Notes from SUSY2018 Conference

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Abstract

Here come the abstract

Contents

1 Collider physics

1.1 Precision calculations and generators

Plenary session - presentation

- **Main ingredients:**
  - notion of *fixed order*, *matched* and *merged* (pros and cons to be identified)
  - NLO fully automatized “NLO revolution”, but NNLO is possible only for $(2) \to (2)$ process
  - importance of mixed-coupling perturbative developpement, especially in tails of distributions (not trivial interplay of higher-order QCD and EW corrections) .
  - This starts to be relevant for EFT parametrization of new physics (mixing between α_s and $1/\Lambda$).

1.2 Precision measurements in the top quark sector

Plenary session - presentation

- **Main ingredients:**
  - two interactions to study: top-gluon vertex and top-W-bottom vertex
  - general strategy: assume one is standard and probe deviation for the other
  - spin correlation for top-gluon interaction (production) and relies on bare top quark decay since the spin information is not diluted in the hadronisation
  - W helicity for top-W-bottom interaction (decay)

1.3 SUSY searches at the LHC

Plenary session - presentation 1, presentation 2

- **Main ingredients:**

- chargino and neutralino are mixing of bino, winos, higgsino
- stong production versus electroweak production
- electroweak cross-section are very small and only started at Run 2
- simplified model (*ie.* 100% BR) are assumed in 2D limit plots, but this doesn't directly rely to nMSSM exclusion
- interesting idea: CMS has low pT trigger with 2 kHz rate but don't record all the information of the event, allowing to keep the statistics at low pT.

1.4 Jet rate and jet/gluon tagging

Models, Phenomenology and Experimental Results 1 - presentation

- **Main ingredients:**
  - good understanding of quark-jet and gluon-jet emission fraction using *functional generation*
  - computation of gluon/quark jets probability for $uu \to uu$, $gg \to gg$ and $gu \to gu$
  - mention of scale invariant structure from QCD in jets based on η, ϕ plane

1.5 Overview of flavour anomalies

plenary session - presentation

- **Main ingredients:**
  - two main anomalies summarized here:
    1. $B \to D^{(*)} \ell \nu$ probing lepton universality with τ and e/μ at the tree level through the ratio between $\ell = \tau$ and $\ell = e/\mu$ BR (R_D).
    2. $B \to K^* \ell^+ \ell^-$ probing lepton universality between e and μ at the 1-loop FCNC level, using angular distribution (*e.g.* P_5) and ratio of BR in $\mu\mu$ and ee (R_K).

Anomaly observed in $B \to D^{(*)} \ell \nu$

Angular anomaly observed in $B \to K^* \ell^+ \ell^-$

Anomaly observed in $B \to K^* \ell^+ \ell^-$

- Attempt to explain it using two main approaches: standard model effective field theory with dimension 9 and 10 operators, and direct model building approach based on coloured neutral boson coupled to $\tau - \mu$ or lepto-quarks.

- Suggestion of other observables to measure in order to better identify which scenario is actually realized (*e.g.* $pp \to \tau\tau + X$ and $B \to K^* \tau\tau$).

2 Theoretical approaches

2.1 3rd generation prediction with SUSY+VLQ

Models, Phenomenology and Experimental Results - presentation

- predicts y_t, y_b, y_τ & 3 gauge couplings α_i using IR fixed points
- *fixed points* is way to naturally stabilize quantum corrections for the UV region, but IR gives a natural values (Asymptotic Safety Beyond the Standard Model, LIO2016)
- start at the GUT scale and run depending on the particle content → explain 6 constants!
- drawback: doesn't deal with 1st and 2nd generation (too light)

2.2 New ideas in BSM

Plenary session - presentation

- **Main ingredients:**
  - EFT of the SM with interesting operator counting depending on the dimension, and it can be *pretty large* (see figure later)!
  - Dimension 5 are called Weinberg operators and dimension 6 was studied extensively. They are fairly understandable (tri-gauge couplings, correction to the Higgs potential, correction to the Higgs-gluon couplings)
  - One new idea to face hierarchy issue is to assume that *electro-weak scale comes from inflation scenario* by adding one field which quickly relax and makes the Higgs potential with a minima.
- **Pros & cons of EFT**
  - General and relatively agnostic parametrization of new physics
  - No new (explicit) degree of freedom

Number of operator for each dimension (3 and 4 generations)

2.3 Constraining low energy EFT SM with DUNE

BSM aspects of flavour physics - presentation

- **Main ingredients**

- effective theory at low energy (weak EFTSM) integrating out heavy fields
- prediction of neutrino-quark and neutrino-lepton interaction
- expected precision from DUNE for three types of process is translated in term of wEFTSM coefficients:
  1. neutrino dffusion over coulomb field of nuclei $\nu \rightarrow \nu \ell^+ \ell^-$
  2. neutrino-electron diffusion $\nu e \rightarrow \nu e$
  3. neutrino-nucleon diffusion $\nu N \rightarrow \nu N$

2.4 Neutrino masses with radiative corrections

BSM aspects of flavour physics - presentation

- **Main ingredients**
  - assumes that only the 3rd heavy right-handed neutrino at the planck scale, namely M=diag(0,0,M)
  - off diagonal terms are generated radiatively from the Planck scale to SM scale, *without any assumption at intermediate scale*
  - what prediction can be tested experimentally: not so clear

3 Cosmology

3.1 Observational cosmology

plenary session - presentation

- **Main ingredients**
  - Review of current measurements based on
    1. cosmic microwave background (CMB)
    2. super noaves (SN), weak gravitational lensing (WL)
    3. baryon acoustic oscillation (BA).
  - Introduction of a "new" observable σ_8 probing large structure flucutation ($\sigma_8 \equiv$ RMS of mass in sphere of $R = 8H^{-1}$Mpc)
  - Constraints starts to be sensitive to neutrino total mass, so results are presented with both floating mass and fixed mass.
- **Emphasis on H_0 tension and precision measurement**
  - there is a $\sim 3\sigma$ tension between SN-based and CMB-based measurements
  - trying to find new data to arbitrate like "distance ladder with BAO"

- how to reach 1% precision on H_0? Inlarge cepheid parallax measurements, include lens time delay, cluster count (mass) and *gravitational waves created by binary system*! Precise measurement could constrain neutrino mass.

Precision on Hubble constant versus time for two classes of measurements

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Impact of few cosmological paramter on the tension

Probability of H_0 value infered on GW of binary system, which a fully idependant measurement of the universe expension

3.2 Last PLANCK results

plenary session - presentation

- **Main ingredients**
  - Legacy data analyzed: constraints/measurements are obtained for
    1. ΛCDM model based on the angular structure of the temperature fluctuations
    2. polarization anisotropies (only E mode), which is a new & difficult measurement (polarizaton come from spin-dependant inverse compton diffusion of CMB photon on matter)
    3. inflation scenario and properties (power spectrum of the fluctuations $P(k)$ where k is the spacial frequency of the fluctuations
    4. sensitivity to weak lensing (CMB photons sentivite to dark matter density between last surface scattering an now), using the four correlation point function (angle-angle correlation function). Weak lensing also convert E-mode into B-mode - which can also be used
    5. Effective number of neutrinos and mass, and correlation with H_0/σ_8 tension
  - Precision of parameter reaching the sub-percent level!

Model parameter	Mean	Std dev	Rel. err.
$\Omega_b h^2$ Baryon density	0.02237	0.00015	0.007
$\Omega_c h^2$ Dark matter density	0.1200	0.0012	0.01
100θ CMB acoustic scale	1.04092	0.00031	0.0003
τ Optical depth to reionization	0.0544	0.0073	0.13
$\ln(A_s 10^{10})$ Primordial amplitude of perturbation	3.044	0.014	0.007
n_s Primordial Scalar spectral index	0.9649	0.0042	0.004
H_0 Hubble parameter today	67.36	0.54	0.008
Ω_m Total matter density	0.3153	0.0073	0.023
σ_8 Matter perturbation amplitude	0.8111	0.0060	0.007

Impact of effective number of neutrinos on H_0

Measurement of the power spectrum index n_s *(defined as* $P(k) \sim k^{n_s}$ *versus time.* $n_s = 1$ *implies inflation but* n_s *has to be lower than 1 to have a end to the inflation phase. This conclusion is very general and additional dependency of power spectrum can be checked, like* $n_n(k)$ *or addional* $\ln(k)$ *term*

Correlation between the effective number of neutrinos, the hubble constant and matter perturbation amplitude. Reducing the tension of H_0 *is possible by increasing* N_{eff} *but then it degrades* σ_8

Weak lensing measurement on CMB photons based on four-point correlation function (ie angle-angle correlation function)

- Presentation of internal anomalies and tension with other experiments, such as:
  - low part of the angular spectrum which is not understood (large angle correlations), so called *lack of power* issue
  - odd-even asymmetry showing different structures for odd ℓ and even ℓ, which is not expected in the current predictions.

3.3 Primordial black holes

plenary session - presentation

- **Main ingredients**
  - these are hypothetical objects with a formation at the early stage of the universe expension
  - formed from a density or a metric curvature fluctuation. Assuming these fluctuations are gaussian, their rate and magnitude can be related to the PBH mass.
  - exisiting constraints says that the density of PBH should be small, leading to some fine tuning of matter density fluctuation paramters
  - LIGO/VIRGO detection of merging BH makes the detection of small PBH possible!
  - Since the origin of super-massive BH (galactic center) is unknown, PBH could be a candidate - which would play a leading role in structure formation
  - possible candidate for dark matter too.

Current exclusions of primordial black holes for different formation rates and masses

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Schematics of masses of objects detected using gravitational waves, and an interesting whole at intermediate masses

3.4 New ideas in inflation

plenary session - presentation

Analogy between particle physics and inflation: correlations functions drives microscopic behaviour of particle interactions that we see with detector, while they might generate original fluctuations that we can detect on earth

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- **Main ingredients**
  - inflation explains how non-causally connected regions get correlated with primordial fluctuations and super fast expansion
  - the talk presented a microscopic approach to explain primodial fluctuations based on (relatively) general assumption
  - particle physics formalism is used, in term of n-points correlation function (*aka* propagator in case of $n = 2$).
  - structure of general 2-points correlation is fully fixed by symetry/locallity/unitarity : need to go beyong *i.e.* 3 and 4-points function
  - Particle creation due to metric curvature (deSitter space in the inflationary phase) appears naturally from mathematical property of the correlation function (continuity)

Basic principle of where these correlations functions manifest, and where do we measure them

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Once analytical structure is studied, a nice paraellel can be done with EFT in particle physics, getting a more complete behaviour of primordial fluctuations structures

- Main drawback of this approach is that predictions are quite blow current experimental sensitivities, but not without reach (with optimistic extrapolations)

4 My personal notes

4.1 Process simulation in HEP

1. Fixed-ordered vs Matching vs Merging (not confirmed)

a. fixed-order this is pure matrix element (ME) calculation with a fixed multiplicity in the final state, *e.g.* no additional hard jet, but additional jets are possible via parton showering (PS)

b. matching this approach corrects parton kinematics generated by PS using the ratio ME to PS prediction in order to match the two prediction in the intermediate region. This works only at LO and allow to have *e.g.* $pp \to t\bar{t} + q\bar{q} + X$ where the X are radiations from PS.

c. merging generate parton either from showering process or matrix-element calculation depending on a given criteria (based on p_T or ΔR or both) to avoid double counting. This can be applied to ME with +1j, +2j, ... +Nj and add all the samples together to have an accurate prediction. This works at NLO too.

Nice talk can be found at TOOL 2017 conference (p.19-20)

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2. What are the key ingredients of the "NLO revolution"?

The "NLO revolution" (*ie.* the automation of NLO differential cross-section computation for any model) was possible using the mathematical structure of the amplitudes:

1. subtraction formalism: enable non-divergent integrands for real corrections. Indeed, real corrections only have IR divergence exactly compensated by IR divergence from virtual corrections. But it's important to be able to compute each contribution independantly.

2. master integrals: enable to reduce 1-loop calculation to a set of standard integral with some coefficients. Those are computable using tensor reduction or unitarty cuts.

3. Matching & merging: enable to exploit most accurate calculations depending on the phase-space region, and group them together to get a final prediction.

4.2 Spin and helicity in top quark physics

How W helicity and top spin correlation analysis are linked?

- W helicity analysis considere every top quark individually and is insensitive to correlation in a given pair
- Spin correlation analysis specifically of the two top in the pair. It is sensitive to the W helicity though.

Mode details

> The two observables are connected simply because of the angular momentum conservation:
>
> $$h \equiv \vec{s} \cdot \vec{p}/|\vec{p}| \ , \ \vec{s}_t = \vec{s}_W + \vec{s}_b + \vec{J}_{W,b}$$
>
> But:
>
> 1. the helicity analysis consider all top quarks together where the *up* and *down* states are averaged. Helicity of W are sentitive to the top quark decay
> 2. the spin correlation analysis looks at the correlation of the top and the anti-top in the same event. It does rely on the W helicity (since what is detected is the lepton coming from $t \to W b \to \ell \nu b$), but it primarily probes the correlation of the top and the anti-top (e.g. (*up*,*up*) or (*down*,*down*)) induced in the production mode.

4.3 Quantum field theory

1. What a dipole moment means for elementary particle?

- This was discussed in the context of the top quark (chromo-electric/magnetic dipole)
- To dig out: look at $e - n$ diffusion with structure functions
- For a given vertex, radiatiative correction or additional interaction can give an effective "structure" which leads to *dipole*

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2. What are Wilson loops and how do they link EFT and operators

- Mentioned everywhere with EFT
- It is a way to intergrate out heavy degree of freedom of the theory

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3. What is the dimension of an operator and why it's relevant for EFT?

- Based on the dimension of the action $[S] = \hbar = 1$
- Dimension on usual fields can be deduced

$$[\phi] = 1 \ , \ [\psi] = 3/2 \ , \ [A_\mu] = 1 \ , \ [D_\mu] = 1 \ , \ [g_{\text{gauge}}] = 0.$$

- Dimension of a lagrangian term encodes information about divergences, and then renormalizability: $[g] < 0$ is not renormalizable

- EFT consist in adding non-renormalizable term:

$$\mathscr{L}_{\text{EFT}} = \sum_{d,i} \frac{c_i^d O_i^d}{\Lambda^{d-n}} = \sum_d \frac{\mathscr{L}_d}{\Lambda^{d-n}} = \mathscr{L}_{d\leq 4} + \frac{\mathscr{L}_5}{\Lambda} + \frac{\mathscr{L}_6}{\Lambda^2} + \ldots$$

Detailed informations

> The dimension of an operator (or interaction term in the lagrangian density) is given by the dimension of the action S which $\hbar$ or 1 in natural unit:
>
> $$S = \int \mathscr{L}(x)\, \mathrm{d}^n x$$
>
> Then, the dimension of lagrangian density is n ($n = 4$ in the SM). It is possible then to get the dimension of every field (scalar, spinnor, vector) and their derivatives and coupling g, based on $[\mathscr{L}] = n$:
>
> $$[\phi] = 1\,, \quad [\psi] = 3/2\,, \quad [A_\mu] = 1\,, \quad [D_\mu] = 1\,, \quad [g_{\text{gauge}}] = 0.$$
>
> The last equality is related to renomarlisabitlity of the a theory (by counting momenta power in a an amplitude including loops): $[g] < 0$ means that the theory is not renormalizable. EFT is a parametrization based on interaction terms (operators) of dimension d divided by a cut-off scale Λ^{d-n} so that $[\mathscr{L}] = n$:
>
> $$\mathscr{L}_{\text{EFT}} = \sum_{d,i} \frac{c_i^d O_i^d}{\Lambda^{d-n}} = \sum_d \frac{\mathscr{L}_d}{\Lambda^{d-n}} = \mathscr{L}_{d\leq 4} + \frac{\mathscr{L}_5}{\Lambda} + \frac{\mathscr{L}_6}{\Lambda^2} + \ldots$$
>
> where terms with $d > 4$ are not renomarlizable (divergences when $\Lambda \to \infty$ can't be absorbed by a finit number of redefinition) and are valid only for momentum lower than Λ. A nice review can be found in arXiv:1804.05863.
>
> Apprently dimension 5 operators are knows since the 80's and contains neutrino masses and oscillations. The number of operators for a given dimension can quickly explode (cf. figure).