Deployment of a Matrix Element Method code for the *ttH* channel analysis on GPU's platform

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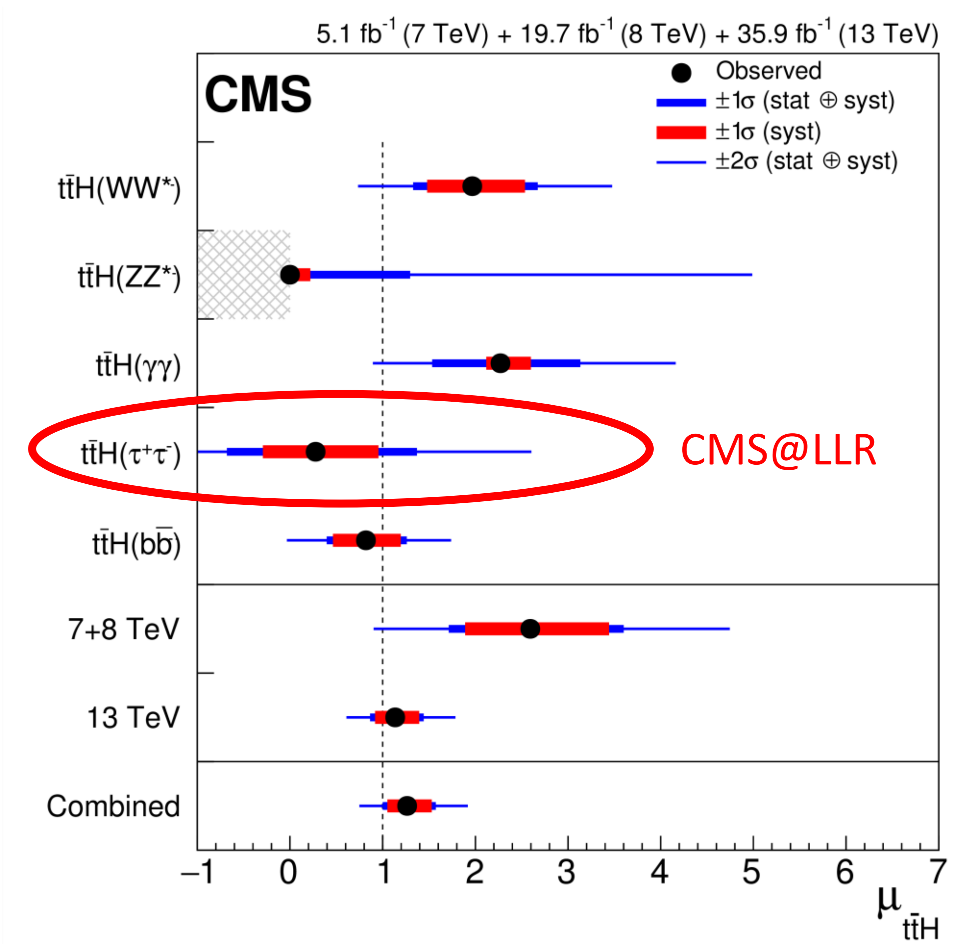
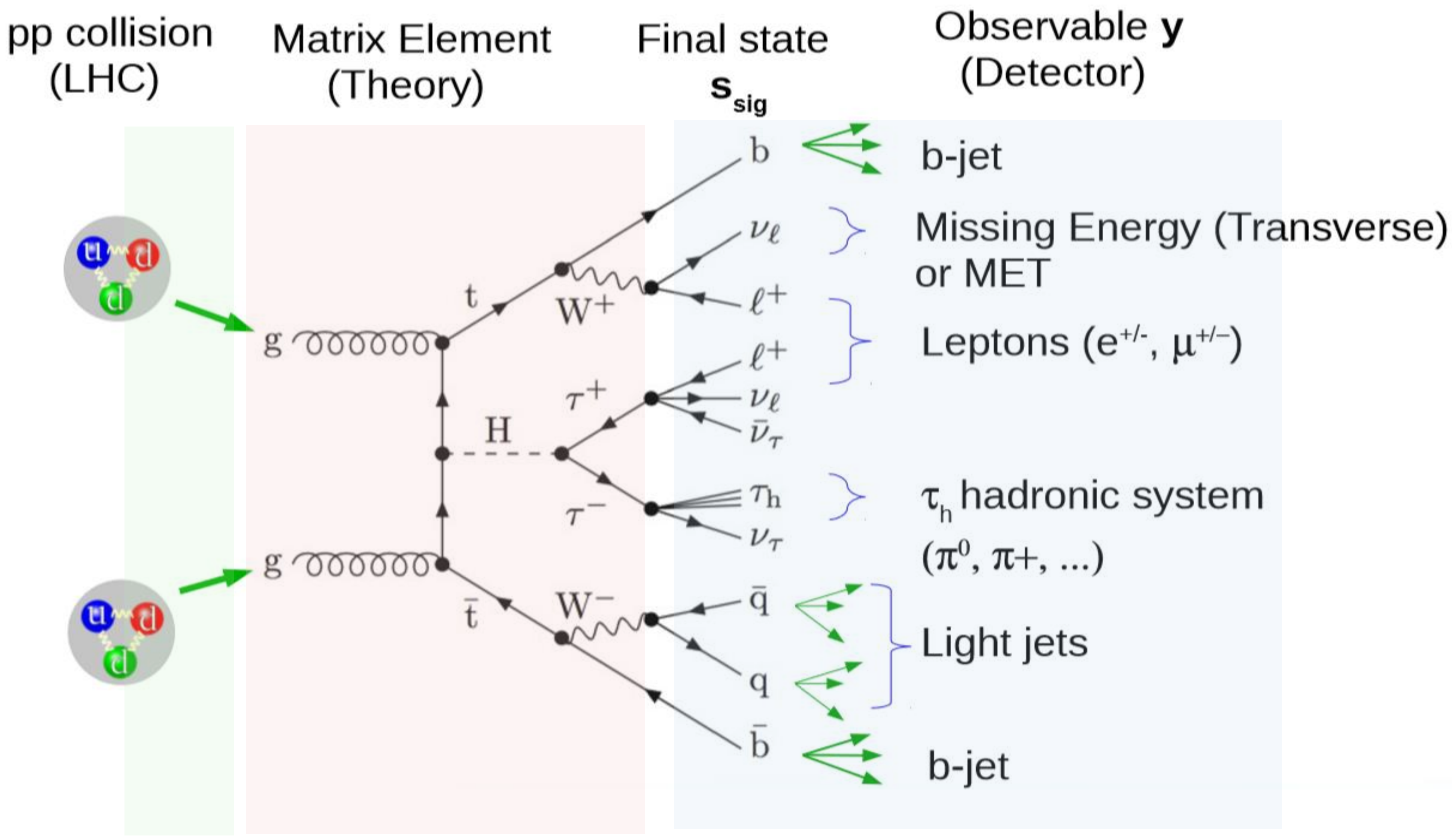
Recent discovery of H boson in *ttH* channel



- Higgs decays into γγ, ZZ, WW, and ττ final states have been observed (discovery 2012) and there is evidence for the direct decay to the bb final state,
- In the SM, the Higgs boson couples to fermions, with a strength proportional to the fermion mass (Yukawa-type interaction).
- The decay to the tt final state is not kinematically possible. Therefore, it is of paramount importance to probe the coupling of the Higgs boson to the top quark, the heaviest known fermion, by producing the Higgs in the fusion of a top quark-antiquark pair or through radiation from a top quark.
- First observation of the simultaneous production of a Higgs boson with a top quark-antiquark pair (ttH channel) April 2018
- It is an important step forward in our understanding of the origin of mass.
- Our (CMS@LLR) contribution **in ttH -> ττ** sub-channel

A. M. Sirunyan et al. (CMS Collaboration), "Observation of tt̄ H Production", Phys. Rev. Lett. 120, 231801 (2018)

Matrix Element Method (MEM)

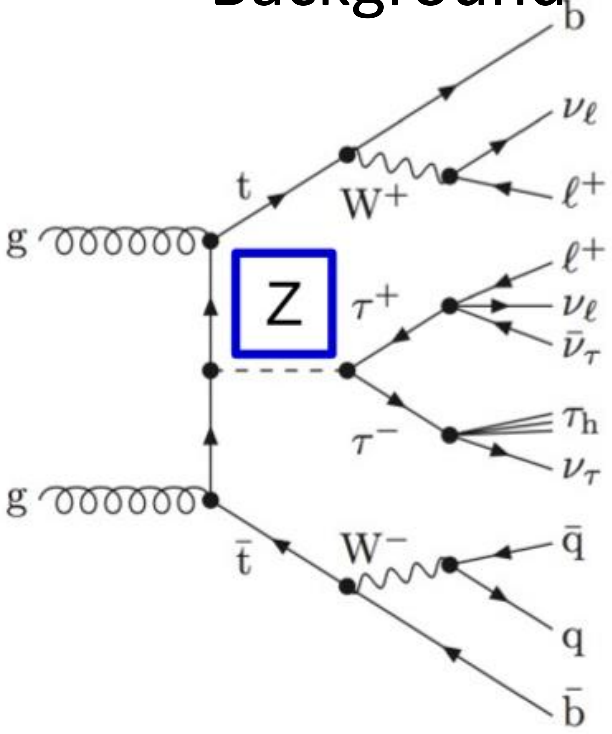


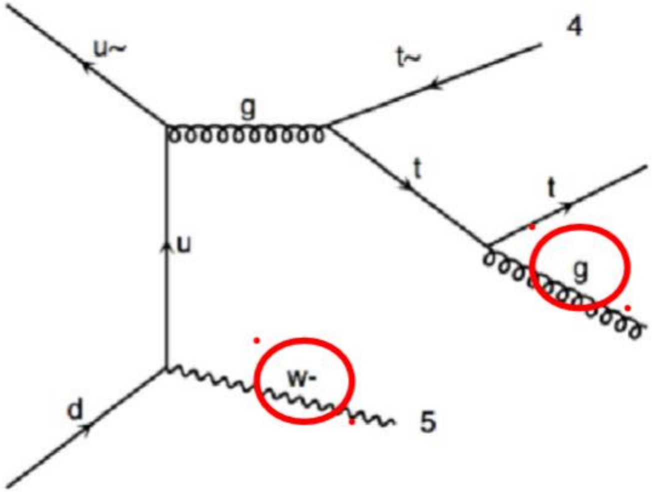
- Physic driven analyses (not data driven). Important to have this approach among Machine Learning or statistical approaches
- Signal final state: S_{sig}
- Principle:
  - Compute the probabilities that an event is S or B one.
  - Compute the likelihood ratio

$$w_i(\mathbf{y}) = \frac{1}{\sigma_i} \sum_p \int d\mathbf{x} dx_a dx_b \frac{f(x_a, Q) f(x_b, Q)}{x_a x_b s} \delta^2 (x_a P_a + x_b P_b - \sum p_k) |\mathcal{M}_i(\mathbf{x})|^2 W(\mathbf{y}||\mathbf{x})$$

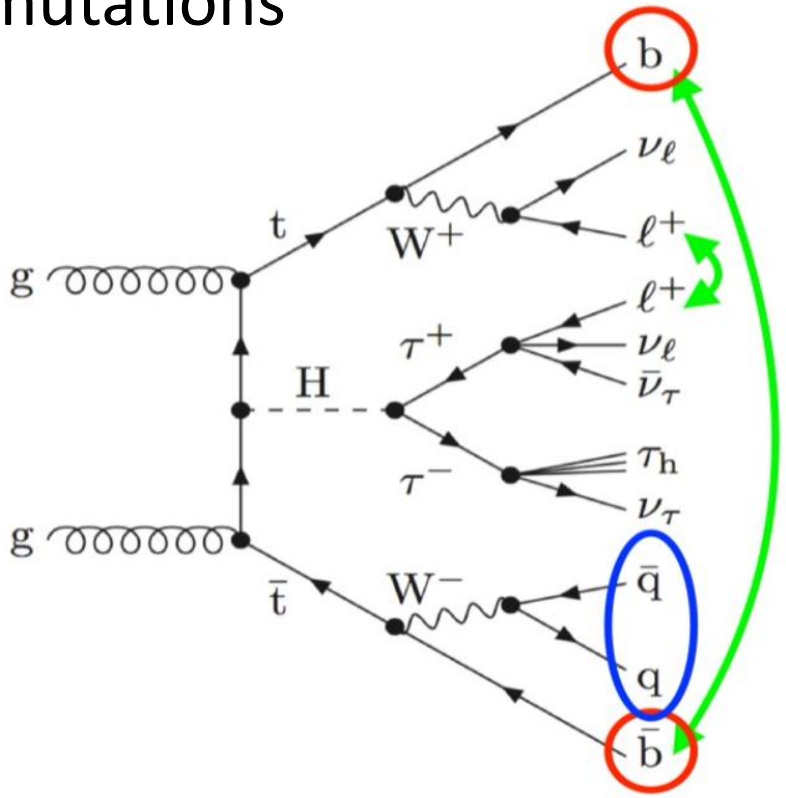
MEM: time consuming computations

- Background





- Permutations

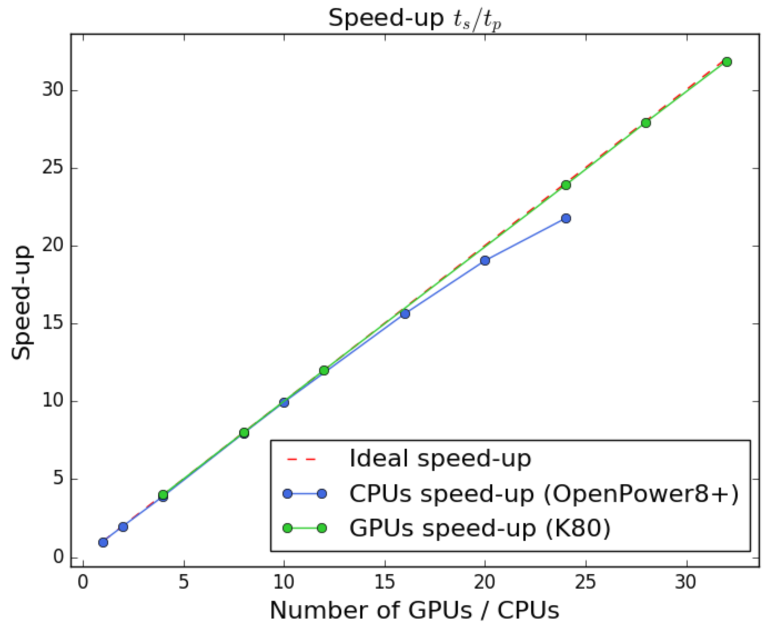


MPI MEM Code

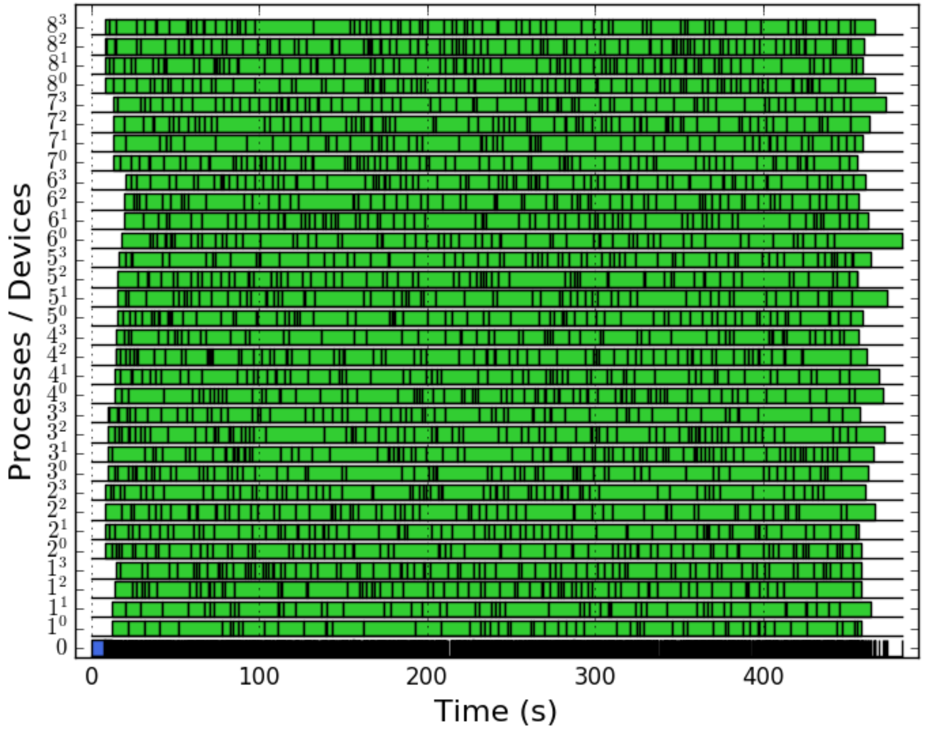
- Processing time for a typical data set (2395 ev.) 55 days (14 hours / 96 vcores)
- MEM code features: MPI/OpenCL/Cuda to aggregate numerous computing resources (HPC)
- Main kernel (one Vegas iteration)
  - MadGraph extension to generate the OCL/Cuda kernel codes
  - LHAPDF lib.: Fortran to C-kernel translation
  - ROOT tools: Lorentz/geometric arithmetic's
- →big kernels (10-20 x 10^3 lines)
- OpenCL/Cuda bridge

MEM code performance

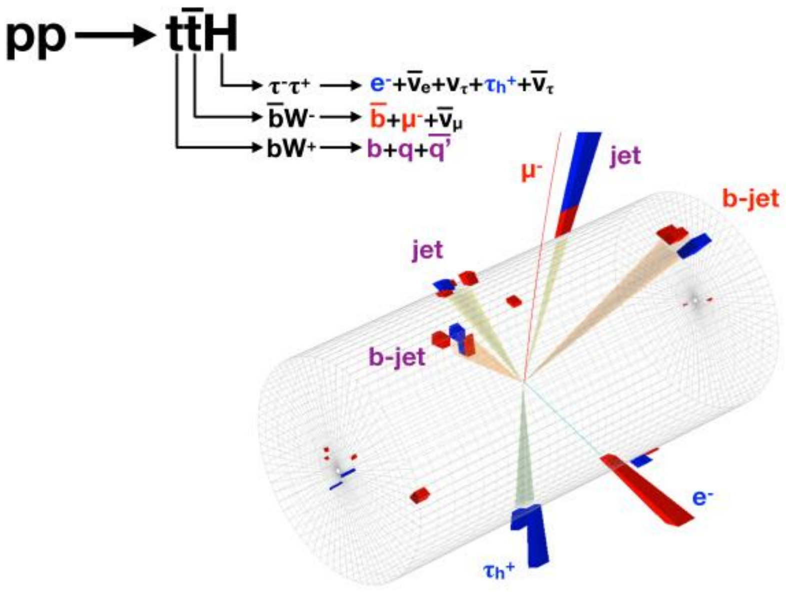
- MPI C++ version versus MPI / OpenCL/CUDA - compilation -O 3, nvcc
- 1 node @CC-IN2P3:
  - Intel Xeon 2 x E5-2640, 8 cores, 2.6 GHz
  - 2 NVidia K80 cards -> 4 Kepler GPUs
- Good scalability (MPI & kernels async. mechanisms ok)



- Data set with 2395 ev.:
  - 55 days on 1 core (or 3. 5 days on a node)
  - 450 sec. on 32 GPUs (8 nodes)



Conclusion / perspective



- Results (T. Strebler) who participated to the ttH discovery - April 2018.
- Gain:
  - Restitution time (several days against ~10 mn)
  - Computing efficiency (cost, power supply, cooling, …) 1 K80-GPUs is equivalent - for C++ MEM case - to ~20 nodes with 16 cores.
- Physic program:
  - New runs only on GPUs for (C. Perez) ttH(tautau) analysis
- New developments
  - If funded by ANR : one code for CPU and GPUs
  - Optimizations

Acknowledgments

- Funding project P2IO Accelerated Computing for Physics
- Tiers 1 CC-IN2P3 benchmarks
- Computing Center GENCI/IDRIS
- IN2P3 project: DECALOG/Reprises