Studies of Hadrons Production in Nuclear Medium by LHCb.

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EMMI. GSI. Darmstadt. 22-June-2017.

Outline

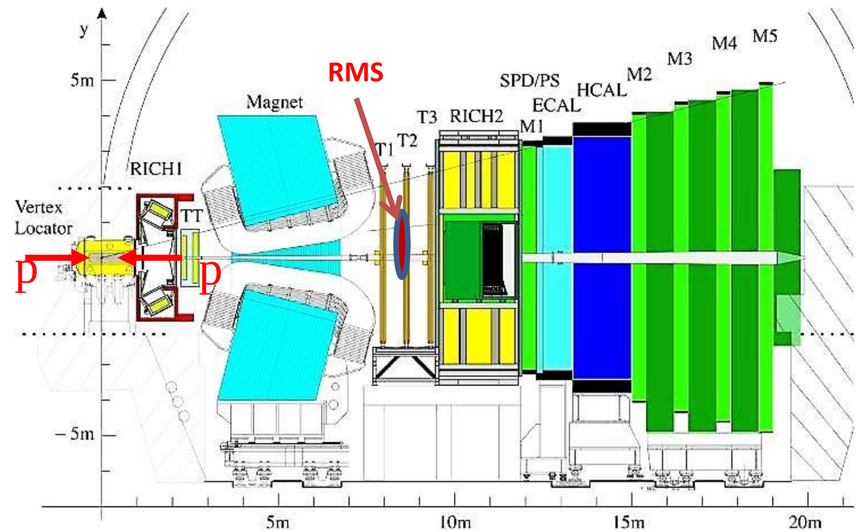
- Introduction
  - Searching for QGP signatures in hadron production
- Colliding mode studies (p-p and p – Pb) at the LHCb detector
  - Prompt non-prompt J/ψ
  - Prompt D^0
- Fixed target collisions
  - p – Ar, p- Ne, p- He
  - Extending range of nuclei and energies:
    - Physics and Techniques of the Multi-Target Setup in a halo of the LHC beam
- Summary and Outlook

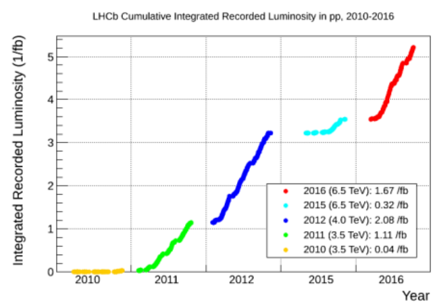
The LHCb experiment

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

The LHCb detector – forward spectrometer with excellent characterisitics for B-physics studies:

- Acceptance $2 < \eta < 5$
- Momentum resolution about 0.5 %
- Track reconstruction efficiency > 96 %
- 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 (ID efficiency > 90%)

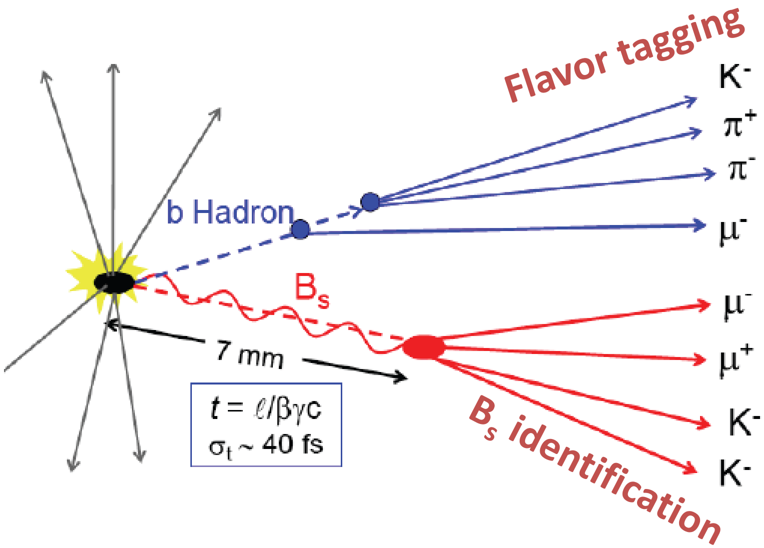




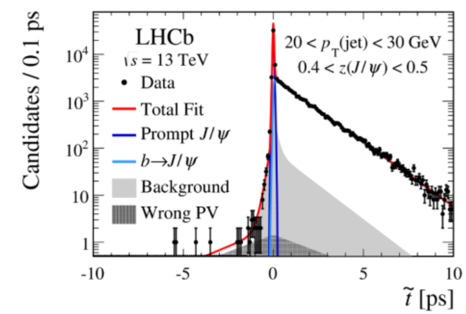
64 papers - 2016 year,
20 already in 2017 year,
+several conference reports.

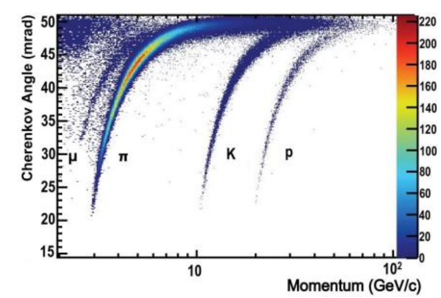
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

Beauty @ LHCb & of LHCb



VErtex Locator – the best vertex system

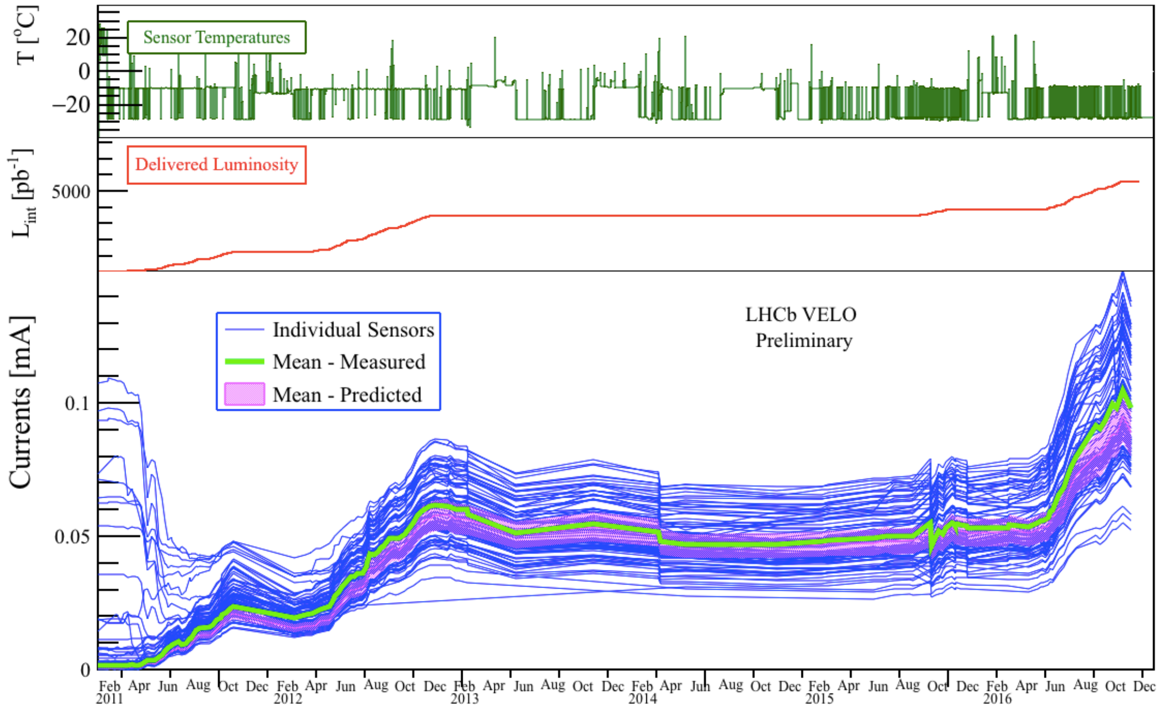




RICH system - PID

- **Efficient trigger selecting B-hadrons decay products**
- **Excellent separation of secondary vertex**
  - **study B_s oscillations with time bins of 40 fs.**
- **Background suppression:**
  - **high invariant mass-resolution (~14 MeV/c^2)**
  - **Perfect particles identification**
  - **Magnetic field flipping up-and-down**

Understanding of detector.
Long term reliable performance



Detector is ageing gracefully, and as expected.

e.g. leakage currents in VELO are tracking predictions remarkably well.

Guy Wilkinson. LHCb Spokesperson
LHCP 2017

Within the EMMI invitation for my visit to GSI/Uni-Tuebingen I hope to implement the above mentioned statement **'detector performs as expected'** into the Production Readiness Report for the CBM STS Silicon Microstrip Sensors.
The CBM STS team makes all the necessary studies also to be able to say after nearly 5 years of operation: "No need to install spare detector during run 2 (although we have one !). Rather monitor situation and gradually increase operating voltage."

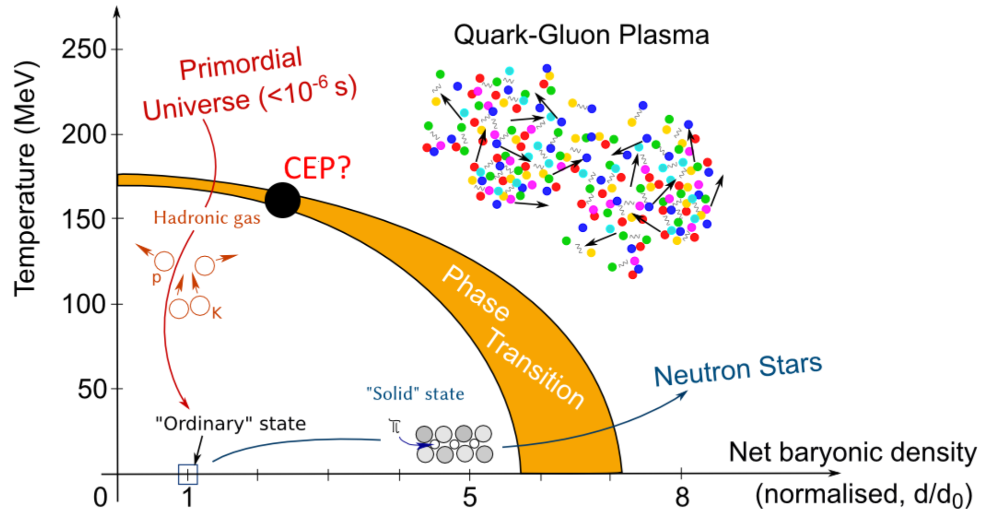
Searching for QGP signatures.

Impact of Nuclear Medium on quark – gluon processes

Known phenomena – still narrow portal to the world of quarks and gluons:

- Cronin effect
- EMC effect
- Chiral Magnetic Effect
- Parton Distribution Functions – are different in p-p and p-A, A-A interactions:
  - More data are required at low X and negative X_F for the theory progress
  - Differential Cross-sections for different probes (J/ψ, ψ(2S),strangeness)
    - ➢ as signatures of hot matter evolution

Development of new methods of data analysis – search for new observables, sensitive to hot nuclear matter properties (shifts and widening/narrowing of invariant mass distributions, change of relative contribution of quarkonium produced in cold and hot nuclear matter, …)



The phase diagram. © 2011 CERN – Antonin Maire)

Search for boundaries and critical point on the QCD phase diagram :

- Requires energy as well nuclear species scan

➢Nuclear Modification Factor measurements

Observables sensitive to nuclear medium effects

- **Spectrum modification** (from hot to warm and cold matter) – measuring relative contribution of quarkonia production at different states (1S, 2S, 3S, …) , resonance position, width, etc.,
- **Differential cross-sections (p_T and rapidity distributons):**
  - **absolute values**
  - **nuclear modification factors**
  - **forward-backward asymmetry**
  - **Eliptic flow**

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

$$R_\mathrm{FB}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}}) \equiv \frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(+|y^*|, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/(\mathrm{d}y^* \mathrm{d}p_\mathrm{T})}{\mathrm{d}\sigma_{p\mathrm{Pb}}(-|y^*|, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/(\mathrm{d}y^* \mathrm{d}p_\mathrm{T})}$$

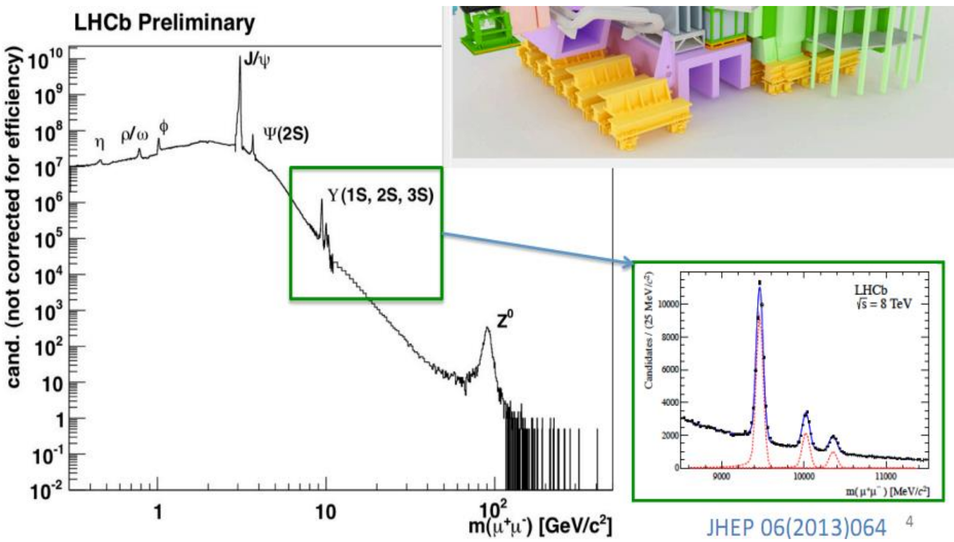
- ➢ **compared to theory predictions (dependent on pdfs, nuclear medium impact, etc.,)**

e.g. **A. Andronic, P Braun-Munzinger, K Redlich, and J Stachel** Hadron yields, the chemical freeze-out and the QCD phase diagram. arXiv:1611.01347v2 [nucl-th] 9 Nov 2016

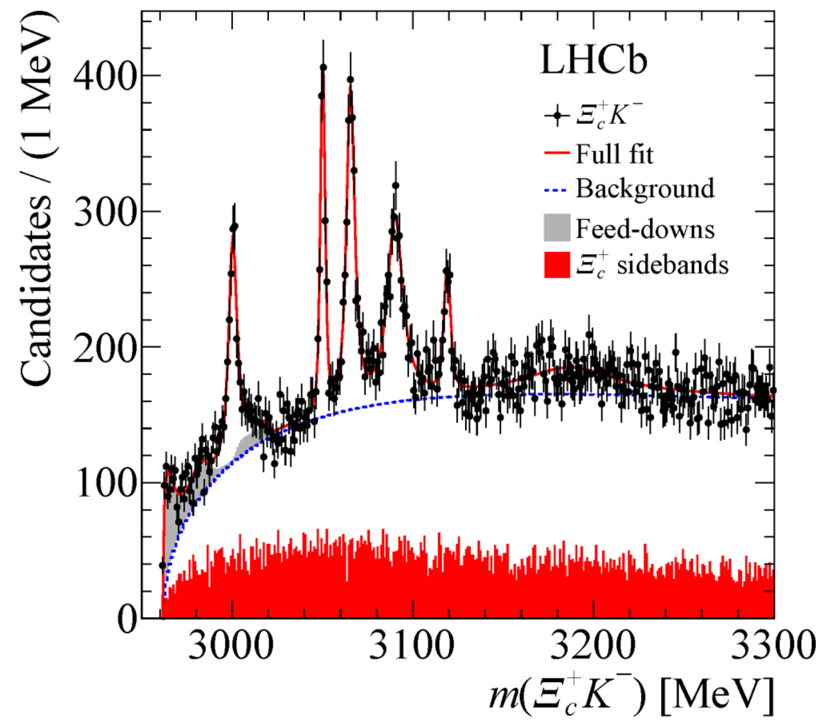
Beauty @ LHCb & of LHCb. LHCb Spectroscopy
p-p collsions

Spectroscopy is a perfect tool for searching “NEW”.

[arXiv:1703.04649]



JHEP 06(2013)064

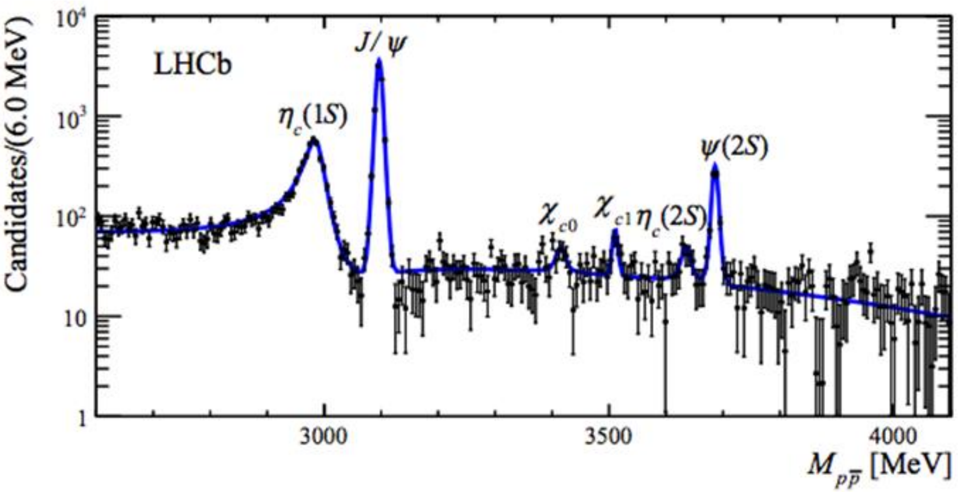


All u-, d-, s-, c-, b-hadron species (but top-quark containing) were identified and studied, in details.

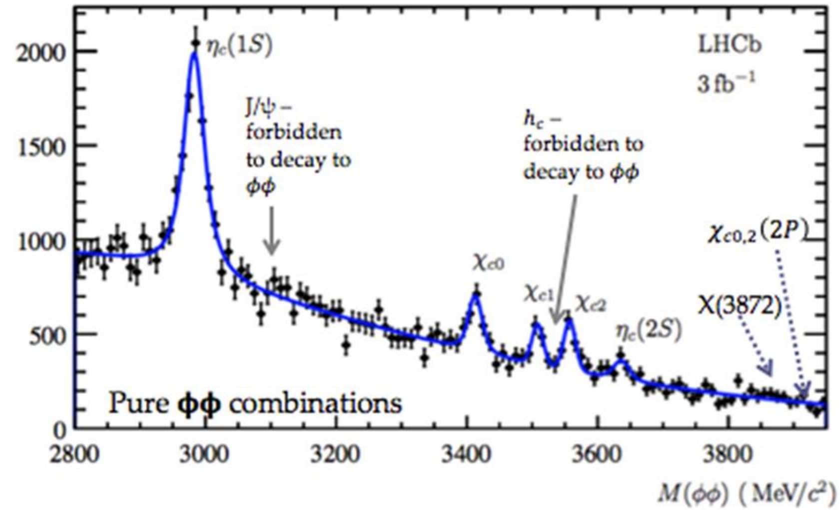
Recently, new narrow states found in the Ξ_c^+ K^- spectrum → excited Ω_c^0 baryons.

Charmonia production in b-hadron decays.
p –p collisions

$B^+ \to (\eta_c(1S) \to p\bar{p})K^+$
PLB 769 (2017) 305

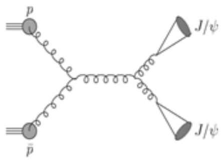


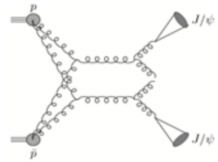
LHCb-PAPER-2017-007



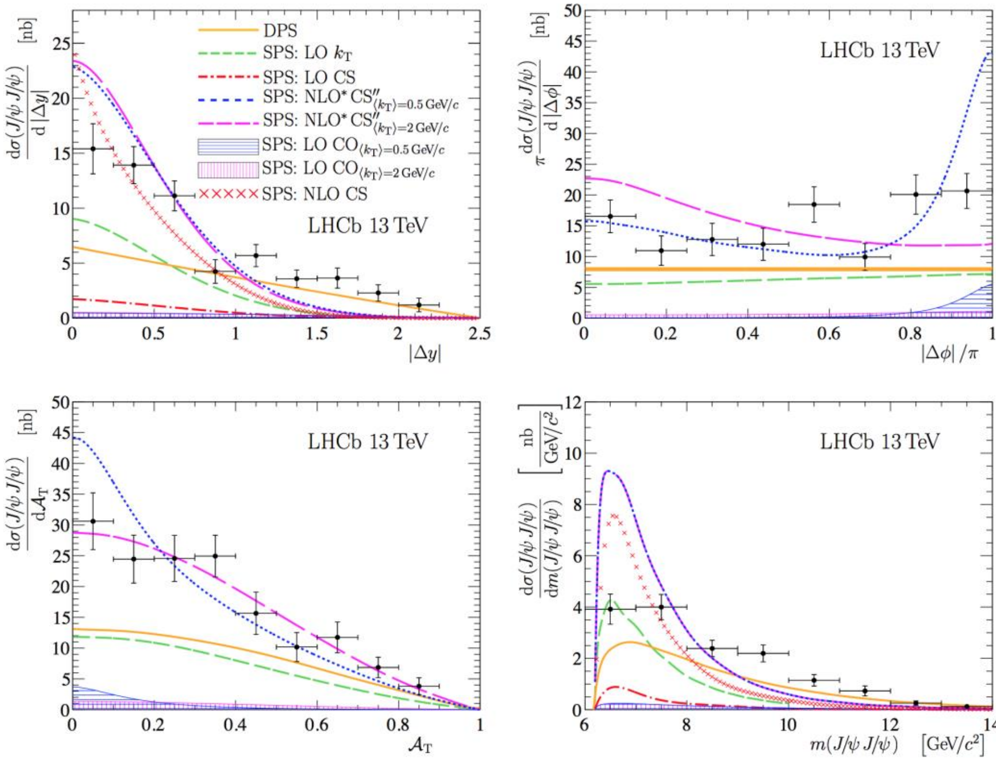
Rich spectra for comparison data with p-A and A-A collisions: "from hot to lower temperature of medium".

Double prompt J/Psi production
p –p collisions





JHEP 06 (2017) 047



Large DPS contributions:
measured σ_{eff} = 10 – 12.5 mb
larger than those from other experiments

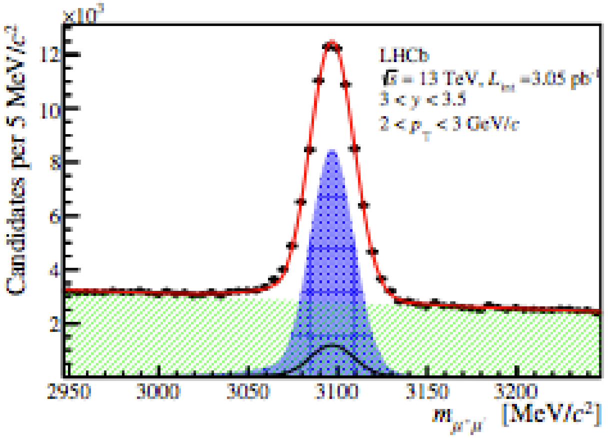
Measurement of Y+D suggests large (~10 %) contribution of DPS
(**Y+ D** production associated [JHEP 07 (2016) 052)

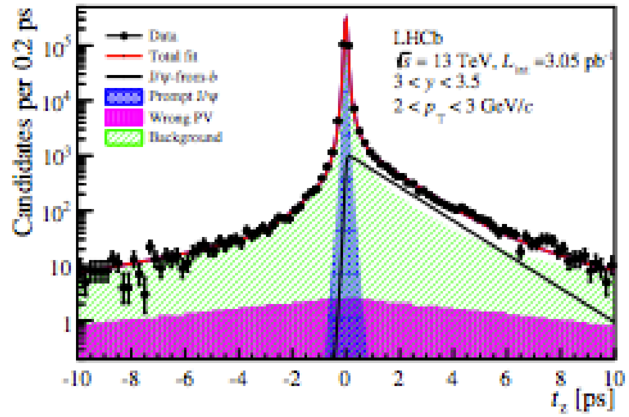
LHCb double J/Psi measurement requires strong contribution of DPS

Plans to see DPS in heavy ion collisions:
expected to be enhanced

J/ψ (1S, 2S) production
p-p collisions (prompt and from b-decays)

LHCb provides perfect separation of prompt J/ψ and J/ψ from b-decays





$$t_z = \frac{(z_{SV} - z_{PV}) \times M_{J/\psi}}{p_z}$$

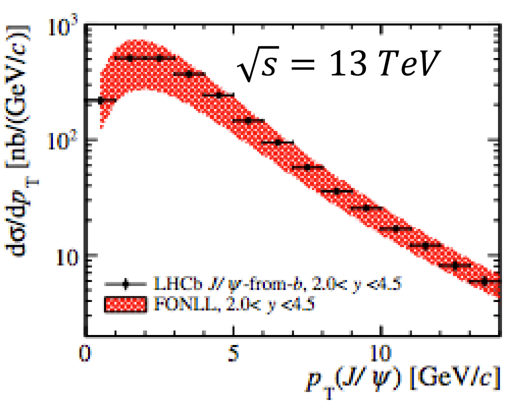
FONLL: arXiv:1507.06197

FONLL –

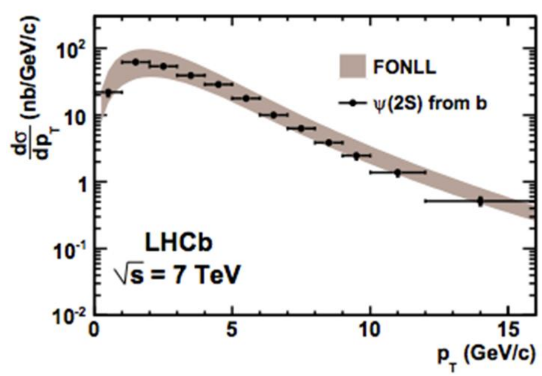
FO- fixed-order approach,

NLL -next-to-leading logarithmic terms

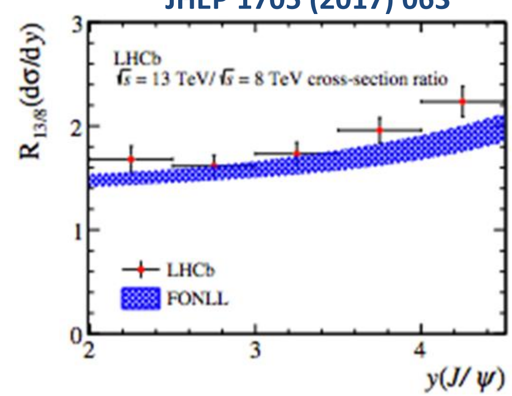
Cross-sections are well approximated by NRQCD FONLL theory:



Eur.Phys.J.C72 (2012) 2100



JHEP 1705 (2017) 063

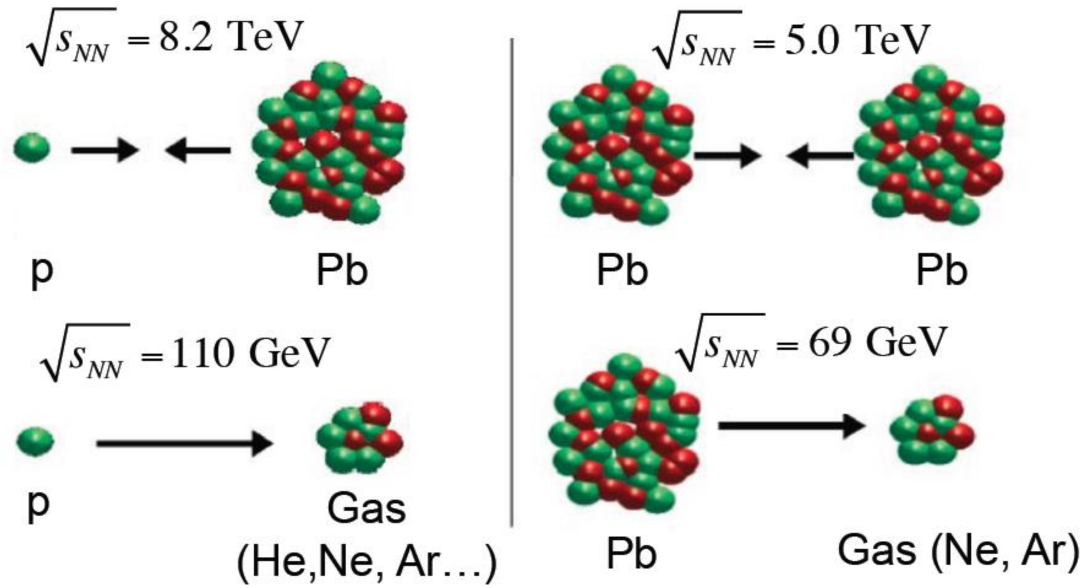


- the absolute scale of the cross-section
- the increase in cross-section due to the increase in √s

Heavy ion collisions studied by the LHCb detector

Collider mode

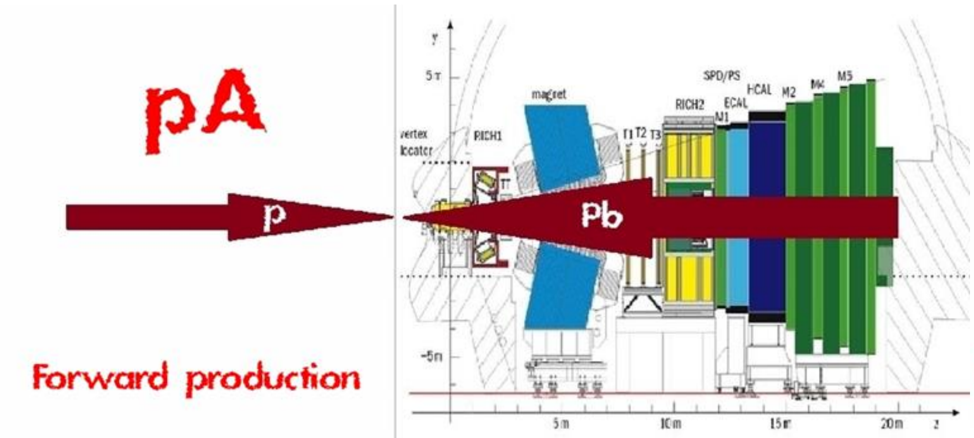
Fixed target mode

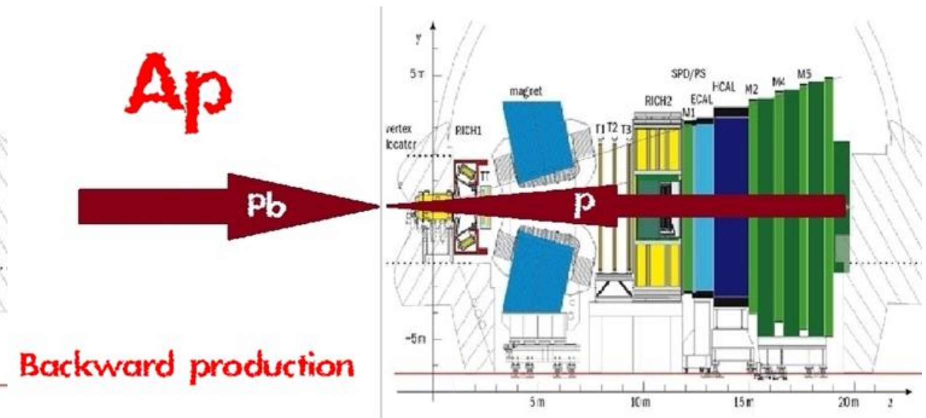


On the way to QGP signatures:

- **Study collisions at various center-of-mass energies**
- **Explore different beam-target systems**
- **Compare results with pp collisions**

Heavy ion collisions at the LHCb experiment. Collider mode.





p-Pb: 1.5 < y < 4.0

Pb–p: -5.0 < y < -2.5

Compare quarkonium production in pp and p-Pb collisions
To develop methods of quark-gluon-plasma identification

- To clarify possible ‘cold’ nuclear effects (parton shadowing, energy loss in nuclear medium, etc.,)
- To disentangle shadowing and energy loss by measuring prompt and non-prompt charmonium

Physics highlights from the LHCb experiment.
M. Schmelling, EMMI, July 22, 2015

Nuclear modification factors

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

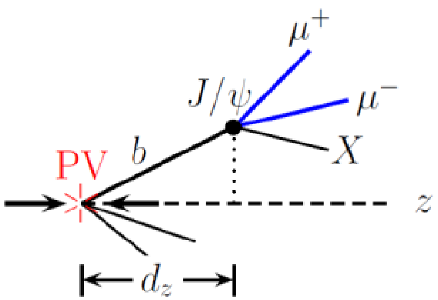
Comparison of p-pB and p-p data for prompt and non-prompt hadron production:

- **Expectation: production of J/ψ from B -mesons is less affected than prompt J/ψ**

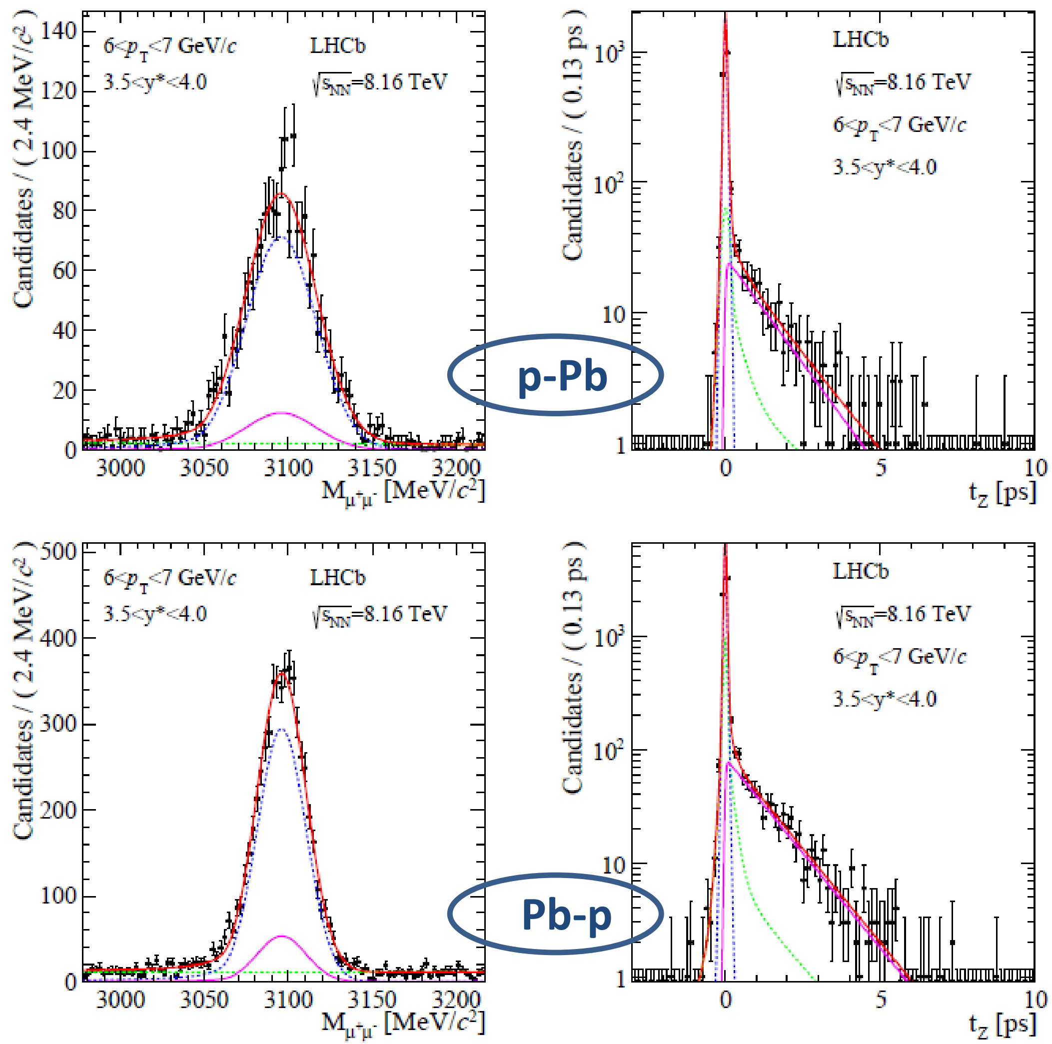
- energy loss and shadowing

(J/ψ data agree with “energy loss + NLO shadowing”)

J/ψ (prompt and non-prompt) production cross-sections.
p-Pb (Pb-p) collisions

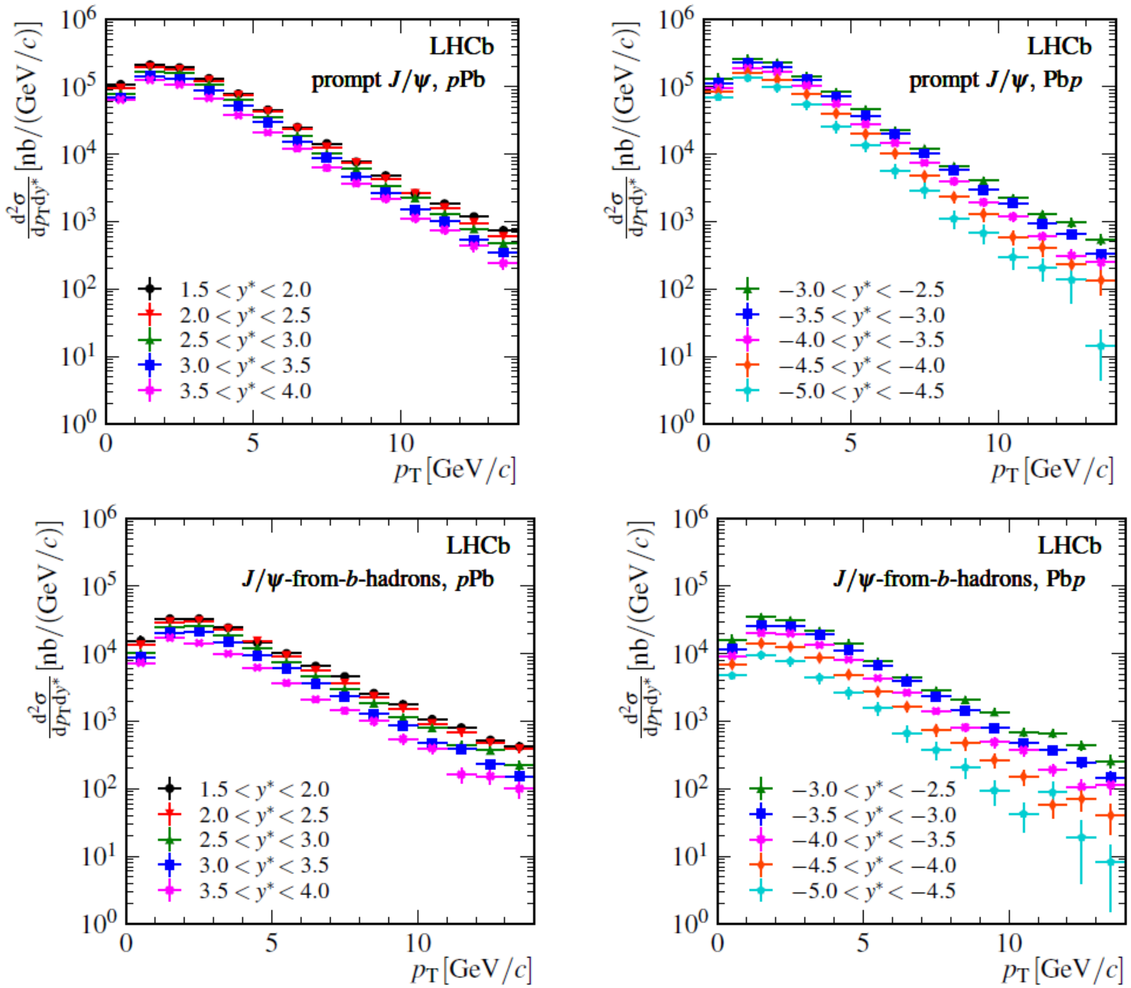


$$t_z = \frac{(z_{SV} - z_{PV}) \times M_{J/\psi}}{p_z}$$



[LHCb-PAPER-2017-014]

J/ψ production cross-sections p-Pb collisions

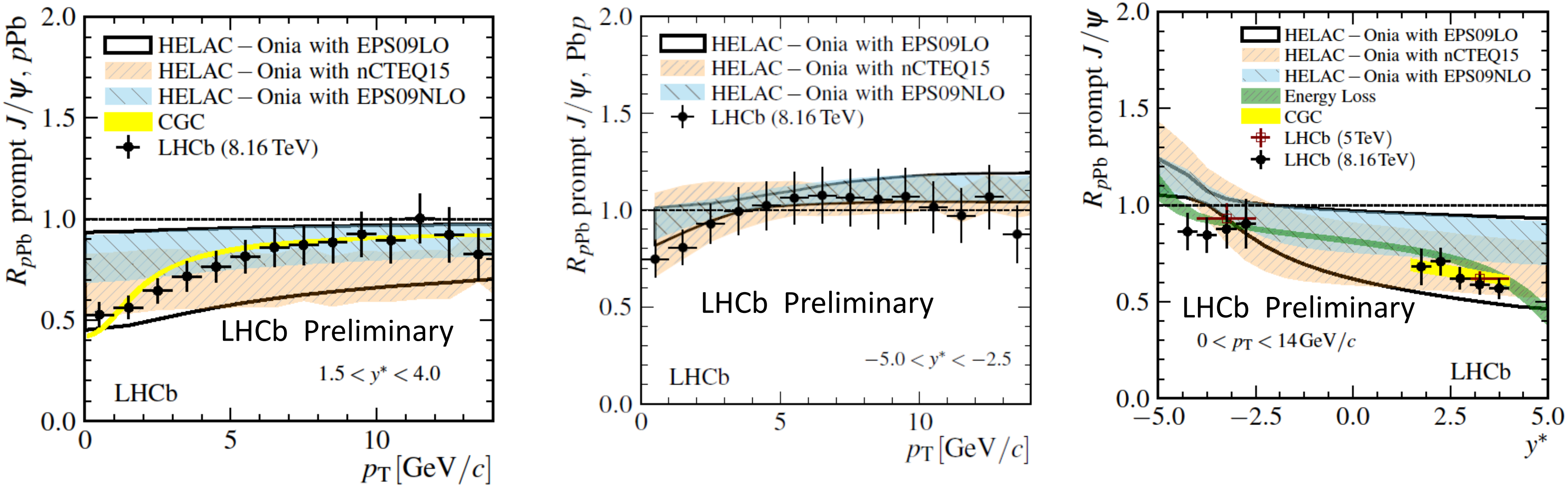


Prompt J/ψ production cross-section in pPb (Pbp) In different rapidity ranges

Non-prompt J/ψ production

J/ψ (prompt) nuclear modification factor.
p-Pb, Pb-p collisions

[LHCb-PAPER-2017-014]



~ High suppression at low p_T (not measured by other LHC experiments) ,
approaching unity at high p_T

Overall agreement with models (some have large uncertainties):

Collinear factorization: nuclear PDF [Comp. Phys. Com. 184 (2013) 2562 & 198 (2016) 238

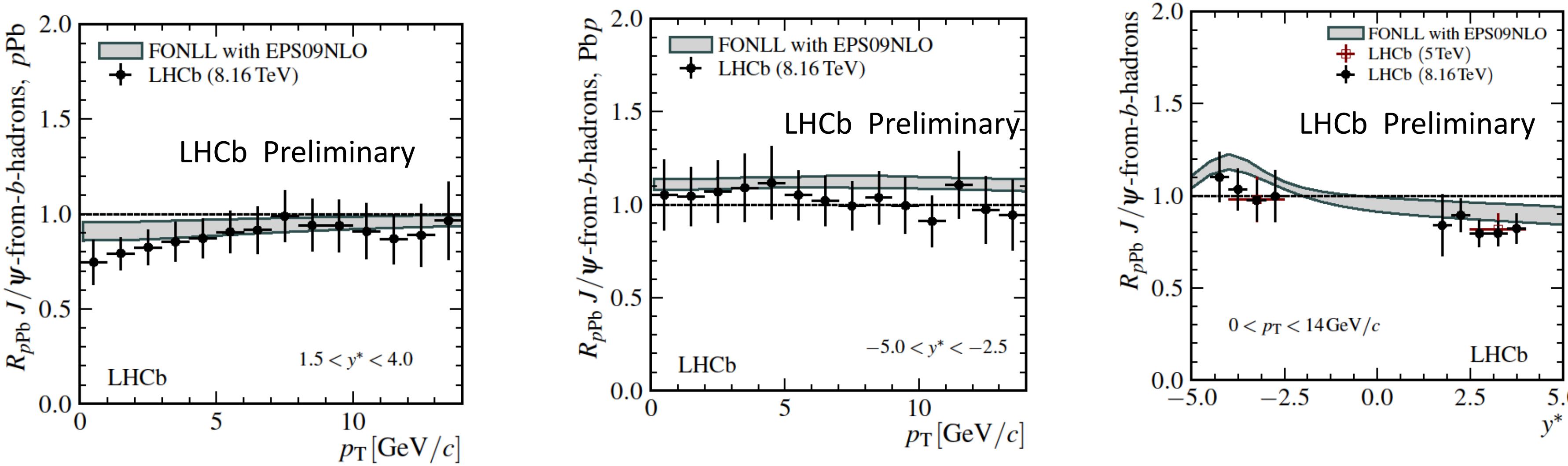
Color Glass Condensate [Phys. Rev D91 (2015) 114005 ; Phys. Rev D94 (2016) 074031]

Coherent energy loss [JHEP 03 (2013) 122]

Results at 8.2 TeV are compatible with LHCb results at 5 TeV [JHEP 02 (2014) 072]

- No strong dependence on the energy of colliding beams.

J/ψ (from b-mesons) nuclear modification factor.
p-Pb, Pb-p collisions



p-Pb collisions: Suppression of $R_{p\text{-}Pb}$ at low p_T)**less pronounced than for 'prompt' case**, moving to ~1 at high p_T

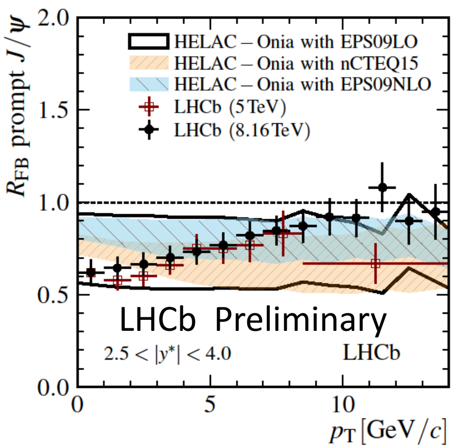
Pb-p collisions: **$R_{Pb\text{-}p}$ - ~1, no p_T dependence**

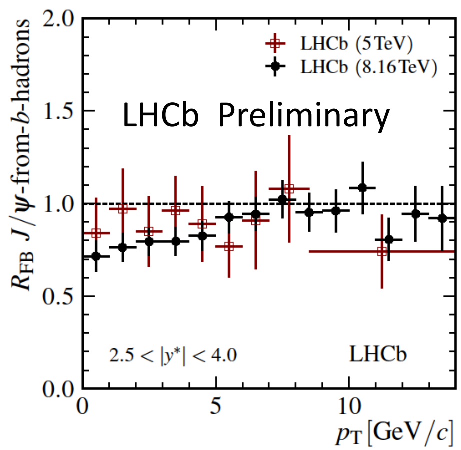
Agreement with FONLL (nPDF) [JHEP 04 (2009) 065]

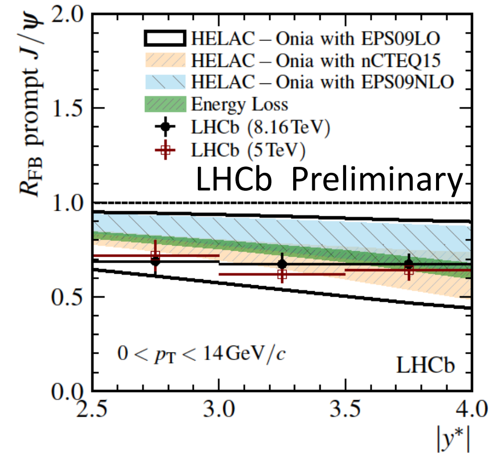
Results are compatible with LHCb results at 5 TeV [JHEP 02 (2014) 072]

(Now - much higher precision)

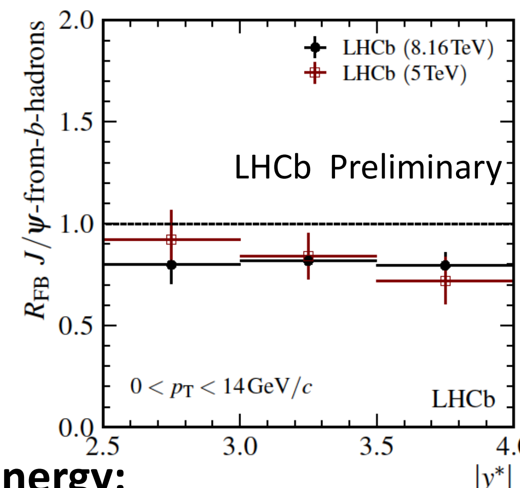
J/ψ FWD:BWD asymmetry.
Prompt and non-prompt production







Well pronounced forward-backward asymmetry for prompt J/ψ at low p_T;



for J/ψ from b: R_{FB} -> ~ 1.

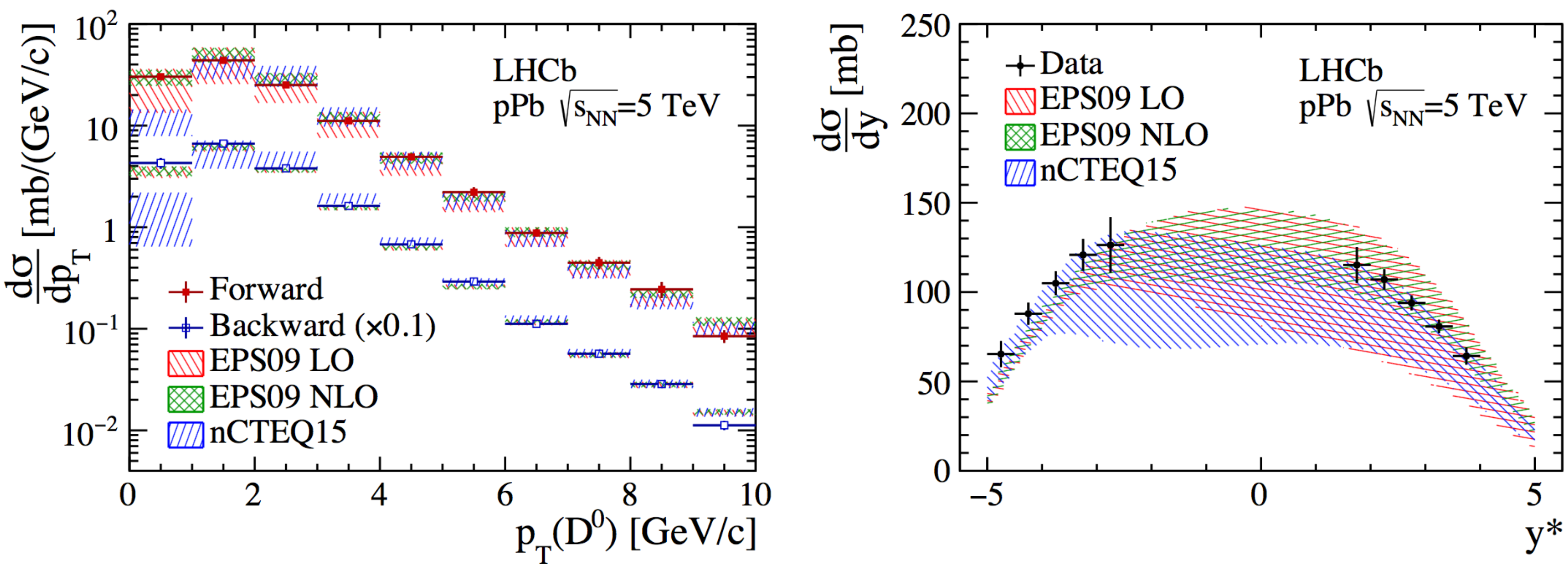
Theoretical calculations are available for prompt J/ψ, only.

Burkhard Schmidt
LHCP May 15 - 20, 2017, Shanghai

No dependence on the energy:
The 5 and 8.2 TeV data are close to each other

D^0 PRODUCTION CROSS-SECTIONS

D0 -> $K^- \pi^+$ + CC [LHCb-PAPER-2017-015]



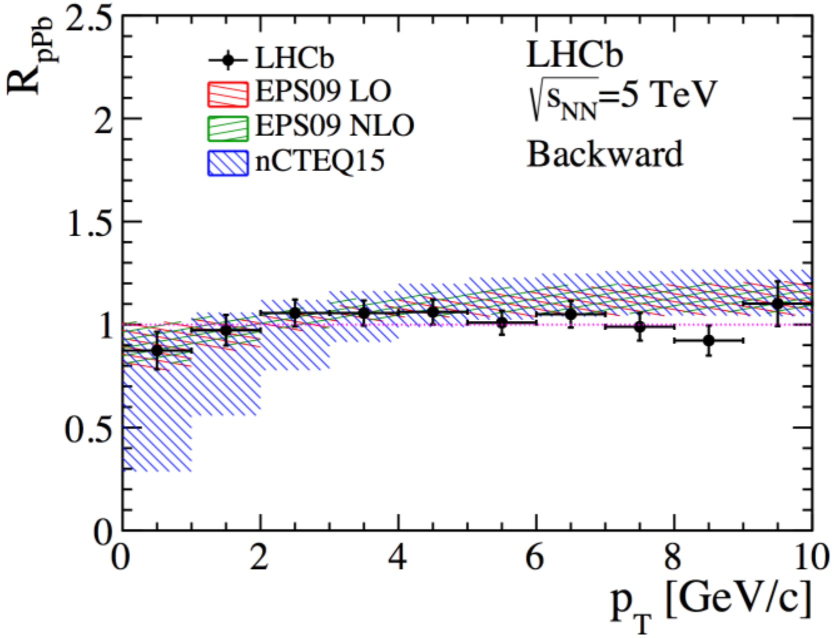
Results compared with calculations using nuclear parton distribution functions (nPDF)

EPS09LO, EPS09NLO and nCTEQ15 [EPJC 77 (2017), Comp. Phys. Com. 198 (2016), Comp. Phys. Com. 184 (2013)]

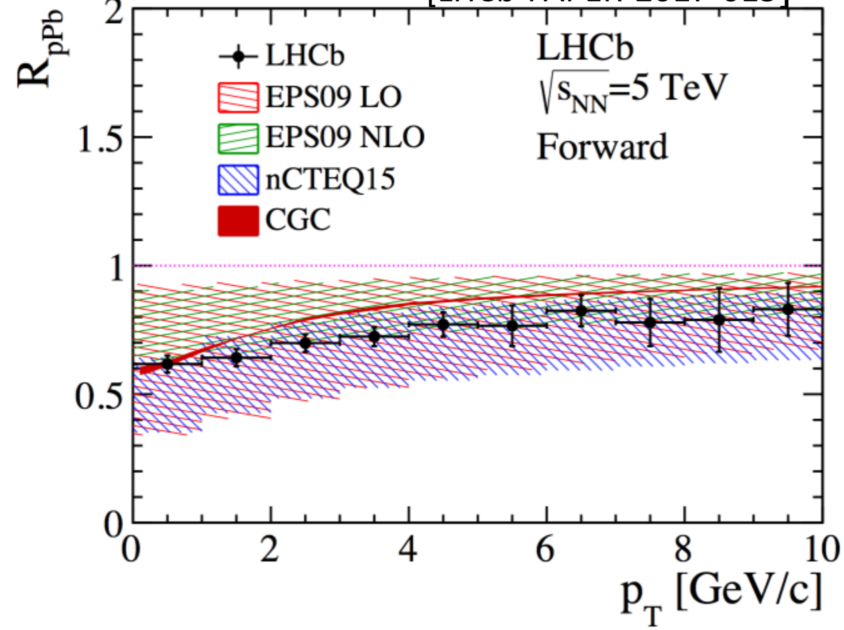
Good agreement.

nCTEQ15 underestimates values at low p_T and negative y*

D^0 (prompt) nuclear modification factor.
p-Pb, Pb-p collisions



[LHCb-PAPER-2017-015]



No strong p_T dependence of R_{pPb} in BWD region

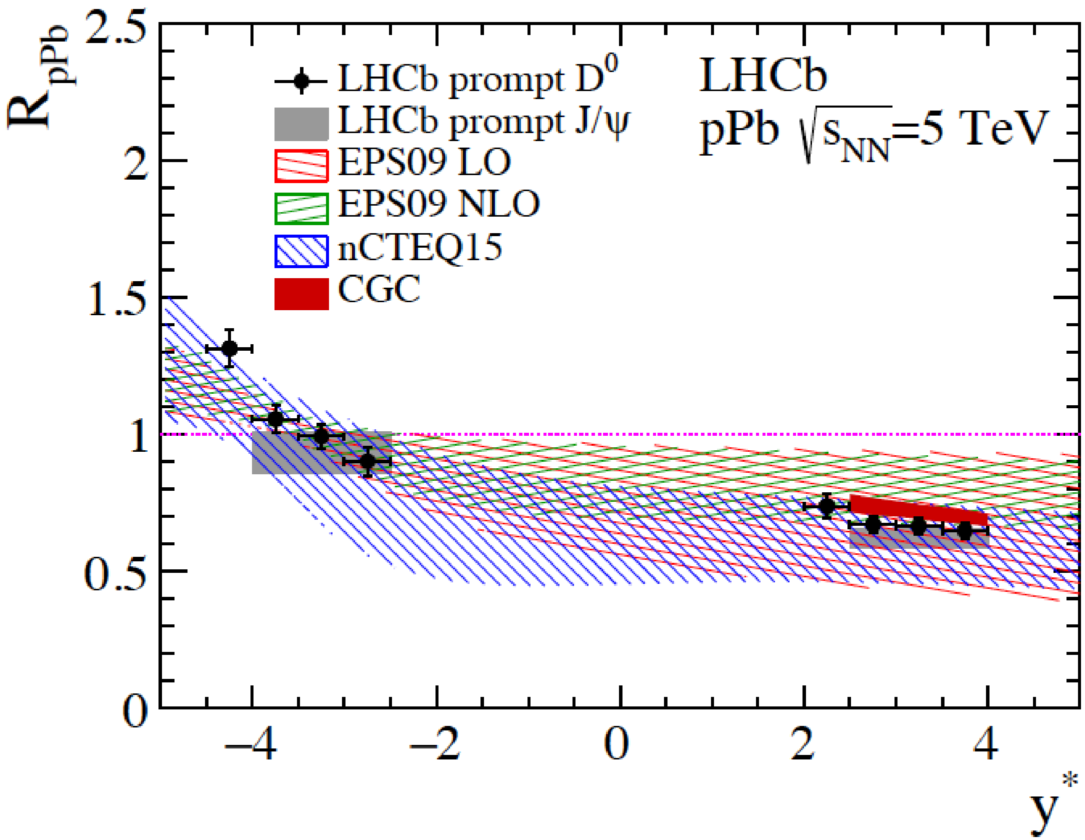
R_{pPb} is strongly suppressed at low p_T grows up with p_T for FWD region,

Measurements are consistent with predictions using nPDFs or CGC framework

[EPJC 77 (2017), Comp. Phys. Com. 198 (2016), Comp. Phys. Com. 184 (2013)]

In general: NMF tendencies (R_{pPb}) for prompt D^0 are similar to those of prompt J/ψ

D^0 (prompt) nuclear modification factor.
p-Pb, Pb-p collisions
(rapidity dependence)



LHCb-PAPER-2017-015

Theory space constrained

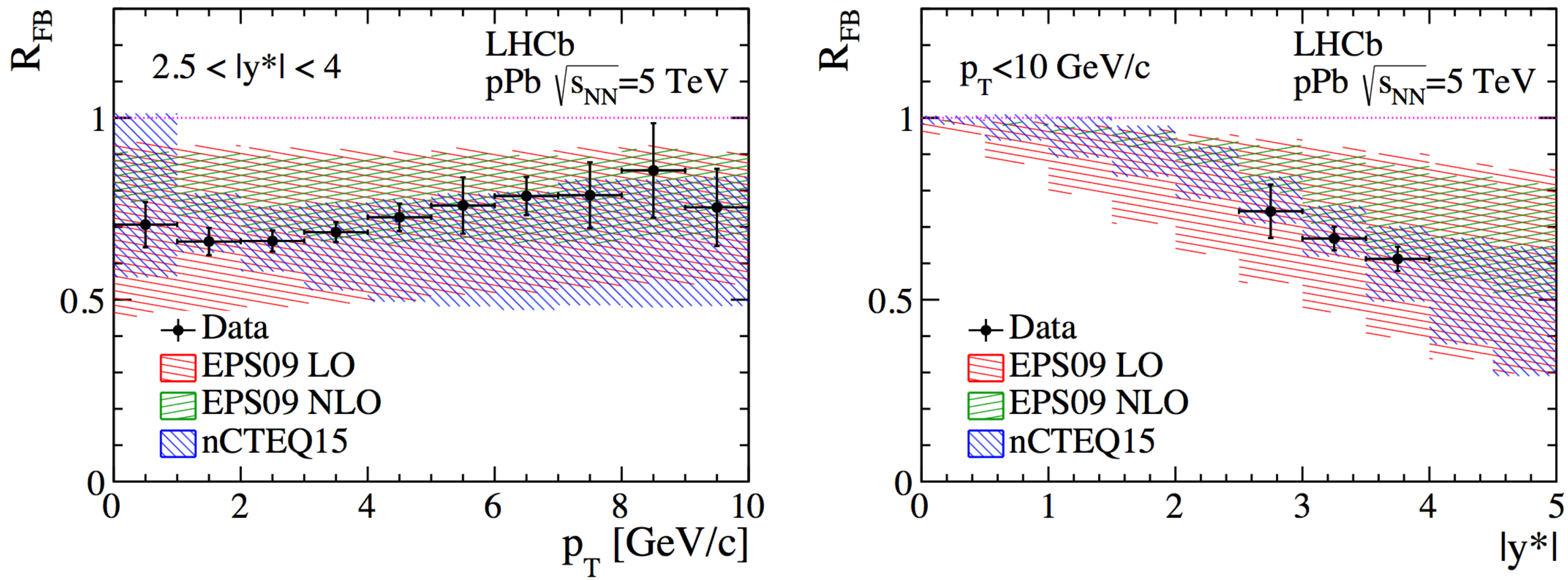
- Small excess in backward rapidity

- **NMF tendencies for D^0 are similar to R_{pPb} for J/ψ**

D^0 (prompt) FWD:BWD asymmetry.

$$R_{FB}(y^*, p_T, \sqrt{s_{NN}}) \equiv \frac{d\sigma_{pPb}(+|y^*|, p_T, \sqrt{s_{NN}})/(dy^* dp_T)}{d\sigma_{pPb}(-|y^*|, p_T, \sqrt{s_{NN}})/(dy^* dp_T)}$$

Part of experimental and theoretical uncertainties cancel



R_{FB} is strongly suppressed at low p_T (slightly increasing with p_T and decreasing with $|y^*|$)

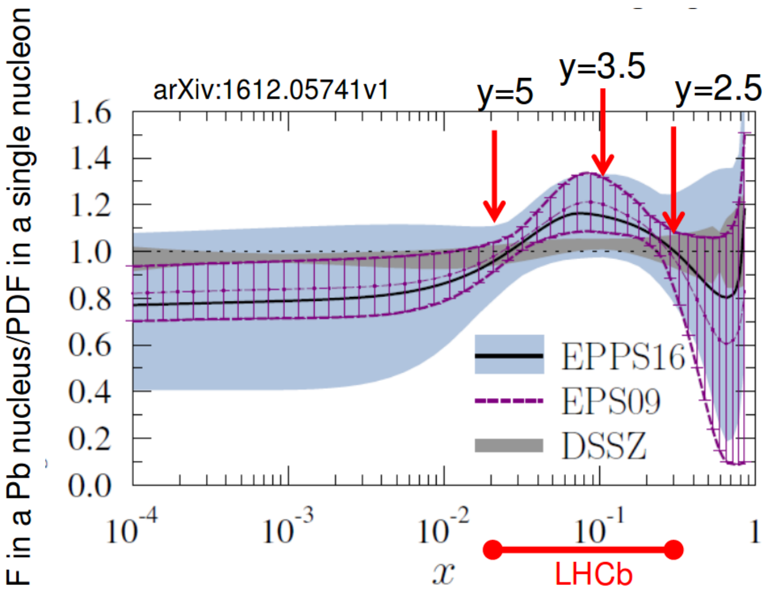
Measurements are consistent with calculations (large uncertainties) using nPDFs.

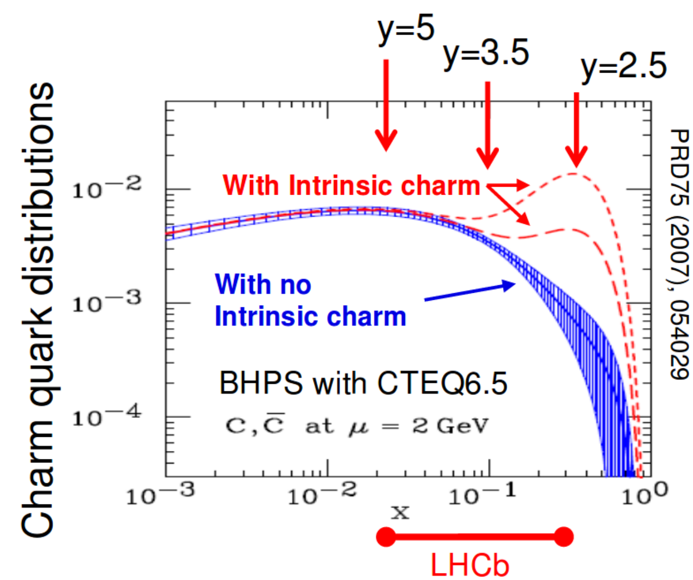
Fixed-target heavy ion physics at LHCb

Motivation to perform fixed-target heavy ion physics at LHCb:

Access to intrinsic charm content

Access to nPDF in anti-shadowing region in the nucleon





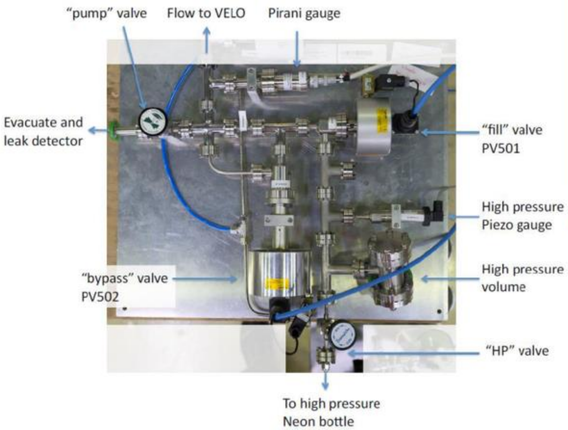
Bjorken-x = fraction of the nucleon momentum carried by a parton

Forward measurement of hidden and open charm production (J/ψ, D_0 …) down to low p_T

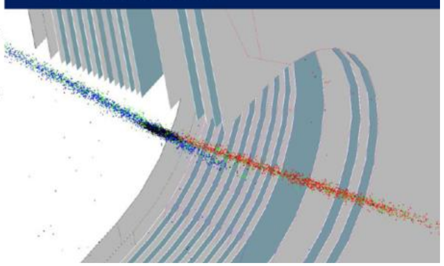
Large rapidity coverage at large Bjorken-x

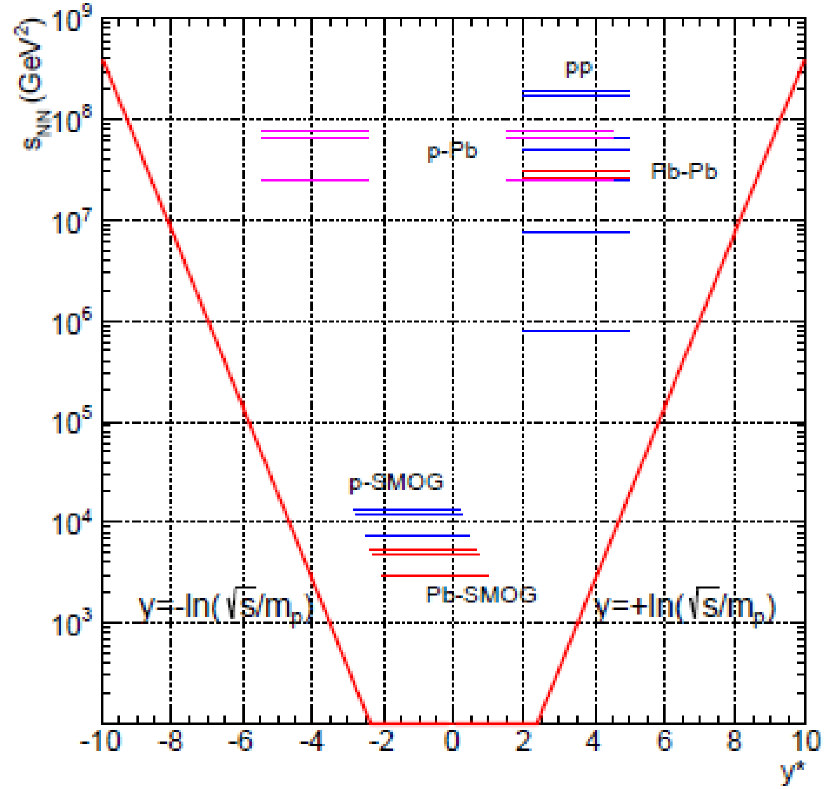
Heavy ion collisions at the LHCb experiment. Fixed Target mode.

LHCb is the only experiment at the LHC running in fixed-target mode, making use of unique gas-injection SMOG system.



- injection of (Ne) gas into interaction region
- very simple robust system
- used for a precise luminosity determination





Gas – He, Ne, Ar. JINST 9 (2014) P12005

p-gas and Pb-gas interactions at the NN-cms energy of 70 - 110 GeV (-3.0 <y*<1.0)

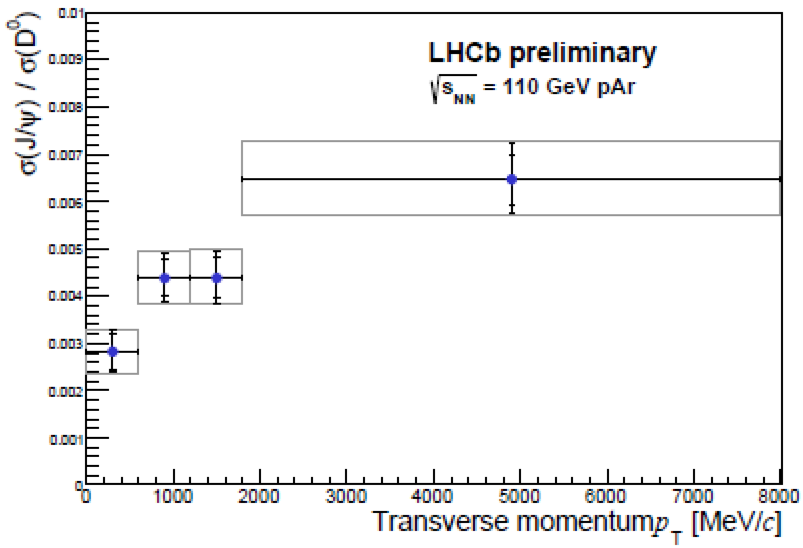
Bridging the gap between the SPS and RHIC/LHC energy scales

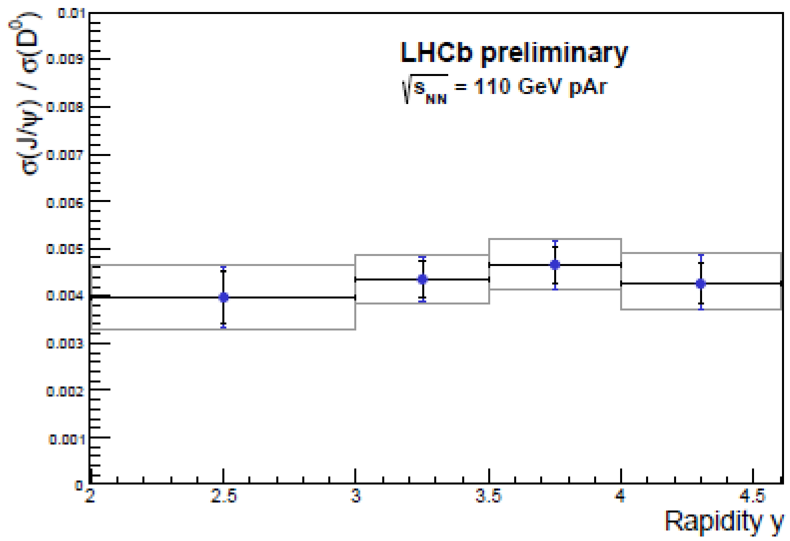
Fixed Target mode.

p+Ar: Ratio of production cross-sections

J/ψ / D^0

[LHCb-CONF-2017-001]





Preliminary results :

- No relative dependence of production mechanism in explored rapidity range
- Increase towards higher transverse momenta

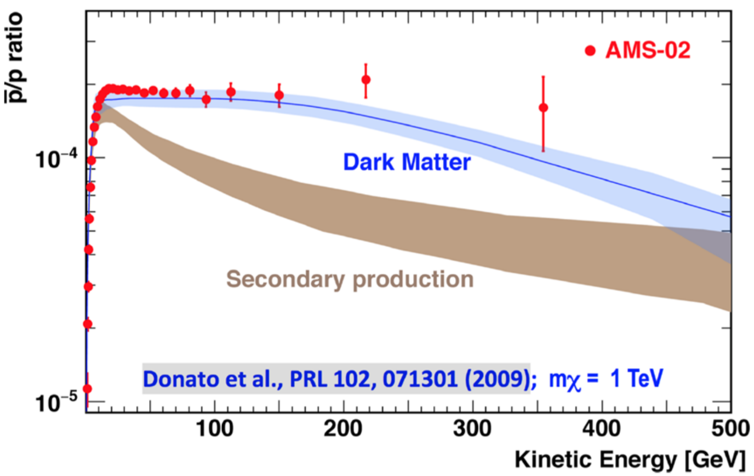
Theoretical calculations are welcome!

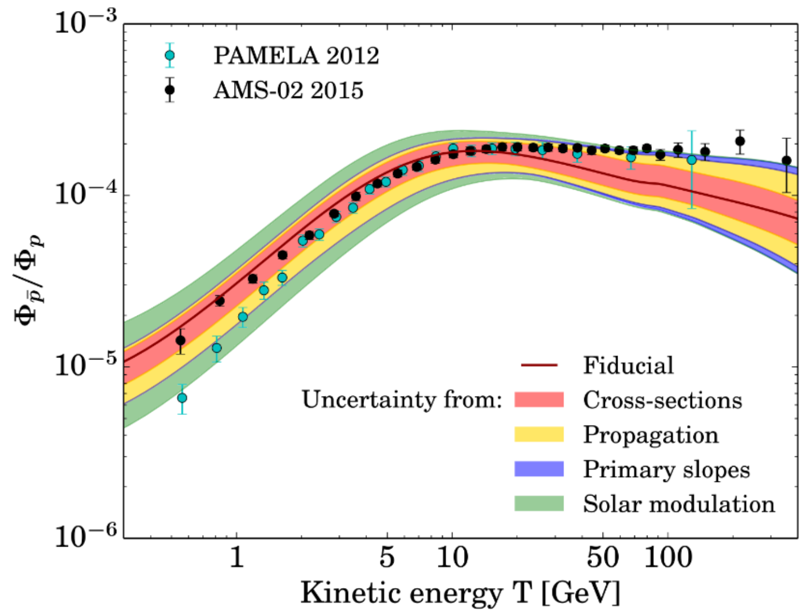
Fixed Target mode.

p + He: cosmic ray physics and cosmology

Studies of anti-protons in space have shown an excess which might originate from annihilating dark matter.

AMS $\bar{p}/p$ results and modeling





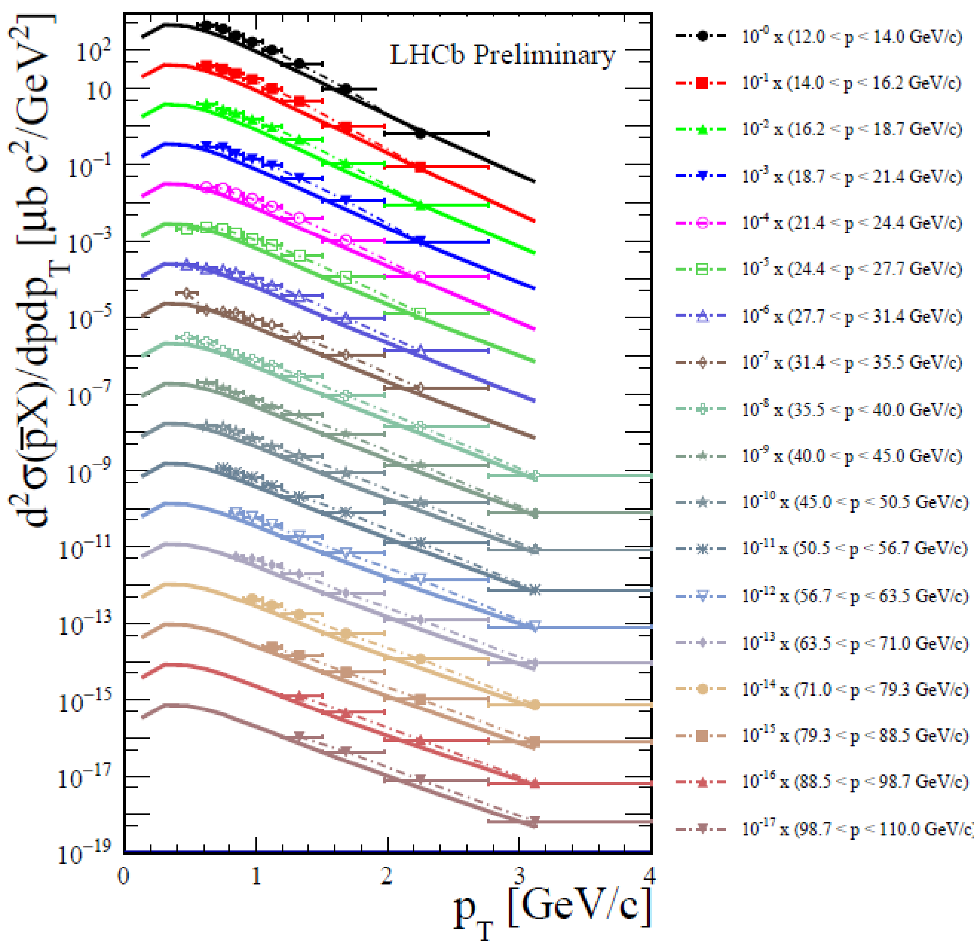
Uncertainties from SM background coming from cosmic ray collisions are large.

→ Need to measure cross-sections better.

Fixed Target mode.

p + He: (anti-proton production)

LHCb-CONF-2017-002



$\sqrt{s}_{NN}$ = 110 GeV

Prompt production
EPOS-LHC: data/MC ~ 1.5
Plans to also measure anti-protons from strangeness decays

Total inelastic cross-section:
σ_{inel} = (140±10) mb

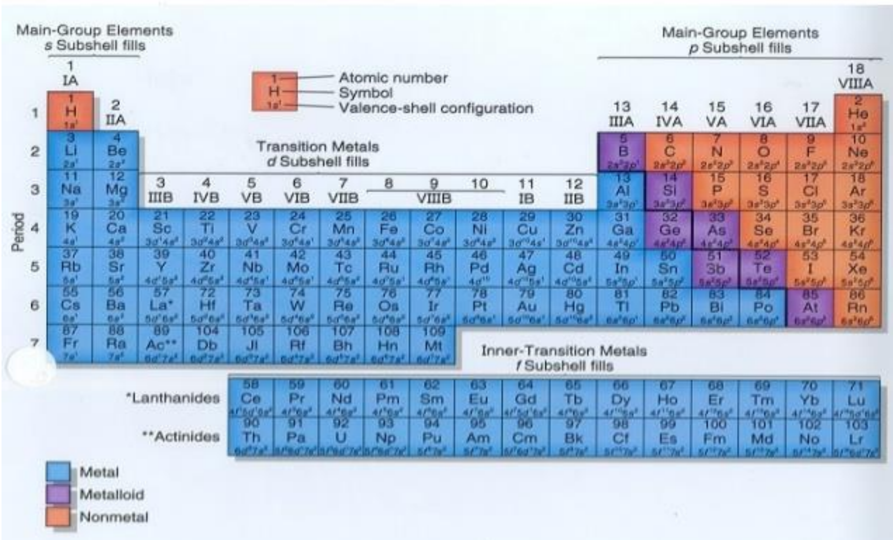
EPOS LHC: 118 mb
[Phys. Rev C92 (2015), 034906]
Ratio 1.19 ±0.08

Momentum spectrum in good agreement with simulation EPOS LHC

Extending range of nuclei and energies for heavy ions collisions at LHC

(proposal for Multi-Target setup in a halo of LHC beam)

Metals, Nonmetals, Metalloids



Nucleus-nucleus collisions studied in HEP:

p-p ; p – Pb; p –Au; p – Ne; p – He; d – Au;

Pb – Pb; …

Large, yet limited range for knowledge about an impact of the initial state on nucleus-nucleus collisions

Immense variety of metal targets-nuclei (BLUE color in the table):

^{6,7}Li (1^+, $3/2^-$); ^{9}Be ($3/2^-$); ^{12,13}C ($1/2^-$, 0^+); ^{27}Al ($5/2^+$); $^{46-50}$Ti (0^+ - $7/2^-$); ^{56}Fe (0^+); ^{63,65}Cu ($3/2^-$); ^{116,117,118,119,120}Sn(0^+) … up to ^{252}Cf

Different ground state properties:

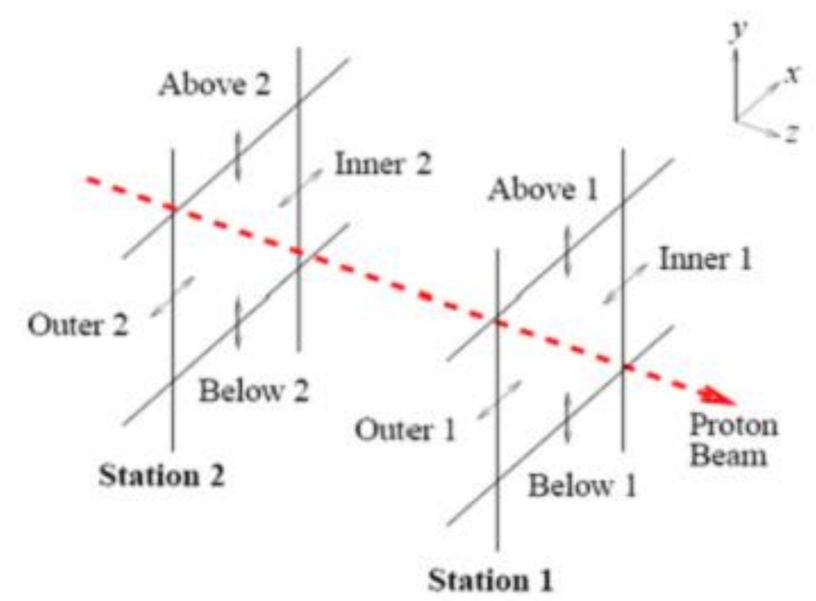
- Isotopes
- Spin and parity
- Deformation
- Closed shells (magic nuclei)
- Neutron skin
- …

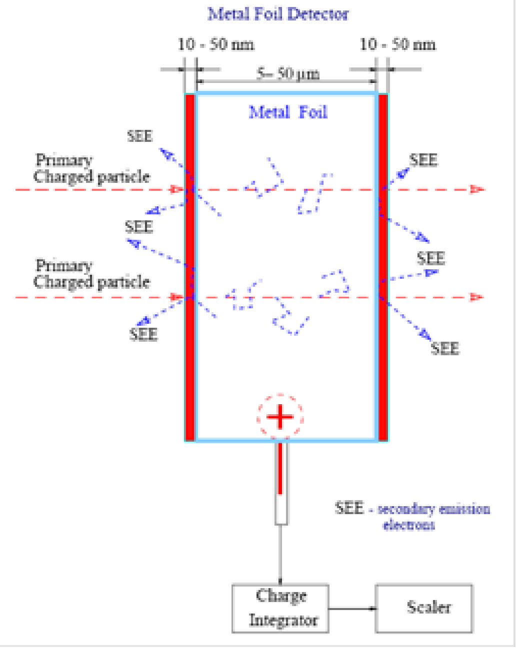
Motivation for Metal Targets in a Halo of the LHC Beam

- **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 cms)**
- **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**
    - **p_T broadening**
    - **Crystall lattice effects**
- **Multi-target setup: Physics data from N interaction points**
  - – **(N metal targets in LHC beam, simultaneously.**

Techniques of Multi-Target setup.
HERA-B experience, p-A scattering, p- 920 GeV – 40.6 GeV - cms)

Principle: **Metal** **wire-targets move in/out of the proton beam halo – to provide Interaction rate (luminosity) equally distributed among the targets.**



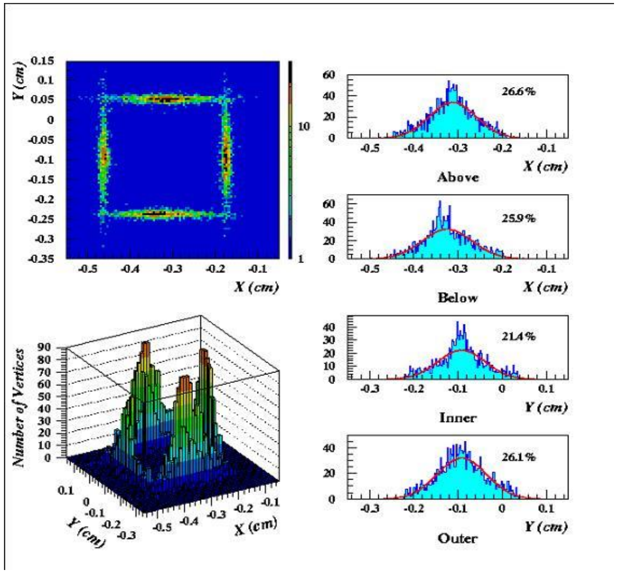


Luminosity Equalization: Target – Metal Detector

Steering of the target position
by the charge generated in it due to SEE
initiated by the incident proton beam

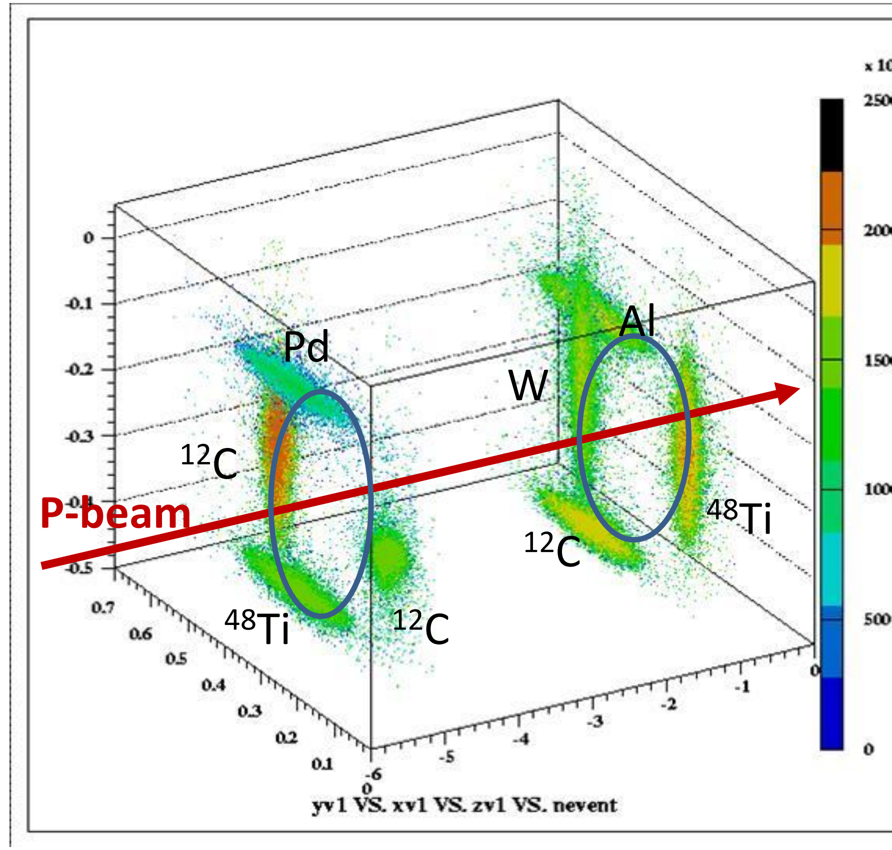
Equalization of the luminosities

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



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

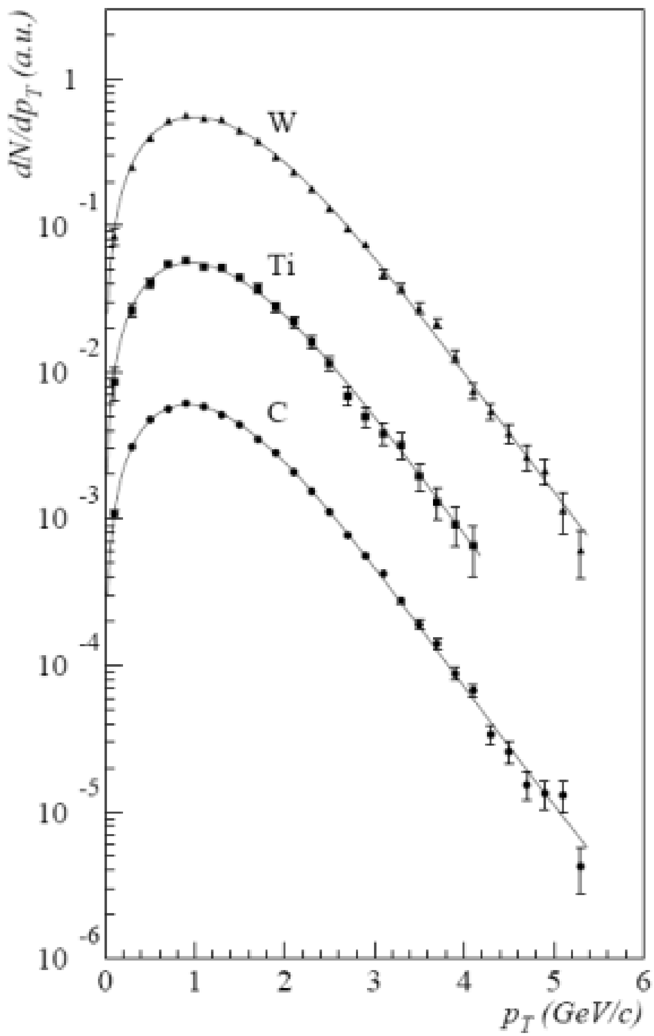
http://dx.doi.org/10.1063/1.1291460

Charmonium as a signature of QGP

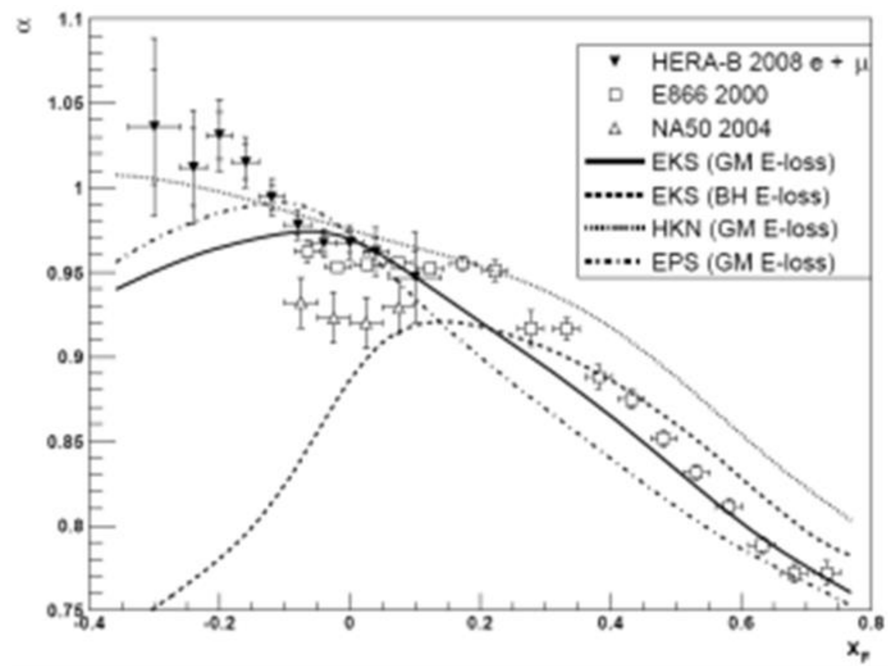
QCD phase diagram probed by 10–100 GeV beams on fixed target may shed light on the mechanism of hard production and suppression by hadronic dissociation in QGP of charmonium, J/ψ, and ψ(2S).

- **Preliminary results for J/ψ and D_0 from p (6.5 TeV) - Ar (SMOG) data indicate:**
  - **a fixed-target LHCb provides unique opportunity to measure heavy-flavor production covering:**
    - **Large Bjorken-x 0:03 < x_2 <0:5 (anti-shadowing region of the gluon nuclear PDF)**
    - **Negative Feynman-x_F region (no data available)**

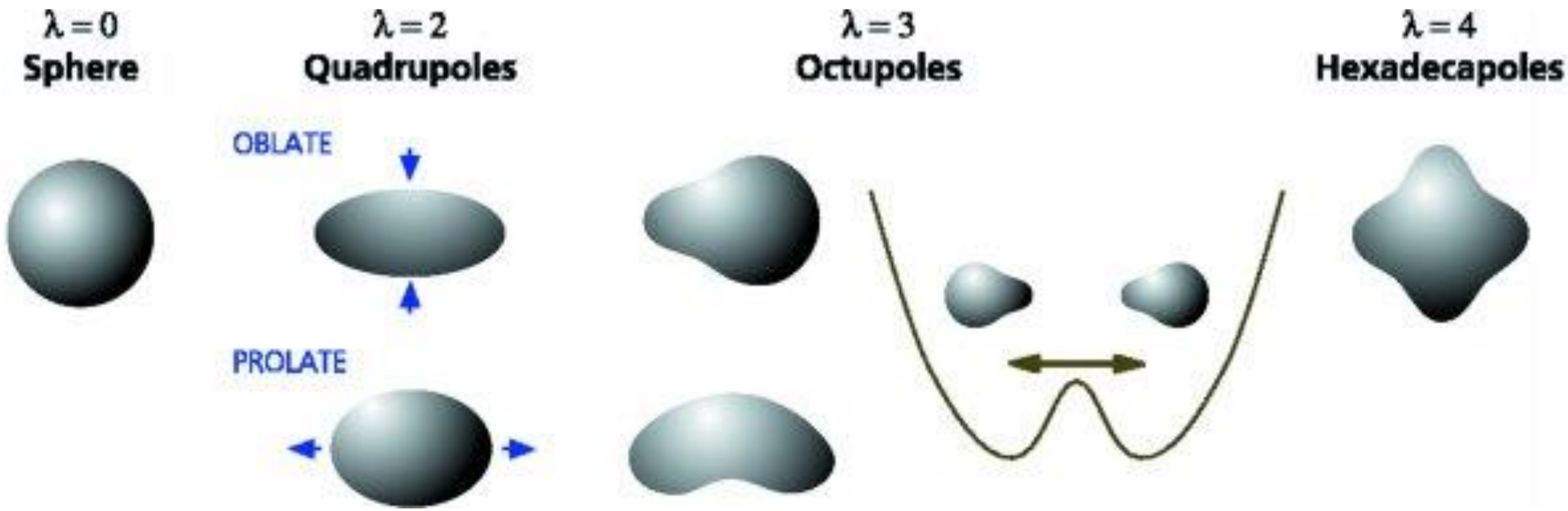
Some Physics Results at the HERA-B Multi-Target setup.
J/ψ from C, Ti, W.



$$\sigma_{pA} = \sigma_{pN} \cdot A^{\alpha}$$



Extension of the range of nuclei for studies of Nuclear Modification Factor (NMF) in relativistic nucleus-nucleus collisions (fixed target mode)



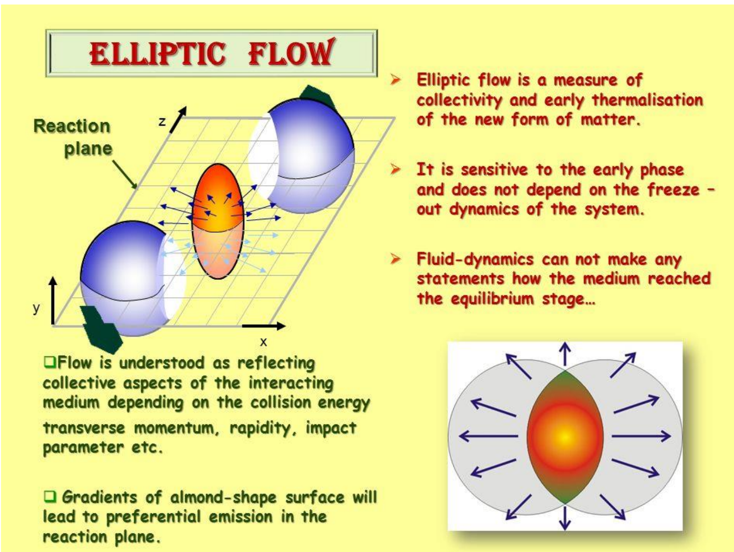
https://web-docs.gsi.de/~wolle/TELEKOLLEG/KERN/index-s.html

- **Nuclei in ground state have different shape (deformation parameter β), 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 ?**

Different fixed targets behave differently …

[Bullet Time | City Gallery Wellington]

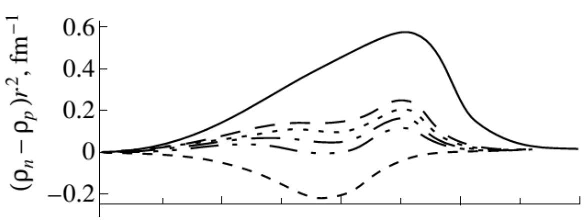
Extension of the range of nuclei for studies of Nuclear Modification Factor (NMF) in relativistic nucleus-nucleus collisions (fixed target mode)



http://images.slideplayer.com/15/4739780/slides/slide_4.jpg

Nuclei in ground state have different shape (deformation parameter β), angular momentum, …

- Impact of charge polarization at initial phase of collisions
- Primary excitation of nuclei – Giant resonances (isovector dipole, isoscalar quadrupole, ….
- Nuclear matter density distribution is not uniform inside nucleus (Strutinsky's Shell model corrections)
- 'Elliptic Flow' may depend upon the individual properties of colliding nuclei – neutron skin effect
- **Neutron-rich nuclei have large radius**



Radial distributions of the proton-neutron density

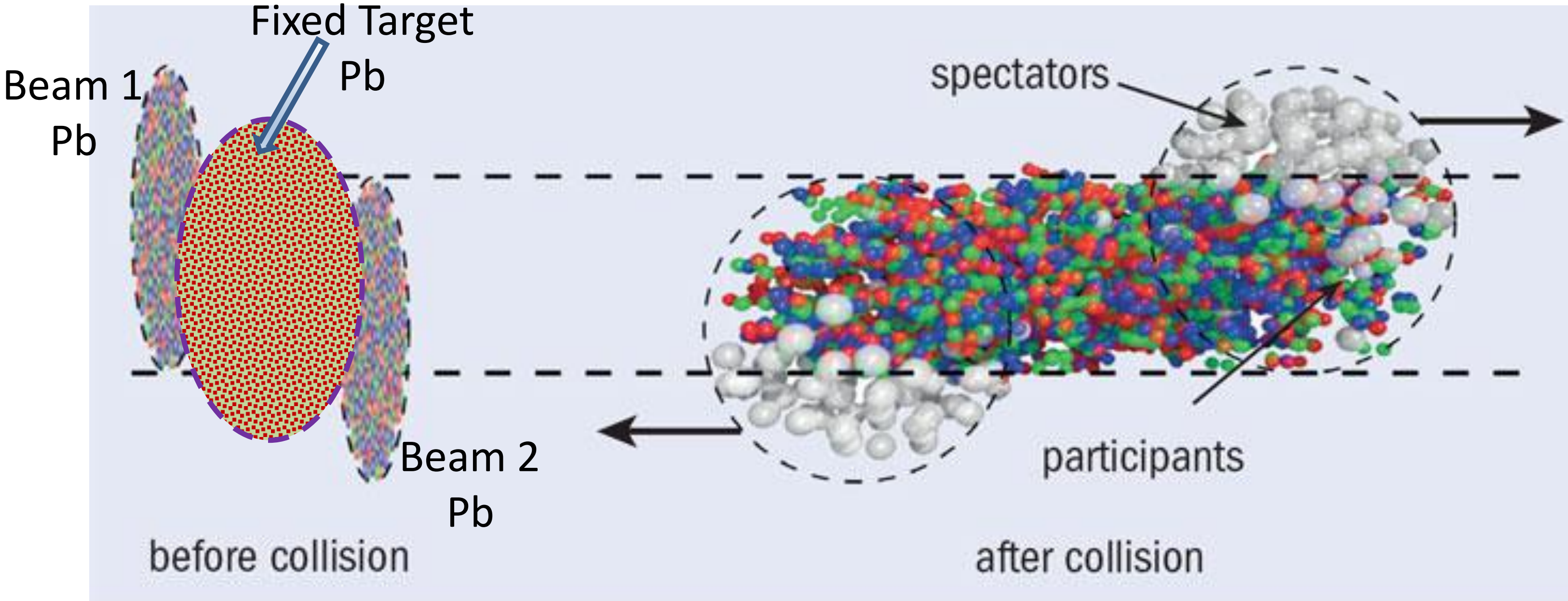
V. Yu. Denisov* and V. A. Nesterov

Physics of Atomic Nuclei, Vol. 65, No. 5, 2002, pp. 814–823.

I.V. Simenog, B.E. Grinyuk , Yu.M. Bidasyuk *Bogolyubov Institute for Theoretical Physics, Nat. Acad. of Sci. of Ukraine,* **'Can tetraneutron exist from theoretical point of view ?'** arXiv:nucl th/0511006v1

V.M. Pugach, O.F. Nemets. 'Neutron nuclei and the possibility to identify them in correlation experiments' . "Exotic Nuclei", Proceedings International Conference, Foros, Crimea. 1-5 Oct. 1991, World Scientific, p. 149-157).

Un-known: Three-nuclei interaction – two nuclei from LHC beams and one from the Metal Microstrip Target



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

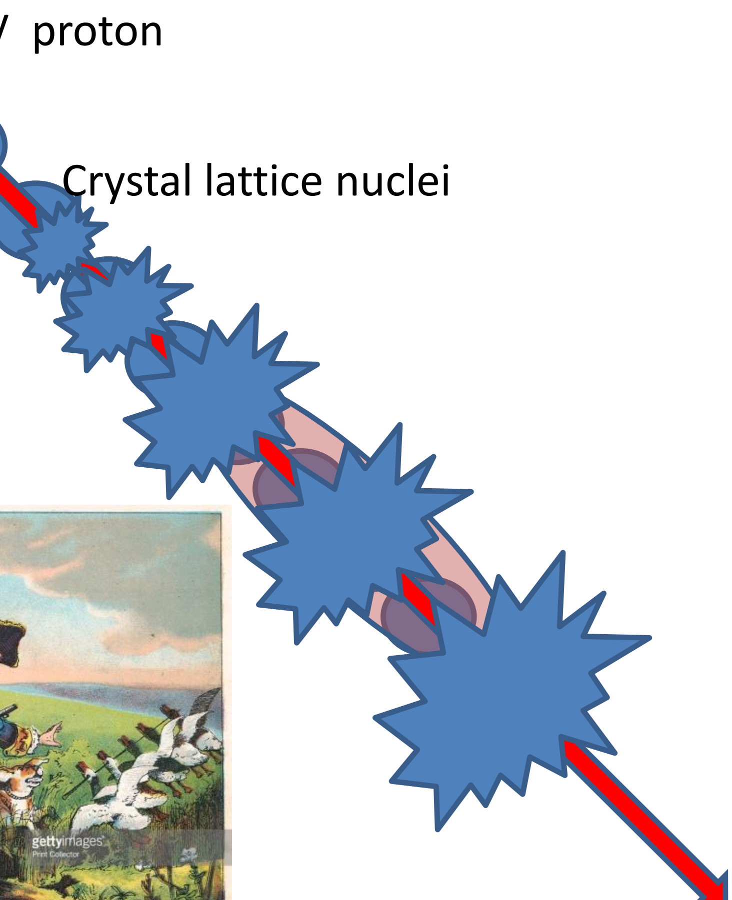
Events with three Pb nuclei interaction !

Never considered in earlier experiments:

- Interesting phenomena – pairs of nucleons will interact at 0.1 or 5 TeV, and three-nucleons at … TeV …
- **What will be the Equation of State ? Which temperatures and densities of the hot matter might be ?**

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 ?**
- **…**

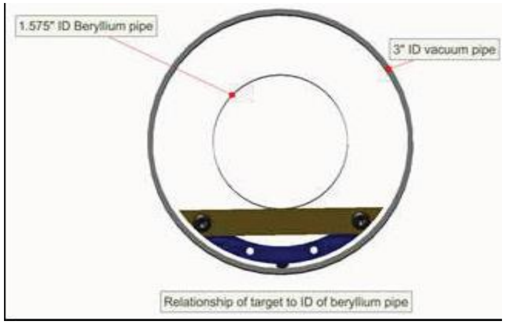
Recent proposals for Fixed Target HEP experiments

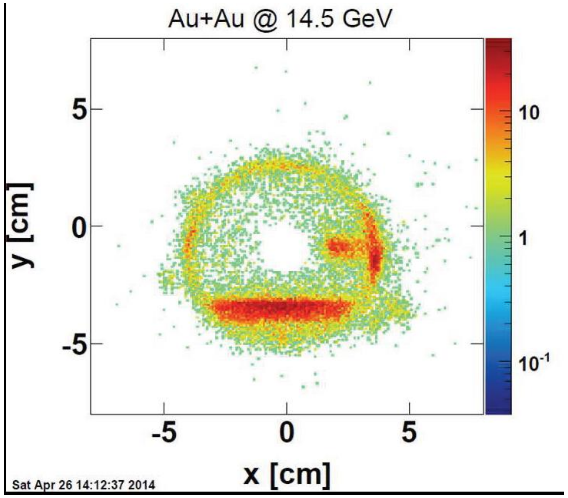
1. Experiment "AFTER"
S. J. Brodsky, F. Fleuret, C. Hadjidakis, J. P. Lansberg,
Phys. Rept. 522, 239 (2013).
https://arxiv.org/pdf/1504.05145v2.pdf

http://arxiv.org/pdf/1510.03976.pdf

2. A.B. Kurepin and N. S. Topilskaya.
Quarkonium Production and Proposal of the New Experiments on Fixed Target at the LHC. Advances in High Energy Physics. Volume 2015, Article ID 760840, http://dx.doi.org/10.1155/2015/760840

3. C. Montag, BNL, Upton, NY 11973, USA
WEOCA02 Proceedings of IPAC 2016, Busan, Korea
FIRST OPERATIONAL EXPERIENCE WITH AN INTERNAL HALO TARGET AT RHIC in 2016.
A thin (750 µm) gold foil was installed (upper figure).





An image of the target from vertex cuts of collision events in the target vicinity

Some beneficial features of the Metal targets

- **Physics**
  - Extension of the nuclei range for measuring known observables as well as searching for new ones, also at isotopically enriched targets
  - Impact of the individual nuclear properties (nuclear shell effects, spin, parity, deformation) on quark-gluon interactions and their hadronization, in particular via QGP stage.
- **Technique:**
  - Well localized interaction region (up to 10 μm) – high accuracy of vertexing, reduction of background etc.
  - Simultaneous data taking for many targets in a single run - errorless comparison of physical observables
  - Safe and reliable tuning/monitoring of the overall and partial luminosity
  - Robust and comparatively simple construction in terms of integration into UHV and RF environment of the LHC.

Summary & Outlook

Hadrons production in nuclear medium:

- **Colliding mode:**
  - p+Pb collisions at $\sqrt{s}_{NN}$ = 5 and 8.16 TeV
  - High precision of NMF for prompt and non-prompt J/ψ.

    - observed strong NMF in D^0 and J/ψ production

- **Fixed-target mode**
  - Study various nuclear systems at different energies to constrain cold nuclear matter effects
  - LHCb data for cosmic ray physics
    - First results
      - anti-proton production in p+He at $\sqrt{s}_{NN}$ = 110 GeV
      - J/ψ and D^0 production in p+Ar at $\sqrt{s}_{NN}$ = 110 GeV

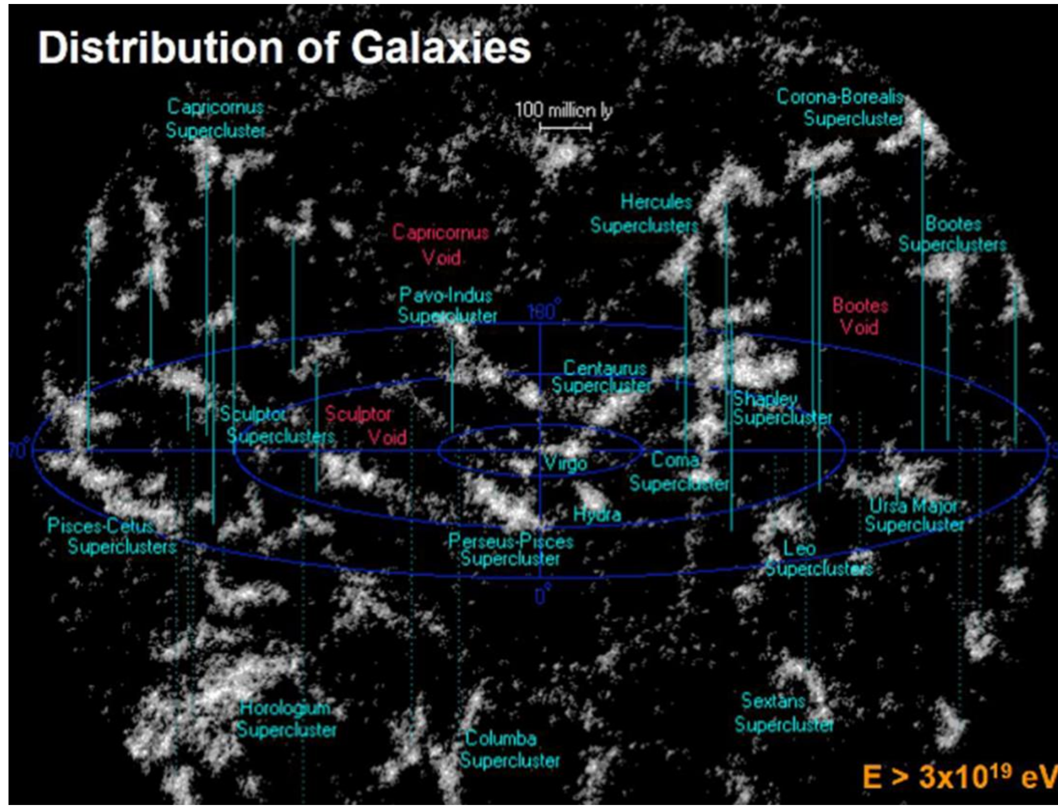
There ... New Physics !
THANK YOU FOR YOUR ATTENTION !

There are new directions for HEP studies.

There are 'white' areas on QCD phase diagram with new phenomena to be discovered and studied in forthcoming experiments at FAIR.

New Physics ?!

It might require new tools and methods to be developed for its observation. There might be observables which have to be discovered to study New Physics !



Distribution of Galaxies visible in cosmic rays with E >10^{19} eV).
Scale: ⟺ 10^{24} m.
The Earth diameter - ~10^7 m, The LHC diameter – ~10^4 m

BACKUP SLIDES

CGC approach:

Forward J/ψ production in proton-nucleus collisions at high energy

B. Duclou´e,1, 2 T. Lappi,1, 2 and H. M¨antysaari1 1 Department of Physics, University of Jyv¨askyl¨a P.O. Box 35, 40014 University of Jyv¨askyl¨a, Finland 2 Helsinki Institute of Physics, P.O. Box 64, 00014 University of Helsinki, Finland

Inclusive production of J/ψ mesons, especially at forward rapidities, is an important probe of small-x gluons in protons and nuclei. In this paper **we re-evaluate the production cross sections in the Color Glass Condensate framework, where the process is described by a large x gluon from the probe splitting into a quark pair and eikonally interacting with the target proton or nucleus.** Using a standard collinear gluon distribution for the probe and an up to date dipole cross section fitted to HERA data to describe the target we achieve a rather good description of the cross section in proton-proton collisions, although with a rather large normalization uncertainty. More importantly, **we show that generalizing the dipole cross section to nuclei in the Glauber approach results in a nuclear suppression of J/ψ production that is much closer to the experimental data than claimed in previous literature.**