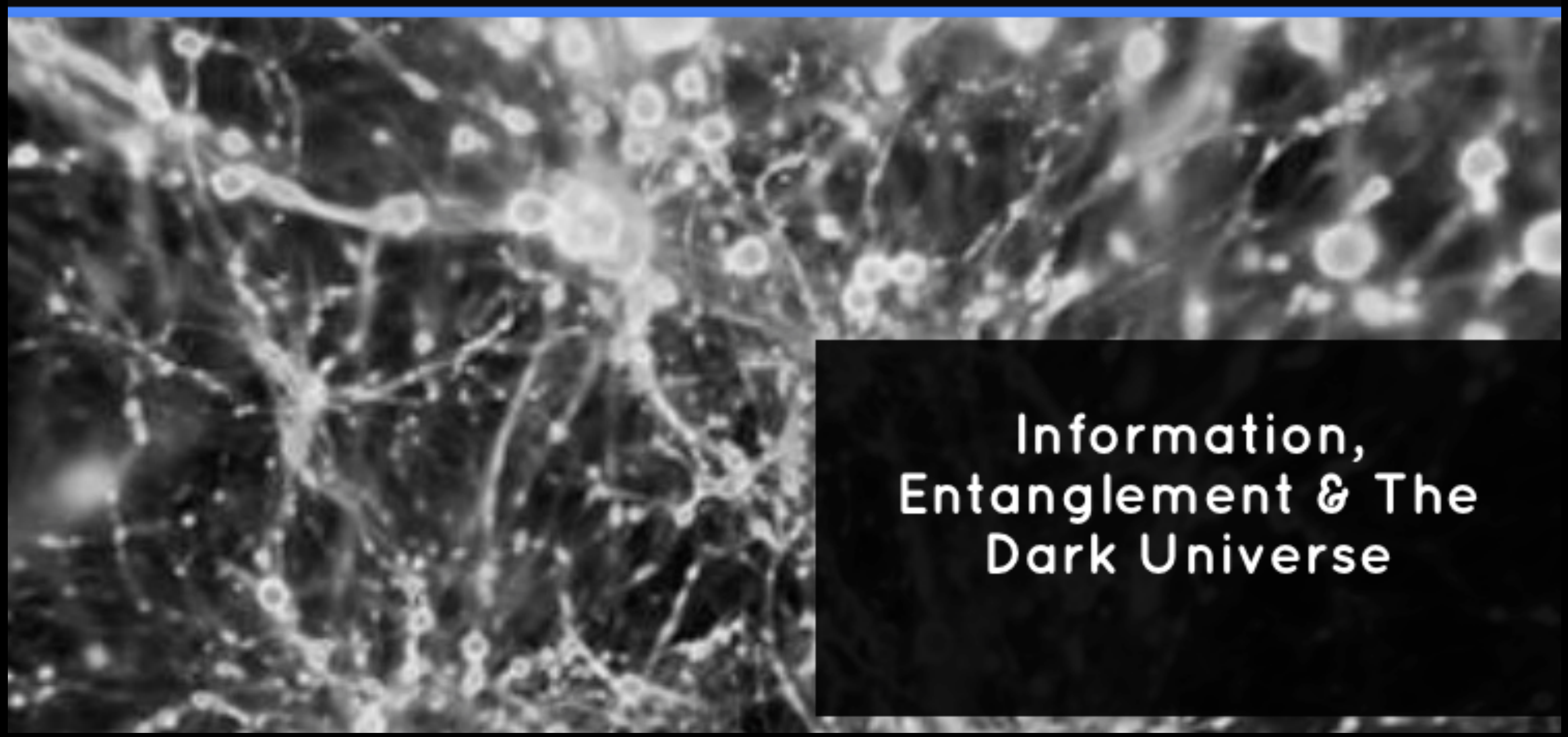
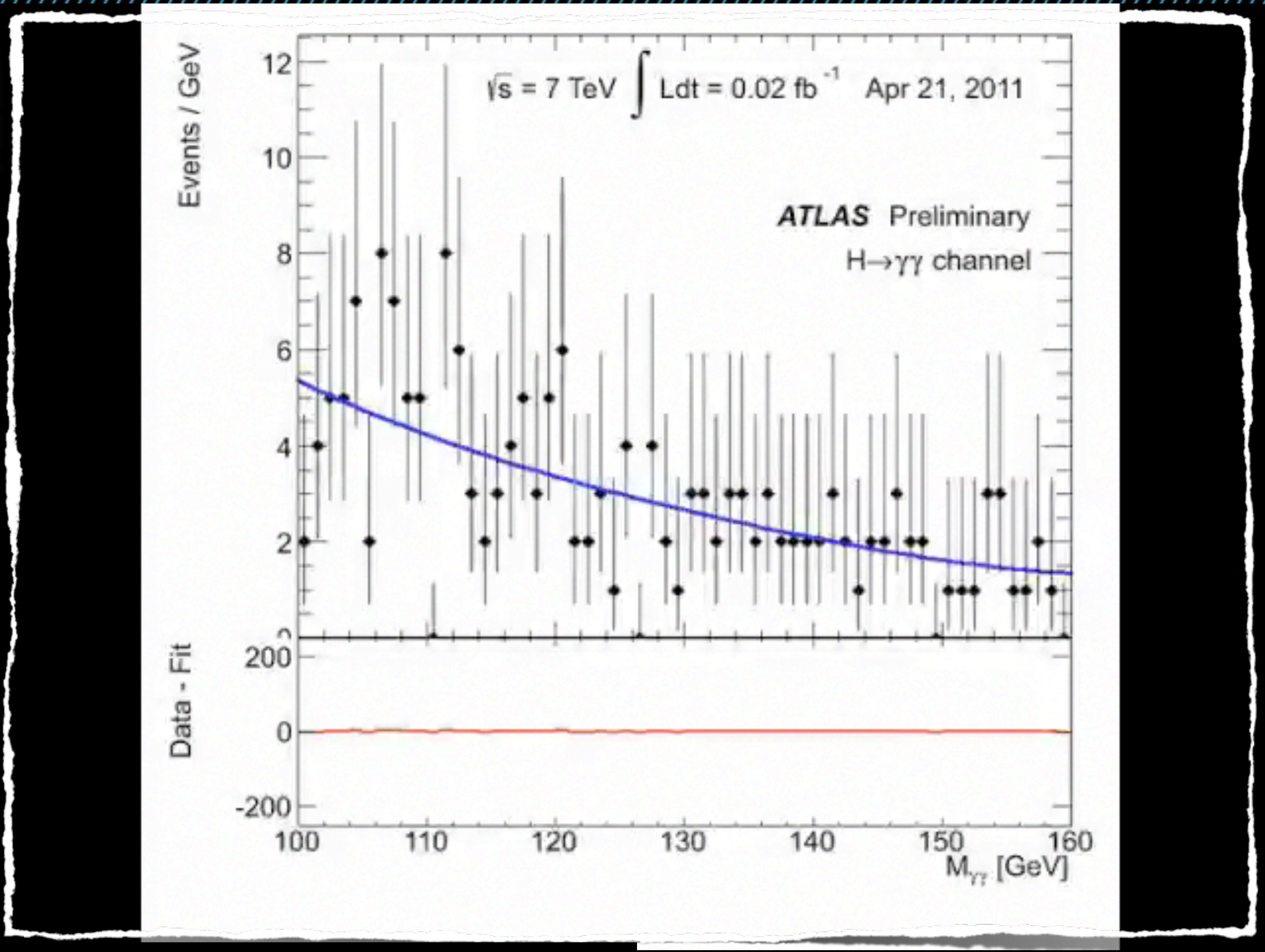
ASCR WORKSHOP ON QUANTUM COMPUTATION

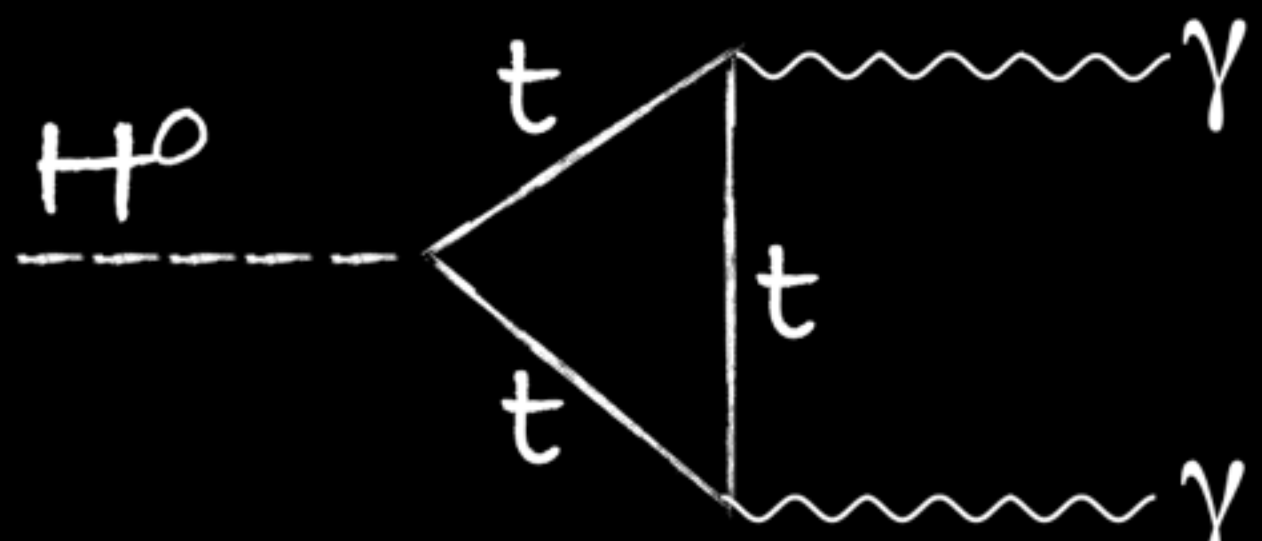


smaria@caltech.edu

EXAMPLE: HIGGS

- Very large Standard Model backgrounds, very small Higgs signal
- Need large, hight purity sample of higgs signal to measure the higgs properties
- Machine learning techniques to optimize significance of signal
- Result is expressed as a ROC curve





MOTIVATION

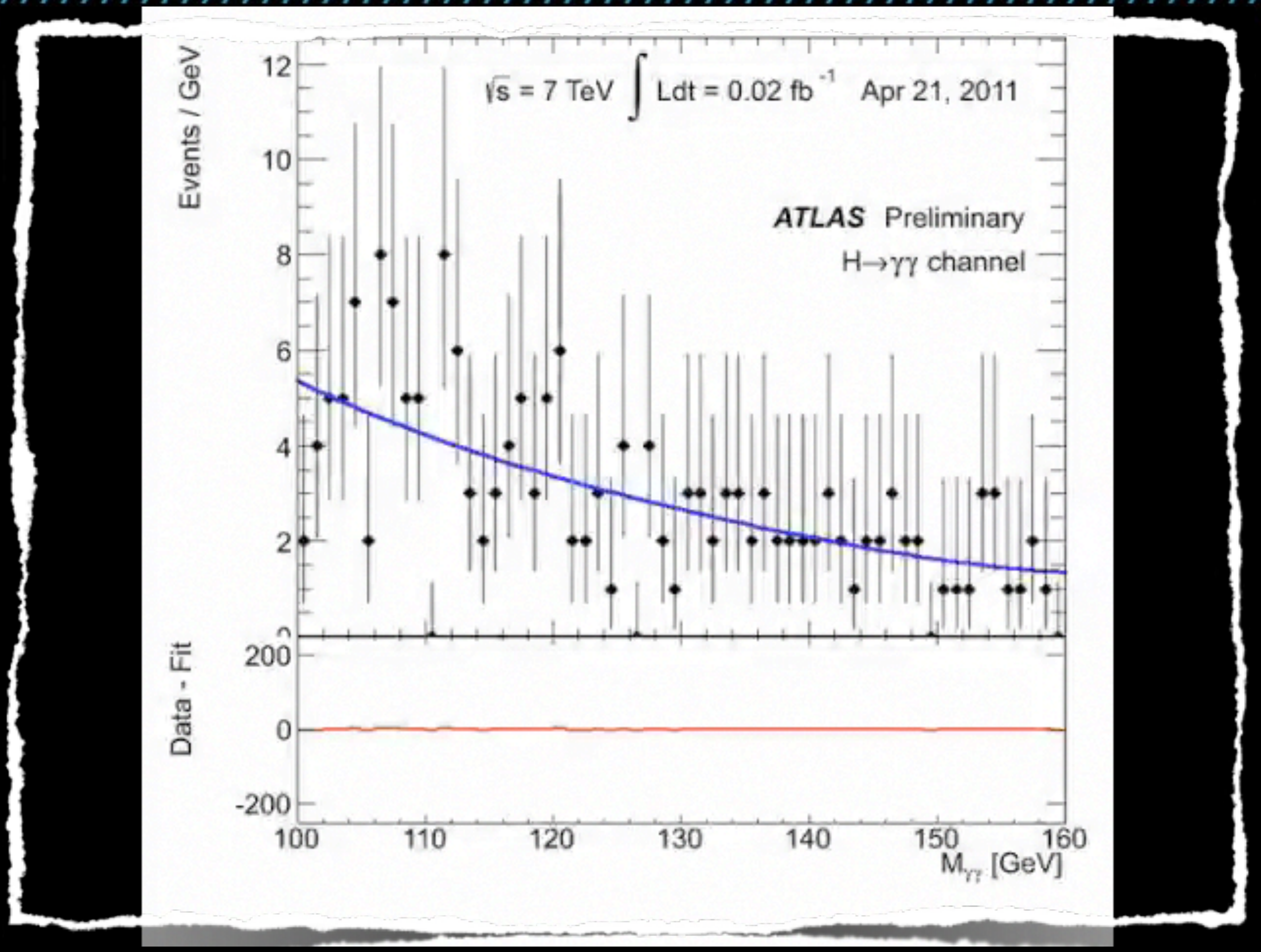
– This is a physics problem that we know the solution of both experimentally and theoretically.

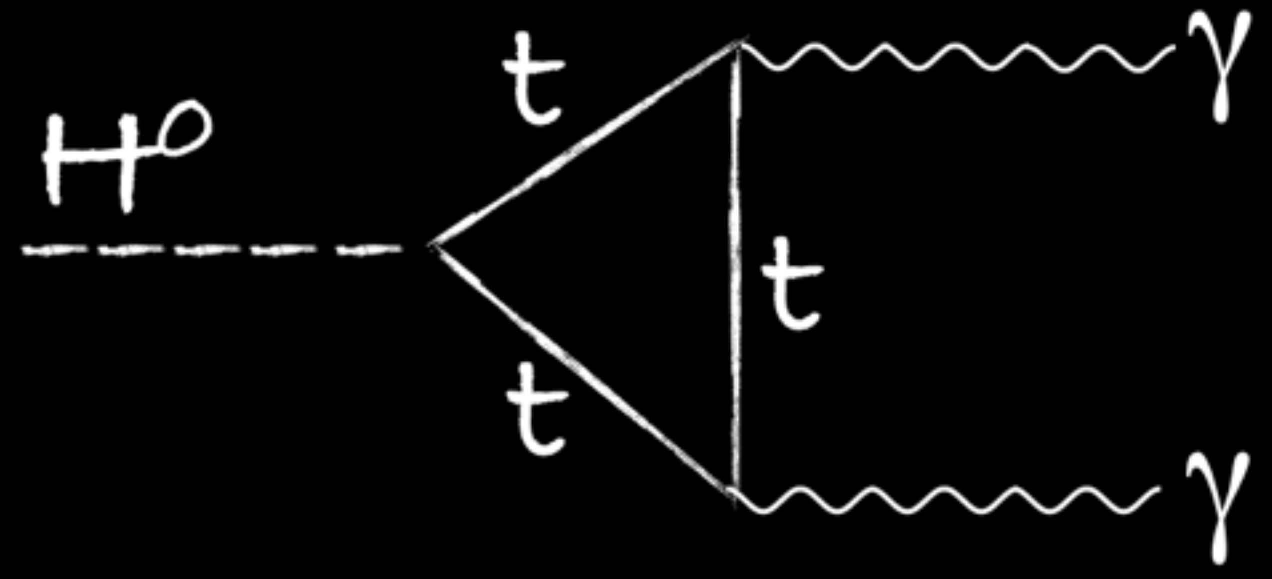
– We can scale the problem to be able to embed it in a quantum annealer with the number of qubits that are currently available.

– We can find optimal classifier configurations with the quantum annealer and given the smallness of the problem we can check the relative correctness of the results by evaluating all network configurations.

– We can explore added-value if the quantum implies a qualitative different set of solutions (including not only ground state but excited ones)

– We can investigate if correlations in the quantum annealer (intrinsic and with the environment) are giving us some extremum of systematics and we can calibrate by changing operation temperature and annealing time.





COLLABORATION

– Alex Mott-, Caltech PhD candidate, physics (hep)

– Josh Job, USC PhD candidate physics (quantum computation)

– Jean-Roch Vlimant, Caltech postdoc (entering now)

– Daniel Lidar, Scientific Director of the USC-Lockheed Martin QC Center, Director UC Center for Quantum Information and Technology

– MS, Caltech

30 under 30: Searching for the Higgs Boson

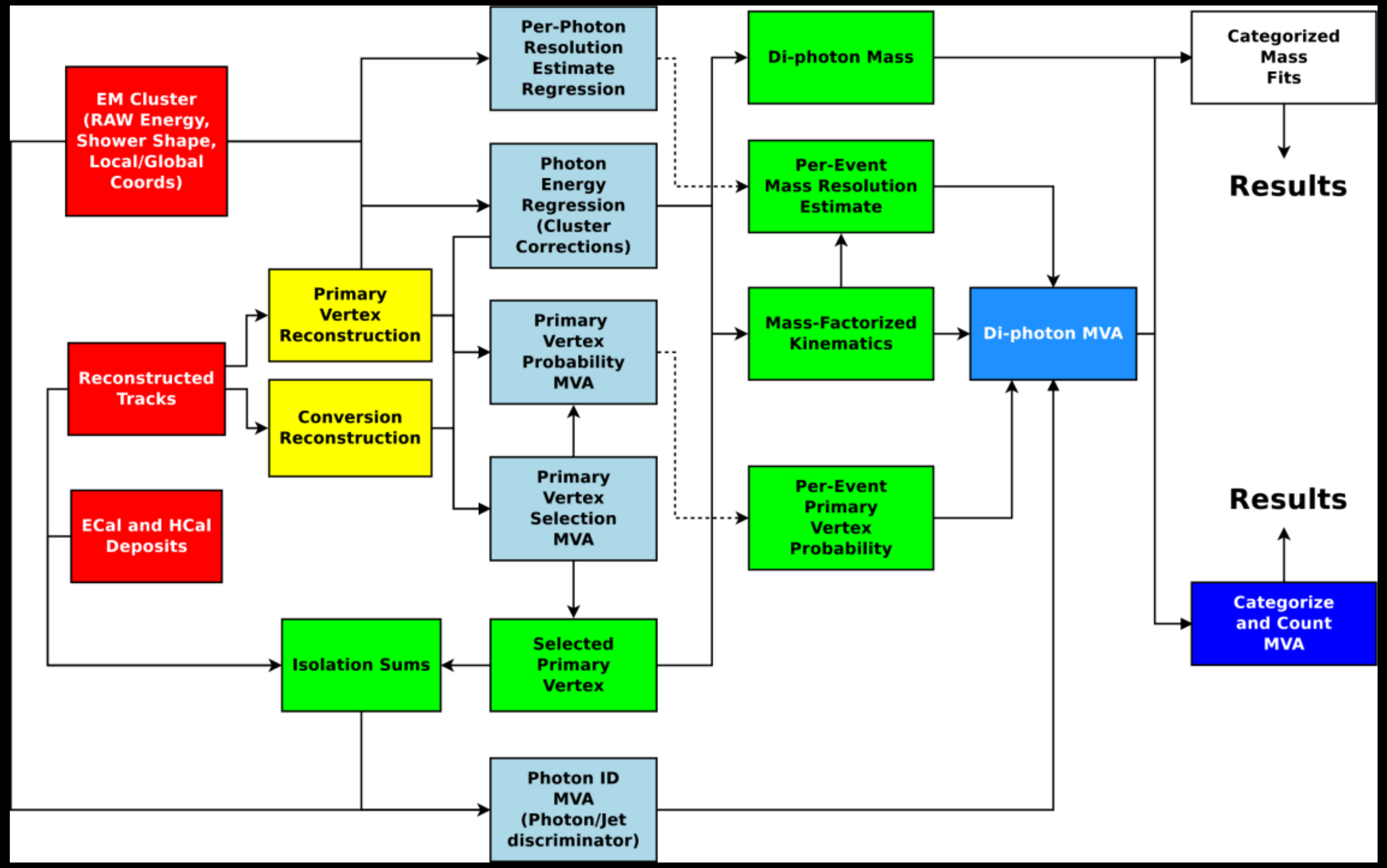
Meet Alexander Mott, 24, one of the up-and-coming physicists attending this year's Lindau Nobel Laureate Meeting

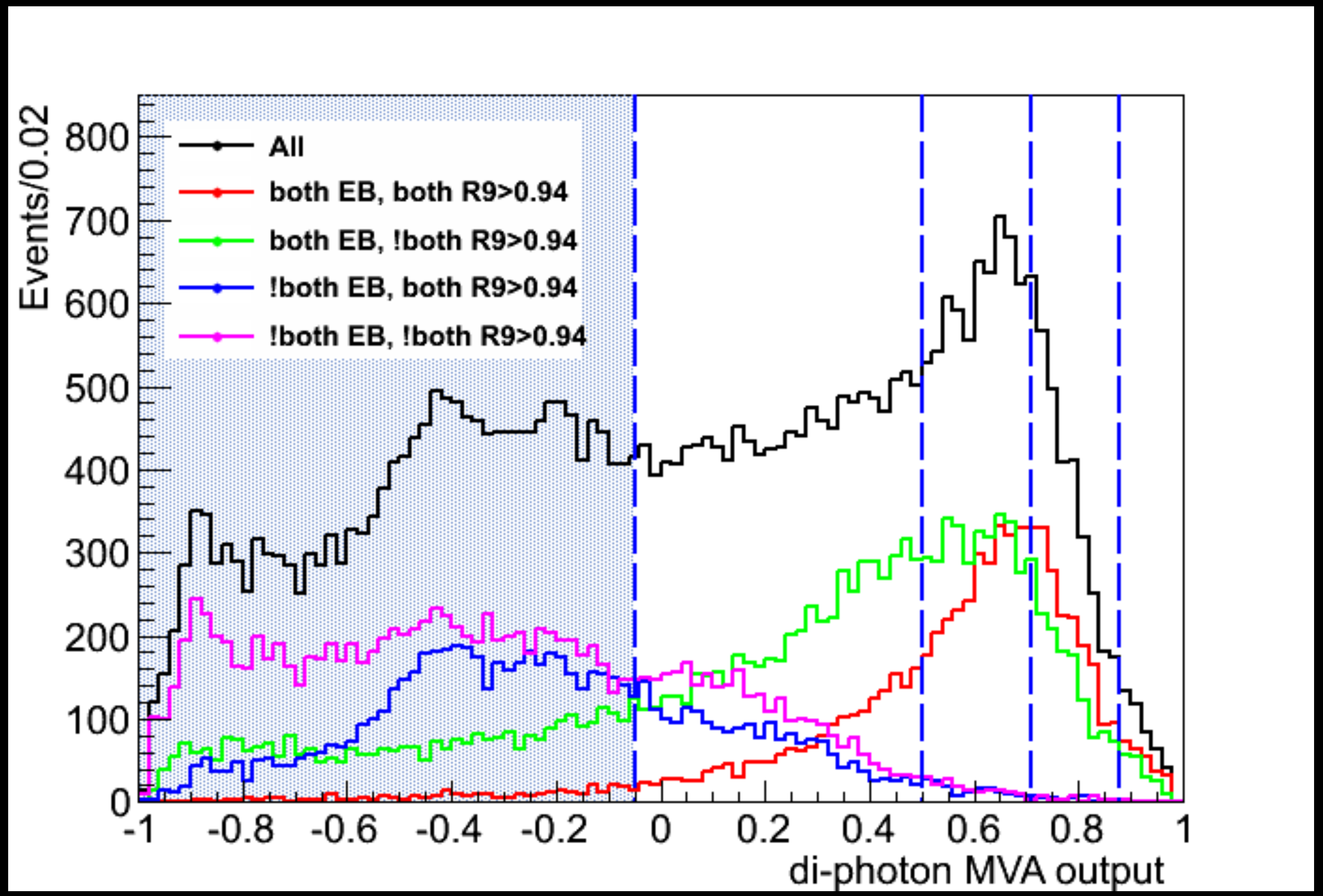
Jun 27, 2012

The annual Lindau Nobel Laureate Meeting brings a wealth of scientific minds to the shores of Germany's Lake Constance. Every summer at Lindau, dozens of Nobel Prize winners exchange ideas with hundreds of young researchers from around the world. Whereas the Nobelists are the marquee names, the younger contingent is an accomplished group in its own right. In advance of this year's meeting, which focuses on physics, we are profiling several promising attendees under the age of 30. The profile below is the 25th in a series of 30.

MVAs

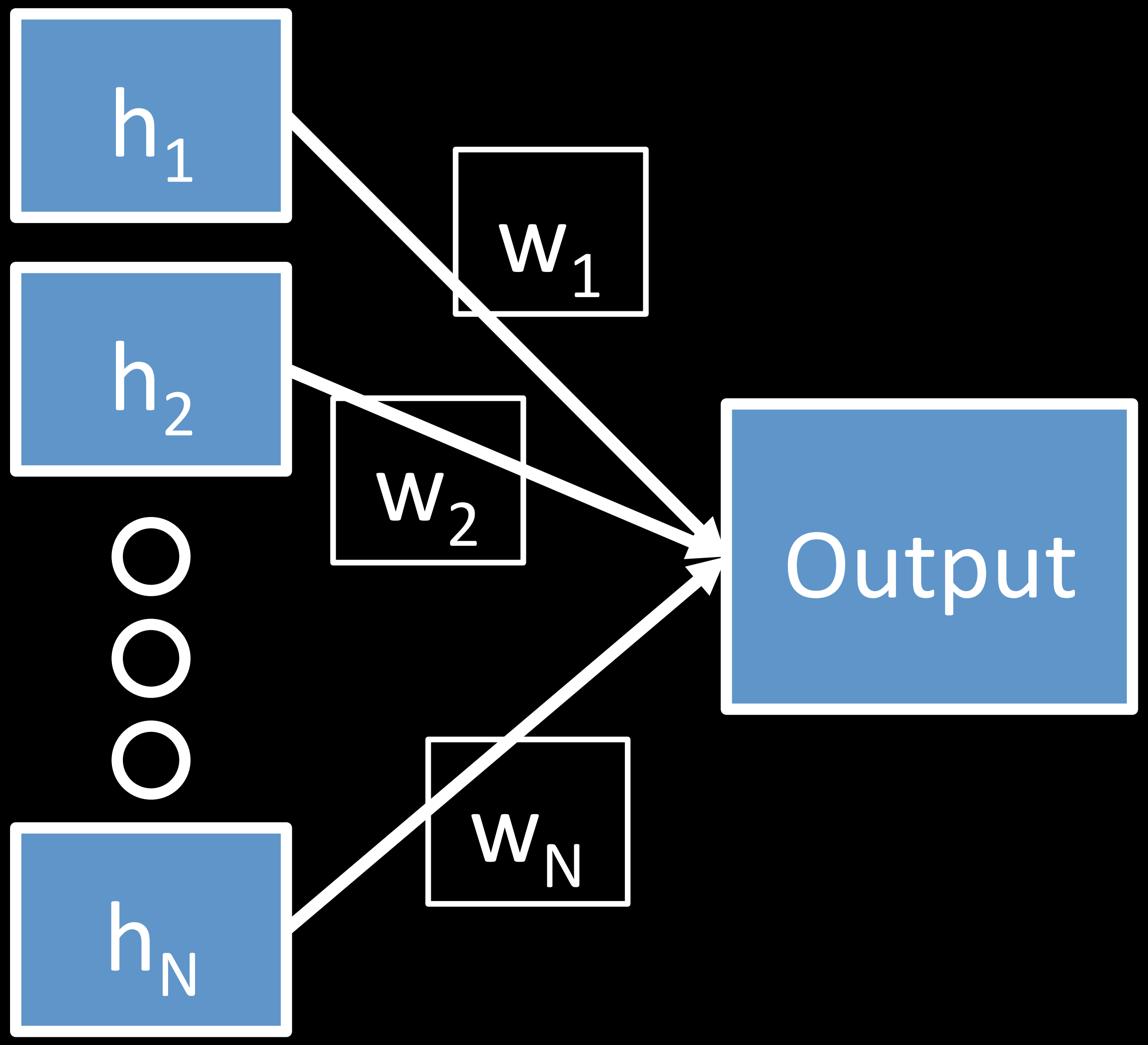
- State of the art at the LHC : MVAs
  - The H(γγ) uses 6 BDTs (outputs feed into each other)
- Single classifier
- Complexity challenges
  - adapt to changing conditions
  - understand systematic errors
  - interprete deviations





LINEAR CLASSIFIER

- Use various kinematic properties of the event
  - photon momenta, positions, correlations
- Design Classification Network
- Map this network to a Quadratic Binary Optimization problem (QUBO)
  - the minimum energy solution of the QUBO corresponds the network that minimizes training error



$$O(x) \equiv \sum_{i=1}^{N} w_i h_i(x)$$

O(x) > 0: signal (H→γγ)
O(x) < 0: background

$$\delta(\vec{w}) \propto \sum_{i=1}^{N} \sum_{j=1}^{N} C_{ij} w_i w_j + \sum_{i=1}^{N} (\lambda - 2C_{iy}) w_i$$

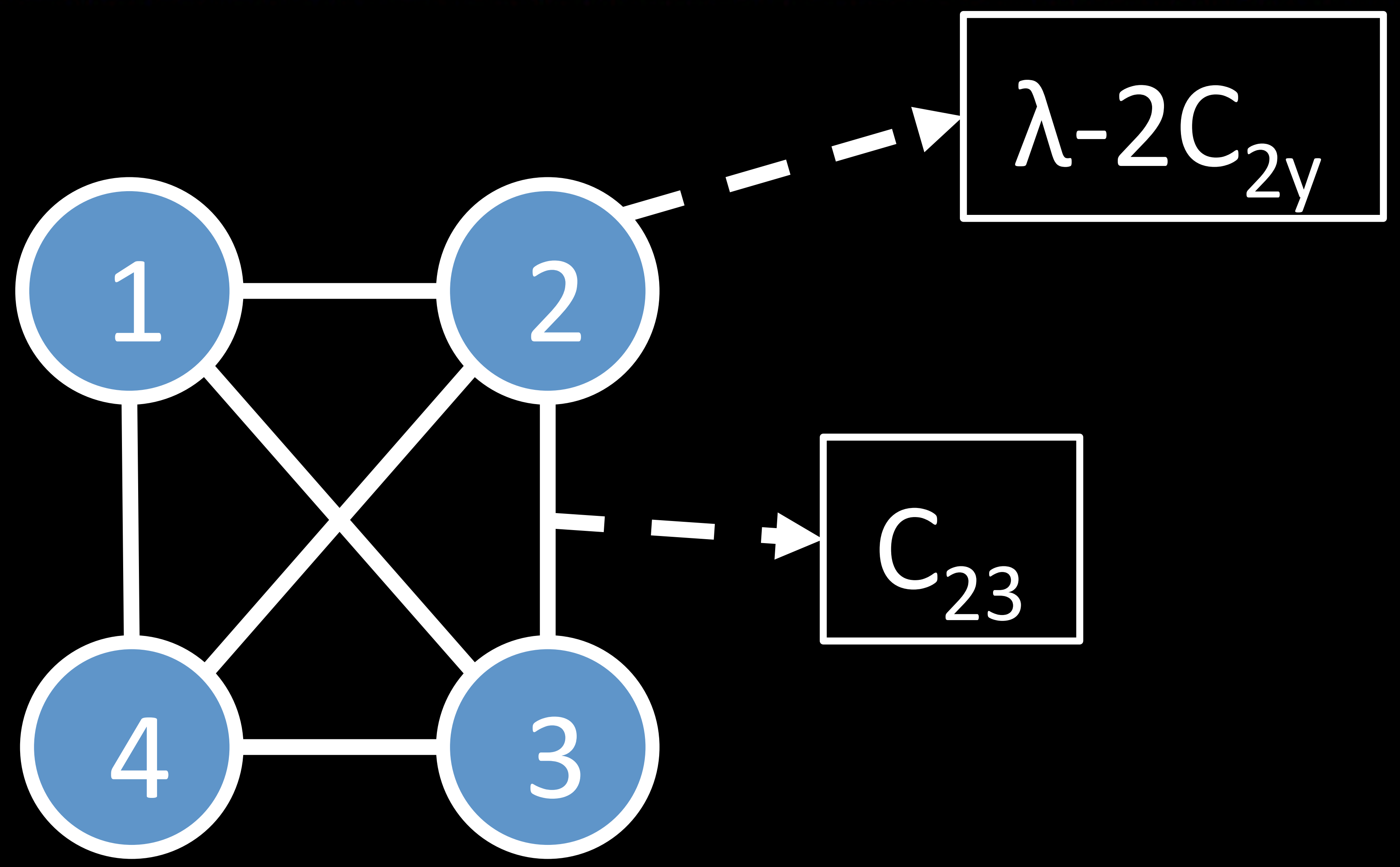
K. Pudenz, D. Lidar. “Quantum Adiabatic Machine Learning”. Quant. Inf. Proc. **12** 5 (2013) 2027-2070

NEXT : CONVERT QUBO TO HAMILTONIAN

QUBO TO HAMILTONIAN

$$\delta(\vec{w}) \propto \sum_{i=1}^{N}\sum_{j=1}^{N} C_{ij} w_i w_j + \sum_{i=1}^{N} (\lambda - 2C_{iy}) w_i$$

- Each qubit is a spin
- Local magnetic field (λ-2Ciy)
  - spin misalignment penalty
- Coupling field Cij
  - neighbor spin misalignment penalty



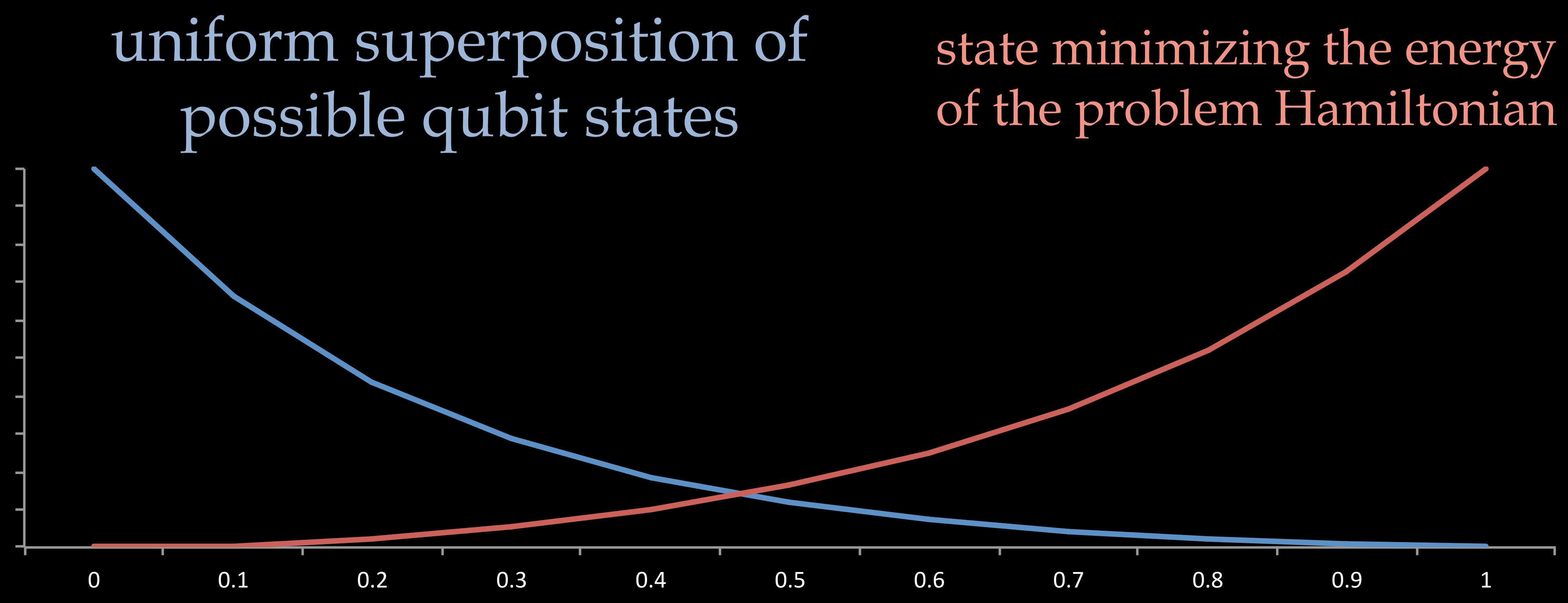
Each qubit (node) is a weak classifier (input variable)

w(0,1) → s(-1, +1)

ADIABATIC QUANTUM ANNEALING/OPTIMIZATION

Start from setup Hamiltonian H(0), easy to construct ground state (large transverse magnetic field)

Turn on our problem Hamiltonian H_P while turning off slowly and smoothly the setup Hamiltonian



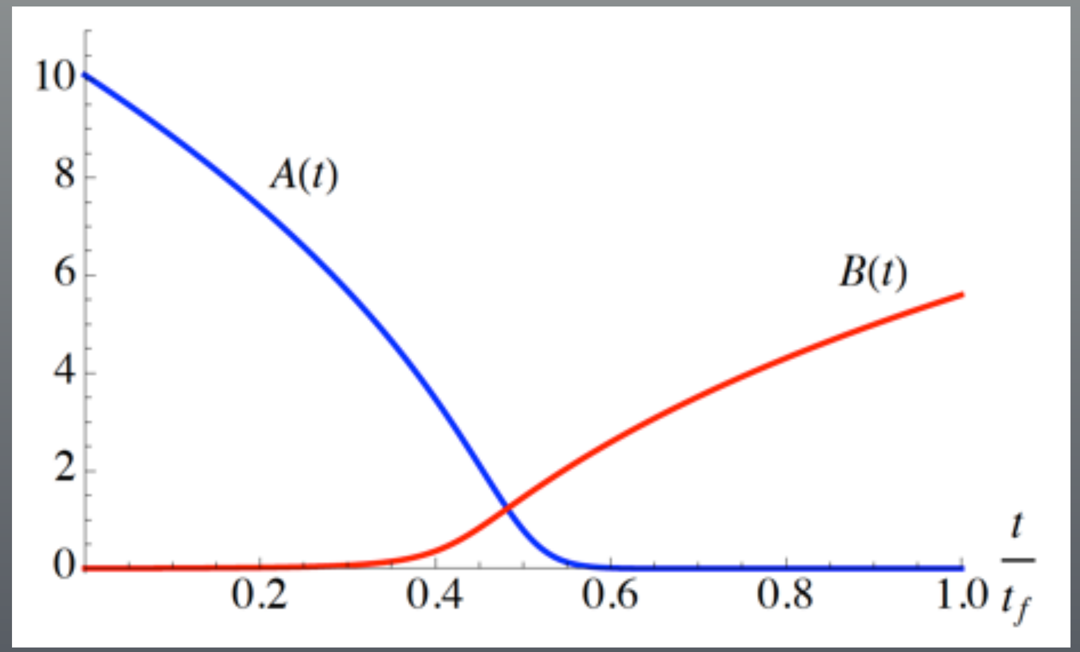
$$H(t) = A(t)H(0) + B(t)H_P$$

ARRIVE IN GROUND STATE OF HP , I.E. SOLUTION OF QUBO PROBLEM

$$E(\vec{s}) = \sum_i h_i s_i + \sum_{ij} J_{ij} s_i s_j \quad , \quad s_i \in \{-1, +1\}$$

$$H_{\text{Ising}} = \sum_i h_i \sigma_i^z + \sum_{ij} J_{ij} \sigma_i^z \sigma_j^z$$

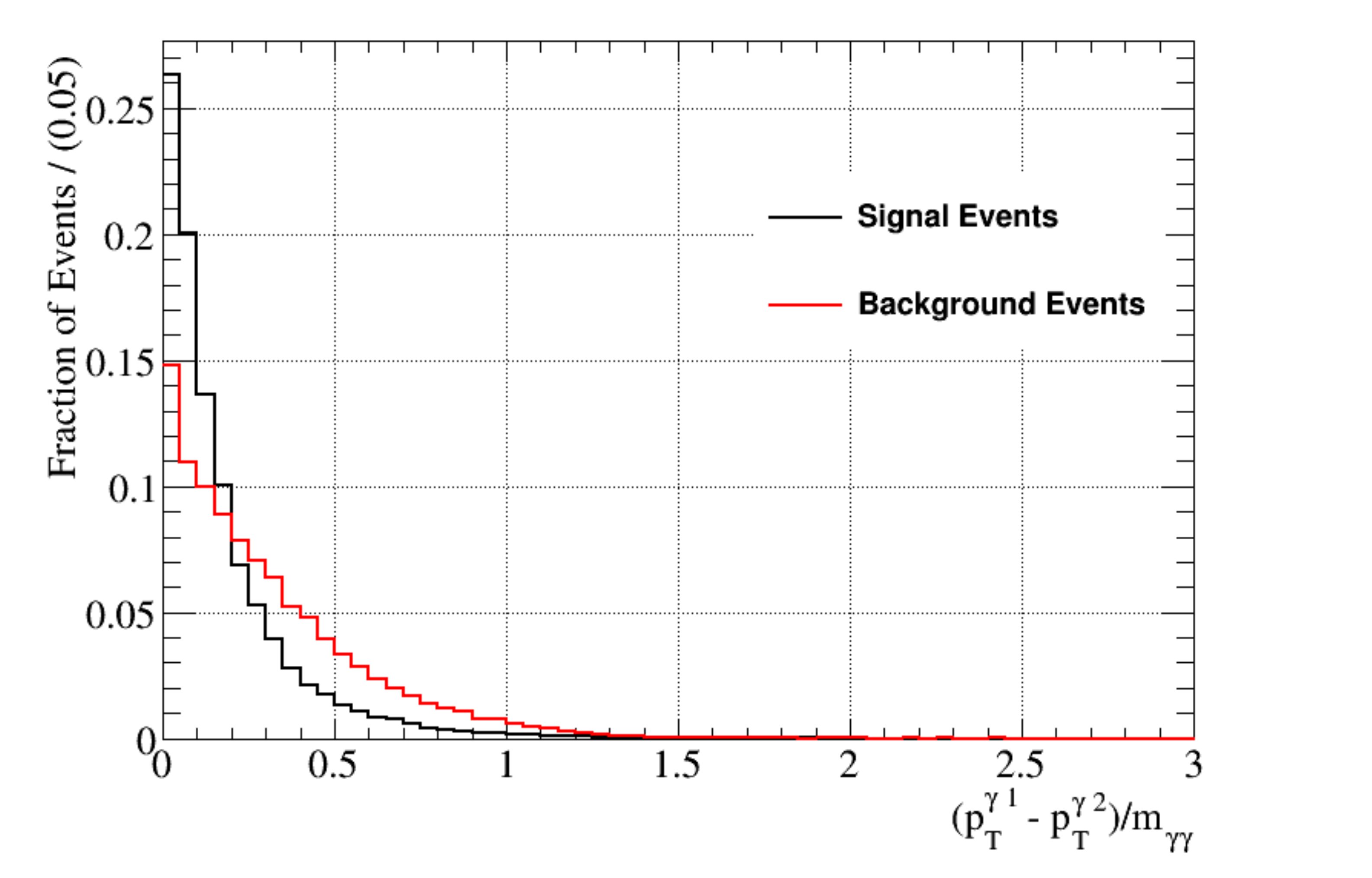
$$H(t) = A(t) \sum_j \sigma_j^x + B(t) H_{\text{Ising}} \quad , \quad t \in [0, t_f]$$

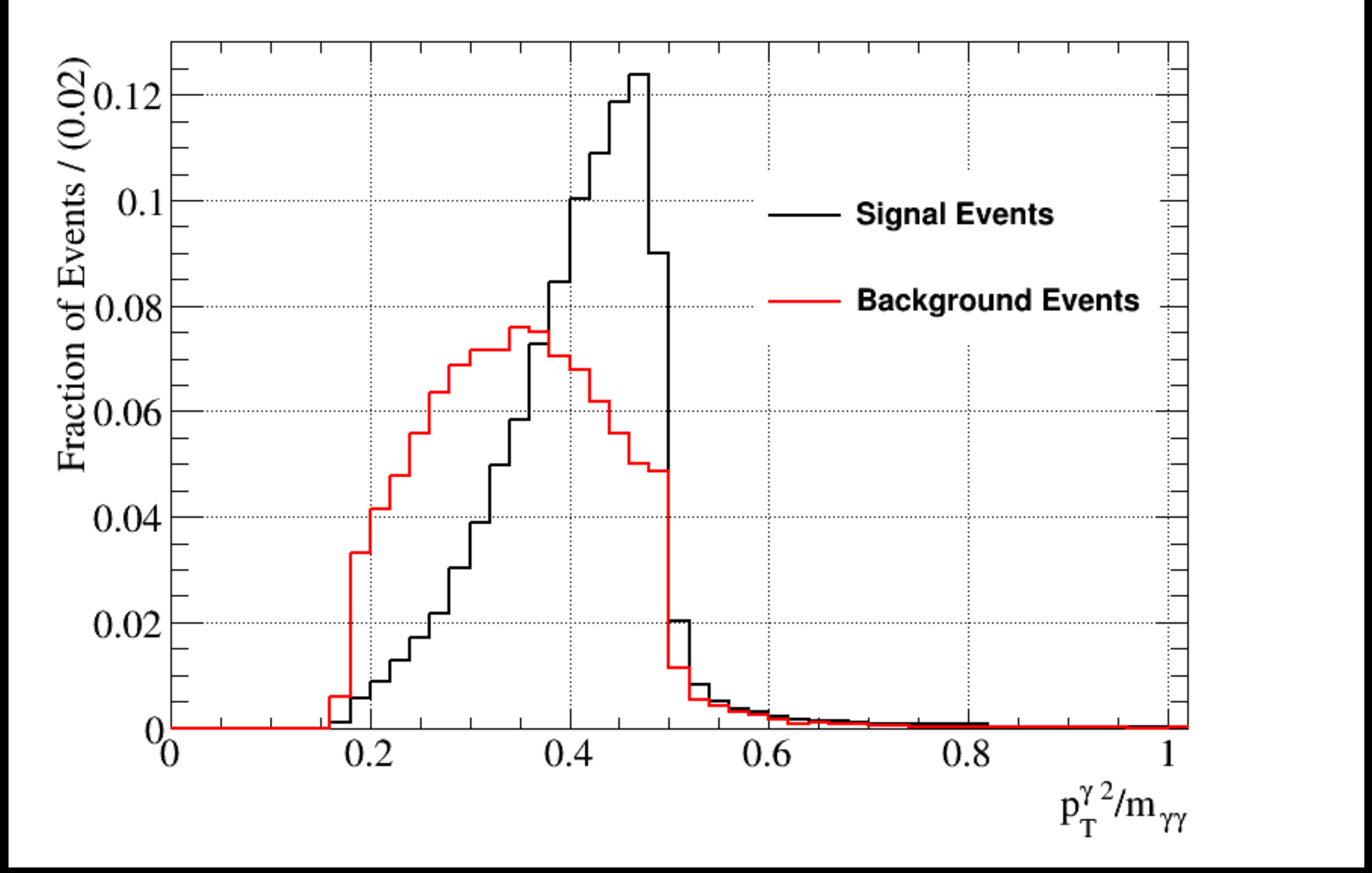


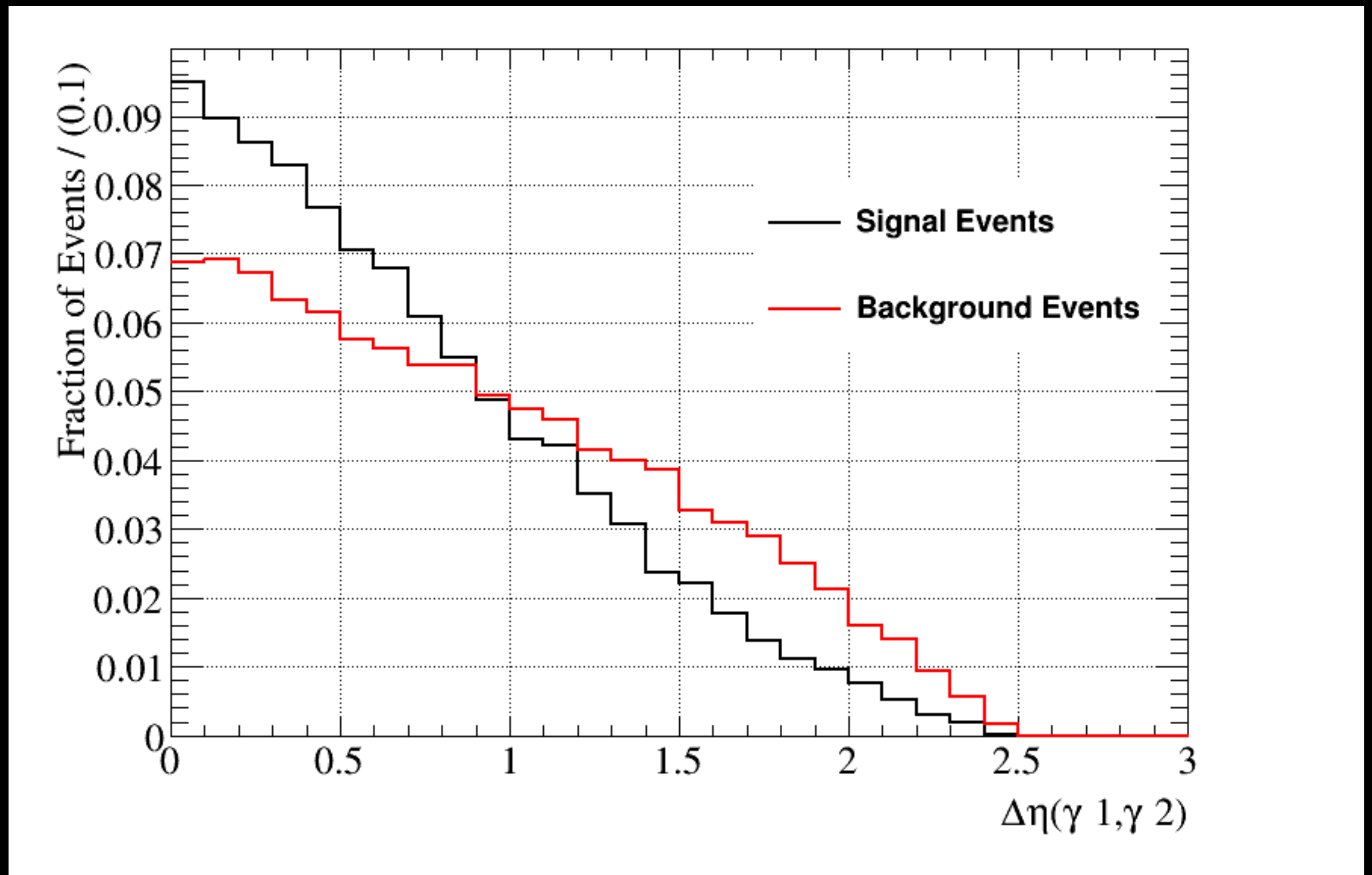
February 17 2015, ASCR Workshop on QC Maria Spiropulu

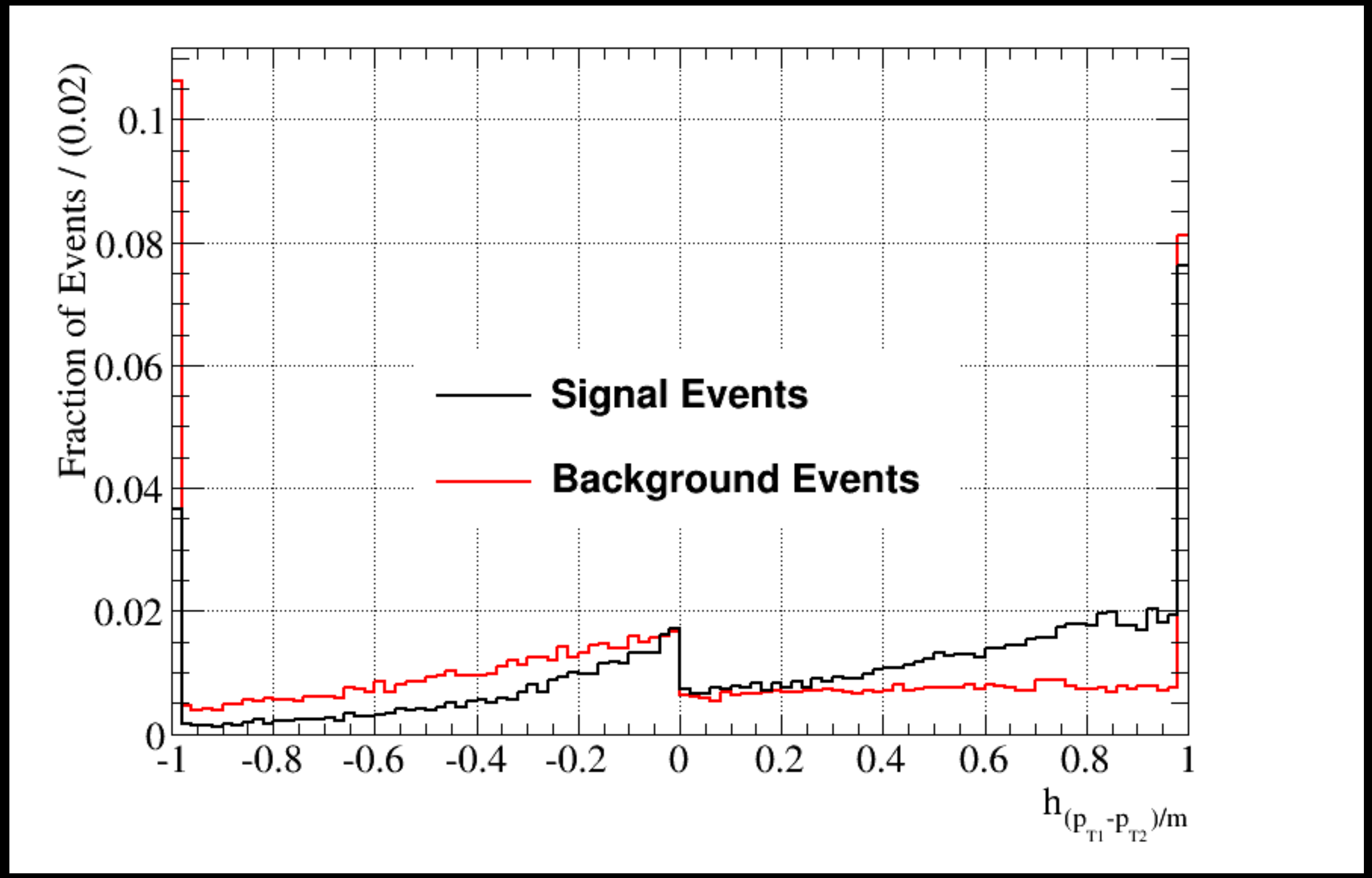
Farhi *et al.* DOI: 10.1126/science.1057726

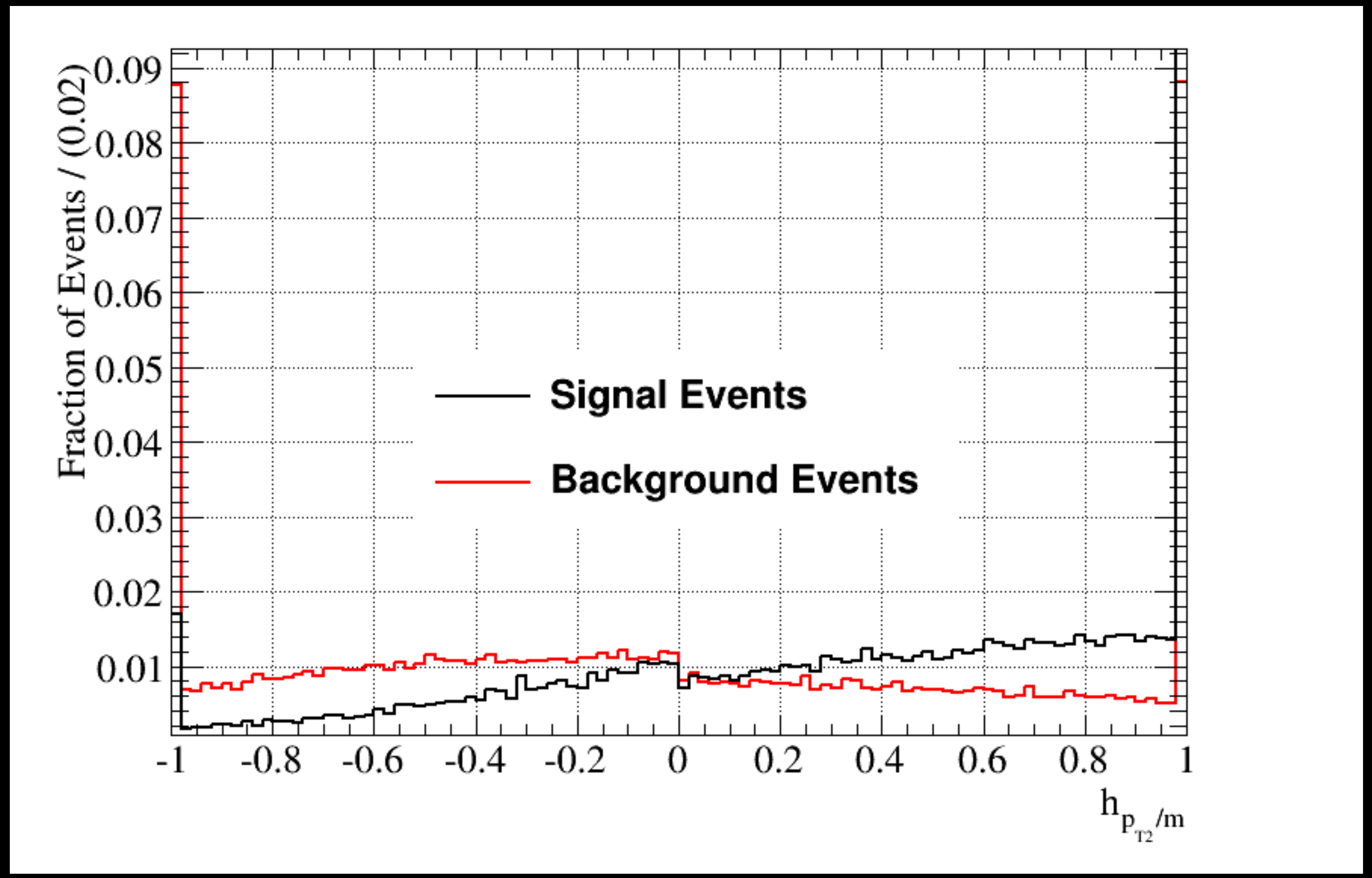
KINEMATICS TO WEAK CLASSIFIERS

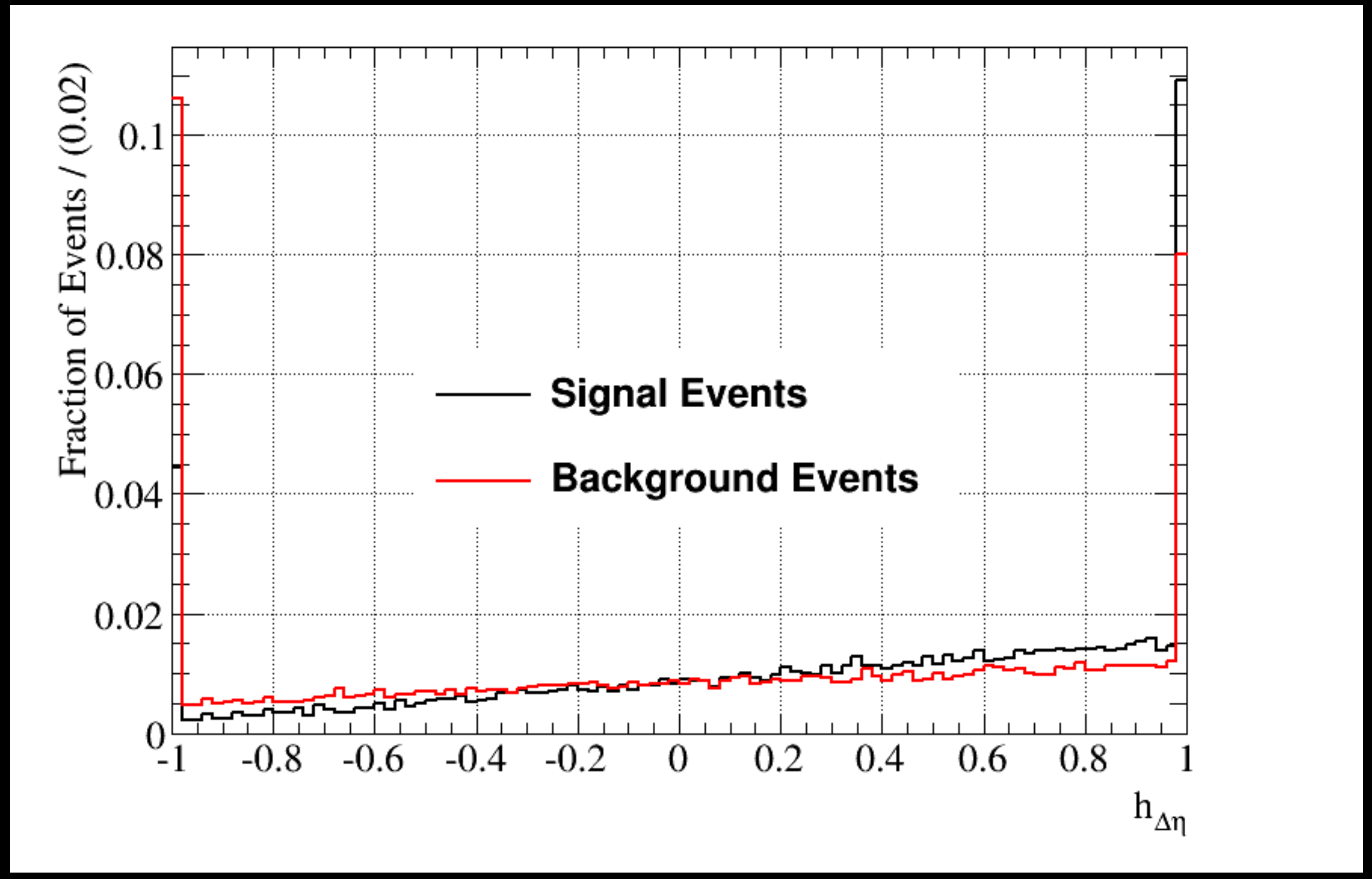












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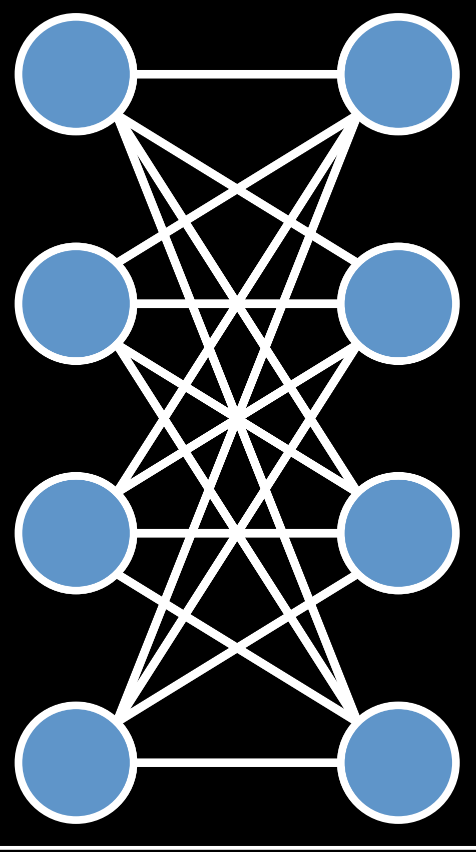
MAP & RUN ON DWAVE 2™

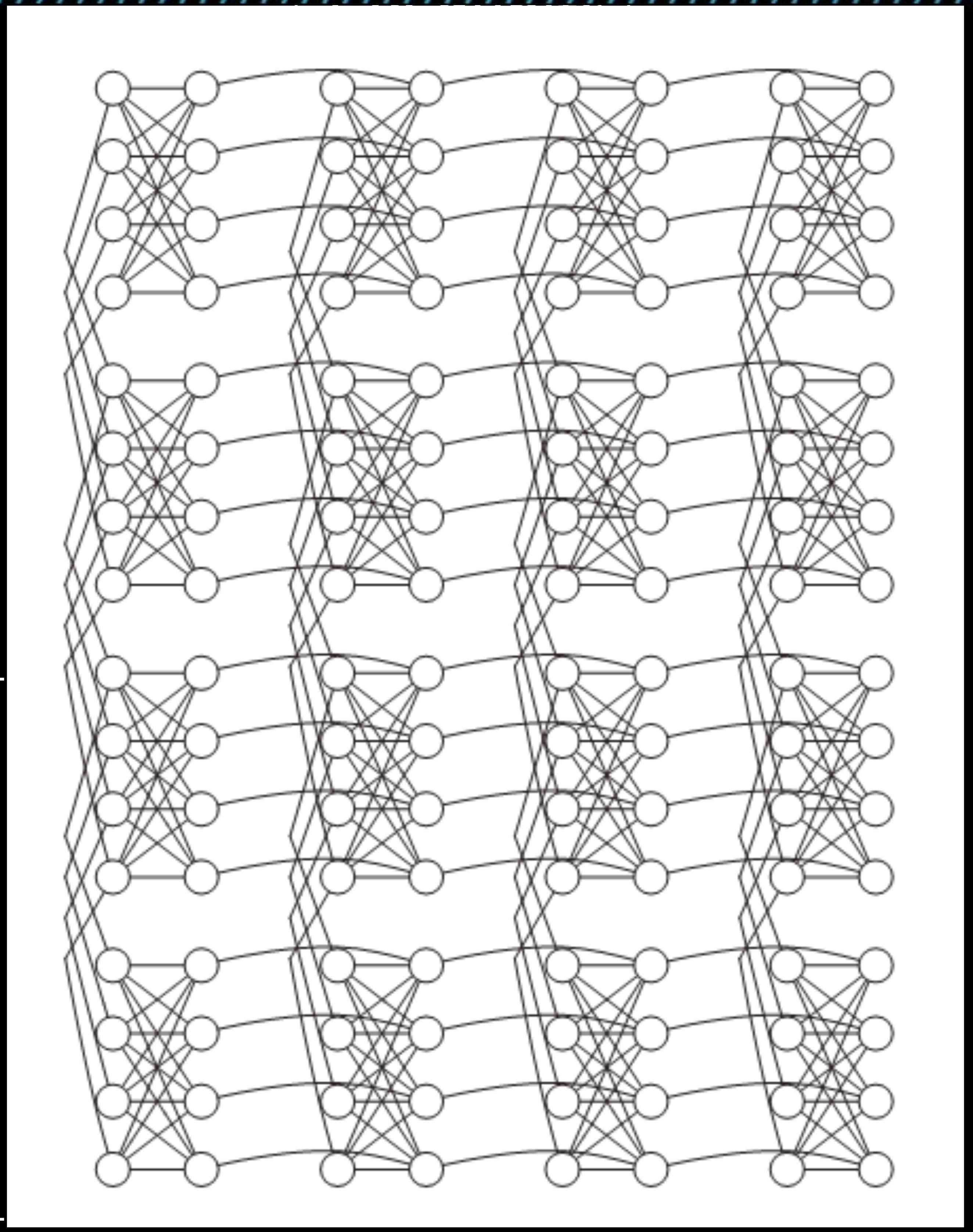
- System has 512 qubits
  - graph is not fully connected
  - each qubit connects to 5-6 neighbors
  - embedding goes as

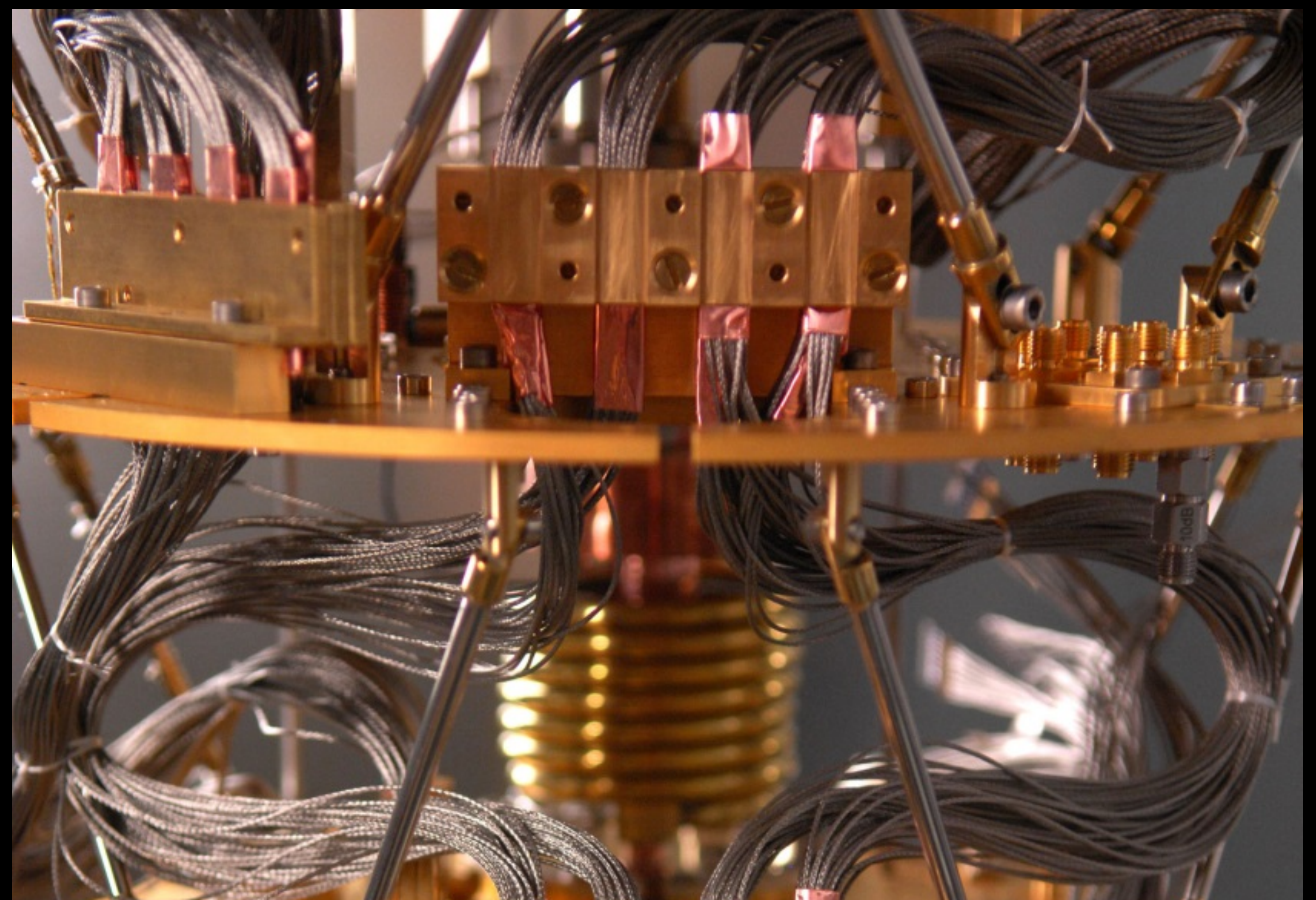
$$\sqrt{\#\ \text{of Physical qubits}}$$

- qubit=pair of SC Josephson junctions
- apply local magnetic field and neighbor coupling fields
- computation runs at 20 mK, each run 20 μs
- results are statistical in nature



- $K_{4,4}$ is the basic sub-unit
- These units are connected together in a specific way as shown





MAP & RUN ON DWAVE 2™

– Trained a classifier to select higgs events and compare with machine learning techiques (comparison/closure/validation/benchmarking).

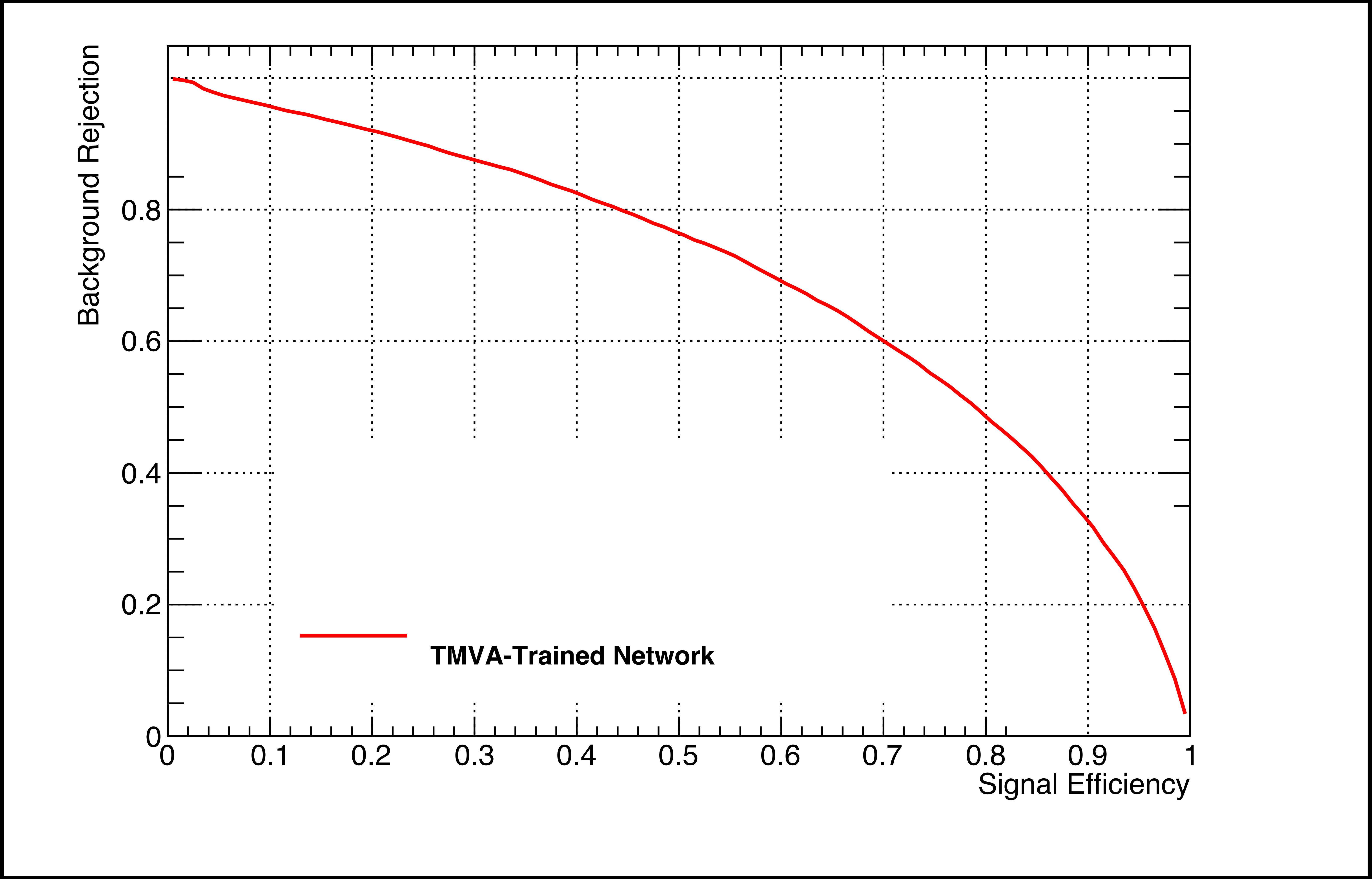
– Measured the power using ROC curves (with ground and excited states).

– Measure the success probability as a function of the problem size.

– Different input variable survey.

– Dynamic pruning/marginalization of low weight variables.

RESULT MAP & RUN ON DWAVE 2™



Not showing the DW result (will be out soon in paper)

OPPORTUNITY AND IMPOSSIBILITIES

Opportunity is missed by most people because it is dressed in overalls and looks like work.

Thomas A. Edison

People who say it cannot be done should not interrupt those who are doing it.

GB Shaw