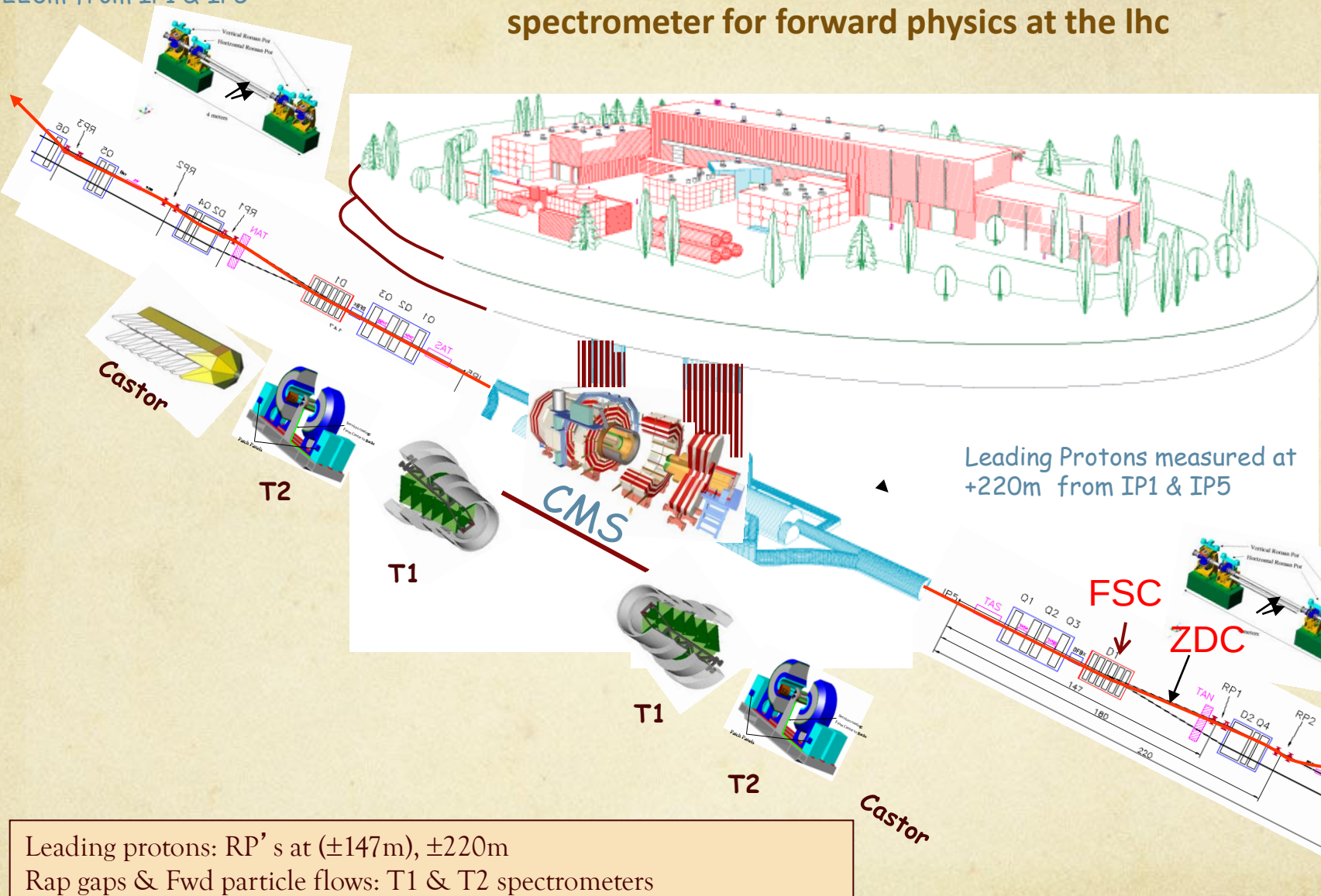
INELASTIC DIFFRACTION AT THE LHC – RECENT TOTEM MEASUREMENTS

Image from "The Daily Galaxy"

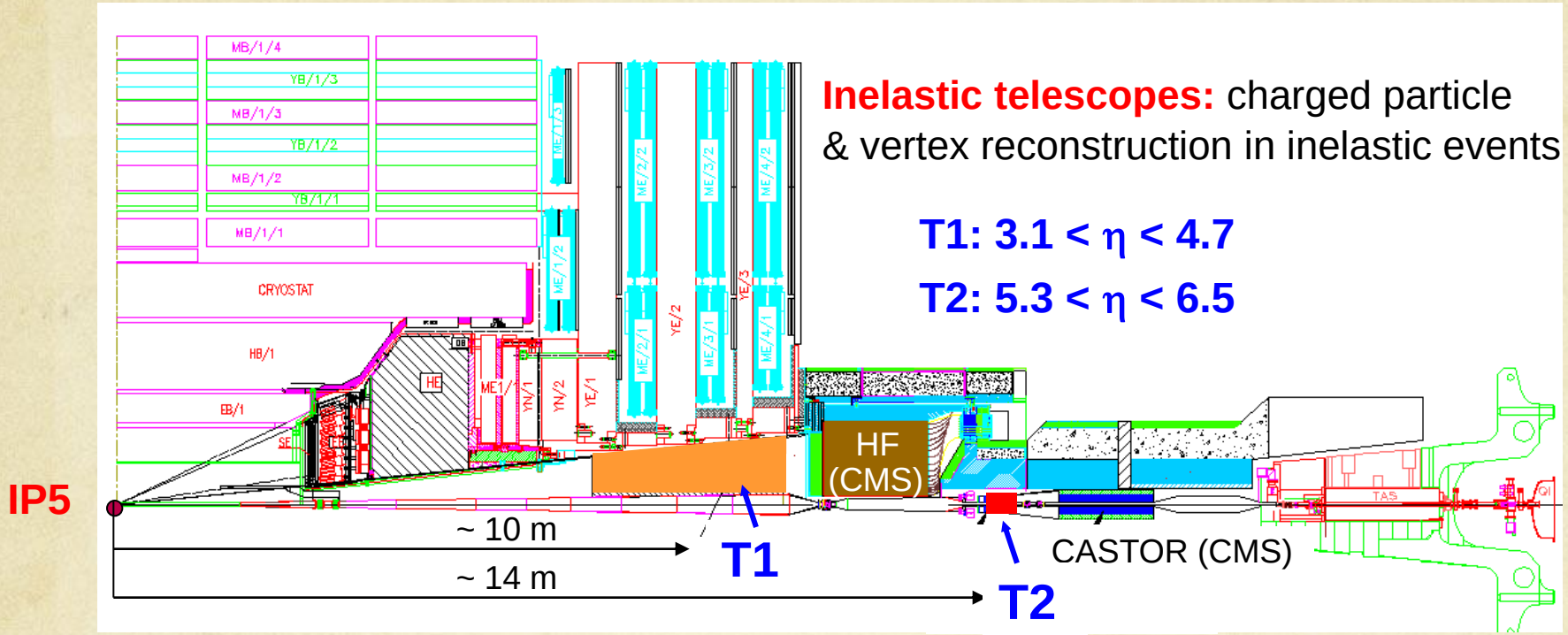
Leading Protons measured at
-220m from IP1 & IP5

cms-calorimetry + totem-tracking: unique fwd physics spectrometer for forward physics at the lhc



Leading protons: RP's at (±147m), ±220m
Rap gaps & Fwd particle flows: T1 & T2 spectrometers
Fwd energy flows: Castor & ZDC
Fwd counters at: ±60m to ±100 (140)m - FSCs

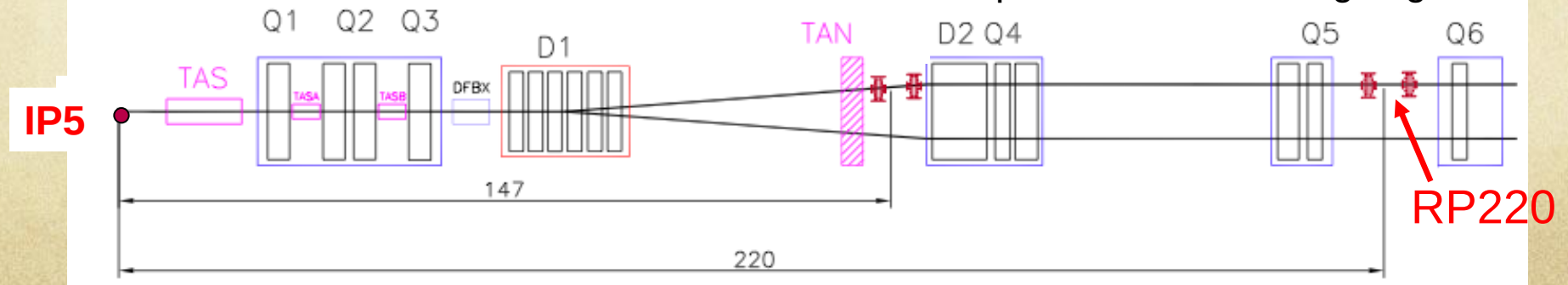
Experimental Setup



Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

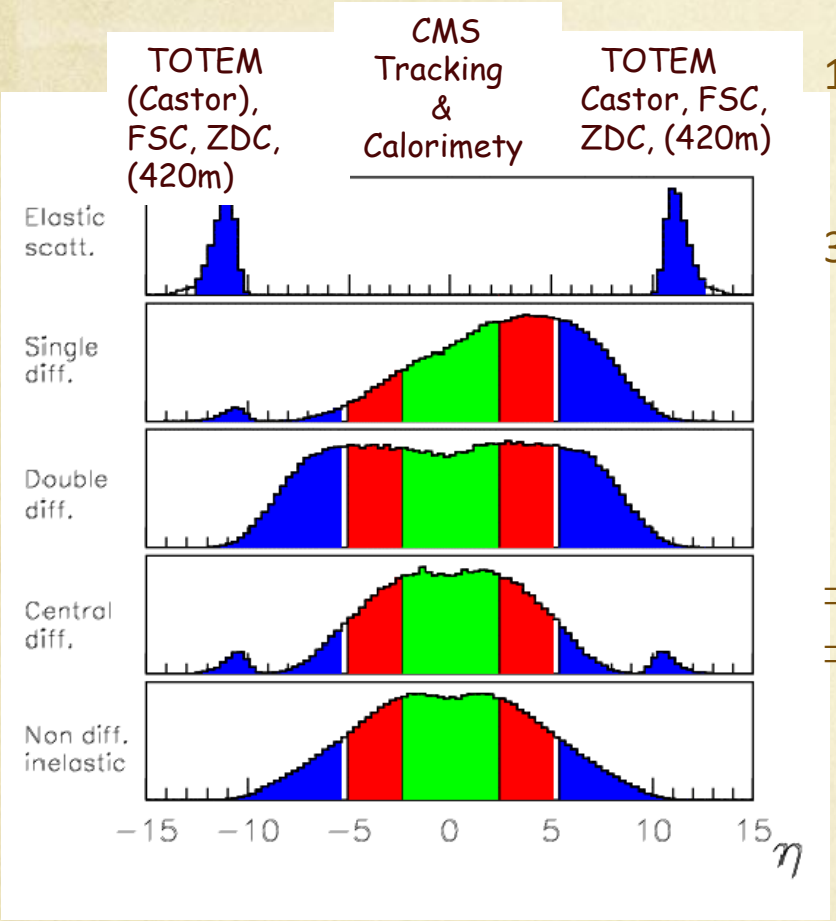
T1: 3.1 < η < 4.7

T2: 5.3 < η < 6.5



Roman Pots: measure elastic & diffractive protons close to outgoing beam

TOTEM⊕CMS measurements



1. Total pp cross section & Elastic pp scattering (see the talk by **Frigi Nemes**)

3. Leading particles:
   $2\times10^{-2(3?)} < \xi < 2 \times 10^{-1}$

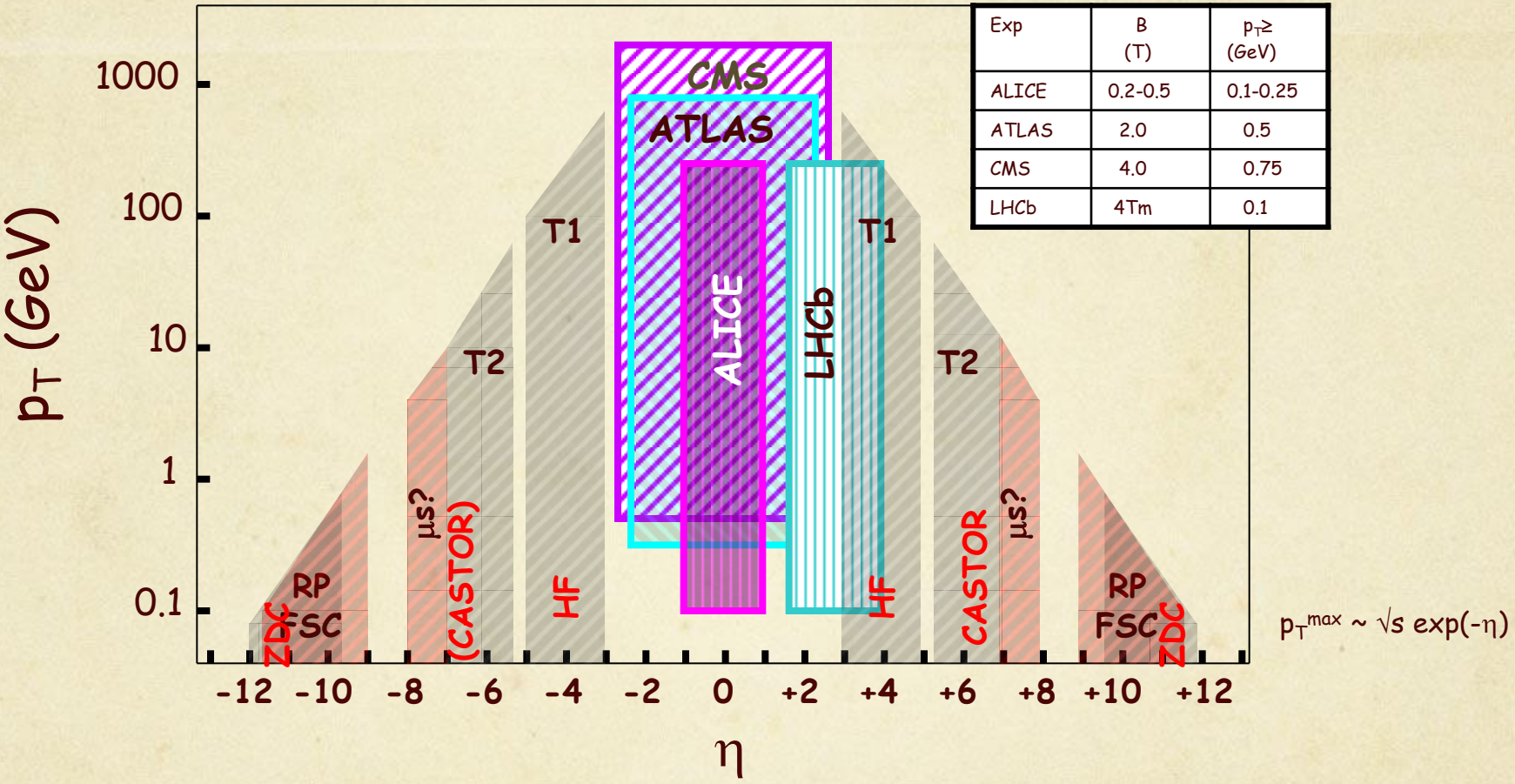
   Particle flows, ”rap gaps”:
   ...$3.1 < \eta < 4.7$ and $5.3 < \eta < 6.5$...

⇒ **Measure sd, dd , ced cross sections**

⇒ **Investigate diffractive & forward phenomena together with CMS⁺**
(=CMS+Castor+FCS+ZDC+fp420m?)

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

Forward detectors can be deployed as diffractive mass selectors.

+ fp420m?

TOTEM Collaboration

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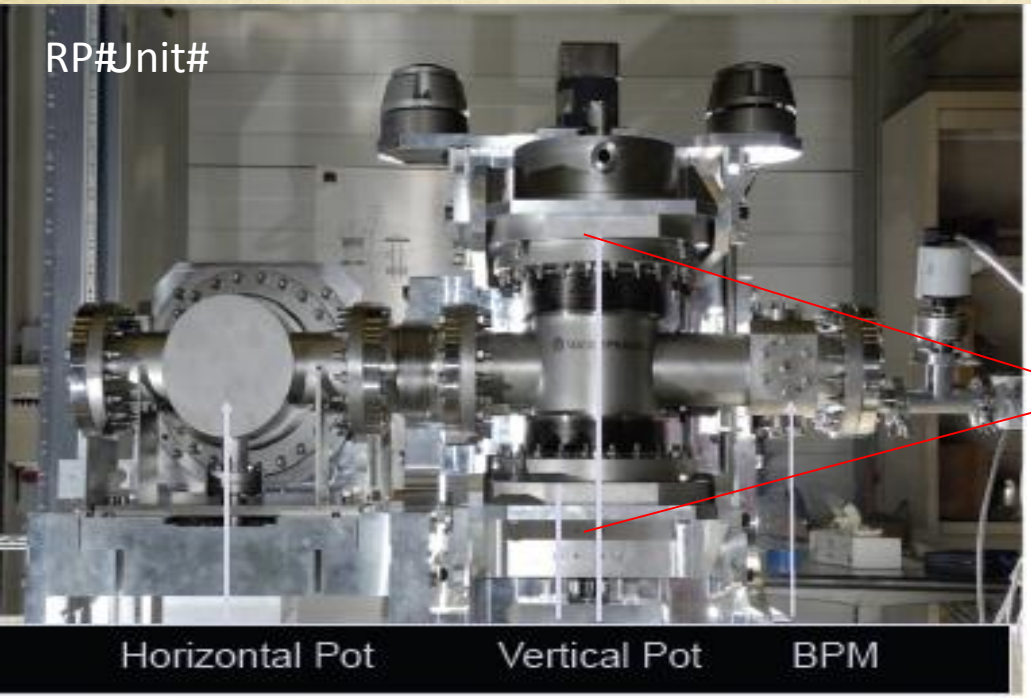
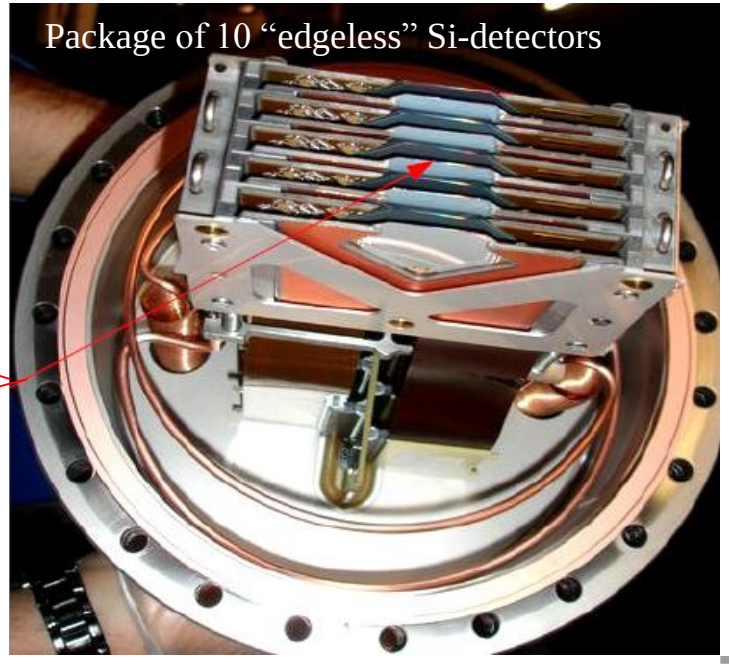
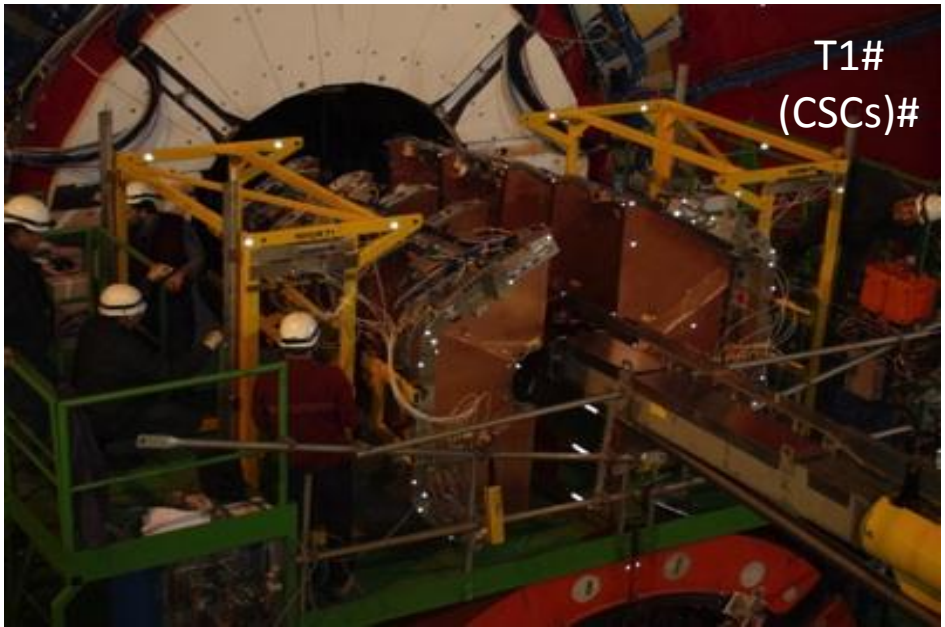
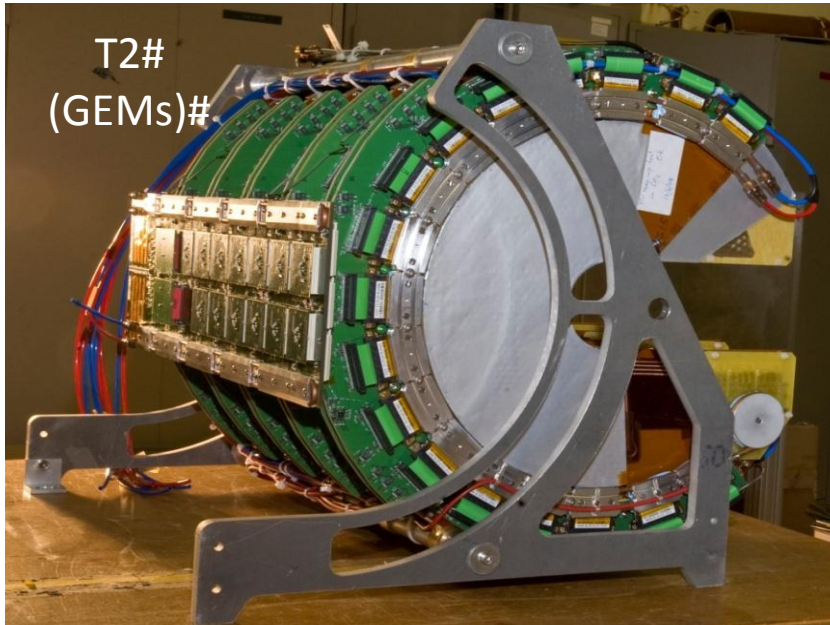
TOTEM DETECTORS

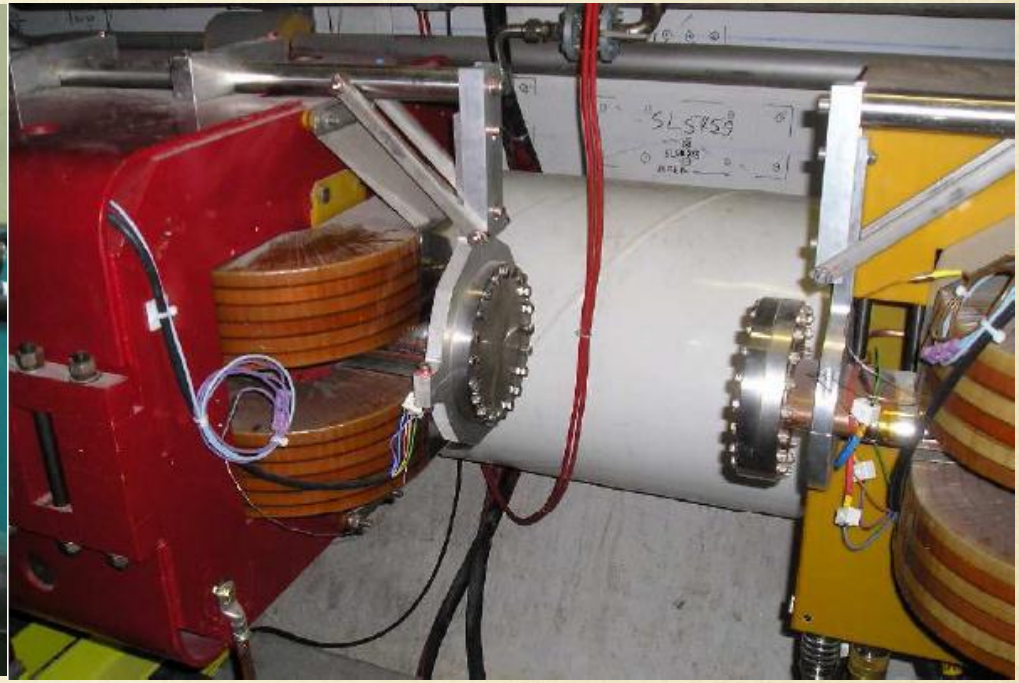








FORWARD SHOWER COUNTERS - FSCs



CORRELATION WITH THE CMS SIGNATURES

- e, γ, μ, τ, and b-jets:
  - tracking: $|\eta| < 2.5$
  - calorimetry with fine granularity: $|\eta| < 2.5$
  - muon: $|\eta| < 2.5$
- Jets, E_T^{miss}
  - calorimetry extension: $|\eta| < 5$
- High p_T Objects
  - Higgs, SUSY,...
- Precision physics (cross sections...)
  - energy scale: e & μ 0.1%, jets 1%
  - absolute luminosity vs. parton-parton luminosity via "well known" processes such as W/Z production?

Leading Proton Measurements

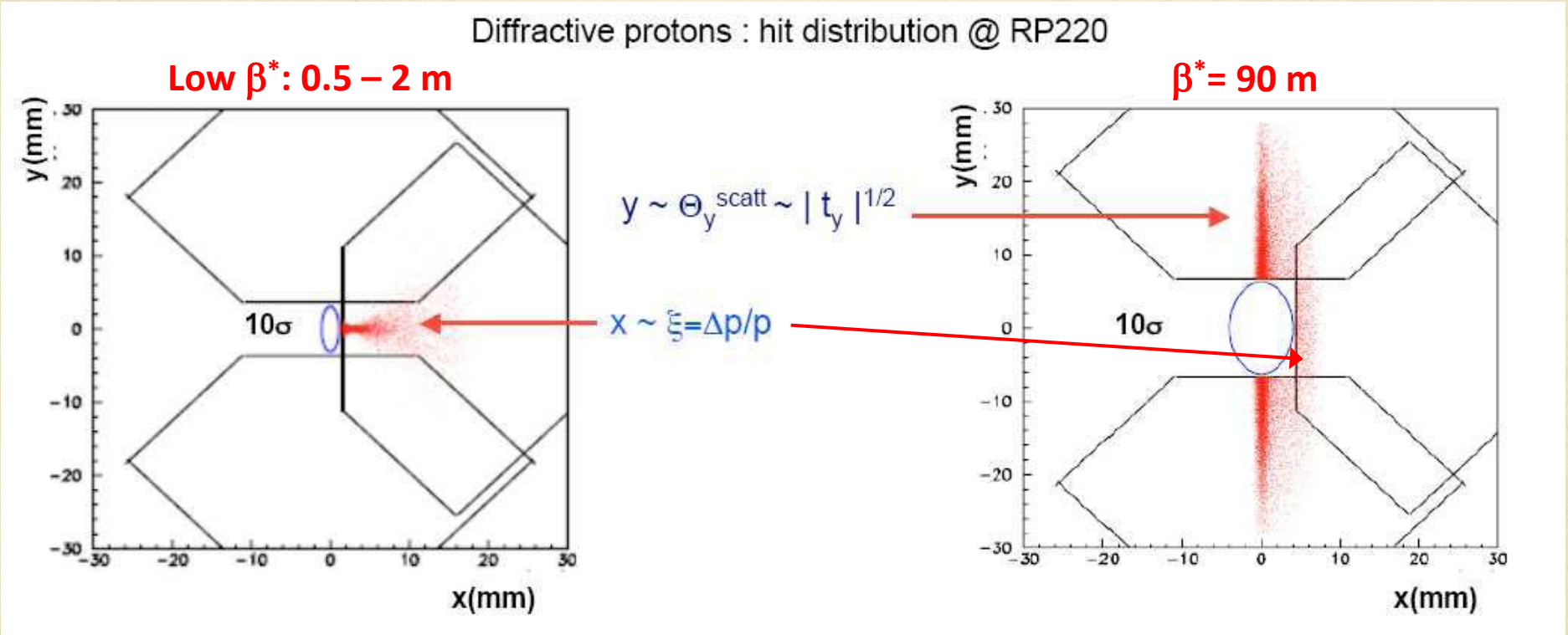
Measure the deviation of the leading proton location from the nominal beam axis ($\Rightarrow\xi$) and the angle between the two measurement locations ($\Rightarrow$-t) within a doublet.

Acceptance is limited by the distance of a detector to the beam. Resolution is limited by the transverse vx location (small ξ) and by beam energy spread (large ξ).

Diffractive forward protons @ RPs

$$y(s) = v_y(s) \cdot y^* + L_y(s) \cdot \Theta_y^*$$
$$x(s) = v_x(s) \cdot x^* + L_x(s) \cdot \Theta_x^* + \xi \cdot D(s)$$

Dispersion shifts diffractive protons in the horizontal direction

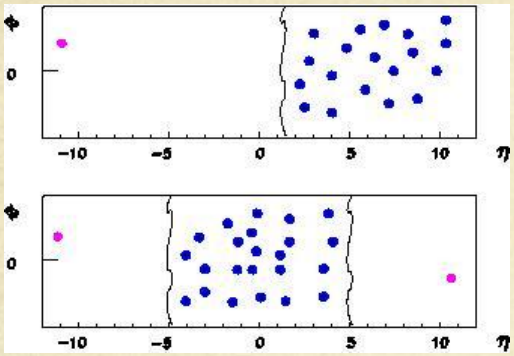


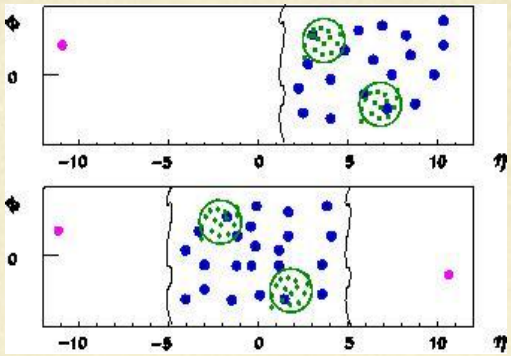
- For low-β* optics L_x, L_y are low
- v_x, v_y are not critical because of small IP beam size
- $\xi=\Delta p/p \sim x$, uncertainty due to (x*,y*)

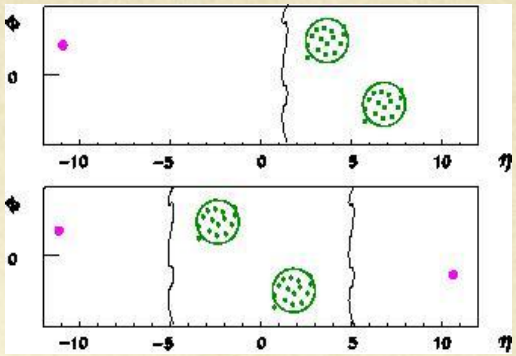
- $L_x=0$, L_y is large
- beam σ = 212 μm → v_x, v_y important (deterioration of rec. resolution)
- measure p through $\Theta_y \propto p_T \approx \sqrt{|t_y|}$
- sensitivity to x* - measure elastics

TOTEM ⊕ CMS RUN SCENARIOS

TOTEM + CMS run scenarios







pp->pX
pp->pXp

soft diffraction

pp->pjjX
pp->pjjXp

(semi)-hard diffraction

pp->pjj (bosons, heavy
pp->pjjp quarks,Higgs...)

hard diffraction

Cross section → Luminosity

β^* (m)	1540	**500**	90	2	0.55
L ($cm^{-2}\ s^{-1}$)	10^{29}		10^{30}	10^{32}	10^{34}

TOTEM LHC runs

Standard LHC runs

S. Giani

COMMON DATA WITH CMS

TRIGGER INFORMATION EXCHANGE – EVENTS FIRST COMBINED BY USING BEAM ORBIT SYNCHRONIZATION

2011 Heavy Ion run: validation of the trigger exchange, data combination T2-CASTOR

2012 Alignment of Roman Pots: CMS jet trigger to TOTEM, events (low statistics) collected

2012 Low pile-up data: 8M events collected, complete trigger menu, exchange of triggers TOTEM $\Leftrightarrow$ CMS (CMS jet trigger, TOTEM min bias, RPs not in)

COMMON DATA WITH CMS

Foreseen in 2012:

- β^* = 90 m, 156 bunches, **expect $\int L \sim 6 nb^{-1}/h$**
- Leading protons for the full range in $\xi \sim 0$, $|-t| > 0.02$ GeV^2
- Triggers vs. Physics aims: min bias, elastic /TOTEM stot), di-jets, leptons,...

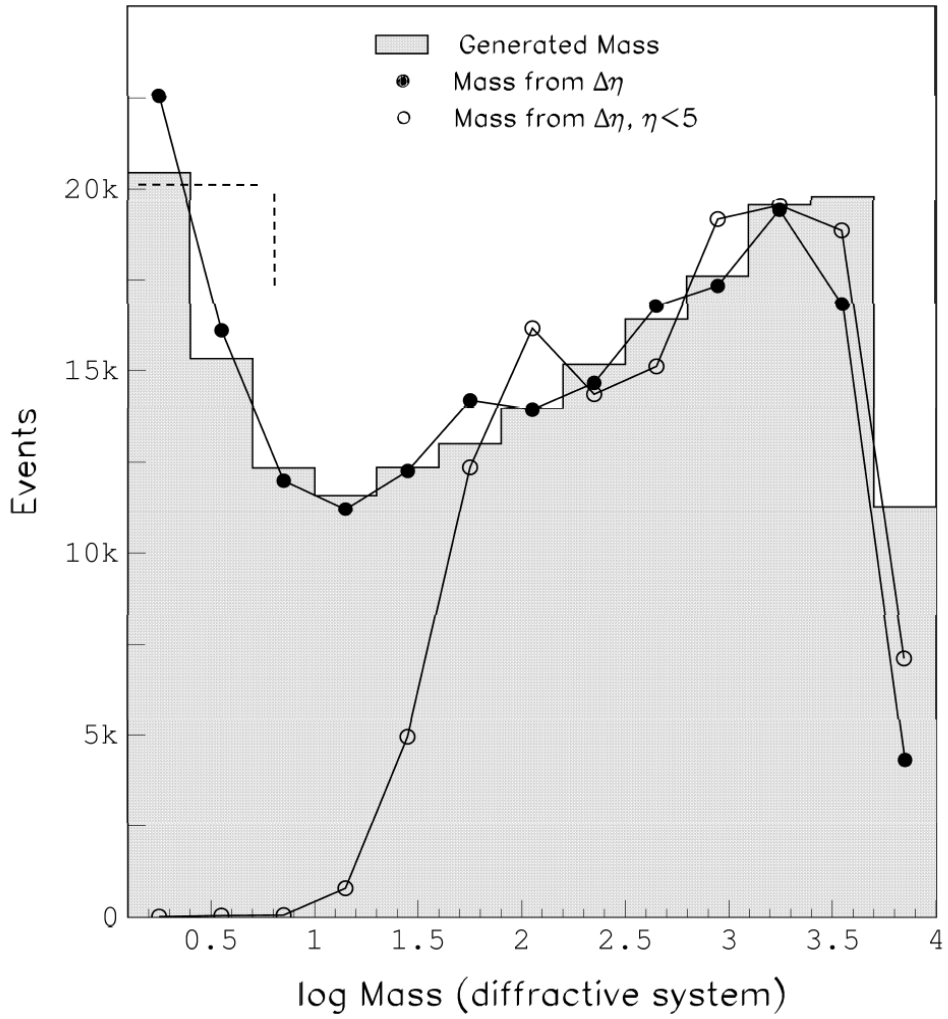
- Standard LHC optics, some 1400 bunches, full lumi
- Leading protons for the full range in $|-t|$, ξ > 2-3%
- CMS triggers include jet, μ, ε, γ, p combinations with the TOTEM RP trigger
- Data taking asap after aligning the RPs & allowed to be inserted at high lumi

Single Diffraction (sd)

Central Exclusive Diffraction (ced):

Forward multiplicities

Forward Detectors – Mass Selectors



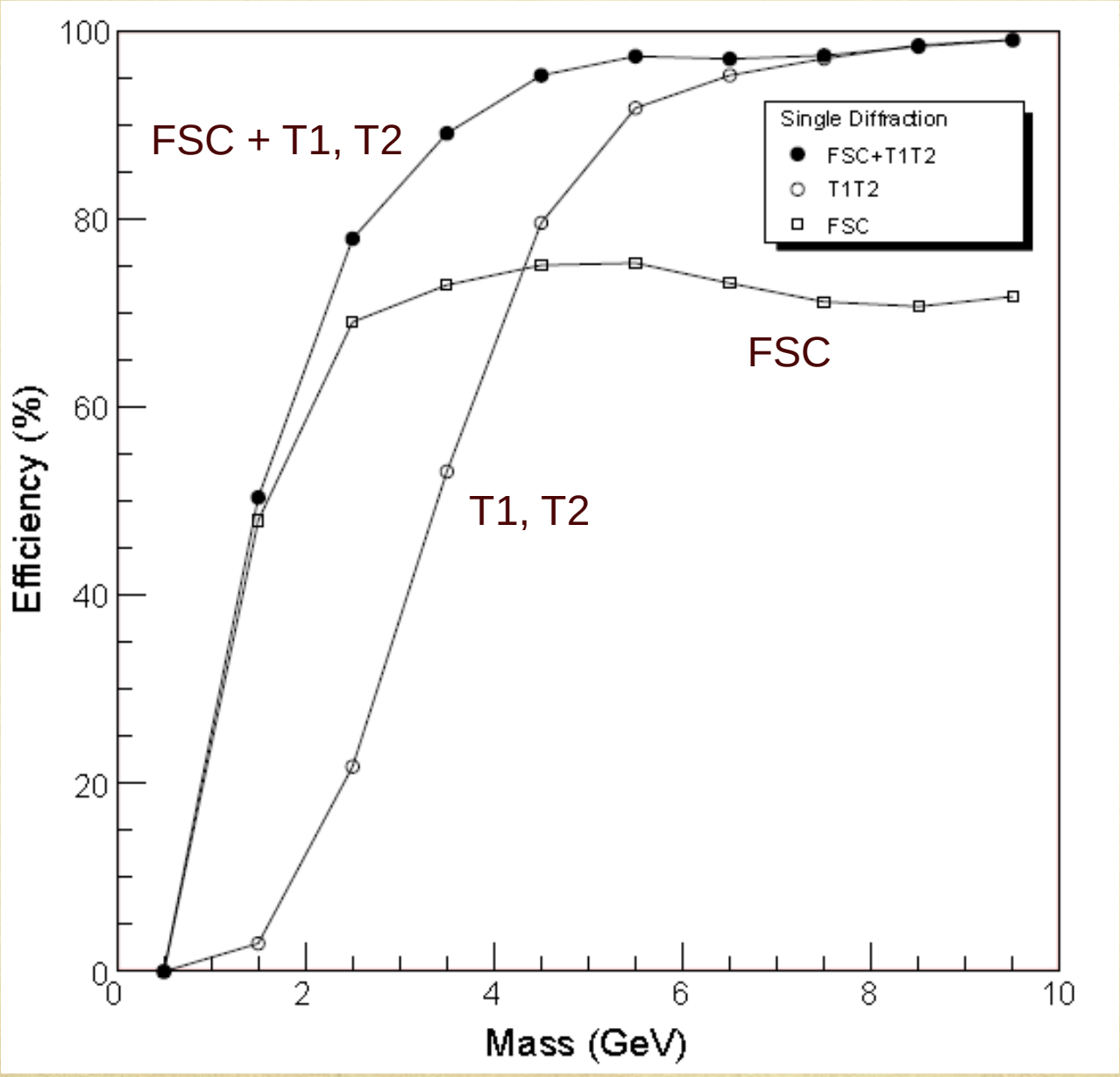
Calculate using the rap gap:

$\ln M_X^2 = \Delta\eta$

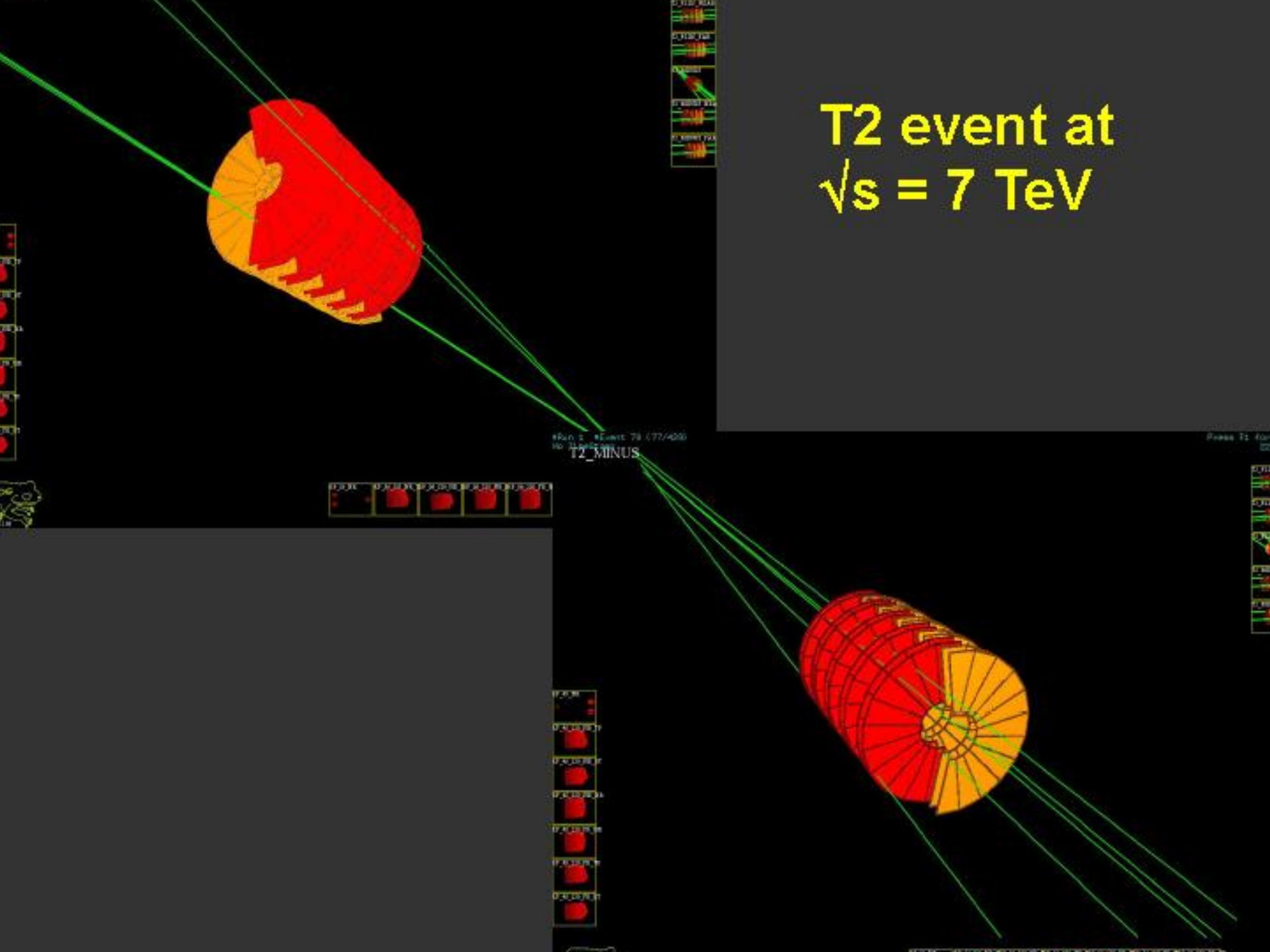
Access to small M_X iff forward detectors at $|\eta| > 5$.

T1, T2 and the FSCs see diffractive systems with decreasing masses – a natural way to select.

EFFICIENCY OF DETECTING sd EVENTS

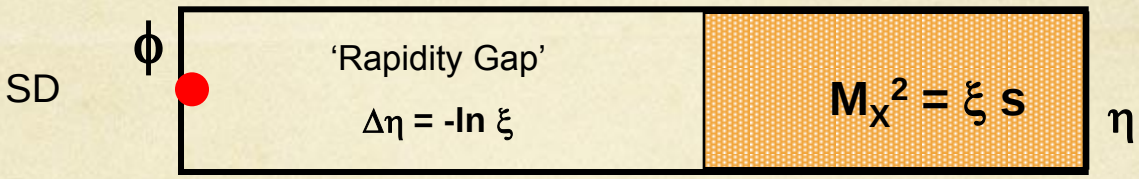


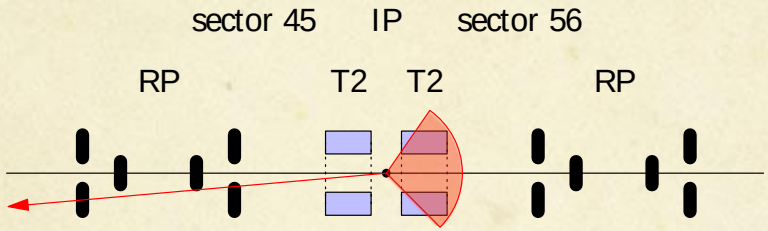
WITH FSC, DETECT sd EVENTS DOWN TO $M_{diff} \geq 1.1$ GeV

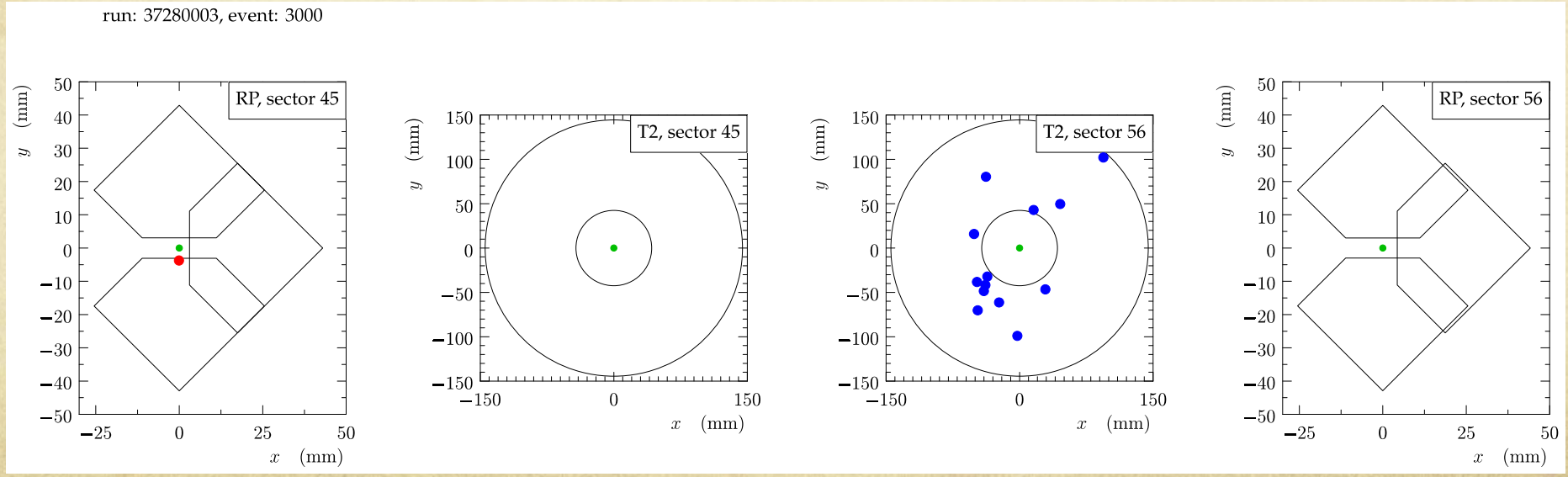

T2 event at
√s = 7 TeV
T2_MINUS

Single diffraction low ξ

Correlation between leading proton and forward detector T2

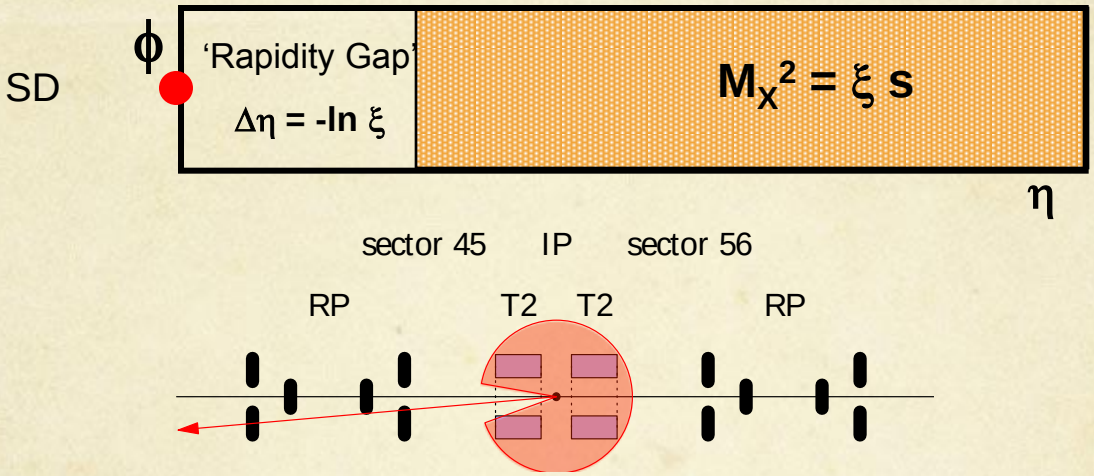


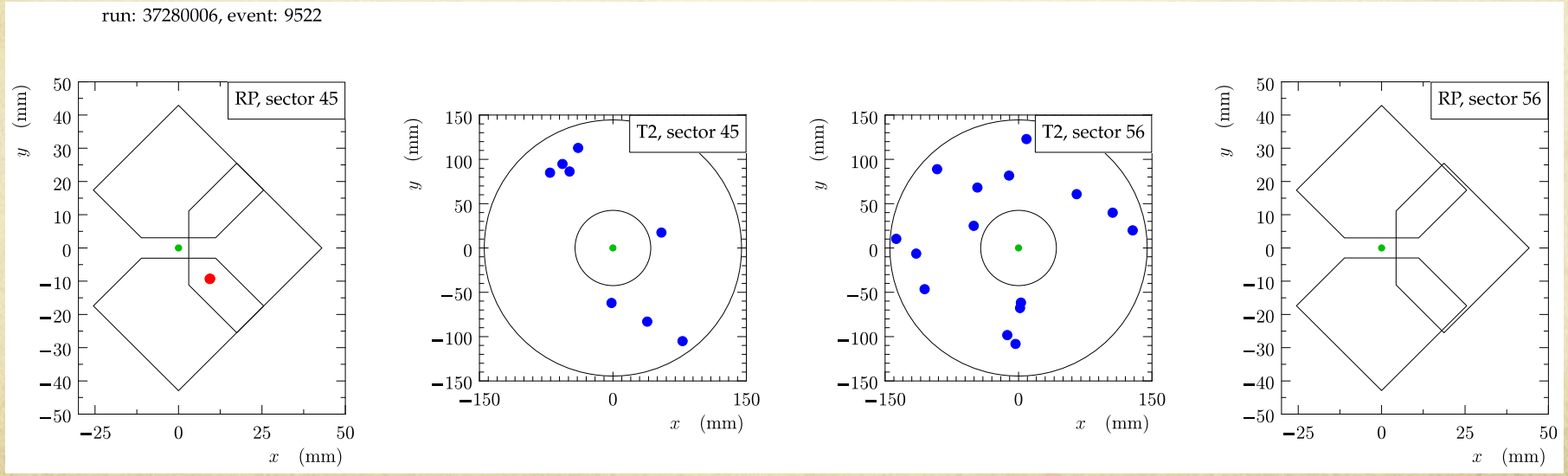




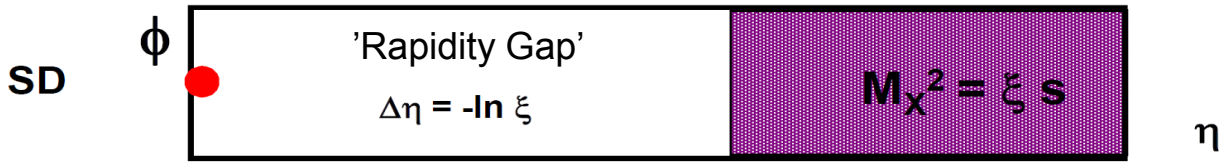
Single diffraction large ξ

correlation between leading proton and forward detector T2

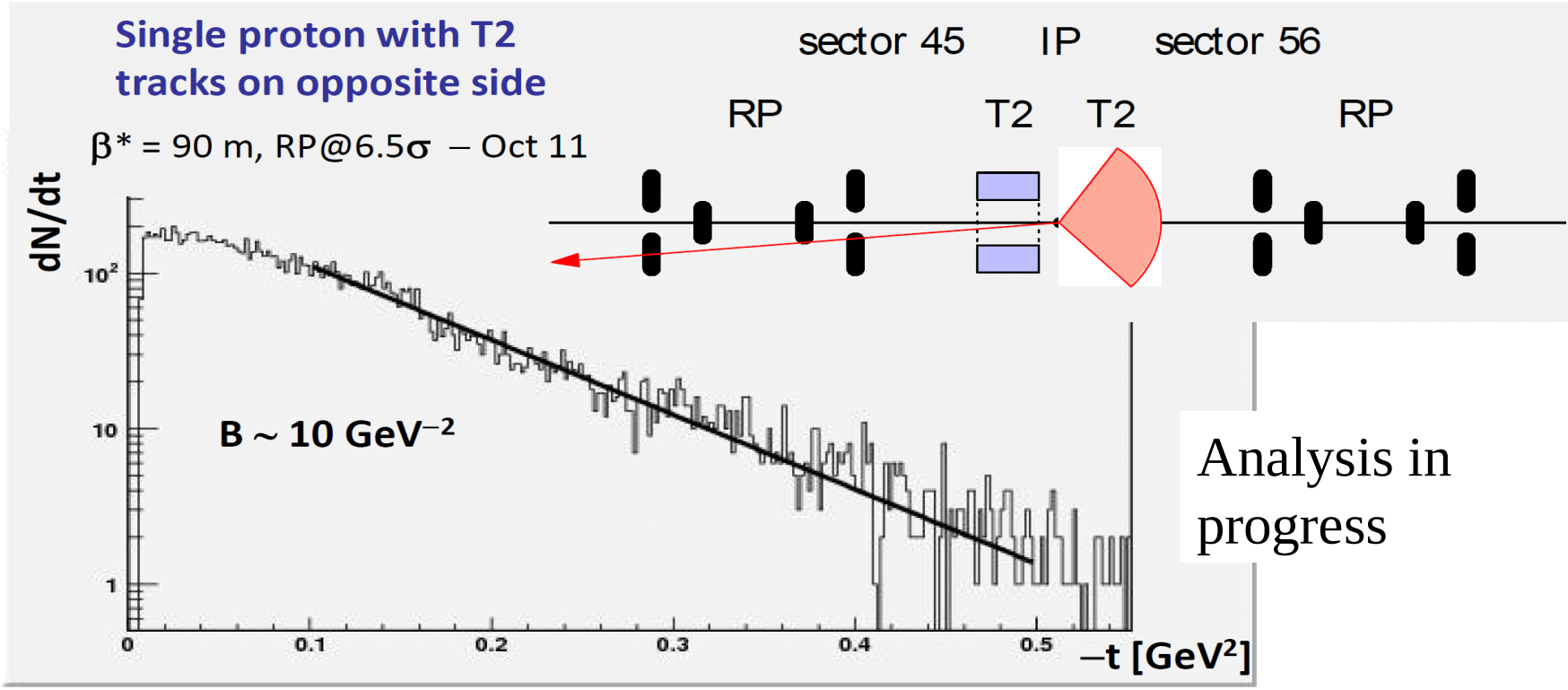




$d\sigma_{SD}/dt$ & σ_{SD}



Preliminary

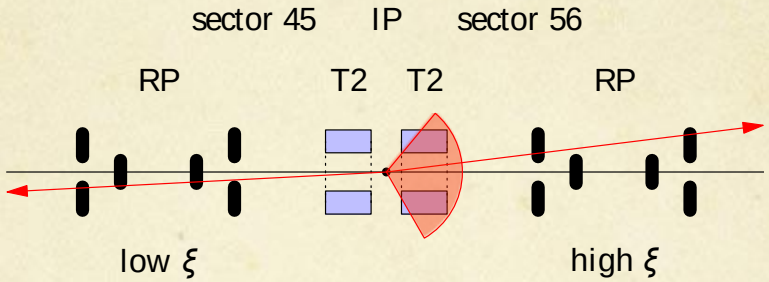


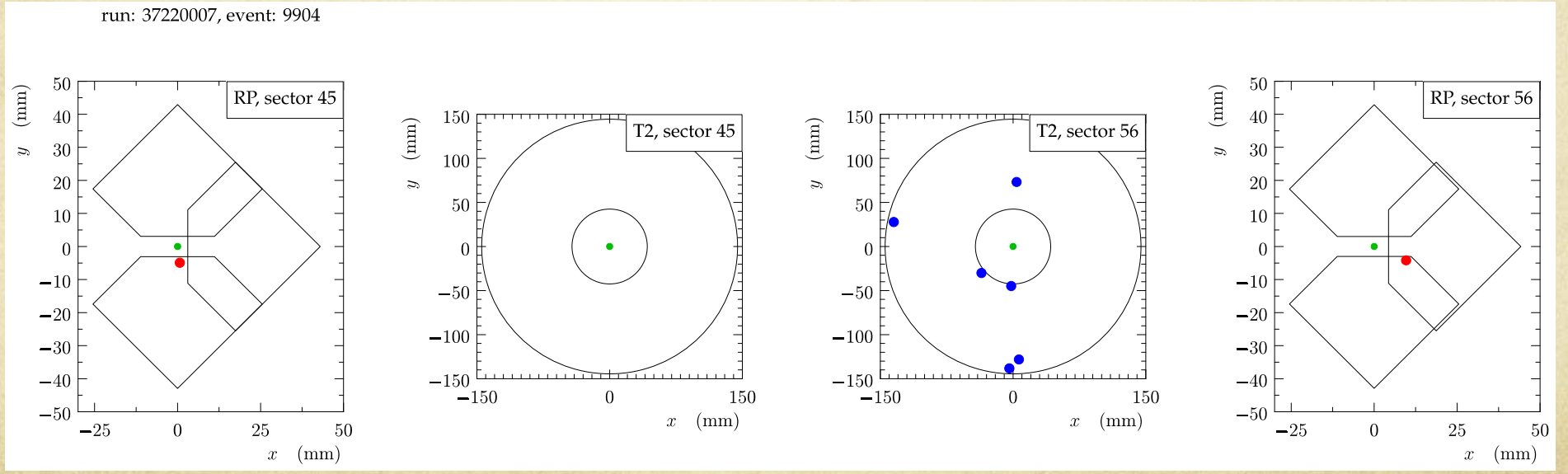
Analysis in progress

Raw distribution (to be corrected for acceptance, ...)

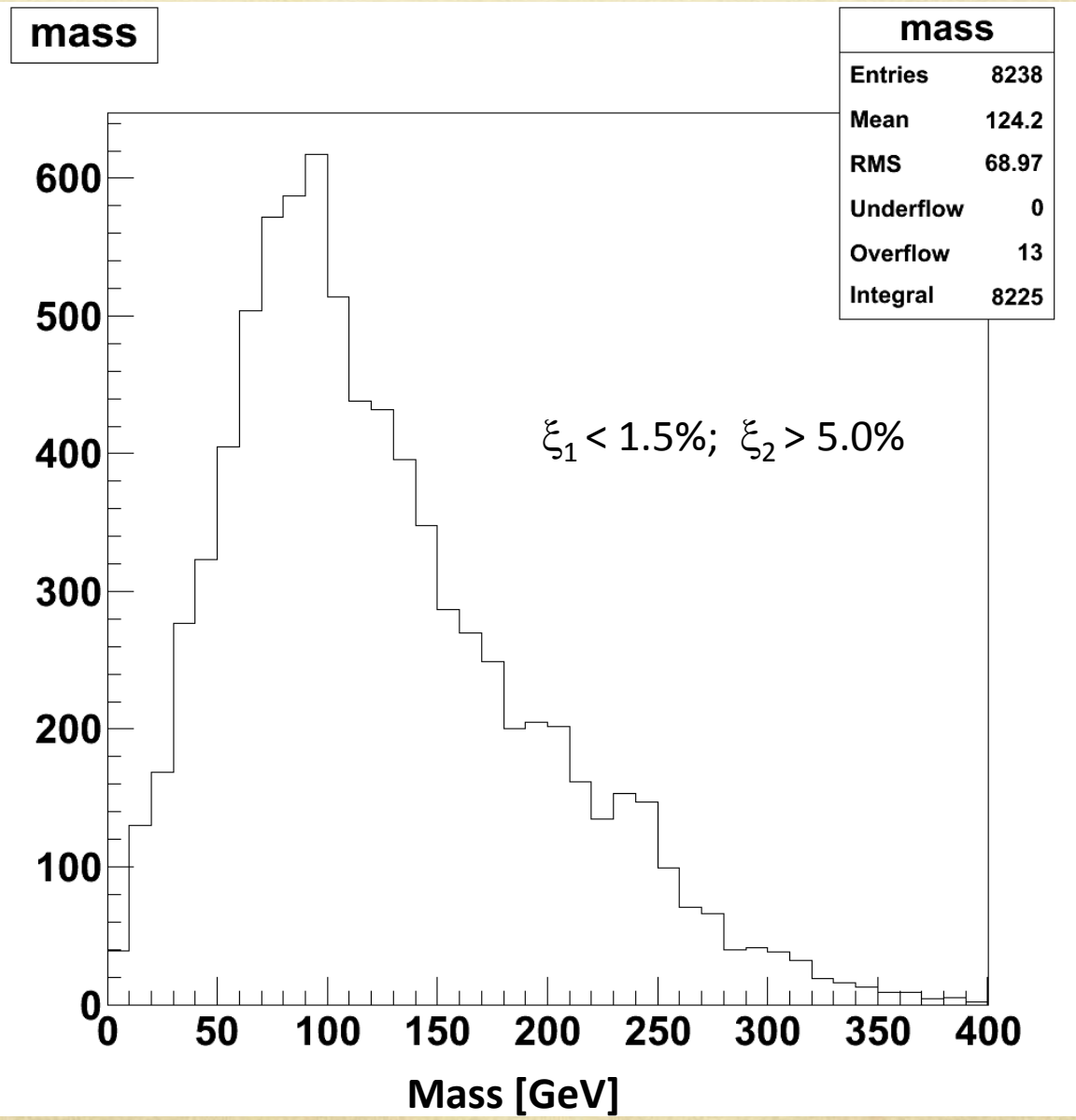
Central Exclusive Diffraction (ced)

correlation between leading protons and forward detector T2





Example of ced Mass Reconstruction



Low-β

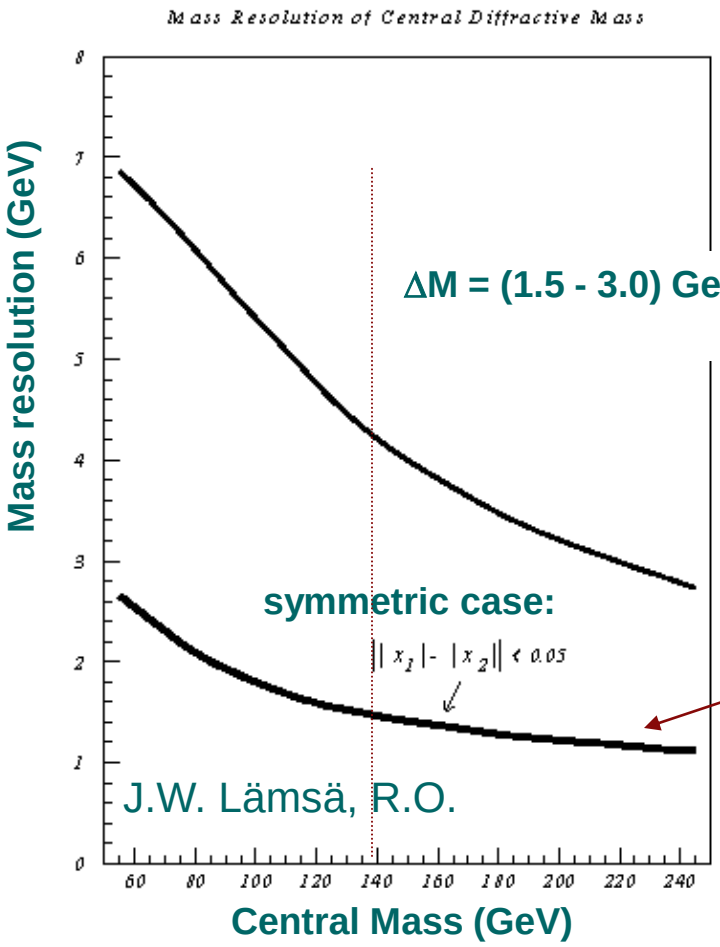
RP vertical

RP horizontal

T2

A historical note....

ced mass measurement at 420m...



Mass resolution vs. central mass assuming $\Delta x_F/x_F = 10^{-4}$

ΔM = (1.5 - 3.0) GeV ($\Delta x_F/x_F = (1\text{-}2)\times 10^{-4}$)

Stable result since 2001.

≈ 65% of the data

20 GeV < M_X < 160 GeV

(M_{Xmax} determined by the aperture of the last dipole,B11,
M_{Xmin} by the minimum deflection = 5mm)

LISHEP 2002

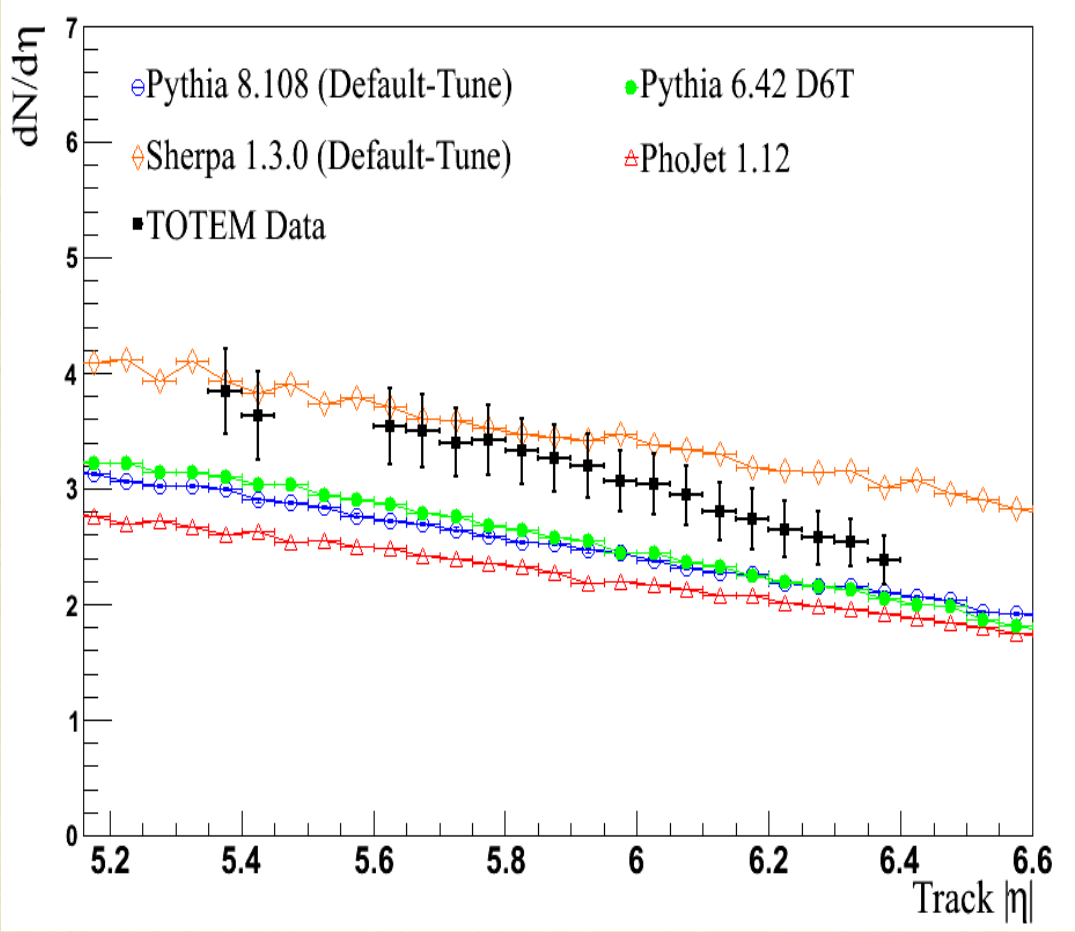
Workshop on Diffractive Physics
4. – 8. February 2002
Rio de Janeiro, Brazil

Forward Multiplicities

Forward Multiplicities – Event Selection

- Low luminosity runs
- Trigger by T2 – at least 1 rec track
- Primary particles: $t > 0.3 \cdot 10^{-10}$ s, $p_t > 40$ MeV
- Use impact parameter (z) for primary/sec
- Evaluate primary track reconstruction efficiency event-by-event $\Rightarrow$ ~80%

Charged particles vs. pseudorapidity

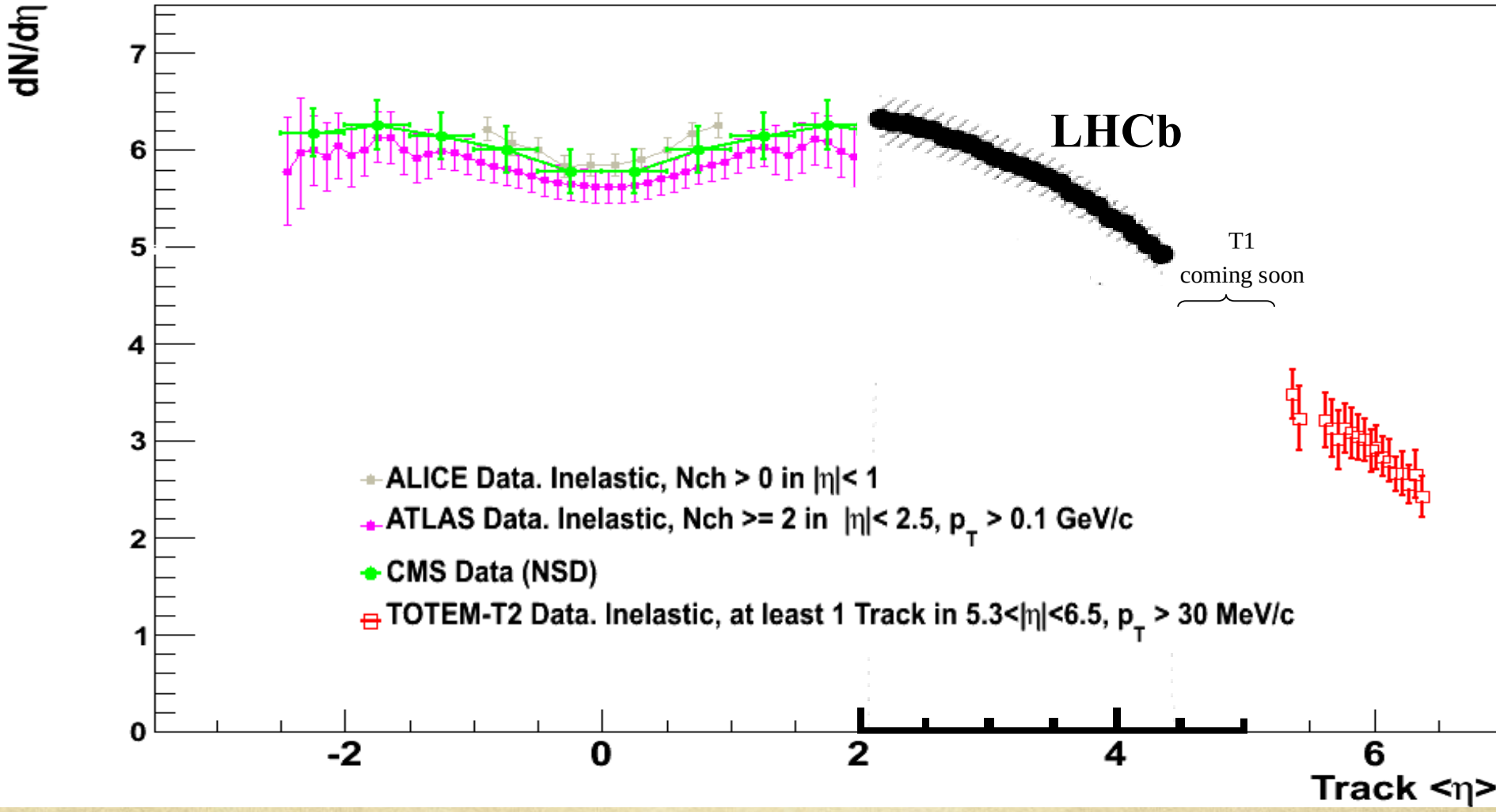


The experimental points (black squares) - the average of 4 T2 quarters. Bars include both statistical and systematic errors.

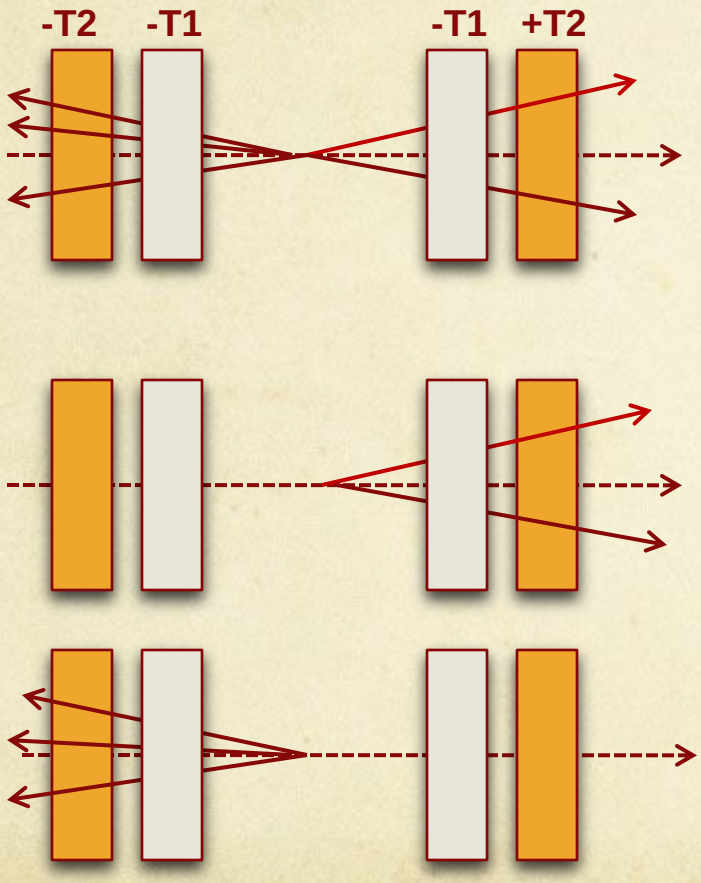
Red triangles, blue circles, green circles and orange diamonds: the Phojet, Pythia8, Pythia6 and Sherpa predictions for charged particles with p_T > 40MeV/c in events with at least one charged particle within the range $5.3 < |\eta| < 6.5$

EPL 98(2012)31002

dN/dh from ALICE, ATLAS, CMS, LHCb & TOTEM-T2



Event Classification by the T2s

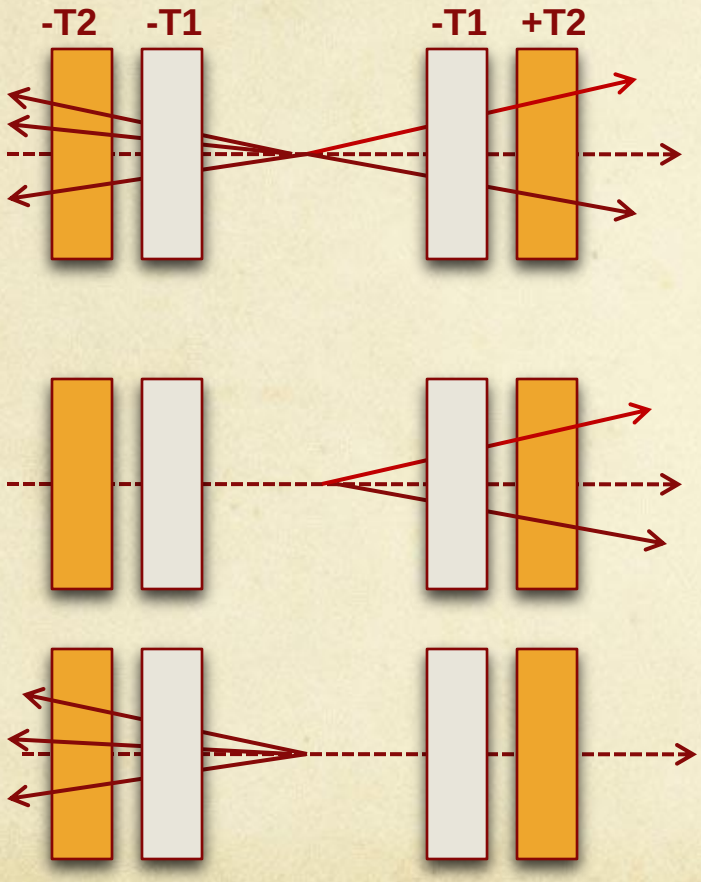


See the talk by Tuula Mäki!

Tracks in both T2s: dd & nd

Tracks in ±T2: mostly sd
(M* > 3.4 GeV)

Event Classification by the T1s&T2s



Tracks in both ±T2s
No Tracks in ±T1s : Clean dd!
- See the talk by **Tuula Mäki**

Tracks in either +T2 or –T2
No Tracks in T1s:
Mostly sd (M* > 3.4 GeV),
- But not so clean

CROSS SECTION σ_{inel}

- trigger efficiency: measured from zero bias data vs. track multiplicity for each event category ~2.3%
- track reconstruction efficiency, based on MC tuned to data ~1%
- beam-gas background, measured with non-colliding bunch data ~0.54%
- pile-up (μ~0.03), measured by zero bias data ~1.5%

σ_{inel}(visible in T2; M_{fwd} > 3.4 GeV) = 69.7 $\pm$ 0.1(stat.) $\pm$ 0.7(syst.) $\pm$ 2.8(lumi) mb

CROSS SECTION σ_{inel}

Contribution from the unseen low mass (diffractive) systems below M ≈ 3.4 GeV, estimated (preliminary) to be abot 3.7%.

- Low mass component will be measured independently.

σ_{inel} = 73.7 ± 0.1(stat.) ± 1.7(syst.) ± 2.9(lumi) mb

Fwd Analysis Plans

- **Charged multiplicities & Correlations**
  for a maximal $\Delta\eta$
- **Proton-proton σ_{inel}**
  revisited at 8 TeV
- **Event Classification¨**
  Pile-Up, Underlying Events, sd, dd, ced, ...
- **Central Exclusive Production**

Ambitious plans for 2012 & beyond!

STATUS OF THE MULTIDIMENSIONAL EVENT CLASSIFICATION

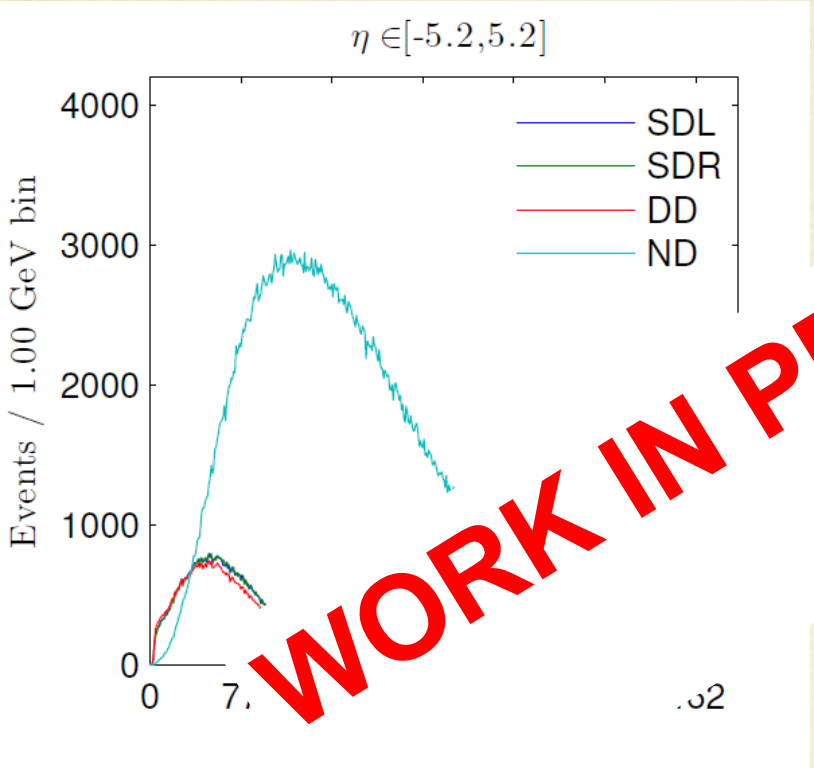
-Good & Walker inspired approach

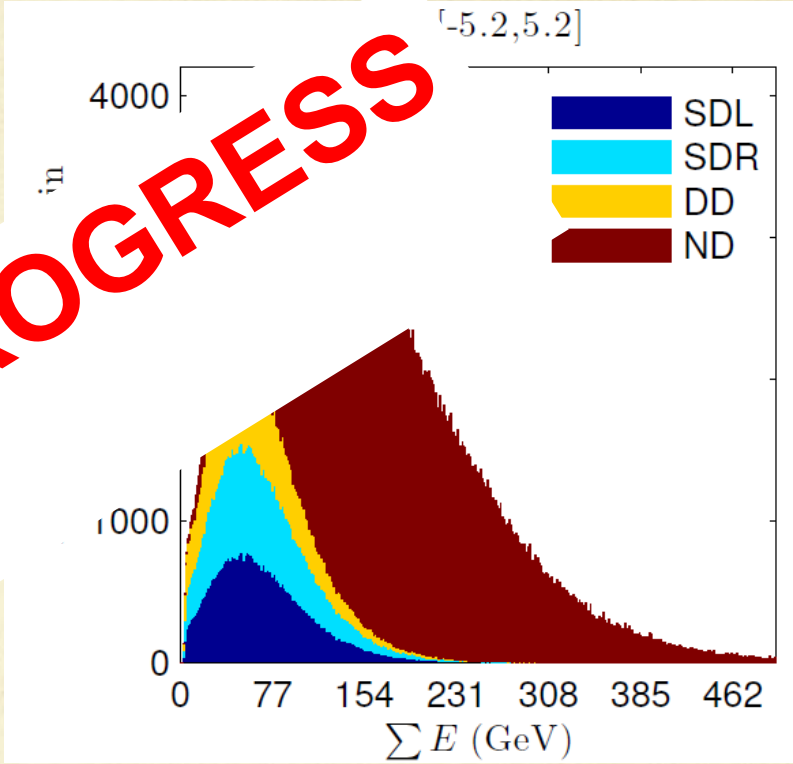
- Classifier algorithms implemented
- Integrated cross sections: σ(sdl,sdr,dd,nd) obtained
- Effects of (theoretical) prior cross sections obtained
- Being worked on: Experimental sample selection

Diffraction:
fluctuations in impact parameter, no. of contributing entities (wees), rapidity

Mikael Mieskolainen & RO

SOFT EVENT CLASSIFICATION - AN EXAMPLE PLOT





WORK IN PROGRESS

Normalized to: σ_{inel}(CDF) = 58.96 mb

SDL	SDR	DD	ND
5.42	5.42	4.97	43.15 [mb]