B Physics(I)

2010 CTEQ - MCnet Summer School
on QCD Phenomenology and Monte Carlo Event Generators

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What is B Physics?

Production of b-hadron

play ground of strong interactions

LHC results are becoming available

Decay of b-hadron

interplay between the weak and strong interactions

dominated by BABAR and Belle

Extraction of the CKM matrix elements

mainly limited by the strong interactions

Indirect search of new physics

loop effect

What is B Physics?

Production

Decays

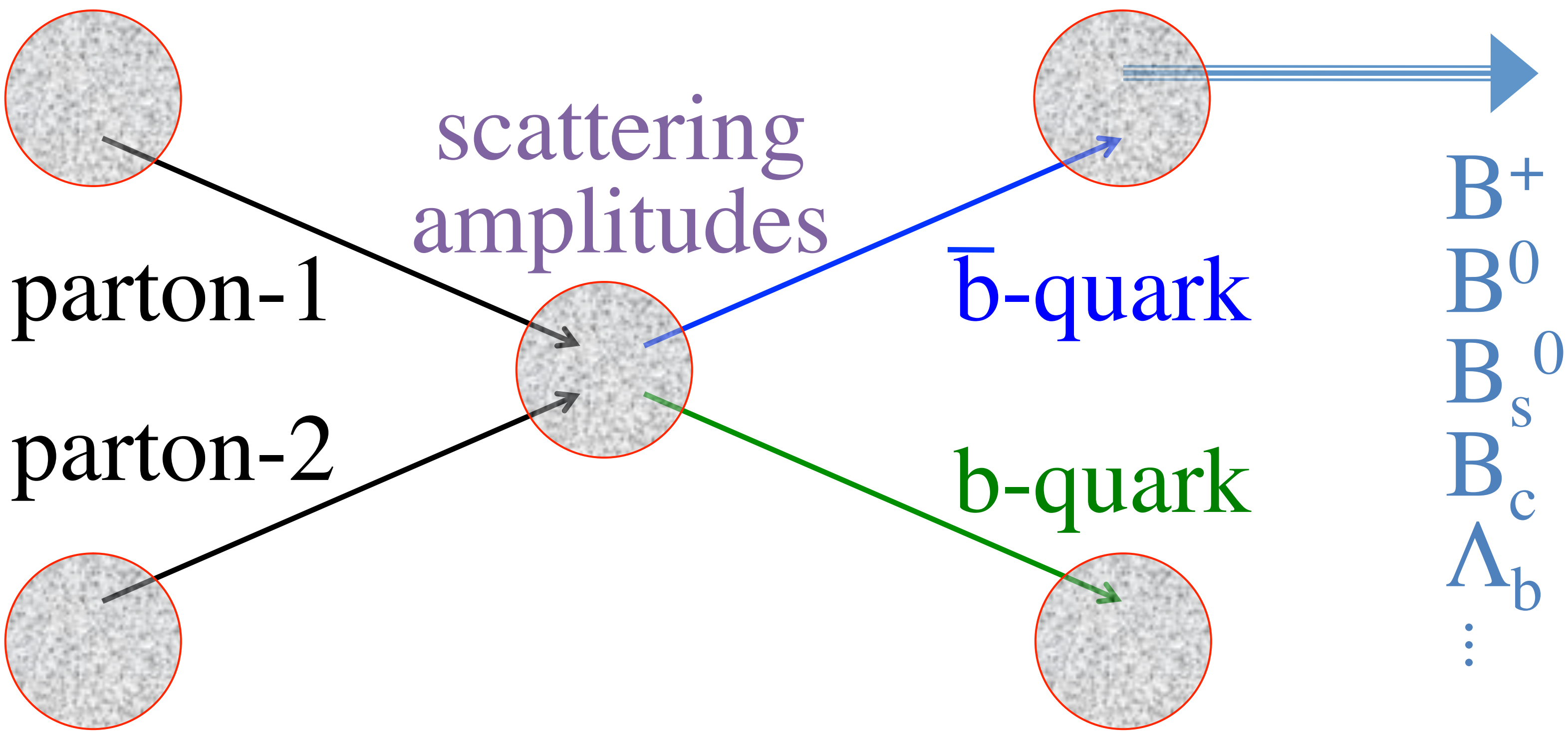
What is B Physics?

Production

in pp interactions

parton density function

fragmentation and hadronisation



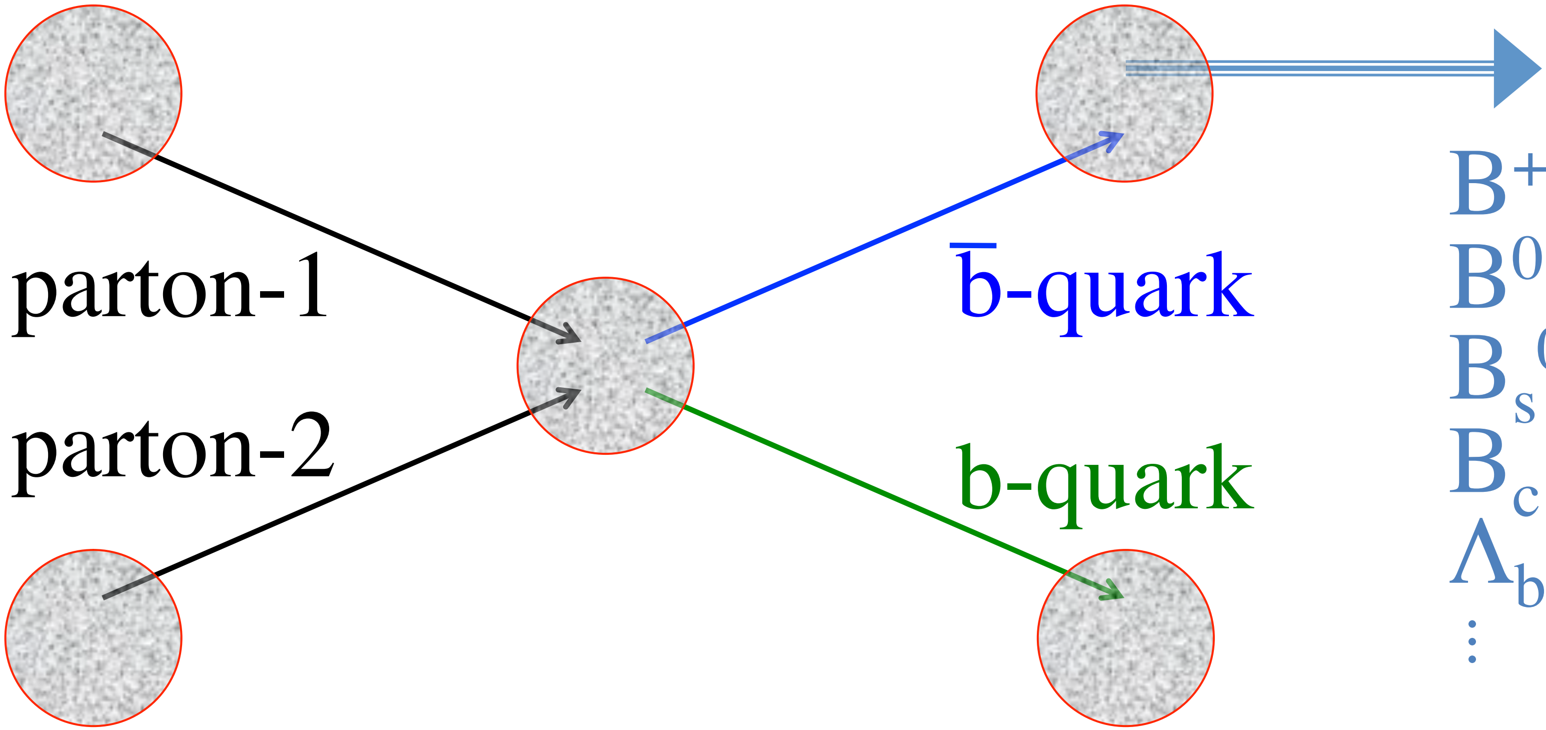
What is B Physics?

$\boxed{\text{Production}}$

in pp interactions

experimentally measured
in ep, μp and νp scatterings

parton density
function

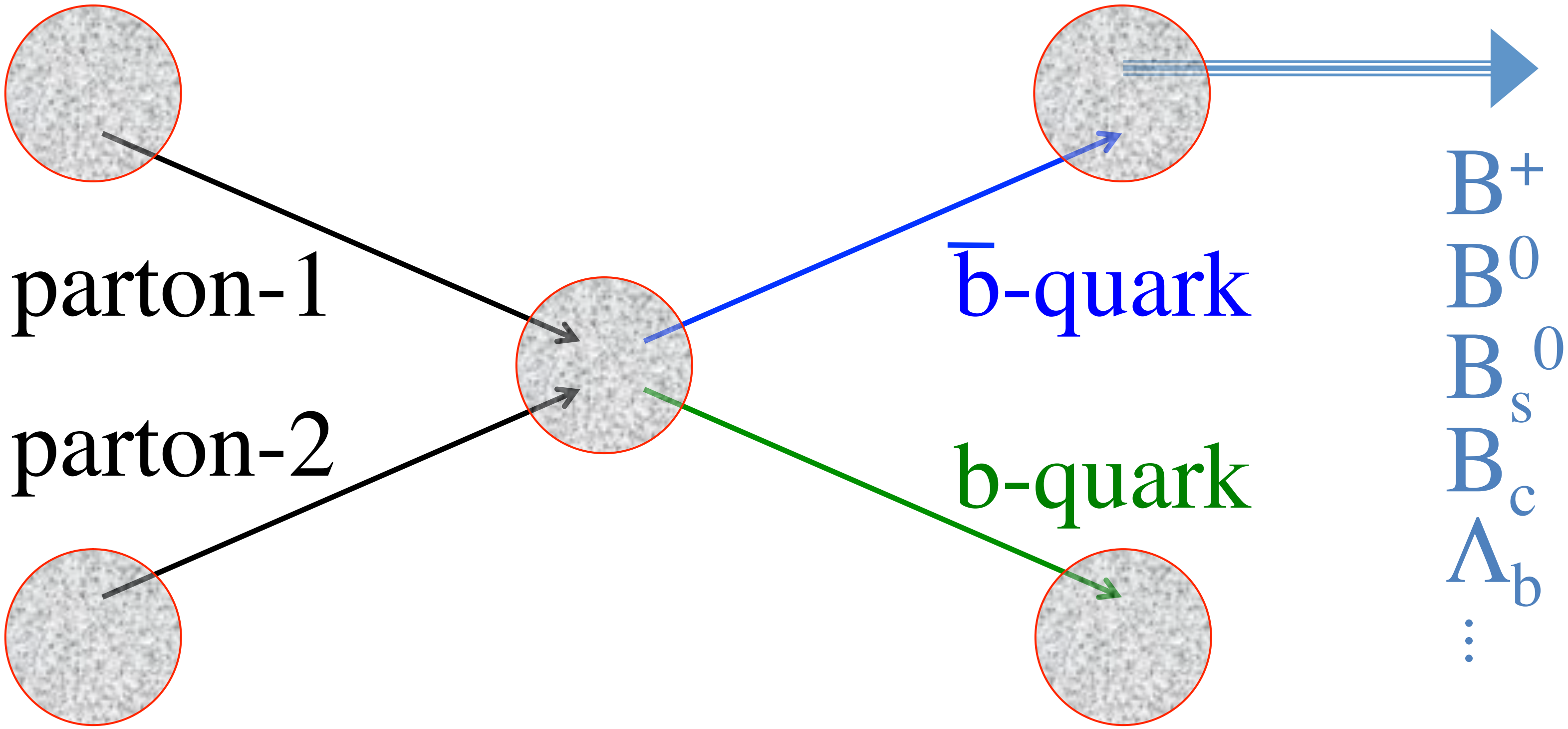


What is B Physics?

Production
in pp interactions

experimentally measured
in $e^+e^- \rightarrow qq, qqg, \ldots$

fragmentation and
hadronisation

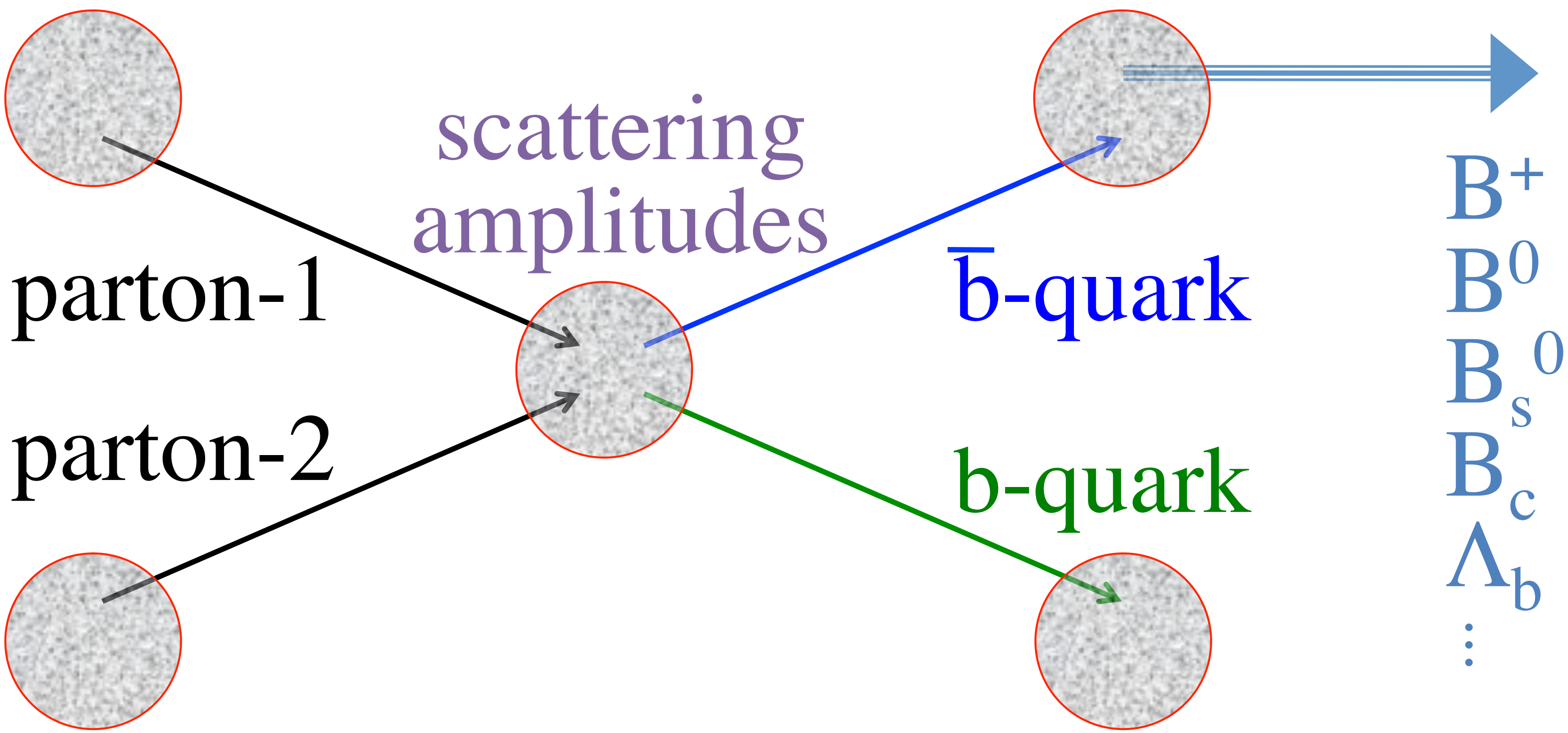


What is B Physics?

$\boxed{\text{Production}}$

in pp interactions

theoretically calculated



What is B Physics?

Production

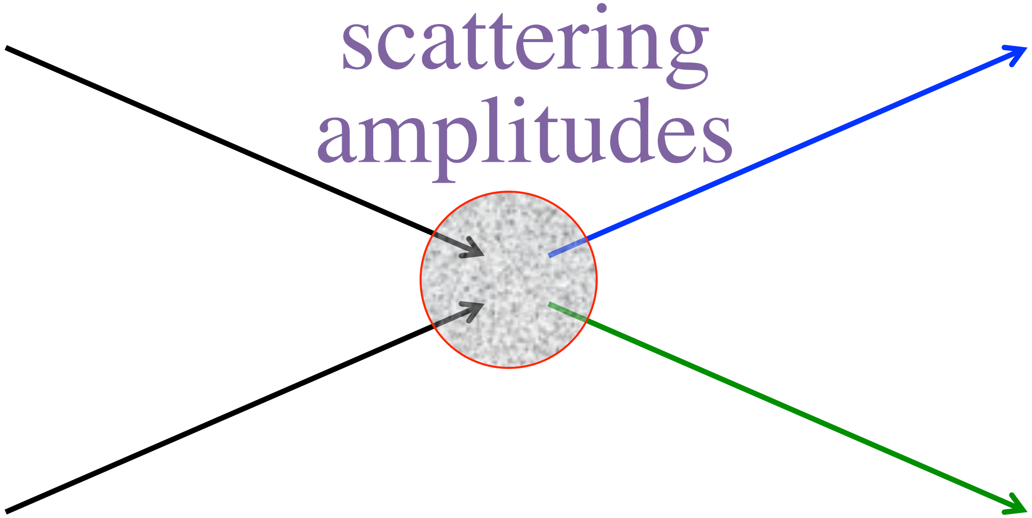
in pp interactions

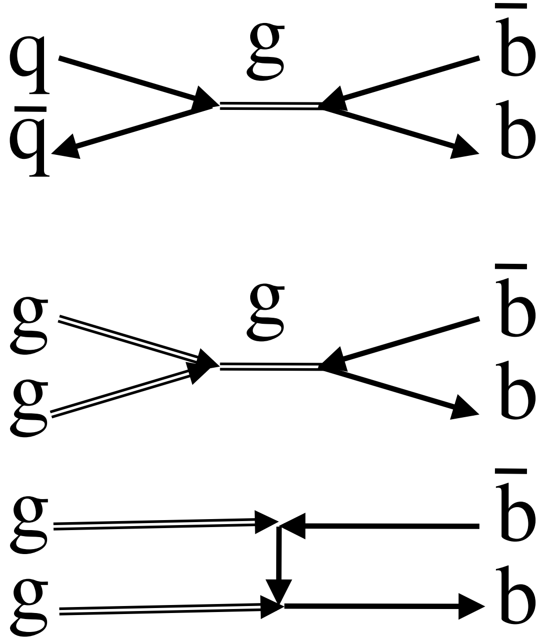
theoretically calculated

Leading Order

$q\bar{q} \to b\bar{b}$

$gg \to b\bar{b}$





What is B Physics?

Production

in pp interactions

theoretically calculated

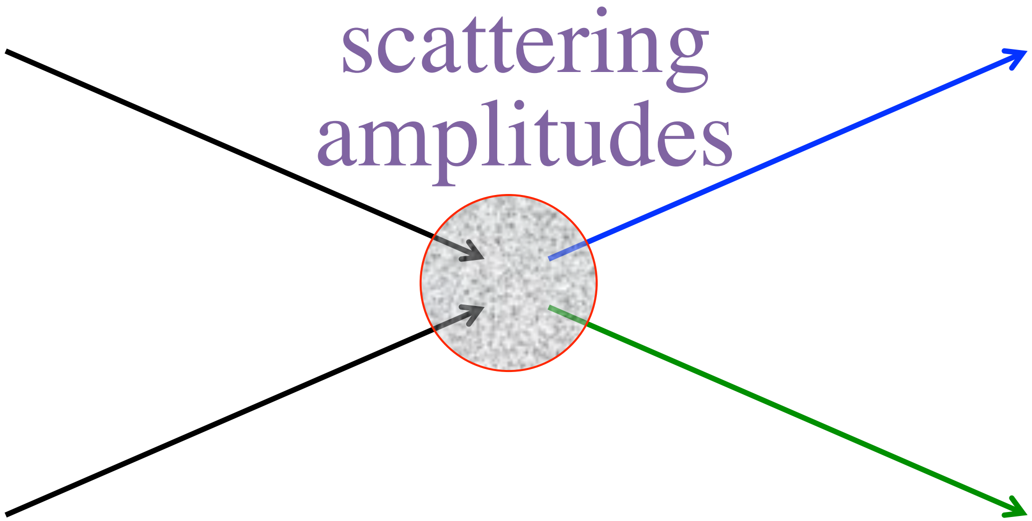
Leading Order

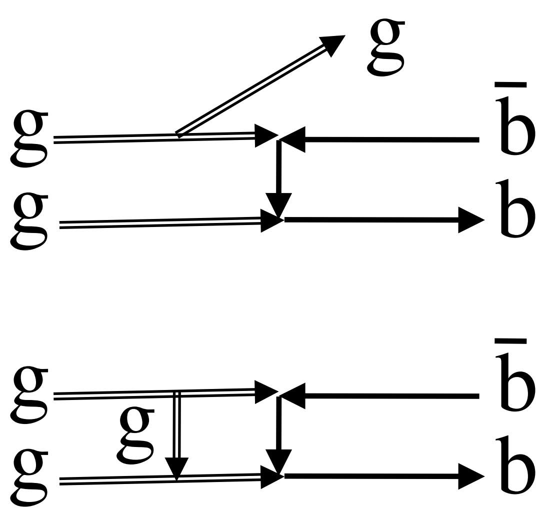
$q\bar{q} \to b\bar{b}$

$gg \to b\bar{b}$

+ Next to LO

i.e. adding one g





What is B Physics?

Production

in pp interactions

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Leading Order

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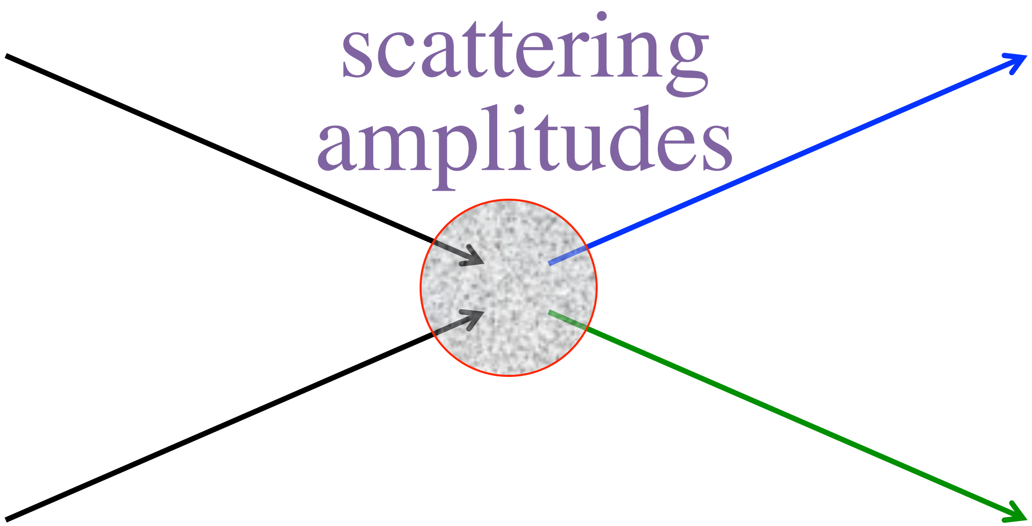
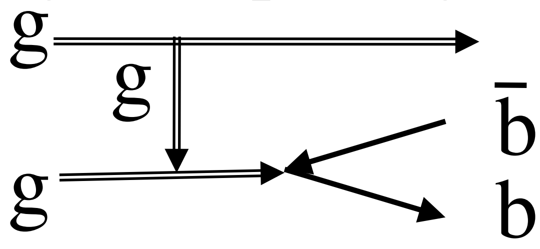
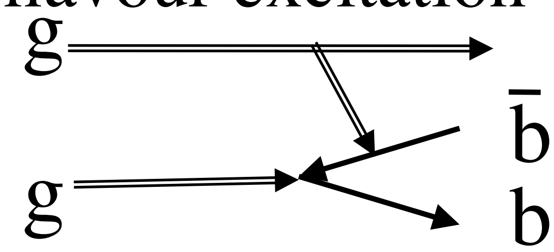


gluon splitting



flavour excitation

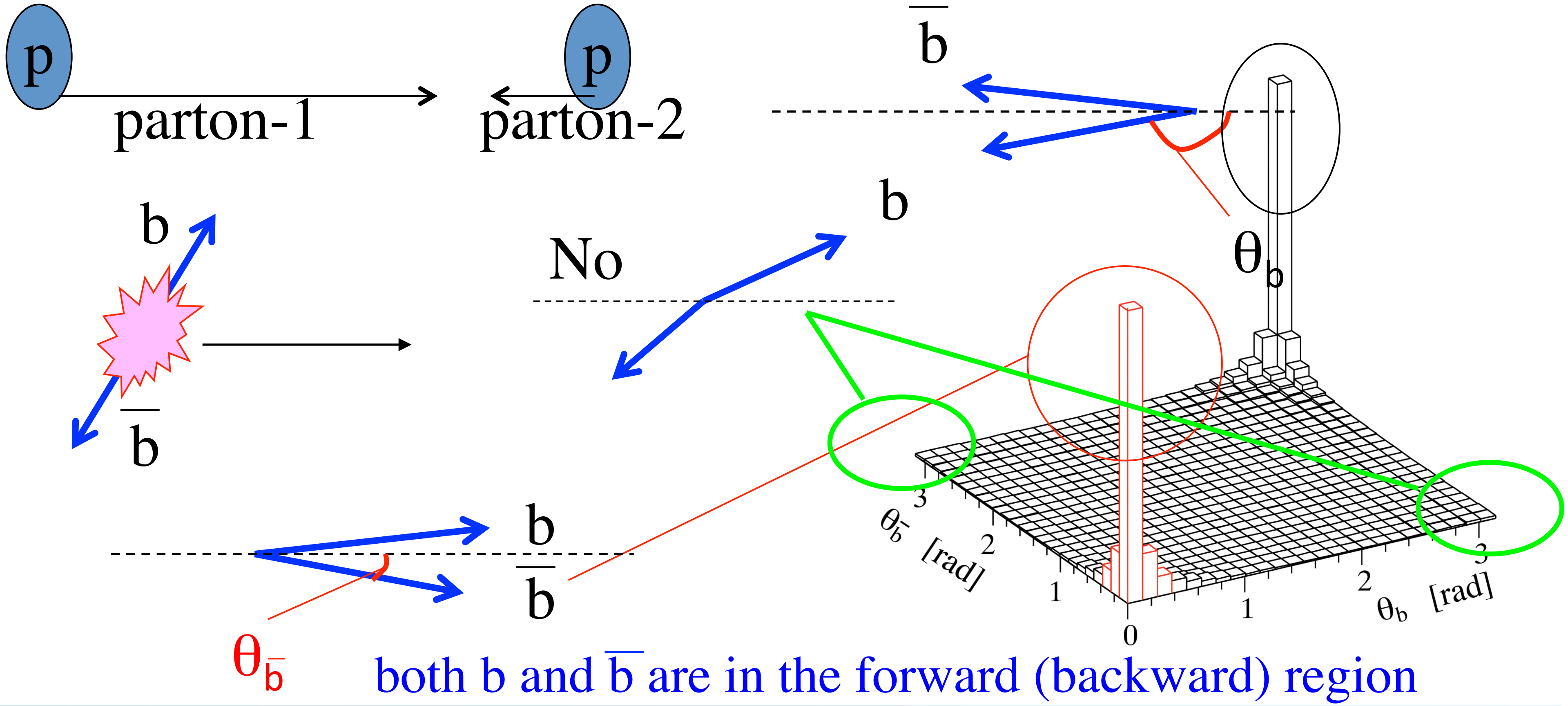


What is B Physics?

Production

in pp interactions

important input for designing an experiment



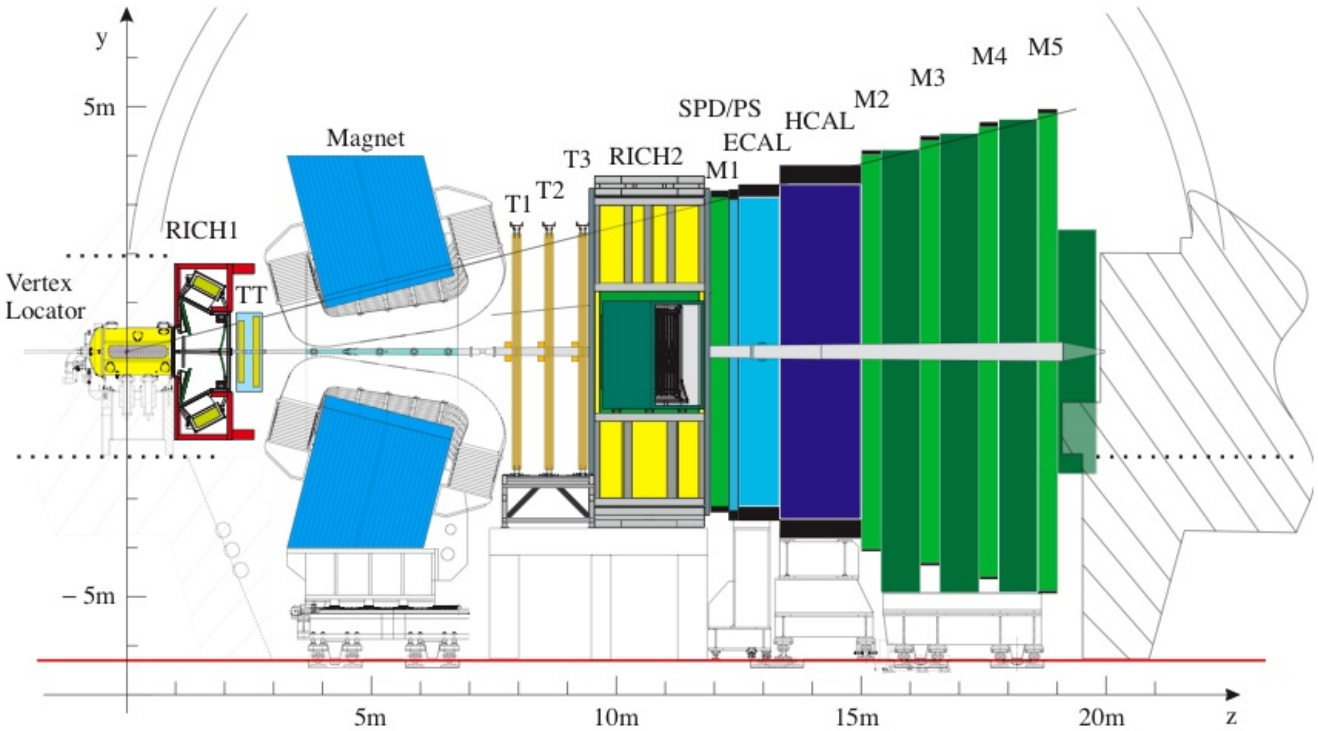
both b and $\bar{b}$ are in the forward (backward) region

What is B Physics?

Production

in pp interactions

that is why LHCb is a forward spectrometer



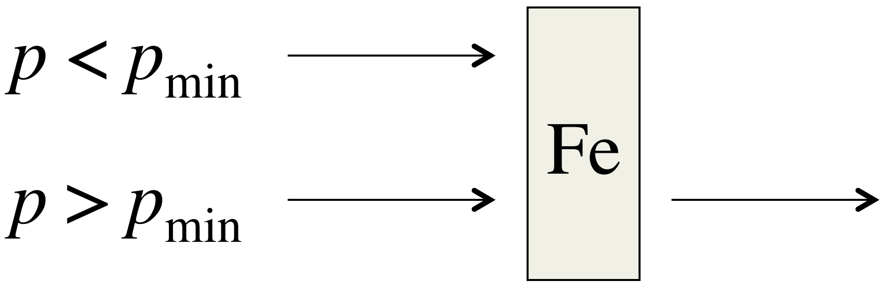
What is B Physics?

Production

in pp interactions

For triggering…. $p > p_{\mathrm{min}}$

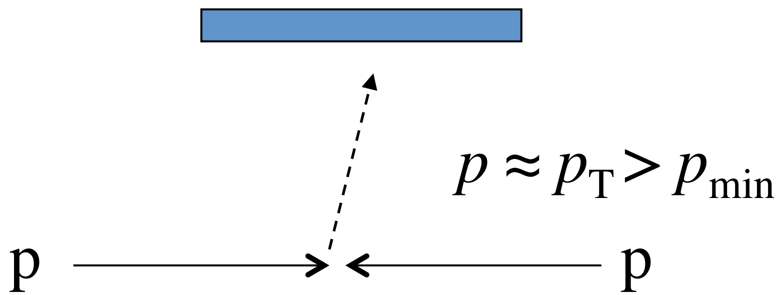
muon: identification



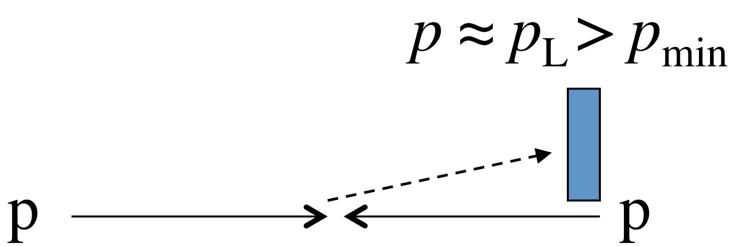
hadron: energy resolution

$\sigma_E/E \approx \sqrt{70\%}/\sqrt{E}$

central detector



forward detector



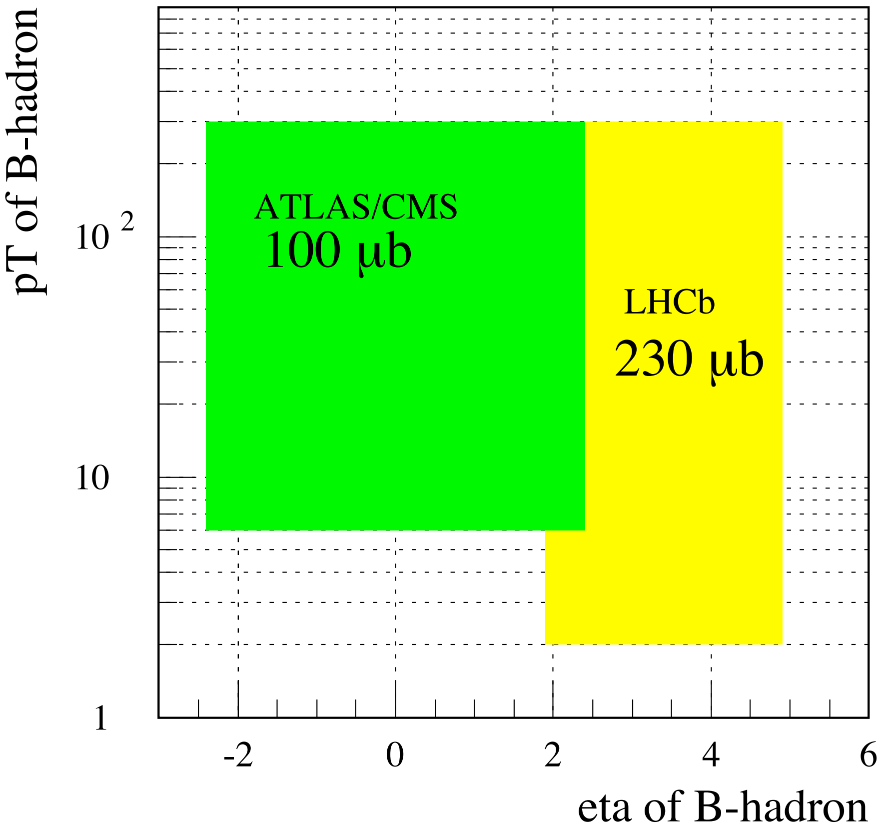
forward: p_T threshold can be set low: → high b efficiency

What is B Physics?

Production

in pp interactions

can exploit low p_T particles



$\sigma_{b\bar{b}}$ expected in pp collisions at
$\sqrt{s}$ = 14 TeV: 500μb
5×10^{11} bb pairs in 10^7 s with
$L = 10^{32}$ cm^{-2}s^{-1}

What is B Physics?

$\boxed{\text{Production}}$
in pp interactions

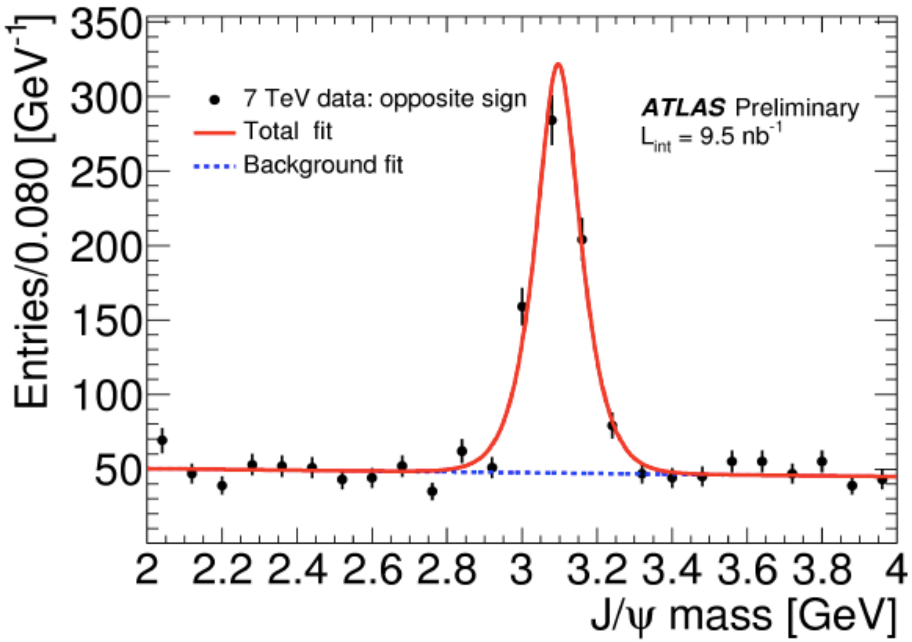
LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

What is B Physics?

Production

in pp interactions

ATLAS J/ψ signal



Clean $\mu^+\mu^-$ mass distribution

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

What is B Physics?

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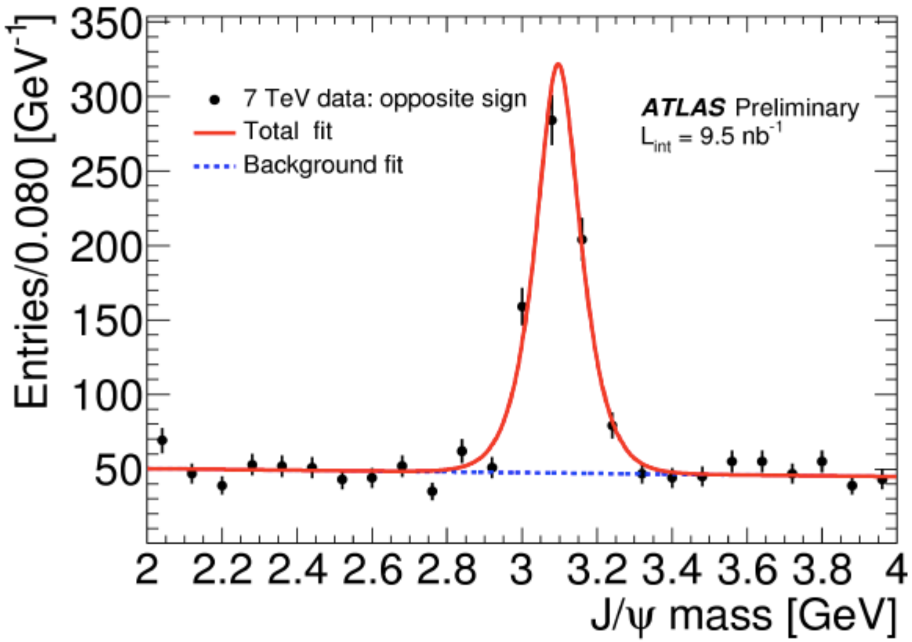

Clean $\mu^+\mu^-$ mass distribution

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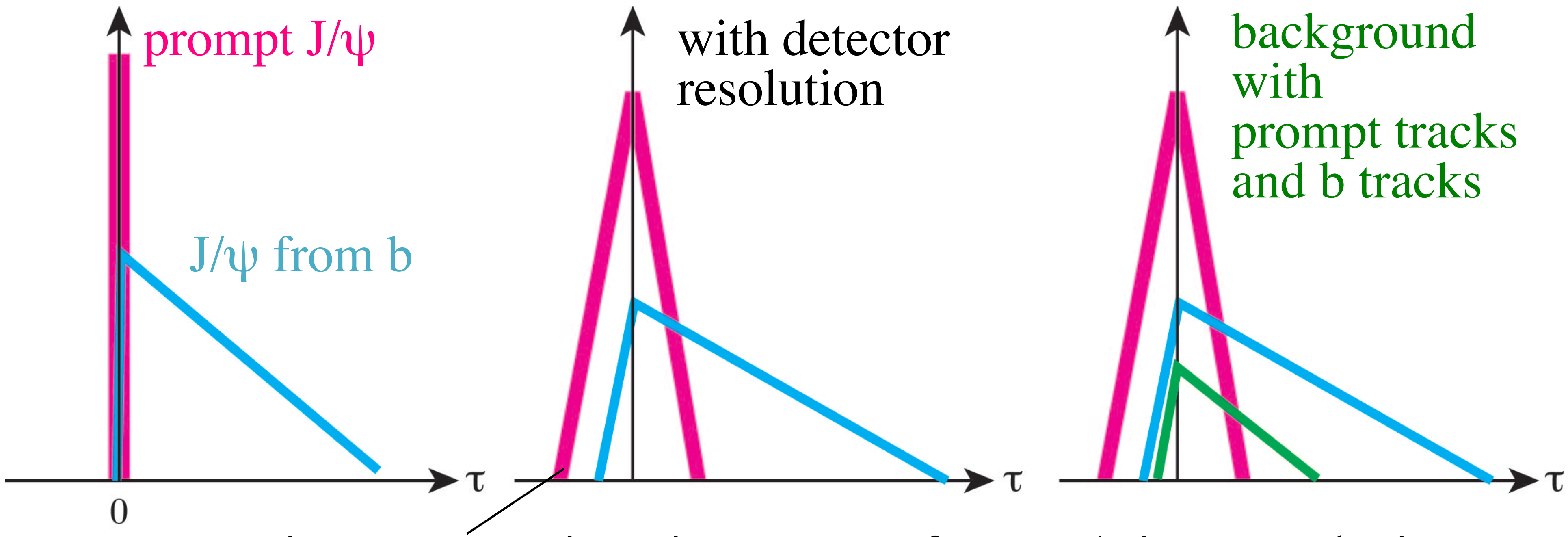
LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

ATLAS J/ψ signal

proper time distribution of J/ψ



negative proper time important for studying resolution

What is B Physics?

Production

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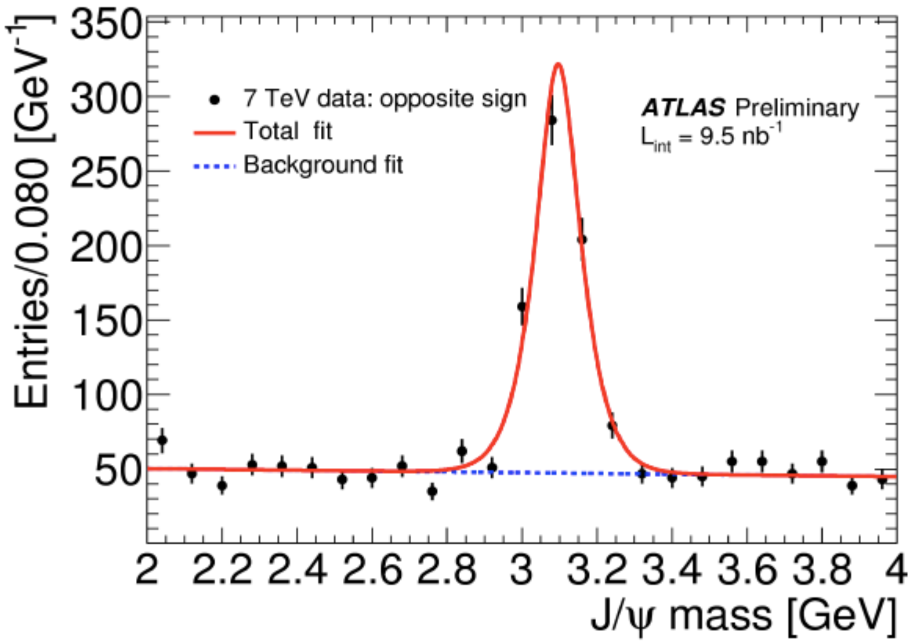
LHC experiments have started to measure the b cross section at $\sqrt{s} = 7$ TeV

ATLAS J/ψ signal



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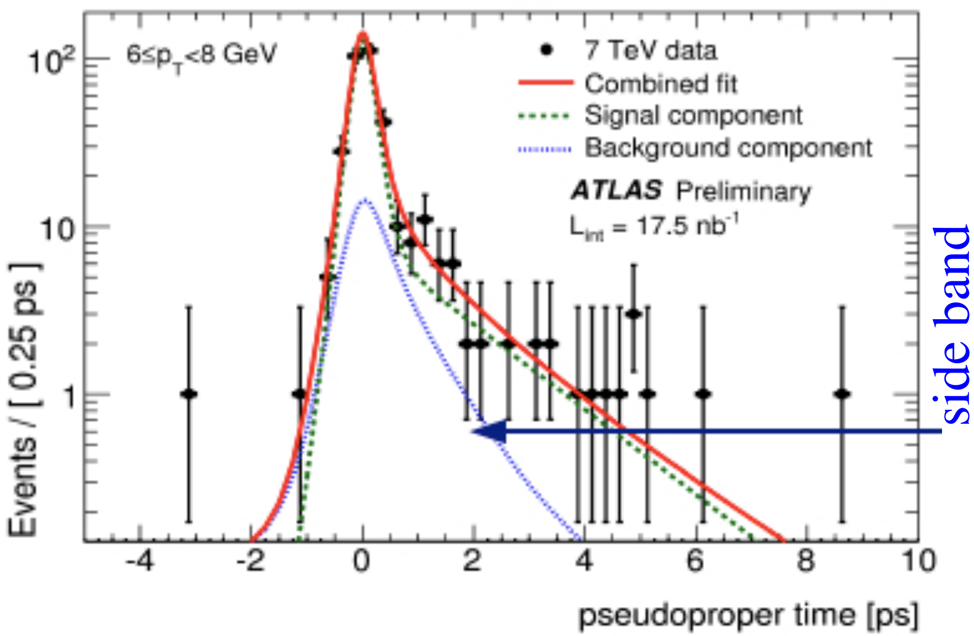


J/ψ with a long proper time due to b-hadron decays

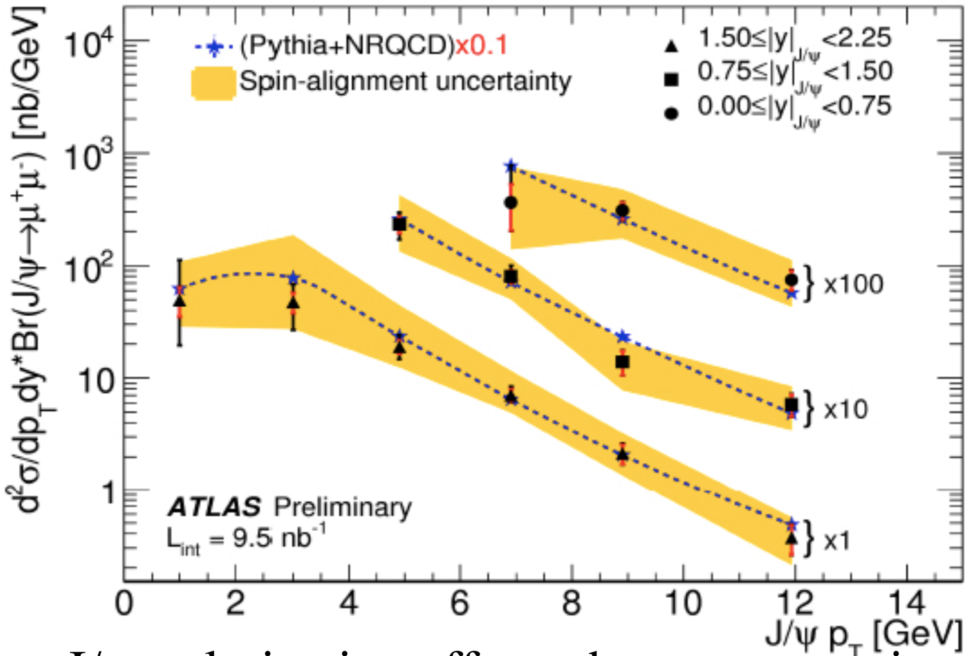
What is B Physics?

Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

ATLAS J/ψ inclusive



J/ψ polarization affects the reconstruction efficiencies. Shape agree with a model but not the absolute value.

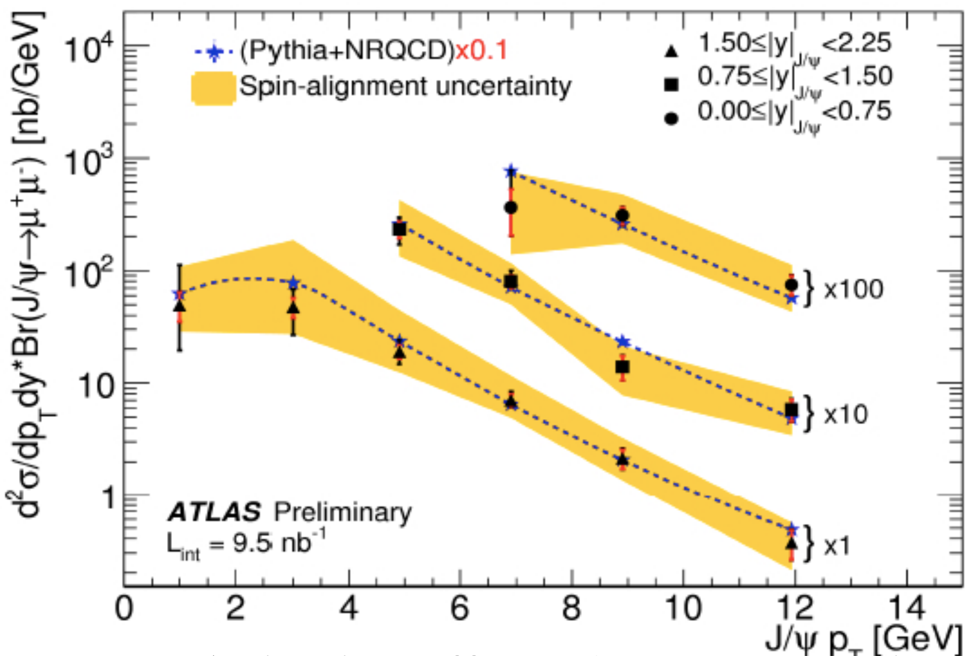
What is B Physics?

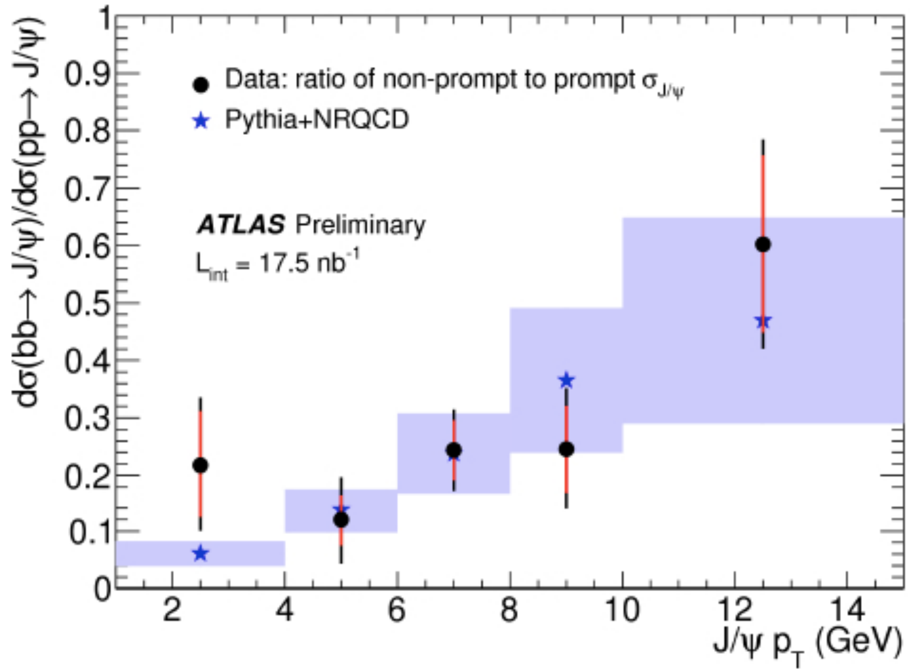
Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

ATLAS J/ψ inclusive and from b-hadrons





J/ψ polarization affects the reconstruction efficiencies. Shape agree with a model but not the absolute value.

Fraction of J/ψ from the b-hadron. Agree with a model prediction.

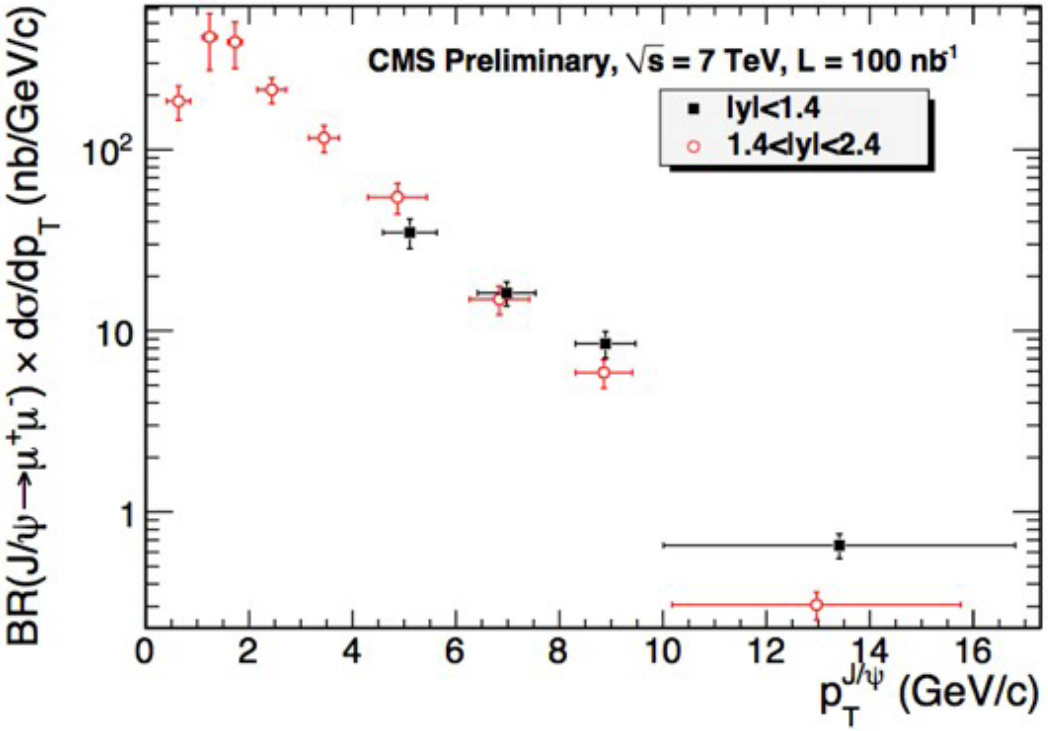
What is B Physics?

Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s} = 7$ TeV

CMS inclusive J/ψ



In agreement with the ATLAS result.

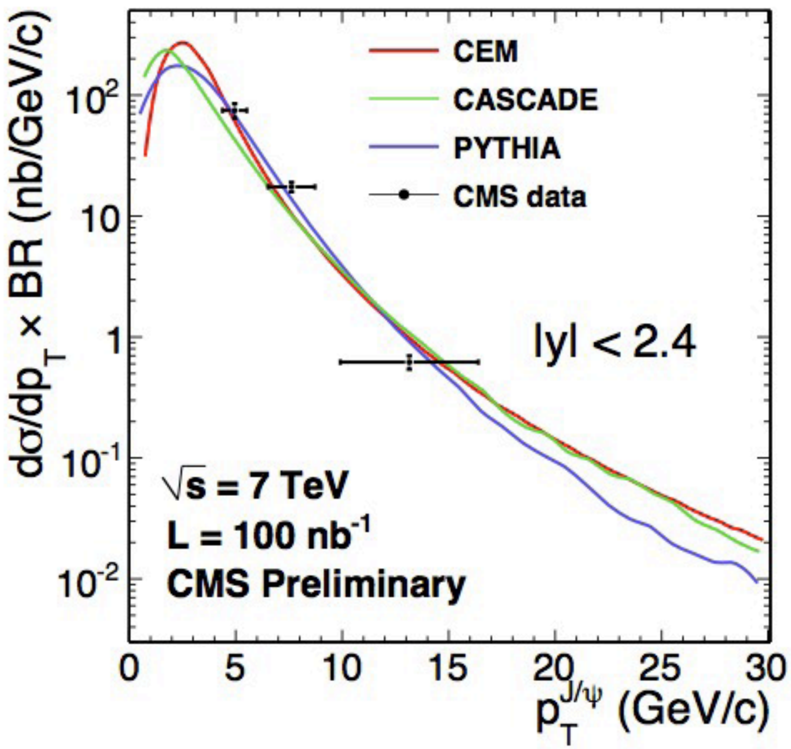
What is B Physics?

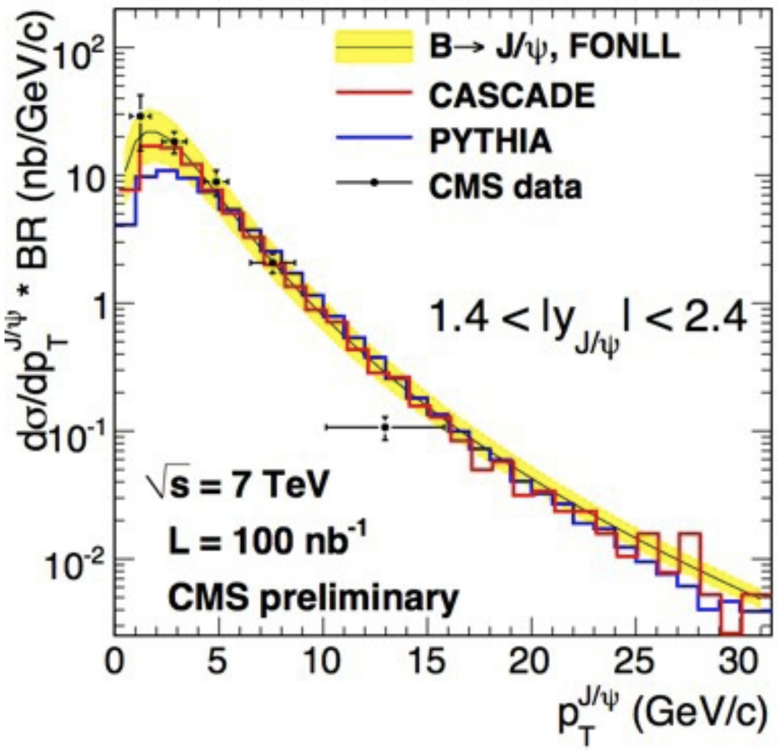
Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s} = 7$ TeV

CMS J/ψ prompt and from b





In agreement with models. Contradiction to the ATLAS model calculation?

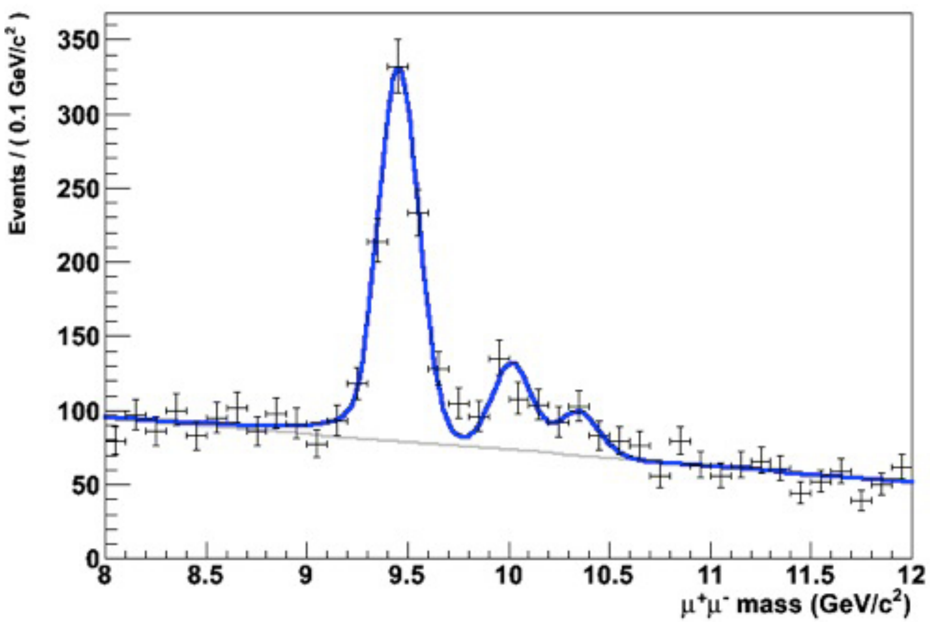
What is B Physics?

Production

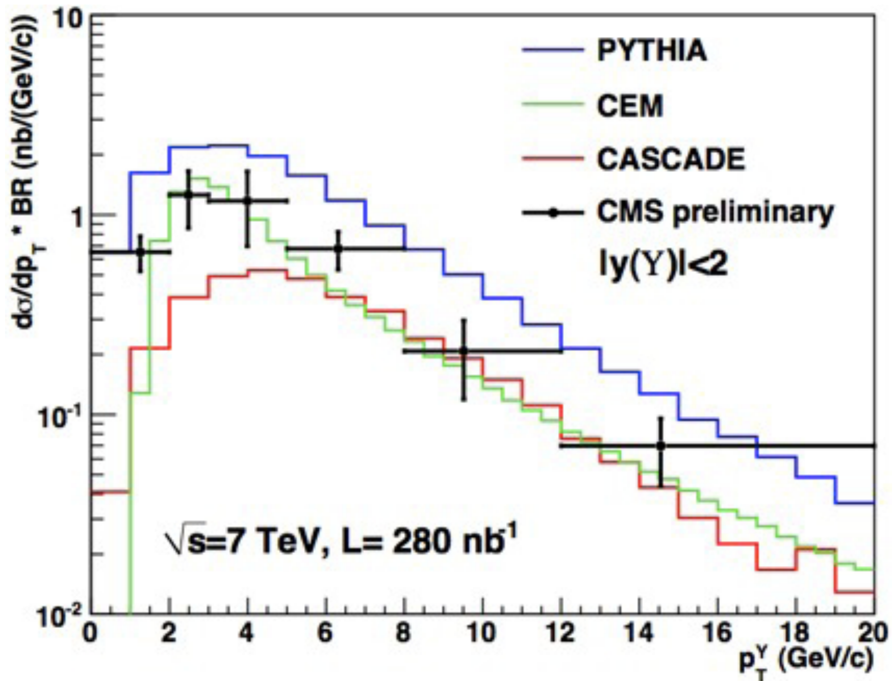
in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

CMS already see ϒ's



Clean $\mu^+\mu^-$ mass distribution



$\Upsilon(1\sigma) \rightarrow \mu^+\mu^-$ cross section

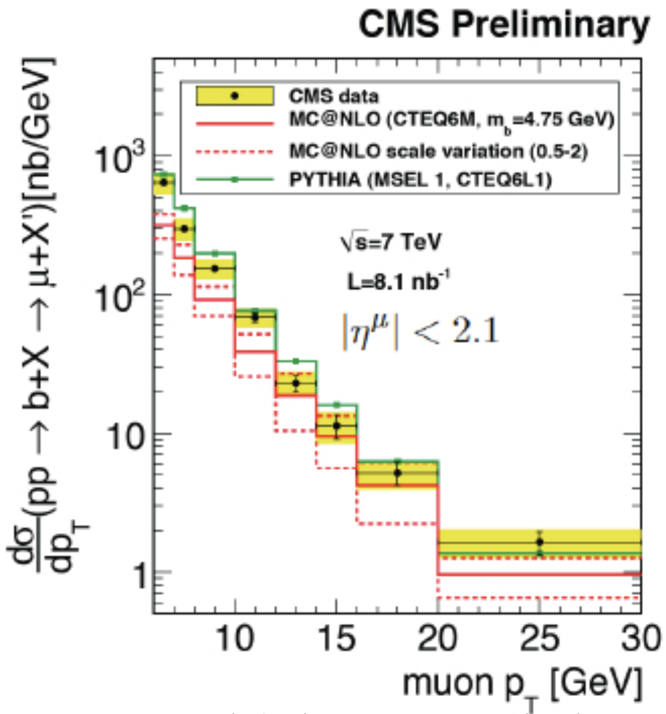
What is B Physics?

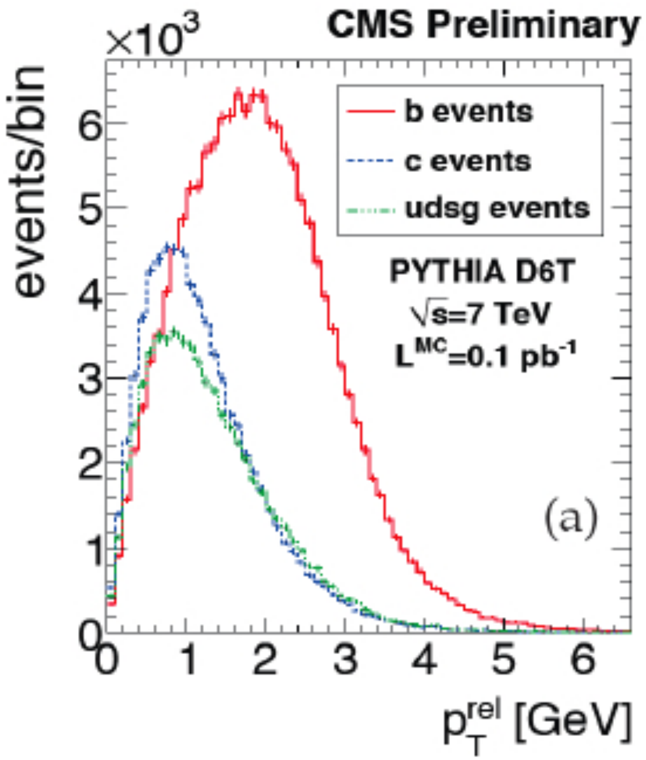
Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

CMS b with single μ,





$b \to \mu X$: μ with large p_T relative to the jet direction

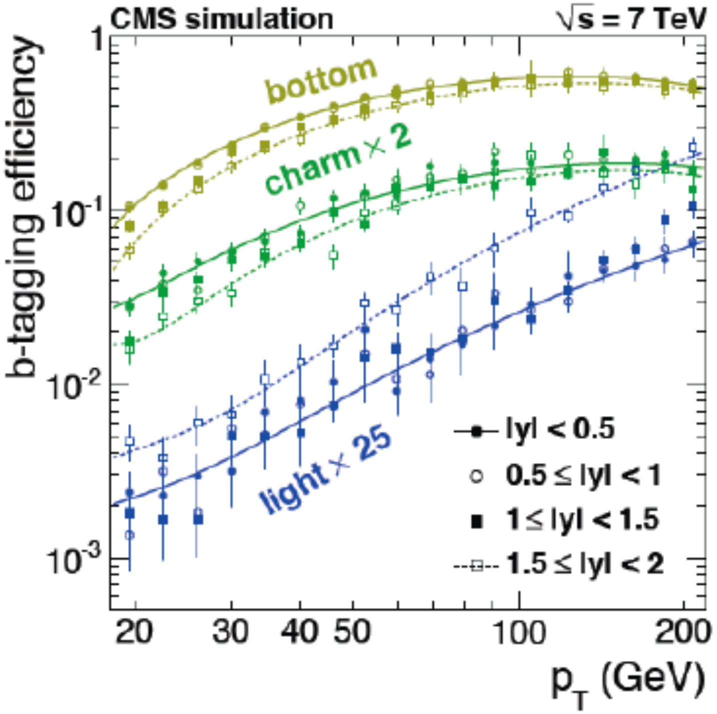
What is B Physics?

Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

CMS b with b-jet tagging



Efficiency for a b-jet tagging algorithm based on the secondary vertex in a jet

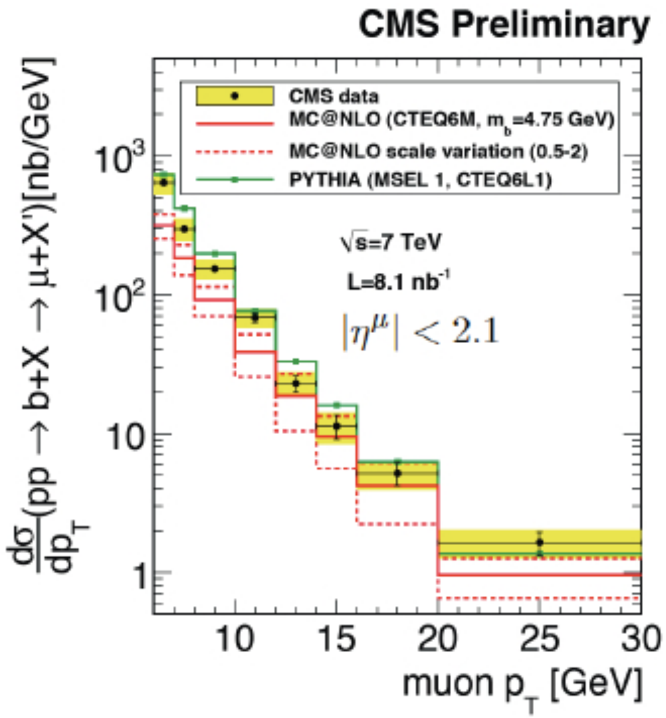
What is B Physics?

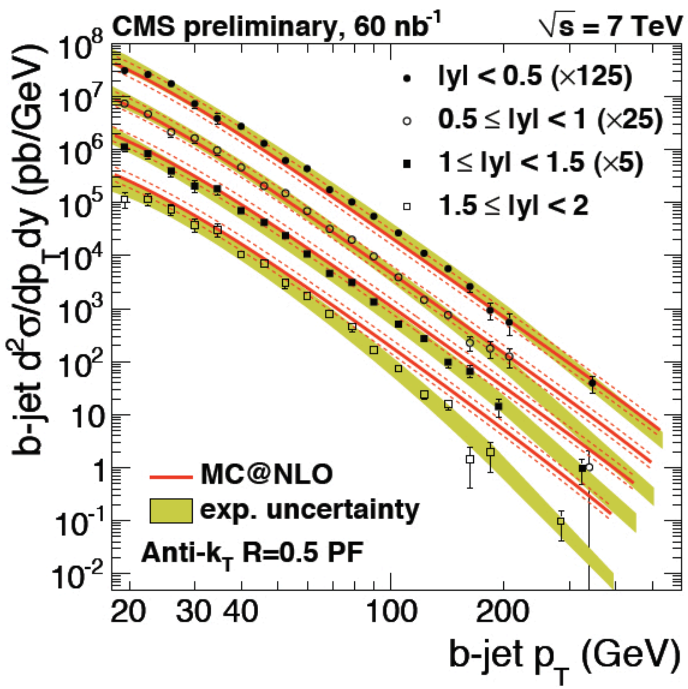
Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

CMS b with single μ, and b-jet tagging





agree with model calculations

What is B Physics?

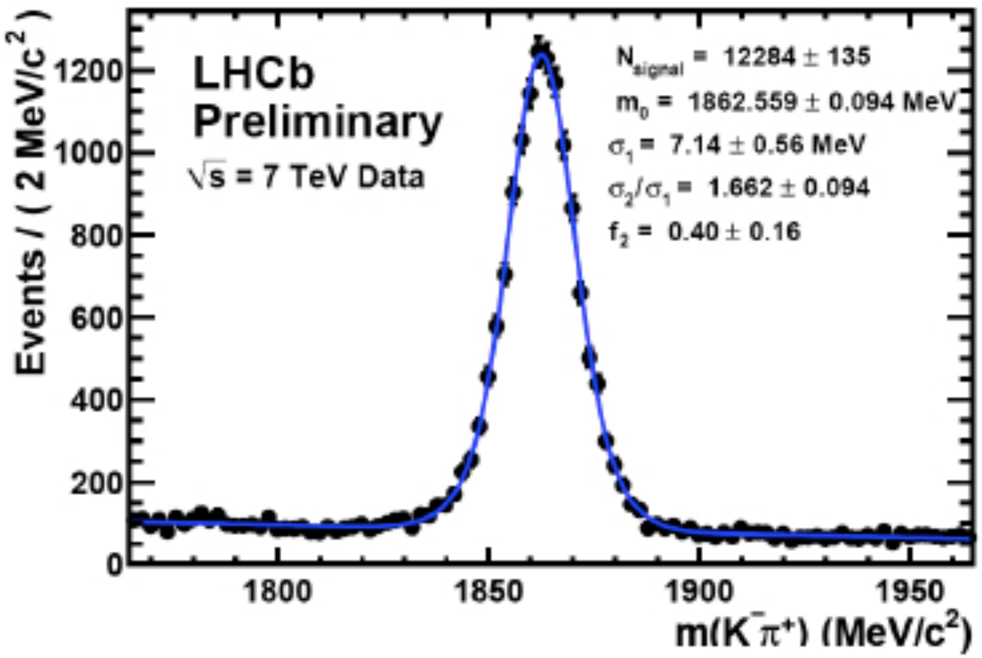
Production

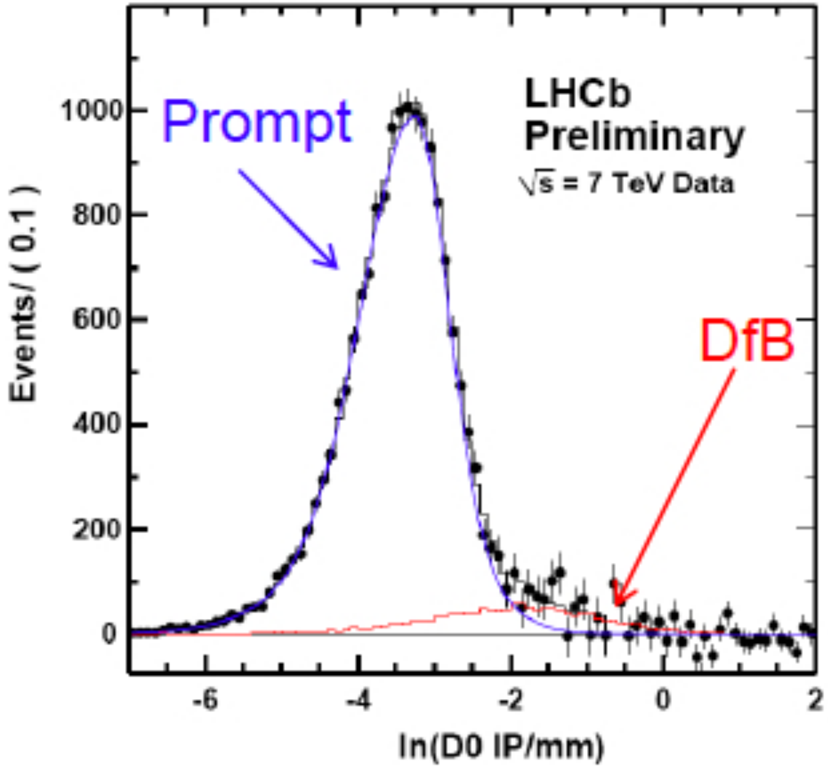
in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

LHCb b from B→DlX

Inclusive D:
dominated by the prompt production





What is B Physics?

Production

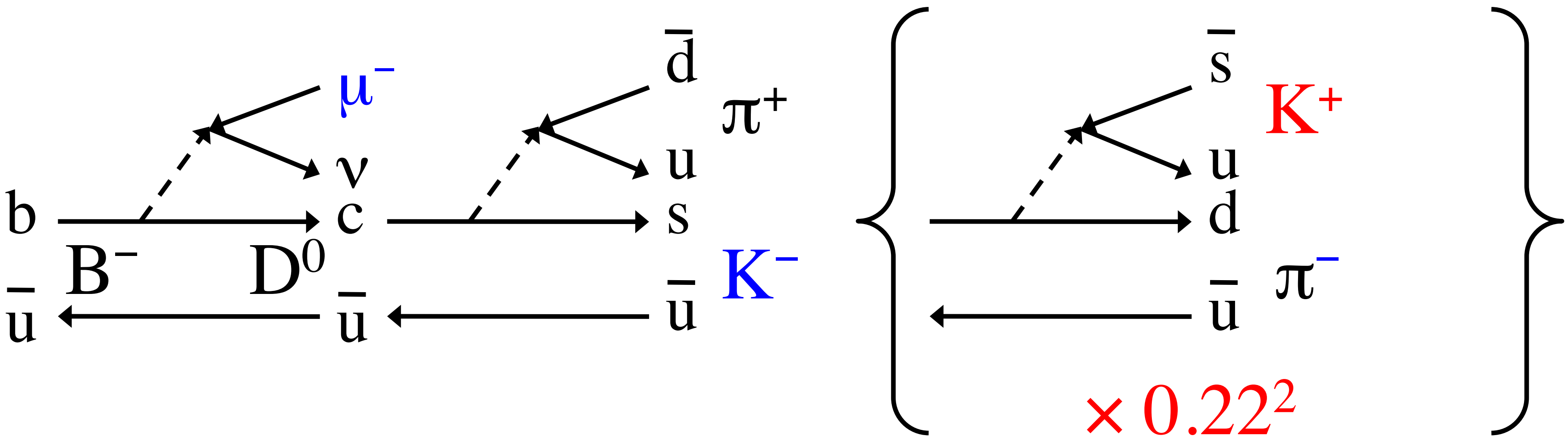
in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

LHCb b from $B \to D l X$

Adding μ with a right sign enhances D from B:

e.g. $B^- \to D^0(\to K^- \pi^+)\mu^- X$ [$B^- \to D^0(\to K^+ \pi^-)\mu^- X$ only through DCSD]



What is B Physics?

Production

in pp interactions

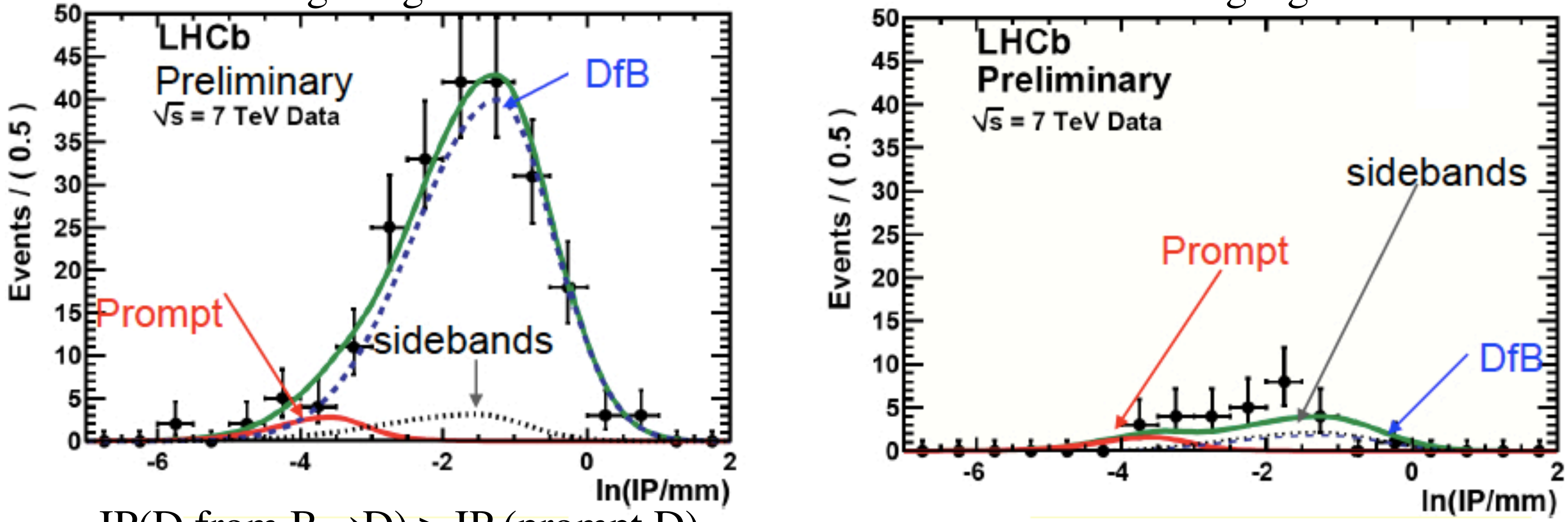
LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

LHCb b from B→DlX

Adding μ with a right sign enhances D from B:

e.g. $B^-\to D^0(\to K^-\pi^+)\mu^-X$ [$B^-\to D^0(\to K^+\pi^-)\mu^-X$ only through DCSD]

with right sign muons | with wrong sign muons



IP(D from B→D) > IP (prompt D)

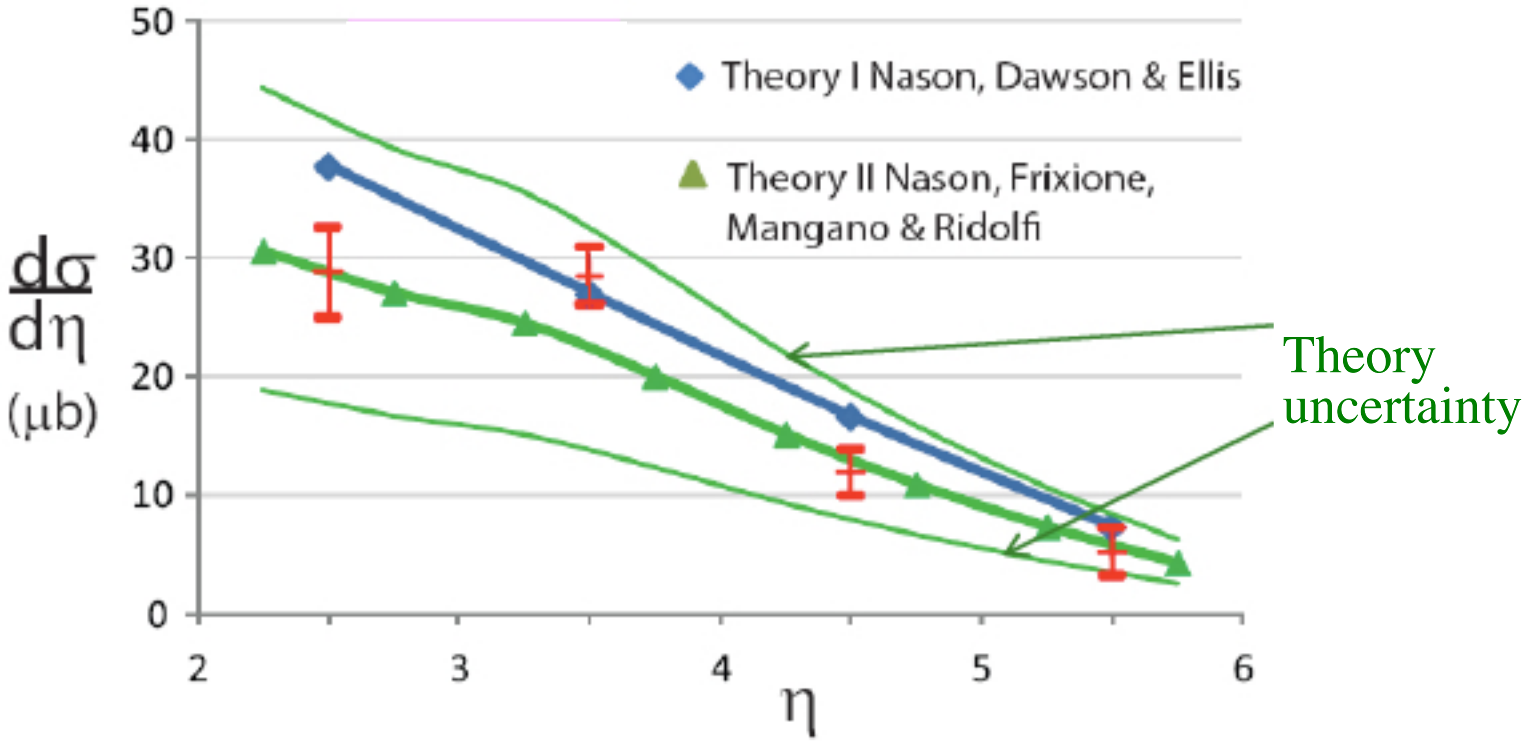
What is B Physics?

Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s}$ = 7 TeV

LHCb b from B→DlX



What is B Physics?

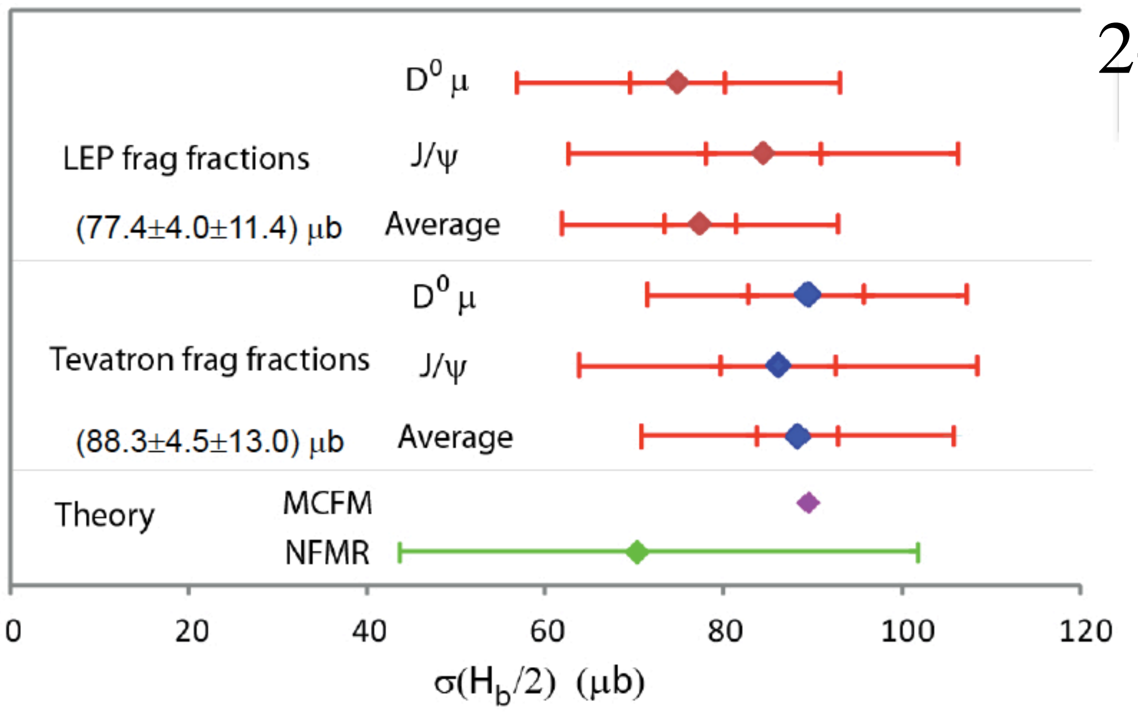
Production

in pp interactions

LHC experiments have started to measure the b cross section at $\sqrt{s} = 7$ TeV

LHCb σ_b from different processes

$2<\eta<6$



σ_{bb} in $4\pi = 292 \pm 15 \pm 43$ μb (with LEP $B_u/B_d/B_s/\Lambda_b$)

What is B Physics?

Production
in pp interactions

ATLAS, CMS and LHCb already producing results on b production in pp interactions at $\sqrt{s} = 7$ TeV

By the autumn this year, 100 times or even more data expected:

- finer binning for $d^2\sigma/dp_T dy$
- $d^2\sigma/dp_T dy$ for Υ
- polarization for J/ψ and Υ

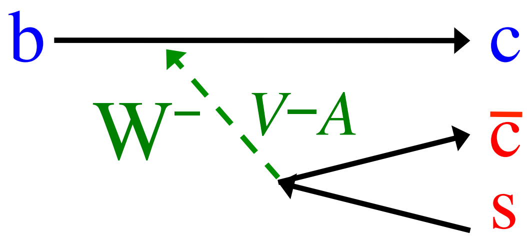
will lead to a detailed comparison with theory

What is B Physics?

Decays

decay and oscillation amplitudes

lowest order weak interactions



What is B Physics?

$\boxed{\text{Decays}}$

$\boxed{\text{decay and oscillation amplitudes}}$

lowest order weak interactions

$(\bar{c}_i\, b_i)_{V-A}\, (\bar{s}_j\, c_j)_{V-A}$

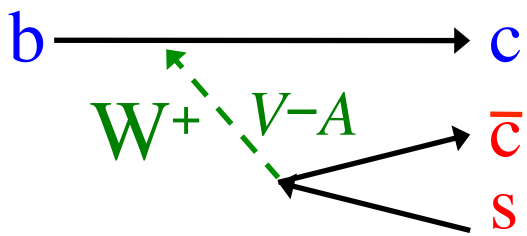
No QCD tree diagram

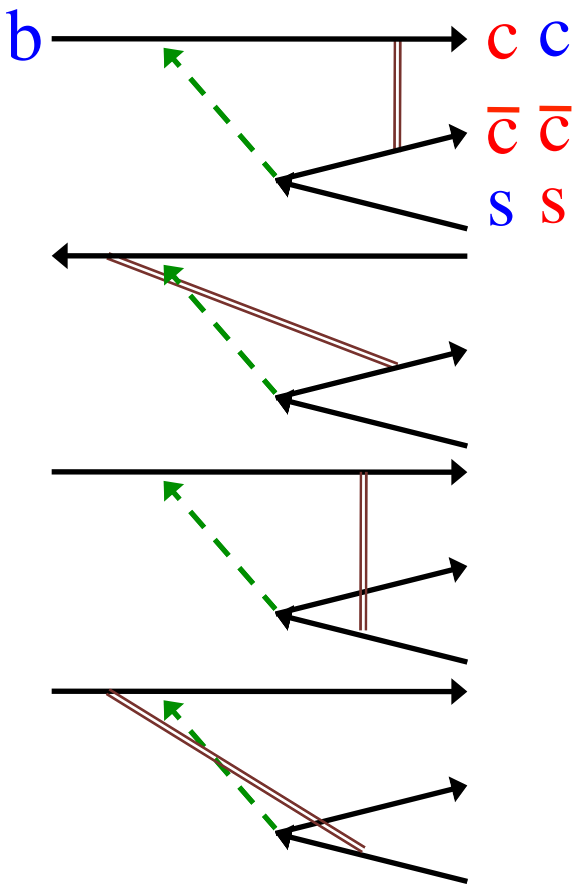
What is B Physics?

Decays

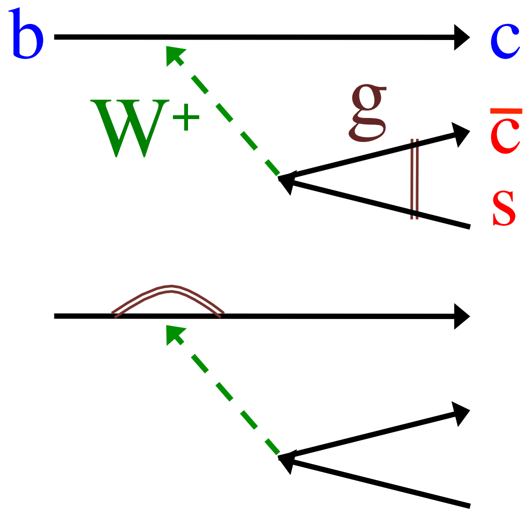
decay and oscillation amplitudes

lowest order weak interactions





Switching on QCD



What is B Physics?

Decays

decay and oscillation amplitudes

lowest order weak interactions

$(\bar{c}_i b_i)_{V-A}\,(\bar{s}_j c_j)_{V-A}$

No QCD tree diagram

+ one gluon
tree diagrams with two different colour structures

$(\bar{c}_i b_i)_{V-A}\,(\bar{s}_j c_j)_{V-A}$

$(\bar{c}_j b_i)_{V-A}\,(\bar{s}_i c_j)_{V-A}$

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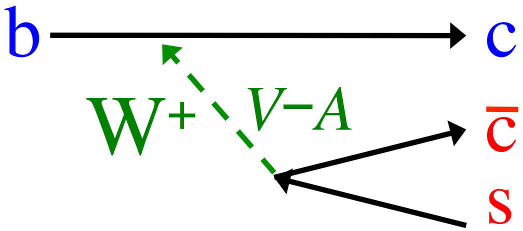
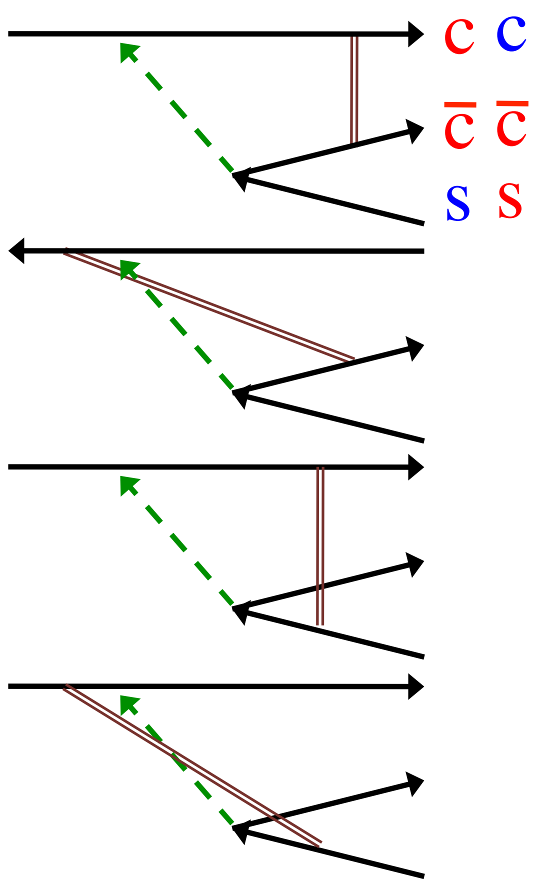
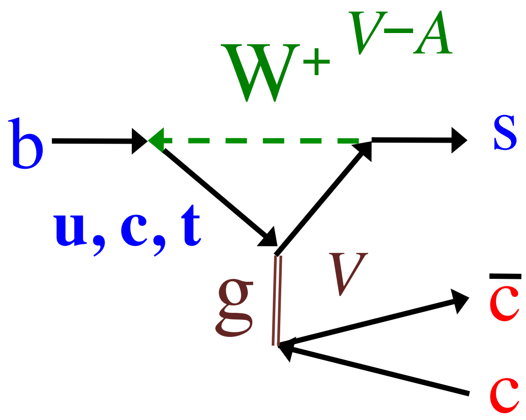
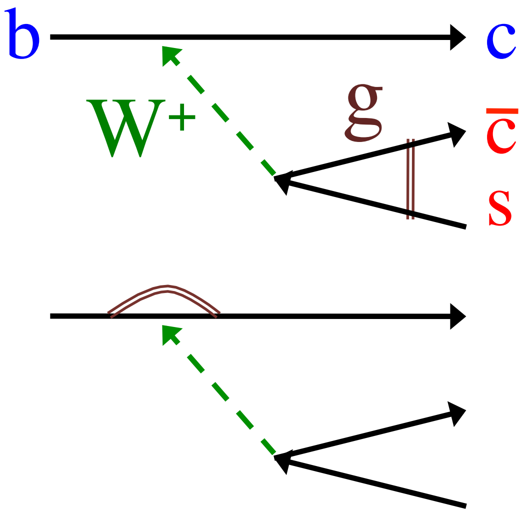
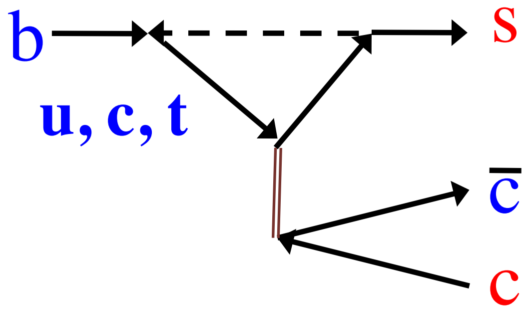






Switching on QCD





gluon penguins

What is B Physics?

Decays

decay and oscillation amplitudes

lowest order weak interactions

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

No QCD tree diagram

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$

+ one gluon
tree diagrams with two
different colour structures

$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_V$

+ gluon penguins with two
different colour structure
gluon = V

$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_V$

What is B Physics?

Decays

decay and oscillation amplitudes

lowest order weak interactions

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

No QCD tree diagram

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$

+ one gluon
tree diagrams with two
different colour structures

$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V-A}$

$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V+A}$

+ gluon penguins with two
different colour structure
gluon = V
→ split to $(V-A) + (V+A)$

$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V-A}$

$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V+A}$

What is B Physics?

Decays

decay and oscillation amplitudes

lowest order weak interactions

operators

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

No QCD tree diagram

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$ Q_2

$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$ Q_1

+ one gluon
    tree diagrams with two different colour structures

$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V-A}$ Q_3

+ gluon penguins with two different colour structure
    gluon = V
    $\rightarrow$ split to $(V-A) + (V+A)$

$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V+A}$ Q_5

$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V-A}$ Q_4

$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V+A}$ Q_6

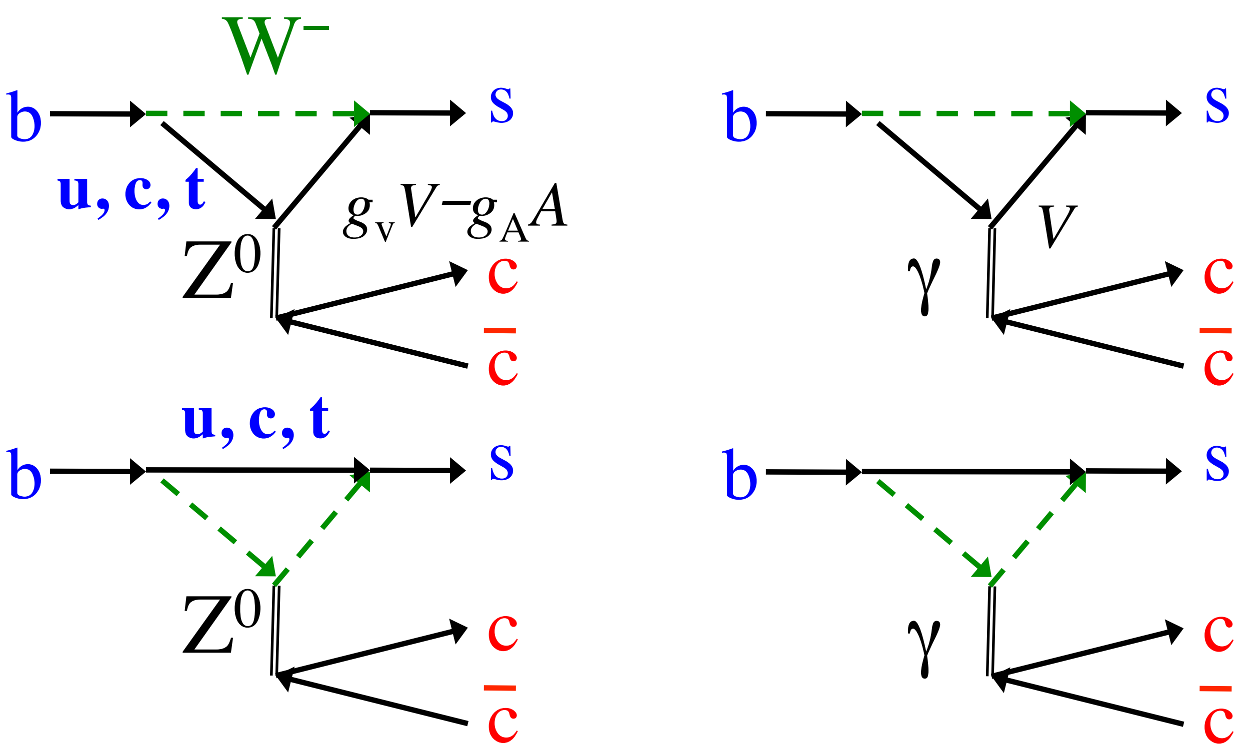
What is B Physics?

Decays

decay and oscillation amplitudes

then proceed to the second order electroweak interactions

electroweak penguins



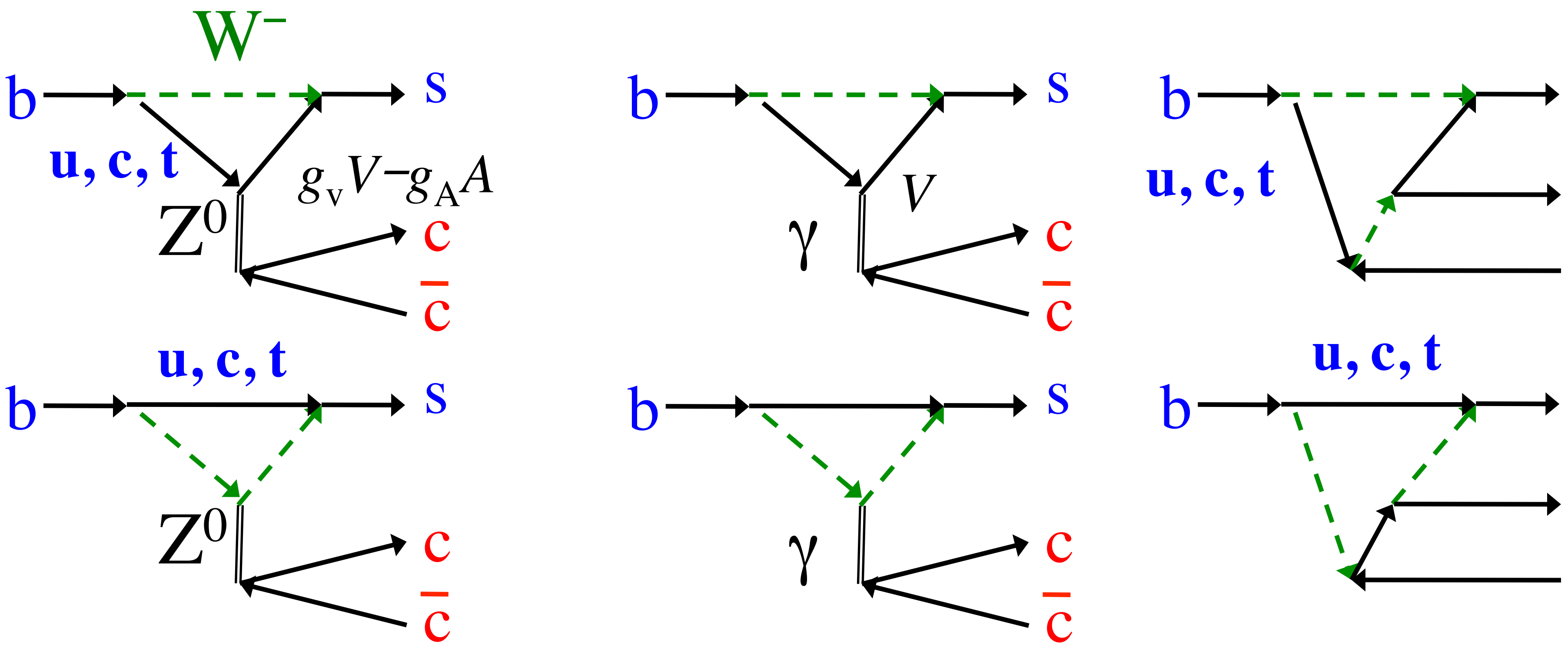
What is B Physics?

Decays

decay and oscillation amplitudes

then proceed to the second order electroweak interactions

electroweak penguins box



What is B Physics?

Decays

decay and oscillation amplitudes

Theoretical tool to describe the decay amplitude for M→F

$$A(M \to F) = \left\langle F \middle| H^{\text{weak decay}}_{\text{effective}} \middle| M \right\rangle = \frac{G_{\mathrm{F}}}{\sqrt{2}} \sum_i \xi^i_{\mathrm{CKM}} C_i(\mu) \left\langle F \middle| Q_i(\mu) \middle| M \right\rangle$$

G_{F}: Fermi constant,
$Q_i(\mu)$: Local four-fermion operators evaluated at energy scale μ
calculable in perturbation
$C_i(\mu)$: Coupling constants for $Q_i(\mu)$ at energy scale μ
i.e. Wilson coefficient, calculable in perturbation
$<F|Q_i(\mu)|M>$: Hadronic matrix element
long distance effect
ξ_i^{CKM}: Combination of the CKM elements
the ultimate interest for B physics
extraction of the CKM matrix, search for new physics

What is B Physics?

Decays

decay and oscillation amplitudes

Theoretical tool to describe the decay amplitude for M→F

$$A(M \to F) = \left\langle F \middle| H_{\text{effective}}^{\text{weak decay}} \middle| M \right\rangle = \frac{G_{\text{F}}}{\sqrt{2}} \sum_i \xi_{\text{CKM}}^i C_i(\mu) \langle F | Q_i(\mu) | M \rangle$$

- Comparing the full and effective theory at $\mu = m_{\text{W}}$
  $\to C_i(\mu = m_{\text{W}})$

- Scale C_i down to $\mu \approx 1$ GeV (K), m_{c} (D), m_{b} (B)

$$C_i(\mu) = U_{ij}(\mu,\ \mu = m_{\text{W}}) C_j(\mu = m_{\text{W}})$$

U_{ij} not diagonal ⇒ mixing of the operators in the evolution

- Evaluate $\langle F|Q_i(\mu)|M\rangle$ (hadronic matrix element)
  with non perturbative methods at μ
  lattice, HQET, QCD sum rule, etc. **major source of uncertainties**