Early Forward Physics at the LHC; Low Mass Diffraction

Low-x Workshop

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Kolimbari, 9 July 2008

Early Forward Physics at the LHC; Low Mass Diffraction

Discuss:

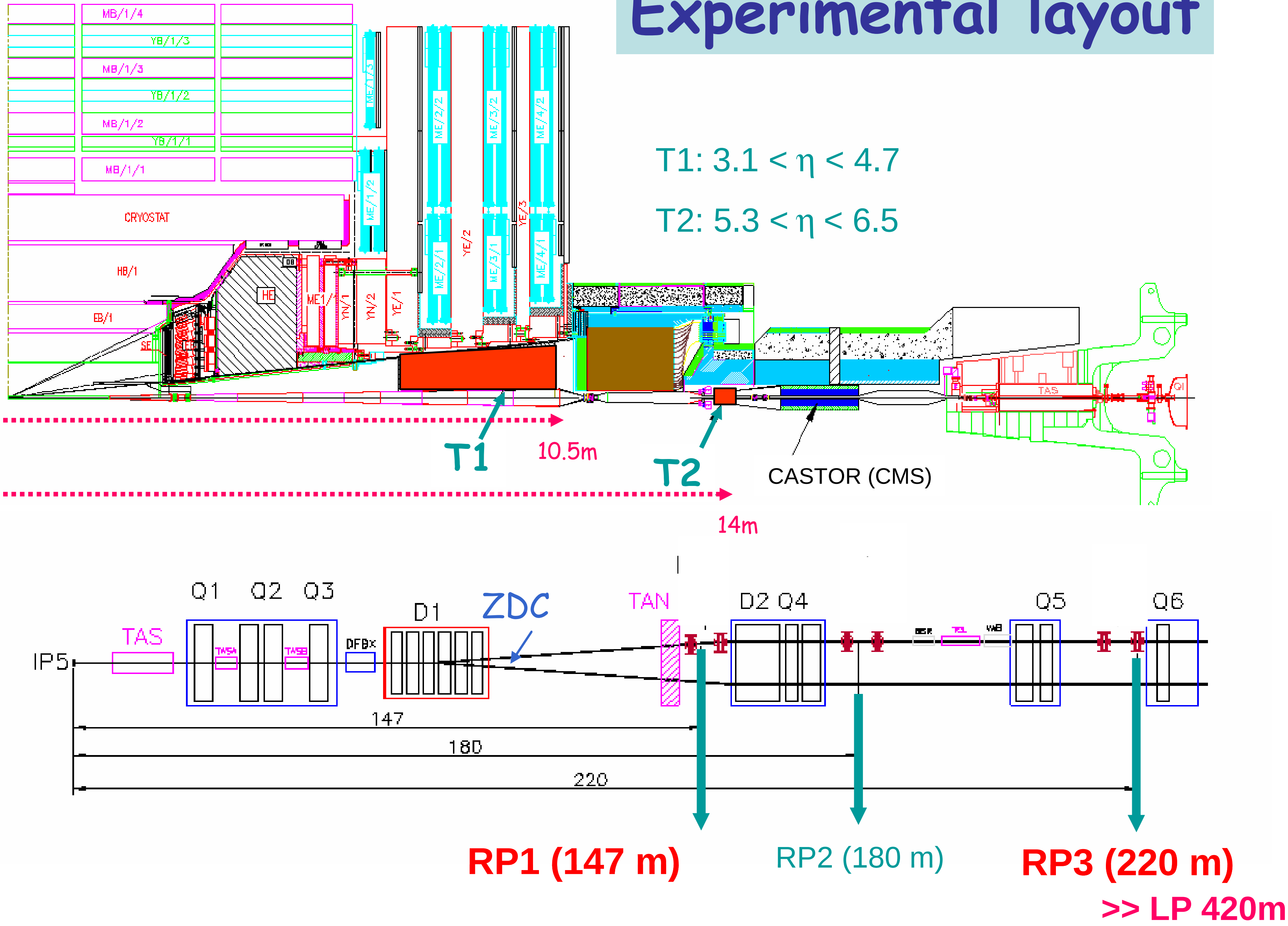
- Rap Gaps $\Rightarrow$ cross-sections for soft diffraction
- Efficiencies of TOTEM/CMS fwd detectors
- Proposal for Forward Shower Counters
- Fast Triggering of forward physics events

Assume:

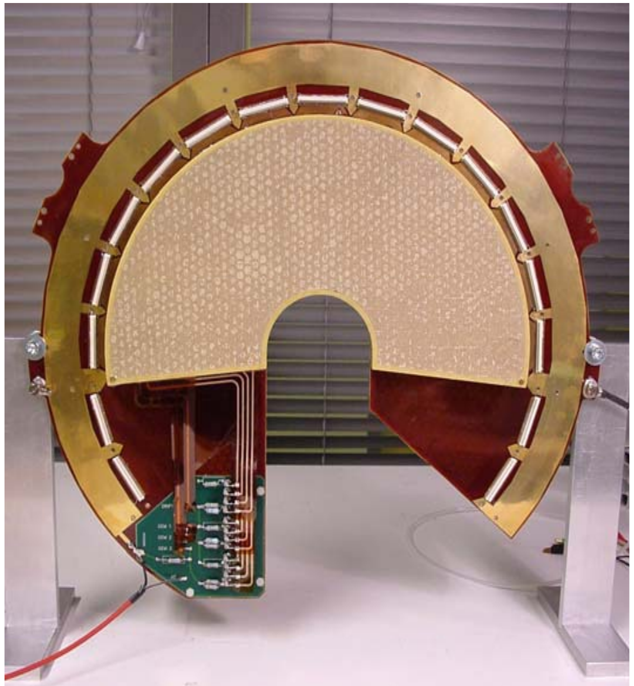
- Low luminosities – low no. of protons per bunch

$\Rightarrow$ no pile-up

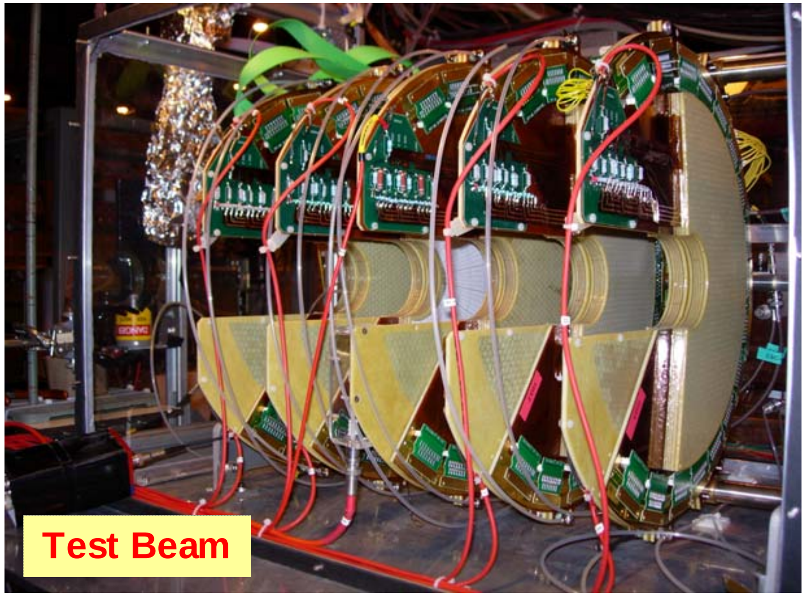
Experimental layout

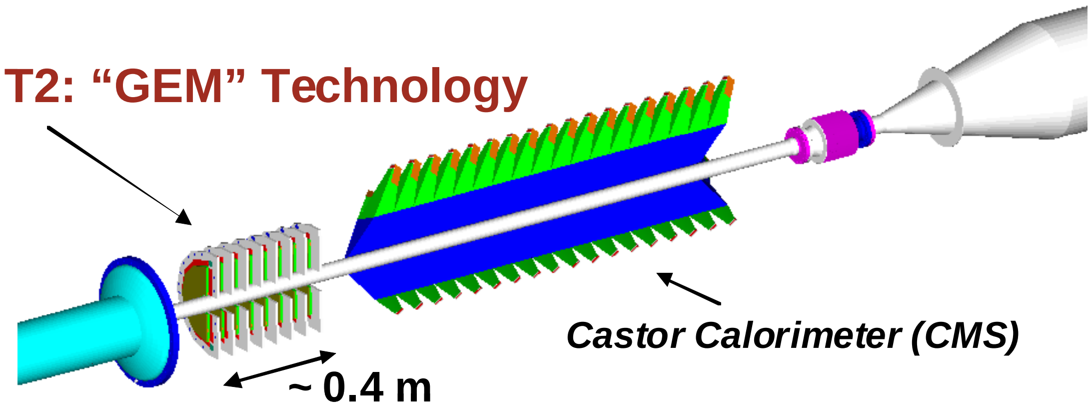


T2 Telescope



- 10 planes formed by 20 triple-**GEM** semi-circular modules
- Back-to-back assembly and Overlap between modules
- Double Read-out layer: Strips for radial position, Pads for η,ϕ.
- Trigger from Pads, 1560/chamber, Tot 60K channels
- Resolution σ_{strip}~70µm





FSC proposal:

Add:

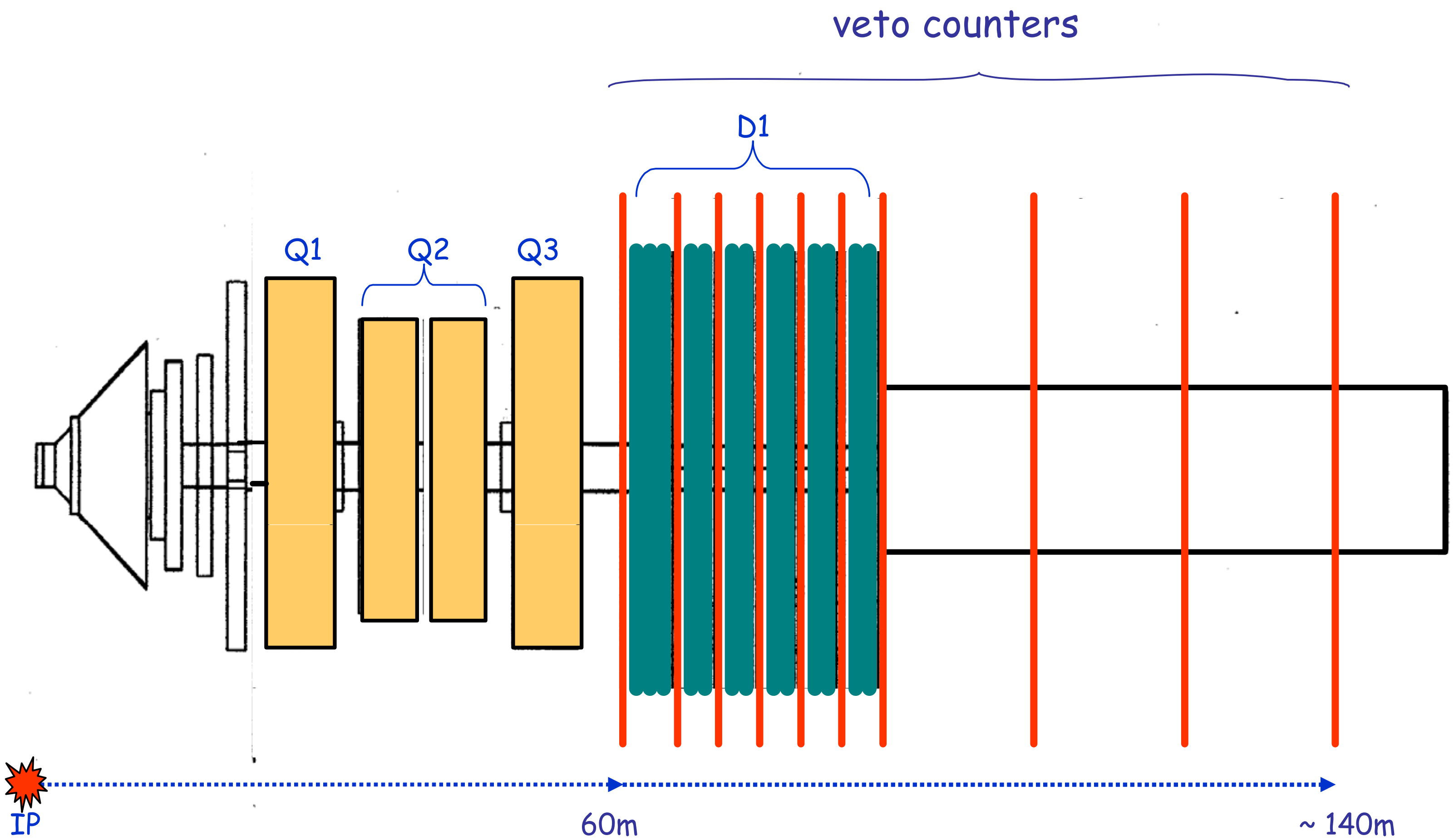
- scintillation counters and GEM's along the beam pipes, with $\pm 59 < z < \pm 85$m, and possibly further out to ± 128m.
- detect showers from very forward particles interacting in the beam pipe and surrounding material.

Motivation:

- reject non-diffractive pile-up events in diffractive collisions
- detect rapidity gaps in diffractive collisions – σ^{SD}, σ^{CD}
- real-time monitoring of both incoming and outgoing beam halo and beam conditions, testing simulation of forward particle flow.
- provide an additional luminosity monitor

A follow-up to a proposal with M. Albrow, J. Lamsa, et al.

Rapidity Gap Veto - Detector Lay-Out



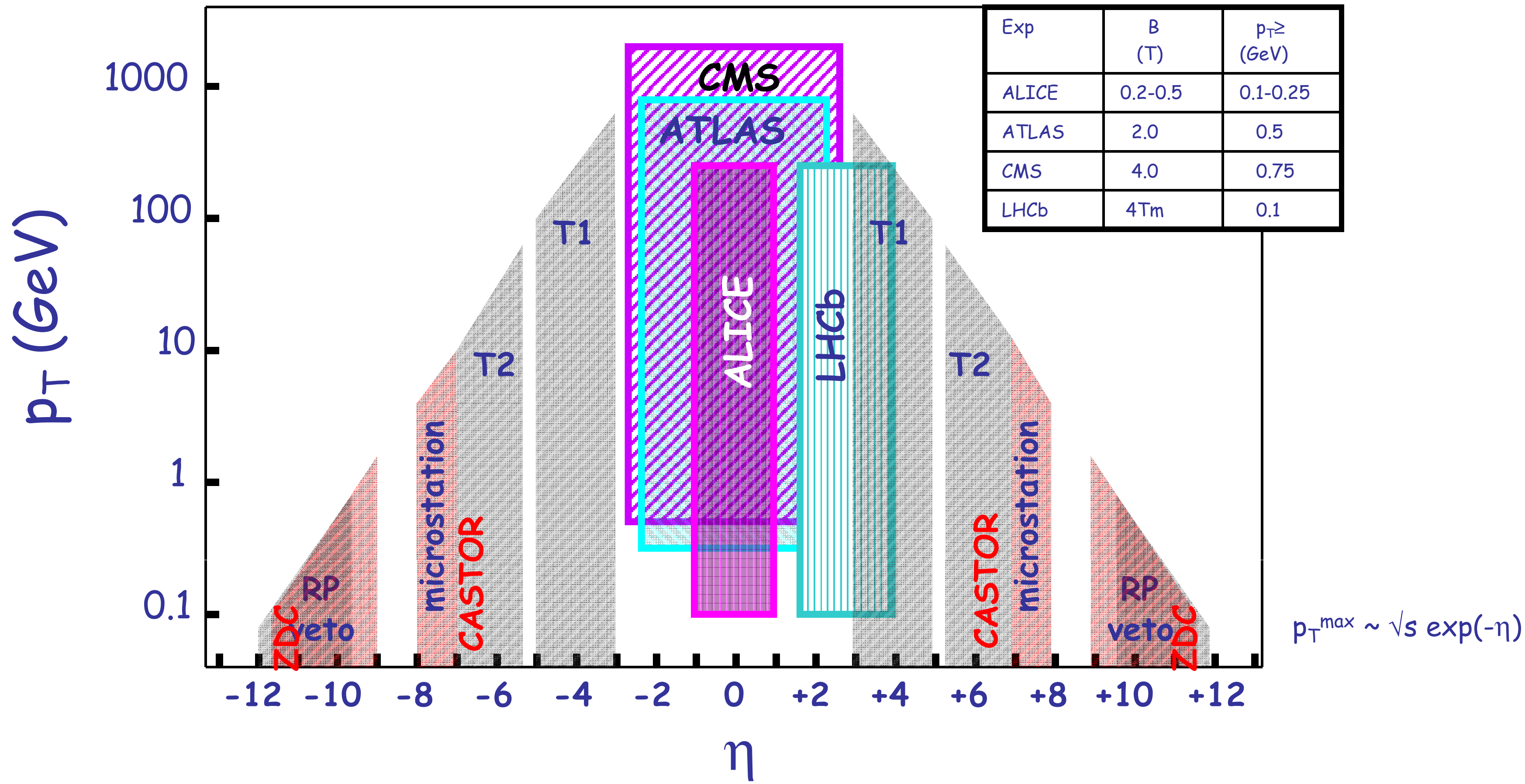
J. Lämsä & R.Orava -02

FSC's: in front of and behind the separation dipole D1, between each of the six (MBXW) elements of D1, three counters at 15, 35 and 55m beyond D1.
⇒ ten 50x50 cm detectors on both sides

magnification x vs. y: 70

LHC Experiments: p_T-η coverage

CMS fwd calorimetry up to $|\eta| \approx 5$ + Castor + ZDC



Exp	B (T)	$p_T \geq$ (GeV)
ALICE	0.2-0.5	0.1-0.25
ATLAS	2.0	0.5
CMS	4.0	0.75
LHCb	4Tm	0.1

The base line LHC experiments will cover the central rapidity region.
TOTEM⊕CMS⁺ will complement the coverage in the forward region.

+ fp420m

Single diffraction: Significance

- Single diffractive dissociation to a large mass system, M*, is not fully understood:
  Both the *triple-Pomeron* based description and prediction of *"multi-Reggeon"* events - events with a few large rapidity gaps - lead to σ^{SD} *that grows faster than* σ_{tot}.

- Single diffractive dissociation into a small mass system M* (N*), is not well understood or measured

⇒ A measurement of σ^{SD} and the cross section of *multiple large rapidity gaps* at the LHC will test the proposed models (see CDF/Dino, Uri Maor, KMR…).

- For understanding the asymptotics of the strong interaction amplitude, it is crucial to measure the -t-dependence of σ^{SD}.

- Vanishing of triple-Pomeron coupling, $G_{3\mathbb{P}}$, at -t $\rightarrow$ 0, might cure the problem of excessive σ^{SD}

⇒ A measurement of the cross section $d\sigma^{SD}/dt$ *at* $t \rightarrow 0$, would test the 'weak coupling' scenario

Single diffraction: Significance...

- Measurement of the ***location of the diffractive minimum*** (predicted as a result of the destructive interference between the pole and cut contributions)

⇒ further testing of the 'weak coupling' scheme.

- 'Screening corrections' due to multi-loop Pomeron graphs

⇒ gap survival factor $S^2 \to 0$ when $s \to \infty$, or gap size $\Delta\eta \to \infty$?

⇒ investigate the ***dependence of S^2 on c.m.s. energy, gap size and the number of gaps***.

- SD dominated by the periphery of the interaction disk?

⇒ particles produced within the diffractive system have *smaller average transverse momenta* (compared to the secondaries at energies $\sqrt{s} \approx M^*$)?

Single diffraction: Measurements

- Based on tagging rapidity gaps in inelastic events.

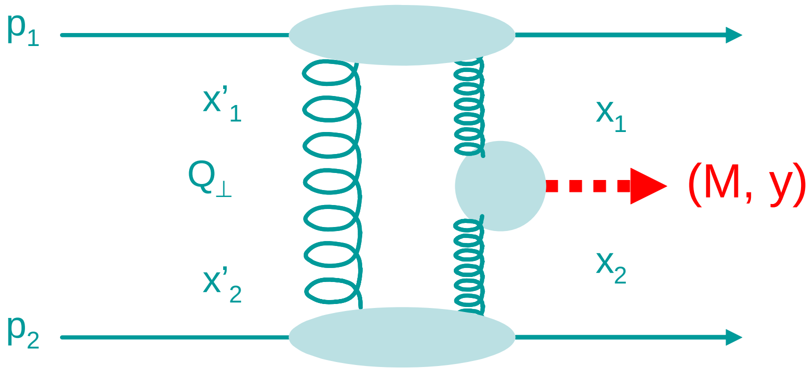
- The pilot runs with β^* = 18 m - 2 m, planned for the initial stages of the LHC operation, suit well for measurements of *soft* diffractive scattering.

- The diffractive mass, M*, acceptance better than 50% down to M* ~ 3 GeV (1.1 GeV with the FSC's).

- The diffractive systems are measured over the full azimuthal angle and the diffractive protons within the acceptance of the elastic ones.

- At low diffractive masses, the acceptance could be – importantly - extended down to $\approx$1.1 GeV by installing additional veto counters at ± 60 to ± 140m.

Central diffraction: Significance



- A good environment for the production of exotic meson states (glueballs, hybrids,...) via $gg \rightarrow M$ in

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

- A strong coupling for glueballs and hybrids as a result of the assumed two-gluon exchange?

- High statistics studies possible with the '*gluon collider*' mode of the LHC.

- Here azimuthal correlations with the quasi-elastic pair of leading protons can be particularly significant.

Low-x measurements

The aim of the TOTEM⊕CMS set-up is to measure jets at rapidities $\eta \approx 6$ up to transverse energies of $E_T \approx 10$ GeV to reach $x \leq 10^{-6}$ $\Rightarrow$ transform LHC into a *deeply inelastic scattering (DIS) machine.*

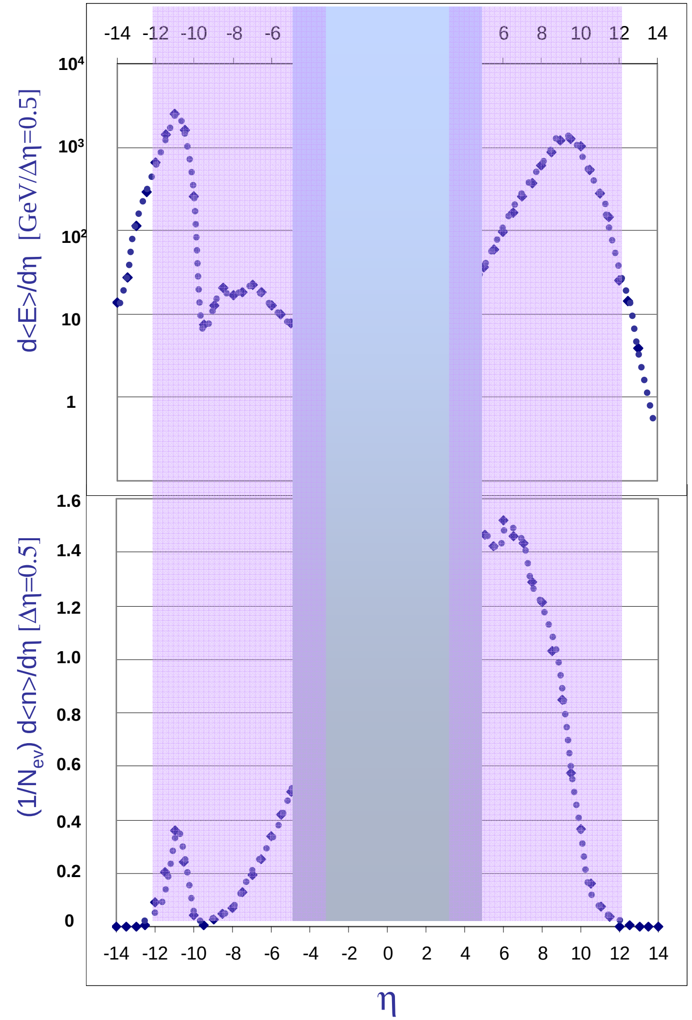
- Correlations between the forward ($\xi << 10^{-2}$) and central jets ($\xi > 10^{-2}$), heavy quarks and heavy bosons $\Rightarrow$ proton - parton configurations in *three* dimensions.

- Forward jets in *triggering* for new phenomena in high-E_T central processes; parton dissociation into 3 jets? (Frankfurt&Strikman, Braun,Ivanov&Schäfer)

- The CASTOR calorimeter covers the pseudorapidity region of $5.4 < \eta < 6.7$, similar to the coverage of the T2 tracking station $\Rightarrow$ measure the forward jets.

- With a modest (veto)detector upgrade, the rapidity acceptance could be extended up to $|\eta| \approx 11 \Rightarrow$ reach $x \sim 10^{-8}$.

Single diffraction: Energy & Multiplicity Flows



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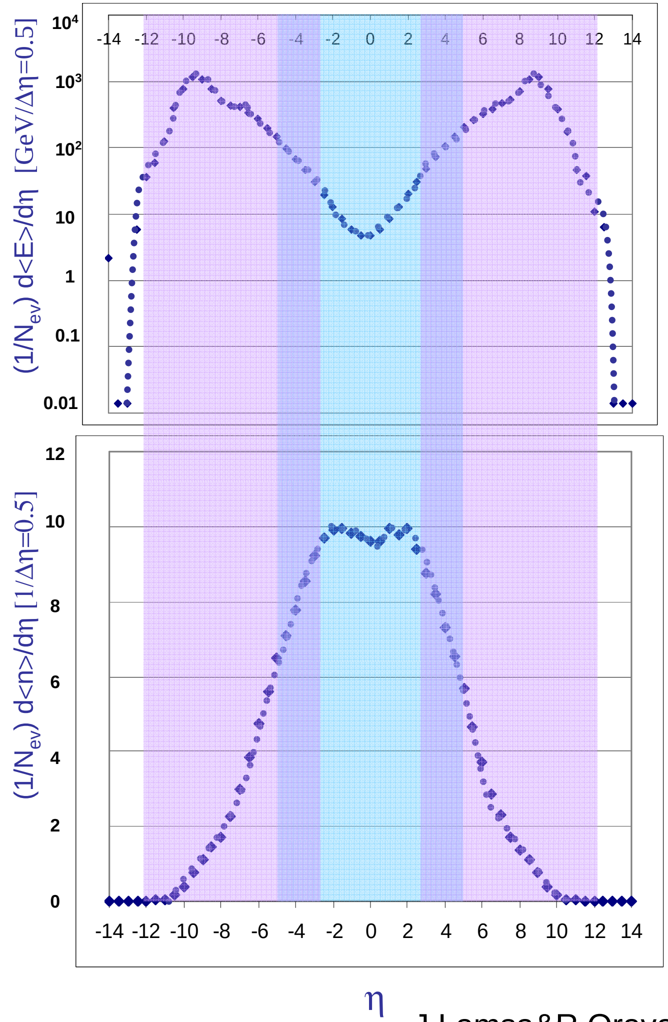
Single diffractive *energy flows* populate the forward detectors

...while much of the soft particle *multiplicities* are seen in the central system.

The "minimum-bias" events: Energy & Multiplicity Flows



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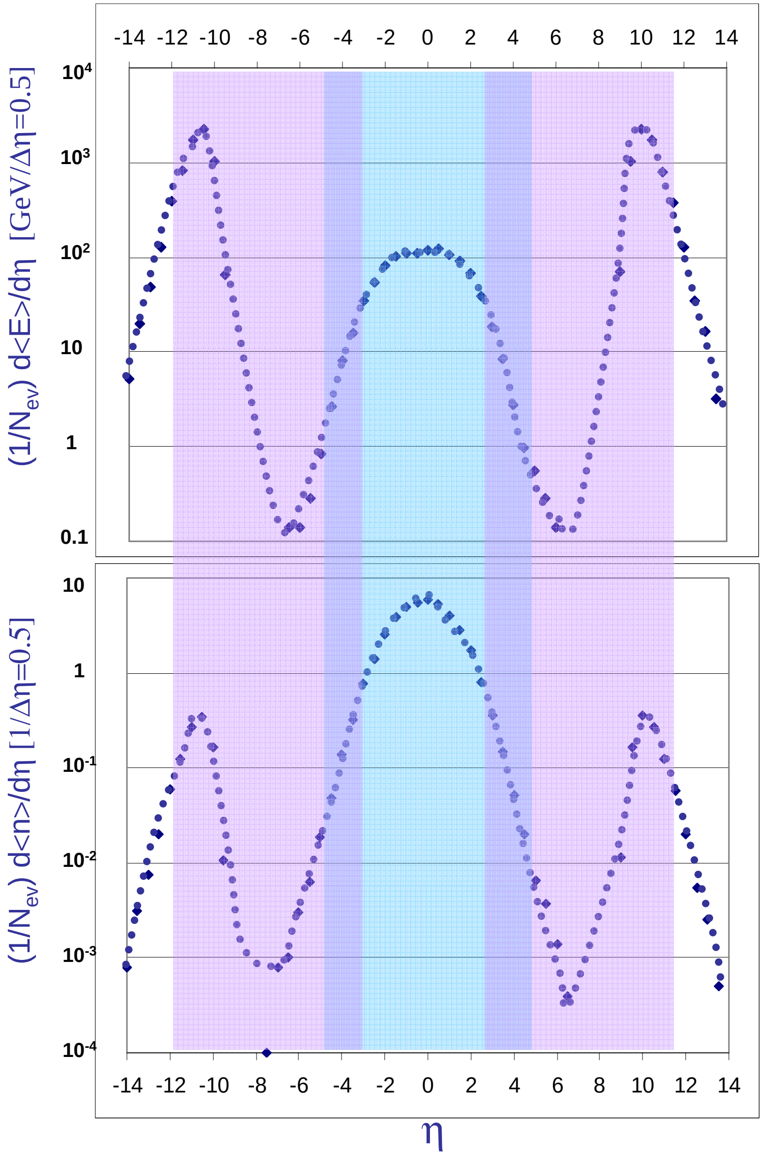
The minimum-bias *energy flows* populate the forward detectors

... while the central detectors are flooded by a large *multiplicity* of soft particles...

Underlying events probed by the forward tags.

Central diffraction: Energy & Multiplicity Flows



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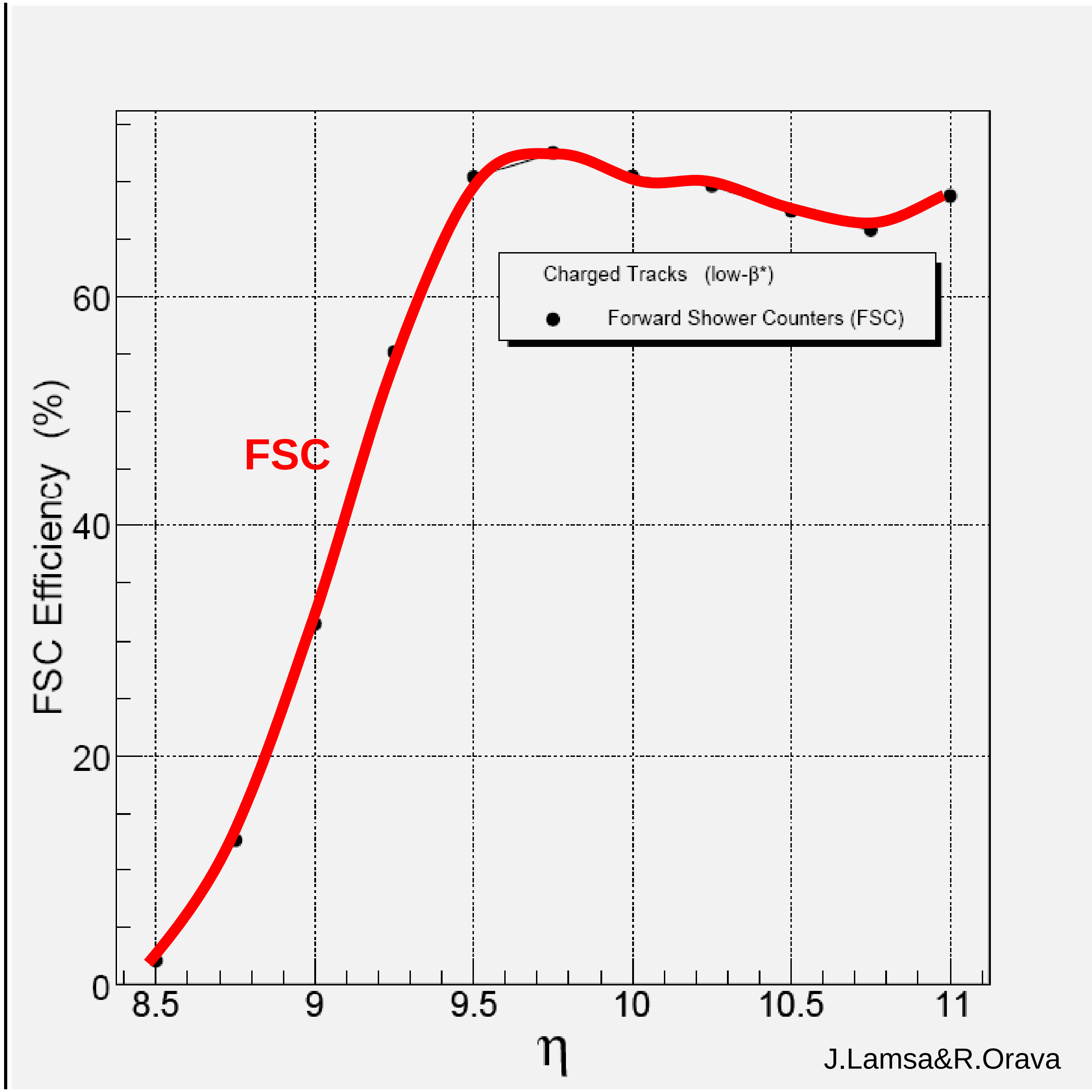
Central system within ±4 units of η

Rap gaps around η = ±6

FSC Detection Efficiencies – Charged Particles at lowβ*



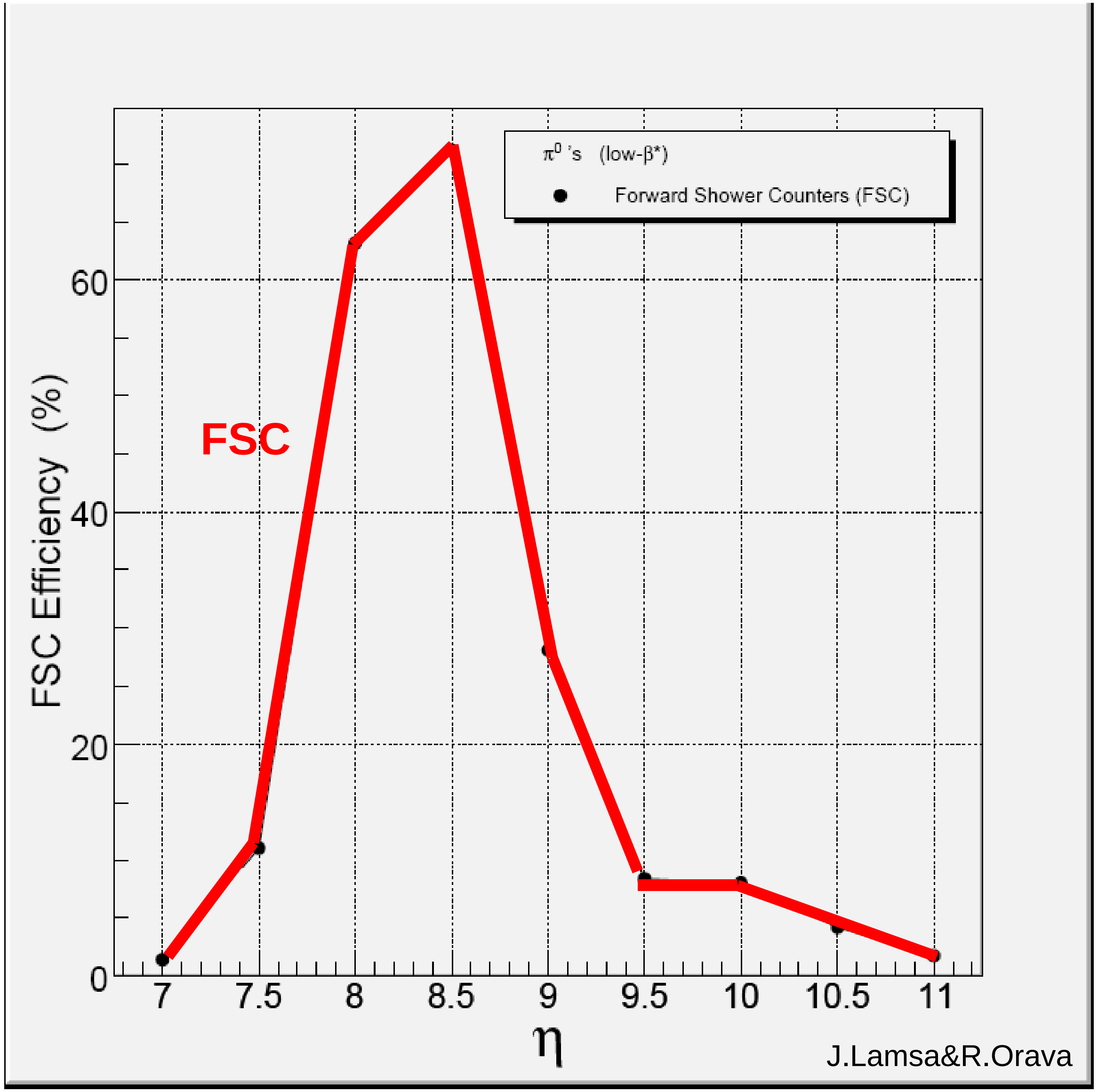
- positive, negative, and neutral pions as a function of η.

- a hit in any of the FSC counters is required

- p_T-distribution: $\exp(-p_T^2/0.12)dp_T^2$, (corresponds to that obtained from Pythia)

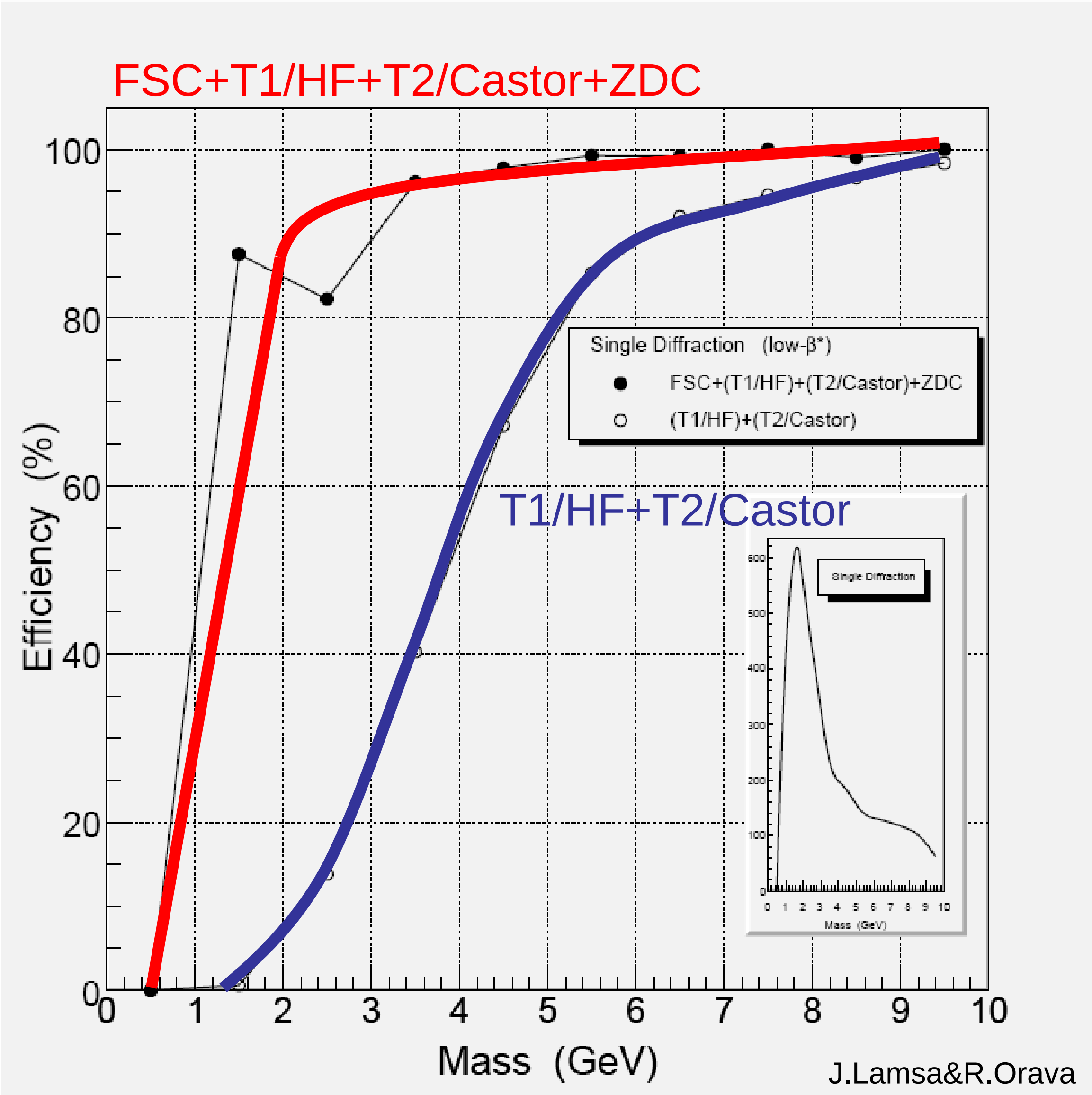
⇒ efficiency of the FSC's for detecting charged particles is above 70% for η > 9.5.

FSC Detection Efficiencies – π^o's at lowβ^*



For π^o's the efficiency is about 60% between $8 < \eta < 9$

FSC Detection Efficiencies for SD events at lowβ*

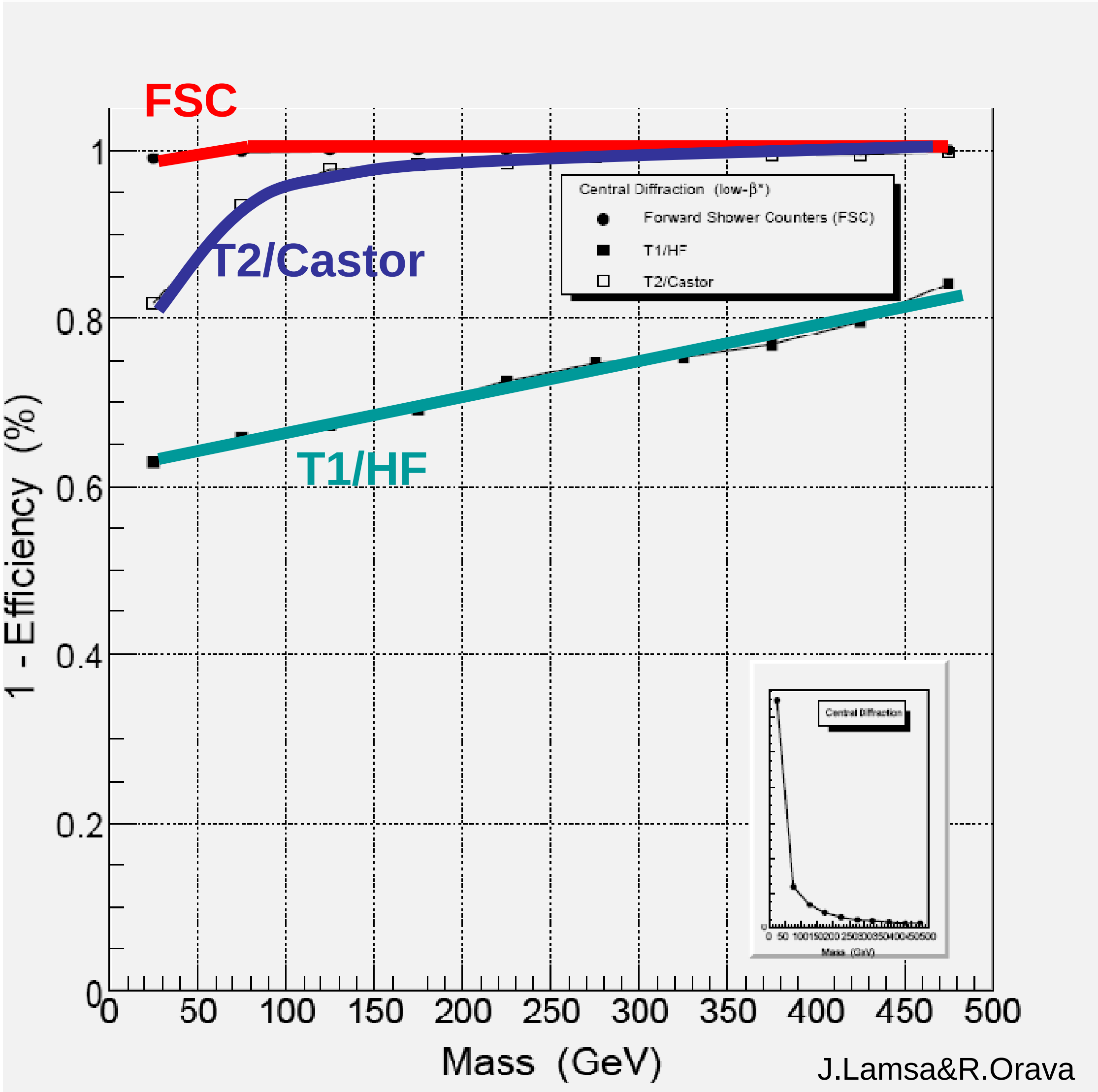


-efficiency is >90% for the lower mass region, ~100% for the mass region above 10 GeV (approx 25% of the single-diffractive cross-section is below 10 GeV!)

- Note: forward systems of this type could be produced from CID reactions would have a similar detection efficiency as for single-diffraction.

- simulations have also been made for exclusive diffractive baryon-resonance production: p p → p N*(1400), where N* → p π^o, n π^+, $\Delta^{++}\pi^-$.

FSC 1-Efficiencies For CED Events at lowβ*

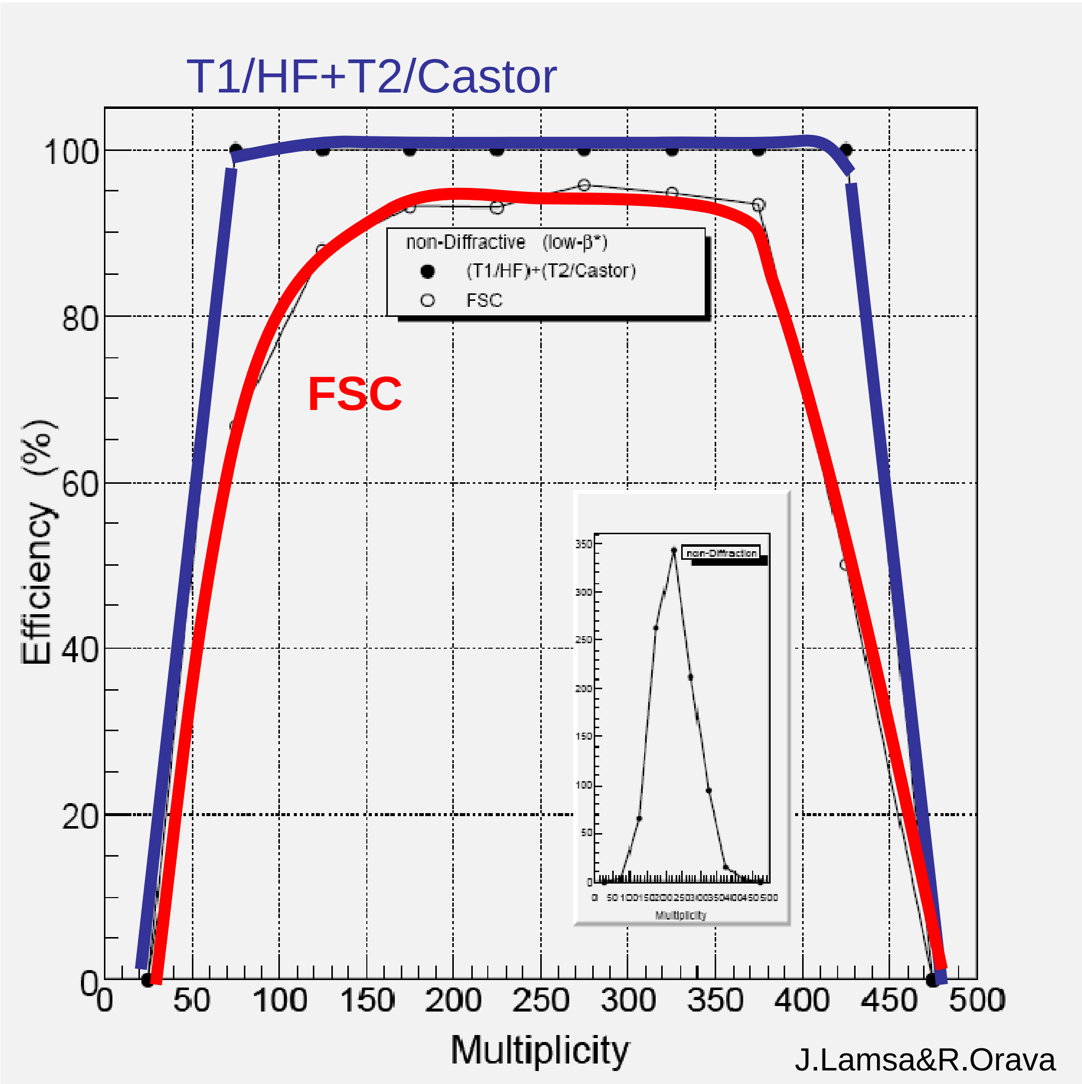


-detection efficiencies, considered as a veto for central-diffractive (CD) events (simulated by PYTHIA)

- 1-efficiencies are displayed as a function of the diffractive mass separately for the Forward Shower Counters (FSC), for T1/HF, and for T2/Castor.

⇒ for FSC's obtain ~100% veto efficiency

FSC Detection Efficiencies For ND Events at lowβ*

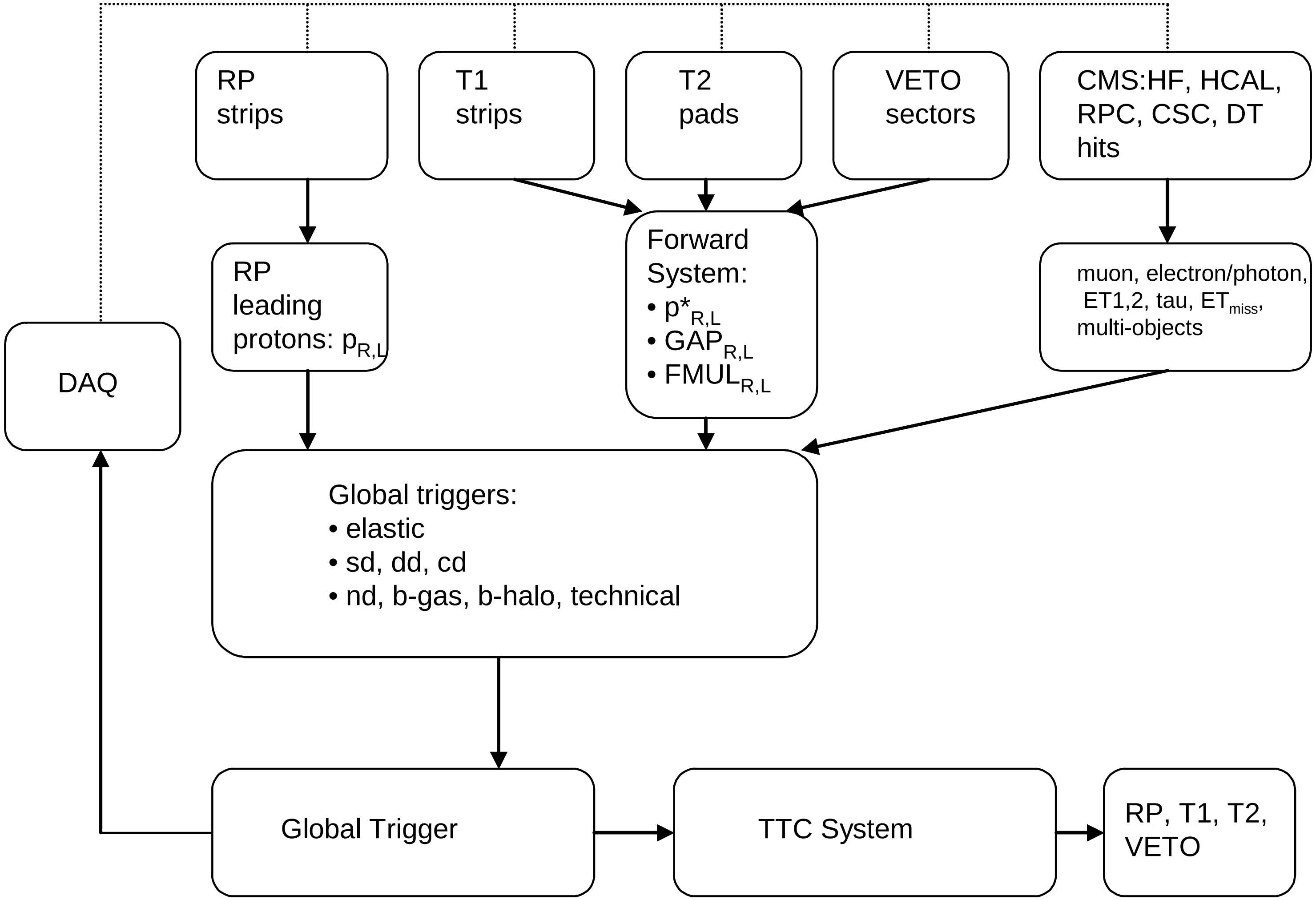


-detection efficiencies for non-diffractive events (ND) as a function of charged multiplicity.

- at least one hit is required in any of the Forward Shower Counters (FSC), or in the eta-regions spanned by T1/HF or T2/Castor.

-T1/HF and T2/Castor are sufficient to provide a ~100% efficiency

- efficiency of the FSC's is 90-95%.



RP strips
T1 strips
T2 pads
VETO sectors
CMS:HF, HCAL, RPC, CSC, DT hits
RP leading protons: $p_{R,L}$
Forward System:
• $p^*_{R,L}$
• $GAP_{R,L}$
• $FMUL_{R,L}$
muon, electron/photon, ET1,2, tau, ET_{miss}, multi-objects
DAQ
Global triggers:
• elastic
• sd, dd, cd
• nd, b-gas, b-halo, technical
Global Trigger
TTC System
RP, T1, T2, VETO

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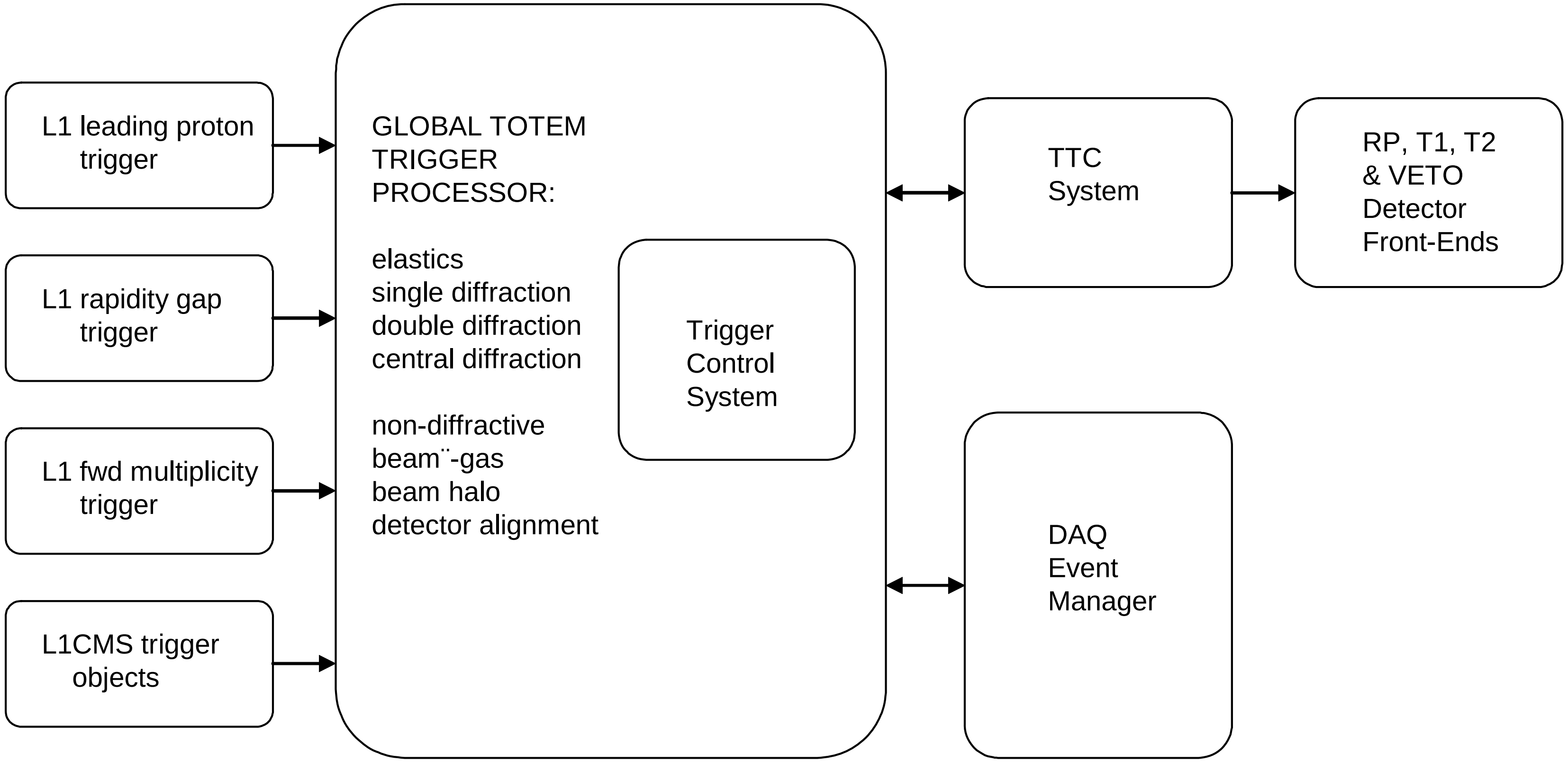
L1 leading proton trigger
L1 rapidity gap trigger
L1 fwd multiplicity trigger
L1CMS trigger objects
GLOBAL TOTEM TRIGGER PROCESSOR:
elastics
single diffraction
double diffraction
central diffraction
non-diffractive
beam¨-gas
beam halo
detector alignment
Trigger Control System
TTC System
RP, T1, T2 & VETO Detector Front-Ends
DAQ Event Manager

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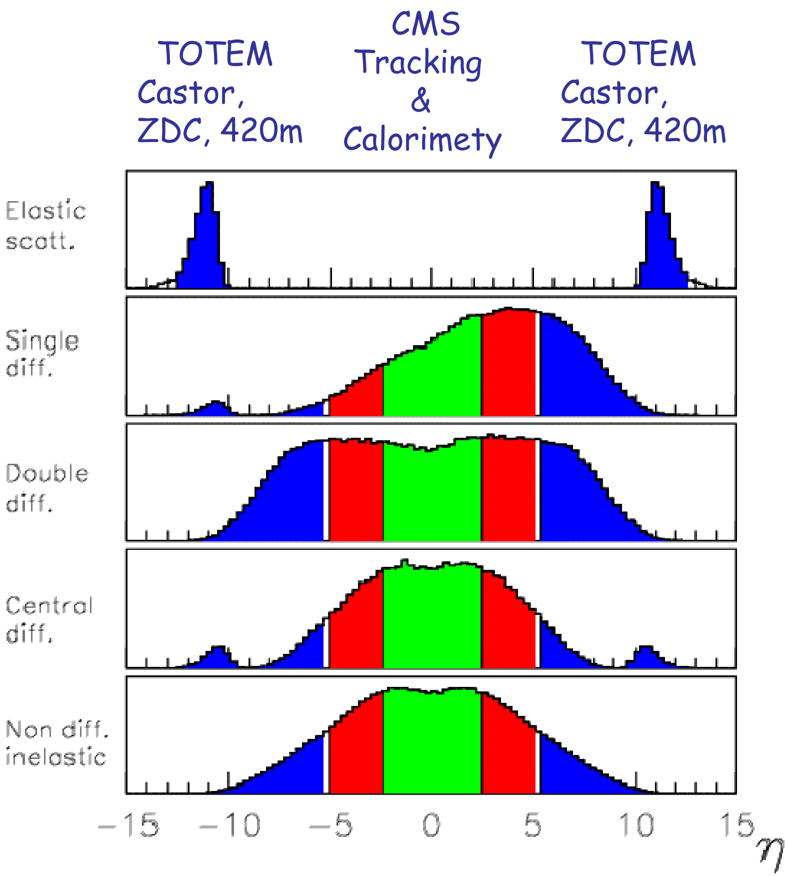
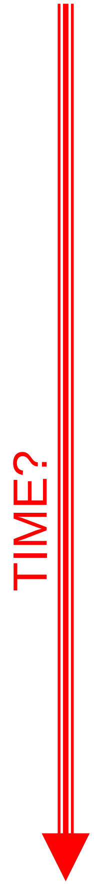
Appendix 2. Algoritm for classifying sd+dd+cd events vs. nd events - includes totem default detectors and the veto scintillators.

```
//------------------------------------------------------------
// Code generated by Risto Orava on 14.7.2007 12:37:10
// Training Samples: 200
// Testing Samples: 199
// Fitness Function: Sensitivity/Specificity
// Training Fitness: 947.333333333333
// Training Accuracy: 97.00%
// Testing Fitness: 883.221476510067
// Testing Accuracy: 93.97%
//------------------------------------------------------------

#include <math.h>

int gepModel(double d[]);
double gepMin4(double a, double b, double c, double d);
double gepMax4(double a, double b, double c, double d);
double gepLogi4(double a, double b, double c, double d);

int gepModel(double d[])
{
	const double ROUNDING_THRESHOLD = 0.5;

	const double G1C0 = 7.372467;
	const double G1C1 = -1.633362;
	const double G2C0 = 1.083526;
	const double G2C1 = -1.758148;
	const double G3C0 = 1.699433;
	const double G3C1 = -0.824372;

	double dblTemp = 0.0;

	dblTemp = ((gepLogi4(d[1],d[4],G1C0,d[0])-(d[5]+G1C1+G1C1+d[1])-
d[2])+gepMax4(d[5],d[9],G1C0,d[1]));
	dblTemp += ((d[5]+(((gepMin4(d[3],G2C1,G2C1,d[9]) < 0) && ((((d[0] >= 1) || (d[2] >= 1)) ? 1 : 0) <
0)) ? 1 : 0))/2);
	dblTemp += (((((d[8]*d[1]*d[0]*d[8]) <= 1) || (d[6] <= 1)) ? 1 : 0)-G3C0-d[4]);

	return (dblTemp >= ROUNDING_THRESHOLD ? 1 : 0);
}

double gepMin4(double a, double b, double c, double d)
{
	double varTemp = a;
	if (varTemp > b)
		varTemp = b;
	if (varTemp > c)
		varTemp = c;
	if (varTemp > d)
		varTemp = d;
	return varTemp;
}

double gepMax4(double a, double b, double c, double d)
{
	double varTemp = a;
	if (varTemp < b)
		varTemp = b;
	if (varTemp < c)
		varTemp = c;
	if (varTemp < d)
		varTemp = d;
	return varTemp;
}

double gepLogi4(double a, double b, double c, double d)
{
	return 1/(1+exp(-(a+b+c+d)));
}
```

Physics priorities vs. the initial phases of the LHC – Single diffraction & low-x



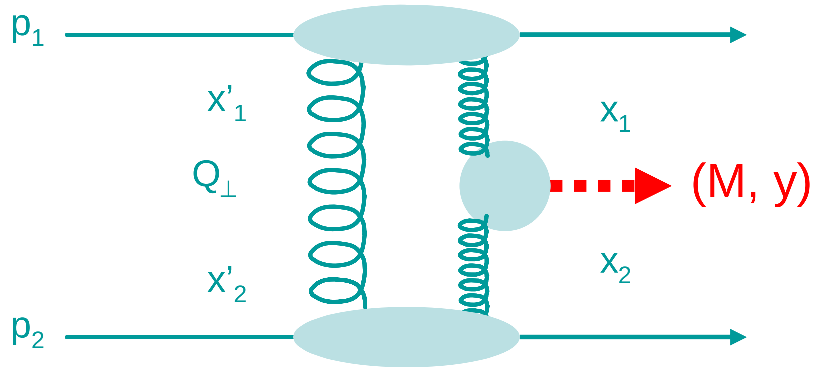


(1) β* = 2m -18m??
$d\sigma^{SD}/d\xi dt$ (rap gaps)

(2) β* = 0.55m
$d\sigma^{SD}/d\xi dt$ (rap gaps)
low-x phenomena

(3) β* = 90, 1540m
$d\sigma^{SD}/d\xi dt$ (RP protons/50-85%)
semi-hard diffraction
low-x phenomena

Physics priorities vs. the initial phases of the LHC – Central diffraction



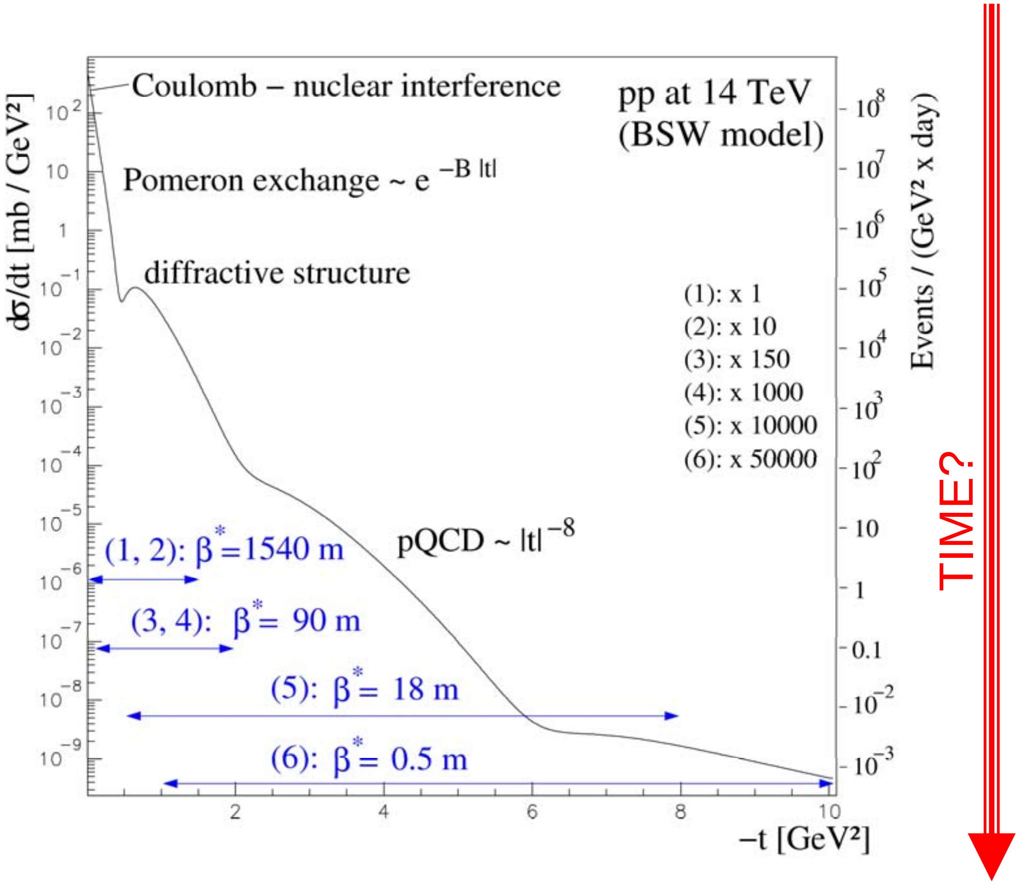
TIME?

(1) β^* = 2m, 6m, 18m??
$d\sigma^{CD}/dM_X dt$ (veto ND)

(2) β^* = 0.55m
$d\sigma^{CD}/dM_X dt$ (veto ND)

(3) β^* = 90m, 1540m
$d\sigma^{CD}/dM_X dt$ (RP protons/50-85%)

Physics priorities vs. the initial phases of the LHC – Elastic scattering & σ_{tot}



(1) β^* = 2m-18m??

$d\sigma_{el}/dt$ (large –t)

(2) β^* = 0.55m

$d\sigma_{el}/dt$ (large –t)

(3) β^* = 90m

$d\sigma_{el}/dt$ (moderate –t)

σ_{tot} & L(quick & dirty?)

(4) β^* = 1540m

$d\sigma_{el}/dt$ (small –t)

σ_{tot} & L (TOTEM TDR)