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Title: LHCb: Recent results and future plans

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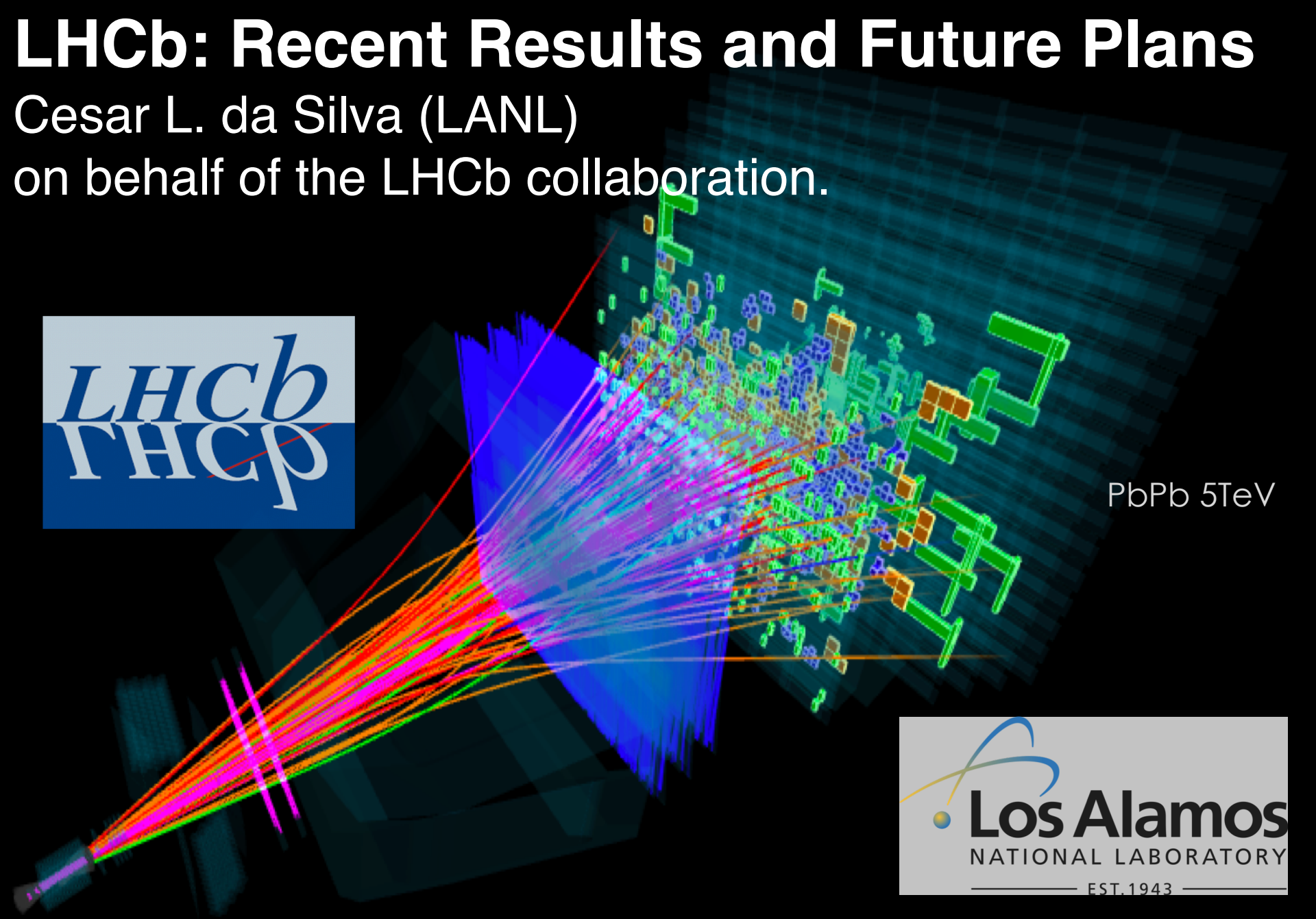
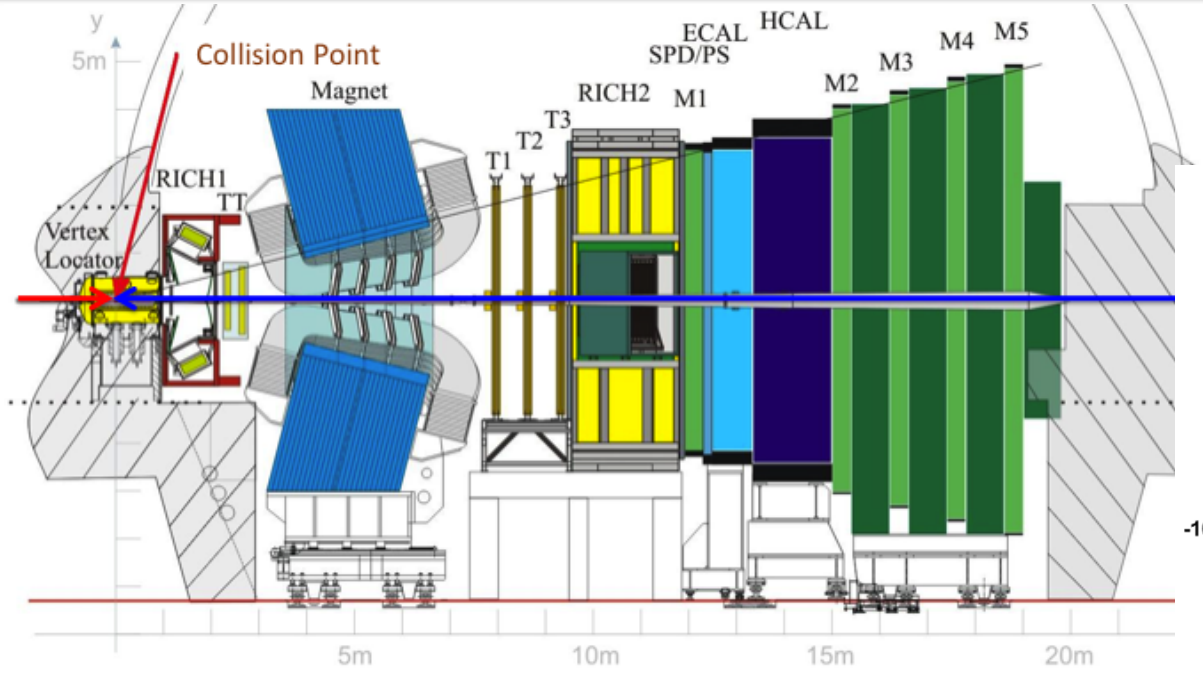
# LHCb: Recent Results and Future Plans

Cesar L. da Silva (LANL)
on behalf of the LHCb collaboration.

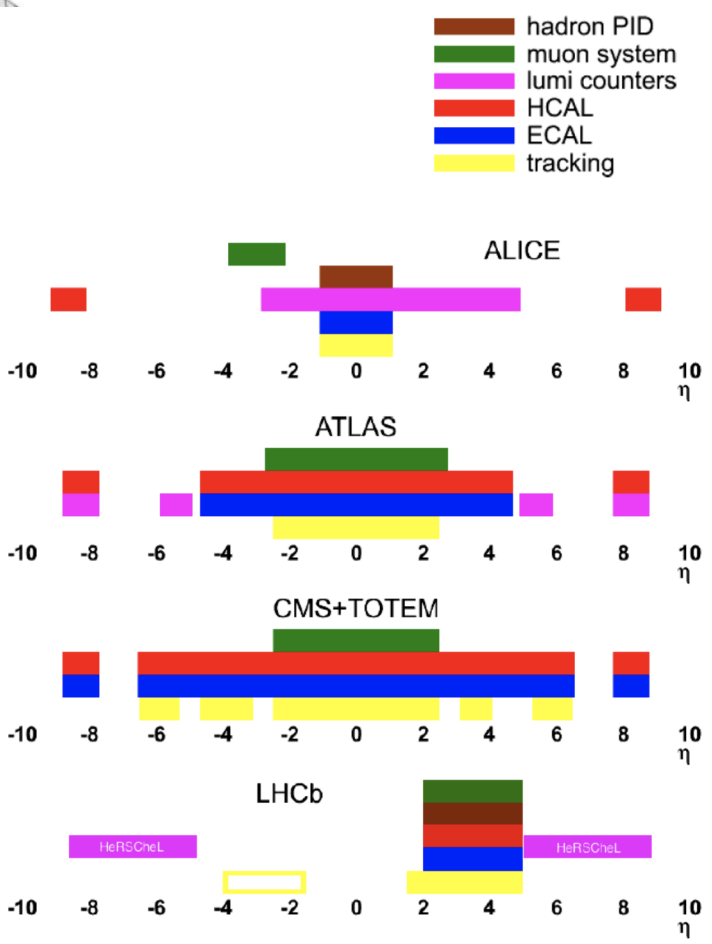



10th Hard Probes – June 2020

# LHCb

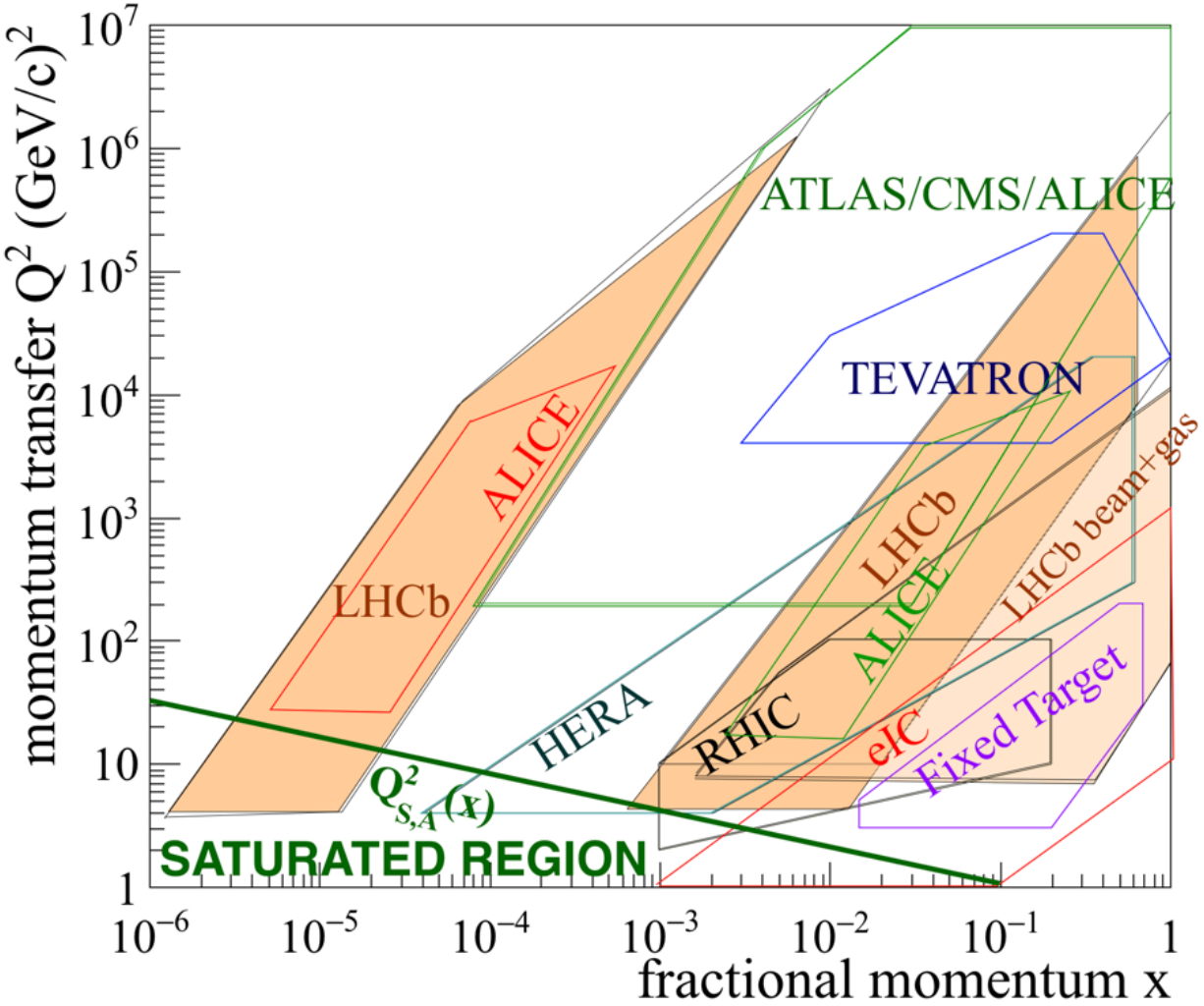



J. of Instr.,3(08):S08005, 2008




- $1.6 < \eta < 4.9$
- $e, \mu, \pi, K, p, \gamma$ identification for $1 < p[GeV/c] < 100$
- jet reconstruction
- interaction point resolution $<80\ \mu$m
- 1 MHz DAQ rate, 40 MHz after LHC shutdown upgrades

# Kinematic Coverage

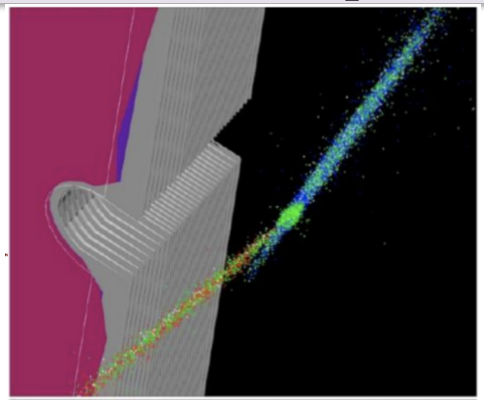



- Broad and unique kinematic coverage

$Q^2_{S,A}(x)$ based on PRL100, 022303(2008)

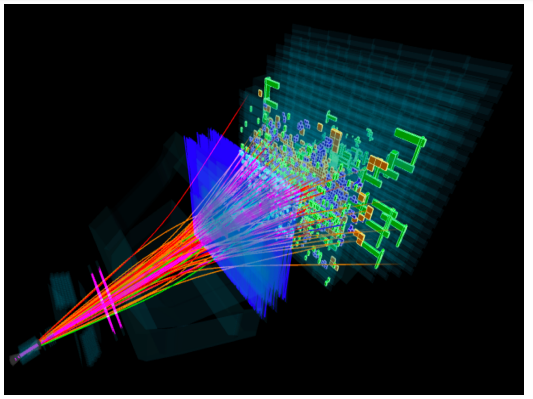
# Heavy Ion Data Sets

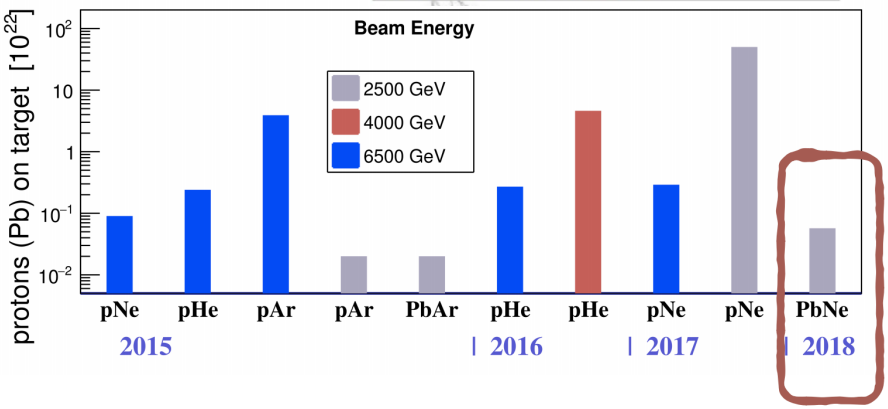
SMOG
Beam-gas
collisions

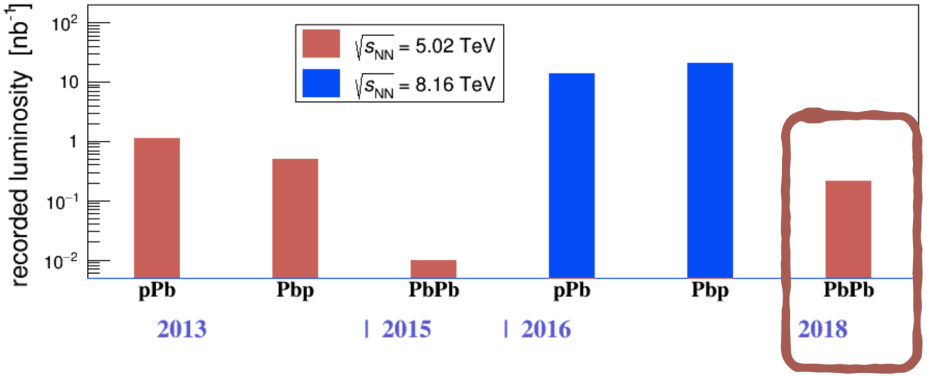


Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

Beam-beam
collisions






~ 20 times 2015 luminosity

PbPb collisions limited to 40% most peripheral caused by saturation in the inner vertex detector (VELO).

SMOG has no centrality limitations.

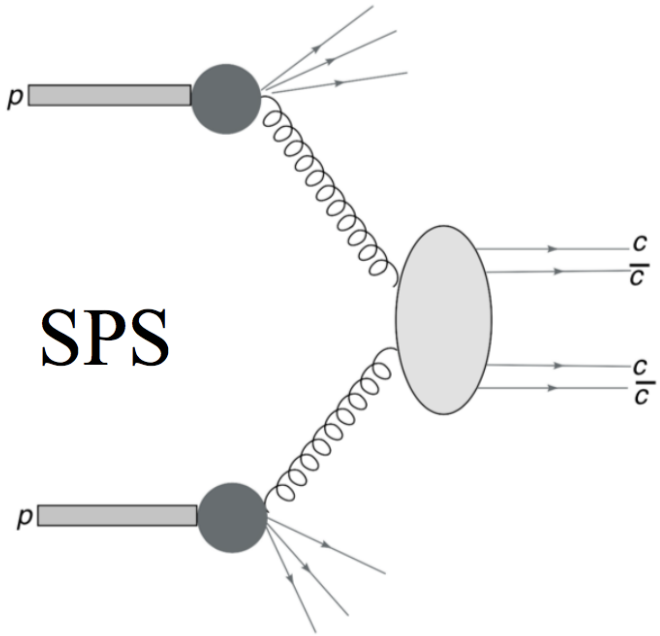
# LHCb Talks

- LHC Run3 and Run4 prospects for heavy-ion physics with LHCb (Samuel Belin https://indico.cern.ch/event/751767/contributions/3771217/)
- X(3872) production in high multiplicity pp (Cameron Dean https://indico.cern.ch/event/751767/contributions/3770929/ )
- Open heavy flavor production in pA collisions (Jianqiao Wang https://indico.cern.ch/event/751767/contributions/3770930/ )
- Quarkonia production in pPb collisions (Oscar Boente Garcia https://indico.cern.ch/event/751767/contributions/3770928/ )
- Z production in pPb collisions at LHCb (Hengne Li https://indico.cern.ch/event/751767/contributions/3772965/ )

# Double Charm Production I

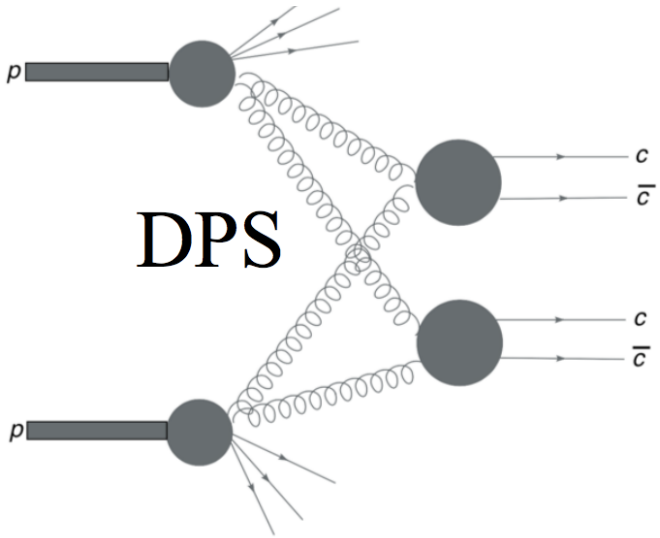
Jianqiao Wang's talk

## Single Parton Scattering




## Double Parton Scattering

Phys. Rev. D **96**, 074013

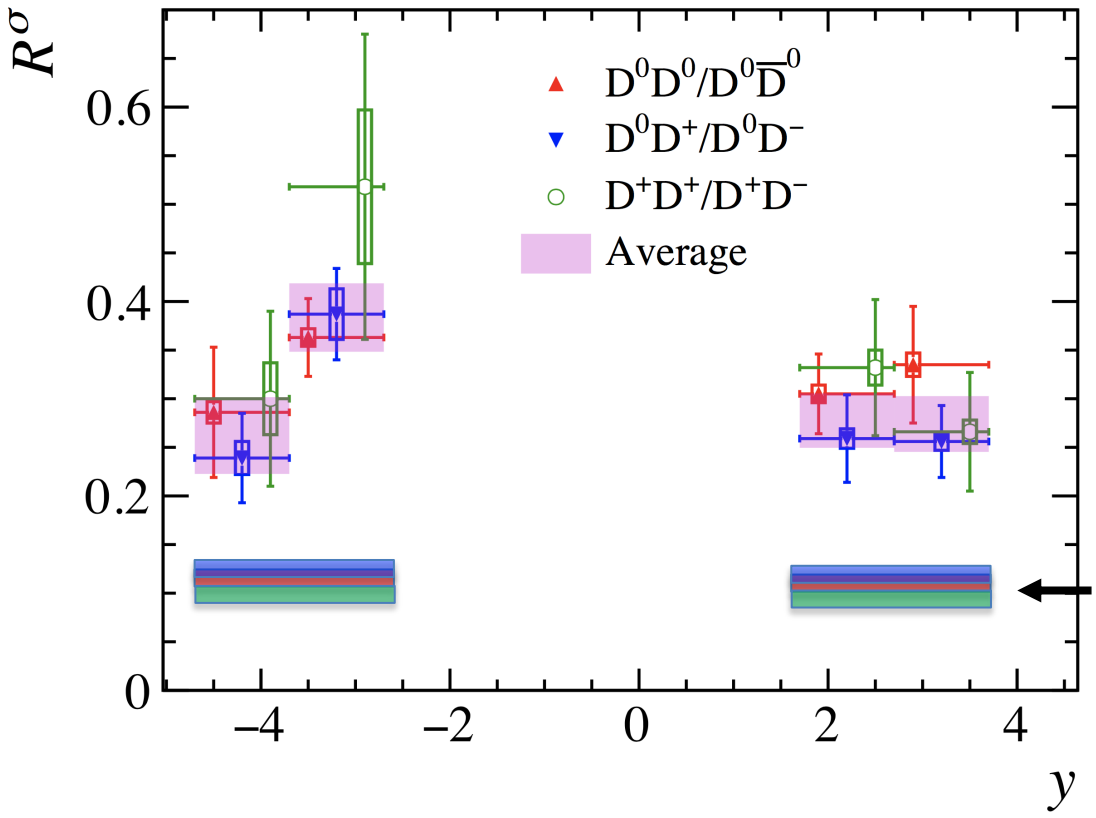



**Opposite-sign (OS):** D-mesons are formed in SPS

**Like-sign (LS):** D-mesons are produced in DPS. Should be uncorrelated if there is no parton correlation.

# Double Charm Production II

Jianqiao Wang's talk



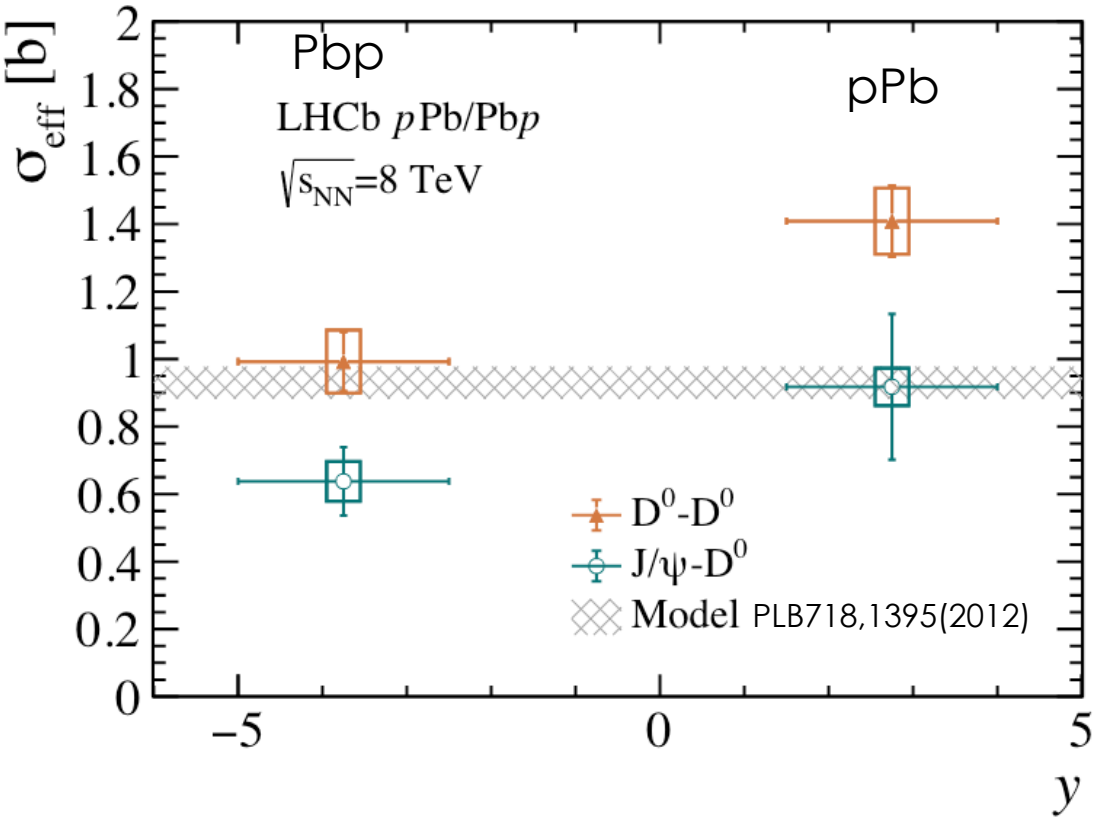

LHCb-PAPER-2020-010
(in preparation)

pp results [JHEP06,141(2012)]

Like-sign production enhanced by a factor ~3 in pPb and even more in Pbp

# Double Charm Production III

LHCb-PAPER-2020-010 (in preparation)




Jianqiao Wang's talk

$$\sigma_{\rm eff} = \frac{\sigma^A \sigma^B}{(1+\delta_{AB})\sigma^{AB}_{\rm DPS}}$$

$$\sigma_{\rm eff} = \left[\int d^2b t^2(\mathbf{b})\right]^{-1}$$

$$t(\mathbf{b}) = \int f(\mathbf{b_1}) f(\mathbf{b_1}-\mathbf{b}) d^2b_1$$

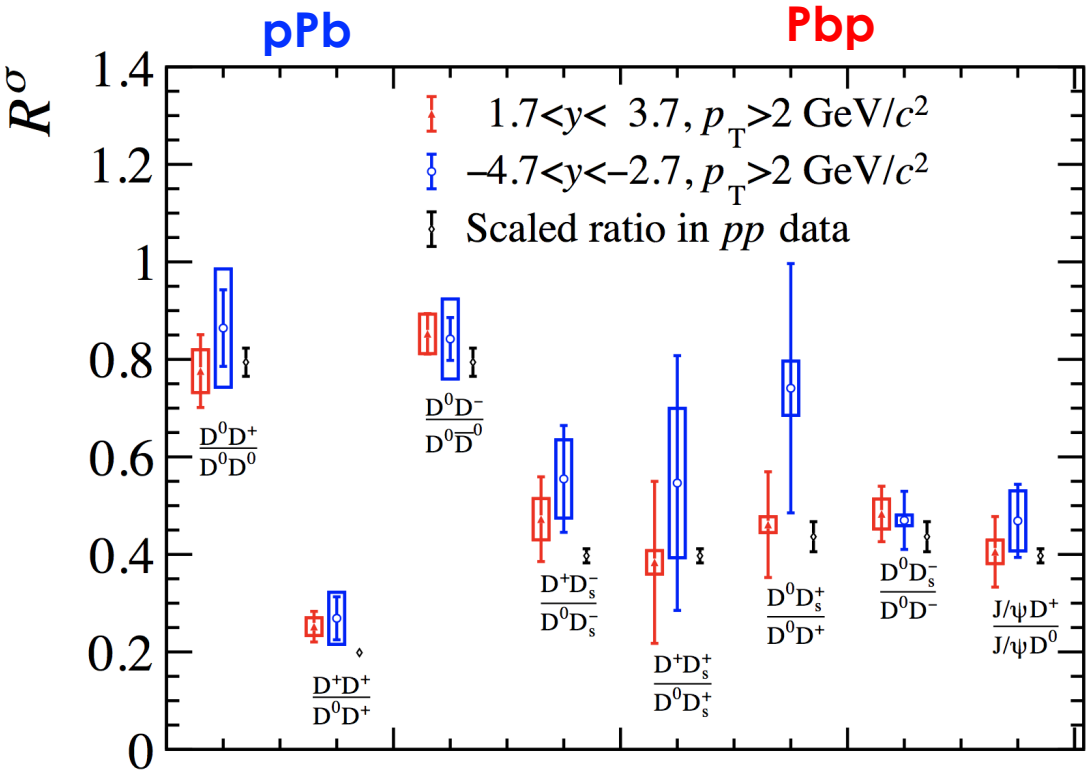
- $\sigma_{\rm eff}$ is a process independent effective transverse overlap area of the partonic correlations that produce DPS
- depends on the partonic impact parameter $\mathbf{b}$

# Double Charm Production

$\sqrt{s_{NN}} = 8.16TeV$

LHCb-PAPER-2020-010
(in preparation)

Jianqiao Wang's talk




$$\sqrt{s} = 5TeV$$

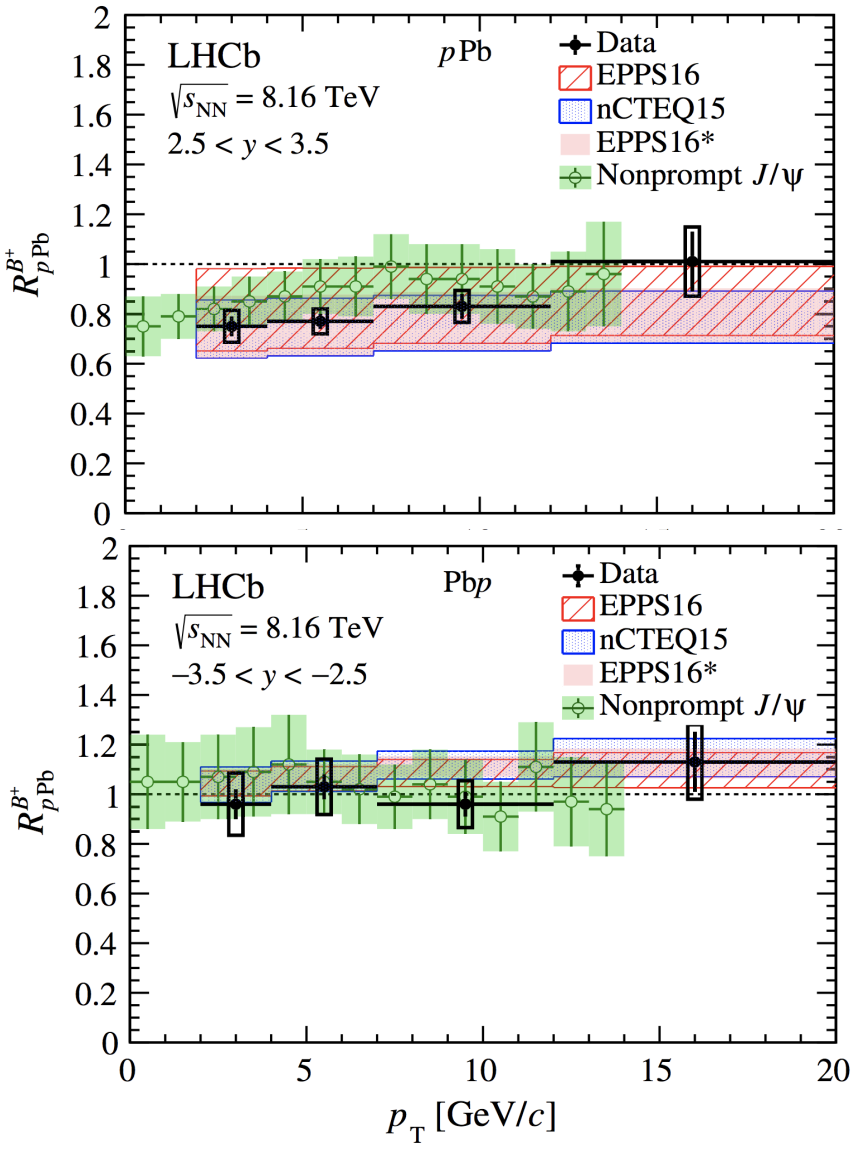
$$\sigma(pp \to D^0X) = 1004 \pm 3 \pm 54\,\mu\text{b},$$
$$\sigma(pp \to D^+X) = 402 \pm 2 \pm 30\,\mu\text{b},$$
$$\sigma(pp \to D_s^+X) = 170 \pm 4 \pm 16\,\mu\text{b},$$
$$\sigma(pp \to D^{*+}X) = 421 \pm 5 \pm 36\,\mu\text{b},$$

JHEP06(2017)147

pp ratios scaled by the number of charm-quark hadronization paths into charm pairs

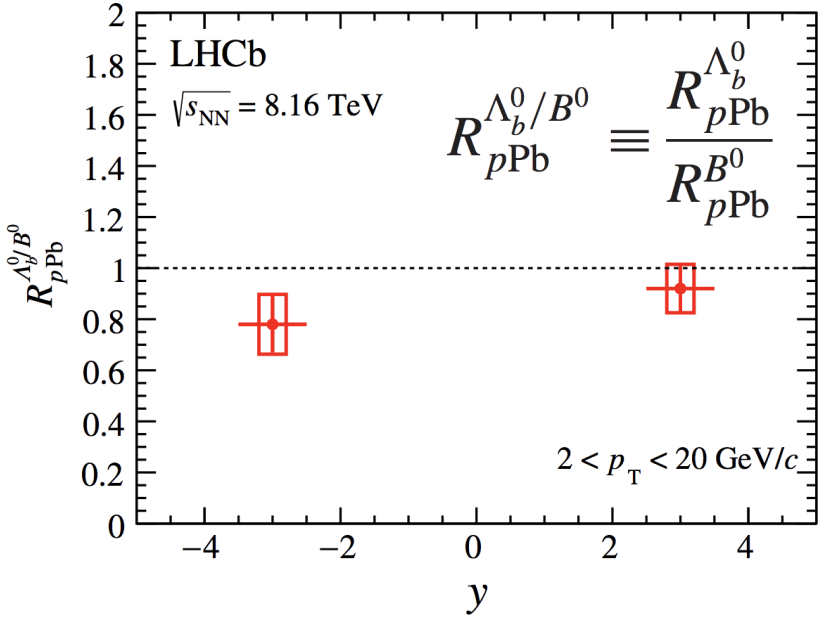
No significant modification of charm hadronization in pPb and Pbp collisions compared to pp collisions.

# B-Hadrons




PRD99,052011(2019)

Jianqiao Wang's talk




- No strong modification of baryon/meson ratio
- Nuclear modification of $B^+$ consistent with nPDFs
- EPPS16* is EPPS16 constrained by LHCb D-meson and J/Ψ data

# The Mysterious X(3872)

Also known as $\chi_{c1}(3872)$.

Cameron Dean's talk

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

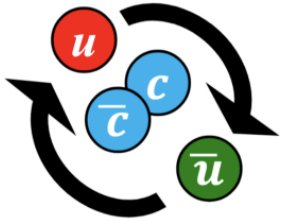
Quantum numbers of $\chi_{c1}(3872)$ were determined as $J^{PC} = 1^{++}$.

*"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

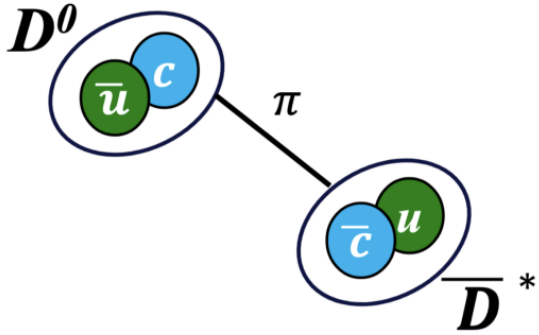
**Compact tetraquark/pentaquark**


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




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

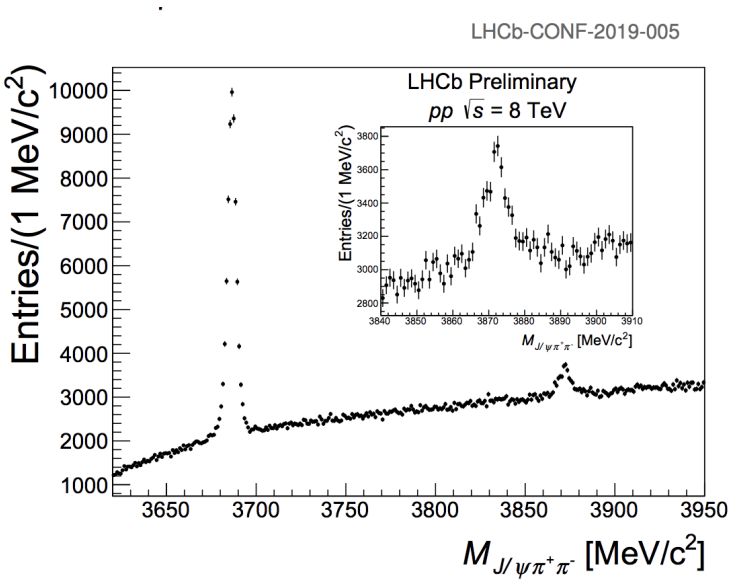
**Hadronic Molecules**
*PLB 590 209 (2004)*
*PRD 77 014029 (2008)*
*PRD 100 0115029(R) (2019)*

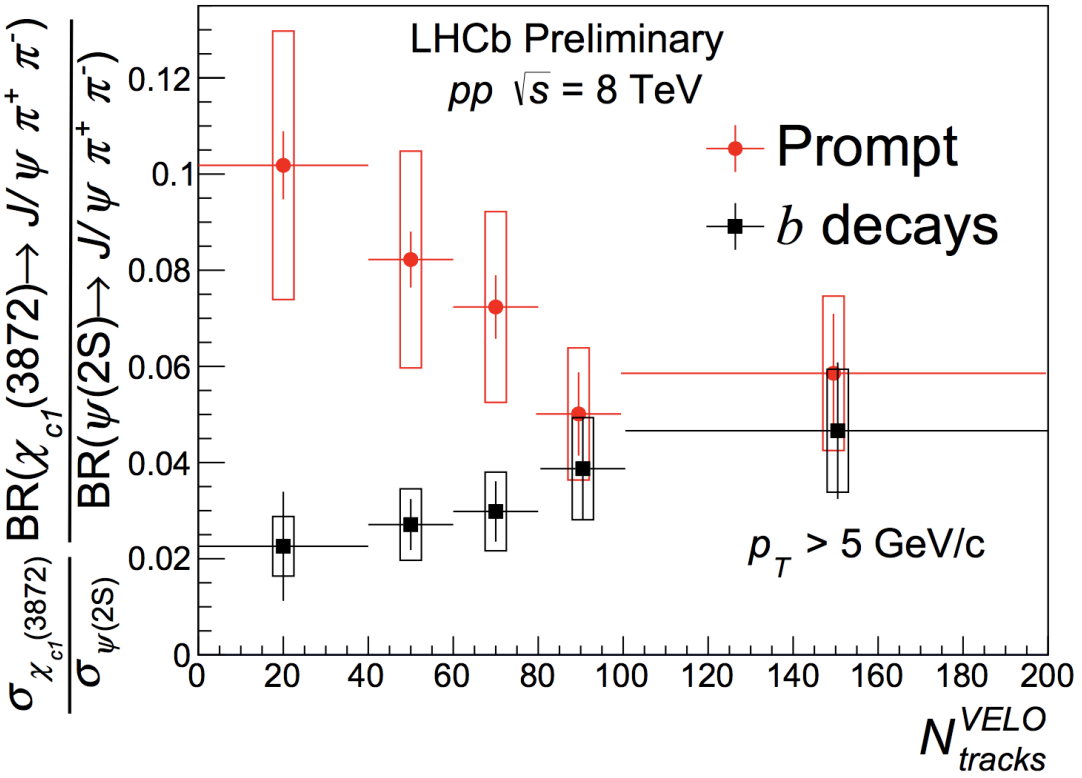


# The Mysterious X(3872)

Cameron Dean's talk

LHCb-CONF-2019-005




- non-prompt X(3872) (from B decays and away from interaction point) shows no significant dependence with multiplicity
- prompt indicate a strong dependence with multiplicity, systematic uncertainties are point-to-point correlated

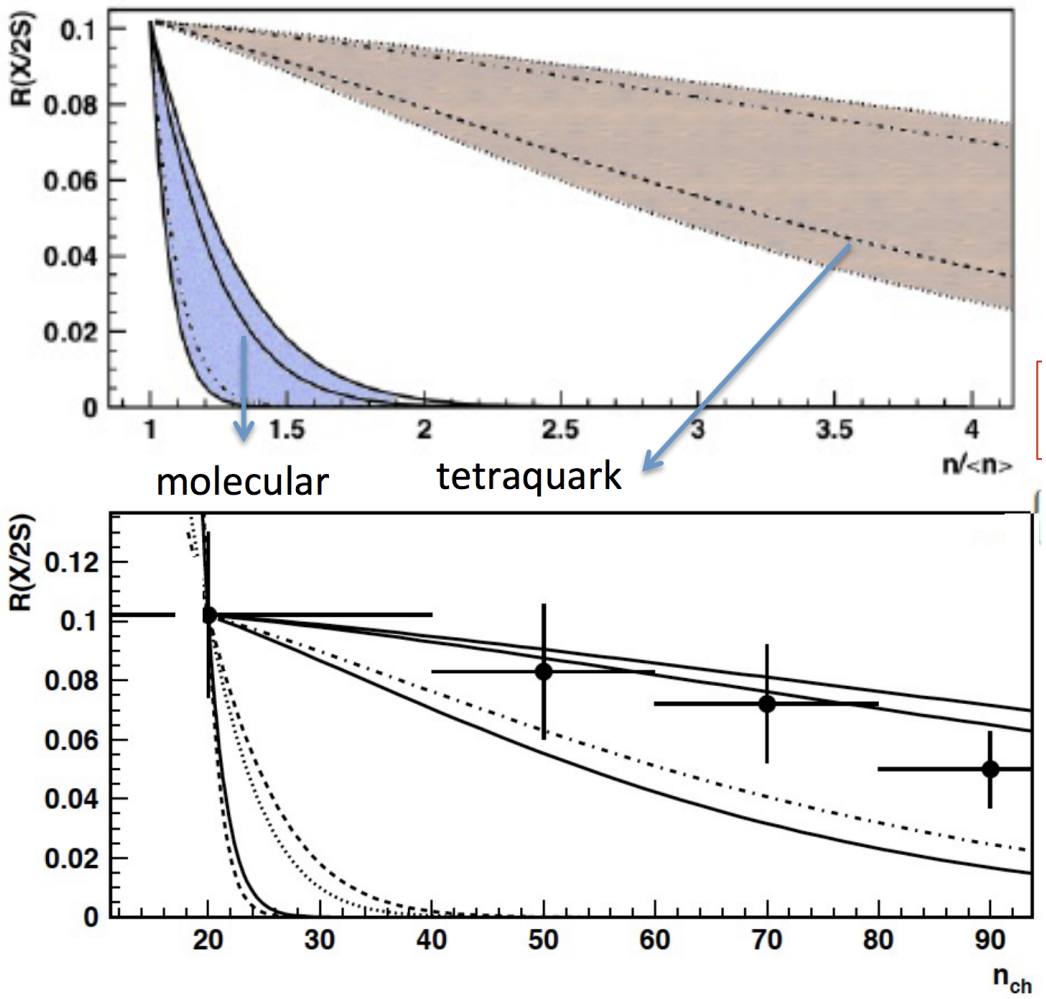
# The Mysterious $\chi_{c1}(3872)$

"Probing X(3872) structure via final state interactions"
A. Esposito, E. Ferreiro, L. Maiani,, A. Pilloni, A. Polosa and C. Salgado.
Paper in preparation

Cameron Dean's talk

Elena Ferreiro's talk

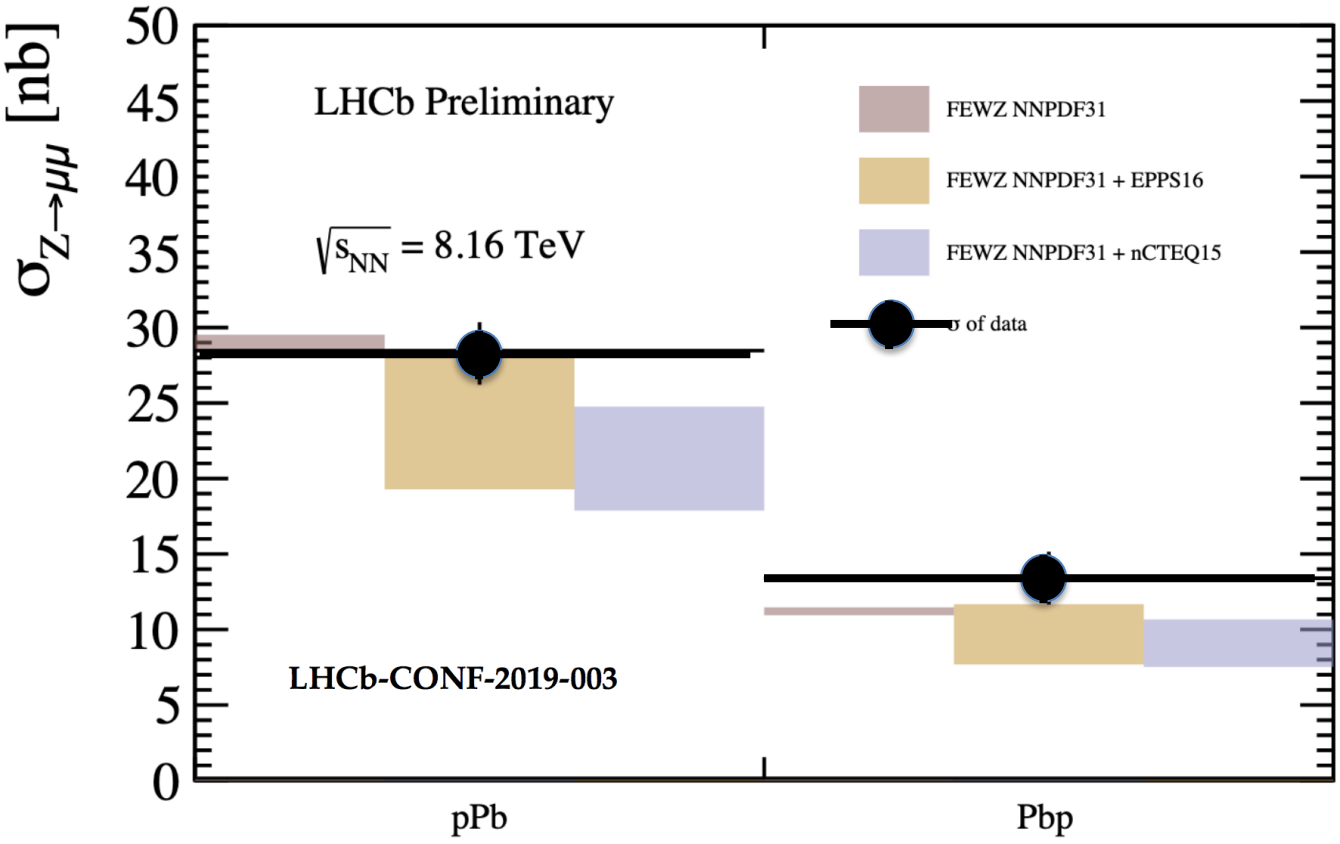
https://indico.cern.ch/event/751767/contributions/3770953/




- Theoretical curve normalized to experimental result in the first bin
- <n> mean pp multiplicity
- Molecular particle would disappear with modest multiplicity
- **Tendency that X(3872) is a compact tetraquark of 1.3 fm**

# Z-bosons in pPb and Pbp

Henge Li's talk



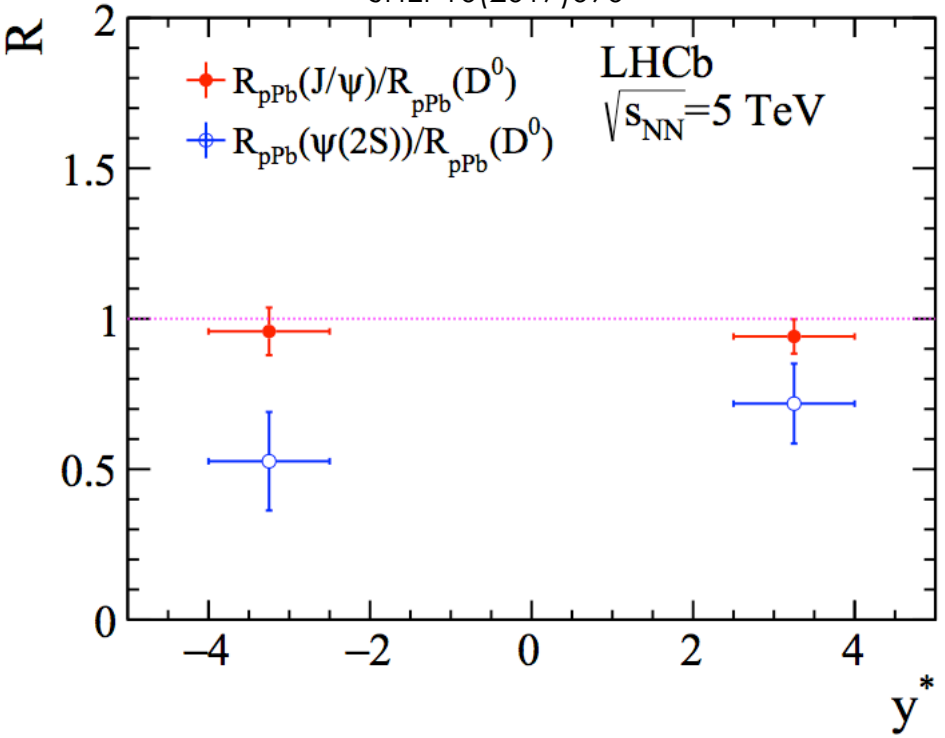

x~$10^{-3}$ x~0.3

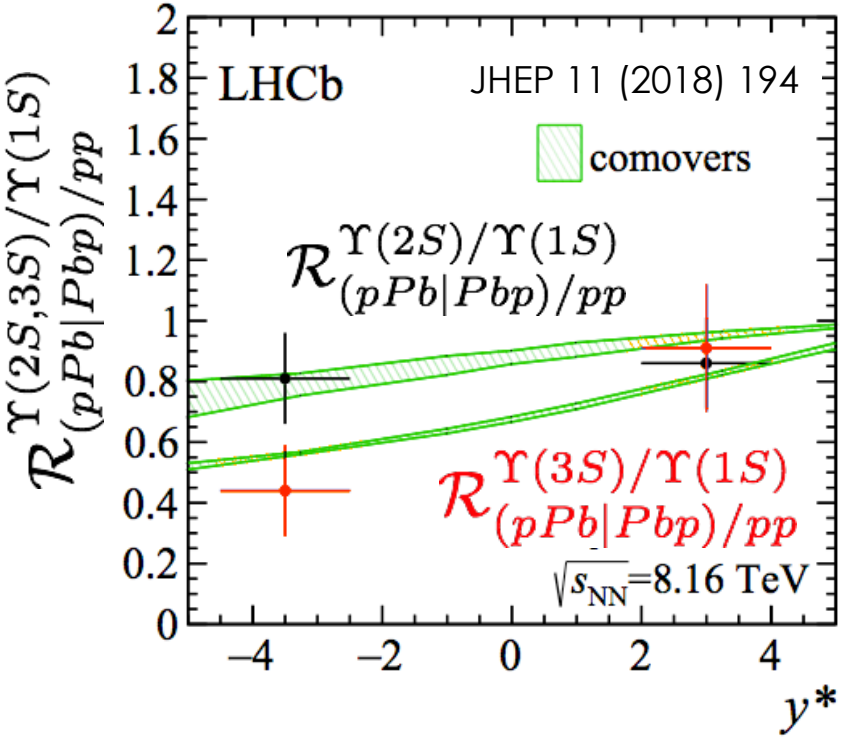
**Experimental uncertainty smaller than nPDFs.**

# Final-State Effects in Quarkonia

Oscar Boente Garcia's talk

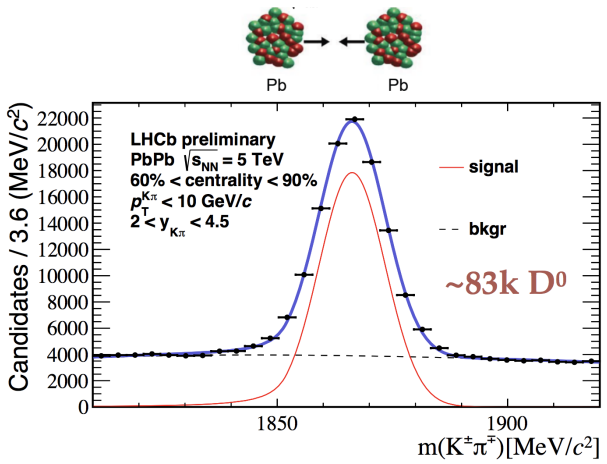
JHEP10(2017)090



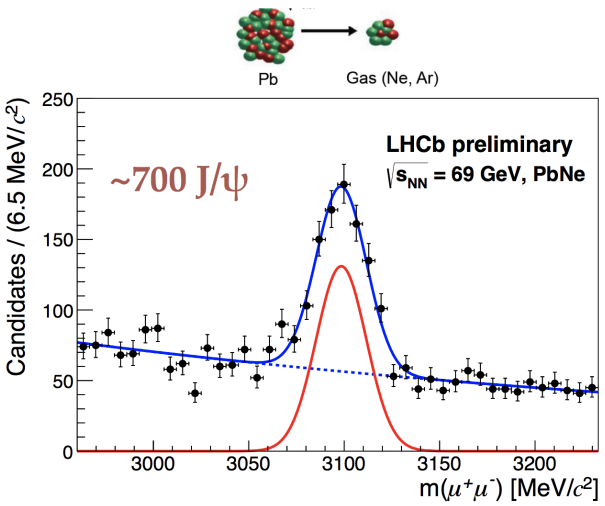



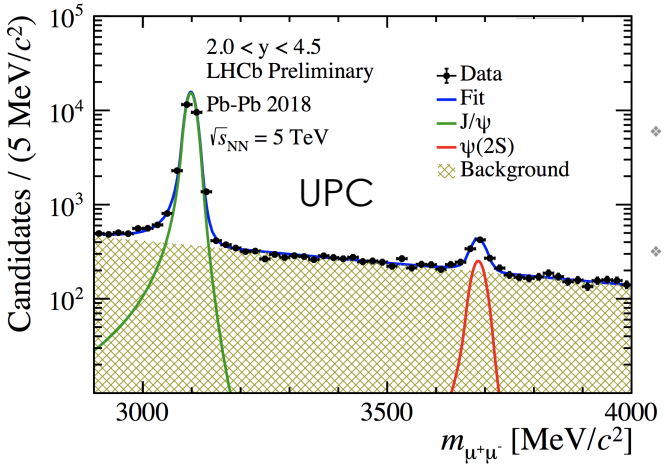

- LHCb can measure J/$\psi$, $\psi$(2S), $\Upsilon$(1S,2S,3S) and $D^0$s from $p_T > 0$
- the J/$\psi$/$D^0$ and $\Upsilon(2S, 3S)/\Upsilon(1S)$ should have initial state effects canceled
- error bars are the quadratic sum of statistical and systematic uncertainties
- finial-state effects in excited state quarkonia

# Some Results in the Pipeline

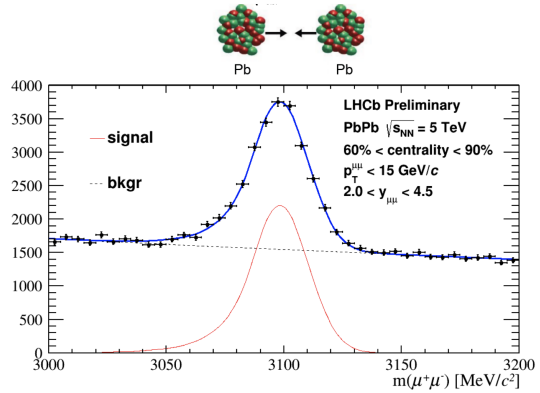


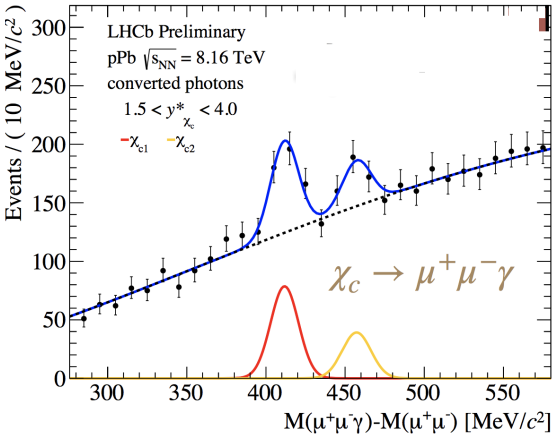

LHCB-FIGURE-2019-020

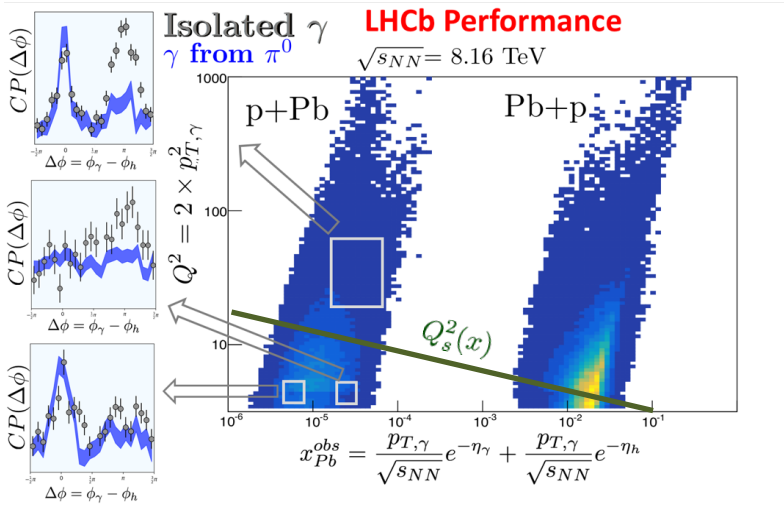



LHCB-FIGURE-2019-019



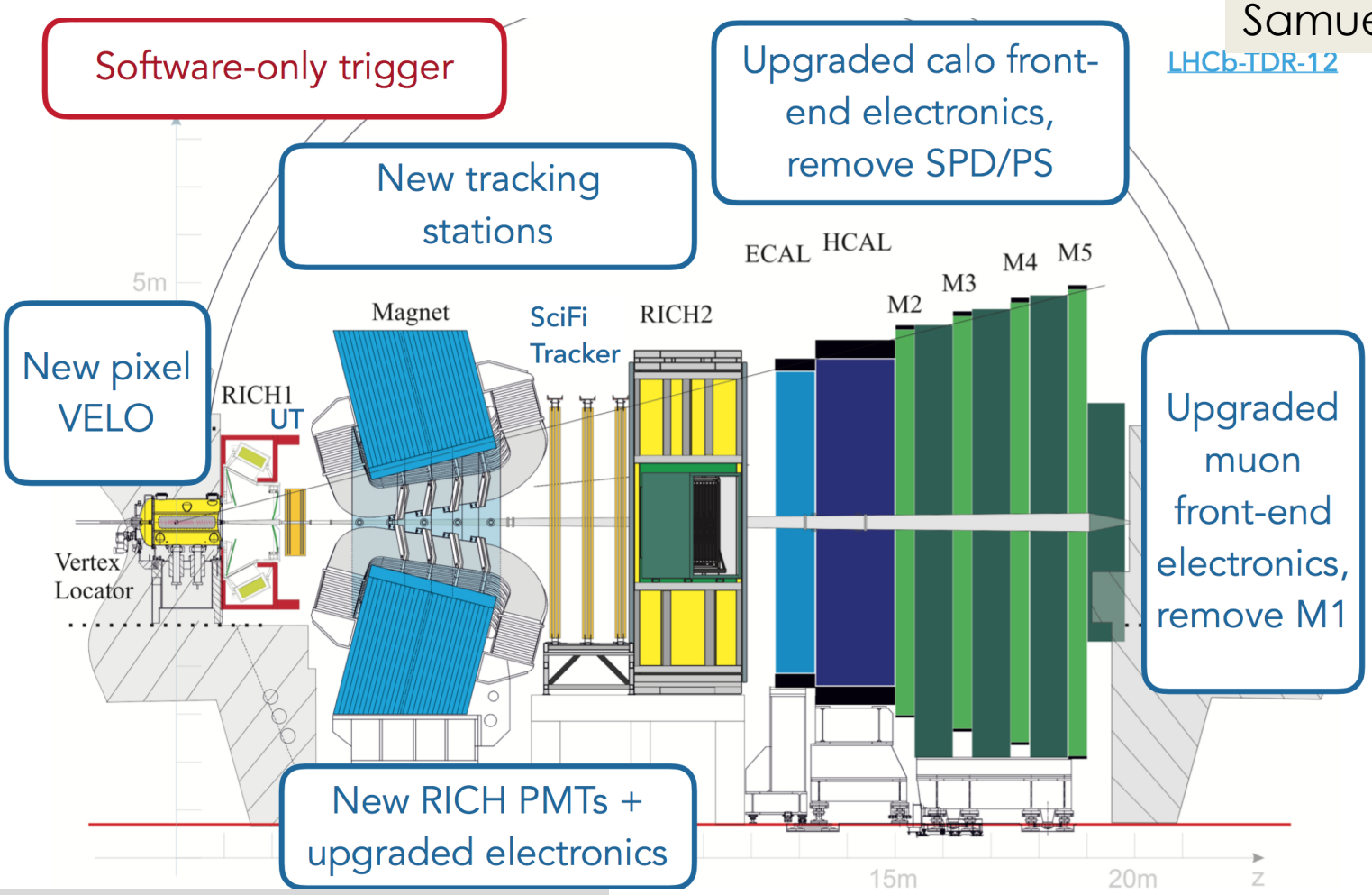



# FUTURE PLANS

# A New Detector in LHC

Samuel Belin's talk

LHCb-TDR-12




40 MHz data acquisition
No hardware trigger
Real time data reconstruction

PbPb limited to the 70% most peripheral events.

# A New Detector in LHC

Samuel Belin's talk

To be upgraded

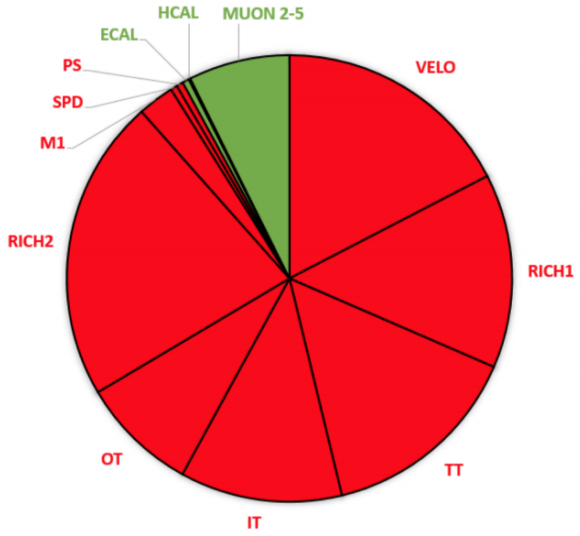
To be kept

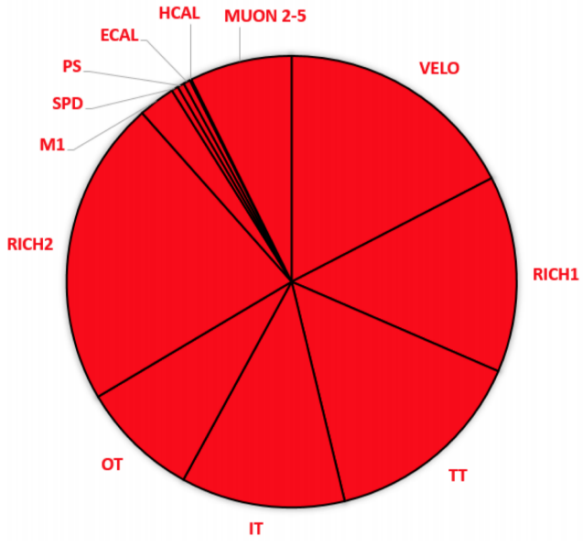
Upgraded LHCb detector

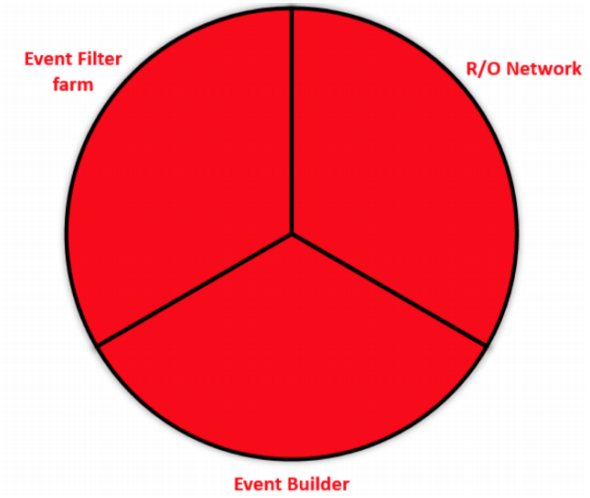
Detector channels

Readout electronics

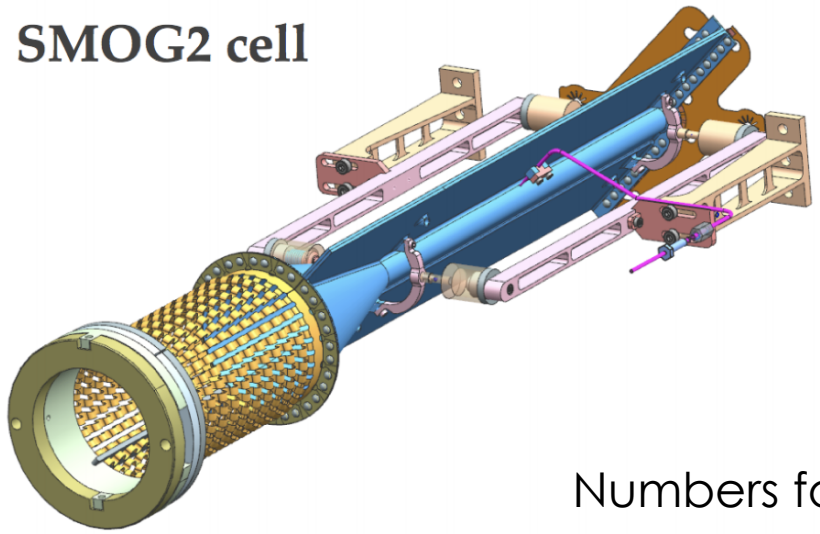
Data acquisition



# SMOG2




Samuel Belin's talk

- 100x higher gas pressure
- <6% luminosity uncertainty
- No centrality limitation
- **Can run during pp runs**

Numbers for one run year operation

LHCb-PUB-2018-015

| | SMOG published result $p$He@87 GeV | SMOG largest sample $p$Ne@69 GeV | SMOG2 example $p$Ar@115 GeV |
|---|---|---|---|
| Integrated luminosity | 7.6 $\text{nb}^{-1}$ | $\sim$ 100 $\text{nb}^{-1}$ | $\sim$ 45 $\text{pb}^{-1}$ |
| syst. error on $J/\psi$ x-sec. | 7% | 6 - 7% | 2 - 3 % |
| $J/\psi$ yield | 400 | 15k | 15M |
| $D^0$ yield | 2000 | 100k | 150M |
| $\Lambda_c^+$ yield | 20 | 1k | 1.5M |
| $\psi(2S)$ yield | negl. | 150 | 150k |
| $\Upsilon(1S)$ yield | negl. | 4 | 7k |
| Low-mass Drell-Yan yield | negl. | 5 | 9k |

# CONCLUSIONS

- LHCb data is already providing essential information for the understanding of hard probes in Heavy Ion collisions
- New results on double charm production provide rich material for the study of parton correlations
- LHCb presents the first result where comoving particles can be used to understand exotica composition. Other exotic particles may come, thanks to the excellent PID and vertexing of LHCb
- Several results in the pipeline, others waiting for analyzers
- Bright future after LSII with less constraints in PbPb collisions and a high luminosity, fixed target program
- Very nice opportunity to explore new territories in heavy ion collisions. JOIN US !!!