Angular correlation between B-hadrons produced in association with a Z boson at the CMS experiment

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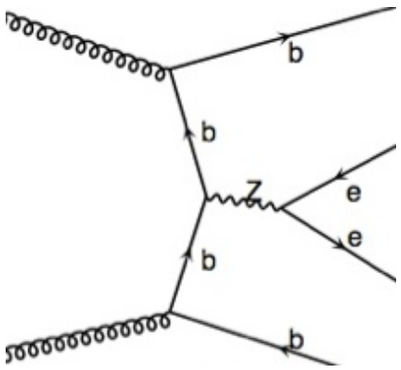
motivations

CMS-PAS-EWK-11-015

$$pp \rightarrow Z/\gamma^* + b\bar{b}\ with\ Z \rightarrow \mu\mu\ or\ ee$$

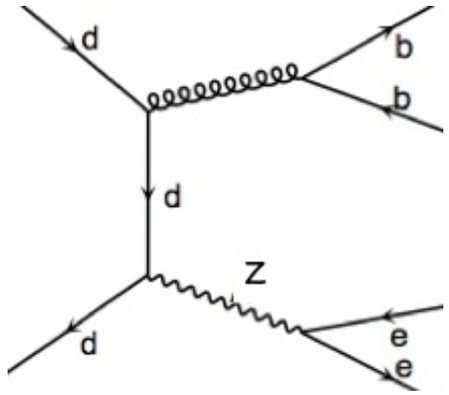
- Z/γ* + bb production is main background to SM Higgs and BSM searches
- Z/γ* + bb differential cross-section as function of **angular variables** is a good test of the description of QCD processes and Monte Carlo simulation

hard scattering



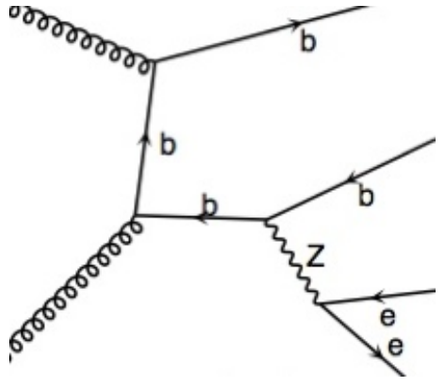
b quark fusion

mostly back-to-back



gluon splitting

mostly collinear



Z radiation

+

Z/γ* + light jets
+
B pair from
Multiple Parton
Interactions

angular separation between B hadrons: $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$

ϕ azymuthal angle
η pseudorapidity

the ingredients

- Z/γ* boson selected through leptonic decay into muons and electrons
- B hadron decays identified through secondary vertex reconstruction
- rejection of backgrounds (top pair production) and extraction of signal yield

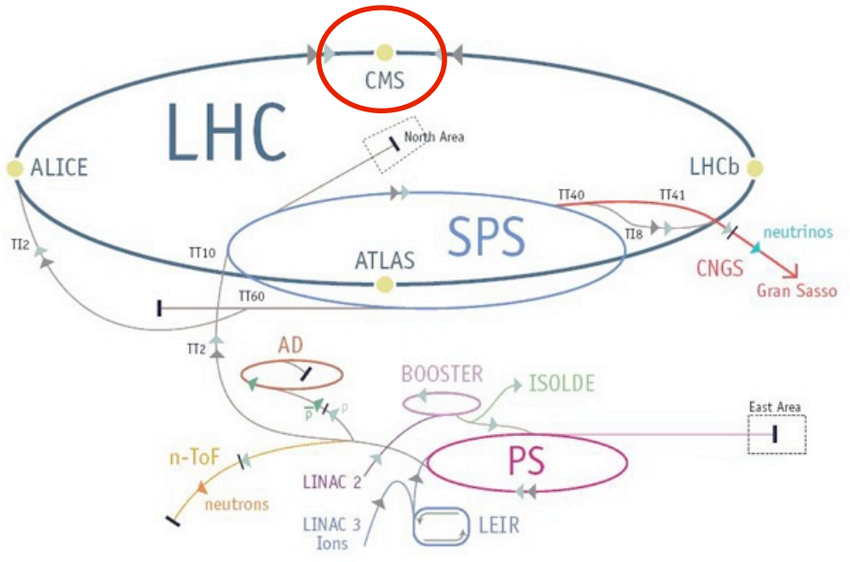
normalized differential cross-section

$$\frac{1}{\sigma}\frac{d\sigma}{d\Delta R} \Rightarrow \frac{1}{\sigma_{visible}}\frac{N_i^{data}\cdot P_i^B}{\epsilon_i^B\cdot\epsilon_i^l\cdot A_i^l} \qquad i=\Delta R\ bin$$

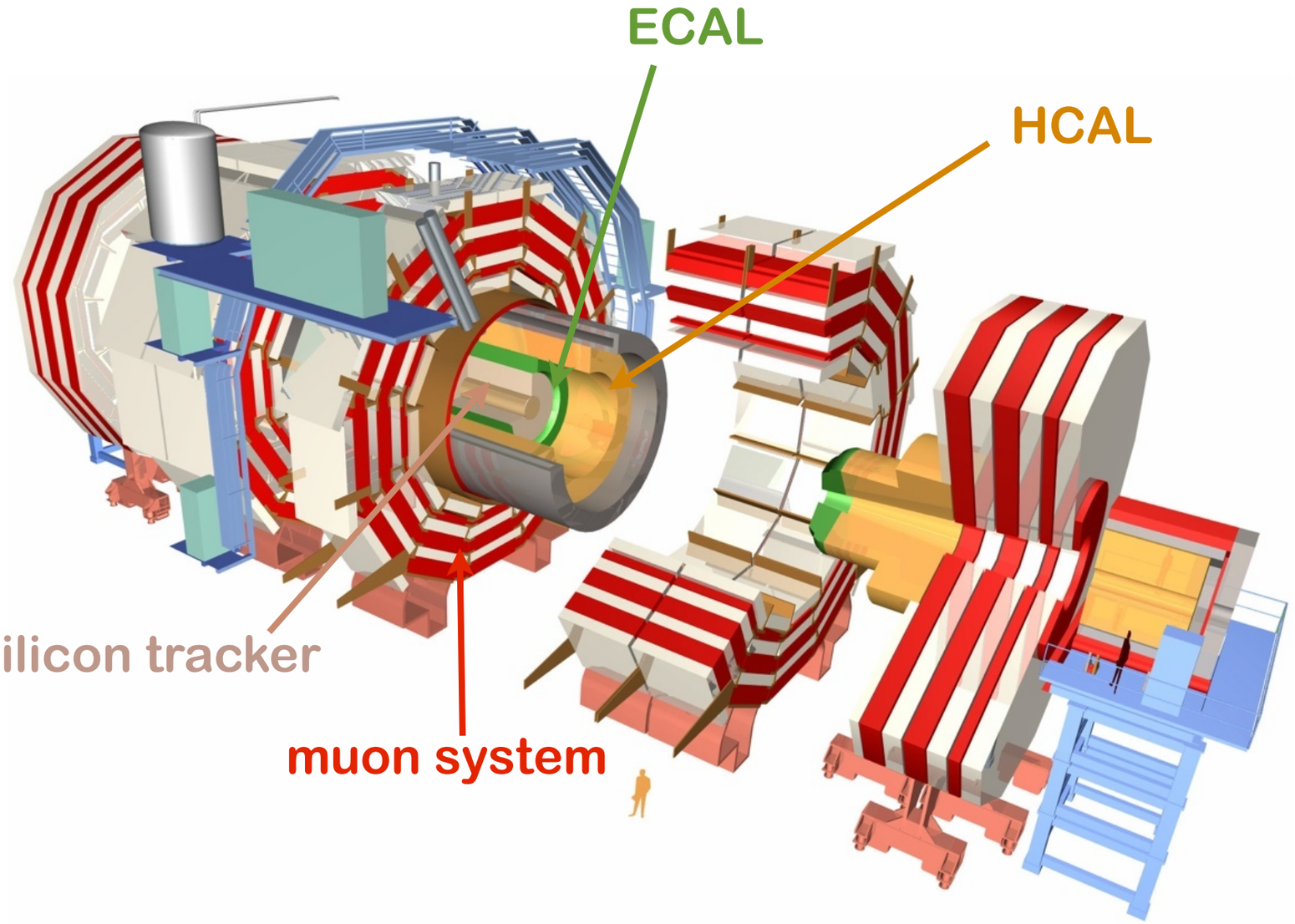
- detector-level number of signal events N_i^{data} to be corrected for
  - lepton acceptance, reconstruction and selection efficiency $\epsilon_i^l \cdot A_i^l$
  - B hadron acceptance, identification efficiency ϵ_i^B, and charm contamination P_i^B

- leptons and Z/γ*: transverse momentum p_T(lepton) > 20 GeV, pseudorapidity |η(lepton)| < 2.4, 60 < M(leptons) < 120 GeV **phase space definition**
- B hadrons: p_T > 15 GeV, |η| < 2.0

the CMS experiment



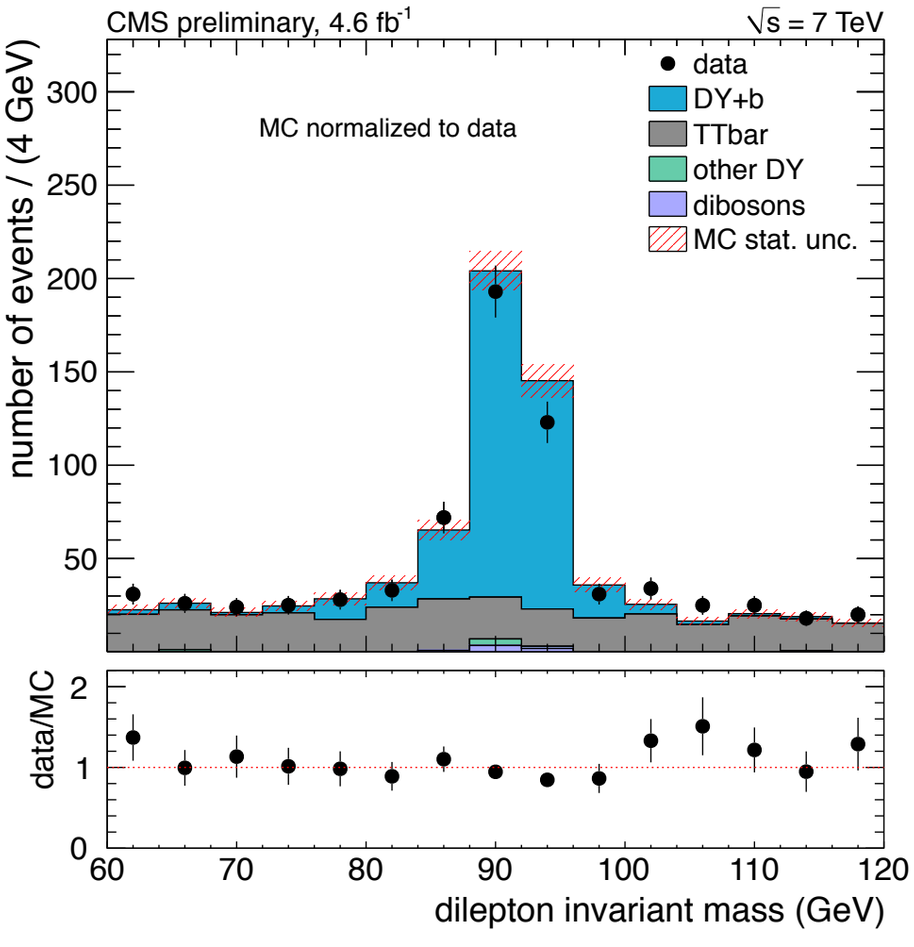
4.6 fb^{-1} of LHC data collected in 2011 used by this analysis

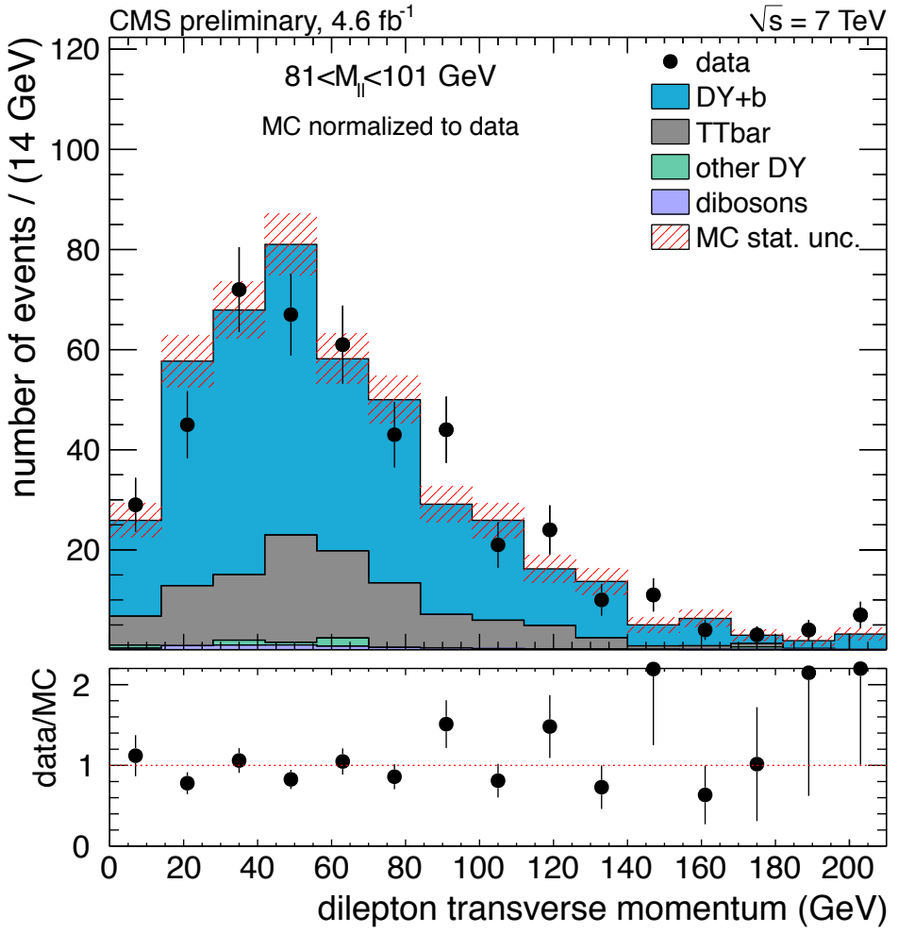


- very good position resolution in tracker (from 5 to 30 μm)
- excellent performance in reconstruction of charged tracks
- very good performance in reconstruction of displaced decays and b identification

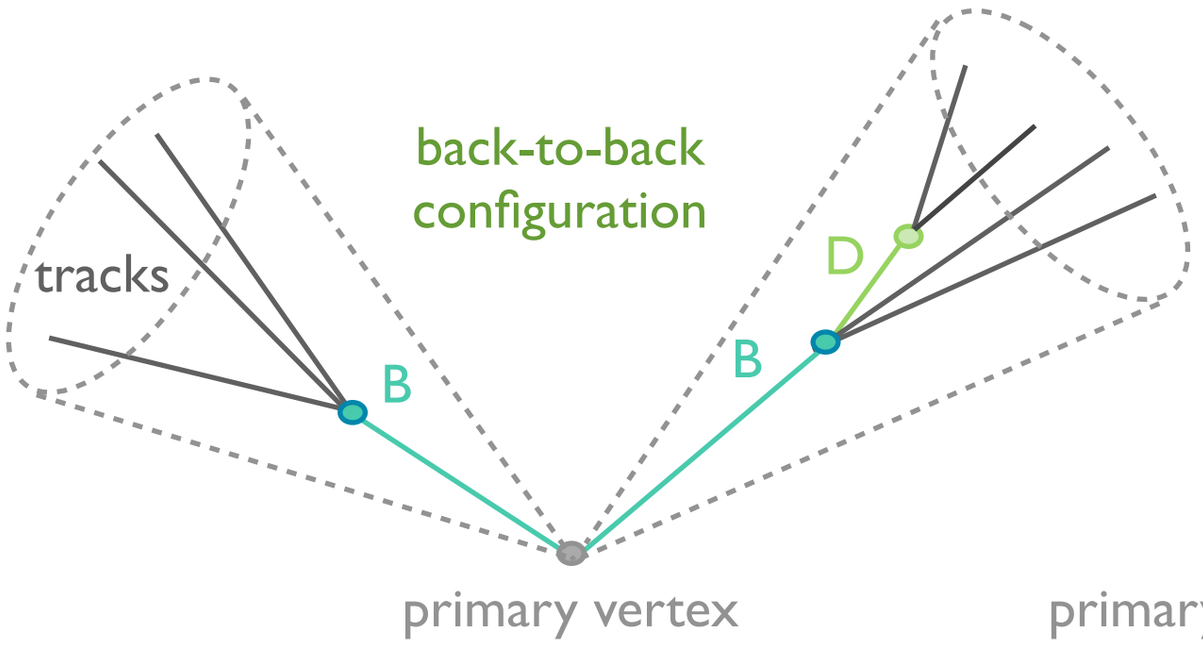
lepton selection and Z reconstruction

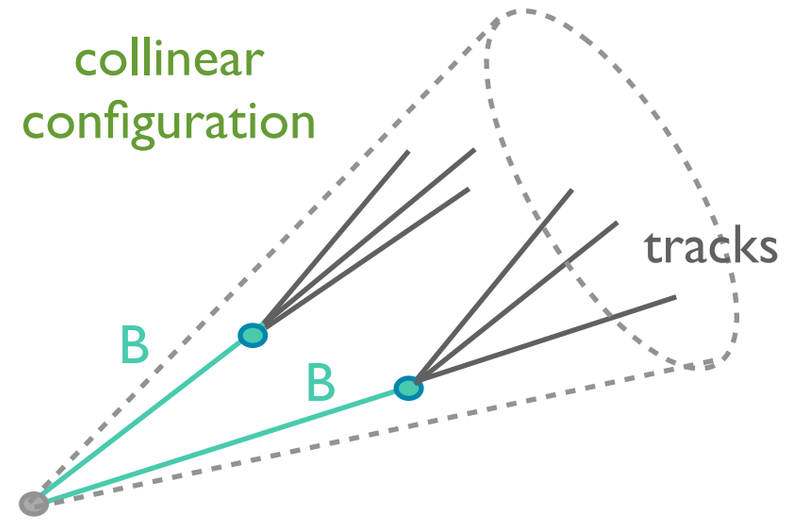
- muon channel: two reconstructed muons:
  - isolated, matched to High-Level Trigger objects, $p_T > 20$ GeV, $|\eta| < 2.1$
- electron channel: two reconstructed electrons:
  - isolated, matched to High-Level Trigger objects, $p_T > 25$ GeV, $|\eta| < 2.4$
- efficiency estimated from simulation and data with Tag & Probe technique





B identification: the Inclusive Vertex Finder



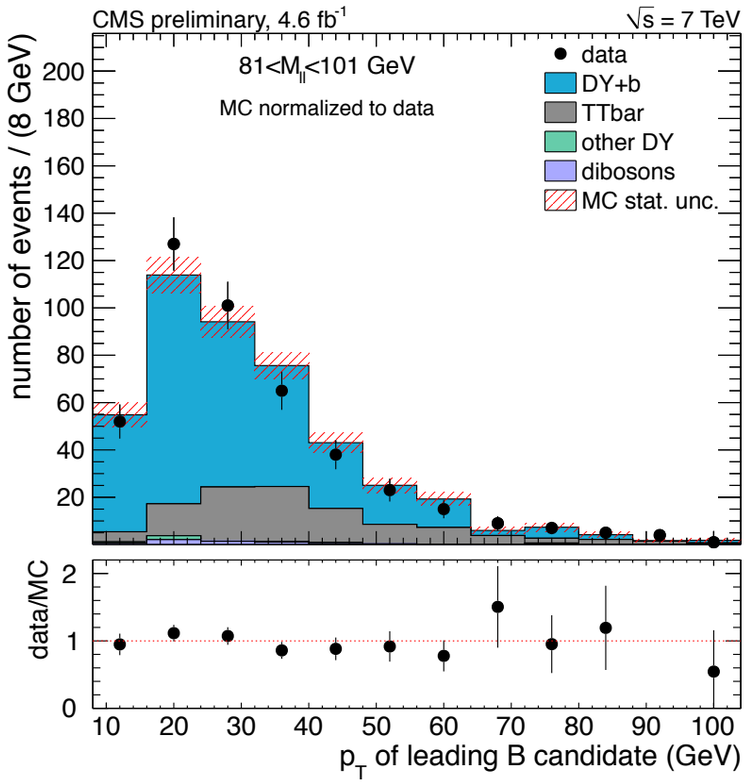


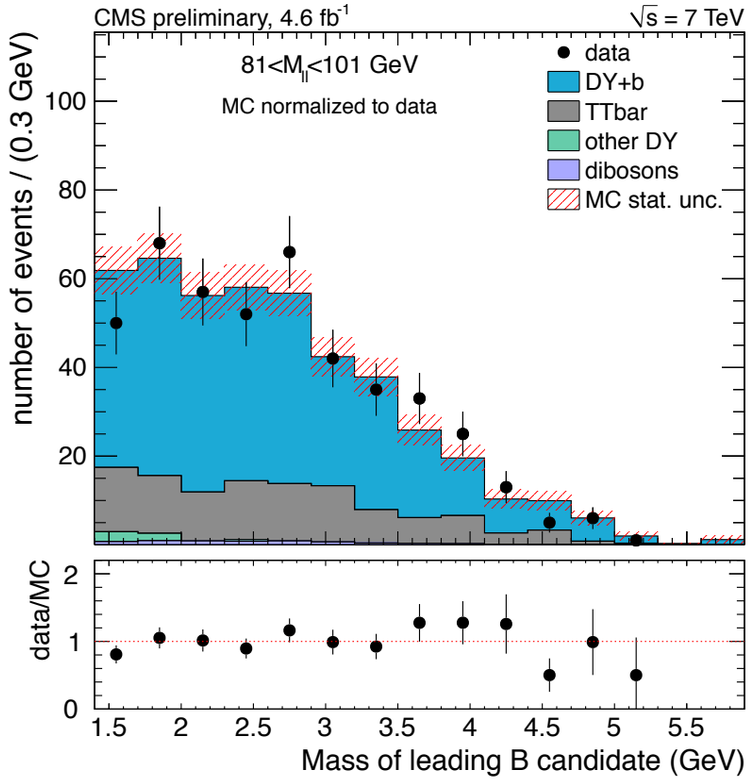
- identification of a B hadron through its **decay vertex**
- vertices from cascade B to charm decays merged into single B hadron candidate
- **no use of jets**, based on tracks displaced w.r.t. the primary interaction
- no limitation from jet cone size, unprecedented **sensitivity to very small angular separation** between B hadrons
- **very good resolution in B hadron flight direction** ($\Delta R(BB) \sim 0.02$) thanks to the excellent CMS performance in track and vertex reconstruction
- sensitivity to low momentum B hadrons

B hadron properties and selection

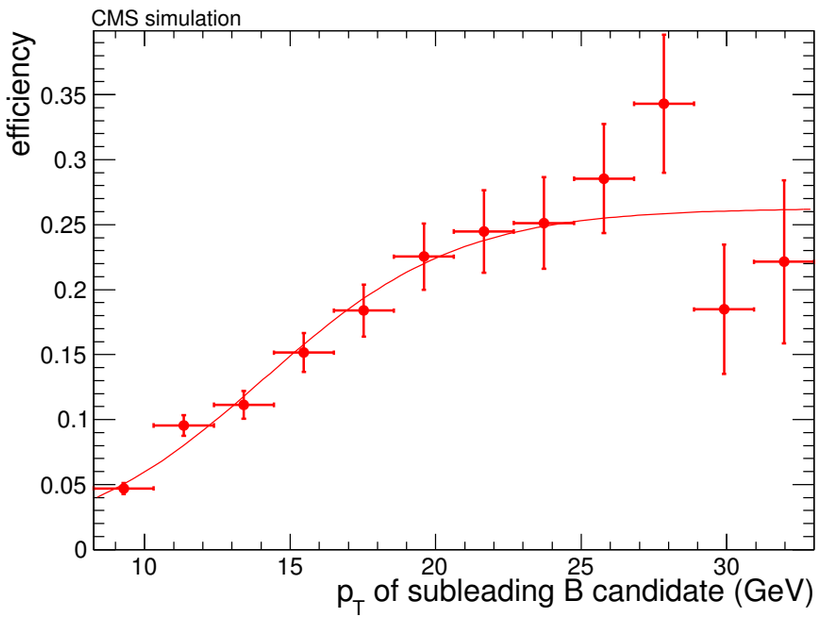
708 events after all selections

- presence of **two B candidates** required
- p_T > 8 GeV, |η| < 2.0, vertex track multiplicity > 3, vertex mass > 1.4 GeV, vertex flight distance significance > 5
- B identification efficiency between 10 and 15% (evaluated from simulation)
- high B purity: charm contamination < 5% (evaluated from simulation)





efficiency of identifying a B hadron pair



extraction of signal yield and corrections

- detector-level number of signal events extracted from **extended maximum likelihood fit** of the lepton pair invariant mass distribution

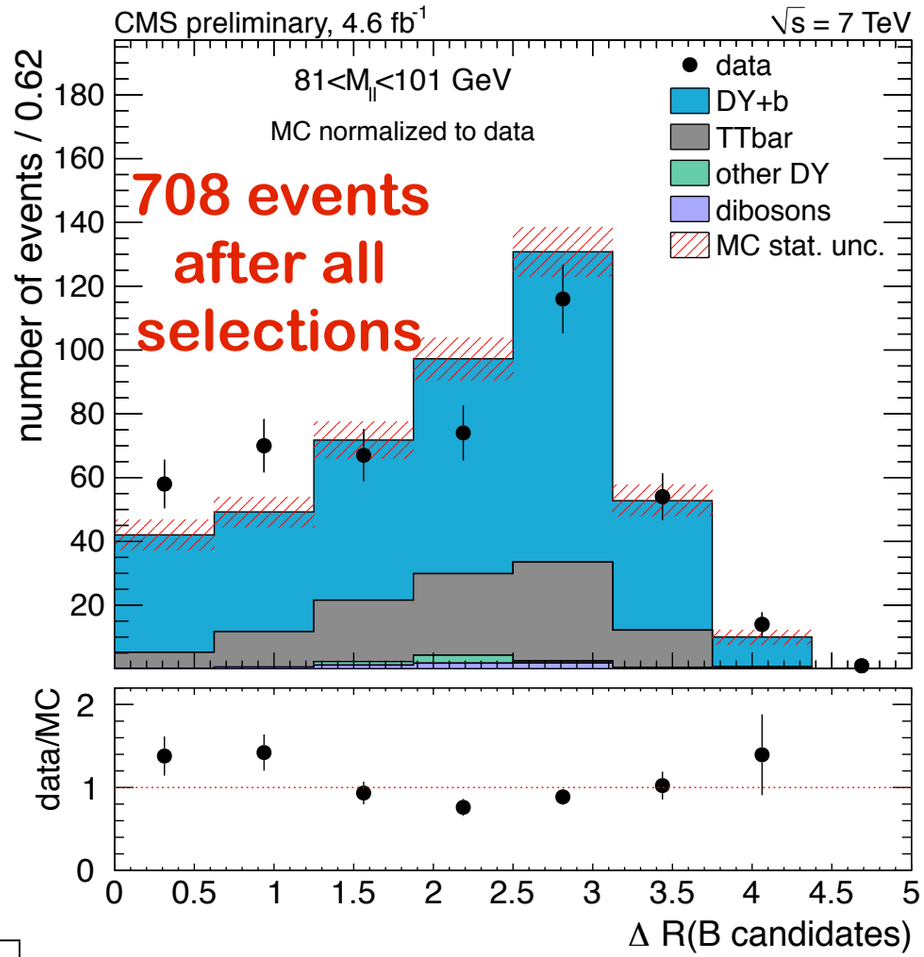
- **no unfolding** is needed, thanks to excellent angular resolution

- **bin-by-bin corrections** for lepton acceptance and selection efficiency, B identification efficiency, B purity, estimated mostly from Monte Carlo simulation

- systematic uncertainties:

Source	Uncertainty
Softer B-hadron p_T and IVF phase-space correction	$\pm 9\%$
IVF purity	$\pm 4\%$
Fit uncertainty	$\pm(1\% - 2\%)$
Leptons kinematics	$\pm 0.5\%$
MC statistics	$\pm(6\% - 10\%)$

detector-level $\Delta R(BB)$ distribution



normalized differential cross-section

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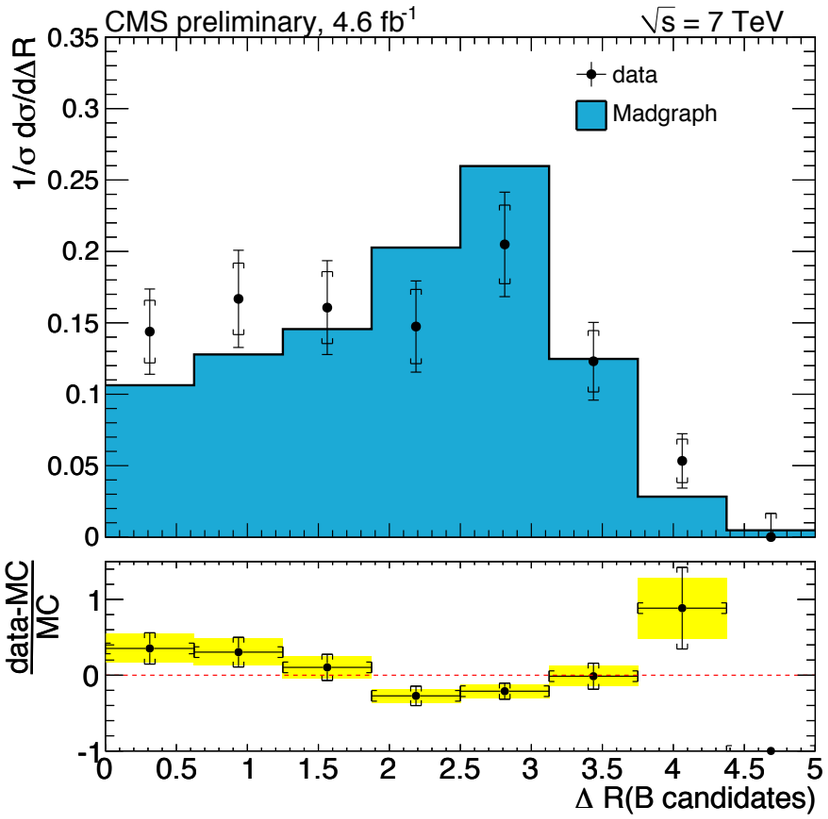

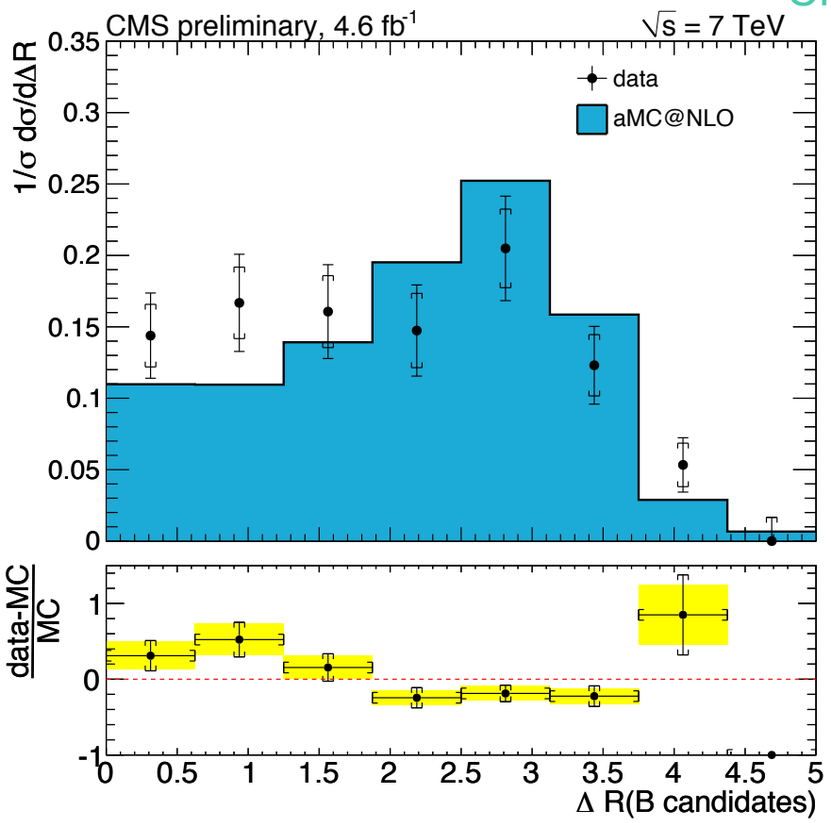

- measured normalized ΔR(BB) distribution compared to Monte Carlo simulation (hadron-level):
  - tree-level prediction by MadGraph (JHEP 0709 (2007) 028) (including events from Z + light jet + B hadron pairs from Multiple Parton Interactions)
  - next-to-leading order prediction by aMC@NLO (JHEP 09 (2011) 061) (not including Z +light jet + B hadron pairs from MPI)
- **reasonable agreement** between data and Monte Carlo simulation, data shows flatter trend compared to prediction

conclusions

- we performed the first measurement of the **angular correlation** between B hadrons produced in association with a Z/γ* boson
- with 4.6 fb^{-1} of integrated luminosity collected by the CMS experiment in 2011
- probing for the first time the region of **collinear B pair production**
- the measured normalized differential cross-section was compared to Monte Carlo simulation at the hadron-level:
- **reasonable agreement** with the tree-level prediction by MadGraph and with the NLO prediction by aMC@NLO, although data suggest a flatter distribution
- the measurement of the absolute differential cross-section will help establishing which model provides the best description of the observed trend
- crucial for the understanding of the backgrounds of the Higgs searches into b quarks.