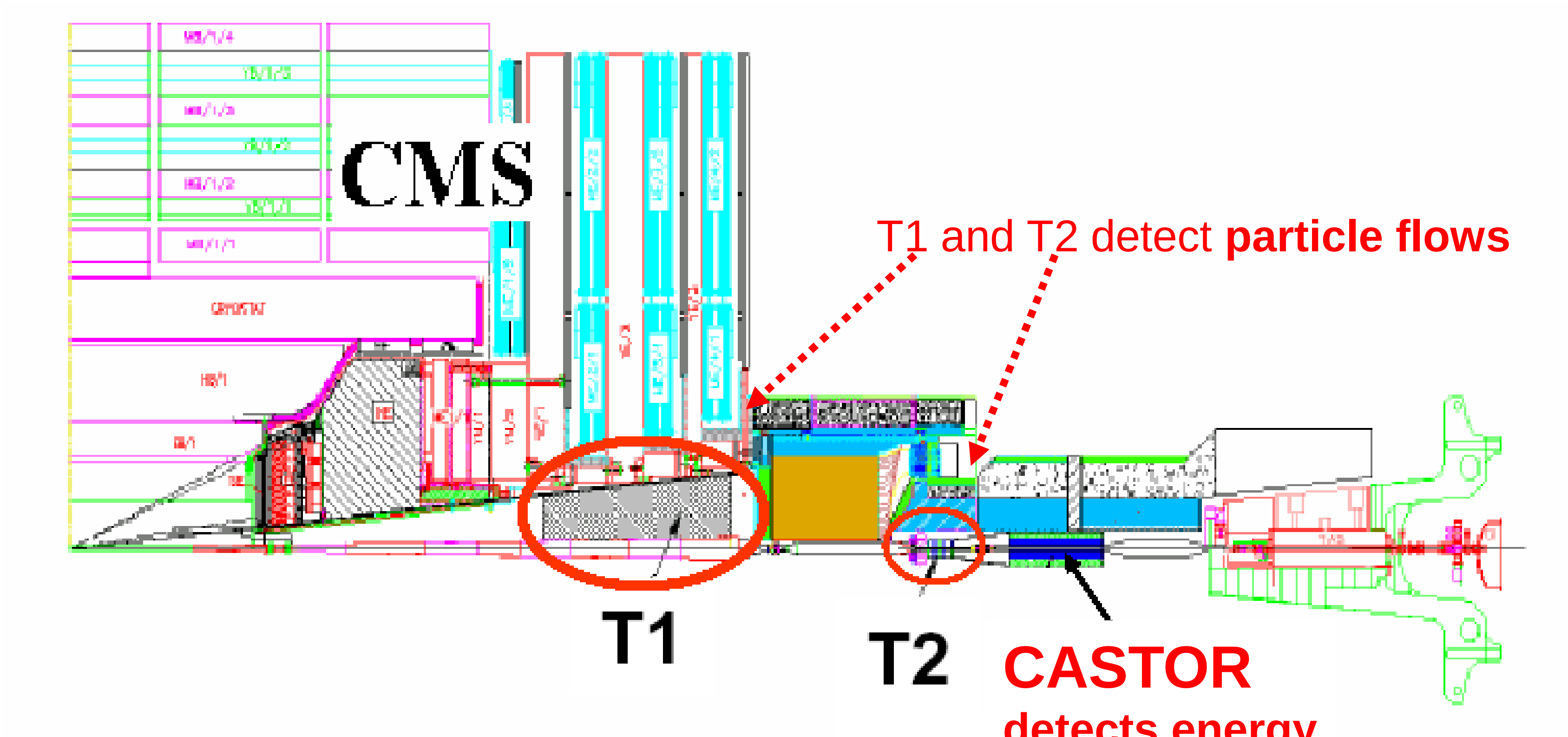


±147m

±220m

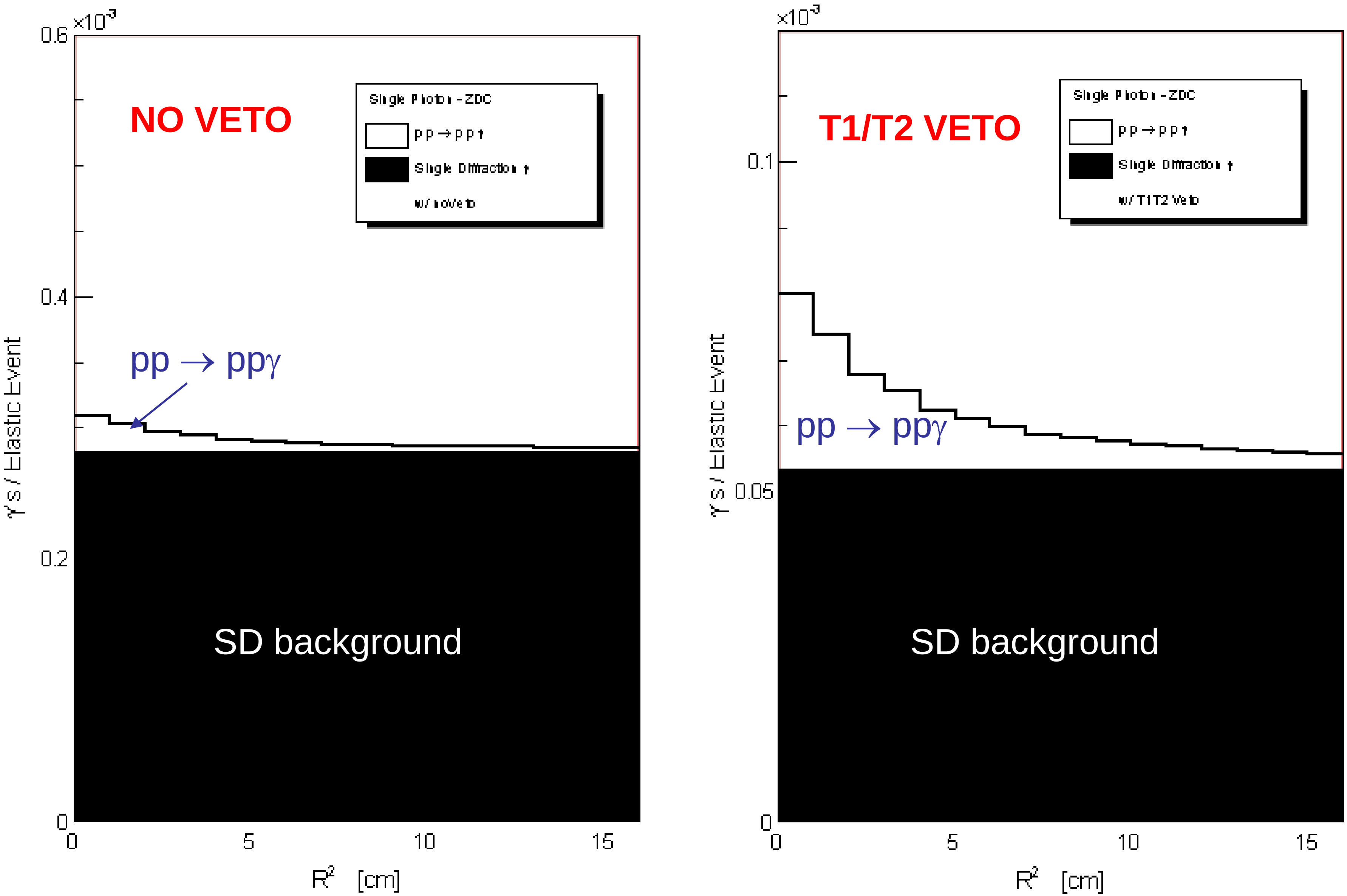
Zero Degree Calorimeter has fine granularity.
Bremsstrahlung photons close to 0 degrees – can be used for alignment (RP's, ZDC), luminosity monitoring.

T1, T2 SPECTROMETERS, CASTOR

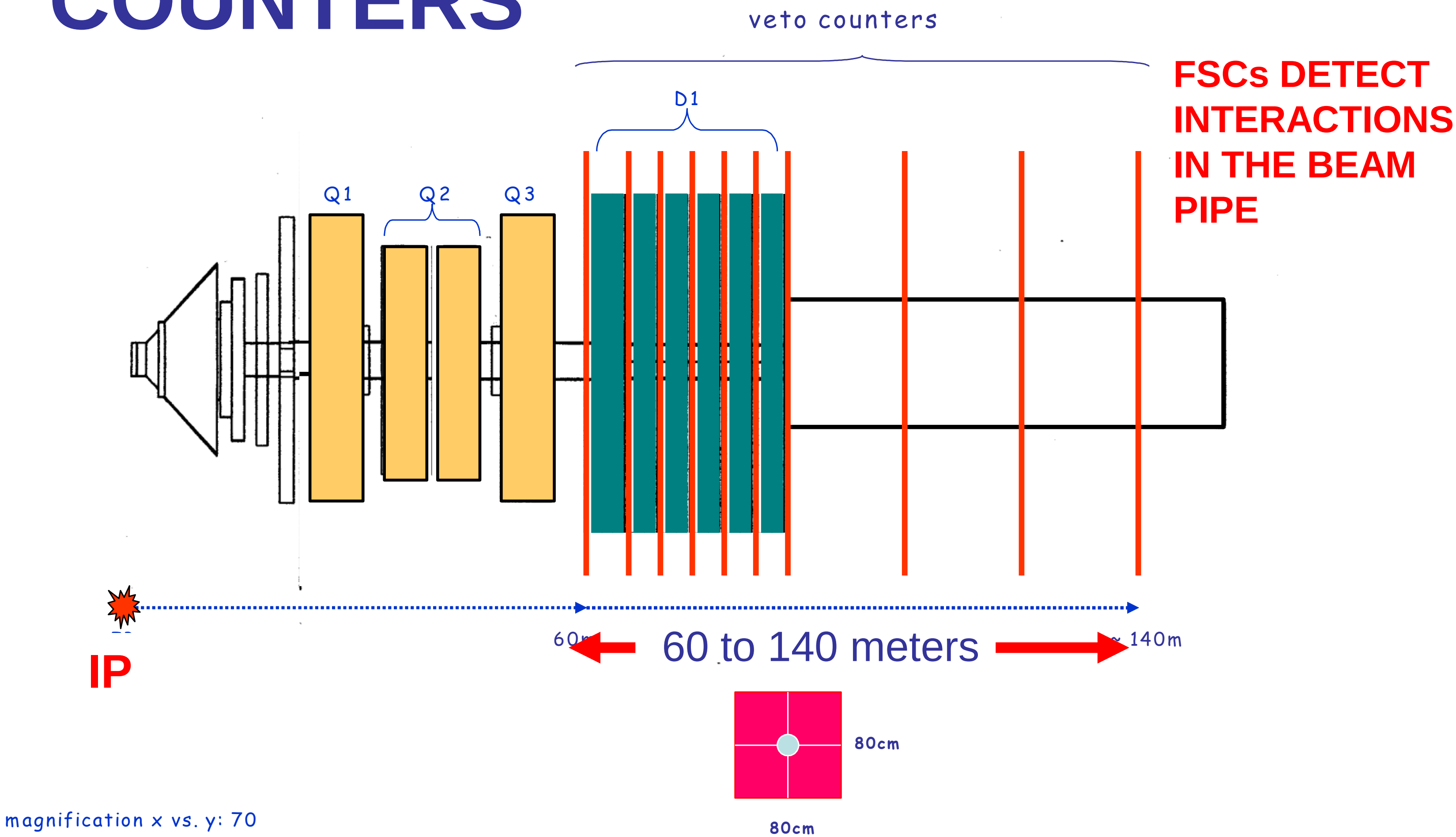


T1, T2 and CASTOR help in rejecting the backgrounds from SD and ND events.

SD BACKGROUND vs. BREMSSTRAHLUNG PHOTONS



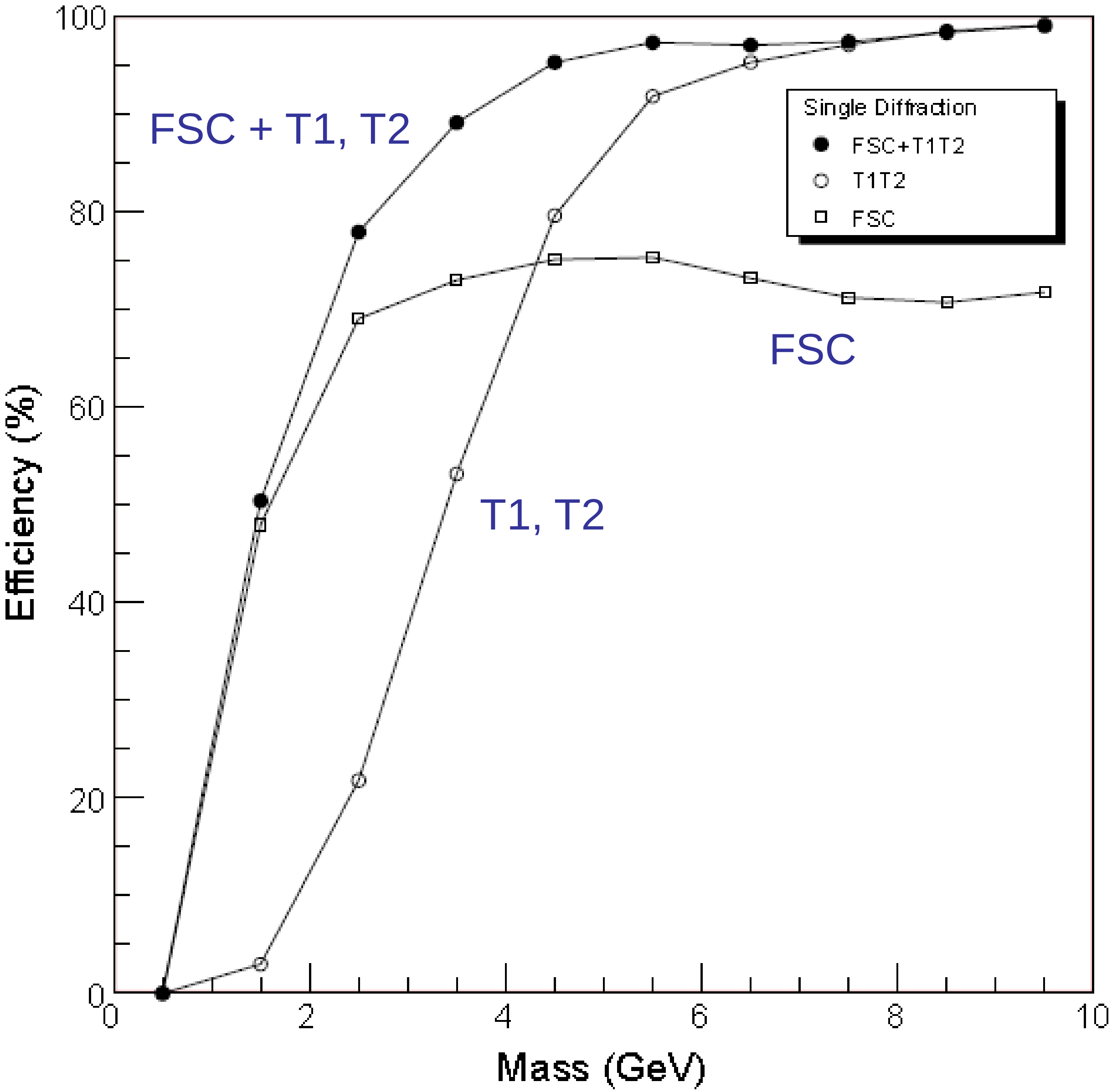
PROPOSED FORWARD SHOWER COUNTERS



Forward Physics with Rapidity Gaps at the LHC.
By USCMS Collaboration (Michael Albrow *et al.*).
FERMILAB-PUB-08-618-E, Nov 2008. (Published Oct 2, 2009). 15pp.
Published in **JINST 4:P10001,2009**.
e-Print: **arXiv:0811.0120** [hep-ex]

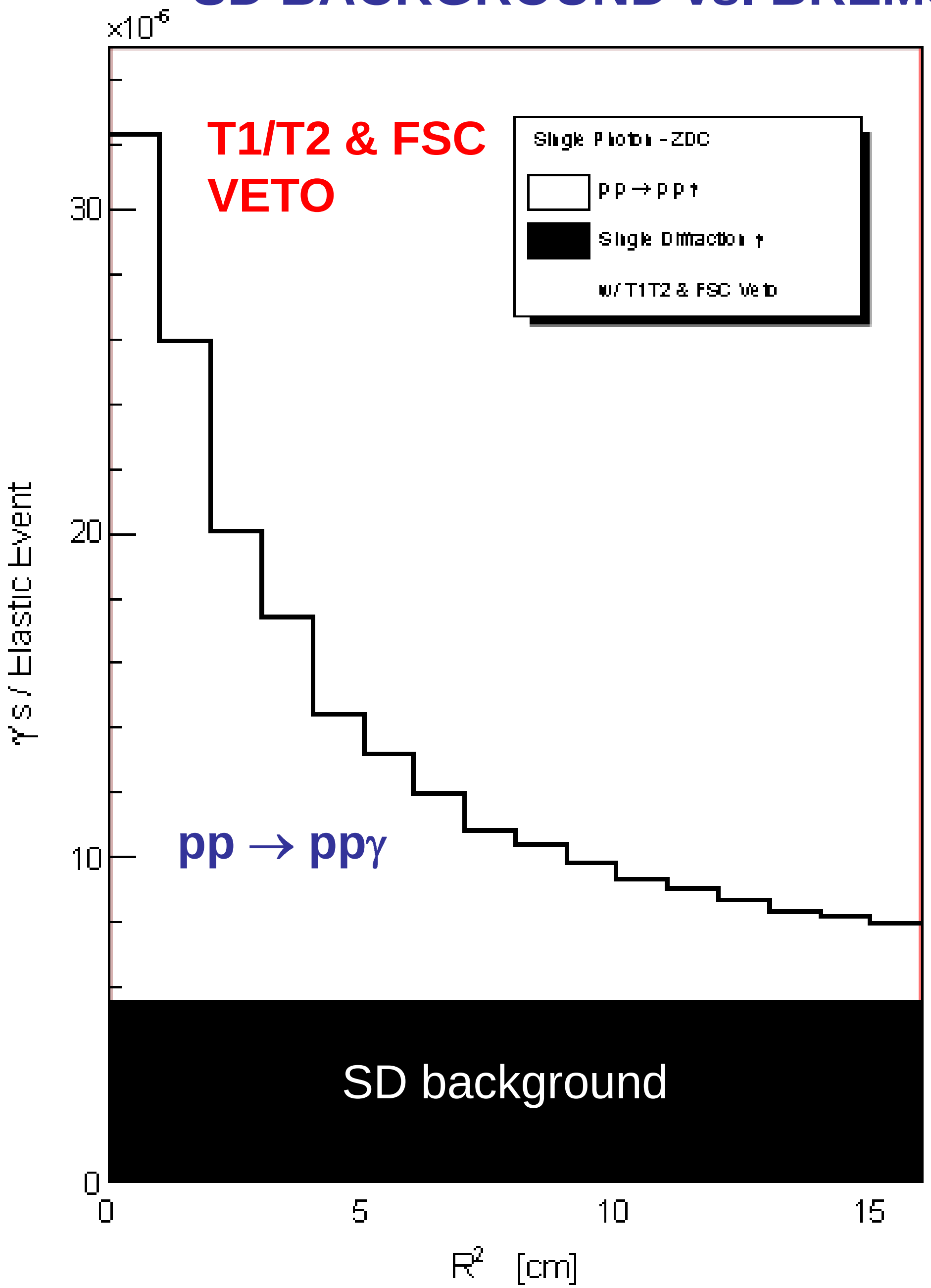
Central Diffraction at the LHCb.
Jerry W. Lamsa, RO . Jul 2009. 10pp.
Published in **JINST 4:P11019,2009**.
e-Print: **arXiv:0907.3847** [physics.acc-ph]

EFFICIENCY OF DETECTING SD EVENTS



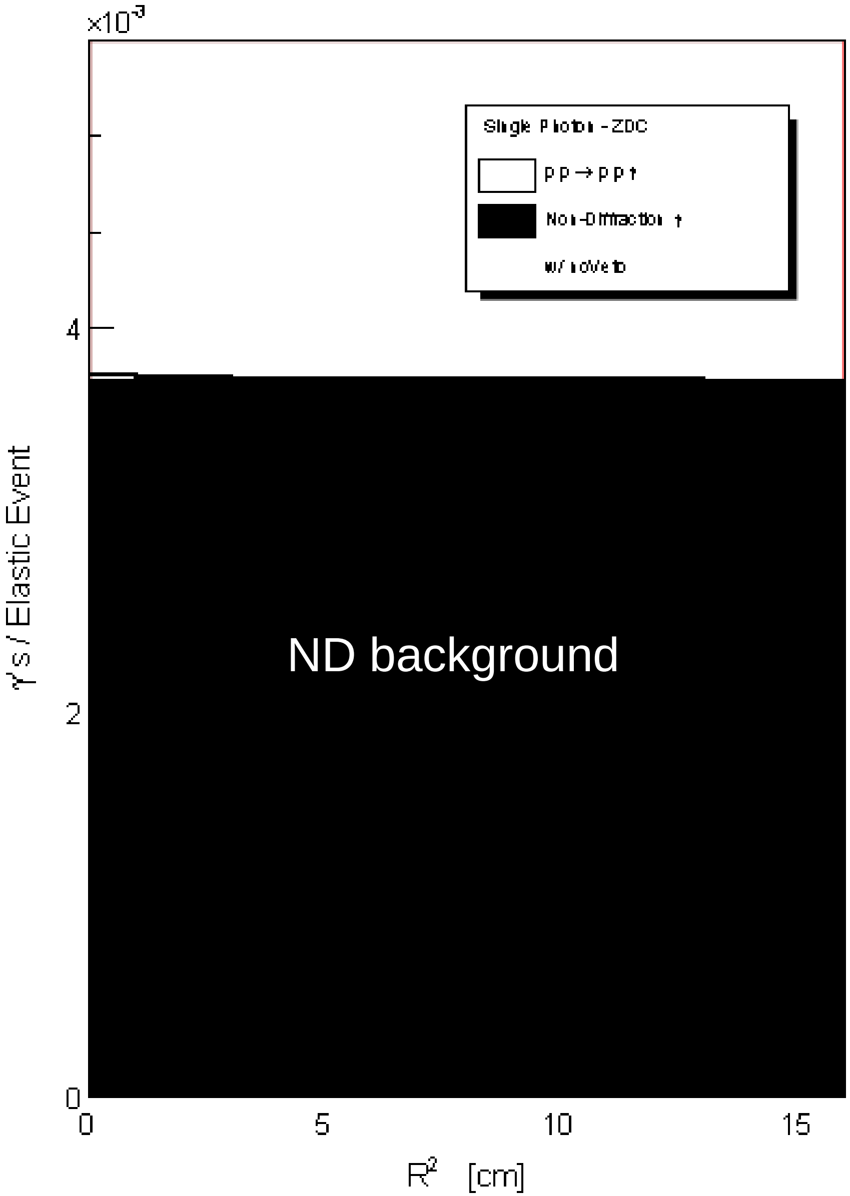
WITH FSC, DETECT SD EVENTS DOWN TO $M_{diff} \geq 1.1$ GeV

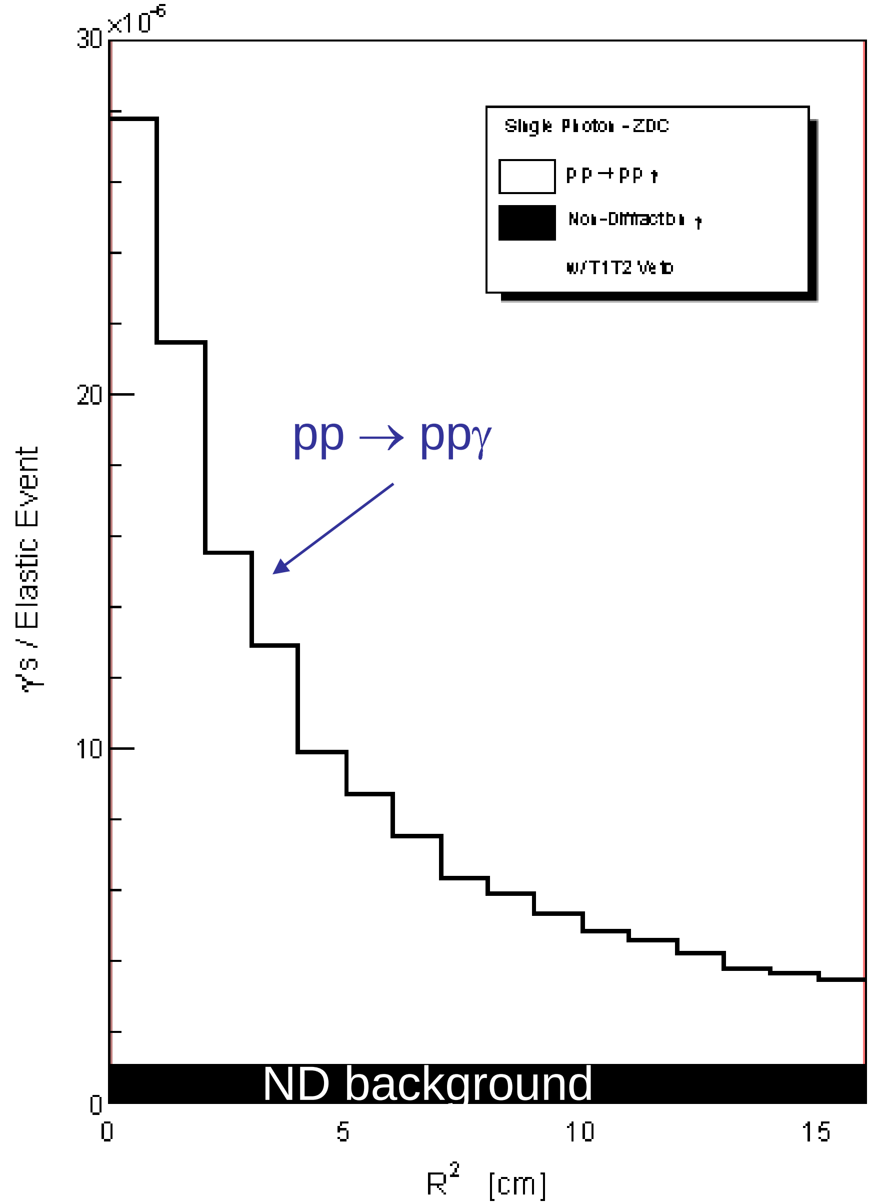
SD BACKGROUND vs. BREMSSTRAHLUNG PHOTONS



With the addition of FSCs get a clean measurement of elastic bremsstrahlung.

ND BACKGROUND vs. BREMSSTRAHLUNG PHOTONS





VETO EFFICIENCIES

Veto Trigger	Veto Efficiency (%)
FSC+T1+T2+ZDC	98.8
FSC+T1+T2	95
T1+T2	85.5
T1	76.8
T2	81.8
FSC	70.6
ZDC	47.1

Multivariate Techniques for Identifying Diffractive Interactions at the LHC.

How to classify pp interactions/diffraction in a consistent way at the LHC?

A selection of multivariate methods by the Helsinki group:
Mikael Kuusela, Jerry W. Lamsa, Eric Malmi, Petteri Mehtala, and RO, Sep 2009. 32pp.

Published in **Int.J.Mod.Phys.A25:1615-1647,2010**.

INPUT INFORMATION FOR MULTIVARIATE EVENT CLASSIFICATION

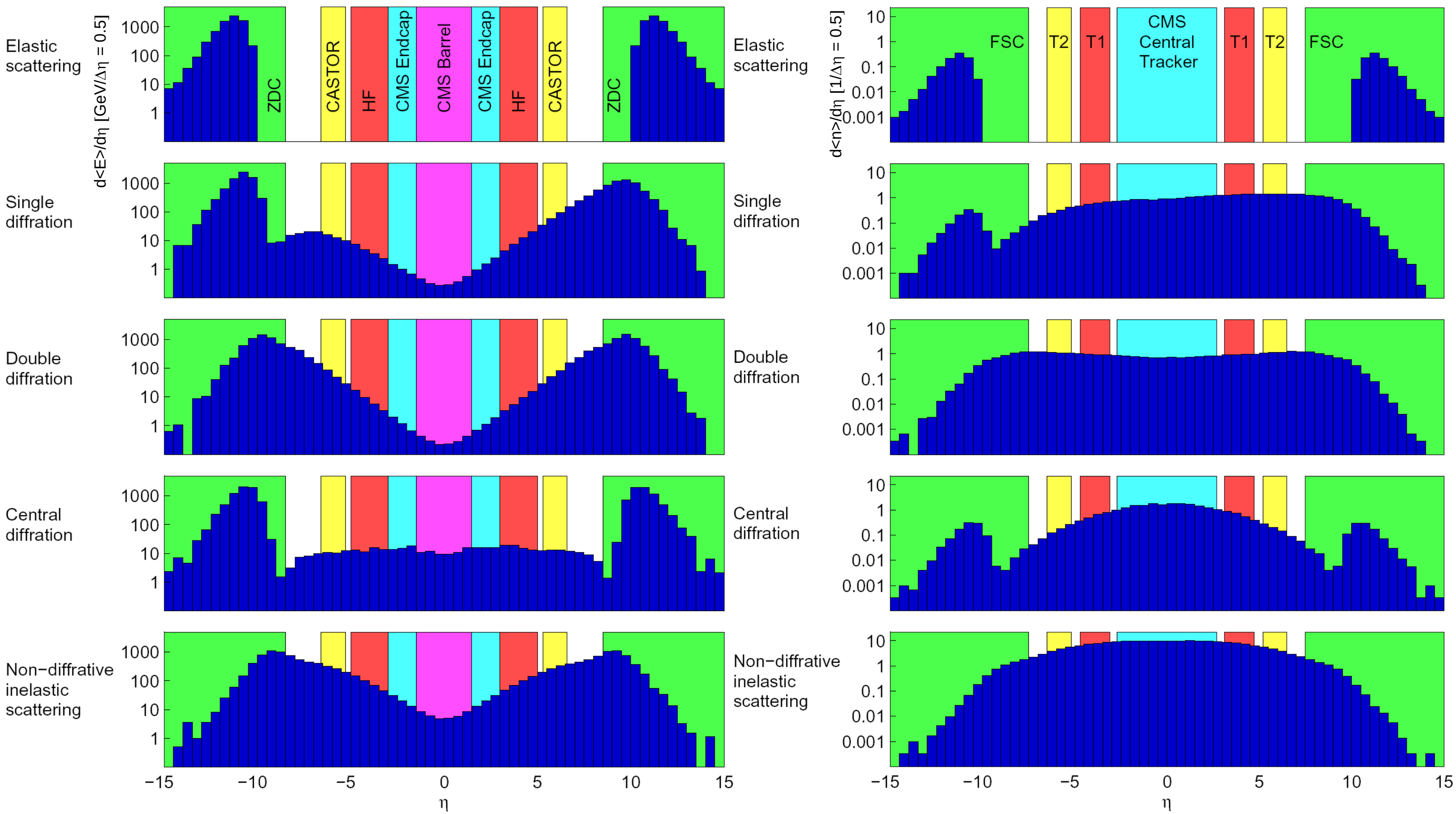
- *particle flows* by TOTEM $T1_{R/L}$, $T2_{R/L}$ spectrometers and CMS $FSC_{R/L}$ counters at ±60 to ±140 m from IP5 [5],

- *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.

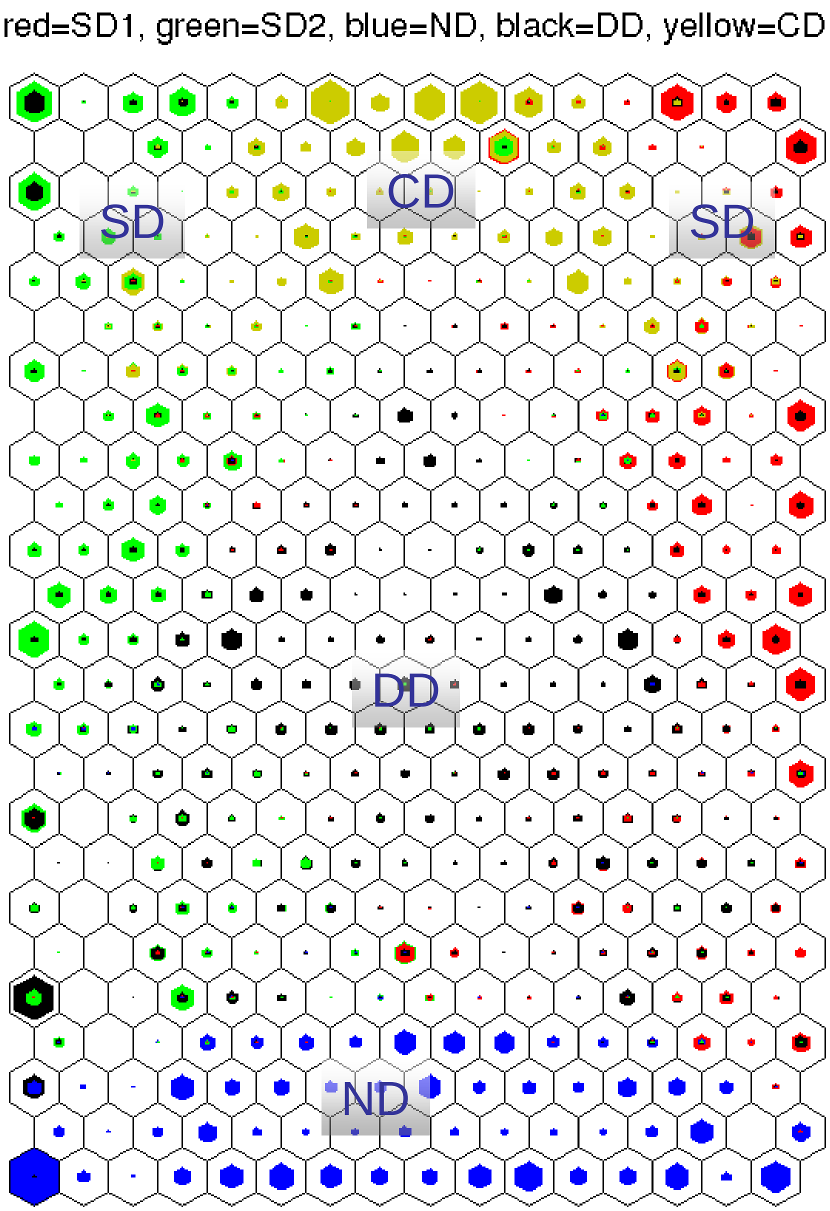
A PROBABILISTIC APPROACH: EACH EVENT BELONGS *TO EVERY ONE* OF THE EVENT CLASSES WITH A WEIGHT ≠ 0.

ENERGIES MULTIPLICITIES



23 INPUTS FOR EVENT CLASSIFICATION

SELF ORGANIZING MAPS



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.

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.

$\Rightarrow$ **94% event classification efficiency**

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.

$\Rightarrow$ **Over 99% classification purity for ND, 96% for CD, 97% for DD, 84% for SD**

THE NEXT STEP: MODEL INDEPENDENT CLASSIFICATION OF INELASTIC EVENTS AT THE LHC

- *Unsupervised* anomaly detection is based on well known background distribution, independent of the distribution of the signal events.

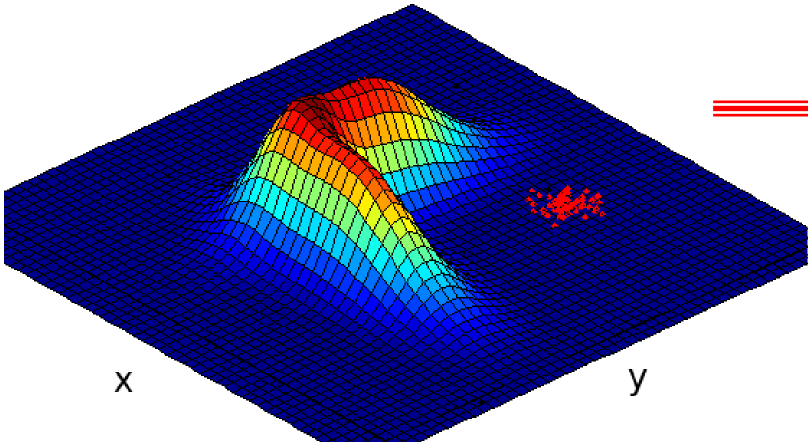
- Insensitive to the uncertainties in the MC models purpoting to describe the new physics signals.

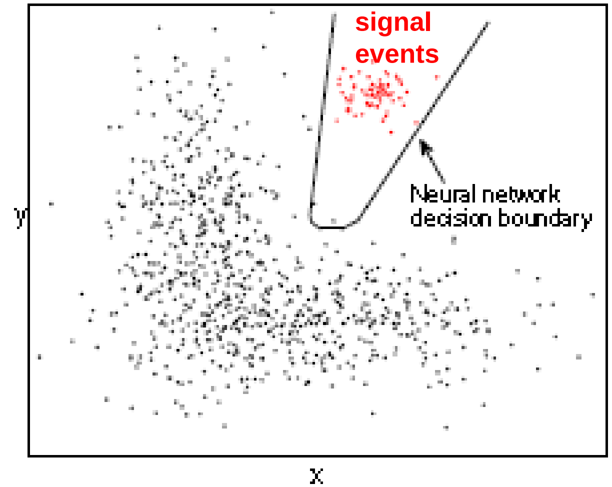
- Based on multivariate probability density estimation and machine learning methods.

- In contrast, *supervised* classification methods, such as Neural Nets (NN) – widely used in hep analysis - use a sample of MC generated signal events and a sample of MC generated background events $\Rightarrow$ inherent sensitivity to the MC ’signal’.

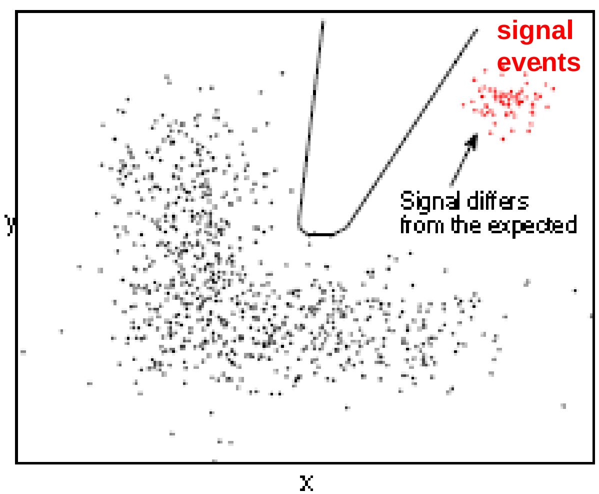
The HELSINKI Group: M.Kuusela, E.Malmi, T.Vatanen and RO, *in progress*

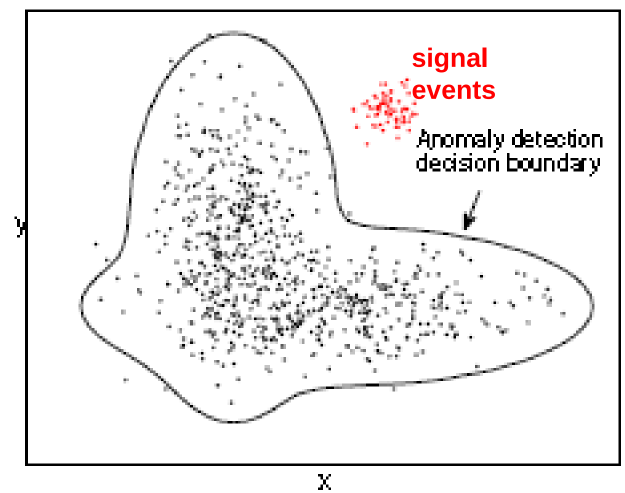
ANOMALY DETECTION vs. NEURAL NETS





NN decision boundary for S/B separation.





NN misses the signal events due to faulty MC based training.

Anomaly detection classifies these events correctly.

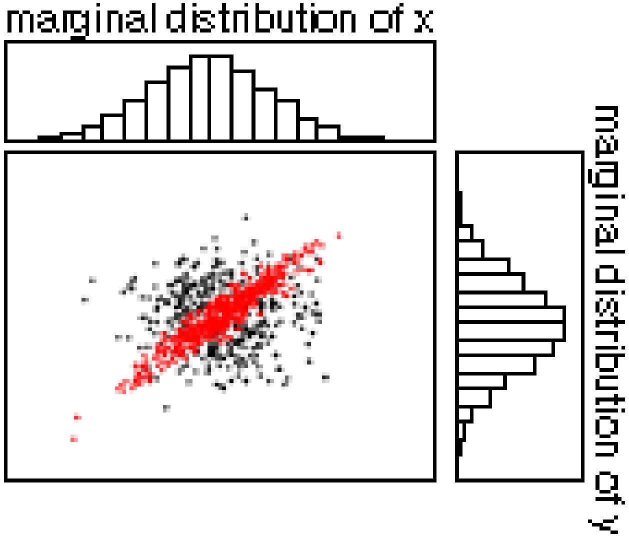
MC MODEL SELECTION

-Which Monte Carlo model should be chosen?

- Estimate a multivariate distribution for the measured data and for the output of each candidate MC.
- Measure the difference between the estimated distribution of the measured data and the data from each MC generator.
- Difference metric (e.g. Kullback-Leibler divergence)

Advantages:

- Handles all variables simultaneously
- Can locate the problem areas



CONCLUSIONS

Can use ***bremsstrahlung photons*** to measure elastic pp cross section: luminometry, RP/ZDC alignment, σ_{el}/σ_{tot}, calibration process for event classification…

The ND background ***is easily rejected*** by 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.

Next step: ***MC model independent approach*** – unsupervised anomaly detection - tested vs. conventional Neural Net analysis. Promises for a major conceptual break-through in identifying diffractive events in a consistent manner.

Can be used for ***systematic evaluation of MC models***.