ПИЯФ В физической программе эксперимента АТЛАС

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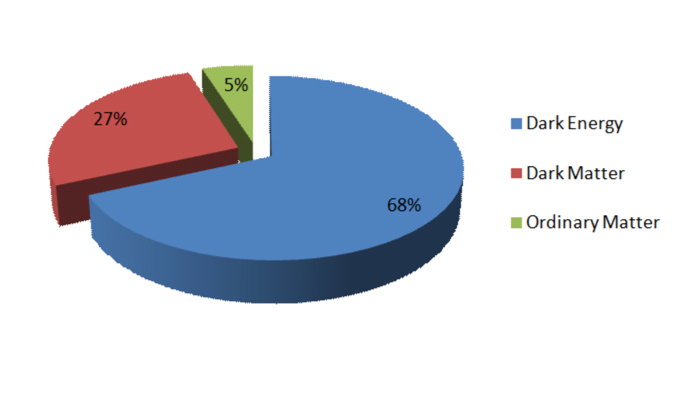
Научная сессия ОФВЭ ПИЯФ, 26.12.2017

Участие ПИЯФ В физической программе эксперимента АТЛАС

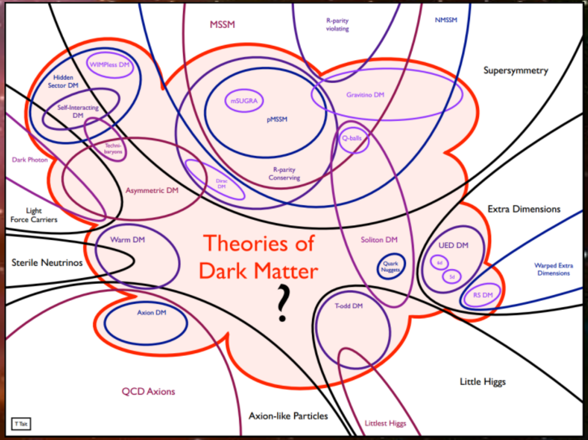
- **Поиски новых явлений за пределами Стандартной модели (BSM):**
  - частиц темной материи в процессе моно-Z
  - тяжелого нейтрального бозона Хиггса
  - новых тяжелых векторных бозонов W’, Z’

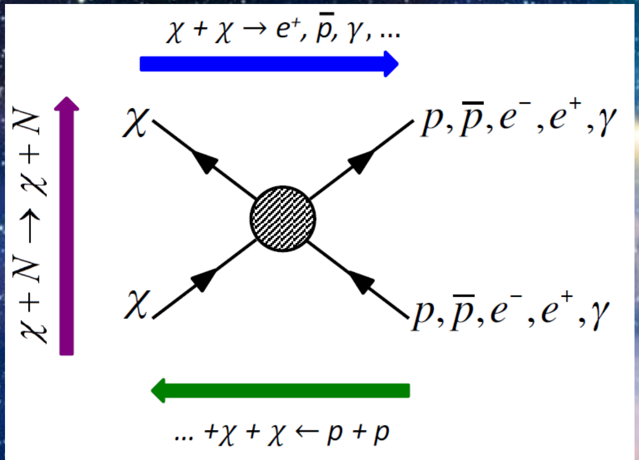
- **Измерение параметров Стандартной модели**
  - Прецизионное измерение спектра поперечного импульса Z-бозона и угловой переменной ф* в процессе $Z \to \ell\ell$
  - Бозе-Эйнштейн корреляции

Search for a Dark Matter

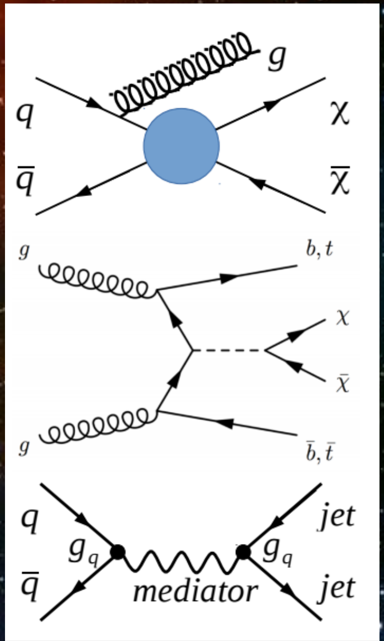


- Indication on the Dark Matter existence follows from the astrophysical observations
- Direct, indirect, collider searches
- Dark Matter particles predicts by some of SM extensions (BSM models): MSSM, 2HDM …



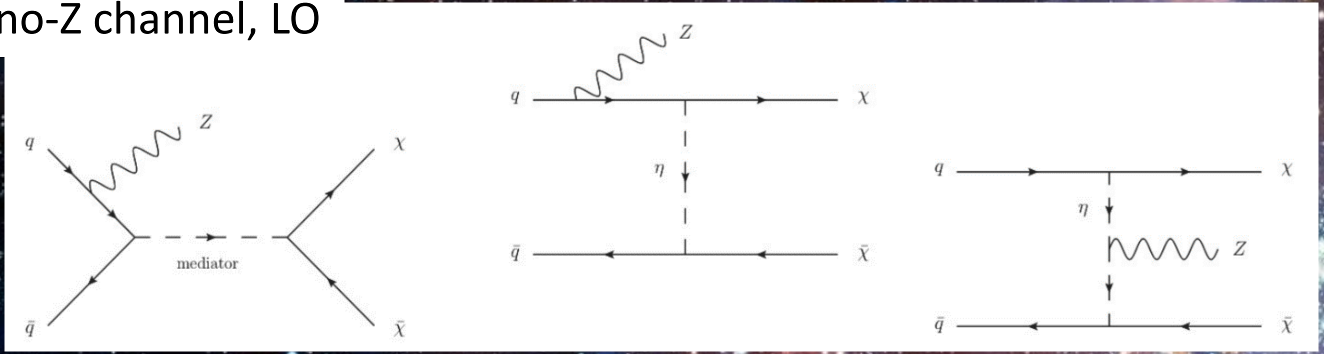


- LHC searches: mono-X, associative production, search for the dark mediator
- Model independent analysis: EFT, simplified models
- For the data analysis wide range of DM mass and mediator mass for different mediator types: axial-vector, vector pseudo scalar ….

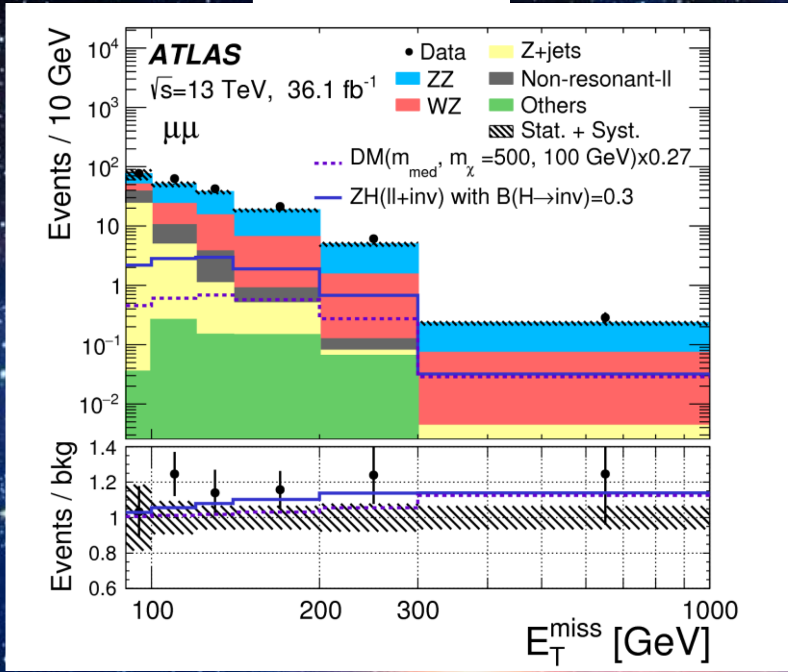


Search for a Dark Matter (WIMP) in mono-Z (ISR) process

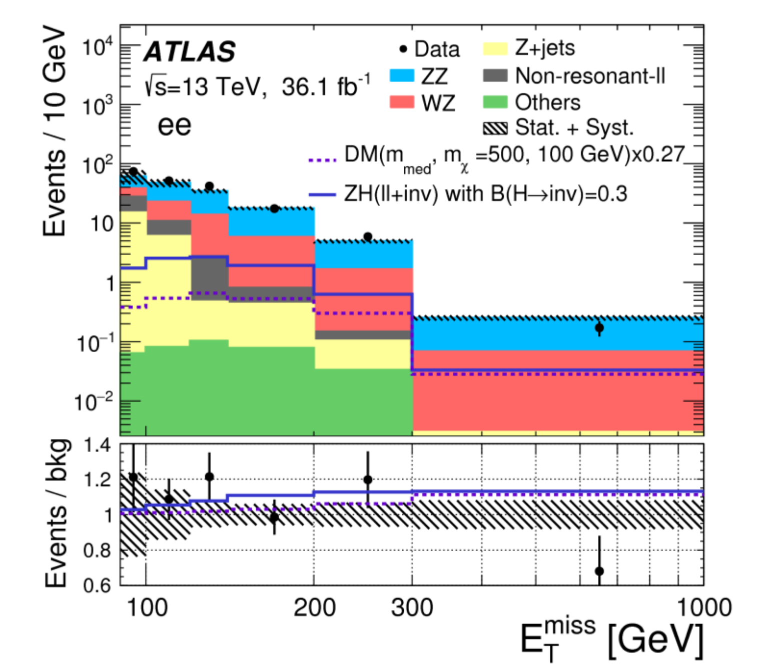
mono-Z channel, LO



ee-channal



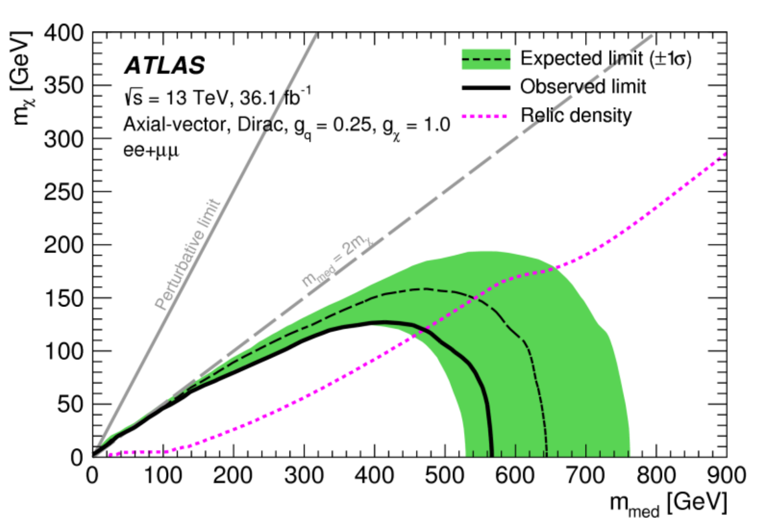
μμ-channal



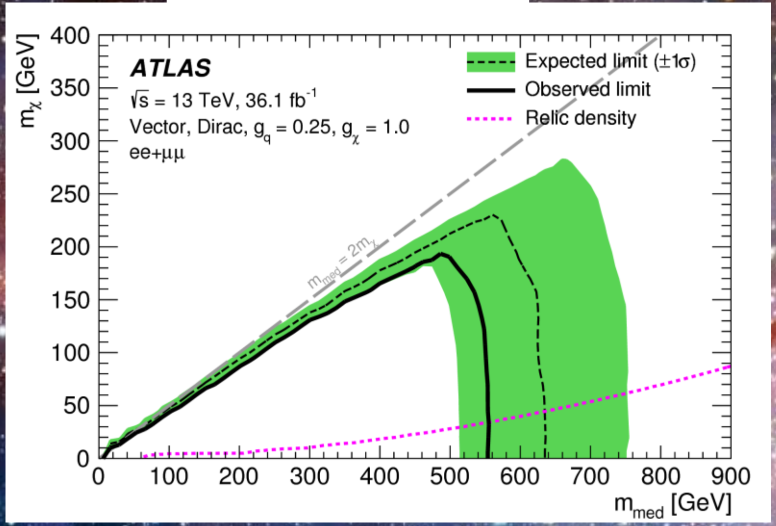
- Discriminating variable – missing energy: E_T^{miss}
- Data on **pp** collisions at $\sqrt{s} = \mathbf{13\ TeV}$ collected in 2015-2016 years of Run II, with the integrated luminosity 36.1 fb^{-1} have been analyzed
- No excess of the data over SM prediction were observed

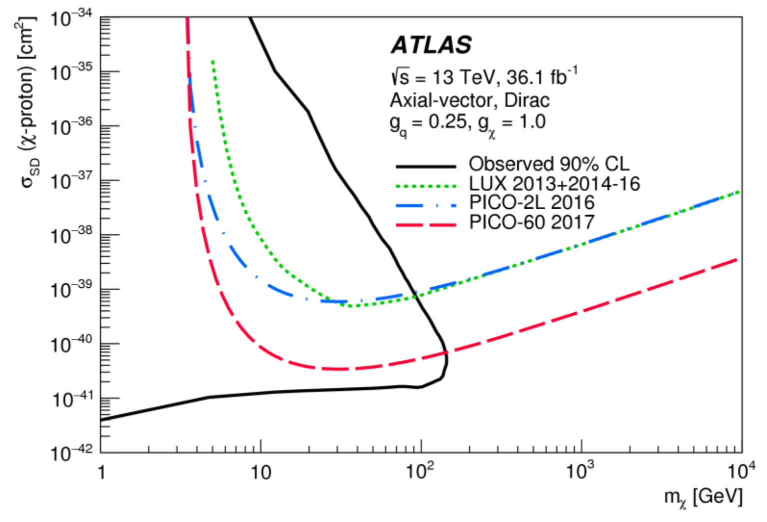
Search for a Dark Matter (WIMP) in mono-Z (ISR) process

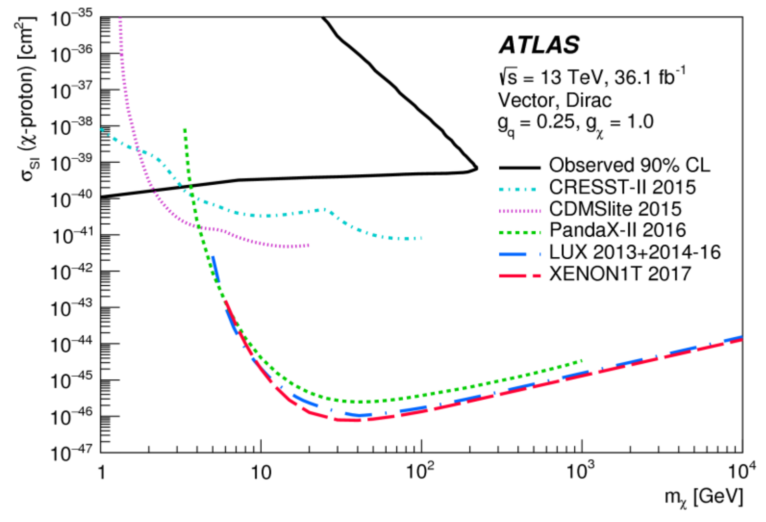
Axial-vector mediator



Vector mediator







- ➢ Upper limits on cross section production vs BSM Higgs mass were obtained
- ➢ Comparison with direct measurements demonstrated that the cross section limits, obtained in ATLAS experiment are much stronger in the mass range 1-150 ГэВ for the spin-dependent cross section and in the mass range 1-2.5 ГэВ for the spin-independent cross sections.

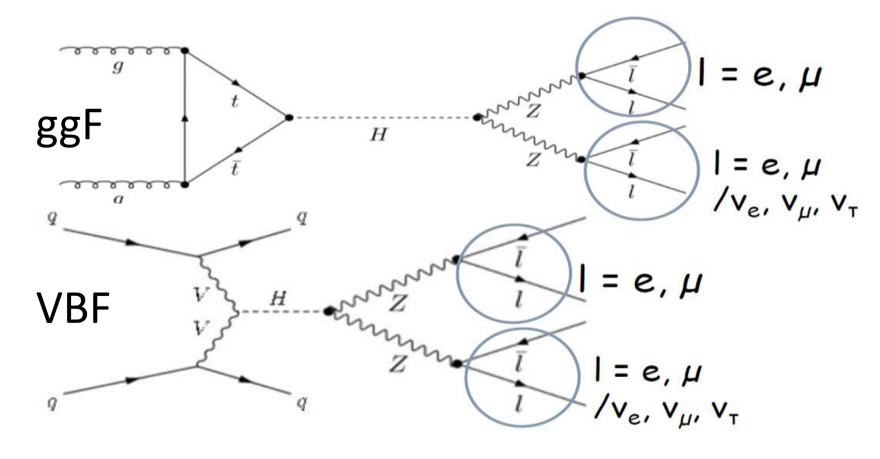
Phys. Lett. B 776, 318-337 (2017)

Search for a Dark Matter (WIMP) in mono-Z (ISR) process

Вклад ЛАФ ОФВЭ в анализ:

- Оптимизация критериев отбора полезных событий
- Участие в Монте-Карло генерировании сигнальных событий
- Проверка эффективности триггеров используемых для анализа данных
- Оценка вклада фоновых процессов
- Установка верхних пределов на сечения рождения частиц темной материи.

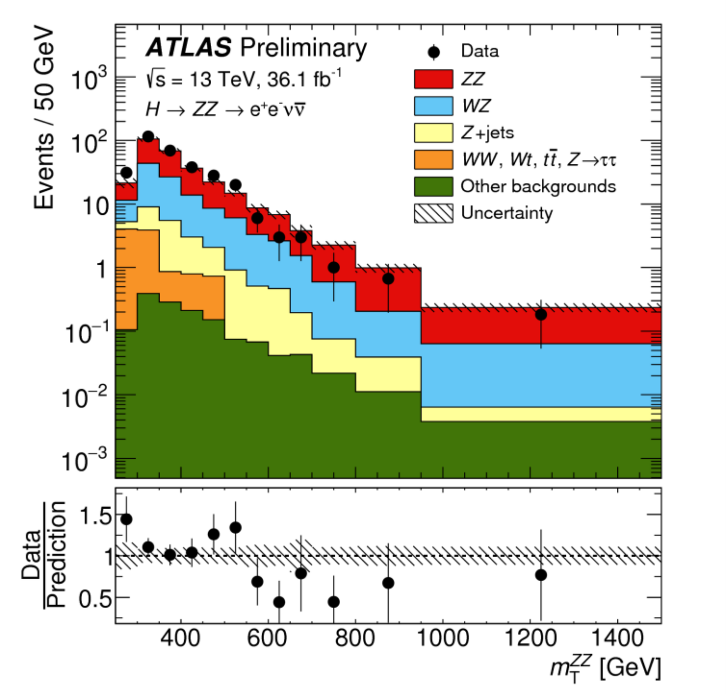
Search for a heavy neutral Higgs boson (BSM)



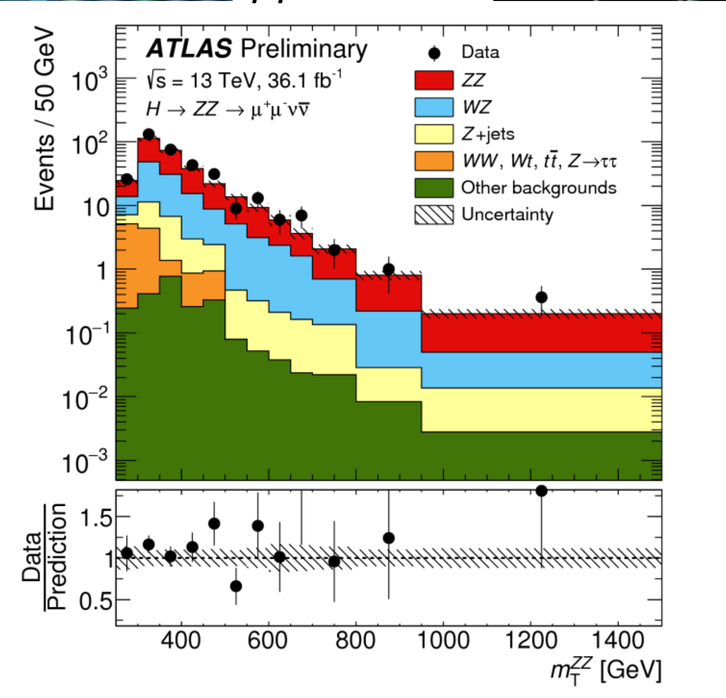
Predicted by the SM extension (BSM):
2HDM, MSSM: CP-even h and H, CP-odd pseudoscalar (A), charged H+ , H-
HTM: H±±, H±, A, H and h, NMSSM, LRSM …

- H→ZZ→$\ell\ell\nu\nu$
- Discriminating variable – transverse mass – m_T
- Data on **pp** collisions at $\sqrt{s} = 13\ TeV$ collected in 2015-2016 years of Run II, with the integrated luminosity 36.1 fb^{-1} have been analyzed
- No deviation from the standard model prediction was found

ee-channal



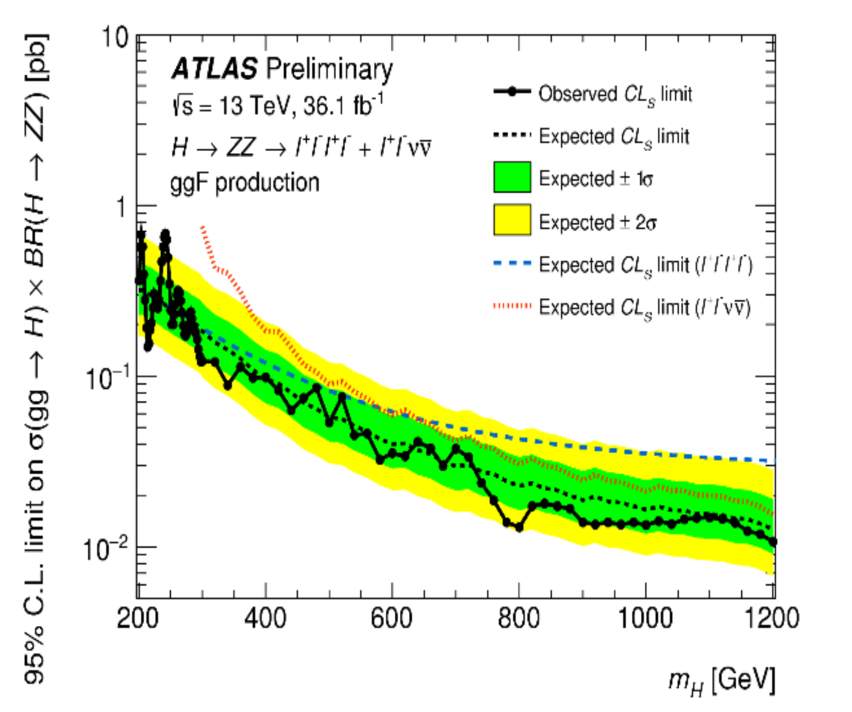
μμ-channal



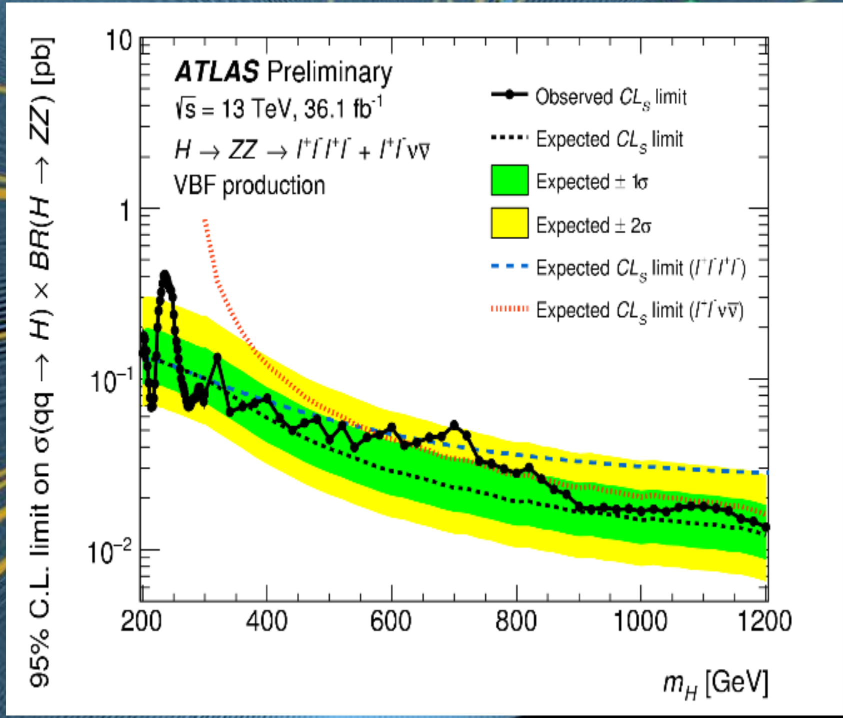
$$m_{\rm T} \equiv \sqrt{\left[\sqrt{m_Z^2 + \left(p_{\rm T}^{\ell\ell}\right)^2} + \sqrt{m_Z^2 + \left(E_{\rm T}^{\rm miss}\right)^2}\right]^2 - \left|\vec{p}_{\rm T}^{\,\ell\ell} + \vec{E}_{\rm T}^{\rm miss}\right|^2}$$

Search for a heavy neutral Higgs boson (BSM)

ggF



VBF



- Data on **pp** collisions at $\sqrt{s} = 13\ TeV$ collected in 2015-2016 years of Run II, with the integrated luminosity 36.1 fb^{-1} have been analyzed
- Upper limits on cross section production vs BSM Higgs mass were obtained

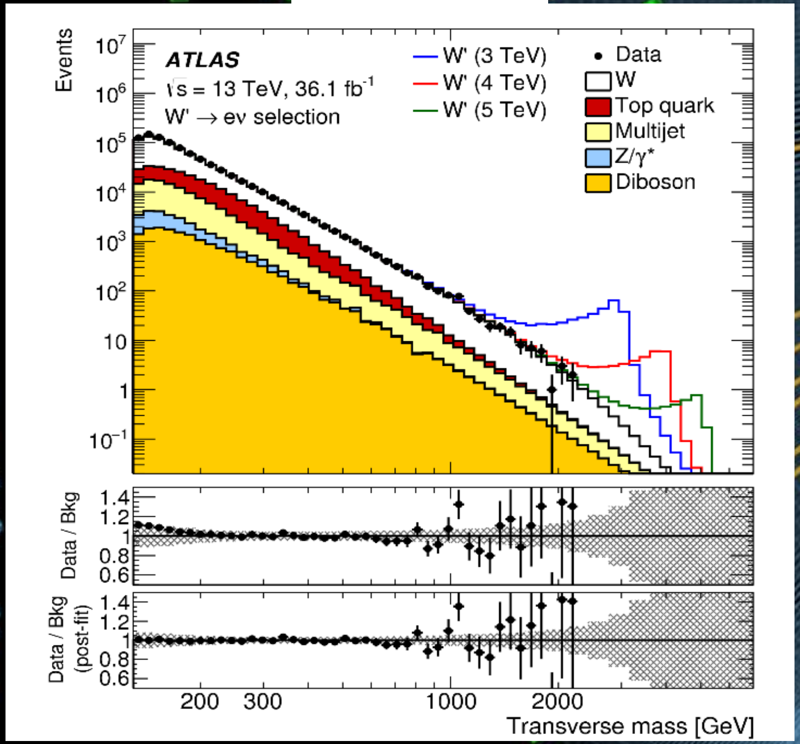
CERN-EP-2017-251

Вклад ЛАФ ОФВЭ в анализ: Оценка вклада фоновых процессов

Search for heavy gauge W’-boson

- BSM models like E6, SSM, LRSM predict new heavy W’ gauge boson
- In SSM W’ has the same couplings as SM W-boson
- Search for high mass states with leptons (W’→eν, W’→μν) plus missing ET
- The observable is transverse mass: $m_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos\phi_{l,E_T^{miss}})}$
- Look for excess above background (SM)

ee-channal



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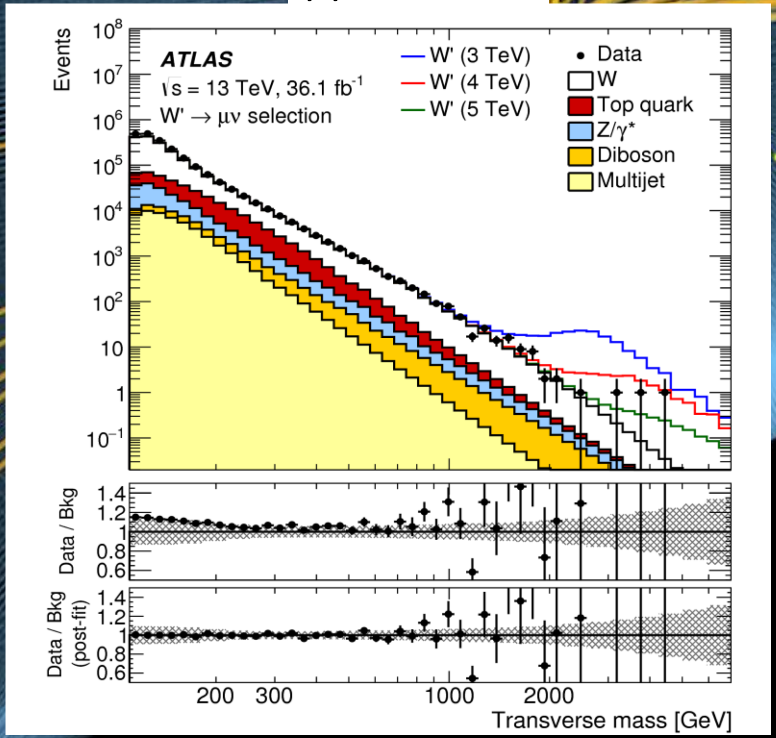
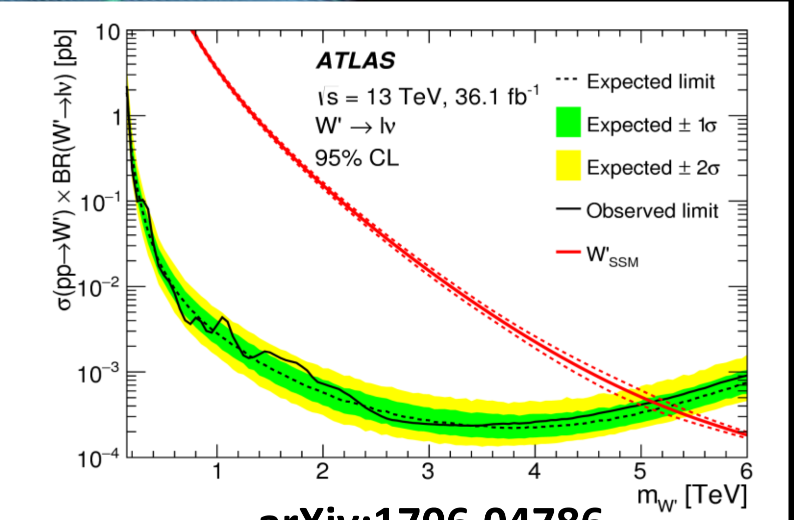


- 2015, 2016 of Run II data with integrated luminosity 36.1 fb^{-1} were analyzed in the mass range 150-6000 GeV
- No deviation from the SM prediction was found
- Upper limits on production cross section vs m $_{W'}$ mass were set
- PNPI contribution: eν-channel

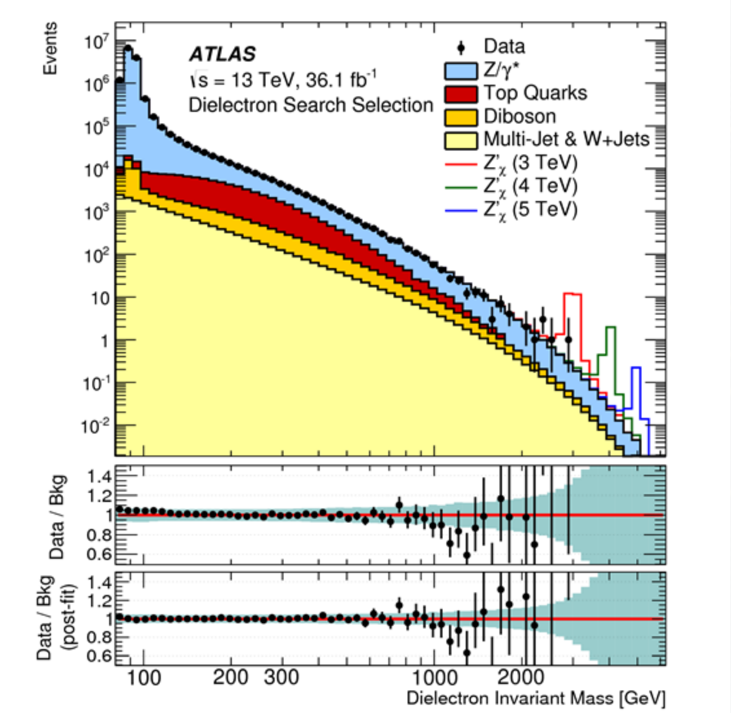


arXiv:1706.04786

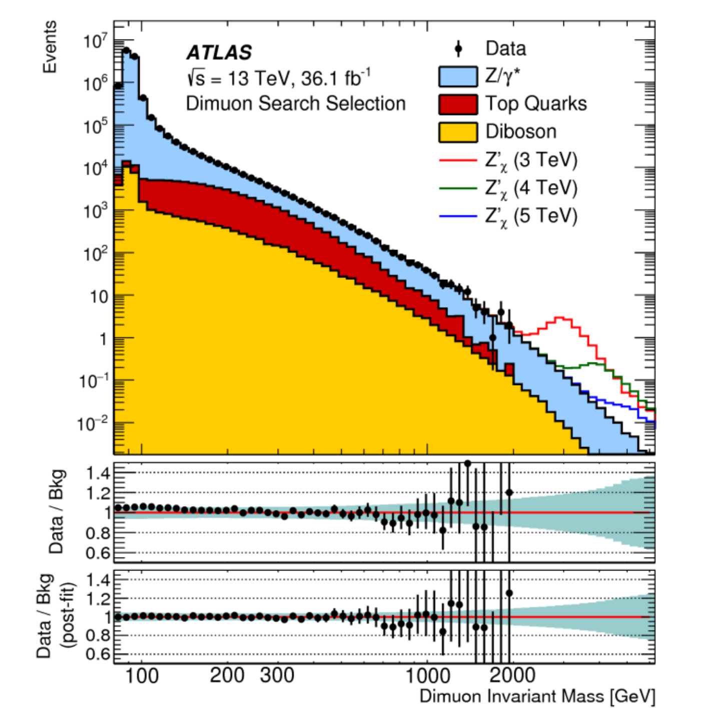
Search for heavy gauge Z'-boson

- BSM models like E6, SSM, LRSM predict new heavy Z' gauge boson
- In SSM Z' has the same couplings as SM Z-boson
- Search for high mass states with leptons ($Z' \to ee$, $Z' \to \mu\mu$)
- The observable is the invariant mass of two leptons: m_{ll}
- Look for excess above background (SM)

ee-channal



μμ-channal



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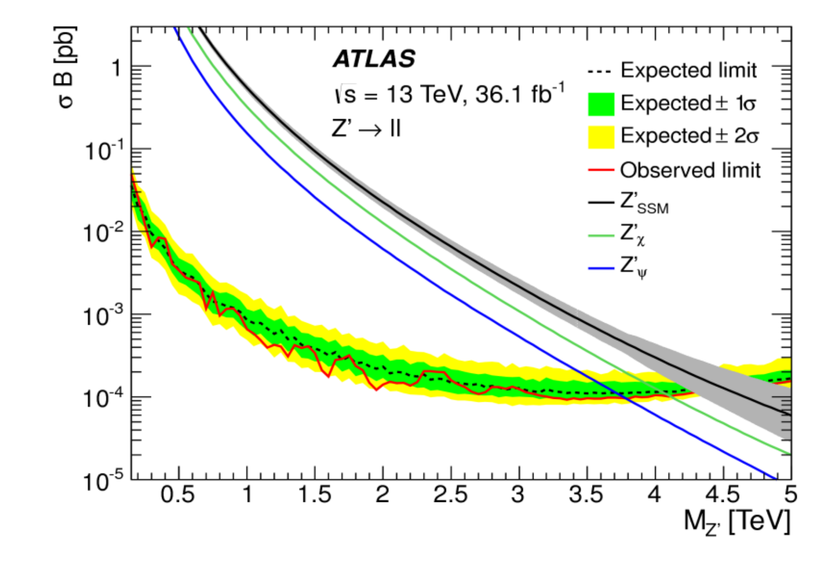

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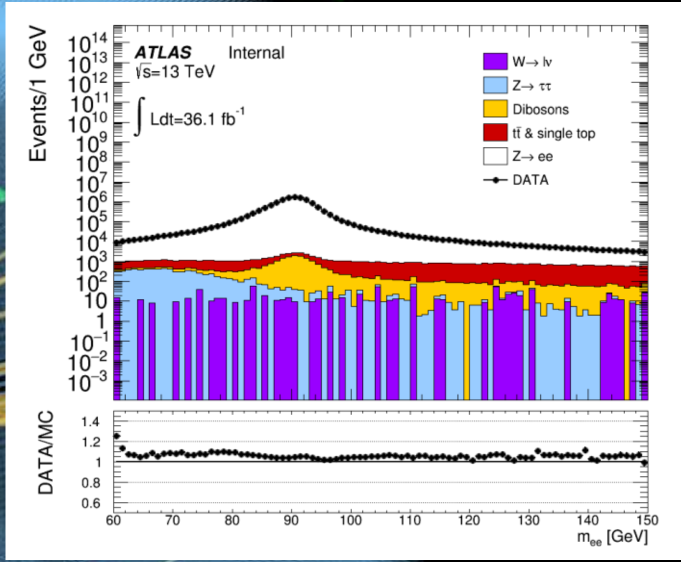
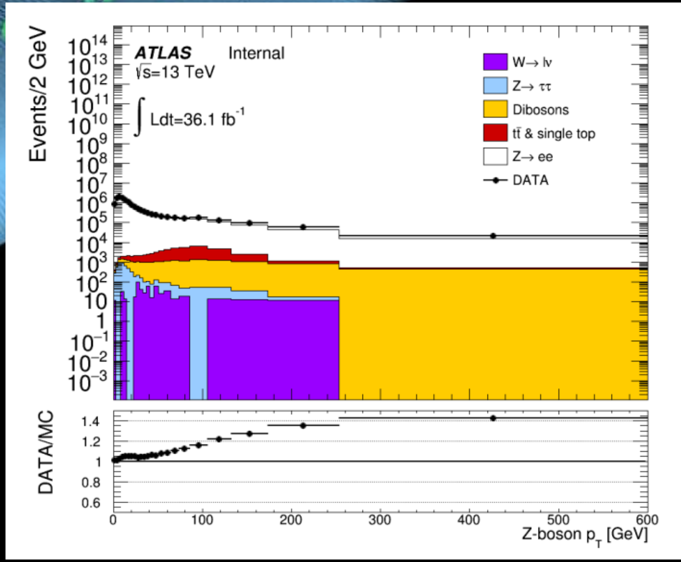
Precision studies of p_T and φ* of Z-boson

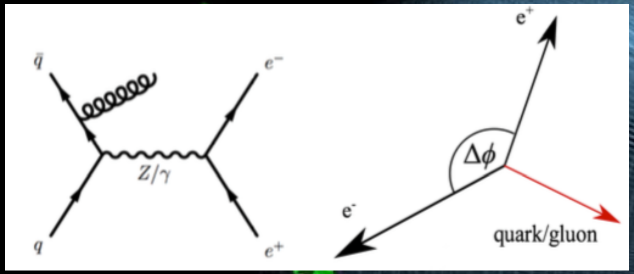
- Test predictions of
  - QCD predictions in all order of α_s complimented with Parton Showers(PS)
  - Soft-gluon resummation and hard jet emission
  - Non-pertubative effects (initristic parton transverse momentum)
- Results can be used for
  - **Improve re-summed analytical calculations**
  - Tune Monte-Carlo generators
  - measurement of electroweak observables (e.g. W boson mass)
  - Important for searches in which Z processes are background





- PNPI team is participating in all activities (from event selection till final result)
- For ATLAS collaboration we contribute to the analysis of electron channel

Precision studies of p_T and φ* of Z-boson

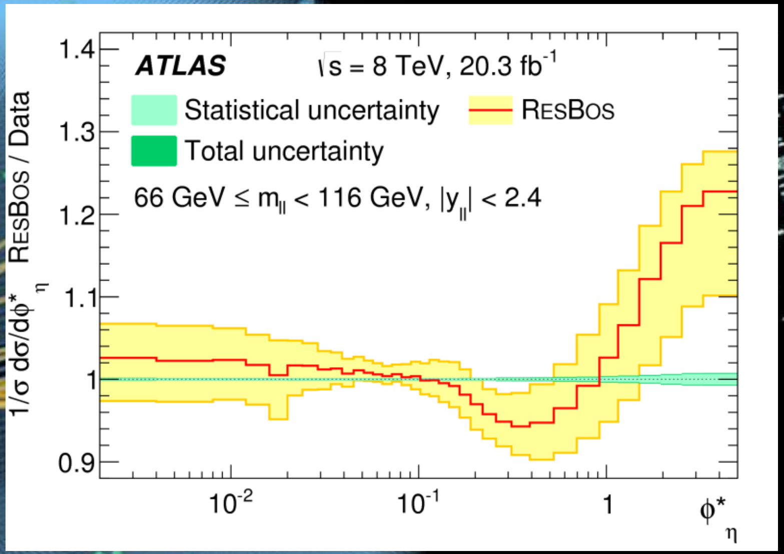


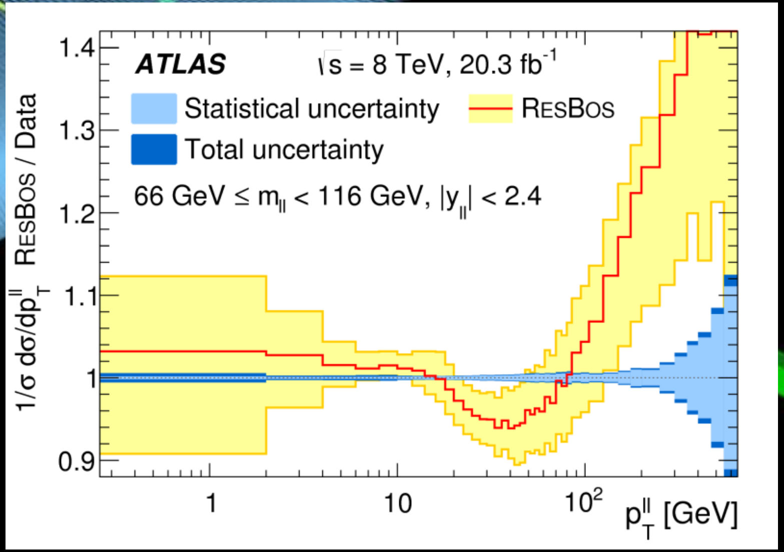
$$\phi^*_\eta = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\cdot\sin(\theta^*_\eta)$$

$$\theta^*_\eta = \arccos\left(\tanh\left(\frac{\eta^- - \eta^+}{2}\right)\right)$$

Advantages and definition of φ*:

- independent for p_T calibration and resolution of the final-state leptons
- ϕ^*_η provide excellent experimental precision at low p^Z_T
- depends only on the directions of the two leptons (measured better than their momenta)





Scale on x-axis are aligned according to the approximate relationship

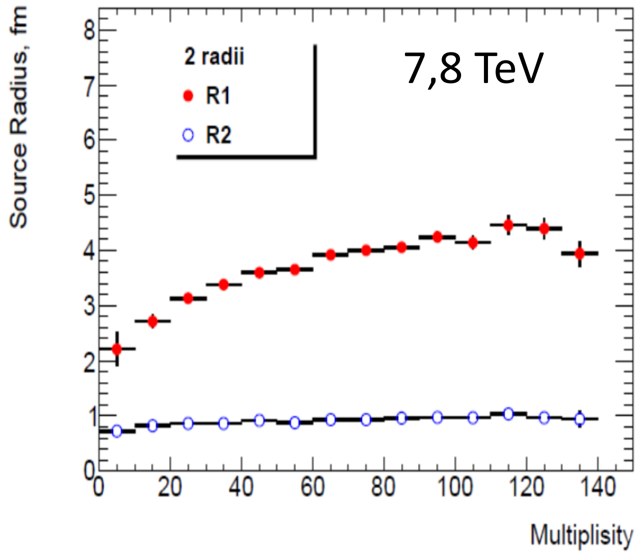
$$\sqrt{2}\, m_z \phi^*_\eta \approx p_T^{ll}$$

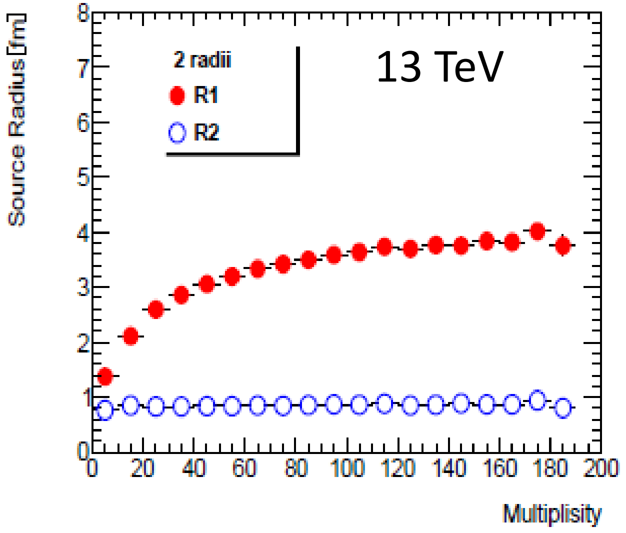
Finer binning in φ* while maintaining smaller systematic uncertainties

Bose Einstein correlation

BEC represent a unique probe of the space-time geometry of the hadronization region and allow the determination the size and shape of the source from which particles are emitted. BEC is usually describes by a function with two parameters: the effective radius R and correlation strength λ: $R(Q) = \lambda e^{-R1Q} + a + bQ$

As it was shown in paper: V.A. Khoze, A.D. Martin, M.G. Ryskin and V.A. Schegelsky, Eur. Phys.J. C76 (2016) 193) that the secondaries produced in high energy hadron collisions may be radiated by small size sources distributed over a much larger area of the proton-proton interaction: $R(Q) = \lambda e^{-R1Q} + (1-\lambda)e^{-R2Q} + a + bQ$
Where R1 – is the distance between two sources and R2-the radius of the source





For the first time it was demonstrated that secondaries are produced but a small size sourcies ofn the radius $R2 \sim R_{\pi}$ which separated by the distance $R1 \sim 2R_N$ between individual sources. These sources may be considered as the individual Pomerons or as some excitations of QCD vacuum medium.

arXiv:1608.05218

Группа ЛАФ ПИЯФ

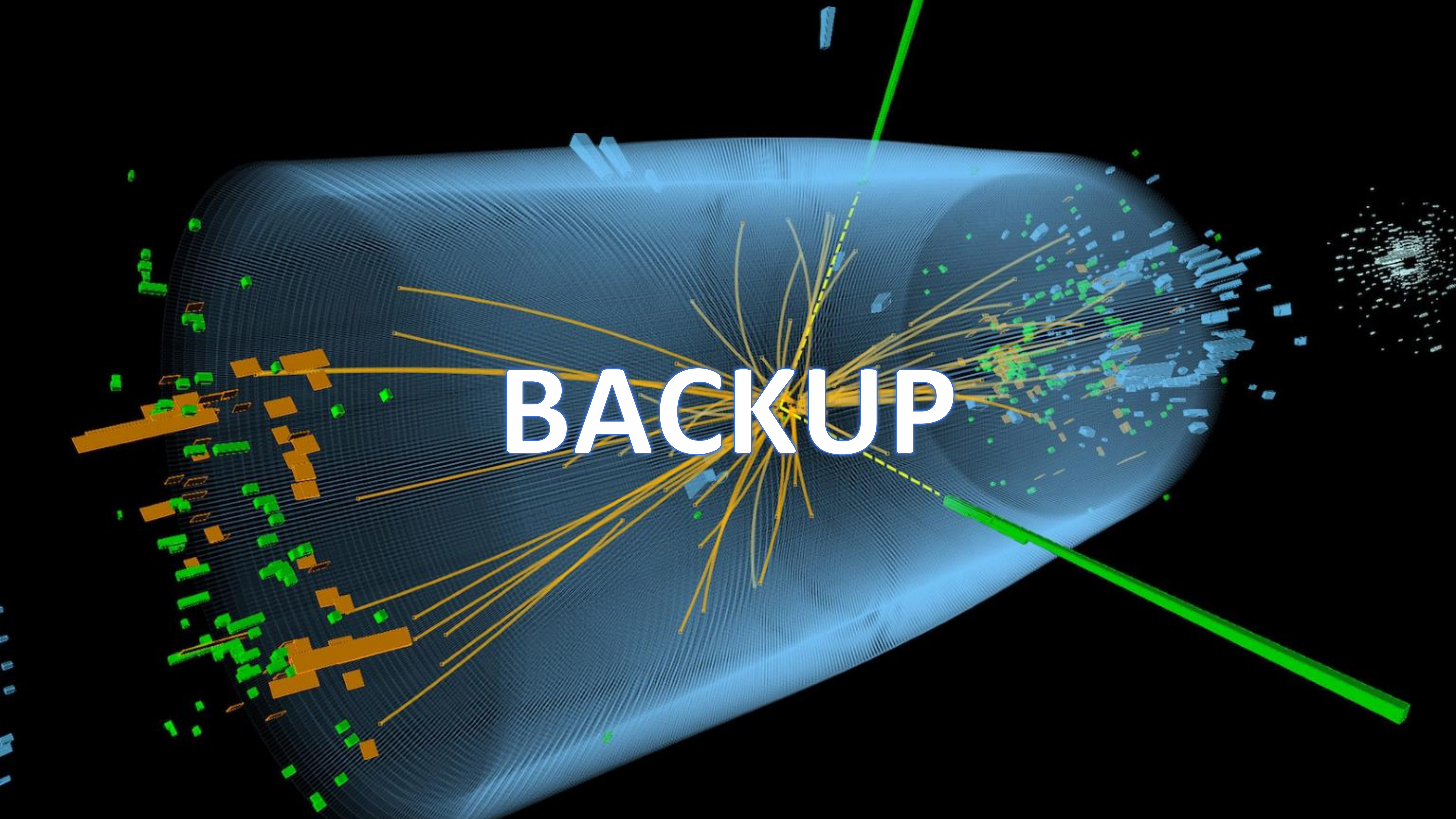
- Руководитель – О.Л. Федин
- **Поиск Z’**: В.П. Малеев, М.П. Левченко
- **Поиск W’**: В.М. Соловьев
- **Прецизионное измерение спектра поперечного импульса Z-бозона и угловой переменной ф* в процессе $Z\to\ell\ell$**:
  А.Е. Ежилов, В.М. Соловьев, Д. Пуджа
- **Бозе-Эйнштейн корреляции**:
  В.А. Щегельский
- **Поиск частиц темной материи**:
  А.Е. Басалаев, Ю.Г. Нарышкин, А.С. Кирьянова
- **Поиск тяжелого нейтрального бозона Хиггса**:
  А.Е. Басалаев, Ю.Г. Нарышкин , А.С. Кирьянова

По результатам работы в 2017 г. :

- **Защищено 2 кандидатских диссертации:**
  В.П.Малеев - “Поиск тяжелых нейтральных бозонов, распадающихся на электрон и позитрон в эксперименте ATLAS”
  В.М.Соловьев - “Поиск тяжелых заряженных векторных бозонов в канале распада на электрон и нейтрино в эксперименте ATLAS”
- **Опубликовано в 2017 году:**
  внутренних препринтов 6
  препринты (CONF notes) 4
  Статей 3+4 (+1 статья TRT)
- **доклады на конференциях 6**

- **Грант РФФИ “Поиск частиц темной материи в эксперименте АТЛАС на ускорителе LHC”**

BACKUP



Поиск тяжелого нейтрального бозона Хиггса: BSM Models

- **2HDM** (Two Higgs Doublet Model) is an extension of Standard Model: second Higgs doublet is added to SM leads to 5 physical states, 3 neutral, 2 charged: CP-even **h** and **H**, CP-odd pseudoscalar (**A**), charged **H^+ , H^-** The minimal model has 6 free parameters: Higgs masses m_h, m_H, m_A, $m_{H\pm}$ and the ratio of doublet vacuum expectation values $\tan\beta = v_1/v_2$ and a mixing angle α between the CP-even Higgs bosons

- **MSSM** (Minimal Supersymmetric Standard Model): extension of SM (each SM particle has a supersymmetric partner). MSSM higgs sector is a particular case of 2HDM type

- **NMSSM**: Higgs singlet is added to MSSM$\rightarrow$7 physics states, 5 neutral, 2 charged: CP-even H_1, H_2, H_3 , CP-odd A_1 A_2, charged H^+, H^-

- **HTM**: (Higgs Triplet Model): Higgs triplet is added, lead to 7 physical states: $H^{\pm\pm}$, $H^{\pm}$, A, H and h

- **LRSM**: (Left Right Symmetric model) several variations: e.g. addition of triplet + two doublets (bi-doublet)

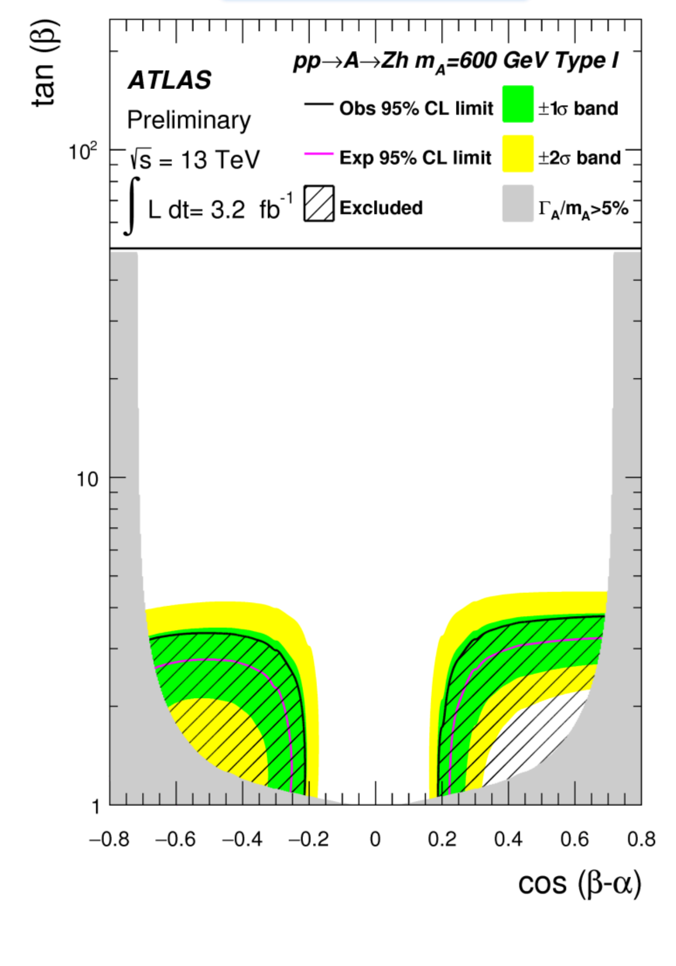
- **... and more ...**

Searches by ATLAS & CMS

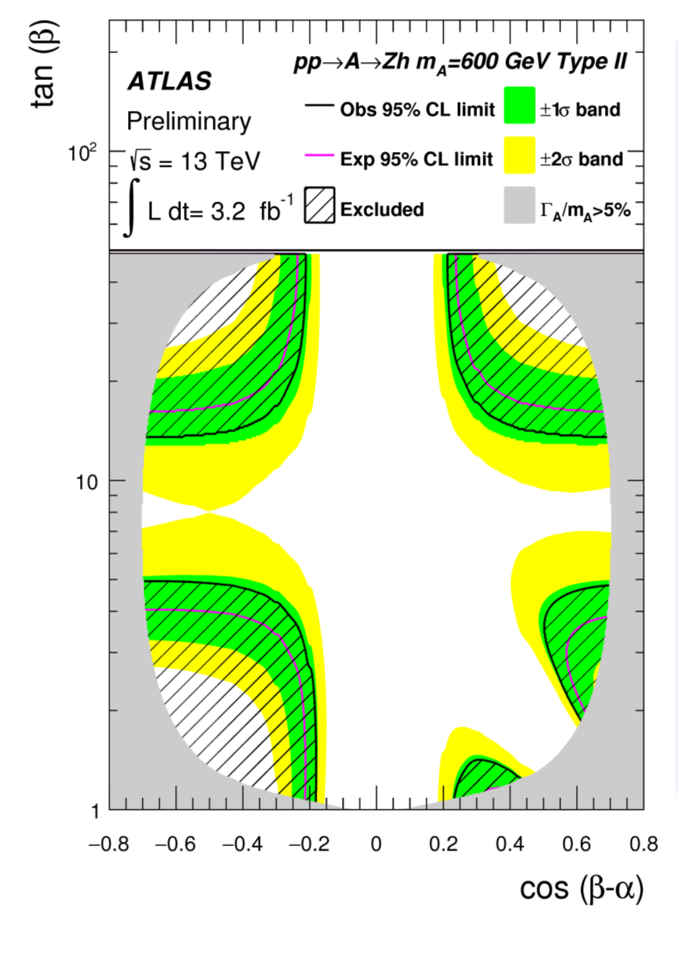
- Neutral Heavy Higgs: $h/H/A \to \tau\tau$, $H \to WW \to \ell\nu\ell\nu$,
  $A \to Zh(Z \to \ell\ell, h \to b\bar{b}(\tau\tau))$, $h/H/A \to t\bar{t}$ …
- Neutral Higgs decaying to di-Higgs: $H \to hh \to bb\tau\tau$, $hh \to b\bar{b}b\bar{b}$,
  $hh \to bb\gamma\gamma$, $hh \to WW\gamma\gamma$, $hh \to WWbb$, $hh \to WWWW$
- Charged Higgs: $H^{\pm} \to \tau\nu$, $H^{+} \to tb$, $H^{+} \to WZ \to 3\ell + \nu_{\ell}$, $H^{+} \to WZ \to 2\ell + 2j$
  $H^{+} \to \mu\nu$, $H^{+} \to Wh/WA/W\gamma$, light $H^{+} \to cs$, cb
- Double charged Higgs boson: $H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$, $H^{++} \to WW$
- … and more …

A→Zh→$\ell\ell b\bar{b}$: ATLAS@13TeV

2HDM Type I



2HDM Type II

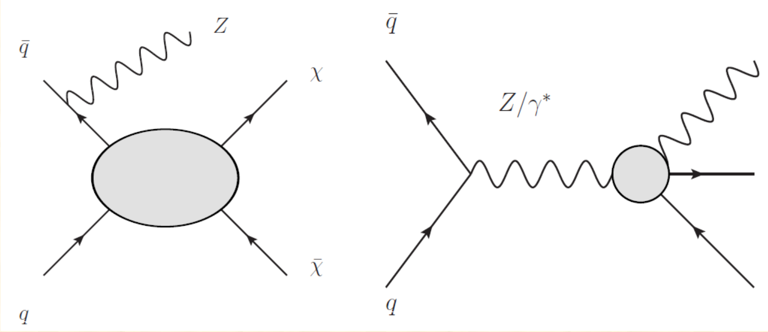


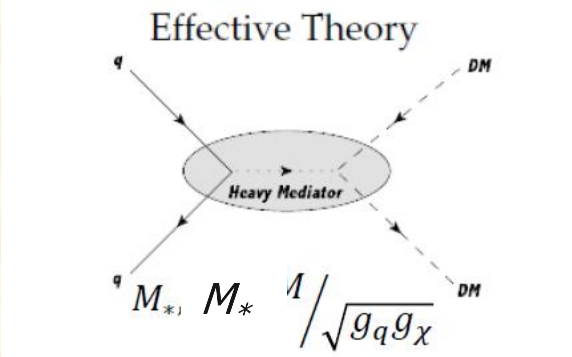
Results are interpreted in the context of 2HDM (type I and II) as a function of the model parameters tanβ and cos(β-α)

- $A \to W^+ H^-$, $A \to ZH$ are assumed to be forbidden
- The width of the A boson is corrected to the width (Γ_A) predicted by the 2HDM.
- Only points in parameter space where $\Gamma_A/m_A < 5\%$ are considered.

ATLAS-CONF-2016-015

EFT: Effective Field Theory





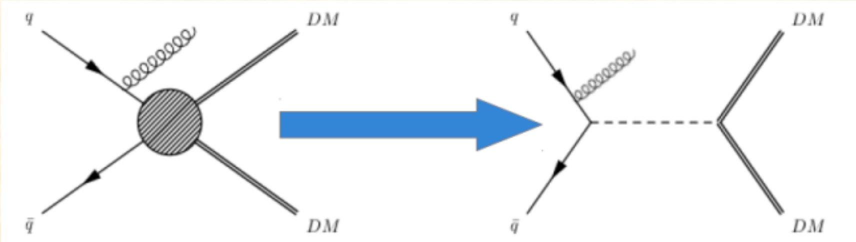
arXiv:1008.1783

Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$

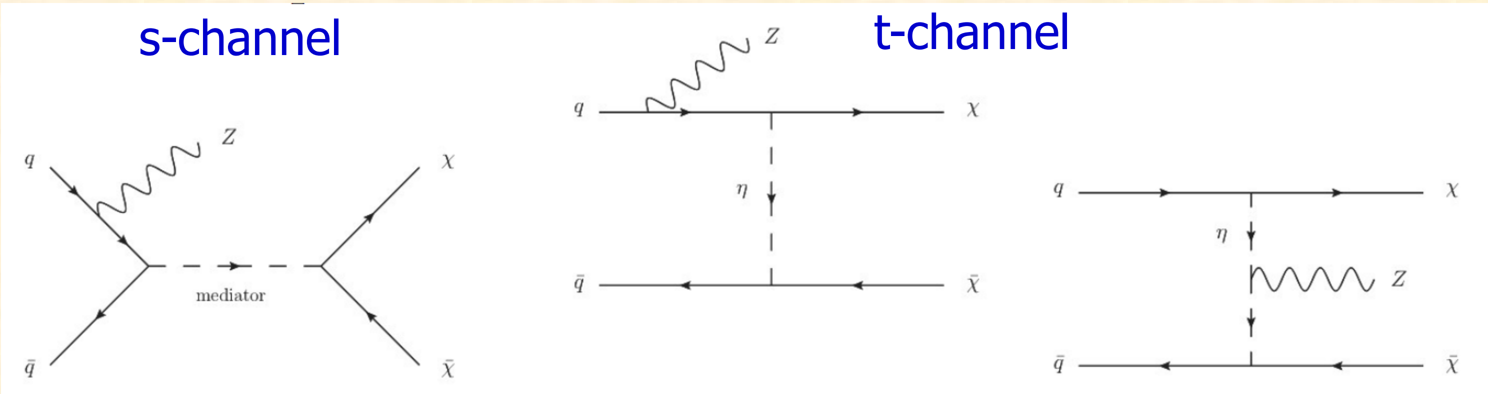
Частицы темной материи описываются как дираковские фермионы
Теория содержит 2 параметра M_* , $m\chi$
Где M_* – характеризует силу взаимодействия и является функцией массы промежуточной частицы M и констант взаимодействия g_q и g_χ

*Важное условие: **M >> Q_{tr}** , где **Q_{tr}** переданный импульс*

Run I →Run II: EFT → Simplified models



Simplified models



Медиаторы:
- для s - канала: vector, axial, scalar, pseudoscalar
- для t - канала: colored scalar mediator.

Теория содержит 5 параметров:

WIMP mass: m_χ
Mediator mass: M
Mediator width: Γ
Coupling between the mediator and the WIMP: g_χ
Coupling between the mediator and the SM particle: g_q

<u>Рекомендации DM форума:</u>

m_χ (GeV)	m_{med} (GeV)										
1	10	20	50	100	200	300	500	700	1000	2000	10000
10	10	15	50	100		300	500				10000
30	10			100		300	500	700			
50	10		50	95	200	300	500	700			10000
100				100		300	500	700			
150	10				200	295	500		1000		10000
500	10						500		995	2000	10000
1000	10								1000	1995	10000

black = recommended, **bold** = requested/simulated initially, red = requested/simulated later to improve limit

Моделирование проводилось с использованием MadGraph

Константы связи:

S-channel, vector and axial-vector case: g_χ = 1.0, g_q=0.25
S-channel, scalar and pseudoscalar case: g_χ = g_q= 1.0
T-channel, coloured scalar case: : g_χ = g_q= 3.0