Kai-Feng Chen
National Taiwan University

CMS Analysis (1)
EXOTIC SEARCHES
High mass $X \rightarrow 2\gamma$

HIGGS PRECISION
$VH, H \rightarrow 2\gamma$
$WH \rightarrow 3L$

HIGGS/TOP SEARCHES
$H^+(\rightarrow tb)b$
(see the following talks)

TOP QUARK PROPERTIES
Top CP Violation
$FCNH, H \rightarrow 2\gamma$

$FCNC, Z'(\rightarrow 2L$
(see the following talks)

B-PHYSICS
$B \rightarrow K^*\mu\mu$ angular analysis
$B \rightarrow \mu\mu$
**Introduction**

- Coupling strength measurement of Higgs boson couplings to W and Z boson (HVV) provides the understanding of electroweak symmetry breaking.

\[ H \sim g'm_W \]

\[ H \sim \frac{g'm_W}{2\cos^2\theta_W} \]

- The research focuses on the signal strength measurement of VH associated production with Higgs to \( \gamma\gamma \) and V leptonic decay in CMS experiment.

- Involve in the official CMS analysis: VH Leptonic analysis with Higgs to diphoton final states

- Analysis Team: National Taiwan University (NTU) and University of Minnesota (UMN)

- Analysis member: You-Ying Li 李侑穎 (PhD student, NTU), Rajdeep Mohan Chatterjee (Post Doc, UMN)

- Supervisor: Stathes Paganis (NTU), Roger Rusack (UMN)
Overview for VH Leptonic Analysis

Three Categories in VH Leptonic Analysis

<table>
<thead>
<tr>
<th>VH Leptonic Tags</th>
<th>ZHLeptonicTag</th>
<th>WHLeptonicTag</th>
<th>VH MET Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_{lepton}</td>
<td>2 leptons</td>
<td>1 lepton</td>
<td>0 lepton</td>
</tr>
<tr>
<td>Target channel</td>
<td>Z(\rightarrow ll)H</td>
<td>W(\rightarrow l\nu)H</td>
<td>W(\rightarrow l^*\nu)H or Z(\rightarrow \nu\nu)H</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>*Mis-reconstructed or mis-identified</td>
</tr>
<tr>
<td>Analysis Strategy</td>
<td>Machine Learning with Boosted Decision Tree (BDT) for Background reduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected Signal strength (137 fb^{-1})</td>
<td>1.00^{+1.09}_{-0.84}(1.21\sigma)</td>
<td>1.00^{+0.45}_{-0.41}(2.78\sigma)</td>
<td>1.00^{+0.40}_{-0.36}(3.21\sigma) Combined</td>
</tr>
</tbody>
</table>

You-Ying Li for VH Leptonic Team VH (H\rightarrow \gamma\gamma) NTU 2020/2/28
Outgoing Plan

- Expected results for VH Met Tag is coming soon by using current calibrated data
- **Simplified template cross sections (STXS)** with categorized GEN/RECO-level phase space is considered for signal significance enhancement

![Diagram showing VH leptonic tags and VH hadronic tag]

- Plan to combine **VH leptonic tags** (contributed by NTU & UMN) and **VH hadronic tag** (contributed by Imperial College London) when final calibration for full runII data is finished
- We expect the significance of final combined inclusive VH signal (leptonic and hadronic) with $H \rightarrow \gamma\gamma$ will be up to $3.5 \sim 4.0 \sigma$

Possible first evidence of VH, $H \rightarrow \gamma\gamma$!
Introduction: WH3l legacy analysis

- The major target is the coupling strength of $g_{HWW}$ with full Run II CMS data (Lumi = 35.7/fb, 41.9/fb, 59.7/fb).
- The associated Higgs is produced via the Higgs-strahlung (VH) process from a prompt W boson, and H decays to $W \rightarrow l\nu$ pairs.

Signal ($m_H = 125$ GeV)
- $W(H)\rightarrow W(WW^*)\rightarrow 3l+3\nu$

Backgrounds
- Tri-boson: VVV
- Di-boson: $WZ$, $WW$, $ZZ$, $V+\gamma$
- Fake: Top($tt\bar{t}$, $tW$), $Z+\text{jets}$

Event categories
- Events with at least one same-flavour opposite-signed (SFOS) lepton pair.
  - Background sources with Z boson fall into this category.
  - Covers 3/4 of the signal decay.
- The rest of the event is labelled with same-flavour same-sign (SFSS)
  - Mainly polluted by background sources with fake leptons.
- Two control regions for two dominant background source ($WZ$, $Z\gamma$)

Pei-Rong Yu, Po-Hsun Chen, Arun Kumar
With our experience on cut-based analysis, it would be worthy to improve the analysis with MVA(multivariable analysis) method, the BDT(Boost decision tree) is chosen as our first step on this field.

### Category definitions:

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>Cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>preselection everywhere</td>
<td>-</td>
<td>min. (m_\gamma &gt; 12 \text{ GeV}), (p_T &gt; 25 \text{ GeV}, p_T &gt; 20 \text{ GeV}), (p_T &gt; 15 \text{ GeV}, p_T &lt; 10 \text{ GeV}, \text{and lepton charge sum} +1)</td>
</tr>
<tr>
<td>OSSF</td>
<td></td>
<td>(\text{Flag}_\text{OSSF} = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No b-jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{Z-veto} (m_\gamma - m_Z &gt; 20 \text{ GeV}))</td>
</tr>
<tr>
<td>SSSF</td>
<td></td>
<td>(\text{Flag}_\text{OSSF} = 0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No b-jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td>3-leptons</td>
<td></td>
<td>(\text{Flag}_\text{OSSF} = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No b-jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(E_T^{\text{miss}} &lt; 40 \text{ GeV} \text{ and } Z \text{ window} (m_\gamma - m_\gamma &lt; 20 \text{ GeV}))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{and } 80 \text{ GeV} &lt; m_\gamma &lt; 100 \text{ GeV})</td>
</tr>
<tr>
<td>WZ</td>
<td></td>
<td>(\text{Flag}_\text{OSSF} = 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{No b-jets with} p_T &gt; 30 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(E_T^{\text{miss}} &gt; 45 \text{ GeV}, m_\gamma &gt; 100 \text{ GeV})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Z \text{ window} (m_\gamma - m_Z &lt; 20 \text{ GeV}))</td>
</tr>
</tbody>
</table>

### Source in training:

- **OSSF**: WZ, ZZ, \(V\gamma\), \(V\gamma^*\), Top and DY(as Fake)
- **SSSF**: WZ, \(V\gamma\), \(V\gamma^*\), Top and DY(as Fake)

### BDT response(take 2016 training as example)
The expected performance, significance and limit, are calculated with both OSSF and SSSF signal regions and WZ and Zamma control region.

All nuisances are included.

<table>
<thead>
<tr>
<th>Year</th>
<th>Result</th>
<th>OSSF</th>
<th>SSSF</th>
<th>Significance</th>
<th>Limit</th>
<th>Signal strength (68% CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>0.88</td>
<td>5.7602</td>
<td>1.0+1.27,-1.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>0.88</td>
<td>7.4728</td>
<td>1.0+1.23,-1.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>1.03</td>
<td>5.2007</td>
<td>1.0+1.19,-1.16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
We briefly review the search of resonant excesses in a high mass diphoton data sample.

The analysis uses 137 fb$^{-1}$ of data collected during 2016–2018 by the CMS detector.

There are two analysis parts involved:
- Search for resonances:
  - heavy SM-like Higgs spin-0
  - Randall-Sundrum graviton spin-2
- Search for non-resonant signal:
  - ADD extra dimensions

Our group is working on the resonant part.

Goal: Repeat the analysis EXO-17-017 for Run2 data.
Analysis overview

➢ **Selection:** Resonant and non resonant are twin analyses. The selection is common apart from the mass cut. The previous mass cuts used were 230(330) GeV for BB (BE). Below a reminder from Chris’s last talk.

```markdown
Selection
- HLT_DoublePhoton70 || HLT_ECALHT800
- Two photons satisfying high-\(p_T\) photon ID v2 with \(p_T > 125\) GeV
- \(M_{WW} > 5\) GeV—currently blinded above 1 TeV
- Analysis regions
  - Barrel-barrel
  - Barrel-endcap
```

➢ **Parametric signal shape:** A two-dimensional parametric model describing both mass and width of the resonance is created. In this way, there is no need for the generation of infinite number of signal points and a fine scan of the mass can be performed.

➢ **Signal normalization:** The normalization is based on efficiency times acceptance.

➢ **Parametric background shape:** Between EXO-16-027 and EXO-17-017 there has been a change in the background determination with the use of data to constrain alternatives background models used to test the accuracy of the chosen background parameterisation.

➢ **Current Status:** We are building and testing the technical tools against 2017 data and RS samples. As soon as they are ready, we will proceed to the rest of the years.
We compare the final parametric signal shape against the reconstructed one. In this way, data and final shape can be inspected.

The first step is to choose an ansatz for the background parametrization. We follow previous analysis and take

\[ g(m_{\gamma \gamma}) = m_{\gamma \gamma}^{a+b \log(m_{\gamma \gamma})} \]

Afterwards, a bias study is performed regarding this choice and an additional term is added in the background model, which has the same distribution as the signal that hypothesis is being tested.
Introduction: Top CP Violation

- Search for CP asymmetries in top pair production and decay using lepton+jets final state
  - Observed CP asymmetries in the SM is insufficient to explain the matter-antimatter asymmetry in the universe
  - Use CEDM as our benchmark BSM model
  - Develop a generic method to find if there is CP violation in $t\bar{t}$ decay

- Measurements through: T-odd triple-products
  - A counting event method
  - SM predicts zero values

$$A_{CP}(O_i) = \frac{N_{\text{events}}(O_i > 0) - N_{\text{events}}(O_i < 0)}{N_{\text{events}}(O_i > 0) + N_{\text{events}}(O_i < 0)}$$

- 8 TeV paper (CMS-TOP-16-001) already published in JHEP 03 (2017) 101
  - O(0.6%) precision reached on raw $A'_{cp}$ value, O(1-2%) on the corrected Acp
  - Systematics roughly matches with statistical uncertainty

\[
O_3 = Q_l \epsilon(p_b, p_{\bar{b}}, p_l, p_{j_1}) \xrightarrow{bb\ CM} Q_l \vec{p}_b \cdot (\vec{p}_l \times \vec{p}_{j_1}) \\
O_6 = Q_l \epsilon(P, p_b - p_{\bar{b}}, p_l, p_{j_1}) \xrightarrow{\text{lab}} Q_l (\vec{p}_{\bar{b}} - \vec{p}_b) \cdot (\vec{p}_l \times \vec{p}_{j_1}) \\
O_{12} = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \xrightarrow{\text{lab}} Q_l (\vec{p}_{\bar{b}} - \vec{p}_b) \cdot (\vec{p}_b \times \vec{p}_{\bar{b}}) \\
O_{13} = Q_l \epsilon(P, p_b + p_{\bar{b}}, p_l, p_{j_1}) \xrightarrow{\text{lab}} Q_l (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_l \times \vec{p}_{j_1})
\]
Analysis Status

• Person power
  — Pu-Sheng Chen (Ph.D student) + Chen-Yu Chuang (Master student) + Kai-Feng Chen

• Use full RunII single lepton dataset
  — 2016 35.9 fb\(^{-1}\) 2017 41.5 fb\(^{-1}\) 2018 59.7 fb\(^{-1}\)

• Single Ele and Single Mu HLT

• Signal: SM \(t\bar{t}\) production process

• Background: single top, DY+jets, W+jets, dibosons

• Signal region SR: 1 isolated tight ID e/\(\mu\) + 2 deep CVSM b-jets + \(\geq 4\) light jets
  — additional loose lepton events rejected

• Control region
  — CR 1 (W+jets dominant control region): background estimation
  — CR 2 (QCD dominant control region): eliminate QCD spikes in CR 1

<table>
<thead>
<tr>
<th>Selection</th>
<th>SR</th>
<th>CR1</th>
<th>CR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good primary vertices</td>
<td>(\geq 1)</td>
<td>(\geq 1)</td>
<td>(\geq 1)</td>
</tr>
<tr>
<td>Lepton passes Selection criteria ((\mu) or e)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lepton passes Veto criteria ((\mu) and e)</td>
<td>0</td>
<td>0*</td>
<td>0</td>
</tr>
<tr>
<td>Inverse lepton isolation cut</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of selected jets</td>
<td>(\geq 4)</td>
<td>(\geq 4)</td>
<td>(\geq 4)</td>
</tr>
<tr>
<td>Number of CSVM-b tagged jets</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of CSVL-b tagged jets</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Upper bound on (M_{bb})</td>
<td>150</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Upper bound on (\chi^2_{min})</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
Summary

Current status

• Data and MC show good agreement, fitted results show high purity of signal (~92-96%).
• No evidence of significant detector bias.
• The systematic uncertainty and statistical uncertainty are both of $O(0.2\%)$, much better than the previous value of $O(0.6\%)$ used in 8 TeV paper
• All of the datasets are in the step before unblinding, now seeking for the CADI line
**FCNH**

- **Top FCNC coupling**
  
  In the SM FCNC transitions:
  - Forbidden at tree level
  - Loop-level highly suppressed by GIM mechanism
  - BF$_t$ of the order $10^{-12}$ $\sim 10^{-15}$

- FCNH can be performed either with ttbar decay, or single top production.
  - Large production cross section of ttbar
  - Nearly the same sensitivity to H-u-t and H-c-t couplings

- Beyond the SM:
  - The theoretical BR of FCNC can be enhanced up to $10^{-4}$ $\sim 10^{-5}$
  - Searches possible in the current LHC data

- H→γγ has small BR but a very clean signature = important contribution among the FCNH channels

- Best limits at LHC
  
  Currently, the best limits on the top FCNH searches are given by ATLAS (2015+2016 data):
  - BF$_t$ (t→Hu) < 0.11%
  - BF$_t$ (t→Hc) < 0.12% set by 36fb$^{-1}$, 13TeV data

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[1] Beyond the SM:
- The theoretical BR of FCNC can be enhanced up to $10^{-4}$ $\sim 10^{-5}$
- Searches possible in the current LHC data

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**FCNH** represents the FCNC processes corresponding to top quark-Higgs boson interactions.
Consider both single top and ttbar FCNC processes

- Higgs decaying into $\gamma\gamma$
- Top decay in hadronic and leptonic channel
- Set limits on $B(t \rightarrow Hu)$ and $B(t \rightarrow Hc)$ and $\kappa_{Hu}$, $\kappa_{Hc}$
Analysis overview

- Full Run 2 data
- Data from DoubleEG (2016/17) and EGamma (2018)
- Diphotons triggers
- Signal MC samples

Preselection:
- Higgs candidate with $M_{\gamma\gamma} > 100$ GeV + 2 channels
- hadronic: >3 jets & >1 btag jet
- leptonic: >1 jet & 1 lepton $p_T > 20$ GeV

Top reconstruction
- hadronic: best candidate selected with min $\chi^2$ method
- leptonic channel: $P_z($neutrino) evaluated by quadratic equation

Matching eff. after min $\chi^2$ method

<table>
<thead>
<tr>
<th></th>
<th>$t\rightarrow bW$</th>
<th>$t\rightarrow qH$</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT had.</td>
<td>✔️</td>
<td>✔️</td>
<td>~ 25%</td>
</tr>
<tr>
<td>ST had.</td>
<td>✔️</td>
<td>✗️</td>
<td>~ 50%</td>
</tr>
<tr>
<td>TT lep.</td>
<td>✔️</td>
<td>✔️</td>
<td>~ 45%</td>
</tr>
<tr>
<td>ST lep.</td>
<td>✔️</td>
<td>✗️</td>
<td>~ 85%</td>
</tr>
</tbody>
</table>

Quadratic method
MVA training

- Train separate BDTs for each channel and each coupling (Hut, Hct)
- Exploring to do the training in exclusive jet categories

Background and signal modelling

- Signal MC fit DCB from MC
- Separate fit per: channel lepton/hadronic, coupling Hut/Hct, production mode ST/TT, 4 signal bins = 32 fits in total
- Estimate resonant (SM Higgs) from fit DCB from MC
- Non resonant from fit parametric model to data in \( m_{\gamma\gamma} \) sidebands

Limits extraction

<table>
<thead>
<tr>
<th>Channel</th>
<th>( \mathcal{B}(t \rightarrow H u) ) (%)</th>
<th>( \mathcal{B}(t \rightarrow H c) ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H \rightarrow \gamma\gamma, \text{Hadronic (41.5 fb}^{-1}) )</td>
<td>0.091</td>
<td>0.105</td>
</tr>
<tr>
<td>( H \rightarrow \gamma\gamma, \text{Leptonic (41.5 fb}^{-1}) )</td>
<td>0.120</td>
<td>0.161</td>
</tr>
<tr>
<td>( H \rightarrow \gamma\gamma, \text{Combination (41.5 fb}^{-1}) )</td>
<td>0.078</td>
<td>0.091</td>
</tr>
<tr>
<td>ATLAS 2016 ( H \rightarrow \gamma\gamma (36.1 fb}^{-1}) )</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>ATLAS 2016 Combination (36.1 fb}^{-1}) )</td>
<td>0.083</td>
<td>0.083</td>
</tr>
</tbody>
</table>

Preliminary! but such improvement possible thanks to:
- adding ST
- more lumi
- MVA versus cut-based
- not yet all systematics

Next Steps

- MVA classification and optimization
- Study and treatment of all systematics
- Once full chain in place → focus on detailed improvement of analysis
Angular analysis of $B^{\pm} \rightarrow K^{*\pm} \mu\mu$ at 8TeV

- Motivated by the 3.7$\sigma$ P5' anomaly reported from LHCb\textsuperscript{†}.
- $B^{\pm} \rightarrow K^{*\pm}(\rightarrow K_{S}\pi^{\pm})\mu\mu$ is a typical $b \rightarrow s$ transition via the $Z/\gamma$ penguin or box diagrams. The angular distribution varies with the energy scale of dimuon mass square($q^2$).
- With negligible S-wave $K\pi$ contribution, the muon forward-backward asymmetry($A_{FB}$) and fraction of kaon longitudinal polarization($F_L$) characterize the angular distribution.

88.8$\pm$13.0 signal events in 3 $q^2$ bins. Adapt the Feldman-Cousins’ method for statistical error estimation.

\textsuperscript{†}[PRL 111, 191801 (2013)]
The measurement is consistent with the SM prediction.
Why $B_{s,d} \rightarrow \mu^+ \mu^-$

- $B_{s,d} \rightarrow \mu^+ \mu^-$ decays only proceed through FCNC processes and are highly suppressed in SM.
- Loop diagram + Suppressed SM + Theoretically clean = an excellent place to look for NP.
- What to measure:
  - **Branching fractions**: $B_s \rightarrow \mu\mu$ may start to enter precision regime, while first evidence of $B_d \rightarrow \mu\mu$ might emerge.
  - **Effective lifetime**: only the heavy $B_s$ state can decay into dimuon in the SM; different composition of states may be allowed by NP.

$$
\tau_{\mu^+ \mu^-} \equiv \frac{\int_0^\infty t \Gamma(B_s(t) \rightarrow \mu^+ \mu^-) \, dt}{\int_0^\infty \Gamma(B_s(t) \rightarrow \mu^+ \mu^-) \, dt} = \frac{\tau_{B_s^0}}{1 - y_s^2} \left( 1 + 2A_{\Delta \Gamma}^{\mu^+ \mu^-} y_s + y_s^2 \right) \frac{1}{1 + A_{\Delta \Gamma}^{\mu^+ \mu^-} y_s} \quad A_{\Delta \Gamma}^{\mu^+ \mu^-} \equiv -\mathcal{R}(\lambda)/(1 + |\lambda|^2)
$$

- **SM predictions**:
  
  Ref:
  Beneke et al, PRL 120, 011801 (2018)
  Bobeth et al, PRL 112, 101801 (2014)

$$
\mathcal{B}(B_s \rightarrow \mu^+ \mu^-) = (3.57 \pm 0.17) \times 10^{-9}
\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (1.06 \pm 0.09) \times 10^{-10}
\tau(B_s \rightarrow \mu^+ \mu^-) = 1.615 \text{ ps}
$$
Results: Branching Fractions

Fitted branching fractions:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Branching fraction</th>
<th>Sign. (obs)</th>
<th>Sign. (exp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow \mu^+\mu^-$</td>
<td>$[2.9^{+0.7}_{-0.6} \text{ (exp)} \pm 0.2(f_s/f_u)] \times 10^{-9}$</td>
<td>$5.6\sigma$</td>
<td>$6.5\sigma$</td>
</tr>
<tr>
<td>$B^0 \rightarrow \mu^+\mu^-$</td>
<td>$(0.8^{+1.4}_{-1.3}) \times 10^{-10}$</td>
<td>$0.6\sigma$</td>
<td>$0.8\sigma$</td>
</tr>
</tbody>
</table>

Consistent with SM

Main result for $B^0 \rightarrow \mu^+\mu^-$

Preliminary CMS (7 TeV) + 5 fb$^{-1}$ (8 TeV) + 20 fb$^{-1}$ (13 TeV) + 36 fb$^{-1}$

Low BDT

High BDT

Combined mass projection for low/high BDT categories

(Correlation: $-0.181$)
**Lifetime Results**

**Primary result from 2D UML:**

Ref. CMS-PAS-BPH-16-004

<table>
<thead>
<tr>
<th>$B_s \rightarrow \mu \mu$</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Lifetime</td>
<td>$1.70_{-0.44}^{+0.61}$ ps</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>$+0.39 -0.30$ ps</td>
</tr>
</tbody>
</table>

Systematic uncertainty is small: 0.09ps

**Consistent with SM**

**Result from sPlot fit:**

$B_s \rightarrow \mu \mu$

<table>
<thead>
<tr>
<th>Effective Lifetime</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.55_{-0.33}^{+0.52}$ ps</td>
<td>$+0.49 -0.31$ ps</td>
</tr>
</tbody>
</table>

Consistent with the 2D UML.

**Combined $m_{\mu\mu}$ & $t$ productions**

$B^0 \rightarrow \mu \mu$ in peaking bkg.

(projection with $1<t<11$ ps, slightly better S/N comparing to BF fit.)

**Combined $m_{\mu\mu}$ production & sPlot in $t$**

**Bin-integrated PDF**

Paper has been submitted to JHEP, already at 3rd iteration with the journal referee… New analysis is in preparation!
Other Studies in Progress/in Preparation

❖ Electron/pion separation with HGCAL beam test configuration (Tien-Hsiang Chen, Stathes Paganis, Wen-Liang Huang, KFC)

❖ Boosted VH (Xing-Fu Su, Min Chen, Stathes Paganis)

❖ Photon+heavy flavor (Rong-Shyang Lu)

❖ QCD UE studies with CMS open data (Meng-Hsiu Kuo, Yang-Ting Chien, KFC)

❖ Few other new initiatives:
   - quark/gluon tagging at phase-II endcap (Zheng-Gang Chen, KFC)
   - Monopole signature in ECAL (Lin Shih, KFC)
   - …+other new ideas?
e/π Separation with HGCAL Beam Test Configuration

- As an example: tagging with convolutional neural network based on HGCAL beam test samples.


“Images” from HGCAL as inputs