Study of neutron-induced background hits in the CMS endcap muon system, and implications for the HL-LHC

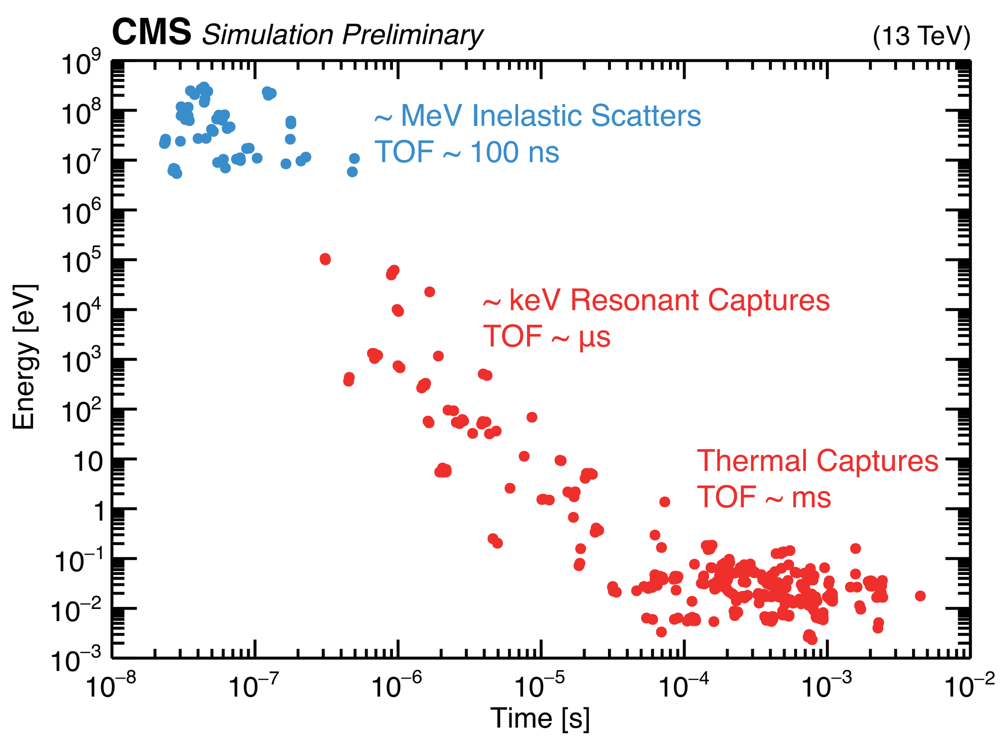
Abhigyan (Riju) Dasgupta (UCLA), *on behalf of the CMS Muon Group, EPS 2017, Venice*

Neutron Background at CMS

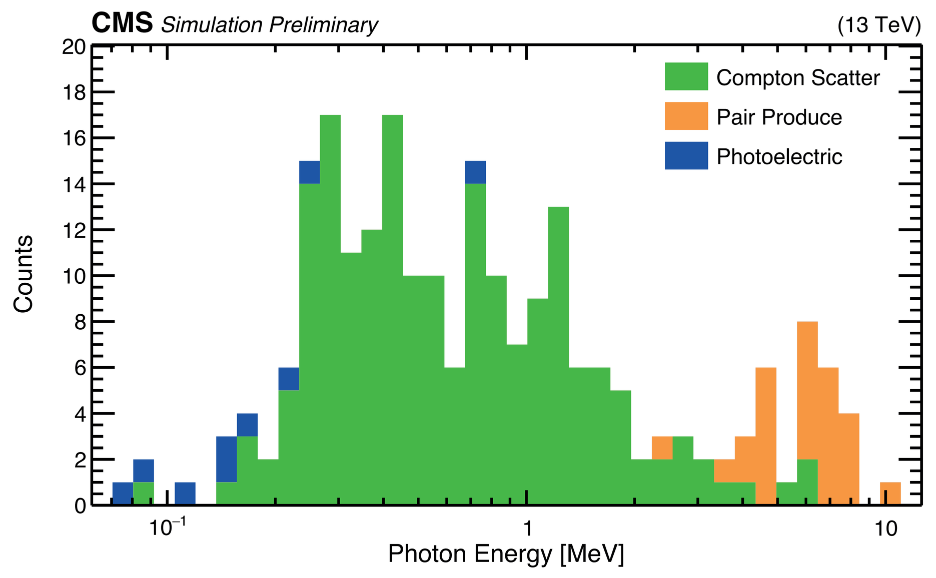
- Proton-proton collisions and subsequent hadronic showers at the LHC produce **neutrons**
- Both **fast (~MeV) and thermal (sub-eV) neutrons** induce delayed hits in the CMS muon detectors
  - Nuclei emit **gammas** via **neutron capture** and **nuclear interactions**
  - Gammas lead to **electrons** which ionize the chamber gas and cause background hits
- The impact of **increased hit rates** in endcap cathode strip chambers (CSCs) is one of the challenges of the High Luminosity LHC (HL-LHC)

Monte Carlo Simulation of Neutrons

- **GEANT4 based Monte Carlo simulation** of neutron-induced hits was studied
- Two changes facilitated neutron study:
  - neutrons tracked for 10 s down to zero energy
  - protons and ions tracked down to 1 keV



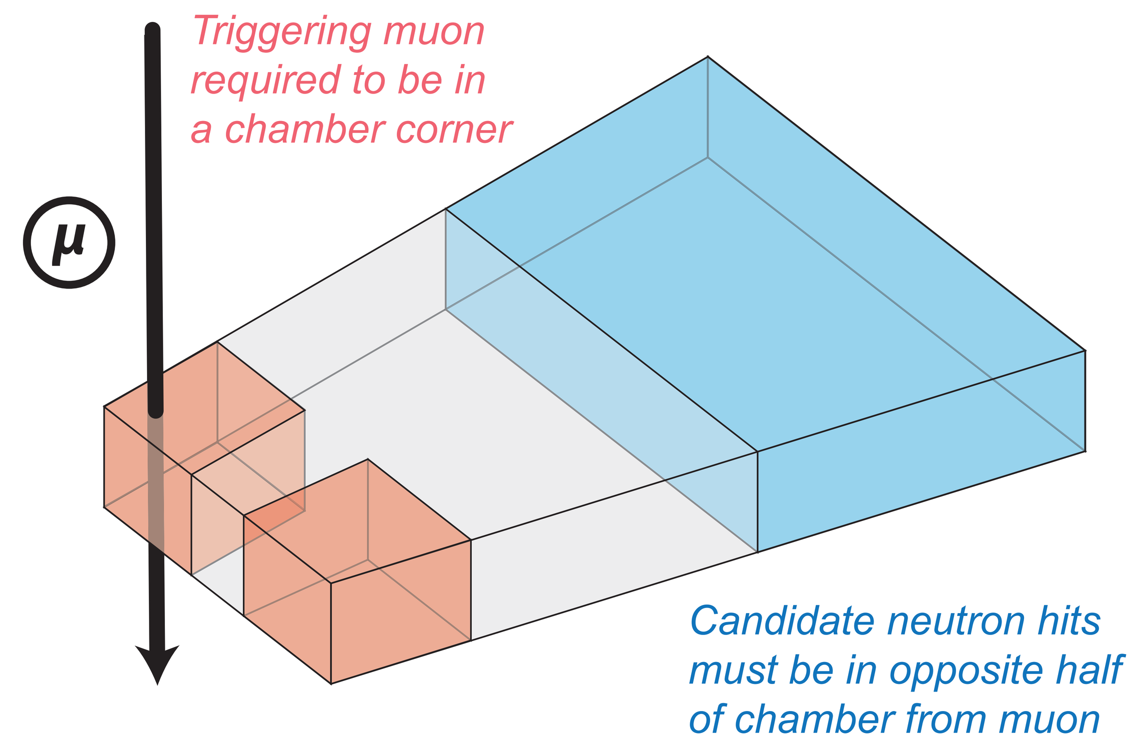
Plot of final neutron energy vs. time since pp collision of simulated hit induced by the photon produced by the neutron.



Energy spectrum of photons leading to simulated hits, categorized by the specific production process that created or scattered the electron responsible.

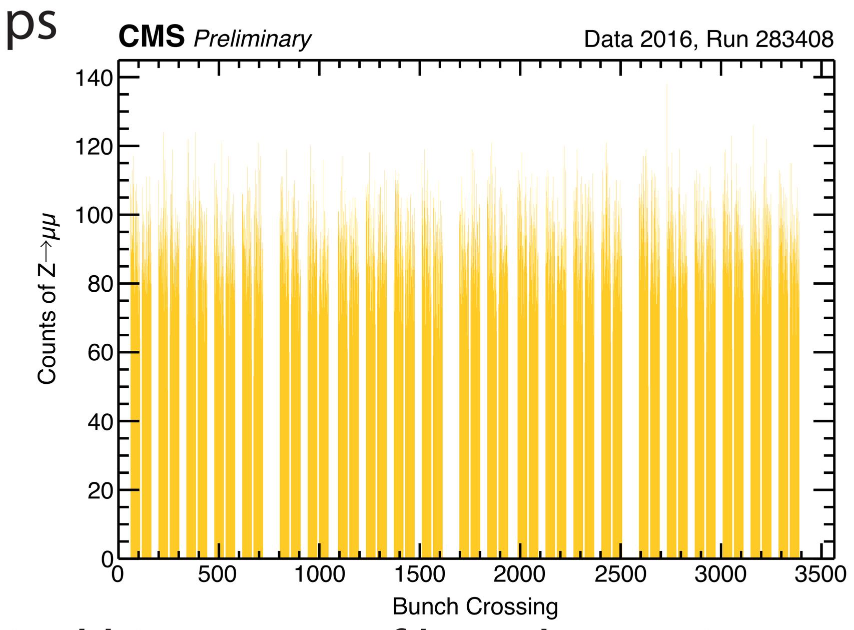
Identifying Neutron Hits in CMS Data

- In CSCs, **a muon is required** to trigger readout of local data, complicating neutron identification
- To reduce stray hadronic activity:
  - Look at clean **Z→μμ events**
- To identify neutron hits in the chamber, we **look away** from the triggering muon:
  - Select chambers with exactly one (to reduce background) triggering muon in a $1/16^{th}$ **corner**
  - Only look at hits in **opposite half** of chamber

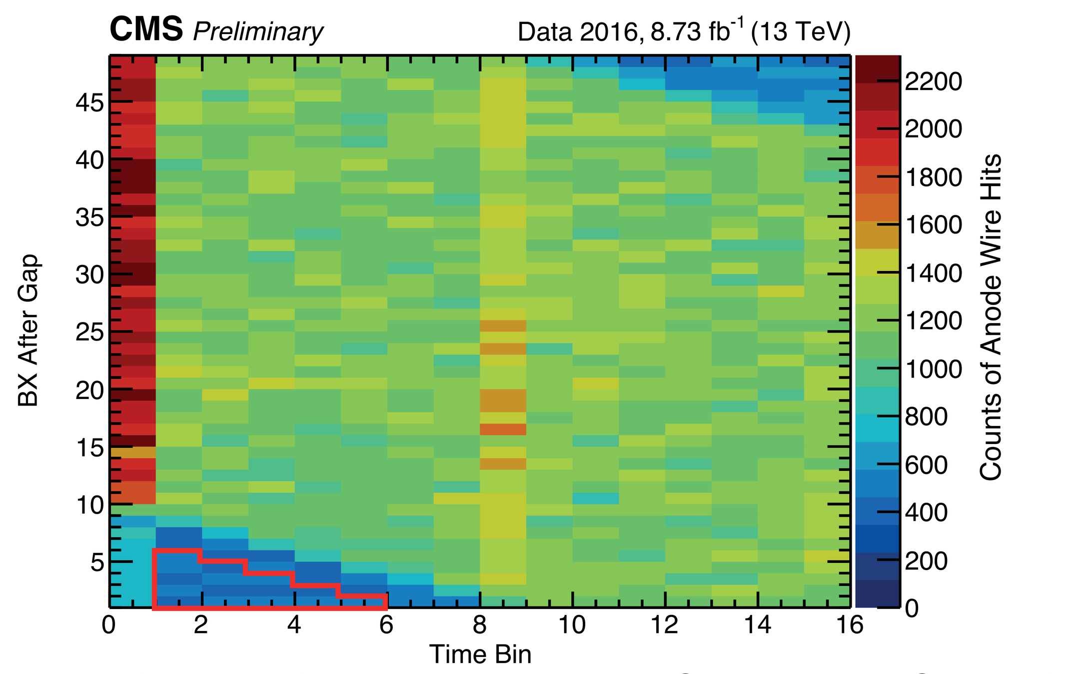


LHC Bunch Structure

- To distinguish neutrons from out-of-time pileup we consider **gaps** in the LHC proton bunch structure of at least 35 bunch crossings (BX) to identify pp collisions occurring just after such gaps



A typical histogram of bunch crossing number in a specific LHC fill, showing the LHC bunch structure

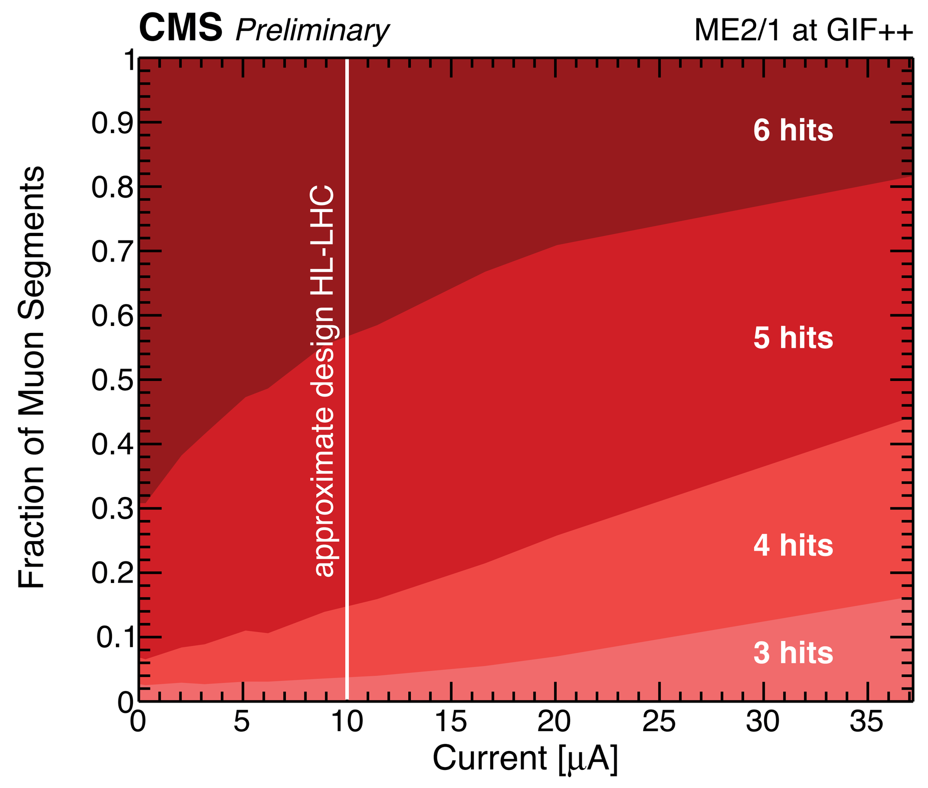


CSC anode wire hit intensity as a function of number of BX after a gap (*y* axis) vs. readout time bin (*x* axis). Both BX and time bins are 25 ns wide. Time bin 8 is in-time with the triggering muon. The lower left blue triangle (red outline) is early hits in early BX, and contains only slow neutron hits.

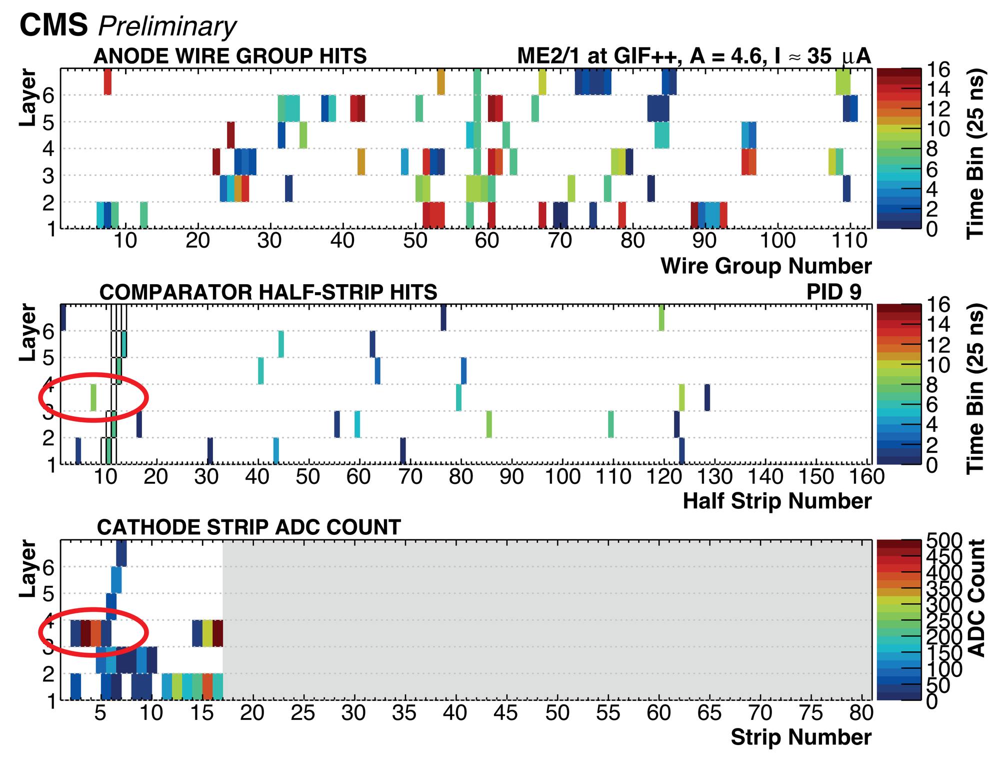
- **Early-time hits** in these BX occur at the end of the previous LHC gap and can only originate from thermal or resonant neutron capture

Muon Hit Displacement at GIF++

- CERN Gamma Irradiation Facility (GIF++) features:
  - 2 CSC chambers
  - A 100 GeV muon test beam from 400 GeV protons on fixed target
  - A 13.9 TBq ^{137}Cs gamma ray source
- GIF++ allows us to study the effect of **increasing ionizing radiation** on detectors for HL-LHC by varying the intensity of the gamma ray source
- The induced chamber anode **current** varies with varying source intensity

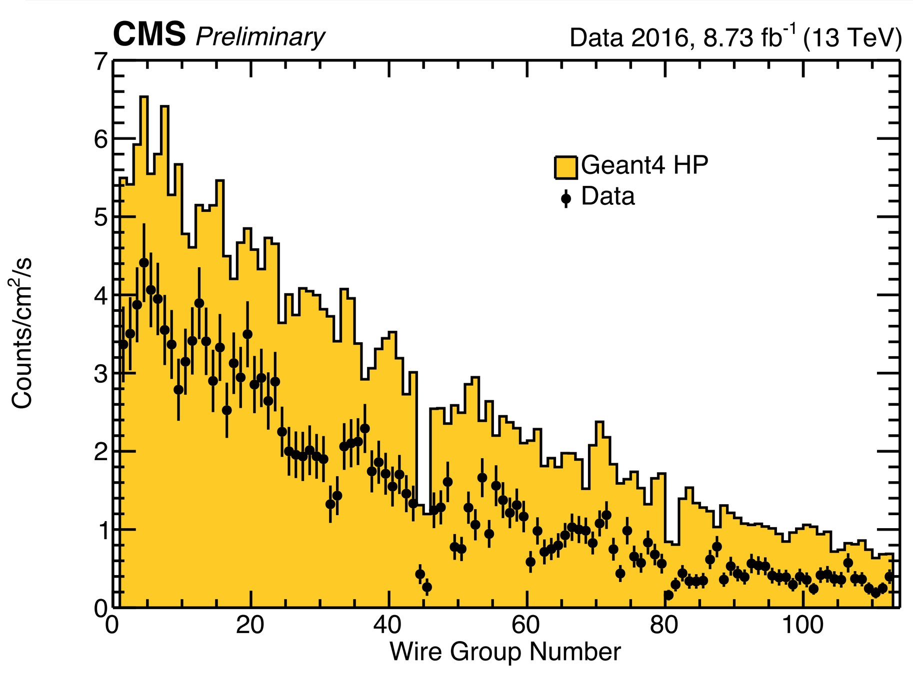


Fraction of offline reconstructed muon segments at GIF++ categorized by the number of hits used to form them. Increasing source intensity may result in lost hits: fewer good quality 6 hit segments and more lower quality 3 hit segments.



Display of an event recorded during a muon test beam at GIF++ showing digitized detector responses: anode wire hits (top), cathode half-strip hits (middle), each colored by the detector time bin, and strip ADC counts proportional to deposited charge (bottom). Each display is with the gas gap layer on the *y* axis and the wire or strip number in which the hit occurred on the *x* axis. The red circles illustrate an example of a muon hit which has been corrupted by a gamma-induced background hit. The muon hit is subsequently displaced and as a result is excluded from segment reconstruction.

Comparing CMS Data and Simulation



Sample distribution of candidate neutron-induced anode wire hits, per chamber area and converted to a per time and per pp collision rate, for CMS data and simulation. Data were selected as above, additionally requiring that hits only be from the lower left triangle outlined in the above figure. The data to simulation agreement for all η and z is good to a factor of 1–3.

Does simulation reproduce the neutron hit patterns found in data? We looked for patterns in contiguous clusters of 3×3 detector hits. Here, each pattern such as ▪▪ represents half-strips horizontally and layers vertically. Plotted is a histogram of counts for each pattern, for CMS data (*right*) and simulation (*left*).