Новости физики высоких энергий по материалам 42-й международной конференции по физике высоких энергий ICHEP 2024

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Семинар ОЭПВАЯ

26.09.2024

Наиболее крупная конференция физики высоких энергий ICHEP 2024 состоялась в Праге 18-24 июля

Три дня секционных, три дня пленарных докладов –

большое количество пленарных докладов как по экспериментальным результатам, так и статусу теоретических подходов

Новости эксперимента ATLAS

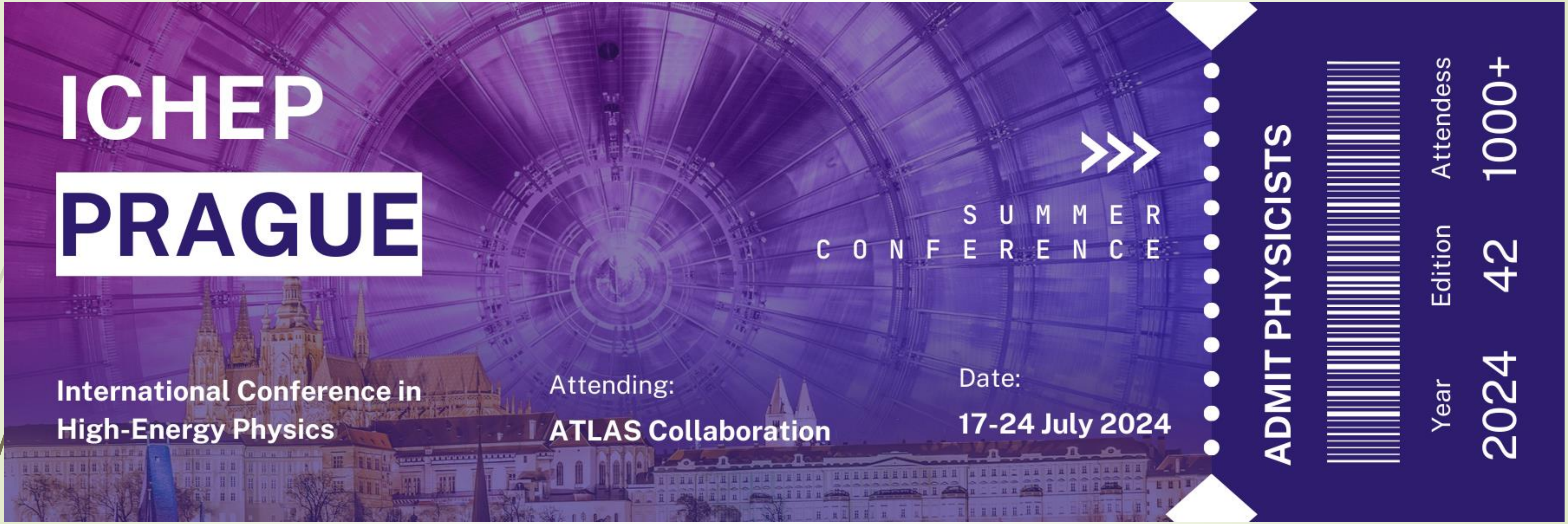
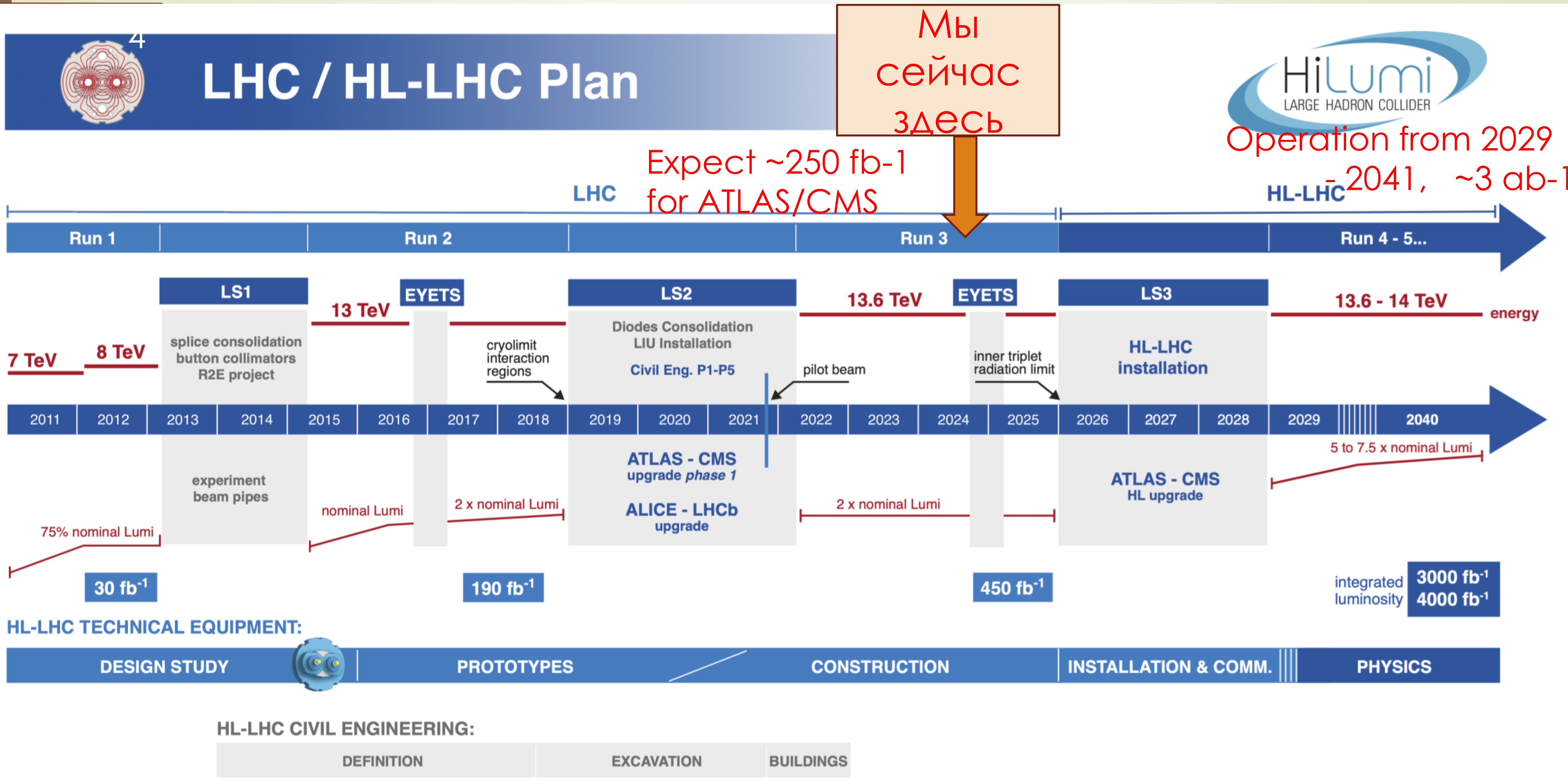
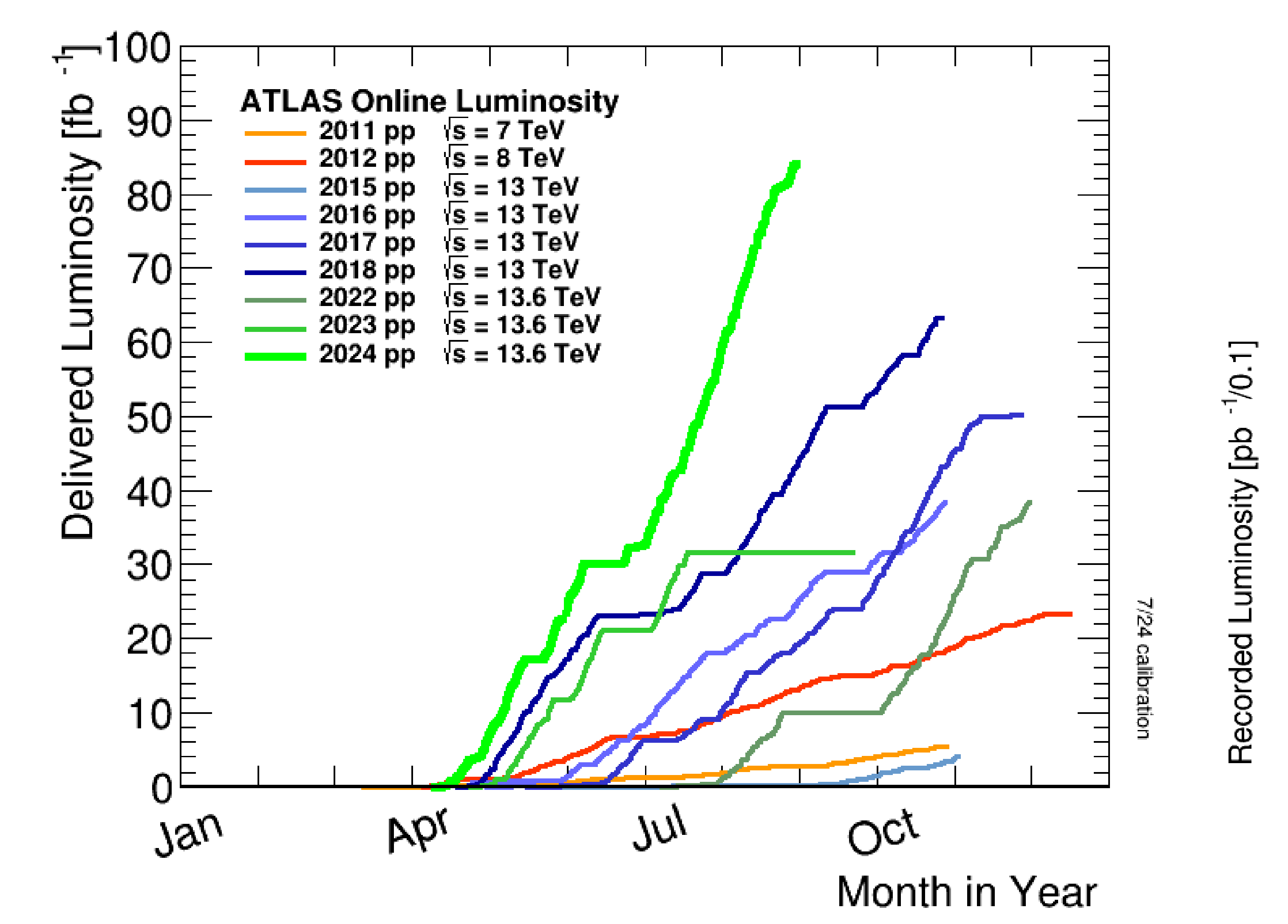
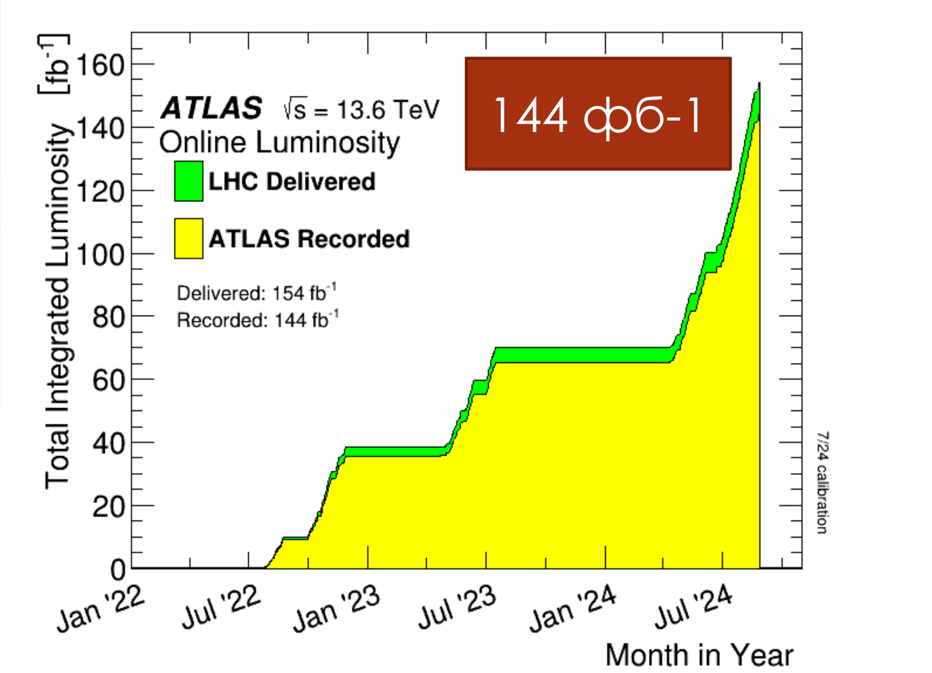


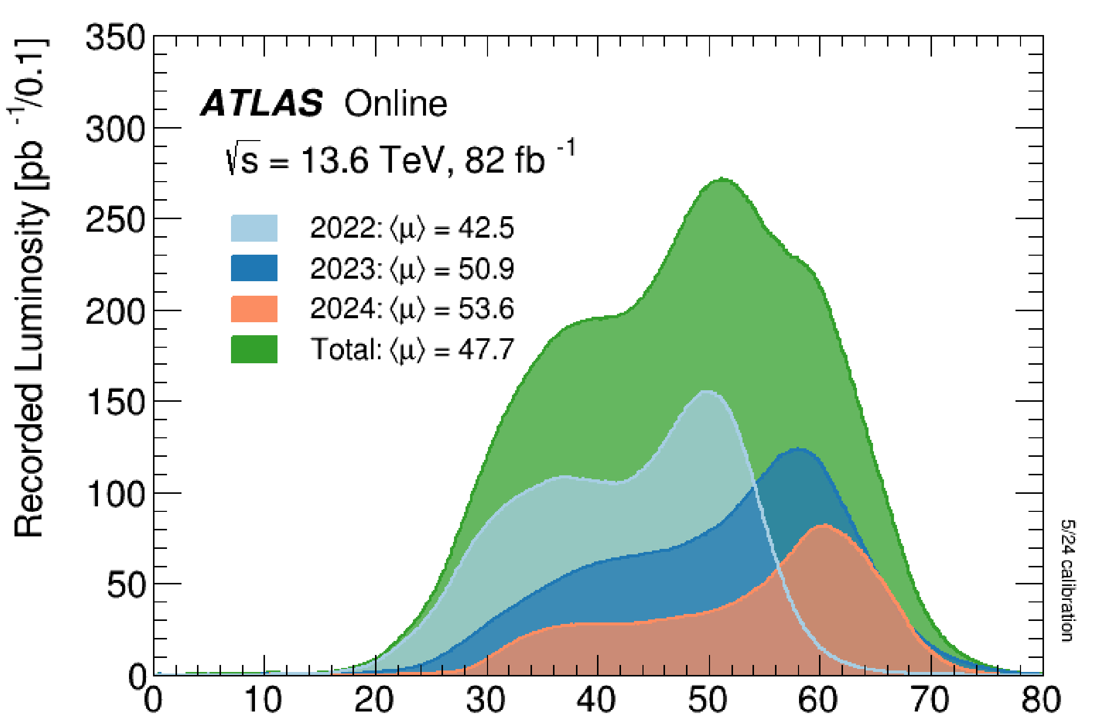
График работы Большого адронного коллайдера



Набор данных на БАК + 1 год 3-го - сеанса Run 3

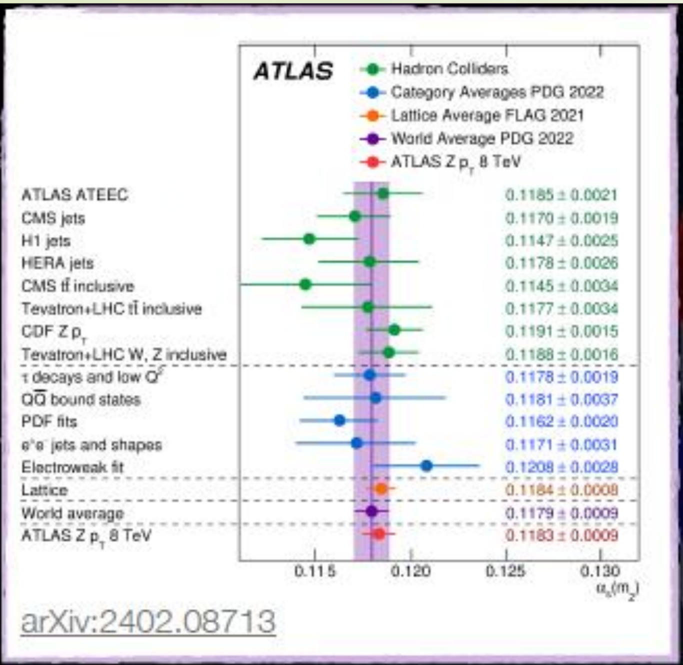




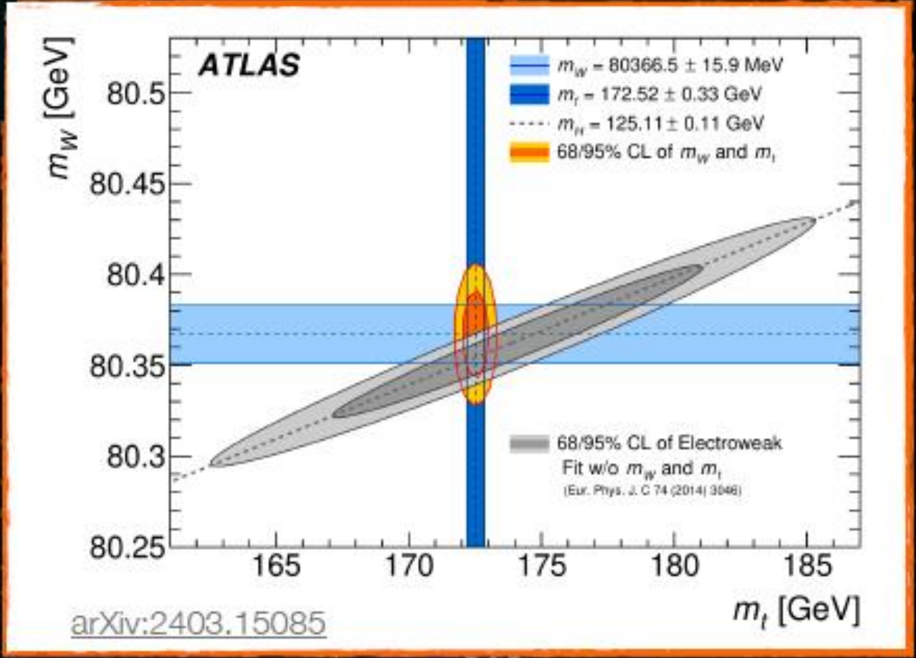


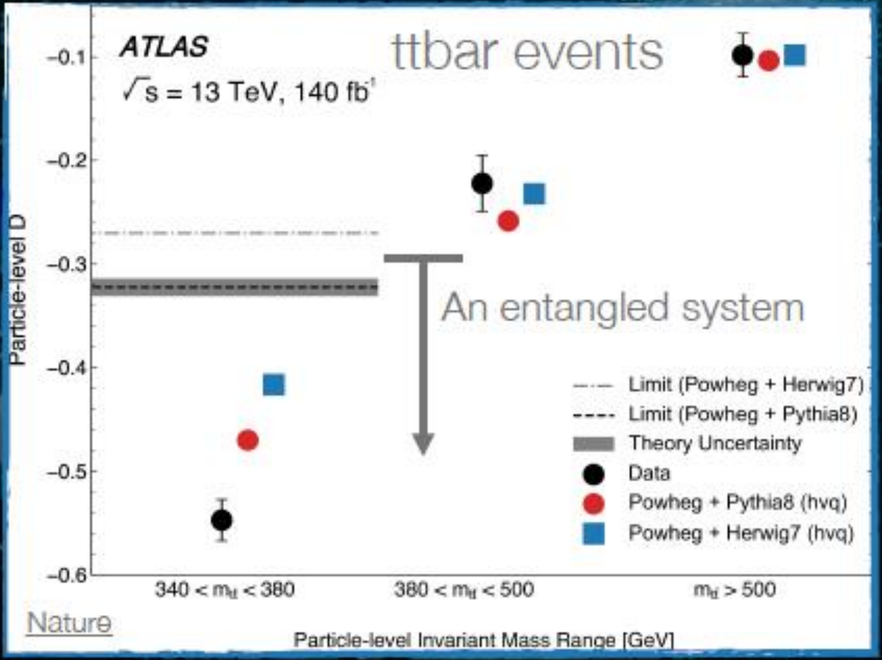
Understanding fundamental parameters

Where we stand - a few examples



0.8% precision on strong force couplings at Z mass





First observation of quantum entanglement at high-energy and among quarks

0.02% precision on W mass

0.2% on top mass arXiv:2308.04775

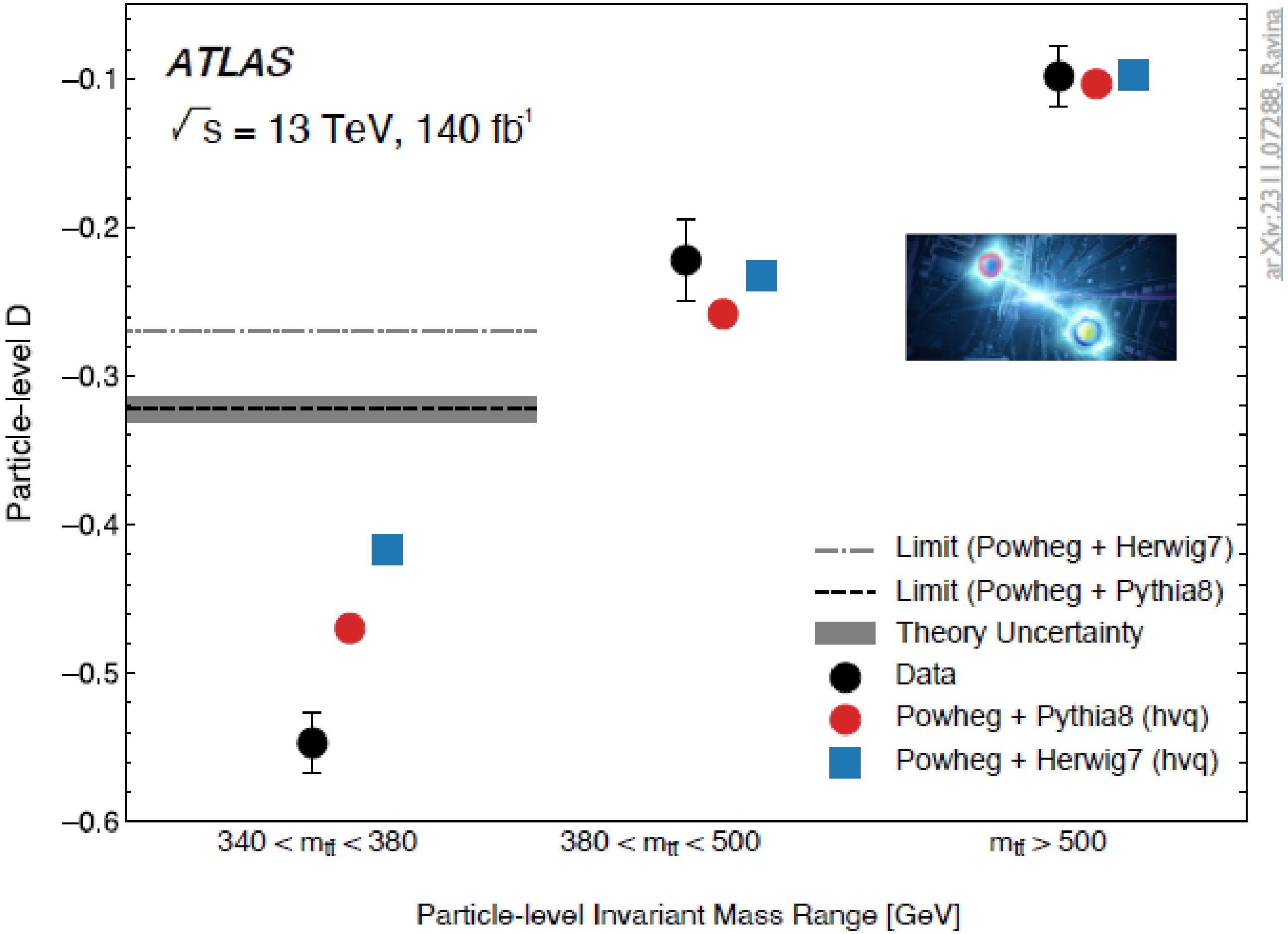
0.09% on Higgs mass arXiv:2309.12986

CERN ACCELERATING SCIENCE

Recent Top Highlights

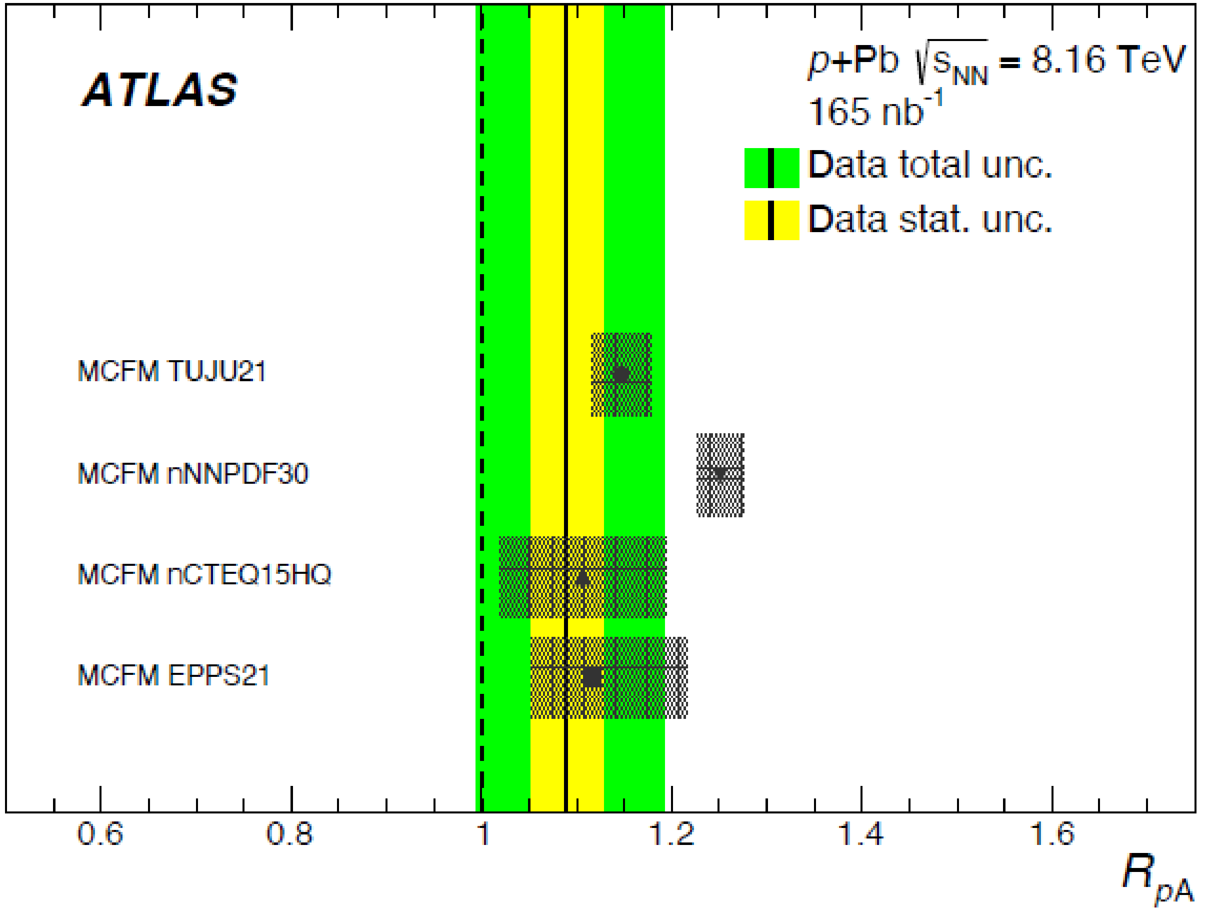
2311.07288

Observation of entanglement in quarks by measuring spin correlations in $t\bar{t}$ events



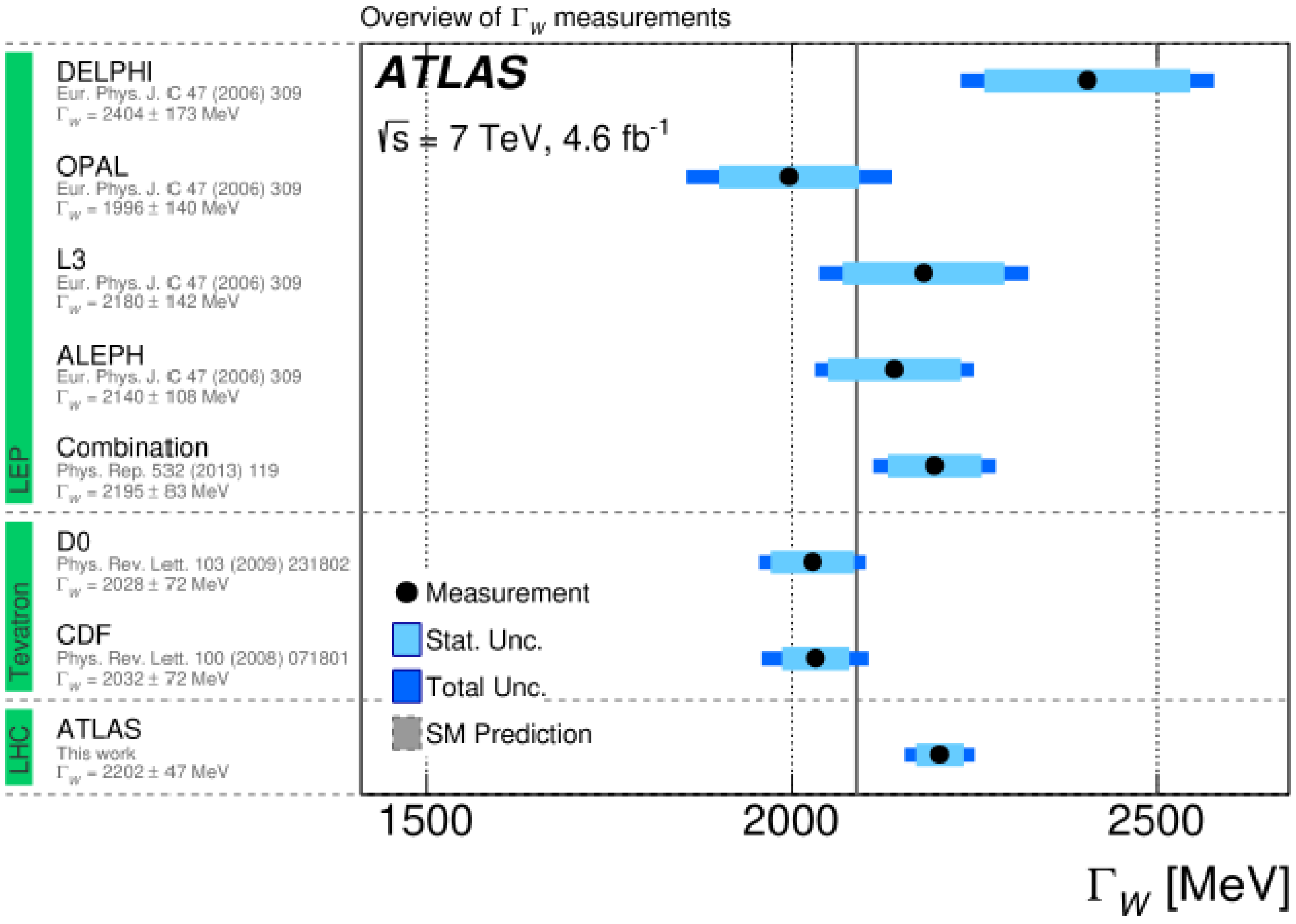
Observation of $t\bar{t}$ production in pPb events

$$\sigma_{t\bar{t}} = 58.1 \pm 2.0(\text{stat.})^{+4.8}_{-4.4}(\text{syst.})\ \text{nb}$$



Properties of the W boson

- First measurement of the W width at the LHC, together with an improved W mass
- Largest systematics from the calibration, the theoretical modeling and the parton density functions



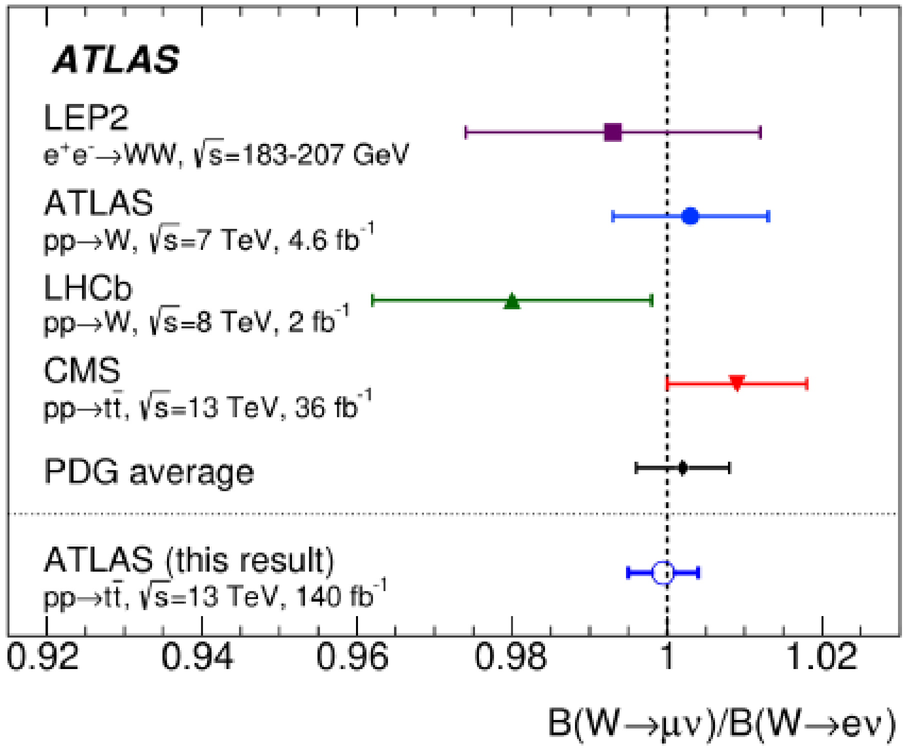
arXiv:2403.0213

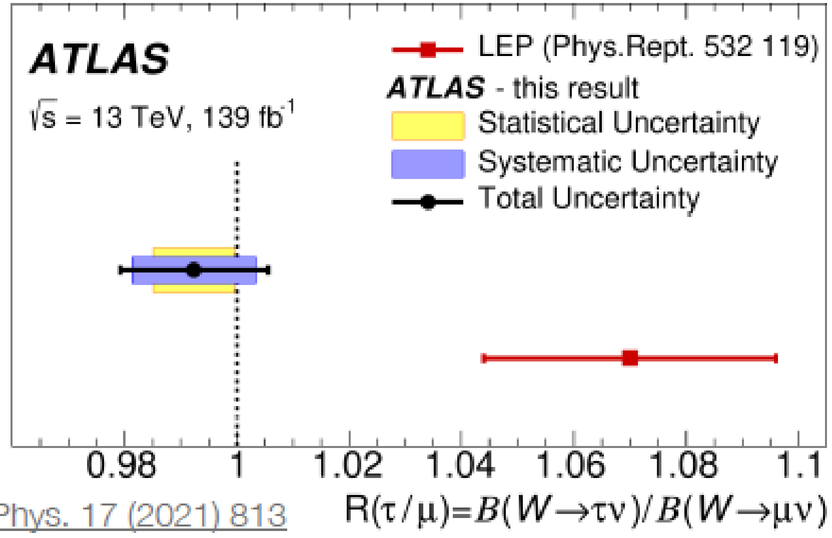
Lepton universality in W decays

- Exploits clean W bosons from top-pair decays
- Higher precision than current world average

$$R_W^{\mu/e} = 0.9995 \pm 0.0045$$

- This adds to a previous result with taus, solving a decade old puzzle from LEP





Nature Phys. 17 (2021) 813

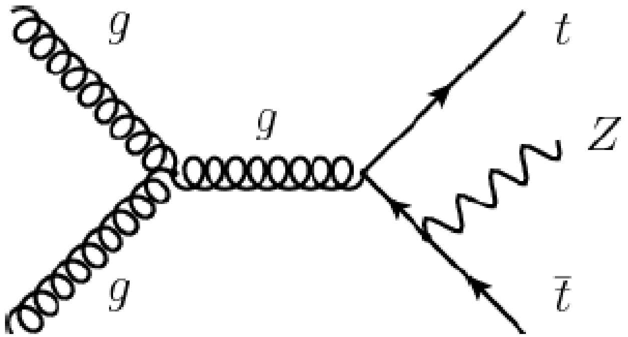
Z boson and top quark couplings

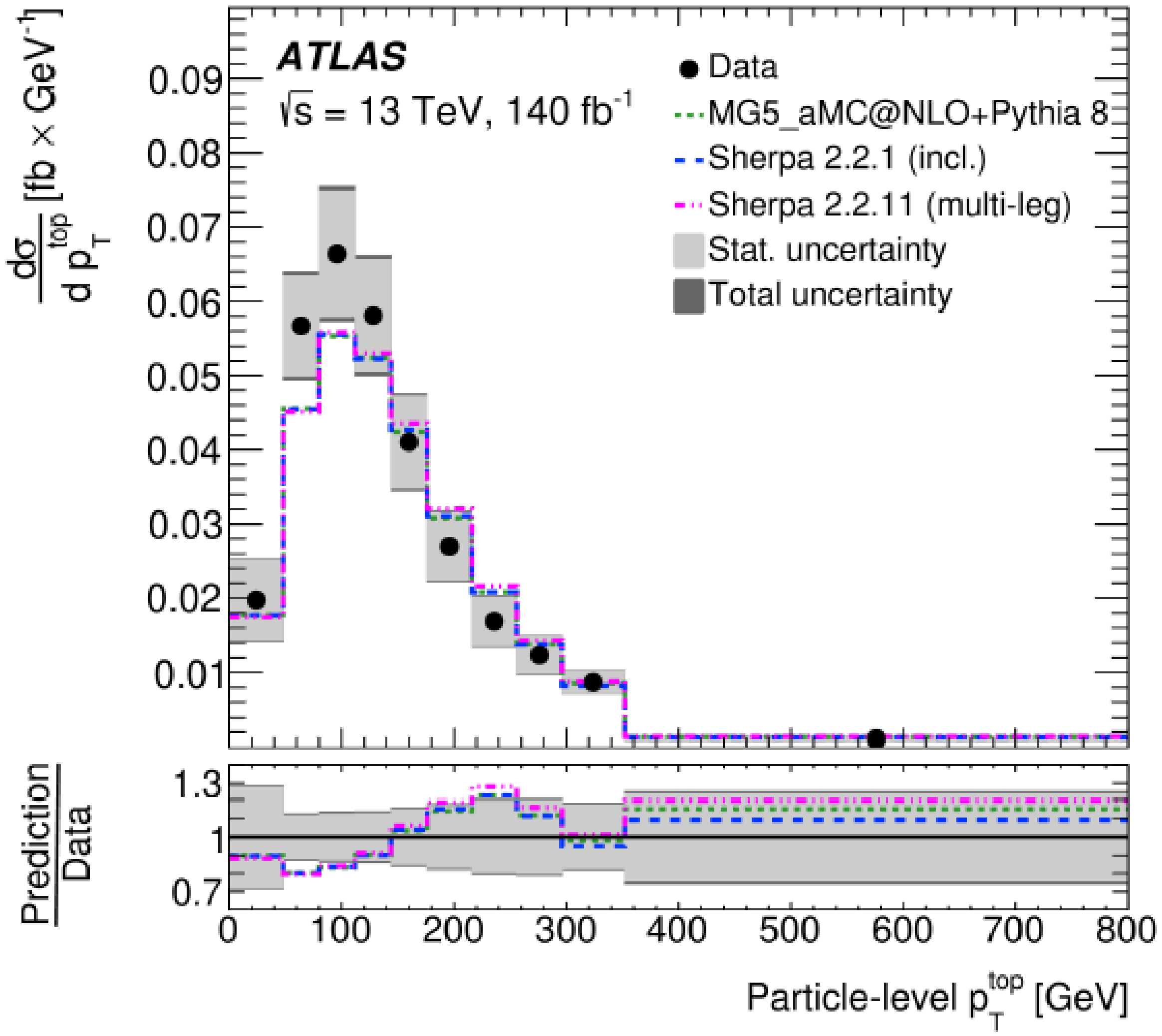
- Measurements of ttbar + Z provide important test of top-Z couplings, which are not well constrained

Measured $\sigma_{t\bar{t}Z} = 0.86 \pm 0.04\ (\text{stat.}) \pm 0.04\ (\text{syst.})\ \text{pb}$

Prediction $\sigma_{t\bar{t}Z} = 0.863^{+0.073}_{-0.085}\ (\text{scale}) \pm 0.028\ (\text{PDF} \oplus \alpha_s)\ \text{pb}$

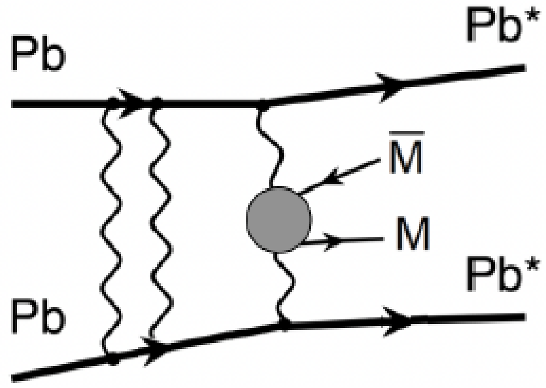
- A factor of two improvement in systematic uncertainties

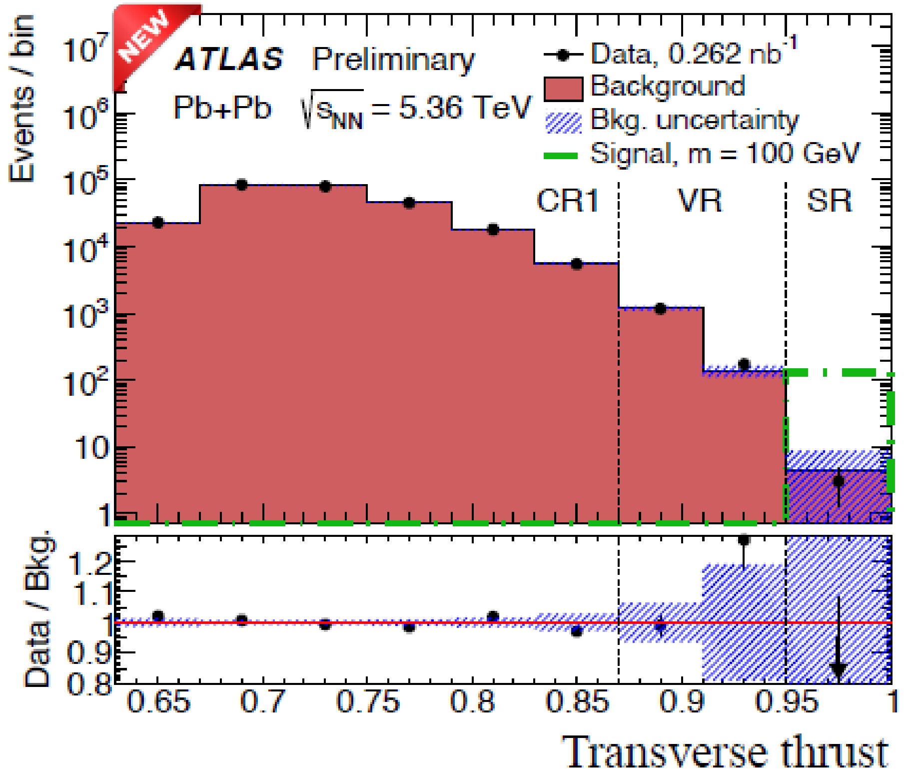


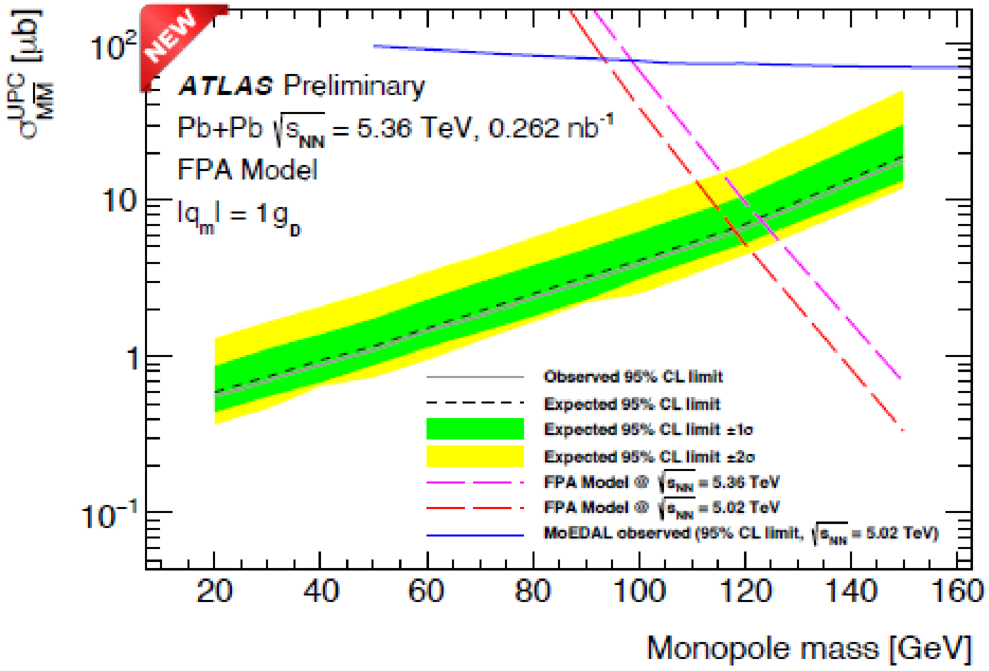


Magnetic monopoles in ultraperipheral lead collisions

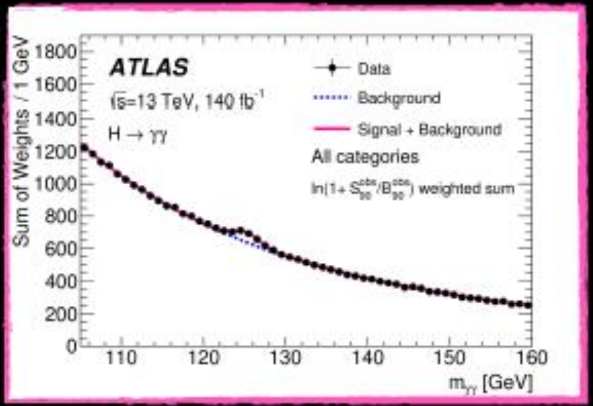
- New data from 2023! New triggers, new methodology
- Achieve up to x8 improvement at masses below 120 GeV



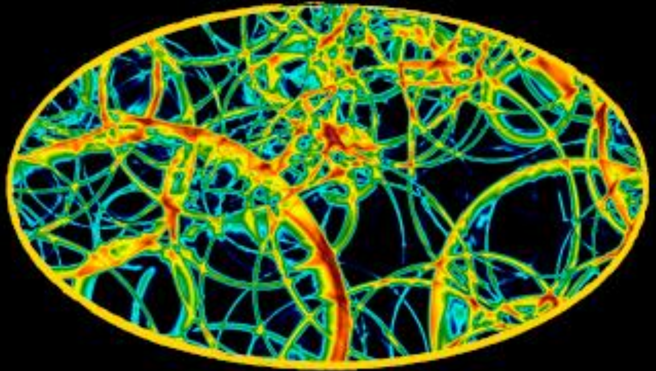




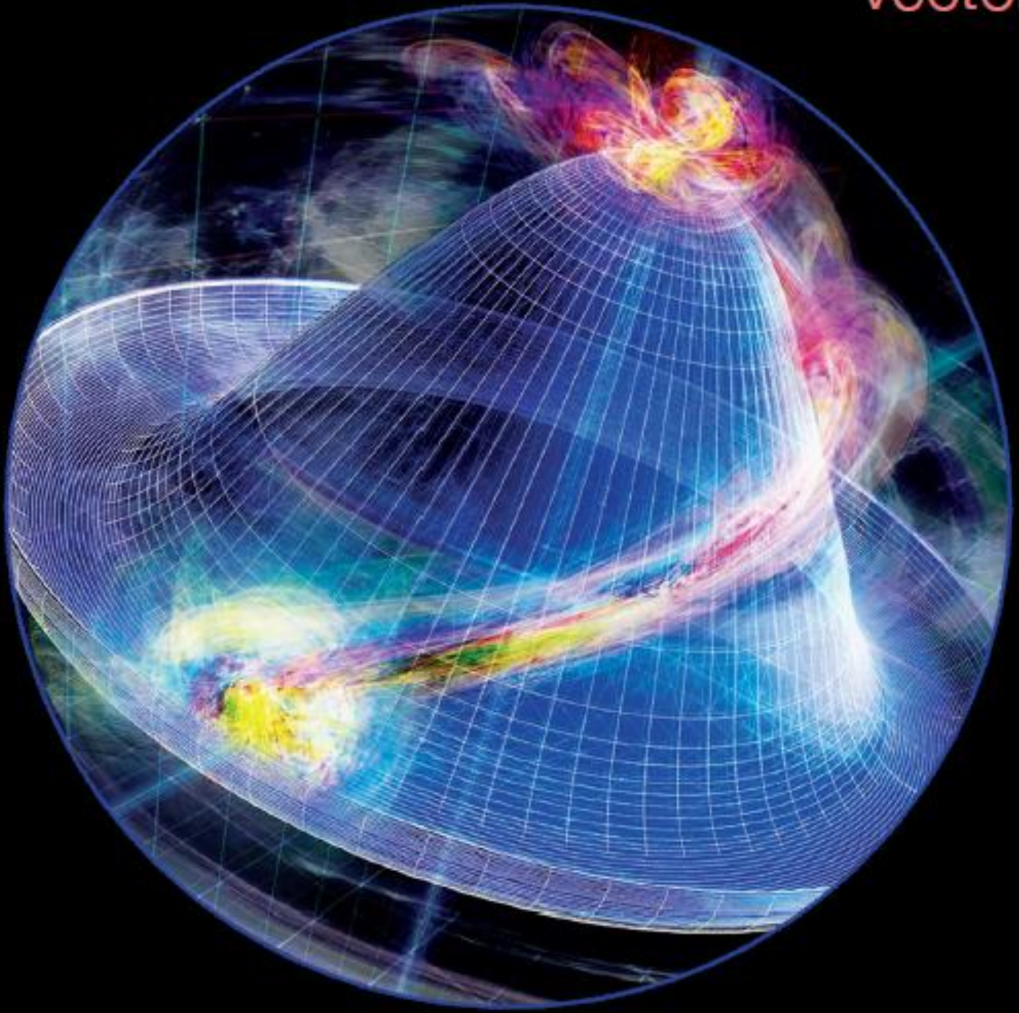
Breaking Electroweak symmetry



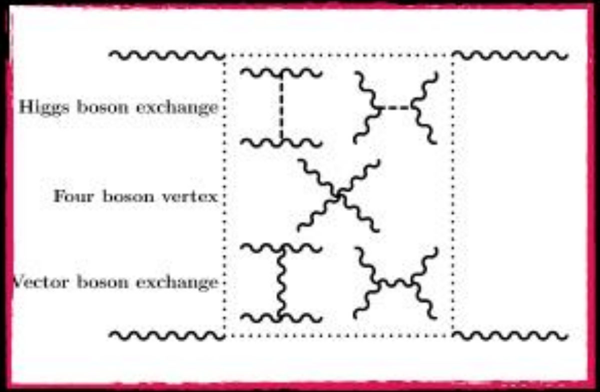
Precision Higgs

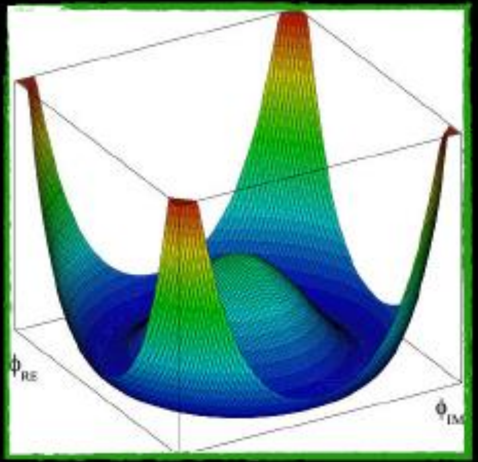


Extended Higgs sector



Vector boson polarisation

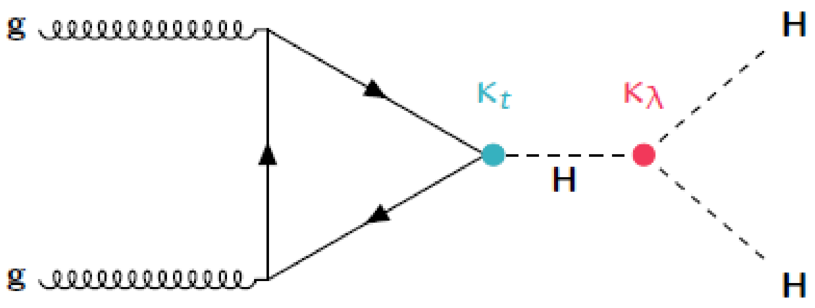




Higgs self-coupling

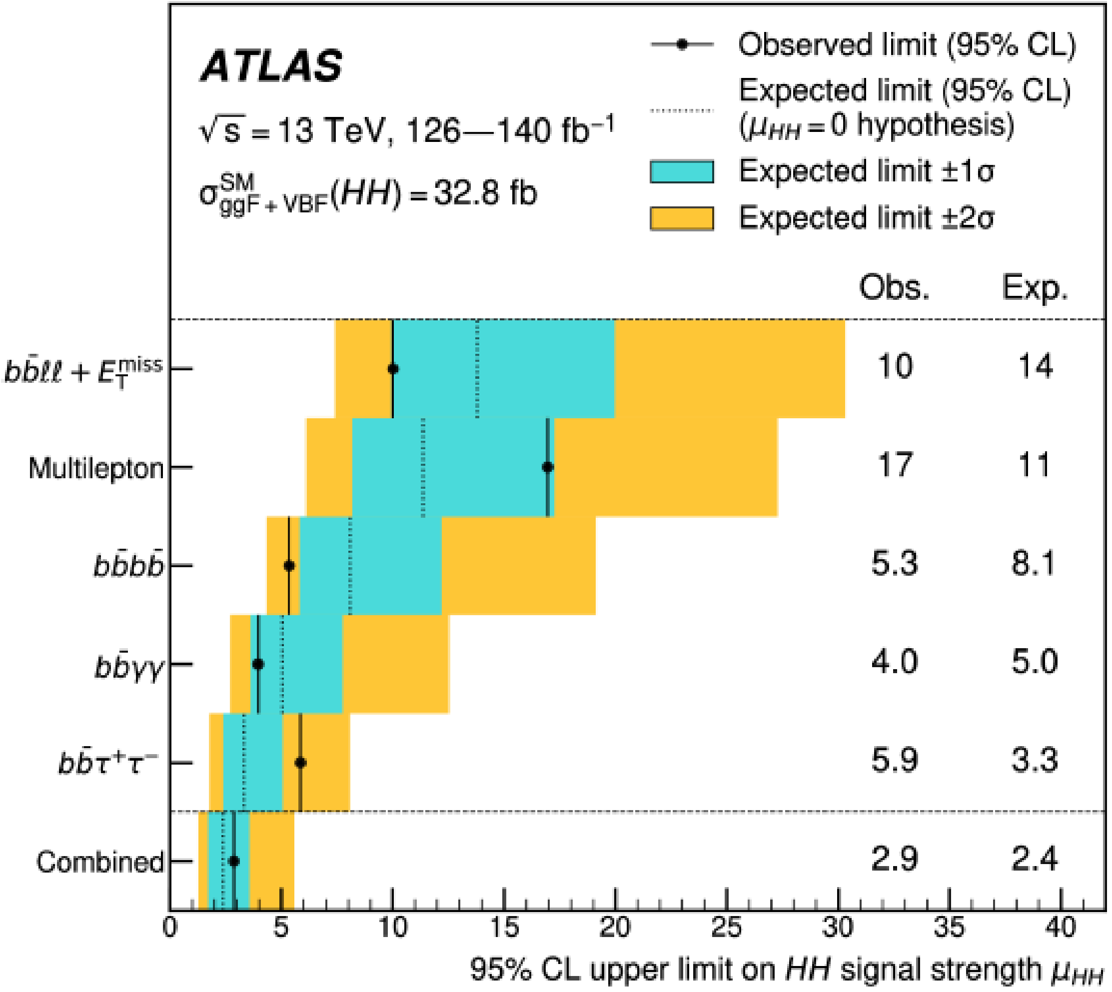
arXiv:2406.09971

Di-higgs production



Best expected sensitivity on HH cross section, self-coupling, κλ

$$\mu_{HH} = 0.5^{+0.9}_{-0.8}(\text{stat.})^{+0.7}_{-0.6}(\text{syst.})$$



New

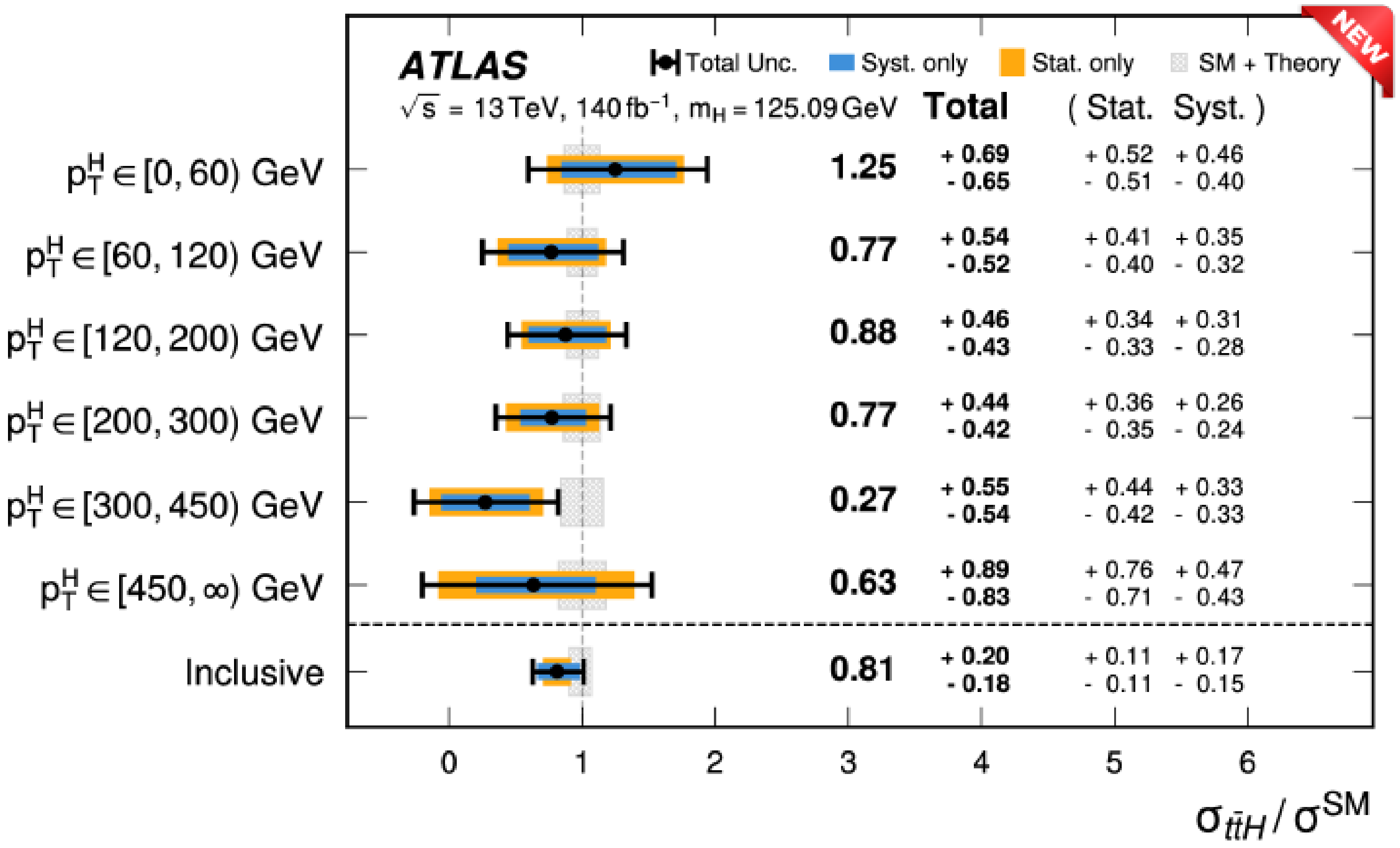
New

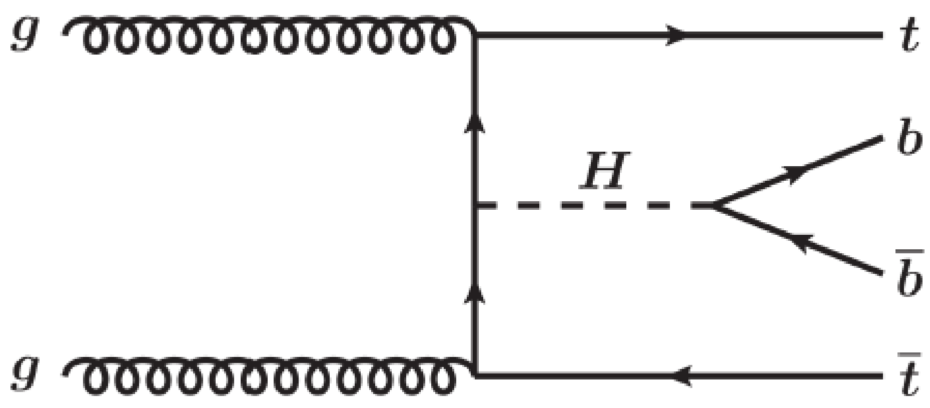
New boosted part

Improved

Improved

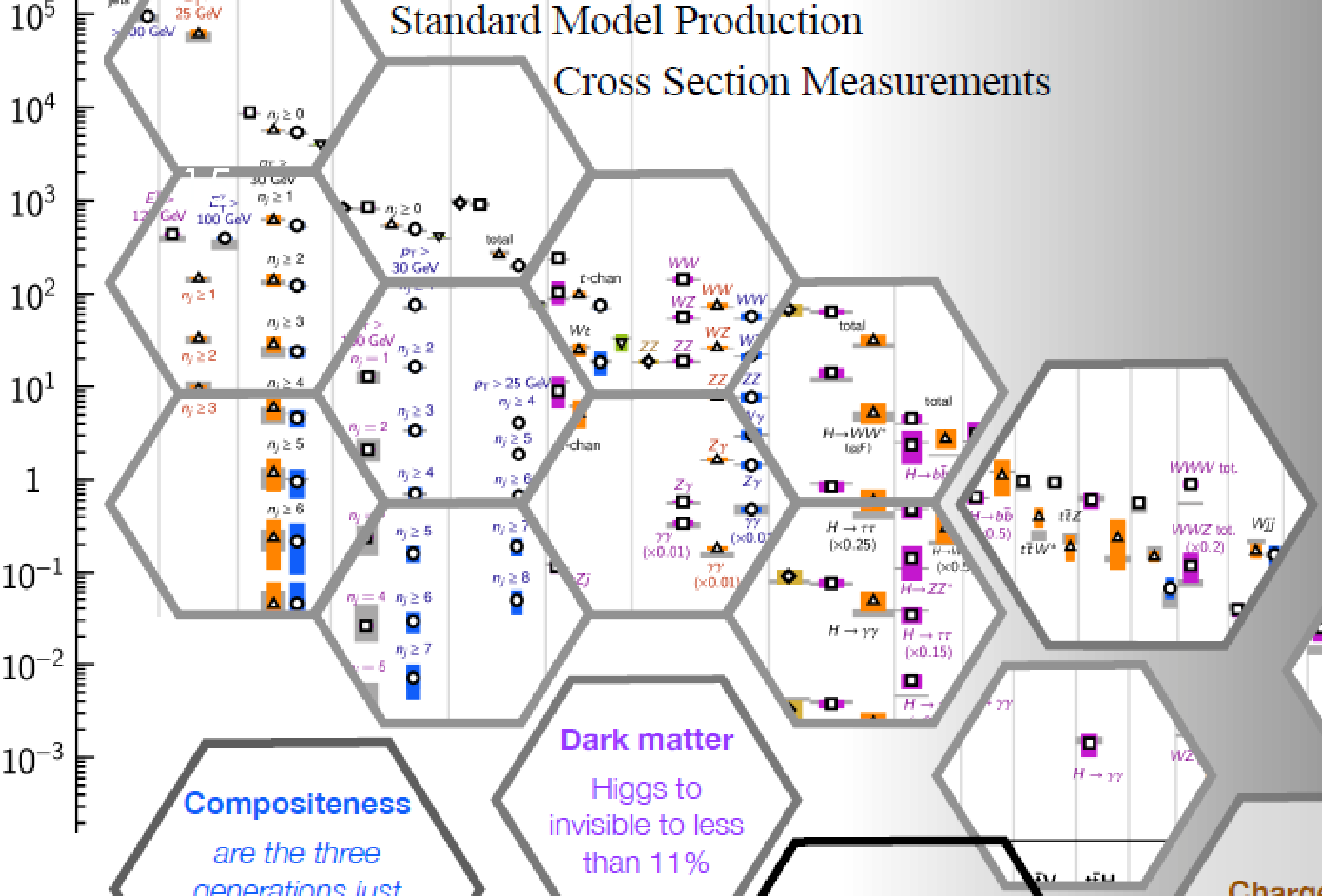
Precision Higgs - ttH to bb





Total uncertainty reduced by factor of ~2, 4.6 σ observed

Dynamics and symmetries



SUSY
Symmetry connecting fermions and bosons
Strong to 2.45 TeV
EW to 1 TeV

Extra dimensions, gravitons, quantum black holes
Explaining gravity's 'weakness'
Extra dimensions mass to 5.9 TeV

Monopoles and co.
Multi-charged particles to 1 TeV

Additional leptons
Seesaw mechanism and small neutrino couplings
Type III seesaw heavy leptons to 790 GeV

Vector-like leptons and quarks
Solving higgs radiative corrections
VLQ T m to 1.27 TeV, VLL tau (4321 model) to 910 GeV

Dark sector portals
Hidden sectors and long lived particles
Dark photon lifetimes to 1000mm

Charged-lepton flavour violation
What forbids it
e-mu BR < 10^{-7}

Axions
Why does QCD preserve CP
BR to 10^{-5}

Leptoquarks
A symmetry connecting the lepton/quark sectors
Scalar leptoquarks to 1.2 TeV

Additional vector bosons
Extended gauge sectors
Z' to 5.1 TeV

Dark matter
Higgs to invisible to less than 11%

Compositeness
are the three generations just smaller constituents
q* to 6.7 TeV

Inspired from ATLAS Exotics, SUSY, extended Higgs physics reports

Новости эксперимента CMS на БАК

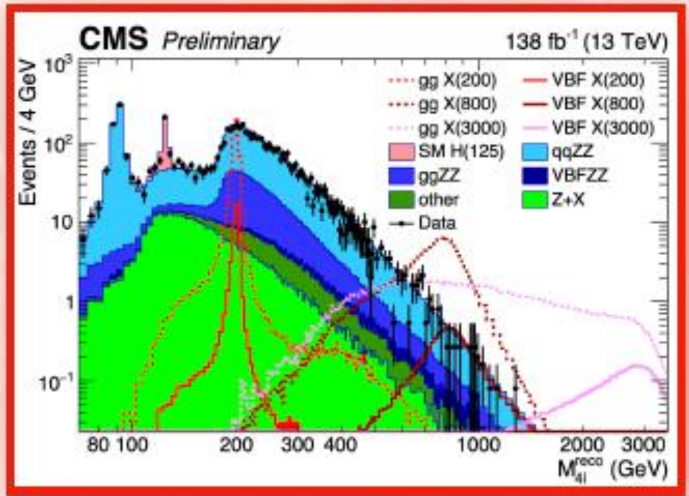
At the middle of our journey

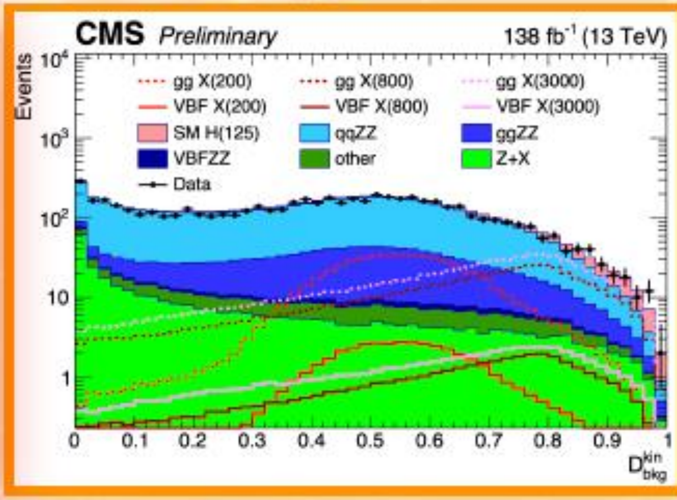
- First phase of LHC program to be completed soon
  - Aiming at >300 fb^{-1} (Run2+Run3) by the end of 2025
- Working on upgrading the detector for the High-Luminosity phase
  - The target is 3000 fb^{-1} by 2041
- Meanwhile, we are pushing the detector beyond its limits
  - Recording up to 63 simultaneous collisions/event (2.5x CMS design, 45% of HL-LHC)
  - Collecting data @7 kHz (70% of HL-LHC, 7x Run2 normal operations)

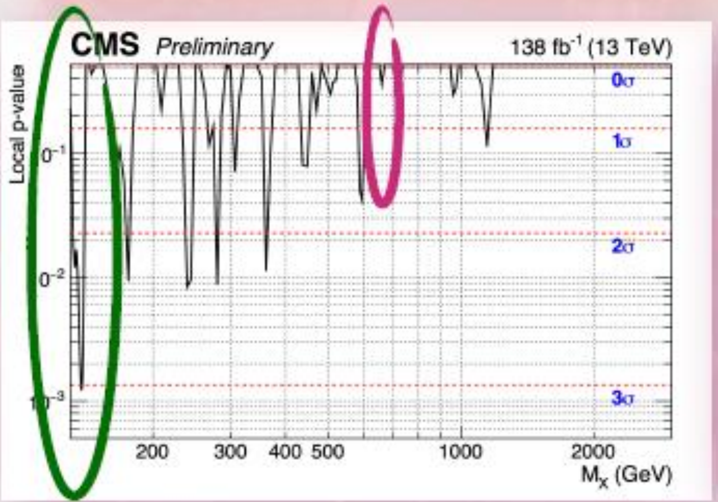
CMS at the Energy frontier

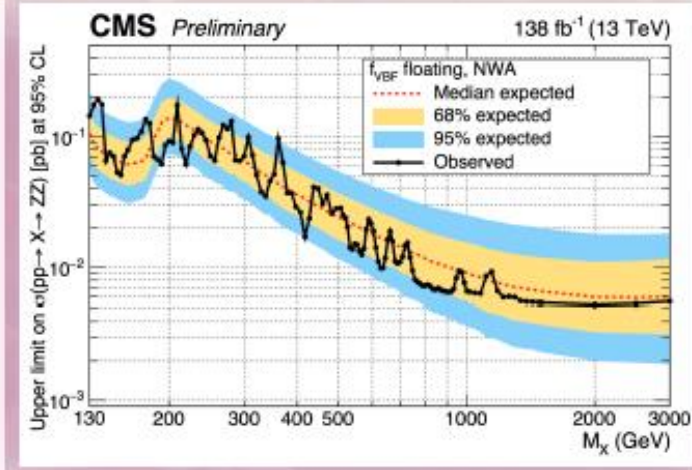
CMS-PAS-HIG-24-002 New

- New search for high-mass scalars $X \rightarrow ZZ \rightarrow 4\ell$
- Enhanced sensitivity, given by 2D approach: invariant mass vs matrix element discriminant D_{bkg}^{kin}
- Addressing claims for a new boson in 650-680 GeV (based on ATLAS data)
  - No excess observed in 650-680 GeV range
- Small excess at 138 GeV, with 1.9 σ significance after look-elsewhere effect





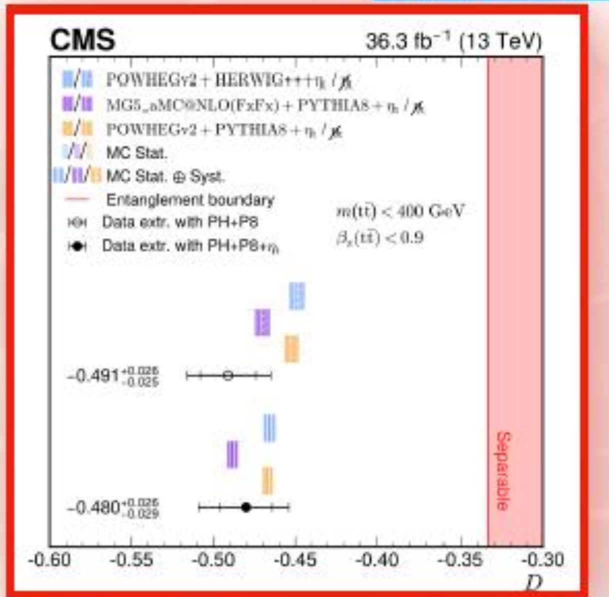


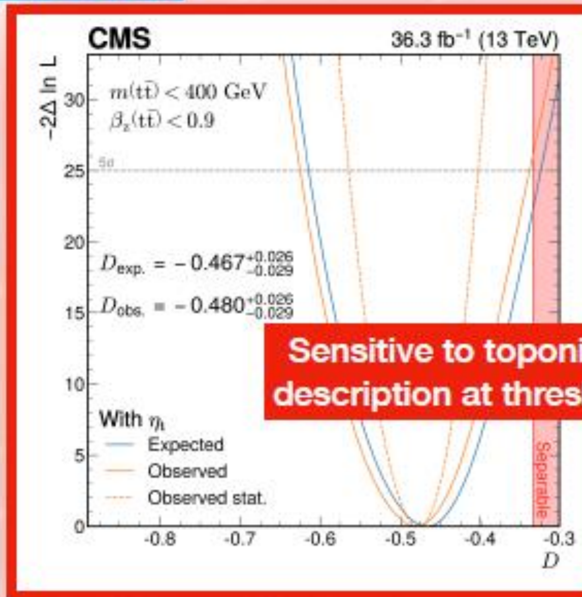


CMS to probe Quantum Entanglement

- $t\bar{t}$ is also a laboratory for quantum entanglement studies at the highest energy ever tested
  - Can test SM in different scenarios than traditional search program
- Probe entanglement via spin correlation matrix
  - At production threshold in $t\bar{t} \to b\ell\nu b\ell\nu$ events (phase space dominated by time-like events)
  - At high m_{tt} with $t\bar{t} \to b\ell\nu bq\bar{q}$ events, (phase space dominated by space-like events)
- Both analyses establish entanglement in agreement with SM predictions
- More details in Didar Dobur's talk on Wednesday

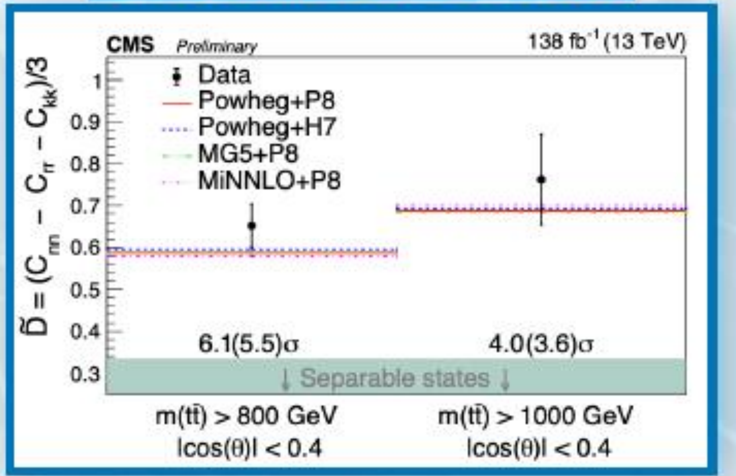
CMS-TOP-23-001

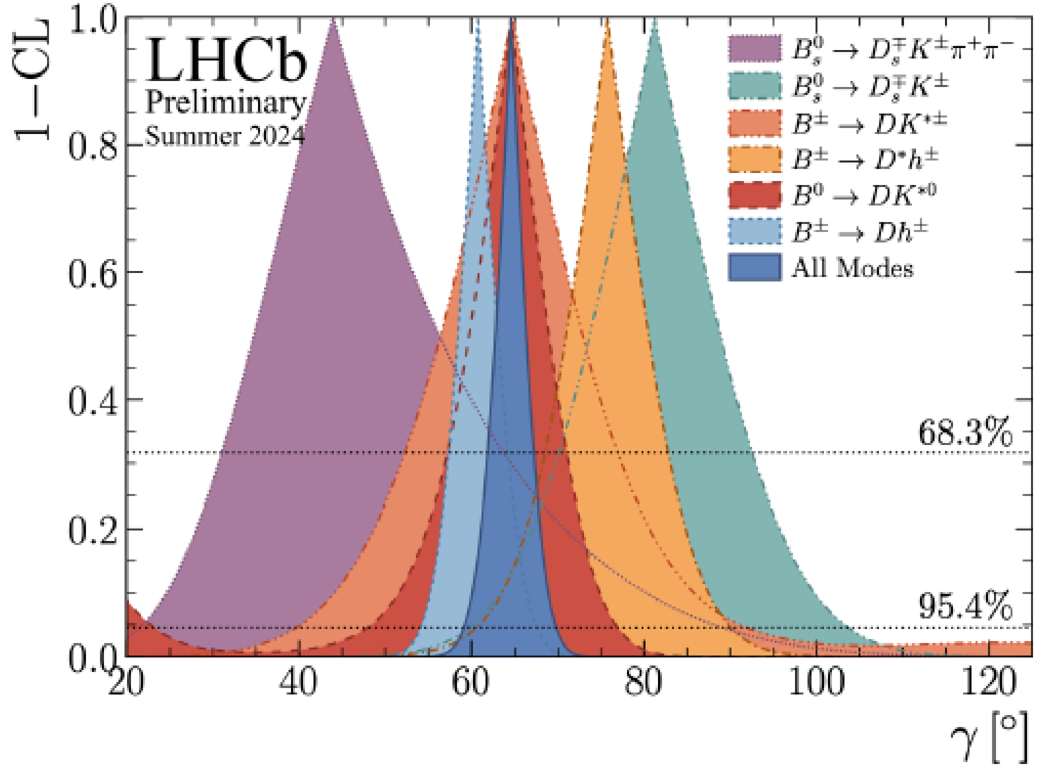




Sensitive to toponium description at threshold

CMS-PAS-TOP-23-007





LHCb highlights

22.07.2024

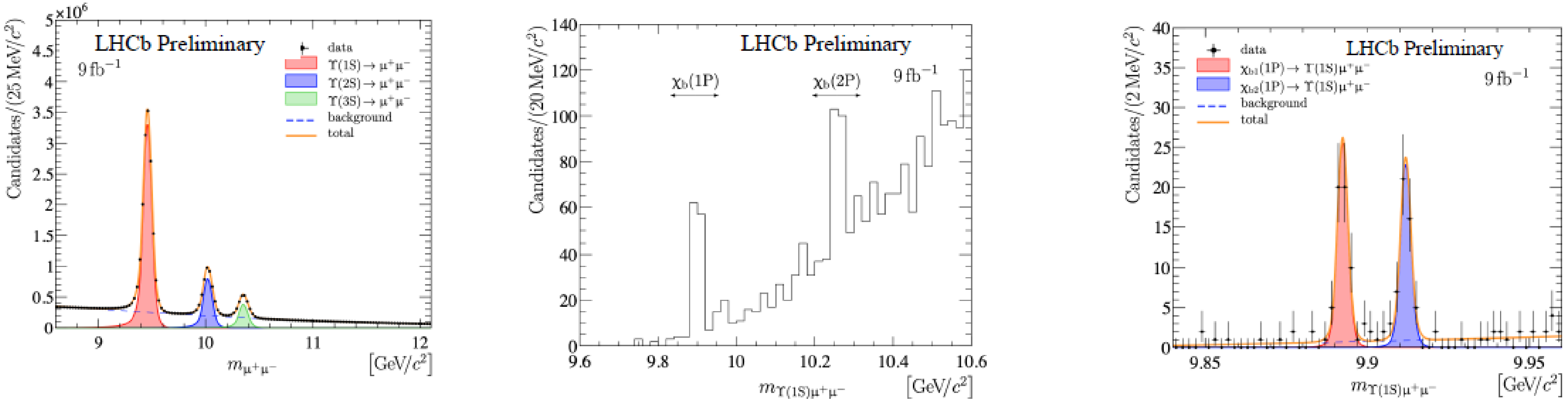
Yasmine Amhis

On behalf of the LHCb collaboration

ICHEP 2024, Prague

Understanding QCD

The muonic Dalitz decays of the $\chi_{b1}(1P)$, $\chi_{b2}(1P)$, $\chi_{b1}(2P)$, and $\chi_{b2}(2P)$ mesons to the Υ(1S) state are observed and used to measure the masses of these states.



Previous e⁺e⁻ experiments relied on the photon energy of the Υ(2S) and Υ(3S)

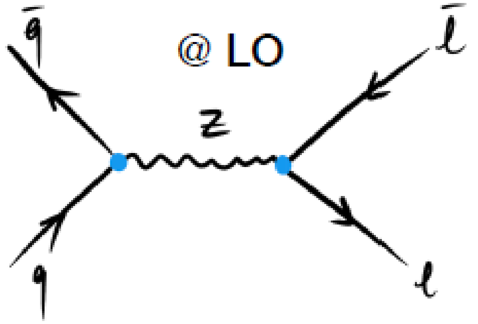
The results are competitive - world best for $\chi_{b1}(1P)$ - and in agreement with the world averages.

$$
\begin{aligned}
m_{\chi_{b1}(1P)} &= 9\,892.50 \pm 0.26 \pm 0.10 \pm 0.10\,\mathrm{MeV}/c^2\,,\\
m_{\chi_{b2}(1P)} &= 9\,911.92 \pm 0.29 \pm 0.11 \pm 0.10\,\mathrm{MeV}/c^2\,,\\
m_{\chi_{b1}(2P)} &= 10\,253.97 \pm 0.75 \pm 0.22 \pm 0.09\,\mathrm{MeV}/c^2\,,\\
m_{\chi_{b2}(2P)} &= 10\,269.67 \pm 0.67 \pm 0.22 \pm 0.09\,\mathrm{MeV}/c^2\,,\\
\delta m_{\chi_b(1P)} &= 19.4 \pm 0.4\,\mathrm{MeV}/c^2\,,\\
\delta m_{\chi_b(2P)} &= 15.7 \pm 1.0\,\mathrm{MeV}/c^2\,,
\end{aligned}
$$

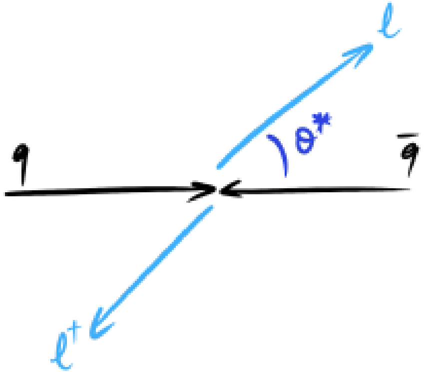
LHCb-PAPER-2024-025 in preparation

Probing the Standard Model via the measurement of the effective leptonic weak mixing angle

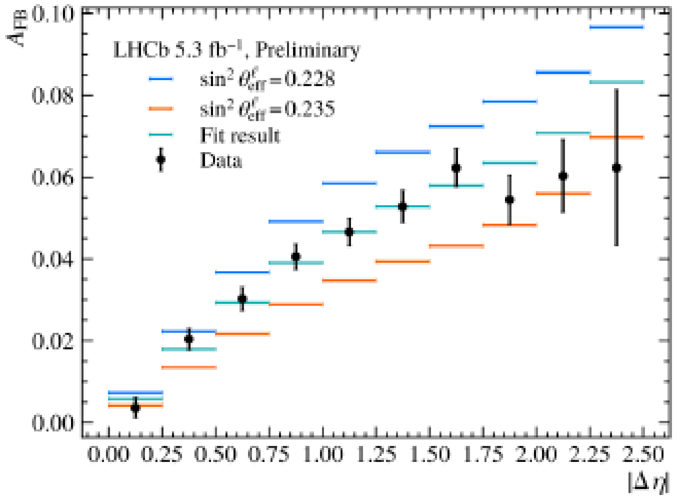
New!

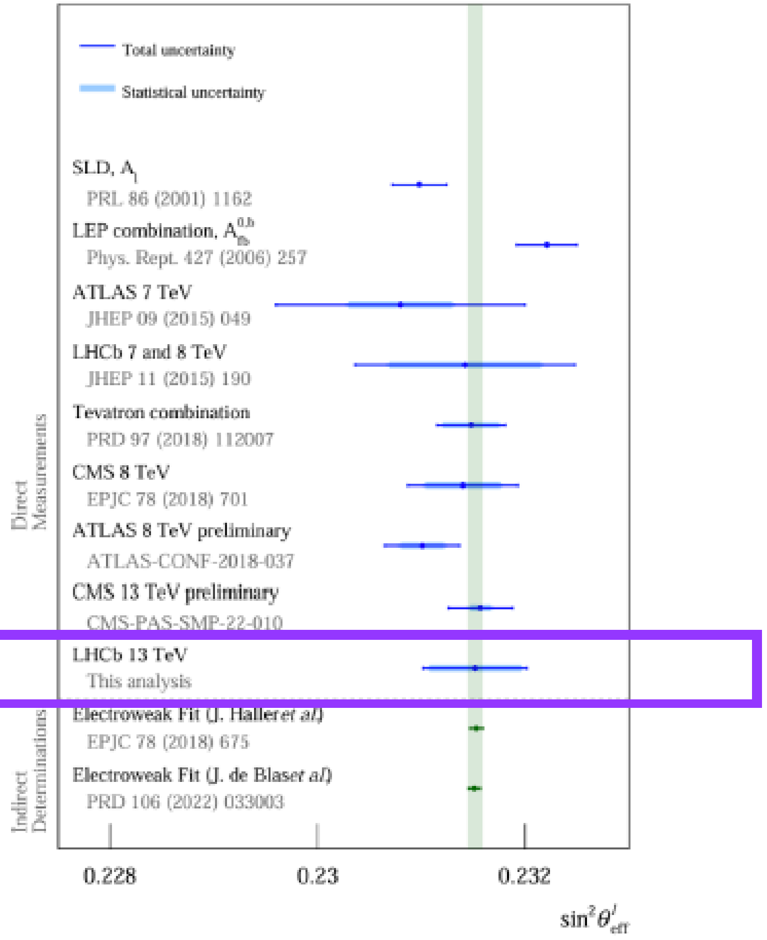


$$\propto a + \cos^2\theta^* + A\cos\theta^*$$



$$A \longleftrightarrow A_{FB}$$





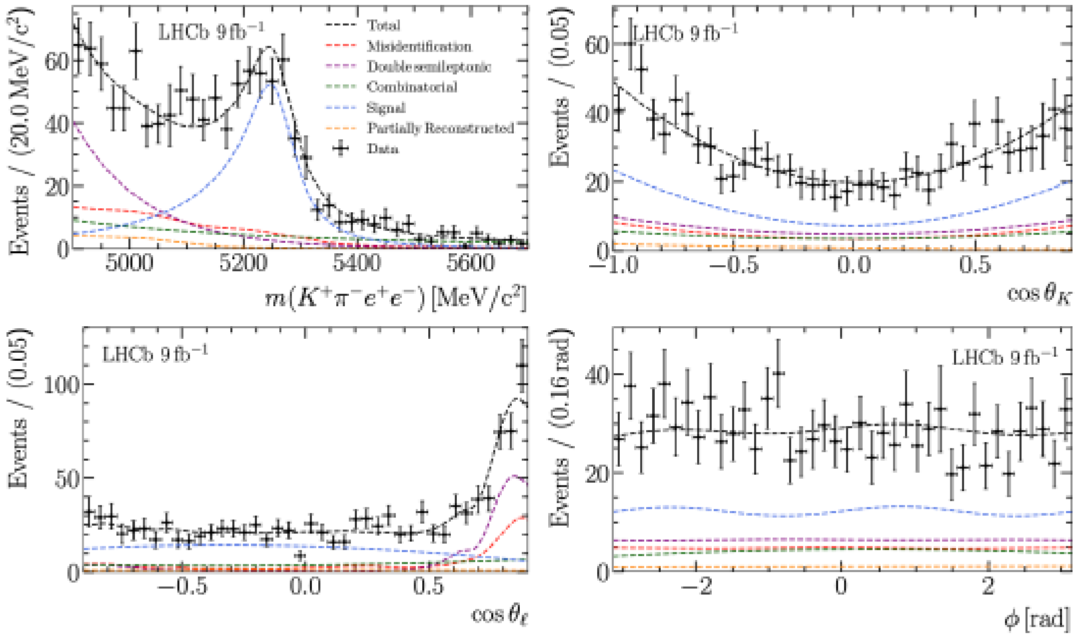
A_{FB} is compared with predictions to NLO in strong and EW couplings to derive:

$$\sin^2\theta^\ell_{eff} = 0.23152 \pm 0.00044 \pm 0.00005 \pm 0.00022$$

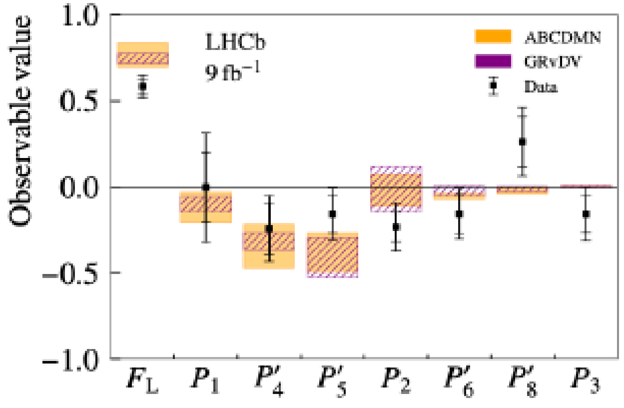
LHCb-PAPER-2024-028 in preparation

Angular analysis of $B \to K^{*}e^{+}e^{-}$

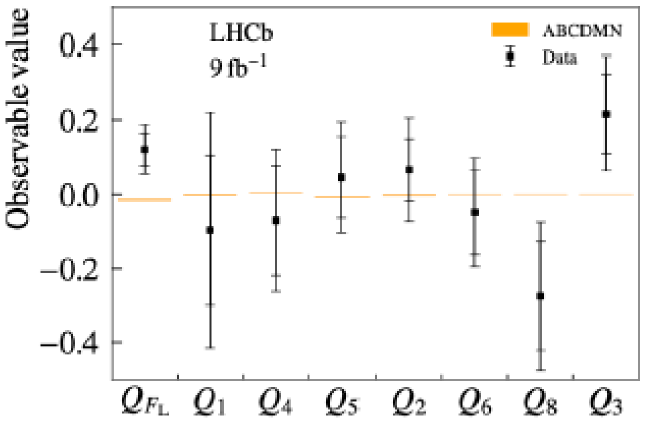
4D unbinned weighted fit to the mass and angular distributions



Allows the extraction of the angular observable in the central q^2 region



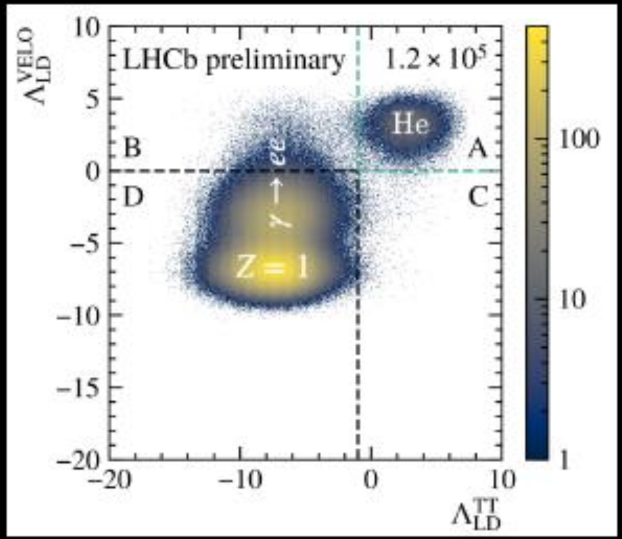
$$Q_i = P_i^{(\mu)} - P_i^{(e)}$$



LHCb-PAPER-2024-022 in preparation

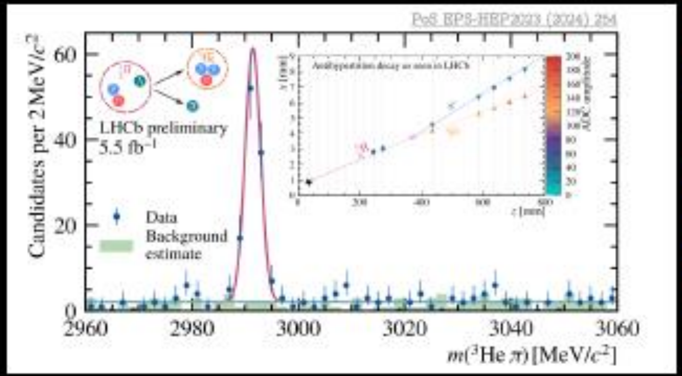
Most precise determination of angular observables and no sign of lepton flavour violating effects are observed

In the last years LHCb opened a new area of physics with heavy ions and fixed targets



LHCb-DP-2023-003

Clean identification of He !

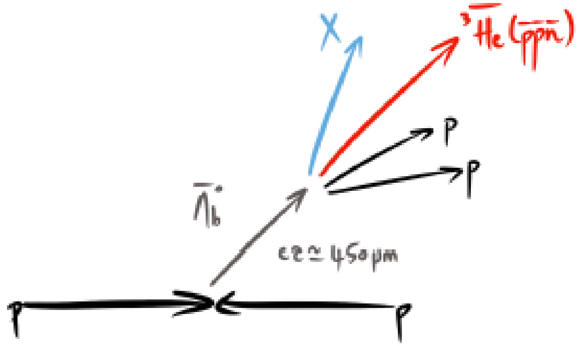


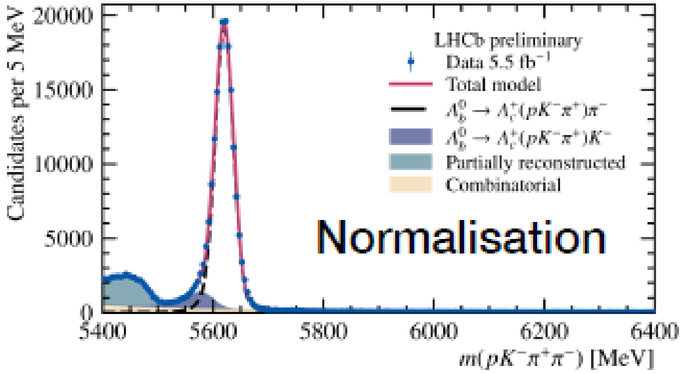
LHCb-CONF-2023-002

Observation of antihypertritons

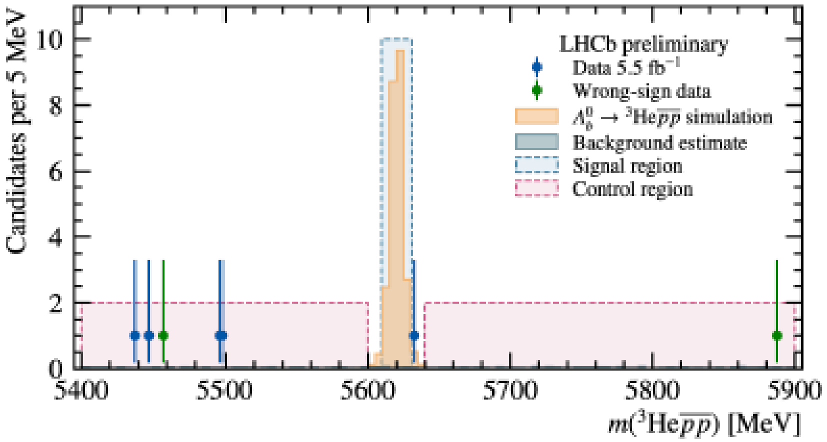
Connecting with Dark Matter

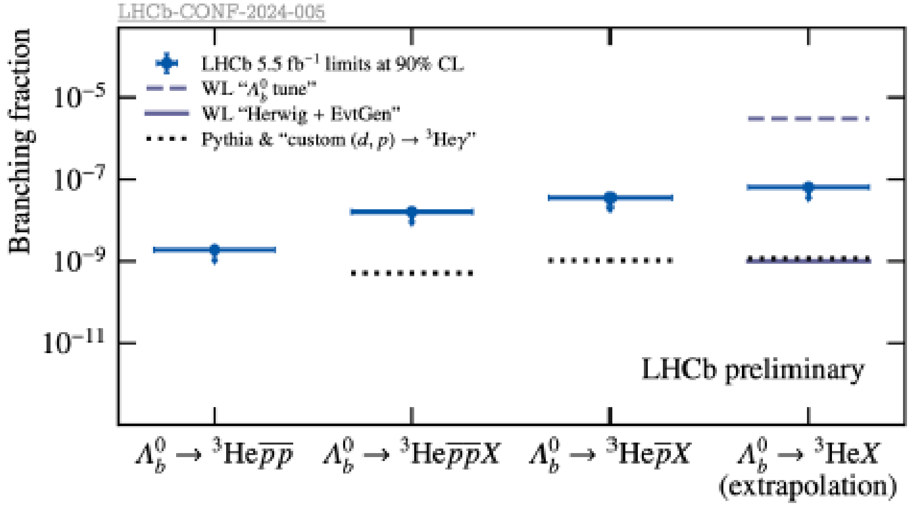
Observation of antihelium in Cosmic Rays could be a signature of physics beyond the standard model.
Interesting scenario where anti-Λ_b are produced in Dark Matter scenario annihilation.





Four exclusive and inclusive final states are investigated





LHCb-PAPER-2024-005 in preparation

These are the first results on (anti)helium production in (anti) Λ_b decays.

Advances in (experimental) hadron physics

Xiao-Rui Lyu
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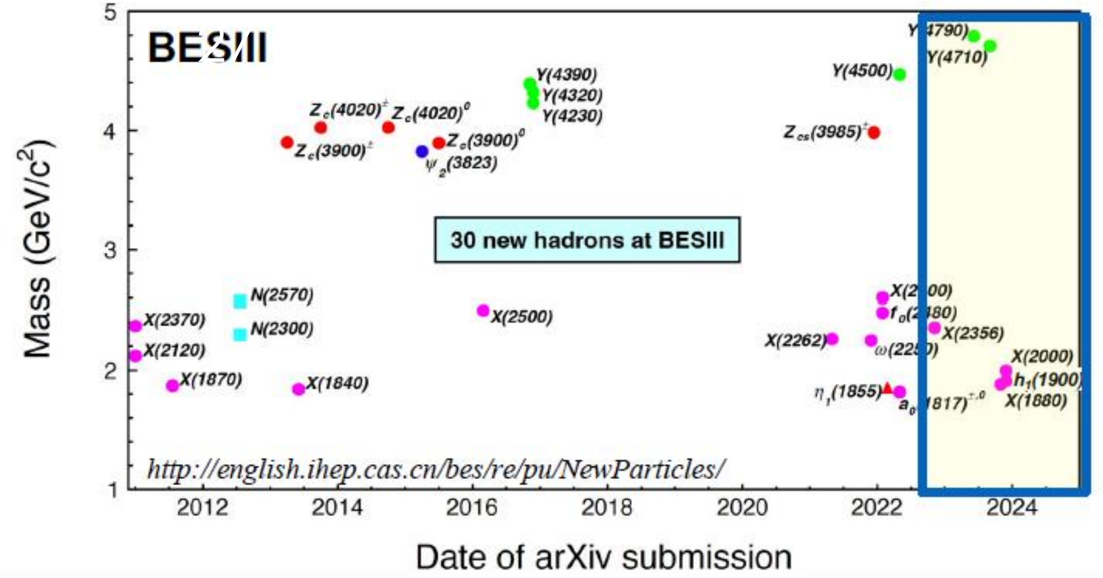
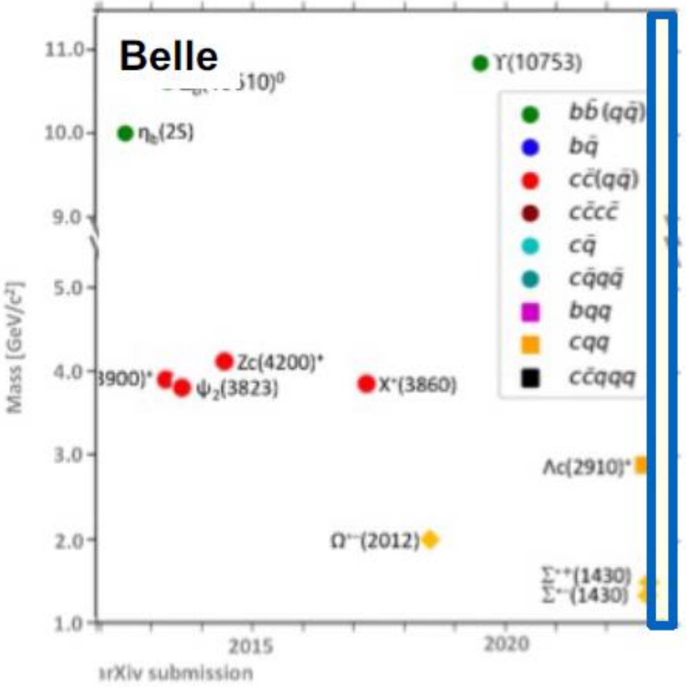
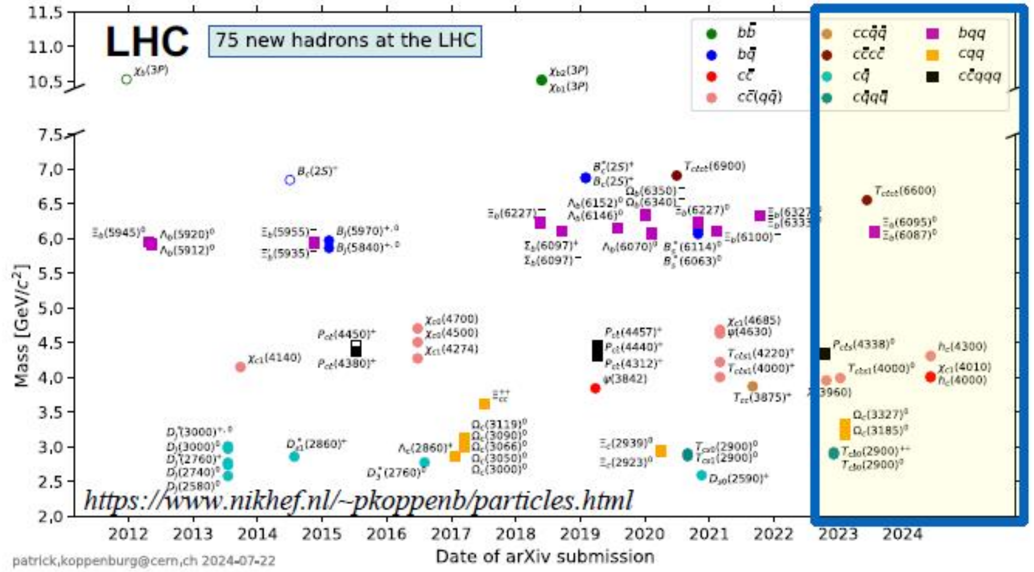
University of Chinese Academy Sciences

Discoveries of many new hadrons



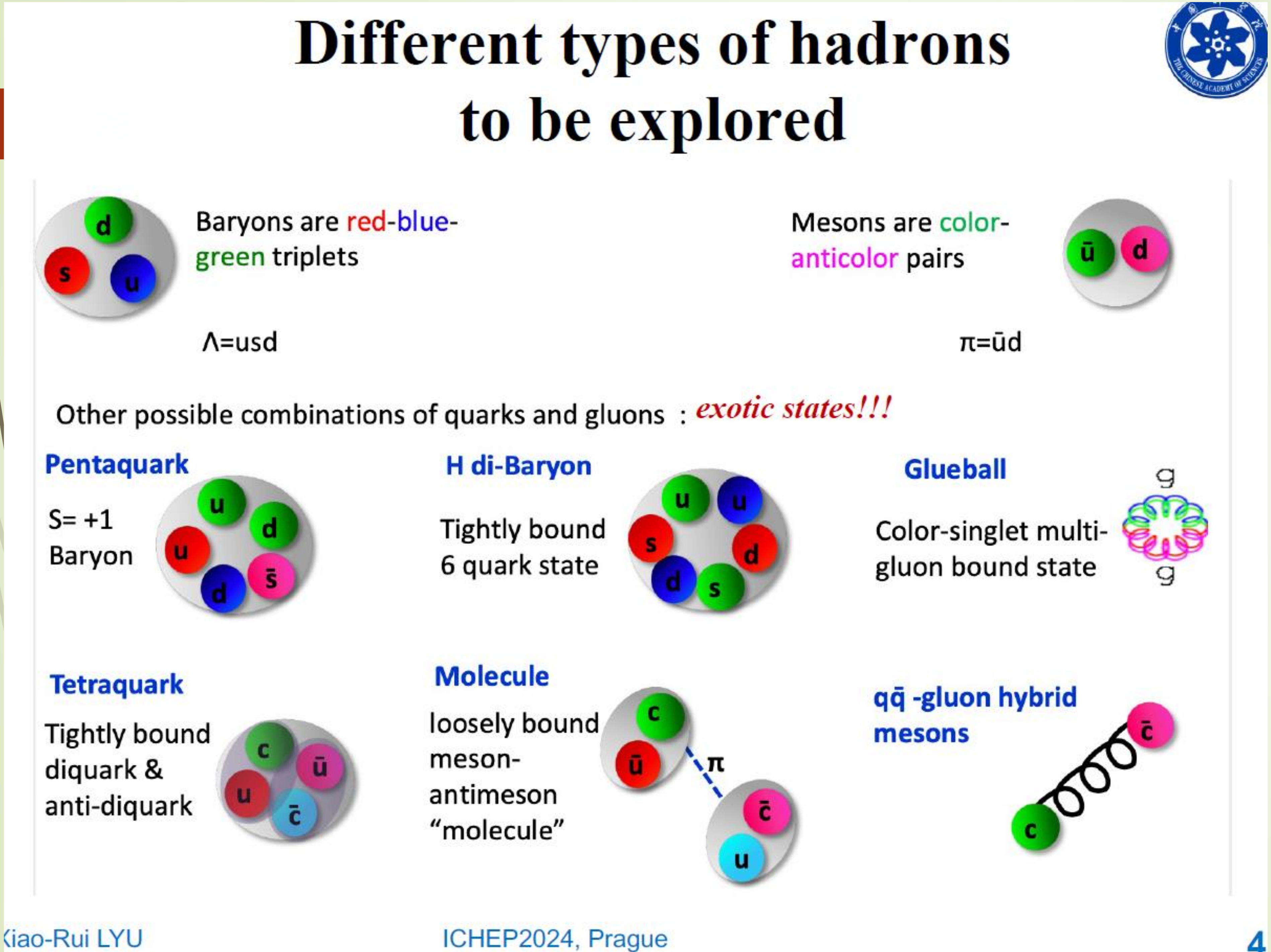




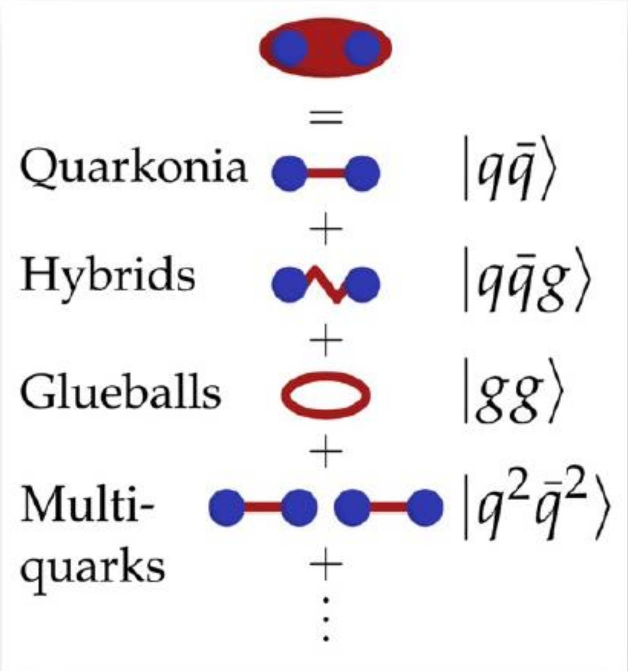
more than 20 new hadrons since the ICHEP2022

Результаты ICHEP 2024 Пленарный доклад по адронам (LYU)

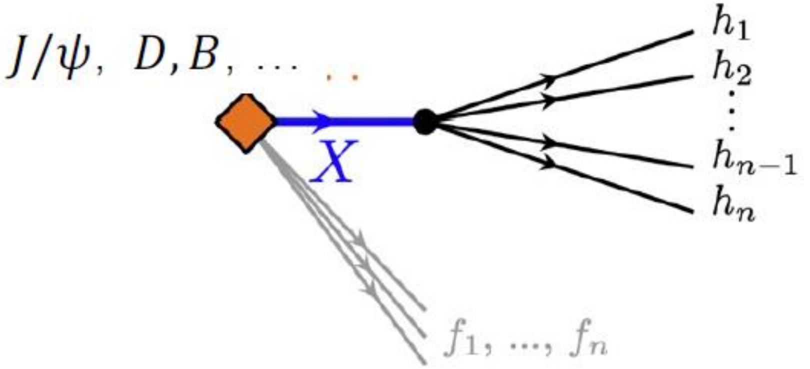
Типы адронов



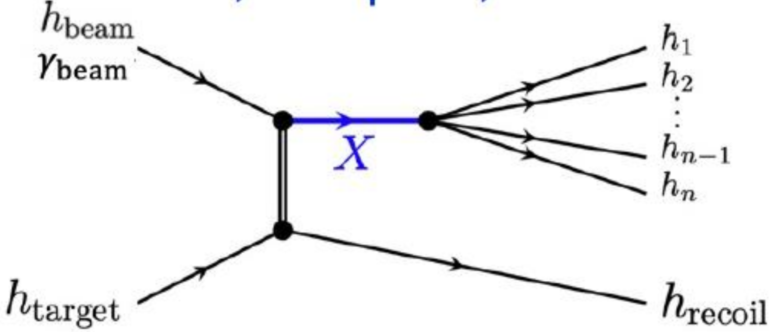
Light hadron spectroscopy



BESIII, LHCb, Belle (II) …

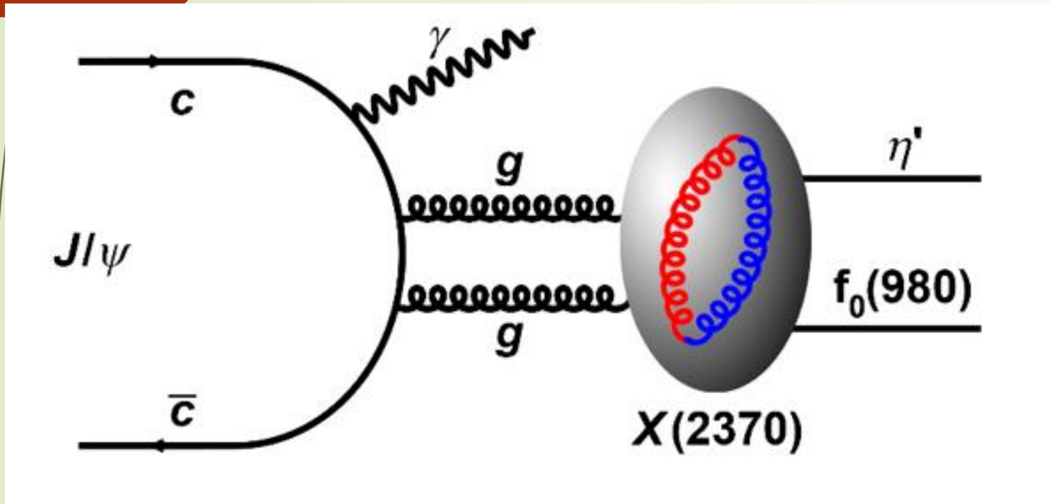


GlueX, Compass, …



Эксперименты по изучению легких адронов

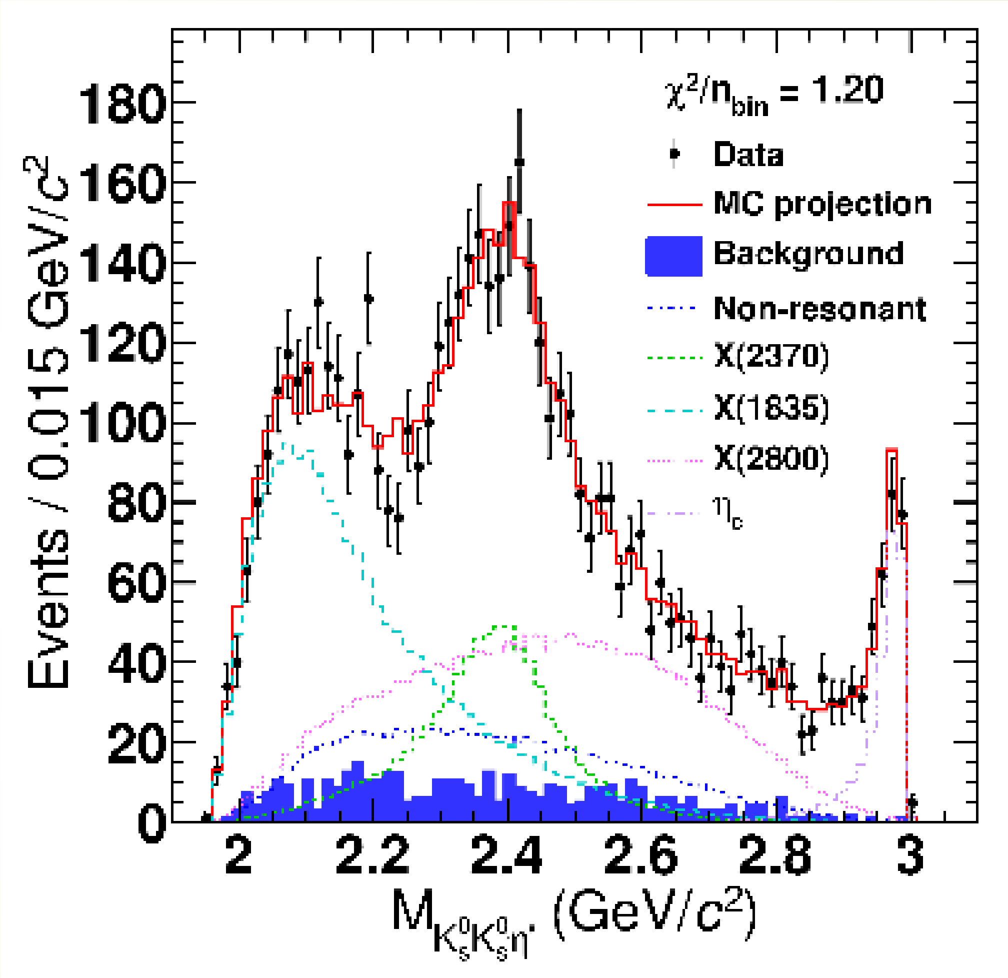
Открытие глюбола X(2370) на BESIII



Принципиальная схема радиационного распада J /ψ на частицу X (2370). (Предоставлено IHEP)

Charmonium decays provide ideal hunting ground for light glueballs and hybrids

14 countries, almost 500 members 43 institutions from China,
 8 others in Asia
16 Europe (inc. Dubna & Novosibirsk),
5 USA



Инвариантный масс-спектр $K_S^0K_S^0$' в J/ψ→γK^{S0}$_K$^{S0}. (

Результаты измерений

- $X(2370)$ observed in the gluon-rich J/ψ radiative decays
  - J^{PC} determined to be 0^{-+}
  - Mass and production rate **consistent** with LQCD
  - Decay modes $X(2370) \to$ $\eta'\pi\pi, \eta' KK, K_S^0 K_S^0 \eta, K_S^0 K_S^0 \pi^0, \eta\pi^0\pi^0, a_0^0(980)\pi^0$ observed, in analog to η_c

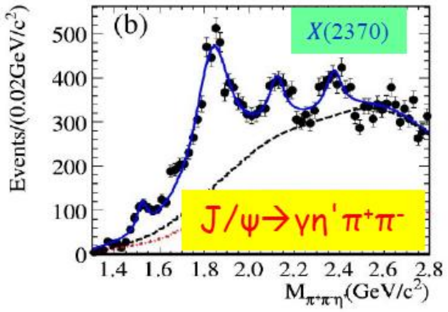
Consistent with 0^{-+} glueball

BESIII

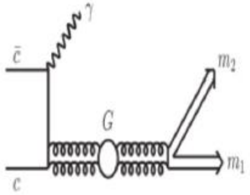
A glueball-like state X(2370)

PRL 132.181901 (2024)

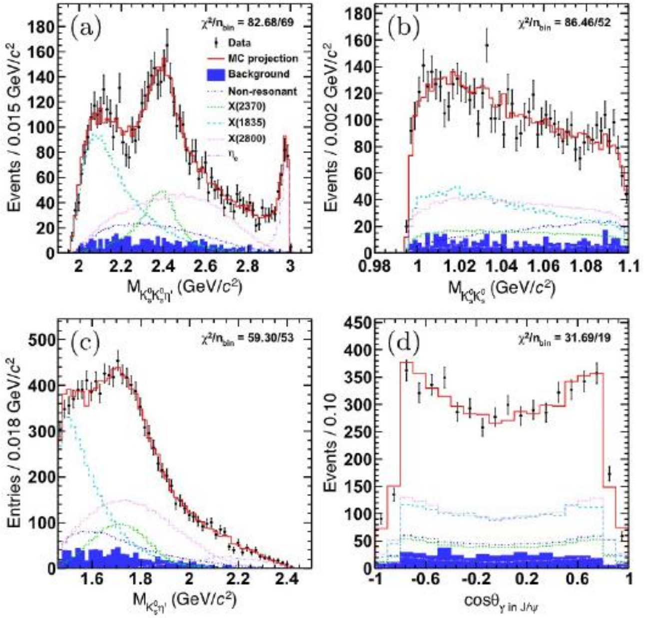
$X(2370)$ firstly seen in $J/\psi \to \gamma\pi^+\pi^-\eta'$



J/ψ radiative decays are gluon-rich processes



- Partial wave analysis $J/\psi \to \gamma K_S K_S \eta'$ in 10B J/ψ decays
- $X(2370) \to K_S K_S \eta'$ significance larger than 14 σ
- mass $2395 \pm 11^{+26}_{-94}$ MeV$/c^2$
- width $188^{+18}_{-17}{}^{+124}_{-33}$ MeV
- spin-parity is determined to be 0^{-+}
- candidate for lightest pseudoscalar glueball predicted by LQCD

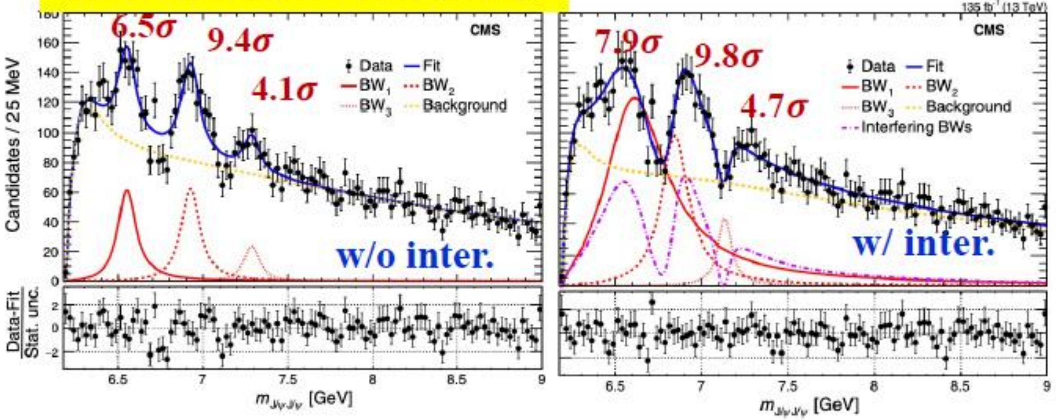


$J^{PC} = 0^{-+}$

Пример нового наблюдения **тетракварка из c кварков**

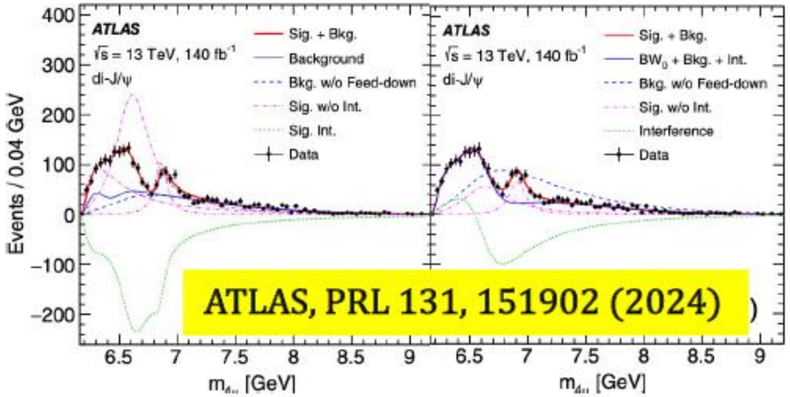
Observations of fully charmed tetraquark state X(6600) [$cc\bar{c}\bar{c}$]

CMS, PRL 132, 111901 (2024)



w/o inter.	BW_1	BW_2	BW_3
m (MeV)	$6552 \pm 10 \pm 12$	$6927 \pm 9 \pm 4$	$7287^{+20}_{-18} \pm 5$
Γ (MeV)	$124^{+32}_{-26} \pm 33$	$122^{+24}_{-21} \pm 18$	$95^{+59}_{-40} \pm 19$
w/ inter.	BW_1	BW_2	BW_3
m (MeV)	6638^{+43+16}_{-38-31}	6847^{+44+48}_{-28-20}	7134^{+48+41}_{-25-15}
Γ (MeV)	$440^{+230+110}_{-200-240}$	191^{+66+25}_{-49-17}	97^{+40+29}_{-29-26}

- ATLAS and CMS both confirm the X(6900) state in J/ψ+J/ψ final states
- CMS observe a new structure X(6600) and find an evidence of the X(7100)
- LHCb, ATLAS and CMS all see a broad enhancement at the low mass region



ATLAS, PRL 131, 151902 (2024)

Di-J/ψ	Model A	Model B
m_0	$6.41 \pm 0.08^{+0.08}_{-0.03}$	$6.65 \pm 0.02^{+0.03}_{-0.02}$
Γ_0	$0.59 \pm 0.35^{+0.12}_{-0.20}$	$0.44 \pm 0.05^{+0.06}_{-0.05}$
m_1	$6.63 \pm 0.05^{+0.08}_{-0.01}$	...
Γ_1	$0.35 \pm 0.11^{+0.11}_{-0.04}$	
m_2	$6.86 \pm 0.03^{+0.01}_{-0.02}$	$6.91 \pm 0.01 \pm 0.01$
Γ_2	$0.11 \pm 0.05^{+0.02}_{-0.01}$	$0.15 \pm 0.03 \pm 0.01$

Заключение пленарного доклада по адронам

Xiao-Rui LYU (China)

Summary

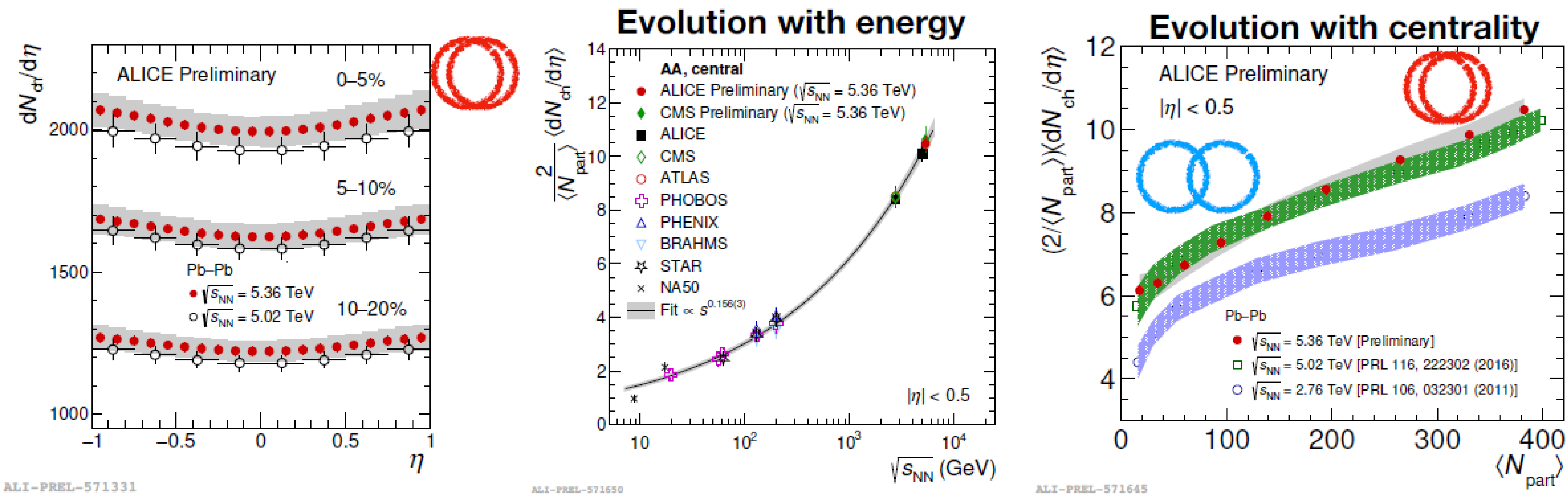
- Two years of exciting period of finding new hadrons (mainly) from BESIII and LHCb, among which most of them are candidates of exotic hadrons
- **Light hadrons:** high statistics data is crucial to identify exotic feature of different known states and find new particles
  - a glueball-like state X(2370)
  - emerging strangenium(-like) states
  - distorted lineshape at thresholds of $p\bar{p}$, $N\bar{K}$ and $\Lambda\eta$
- **Heavy hadrons:**
  - better understanding of the X(3872) via its radiative decays
  - 8 new neutral charmonium(-like) states: **[$c\bar{c}$] or [$c\bar{c}q\bar{q}$]**
  - 7 new tetraquark states: **[$c\bar{c}u\bar{s}$]; [$c\bar{s}u\bar{d}$]; [$c\bar{s}\bar{u}d$]**
  - 1 new pentaquark state with strangeness: **[$c\bar{c}uds$]**
  - 2 new Ω_c states and 2 new Ξ_b states
- More results based on higher statistics data can be expected regarding to the upcoming 3x$\mathcal{L}$ upgraded BEPCII-U, ongoing LHC RUN3 and Belle II.

Новые результаты ALICE

Новые измерения множественности частиц

Multiplicity of charged particles in Pb-Pb

RUN 3



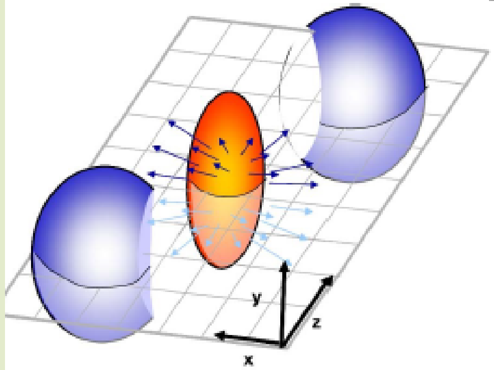
- Multiplicity measured using charged tracks at mid-rapidity
- Energy dependence in line with expectation from lower energies
- Results in agreement with other experiments

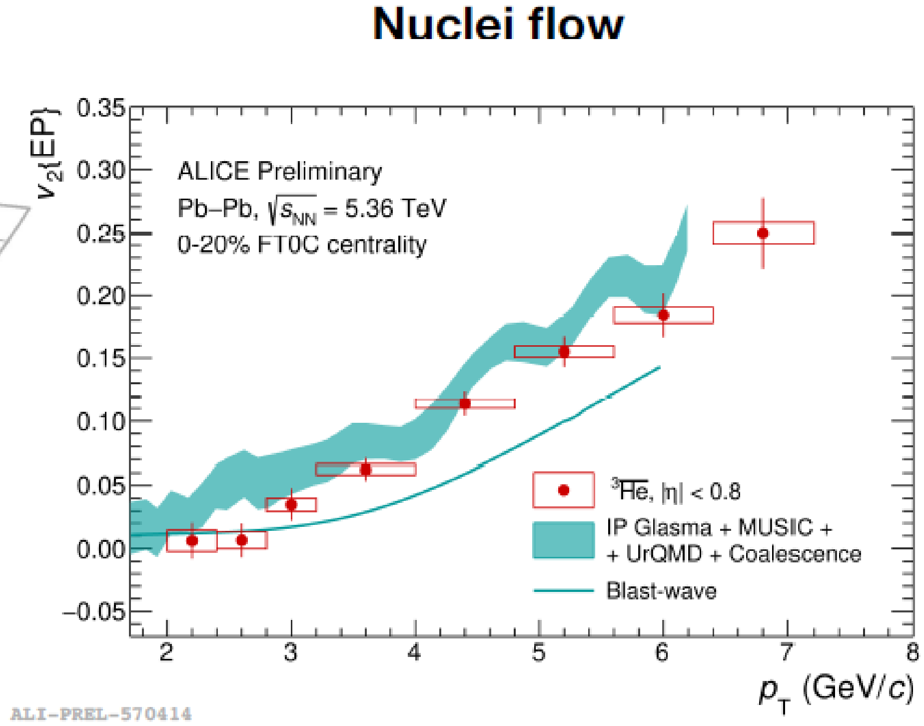
Abhi Modak 18/07/24, 09:55

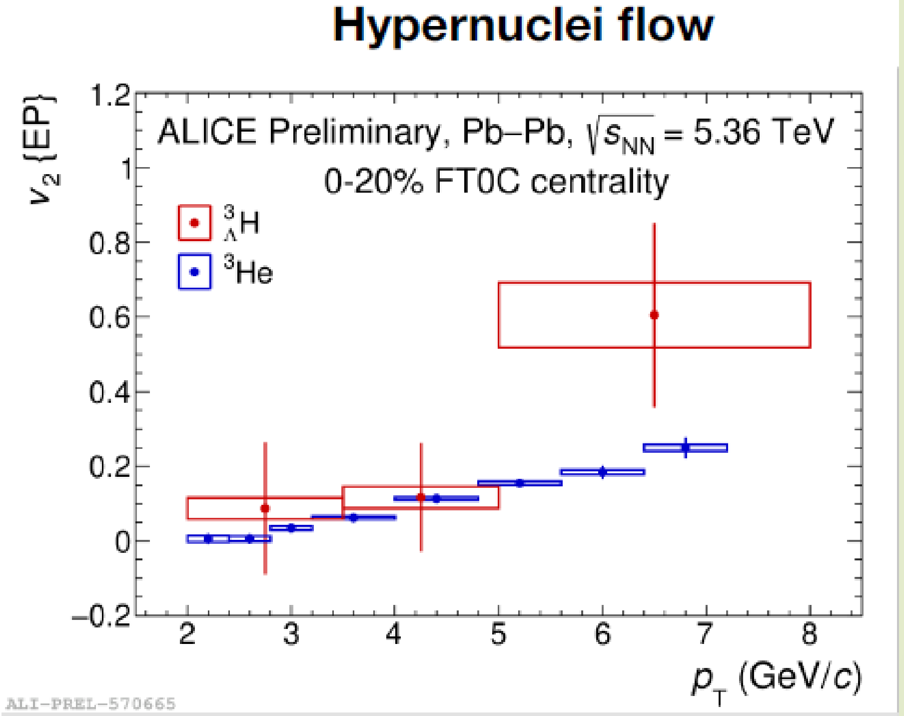
Новые измерения потоков частиц

Studying flow with nuclei and hypernuclei

RUN 3





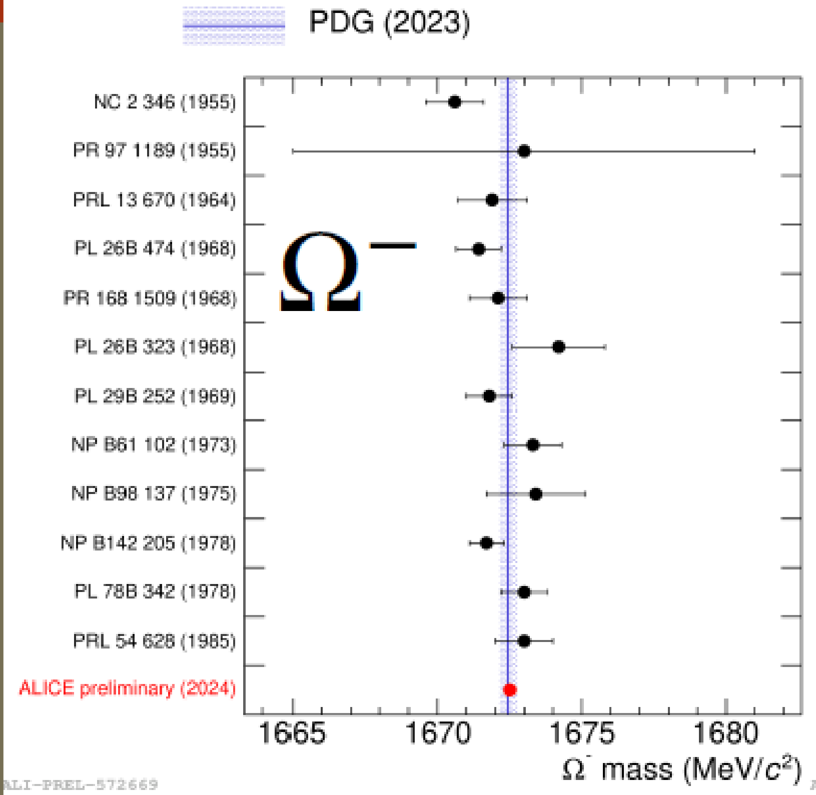


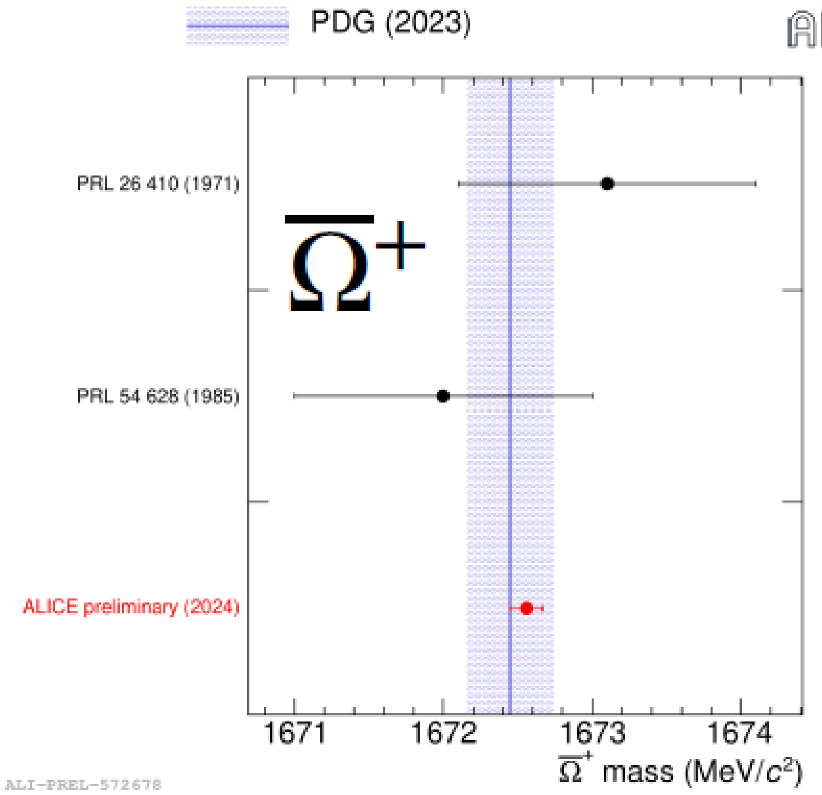
- v_2 of anti-^{3}He in Run 3 Pb-Pb collisions more differential both in p_T and centrality, more precise than Run 2
- Hypertriton flow has been measured **for the first time**
  - Hypernuclei flow compatible with ^{3}He, yet large uncertainties

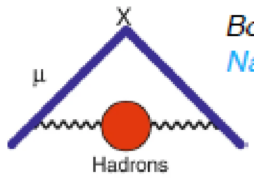
Luca Barioglio 20/07/24, 17:53

Ω^{-} AND $\overline{\Omega}^{+}$ MASS - MUON G-2

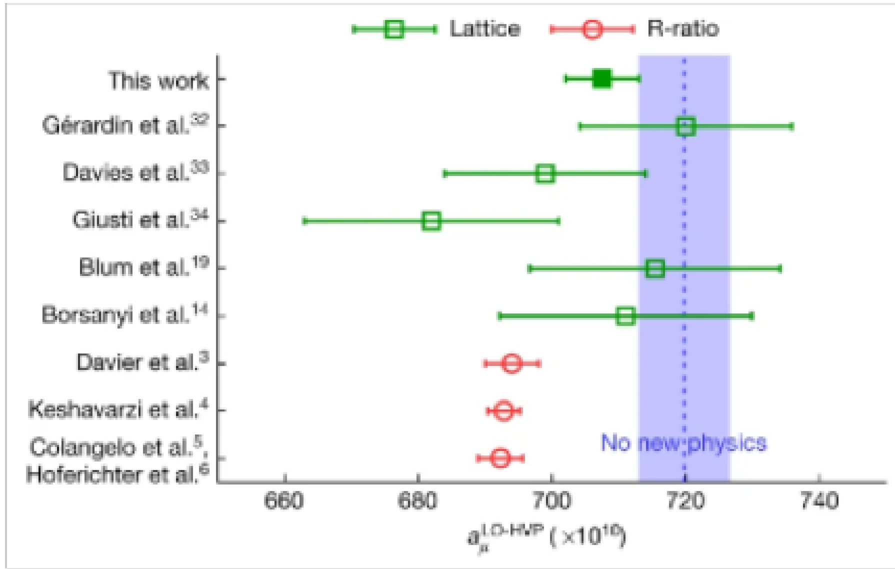
R. Schotter







Borsanyi, Fodor, Guenther, et al.
Nature 593, 51–55 (2021)



high-precision measurement of $\Omega^-$and $\overline{\Omega}^+$ **mass**

3x more precise than **world average** $\Omega^-$and $\overline{\Omega}^+$

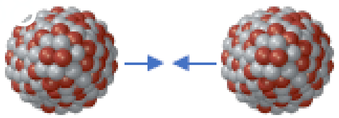
(**world** average **based** on **257 counts**)

$\Omega^-$and $\overline{\Omega}^+$ used to set **physical scale** in **lattice QCD**

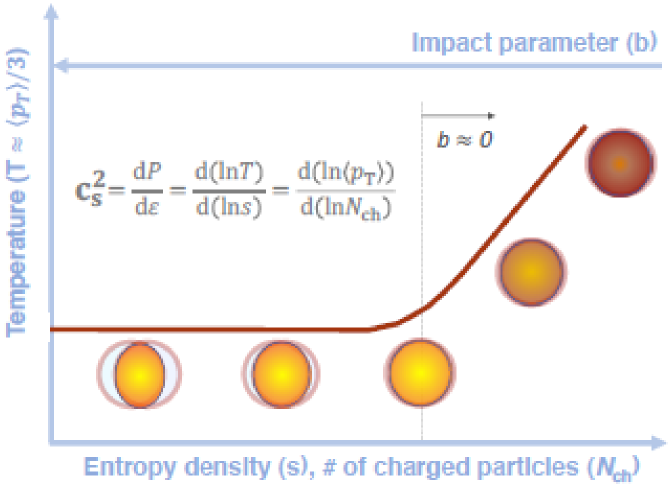
muon g-2, 4σ **discrepancy** between **theory** and **experiment** might be due to **hadron vacuum polarization (HVP)**

calculate HVP in lattice **QCD**

ULTRA-CENTRAL COLLISIONS: SPEED OF SOUND?



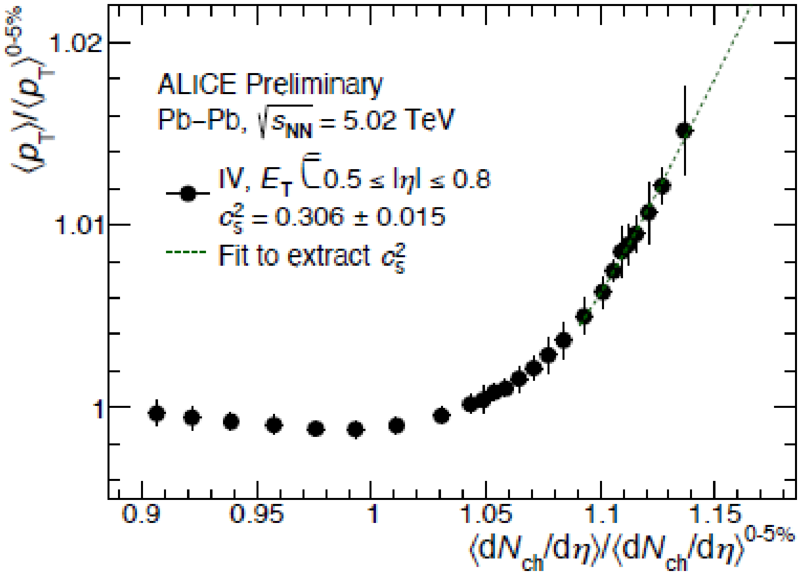
$\langle p_T \rangle$ vs $dN/d\eta$



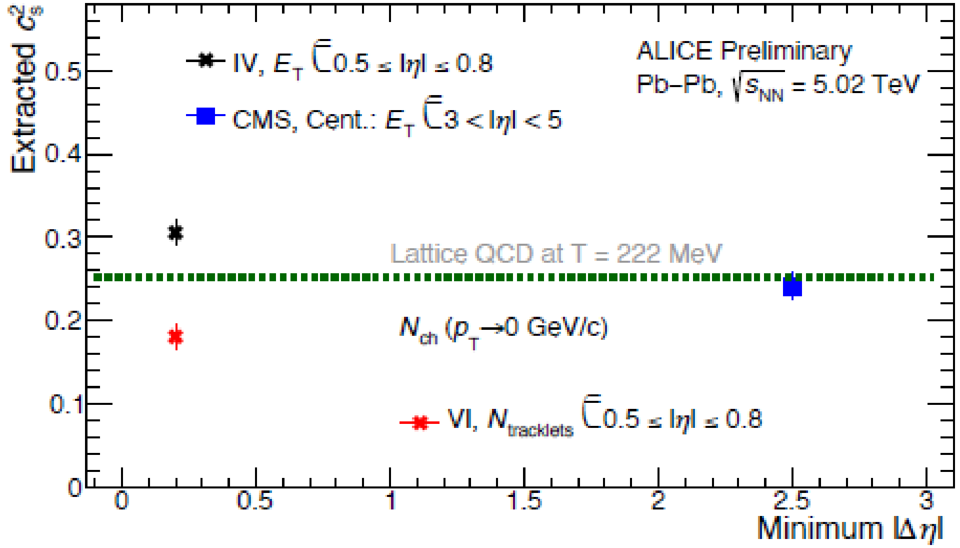
$\langle p_T \rangle$ vs $dN/d\eta$

different centrality selectors

ALICE-PUBLIC-2024-002



Extracted speed of sound vs rapidity gap



Idea: **ultra-central** events **increase entropy** at **constant volume** ⇒ measure **speed of sound**

F Gardim et al, PLB 809, 135749

$$c_s^2 = \frac{d\ln\langle p_t\rangle}{d\ln N_{\rm ch}}$$

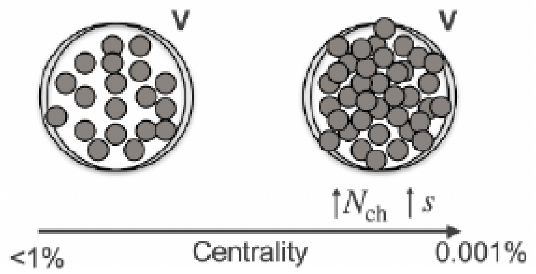
O. Vazquez

First explored by CMS: Rep. Prog. Phys. 87 (2024) 077801
ATLAS: ATLAS-CONF-2023-061

G Nijs and W van der Schee, PLB 853, 138636

Измерения скорости звука в КГП

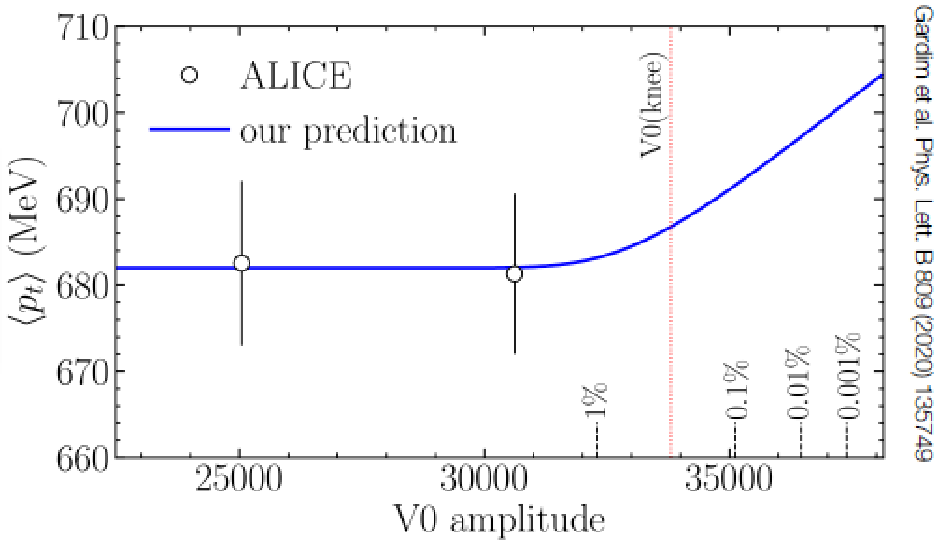
Accessing the speed of sound in the QGP



$$c_s^2 = \left.\frac{sdT}{Tds}\right|_{T_{\rm eff}} = \frac{d\ln\langle p_T\rangle}{d\ln(N_{ch}/d\eta)}$$

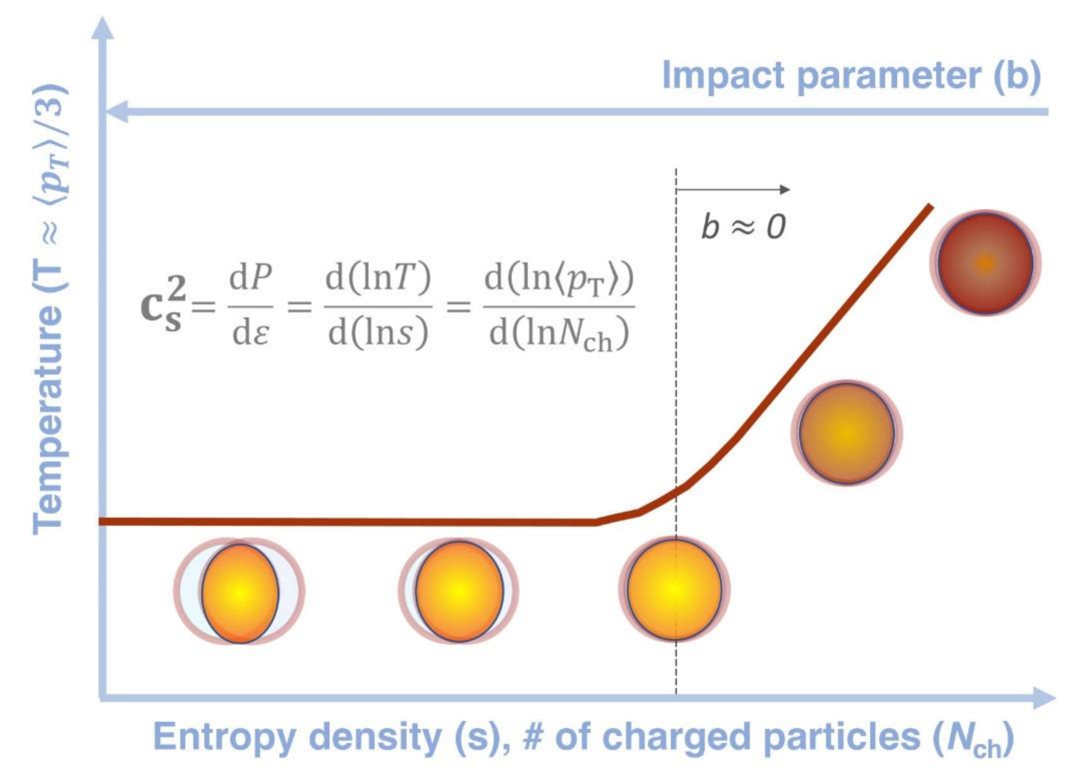
F. G. Gardim et. al, Nature Phys. 16 (2020) 6, 615-619

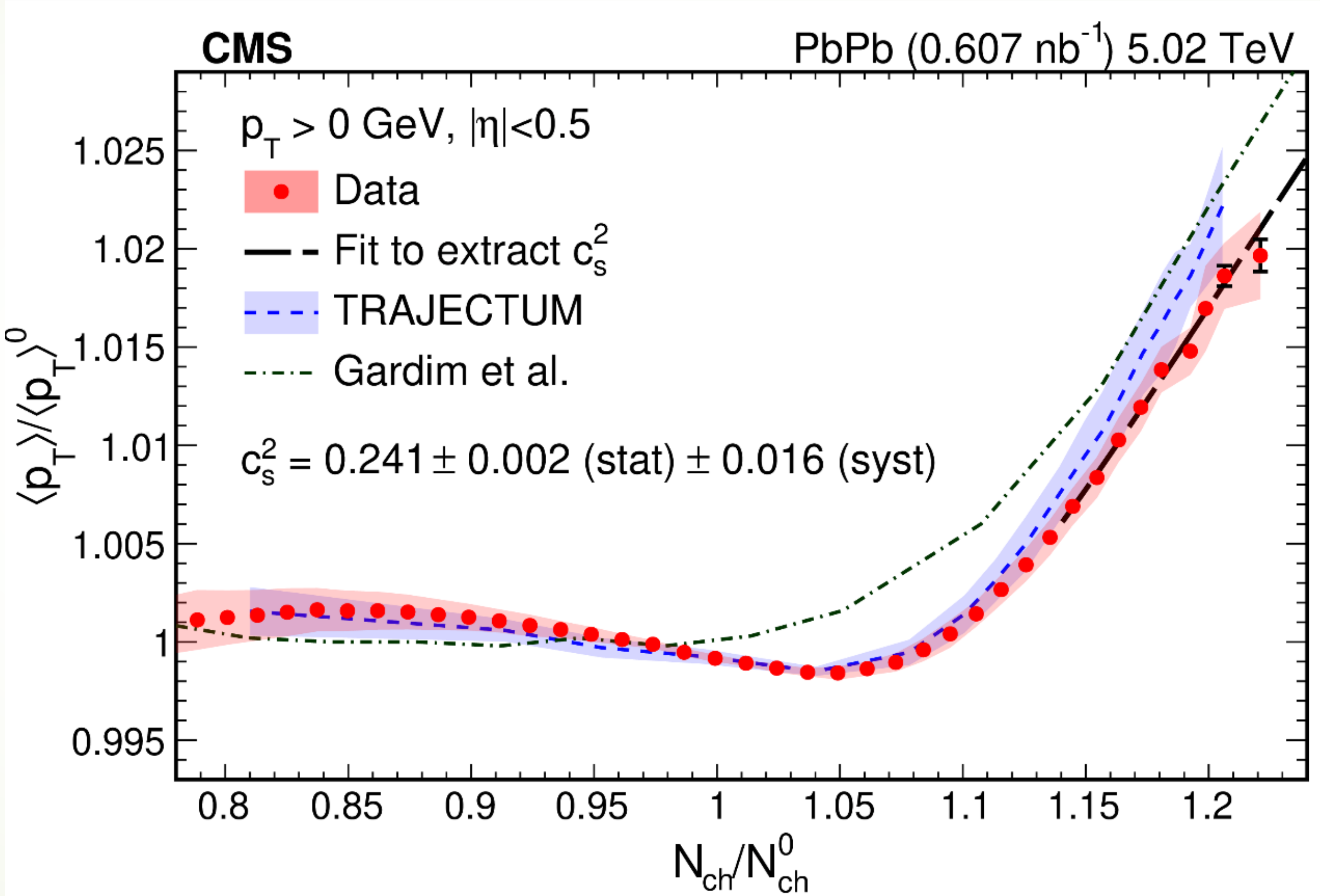
$$\langle p_T\rangle/\langle p_T\rangle^{0-5\%} \propto \left(\frac{N^*_{ch}}{N^*_{ch,knee}}\right)^{c_s^2}$$



- For most central collisions: fluctuations in the average momentum and multiplicity are related to the speed of sound in the medium
- Accessible experimentally in ultracentral collisions

CMS 2401.06896





Из аннотации CMS статьи (arXiv:2401.06896)

В ультрарелятивистских соударениях тяжелых ионов возникает сильно взаимодействующее состояние горячей и плотной кварк-глюонной материи, показывающее значительную асимметрию потоков энергии с минимальной диссипацией энергии за счет вязкости. Продвижение к более глубокому пониманию внутренней природы и фундаментальных степеней свободы этого состояния обеспечено путем определения скорости звука в большом объеме КГП, образующемся в соударениях релятивистских ядер PbPb при энергии 5.02ТэВ/нукл.

- Измерение выполнено при исследовании зависимости от множественности среднего поперечного импульса вылетающих частиц. Показано, что скорость звука в среде примерно составляет половину скорости света. Величина квадрата скорости в естественных единицах составляет 0,241 ± 0,002 (стат.) ± 0,016 (сист.).
- Эффективная температура среды, определяемая по среднему поперечному импульсу частиц, составила 216 ± 8 МэВ (сист.). Полученная величина скорости звука при такой температуре хорошо согласуется с соответствующими расчетами КХД на решетках. Полученные результаты дают наиболее строгое ограничение на уравнение состояния создаваемой среды и прямое свидетельство того, что в ней достигается состояние фазы полного КХД деконфайнмента. (arXiv:2401.06896)

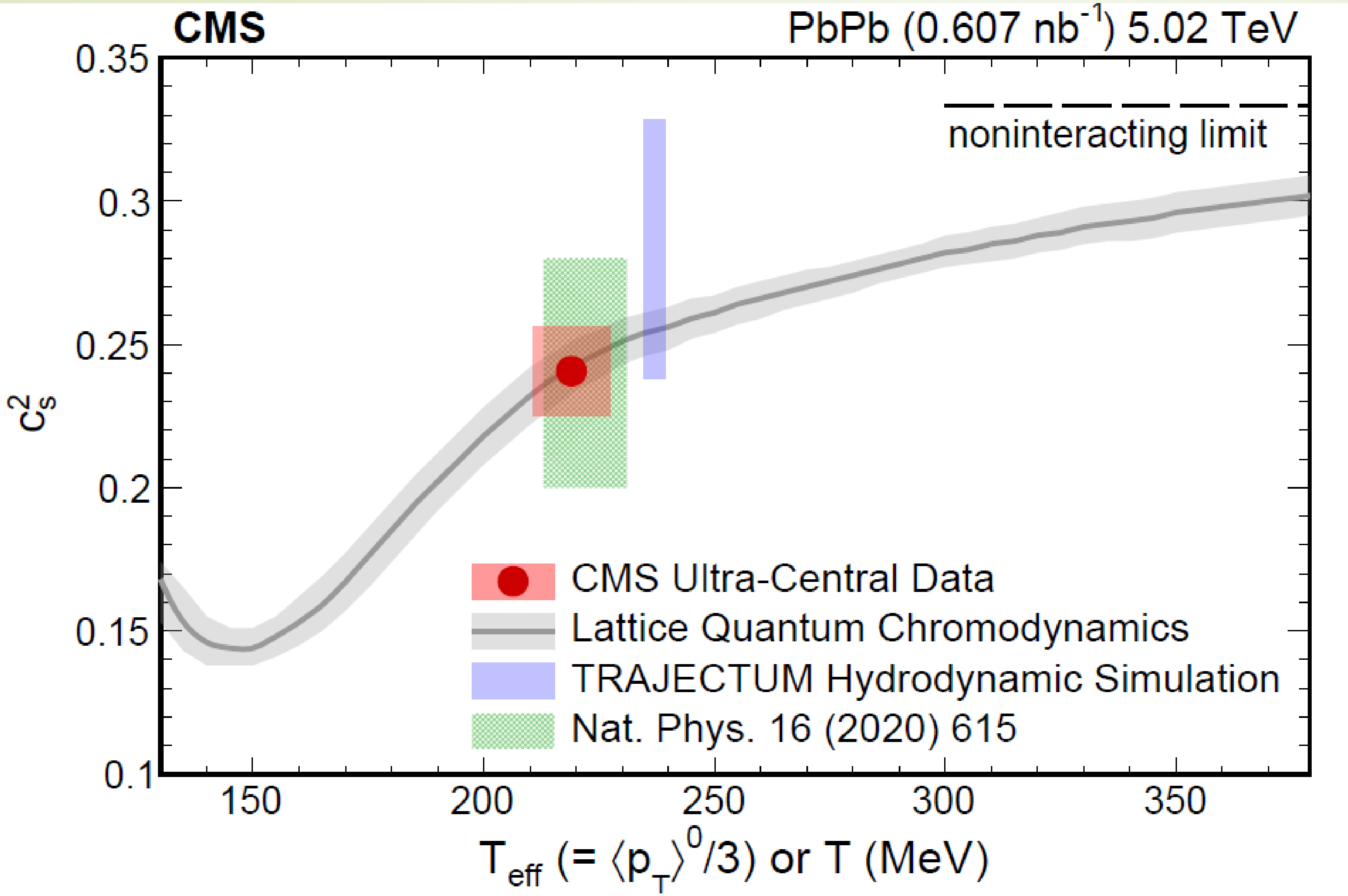


Figure 4: The speed of sound, c_s^2, as a function of the effective temperature, T_{eff}, with the CMS data point obtained from ultra-central PbPb collision data at $\sqrt{s_{NN}} = 5.02$ TeV. The size of the red box indicates systematic uncertainties of c_s^2 and T_{eff}, while statistical uncertainties are smaller than the marker size. Values extracted from the TRAJECTUM simulation [19] following the same fitting procedure as the data and from the earlier work [16] are presented as the other colored boxes. The curve shows the prediction of c_s^2 as a function of T from lattice QCD calculations [6]. The dashed line at the value of $1/3$ corresponds to the upper limit for noninteracting, massless gas ("ideal gas") systems [42].

Анализ результата – пунктир соответствует 1/3 (в единицах k_B=c=1), верхнему пределу для идеального газа.

Заключение

- Мы рассмотрели материалы самой представительной конференции ФВЭ ICHEP 2024
- Продолжаются прецизионные измерения процессов СМ, включая физику бозона Хиггса, с том числе на материалах третьего сеанса БАК, без обнаружения присутствия новой физики
- Ведется интенсивный поиск процессов вне СМ
- Появились интересные результаты для процессов КХД, согласующиеся с СМ : открытие глюбола как нового типа адронов, измерение скорости звука в высокотемпературной КГП.

Благодарю за внимание!