Classification of diffraction at the LHC

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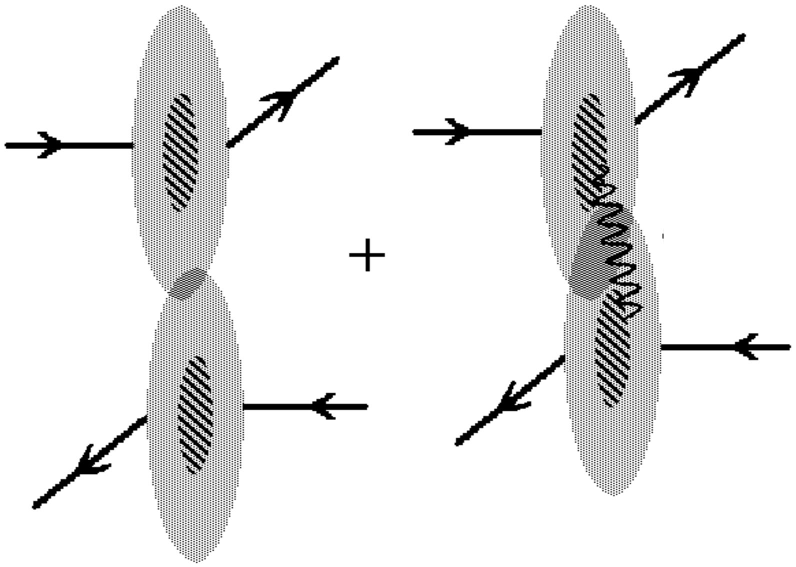
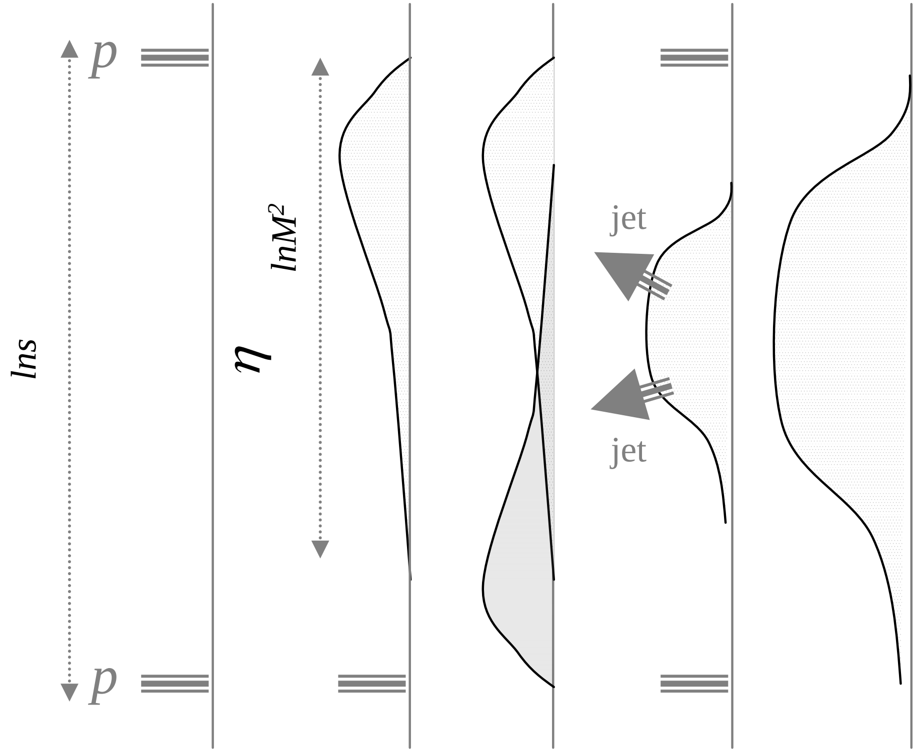
Diffractive measurements at the LHC: Elastic & Inelastic Soft Diffraction

- Elastic pp scattering - indirect
- Low mass Single Diffraction
- Low mass Central Exclusive Diffraction
- Event classification: Diff vs. Non-Diff

HOW TO CLASSIFY INELASTIC LHC EVENTS AS DIFFRACTIVE or NON-DIFFRACTIVE IN AN EXPERIMENT?

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





The event classes are <u>not</u> uniquely defined.

IDEAL EXPERIMENT FOR DIFFRACTION

- Measure rapidity gaps $\Delta\eta \geq 3$ for a maximal η- and p_T-span

and/or

- Measure leading protons for a maximal (ξ, t, φ) range

and

- Measure forward systems for full φ:
  - acceptance down to M* ~ 1 GeV !!
  - charged multiplicities (particle id's!?)
  - transverse energies/momenta

also

- Measure timing (for pile-up discrimination)

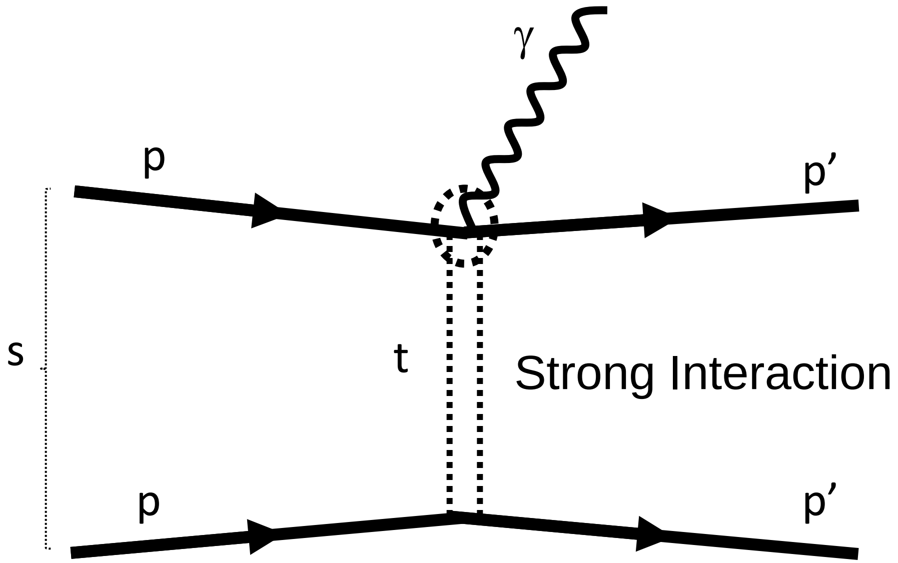
LUMINOSITY MEASUREMENT AND MONITORING.

Luminosity and σ_{el}/σ_{tot} ?

At HERA - bremsstrahlung (from electrons).

At LHC – bremsstrahlung - from protons!

BREMSSTRAHLUNG FROM PROTONS



Detect 50 – 500 GeV gammas at ~ 0 degrees

- SMALL t ⇒ theoretical uncertainties minimal
  ⇒ direct relation between the photon spectra and $(\sigma_{el}/\sigma_{tot})^2$

- Bremsstrahlung cross section is large: ~ 0.18 x 10^{-3} of σ_{el}

Work in progress:

Forward Physics at the LHC, Detecting Elastic pp Scattering by Radiative Photons.
V.A. Khoze, J.W. Lamsa, R. Orava, M.G. Ryskin, . IPPP-10-40, DCPT-10-80, Jul 2010. 10pp.,
arXiv:1007.3721 [hep-ph]

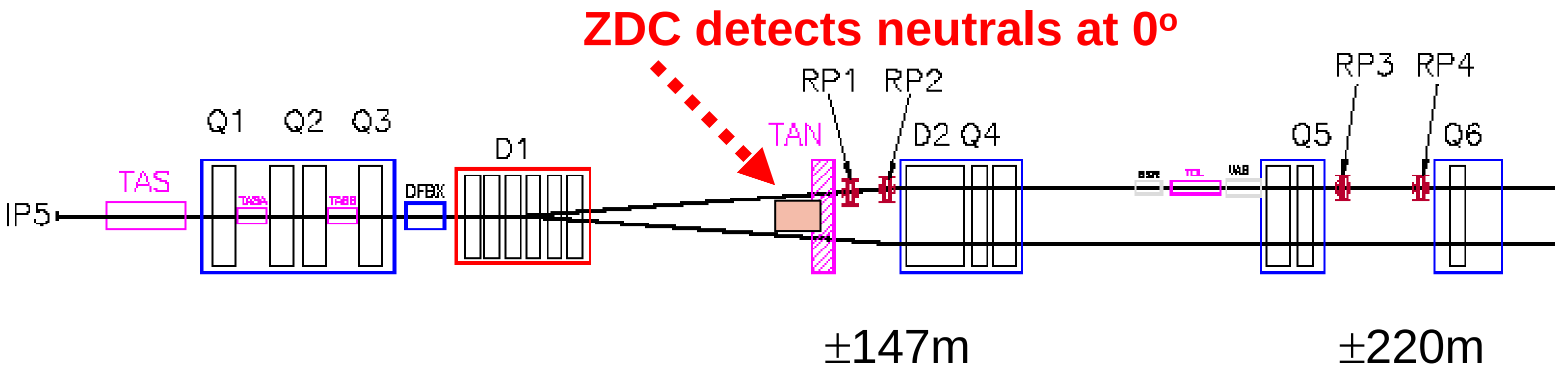
ROAD MAP

- 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.

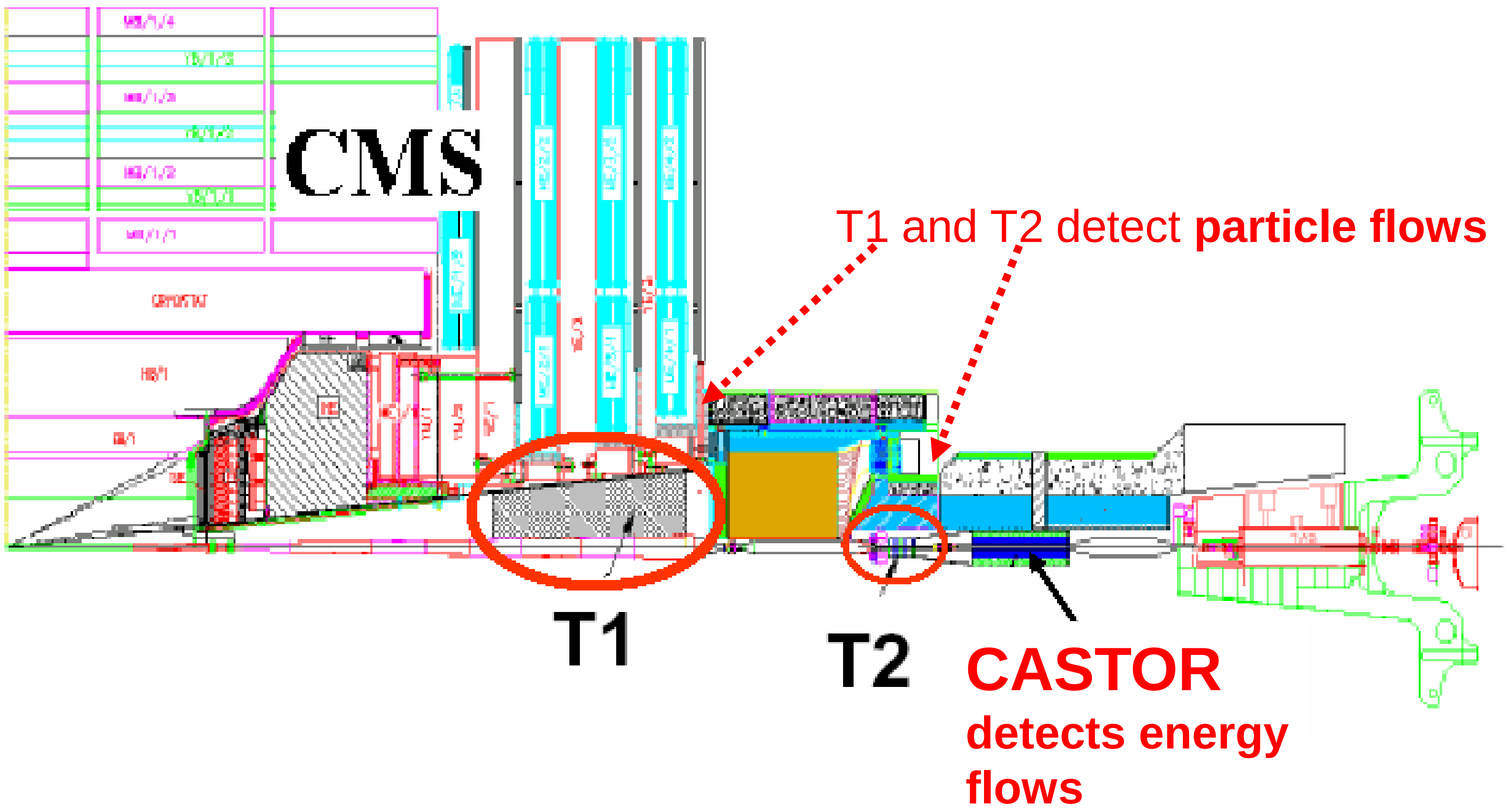
- The set-up of the proposed measurement with k=50-500 GeV and for 3.5 x 3.5 TeV and/or 5 x 5 TeV.

FORWARD DETECTORS: THE ROMAN POTS AND ZDC



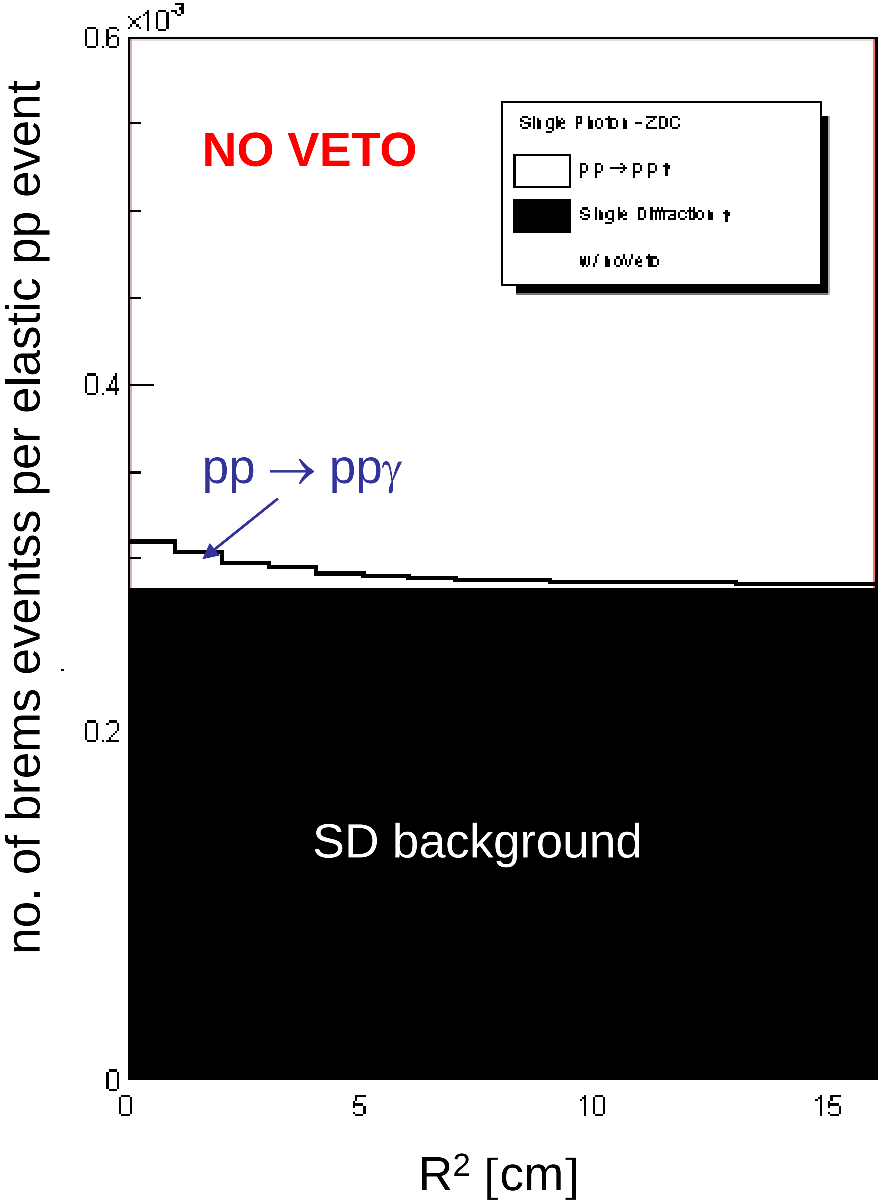
Zero Degree Calorimeter has fine granularity. Bremsstrahlung photons close to 0 degrees – can be used for alignment (RP's, ZDC), luminosity monitoring.

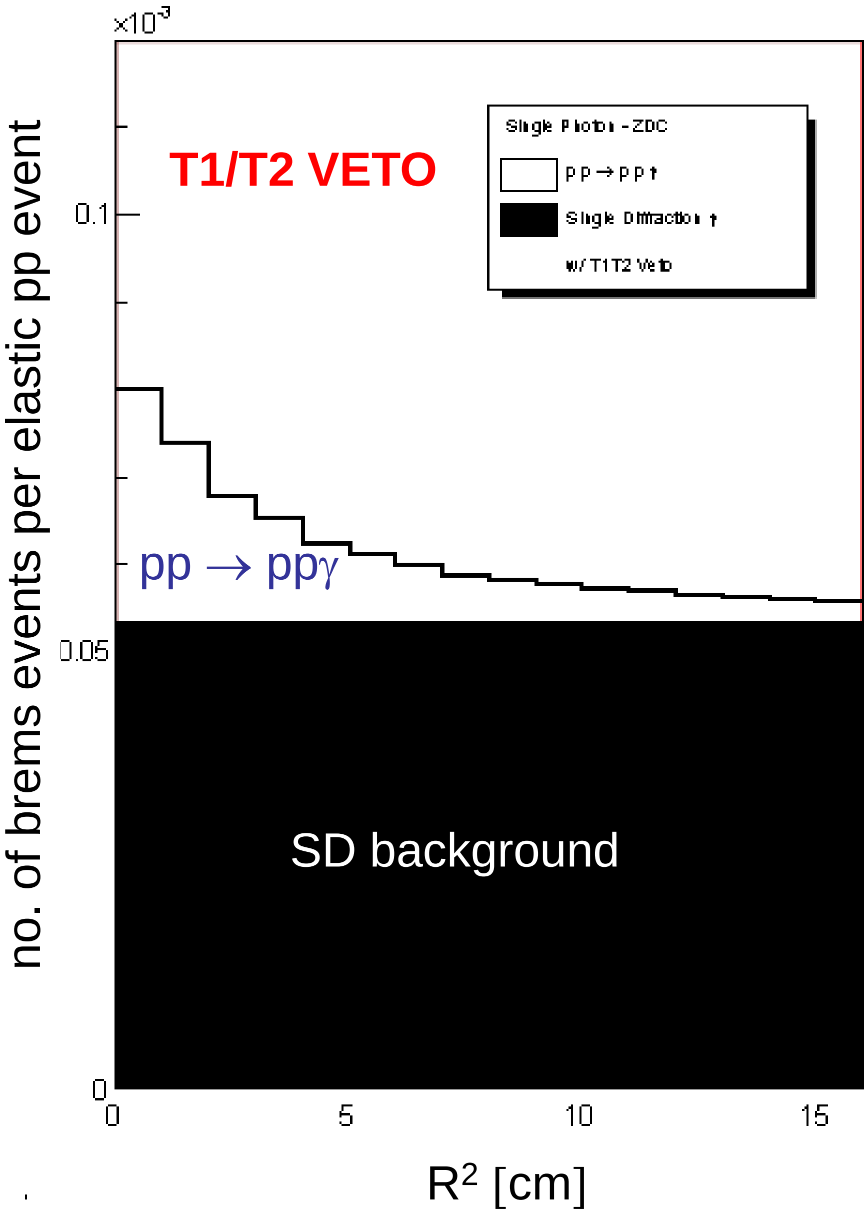
T1, T2 SPECTROMETERS, CASTOR



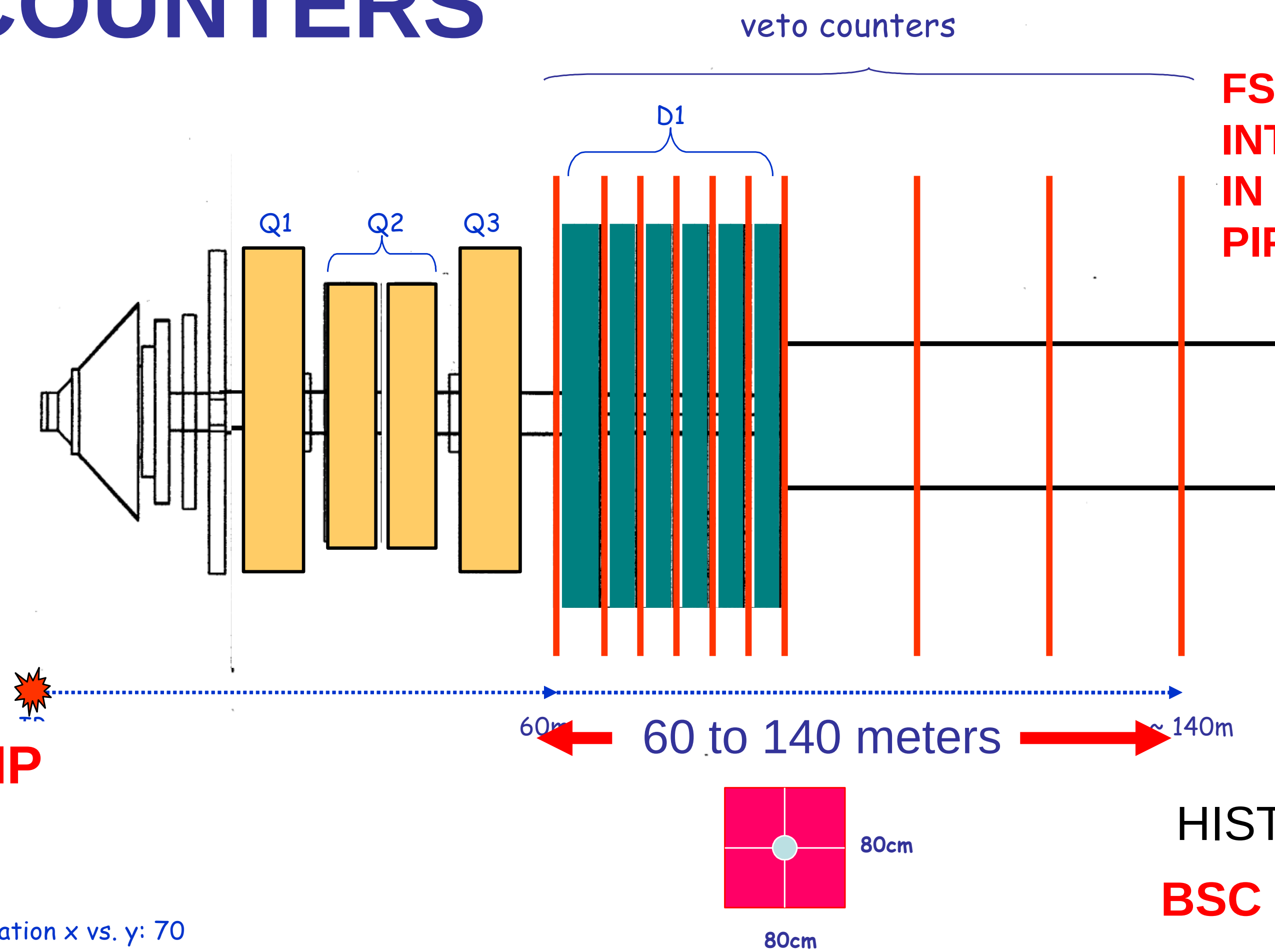
T1, T2 and CASTOR help in rejecting the backgrounds from SD and ND events.

SD BACKGROUND vs. BREMSSTRAHLUNG PHOTONS





PROPOSED FORWARD SHOWER COUNTERS



FSCs DETECT INTERACTIONS IN THE BEAM PIPE

HISTORY:

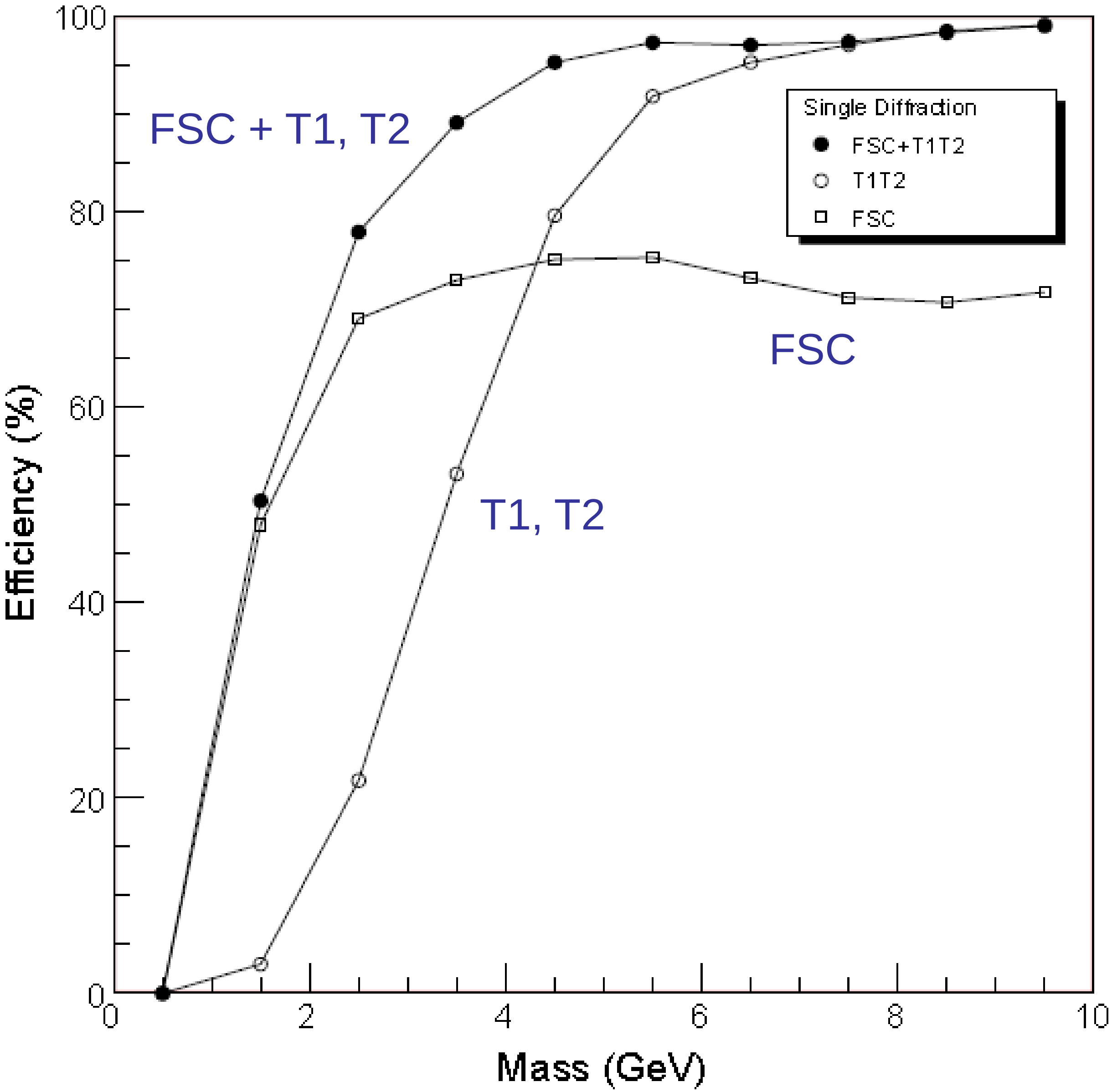
BSC @ CDF!

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]

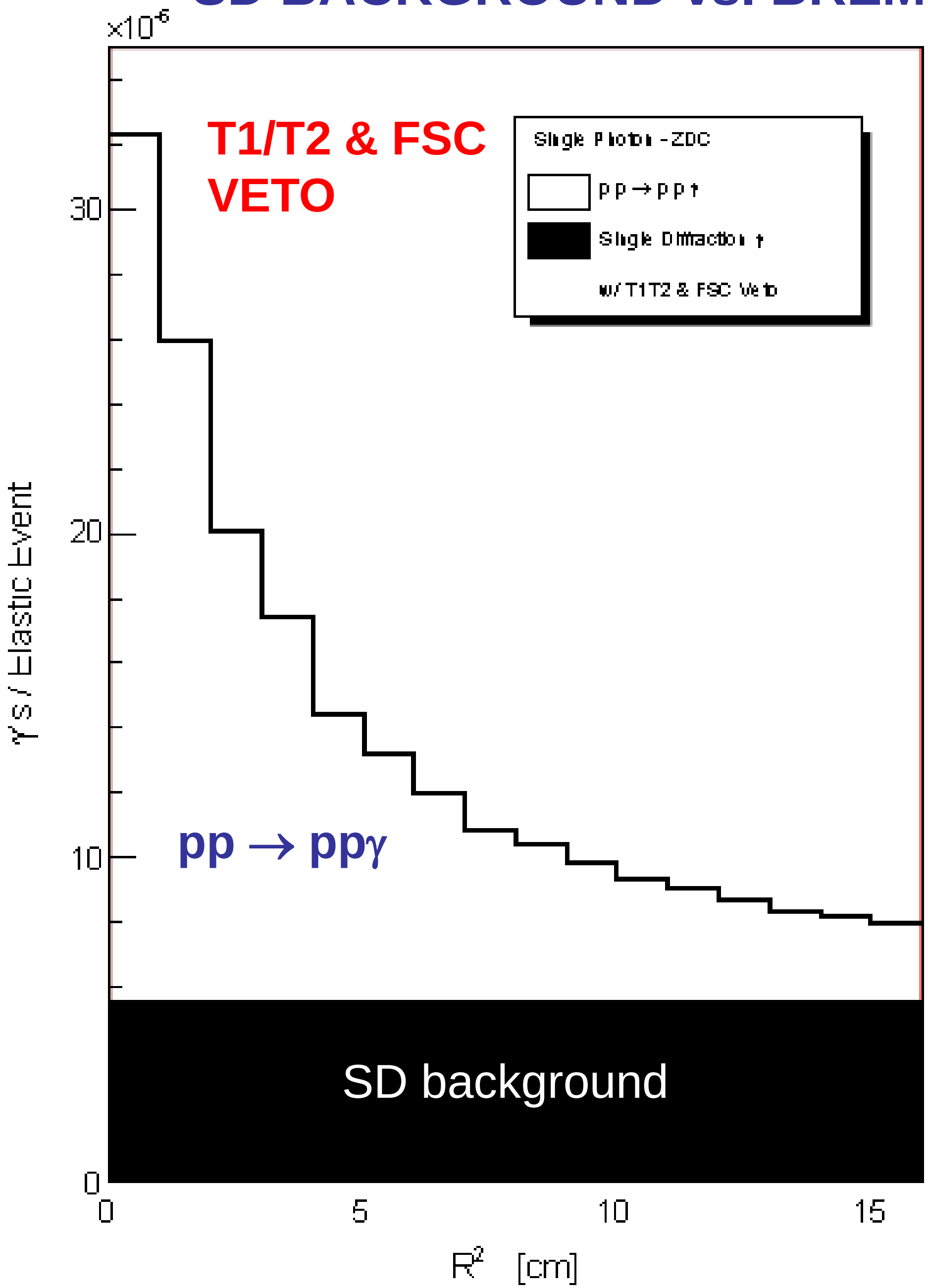
Jerry W. Lämsä and Risto Orava in:
Diffraction at LHC, **Workshop on Diffractive Physics, LISHEP 2002, Rio de Janeiro, Brasil, 4.-8. February 2002**

EFFICIENCY OF DETECTING SD EVENTS



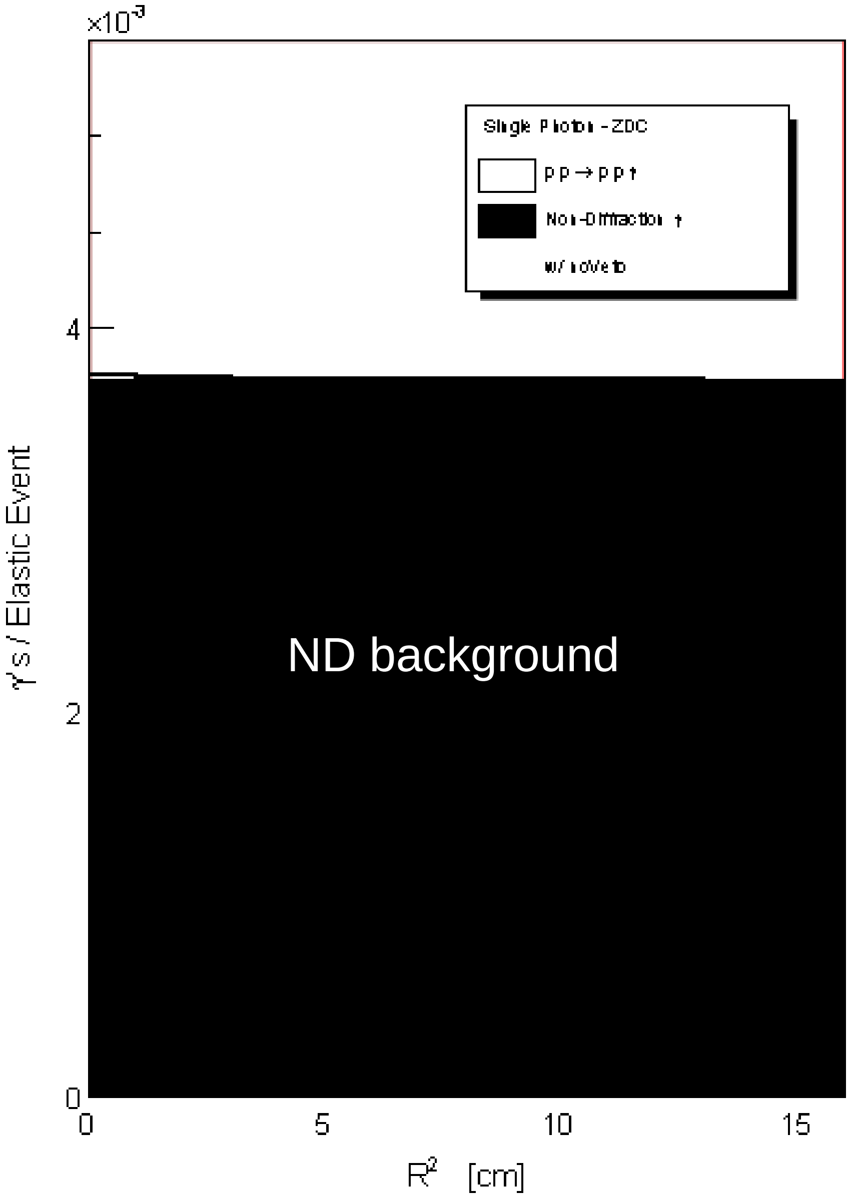
WITH FSC, DETECT SD EVENTS DOWN TO $M_{diff} \geq 1.1$ GeV

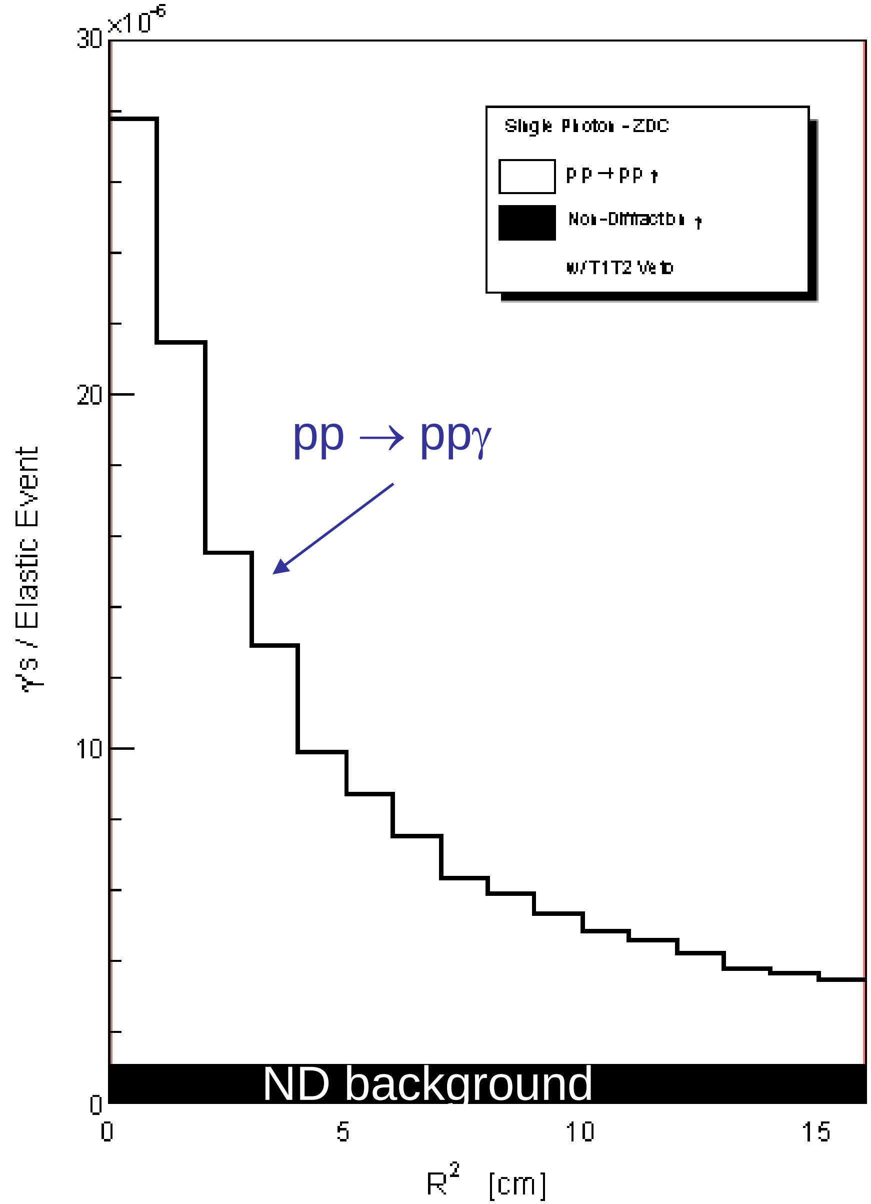
SD BACKGROUND vs. BREMSSTRAHLUNG PHOTONS



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

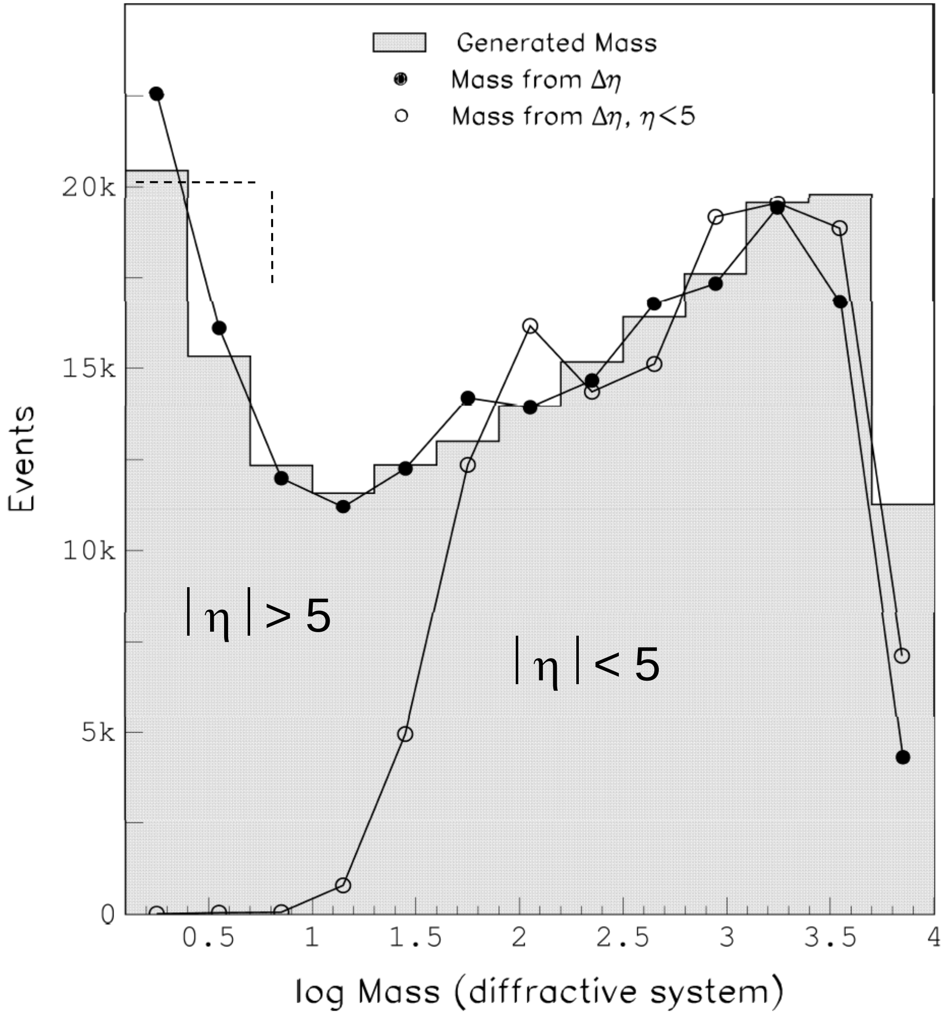
ND BACKGROUND vs. BREMSSTRAHLUNG PHOTONS





Low Mass Single Diffraction

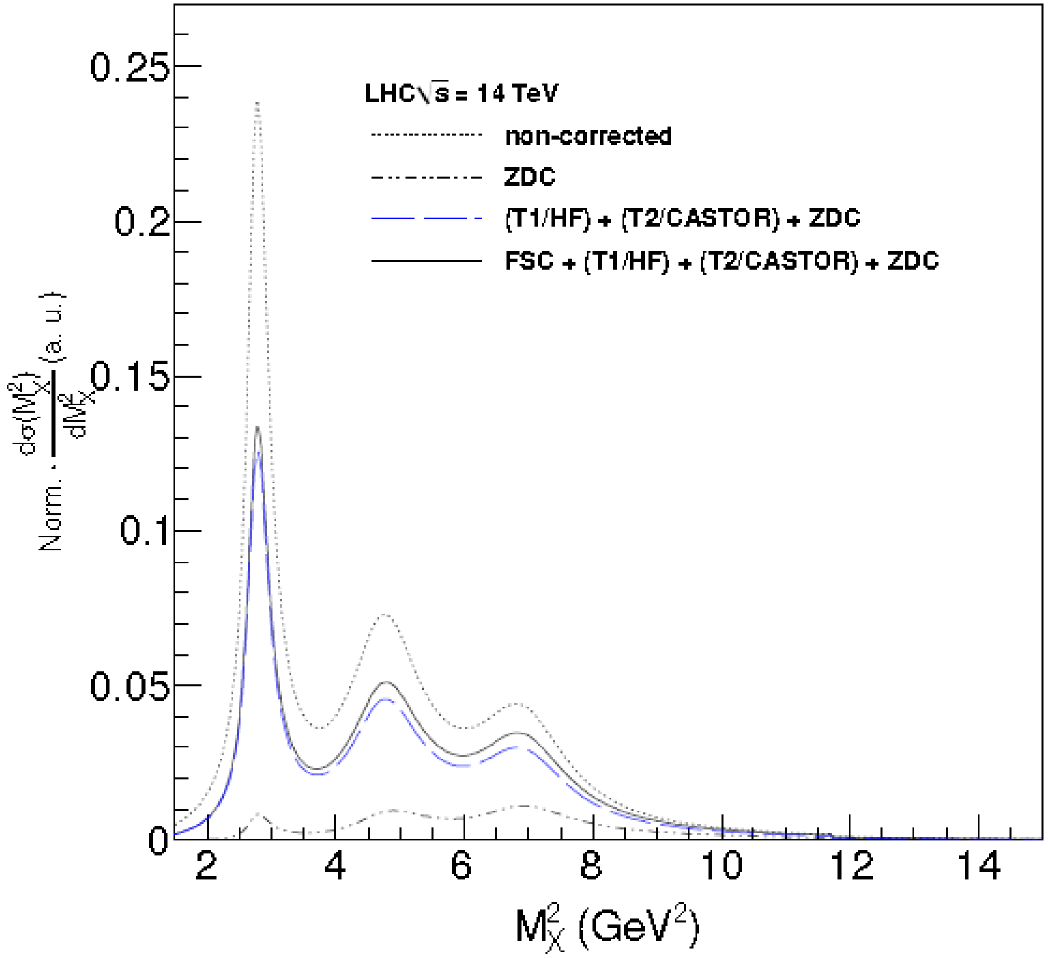
Mass of the diffractive system



Calculate using the rap gap:
$\ln M_X^2 = \Delta\eta$

Access to small M_X iff forward detectors to cover $|\eta| > 5$.

Single Diffraction at $M_X < 10$ GeV



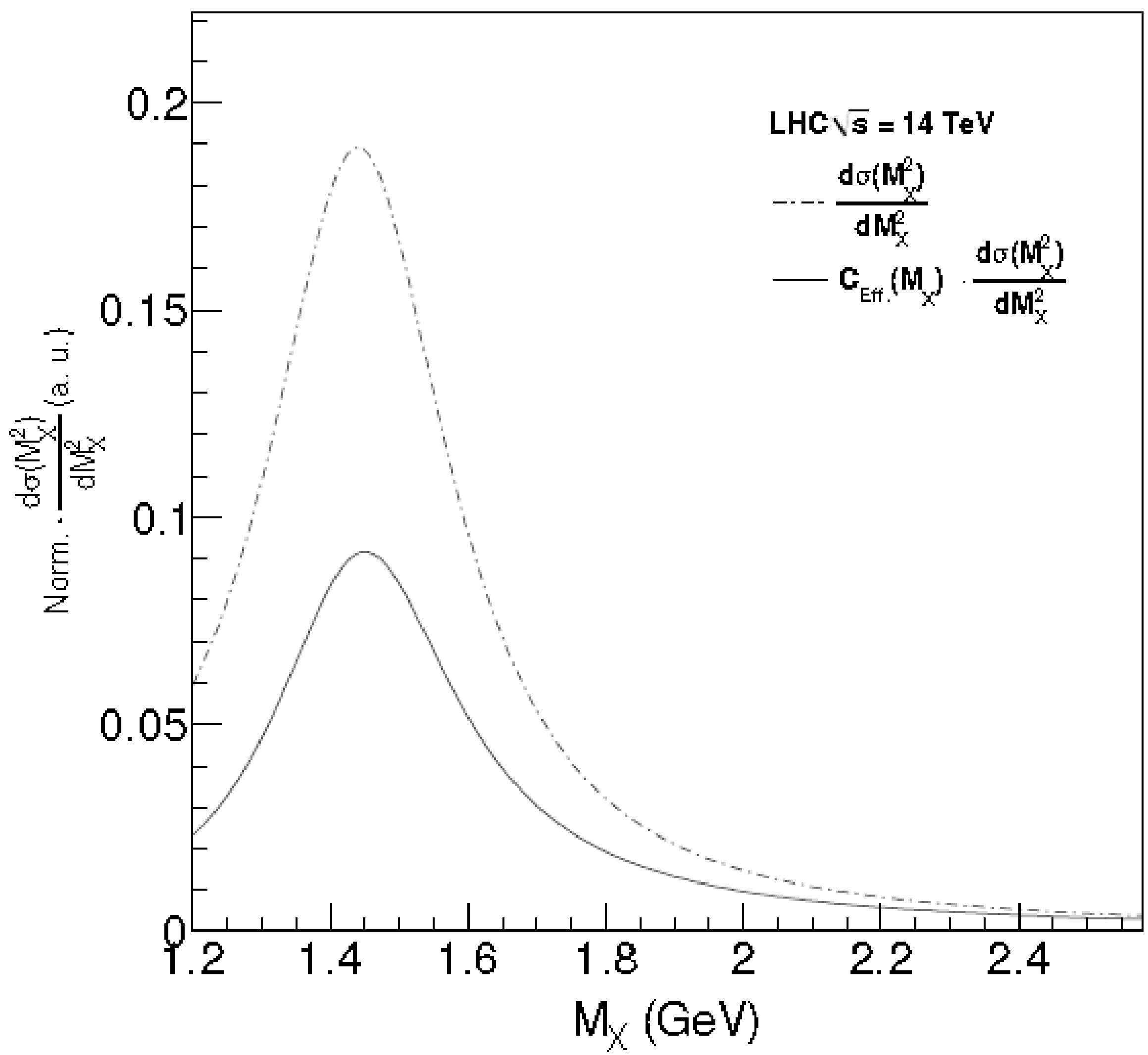
For calculating σ_{tot}^{pp} need to measure the inelastic rate.

$\sigma_{SD}(M_X<10\text{ GeV}) =$

several mb's?

L.Jenkovzsky, O. Kuprash, J.Lämsä, V.Magas, RO, **work in progress**

N*(1440) is covered by the FSCs...



Low Mass Central Exclusive Diffraction

CENTRAL DIFFRACTION AT THE LHCb

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

$$pp \rightarrow p + M + p$$

glueballs, hybrids, heavy quarkonia: χ_c, χ_b

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

HOW TO FACILITATE THIS?

***Central Diffraction at the LHCb*, Jerry W. Lämsä and RO, Jul 2009,**
JINST 4:P11019,2009,
e-Print: arXiv:0907.3847 [physics.acc-ph]

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.

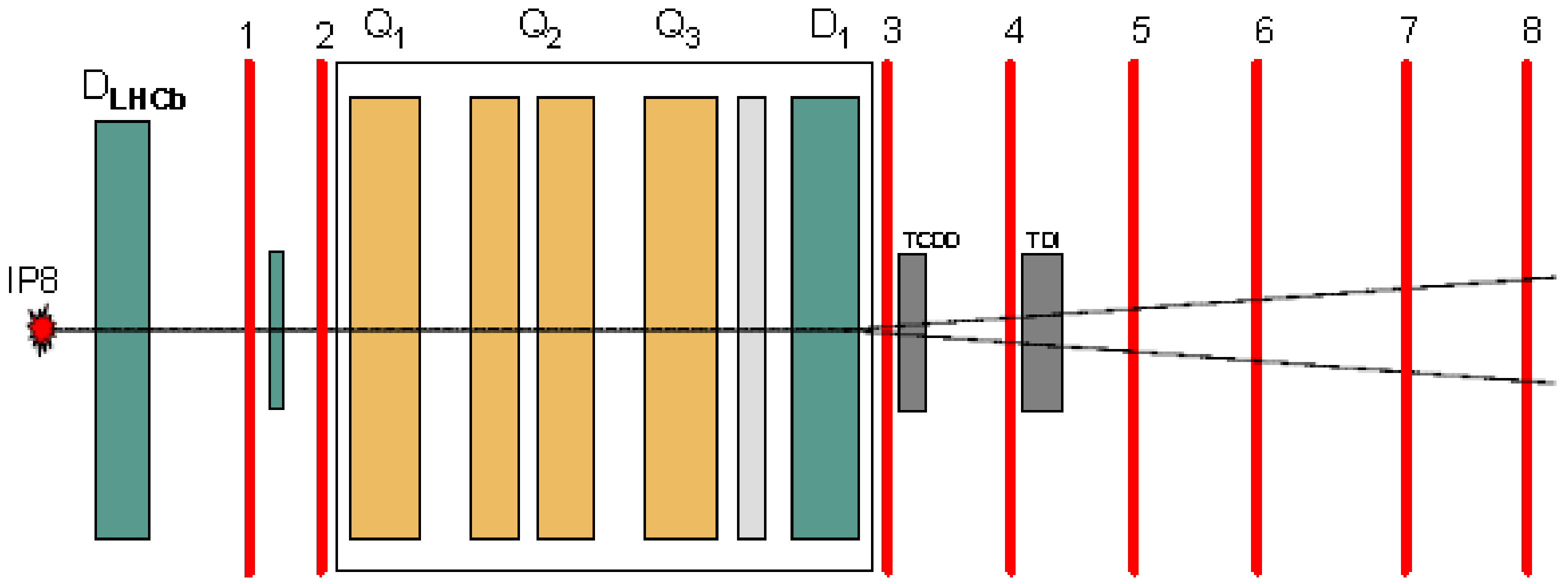
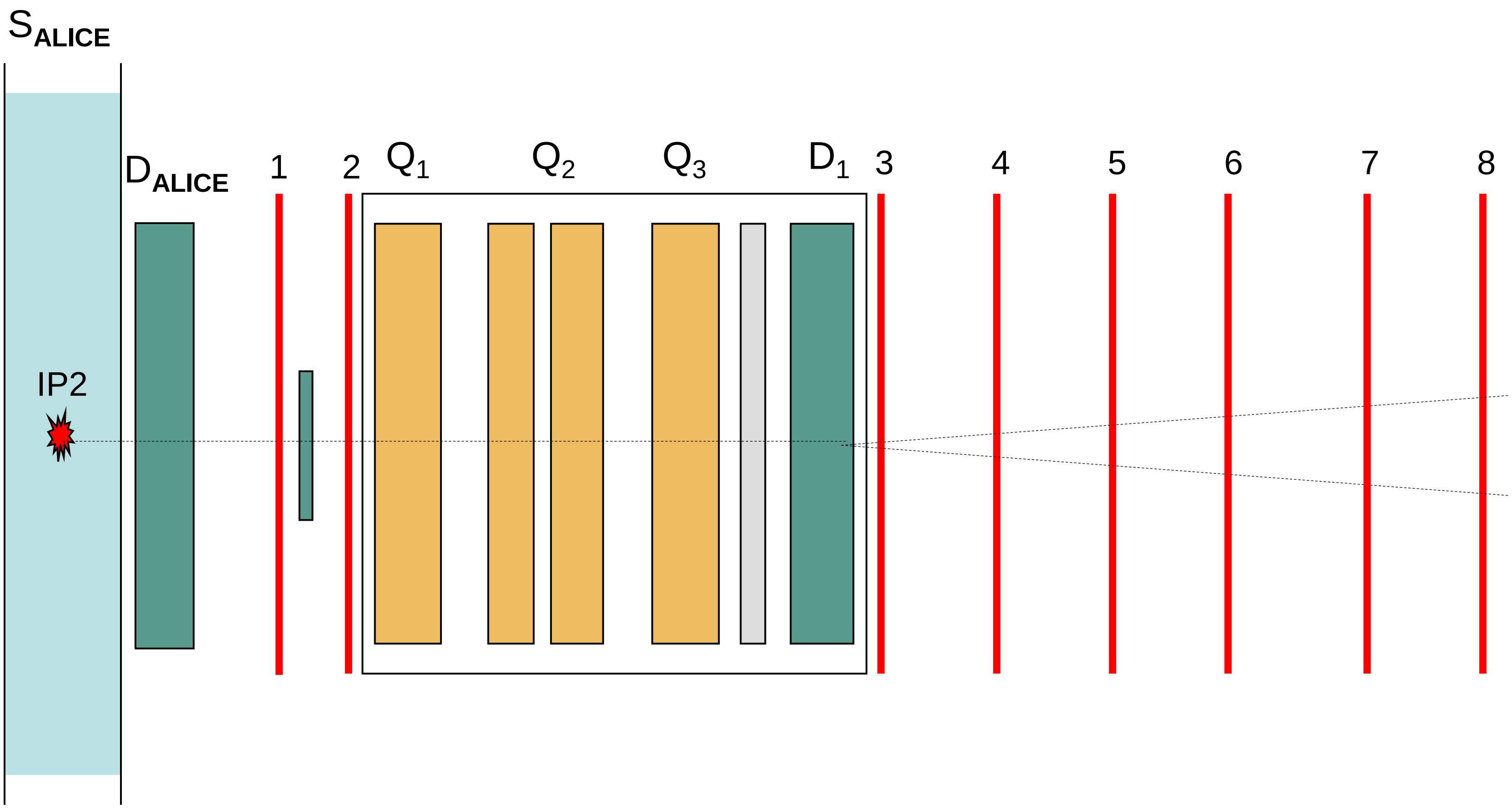
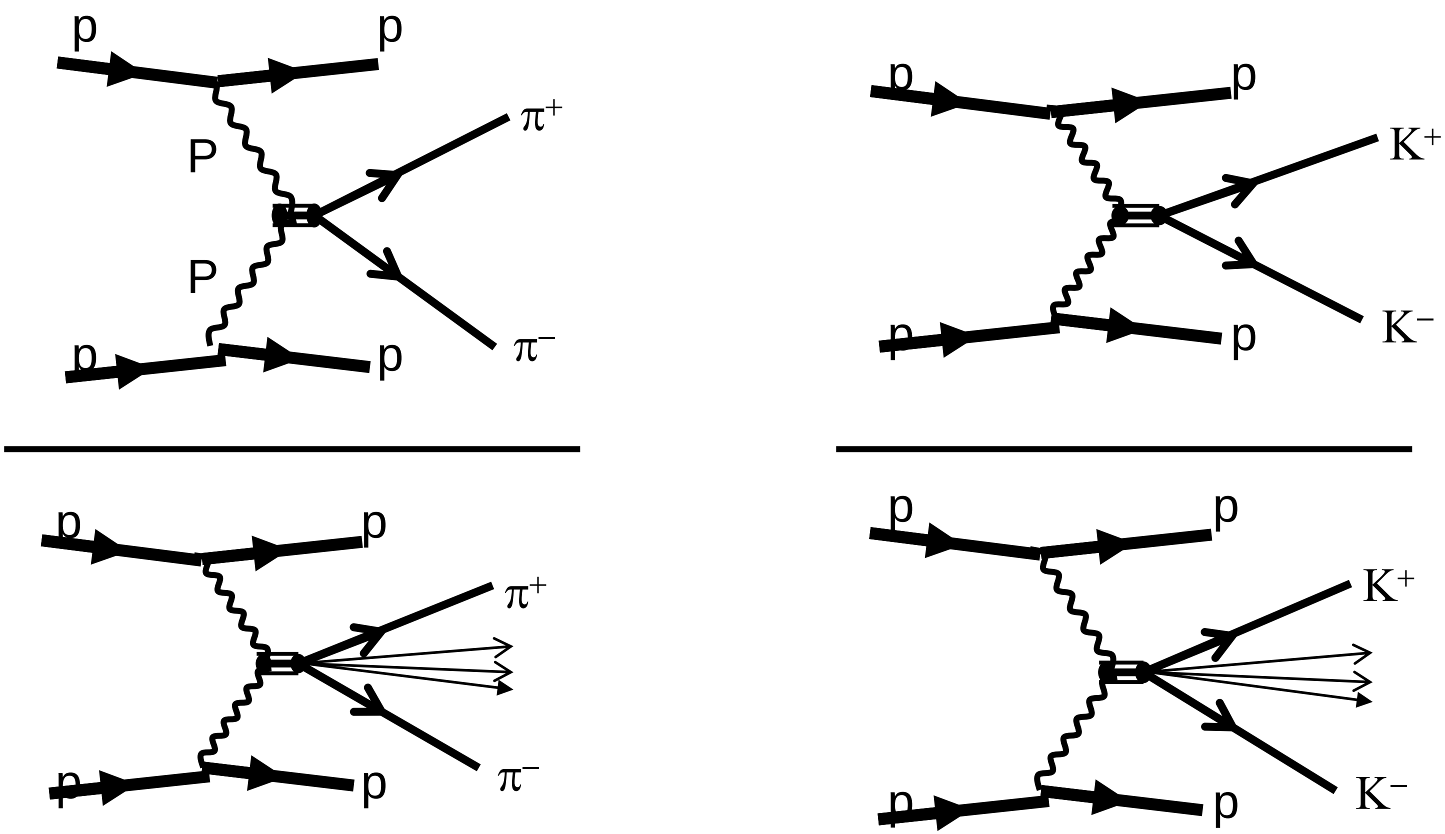


Figure 1. *The layout of LHCb detectors at the LHC Interaction Point (IP8). The proposed Forward Shower Counters (FSCs) are shown as vertical lines (1 to 8). The locations of the dipole (D) and quadrupole (Q) magnet elements are shown as green (dark) and yellow (light) boxes.*

THE PROPOSED ALICE FSC LAY-OUT



PURITIES FOR EXCLUSIVE STATES



$\Delta M \approx 20$ MeV

CENTRAL DIFFRACTION ACCEPTANCE

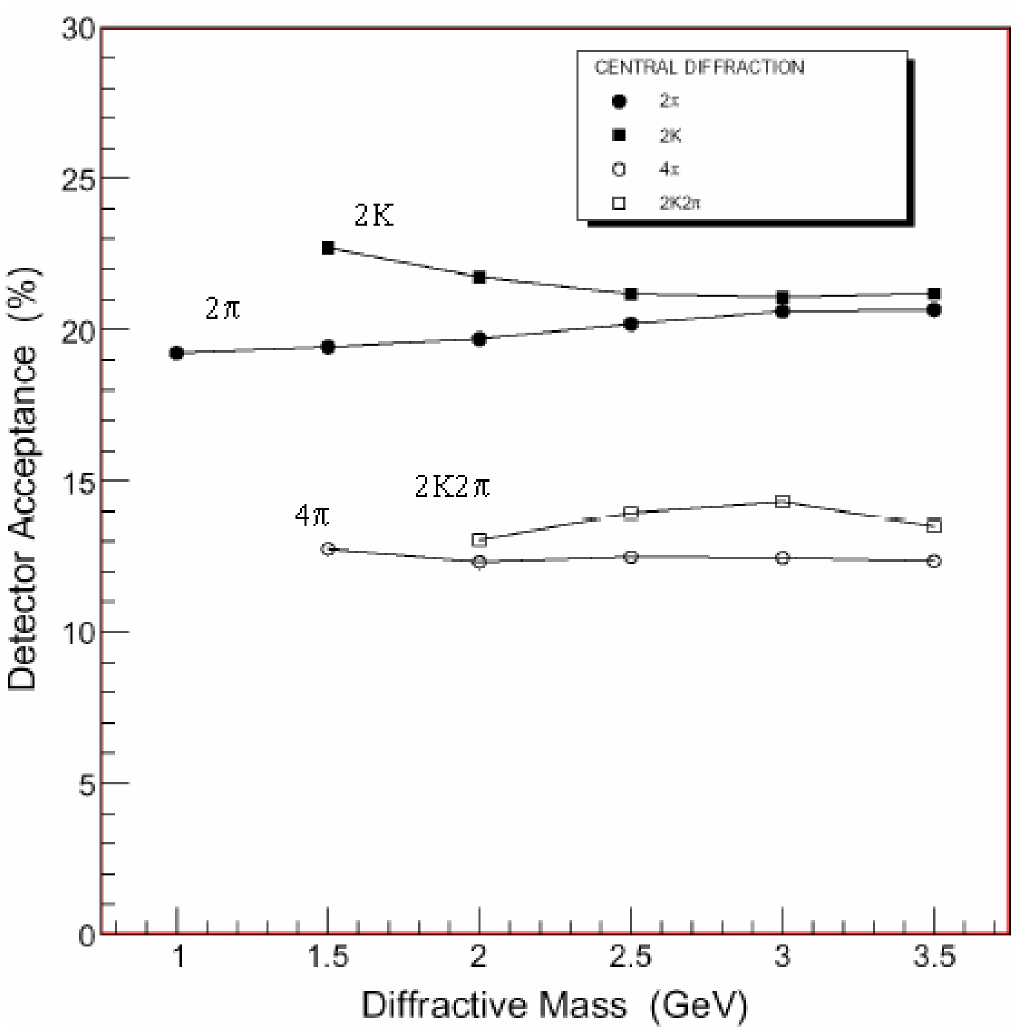


Figure 2. *The detector acceptance as a function of the central diffractive mass for $\pi^+\pi^-$, K^+K^-, $2\pi^+2\pi^-$ and $K^+K^-\pi^+\pi^-$ decay channels.*

SINGLE DIFFRACTION BACKGROUND

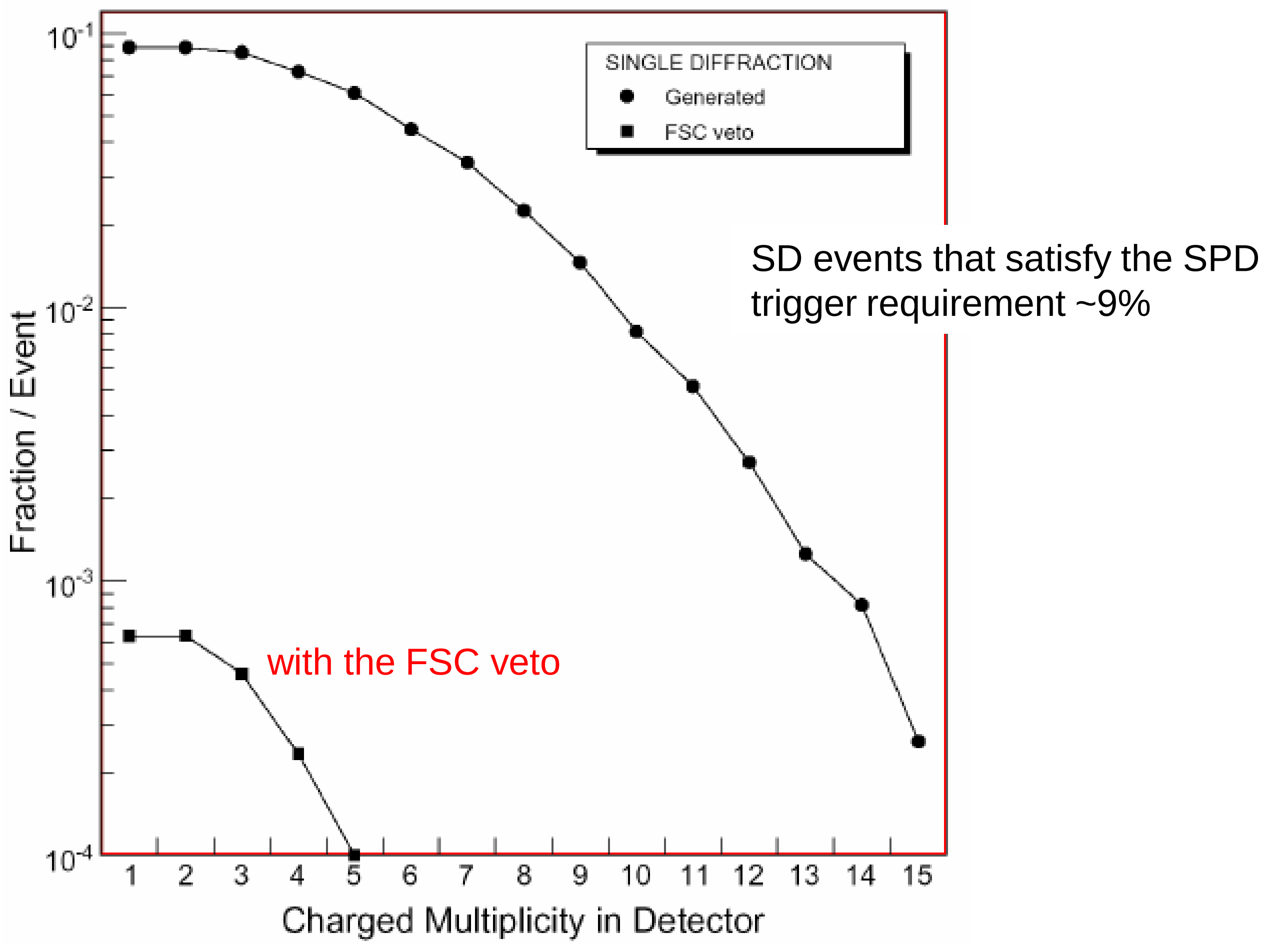


Figure 3. *The probability per event for a given number of charged particles to be emitted within the spectrometer detector acceptance region is given by the upper curve (filled circles), the lower curve (filled squares) gives the acceptance with deployment of the FSCs.*

FSC EFFICIENCY vs. DIFFRACTIVE MASS

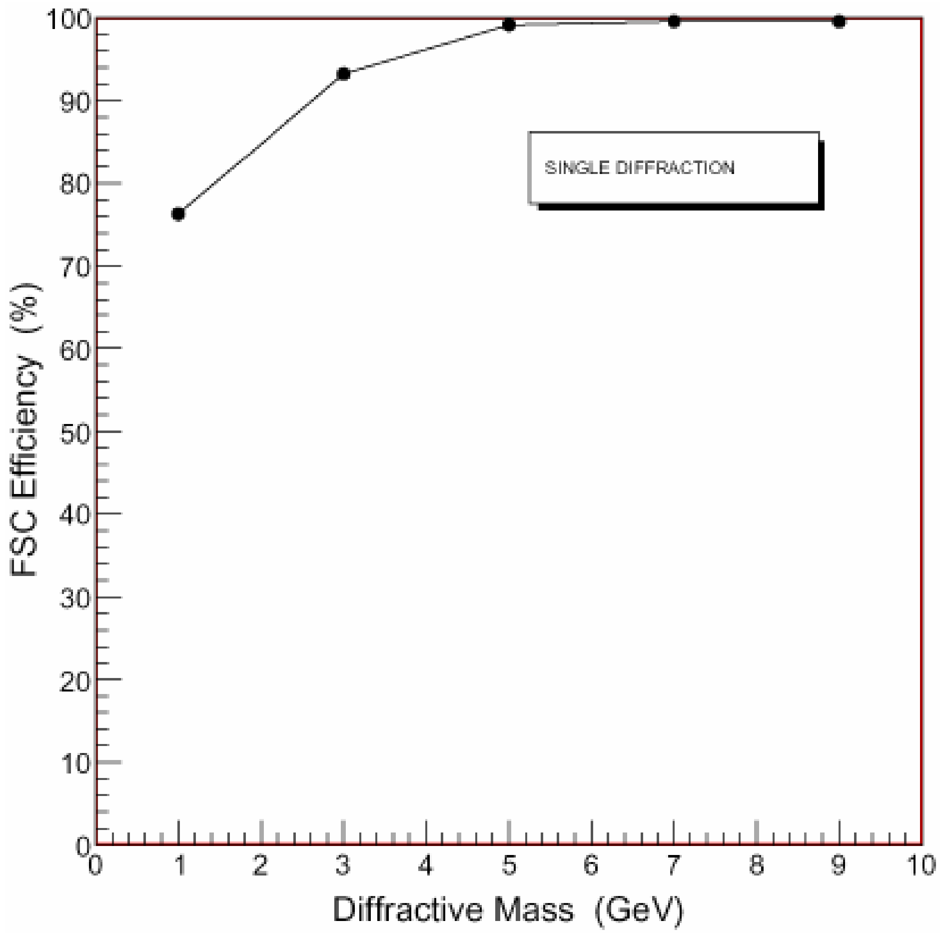


Figure 6. *The efficiency to detect single diffractive events (SD) by the Forward Shower Counters (FSCs) as a function of the diffractive mass.*

NON-DIFFRACTIVE BACKGROUND

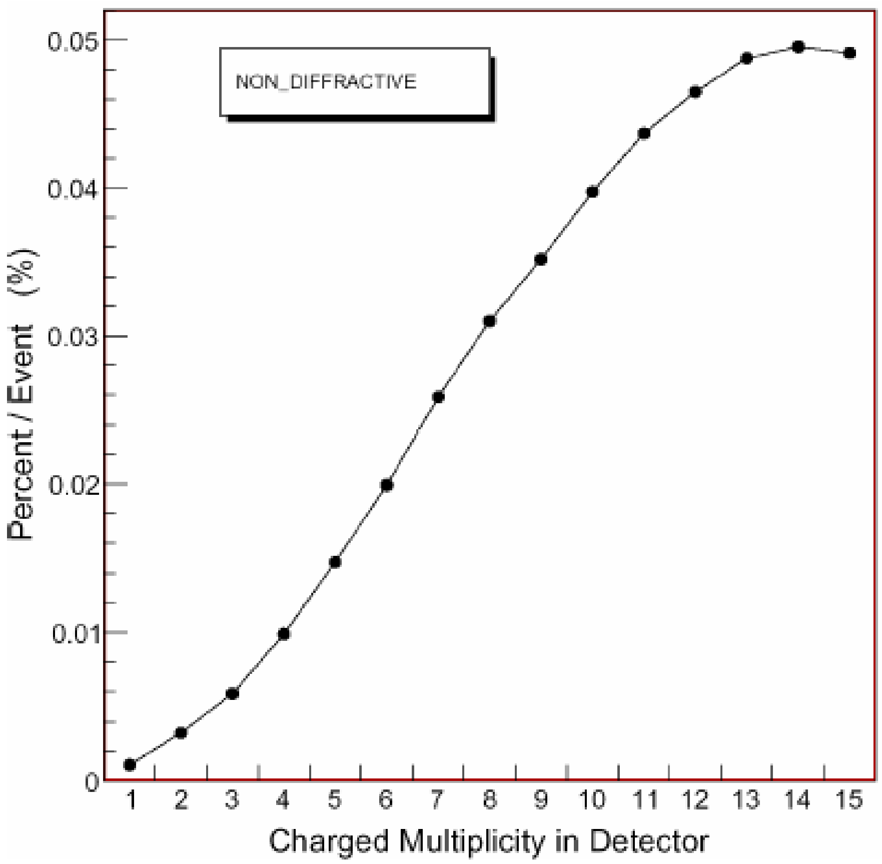


Figure 7. *The efficiency to detect non-diffractive events (ND) by the Forward Shower Counters (FSCs) as a function of the charged multiplicity in the detector.*

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

Use Multivariate Techniques for Accessing Diffractive Interactions at the LHC.

A selection of multivariate methods by the Helsinki group:
Mikael Kuusela, Jerry W. Lamsa, Eric Malmi, Petteri Mehtala, Tommi Vatanen and RO, Sep 2009. 32pp.
Published in **Int.J.Mod.Phys.A25:1615-1647,2010**.

Probability of finding a rap gap (in inclusive QCD events) depends on the p_T cut-off

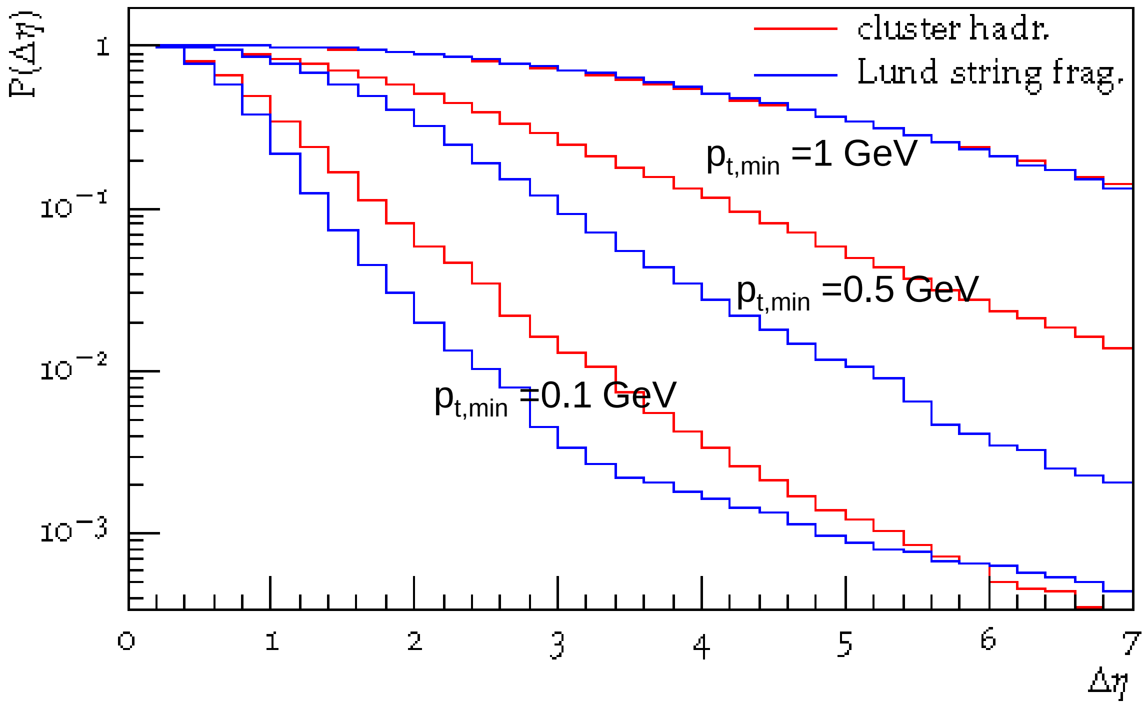


Fig. 4. Probability for finding a rapidity gap (definition 'all') larger than $\Delta\eta$ in an inclusive QCD event for different threshold $p_\perp$. From top to bottom the thresholds are $p_{\perp,\mathrm{cut}} = 1.0$, 0.5 , 0.1 GeV. Note that the lines for cluster and string hadronisation lie on top of each other for $p_{\perp,\mathrm{cut}} = 1.0$ GeV. No trigger condition was required, $\sqrt{s} = 7$ TeV.

KKMRZ:
V.A. Khoze, (Durham U., IPPP & St. Petersburg, INP) , F. Krauss, A.D. Martin, (Durham U., IPPP) , M.G. Ryskin, (Durham U., IPPP & St. Petersburg, INP) , K.C. Zapp, (Durham U., IPPP) . IPPP-10-38, DCPT-10-76, MCNET-10-10, 2010. 19pp.

How to identify diffraction at the LHC?

-Events that have **rapidity gaps** beyond $\Delta\eta > 3$ units.

- experimentally depends on detector **thresholds, $p_{T,min}$**
- **rapidity correlations** ~ $\exp(-\lambda\Delta\eta)$, $\lambda \sim 1$, hadronization models?
- rapidity gaps are **not unique** to diffraction

- Diffraction is a **coherent** phenomenon, each component present with a non-zero probability amplitude in a pp interaction

$\Rightarrow$ Assign each pp event a probability to belong to **every one** of the event classes: SDr/SDl, DD, CD, ND

$\Rightarrow$ Use **all the relevant input** information to characterize the space-time evolution of an event.

”Diffraction enhanced” events/ SD vs. ”Non-SD” events (Atlas/CMS)
- Talk by Andy Pilkington

INPUT INFORMATION FOR MULTIVARIATE EVENT CLASSIFICATION

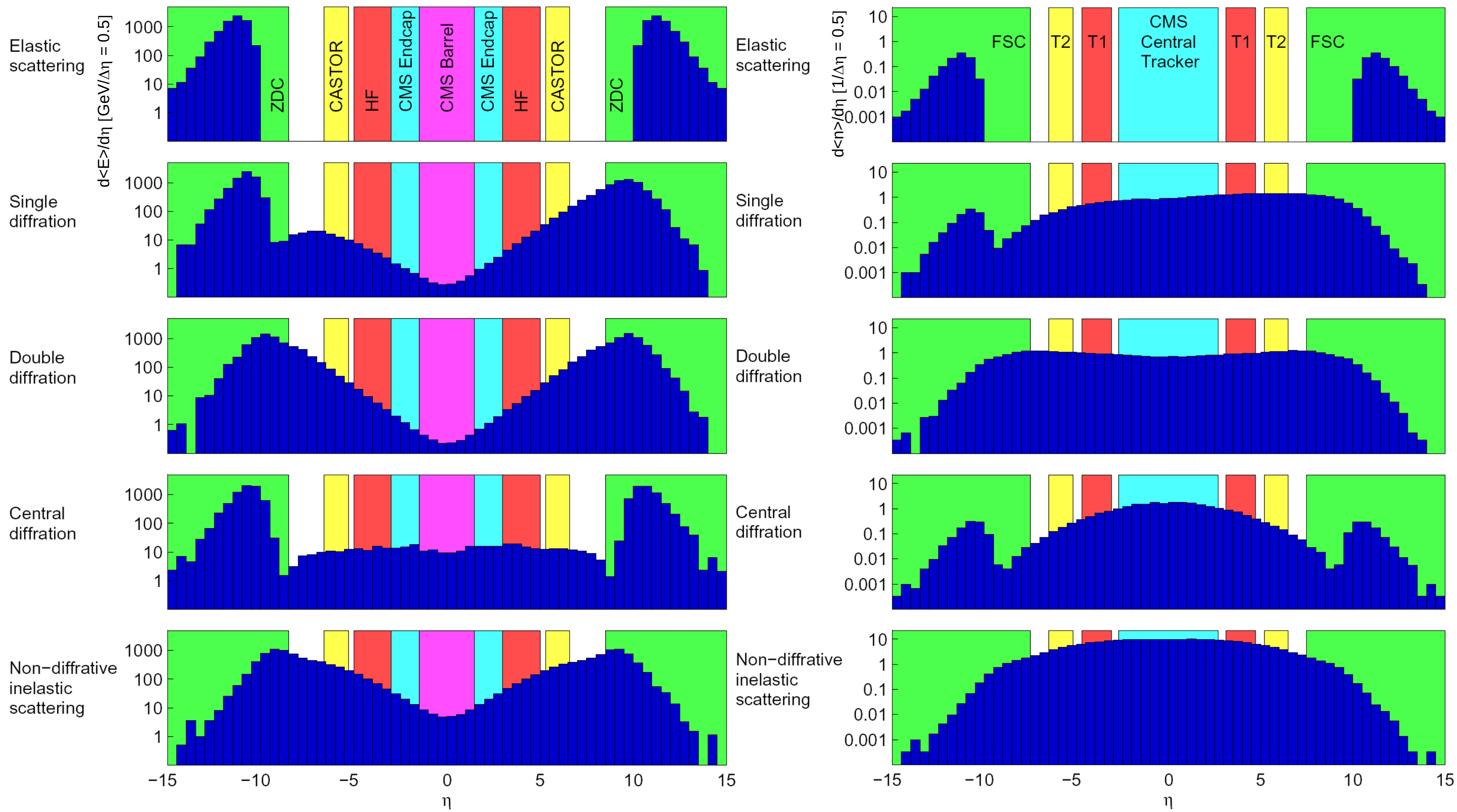
- *particle flows* by TOTEM $T1_{R/L}$, $T2_{R/L}$ spectrometers and CMS $FSC_{R/L}$ counters at ±60 to ±140 m from IP5 [5],

- *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.
THE GOOD-WALKER APPROACH FOLLOWED EXPERIMENTALLY.

ENERGIES MULTIPLICITIES



23 INPUTS FOR EVENT CLASSIFICATION

EXAMPLE!

Multiplicity (DD)

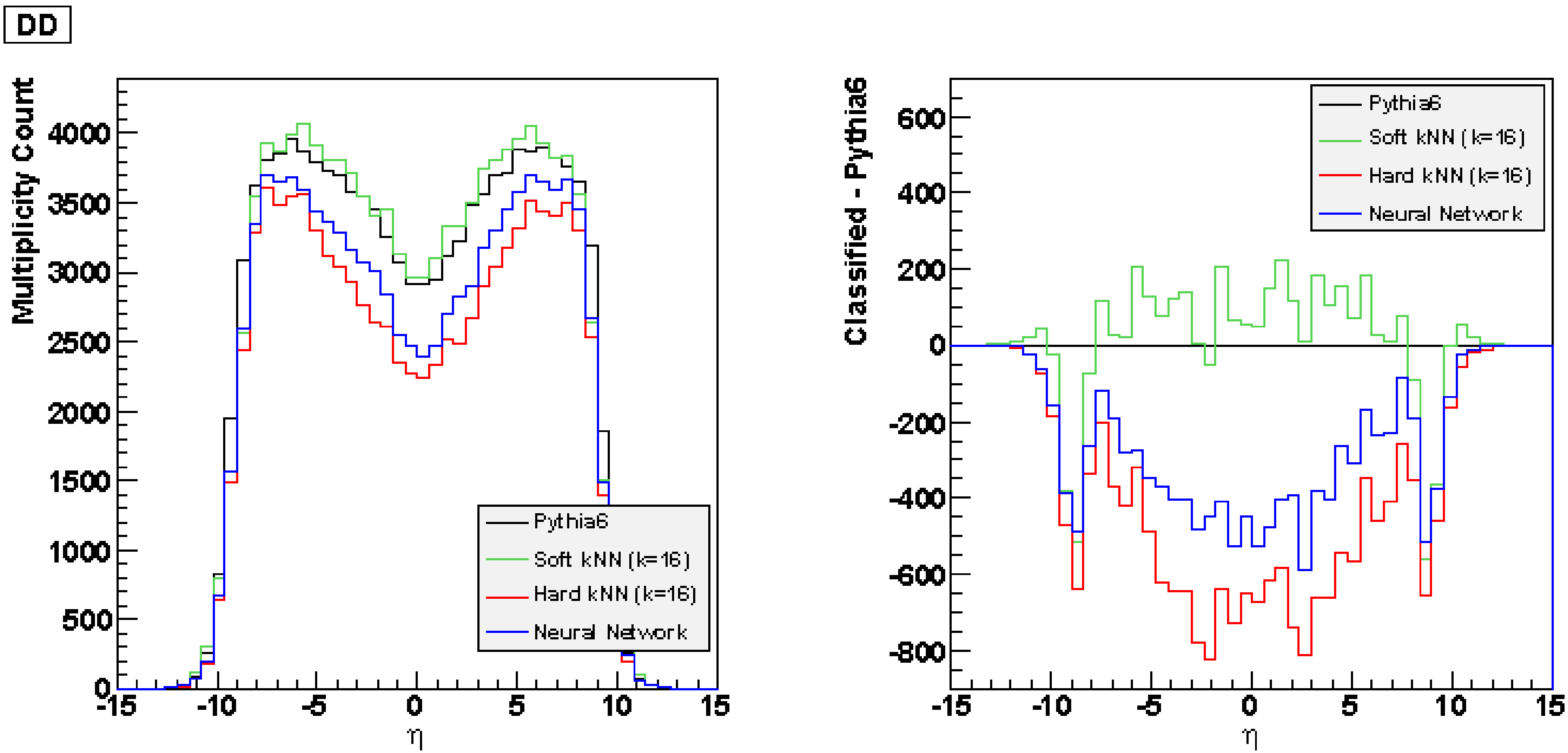


Figure: *Left:* Charged particle multiplicity distribution for double diffractive (DD) events. *Right:* Distributions after subtraction of MC truth. Comparison of soft classification (soft kNN) and hard classification (hard kNN & neural network).

see: Mikael Kuusela's presentation on Wednesday!

CONCLUSIONS

- Photon bremsstrahlung from elastic pp scattering: A new tool for normalization of pp event rates.

- Low mass Single Diffraction: Important for assessing the uncertainties in σ_{tot}

- Low mass Central Exclusive Diffraction: Meson spectroscopy, quarkonia, glueballs..ALICE, LHCb

- Identifying Diffractive Scattering in a consistent way.