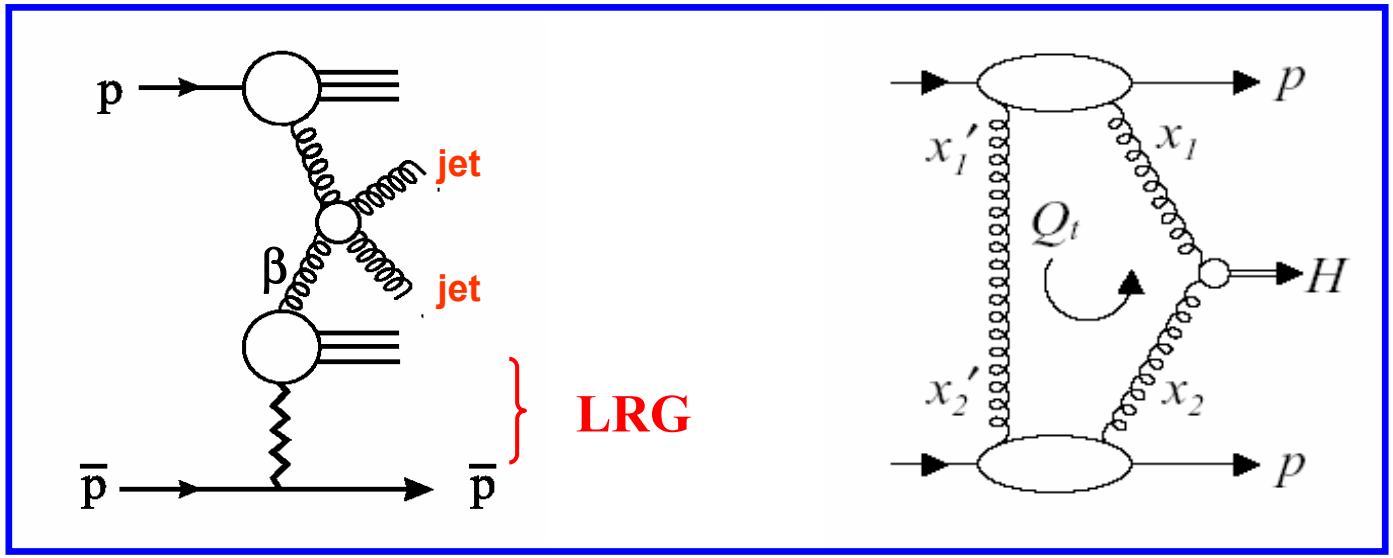
# CMS/TOTEM Diffraction and Forward Physics LOI




Albert De Roeck (CERN)

# Diffraction and Forward Physics: CMS+TOTEM

TOTEM:

- Approved July 2004 (TDR of TOTEM on http://totem.web.cern.ch/Totem/)
- TOTEM stand alone
  - Elastic scattering, Total pp cross section and soft diffraction.
- CMS+TOTEM study started in 2002 (ADR + K. Eggert)
  - Full diffractive program with central activity. TOTEM will be included as a subdetector in CMS (trigger/data stream)

CMS:

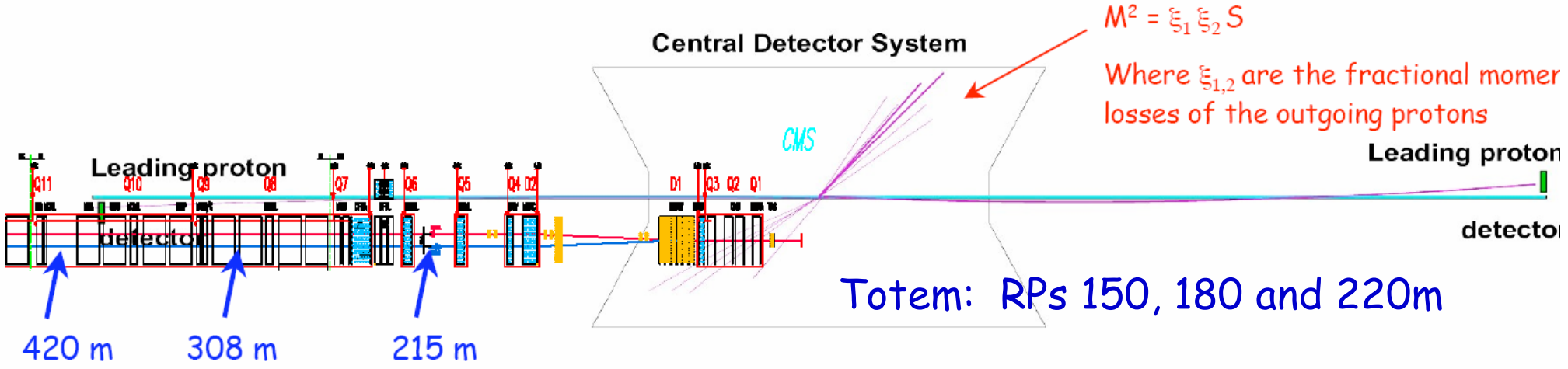
- EOI submitted in January 2004: /afs/cern.ch/user/d/deroeck/public/eoi_cms_diff.pdf
  - Diffraction with TOTEM Roman Pots and/or rapidity gaps
- Technical Proposal in preparation for new forward detectors (CASTOR, ZDC)
  - Additional options being studied (more forward detectors)
  - Diffractive and low-x physics part of CMS physics program (low + high $\beta$)

$\Rightarrow$ September 2004: CMS+TOTEM

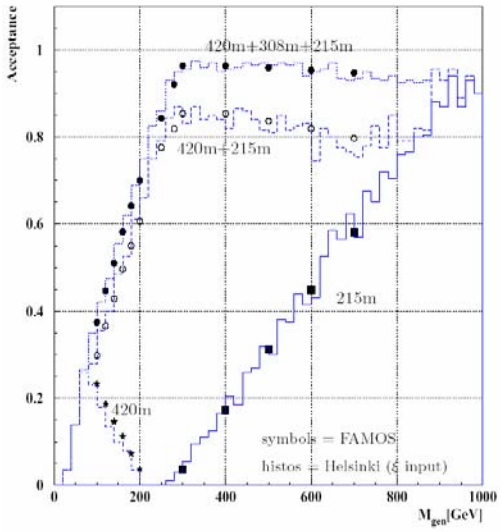
- LOI requested on Diffraction and forward physics for CMS+TOTEM $\rightarrow$ LHCC
- Results also to be included in the CMS Physics TDR (by end of 2005)

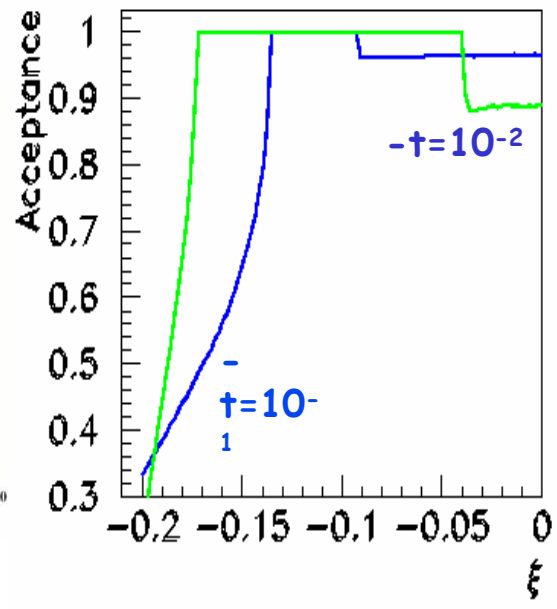
**Aim for spring/summer 2005**

# Roman pot acceptances




Totem: RPs 150, 180 and 220m

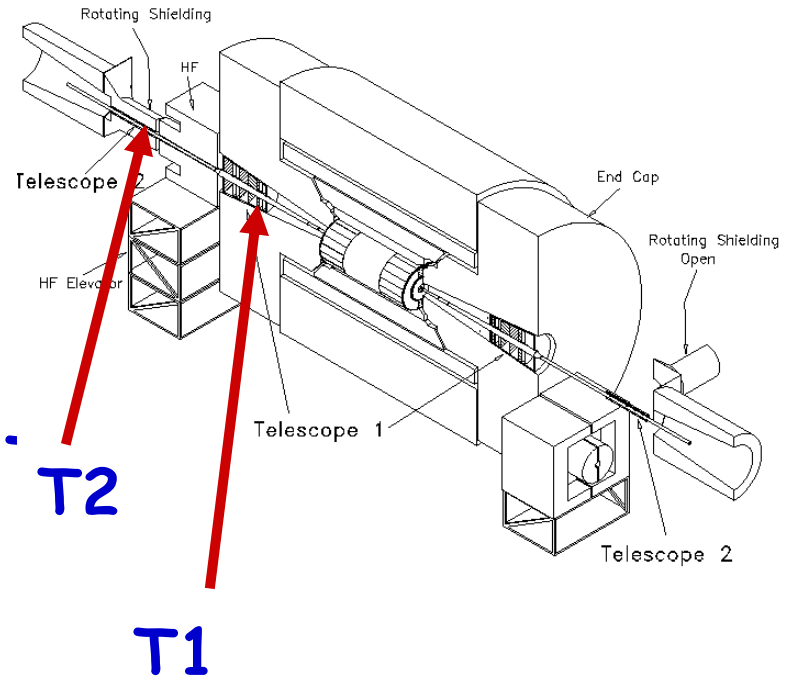



High β* (1540m): Lumi $10^{28}$-$10^{31}$cm$^{-2}$s$^{-1}$
- >90% of all diffractive protons are seen in the Totem Roman Pots.
- Proton momentum measured with a resolution ~$10^{-3}$

Low β*: (0.5m): Lumi $10^{33}$-$10^{34}$cm$^{-2}$s$^{-1}$
- 220m: $0.02 < \xi < 0.2$
- 300/400m: $0.002 < \xi < 0.2$
- (RPs in the cold region/ under discussion in CMS/ATLAS
- First acceptance studies by Helsinki)

# TOTEM/CMS Forward Detectors

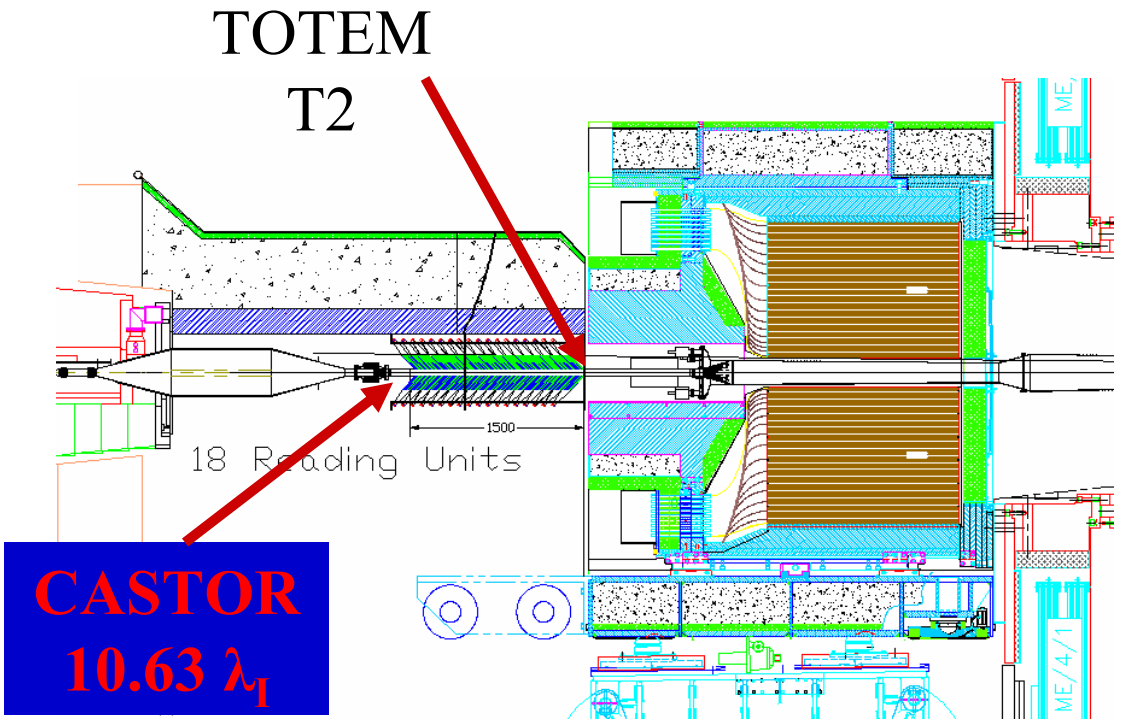



**T1/T2 inelastic event taggers**

- T1 CSC/RPC tracker ('99 LOI)
- T2 GEM or Silicon tracker (TOTEM/New)
- CASTOR Calorimeter (CMS/New)
- ZDC Calorimeter (CMS/New)

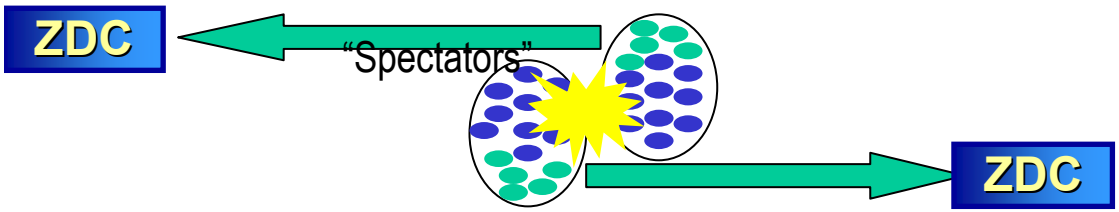
T1 $3.1 < \eta < 4.7$
T2 $5.3 < \eta < 6.7$
Castor $5.25 < \eta < 6.5$

Extend the reach in $\eta$ from $|\eta| < 5$ to $|\eta| < 6.7$

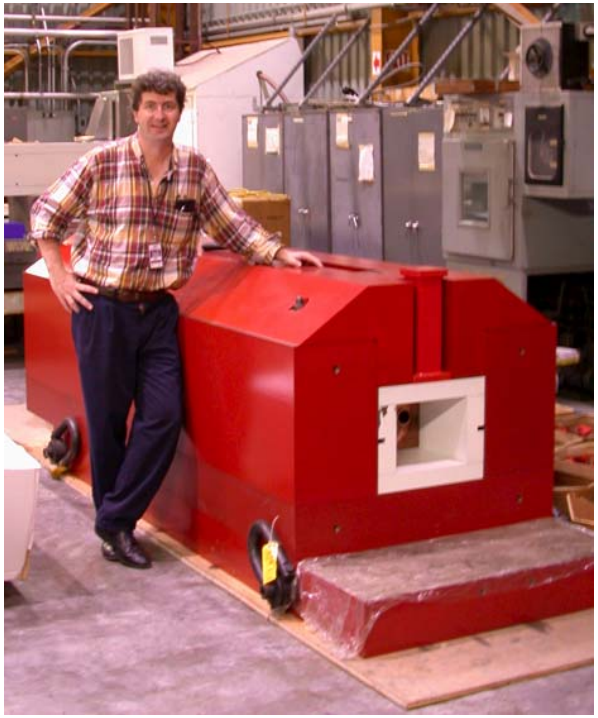



Opportunities to contribute to the LOI !!

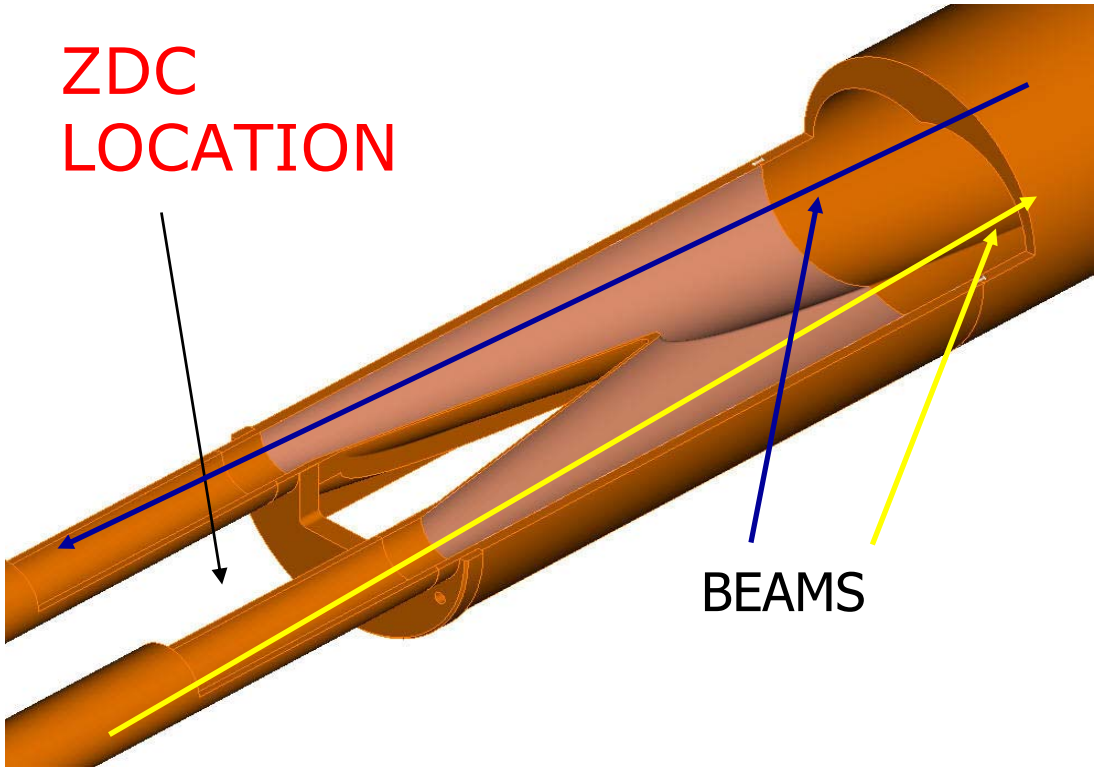
# ZDC: zero degree calorimeter (CMS)




Beam pipe splits 140m from IR



ZDC
LOCATION

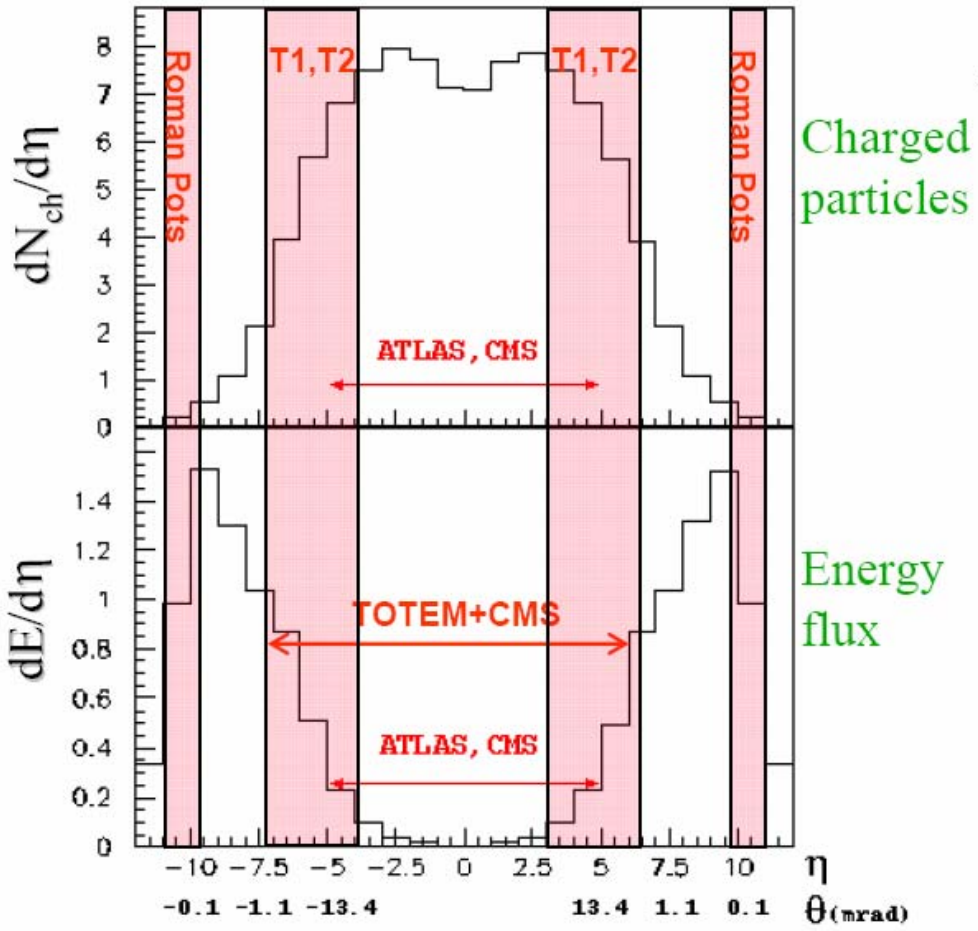


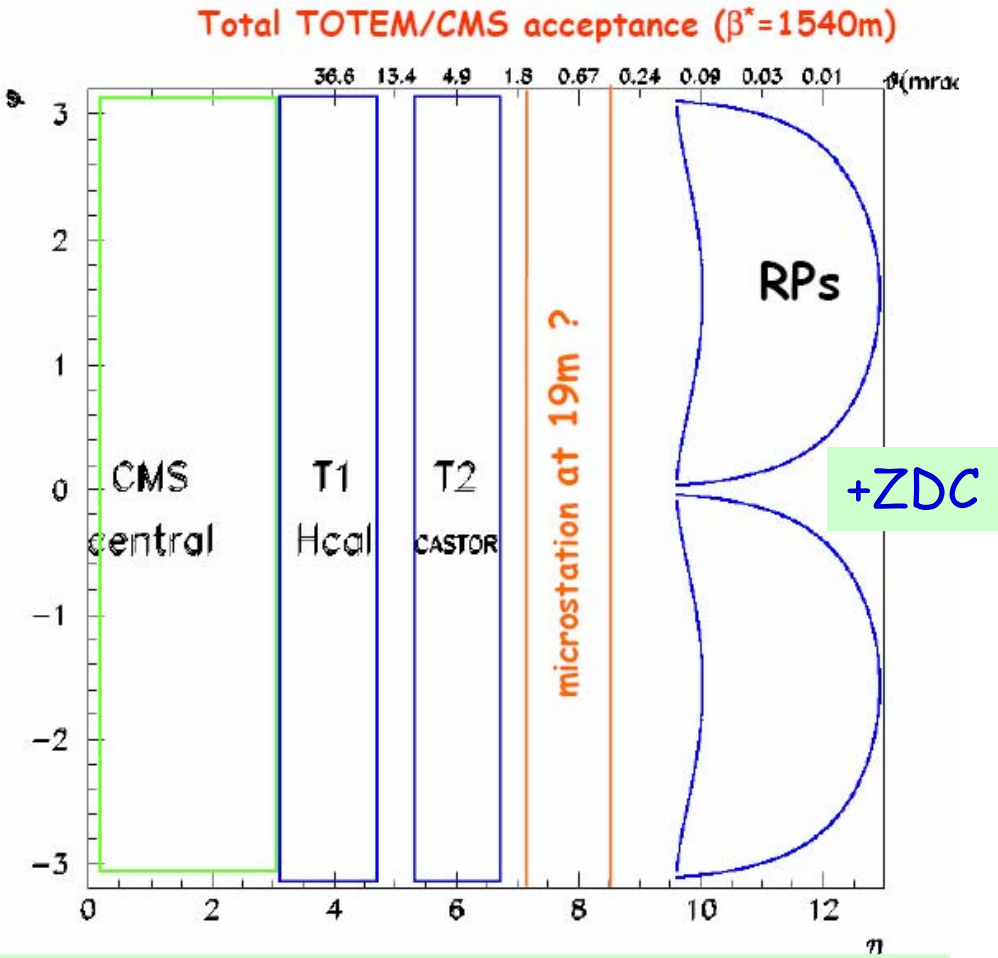

Tungsten/ quartz fiber or
PPAC calorimeter
EM and HAD section

Funding pending in DOE

# CMS/TOTEM: a "complete" LHC detector

CMS/TOTEM will be the largest acceptance detector ever built at a hadron collider




K. Eggert

Both collaborations open for new participants to the diffractive/forward program

# LOI Content

- September 2004: CMS (and TOTEM) management called for TDR
  $\Rightarrow$ To be delivered first part of 2005
- Will include detector description
  - Castor (CMS)
  - T2 (T1) (TOTEM)
  - Roman pots before 250 m (TOTEM)
  - Detectors after 250 m (CMS/TOTEM)
  - Detectors at 19m ($7<\eta<9$) ?? Wait for HERA/LHC workshop results
  - ZDC (CMS)
- Trigger: L1 and HLT
  - CMS only
  - CMS+TOTEM
- DAQ CMS+TOTEM
- Calibration & allignment issues, beam monitoring,…
- Runs: special runs at high $\beta$ and nominal runs at low $\beta$ (but not too many)
- Physics (next slides)

# Diffraction at LHC

Plan to use both rapidity gap and proton tagging techniques

- Rapidity gaps based on the central detector
  - Used extensively at HERA and the Tevatron
  - Uses correlation between the $\eta_{max}$ and $\xi$, the momentum loss of the proton
  - Once detector/readout stable, can be lead first results quickly.
    Many significant HERA papers, like $F_2^D$, are still with rapgaps
  - Only usable if pile up small and can be controled
  - Cannot distinguish between outgoing proton or low mass system
  - Need Monte Carlo based corrections
- Tagging protons based on detectors along the beamline
  - Clean measurement for non-dissociative final protons, kinematics!
  - Need to understand positioning, alignment, acceptance corrections…
    This can take some time (HERA & Tevatron experience)
  - May have reduced luminosity: can insert RPs only when beams/background low and stable

Experience from both HERA and Tevatron vital

# Forward Physics Program (CMS/TOTEM LOI)

- Soft & Hard diffraction
  - Total cross section and elastic scattering (TOTEM, precision of O(1)%)
  - Gap survival dynamics, multi-gap events, proton light cone ($pp \rightarrow 3jets+p$), odderon
  - Diffractive structure: Production of jets, W, $J/\psi$, b, t, hard photons
  - Double Pomeron exchange events as a gluon factory (anomalous W,Z production?)
  - Diffractive Higgs production, (diffractive Radion production?), exclusive SPE??
  - SUSY & other (low mass) exotics & exclusive processes
- Low-x Dynamics
  - Parton saturation, BFKL/CCFM dynamics, proton structure, multi-parton scattering…
- New Forward Physics phenomena
  - New phenomena such as DCCs, incoherent pion emission, Centauro's
- Strong interest from cosmic rays community
  - Forward energy and particle flows/minimum bias event structure
- Two-photon interactions and peripheral collisions
- Forward physics in pA and AA collisions
- Use QED processes to determine the luminosity to 1% ($pp \rightarrow ppee$, $pp \rightarrow pp\mu\mu$)

Many of these studies can be done best with L ~$10^{33}$ (or lower)

# Forward Physics Program (my status)

- Soft & Hard diffraction
  - SPE and DPE: Production of jets, W, J/ψ, b, t, photons — Saclay,Nebraska,Moskou Brazil,,ITEP, Yerevan
  - Gap survival dynamics, multi-gap events, — Nebraska, Goulianos
  - Double Pomeron exchange events as a gluon factory — ???
  - anomalous W,Z production in DPE events (Alan White) — FNAL/CERN
  - Diffractive Higgs production, DPE — Helsinki, Bristol, Wisconsin, CERN, Antwerp
  - Diffractive Higgs production SPE — UCLA, Caltech
  - Diffractive Radion production — Protvino/CERN
  - Diffractive Drell Yan production — Antwerp
  - SUSY & other (low mass) exotics & exclusive processes — ITEP +?
  - proton light cone ($pp \rightarrow 3jets+p$) — ???
  - Diffractive production of low mass systems — TOTEM groups
  - Spin parity analyses of low mass systems — Protvino/Annecy
  - Leading neutron/photon analyses — Kansas
  - Hard color singlet exchange — Brazil
  - Other topics?

Can be studied with $\beta^*=0.5 \leftrightarrow \beta^*=200m$ / gaps $\leftrightarrow$ Roman Pots

# Forward Physics Program

- Low-x Dynamics
  - Parton saturation and proton structure — CERN, Saclay
  - BFKL/CCFM dynamics — Saclay+
  - multi-parton scattering… — ???
- New Forward Physics phenomena
  - New phenomena such as DCCs, incoherent pion emission, Centauro's — Athens, C. Taylor
- Strong interest from cosmic rays community
  - Forward energy and particle flows — R. Engel, Athens
  - minimum bias event structure
- $\gamma\gamma$ , $\gamma p$ interactions and peripheral collisions — Louvain
- Use QED processes to determine the luminosity to 1% ($pp \rightarrow ppee$, $pp \rightarrow pp\mu\mu$) — Louvain+
- Forward physics in pA and AA collisions — HI group
- Other?

Other possible contributions (La Platta, DESY,Aachen,…) under discussion

# Meeting example (last Friday)

| CMS/TOTEM Physics Diffraction (14:00->18:00) | | Chairperson: Albert De Roeck<br>Location: VRVS VENUS<br>Room: 40-2-A01 |
|---|---|---|
| 14:00 | Update on CASTOR (15') ( transparencies ) | A Panagiotou. |
| 14:15 | Update on the ZDC (15') ( transparencies ) | M. Murray |
| 14:30 | New ideas using chrystals for increasing the acceptance (15') ( transparencies ) | K. Eggert |
| 14:45 | Updates on the trigger studies (15') ( transparencies ) | M. Grothe |
| 15:00 | Pile-up in Pythia (15') ( more information ) | M. Ruspa |
| 15:15 | Acceptance paramterizations and new optics (15') ( more information transparencies ) | V. Avati |
| 15:30 | Fast Forward proton simulation (15') ( transparencies ) | X. Rouby |
| 15:45 | POMWIG/CASTOR studies (15') ( more information ) | L. Sarycheva |
| 16:00 | Air shower physics models study (& CASTOR status in OSCAR) (15') ( transparencies ) | V. Popov |
| 16:15 | Diffractive W production (15') ( more information ) | A Loginov |
| 16:30 | Diffractive ttbar production (15') ( more information ) | A. Vilela |
| 16:45 | Diffractive J/Psi and Upsilon production (15') ( transparencies ) | D.J. Damiao |
| 17:00 | DY production and acceptance in CASTOR (15') ( transparencies ) | E. Sarkisyan |
| 17:15 | Diffractive Higgs Production (15') ( more information ) | M. Tasevsky |
| 17:30 | Exclusive Di-electrons in CMS (15') ( transparencies ) | Y Liu |
| 17:45 | The US420 project (15') ( more information ) | M. Albrow |
| 18:00 | LOI updates (15') | All |

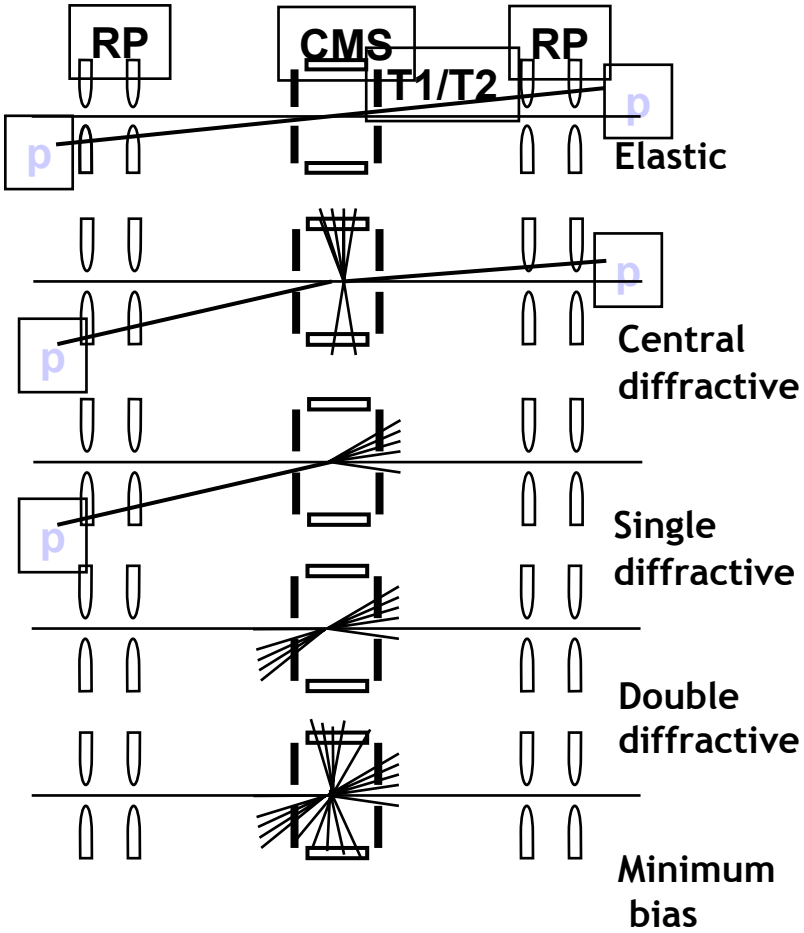
# Examples

- The following contains a number of snapshots of work in progress, very preliminary,just to illustrate the ongoing activity.

- Health warning 
  - Many of these WILL change very soon
  - Do not use outside scope of this talk

# CMS Level-1 Trigger & TOTEM

TOTEM plans for Level-1 Triggers
at $\mathcal{L} = 1.6\ 10^{28}\ cm^{-2}\ s^{-1}$




Courtesy K. Eggert

Totem will act as a CMS trigger and DAQ partition, as any other subdetector

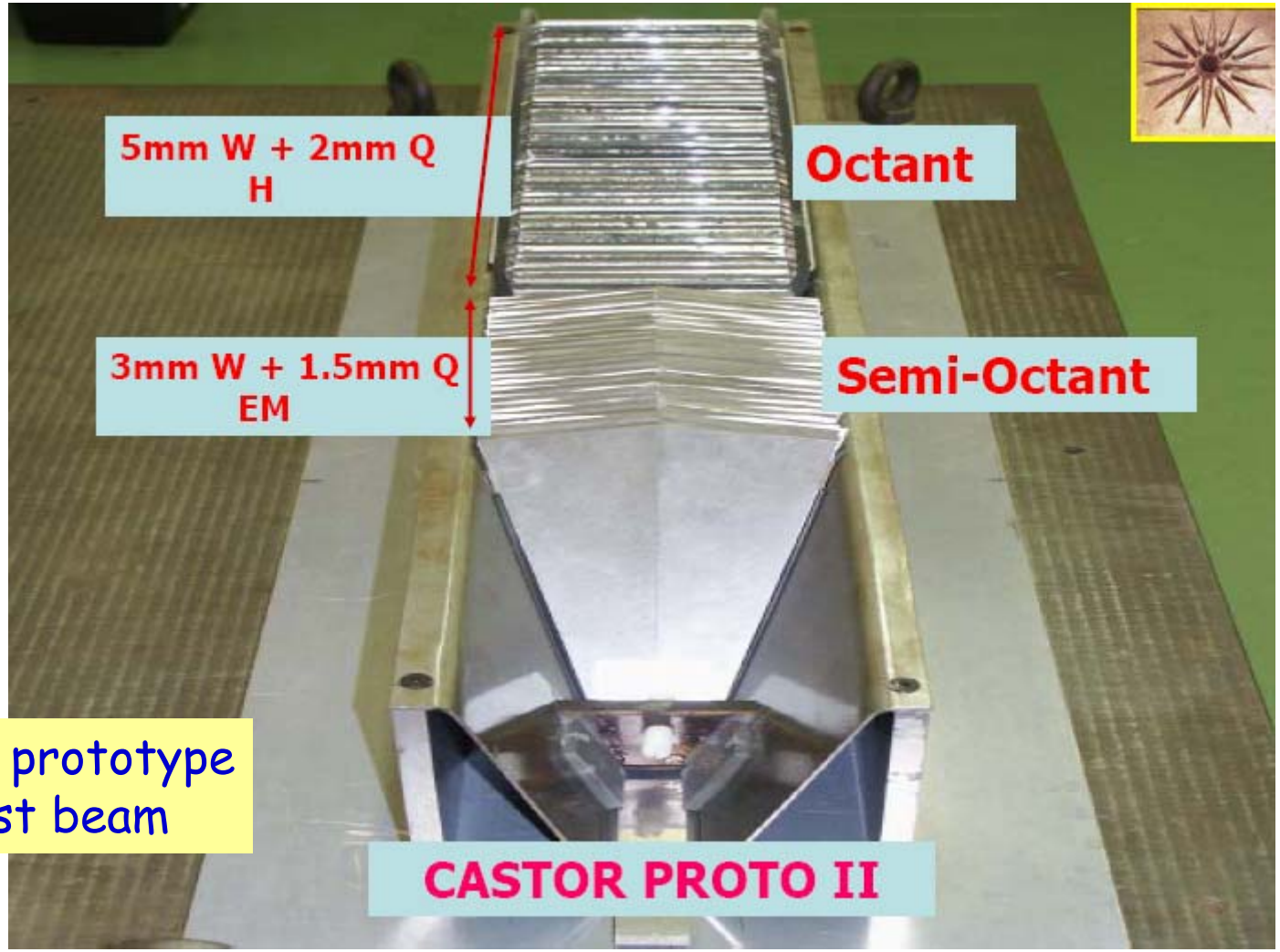
M. Grothe

**Want CMS operational in low-luminosity start-up phase of LHC when TOTEM runs will take place**
**Goal:**
**Study and validate CMS-Calo based diffractive L1- trigger ($E_T/H_T$) with the help of TOTEM's Roman pot-based diffractive triggers**

Special challenge: low mass diffractive H→bb

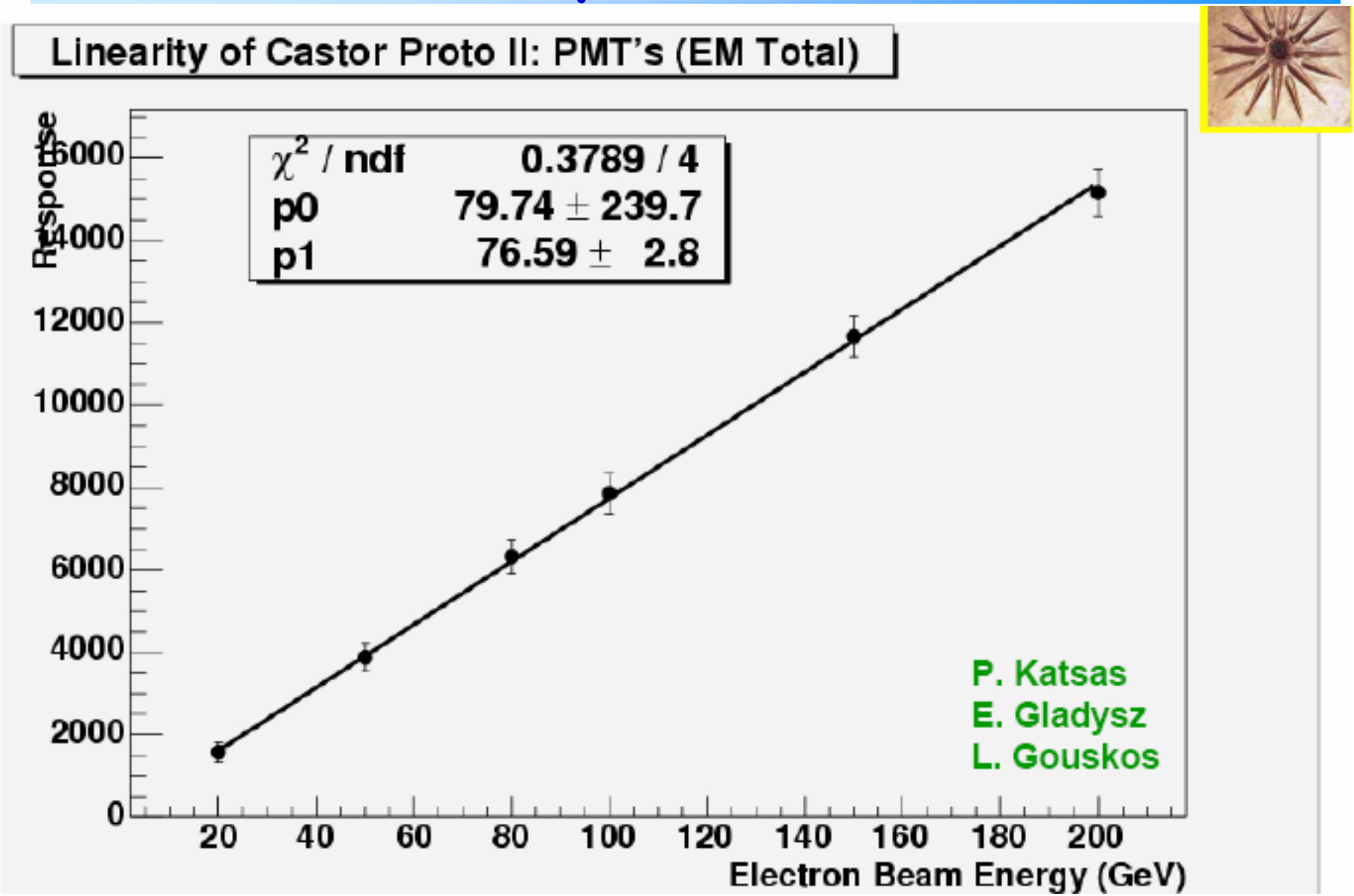
# Detector Progress: CASTOR

A. Panagiotou



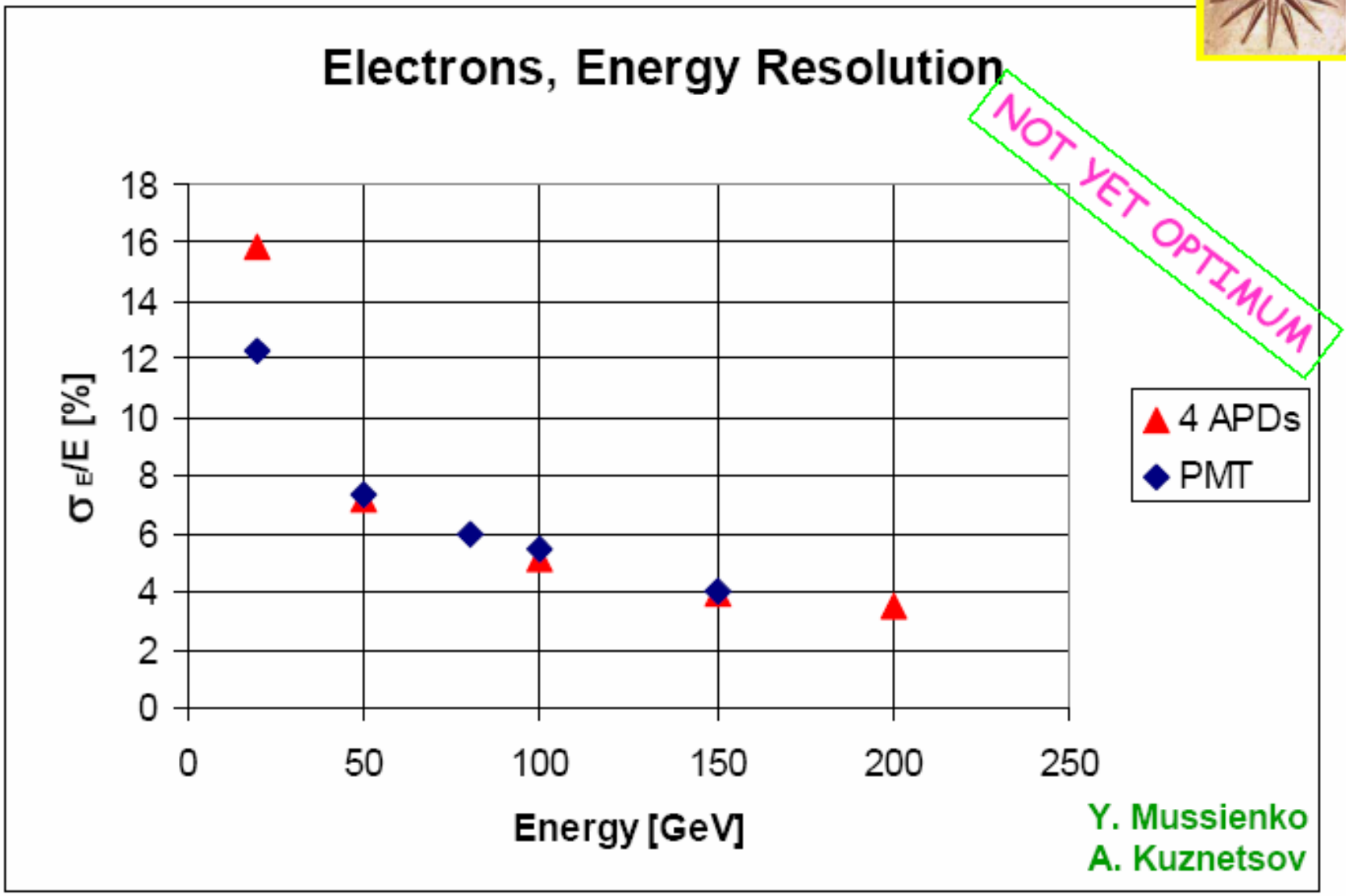

CASTOR prototype in the test beam

# Linearity for electrons

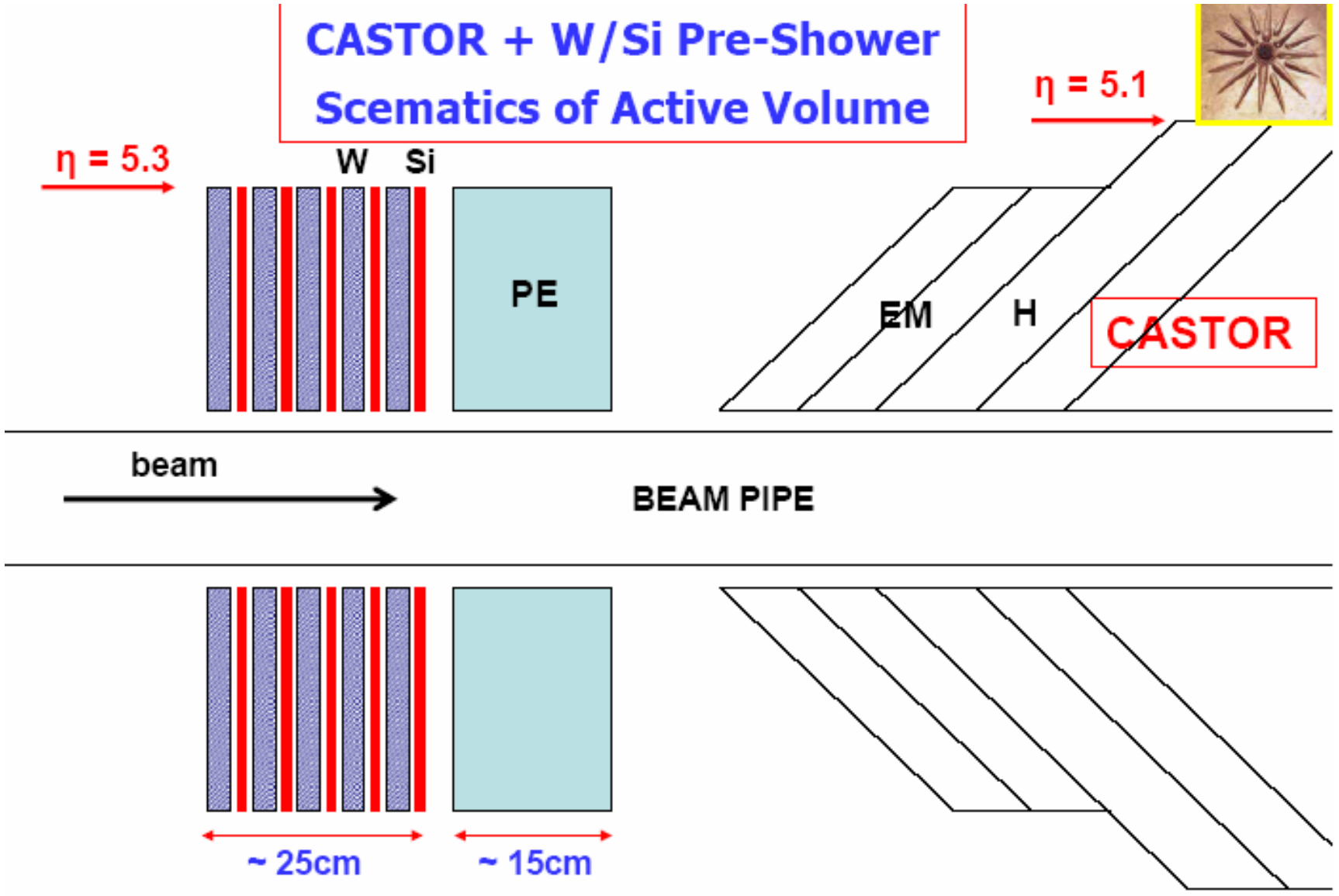


# Resolution for electrons

## Electron Energy Resolution:(4)APDs vs PMTs



# New proposal, including a preshower



# New proposal, inclusding a preshower

## BENEFITS FROM PRE-SHOWER + CASTOR

- pp Interactions

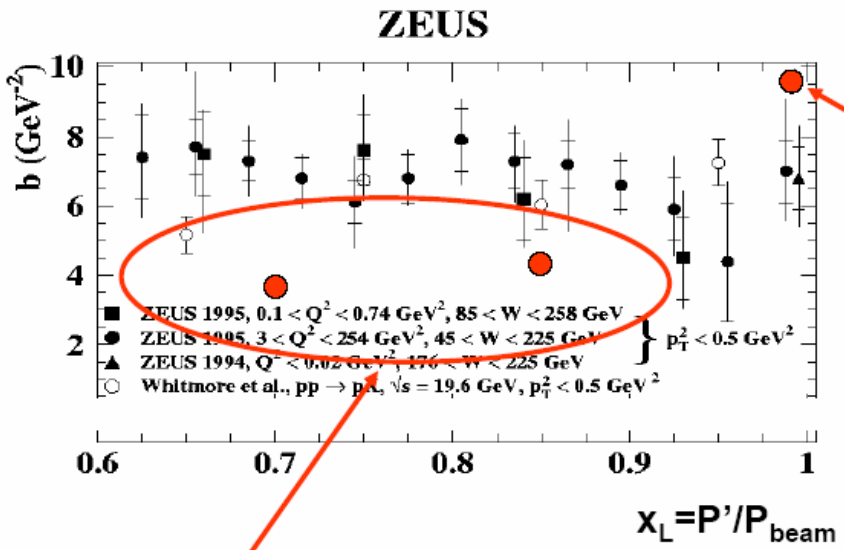
1. Identify γ, e, hadron and jet, their location and the total EM / H multiplicities per event
2. Give information on θ ($p_T$)
3. Two jet separation of order 1 cm
4. Energy cross – calibration
5. Give precise EM – H shower separation and energy with higher accuracy in CASTOR

Preparing INTAS project for CASTOR+PS

# MC leading proton spectra

M. Ruspa

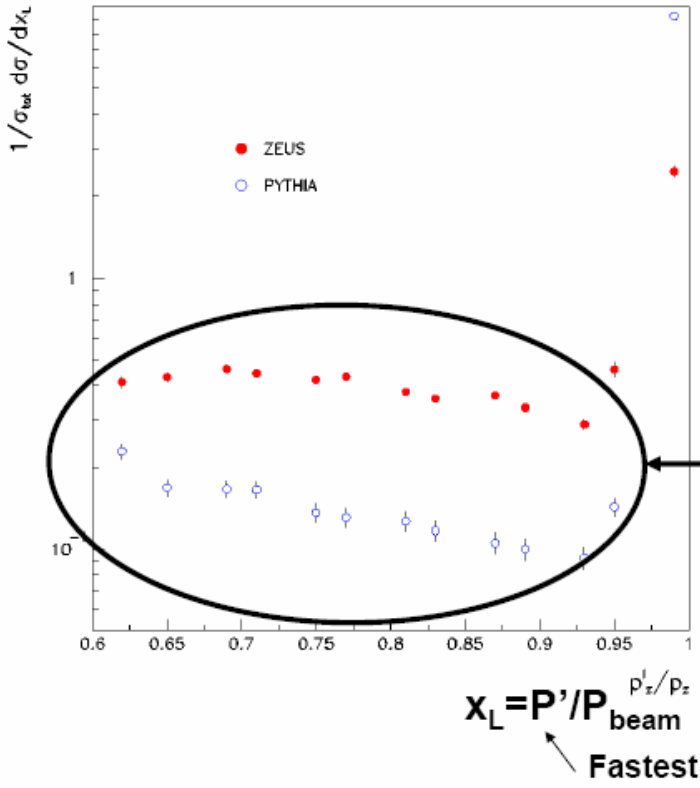
Pythia used for pile-up background studies
How good is it when compared to data, e.g. from HERA??




Pythia approx OK in diffractive Peak, after taking shrinkage ($b = b_0 + 4\alpha' \ln s$) into account

Pythia too low outside diffractive peak

b-slope



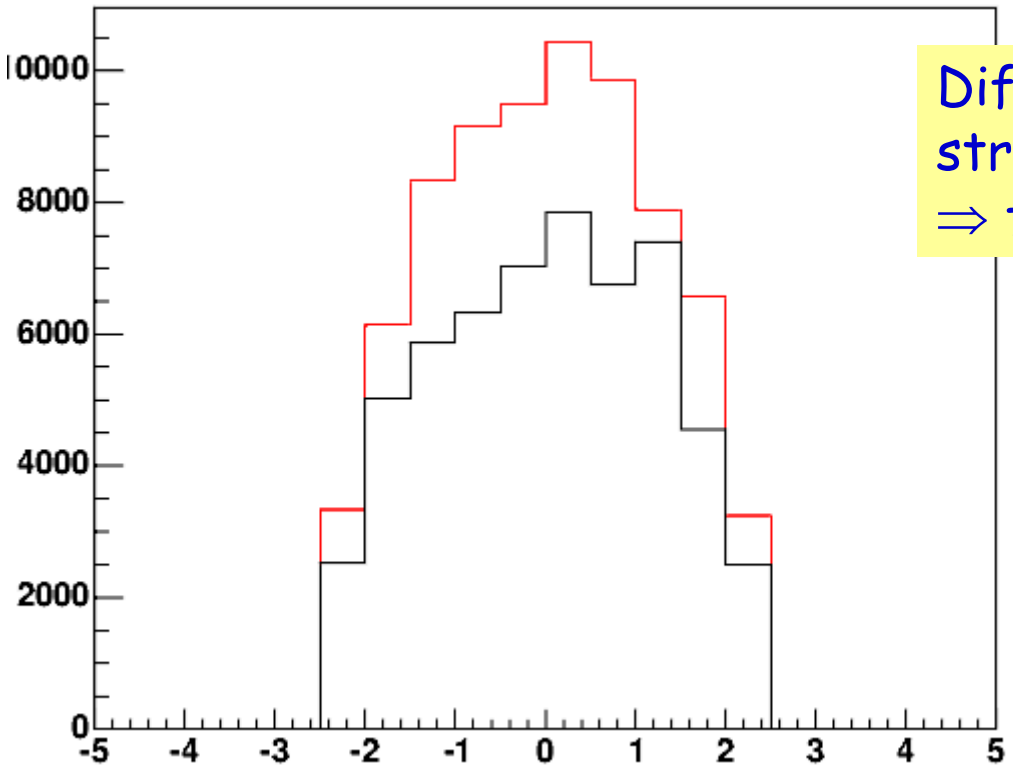

Pythia wrong in shape and normalisation outside diffractive peak (approx factor 2-3)

Leading proton spectra

# Diffractive W production

Pseudorapidity spectrum of the muons from diffractive W's after acceptance cuts, trigger condition and fast simulation

A. Loginov




Different H1 diffractive structure functions
$\Rightarrow$ fit 5 and fit 6

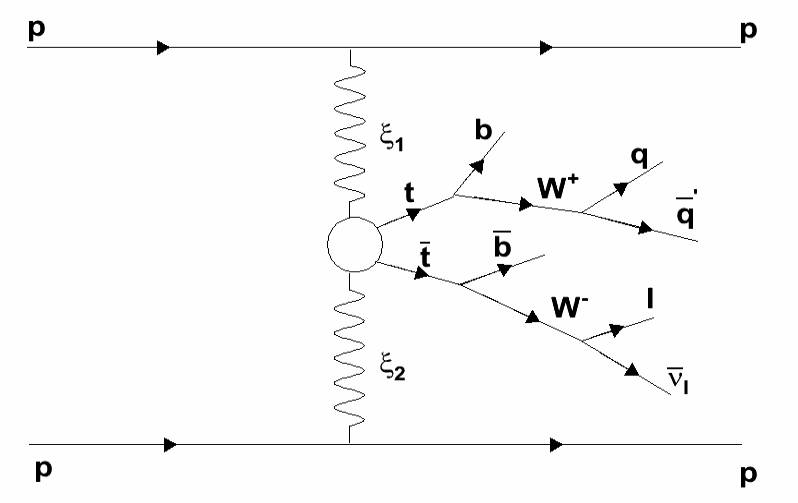
Cross section $W \rightarrow \mu\nu$ (not corrected for survival probability)

17-25 pb

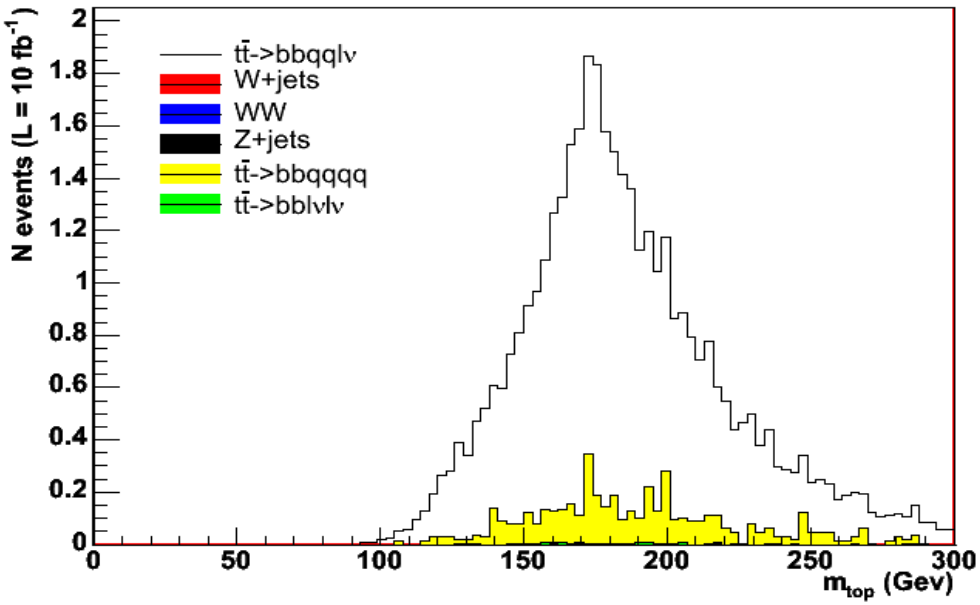
# Novel channels: eg diffractive top

## Decay Channel

A. Vilela



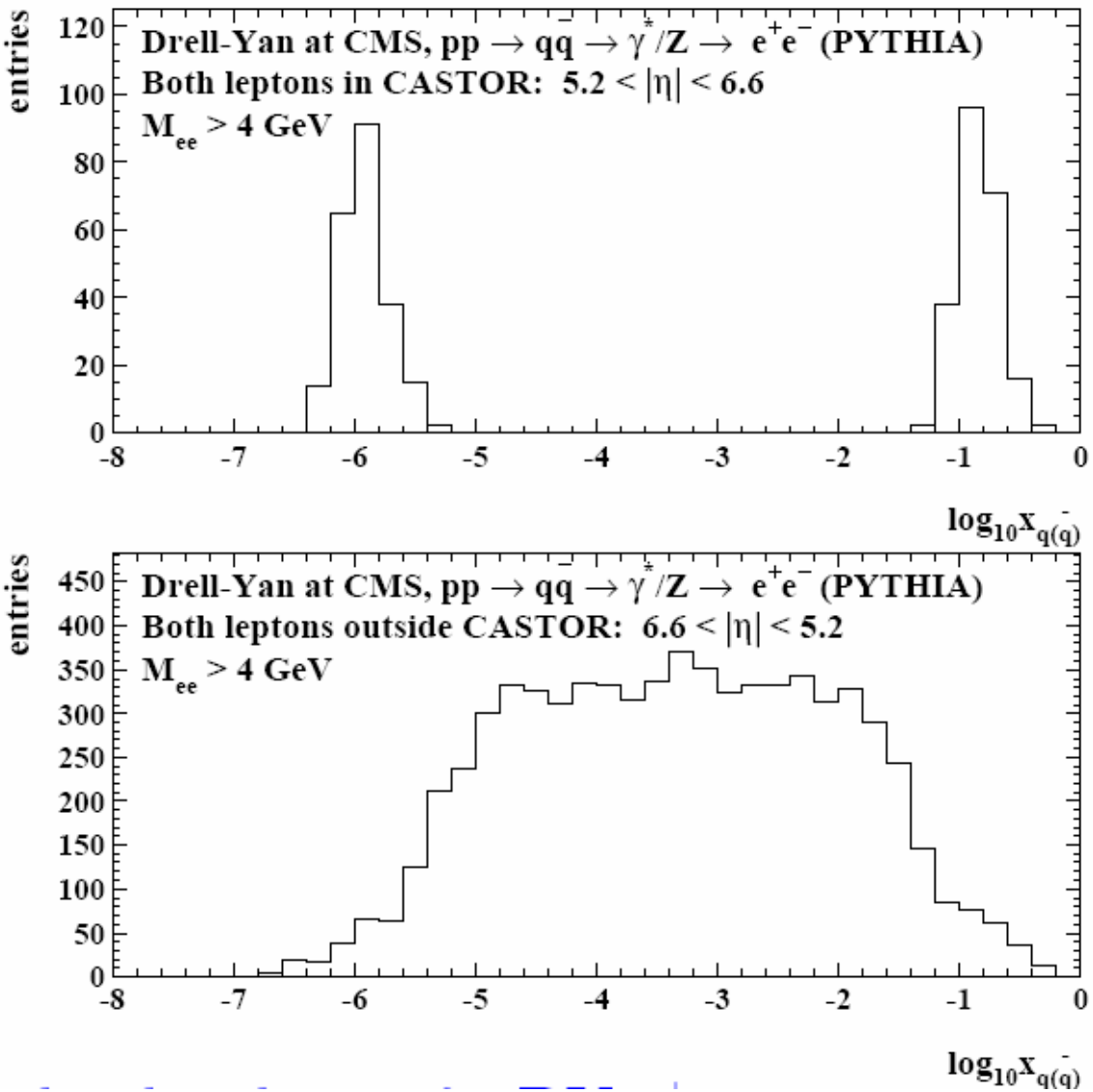

Top mass peak
Efficiency still to be increased




- $pp \rightarrow p + (t\bar{t}) + X + p$
- $t\bar{t} \rightarrow b\bar{b}\, l\bar{\nu}_l q\bar{q}'\, (l = e, \mu)$

With low Etjet cuts O(100) events/10 pb$^{-1}$

# Drell-Yan production




E. Sarkisyan

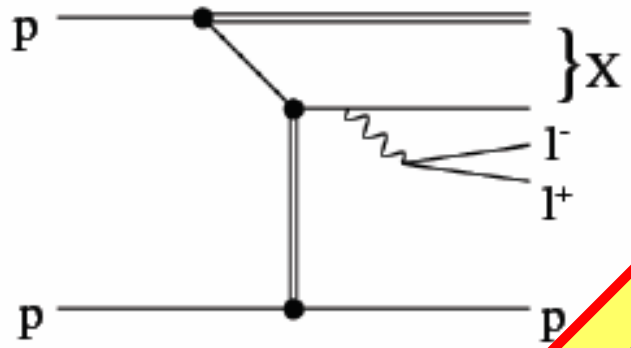
Drell-Yan into electrons

Includes (fast) CASTOR simulation

Large rapidity needed for low-x reach

# Diffractive production of Drell-Yan pairs

The process: $pp \to p\, l^+ l^- X$




CMS+CASTOR+TOTEM acceptance:

(study by Sedlak)

$0.02 < \xi < 0.2$

$< \eta_{l^\pm} < 6.46$

000 events/year, assuming

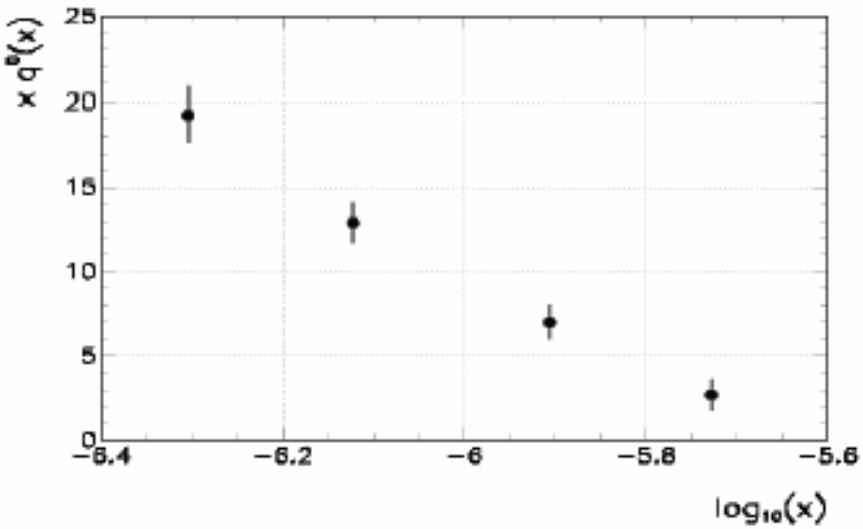
$_{int} = 200$ $2000\ \mathrm{pb}^{-1}$/year

1 interaction/bunch crossing

Physics interest:

- Continuation of the
  structure
- Saturation at l
- Test of fact
- ...

Example measurement:




Came up in the framework of this workshop

P. Van Mechelen

# Diffractive Higgs production: new channel H→WW

## Excl.DPE H->WW:Event yields per L=10 fb-1

- **Both protons accepted in one of two RP's (220, 420)**
- (L1 muons taken from FAMOS. El.+quarks correspond to parton level)
- Various cut scenarios acc.to current CMS L1 thresholds:

M. Tasevsky

- C1) single e: pt>29 GeV, |η|<2.5
- C2) two e: pt>17 GeV, |η|<2.5
- C3) single μ: pt>14 GeV, |η|<2.1
- C4) two μ: pt> 3 GeV, |η|<2.1
- C5) single e: pt>20 GeV, |η|<2.5 + 2 quarks: pt>25GeV, |η|<5
- C6) single μ: pt>10 GeV, |η|<2.1 + 2 quarks: pt>25GeV, |η|<5

Trigger & acceptance study

# Excl.DPE H->WW:Event yield for L=10fb-1
# Exhume 1.0

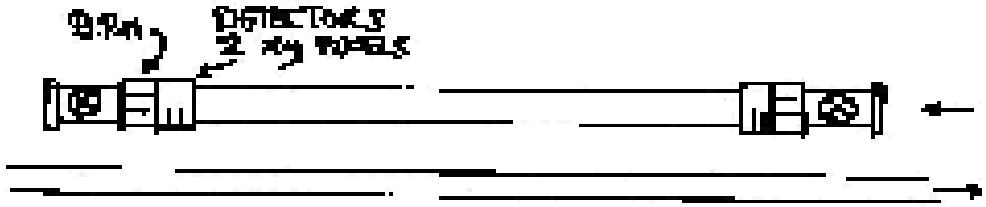
| Mh [GeV] | σxBR [fb] | Acc. [%] | C1 | C2 | C3 | C4 | C5 | C6 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 120 | **0.29** | 61 | 0.11 | 0.01 | 0.23 | 0.02 | 0.02 | 0.03 | **0.4** |
| 135 | **0.57** | 65 | 0.26 | 0.02 | 0.50 | 0.05 | 0.06 | 0.08 | **1.0** |
| 140 | **0.63** | 67 | 0.35 | 0.02 | 0.60 | 0.06 | 0.08 | 0.10 | **1.2** |
| 150 | **0.71** | 69 | 0.48 | 0.04 | 0.73 | 0.07 | 0.13 | 0.13 | **1.6** |
| 160 | **0.75** | 71 | 0.62 | 0.04 | 0.83 | 0.07 | 0.21 | 0.23 | **2.0** |
| 170 | **0.64** | 73 | 0.61 | 0.03 | 0.77 | 0.07 | 0.20 | 0.22 | **1.9** |
| 180 | **0.50** | 74 | 0.45 | 0.03 | 0.62 | 0.06 | 0.14 | 0.15 | **1.4** |
| 200 | **0.27** | 77 | 0.26 | 0.02 | 0.33 | 0.03 | 0.08 | 0.09 | **0.8** |

Note: cross section to low by a factor 2?
Then event rate $\rightarrow$ x 2 ie. 12 events for MH = 160 and 30 $fb^{-1}$

# New Detector Concept for 420 m?

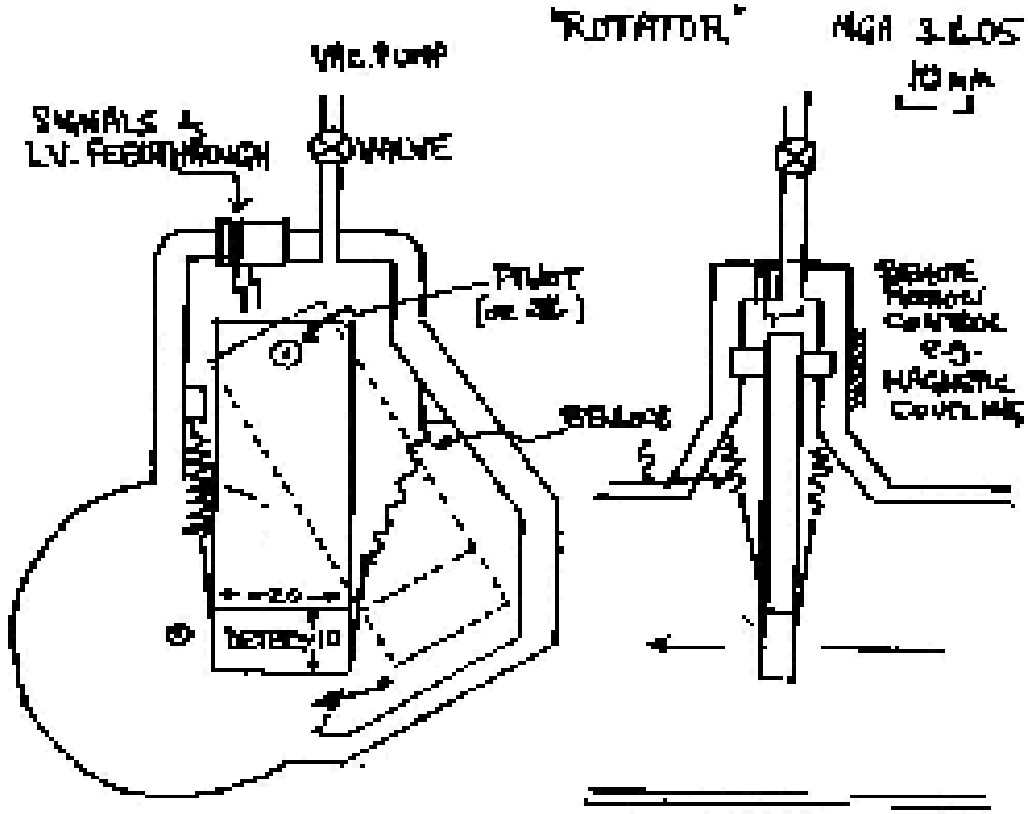
Mike Albrow

## *Vacuum Mechanics*



Roman Pots?
Helsinki Microstations?
Moving Pipe?

***Rotator?***




**Just concept: 0 engineering**
**Could develop at Fermilab**

## Studies of Forward Energy / Particles at LHC

V.Andreev, A.Bunatyan, L.Jonsson, [illegible] M.Kapishin and L.Lytkine

- Requirement: study LHC forward bea[illegible]etector position / type to measure energy / particle flow in the r[illegible]

- Possible solutions:

  Energy flow in the range[illegible]

  ➔ 2 Horizontal Rom[illegible]-stations) at 85 and 95m behind dipole magnet system D[illegible]

  Energy flow i[illegible]eV - 5.5 TeV

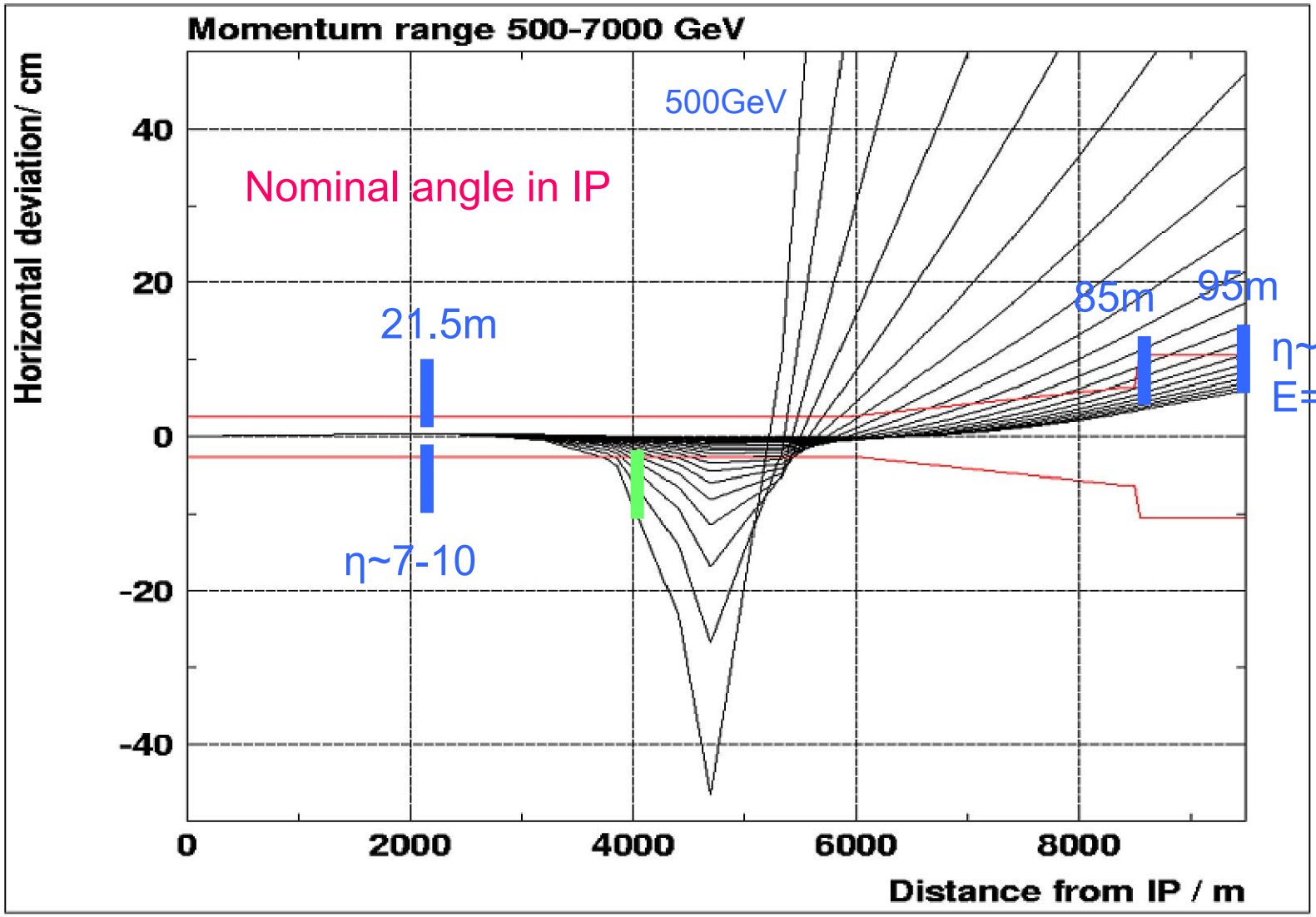
  ➔ or/and had[illegible]meter at 135m in front of TAN absorber

  Charge particle flow integrated over energy up to ~7 TeV
  ➔2 Horizontal Roman Pots (micro-stations) at 21.5m between TAS absorber and cold quadrupole magnet system Q1-Q3

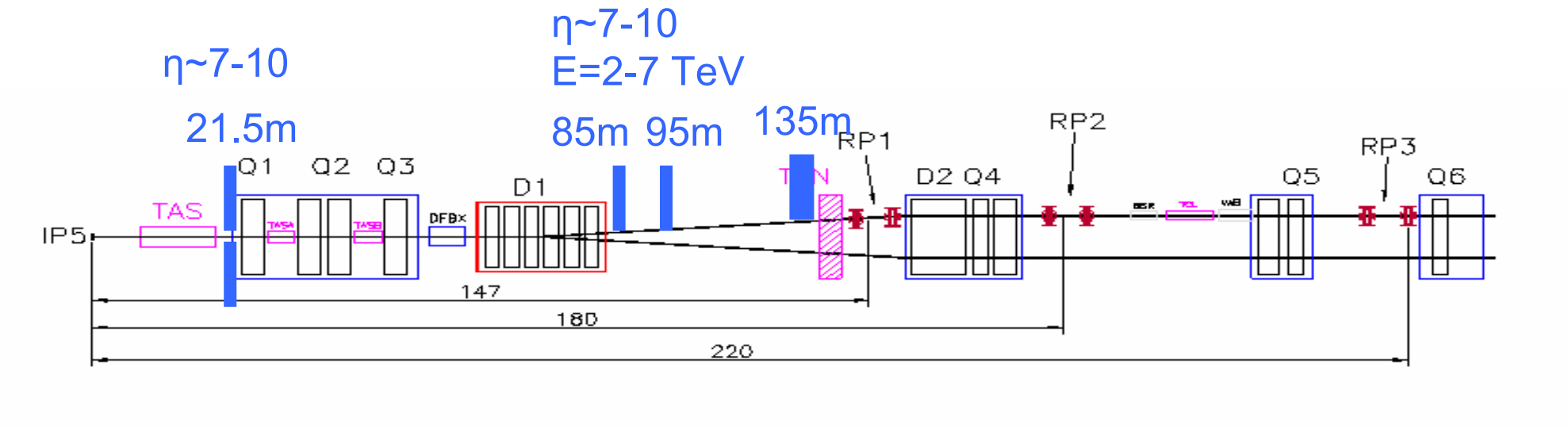
- Next plans ➔ estimate resolution on E / η

Being done in the framework of this workshop

# Trajectory of forward protons

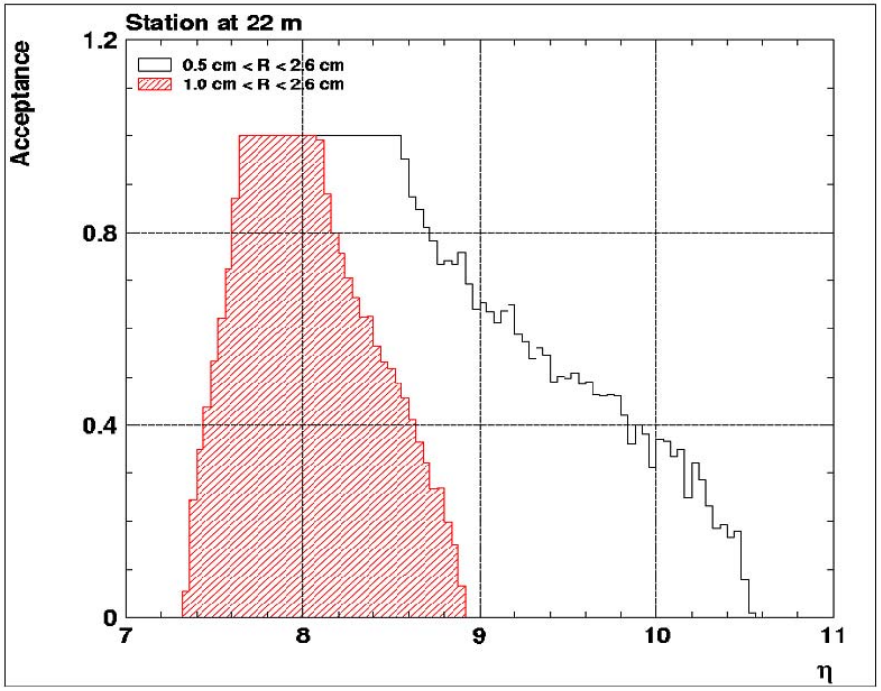


# Possible detector positions



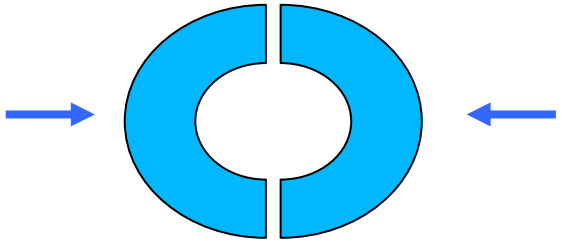
# Acceptance as function of pseudo-rapidity η

## 2 Stations at 21.5m



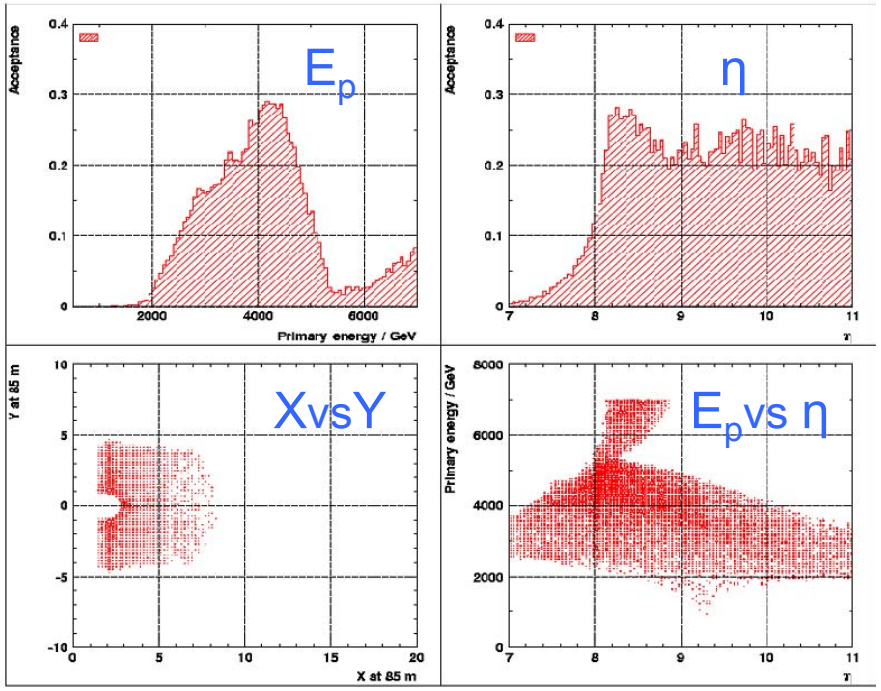

$R_{min}$ = 1.0, 0.5 cm

$R_{max}$ = 2.5 cm

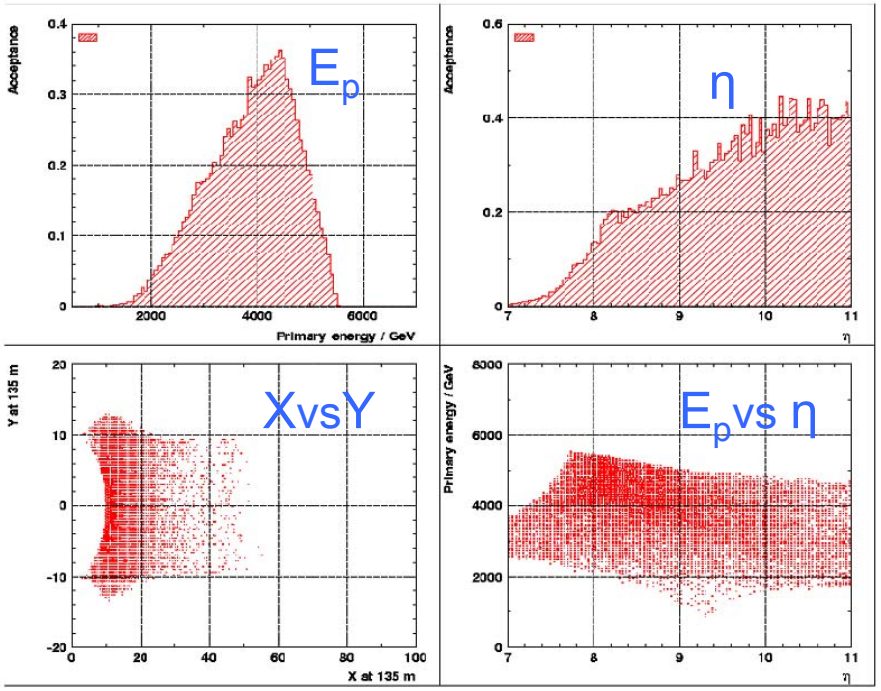


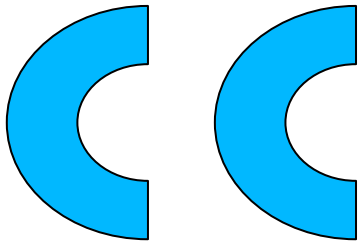
# Acceptance as function of $E_p$ and η

## Stations at 85m and 95m

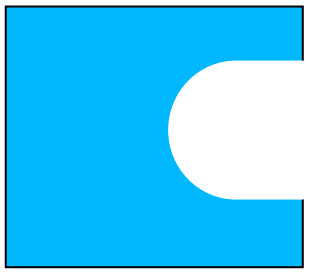



## Hadron calorimeter at 135m



$R_{min}$ = 1.0 cm
$R_{max}$ = 2.5 cm

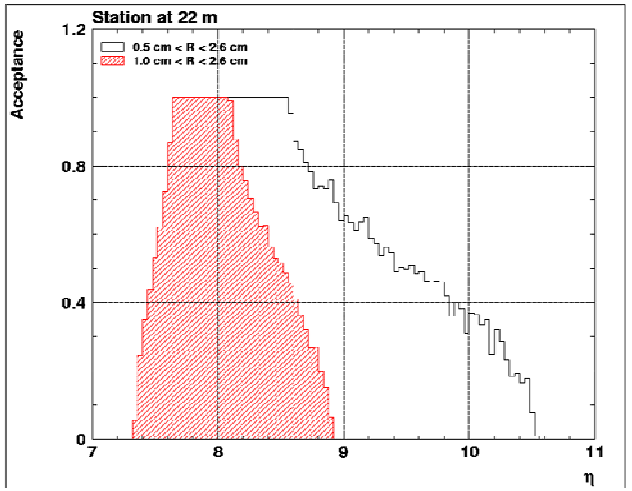


$R_{min}$ = 10 cm

# Acceptance as function of $E_p$ / η

| η / $E_p$ | 0.5-7 TeV | 2-5.5 TeV |
|---|---|---|
| 2 Roman Pots at 85,95m η=7-10 | 11% | 21% |
| η=7-8 | <10% | 10-20% |
| η=8-9 | 15-25% | 30-55% |
| η=9-10 | 20-25% | 55-60% |
| Calorimeter at 135m, η=7-8 | <15% | <25% |
| η=8-9 | 20-25% | 35-45% |
| η=9-10 | 25-40% | 45-60% |

21.5 m acceptance

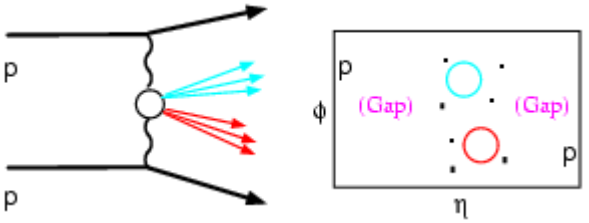


# Summary

- Diffractive and forward physics LOI of CMS/TOTEM well under way.
- Development of the forward detectors is continuing, more groups are joining in but still lot to do and cover. More ideas on forward detectors under study

  $\Rightarrow$ Opportunities for groups to join
- Roman pots at 420 m $\leftrightarrow$ FP420 RD project: Groups will participate
- Work also ongoing on acceptance calculations, detector simulation
- Still more work needed on calibration, alignment,...
- Physics topics: good (but not complete) coverage
  - Hard (& soft) diffraction, QCD and EWSB (Higgs), New Physics
  - Low-x dynamics and proton structure
  - Two-photon physics: QCD and New Physics
  - Special exotics (centauro's, DCC's in the forward region)
  - Cosmic Rays, Luminosity measurement, pA, AA...

# Run Scenarios




- High β runs (low luminosity runs)
  - Large acceptance
  - 10 $pb^{-1}$? Control of systematics (short runs)?
  - Example: di-jets in Double Pomeron Exchange ($\xi < 0.1$, H1 structure function)

| | | | |
|---|---|---|---|
| LHC | pt> 10 GeV | pt> 100 GeV | pt > 500 GeV |
| | $1.2\ 10^6$ pb | 0.9 pb | $5\ 10^{-4}$ pb |
| Tevatron | $1.3\ 10^5$ pb | | |

  - Gain in energy w.r.t. Tevatron and detector acceptance/quality
- Low β runs (high luminosity runs)
  - Lower acceptance for the roman pots
  - Rapidity gaps (till $10^{33} cm^{-2} s^{-1}$)
  - Calibrate understanding with the roman pot acceptance at high β
  - For processes/selections below 1 pb (exclusive Higgs etc.)
- Low β runs (lower luminosity runs)?

# Dedicated Running for SM Diffraction?

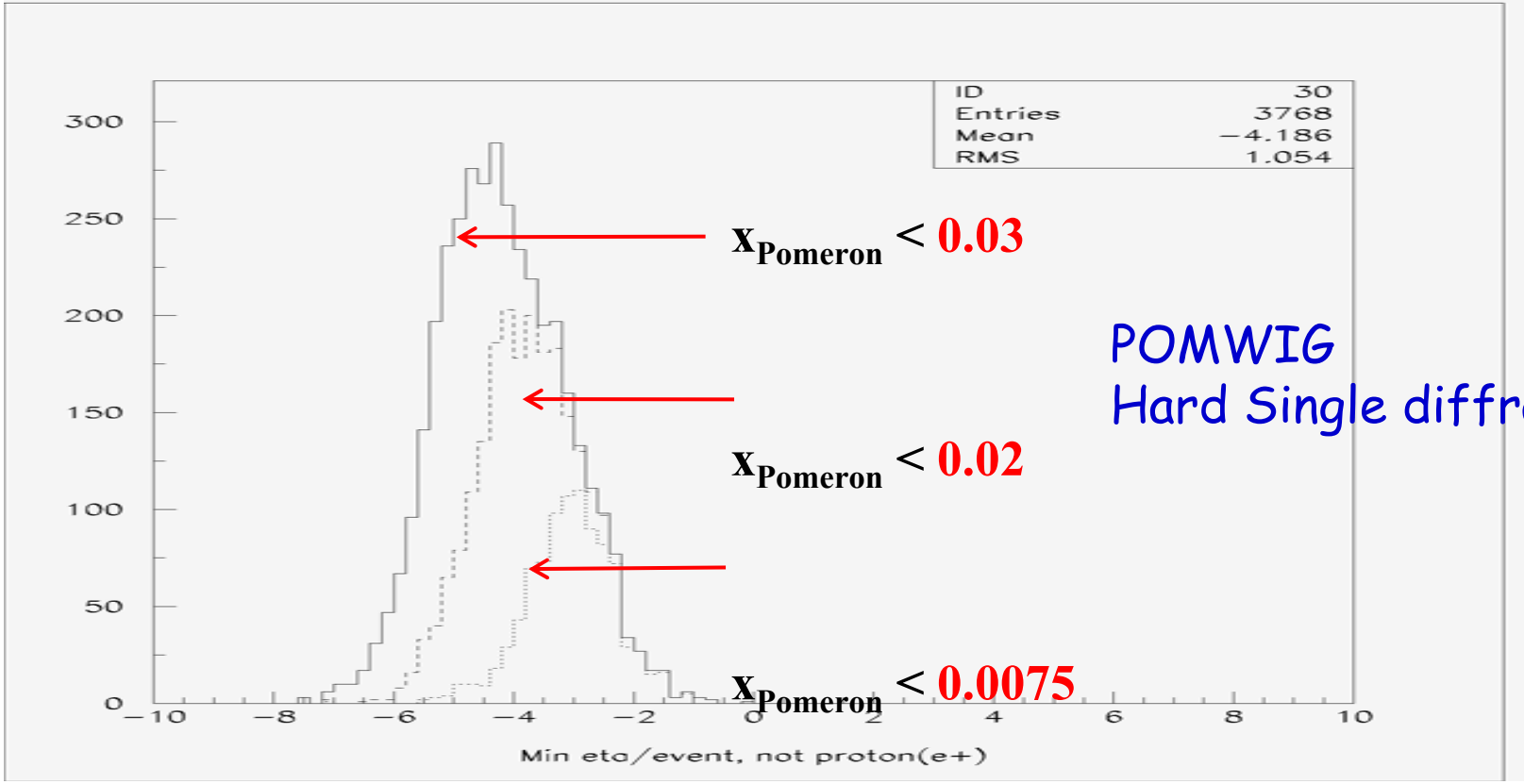
Note: Heavy Ions to get ~ 1 month/year dedicated. M. Albrow
This is a much more modest suggestion for discussion by us.

Much SM physics but especially much diffraction can best
(even only) be done without pile-up … mostly rap gaps.
**Optimal luminosity (all bunches) is 3-5.10^32**
Will get some in 2007, but want also later (eg with v.fwd. pots)

**Suppose had ~ 2 weeks (per year?):**
15d x 20h x 3600s x 5e32 = 5e38 = **500 pb^-1**
(more than TeV Run 2 so far)
e.g. SD **pp → p+WWX** → p+llvvX **~ 30 events** (but only 12 single)
**DPE pp → p+(bj,bj)X+p** (M(bj,bj) > 50 GeV) ~ X events
Other SM physics should benefit, e.g. precision top measurements.
Interesting? Strategy? Get it part of the scenario already soon?

Note: Maybe we can live on the 'end of run' data, triggers for lower lumi
See also proposals by K. Eggert on different optics

# Gap moves farther from outgoing proton for smaller $x_{POM}$




η of minimum-η particle per event

Rapidity gap trigger study