Gap-survival probability and rescattering in diffraction

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On behalf of the ATLAS and CMS collaborations
MPI@LHC Workshop, Perugia, 29 Oct 2008

1. How to establish a hard-diffractive signal at LHC

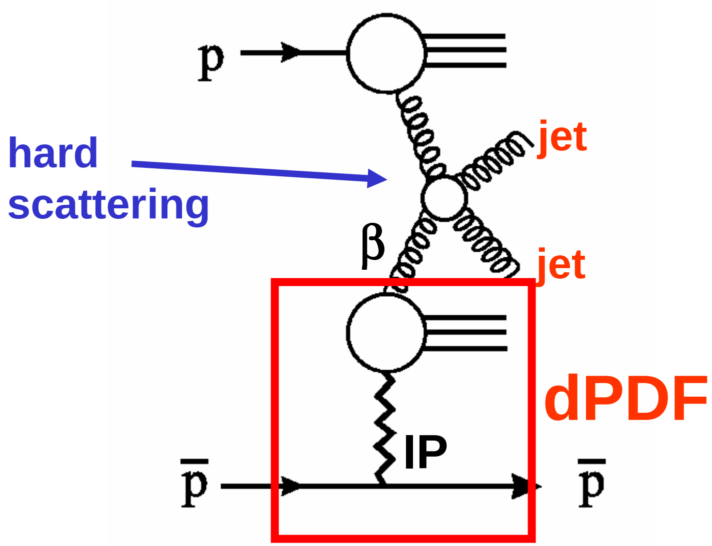
2. Sensitivity to the gap-survival probability

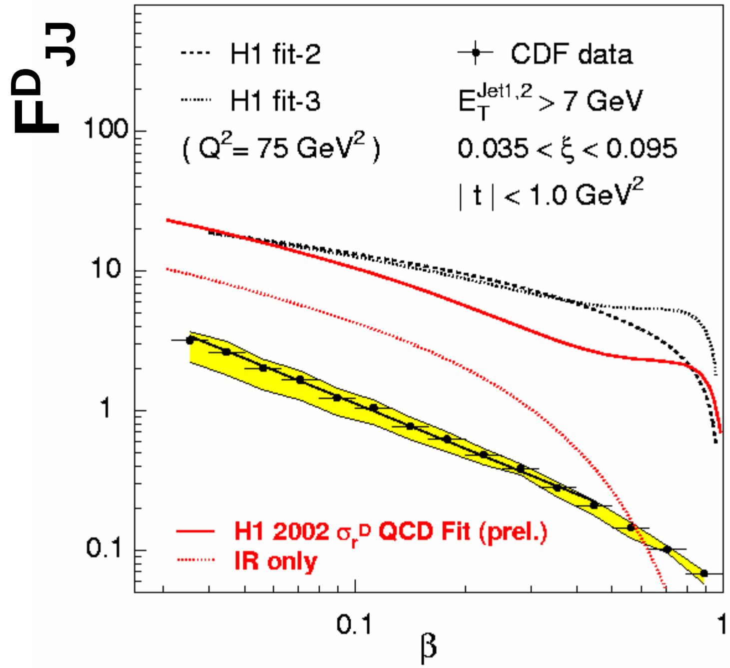
3. A look at the future

Factorisation breaking in $\bar{p}p$, pp

- **Factorisation theorem holds in diffractive ep scattering:**
  $\sigma_{diffr} = \sigma$(hard scatter) x (diffractive PDF) – cf talk by A. Solano

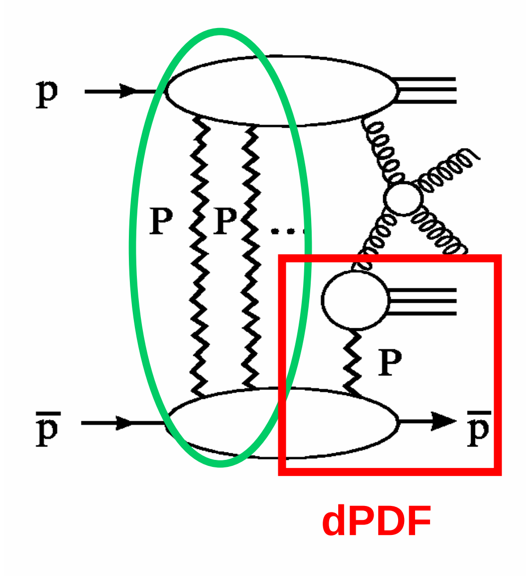
- **Factorisation does not hold in $\bar{p}p$, pp – cf talk by M. Gallinaro:**





Normalisation discrepancy (x10)
(lots more evidence available !)

Factorisation breaking in $\bar{p}p$, pp



Closely related to the underlying event

Factorisation broken at hadron colliders due to soft interactions/rescatterings among spectator partons
→ Fill rapidity gap & slow down outgoing p, $\bar{p}$
→ Hence suppress visible σ_{diffr}

Quantified by rapidity gap survival probability <|S|^2>
σ_{diffr} proportional to <|S|^2>

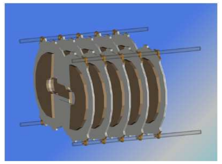
At Tevatron <|S|^2> ~ 0.1, ie suppression by O(10) compared to HERA – diffr. dijets/inclusive dijets ≅ 1%

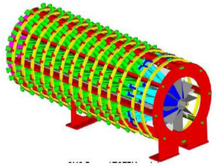
At LHC: some consensus that <|S|^2> ~ 0.05
i.e. diffr. dijets/inclusive dijets ≅fraction of %
but values of <|S|^2> between 0.004 and 0.23 proposed

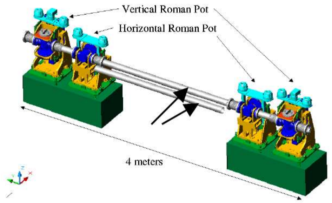
In early LHC running no proton taggers available
Hence try selection via rap gap → Feasible ?

Forward instrumentation at LHC

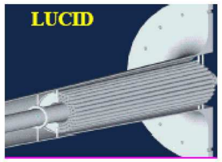
IP5

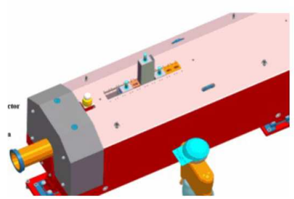


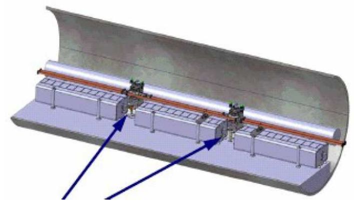




TOTEM-T2	CASTOR	ZDC/FwdCal	TOTEM-RP	FP420
14m	16m	140m	147-(180)-220m	420m
	LUCID	ZDC	ALFA/FP220	FP420





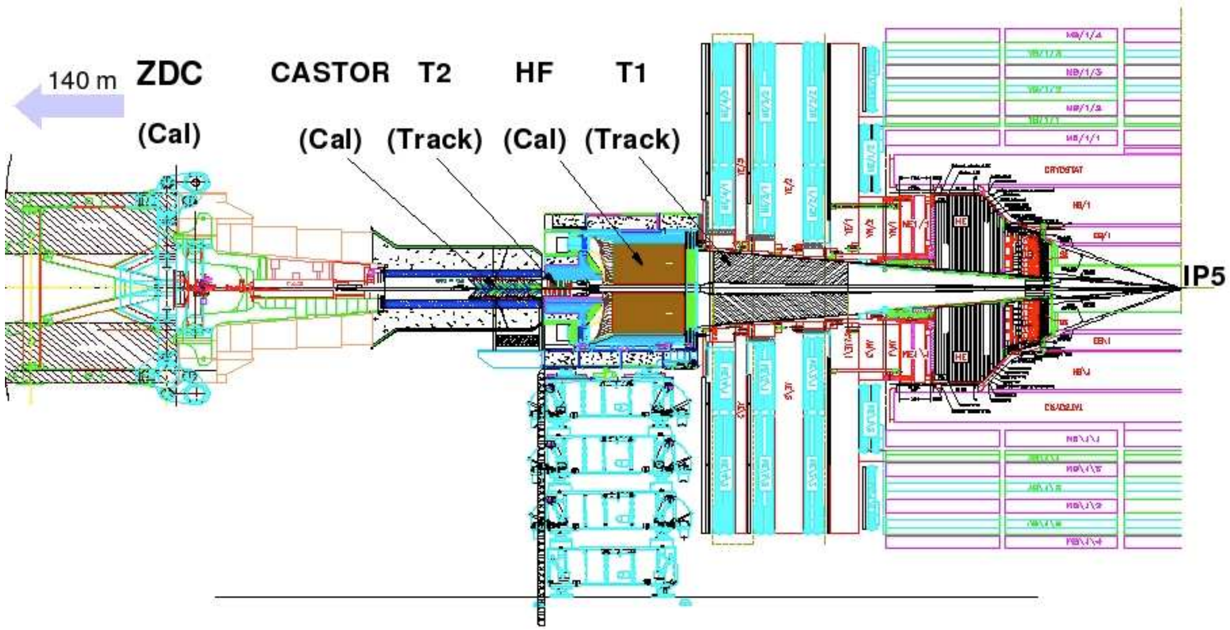


IP1

R&D project

For details on IP1 instrumentation, cf talk by M. Campanelli

Forward instrumentation at IP5



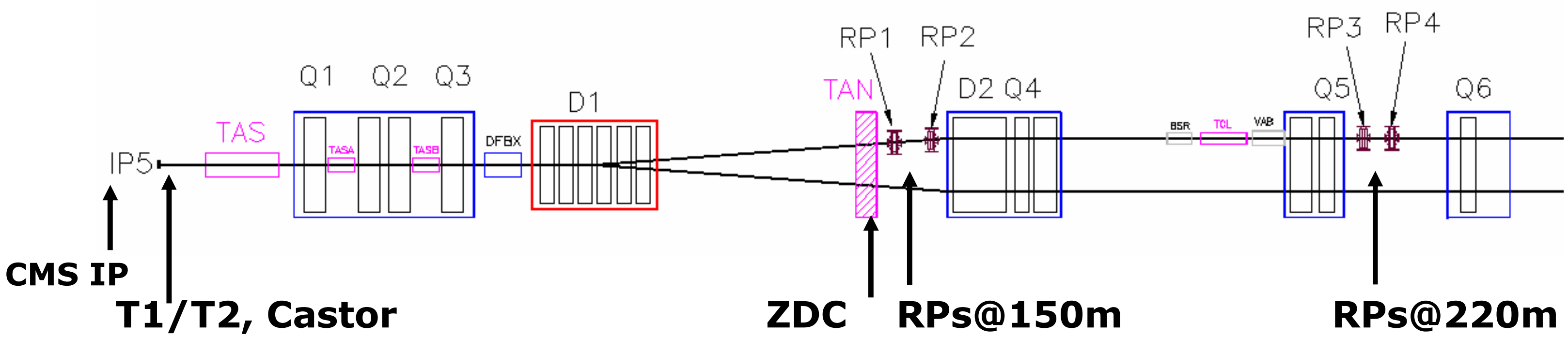
T1 **(CSC)** $3.1 \leq |\eta| \leq 4.7$ **(Totem)**

HF $3 \leq |\eta| \leq 5$ **(CMS)**

T2 **(GEM):** $5.3 \leq |\eta| \leq 6.6$ **(Totem)**

Castor $5.3 \leq |\eta| \leq 6.6$ **(CMS)**

Possible addition FP420:
Near-beam detectors at 420 m



T1/HF, T2/CASTOR: two suites of tracking & calorimetry !

CMS forward hadron calorimeter (HF)

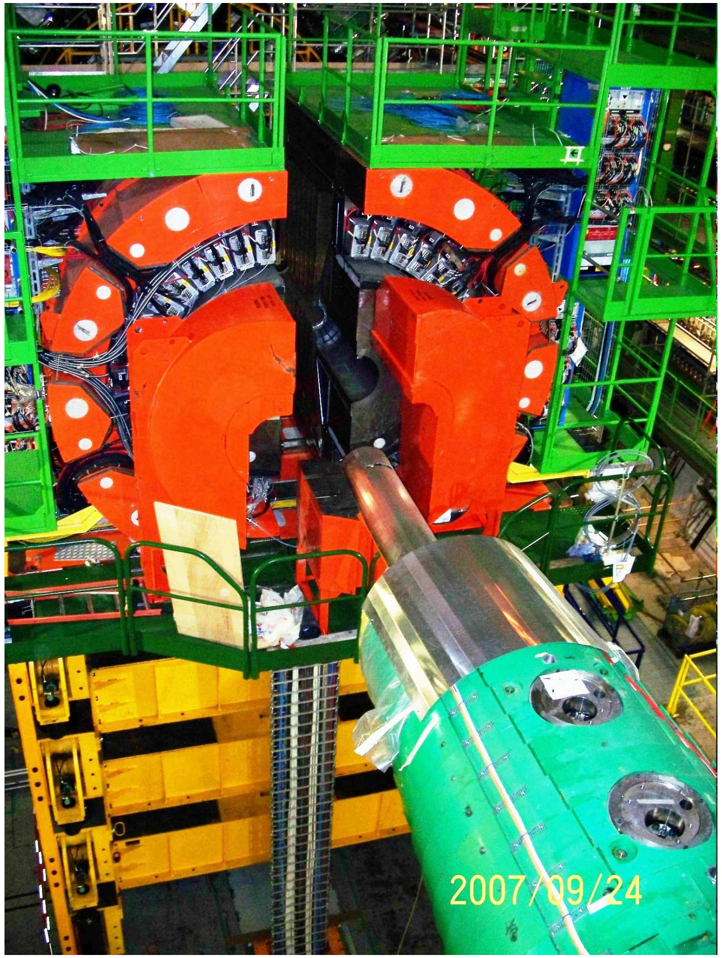
- $3<|\eta|<5$

- Located 11.2 m from the interaction point

- Steel absorbers and embedded radiation hard quartz fibers → fast collection of Cherenkov light

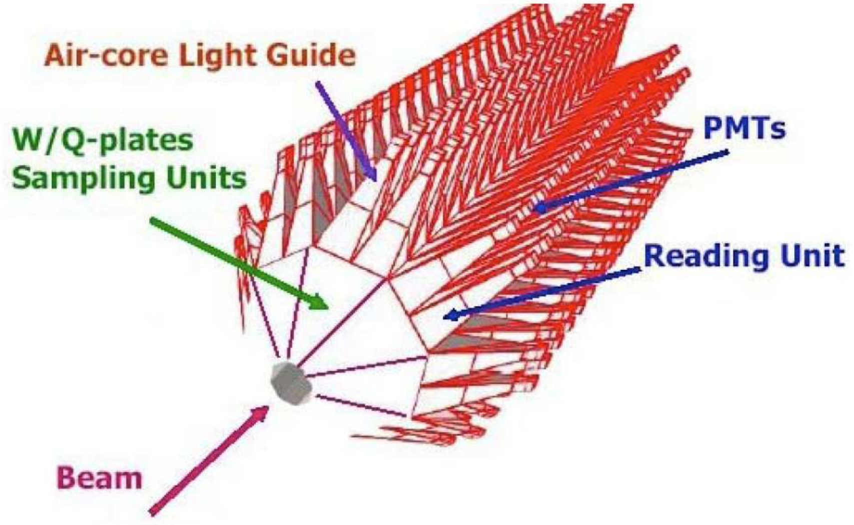
- Each HF module has 18 wedges in non-projective geometry with the quartz fibers running parallel to the beam axis along the length of the iron absorbers

- Long (1.65 m) and short (1.43 m) quartz fibers are placed alternately with a separation of 5 mm.



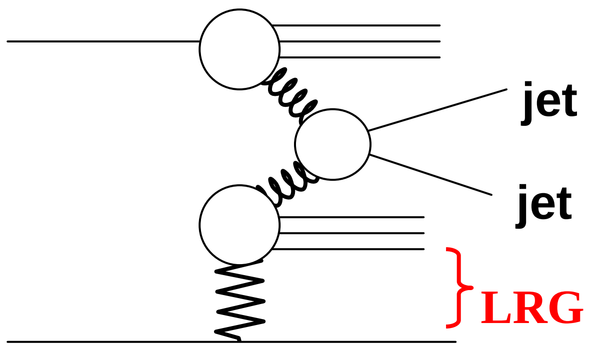
CMS CASTOR calorimeter

- -6.6<η<-5.3
- 14.37 m from the interaction point
- Octagonal cylinder with inner radius 3.7cm, outer radius 14cm and total depth 10.5 λ
- W absorber & quartz plates sandwich, 45° inclination wrt beam axis
- Cherenkov photons transmitted to PMTs through aircore lightguides
- 16 segments in φ, 2 (EM) + 12 (had) segments in z
- No segmentation in η
- For 2009, CASTOR only on one side

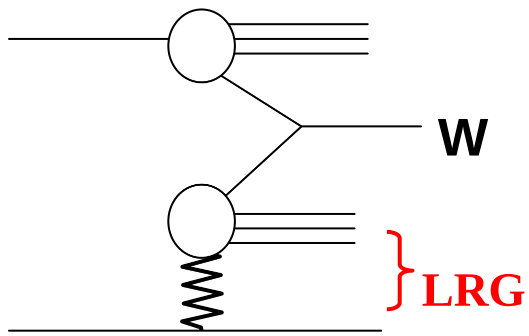


Observing hard diffraction at LHC

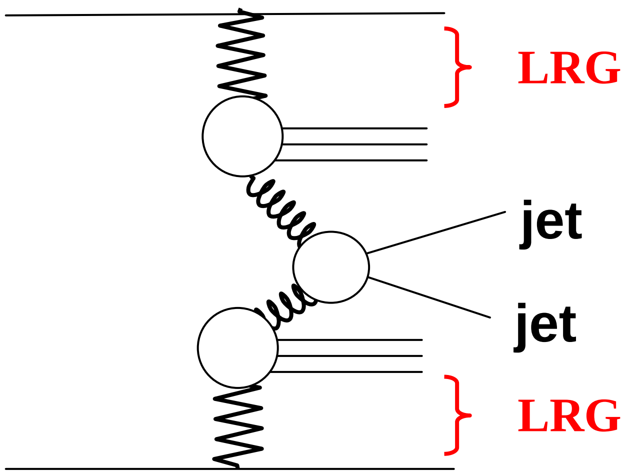
ATLAS plans (cf talk by M. Campanelli):



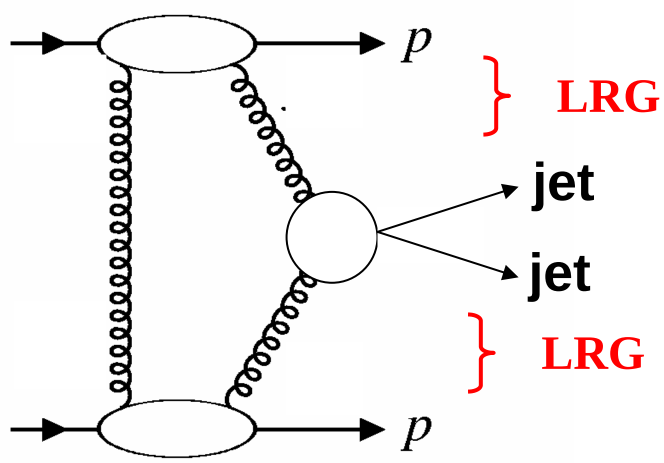
Single diffractive di-jet production



Single diffractive W production



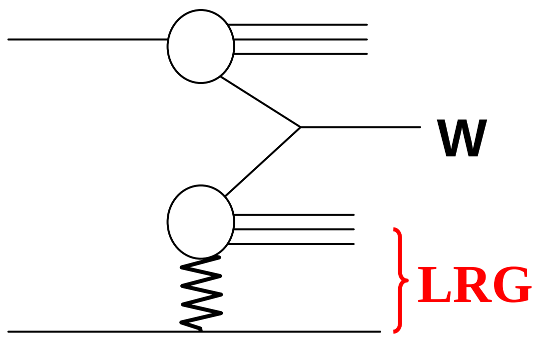
Double-pomeron exchange di-jet production

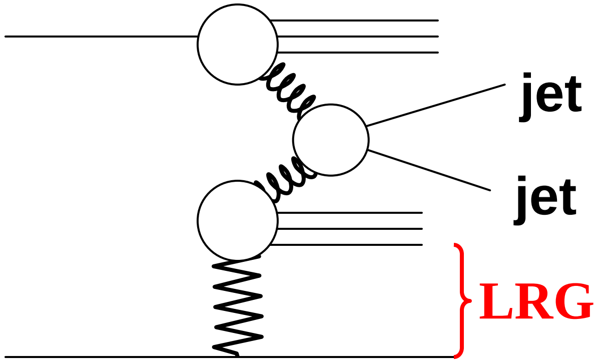


Central exclusive di-jet production

Observing hard diffraction at LHC

CMS feasibility studies:





Single diffractive W production (CMS PAS DIF-07-002)

Single diffractive di-jet production (CMS PAS FWD-08-002)

Available from https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

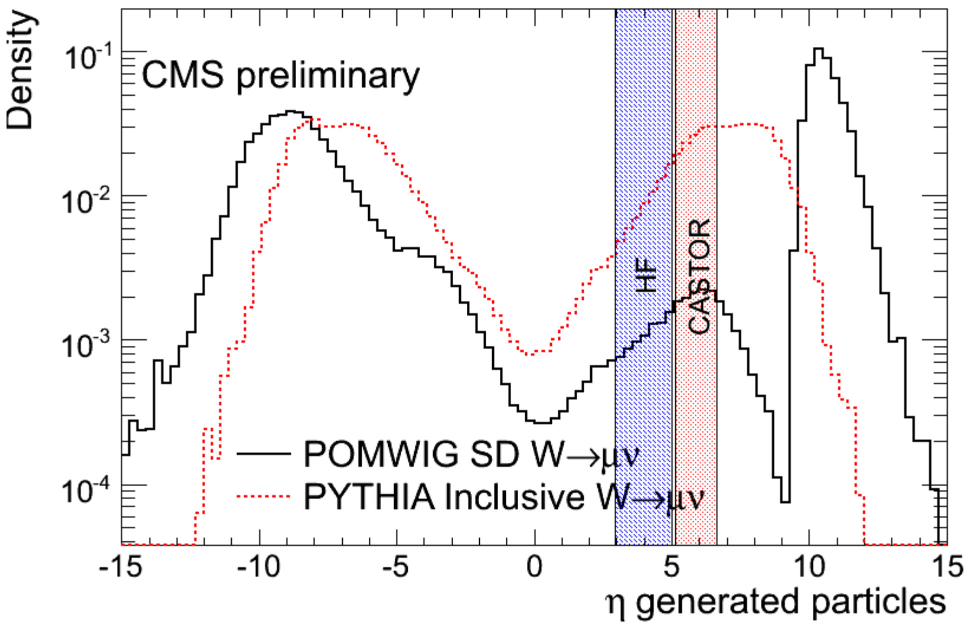
Assume:

- **Rapidity gap survival probability: $<|S|^2>=0.05$**
- **Diffractive PDF: NLO H1 2006 Fit B**
- **Inclusive PDF: CTEQ61**
- **No pile-up**
- **SD MC: Pomwig; non-diffr. generator: Pythia/Madgraph**
- **Complete simulation of detector, trigger & reconstruction (except CASTOR)**

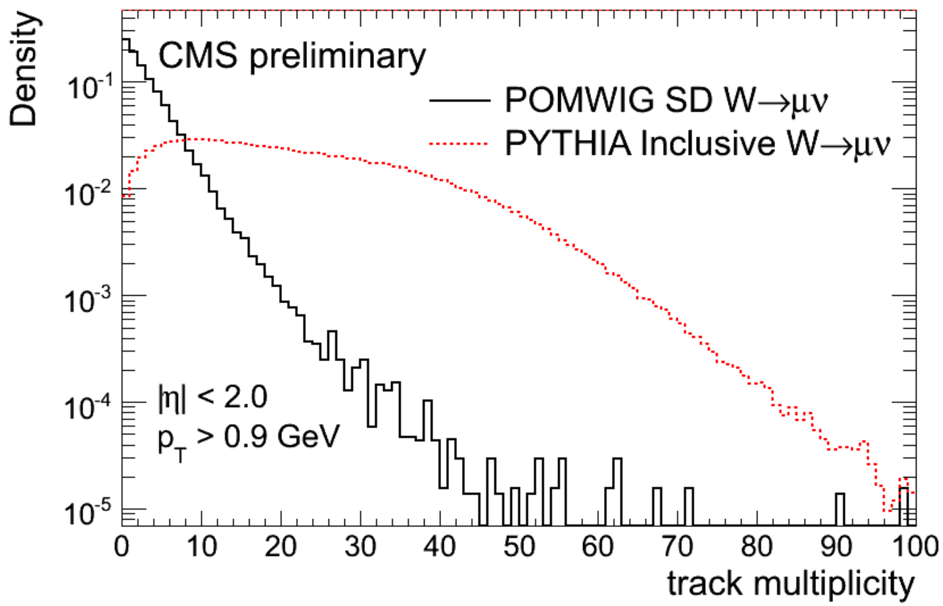
The CMS feasibility studies

Selection of SD events

GENERATED PARTICLES – ENERGY WEIGHTED
(diffractive sample with gap at positive η)



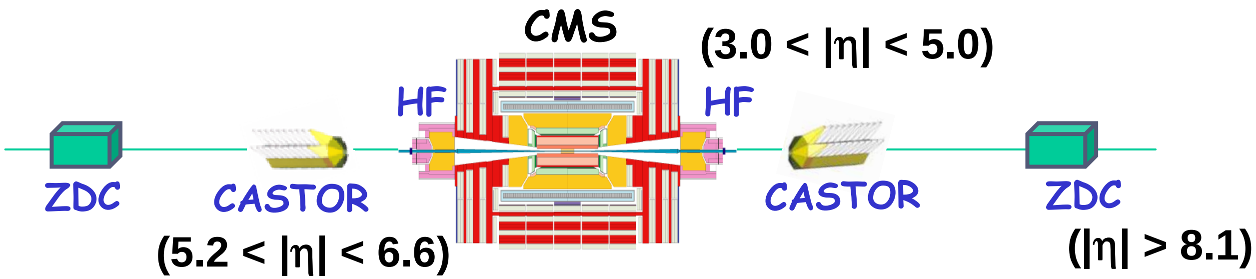
TRACK MULTIPLICITY IN CENTRAL TRACKER



- Diffractive event candidates selected on the basis of multiplicity distribution in the central tracker, in the HF and/or CASTOR [in the gap side]
- Gaps not easy to see at LHC – may start at very large η
- Track multiplicity correlated to ξ (proton fractional momentum loss)
- "Gap side" defined as that with lower hadronic activity in the forward region

Selection of SD events

1. Gap side: side with lower energy sum in HF (HF-plus vs HF-minus)
2. Pre-selection on central tracker multiplicity: maximum number of reconstructed tracks in central tracker, $|\eta| < 2.0$, $p_T > 0.9$ GeV: ≤1, ≤5, no cut
3. HF tower multiplicity in "low-η slice" ($3.0 < |\eta| < 4.0$) vs HF tower multiplicity in "forward slice" ($4.0 < |\eta| < 5.0$), in gap side
4. HF tower multiplicity vs CASTOR sector multiplicity in gap side

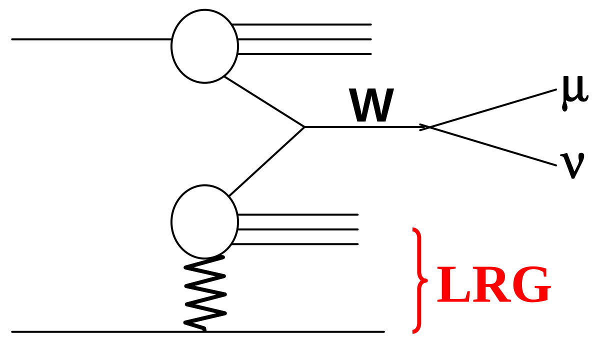


Disclaimer:

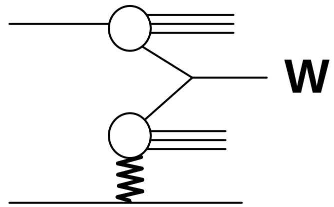
Generator level information used for CASTOR : number of φ-sectors with energy above threshold (E > 10 GeV)

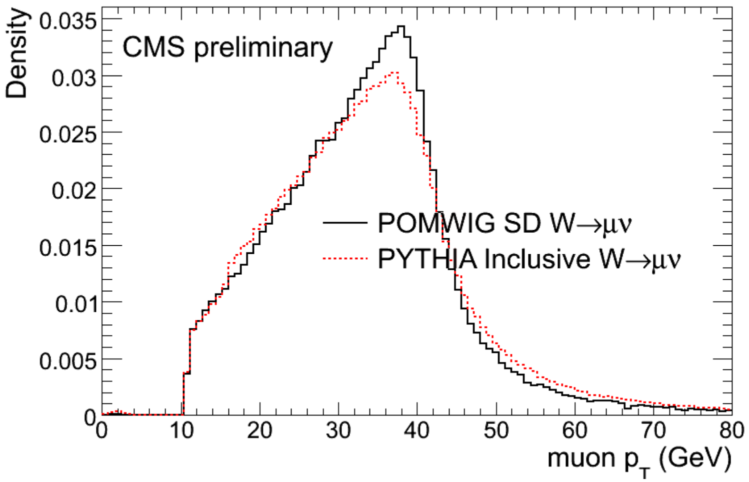
Hence, indicative, order-of-magnitude information only for CASTOR-based results

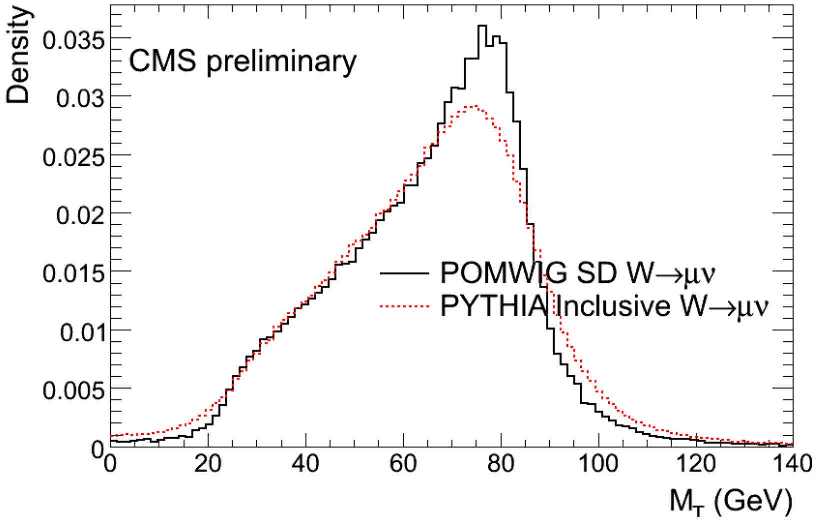
SD W → μν

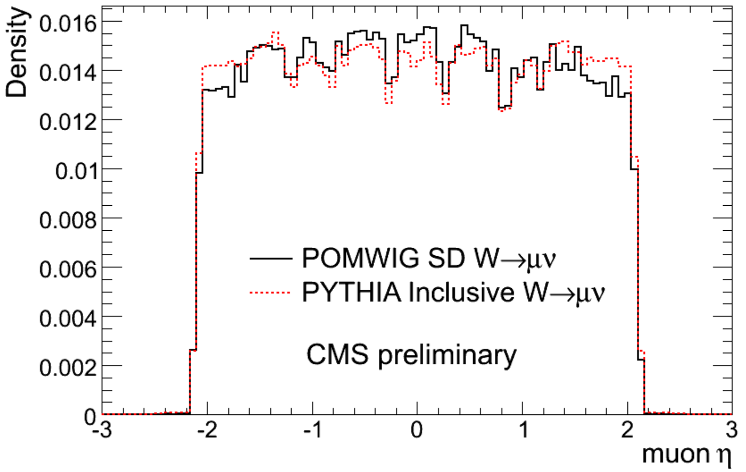


W→ μν selection









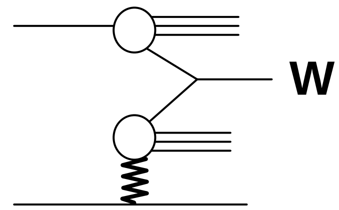
W → μυ selection: (same as inclusive analysis)
1 isolated μ

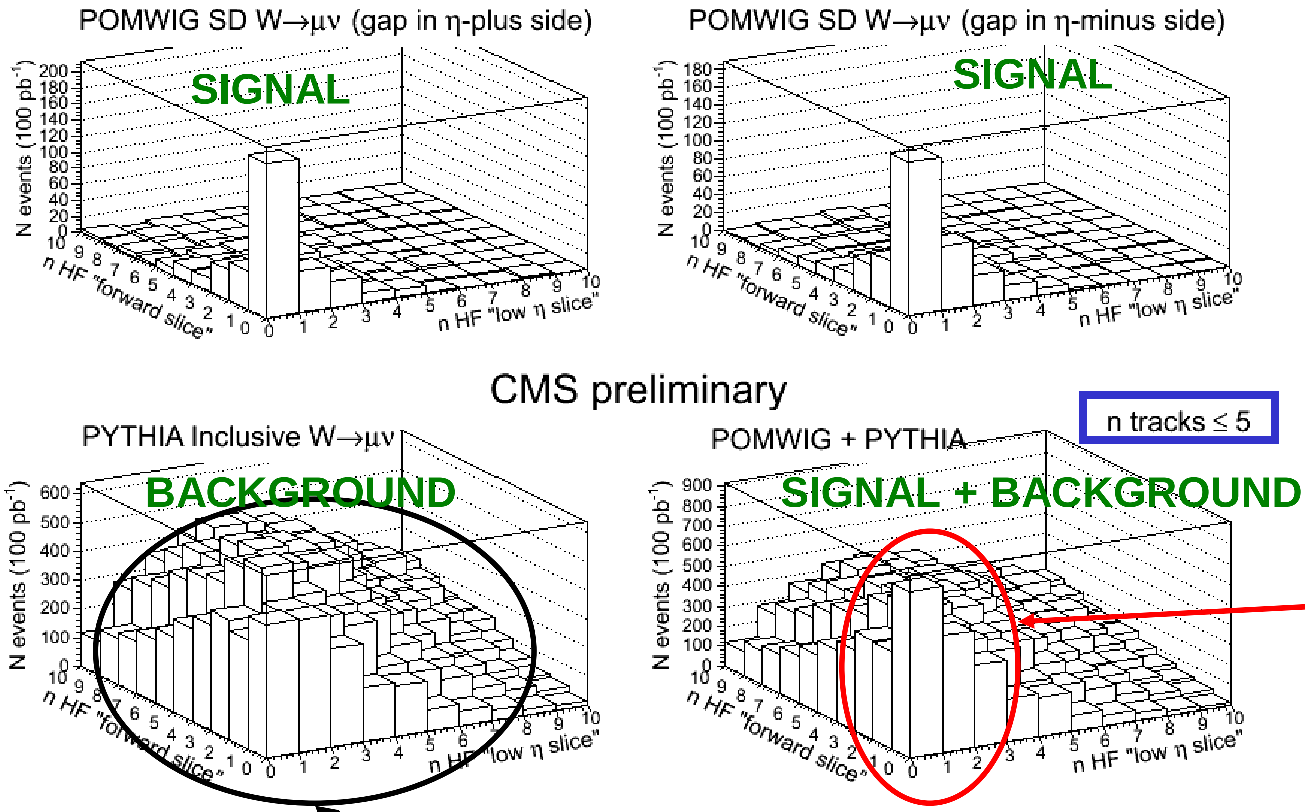
$p_T > 25$ GeV	$50 < M_T < 200$ GeV
$\|\eta\| < 2.0$	$\zeta = \pi - \Delta\varphi(\mu, E_T^{miss}) < 1$ rad
n jets($E_T > 40$ GeV) ≤ 3	n muons($p_T > 20$ GeV) < 2

Overall efficiency:
- Pomwig SD W→μυ: 34% (2.4k evts/100pb^{-1})
- Pythia W→μυ: 28% (600k evts/100pb^{-1})

NB: Diffractive W→μυ: Pomwig v2.0beta (dPDF: NLO H1 2006 Fit B)

SD W: HF multiplicity at "low η" vs "high η" in gap side





HF "low η slice": 3.0 < |η| < 4.0

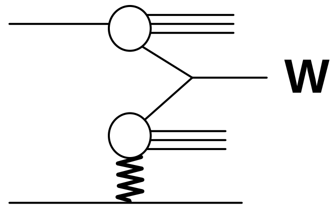
vs

HF "forward slice": 4.0 < |η| <5.0

Excess in low multiplicity visible (note different vertical scales !)

Shape sensitive to underlying event simulation

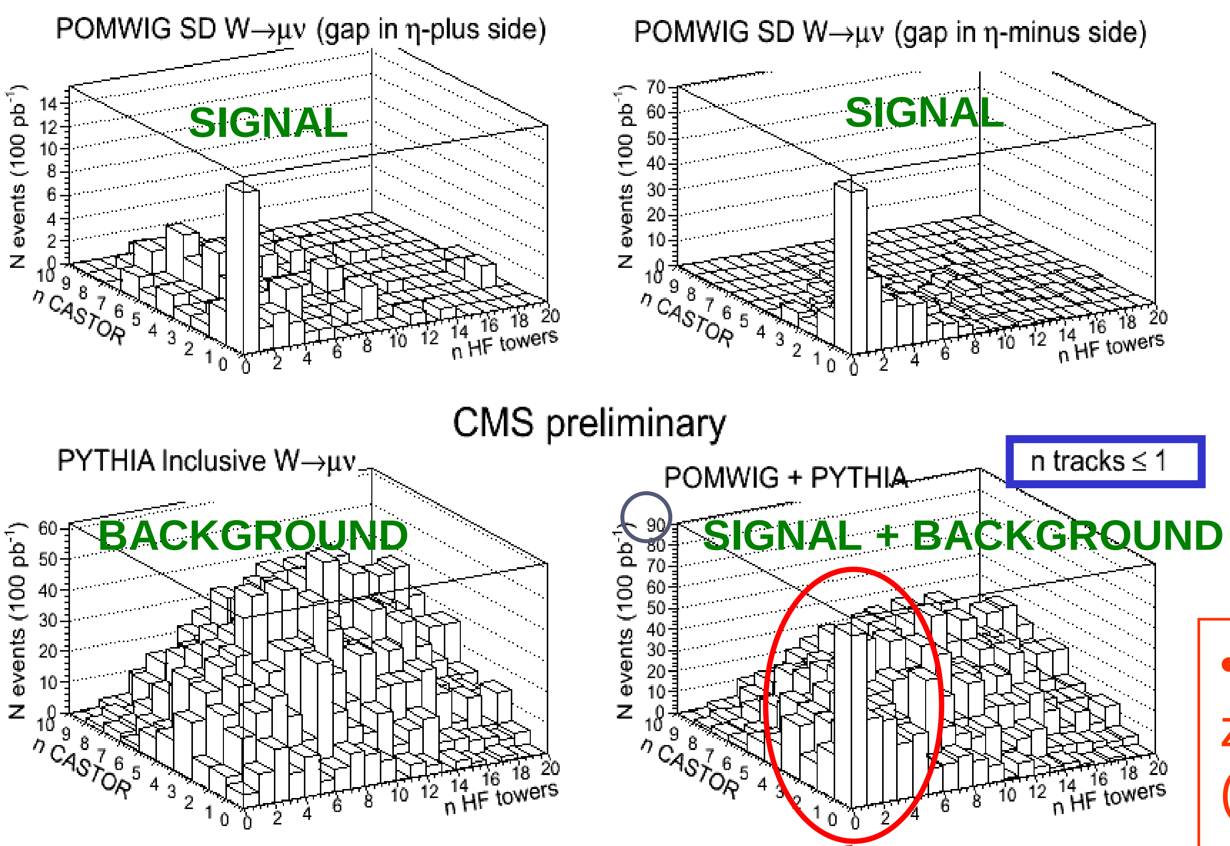
SD W: HF vs CASTOR multiplicity in gap side



HF: 3 < |η| < 5

vs

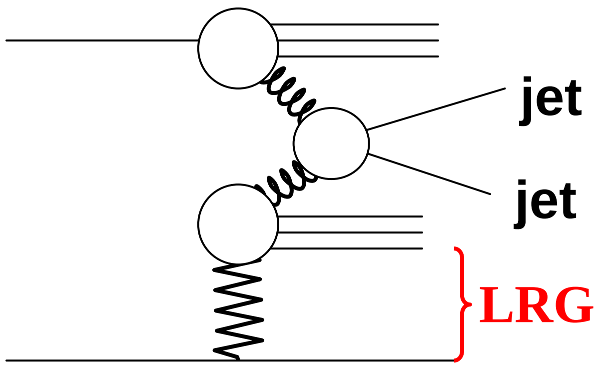
CASTOR: -6.6 < η < -5.2



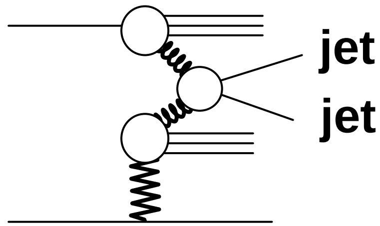
Clear peak at low multiplicity

- ~ O(100) events in zero-multiplicity bin (S/B ~ 6 - 20) for 100 pb^{-1}
- Potential factor 2 increase with CASTOR on both sides
- procedure selects ξ<0.01

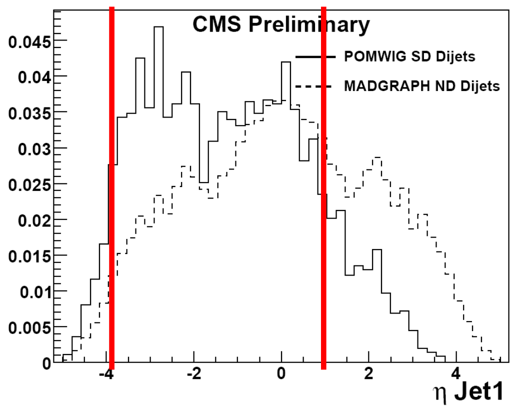
SD di-jets

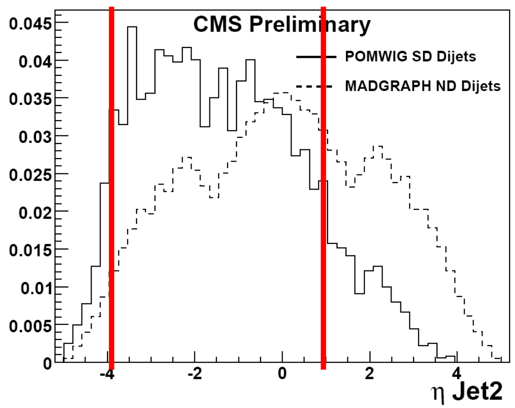


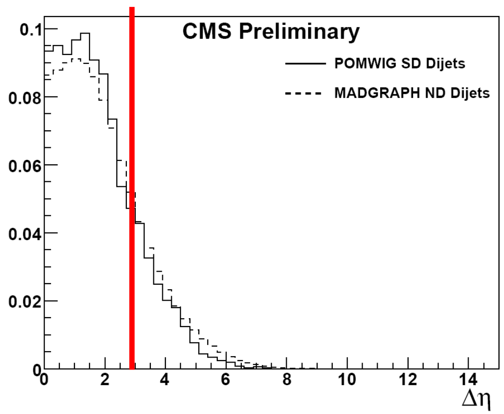
Di-jet selection



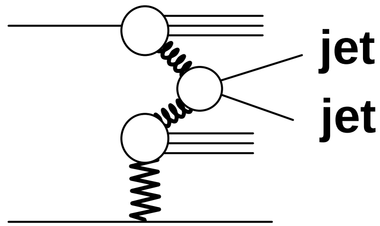
- **At least 2 Jets (SiSCone5) $E_{T1}, E_{T2} > 55$ GeV**
- **If gap side at positive (negative) η, $-4 < \eta_{1,2} < 1$ $(-1 < \eta_{1,2} < 4)$**
- $|\eta_1 - \eta_2| < 3$







SD di-jets

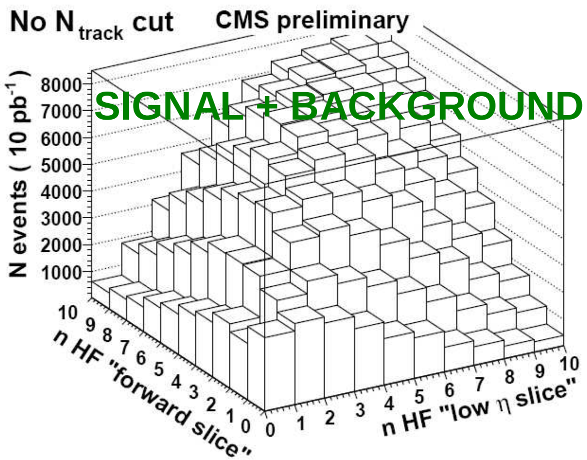


HF “low η slice”: 3.0 < |η| < 4.0

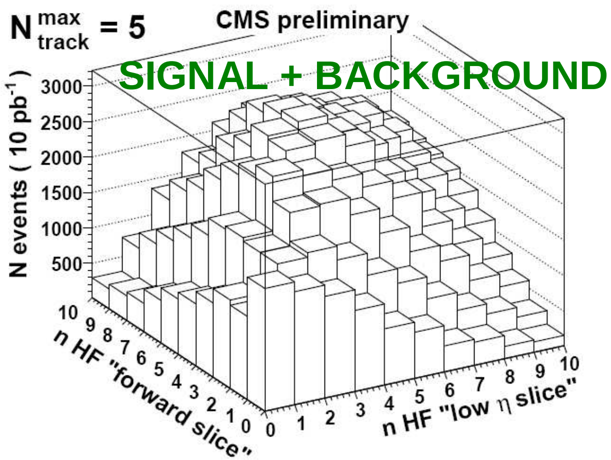
vs

HF “forward slice”: 4.0 < |η| <5.0

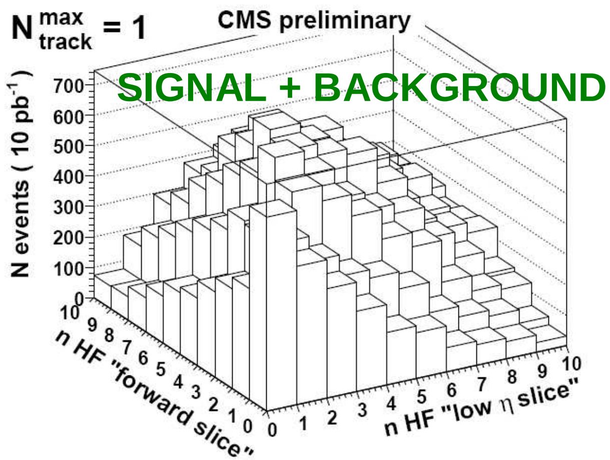
NO Ntrack CUT



Ntrack≤5

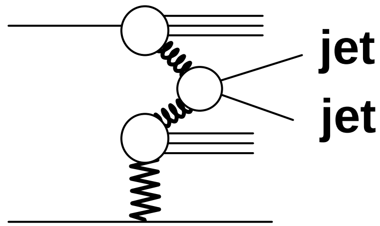


Ntrack≤1



SIGNIFICANCE IS HIGHER WHEN THE NTRACK CUT IS STRICTER

SD di-jets

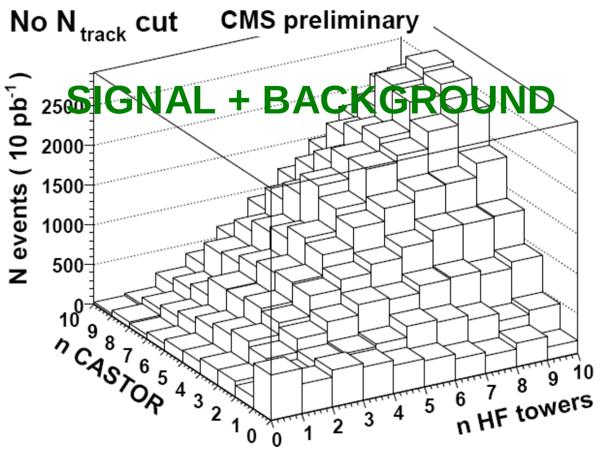


HF: 3 < |η| < 5

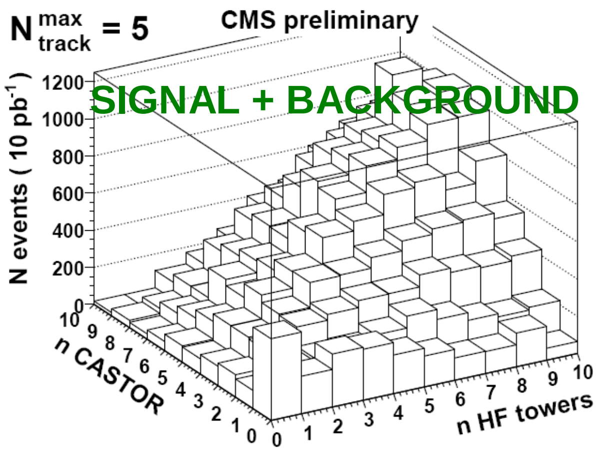
vs

CASTOR: -6.6 < η < -5.2

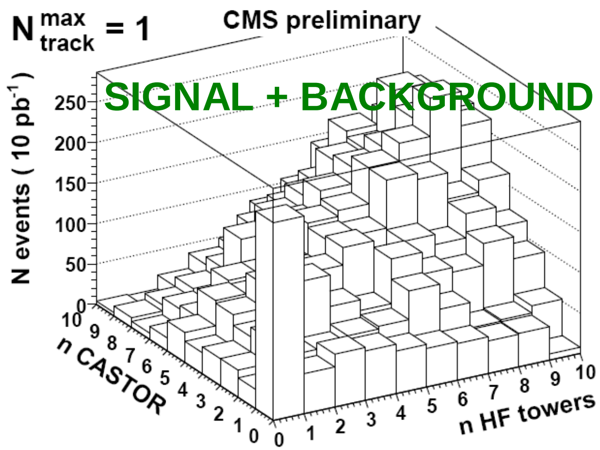
NO Ntrack CUT



Ntrack≤5



Ntrack≤1



SIGNIFICANCE IS HIGHER WHEN THE NTRACK CUT IS STRICTER

AND WHEN THE SIZE OF THE GAP IS LARGER (SUPPRESS GAPS DUE TO FLUCTUATIONS IN BACKGROUND)

SIZE OF SIGNAL CAN BE CONTROLLED IN PREDICTABLE WAY WHEN CHANGING SELECTION CUTS

O(300) events in zero-multiplicity bin for 10 pb^{-1}
$\xi<0.01$

Sensitivity to $<|S|^2>$

Sensitivity to <|S|^2> in SD di-jets

- **So far assumed rap. gap survival probability <|S|^2> = 0.05**

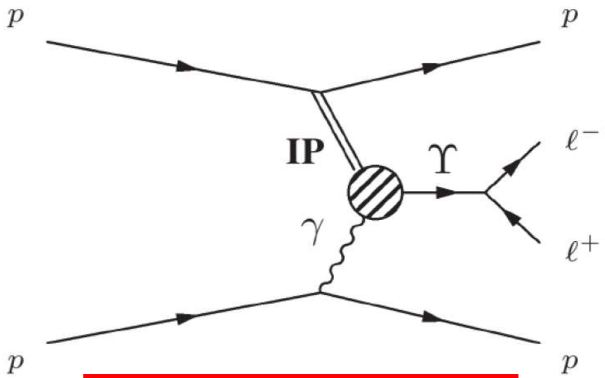
- **Evaluate diffr. yields in (0,0) bins for <|S|^2>=0.004 and 0.23 (J. S. Miller, EPJC 56 (2008) 39)**

	$N_{HF}=0$	$N_{\rm track}^{\rm max}$	<|S|^2> = 0.05 $N_{\rm diff}$ $\langle\|S\|^2\rangle = 0.05$	<|S|^2> = 0.004 $N_{\rm diff}$ $\langle\|S\|^2\rangle = 0.004$	<|S|^2> = 0.23 $N_{\rm diff}$ $\langle\|S\|^2\rangle = 0.23$	$N_{\rm non-diff}$
HF only		no cut	1047 ± 32	84 ± 9	4816 ± 69	1719 ± 41
		5	803 ± 28	64 ± 8	3694 ± 61	943 ± 31
		1	362 ± 19	29 ± 5	1665 ± 41	276 ± 16
	$N_{\rm HF}=0$, $N_{\rm CASTOR}=0$					
HF+Castor		no cut	504 ± 22	40 ± 6	2318 ± 48	67 ± 8
		5	409 ± 20	33 ± 4	1881 ± 43	31 ± 6
		1	236 ± 15	19 ± 4	1086 ± 33	8 ± 3

- **<|S|^2> = 0.004 → marginal observable signal**
- **<|S|^2> = 0.23 → very prominent signal**

Observation of eg 409 ± 20(stat.)$^{+200}_{-160}$ (syst.) would exclude <S^2> = 0.004, for which no signal is visible

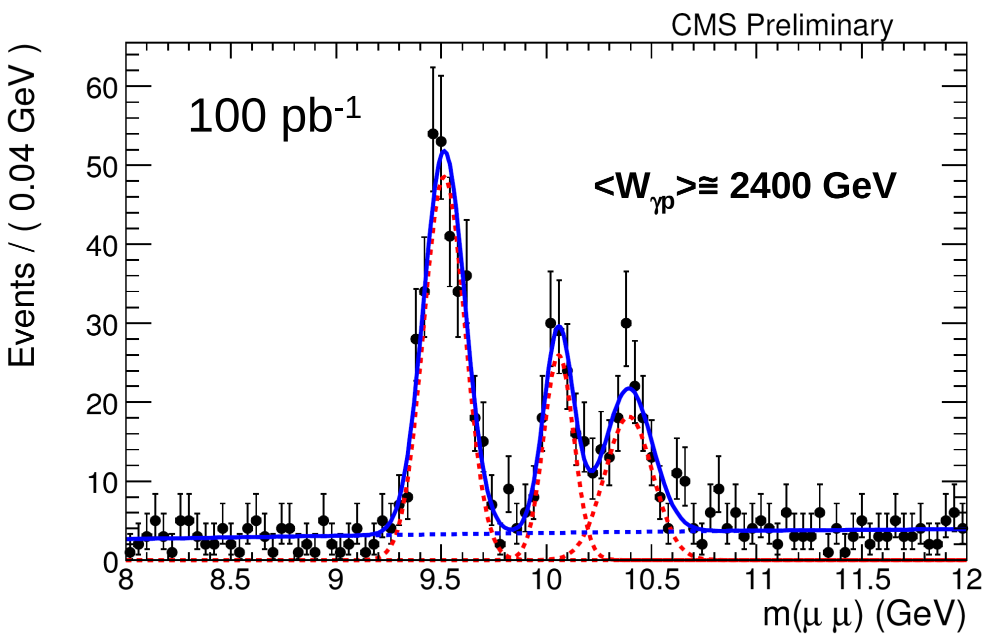
ϒ photoproduction

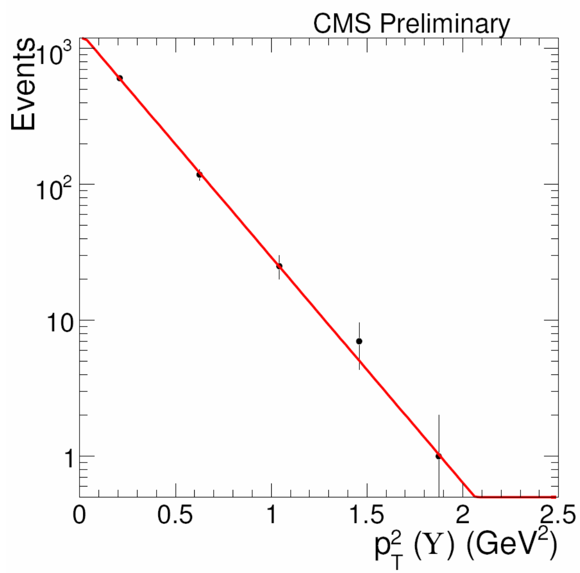


pp → ppϒ, ϒ → μμ

- **$\langle |S|^2 \rangle$ expected to be close to 1**
- **hence important term of comparison in early determinations of $\langle |S|^2 \rangle$**
- **$W_{\gamma p}$ and t dependences sensitive to gluon density – more specifically GPDs**
- **$\langle W_{\gamma p} \rangle \cong$ 2400 GeV (x10 wrt HERA)**

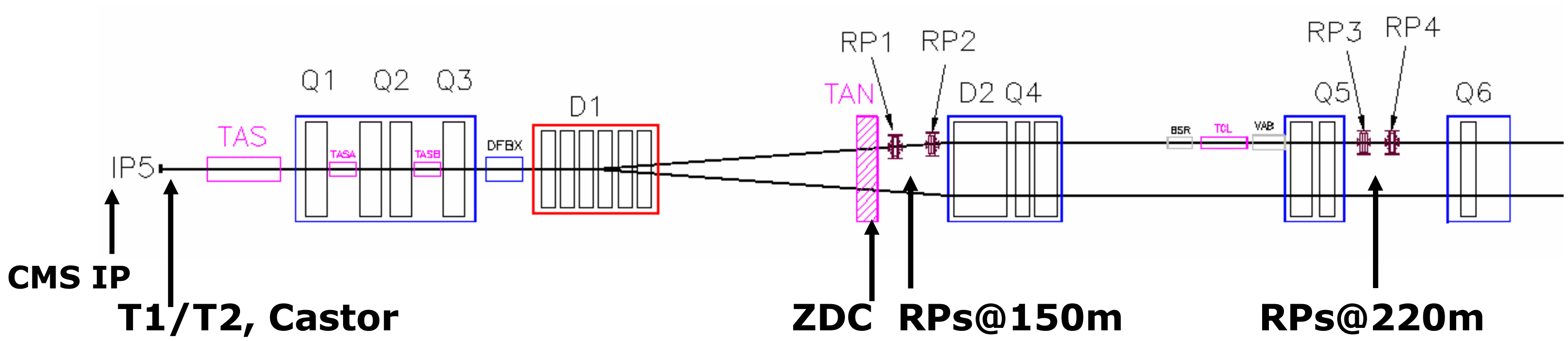
CMS PAS DIF-07-001





A look at the future:
physics with near-beam proton taggers

CMS & TOTEM

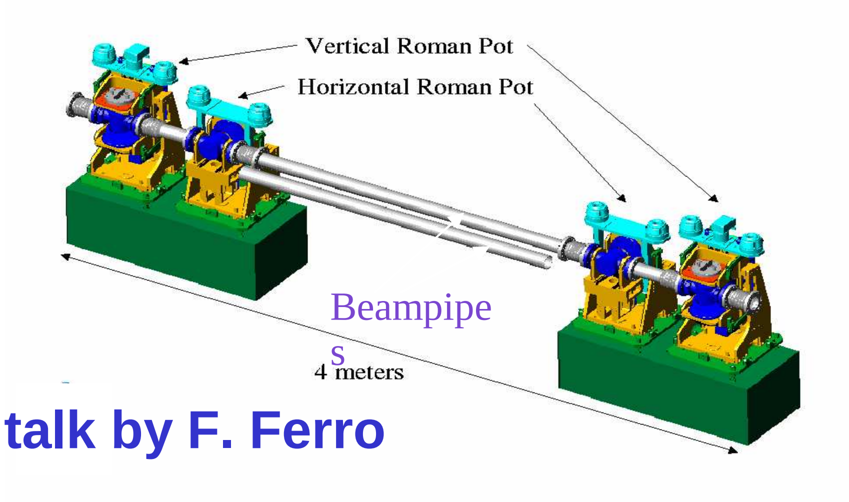


0.02<ξ<0.2 @ high-lumi optics

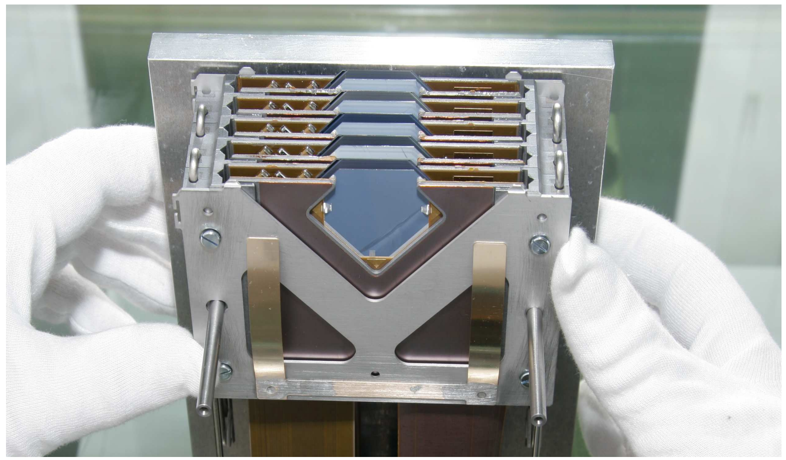
Expression of wish of **CMS + TOTEM to carry out a joint physics program**, with joint CMS+TOTEM data taking:

“Prospects for diffraction and forward physics at the LHC”

CERN LHCC 2006-039 G124, CMS note 2007-02, TOTEM note 06-5



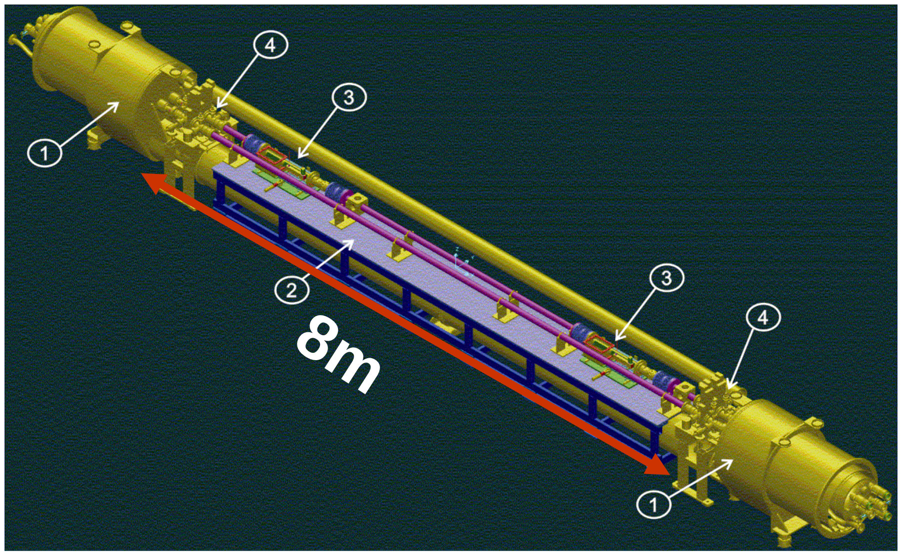
cf talk by F. Ferro

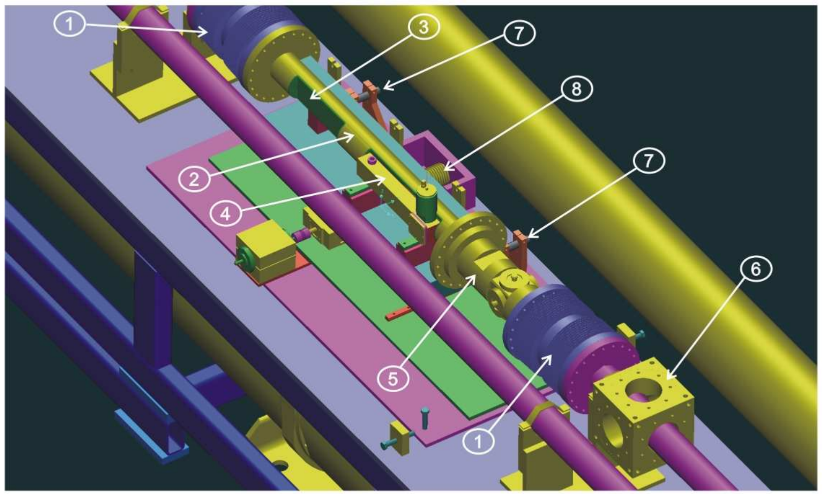


FP420

- Measure scattered protons at ±420m from Atlas/CMS interaction points
- 0.002<ξ<0.02 (complementary to TOTEM / 220m detectors !)
- Si detectors in cryogenic region of LHC, i.e. cryostat redesign needed
- Strict space limitations rule out Roman Pot technology, use movable beampipe
- Radiation hardness comparable to that for SLHC, use novel 3D Si detectors
- To control pile-up background use very fast timing detectors (σ ~ 10ps)
- Currently being evaluated by CMS and ATLAS

arXiv:0806.0302 [hep-ex]





Summary & Outlook

- Detailed, quantitative plans to re-discover hard diffraction at LHC using rapidity gaps; for now no pile-up
- Simple measurement of yields may give early information on $<|S|^2>$
- Shape of background sensitive to underlying event in non-diffractive interactions
- Once signal is established, move on to measurement of ratio of diffractive to inclusive yields à la CDF and D0
- Important to have proton tagging as soon as possible:
  - CMS & TOTEM and later FP420
  - ATLAS & AFP
- Eagerly awaiting data…