Search for Quantum Black Holes at 8 and 13 TeV with ATLAS in 1lepton+1jet channel

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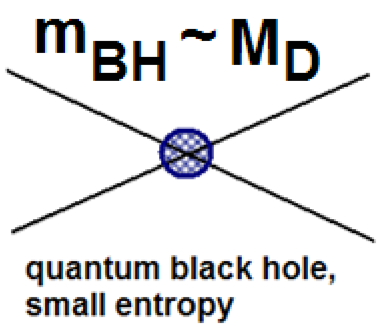
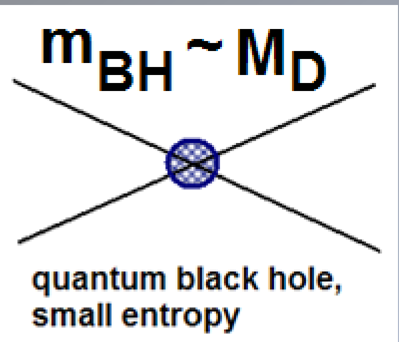


Physics & Computing Russian Institutes meeting, 22-23 September 2015, Dubna

1. Introduction



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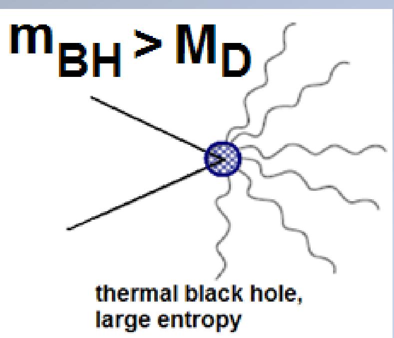


Why LHC? **Quantum Black Holes (QBHs) are predicted in low-scale quantum gravity theories that offer solutions to the mass hierarchy problem of the Standard Model (SM) by lowering the scale of quantum gravity (M_D) from the Planck scale (~10^{16} TeV) to ~1 TeV. That is why a search region for invariant masses of QBH was checked near 1-10 TeV. Here M_D is a multidimensional mass of QBH.**

Features. **QBHs with masses near M_D have to conserve total angular momentum, color and electric charge. The most important: a behavior of QBHs differs from semi-classical black holes, which decay via Hawking radiation to a large number of objects (at the left).**

Signature. **The QBH's decay mode is assumed with 1 lepton (electron or muon) and 1 jet in final state. This mode has the best branching and Signal to Background ratio.**

The Large Extra Spatial Dimension Model with n compact extra dimensions with a gravitational radius R was suggested by Arkani-Hamed, Dimopoulos and Dvali (ADD) [1-3].

[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.

2. Shortly about ADD-model

The Large Extra Spatial Dimension Model with n compact extra dimensions

The multi-dimensional Planck scale is assumed to be equal to the electroweak scale $M_D \approx M_{EWK}$, for removing the hierarchy problem. Where the electroweak scale is M_{EWK} ~1 TeV and the true Planck scale is equal M_{Pl}~10^{16} TeV. The true Planck Scale M_{Pl} is related to multi-dimensional mass M_D as:

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

- Where n – number of extra dimensions. Extra spatial dimensions are large, i.e. the radius R could be from ~1 μm up to 1 mm. Than the gravity becomes strong, and quantum effects are important.
- 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 above M_D, but far below M_{Pl}. There are two phenomenology of black holes production, which markedly distinguished.
- Semi-classical case. If the black hole was produced far above M_D, then it can decay into large quantity of objects via the Hawking radiation.
- Case of Quantum Black Hole. QBH could form near threshold M_{th}. Then QBH can decay into the two-body final states. The production of QBH close to M_{th} dictates a possible quasi-resonant final state with an observable excess for a certain invariant mass.

About branching fractions

- The largest cross section of QBH production for final state with lepton and jet depends on initial state.
- *For initial two u-quarks* and objects with electric charge of +4/3 the branching fraction BF=11%.
- *For initial ud-quarks* and objects with charge of +1/3 the branching fraction BF=5.7%.
- *For initial dd-quarks* and objects with charge of −2/3 the branching fraction BF=6.7%.
- Processes with initial states of anti-quarks and heavier sea-quarks are suppressed by a factor of ~100.

3. Events selection for 8 TeV

1) **Two-body channel:** in events are required to have exactly 1 electron (muon).
2) **Electron candidates** are identified as localized depositions of energy in the EM calorimeter with $p_T > 130$ GeV and $|\eta| < 2.47$, excluding the barrel-endcap transition region, $1.37 < |\eta| < 1.52$, and matched to a track reconstructed in the tracking detectors.
3) **Isolated electrons** are selected by requiring the transverse energy deposited in a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2} = 0.3$ centered on the electron cluster, excluding the energy of the electron cluster itself, to be less than $(0.0055 \cdot p_T + 3.5)$ GeV after corrections for energy due to pileup and energy leakage from the electron cluster into the cone.
4) **Muon candidates** are required to be detected in at least three layers of the muon spectrometer and to have $p_T > 130$ GeV and $|\eta| < 2.4$.
5) **Isolated muons** are required $\Sigma p_T < 0.05 \cdot p_{T\mu}$, where Σp_T is the sum of the p_T of the other tracks in a cone of radius $\Delta R = 0.3$ around the direction of the muon.
6) **Jets** are constructed from three-dimensional noise-suppressed clusters of calorimeter cells using the anti-kt algorithm with a radius parameter of 0.4. All jets are required to have $p_T > 50$ GeV and $|\eta| < 2.5$. In addition, the most energetic jet is required to have $p_T > 130$ GeV.

The experimental efficiency falls from 89(59)% to 81(50)% for masses QBH from 1 TeV to 6 TeV in the electron (muon) channal.

4. Background for QBH

Dominant backgrounds obtained from Monte Carlo simulation:

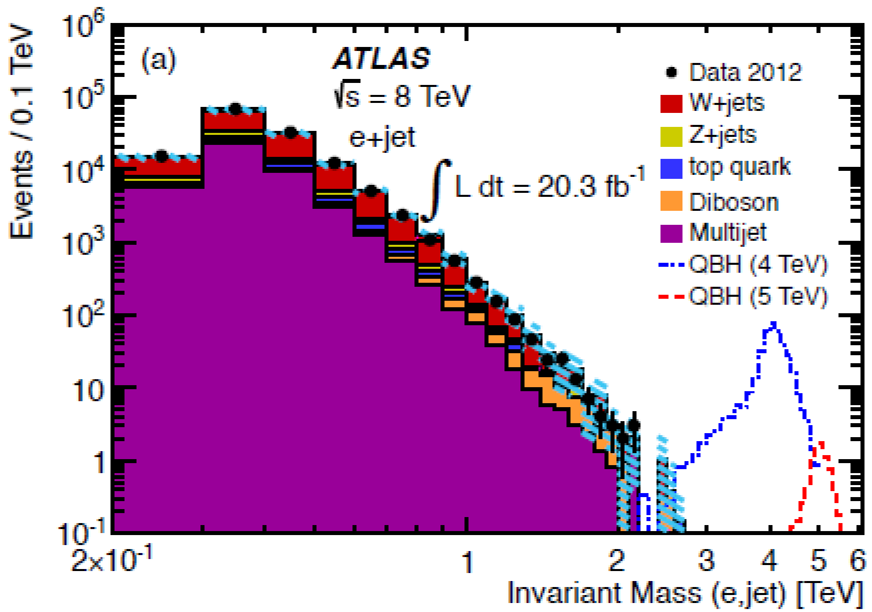
1) **W+jets,**
2) **Z+jets;**
3) **Dibosons: WW, WZ, ZZ;**
4) **ttbar pairs;**
5) **Single top-quarks;**
6) **Multijets (QCD).**

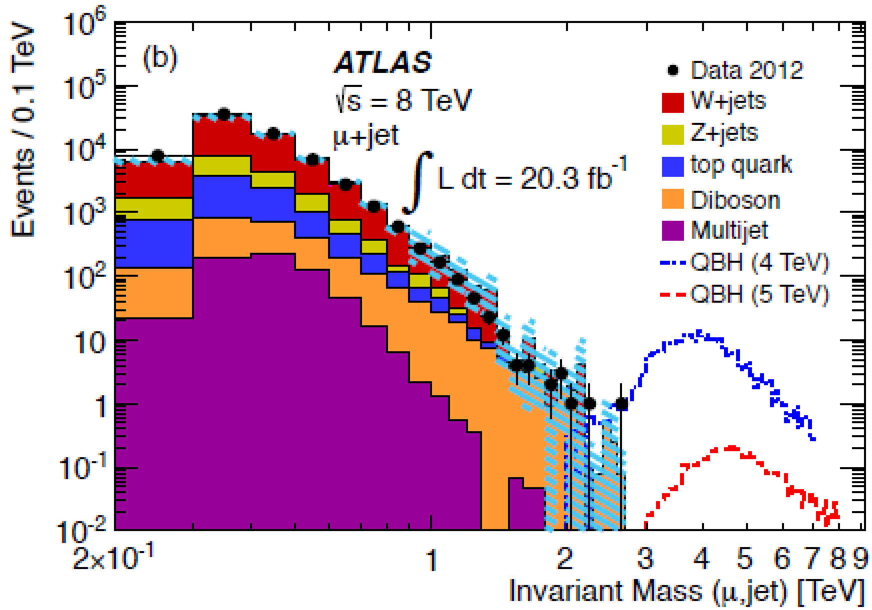
- **Events with a high p_T of lepton and 1 or more jets can arise from electroweak processes. They include a vector-boson production with additional jets and dibosons (WW, WZ, ZZ). Strong processes include top-quark pairs (ttbar), a single top-quark and multijets (QCD) production. Last can be include non-prompt leptons of semileptonic hadron decays and jets, which were misidentied as leptons.**

- **The electroweak background in Signal Region was estimated using Monte Carlo samples, normalized to data in Control Regions. Simulation was based on GEANT4 and with the corresponding model of the ATLAS detector geometry.**

- **Additional inelastic proton-proton's interactions, termed pileup, were included into the event simulation thus, in order to accord with the data distribution over number of interactions per bunch crossing. Average number of interactions per bunch crossing was about 21.**

5.3. Results of search for QBH at √s = 8 TeV





e + jet channel

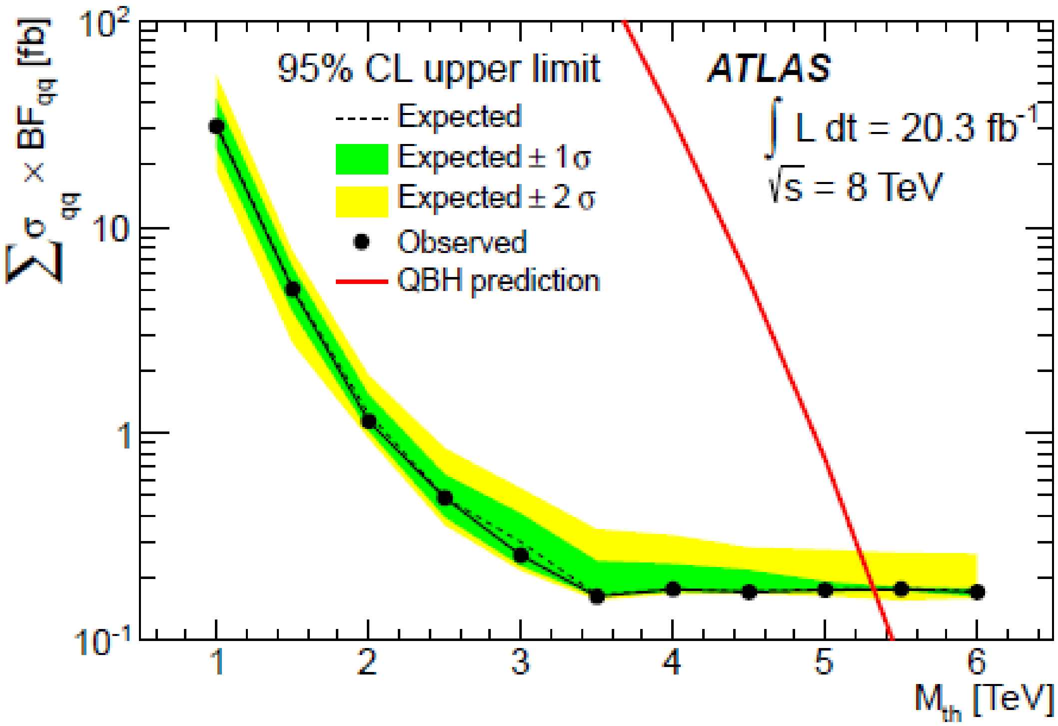
Distributions over the ***Invariant Mass*** of the electron and highest-p_T for data (this are points with error bars) and for SM backgrounds (they are solid histograms).

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].

5.2. 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.

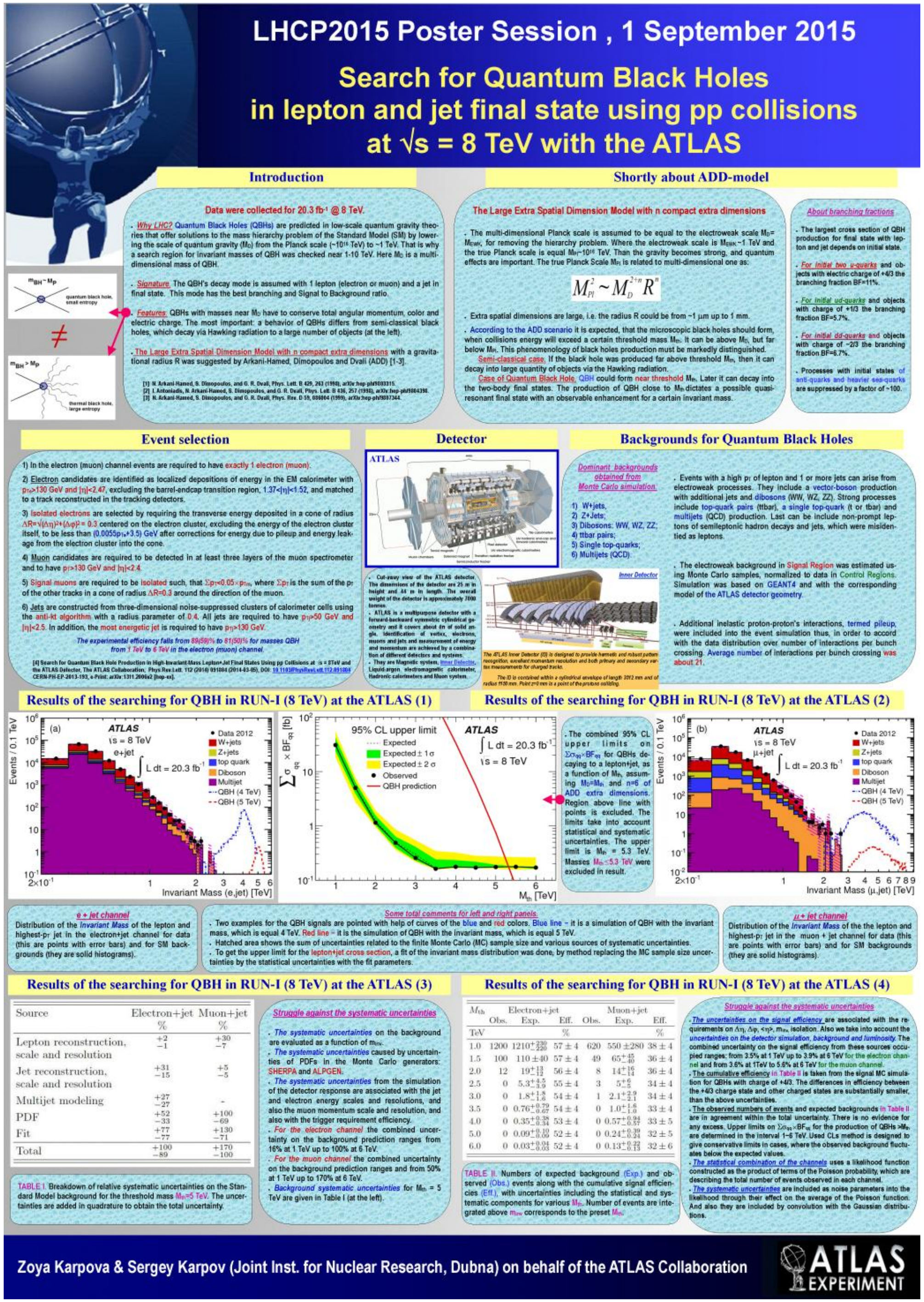
- **The lower limit** on M_{th} is 5.3 TeV. In other words **$M_{th} \leq 5.3$ TeV** was excluded by the QBH searches.

[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].

5.3. Paper and poster

[4] The ATLAS Collaboration, Search for Quantum Black Hole Production in High-Invariant-Mass Lepton+Jet Final States Using pp Collisions at √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].

[5] Z. Karpova, S. Karpov, the ATLAS Collaboration, *Search for Quantum Black Holes in lepton and jet final state using pp collisions at √s = 8 TeV with the ATLAS*, ATL-PHYS-SLIDE-2015-613, 1 September 2015, https://cds.cern.ch/record/2049859



6. Search for QBH at √s=13 TeV

6.1. Generalities

Intentions:

Search for QBH in 1l+1j channel by analysis of first data at 13 TeV (with 50 ns bunch spacing only, ~100 pb^{-1}) with the same strategy, conditions, cuts, CR and SR as in analysis of 2012 data at 8 TeV. Now we do not purpose to make optimization of cuts, new definition of CR and SR or new sensitivity calculation.

Goal: the same analysis with new data → support note → conf note.

Team:

Sergey Karpov (JINR, Russia) – development of code, analysis of data;

Zoya Karpova (JINR, Russia) – analysis of data, preparation of material for support and conf notes;

Douglas Gingrich (University of Alberta, Canada) – generation and validation of signal samples, results interpretation.

6.2. Details of analysis

Root Core AnalysisBase-2.3.22, SUSYTools-00-06-20
One's own code of analysis – QBHLepOneJet package based on "RootCore EventLoop skeleton" and SUSYToolsTester

Baseline object selection, overlap removal, calibrations, resolutions etc. are used by default as in SUSYTools. Results represented below were obtained without pile-up reweighting, trigger matching, scale factors for signal lepton and systematics. But now these are in code and next time results will be with that.

Data: C2-C5 periods; Range of runs: 270806 – 271744;
Integrated luminosity L ≈ 86 pb^{-1} according to Good Runs List:
data15_13TeV.periodAllYear_DetStatus-v64-pro19_DQDefects-00-01-02_PHYS_StandardGRL_All_Good.xml

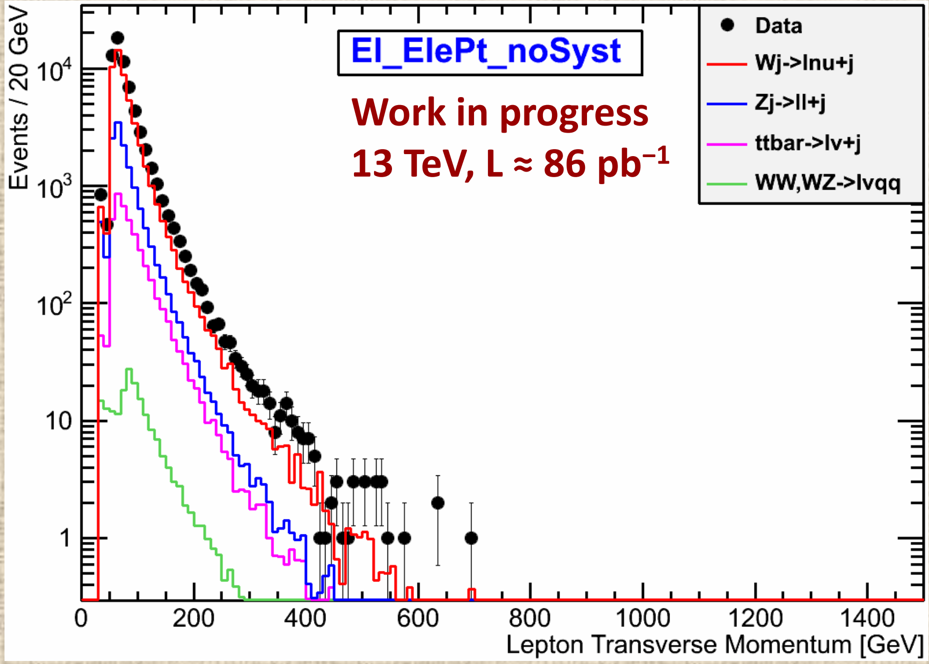
EXOT9 derivation (tag: p2375) by trigger selection: (HLT_mu26_imedium || HLT_mu50 || HLT_mu60_msonly_0eta105 || HLT_e28_tight_iloose || HLT_e60_medium || HLT_g140_loose || HLT_xe100 || HLT_g60_loose_xe60)

MC background: W+jets ($W^{\pm} \to e\nu, \mu\nu$), Z+jets ($Z \to ee, \mu\mu$), ttbar (non all hadronic), Di-Boson (WW, WZ $\to l\nu qq$). Still there are not: Single top, multi-jets

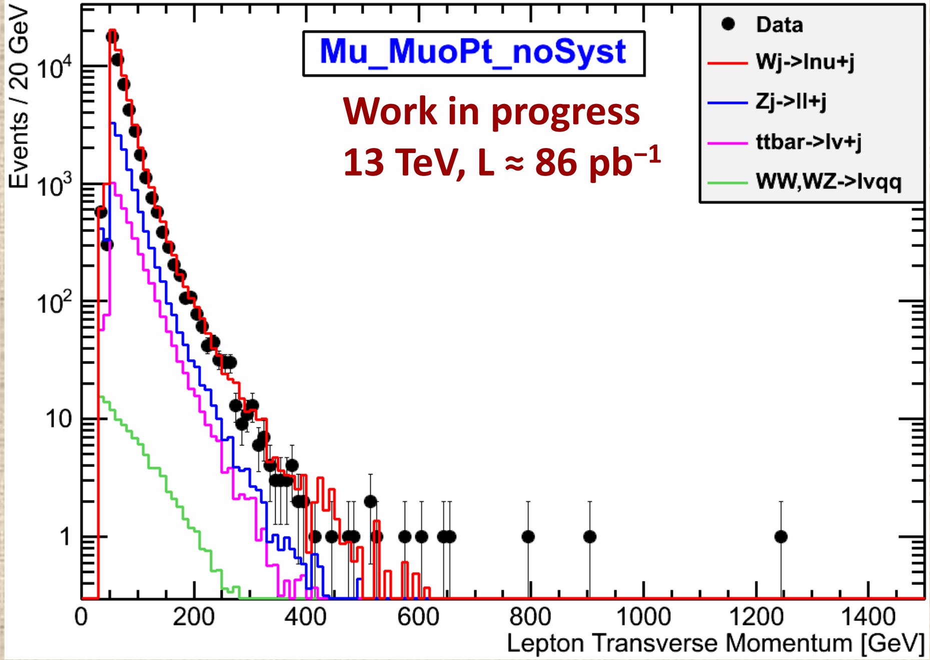
6.3. Distributions of signal leptons over transverse momentum (very preliminary)

Monte-Carlo samples were normalized to integrated luminosity of data with use of corresponding cross-sections. A fit or any additional k-factors were not used.

Electron channel after selection of signal lepton and jet (pT>30 GeV)



Muon channel after selection of signal lepton and jet (pT>30 GeV)

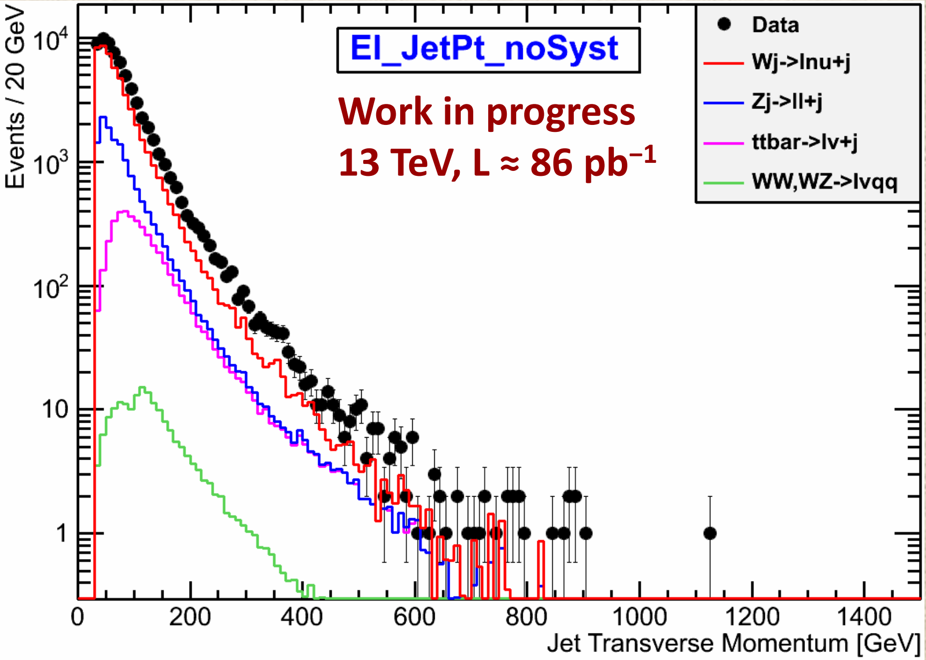


Too much electrons are remained after selection in the data in comparison with Monte-Carlo.

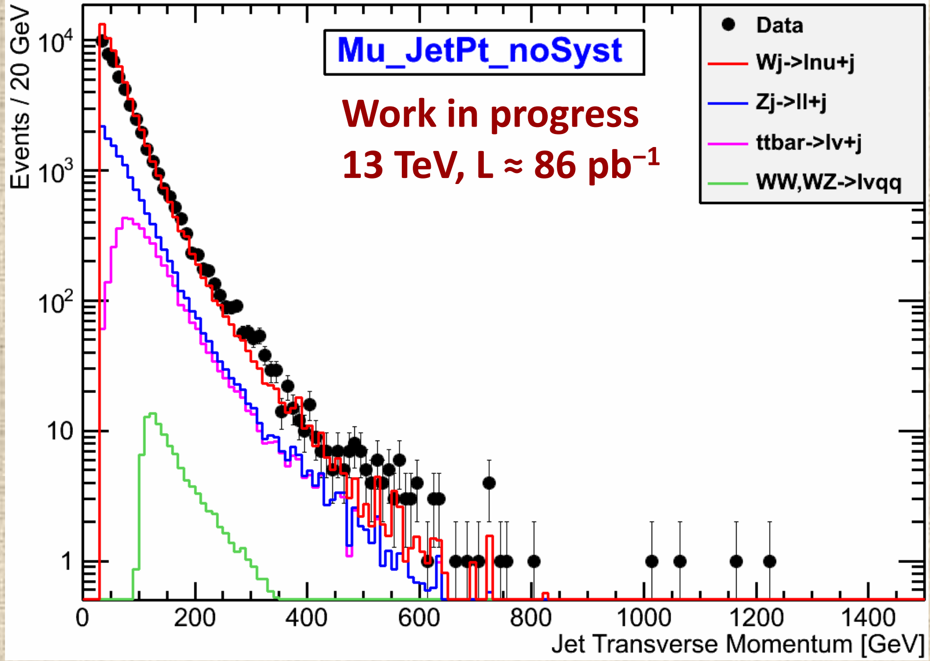
Good enough agreement is observed up to ~500 GeV. Some number of muons have too high pT. → IsHighPtMuon() need to apply.

6.4. Distributions of leading jets over transverse momentum (very preliminary)

Electron channel after selection of signal lepton and jet (pT>30 GeV)



Muon channel after selection of signal lepton and jet (pT>30 GeV)

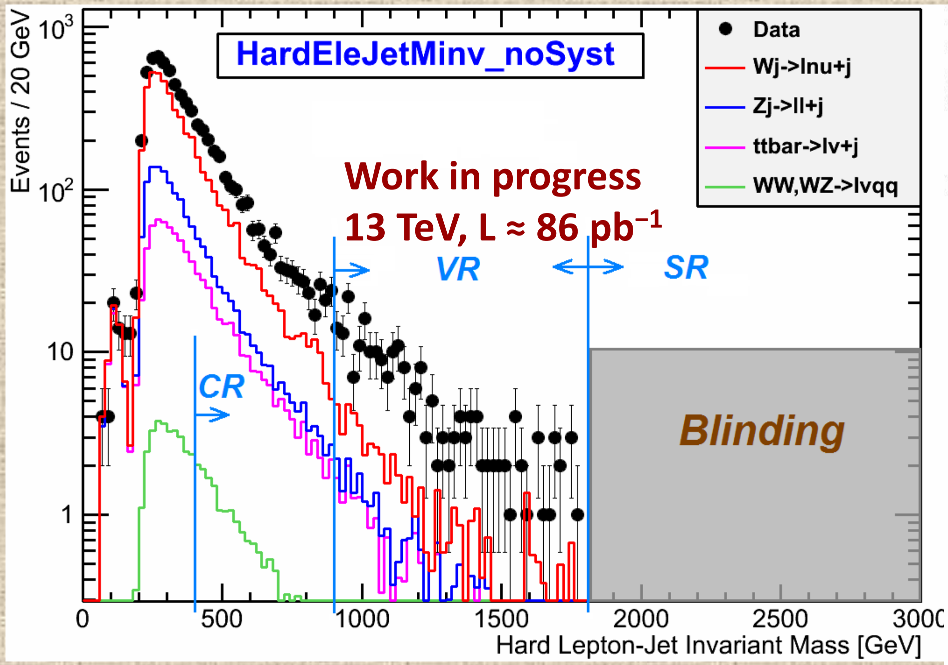


Behavior of distributions of leading jets is similar enough to leptons distributions which were shown at the previous slide.

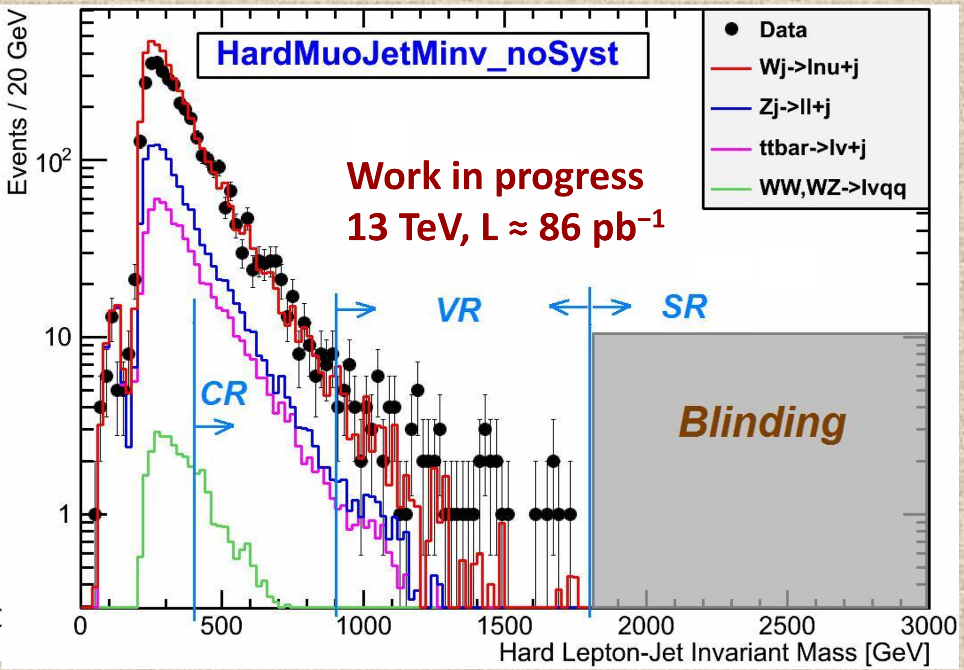
6.5. Distributions of lepton-jet pairs over invariant mass (very preliminary)

Monte-Carlo samples were normalized to integrated luminosity of data with use of corresponding cross-sections. A fit or any additional k-factors were not used.

Electron channel after selection of hard lepton and jet (pT>100 GeV)

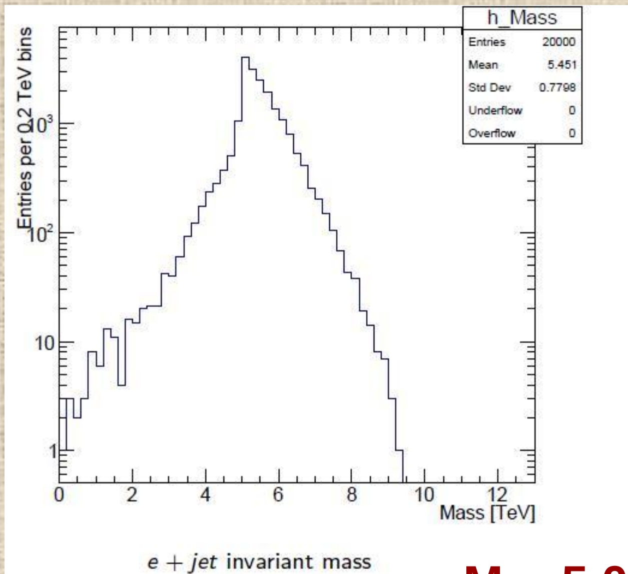


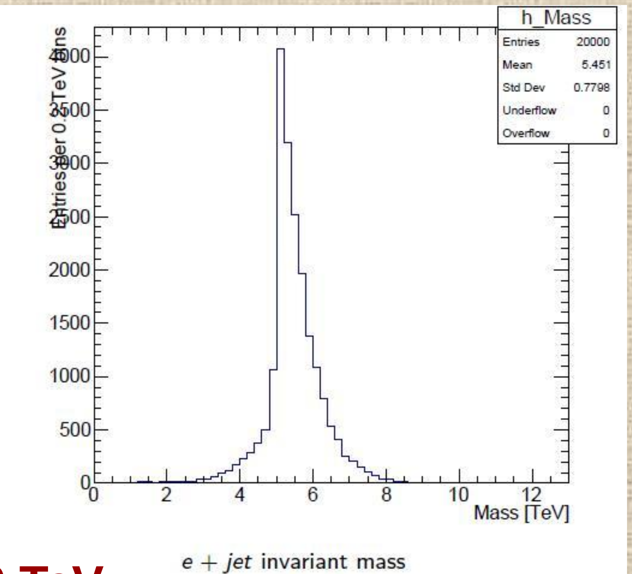
Muon channel after selection of hard lepton and jet (pT>100 GeV)



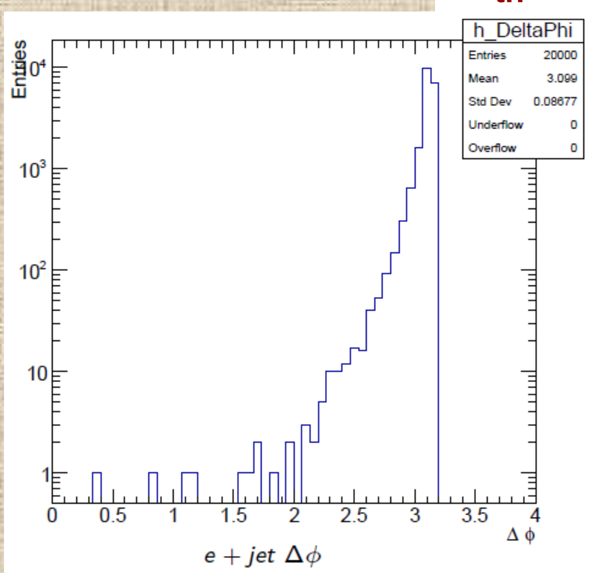
Behavior of data distributions after selection of hard both lepton and leading jet somewhat deviate from background distributions. Difference is in both absolute value and slope of dependences. It may be consequence of unused k-factors and a fit. Signal region is blinded now as required by Publication Committee.

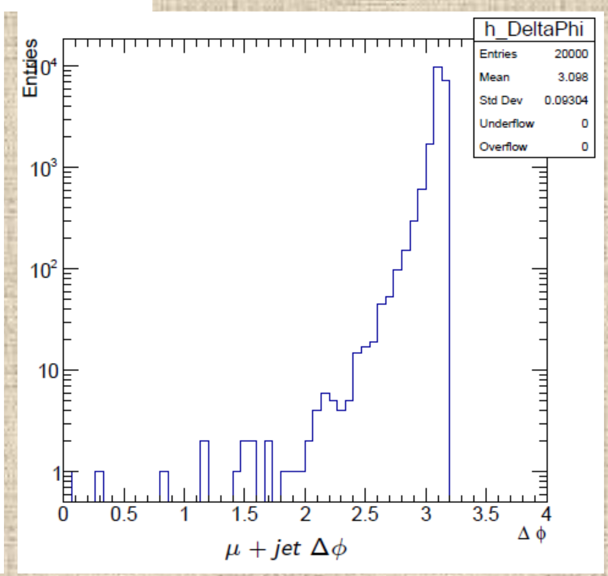
6.6. Generation of signal samples at 13 TeV





M_{th}=5.0 TeV





- ✓**10+10 Signal samples** with threshold mass M_{th}= 5.0–9.5 TeV and with 0.5 TeV step were generated According to the ADD model with large extra dimensions n=6 for e+jet and μ+jet final states of QBH decay.
- ✓**20000 events** per sample has been result of that.
- ✓Distributions of **invariant mass** at M_{th} = 5 TeV in electron+jet channel you can see in upper panels.
- ✓**Delta phi** between lepton and jet momentum is shown in bottom panels. You can see asymmetric distribution. It contrast with symmetric distribution of background.

Conclusions

1. Start of search for QBH in 1lepton+1jet final state at 13 TeV was at the end of June, 2015.
2. Status of analysis of 50-ns early data on search for QBH was represented on two meetings of Exotic L+X sub-group. Now work is continued.
3. Poster with searching for QBH at √s=8 TeV was represented on the LHCP2015 conference on 1 September 2015.
4. Draft of Supporting Note is preparing now: "Search for Quantum Black Holes using pp collisions at √s=13 TeV with the ATLAS, first view on early data".
5. Draft of the ATLAS Conference Note on this topic is also in progress.

ATLAS NOTE
ATL-COM-PHYS-2015-XXX
18th September 2015

Draft version 0.0

Search for Quantum Black Holes using pp collisions at √s=13 TeV with the ATLAS, first view on early data
EXOT-2015-X
Version: 0.0

Supporting internal notes
Quantum black hole https://cds.cern.ch/record/XXXXXXX/files/ATL-COM-PHYS-2015-XXX.pdf

Comments are due by: XXth September 2015

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Abstract

The searches in the dataset of LHC Run-II in final states with leptons and jets are sensitive to the TeV electroweak scale of quantum black holes (QBH) provided that fundamental multidimensional mass (M_D) is less or equal to 10 TeV. Large extra dimensions are equal 6 in the ADD model. In the low gravity scale Planck mass is greater than M_D (then M_D will be less or equal 10 TeV). According to the Run-I data the upper limit constrains the threshold quantum black-hole mass to be above 5.3 TeV in the model considered. The discovery reach in the Run-II at the LHC is expected to be possible, due to the large increase of the pp-collisions energy in the centre-of-mass from 8 TeV to 13 TeV. Expected distributions for signal and background are represented for the several values of integrated luminosity (1−10 fb^{-1}).

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Thank you!

6.5. Control, signal and validation regions

Control region (CR) is a low invariant mass region that is defined for masses between 400 GeV and 900 GeV, and has a negligible contamination of a potential signal (< 2%) for the lowest threshold mass M_{th}. For analysis at the collisions energy of 13 TeV the same Control region was taken as at 8 TeV.

Signal region (SR). Lesser invariant mass M_{inv} is used when defining the Signal region in comparison with 8 TeV analysis, because low statistic in early data. In both electron and muon channels the SR is defined so – it is two times larger, than the right border for Control region. It begins from 1800 GeV and is following into the region of high masses.

Validation region (VR) lies between Control region and Signal region. For both electron and muon channels it is diapason of invariant masses from 900 GeV up to 1800 GeV.

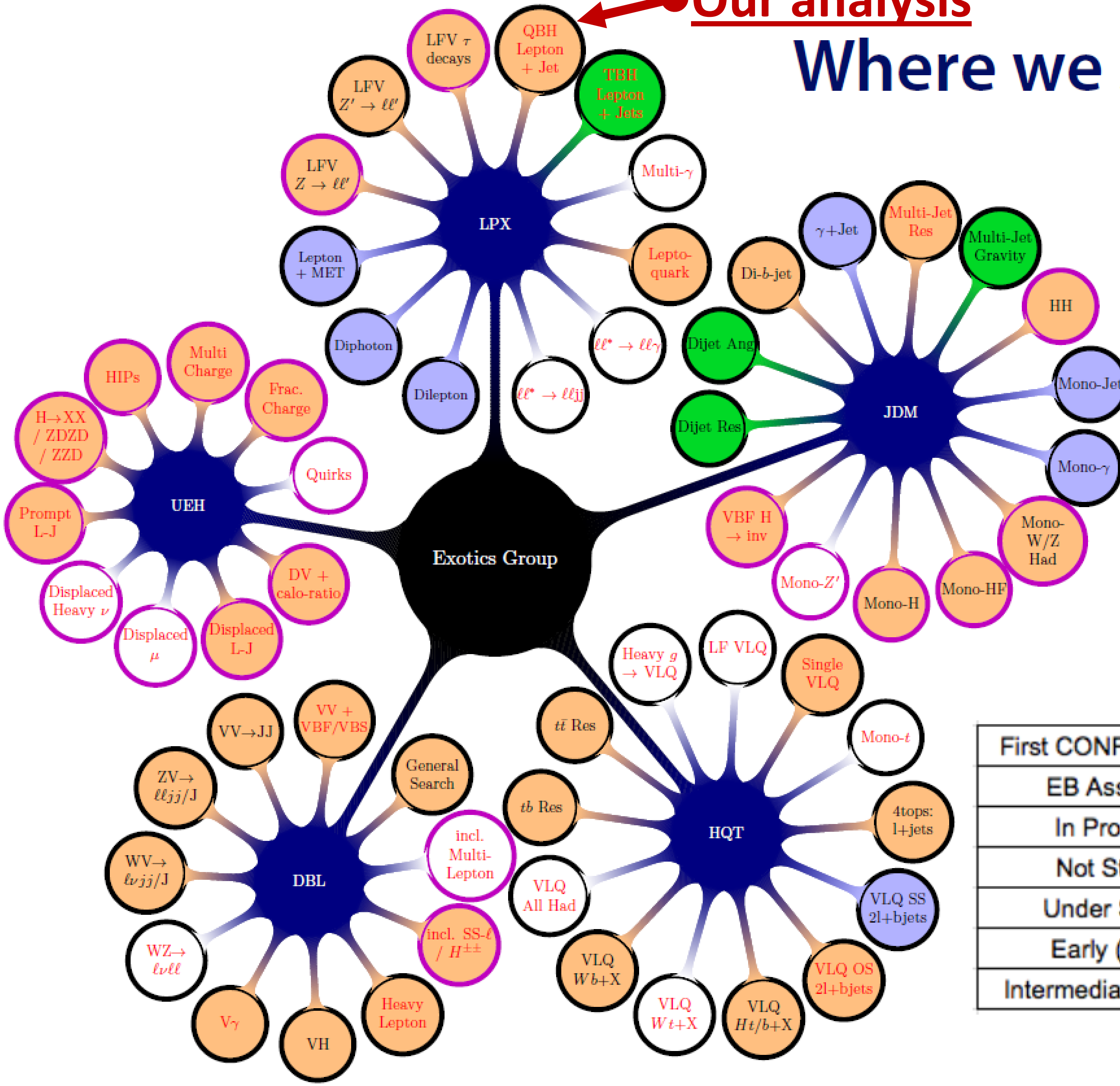
To do:

1. Improvement of analysis code (adaptation to latest SUSYTools, addition of HistFitter trees production, etc.).
2. Selection of events and production of TTrees including all backgrounds and systematics for analysis with HistFitter.
3. Addition of residuary sources of background: single top, certain di-bosons decays, multi-jets.
4. Fit of MC background in control region with HistFitter. Obtaining of events number in validation and signal regions. Plots of comparison of data with background and MC signal.
5. Preparation of a support note and conference note.

Structure of Exotic Group

Our analysis

Where we stand now



First CONF Released	(green)
EB Assigned	(blue)
In Progress	(orange)
Not Started	(white)
Under Staffed	Red Text
Early (2-5fb)	(black ring)
Intermediate (6-10fb)	(purple ring)