Quarkonia in AA with LHCb Results and prospects

I. Quarkonia in AA collisions : which ones and what for
II. LHCb and quarkonia
III. LHCb upgrades and quarkonia

Benjamin Audurier*

Quarkonia as Tools 2020 - Centre Paul Langevin, Aussois - 17 Jan. 2020

*benjamin.audurier@cern.ch

Quarkonia in AA collisions : which ones and what for

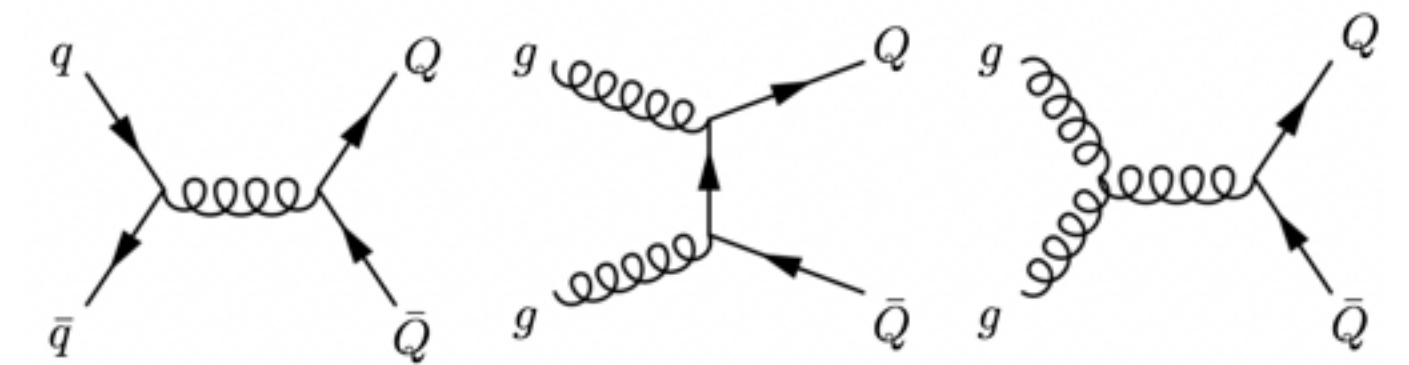# Quarkonia in AA collisions : hadronic

❖ Hadronic quarkonia:

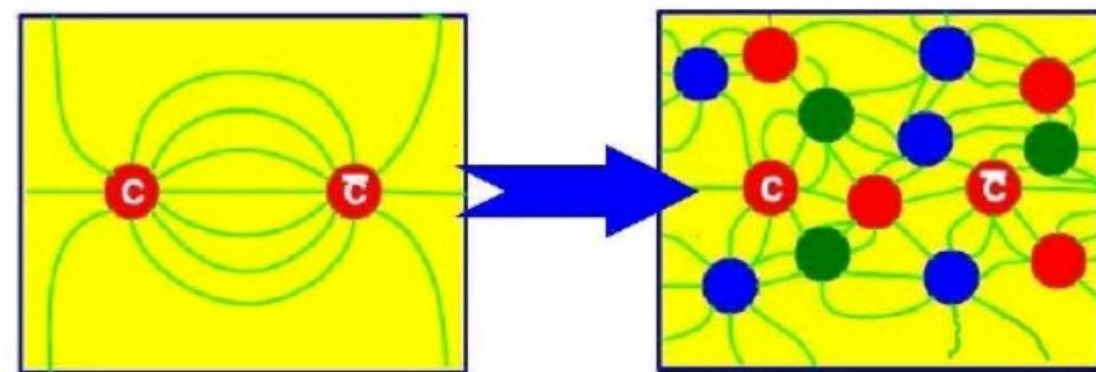➥ Produced mainly via gluon fusion at the LHC energy.

➥ High mass → short formation time → **ideal prob for the QGP.**

- See other presentation given this morning for details.

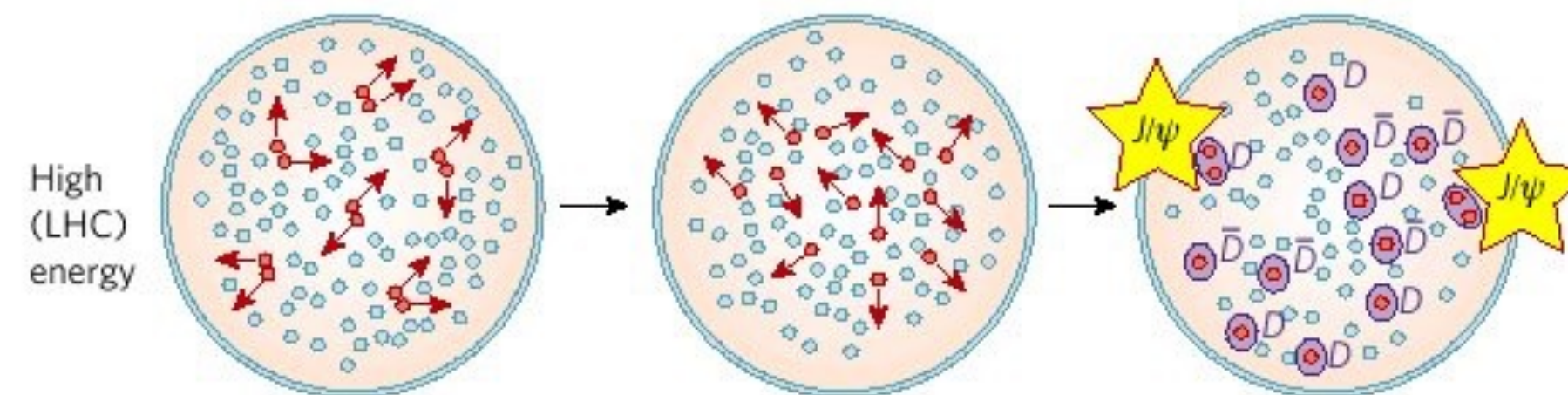➥ Orthodoxe phenomenological picture in AA collisions :

Leading production diagram of QQ pair at LHC

versus

+ energy loss + nPDFS …

Color screening mechanism

(re)combination

Quarkonia in AA collisions : hadronic
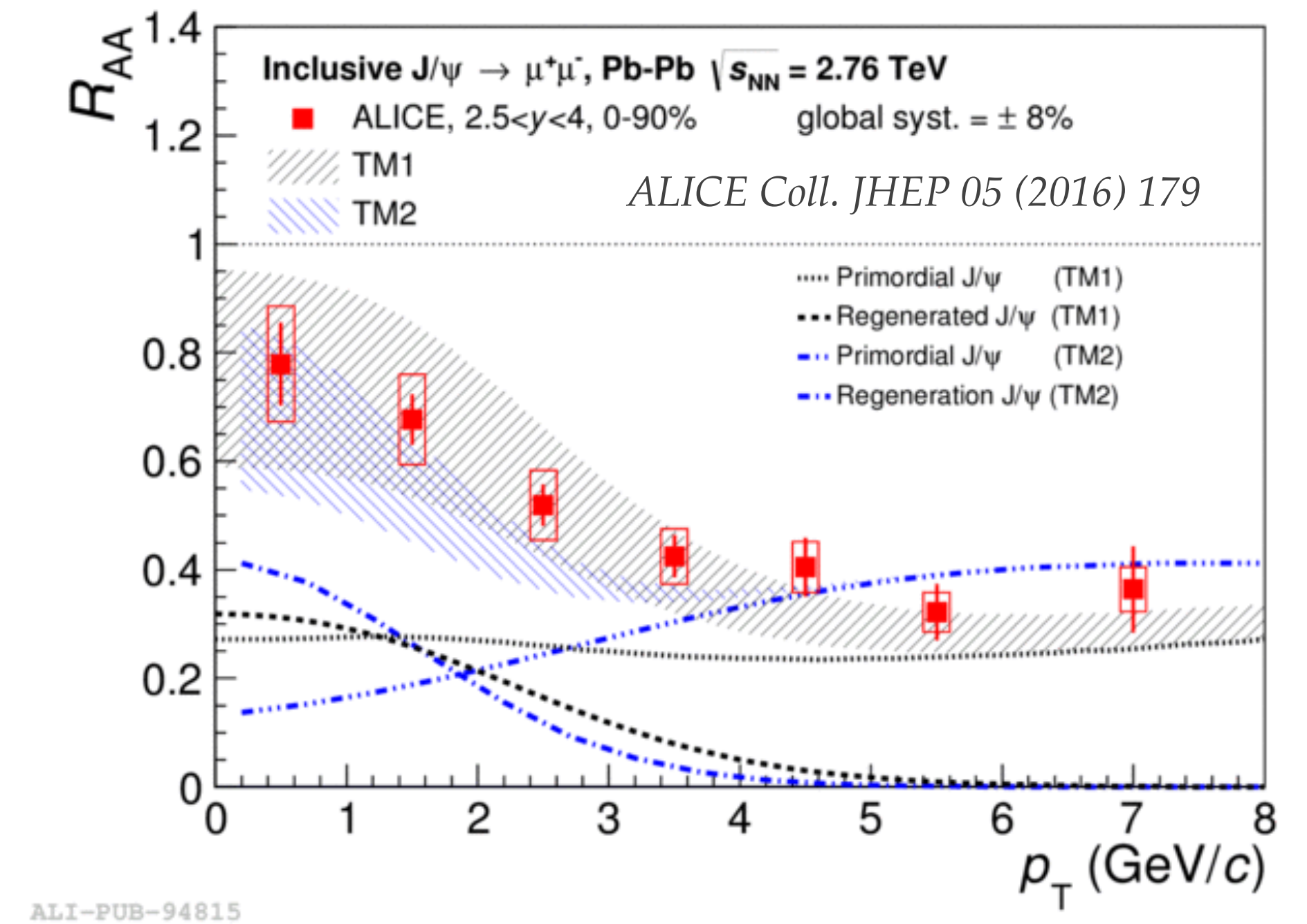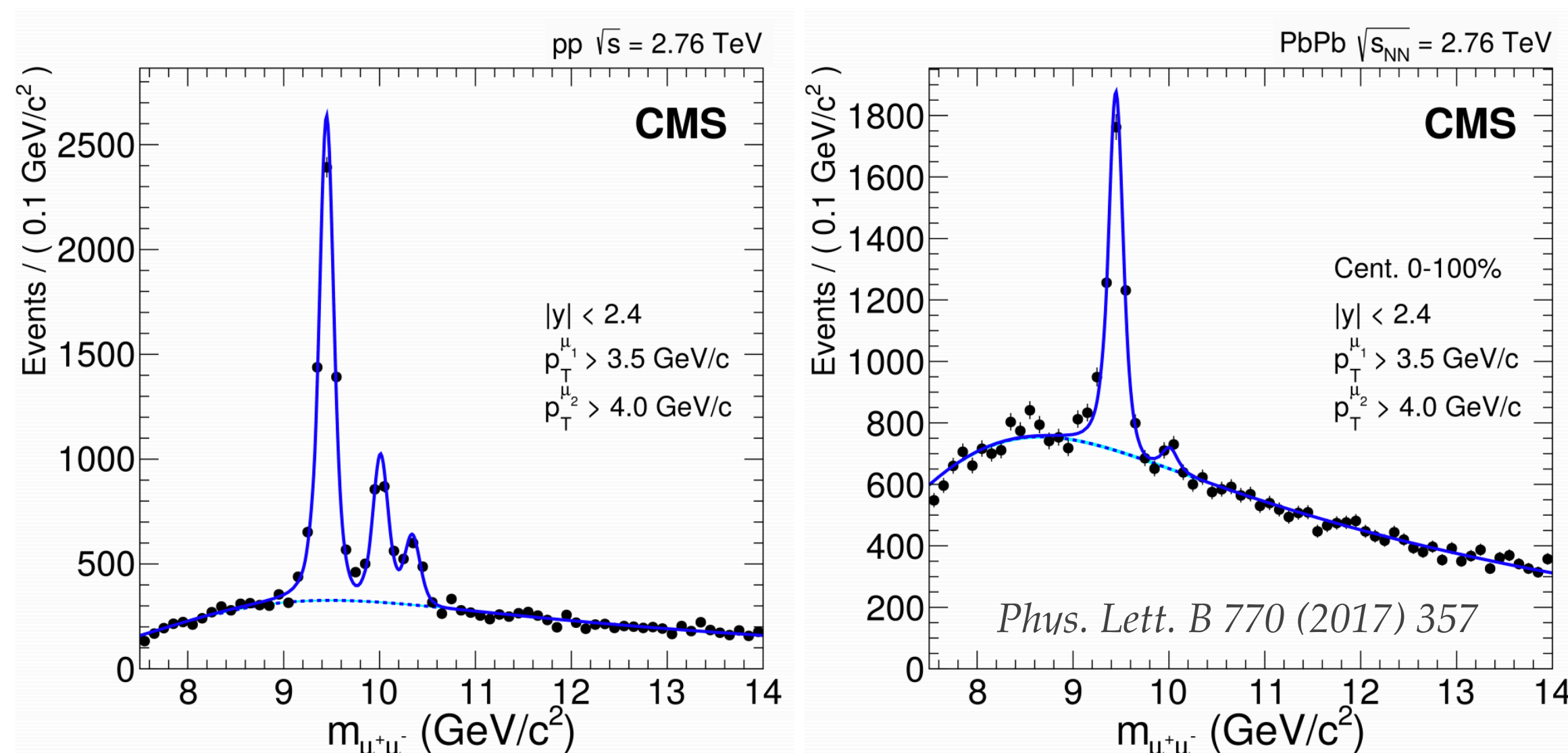
Quarkonia in AA collisions : hadronic

❖ Some observables of hadronic quarkonia :

Quarkonia in AA collisions : hadronic

❖ Some observables of hadronic quarkonia :

➡ Nuclear modification factor R_{AA}

  – **Need good coverage in p_T** from zero to high p_T

  – **Need good mass resolution** to separate the states

  – prompt/non-prompt separation

Phys. Lett. B 770 (2017) 357

ALICE Coll. JHEP 05 (2016) 179

ALI-PUB-94815

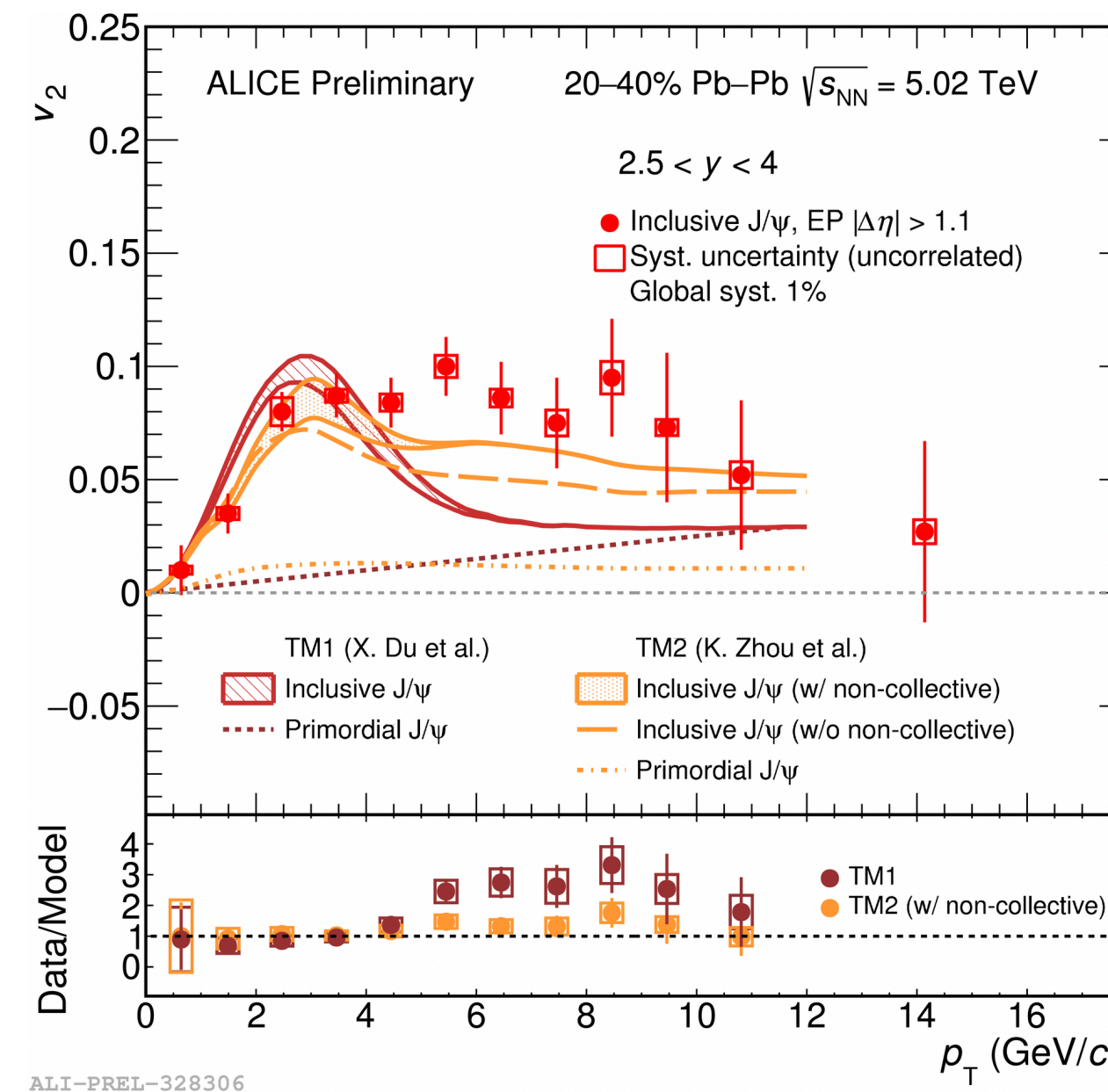# Quarkonia in AA collisions : hadronic

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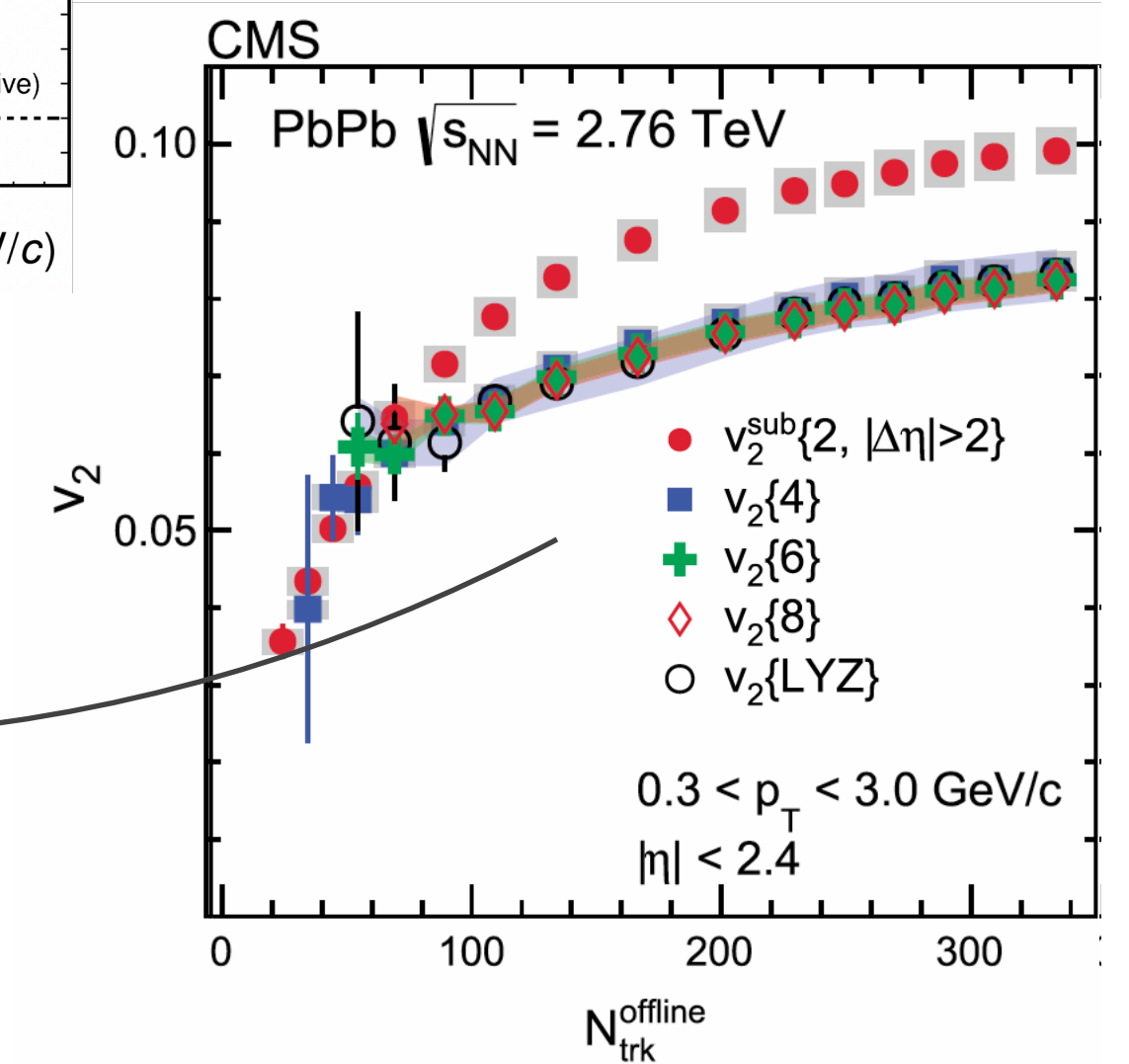
  - prompt/non-prompt separation

➡ Flow measurements

  - Good charged particle reconstructions (cumulants method)
    or good detector resolution (event plane like method)

Use a detector to evaluate the event plane

Use particle correlations

CMS, PLB 765, 193 (2017)

Quarkonia in AA collisions : hadronic

❖ Some observables of hadronic quarkonia :
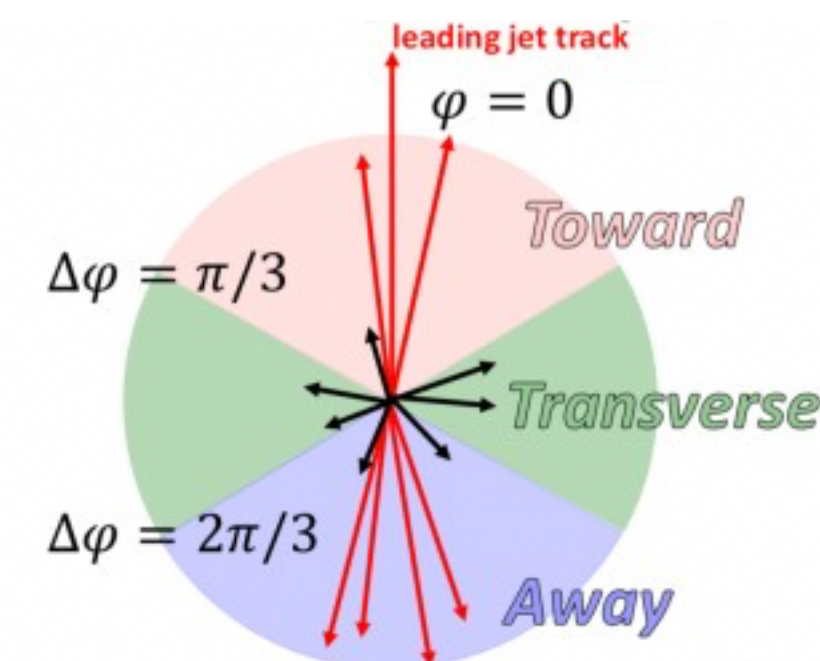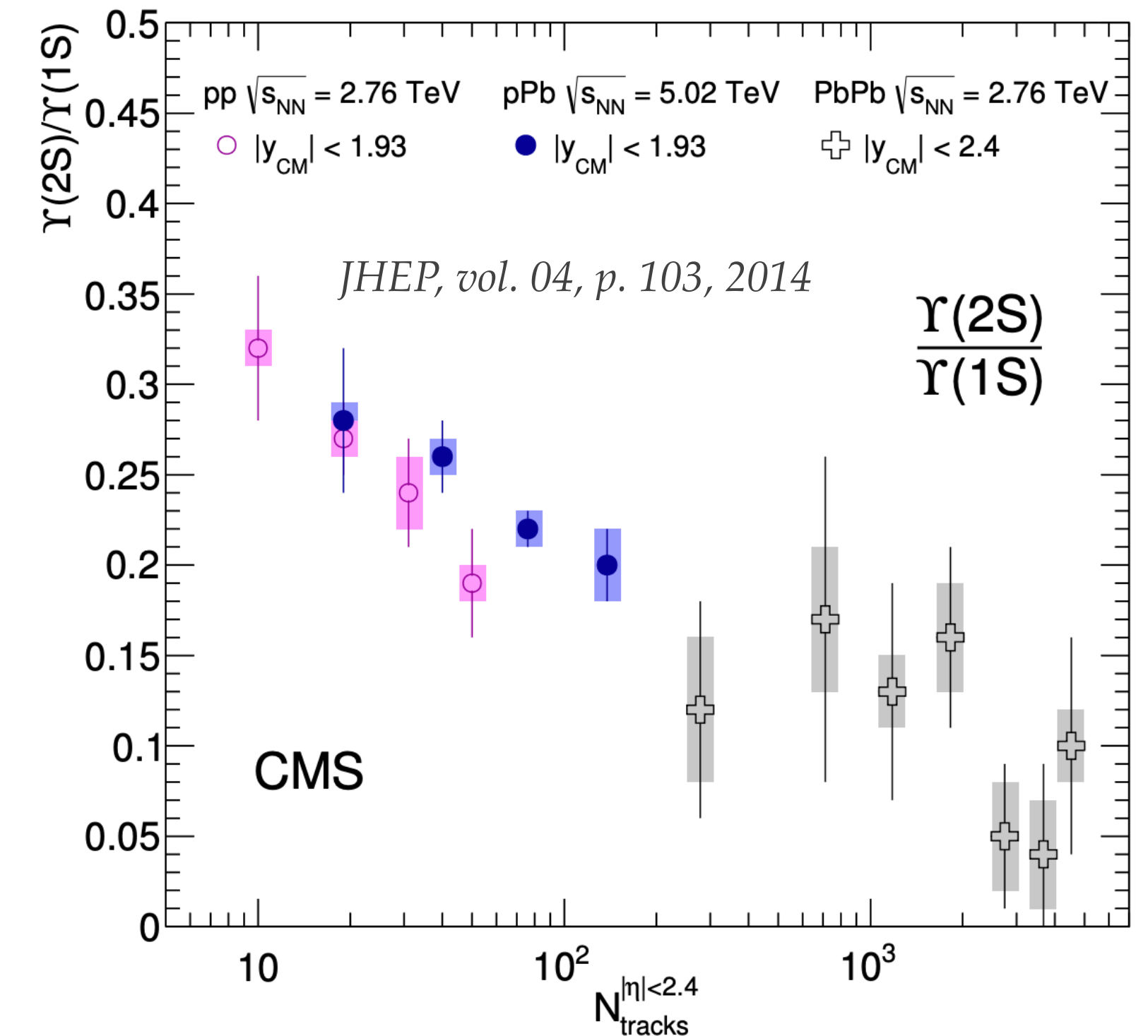
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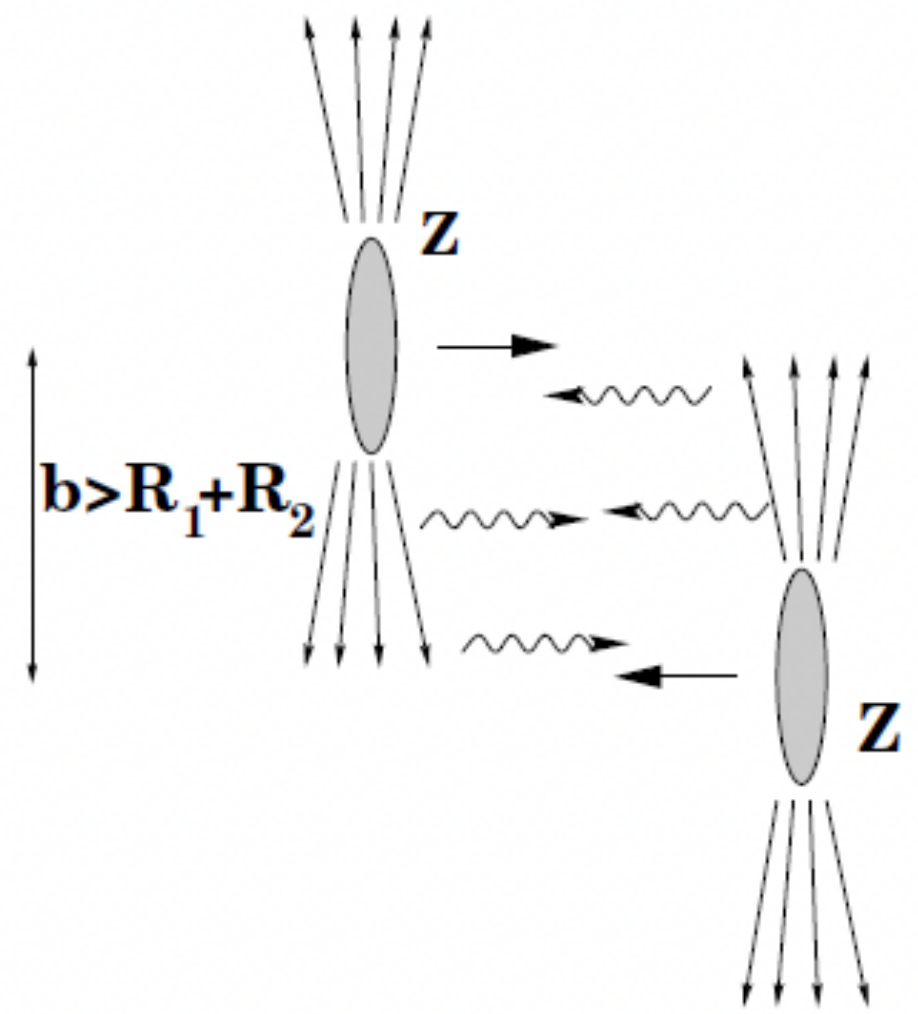
➡ Correlations with N_{ch}

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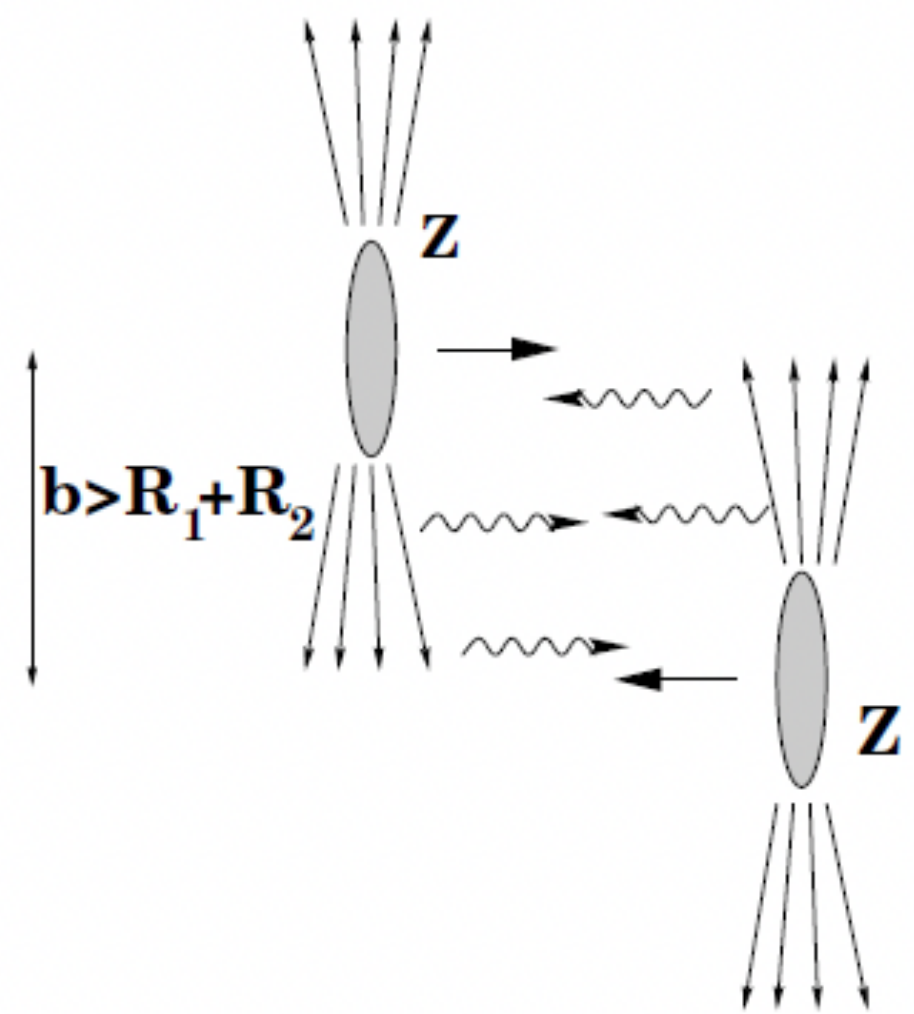
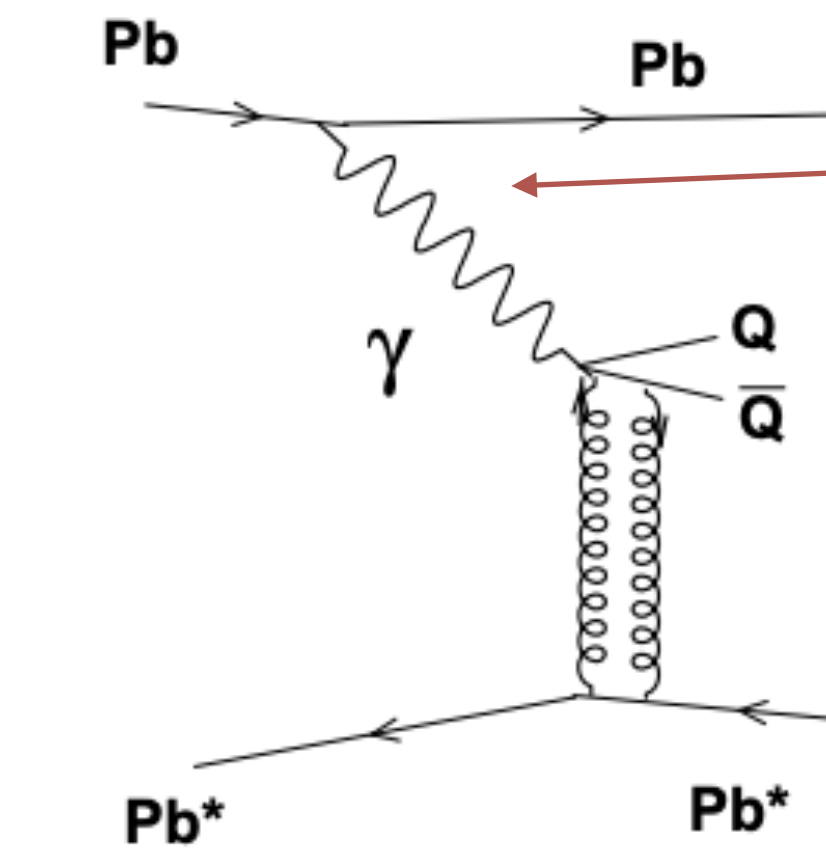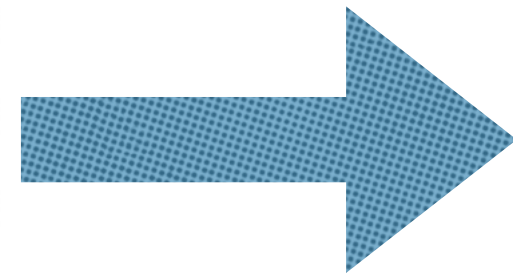➡ Correlation with other probes

4
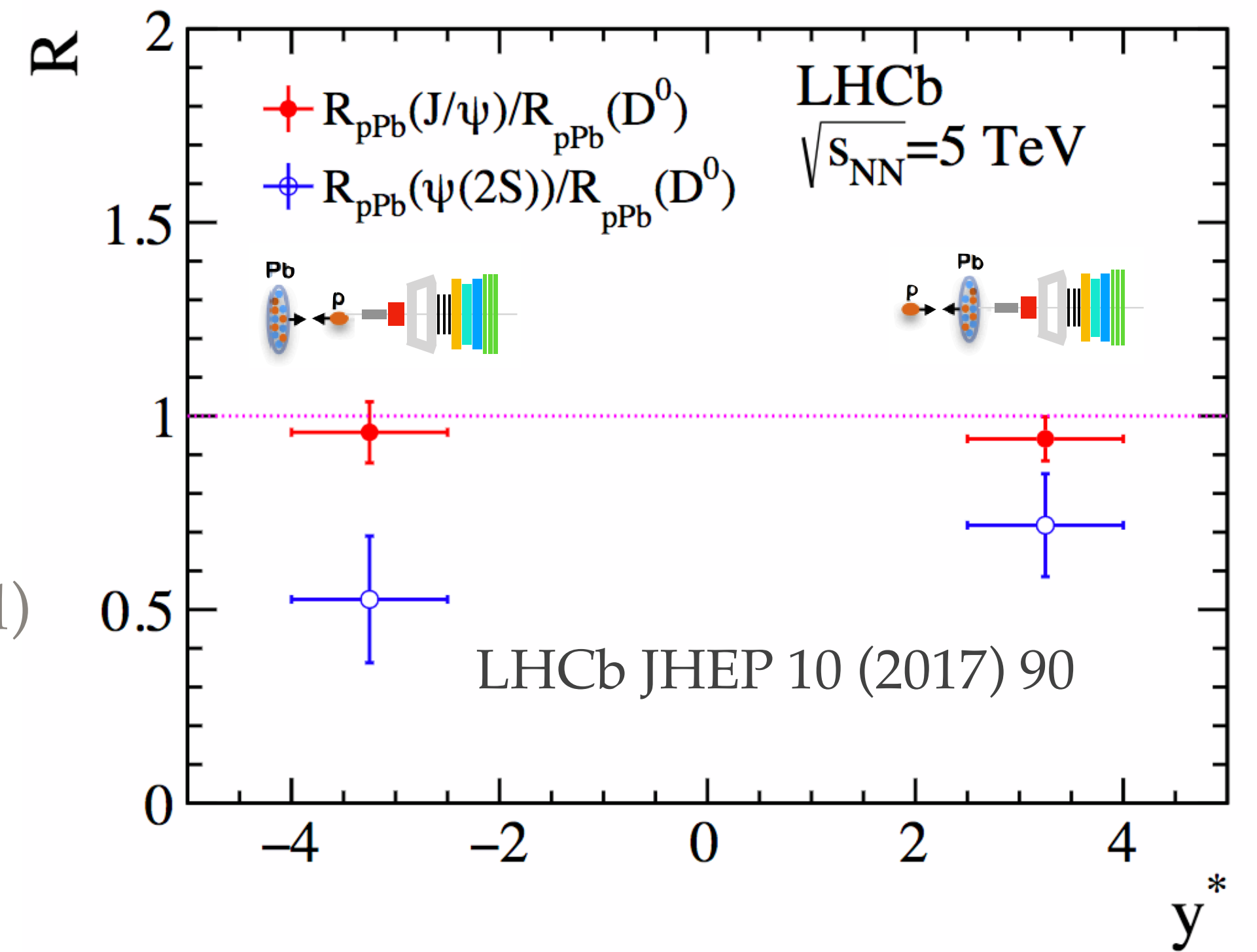
Quarkonia in AA collisions : UPC

Ultra-peripheral collision

Quarkonia in AA collisions : UPC

Ultra-peripheral collision

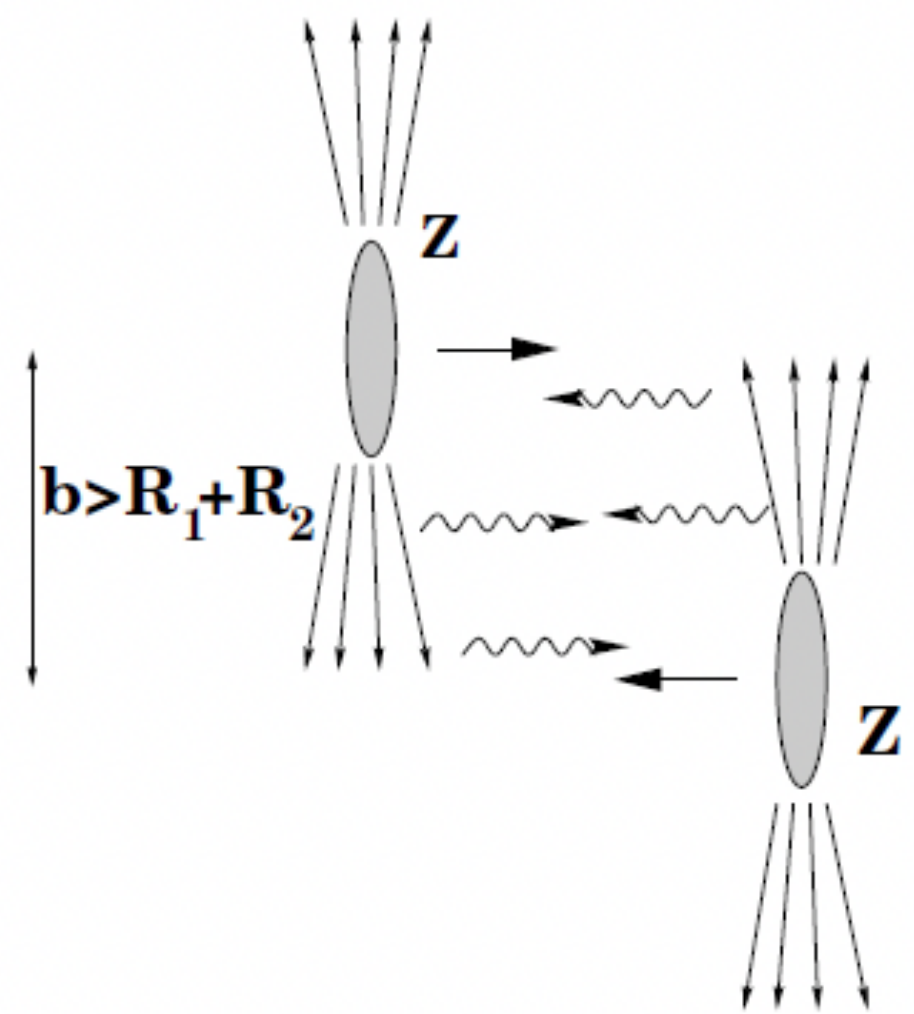Photon flux $\propto Z^2$

Double gluon exchange
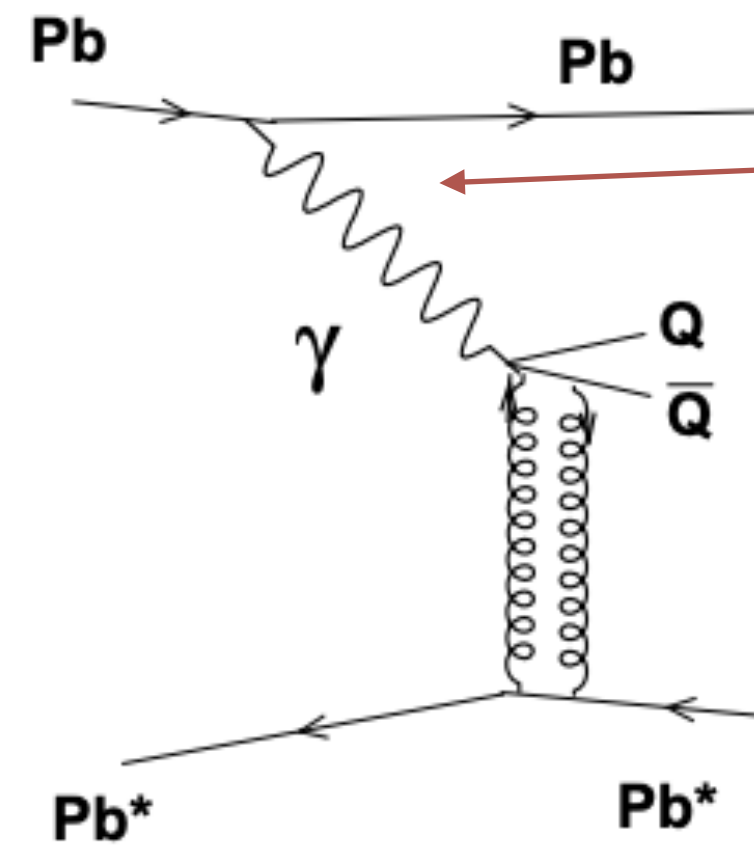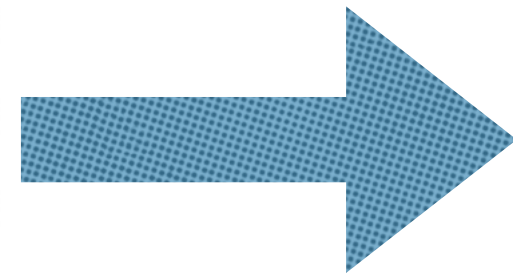
Quark pair production

❖ Quarkonia production in UPC **probe nPDFs/GPDs** with quasi-real photon

➡ See Tuesday's talks for nice discussions

Quarkonia in AA collisions : UPC

Ultra-peripheral collision

Quark pair production

Photon flux $\propto Z^2$
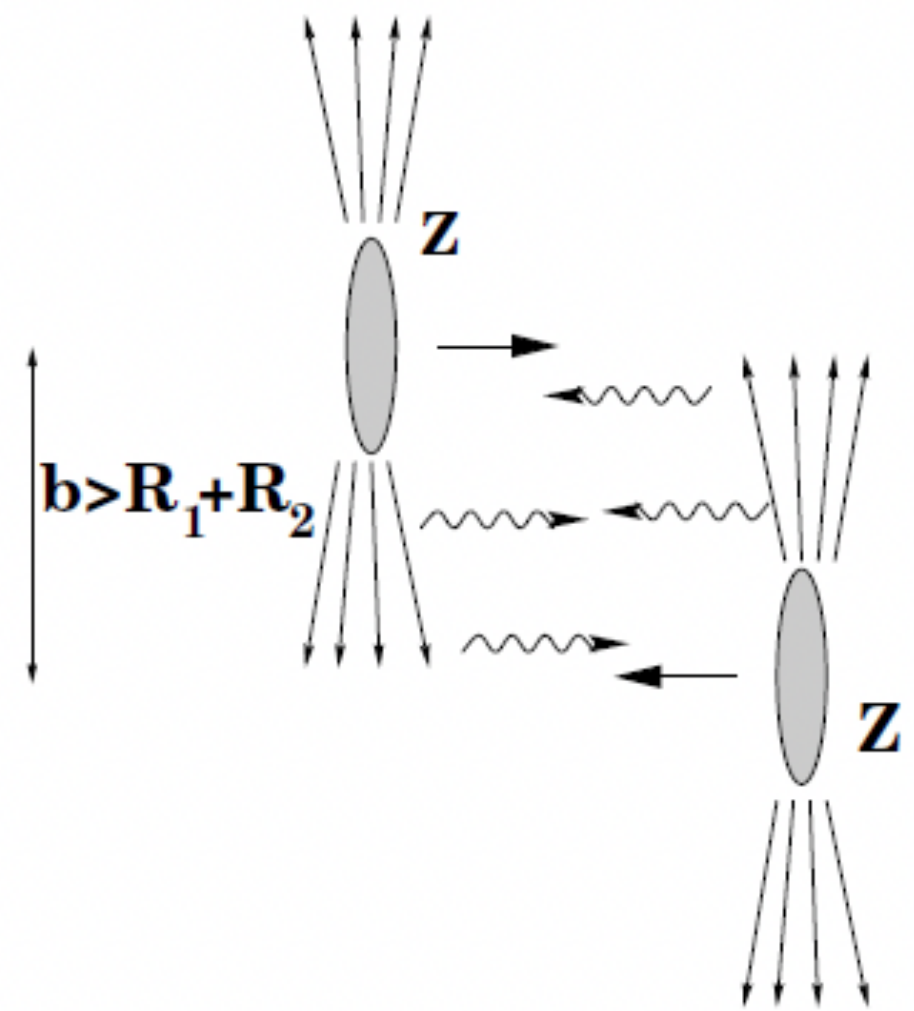
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❖ Quarkonia production in UPC **probe nPDFs/GPDs** with quasi-real photon
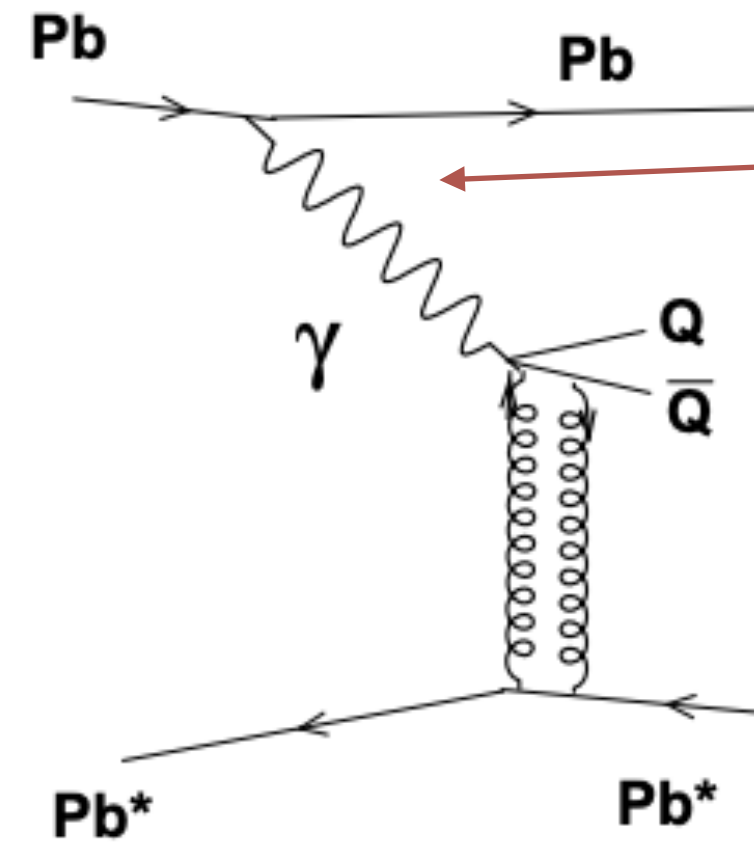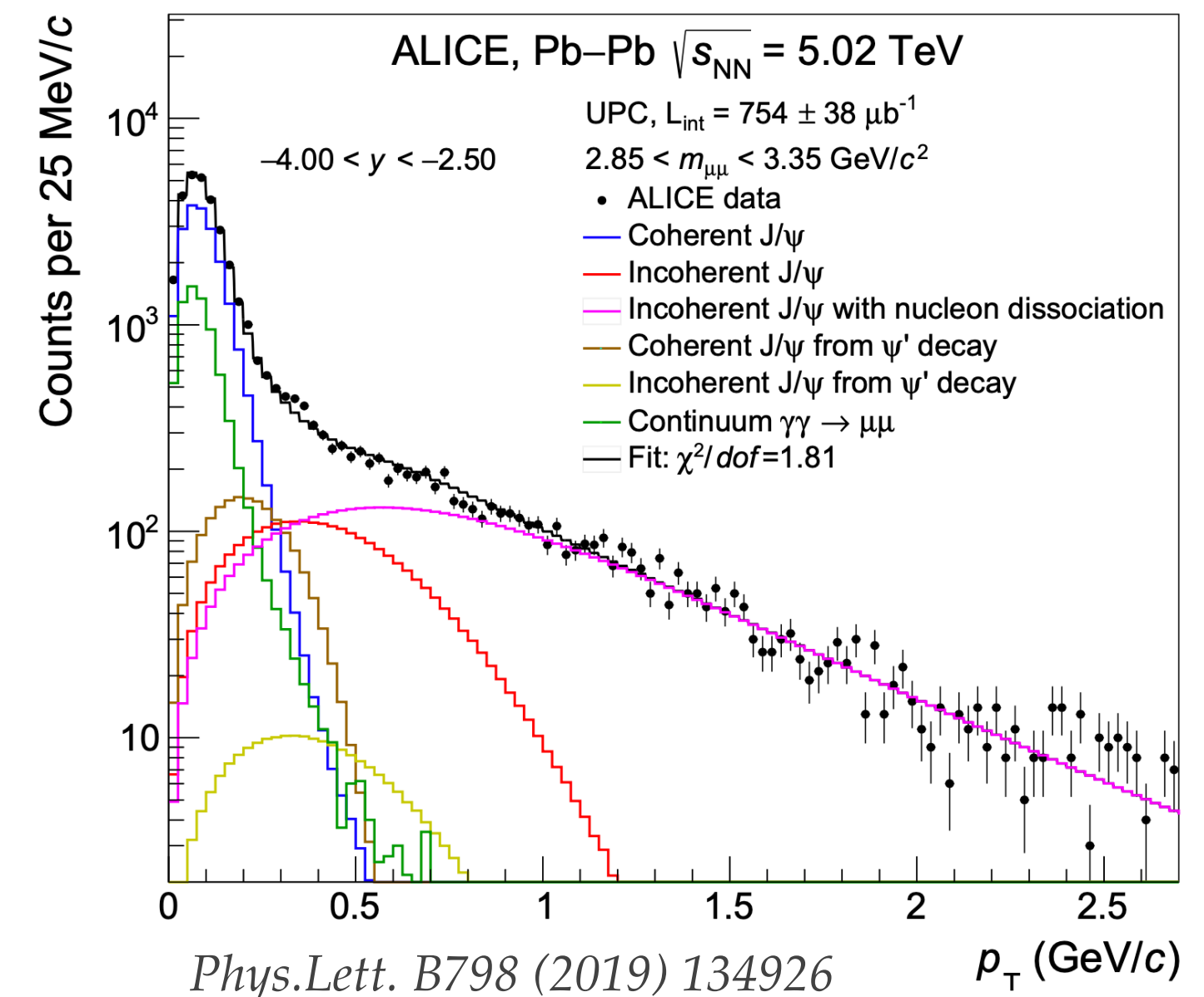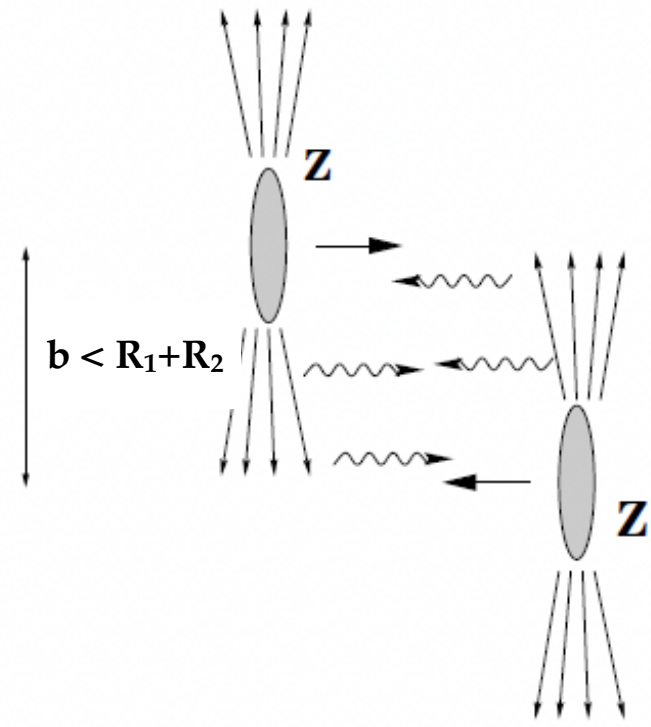
  ➡ See Tuesday's talks for nice discussions

Experimental characteristics :
- clean signal with low activity in the detector
- very low $p_T \propto 1/r_{target}$

Quarkonia in AA collisions : UPC

Ultra-peripheral collision

Photon flux $\propto$ **Z²**

Double gluon exchange

Quark pair production

ALICE, Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- Quarkonia production in UPC **probe nPDFs/GPDs** with quasi-real photon

  ➡ See Tuesday's talks for nice discussions

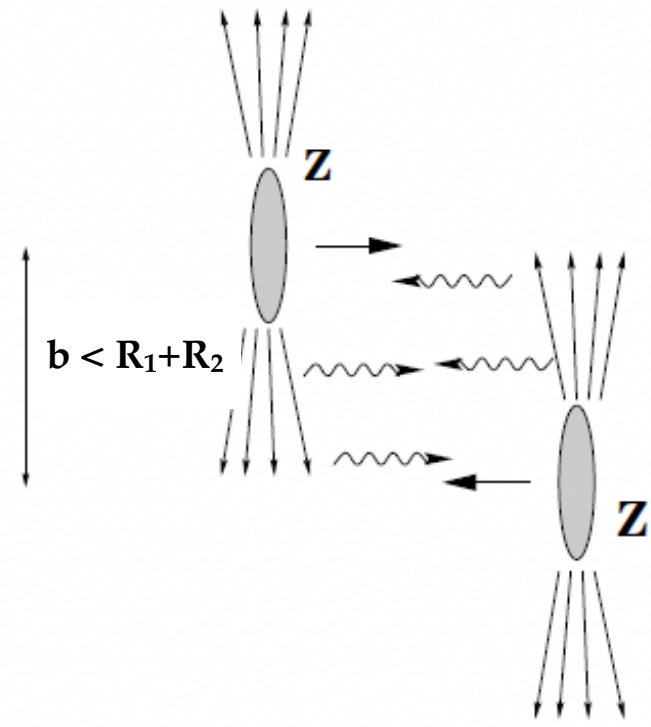- **Good momentum resolution at low-p_T = good control on the background contributions**

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Phys.Lett. B798 (2019) 134926

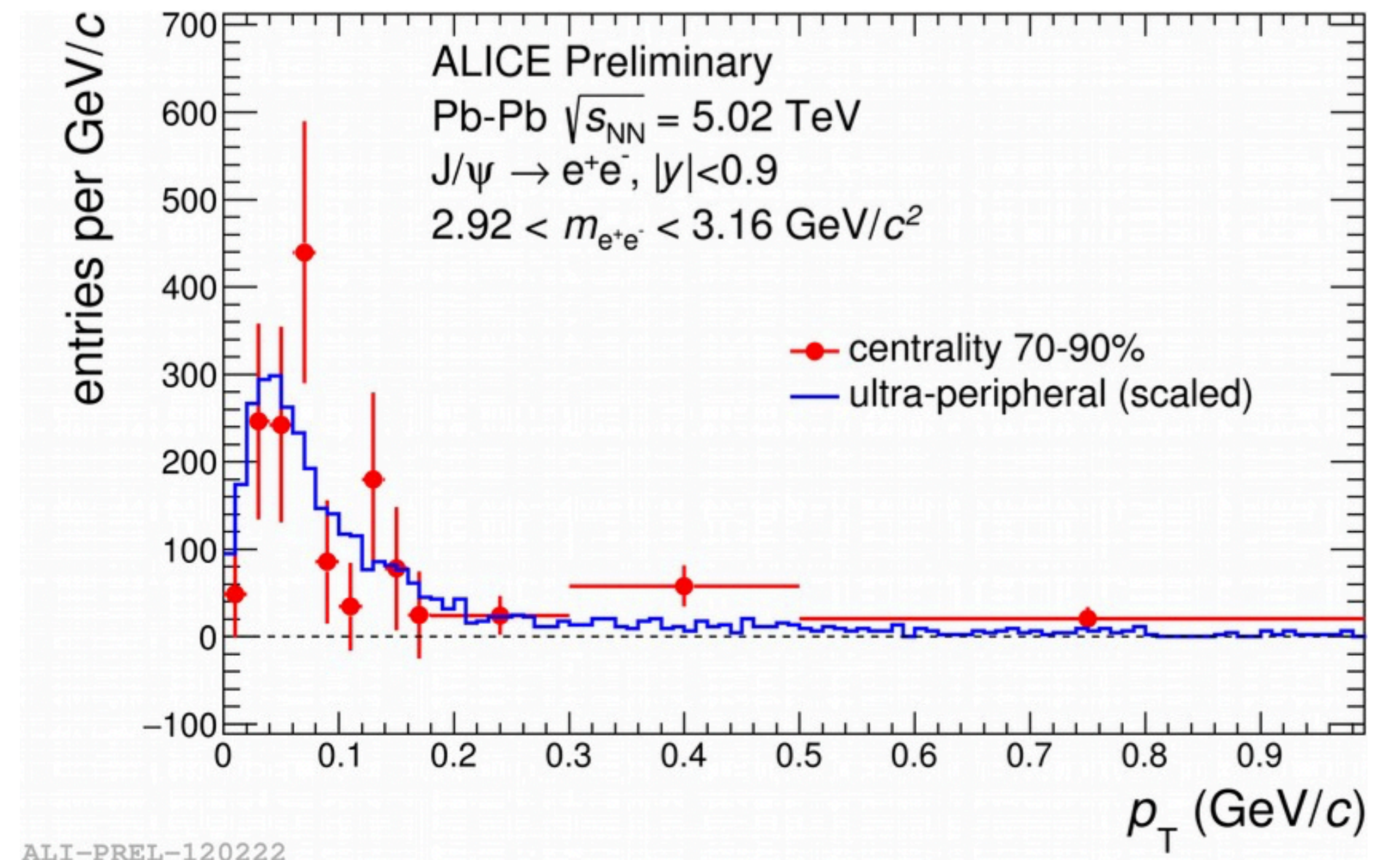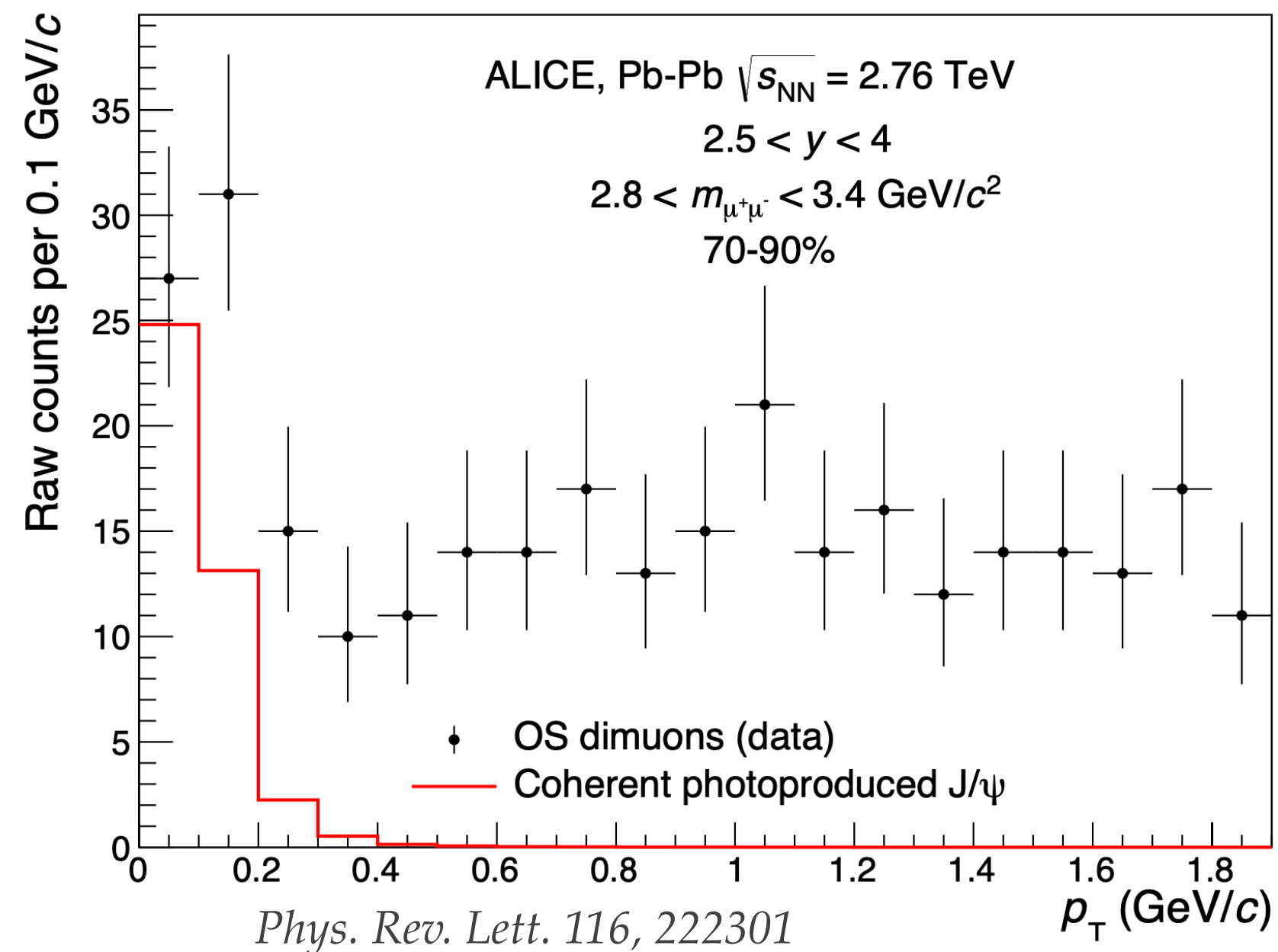*Peripheral collision*

$b < R_1 + R_2$

Quarkonia in AA collisions : UPC with nuclear overlap

Peripheral collision

$b < R_1 + R_2$

❖ Very-low p_T excess measured by ALICE at LHC

➡ Mostly likely photo-production → good p_T resolution

ALICE, Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$2.5 < y < 4$
$2.8 < m_{\mu^+\mu^-} < 3.4$ GeV/c^2
70-90%

OS dimuons (data)
Coherent photoproduced J/ψ

Phys. Rev. Lett. 116, 222301

ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
J/ψ → e⁺e⁻, $|y|$<0.9
$2.92 < m_{e^+e^-} < 3.16$ GeV/c^2

centrality 70-90%
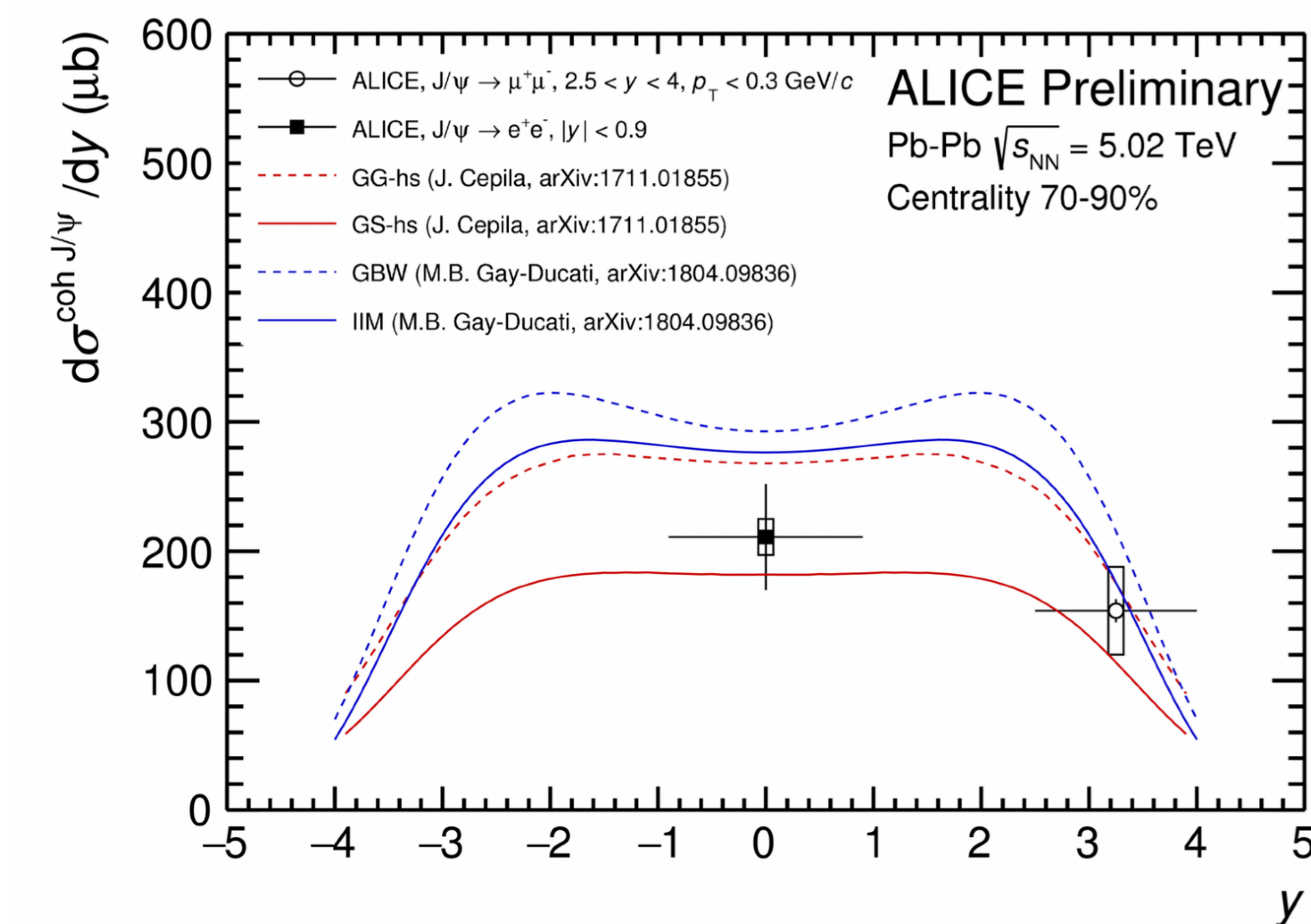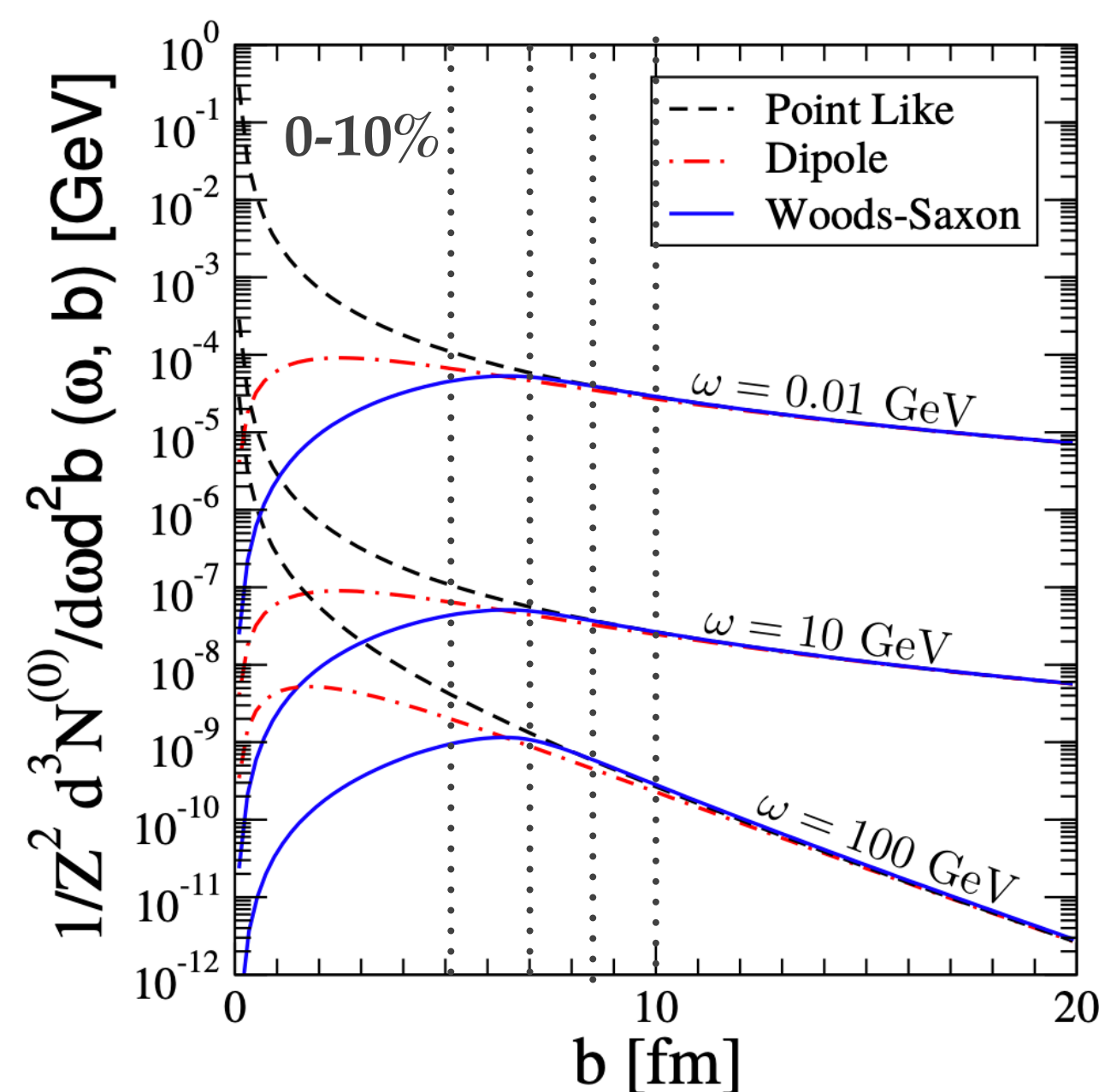ultra-peripheral (scaled)

ALI-PREL-120222

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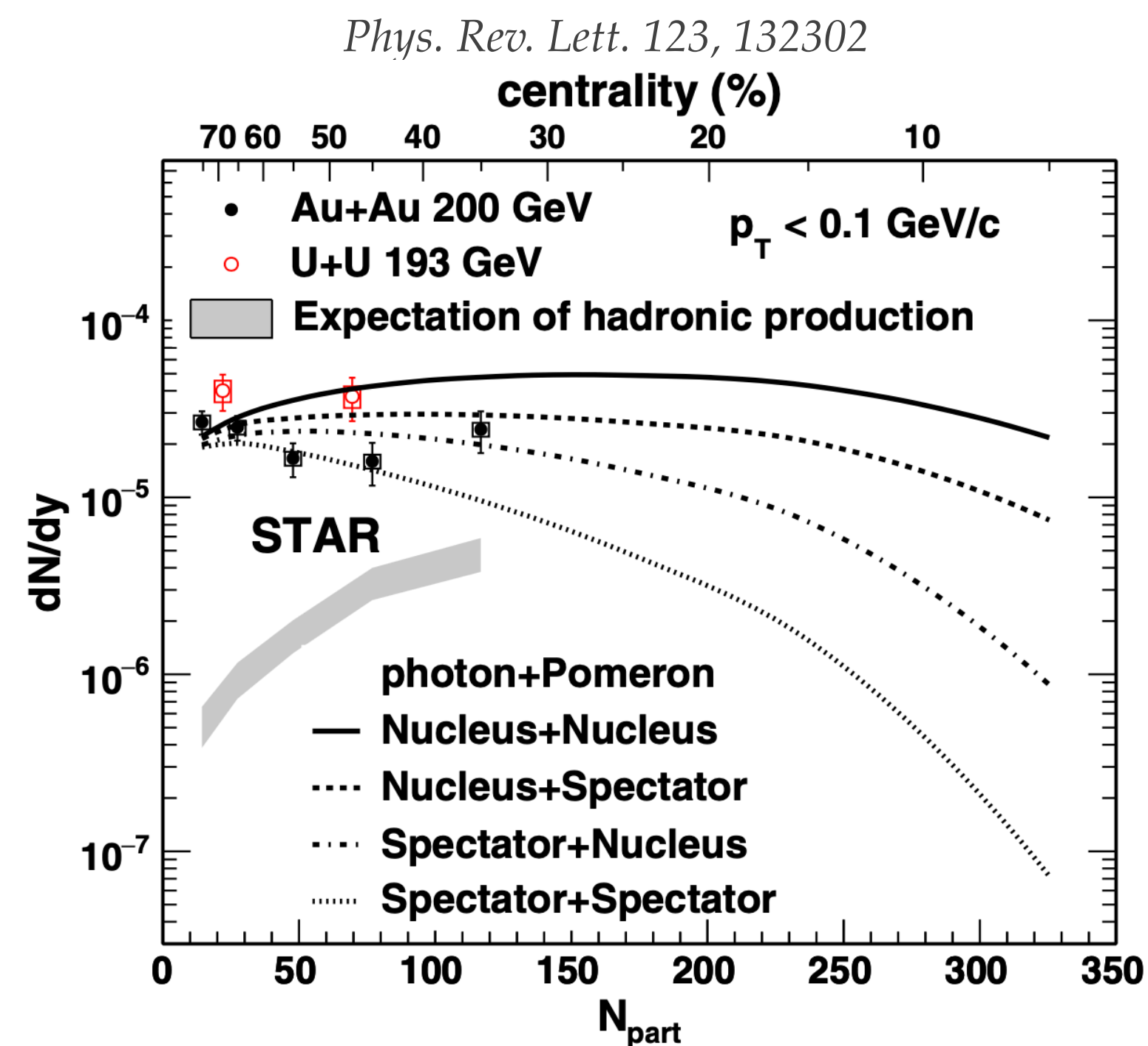# Quarkonia in AA collisions : UPC with nuclear overlap

Peripheral collision

$b < R_1 + R_2$

* Very-low p_T excess measured by ALICE at LHC

  → Mostly likely photo-production → good p_T resolution

* Prob for the **photon flux** and **the geometry** of the collisions

Phys. Rev. D 96, 056014 (2017)

FIG. 1: The b-dependence photon flux distribution for the different form factors of the lead nuclei.

Phys. Rev. Lett. 123, 132302

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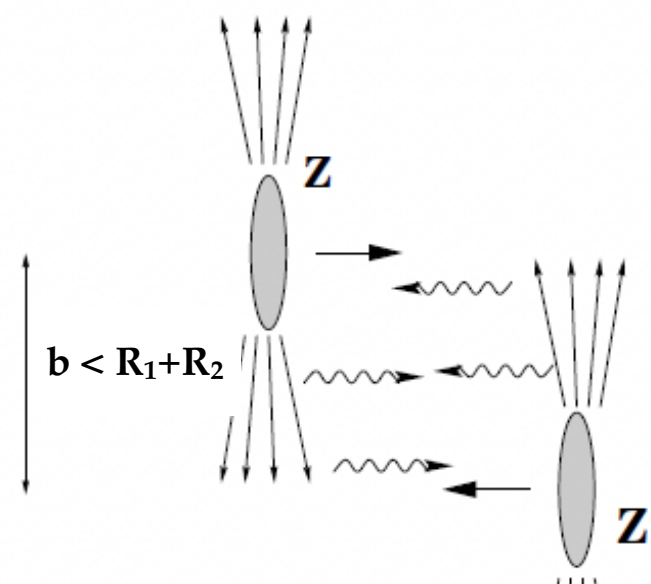# Quarkonia in AA collisions : UPC with nuclear overlap

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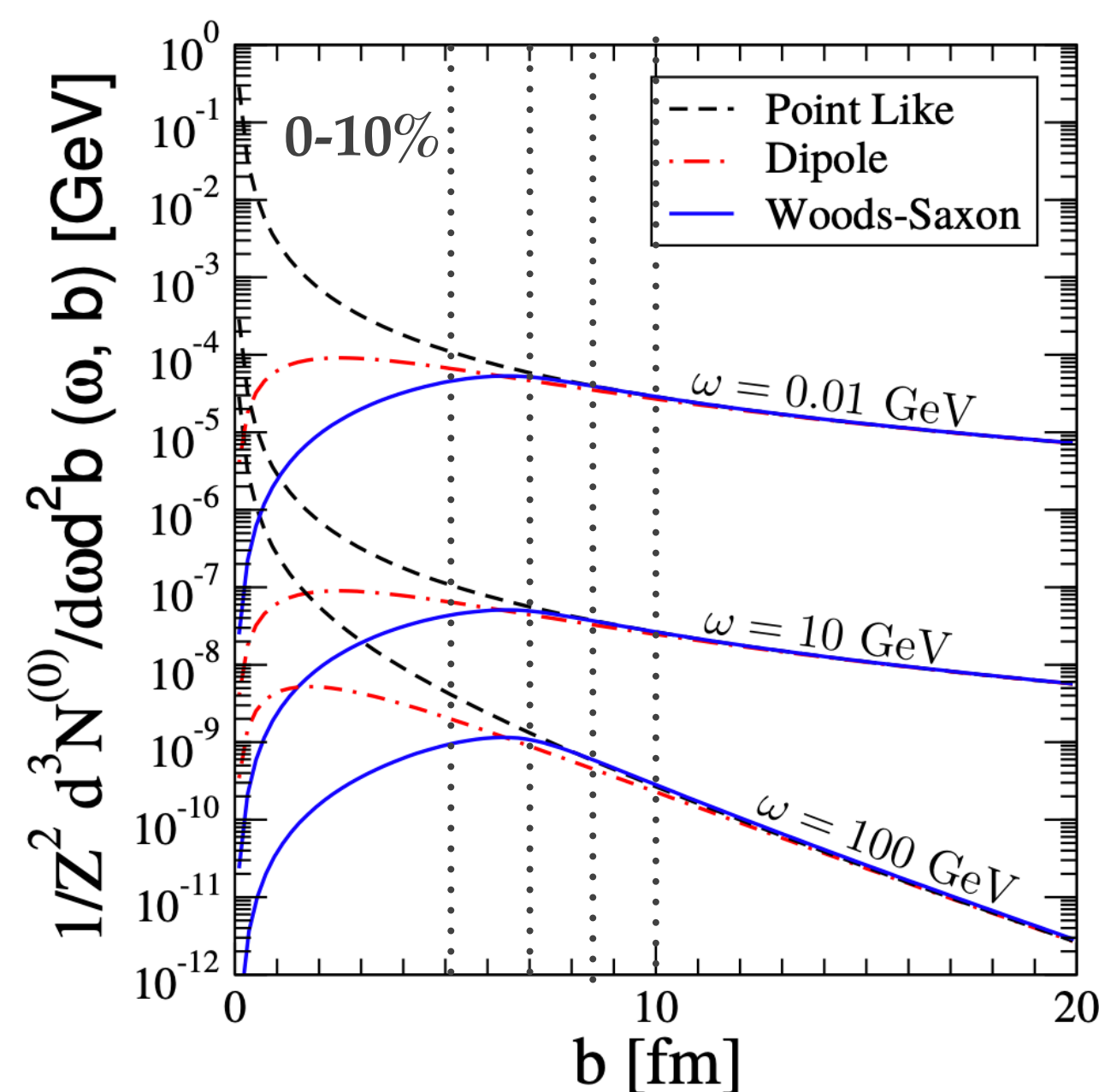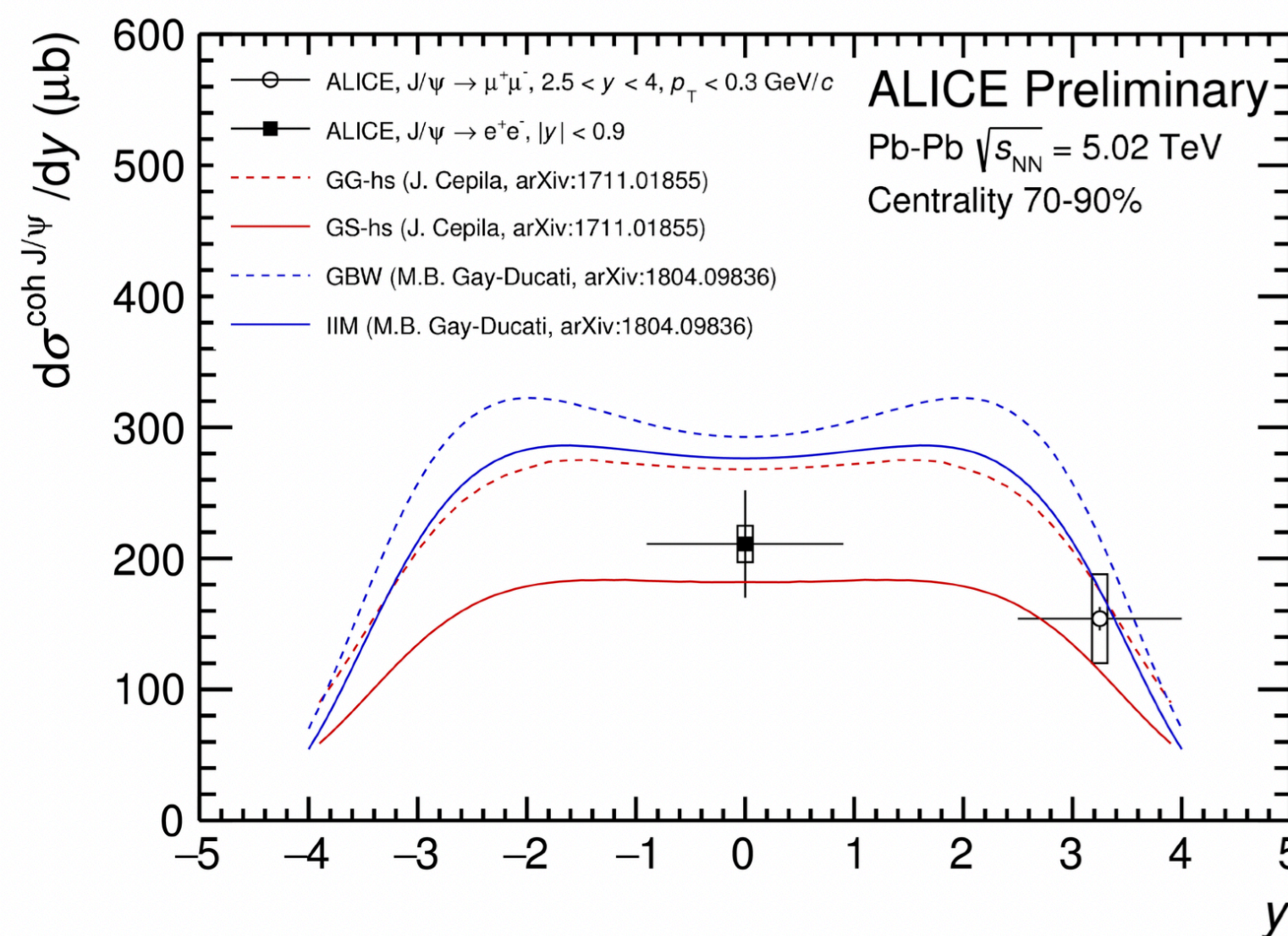❖ Very-low p_T excess measured by ALICE at LHC

➡ Mostly likely photo-production → good p_T resolution

❖ Prob for the **photon flux** and **the geometry** of the collisions

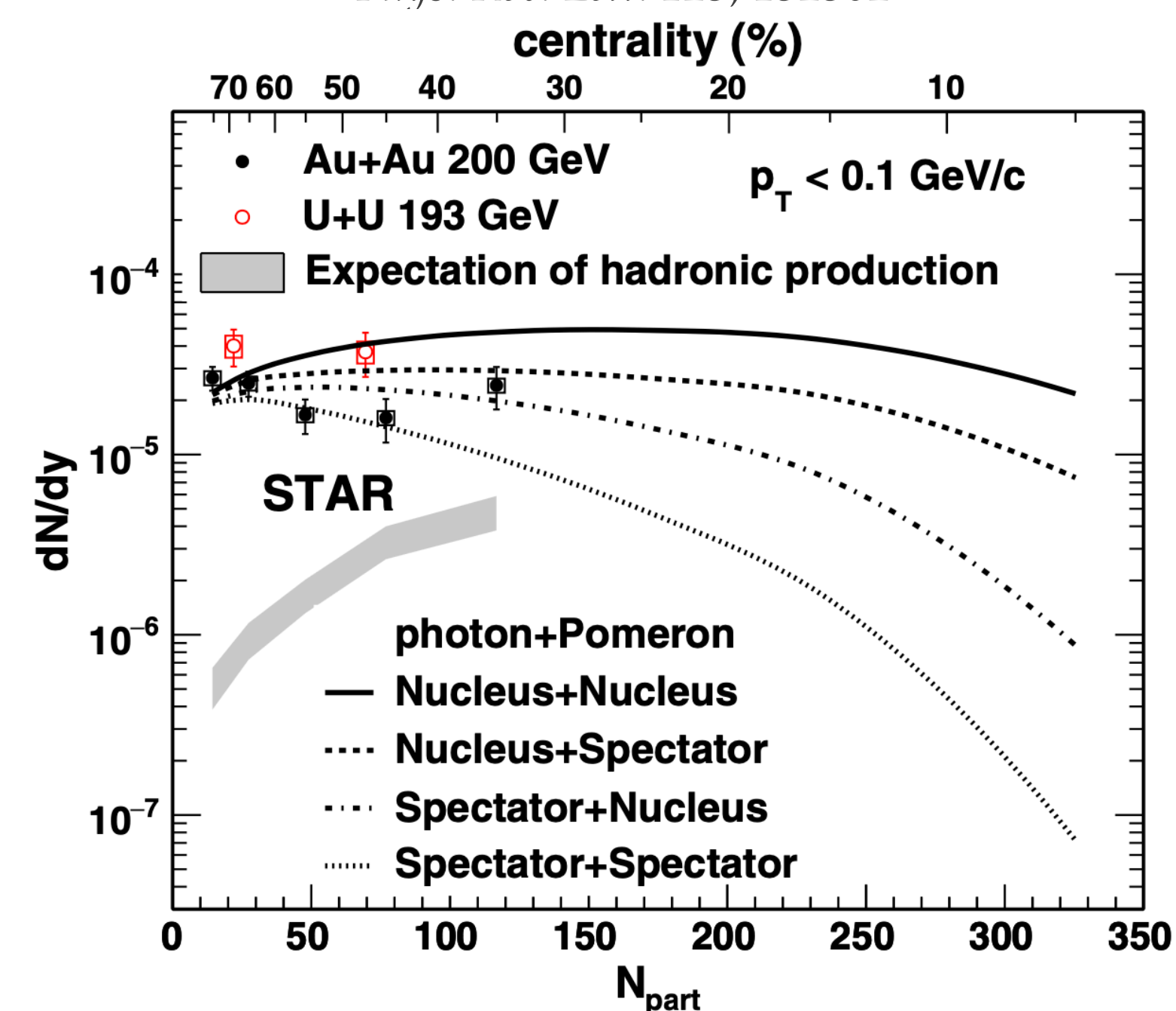❖ Open-question : Could it be useful for QGP studies ?

Phys. Rev. Lett. 123, 132302

LHCb and quarkonia

The LHCb detector

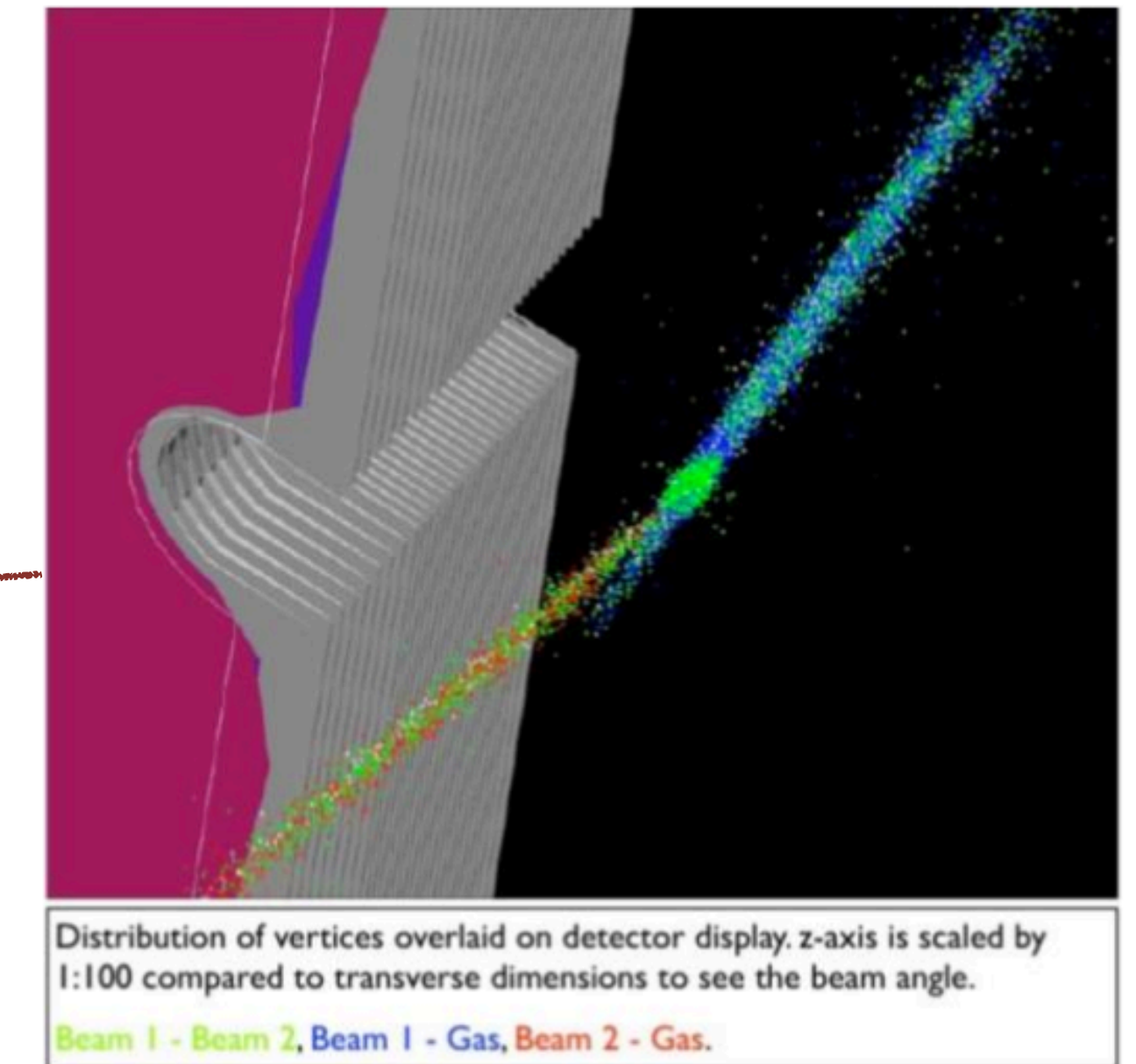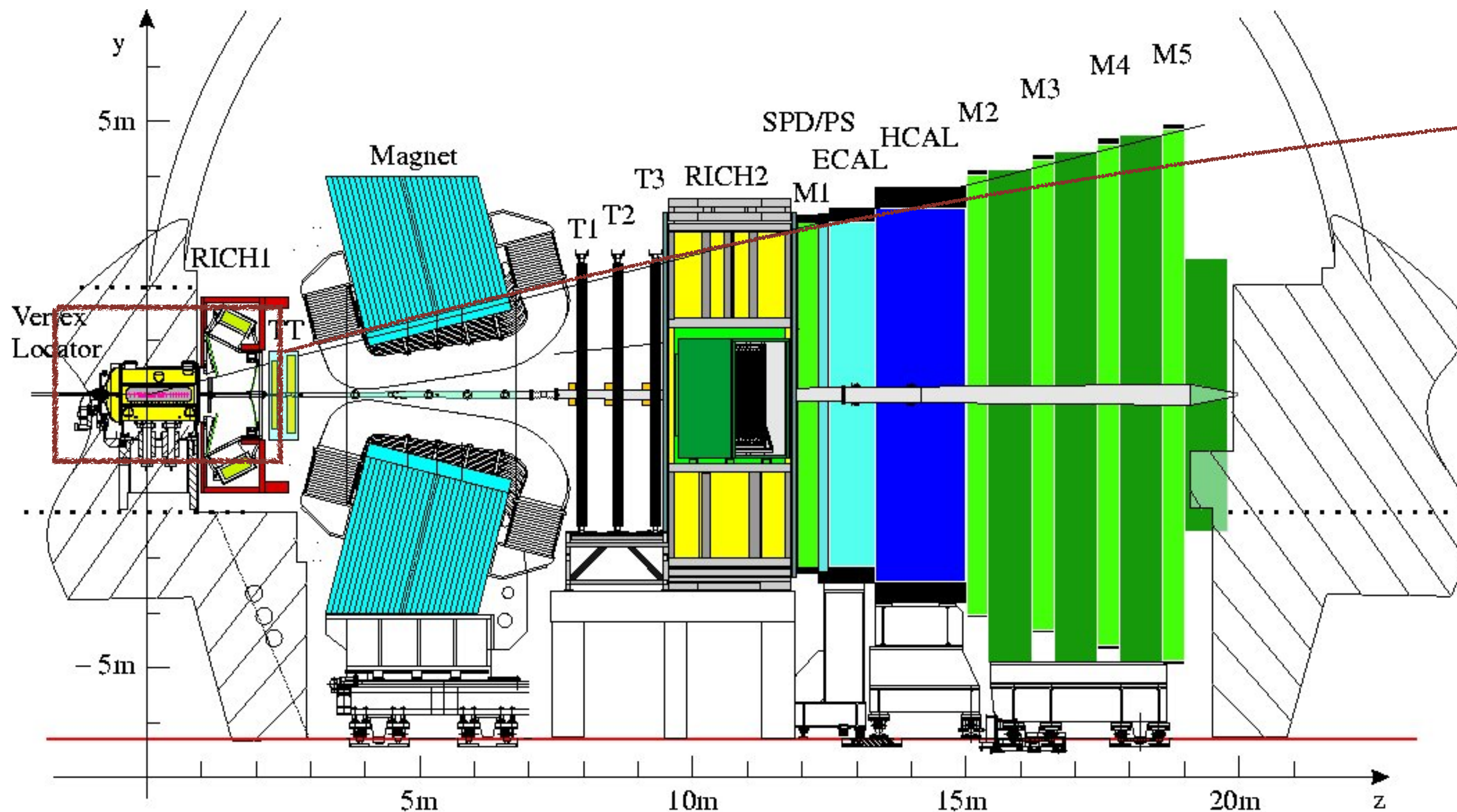LHCb : **single arm spectrometer** **fully instrumented** in pseudo-rapidity range **2 < η < 5**
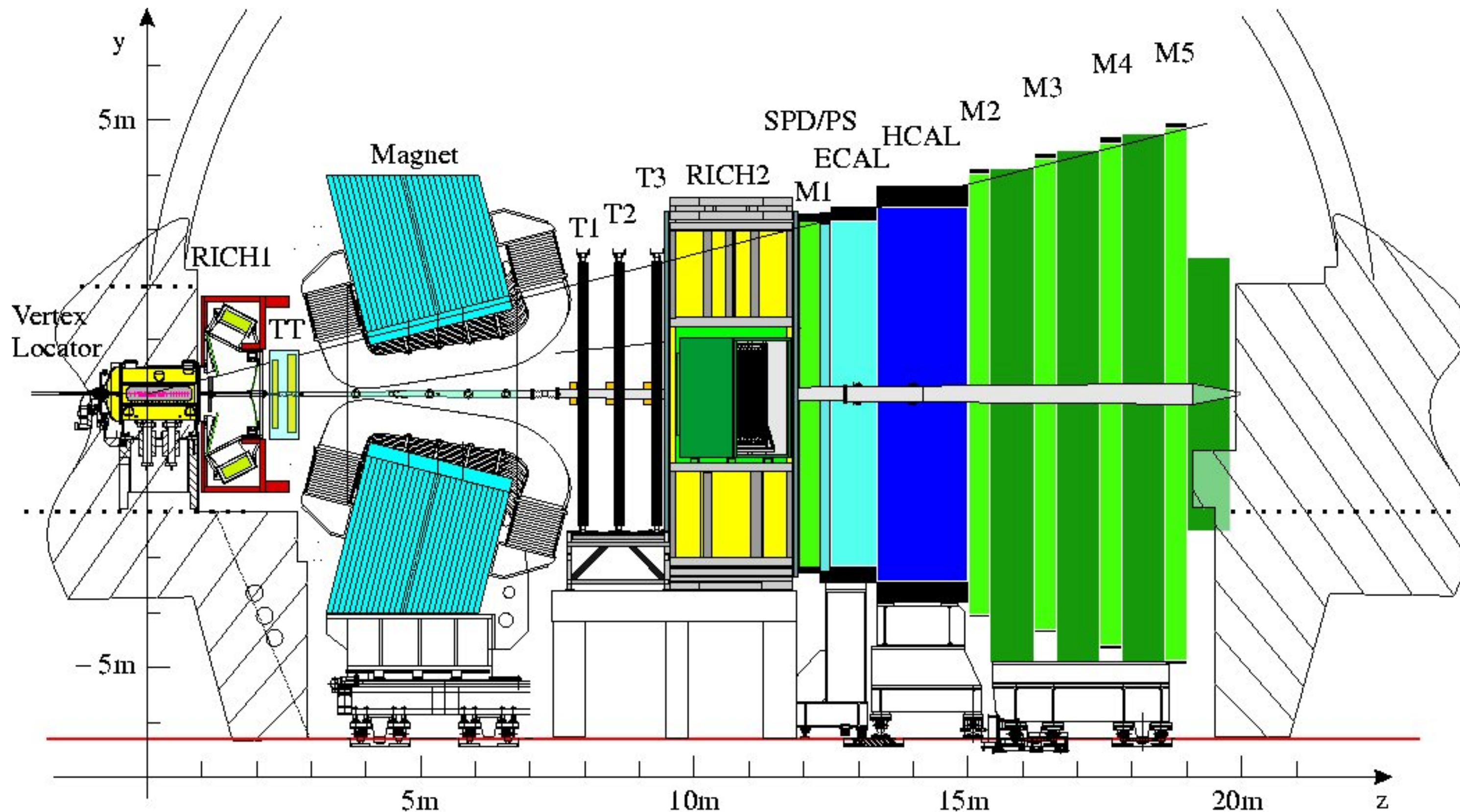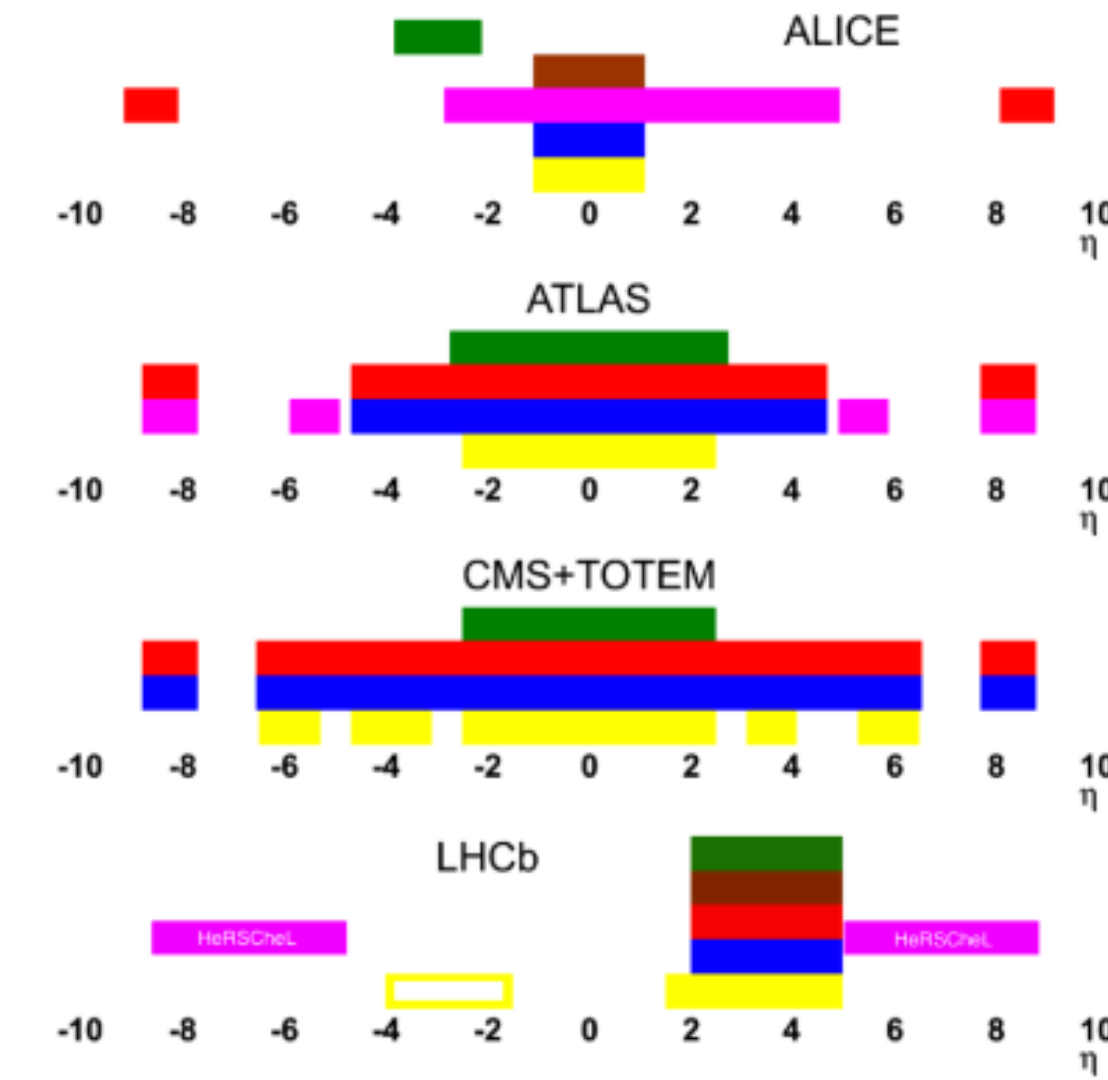
* Track reconstruction **down to p_T = 0**.

* Excellent **p_T and mass resolution.**

* Excellent **particle identification.**

* Precision **vertex reconstruction.**

The LHCb detector

Can operate both in pp/pPb/PbPb and fixed-target !

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.
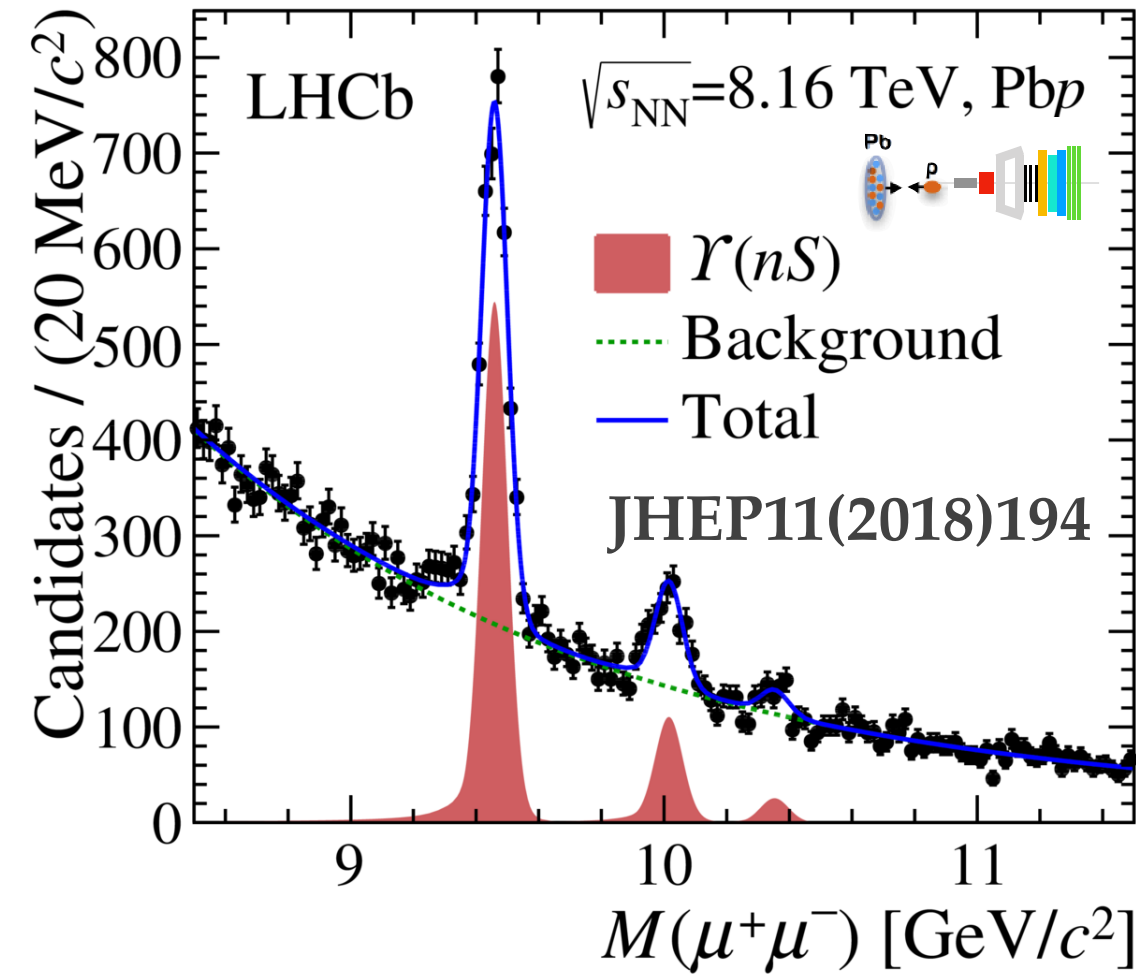
Fixed-target mode: **unique at LHC !**
- Injecting gas in the LHCb VErtex LOcator (VELO) tank.
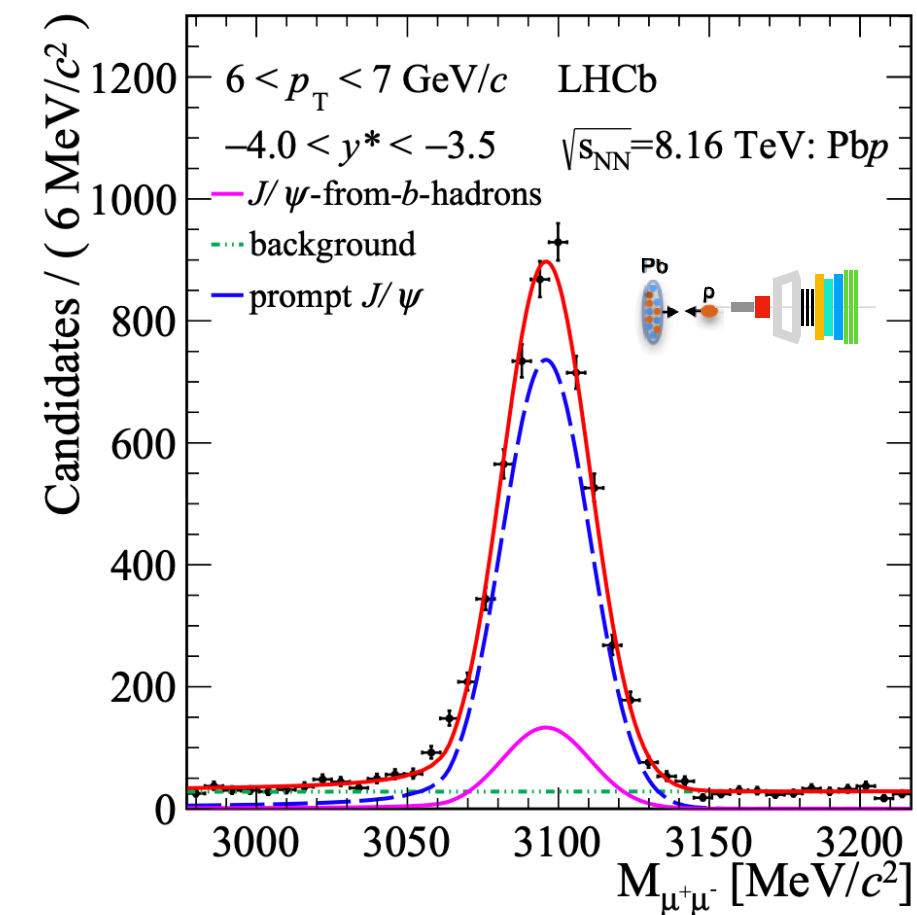- **Noble gas only** : He, Ne, Ar
- Gas pressure : 10^{-7} to 10^{-6} mbar

Expectations from pPb results
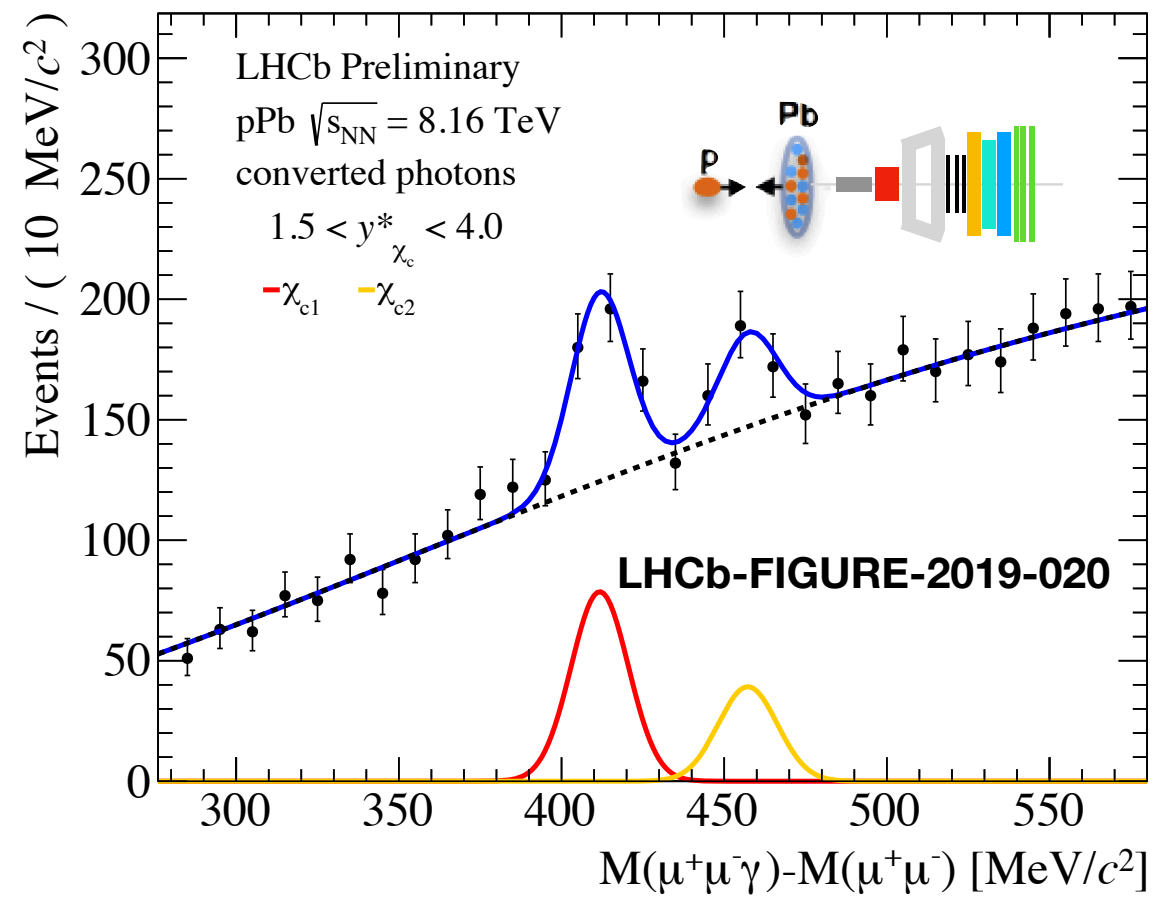
Distinct χ_c pics observed in pPb

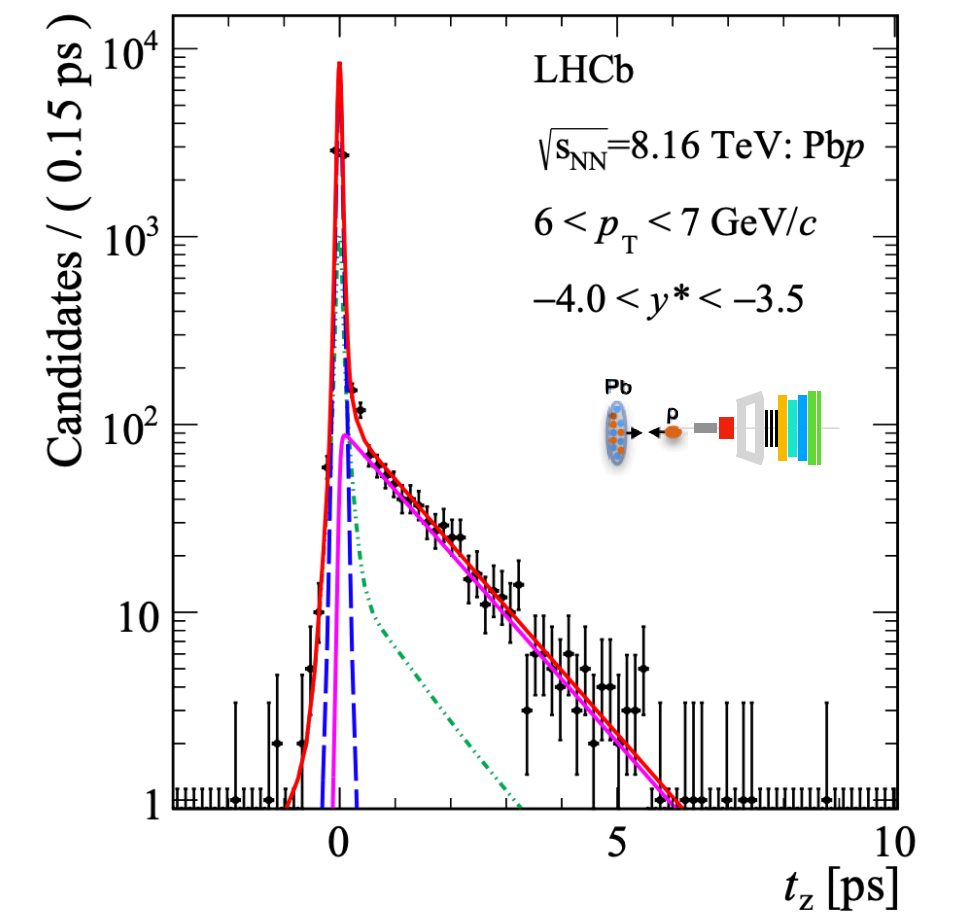**Distinct Υ pics measured in pPb**

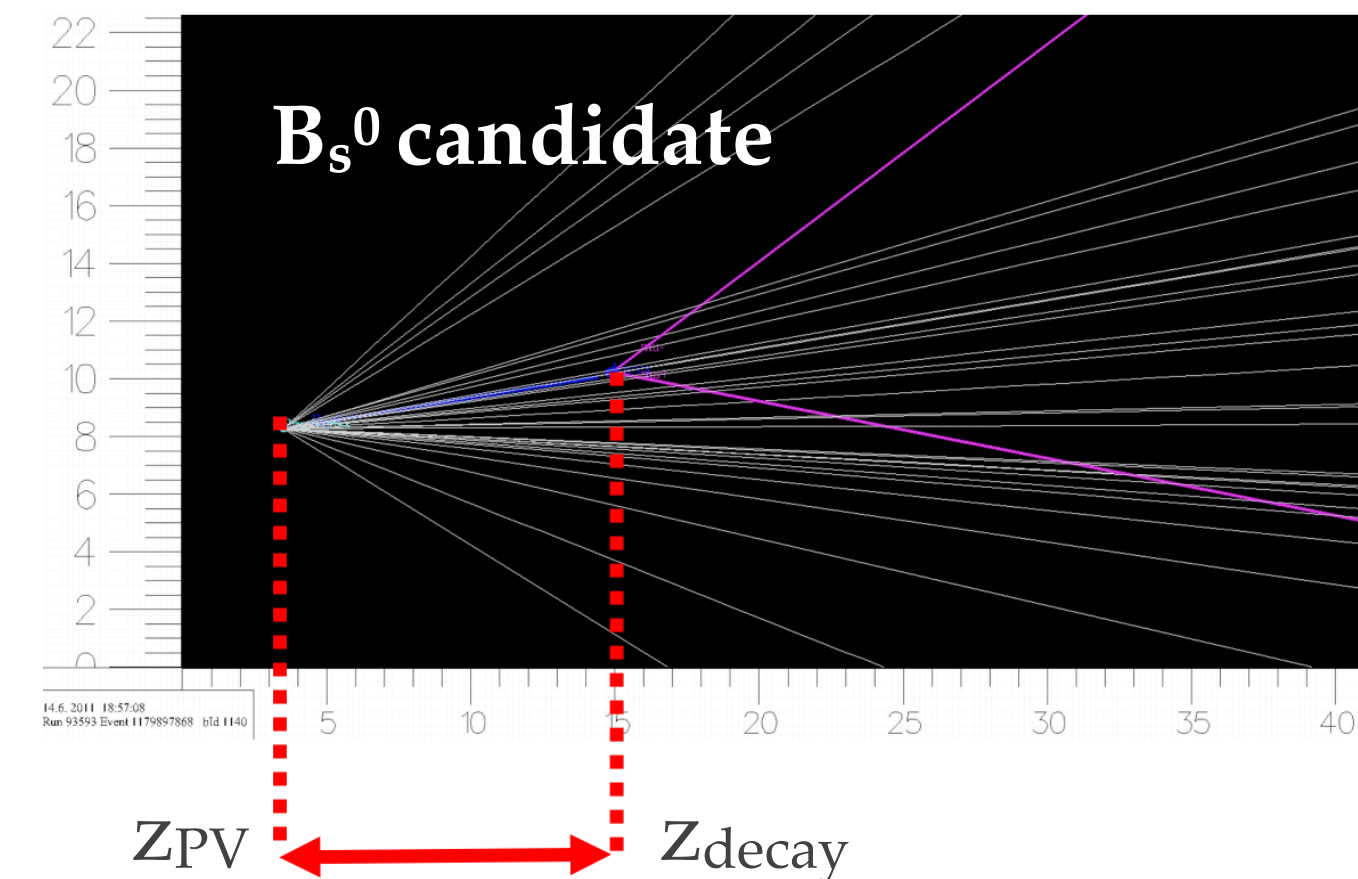**Good prompt/non-prompt separation power**

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

Same performances expected in PbPb collisions
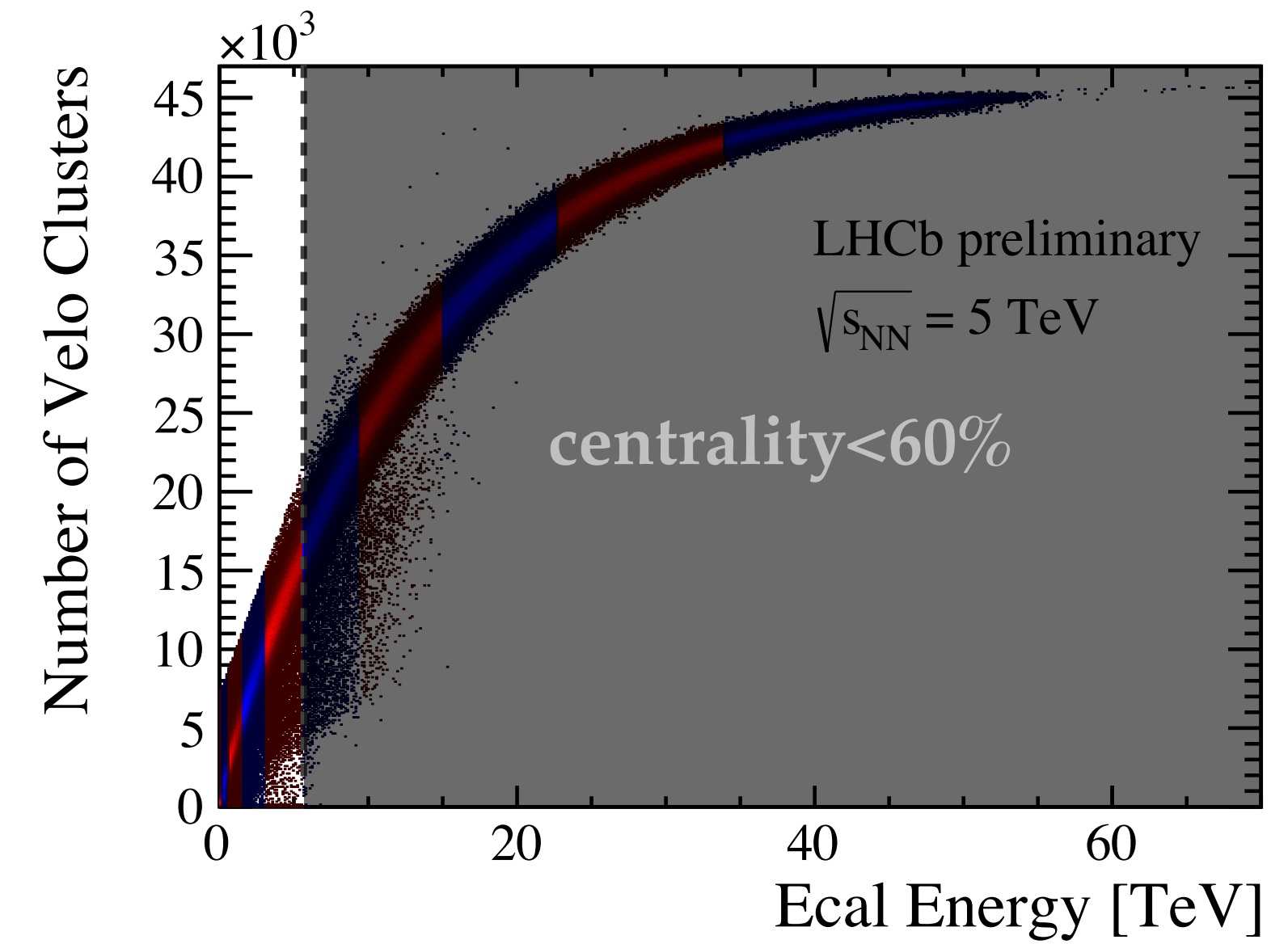
B_s^0 candidate

z_{PV} z_{decay}

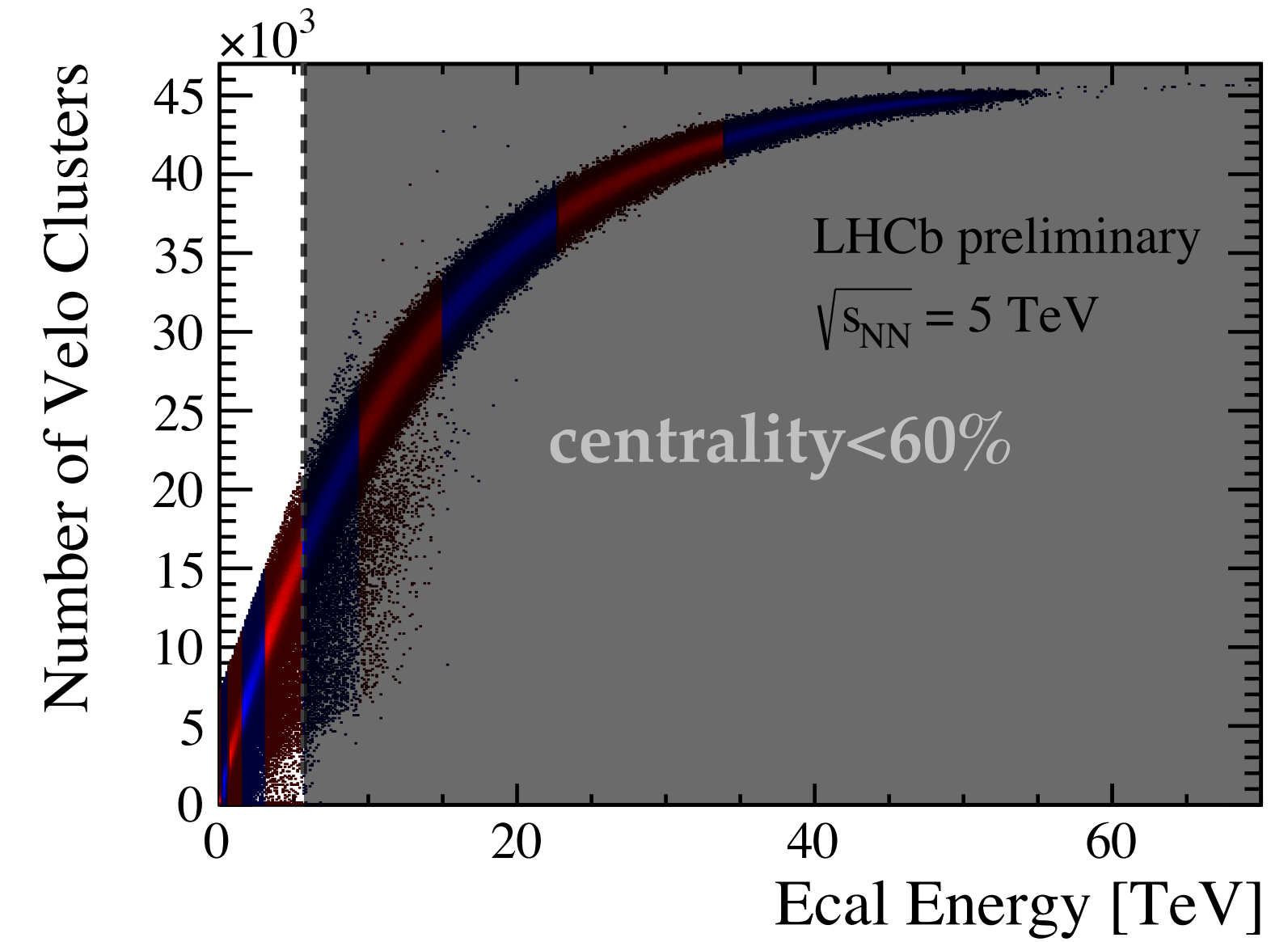# Status in nucleus-nucleus collisions

VELO saturation → loss of tracking efficiency

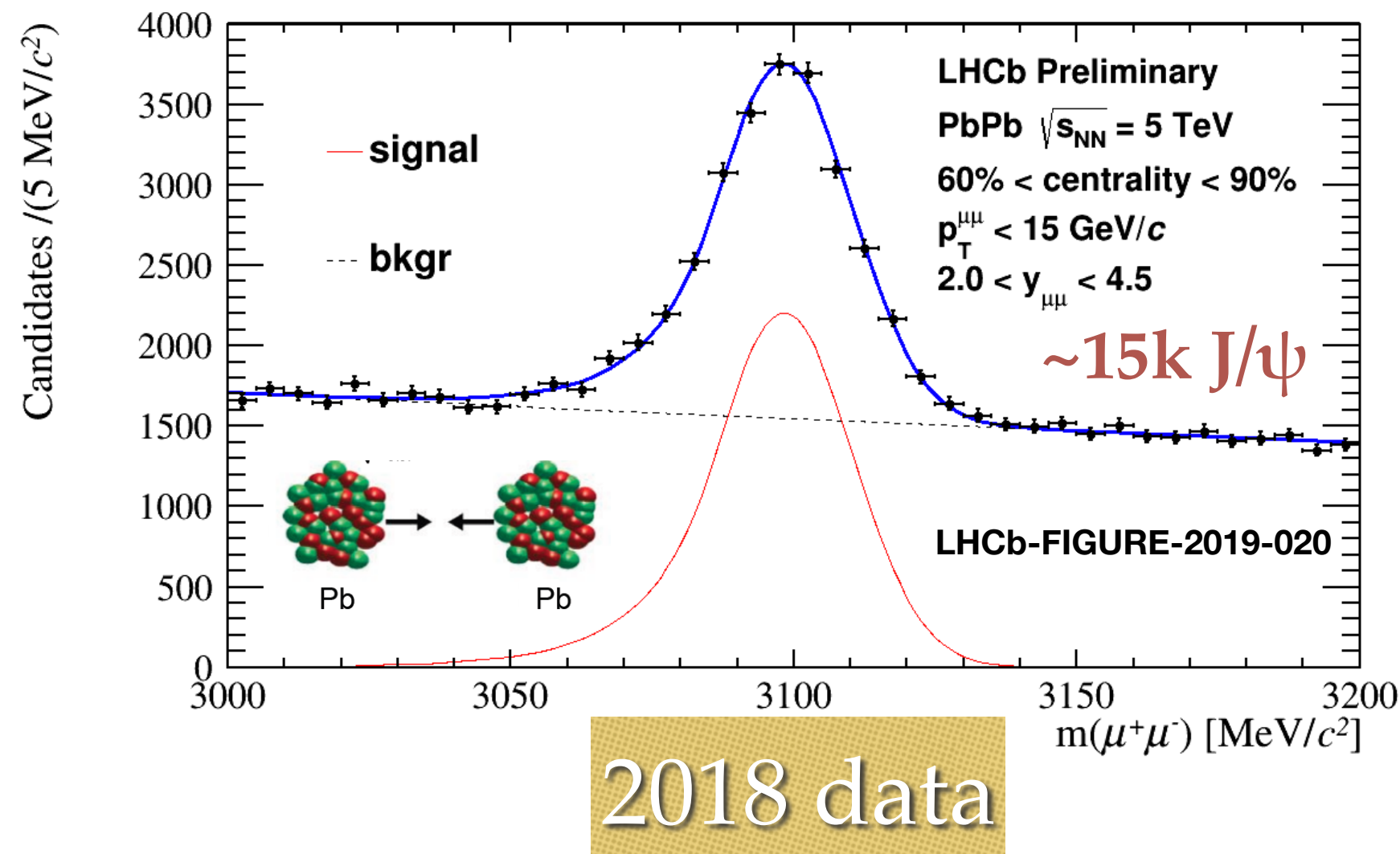# Status in nucleus-nucleus collisions

Studies in PbPb <u>limited to 60%</u> less central collisions.

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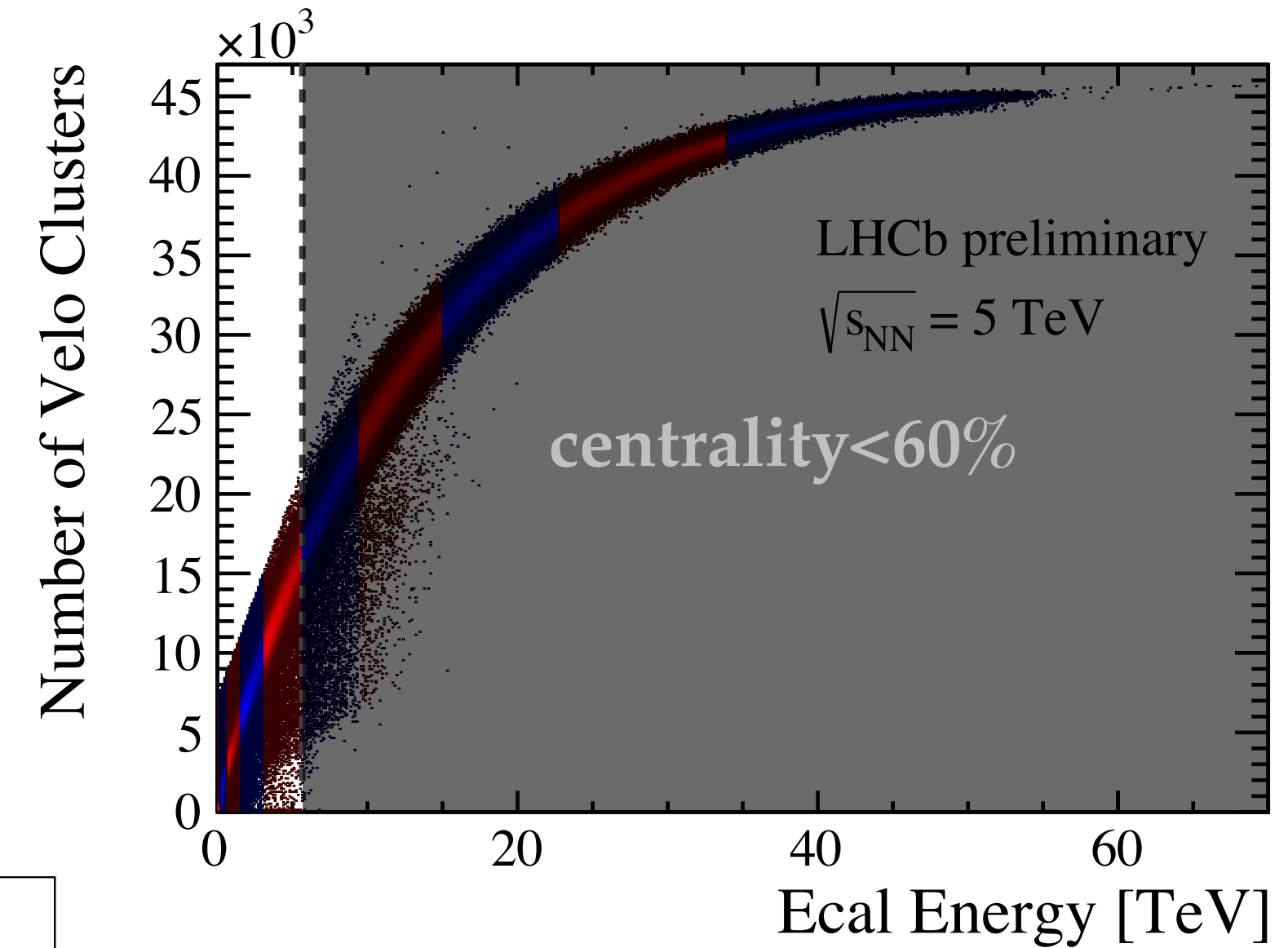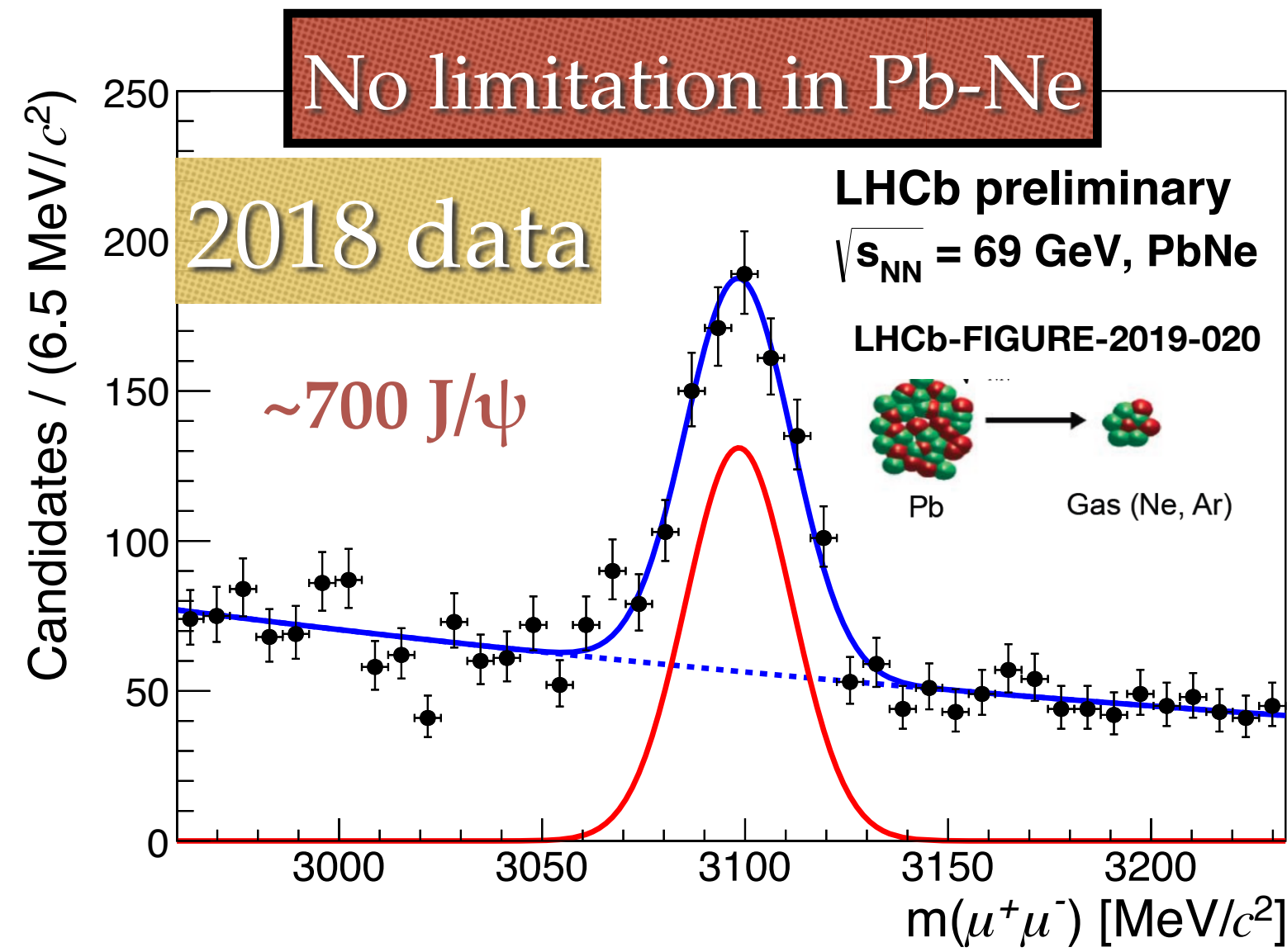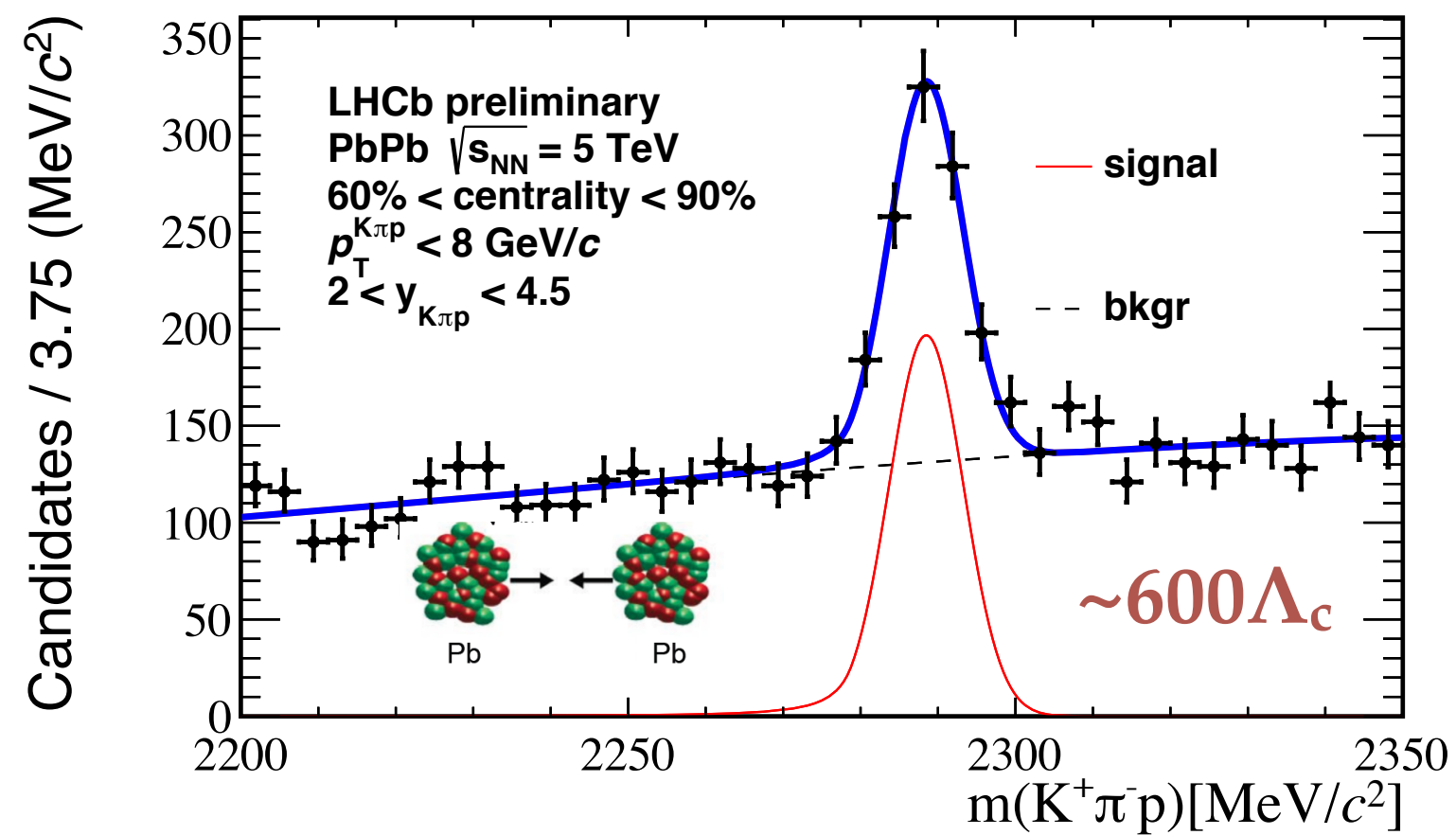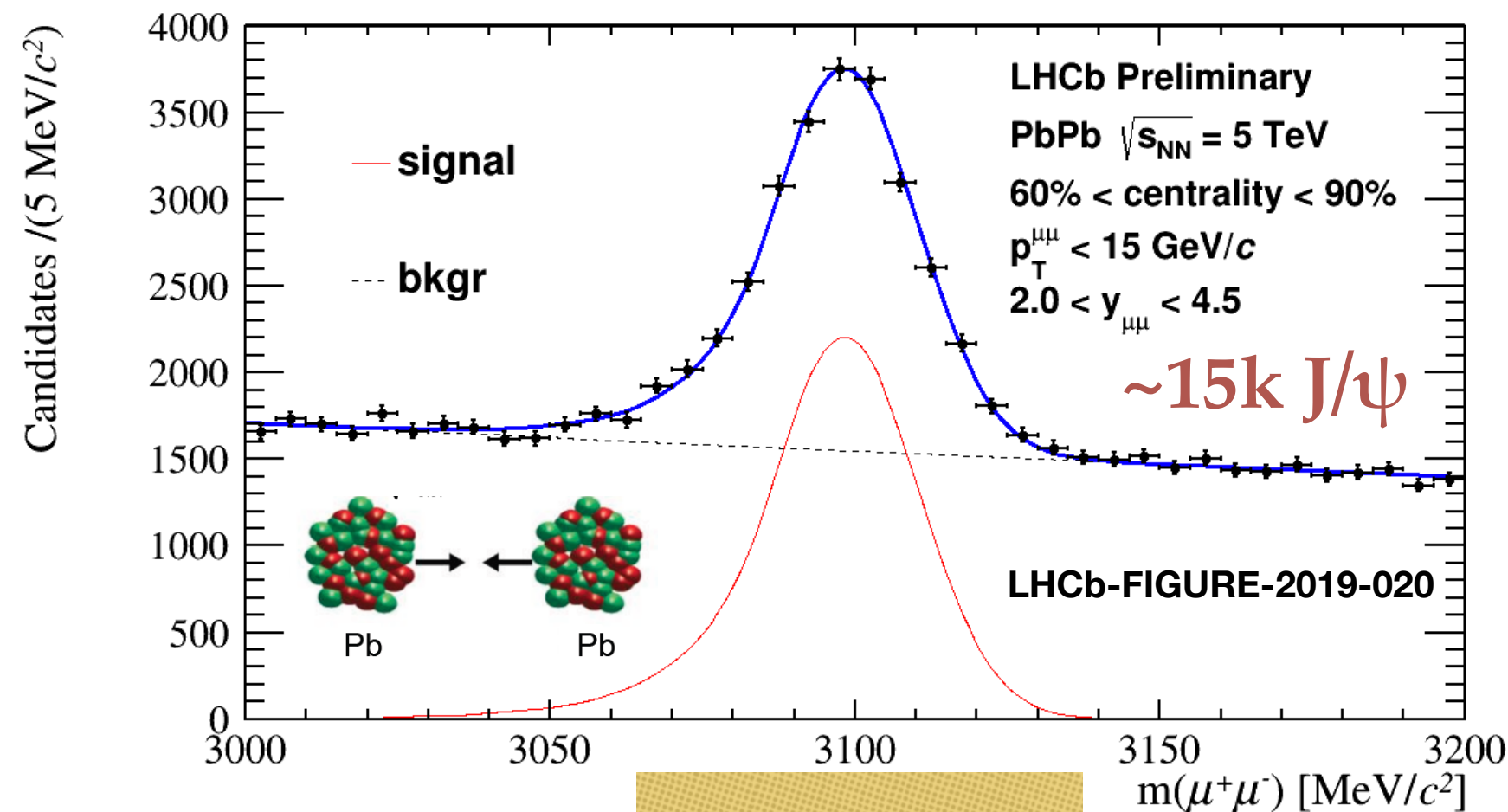
VELO saturation → loss of tracking efficiency

Status in nucleus-nucleus collisions

LHCb Preliminary
PbPb $\sqrt{s_{NN}}$ = 5 TeV
60% < centrality < 90%
$p_T^{\mu\mu}$ < 15 GeV/c
2.0 < $y_{\mu\mu}$ < 4.5

~15k J/ψ

LHCb-FIGURE-2019-020

2018 data

signal
bkgr

Studies in PbPb <u>limited to 60%</u> less central collisions.

Analysis ongoing, stay tuned !

LHCb preliminary
$\sqrt{s_{NN}}$ = 5 TeV

centrality<60%

VELO saturation → loss of tracking efficiency

LHCb preliminary
PbPb $\sqrt{s_{NN}}$ = 5 TeV
60% < centrality < 90%
$p_T^{K\pi p}$ < 8 GeV/c
2 < $y_{K\pi p}$ < 4.5

signal
bkgr

~600Λc
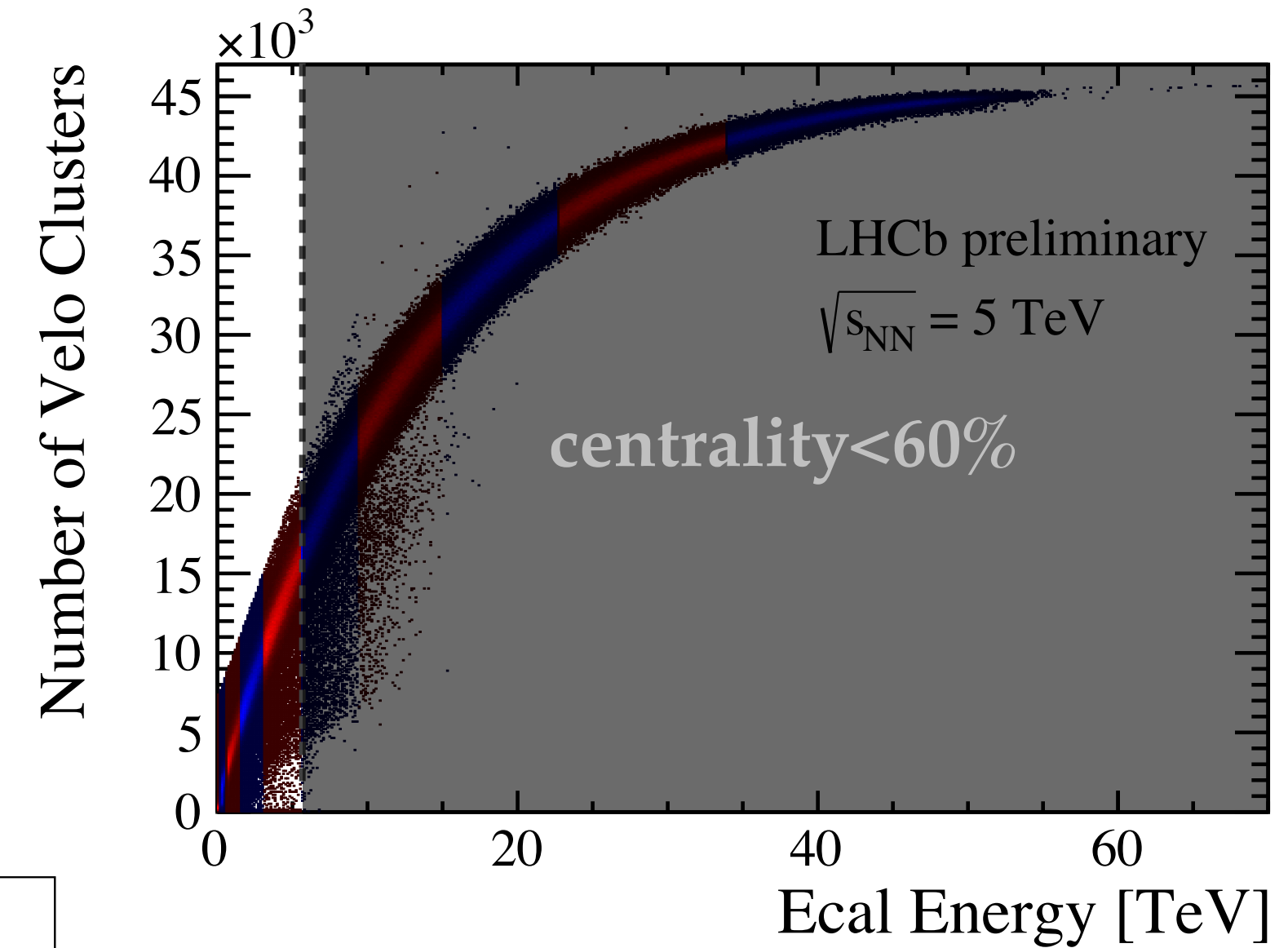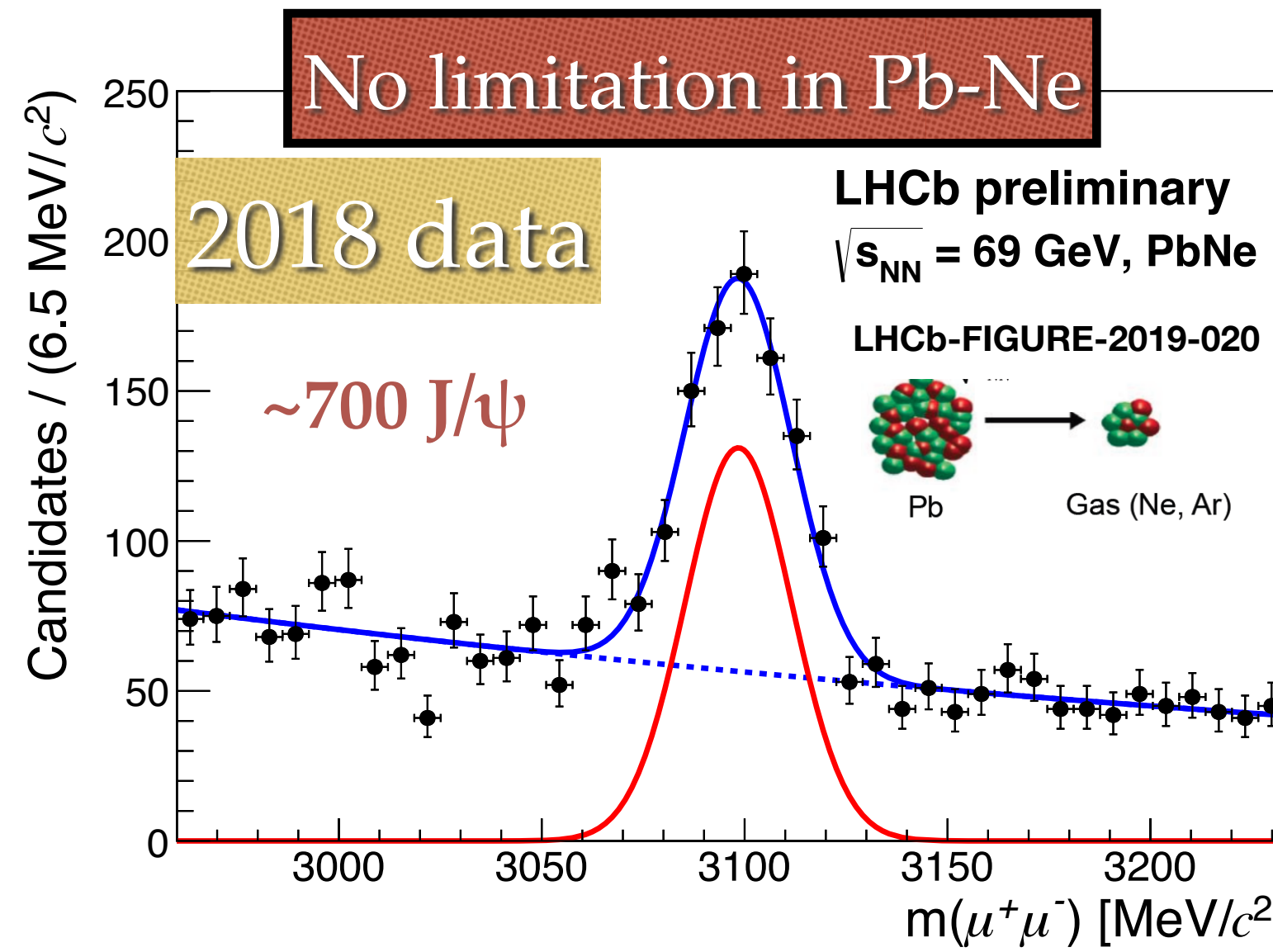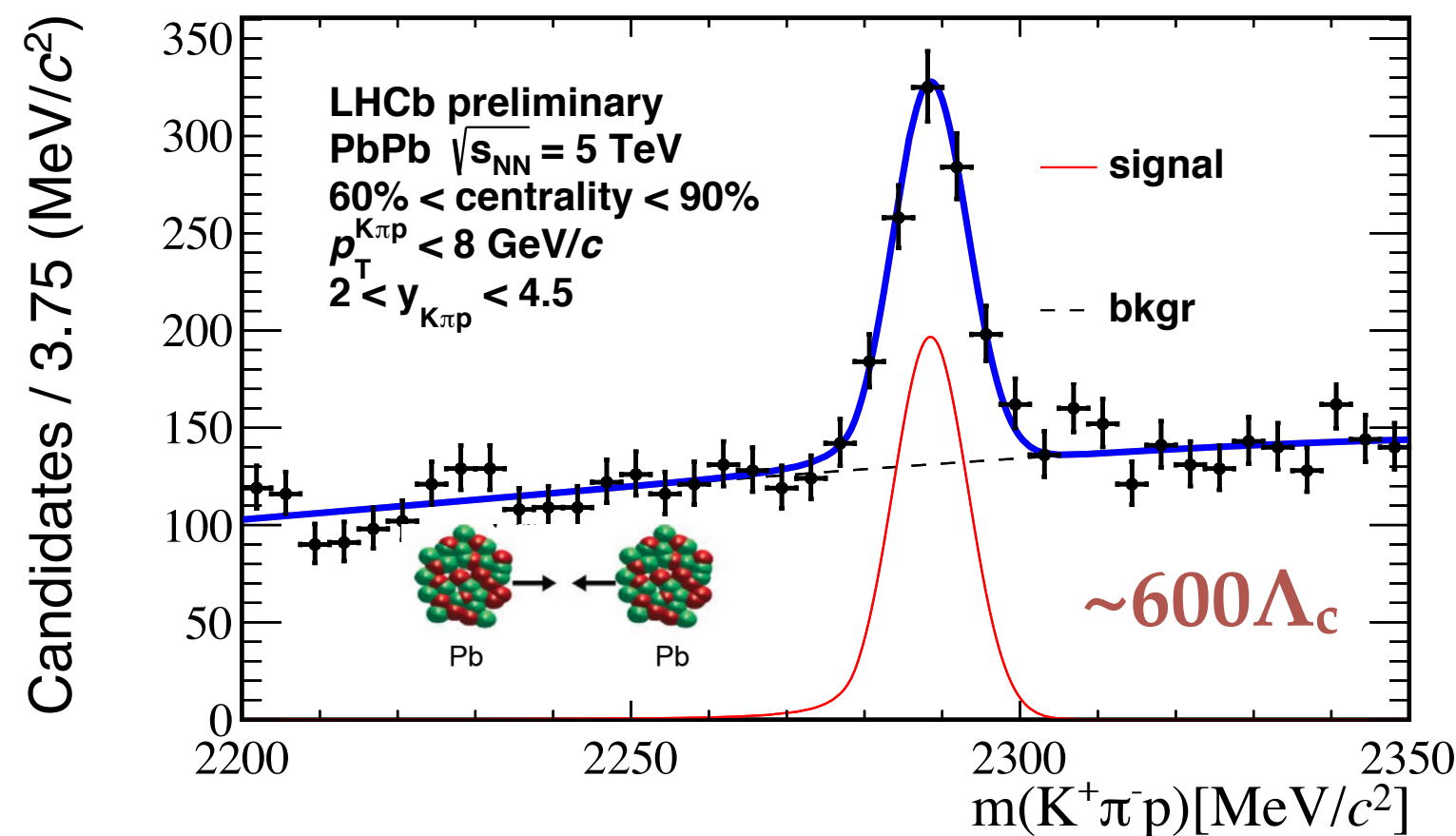
No limitation in Pb-Ne

2018 data

~700 J/ψ

LHCb preliminary
$\sqrt{s_{NN}}$ = 69 GeV, PbNe

LHCb-FIGURE-2019-020

Pb   Gas (Ne, Ar)

Status in PbPb UPC

❖ Preliminary results for coherent J/ψ production measured by LHCb

❖ **Coherent charmonium production analysis ongoing in ultra-peripheral PbPb collisions at √s$_{NN}$ = 5 TeV**

➡ **Factor 20 increase in statistics** compared to previous UPC results
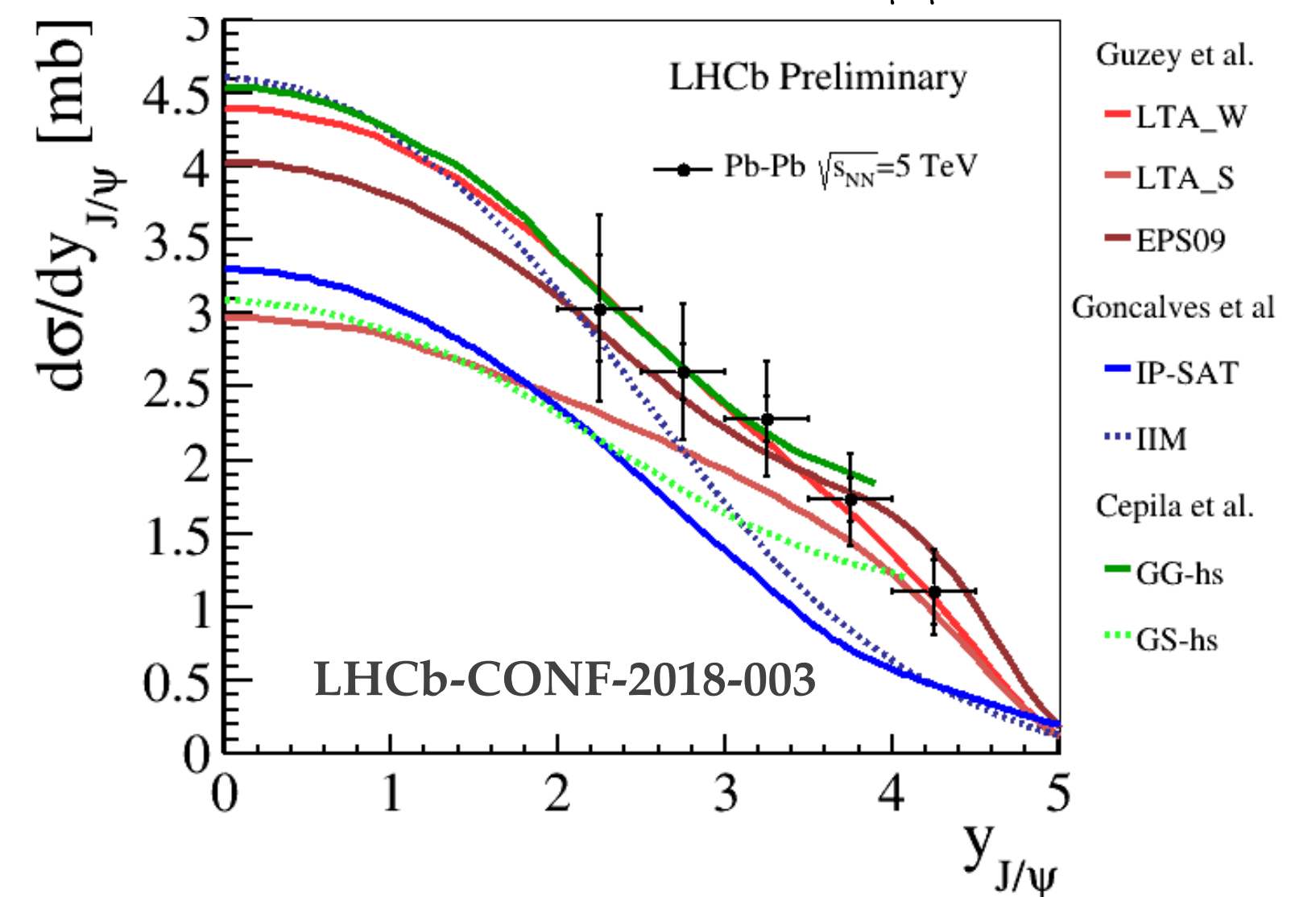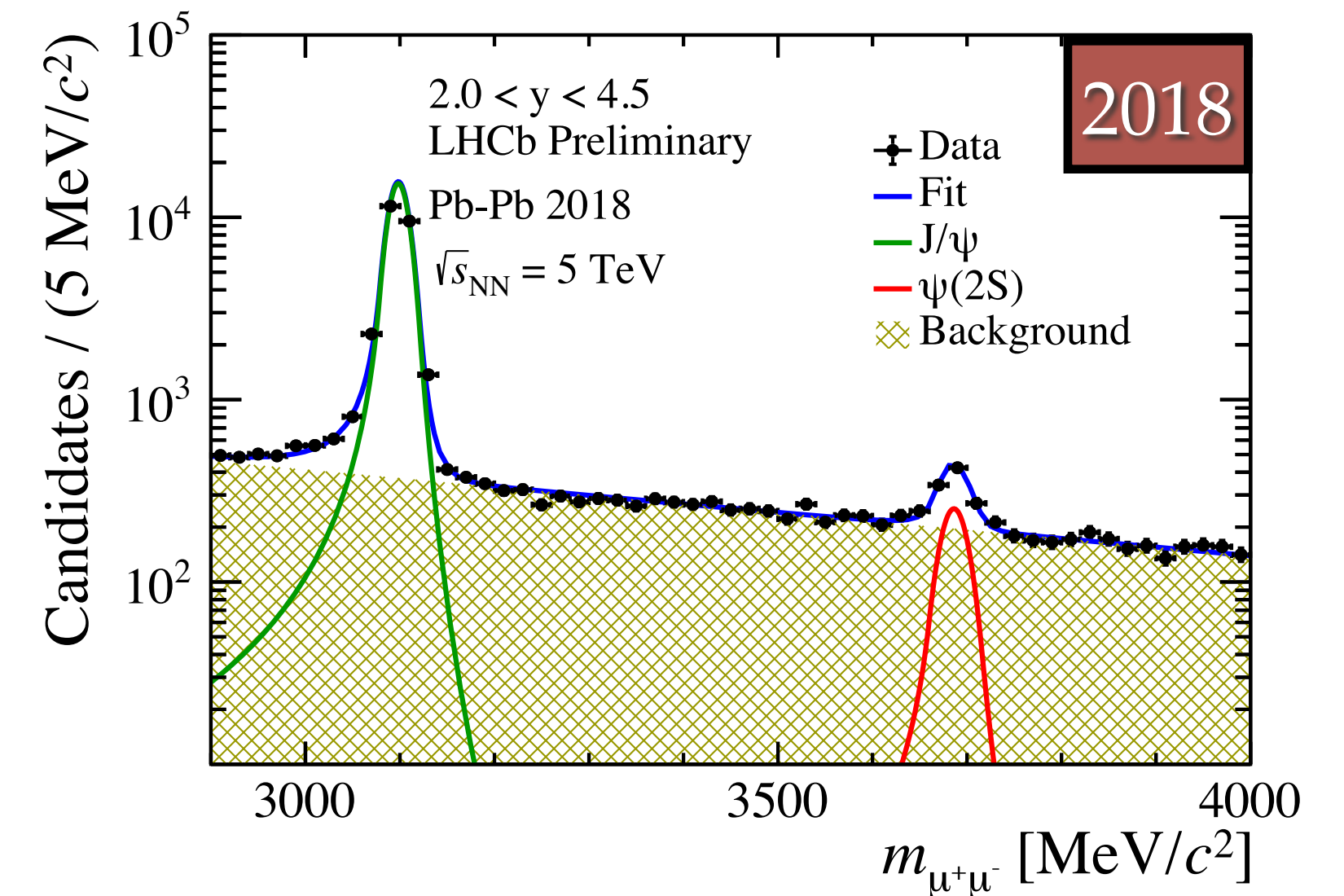
LHCb upgrades

LHCb upgrades
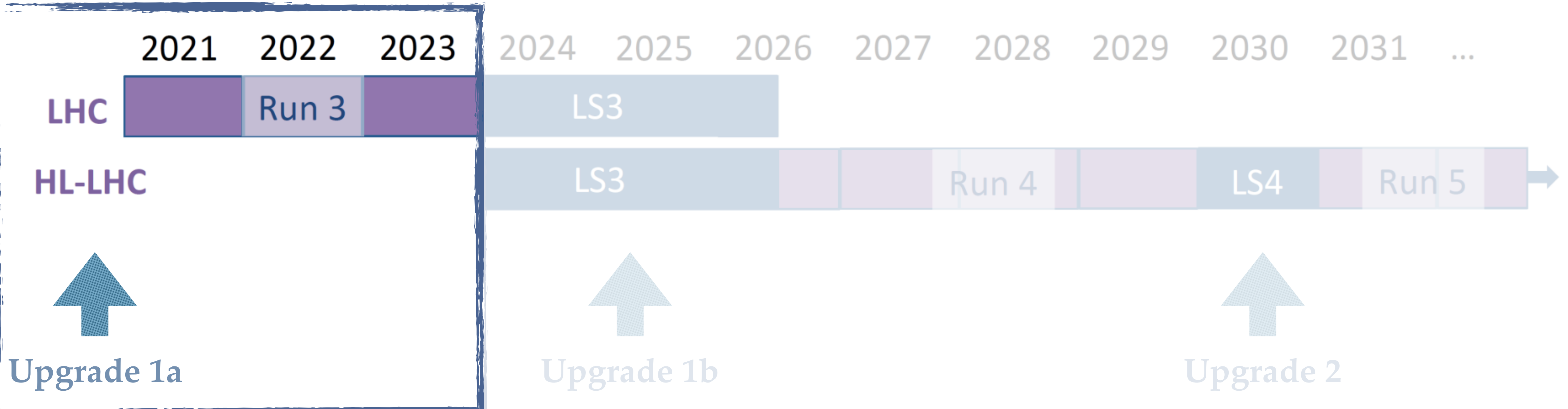
LHCb detector : season 3 (2021)

[CERN-LHCC-2012-007]
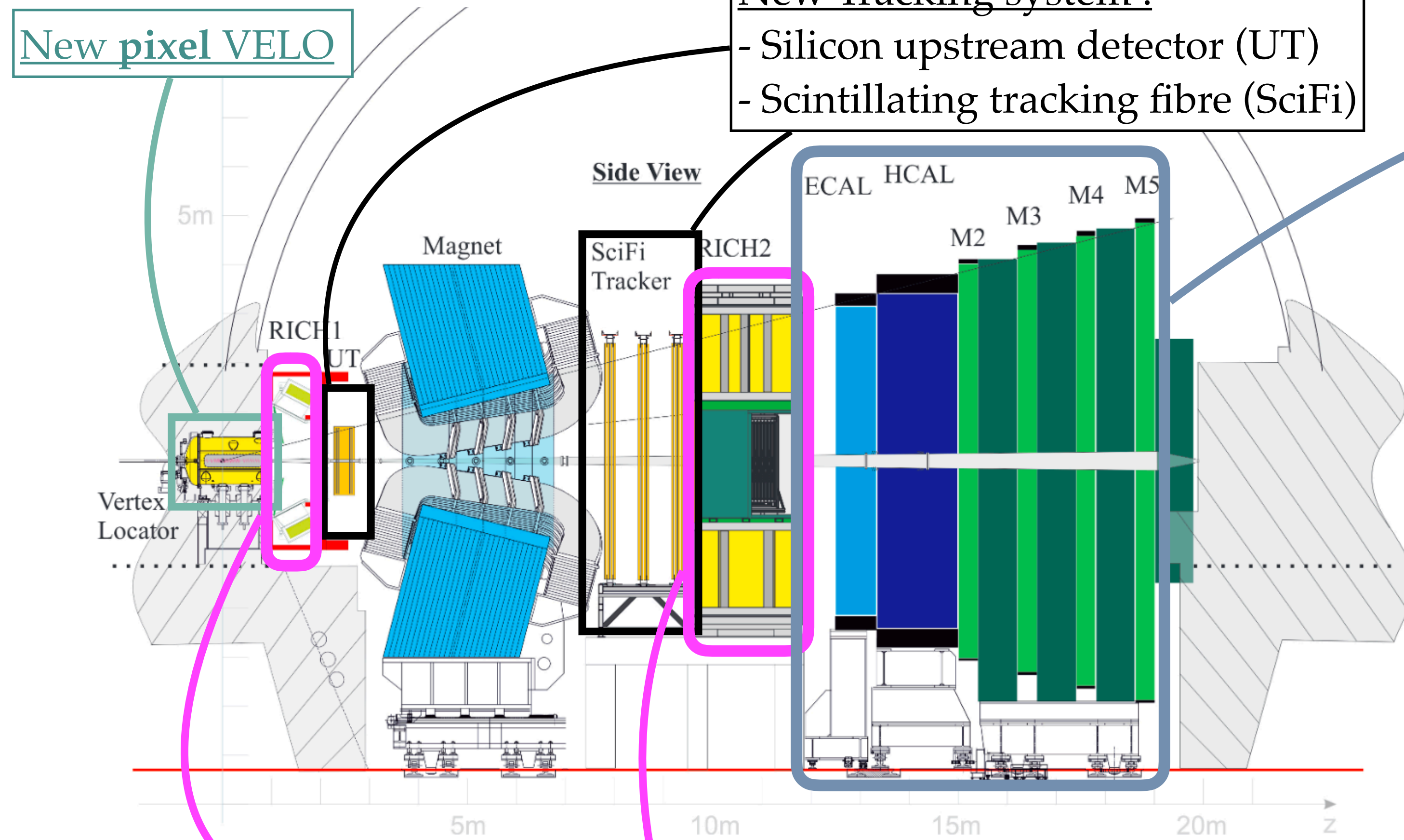
New **pixel** VELO

New Tracking system :
- Silicon upstream detector (UT)
- Scintillating tracking fibre (SciFi)

New electronics for muon
and calorimeter systems

New RICH optics and photodetectors

❖ Upgrade based on pp collision
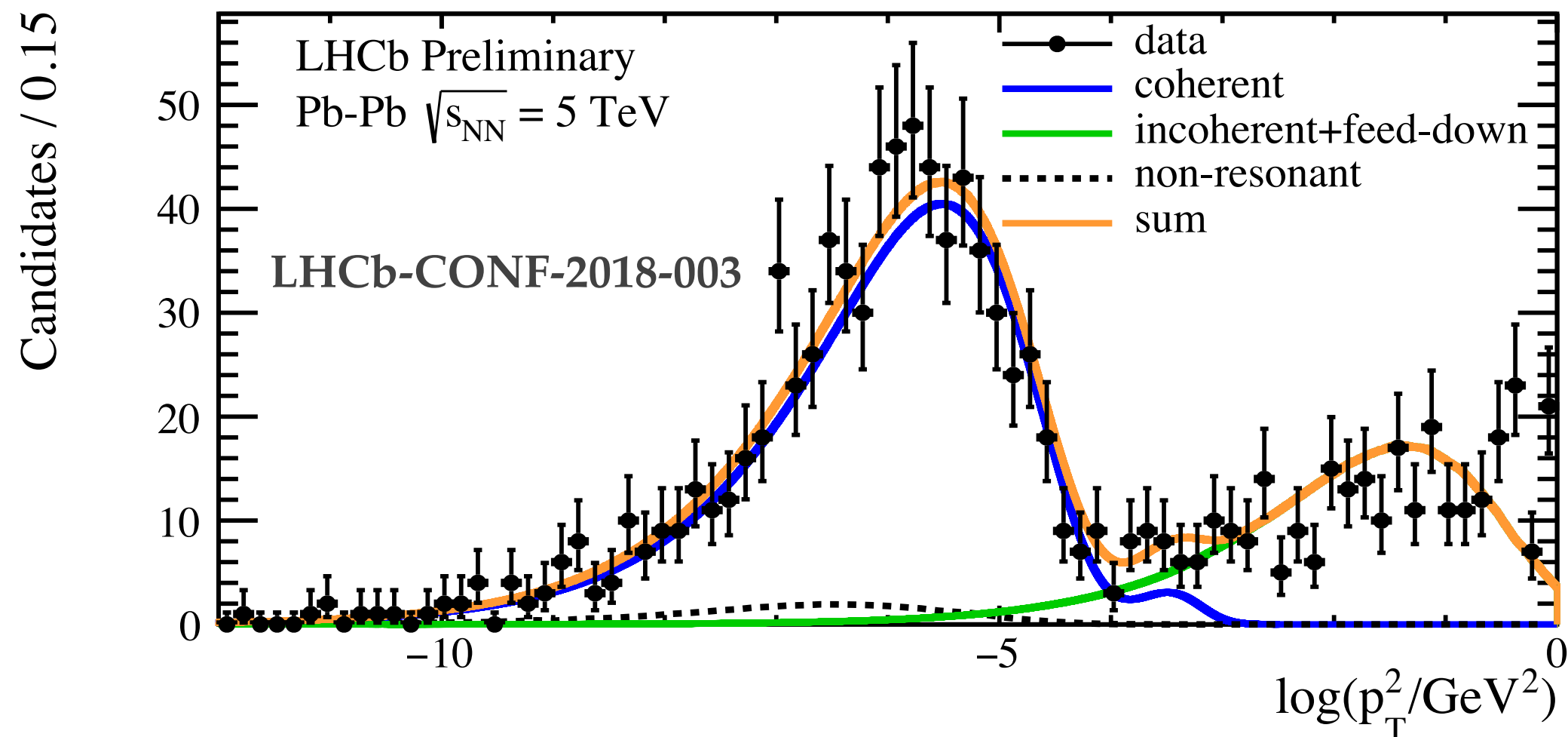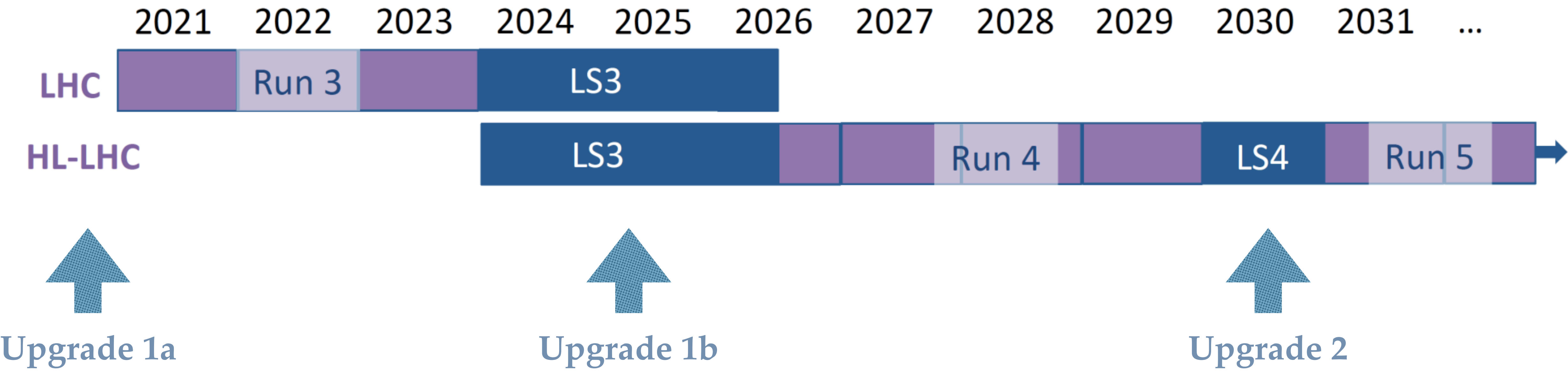   requirements :

   ➡ 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.

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Run 3 prospects for heavy-ion physics with LHCb

Run 3 prospects for heavy-ion physics with LHCb

LHCB-FIGURE-2019-021

15
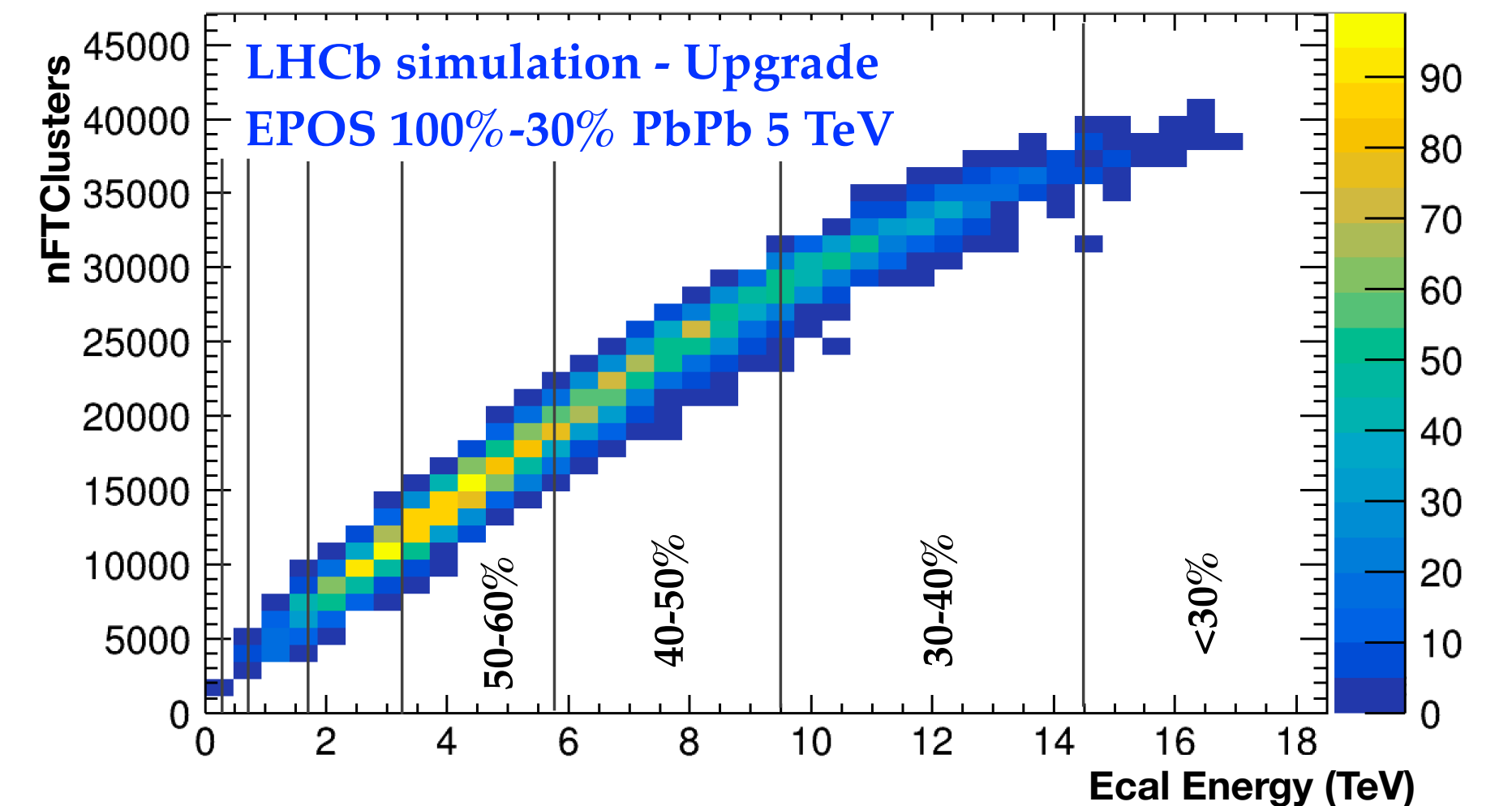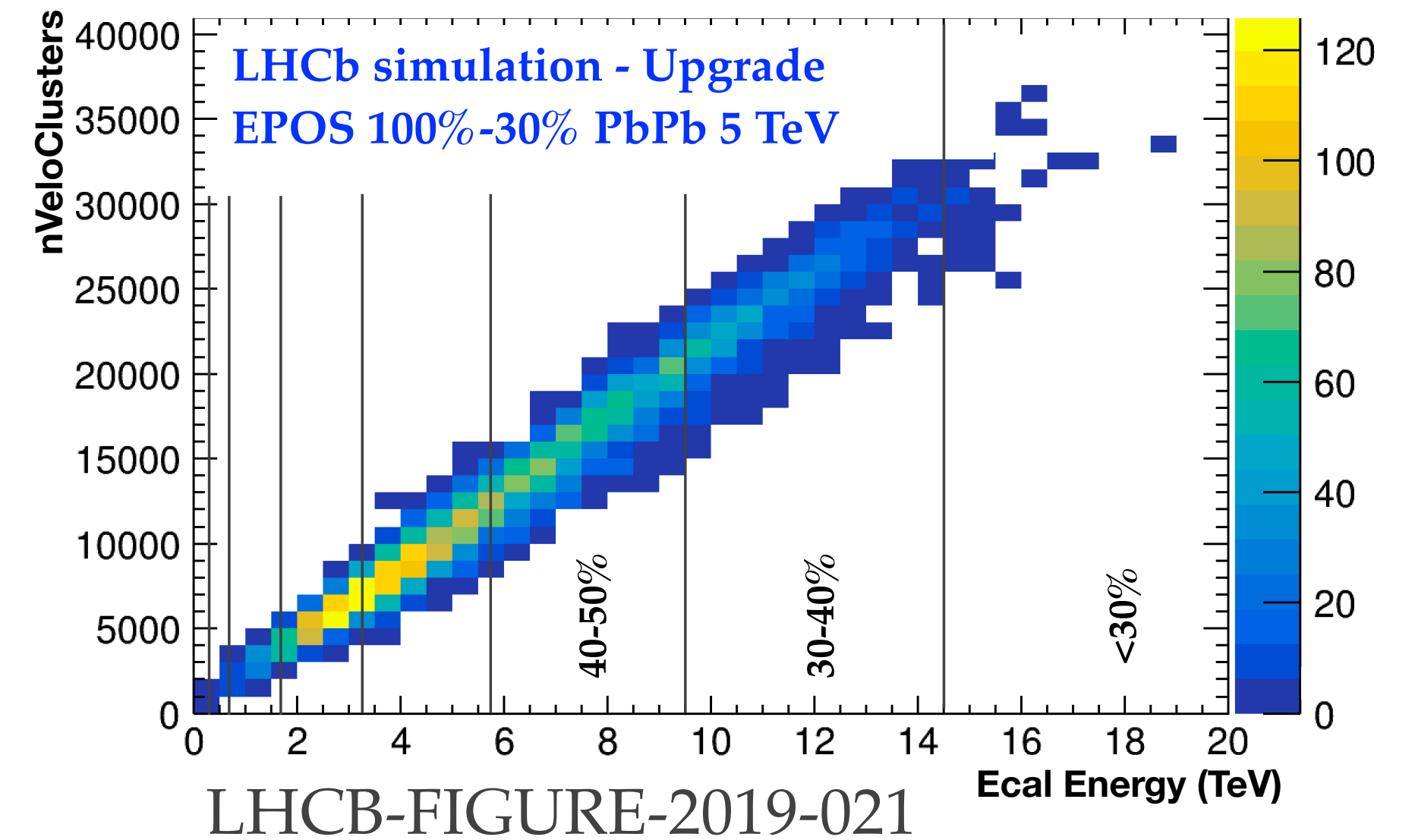
Run 3 prospects for heavy-ion physics with LHCb

❖ <u>No significant saturation</u> of the new LHCb detectors **up to 30%!**

❖ Two proposals for a new tracker (see next slides) :

➡ in 2024 → **reach event more central collisions !**

➡ In 2030 → **no more limitations !**

LHCB-FIGURE-2019-021
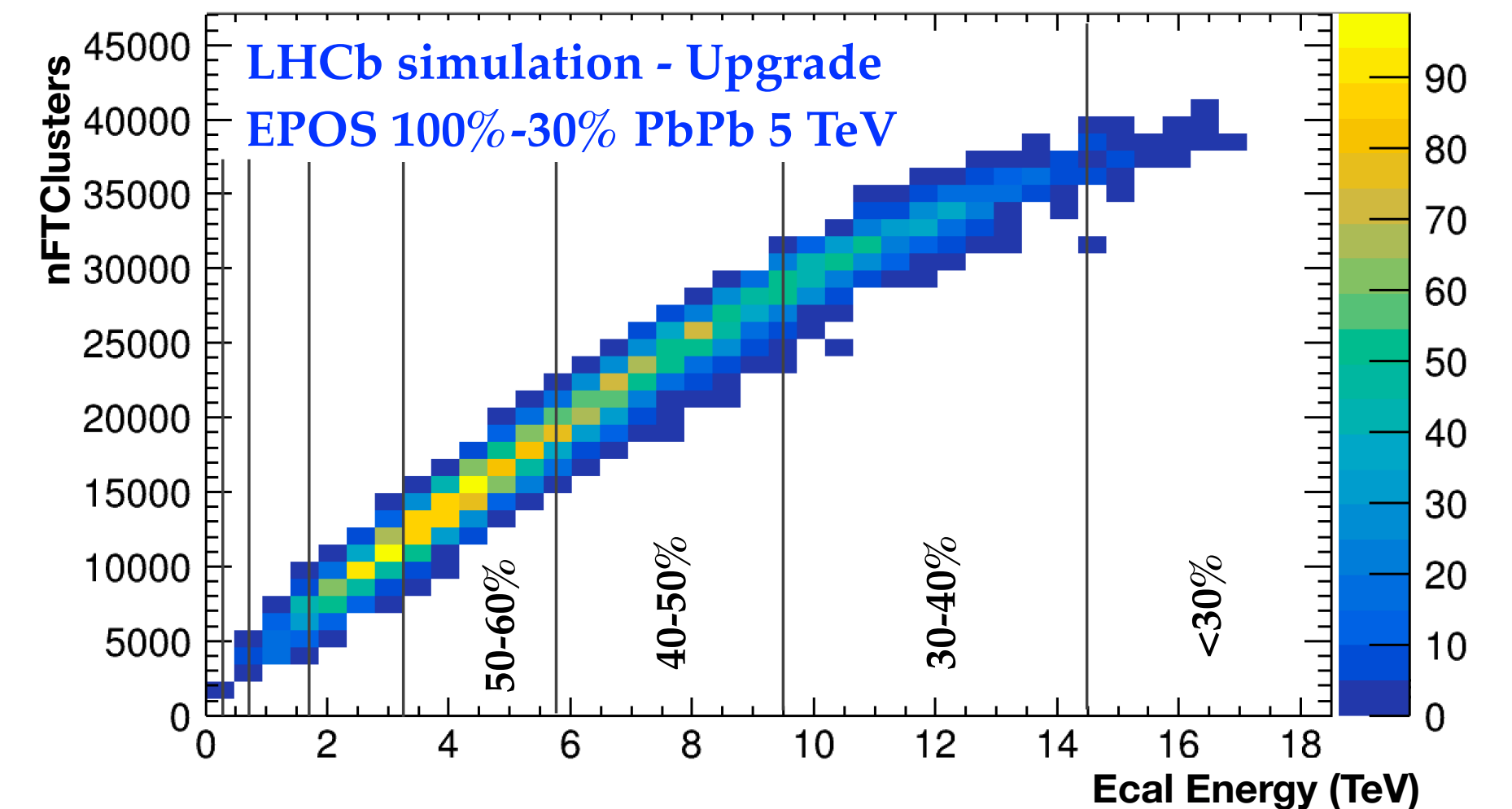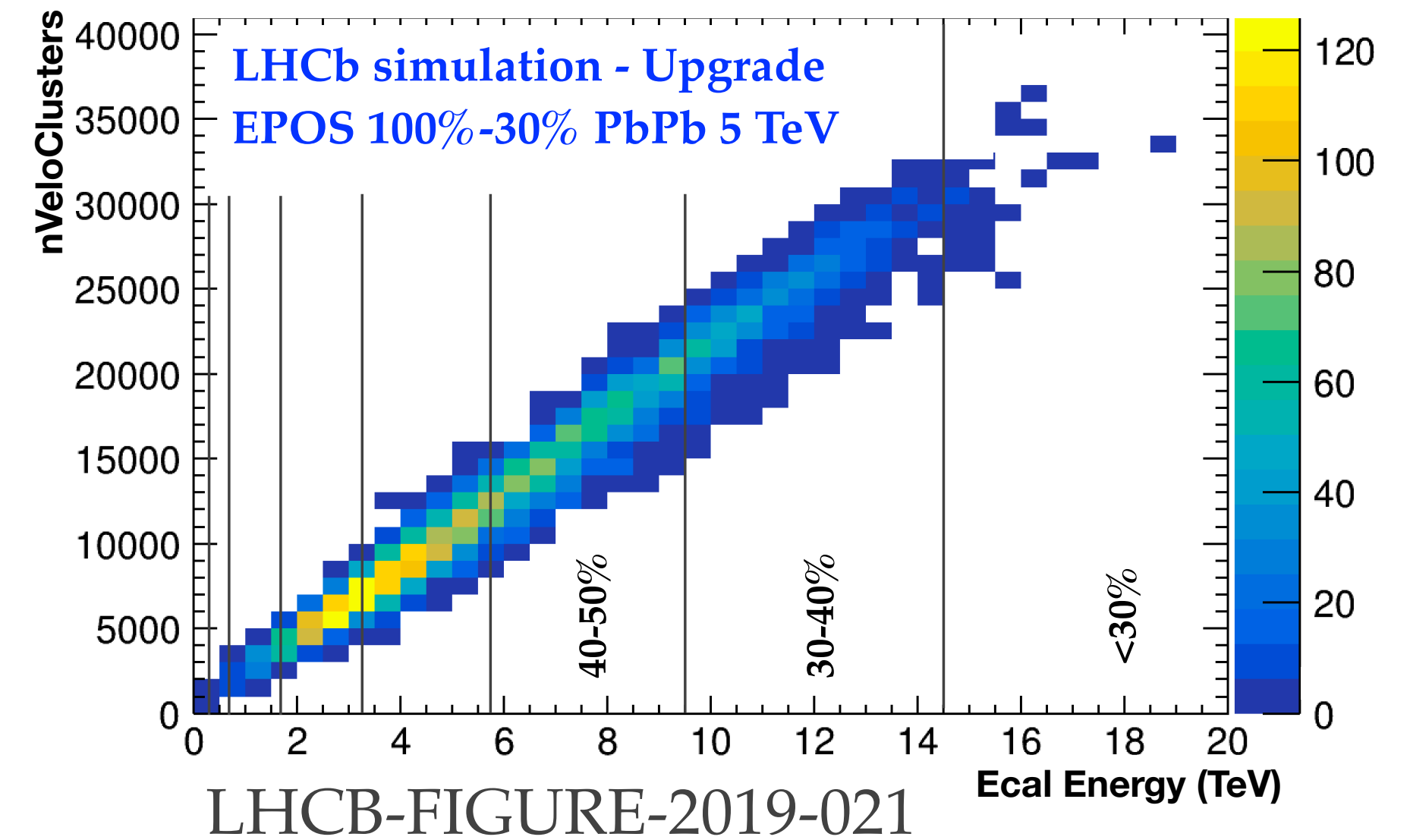
LHCb fixed-target program evolution

SMOG2 cell

Projection of ~1 year data taking in « parasite » mode

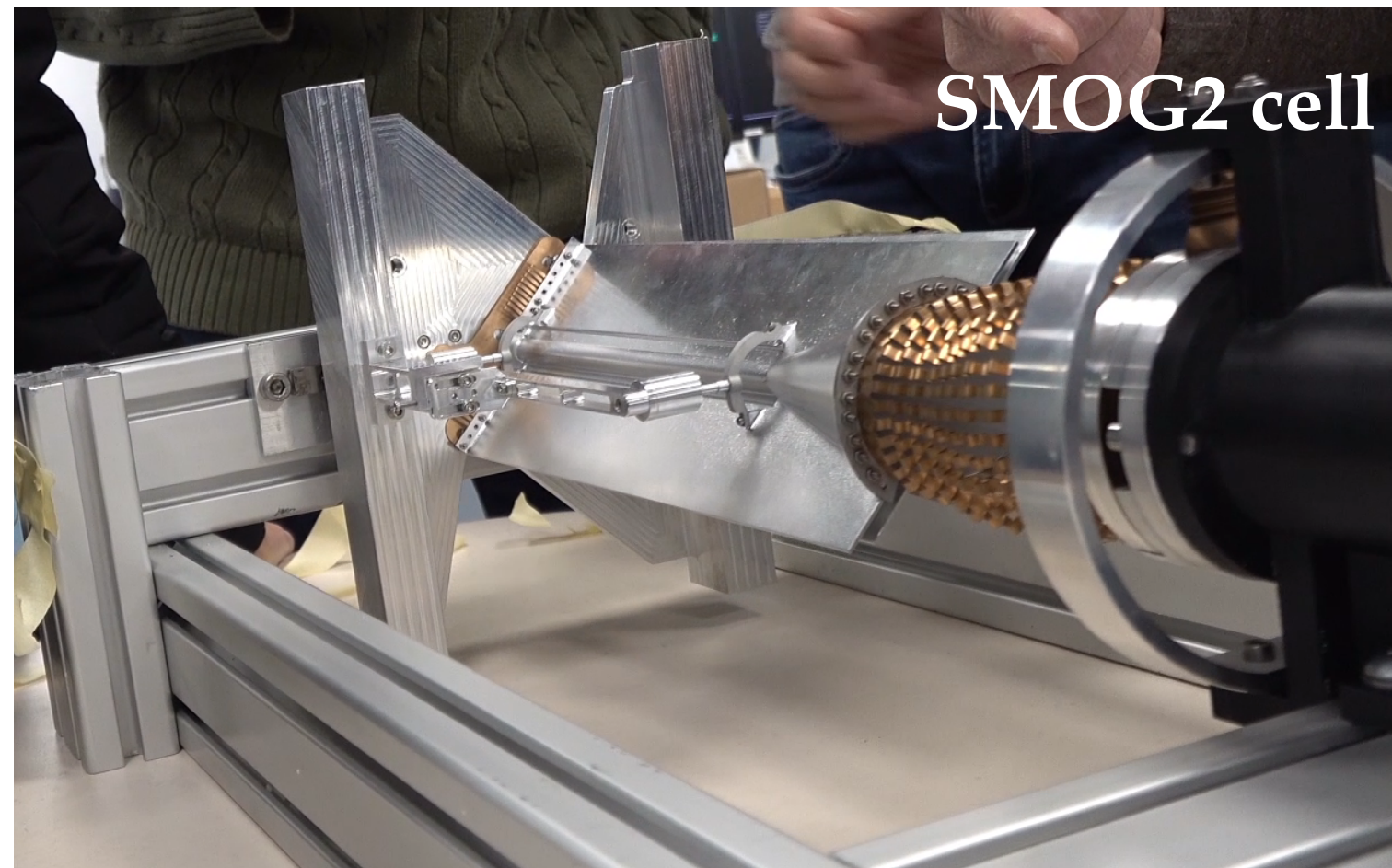| Int. Lumi.		80 pb^{-1}
Sys.error of J/Ψ xsection		~3%
J/Ψ	yield	28 M
D^0	yield	280 M
Λ_c	yield	2.8 M
Ψ'	yield	280 k
$\Upsilon(1S)$	yield	24 k
$DY\ \mu^+\mu^-$	yield	24 k

❖ **SMOG 2** ([TDR]) : Standalone gas storage cell covering $z \in [-500;-300]$ mm :

➡ **Up to x100 higher gas density** with same gas flow of current SMOG.

➡ Gas feed system measures the **gas density with few % accuracy**.

➡ **Possibility to run in parallel of pp collisions and inject non noble Gaz.**

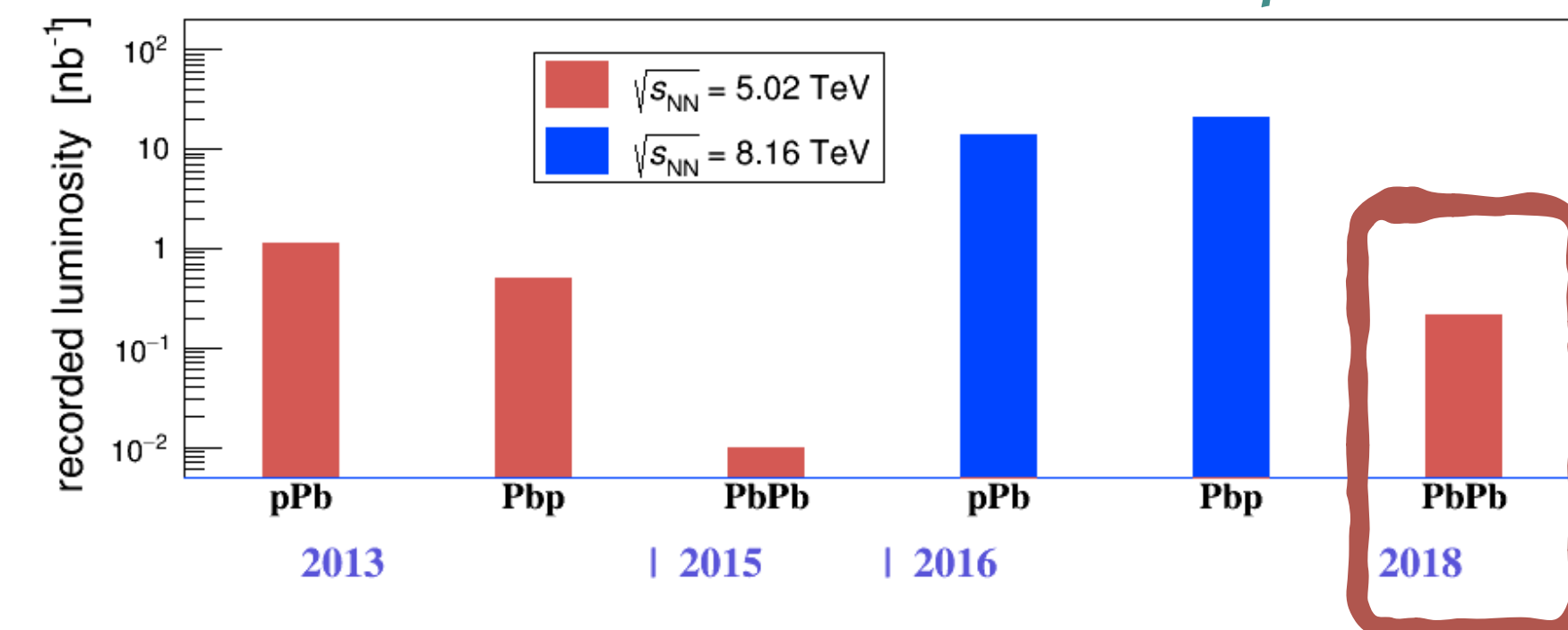Installation ongoing, to be operational from the start of LHC Run 3.

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Conclusions and outlooks

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Collider mode samples

Fixed-target mode samples

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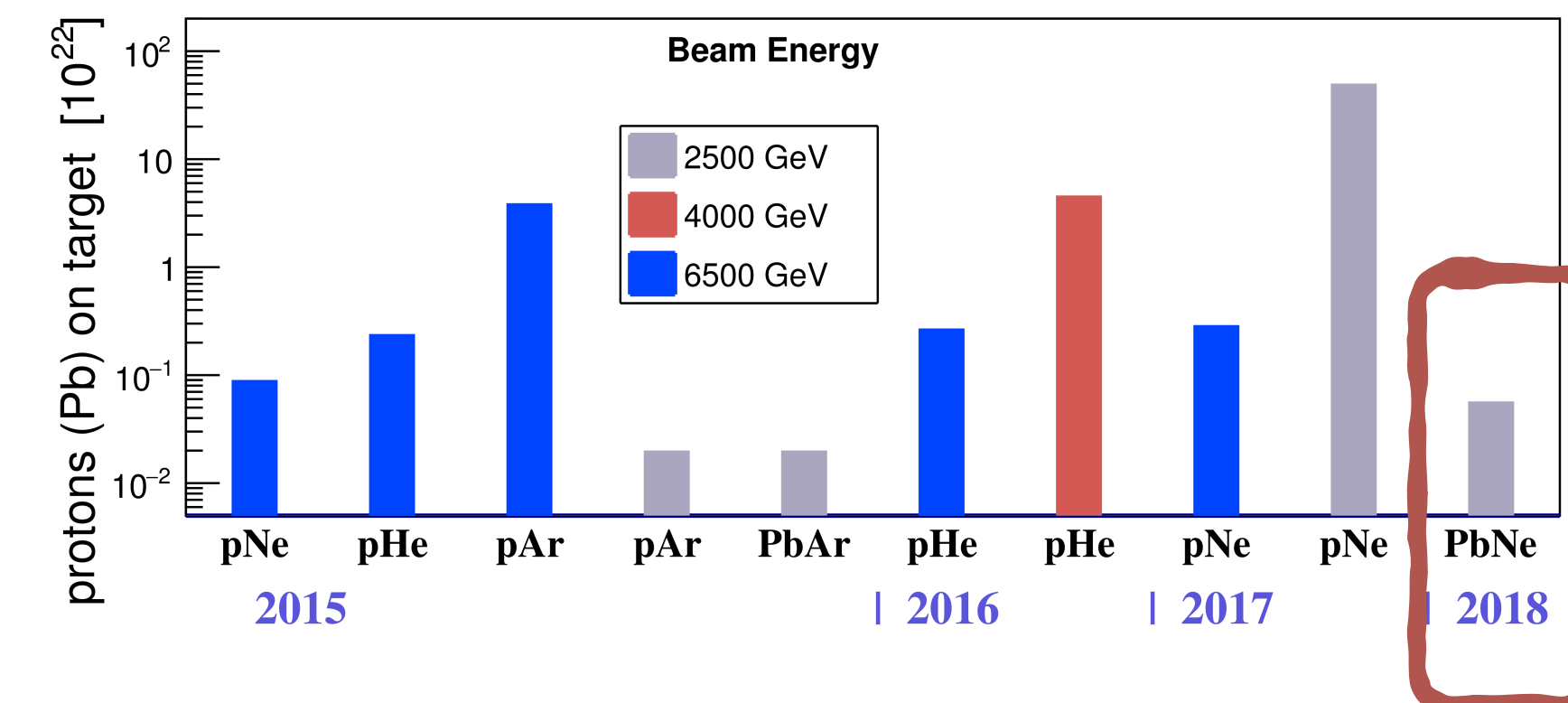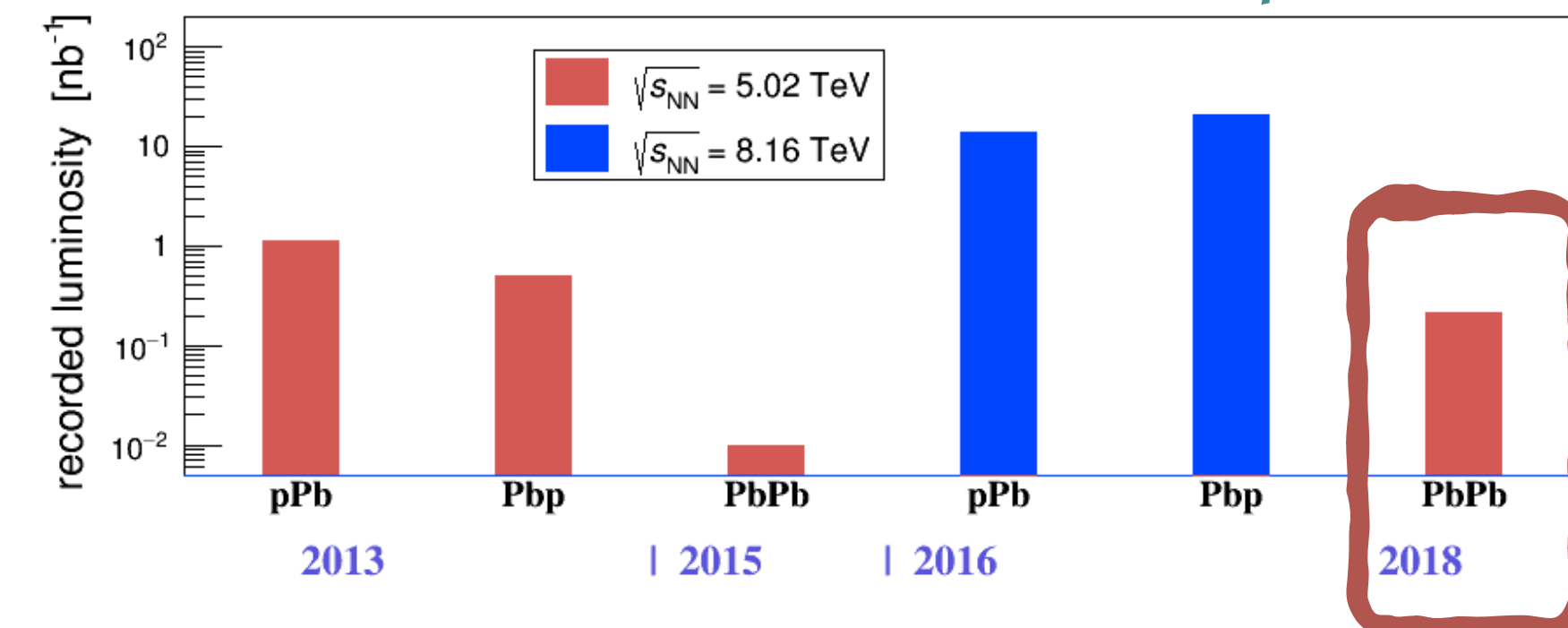
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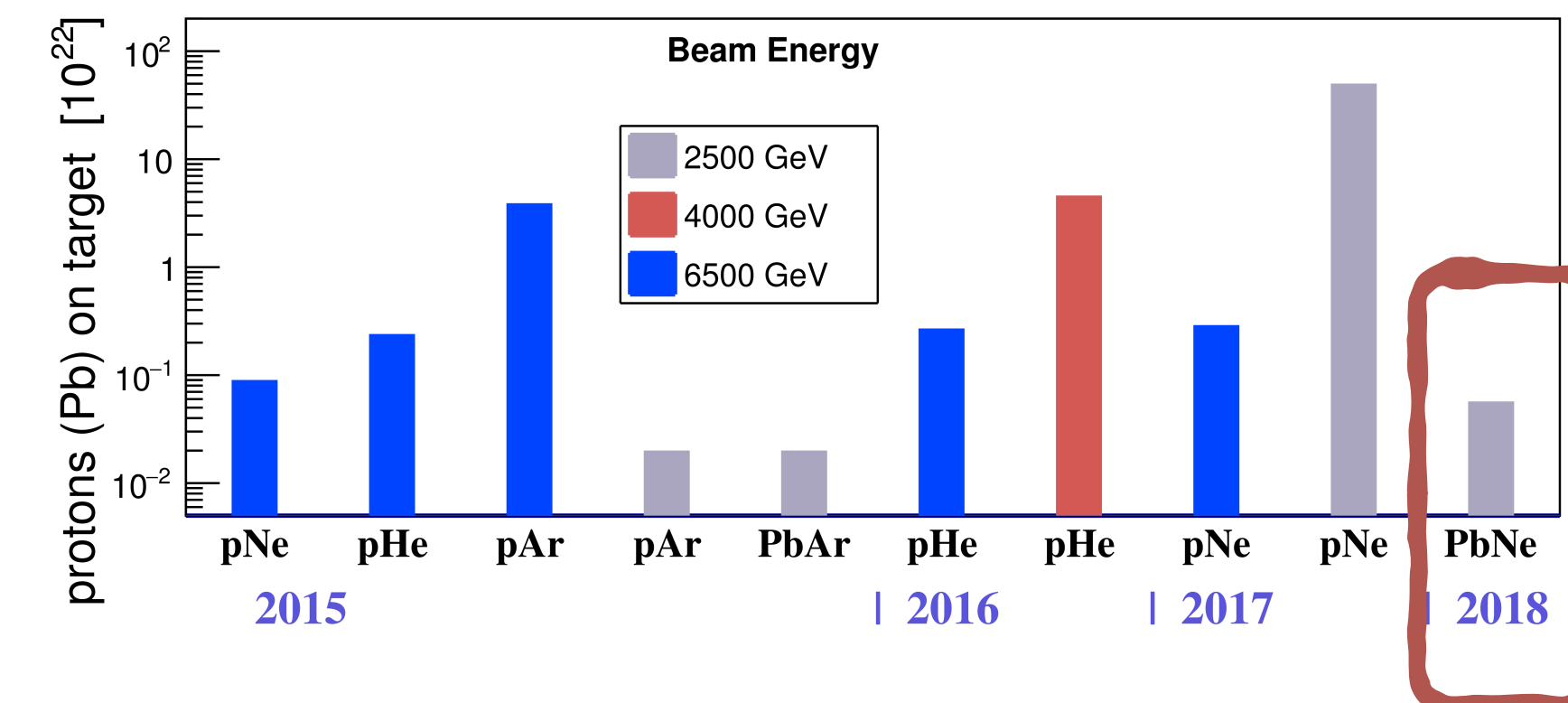
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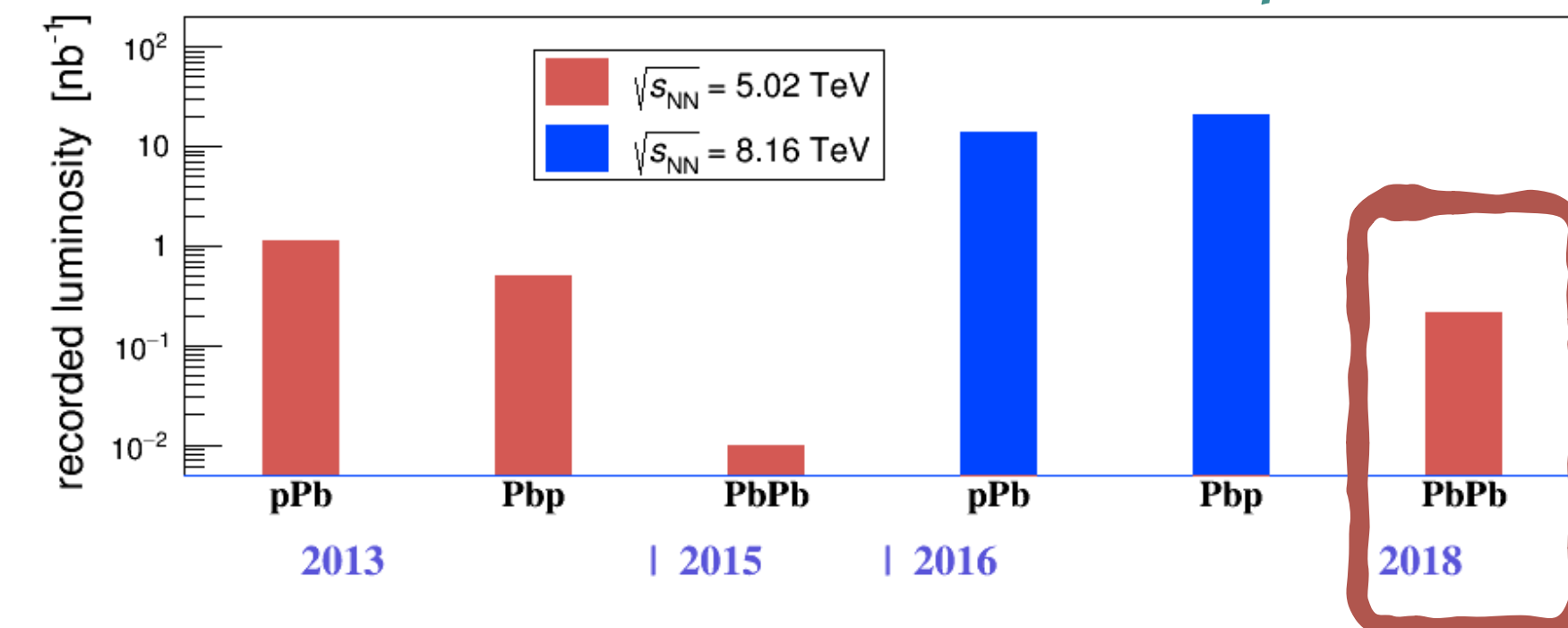
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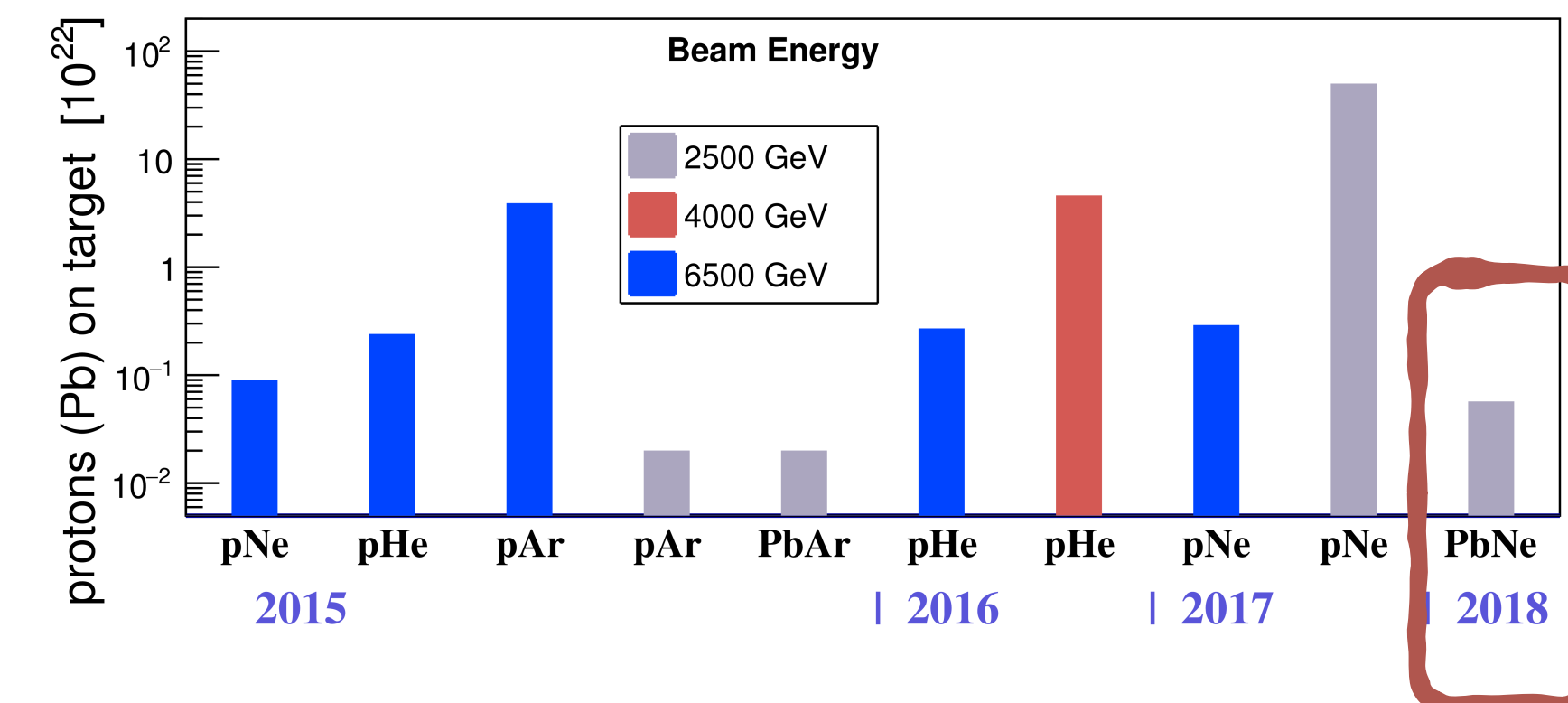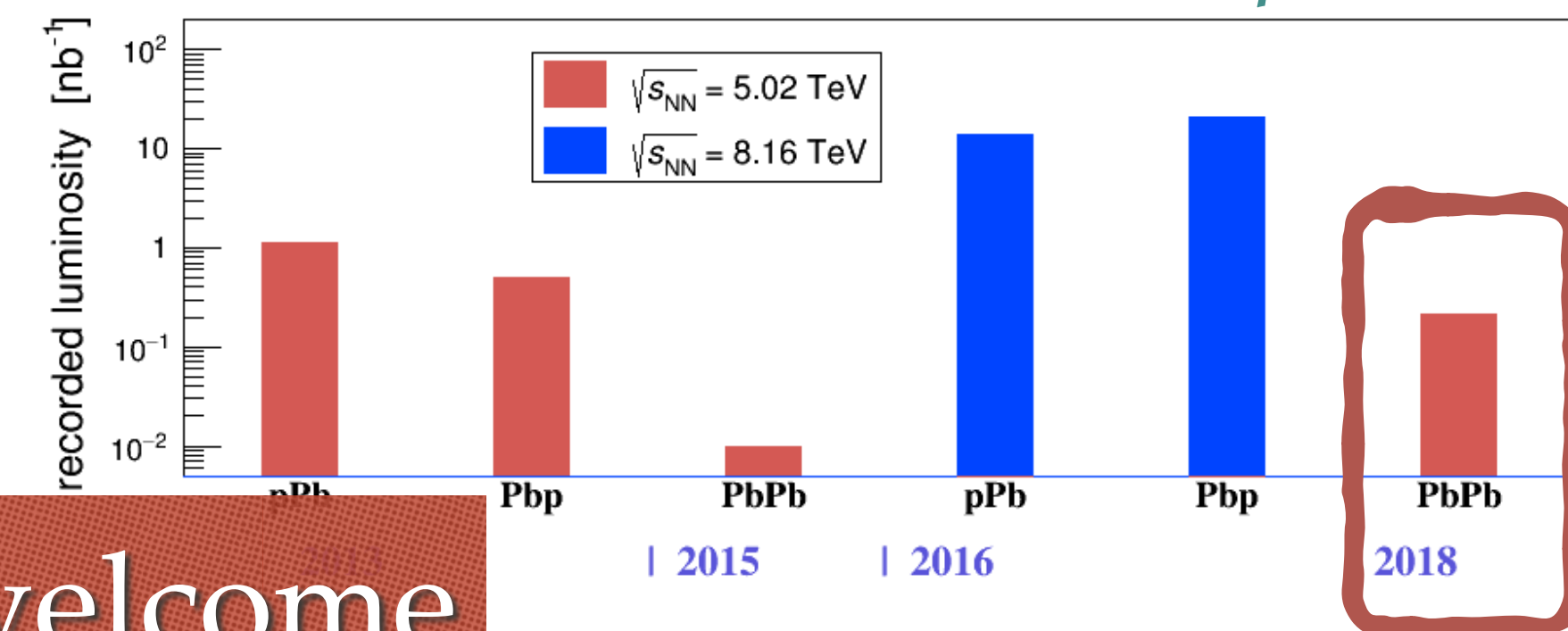➡ **A full UPC physics program** to look at with high precision.
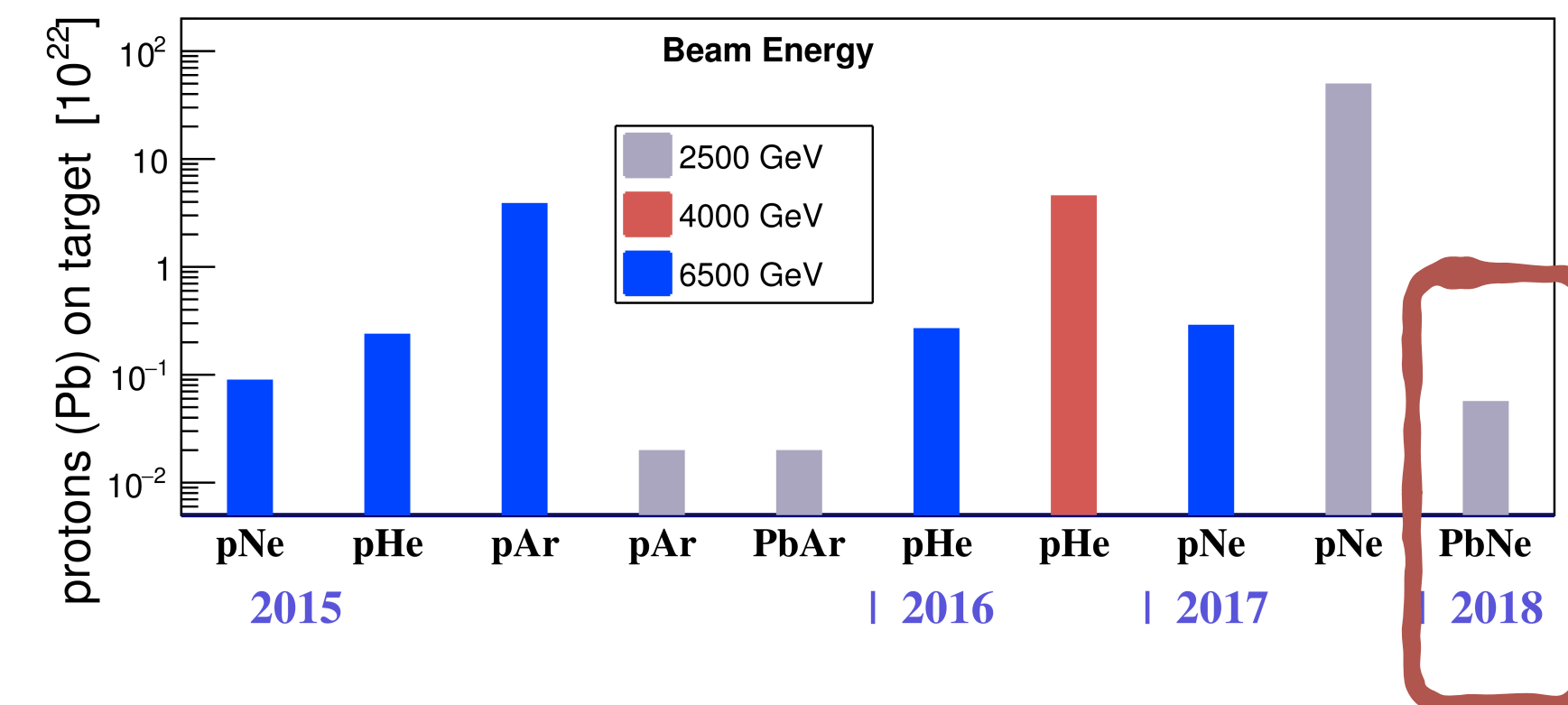
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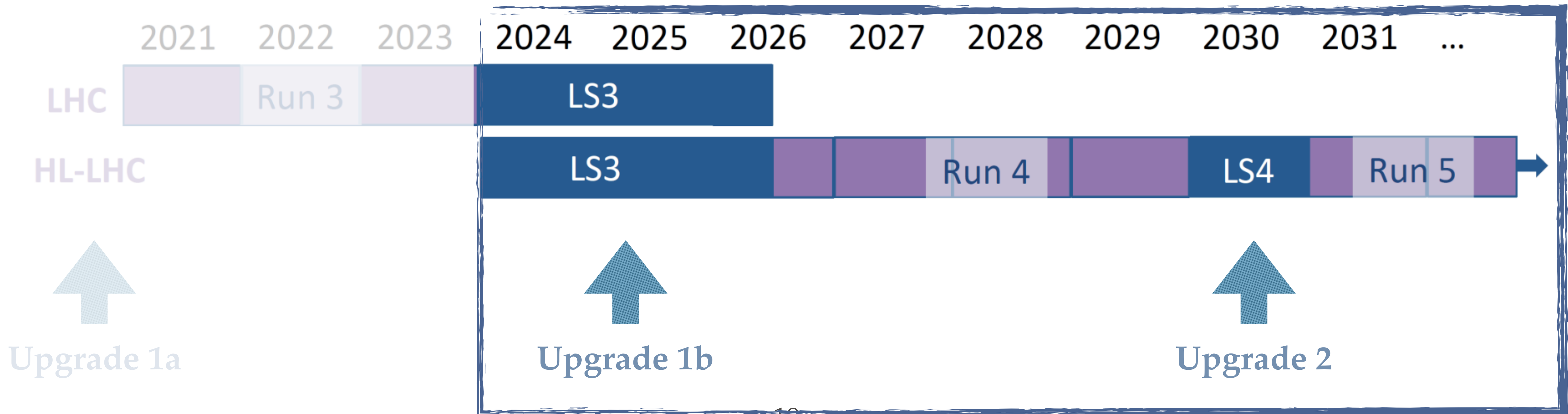
Collider mode samples

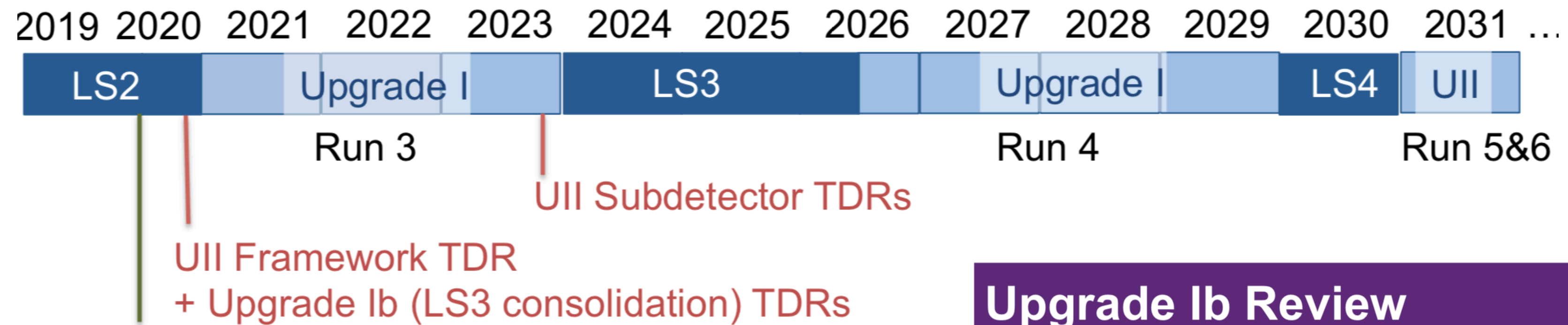*Inputs /suggestions always welcome*

Fixed-target mode samples

Back-up

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LHCb upgrades

Phase II in a nutshell

2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 ...

LS2 | Upgrade I | LS3 | Upgrade I | LS4 | UII

Run 3   Run 4   Run 5&6

UII Subdetector TDRs

UII Framework TDR
+ Upgrade Ib (LS3 consolidation) TDRs

❖ Sub detectors considering timing :

➡ Before the magnet :
- VELO, RICH1

➡ After the magnet :
- TORCH, RICH2, ECAL

Upgrade Ib Review   February & March 2019

LHCb-INT-2019-005
February 5, 2019

Proposal for a Magnet Tracking
Station in LHCb

LHCb-INT-2019-006
February 11, 2019

TORCH physics performance:
improving low-momentum PID
performance during Upgrade IB and
beyond

LHCb-INT-2019-007
February 15, 2019

Mighty Tracker: Design studies for
the downstream silicon tracker in
Upgrade Ib and II

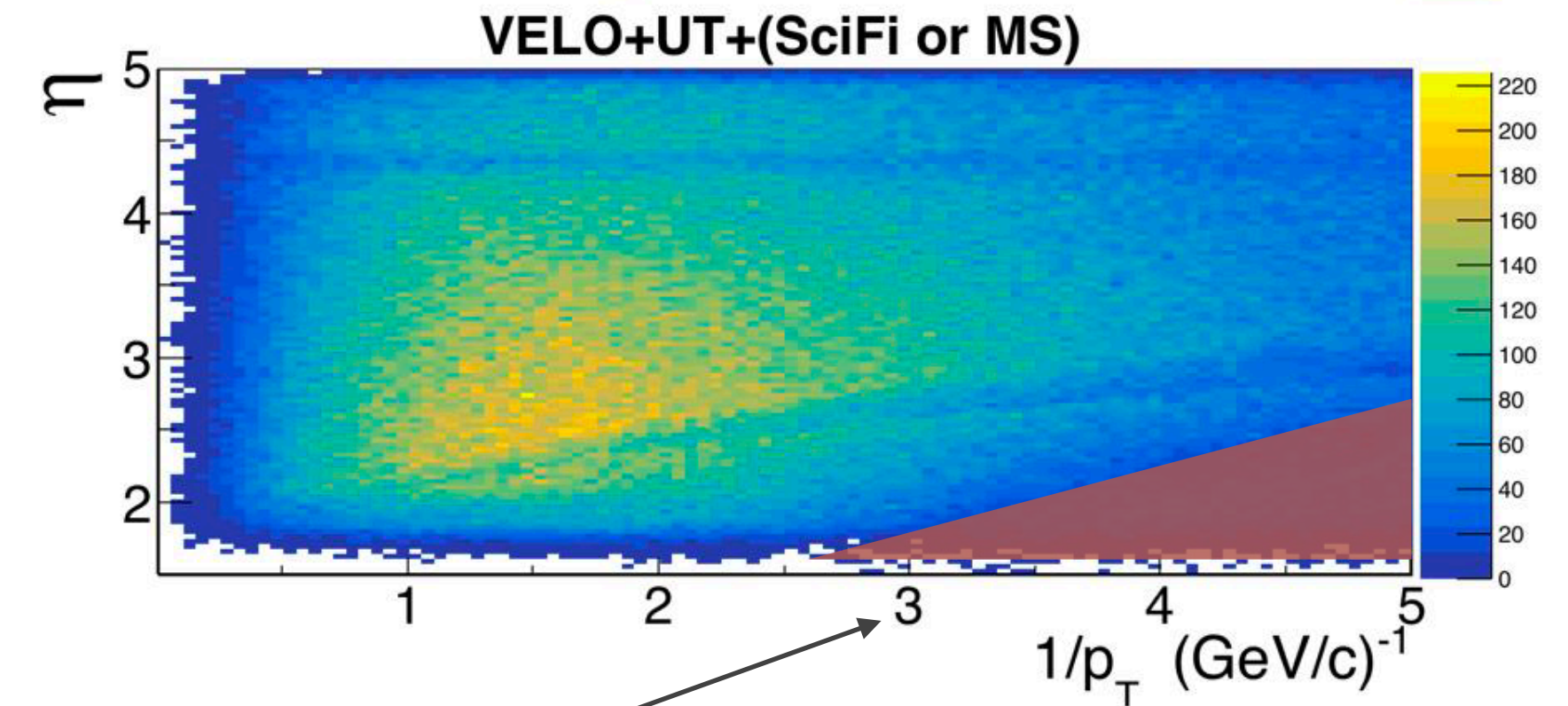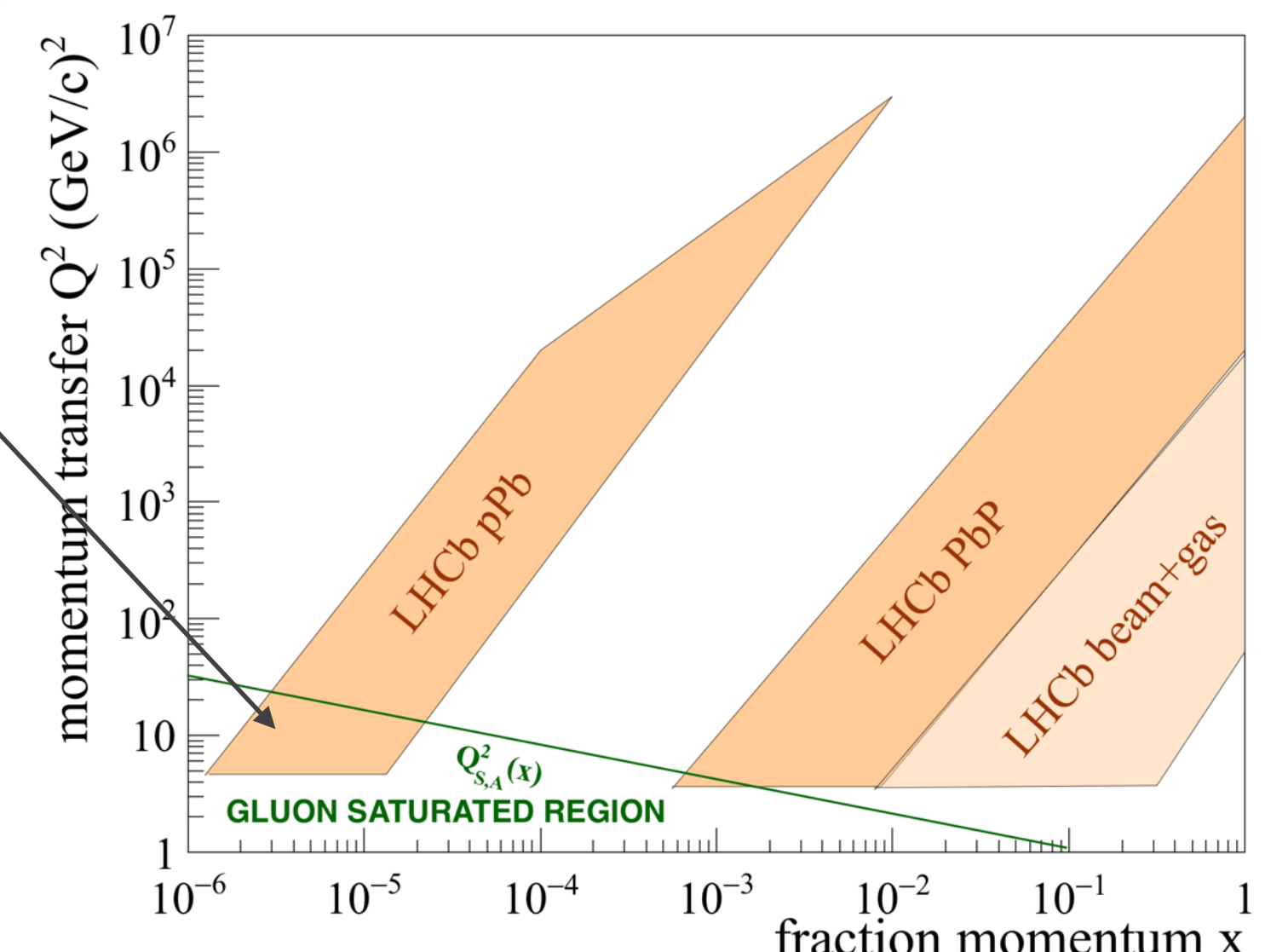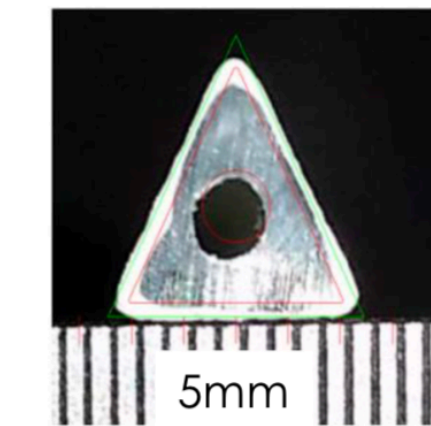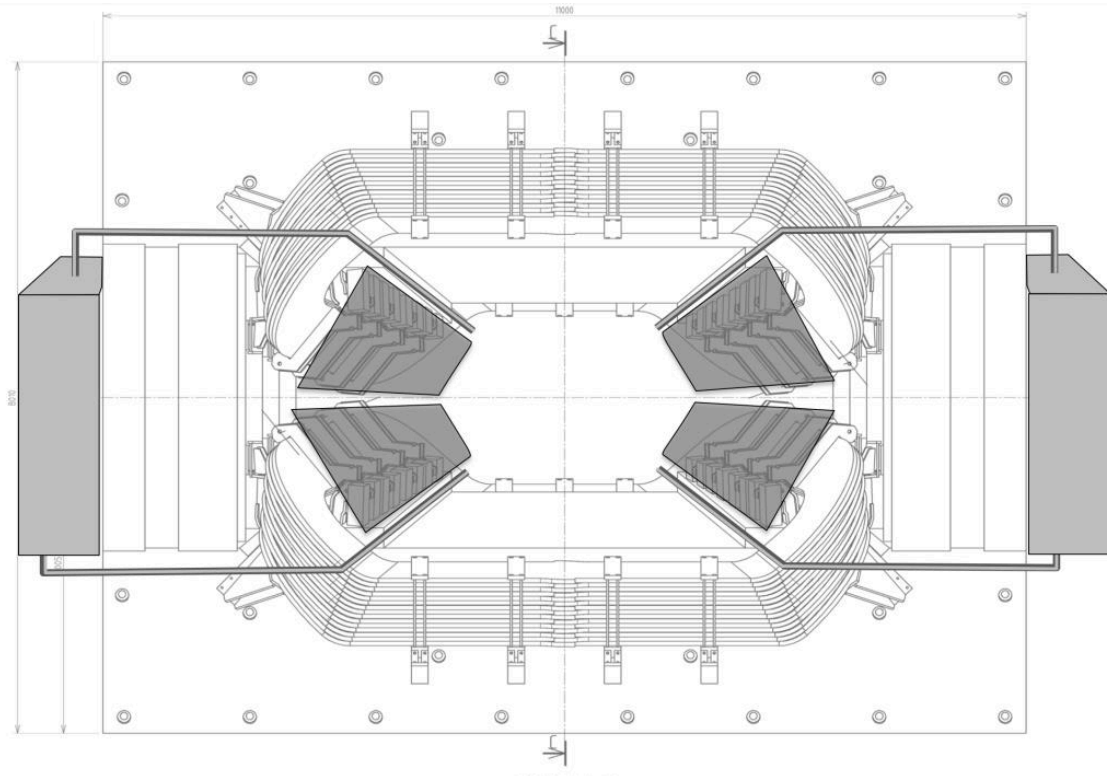LHCb-INT-2019-008
April 4, 2019

Considerations on additional
shielding for the muon detector
phase 2 upgrade

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Magnet Tracking Station

❖ Proposal for tracking station inside the magnet.

  ➡ Triangular Extruded Scintillating Bars

  ➡ Increase coverage of low-p_T tracks.

  ➡ Physics motivations : access to converted photons.

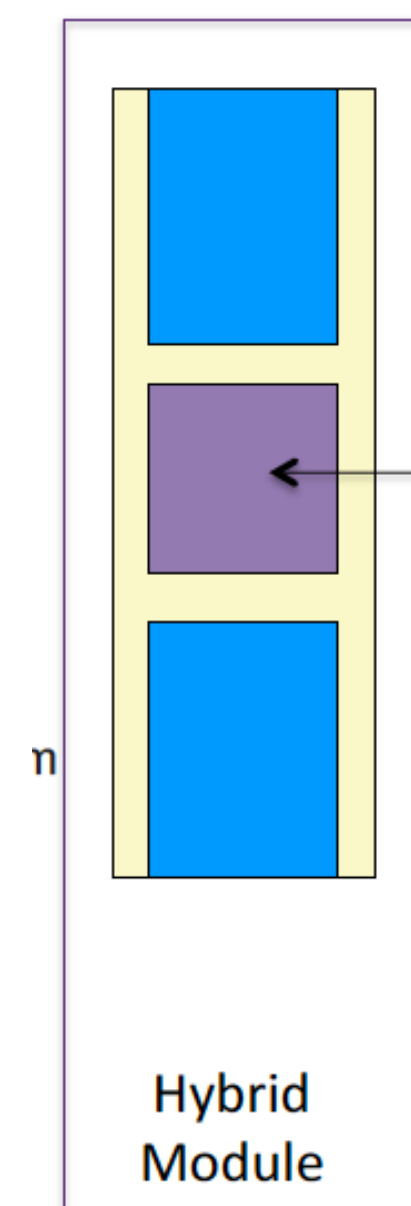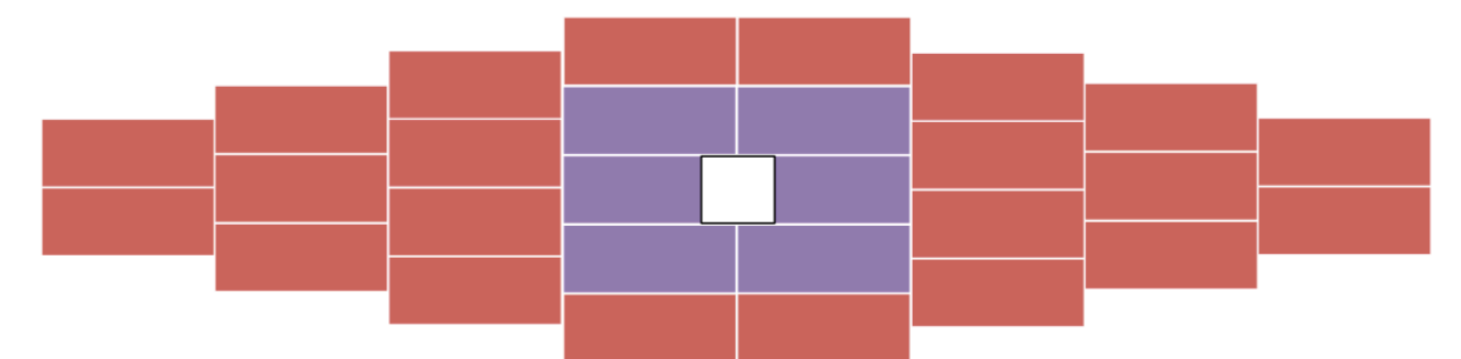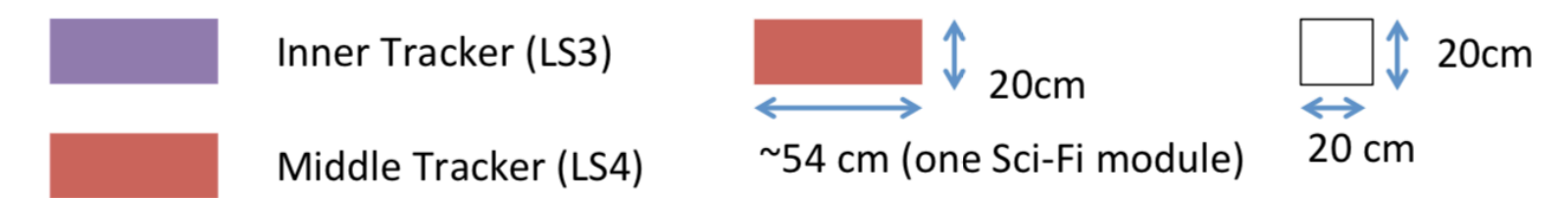❖ **Proposing the installation of a small prototype** inside the magnet during LS3.

Extended acceptance
Extended coverage

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MIGHTY Tracker

- ❖ MIGHTY tracker : biggest silicon tracker built by LHCb.

  - ➡ **Upgrade 1b: Inner Tracker + Scifi.**

    - DMAPs technology for silicon sensors.

  - ➡ **Upgrade II: New mighty silicon tracker covering larger area.**

    - Rebuild of SciFi + reuse IT.

- ❖ Hybrid technology detector, many challenges !

- ❖ First estimations show **no limitation in centrality reach with the complete MIGHTY.**