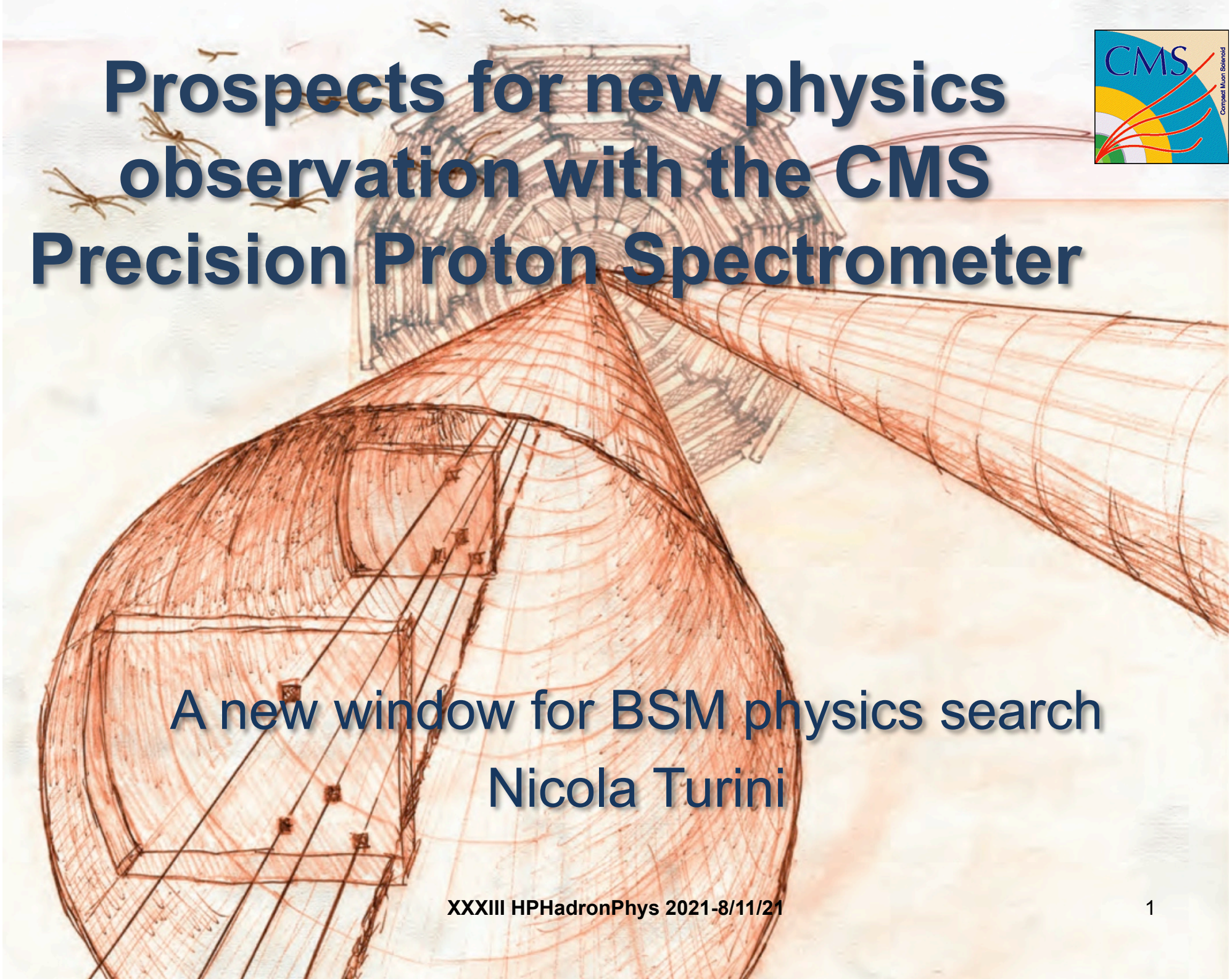


Prospects for new physics observation with the CMS Precision Proton Spectrometer

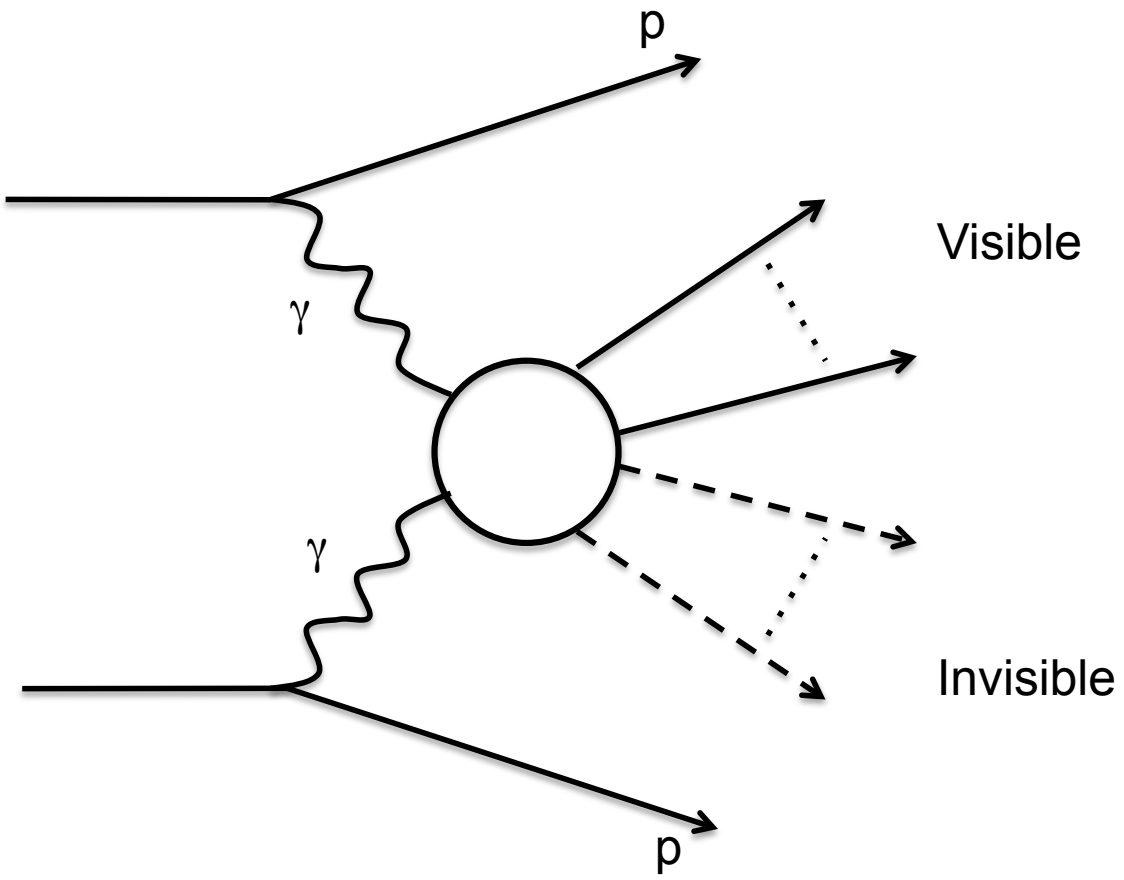
A new window for BSM physics search

Nicola Turini

PPS environment

CERN-LHCC-2014-021](https://inspirehep.net/literature/1614092

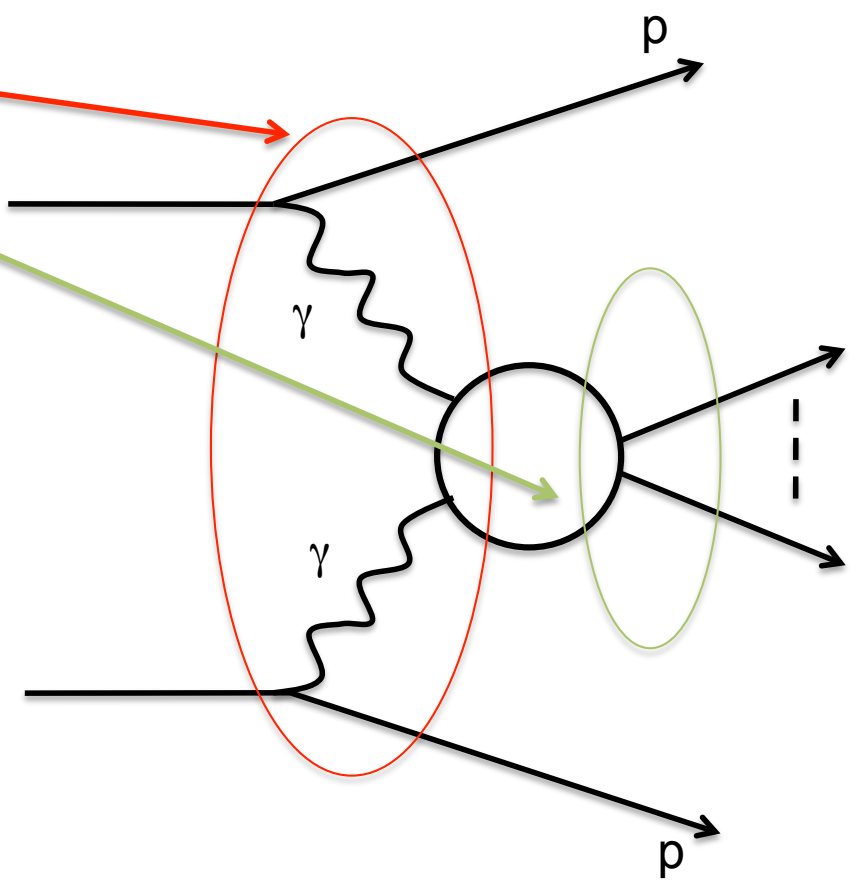
- Threshold mass>350 GeV
- Gluon fusion suppressed
- Gamma fusion dominant



- Protons transverse momentum negligible ~GeV…
- PPS protons acceptance is roughly ~50% with processes involving large masses (<2TeV)
- CMS trigger for central objects

Exclusive (visible)

Kinematical matching of
the production vertex
and decay vertex



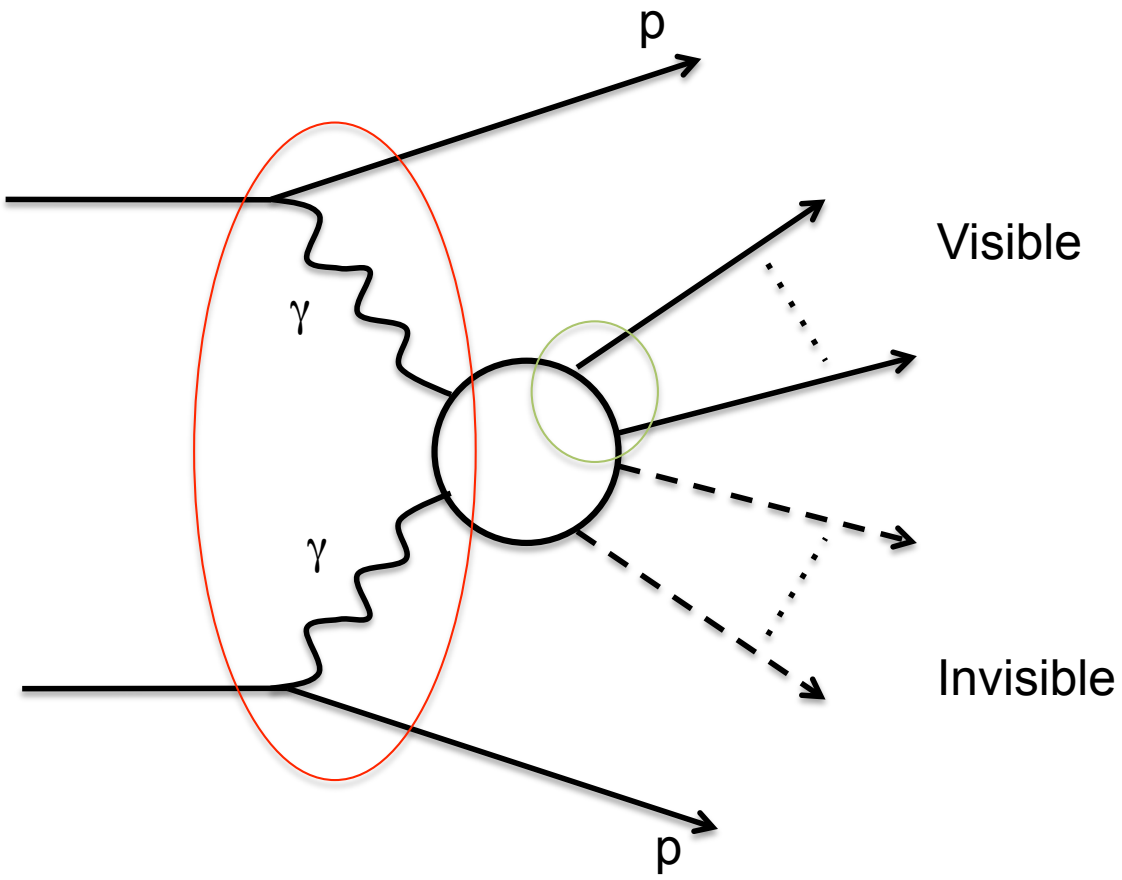
BSM physics:
•Anomalous Quartic Couplings
•Axion Like Particles
• ….

Whatever anomaly!

Exclusive (invisible)

Since the kinematics is closed we can search for any invisible escaping mass by balancing the PPS protons and the central detector visible particles 4 momenta .

If any invisible particle is created in the photon collision it can be detected as a Missing Mass from the event kinematics.



Invisible and Dark Matter

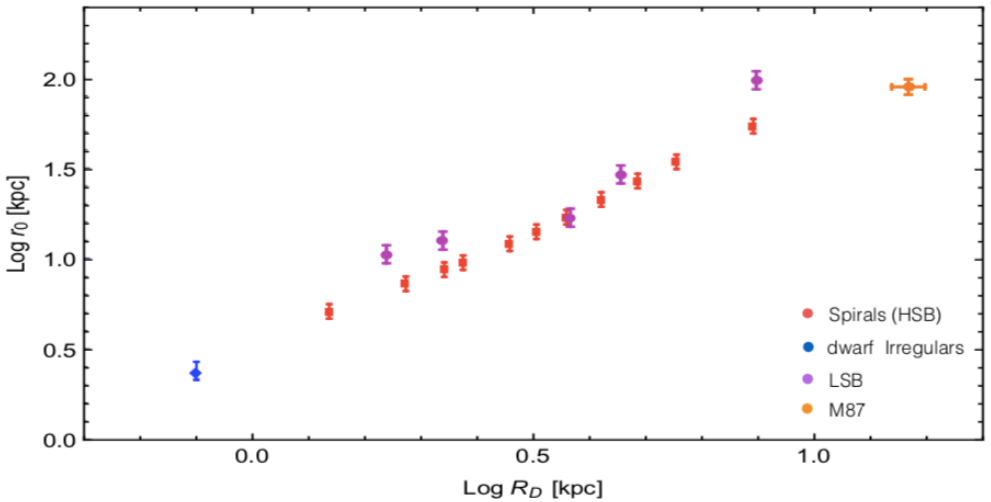
- While envisaging the possibility to detect invisible particle we immediately think about the elusive Dark Matter
- Dark Matter is seen with strong evidence in astrophysics when looking to large scales (galaxy clusters) or medium scales (galaxy scale).
  - Any idea involving feebly interacting matter or more exotic stuff (BH, axions etc…) has been considered as a possible candidate.
  - Up to now we have plenty of ideas that have been put into experimental evaluation.
  - In LHC the exotica groups foresee an extensive program for DM searches basing the studies on SM extensions (SuSy-FET- ALPs etc).
- Recently astrophysics studies on rotation curves have restricted enormously the possible solution of the puzzle.
  - A strong correlation between the baryonic matter distribution and central DM structure suggest a tight “collisional” structure involving both types.

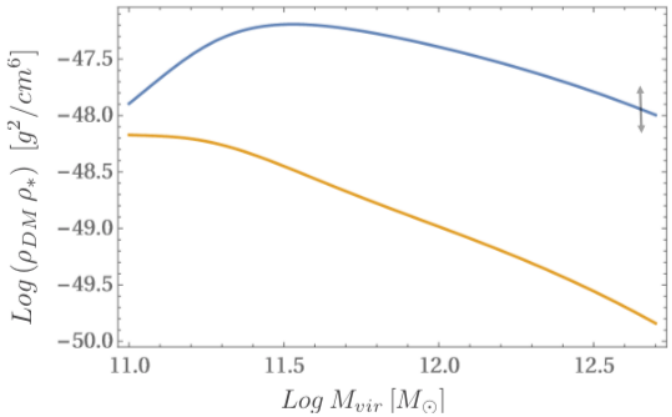
Dark Matter (astrophysics)

Astrophysics evidence for collisional DM:
Rotation curves:

- DM Core (flattening of DM density toward the galaxy center).
- Tight relation between luminous radius and DM core radius over 4 orders of magnitude of galaxy mass (Spirals, Dwarfs and Ellipticals?).
- $\rho_{DM}\rho_S$ (Blue) almost constant at the edge of the visible radius not $\rho_{DM}\rho_{DM.}$ (orange).

- Evolution of the Core Radius from early galaxy formation period with time (increase of the radius from almost NFW distribution up to today values in 10GY).





Salucci, Turini, Di Paolo (Universe 6 (2020) 8, 118)

Dark Matter characteristics

- Recent measurements of the astrophysical DM structures rules out many potential candidates (WIMPS, BH, light Axions …).
- Supernova feed back cannot explain such a diffuse correlation between DM cores and galaxy structures all over the possible type and dimensions of galaxies (Dwarf galaxies as an example cannot build up the observed core being almost made by DM).
- If the DM is a new particle or “Particle Sector” should foresee a non negligible interaction with visible matter.
  - Light DM can exchange momentum with hot regions of the galaxies and be expelled from the center (direct detection)
  - Heavy DM can annihilate when in presence of matter if:
    - Speed correlated self interaction (~100 Km/s?).
    - Density threshold (annihilation in dense object as BH, stars…). This requires a non negligible couplings between DM particles but short range to ensure a sufficient relic density.
- The last possibility is relevant for LHC searches.

DM searches without PPS

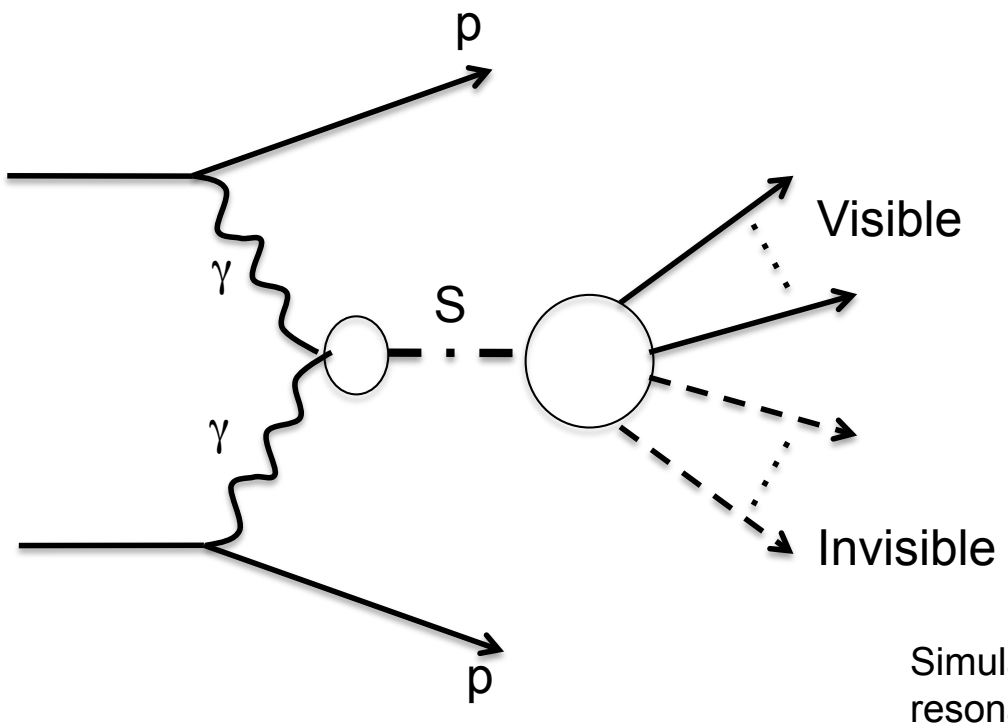
- Many models foresee Vectors or Scalars (Higgs portal models) mediators toward a Dark Sector.
- One can access the DS through quarks or gluon fusion, but with less efficiency also through gamma fusion.
- Standard searches for invisible matter require an imbalance of the event eg. Missing Transverse Momentum (MET).
  - To cope with QCD background only events with enough large MET could give a significant anomaly to be detected.
  - This requires that when accessing the invisible sector the event has enough phase space in its kinematics to generate such visible imbalance.
- Regardless to the models almost all the DM searches look to anomalous MET with different tagging triggers.
- The sensitivity drops dramatically if the production is on the “threshold”.

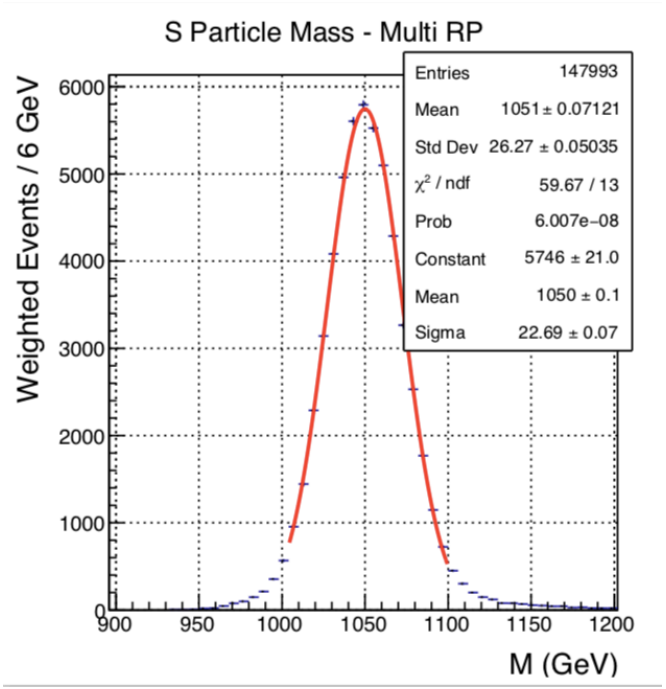
See as example
https://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-20-005/index.html
https://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-19-003/index.html

PPS sensitivity

New narrow Scalar or Tensor resonances:

If a narrow scalar is generated in the $\gamma\gamma$ collision PPS could detect it as a peak in the proton mass distribution

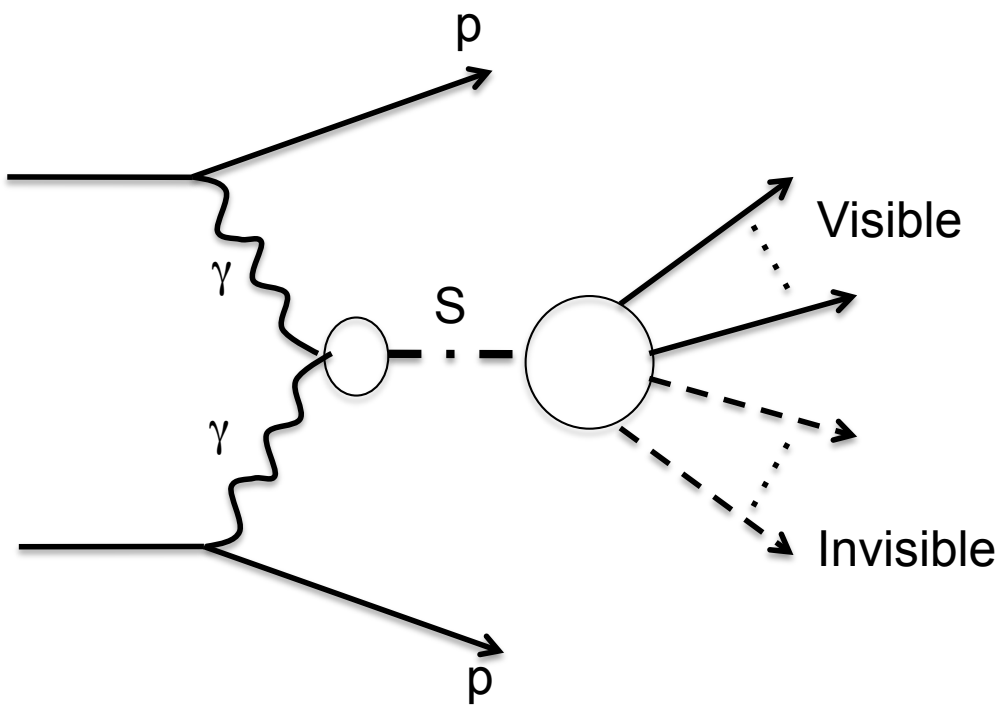


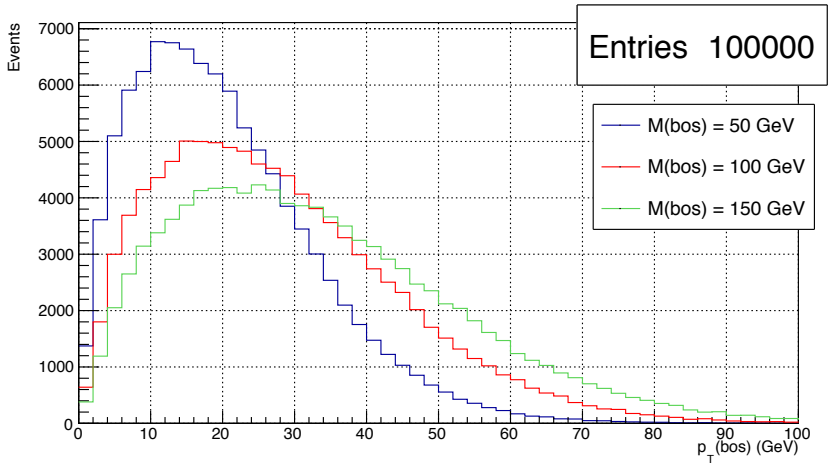


Simulation (Toy MC) of a narrow (10 GeV) Scalar resonance reconstructed by PPS (~20GeV resolution)

PPS sensitivity

New narrow Scalar or Tensor resonances:



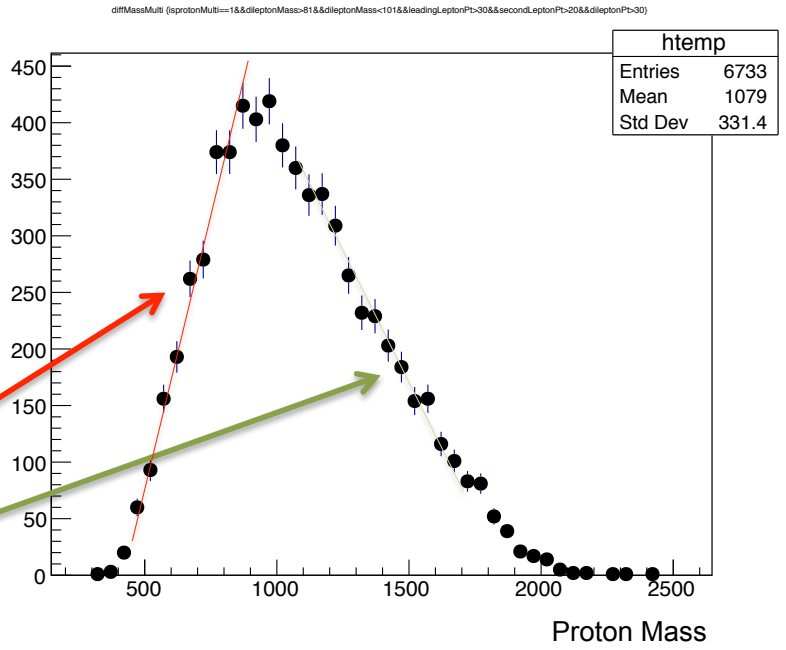


Simulation (Toy MC) of the Higgs transverse momentum for a Scalar decaying into a H + X (invisible) with narrow mass difference between S and X
(MS-MX = 50-100-150 GeV)

The recoil momentum is absolutely negligible.
The S Mass peak is well visible.

PPS Background 1

- The PPS background for escaping mass searches is dominated by Single Diffractive protons from the pileup reaching the Roman Pots + central non diffractive production of the searched channel.
- The shape of the background comes from the convolution of the minimum mass acceptance cut and the typical SD protons momentum loss shape with one arm at large ξ.



Simulation (Toy MC) of the Protons Mass reconstructed from DY Z production plus random protons.

What to search

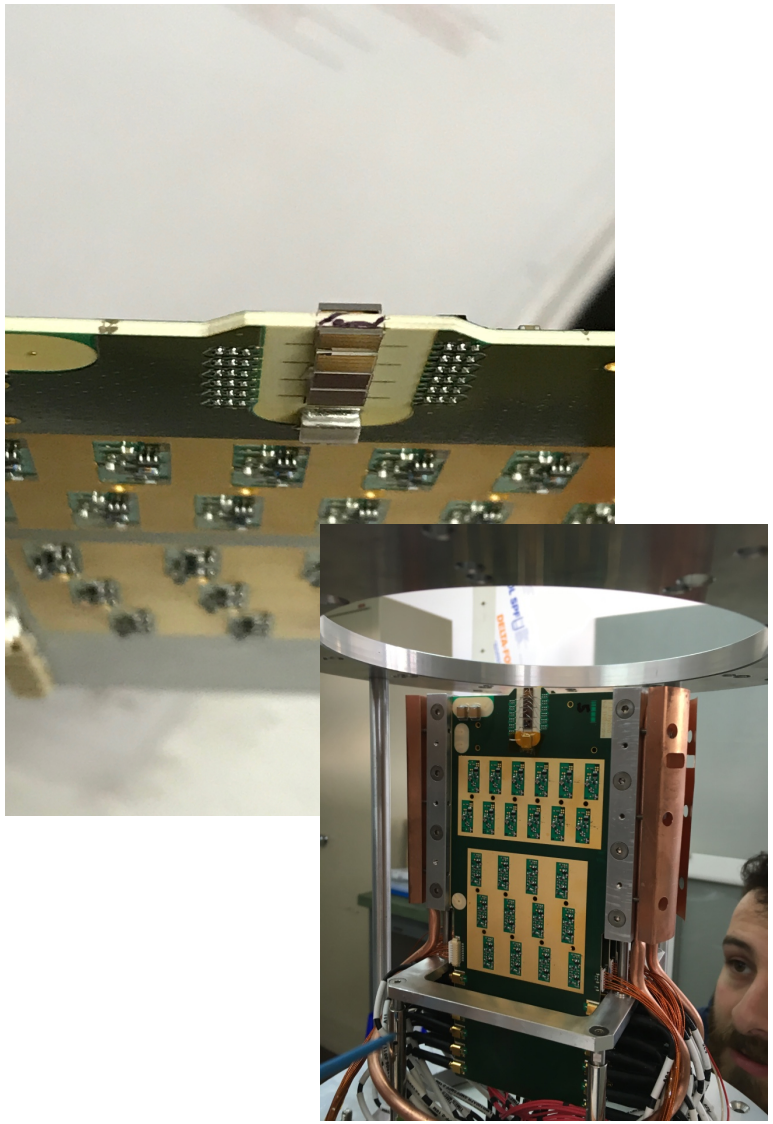
- From the point of view of production some calculation suggest that ~100 fb cross section can be reached by PPS with ~100 fb^{-1} of CMS integrated luminosity.
- Given the specificity of the type of search we can move around several different hypothesis:
  - DM Higgs portals
    - Higgs + narrow Scalar (not heavy Higgs)
    - Z + narrow Scalar
  - Z' portal
    - Z + missing Mass
  - Top + missing Mass (in many models)
  - Ws + missing Mass
  - …
- The presence of any new physics will appear as a bump over the background either on the proton mass distribution or on the Missing Mass made from the balancing of the protons 4 momenta and the central object.
- While the proton Mass is solely dependent on the PPS resolution the Missing Mass search is somewhat dependent also from the resolution of the central object (Jets etc…).

How to search

- The bump search is somewhat model independent given a specific kinematical constrain.
- In principle one can perform a systematical search on different final visible states (Higgs, Z, Top …) creating different kinematical environment (eg. Scalar resonance mass and decay hypothesis).
- Theoretical guidance is relevant, but given the absolute ignorance on the hypothetical Dark Sector the phase space of the parameters explode.
- Of great importance is the control of the background for each search channel.

Timing Detectors

- An independent way to reduce the background from pileup is the constrain of the vertex.
- PPS has developed diamond timing detectors that can reconstruct the proton longitudinal vertex position with ~1cm resolution.
- We expect a factor 10 of background suppression by matching the central CMS tracker vertex with the timing proton vertex.



Conclusions

- PPS is a novel opportunity to search for new physics at LHC opening a new observational channel driven by gamma gamma interaction.
- The possibility to measure the interaction vertex properties add to the analysis an unprecedented sensitivity for pure exclusive measurement or search for invisible object.
- The Dark Matter phenomenon, that is intriguing the physics community, is solely seen in astrophysical measurement but no evidence is still appearing either in direct measurements or collider searches.
- Astrophysics is constraining many of the possible SM extensions on this regard. Any further theoretical development should take into account the information given by the recent developments on this field.
- Astrophysics tell us that DM is not non-collisional as thought since now but a non negligible interaction, that can develop in many different ways, between the Visible matter and Dark matter is at the base of the evolving galaxies.
- PPS can play a role on this search given his peculiar background and eventual signal features.