Status and prospects with charm production studies at LHCb

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The LHCb detector

❖Forward single arm spectrometer.

❖Designed to study heavy flavour physics in *pp* collisions.

❖Only LHC experiment fully instrumented in the region $2 < \eta < 5$.

❖Some nice features:

- ✤Excellent vertex, IP and decay time resolution thanks to VELO.

  $\Rightarrow \sigma(\text{IP}) \approx 20\,\mu\text{m}$.

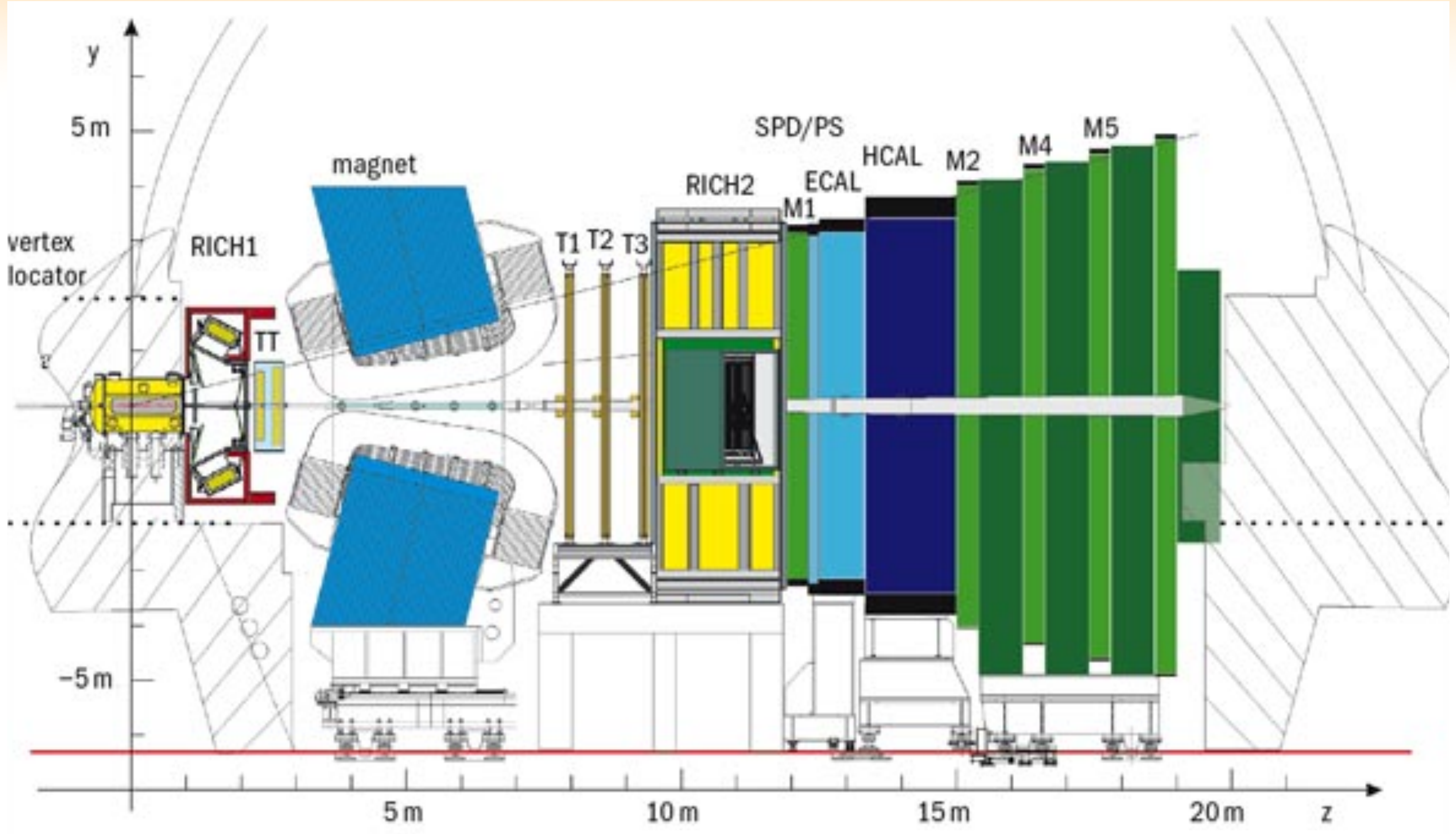
- ✤Very good momentum resolution.

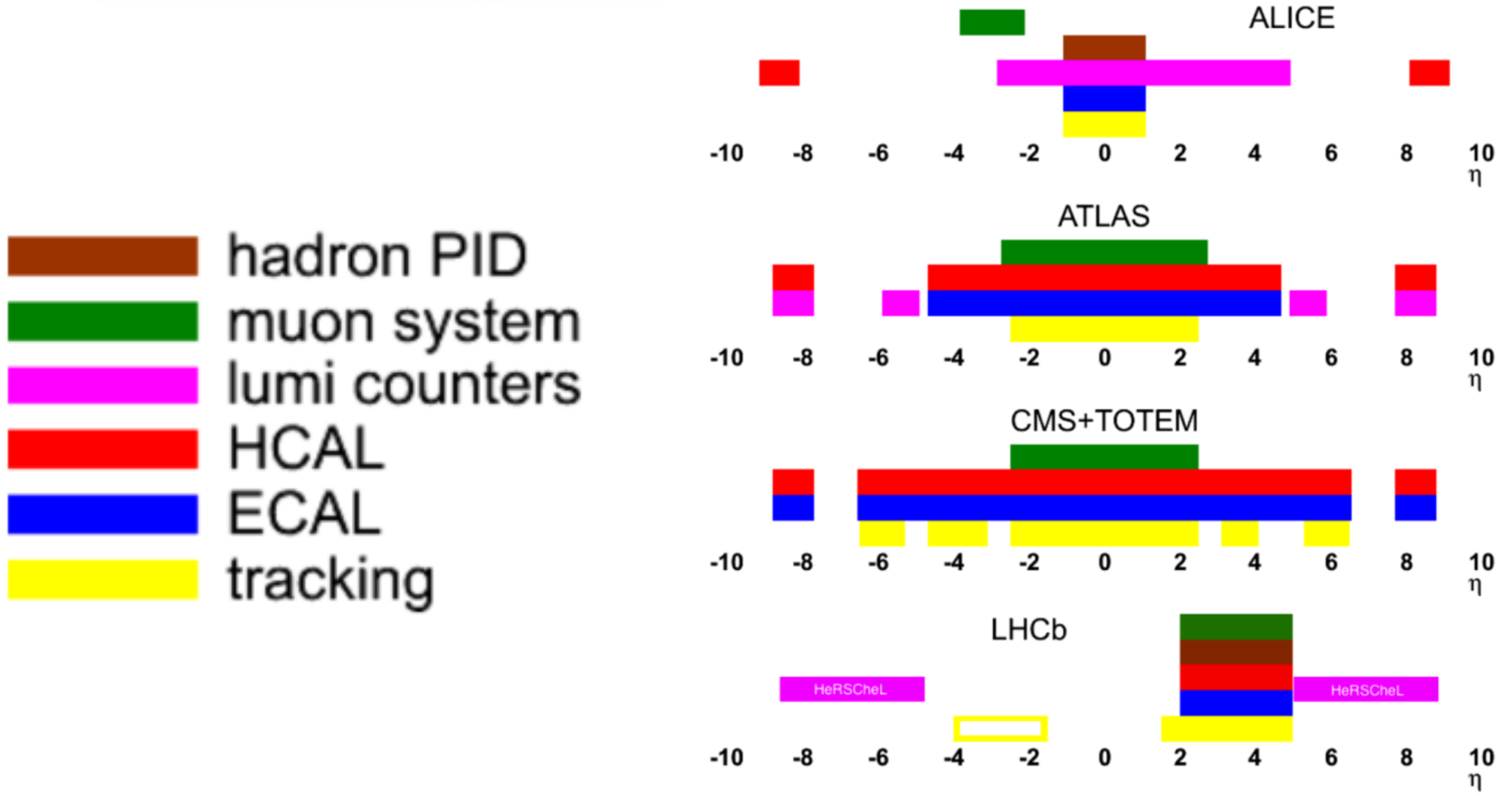
  $\Rightarrow \delta p/p \approx 0.5 - 1.0\,\%$ for $0 < p < 200$ GeV/c.

- ✤Particle identification.

  $\Rightarrow \varepsilon_{K\to K} \approx 95\,\%$ for $\varepsilon_{\pi\to K} \approx 5\,\%$ up to 100 GeV/c.
  $\Rightarrow \varepsilon_{\mu\to\mu} \approx 97\,\%$ for $\varepsilon_{\pi\to\mu} \approx 1 - 3\,\%$.

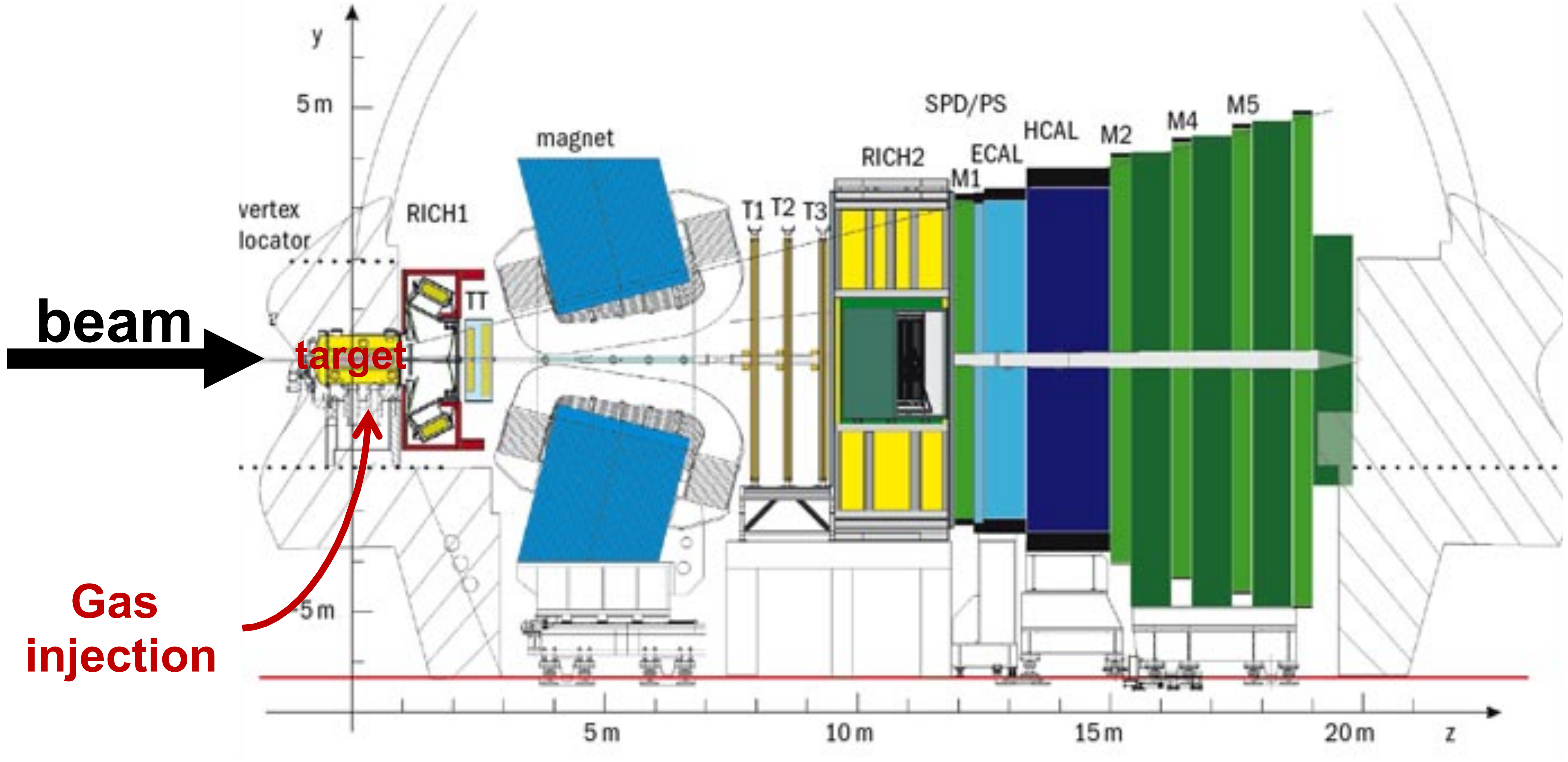
❖LHCb can also operate in *p*-Pb and Pb-Pb collisions.





The LHCb detector

Fixed-target operation



❖Unique feature at LHC.

❖Inject noble gas into the VELO tank (interaction region).

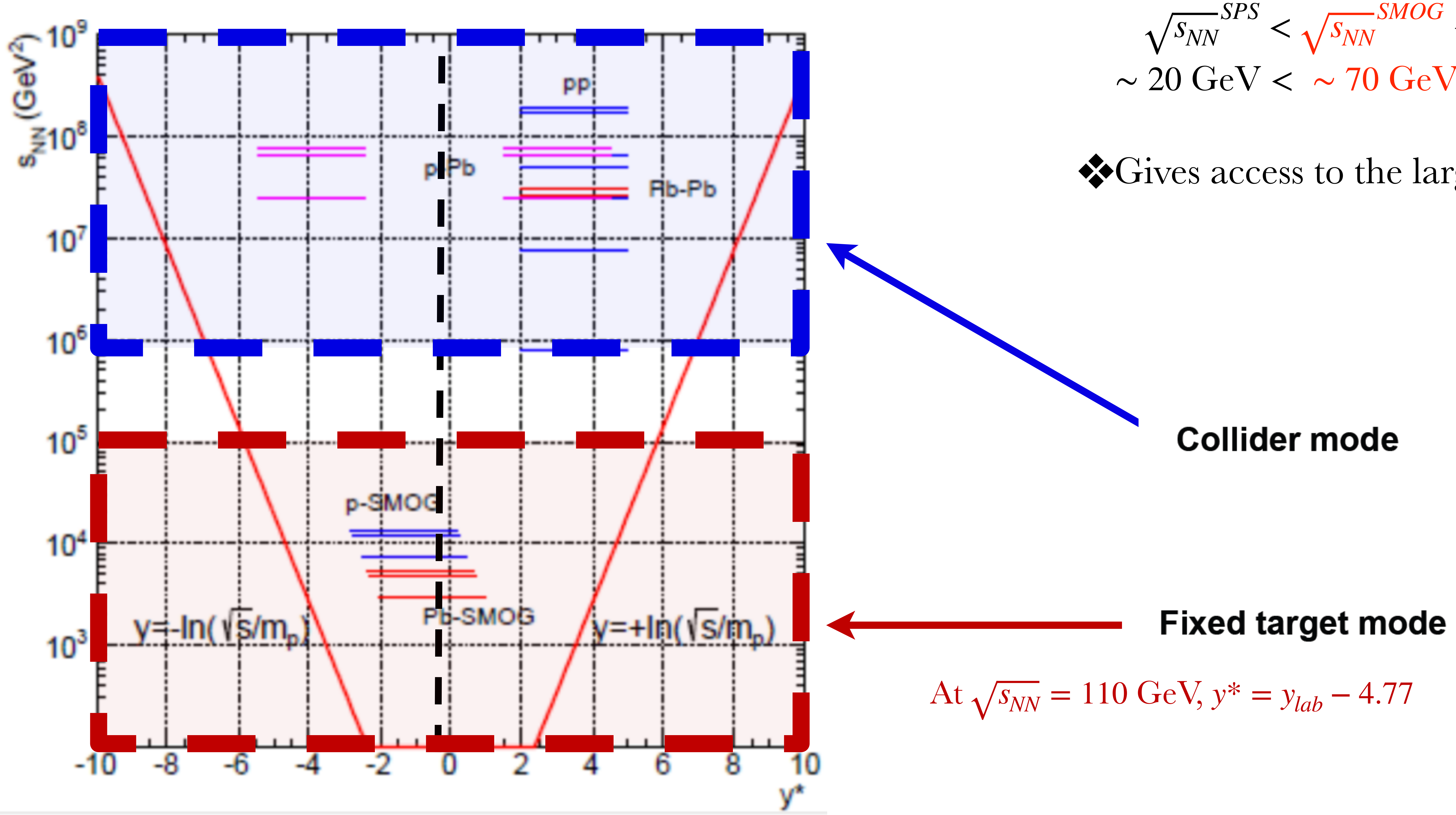
❖Gas target for *p*-gas and Pb-gas collisions.

❖So far have been used: He, Ne and Ar.

❖Typical pressure $\sim 2 \times 10^{-7}$ mbar (about two orders of magnitude higher than nominal pressure).

LHCb operations for heavy ion physics

LHCb rapidity coverage in the cms



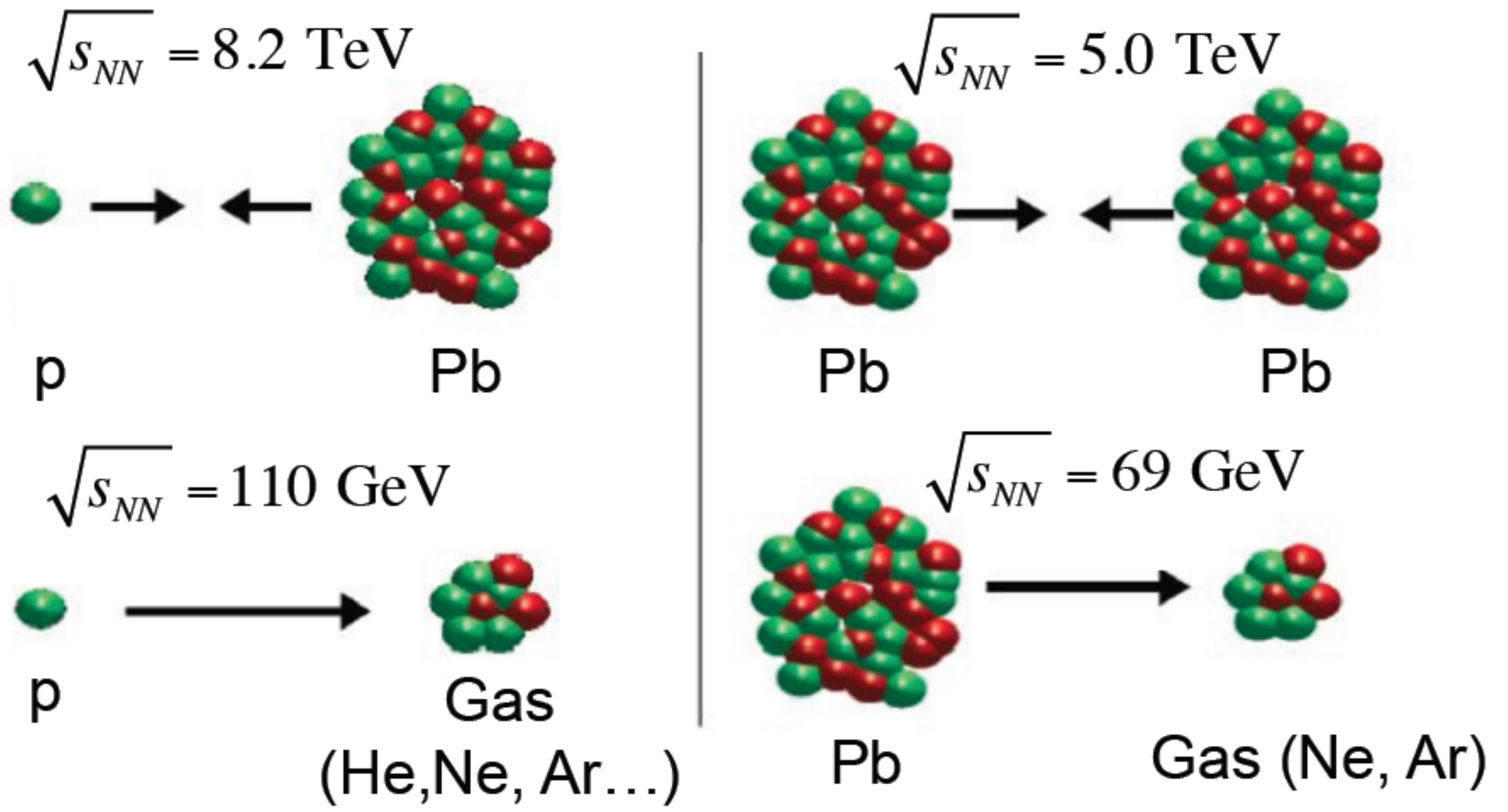
At $\sqrt{s_{NN}} = 110$ GeV, $y^* = y_{lab} - 4.77$

❖Fills the existing energy gap between SPS and RHIC.

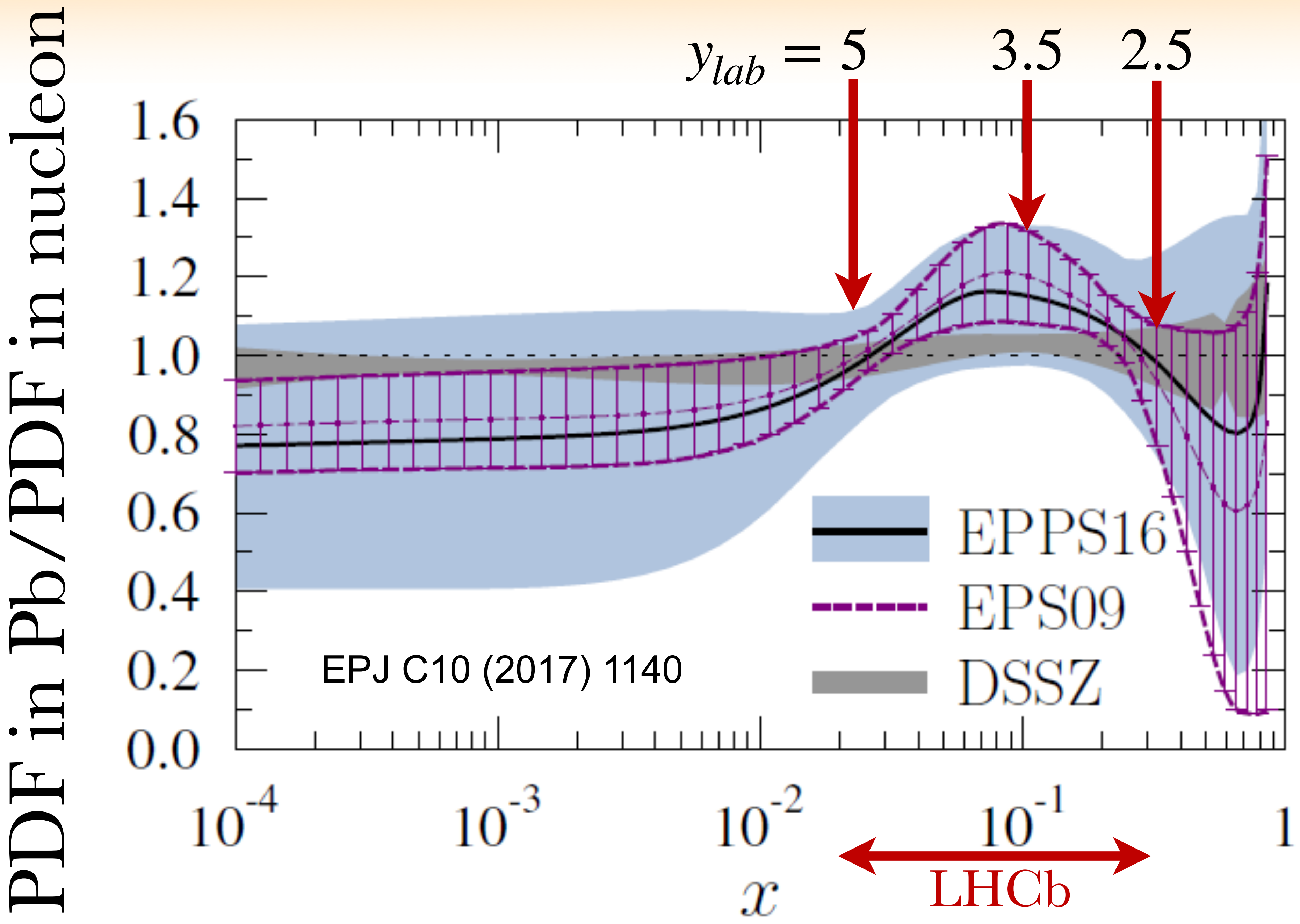
$\sqrt{s_{NN}}^{SPS} < \sqrt{s_{NN}}^{SMOG} < \sqrt{s_{NN}}^{RHIC} < \sqrt{s_{NN}}^{LHC}$

$\sim$ 20 GeV < $\sim$ 70 GeV < 200 GeV < 5 TeV

❖Gives access to the large Bjorken-x region in the target.

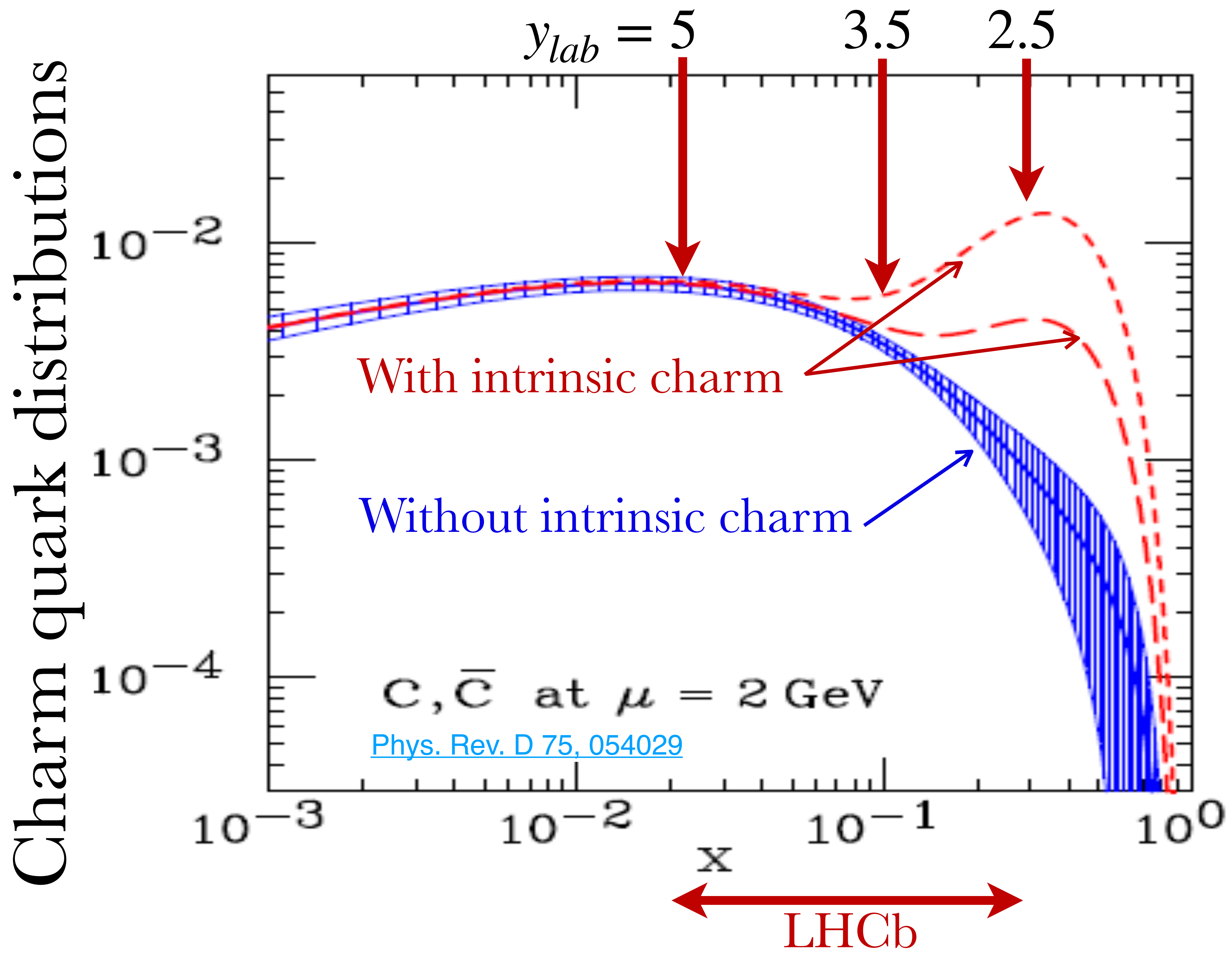


Charm in fixed-target p-A and Pb-A collisions



❖**Nucleus-nucleus collisions** ($\sqrt{s_{NN}}$ = 69 GeV): 2.5 TeV Pb beam on fixed target.

- No regeneration of charmonium ($\sigma_{c\bar{c}}^{FT} \approx \frac{1}{100}\sigma_{c\bar{c}}^{LHC}$).
- Probe the Quark Gluon Plasma (QGP) phase transition via colour screening.
- LHCb allows for new opportunities for charm: $J/\psi, \psi', \chi_c, D^0, D^{+/-}, D^*, \Lambda_c$, ...

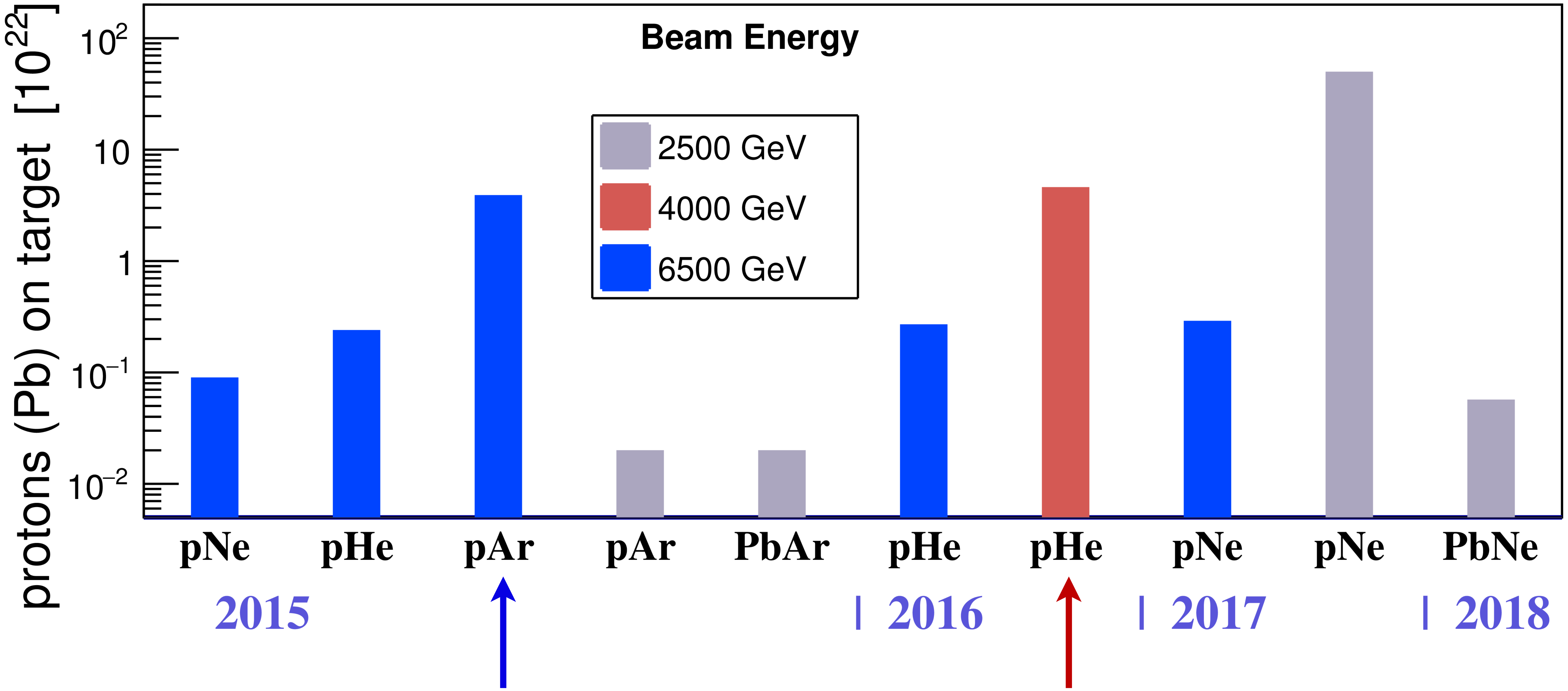


❖**Proton-nucleus collisions.**

- Baseline for the nucleus-nucleus collisions, study of nuclear PDF, and other effects.
- At LHCb, 3 units of rapidity coverage, at large Bjorken-x in the target (x_2).
  - Access the nPDF anti-shadowing region and intrinsic charm content in the nucleon

Fixed-targets so far

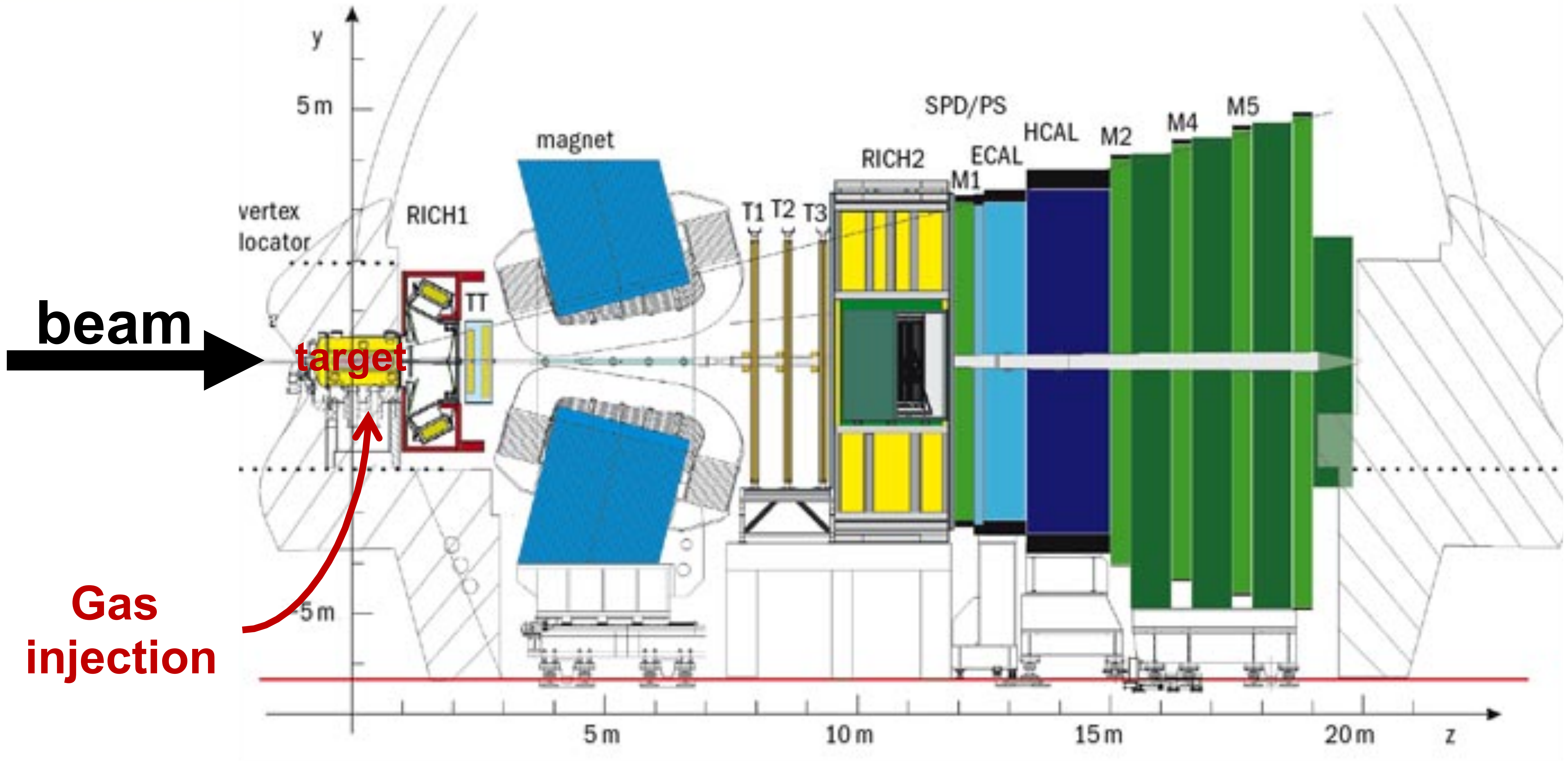
Data samples: two datasets in this presentation.



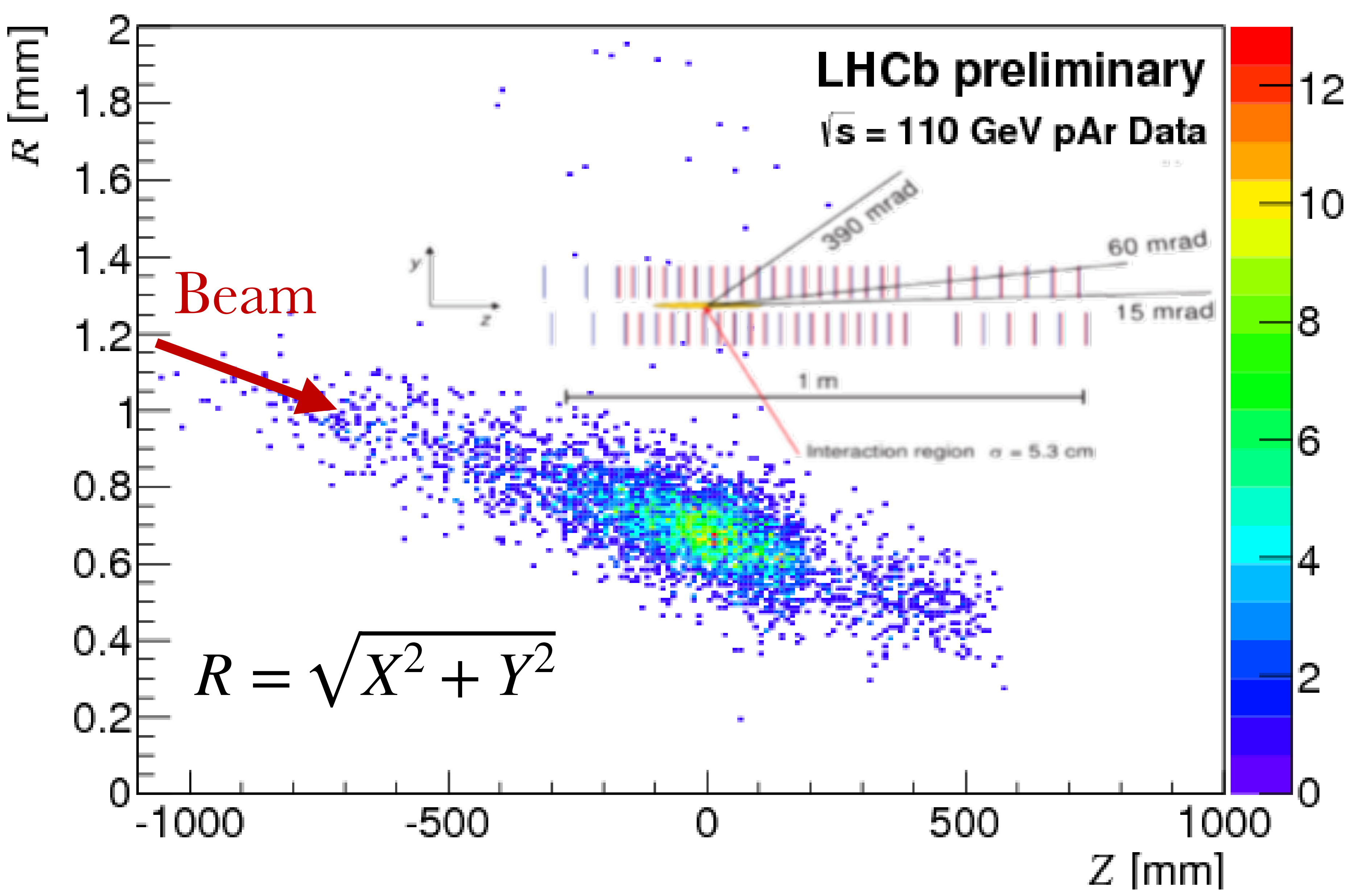
$\sqrt{s_{NN}} = 110$ GeV proton-Ar collisions
$\sim 4 \times 10^{22}$ protons on target

$\sqrt{s_{NN}} = 86.6$ GeV proton-He collisions
$\sim 4 \times 10^{22}$ protons on target
$\mathscr{L}_{pHe} = 7.6 \pm 0.5\ \mathrm{nb}^{-1}$

Charm production in p-A collisions



(R, Z) position of primary vertex



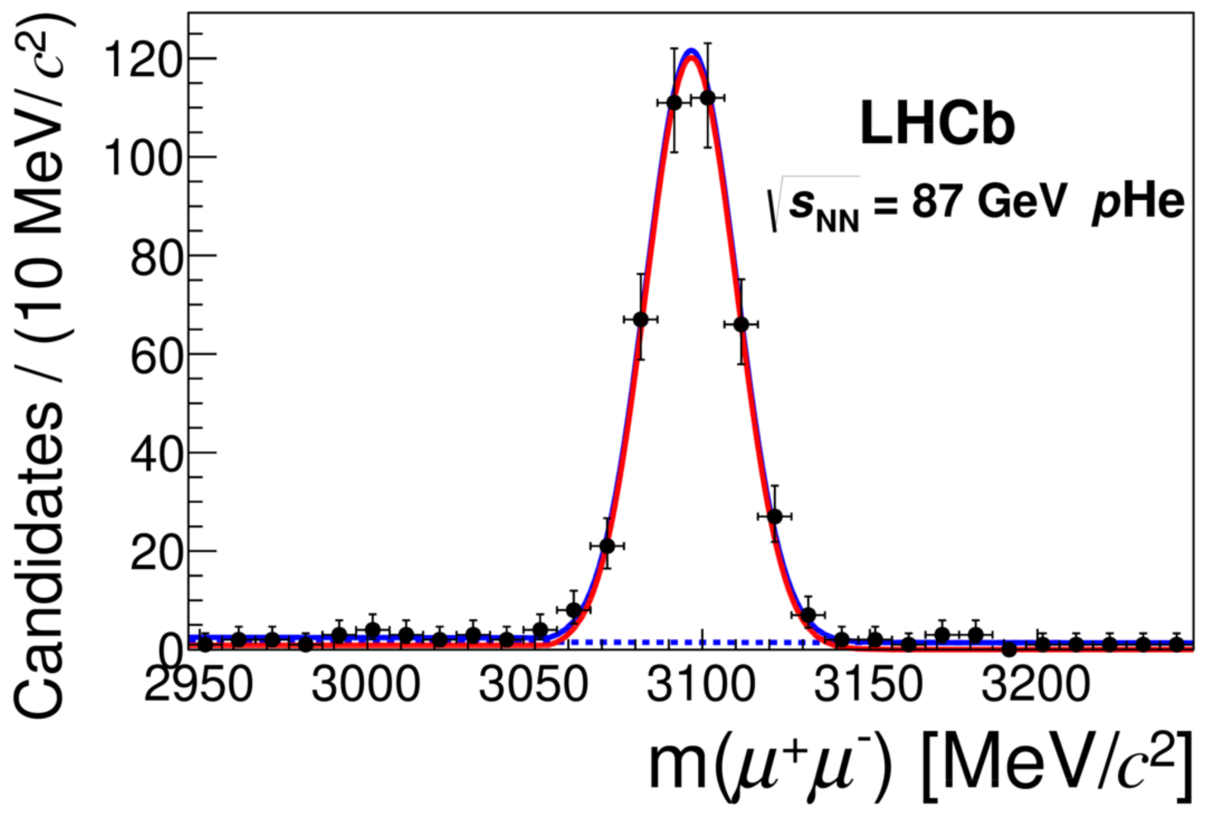
❖Select events with only Beam 1 at the interaction point.

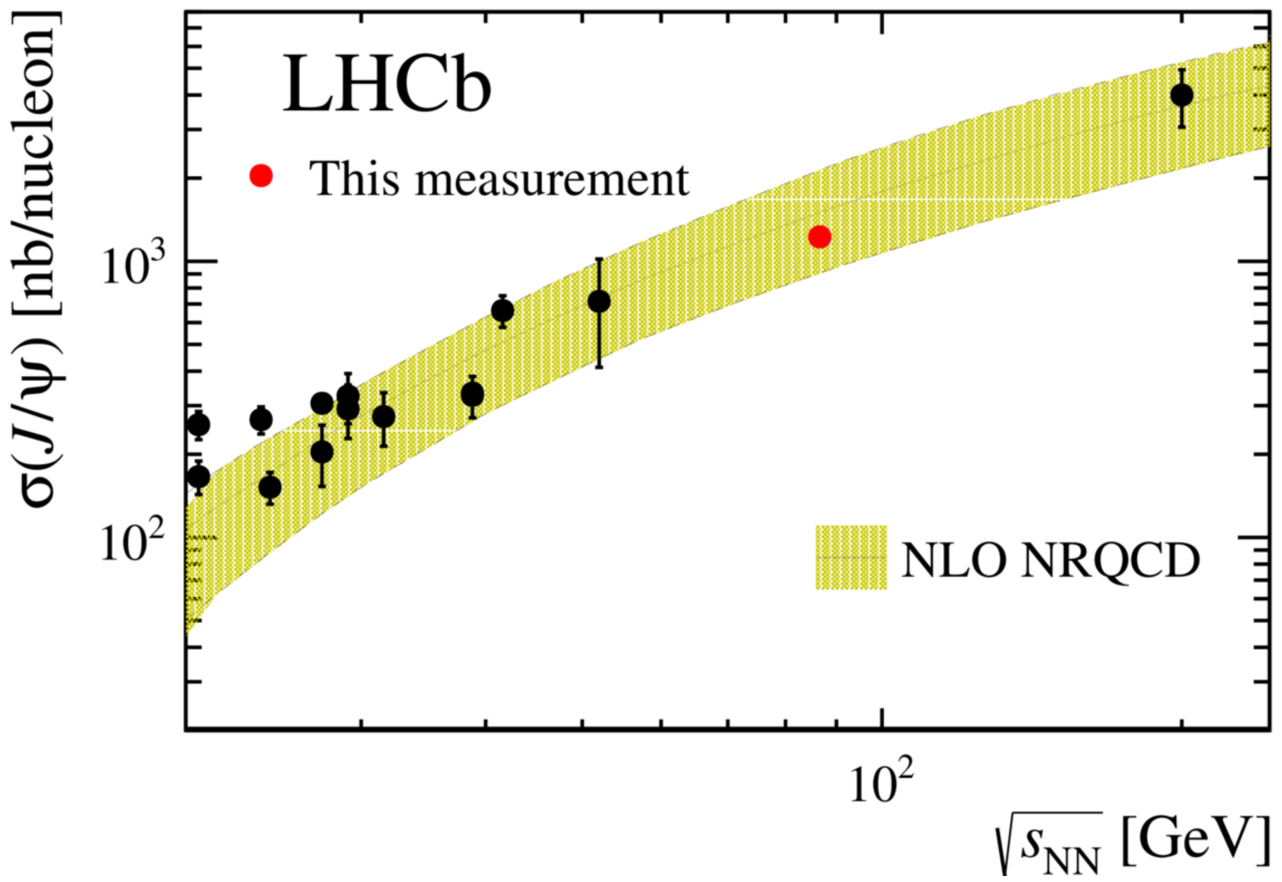
❖Select only events within the VELO ⇒ $Z_{vertex} \in [-200,200]$ mm.

Charm production in p-A collisions

❖ $J/\psi \to \mu^+\mu^-$ and $D^0 \to K^\mp\pi^\pm$ inclusive cross sections in p-He at $\sqrt{s_{NN}} = 86.6$ GeV.

Phys. Rev. Lett. 122, 132002





❖ J/ψ measurement.

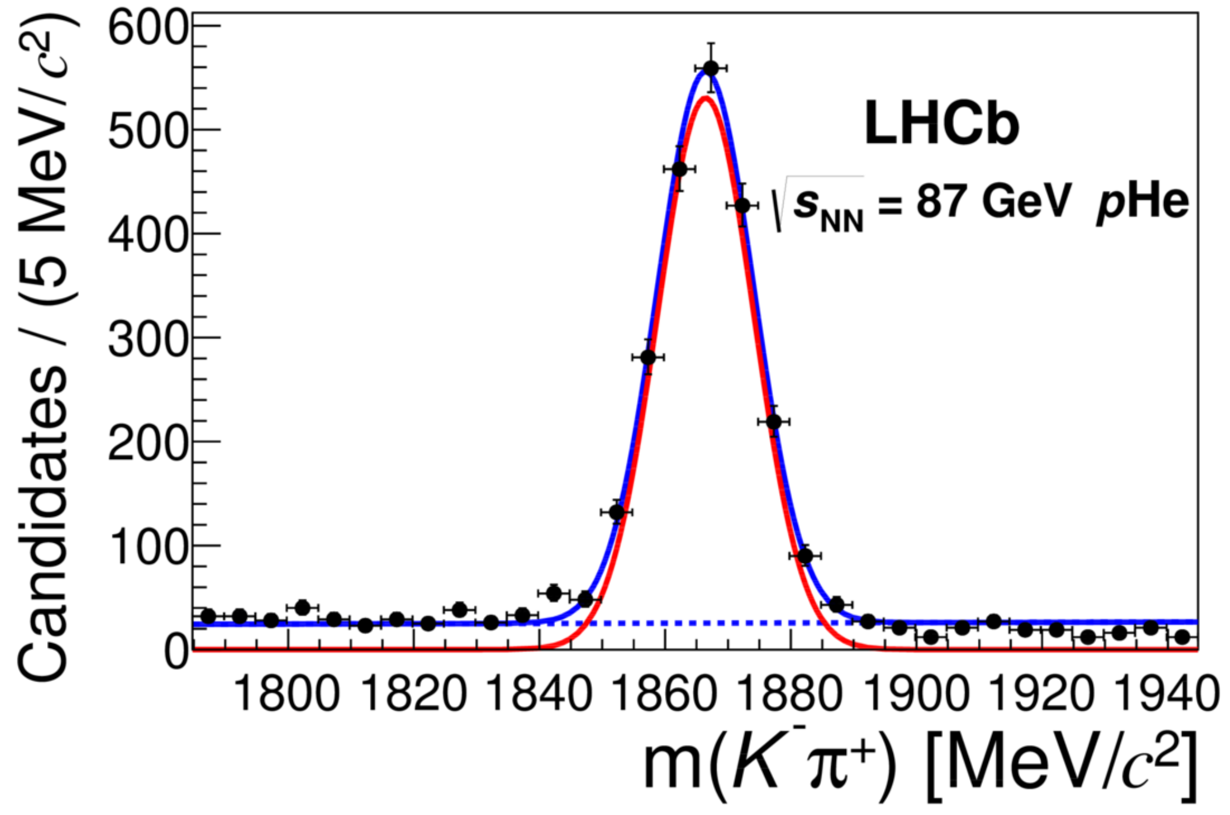
- $\sigma_{J/\psi} = 1225.6 \pm 100.7$ nb/nucleon.
- LHCb result in good agreement with other measurements.

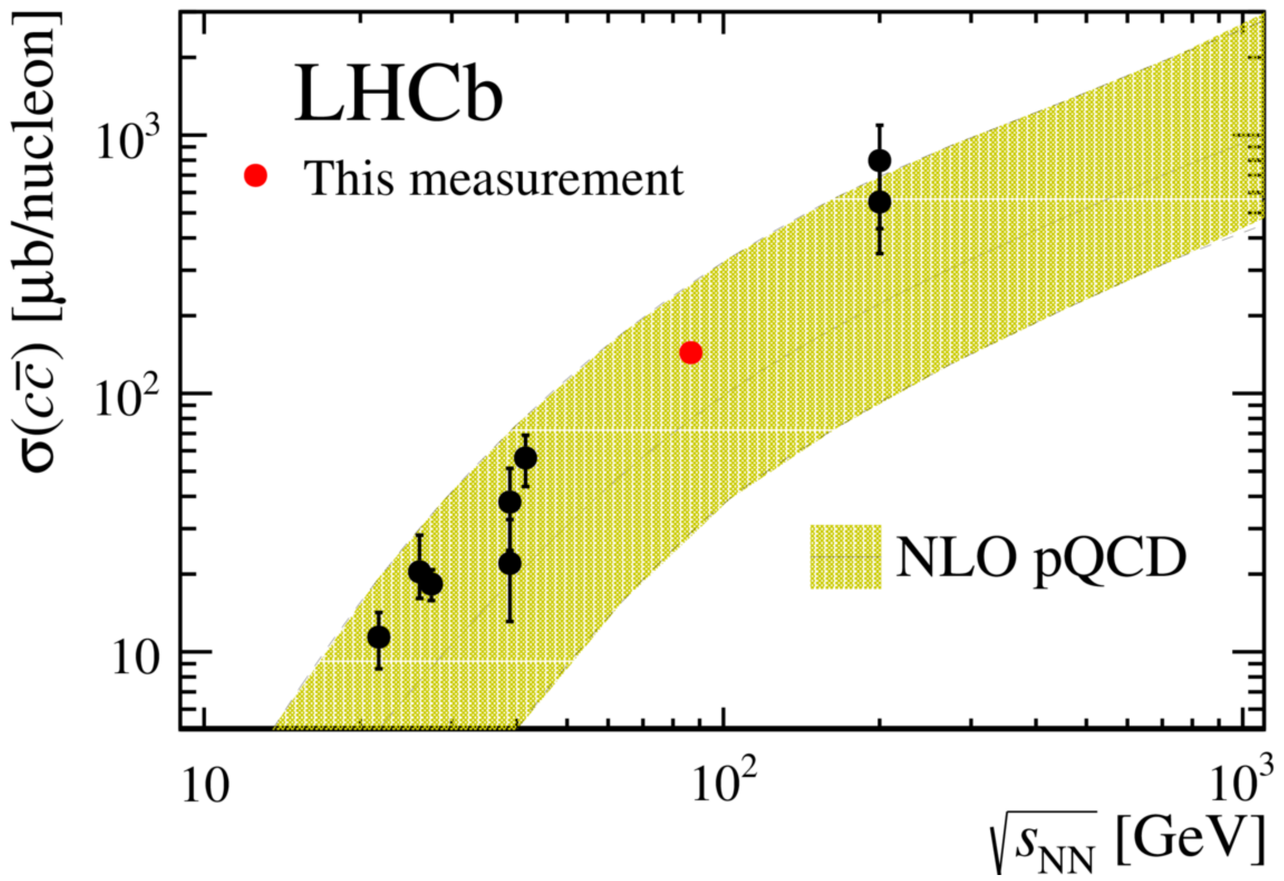
❖ D^0 measurement.

- $\sigma_{D^0} = 156.0 \pm 13.1\ \mu$b/nucleon.

  With fraction $(c \to D^0) = 0.542 \pm 0.024$:

- $\sigma_{c\bar{c}} = 144 \pm 13\ \mu$b/nucleon.
- LHCb result in reasonable agreement with NLO pQCD predictions and other measurements.



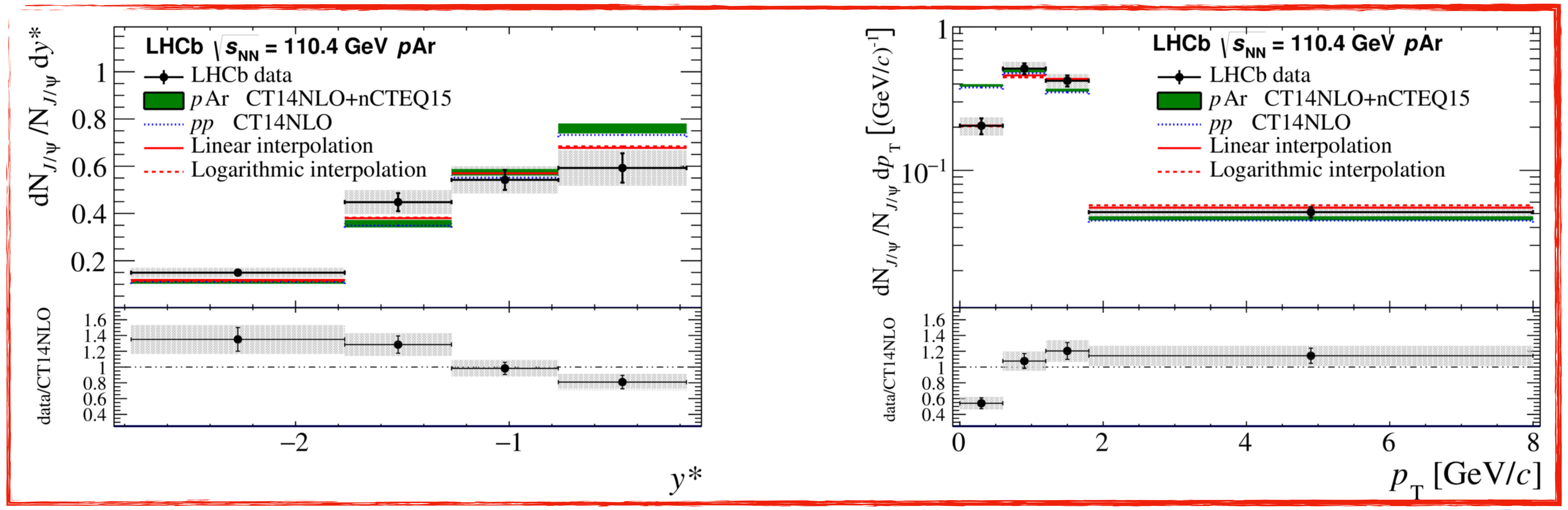


Charm production in p-A collisions

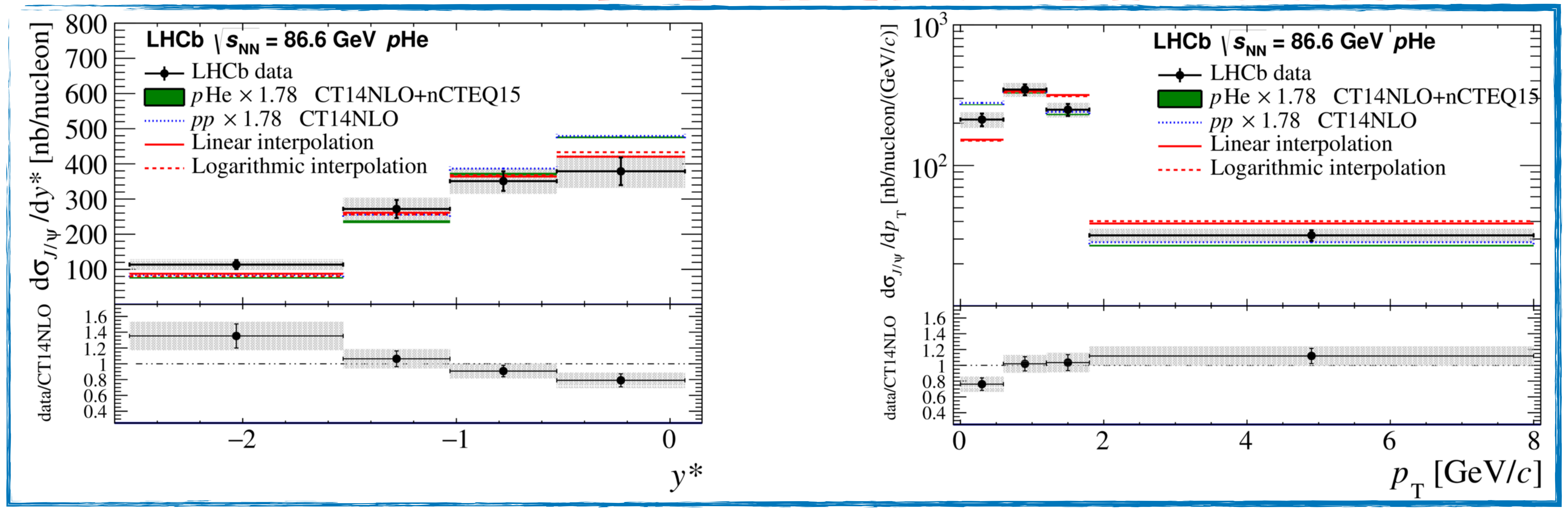
❖J/ψ differential yields in *p*-Ar and cross sections in *p*-He. [Phys. Rev. Lett. 122, 132002](#)

- Plain and dashed red lines are phenomenological parametrisation: JHEP 05 (2013) 155
- HELAC-ONIA predictions for *p*-*p* (blue lines) and *p*-A (green boxes): EPJC(2017) 77:1

❖*p*-Ar yields at $\sqrt{s_{NN}} = 110$ GeV.



❖*p*-He cross sections at $\sqrt{s_{NN}} = 86.6$ GeV.



- HELAC-ONIA underestimates the J/ψ cross section on *p*-He by a factor 1.78.
- Good shape agreement with the predictions.

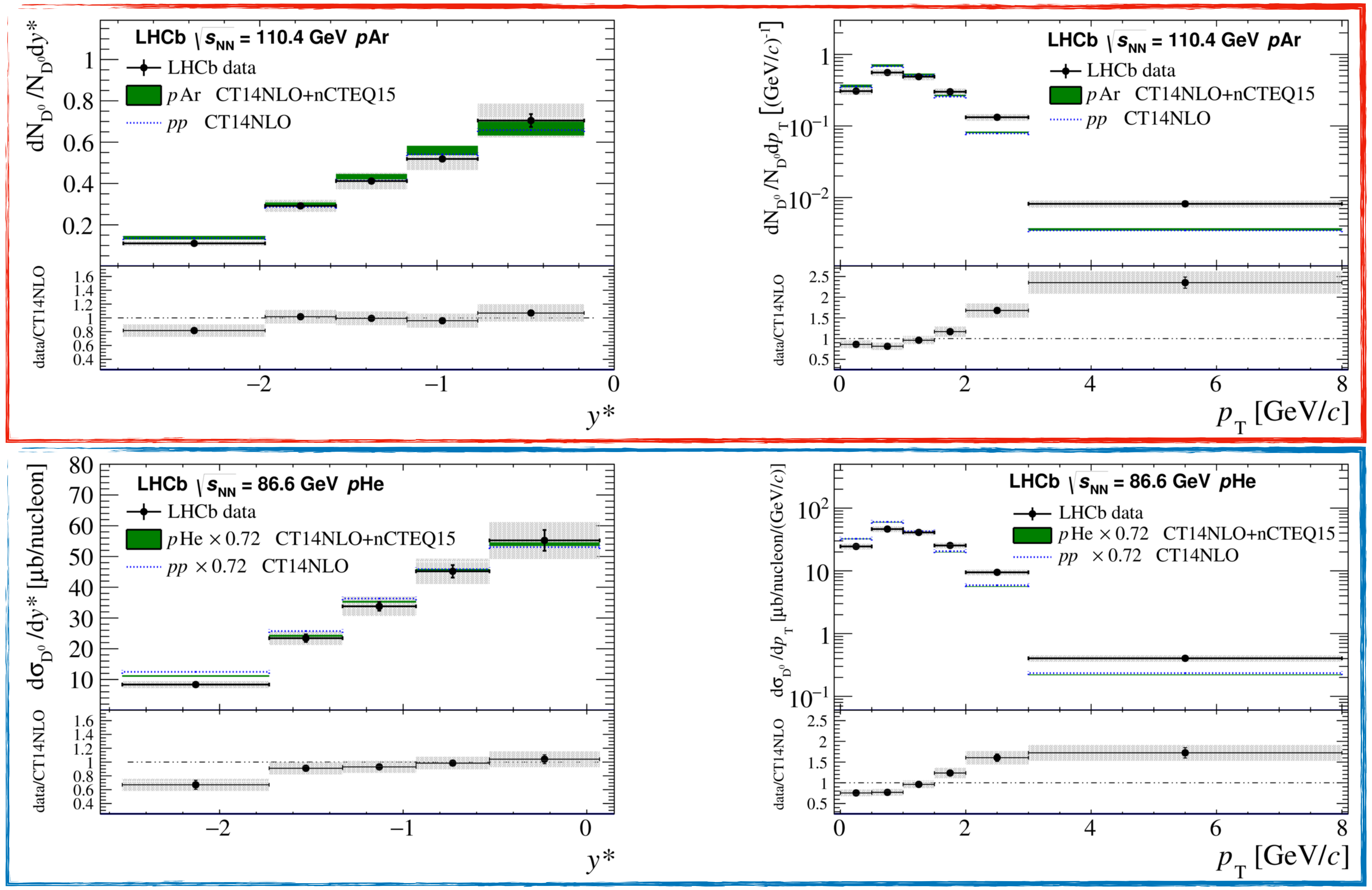
Charm production in p-A collisions

❖ D^0 differential yields in p-Ar and cross sections in p-He. [Phys. Rev. Lett. 122, 132002]

- HELAC-ONIA predictions for p-p (blue lines) and p-A (green boxes): EPJC(2017) 77:1

❖ p-Ar yields at $\sqrt{s_{NN}} = 110$ GeV.

❖ p-He cross sections at $\sqrt{s_{NN}} = 86.6$ GeV.

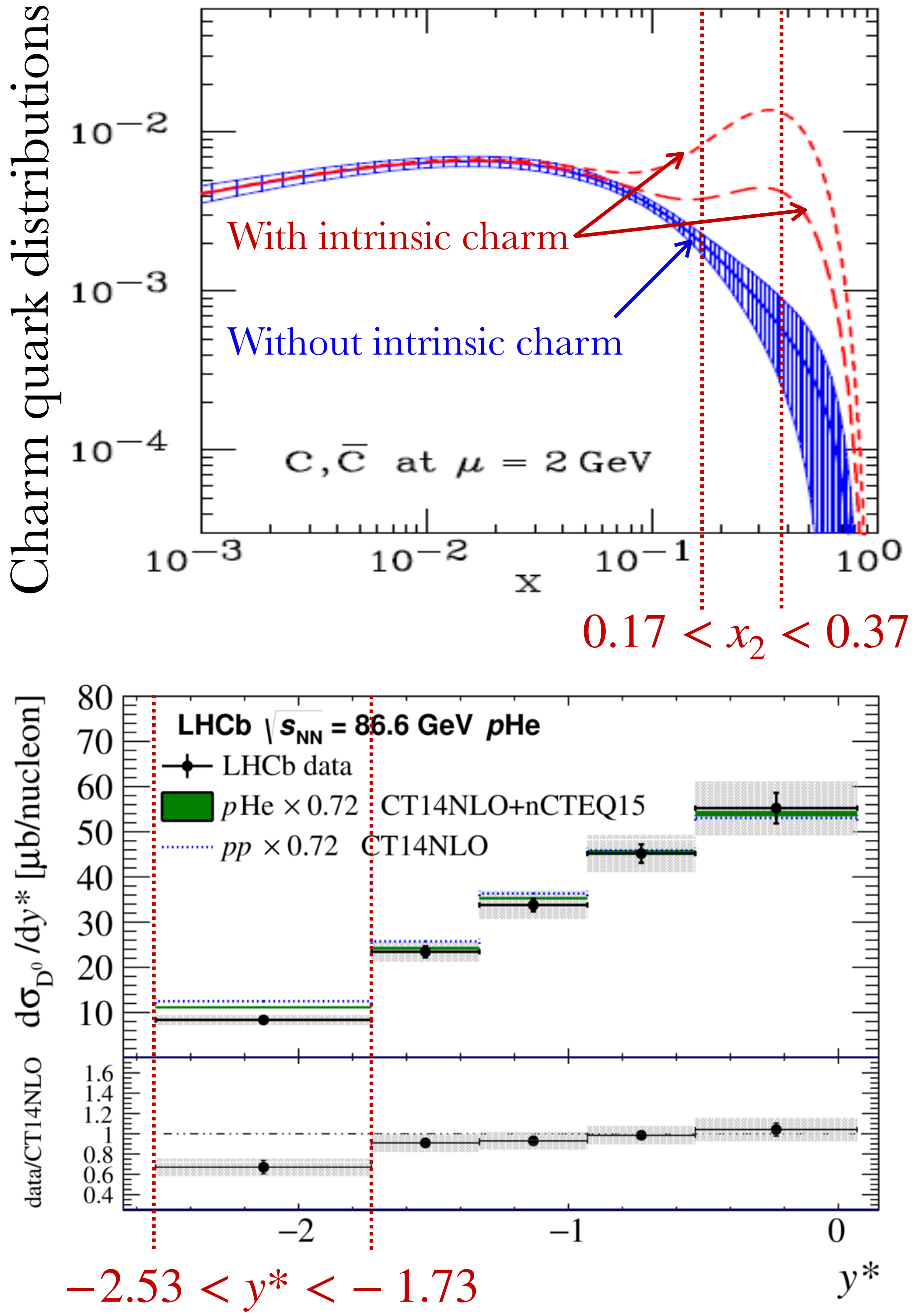


- HELAC-ONIA underestimates the D^0 cross section on p-He by a factor 0.72.

- Good rapidity shape agreement with the predictions.

Charm production in p-A collisions

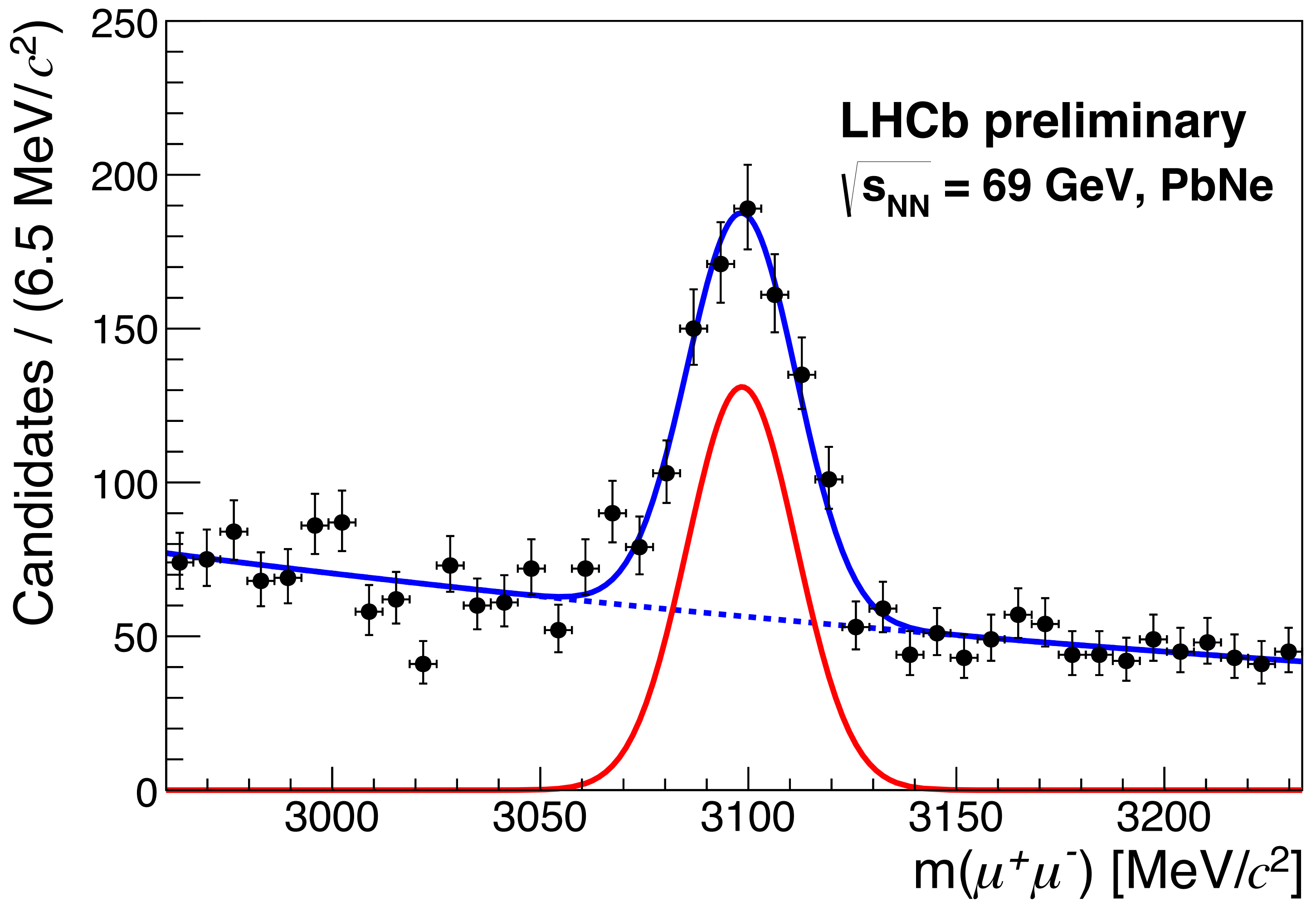
Phys. Rev. Lett. 122, 132002

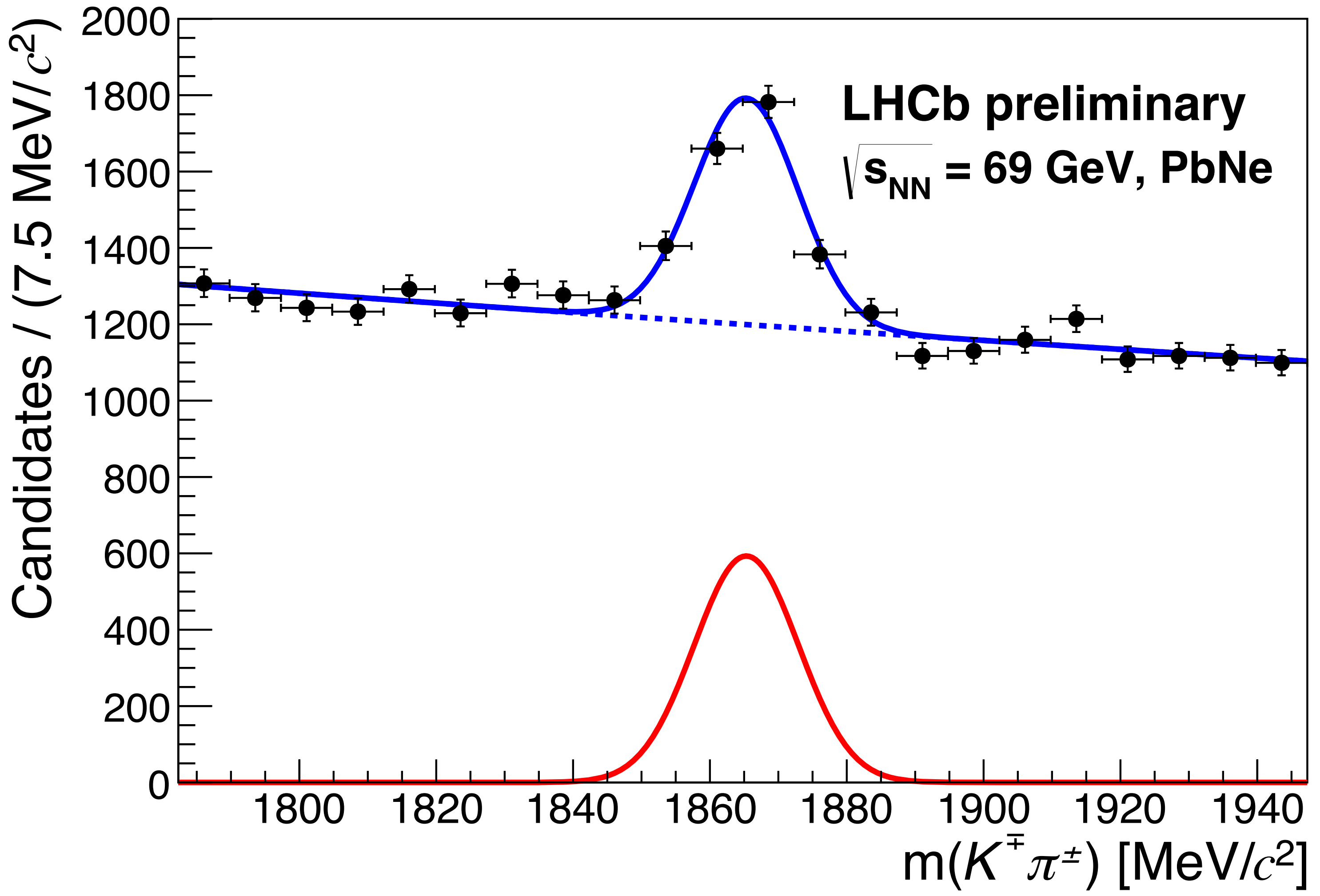


- D^0 cross sections from *p*-He at $\sqrt{s_{NN}} = 86.6$ GeV and intrinsic charm
  - HELAC-ONIA predictions for *p*-*p* (blue lines) and *p*-A (green boxes): EPJC(2017) 77:1
  - With $x_2 \approx \frac{2m_c}{\sqrt{s_{NN}}}\exp(-y^*)$ we have: $y^* \in [-1.73, -2.53] \Leftrightarrow x_2 \in [0.17, 0.37]$

- HELAC-ONIA does not contain intrinsic charm contribution.
- For the moment, **no evidence** of strong valence-like intrinsic charm contributions.

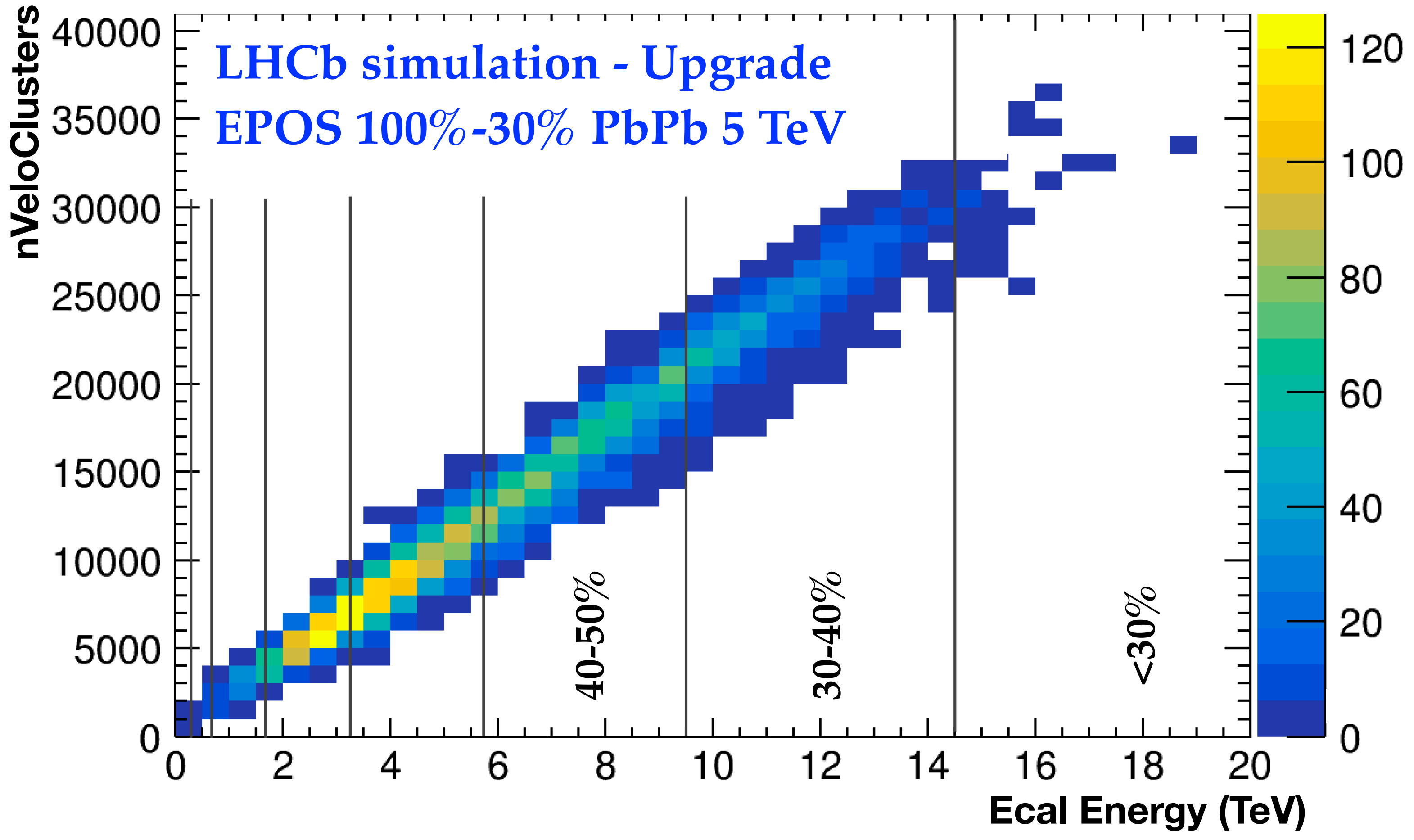
Charm production in the future

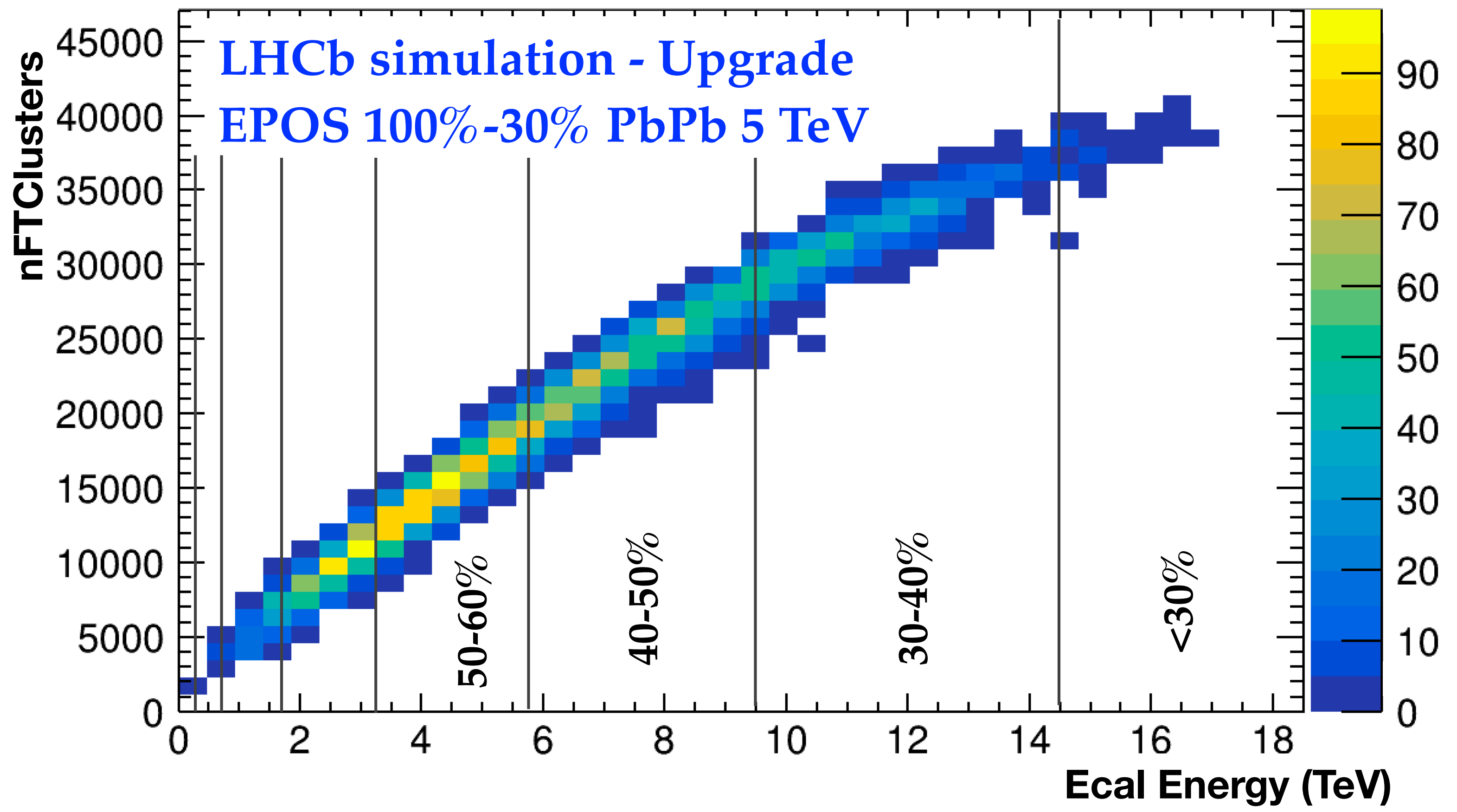




- Ongoing analyses of existing data:
  - 2017 p-Ne at $\sqrt{s_{NN}} = 69$ GeV
  - 2018 Pb-Ne at $\sqrt{s_{NN}} = 69$ GeV
    - Expected to reach much more central events than in Pb-Pb scenario.

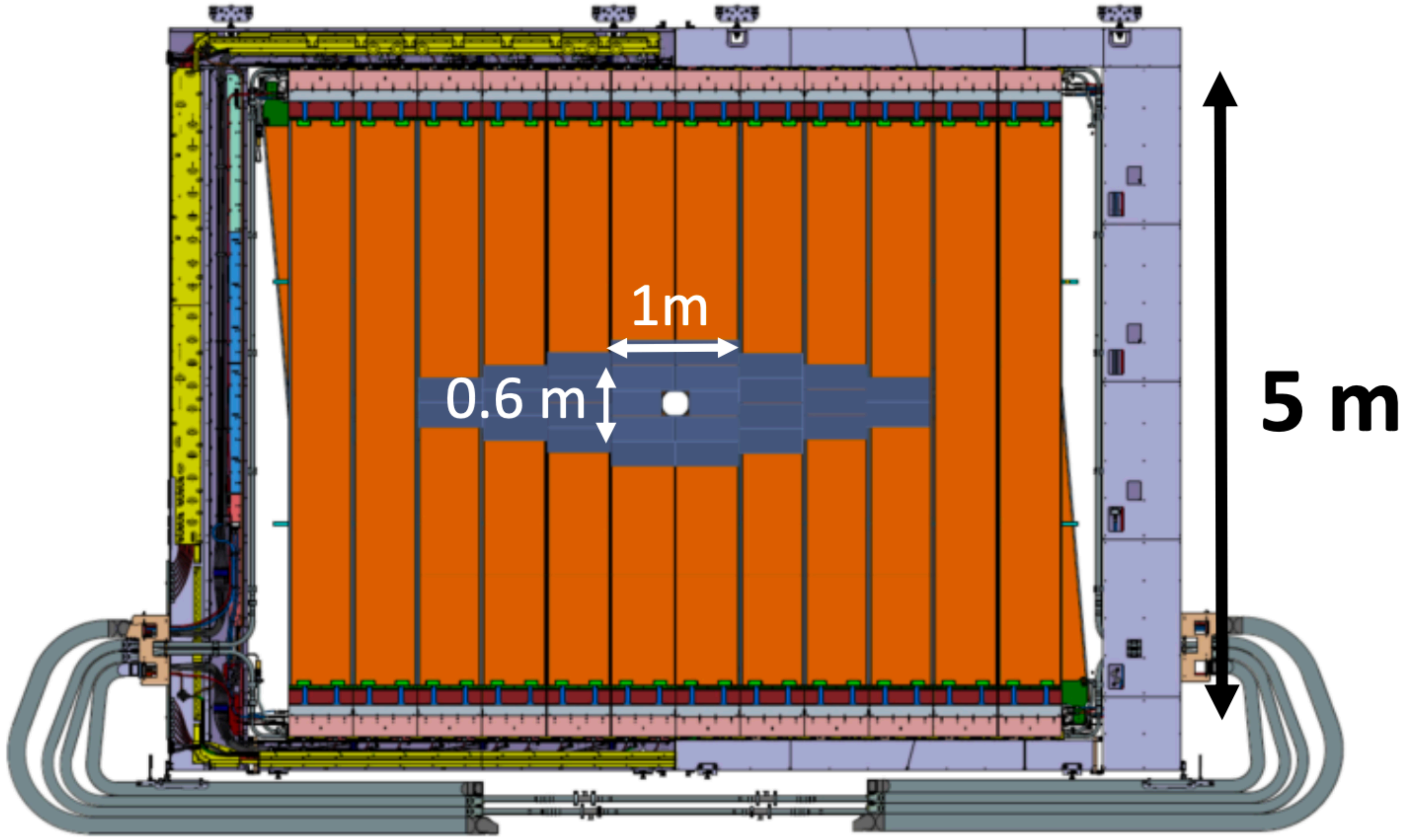
Charm production in the future

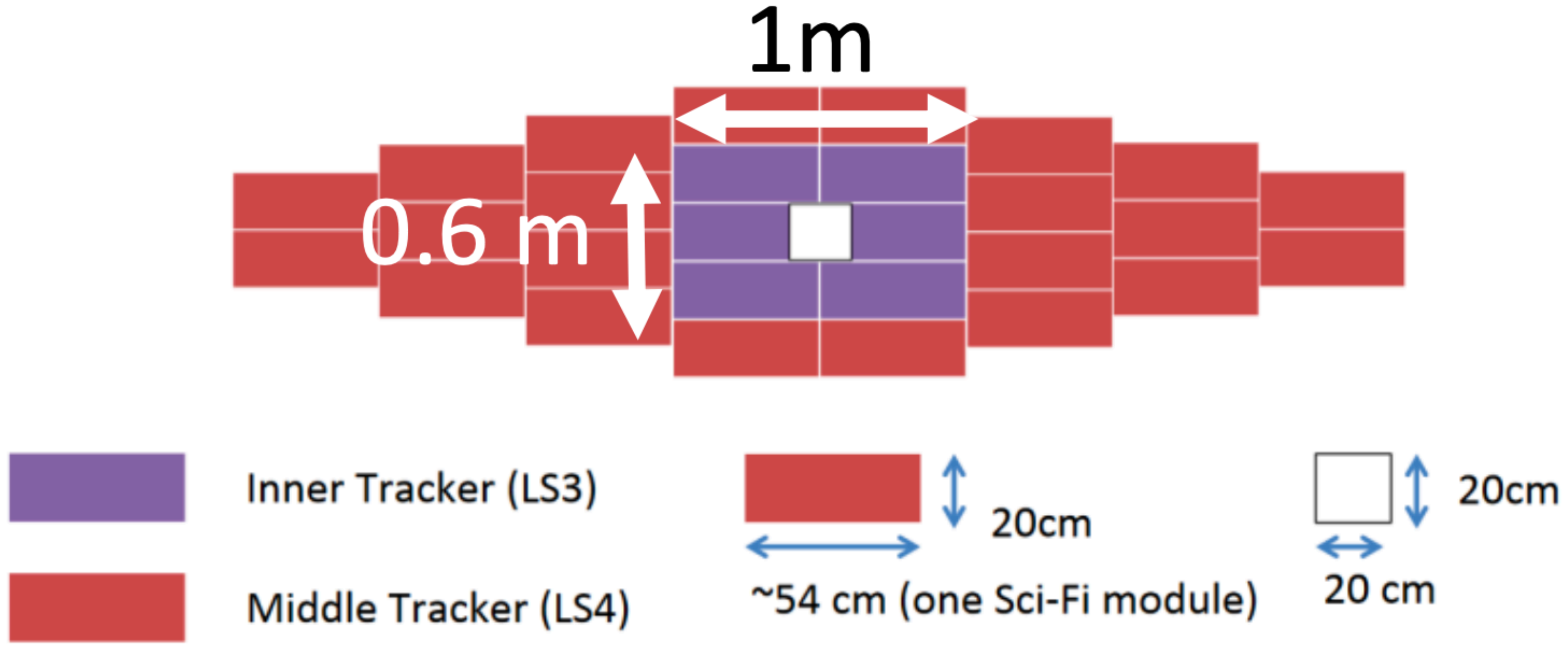




- For Run 3 of LHC:
  - For FT: New gas feed system (SMOG2)
    ⇒ Start with known gasses (He, Ne, Ar) before new ones.
  - VELO upgraded
  - Scintillating Fibre (SciFi) tracking station to be installed
    ⇒ Improvement of the track reconstruction in very dense environments (nuclei-nuclei).
    ⇒ Still saturate for most central Pb-Pb collisions.
  - We should have no centrality limitation in the previous nuclei-nuclei FT collisions in Run 3.
  - Start using new gas species (H, D, O).

Charm production in the future





❖ Tracking system upgrades in the future:

- ✤ Run 3: SciFi → Push Pb-Pb to 30% centrality.
- ✤ Run 4: Add silicon Inner Tracker to SciFi → Push Pb-Pb to 10-20%.
- ✤ Run 5: Add Middle Tracker to the set up → Push Pb-Pb to 0%.

⇒ For Run 4 and 5 we are confident to have no centrality limitation for the fixed-target scenario, for any chosen target!

Charm production in the future

LHCb-PUB-2018-015

System	$\sqrt{s_{NN}}$ (GeV)	< pressure> (10^{-5} mbar)	ρ_S (cm^{-2})	$\mathcal{L}$ ($cm^{-2}s^{-1}$)	Rate (MHz)	Time (s)	$\int \mathcal{L}$ (pb^{-1})
pH_2	115	4.0	2.0×10^{13}	6×10^{31}	4.6	2.5×10^6	150
pD_2	115	2.0	1.0×10^{13}	3×10^{31}	4.3	0.3×10^6	9
pAr	115	1.2	0.6×10^{13}	1.8×10^{31}	11	2.5×10^6	45
pKr	115	0.8	0.4×10^{13}	1.2×10^{31}	12	2.5×10^6	30
pXe	115	0.6	0.3×10^{13}	0.9×10^{31}	12	2.5×10^6	22
pHe	115	2.0	1.0×10^{13}	3×10^{31}	3.5	3.3×10^3	0.1
pNe	115	2.0	1.0×10^{13}	3×10^{31}	12	3.3×10^3	0.1
pN_2	115	1.0	0.5×10^{13}	1.5×10^{31}	9.0	3.3×10^3	0.1
pO_2	115	1.0	0.5×10^{13}	1.5×10^{31}	10	3.3×10^3	0.1
PbAr	72	8.0	4.0×10^{13}	1×10^{29}	0.3	6×10^5	0.060
PbH_2	72	8.0	4.0×10^{13}	1×10^{29}	0.2	1×10^5	0.010
pAr	72	1.2	0.6×10^{13}	1.8×10^{31}	11	3×10^5	5

	SMOG published result pHe@87 GeV	SMOG largest sample pNe@69 GeV	SMOG2 example pAr@115 GeV
Integrated luminosity	7.6 nb^{-1}	$\sim$ 100 nb^{-1}	$\sim$ 45 pb^{-1}
syst. error on J/ψ x-sec.	7%	6 - 7%	2 - 3 %
J/ψ yield	400	15k	15M
D^0 yield	2000	100k	150M
Λ_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

- The possible catalog of systems to be studied is broad.
- Expected data to be recorded in Run 3 of LHC.
- Assumptions:
  - Simultaneous to p-p.
  - 1/3 of beam time.
  - All available beam bunches to be used.
- Estimates of expected charmed particles production are extrapolated from p-He result.
- Important increase in statistics, and reduction of systematic errors.
- The measurements of $\psi(2S)$ and possibly χ_c would provide important inputs to the study of sequential suppression of charmonia.

Conclusions

- LHCb is the only LHC experiment capable of running in both collider and fixed-target modes.
- LHCb has unique capabilities for heavy-flavour measurements at LHC.
- Fixed-target programme has delivered J/ψ and D^0 cross sections and yields measurements:
    - In $\sqrt{s_{NN}} = 110$ GeV p-Ar collisions.
    - In $\sqrt{s_{NN}} = 86.6$ GeV p-He collisions.
    - No evidence for strong intrinsic charm contribution.
    - Other analyses ongoing (p-Ne and Pb-Ne at $\sqrt{s_{NN}} = 69$ GeV).
- The SMOG2 and LHCb general detector upgrade, will significantly enhance performance and allow more ambitious measurements in fixed-target mode.
- Prospects for charm physics at LHCb are promising, and will give unique and decisive input to Heavy Ion physics

Thank You!