H1b? $B \to J/\psi X$ at H1

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Doktorandenseminar 2001
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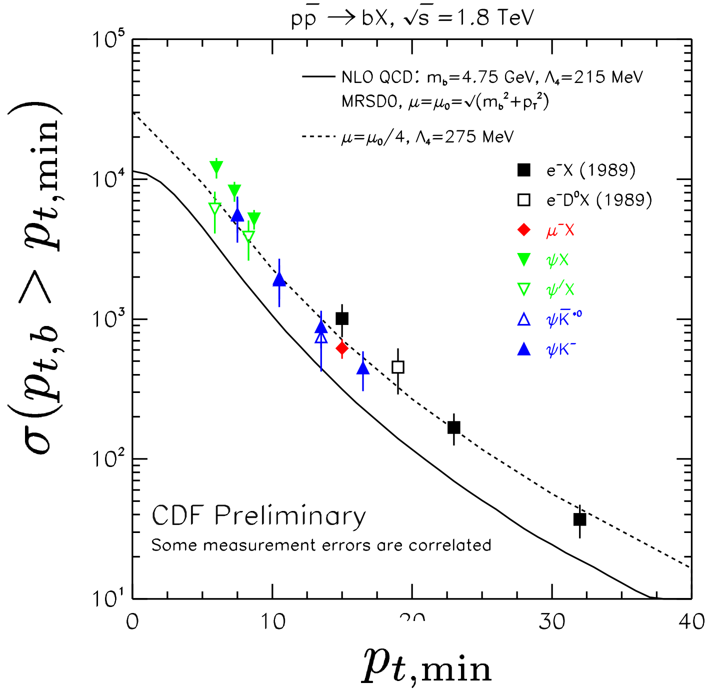
- Motivation: The Last Decade
- Beauty and J/ψ Production at HERA
- Selection of J/ψ Candidates
- Reconstruction of the Signed Decay Length
- The Log–Likelihood Minimization
- First Results on $\sigma_{\rm tot}(ep \to b\bar{b}X)$

The Last Decade



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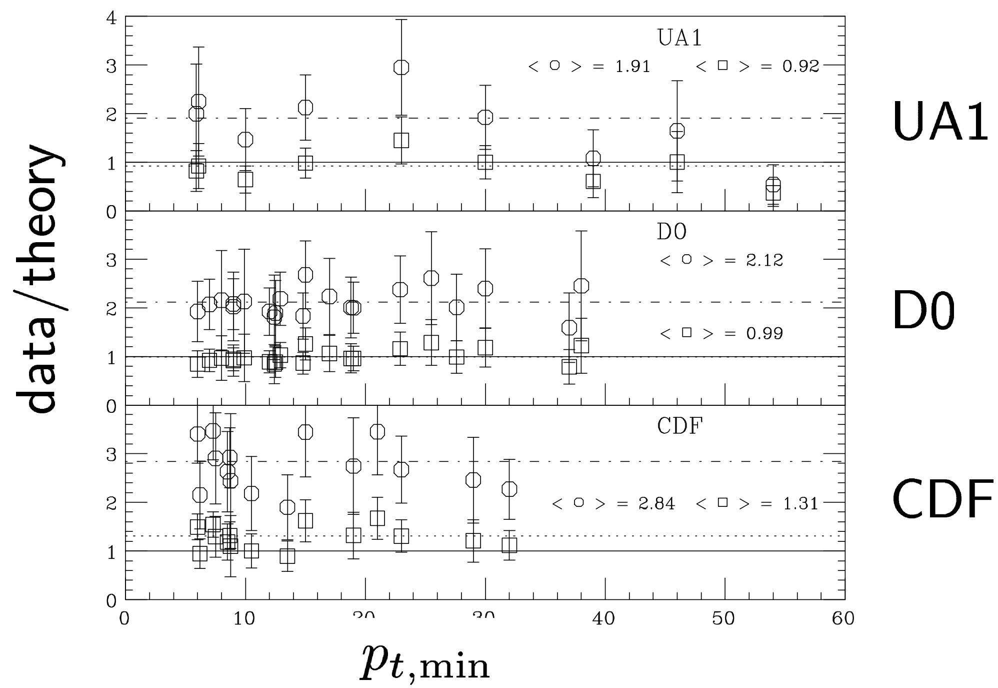


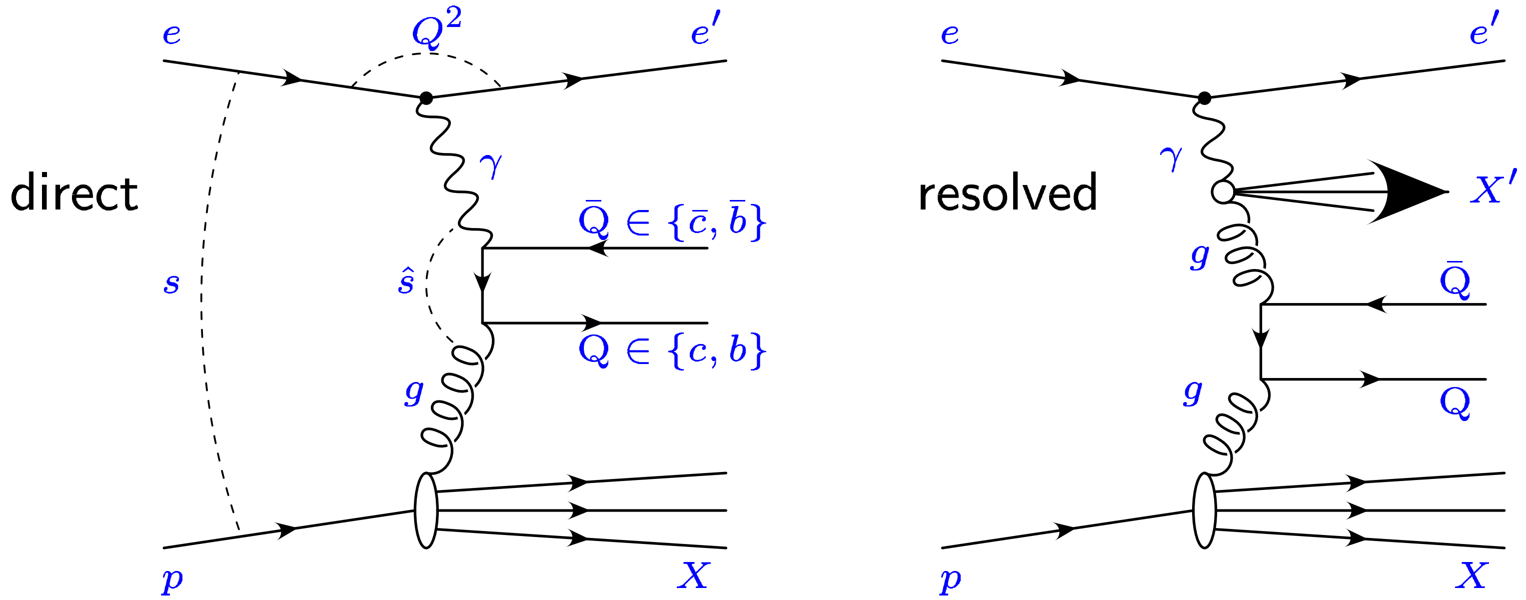
- $m_b \approx 4.5\,\mathrm{GeV/c^2}$ should be high enough to make pQCD applicable, $\alpha_s(m_b) \approx 0.2$

  $\Rightarrow$ Thus this should give a good theoretical discription

- But NLO QCD predictions underestimate measurements in hadroproduction by factor of 2 to 3
- Only with extreme choices for free parameters (m_b, μ_r, μ_f, parton densities) a match can be achieved
- Especially radiative effects at small x_g induce large NLO corrections
- Also observed at LEP and in photon–proton collisions at HERA

  Highly interesting to perform independent measurement at HERA

Beauty Production



- Kinematical variables:

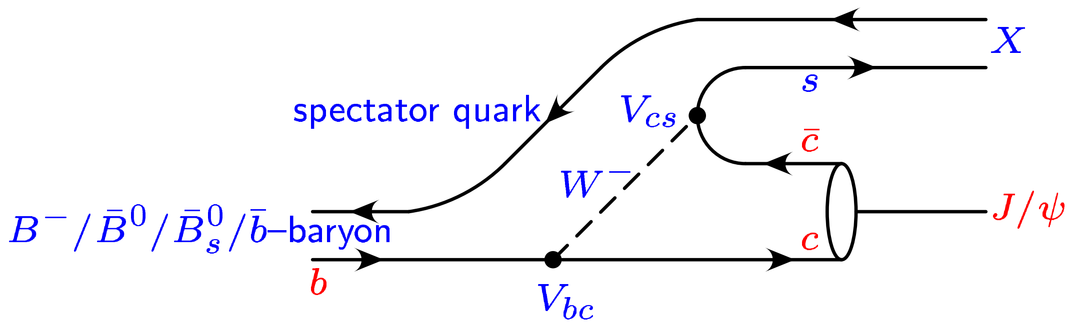
Virtuality Q^2

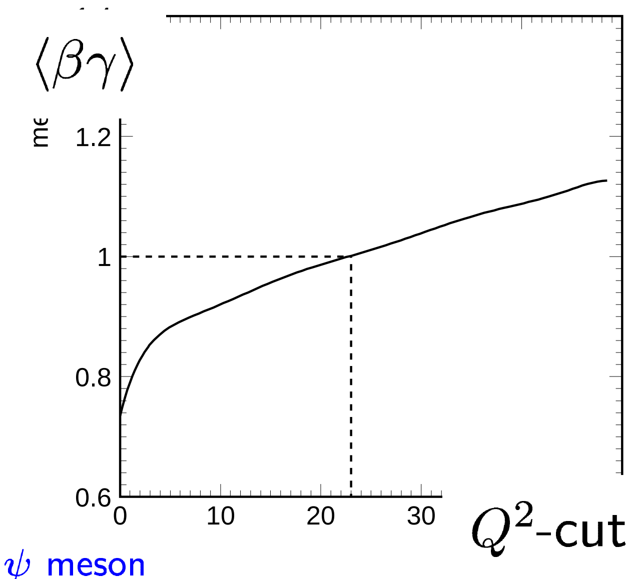
squared center–of–mass energy $s \simeq 4 \cdot E_e \cdot E_p$

squared center–of–mass energy of the heavy quark pair $\hat{s} = (P_Q + P_{\bar{Q}})^2$

- Factorization of hard process and successive hadronization
- Hard process can be calculated in pQCD, but might vary by a factor 2
- Resolved process contribute up to $40\,\%$, with variations of factor 3
- Largest uncertainties are the beauty–quark mass, gluon densities in the proton and photon and on μ_r and μ_f
- Hadronic final states contain at least B–mesons or b–baryons

$B \to J/\psi X$





- Following CKM Matrix elements, $b \to c$ and $c \to s$ are preferred
- c and $\bar{c}$ can form colour singlet state with quantum numbers of J/ψ meson

$$BR(B^+/B^0/B_s^0/b\text{–baryon} \to J/\psi X) = (1.16 \pm 0.10)\,\%$$

- J/ψ mesons decay immediately

$\Rightarrow J/\psi$ decay vertex equals B decay vertex

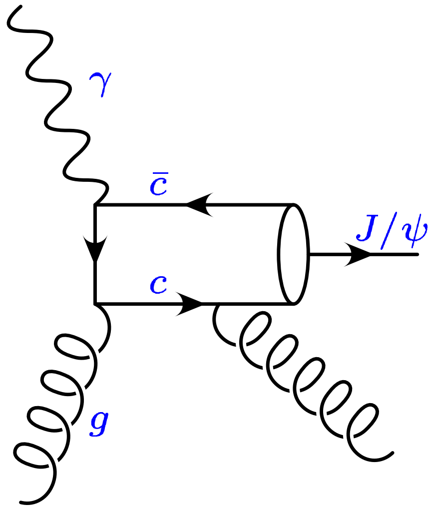
- Due to weak decay of B hadron, long lifetime $c\tau \approx 466\,\mu\text{m}$
- But average transversal boost at HERA is only 0.7 at low Q^2

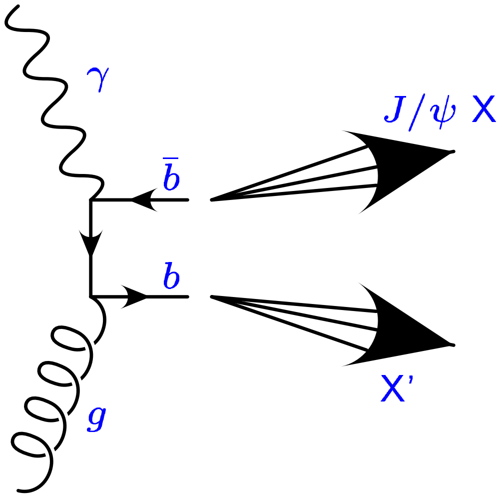
$\Rightarrow$ mean decay length $\langle d \rangle = \beta\gamma \cdot c\tau \approx 326\,\mu\text{m}$

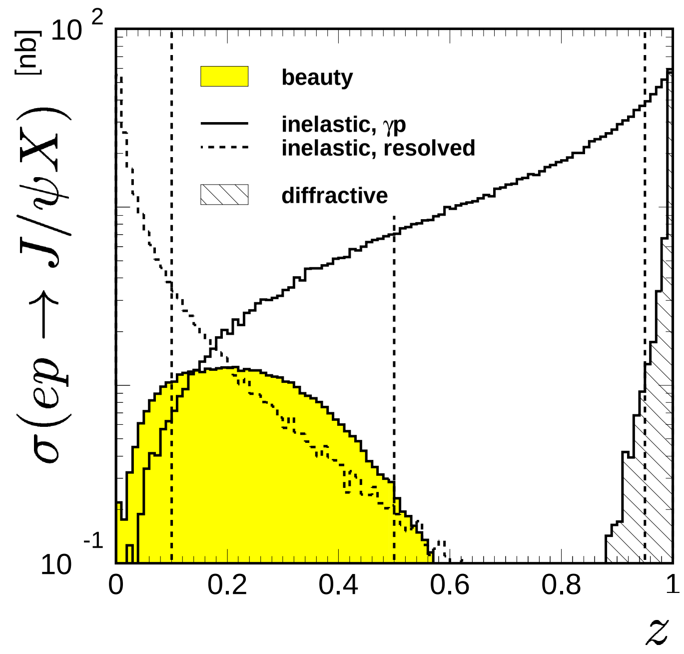
- Precision of H1's Central Silicon Detector $\mathcal{O}(100\mu m)$ will allow for reconstruction of decay lengths

For the first time at HERA, the decay $B \to J/\psi X$ will be used
to determine the beauty cross section in photoproduction by means of secondary vertex tagging

J/ψ Production







- Photon–gluon fusion also produces $c\bar{c}$ pairs, which might aquire same quantum numbers as J/ψ meson via emission of gluons
- J/ψ mesons decay electromagnetically into a pair of leptons

$$BR(J/\psi \to \mu^+\mu^-) = (5.88 \pm 0.10)\,\%$$

- Direct J/ψ production still dominates the interesting inelasticity range, $0.1 < z < 0.5$
- Inelasticity defines the fraction of energy transferred to the J/ψ meson

$$z = \frac{P_p \cdot P_{J/\psi}}{P_p \cdot p_\gamma}$$

J/ψ Candidate Selection

- e^+p running of 1997, 1999, 2000
- All relevant components must be operational

  $\int L\,dt = 56.1\,\mathrm{pb}^{-1}$
- Restriction to low virtualities

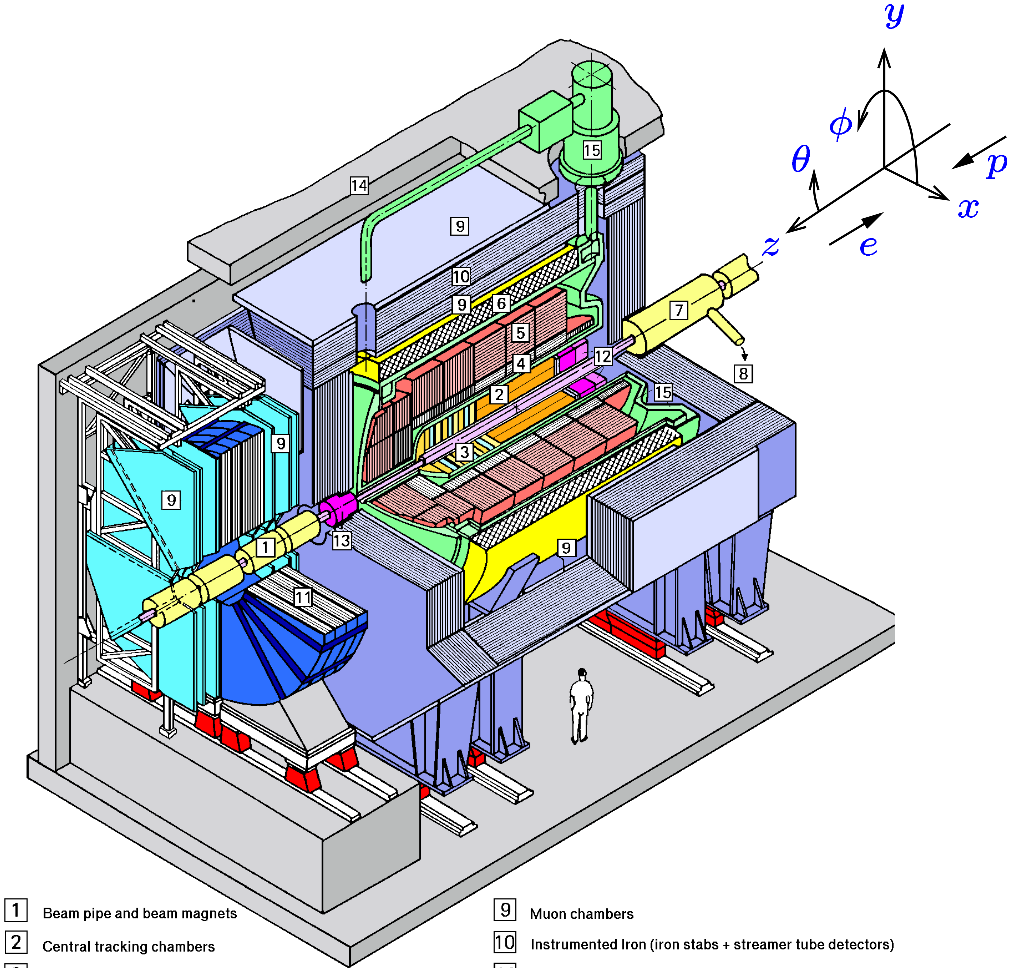
  $Q^2 < 1\,\mathrm{GeV}^2$ (photoproduction)
- Reconstructed primary vertex inside H1

  $-35\,\mathrm{cm} < \mathrm{v_z} < 35\,\mathrm{cm}$
- All tracks with $> 15\,\mathrm{cm}$ track length, starting in inner jet chamber
- Two identified muons in calorimeter or iron in central region $20^\circ < \theta_\mu < 160^\circ$

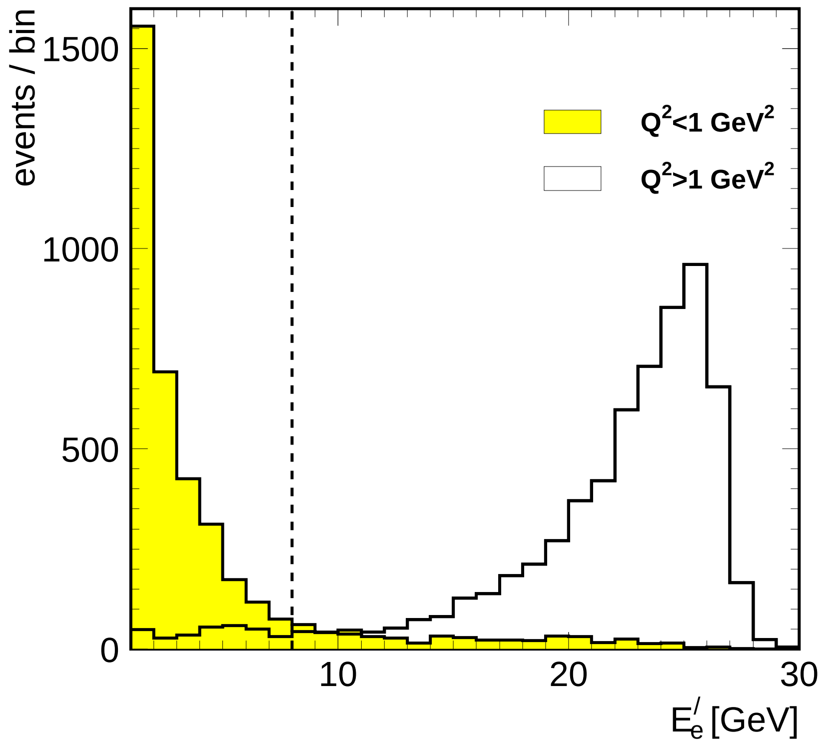
  Acceptance($b\bar{b}$–MC): $54.1\,\%$

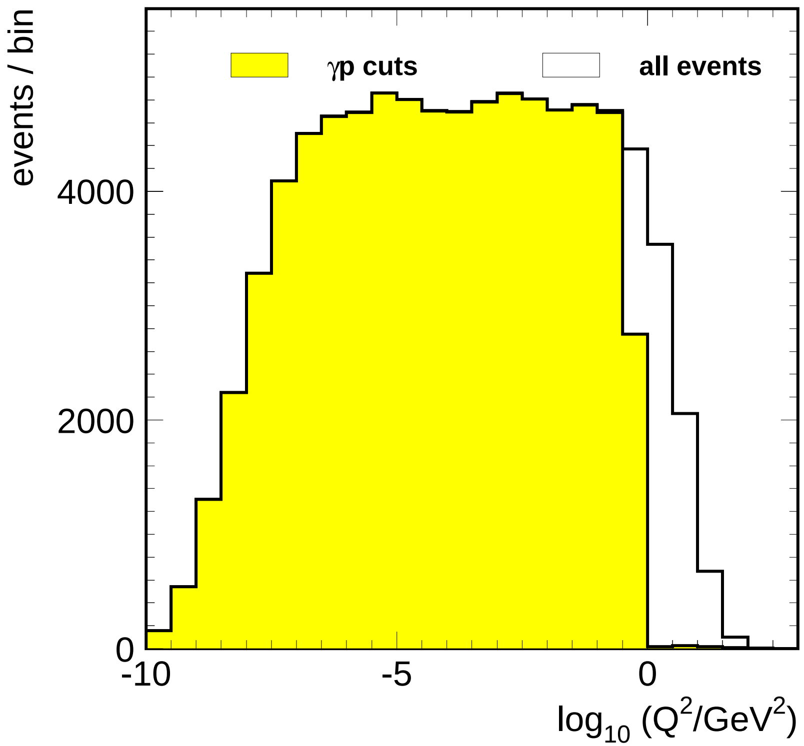
  with $p_t > 800\,\mathrm{MeV/c}$
- At least one identified muon in iron
- Rejection of muons from cosmic ray showers
- Reconstruction of a J/ψ candidate within

  $2.1\,\mathrm{GeV/c^2} < \mathrm{m}_{\mu\mu} < 4.1\,\mathrm{GeV/c^2}$
- Subtriggers S15, S19 or S22



Photoproduction



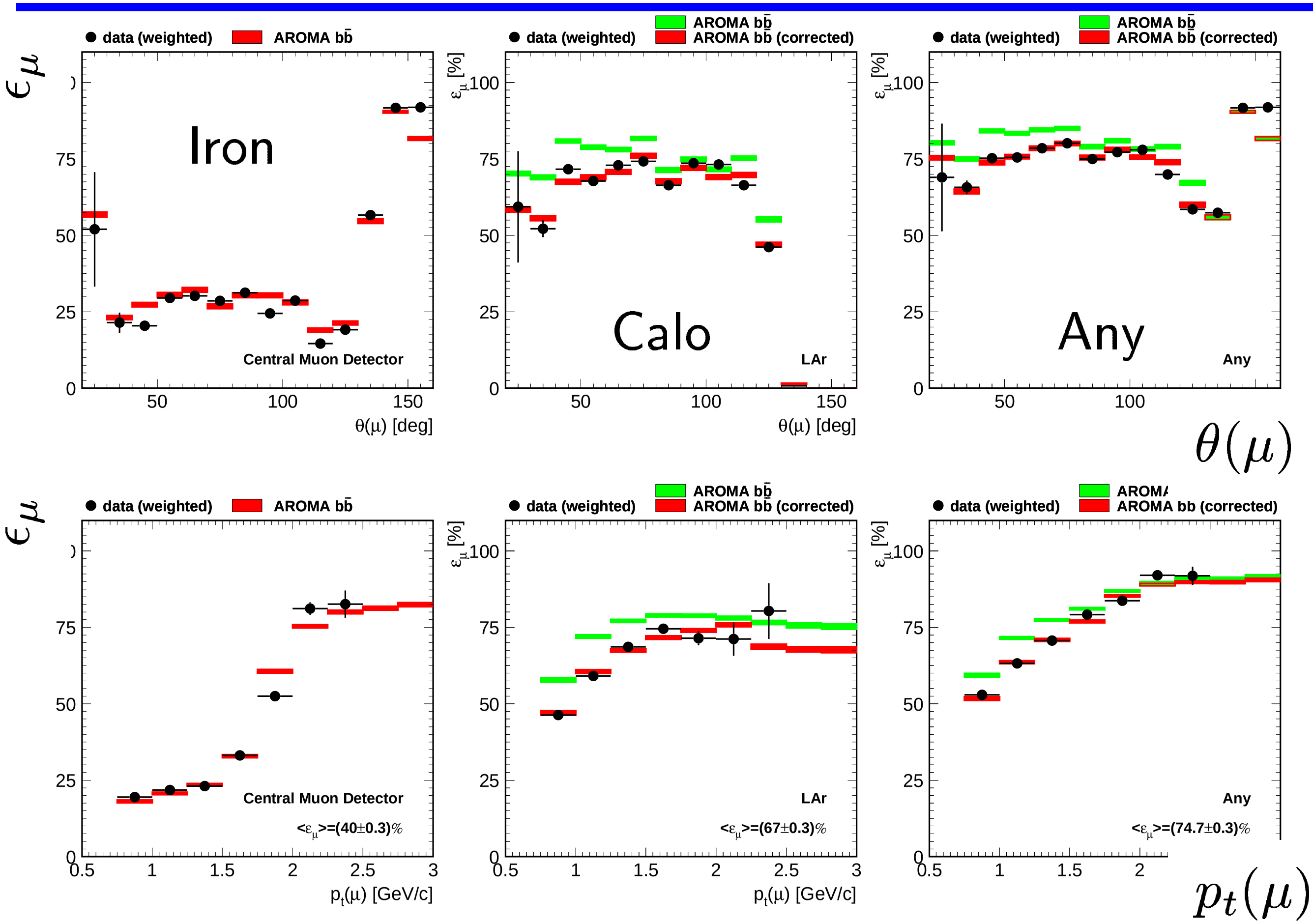


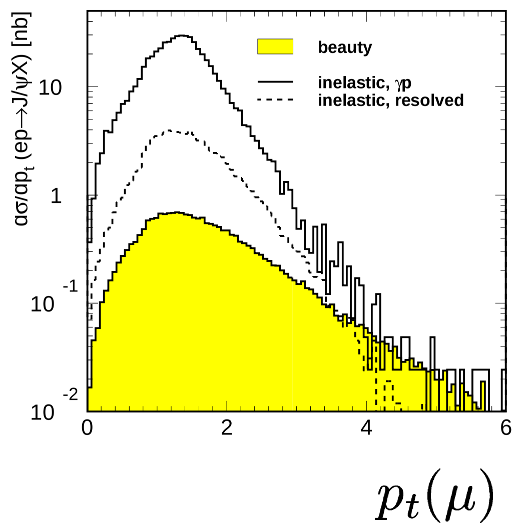
- No scattered positron detected in the LAr calorimeter or Spaghetti Calorimeter, $E_e' < 8\,\mathrm{GeV}$
- Quality verified in MC

$$Q^2 = 2 \cdot E_e \cdot E_e' \cdot (1 + \cos\theta_e)$$

$\Rightarrow$ Nearly pure photoproduction sample

Muon Identification Efficiency

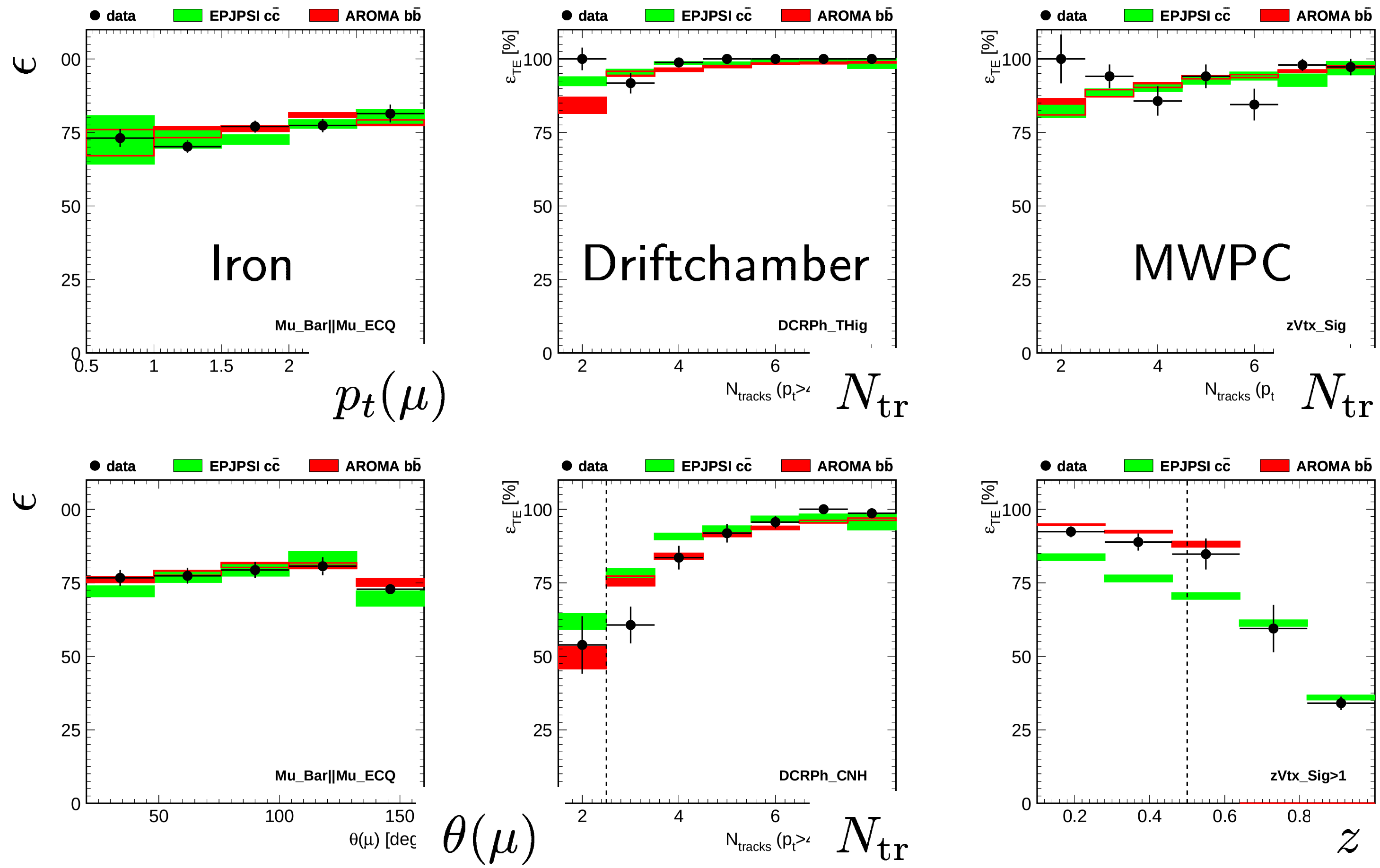




- $b\bar{b}$–MC simulation used to estimate selection and trigger efficiencies
- Selection efficiency is dominated by muon candidate identification
- Efficiency in the iron is described, calorimeter efficiency has to be reweighted in $b\bar{b}$–MC to match with data

$\Rightarrow$ Overall selection efficiency is $\epsilon_{\text{sel.}} = 30.7\,\%$

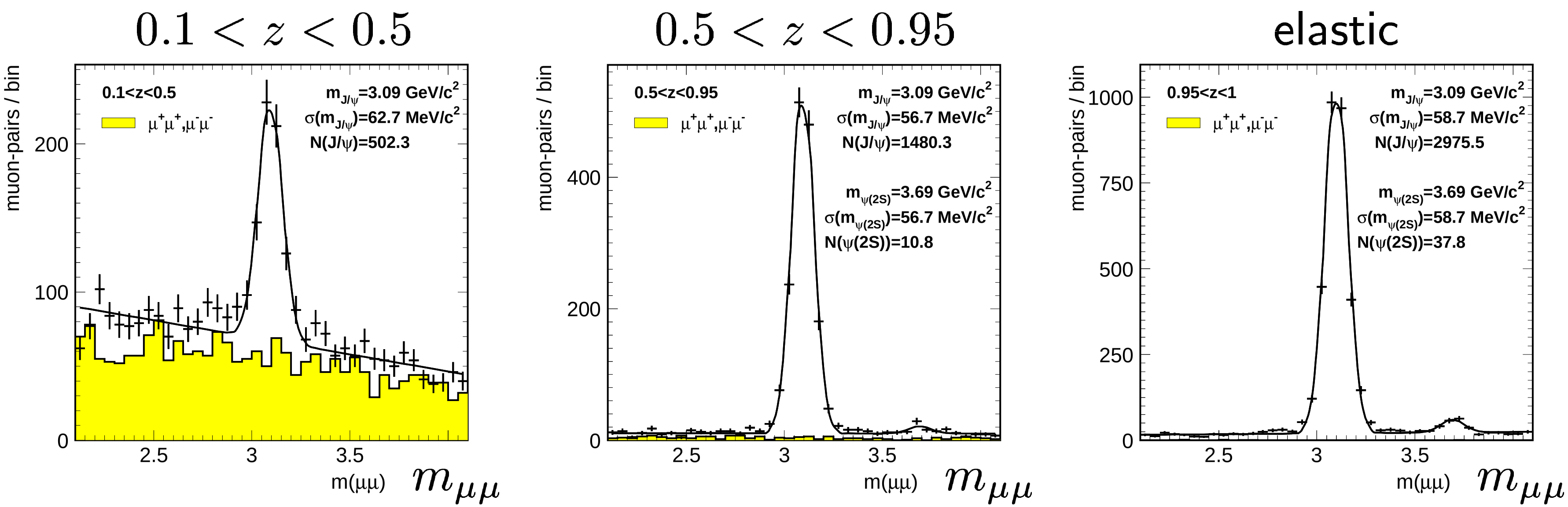
Trigger Efficiency



- Subtriggers are combined from trigger elements
- Efficiency is well described by $b\bar{b}$–MC simulation

$\Rightarrow$ Overall trigger efficiency is $\epsilon_{\mathrm{trig.}} = 73.3\,\%$

J/ψ Meson Candiates



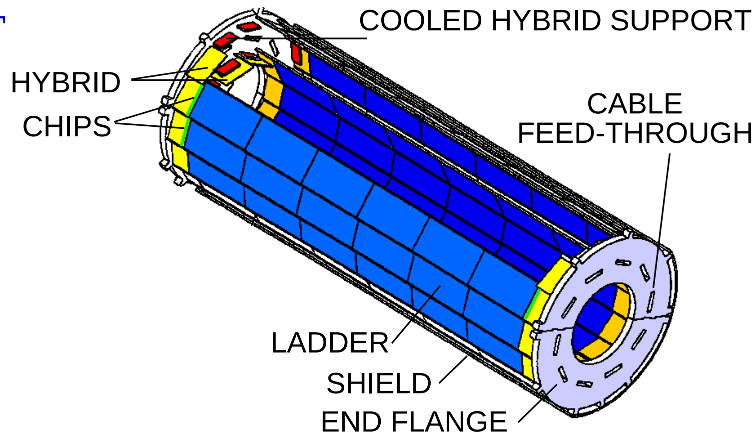
- Clear J/ψ signal at low inelasticities, indication of $\psi(2S)$

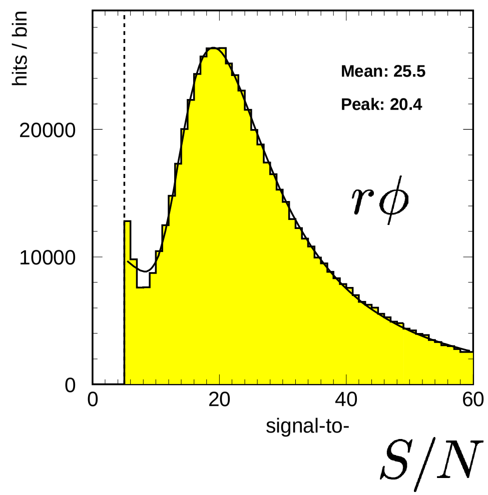
— — — Break — — —

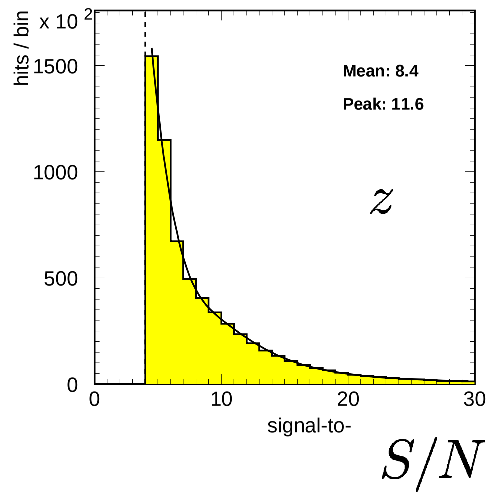
- Central Silicon Tracker is used to improve resolution and to reconstruct J/ψ decay vertex in 3D
- The ep interaction (primary) vertex corresponds to beauty production vertex
- Calculate transversal decay length between decay and primary vertex
- Extract fraction of beauty–flavoured events from decay length distribution

CST Improved Vertexing

CST







- Acceptance of CST is $66.6 \pm 0.2\,\%$ for events with two muon candidates
- Both candidates are extrapolated to the surface of the CST and then linked to 2 hits each
  But the central tracks have coarse resolution along z–axis ($2\,\mathrm{cm}$ resp. $380\,\mu\mathrm{m}$) and the z–side S/N is bad

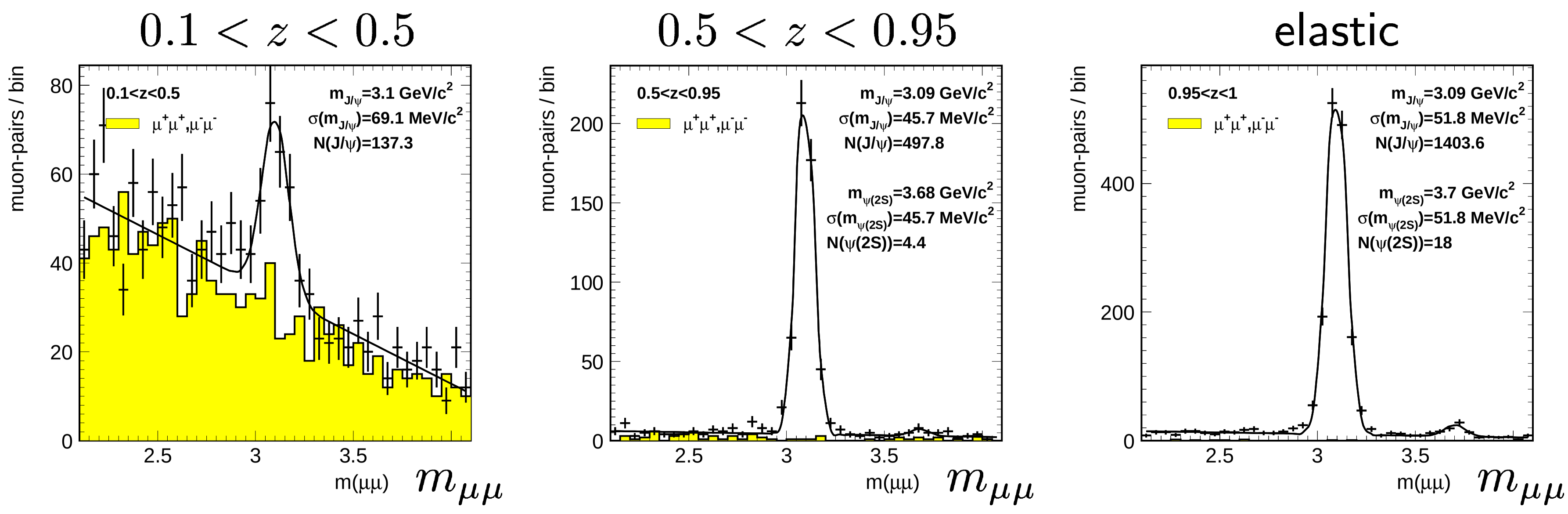
  $\Rightarrow$ Multi–Hypothesis Ansatz for Linking

- All hits within a certain search window are linked. The common decay vertex is used as additional contraint

$$\chi^2 = \chi^2_{\mathrm{vtx}} + \sum_{\mathrm{muons}} \chi^2_{\mathrm{link},r\phi} + \chi^2_{\mathrm{link},z}$$

$\Rightarrow$ The decay vertex results from the χ^2–minimization

CST Improved J/ψ Meson Candiates



- CST hit finding and linking efficiency is $\epsilon_{4-\mathrm{of}-4} = 33.2\,\%$
- Mass resolution improved by 8 to 15 %
- Separated into 12 samples:

  mass peak ($2.9\,\mathrm{GeV/c^2} < \mathrm{m}_{\mu\mu} < 3.3\,\mathrm{GeV/c^2}$) and sidebands

  $\otimes$

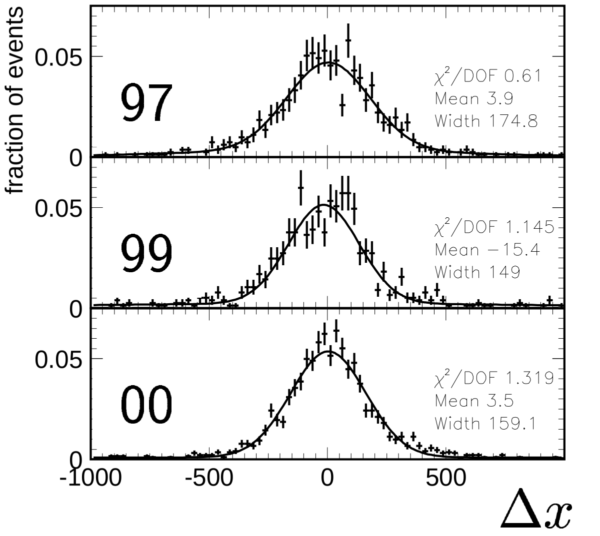
  $0.1 < z < 0.5$, $0.5 < z < 0.95$ and the elastic domain

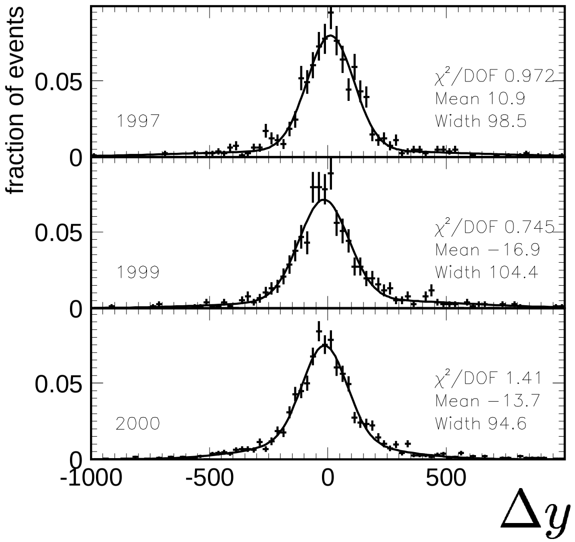
  $\otimes$

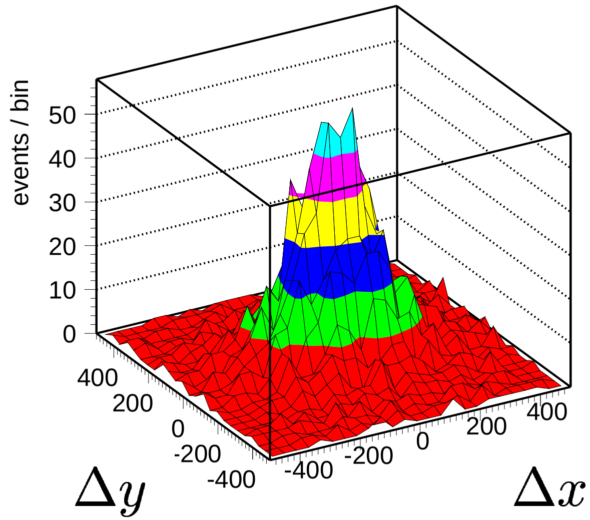
  unlike–sign and like–sign charge combinations of both muon candidates

- Only the signal sample contains beauty–flavour: mass peak $\otimes$ $0.1 < z < 0.5$ $\otimes$ unlike–sign

Vertex Resolutions





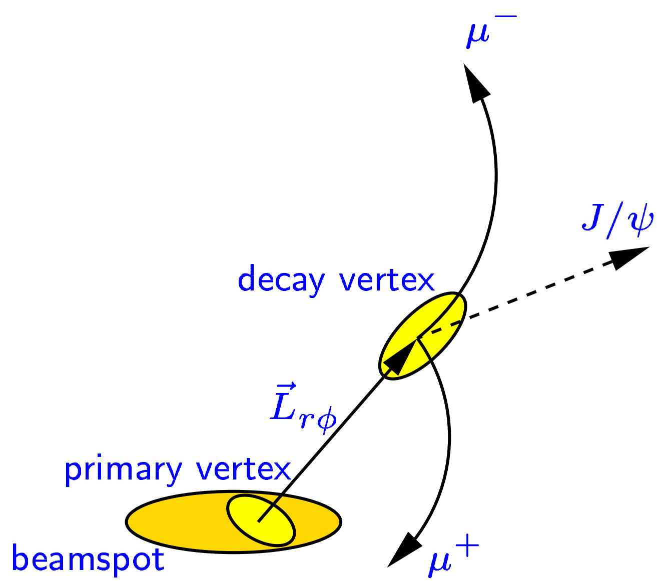


- For the bulk of data primary and decay vertex agree in x– and in y–direction:
  $\Delta x = x_{\mathrm{1st}} - x_{\mathrm{decay}}$, $\Delta y = y_{\mathrm{1st}} - y_{\mathrm{decay}}$
- Resolutions are $\sigma_x = 150\,\mu\mathrm{m}$ and $\sigma_y = 100\,\mu\mathrm{m}$

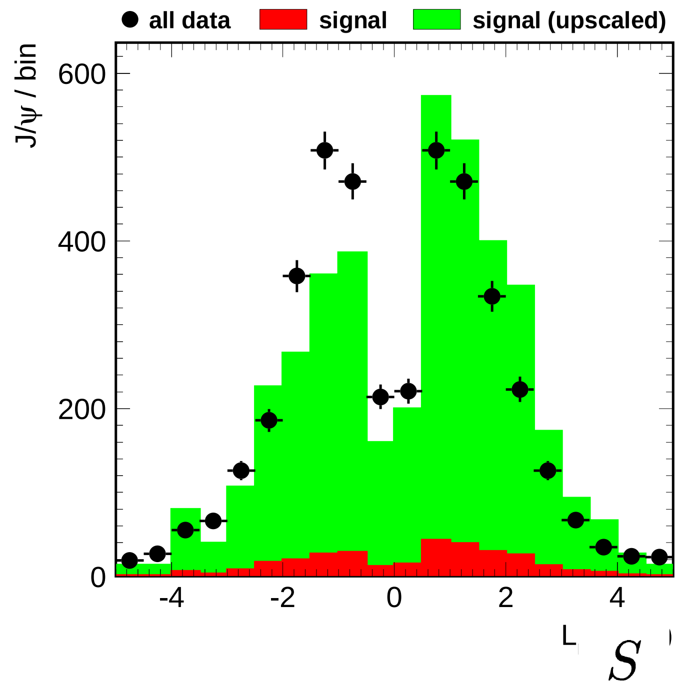
  $\Rightarrow$ Accurate enough to resolve decay lenght

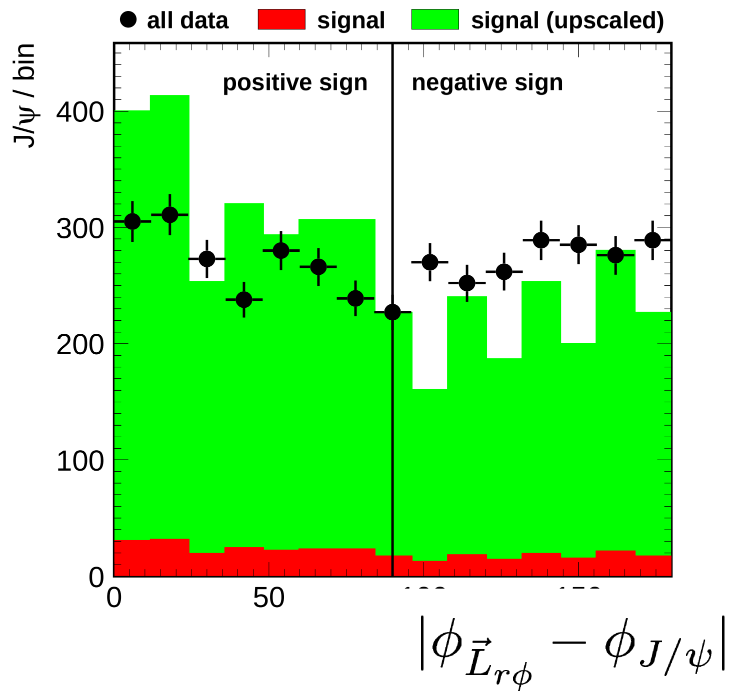
- Define signed decay length

$$L_{r\phi} = \sqrt{\Delta x^2 + \Delta y^2} \cdot \mathrm{sign}\left[\cos\left(\phi_{\vec{L}_{r\phi}} - \phi_{J/\psi}\right)\right]$$



The Significance





- For zero lifetime sample, decay length distribution is given by

$$\frac{d\mathcal{P}}{dL_{r\phi}} = 2\pi L_{r\phi} \cdot \frac{1}{\sqrt{2\pi} \cdot \sigma_{L_{r\phi}}} \exp\left[-\frac{1}{2}\left(\frac{L_{r\phi}}{\sigma_{L_{r\phi}}}\right)^2 \right]$$

$\Rightarrow$ Introduce Significance $S = \frac{L_{r\phi}}{\sigma_{L_{r\phi}}}$

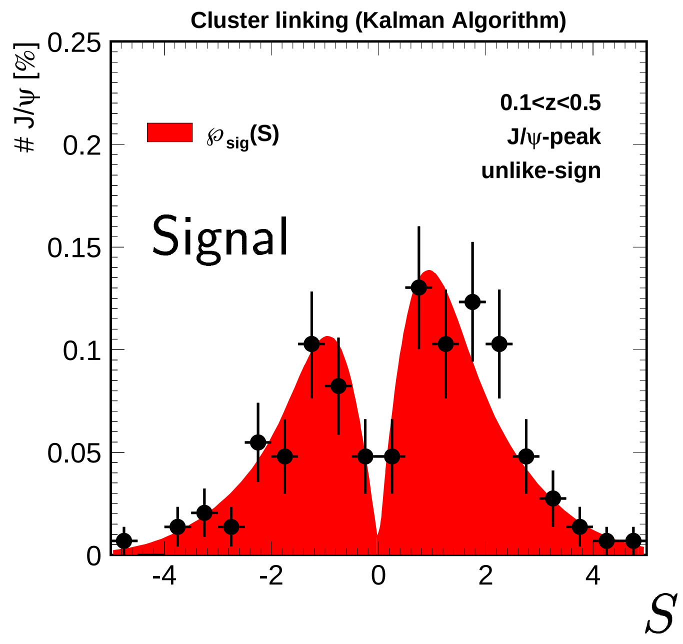
- Significance distribution is symmetric for zero lifetime (background) samples

$\Rightarrow$ Only the signal subsample shows some excess at positive values

Log–Likelihood Minimization

- Minimization of the Extended Log–Likelihood Function

$$-\ln L = \sum_{\text{samples}} \sum_{i} \left[\mathcal{P}(S_i) - \ln \mathcal{P}(S_i) \right]$$



- Background samples are symmetrically parameterized with two Gaussian distributions (means fixed to zero):

$$\mathcal{P}_{\text{bkg}}(S_i) = |S_i| \cdot \left[f_a \cdot G_a(S_i) + f_b \cdot G_b(S_i) \right]$$

3 free parameters f_a, σ_a, $f_b = 1 - f_a$ and σ_b

- Signal sample is asymmetrically parameterized:

$$\mathcal{P}_{\text{sig}}(S_i) = f_{\text{bkg}} \cdot \mathcal{P}_{\text{bkg}}(S_i) + f_{\text{sig}} \cdot |S_i| \cdot \frac{1}{\mu^2} \cdot \exp\left(-\mu \cdot S_i\right) \quad \text{for} \quad S_i > 0$$

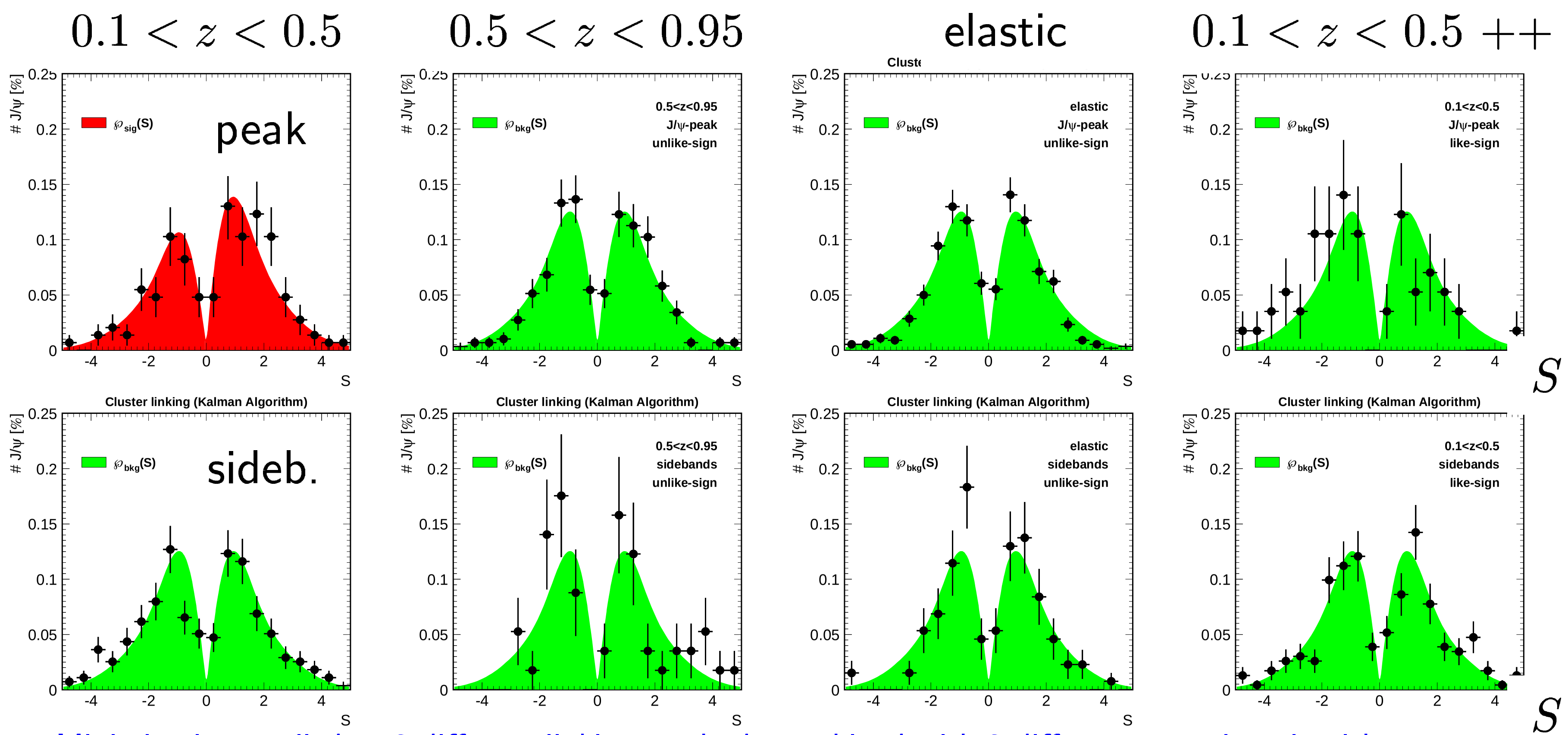
$$\mathcal{P}_{\text{sig}}(S_i) = f_{\text{bkg}} \cdot \mathcal{P}_{\text{bkg}}(S_i) + 0. \quad \text{for} \quad S_i < 0$$

- Exponential accounts for beauty–flavoured weak decays

2 more free parameters f_{sig}, $f_{\text{bkg}} = 1 - f_{\text{sig}}$ and μ

- Fit function describes nicely the signal and background samples

Results of the Log–Likelihood



- Minimization applied to 2 different linking methods combined with 2 different vertexing algorithms

  ⇒ all results compatible, excess mean value : $f_{\mathrm{sig}} = \left[18.6 \pm 7.6(\mathrm{stat.}) \pm 0.9(\mathrm{syst.})\right]\ \%$

- Omitting background samples does not change result
- Assigning any of the background samples as “signal” does not give an excess
- Excess is genuine property of the signal sample

⇒ the beauty–flavoured events

Results

- Thus the fraction of beauty–events has been obtained:

$$f_{b\bar{b}} = f_{\text{sig}} \cdot \frac{N_{\text{events}}}{N_{J/\psi}}$$

$$f_{b\bar{b}} = [28.4 \pm 13.3(\text{stat.}) \pm 3.9(\text{syst.})]\ \%$$

(in agreement with MC estimation of K. Krüger ✓)

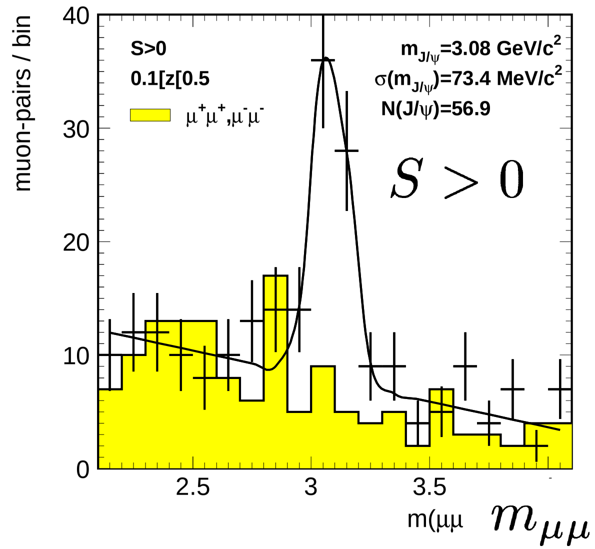
- Number of beauty events is $N_{b\bar{b}} = N_{J/\psi} \cdot f_{b\bar{b}}$

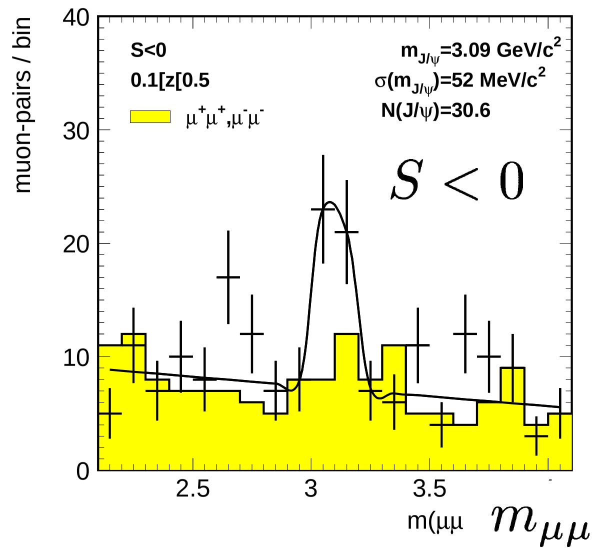
$$30.4 \pm 15.1(\text{stat.}) \pm 2.3(\text{syst.})$$

and can be compared to number of J/ψ 's at positive and negative significances:

$$N_{b\bar{b}} = N_{+} - N_{-} = 56.9 - 30.6 = 26.3$$ ✓

⇒ Ready for cross section

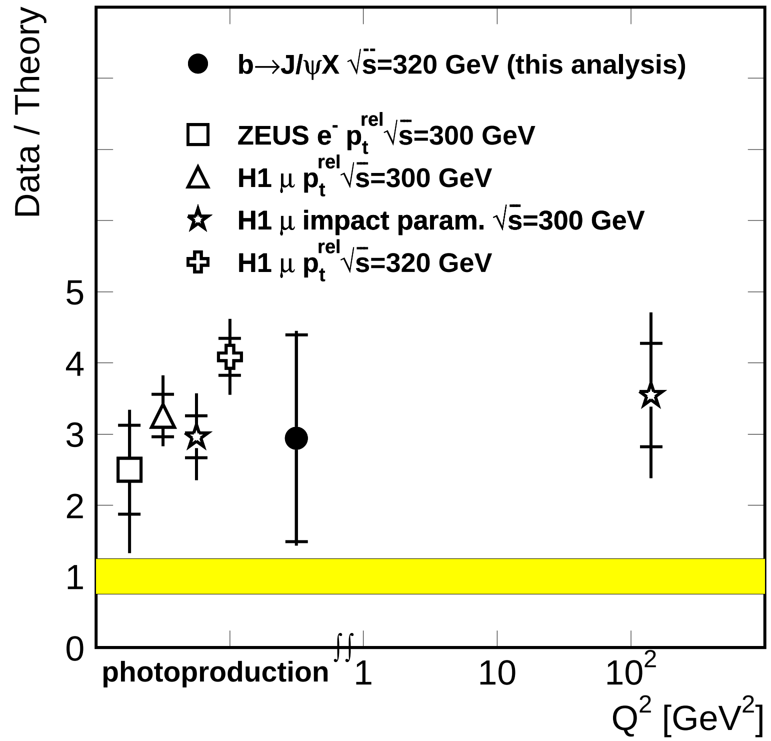




H1b !

$$\sigma_{\text{tot}}(ep \to b\bar{b}X) = \frac{N_{b\bar{b}}}{\int \mathcal{L}\,dt \cdot \mathcal{A}_{\text{CST}} \cdot \epsilon \cdot BR \cdot \mathcal{A}}$$

$$\begin{aligned}
N_{b\bar{b}} &= 30.4 \\
\int \mathcal{L}\,dt &= 56.1\,\text{pb}^{-1} \\
\mathcal{A}_{\text{CST}} &= 66.6\,\% \\
\epsilon &= \epsilon_{\text{sel.}} \cdot \epsilon_{\text{trig.}} \cdot \epsilon_{\text{CST}} \\
&= 6.3\,\% \\
BR(b\bar{b} \to J/\psi X) &= 2 \cdot BR(b(\bar{b}) \to J/\psi X) \\
&\quad \cdot BR(J/\psi \to \mu^+\mu^-) \\
&= 0.14\,\% \\
\mathcal{A} &= 54.1\,\%
\end{aligned}$$



Beauty Production Cross Section in Photoproduction at HERA:

$$\sigma_{\text{tot}}(ep \to b\bar{b}X) = [15.0 \pm 7.4(\text{stat.}) \pm 2.2(\text{syst.})]\ \text{nb}$$

H1 published (97): $[14.8 \pm 1.3(\text{stat.})^{+3.3}_{-2.8}(\text{syst.})]$ nb, compared to 5.10 nb NLO QCD prediction from FMNR

Conclusions & Outlook

- For the first time at HERA the decay $B \to J/\psi X$ has been used to extract the $b\bar{b}$ production cross section
- The CST provides sufficient precision to reconstruct decay lengths
- The log–likelihood minimization results agrees with the brute–force number counting:

  30.4 b–candidates have been found in $56.1\,\mathrm{pb}^{-1}$

- Corresponding to a fraction of $28.4\,\%$ in the inelasticity range of $0.1 < z < 0.5$
- The beauty production cross section in photoproduction has been measured

$$\sigma_{\mathrm{tot}}(ep \to b\bar{b}X) = \left[15.0 \pm 7.4(\mathrm{stat.}) \pm 2.2(\mathrm{syst.})\right]\,\mathrm{nb}$$

- The value is factor 3 higher than NLO QCD calculations predict
- Nice small systematical error, but due to very small branching ratio high statistical error

  Fourfold increase of luminosity anticipated in HERA upgrade

  Dedicated trigger — the Fast Track Trigger — to be commissioned in 2002

To Do:

- As a last cross–check the direct J/ψ production cross section will be determined
- Finalize statistical and systematical errors
- ....