Search for new physics through virtual effects at the LHC

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Introduction

Quark contact interactions

Anomalous Top Quark couplings

Conclusions
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Anomalous Top Quark couplings

Conclusions
Test of Standard Model

- Discovery of SM Higgs-like boson; precision test of SM electroweak and QCD sector.

CMS $0.87 \pm 0.23$

\[ -2\ln(\chi^2_{\text{null}}) < 1 \text{ Intervals} \]

\[ \text{2011+2012 Data} \]

\[ \text{ATLAS Internal} \]

- $W,Z H \rightarrow b\bar{b}$
- $H \rightarrow \tau\tau$
- $H \rightarrow \gamma\gamma$
- $H \rightarrow WW^* \rightarrow lvlv$
- $H \rightarrow ZZ^* \rightarrow llll$

Combined

\[ m_H = 126 \text{ GeV} \]

\[ \mu = 1.4 \pm 0.3 \]

\[ \sigma_{\text{total}} \]

\[ \text{ATLAS Preliminary} \]

LHC pp $\sqrt{s} = 7 \text{ TeV}$

- Theory
- Data 2010 ($L = 35 \text{ pb}^{-1}$)
- Data 2011 ($L = 1.0 - 4.7 \text{ fb}^{-1}$)

LHC pp $\sqrt{s} = 8 \text{ TeV}$

- Theory
- Data 2012 ($L = 5.8 \text{ fb}^{-1}$)
Search for new physics at the LHC

- Unsolved problems of SM: neutrino mass and mixing, dark matter candidate, gauge unification, Higgs mass stability, flavor hierarchy.
- Tons of NP model candidates: e.g., SUSY, technicolor, extra dimensions, little Higgs...
Ways to look for new physics

- Direct discovery of new particles from NP at the LHC would be wonderful. But it may happen that the NP scale lies above LHC energy threshold. Thus at the LHC we may only be able to find their hints through some virtual effects.

- NP at a high scale $\Lambda$ will manifest themselves at energies well below $\Lambda$ through small deviations from the SM, described by higher dimension operators. Assuming NP preserves SM gauge symmetry and lepton, baryon number conservation, then the leading contributions consist of 59 dimension-six operators.

W. Buchmuller, et. al., NPB 268:621(1986)
Uncertainties of theoretical predictions at LHC

- Theoretical uncertainties become more and more important at the LHC.

\[
\begin{align*}
M_H &= 126 \text{ GeV} \\
R_{H \to \gamma\gamma} &= \frac{\sigma_{\text{obs}}}{\sigma_{\text{SM}}} \\
\sqrt{s} &= 7 \oplus 8 \text{ TeV}
\end{align*}
\]

\[\Delta_{\mu}^{\text{th}-\text{PDF+QCD}} \quad \Delta_{\text{LHCHWC}}^{\text{th}}\]

\[\text{CMS} \quad \text{ATLAS} \quad \text{ATLAS} \oplus \text{CMS}\]

\[\sigma_{\text{obs}} / \sigma_{\text{SM}}\]

**ATLAS Preliminary**

15 May 2012

Data 2011

- Single lepton: 0.70 fb\(^{-1}\) = 179 ± 4 ± 9 ± 7 pb
- Dilepton: 0.70 fb\(^{-1}\) = 173 ± 6 ± 11 ± 7 pb
- All hadronic: 1.02 fb\(^{-1}\) = 167 ± 18 ± 78 ± 6 pb
- Combination = 177 ± 3 ± 5 ± 7 pb

New measurements

- \(\tau_{\text{had}} + \text{jets}\): 1.67 fb\(^{-1}\) = 200 ± 19 ± 42 ± 7 pb
- \(\tau_{\text{had}} + \text{lepton}\): 2.05 fb\(^{-1}\) = 186 ± 13 ± 20 ± 7 pb
- All hadronic: 4.7 fb\(^{-1}\) = 168 ± 12 ± 60 ± 57 ± 6 pb

arXiv:1207.1451
pQCD corrections for hard scattering at LHC

- NLO; threshold or $p_T$ resummation; NLO+PS; NNLO

1204.5201

1110.2375
Global fit of PDF

- Precise determination of gluon PDF is important for the measurement of couplings of SM Higgs boson and also many new physics searches.

Above luminosity plots show comparisons of the gluon PDFs from different collaborations.
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Quark Contact Interactions

- Four quark contact interactions, \( \mathcal{L}_{NP} = \frac{1}{2\Lambda^2} \sum_{i=1}^{6} c_i O_i \), with

\[
O_1 = \delta_{ij} \delta_{kl} (\bar{q}_{Lci} \gamma_{\mu} q_{Lcj} \bar{q}_{Ldk} \gamma^\mu q_{Ldl}), \quad O_2 = T_{ij}^a T_{kl}^a (\bar{q}_{Lci} \gamma_{\mu} q_{Lcj} \bar{q}_{Ldk} \gamma^\mu q_{Ldl})
\]

\[
O_3 = \delta_{ij} \delta_{kl} (\bar{q}_{Lci} \gamma_{\mu} q_{Lcj} \bar{q}_{Rdk} \gamma^\mu q_{Rdl}), \quad O_4 = T_{ij}^a T_{kl}^a (\bar{q}_{Lci} \gamma_{\mu} q_{Lcj} \bar{q}_{Rdk} \gamma^\mu q_{Rdl})
\]

\[
O_5 = \delta_{ij} \delta_{kl} (\bar{q}_{Rci} \gamma_{\mu} q_{Rcj} \bar{q}_{Rdk} \gamma^\mu q_{Rdl}), \quad O_6 = T_{ij}^a T_{kl}^a (\bar{q}_{Rci} \gamma_{\mu} q_{Rcj} \bar{q}_{Rdk} \gamma^\mu q_{Rdl})
\]

- Of particular interest, if the quarks are composite state at a high energy scale \( \Lambda \) (quark compositeness), then at energy well below there will be four quark contact interactions due to residual effects of the underlying strong dynamics. E. Eichten, et. al., PRL 77:5336(1996)
Contact interactions in dijet production

Jet angular observable $\chi = \exp(|y_1 - y_2|)$: SM QCD dijet production is t-channel dominant with $d\sigma/d\chi \sim \text{constant}$. The contact interaction contributions prefer small $\chi$ region, e.g.,

$$d\sigma/d\chi \sim 1/(1 + \chi^2).$$


Contact interaction prefers central in angular and high invariant mass region; Small systematic uncertainties as compared to other jet measurements

At LO contact interactions can contribute to dijet production through several subprocesses of quark-quark scattering, including

\[ qq'(q) \rightarrow qq'(q), \quad q\bar{q}' \rightarrow q\bar{q}', \quad q\bar{q} \rightarrow q\bar{q}(q'\bar{q}') \]

QCD one-loop diagrams for both SM QCD and NP production:

Beside of renormalization of QCD coupling constants and quark wave functions, we also need to introduce renormalization of the operators, 

\[ O^{(0)}_i = (1 + \delta Z)_{ij} O_j \], to absorb remaining UV divergences.
The Wilson coefficients run with the renormalization scale in the $\overline{MS}$ scheme. When $\Lambda$ is much higher than the physics scale considered, large logarithm of $\Lambda$ occurs in fixed order calculation. And RG equation can be used to sum them and improve the convergency.

Real radiation processes (crossing diagrams not shown)

We use both two cutoff and dipole subtraction method to extract the infrared divergences and perform numerical calculations for a cross-check. RMP68, 1125(1996), PRD65:094032(2002), NPB485, 291(1997)
Inputs for numerical calculations:

- For the numerical results shown here, we assume only $c_1(\Lambda)$ and $c_2(\Lambda)$ are non-zero and rewrite them as $c_{1(2)}(\Lambda) = 4\pi \lambda_{1(2)}$. For the color-singlet case studied in the experiments, it corresponds to $\lambda_{1(2)} = \pm 1(0)$.

- Following the CMS measurement we use anti-$k_T$ jet algorithm with $D = 0.5$ and require the two leading jet satisfying $|y_b| = |y_1 + y_2|/2 < 1.11$, $\chi < 16$. CMS Col., PRL106, 201804(2011)

- We only consider the kinematic region with dijet invariant mass between 2 and 3 TeV since the NP contributions are only significant there and above. Instead of calculating the differential cross sections w.r.t. $\chi$, we choose two representative bins in $\chi$, i.e., bin 1, $[1, 6]$ and bin 2, $[6, 11]$, to simplify the analysis.

- Both factorization and renormalization scales are set to the average $p_T$ of the two leading jets.
LO results and analysis:

- Dependence of the NP contributed cross sections on the compositeness scale and couplings can be written as

\[
\sigma_{LO} = \frac{(\lambda_1 b_{L,1} + \lambda_2 b_{L,2})}{\Lambda^2} + \frac{(\lambda_1^2 b_{L,11} + \lambda_2^2 b_{L,22} + \lambda_1 \lambda_2 b_{L,12})}{\Lambda^4}
\]

with the coefficients given by

<table>
<thead>
<tr>
<th>[fb \cdot (5 \text{ TeV})^{2(4)}]</th>
<th>(b_{L,1})</th>
<th>(b_{L,2})</th>
<th>(b_{L,11})</th>
<th>(b_{L,22})</th>
<th>(b_{L,12})</th>
</tr>
</thead>
<tbody>
<tr>
<td>bin 1</td>
<td>-258</td>
<td>-179</td>
<td>614</td>
<td>93.4</td>
<td>259</td>
</tr>
<tr>
<td>bin 2</td>
<td>-99.1</td>
<td>-70.4</td>
<td>113</td>
<td>17.2</td>
<td>46.8</td>
</tr>
</tbody>
</table>

- We can see that the absolute values of \(b\) are much larger in bin 1 than in bin 2 especially for the NP squared terms, since the NP contributions prefer small \(\chi\) values.
NLO results and analysis:

- At NLO the dependence on $\Lambda$ includes additional logarithm term, $r = \ln(\Lambda/p_0)$, from running of Wilson coefficients

\[
\sigma_{\text{NLO}} = \left( \lambda_1 (b_{N,1} + a_1 r) + \lambda_2 (b_{N,2} + a_2 r) \right) / \Lambda^2 + \left( \lambda_1^2 (b_{N,11} + a_{11} r) + \lambda_2^2 (b_{N,22} + a_{22} r) + \lambda_1 \lambda_2 (b_{N,12} + a_{12} r) \right) / \Lambda^4
\]

with $a$ and $b$ given by

<table>
<thead>
<tr>
<th>[fb \cdot (5 \text{ TeV})^{2(4)}]</th>
<th>$b_{N,1}(a_1)$</th>
<th>$b_{N,2}(a_2)$</th>
<th>$b_{N,11}(a_{11})$</th>
<th>$b_{N,22}(a_{22})$</th>
<th>$b_{N,12}(a_{12})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>bin 1</td>
<td>-232(20)</td>
<td>-159(19)</td>
<td>506(-26)</td>
<td>74.3(-12)</td>
<td>172(-51)</td>
</tr>
<tr>
<td>bin 2</td>
<td>-68.3(8.7)</td>
<td>-44.1(9.2)</td>
<td>89.2(-4.9)</td>
<td>13.0(-2.3)</td>
<td>33.1(-9.8)</td>
</tr>
</tbody>
</table>

- The NLO QCD corrections reduce the NP contributions significantly mainly due to the large negative constant terms in the virtual corrections and also the logarithms of $\Lambda$ from running of the Wilson coefficients.
NLO K-factors and scale variations of the cross sections:

Note that the K-factors depend on scale choice and definition of LO cross sections in perturbation series.
Comparison of K-factors for pure SM dijet production cross sections and NP induced contributions:

In this work we develop two numerical programs, MEKS for the NLO computation of SM double differential jet cross sections, and CIDIJET for contact interactions including all chiral and color structures.
Exclusion limits of compositeness scale at the LHC:

- To derive the expected exclusion limits of the compositeness scale, we further divide the invariant mass region \([2 \text{ TeV}, 3 \text{ TeV}]\) into 10 mass bins with equal width, and define the measure in each mass bin,
  \[ F_\chi(M_{jj}) = \frac{\sigma_{\text{bin1}}(M_{jj})}{\sigma_{\text{bin2}}(M_{jj})}. \]

- We take the pure SM QCD contributions as the expected experimental data. The experimental errors of \(F_\chi\) include statistical errors (calculated assuming \(L = 5 \text{ fb}^{-1}\)), and systematic ones mainly from jet energy calibration, jet \(p_T\) resolution, and unfolding corrections. Most of the systematic uncertainties cancel in the ratio \(F_\chi\). We estimate an overall systematic uncertainty of 3% on \(F_\chi\) in all mass bins based on the CMS results. We don’t consider possible correlations of errors in different mass bins.

CMS Col., PRL106, 201804(2011)
Comparison of SM and NP cross sections and NP predictions for $F_\chi$ compared to expected data:
On another hand we also need to consider theoretical uncertainties while comparing theory predictions to data, which include ones from PDFs, non-perturbative corrections, and most importantly the unknown higher order QCD corrections. The former two can be neglected here for $F_\chi$.

Conventional way to estimate the last one is to look at QCD scale variations of the observable. Here we take half of the total scale variations of $F_\chi$ as the error assuming a Gaussian distribution.
We perform a log-likelihood $\chi^2$ test on the NP hypothesis with

$$\chi^2 = \sum_{i=1,10} \frac{(F_{\chi}^{SM+NP}(i) - F_{\chi}^{SM}(i))^2}{\Delta^2_{exp}(i) + \Delta^2_{th}(i)}$$

Below we show $\chi^2$ as functions of compositeness scale $\Lambda$ for 3 cases. The 95% C.L. exclusion limits can be read directly as intersections of curves with the horizontal line.
**Exclusion limits from CMS:**

- **NLO**
  - $\Lambda^{+}_{LL/RR}$
  - $\Lambda^{-}_{LL/RR}$

- **LO**
  - $\Lambda^{+}_{LL/RR}$
  - $\Lambda^{-}_{LL/RR}$
  - $\Delta_{VV/AA}^{+}$
  - $\Delta_{VV/AA}^{-}$
  - $\Delta_{(V-A)}^{\pm}$

**CMS**
- $\sqrt{s} = 7$ TeV
- $L = 2.2$ fb$^{-1}$
- **Expected**
  - **Expected $\pm 1\sigma$**
  - **Expected $\pm 2\sigma$**

**Observed**
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Top FCNC couplings

- Top quark may have strong connections to new physics BSM. And the huge production rate at the LHC makes it an ideal probe for new physics through production or decay.

- Within all the top quark effective operators, flavor-changing neutral-current coupling is of particular interest due to the characteristic collider signature.

<table>
<thead>
<tr>
<th></th>
<th>SM</th>
<th>QS</th>
<th>2HDM</th>
<th>FC 2HDM</th>
<th>MSSM</th>
<th>R</th>
<th>SUSY</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \rightarrow uZ$</td>
<td>$8 \times 10^{-17}$</td>
<td>$1.1 \times 10^{-4}$</td>
<td>$-$</td>
<td>$-$</td>
<td>$2 \times 10^{-6}$</td>
<td>$3 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow u\gamma$</td>
<td>$3.7 \times 10^{-16}$</td>
<td>$7.5 \times 10^{-9}$</td>
<td>$-$</td>
<td>$-$</td>
<td>$2 \times 10^{-6}$</td>
<td>$1 \times 10^{-6}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow ug$</td>
<td>$3.7 \times 10^{-14}$</td>
<td>$1.5 \times 10^{-7}$</td>
<td>$-$</td>
<td>$-$</td>
<td>$8 \times 10^{-5}$</td>
<td>$2 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow uH$</td>
<td>$2 \times 10^{-17}$</td>
<td>$4.1 \times 10^{-5}$</td>
<td>$5.5 \times 10^{-6}$</td>
<td>$-$</td>
<td>$10^{-5}$</td>
<td>$\sim 10^{-6}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow cZ$</td>
<td>$1 \times 10^{-14}$</td>
<td>$1.1 \times 10^{-4}$</td>
<td>$\sim 10^{-7}$</td>
<td>$\sim 10^{-10}$</td>
<td>$2 \times 10^{-6}$</td>
<td>$3 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow c\gamma$</td>
<td>$4.6 \times 10^{-14}$</td>
<td>$7.5 \times 10^{-9}$</td>
<td>$\sim 10^{-6}$</td>
<td>$\sim 10^{-9}$</td>
<td>$2 \times 10^{-6}$</td>
<td>$1 \times 10^{-6}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow cg$</td>
<td>$4.6 \times 10^{-12}$</td>
<td>$1.5 \times 10^{-7}$</td>
<td>$\sim 10^{-4}$</td>
<td>$\sim 10^{-8}$</td>
<td>$8 \times 10^{-5}$</td>
<td>$2 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow cH$</td>
<td>$3 \times 10^{-15}$</td>
<td>$4.1 \times 10^{-5}$</td>
<td>$1.5 \times 10^{-3}$</td>
<td>$\sim 10^{-5}$</td>
<td>$10^{-5}$</td>
<td>$\sim 10^{-6}$</td>
<td></td>
</tr>
</tbody>
</table>

hep-ph/0409342
Here we considered $tqg$ FCNC couplings with

$$\mathcal{L} = g_s \sum_{q=u,c} \kappa_{tqg} \bar{t} \sigma^{\mu\nu} T^a \left( f_q^L P_L + f_q^R P_R \right) q G^a_{\mu\nu} + h.c.,$$

Ways to look for above couplings: 1, direct top quark production; 2, single top quark production; 3, top quark rare decays.

D0, 1006.3575, $BR(t \rightarrow gu(c)) < 2.0(39) \times 10^{-4}$
Direct top quark production at NLO

- We studied the exclusive NLO QCD effects on direct top quark production with subsequent SM decay at the LHC. The QCD effects in the top quark decay part are also included by using the modified narrow width approximation.

Based on our NLO calculations we perform a detailed phenomenology study of the process.
Event topologies and selection: charge lepton + b-tagging jet + missing $E_T$, basic cuts

$$p_{Tl} > 20 \text{ GeV}, \quad p_{Tb} > 50 \text{ GeV}, \quad \not{E}_T > 30 \text{ GeV},$$

$$|\eta_l| < 2.4, \quad |\eta_b| < 2.0, \quad \Delta R_{bl} > 0.7,$$

b-tagging efficiency (50%), mis-identification (8(0.2)%), kinematics smearing

$$\Delta E_l/E_l = 0.1/\sqrt{E_l/\text{GeV}} \pm 0.007,$$
$$\Delta \eta_l = \Delta \phi_l = 0.001,$$
$$\Delta E_{b(j)}/E_{b(j)} = 0.5/\sqrt{E_{b(j)}/\text{GeV}} \pm 0.02,$$
$$\Delta \eta_{b(j)} = \Delta \phi_{b(j)} = 0.01,$$
$$\Delta \not{E}_{T,x(y)} = 0.46 \sqrt{H_T/\text{GeV}},$$

Top quark reconstruction and mass cut, $160 \text{GeV} < m_{r,\text{top}} < 185 \text{GeV}$.

Jet veto to suppress SM single top backgrounds: events with additional jet $|\eta| < 3$ and $p_T > 30 \text{ GeV}$ are vetoed.
### Signal rate (assuming $\frac{\kappa_{tqg}}{\Lambda} = 0.01 \text{TeV}^{-1}$):

<table>
<thead>
<tr>
<th></th>
<th>$\sigma_{LO}$ [fb]</th>
<th>$K_{pro}$</th>
<th>$K_{tot}$</th>
<th>$K_{veto}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$tug$ (L)</td>
<td>148 (40.5)</td>
<td>1.36 (1.32)</td>
<td>1.27 (1.23)</td>
<td>0.91 (0.96)</td>
</tr>
<tr>
<td>(R)</td>
<td>164 (41.3)</td>
<td>1.34 (1.32)</td>
<td>1.24 (1.22)</td>
<td>0.90 (0.94)</td>
</tr>
<tr>
<td>$tcg$ (L)</td>
<td>21.7 (—)</td>
<td>1.37 (—)</td>
<td>1.27 (—)</td>
<td>0.96 (—)</td>
</tr>
<tr>
<td>(R)</td>
<td>21.8 (—)</td>
<td>1.36 (—)</td>
<td>1.26 (—)</td>
<td>0.95 (—)</td>
</tr>
</tbody>
</table>

### Background rate (calculated to NLO in QCD):

<table>
<thead>
<tr>
<th>[pb]</th>
<th>$Wu(d, s, g)$</th>
<th>$Wc$</th>
<th>$Wbb(bq)$</th>
<th>single top</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$l^+$</td>
<td>33</td>
<td>2.67</td>
<td>0.14</td>
<td>0.632</td>
<td>0.666</td>
</tr>
<tr>
<td>$l^-$</td>
<td>18</td>
<td>2.81</td>
<td>0.077</td>
<td>0.320</td>
<td>0.460</td>
</tr>
<tr>
<td>14 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$l^+$</td>
<td>69</td>
<td>7.60</td>
<td>0.28</td>
<td>2.27</td>
<td>2.02</td>
</tr>
<tr>
<td>$l^-$</td>
<td>47</td>
<td>8.16</td>
<td>0.18</td>
<td>1.33</td>
<td>1.50</td>
</tr>
</tbody>
</table>
Discovery limits at LHC:
Charge ratio $N(\bar{t})/N(t)$ as a probe of generation structure:

[Diagram showing the relationship between $\kappa_{t\bar{c}g}/\Lambda$ and $\kappa_{t\bar{u}g}/\Lambda$ for Tevatron and LHC limits.]
- Lepton angular distribution as a probe of chiral structure:

\[
\begin{align*}
\text{spin left-handed} & : g \rightarrow t \rightarrow q \\
\text{spin right-handed} & : g \rightarrow t \rightarrow q
\end{align*}
\]
Exclusion limits from ATLAS:

\[
\int L \, dt = 2.05 \, fb^{-1} \quad \sqrt{s} = 7 \, TeV
\]

ATLAS

Excluded region

---

\[
\frac{\kappa_{ct}}{\Lambda} \times 10^{-3}
\]

\[
\frac{\kappa_{ugt}}{\Lambda} \times 10^{-3}
\]

Observed

Expected

PLB712, 351(2012), \( BR(t \rightarrow gu(c)) < 5.7(27) \times 10^{-5} \)
We also calculated the NLO QCD corrections for FCNC single top quark production, which can be used in LHC single top process analysis.

NLO QCD corrections to top quark FCNC decay are straightforward:

<table>
<thead>
<tr>
<th>Width [in unit of ((\frac{\kappa_{tg}}{\Lambda})^2) TeV² GeV]</th>
<th>LO</th>
<th>NLO</th>
<th>NLO/LO</th>
</tr>
</thead>
<tbody>
<tr>
<td>(t \to q + g)</td>
<td>1.443</td>
<td>1.577</td>
<td>1.09</td>
</tr>
<tr>
<td>(t \to q + \gamma)</td>
<td>0.078</td>
<td>0.071</td>
<td>0.91</td>
</tr>
<tr>
<td>(t \to q + Z)</td>
<td>0.065</td>
<td>0.060</td>
<td>0.93</td>
</tr>
</tbody>
</table>
SM top quark decay $t \rightarrow W(l\nu) + b + X$

- Top quark mass measurement; Search for anomalous top quark couplings through $W$ boson helicity (charged lepton angular distribution) measurement. We calculated NNLO QCD + NLO EW corrections to the fully differential decay width.
Conclusions

- LHC works great. We are almost there for SM Higgs boson. All the measurements agree well with the SM predictions.
- LHC has set very strong limits for low energy supersymmetry and other exotic physics.
- It may imply that new physics lies beyond LHC energy threshold. More likely we would find their hints through virtual effects.
- Thanks to the great job from experimentalists, experimental errors keep going down. On another hand, uncertainties of theoretical predictions will become more and more important.