Production Studies in LHCb using Proton Beams, Lead Beams and Fixed Targets

QCD challenges in pp, pA and AA collisions at high energies
ECT Trento Italy*

Albert Frithjof Bursche
Università degli Studi di Cagliari and INFN Cagliari
on behalf of LHCb

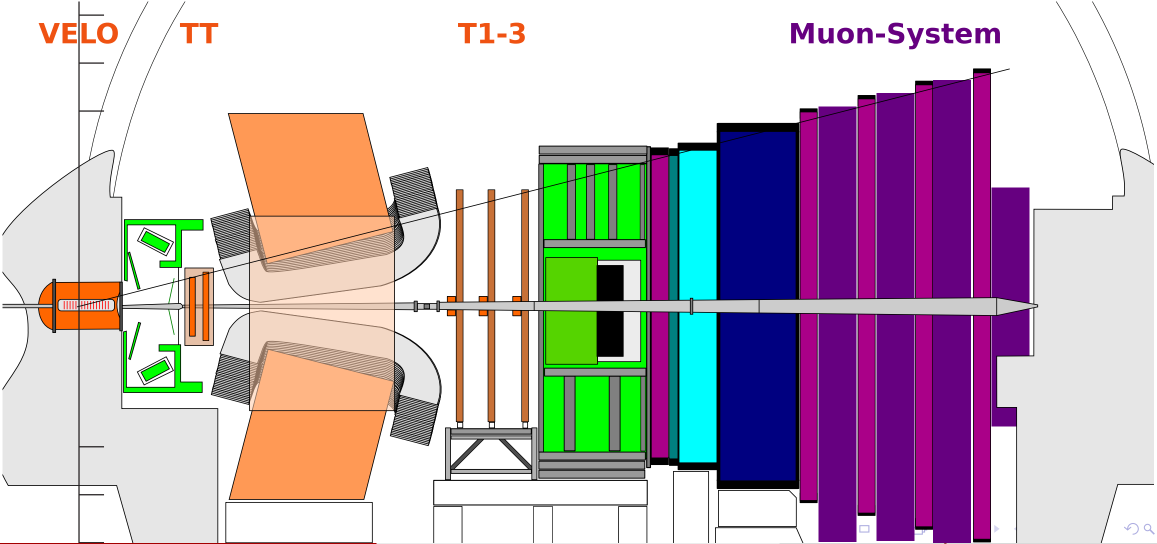
27th February 2017

European Research Council

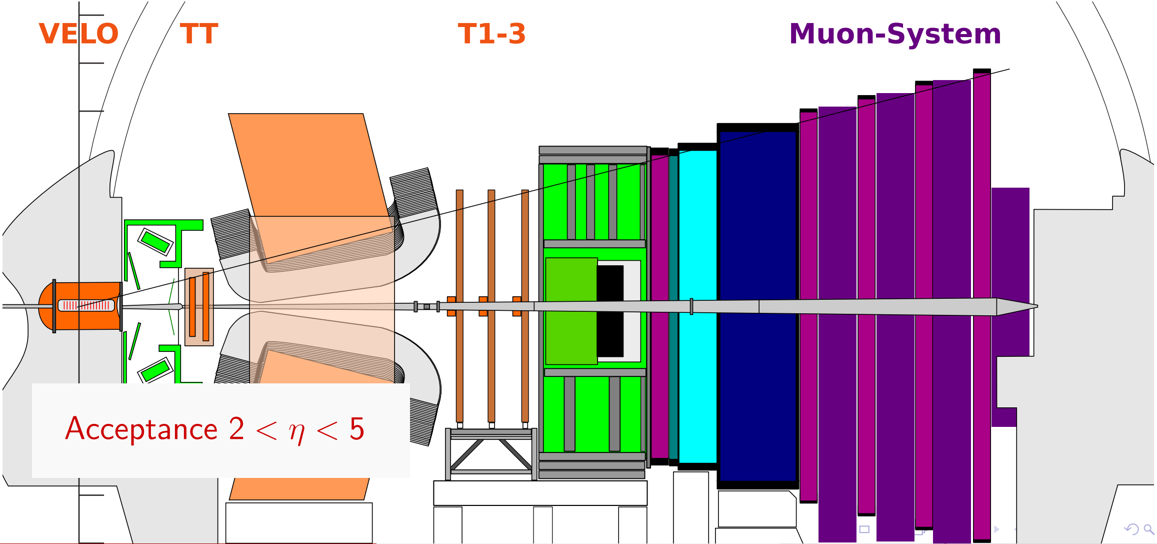
INFN

Outline

LHCb Experiment

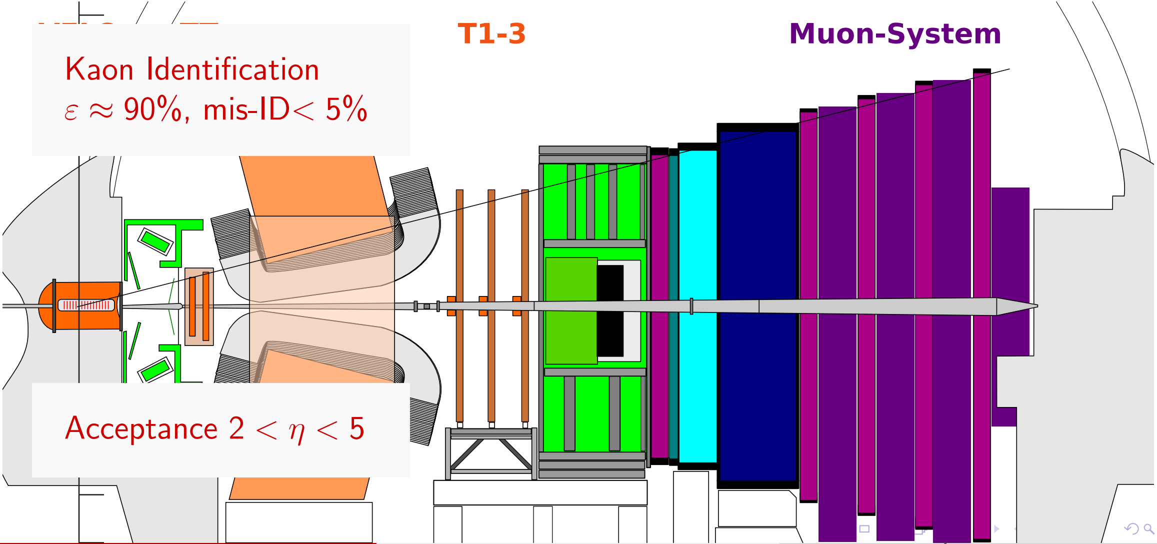


LHCb Experiment



Acceptance $2 < \eta < 5$

LHCb Experiment

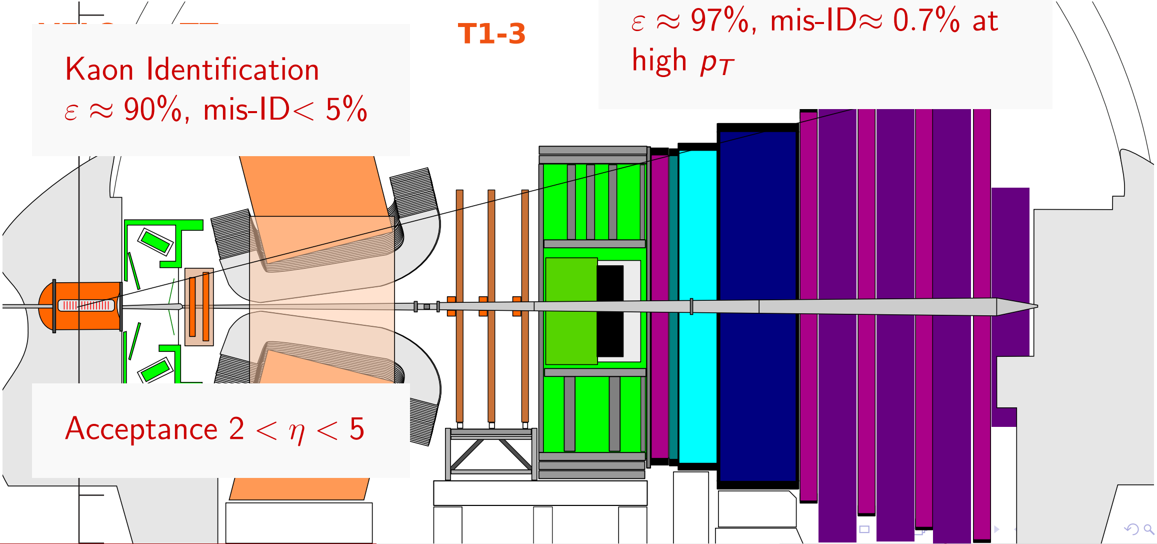


Kaon Identification

$\varepsilon \approx 90\%$, mis-ID$< 5\%$

Acceptance $2 < \eta < 5$

LHCb Experiment

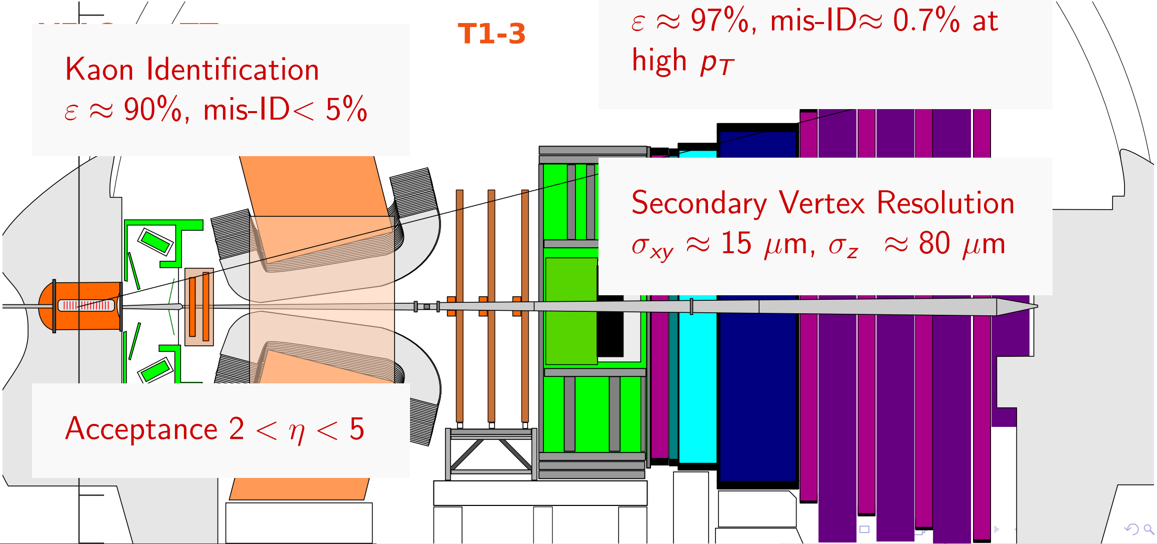


Kaon Identification
$\varepsilon \approx 90\%$, mis-ID$< 5\%$

Muon Identification
$\varepsilon \approx 97\%$, mis-ID$\approx 0.7\%$ at high p_T

Acceptance $2 < \eta < 5$

LHCb Experiment



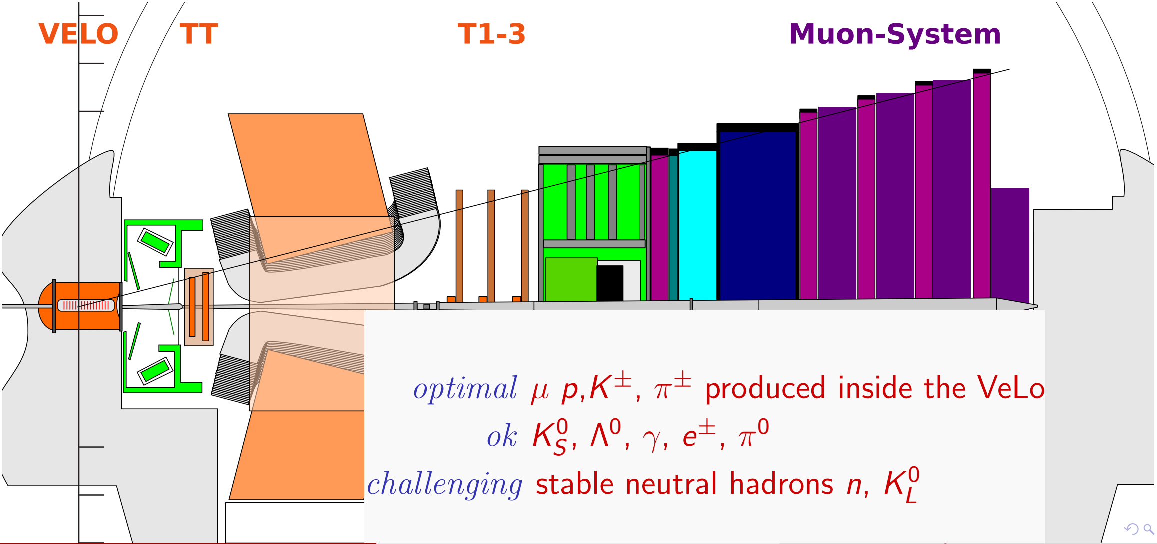
Kaon Identification
$\varepsilon \approx 90\%$, mis-ID$< 5\%$

Muon Identification
$\varepsilon \approx 97\%$, mis-ID$\approx 0.7\%$ at high p_T

Secondary Vertex Resolution
$\sigma_{xy} \approx 15\ \mu$m, $\sigma_z \approx 80\ \mu$m

Acceptance $2 < \eta < 5$

LHCb Experiment

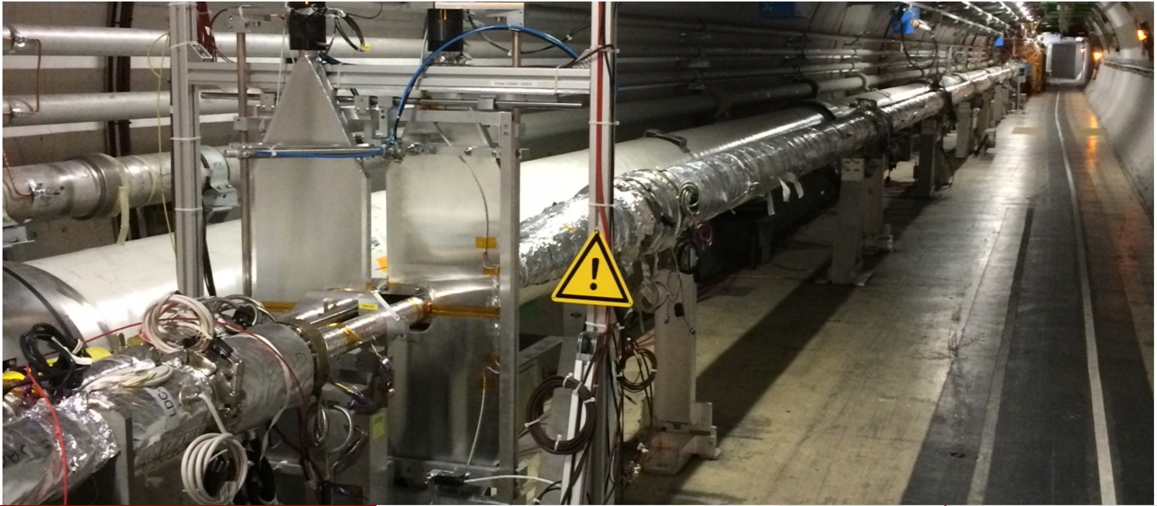


optimal μ $p, K^{\pm}$, $\pi^{\pm}$ produced inside the VeLo

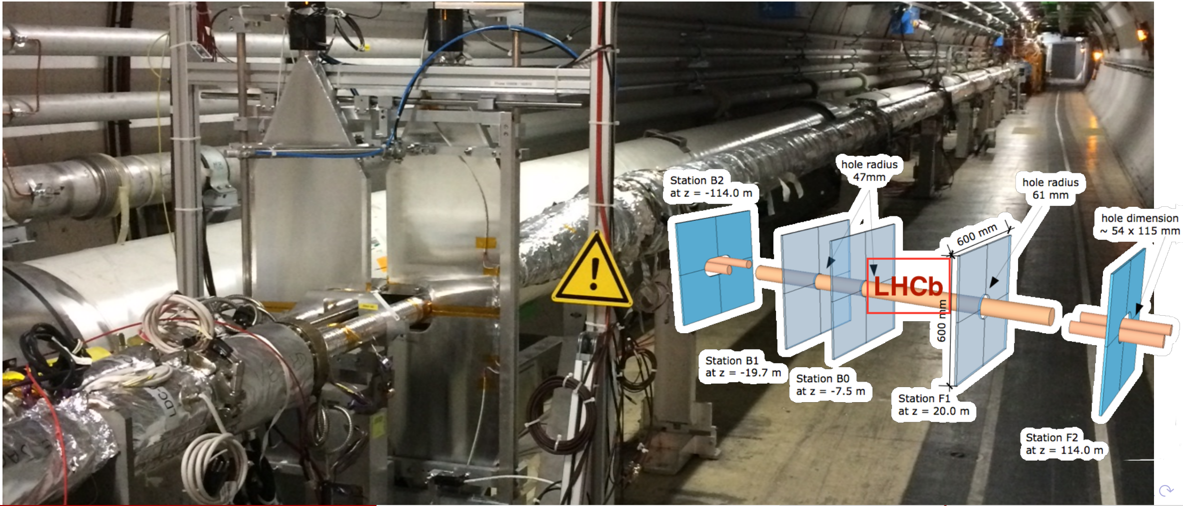
ok K^0_S, Λ^0, γ, $e^{\pm}$, π^0

challenging stable neutral hadrons n, K^0_L

HeRSCHeL - Forward Scintillators

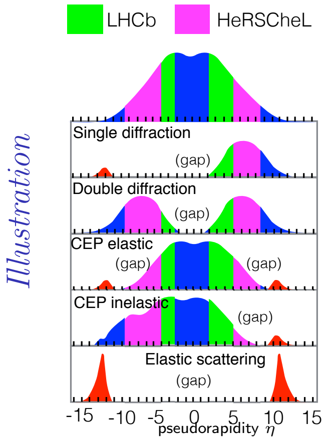


HeRSCHeL - Forward Scintillators



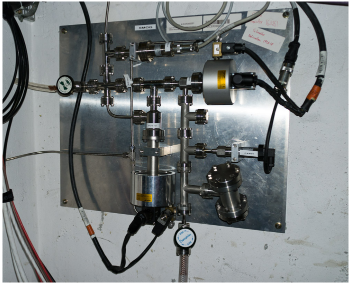
HeRSCheL Concept

- If the Proton breaks up it will leave Debris in $5 < \eta < 7.5$
- Extend present LHCb to observe the Presence of a these Debris
- Much easier than Proton Taggers inside the Beam Pipe ("Roman Pots")



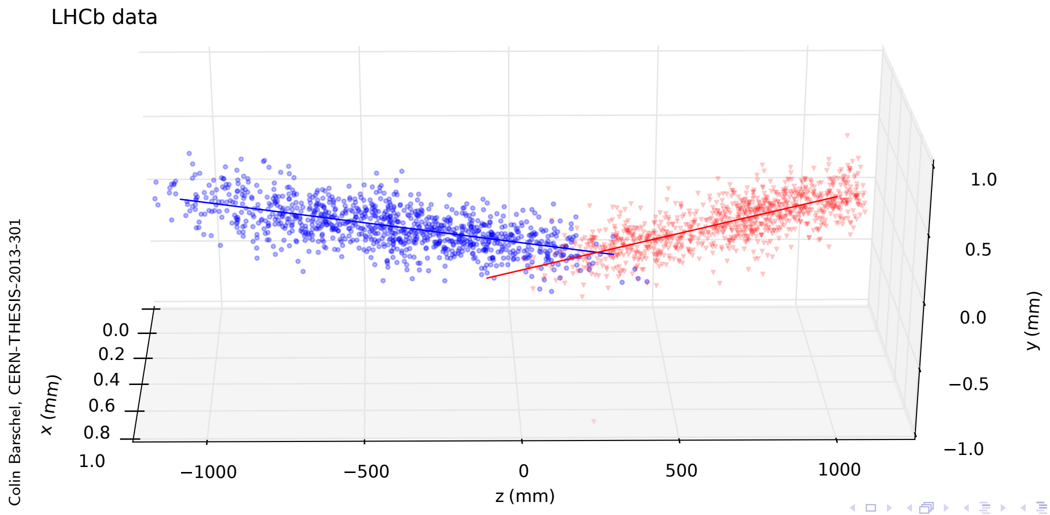
SMOG - Gas Target

- SMOG System for Measuring Overlap with Gas
- Inject Gas into the Accelerator Vacuum
- Increase Pressure from 10^{-9} to 10^{-7} mbar
- Built for a Precise Measurement of the Beam Profiles (Luminosity)
- Enabled Best Luminosity Measurement at LHC

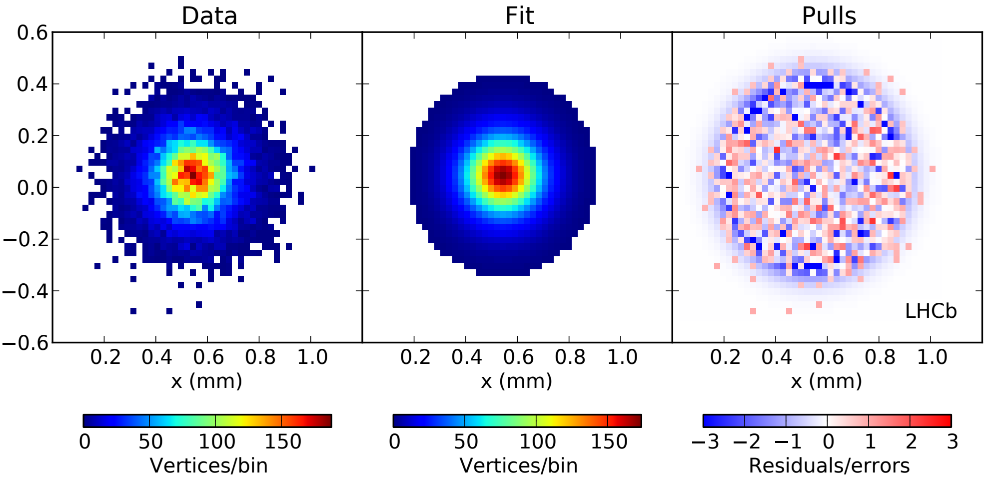


J. Instrum. 9 (2014) P12005

SMOG - Vertices

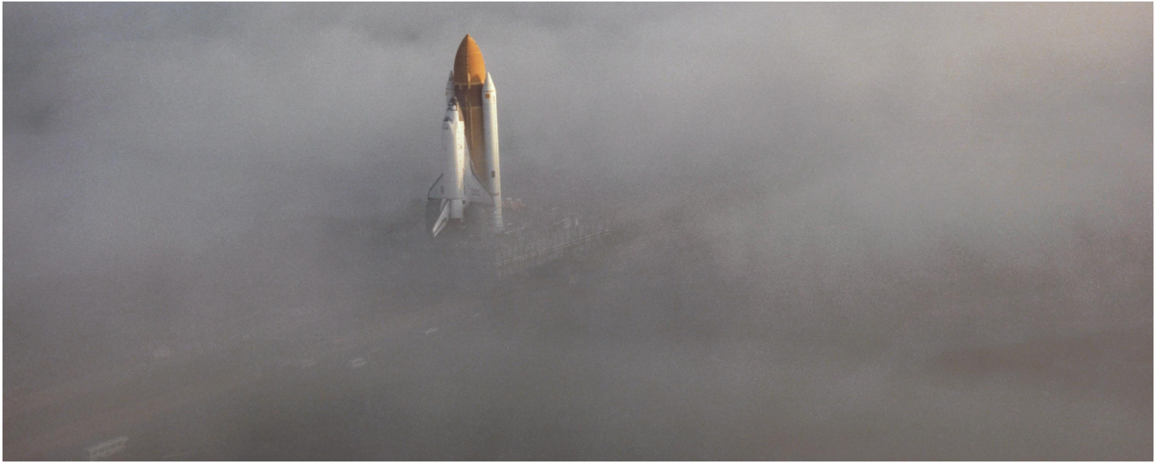


SMOG - Performance



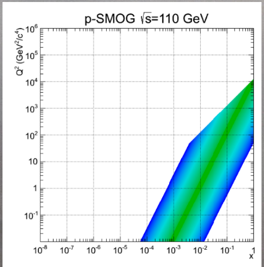
Colin Barschel, CERN-THESIS-2013-301

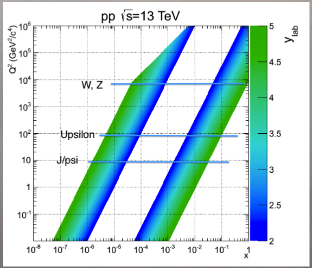
SMOG for Physics



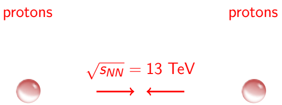
SMOG for Physics

- $\sqrt{s_{NN}} = \mathcal{O}(100\ \mathrm{GeV})$
- LHCb Acceptance becomes Central or Backward
- Injected Helium, Neon and Argon so far

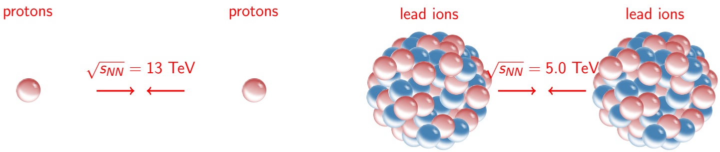




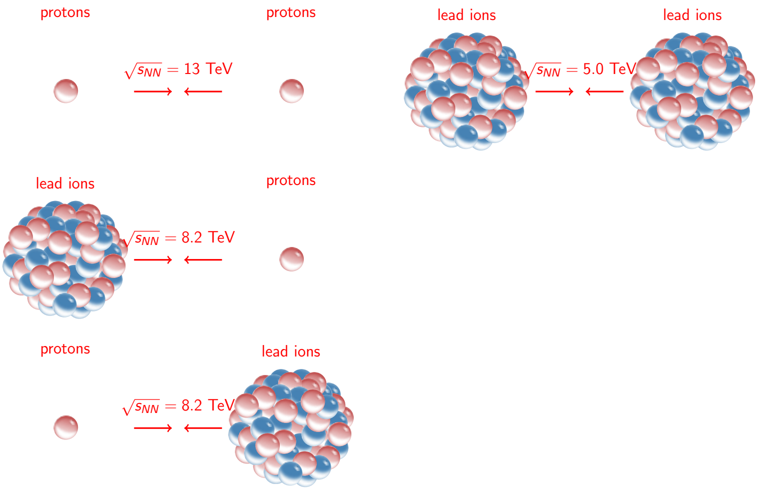
Types of Collisions in LHCb



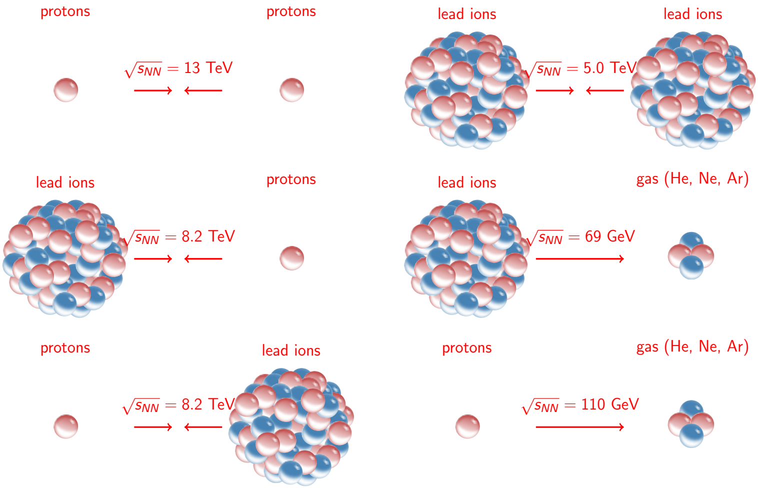
Types of Collisions in LHCb



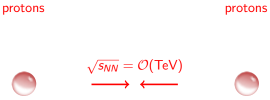
Types of Collisions in LHCb



Types of Collisions in LHCb

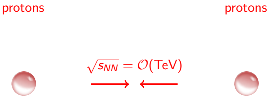


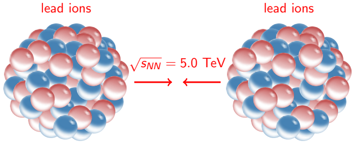
Wide Range of Physics to explore



- High Luminosity and High Energy
- LHCb Flavour Physics Programme
- New Physics Searches at the Energy Frontier

Wide Range of Physics to explore

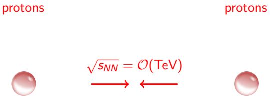




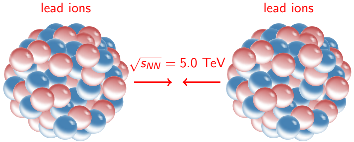
- High Luminosity and High Energy
- LHCb Flavour Physics Programme
- New Physics Searches at the Energy Frontier

- Study Baryonic Matter at extreme temperatures
- Probe Quark Gluon Plasma (QGP)
- Disentangle QGP signals from cold Nuclear Matter effects

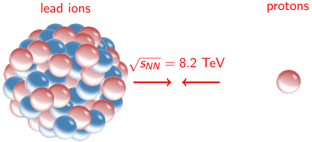
Wide Range of Physics to explore



- High Luminosity and High Energy
- LHCb Flavour Physics Programme
- New Physics Searches at the Energy Frontier



- Study Baryonic Matter at extreme temperatures
- Probe Quark Gluon Plasma (QGP)
- Disentangle QGP signals from cold Nuclear Matter effects



Cold Nuclear Matter effects:

- Gluon Shadowing in the Nucleus
- Gluon Saturation at low Bjorken-x
- Nuclear absorption in the final state
- Coherent energy loss in Nuclear Matter

Proton Proton Collisions

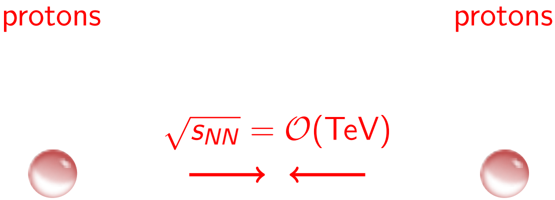
$\sqrt{s}$		Luminosity		Conditions	Year
0.9	TeV	0.2	nb^{-1}	low pileup	2010
7	TeV	36.0	pb^{-1}	high pileup	2010
7	TeV	3	million evt	low pileup	2010
7	TeV	1.0	fb^{-1}	high pileup	2011
2.76	TeV	71	nb^{-1}	low pileup	2011
8	TeV	2.0	fb^{-1}	high pileup	2012
2.76	TeV	3.1	pb^{-1}	low pileup	2013
5	TeV	8.6	pb^{-1}	low pileup	2015
13	TeV	320	pb^{-1}	high pileup	2015
13	TeV	1.9	fb^{-1}	high pileup	2916

Low pileup ($\mu \approx 0.1$) , *High pileup* ($\mu \leq 2$)

Recorded Nucleus Collisons

year	Beam 1	Beam 2	SMOG	$\sqrt{s_{NN}}$	amount
2012	p	p	Ne	87 GeV	$< 1h$
2013	Pb	p	Ne	54 GeV	$< 1h$
2013	p	Pb	–	5 TeV	1.1 nb^{-1}
2013	Pb	p	–	5 TeV	0.5 nb^{-1}
2015	p	p	He	110 GeV	$8h$
2015	p	p	Ne	110 GeV	$12h$
2015	p	p	Ar	110 GeV	$3d$
2015	Pb	p	Ar	69 GeV	few hours
2015	p	Pb	Ar	69 GeV	$1.5w$
2015	Pb	Pb		5 TeV	$3-5\ \mu\text{b}$
2016	Pb	p	Ar	110 GeV	$2d$

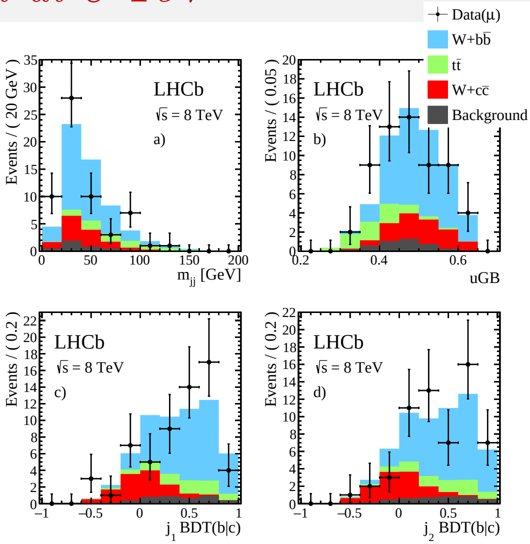
LHCb Results from Proton Proton Collisions



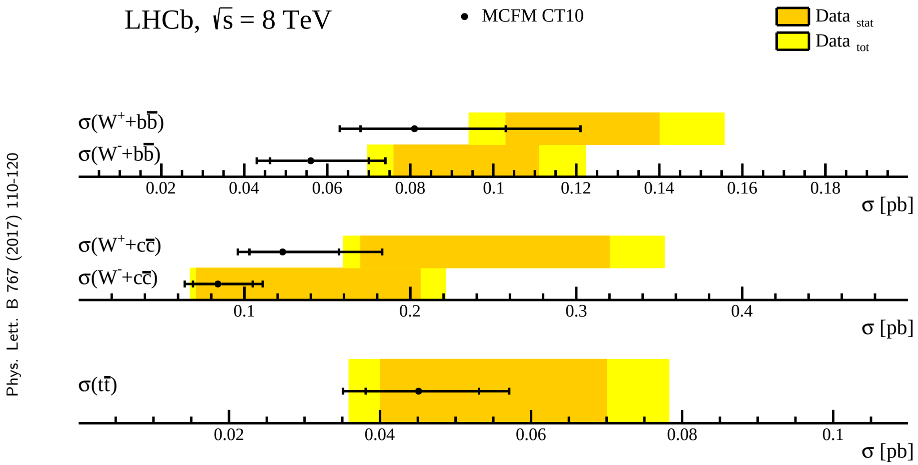
$Wc\bar{c}$, $Wb\bar{b}$ and $t\bar{t}$ Cross Section at 8 TeV

- Isolated electrons and muons
- $p_{T,\ell} > 20\,\mathrm{GeV}$, $2 < \eta_\mu < 4.5$, $2 < \eta_e < 4.25$
- Two reconstructed Jets with $12.5 < p_T < 100\,\mathrm{GeV}$, $\Delta_R > 0.5$
- Two Boosted Decision Trees (BDTs) for *heavy – light* and for *beauty – charm* separation
- Multivariate Discriminant (uGB) with minimal correlation to m_{jj} to discriminate $t\bar{t}$
- Signal from fit to Standard Model templates ($Wc\bar{c}$, $Wb\bar{b}$, $t\bar{t}$, multi-jet BG) in $\mathrm{BDT}_{(b|c)}$ response, uGB and m_{jj}

Phys. Lett. B 767 (2017) 110-120



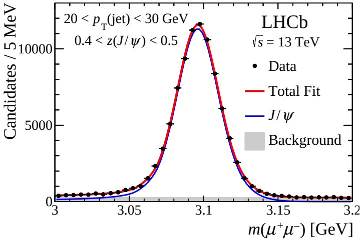
Results

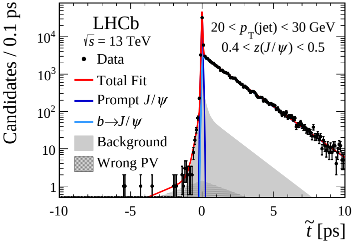


LHCb, √s = 8 TeV
MCFM CT10
Data stat
Data tot
σ(W⁺+bb̄)
σ(W⁻+bb̄)
0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18
σ [pb]
σ(W⁺+cc̄)
σ(W⁻+cc̄)
0.1 0.2 0.3 0.4
σ [pb]
σ(tt̄)
0.02 0.04 0.06 0.08 0.1
σ [pb]
Phys. Lett. B 767 (2017) 110-120

J/ψ in Jets

- Reconstructed $J/\psi \rightarrow \mu^+\mu^-$
- Input for $\not{k}$ jets
- Measure ratio $z = \frac{p_{T,J/\psi}}{p_{T,jet}}$
- Separate Prompt and "from b" component
- Bins of z and $p_{T,\text{jet}}$ combined
- $\tilde{t} = \frac{l_z m_{J/\psi}}{p_{zJ/\psi}}$





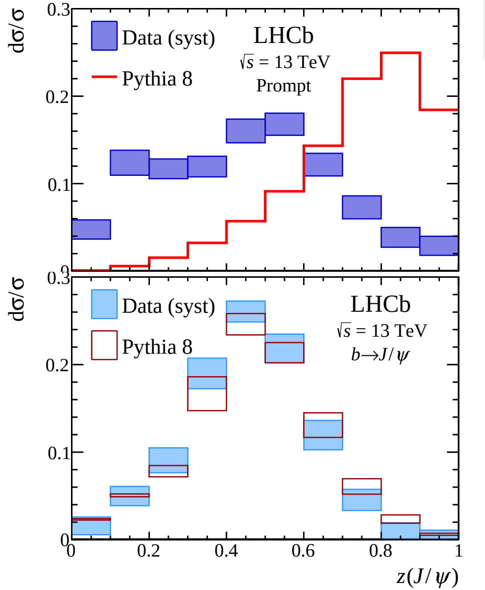
Motivation

Study J/ψ production in hadronisation and shed additional light on J/ψ Polarisation.

arXiv:1701.05116 (submitted to PRL)

J/ψ in Jets

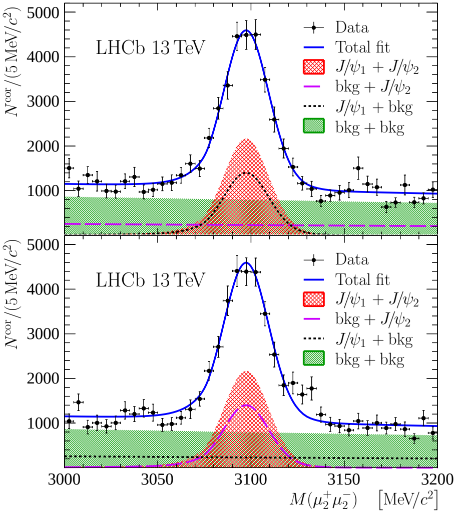
- Measure Ratio $z = \frac{p_{T,J/\psi}}{p_{T,\text{jet}}}$
- Compared to NRQCD prediction in Pythia 8
- Good agreement for "from b" distributions
- Prompt distribution is less isolated
  - $p_{T,\text{jet}} > 20$ GeV
  - $2.5 < \eta_{\text{jet}} < 4.5$
  - $2 < \eta_{J/\psi} < 4.5$



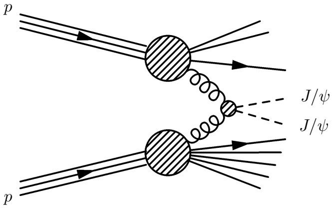
Precision Measurement of J/ψ Pair Production

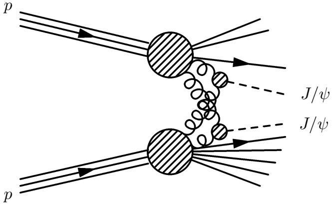
- 1000 double $J/\psi \rightarrow \mu^+\mu^-$ events selected
- Measure differentially in p_T, y, Δ_y, $\mathcal{A}_T = \left|\frac{p_{T,J/\psi,1} - p_{T,J/\psi,2}}{p_{T,J/\psi,1} + p_{T,J/\psi,2}}\right|$
- $p_{T,\mu} > 650\,\mathrm{MeV}$, $6 < p_\mu < 200\,\mathrm{GeV}$, $2 < \eta_\mu < 4.5$
- Measurements with $p_{T,J/\psi} > 0\,\mathrm{GeV}$, $p_{T,J/\psi} > 1\,\mathrm{GeV}$ and $p_{T,J/\psi} > 3\,\mathrm{GeV}$
- Prompt J/ψ corrected for J/ψ "from b"
- Using $279 \pm 11\,\mathrm{pb}^{-1}$ of Luminosity

arXiv:1612.07451 (submitted to JHEP)



Double J/ψ Production - Production Mechanisms





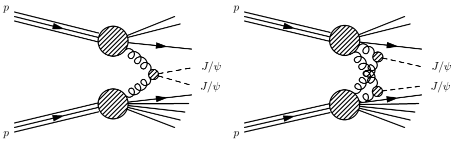
- Several Production Mechanisms for double J/ψ
- Single Parton Scattering (SPS)
- Double Parton Scattering (DPS)

Common Approximation

$$\sigma_{J/\psi\, J/\psi} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma_{\mathrm{eff}}}$$

σ_{eff}: Effective Double Parton Scattering Cross Section
σ_{eff} is expected to be constant for different production processes and energies.

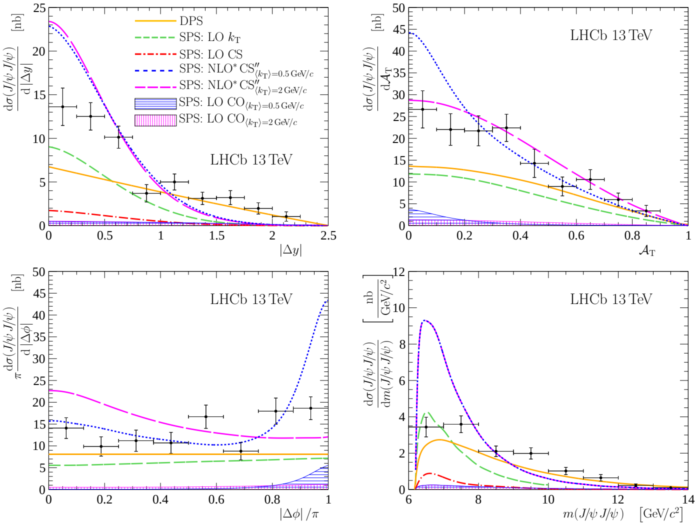
Double J/ψ Production - Results



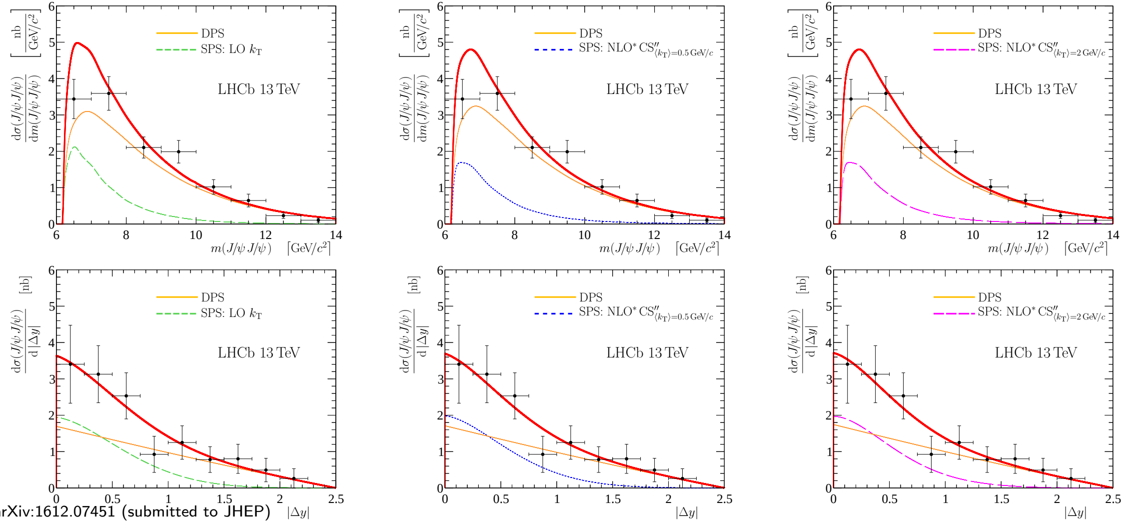
- Both SPS and DPS contribute
- Fit DPS Fraction

references

arXiv:1612.07451 (submitted to JHEP)



Double Parton Scattering Fraction - Fits

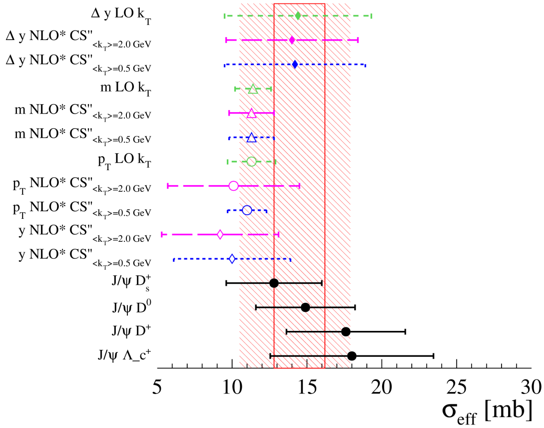


arXiv:1612.07451 (submitted to JHEP)

Double J/ψ Production - Effective DPS Cross Section

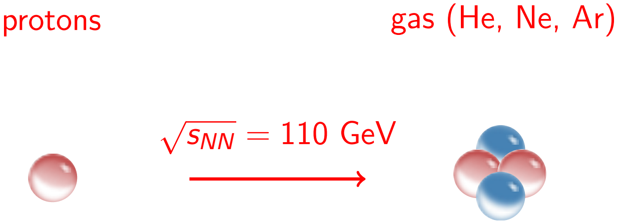
- $\sigma_{J/\psi\, J/\psi} = 13.5 \pm 0.9 \pm 0.8\,\text{nb}$
- $\frac{1}{2}\frac{\sigma_{J/\psi\, J/\psi}}{\sigma^2_{J/\psi}} = 8.5 \pm 0.6 \pm 1.1\,\text{nb}$
- Significant DPS fraction
  σ_{eff} between $9.2\,\text{mb}$ and $14.4\,\text{mb}$
- Only a selection of the results was shown

arXiv:1612.07451 (submitted to JHEP)

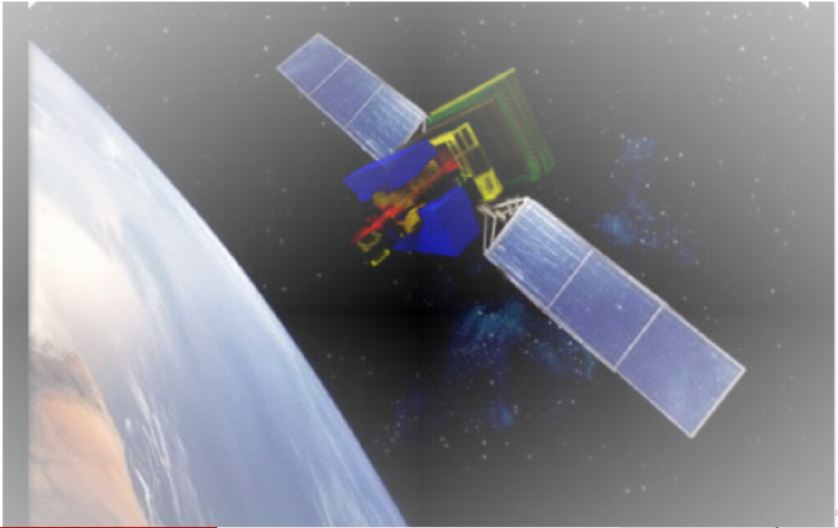


From Table 4 in arXiv:1612.07451 (submitted to JHEP) and Table 11 in JHEP 06 (
12% correlated uncertainty is not shown.
Compared to CDF Collaboration Phys. Rev. Lett. 79, 584

LHCb Results from Proton Gas Collisions

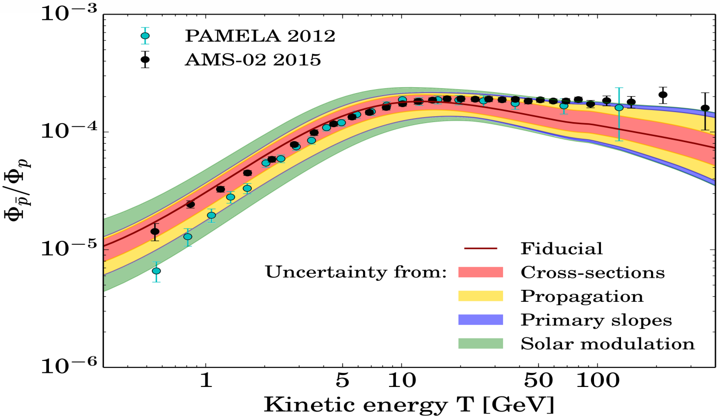


Antiproton Production in Proton Helium at 110 GeV



Antiproton Production in Proton Helium at 110 GeV Motivation

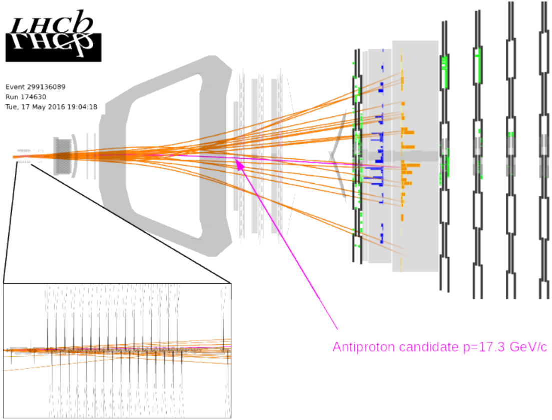
- Antiproton production from Cosmic Rays
- Large uncertainty from Production in pHe
- Aids Interpretation of AMS results



Giesen et. al. arxiv:1504.04276

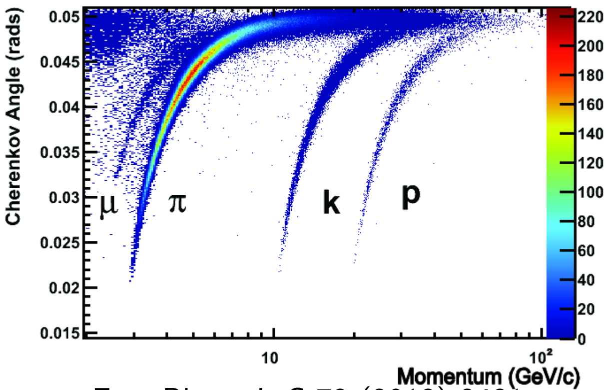
Analysis Strategy

- SMOG to inject He into LHC Vacuum
- RICH detectors for Proton ID
- Unusual Challenges
  - Luminosity Determination
    - Luminosity depends on Local Gas Density
    - Use Single Electron Events to measure Electron Density
  - He Purity in Accelerator
    - Residual Gas Analysis after the fill is dumped



Analysis Strategy

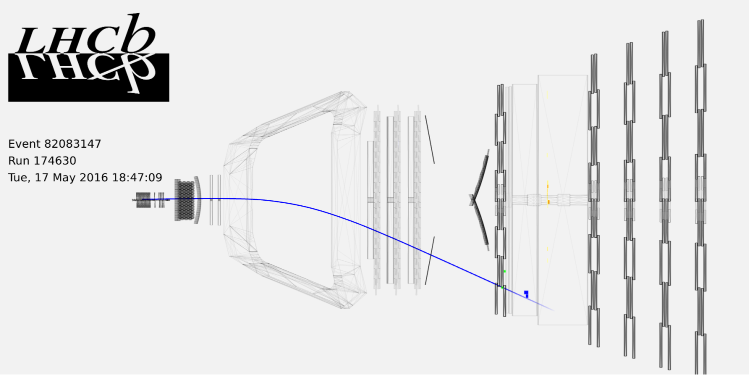
- SMOG to inject He into LHC Vacuum
- RICH detectors for Proton ID
- Unusual Challenges
  - Luminosity Determination
    - Luminosity depends on Local Gas Density
    - Use Single Electron Events to measure Electron Density
  - He Purity in Accelerator
    - Residual Gas Analysis after the fill is dumped



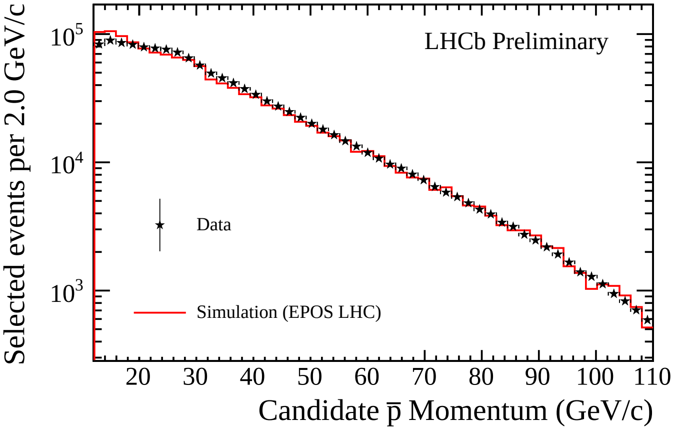
Eur. Phys. J. C 73 (2013) 2431

Analysis Strategy

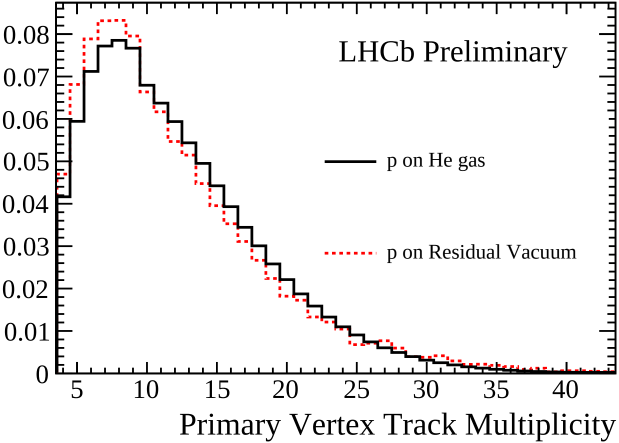
- SMOG to inject He into LHC Vacuum
- RICH detectors for Proton ID
- Unusual Challenges
  - Luminosity Determination
    - Luminosity depends on Local Gas Density
    - Use Single Electron Events to measure Electron Density
  - He Purity in Accelerator
    - Residual Gas Analysis after the fill is dumped



Glimpse at the Results

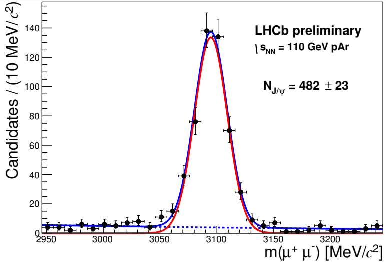


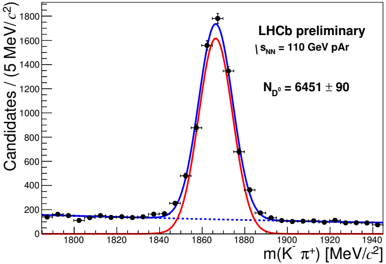
Glimpse at the Results



Charm Production in Proton Argon at 110 GeV

- 500 $J/\psi \rightarrow \mu^+\mu^-$ Candidates
- 6500 $D^0 \rightarrow K^-\pi^+$ Candidates
- Measure Ratios and Yields with $0 < p_{T\,D^0,J/\psi} < 8\,\mathrm{GeV}$
- $p_{T,\pi^\pm K^\pm} > 500\,\mathrm{MeV}$
- CM frame at rapidity -4.77
- $2 < y_{\mathrm{lab}} < 4.9$ and $-2.77 < y* < 0.13$

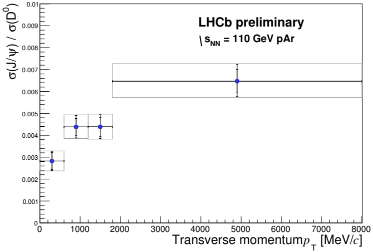


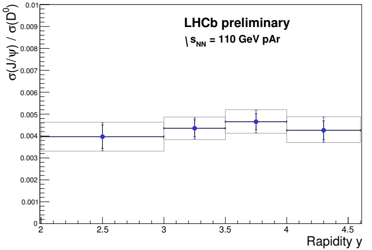


Charm Cross Section Ratios in Proton Argon at 110 GeV

- No significant dependence on Rapidity
- J/ψ tends to be produced at higher transverse momentum
- $\frac{\sigma_{J/\psi}}{\sigma_{D^0}} = \frac{n_{J/\psi}}{\epsilon_{J/\psi} \mathcal{B} J/\psi \to \mu^+ \mu^-} \frac{\epsilon_{D^0} \mathcal{B} D^0 \to K^- \pi^+}{n_{D^0}}$

LHCb-CONF-2017-001

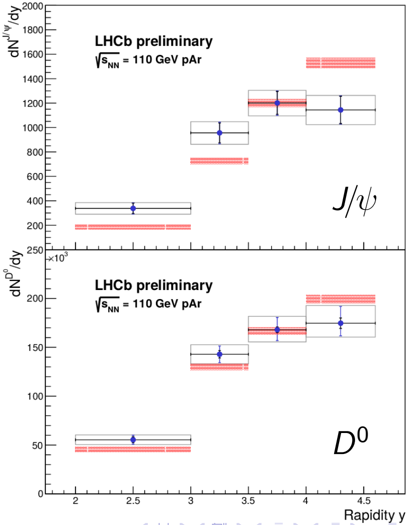




Charm Yield in Proton Argon at 110 GeV - y

- J/ψ is suppressed at Central Rapidity
- $p_{T,\pi^\pm K^\pm} > 500\,\mathrm{MeV}$
- CM Frame at Rapidity -4.77
- $2 < y_{\rm lab} < 4.9$ and
  $-2.77 < y* < 0.13$

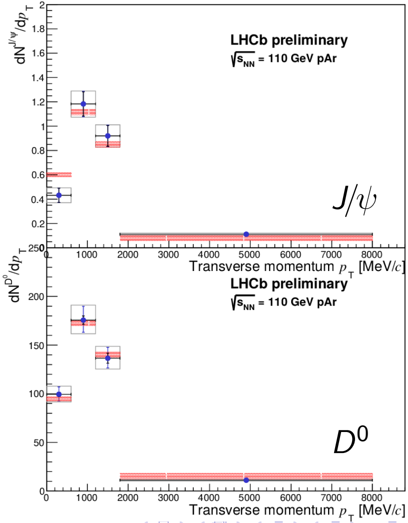
LHCb-CONF-2017-001



Charm Yield in Proton Argon at 110 GeV - p_T

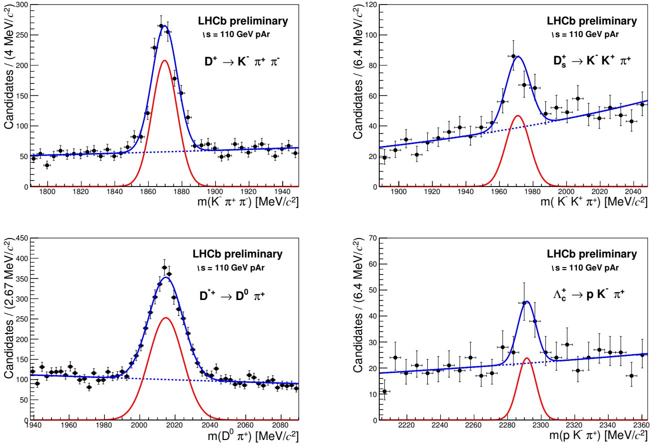
- J/ψ is suppressed at low p_T
- $p_{T,\pi^\pm K^\pm} > 500\,\mathrm{MeV}$
- CM Frame at Rapidity -4.77
- $2 < y_{\text{lab}} < 4.9$ and $-2.77 < y* < 0.13$

LHCb-CONF-2017-001



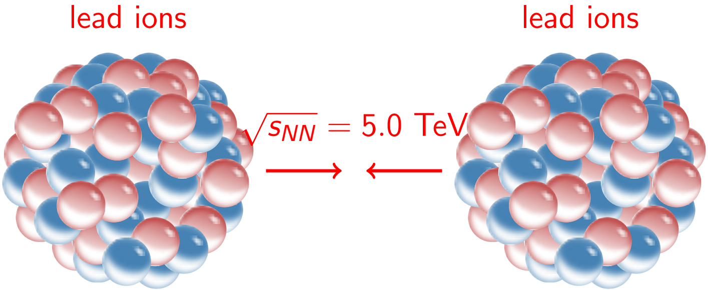
More Charming Signals in Proton Argon at 110 GeV

- Also signals for:
  - $D^+ \rightarrow K^-\pi^+\pi^+$
  - $D^{*+} \rightarrow D^+\pi^+$
  - $D_s^+ \rightarrow K^+K^-\pi^+$
  - $\Lambda_c^+ \rightarrow pK^-\pi^+$
- No signal for $\psi(2S)$ and χ_c yet

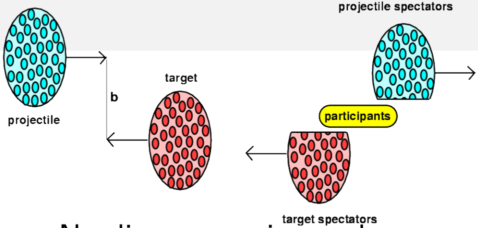


LHCb-CONF-2017-001

LHCb Results from Lead Lead Collisions



Centrality



The size and the shape of the medium as well as the energy density depend on the geometry of the collision

Centrality

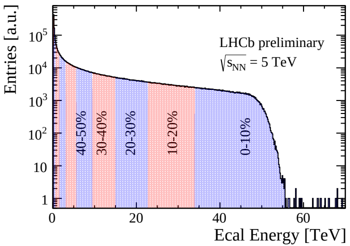
- b: Impact Parameter, transverse distance between the centres of the two nuclei
- n_{part}: Participating Nucleons (geometrically)
- n_{coll}: Number of nucleon-nucleon binary collisions (involves the NN interaction probability)

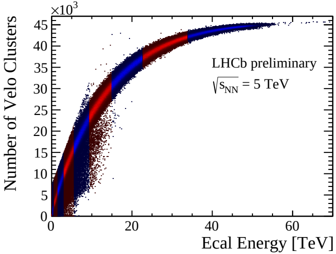
- No direct experimental measurement of b
- Need to infer centrality from indirect measurements
- Example: number of charged particles at mid rapidity, energy deposition at zero degree
- LHCb: not equipped with a dedicated detector

Centrality determination

- Experimental observables: Total Energy in the Calorimeters, EM (ECal) or Hadronic (HCal)
- No saturation of calorimeter signals even for most central collisions

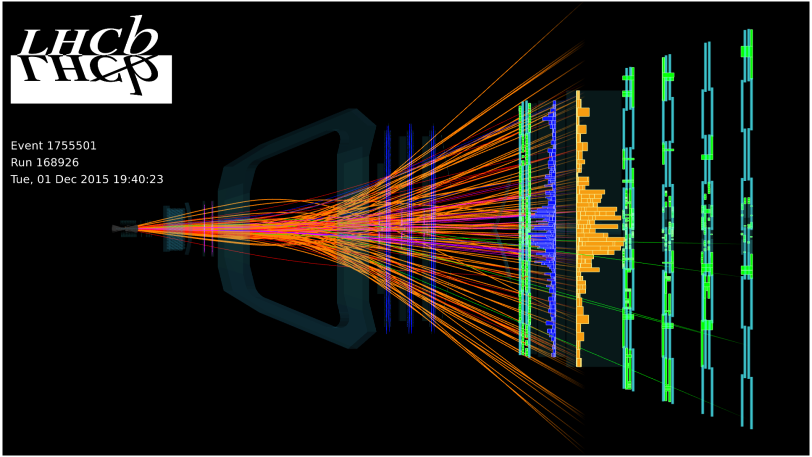
- Glauber fit to the ECal spectrum to determine Centrality Classes
- Saturation in Vertex Locator (VeLo) clearly visible. Track reconstruction was performed up to ∼15k clusters
- Corresponding range: 50-100% Event Activity



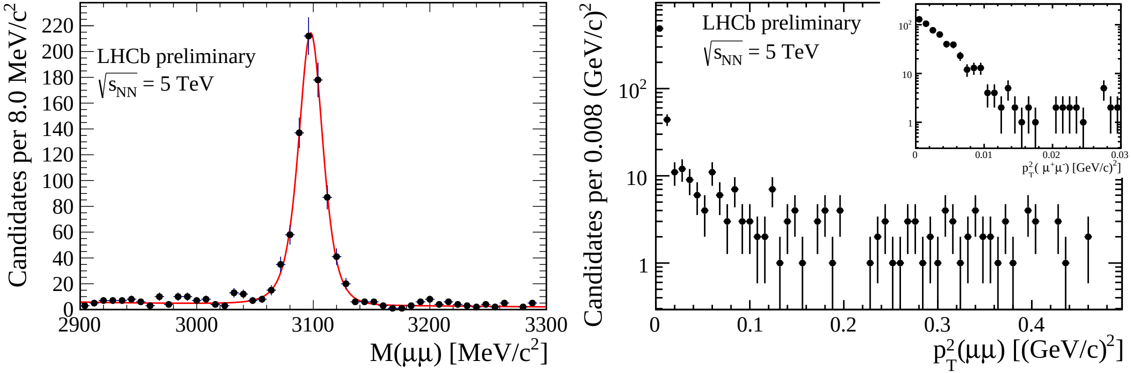


Tracking the full Detector

- LHCb is optimised for Material Budget and not for Granularity
- Central PbPb and PbAr collisions challenge Tracking Capability
- Final Centrality Reach still under Study



Ultraperipheral Collisions



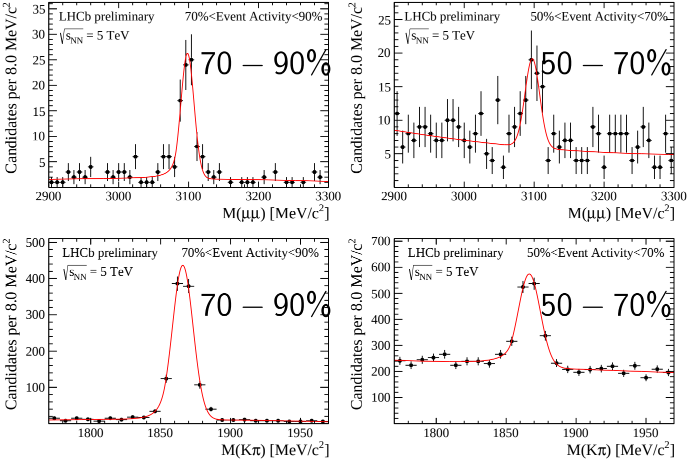
Select *exactly* two tracks in the event and veto additional Activity

Clear Signal of *exclusive* J/ψ production in PbPb collisions.

More about our CEP results in pp in the talk by Murilo Rangel on Thursday

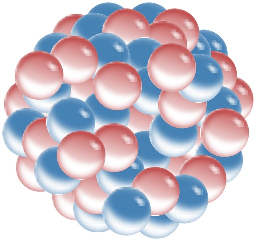
Charm Signals...

- Strong Exclusive Contamination/Signal visible in bin 90% – 100%
- Herschel Scintillators can shed more light on this
- $p_{T,\mu} > 750\,\mathrm{MeV}$, $t_{z,J/\psi} < 0.3\,\mathrm{ps}$
- Efficiency calculation being finalised



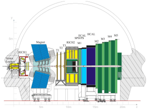
LHCb Results from Proton Lead Collisions

lead ions



Beam 1

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



backward

protons

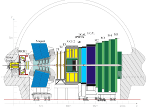
Beam 2

LHCb Results from Proton Lead Collisions

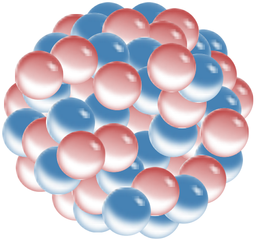
protons

lead ions

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



forward



Beam 1

Beam 2

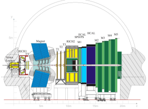
LHCb Results from Proton Lead Collisions

- $\frac{Q}{m}$ is different for Lead and Protons
- LHC Beam Rigidity must be equal for both Beams
- Both Beams have different Energies
- CM frame Rapidity ± 0.465 in Lab Frame

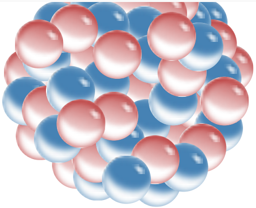
protons

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

→



←



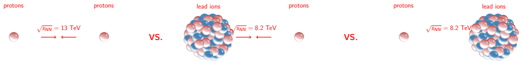
forward

Beam 1

Beam 2

Main Observables

Nuclear Modification Factor



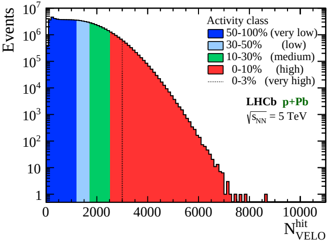
Ratio of a Cross Section in pPb over pp. Needs Reference Cross Section from pp at the same Energy. Two of these Numbers in Proton Ion (Forward R_{pPb}/Backward R_{Pbp}).

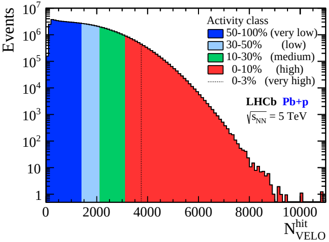
Forward Backward Ratio

Ratio of a Cross Section in pPb over Pbp in overlapping Rapidity range. R_{FB}

Angular Correlations in Proton Lead Collisions

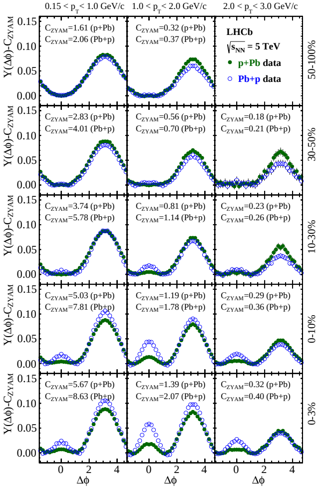
- Use $n_{\text{Velo Cluster}}$ Distribution for Centrality determination
- Main VeLo acceptance $1.9 < \eta < 4.9$ and Backward acceptance $-2.5 < \eta < 2$ (no momentum measurement)
- p_T ranges:
  $0.15 < p_T < 1\,\text{GeV}$,
  $1 < p_T < 2\,\text{GeV}$,
  $2 < p_T < 3\,\text{GeV}$
- forward backward

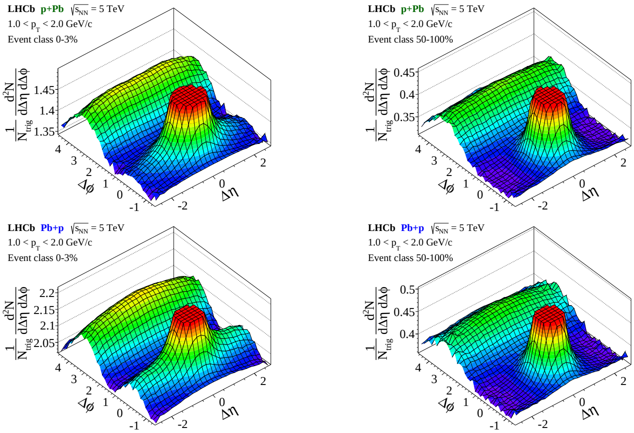




Phys. Lett. B 762 (2016) 473-483

Results



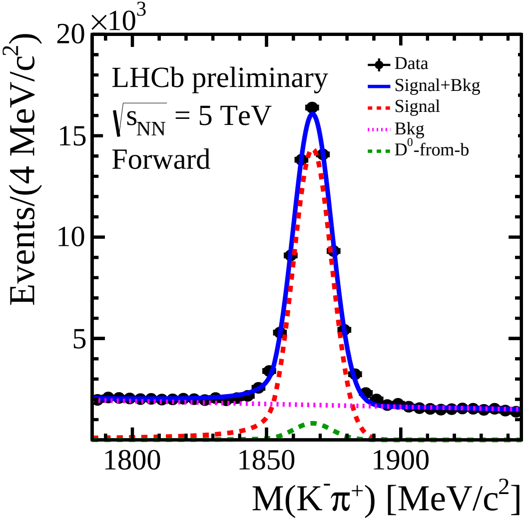


Phys. Lett. B 762 (2016)

$D^0 \rightarrow K^- \pi^+$ in Proton Ion Collisions

- Double differential Cross Section (y, p_T)
- Nuclear Modification Factor in y, p_T
- Prompt D^0 corrected with χ^2_{IP} fit
- $p_{T,D^0} < 8\,\mathrm{GeV}$

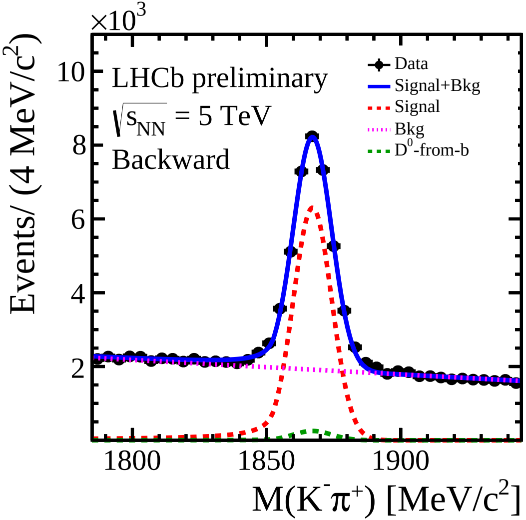
LHCb-CONF-2016-003



$D^0 \rightarrow K^-\pi^+$ in Proton Ion Collisions

- Double differential Cross Section (y, p_T)
- Nuclear Modification Factor in y, p_T
- Prompt D^0 corrected with χ^2_{IP} fit
- $p_{T,D^0} < 8\,\mathrm{GeV}$

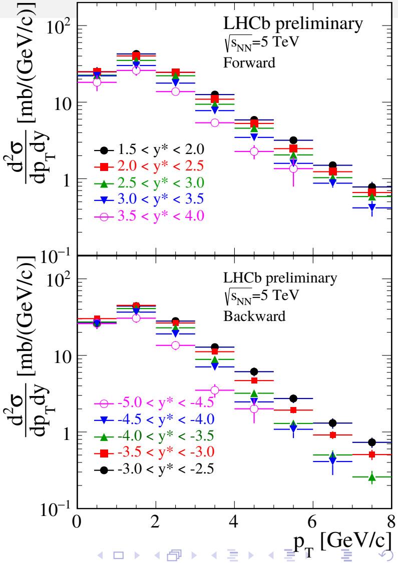
LHCb-CONF-2016-003



D^0 Production Cross Section in Proton Ion Collisions

- $y*$ Rapidity in Centre of Mass Frame of the Collisions
- $\sigma_{\text{forward}} = 237 \pm 1 \pm 15\,\text{mb}\ (1.5 < y* < 4.0)$
- $\sigma_{\text{forward}} = 124 \pm 1 \pm 8\,\text{mb}\ (2.5 < y* < 4.0)$
- $\sigma_{\text{backward}} = 259 \pm 3 \pm 19\,\text{mb}\ (2.5 < y* < 5.0)$
- $\sigma_{\text{backward}} = 174 \pm 2 \pm 13\,\text{mb}\ (2.5 < y* < 4.0)$

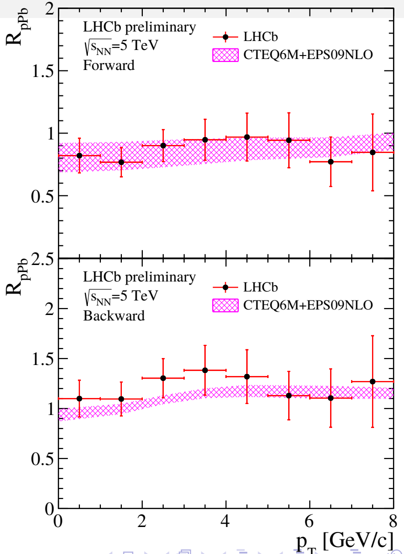
preliminary LHCb-CONF-2016-003



D^0 Nuclear Modification Factor in Proton Ion Collisions

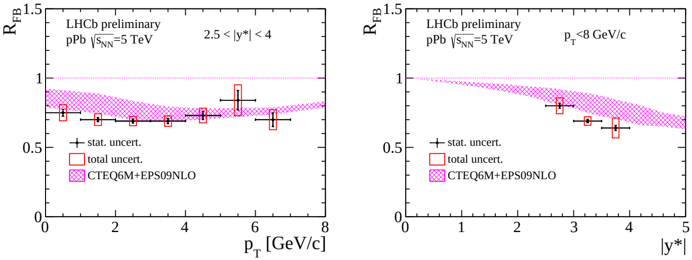
- Agreement with NLO prediction
- M. L. Mangano, P. Nason, and G. Ridol , *Nucl. Phys. B373 (1992) 295.*
- Still large uncertainties

preliminary LHCb-CONF-2016-003



D^0 Forward Backward Ratio in Proton Ion Collisions

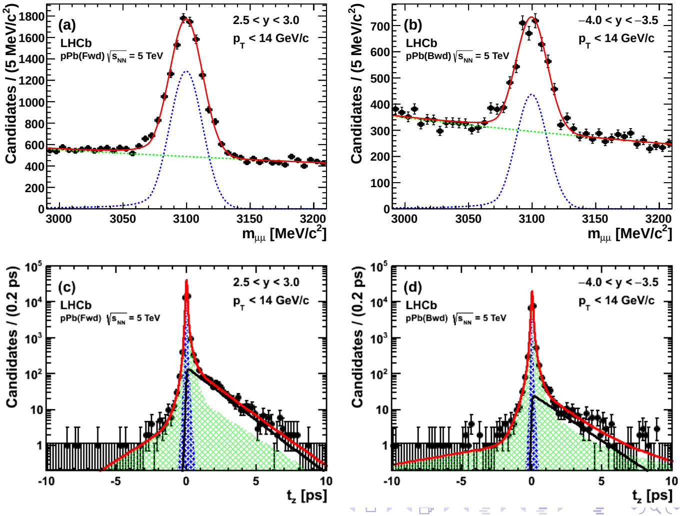
- Agreement with NLO prediction
- M. L. Mangano, P. Nason, and G. Ridol , *Nucl. Phys. B373 (1992) 295.*
- Many uncertainties cancel



preliminary
LHCb-CONF-2016-003

$J/\psi \rightarrow \mu^+\mu^-$ in Proton Ion Collisions

- $J/\psi \rightarrow \mu^+\mu^-$ events
- $1.1\,\mathrm{nb}^{-1}$ ($0.5\,\mathrm{nb}^{-1}$)
- $p_{T,\mu} > 700\,\mathrm{MeV}$
- Prompt and “from b” components separated
- Reference Cross Section: LHCb pp data at 2.76, 7,8 TeV extrapolated to 5 TeV (power-law)

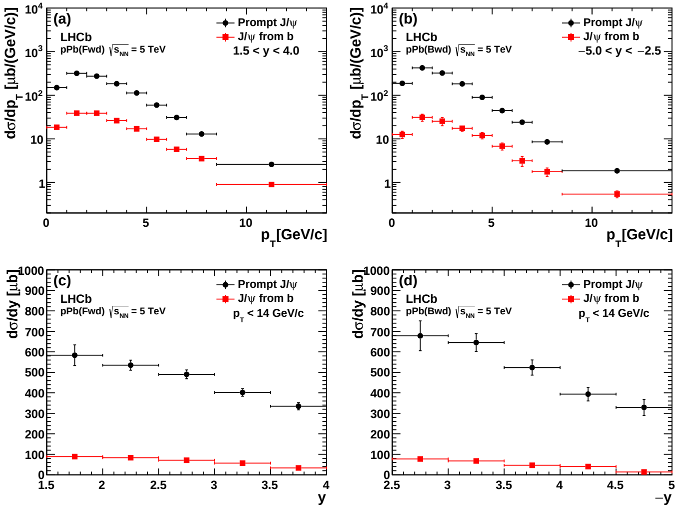


JHEP 02 (2014) 72

$J/\psi \rightarrow \mu^+\mu^-$ in Proton Ion Collisions

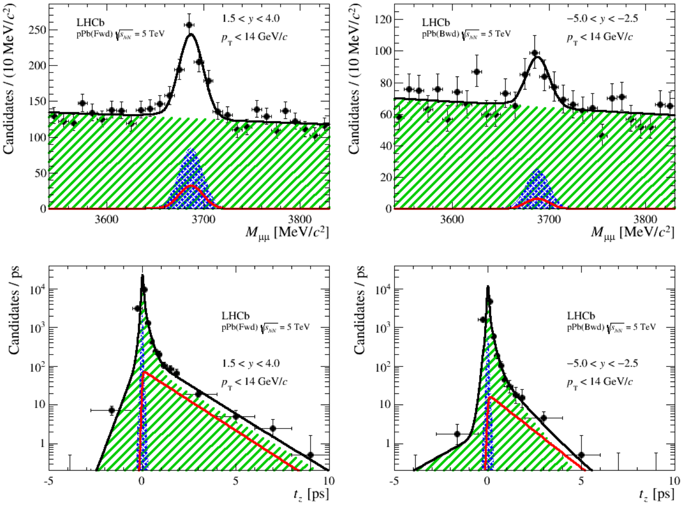
- Differential in p_T and y and Double Differential in both.

JHEP 02 (2014) 72



$\psi(2S) \to \mu^+\mu^-$ in Proton Ion Collisions

- $\psi(2S) \to \mu^+\mu^-$ events
- $1.1\,\mathrm{nb}^{-1}$ ($0.5\,\mathrm{nb}^{-1}$)
- $p_{T,\mu} > 700\,\mathrm{MeV}$
- Prompt and "from b" components separated
- Nuclear Modification Factor is measured relative to J/ψ assuming $\frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi}}$ identical at 5 TeV and 7 TeV

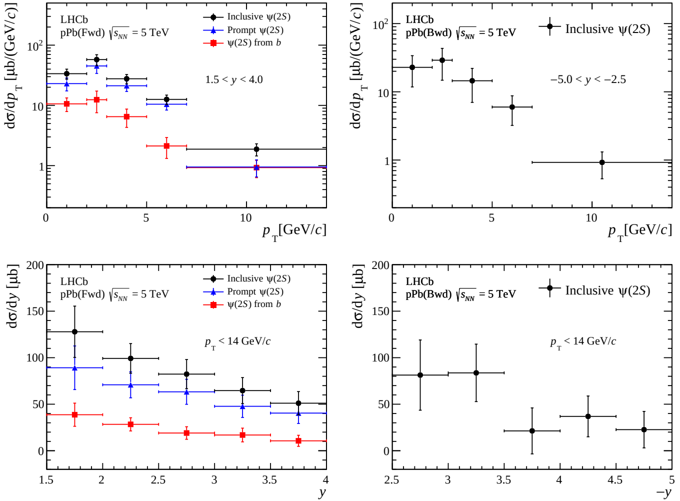


JHEP 03 (2016) 133

$\psi(2S) \to \mu^+\mu^-$ in Proton Ion Collisions

- Differential in p_T and y
- Too few events to separate "from b" component in Backward sample

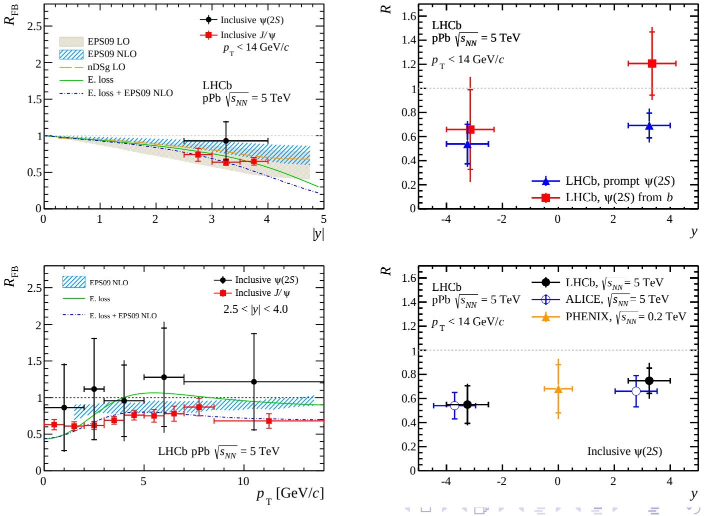
JHEP 03 (2016) 133



$\psi(2S) \to \mu^+\mu^-$ in Proton Ion Collisions

- Nuclear Modification Factor R_{pPb}
- Forward - Backward Ratio R_{FB}

- E. Ferreiro, F. Fleuret, J.P. Lansberg and A. Rakotozafindrabe, Phys. Rev. C 88 (2013) 047901
- J. Albacete et al., Int. J. Mod. Phys. E 22 (2013) 1330007
- F. Arleo and S. Peigné, JHEP 03 (2013) 122
- ALICE Collaboration JHEP 12 (2014) 073
- PHENIX Collaboration Phys. Rev. Lett. 111 (2013) 202301

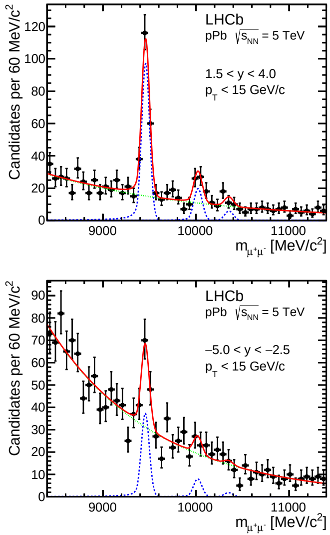


JHEP 03 (2016) 133

$\Upsilon \rightarrow \mu^+\mu^-$ in Proton Ion Collisions

- $\Upsilon \rightarrow \mu^+\mu^-$ events
- $1.1\,\mathrm{nb}^{-1}$ ($0.5\,\mathrm{nb}^{-1}$) fw. (bw.)
- $p_{T,\mu} > 1\,\mathrm{GeV}$

JHEP 07 (2014) 094



$\Upsilon \to \mu^+\mu^-$ in Proton Ion Collisions

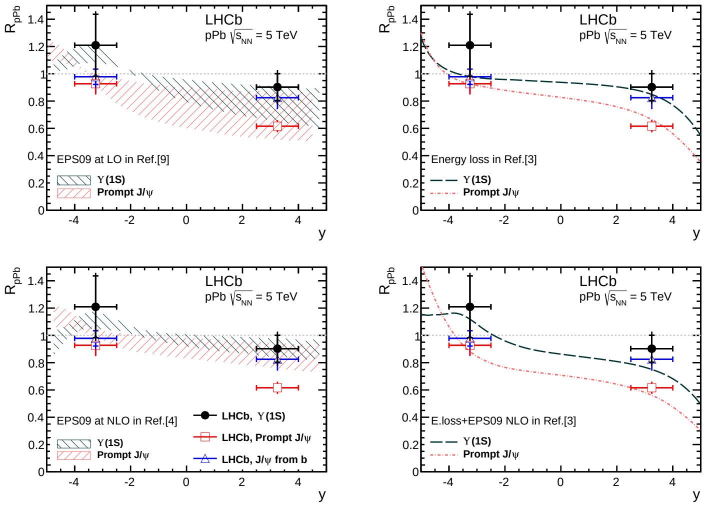
- Nuclear Modification Factor R_{pPb}
- Reference Cross Section: LHCb pp data at 2.76, 7,8 TeV extrapolated to 5 TeV (power-law)

3 J.L. Albacete et al., Int. J. Mod. Phys. E 22 (2013) 1330007

4 A. Adeluyi and T. Nguyen, Phys. Rev.C 87 (2013) 027901

9 D. Kharzeev and H. Satz JHEP07(2014)094 Phys. Lett. B 366 (1996) 316

JHEP 07 (2014) 094



$\Upsilon \to \mu^+\mu^-$ in Proton Ion Collisions

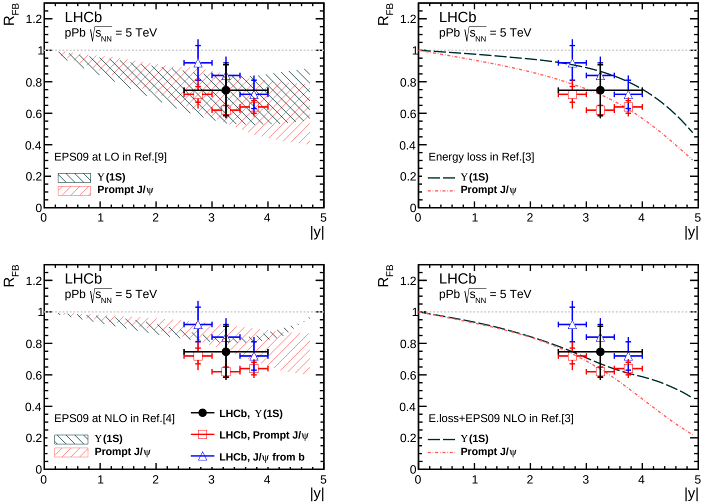
- Forward - Backward Ratio R_{FB}

  3 J.L. Albacete et al., Int. J. Mod. Phys. E 22 (2013) 1330007

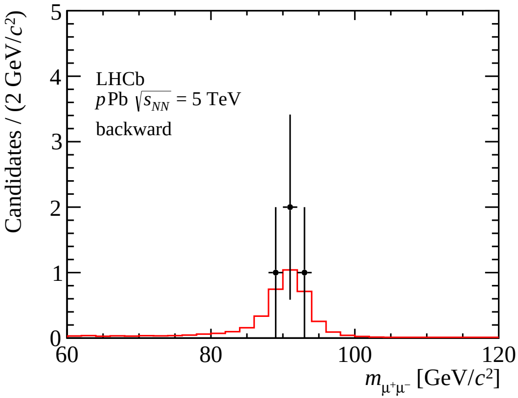
  4 A. Adeluyi and T. Nguyen, Phys. Rev.C 87 (2013) 027901

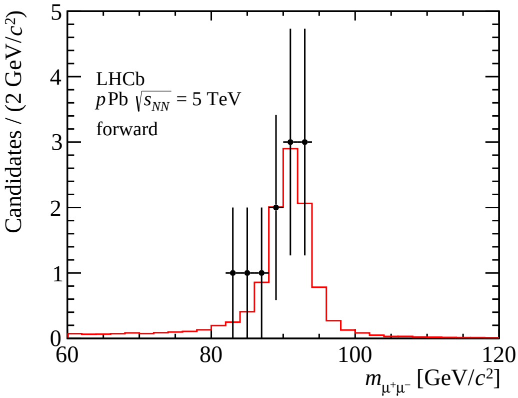
  9 D. Kharzeev and H. Satz JHEP07(2014)094 Phys. Lett. B 366 (1996) 316

JHEP 07 (2014) 094



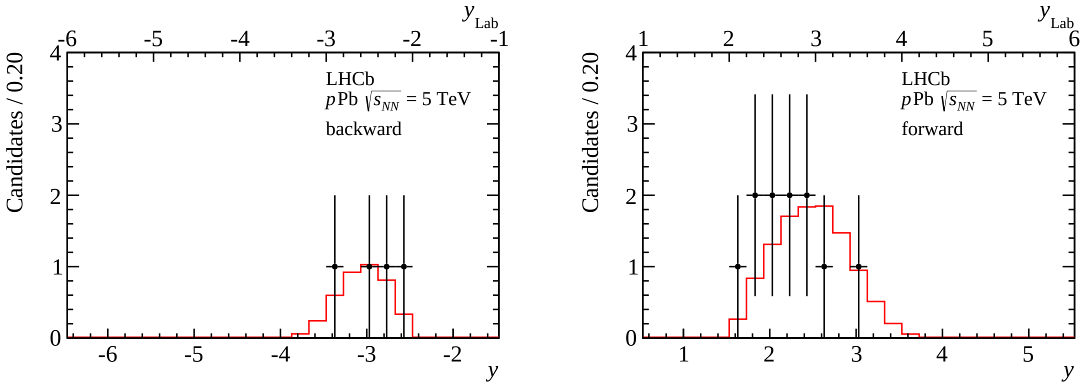
Z in Proton Ion Collisions





- $p_{T,\mu} > 20\,\mathrm{GeV}$, $2 < \eta_{T,\mu} > 4.5$, $60 < m_{\mu^+\mu^-} < 120\,\mathrm{GeV}$
- Purity $\rho > 0.995$
- 4 Backward and 11 Forward Candidates

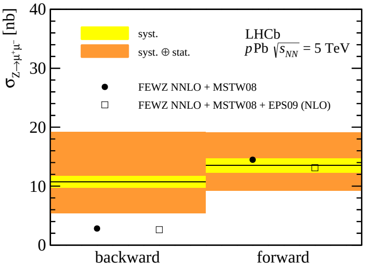
Z in Proton Ion Collisions



- Comparison to PYTHIA 8 (MSTW08)
- In this region nuclear PDFs have large uncertainty

JHEP 09 (2014) 30

Z in Proton Ion Collisions



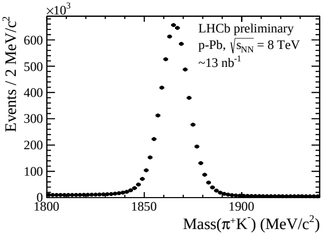
$$\text{Forward} \quad \sigma = 13.5^{+5.4}_{-4.0}(stat) \pm 1.2(syst)\,\mathrm{nb}$$

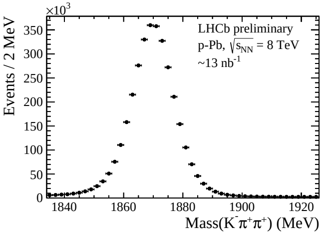
$$\text{Backward} \quad \sigma = 10.7^{+8.4}_{-5.1}(stat) \pm 1.0(syst)\,\mathrm{nb}$$

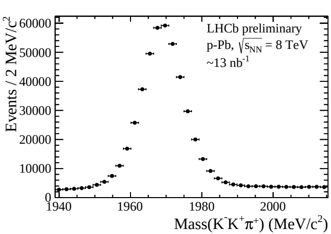
$$R_{FB}(2.5 < |y| < 4.0) = 0.094^{+0.104}_{-0.062}(stat)^{+0.004}_{-0.007}(syst)$$

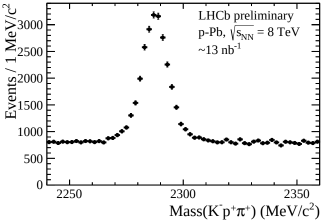
JHEP 09 (2014) 30

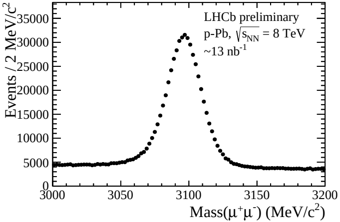
More to come in 8 TeV Proton Lead











The usual suspects are around in big numbers...

Conclusion

- LHCb delivers excellent results on particle and multi particle production in a unique kinematic region
- We have a very diverse data set with pp, pHe, pNe, pAr, pPp and PbPb collisions
- LHCb is a forward general purpose detector
- HeRSCheL will improve LHCbs Diffraction Physics Program
- Many new Results under way

Conclusion

- LHCb delivers excellent results on particle and multi particle production in a unique kinematic region
- We have a very diverse data set with pp, pHe, pNe, pAr, pPp and PbPb collisions
- LHCb is a forward general purpose detector
- HeRSCheL will improve LHCbs Diffraction Physics Program
- Many new Results under way

Thank You!

Table of Contents

Backup Double J/ψ

LO CS A. K. Likhoded, A. V. Luchinsky, and S. V. Poslavsky, *Phys. Rev. D94 (2016) 054017*,

LO CO H.-S. Shao, *Comput. Phys. Commun. 184 (2013) 2562*, *Comput. Phys. Commun. 198 (2016) 238*,

LO k_T J. R. Andersen et al. , Eur. Phys. J. C48 (2006) 53,

NLO CS'* A. K. Likhoded, A. V. Luchinsky, and S. V. Poslavsky, *Phys. Rev. D94 (2016) 054017*,

NLO CS"* L.-P. Sun, H. Han, and K.-T. Chao, *Phys. Rev. D94 (2016) 074033*, J.-P. Lansberg and H.-S. Shao, *Phys. Lett. B751 (2015) 479*, H.-S. Shao, *Comput. Phys. Commun. 184 (2013) 2562*, *Comput. Phys. Commun. 198 (2016) 238*, J.-P. Lansberg and H.-S. Shao, *Phys. Rev. Lett. 111 (2013) 122001*, *Nucl. Phys. B900 (2015) 273*

DPS CDF collaboration, *Phys. Rev. Lett. 79 (1997) 584.*, LHCb collaboration, *JHEP 10 (2015) 172*, CDF collaboration, *Phys. Rev.D56(1997) 3811.*

back