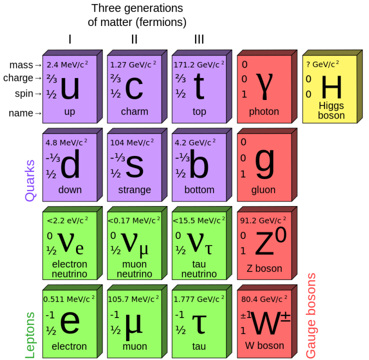
Physics Highlights from the LHCb Experiment

Michael Schmelling – MPI for Nuclear Physics

Outline

- Introduction
- The LHCb Detector
- Flavour Physics and Spectroscopy
- Ion Physics
- New Developments
- Summary and Outlook

➜ *an extremely successful theory: the Standard Model*



➜ *unexplained findings:*

- 1 fundamental scalar
- 2 types of fermions
- 3 generations
- 4 fermions/generation
- 3 gauge interactions
- 4 gauge bosons

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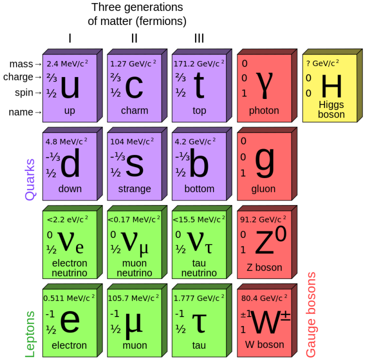

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➜ *some of today's big physics questions . . .*

What is the origin of mass?

➜ *how do fundamental particles acquire mass?*

- Standard Model: Higgs mechanism
  - ➜ space is filled with a Higgs background field
  - ➜ mass arises as resistance to movement through this field
  - ➜ if the model is correct, then a Higgs particle must exists
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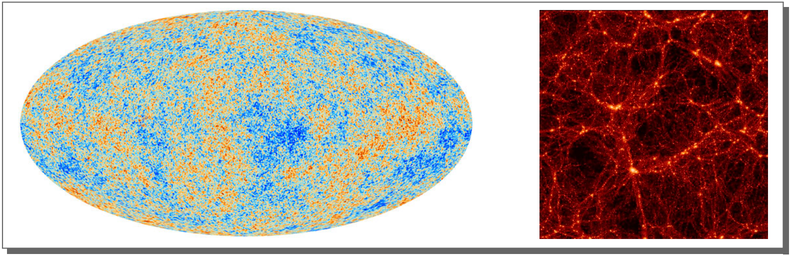
➜ *what determines the mass values?*

- the Higgs mechanism does not predict mass values
- understanding mass hierarchy requires New Physics
  - ➜ new (heavy) particles and fields
  - ➜ rich new phenomenology

cosmic microwave background & structure formation:



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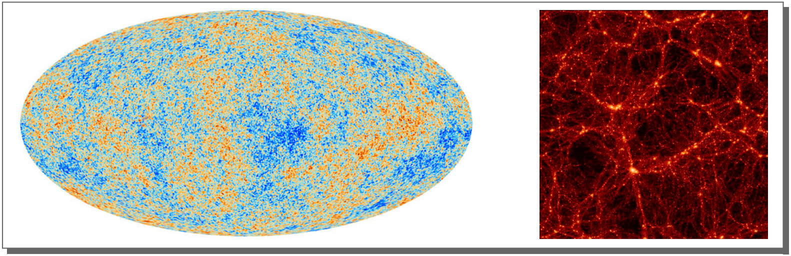
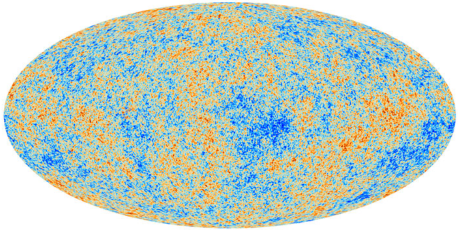
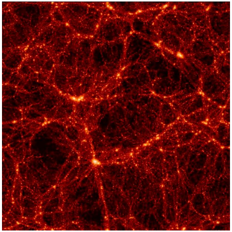


- the universe is “flat” (euclidean)

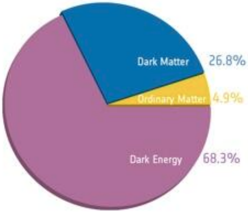
What is Dark Matter made of?

➜ *cosmic microwave background & structure formation:*





- the universe is “flat” (euclidean)
- its energy content is [Planck]
  - ➜ 68.3% dark energy
  - ➜ 4.9% ordinary matter
  - ➜ 26.8% dark matter (heavy particles?)



Where is the Antimatter?

➜ *the puzzle*

- antimatter (in small quantities) is observed in lab-experiments
- always same amounts of matter and antimatter created
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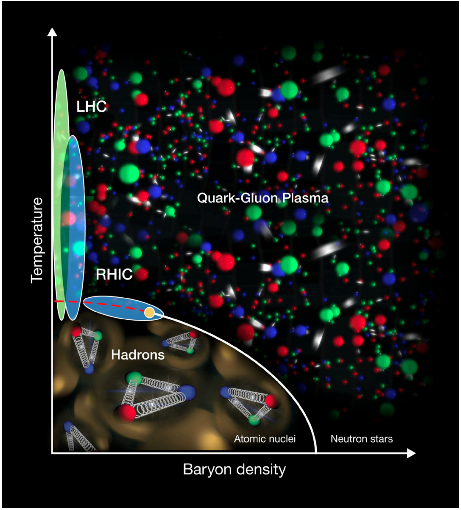
(image: HST)

- no evidence for anti-matter annihilation radiation
- no evidence for anti-nuclei in cosmic rays

Properties of matter at extreme conditions?



➜ *open questions*

- behaviour of hadronic matter
  - ➜ at extreme densities
  - ➜ at extreme temperatures
- study phase transitions
  - ➜ deconfinement
  - ➜ order of phase transition

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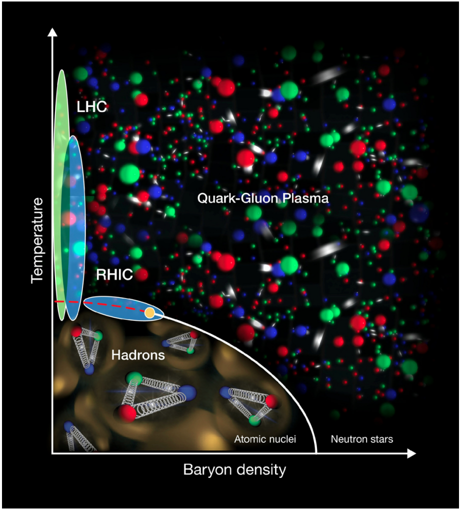

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❖ ultimate goal:

understanding of our universe from the big bang until today

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  - ➜ probe by precision measurements in flavour physics (LHCb)
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    - weak interaction couples to all known fields
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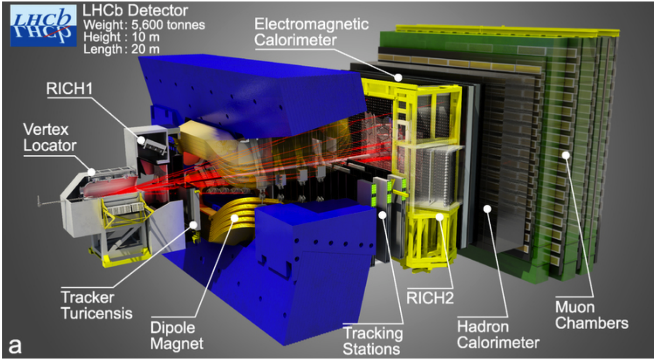
- strong interaction physics
  - ➜ the QCD Lagrangian is well known and tested
  - ➜ many open questions in the non-perturbative regime
    - ◆ soft processes and bound states
    - ◆ Quark Gluon Plasma - high densities and temperatures (ALICE)

2. THE LHCb DETECTOR

- forward spectrometer with $15 < \Theta < 300$ mrad and $\int Bdl = 4$ Tm



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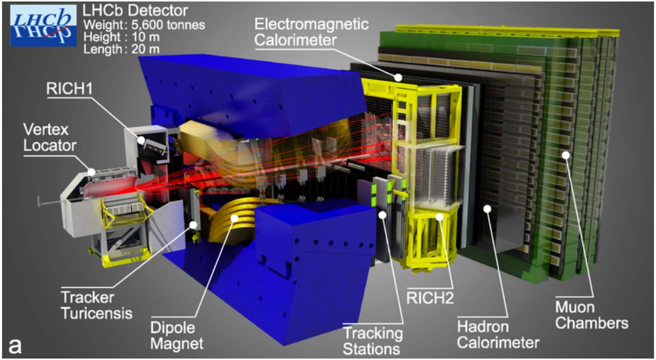
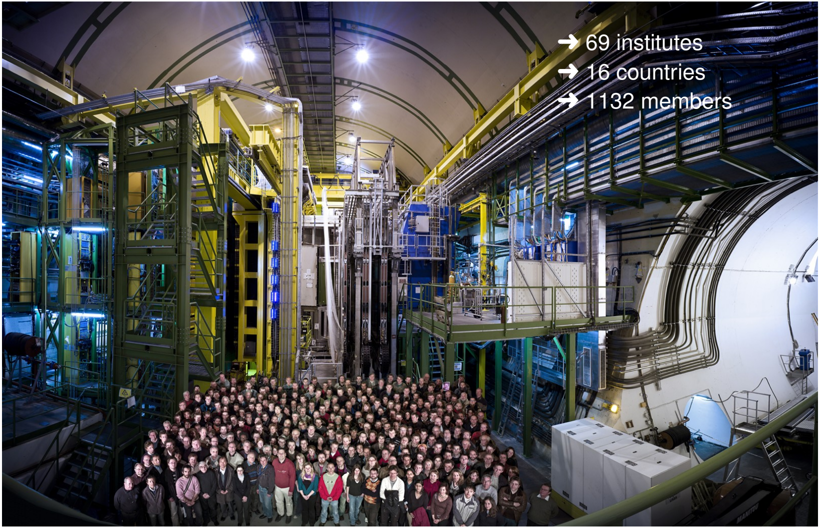


- VELO: silicon strip detector for precise secondary vertex reconstruction
- TT,T1,T2,T2: tracking stations, silicon strip and straws for charged particles
- RICH1, RICH2: ring imaging cherenkov detectors for $\pi / K / p$-separation
- ECAL, HCAL: electromagnetic & hadronic calorimeters for trigger and neutrals
- M1-M5: tracking stations for muon identification

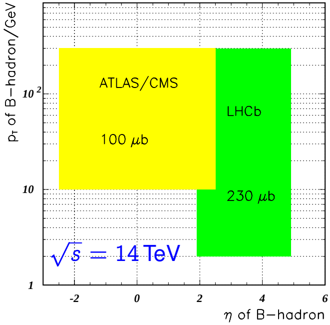
Installation in the cavern

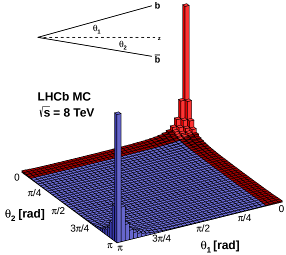


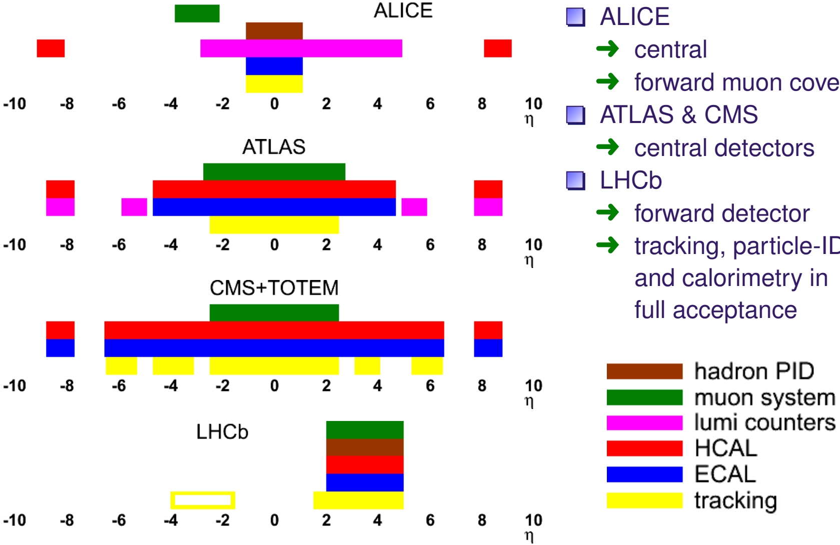
Inside the spectrometer magnet

➜ *optimization for B-Physics – but can do much more*

- forward angular coverage ➜ large boosts: B decay lengths O(1 cm)
- focus on vertex reconstruction and particle identification
- phase space coverage down to low p_T, small x_{Bj} and large η
- flexible and highly selective trigger

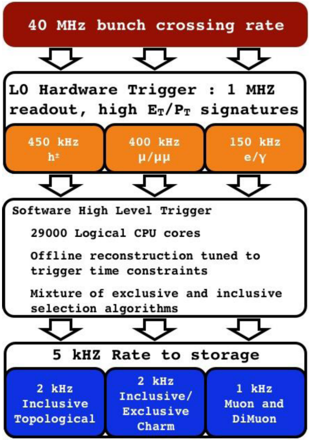






- ALICE
  - ➜ central
  - ➜ forward muon coverage
- ATLAS & CMS
  - ➜ central detectors
- LHCb
  - ➜ forward detector
  - ➜ tracking, particle-ID and calorimetry in full acceptance

The LHCb trigger



ca. 50 kB/event

➜ *allow selection of rare processes*

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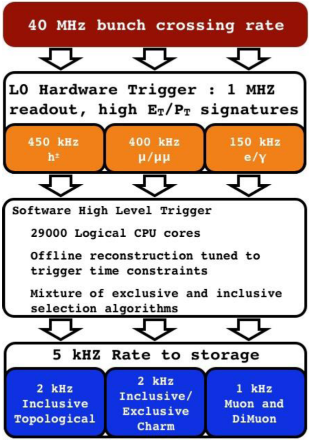

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➜ *allow selection of rare processes*

- Level-0 Trigger: hardware
  - ➜ fully synchronous at 40 MHz
  - ➜ use calorimeters and muon system
  - ➜ selection of high-p_T particles
    - $p_T(\mu) > O(1)$ GeV/c
    - $p_T(h, e, \gamma) > O(3)$ GeV/c

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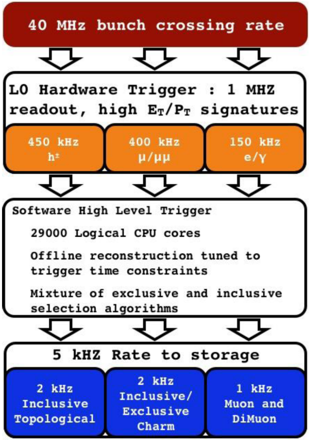

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- High-Level Trigger: software
  - ➜ HLT1: add VELO information
    - impact parameter- and lifetime cuts
  - ➜ HLT2: global event reconstruction
    - exclusive & inclusive selections

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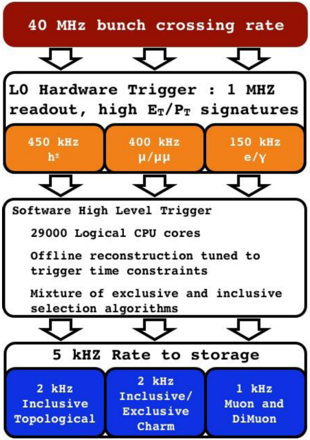

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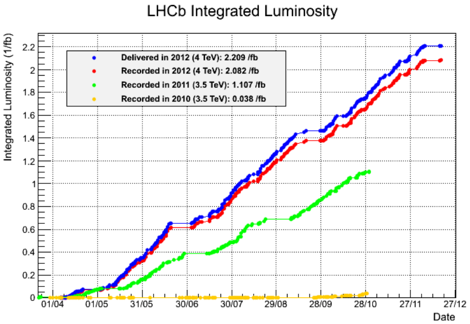
    - exclusive & inclusive selections
- up to $O(30)$ kHz “deferred” triggering

Run-I LHCb data taking history



- DAQ efficiency $\approx$ 95%
- instantaneous luminosity up to $L = 4 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - ➜ twice design value at double the nominal bunch spacing
  - ➜ luminosity leveling for LHCb by beam steering
- a total of 2×10^{14} pp-collisions scrutinized

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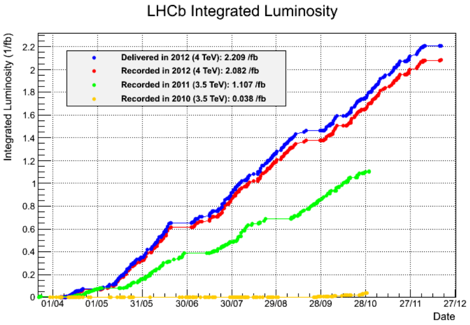

year	luminosity	E[TeV]
2009	$6.8\,\mu b^{-1}$	0.9
2010	$0.3\,nb^{-1}$	0.9
2010	$0.37\,pb^{-1}$	7
2011	$0.1\,pb^{-1}$	2.76
2011	$1\,fb^{-1}$	7
2012	$2\,fb^{-1}$	8
2013	$1.3\,nb^{-1}$	5 (pA)
2013	$0.6\,nb^{-1}$	5 (Ap)

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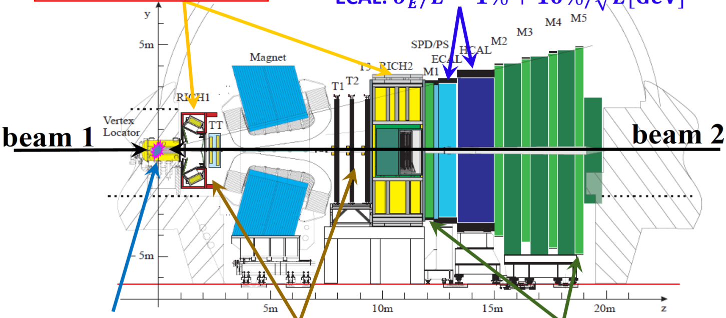
LHCb detector performance

JINST 3 (2008) S08005

Pseudorapidity acceptance
$2 < \eta < 5$

RICH1 & RICH2
$\epsilon(K \to K) \sim 95\%$
$\pi \to K$ mis-id: $\sim 5\%$

Calorimeters
ECAL: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\mathrm{GeV}]}$



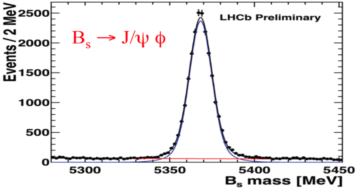
Int.J.Mod.Phys.A 30(2015)1530022

VELO
$\sigma_{IP} \sim 20\ \mu\mathrm{m}$
for high-p_T tracks

Tracking System
$\Delta p/p = 0.4\%@5\ \mathrm{GeV}/c$
to $0.6\%@100\ \mathrm{GeV}/c$

Muon System
$\epsilon(\mu \to \mu) \sim 97\%$
$\pi \to \mu$ mis-id: $1 \sim 3\%$

- excellent mass resolution for complex decays



➜ B-mass resolution:
$\sigma(m_B) = 8\,\mathrm{MeV}/c^2$
for $B_s \to J/\psi X$
with J/ψ mass constraint

Tracking, vertexing and PID performance

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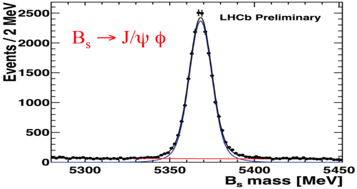

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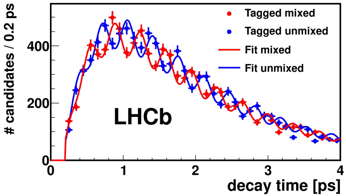

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$\sigma_t \sim 45\,\mathrm{fs}$
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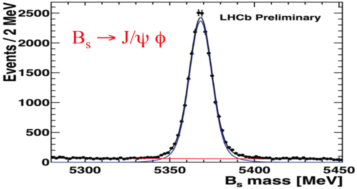

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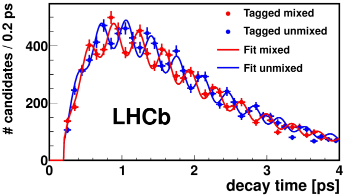

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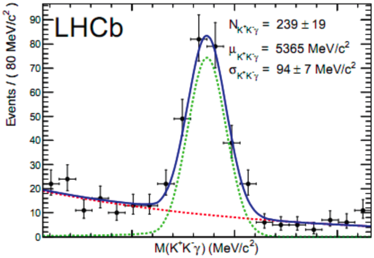
❖ particle identification essential to reconstruct decay modes
❖ polarity switching of dipol magnet allows to control systematics

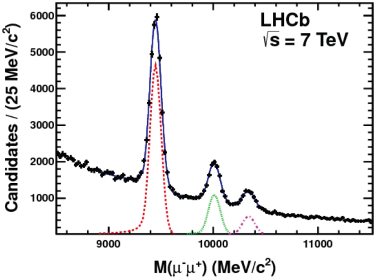
- ECAL: optimized to measure radiative B-decays
- HCAL: for triggering on hadronic final states
- Muon system for quarkonium and semi-leptonic decays

$B_s \to \phi\,\gamma$



[arXiv:1202.6267]

$\Upsilon \to \mu^+\mu^-$



[arXiv: 1202.6579]

➜ *only part of the current LHCb physics portfolio. . .*

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  - ➜ particle production, particle ratios, forward energy flow
  - ➜ b- and c-hadron spectroscopy
  - ➜ charmonium, bottomonium
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  - ➜ rare decays
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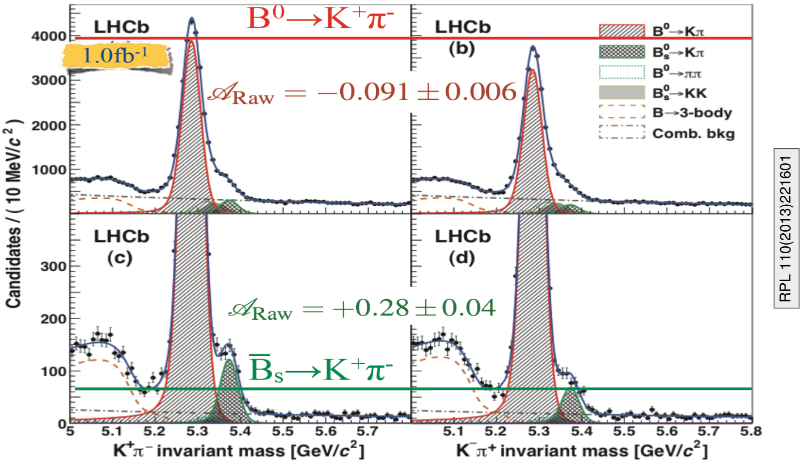
a few selected topics ➜

Direct CP-violation in B-decays

→ study $B_d, \bar{B}_s \to K^+\pi^- + c.c.$ decays



Results based on 1 fb^{-1}

→ *corrections for detector and production asymmetries*

$$A_{CP} = A_{\mathrm{raw}} - (A_{\mathrm{det}} + A_{\mathrm{prod}})$$

- LHCb made of matter
- LHCb not perfectly symmetric for positive and negative tracks
- initial pp state is purely matter

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➜ *most precise single measurement in B_d system*

$$A_{CP} = \frac{\Gamma(\overline{B}_d \to K^-\pi^+) - \Gamma(B_d \to K^+\pi^-)}{\Gamma(\overline{B}_d \to K^-\pi^+) + \Gamma(B_d \to K^+\pi^-)} = -0.080 \pm 0.007_{\mathrm{stat}} \pm 0.003_{\mathrm{syst}}$$

- dominant systematics from detector and production asymmetries

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→ *first observation of CPV in B_s system*

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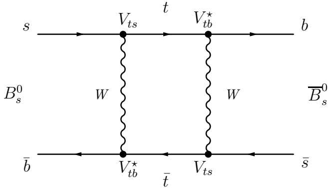
- dominant systematics from fit model

The B_s-mixing frequency

→ *measure by means of flavour-specific B_s-decays*

- second-order weak process
- only small phase from CKM-couplings
- decay modes studied
  - → $B_s^0(\bar{b}s) \to D_s^-(\bar{c}s)\,\pi^+$
  - → $\bar{B}_s^0(b\bar{s}) \to D_s^+(c\bar{s})\,\pi^-$



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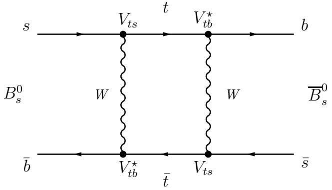
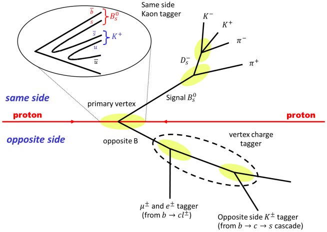
  - ➜ $\bar{B}_s^0(b\bar{s}) \to D_s^+(c\bar{s})\,\pi^-$





- flavour tagging of initial state
  - ➜ opposite side taggers: partial reconstruction of 2nd B-hadron
  - ➜ same side kaon tagger: self-tagging from hadronization
  - ➜ combined tagging power: $\varepsilon(1-2\omega)^2 = 3.5 \pm 0.5\,\%$

➜ *measure by means of flavour-specific B_s-decays*

- second-order weak process
- only small phase from CKM-couplings
- decay modes studied
  - ➜ $B_s^0(\bar{b}s) \to D_s^-(\bar{c}s)\,\pi^+$
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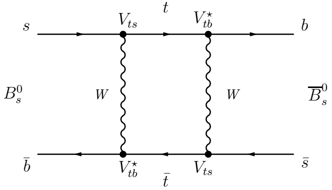

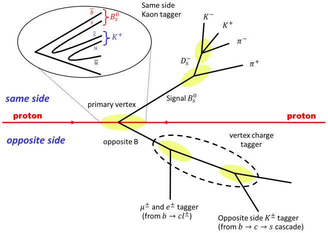

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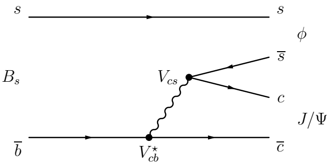
  - ➜ combined tagging power:
    $\varepsilon(1 - 2\omega)^2 = 3.5 \pm 0.5\,\%$

result: $\Delta m_s = 17.768 \pm 0.023 \pm 0.006\,\text{ps}^{-1}$

NJP 15(2013)053021

The "golden" decay $B_s \to J/\psi\phi$

→ *CP-violation from interference between mixing and decay*



- SM-dominated tree-level decay
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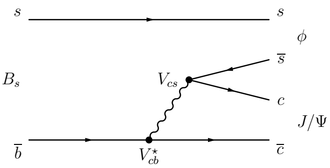
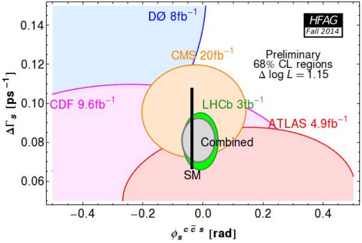


- SM-dominated tree-level decay
- small SM phase between mixing & decay
  - → "null-test" of the Standard Model
  - → sensitive to New Physics in mixing

- measure mixing phase and lifetime-difference
- study flavour symmetric decay modes
  - → $B_s \to J/\psi\phi$, $B_s \to J/\psi\pi^+\pi^-$
- LHCb analysis for vector-vector states
  - → $\phi_s = -0.010 \pm 0.039\,\text{rad}$
  - → $\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007\,\text{ps}^{-1}$

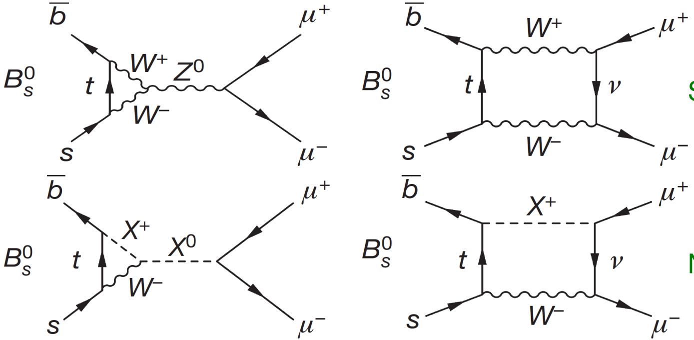
  consistent with Standard Model



PLB 736(2014)186

The rare decays $B_{d,s} \to \mu^+\mu^-$

→ *very rare FCNC decays*



Standard Model

New Physics

The rare decays $B_{d,s} \to \mu^+\mu^-$

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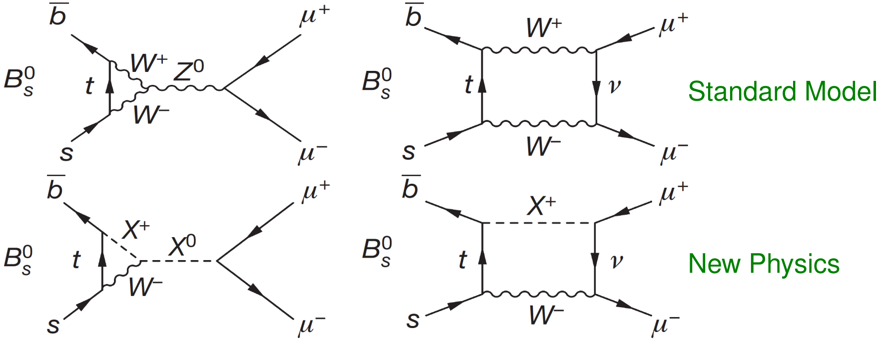


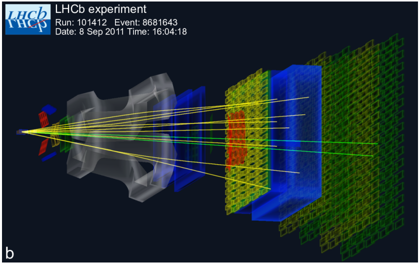
- SM prediction PRL 112(2014)101801 [Eur.Phys.J. C72(2012)2172]

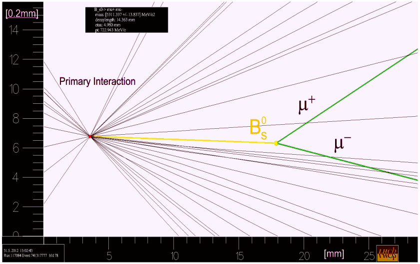
  $BR(B_s \to \mu^+\mu^-) = (3.66 \pm 0.23) \cdot 10^{-9}$ $[(3.23 \pm 0.27) \cdot 10^{-9}]$

  $BR(B_d \to \mu^+\mu^-) = (1.06 \pm 0.09) \cdot 10^{-10}$ $[(1.07 \pm 0.10) \cdot 10^{-10}]$

- possibly strong enhancements in MSSM $BR(B \to \mu^+\mu^-) \propto \tan^6\beta$

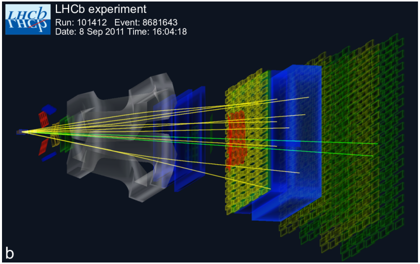
➜ *clean signature*

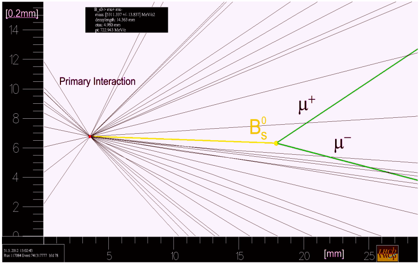




experimental aspects

➜ *clean signature*





- challenging analysis since also rare background processes contribute
  - ➜ random combinatorial background
  - ➜ semileptonic decays with misidentified hadron, e.g. $B^0 \to \pi^- \mu^+ \nu$
  - ➜ two-body decays with misidentified daughters e.g. $B^0 \to K^+ \pi^-$

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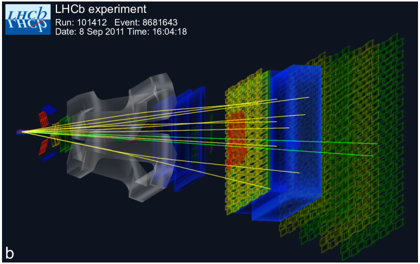

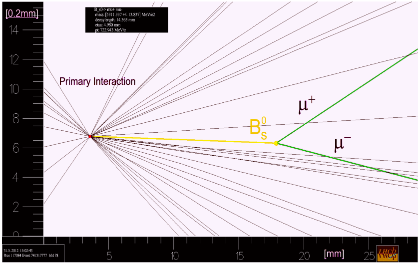

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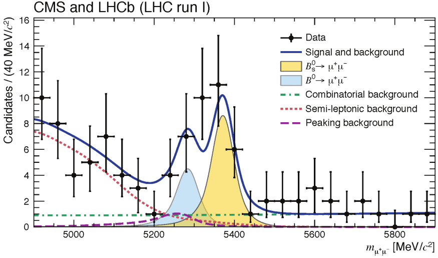
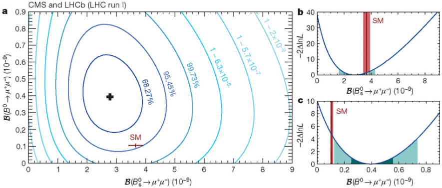
  - ➜ two-body decays with misidentified daughters e.g. $B^0 \to K^+ \pi^-$
- multivariate classifiers (geometrical likelihood, BDT)
- evidence (<5σ) for the decay by LHCb (3 fb^{-1}) and CMS (25 fb^{-1})

→ *final result from LHC Run-I*





Nature 522(2015)68

- 6.2σ observation of $B_s \to \mu^+\mu^-$

  $BR(B_s \to \mu^+\mu^-) = (2.8 \pm^{0.7}_{0.6}) \cdot 10^{-9}$

  → consistent with Standard Model
- 3.2σ evidence for $B_d \to \mu^+\mu^-$

  $BR(B_d \to \mu^+\mu^-) = (3.9 \pm^{1.6}_{1.4}) \cdot 10^{-10}$

  → larger than SM expectation

  but still compatible
- statistics limited result

  → $\sigma_{\mathrm{experiment}} > \sigma_{\mathrm{theory}}$

  → include Run-II data . . .

Implications of the results for SUSY

- strong constraints on New Physics
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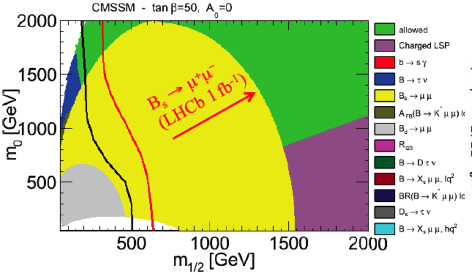
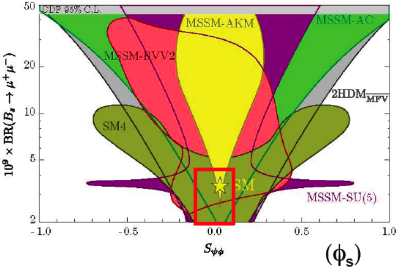
Implications of the results for SUSY

- strong constraints on New Physics
- complementary approach to direct searches by GPDs
- two recent examples:
  - ➜ limits on MSSM mass-scales from $B_s \to \mu^+\mu^-$
  - ➜ accessible $\{\phi_s, BR(B_s \to \mu^+\mu^-)\}$ range for various models

[N. Mahmoudi, Moriond QCD]



[D. Straub, arXiv:1107.0266]



limits based on summer 2012 data

The $X(3872)$ state

➜ *determination of the quantum numbers of the X(3872)*

- exotic state which does not fit into the standard scheme of hadrons
- first observed by Belle: $B^+ \to X(3872)K^+ \to (J/\psi\pi^+\pi^-)K^+$
- quantum numbers limited to J$^{PC} = 1^{++}$ or J$^{PC} = 2^{-+}$ by CDF

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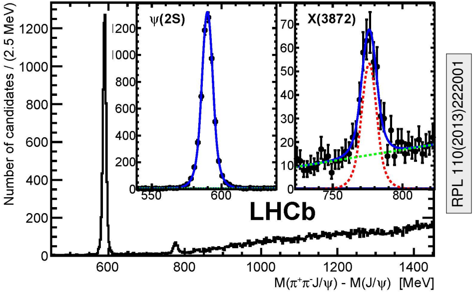


➜ clean signal seen by LHCb

➜ interpretation open

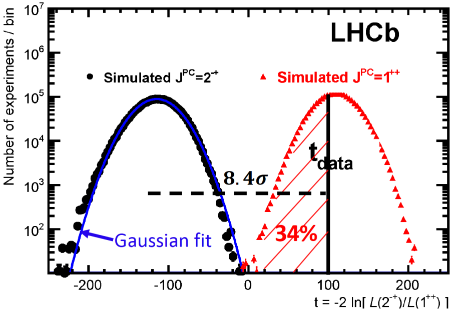
- $D\bar{D}$ molecule (?)
- tetra-quark state (?)

➜ enough statistics to test quantum number assignments

Quantum numbers of the X(3872)

➜ *likelihood-ratio test to decide between hypotheses*

- full 5-dim space of helicity angles
- test variable $t = -2\ln L(2^{-+})/L(1^{++})$



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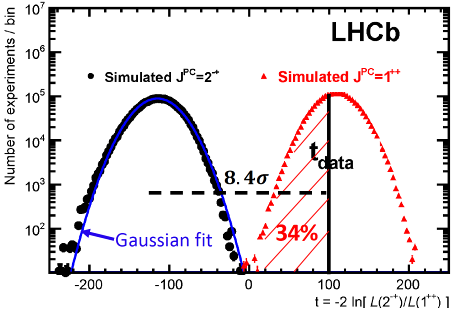
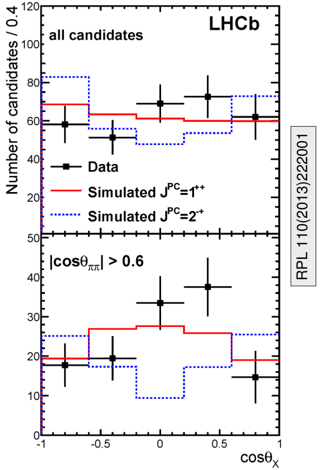


projections on $\cos\Theta_X$

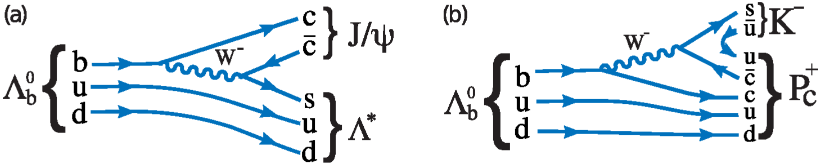


→ 8-sigma exclusion of $J^{PC} = 2^{-+}$

→ p-value $p = 0.34$ for $J^{PC} = 1^{++}$

New and unexpected resonances

➜ *discovery in* $\Lambda_b \rightarrow J/\psi p K$ *decays*



expected **discovered**

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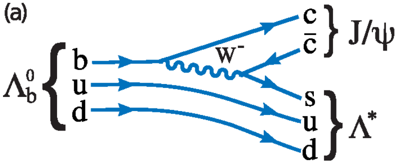

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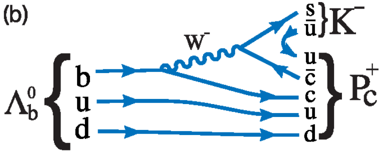
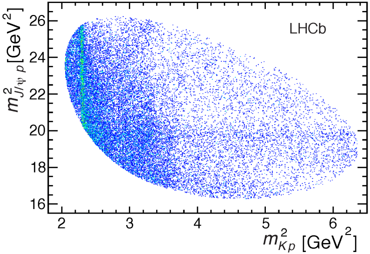


discovered

- reconstruct J/ψ in $\mu^+\mu^-$
- look for Λ^* states in pK decay
- study Dalitz plot



arXiv:1507.03414

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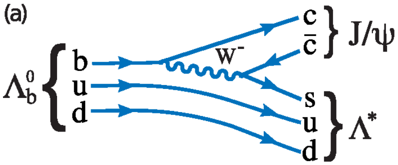
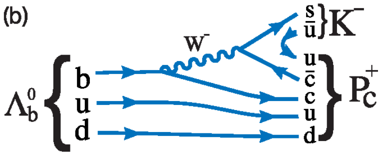


expected



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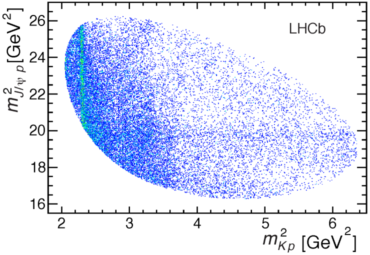
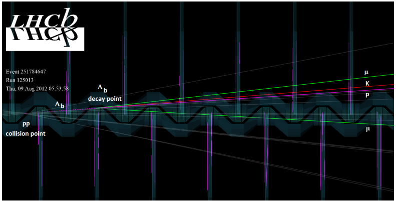


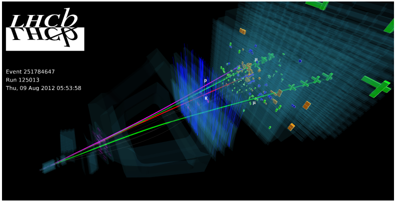
arXiv:1507.03414

➜ *unexpected structure in $J/\psi p$*

- ➜ narrow resonance
- ➜ baryon
- ➜ new particle or artefact?

➜ *event displays*





- clean signatures

Checks

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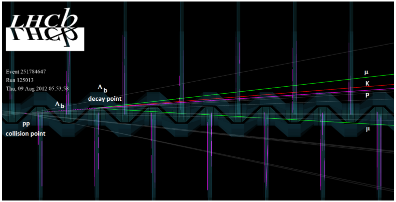
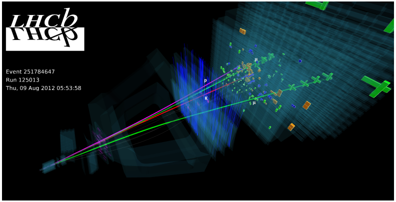
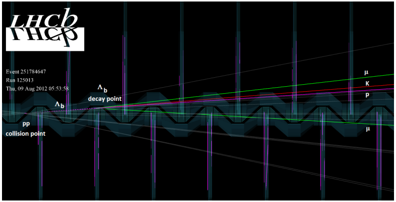


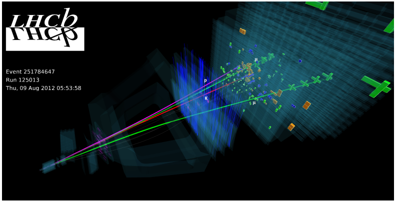


- clean signatures
- check that the signal is no kinematic reflection
  ➜ $J/\psi \to \mu^+\mu^-$, clone μ^+ and assign proton mass ➜ passed

Checks

➜ *event displays*





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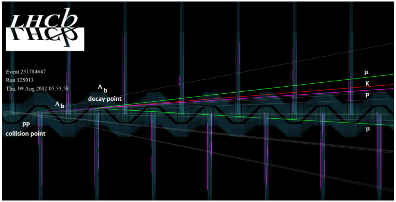

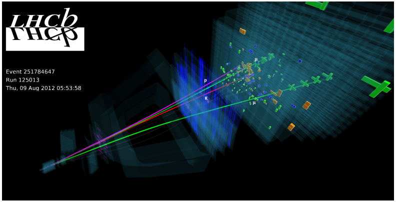

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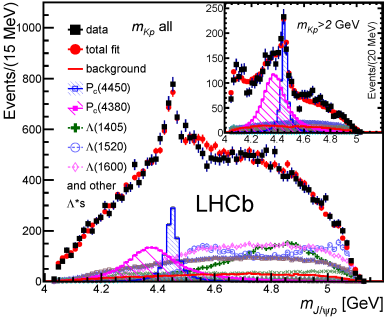
- check that the signal is no detector artefact
  - ➜ signal independent of the azimuth around the beam ➜ passed
- many other checks ➜ passed

try to understand the mass spectrum ➜

The invariant mass spectrum



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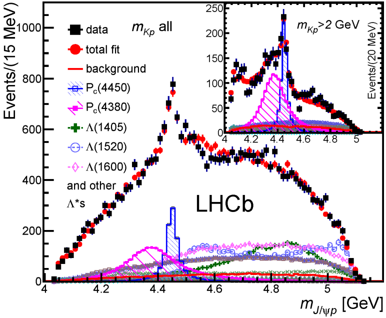

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  - ➜ require a narrow state $P_c(4450)$ and a wide state $P_c(4380)$

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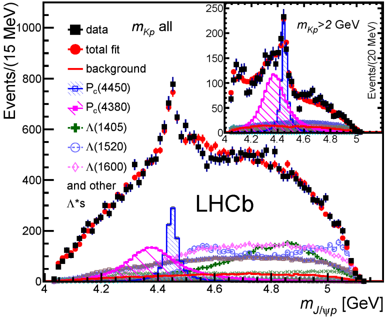

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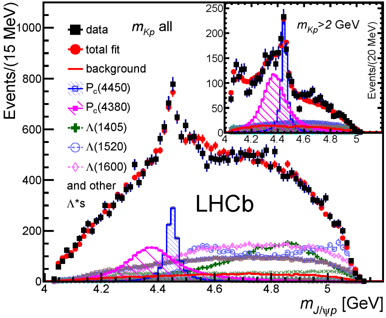

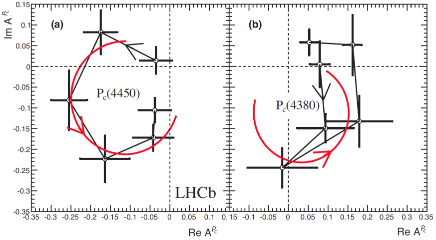

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- fit OK but not perfect
  - ➜ high-mass spectrum better described when omitting light Λ^* states
- important check: phase motion of amplitudes over the resonance ➜ passed

Results and interpretation

➜ *two new resonances*

	$P_c(4380)^+$	$P_c(4450)^+$
significance	9 σ	12 σ
mass	$4380 \pm 8 \pm 29$ MeV	$4449.8 \pm 1.7 \pm 2.5$ MeV
width	$205 \pm 18 \pm 86$ MeV	$39 \pm 5 \pm 19$ MeV
fit fractions	$8.4 \pm 0.7 \pm 4.2\%$	$4.1 \pm 0.5 \pm 1.1\%$
best fit J^P	$3/2^-$	$5/2^+$

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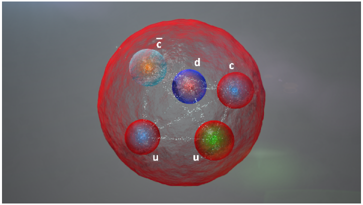
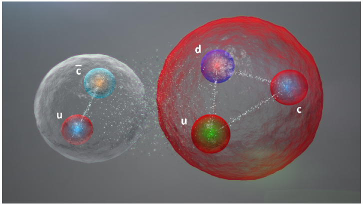
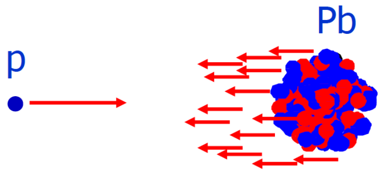
- alternative spin-parity assignments have almost the same fit quality
- discussion on the interpretation has started. . .





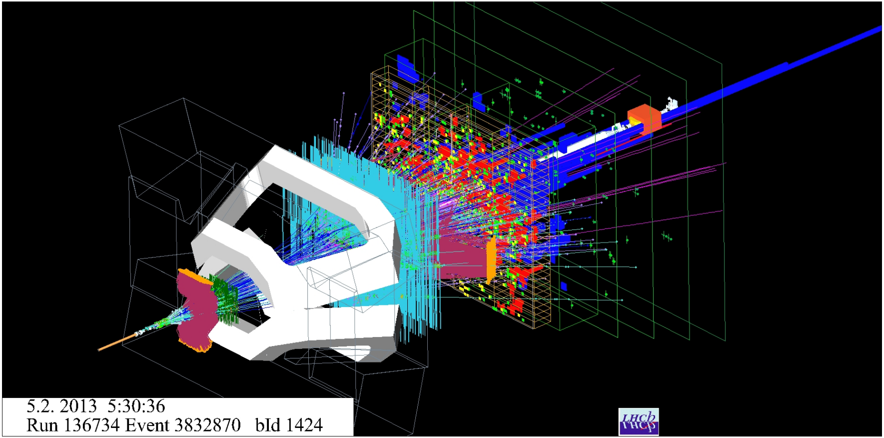
e.g. $\overline{D}^* \Sigma_c - \overline{D}^* \Sigma_c^*$ (arXiv:1507.04249)

→ *measure quarkonium production in p-Pb and compare to pp*



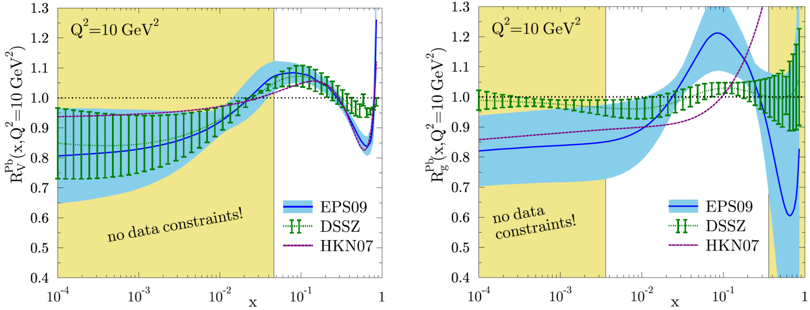
- pA collisions are an ideal laboratory to probe cold nuclear effects, e.g.
  - → parton shadowing as parameterized in nuclear PDFs
  - → (coherent) energy loss
- needed for the interpretation of quark-gluon-plasma signatures in heavy-ion collisions
- measure quarkonium states (J/ψ, Υ) to probe the hadronic environment
- combine information to disentangle shadowing and energy loss
  - → e.g. differentiate between prompt J/ψ and J/ψ from b

A typical pPb interaction



Current knowledge of nuclear PDFs

➜ *ratios of nucleon PDFs:* $F_N(\mathrm{Pb}) / F_N(\mathrm{free})$



- currently still large unexplored regions
- access to nuclear structure via inclusive production of heavy systems

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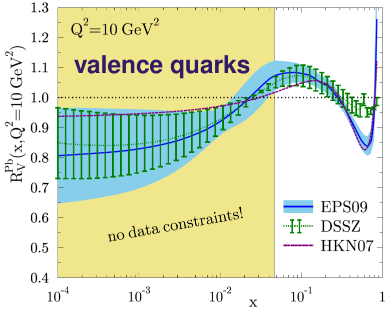
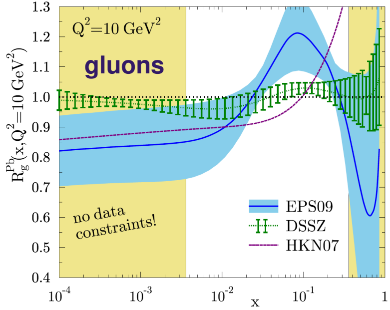




arXiv:1401.2345

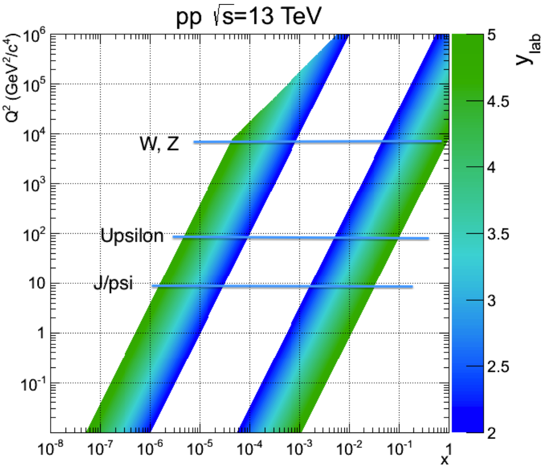
- currently still large unexplored regions
- access to nuclear structure via inclusive production of heavy systems

➜ *kinematics - ignoring masses and transverse momenta*

$$x_1\, x_2 = \frac{Q^2}{s} \quad \text{and} \quad \frac{x_1}{x_2} = e^{2\,y}$$

Accessible phase space

➜ *proton-proton collisions at* $\sqrt{s} = 13$ *TeV*

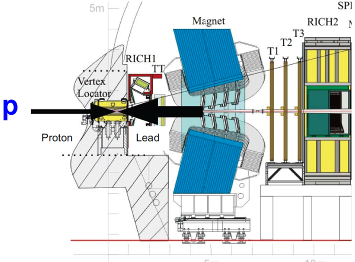


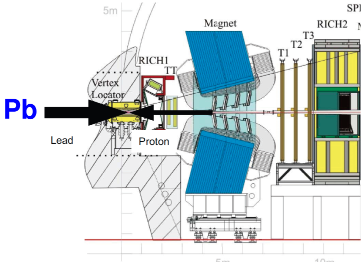
❖ combination of Drell-Yan, J/ψ, Υ and Z probes $10^{-6} \lesssim x \lesssim 1.0$

nuclear modification factor: $$R_{pA}(y) = \frac{1}{A} \cdot \frac{d\sigma_{pA}/dy}{d\sigma_{pp}/dy}$$

forward-backward asymmetry: $$R_{FB}(y) = \frac{R_{pA}(+|y|)}{R_{pA}(-|y|)}$$

- positive rapidity in direction of the proton
- pp cross-section cancels in R_{FB}
- exploit asymmetric layout of LHCb to measure forward and backward

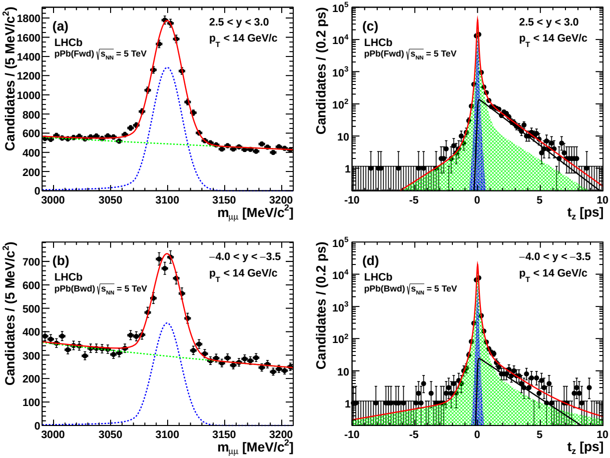




results from 1.6 nb^{-1} pPb-data recorded in 2013 ➜

Separating prompt and delayed components

simultaneous fit of mass and pseudo-proper-time $t_z = (z_{J/\psi} - z_{PV}) \cdot M_{J/\psi}/p_z$



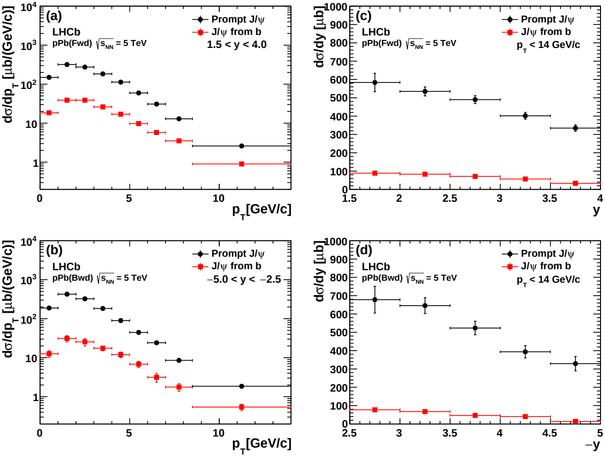
pA collisions:
forward hemisphere
$2.5 < y < 3.0$
$p_T < 14\,\mathrm{GeV}/c$

Ap collisions:
backward hemisphere
$-4.0 < y < -3.5$
$p_T < 14\,\mathrm{GeV}/c$

JHEP02(2014)072

Single differential cross-sections

❖ $\sqrt{s} = 5\,\text{TeV}$, transverse momentum $0 < p_T < 14\,\text{GeV}/c$

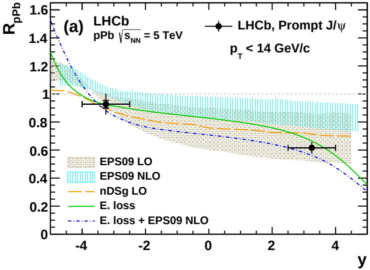


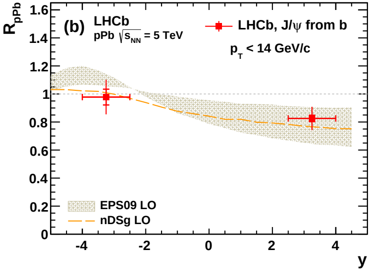
pA collisions:
forward hemisphere
$1.5 < y < 4.0$

Ap collisions:
backward hemisphere
$-5.0 < y < -2.5$

JHEP02(2014)072

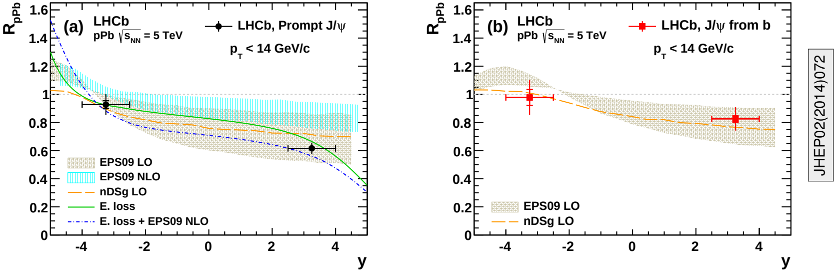
➜ *common range of forward and backward acceptance:* $2.5 < |y| < 4.0$





Results: nuclear modification factors

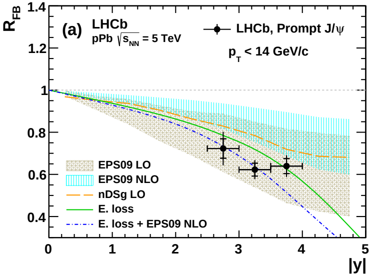
➜ *common range of forward and backward acceptance:* $2.5 < |y| < 4.0$

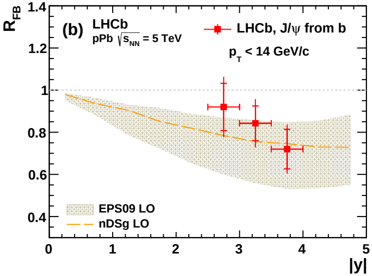


- results require interpolation of pp cross-section to $\sqrt{s} = 5$ TeV
- $R_{pPb} \neq 1$: the nucleus is not a loose collection of independent nucleons
- tighter bound B-mesons less affected than prompt J/ψ
- energy loss and shadowing are about equally important
- J/ψ data agree with “energy loss + NLO shadowing”

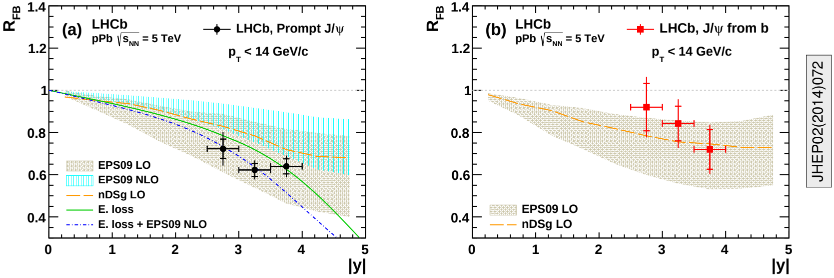
Results: forward-backward asymmetries

➜ *interpolated pp cross-section not required*





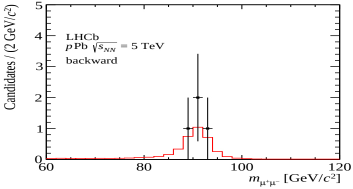
→ *interpolated pp cross-section not required*

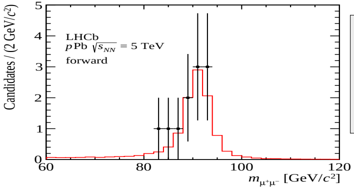


- differential measurement in $|y|$
- same observations/conclusions as for R_{pPb}
- $\Upsilon(1S)$ (not shown) similar to J/ψ from B

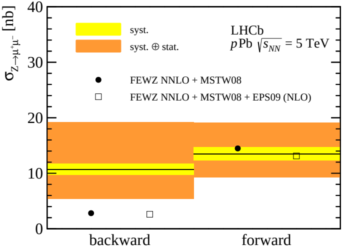
Z production in pA collisions

➜ *clean signals: 4 backward-candidates, 11 forward-candidates*





arXiv:1406.2885



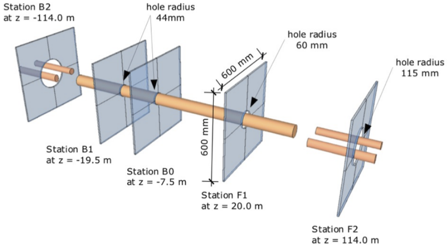
➜ *muon selection*

- $p_T > 20\,\text{GeV}/c$, $2.0 < \eta < 4.5$
- $60 < M(\mu^+\mu^-) < 120\,\text{GeV}/c^2$

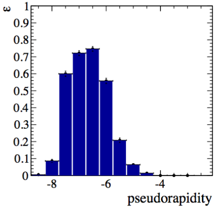
➜ *cross-section results*

$$\sigma_{\text{fwd}} = 13.5 \pm^{5.4}_{4.0}\text{(stat)} \pm 1.2\text{(syst)}\,\text{nb}$$
$$\sigma_{\text{bwd}} = 10.7 \pm^{8.4}_{5.1}\text{(stat)} \pm 1.0\text{(syst)}\,\text{nb}$$

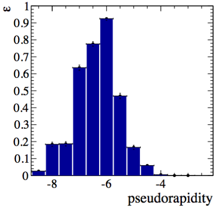
➜ HeRSCheL: High Rapidity Shower Counters for LHCb



- forward scintillators for selecting rapidity gaps
- up to ± 114 m from IP
- central region not covered
- gap size $2 < \eta < 8$
  - ➜ huge gain for diffractive physics and central exclusive production (e.g. J/ψ photoproduction on the proton in pA)



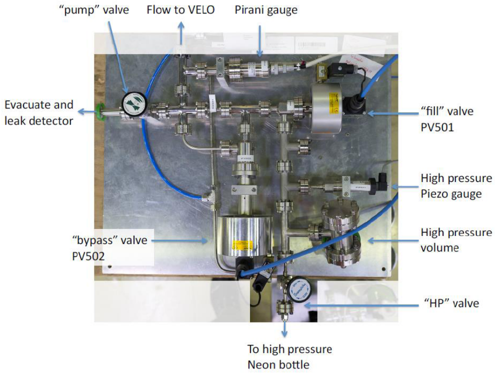
$p_T > 0.5\,\mathrm{GeV}/c$



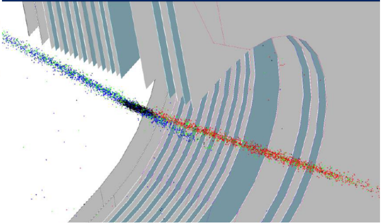
$p_T > 1.5\,\mathrm{GeV}/c$

LHCb simulation results for the efficiency to see charged pions

➜ SMOG: System for Measuring Overlap with Gas



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

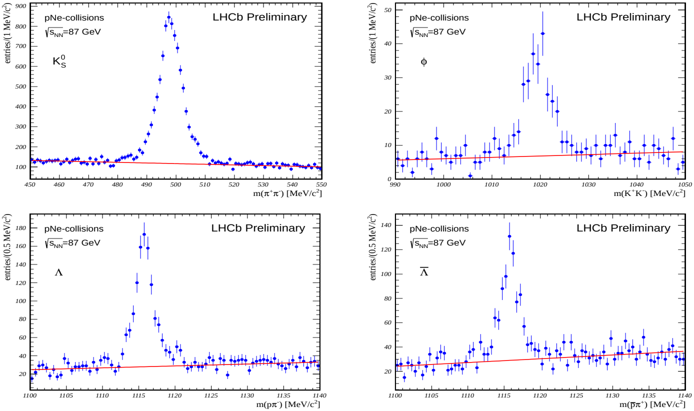


- possibility to inject (noble) gases: Ne or He, Ar, Kr (under discussion)
- fixed target physics in pA and PbA configuration

Fixed target strangeness production

➜ *proton-Neon collisions*

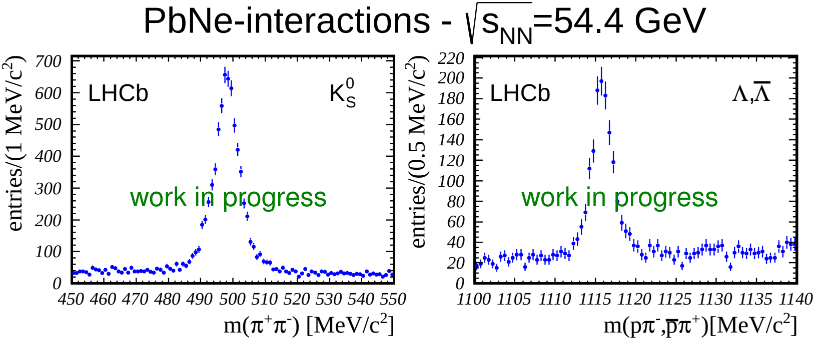
- $\sqrt{s_{NN}} = 87\,\text{GeV}$, boost to center-of-mass $\Delta y \approx 4.5$
- LHCb: backward direction in the nucleon-nucleon center-of-mass



LHCb-CONF-2012-034

Nucleus-nucleus interactions

➜ *first look at PbNe collisions using data from O(10) min running*



❖ physics potential:

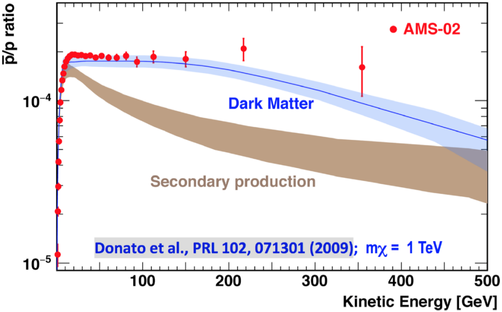
- ➜ explore nuclear structure at large x
- ➜ conditions between SPS and RHIC for QGP studies

Links to other communities

➜ *cosmic ray physics and cosmology*

- understanding of extensive air showers ➜ MC tuning
- understanding the AMS antiproton/proton ratio

AMS p̄/p results and modeling



❖ use fixed target measurements to clarify: QCD or Dark Matter annihilation

6. SUMMARY AND OUTLOOK

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  - ➜ direct CP violation in the B_s system
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  - ➜ mixing phase consistent with the Standard Model
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- further extended physics scope for LHC Run-II
  - ➜ join Pb-Pb physics
  - ➜ add a fixed target ion physics program

❖ much more to come in LHC Run-II. . .