FCC-hh Trigger & DAQ

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The Trigger & Readout Challenge

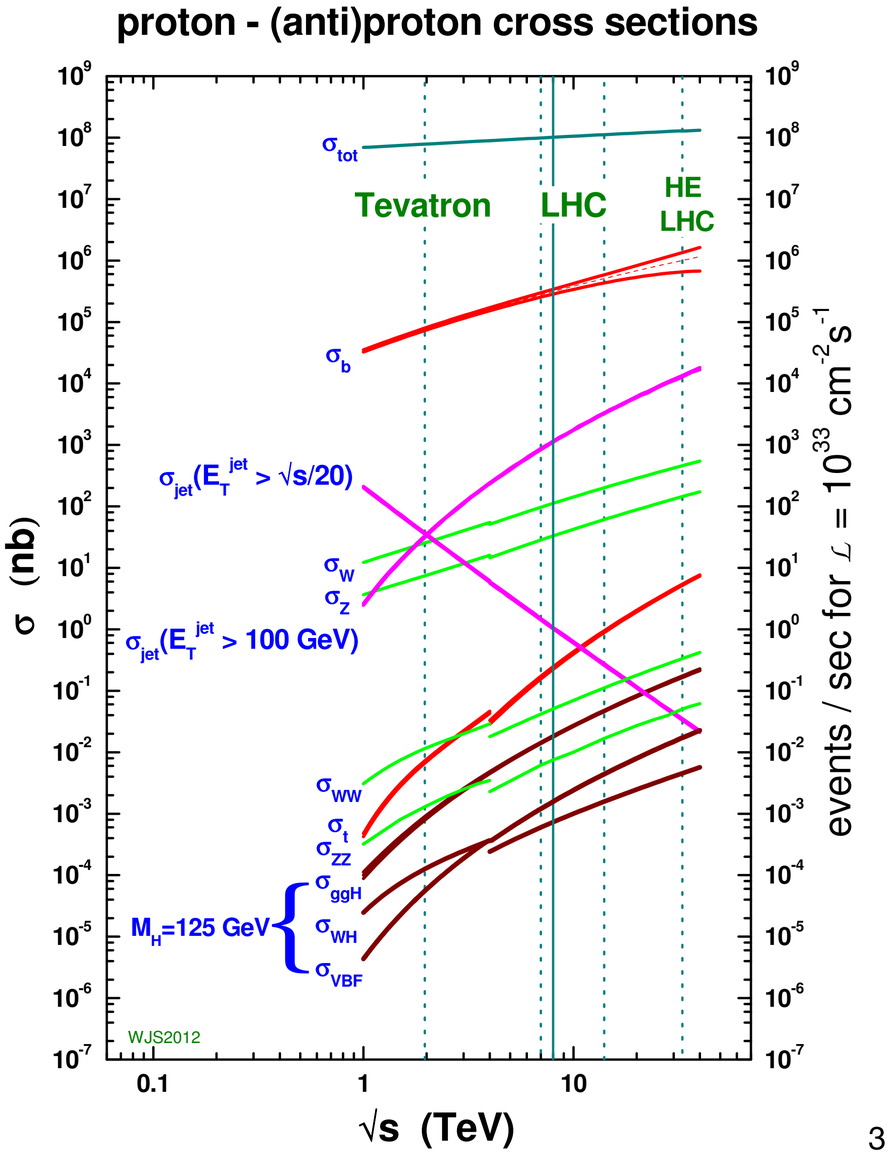
Readout Options

Extrapolating from HL-LHC

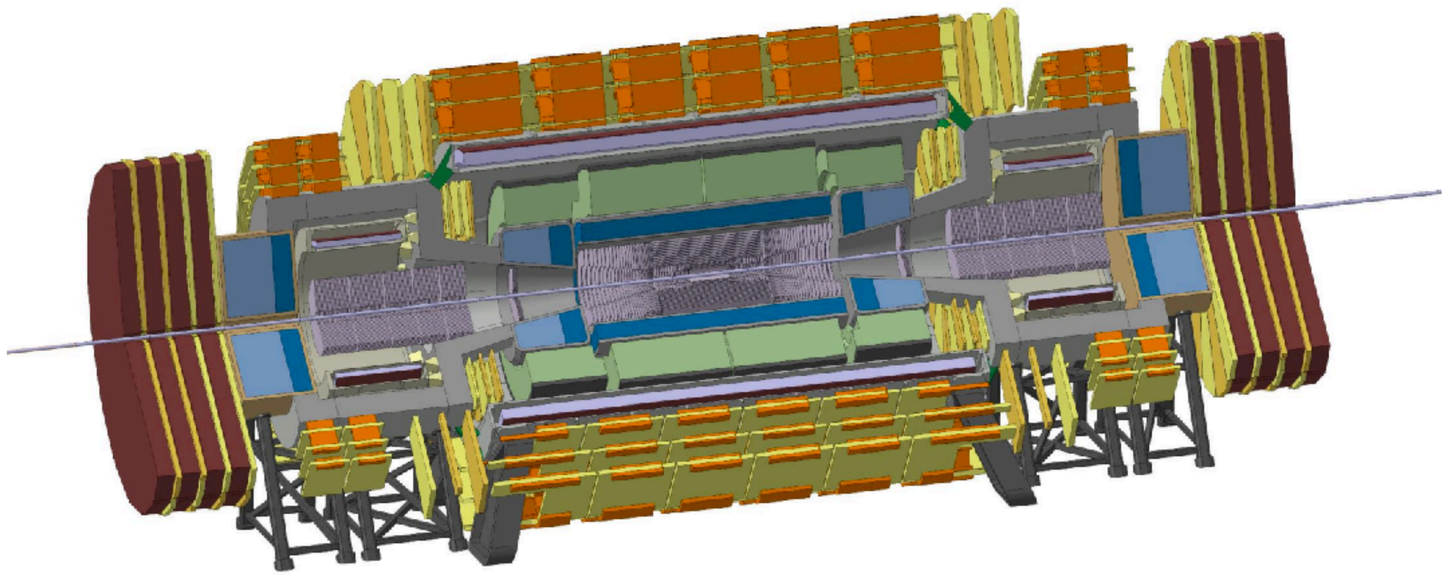
Towards CDR

The Big Question !

- **Do we require a trigger for FCC-hh ?**
  - Yes ! We're not going to store every bunch-crossing forever
  - Depends what you mean by trigger…
- **Where is the data buffered whilst events are being selected ?**
  - On-detector ? Off-detector ? A combination of them both ?
  - Depends on link speeds, power, material budget, DAQ capacity
- **How are the events selected ?**
  - Depends on what data is available, processing capabilities, backgrounds and physics goals…



FCC-hh data rates



- Front end detector data rates are *substantial* :
  - **Tracker** : ~800 TB/s [1]
  - **LAr+Tile Calo** : ~200 TB/s [2]
  - **Si/W Calo** : *O(1000 TB/s) ?* guesstimate !
- Is this conceivable?
  - 1-3 M optical fibres @ 10Gb/s
  - O(10-30) Pb/s event builder network
  - Material budget ?
  - Processing farm requirements ?
  - Processing farm power ?

See talks for more info :
1 - Zybnek Drasal
2 - Martin Aleksa

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Readout Options

1) Continuous readout

- Data for every bunch-crossing is transferred off detector
- Event selection has access to FULL event data

2) Triggered readout

- A subset of data transferred off-detector for each crossing
- This is used to generate a trigger, on which full detector data is read out

3) Increasing sophistication

- Multi-stage trigger, regional readout, …

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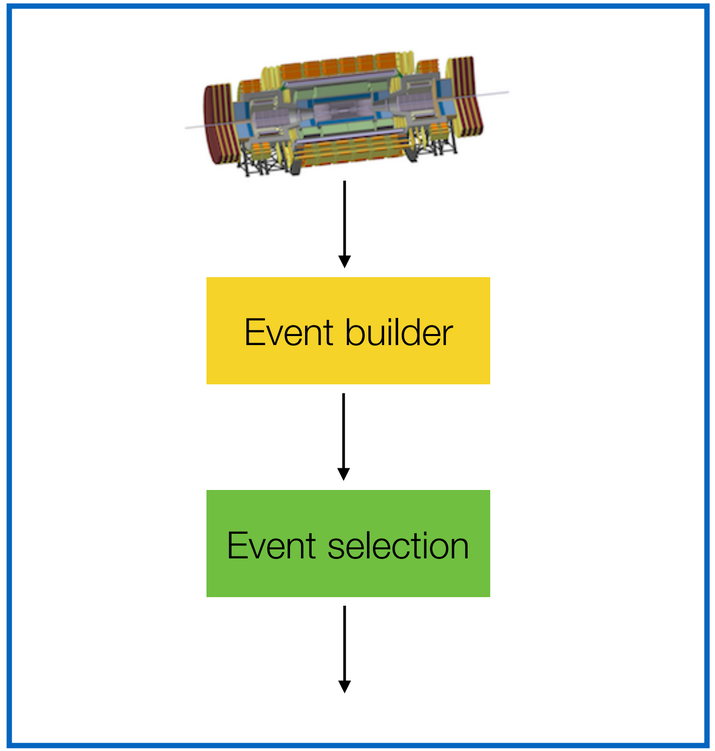

Rad hard link capacity ?
Link power / material budget ?
Event builder bandwidth ?
Event selection processing / power ?

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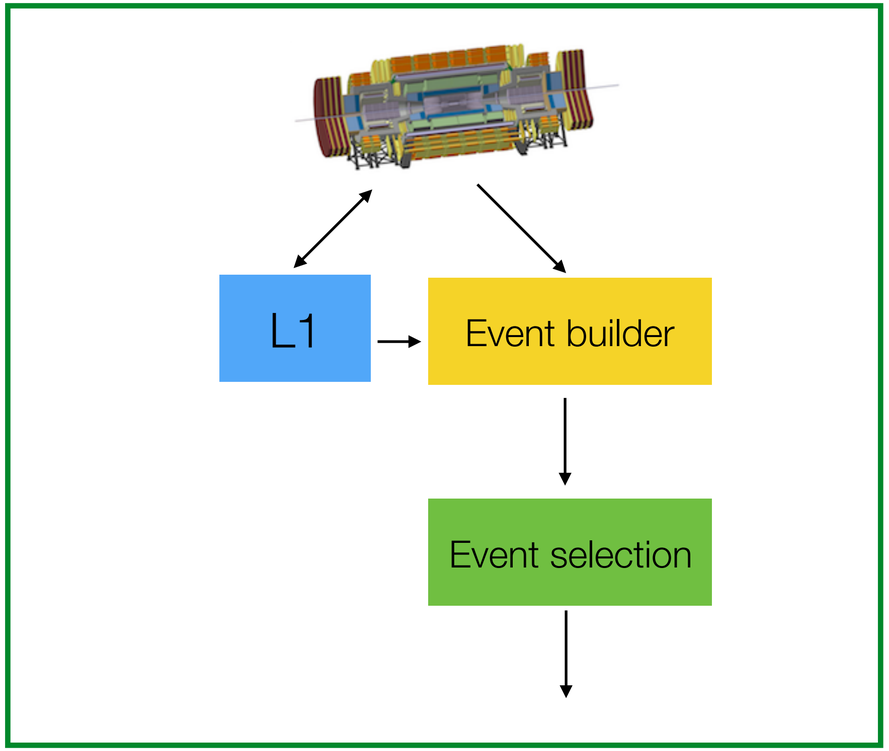

Which detectors need a trigger ?
Which detectors can provide a trigger ?
Trigger data bandwidth requirements ?
Latency constraints ?
Trigger performance ?

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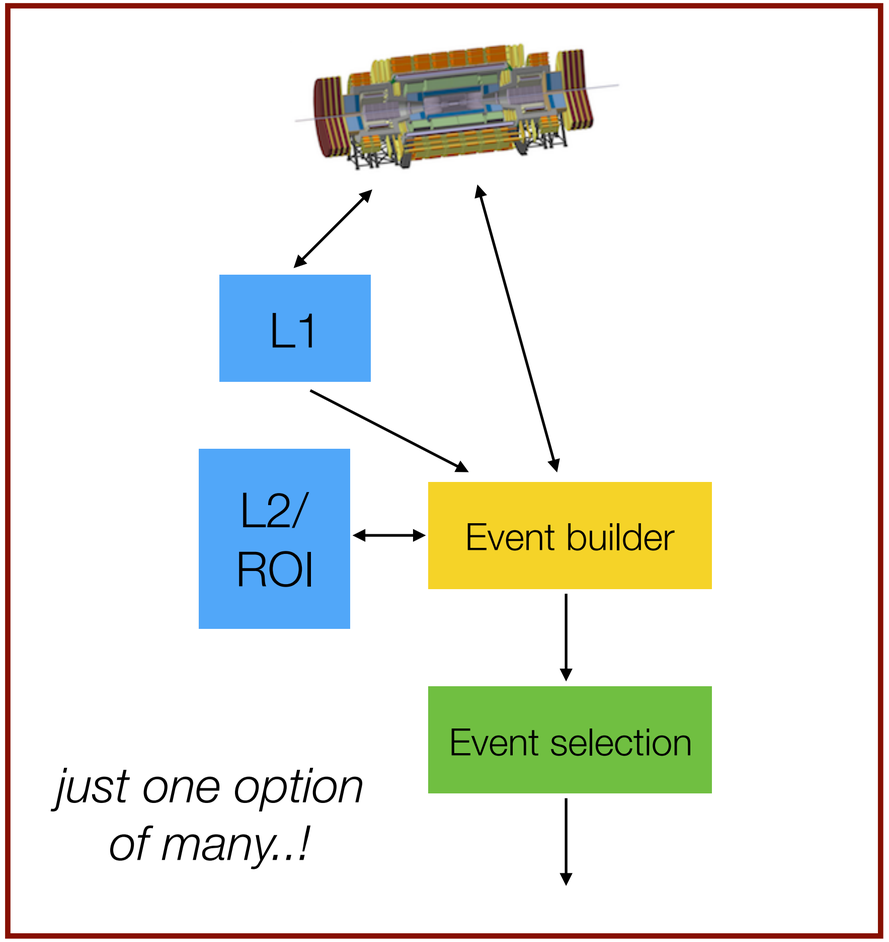


What are the gains over a simple trigger ?
Cost / benefit / risk

Readout Options

- **How do we choose ? There is no simple route**
  - A variety of studies are required :

- **Detector readout capacity**
  - Implications of rad hard links, cost, power, material budget

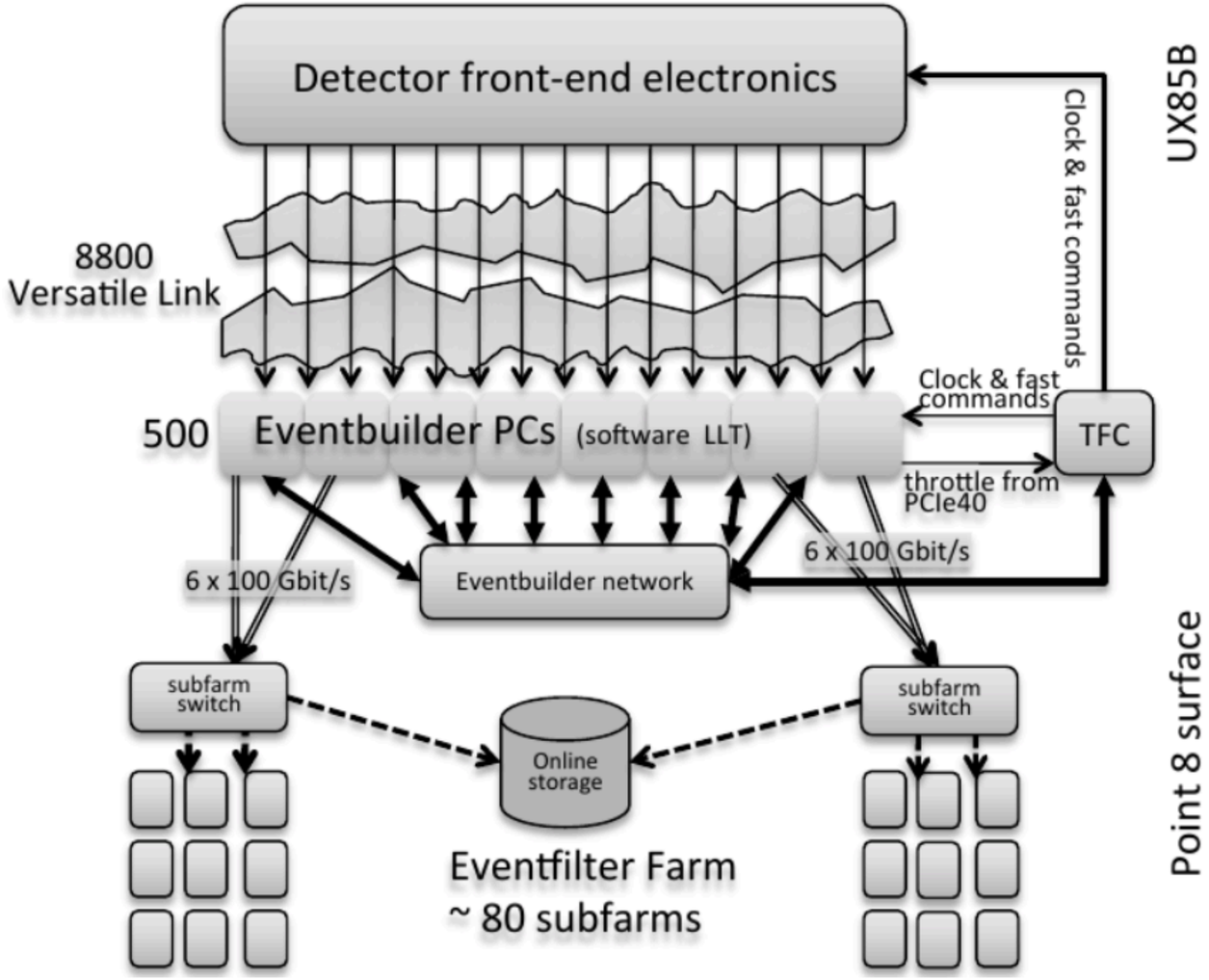
- **Potential trigger performance**
  - Impact on physics of different options for generating a trigger(s)

- **Off-detector event processing capabilities**
  - DAQ event building capacity, processing farm requirements, cost, power

Continuous Readout

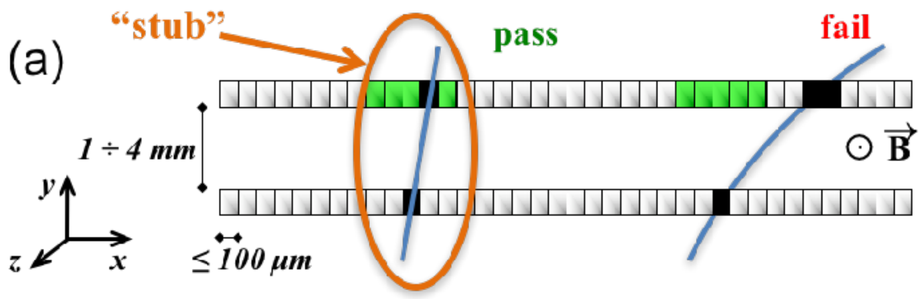
LHCb HL-LHC

- **Detectors are readout at 40 MHz**
  - 30Tb/s event builder network
- **Full event selection in software**
  - Substantial processing farm & power requirements
  - *Some hardware assist for data unpacking*

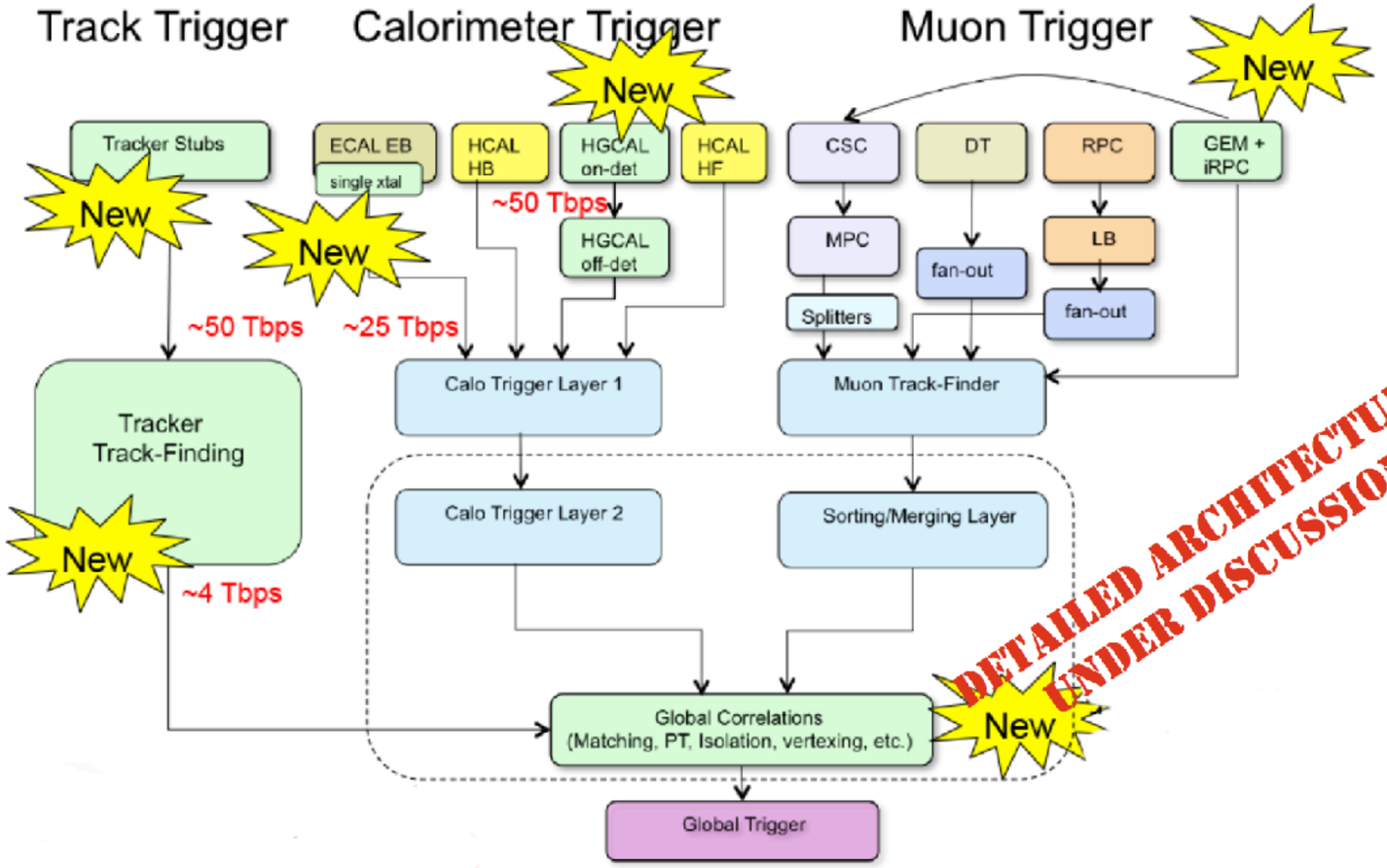


Single Level Trigger

- **All sub-detectors contribute to Level-1 trigger**
  - Rate reduction to 750 kHz
- **Tracking at L1 depends on 'stacked' layers of silicon**
  - Two layer coincidence selects tracks with p_T > 2-3 GeV



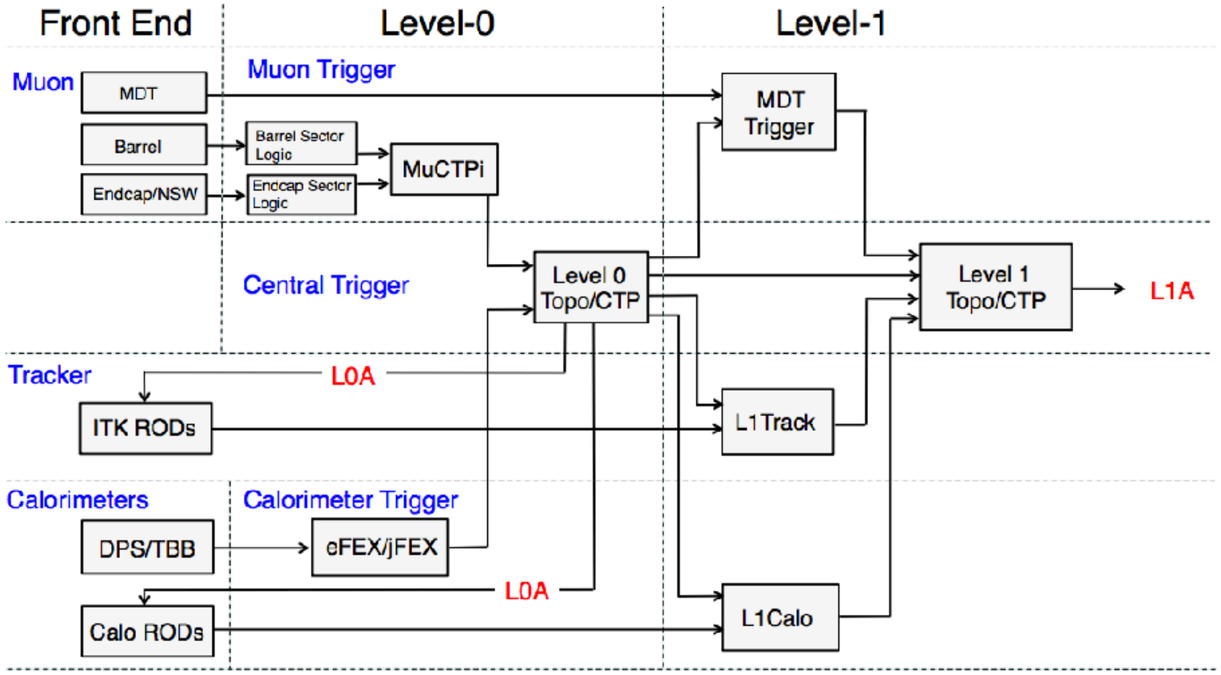
CMS HL-LHC



Multi-Level Trigger

- **Level-0 trigger using calorimeter and muon information only**
  - Reduce rate to < 1 MHz
- **Addition of tracking information at Level-1**
  - Reduced rate decouples tracker geometry from trigger requirements
- **Important question for FCC-hh**
  - Can a suitable reduction in rate be achieved using only calo + muon data, with minimal loss of physics ?

ATLAS HL-LHC



The Trigger & Readout Challenge
Readout Options
Extrapolating from HL-LHC
Towards CDR

Extrapolating from HL-LHC

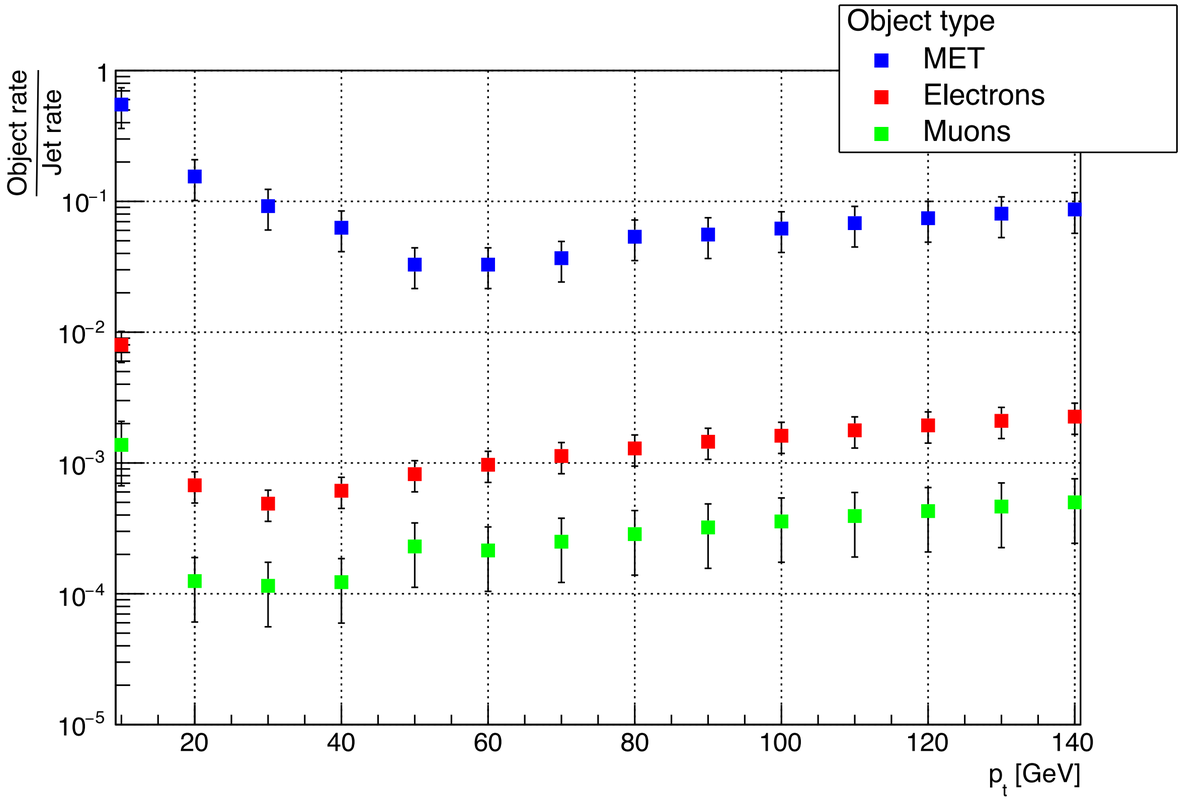
- **How do we estimate trigger performance at conceptual level ?**

- Estimating trigger rates from simulation requires significant *detail*
  - Soft muon mis-measurement
  - Punch through to muon system
  - Conversions, bremsstrahlung
  - Energy mis-measurement
  - …

- **Can we extrapolate from HL-LHC ?**

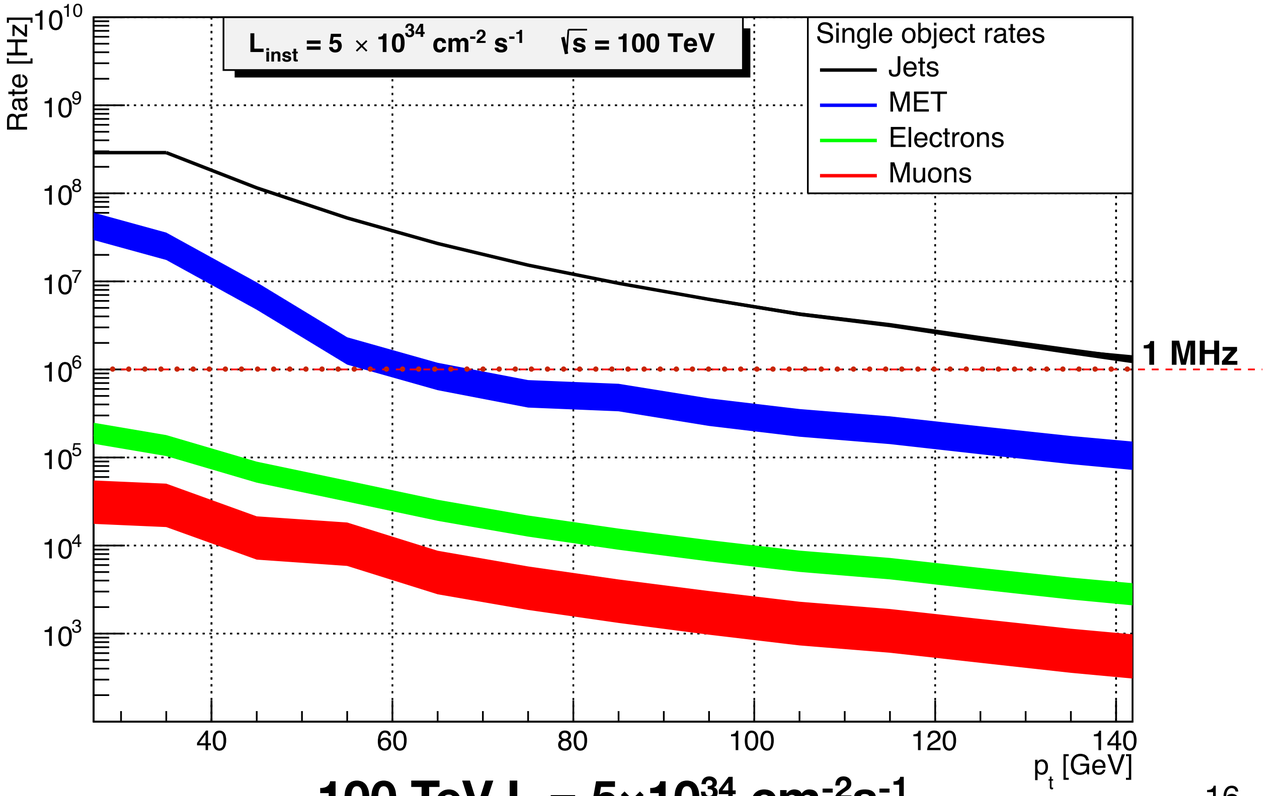
- Starting assumptions :
  1) Backgrounds scale with jet cross-section
  2) Rejection factors as for CMS L1 @ HL-LHC
  3) L1 trigger with 1 MHz readout rate
  4) Bandwidth assignment as CMS HL-LHC
  5) Use single lepton triggers to select electroweak physics

Extrapolating from HL-LHC



Equivalent to scaling HL-LHC trigger rates by jet σ(p_T) from 13 to 100 TeV

- Assume background rejection as for CMS Phase 2*
- Extrapolate to 100 TeV, 5x10^{34} $cm^{-2}s^{-1}$
- Obtain single jet, electron, muon, MET rates
  - *NB : isolation not considered here !*



100 TeV L = 5×10^{34} $cm^{-2}s^{-1}$

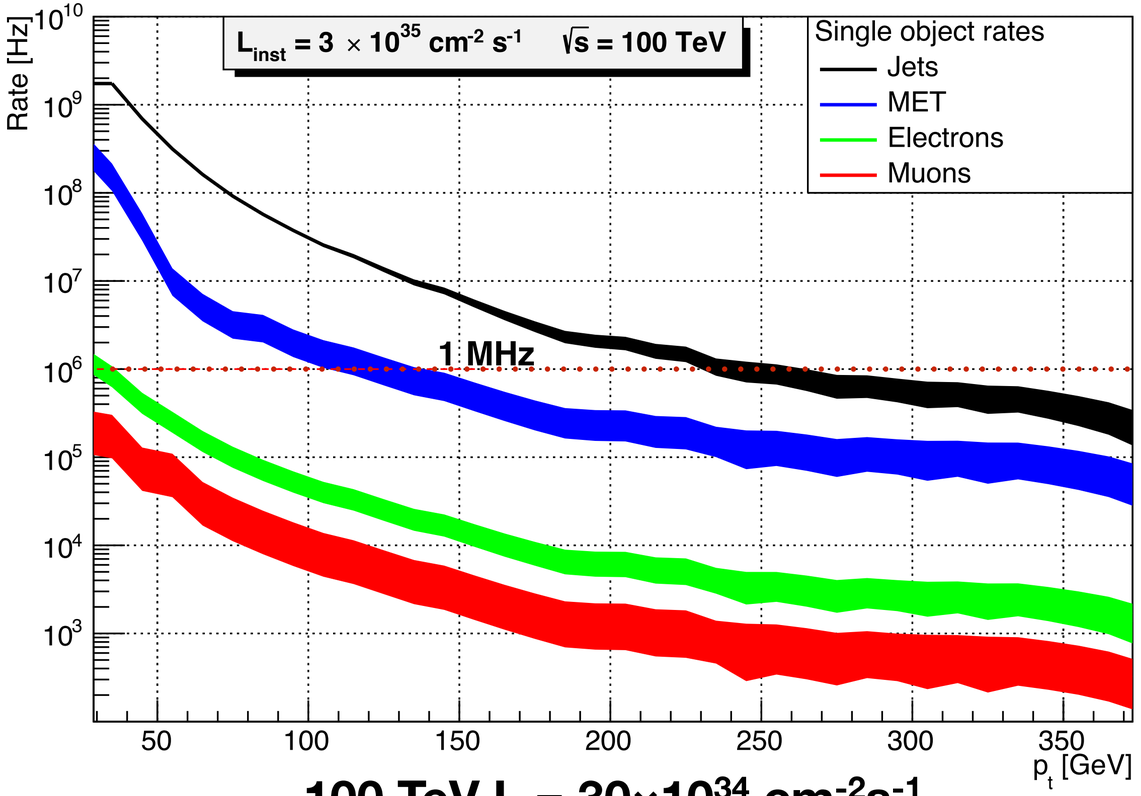
* - *from CMS Phase 2 Upgrade Technical Proposal*

Extrapolating from HL-LHC

- Assume total L1 trigger rate of 1 MHz
- Breakdown of trigger bandwidth between objects as for HL-LHC
  - *CMS phase 2 technical proposal allocates ~6% for single objects*
- Obtain thresholds for single e, μ, MET

		Threshold L=5E34	Threshold L=3E35
electron	60 kHz	55 GeV	90 GeV
muon	60 kHz	35 GeV	60 GeV
MET	60 kHz	160 GeV	*>350 GeV*

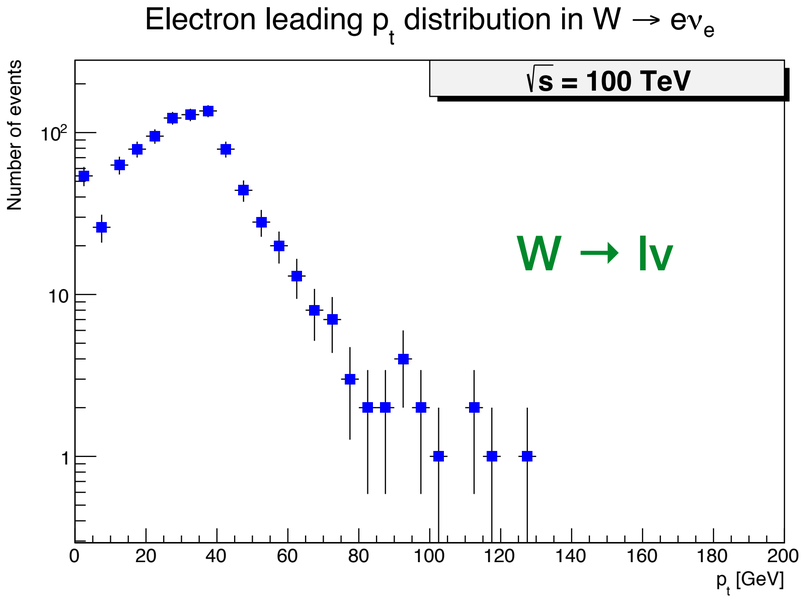
Thresholds are **indicative**, *clearly depend on details of bandwidth allocation*

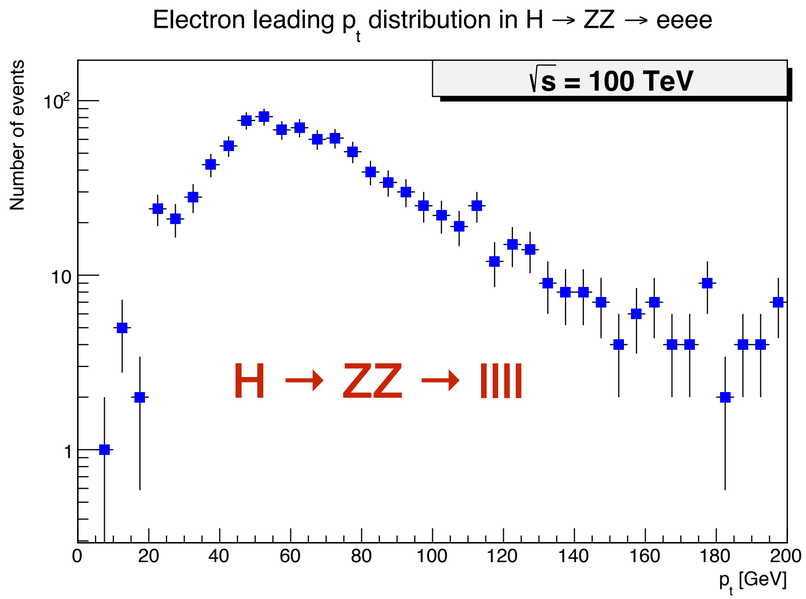


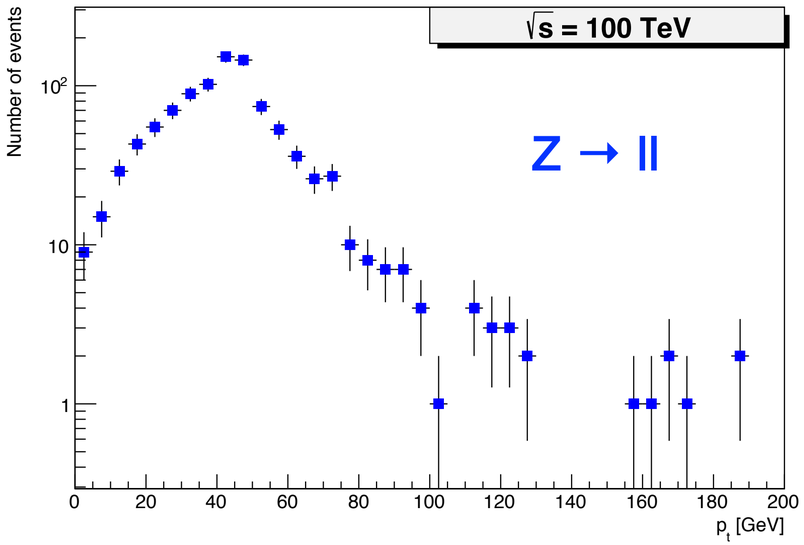
100 TeV L = 30×10^{34} $cm^{-2}s^{-1}$

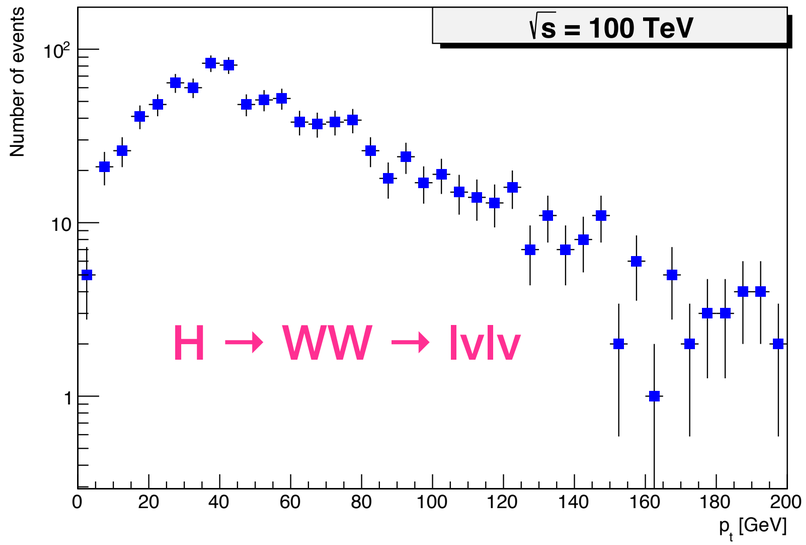
Extrapolating from HL-LHC

How do single lepton triggers perform for electroweak physics ?





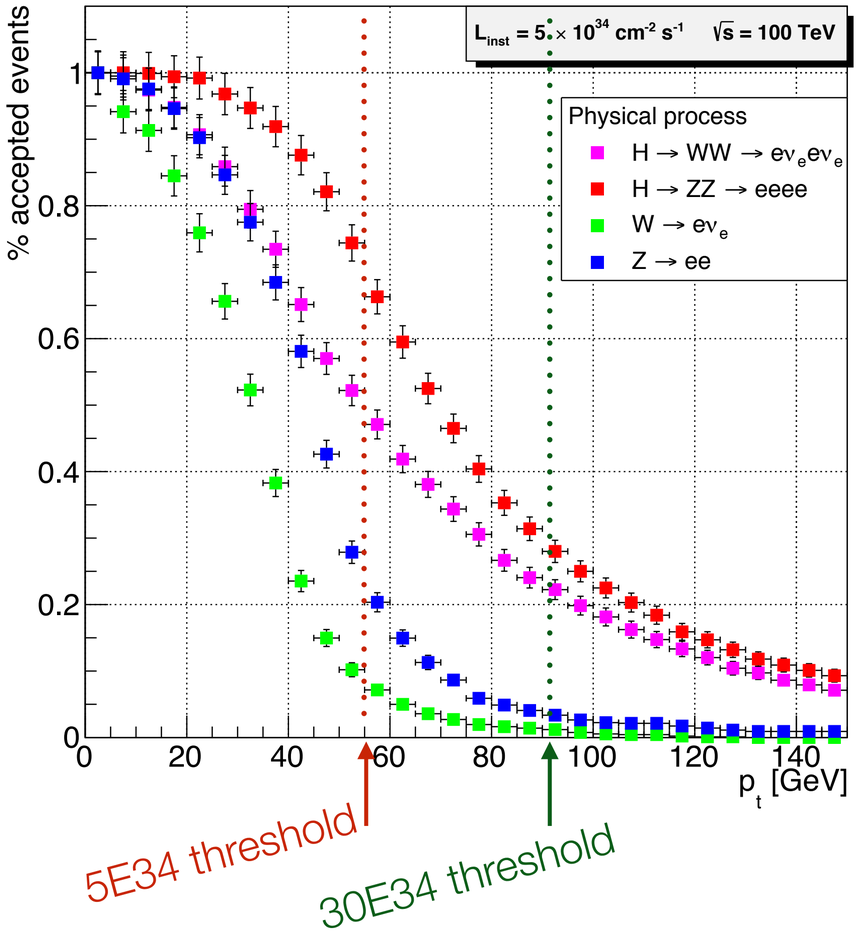




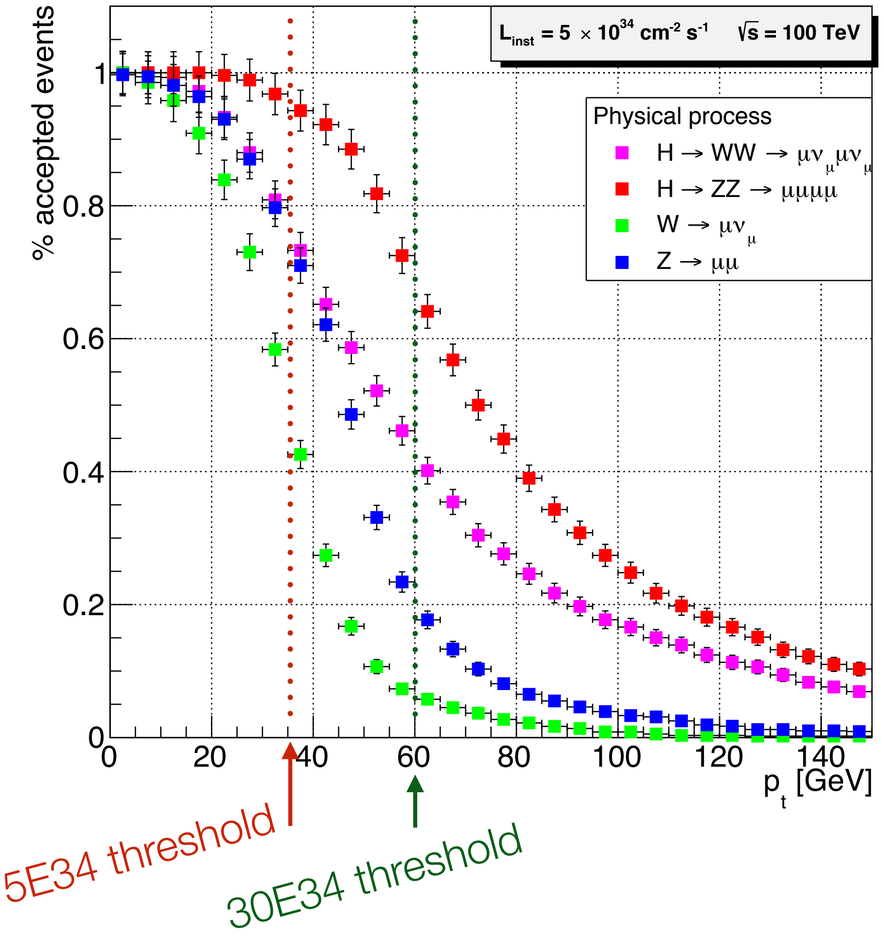
Extrapolating from HL-LHC

Single lepton triggers for electroweak physics

electron



muon



Possible Further Work

- **Rate estimates presented are clearly based on some sweeping assumptions**
  - Backgrounds scale with jet cross section
  - Rejection factors from CMS HL-LHC assume 140 PU and tracking at L1

- **Possible refinement of trigger performance extrapolation :**
  - Repeat the procedure for ATLAS HL-LHC, and CMS/ATLAS LHC Run 2, including software triggers
  - Can we increase sophistication of background modelling ? Higher PU, impact of boosted objects etc.
  - Can we pick apart the HL-LHC rejection factors to understand better how they translate to FCC ?

- **Also interesting to extrapolate processing requirements to FCC conditions**
  - Get a handle on trigger/DAQ/event filter cost & power, given current technology
  - Look at future trigger/event filter processing technologies

The Trigger & Readout Challenge
State of the Art
Extrapolating from HL-LHC
Towards CDR

CDR Goals

- **Introduction to the trigger & readout challenge**
  - Links to the physics goals and the motivation for basic selection criteria
- **Review of the state-of-the-art, ie. CMS, ATLAS & LHCb at HL-LHC**
  - Extrapolation of LHC / HL-LHC rates to FCC via Pythia
- **Discussion of a few possible trigger scenarios for FCC-hh, and their relative merits & challenges**
  - Describing the performance requirements;
  - Physics driven thresholds, rates that must be achieved at each stage of data reduction
- **Strategic R&D required needed to finalise & implement a readout architecture**
- ***Possibly, discussion of trigger performance in terms of benchmark signal and backgrounds ???***

Conclusions

- **FCC-hh presents a substantial readout and trigger challenge**
  - Although this is not insurpassable, given future technology and ingenuity
- **Presented first studies of trigger rates by extrapolating from CMS predictions for L1 at HL-LHC**
  - Identified several areas where the extrapolation could be refined
    - Background modelling, extrapolation to high PU, boosted objects, etc.
  - Plan to repeat the exercise for other LHC & HL-LHC trigger scenarios
- **Defined goals for CDR**

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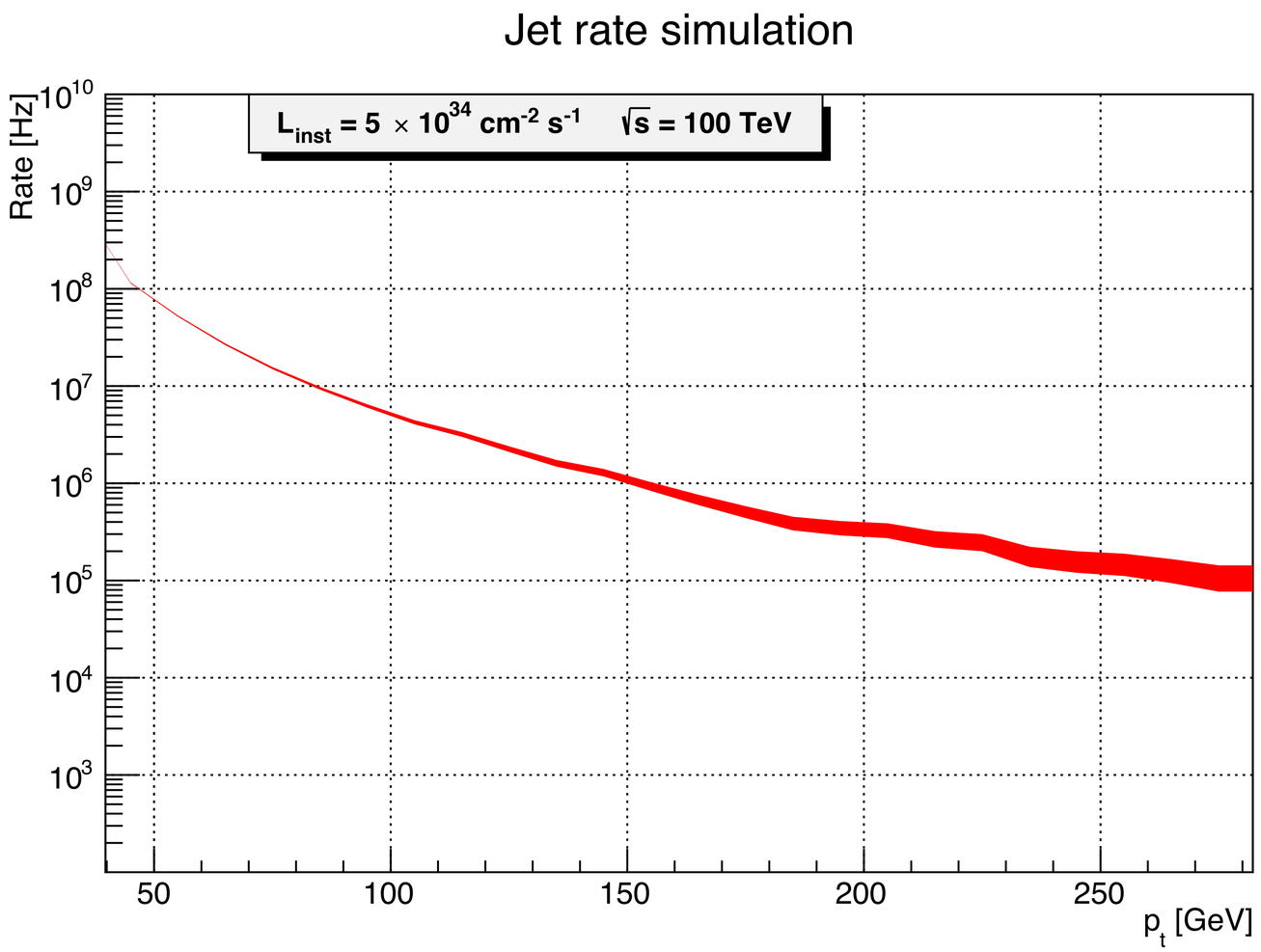
Plenty of work to be done
Plenty of room for new ideas - and new collaborators !

Backup

LHC Trigger Strategy

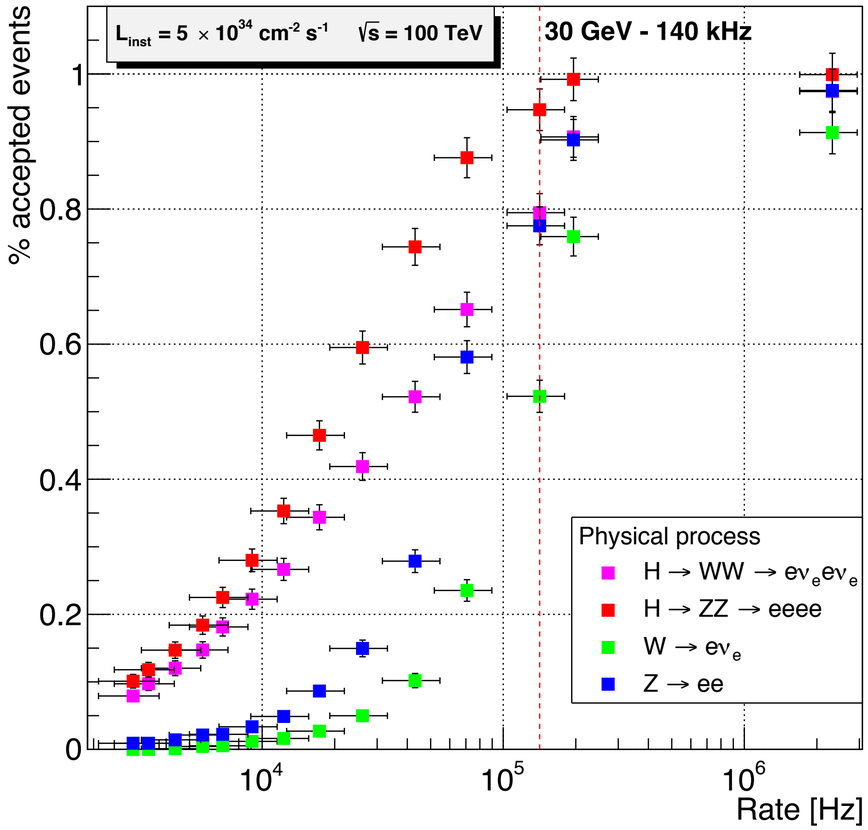
- Goal is to record electroweak scale physics
- Identify :
  - Leptons (with/without isolation)
  - Photons
  - Jets, hadronic tau
  - Global sums : E_T^{miss}, H_T
- Select events based on combinations of objects
  - E_T thresholds
  - Also compute eg. invariant mass
- Achieve this using :
  - Multi-level triggers
  - Increasing granularity at each level
  - Custom hardware -> COTS cpu
- Total rejection factors in the range ~3-5x10^4

Jet trigger rate

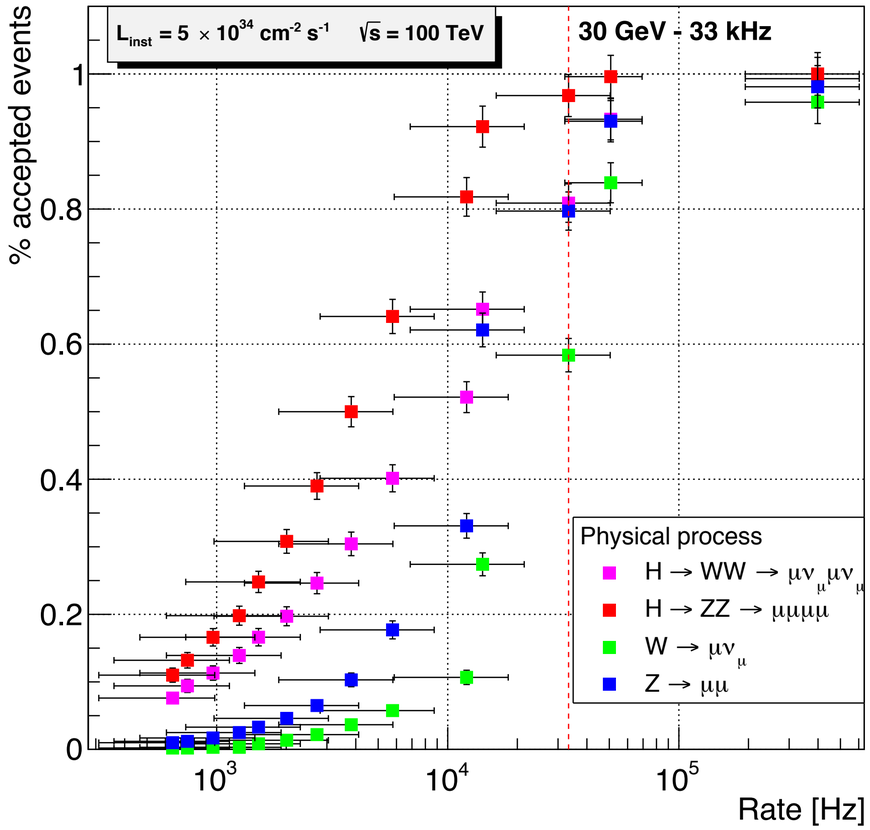


Extrapolating from HL-LHC

electron



muon



Can we trigger on electroweak physics at FCC ?