Diffraction with Forward Shower Counters FSC

Mike Albrow, Fermilab

What: We propose to install a set of scintillation counters around both outgoing beam pipes at CMS, ~ 60m – 100 m

Why:

! ?

(a) As veto in Level 1 diff. triggers to reduce useless pile-up events.
(b) To detect rapidity gaps in diffractive events (p or no-p).
(c) Measure "low" mass diffraction and double pomeron exchange.
(d) Measure σ_{INEL} (if luminosity known, e.g. by Van der Meer)
(e) Help establish exclusivity in central exclusive channels
(f) To monitor beam conditions on incoming and outgoing beams.
(g) To test forward flux simulations (MARS etc.)
(h) Additional Luminosity monitor.

Also: They may provide valuable tests of radiation environment to be expected for HPS = High Precision Spectrometers

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Forward physics with rapidity gaps at the LHC

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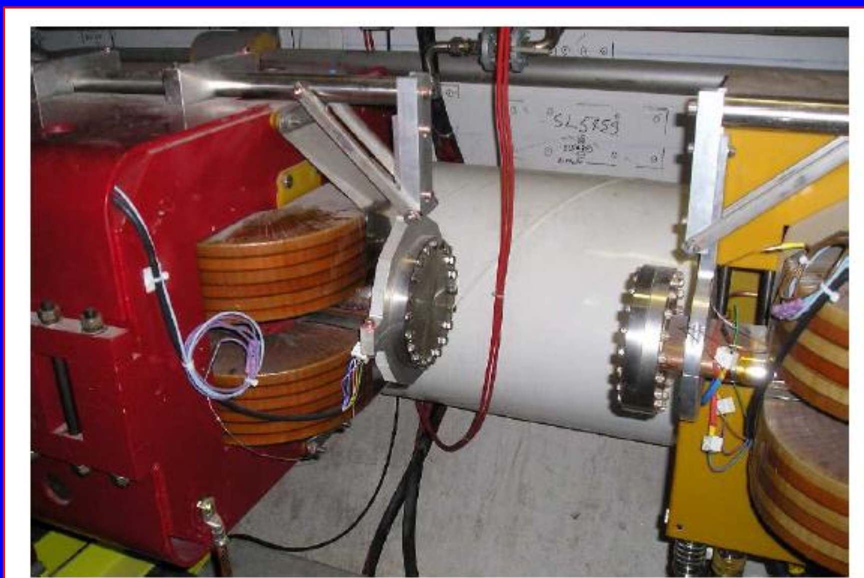
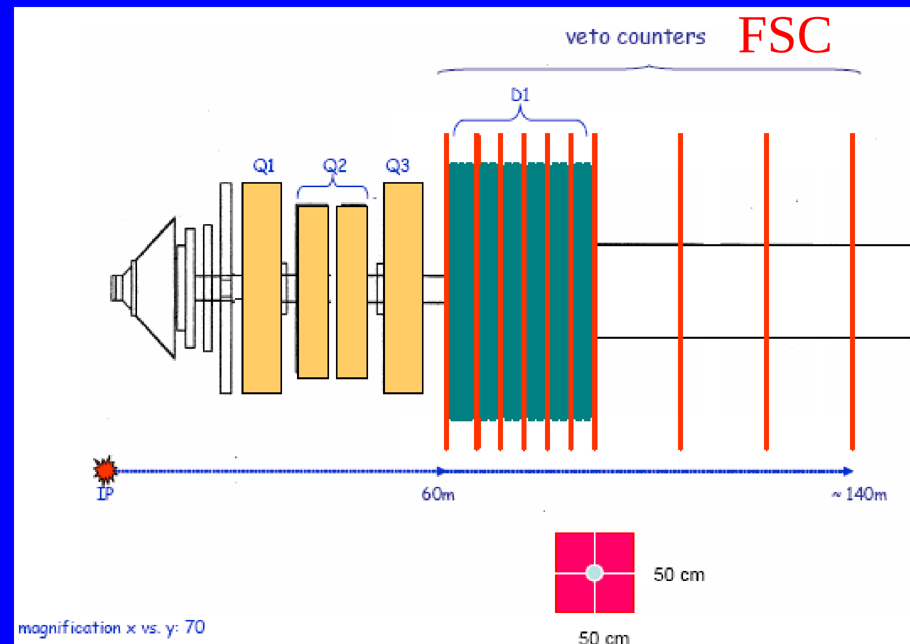


Accessible warm beam pipe between BMX magnets



Can put scintillators at several z-locations
FSC = Forward Shower Counters

Do not see primary particles, but showers in pipe and other material.

Central Diffraction at the LHCb, Lamsa and Orava, arXiv:0907.3847 (JInst)

The same idea:

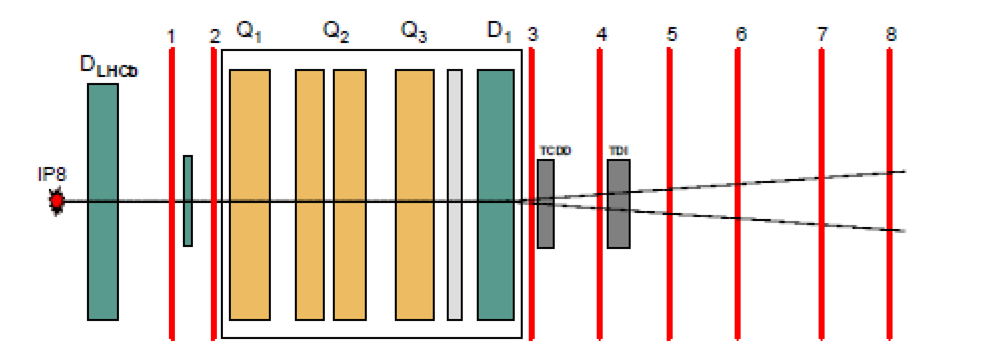


Figure 1. *The layout of LHCb detectors at the LHC Interaction Point (IP8). The proposed Forward Shower Counters (FSCs) are shown as vertical lines (1 to 8). The locations of the dipole (D) and quadrupole (Q) magnet elements are shown as green (dark) and yellow (light) boxes.*

Diffractive states with M > 5 GeV are very efficiently detected by "OR" of FSC

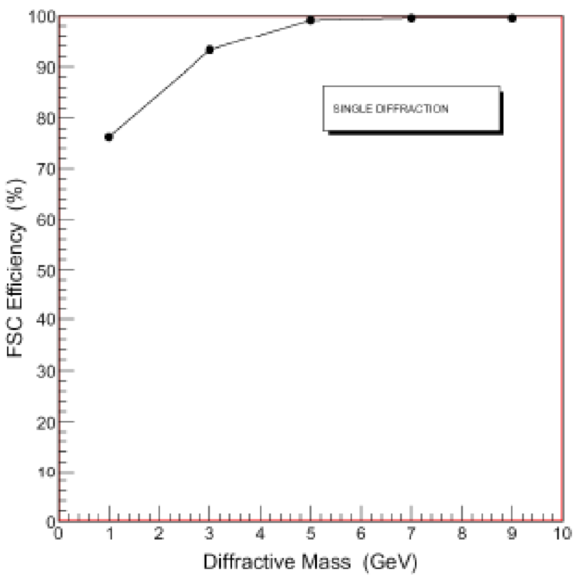
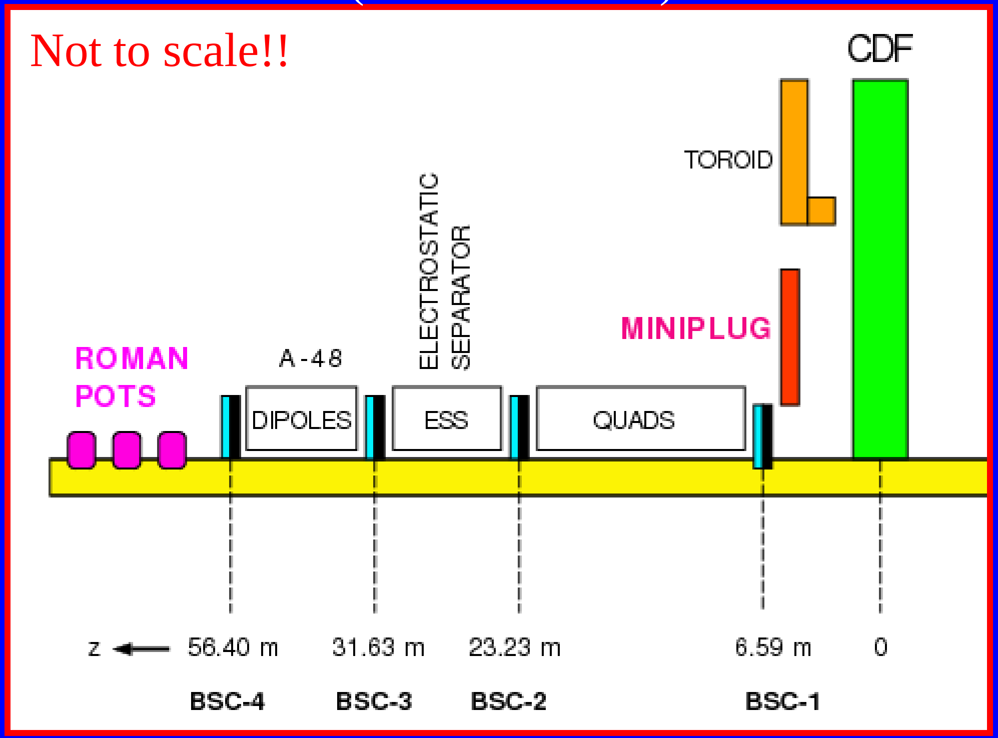
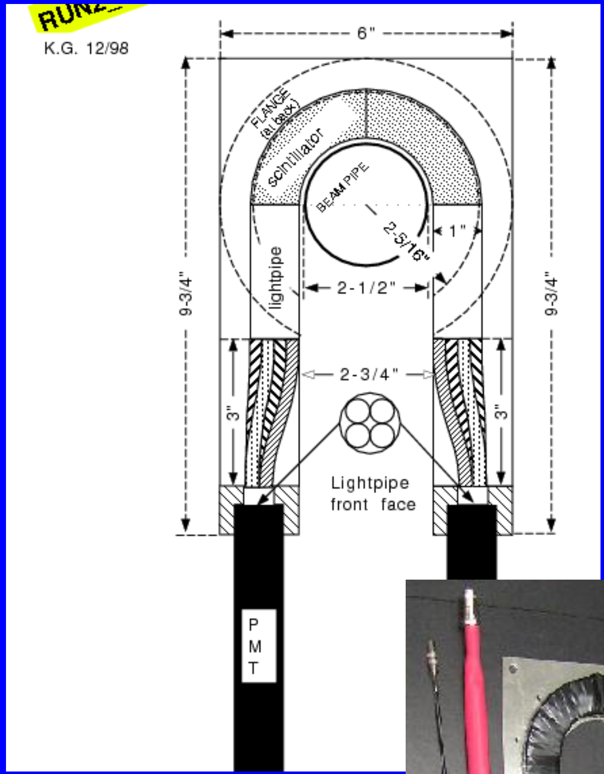


Figure 6. *The efficiency to detect single diffractive events (SD) by the Forward Shower Counters (FSCs) as a function of the diffractive mass.*

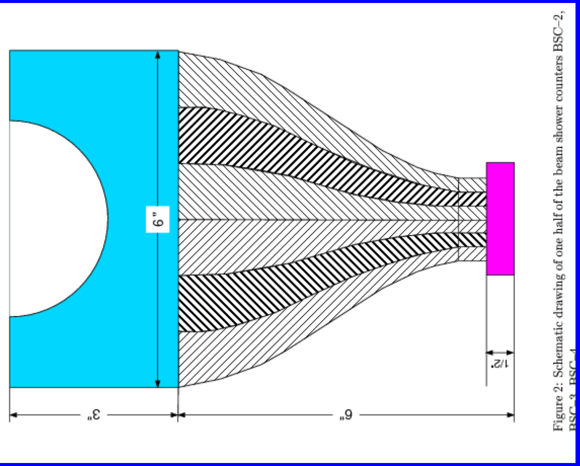
Beam Shower Counters in CDF

(Rockefeller Univ)





BSC1:
4 counters
on each side,
with 1.7 Xo Pb



BSC2,3,4
2 counters
on each side

(Very rough) **study of single diffraction in CDF using only BSC counters + rest of CDF in veto:**

Not an approved CDF plot, consider it purely schematic.

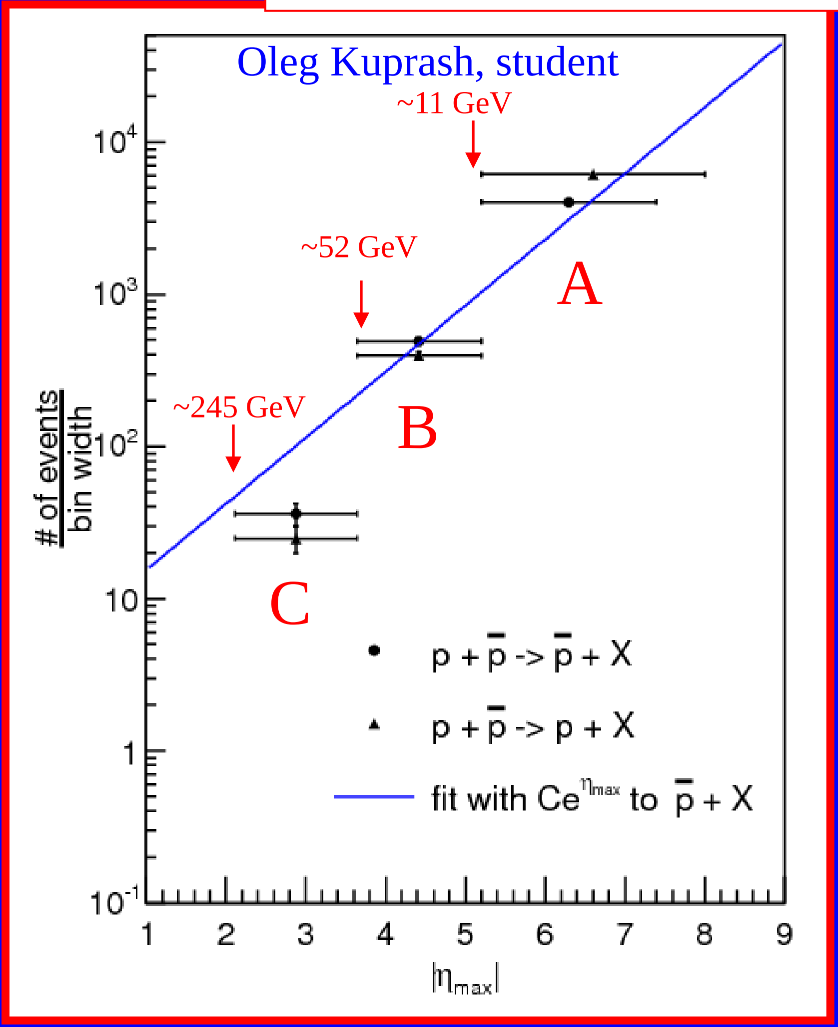
Trigger = zero-bias (= bunch crossing)

Select events with no tracks and all CDF calorimeters empty EXCEPT:

A: BSC1&2&3 $5.4 < \eta < 7.4$
B: " & miniplug: $3.6 < \eta < 5.2$
C: " & Forward Plug: $2.1 < \eta < 3.64$

Can be more differential as BSC have 3 η-ranges and Miniplugs and Fwd Plug are also segmented.

Can repeat for X-G-X events, double diffraction testing factorisation.



Need to compare with a full simulation, beam line, showers etc.
& can tune diffraction models and cross sections

Experience from CDF diffractive W,Z : Single Interactions Imperative

Events with Roman Pot $\bar{p}$ ($\xi^{RP} < 0.1$) and central W

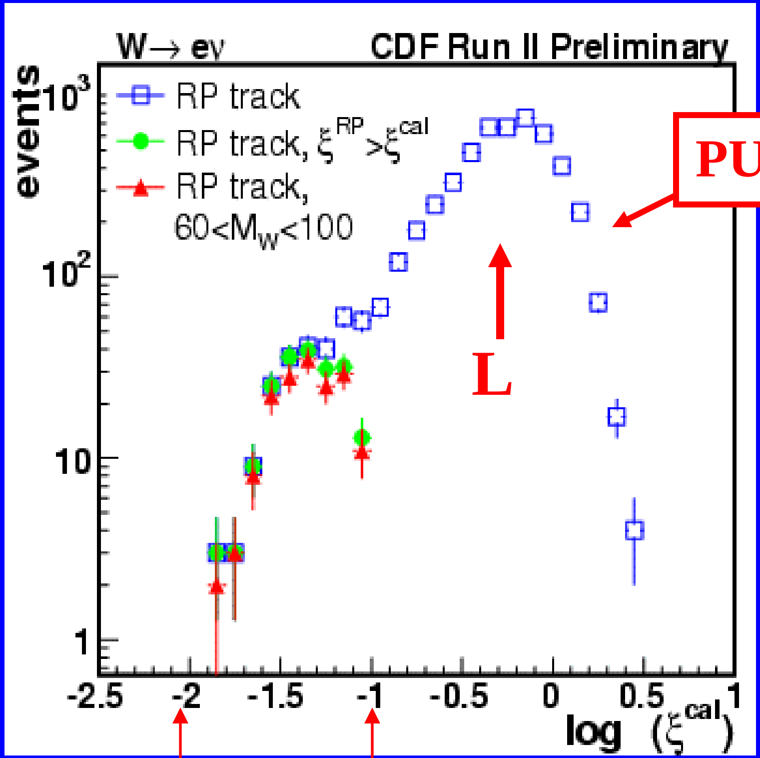
Calculate ξ^{CAL} from full calorimetry. Only "agree" if no PU

Very small fraction of all events. **Cannot use PU events.**

$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

Require $\xi^{RP} > \xi^{CAL}$ kills PU, so does BSC veto

For no PU events, can find $\eta(\nu)$ by balancing ξ^{RP} and ξ^{CAL} (unique in pp)

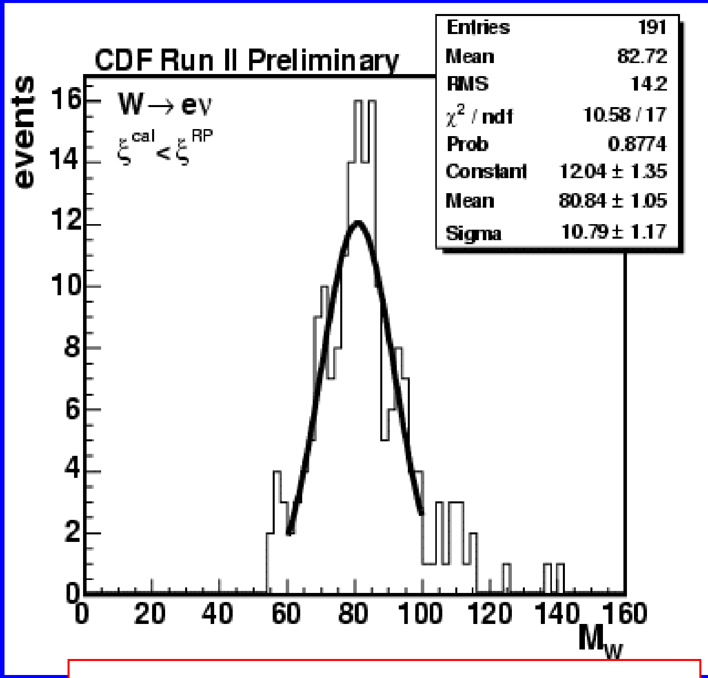


PU!

L

0.01

0.1



Very large η crucial!

M(W) (not transverse mass!)

→ Exclusive: e^+e^-, $\mu^+\mu^-$, J/ψ, ψ(2S), χ_c, γγ … all published (CDF)

Why are those interesting?

- e+e-, μ+μ- are ~ pure QED: γγ → μ+μ-
  Possible luminosity calibration & p-calibration (& resln.) fwd p
  But if p ⟶ p* ⟶ Nπ, Nππ , L_{cal} screwed up.
  Use FSC at lower L to select exclusive templates (p_T,Δφ)

- J/ψ, ψ(2S), Y, photoproduction: Y*-p elastic scattering (IP exchange)
  Will be looking for Z-photoproduction: p+p → p+Z+p, γ+IP → Z.

Had a good candidate in CDF, except BSC showed inelastic activity!

- χ_c, γγ : same IP+IP process that produces exclusive H.
  (Standard candle for H)

Much interesting QCD/Diffr: IP as CS-gg, Sudakov suppression, gap survival, etc

Cannot detect p's in this mass region.
Must have FSC to use gaps.

For central exclusive studies (no p/p^{bar}) require all BSC empty.

→ Exclusive: e^+e^-, $\mu^+\mu^-$, J/ψ, ψ(2S), χ_c, γγ … all published

Zero-bias data essential, divide in INT/NO-INT classes.
Good way: Hottest PMT of BSCx

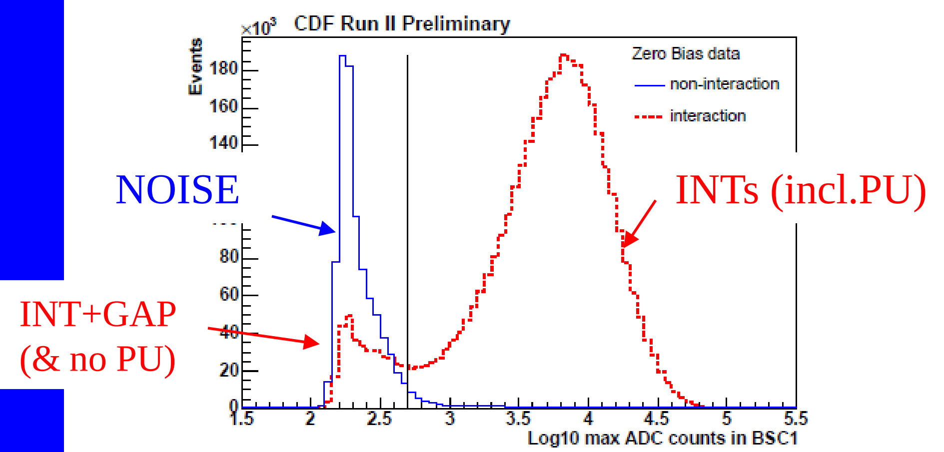


Figure 9: Log10(ADC counts - pedestal) in BSC1 for interaction and non-interaction samples. The line shows the cut value in ADC counts. $10^{2.7} = 500$ counts. The noise peaks at $10^{2.25} = 180$ counts, and the interaction distribution peaks at $10^{3.8} = 6300$ counts. Plotted is the PMT in the BSC1 counters with the highest pulse height (One entry per event).

This sees collisions directly and has Pb radiator for π^0

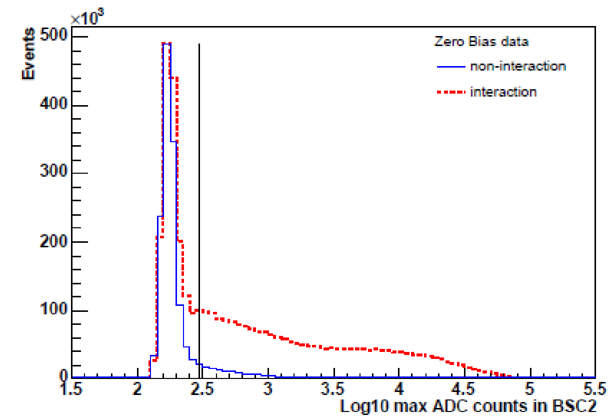


Figure 10: Log10(ADC counts - pedestal) in BSC2 for interaction and non-interaction samples, the line shows the exclusivity cut.

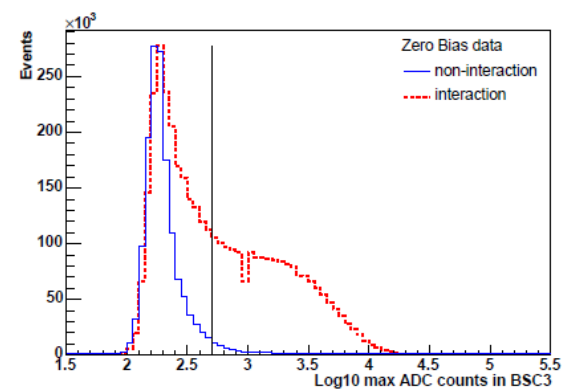


Figure 11: Log10(ADC counts - pedestal) in BSC3 for interaction and non-interaction samples, the line shows the exclusivity cut.

These see showers only; less clean.
>= 2 counters/station useful

Noise levels in calorimeters

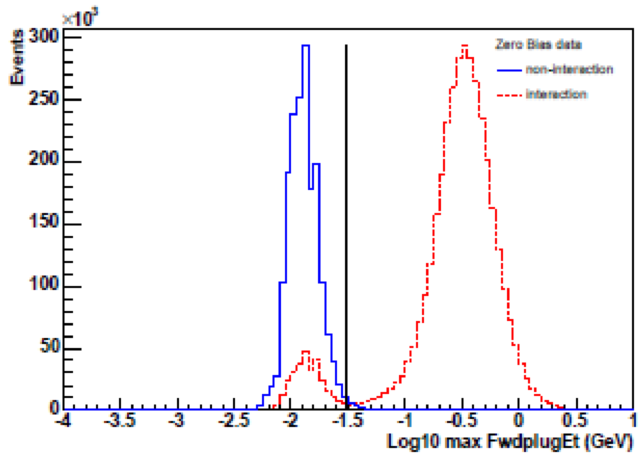


Figure 14: Log10(Max Et) for forward-plug E_T, for interaction and non-interaction samples, the line shows the value of the exclusivity cut applied (30 MeV).

Signal-Noise separation in CDF calorimeters:
Hottest PMT in regions:
0-bias with tracks
0-bias with no tracks

Forward PlugCal:
$2.11 < \eta < 3.64$

Central EM Cal:
$-0.66 < \eta < +0.66$

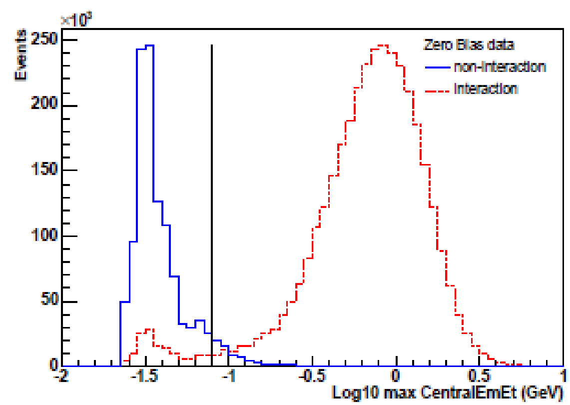


Figure 12: Log10(Max Et) for Central EM E_T, for interaction and non-interaction samples. The line shows the values of the exclusivity cut applied, at $10^{-1.1} = 80$ MeV. The peak of the noise is at $10^{-1.5} = 32$ MeV, and the peak of the interaction sample at $10^{-0.1} \approx 800$ MeV. Note that these are the "hottest" towers in the events (one entry per event).

Other choices (Sums)
can be used.

Zero-bias data is essential!

What about total inelastic cross section σ_{INEL}? And total σ_{TOT} if you know σ_{EL} ?

Not done at Tevatron!

Can measure rate of totally empty events, $P(0) = \exp(-<n_{inel}>)$
But this misses all the low mass diffraction that give hits only with $|\eta| >\sim 6$, or $M <\sim 5$ GeV/c^2
This is many mb!

Nobody can measure σ_{INEL} directly, only $\sigma_{TOT} - \sigma_{EL}$ (?)

With FSC, P(0) only faked by events with all particles in cracks (can study with fake cracks) or inefficient regions (small); and inefficient because of noise (can study with data).

FSC fills 2 huge cracks: $5(6) < |\eta| < 8(9\ldots)$

η poor variable here!

Diffractive and Non-diffractive Interactions

CMS 1st paper (p_T and η distributions) :
"For non-single-diffractive interactions…." Means what?
Required HF+ and HF- to each have E > 3 GeV (a bias, even for "ND")
Calculated SD "contamination" using PYTHIA or PHOJET (MODELS)

But there is no absolute distinction between ND and SD !!
Any attempt is model dependent.

Only absolute distinction is between elastic and inelastic collisions

Diffractive or non-diffractive? p + p → p + X

$x_F(p) = 1 - \xi(p)$ distibutions continuous.

Peak for $x_F(p) > 0.95$ from ISR → Tevatron.

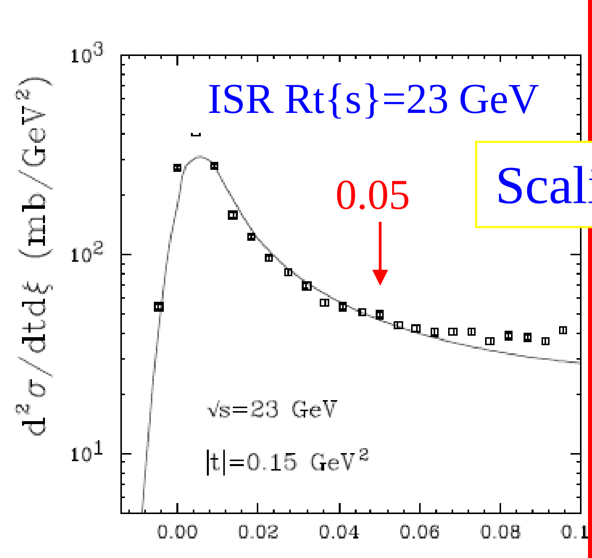
No way **in principle** to say if event with xF(p) = 0.95 is/is not diffracti

Can only fit with some **model**, e.g. Regge, and give integrals of IR and IP te

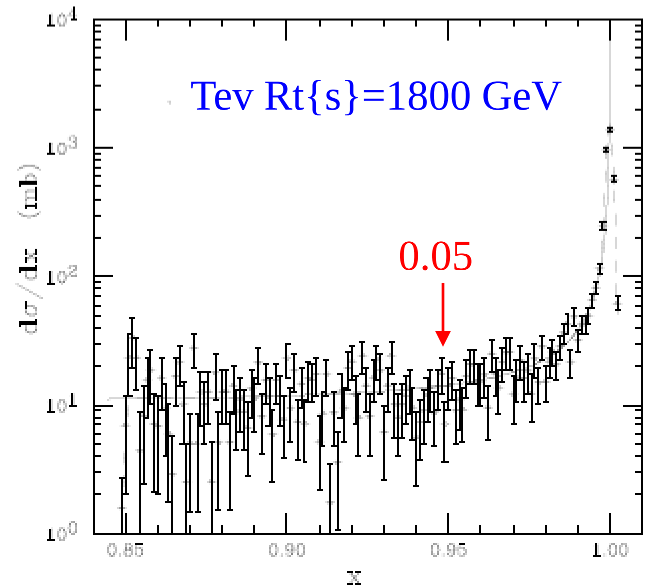
OR you can DEFINE diffractive events as any event

with a p with xF(p) > 0.95 or 0.93 or 0.96 or whatever, if every experiment agreed.

INTERFERENCE!



Scaling peak



Figures 2a (top) and 2b (bottom)

CDF cross sections $d\sigma/dx_F$ (integrated over t); the solid curves represent formula (7) and the dashed curves formula (8).

Same in rapidity: GAP > 3
(~ $\xi(p) < 0.05$)

MUSHY

A p with $x_F = 0.98$ is "predominantly" diffractive;
a p with xF = 0.92 is "predominantly" non-diffractive

So:

If there is a p with $x_F(p) \sim 0.98$ it is most likely diffractive, coherently scattered by pomeron exchange.
If there is a p with $x_F(p) \sim 0.92$ it is most likely not diffractive, incoherently scattered by reggeon exchange. (in Regge theory).
……. but in CMS we can not detect the scattered p anyway, so we cannot use this distinction.

Similarly if there is a very forward rapidity gap of > 4 units it is most likely diffractive,
If there is no gap bigger than 2 units it is most likely not diffr.
……. but in CMS we can not detect forward gaps anyway, so we cannot use this distinction either!

The missing 2-3 units!

Forward η – regions covered in CMS:

η ~ 3 - 5 HF (hadron forward) & T2
CASTOR (1-side) η = 5.2 – 6.4
ZDC 0° neutrals only

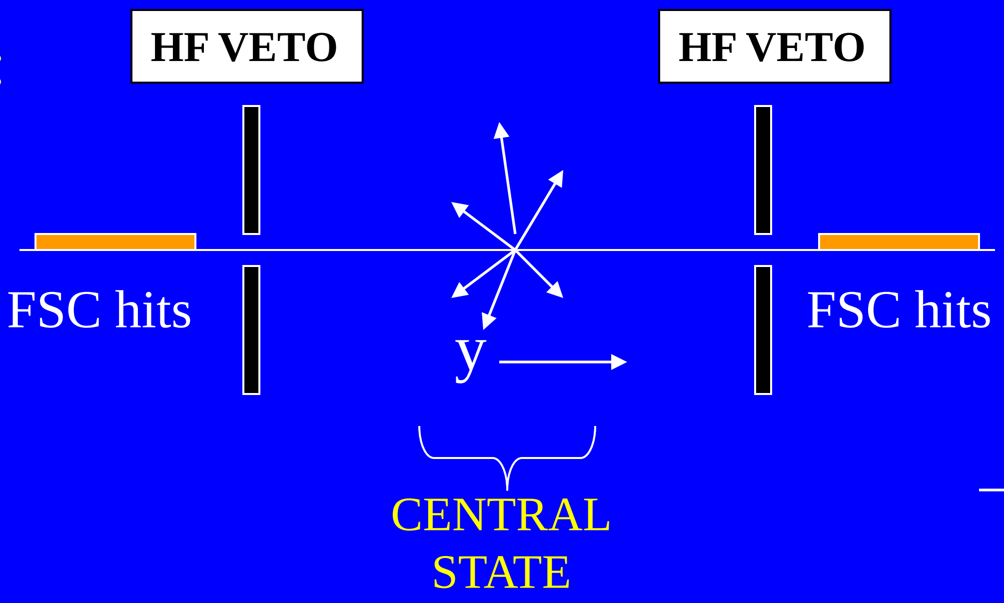
$$y_{\mathrm{BEAM}} = \ln\left(\frac{\sqrt{s}}{m_p}\right) = 8.9\ (9.6)$$

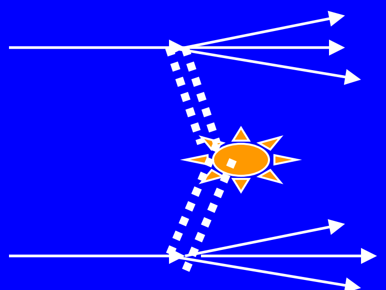
at $\sqrt{s} = 7\ \mathrm{TeV}\ (14\ \mathrm{TeV})$

$y \neq \eta$, but still, e.g.:
π with $p_T = 0.5\ \mathrm{GeV}, p_L = 1\ \mathrm{TeV}$
has $\eta = 8.3$

Central events (0-bias trigger) with forward rap-gaps
(FSC, ZDC, CASTOR, HF)
studied for generic Double Pomeron Exchange processes (~ 0.1 mb)

Low mass DPE:





Even without seeing quasi-elastic protons,
gaps >~ 4 units select D IP E

Efficiency for detecting forward particles (Orava):
Low- β : > 20% for η > 9.0, > 60% for 9.5 < η < 11.5 (integrated over pT)

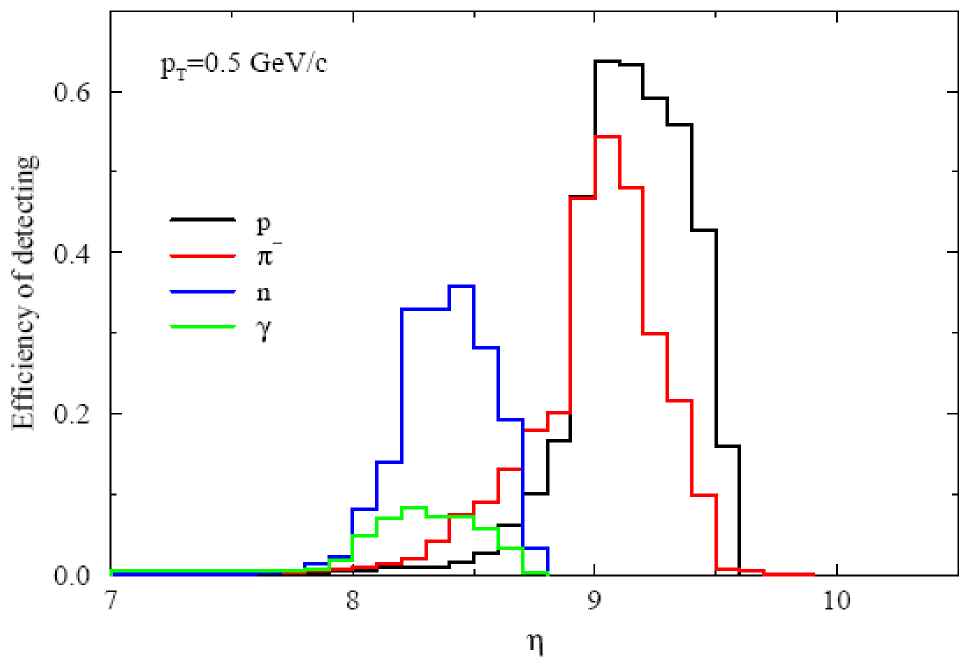


Figure 12: Efficiency of detecting different particles produced at $p_T = 0.5$ GeV/c vs η. Protons and neutrons are the most abundant particles at such large rapidity.

Simulations of FSC efficiency for very forward pions (Jerry Lamsa, Risto Orava with GEANT)

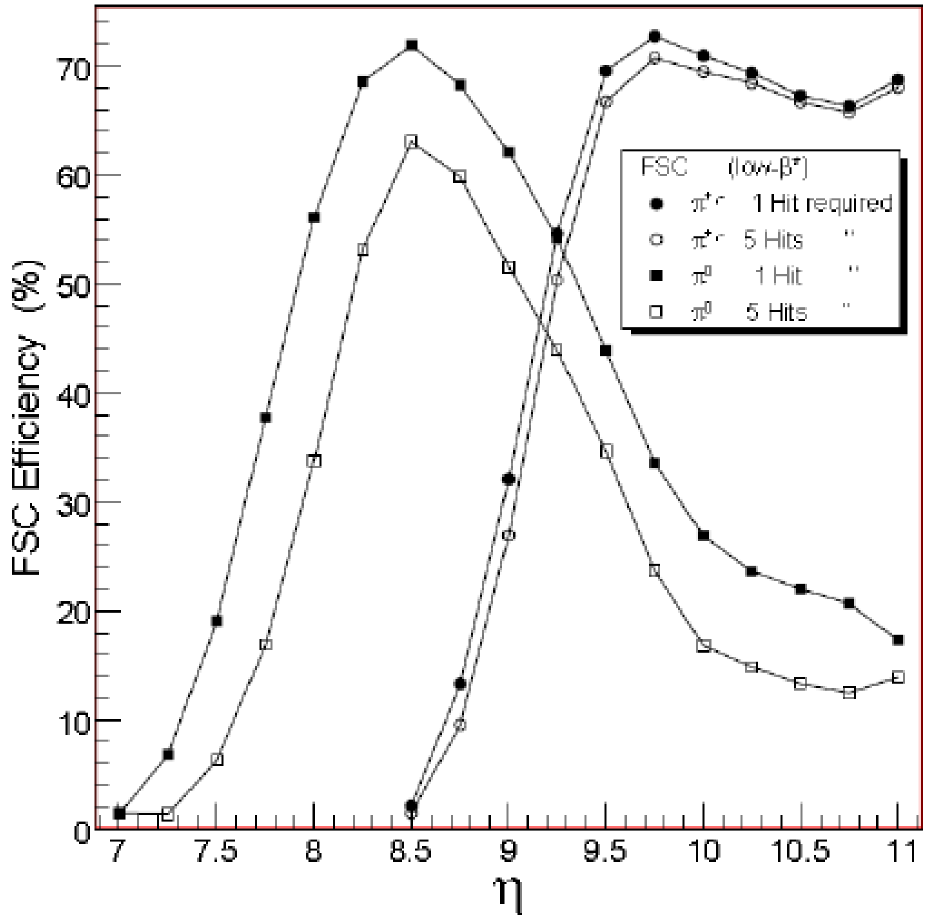
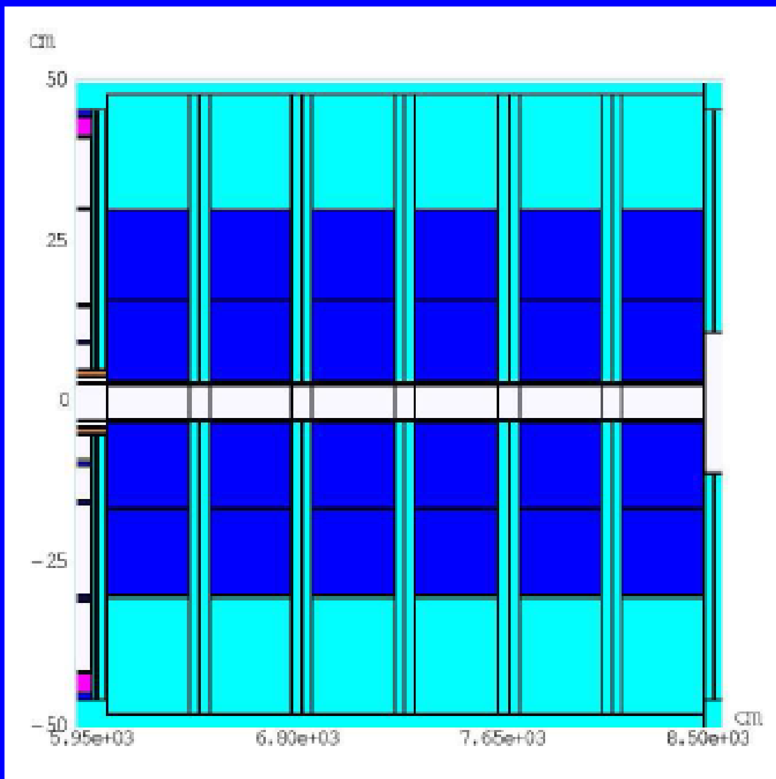


Figure 3 *The efficiency (%) of the Forward Shower Counters (FSC) to register charged particle(shower) tracks induced by primary $\pi^{\pm}$'s and π^{0}'s at low-β^* run conditions as a function of pseudorapidity η.*

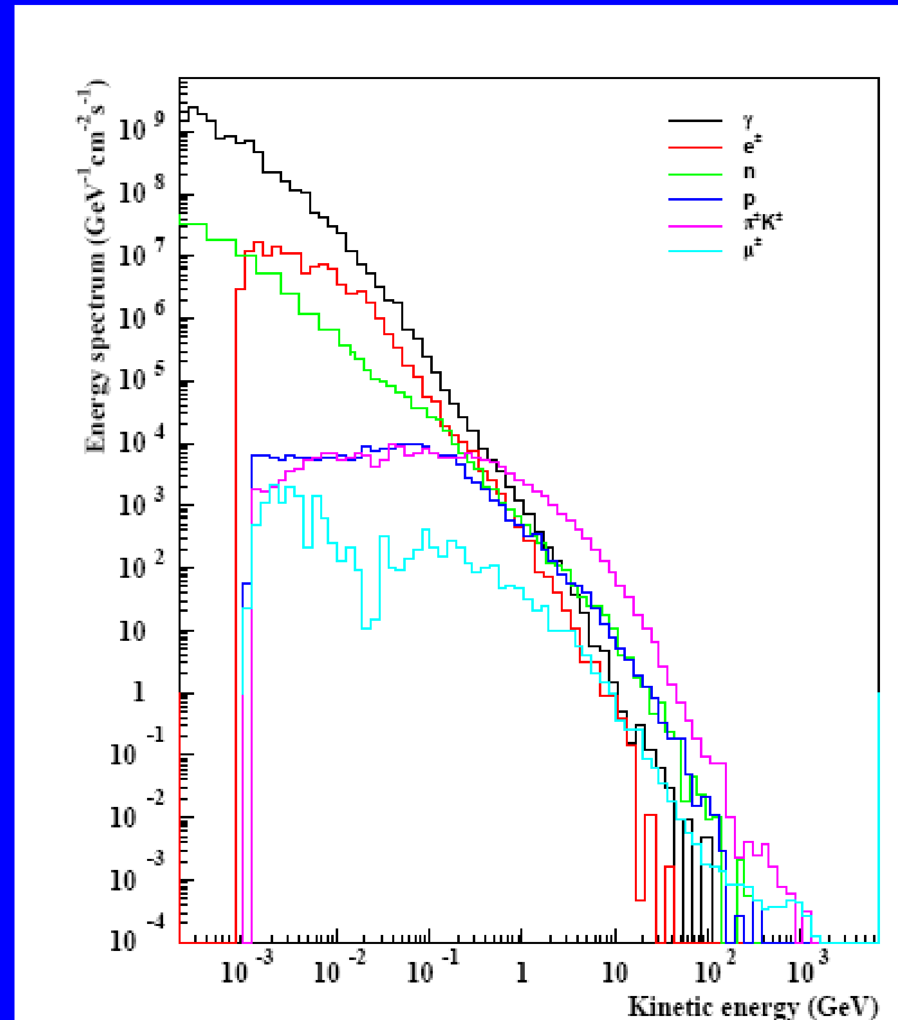
MARS simulations (Mokhov, Rakhno)

Lumi = 10^33 cm^-2s^-1



(x-z) of seven possible counter locations,

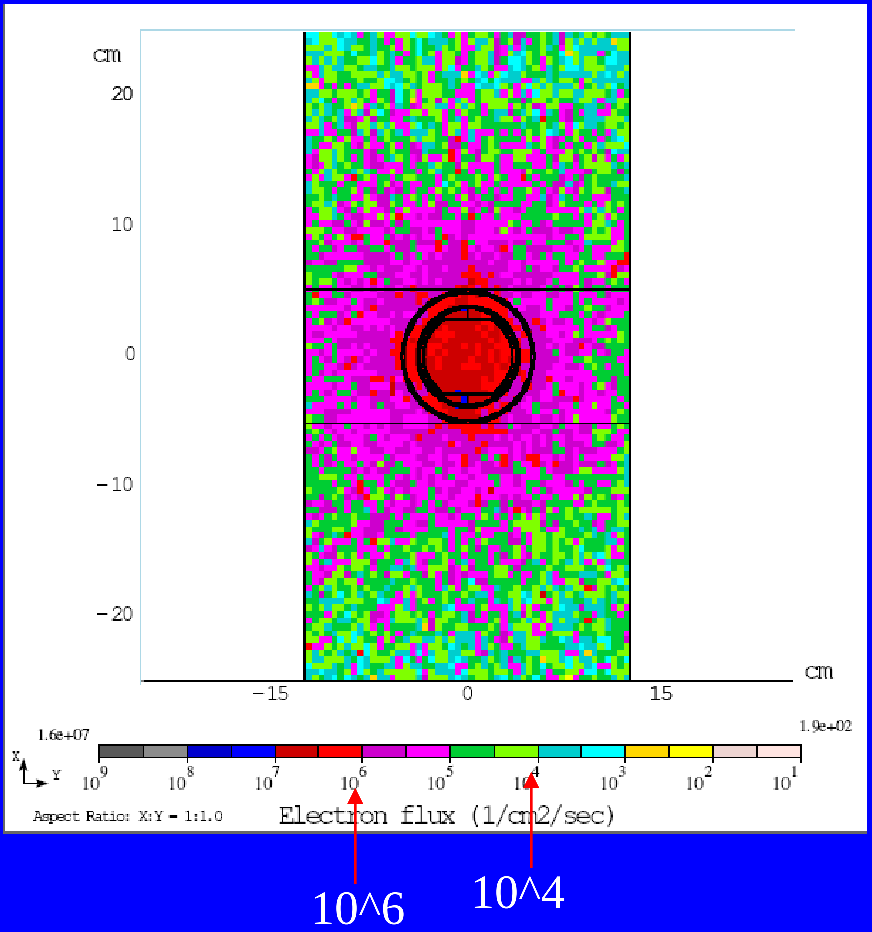
Energy spectrum of different particles



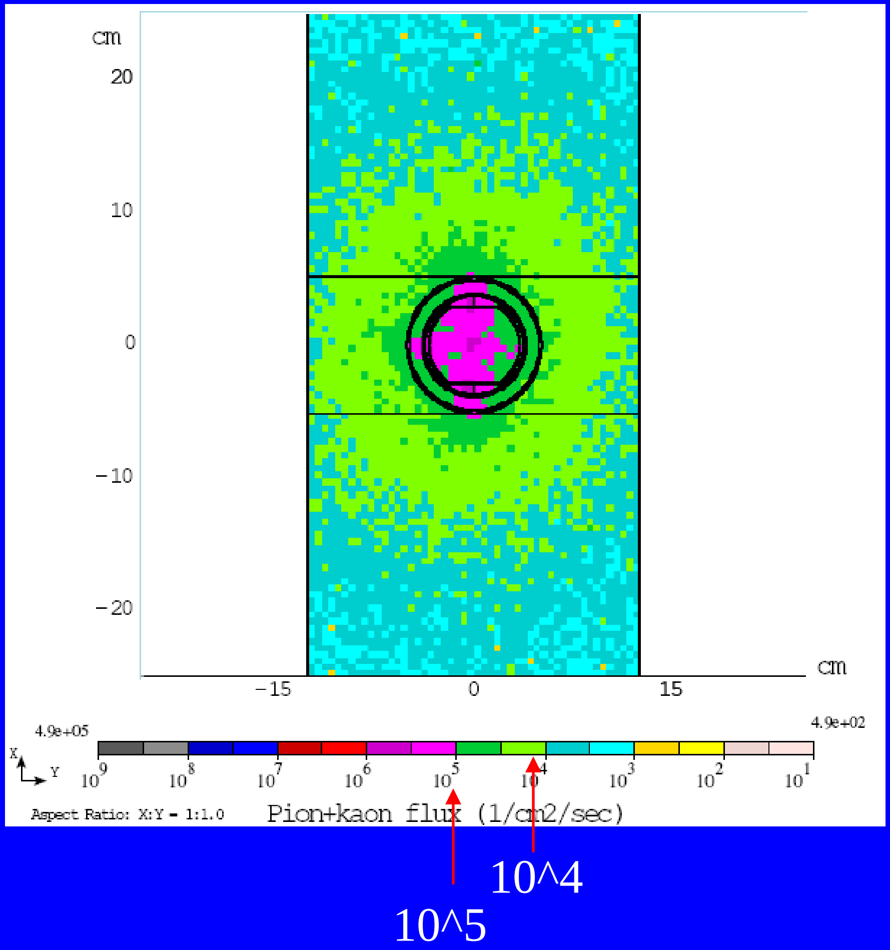
MARS simulations x-y plane at one z

These simulations need checking

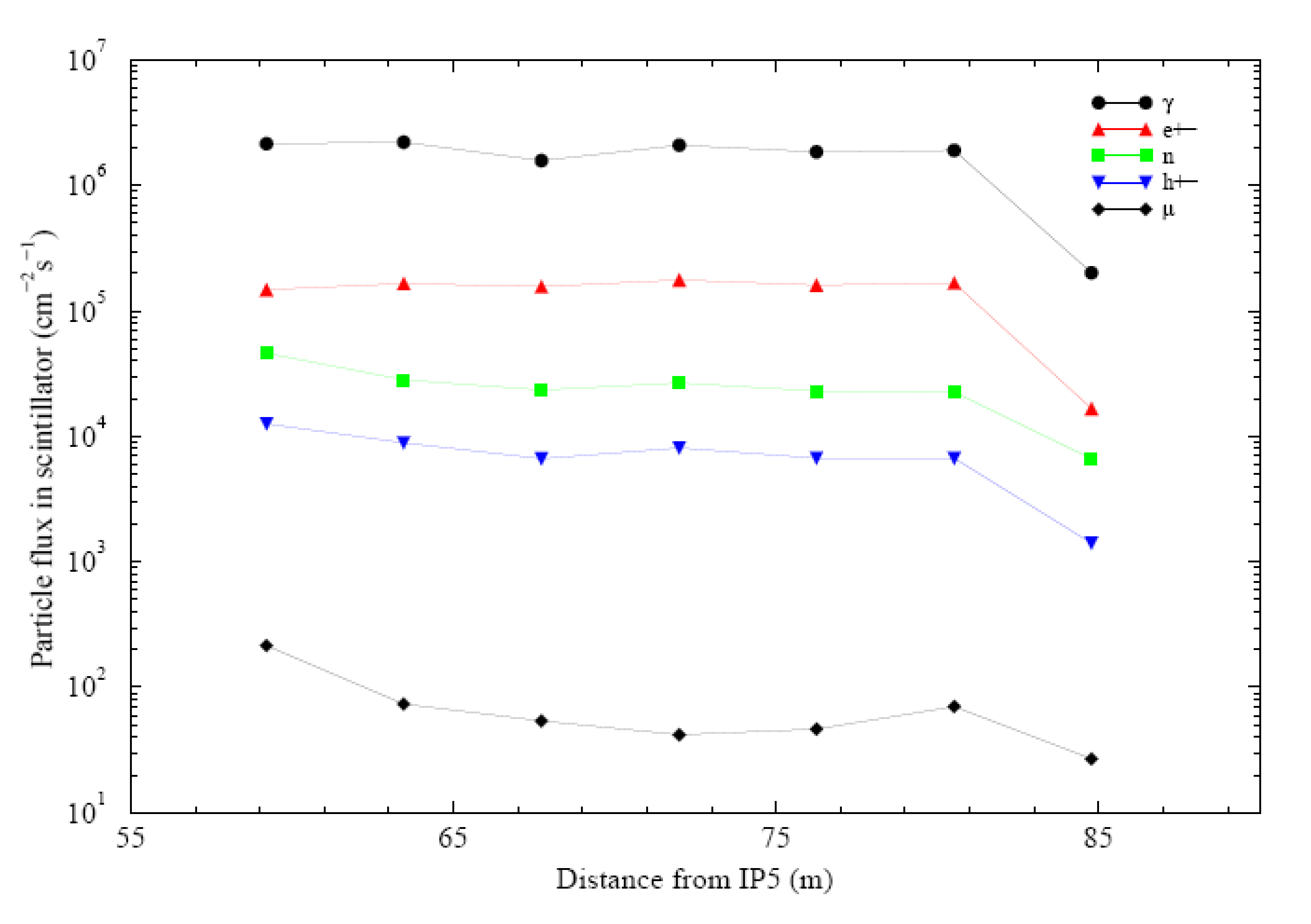
Electrons



Pions and Kaons



MARS simulations: **fluxes (10^33) at different z-locations**



Fairly independent of z

Status:

Has been presented in CMS forward group meetings (dates)

CMS notes being prepared for May:

A) Physics issues (MGA drafting it)

B) Technical issues (Richard Hall-Wilton (Austin Ball's gp.))

They will provide not only physics, but beam conditions etc.: MBR

Will propose to CMS Management Board, hope for June decision to go ahead.
Aim to be ready for installation in end-2010 6-week shutdown.

Conclusions:

Hard single diffraction (jets, W, Z, etc) can only be done with only 1 interaction in the bunch crossing.

This effective luminosity will probably be very limited and we need to be efficient. Requiring very forward rapidity gaps in Level 1 triggers will greatly increase efficiency and purity. We have very little hardware to do this. ZDC can be (should be) used but only sees neutrals. HF and T2 can be but are really too central: $\eta < 6.5$, which limits upper diffractive mass range.

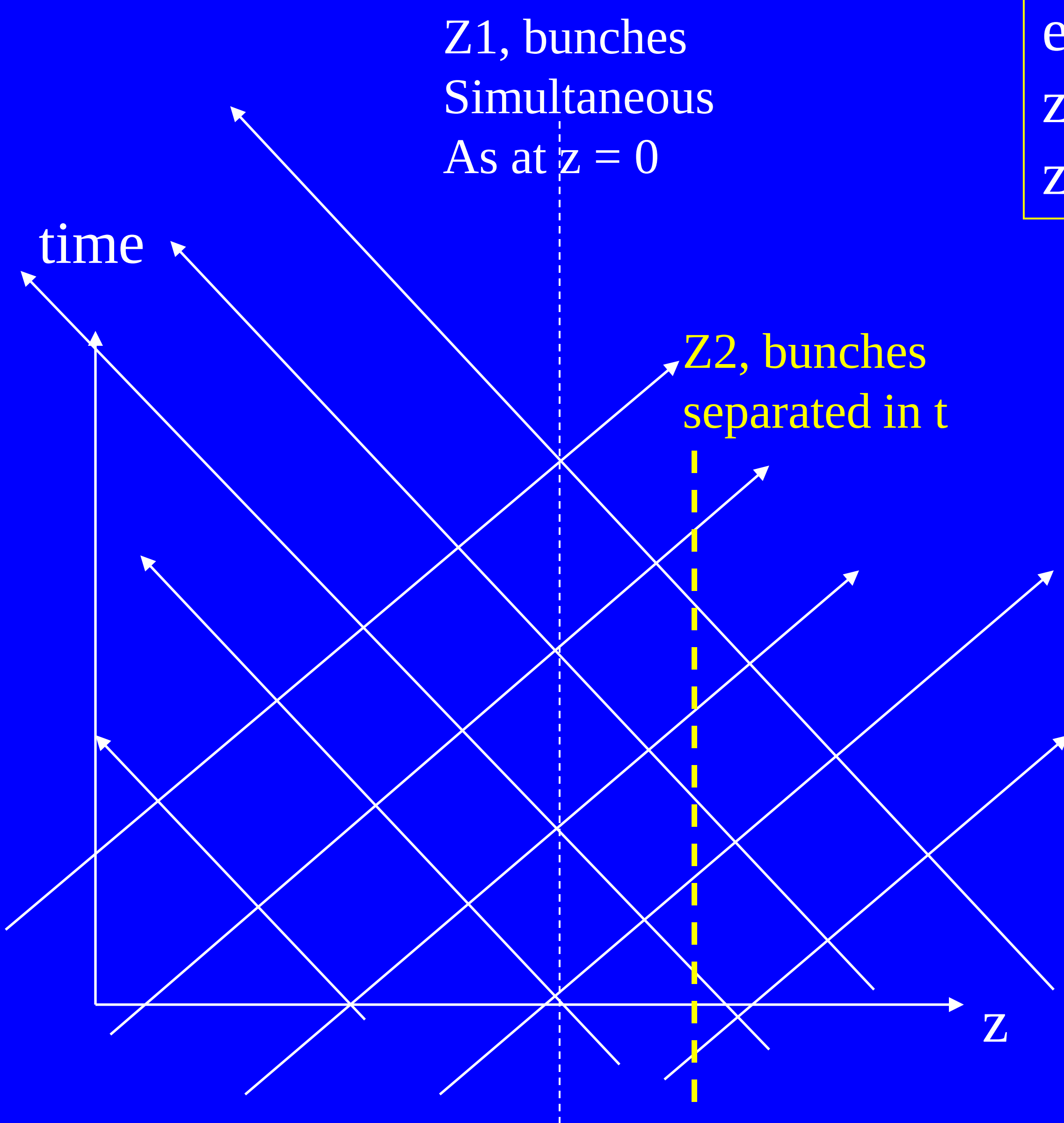
We have a simple cheap and fast solution:
Forward Shower Counters FSC : Scintillation counters

N.B. We put these in CDF (BSC) and they were essential for central exclusive production purity.

+ Study of forward particle fluxes for accelerator and HPS b/g

Thank you

Bunches spaced by 25ns = 7.5 m



dt = 3.333ns x z(mod7.5m)
e.g.
z = 59.426m dt=1.9ns
z = 85.126m dt=8.8ns

Counter	z(mm)
1U-I	59426
1D-O	59426
2U-I	68026
2D-O	68026
3U-I	76576
3D-O	76576
4U-I	85126
4D-O	85126

4 shown, could be 5 or 6