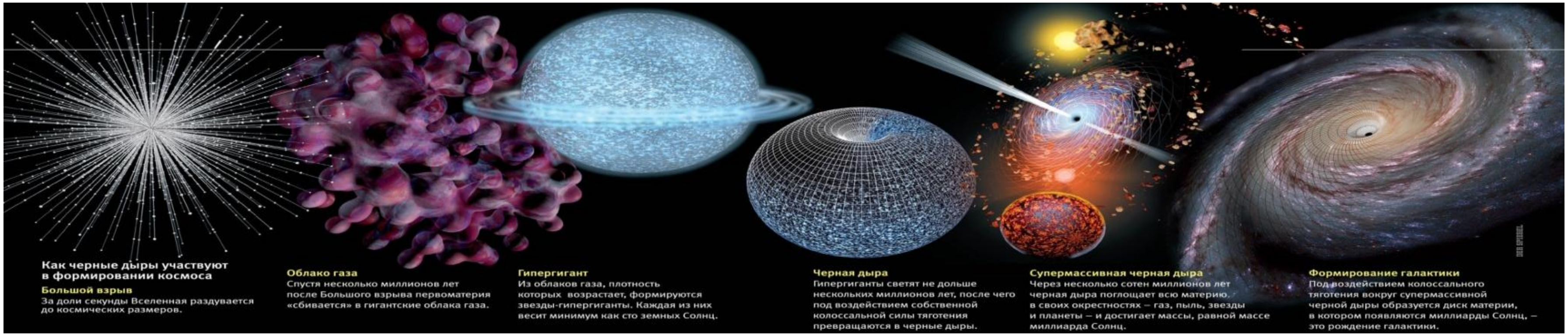
The search for Quantum Black Holes at the LHC energy of p-p collisions of $\sqrt{s}$=13 TeV

speaker: Z.M. Karpova

JINR, Dubna, RUSSIA

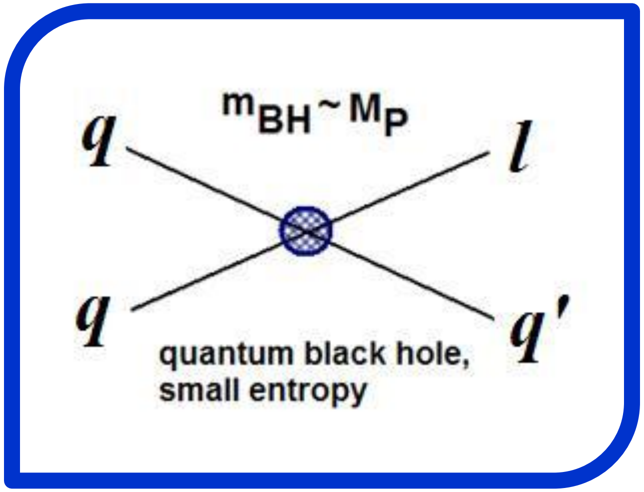
Outlook

1. **Introduction (*motivations to searching for Quantum Black Holes*).**
2. **From Astronomy to Quantum Black Holes.**
3. **Model with extra space dimensions: ADD.**
4. **Expected discovery of QBH in low scale of gravity at the LHC energy of proton-proton's collisions of √s=13 TeV.**
5. **Analysis of the ATLAS data at √s=13 TeV.**
6. **Summary.**



1. Introduction-1

The brief theoretic view on the possibility of observations of Quantum Black Holes at the LHC will be considered in some first points. The search assumes the sensitivity of ATLAS to the TeV scale gravity and to quantum black holes in final states with leptons and jets. In this case mass range of the multidimensional mass M_D is equal or less of the ~10 TeV. According to the ADD model with large extra dimensions the discovery reach is expected to be able due to the increase of the proton-proton-collisions energy at the center-of-mass from 8 to 13 TeV and due to the high enough luminosity (36.1 fb^{-1}) of the LHC in 2015-2016.



- **Motivation for starting of searching for Quantum Black Holes (QBH) has origin in a problem of hierarchy in Standard Model of elementary particles.**

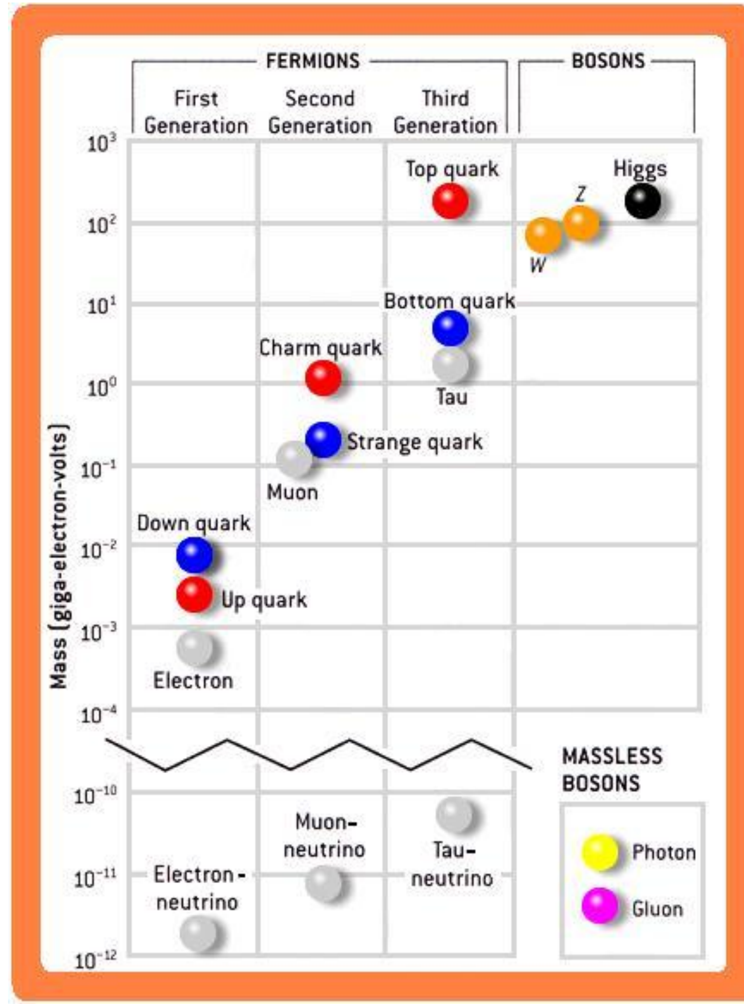
1. Introduction-2

The hierarchy problem: ***masses of three generations fermions (leptons and quarks) differ between themselves in ten times and more. But other properties of the particles and their quantum numbers are identical.***

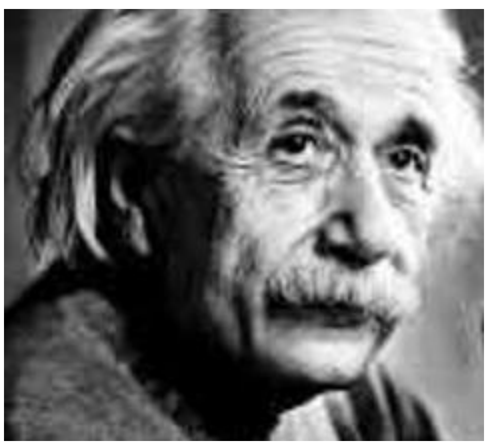
❑ What we can do?

We can take into account some assumptions. The reasons of the hierarchy problem one can search in following:

- Existence of the additional spontaneously-violation of global symmetry, which is linking **the generations of the fermions.**



- **Existence of Multi-Dimensional model of the Universe.**



"We can not solve problems, using the same type of mentation…"

2. From Astronomy to Quantum Black Holes - 1

S. Chandrasekhar,
The Mathematical Theory of Black Holes

• In the of thirties of 20th century young Indian physicist-theorist Subrahmanyan Chandrasekhar, working with the theory of "white dwarf stars", has formulated the important consequence (from *Pauli exclusion principle*). If a mass of a star more of the limit equaling about 1.4 mass of the Sun, then the gravitational forces will be more strong than the pressure forces of degenerate gas, and the collapse of star will be continuing. This mass of **$M=1.4\ M_{Sun}$** is named **«a limit of Chandrasekhar»**.

• However more massive stars will continue squeeze, up to flashing of supernova.

• The destiny of a star is determined by its mass and the basic processes of burning of a star. After complete burning-out all thermonuclear fuel the massive star can be transformed into a black hole.

• About fifty years ago the quantum theory of black holes generated whole direction of development in the quantum-field theory. The black hole is a such physical object, in which *the concepts of Geometry of Space-Time, the Quantum Theory of a Field and Thermodynamics together merge.*

• The question (*S. Hawking*) about possible existence of the primary black holes with a small mass ~ **$(10^{12} – 10^{23})$kg**, formed at early stages of the cosmological expansion, and their influence on the subsequent evolution of the Universe still costs on the agenda. Dynamics of formation and decay of such black holes depends on assumptions concerning *the properties of elementary particles* at ultrahigh energies up to **10^{19} GeV**. ➔ **Here the Cosmology and the Physics of Black Holes are jointed with the Theory of Elementary Particles.**

2. From Astronomy to Quantum Black Holes - 2

❑ Types of black holes

A. Black holes of star masses ($\geq 3 \div 10\ M_{Sun}$)

They observed like flashing of supernova.

B. Supermassive black holes ($\geq [3 \div 6]\cdot 10^5\ M_{Sun}$)

As a rule they form the active galactic nuclei. The closest to the Sun massive black hole in a nucleus of our Galaxy is *Sagittarius A* (with mass of 4,31•10^6 M_{Sun}).* Coma Berenices contains *galaxy NGC 4889*, which has SBH *(with mass of 21•10^9 M_{Sun}).*

C. Primordial black holes ~($10^{12} \div 10^{23}$) kg

Idea about origin of Black Holes with a small mass ~(10^{12}–10^{23}) kg at an initial stage of the Universe formation simultaneously with Big Bang was proposed by English physicist *Stephen William Hawking.* Black Holes can be evaporating with thermal photons. Last stage of a life of such black hole - explosion. The effect is not yet confirmed by observations.

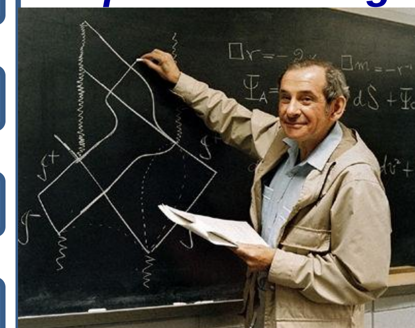
D. Microscopic (thermal) black holes ($\geq 1 \div 10$) TeV/c^2

Search for them was made at the energy of pp-collisions of $\sqrt{s}$=8 TeV and at $\sqrt{s}$=13TeV in the framework experiment ATLAS at the LHC. There was no excess.

E. Quantum black holes ($\geq 1 \div 10$) TeV/c^2

Search for QBH made at the energy of pp-collisions of $\sqrt{s}$=8 TeV. Now experiment is yet continued at $\sqrt{s}$=13 TeV in the framework experiment ATLAS at the LHC.

Stephen Hawking



Karl Schwarzschild

Georges Lemaitre

2. From Astronomy to Quantum Black Holes - 3

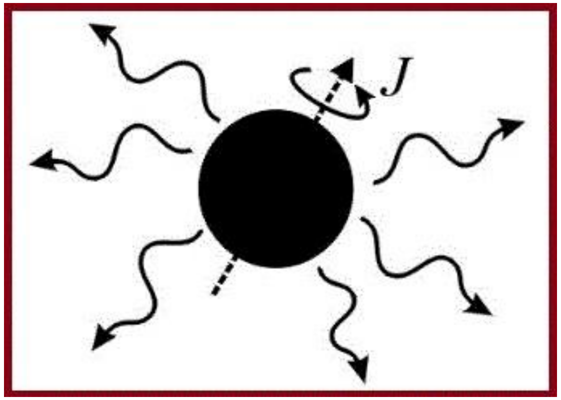
- **Maximon** (1965) is a particle with upper limit mass of elementary particles. Maximon has maximum mass in the mass spectrum of elementary particles:

$$M_P \approx 1.2209 \cdot 10^{19}\ GeV/c^2$$

- **Maximons** can be hot or cold (with internal temperature of ~absolute zero), and have a spin. They can be electrically charged or neutral.
- **Maximons** can look like Black Holes.

Markov M. A.

Kip Thorne



Characteristics of black holes

Characteristics of Black Hole (BH) are Mass (M), Electrical charge (Q), Angle moment (L) and Color charge (C). BH has no a metric radius, but only gravitational radius. This feature called – "BH has no hairs" (theorem).

A. **Mass** – main characteristic of Black Hole (see previous slide).

B. **Electrical Charge** – is defined by charge of initial particles.

C. **Angle Moment** – is defined by rotation of BH.

D. **Color charge** – is defined by colored objects of BH.

3. Model with extra space dimensions: ADD* - 1

JINR

ATLAS

ADD-model. Extra space dimensions are equal **n=6.** Total number of dimensions D=n+(3+1)=**9+1**. Every extra space dimension is sufficiently large with R~0.01 mm. QBH is a multidimensional object like a quasi-particle. QBH is a massive resonance can decay into some well detected usual particles. Strong gravitation interactions do not need to conserve the global symmetries of the Standard Model. However, the local gauge symmetries of QCD color and electric charge are conserved. We do not make any similar assumption about global charges like baryon and lepton number. Only the gravitational field is allowed to penetrate the n extra dimensions. All the SM fields are localized in the usual four-dimensional space-time. Gravity is stronger at small distances. Event horizon for M_{QBH} ~TeV is r_g *(and according to Model ADD, ~M_D^{-1}).*

(*) Model ADD is offered by authors: Arkani-Hamed, Dimopoulos, Dvali

The multi-dimensional mass scale is assumed approximately equal to the electroweak scale $M_D \approx M_{EWK}$ ~1 TeV for removing the hierarchy problem. The true Planck scale (4-dimentional) is equal M_{Pl}~10^{16} TeV. It is related to multi-dimensional mass M_D according to formula:

$$M_{Pl}^2 \sim M_D^{2+n} R^n \tag{1}$$

- **where n – number of extra dimensions (n = 6 in our case). Extra spatial dimensions are large. According to the ADD scenario it is expected, that the microscopic black holes should form, when collisions energy will exceed a certain threshold mass M_{th}. It can be some above M_D, but far below M_{Pl}.**
- **Case of Quantum Black Hole. If QBH forms near threshold M_{th}, then they can decay into the two-body final states. The production of QBH close to M_{th} dictates a resonant final state with an observable excess for a certain invariant mass. Therefore, we will search for a "bump" in spectrum of lepton-jet invariant mass M_{inv}.**

[*] Douglas M. Gingrich, Quantum black holes with charge, color, and spin at the LHC, arXiv:0912.0826v4 [hep-ph] 13 Jul 2010

3. Model with extra space dimensions: ADD - 2

➢ **Key moment: Production of Quantum Black Holes,** [*]

❖ Quantum Black Holes (QBH) can be classified according to their $SU(3)_c$ and $U(1)_{em}$ representations. For proton-proton collisions at **LHC** the allowed particles forming the QBHs are ***quarks, antiquarks and gluons***. And also 9 possible electric charge states can be formed: **±4/3, ±1, ±2/3, ±1/3, 0**.

-- The ±4/3 charge state can only be formed by ***quark pairs***.
-- The ±2/3 charge state can be formed either by ***an antiquark-antiquark or a quark-gluon pair.***
-- The ±1/3 charge state can be formed either by ***a quark-quark pair or an antiquark-gluon pair.***
-- The ±1 charge state can only be formed by ***a quark-antiquark pair.***
-- The 0 charge state can be formed by ***a quark-antiquark or a gluon-gluon pair.***

❖ A priori the cross section for QBH production is not known. Based on classical arguments and only one available scale, the cross section is most often taken such, that to be the geometrical cross section:

$$\sigma \sim \pi r_g^2, \qquad (2)$$

where r_g is the **gravitational radius** of the *two-particle system*.

[*] Douglas M. Gingrich, Quantum black holes with charge, color, and spin at the LHC, arXiv:0912.0826v4 [hep-ph] 13 Jul 2010

3. Model with extra space dimensions: ADD - 3

➢ **Key moment:** **Production of Quantum Black Holes**

❖ Then the gravitational radius $\mathbf{r_g}$ of a quantum black hole of mass M is:

$$r_g = k(D)\frac{1}{M_D}\left(\frac{M}{M_D}\right)^{\frac{1}{D-3}}, \qquad (3)$$

where D is the total number of Spacetime Dimensions, and $k(D)$ is a numerical coefficient, depending on the number of dimensions and the definition of the fundamental Plank scale (for low gravity scale). At energies of the fundamental Plank scale M_D, the sizes in Spacetime of the incoming partons and the gravitational radius r_g of the QBH are both of order M_D^{-1}. If Γ is a width of the QBH resonance, for PDG the definition of the Planck scale we have:

$$k(D) = \left(2^{D-4}\sqrt{\pi}^{D-4}\frac{\Gamma\left(\frac{D-1}{2}\right)}{D-2}\right)^{\frac{1}{D-3}}. \qquad (4)$$

❖ Some fraction of the total centre-of-mass energy $\sqrt{s}$ in a proton-proton collision is available in the hard scattering process. One can define $sx_a x_b = sx_{min} = \hat{s}$, where x_a and x_b are the fractional energies of the two partons relative to the proton energies. The full particle-level cross section is given by:

$$\sigma(QBH^q_{p_1 p_2}) = \sum_{a,b}\int_{M^2/s}^{1} dx_{min}\int_{x_{min}}^{1}\frac{dx}{x} f_a\left(\frac{x_{min}}{x}\right) f_b(x)\pi r_g^2, \qquad (5)$$

where a and b are the parton types in the two protons, and f_a, and f_b are the parton distribution functions (PDFs) for the proton. The sum is over all the possible quark and gluon pairings that can make a particular quantum black hole state, [*].

3. Model with extra space dimensions: ADD - 4

➢ Key moment: Decay of Quantum Black Holes

• Fluctuations of the mean multiplicity can be described using a Poisson distribution. The Poisson distribution can also be used to estimate the relative probabilities of two-particle, three-particle, etc. final states. Approximately 50% of the decays of QBH are two-particle, while three-particle and four-particle decays are not insignificant, where the multiplicities depend on the definition of the Planck scale.

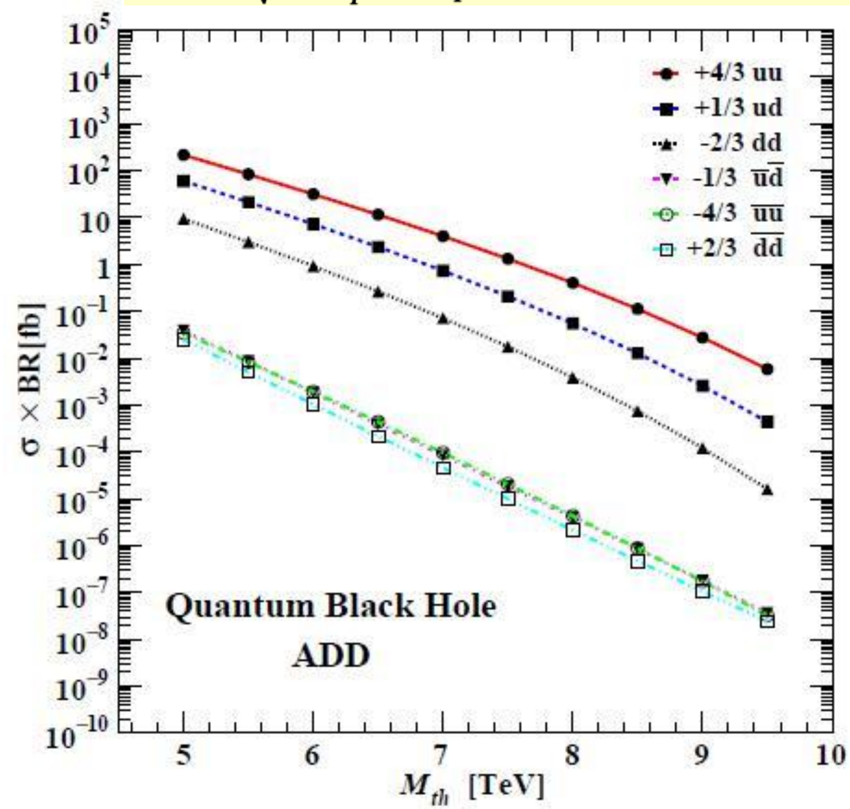
For the Dimopoulos-Landsberg definition in the case of ***D=10*** the **Probability of a two-particle decay of QBH is about 80%.** ⟺

$$R_S = \frac{1}{\sqrt{\pi} M_P}\left[\frac{M_{BH}}{M_P}\left(\frac{8\Gamma(\frac{n+3}{2})}{n+2}\right)\right]^{\frac{1}{n+1}}$$

❑ 14 states of QBH are possible, in which six states can decay to a lepton and a jet,[*]:

- ➢ ***u + u → QBH$^{+4/3}_{uu}$ → e$^+$ + dbar;***
- ➢ ***dbar+ dbar → QBH$^{+2/3}_{dbardbar}$ → e$^+$ + d;***
- ➢ ***u + d → QBH$^{+1/3}_{ud}$ → e$^+$ + ubar;***
- ➢ ***ubar + dbar → QBH$^{-1/3}_{ubardbar}$ → e$^-$ + u;***
- ➢ ***d + d → QBH$^{-2/3}_{dd}$ → e$^-$ + dbar;***
- ➢ ***ubar + ubar → QBH$^{-4/3}_{ubarubar}$ → e$^-$ + d.***

Cross-section for QBH$_{qq}$ state about > 10^2 times higher , than cross-section for QBH$_{qbarqbar}$ state.

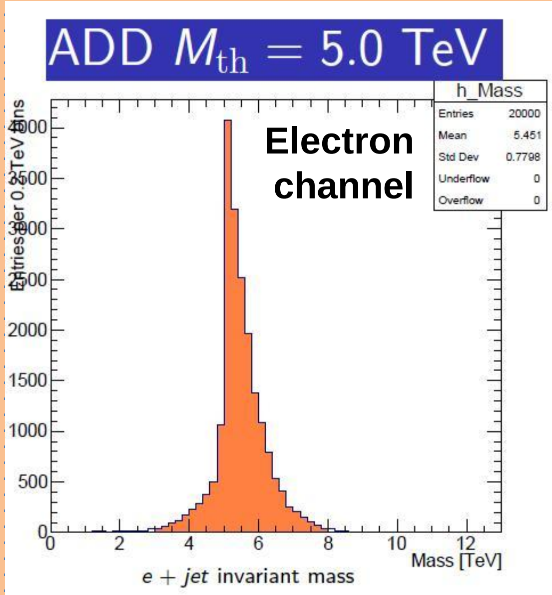


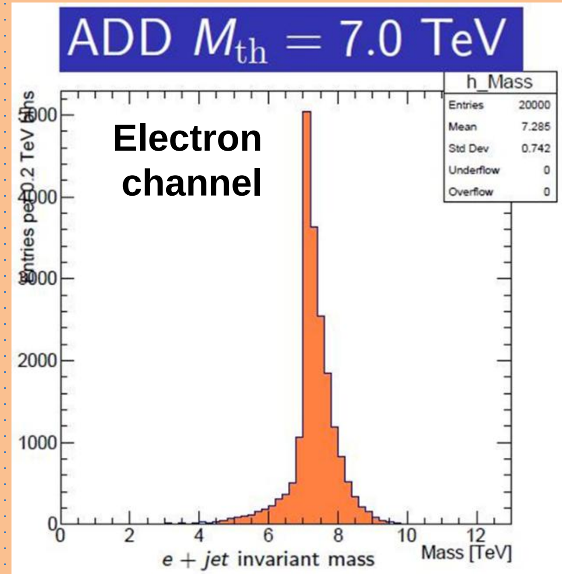
- **11% branching fraction for *QBH$^{\pm4/3}$*→e + jet**
- **7% branching fraction for *QBH$^{\pm2/3}$*→e + jet**
- **6% branching fraction for *QBH$^{\pm1/3}$*→e + jet**

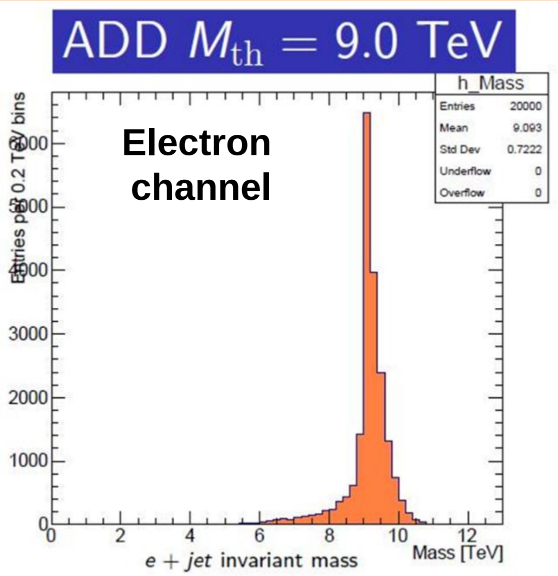
[*] https://indico.cern.ch/event/340438/contribution/0/material/1/0.pdf

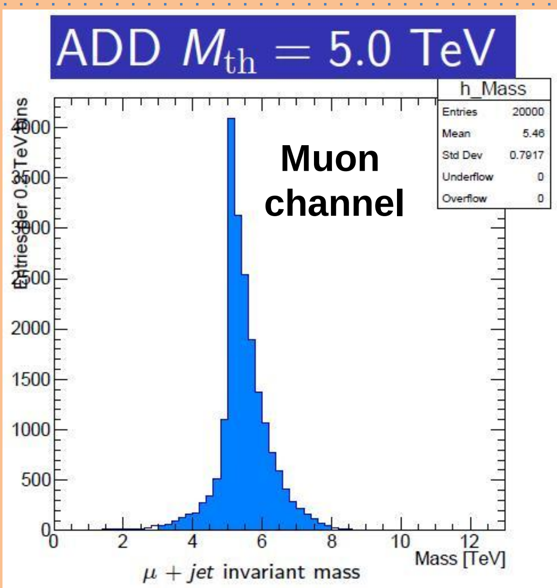
3. Model with extra space dimensions: ADD - 5

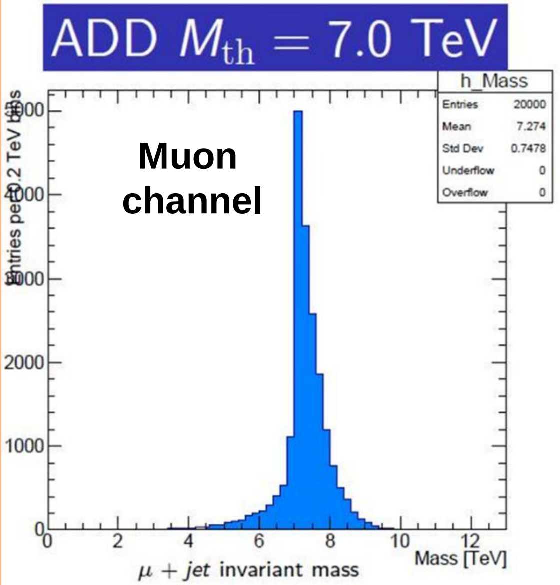
- QBH **Signal** at the ATLAS, M_{th} = (5.0, 7.0, 9.0) TeV

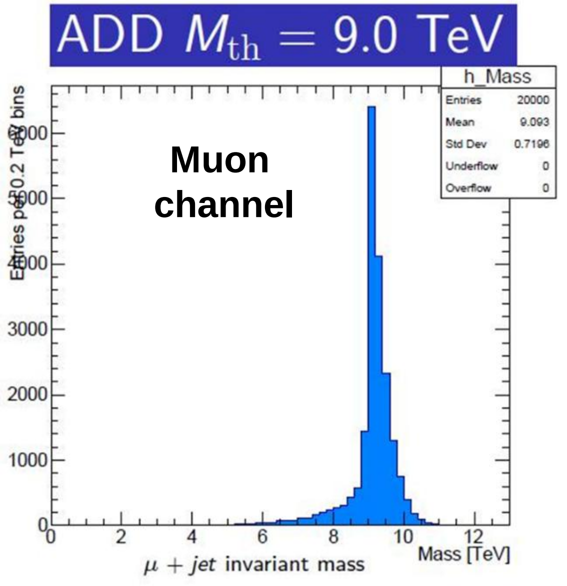












[*] https://indico.cern.ch/event/340438/contribution/0/material/1/0.pdf

4. Expected discovery of QBH in low scale of gravity at the LHC energy of pp-collisions of $\sqrt{s}$=13 TeV

✓ Probability. QBH likes a resonance. For the Dimopoulos-Landsberg definition in the case of D=10 the probability of a two-particle decay is about 80%.

✓ Branching fractions:

for $QBH^{\pm 4/3} \rightarrow e(\mu) + jet$ - 11%

for $QBH^{\pm 2/3} \rightarrow e(\mu) + jet$ - 7%

for $QBH^{\pm 1/3} \rightarrow e(\mu) + jet$ - 6%

(11+7+6)×2=48%

Cross Sections:

$QBH \rightarrow \ell + jet$

$N = \sigma \cdot L \cdot Br \cdot Acc \cdot Eff$

$N(5\ TeV)_{e+\mu} \approx$ 1950+1200 = 3250 evt.

$N(6\ TeV)_{e+\mu} \approx$ 270+160 = 430 evt.

$N(8\ TeV)_{e+\mu} \approx$ 3+2 = 5 evt.

M_{th}	Cross Section		M_{th}	Cross Section	
TeV	pb	pb	TeV	pb	pb
	ADD (n=6)	RS-1 (n=1)		ADD (n=6)	RS-1 (n=1)
3.0	--	0.19	6.5	0.0426	0.000136
3.5	--	0.066	7.0	0.0145	0.0000445
4.0	--	0.00238	7.5	0.0464	0.0000136
4.5	--	0.0087	8.0	0.00139	--
5.0	0.862	0.00317	8.5	0.000376	--
5.5	0.326	0.00114	9.0	0.0000908	--
6.0	0.119	0.0004	9.5	0.0000188	--

Analysis Team:

S.N. Karpov[1], Z.M. Karpova[1], Douglas M. Gingrich[2]

(1) JINR, Dubna, Russia,
(2) Centre for Particle Physics, Department of Physics, University of Alberta, Canada

Exotic Working Group, LPX subgroup (lepton+X)

Literature

[1] N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B 429, 263 (1998), arXiv:hep-ph/9803315.
[2] I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B 436, 257 (1998), arXiv:hep-ph/9804398.
[3] N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Rev. D 59, 086004 (1999), arXiv:hep-ph/9807344.

[4] Douglas M. Gingrich, Quantum black holes with charge, color, and spin at the LHC, arXiv:0912.0826v4 [hep-ph] 13 Jul 2010.

[5] Savas Dimopoulos and Greg Landsberg, Black Holes at the LHC, arXiv:hep-ph/0106295v1 27 Jun 2001.

[6] Igor Volovich, Sakharov's Extra Timelike Dimensions and Hawking's Chronology Protection Principle, 4th International Sakharov Conference on Physics, FIAN, Moscow, May 18-23, 2009.

[7] The ATLAS Collaboration, Search for Quantum Black Hole Production in High-Invariant-Mass Lepton+Jet Final States Using pp Collisions at $\sqrt{s}$=8 TeV and the ATLAS Detector, arXiv:1311.2006v2 [hep-ex] 6 Mar 2014.

[8] Karpova Zoya, Karpov Sergey, ATLAS Collaboration, Search for Quantum Black Holes in Lepton+Jet Final State Using pp-collisions at $\sqrt{s}$ = 8 TeV with the ATLAS, 09 Dec 2015, 5 p., ATL-PHYS-PROC-2015-182.

[9] Karpov Sergey, Karpova Zoya, Gingrich Douglas, ATLAS Collaboration, Supporting note of Search for Quantum Black Holes using pp collisions at $\sqrt{s}$ =13 TeV with the ATLAS, 04 Dec 2016, mult. p., ATL-COM-PHYS-2016-1762.

5. Analysis: Event cleaning and object pre-selection

1. **Data quality and event cleaning:** GRL, problematic regions of the Lar and TileCal, incomplete events, check of primary vertex with ≥2 tracks.
2. **Trigger:** HLT_e26_lhtight_iloose, HLT_e26_lhtight_nod0_iloose, HLT_e60_lhmedium, HLT_e120_lhloose, HLT_mu26_imedium, HLT_mu26_ivarmedium, HLT_mu50
3. **Candidates of electrons ("Baseline"):** "LooseAndBLayerLLH" quality, $|\eta| \leq 2.47$ and $p_T > 10$ GeV after calibration.
   "Baseline" muons: "Medium" quality, $|\eta| \leq 2.7$ and $p_T > 10$ GeV.
   "Baseline" jets: "AntiKt4EMTopojets", JVT cut, $|\eta| \leq 2.8$ and $p_T > 20$ GeV.
4. **Bad Jet Veto:** "LooseBad" condition in the JetCleaningTool package.
5. **Overlap Removal: a)** if $\Delta R(\text{jet,lepton}) < 0.2$ and jet is b-jet, then lepton is removed and jet is kept; if jet is no b-jet, then vice versa jet is removed;
   b) using only remaining jets if $\Delta R(\text{jet,lepton}) < 0.4$, we need to remove the lepton and keep the jet.
5. **Bad muon veto:** muon is "bad", if $\sigma(q/p) / \text{abs}(q/p) > 0.2$.
6. **Cosmic muon veto:** muon is cosmic, if it has a track with $|z_0^{PV}| \geq 1$ mm and $|d_0^{PV}| \geq 0.2$ mm.
7. **Selection of "Final" objects:** isolated lepton with the "GradientLoose" condition, trigger matched and with $p_T > 30$ GeV; good jets with $p_T > 20$ GeV.
8. **Event pre-selection:** one or more "Final" lepton and one or more "Final" jet.

5. Analysis: Selection of events with signal signature

1. There is only **one hard lepton** with **p_T>130 GeV.** There is no one other "baseline" lepton with p_T>10 GeV (with exception of Z+jet control region only).
2. The most energetic **(leading) jet** has **p_T>130 GeV.**
3. All sub-leading **jets, photons and tau-jets** have **p_T<60 GeV** and **E_T^{miss}<60 GeV.** It is condition of hard two-body final state.

Control, signal and validation regions

The control, signal and validation regions are defined with using of **invariant mass M_{inv}** of lepton and leading jet. All these regions are like to that in analysis at 8 TeV.

1. **Control region (CR)** is a **low invariant mass region** with **0.5<M_{inv} ≤1.5 TeV,** and has a negligible contamination of a potential signal (less than 0.3%) for the lowest threshold mass (M_{th} = 5.0 TeV).
2. **Signal region (SR)** is a **high invariant mass region** with **M_{inv}>2 TeV** for both electron and muon channel. Lesser invariant mass is used in comparison with the constraints (M_{th} ≥5.3 TeV) obtained with 8 TeV data, because no events were observed above 2.5 TeV in electron channel and only 1 event was observed above 3 TeV in muon channel.
3. **Validation region (VR)** is situated **between CR and SR** for both electron and muon channels. It is diapason of invariant masses from **1.5 TeV** up to **2 TeV.**

5. Analysis: Background for QBH

MC samples simulated with Sherpa 2.2.1: **W+jets ($W^{\pm} \to e\nu, \mu\nu, \tau\nu$)** sliced on max($H_T$, W_{pT}) (364156-364197), **Z+jets ($Z \to ee, \mu\mu, \tau\tau$)** sliced on max($H_T$, Z_{pT})(364100-364141), di-bosons **WW, WZ, ZZ → lvqq, llqq, lvvv, llvv** (363356, 363358-363360, 363489, 363492, 363493).

MC simulated with Powheg+Pythia+EvtGen: **ttbar** non all hadronic (410000), **Wt** (410013, 410014), **single top** t-channel (410011, 410012) and s-channel (410025, 410026).

Fake leptons background from multi-jet events (QCD) was estimated for electron channel with data-driven matrix method by the **LPXMatrixMethod-00-00-02** package.

Some details of analysis

One's own code of analysis – **QBHLepOneJet** package based on **RootCore EventLoop** and **SUSYTools.** Software versions: **Root Core AnalysisBase-2.4.29 + SUSYTools-00-08-58 + Moriond 2017 recommendations.**

Baseline object selection, overlap removal, calibrations, systematics etc. are used by default as in SUSYTools. Results represented below were obtained with pile-up reweighting, trigger matching, scale factors for signal lepton and b-tagging. These results include systematics.

Data: D-J periods of 2015, L = 3.213 fb^{-1} and **A-L periods of 2016, L = 32.862 fb^{-1}** according to "PHYS_ StandardGRL_All_Good_25ns" Good Runs Lists. In total **L = 36.075 fb^{-1}.**

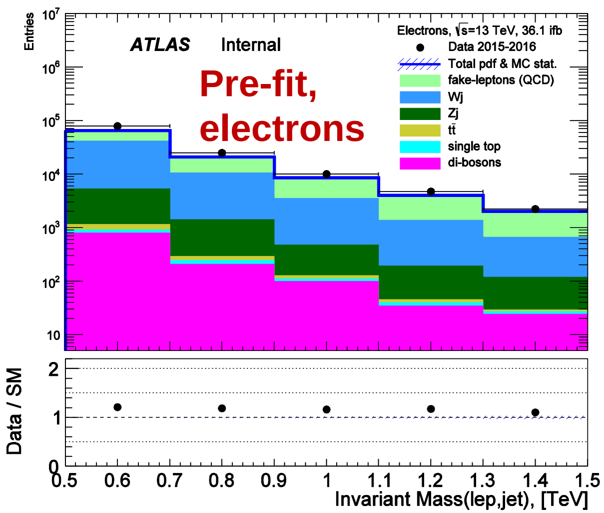
The **SUSY5 derivations** (1-lepton SUSY) is quite suitable for our analysis. The tags of **p2950** for data and **p2949** for the MC samples are the latest bulk production of SUSY5 derivations for Moriond 2017 and for summer conferences.

5. Analysis: Some other features of analysis

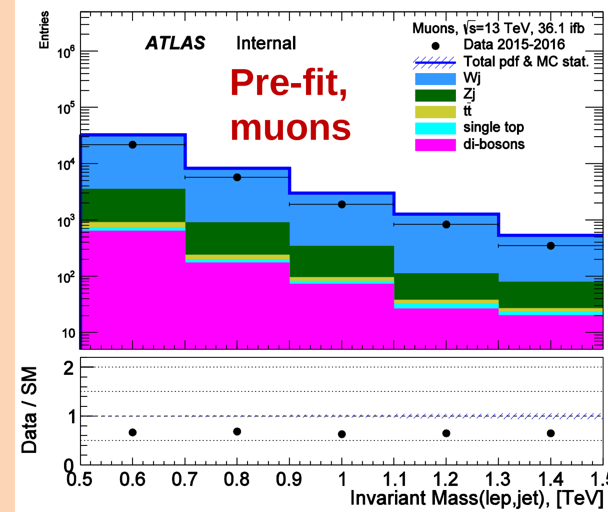
- **Statistical analysis is done with using of the HistFitter package v0.54.0.**
- We use the **W+jet, Z+jet** and **TTbar** control regions **(WCR, ZCR and TCR)** for both electron and muon channels. These samples are normalized and fitted in CRs and extrapolated to VR, because they are main three background modeled by MC.
- **Each control region** is fitted in **5 bins over M_{inv}** (from **0.5 to 1.5 TeV** with step of **0.2 TeV**), what allows us to use shape information of distributions.
- **Systematic uncertainties** are added as nuisance parameters. They are constrained also by the fit with taking into account of mutual correlations.
- **The background-only fit** is applied now: the control regions are used to constrain the fit parameters and to extrapolate distributions into validation region.
- **Small backgrounds** (W+t, single top and di-bosons) are not fitted and used as it is. Nevertheless, small variations within their systematic uncertainties are allowed for better performance of the fit.
- **All MC events are weighted** with following factors:
  totWeight = genWeight * mcEvtWeight * pileupWeight * lepSF * btagSF * jvtSF * tauSF,
  where **genWeight = (σ * L) / (∑mcEvtWeight)** and **lepSF= trigSF * idSF * recSF * isoSF.**
- **Background of fake leptons** is estimated with **data-driven matrix method.** It is not fitted. Special weights are calculated for events selected from the data by the LPXMatrixMethod package. Fake leptons bring a **second-large contribution** in total SM background in some regions in **electron channel.** However, this background can be **neglected for muons.**

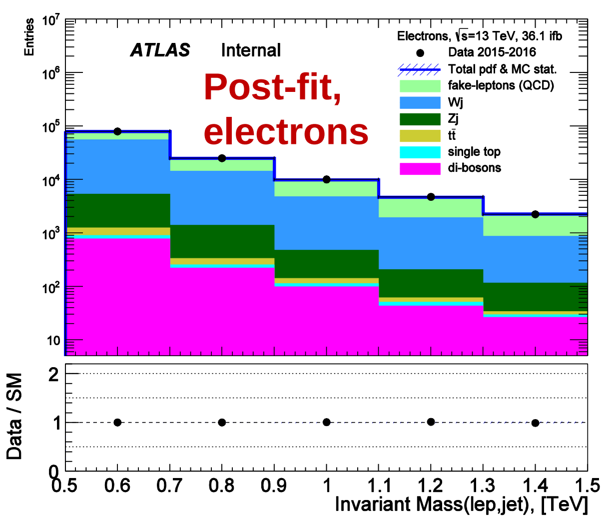
W+jet control region over M_{inv} before and after the fit with HistFitter

Definition of W+jet control region (WCR): 1 lepton with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + $0.5<M_{inv} \leq 1.5$ TeV + b-jet veto

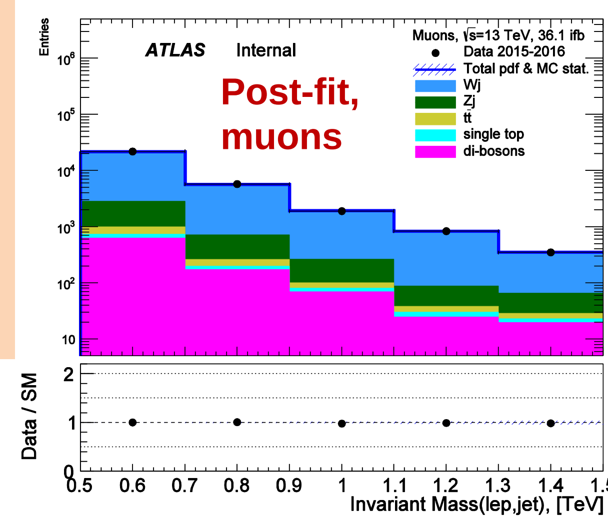


There is small disagreement of MC with data before the fit (upper panels). Some deficit of MC events is observed for electrons and some surplus for muons. But shape of MC and data distributions is very similar in both cases. Difference can be due to not quite correct weights, scale factors or some mis-modeling.



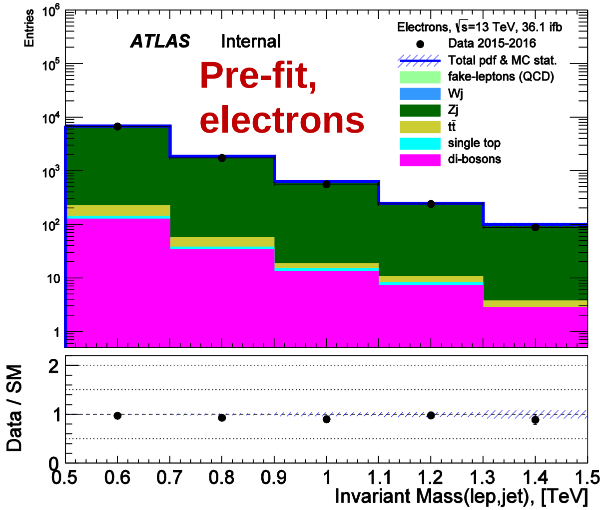


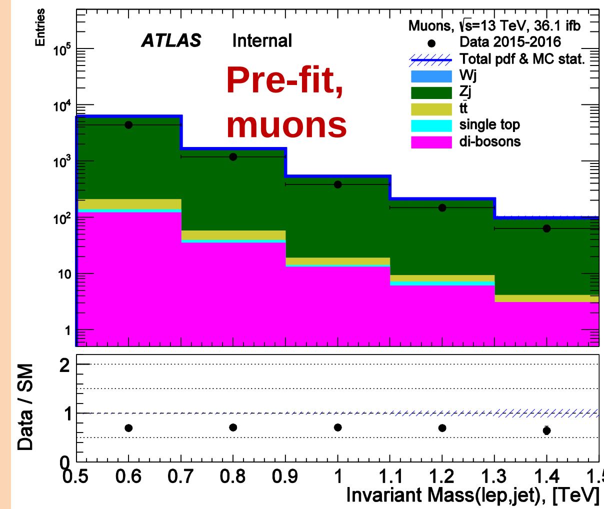
The fit (bottom panels) gives a good agreement within errors and systematic uncertainties in both electron and muon channels.



Z+jet control region over M_{inv} before and after the fit with HistFitter

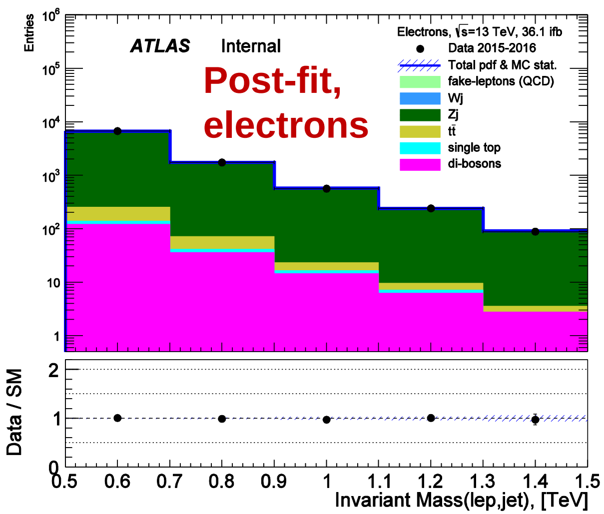
Definition of Z+jet control region (ZCR): 1 lepton with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV+0.5<M_{inv}≤1.5 TeV+second OS and SF lepton

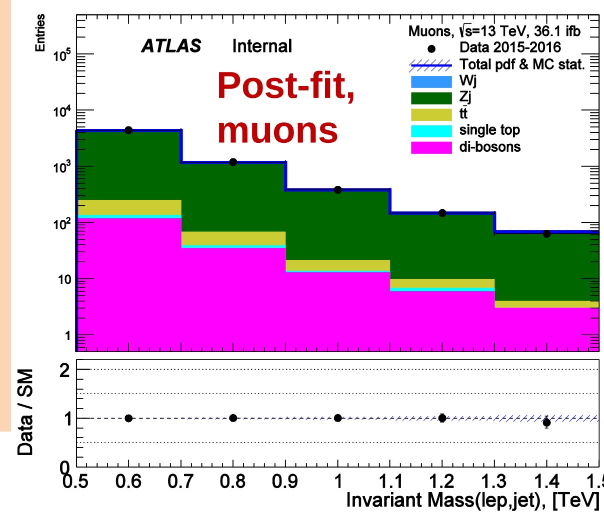




The Z+jet events give main part of background as it is expected in this control region.
The agreement of MC with data for electrons is good even before the fit. But for muons there is some excess of MC above data in whole region of M_{inv}. Shape of distributions is very similar (upper panels).

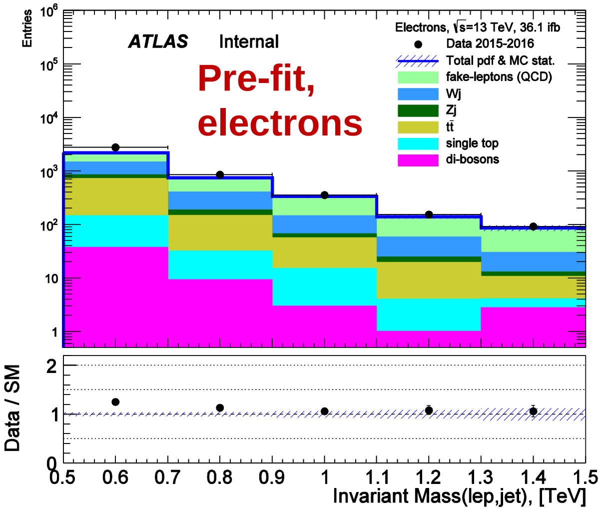
The fit (bottom panels) changes electron distributions slightly and makes accordance a little bit better. Very good agreement of MC with data for muons is obtained also after the fit.

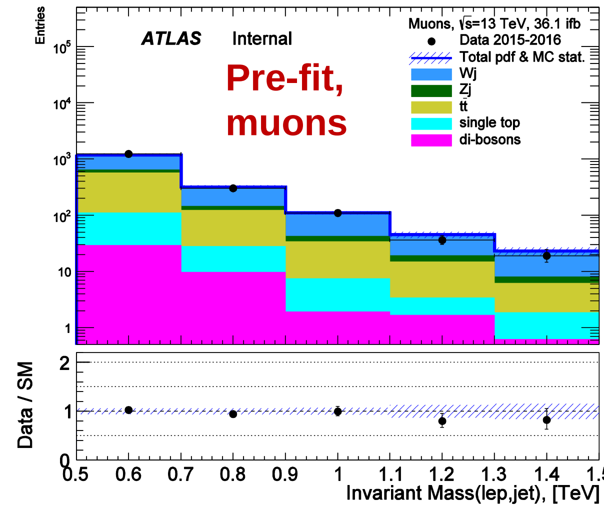




TTbar control region over M_{inv} before and after the fit with HistFitter

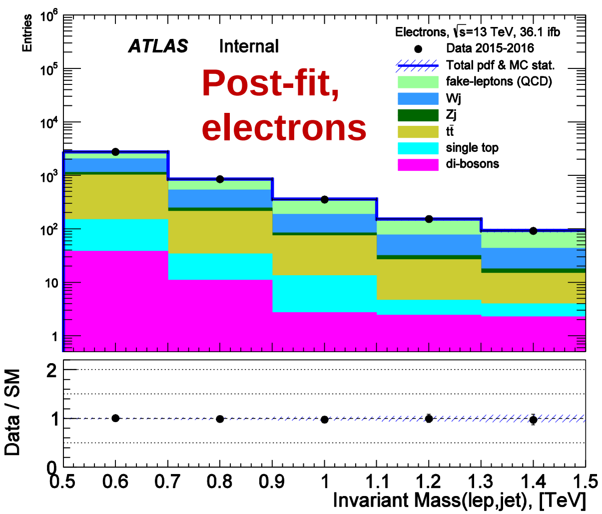
Definition of TTbar control region (TCR): 1 lepton with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + $0.5<M_{inv}\leq 1.5$ TeV + ≥4 final jets + ≥1 b-jet

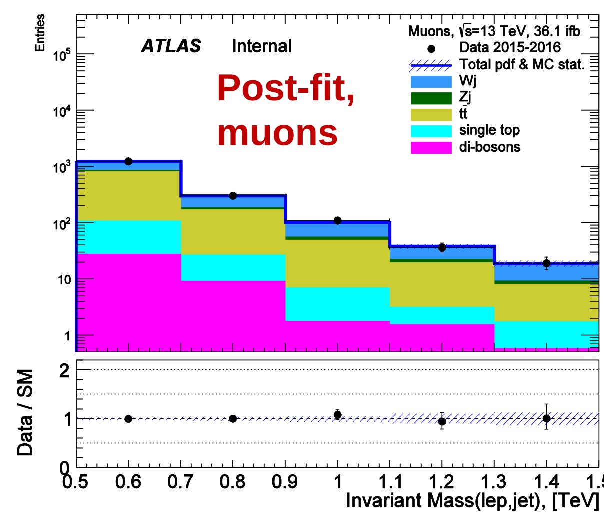




There is some deficit of MC and some disagreement in shape of MC and data distributions before the fit for electrons. One can see a drift up of MC relatively of data with increase of M_{inv}. But for muons the agreement of MC with data is good even before the fit (upper panels).

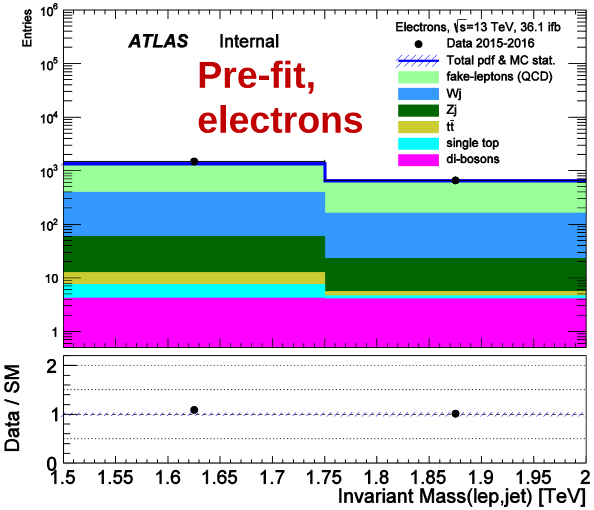
The fit (bottom panels) gives a good agreement for electrons and makes accordance a little bit better for muons too.

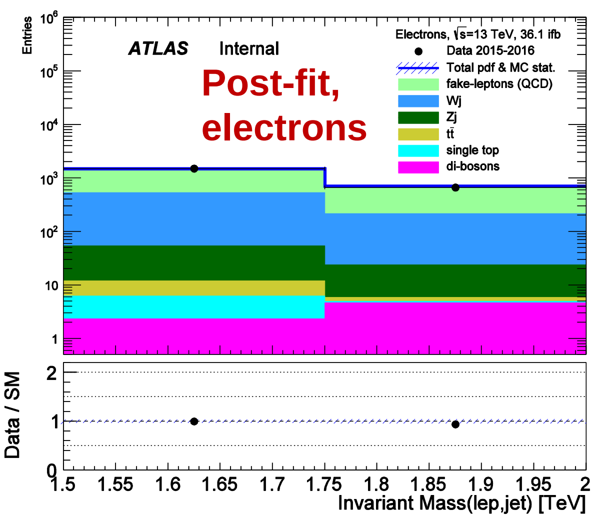




Validation region over M_{inv} before and after the fit with HistFitter

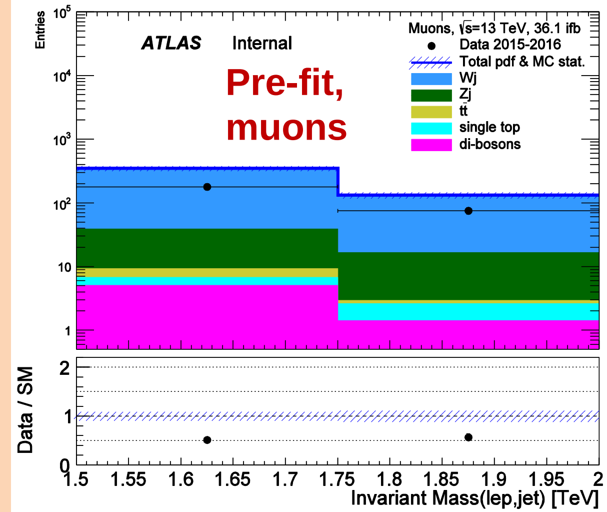
Definition of validation region (VR): 1 lepton with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + $1.5<M_{inv}\leq 2.0$ TeV.

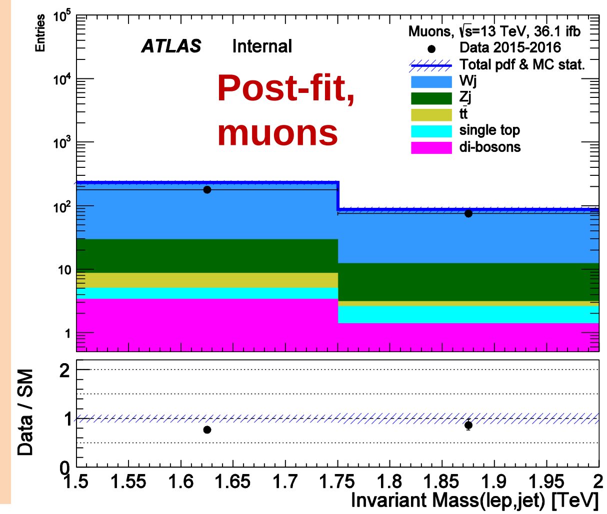




The VR does not fitted directly. It is changed only due to the fit in control regions.
There is good enough agreement of MC with data before the fit for electrons. But for muons there is a visible deficit of data in comparison with MC events before the fit (upper panels).

The fit (bottom panels) changes distributions of electrons slightly. The residual difference is within statistical errors and systematic uncertainties. For muons the fit gives agreement of MC with data significantly better. Nevertheless, small deficit of data events is observed after the fit.





The fitted and MC expected yields for Control and Validation regions of electron channel.

Yield of channel	WCR	ZCR	TCR	VR
Observed events	120580	9308	4188	2141
Fitted bkg events	120530.05 ± 346.85	9308.23 ± 97.54	4198.04 ± 64.83	2188.85 ± 73.14
Fitted dd events	43479.12 ± 409.42	$26.66^{+43.25}_{-26.66}$	1300.24 ± 59.40	1440.57 ± 61.00
Fitted Wj events	69551.01 ± 562.70	6.91 ± 1.03	1371.99 ± 75.64	670.51 ± 27.03
Fitted Zj events	5674.55 ± 116.05	8910.44 ± 107.90	174.97 ± 9.06	59.80 ± 3.96
Fitted Tt events	474.84 ± 104.04	157.05 ± 24.91	1144.46 ± 120.41	6.70 ± 3.00
Fitted sT events	181.41 ± 17.45	25.06 ± 1.65	149.47 ± 13.85	4.27 ± 0.58
Fitted DB events	1169.13 ± 66.79	182.12 ± 10.81	56.91 ± 5.25	7.00 ± 1.23
MC exp. SM events	100869.23 ± 653.84	9723.70 ± 101.51	3495.55 ± 139.21	2006.14 ± 70.82
MC exp. dd events	43062.10 ± 480.55	$39.39^{+54.82}_{-39.39}$	1357.47 ± 82.13	1440.57 ± 61.00
MC exp. Wj events	50241.66 ± 249.78	5.07 ± 0.74	989.05 ± 54.62	482.49 ± 24.56
MC exp. Zj events	5913.81 ± 47.40	9365.38 ± 79.25	187.59 ± 8.81	64.79 ± 3.82
MC exp. Tt events	313.06 ± 35.64	106.22 ± 7.96	759.41 ± 38.11	6.08 ± 1.45
MC exp. sT events	176.70 ± 17.57	24.29 ± 1.61	148.08 ± 16.88	3.82 ± 0.48
MC exp. DB events	1161.91 ± 77.92	183.35 ± 10.64	53.94 ± 7.32	8.38 ± 1.26

There is very good agreement between MC and data in all control regions (WCR, ZCR, TCR) after the fit. A very good accordance of data and fitted MC background is also in validation region (VR) after the fit. Residual difference is not more 0.5 σ (statistic + systematic).

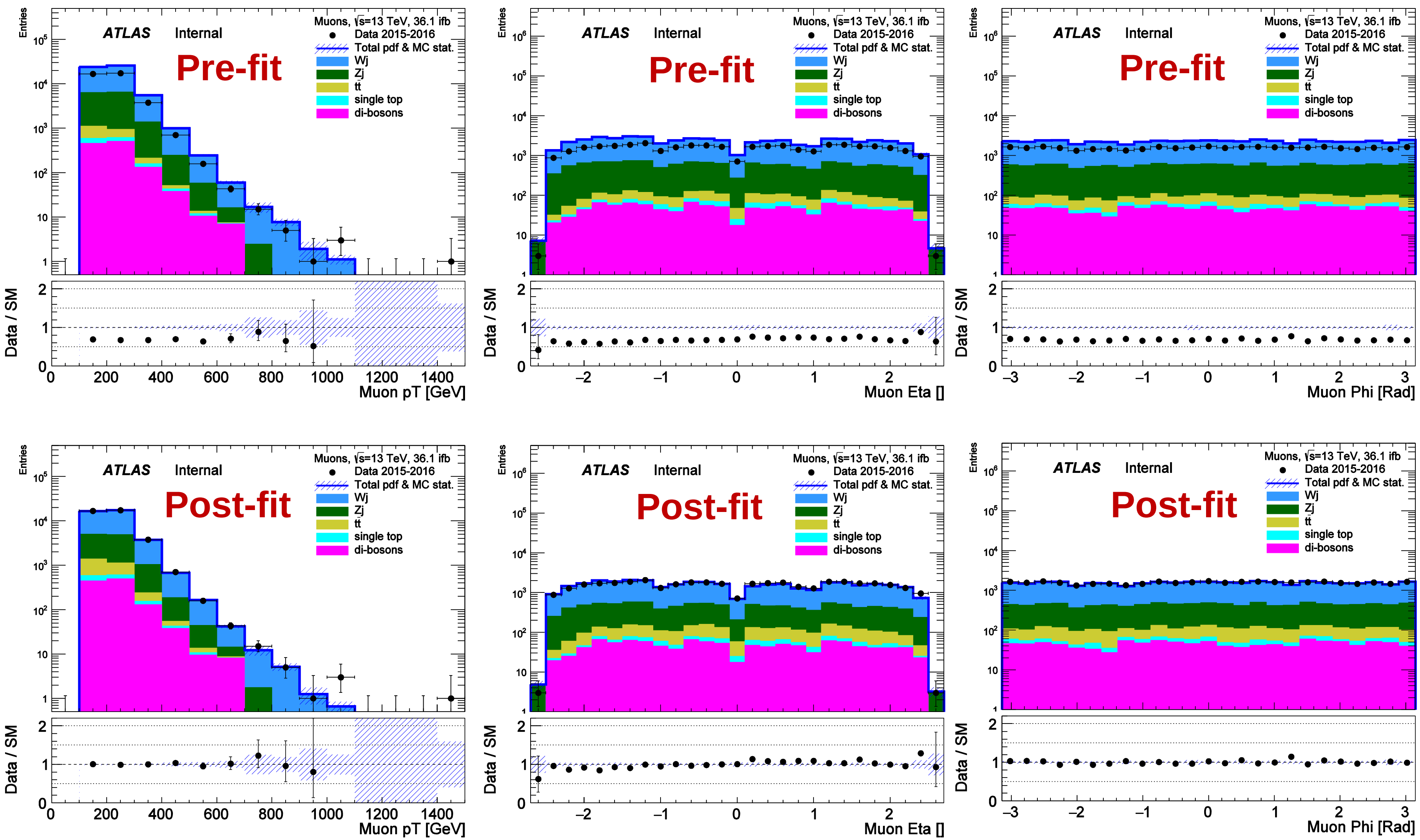
The fitted and MC expected yields for Control and Validation regions of muon channel.

Yield of channel	WCR	ZCR	TCR	VR
Observed events	30600	6182	1691	254
Fitted bkg events	30602.50 ± 175.28	6181.82 ± 78.77	1689.26 ± 41.27	318.89 ± 19.40
Fitted Wj events	26631.17 ± 210.56	0.34 ± 0.03	545.26 ± 26.54	277.10 ± 17.08
Fitted Zj events	2541.31 ± 64.19	5825.81 ± 80.80	79.26 ± 4.83	29.96 ± 2.46
Fitted Tt events	359.42 ± 70.32	156.98 ± 15.93	918.18 ± 58.09	4.15 ± 0.76
Fitted sT events	149.30 ± 13.50	22.48 ± 1.78	105.85 ± 9.60	2.86 ± 0.36
Fitted DB events	921.30 ± 44.17	176.20 ± 8.89	40.71 ± 5.92	4.81 ± 2.36
MC exp. SM events	45950.81 ± 377.33	8826.28 ± 95.72	1691.86 ± 88.36	480.58 ± 30.33
MC exp. Wj events	40944.01 ± 328.22	0.55 ± 0.07	829.45 ± 46.33	424.92 ± 27.05
MC exp. Zj events	3694.33 ± 63.45	8526.67 ± 91.64	113.27 ± 7.16	43.39 ± 3.13
MC exp. Tt events	232.55 ± 28.23	98.37 ± 7.02	597.31 ± 31.03	2.77 ± 0.76
MC exp. sT events	146.83 ± 14.36	21.88 ± 1.99	108.61 ± 12.63	3.00 ± 0.40
MC exp. DB events	933.09 ± 51.92	178.81 ± 9.46	43.22 ± 8.84	6.50 ± 3.54

There is very good agreement between MC and data in all control regions (WCR, ZCR, TCR) after the fit. Some deficit of data in comparison with MC is remained in validation region (VR) after the fit. Nevertheless, we can say that there is a good enough agreement between data and fitted MC background.

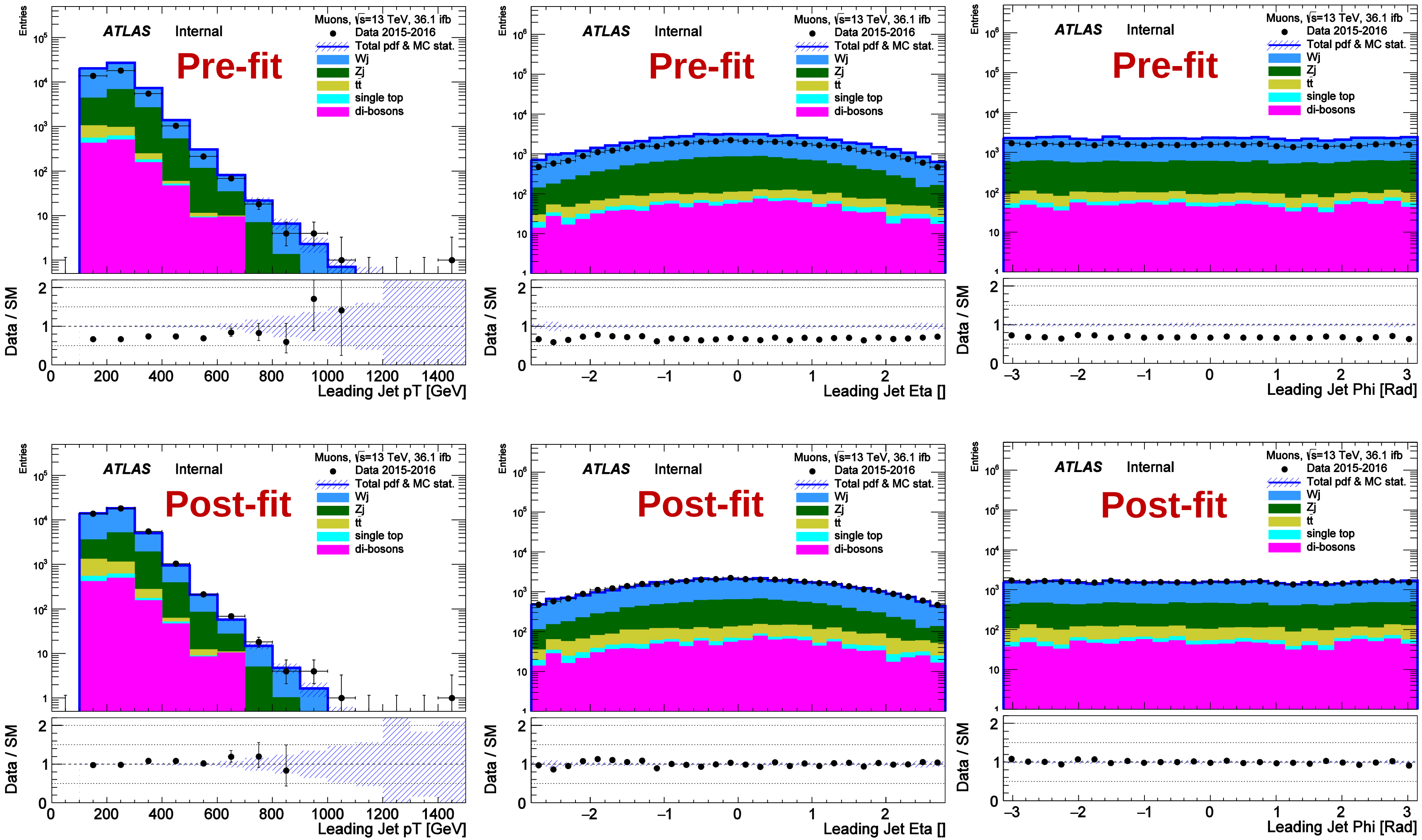
Kinematic distributions (p_T, η, φ) of muons before and after the fit with HistFitter

All events with signal signature (WCR+ZCR+TCR+VR+SR): 1 muon with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + M_{inv}>0.5 TeV



Kinematic distributions (p_T, η, φ) of leading jets in muon channel before and after the fit with HistFitter

All events with signal signature (WCR+ZCR+TCR+VR+SR): 1 muon with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + M_{inv}>0.5 TeV



6. Summary

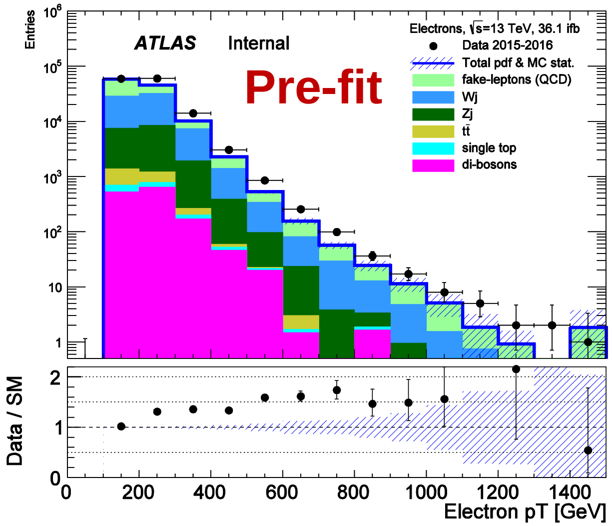
1. SM background modeled by MC was fitted with HistFitter package in three control regions and was extrapolated to validation region. Fake leptons background from multi-jet events (QCD) was estimated for electron channel with data-driven matrix method by the LPXMatrixMethod package. Last background can be neglected for muon channel.
2. Some deficit of MC events in comparison with data is observed in the control and validation regions before the fit with HistFitter tools in electron channel. On the contrary, the surplus of MC events above data is observed in muon channel before the fit. The fit practically eliminates these both disagreements. Conformity of MC with data after the fit is very good in all control regions.
3. Very good accordance of data and fitted MC background is observed also in validation region (VR) of electron channel after the fit. Some deficit of data in comparison with MC is remained in validation region of muon channel after the fit.
4. All additional kinematic distributions (lepton p_T, leading jet p_T, η, φ, H_T, N_{jet}, $N_{b\text{-}jet}$) have small enough residual discrepancy between MC and data after the fit. Differences are within statistical errors and systematic uncertainties in the majority of distributions.
5. Draft of Supporting Note at $\sqrt{s}$=13 TeV and 36.1 fb^{-1} is in CDS:

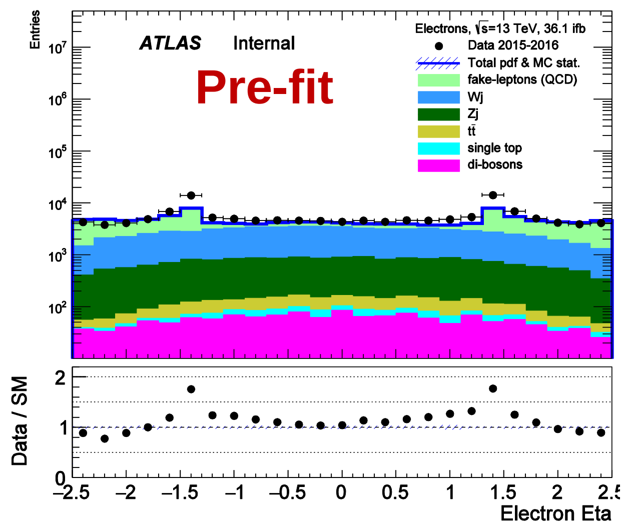
   ATL-COM-PHYS-2016-1762
6. We don't have unblinding now. Therefore, we can not show signal region. Our work is in progress.

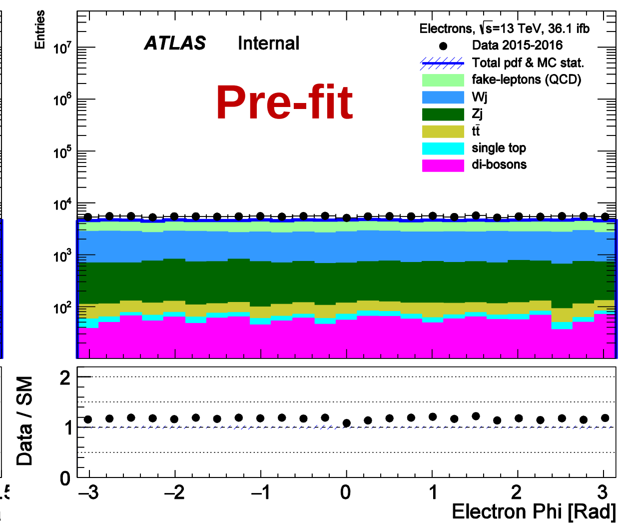
Hunting for quantum black holes will be continued

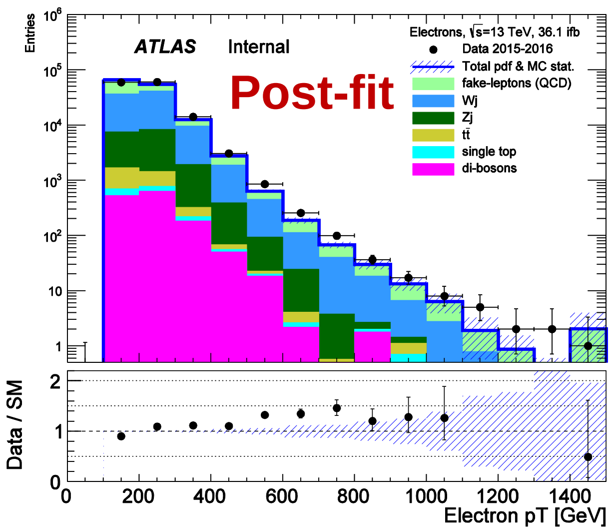
Kinematic distributions (p_T, η, φ) of electrons before and after the fit with HistFitter

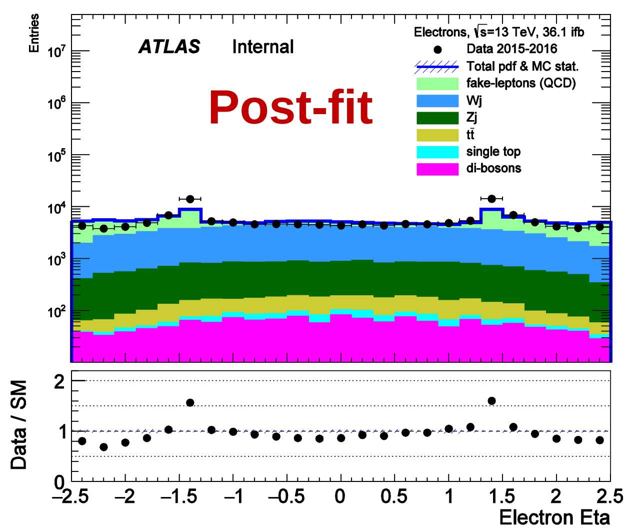
All events with signal signature (WCR+ZCR+TCR+VR+SR): 1 electron with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + M_{inv}>0.5 TeV

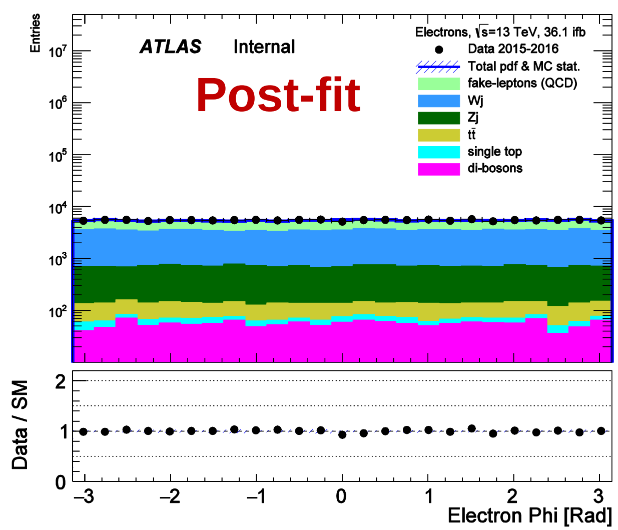






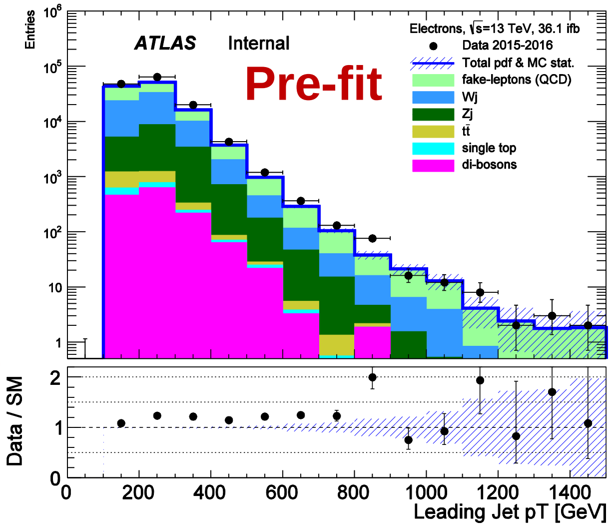


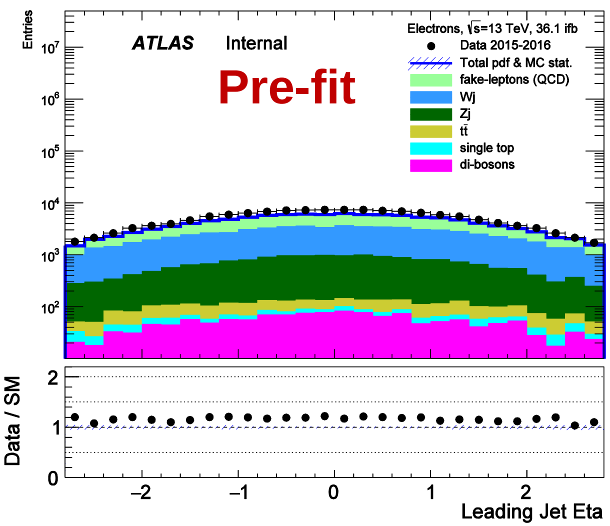


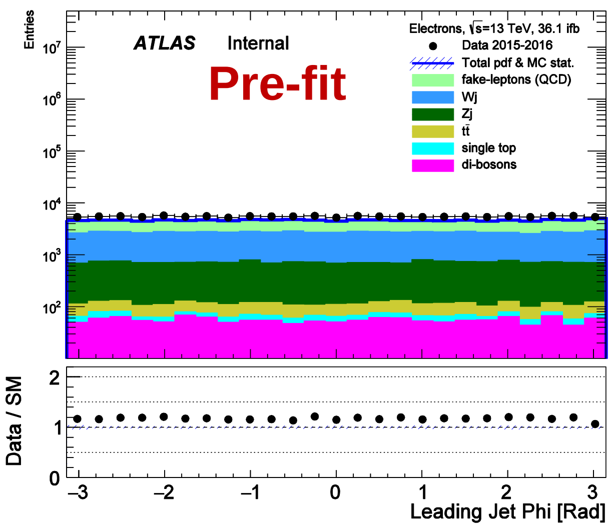


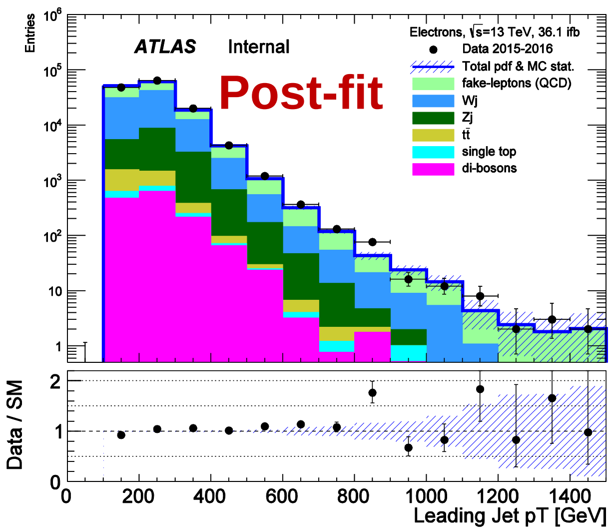
Kinematic distributions (p_T, η, φ) of leading jets in electron channel before and after the fit with HistFitter

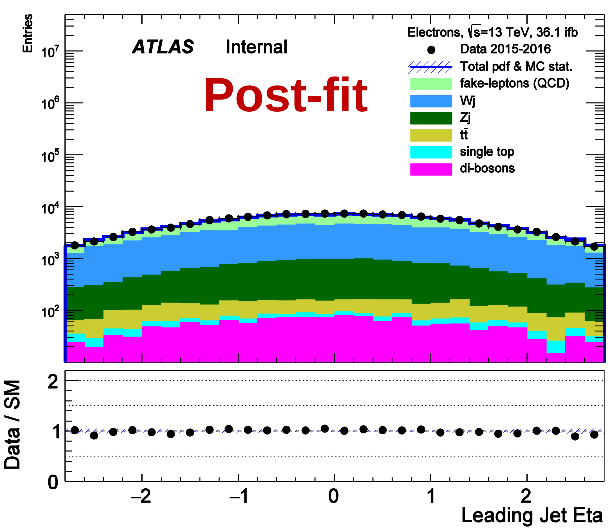
All events with signal signature (WCR+ZCR+TCR+VR+SR): 1 electron with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + M_{inv}>0.5 TeV

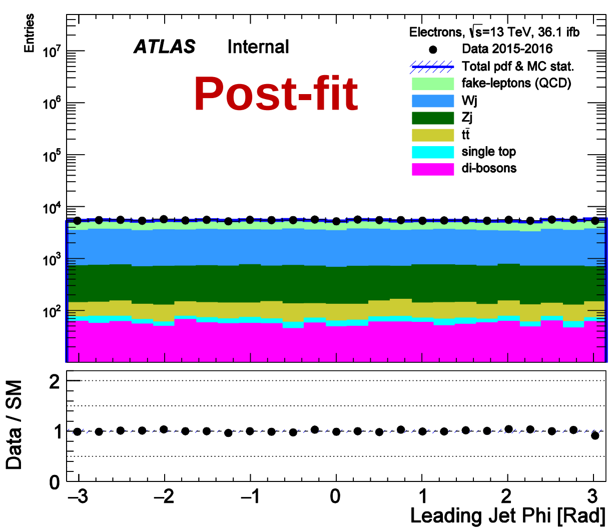






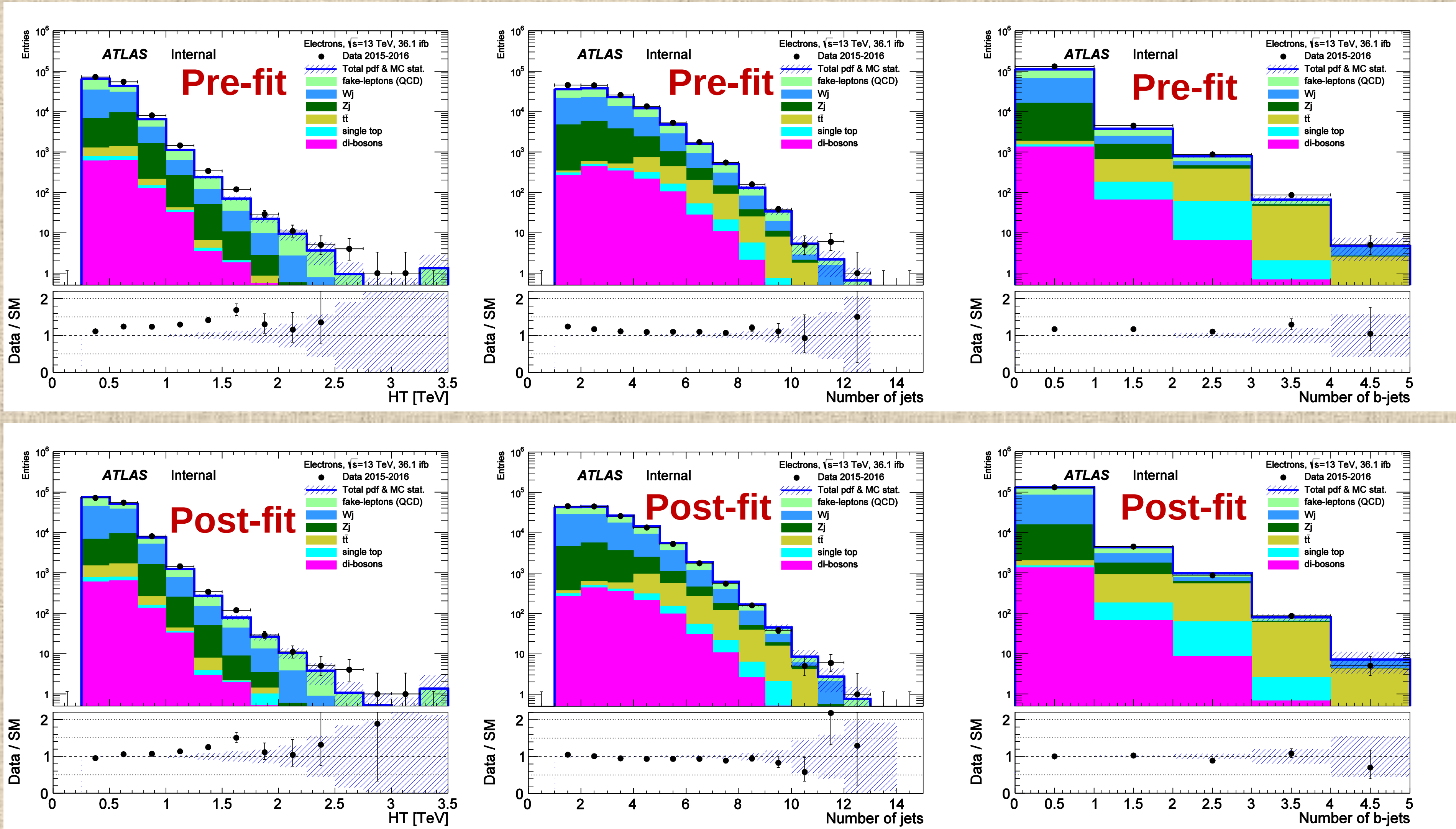






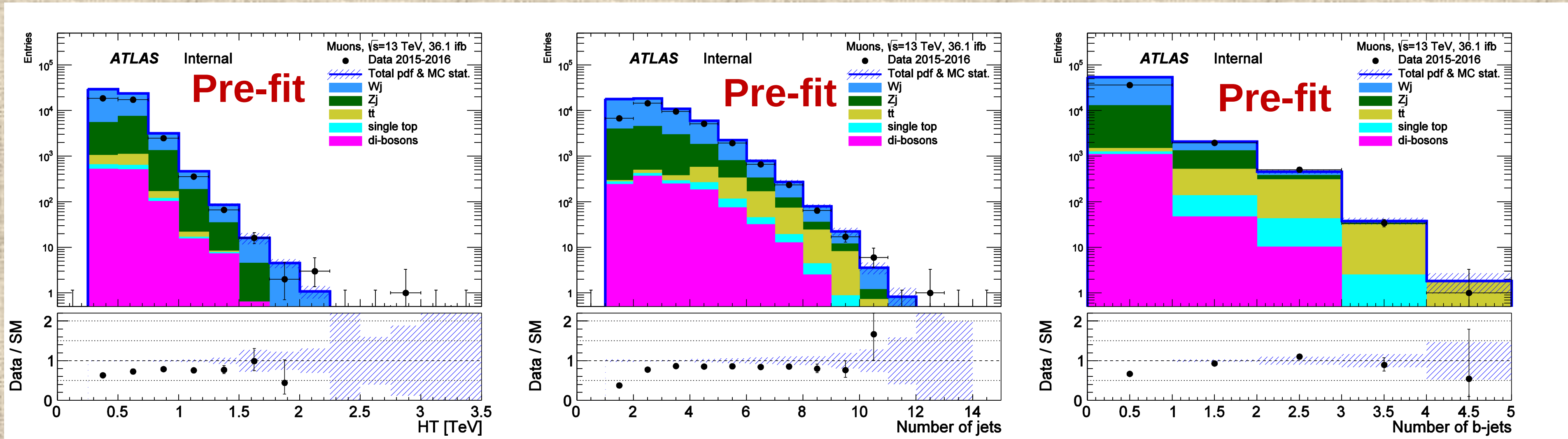
Distribution of events over H_T, N_{jets} and $N_{b\text{-}jets}$ in electron channel before and after the fit with HistFitter

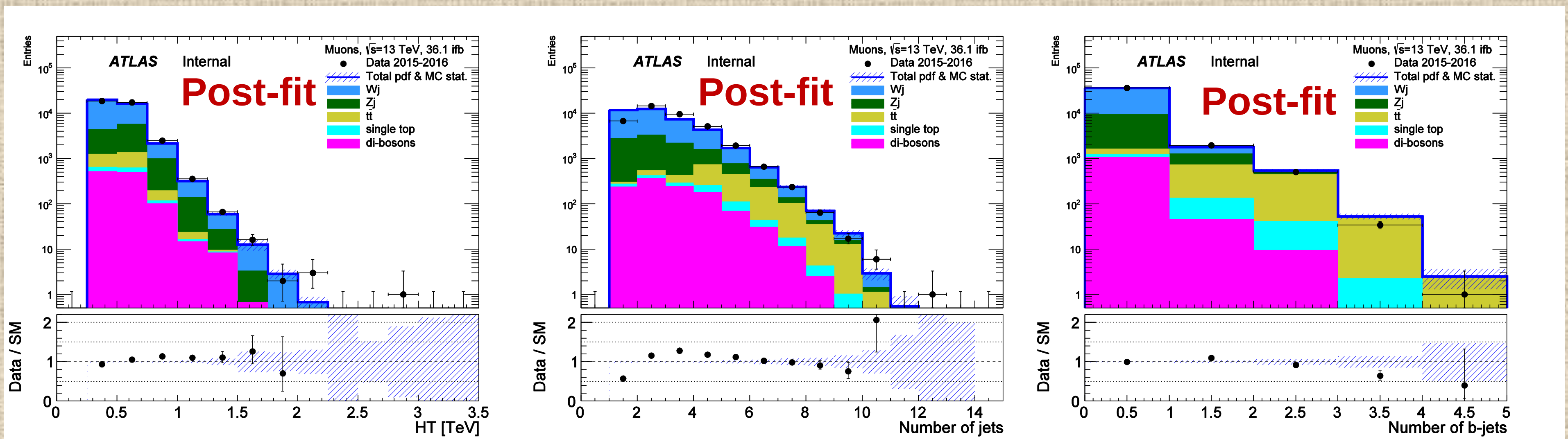
All events with signal signature (WCR+ZCR+TCR+VR+SR): 1 electron with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + M_{inv}>0.5 TeV



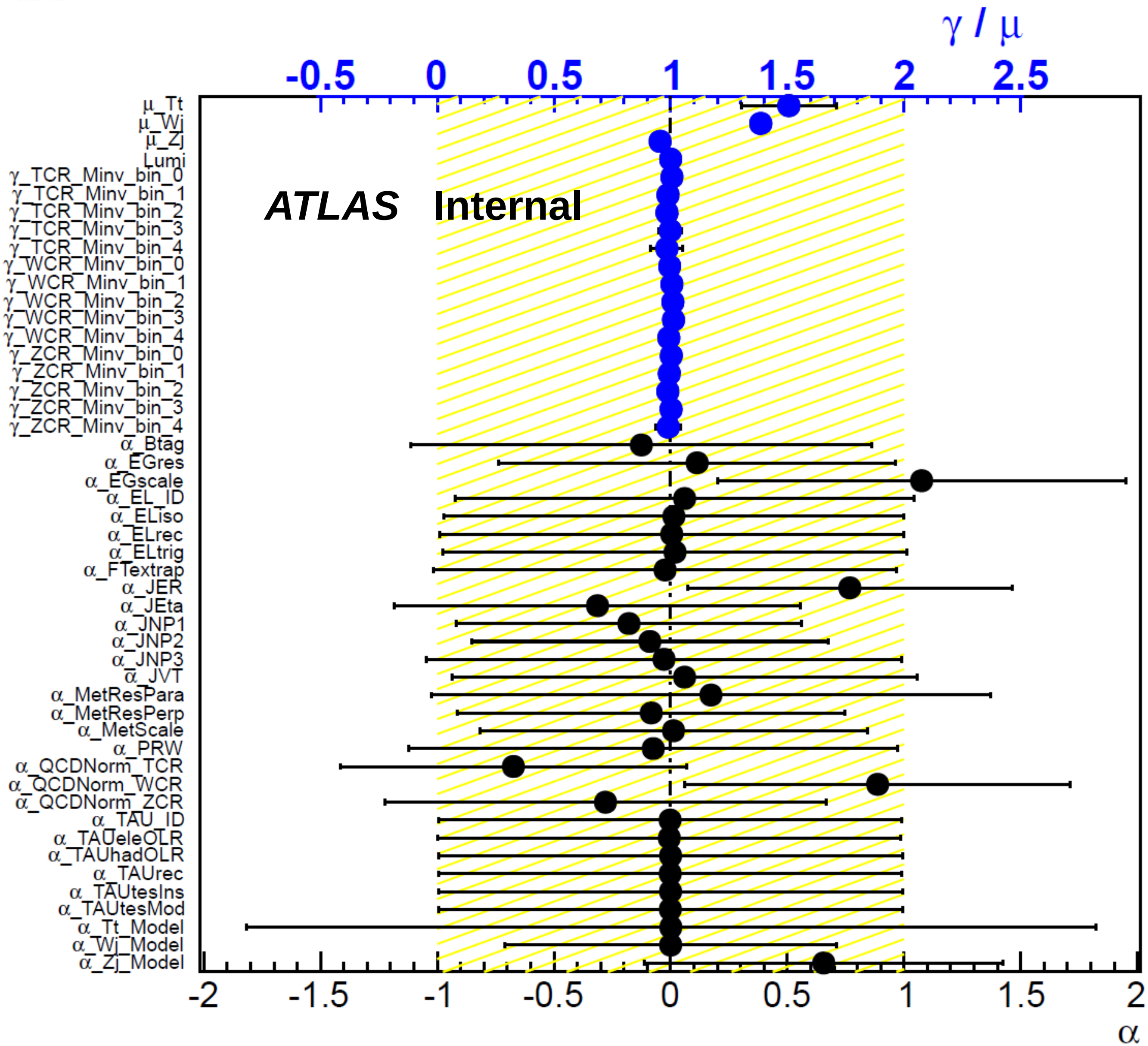
Distribution of events over H_T, N_{jets} and $N_{b\text{-}jets}$ in muon channel before and after fit with HistFitter

All events with signal signature (WCR+ZCR+TCR+VR+SR): 1 muon with p_T>130 GeV + 1 jet with p_T>130 GeV + other jets, photons, taus p_T<60 GeV + MET<60 GeV + M_{inv}>0.5 TeV





The fit parameters of electron channel



mu_ (μ) is the normalization factor of fitted MC sample, unconstrained in the fit;

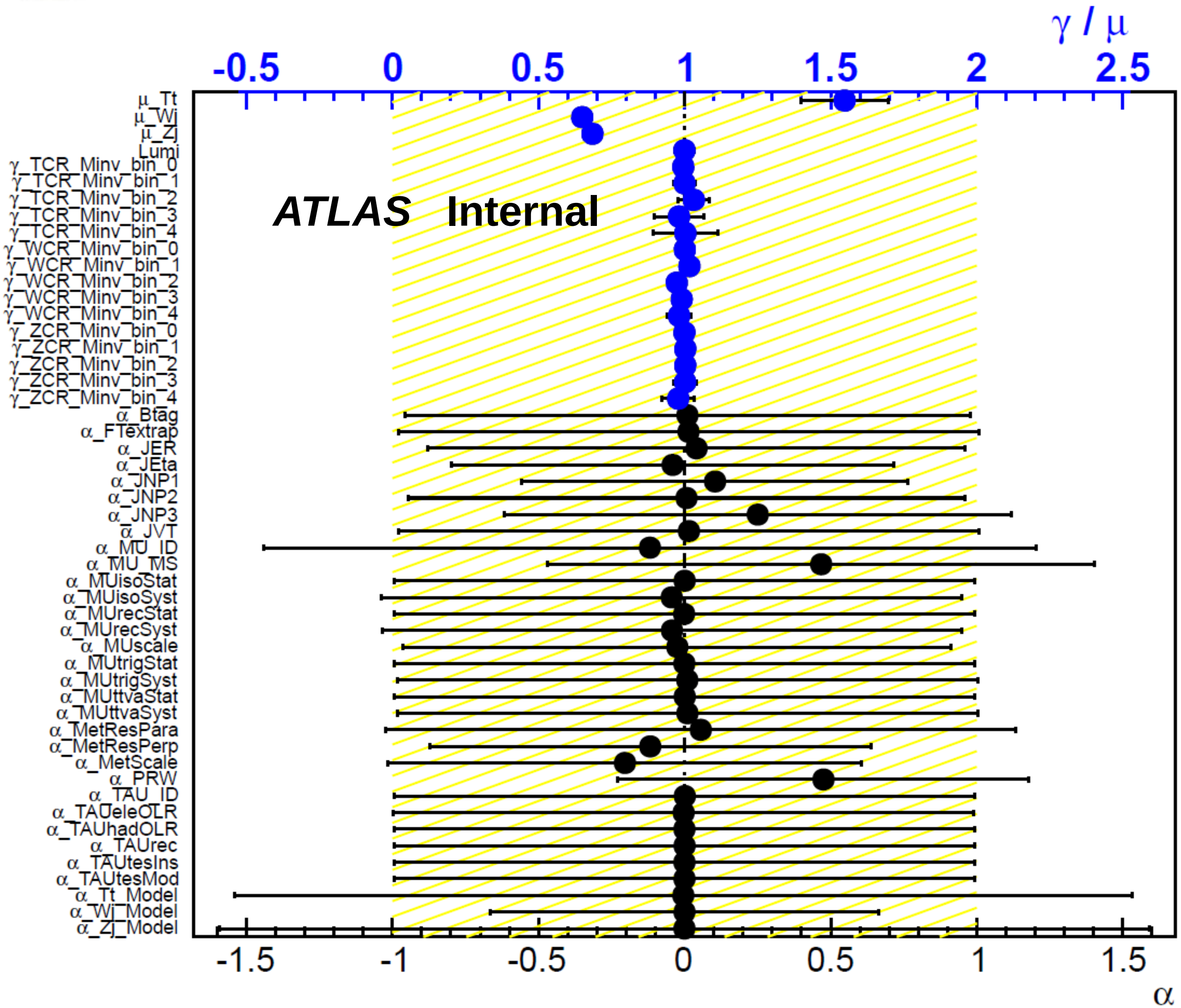
gamma_stat_ (γ) is bin-by-bin uncertainty from the MC statistics; constrained parameter (Poisson); it is used mainly for propagating errors, not to constrain information in bin;

- value of γ represents width of Poisson;
- error of γ represents error on width;

alpha_ (α) is constrained parameter on systematic uncertainty;

- value of α represents preferred mean value of Gaussian;
- error of α represents preferred gamma value of Gaussian in units of input sigma;

The fit parameters of muon channel



mu_ (μ) is the normalization factor of fitted MC sample, unconstrained in the fit;

gamma_stat_ (γ) is bin-by-bin uncertainty from the MC statistics; constrained parameter (Poisson); it is used mainly for propagating errors, not to constrain information in bin;

- value of **γ** represents width of Poisson;
- error of **γ** represents error on width;

alpha_ (α) is constrained parameter on systematic uncertainty;

- value of **α** represents preferred mean value of Gaussian;
- error of **α** represents preferred gamma value of Gaussian in units of input sigma;

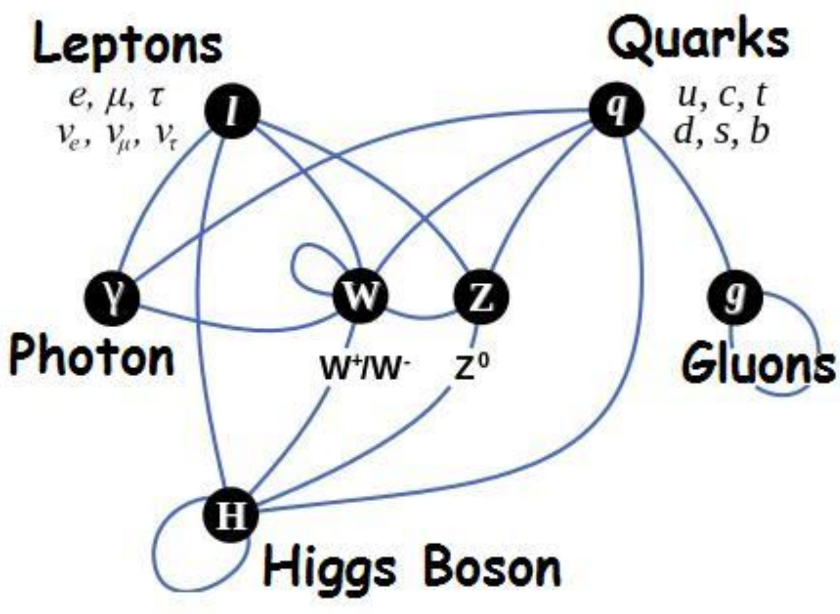
motivations to searching for QBH

- **Motivations for starting of searching for Quantum Black Holes (QBH) have origins in a problem of hierarchy in Standard Model of elementary particles.**

Main thesises

- *In Standard Model all fermions are formed by three generations.*

- *The hierarchy problem (of fermions masses) consists of next fact: masses of three generations fermions (leptons and quarks) differ between themselves in ten times and more. But other properties of the particles and their quantum numbers are identical.*



- *By the way, mass matrixes of quarks and neutrino also show the hierarchical structure. So for a quark mass matrix diagonal elements and not diagonal elements behave differently. In this case mixing is suppressed. For a neutrino's mass matrix on the contrary, mixing is brightly expressed. These are neutrino oscillations.*

- *Mass of particles in Standard Model is defined by interactions with scalar field of Higgs.*

1. Introduction-4

❑ Some details of a problem of hierarchy

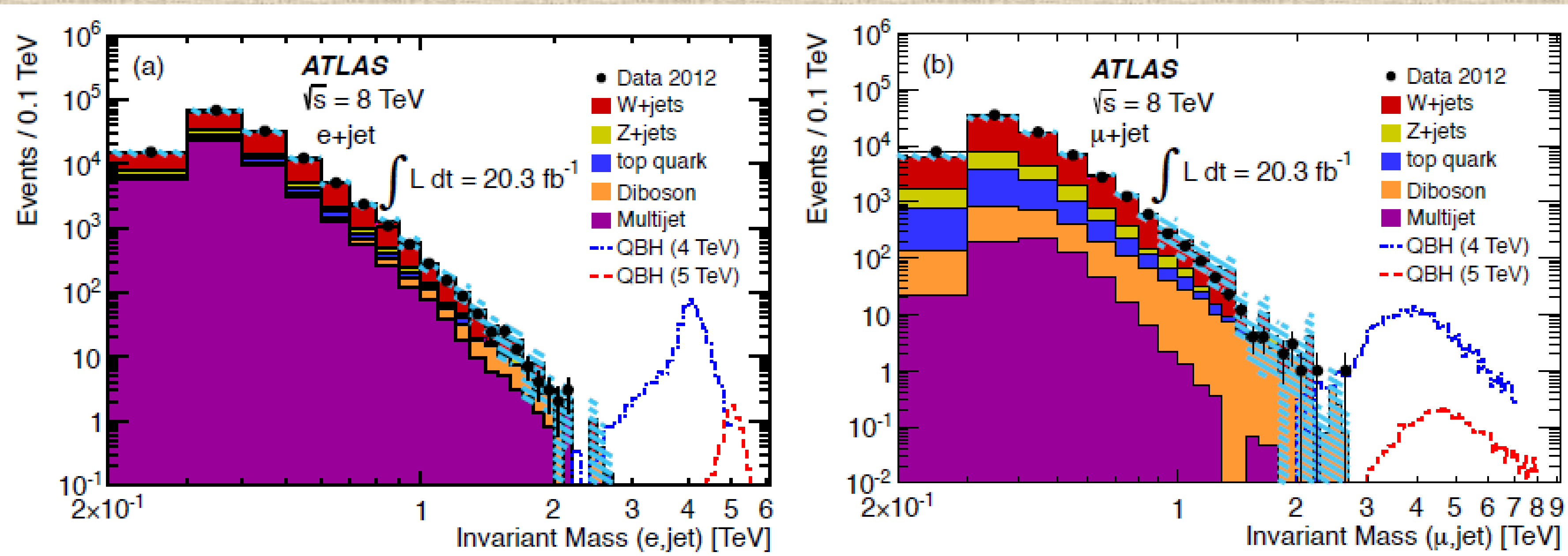
• Mass of particles in Standard Model is defined by interactions with scalar field of Higgs. But how?

• Let's remember. In the quantum theory of elementary particles the vacuum is the constantly boiling sea of virtual particles. All particles of which our Universe consists, and even those particles are produced on colliders, are already the particles, "wrapped up" by a virtual fur coat. Thus they change properties of all the wrapped up particles: **masses**, charges and other characteristics.

• Before a discovery of Higgs boson the Standard Model had some problems in the theoretical predictions. In the case of Higgs boson, a quant of scalar field of Higgs, the influence of virtual particles was very strong in theoretical calculations, and it was too changing mass of boson up to very high mass. By reason of a fact, that in the Standard model there is no any parameter, which would stop growth of mass of Higgs boson at the expense of virtual particles, that is why the Standard model tries reaching a high energy scale, too larger, than real scale of the electroweak phenomena. This difficulty is called **a hierarchy problem.**

• But what is happened after discovery of Higgs boson? Quantity of the physical Higgs bosons increases in multi-doublet models of Higgs, when every fermion can have one own doublet, that allows to eliminate the problem of hierarchies of fermion's masses. Now we know only one-doublet-model of Higgs with one standard Higgs boson. And **the hierarchy problem stays.**

Results of search for QBH at √s = 8 TeV



e + jet channel

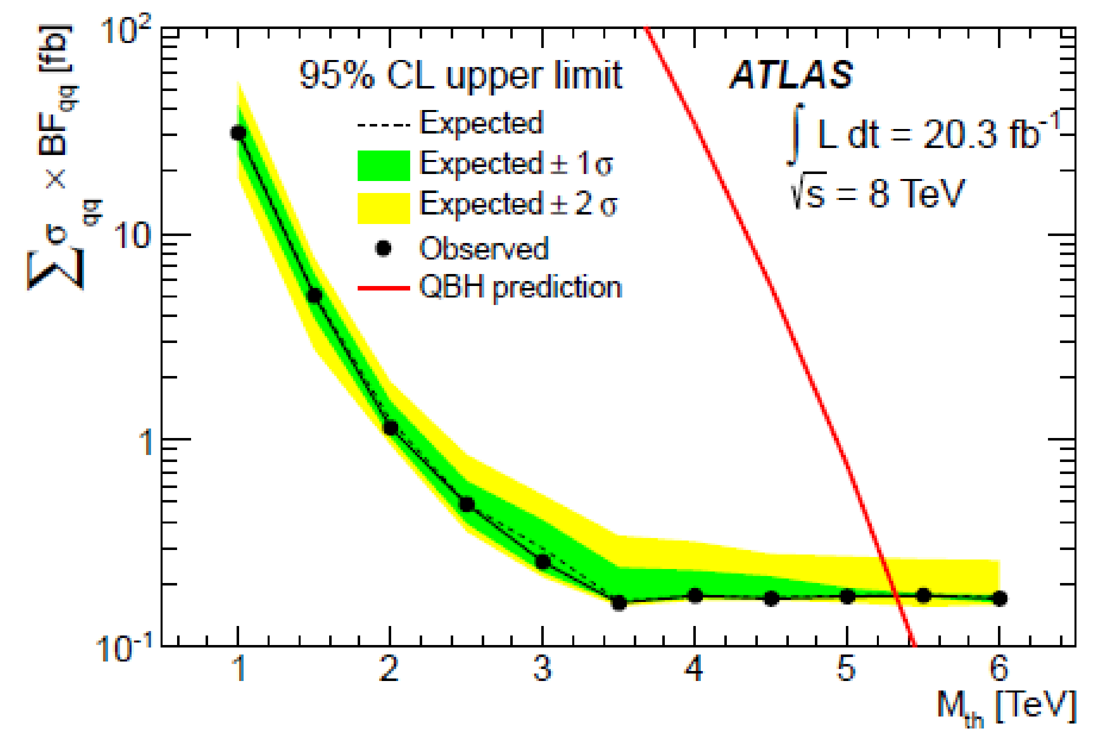
Distributions over the ***Invariant Mass*** of the electron and highest-p_T for data (this are points with error bars) and for SM backgrounds (they are solid histograms).

m + jet channel

Distributions over the ***Invariant Mass*** of the muon and highest-p_T jet for data (this are points with error bars) and for SM backgrounds (they are solid histograms).

[4] The ATLAS Collaboration, Search for Quantum Black Hole Production in High-Invariant-Mass Lepton+Jet Final States Using pp Collisions at √s = 8 TeV and the ATLAS Detector, Phys.Rev.Lett. 112 (2014) 091804 (2014-03-05), DOI: 10.1103/PhysRevLett.112.091804 CERN-PH-EP-2013-193, e-Print: arXiv:1311.2006v2 [hep-ex].

Results of search for QBH at $\sqrt{s}$ = 8 TeV



• **The combined 95% CL upper limits** on $\Sigma\sigma_{qq} \times BF_{qq}$ for QBHs decaying to a lepton and jet, as a function of M_{th}, assuming $M_D = M_{th}$ and n=6 of ADD extra dimensions.

• **The lower limit** on M_{th} is 5.3 TeV. In other words **$M_{th} \leq 5.3$ TeV** was excluded by the QBH searches.

[4] The ATLAS Collaboration, Search for Quantum Black Hole Production in High-Invariant-Mass Lepton+Jet Final States Using pp Collisions at $\sqrt{s}$ = 8TeV and the ATLAS Detector, Phys.Rev.Lett. 112 (2014) 091804 (2014-03-05), DOI: 10.1103/PhysRevLett.112.091804 CERN-PH-EP-2013-193, e-Print: arXiv:1311.2006v2 [hep-ex].

What constraints on the QBH properties we can put on?

- We see at large distances only 3 spacial dimensions, so these extra dimensions have to be compactified.

How large can they be?

Surprisingly, we have not measured very well gravity at distances smaller ~ 0.1 mm

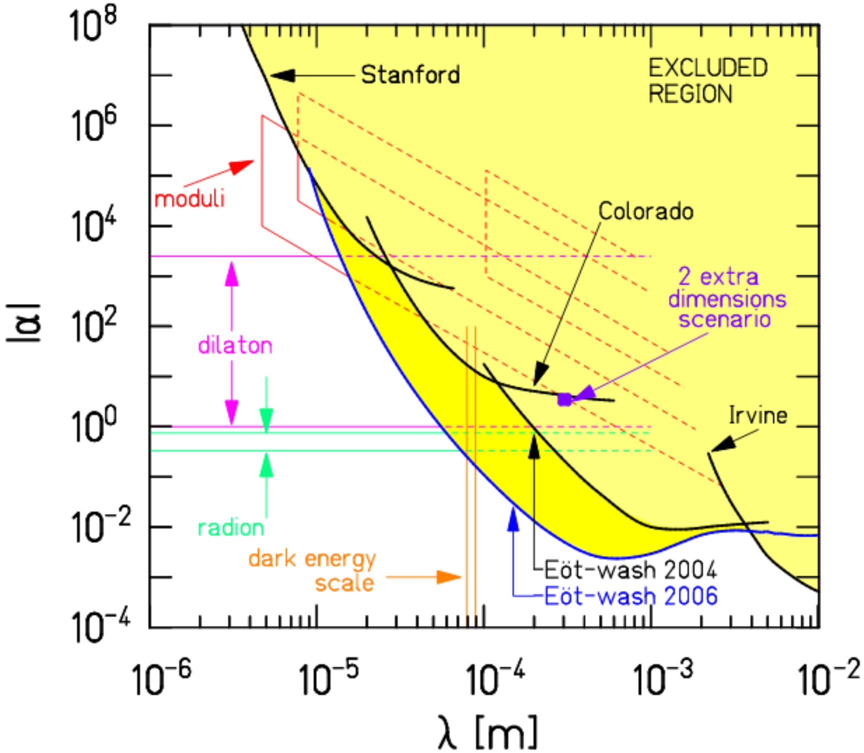
Constrains on extra forces:

$$F_{KK}(r) = -\alpha G_N \frac{m_1 m_2}{r} e^{-r/\lambda},$$

α = measures the strength of the interaction (α=1 ➞ Gravit. strength)

λ = range of the interaction

Gravity coud be different at sub-mm scales: Extra dim of radius R~0.04 mm possible!



http://indico.cern.ch/event/66852/material/slides/0?contribId=47