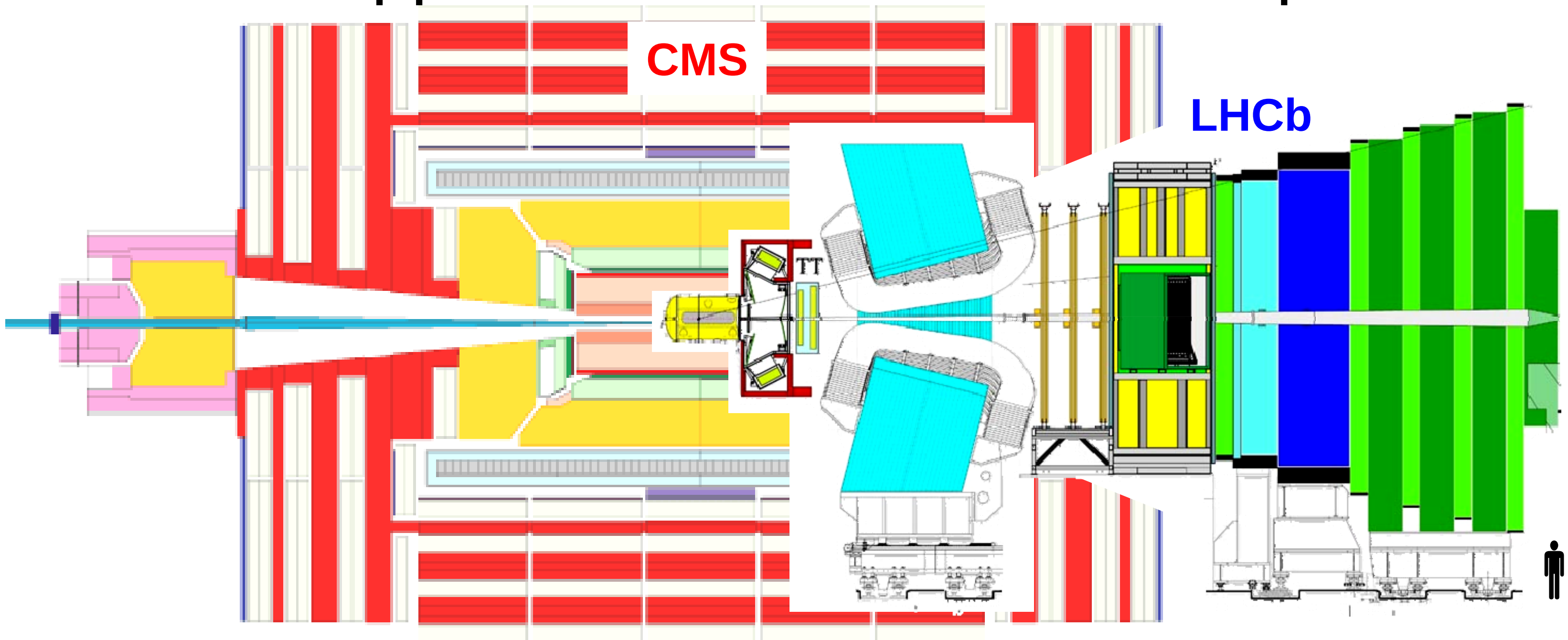
Early Physics in LHCb

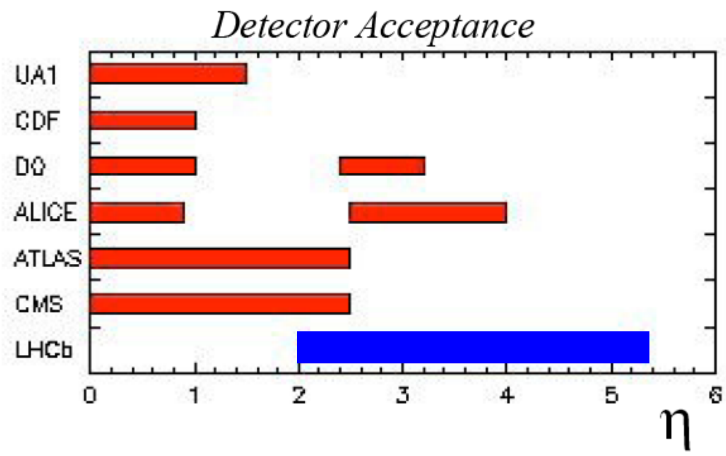
Tomasz Skwarnicki

Representing LHCb collaboration

LHCb Detector

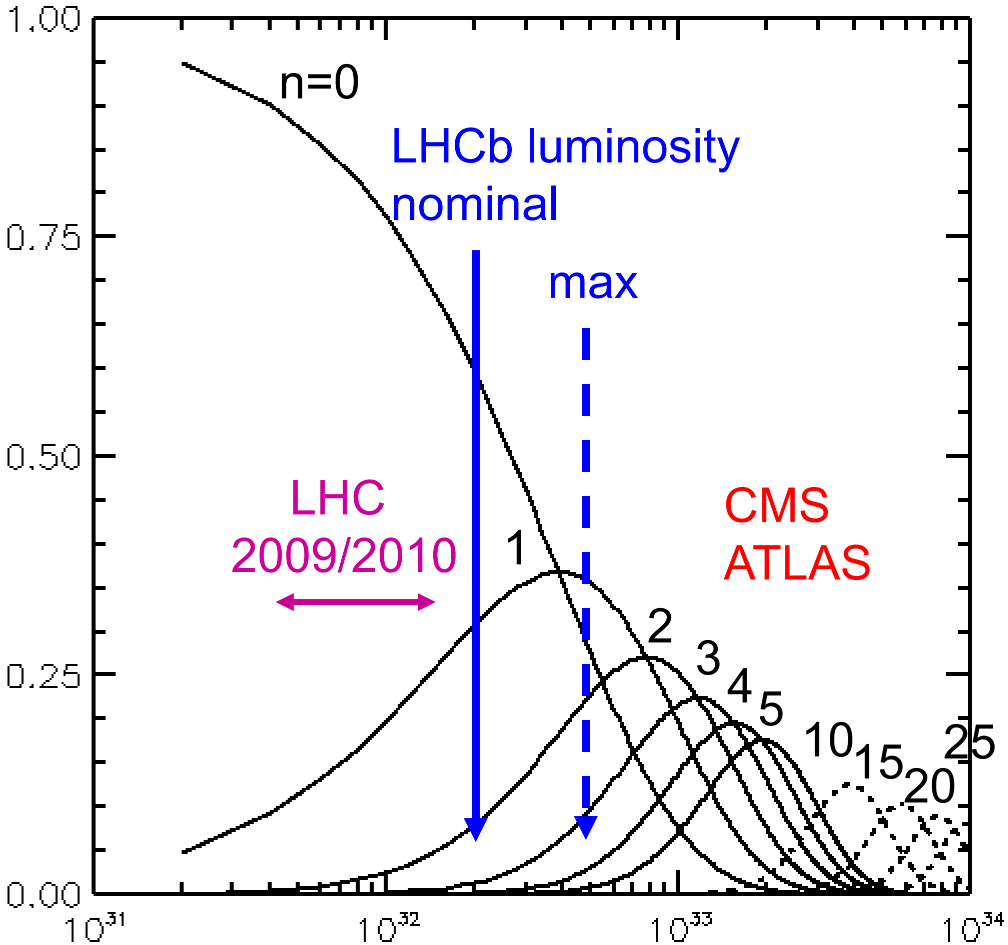
- Looks at pp collisions at LHC in a unique wav





- Forward acceptance:
  - Optimal for $b\bar{b}$ physics, affordable
  - Will complement the central detectors in studies of hadronic physics in early stages of LHC

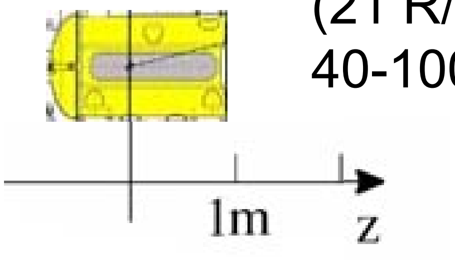
Design luminosity



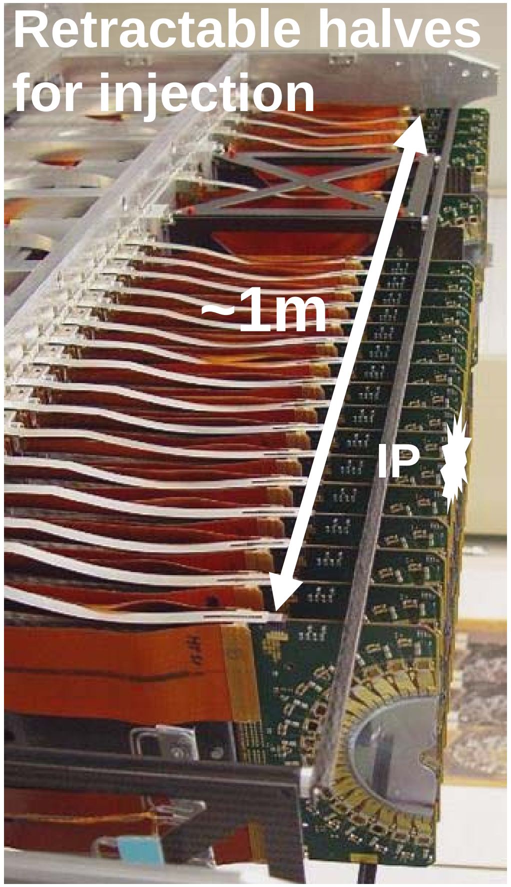
- LHCb design luminosity is much smaller than the LHC design luminosity of 10^{34} cm^{-2}s^{-1}:
  - Smaller occupancies, less confusion
  - Little pile-up (n=0.5)
  - Less radiation damage
  - Nominal design luminosity is 2×10^{32}cm^{-2}s^{-1}
  - Detector can withstand up to 5×10^{32}cm^{-2}s^{-1} (beams will be defocused to prevent further increase in instantaneous luminosity) but only channels with muons benefit from the increase
- LHC 2010 run will approach optimal running conditions for LHCb

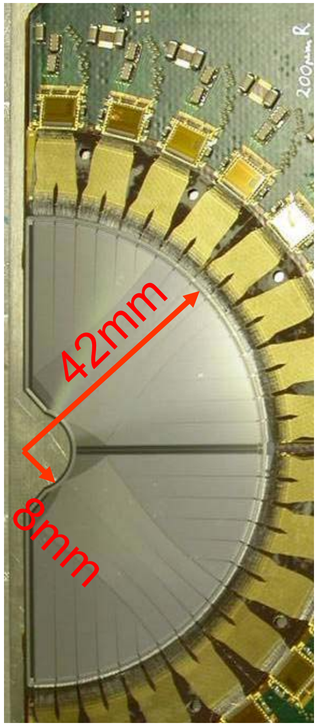
- After a few years of running LHCb physics reach will saturate
- LHCb detector upgrade plan for 2015:
  - rebuilt the detector to operate at luminosities up to 2×10^{33}cm^{-2}s^{-1}

Vertex detector (VELO)



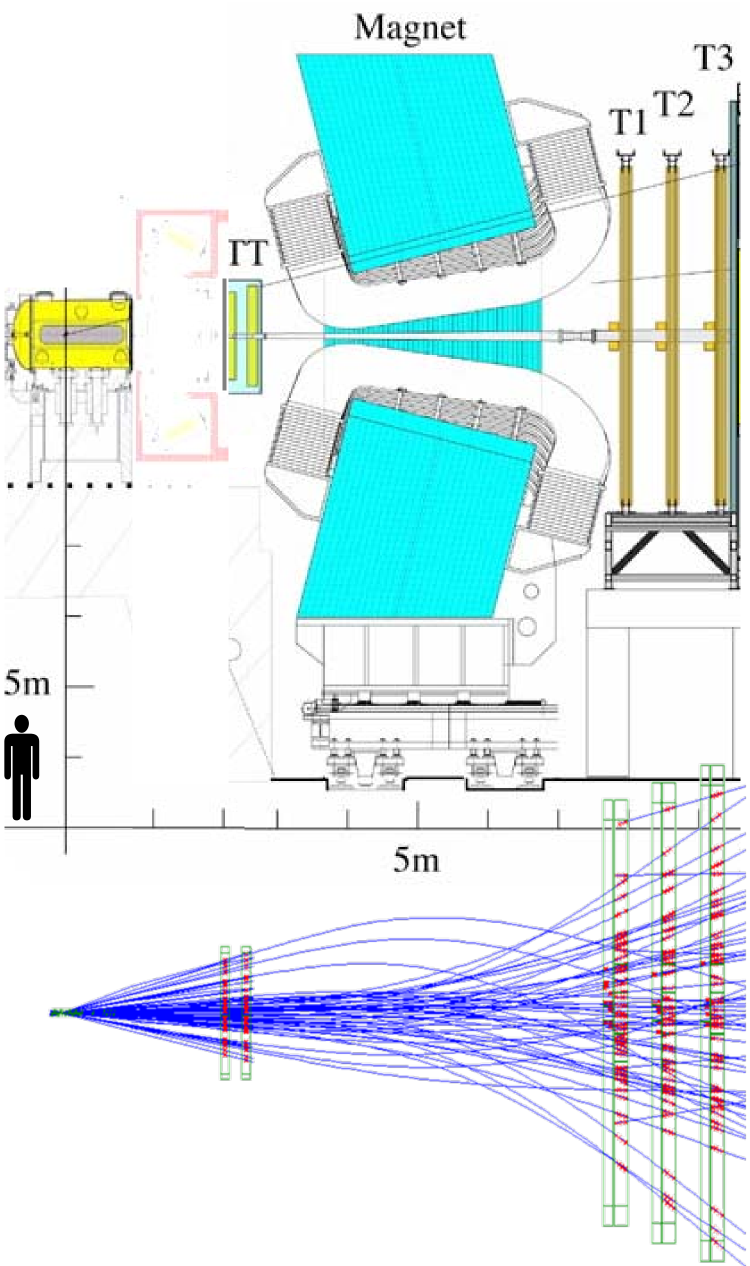
Silicon strip detector
(21 R/ϕ stations)
40-100 μm pitch

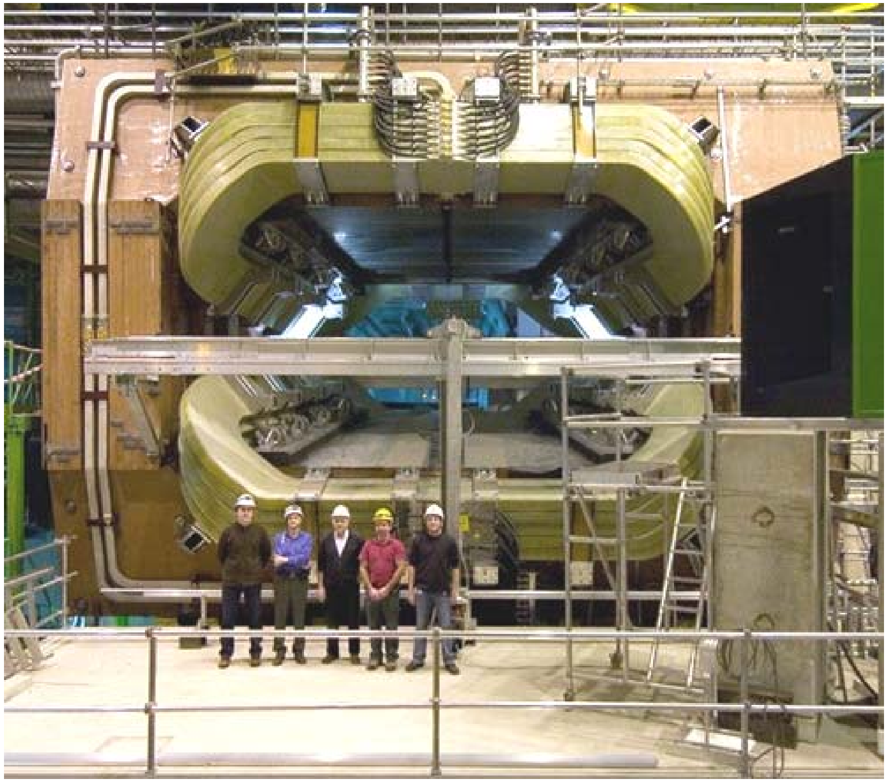




- **Long vertex detector, very close to the beam:**
  - Forward particle momenta minimize multiple scattering effects
  - Excellent impact parameter (~30μm) and decay time resolutions (~40 fs)
  - Designed for beauty and charm detection:
    - triggering, background suppression and measurement of time dependent CP-asymmetries
  - In very early LHC phases it will aid production studies of strange V0s ($K^0_s \to \pi\pi$, $\Lambda \to p\pi$)
  - Unique sensitivity to NP particles decaying to $b\bar{b}$ with long lifetime

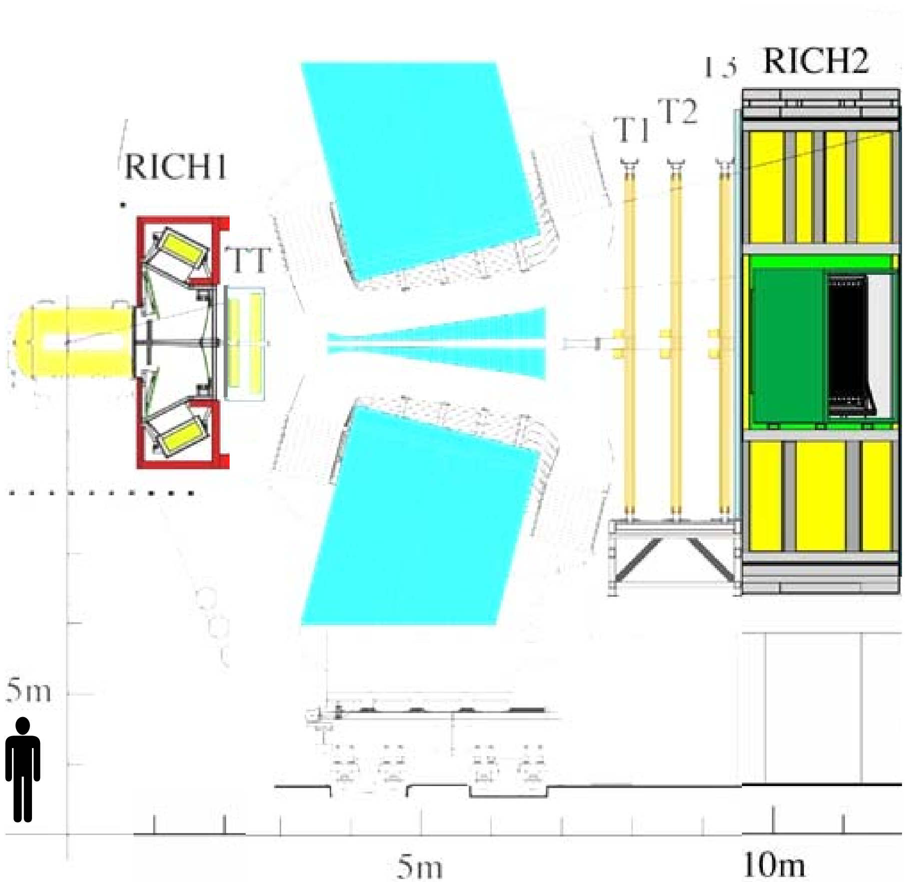
Tracking system



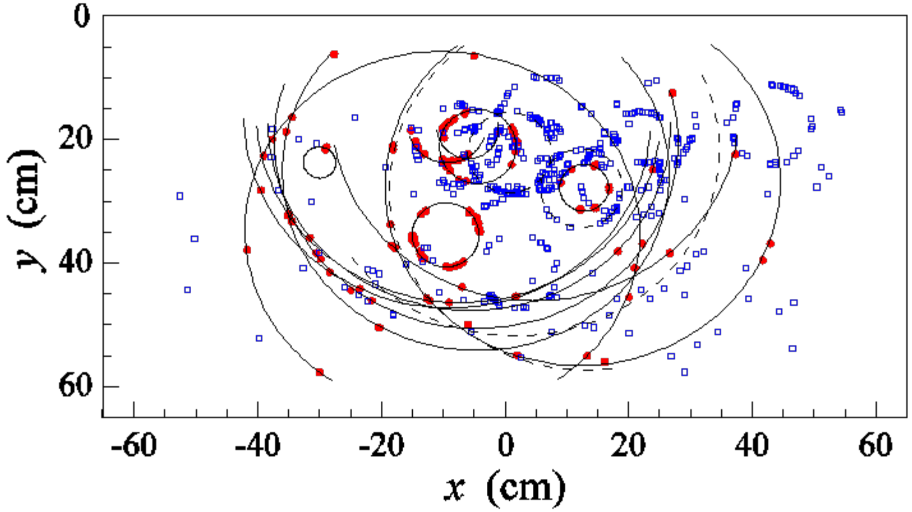


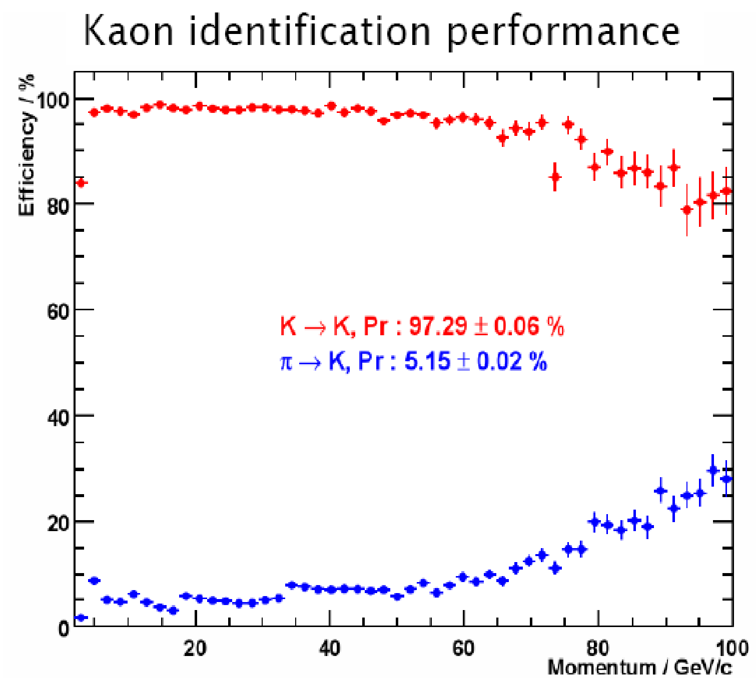
- Good momentum (0.35-0.5%) and mass resolution (~15 MeV for B)

Hadron identification



RICH1: C_4F_{10} and aerogel radiators (RICH2: CF_4)

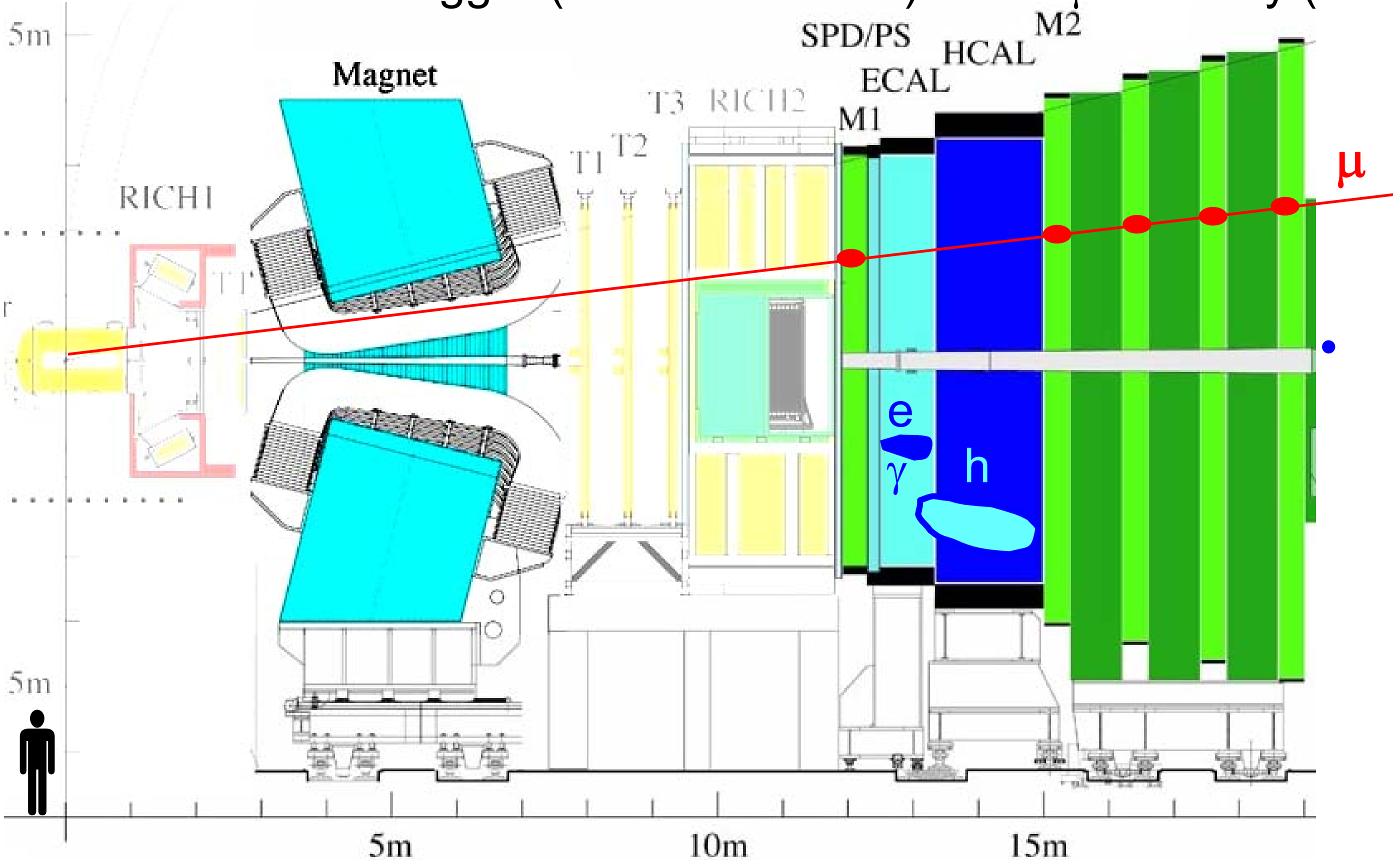




- **Good π/K/p separation is a unique feature compared to central detectors:**
  - Important for background suppression in B and D reconstruction and for **flavor tagging:** εD^2 ~ 6% (4%) for B_s (B_d)
  - inclusive charged hadron spectra from early data

Muon detector, calorimeters and L0 trigger

L0 hardware trigger (customs boards) with 4 μs latency (40MHz→1MHz):

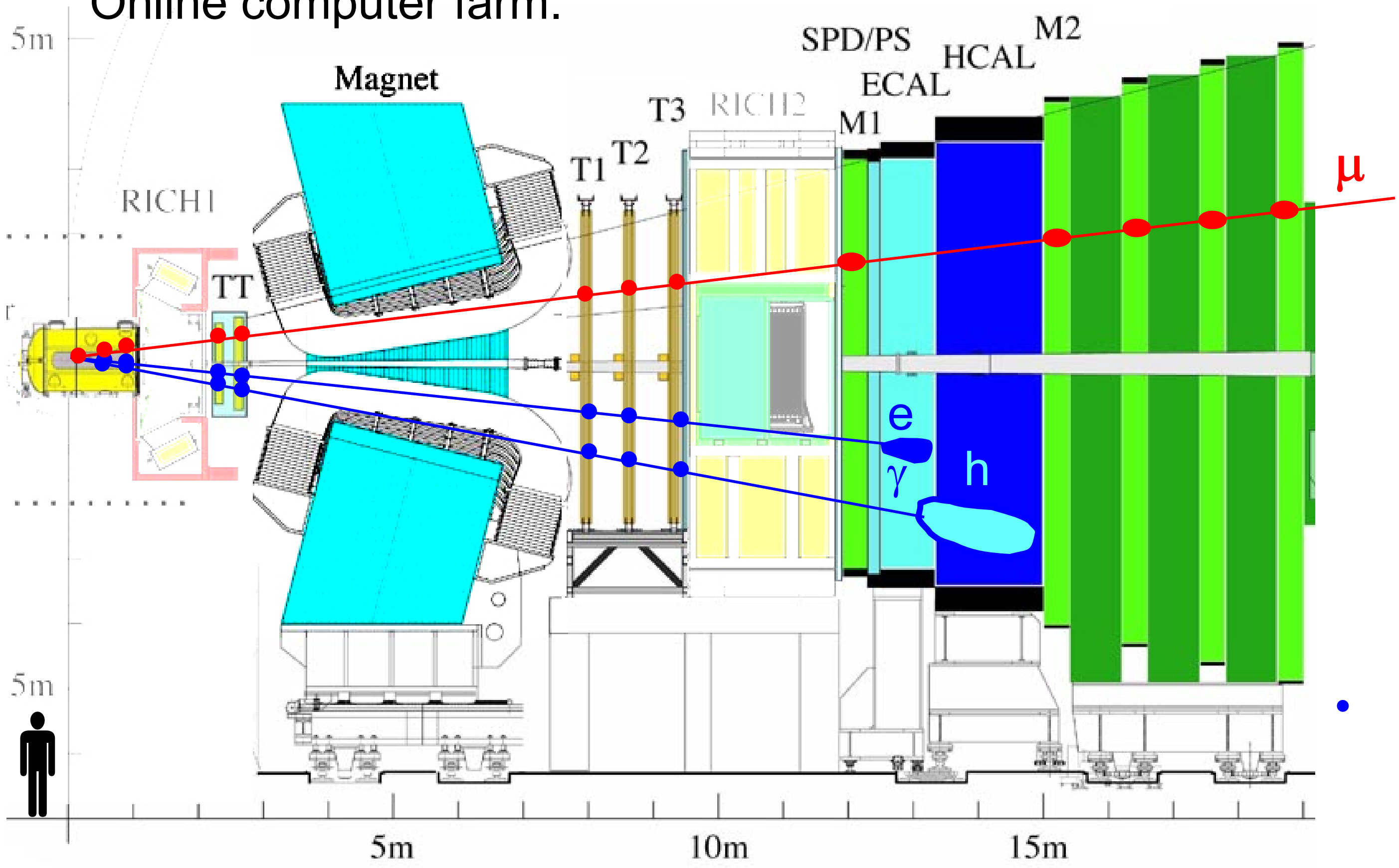


Extrapolation through the magnet to the interaction region gives μ momentum in L0

- Muon detector:
  - Low reconstruction thresholds in offline and trigger: p>3 GeV, p_t>0.5 GeV
  - Single- and di-muon triggers: $p_{t1} + (p_{t2}) >\sim 1.3$ GeV
- HCAL:
  - triggering on purely hadronic B decays: $E_t > \sim 3.6$ GeV
- ECAL:
  - triggering on electrons and photons: $E_t > \sim 2.7$ GeV
  - Offline electron ID, photon and π^0 reconstruction ($\sigma(E)/E \sim 8.2\% /\sqrt{E} + 0.9\%$)
- Minimum bias trigger in early running based on total energy in calorimeters

HLT trigger

Online computer farm.

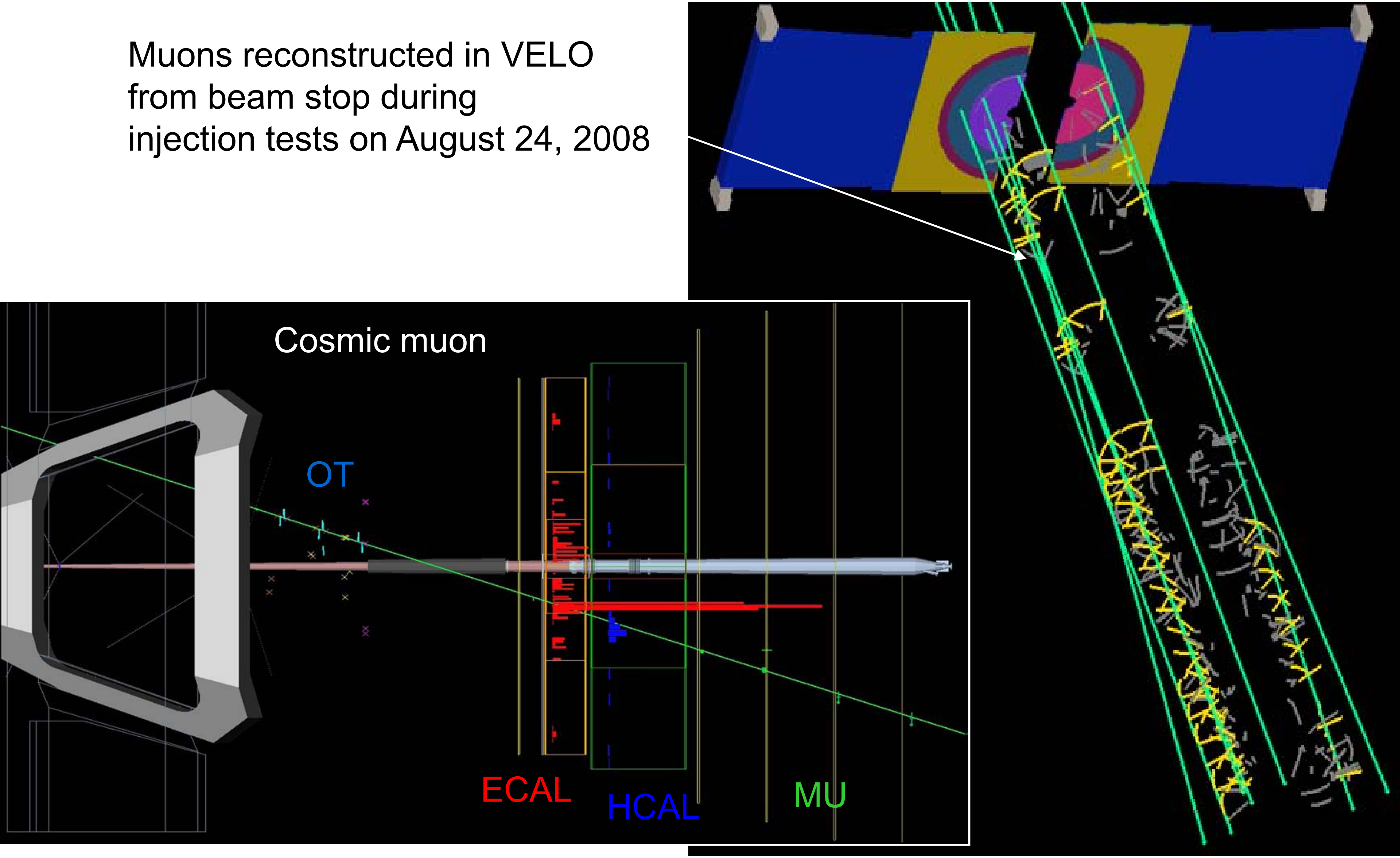


- HLT1: 1MHz→30kHz
  - Confirm L0 seeds with tracking detector hits/tracks
  - Improve p_t determination.
  - Reconstruct primary vertices.
  - Optionally add Impact Parameter cuts
  - Add companion tracks for secondary vertex cuts
- HLT2: 30MHz→2kHz
  - Full event reconstruction.
  - Inclusive and exclusive physics selections.

- Early running:
  - Write data out at nominal frequency:
    - Offline data processing assumes ~2kHz but we can actually log data at higher rates (event size ~35 kB)
  - Tighten trigger criteria with increasing luminosity
  - Muon triggers provide safe fall back strategy

Commissioning

Muons reconstructed in VELO from beam stop during injection tests on August 24, 2008

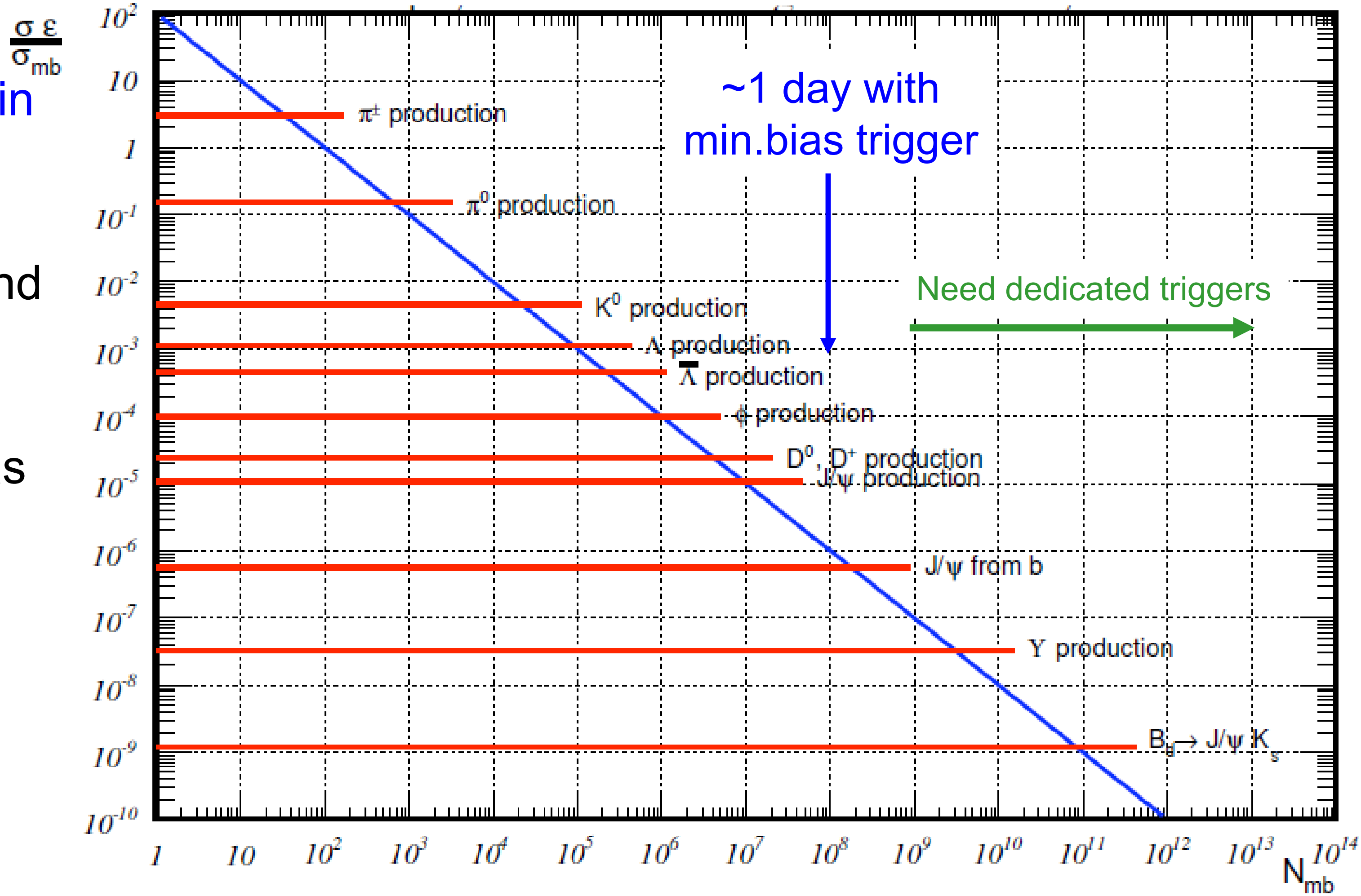


- Detector is installed and ready for data

First Measurements

- Late 2009/early 2010
- Inelastic collision rate reaches our event logging rate (~2kHz) already at luminosity of ~$4x10^{28}cm^{-2}s^{-1}$
- Use minimum bias trigger
- ~10^8 events in a day
- Detector calibration and alignment
- Physics of minimum bias interactions, tuning of MC generators

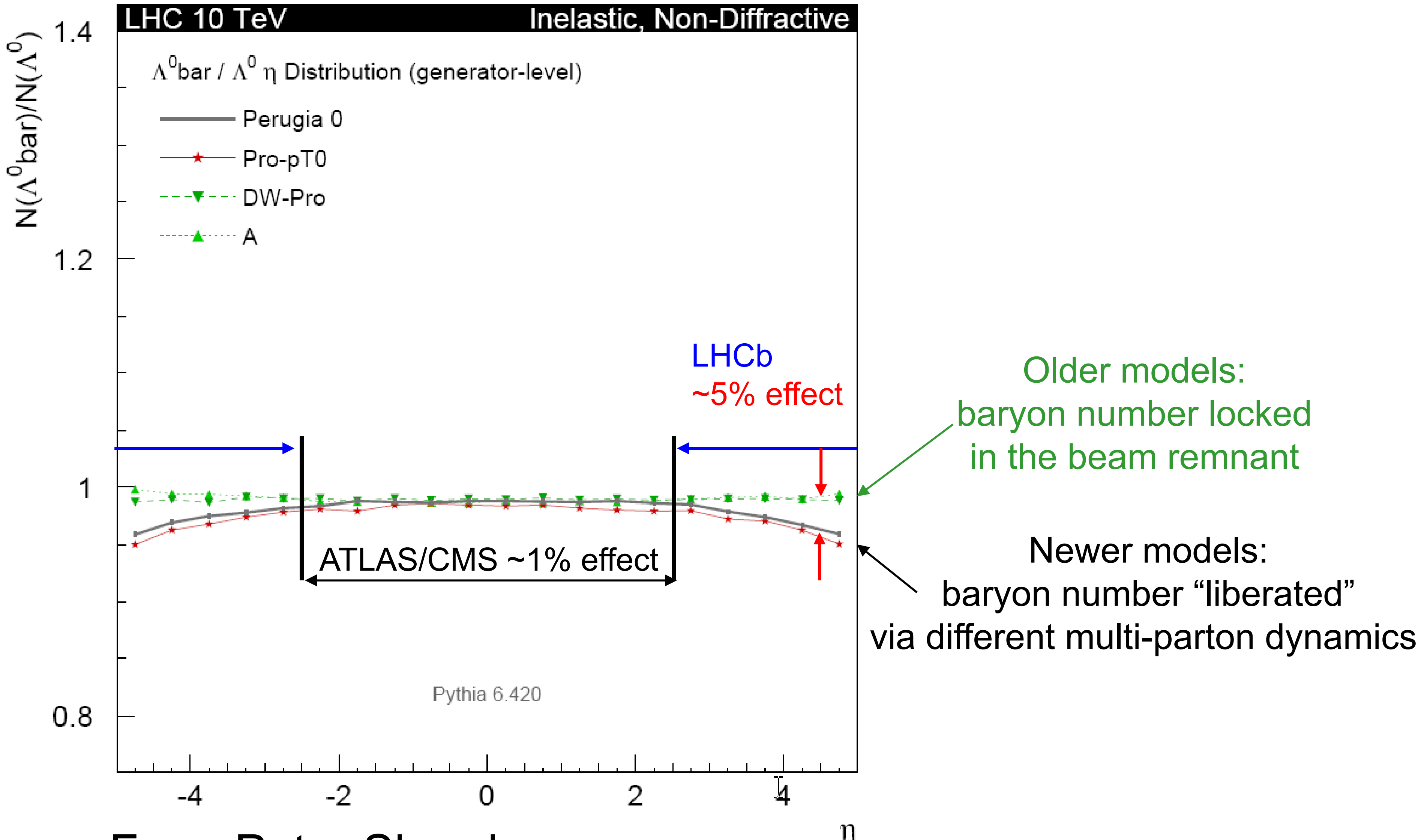
Physics reach vs accumulated minimum bias statistics



Example: Strange baryon production

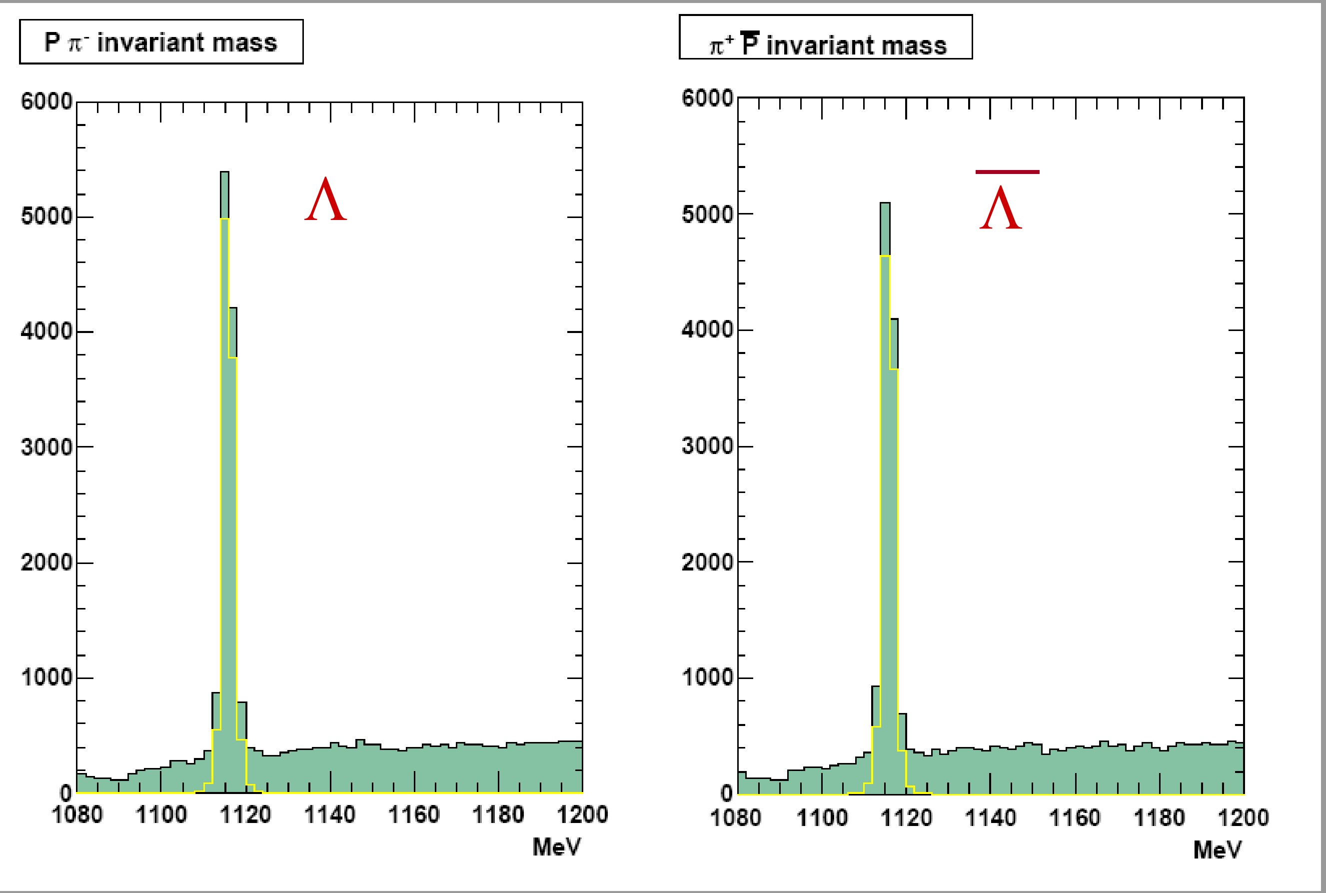
- Strangeness is a good probe for fragmentation processes:
  - Created in fragmentation
  - Heavier, but not too heavy s-quark mass
- Existing minimum bias/underlying event models tuned to CDF/D0 data (central region, higher p_t):
  - Need also measurements in forward region and lower p_t to distinguish different models at LHC – LHCb is well suited for this!
- Transport of beam baryon number can distinguish different models of color flow:
  - Strange baryon / anti-baryon asymmetries
  - Effects are larger closer to the beam: larger η smaller p_t – LHCb!

$\overline{\Lambda}/\Lambda$ ratio vs η



- From Peter Skands: http://home.fnal.gov/~skands/leshouches-plots/

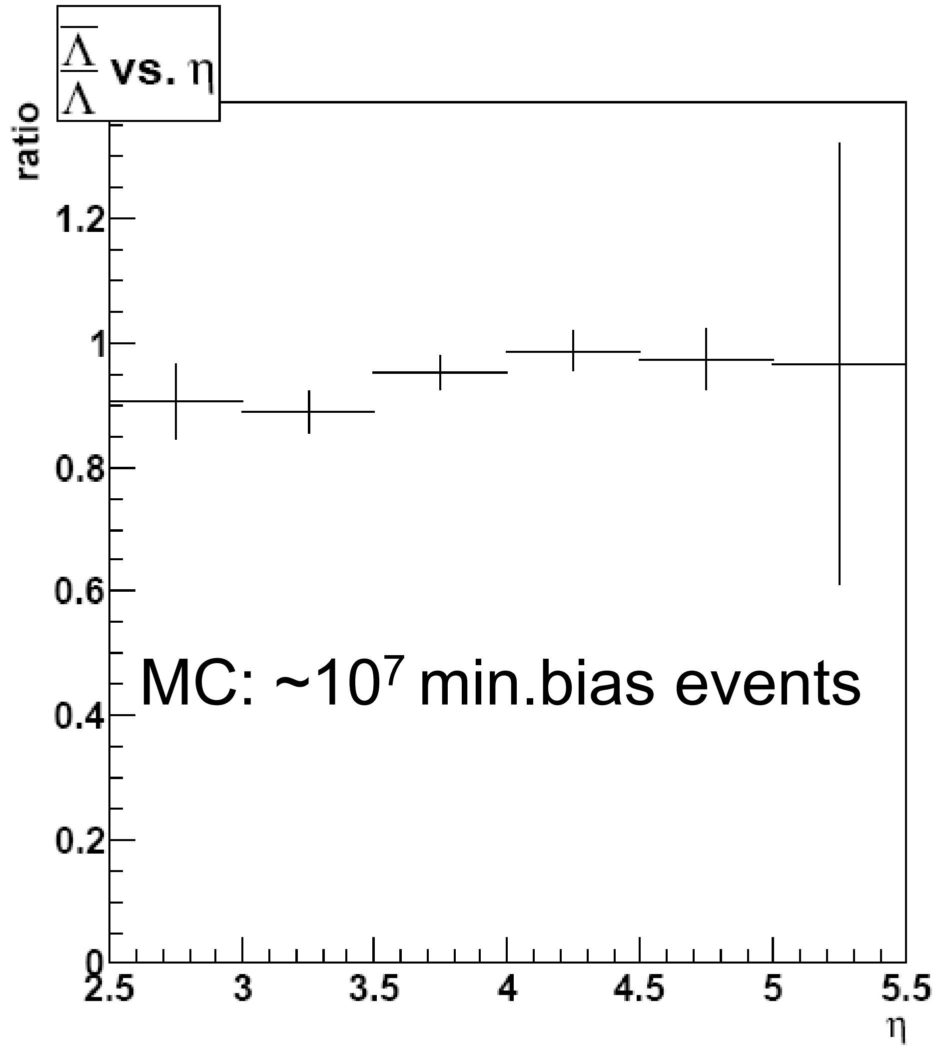
$\overline{\Lambda}/\Lambda$ ratio with LHCb



Cuts: DoCA $\leq$ 0.3 mm, $ct \geq$ 4 mm, IP $\leq$ 0.1 mm, $p_{t,\mathrm{wrt\ mother}} \geq$ 10 MeV (no PID cuts)

- MC: ~10^7 minimum bias events

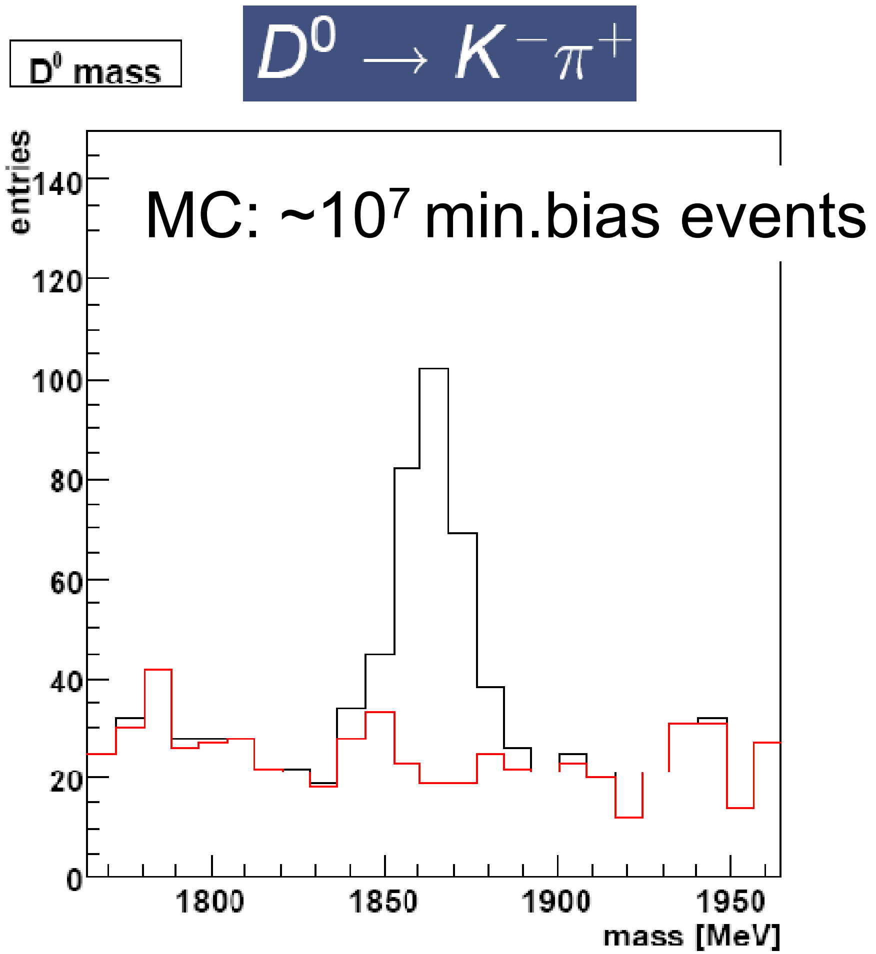
$\overline{\Lambda}/\Lambda$ ratio with LHCb

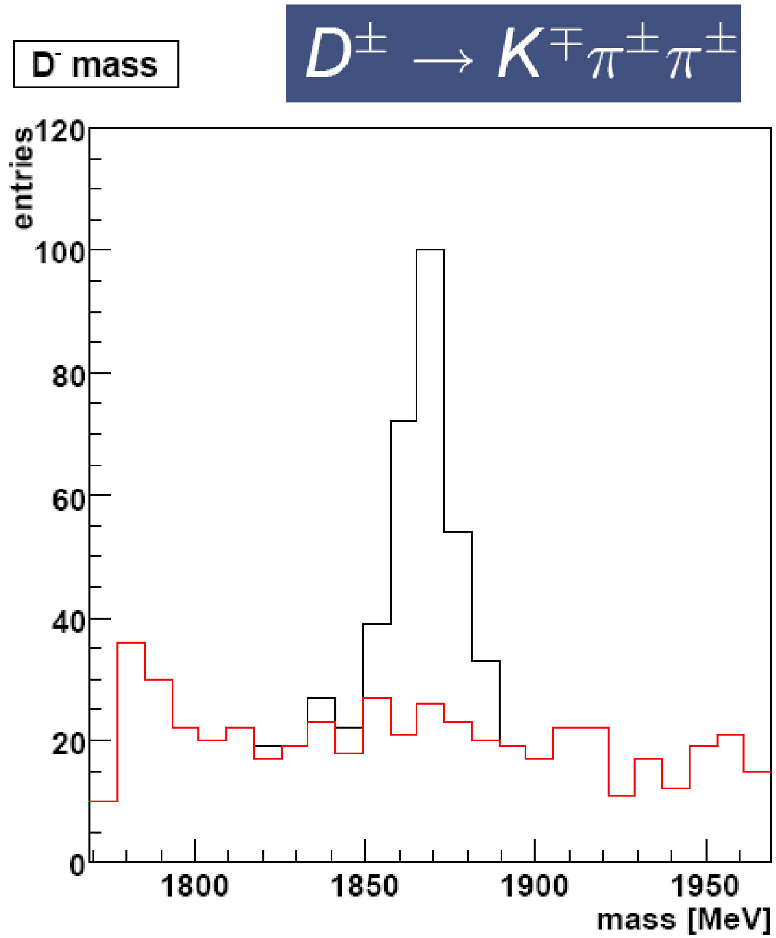


- With 10^8 minimum bias events expect statistical errors of ~1.3% per bin
- We will be able to distinguish between the old and new MPI models

See talk by Markward Britsch at DIS 2009, 26-30 April 2009, Madrid

$\overline{D}$/D ratios with LHCb



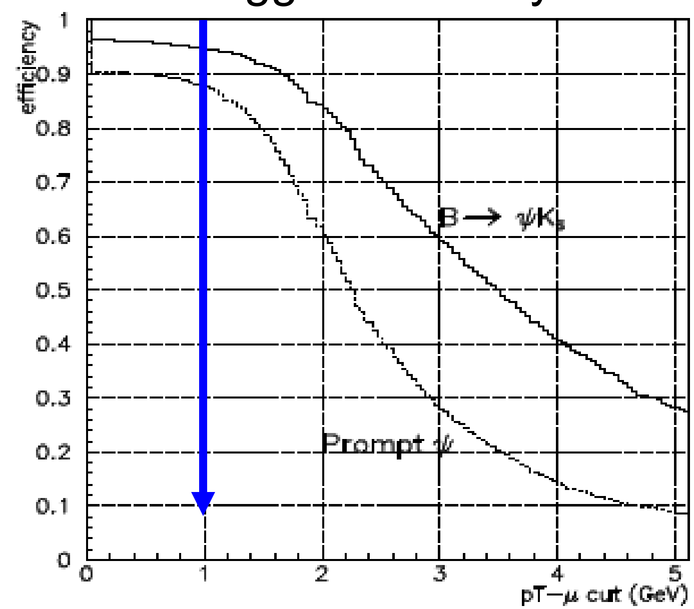


- Geometric and kinematic cuts only (no PID used)
- For $1.8<\eta<3.5$ with 10^8 minimum bias events expect:
  - ~5% error on $\overline{D^0}/D^0$
  - ~6% error on D^-/D^+

Early running with loose muon trigger

- Spring 2010, ~5 pb^{-1}
- Use lifetime unbiased single muon trigger with p_t >1 GeV
- Clean $J/\psi \rightarrow \mu\mu$ signal without biasing the 2nd muon:
  - Can study trigger and muon identification efficiencies

Trigger efficiency

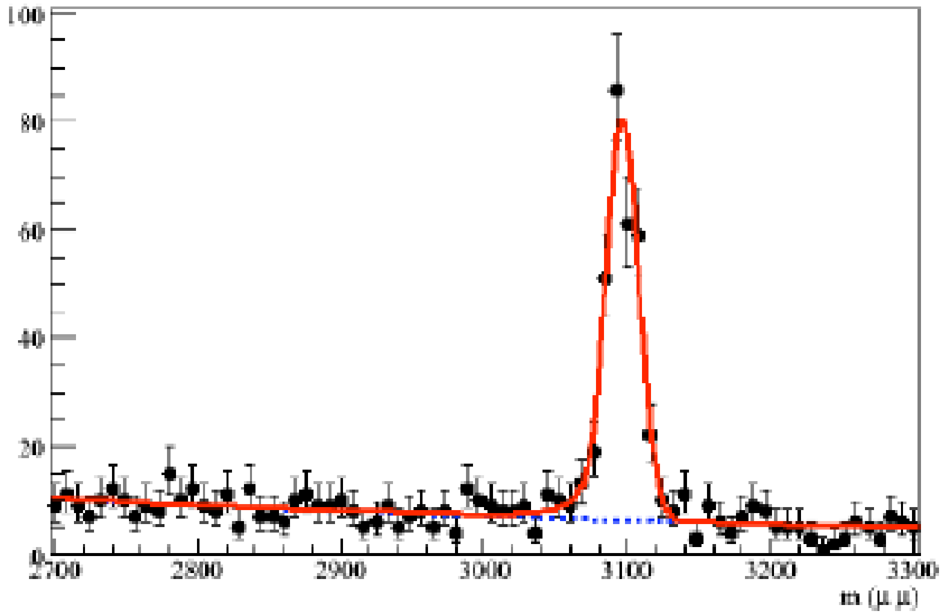


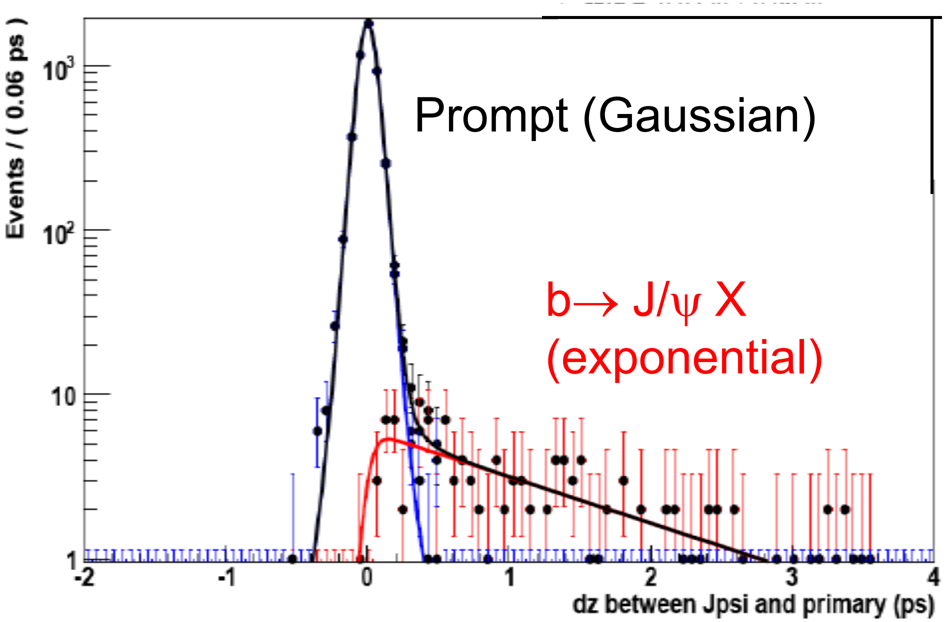
- Physics with J/ψ:
  - Prompt production studies, including polarization: σ_{prompt}~3100 nb with both muons in $2.5<\eta<5.5$
  - $b\bar{b}$ cross-section via $b \rightarrow J/\psi X$: $\sigma_{b\rightarrow J/\psi}$ ~240 nb (7%)
  - Other charmonium states via decays to J/ψ

(Wenbin Qian who was supposed to report on J/ψ studies at this workshop did not receive US visa on time)

J/ψ production studies

MC: ~ 2x10^7 minimum bias events



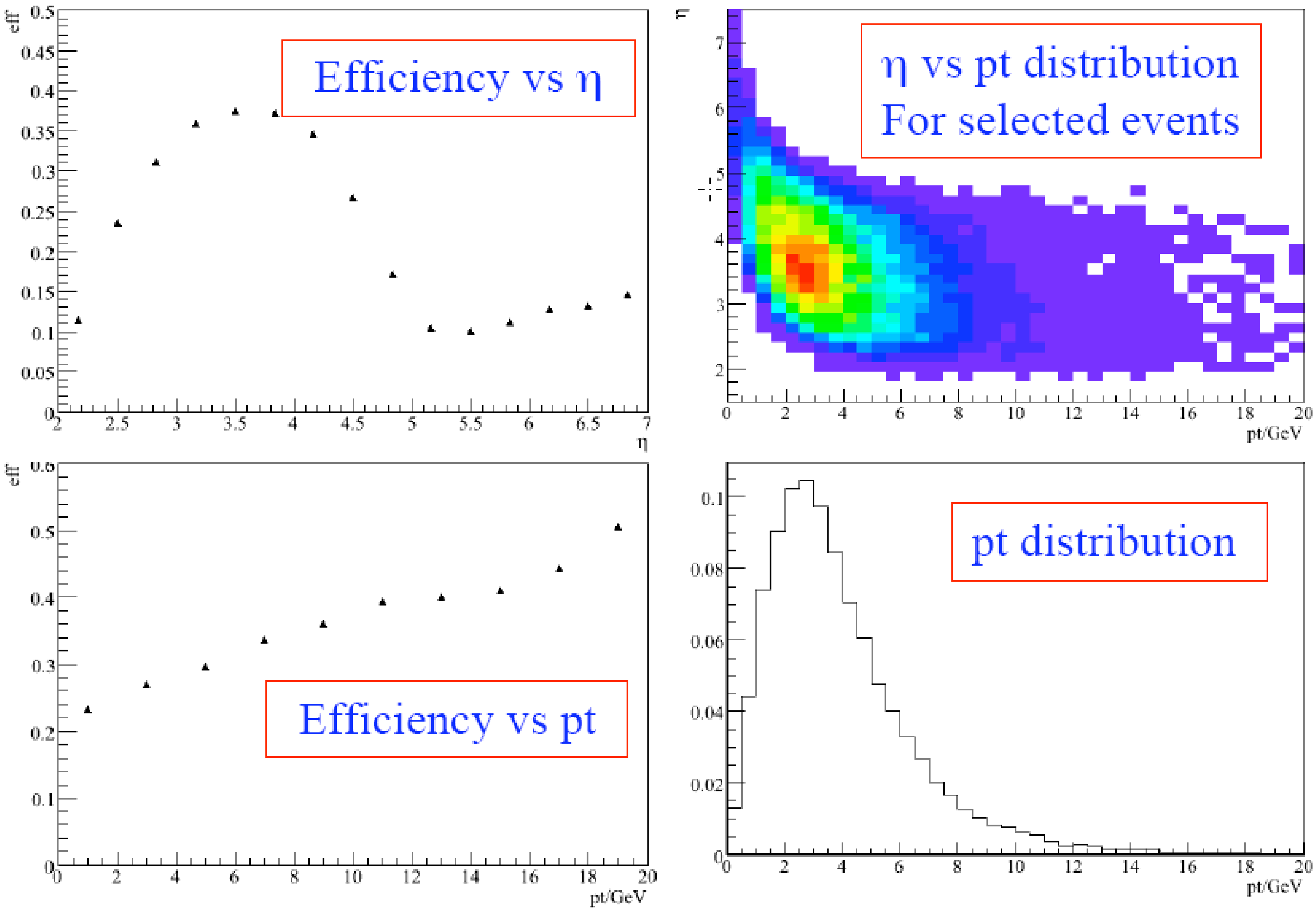


- Selection:
  - 1 primary vertex
  - 2 identified muons, forming a common vertex
  - 1 muon with p_t >1.5 GeV

- Expect ~2.1x10^6 events in 5 pb^-1 at 8 TeV
- Mass resolution ~11 MeV
- S/B~4 (background dominated by decays in flight)

- Use fit to proper time distribution to disentangle prompt and b components

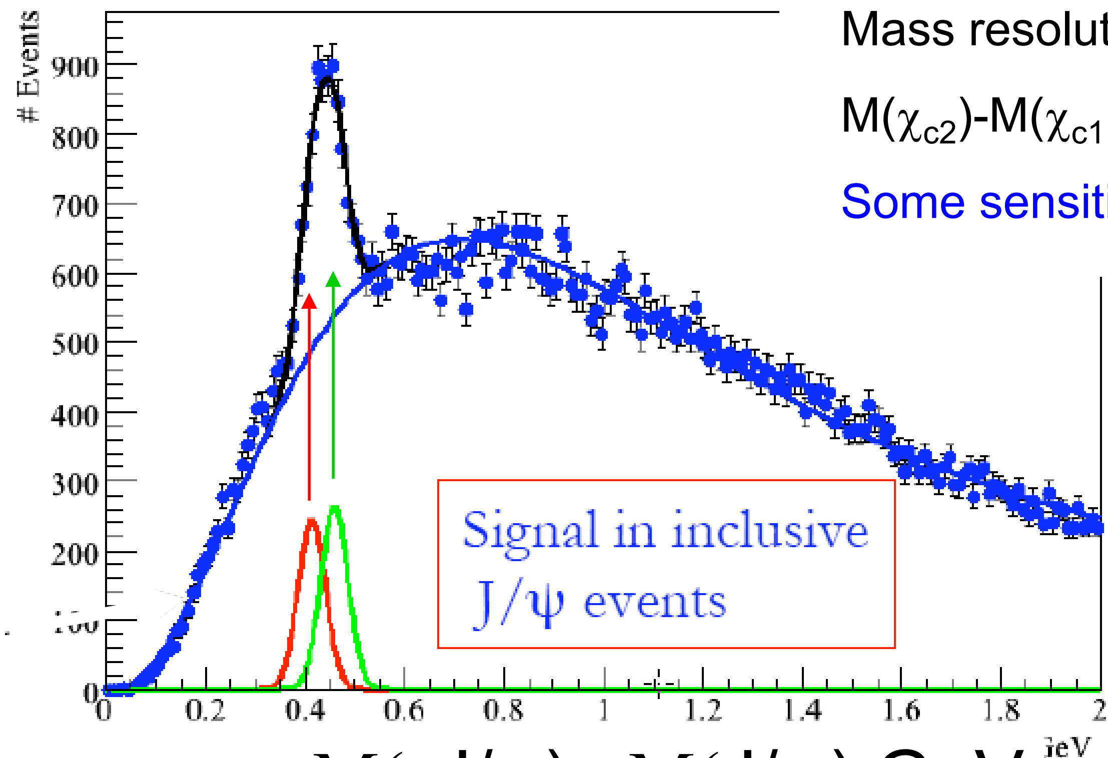
J/ψ production studies



- We will measure prompt J/ψ and $b\bar{b}$ cross section in a region not accessible to other collider experiments

χ_c production studies

- At Tevatron ~30% of J/ψ come from $\chi_{c1,2} \rightarrow \gamma J/\psi$
- Model builders interested in measurements of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$



$M(\gamma J/\psi) - M(J/\psi)$ GeV

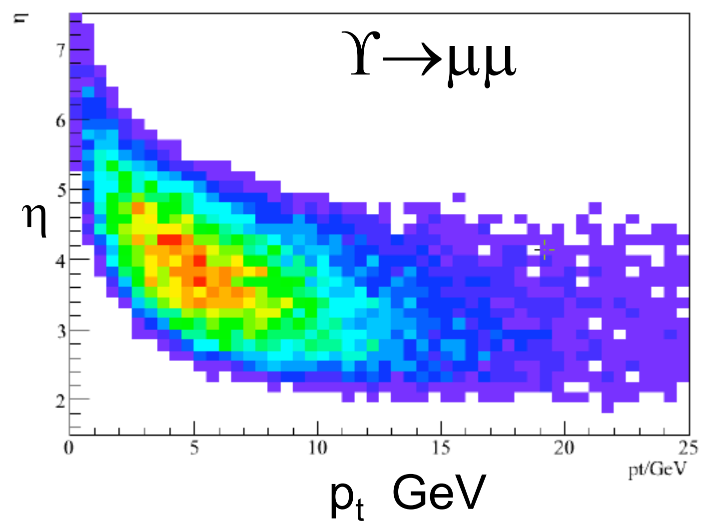
Mass resolution is ~ 27 MeV

$M(\chi_{c2})$-$M(\chi_{c1})$ = 55 MeV

Some sensitivity to $\sigma(\chi_{c2})/\sigma(\chi_{c1})$

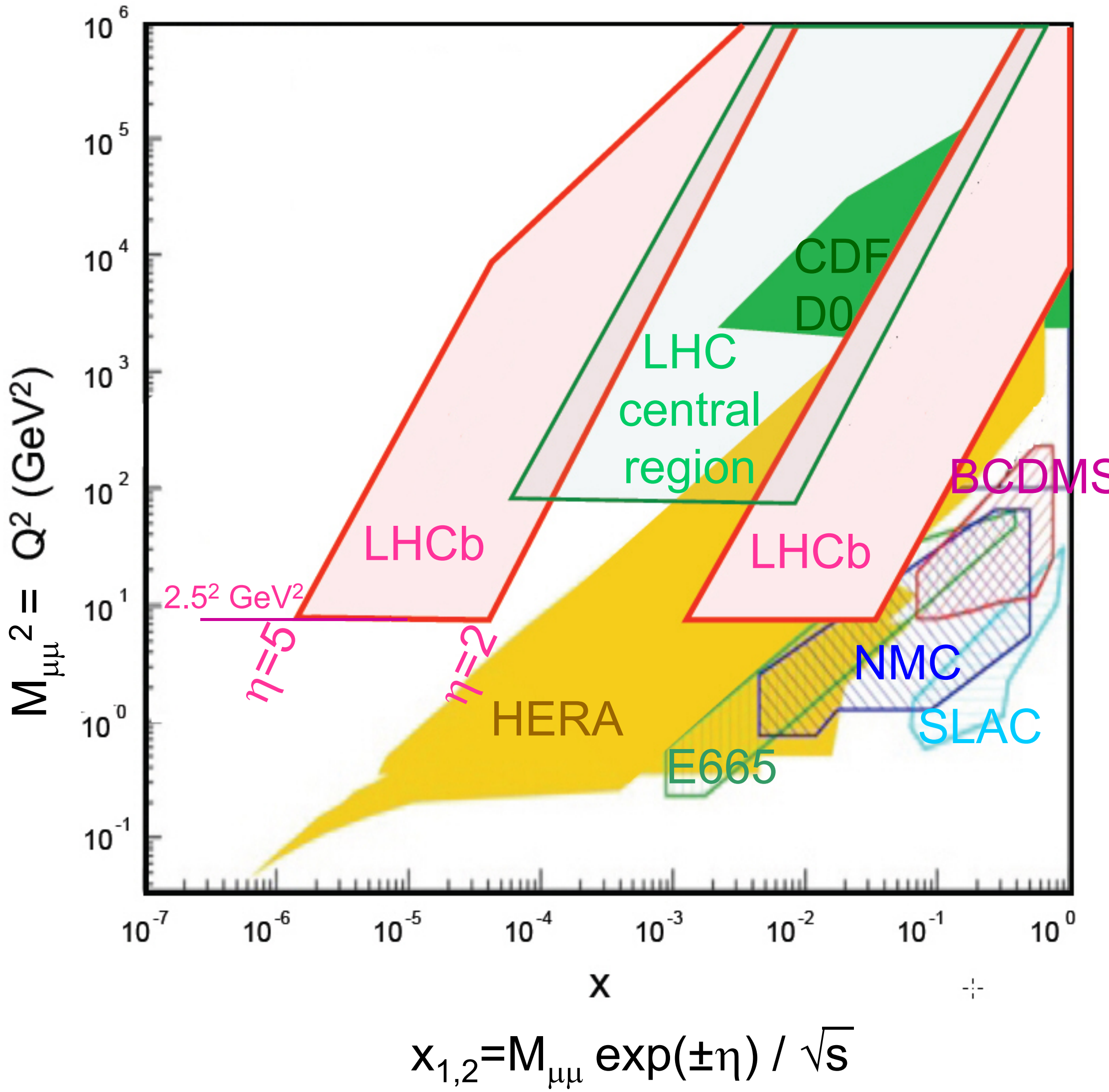
Other charmonium/bottomonium studies

- $\psi(2S) \to \pi\pi J/\psi$ production
  - measure $\sigma(\psi(2S))/\sigma(J/\psi)$
  - polarization
- $X(3872) \to \pi\pi J/\psi$
  - CDF has the world largest sample
  - About ~20% from $B \to X(3872)$ K
    - Especially useful for J^{PC} determination (1^{++} or 2^{-+} ?) because of known polarization
    - Advantages of LHCb:
      - Higher cross-section. Kaon ID.
- $B \to Z(4430)^+ K$, $Z(4430)^+ \to \psi(2S)\, \pi^+$
- Production and polarization of $\Upsilon \to \mu\mu$ (~37 MeV mass resolution)
- $\Upsilon(nS) \to \pi\pi\Upsilon$, including possible $Y_b(10890)$ hybrid state

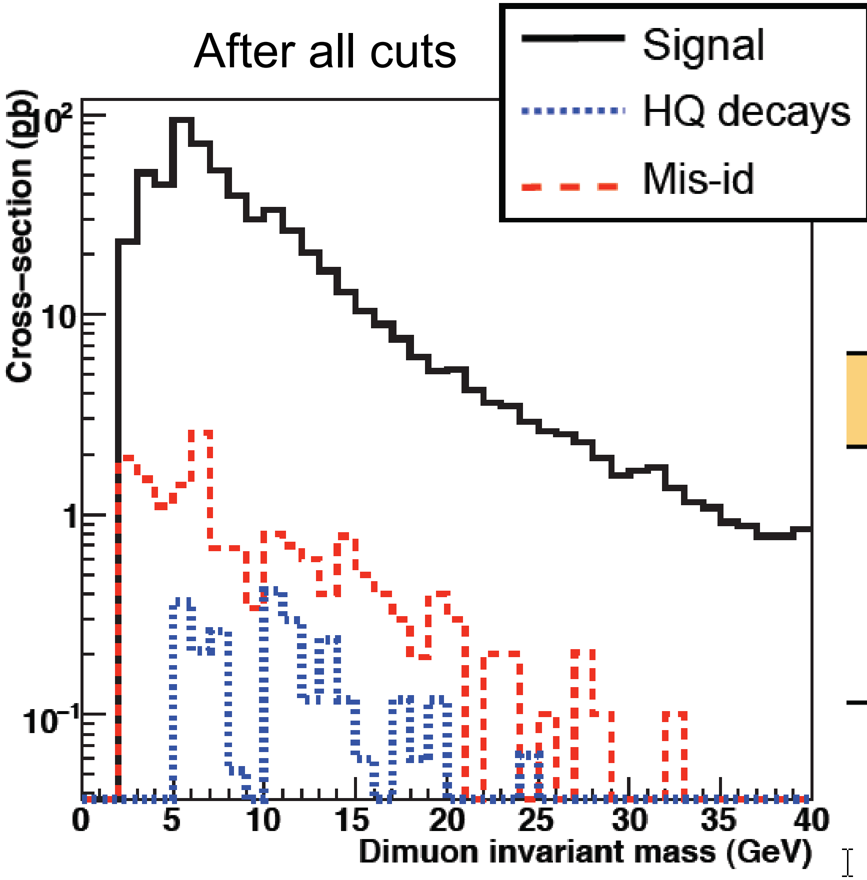


Drell-Yan at low-x

- LHCb has unique coverage in η reaching towards low-x
- LHCb muon reconstruction and trigger thresholds are low:
  - Reconstruction:
    - p > 3GeV, p_t >0.5 GeV
  - Prompt di-muon trigger:
    - $p_{t1}+p_{t2}$ > 1.5 GeV,
    - $M_{\mu\mu}$ > 2.5 GeV
    - no IP cuts
- LHCb will provide unique constraints on PDFs



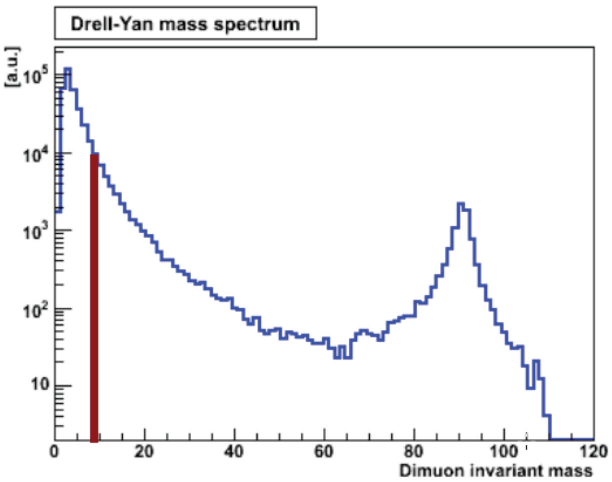
Drell-Yan at low-x

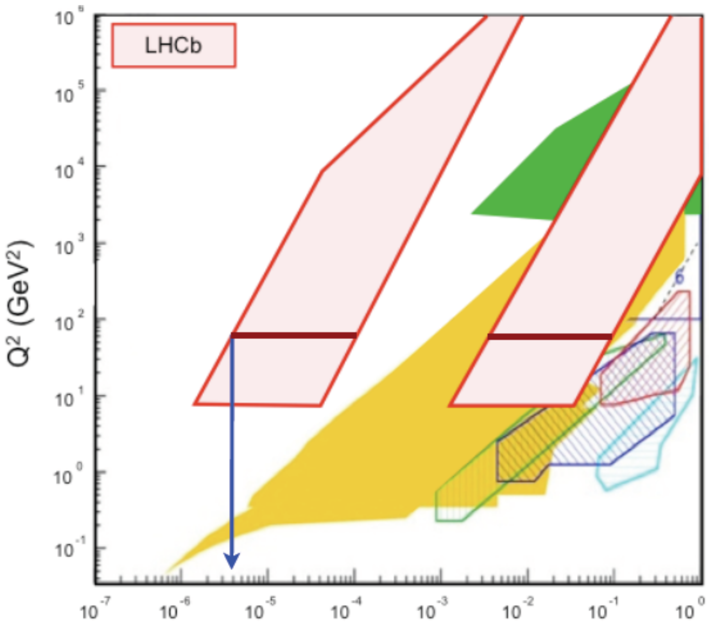


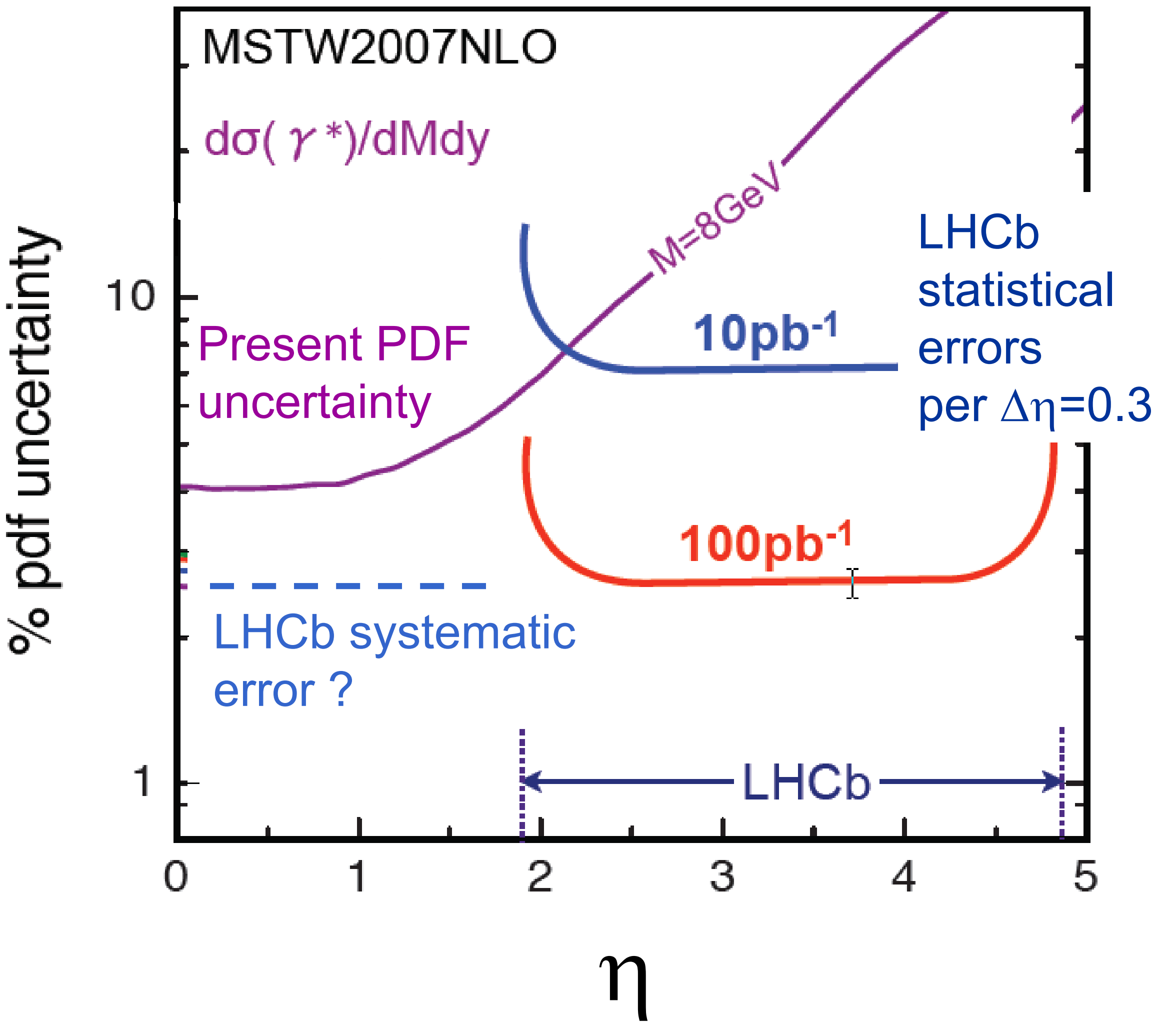
Mass range (GeV)	Events/pb-1
$2.5 < M_{\mu\mu} < 5$	119.1 ± 1.0
$5 < M_{\mu\mu} < 10$	287.3 ± 1.6
$10 < M_{\mu\mu} < 20$	147.6 ± 0.9
$20 < M_{\mu\mu} < 40$	42.3 ± 0.4

- *See Jonathan Anderson talk at DIS 2009, 26-30 April 2009, Madrid*

Drell-Yan at low-x





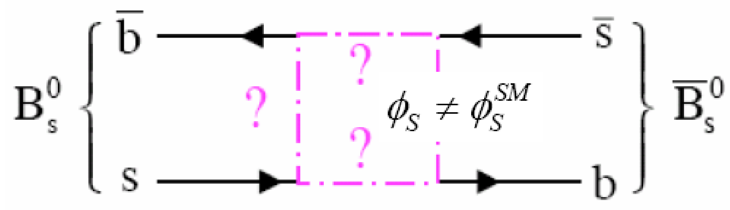


- Substantial constraints at low-x (down to ~ $1.5x10^{-6}$)

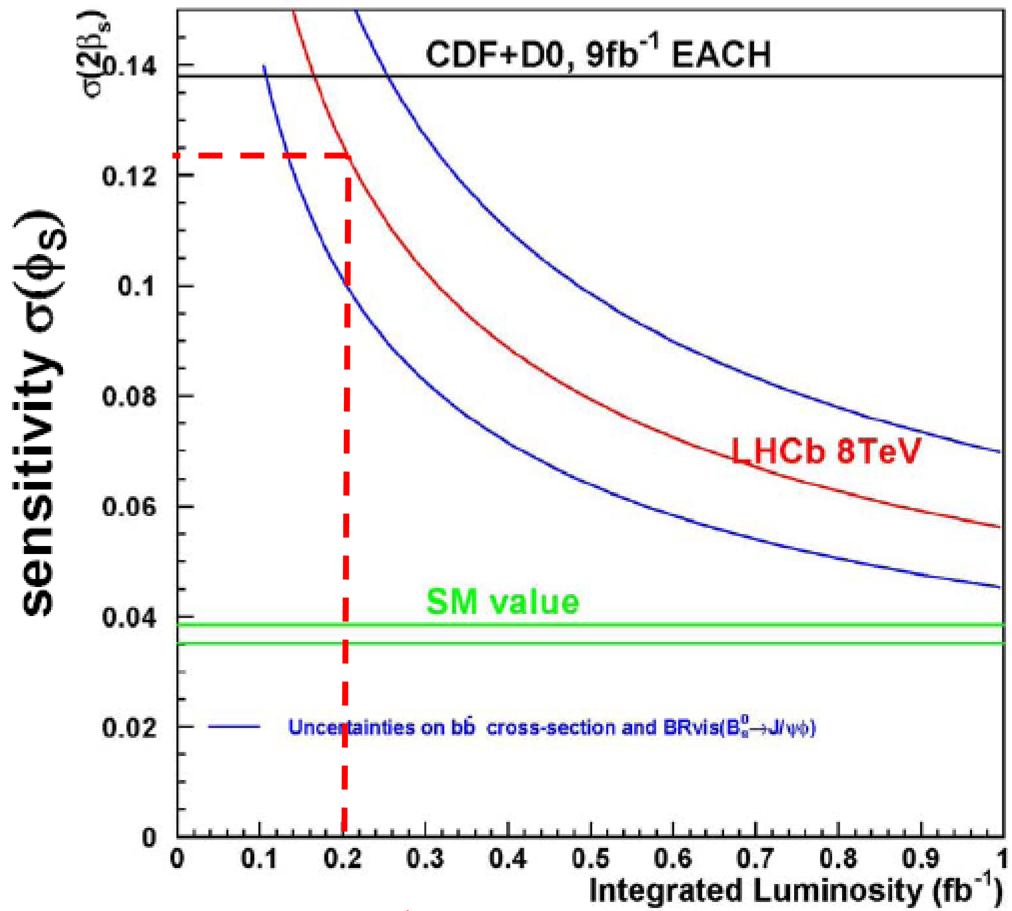
Early B physics results

- Early analyses, even though interesting in their own right, are stepping stones for B physics program
- Best world measurements in many important B decay channels can be obtained even with as little as 200 pb^{-1}
- Late 2010: as luminosity increases, muon triggers will be tightened while continuing to commission hadronic and e,γ triggers
- Show two examples for B_s results relying on muon triggers only (see next)
- First measurements of angle γ relying on hadronic triggers are also likely

Measurement of ϕ_s



B_s oscillation "box diagram"

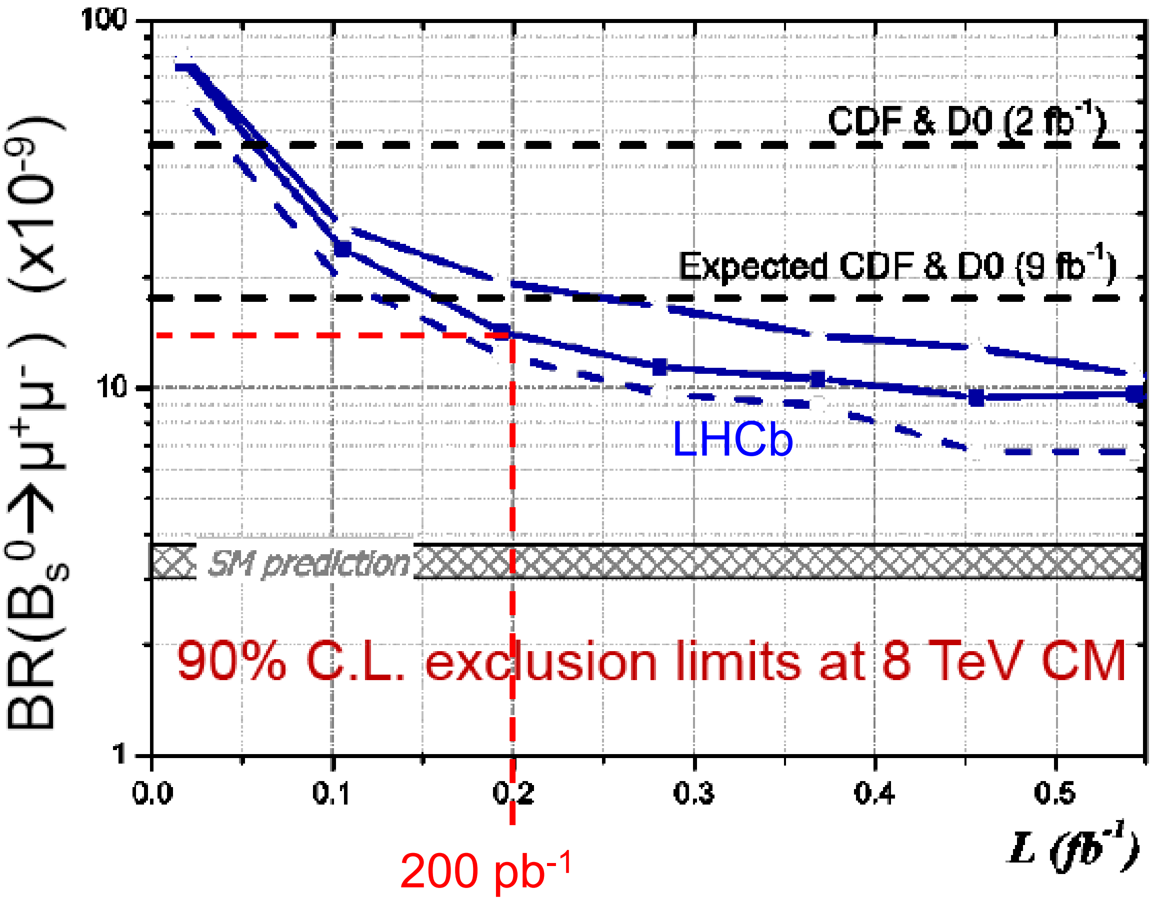


200 pb^{-1}

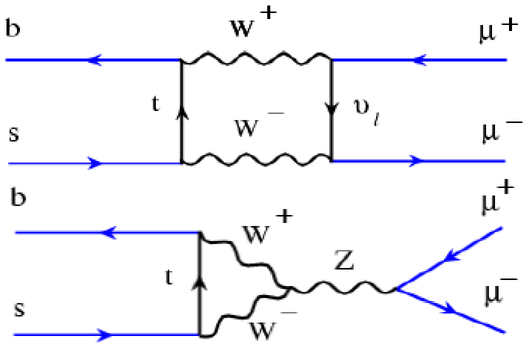
- Phase of B_s-$\overline{B}_s$ oscillations
- Very small in SM. Sensitive to NP contributions.
- $B_s \to J/\psi\ \phi$
  - Simultaneous fit of CP asymmetry to time and angular distributions (to disentangle CP-odd and -even amplitudes)
- At present CDF+D0 results ~2.2σ away from SM prediction
- LHCb has much better sensitivity:
  - Large signal yield (13k/200 pb^{-1}), excellent time resolution (~40 fs) and flavor tagging (~6%)

$BR(B_s \to \mu\mu)$

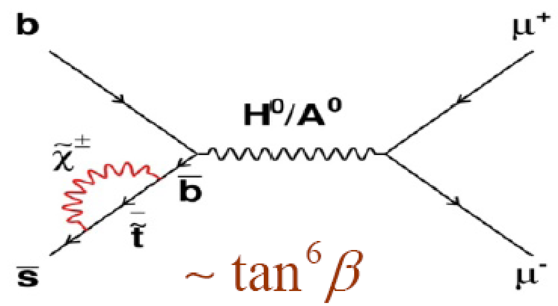
- Very small in SM. Sensitive to NP contributions.
- LHCb exploits high cross-section, high trigger efficiency, good mass resolution (~18 MeV) and vertexing, and good muon ID.
- Background from two semileptonic b decays



Standard Model:

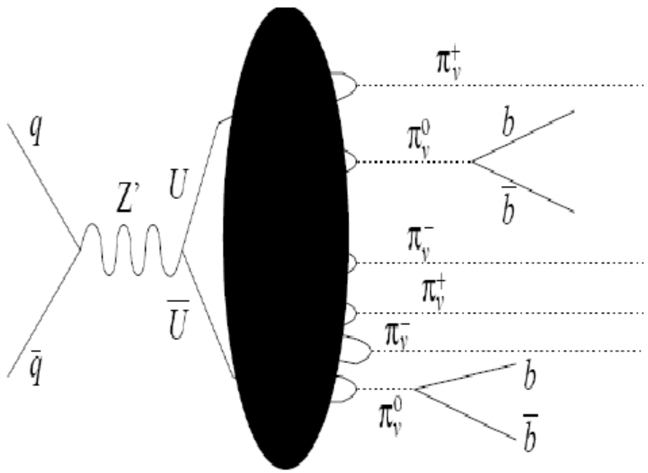


SUSY (MSSM):

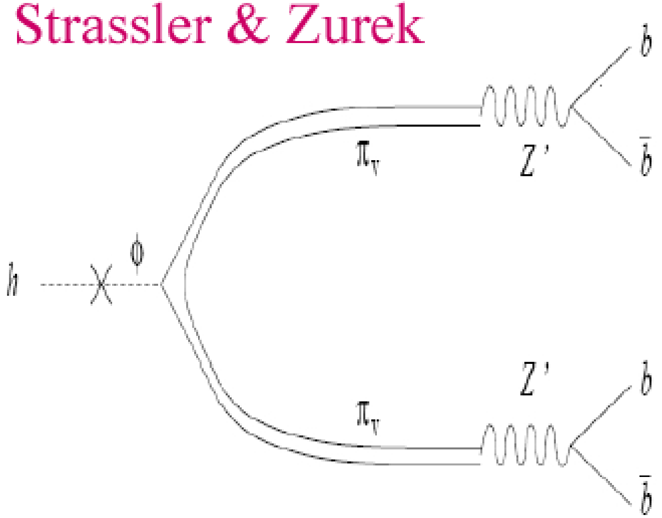


Could be strongly enhanced.

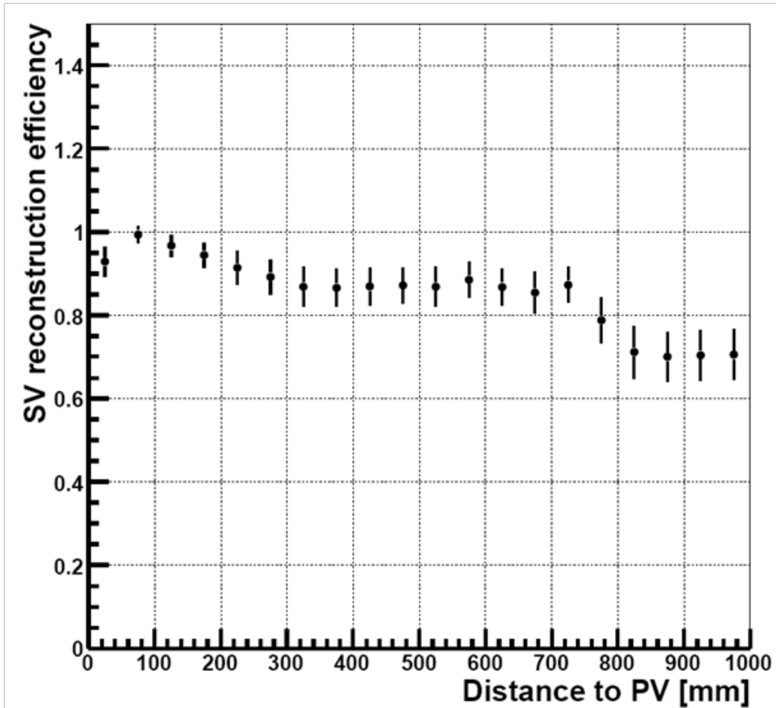
Hidden Valley NP



Strassler & Zurek



- Hidden Valley models:
  - Predict light new particles, hidden from us at existing accelerators, since their production goes via heavy intermediate particles
  - LHCb has unique capabilities for detection of anything decaying to $b\bar{b}$, even with a substantial lifetime (hundreds of ps).



For favorable model parameters LHCb could observe a few hundred events in 200pb^{-1} with small background if m_h~120 GeV

Conclusions

- With 10^8 minimum bias events (1 day of running with minimum bias trigger at low luminosity) LHCb will do interesting measurements testing theoretical models:
  - Complementary to ATLAS/CMS since at larger η and lower p_t
  - Strange particles ratios in forward region will distinguish old and new fragmentation models
- With 5-10 pb^{-1} and muon triggers
  - J/ψ production studies in forward region:
    - Prompt and b- production
    - Measurements of $b\bar{b}$ cross-section
    - Heavier charmonium states including exotics
  - Meaningful constraints on PDFs at low-x from Drell-Yan at low Q^2
- With 200 pb^{-1} first results from rare B decays. LHCb will take over Tevatron in B_s physics:
  - Will the disagreement with SM in ϕ_s deepen or ease up?
  - Any hints of NP in $BR(B_s \to \mu\mu)$?