Probing the Structure of Exotic Hadrons at the EIC

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NATIONAL LABORATORY

Center for Frontiers in Nuclear Science
Workshop series

EIC opportunities for Snowmass

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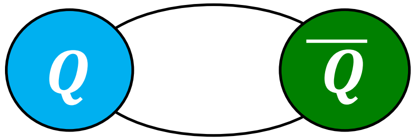
Online

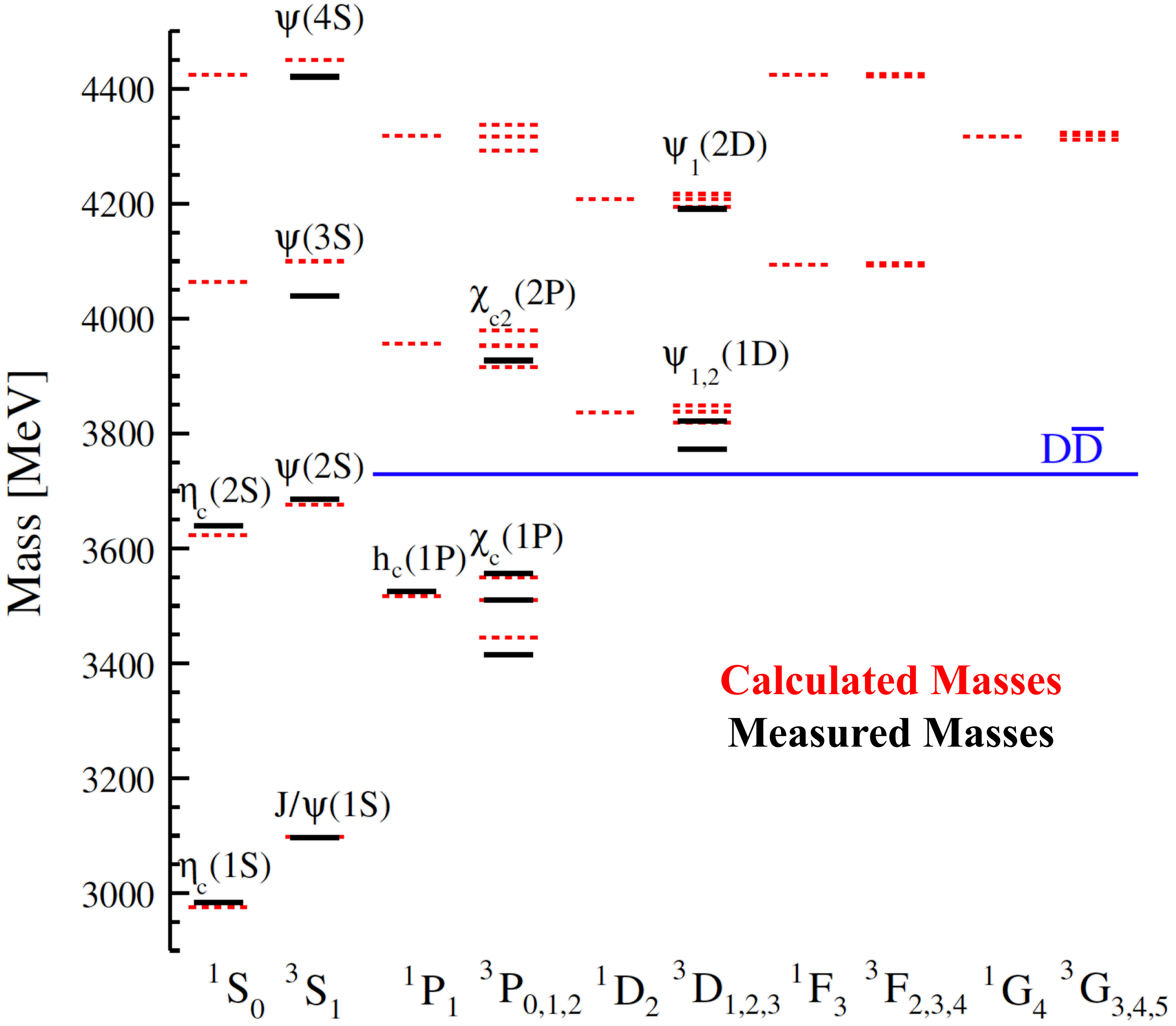
Heavy Quark Conventional Hadrons



Solve Schrodinger equation with the potential

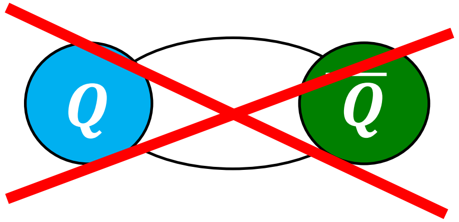
$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\tilde{\delta}_\sigma(r)\vec{S}_c\cdot\vec{S}_{\bar{c}}$$

Phys. Rev. D 72, 054026 (2005)



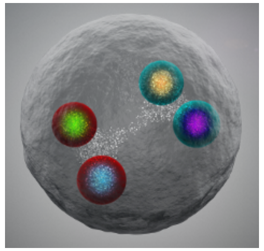
Rev. Mod. Phys. 90, 015003 (2018)

Heavy Quark Exotic Hadrons

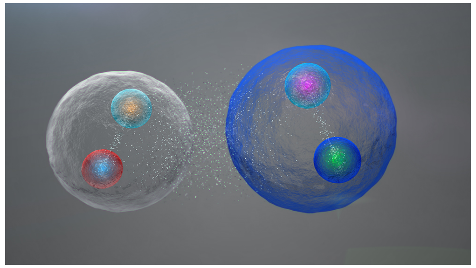


Dozens of charmonium-like states have been discovered that are not predicted by any $Q\overline{Q}$ potential model

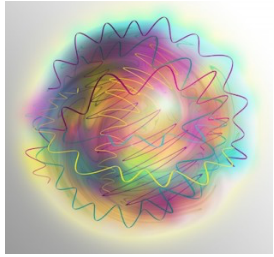
Many competing interpretations:



Tetraquark?



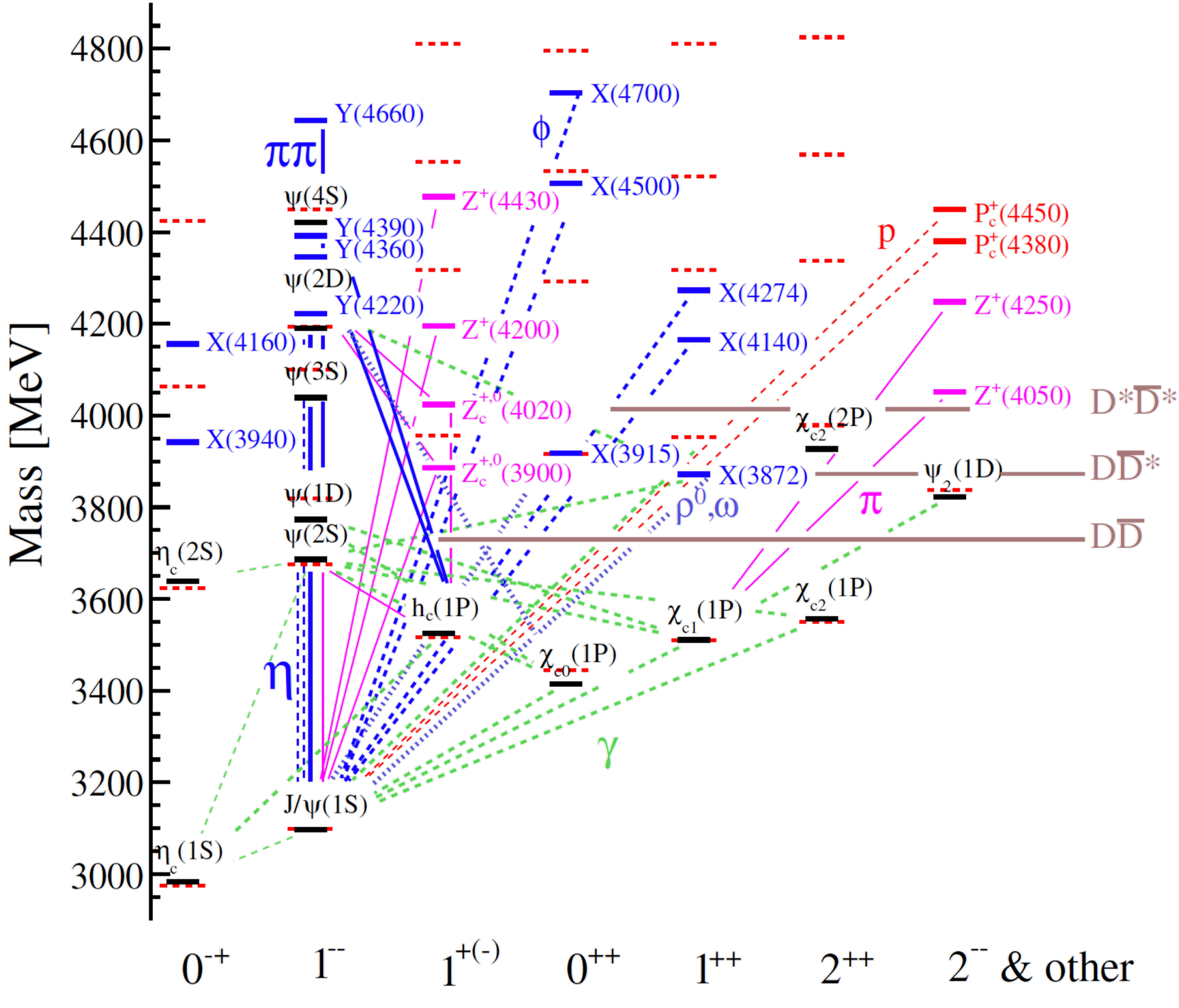
Hadronic molecule?



Glueball?

Mixtures of conventional + exotic states?

- Exact solutions to many-body Schrodinger are difficult
- Exploring large multi-quark structure on lattice is difficult
- **Study of exotics is primarily driven by experiment**

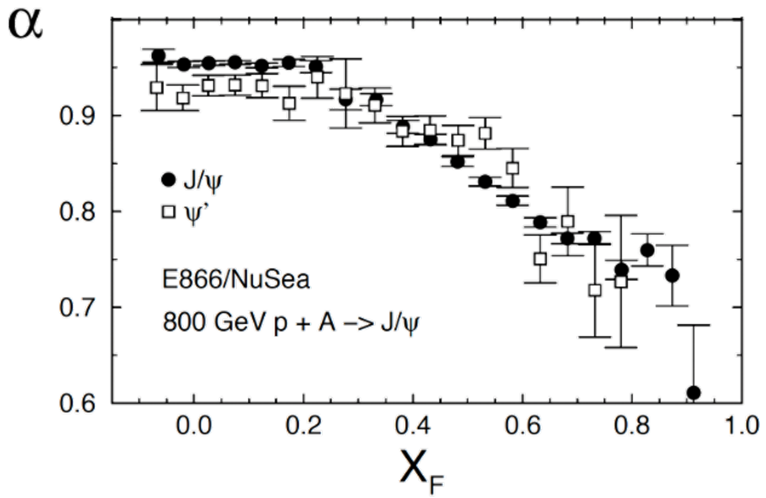


Rev. Mod. Phys. 90, 015003 (2018)

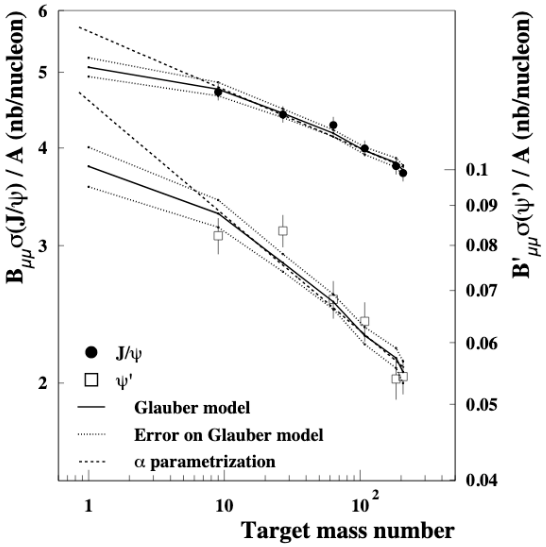
Filtering States with the Nucleus

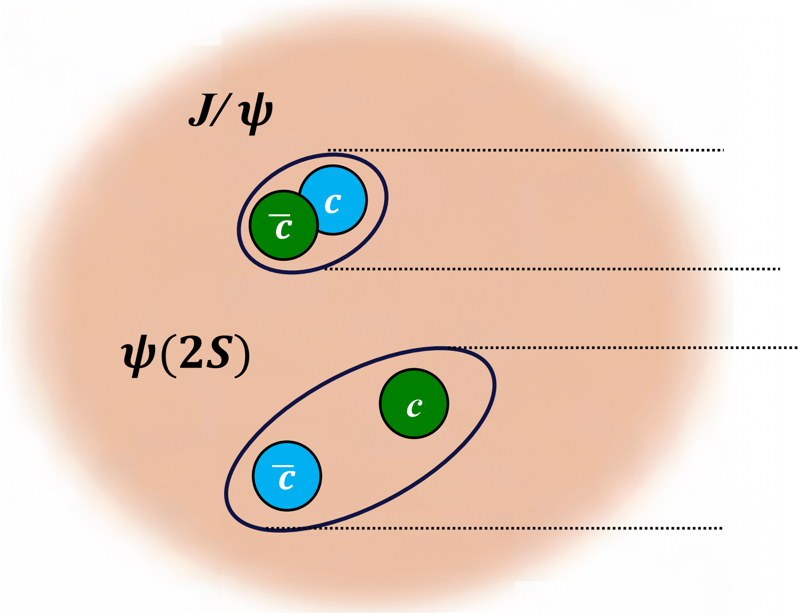
- At the EIC, hadronization inside the nucleus becomes an important effect (Vitev, 1912. 10965)
- Quarkonia is subject to breakup as it crosses the nucleus – suppression due to disruption of the $Q\bar{Q}$ pair

E866, PRL 84 (2000) 3256-3260



NA50, EPJC 48 329 (2006)

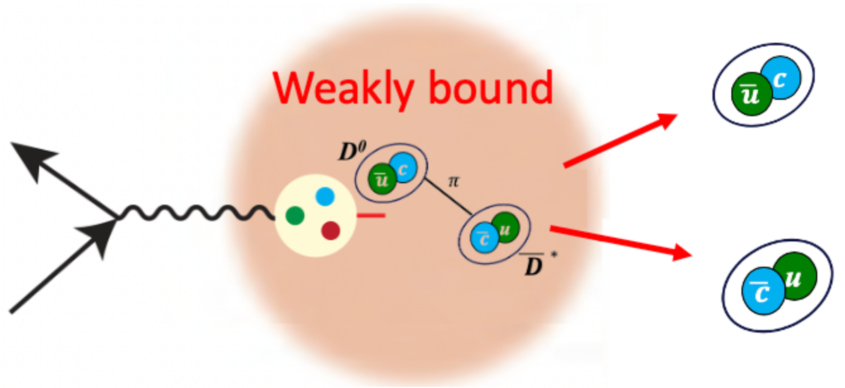




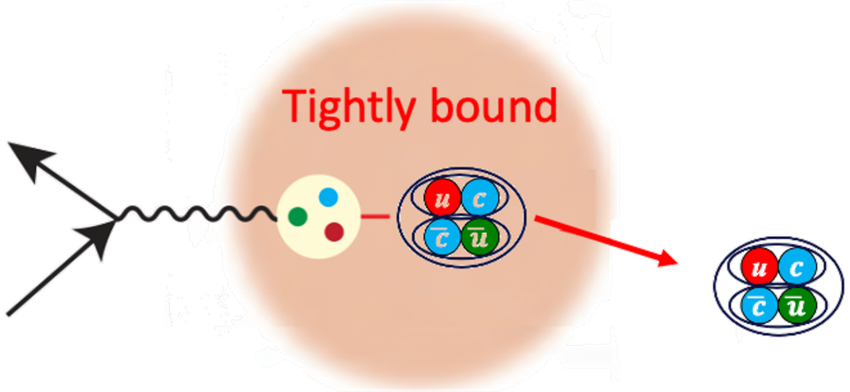
- Larger (weakly bound) states sample a larger volume of the nucleus while passing through – larger absorption cross section   Arleo, Gossiaux, Gousset, Aichelin PRC 61 (2000) 054906
- Explains trends observed in fixed target data at FNAL, SPS
- As expected, fails at RHIC (hadronization occurs outside nucleus)   PHENIX PRL 111 202301 (2013)

Filtering States with the Nucleus – X(3872)

Apply the same idea to exotic state X(3872):



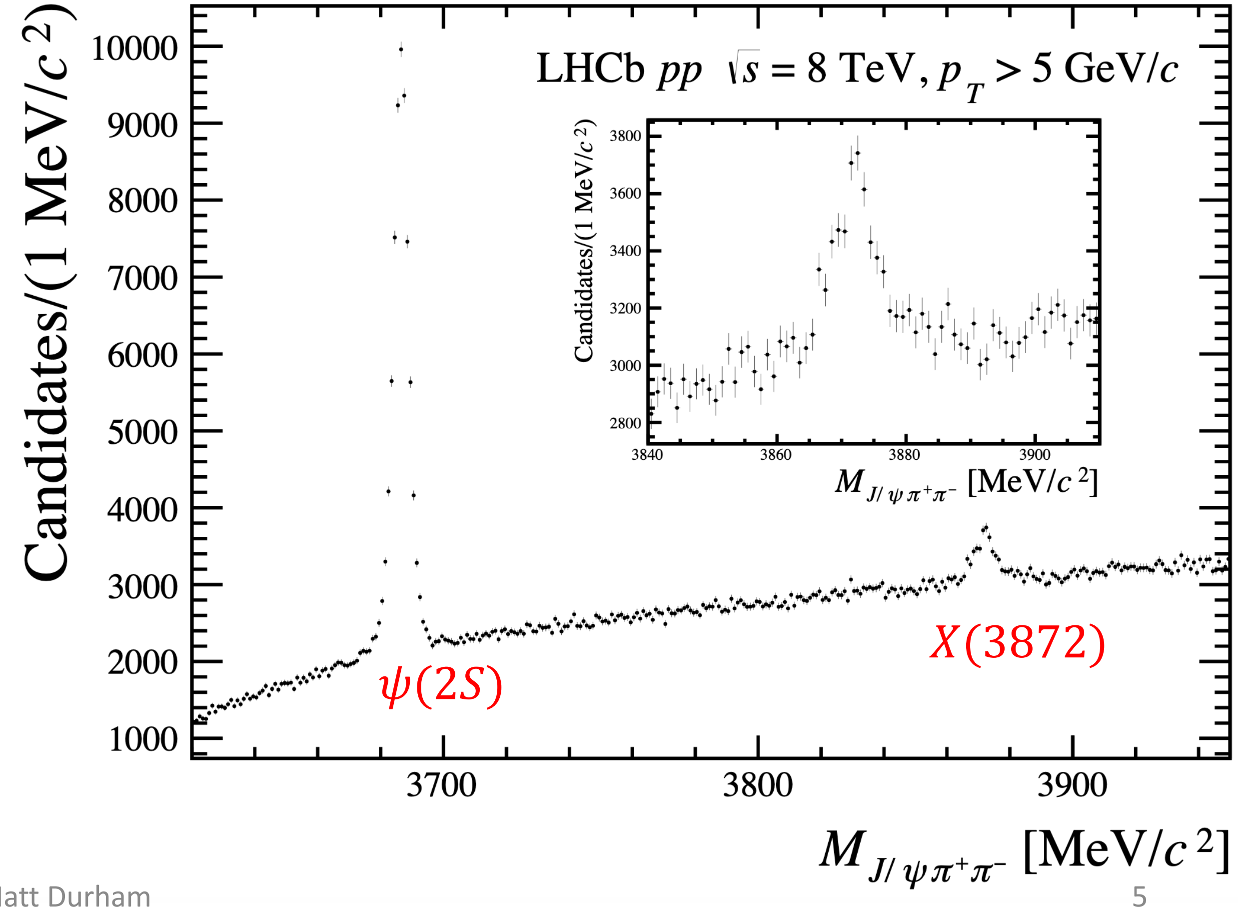
Weakly bound hadronic molecule has large radius, samples large volume of nucleus



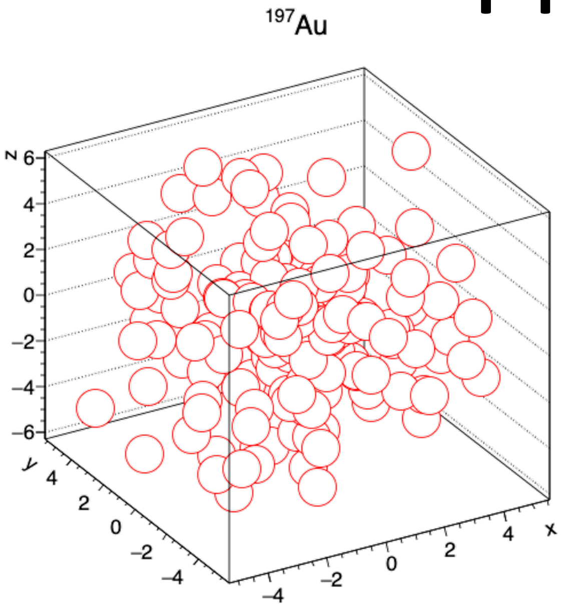
Tightly bound compact tetraquark has small radius, could more easily escape nucleus unscathed

The well-known conventional $\psi(2S)$ and exotic X(3872) are both accessible through $J/\psi\pi^+\pi^-$ decays:

LHCb 2009.06619, accepted in PRL



Propagation through Nuclei



- In Monte Carlo simulation, populate a Glauber nucleus, using parameters from PHOBOS model: arXiv:1408.2549
- Randomly select starting point for $Q\bar{Q}$ pair
- Propagate $Q\bar{Q}$ along z axis

- Following model of Arleo *et al.* in Phys Rev C, 61 054906 (2000), expand $Q\bar{Q}$ radius as a function of time:

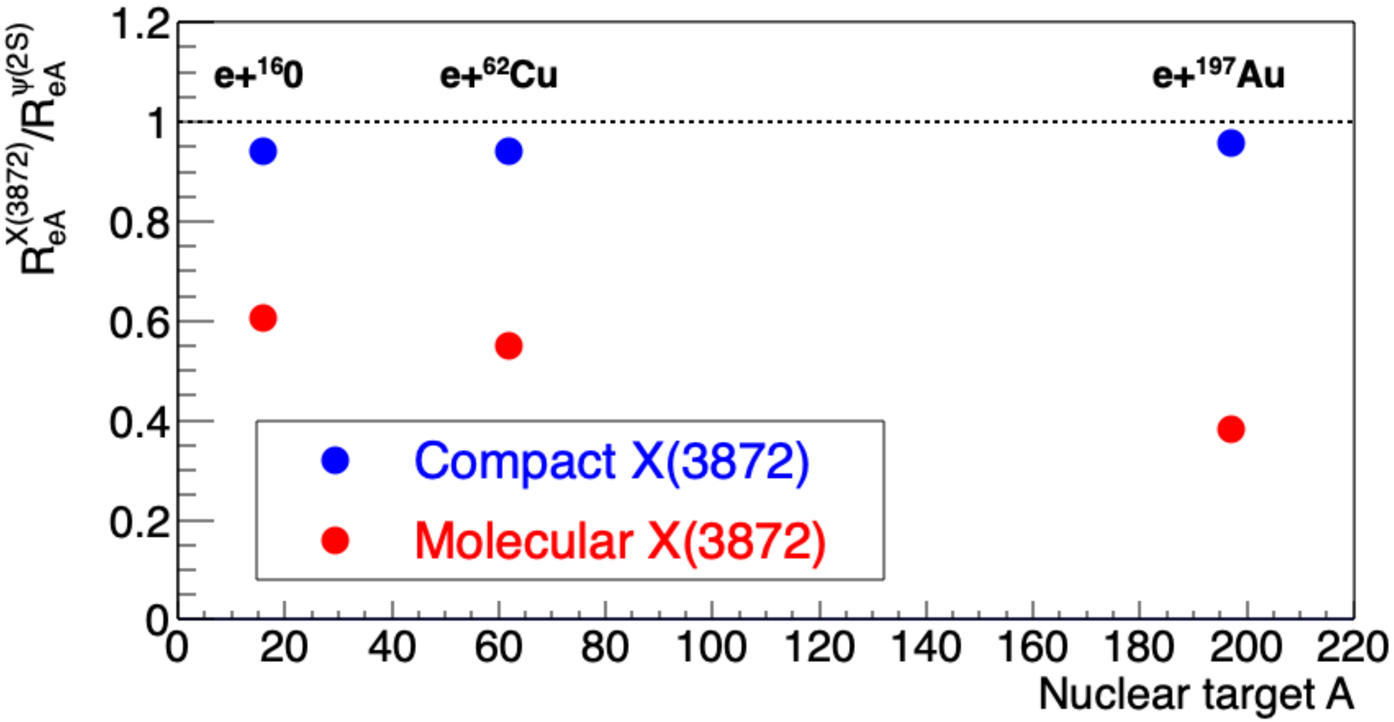
$$r_{c\bar{c}}(\tau) = \begin{cases} r_0 + v_{c\bar{c}}\ \tau & \text{if } r_{c\bar{c}}(\tau) \leqslant r_i \\ r_i & \text{otherwise} \end{cases}$$

- Calculate radius-dependent cross section: $\sigma_{(c\bar{c})_1 N} = \sigma_{\psi N}(s) \cdot (r_{c\bar{c}}/r_\psi)^2$

- If the state comes within a distance of $\sqrt{\sigma_{c\bar{c}}/\pi}$ to a nucleon, consider it disrupted.

- Three cases: $\psi(2S)$ with radius 0.87 fm, compact X(3872) with radius 1 fm, molecular X(3872) with radius 7 fm

Relative modification of X(3872)/ $\psi(2S)$ at EIC



$$\frac{R_{eA}^{X(3872)}}{R_{eA}^{\psi(2S)}} = \frac{\sigma_{eA}^{X}}{\sigma_{eA}^{\psi}} \bigg/ \frac{\sigma_{ep}^{X}}{\sigma_{ep}^{\psi}}$$

- **Little difference in suppression between model of compact X(3872) and $\psi(2S)$, as expected.**
- **Large difference between model of molecular X(3872) and $\psi(2S)$.**

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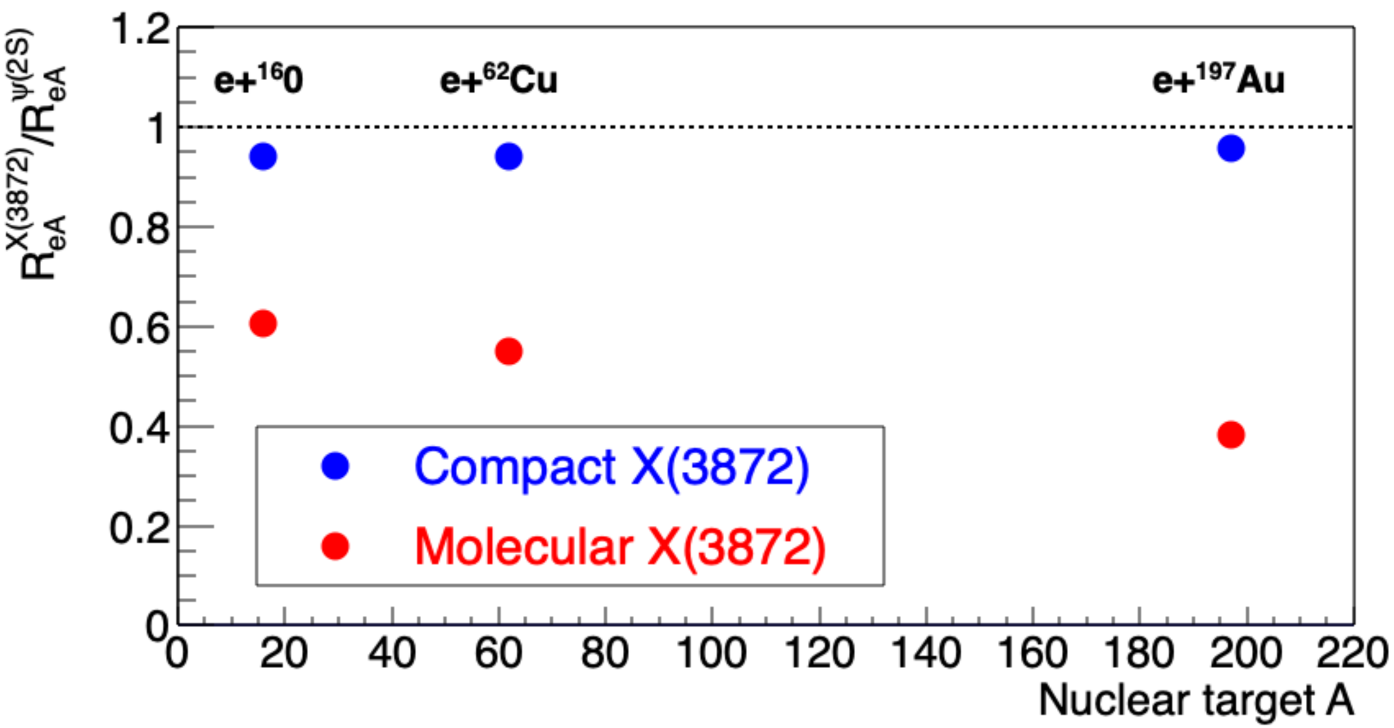

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- What uncertainties do we expect on this data from EIC?
- Need to know X(3872) production rate in eA collisions at ~100 GeV
- Current data is from:
  - B factories (via decays, not so relevant for prompt production)
  - Tevatron and LHC (~TeV to ~10 TeV)

Constraining EIC projections: LHCb SMOG

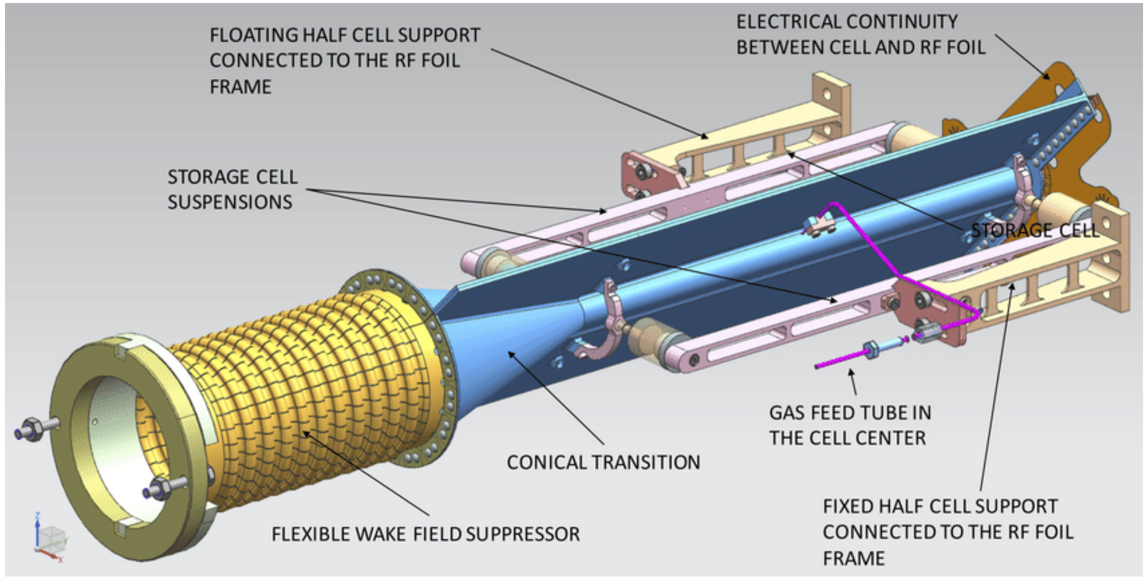
- Fixed target collisions at LHCb enabled by injecting gas into storage cell in front of spectrometer
  - p+gas, Pb+gas, O+gas (?)

- Operates in kinematic range similar to EIC:
  $\sqrt{s} \approx 70$ to 115 GeV

- Very large heavy flavor samples expected:

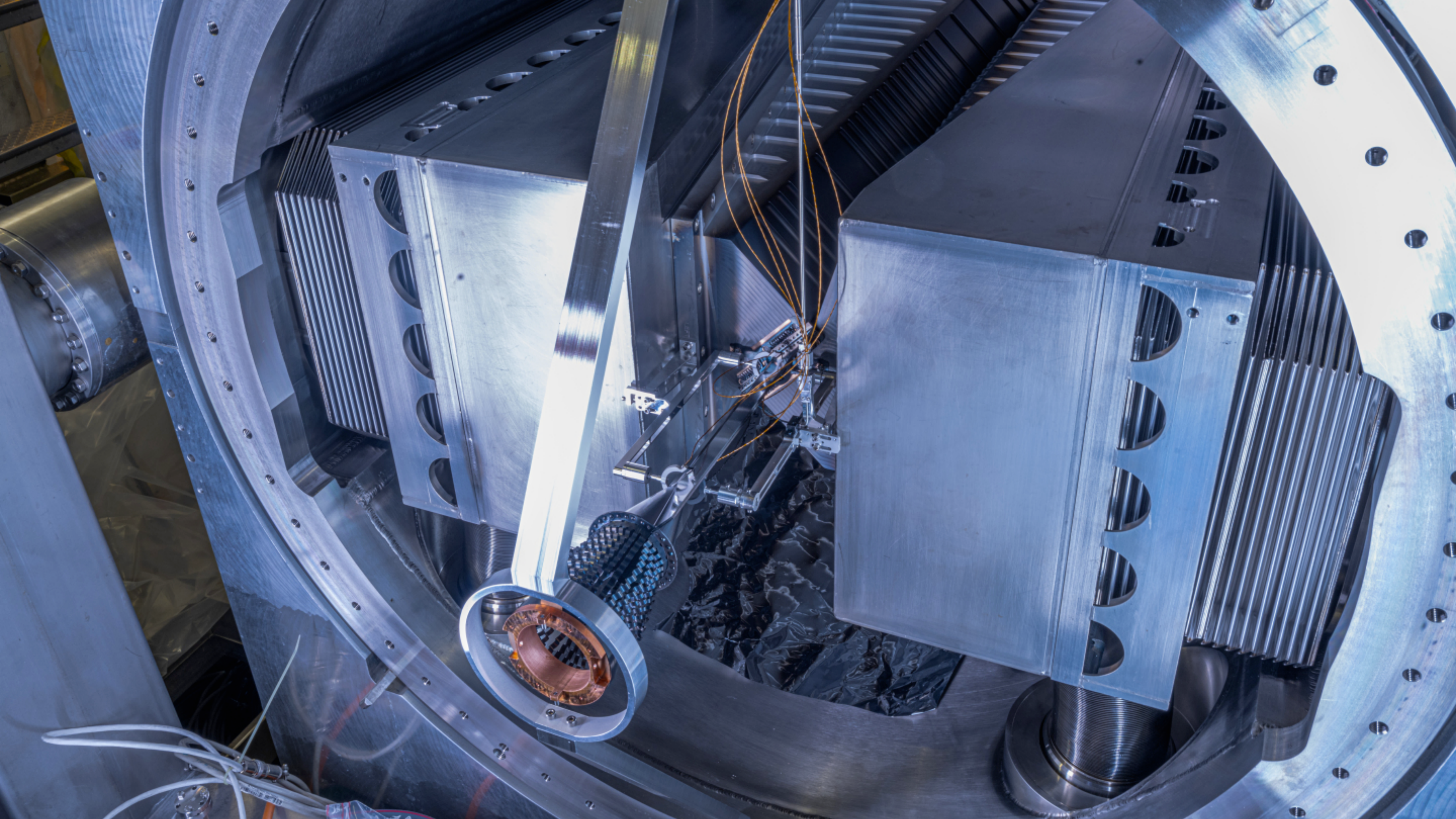
Example SMOG2 pAr at 115 GeV for one year

Int. Lumi.		80 pb^{-1}
Sys.error of J/Ψ xsection		~3%
J/Ψ	yield	28 M
D^0	yield	280 M
Λ_c	yield	2.8 M
Ψ'	yield	280 k
$\Upsilon(1S)$	yield	24 k
$DY\ \mu^+\mu^-$	yield	24 k



https://cds.cern.ch/record/2673690/files/LHCB-TDR-020.pdf

Unique access to heavy quark exotic states in unexplored regime near EIC energies

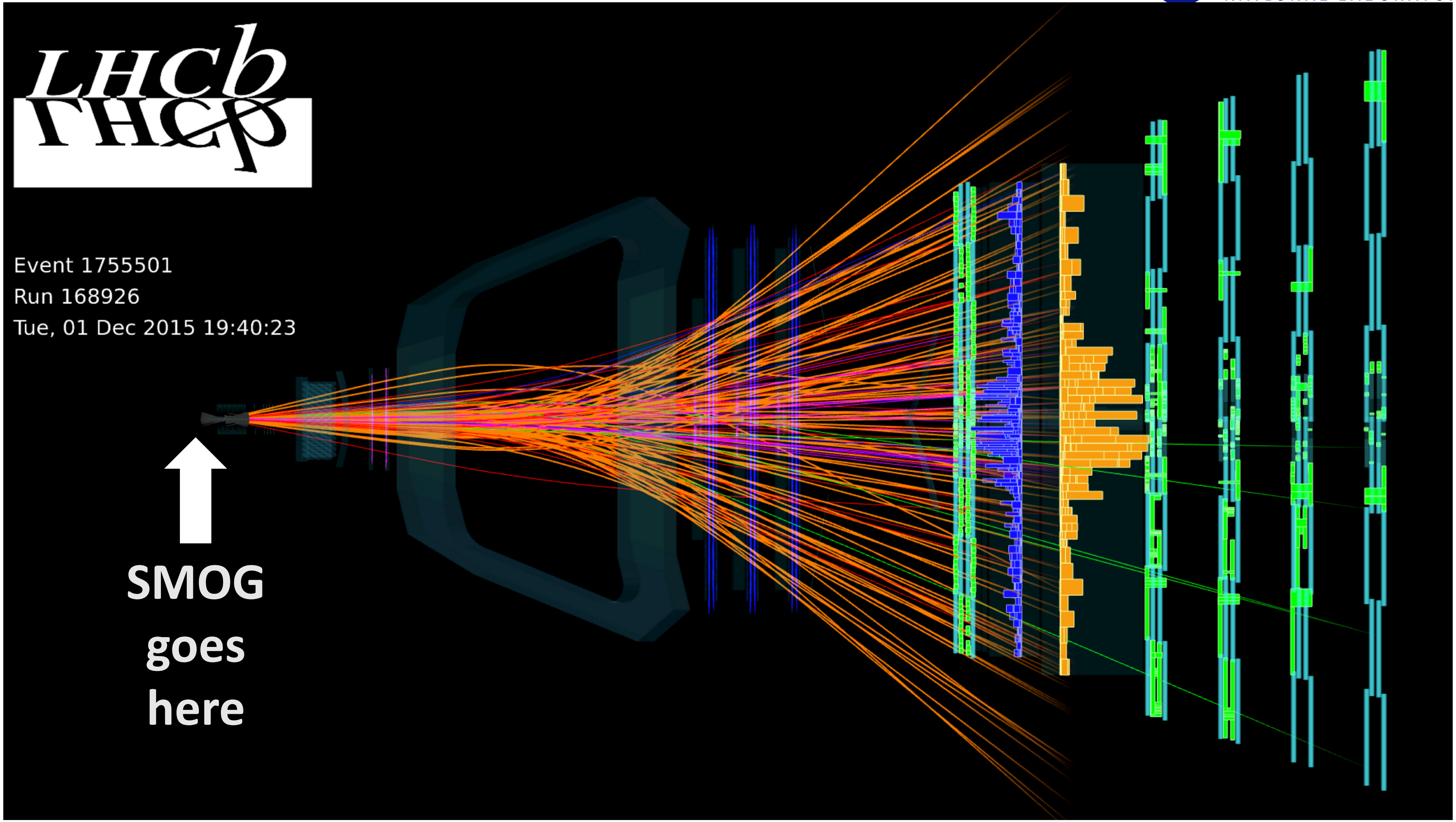


Summary

- The EIC has the potential to provide decisive discrimination between exotic structure models.
- Projections can be constrained by LHCb fixed-target data to come in near future.
- X(3872) is only one example, technique can be applied to other exotics.
  - Matt’s opinion: it is likely many more exotics will be discovered before EIC turns on

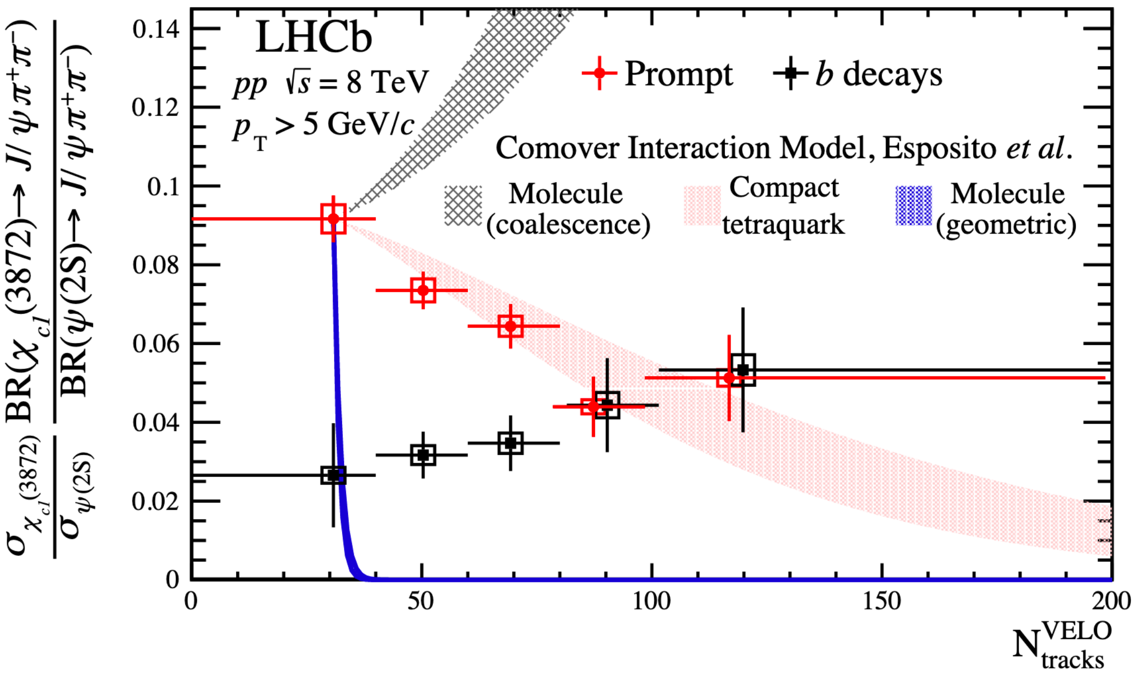
This work is supported by LANL LDRD

BACKUP

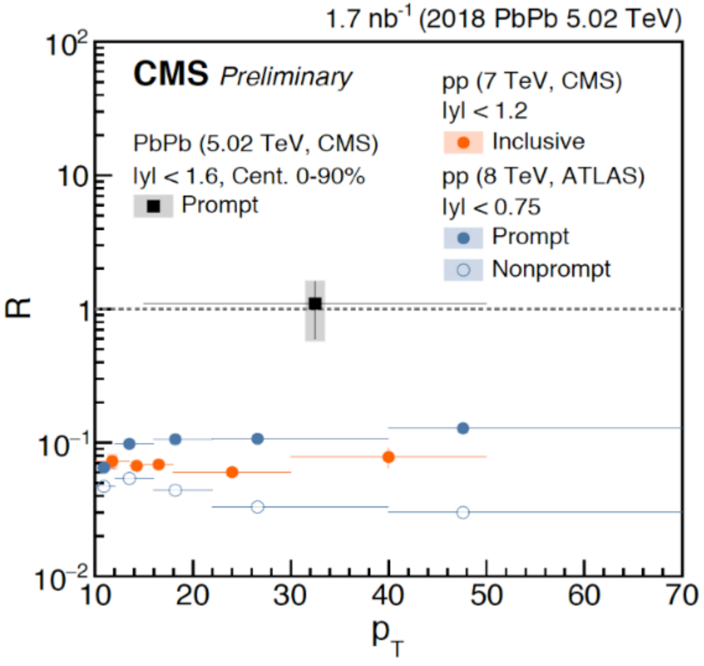

LHCb
Event 1755501
Run 168926
Tue, 01 Dec 2015 19:40:23
SMOG
goes
here

Interactions of exotics with QCD medium

LHCb 2009.06619, accepted in PRL



CMS PAS HIN-19-005



$$R = 1.10 \pm 0.51 \text{ (stat.) } \pm 0.53 \text{ (syst.)}$$