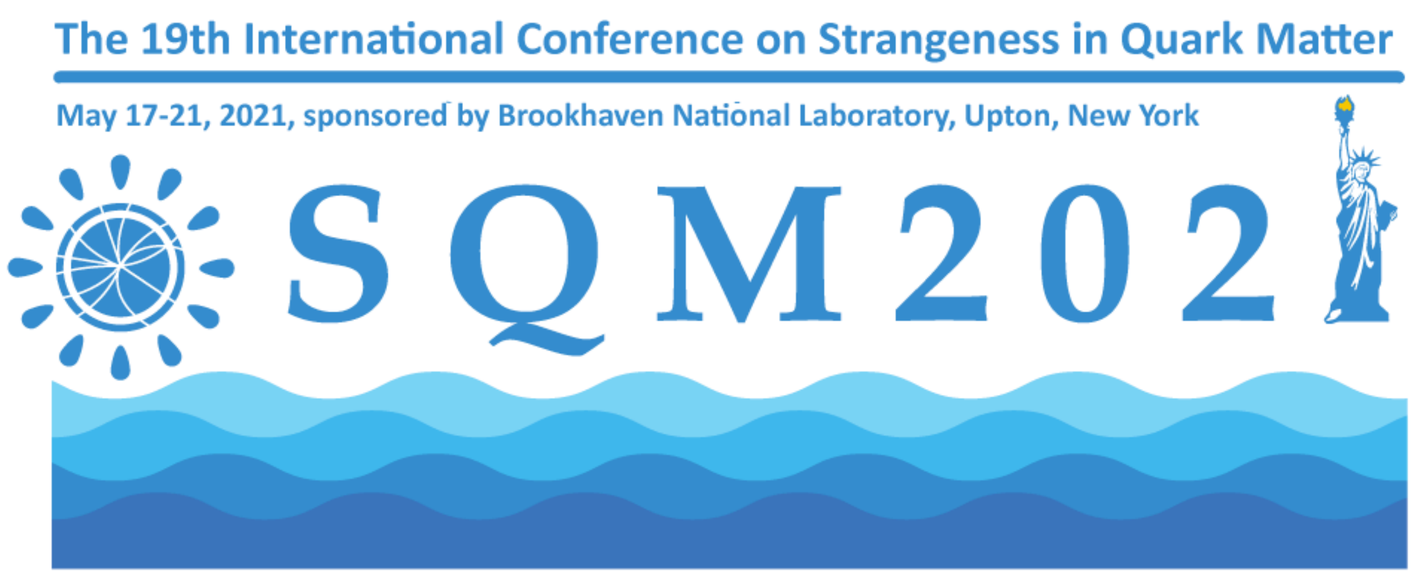
Heavy ion results from LHCb

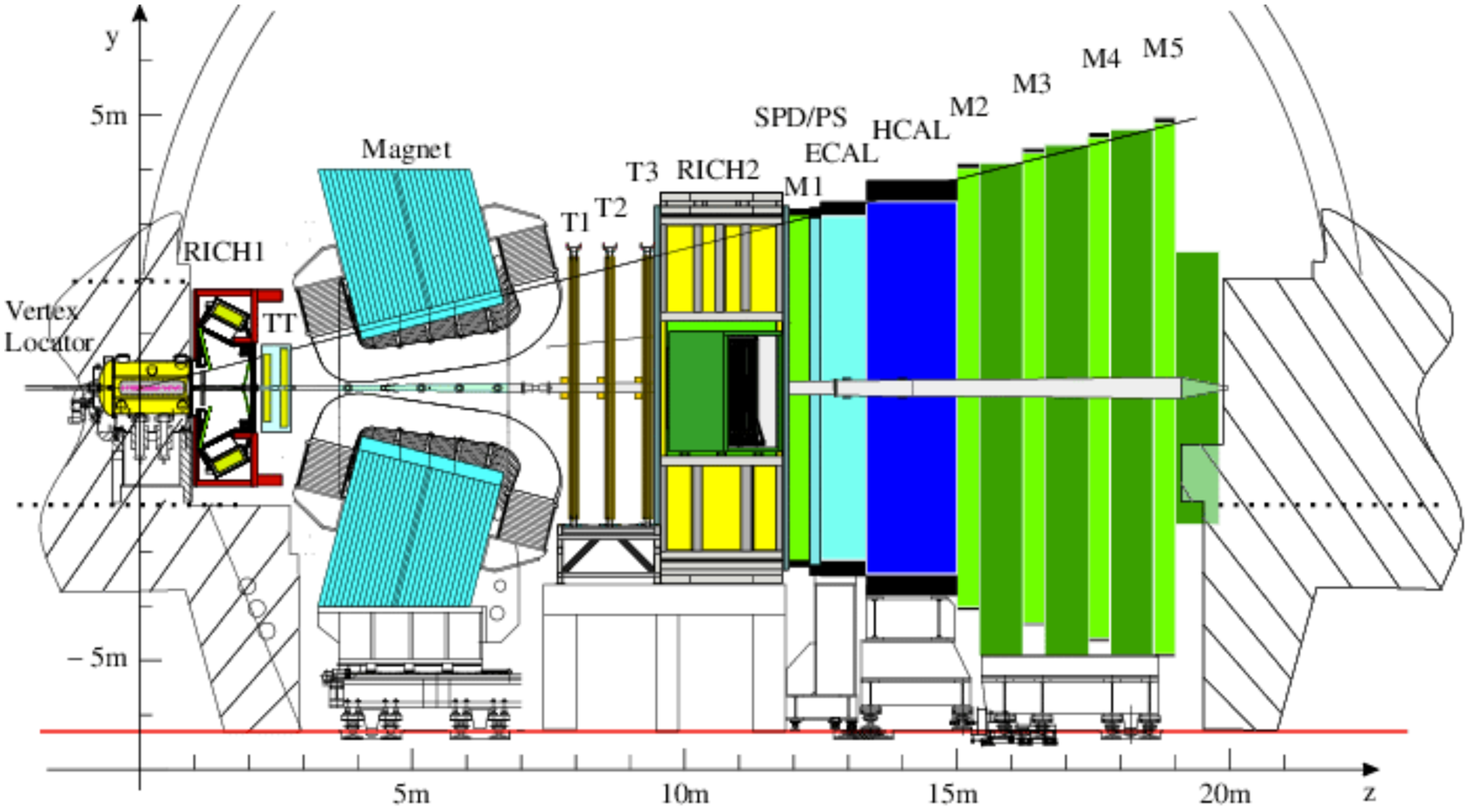
Jiayin Sun, on behalf of the LHCb collaboration
Università e INFN Cagliari
17th May 2021



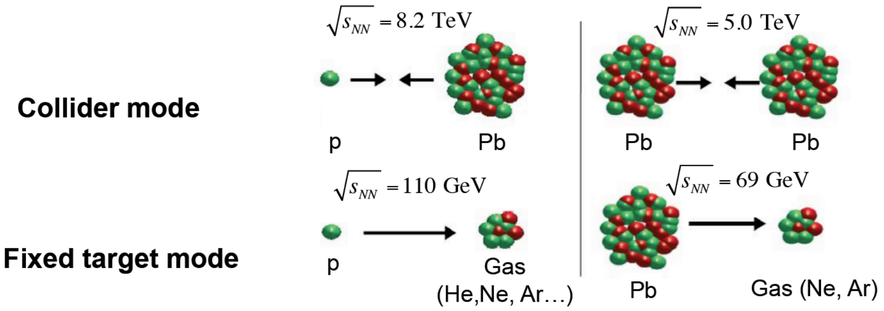
LHCb detector

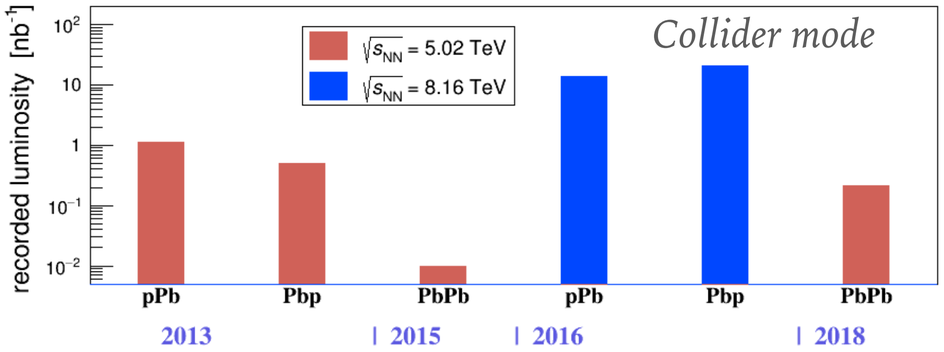
- Acceptance: $2 < \eta < 5$
- Vertex detector (VELO)
  - IP resolution ~ $20\mu m$
- Tracking system
  - $\frac{\Delta p}{p} = 0.5 - 1\,\%$ (5-200 GeV/c)
- RICH
  - K/π/p seperation
- Electromagnetic + hadronic calorimeters
- Muon system

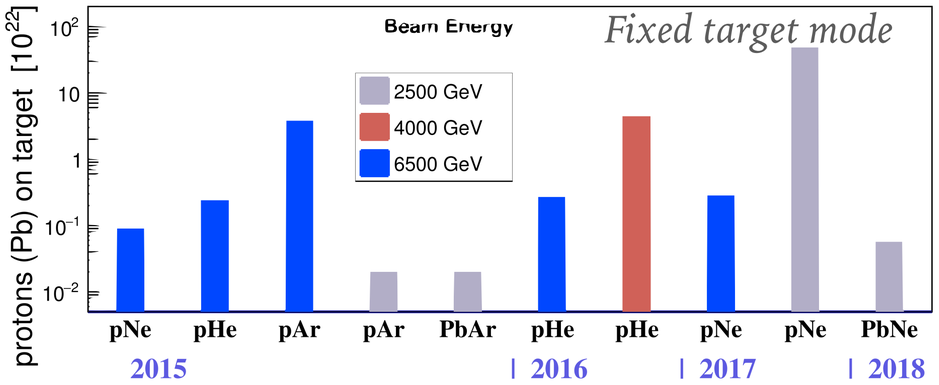
- A single arm spectrometer in forward rapidity, optimized in measuring particles containing c or b quark.

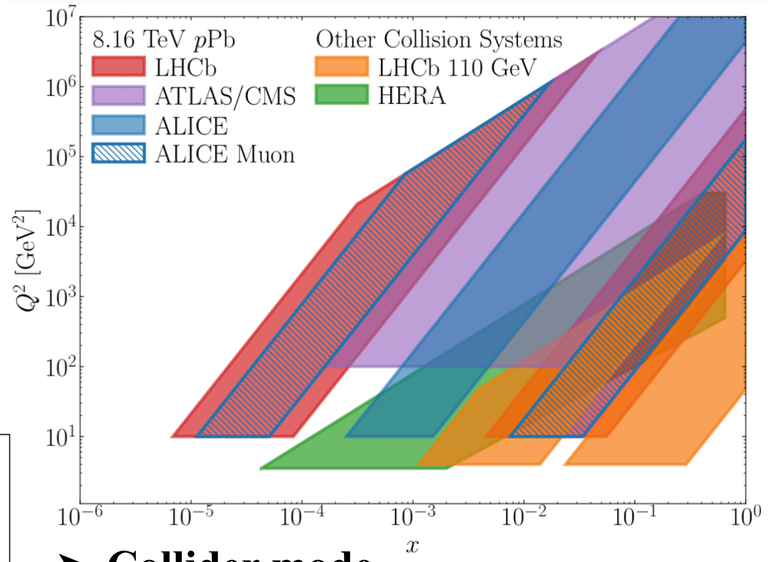


LHCb heavy ion collision modes and datasets









➤ Collider mode

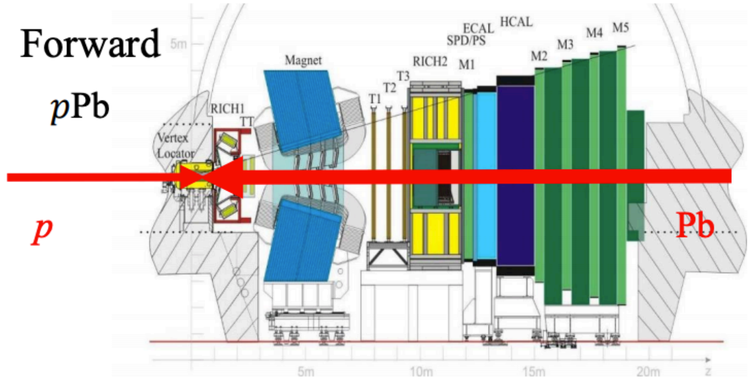
- pPb/Pbp:
  - 5.02 TeV and 8.16TeV
  - Probes saturation region and small Bjorken-x physics
- PbPb: centrality-limited to 60%

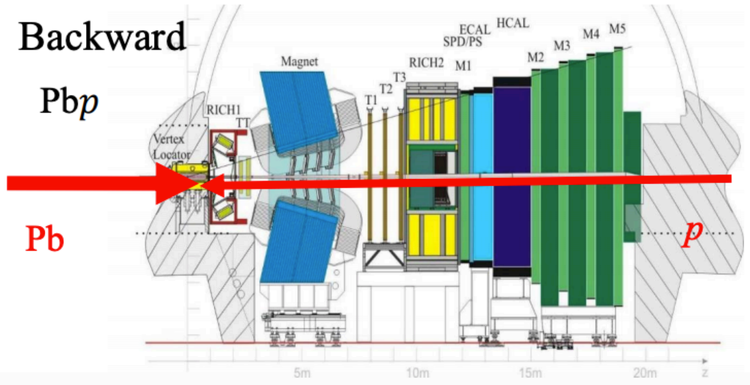
➤ Fixed-target mode (SMOG)

- pNe, pHe, pAr: $\sqrt{s_{NN}}$~ 100 GeV
- PbNe: $\sqrt{s_{NN}}$ ~ 68.6 GeV
- Covers mid to backward rapidity: anti-shadowing region

➤ pPb/Pbp rapidity coverage

- y^*: rapidity in nucleon-nucleon cms
- $y^* = y \pm 0.465$
- Forward: $1.5 < y^* < 4.0$
- Backward: $-5.0 < y^* < -2.5$
- Common region: $2.5 < |y^*| < 4.0$





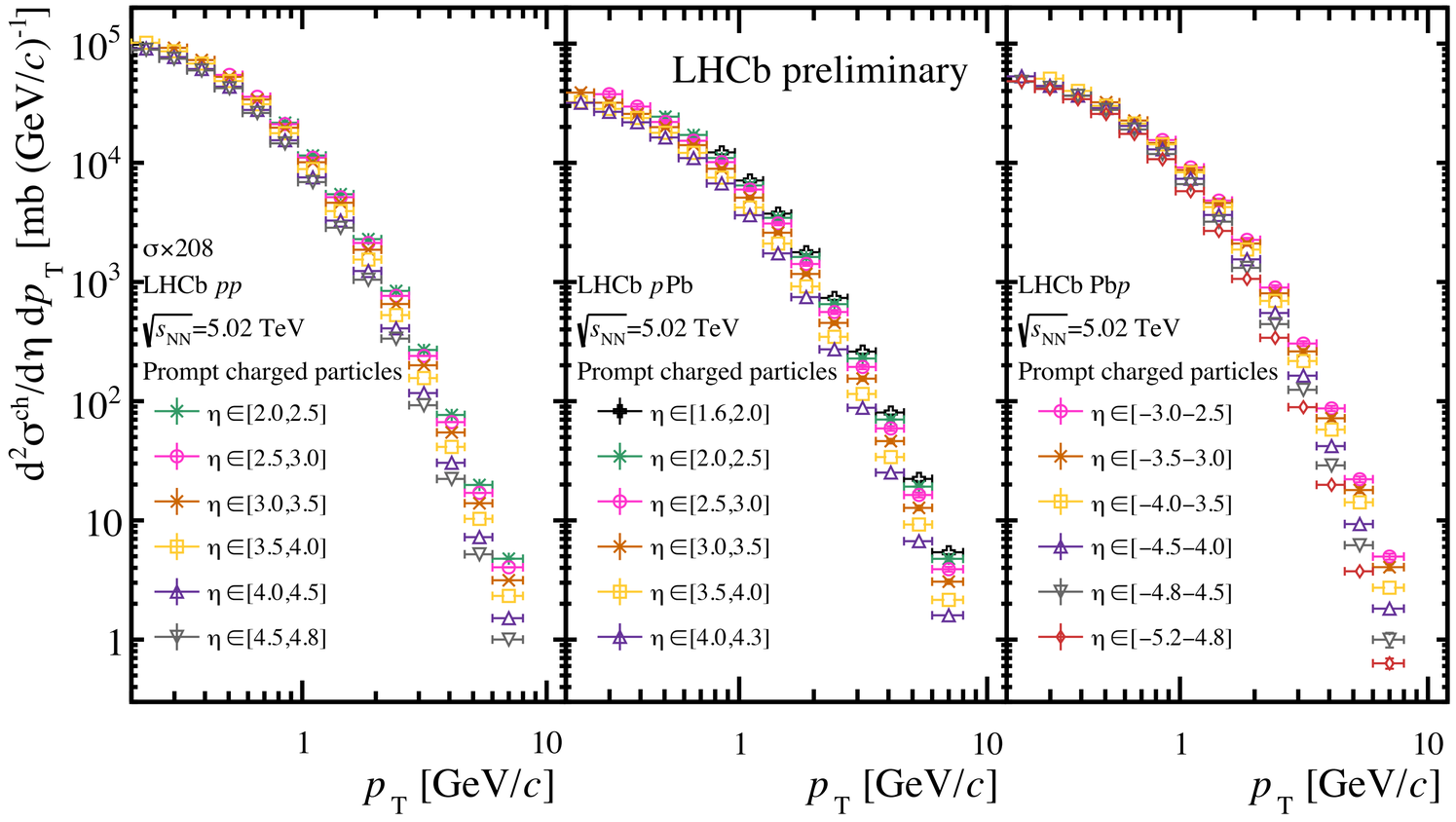
List of recent results

- **PbPb results**:
  - Low p_T J/ψ photo-production in PbPb peripheral collisions at 5 TeV *LHCb-PAPER-2020-043, in preparation*
- ***p*Pb/*pp* results**:
  - Charged hadron production:
    - Prompt charged hadrons production in *p*Pb and *pp* collisions at 5 TeV *LHCb-PAPER-2021-015, in preparation*
  - Quarkonia production:
    - Prompt production ratio of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in *p*Pb at 8.16 TeV *arXiv:2103.07349*
    - Multiplicity dependence of prompt $\chi_{c1}(3872)$ and $\psi(2S)$ production in *pp* collisions *PRL126(2021)092001*
  - Open heavy flavor production:
    - Double parton scattering in *p*Pb collisions at 8.16 TeV *PRL125(2020)212001*
- **SMOG results**:
  - First Measurement of Charm Production in its Fixed-Target Configuration at the LHC *PRL122(2019)132002*
  - Measurement of antiproton production in pHe collisions at $\sqrt{s_{\rm NN}} = 110$ GeV *PRL121(2018)222001*

Prompt charged hadrons production in *p*Pb and *pp* collisions at 5 TeV

- Inclusive prompt charged particle spectra shed light on the initial state of the collision
- LHCb probes unprecedented Bjorken-x range with forward coverage:
  - Forward: $10^{-6} \leq x \leq 10^{-4}$
  - Backward: $10^{-3} \leq x \leq 10^{-1}$
- Prompt charged particle yields measured with tracking system
- Kinematic coverage:
  - $p > 2GeV/c$, $0.2 < p_{\mathrm{T}} < 8GeV/c$
  - pp: $2 < \eta < 4.8$
  - pPb: $1.5 < \eta < 4.3$
  - Pbp: $-5.3 < \eta < -2.5$
- Total uncertainty
  - Down to 2.8% in $d^2\sigma/d\eta dp_{\mathrm{T}}$
  - Down to 4.2% in $R_{p\mathrm{Pb}}$

LHCb-PAPER-2021-015, in preparation



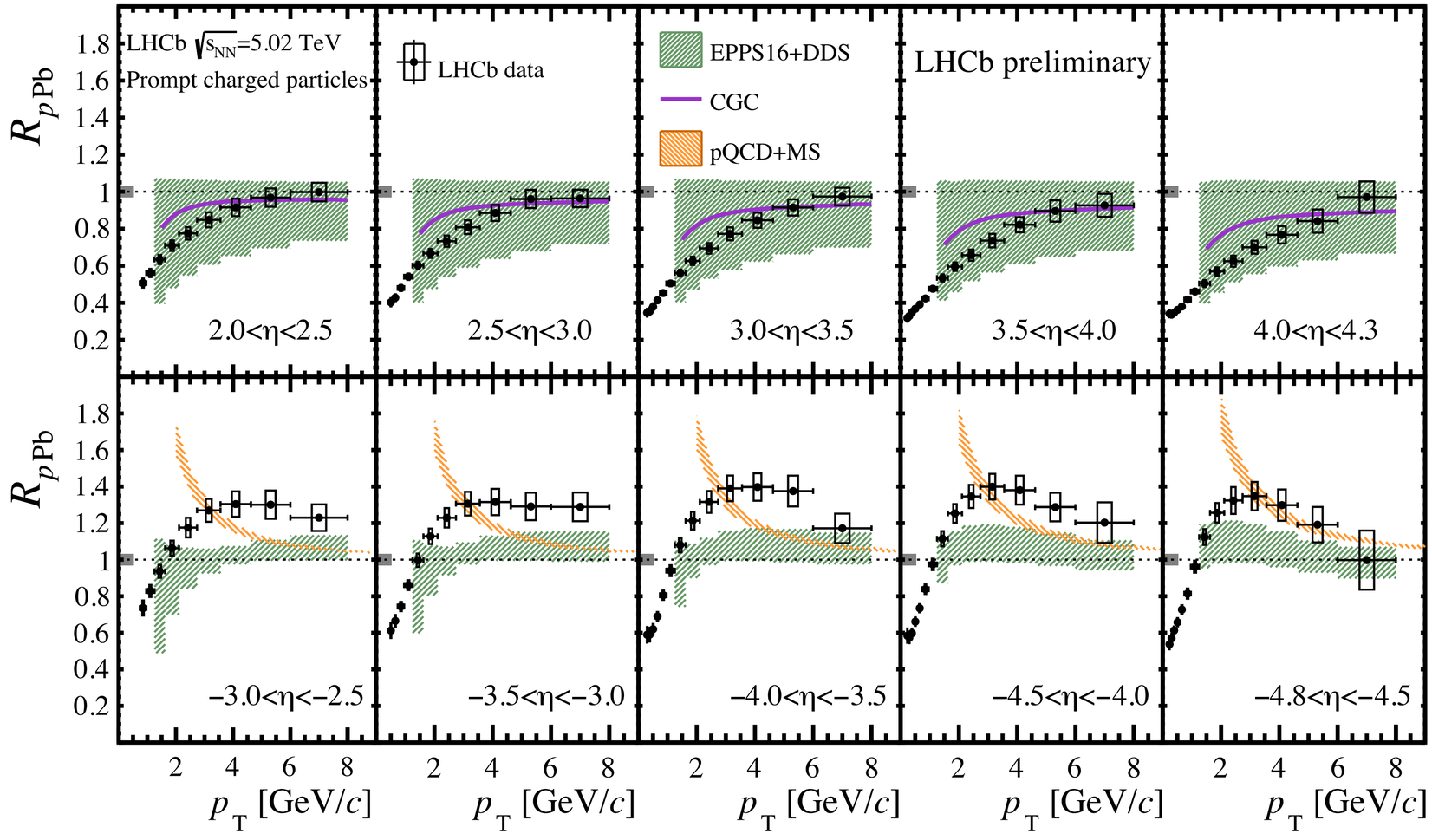
Prompt charged hadrons production in pPb and pp collisions at 5 TeV

- Nuclear modification factor:

$$R_{p\mathrm{Pb}} = \frac{1}{A}\frac{d^2\sigma_{p\mathrm{Pb}}(\eta, p_\mathrm{T})/d\eta dp_\mathrm{T}}{d^2\sigma_{pp}(\eta, p_\mathrm{T})/d\eta dp_\mathrm{T}}$$

$$A = 208$$

- Strong suppression at forward rapidity
- Enhancement at backward rapidity for $p_\mathrm{T} > 1.5\mathrm{GeV}/c$
- pQCD+Multiple Scattering model can describe PHENIX backward data, but is unable to reproduce backward data from this measurement
- No model can successfully describe the data across the full rapidity range



LHCb-PAPER-2021-015, in preparation

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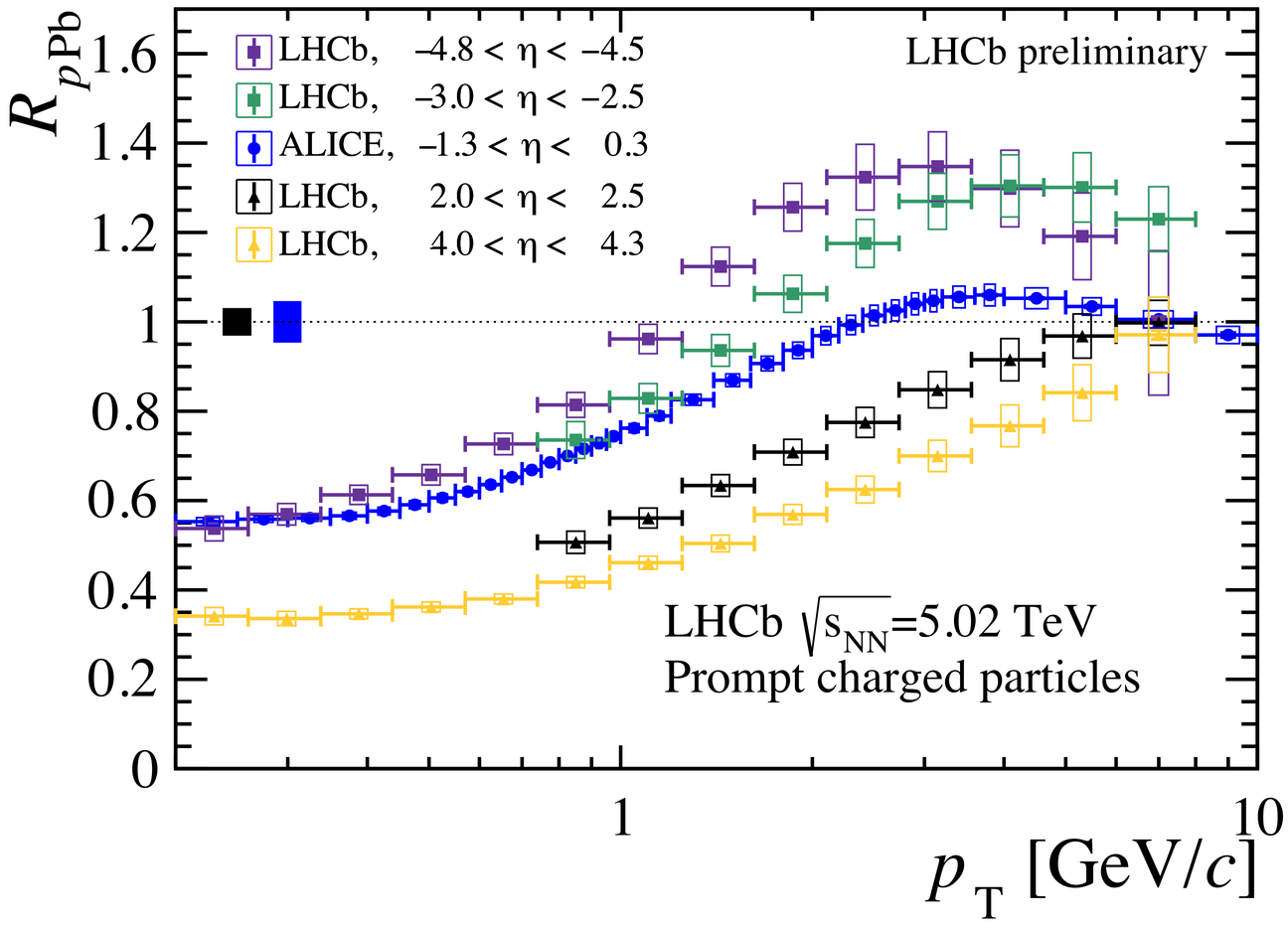
$$A = 208$$

- Strong suppression at forward rapidity
- Enhancement at backward rapidity for $p_\mathrm{T} > 1.5\mathrm{GeV}/c$
- Continuous trend from forward to backward rapidity
- Enhancement in the backward region starts at lower p_T for higher $|\eta|$

ALICE: JHEP1811(2018)013



LHCb-PAPER-2021-015, in preparation

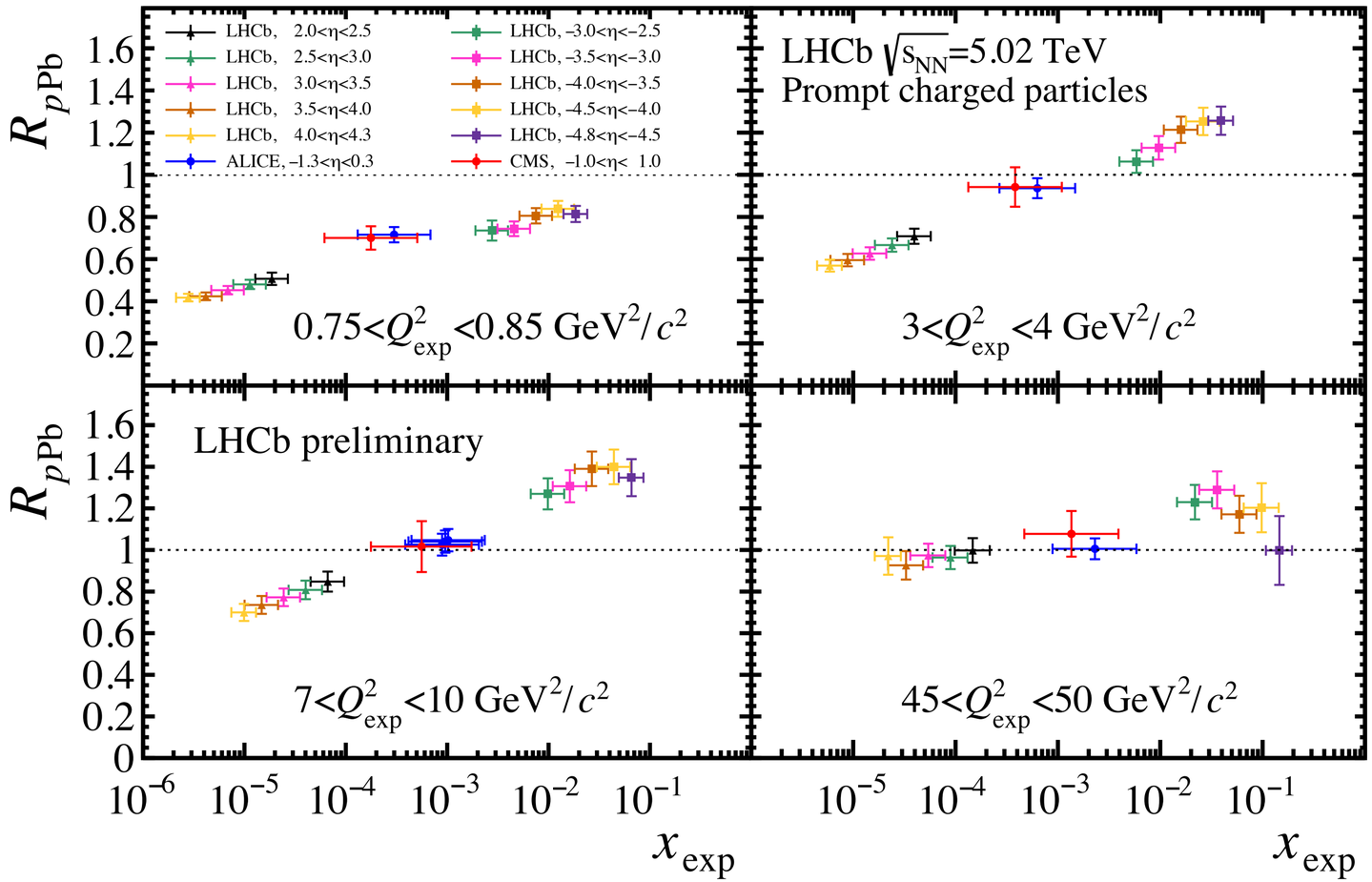
Prompt charged hadrons production in pPb and pp collisions at 5 TeV

$$Q^2_{exp} \equiv m^2 + p_T^2 \qquad x_{exp} \equiv \frac{Q_{exp}}{\sqrt{s_{nn}}} e^{-\eta}$$

ALICE: JHEP1811(2018)013

CMS: JHEP 04(2017)039

- Auxiliary variables x_{exp} and Q^2_{exp}
  - η and p_T the center of each bin
  - $m = 256\ GeV/c^2$
  - Indirect study of the evolution of $R_{p\mathrm{Pb}}$ with x and Q^2
- Continues trend of $R_{p\mathrm{Pb}}$ with x_{exp} at different Q^2_{exp} across forward, middle and backward rapidity regions.



LHCb-PAPER-2021-015, in preparation

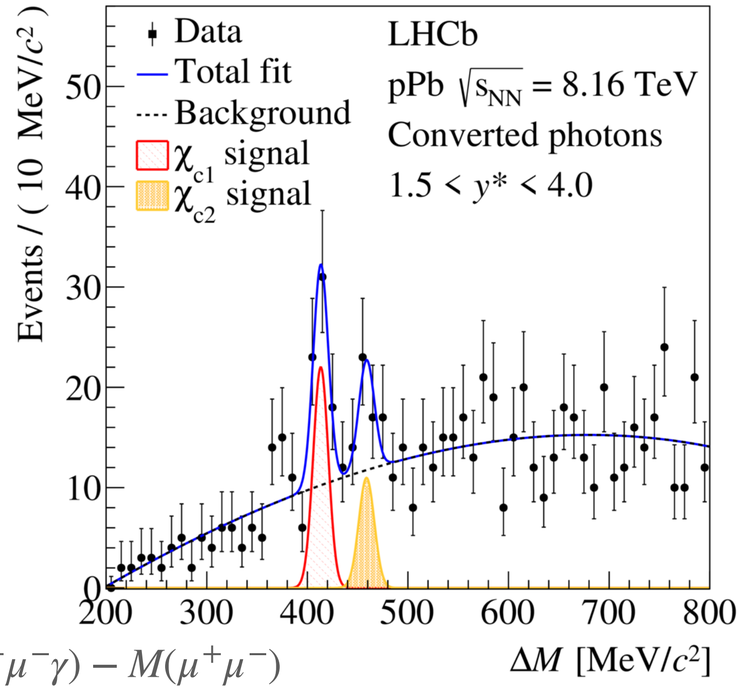
Prompt production ratio of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in pPb at 8.16 TeV

- **First χ_{c2}, χ_{c1} measurement in nuclear collisions at the LHC**
- χ_{cJ} is a triplet charmonium state with masses between J/ψ and $\psi(2S)$, the masses of these 3 states sequentially differ by < 100 MeV.
- Binding energy of χ_{cJ} between J/ψ and $\psi(2S)$. Measuring the suppression of χ_{cJ} in pPb will add additional points on the binding energy axis.
- Non-prompt χ_{cJ} removed with t_z selection.
- Two different analysis samples:
  - Converted photons reconstructed from downstream track electrons
  - Non-converted photons

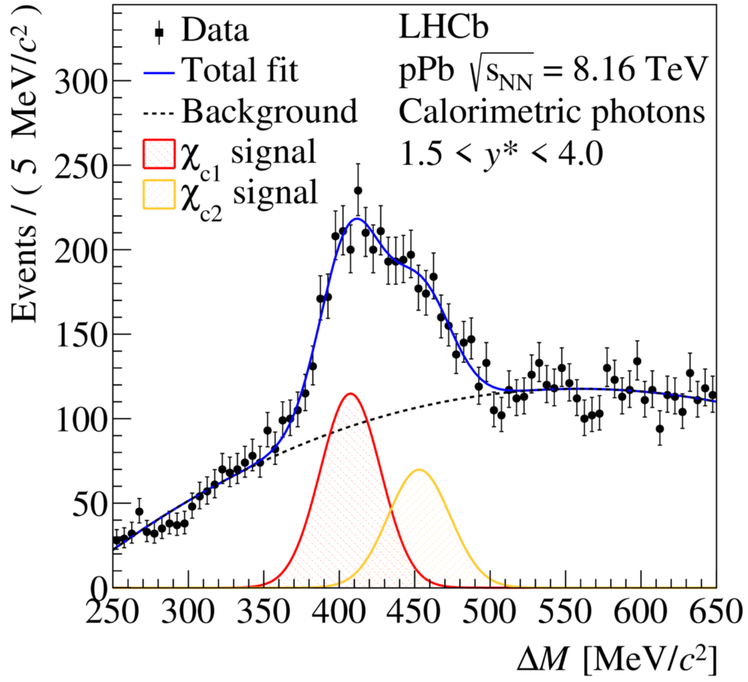
Data sample		$N_{\chi_{c1}}$	Significance	$N_{\chi_{c2}}$	Significance
Converted photons	$1.5 < y^* < 4.0$	41 ± 9	6.0	21 ± 8	3.1
	$-5.0 < y^* < -2.5$	38 ± 9	4.4	21 ± 8	3.0
Calorimetric photons	$1.5 < y^* < 4.0$	1151 ± 69	15.7	721 ± 76	9.8
	$-5.0 < y^* < -2.5$	1004 ± 73	13.3	676 ± 82	8.5

$\chi_{cJ} \to J/\psi\gamma$

Converted photons



$\Delta M \equiv M(\mu^+\mu^-\gamma) - M(\mu^+\mu^-)$



Calorimetric photons

arXiv:2103.07349
Accepted for publication in Phys. Rev. C Lett.

Prompt production ratio of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in pPb at 8.16 TeV

- Converted photon method: $3 < p_T < 15$ GeV/c

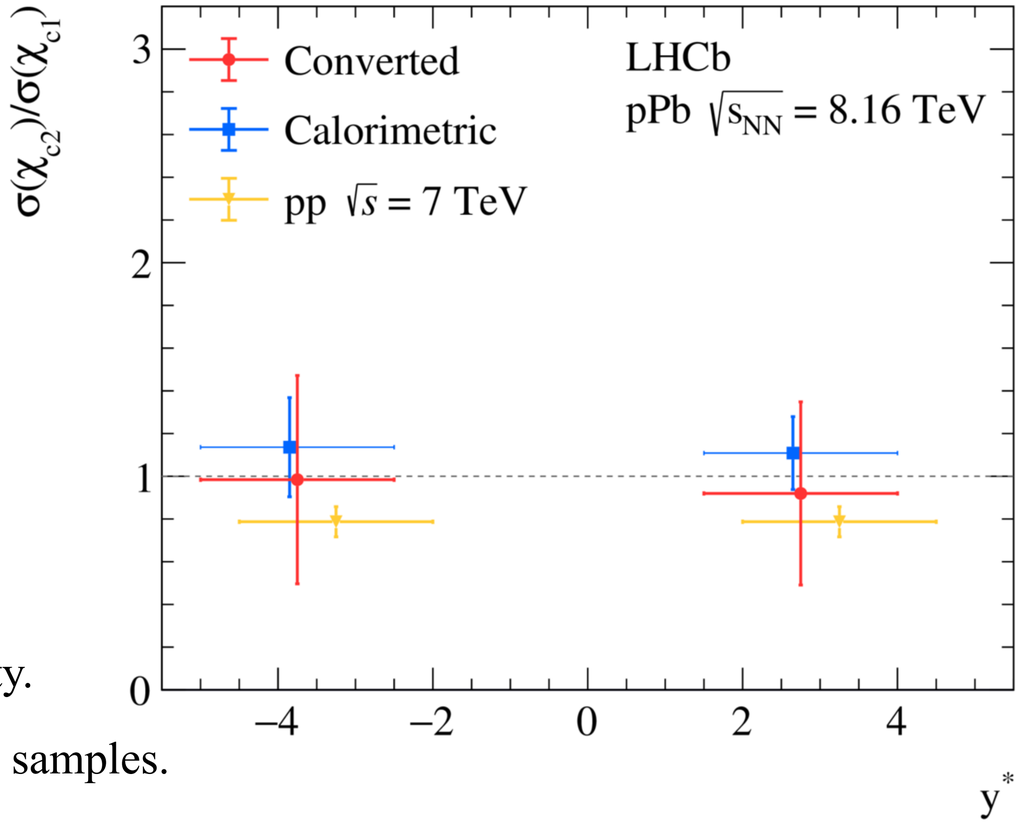
$$\textit{Forward:} \quad \frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = 0.92 \pm 0.42 \pm 0.11$$

$$\textit{Backward:} \quad \frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = 0.98 \pm 0.46 \pm 0.15$$

- Calorimetric photon method: $5 < p_T < 15$ GeV/c

$$\textit{Forward:} \quad \frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = 1.11 \pm 0.14 \pm 0.10$$

$$\textit{Backward:} \quad \frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = 1.14 \pm 0.16 \pm 0.17$$



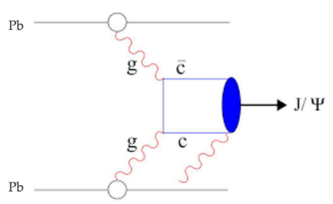
- $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ ratio is consistent with unity at forward and backward rapidity.
- Also consistent between converted photon sample and calorimetric photon samples.
- $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ ratio larger in pPb than in pp, although they are consistent within statistical uncertainty.
- Similar level of relative suppression between χ_{c1} and χ_{c2} in both rapidity regions.

arXiv:2103.07349
Accepted for publication in Phys. Rev. C Lett.

Low p_T J/ψ photo-production in PbPb peripheral collisions at 5 TeV

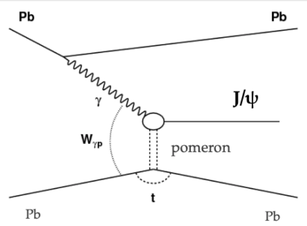
- **One of the first PbPb results**, using data collected in Nov-Dec 2018, with luminosity L~230 μb^{-1}
- Low p_T J/ψ excess observed by ALICE in PbPb and STAR in AuAu (PRL123, 132301, PRL116, 222301)
- Measure the photo-produced J/ψ yield in peripheral PbPb collisions (60-85%)
- The coherent and incoherent J/ψ production can be distinguished from their p_T shapes

Hadronic production



$gg \to J/\psi$

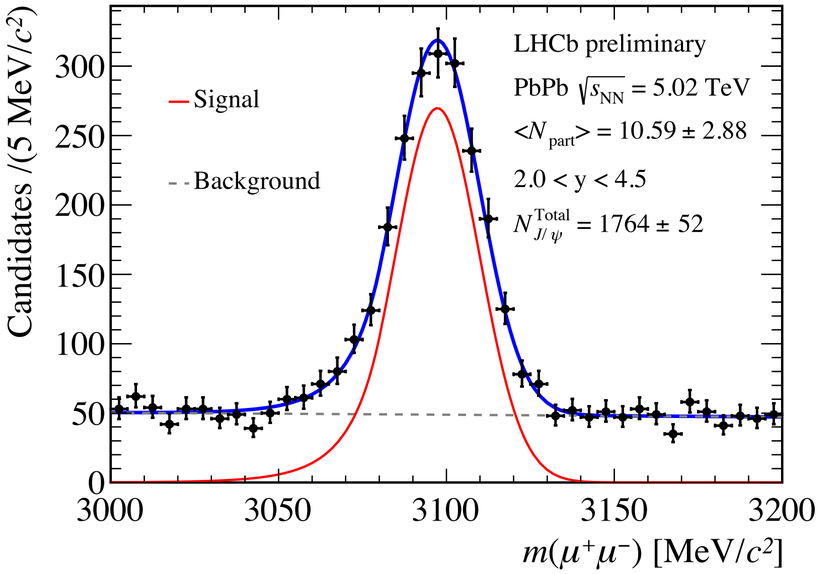
Coherent photo-production

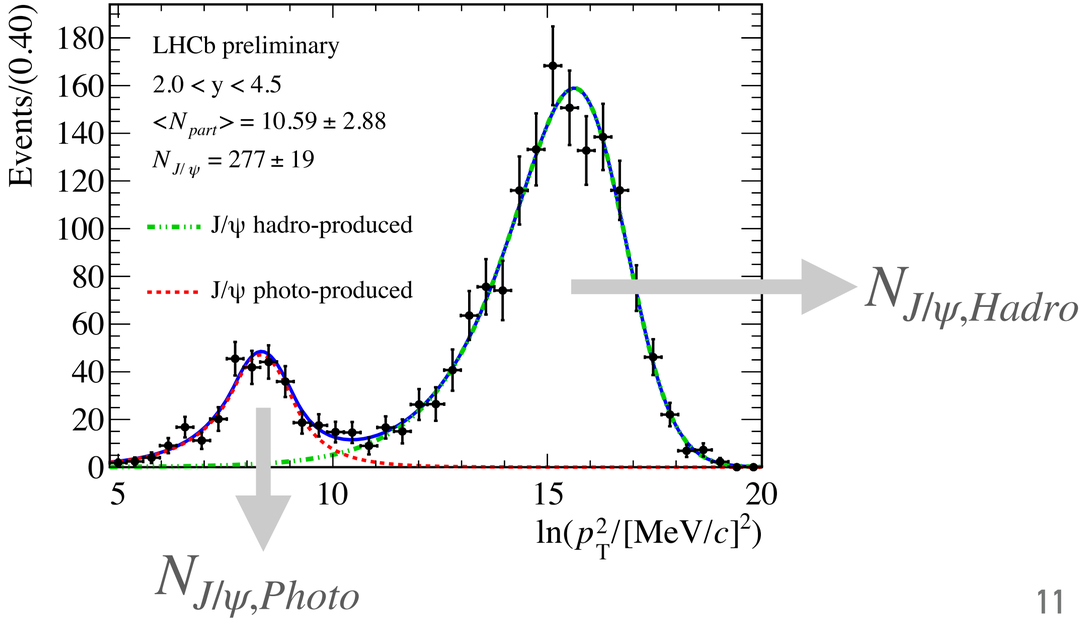


$\gamma(pomeron) \to J/\psi$

LHCb-PAPER-2020-043, in preparation

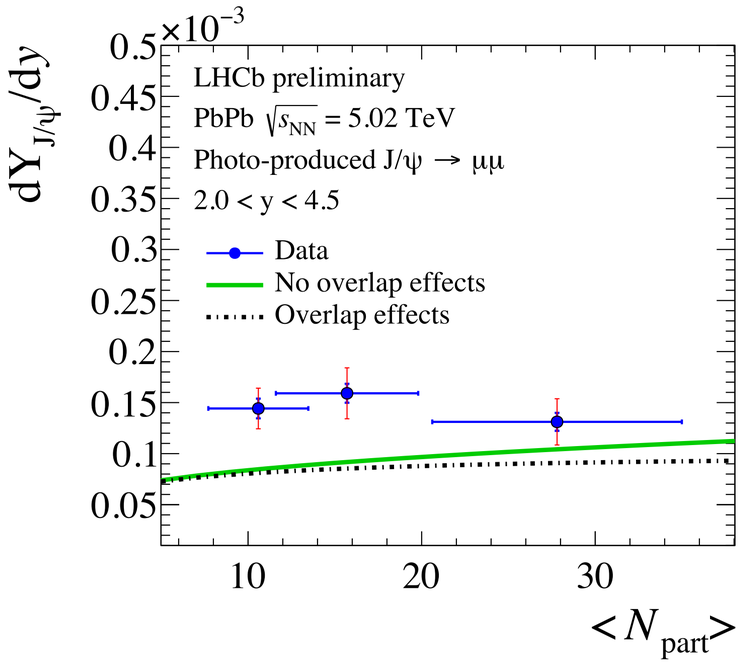
- Non-prompt J/ψ removed with t_z selection.
- Centrality determined by energy deposited in ECAL and Glauber model

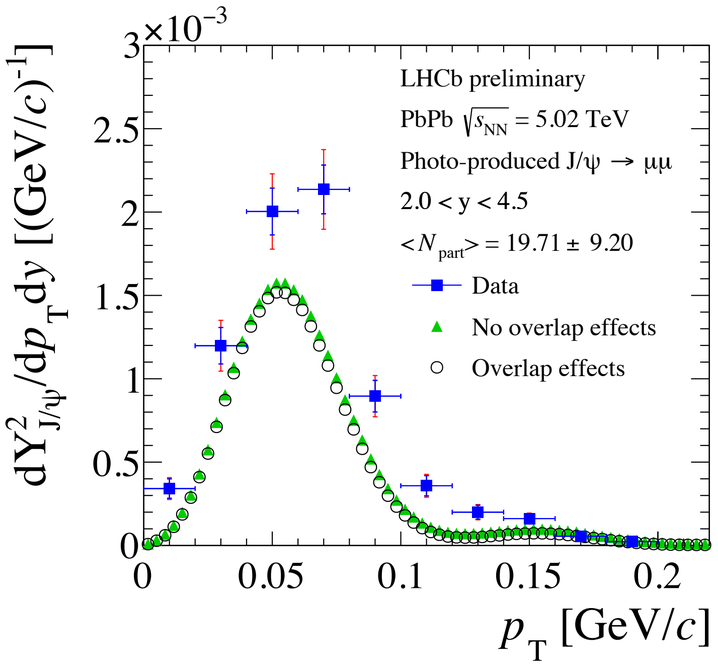


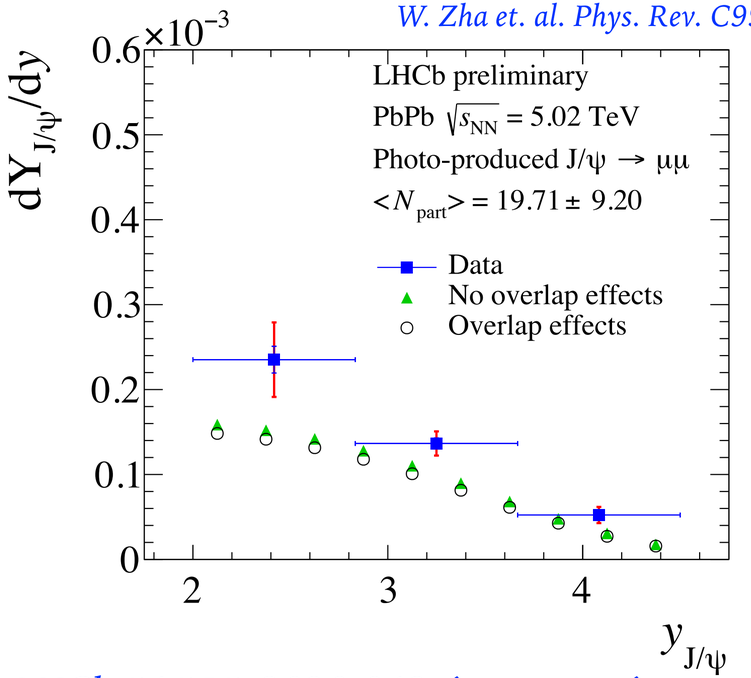


Low p_T J/ψ photo-production in PbPb peripheral collisions at 5 TeV

- Photo-produced J/ψ yields measured with high precision
  - Higher at low rapidity than at high rapidity
  - Consistent with constant with respect to $\langle N_{part} \rangle$
- The shape of coherent J/ψ transverse momentum distribution is measured for the first time at the LHC
- Data qualitatively well reproduced by models, with and without nuclear overlap effects







W. Zha et al. Phys. Rev. C97 (2018) 044910
W. Zha et. al. Phys. Rev. C99, 061901(R)

LHCb-PAPER-2020-043, in preparation

LHCb phase-I upgrade

Full software trigger

- Remove L0 hardware triggers
- Read out full detector at 40MHz
- *pp* requirements: 40MHz collision rate, pile-up factor ~5

New tracking systems:

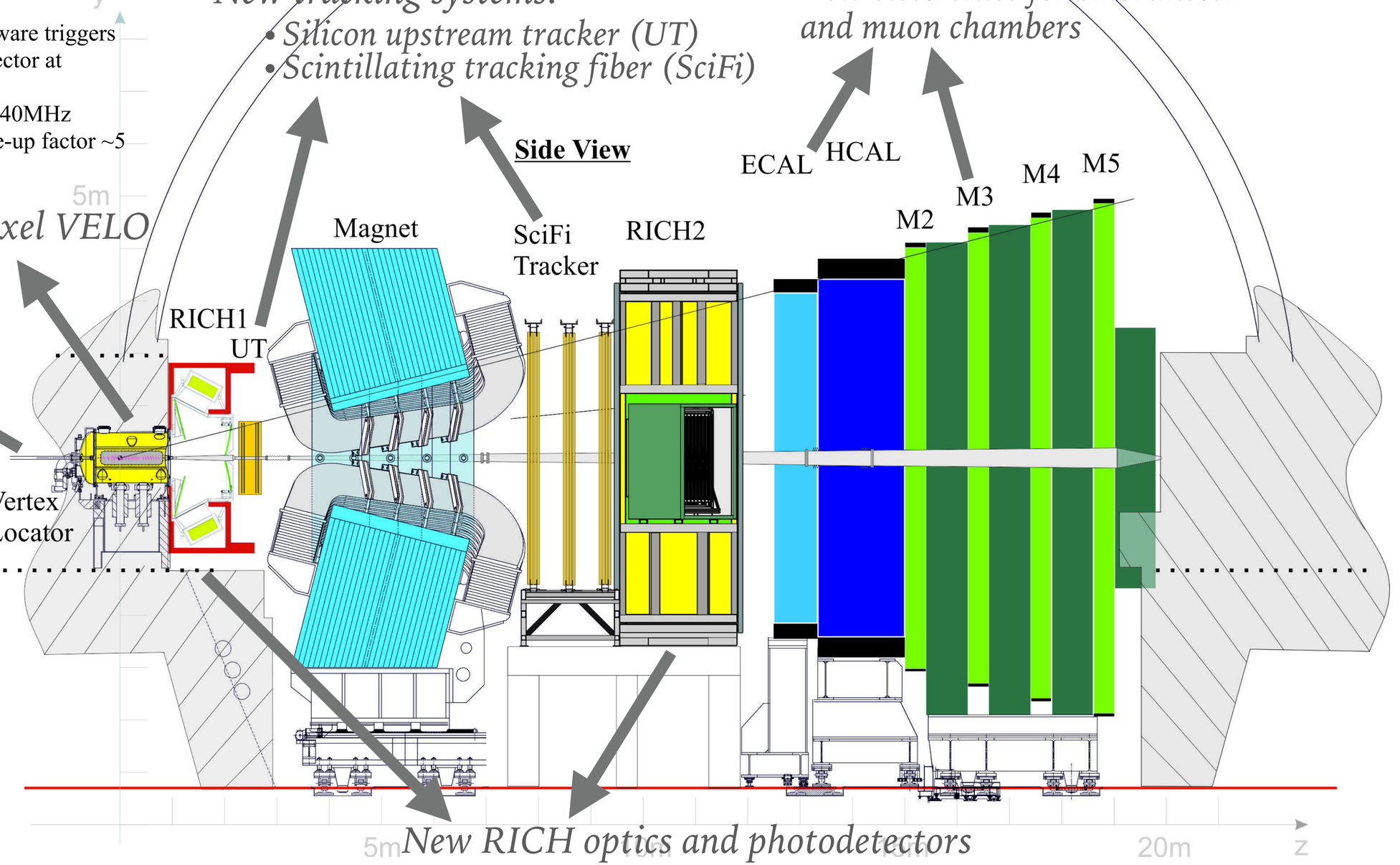
- *Silicon upstream tracker (UT)*
- *Scintillating tracking fiber (SciFi)*

New electronics for calorimeter and muon chambers

New Pixel VELO

SMOG2

Talk by Edoardo Franzoso, 18/05, Tuesday, 11:30

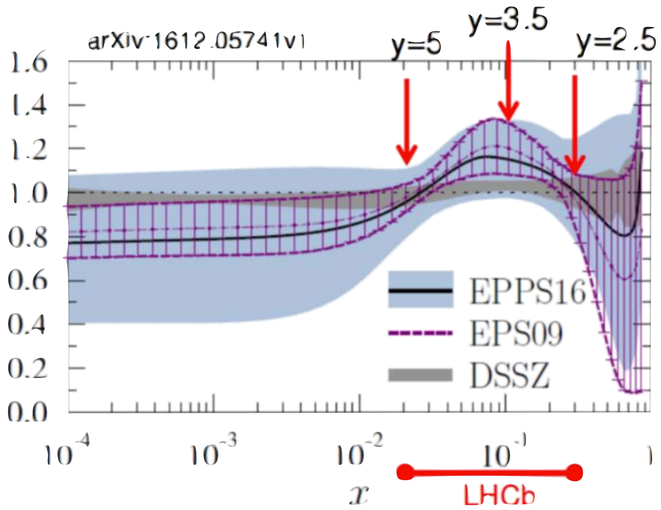


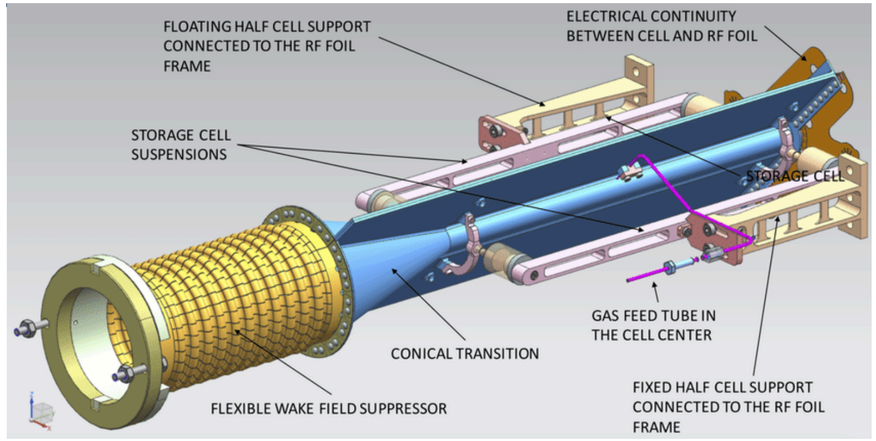
New RICH optics and photodetectors

SMOG2 upgrade at LHCb

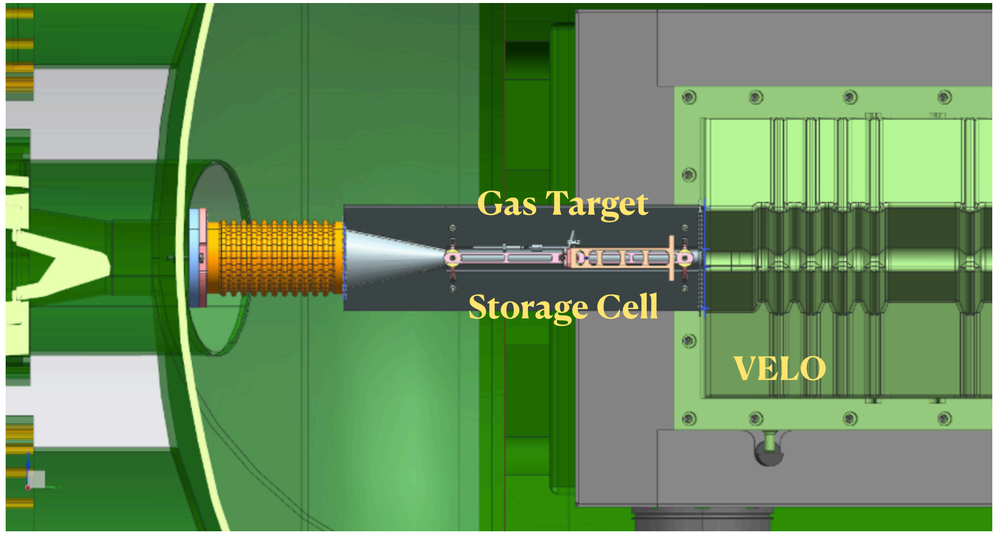
Talk by Edoardo Franzoso, 18/05, Tuesday, 11:30

- SMOG: System for Measuring Overlap with Gas
- SMOG2: Storage Cell for the gas upstream of the nominal IP (z in [-500, -300] mm) and precisely calibrated Gas Feed System.
  - Gas density increased by up to two orders of magnitude —> much higher luminosity
  - More gas targets: H_2, D_2, He, N_2 , O_2, Ne, Ar, Kr, Xe
- *pp* and SMOG2 separate luminous regions —> simultaneous *pp*-SMOG2 data-taking.
- $\sqrt{s_{NN}}$ = 69-110 GeV between SPS & RHIC
- $-3.0 < y^* < 0$
- Access nPDF anti-shadowing region

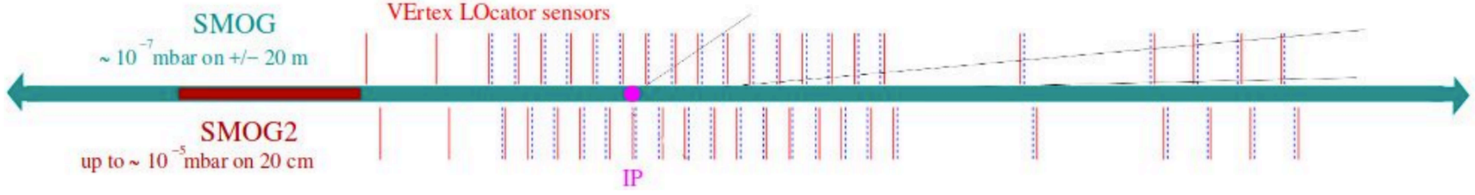




LHCb-TDR-020



LHCb-TDR-020



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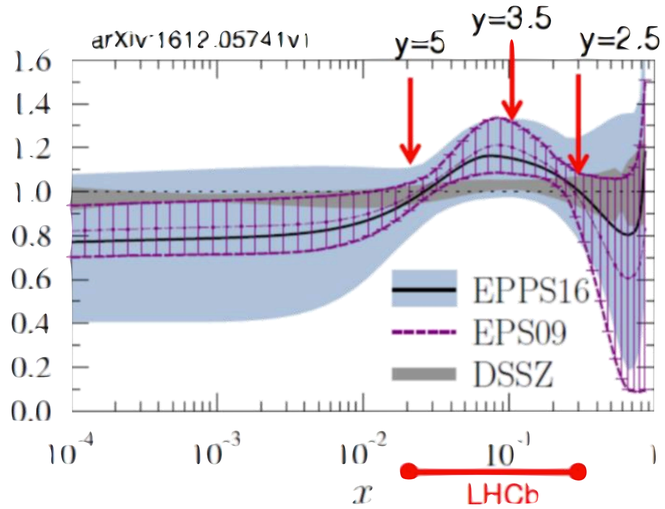

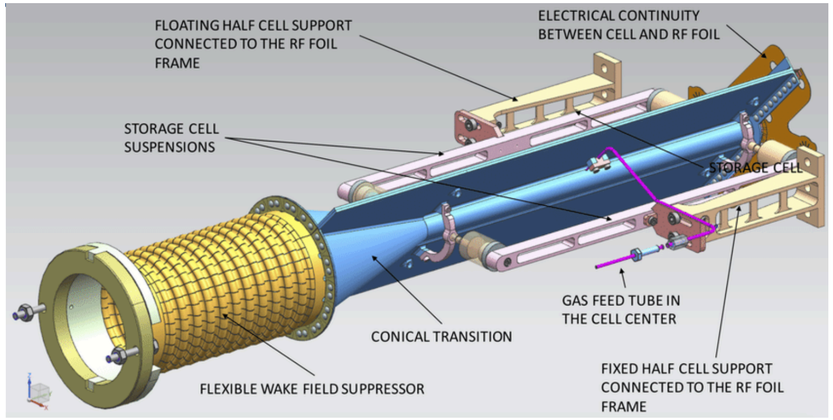

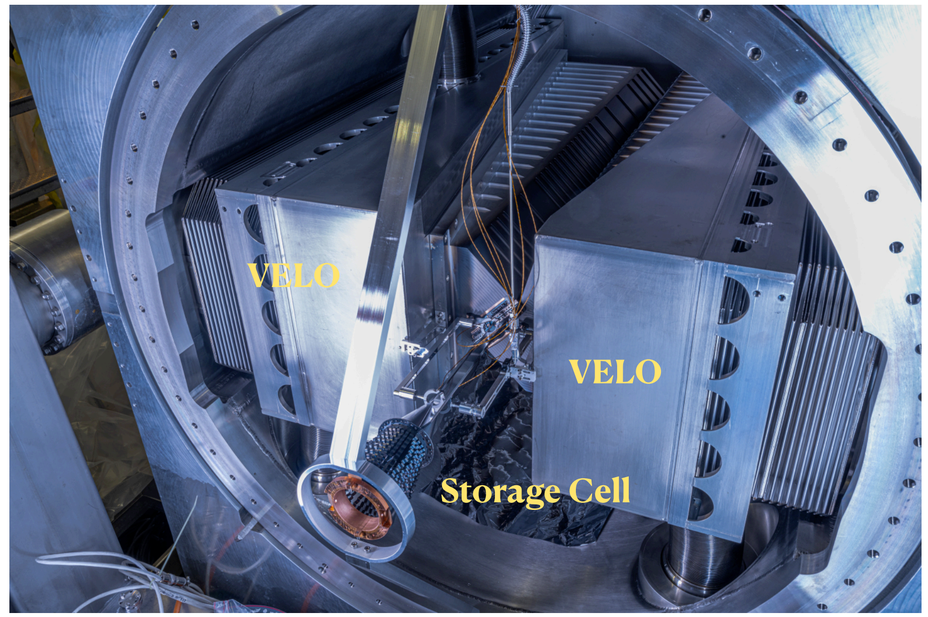

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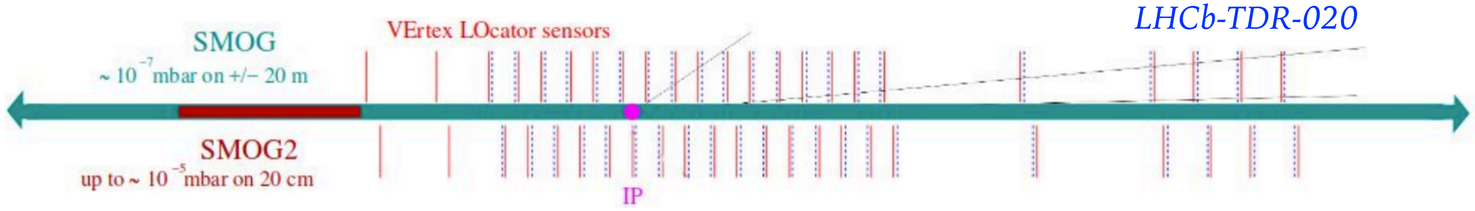


SMOG2: statistics in 1 year data taking

simultaneous *pp*-SMOG2 data-taking

Storage cell assumptions	gas type	gas flow (s^{-1})	peak density (cm^{-3})	areal density (cm^{-2})	time per year (s)	int. lum. (pb^{-1})
SMOG2 SC	He	1.1×10^{16}	10^{12}	10^{13}	3×10^{3}	0.1
	Ne	3.4×10^{15}	10^{12}	10^{13}	3×10^{3}	0.1
	Ar	2.4×10^{15}	10^{12}	10^{13}	2.5×10^{6}	80
	Kr	8.5×10^{14}	5×10^{11}	5×10^{12}	1.7×10^{6}	25
	Xe	6.8×10^{14}	5×10^{11}	5×10^{12}	1.7×10^{6}	25
	H_2	1.1×10^{16}	10^{12}	10^{13}	5×10^{6}	150
	D_2	7.8×10^{15}	10^{12}	10^{13}	3×10^{5}	10
	O_2	2.7×10^{15}	10^{12}	10^{13}	3×10^{3}	0.1
	N_2	3.4×10^{15}	10^{12}	10^{13}	3×10^{3}	0.1

Talk by Edoardo Franzoso, 18/05, Tuesday, 11:30

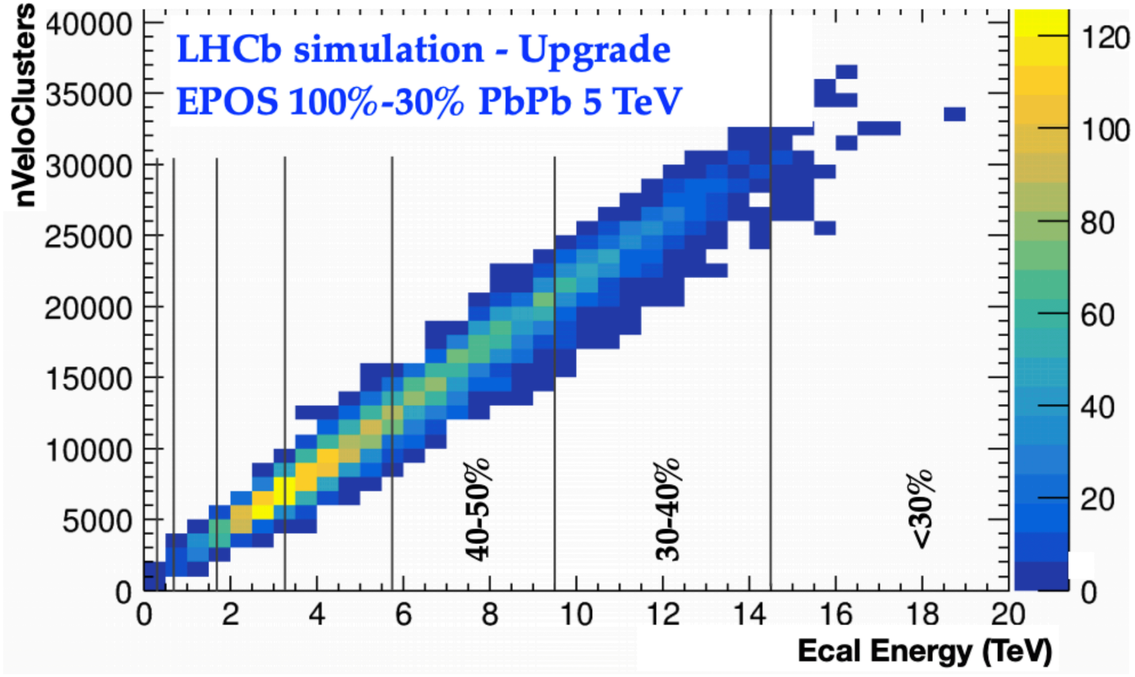
No centrality limitation!

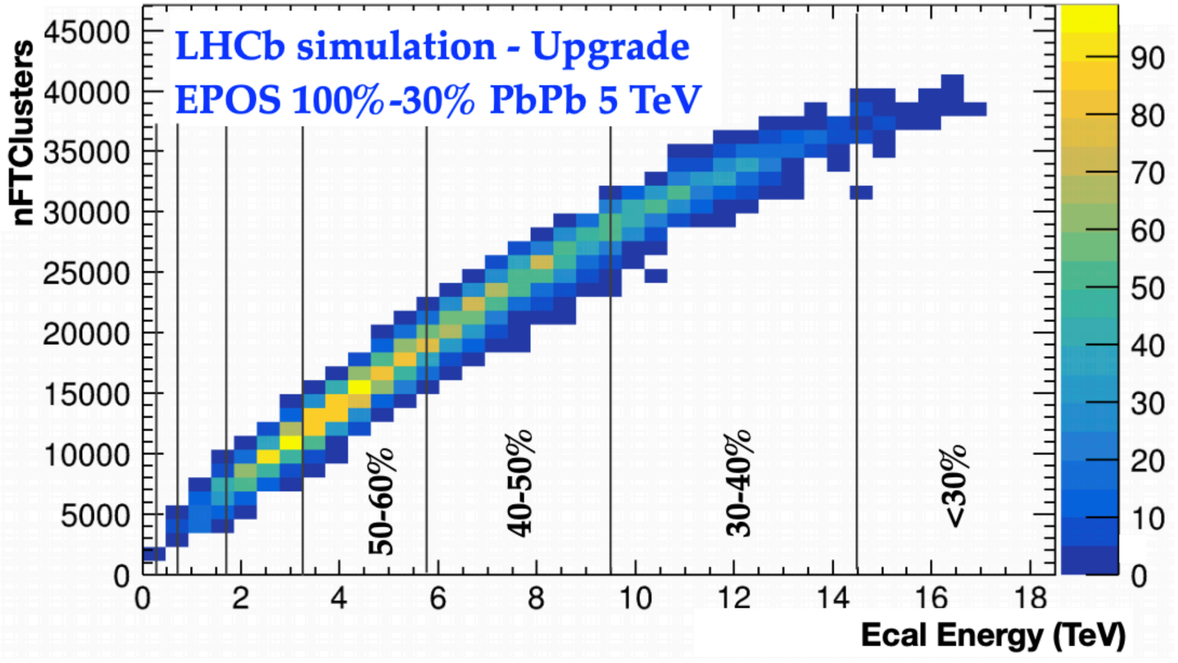
SMOG2 *p*Ar @ 115 GeV

Int. Lumi.		80/pb
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

Performance in Run3 heavy ion mode

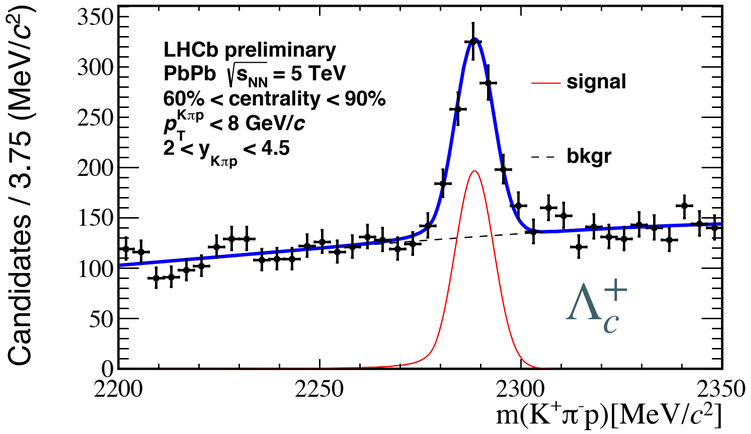
- No significant saturation up to 30% central PbPb collisions
  - Simulations of more central events are under study
- QGP study possible up to mid-central PbPb events
- No saturation in fixed-target mode
- Improvement of UPC measurements from increased luminosity





Conclusion

- LHCb has a rich heavy ion physics program, with excellent detector performance and unique kinematic coverage.
- High statistical *p*Pb datasets offer opportunities to perform precision measurements, study rare probes and investigate small-*x* physics.
- First result from PbPb datasets presented, many more to come!



- After the current upgrade:
- Unlock PbPb collisions up to mid-central events, study QGP
- SMOG2:
  - rich program in unexplored energy and kinematic regions
  - High statistics without centrality limitation