Long-standing conference bringing together researchers and students from various fields of subatomic physics.

The conference location is Bormio, a beautiful mountain resort in the Italian Alps.

Heavy Ion Results from the LHCb

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58th International Winter Meeting on Nuclear Physics
January 20 to 24, 2020 Bormio, Italy

Outline

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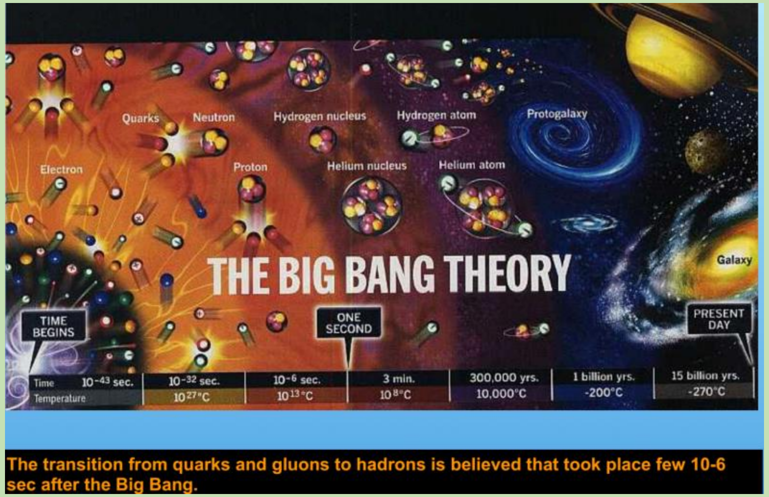
2. **Heavy Ions at the LHCb experiment:**
   2.1 Physics goals, methods for studies
   2.2 Technical capabilities. Collider and Fixed target modes.

3. **Selected Results. Production cross-sections for hadrons, Z-bozon**
   3.1 p_T – spectra
   3.2 Rapidity distributions
   3.3 Prompt , delayed production
   3.4 Cross-section Ratios (NMF, FWD/BWD, 2S/1S, …, mesons/baryons)
   3.5 Theoretical approaches

4. **Summary and Outlook**

1. Introduction



Sonia Kabana, Heavy Ion collisions at RHIC, 28 March-1 April 2018, Athens,Greece

Large Hadron Collider (CERN) –

Nuclei collisions for simulation of the "Big Bang" event

The Big Bang – (The Standard Model) – Universe - ~ 14 billion years ago

For reasons still unknown its evolution was mysterious:

- Anti-matter disappeared

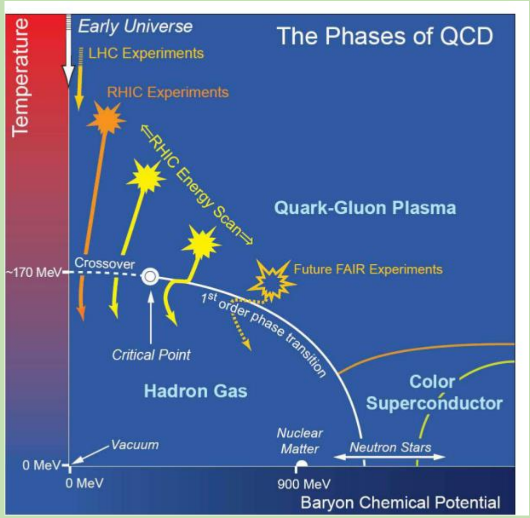
- quarks and gluons (the bricks of matter) have got confined

In the LHCb experiment the studies include:

1. **CP-violation in B-mesons decay – as possible reason of asymmetric (no anti-matter) Universe**

2. Search for signals of deconfined matter –

Quark-Gluon Plasma (QGP)



QCD phase diagram

Temperature vs net baryon density

2. Heavy Ions at the LHCb experiment:
2.1 Physics goals

Heavy ion sector since the year 2013:

- **proton-lead ($\sqrt{s_{NN}}$ = 5 and 8 TeV):**
- **lead-lead, ($\sqrt{s_{NN}}$ = 5 TeV)**
- **proton and lead ions at fixed targets Ar, He, Ne, at energies of $\sqrt{s_{NN}}$ ~ 0.1 TeV**

  - Synergy - from RHIC. SPS to LHC physics within a single experiment

➢ **production cross-sections, nuclear modification factors:, forward –backward asymmetries, prompt/delayed ...**

❖ **Observables - D^0 , J/Ψ, ψ(2S), Υ(nS), anti-protons, B-mesons, ...**

Physics-

- **EOS - hadronic matter at high densities and temperatures (QGP - ?)**
- **Nucleon PDFs and nuclear nPDFs**
- **Dynamics of multi-nucleon interaction, hadronisation**
- **QED at high electro-magnetic field strengths**
- **...**

2. Heavy Ions at the LHCb experiment:
2.1 Physics goals, methods

Emphasis in this talk – Search for possible signals of deconfined state of matter – Quark Gluon Plasma (CGP)

Methods – compare physics observables and their derivatives (NMF, FWD/BWD, 2S/1S, …, mesons/baryons) in various collisions assuming "YES / NO" probability for the QGP :

1. Different size of colliding objects:
- small system – (proton-proton) – NO (low probability)
- large system – (HI - HI)– YES (high probability)
- intermediate case – (proton-HI) – NO (yes ?) – studies of the "cold" nuclear matter effects

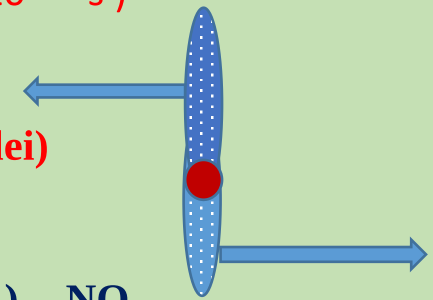
2. Prompt and delayed (non-prompt) hadrons decays:
- prompt – YES (Time scale - - 10^{-23} s)
- delayed – NO (Time scale - - 10^{-12} s)

3. Centrality of collisions (measure of overlap of colliding nuclei)

80 – 100 % - YES

0 - 10 % - NO (yes ?)

Ultra-peripheral collisions (0 %) - NO



4. FLOWS (?)

OBSERVABLES

Differential Cross Sections over momentum and rapidity

$$\frac{d^2\sigma}{dp_T dy^*} = \frac{\overset{\text{Prompt signal yields}}{N}}{\underset{\text{Integrated luminosity}}{\mathscr{L}} \times \underset{\text{Total efficiency}}{\epsilon_{tot}} \times \underset{\text{Branching ratio}}{\mathscr{B}} \times \Delta p_T \times \Delta y^*}$$

Compare them and their ratios for :

1. p – p (SMALL) and p –Pb (Intermediate) systems colliding at the same N-N cms energy (in this talk at $\sqrt{s_{NN}}$ = 5 TeV .and 8.16 TeV)
2. Forward and Backward configuration
2. 'Prompt' – from primary vertices – proximity to 'QGP'
   'non-prompt '- from b-hadron decay - far from 'QGP'
3. 2S/1S, 3S/2S

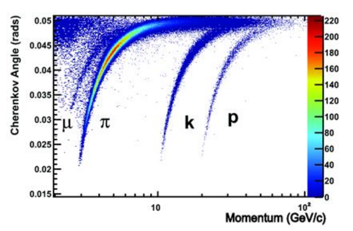
2.2 Technical capabilities. Collider and Fixed target modes.

LHCb

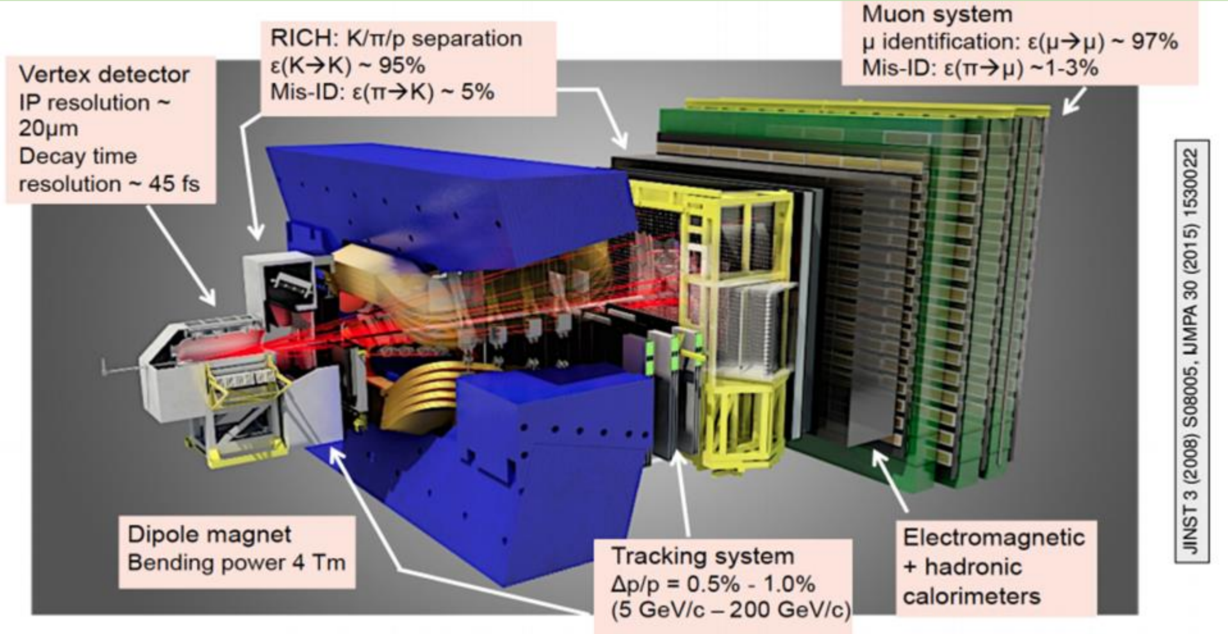
The Large Hadron Collider Beauty Experiment for Precise Measurements of CP-Violation and Rare Decays

The LHCb detector – forward spectrometer with excellent characteristics

- Acceptance $2 < \eta < 5$ & HERSHEL $8 < \eta < 10$
- Momentum resolution about 0.5 %
- Track reconstruction efficiency
  > 96 % (pp-collisions)
- Impact parameter resolution: ~ 20 µm
- Decay time resolution: ~45 fs
- Invariant mass resolution:
  ~(10-20) MeV/c^2
- Ring-Imaging Cherenkov Detectors
  and Muon system
  -> particle identification with high efficiency



The only LHC experiment fully instrumented at large η (2<η<5)



Fixed target mode

System for Measuring Overlap with Gas (SMOG)
Explored as a gas target

Noble gas only (very low chemical reactivity)			
	He	**Ne**	**Ar**
A =	4	20	40

2.2 Technical capabilities.
Collider and Fixed target modes.

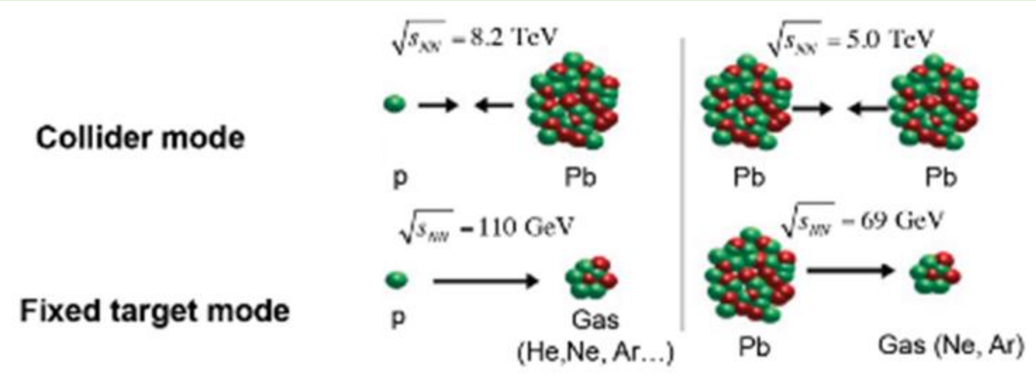
The phase space compared to other experiments has the unique advantages for physics events reconstruction

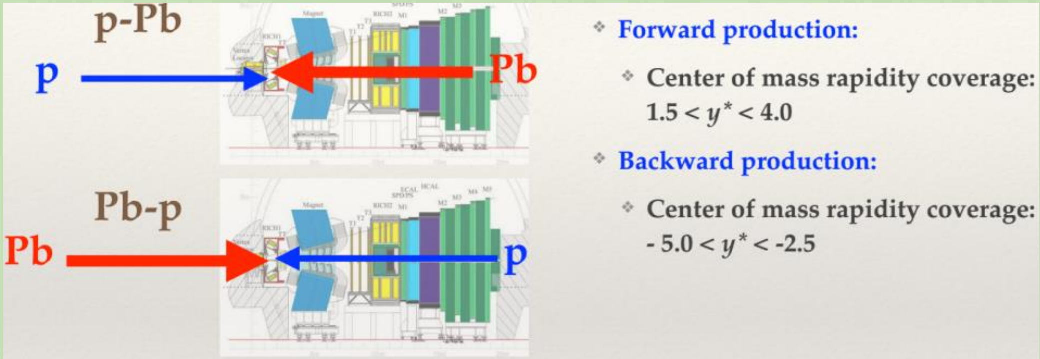
- precise tracking /vertexing, calorimetry and powerful particle identification in the full acceptance.

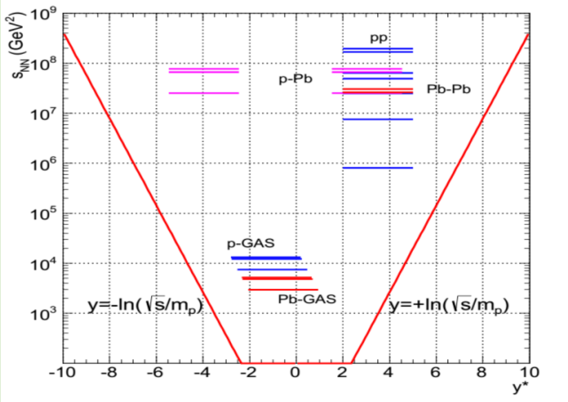
For fixed target mode:

- **the acceptance is central to backward.**
- **AA collisions at energies between those achieved at the SPS (20 GeV) and RHIC (200 GeV)**
- **p-A collisions at the proton energy T = 7 TeV:**
  - ➢ **69 GeV < $\sqrt{s_{NN}}$ < 114.6 GeV.**
- **measurements in a fixed target and in colliding beams mode bridge the gap between the SPS, RHIC and LHC**
- **Measurement of hadrons production at FWD & BWD rapidity probes two x_B values:**

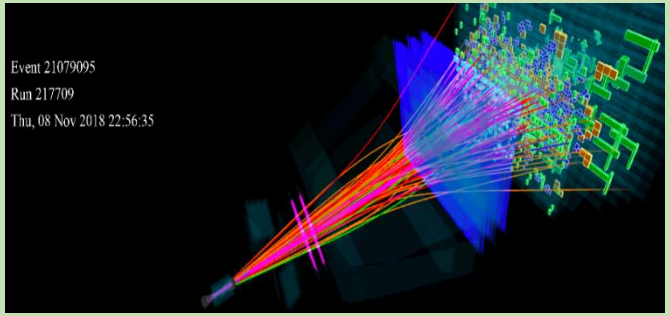
$$x_{1,2} \approx e^{\pm y^*} \frac{M}{\sqrt{s}}$$







THE LHCB ACCEPTANCE



3. LHCb Heavy Ion Physics Selected Results

Production cross-sections for

D^0, $J/\psi(nS)$, $Y(nS)$, B^0, B^+, Z – bosons, J/ψ from UPC,

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

3.1 p_T – spectra

3.2 Rapidity distributions

3.3 Prompt, delayed events

3.4 Cross-section Ratios

(NMF, FWD/BWD, 2S/1S, mesons/baryons)

3.5 Theoretical approaches to experimental data

Study of nuclear matter effects (initial and final state)

- ❑ **Nuclear effects on parton densities (nPDF) (shadowing/antishadowing)=> EPS09 ,EPPS16**
- ❑ **Energy loss by incident partons => JHEP 1303 (2013) 122**
- ❑ **Saturation: Color Glass Condensate =>Ann.Rev.Nucl.Part.Sci.60:463-489,2010**
- ❑ **Nuclear break-up, Comovers => Phys. Lett. B749(2015) 98, arXiv:1411.0549**

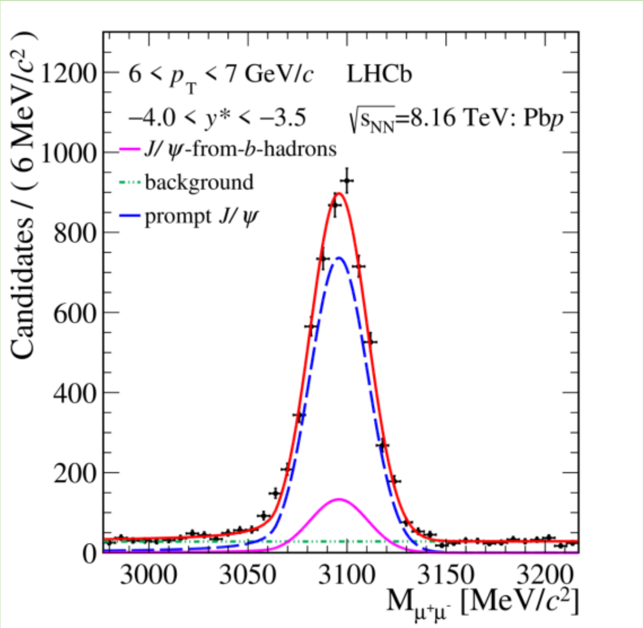
- ❑ **Partons unconstrained at LHC energy in the forward region => LHCb can explore the low-Bjorken x region with high precision,**
  - ✓ **especially @low Q^2 , down to 0 p_T**

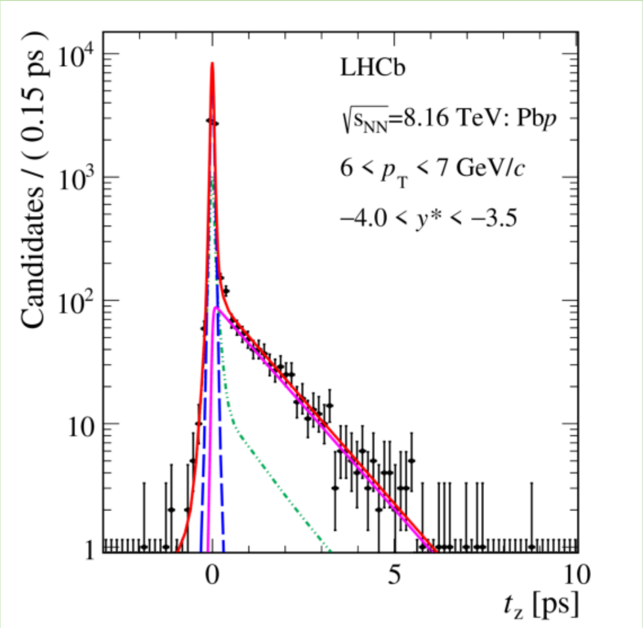
Data on p – p and p – Pb provide basics for interpretation of Pb-Pb collisions

J/ψ production in p-Pb collisions at 8.16 TeV

LHCb has **powerful vertexing tool (few tens fs in time) for separation prompt and delayed events)**

PLB 774 (2017) 159.

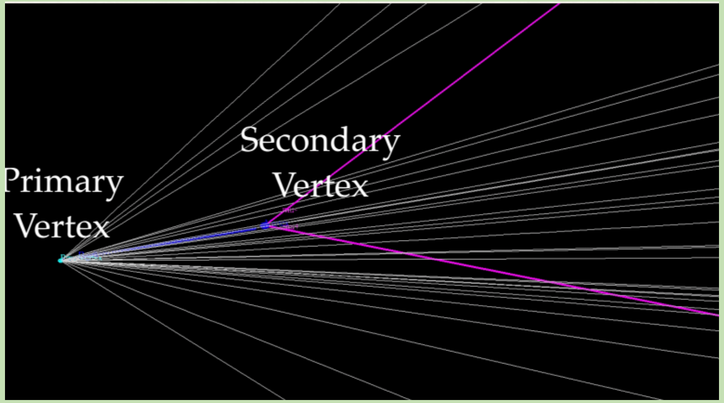




Principle of separation:

- **'Prompt'** – from primary vertices
- **'non-prompt'-** from b-hadron decays

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



Nuclear Modification Factor

$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) \equiv \frac{1}{A} \frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*},$$

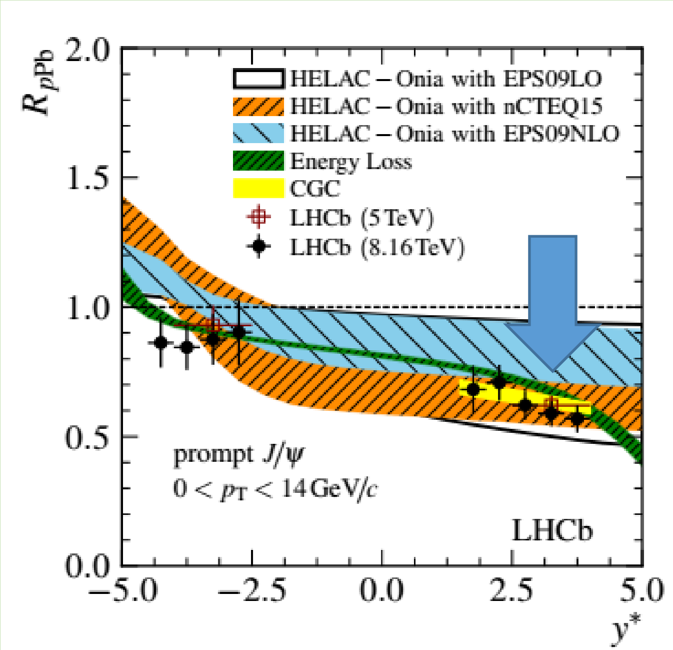
J/Ψ production in proton-lead @ 5 and 8.16 TeV

Comparison of 'prompt' – 'non-prompt' results (continued)

Established significant difference in the FWD rapidity.

PLB 774 (2017) 159-178

Nuclear modification factor -
prompt J/Ψ



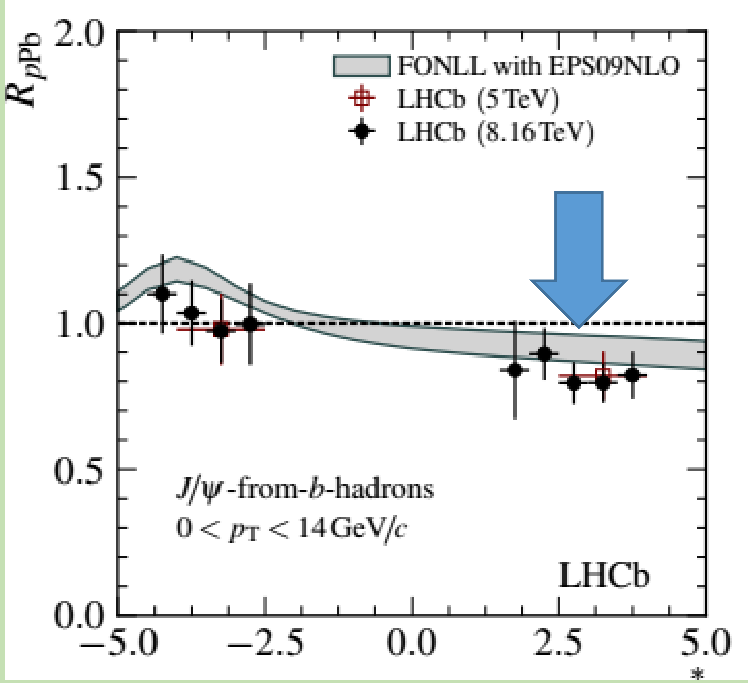
Strong suppression in the FWD y*
Consistent results for data at 5 and 8.16 TeV

Remarkable difference
For two cases!

Illustration of the hot
environment impact
or 'cold' nuclear matter effect ?
Theories:
- 'prompt' described
by NLO nPDFs
plus energy loss effects

- 'non – prompt '
described
by effects of NLO nPDFs

Nuclear modification factor –
non-prompt J/Ψ (from b)



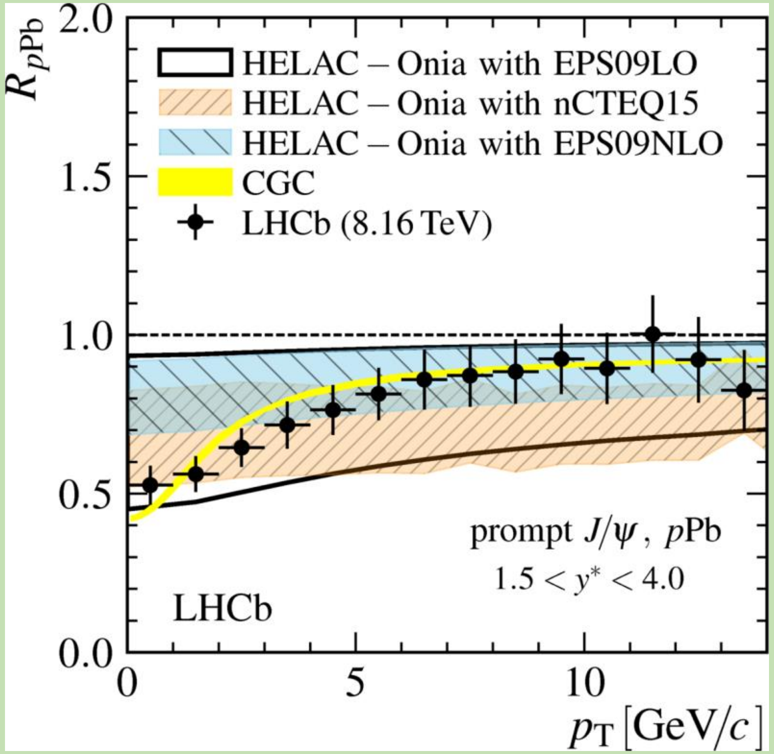
Suppression in FWD y*
- much less
pronounced

J/Ψ production in proton-lead @ 8.16TeV

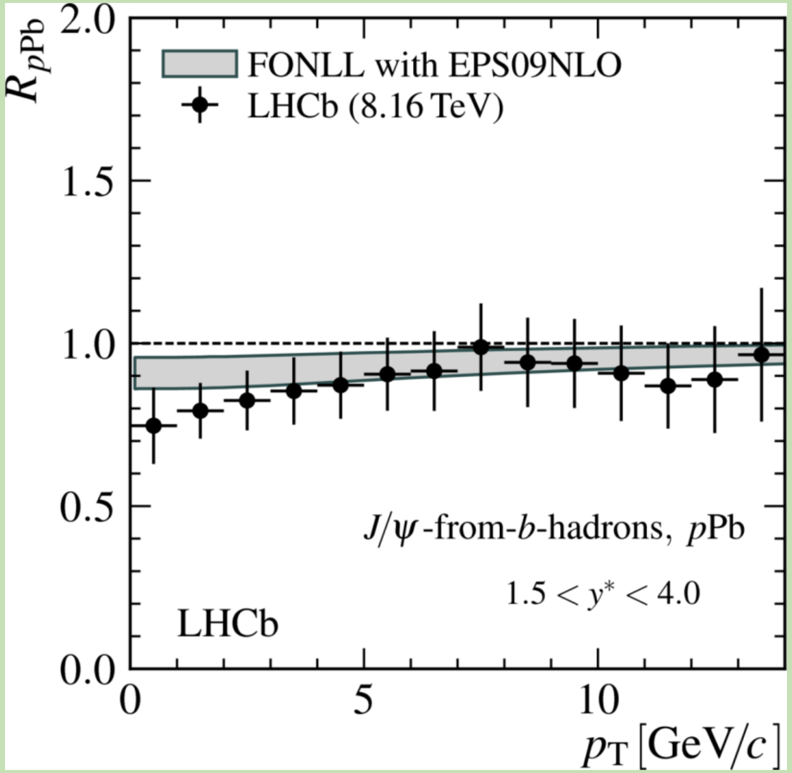
Exploring powerful LHCb vertexing tool (few tens fs in time) for separation prompt and delayed events

PLB 774 (2017) 159-178

Nuclear modification factor – prompt J/Ψ



Nuclear modification factor – delayed J/Ψ from b



Remarkable difference!

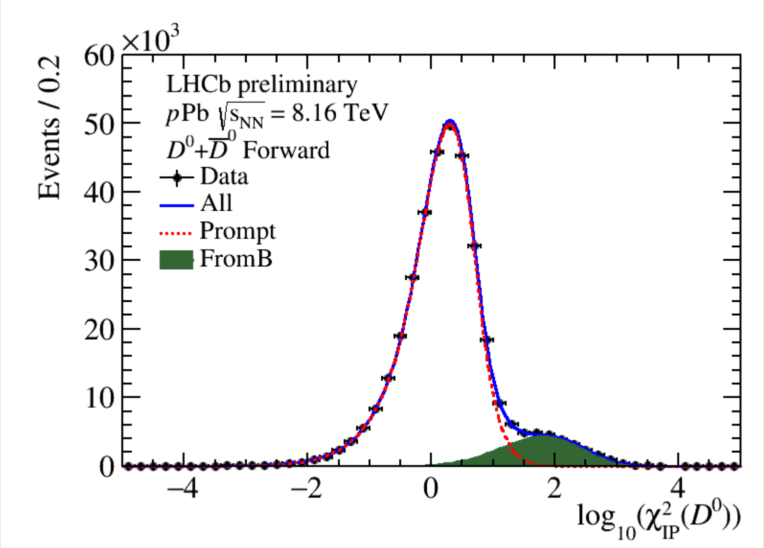
Illustration of the hot environment impact (?)... or cold nuclear matter effect ...?

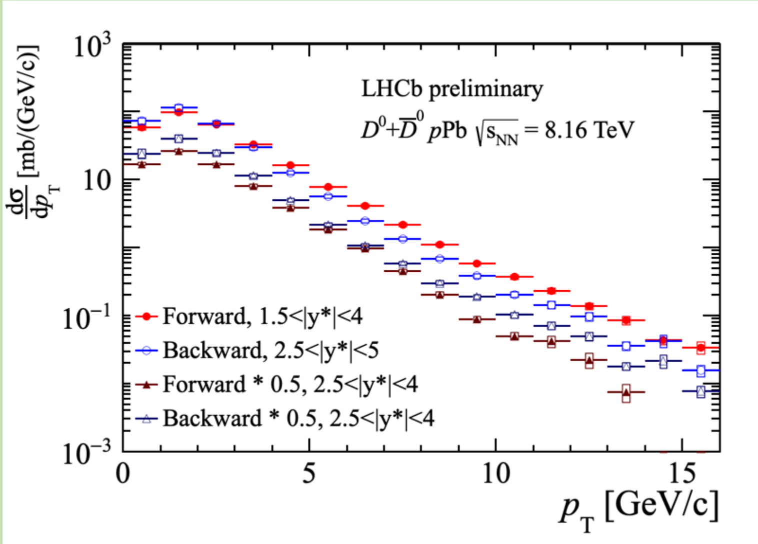
Theories:

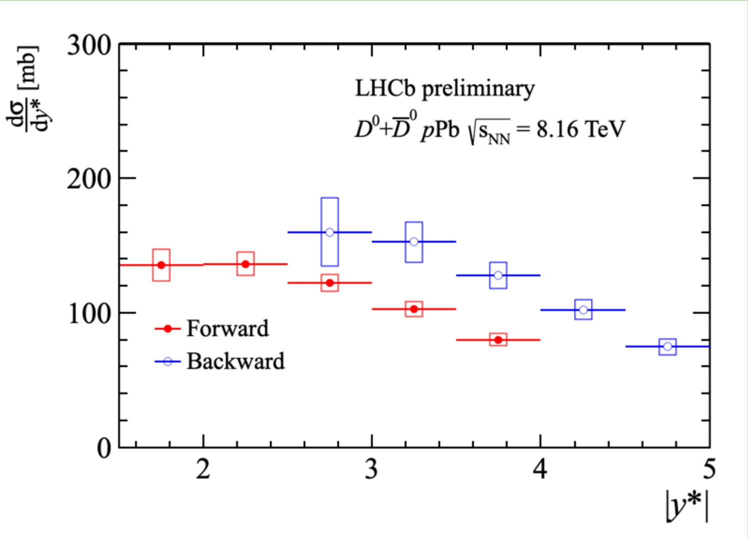
nuclear nPDFs EPJC77 (2017) 1
& Color Glass Condensate
PRD91(2015) no.11, 114005
accounting for coherent energy-loss
JHEP 1303 (2013) 122
accounting for rapidity dependence
Constraints nPDFs at low-x, PRL 121, 052004 (2018)

Prompt D^0 meson production in p-Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

[LHCb-CONF-2019-004]







Selection of the prompt events:

- by fitting the $\log_{10}\chi^2_{IP}$ distribution

(the difference in the vertex-fit χ^2 of a given primary vertex reconstructed with and without the D^0 candidate)

The kinematics: 2.0 < p_T < 3.0 GeV/c, 3.0 < y∗ < 3.5.

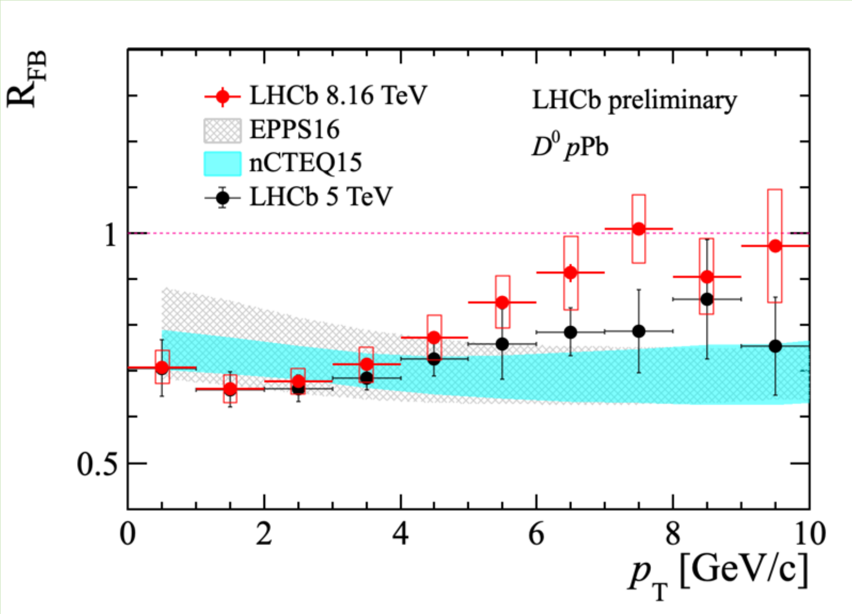
Differential cross-sections of prompt D^0 mesons in p-Pb collisions

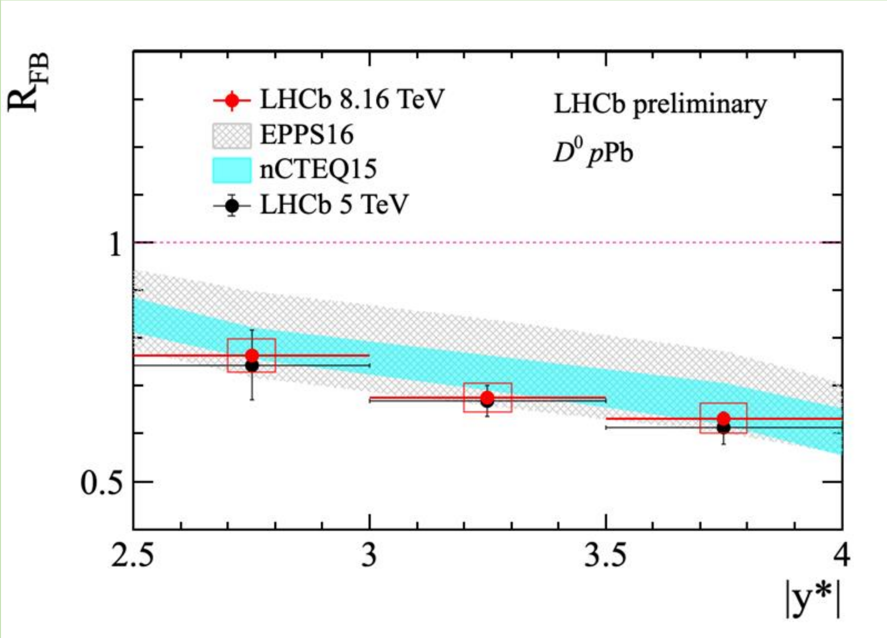
as a function of (left) $\mathbf{p_T}$ and (right) **y∗**

in the forward and backward configurations

Prompt D^0 meson production in p-Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

[LHCb-CONF-2019-004]



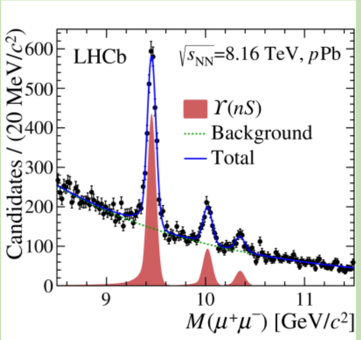


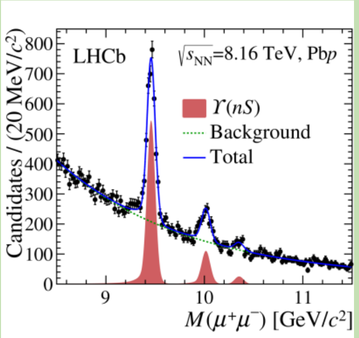
Forward and backward production ratio R_{FB} (left) as a function of p_T and (right) of rapidity (y∗)
The theoretical calculations - HELAC-Onia generator,
incorporating nPDFs EPPS16 (grey) and nCTEQ15 (blue).

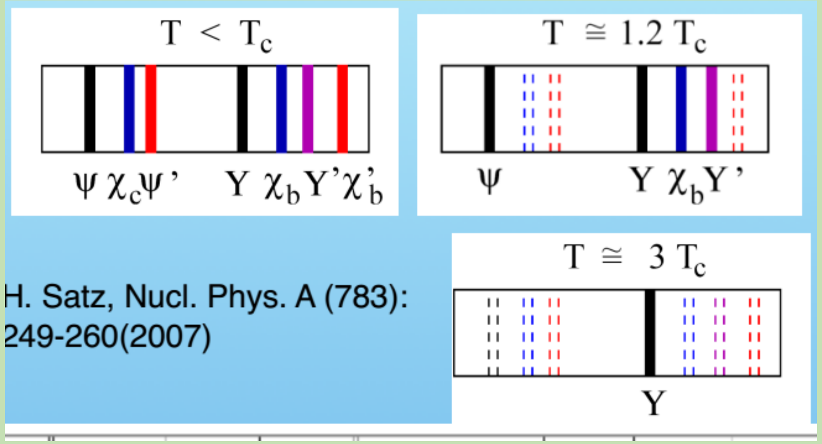
Observation: A large asymmetry between the forward and backward productions.
Cold nuclear matter effects ?

ϒ(nS) Nuclear Modification Factors p – Pb @ 8.16 TeV

JHEP11(2018)194



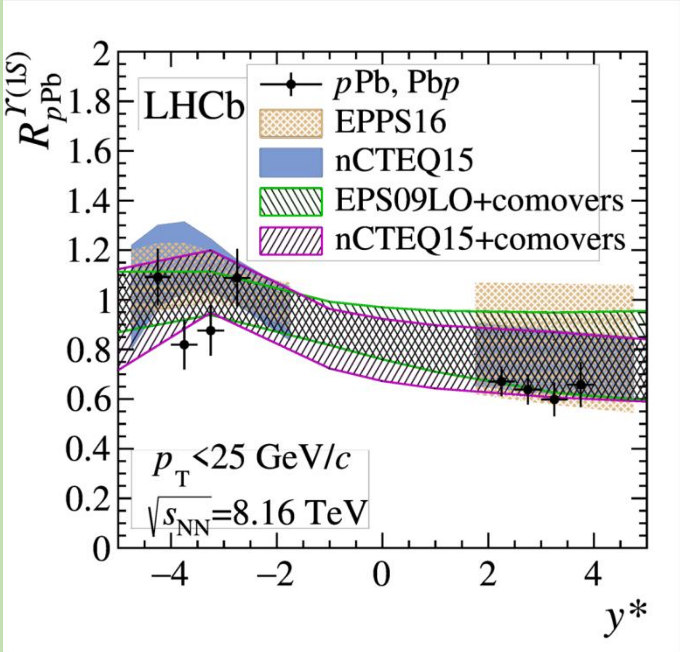




'Melting' of excited states with increasing temperature

Theories:

EPPS16: Eur. Phys. J. C (2017) 77: 163
EPS09: JHEP 04 (2009) 065, arXiv:0902.4154.
nCTEQ15: Phys. Rev. D93 (2016) 085037.
Comovers: arXiv:1804.04474;
Phys. Lett. B749 (2015) 98, arXiv:1411.0549



ϒ(1S) – rapidity distribution

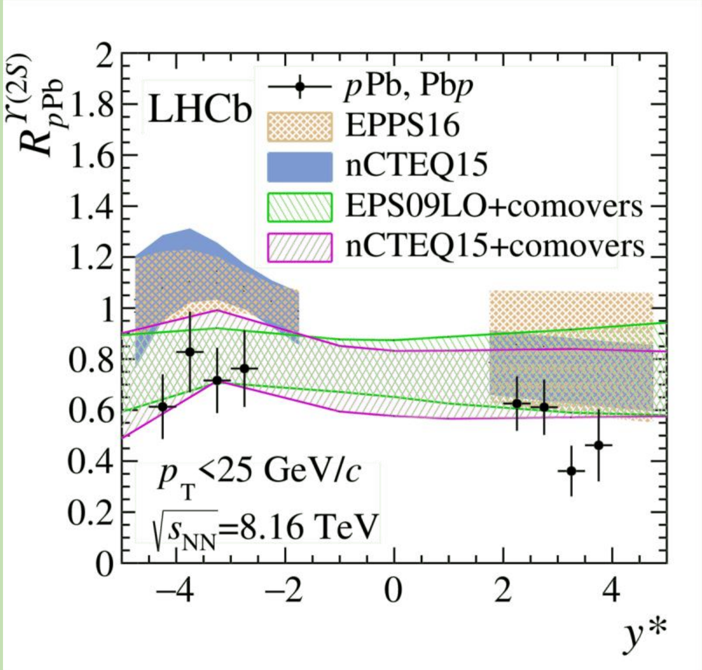
Data Integrated over p_T

Observations:

1.Strong suppression of ϒ(1S) and ϒ(2S) in the forward rapidity

2. 2S and 3S stronger suppressed compared to 1S

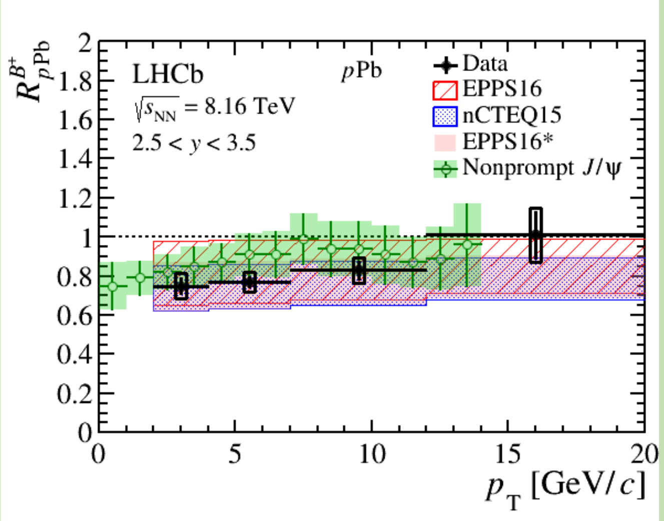
(Well interpreted in COMOVER Model, as final state effect)

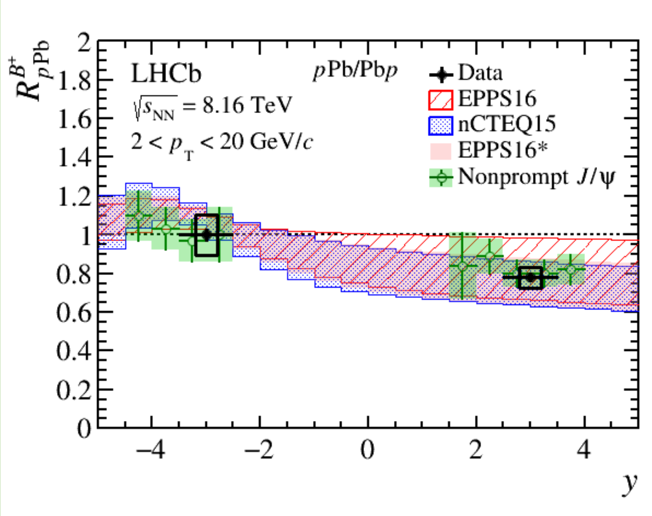


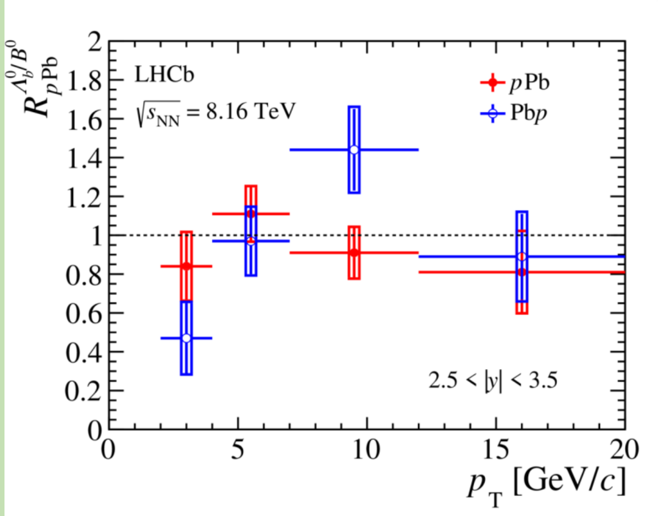
ϒ(2S) – rapidity distribution

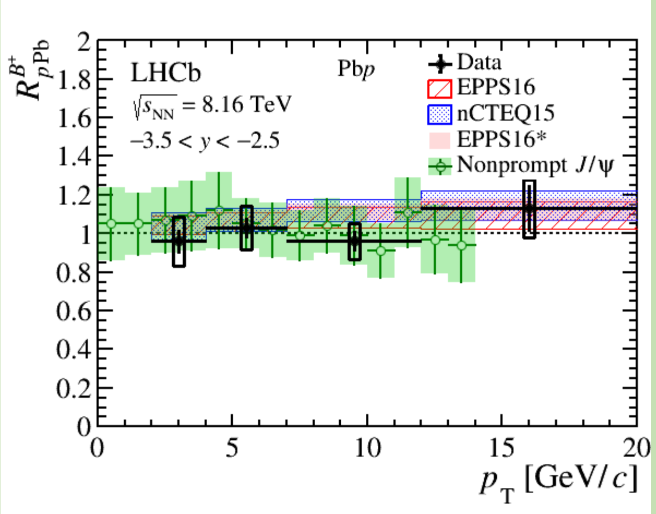
b-hadrons (B^+, B^0 and Λ^0_b) production in p-Pb collisions at 8.16 TeV

PHYS. REV. D99 052011 (2019)









Nuclear modification factors indicate a significant nuclear suppression at forward rapidity compared to p-p collisions.

b-hadron results confirm the suppression of b-production at FWD rapidity measured via non-prompt J/ψ mesons (from b-decays). (green inserts)

The baryon-to-meson ratio of Λ^0_b / B^0 :

- **consistent with the p-p collisions at forward rapidity.**
- **constraints the fragmentation of the b quarks in a nuclear environment.**

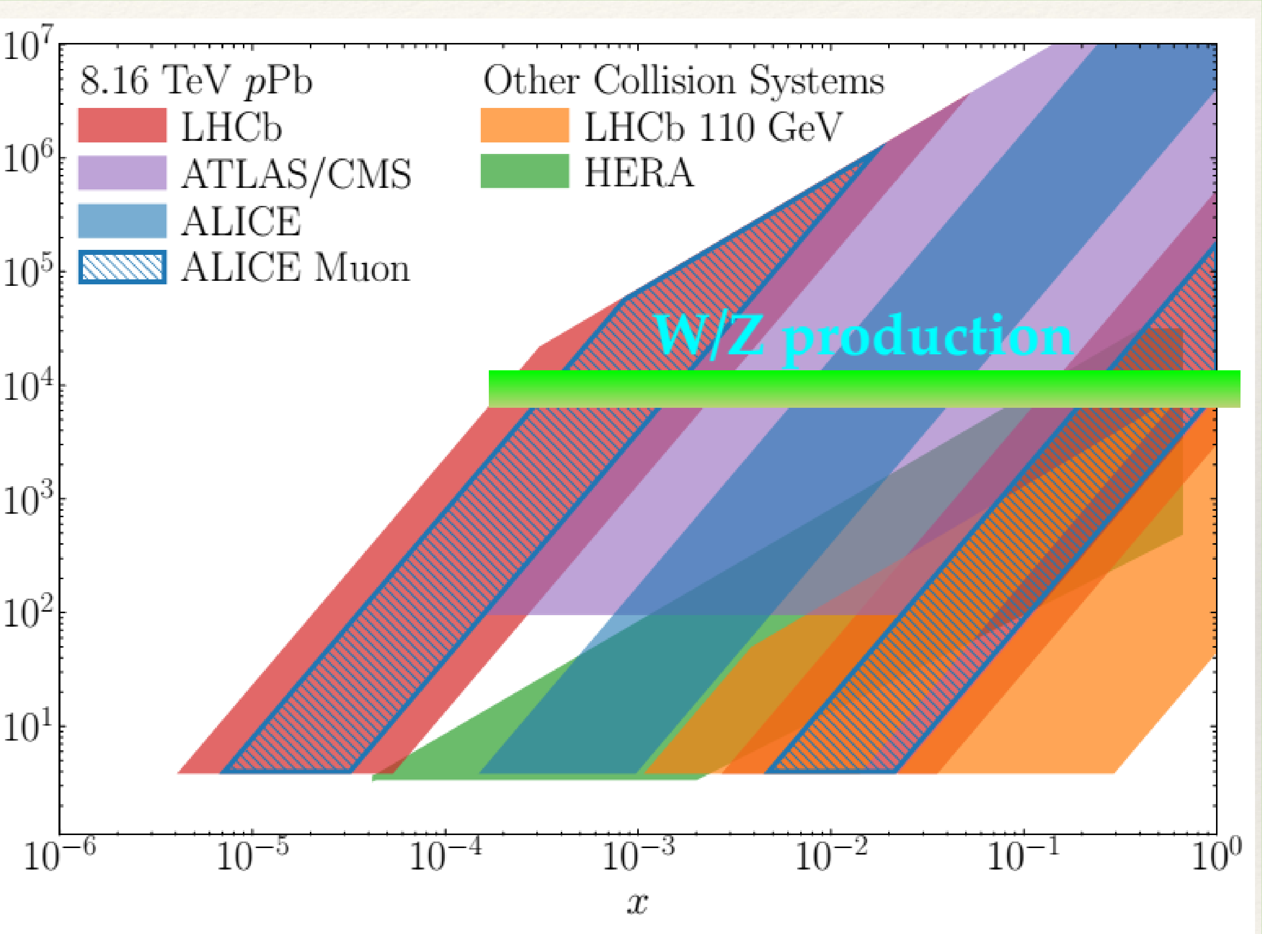
Z boson production in p-Pb at 8.16 TeV

Peculiarity:

Electroweak bosons passing through the hot/dense nuclear medium are not affected by the strong interaction.

- ***perfect probe of "cold" nuclear matter effects***

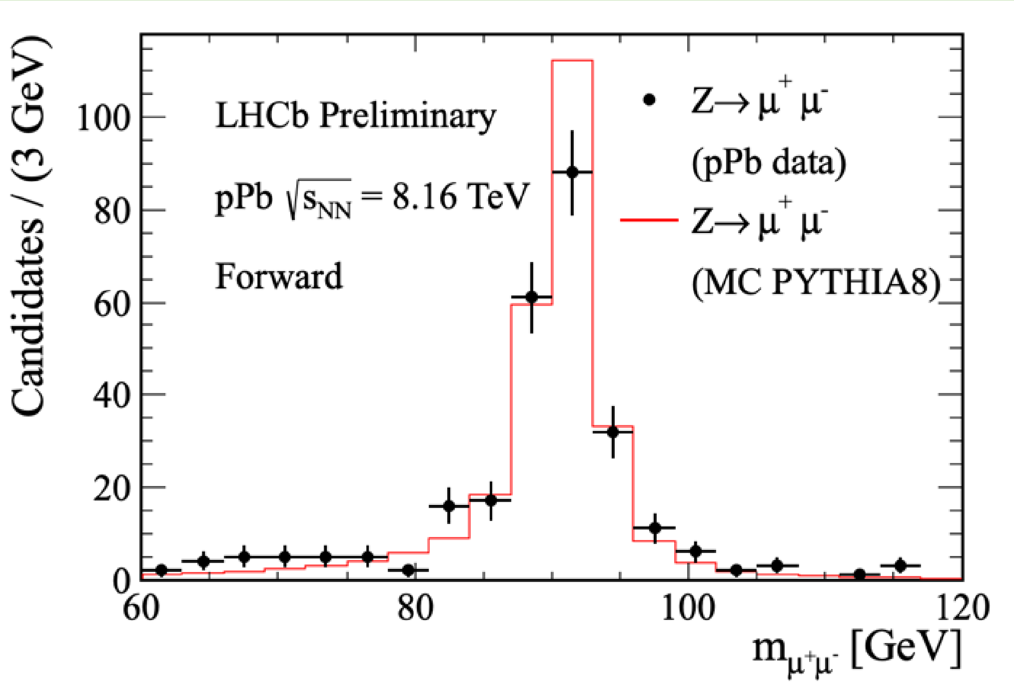
- **data constraint nPDFs for Bjorken-x from ~10 $^{-4}$ to 1 at Q^2 ~ 10^4 GeV^2**

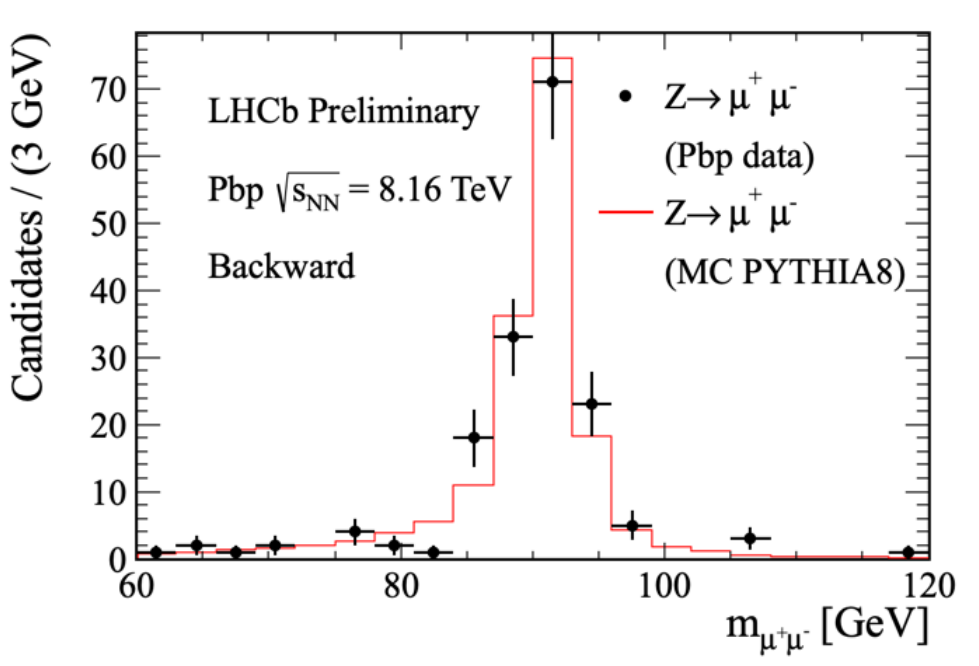


Z boson production in pPb at 8.16 TeV

(LHCb-CONF-2019-003)

Integrated luminosity: forward (12.2 ± 0.3 nb $^{-1}$) / backward (18.6 ± 0.5 nb $^{-1}$)

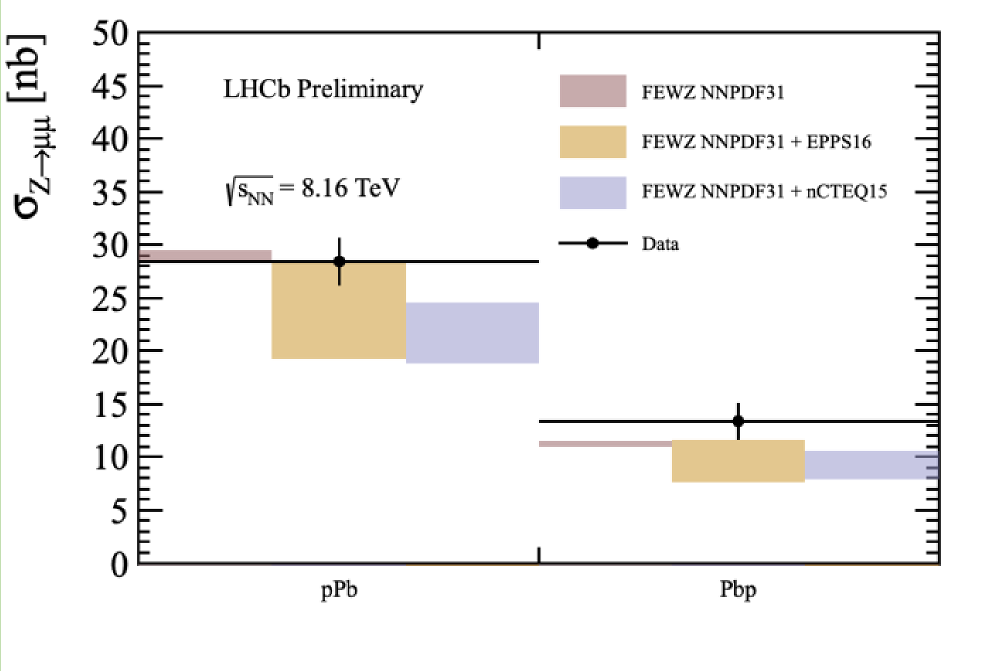


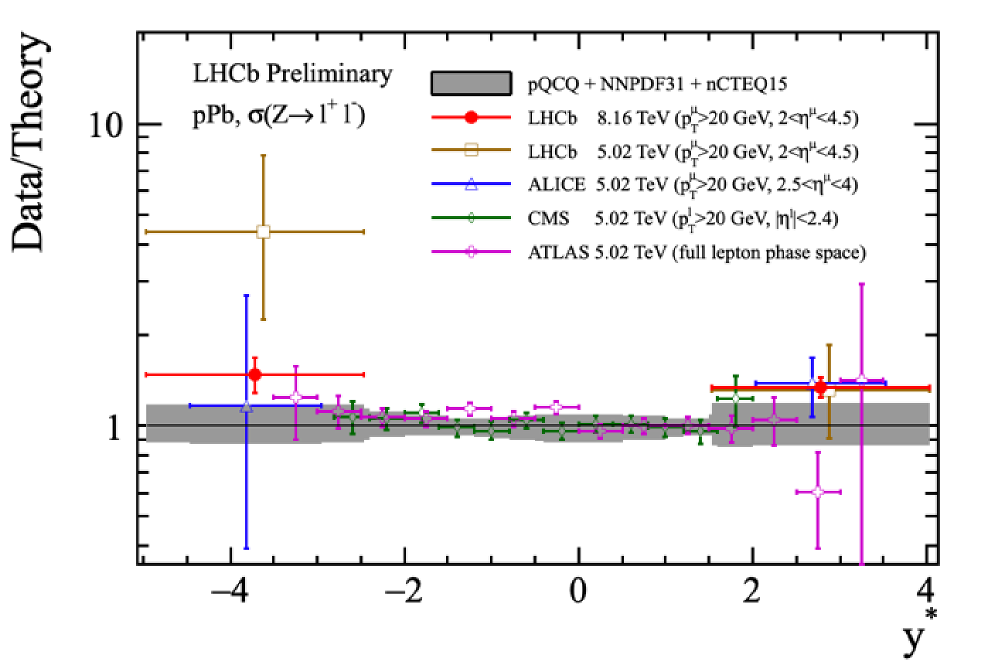


Measured forward/backward ratio of cross-sections : R_{FB} = 1.28±0.14(stat.)±0.14(syst.)±0.05(lumi.)
Theoretical predictions within current uncertainties provide compatible results :
(1.59 +\- … -> NNPDF3.1) and 1.44 +/- … -> NNPDF3.1+nCTEQ15

Z boson production in pPb at 8.16 TeV

(LHCb-CONF-2019-003)

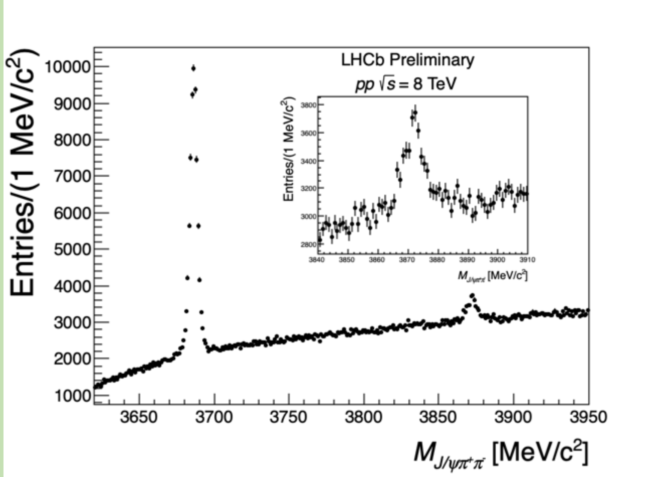


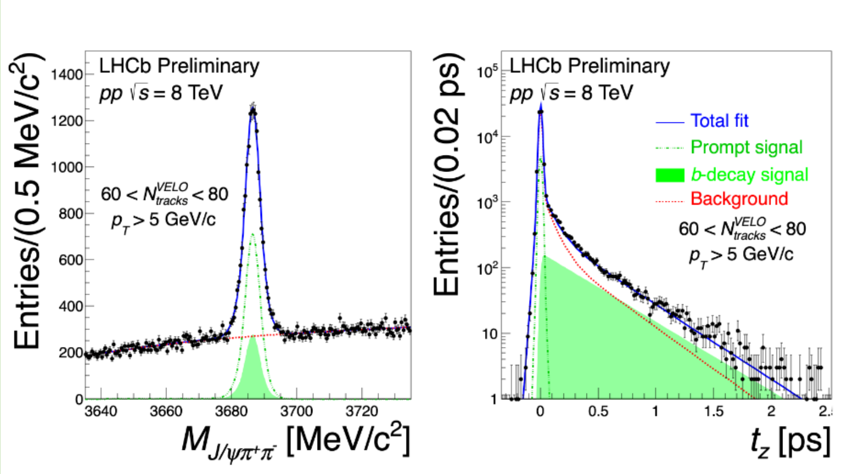


Cross-section results are compatible within errors with theoretical predictions using :
-> for protons - FEWZ(NNLO pQCD+NLO pEW) with NNPDF3.1(PDF)
-> for Pb - NNPDF3.1(PDF), EPPS16 (nPDF), nCTEQ15 (nPDF)

Multiplicity-dependent modification of χ_{c1}(3872) and ψ(2S) production in *pp* collisions at $\sqrt{s}$ = 8 TeV

LHCb-CONF-2019-005





χ_{c1}(3872) and ψ(2S) , pp collisions ($\sqrt{s}$ = 8 TeV, integrated luminosity of 2 fb^{-1}.) as a function of the event activity (the number of tracks in the vertex detector(VELO): two cases studied:
prompt and delayed production.
χ_{c1}(3872) and ψ(2S) → Reconstruction via decays to J/ψ $\pi^+\pi^-$.

χ_{c1}(3872) - could be assumed as a hadronic molecule, consisting of two D-mesons

- binding energy of the χ_{c1}(3872) molecule is close to zero,

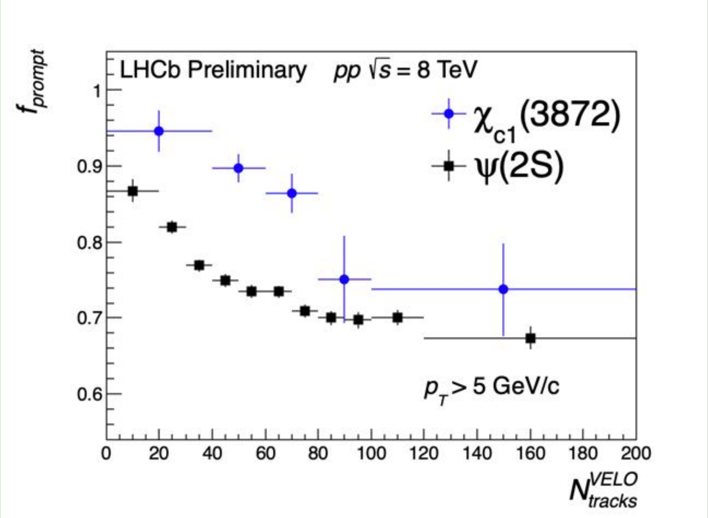
-a large radius, of order 7 fm

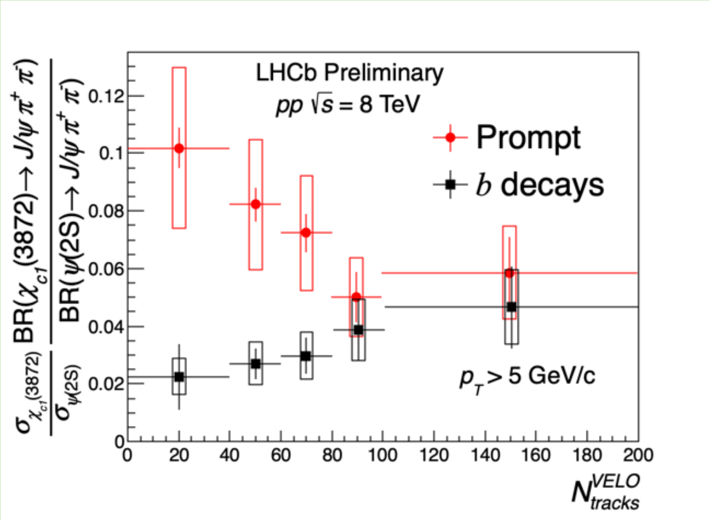
Previous weakly bound quarkonium states studies showed:

- **the ψ(2S) is suppressed more than the J/ψ**
- **the Y(2S) and Y(3S) states are suppressed more than the Y(1S)**
- **final state effects, (breakup via interactions with co-moving hadrons), describe the relative suppression of excited quarkonium states in p-A collisions .**

Multiplicity-dependent modification of χ_{c1}(3872) and ψ(2S) production in pp collisions at $\sqrt{s}$ = 8 TeV

LHCb-CONF-2019-005



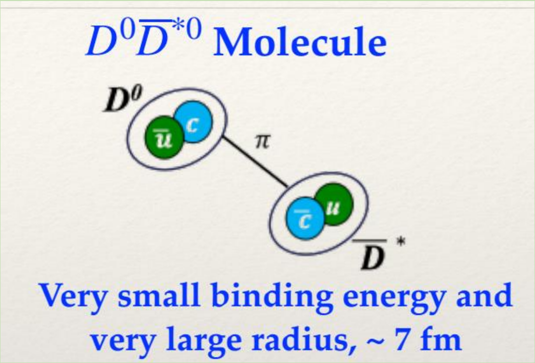


χ_{c1}(3872) and ψ(2S) states are produced promptly at the primary vertex

or in decays of b hadrons.

If the χ_{c1}(3872) is a hadronic molecule

final-state effects could disrupt its formation



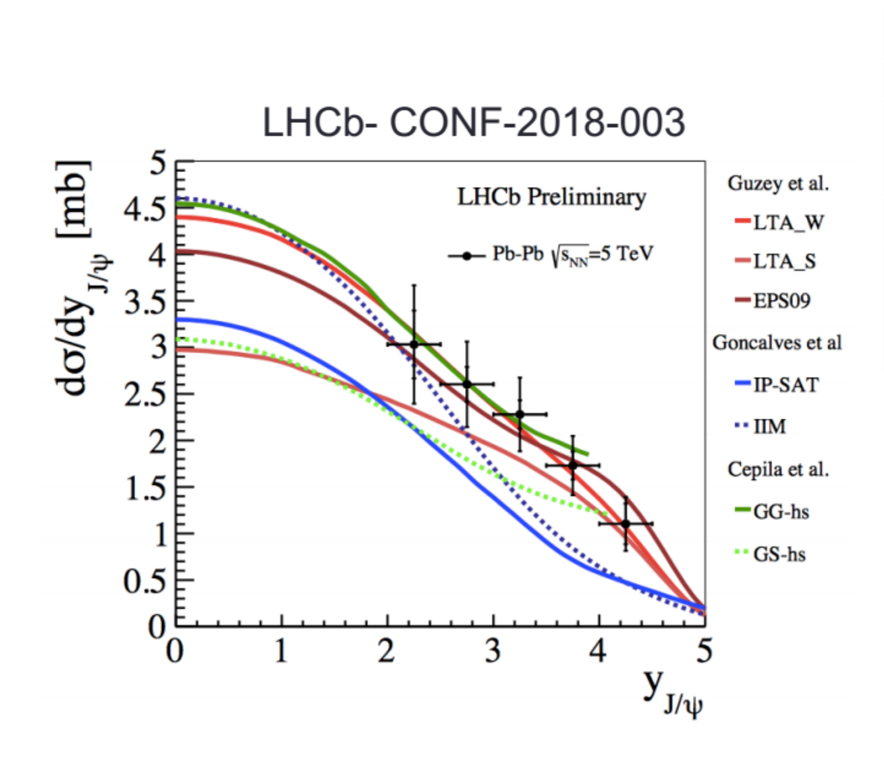
The fraction of promptly produced χ_{c1}(3872) and ψ(2S) decreases with multiplicity for both *species*

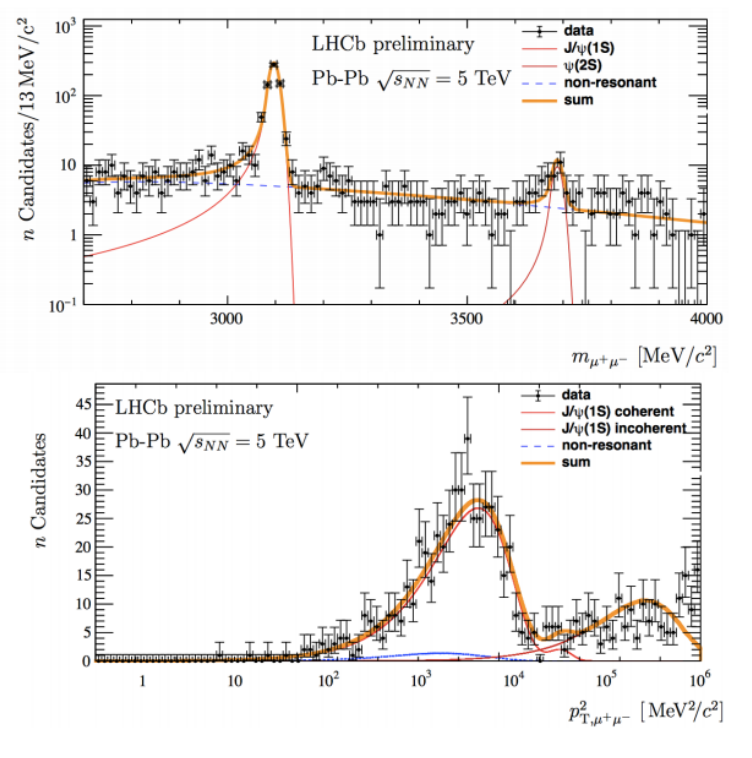
The ratio of cross-sections $\sigma\chi_{c1}$(3872)/$\sigma\psi$(2S) with increasing multiplicity:

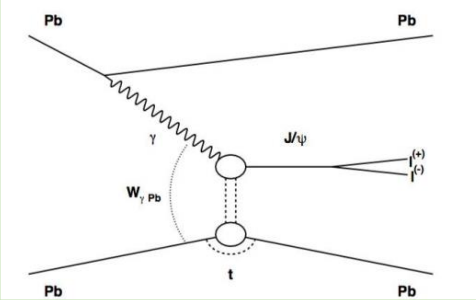
- **prompt production -> decreases**
- **delayed production** (b-hadron decays) - **no dependence**

Possible interpretation:
the χ_{c1}(3872) is a weakly bound D^0D^{0*} hadronic molecule.

J/ψ production at ultra-peripheral collisions. Pb - Pb at 5TeV







pA collisions

- $\sigma_{P\gamma}$ enhanced by Z^2 in UPC
- σ_{PP} enhanced by $A^{1/3}$

AA collisions

$\sigma_{\gamma\gamma}$ enhanced by Z^4 in UPC

Consider UPC as a calibration tool for Pb-Pb data at high multiplicity: Compare p_T spectra of J/ψ ratio 2S/1S for two cases. UPC and prompt production

- **Gluon saturation at low *x*, nPDFs, CGC**
- **Transverse momentum fit allows to separate coherent and incoherent events**
- **σ (γA) -> nuclear PDFs (or shadowing)**

2018: 10x luminosity

Also other J/Psi states become reachable

Fixed target regime at the LHCb

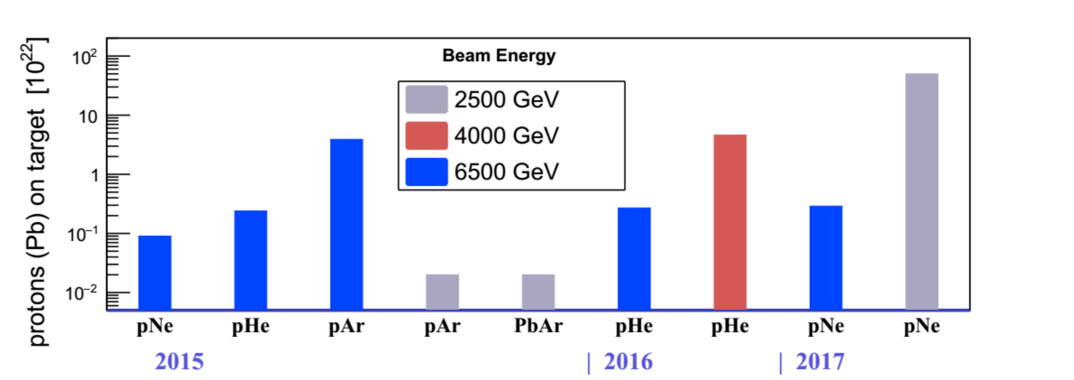
Fixed Target regime extends the LHCb physics programme.

Internal gas target (SMOG):

- **He, Ne or Ar with unique coverage of the high-x regime in the target nucleon.**
- **Collisions at an energy scale of $\sqrt{s_{NN}} \sim 100$ GeV . QCD phase diagram may have here interesting features**
- **J/ψ and $\psi(2S)$ modification of cross-sections due to hard production and suppression by hadronic dissociation in QGP.**
- **particle production in the soft QCD regime**

Energy between 20 GeV (SPS) and 200 GeV (RHIC) ,

- **Measurements for cosmic ray physics**
- **collection samples of charmed mesons**
  - **To discriminate CNM effects from deconfinement,**
  - **nuclear PDFs at large x.**



Internal Gas-Target SMOG.
Acquired SMOG data sample sizes, given in terms of proton (or Pb) on target.
The unit of 10^{22} corresponds to about 5/nb per 1 m of gas, at the nominal SMOG pressure.

p + He->anti-p + X @ $\sqrt{s_{NN}} = 110$ GeV
an input for cosmic rays physics

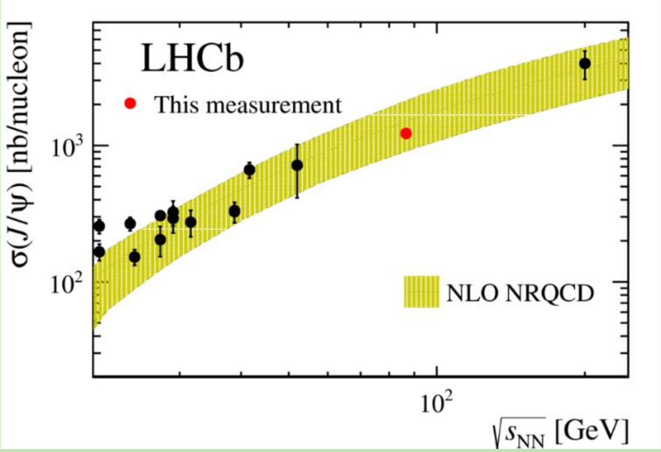
Anti-proton production cross sections in *p*-He -> A contribution to shrink background uncertainties in dark matter searches in space.

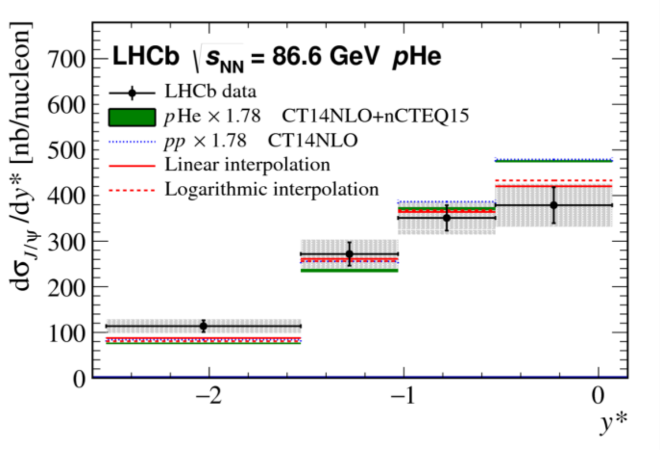
(Phys. Rev. Lett. 121 (2018), 222001)

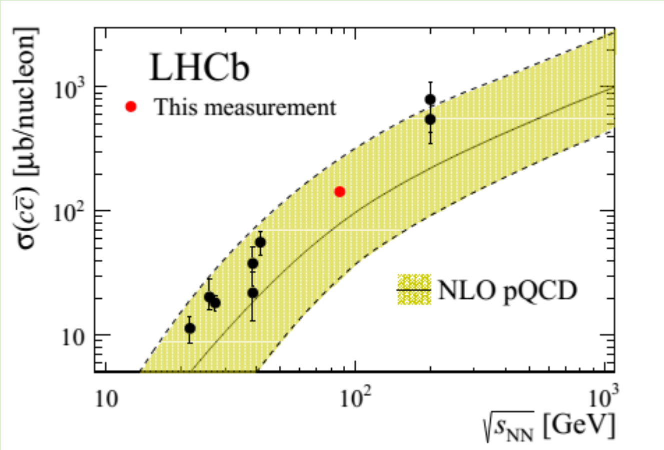
Production Cross-sections

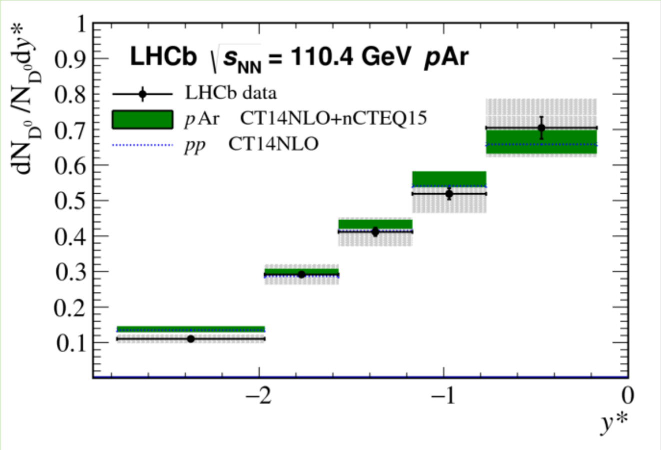
J/ψ, D^0 in pHe @ $\sqrt{s_{NN}}$ = 86.6 GeV
J/ψ, D^0 in pAr @ $\sqrt{s_{NN}}$ = 110 GeV

Phys. Rev. Lett. 122, 132002 (2019)









The J/ψ and D^0 (including charge conjugate) production cross sections in p-He collisions in the rapidity range [2, 4.6] are found to be $\sigma_{J/\psi}$ = 652±33 (stat)± 42 (syst) nb/nucleon and σ_{D^0} = 80.8 ± 2.4 (stat) ± 6.3 (syst) μb/nucleon,

Access nPDF anti-shadowing region and intrinsic charm content in the nucleon

- **Reasonable agreement with nPDF predictions**
- **No strong intrinsic charm contribution observed**

The LHCb collaboration is presently considering several proposals to extend Heavy Ion Fixed Target programme

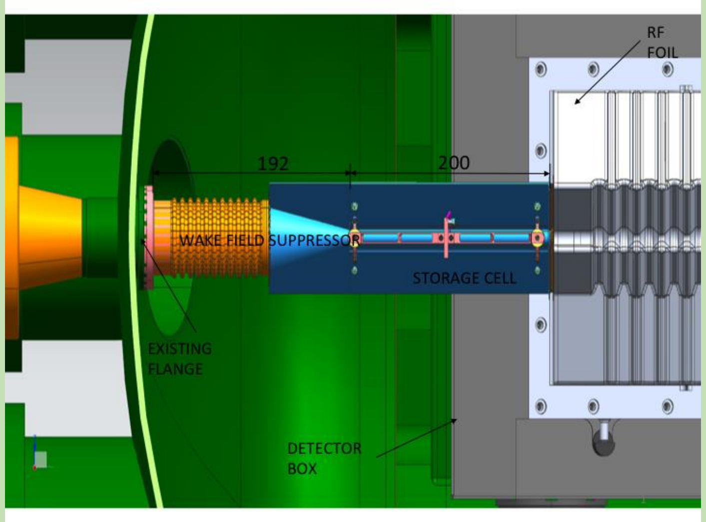
Upgrades with crystal target for c-quark MDM, EDM, polarised target further upstream & wire targets are under discussion

LHC ERA   HL-LHC ERA

3 fb-1		♦5 fb-1				50 fb-1		300 fb-1
2011-2012		2015-2018	LS2	2021-2023	LS3	2026-2029	LS4	2031-...

Run 1   Run 2   Run 3   Run 4   Run 5...

LHCb Upgrade I   LHCb LS3 Consolidation LHCb Upgrade II



SMOG2

OTHER TARGETS

Bent crystals?   Polarised gas?   Metal wires?

SMOG2: the injected gas inside a 20 cm long storage cell (1 cm in diameter) in front of the VELO.

-**Up to two order of magnitude higher luminosity,**

- Will operate also deuterium and noble gases

All roads lead to Rome …

The results may indicate the way to observation of QGP signals :

- **Change of the p_T spectra and rapidity distributions in p-Pb compared to p- p system**
- **Suppression of hadrons production in forward rapidity**
- **Different suppression in prompt and delayed events: stronger for the prompt case (in proximity to hot medium)**
- **Stronger suppression of 2S compared to 1S states**
- **Testing new tools for the QGP signals search**

Z-boson, $\sigma\chi_{c1}(3872)/\sigma\psi(2S)$

- **Further theoretical and experimental studies with less uncertainties are required on the way to the QGP signals**
- **Upgraded LHCb experiment will provide order of magnitude higher statistics in collider and fixed target regime in Run3**
- **More probes will be explored – Strange hadrons , vector mesons, flows etc.**

4. Summary and Outlook

- LHCb contributes successfully into the Heavy Ion Sector of research
- Precise data on quarkonia production cross-sections in collider and fixed target modes were measured.
- Double differential cross-sections for hadrons production of hadrons were measured at 5, 8 and ~0.1 TeV. The striking feature was observed – essential suppression of cross sections at low p_T & forward rapidity compared to p-p data.
- Interpretation of the obtained results has been performed in frames of theoretical approaches. The experimental and theoretical uncertainties have to be reduced for improving extraction of nPDFs.
- Fixed Target mode is unique for the experiments at LHC. The upgraded version of the gas target (SMOG2) will allow to increase the instantaneous luminosity up to two orders of magnitude.

Acknowledgements

The studies have been partially supported in frames of the NAS of Ukraine Targeted research program «Fundamental research on high-energy physics and nuclear physics (international cooperation)» and within the LIA IDEATE activity (STCU Project P9903)

Thank you for your attention!

Welcome to Kyiv !

BACKUP Slides

Motivation for the Fixed Metal Targets in the LHCb Experiment

- LHCb success in the Ion Physics and Fixed (Gas) Target studies
- Fixed Metal Targets: New domains of colliding nuclei and energies at LHC

  (~ 80 - 110 GeV, nucleon/nucleon c.m.s.) http://dx.doi.org/10.1155/2015/760840
- Immense variety of colliding nuclei: enrichment of LHC physics tasks
  - QGP signatures (Nuclear Modification Factors)
    - possible dependence on ground state properties of colliding nuclei
  - Nuclear (and possibly atomic) dependence of the quarkonia production

    - from N interaction points:
      - N metal targets in LHC beam, simultaneously.

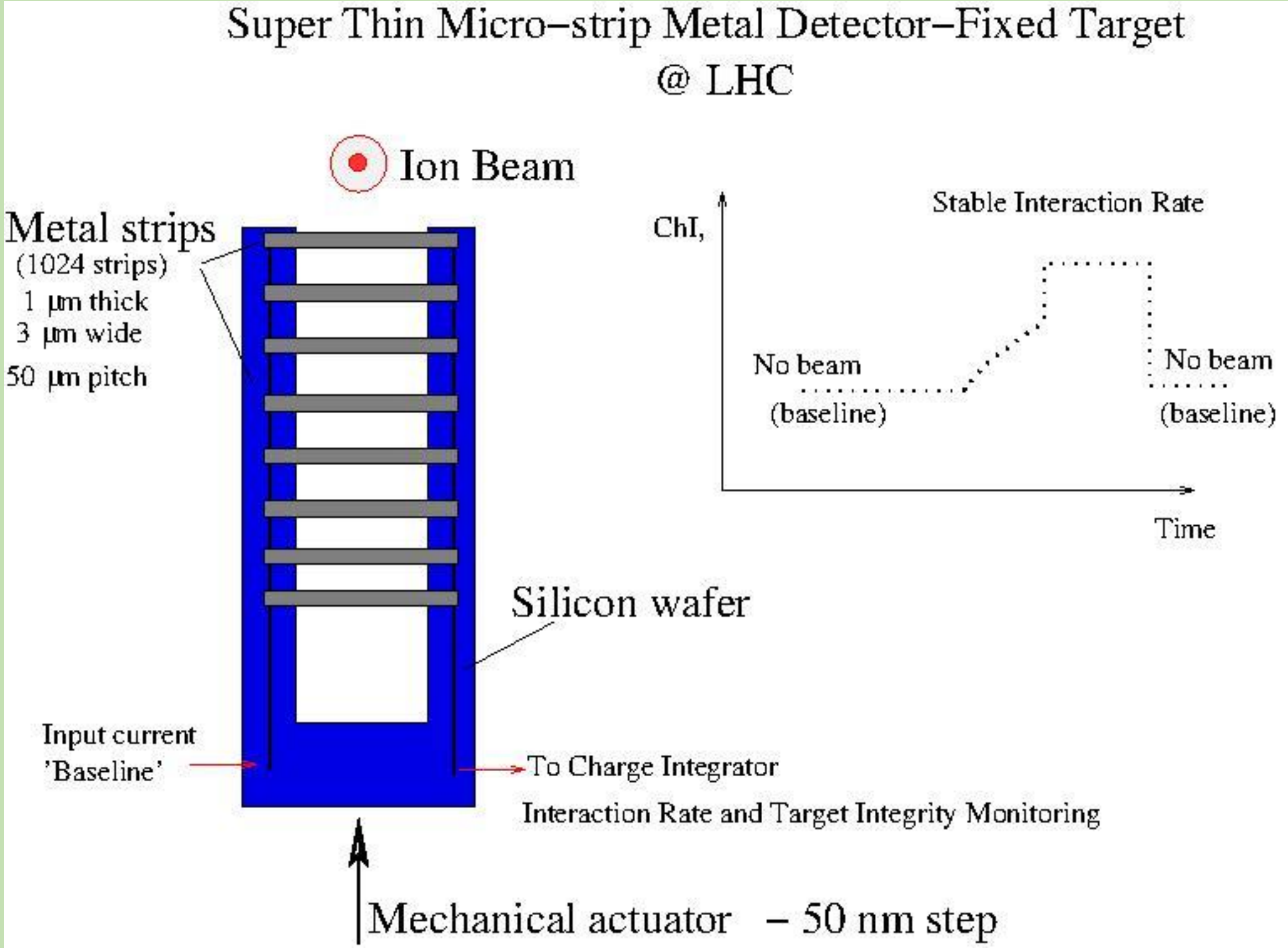
Some beneficial features of the LHCb Metal Microstrip Fixed Target setup

- **Physics**
  - Extension of the nuclei range for Nuclear Modification Factor studies (including isotopic enriched targets)
  - Impact of the individual nuclear properties (nuclear shell effects, spin, parity, deformation) on quark-gluon plasma generation
  - Nuclear Modification Factor for neutron-rich nuclei
  - Search for Neutron nuclei
  - …
- **Technique:**
  - Well localized interaction region (about 100 μm)
  - Taking data for many targets in a single Run
    - relative comparison of physics data with minimized systematic errors
  - Perfect tuning/monitoring of the individual luminosity
  - Safe and reliable operation

Techniques:

➢Metal microstrip detector-target

Superthin Wire Target - HOW-and When TO-DO it at LHCb ?
VELO – VErtex Locator construction after (LS3 ?) upgrade



Metal Microstrip Detector –MMD-1024.

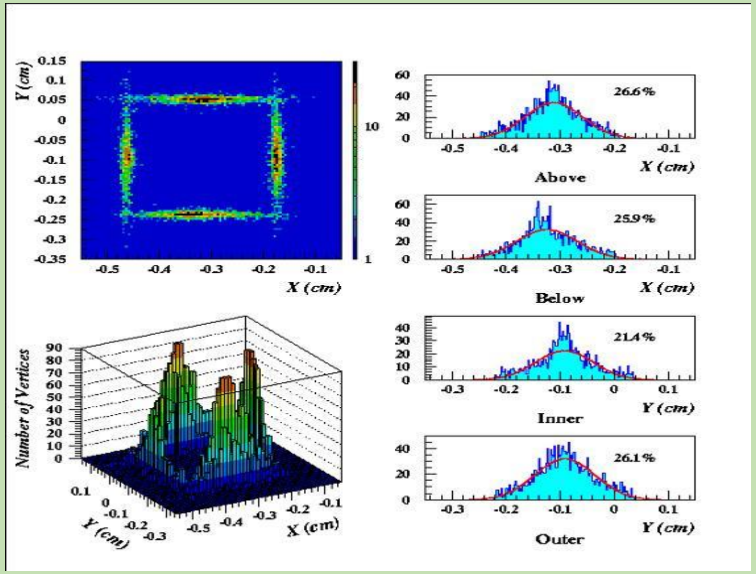
Nano-technologies evolve fast
– already nowadays- carbon nano-tubes, fullerene structures, graphenes, …
May become a nano-wire target components.

Techniques:

- **Metal microstrip detector-target**
- **Steering of the targets**

Equalization of the luminosities

Charge Integrated in Individual Targets - data for the steering feedback system at HERA



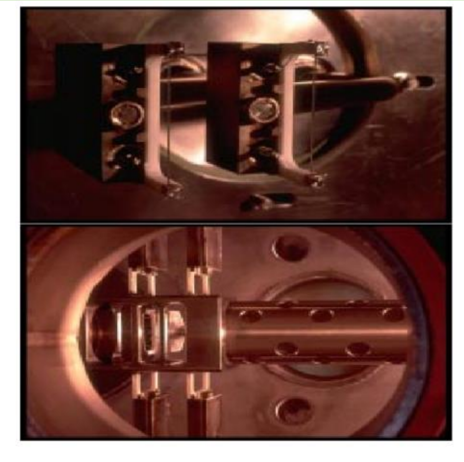
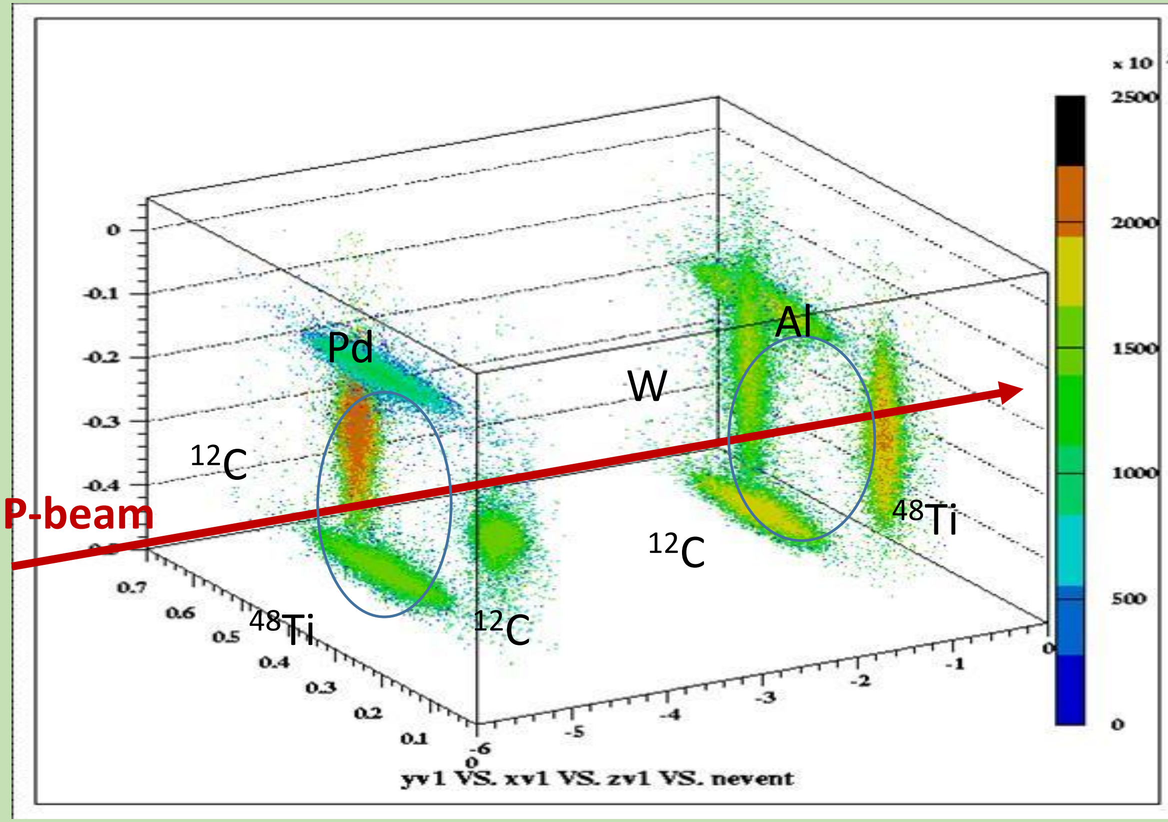


Figure 9: Targets mounted in the VDS vessel.



Wire	Charge Integrators %	Vertices %
Above	26.06 ± 0.08	26.6 ± 0.7
Below	24.26 ± 0.10	25.9 ± 0.7
Inner	23.49 ± 0.06	21.4 ± 0.7
Outer	26.20 ± 0.07	26.1 ± 0.7

Four targets

Eight targets

Proof of the principle – **Vertices are equally distributed over inserted targets.**

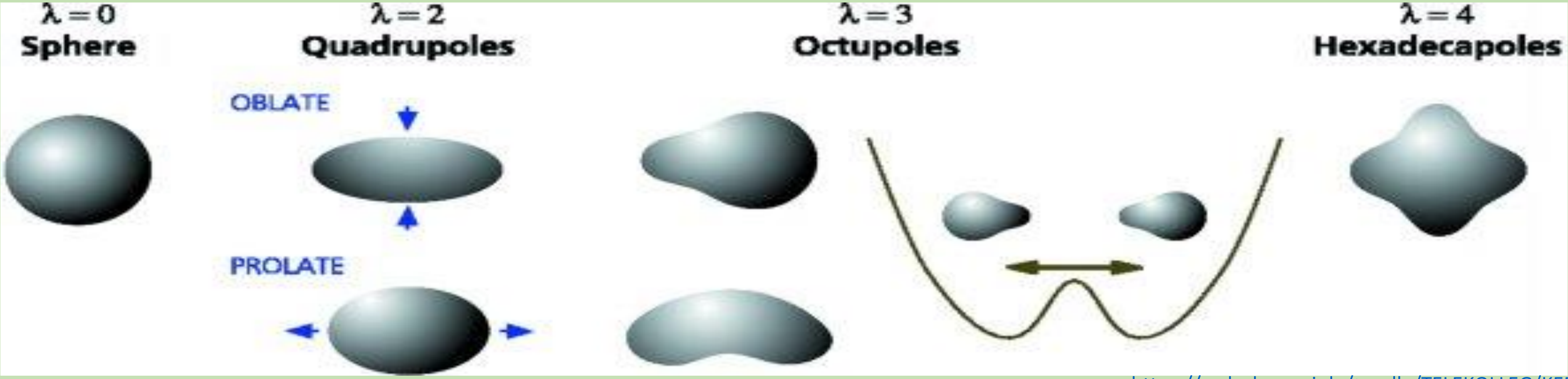
8 targets simultaneously could be handled providing 40 MHz interaction rate

http://dx.doi.org/10.1063/1.1291460

Different fixed targets
behave differently in collisions …

[Bullet Time | City Gallery Wellington]

Impact of the ground state properties on Nuclear Modification Factor ?



https://web-docs.gsi.de/~wolle/TELEKOLLEG/KERN/index-s.html

- Nuclei in ground state have different shape, angular momentum, …
- Nuclei with closed p-, n-shells (double-magic) are spherical
- Nuclear matter density distribution is not uniform
- Neutron-rich nuclei have large radius
- Neutron excess may create neutron nuclei in collisions ?

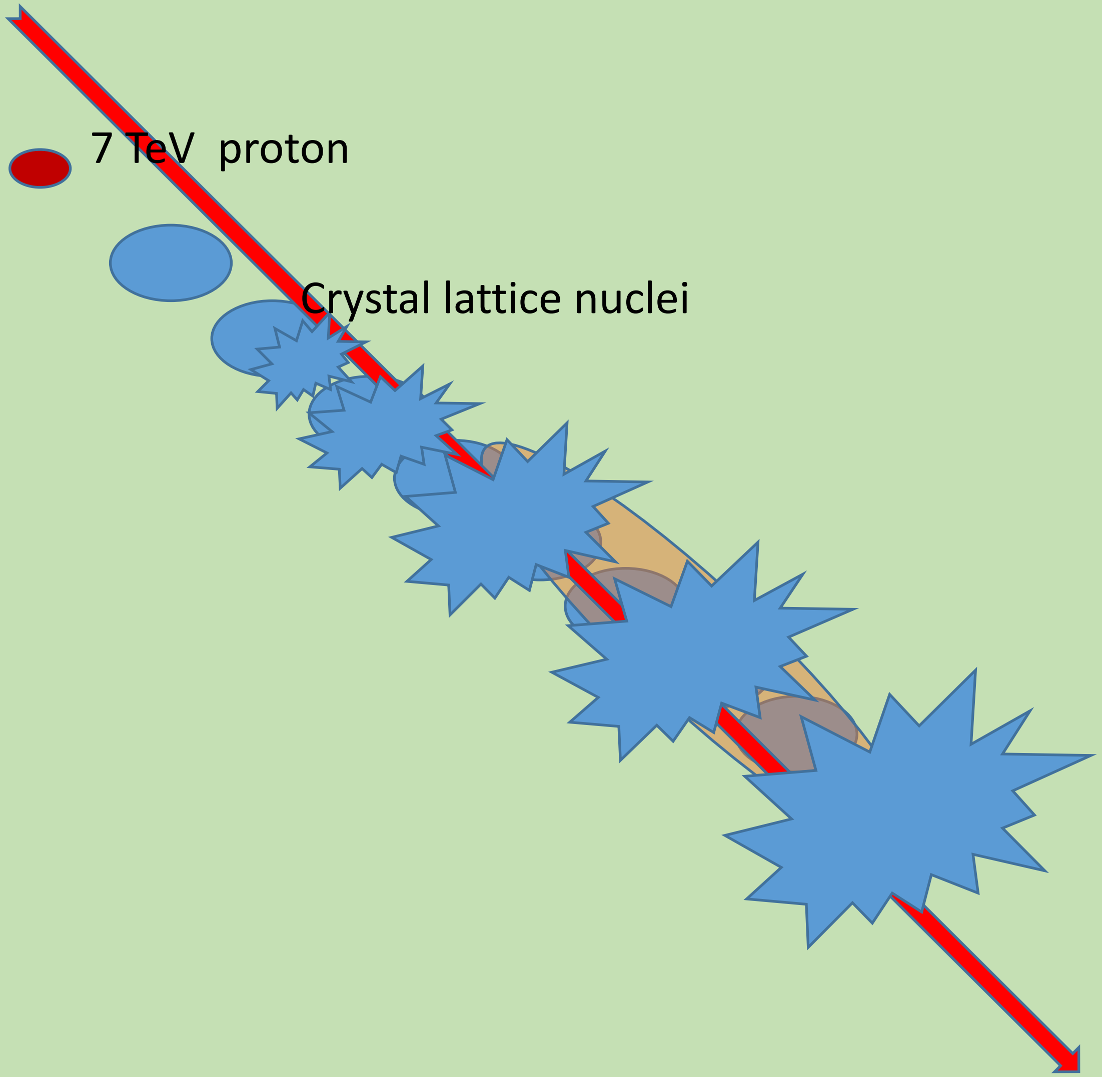
Physics:

➢QCD at the ~100 GeV NN cms energy

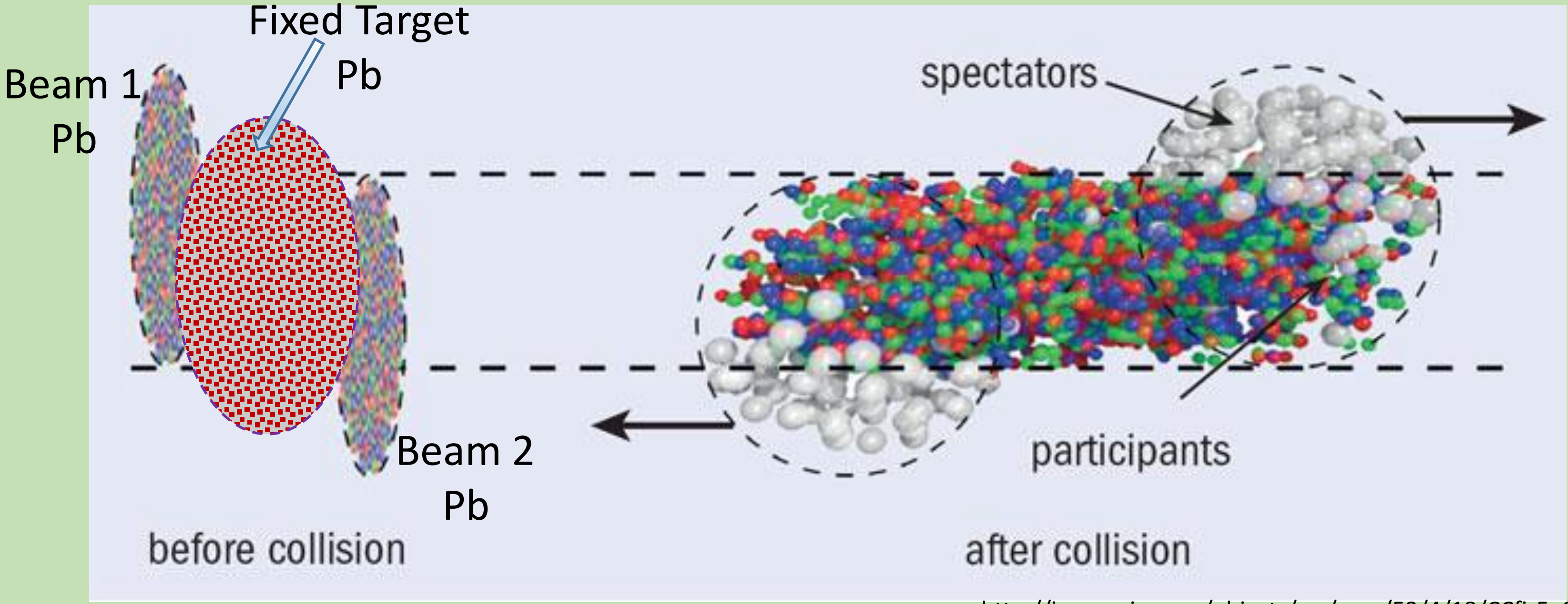
Crystalline Targets

Crystall structure – alligned atoms&nuclei – sequential scattering of high energy nucleus:

- **Cascade of nuclear interactions – Multiplicity of event– 10^{5-8} - ?**
- **Fusion to super heavy nuclei ?**
  - **Mass-spectrometry, gamma-rays analysis after irradiation**
- **Neutron rich or even neutron nuclei production ?**
- **Scattering at excited short-lived nuclei - new RBF ?**
- **…**



Three-nuclei interaction
– two nuclei from LHC beams
and one from the LHCb Microstrip Target

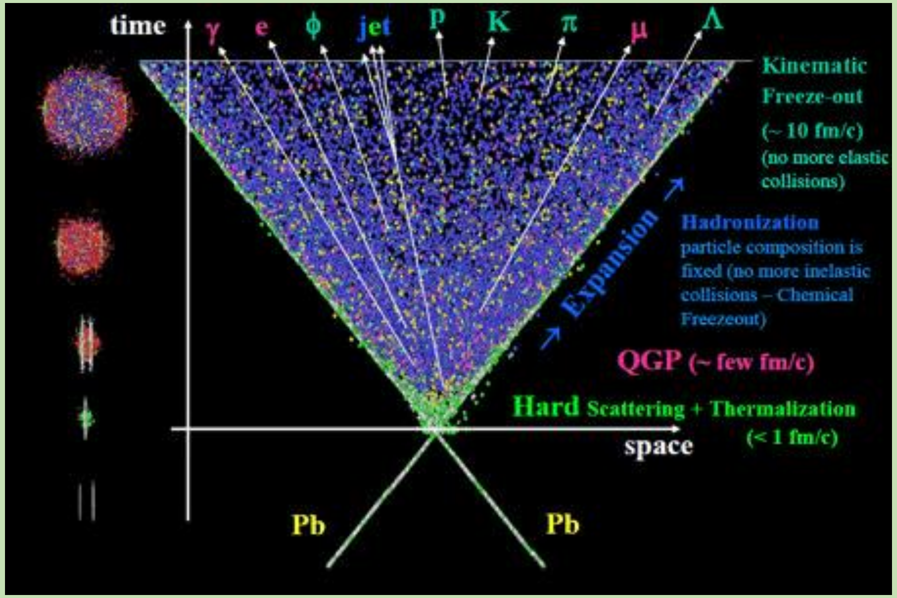


http://images.iop.org/objects/ccr/cern/53/4/18/CCfir5_04_13.jpg

Events with three nuclei interaction !

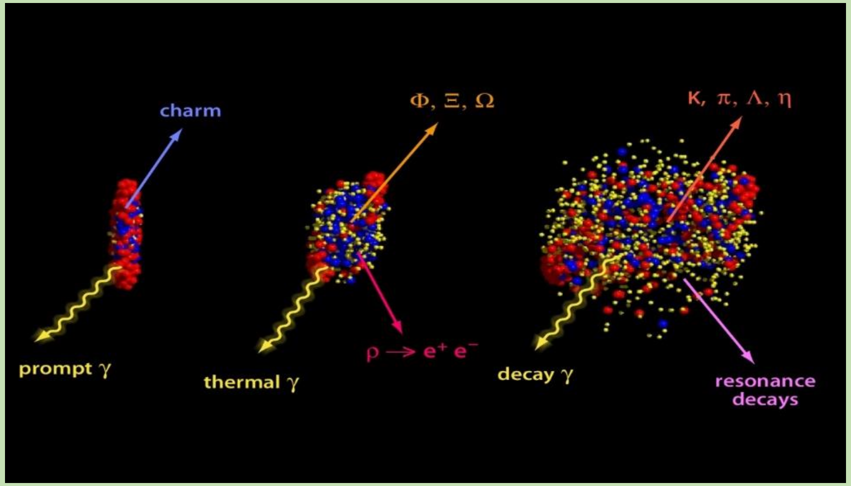
- Intriguing opportunity with metal microstrip target – never explored in earlier experiments !
- Might be very interesting phenomenon – what is the interaction energy of three nucleons (two from LHC beams and one from the fixed target) ?
- **What will be the Equation of State ?**
- **Which temperatures and densities of the hot matter part might be ?**

1.Introduction (continue)



The space time evolution
of the heavy ion collision.
QGP formation – high temperature/density
in A – A collision at the time of few fm/c

https://www.researchgate.net/profile/G_V_Margagliotti/publication/241771918/figure/fig4/AS:669528413446144@1536639421022/The-space-time-evolution-of-the-heavy-ion-collision-The-various-stages-of-the.ppm



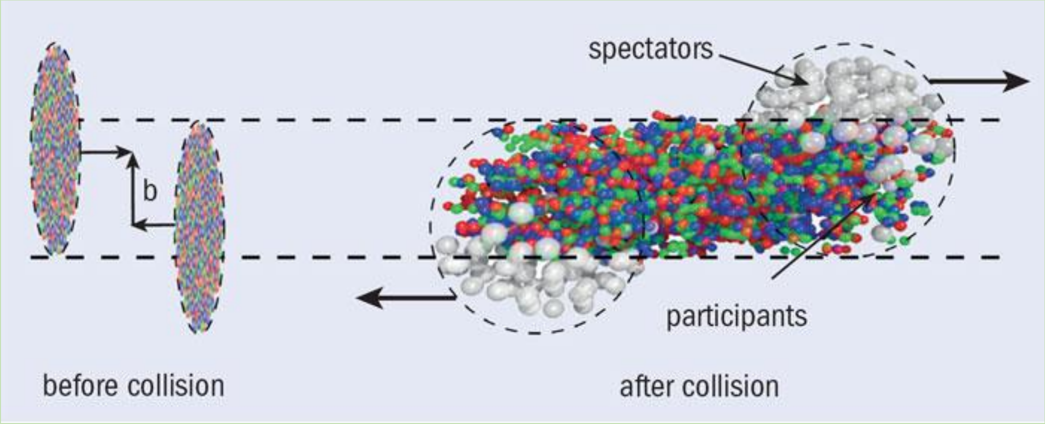
Signatures of the Quark Gluon Plasma

- **Direct photons from QGP -> T(QGP)**
  Differential cross-sections for quarkonia production:
- **Shape (p_T slopes), magnitude (suppression/enhancement)**
- **Hadronic mass spectra, width & branching fractions etc.**
- Multiquark states from QGP, Jet quenching
- Fluctuations near the critical point (<pT>, K/π etc)

One may establish definite tendencies

- **related to status of the expanding matter,**
- **depending on assumed equation of state (EOS).**

Multiplicity dependence of observables measured in p-p, p-Pb and Pb – Pb collisions



The highest multiplicity of event -a signature of the central collision – most probable condition for the 'ignition' of the QGP in the environment of the largest amount of participants

-Prompt production at the collision vertex

- **hot region, sea quarks and gluons ?)**

-from *b* hadrons, which travel several mm before decaying

- **cold region, vacuum).**

High-multiplicity p-p collisions provide a hadronic environment that approaches **heavy ion collisions**.

Observations:

- near-side ridge in two-particle angular correlations
- strangeness enhancement
- collective flow

Assumption:

high-multiplicity p-p collisions

- **a testing platform** for final-state effects **in pA collisions.**

Compare features of observables at high and low multiplicities (prompt and delayed events)

RESULTS (next slides) present:

- **multiplicity dependence of $\psi(2S)$ and $\chi_{c1}(3872)$**
- **low multiplicity –*J/ψ in* Pb-Pb UPC**