IPNL-PKU Collaboration on ttH at CMS

FCPPL - 22/05/2018, Marseille

Nicolas Chanon - IPNL, CNRS/IN2P3

IPNL-PKU collaboration

IPNL-PKU is former IPHC-PKU collaboration

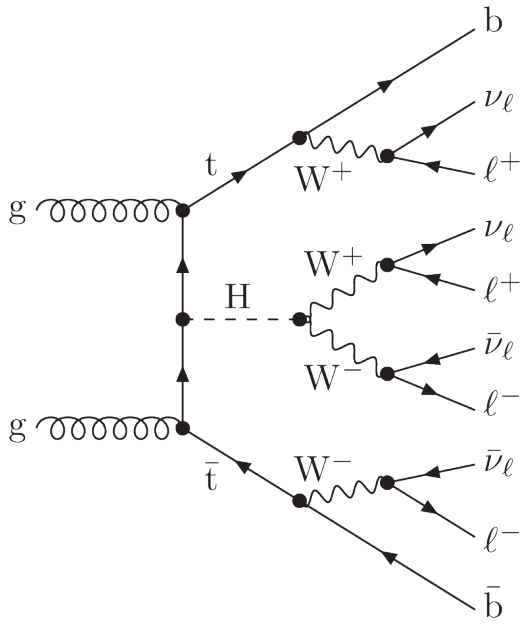
- The collaboration started in 2014, and was **formalised in 2015 within the FCPPL framework**
- **In 2016 and 2017: Ms. Jing Li visited IPHC for 3 months twice** (supported by FCPPL, IPHC, PKU)
- End of 2017 and **beginning of 2018, Junho Lee visited IPNL** 1 week twice, with support from FCPPL

Goals of the collaboration

- **New analysis techniques for CMS ttH multilepton analysis**
- Development of the **Matrix Element Method** (MEM)
- **Combination of MEM with multivariate techniques** (NN, BDT)
- Developments of new tools with **Deep Learning**

$t\bar{t}H$ multilepton

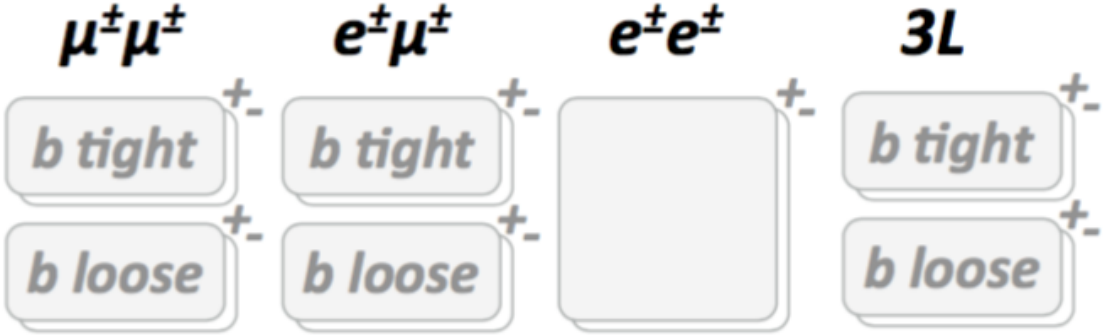
CMS HIG-17-004



Targeting final states with electrons and muons

- **2 same sign leptons:** ≥4 jets, ≥1 b-tag (same-sign required to reduce Drell-Yan and ttZ)
- **3 leptons:** ≥2 jets, ≥1 b-tag
- **4 leptons:** same as 3 leptons, veto H→4ℓ (dedicated H→ZZ)
- Veto presence of τ_h (dedicated H→$\tau\tau$ analysis, see later)

Analysis categories:

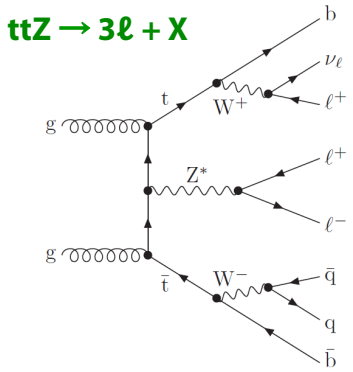


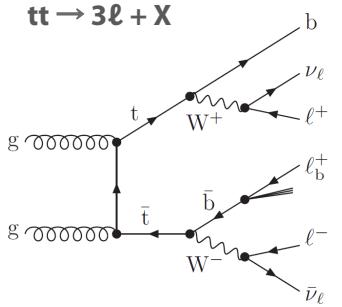
Analysis sensitivity:

- 2ℓss and 3ℓ categories: Train **2 kinematic BDTs, against ttbar and ttW/Z**
- Map 2D BDTs into 1D discriminant (group into bins with similar s/b)

$t\bar{t}H$ multilepton: backgrounds

CMS HIG-17-004

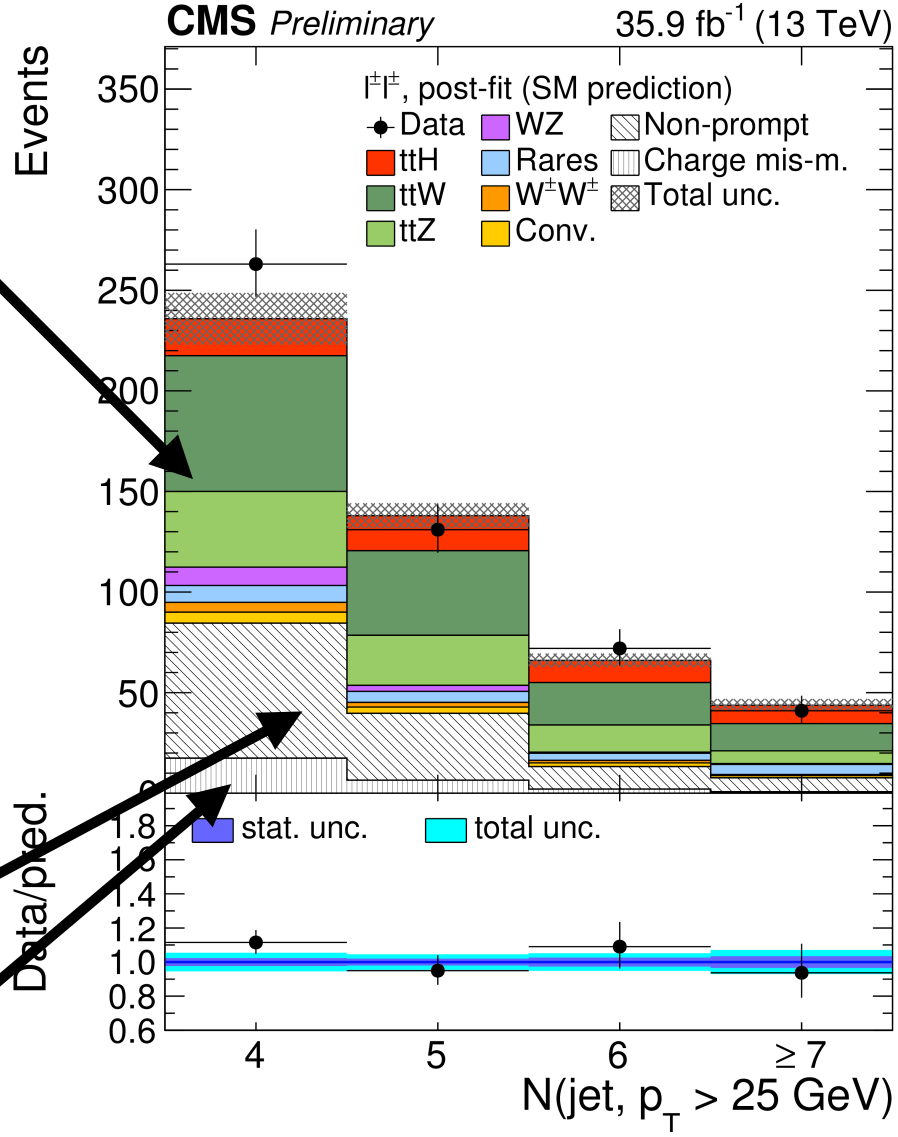




Irreducible: tt+W/Z/γ*
- from Monte Carlo,
- O(10%) uncertainty

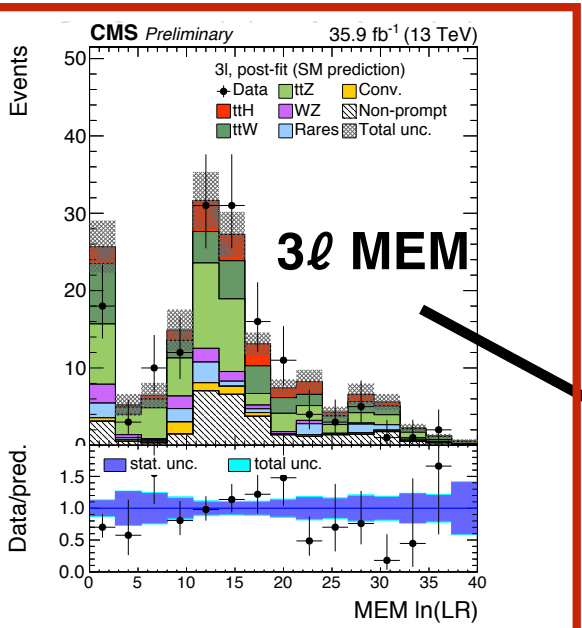
Reducible: mainly tt+jets,
- shape obtained from data,
- O(30%) uncertainty

- **Jets faking leptons:** fake rate computed from QCD control region with loosened identification
- **Charge mis-assignment** (2ℓss only)**:** flip rate from Z→ℓ±ℓ± data

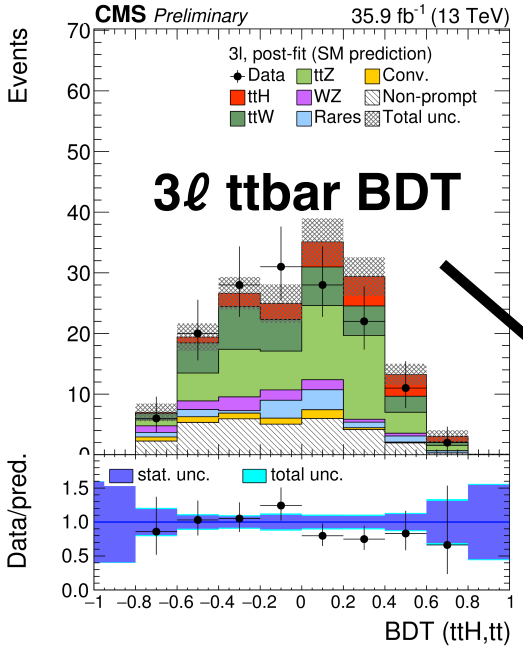


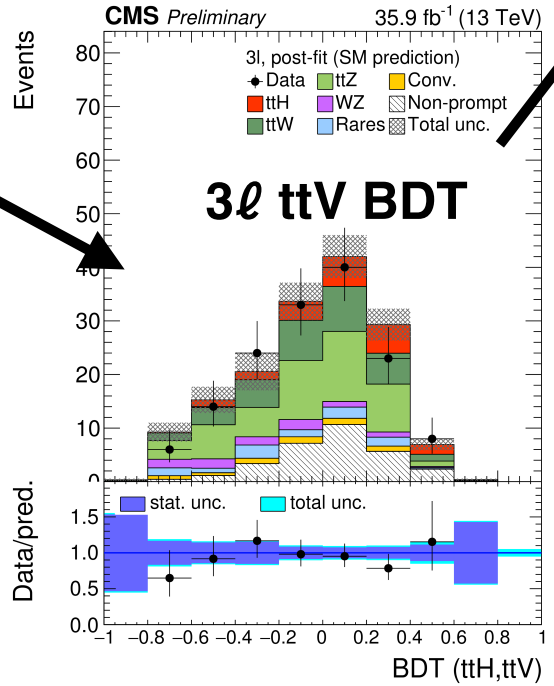
$t\bar{t}H$ multilepton discriminants

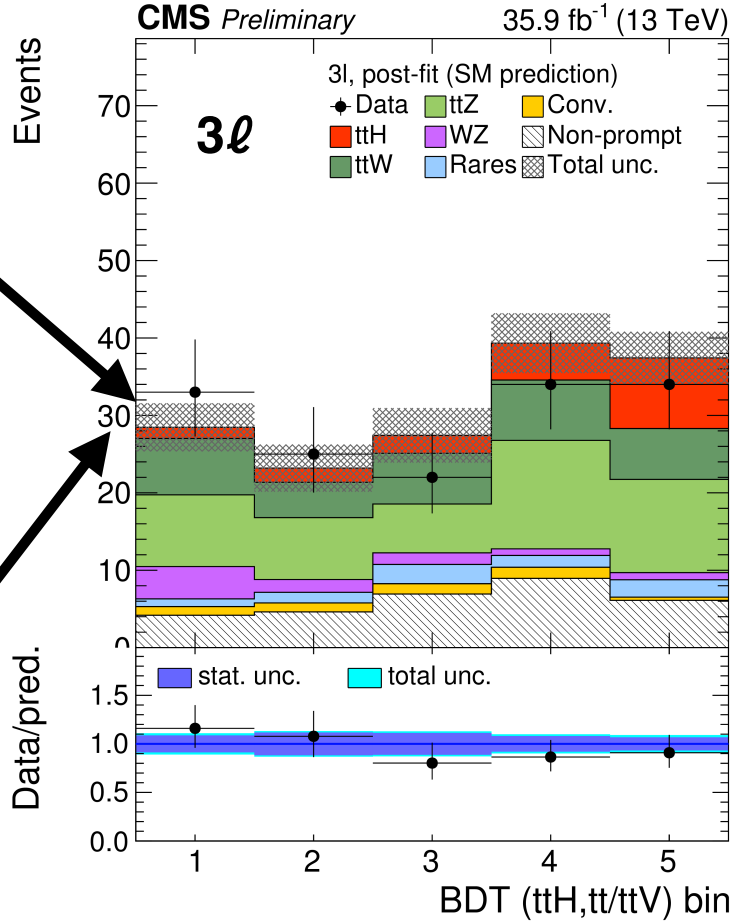
CMS HIG-17-004



- 3ℓ vs ttW/Z: Includes **Matrix Element Method** likelihood ratio of ttH vs ttW+ttZ







$t\bar{t}H$ multilepton : Matrix Element Method

Jing Li (PKU), NC

MEM weight

Integration with VEGAS

Matrix Element from Madgraph

$$w_{i,\alpha}(\Phi') = \frac{1}{\sigma_\alpha} \int d\Phi_\alpha \cdot \delta^4\left(p_1^\mu + p_2^\mu - \sum_{k\geq 2} p_k^\mu\right) \cdot \frac{f(x_1,\mu_F) f(x_2,\mu_F)}{x_1 x_2 s} \cdot \left|\mathcal{M}_\alpha(p_k^\mu)\right|^2 \cdot W(\Phi'|\Phi_\alpha)$$

Phase-space enforcing 4-momentum conservation

Parton distribution function from LHAPDF

Transfer functions from CMS simulation

Evaluate MEM weights under ttH, ttW, ttZ/γ* hypotheses:

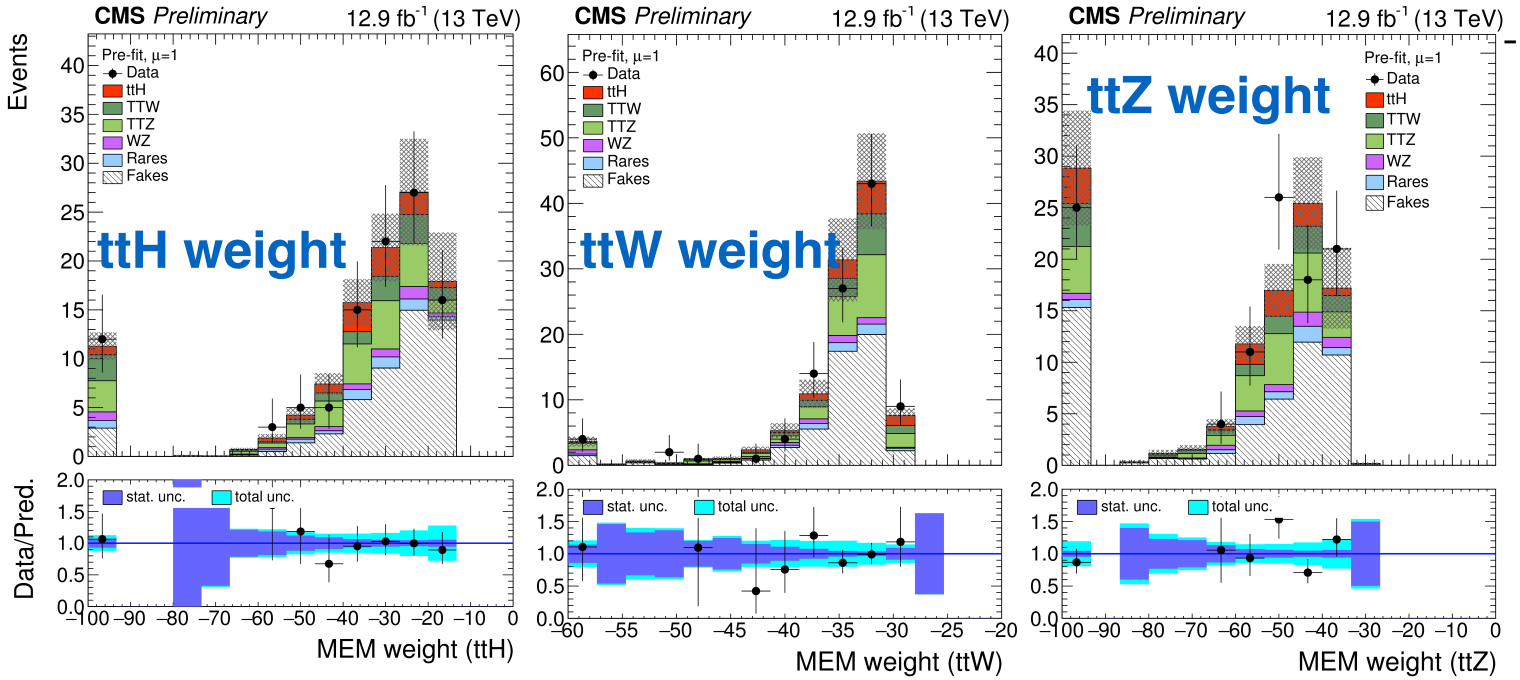
- Custom framework in C++
- **If jets are needed at ME level and are not reconstructed ("mising jets"):** included, as supplementary phase space to integrate
- MEM weight is the average weight of all possible **lepton, jets, b-jets permutations**

$t\bar{t}H$ multilepton : MEM in 3l category

CMS HIG-16-022, HIG-17-004

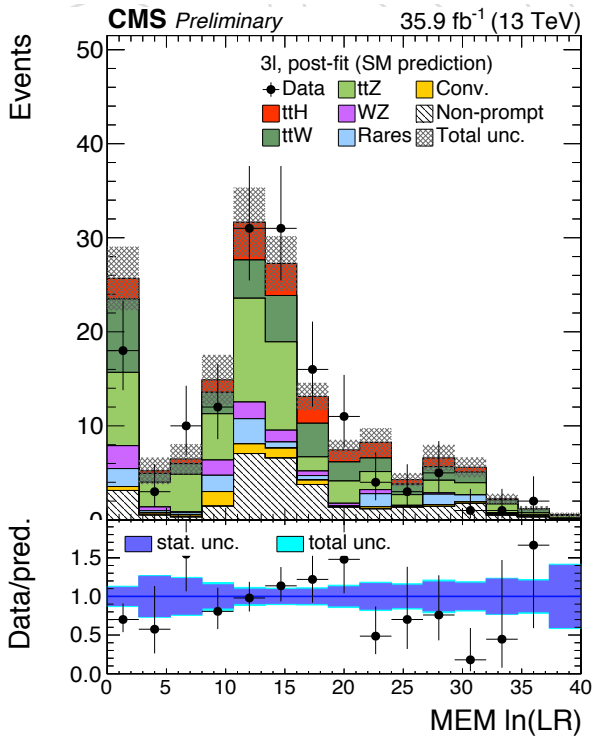
Jing Li (PKU), Xavier Coubez (formerly IPHC), Daniel Bloch (IPHC), NC

MEM weights under ttH, ttW, ttZ/γ* hypotheses



HIG-16-022 (ICHEP 2016):

- **improved discrimination by 10% in 3ℓ category**
- Include log(weights) as input to a kinematic BDT trained against ttV



HIG-17-004 (Moriond 2017): include the likelihood of ttH vs ttV weights inside the ttW/Z BDT

Likelihood ratio of ttV vs ttH+ttV

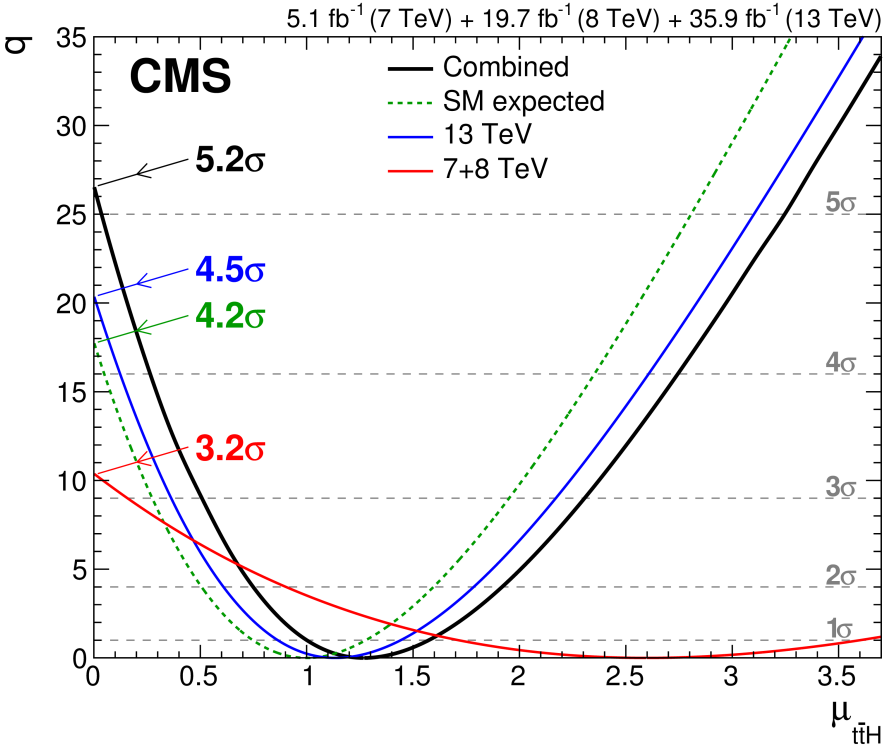
$$-log\left(\frac{\sigma_{t\bar{t}Z}w_{t\bar{t}Z} + k\cdot\sigma_{t\bar{t}W}w_{t\bar{t}W}}{\sigma_{t\bar{t}H}w_{t\bar{t}H} + \sigma_{t\bar{t}Z}w_{t\bar{t}Z} + k\cdot\sigma_{t\bar{t}W}w_{t\bar{t}W}}\right)$$

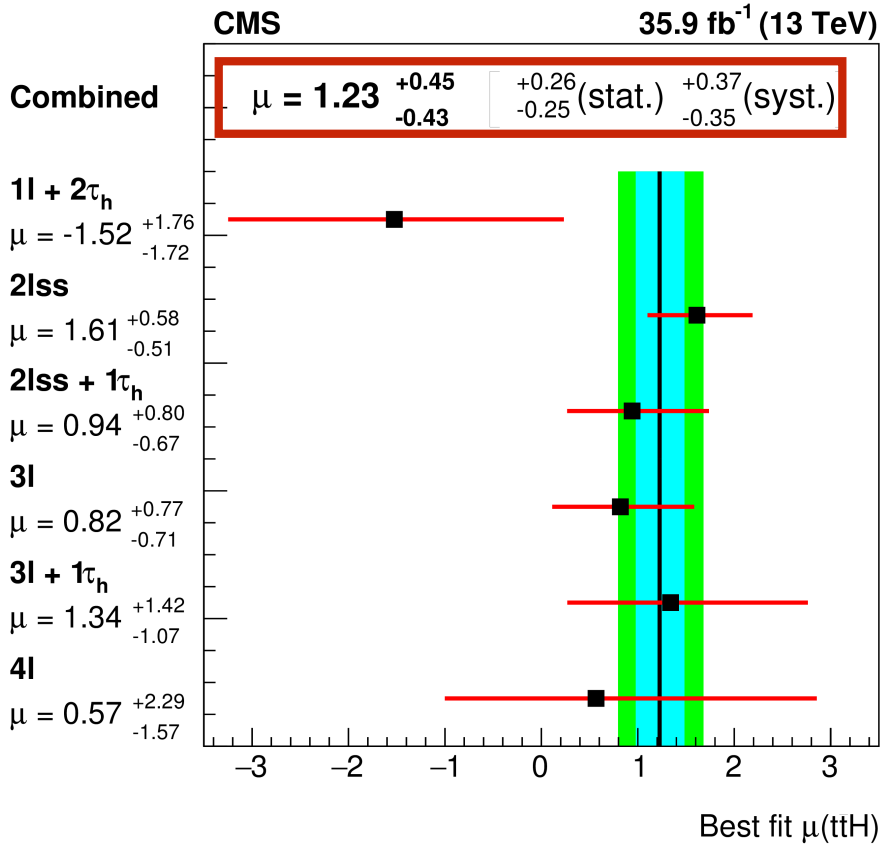
$t\bar{t}H$ multilepton results

arxiv:1803.05485, submitted to JHEP

Significance, combining ttH multilepton and tau analyses:
Observation: 3.2σ (2.8σ expected)

Our collaboration presented at
- **Moriond QCD 2017 (NC)**
- **Poster at LHCP 2017 (Jing Li)**





$t\bar{t}H$ observation

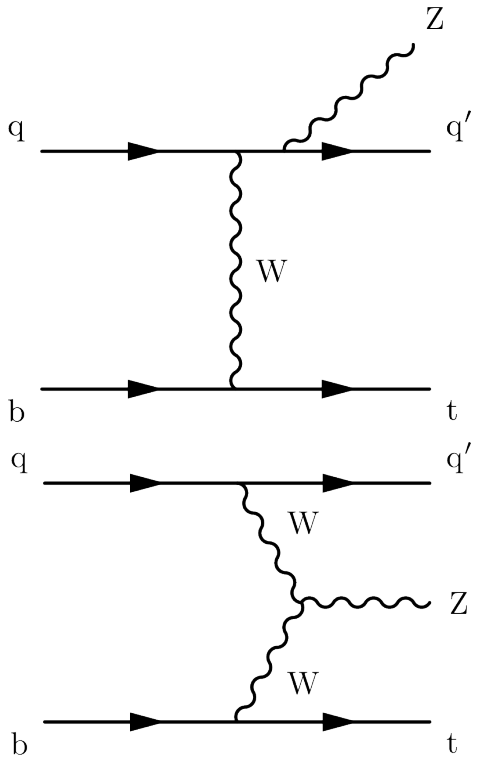
arxiv:1804.02610, accepted by Phys. Rev. Lett.

Full combination (Run 1, Run 2 ttH multilepton, τ_h+X, γγ, ZZ and bb):
5.2σ observed (4.2σ expected)

MEM in single top + Z

Phys. Lett. B 779 (2018) 358

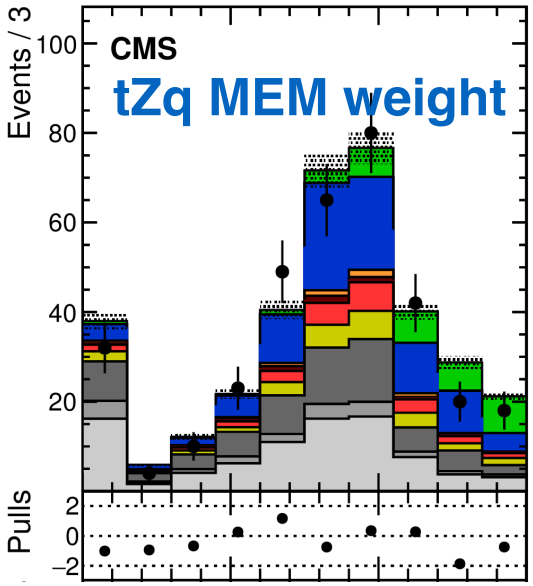
Nicolas Tonon (IPHC), Jeremy Andrea (IPHC), NC

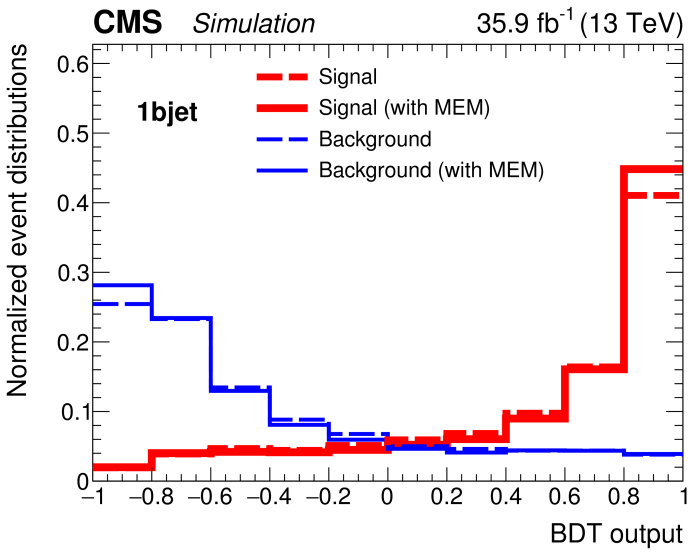


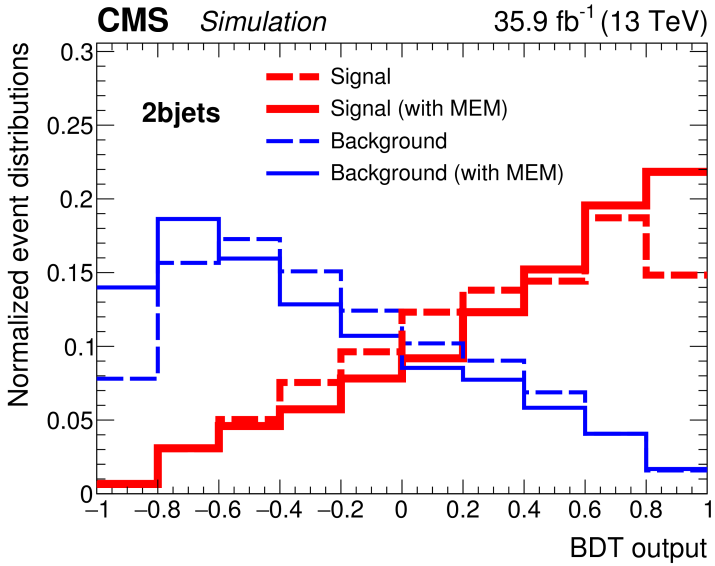
As a spin-off, include MEM in CMS tZq analysis with 2016 data

- tZq is a rare process in the SM
- **Same MEM framework as developed for ttH multi lepton analysis**
- MEM is a powerful tool to use process kinematics: especially forward jet in tZq
- Include MEM weights and MEM as a kinematic fit
- **Observation 3.7σ (3.2σ expected)**

MEM improves the analysis significance by 20%





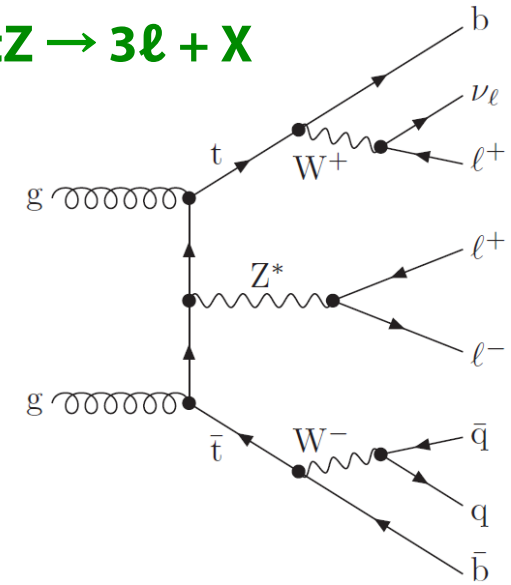


Going further with MEM (2017-)

(Preliminary)

Jing Li (PKU), NC

ttZ → 3ℓ + X

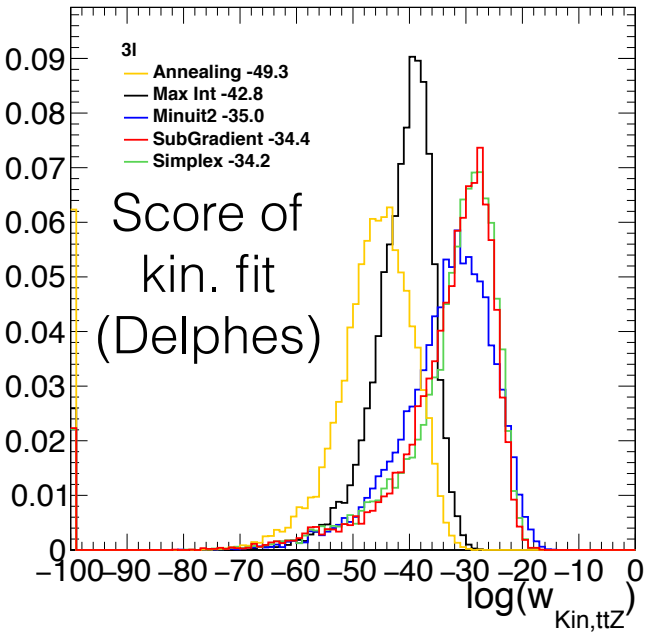


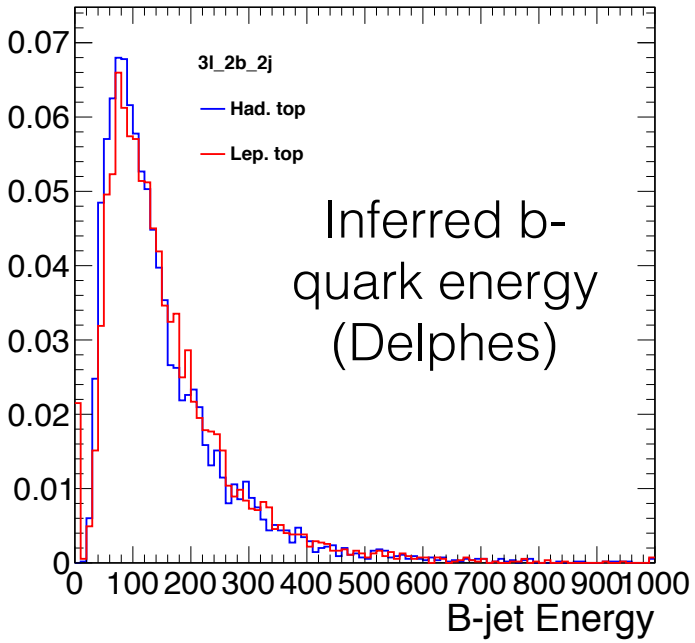
Studying MEM as kinematic fit

- Given reconstructed particles in the event, a MEM score can be attributed to the **most probable kinematic configuration**
- Also obtain unreconstructed quantities : neutrino momenta, etc.

- Studies on behaviour of MEM function
- Explore several minimisation algorithms
- **Target: phenomenology publication**

ttZ in 3ℓ category, Delphes simulation





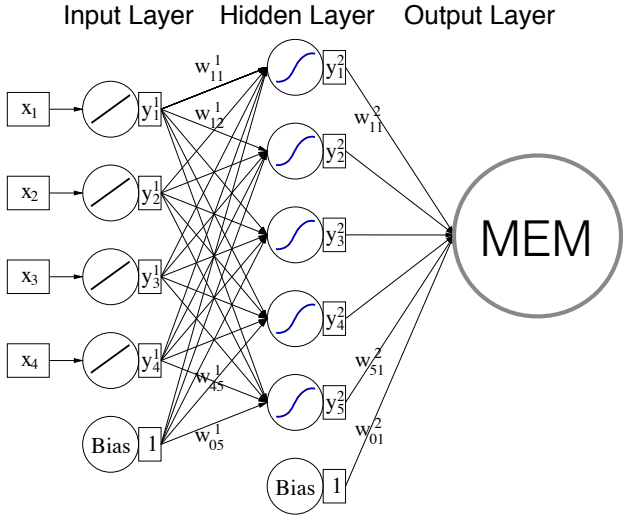
MEM and Deep Learning

(Exploratory work)

Jing Li (PKU), Junho Lee (PKU), Qiang Li (PKU), NC

Working on new hybridisations of MEM and multivariate techniques

- Infer unknown parton-level quantities needed to compute the MEM, using neural network
- **First studies performed** with custom code (Jing Li): showed the need for more powerful tools
- Moving to **modern Deep Learning tools** : Keras + Tensorflow (Junho Lee)
- As a first step, working on a regression of MEM : can be useful to accelerate evaluation of MEM in CMS analysis



Perspectives

- Involvement in **CMS ttH multi lepton analysis** with 2017 data and planned contribution to Run 2 legacy paper

- Working on a **phenomenology publication** to expose new analysis techniques, with MEM and Deep Learning

- Possible involvement in **CMS tHq analysis** with 2017 data

- Consider later possible contributions to VBS WW analysis

- FCPPL support in 2018 will allow a **3 months stay of Junho Lee at IPNL in Autumn**

- PKU, IPHC and IPNL are **grateful for continued FCPPL support** since the start of our collaboration

Back-up slides