CMS Trigger: CEP of a SM Higgs as an interesting test case

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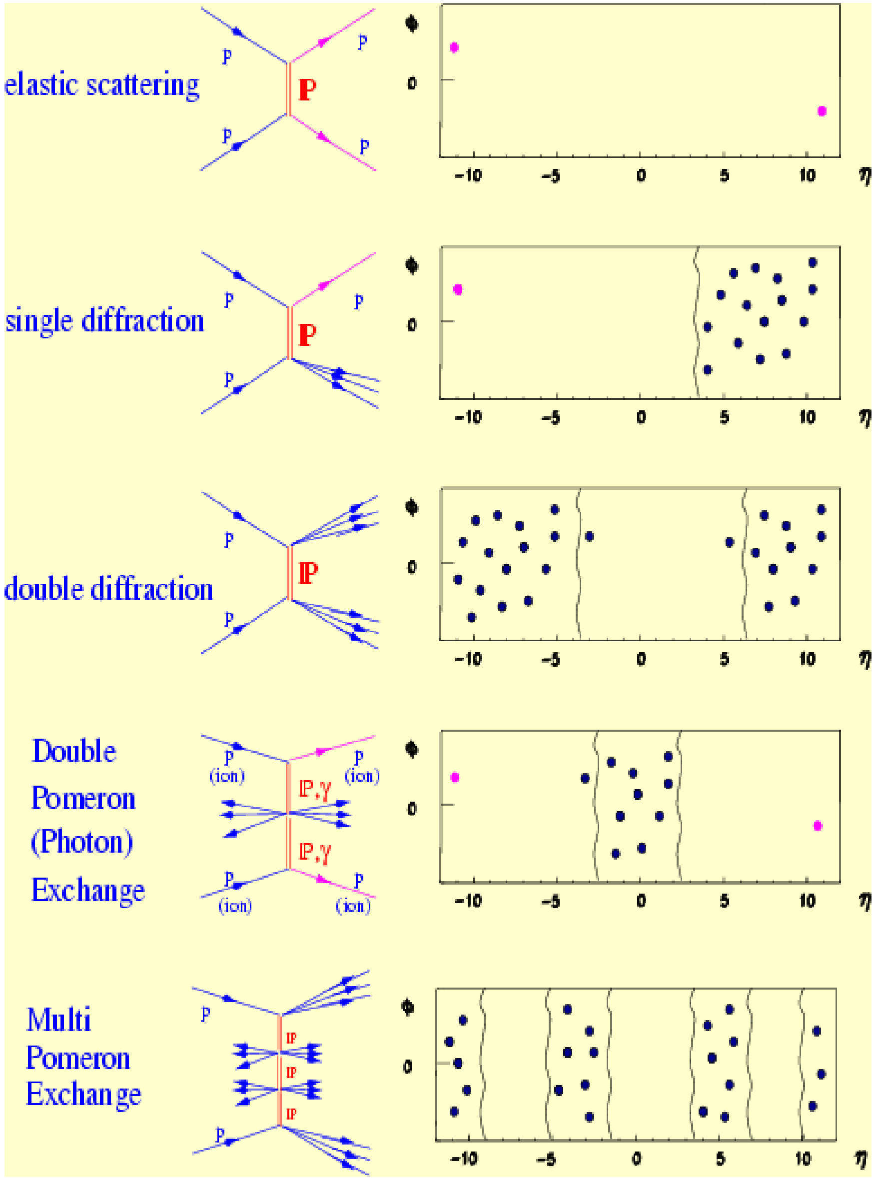
Diffraction at the LHC

• Substantial fraction of total cross-section at LHC is due to diffractive interactions.

•Phenomenologically may be described as scattering processes involving the exchange of an object with vacuum QNs -> The 'Pomeron'.

• Characteristically outgoing hadrons / systems are very forward and have energies within a few % of incoming beam energies.

• Outgoing hadrons / systems well separated in phase space -> Presence of rapidity 'gaps' (I.e. regions of no activity).



CEP: What is it and why is it interesting?

• Central Exclusive Production

•LHC as a gluon-gluon collider

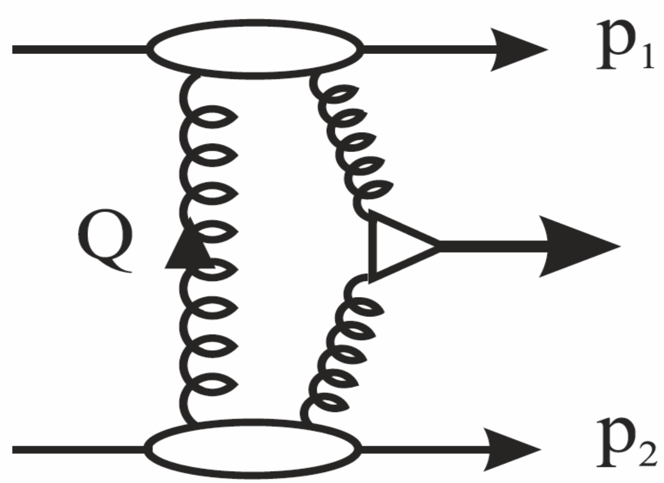
• Selection rules force central system to be $J^{PC} = 0^{++}$

• Two independent ways of measuring mass: Reconstruct central system or measure leading protons ($\xi_1 \xi_2 s = M^2$)

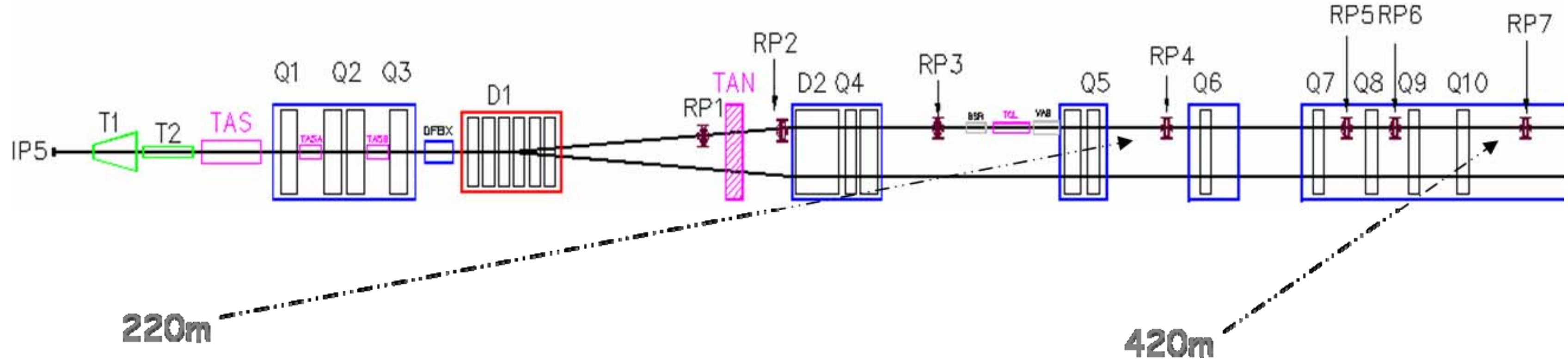
• BSM potential:

  • Opens up some 'difficult' regions of MSSM phase-space.

  • CP violation in the Higgs' sector gives rise to azimuthal asymmetry of leading protons.

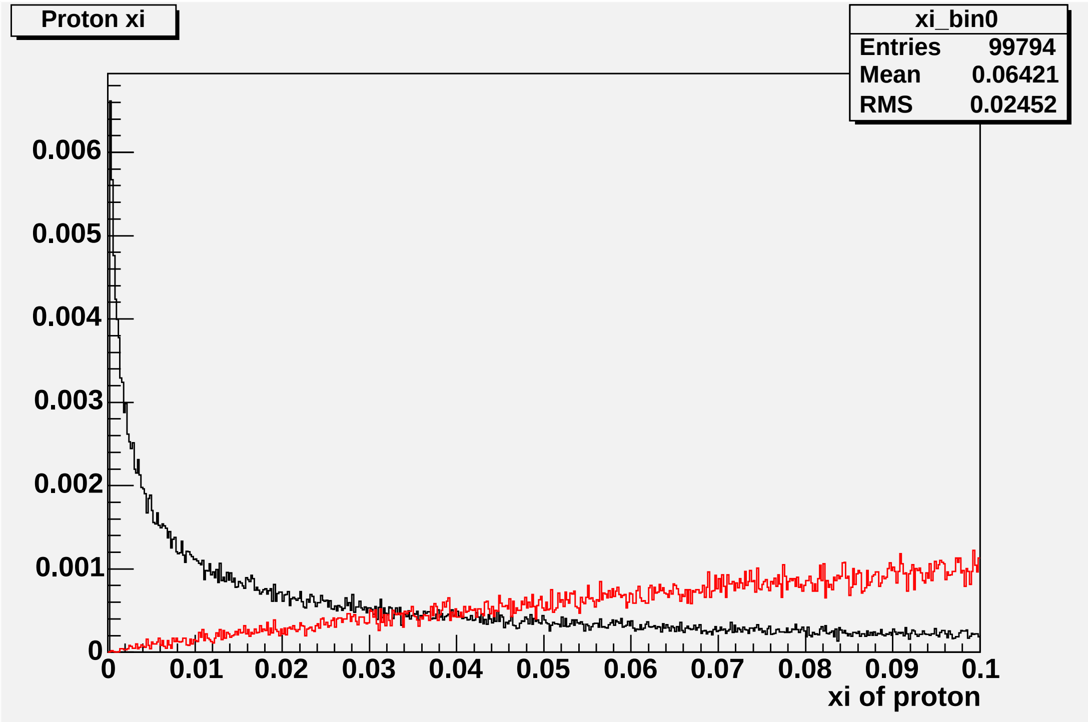


$pp \rightarrow p + \phi + p$



- CMS acts as host experiment for TOTEM. CMS+TOTEM form the largest acceptance detector built at a Hadron Collider
- Diffractive events typically produce fast protons in the final state.
- Combine information from CMS (central activity) with RP-based forward tracking stations to tag leading protons
- TOTEM provides stations up to ±220m from IP5. Plans to extend RP coverage up to ± 430m (FP420 project).

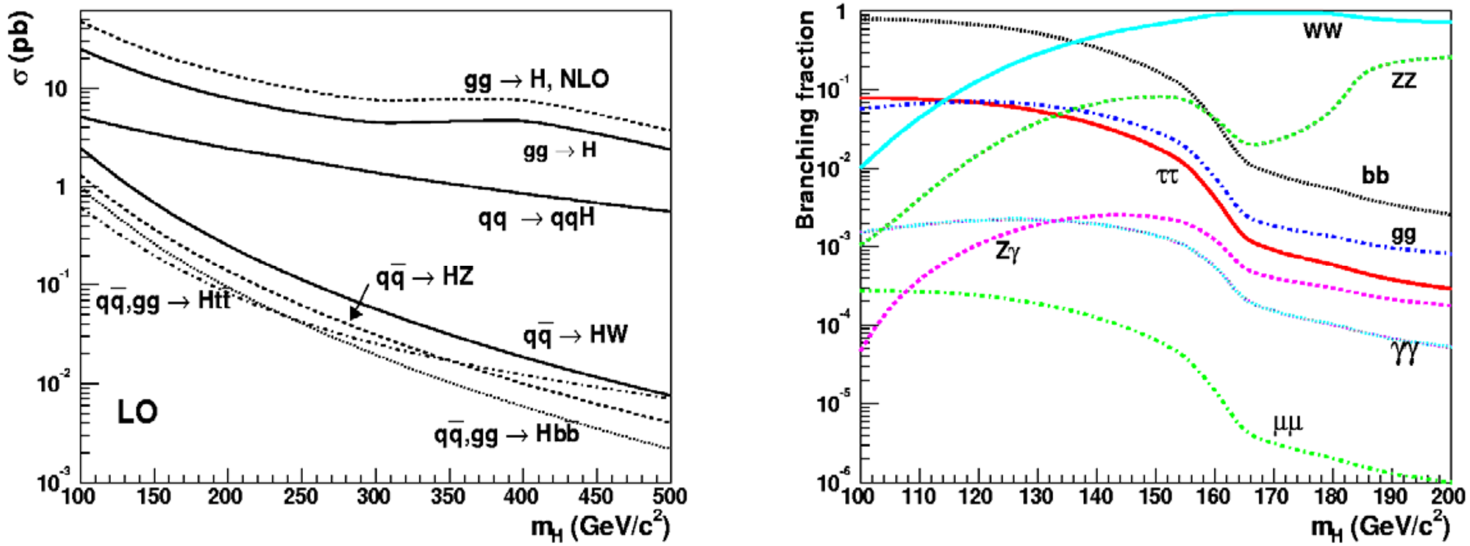
Proton Tagging



ξ-spectra for leading proton in single-diffracive dijet events.

- High β^* optics for special low luminosity runs allow TOTEM to see > 90% of all diffractive protons.
- For standard LHC running, low β^* optics used (0.5m). 220m RPs now sit in tail of distribution ($0.02 < \xi < 0.2$).
- FP420 complements 220m at $\beta^* = 0.5$m by sitting inside diffractive peak ($0.002 < \xi < 0.02$).
- Excellent mass resolution (~1 GeV) if we tag both protons.

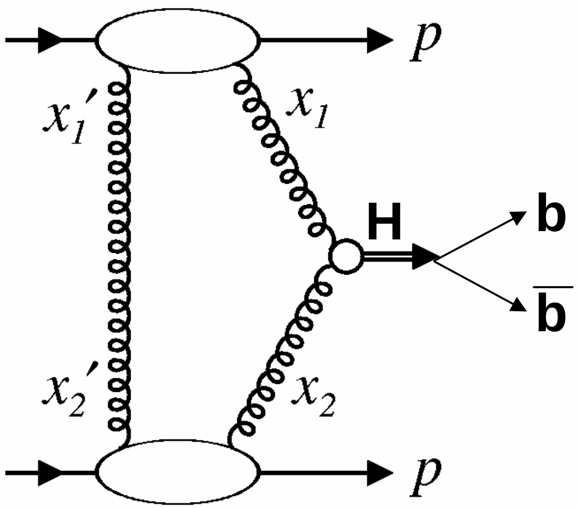
CEP of a light SM Higgs - An interesting test case



• Look at a technically difficult trigger: e.g. 120 GeV Higgs to bb_bar.

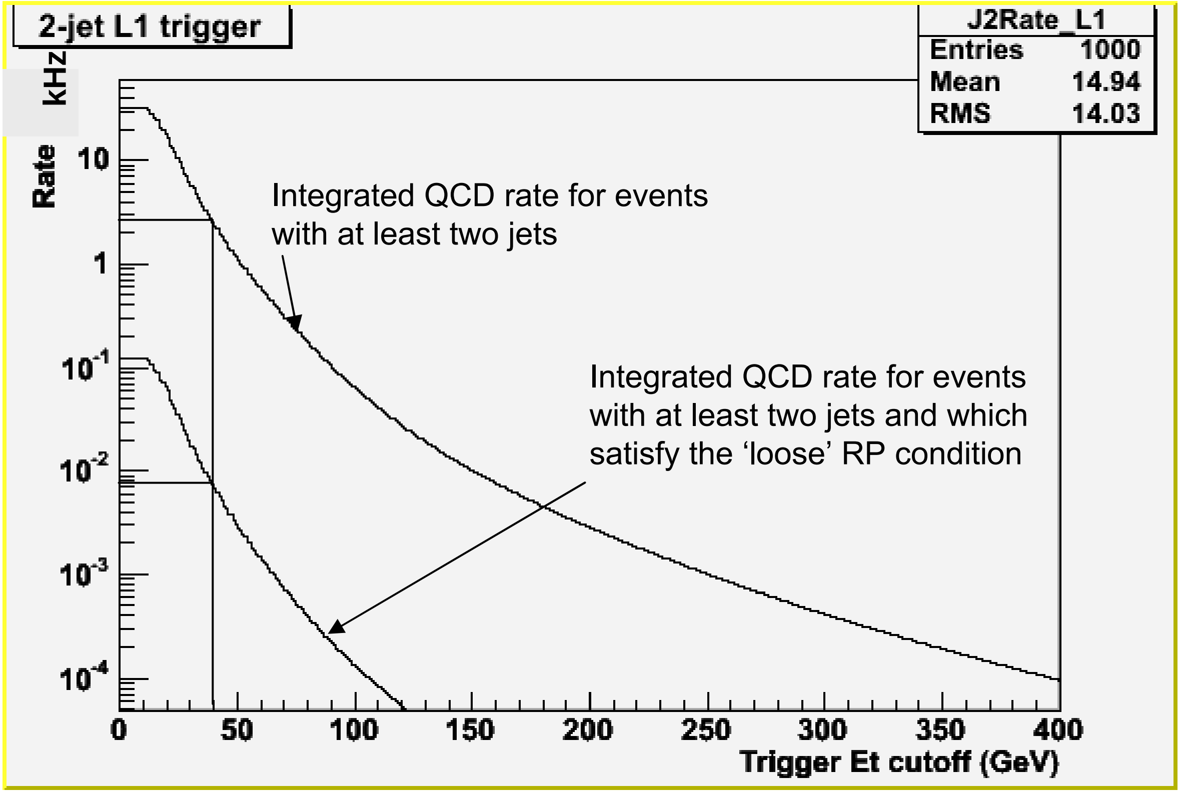
• gg->H, H->bb_bar has the highest branching ratio, but is swamped by QCD background (gg->bb_bar).

CEP of a light SM Higgs - An interesting test case



- For M_H = 120 GeV, σ ~ 3-10 fb.
- $J^{PC} = 0^{++}$ suppresses gg->bb_bar background to order m_b^2 / E_t^2 .
- Triggering on CEP of a light higgs still technically challenging.
- Typical signature: 2 Jets in CMS calorimeter, Et< 60GeV.
- L1 rate, (no proton tagging), for 2 central jets with a jet Et cut-off of 40GeV is ~50kHz. Allocated bandwidth will be O(1kHz).
- Corresponding L1 efficiency little more than 20%.

L1 -Roman Pots at Low Luminosity Running (1x10^{32})



L1 QCD dijet rate at 10^{32}. Generated with PYTHIA. Full simulation & reconstruction done with OSCAR / ORCA

- Unlikely we would be able to get a signal back from 420m in time for L1.
- Examine L1 trigger of the form >=2 central jets + tagged proton at 220m.
- Plot given to illustrate the effect of adding the 'loosest' RP condition, (i.e. hit from any final state proton in either 220m pot), on the QCD dijet rate.
- Reduction in rate of around 350 at 40GeV.

L1 - Roman Pots at Higher Luminosity

• Dominant background (at L1): Inclusive QCD dijet production + leading proton from overlying event. Very few FS protons from inclusive events lie within acceptance of RPs.

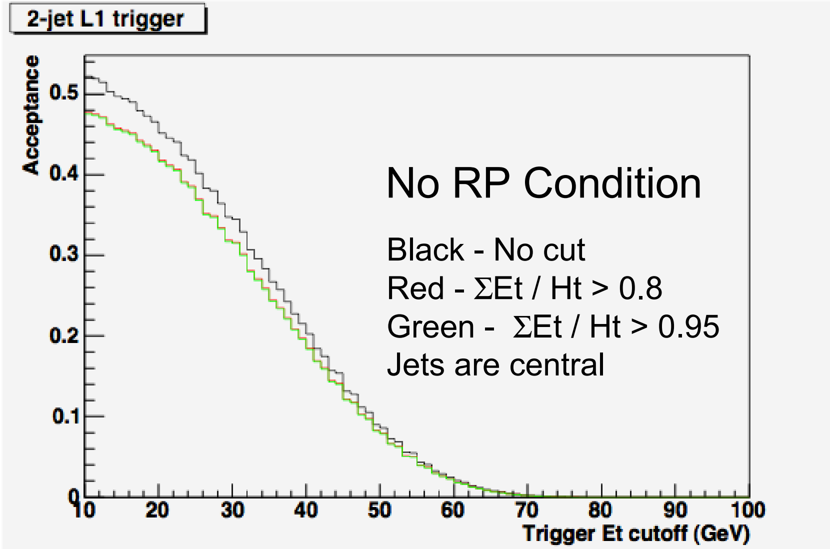
• Table gives reduction in QCD background rate for a single-sided 220m RP trigger, for various LHC Luminosities.

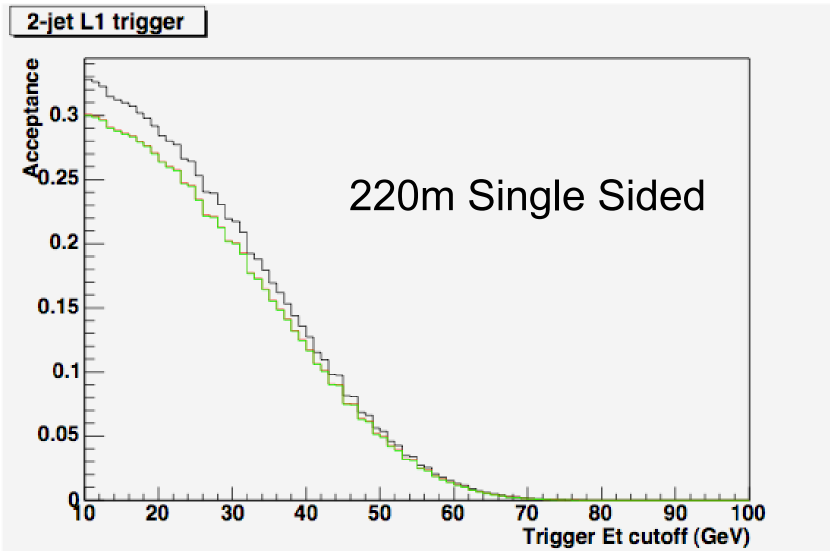
• Significantly more overlying events per bunch crossing, as we include the elastic+diffractive component of σ_{tot} .

Luminosity / $cm^{-2}s^{-1}$	Events per b-x	Rate at 40 GeV	Reduction
1x10^33	3.5	4 (1.8)	7 (16)
2x10^33	7	14.5 (6.8)	4 (8.5)
5x10^33	17.5	73 (39)	2 (3.8)
1x10^34	35	210 (128)	1.2 (2)

Estimated Reduction in rate for single-sided 220m RP condition - () implies cut of xi <0.1

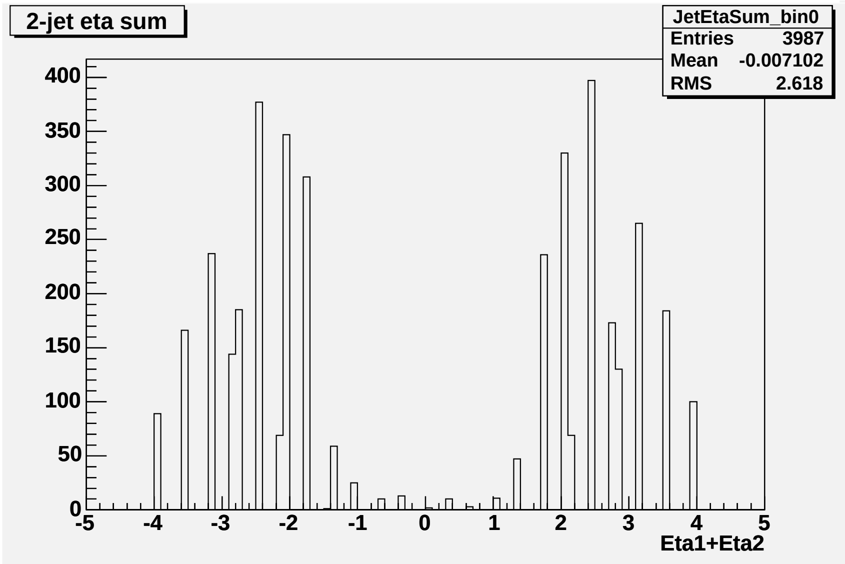
Signal Efficiency

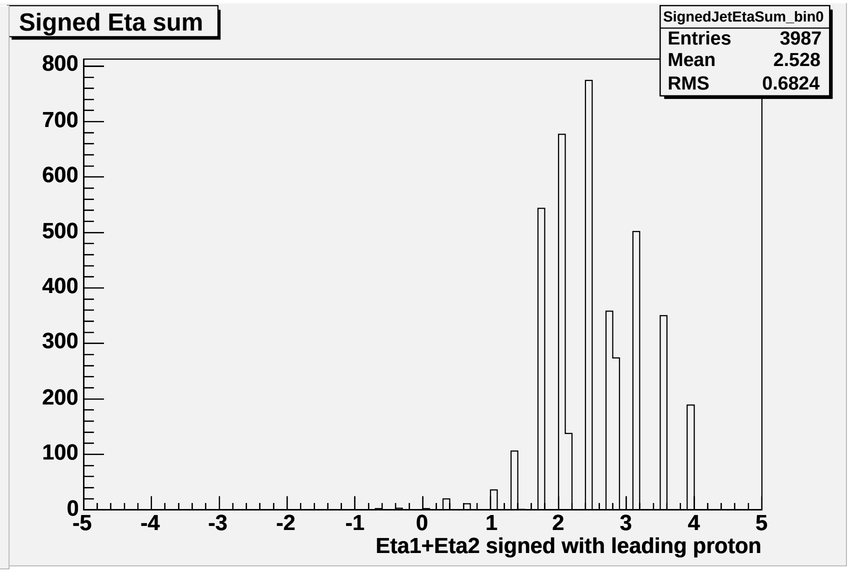




- Plots give integrated L1 dijet efficiency with respect to a cut on Et of the 2nd most energetic jet in the event.
- Plots also show effectiveness of a cut on the ratio of (Et1+Et2) / Ht (Jet isolation condition).
- Ht = scalar sum of Et of all jets in event with Et > threshold.
- Reduces QCD background rate by a factor of ~2.
- Typical L1 efficiency of ~12-13% with RP condition.
- Signal generated with ExHuME.

Additional Topological Cuts





At level-1, want simple but effective cuts to reduce background.

Only asymmetric events seen at 220m.

Take eta-sum of jets. Multiply with sign of direction of proton seen in 220m pot.

No correlation between protons and jets in QCD background events
=> Wins us another factor of two.

Bottom line: can keep rate at 1kHz at 40 GeV up to $L=2x10^{33}cm^{-2}s^{-1}$.

HLT - Basic Strategy

- L1 Trigger => Require 2 central L1 jets + tagged proton at 220m (+ cut on Ht).

- To fit within L1 bandwidth, realistically cannot cut lower than 40 GeV in Et. Need to retain as much of remaining signal as possible.

- Possible to reconstruct ξ from jets in the central detector:

$$\bullet\ \xi_{+(-)} = s^{-\frac{1}{2}} \sum Et_i \exp(-(+)\eta_i)$$

- Look at the resolution of jet-reconstructed ξ wrt to what we get from Roman Pots. Introduce requirement that ξ from jets is within a certain distance of ξ from pots.

- See how effective this is at reducing the background, while minimising loss of signal.

HLT Rates and Efficiencies

- Baseline at L1 is ~1kHz at 40 GeV.
- Need to find a factor of 1,000 at the level of the HLT (aim for O(1Hz)).
- Current cuts at HLT level:
  - Repeat L1 selection with HLT quantities.
  - $2.8 < |\phi 1 - \phi 2| < 3.5$
  - $(E_{t2}-E_{t1})/E_{t1} < 0.4$
  - ξ_{Jet} within 2σ of ξ_{Proton}
  - Also require 2nd proton at 420m.

Output Rate at $2x10^{33}$ = 1.2Hz

Combined Efficiency (L1+HLT)= 5%

Summary

• CEP offers a mechanism for production of a Higgs boson and other exotics, complementary to ‘conventional’ inclusive processes.

• Potential for precision physics at a hadron collider (mass,spin,parity).

•For production of light SM Higgs via CEDP, the L1 two-jet rate is likely sustainable up to L=2×10^{33}, (220m tag, 40GeV cut-off).

• Typical L1 efficiency ~ 12% for jets (40GeV, 220m tag). Combined trigger efficiency of 5-11%, depending on HLT trigger.

• Exploit other characteristics of event topology. E.g. rapidity-gap trigger for low luminosity running.

• Simple L1 rap-gap trigger$\rightarrow$ No HF activity above threshold. Hopefully veto on all forward activity (e.g. CASTOR), but this not implemented in software at present.

• HLT rate sustainable, without prescale, if information from RP at 420m can be accessed by the HLT.