Multiplicity dependent production of $\chi_{c1}(3872)$

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The mysterious $\chi_{c1}(3872)$

The $\chi_{c1}(3872)$ exotic hadron was first observed in 2003 by Belle in decays of $B \to J/\psi\pi^+\pi^-$.
Belle, PRL 91 (2003) 262001

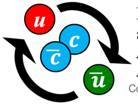
Quantum numbers of $\chi_{c1}(3872)$ were determined as $J^{PC} = 1^{++}$.

"This result rules out the explanation of the $X(3872)$ meson as a conventional $\eta_{c2}(1^1D_2)$ state. Among the remaining possibilities are the $\chi_{c1}(2^3P_1)$ charmonium, disfavored by the value of the $X(3872)$ mass, and unconventional explanations such as a $D^{*0}\bar{D}^0$ molecule, tetraquark state or a charmonium-molecule mix."

LHCb, PRL 110 (2013) 222001

Compact tetraquark/pentaquark

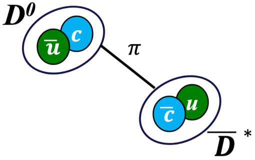
Diquark-diquark
PRD 71, 014028 (2005)
PLB 662 424 (2008)

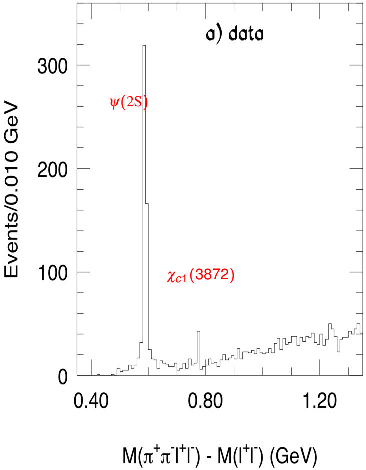


Hadrocharmonium/ adjoint charmonium
PLB 666 344 (2008)
PLB 671 82 (2009)

Courtesy of Matt Durham

Hadronic Molecules
PLB 590 209 (2004)
PRD 77 014029 (2008)
PRD 100 0115029(R) (2019)

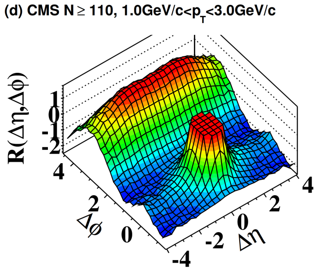


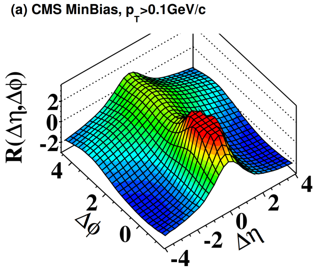


High multiplicity *pp* collisions

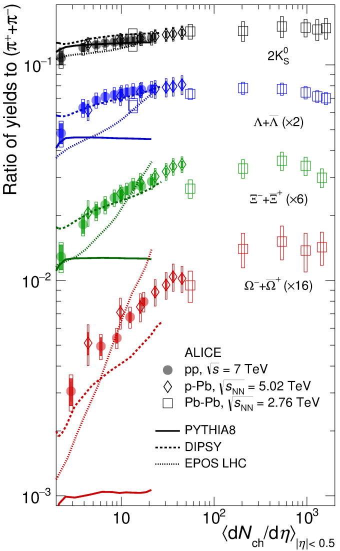
Phenomena known from nuclear collisions observed in high multiplicity pp collisions over the past years.

CMS, JHEP 09 (2010) 091





ALICE, Nat. Phys. 13 (2017) 535



Proton-proton collisions provide testing ground for examining nuclear effects observed in pA collisions.

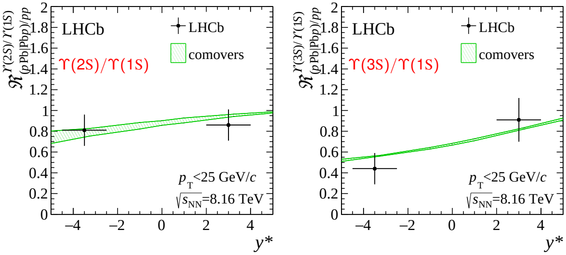
Conventional charmonia in nuclear medium

Production of quarkonia is modified in nuclear collisions compared to that in pp.

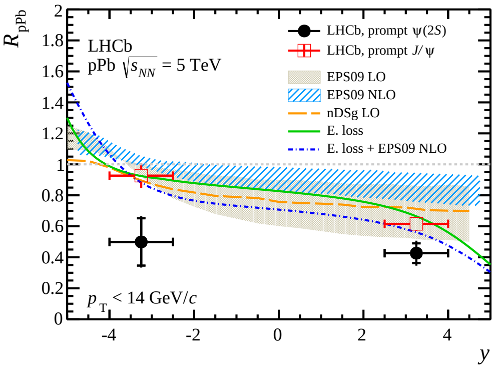
$$R_{p\mathrm{Pb}} = \frac{1}{A}\frac{\sigma_{p\mathrm{Pb}}(\Delta p_{\mathrm{T}}, \Delta y^{*})}{\sigma_{pp}(\Delta p_{\mathrm{T}}, \Delta y^{*})}$$

Higher excited states are more suppressed, as they are increasingly weakly bound.

LHCb, JHEP 11 (2018) 194



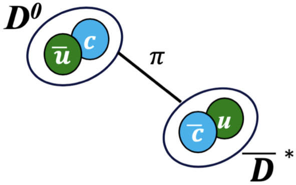
LHCb, JHEP 1603 (2016) 133



Such difference in suppression of states with the same quark content can be explained with final-state effects.

Probing the $\chi_{c1}(3872)$ structure via interactions with the underlying event

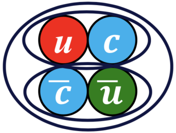
The nature of $\chi_{c1}(3872)$ can be scrutinised by studying its multiplicity dependent relative suppression compared to a conventional charmonium state such as $\psi(2S)$.



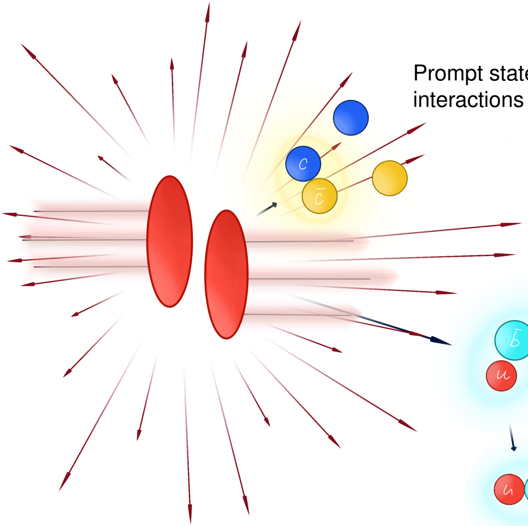
Hadronic molecule $\Rightarrow$ very weakly bound with a large radius $\sim$ 10 fm.

$$M_{\chi_{c1}(3872)} - M_{\bar{D}} - M_{D^*} = 0.1 \pm 0.27 \text{ MeV}$$

Compact tetraquark $\Rightarrow$ tightly bound with small radius $\sim$ 1 fm.

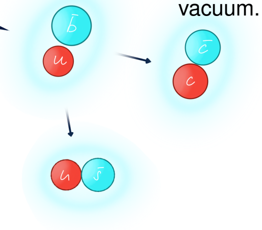


Probing the $\chi_{c1}(3872)$ structure via interactions with the UE (cont'd)



Prompt states produced at the interaction vertex may dissociate via interactions with the comoving matter.

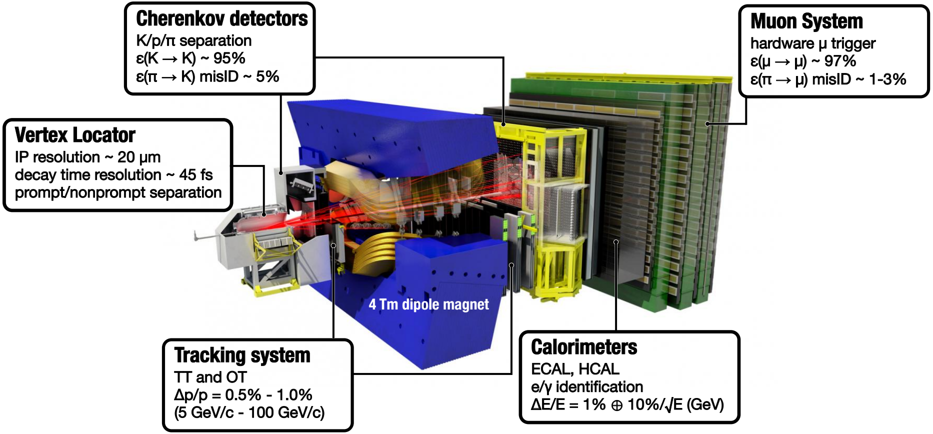
The delayed states, from *b*-decays, will decay in vacuum.



LHCb detector

LHCb, JINST 3 (2008) S08005

LHCb is a single arm spectrometer fully instrumented in $2 < \eta < 5$, designed for studies of heavy quarks.
LHCb has excellent vertexing, tracking, and PID capability, and can reconstructs heavy hadrons down to $p_{\mathrm{T}} = 0$.



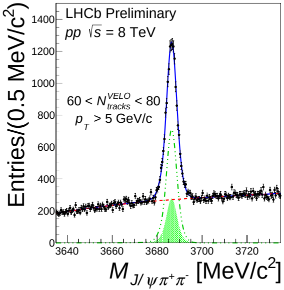
$\chi_{c1}(3872)/\psi(2S)$ cross-section analysis

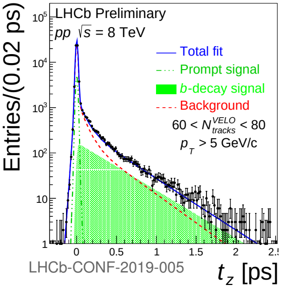
Candidates reconstructed from $J/\psi\pi^+\pi^-$ at $p_T > 5$ GeV/c and within $2 < \eta < 4.5$.

LHCb-CONF-2019-005

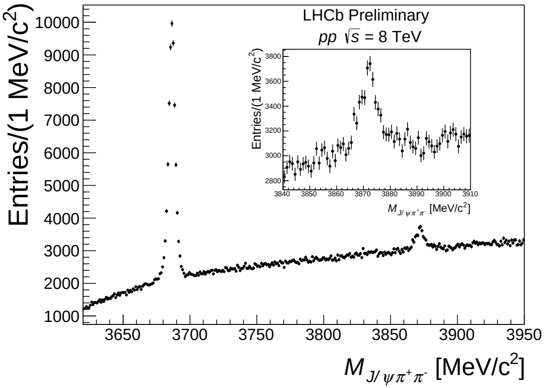
Prompt and delayed component are extracted via simultaneous fits to the invariant mass and pseudo-propertime

$$t_z = \frac{z_{decay} - z_{PV}}{p_z} M$$





LHCb-CONF-2019-005



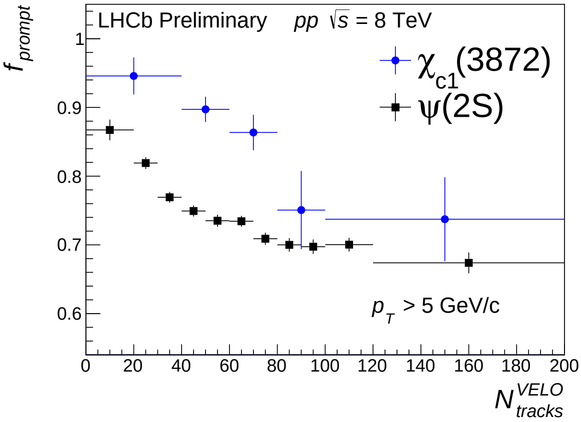
Fraction of prompt of $\chi_{c1}(3872)$ and $\psi(2S)$

$$f_{prompt} = \frac{N_{prompt}}{N_{prompt} + N_{delayed}}$$

LHCb-CONF-2019-005

Prompt fraction of both states decreases with multiplicity. This may be explained with combination of effects.

- The delayed production increases with increased *b*-production in harder events.
- The prompt production decreases with raising probability of dissociation in events with higher occupancy while the delayed states, decaying in vacuum, remain unaffected.



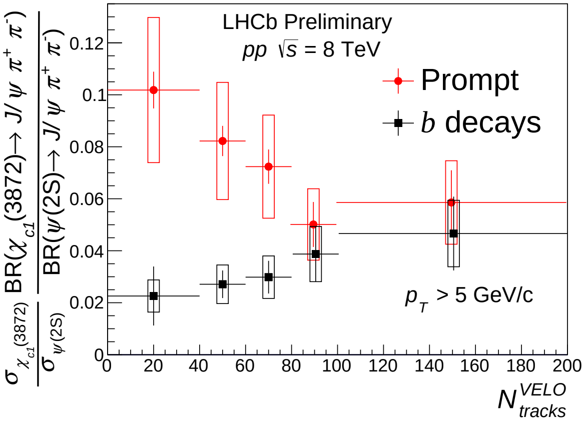
Cross-section ratio $\sigma(\chi_{c1}(3872))/\sigma(\psi(2S))$

$$\frac{\sigma_{\chi_{c1}(3872)}}{\sigma_{\psi(2S)}}\frac{\mathscr{B}[\chi_{c1}(3872)\to J/\psi\pi^+\pi^-]}{\mathscr{B}[\psi(2S)\to J/\psi\pi^+\pi^-]}=\frac{N_{\chi_{c1}(3872)}\, f^{\chi_{c1}(3872)}_{prompt}}{N_{\psi(2S)}\, f^{\psi(2S)}_{prompt}}\frac{\varepsilon_{\psi(2S)}}{\varepsilon_{\chi_{c1}(3872)}}$$

LHCb-CONF-2019-005

- The ratio of promptly produced $\chi_{c1}(3872)/\psi(2S)$ decreases with multiplicity - increased suppression of $\chi_{c1}(3872)$ compared to $\psi(2S)$.
- The non-prompt emerge far away from the interaction region and are unaffected by the underlying event. The ratio is constant in multiplicity.

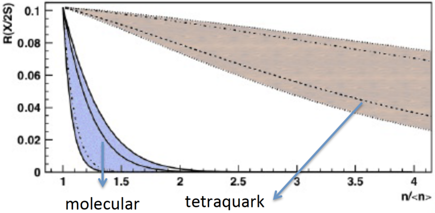
Consistent with the idea of weakly-bound $\chi_{c1}(3872)$ being more dissociated than a more tightly bound $\psi(2S)$.



Sneek peek on theory explanations

The nature of the X(3872): pp collisions WORK IN PROGRESS

- In order to measure the effects of the comovers with increasing multiplicity, we calculate the rate X(3872)/ψ(2S) vs n/<n> being <n> the mean pp multiplicity



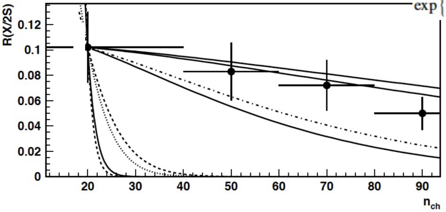
Our results are normalized to the experimental value obtained for the first bin, i.e. 0.1

(no interaction for n=<n>)

$$\tau \frac{\mathrm{d}\rho^{Q}}{\mathrm{d}\tau}(b,s,y) = -\sigma^{co-Q}\,\rho^{co}(b,s,y)\,\rho^{Q}(b,s,y)$$

$$\exp\left\{-\sigma^{co-Q}\rho^{co}(b,s,y)\,\ln\left(\rho^{co}(b,s,y)/\rho_{pp}(y)\right)\right\}$$

n   n/<n>



pp collisions at 8 TeV and forward rapidity

LHCb data QM2019

E. G. Ferreiro USC   Comovers   GSI 16/20 Dec 2019

EMMI Meeting on the Suppression and (re)generation of quarkonium in heavy-ion collisions at the LHC

Elena Ferreiro's talk at https://indico.gsi.de/event/9314/overview.

Dissocitation with comovers would dissociate the molecule immediately.

Scenario with a tetraquark shows better qualitative correspondence to the behaviour seen in data.

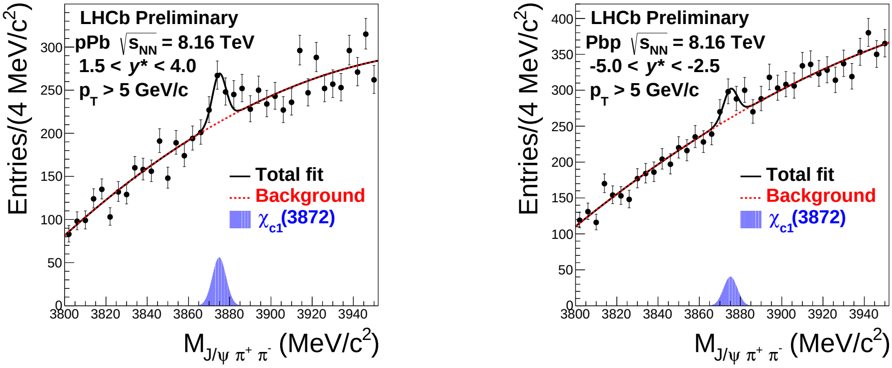
Calculation based on number of charged particles, while the event activity in data is uncorrected for detector effects.

$\chi_{c1}(3872)$ production in pPb

Ongoing analysis of $\chi_{c1}(3872)$ in pPb data at $\sqrt{s_{NN}} = 8.16$ TeV.

Measurement in pPb will add two additional points on the event activity axis as well as enable to study suppression of $\chi_{c1}(3872)$ as a function of rapidity.

LHCb-FIGURE-2019-019



Summary

Proton-proton collisions provide new insight into nuclear effects observed in pA and AA collisions.

Modification of production of conventional charmonia due to nuclear effects is a typical probe of said effects. On the other hand, studying the nuclear modification of exotic hadrons such as $\chi_{c1}(3872)$ can unveil more about its character.

Measurement of relative suppression of $\chi_{c1}(3872)/\psi(2S)$ as a function of multiplicity in pp collisions at $\sqrt{s} = 7$ TeV showed that:

- Ratio of prompt $\chi_{c1}(3872)/\psi(2S)$ shows a decrease with increasing multiplicity.
- Ratio of delayed $\chi_{c1}(3872)/\psi(2S)$ shows no significant evolution with multiplicity.

The $\chi_{c1}(3872)$ seems to show stronger suppression than conventional $\psi(2S)$, which indicates its weaker bond.

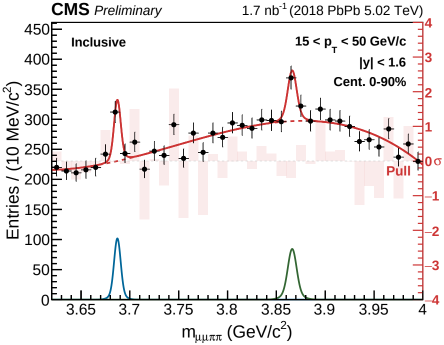
Comovers calculations (Work in Process!) disfavour the scenario with pure hadronic molecule. This conclusion is supported by other measurement, e. g. evidence of $\chi_{c1}(3872) \to \psi(2S)\gamma$ by LHCb, Nucl. Phys. B886 (2013) 665.

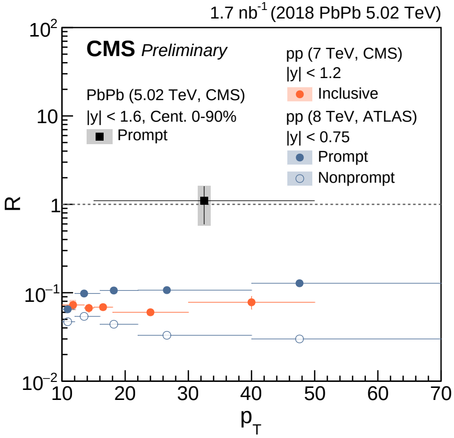
Thank you for your attention and see you in my ZOOM room:
https://cern.zoom.us/j/3521773587?pwd=SUFncU5Xd3VtZTI2VDMvczcrMDIxUT09

Backup

$\chi_{c1}(3872)$ production in PbPb

CMS PAS HIN-19-005



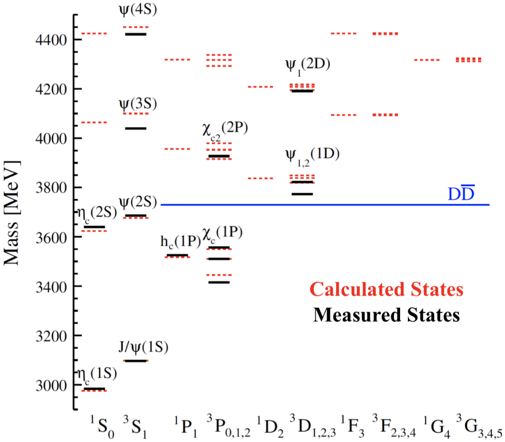


CMS measured $\chi_{c1}(3872)/\psi(2S)$ in PbPb at high $p_{\mathrm{T}} > 15$ GeV$/c$ in the central region $|y| < 1.6$.

$$R = 1.10 \pm 0.51 \pm 0.53$$

Compared with pp ratio at 8 TeV $R = 0.106 \pm 0.061 \pm 0.020$.

Conventional $c\bar{c}$ States

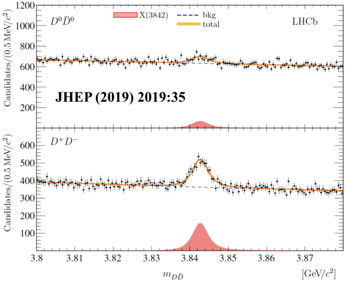


Rev. Mod. Phys. 90, 015003 (2018)

Barnes, Godfrey, Swanson, PRD 72 (2005) 054026

Nonrelativistic potential model: solve Schrodinger equation with the potential

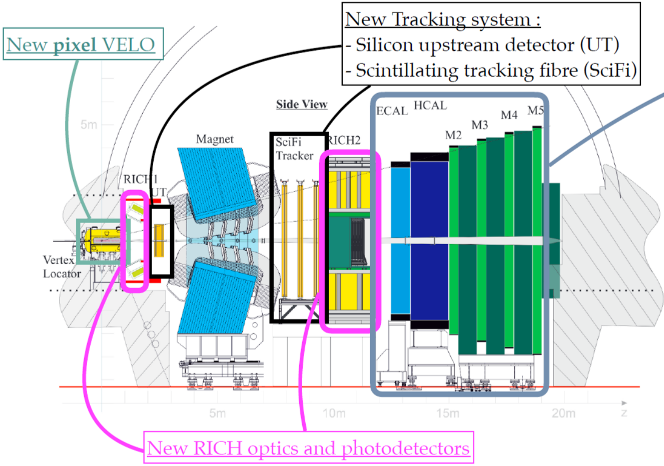
$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\tilde{\delta}_\sigma(r)\vec{S}_c \cdot \vec{S}_{\bar{c}}$$



New charmonium states still being found: LHCb observed state consistent with $\psi_3(1^3D_3)$ found in $\boldsymbol{D\bar{D}}$ and $\boldsymbol{D^+D^-}$ mass spectra in 2019

LHCb Upgrade for Run 3

[CERN-LHCC-2012-007]

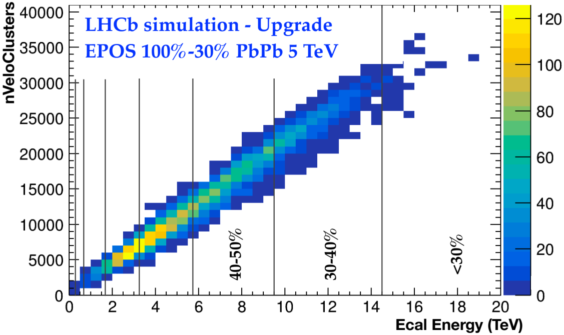


- Upgrade based on pp collision requirements :
  - Collision rate at 40 MHz.
  - Pile-up factor $\mu \approx 5$
- **Replace the entire tracking system.**
- Full **software trigger.**
  - Remove L0 triggers.
  - Read out the full detector at 40 MHz.

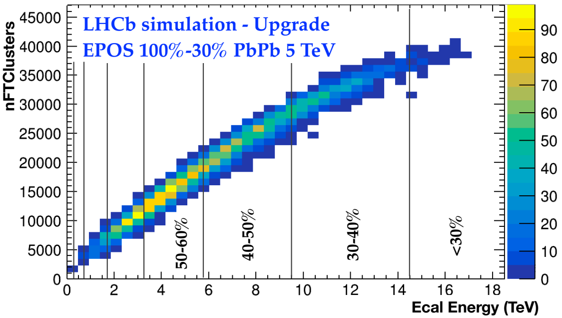
Benjamin Audurier - benjamin.audurier@cern.ch 17

The bright future of HI in LHCb during Run 3

MC studies for the upcoming PbPb data taking show no significant saturation in the future LHCb tracking detectors - the new VELO and the SciFi detectors - down to $\sim 30\%$ of centrality.

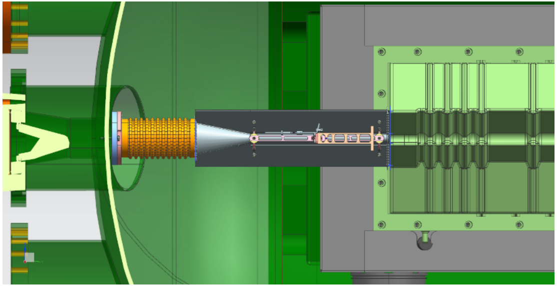


VELO



SciFi

SMOG2



- Standalone gas storage cell to be installed at $-500 < z < -300$ mm.
- Up to 100$\times$ higher gas density the with same gas flow as the current SMOG.
- Gas feed system measures the gas density at a few % accuracy.

Installation postponed to $\sim$ Summer 2020, to be operational from the start of the LHC Run 3.