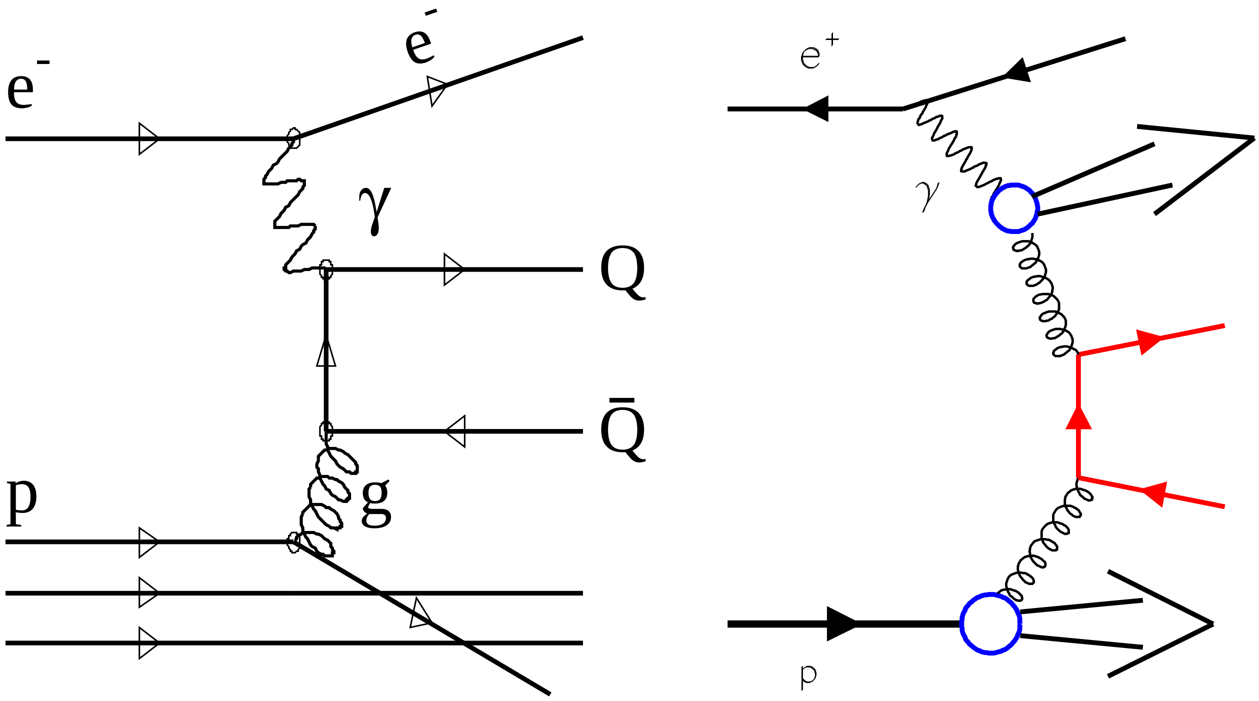
Light sbottom at HERA ?

- Introduction: Heavy Quark in ep-Collisions
- Motivation: discrepancies at LEP, Tevatron and HERA
- Sbottom
- What to measure: $p_{t,rel}$
- μ-events
- Dimuon-events
- Conclusion

Heavy flavour in *ep* Collisions

- In LO: boson Gluon Fusion dominates (left)
- In higher order sum of direct and resolved (right)

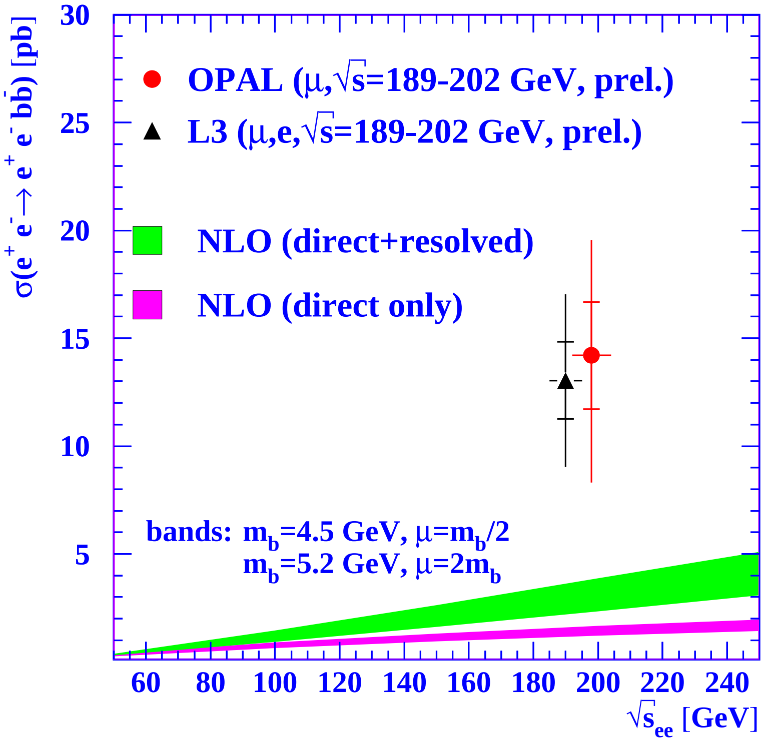


- At HERA Boson-Gluon Fusion dominates production of heavy Quarks
- b-Mass provides hard scale, perturbative QCD is expected to be reliable

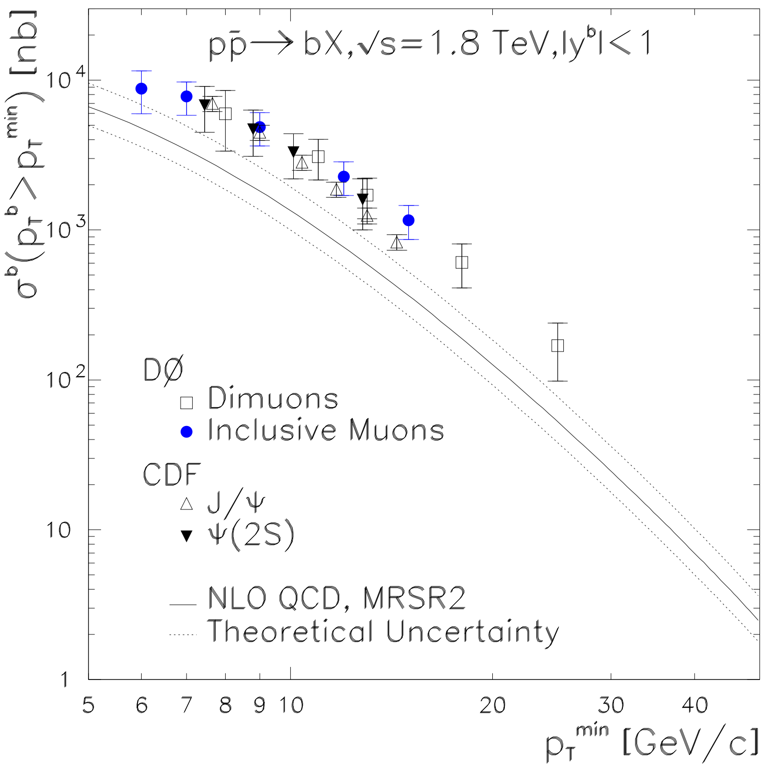
$\Longrightarrow$ good testing ground for pQCD

- BUT .....
  $\Longrightarrow$ measurements and QCD calculations disagree
  (next transparencies)

Beauty Production at LEP and Tevatron

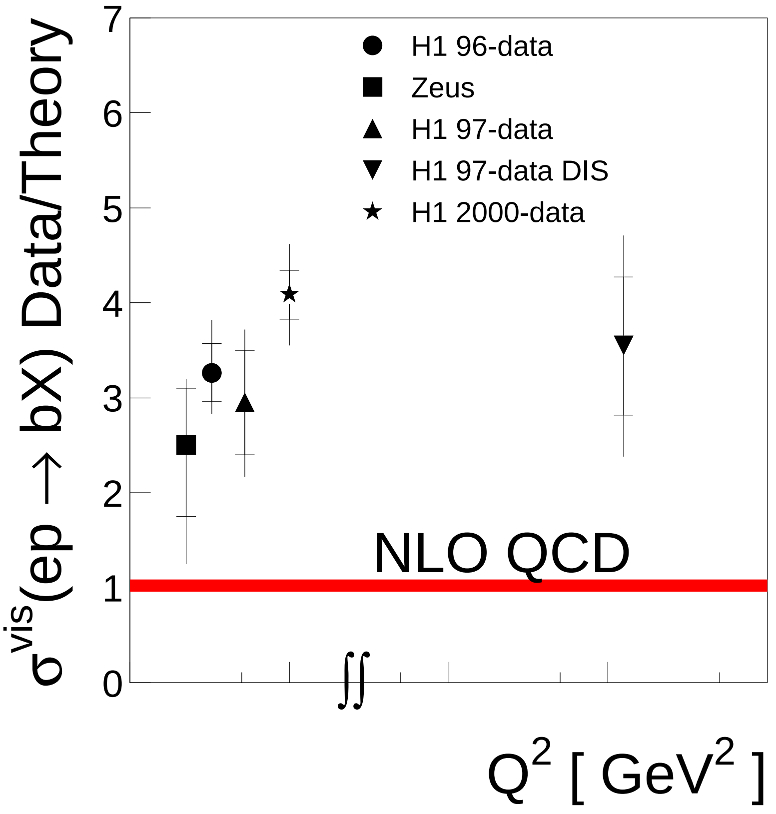


- L3 and OPAL
- Two photon collision (like BGF)
- HQ tag with μ ($p_t^\mu > 2\,\mathrm{GeV}$)
- using $p_{t,rel}^\mu$
- charm in agreement with QCD prediction



- using the leptonic decay of beauty
- data ∼factor 2.5 higher than NLO predictions

Beauty Production at HERA



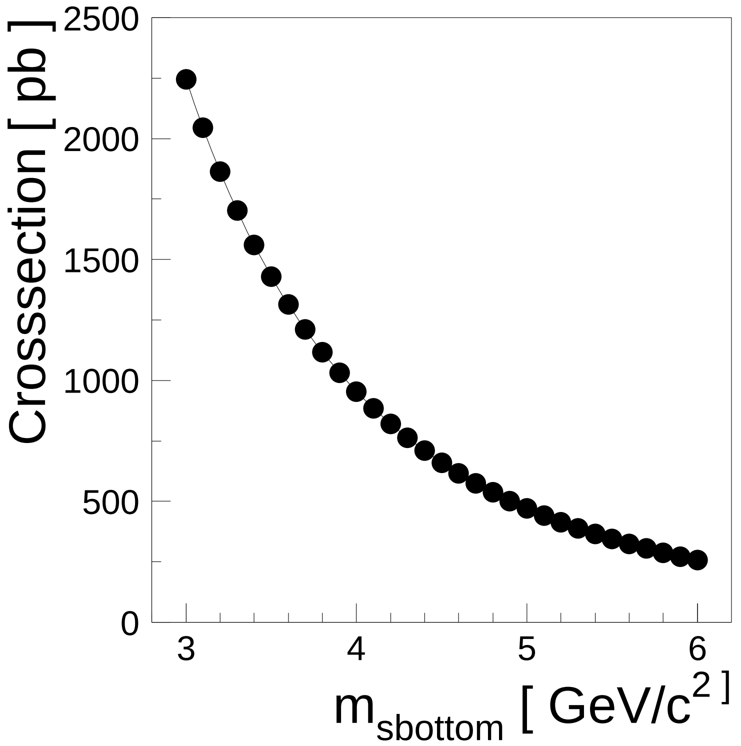
- b-tag via semileptonic decay (Zeus: e, H1: μ)
- σ_B at HERA exceeds NLO QCD
- excess in γp and DIS is very hard to justify (P.Nason)

$\Longrightarrow$ look for explanation

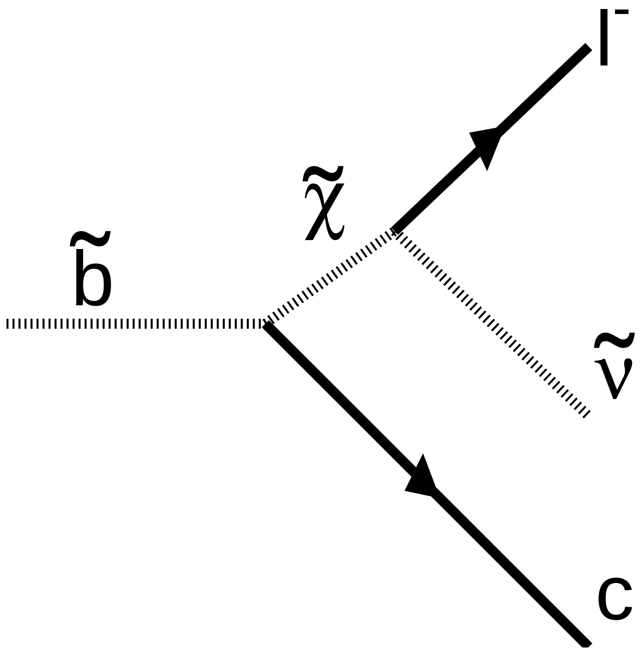
Need a b-like particle that decays to $\mu\, X$

- there is more: supertag events at CDF
- R in e^+e^- Collisions
- ...

Sbottom Production



- Production of $\bar{\tilde{b}}\tilde{b}$-Pair in BGF like $b\bar{b}$
- LO cross section $\approx$ 8 times smaller then beauty in LO: $\sigma(ep \to b\bar{b}X) = 4.1\,\mathrm{nb}$



- $\mathrm{BR}(\tilde{b} \to c\mu\tilde{\nu}) = 50\%$

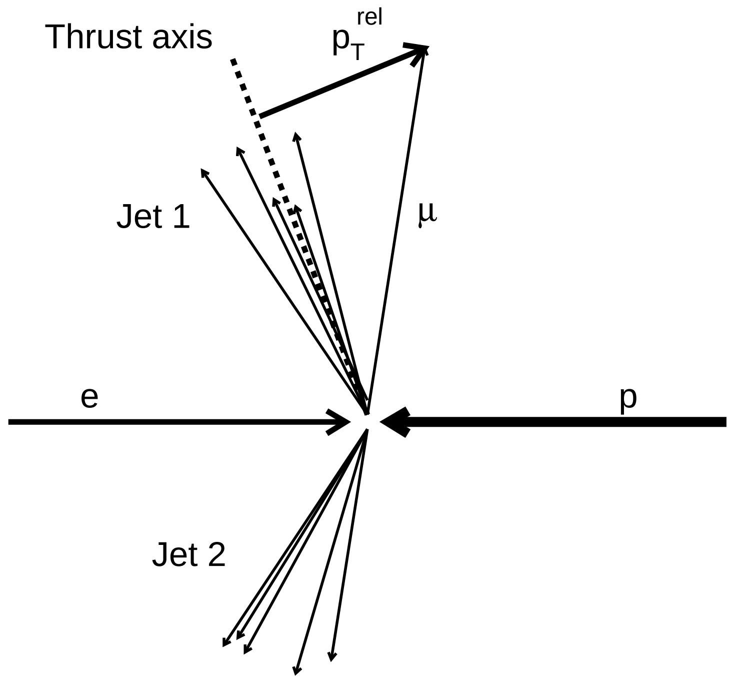
$\Longrightarrow$ interpret the observed b-like events as mixture from Beauty and Sbottom with $m_{\tilde{b}} \sim m_b$

Detection strategy for beauty events and Observable $p_{T,rel}^{\mu}$

Look for semileptonic decay $b \to \mu X$

- with a high p_T-Lepton ($p_T^{\mu} > 2\,\mathrm{GeV}$) (suppress light quarks)
- in 2− Jet events (suppress soft events)

Observable $p_{T,rel}^{\mu}$ boost invariant with respect to boost along the jetaxis
$\Rightarrow$ measure of the mass of the primary quark



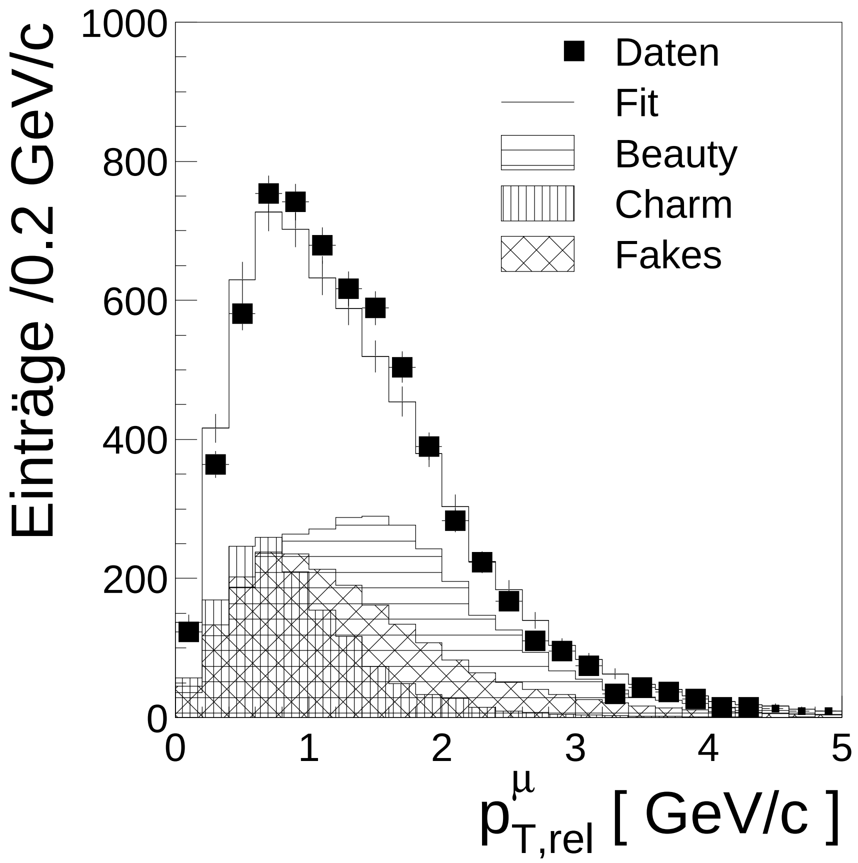
- μ belongs to jet (cone algorithmus)
- momentum of μ relative to Thrustaxis of jet

shape of $p_{T,rel}^{\mu}$-Distribution for b and c from MC,
Background (i.e. uds-Events) from data $\otimes \mathcal{P}$.

- count candidates for faking a muon
- assign a particle id to the track
- weight events with misidentification probability $\mathcal{P}(p_T, \Theta, id)$
  $\mathcal{P}$ dermined with MC checked for Pions by means of $K_s^0 \to \pi\pi$.

Sbottom + Beauty Events

Data 2000, Luminosity $\mathcal{L} = 45431\text{pb}^{-1}$:



- beauty fraction
  $f_b =$
  $46.5\% \pm 3\%$
  charm 22.0%
  fakes: 31.2% (fix)
- visible range:
  $35 < \Theta_\mu < 130$,
  $Q^2 < 1\text{GeV}^2$,
  $p_T^\mu > 2\,\text{GeV/c}$

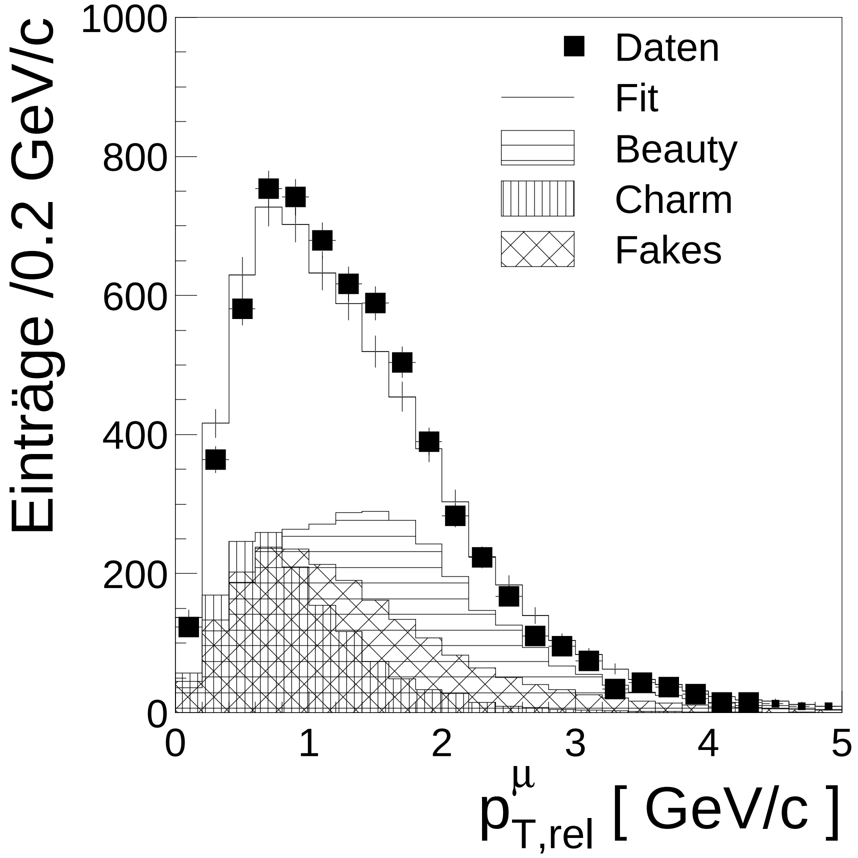
- after cuts: visible crosssection for Sbottom $\sim$ 55% of visible crosssection for Beauty $\sigma_{\tilde{b}}^{vis} \approx 55\% \cdot \sigma_b^{vis}$
- In LO: expected Events: 516(Beauty) + 284(Sbottom)
- measured Events: 3055

$\Longrightarrow$ $N_{\text{measured}}/N_{\text{expected}}^{\tilde{b}+b} = 3.8$ in LO

- Sbottom could contribute but does not explain the observed excess in the Beauty sector

Only Beauty

Data 2000, Luminosity $\mathcal{L} = 45431 \mathrm{pb}^{-1}$:



- beauty fraction
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  $35 < \Theta_\mu < 130$,
  $Q^2 < 1 \mathrm{GeV}^2$,
  $p_T^\mu > 2\,\mathrm{GeV/c}$

- visible cross section for beauty:

$$\sigma^{\mathrm{vis}}(ep \to b\bar{b}X \to \mu X') = (237 \pm 15 \pm 27)\ \mathrm{pb}$$

  for $\sqrt{s} = 318.4\,\mathrm{GeV}^2$

- NLO QCD (FNMR) predicts $\sigma^{\mathrm{vis}} \approx 60 \pm 10\,\mathrm{pb}$ ($m_b = 4.75\,\mathrm{GeV}$, MRSG, GRV-HO)

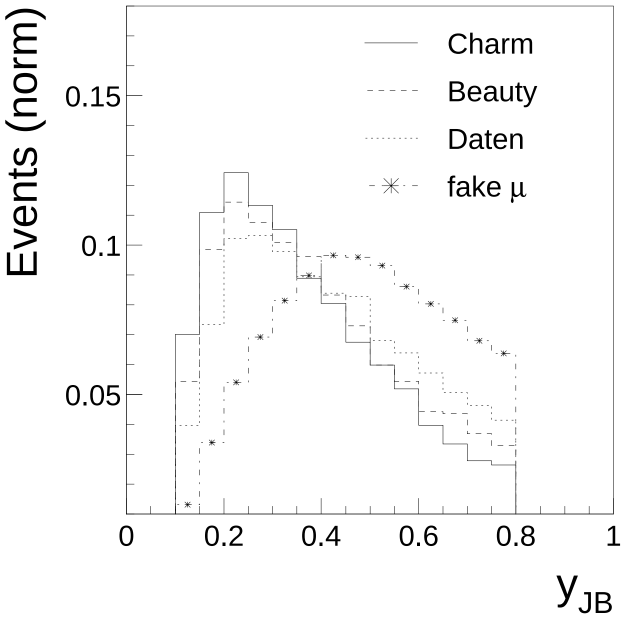
- is consistent with published H1 result of $(176 \pm 16\ \ ^{+27}_{-17})$ pb for $\sqrt{s} = 300\,\mathrm{GeV}^2$.
  NLO QCD expects rise in σ^{vis} by $\approx 10\,\%$ for $\sqrt{s} = 300\,\mathrm{GeV}^2 \to \sqrt{s} = 318.4\,\mathrm{GeV}^2$

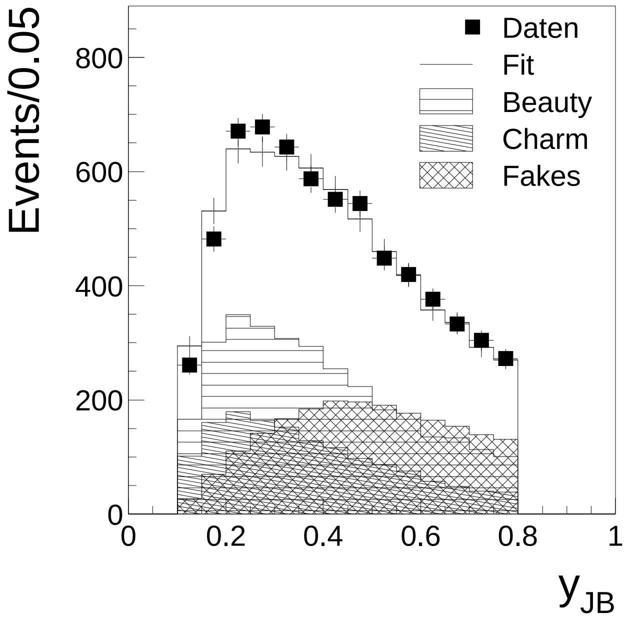
y-Distribution

- y-distribution serves as a good test for the fake fraction

Inelasticity y describes energy of Photon from Lepton:

$$y = \frac{q \cdot P}{l \cdot P} = \left[\frac{E_\gamma}{E_e}\right]_{Q^2=0} \qquad y_{JB} = \frac{\Sigma_i (E_i^h - p_{z_i}^h)}{2E_e} \tag{1}$$





- light quarks: large y needed to have sufficient $\sqrt{\hat{s}}$ because of large contribution from resolved processes
- can be used for an two-dimensional fit in $p_{T,rel}^{\mu}$ and y: two-dimensional fit gives the same b-fraction
- cut $y < 0.4$ reduces the fake-fraction. Result for $y < 0.4$ is consistent.

Dimuon Events

- If there is sbottom you expect higher Dimuon-Rate !!

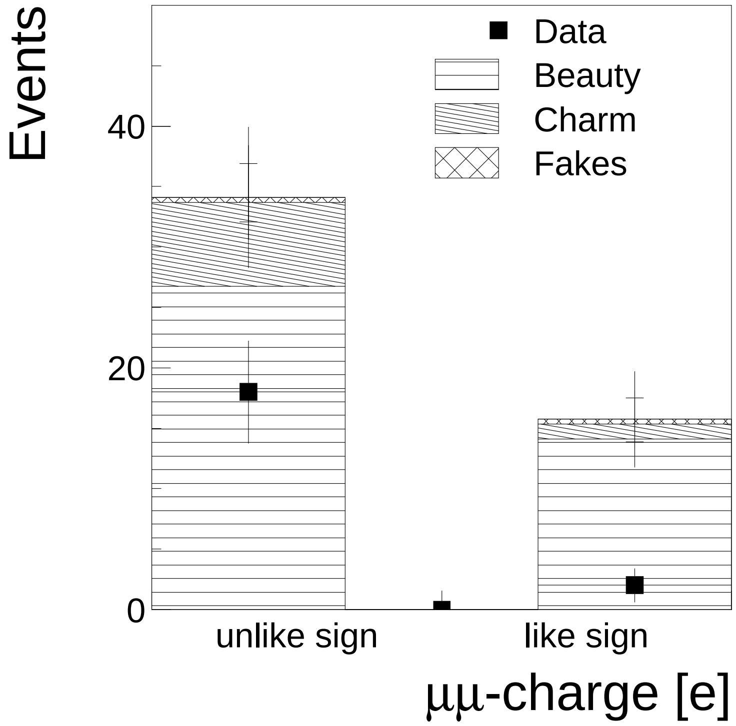
$\Longrightarrow$ Look at Dimuon Events !

- find SM expectation of Dimuon-Events:
  - take number of 1μ-Events from data
  - take ratio 2μEvents/1μ-Events from MC (for Charm and Beauty)
  - number of fake 2μEvents directly from data

  $\Longrightarrow$ get SM expectation for $\mu\mu$ Events.

- if there is Beauty and Sbottom ratio 2μEvents/1μ-Events is higher !!!

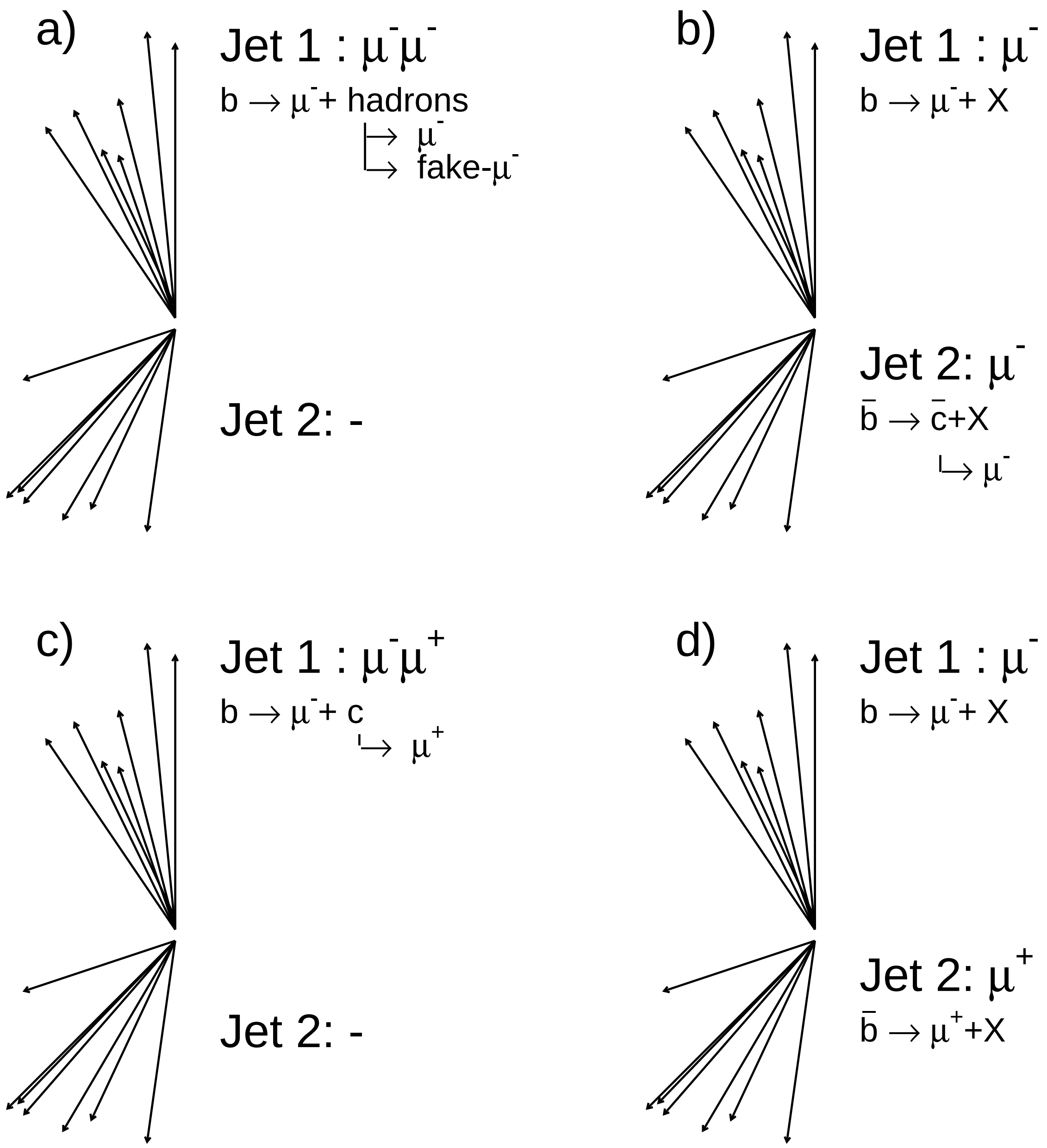
$\Longrightarrow$ expect more 2μEvents



Example:

- Two muons in different jets
- No sbottom assumed

Dimuonevents, combinations



	in 1 jet	in different jets
like sign ++/- -	a)	b)
opposite sign +-/-+	c)	d)

Dimuons compared to single μ-Events

- Black : measured events
- coloured : expected events

Sbottom and Beauty ("$b = \sigma^b_{vis}$")

$$N_{expected} = \left[\left(\frac{\mu\mu}{\mu}\right)_b \cdot \left(\frac{b}{b+\tilde{b}}\right)_{LO} + \left(\frac{\mu\mu}{\mu}\right)_{\tilde{b}} \cdot \left(\frac{\tilde{b}}{b+\tilde{b}}\right)_{LO} \right] \cdot N^{\mu}_{meassured} \quad (2)$$

	in 1 jet	in different jets
like sign ++/- -	1/2.6	2/12.3
opposite sign + -/- +	21/35.3	18/67.5

$\Longrightarrow$ measured events and expected events not in agreement

only Beauty

$$N_{expected} = \left(\frac{\mu\mu}{\mu}\right)_{\mathrm{AROMA}} \cdot N^{\mu}_{meassured} \quad (3)$$

	in 1 jet	in different jets
like sign ++/- -	1/2.6	2/15.7
opposite sign + -/- +	21/17.5	18/33.8

$\Longrightarrow$ discrepancy smaller but still striking

Dimuon vs. NLO

- "Theorist point of view": use single Muon number QCD calculation

$\Longrightarrow$ scaling taken from QCD-Calculation, not from 1μ-Events

Sbottom and Beauty

$$N^{\mu\mu}_{expected} = \left[\left(\frac{\mu\mu}{\mu}\right)_b \cdot \left(\frac{b}{b+\tilde{b}}\right)_{LO} + \left(\frac{\mu\mu}{\mu}\right)_{\tilde{b}} \cdot \left(\frac{\tilde{b}}{b+\tilde{b}}\right)_{LO} \right] \cdot N^{\mu}_{LO/NLO} \quad (4)$$

	in 1 jet	in different jets
like sign ++/- -	1/1.1 (1.4)	2/4.3 (5.8)
opposite sign + -/- +	21/12 (16.2)	18/23.1 (23.1)

$\Longrightarrow$ prediction and Dimuon-data are similar

only Beauty

$$N^{\mu\mu}_{expected} = \left(\frac{\mu\mu}{\mu}\right)_{\mathrm{AROMA}} \cdot N^{\mu}_{NLO} \quad (5)$$

	in 1 jet	in different jets
like sign ++/- -	1/1.1	2/5
opposite sign + -/- +	21/7	18/14

$\Longrightarrow$ prediction and Dimuon-data are similar
(but worse then sbottom & beauty)

Conclusions

- clear and non-ambiguous statement is not possible
- Relying on the single Muon analysis the observed number of Dimuon events does not favour light Sbottom.

$\Longrightarrow$ light sbottom can neither be ruled out nor confirmed.

Beauty-only scenario:

- Observed number of Dimuon events shows strong discrepancy with expected Dimuon-Events in Beauty-only scenario.
- In Data 2000 ($\mathcal{L} = 45431\text{pb}^{-1}, \quad E_p = 920\,\text{GeV}$) determined Beauty-Crosssection is again above NLO prediction (confirms older results).

y-Distribution (2)

Partonic cms energy $\sqrt{\hat{s}}$ must produce two jets with q $E_T^{\text{jet}} > 6\,\text{GeV}$

$$\sqrt{\hat{s}} = \sqrt{x_p \cdot y \cdot x_\gamma \cdot s} \tag{6}$$

- $\sqrt{\hat{s}}$ partonic cms energy
- $x_p = p_{\text{parton}}/P$ fractional momentum of proton carried by the parton
- y inelasticity
-
  - $x_\gamma = 1$ direct processes (dominant for heavy quark)
  - $x_\gamma < 1$ resolved processes (dominant for uds)
- s cms of Proton and electron beam