Wrap-Up Thursday

Christoph Blume

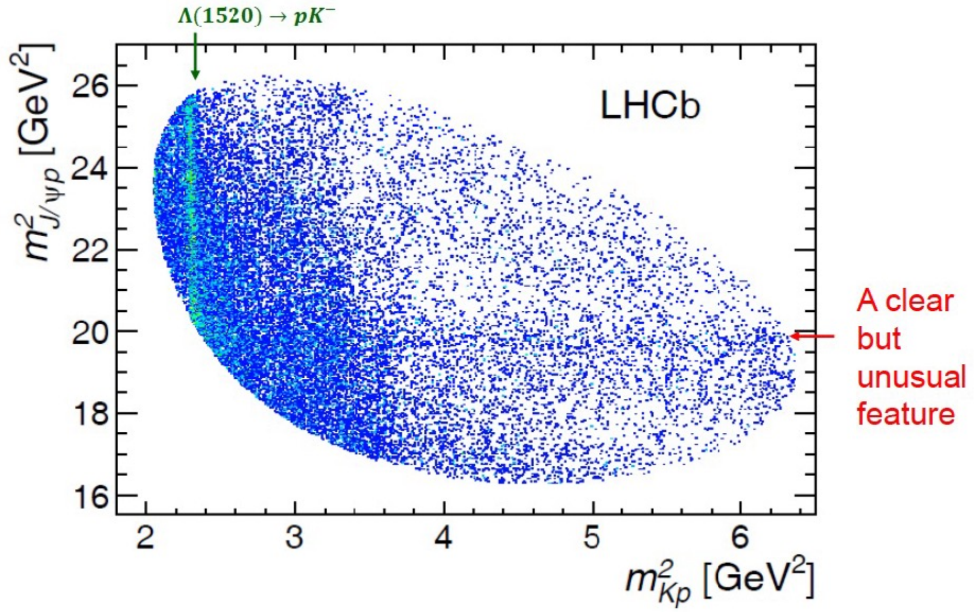
GOETHE UNIVERSITÄT
FRANKFURT AM MAIN

4th EMMI-Workshop on
“Anti-matter, hyper-matter and exotica production at the LHC“

Bologna, Italy
Feb. 13. – 17., 2023

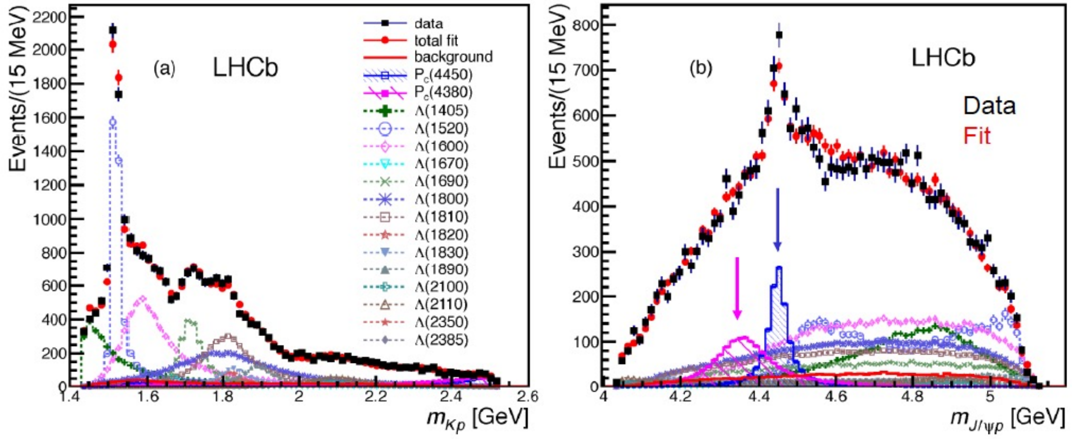
1st EMMI Workshop 2015: Announcement of P_c^+

"Dalitz-plot"



Extended model fits with 2 P_c^+

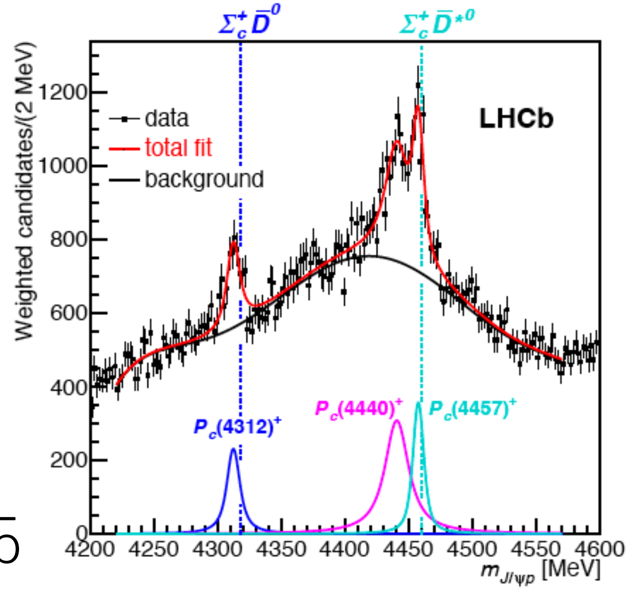
- Leads to a good fit
- The second broad P_c^+ is visible in other projections (shown later)
- It also modifies the narrow P_c^+'s decay angular distribution via interference to match with the data distribution



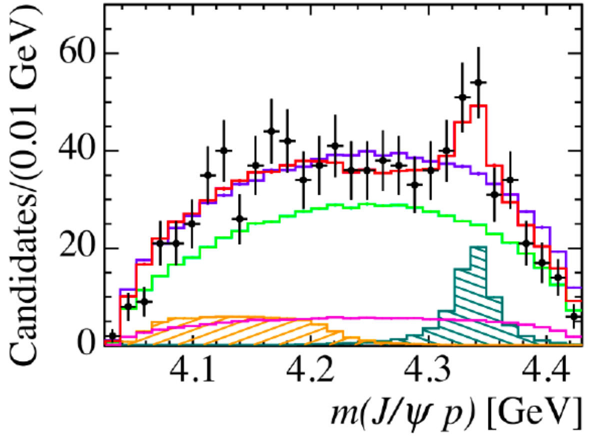
Pentaquarks today (LHCb)

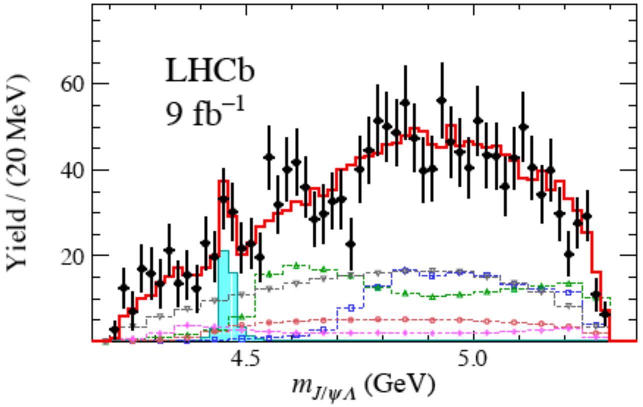
Lorenzo Capriotti

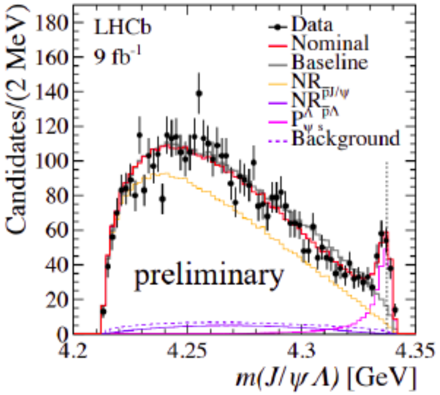
Run 1–2 data
$P_c(4450)^+$ contribution resolved into two separate peaks
$P_c(4312)^+$ established



Other new pentaquark states: $[c\bar{c}uud]$, $[c\bar{c}uds]$
$P_c(4337)^+$ in $B^0_s \longrightarrow J/\psi\, p\bar{p}$,
$P_{cs}(4459)^0$ in $\Xi_b^0 \longrightarrow J/\psi \Lambda K^-$,
$P^\Lambda_{\psi s}$ in $B^- \longrightarrow J/\psi \Lambda \bar{p}$







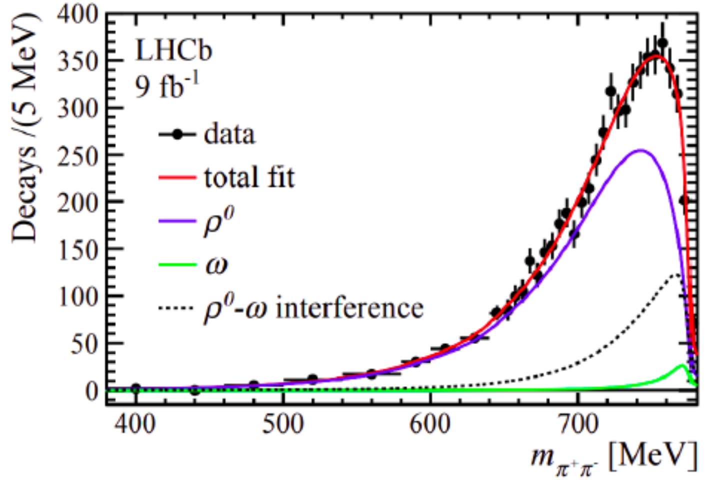
Tetraquark States (LHCb)

Lorenzo Capriotti

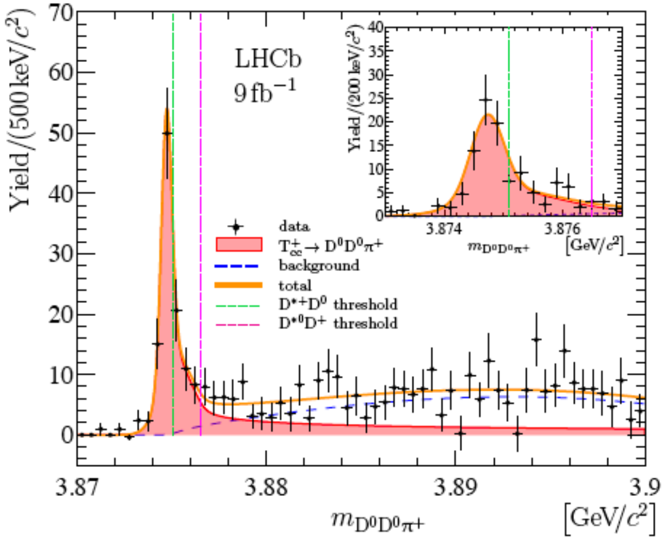
Evidence for ω-contribution to X(3872)

Ratio of couplings larger by one order of mag. as expected for pure $c\bar{c}$ states

$$\frac{g_{\chi_{c1}(3872)\to\rho J/\psi}}{g_{\chi_{c1}(3872)\to\omega J/\psi}} = 0.29 \pm 0.04$$



Observation of narrow peak in $D^0D^0\pi^+$ spectrum
Consistent with doubly-charmed tetraquark T^+_{cc} $[cc\bar{u}\bar{d}]$

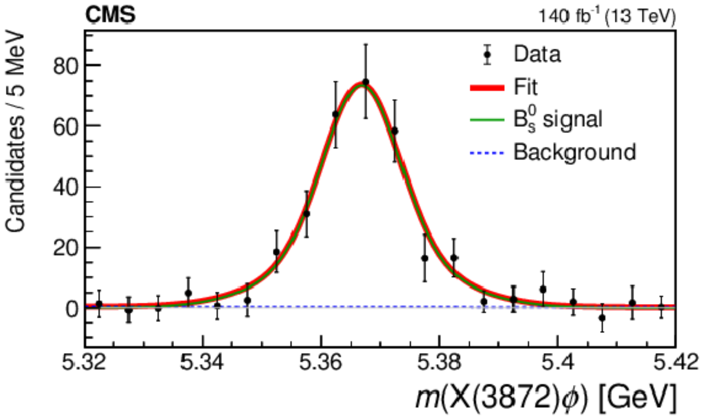


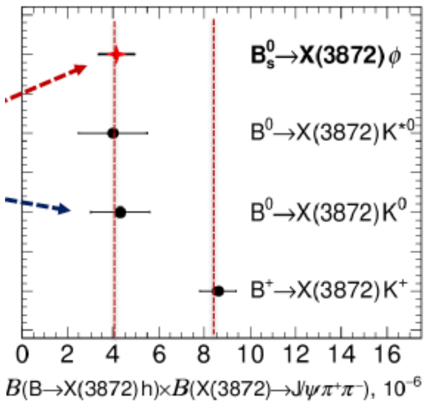
- Exotics are not rare!
- However, still mostly unexplored territory!

Exotica from CMS

Alexis Pompili

First observation of $B^0_s \longrightarrow X(3872)\ \phi$
Significant difference in
neutral-to-charged BF-ratio
⟹ Different to ψ(2S)
⟹ Nature of X(3872) tetraquark (?)





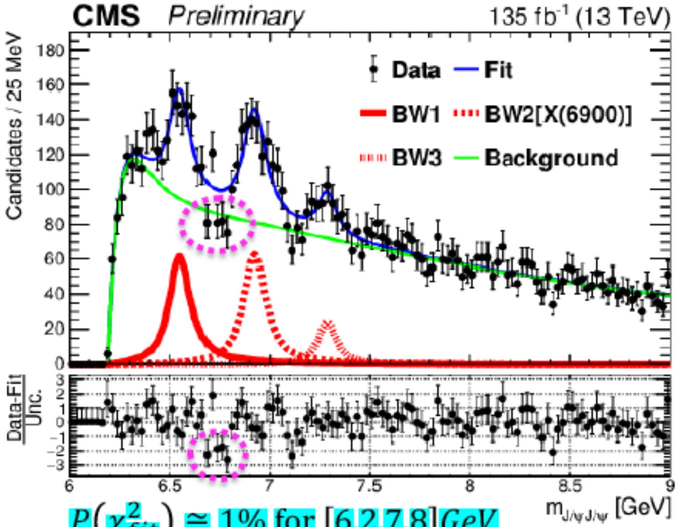
Three new structures in Di-J/ψ

	BW1	BW2	BW3
m	$6552 \pm 10 \pm 12$	$6927 \pm 9 \pm 5$	$7287 \pm 19 \pm 5$
Γ	$124 \pm 29 \pm 34$	$122 \pm 22 \pm 19$	$95 \pm 46 \pm 20$
St.Sig.	$> 5.7\sigma$	$> 9.4\sigma$	$> 4.1\sigma$

OBSERVATION of $X(6600)$

CONFIRMATION of $X(6900)$

EVIDENCE for $X(7300)$



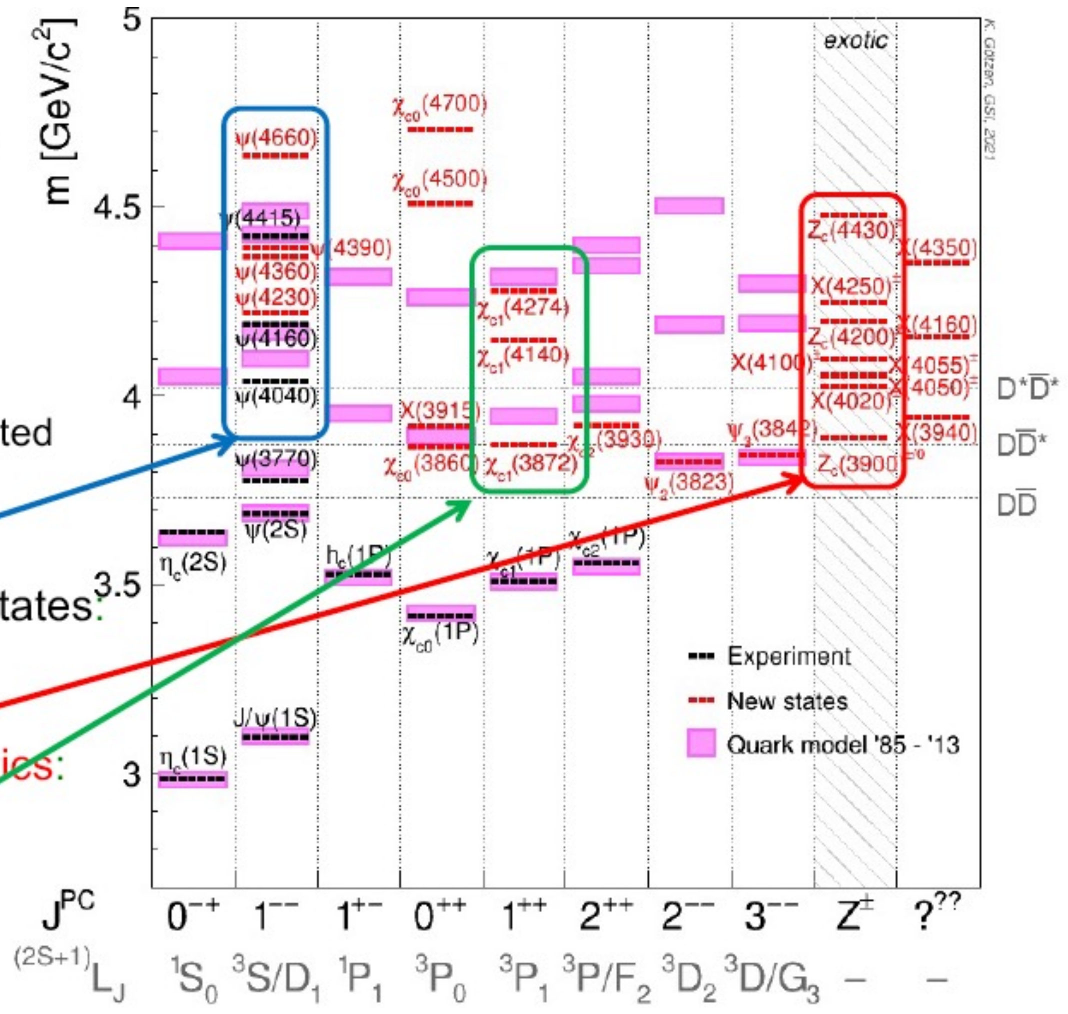
$P(\chi^2_{fit}) \cong 1\%$ for $[6.2, 7.8]\,GeV$

Exotica from BESIII

Frank Nerling

Charmonium spectrum [$c\bar{c}$]

- Before 2003:
  - ➢ Good agreement between theory and experiment, particularly beneath open charm thresholds
- After 2003:
  - ➢ Severe mismatch between predicted and observed spectrum
- Several supernumerary vector states: Y(4260), ..., Y(4660)
- Several charged manifestly exotics: $Z_c(3900)^{+/-}$, ..., $Z_c(4430)^{+/-}$
- The X states – the $\chi_{c1}(3872)$ was the first observed in 2003



Exotica from BESIII

Frank Nerling

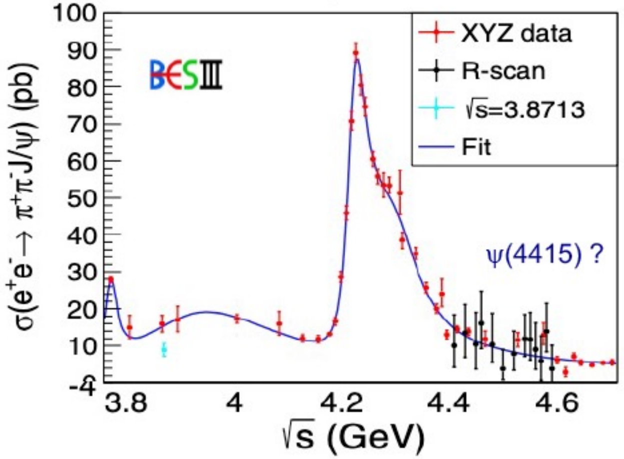
Two states resolved Y(4260) ⟶ Y(4230) + Y(4360)

Z_{cs} candidate ([$c\bar{c}s\bar{u}$]), strange partner of Z_c(3900)

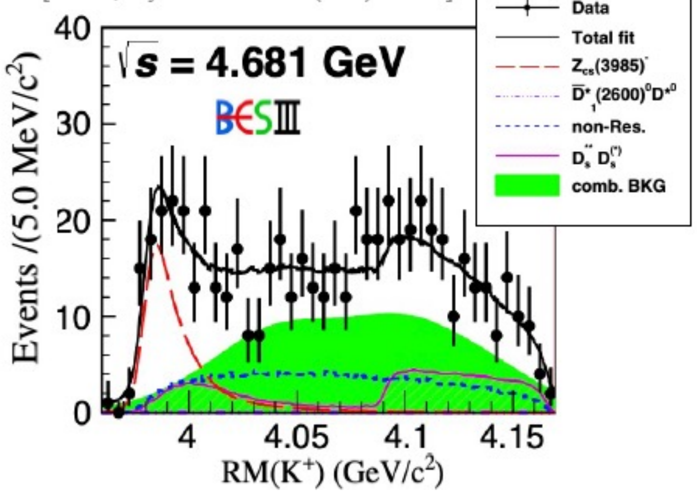
First observation of e^+e^- ⟶ γ X(3872) ⟶ γ $\pi^+\pi^-$ J/ψ
First observation of e^+e^- ⟶ γ X(3872) ⟶ γ ω J/ψ

$e^+e^- \to J/\psi\pi^+\pi^-$

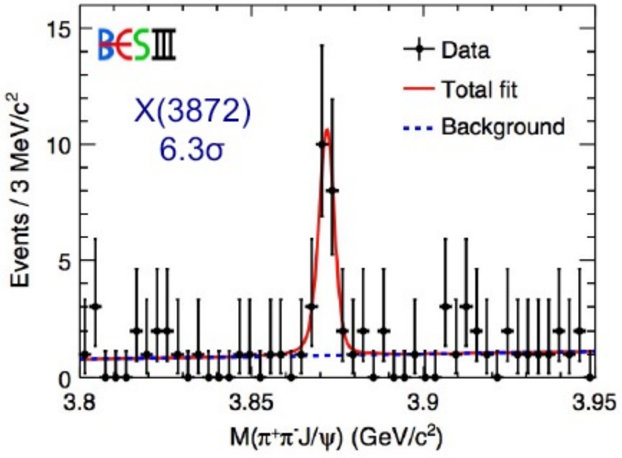
[Phys. Rev. D 106, 072001 (2022)]



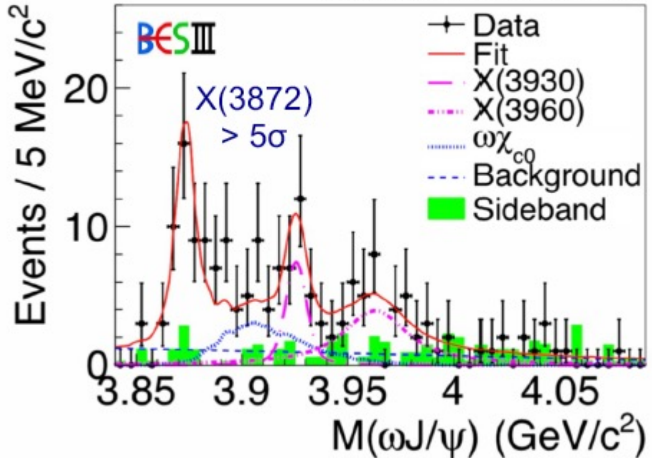
[BESIII, Phys. Rev. Lett. 126 (2021) 102001]



[Phys. Rev. Lett. 112 (2014) 092001]



[Phys. Rev. Lett., 122 (2019) 232002]

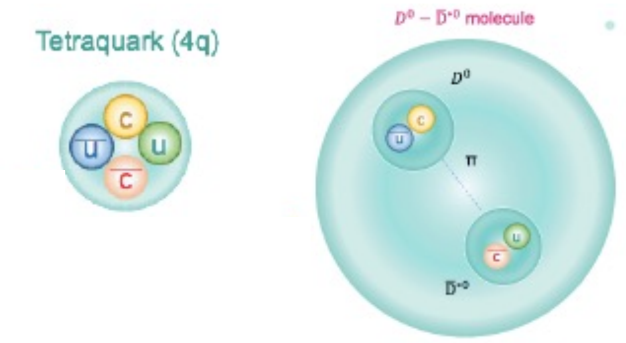


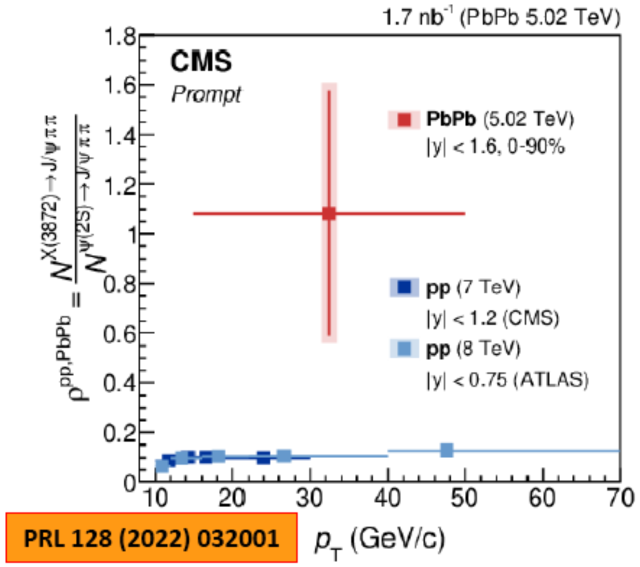
X(3872) in PbPb (CMS) and pPb (LHCb)

Alexis Pompili

Additional information on X(3872) nature from heavy-ion

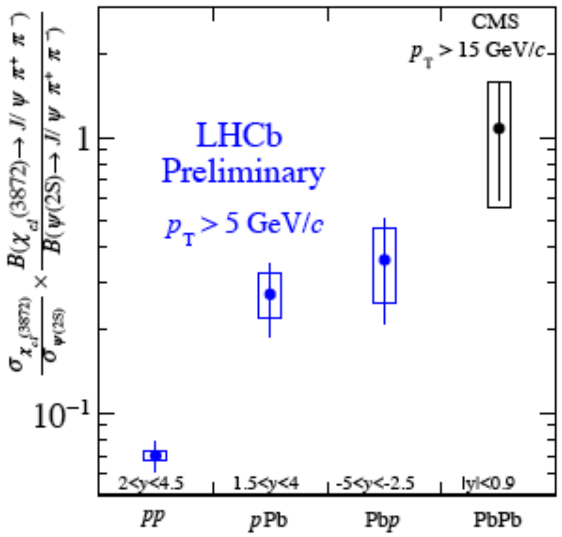
Move to nuclear modification factor in near future





Lorenzo Capriotti

Increased cross section of X(3872) observed in pPb already



Heavy Flavour Medium Modifications

Glòria Montaña Faiget

EFT Lagrangian

Lagrangian at NLO in the chiral expansion and LO in the heavy-quark mass expansion:

Tree-level scattering amplitude:

$$V^{ij}(s,t,u) = \frac{1}{f_\pi^2}\Big[\frac{C_{\rm LO}^{ij}}{4}(s-u) - 4C_0^{ij}h_0 + 2C_1^{ij}h_1 - 2C_{24}^{ij}\big(2h_2(p_2\cdot p_4) + h_4((p_1\cdot p_2)(p_3\cdot p_4)+(p_1\cdot p_4)(p_2\cdot p_3))\big) + 2C_{35}^{ij}\big(h_3(p_2\cdot p_4) + h_5((p_1\cdot p_2)(p_3\cdot p_4)+(p_1\cdot p_4)(p_2\cdot p_3))\big)\Big]$$

C_k^{ij} isospin coefficients

LECs fitted to lattice QCD data

[Guo, Liu, Meißner, Oller and Rusetsky (2019)]

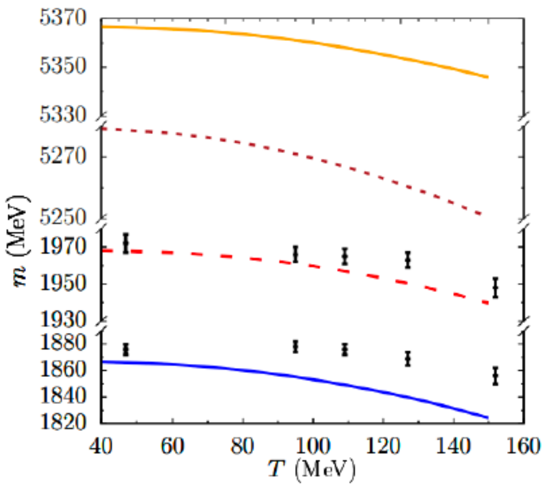
Self-consistent solution of coupled equations

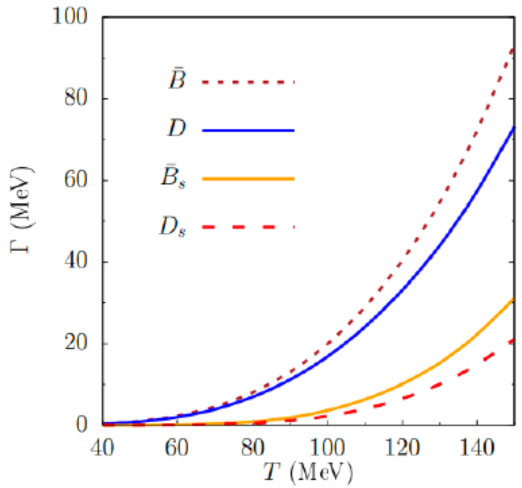
At LO in HQSFS: $h^B_{0,\dots,3}\hat{M}_B^{-1} = h^D_{0,\dots,3}\hat{M}_D^{-1}$, $h^B_{4,5}\hat{M}_B = h^D_{4,5}\hat{M}_D$

Recent results for $D\pi$ and DK from femtoscopy from ALICE pp, $\sqrt{s} = 13\,\mathrm{TeV}$ at high multiplicity

[ALI-PREL-513658]

Thermal masses and widths of heavy flavour mesons

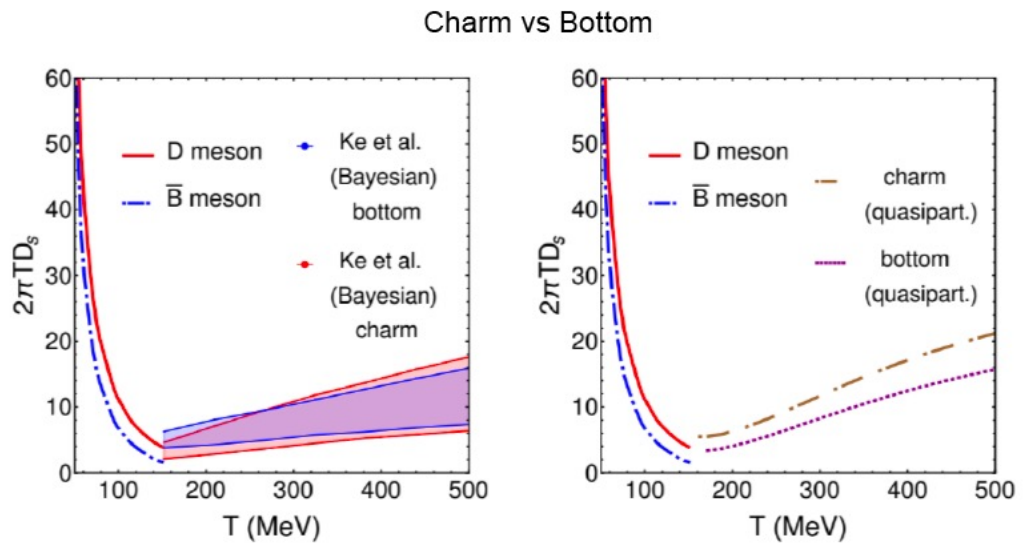




Heavy Flavour Medium Modifications

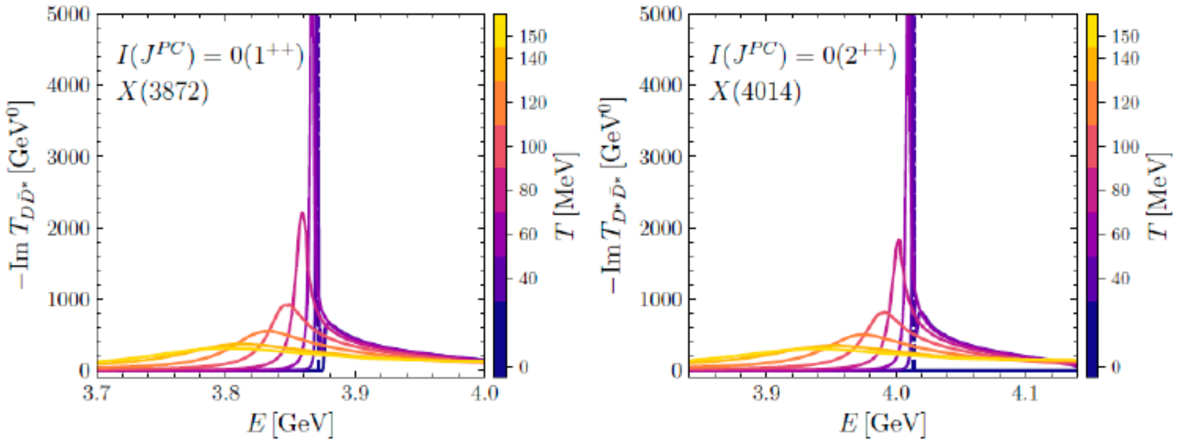
Glòria Montaña Faiget

Spatial diffusion coefficients
for B and D mesons



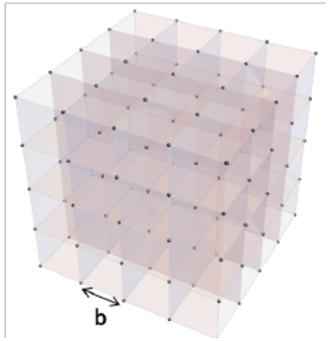
Thermal modifications of
the X(3872) and X(4014)

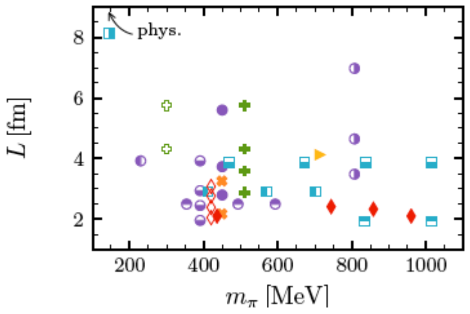
Masses decrease ⟹ lower thresholds
Non-zero decay widths at finite T

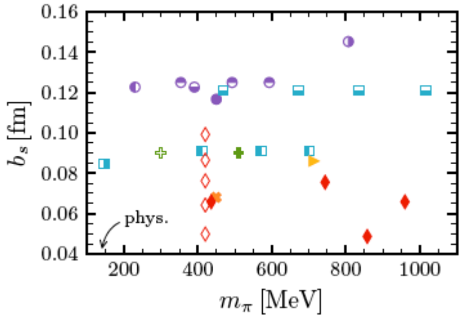


Nuclear Physics with Lattice QCD (NPLQCD)

Assumpta Parreño

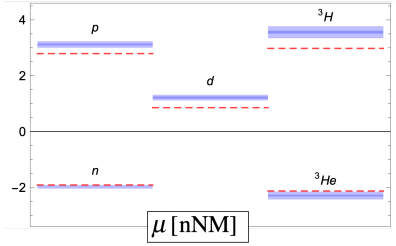






M. Illa, e-Print: 2109.10068 [hep-lat]

Nuclear magnetic moments
NPLQCD, Phys. Rev .Lett. 113 (2014)

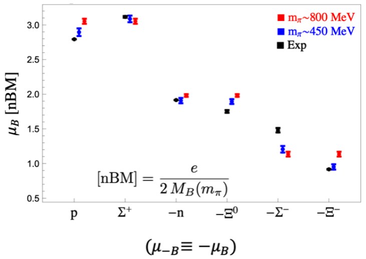


$$\text{nNM} = \frac{e}{2M_N^{\text{latt}}} = \frac{e}{2M_N(m_\pi^{\text{latt}})}$$

LQCD @ $m_\pi \sim 800$ MeV
experiment

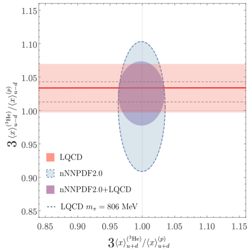
Shell-model predictions
$\mu(^3H) = \mu_p$
$\mu(^3He) = \mu_n$
$\mu_d = \mu_n + \mu_p$

Octet baryon magnetic moments
NPLQCD, PRD95, 114513 (2017)

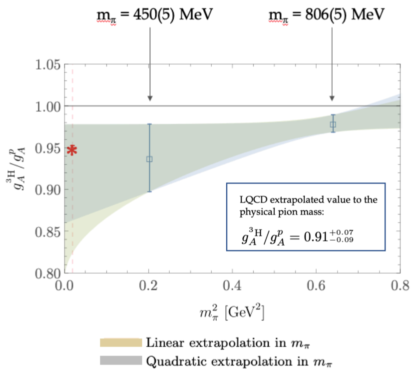


$(\mu_{-B} \equiv -\mu_B)$

Momentum fraction of ^3He, $\langle x\rangle_q = \langle h|\bar{q}\gamma_{\{\mu}\overleftrightarrow{D}_{\nu\}}q|h\rangle$
NPLQCD, PRL 126 (2021)



Triton axial charge, $g_A = \langle h|\bar{q}\gamma_3\gamma_5 q|h\rangle$
NPLQCD, PRD 103 (2021)



In agreement with the phenomenological result:
$g_A^{^3H}/g_A^p = 0.9511(13)$

Baroni, Girlanda, Kievsky, Marcucci, Schiavilla, Viviani, Tritium β-decay in chiral effective field theory, Phys. Rev. C 94, 024003 (2016); Erratum, Phys. Rev. C 95, 059902 (2017).

Very few calculations at physical pion mass

Bound States from NPLQCD

Assumpta Parreño

Binding energies of BB systems

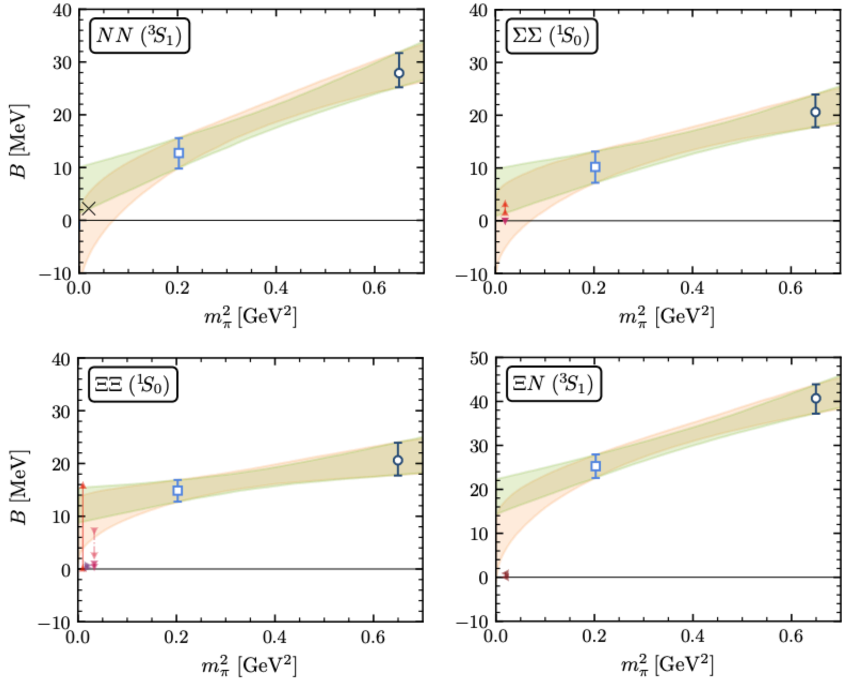
Quark mass extrapolations

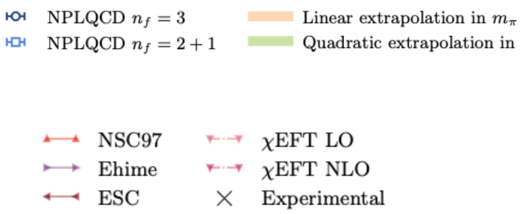
$SU(3)_f$

m_π ~ 800 MeV

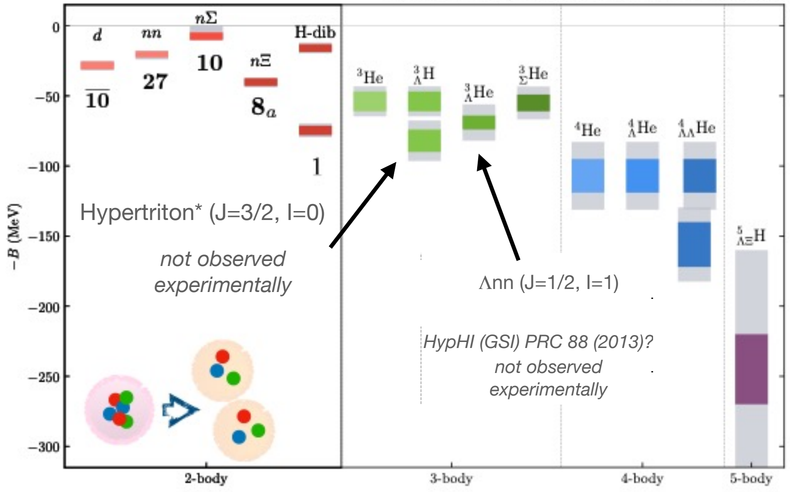
no e.m. interactions

Marc Illa et al (NPLQCD) PRD 103 (2021) 5, 05450





NPLQCD, Phys.Rev. D87 (2013) no.3, 034506;



Updated in PRD96 (2017) 114510

Not all hypernuclei states seen experimentally

Work in progress, on-going:
m_π ~ 450 MeV + larger volumes

$$B_{\text{lin}}(m_\pi) = B_{\text{lin}}^{(0)} + B_{\text{lin}}^{(1)} m_\pi$$

$$B_{\text{quad}}(m_\pi) = B_{\text{quad}}^{(0)} + B_{\text{quad}}^{(1)} m_\pi^2$$

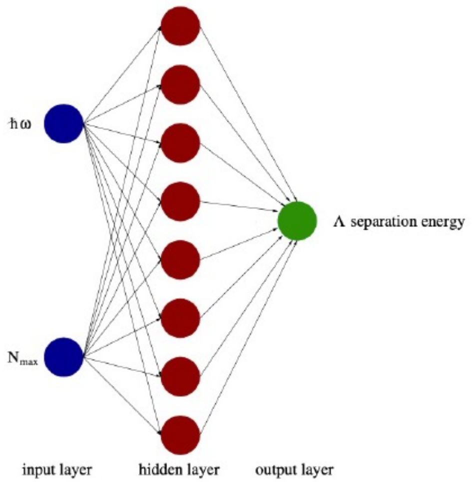
Hypernuclei Theory: Machine Learning

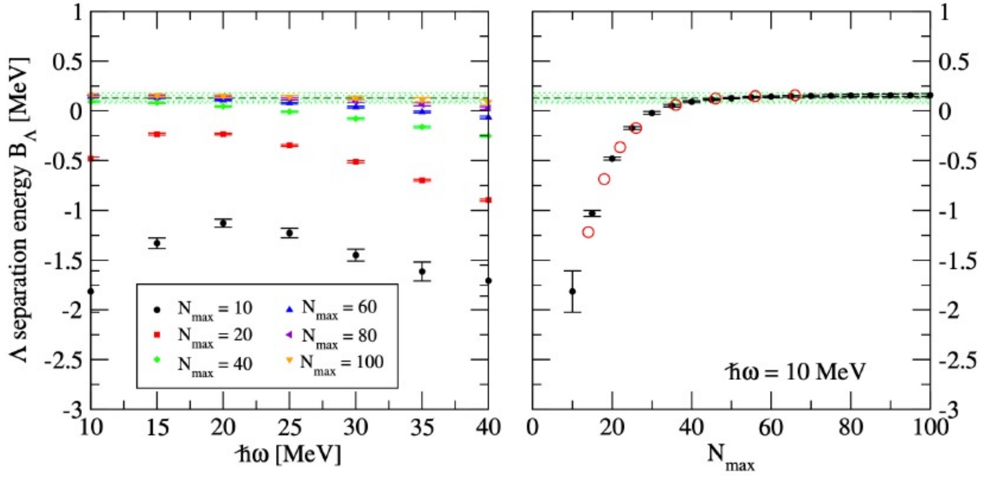
Isaac Vidaña

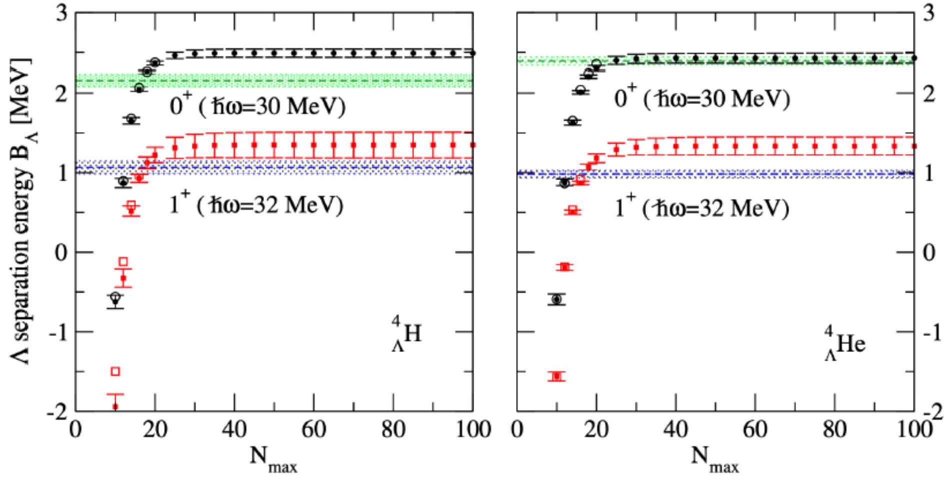
Use FF-ANN to extrapolate NCSM calculation
(Gazda et al., PRC97 (2018) 064315)
to large model space

Enlargement of input sample by cubic interpolation

Addition of Gaussian noise







Hypernuclei Theory: Machine Learning

Isaac Vidaña

Good agreement with other methods to extrapolate NCSN calculations

Hypernucleus	ANN Prediction	Extrapolated results of [1] & [2]	Experimental Vaue
${}^{3}_{\Lambda}$H (g.s.)	0.16 ± 0.02	0.158 [1]	0.13 ± 0.05
${}^{4}_{\Lambda}\mathrm{H}(0^{+})$	2.49 ± 0.05	2.48 ± 0.04 [2]	2.157 ± 0.077
${}^{4}_{\Lambda}\mathrm{H}(1^{+})$	1.35 ± 0.16	1.40 ± 0.28 [2]	1.067 ± 0.08
${}^{4}_{\Lambda}\mathrm{He}(0^{+})$	2.43 ± 0.06	2.45 ± 0.04 [2]	2.39 ± 0.05
${}^{4}_{\Lambda}\mathrm{He}(1^{+})$	1.33 ± 0.11	1.34 ± 0.28 [2]	0.984 ± 0.05

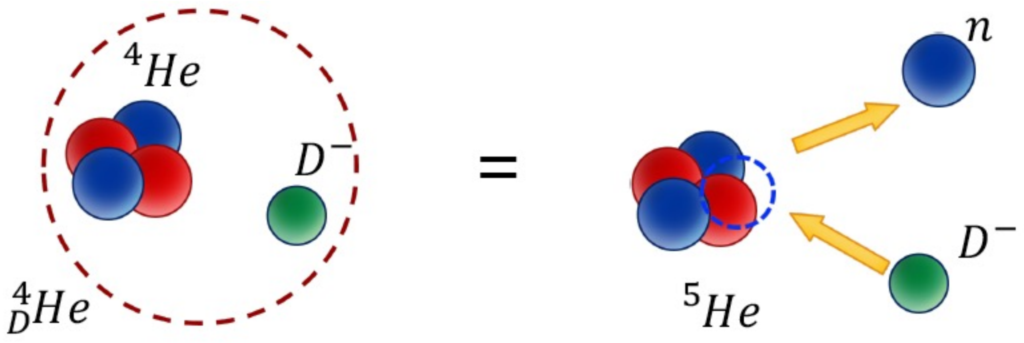
Htun *et al.*, FBS 62 (2021) 94 [1] & Wirth *et al.*, PRC 97 (2018) 064315 [2]

Stable Charmed Mesic Nucleus ${}^4_D$He

Zhangbu Xu

E.g.: D⁻ + ⁴He: stable against strong decay
B ≈ 16 MeV

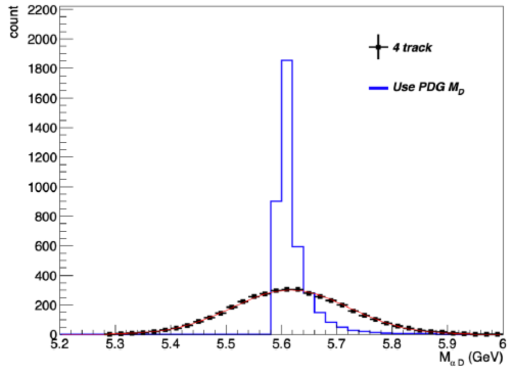
Expected yield in STAR Forward (half a year)
Kππ channel (incl. ε and BR): $n \sim 4 \times 10^3$
e⁻ channel (incl. ε and BR): $n \sim 1 \times 10^3$

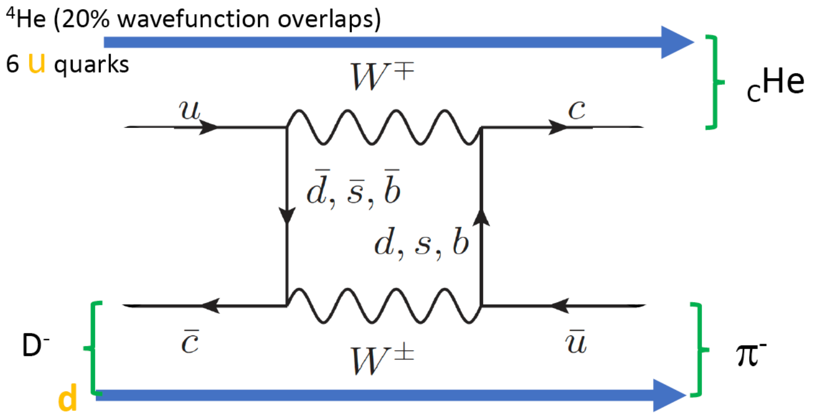


$$n = N^{STAR,F}_{{}^4_DHe} \times 10^5 \cdot 3600 \cdot 24 \cdot 365 \cdot 0.5 \sim 8\times10^4$$

Access at c-quark oscillations

Difficult to detect at RHIC,
Likely at LHC or EIC forward





Stable Charmed Mesic Nucleus $^4_D He$

Zhangbu Xu

J. Steinheimer, A. Botvina, M. Bleicher, PRC 95 (2017) 014911

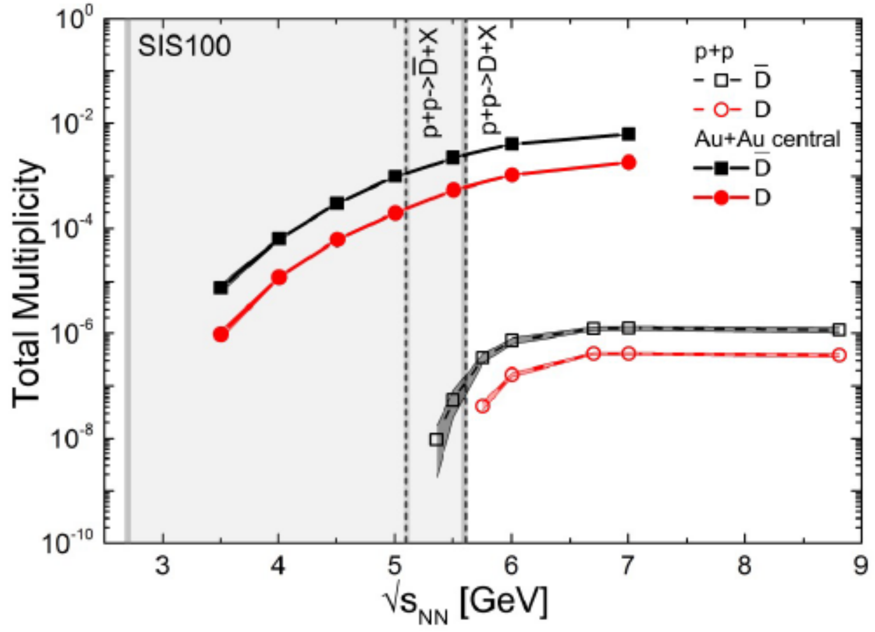


FIG. 5. [Color online] Production yields of D and $\overline{D}$ mesons in p+p and central Au+Au reactions as a function of the collision energy. The threshold energies of the corresponding channels in p+p reactions are again indicated as vertical lines. The grey area corresponds to the beam energy range expected for heavy ion collisions at the SIS100 accelerator.

FAIR vs RHIC/LHC:

He4: 10^5—10^6
Charm: 10^{-1}—10^{-2}
FXT luminosity: 10-100
Secondary Vertex and boost

14

~~Likely at LHC or EIC forward~~

Promising prospects for CBM@FAIR

To be explored!

Hypernuclei with CBM@FAIR

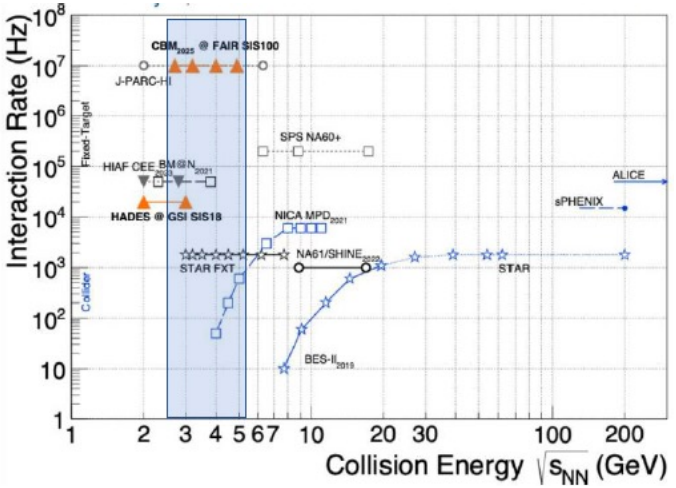
Iouri Vassiliev

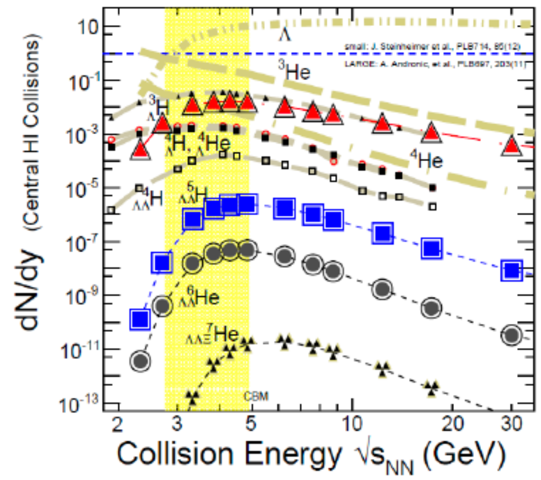
High interaction rates and
high production cross section
⟹ CBM will be hypernuclei factory

4D-Event building and reconstruction
Vertexing (MVD, STS)
Particle ID (TOF, TRD, STS)
KFParticleFinder

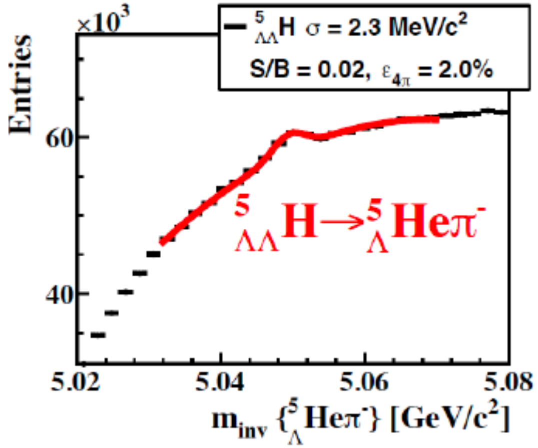
Multi-differential measurements

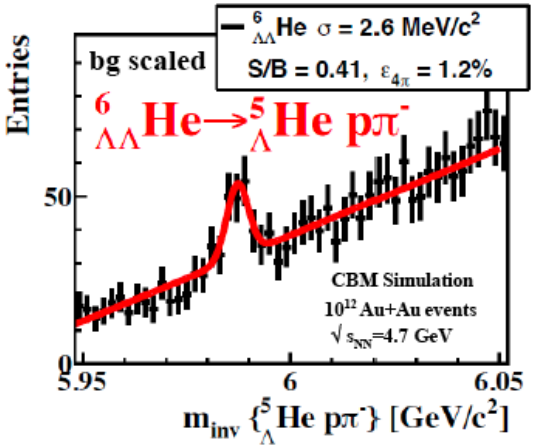
Expected collection rate: ~60 ${}^{6}_{\Lambda\Lambda}$He
in 1 week at **10MHz IR** (not day-1)





Nu Xu et al., arXiv:2209.05009





AuAu, 10 AGeV, 10^{12} central UrQMD events equivalent

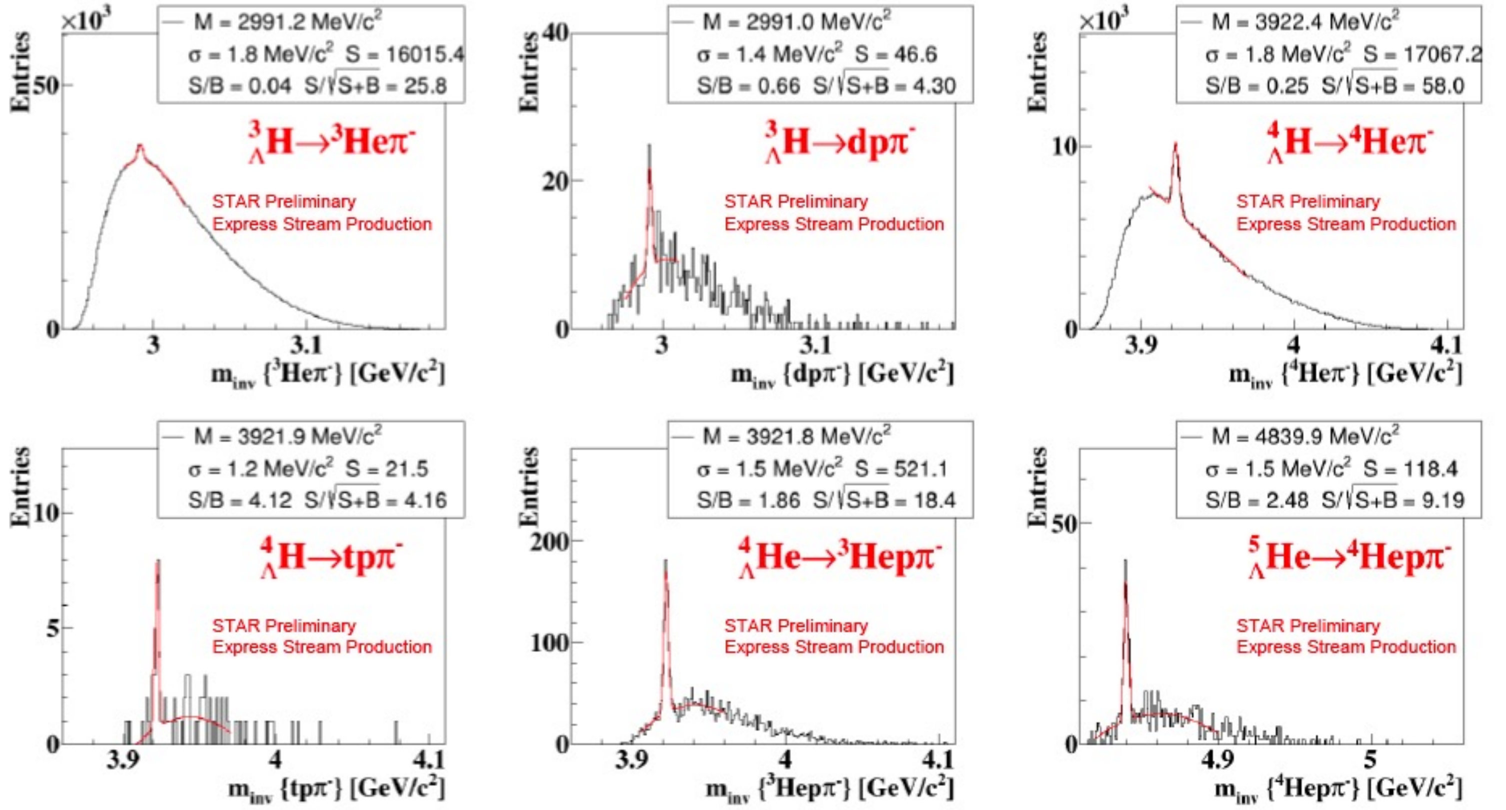
Hypernuclei with CBM@FAIR

Iouri Vassiliev

FAIR Phase-0 program:
mCBM@ SIS18
CBM-RICH in HADES
eTOF@STAR
CBM-FLES@STAR-HLT

Trigger on He ⟹ enhanced hypernuclei signal

Signal utilizing 437M AuAu HLT triggered events at $\sqrt{s}$ = 3.0 GeV Fixed Target, 2021 BES-II (x)production

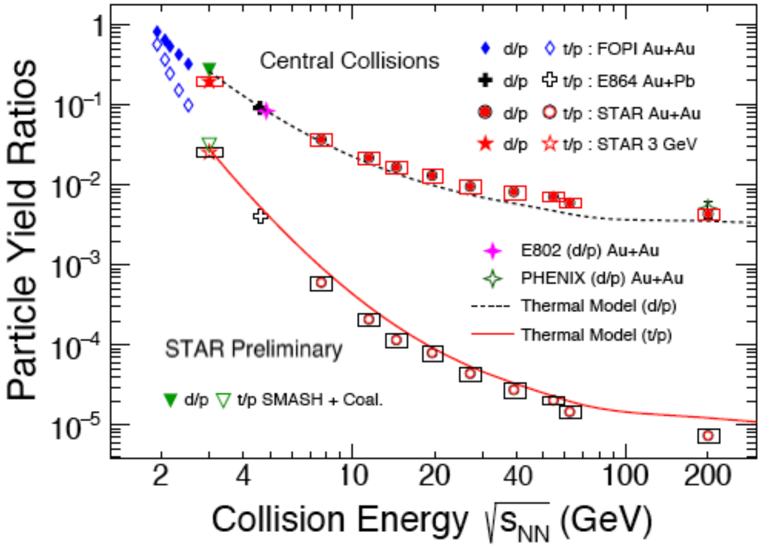


Light Nuclei and Hypernuclei with STAR@RHIC

Hui Liu

Energy dependence of d/p and t/p ratios

Qualitatively described by thermal model

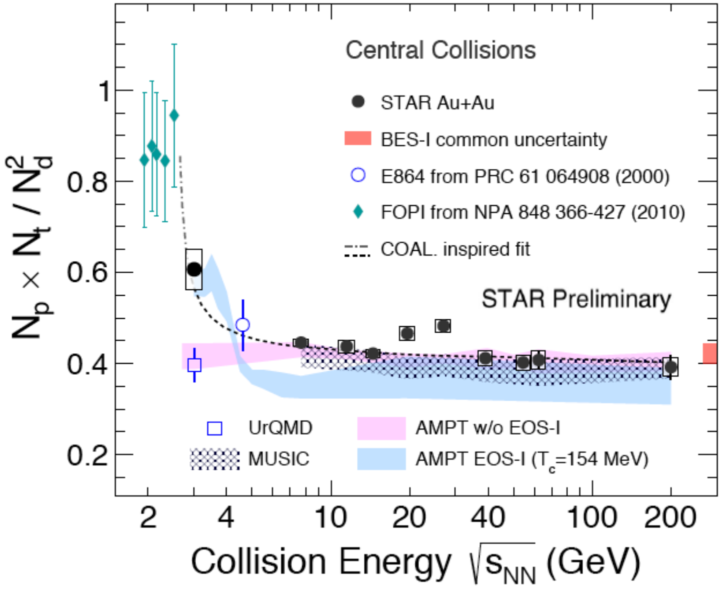


Ratio $N_p \times N_t / N^2_d$

Described by coalescence-inspired fit

$$\frac{N_p \times N_t}{N_d^2} \propto \left(\frac{R^2+\frac{2}{3}r_d^2}{R^2+\frac{1}{2}r_t^2}\right)^3, \quad R \propto (dN_{ch}/d\eta)^{1/3}$$

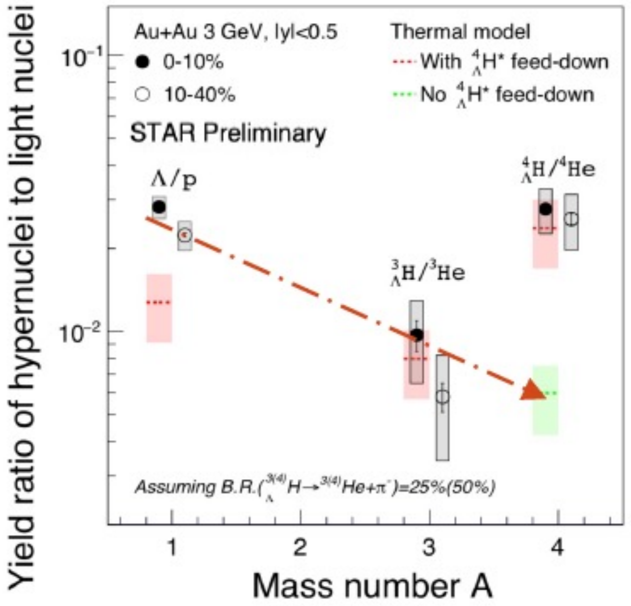
Evidence for non-monotonic behaviour (4.1σ significance)?



Light Nuclei and Hypernuclei with STAR@RHIC

Hui Liu

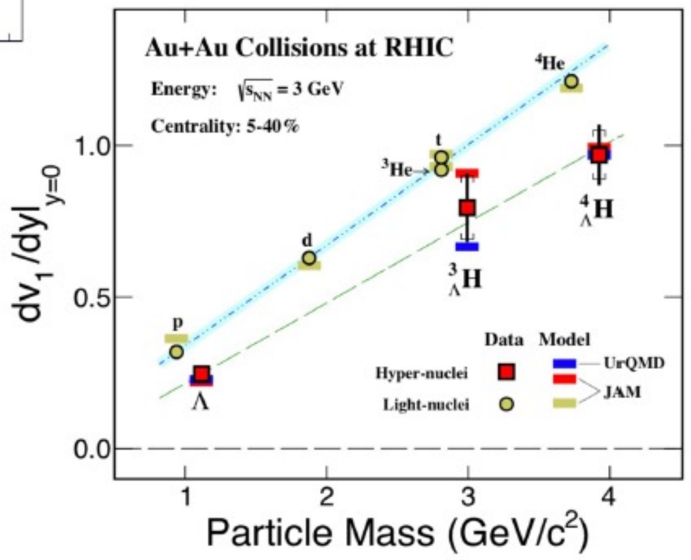
$^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$:
p_t and rapidity dependence



$$^{4}_{\Lambda}H^{*}(J^{+}=1)\rightarrow{}^{4}_{\Lambda}H(J^{+}=0)+\gamma$$

$^{4}_{\Lambda}H$/He-ratio above
exponential extrapolation
⟹ Feed-down from excited states (?)

First measurement of
directed flow of hypernuclei



Many Thanks!