Diffraction at CMS

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(On behalf of CMS Collaboration)

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(13th "Blois Workshop")

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Outline

- Forward Physics Program with CMS
- Forward Detectors at CMS
- Studies in Preparation for Data
  - Single Diffractive Production (W and Di-Jets)
  - Υ Photoproduction
- Summary

Forward Physics Program with CMS

A long term program in Forward Physics is envisaged to be carried out with CMS:

- **At low luminosities: Inclusive single diffraction (SD) and double Pomeron exchange (DPE).**
- **At moderate luminosities: Diffraction in the presence of a hard scale; production of jets, vector bosons, heavy quarks.**
- **At the highest luminosities: Central exclusive production, which may even become a tool for discovery.**

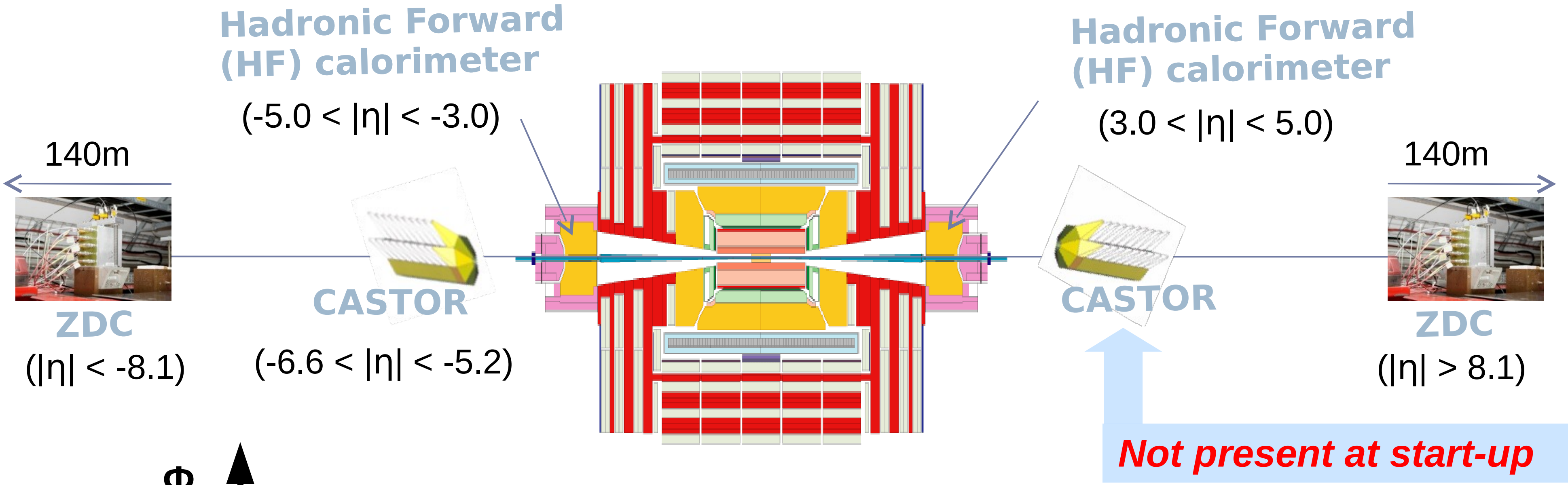
No proton tagger at the beginning. All analyses will be based on rapidity gap technique. (*For plans on future forward detectors in CMS, see K. Piotrzkowski's talk in this Conference*)

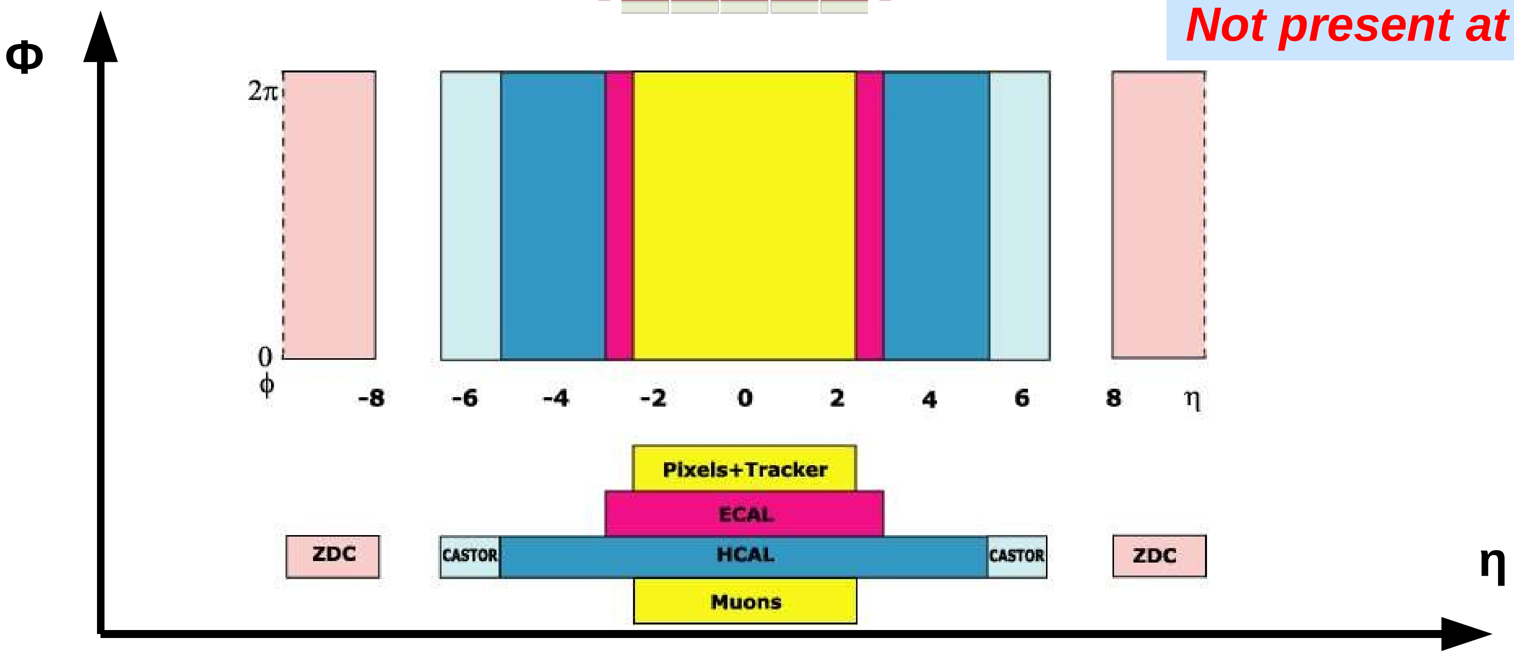
Forward Physics Program with CMS

Some topics that can be investigated with CMS early data:

- Observation of hard diffraction in W and di-jet production
- Measurement of the ratio of SD to Total yields for di-jet and W production: $R = N^{SD}/N^{Tot}$
- Assessment of the rapidity gap survival probability $\langle S^2 \rangle$ @ LHC energies ($\langle S^2 \rangle \sim 0.1$ @ Tevatron)
- Probing of the proton diffractive PDF's
- Observation and study of the production dynamics of exclusively photoproduced ϒ ; cross section sensitive to the generalized parton distribution function (GPD) for the gluons

Forward Detectors at CMS





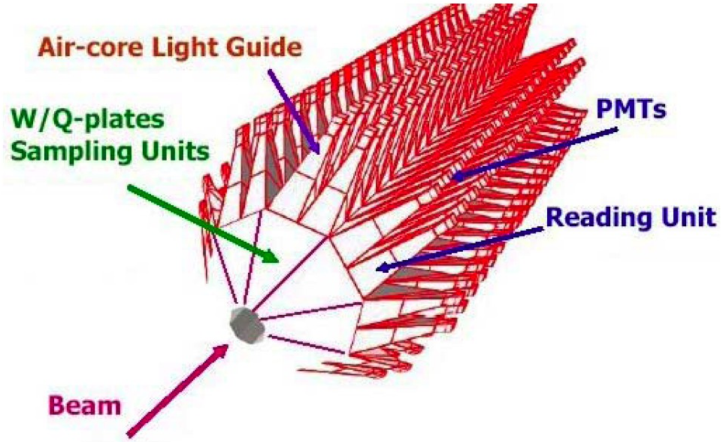
Forward Detectors at CMS

Hadronic Forward (HF) Calorimeter

- Located at 11.2m from IP
- Rapidity coverage: **3 < |η| < 5**
- **0.175 × 0.175** segmentation in η, φ
- Steel absorbers and embedded radiation-hard quartz fibers for fast collection of Cherenkov light
- Long (**1.65m**) and short (**1.43m**) fibers are placed alternately and run parallel to the beam axis along the iron absorbers.

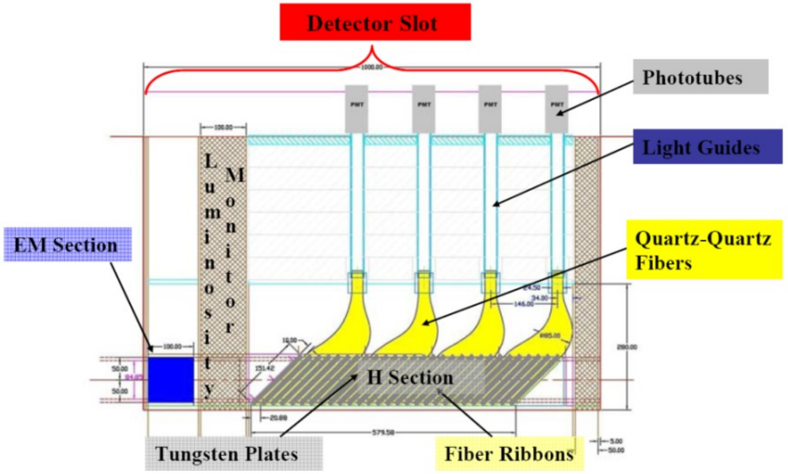
Forward Detectors at CMS

CASTOR & ZDC



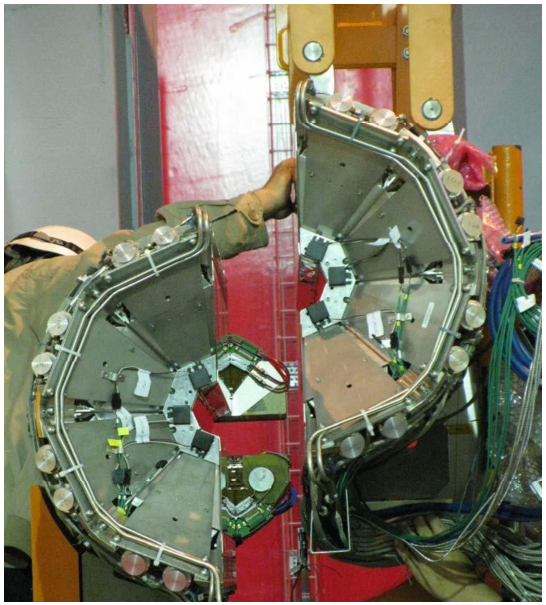
- Located at **14.3m** from IP
- Rapidity coverage: **$-6.6 < \eta < -5.2$**
- Only segmented in φ (16 sectors)
- Depth (z) segmentation: 14 modules (**2 EM + 12 HAD**) corresponding to **10.5λ**
- Alternate tungsten absorbers and quartz plates. Cherenkov light collected through aircore lightguides and PMT's

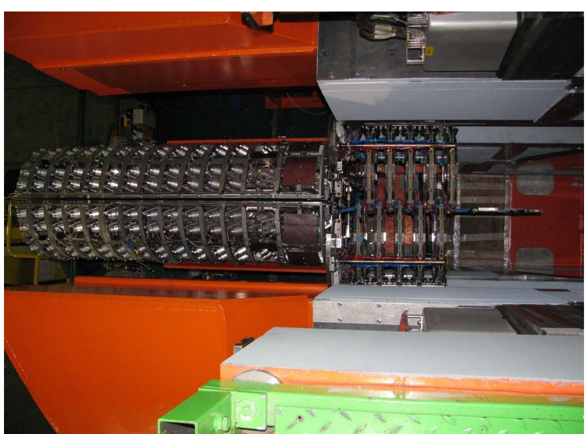
- Located at **140m** from IP
- Rapidity coverage: **$|\eta| > 8.1$**
- Tungsten/quartz Cherenkov calorimeter with separate **EM and HAD sections**
- For detection of neutrals (γ, π^0, n)



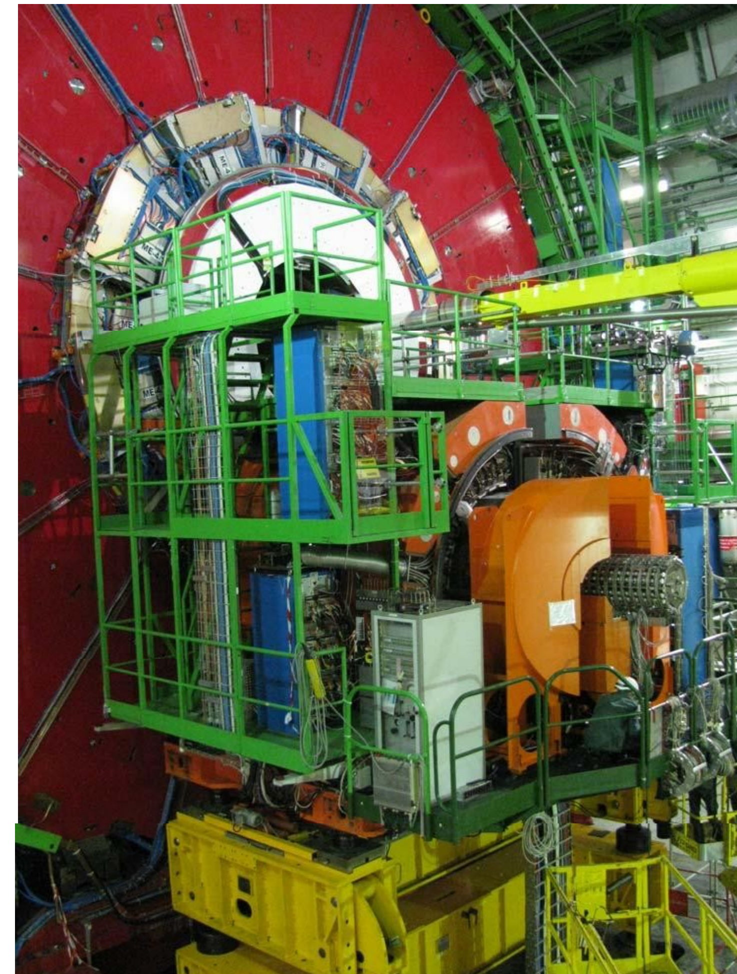
Forward Detectors at CMS

Last week CASTOR Installation!!





I told you we
would do it !!



Studies in preparation for Data

Analyses based on Monte Carlo performed in preparation for data taking:

- **Single diffractive W production** — CMS PAS DIF-07-002
- **Single diffractive di-jet production** — CMS PAS FWD-08-002
- **Exclusive di-lepton production** — CMS PAS DIF-07-001

  (Only ***Υ production*** *discussed here; see* ***J. Hollar*** *talk in this Conference for a complete discussion of di-leptons)*
- **Forward jet p_T spectrum** — CMS PAS FWD-08-001

  (Not discussed here; see ***D. d'Enterria*** *talk in this Conference for a discussion of this topic)*

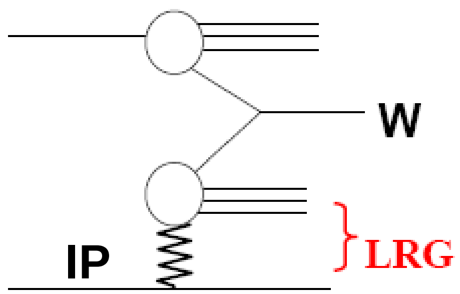
All these analyses are publicly available at:

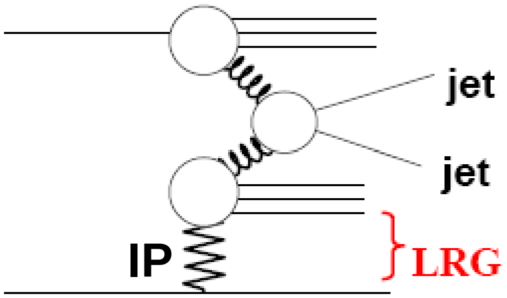
https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

Single Diffractive production of W bosons and di-jets

CMS PAS DIF-07-002 & CMS PAS FWD-08-002

- Both are hard diffractive processes characterized by the presence of a hard scale and a Large Rapidity Gap in the final state.
- Sensitive to the diffractive structure function of the proton.





Mainly sensitive to the **quark** component of the proton

Sensitive to the **gluon** component of the proton

SD production of W bosons and di-jets

Both analyses use samples produced under similar conditions...

- MC Samples:
  - Diffractive signal: POMWIG with PDF NLO H1 2006 fit B
  - Non-diffractive: PYTHIA/MADGRAPH with PDF CTEQ61
- Rapidity gap survival probability: $\langle S^2 \rangle = 0.05$
- Full detector simulation, trigger emulation and reconstruction, except by CASTOR treated at generator level
- E_{CM} = 14 TeV
- No pile-up scenario

SD production of W bosons and di-jets

... and follow the same methodology:

- Apply standard trigger and offline cuts to select a subsample of hard object (W or di-jets) candidates
- Define a "gap side" as the one with lower energy sum in HF
- Select diffractive candidates based on the multiplicity distributions in the central tracker and in the HF and CASTOR calorimeters (as at Tevatron and HERA)
- Obtain multiplicity distributions and yields for diffractive signal and background events which satisfy selection criteria
- Study the feasibility of observing statistically meaningful signals for some value of integrated luminosity

SD production of W bosons and di-jets

STANDARD CUTS

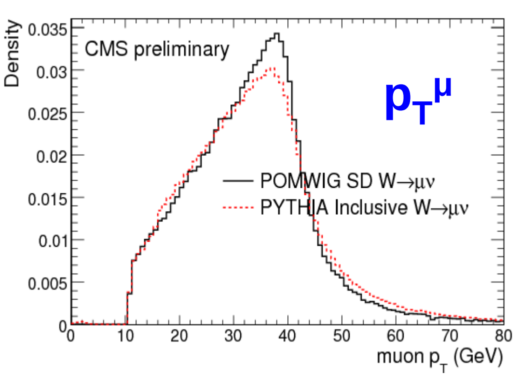
SD W Production

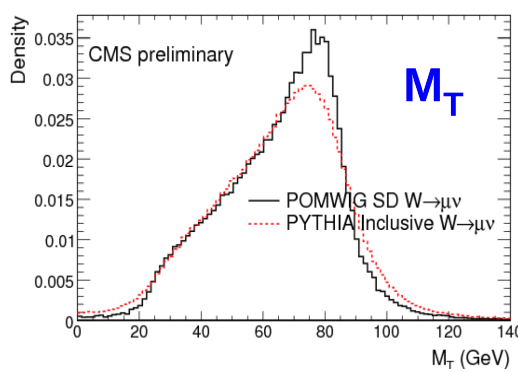
SD Di-jet Production

W → μν selection:

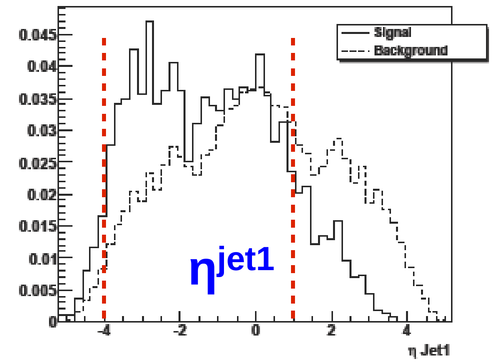
- $|\eta^{\mu}| \leq 2.0$, $p^{\mu}_{T} \geq 25$ GeV
- NO events with ≥ 2 muons with $p_T \geq 20$ GeV
- $\sum p_T^{tracks} < 3$GeV @ $\Delta R \equiv (\Delta\eta^2 + \Delta\Phi^2)^{1/2} \leq 0.3$ around μ
- $M_T > 50$ GeV
- ≤ 3 jets with $E_T > 40$ GeV
- $\zeta \equiv \pi - \Delta\Phi(\mu, E_T^{miss}) \leq 1$ rad

CMS PAS EWK-07-002

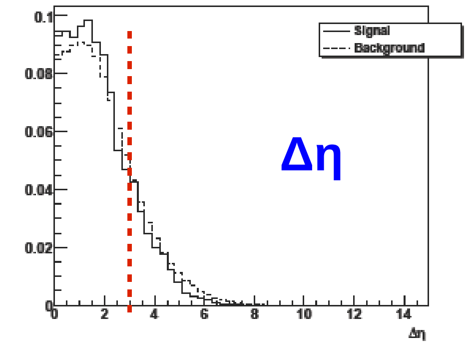




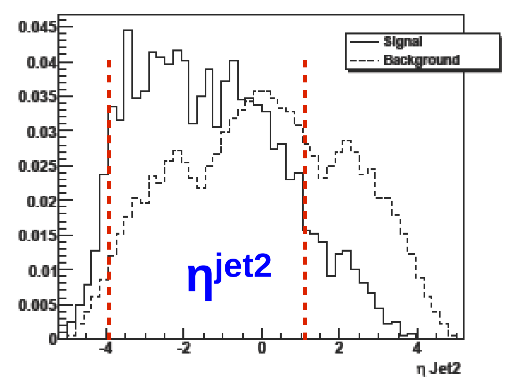
Inclusive di-jet selection:



At least 2 jets with $E_T \geq 55$ GeV



scattered proton at η>0



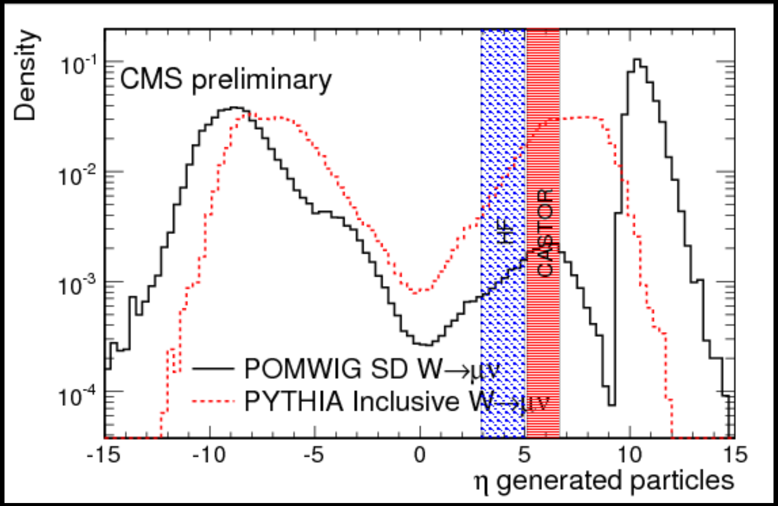
Aditional cuts:

- ✓ $-4 < \eta < 1$
- ✓ $\Delta\eta < 3$

SD production of W bosons and di-jets

GAP SIDE SELECTION

Energy flow for stable particles in diffractive and non-diffractive $W \rightarrow \mu\nu$



- SD events generated with scattered proton at $\eta>0$
- Neutrinos excluded

GAP SIDE
defined as the one with
LOWER ENERGY SUM IN HF

Probability of wrongly selecting the Gap Side:

- **$W \rightarrow \mu\nu$: ~ 30%**
- **Di-jets : ~ 10%**

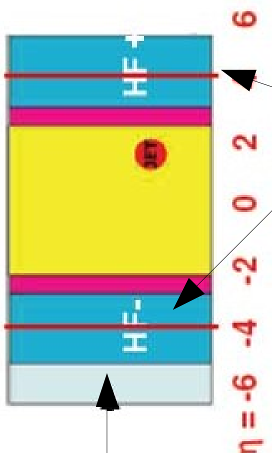
SD production of W bosons and di-jets

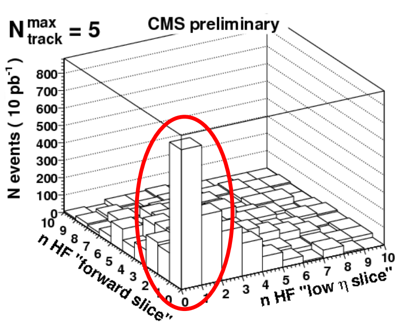
MULTIPLICITIES AND DIFFRACTIVE CANDIDATES

FORWARD CALORIMETERS

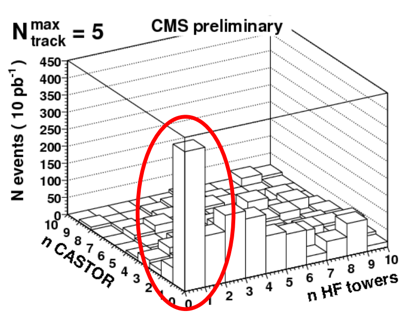
- **HF** is segmented in **TOWERS**
- **CASTOR** is segmented in **Φ sectors**

HF
- towers above threshold
- divided into 2 η-slices:
  - ✓ $2.9 < |\eta| < 4.0 \rightarrow$ "low η"
  - ✓ $4.0 < |\eta| < 5.2 \rightarrow$ "forward"





HF forward vs. **HF low**

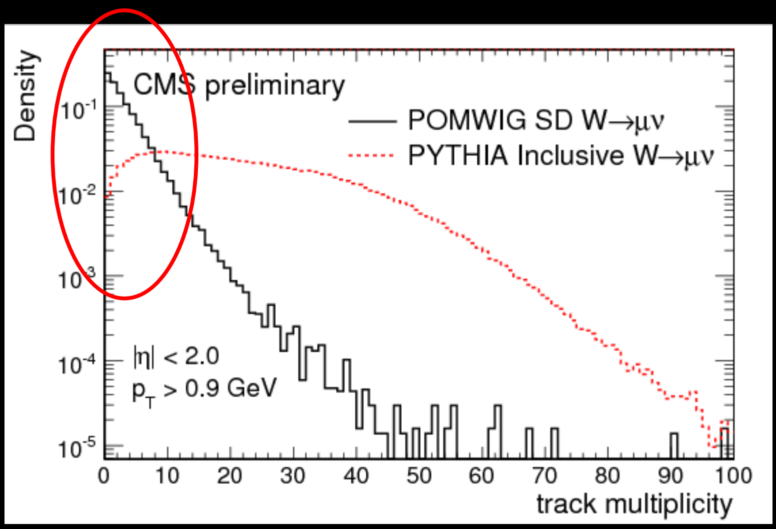


Castor vs. **HF**

CASTOR
- only at ONE SIDE
- generator level information
- φ sector with activity

TRACKER

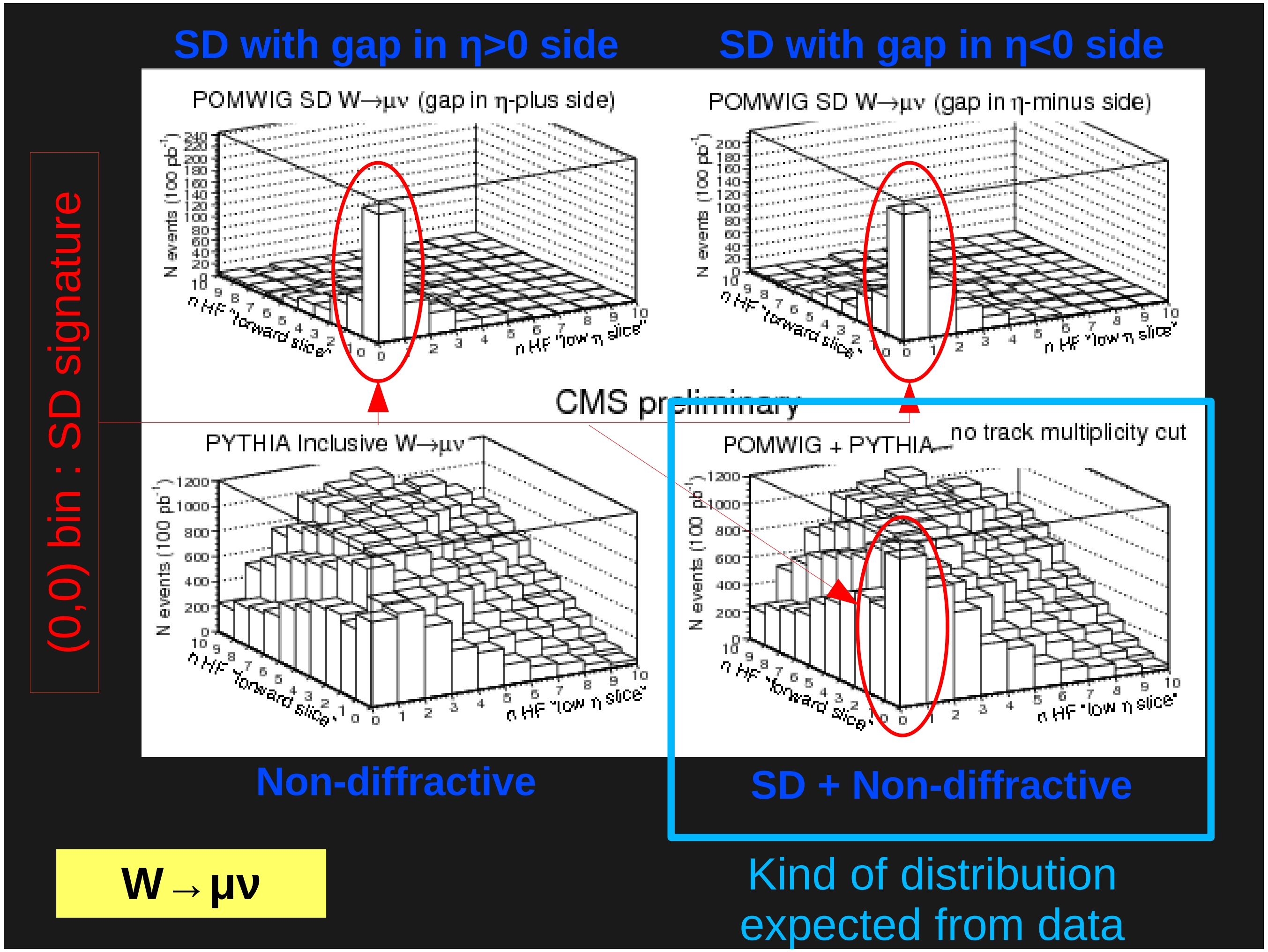
Multiplicity distribution in the central tracker after W selection cuts



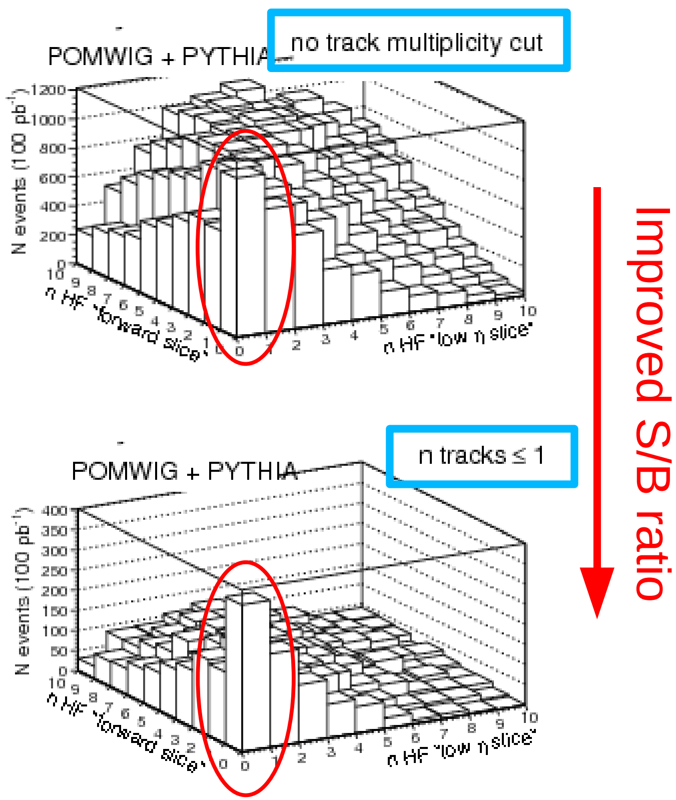
- μ candidate track excluded for $W \rightarrow \mu\nu$
- jet tracks excluded for Di-jets

SD production of W bosons and di-jets

HF ONLY: “low η slice” vs. “forward slice”



How does the excess in (0,0) bin change with track multiplicity cut?

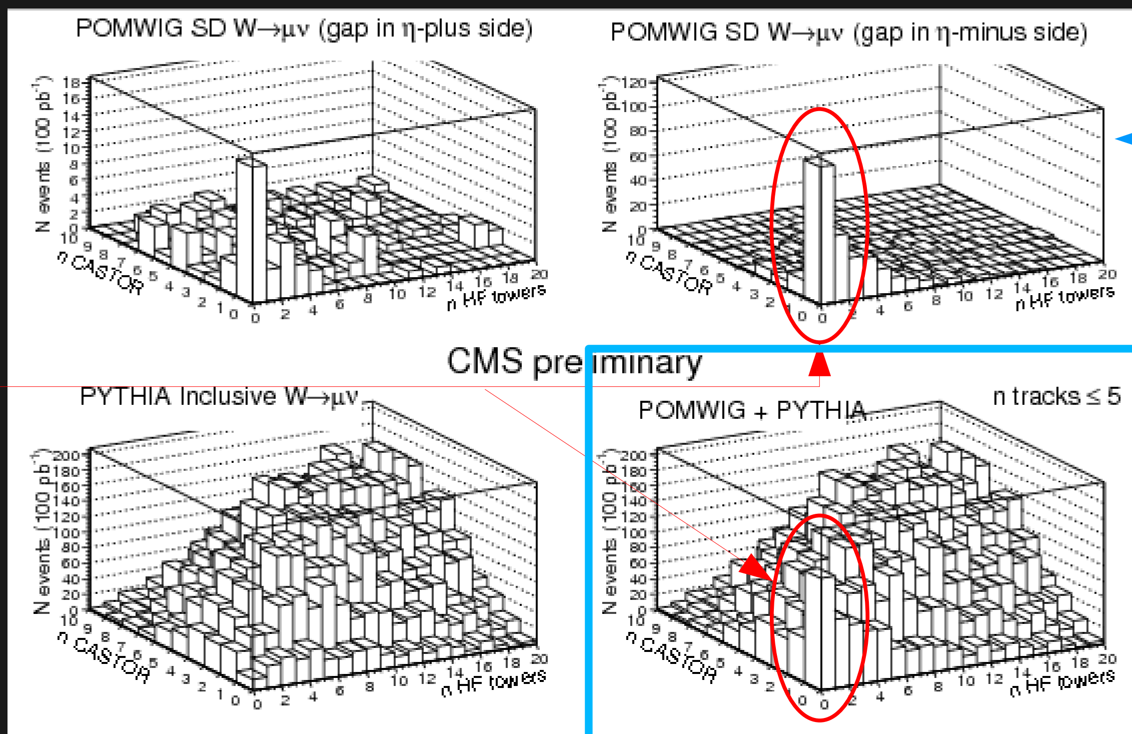


SD production of W bosons and di-jets

HF vs. CASTOR MULTIPLICITIES

Gap in the wrong side | **Gap in the right side**

(0,0) bin : SD signature



Non-diffractive | **SD + Non-diffractive**

W → μν

Kind of distribution expected from data

In the early running of LHC, CASTOR will be present only at one side (η<0)

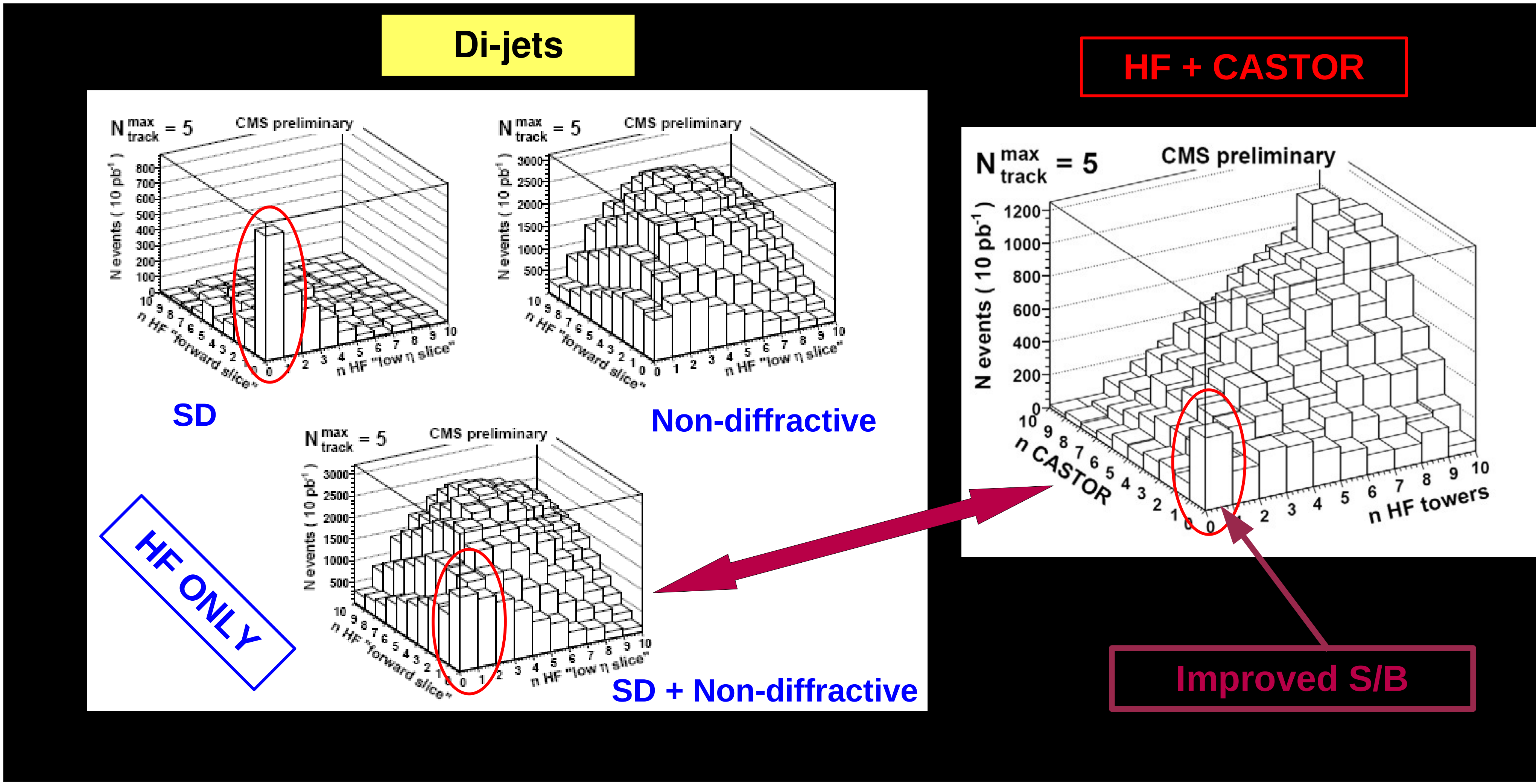
For Ntrack ≤ 5:

S/B(HF only) ~ 1
S/B(HF+CASTOR) ~ 10

HF + CASTOR define a larger rapidity gap

SD production of W bosons and di-jets

MULTIPLICITIES



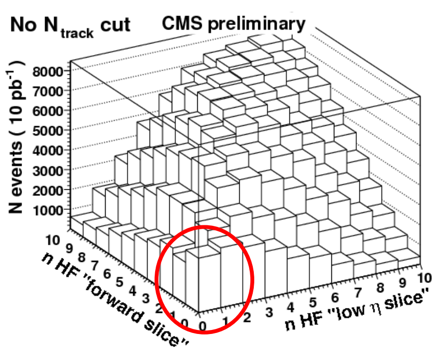
SD production of W bosons and di-jets

ESTABLISHING DIFFRACTIVE SIGNAL IN DATA

Di-jets

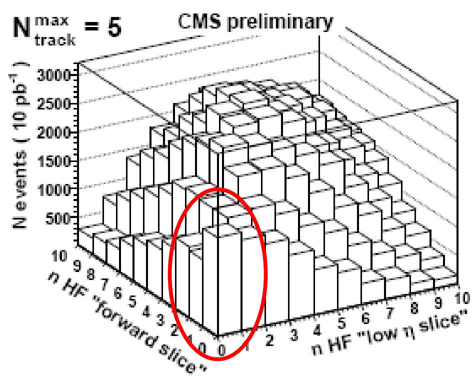
By varying the central tracker multiplicity cut, the diffractive peak at (0,0) bin can be controlled in a predictable way

$N_{track} \leq \infty$



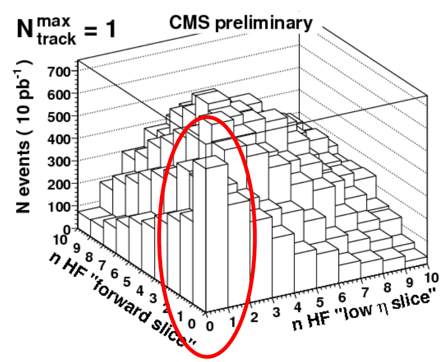
S/B ~ 0.6

$N_{track} \leq 5$



S/B ~ 0.9

$N_{track} \leq 1$



S/B ~ 1.3

HF only case

The stricter the cut, the higher the significance

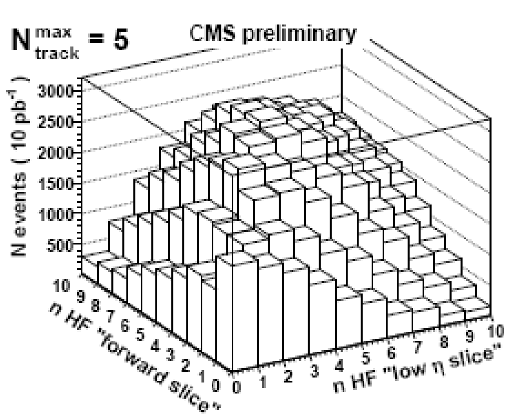
SD production of W bosons and di-jets

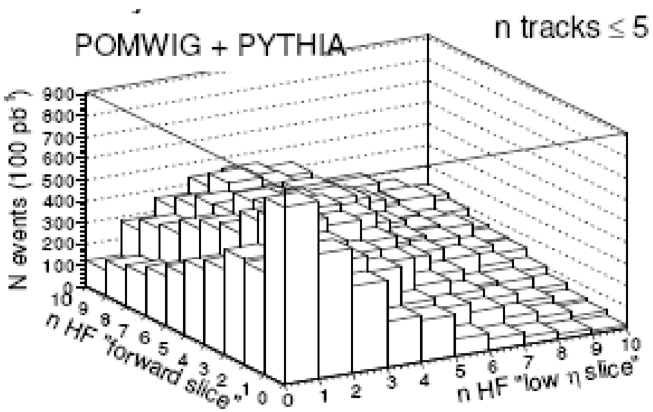
FEASIBILITY STUDIES

Di-jets (10 pb^{-1})

$W \rightarrow \mu\nu$ (100 pb^{-1})

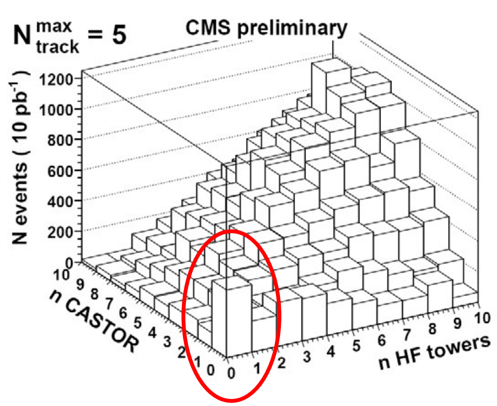
HF only

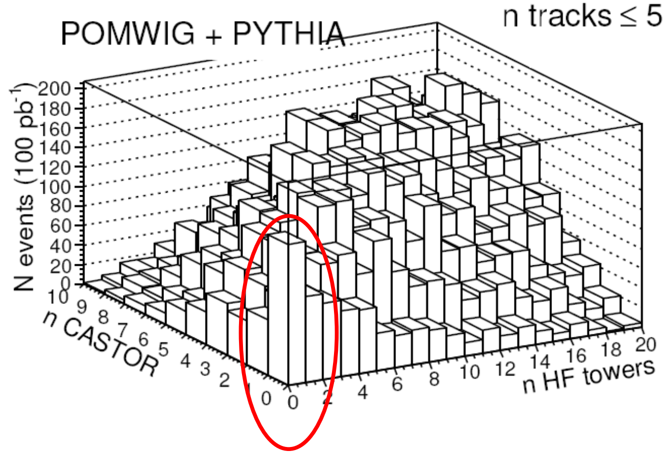




$\langle S^2 \rangle = 0.05$

HF + CASTOR





O(400) events

O(100) events

SD production of W bosons and di-jets

SENSITIVITY TO $<S^2>$

- At LHC energies, values of Rapidity Gap Survival Probability as low as **0.004** and as high as **0.23** have been reported
- The feasibility of observing **SD Di-jet** production has been assesed for these extreme values of **$<S^2>$**

	$N_{HF}=0$	N^{max}_{track}	N_{diff} $\langle\|S\|^2\rangle=0.05$	N_{diff} $\langle\|S\|^2\rangle=0.004$	N_{diff} $\langle\|S\|^2\rangle=0.23$	$N_{non-diff}$
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
	$N_{HF}=0, N_{CASTOR}=0$					
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

- Conclusion:
  - ✓ **$<S^2>$ = 0.004** : marginally observable signal
  - ✓ **$<S^2>$ = 0.23** : very prominent signal in any scenario

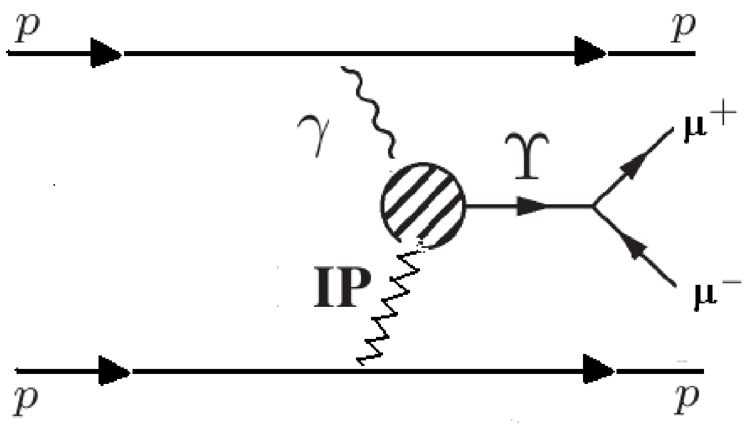
Observation of a signal may exclude extremely low values of $<S^2>$

Exclusive Υ photoproduction

CMS PAS DIF-07-001

- Elastic production of di-lepton final states through *γp* interaction

$$\gamma p \to \Upsilon p \to l^+ l^- p$$

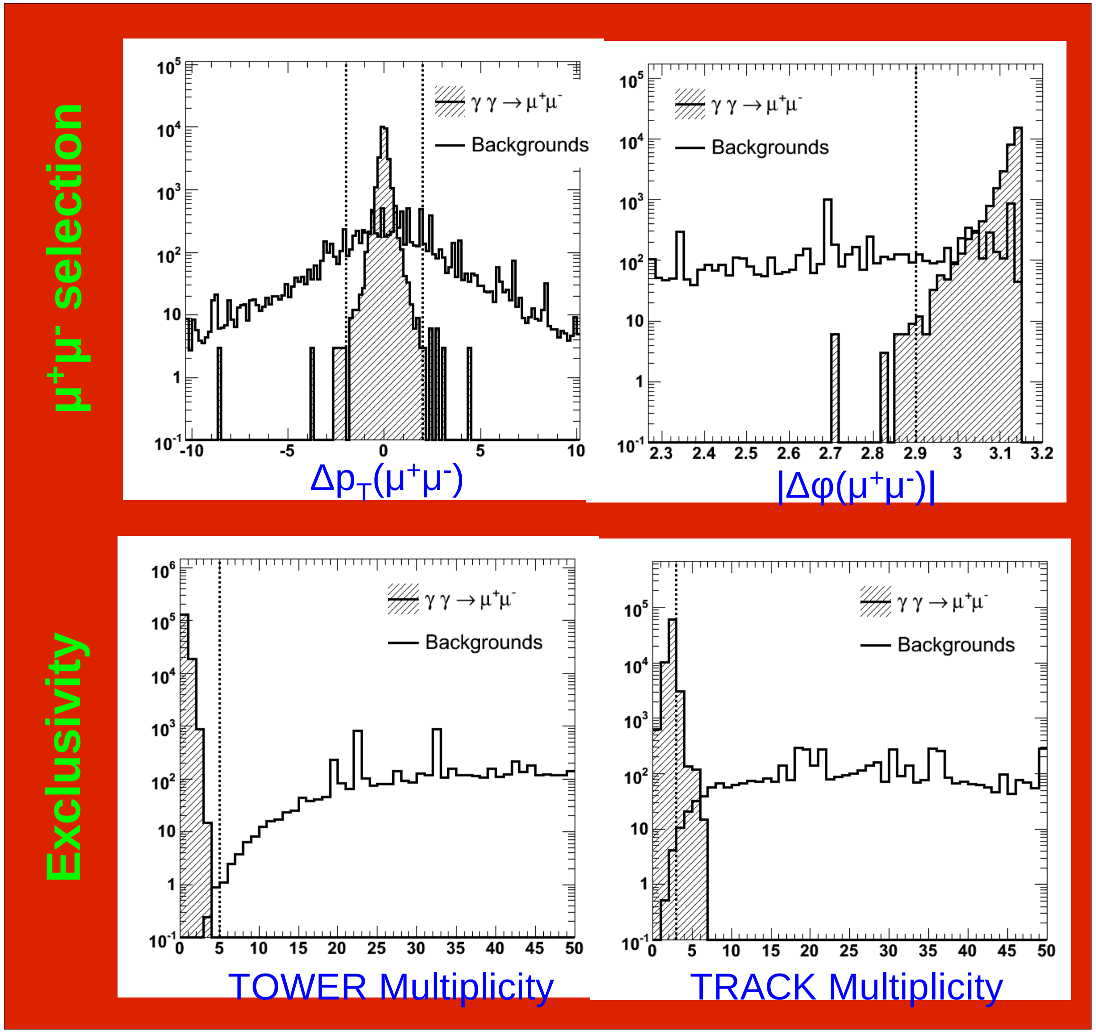


- Experimental signature is identical to $\gamma\gamma \to \ell^+\ell^-$, so the event selection is the same for both analyses
- Analysis to be done with first **100 pb^{-1}** of data, when luminosity will be low and average number of interactions per bunch crossing < 1 (low pile-up)
- Measured cross section will constrain QCD models

Exclusive Υ photoproduction

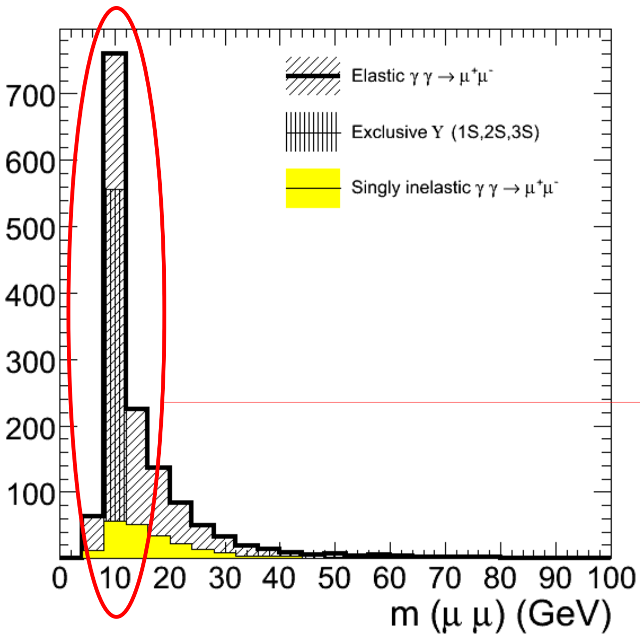
MC SIMULATION & EVENT SELECTION

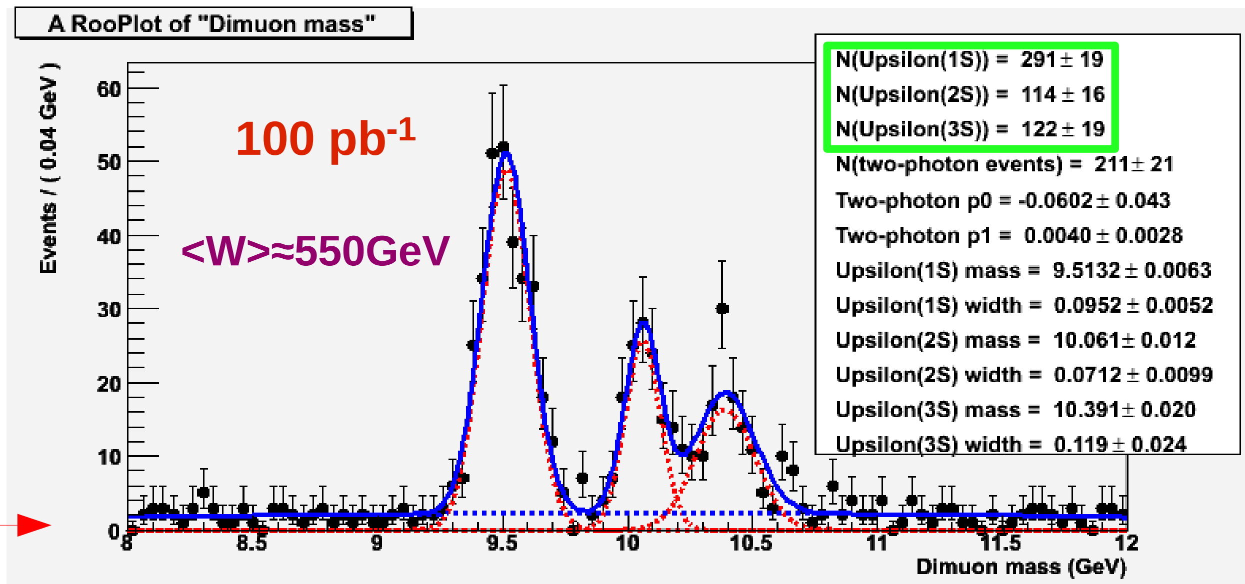
- **STARLIGHT** generator used for signal, with **σ × BR**:
  - ✔ Υ(1S) = 39 pb
  - ✔ Υ(2S) = 33 pb
  - ✔ Υ(3S) = 10 pb
- Backgrounds (Drell-Yan, quarkonium, heavy-flavour jets) simulated with **PYTHIA**
- **LPAIR** for two-photon exchange process
- MC samples subject to full detector simulation, trigger emulation and reconstruction
- No pile-up scenario assumed
- E_{CM} = 14 TeV



Exclusive ϒ photoproduction

DIMUON SPECTRUM & ϒ YIELD





Assuming STARLIGHT cross-sections, significant signals of the 3 ϒ resonances should be visible!

Given the expected event yield, studies of ϒ production dynamics may be possible, in particular extracting the *t* distribution from the measured p_T^2 distribution of the ϒ's (*see J. Hollar's talk in this Conference*)

Summary

CMS is ready to study hard diffractive processes with the LHC early data, using the Large Rapidity Gap / exclusivity techniques.

10 pb^{-1}

***O*(300) SD Di-jet events are expected, assuming <S^2>=0.05. Depending on the event yield, it might be possible to put some constraints on <S^2>.**

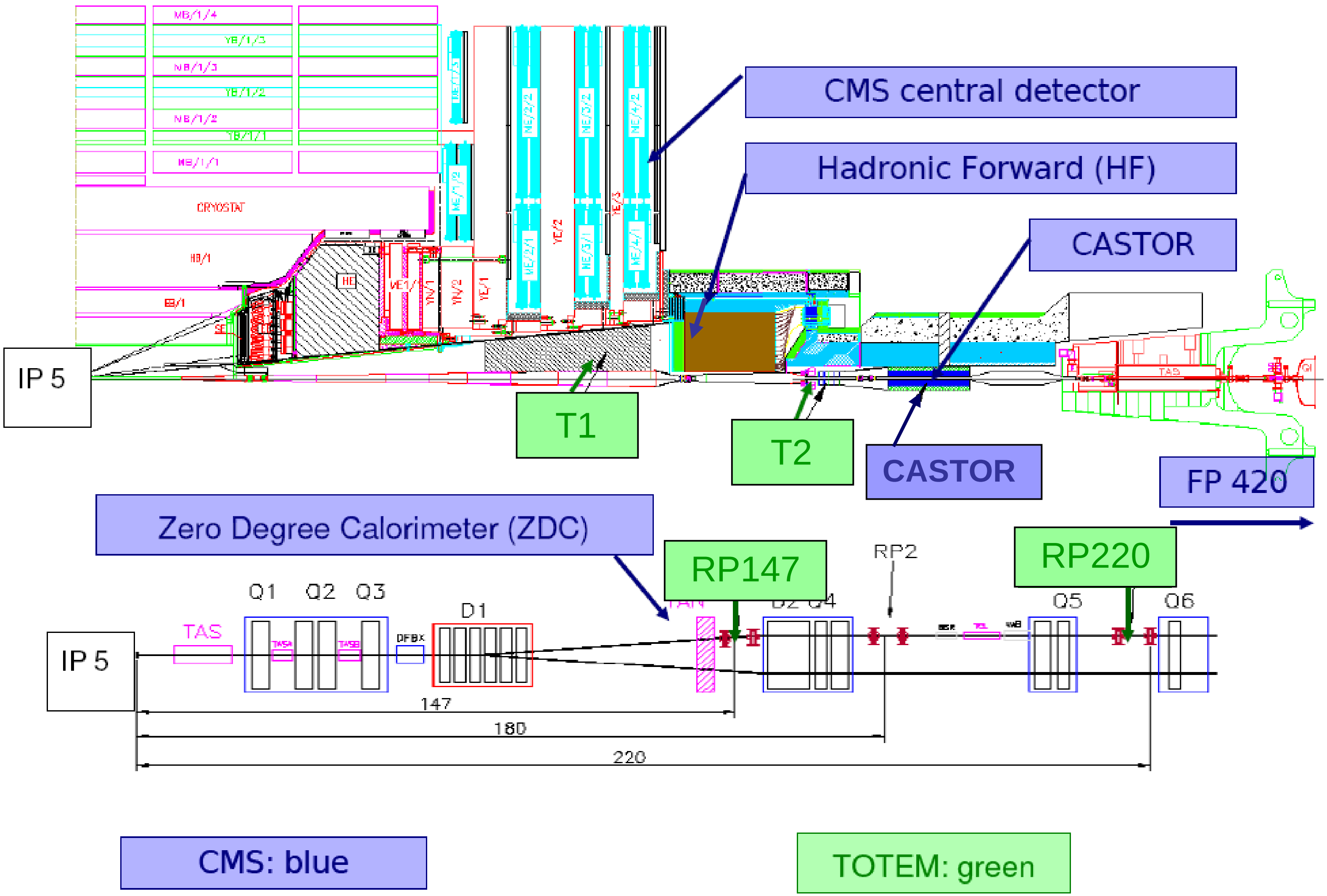
100 pb^{-1}

Measurable signals of SD W production, *O*(100), and ϒ photo-production, with all 3 resonances becoming visible.

All the analyses presented here assume low luminosity and no pile-up. In the long term, with higher luminosities, it will be essential to be able to tag on protons to keep a diffractive program ongoing.

BACKUP SLIDES

Forward Detectors in CMS



Exclusive ϒ photoproduction

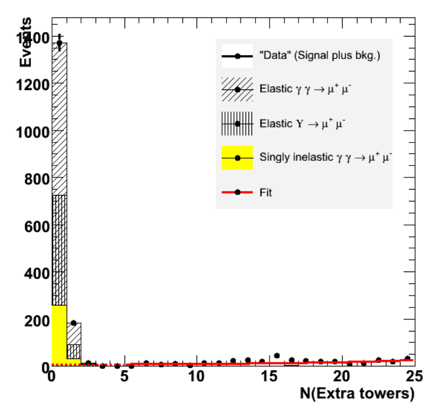
BACKGROUNDS

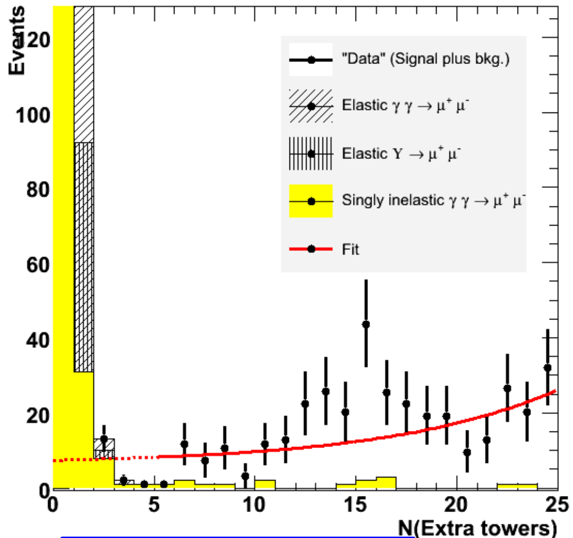
Inelastic photon exchange

- Dominant background: proton remnants escape undetected outside calorimeter coverage
- VETOing with CASTOR (one side) and ZDC (both sides) forward detectors, may significantly reduce this background by approximately 2/3 (based on generator-level acceptance)

Other non-exclusive processes

- The contribution will be estimated in data by fitting the sideband of the calorimeter towers multiplicity distribution
- Simulation gives 6%, much less than 31% (CASTOR + ZDC veto) to 90% for inelastic





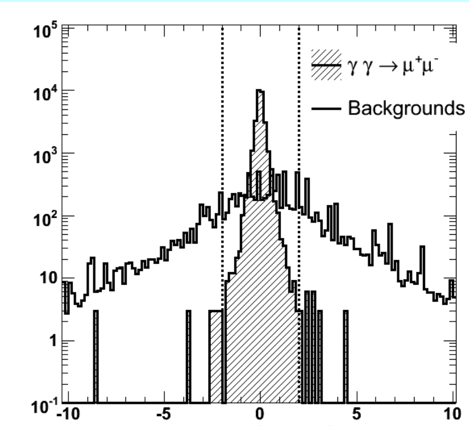
Zoomed view

Exclusive Υ photoproduction

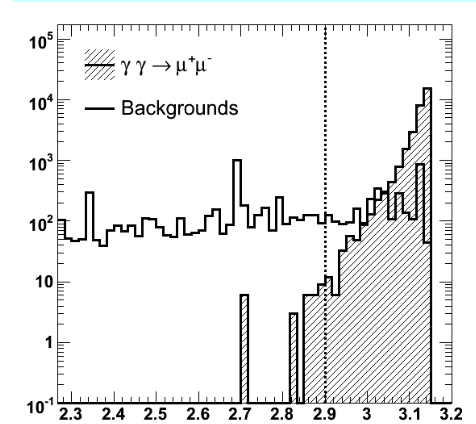
EVENT SELECTION

- e^+e^- channel killed by the high trigger thresholds

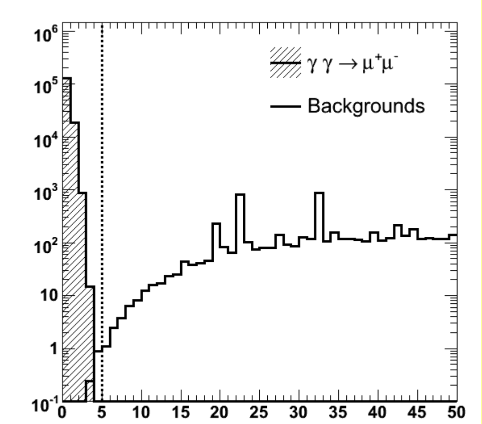
- Di-muon cuts:
  - ✔ p_T balance: $|\Delta p_T(\mu^+\mu^-)| < 2.0$ GeV
  - ✔ back-to-back μ's: $|\Delta\varphi(\mu^+\mu^-)| > 2.9$



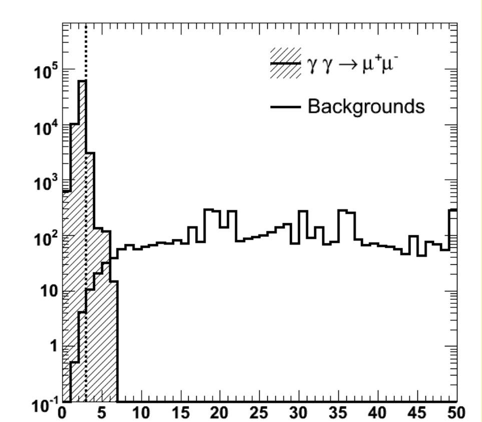
$\Delta p_T(\mu^+\mu^-)$



$|\Delta\varphi(\mu^+\mu^-)|$



TOWER Multiplicity



TRACK Multiplicity

- Exclusivity conditions:
  - ✔ Calorimeter: < 5 towers above noise threshold (5 GeV)
  - ✔ Tracker: no additional charged candidate