Perspectives for new studies of high energy photon interactions at the LHC

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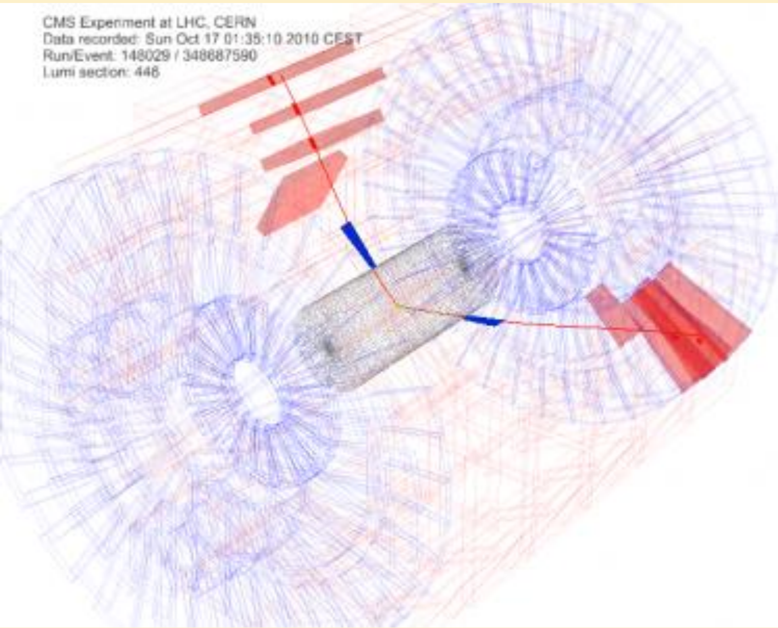

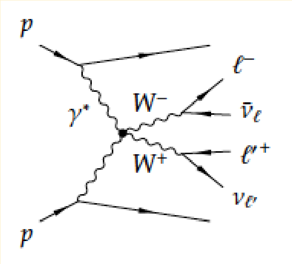

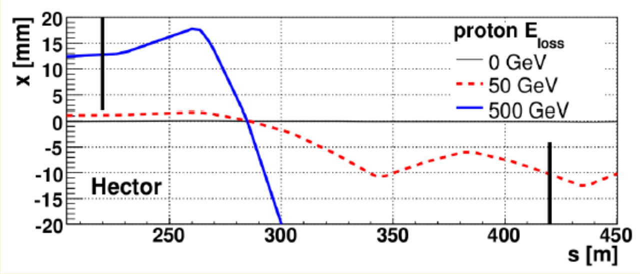

Workshop on photon-induced collisions at the LHC

CERN, June 2-4, 2014

How to continue?

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LHC PHYSICS

CMS sees first direct evidence for $\gamma\gamma \to WW$

In a small fraction of proton collisions at the LHC, the two colliding protons interact only electromagnetically, radiating high-energy photons that subsequently interact or "fuse" to produce a pair of heavy charged particles. Fully exclusive production of such pairs takes place when quasi-real photons are emitted coherently by the protons rather than by their quarks, which survive the interaction. The ability to select such events opens up the exciting possibility of transforming the LHC into a high-energy photon–photon collider and of performing complementary or unique studies of the Standard Model and its possible extensions.

The CMS collaboration has made use of this opportunity by employing a novel method to select "exclusive" events based only on tracking information. The selection is made by requesting that two – and only two – tracks originate from a candidate vertex for the exclusive two-photon production. The power of this method, which was first developed for the pioneering measurement of exclusive production of muon and electron pairs, lies in its effectiveness even in difficult high-luminosity conditions with large event pile-up at the LHC.

The collaboration has recently used this approach to analyse the full data sample collected at $\sqrt{s}$=7 TeV and to obtain the first direct evidence of the $\gamma\gamma \to WW$ process. Fully leptonic W-boson decays have been measured in final states characterized by opposite-sign and opposite-flavour lepton pairs where one W decays into an electron and a neutrino, the other into a muon and a neutrino (both neutrinos leave undetected). The leptons were required to have: transverse momenta p_T>20 GeV/*c* and pseudorapidity $|\eta|$<2.1; no extra track associated with their vertex; and for the pair, a total p_T>30 GeV/*c*. After applying all selection criteria, only two events remained – compared with an expectation of 3.2 events: 2.2 from $\gamma\gamma \to WW$ and 1 from background (figure 2).

The lack of events observed at large values of transverse momentum for the pair, which would be expected within the Standard Model, allows stringent limits on anomalous quartic $\gamma\gamma WW$ couplings to be derived. These surpass the previous best limits, set at the Large Electron–Positron collider and at the Tevatron, by up to two orders of magnitude (figure 3).

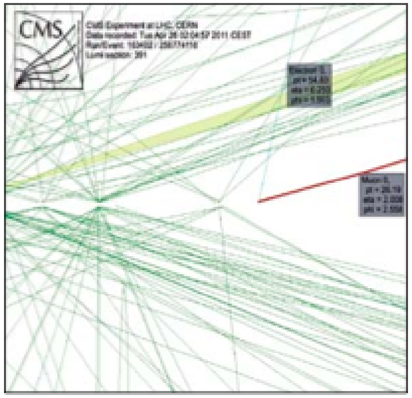


Fig. 1. Above: Proton–proton collisions recorded by CMS at $\sqrt{s}$=7 TeV, featuring candidates for the exclusive two-photon production of a W^+W^- pair, where one W boson has decayed into an electron and a neutrino, the other into a muon and a neutrino.

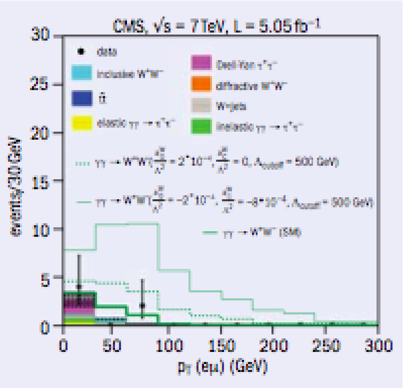


Fig. 2. Top right: The p_T distribution of eμ pairs in events with no extra tracks compared with the Standard Model expectation (thick green line) and predictions for anomalous quartic gauge couplings (dashed green histograms).

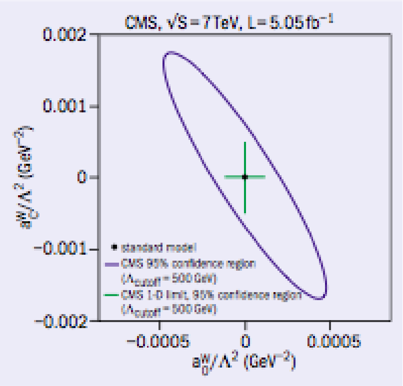
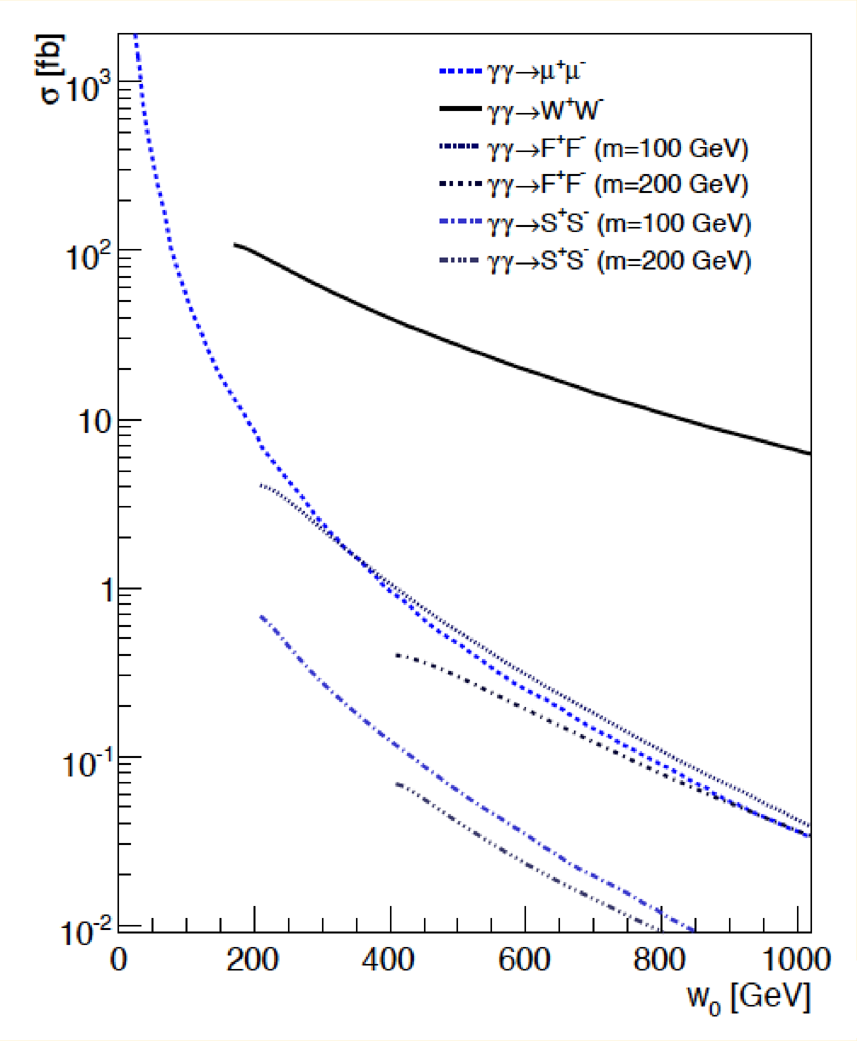


Fig. 3. Right: Limits on anomalous quartic $\gamma\gamma WW$ couplings.

Further reading

CMS collaboration 2013 arXiv:1305.5596 [hep-ex], submitted to *JHEP*.

Two-photon pair production @ LHC



arXiv:0908.2020v1 [hep-ph]

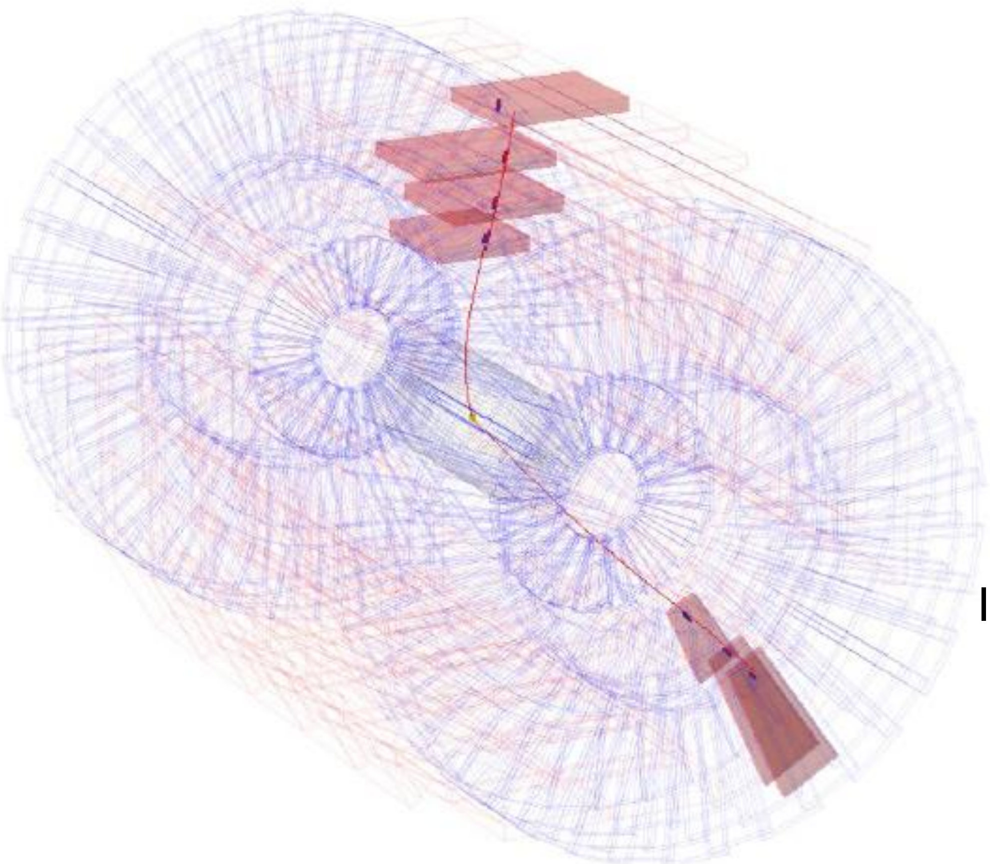
Small production cross-sections determined completely by the particle mass (+charge) and spin

At low invariant γγ masses the μμ pairs dominate but at high energy WW pairs rule !

(Results for 14 TeV)

W_0 is a minimal γγ CM energy

Exclusivity conditions



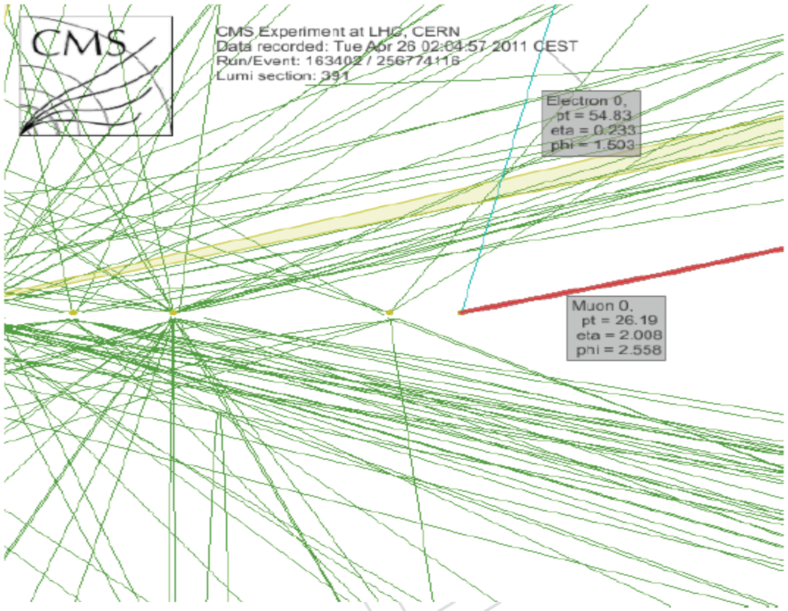
In (very) low luminosity era:
2 muons and "nothing else"
in the tracker and calorimeters

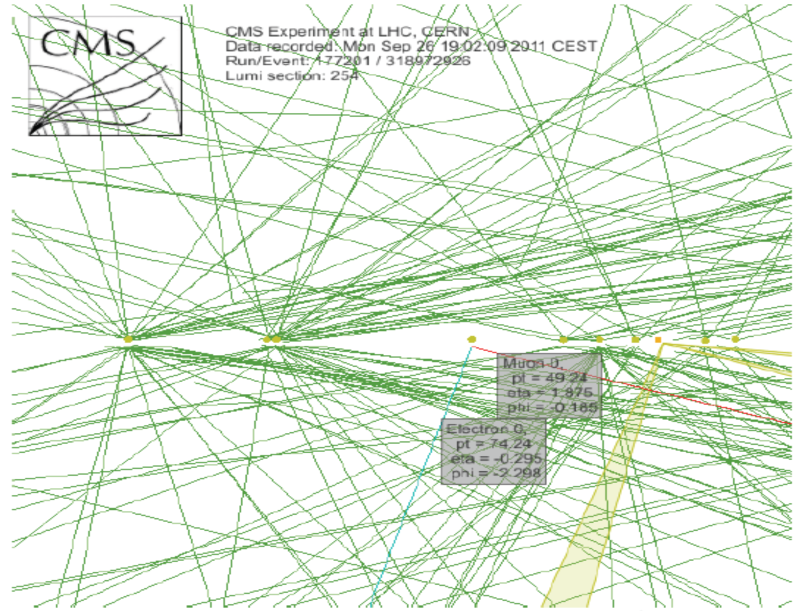
In 2010, each event of interest accompanied by extra "PileUp" events within the same bunch crossing:
~ 2-3 pileup interactions

In 2011, roughly 7 PU and in 2012 about **15 PU** per crossing

Restricting the analysis to single interaction events only would have reduced the data sample to < 0.1% of the total → **impose exclusivity using tracking only**

Two golden candidates for $\gamma\gamma \to WW$





Variable	Event 1	Event 2
Run	163402	177201
LumiSection	391	254
Event number	256774116	318972926
$m(\mu^{\pm}e^{\mp})$ [GeV]	85.5	190.3
1 - $\lvert\Delta\phi(\mu^{\pm}e^{\mp})/\pi\rvert$	0.66	0.33
$p_{\mathrm{T}}(\mu^{\pm})$ [GeV]	26.2	49.2
$E_{\mathrm{T}}(e^{\pm})$ [GeV]	54.8	74.2
$\eta(\mu^{\pm})$	2.01	1.88
$\eta(e^{\pm})$	0.23	-0.30

- Only eμ channel analyzed
- 2012 data still being analyzed
- Should be repeated with 2015/16 data

Photon Tagging is a Must

•Beyond 2016 event pileup will make untagged measurements quasi-impossible (average PU>20) – catching forward scattered protons becomes mandatory → AFP and CT-PPS projects

•Even simple tag will help to beat down the non-exclusive backgrounds, but if precision timing is added new channels become feasible:

- μμ **and** ee **(fully leptonic) channels can be used**
- semi-leptonic WW decays can be studied too!

•Even more – photon energies **can be precisely measured, so full event kinematics can be reconstructed, even for fully leptonic events! Semi-leptonic events are then over-constrained** → yet another tool to beat the backgrounds); transverse momentum measurement is very difficult – maybe 0.2-0.3 GeV/c resolution can be achieved eventually.

WW production: extrapolations from data

arXiv.org > hep-ex > arXiv:1305.5596

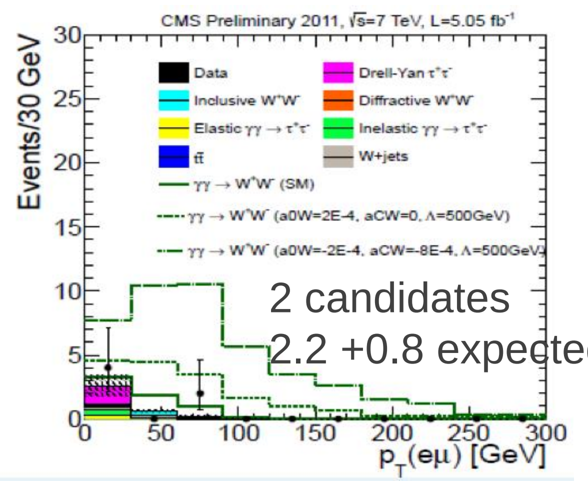
Search or Ar

High Energy Physics – Experiment

Study of exclusive two-photon production of W(+)W(-) in pp collisions at sqrt(s)=7 TeV and constraints on anomalous quartic gauge couplings

CMS Collaboration

(Submitted on 24 May 2013)



Extrapolation from 2011 data:

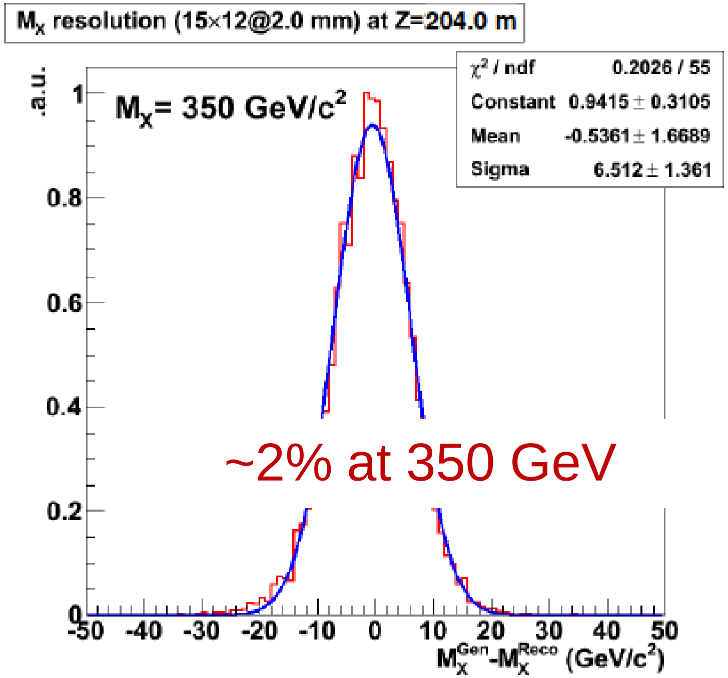
- estimate that with 200 fb^{-1} PPS will collect about 200 fully leptonic
- and 1000 semi-leptonic WW events.

This statistics allows a sensitivity to anomalous parameters a_0^W/Λ^2 and a_C^W/Λ^2 close to 10^{-6} GeV^{-2} .

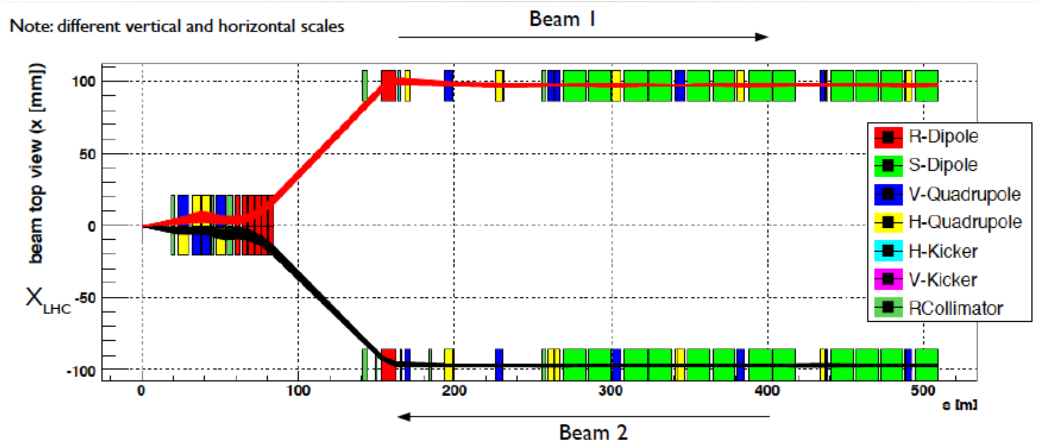
- **$10^{3\text{-}4}$ times** better than the limits established at LEP and Tevatron.
- **Two orders of magnitude** better than what is expected with the CMS central detectors only for the same luminosity.

Mass resolution

Includes vertex and hit smearing



~2% at 350 GeV

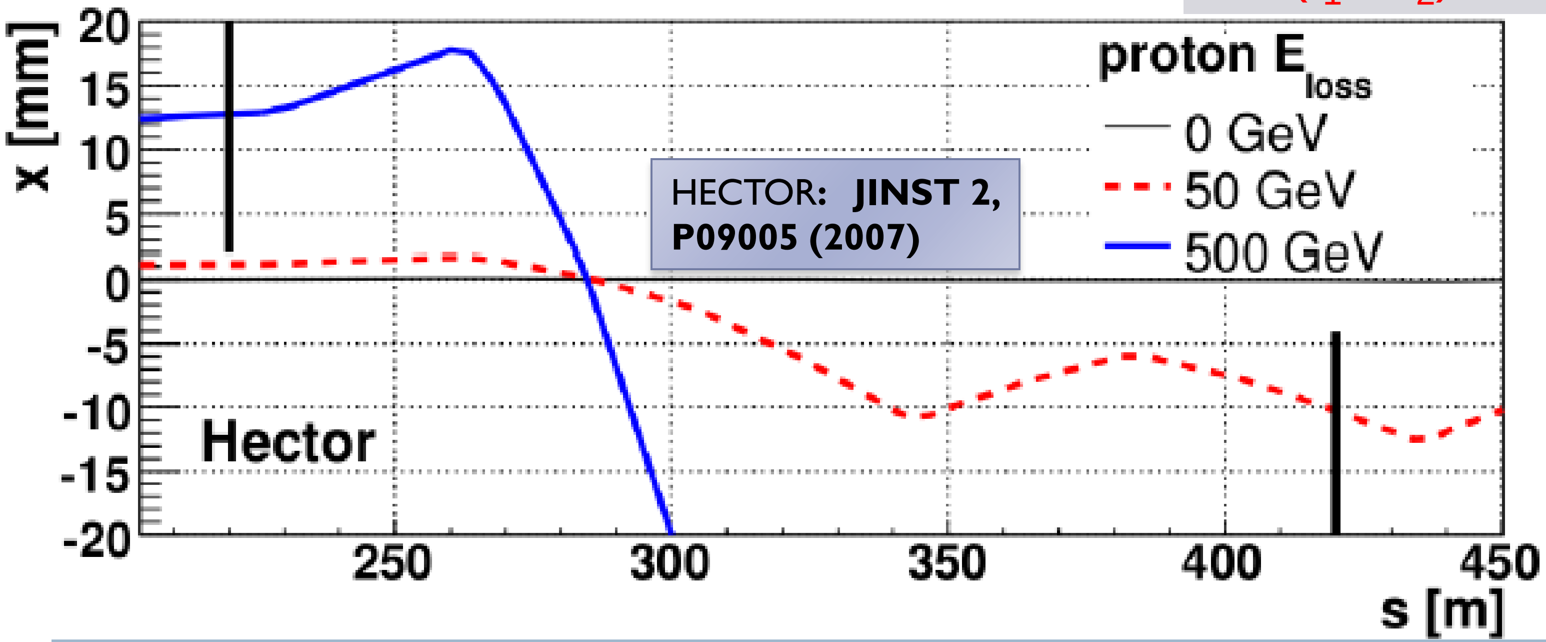


- HECTOR, a fast simulator for the transport of particles in beam lines
  JINST, 2(2007)P09005
- Excellent agreement with MADx

- The mass resolution was estimated with the stations at 210 m (before Q6) and 240 m (after Q6).
- The resolution is better at the upstream location
  - for M(X) > 600 GeV, σ= 5.8 GeV cf. 7.7 GeV.

Picosecond ToF detectors @ LHC

Use very fast ToF detectors to measure *longitudinal vertex position* from *z-by-timing* from forward proton arrival time difference: $z = (t_1 - t_2)/2c$



Path length differences are very small for forward protons at LHC, typically << 100 μm corresponding to sub-picosecond time differences.

Ultra fast timing detectors are essential for measuring the exclusive production at LHC, pp → pXp, JINST 4 (2009) T10001

Final remarks and hopes

If in 2016 PPS (AFP) starts running:

Studies of the $\gamma\gamma$WW couplings might be possible, as well as for $\gamma\gamma$ZZ; in case the U(1)xSU(2) gauge invariant models (as discussed by *O. Nachtmann et al***.) !**

Search of new heavy charged particles:
-**Stable, 'heavy muons' (completely model independent, a la LEP) up to about 400 GeV**

If enough luminosity is integrated at low/medium PU, some high energy photo-production might be possible (e.g. $\gamma p \rightarrow WX$**)**

In case of proton-ion collisions, forward protons can also be detected

In Phase 2 LHC one can contemplate detectors also at 420m (capable to catch forward, medium ions, like Ar**!)**

We must make the best out of LHC !