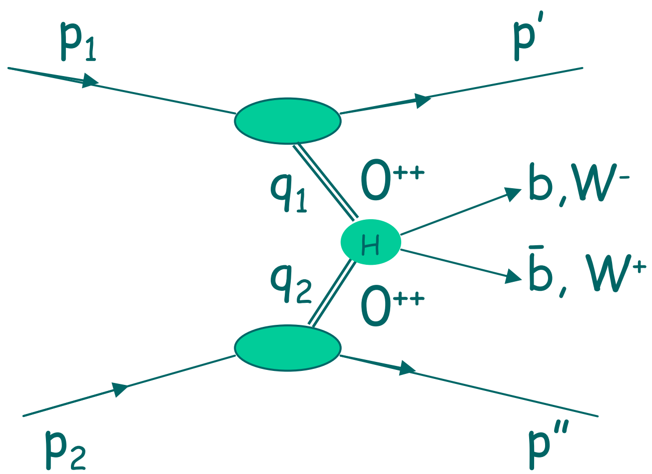
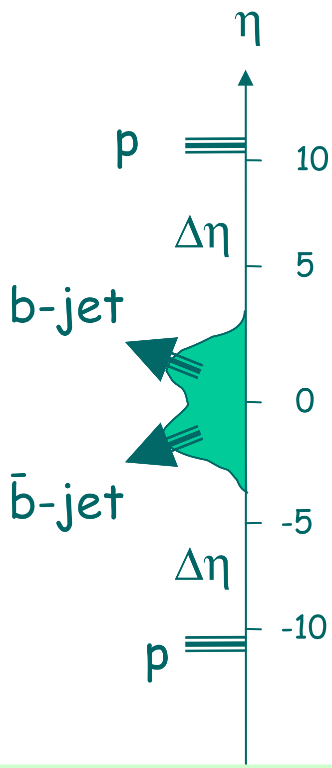
Central Diffraction at the LHC - an Update

- acceptance & central mass resolution
- bench mark process: pp $\rightarrow$ p + X + p

The process: pp → p + H + p



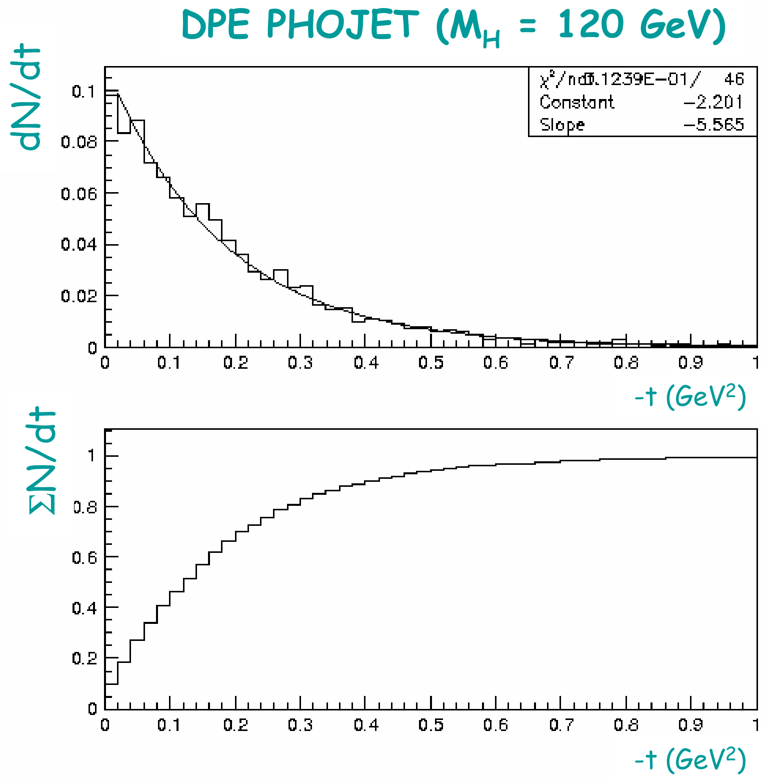


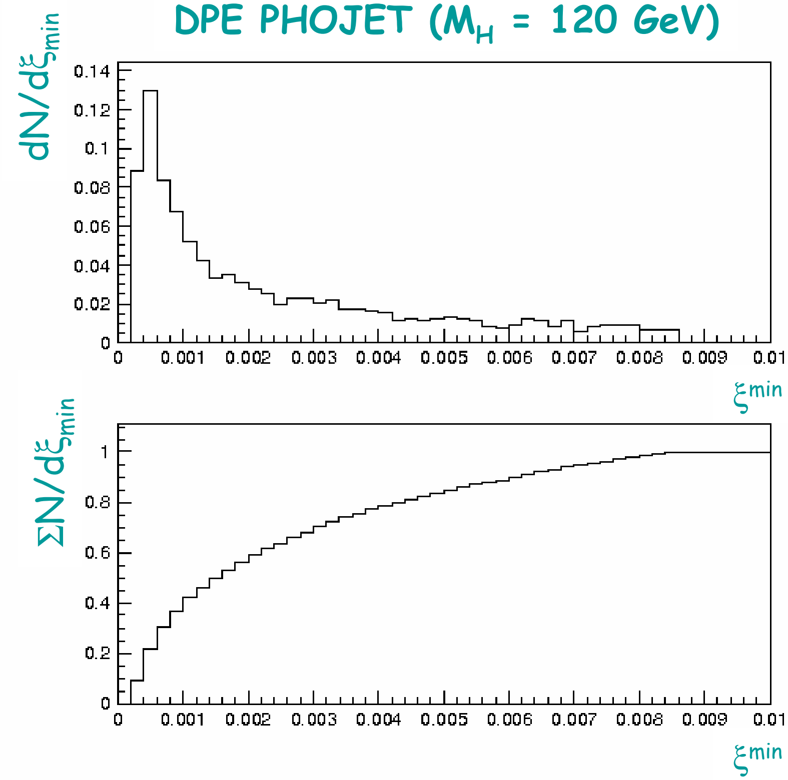
$M_H^2 = (p_1 + p_2 - p' - p'')^2 \approx \xi_1 \xi_2 s$ (at the limit, where p_T' & p_T'' are small)

Event Characteristics: $d\sigma/dt$ & ξ_{min}

$-t < 1\ GeV^2$

ξ acceptance?



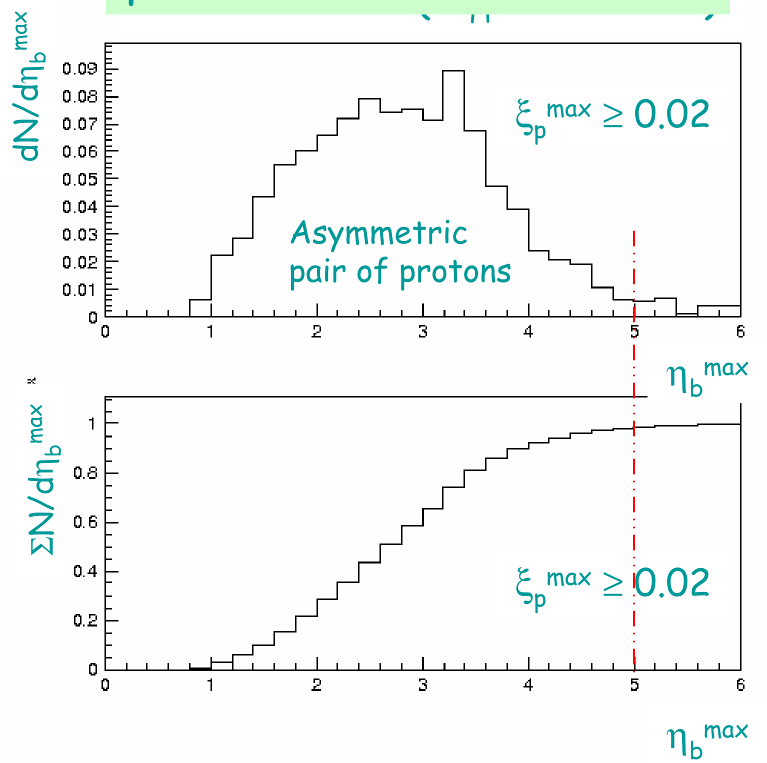


$\Rightarrow dN/dt \propto \exp(-10t)$

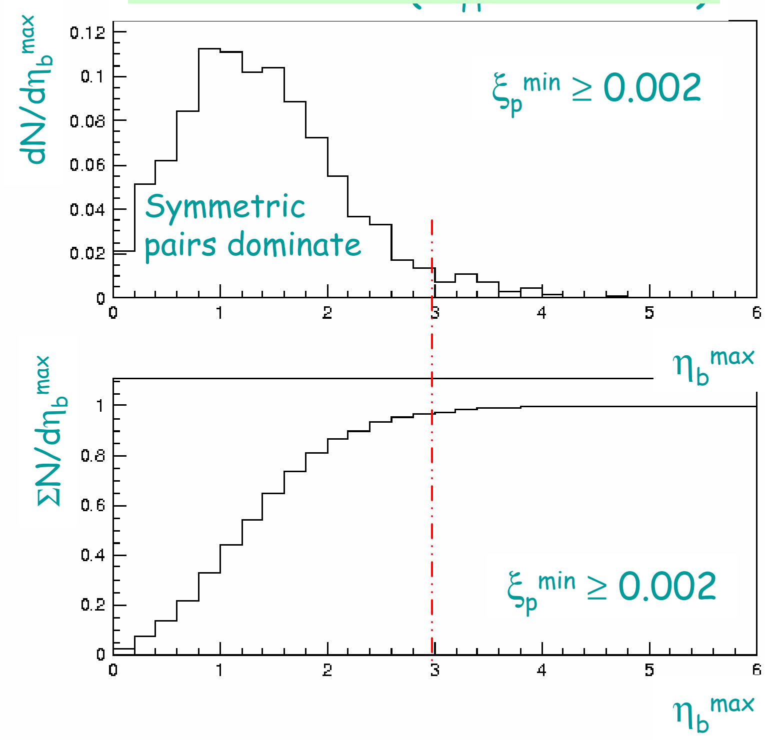
$\Rightarrow$ should detect p's down to $\xi \leq 10^{-3}$

Event Characteristics: Where do the decay b-jets go?

Asymmetric pair of protons

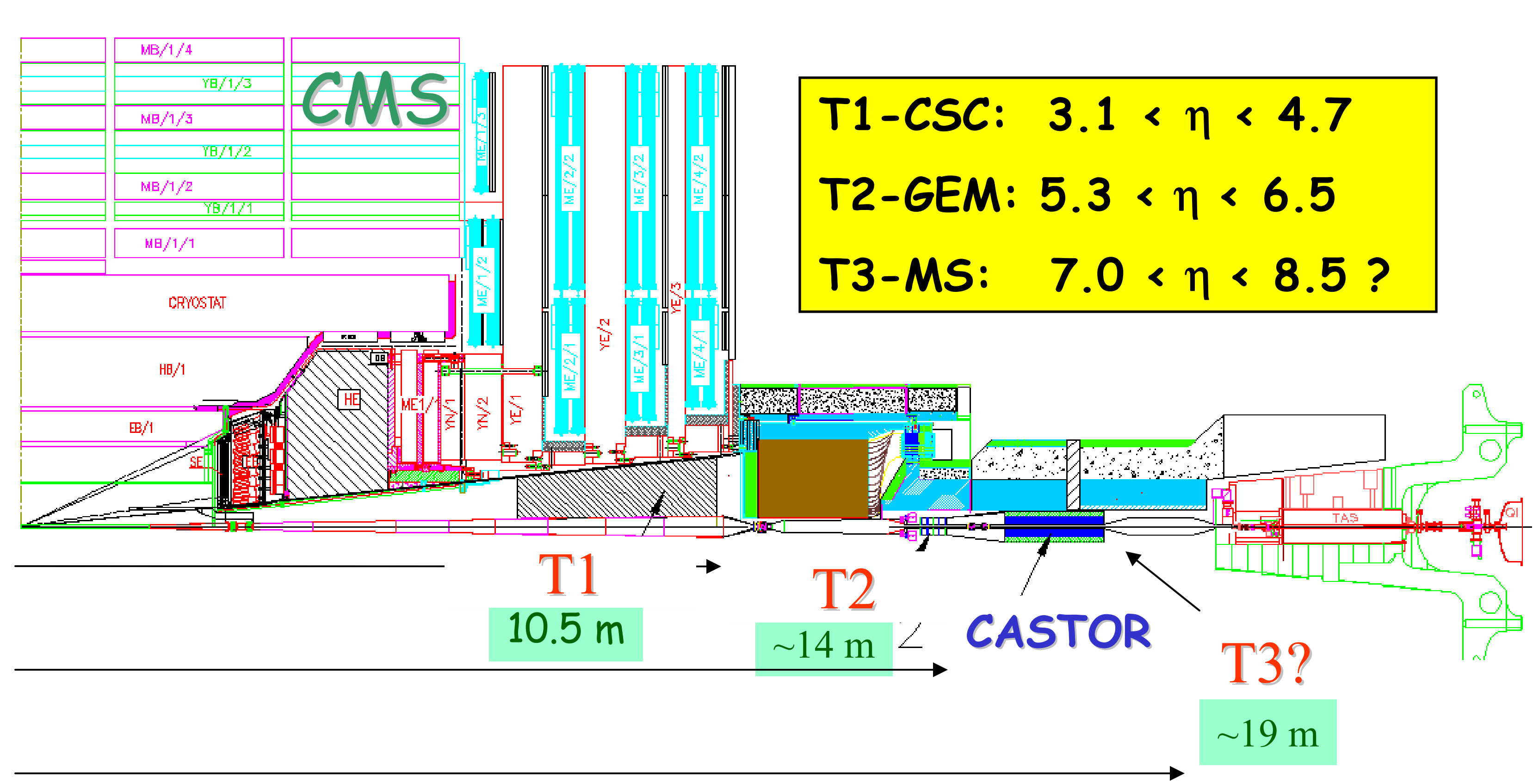


A typical - symmetric - pair of protons



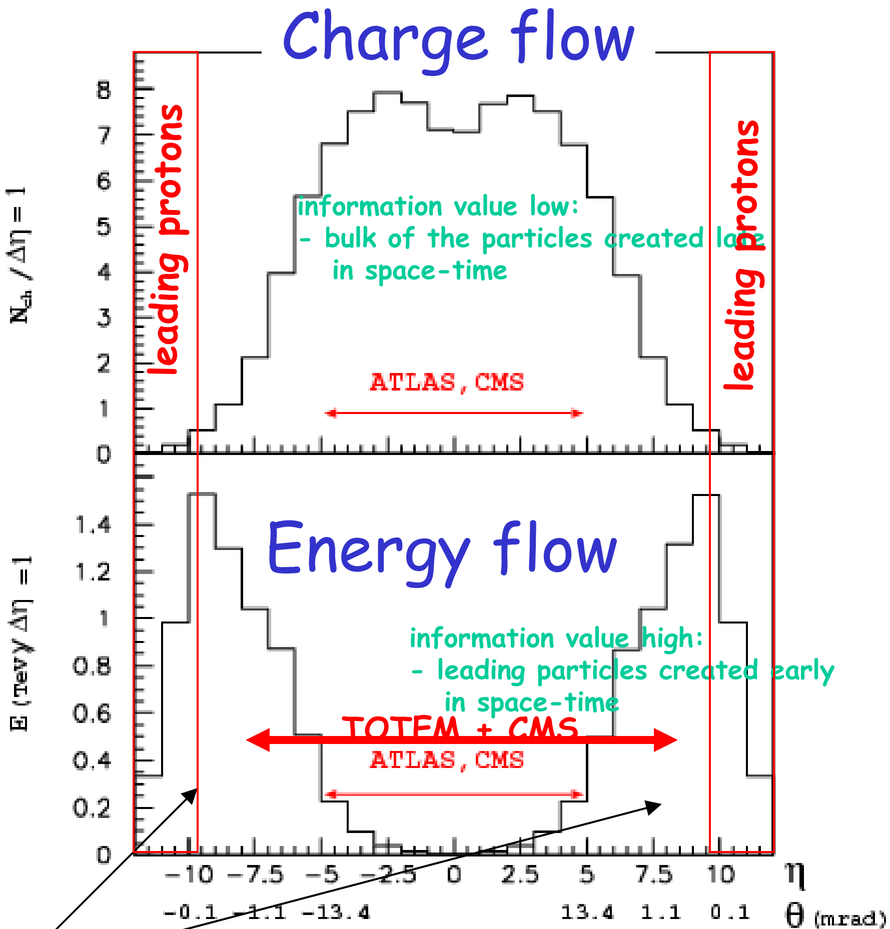
$\Rightarrow$ All the b-jets are confined within $|\eta| \leq 5$.

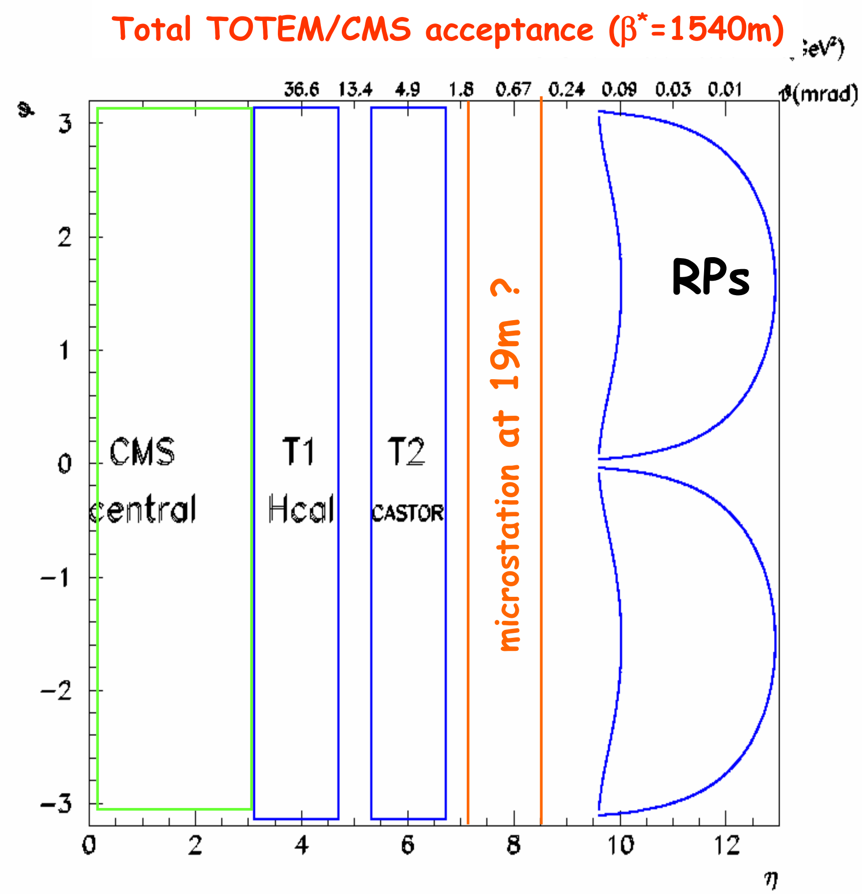
CMS tracking is extended by forward telescopes on both sides of the IP



- A microstation (T3) at 19m is an option.

Important part of the phase space is **not** covered by the generic designs at LHC. **TOTEM ⊕ CMS Covers more than any previous experiment at a hadron collider.**





In the forward region (|η| > 5): few particles with large energies/small transverse momenta.

Leading proton studies at low β^*

GOAL: New particle states in Exclusive DPE

- L > few $\cdot 10^{32}$ cm^{-2} s^{-1} for cross sections of ~ fb (like Higgs)
- Measure <u>both</u> protons to reduce background from inclusive
- Measure jets in central detector to reduce gg background

Challenges:

- M ~ 100 GeV ⇒ need acceptance down to ξ's of a few ‰
- Pile-up events tend to destroy rapidity gaps ⇒ L < few $\cdot 10^{33}$ cm^{-2} s^{-1}
- Pair of leading protons ⇒ central mass resolution ⇒ background rejection

A 140 GeV Higgs as a bench mark.

A study by the Helsinki group in TOTEM.

Leading proton acceptance & resolution studies

- pp $\rightarrow$ p + X + p simulated using PHOJET1.12
- Protons tracked through LHC6.2 optics using MAD8

Uncertainties included in the study:

- Initial conditions at the interaction point
  - Transverse vertex position ($\sigma_{x,y}$ = 16 $\rightarrow$11 μm)
  - Beam energy spread (σ_E = 10^{-4})
  - Beam divergence (σ_θ = 30 μrad)
- Conditions at detector location
  - Position resolution of detector ($\sigma_{x,y}$ = 10 μm)
  - Resolution of beam position determination ($\sigma_{x,y}$ = 5 μm)
  - Off-sets at detector locations

T. Mäki, MSc (eng.)thesis;
HIP-2003-11/EXP

Update by Jerry Lamsa & RO

Uncertainties of The Initial Conditions

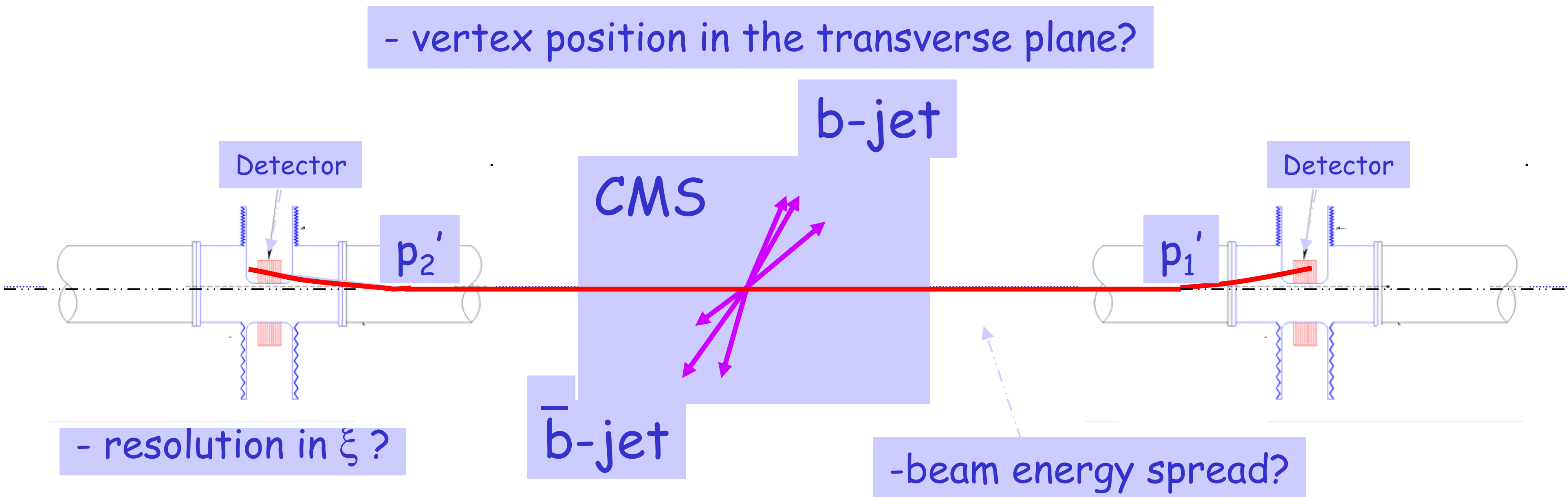
LHC beams

- beam energy spread (RF, field values, ground movement...)
- resolution of the beam position measurement
- absolute beam position

Interaction vertex

- spread of the coordinates (x,y,z)
- uncertainty of the scattering angle

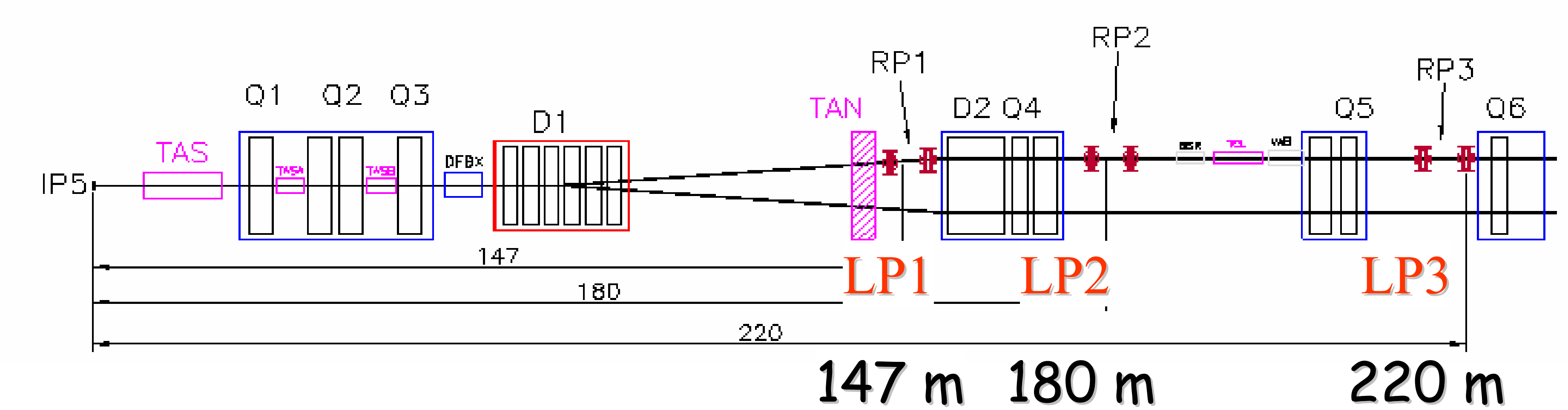
The Experimental Signatures:
$pp \rightarrow p + X + p$



Aim at measuring the:

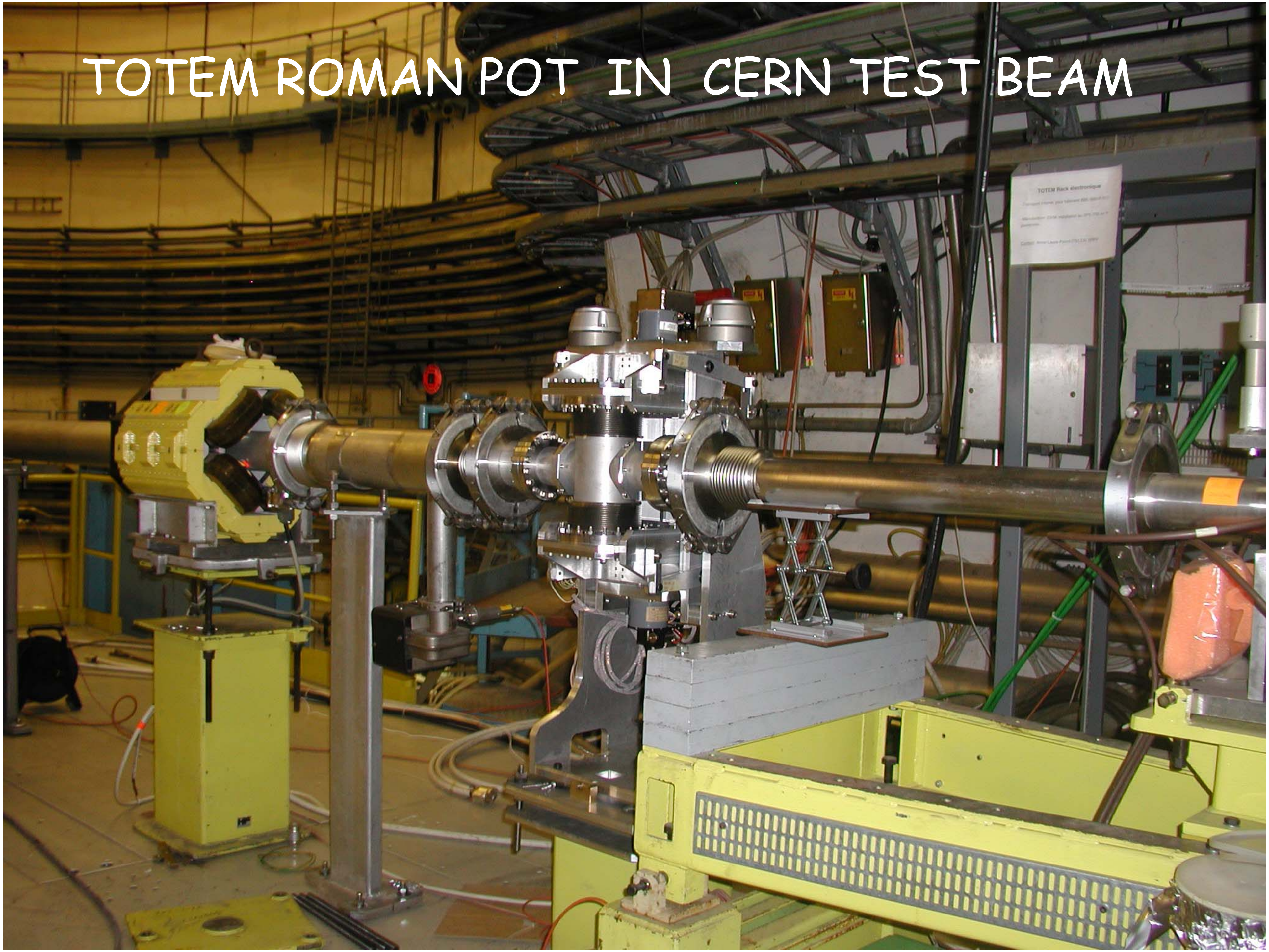
- Leading protons on both sides down to $\Delta\xi \approx 1‰$
- Rapidity gaps on both sides – forward activity – for $|\eta| > 5$
- Central activity in CMS

Need to Measure Inelastic Activity and Leading Protons over Extended Acceptance in η, ξ, φ and -t. Measurement stations (RP's/μS's) at locations optimized vs. the LHC beam optics. Both sides of the IP.



Measure the <u>deviation</u> of the leading proton location from the nominal beam axis (⇒ξ) and the angle between the two measurement locations (⇒-t) within a doublet.
Acceptance is limited by the <u>distance</u> of a detector to the beam.
Resolution is limited by the <u>transverse vx location</u> (small ξ) and by <u>beam energy spread</u> (large ξ).

For Higgs, SUSY etc. heavier states need LP4,5 at 300-400m!


TOTEM ROMAN POT IN CERN TEST BEAM

Potential locations for measuring the leading protons from O(100 GeV) mass DPE.

Cryogenic ("cold") region (with main dipole magnets)

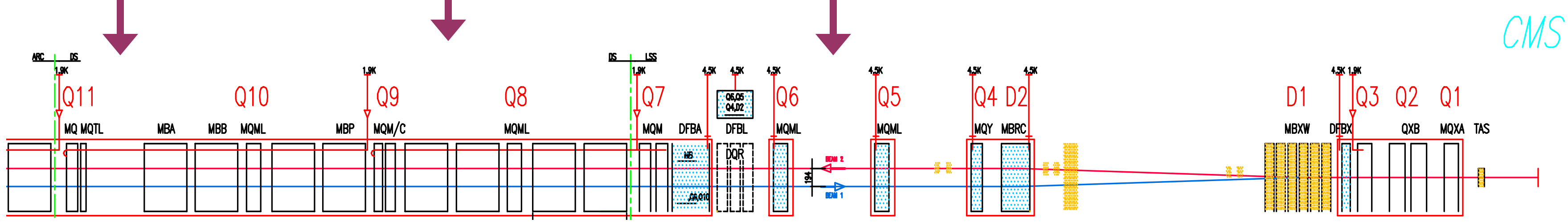
location of currently planned TOTEM pots!!

420 m

308/338 m

220 m

CMS



Dispersion suppressor

Matching section

Separation dipoles

Final focus

LHC Beams

Energy spread:

– $\sigma_E = 1.1 \cdot 10^{-4}$ (fill-to-fill variation $\leq 10^{-4}$, magnets can be controlled to 10^{-6}!)

Beam position resolution:

- given by the BPM's to 5 μm

Absolute beam position:

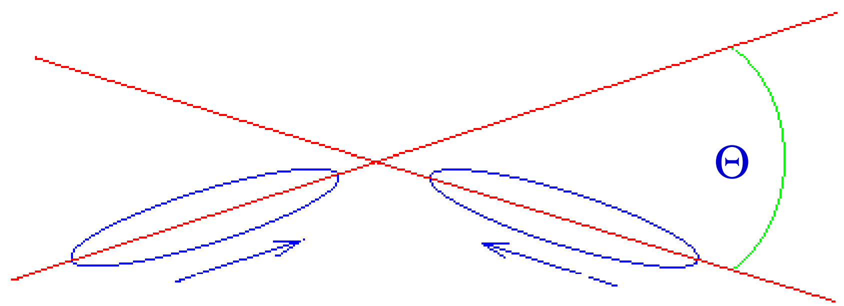
- introduces an offset ≈10μm

Interaction Vertex

Spread of the coordinates: $\begin{cases} \sigma_x \approx \sigma_y \approx 16\ \mu m \Rightarrow \text{Interaction Spot} \approx 11\ \mu m \\ \sigma_z \approx 5cm \text{ (negligible effect)} \end{cases}$

(Note: CMS measures IP independently to 10μmx10μmx15μm)

a Gaussian in x and y
is assumed



Uncertainty of the scattering angle: $\sigma_{\Theta^* x,y} \approx 30\mu rad$ (beam divergence)

- fill-to-fill variations?
- assume that variations in z can be suppressed in off-line analysis

Summary on stability and accuracy

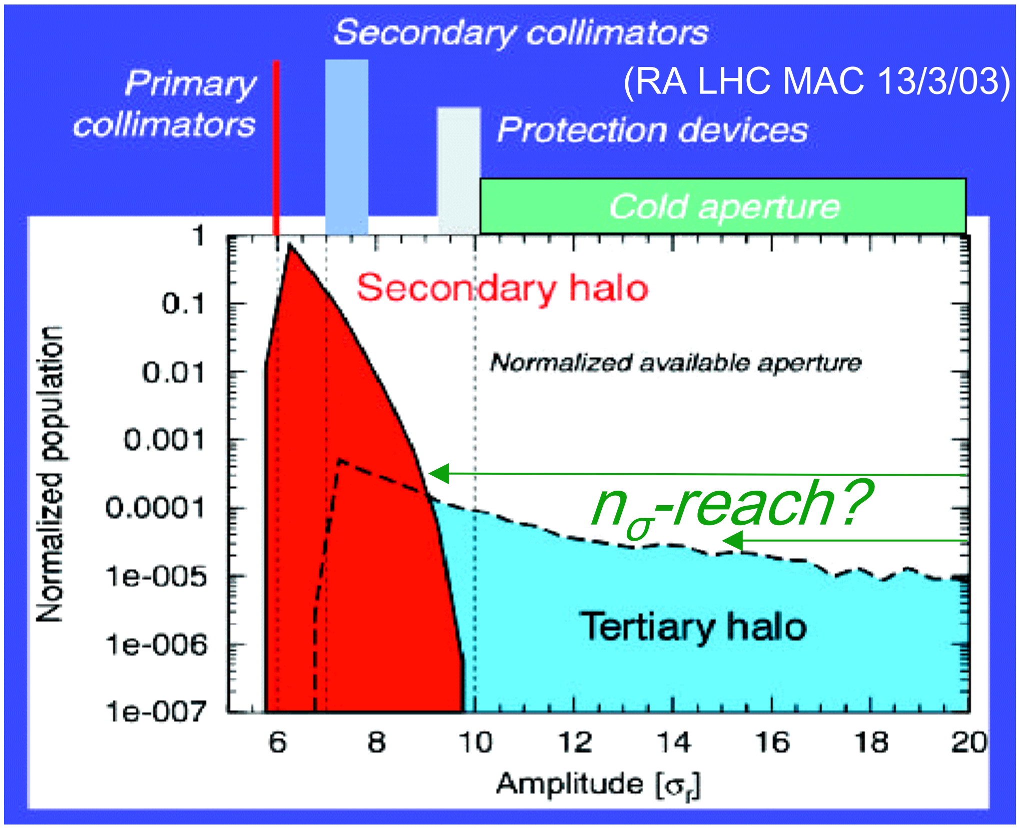
Contribution	Absolute calibration : rel. accuracy (10^{-4})	Stability (10^{-4})
Dipoles	≈ 7	< 1
Quadrupoles	≈ 2	4-5
Others	< 1	< 1

- The momentum is expected to vary by :
  - $4\text{-}5 \times 10^{-4}$ over a year
  - $1\text{-}2 \times 10^{-4}$ over 24 hours
- The variations are driven mostly by circumference changes that can be measured / predicted to $< 5 \times 10^{-5}$ (or better). We can build on the LEP experience !

Jorg Wenninger, CERN -04

Detector Distance vs. Beam

Detector distance vs. beam is determined by the beam halo.



$n_\sigma = d_{min}/\sigma_{x,y}(z) \approx 9\text{-}15$

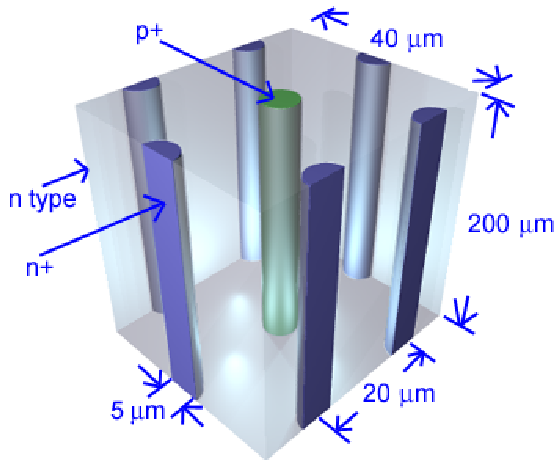
Expected halo rate: 6kHz (for 43 bunches, Np = 10^{10}, ε_N = 1μm, n_σ = 10)

Active detector starts at the distance δ from the physical edge, δis determined by the guard ring/detector design: *planar* vs. *3D* electrode structures
$\Rightarrow \delta \approx$ 10-100μm

In this study we use:

$$\begin{cases} n_\sigma = 10 \\ \delta = 100\mu m \end{cases}$$

Detector Resolution



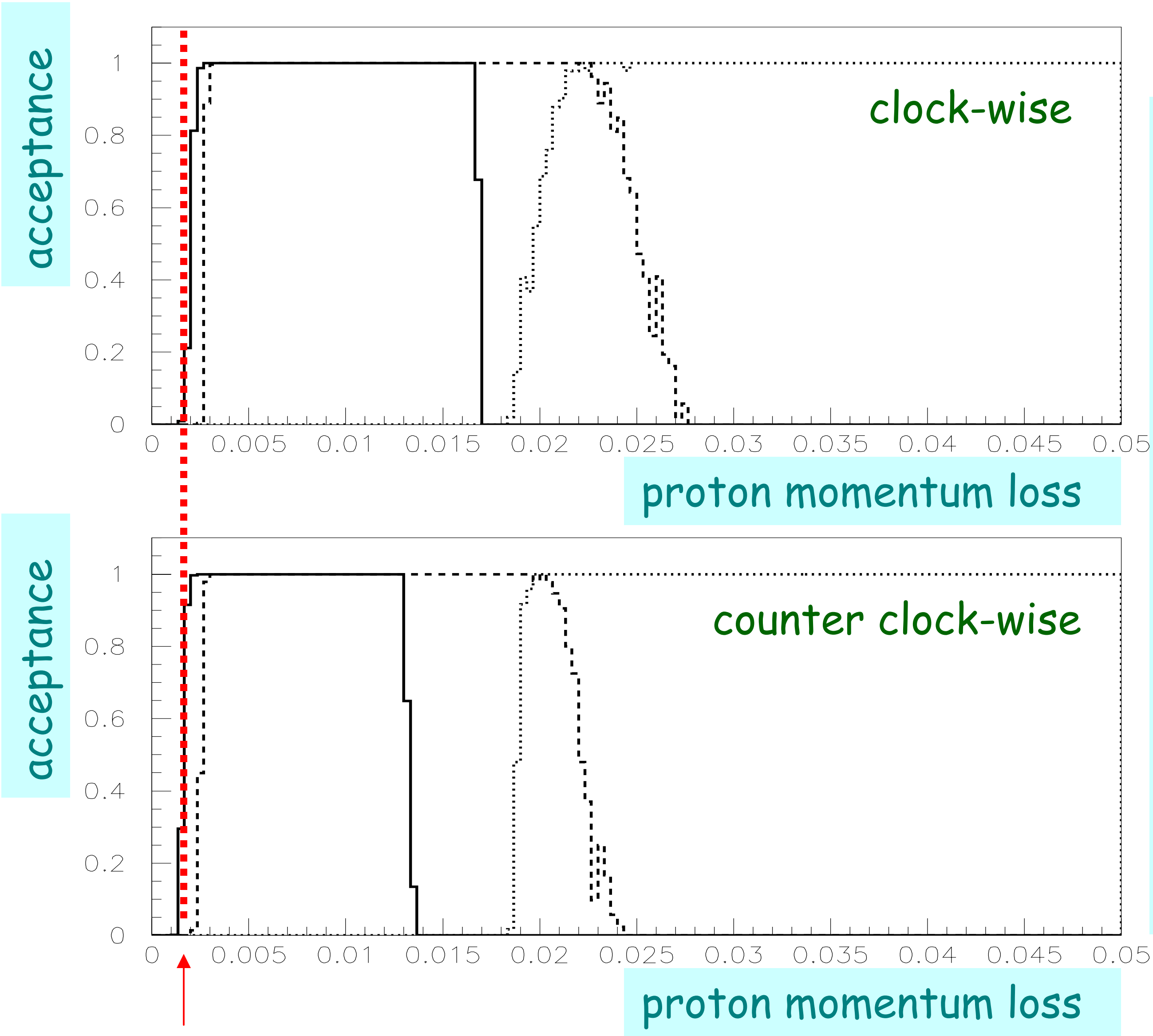
Detector resolution (σ_x = 10µm): simulated by smearing the predicted proton hit location according to Gaussian distributions for the two sensor planes per a leading proton detector.

Effect of the spread of the beam position ($\sigma_{x,y}$ = 5µm) at each detector location: accounted for by smearing the detector coordinates with a Gaussian distribution.

Uncertainty in absolute beam position: an offset of 10µm added to the detector coordinates in correlation.

Possible misalignement of the pair of sensor planes: an offset of -10µm introduced for the 2nd sensor plane vs. the 1st one in each detector location.

Leading proton acceptance



Detector locations at

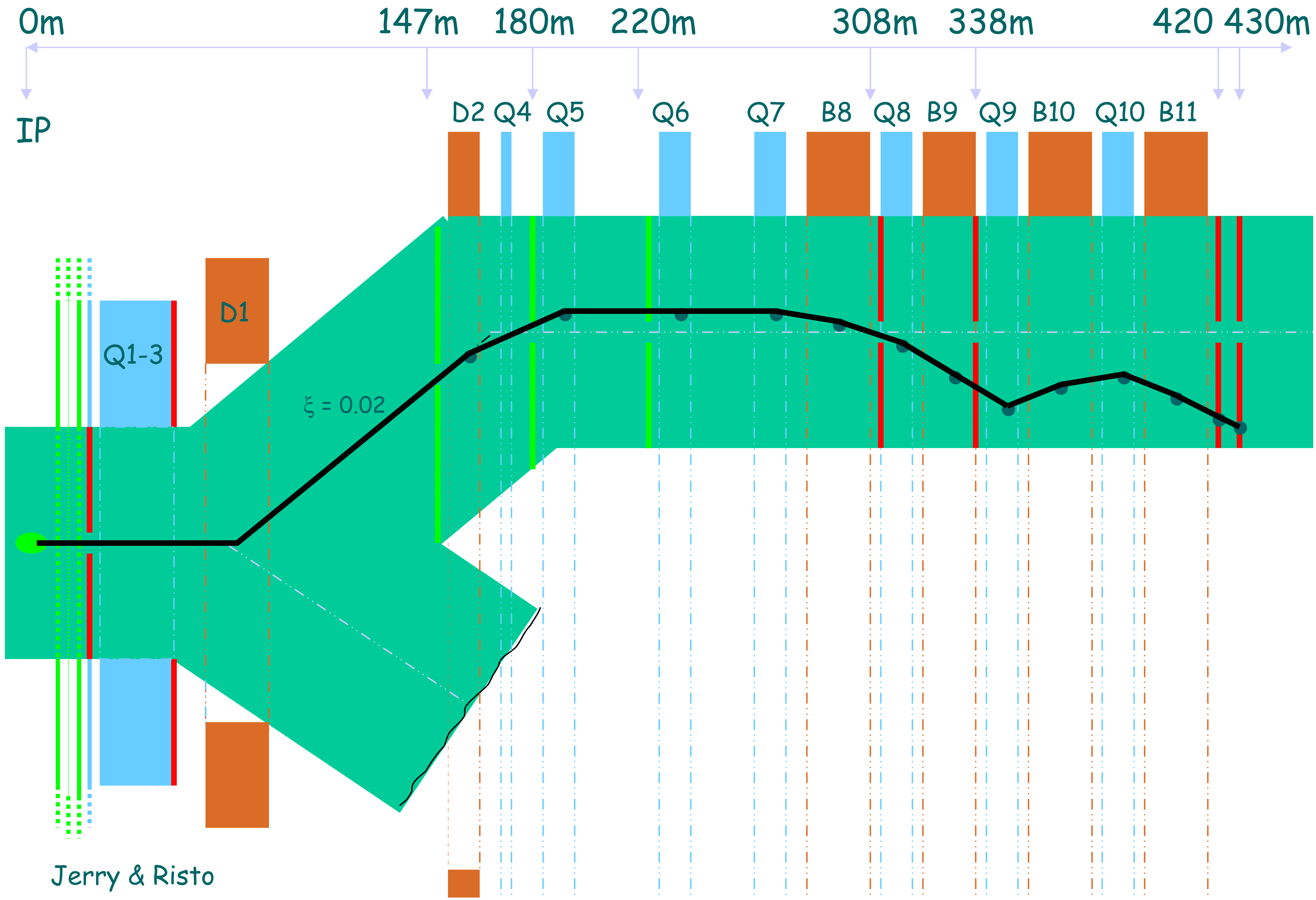
- 220 m (dotted)
- 308/338 m (dashed)
- 420 m (solid)

With (an optimistic?) assumption on approach:

$10 * \sigma_{beam}$ + 0.1 mm

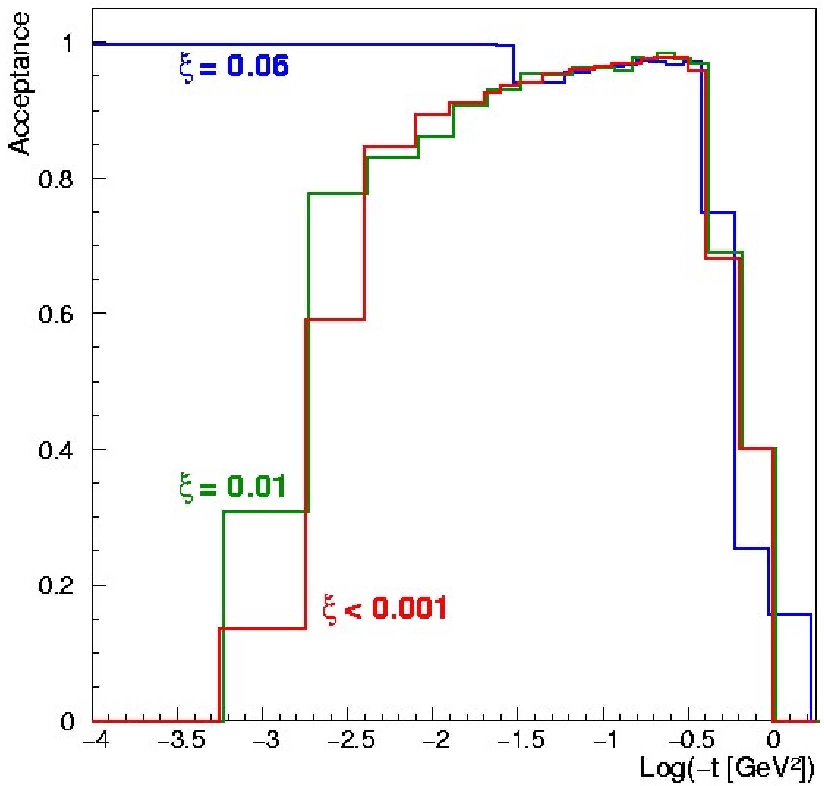
$\Rightarrow$ acceptance down to 0.2 %

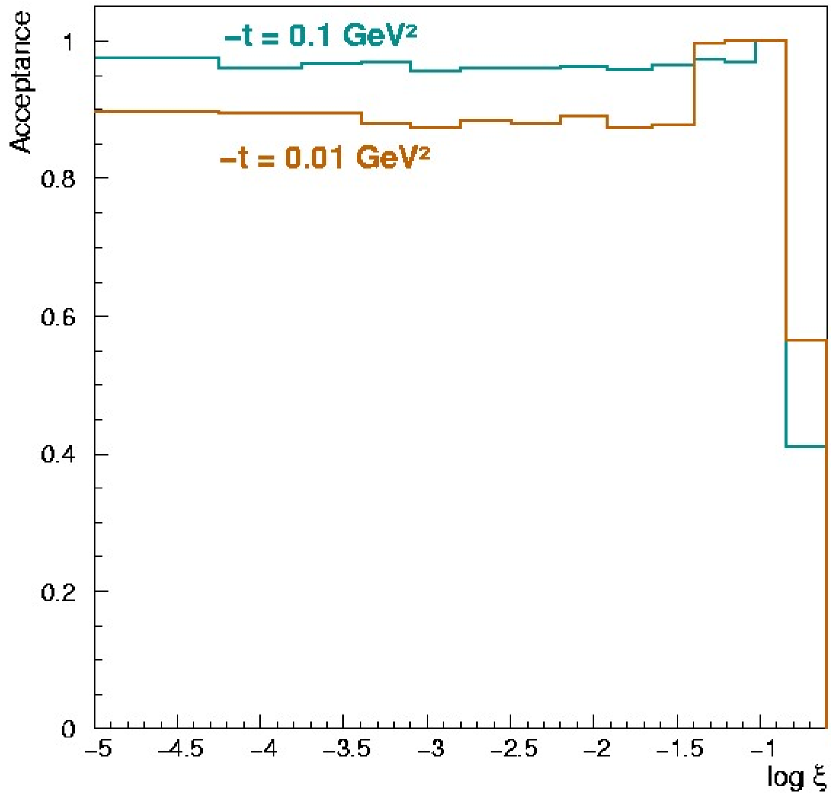
Leading Proton Detection



Diffraction at high β*: Acceptance

Luminosity 10^{28}-$10^{30}cm^{-2}s^{-1}$ (few days or weeks)

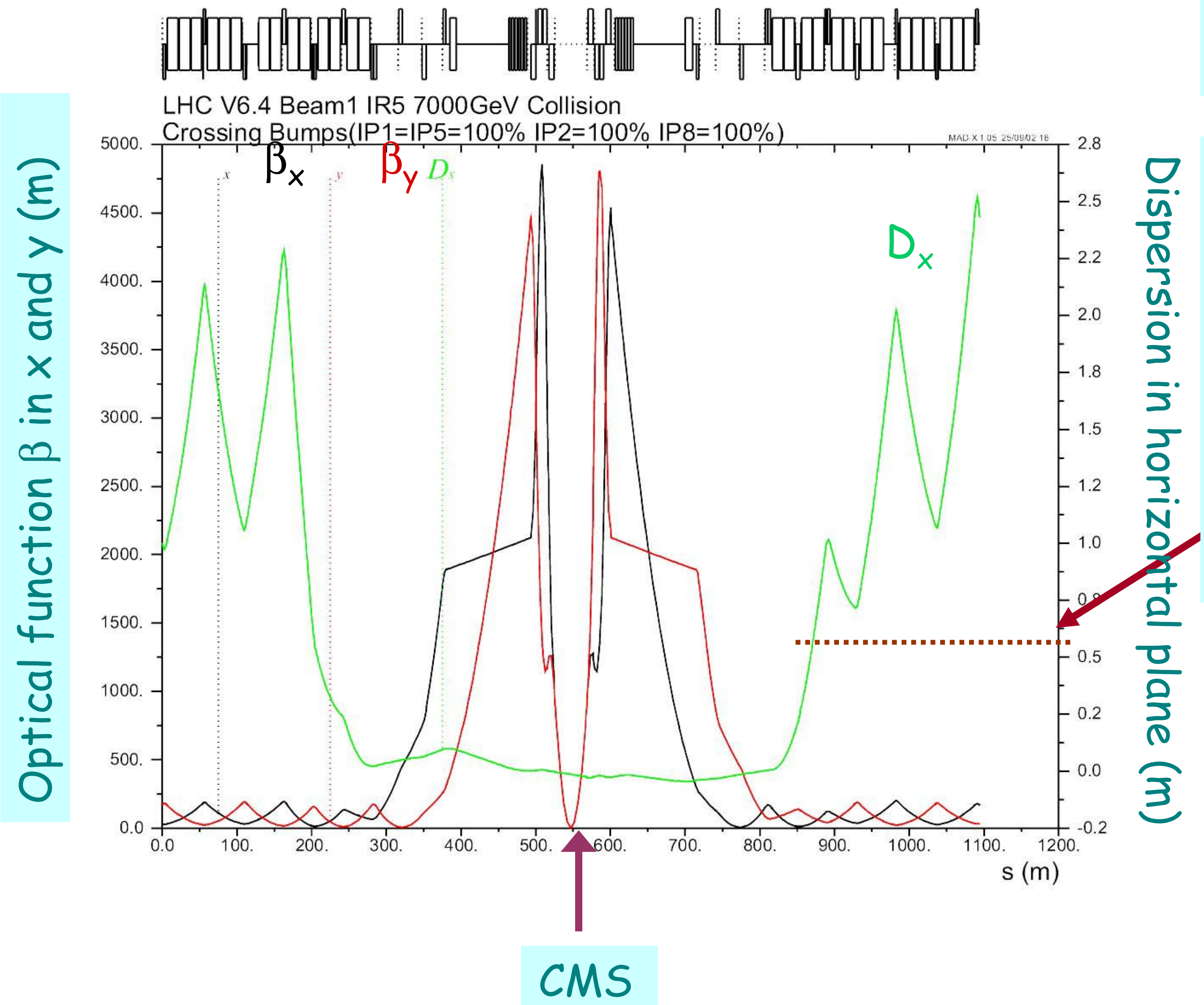




- more than 90% of all diffractive protons are seen!
- proton momentum can be measured with a resolution of few 10^{-3}

Dispersion function - low β* optics (CMS IR)

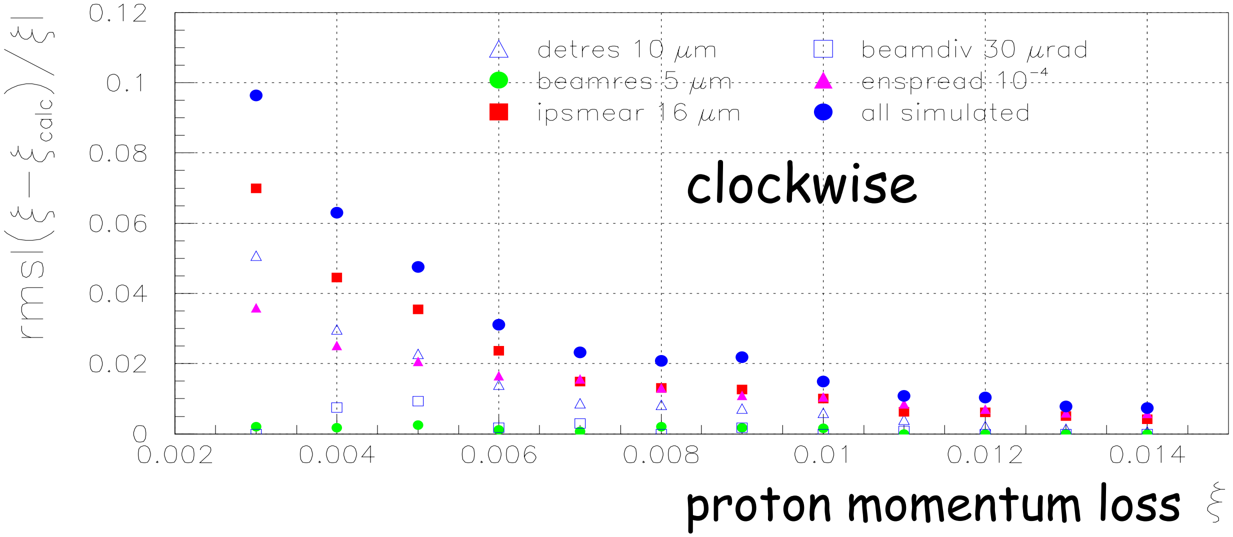
horizontal offset = $\xi \cdot D_x$ (ξ = momentum loss)

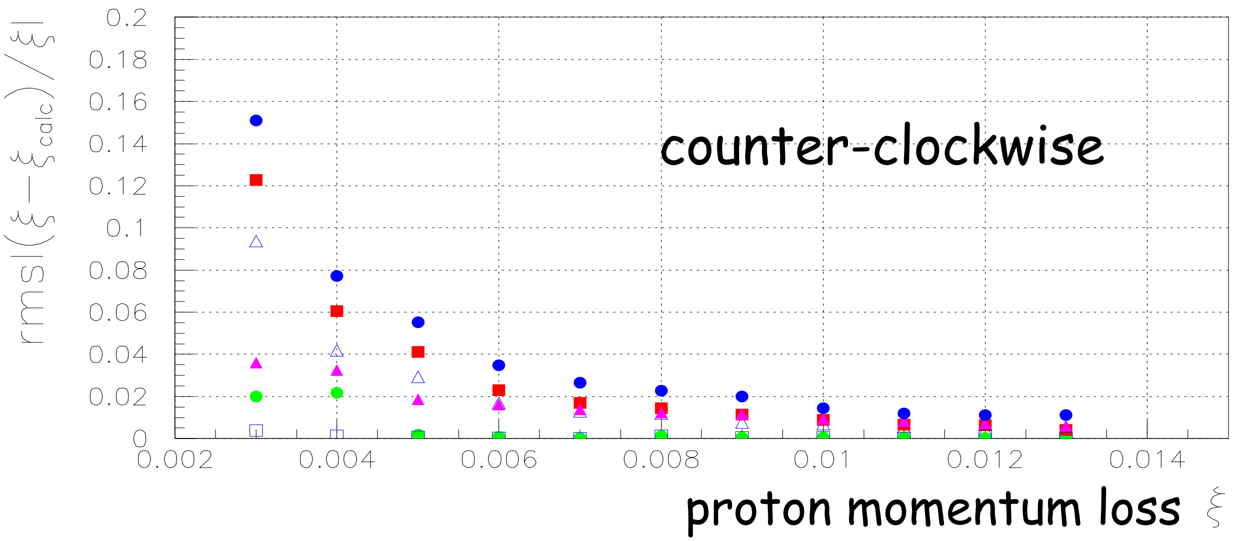


For a 2.5 mm offset of a $\xi \sim 0.5$ % proton, need dispersion ≥ 0.5 m.

⇒ Proton taggers to be located at > 250 m from the IP (i.e. in a "cryogenic section" of the LHC).

Momentum loss resolution at 420 m

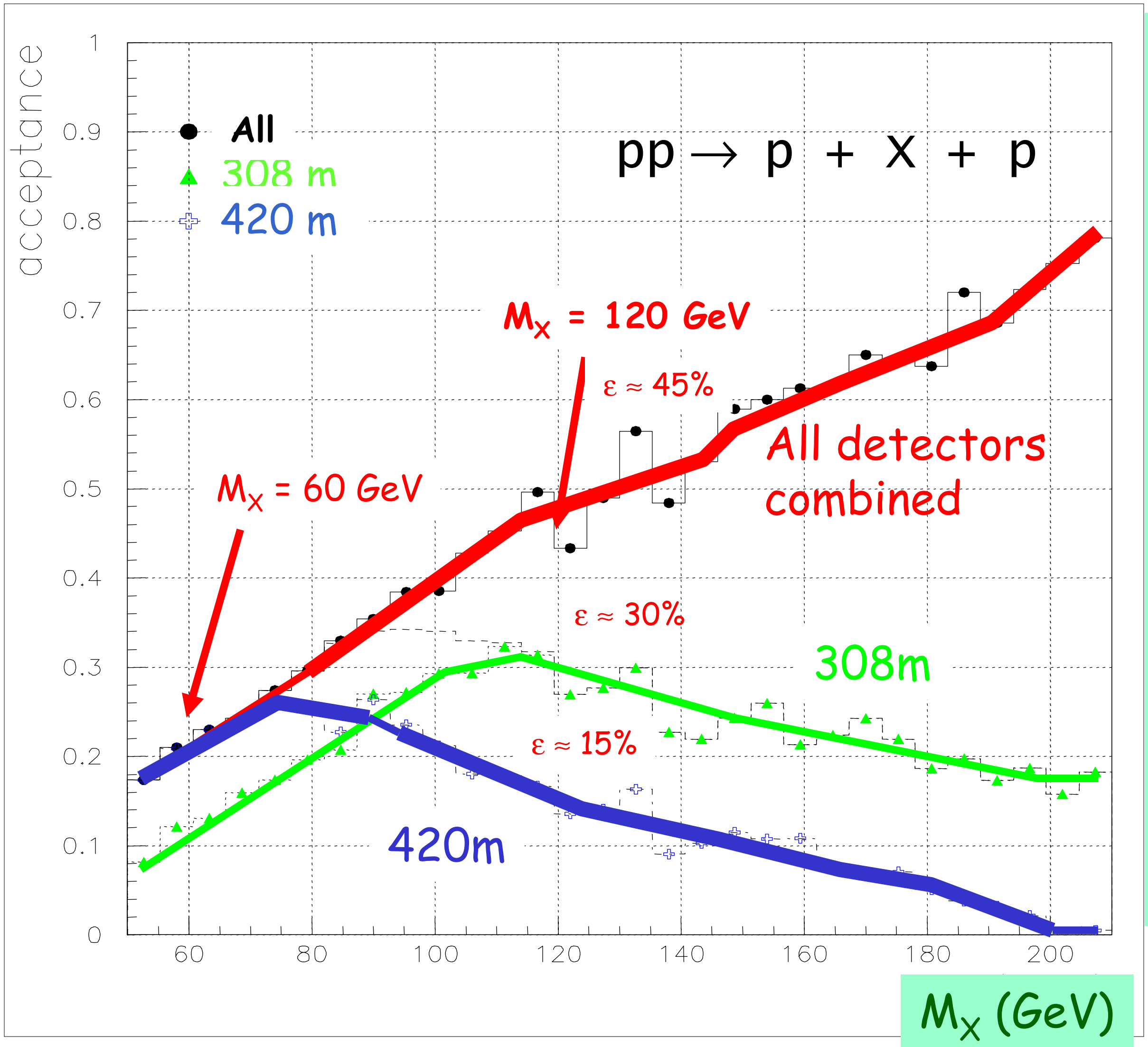




Resolution improves with increasing momentum loss

Dominant effect: transverse vertex position (at small momentum loss) and beam energy spread (at large momentum loss, 420 m)/detector resolution (at large momentum loss, 215 m & 308/338 m)

Mass Acceptance

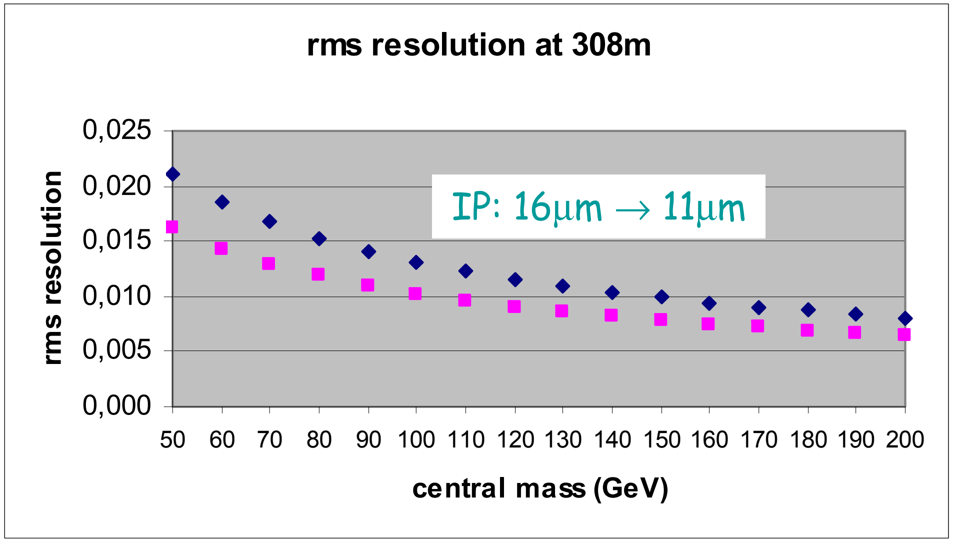


Both protons are seen with ~ 45 % efficiency at M_X = 120 GeV

Some acceptance down to: M_X = 60 GeV

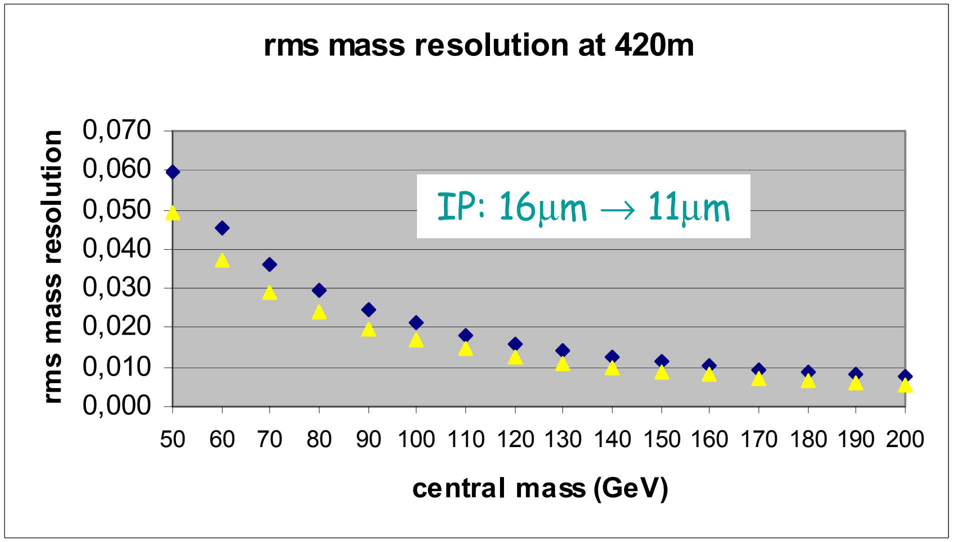
308m & 420m locations select symmetric proton pairs ⇒ acceptance decreases.

Mass resolution at the 308m and 420m locations

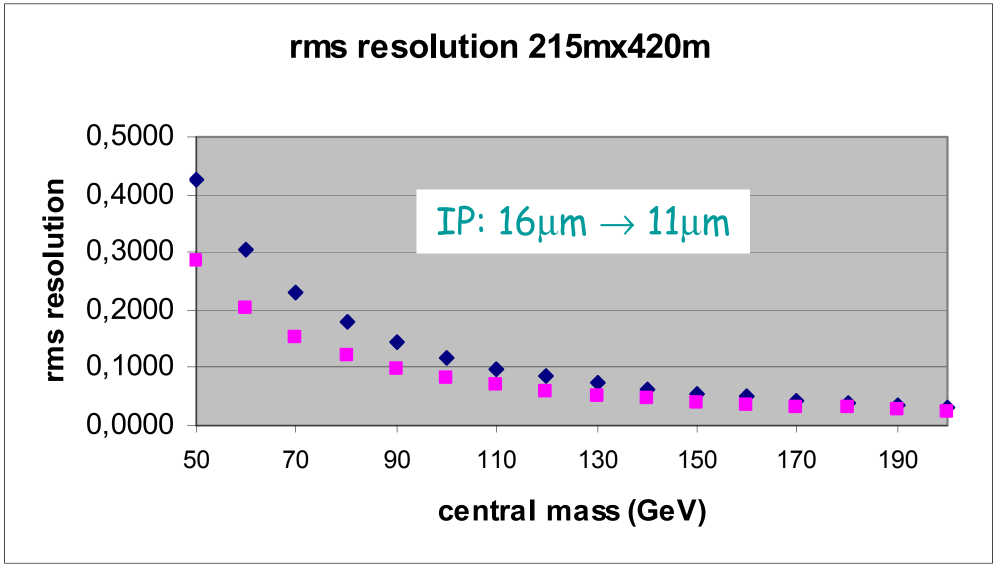


M_X = 140 GeV

$\Delta\sigma/\sigma$ = 1.2% → 0.9%



$\Delta\sigma/\sigma$ = 1.3% → 1.0%



$M_X = 140$ GeV

$\Delta\sigma/\sigma = 6.4\% \rightarrow 4.6\%$

Conclusions

$pp \rightarrow p + X + p$ is an excellent bench mark process for forward physics!

Need to retain **experimental approach** with the challenges of
(1) detectors beyond 250m,
(2) acceptance.

Ongoing further work concentrates on:

- Updating central mass acceptance & resolution studies
- Improvements in acceptance: Asymmetric pairs
- Improvements in resolution: Independent IP measurement
- Tagging/triggering
- $H \rightarrow W^+W^-$
- Novel analysis methods - DLM

Triggering diffractive events at low β*

Basic trigger conditions for diffractive events

• TOTEM LvL-1 leading proton available at < 220 m from IP, only.

• Asymmetric proton pairs yield worse mass resolution

⇒ for the central states of mass ≤ 180 GeV, LvL-1 trigger is independent of the leading protons.

• CMS LvL-1 trigger based on calorimetry & muon chambers – no track info available at that stage.

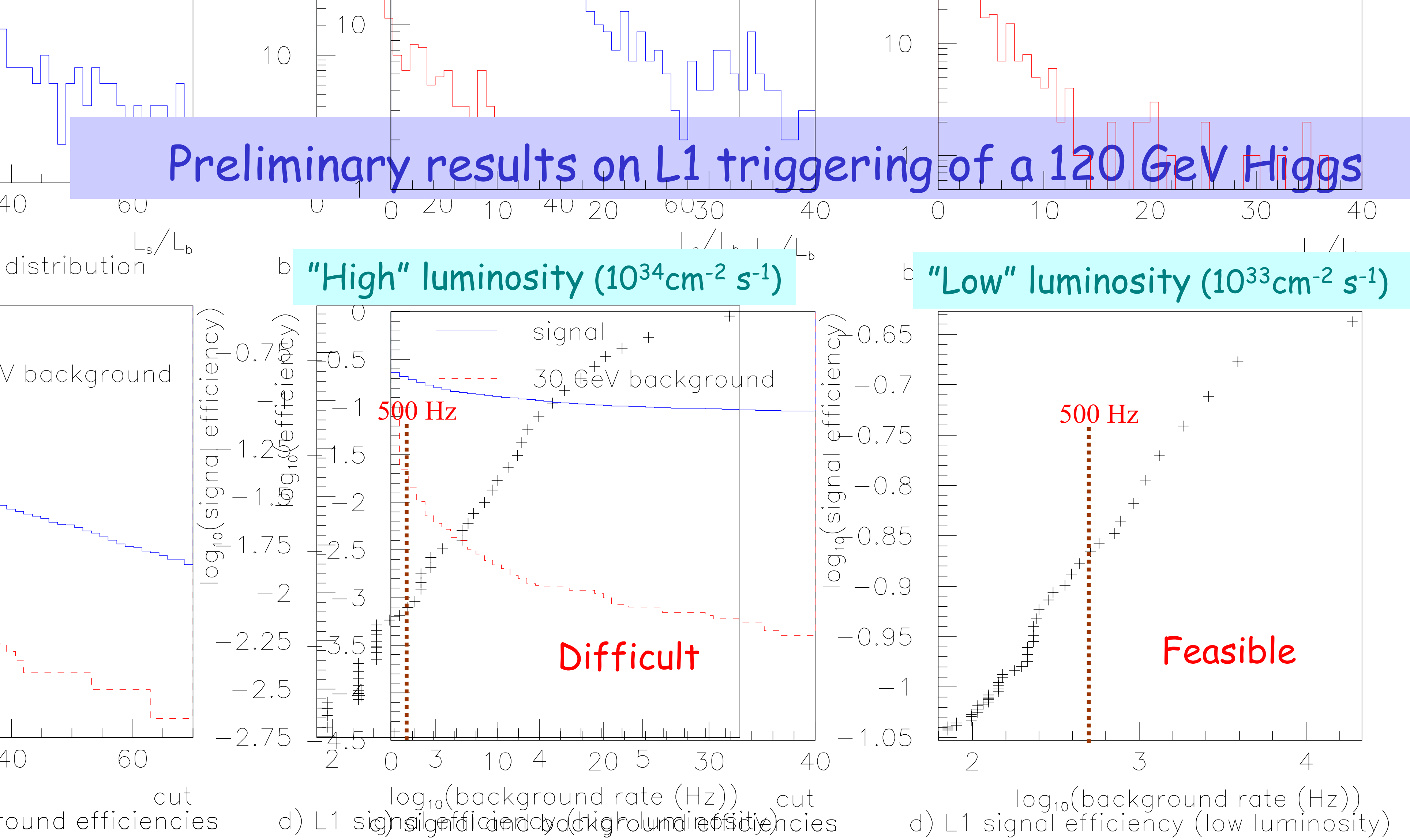
• E_T threshold of inclusive jet trigger is too high to be useful.

• Pile-up likely to destroy some rapidity gaps (~2(20) inelastic events at $10^{33}(10^{34})$ cm^{-2} s^{-1}) & cause accidental leading proton pair events (SD+SD)

• Allowed LvL-1 trigger rate for a special diffractive new particle trigger could be ~500 Hz (?)(out of 100 kHz, no prescaling). MinBias (E_T > 30 GeV) ~ 0.22 mb ⇒ $10^3/10^4$ suppression at $10^{33}/10^{34}$ cm^{-2} s^{-1}

Case study for a 120 GeV Higgs using topological variables (forward E_T, jet E_T's, η's & ϕ-angles) of the 2-jet final state with a "CMS-like" L1 calorimetry trigger.

Preliminary results on L1 triggering of a 120 GeV Higgs



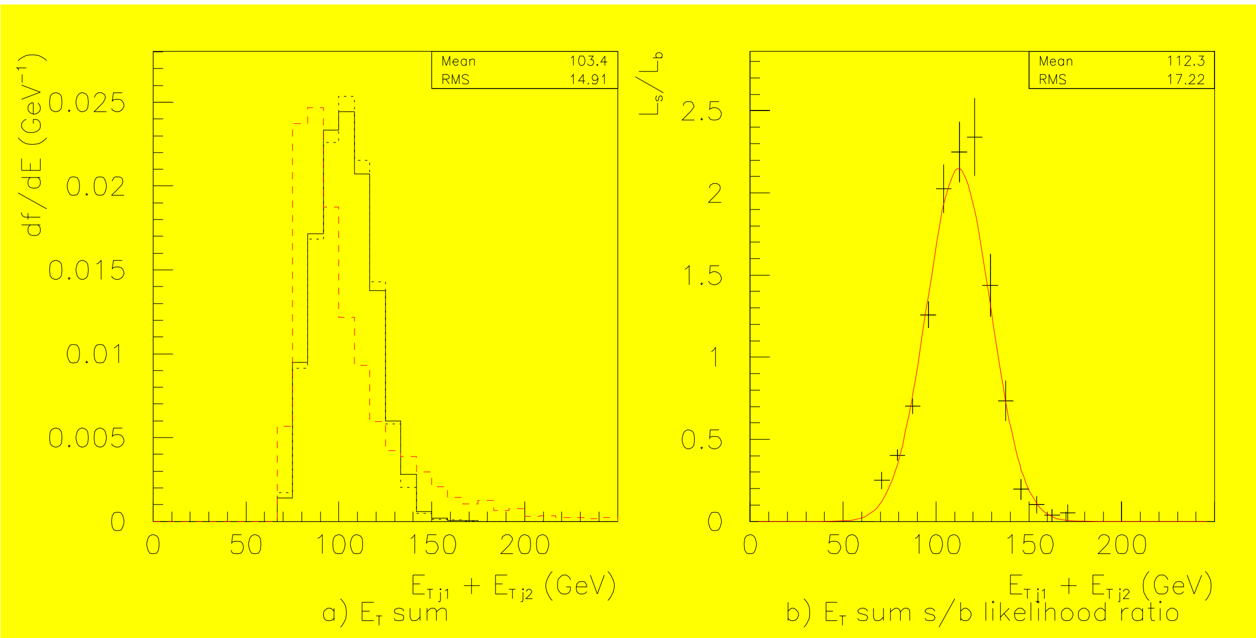
- Efficiency includes "usefulness" cuts (protons & b-jets seen)
- Will be repeated with complete CMS trigger simulation
- Improvements should be possible by using also T2 & CASTOR

120 GeV Higgs Level 1 Trigger Selection

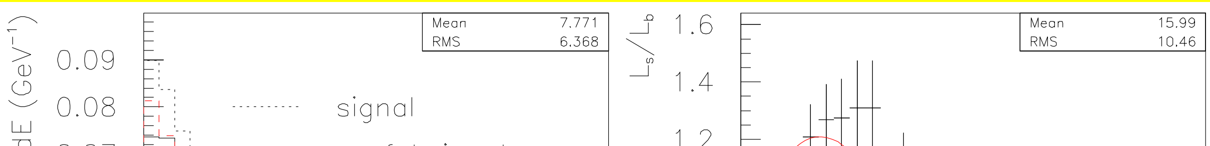
Based on combined likelihood functions of:

(∗) most selective trigger variables

- Sum(∗) & difference of jet E_T
- Sum & difference of jet η
- Difference of jet phi (∗)
- Forward scalar E_T ($3 < \eta < 5$) ("rapidity gaps") (∗)



Sum of jet E_T's



Background events (10^6 events) generated by Phojet:

(4) Non-diffractive: $pp \rightarrow$ non-diffractive
(5) Single diffractive: $pp \rightarrow pp^*$
(6) Double diffractive: $pp \rightarrow p^*p^*$

The event types (1) – (6) were used to calculate the trigger efficiencies. Both charged and neutral particles were considered.

The protons: Protons assumed to have ≈1% energy loss and 110-140 GeV central mass)

The trigger: (1) Rapidity gap of at least two units of η on each side of the event with $2.5 < |\eta| < 7$.

(2) Transverse energy, E_T, is required to be $E_T > 100$ GeV within $|\eta| < 2.5$.

(3) Rapidity gaps of $\Delta\eta=2$ in the region $5<|\eta|<7$ were also assessed.

Efficiency Budget - Diffractive Higgs Events

Exclusive diffractive Higgs events (M_H= 120 GeV)

- Both protons within acceptance of proton taggers (45 %)
- Both b-jets within Tracker acceptance ($|\eta|<2.5$) (85 %)

(need b-tag to reduce gg background)

- Br ($H \to bb$) (in SM ~ 68 %)
- Efficiency of b-tagging, ε_b ($\varepsilon_b^2 = (0.77)^2$ ~ 60 %)
- Level 1 trigger efficiency at $10^{33} cm^{-2} s^{-1}$ (~ 35 %)

Total exclusive diffractive Higgs efficiency: **(~ 5.5 %)**

Improvements under study: b-tag efficiency & Level 1 trigger efficiency (include other trigger detectors: T2, CASTOR ...)

$H \to W^+W^-$ under study...