The polarization of J/ψ in jet in pp collisions at $\sqrt{s} = 13.6$ TeV

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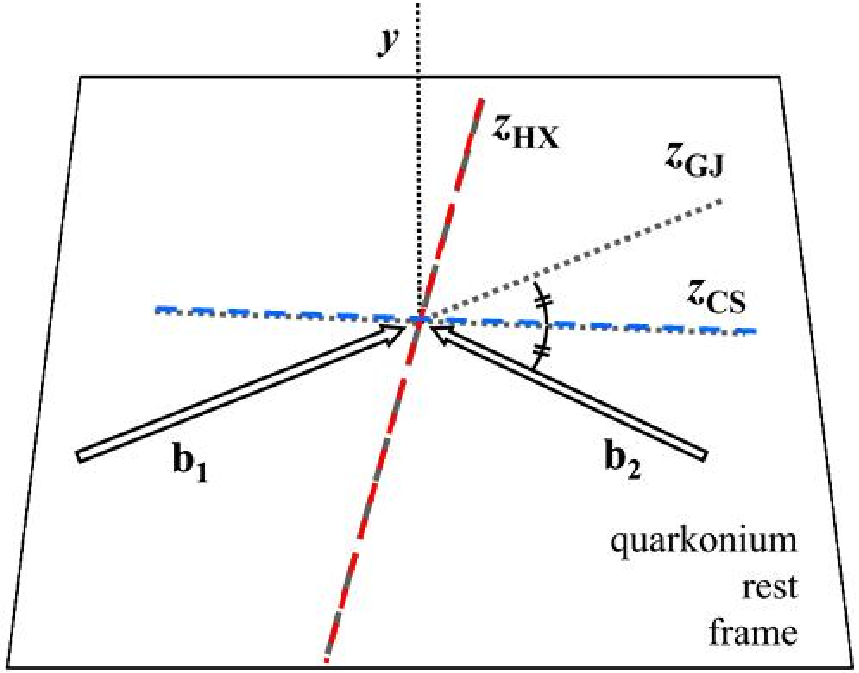
Motivation

- Quarkonia in high-energy proton-proton (pp) collisions are important probes for studying the quantum chromodynamics (QCD) in vacuum.

- The polarization of quarkonia in pp collisions is a powerful observable to discriminate among several QCD-based model calculations of quarkonium production.

- J/ψ polarization measurement in pp collisions can also provide a reference for investigating the fate of charmonium in the quark-gluon plasma formed in nucleus-nucleus collisions.



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Helicity (HX): direction of vector meson in the collision center of mass frame.

Collins-Soper (CS): the bisector of the angle between the beam and the opposite of the other beam, in the vector meson rest frame

Polarization is defined as the alignment of spin along a chosen direction.

Motivation

Even though all these groups can describe the inclusive J/ψ production cross section, i.e., the p_T spectrum, they have not been able to fully explain the polarization of high-p_T heavy quarkonia produced at the Tevatron and the LHC.

- Measuring the polarization of J/ψ mesons inside jets should be possible to provide better constraints for the Long-Distance Matrix Elements(LDMEs) in global fits and more accurate information on the nonperturbative formation of heavy quarkonia.

$$F^{J/\psi}(z_h, p_T) = \frac{d\sigma^{J/\psi}}{dp_T d\eta dz_h} \Big/ \frac{d\sigma}{dp_T d\eta}$$

The polarization of J/ψ in jet in theory

J/ψ polarization in the jet.—Besides measuring the J/ψ distribution in the jet, one can study the polarization of the produced J/ψ. The polarization can be determined analogously to single inclusive J/ψ production, e.g., by measuring the angular distribution of the decay lepton pair $\ell^+\ell^-$ in the so-called helicity frame [36]

$$\frac{d\sigma^{J/\psi(\to\ell^+\ell^-)}}{d\cos\theta} \propto 1 + \lambda_F \cos^2\theta. \qquad (5)$$

Here, λ_F denotes the J/ψ polarization measured in a jet, and $\lambda_F = 1(-1)$ corresponds to a purely transversely (longitudinally) polarized J/ψ. Based on the factorization formalism in Eq. (2), λ_F can be computed as follows:

$$\lambda_F(z_h, p_T) = \frac{F_T^{J/\psi} - F_L^{J/\psi}}{F_T^{J/\psi} + F_L^{J/\psi}}, \qquad (6)$$

where $F_{T,L}^{J/\psi}$ are the jet fragmentation functions for producing a J/ψ with transverse (or longitudinal) polarization.

transverse momentum, respectively. Furthermore, $z_h = p^+_{J/\psi}/p^+_{\text{jet}}$ denotes the momentum fraction of the jet carried by the J/ψ. The plus momentum is defined for any four vector v^μ as $v^+ = v^0 + v^z$ in a frame where the "z" axis is along the jet direction. The factorized form of the differ-

The analysis needs to be performed in bins of z_h and p_T.

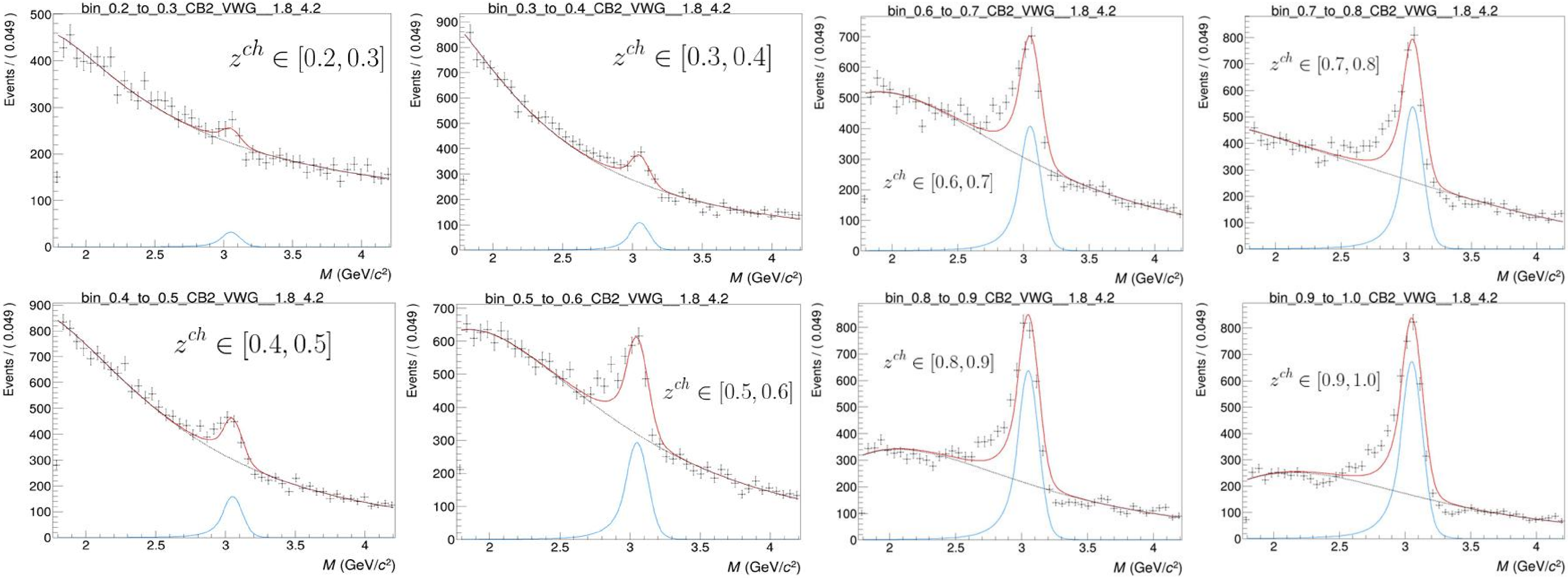
$$z = \frac{p_{T,e^+e^-}}{p_{T,jet}}$$

J/ψ in jet in Run3 by Lucas Ferrandi

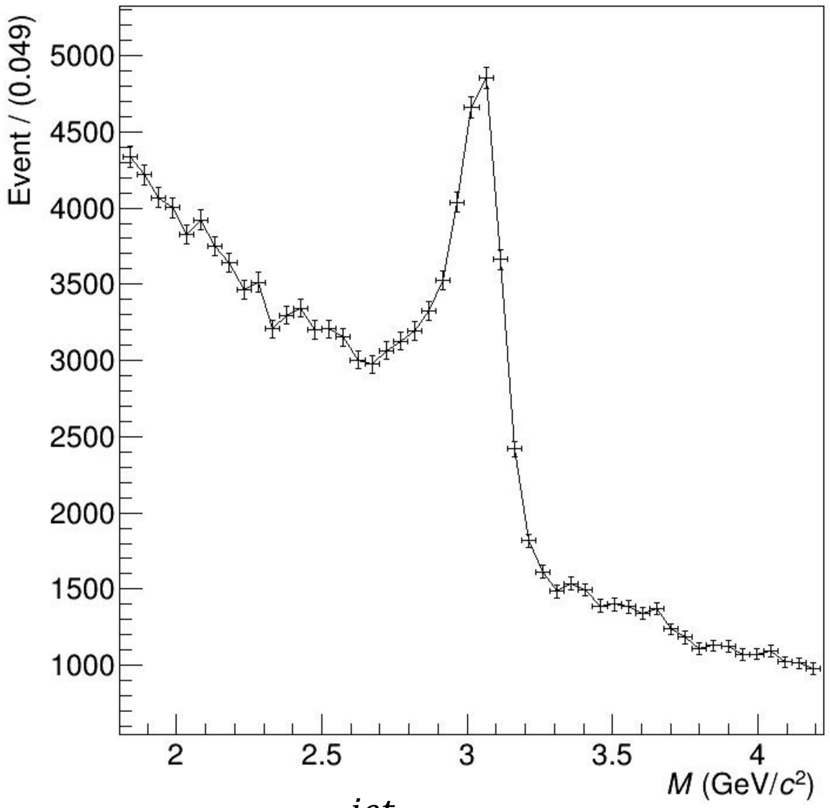
- Dataset: 53 runs from JE_DQ_LHC24am_pass1_skimmed_Maker_JE_DIELC_R4_4 (HY)
  - 25-01-21 version
  - pp at 13.6 TeV
  - Anti-kt with R = 0.4
  - $p_T^{jet} > 4$ GeV
  - 86950 events
- Workflow:
  - jet-finder-dielectron-data-charged: runs FastJet
  - PWGJE/Tasks/jpsiFragmentationFunction.cxx: my task (not in repo yet)
- Selection cuts:
  - "eventStandardSel8NoTFBNoITSROFB"
    - $|Z| < 10$ cm
    - "Sel8"
    - "NoTFBorder"
    - "NoITSROFBorder"
  - "paira_prefilter1"
    - mass > 0.06 GeV
  - "electronSelection1_ionut"
    - "jpsiStandardKine"
      - $p_T > 1$ GeV
      - $|\eta| < 0.9$
    - "electronStandardQualityForO2MCdebug"
      - "TrackQuality"
      - "IsEMC"
    - "dcaCut1_ionut"
      - $0 < DCA_{xy} < 1$
      - $0 < DCA_z < 3$
    - "electronPIDnsigmaMedium"
      - $|TPC\ n\sigma_e| < 3$

J/ψ in jet in Run3 by Lucas Ferrandi

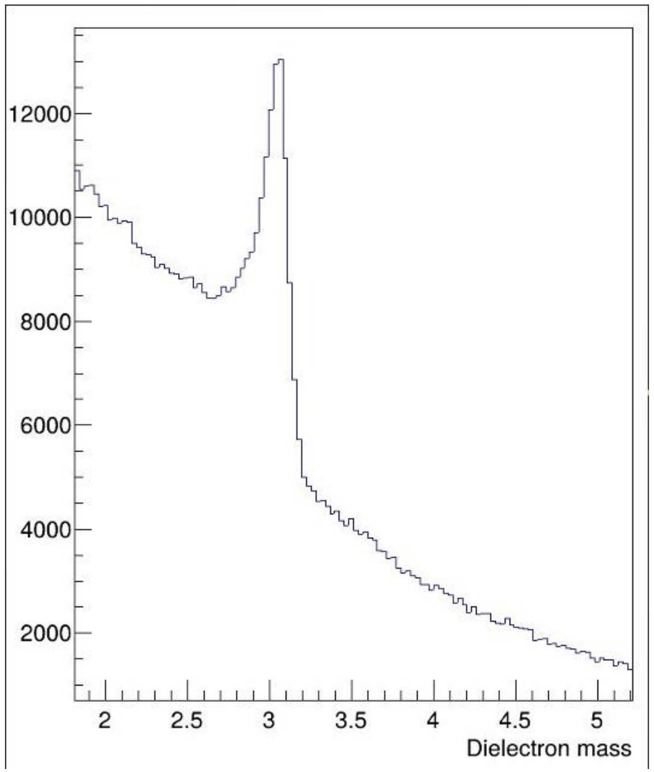
$$7GeV/c < p_{T,jet} < 15GeV/c$$



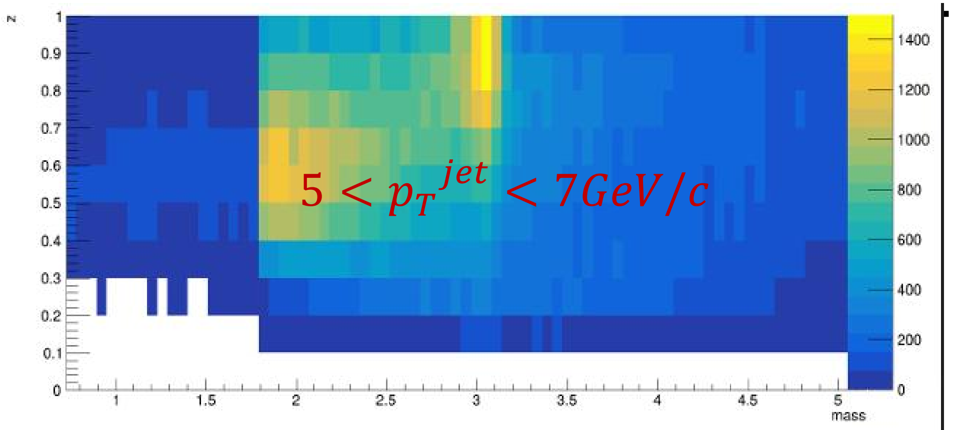
The estimation of uncertainty

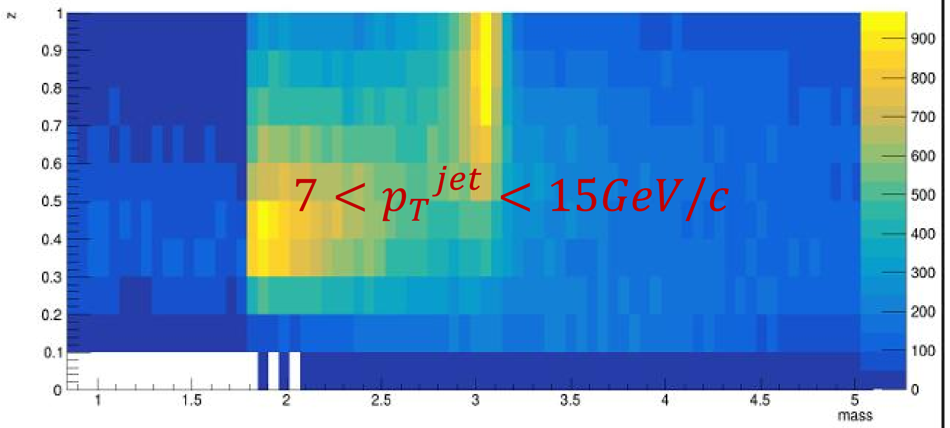


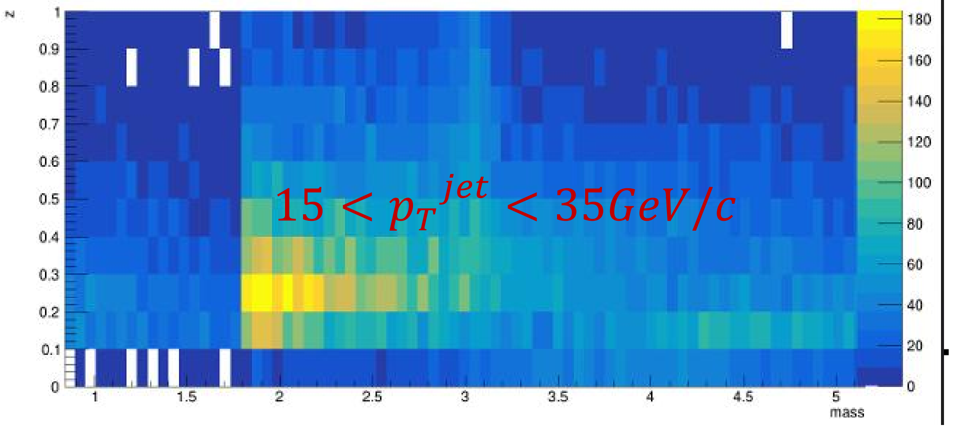
$7 < p_T{}^{jet} < 15\ GeV/c$



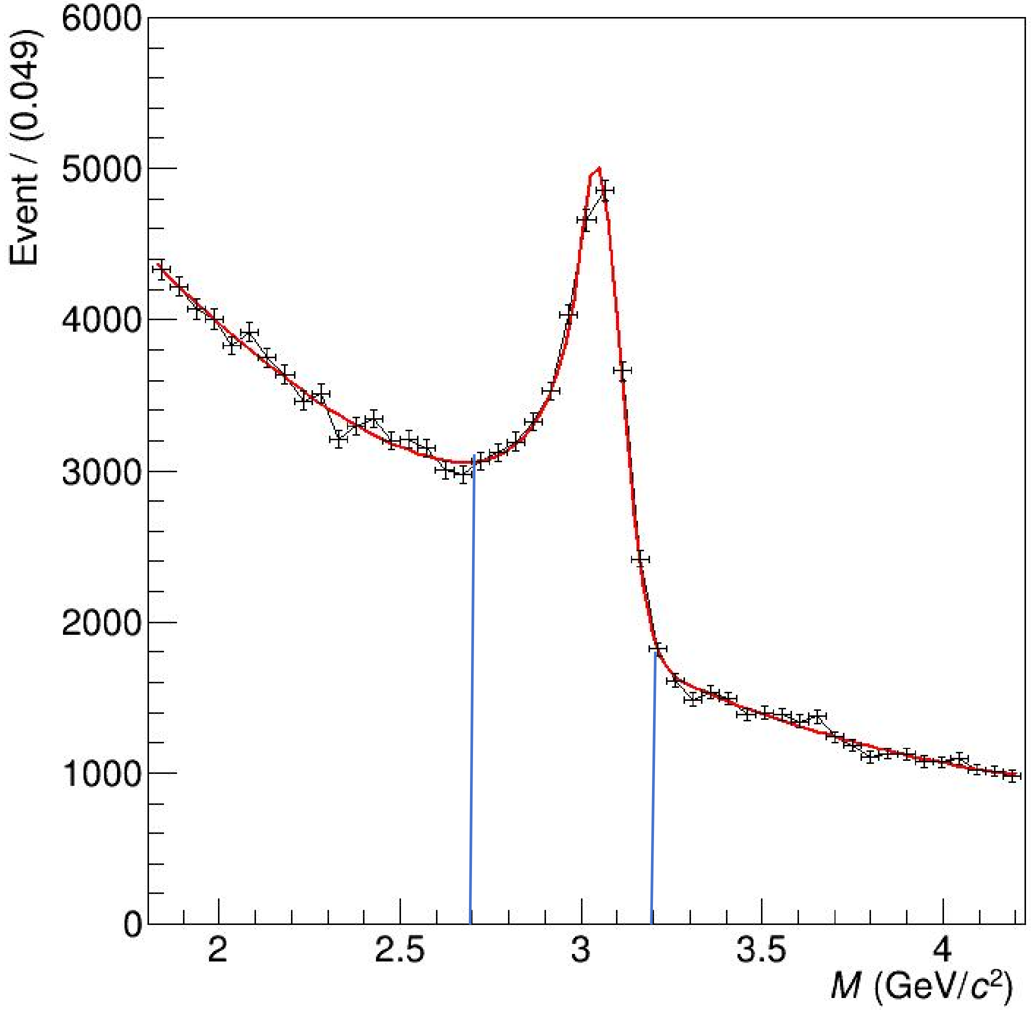
$5 < p_T{}^{jet} < 35\ GeV/c$







The estimation of uncertainty



Mass Window：2.7-3.2

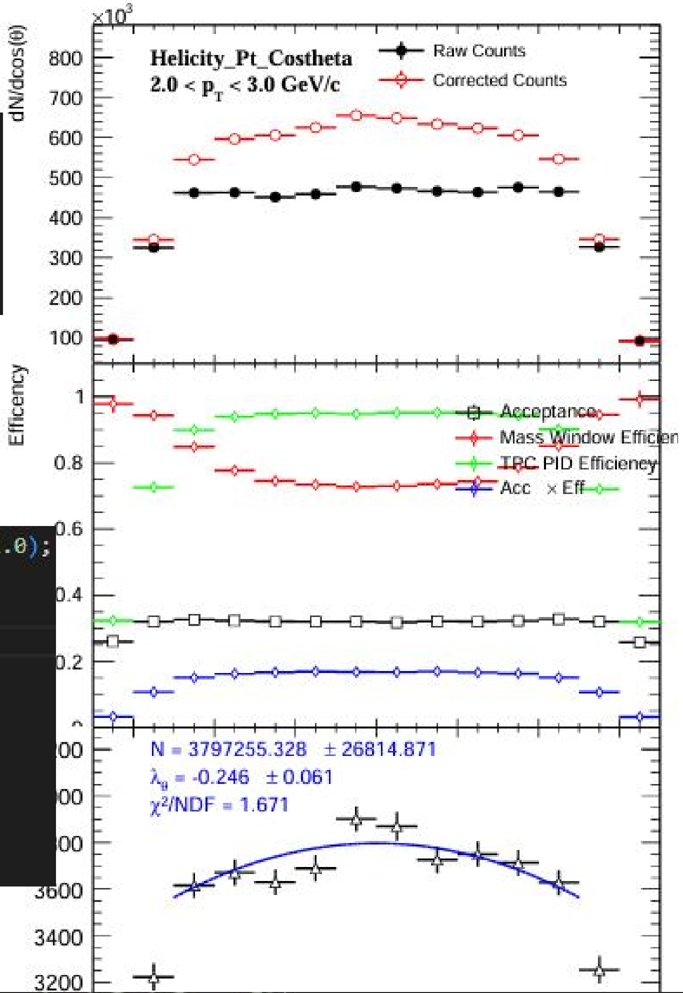
```
Signal integral = 15748.8 ± 982.042
Background integral = 20365.4 ± 300.433
```

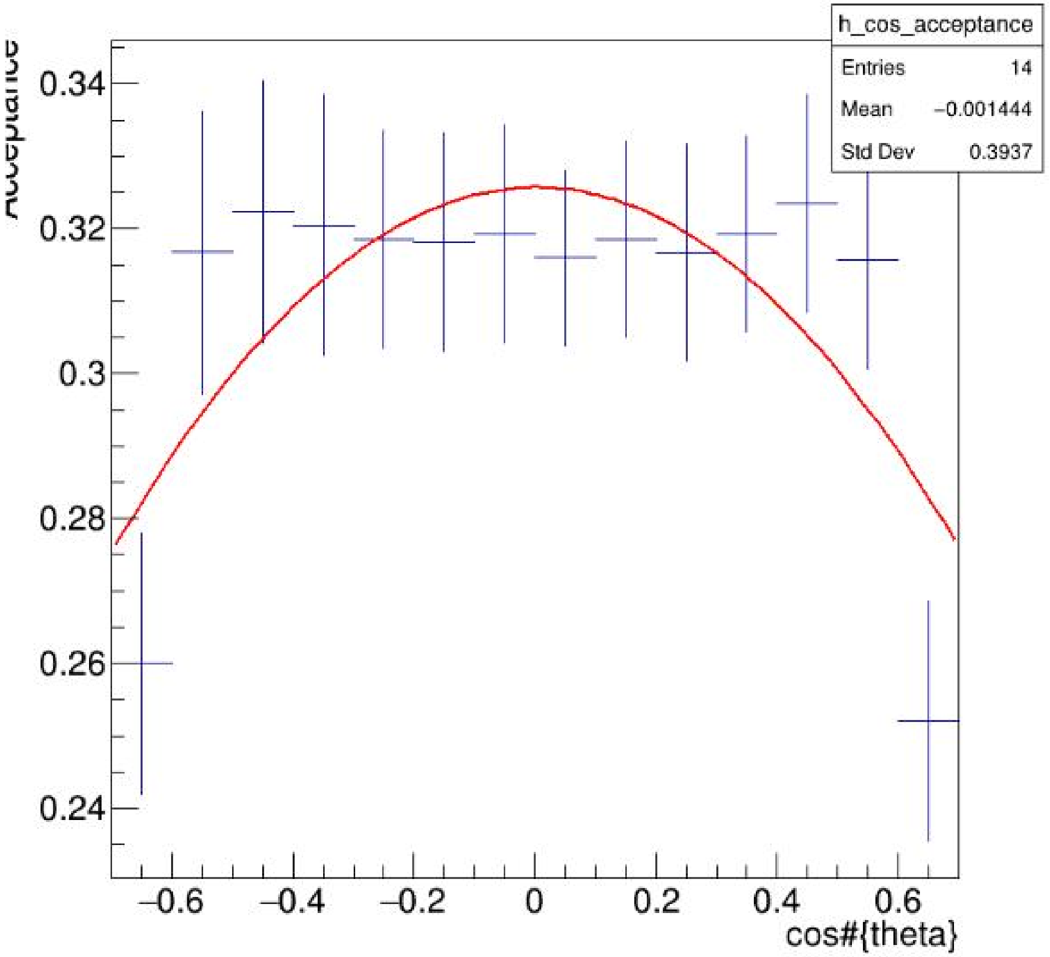
The estimation of uncertainty

```cpp
TRandom3 *r = new TRandom3(0);
for(int k =0; k < static_cast<int>(Sg); ++k){
  double cos_theta = r->Uniform(-1,1);
  h_cos_theta->Fill(cos_theta);
}
```

```cpp
double b = -0.5 + 0.002*i;
double a = (3*Sg - 2*b)/6;
```

```cpp
TF1 *f1 = new TF1("f1", "[0]+[0]*[1]*pow(x,2)", -1.0, 1.0);
f1->SetParameter(0, a);
f1->SetParameter(1, b);
f1->SetParLimits(1, -0.6, 0.6);
//按照f1的函数分布随机填充Sg的counts数
std::vector<double> cos_theta_samples;
for(int k = 0; k < static_cast<int>(Sg); ++k){
    double cos_theta = f1->GetRandom(-1, 1);
    cos_theta_samples.push_back(cos_theta);
    h_cos_theta->Fill(cos_theta);
}
```






```cpp
for(int n=1; n<=20; n++){
  h_cos_theta->SetBinError( n , h_cos_theta->GetBinError(n)/sqrt(Sg/(Sg + Bg))/acceptance_20[n-1]);
  //h_cos_theta->SetBinError( n , h_cos_theta->GetBinError(n)/sqrt(Sg/(Sg + Bg)));
}
```

The estimation of uncertainty

```
TF1 *f1 = new TF1("f1", "[0]+[0]*[1]*pow(x,2)", -1.0, 1.0);
f1->SetParameter(0, a);
f1->SetParameter(1, b);
f1->SetParLimits(1, -0.6, 0.6);
//按照f1的函数分布随机填充Sg的counts数
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    double cos_theta = f1->GetRandom(-1, 1);
    cos_theta_samples.push_back(cos_theta);
    h_cos_theta->Fill(cos_theta);
}
```
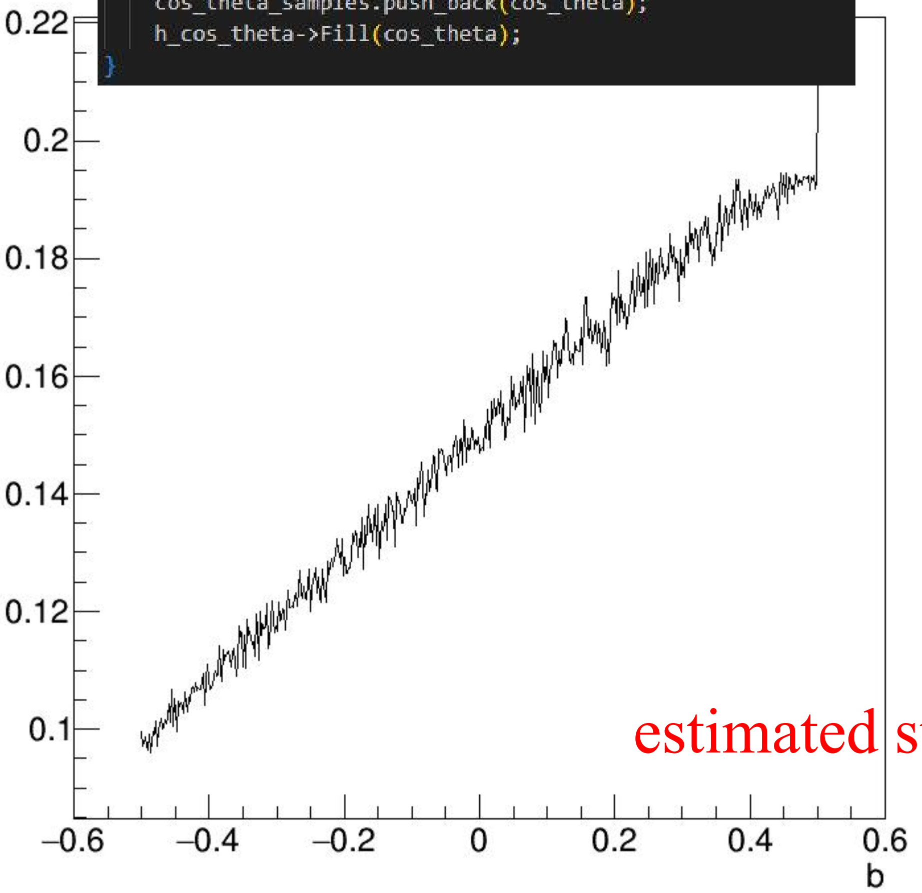
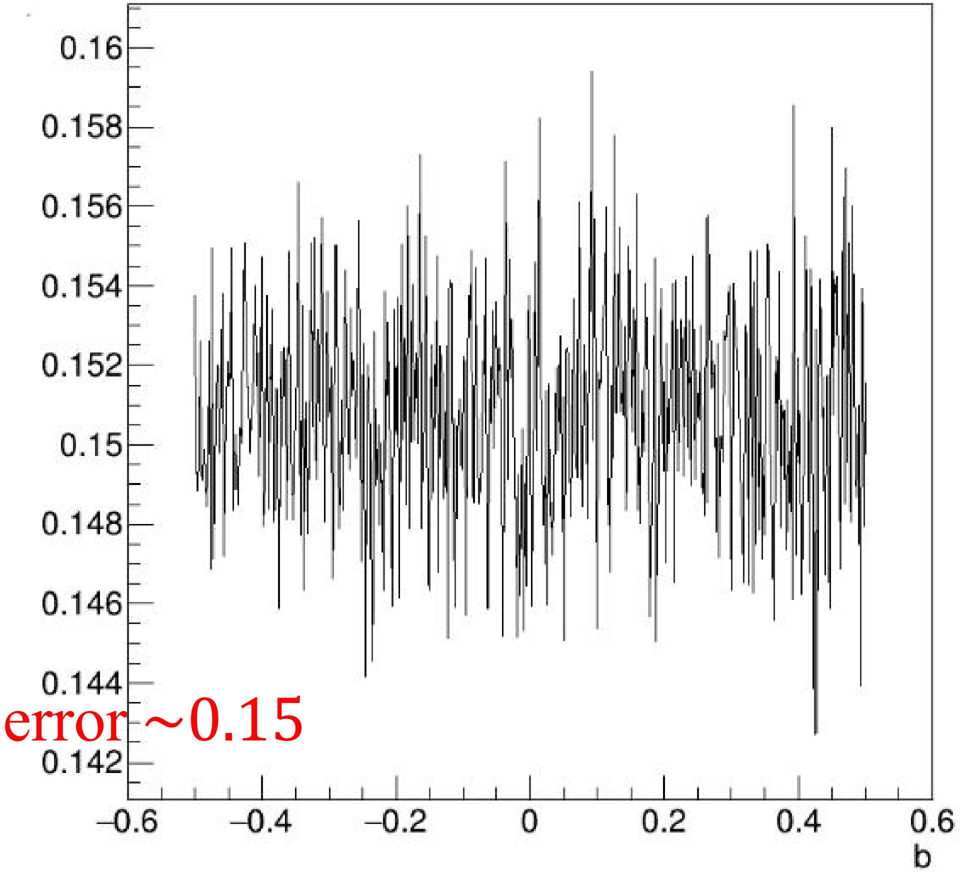
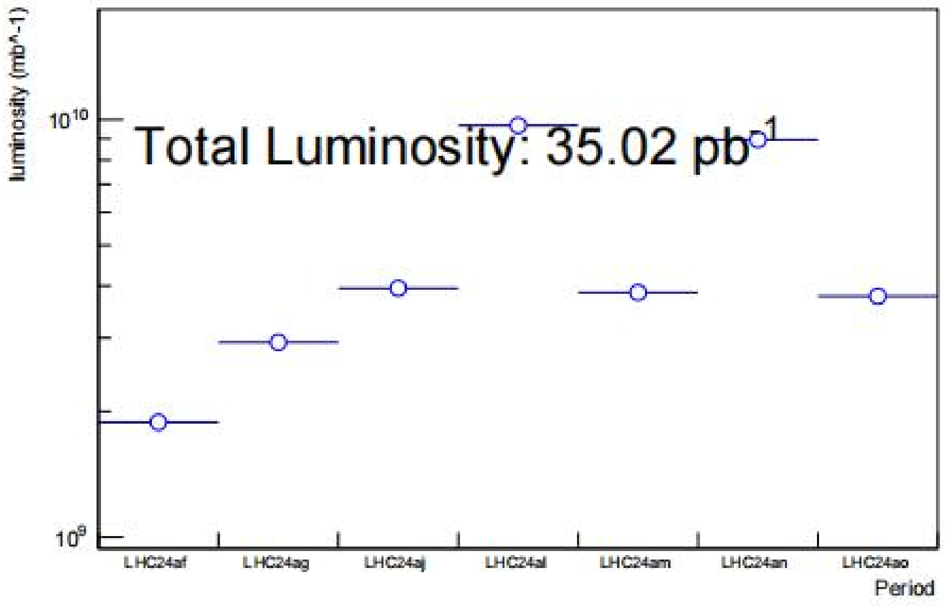




```
TRandom3 *r = new TRandom3(0);
for(int k =0; k < static_cast<int>(Sg); ++k){
  double cos_theta = r->Uniform(-1,1);
  h_cos_theta->Fill(cos_theta);
}
```



estimated statistical error ~0.15

The estimation of uncertainty

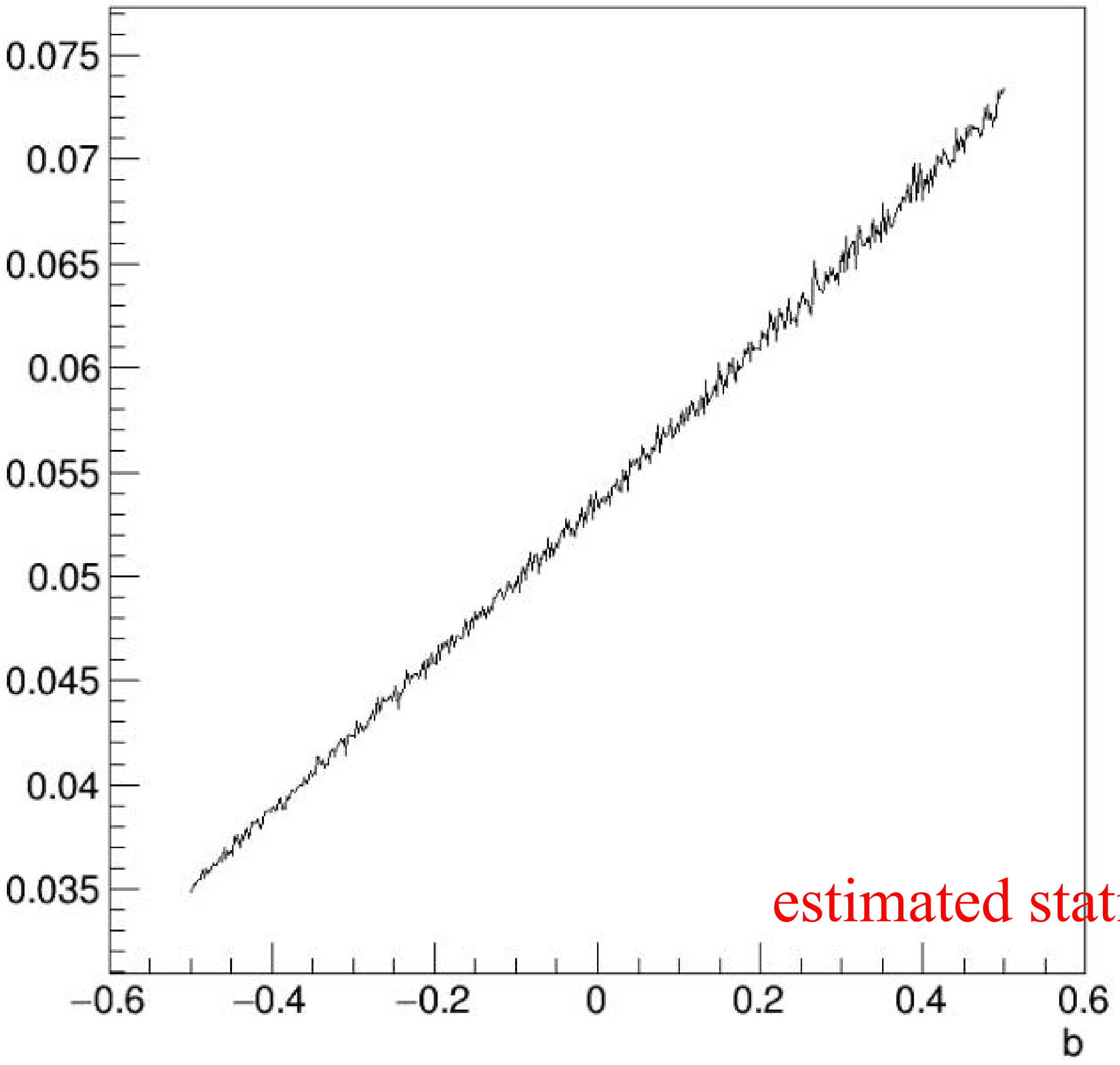


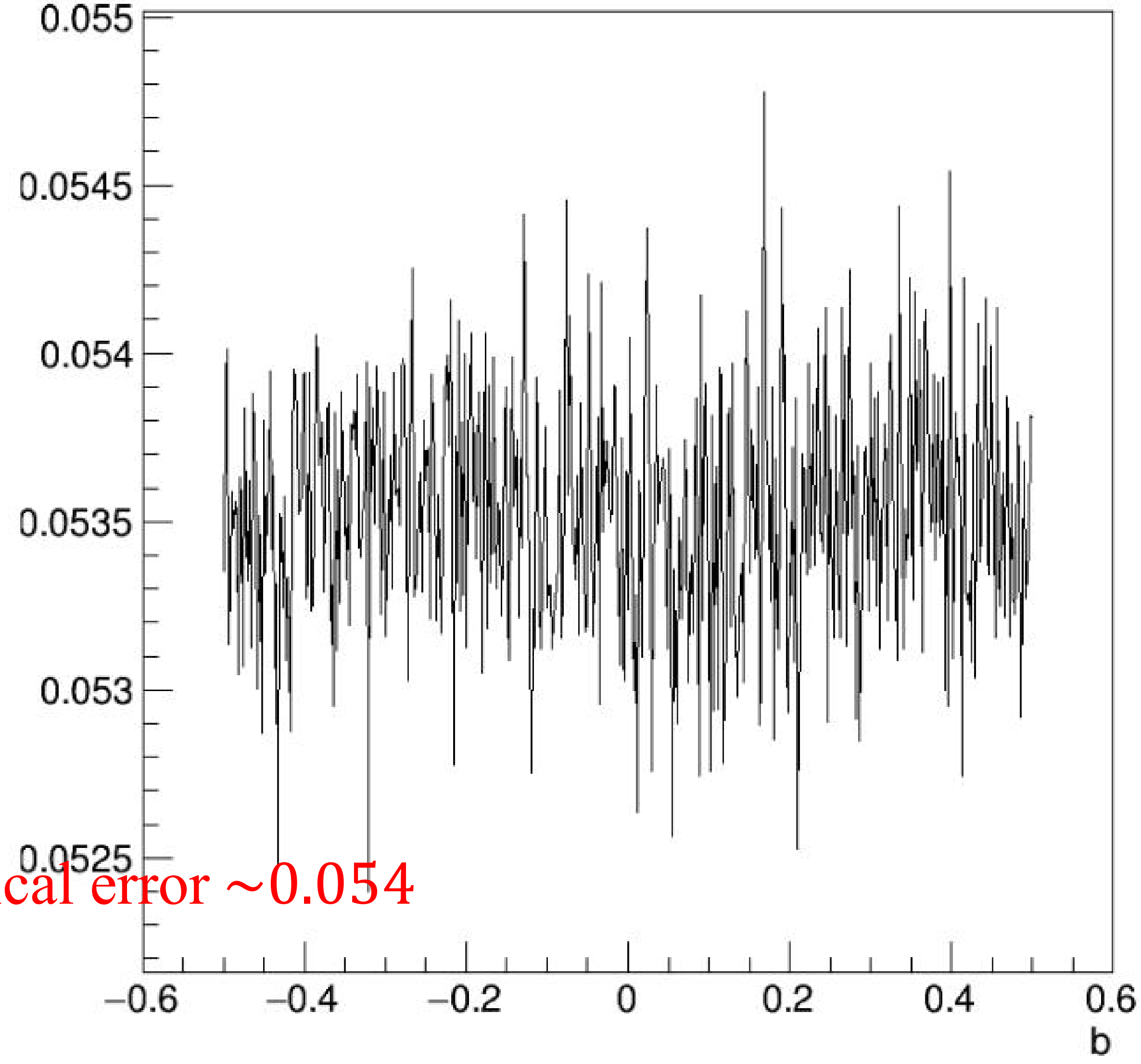
LHC24 pass1 new:

Maker $\rightarrow$ 35.02 pb^{-1}

$$Ratio = \frac{1}{8}$$

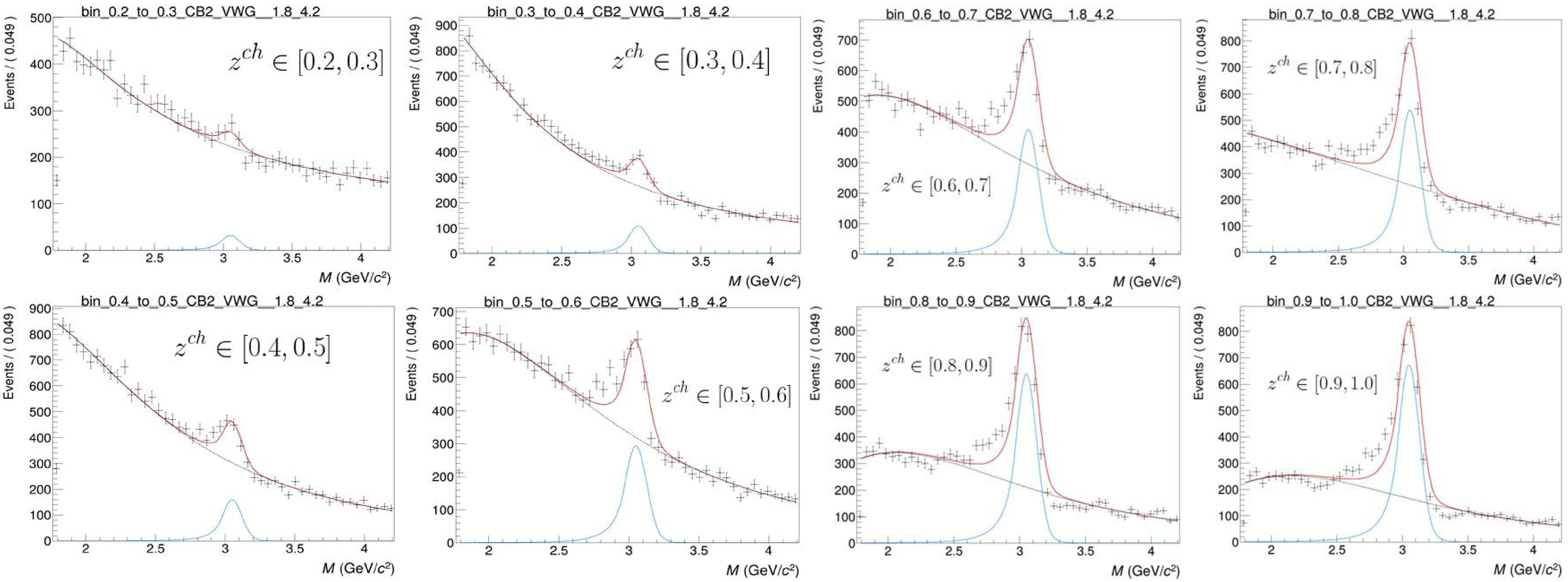
The estimation of uncertainty





estimated statistical error ~0.054

The estimation of uncertainty



z^{ch}: 0.2-0.7 ; 0.7-0.85 ; 0.85-0.9

The Summary

- Considering the acceptance and the luminosity, the statistical error on λ_θ is estimated as 0.054.
- The statistical uncertainty is estimated using Lucas Ferrandi's J/ψ-in-jet analysis (Run 3) at $7GeV/c < p_{T,jet} < 15GeV/c$ and $0.2 < z^{ch} < 1.0$.
- We can divide z into three bins by increasing the width of the cosθ bins.

Backup

5 Jet Reconstruction

The FASTJET CITE package was used to reconstruct the jets. In particular, the anti-k_T algorithm CITE was employed to reconstruct signal jets. This algorithm is infrared-safe (not sensitive to low energy radiations) and collinear-safe (not sensitive to collinear particle splitting). Resolution parameters of R=0.4 were used for jets in pp. For this analysis, only charged tracks are used to reconstructed the jets (charged jets). The underlying event is not subtracted.

The set of tracks given as input to the jet finder has the J/ψ daughters replaced by the 4-momentum of the pair candidate (sum of the 4-momenta of the daughters). The procedure is repeated independently for each D-meson candidate in each event, i.e. each candidate is treated as if it were the only one in the event, then (if there is more than one candidate) the procedure is repeated for each candidate one by one. This is done because two (or even more) candidates can share the same daughter.