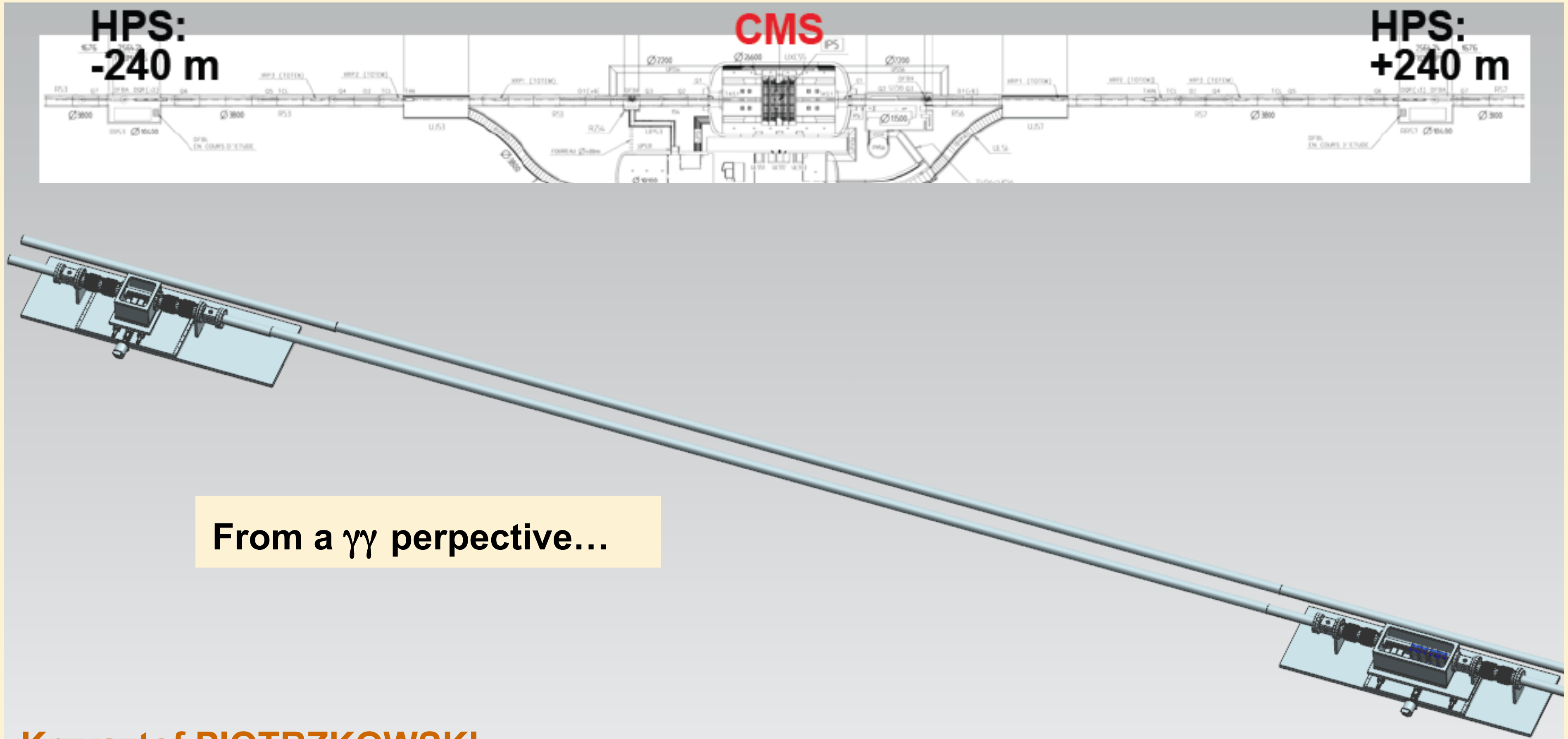
High Precision Spectrometer Project



From a $\gamma\gamma$ perpective…

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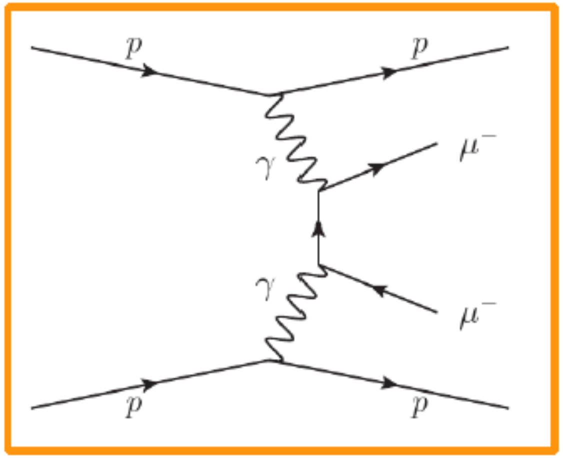
Center for Cosmology, Particle Physics and Phenomenology (CP3), Université Catholique de Louvain

@ PHOTON 2013, Paris

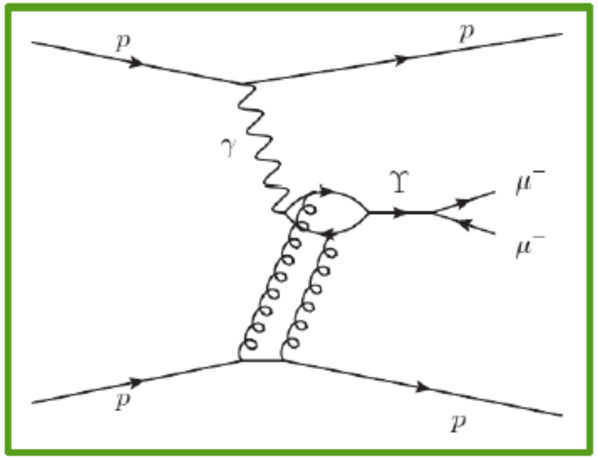
Exclusive production @ LHC

Two-photon production



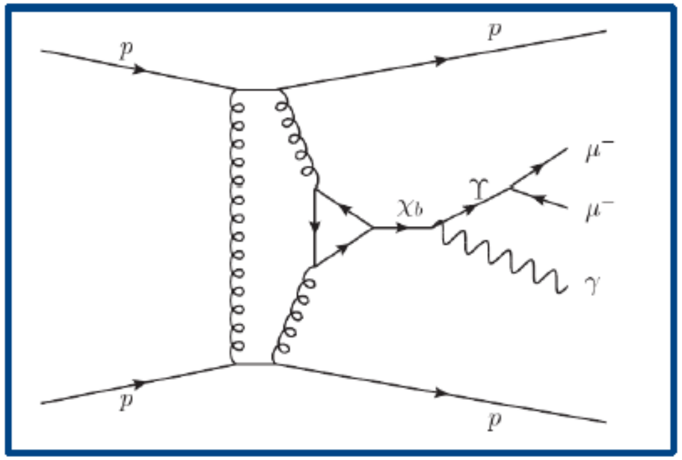
$\mu^+\mu^-$, e^+e^-, $\pi^+\pi^-$
W^+W^-, H^+H^-, Ĩ+Ĩ-, ...

Photo-production



ρ, J/Ψ, Υ, Z, ...

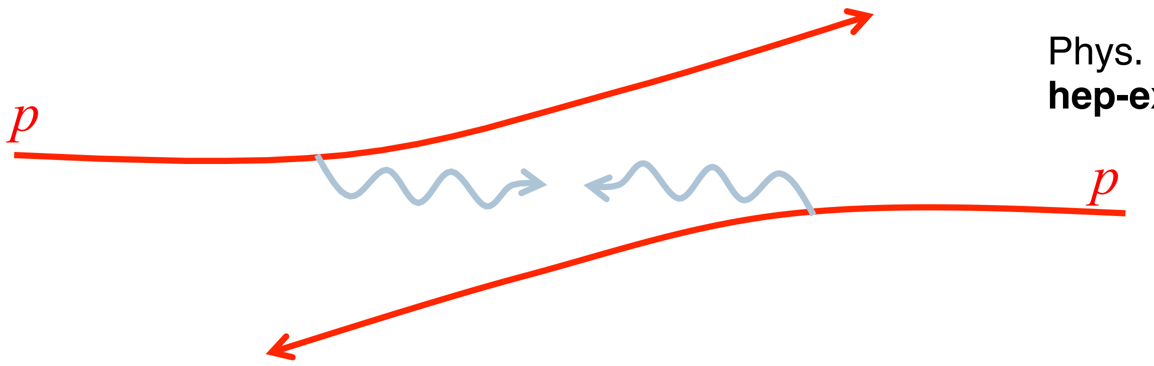
Central Exclusive Production



χ_c, χ_b, $\pi^+\pi^-$,dijets, γγ,
Higgs, ...

→ Present: studies of the SM physics and BSM searches by imposing exclusivity conditions using central detectors of CMS
→ Future: detect also (both) forward scattered protons with the proposed 'High Precision Spectrometer' (HPS)

LHC as a High Energy γγ Collider

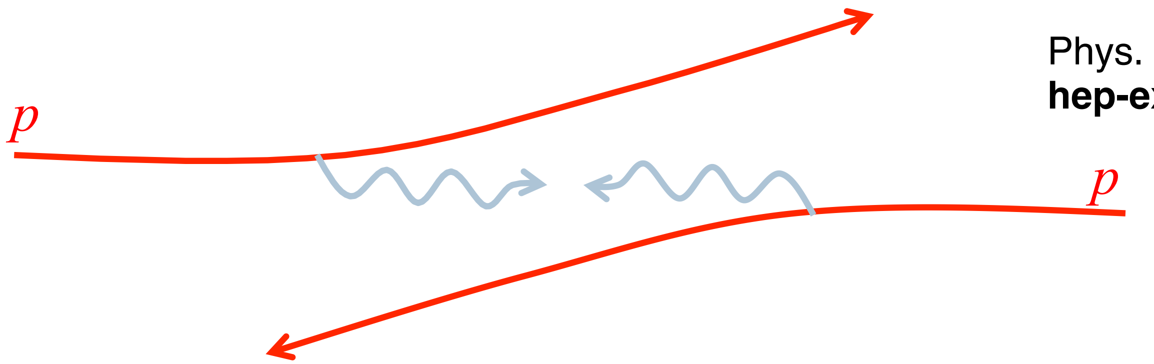


Phys. Rev. **D63** (2001) 071502(R)
hep-ex/0201027

Observation:
Provided <u>efficient</u> measurement of very forward-scattered protons one can study high-energy γγ collisions at the LHC

<u>Highlights</u>:
- **γγ CM energy *W* up to/beyond 1 TeV (and under control)**
- **Large photon flux *F* therefore significant γγ luminosity**
- **Complementary (and clean) physics to *pp* interactions, eg studies of exclusive production of heavy particles might be possible ➡ opens new field high energy γγ (and γp) physics à la LEP…**

LHC as a High Energy γγ Collider



Phys. Rev. **D63** (2001) 071502(R)
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RAPID COMMUNICATIONS

PHYSICAL REVIEW D, VOLUME 63, 071502(R)

Tagging two-photon production at the CERN Large Hadron Collider

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(Received 17 October 2000; published 6 March 2001)

Tagging two-photon interactions offers a significant extension of the CERN LHC physics program. The effective luminosity of high-energy $\gamma\gamma$ collisions reaches 1% of the proton-proton luminosity. The standard detector techniques used for measuring very forward proton scattering will allow a reliable separation of interesting two-photon interactions. Particularly exciting is the possibility of detecting exclusive Higgs boson production via the $\gamma\gamma$ fusion.

DOI: 10.1103/PhysRevD.63.071502 PACS number(s): 13.85.−t

Kinematics/EPA

Virtuality Q^2 of colliding photons vary between kinematical minimum = $M_p^2x^2/(1-x)$ where x is fraction of proton momentum carried by a photon, and $Q^2_{max} \sim 1/\text{proton radius}^2$

EQUIVALENT PHOTON APPROXIMATION (**EPA**) allows for representing a *pp* process involving the two-photon exchange, as a convolution of two photon fluxes and the **photon-photon** cross section at the γγ CM energy W (note that is just like use of pdf for partons…)

$$W^2 = s\, x_1\, x_2$$

Photon flux $\propto 1/Q^2$ and $Q^2 - Q^2_{min} \approx s\theta^2/4$

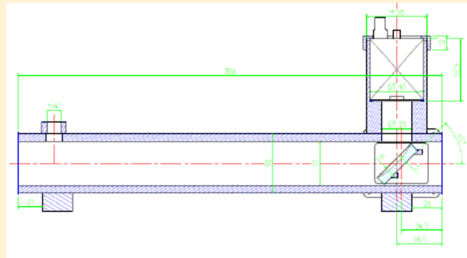
↓

protons scattered at `zero-degree' angle

Photon fluxes are larger if one of protons is allowed to break up but virtuality increases too, $Q^2_{min} = M_N^2 x$

Quick story of Photon Physics at LHC

2002-6: Building from scratch necessary tools



2005: Join R&D effort for novel forward detectors @ LHC (FP420 collaboration, recognized by CERN)

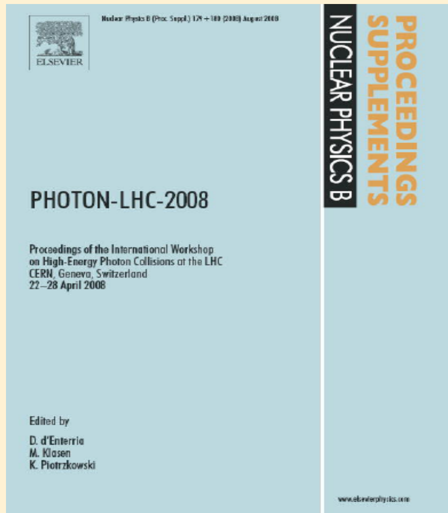
2006: Developing moving (Hamburg) pipe concept system and GasToF/Quartic picosecond detectors

2007: Releasing HECTOR (published in JINST **2**, P09005**) - A fast LHC beam-line simulation program**

(note: DELPHES project initiated for γp studies)

2008: EPA model for γγ and γp interactions in pp collisions implemented in MadGraph, CalcHEP, Pythia and Sherpa;

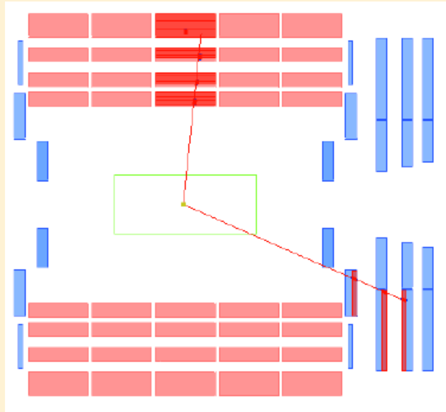
PHOTON-LHC workshop at CERN


ELSEVIER
NUCLEAR PHYSICS B
PROCEEDINGS SUPPLEMENTS
PHOTON-LHC-2008
Proceedings of the International Workshop on High-Energy Photon Collisions at the LHC
CERN, Geneva, Switzerland
22–28 April 2008
Edited by
D. d'Enterria
M. Klasen
K. Piotrzkowski

Quick story of Photon physics at LHC II

2009: FP420 report published in JINST **4** (2009) T10001 **– 98 authors from 30 institutes; High Precision Spectrometer (HPS) R&D project initiated in CMS**

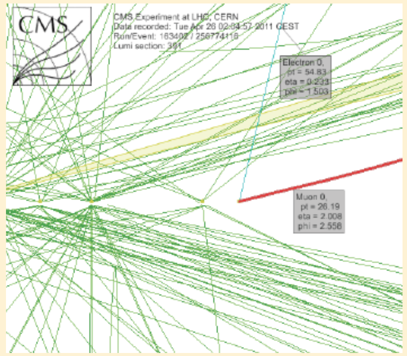
2010: Work on exclusive triggers in CMS and observation of first $\gamma\gamma \to \mu\mu$ events



2011: First two-photon measurement in CMS (and at the LHC!) pp → p $\mu\mu$ p, **JHEP 1201** (2012) 052

PHOTON 2011 conference in Spa

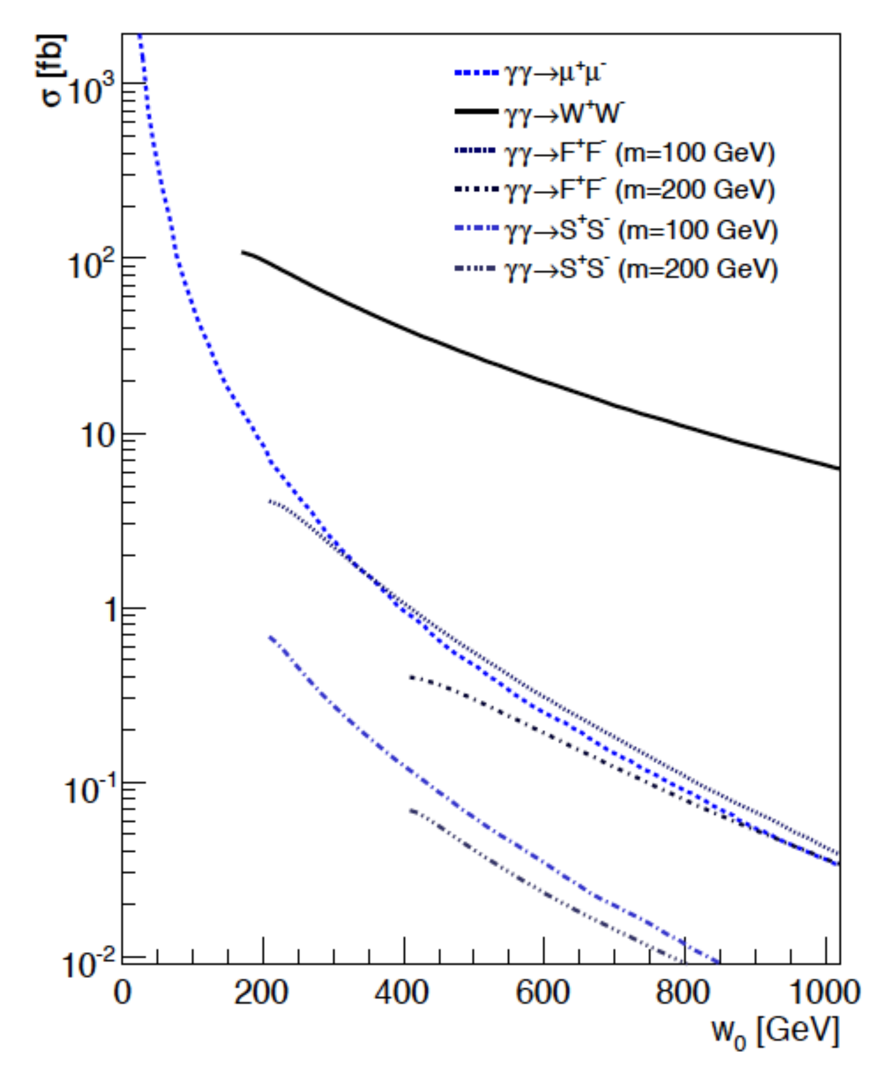
2012: First evidence for pp → p WW p
CMS PAS FSQ-12-010



2013: First measurement of pp → p WW p

Approval and start of HPS construction?

Two-photon pair production @ LHC



arXiv:0908.2020v1 [hep-ph]

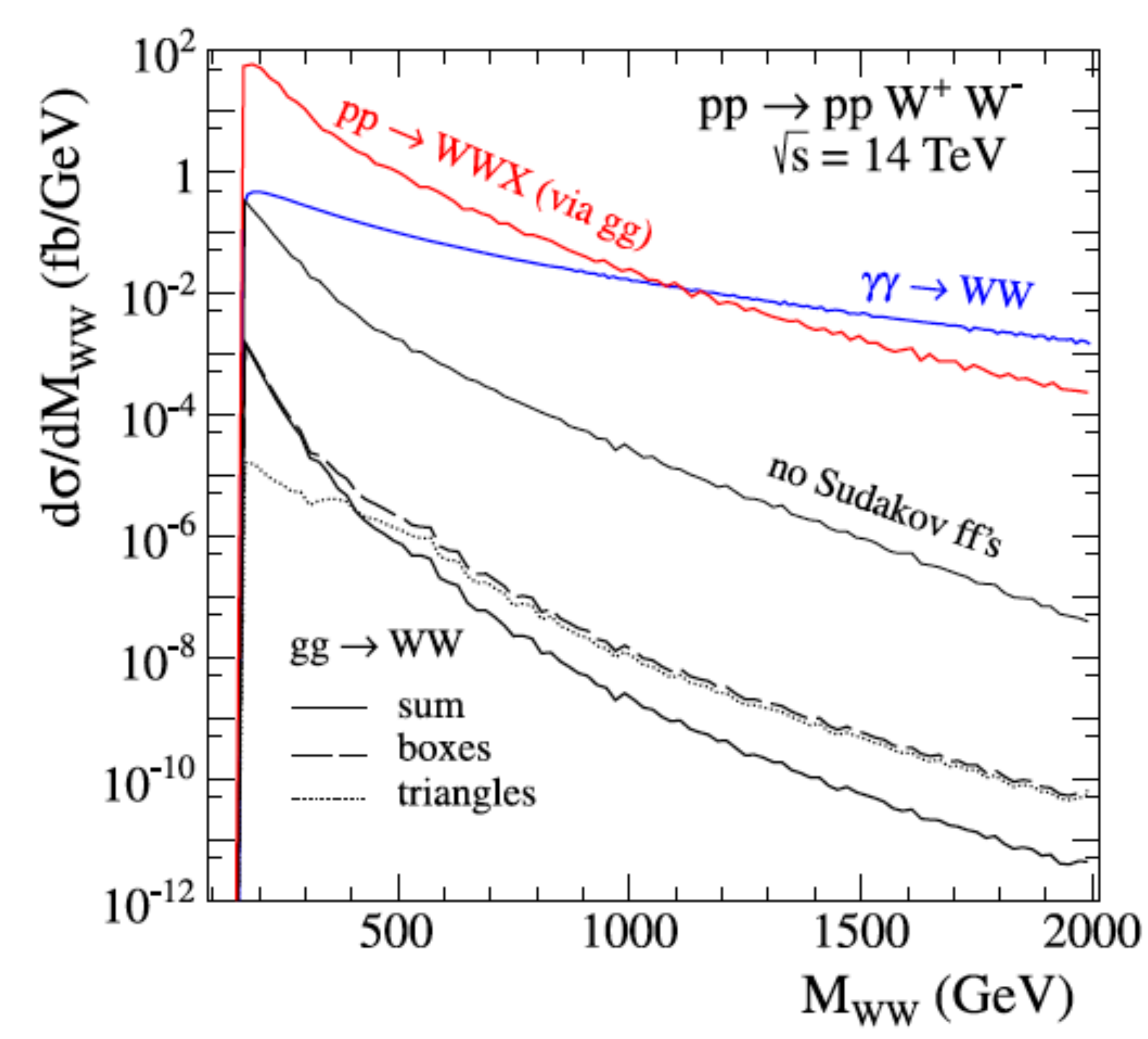
Production cross-sections determined completely by the particle mass and spin (& charge)

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

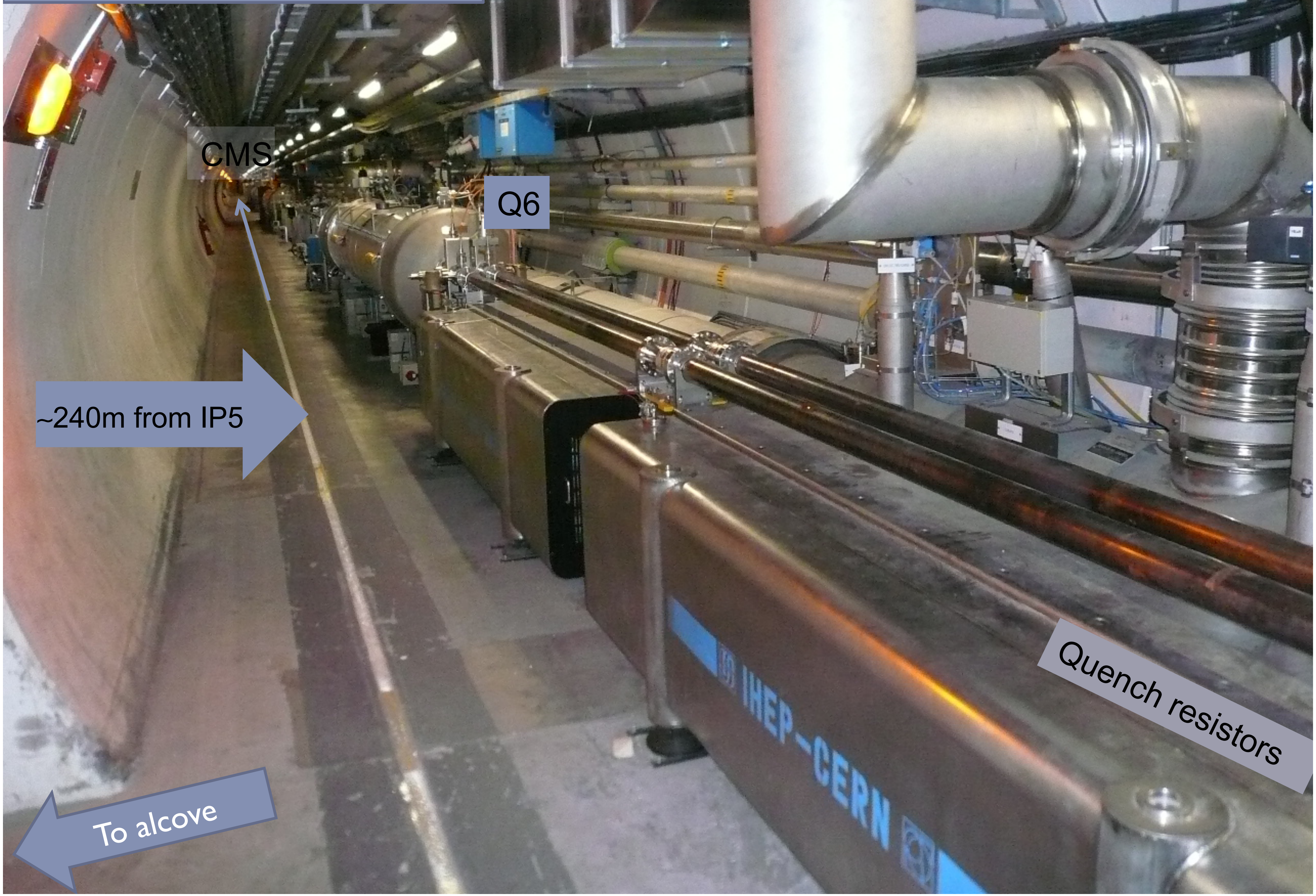
WW pair production @ LHC



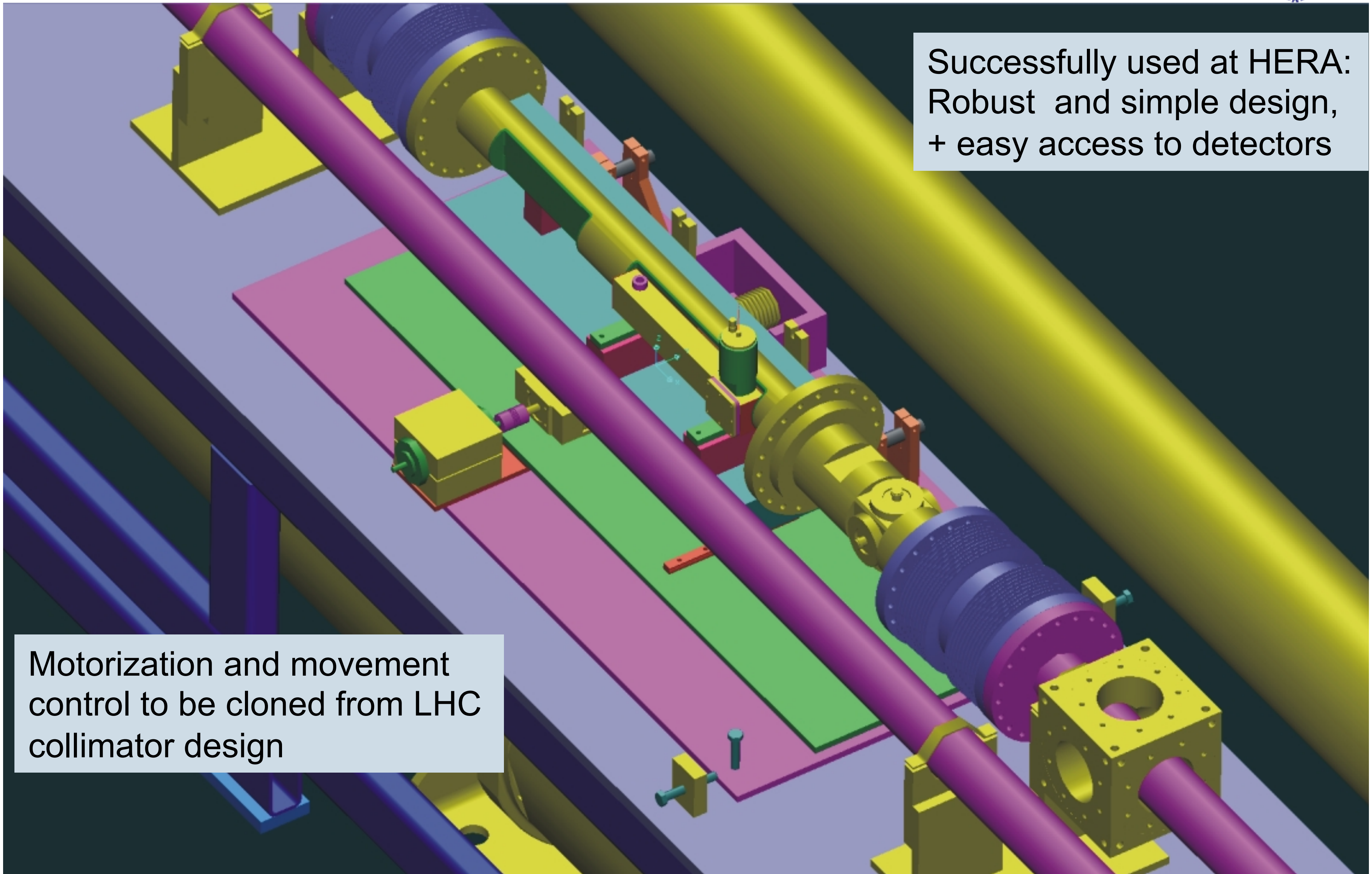
At very high energy γγ wins over 'inclusive' production (even when production via qq is included) !

Nucl. Phys. B ***867*** *(2013) 61*

HPS for CMS ?



Moving Hamburg pipe concept

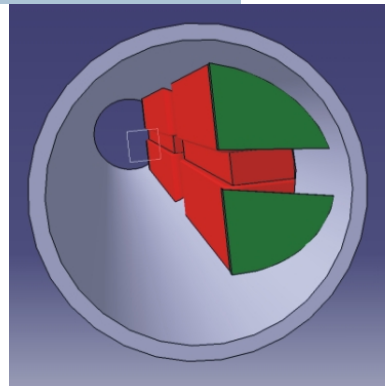


Forward proton detectors @ 240 m

• Tracking detectors installed in special 'pockets' allow to measure forward scattered proton deviation wrt beam axis

• Movable beampipe should be displaced with a precision of several microns

• Two stations per arm (about 8 m apart) should allow to measure proton angle to 1-2 μrad



Acceptance: (At nominal LHC $\beta^* = 0.55$ m) if min. approach 2.5 mm

$0.02 < \xi < 0.1$

In later stage detectors at 420 m, min. approach 5 mm would provide acceptance in

$0.002 < \xi < 0.02$

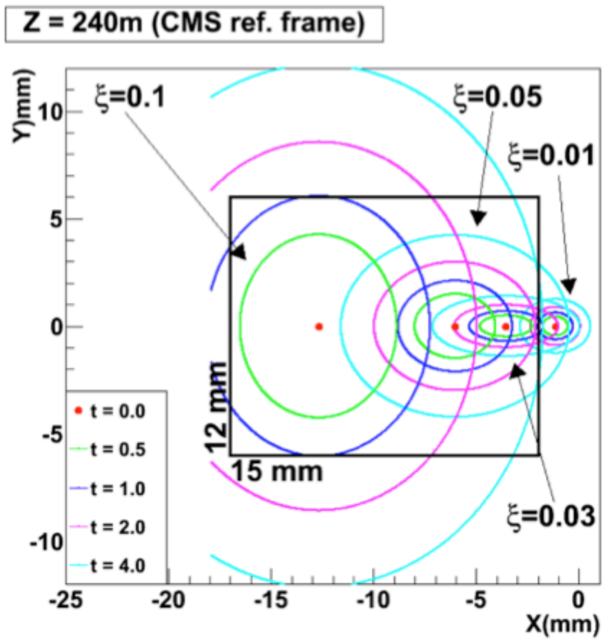
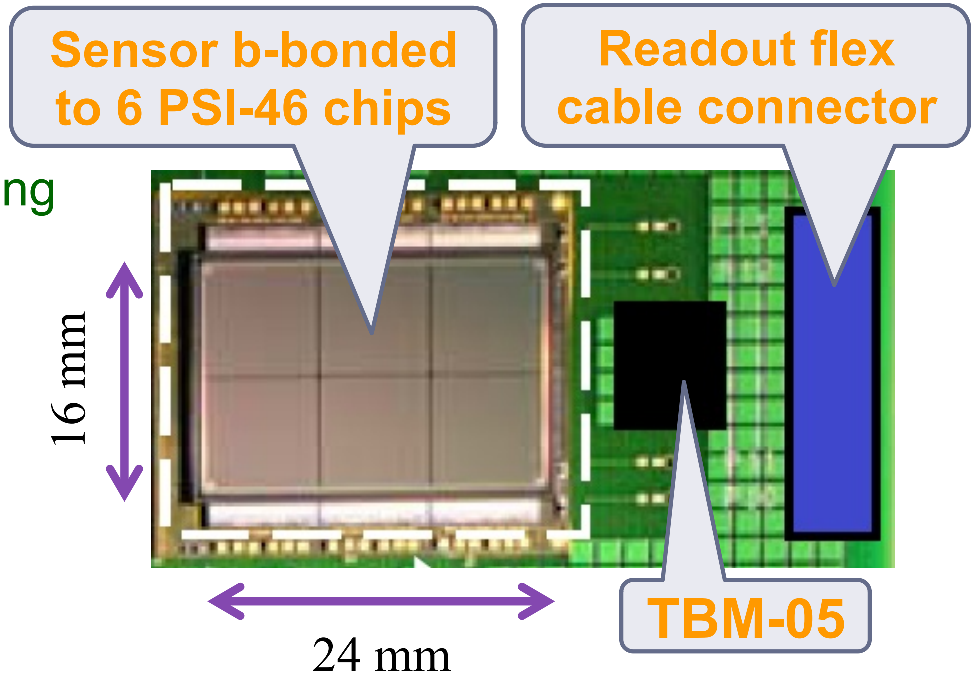


Figure 6: $t-\xi$ ellipses for the protons at 240 m. The black rectangle (12 mm x 15 mm) signifies where the detector components would be with respect to the beam.

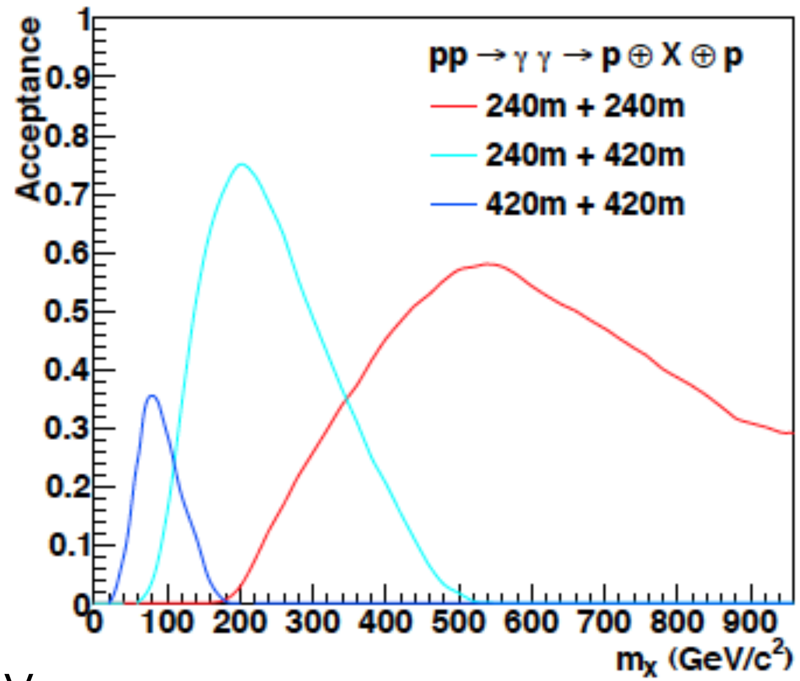
Silicon Tracking Detector

- To cover required area we can use the following detector configuration, based on current FPix PSI-46 ROC::
  - 16 x 24 mm^2 sensor (X150 x Y100 um^2 pixel pattern)
  - Six PSI-46 front-end ASICs
  - One TBM-05 readout ASIC
  - 60 x 40 um x/y resolution even without tilting detectors for charge sharing



Forward proton detectors @ 240 m

Acceptance as function of invariant mass exclusively produced (or W in $\gamma\gamma$ collisions):
(At nominal LHC $\beta^* = 0.55$ m)



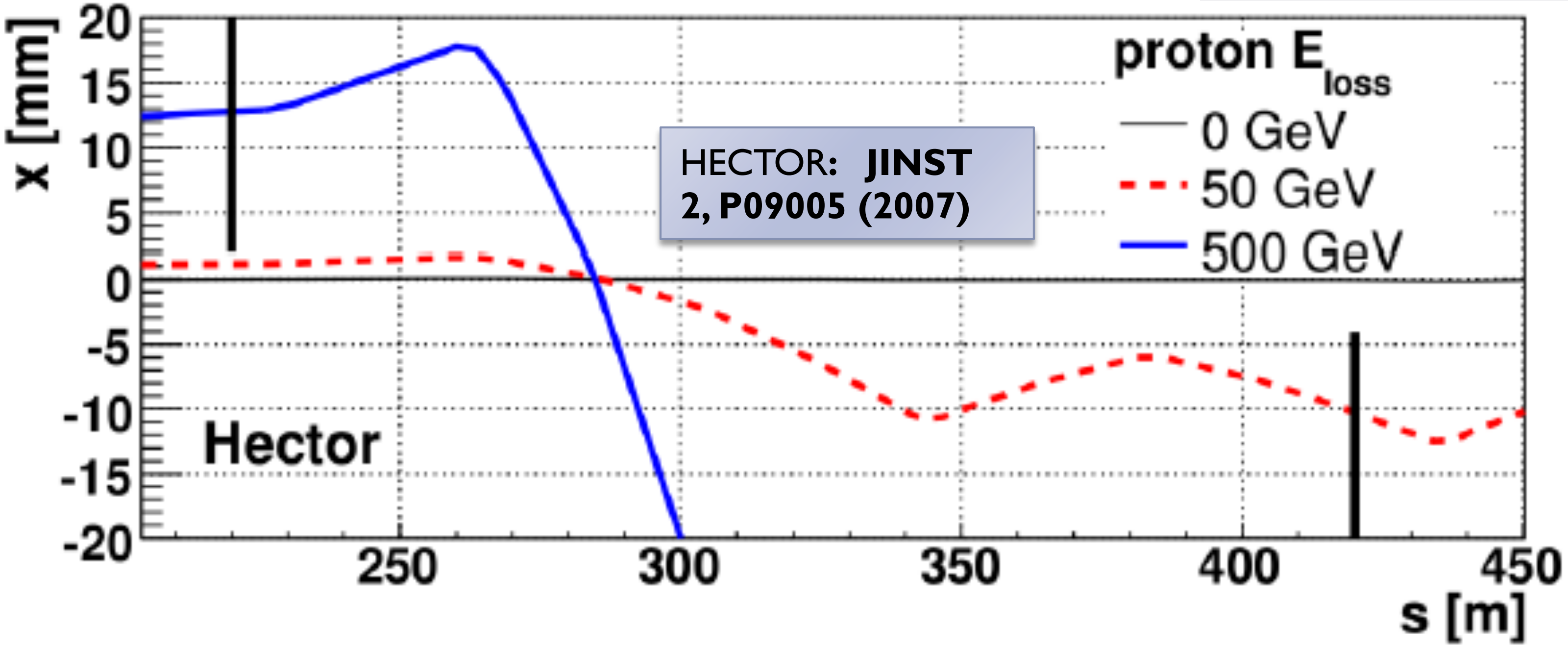
- Expected missing mass resolution is 10-20 GeV
- Both acceptance and energy resolutions will be very well controlled using exclusive $\mu\mu$ pairs
- Reconstruction of proton scattering angle difficult due to beam divergence at IP; ultimate proton $p_T^{x,y}$ resolution is about 0.3 GeV/c

- To control accidental (triple) coincidence background need very fast timing detectors (σ ~ 10ps)

Picosecond ToF detectors @ LHC

Use very fast ToF detectors to measure *longitudinal vertex position* by *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.

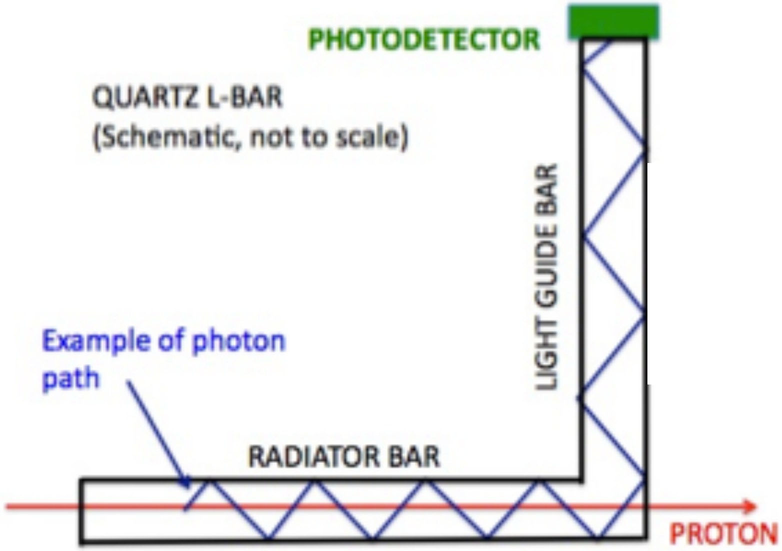
Vertex z-size at LHC ≈50 mm and 2 mm z-by-timing resolution corresponds to 10 ps timing per arm → about 20 background suppression

L-bar QUARTIC principle

All Cherenkov light is totally internally reflected along radiator bar and about 66% goes promptly along light guide to SiPM or segmented MCP-PMT.
No light "leaks out".

Conditions:

1) protons are parallel to radiator
2) n (refractive index) > √2
   so TIR maintained in LG-bar



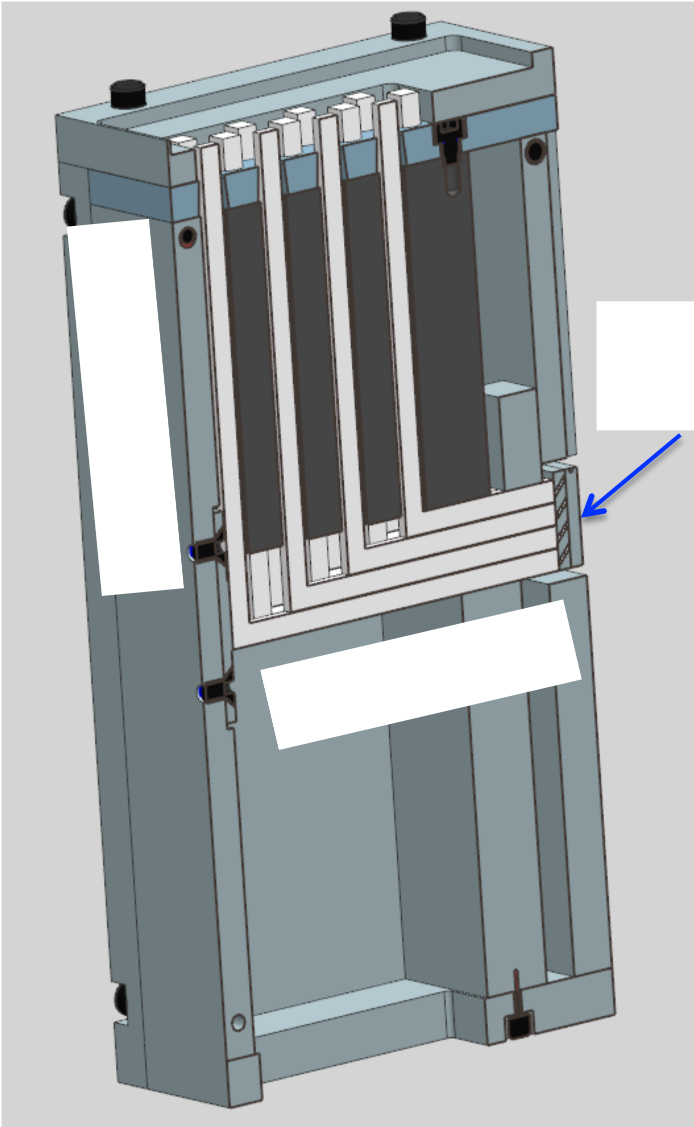
Radiator close to beam while photo-detector remote (and may be shielded)

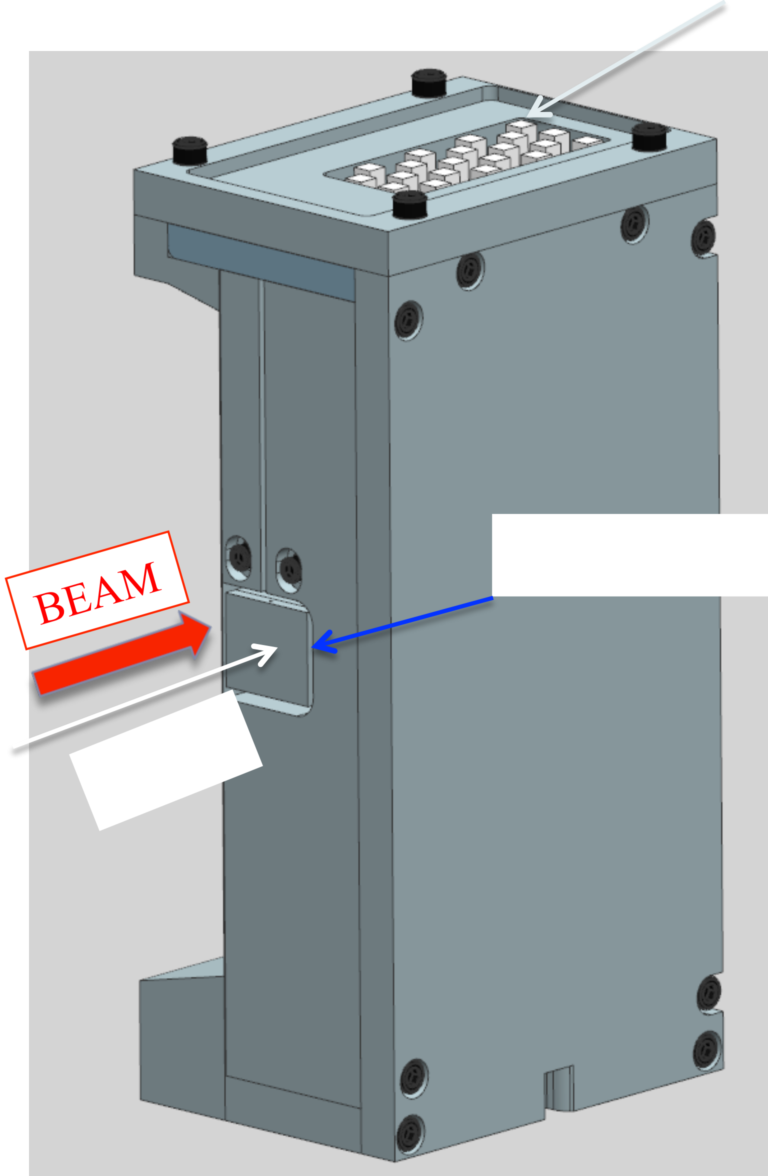
NO MIRRORS!

Hodoscope of 3mm x 3mm independent elements
Repeat N times in depth for sqrt{N} improvement (timetrack)
Finer segmentation eg 2x2 mm^2 possible in principle

QUARTIC: L-bar design, 4x5 channel Module

Vertical slice through:





Summary

In 2016 HPS should start running and will allow for big advancement in γγ physics at the LHC:

- **About 100 fully leptonic and 500 semi-leptonic WW pairs will be detected with** *double tags*
- **Another sample of 100 fully leptonic WW pairs will be taken with single tagging**

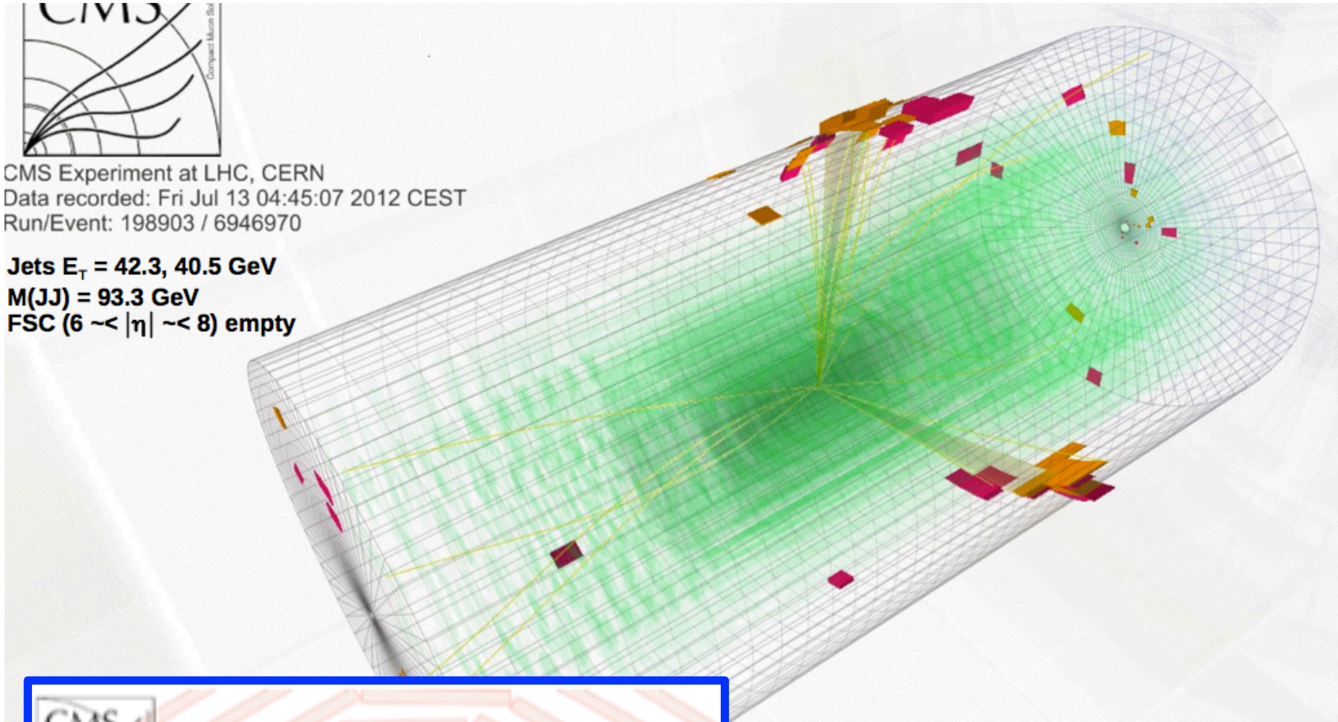
Double tagging (with both protons measured) allows to fully reconstruct kinematics of the final states, so one can perform precision studies of anomalous couplings à la *O. Nachtmann et al*.**, using all information of each γγ event (4 momenta at a given W).**

Search of new heavy charged particles:

- **Stable, 'heavy muons' (completely model independent, a la LEP) up to about 400 GeV (LEP limits are at 100 GeV)**
- **Unstable, non-strongly interacting particles (very model dependent, like sleptons or charginos)**

We must make the best of out of LHC !

From 90 m β* Run with TOTEM: p + JJ + p



REAL CMS+TOTEM EVENTS