Exclusive reconstruction of open heavy flavor from CMS

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Exclusive reconstruction of open heavy flavor from CMS

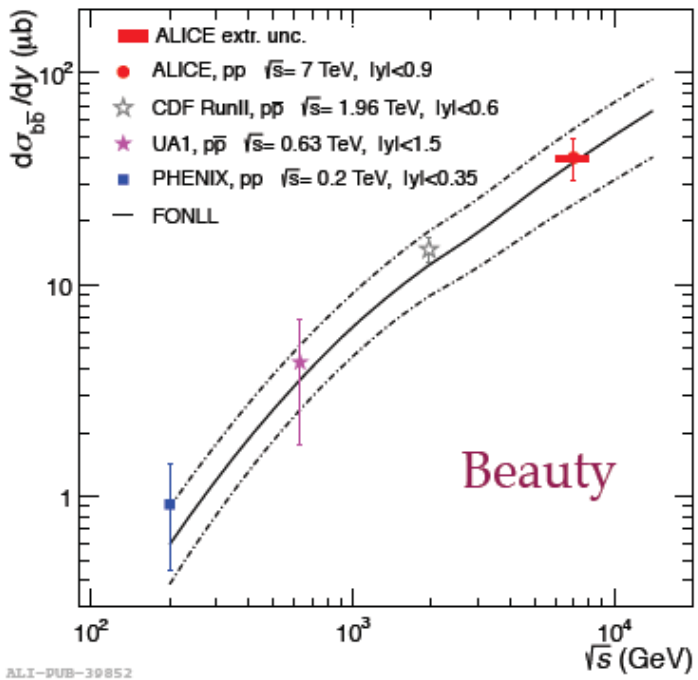
- Introduction of open heavy flavor analysis
- Overview of Interesting channels
- Exclusive reconstruction process in CMS
- Experimental results
  - pPb collisions in 2013
  - 7 TeV pp, 2.76 TeV PbPb (inclusive)
- Summary

"Beauty" of open heavy flavor

Open heavy flavor meson = heavy quark + light quark

- Heavy quark (charm and bottom)
  - Heavy quark produced at hard scattering of partons
    - production time ~ 0.05~0.15 fm/c
  - Critical tool to test perturbative QCD calculations
    - With LO only access to qualitative results
    - With NLO, we can get the significant quantitative values
  - Heavy quarks in heavy-ion collisions : reflect the effect of hot and dense medium as produced at early stage

[ALICE Coll. arXiv: 1208.1902 (2012)]



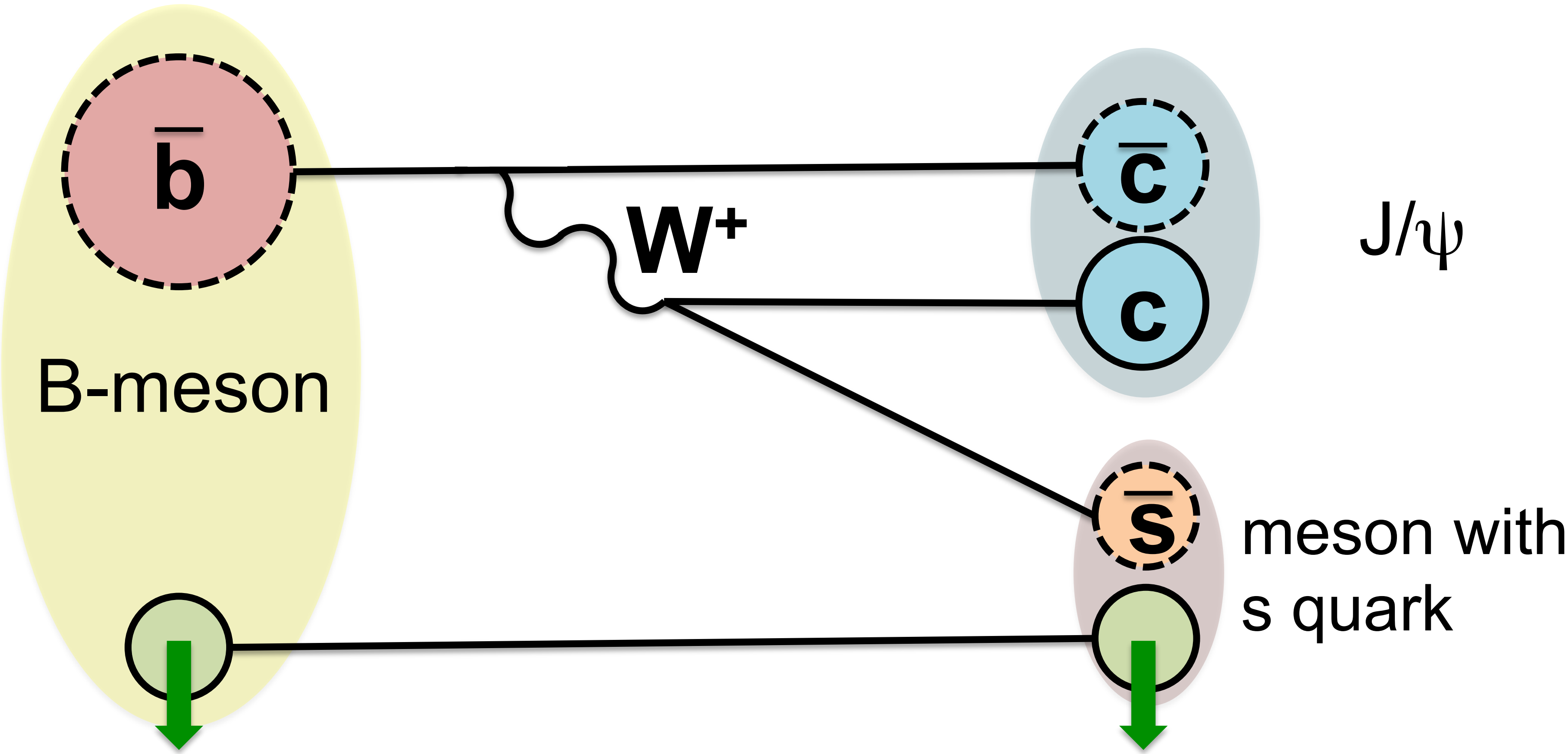
"Beauty" of open heavy flavor

Open heavy flavor meson = heavy quark + light quark

- Heavy quark such as charm and bottom
  - Heavy quark produced at hard scattering of partons
    - production time ~ 0.05~0.15 fm/c
  - Critical tool to test perturbative QCD calculations
    - With NLO, we can get the significant quantitative values
    - With LO only access to qualitative results
  - Heavy quarks in heavy-ion collisions : reflect the effect of hot and dense medium as produced at early stage
- Light quark
  - To investigation of flavor dependence

- CMS have presented interesting results with open heavy flavor

Schematic view of open beauty



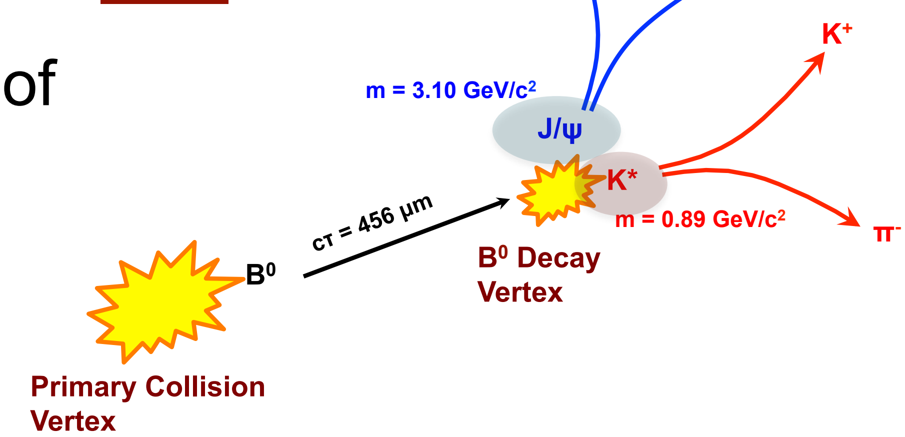
B^+ : u – 5.279 GeV
B^0 : d – 5.280 GeV
B_s : s – 5.367 GeV

u : K^+
d : $K^{*0}(892)$
s : ϕ

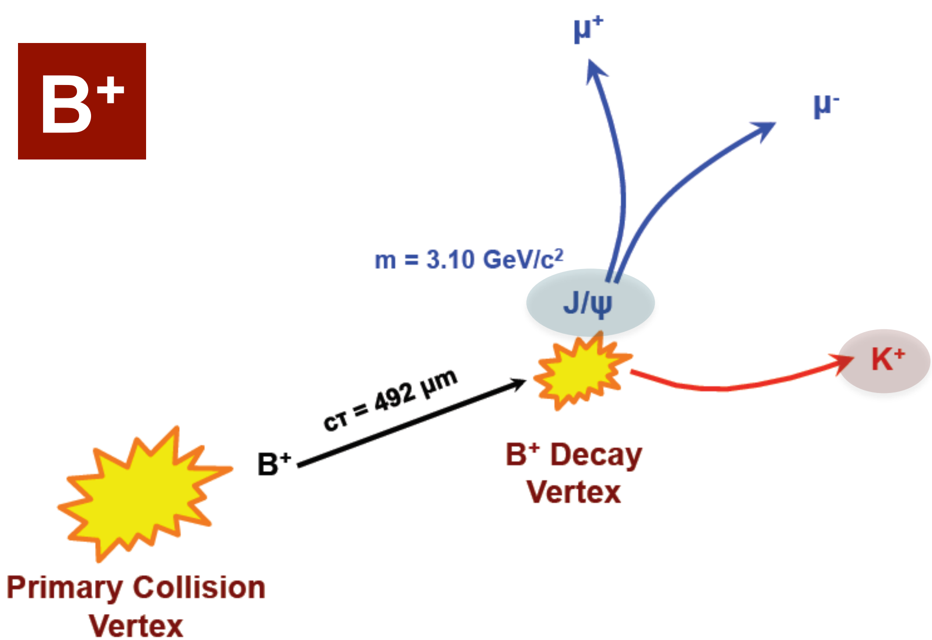
B-meson decay channel

- Easiest decay channel for each B-meson species
- Reconstructed by combination of
  - J/ψ (decay to muon pair)
  - tracks (charged pion or kaon)

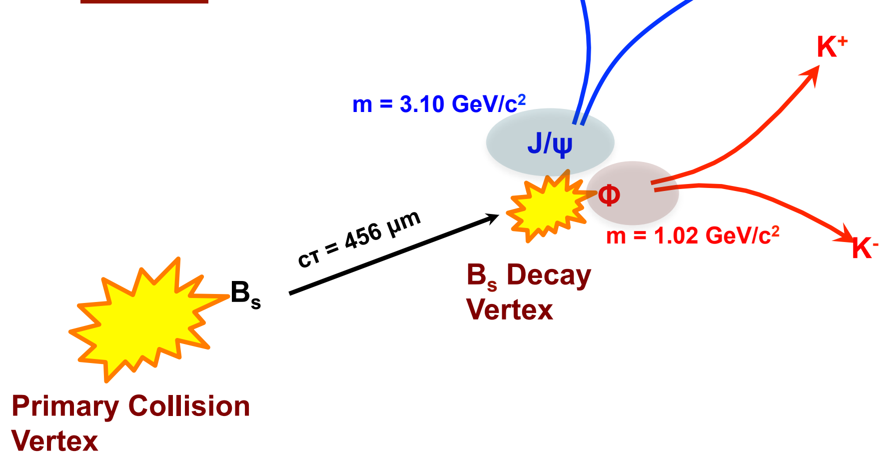
B^0



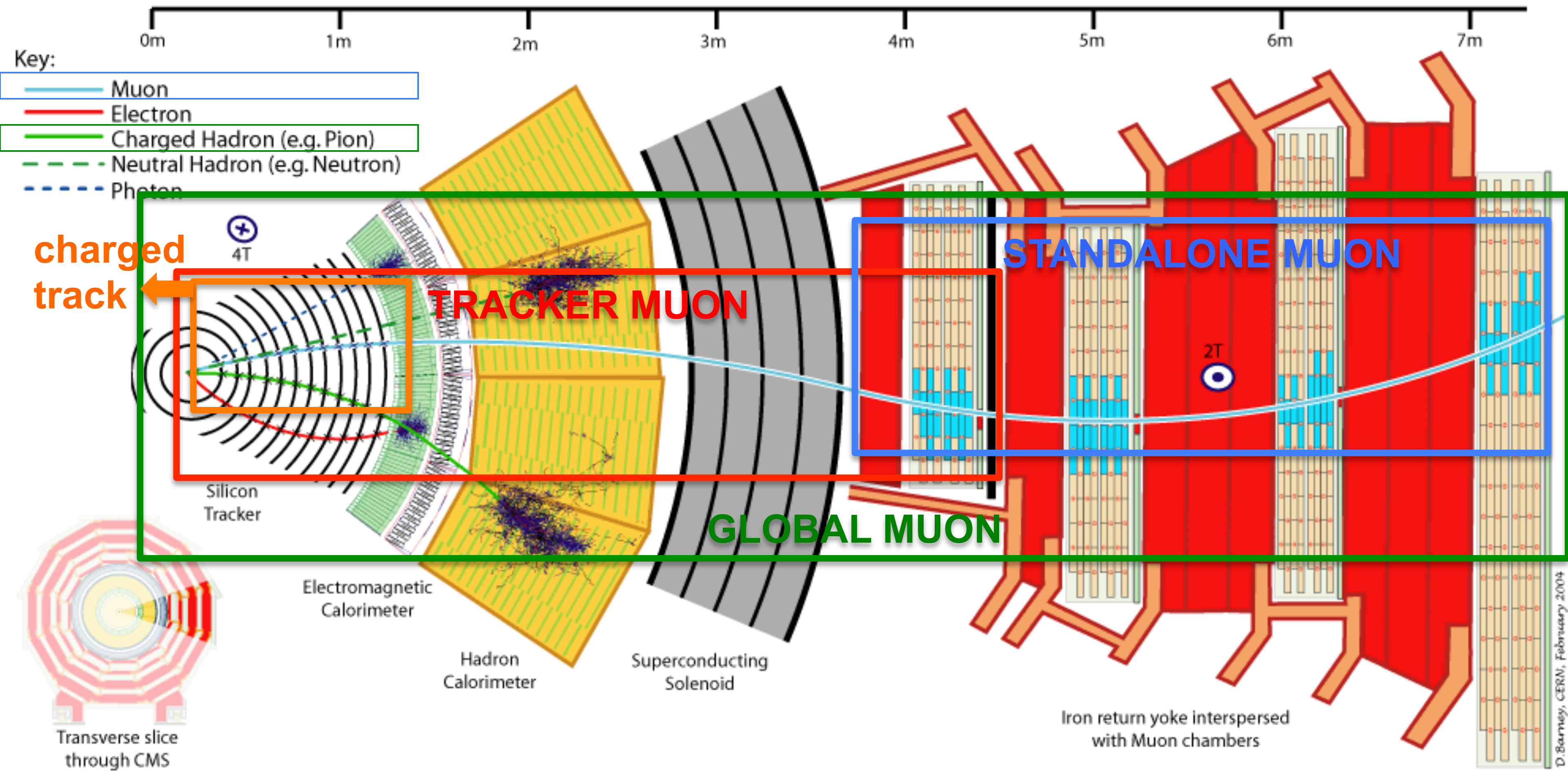
B^+



B_s

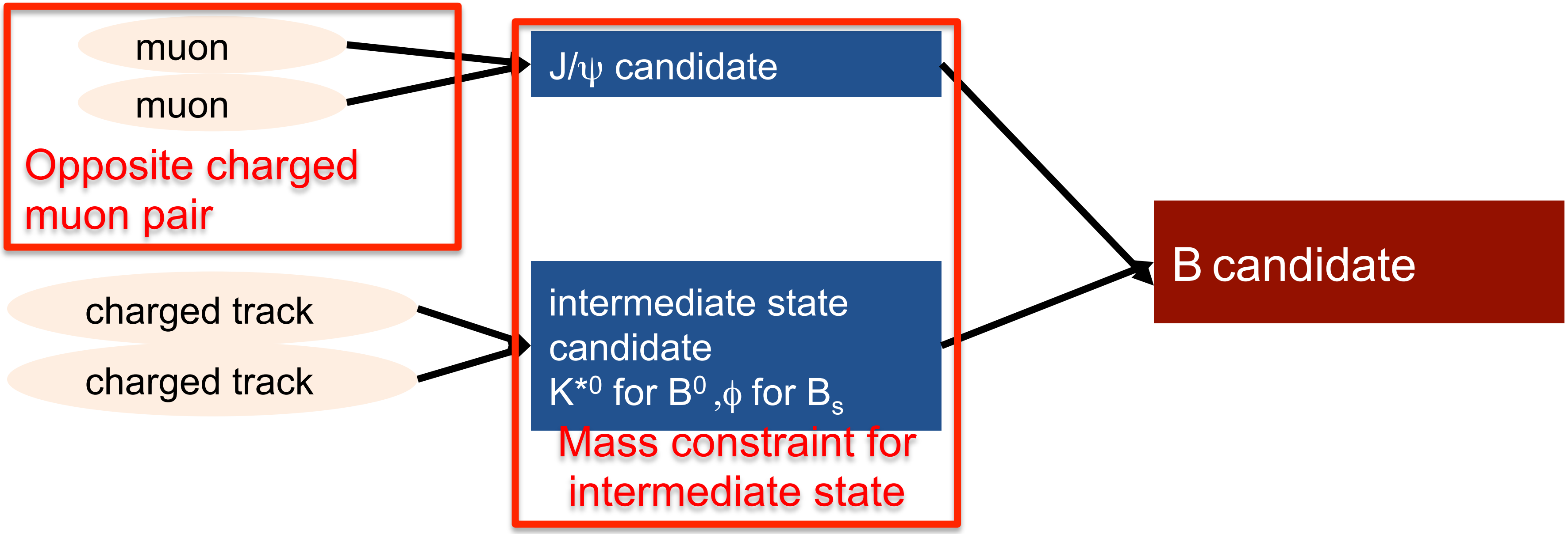


Reconstruction of particles in CMS detector



- Muon : inner track with matched segment in muon station
  - tracker and global muon (tracker track + standalone muon)
- Charged kaon or pion : charged track from inner tracker

Reconstruction of B mesons

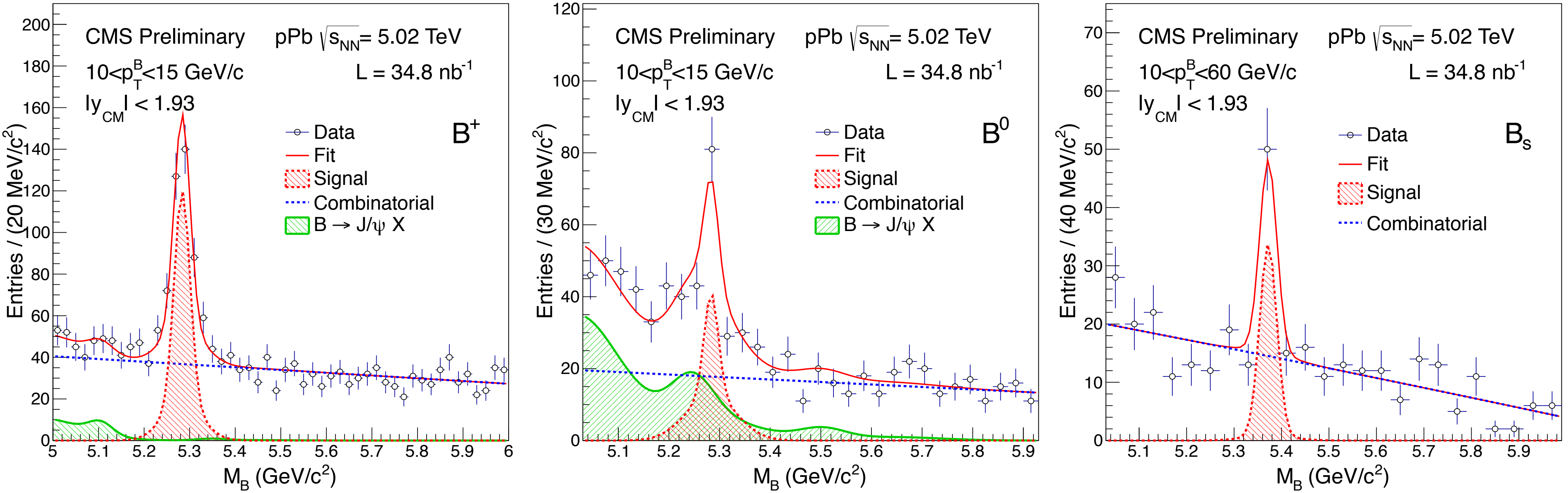


- J/ψ + 1~3 tracks (charged track applied p_T cut)
- Charged tracks and muons are reconstructed within $|\eta| < 2.4$
- Trigger on single muon (ex.p_T > 3 GeV/c for pPb analysis) or dimuon trigger
- Assigned the mass of kaon or pion to charged track

@ 5.02 TeV pPb collisions

- https://cds.cern.ch/record/1703520/files/HIN-14-004-pas.pdf

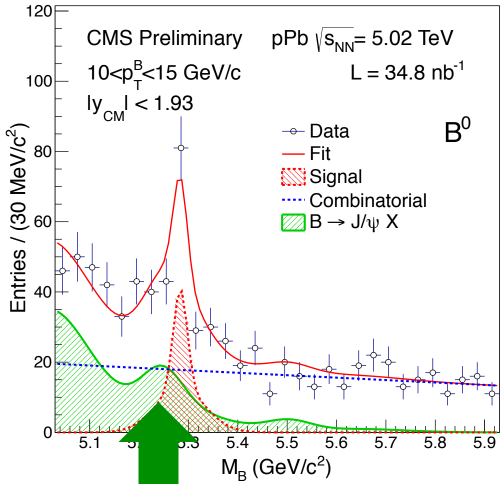
Signal extraction – B^+, B^0, B_s

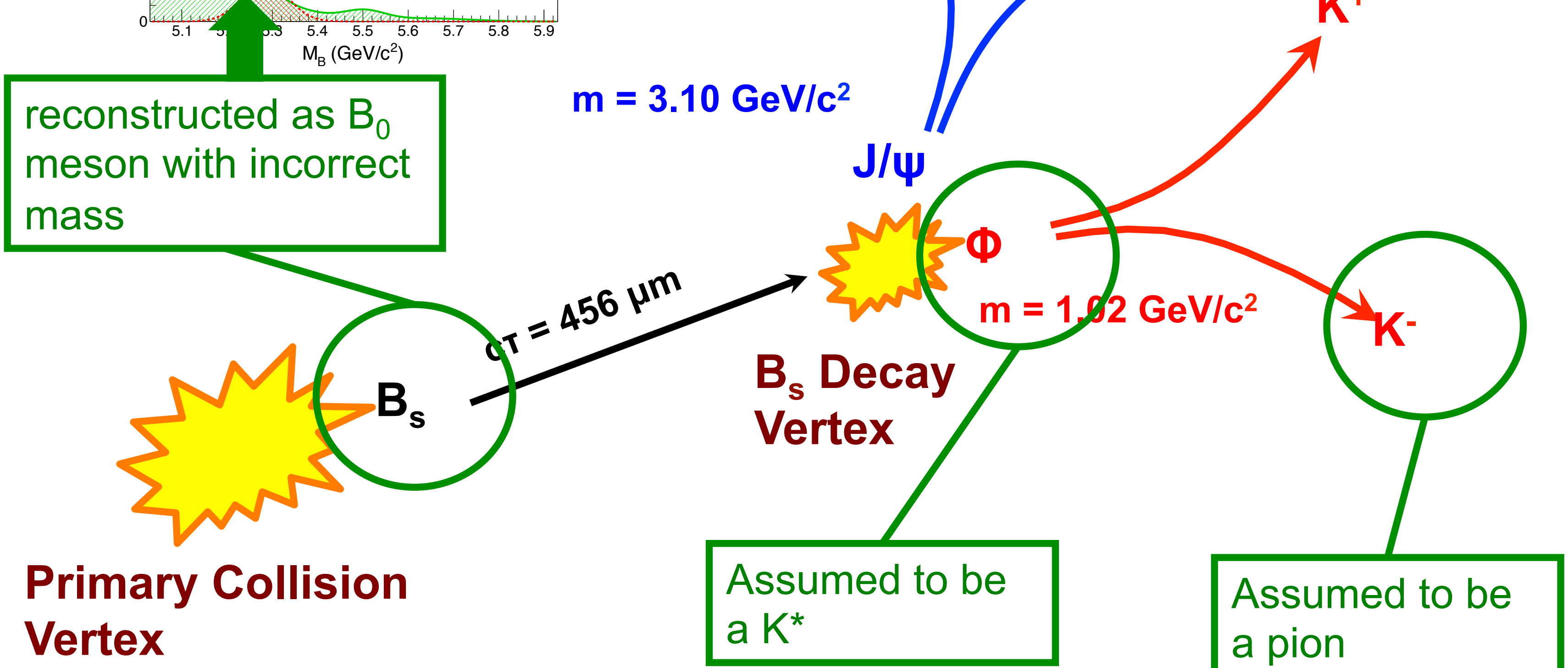


- Signal : double Gaussian
- Background
  - Combinatorial background
    - 1st-order (for B^+, B^0) or 2nd-order (for B_s) polynomial
  - Peaking background (not for B_s)
    - Misreconstructed B-mesons except our signal (example at next slide)

Example of peaking backgrounds

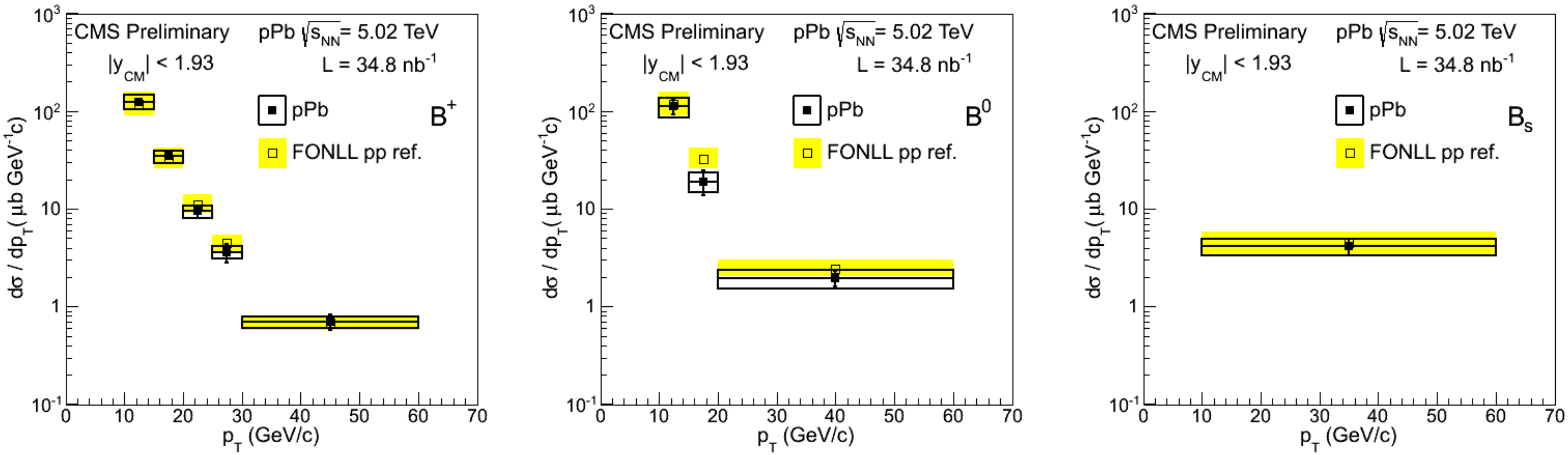
Lower mass peak due to B_s background





Differential cross-section

$$\left.\frac{d\sigma^{B}}{dp_T}\right|_{|y_{CM}|<1.93} = \frac{1}{2}\frac{1}{\Delta p_T}\frac{\left.N^{B}\right|_{|y_{CM}|<1.93}}{(\mathrm{Acc}\times\epsilon)\cdot \mathrm{BR}\cdot L}.$$

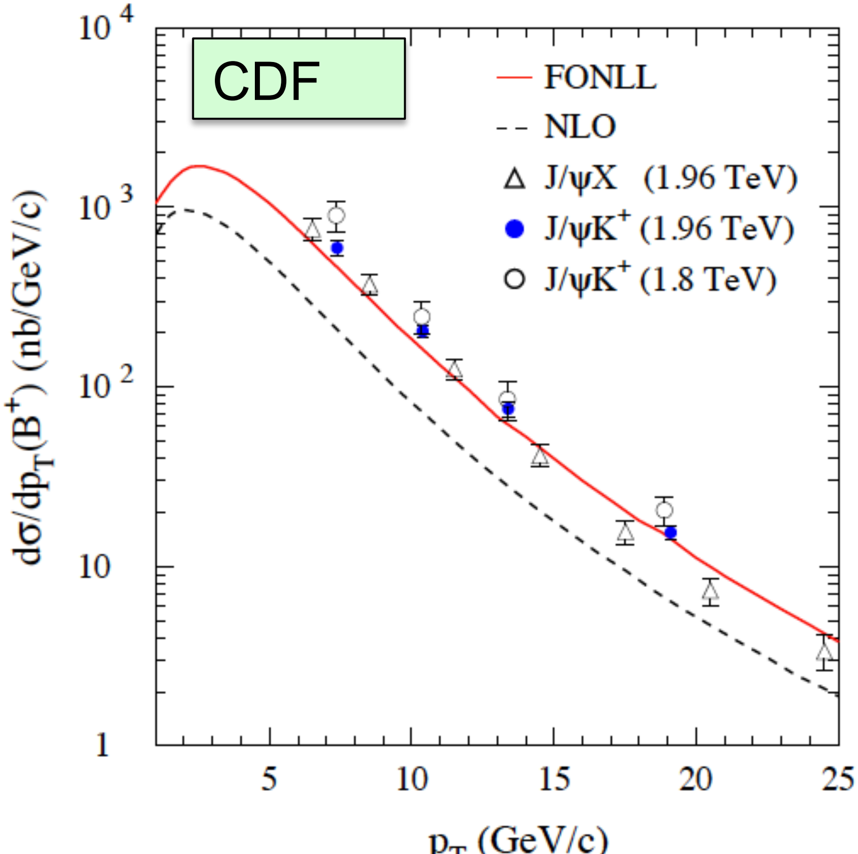


- FONLL expectation as pp reference is calculated by

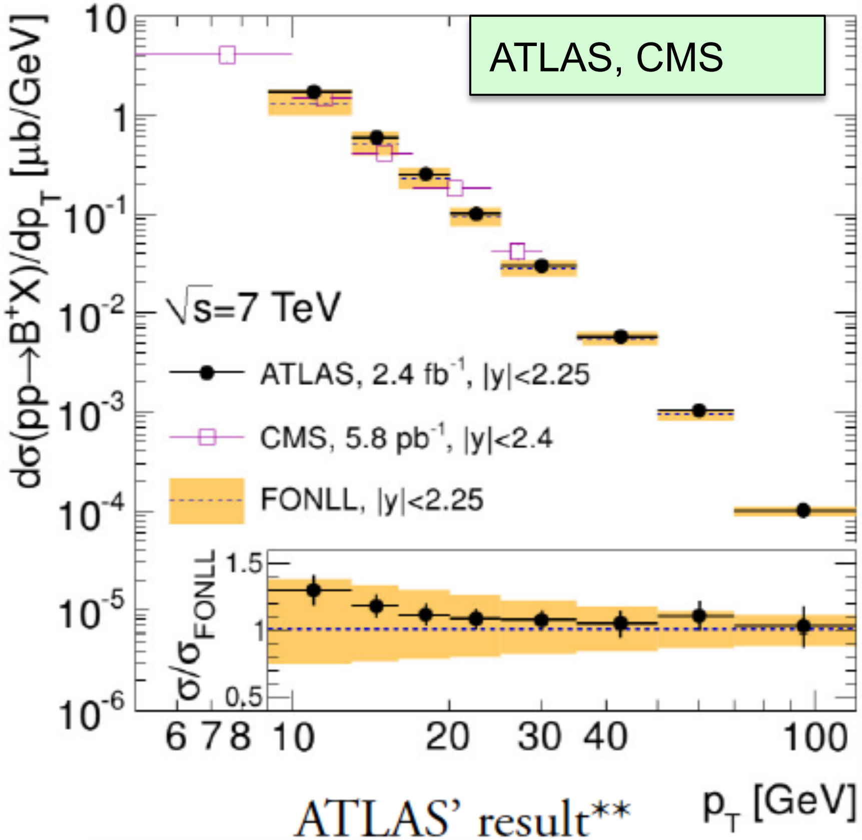
http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html

FONLL – for pp reference

- For comparison, pp reference is needed but we don't have data
- Alternative way : using FONLL (Fixed Order plus Next-to-Leading Logarithm) expectation
- Data agrees with the FONLL expectation at 1.96(p-pbar, CDF) and 7 TeV(p-p, ATLAS,CMS)
- Expect the same agreement at 5TeV collision also



Phys. Rev. D 75, 012010 (2007)

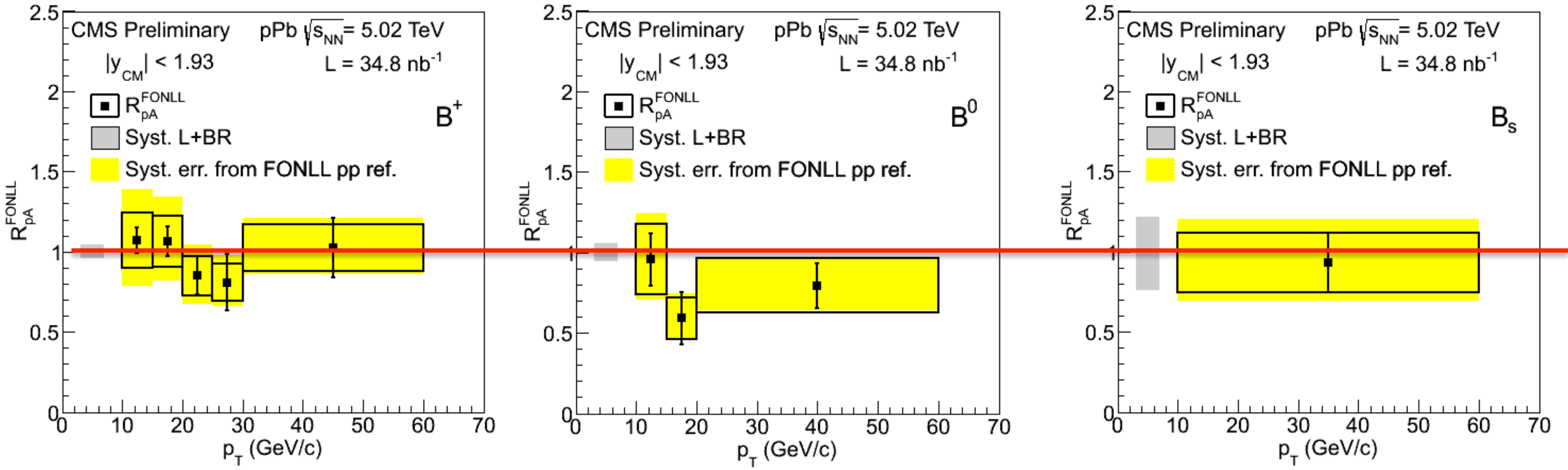


ATLAS' result**

arXiv: 1307.0126v2

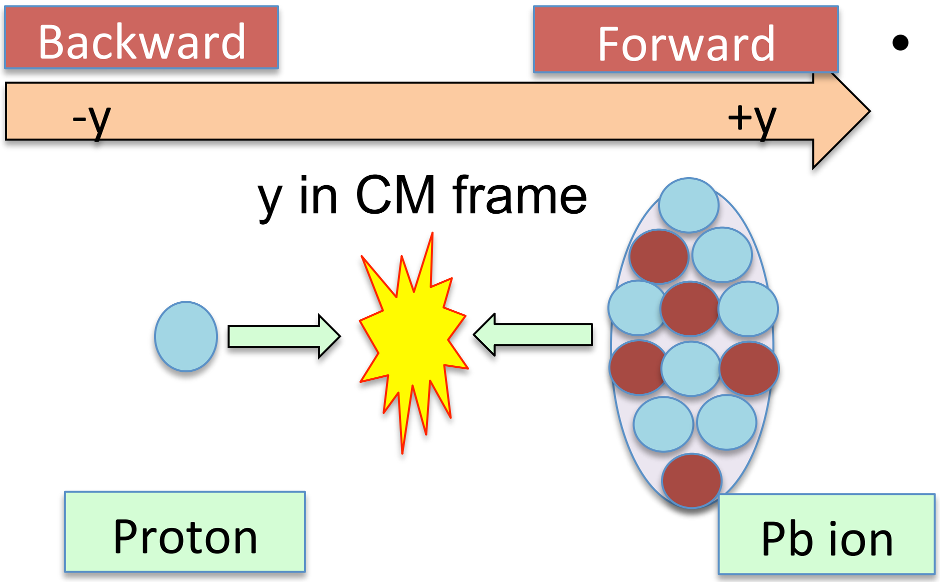
Nuclear modification factor : R_{pA}^{FONLL}

$$R_{pA}^{FONLL}(p_T) = \frac{\left(\frac{d\sigma}{dp_T}\right)_{pPb}}{A \times \left(\frac{d\sigma^{FONLL}}{dp_T}\right)_{pp}}$$



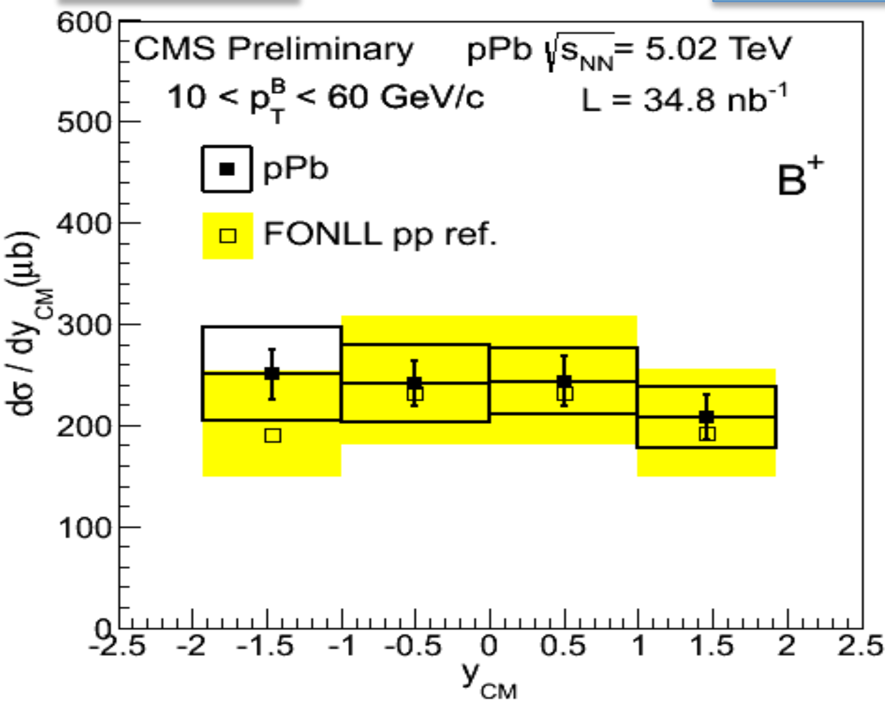
- Within uncertainties, R_{pA}^{FONLL} imply no modification in pPb collisions compared by pp collisions for all three B-mesons

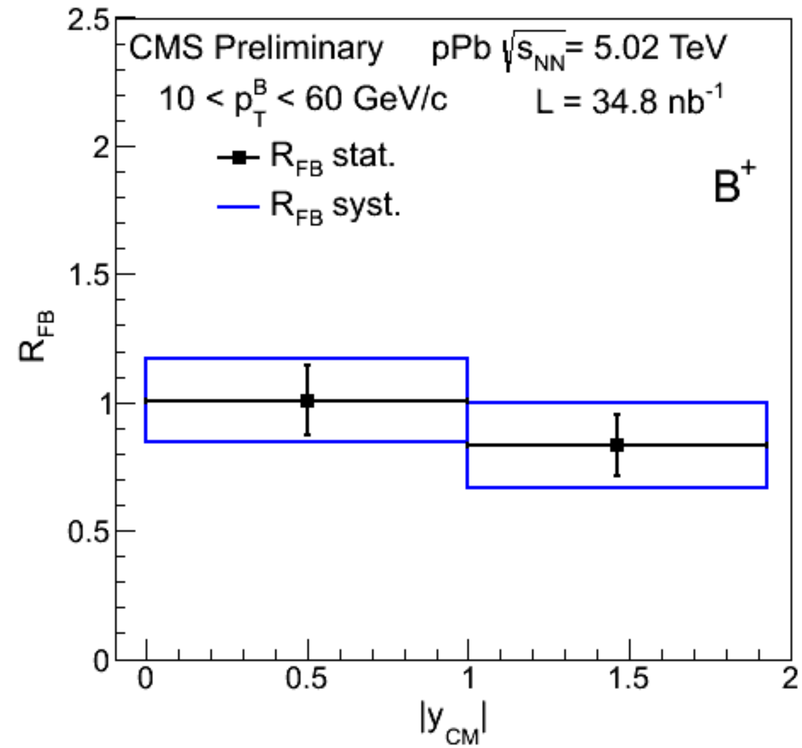
Rapidity dependence of B^+ production



- Forward-to-backward ratio R_{FB} is unity within large uncertainties.

$$R_{\mathrm{FB}} = \frac{N^{corr}_{forward}}{N^{corr}_{backward}}$$

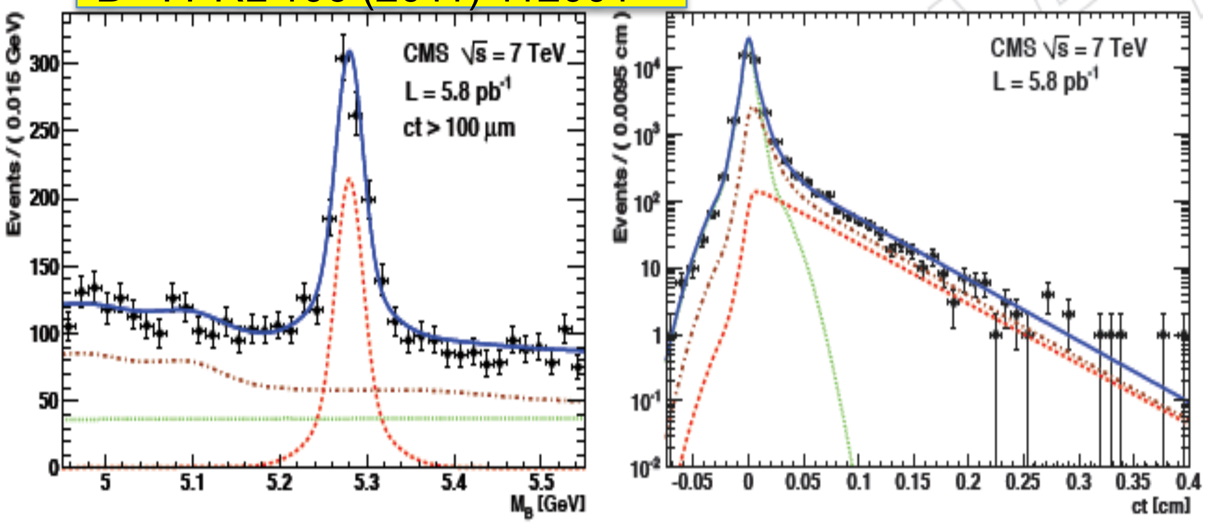




@ 7 TeV pp collisions
@ 2.76 TeV PbPb collisions (inclusive)

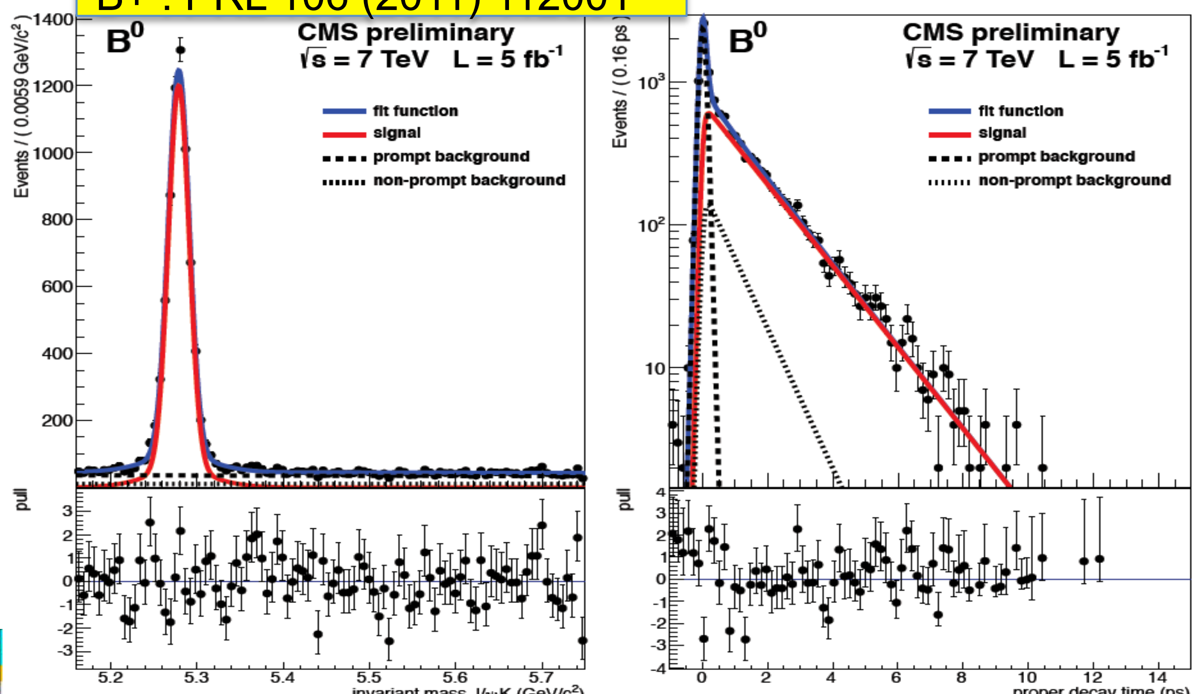
pp results – reconstruction of candidates

B+ : PRL 106 (2011) 112001

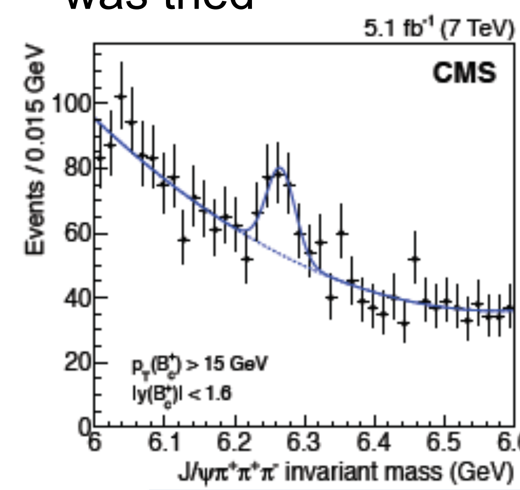


- Using 2D simultaneous fit with invariant mass and proper decay length
- Need larger statistics to use this method

B+ : PRL 106 (2011) 112001

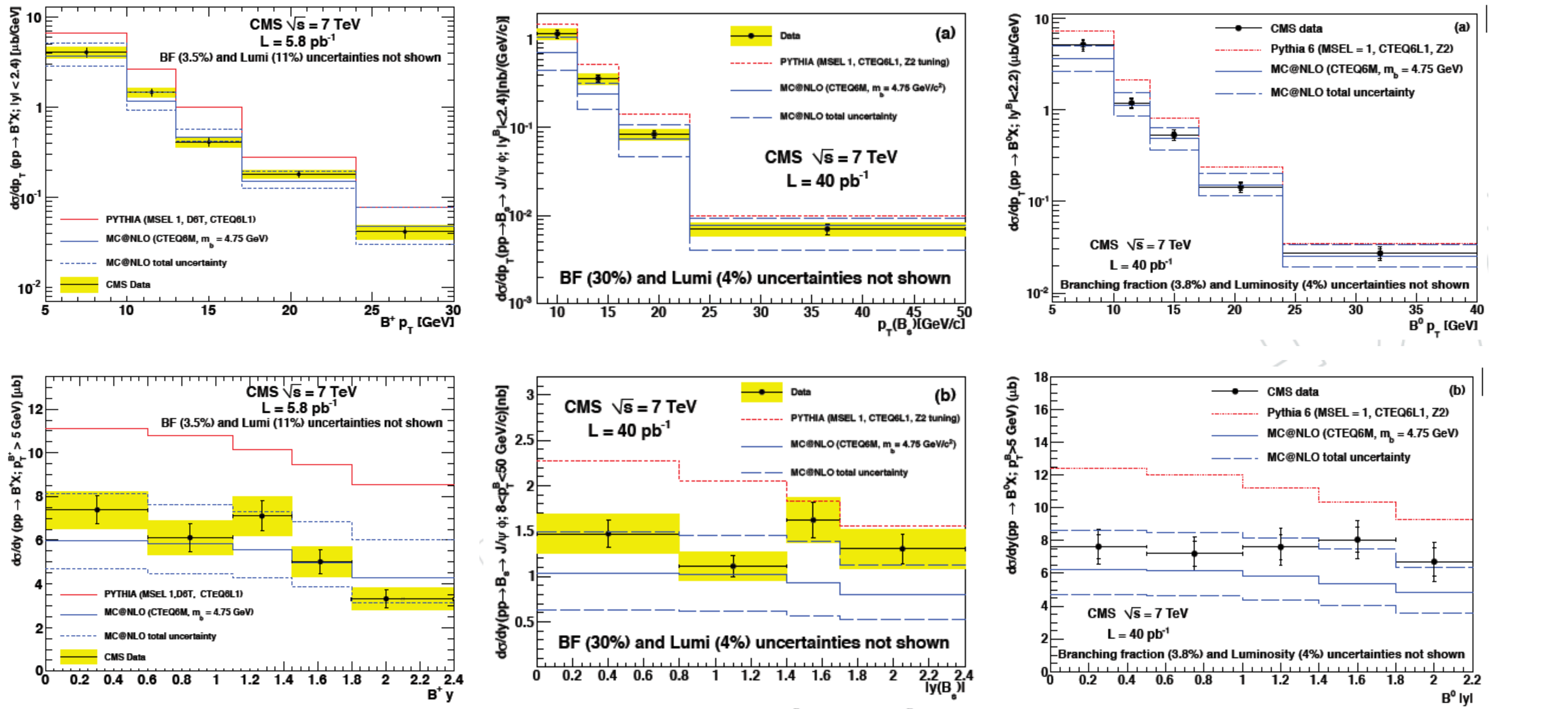


- Until now, channel with J/ψ + 3 charged particles was tried



B_c : arXiv 1410.5729, submitted to JHEP

pp results – comparison with theory



B⁺ : PRL 106 (2011) 112001

B⁰ : PRL 106 (2011) 252001

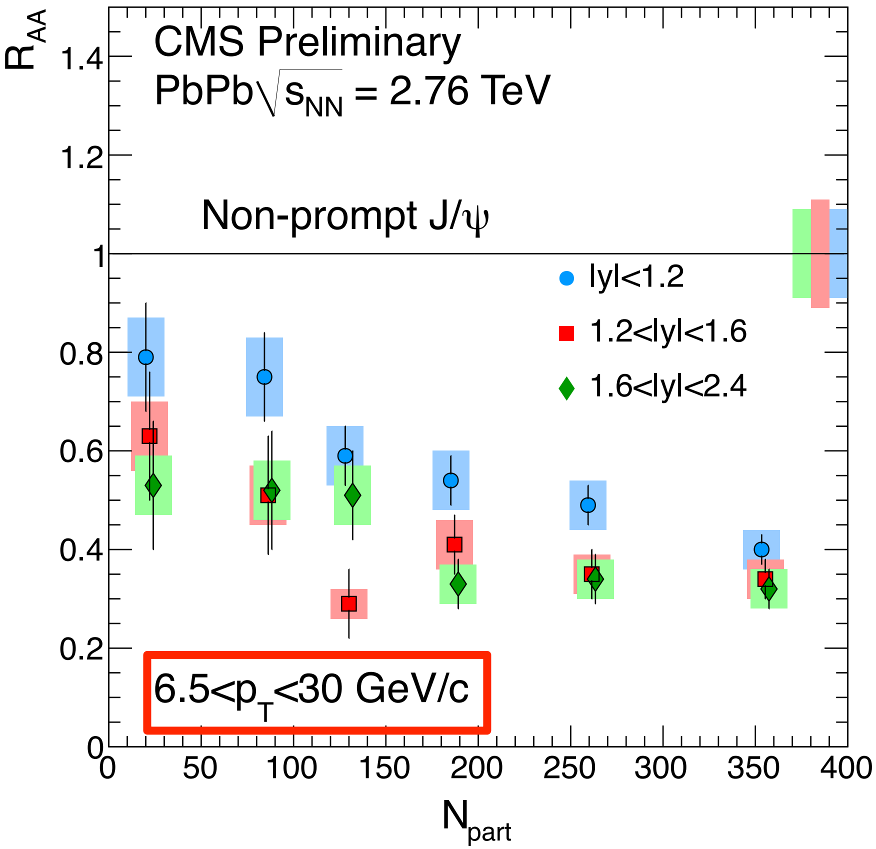
Bs : PRD 84 (2011) 052008

- All the data is agreed with MC@NLO calculations “usually” within systematical uncertainties calculated by the variation of renormalization and factorization factors and different PDF functions
- PYTHIA is overestimated to data
- Motivation of pp reference for pPb analysis

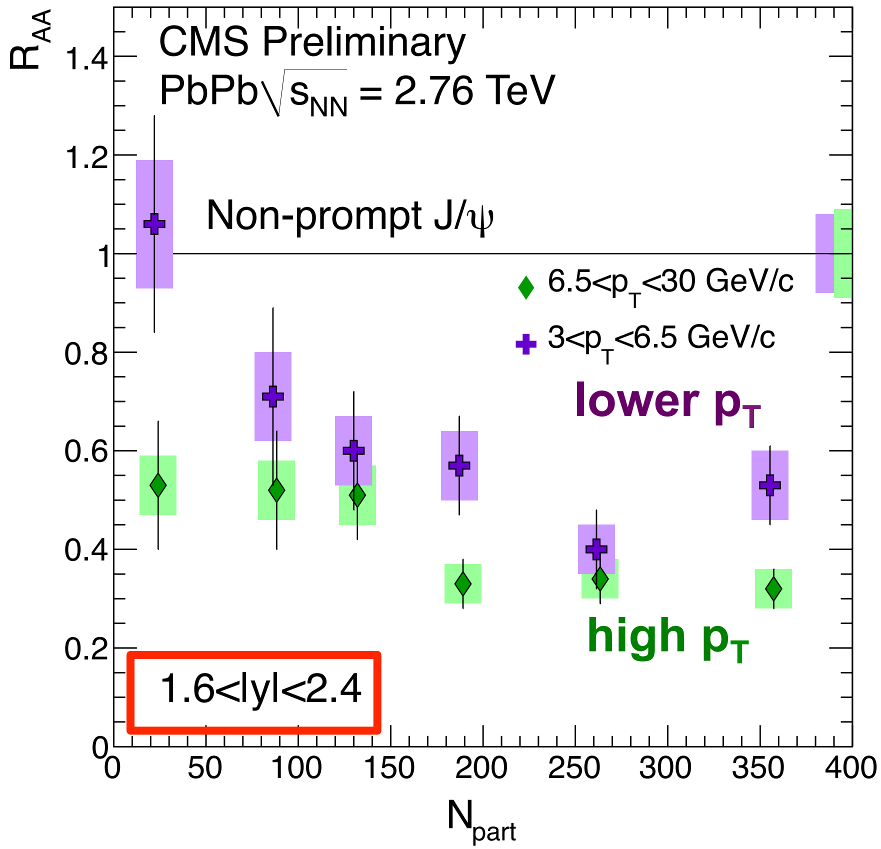
Results@2.76 TeV PbPb collisions

CMS-PAS HIN-12-014

Rapidity dependence

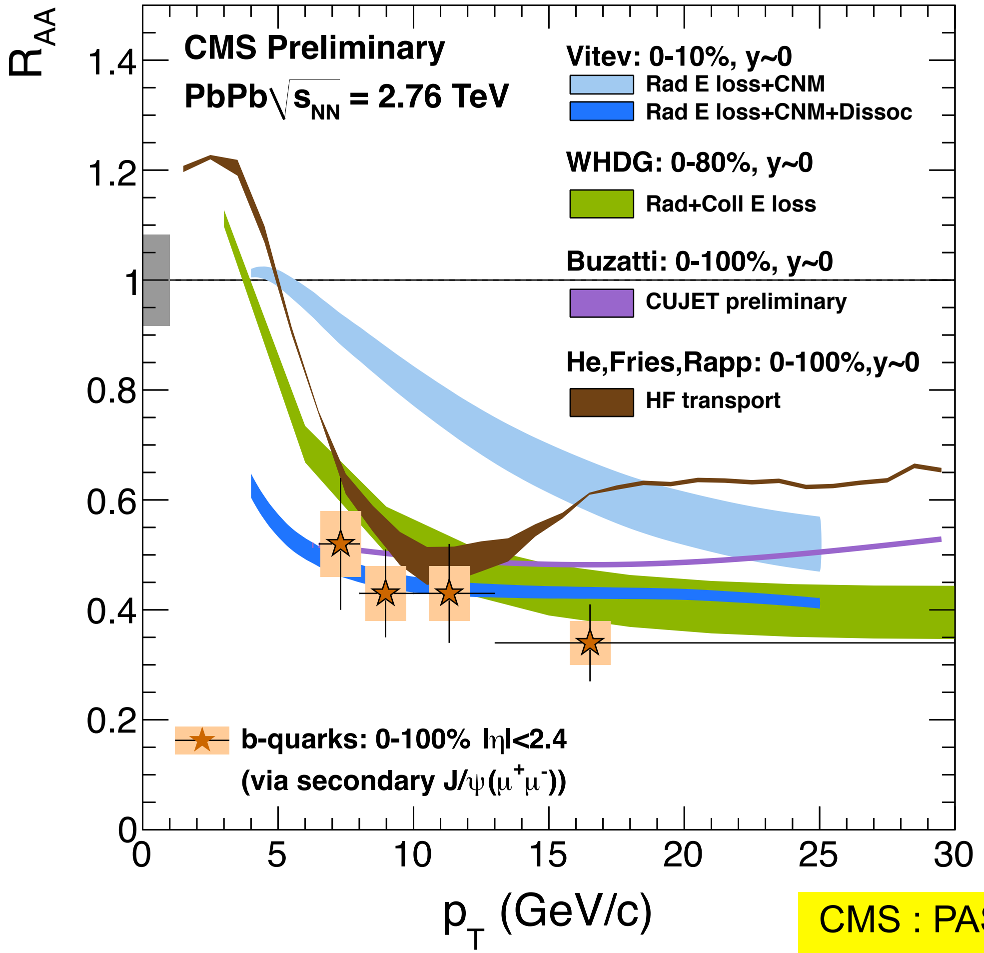


p_T dependence



- Left : In all rapidity bins at high p_T region, centrality dependent suppression is shown.
- Right : In the forward region, lower p_T J/ψ has strong centrality dependence and less suppressed than high p_T J/ψ

Results@2.76 TeV PbPb collisions



- Data point should be shift to higher p_T
- Only with energy loss and CNM effect, suppression is not explained
- First measurement of b-quark energy loss via non-prompt J/ψ

Prompt J/ψ results can be shown at Songkyo's talk

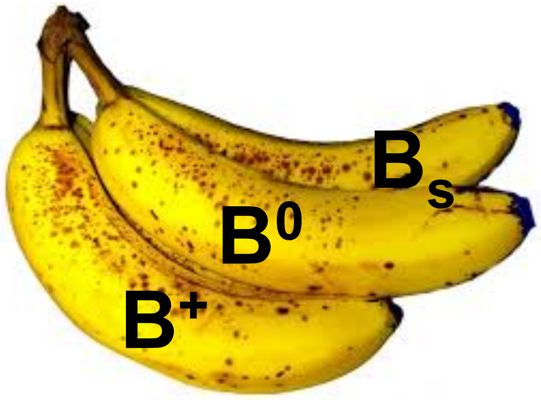
CMS : PAS HIN-12-014

Vitev: J. Phys.G35 (2008) 104011 + private communications
Horowitz: arXiv:1108.5876 + private communications
Buzzatti, Gyulassy: arXiv: 1207.6020+ private communications
He, Fries, Rapp: PRC86(2012)014903+ private communications

Summary

- In 7 TeV pp collisions, CMS measured data is compatible with NLO calculations within uncertainties
- In 2.76 TeV PbPb collisions, via non-prompt J/ψ CMS measured b-quark energy loss
- In 5.02 TeV pPb collisions, nuclear modification factor with FONLL expectation is measured as unity within uncertainties

Stay tune to
2015 pp and PbPb collisions



Backup

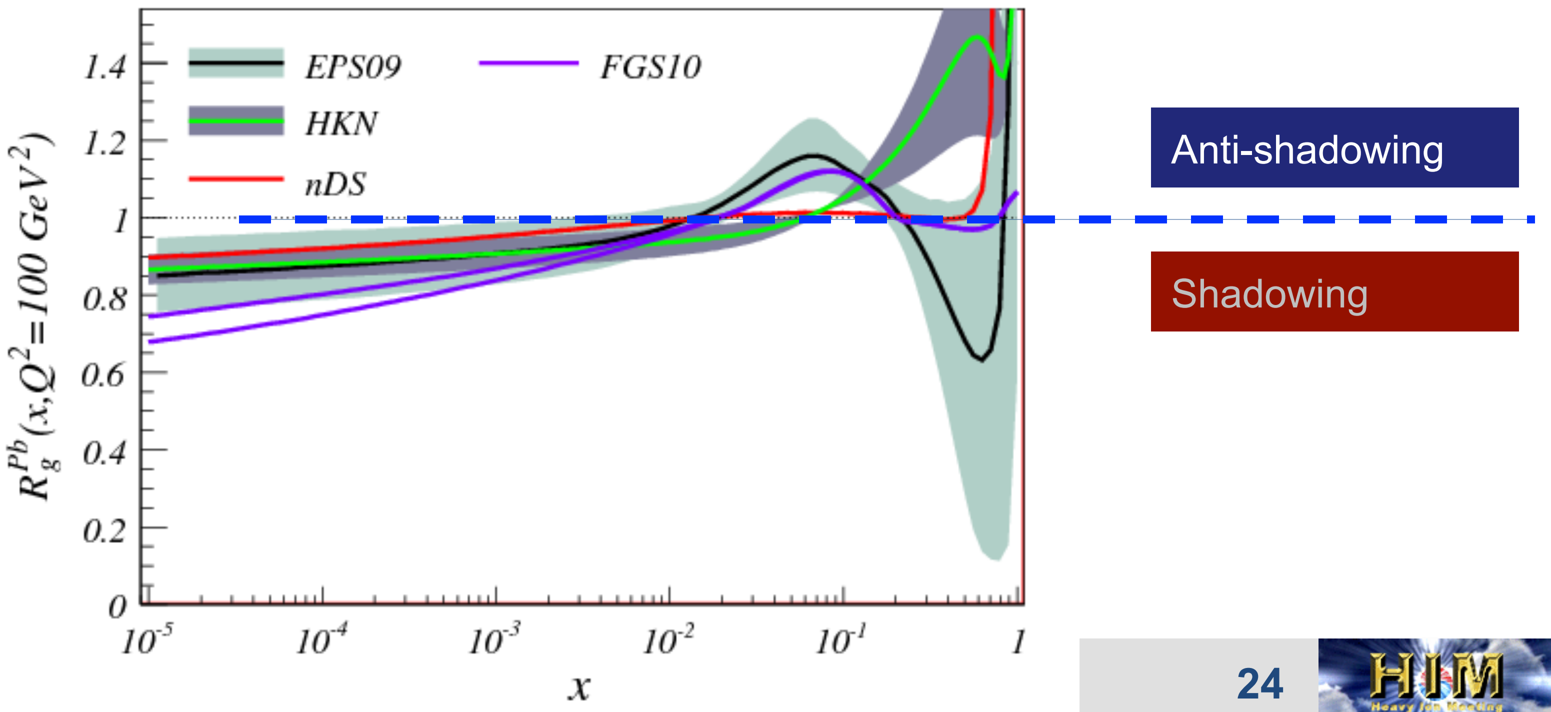
Motivation for pp collisions

- Comparison between data and perturbative QCD prediction is critical test of NLO calculations
- In spite of the measurement with SPS and Tevatron, still exist large theoretical uncertainties remain due to the dependence on the renormalization and factorization scales
- Results by the LHC is expected to reduce the scale dependence of NLO QCD calculations

Why pPb collisions?

- Measure initial state modification of heavy quark production and cold nuclear matter effect and subtract them from final state effect (for pure effect of HI collisions)
- First measurement of exclusive B-meson production in pPb collisions

J. Phys. G 39 (2012) 015010



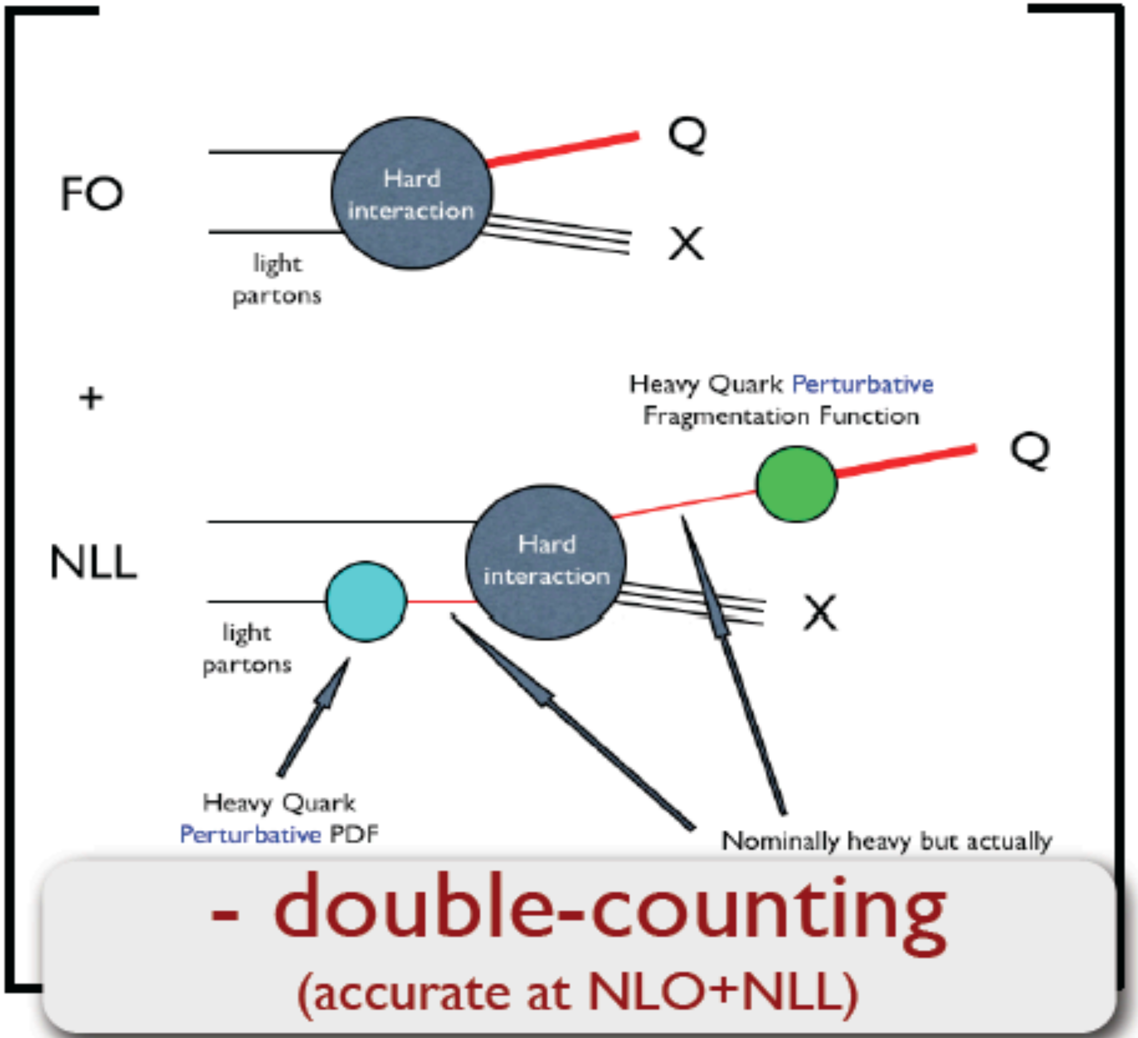
B-meson measurement in pPb collisions

- CMS recorded 5.02 TeV pPb collision data in 2013
  - LHC delivered 4 TeV (p) and 1.58 TeV/nucleon (Pb) beam
  - Integrated luminosity : 34.8±1.2 nb^{-1}
  - Rapidity boosted to proton going side(forward) by 0.465 in lab frame : asymmetric collision

- Open beauty measurement in pPb collisions
  - B^+, B^0, B_s trio is measured via dimuon decayed J/ψ
  - Kinematic range covered
    - p_T : 10 – 60 GeV/c
    - rapidity : $|y_{CM}|<1.93$ (ongoing to change to $|y_{LAB}|<2.4$)
  - Consider charge conjugated mesons (i.e. B^+ stands for both signs)

FONLL (Fixed Order plus Next-to-Leading Logarithms) is a code for calculating double-differential, single inclusive heavy quark production cross sections in pp(bar) and (electro)photoproduction

FONLL



$\otimes \; D_{Q \to H}$

Fitted to e+e- data in the **same scheme**

Matteo Cacciari - LPTHE 23/11/2010 5

Summary of selection cuts

- Muon selection
  - tracker muon or global muon
  - pass TMOneStationTight
  - soft muon ID cut by muon POG
    - number of valid tracker layers > 5
    - number of pixel layers with valid hits > 0
    - chi2/ndf < 1.8
    - dxy < 3.0cm, dz < 30.0 cm
- J/ψ candidates
  - opposite sign muons
  - PDG mass within 0.3 GeV
  - Vertex probability > 1%
- Track selection
  - track p_T>0.9 GeV (B^+), >0.7 GeV(B^0, B_s)
  - track $|\eta|$ < 2.4 in lab frame
  - chi2/ndf < 5
- Intermediate meson
  - probability of vertex > 1%
  - PDG mass within 0.9±0.4 GeV for K*, 1.0±0.1 GeV for ϕ
- B candidate
  - probability of vertex > 1%
  - PDG mass within [5,6] GeV

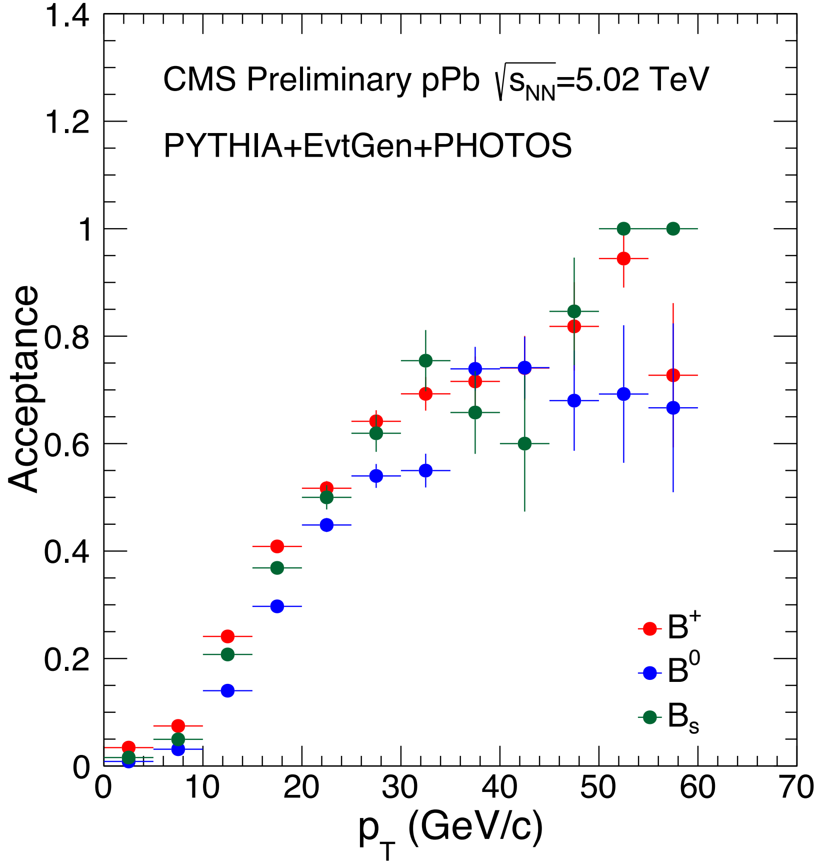
Summary of optimized selection criteria

Variable for B-meson selection	B^+	B^0	B_s
χ^2 confidence level of B vertex fit	>0.013	>0.16	>0.037
distance between the primary and the B-decay vertices	>3.4	>4.2	>3.4
cosine value of angle between the displacement and the momentum of the B-meson in the transverse plane	> -0.35	> 0.75	> 0.26
difference of the mass between track-pair and resonant meson (unit : GeV/c^2)		<0.23	< 0.016

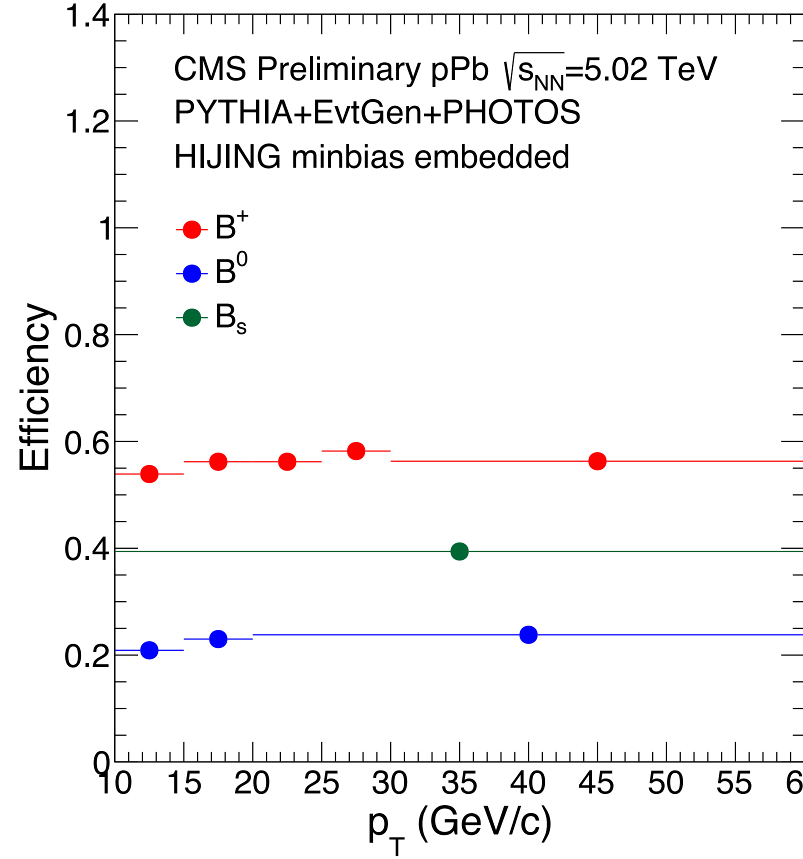
Acceptance and efficiency

- Raw yields are corrected for acceptance and efficiency

Acceptance



Efficiency



Rapidity conversion in between lab and CM frame

- General
  - Proton going direction have plus rapidity in CM frame
  - Merge bins with same rapidity in CM frame(same color in tables)
- 1st run
  - proton going to minus eta

$$y_{CM} = -y_{lab} - 0.465$$

yLAB	-2.4	-1.465	-0.465	+0.535	+1.470	+2.4
yCM	1.935	1.0	0.0	-1.0	-1.935	-2.865

← proton going direction

- 2nd run
  - proton going to plus eta

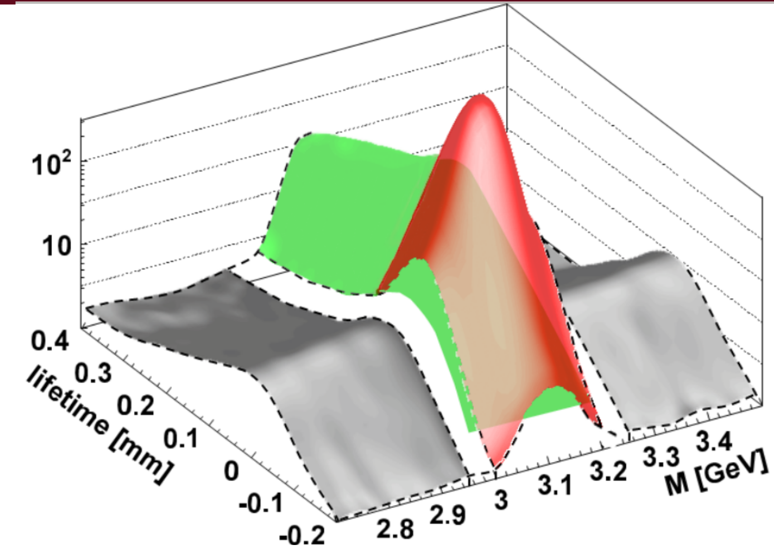
$$y_{CM} = y_{lab} - 0.465$$

yLAB	-2.4	-1.470	-0.535	+0.465	+1.465	+2.4
yCM	-2.865	-1.935	-1.0	0.0	1.0	1.935

proton going direction →

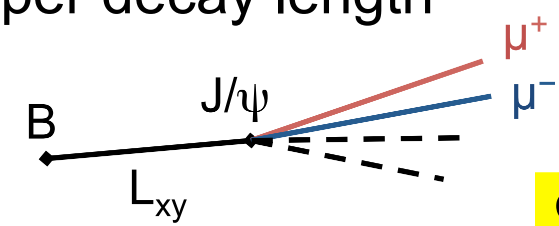
Prompt, non-prompt J/ψ signal extraction

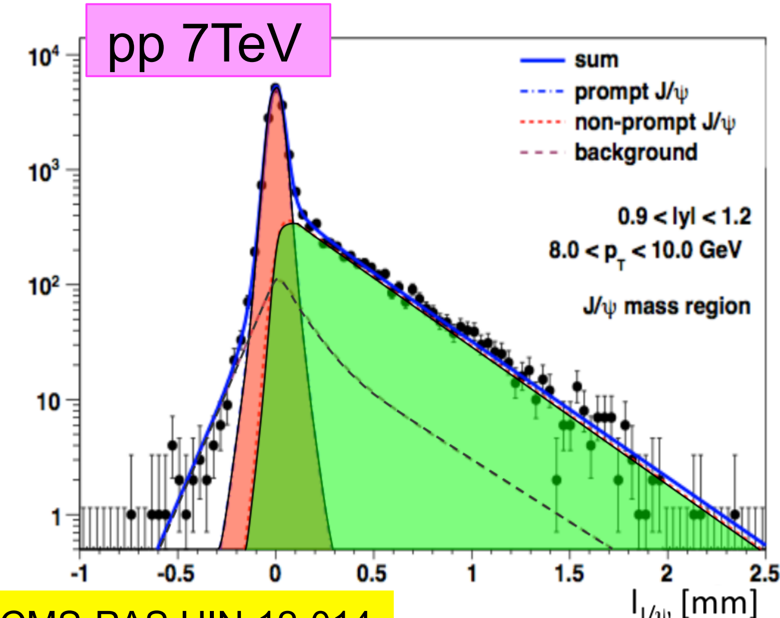
- Inclusive J/ψ
  - Prompt J/ψ
    - Direct J/ψ
    - Feed-down from ψ' and χ_c
  - Non-Prompt J/ψ from B decays



- **Reconstruct $\mu^+\mu^-$ vertex**
- **Separation of prompt and non-prompt J/ψ**
  - by 2D simultaneous fit of $\mu^+\mu^-$ mass and pseudo-proper decay length

$$\ell_{J/\psi} = L_{xy}\frac{m_{J/\psi}}{p_T}$$





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Source of peaking background

- B^+
  – lower mass : B+ decays J/ψ + resonant meson decayed to kaon + X
  – B+ mass : B+ decays J/ψ + pion misidentified as kaon
- B^0
  – B decayed to J/ψ + track + track
    - (ex. B^0->J/ψ $K(1270)^0$, B^+->J/ψ $K(1270)^+$)
  – B_s^0->J/ψ ϕ (K misidentified as π), B^0-> J/ψ K^+ π^-
  – B^+ decays J/ψ + X
- B_s^0
  – no peaking structure

Calculation of bjorken x

$$x = \frac{\sqrt{{M_B}^2 + p_T^2}}{5.02 \times 10^3} e^{y_{CM}}$$

y_{CM} B⁺ p_T	10	60
-2.865	$1.28*10^{-4}$	$6.84*10^{-4}$
0	$2.25*10^{-3}$	$1.20*10^{-2}$
+1.935	$1.56*10^{-2}$	$8.31*10^{-2}$