ETH Institute for
Particle Physics

Charm–photoproduction at HERA

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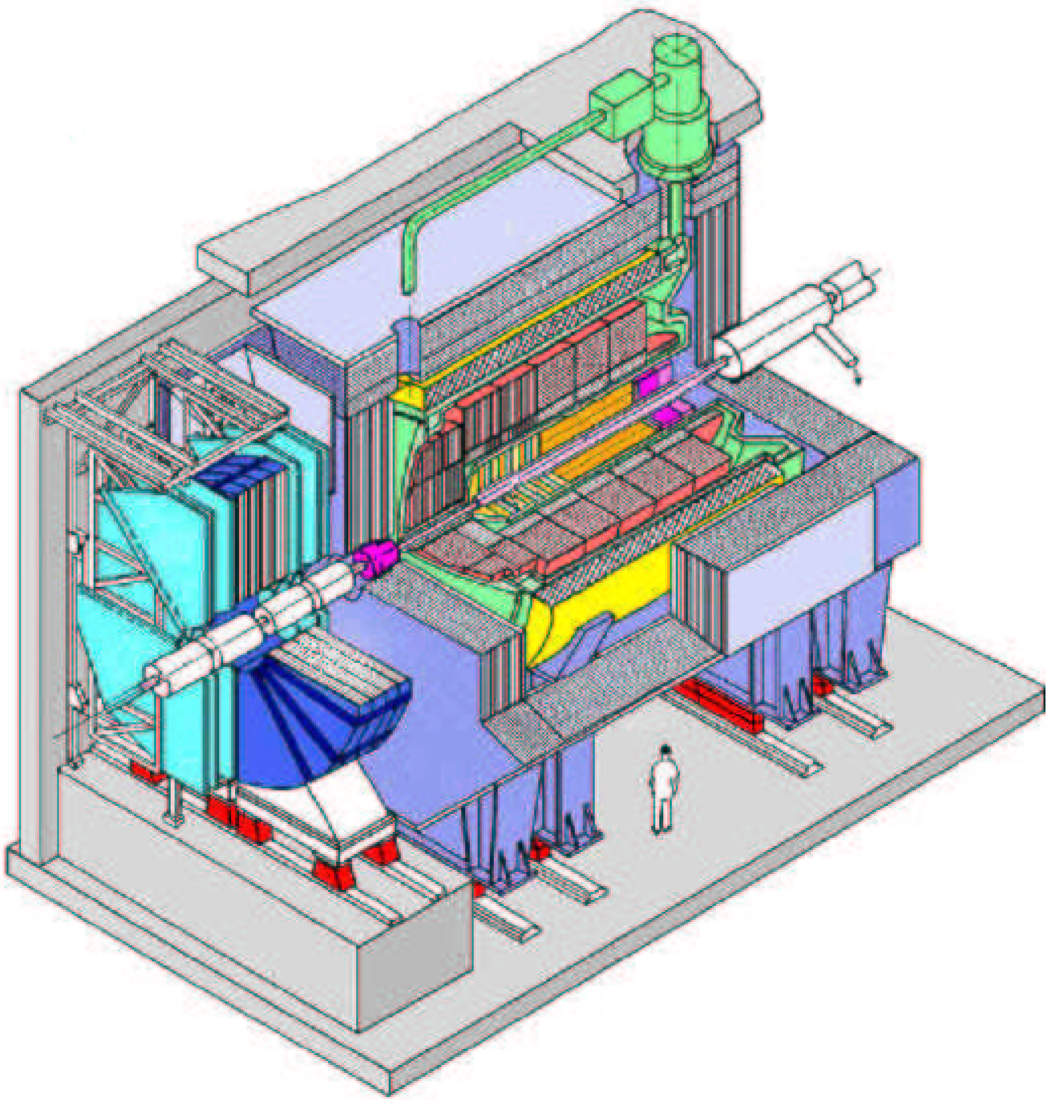
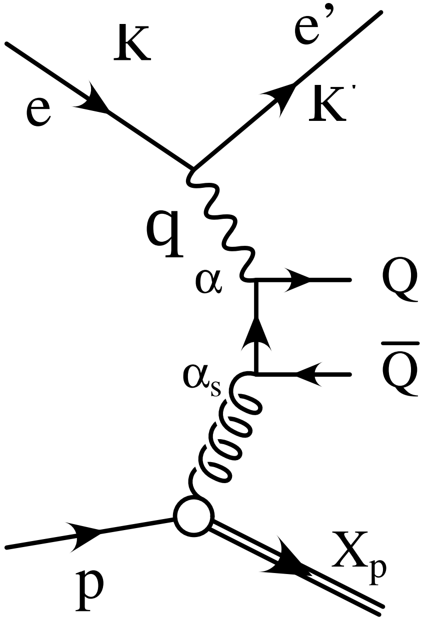
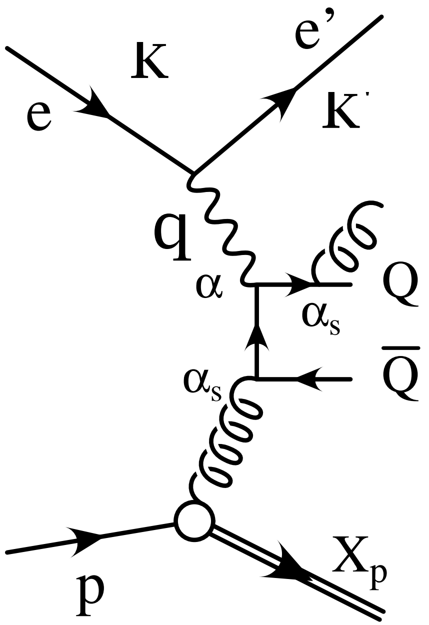


Heavy quark production

- Main process: Boson−gluon fusion
- LO



NLO



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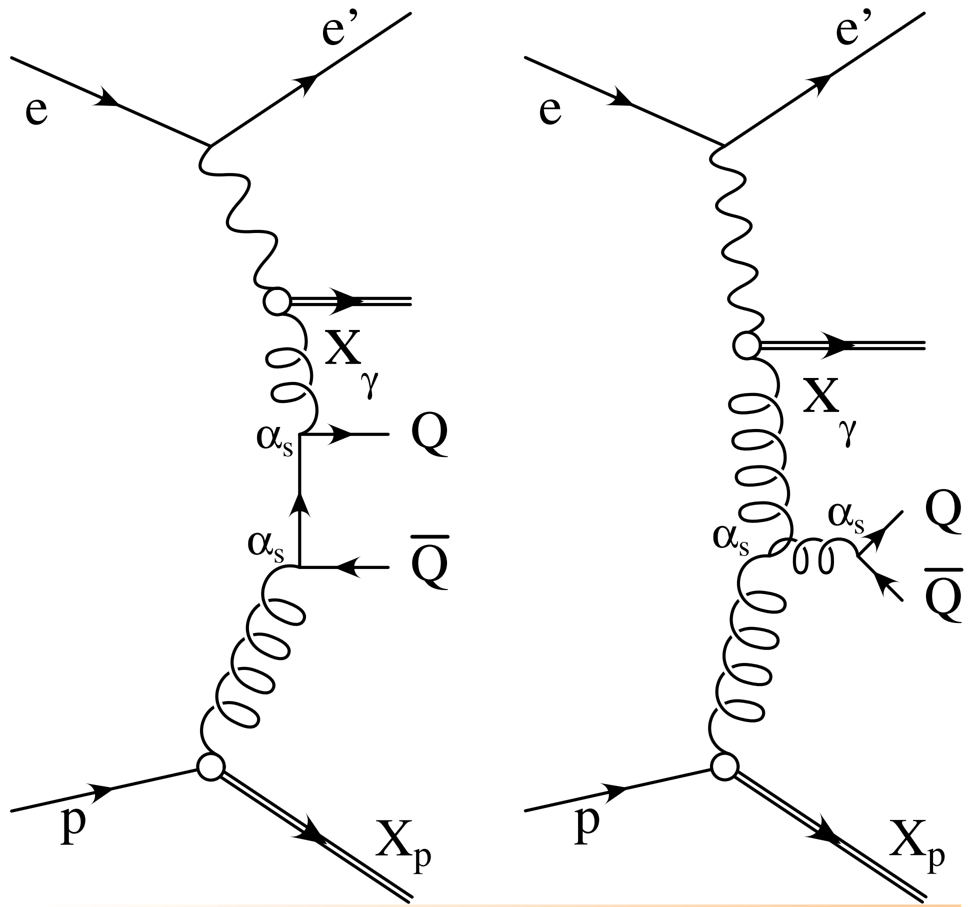
- Quark, gluons: hadronisation → jet of particles
- Kinematic variables: $x = \frac{Q^2}{q \cdot P}, \quad y = \frac{q \cdot P}{k \cdot P}, \quad Q^2 = -q^2 = x \cdot y \cdot s$

Photo production

- Photo production:
  $Q^2 \to 0$ GeV^2
  - small virtuality of photon
- in NLO: experimental separation between direct / resolved processes not possible

- direct vs. resolved processes



Exclusive charm tagging with D^*?

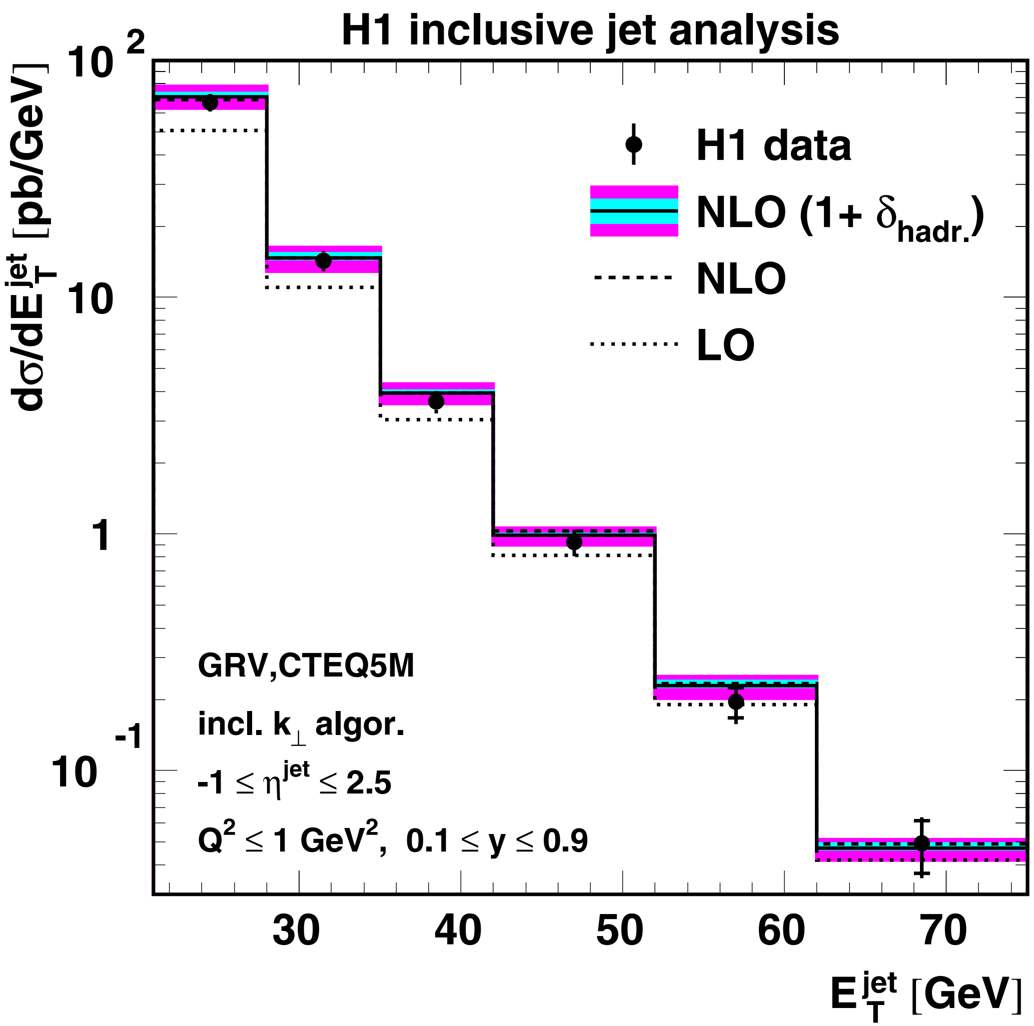
- $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+$
  "Golden channel": small $\Delta m_{\pi s}$
- Low branching ratio: 0.235 · 0.677 · 0.0383 = 0.61 %
- Low statistic, try inclusive method.

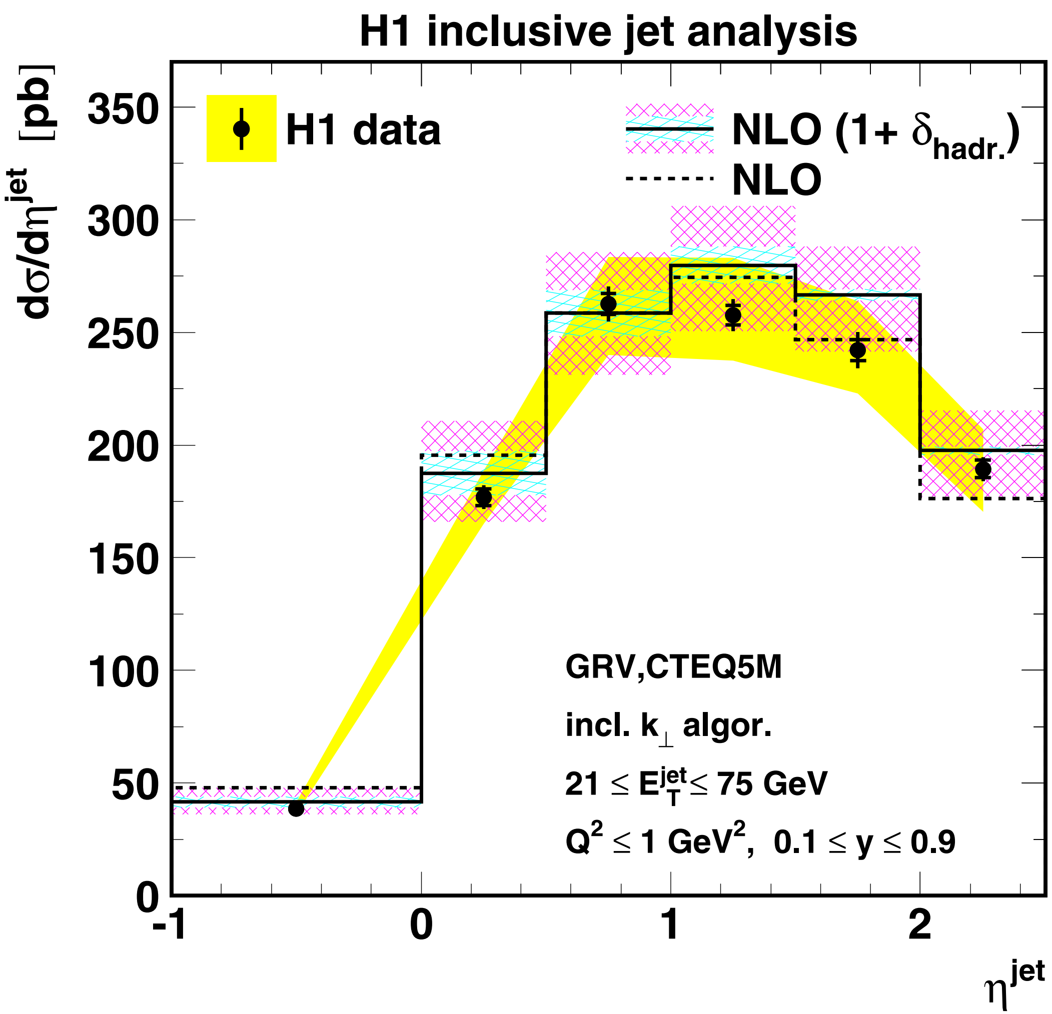
$\rightarrow$ Look for jets

Physical motivation: Compare experiment and theory

- Bulk of cross section is dominated by jets from light quarks; good theoretical description of jets from light quarks
- Jets from heavy quarks:
  - *c*: uncertainty in theoretical predictions: ~45%
  - *b*: smaller uncertainty in theoretical predictions: ~10%
    - in pQCD: expansion parameter proportional to $\ln(1/m_q^2)$
    - $m_b \approx 4 \cdot m_c$
- Experimental finding contradicts naïve expectation

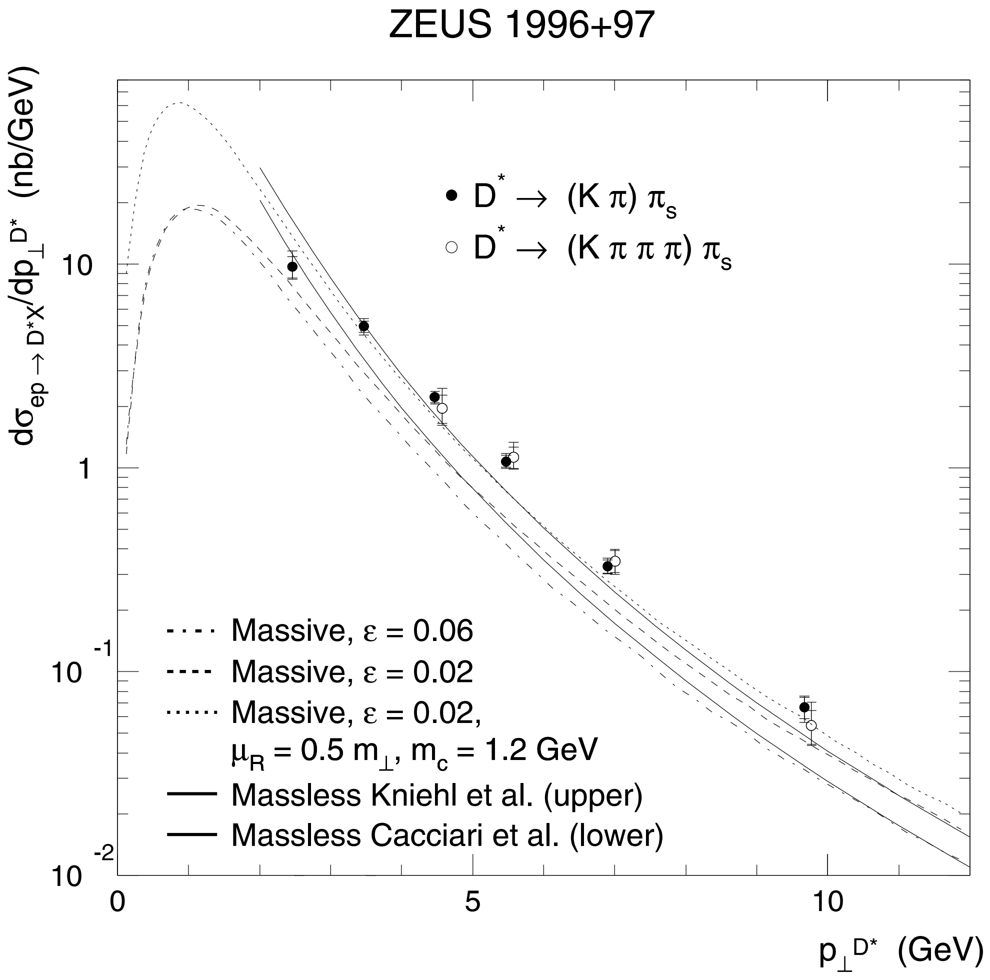
Inclusive differential jet cross sections (photoproduction)

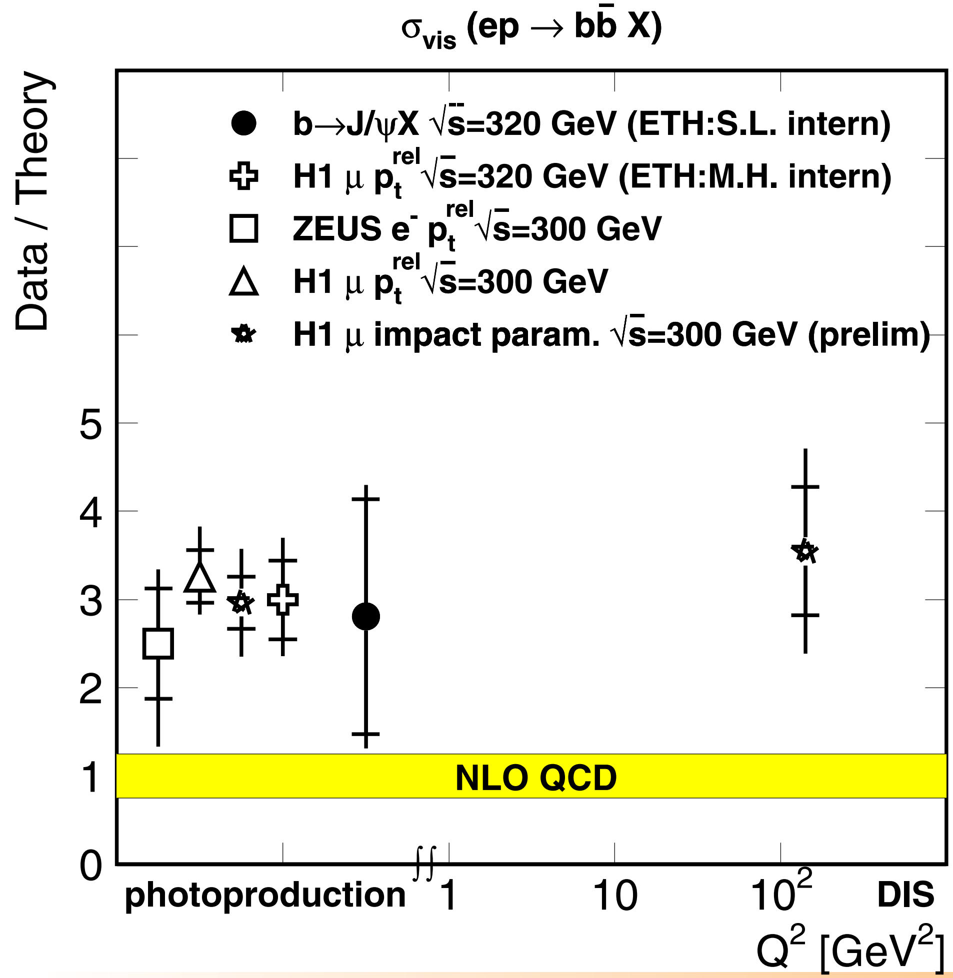




But: total cross section

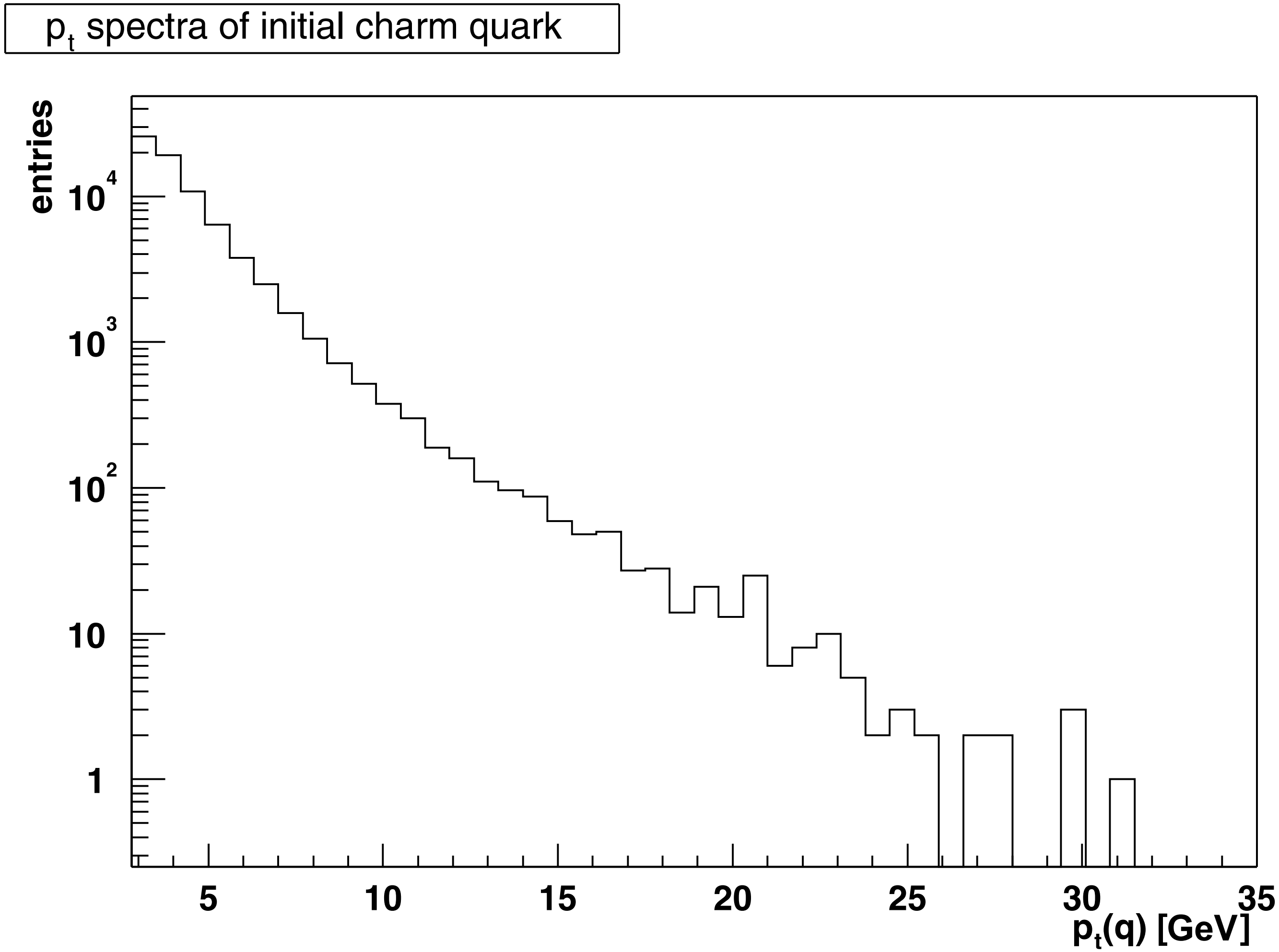
- Charm
- Beauty





Energy spectra of charm

- Heavy quarks are produced at their mass threshold $\rightarrow$steep p_t spectra
- Find all quark fragments with a jet algorithm
- Apply a jet cut



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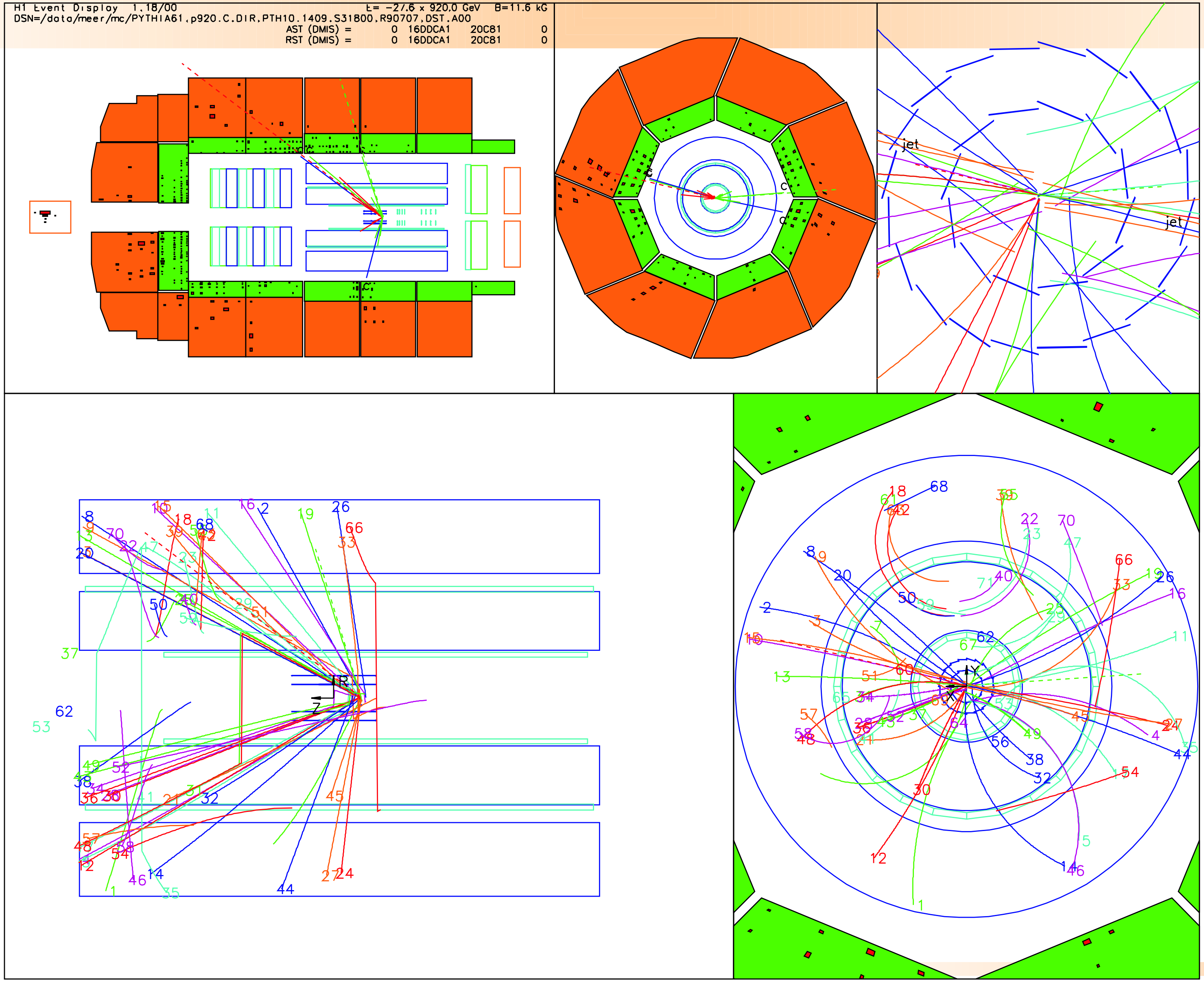
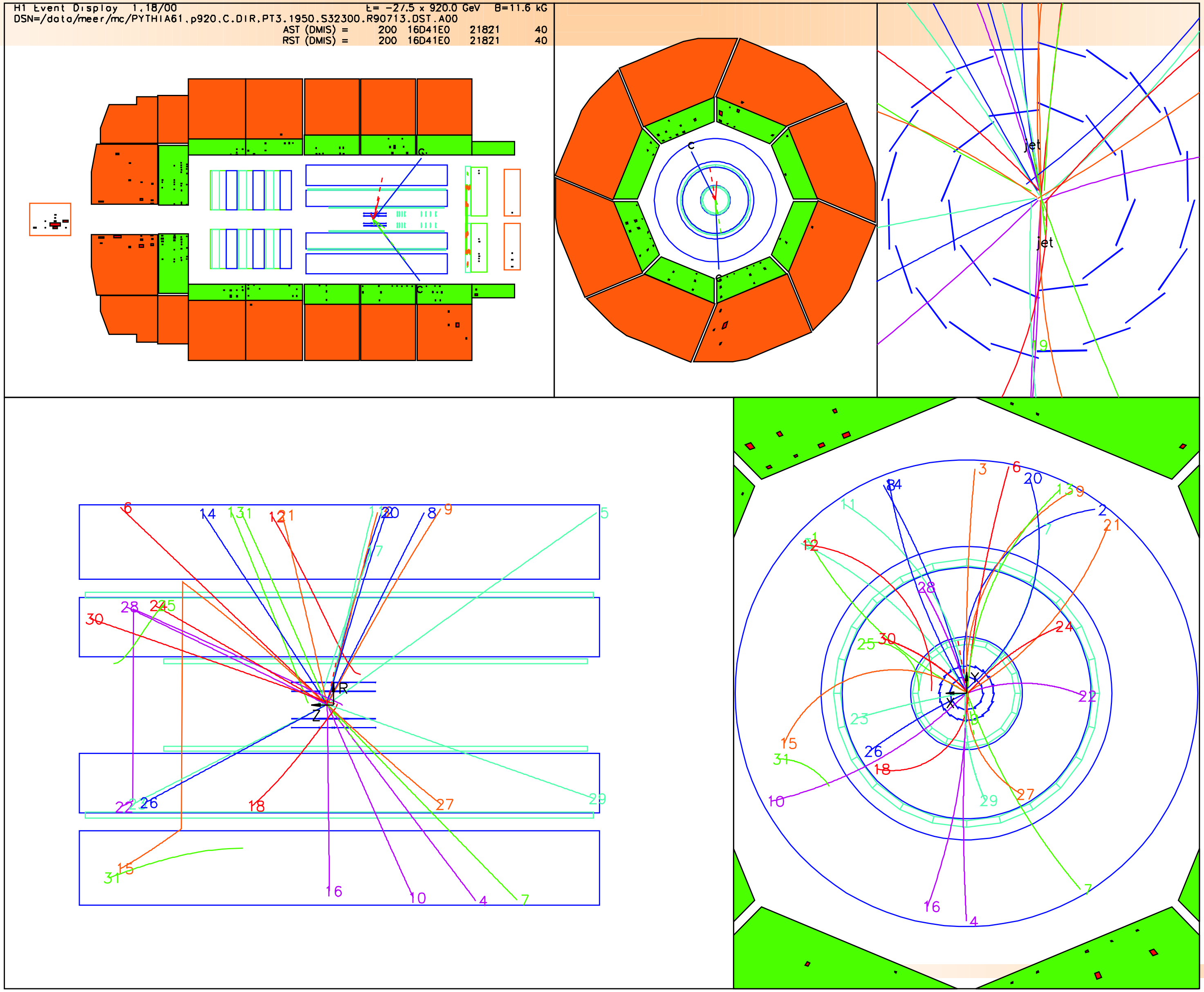
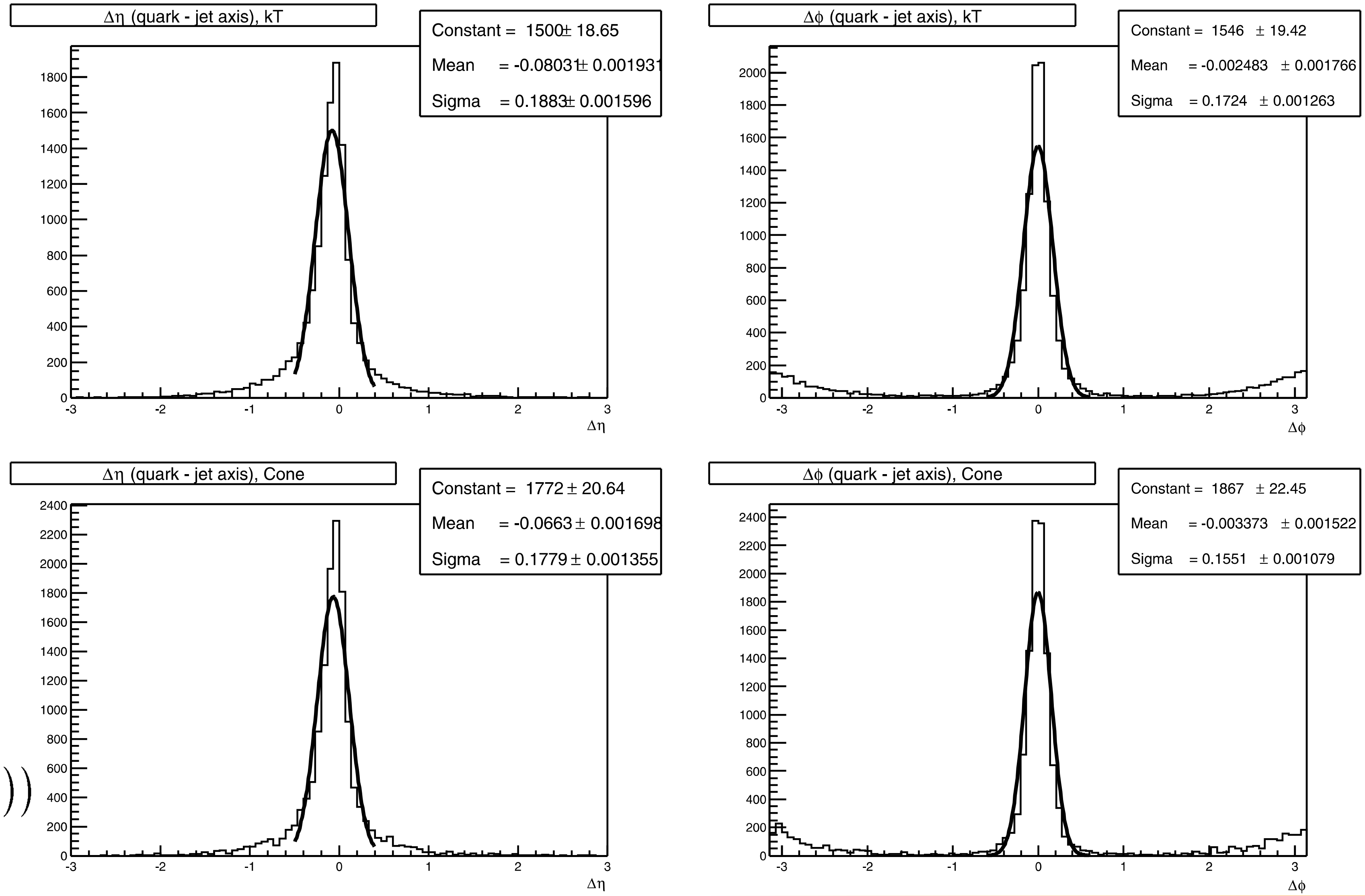
Charm event $p_t(c) > 10$ GeV



Charm event $p_t(c) < 10$ GeV



Reconstruction of c−quark direction with jet algorithm



$$\eta = -\ln\left(\tan\left(\frac{\vartheta}{2}\right)\right)$$

Charm quark fragments

- Each fragmenting charm ends up in a long−lived charmed meson or baryon

Hadron	Name	PDG code	q_1	q_2	q_3	f	σ_f	$c\tau$ [μm]
Mesons	D^+	411	c	d~	-	0.232	0.025	315
	D^0	421	c	u~	-	0.549	0.036	123.7
	D_s^+	431	c	s~	-	0.101	0.034	148.6
Baryons	Λ_c^+	4122	d	u	c	0.076	0.027	61.8
	Ξ_c^+	4232	u	s	c			98
	Ξ_c^0	4132	d	s	c			29
	Ω_c^0	4332	s	s	c			19

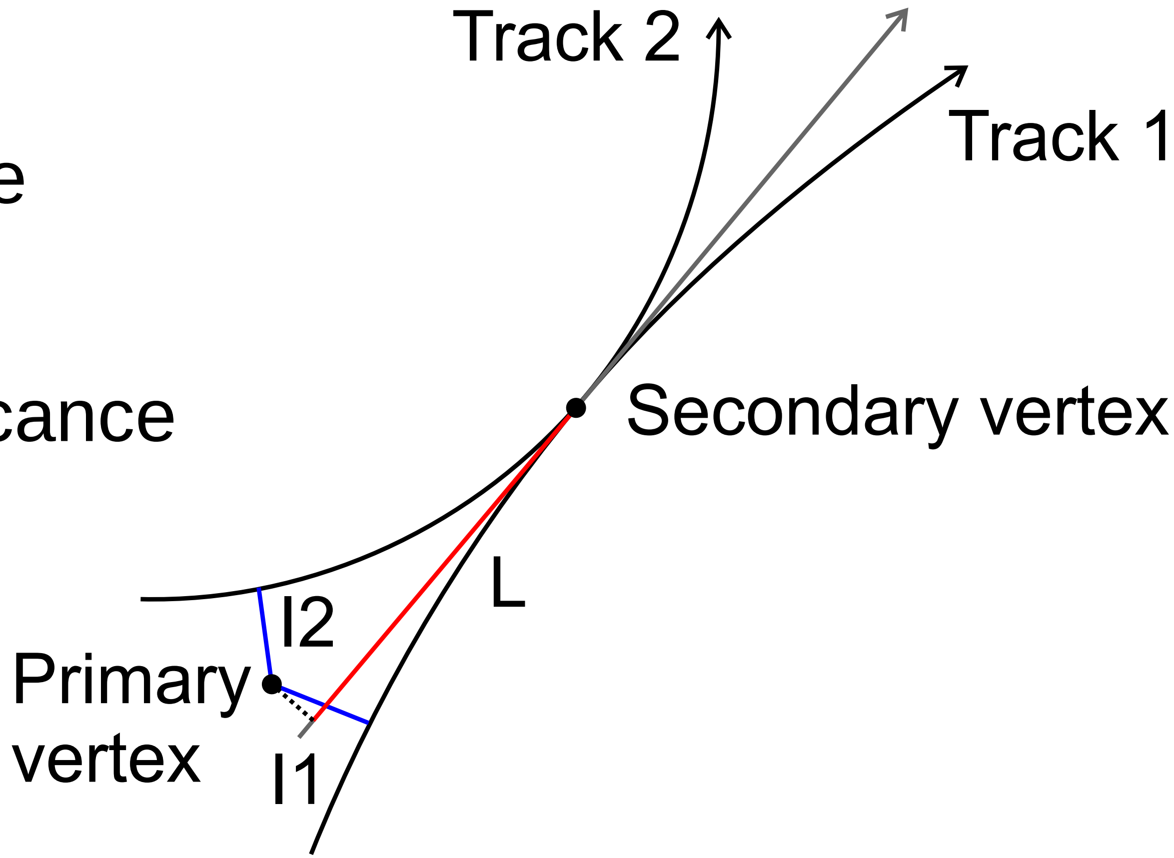
- Long−lived particles $\rightarrow$ secondary vertex

Charm tagging (Inclusive method)

- Run jet algorithm to define jets in a event
  - Correct energy treatment of tracks and clusters (HFS package)
- Select only good tracks in jet
- For each pair of good tracks in a jet:
  - Fit to 2nd vertex in jet (separation to primary vertex)
  - If fit converges, add to list of hypotheses
  - Cut on significance of decay length and impact parameter

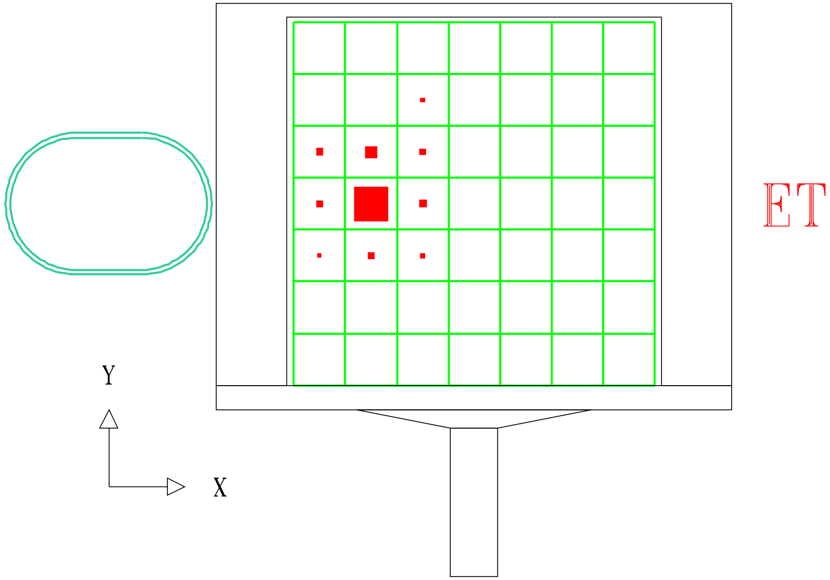
Vertexing

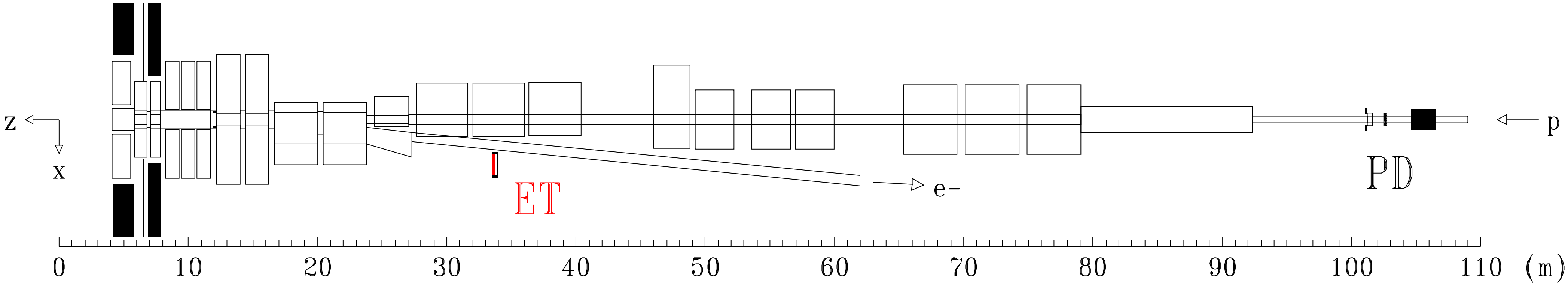
- Fit two good tracks to secondary vertex
  - SV package from Wolfram Erdmann
  - Use 2du fitter
- Decay length significance
  $S_L = L / \sigma L$
- Impact parameter significance
  $S_I = I / \sigma I$
- If fit converges,
  add this 2nd vertex
  to list of hypotheses



Selecting photoproduction: Electron tagger

- Electron Tagger (ET):
  - 49 channel crystal Cherenkov calorimeter
  - Position in the tunnel: $z = -33.4\ \mathrm{m}$





Luminosity system. Top view

Selecting photoproduction events: Reconstruction of kinematic

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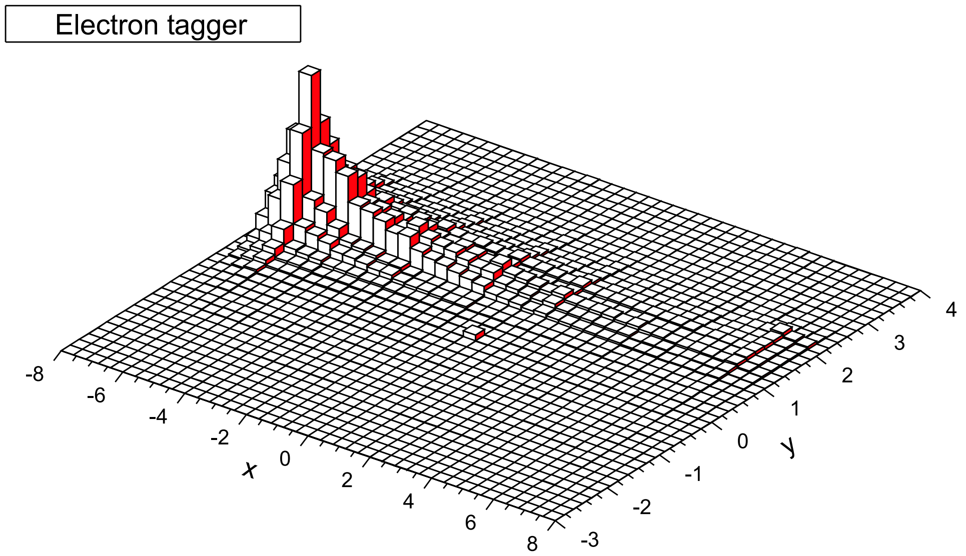
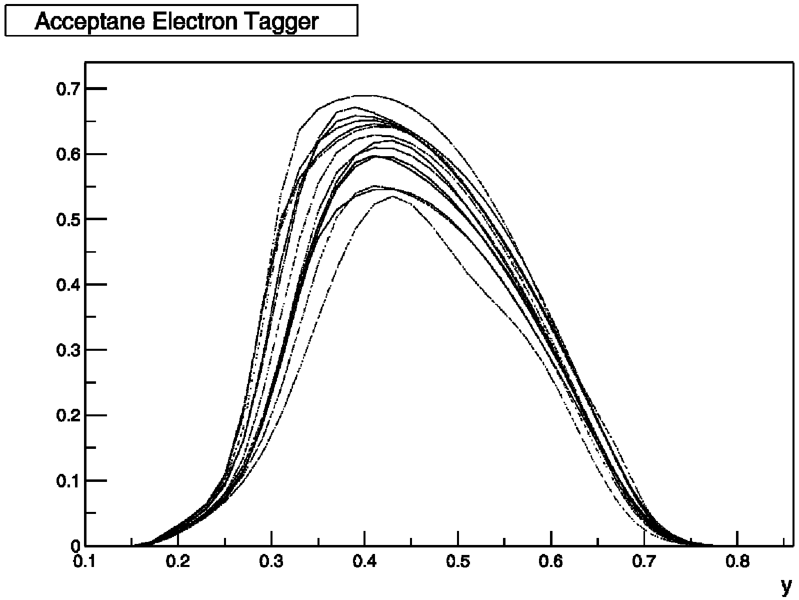
- Get energy of scattered electron from ET, this defines event kinematic

$$y=\frac{E_{el}-E_{el}'}{E_{el}}, \quad Q^2<0.01\ \text{GeV}$$





- Acceptance of ET is energy dependent
  → Visible range $0.24<y<0.68$

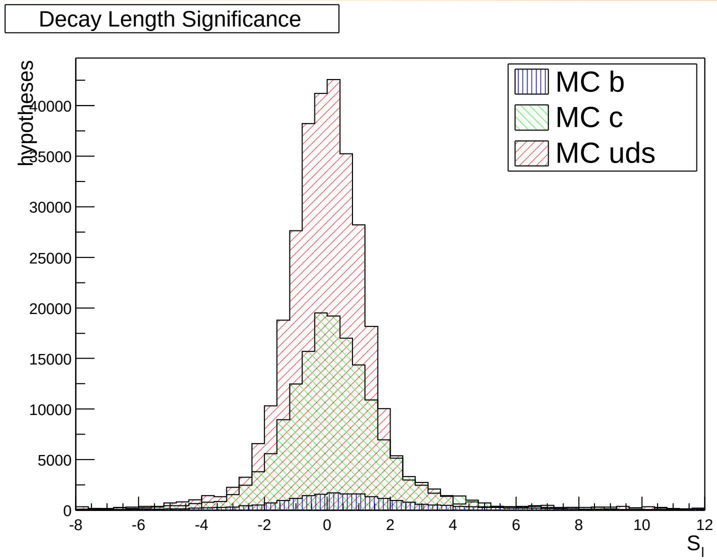
MC set

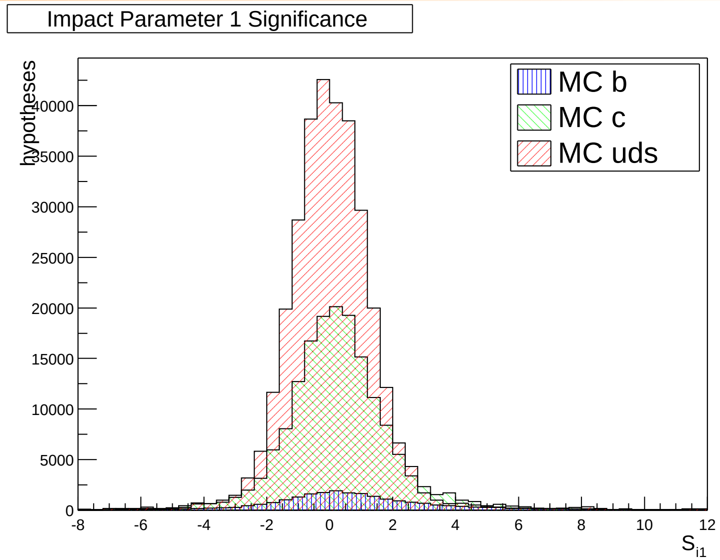
- Event generator: Pythia 6.1
  - c, 100k events (2.8 pb^{-1})
  - uds, 100k events (1.22 pb^{-1})
  - b, 100k events (77.3 pb^{-1})
- At least 1 quark with p_t > 3 GeV in central part
- (Up to now) Only direct processes
- No simulation of electron tagger, correction of tagger acceptance in data

Event / Track selection criteria

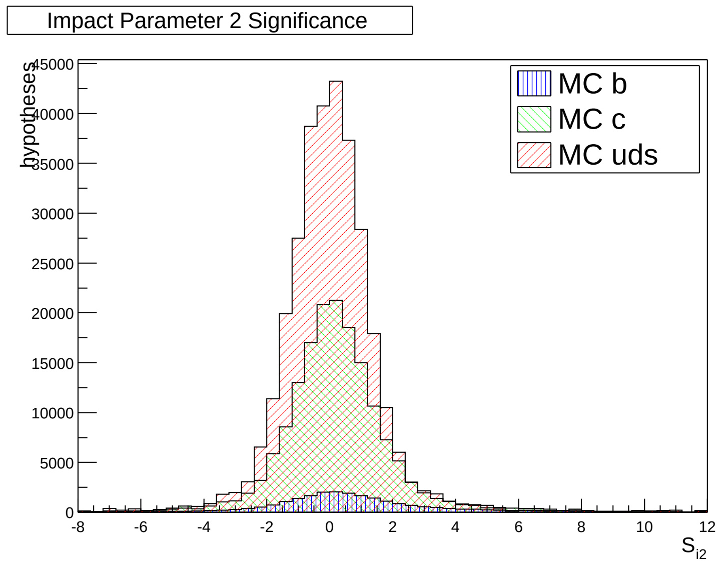
- 1 jet p_t > 4 GeV in central part ($|\eta| < 1.5$)
- Tracks used for 2nd vertex fit
  - $p_t > 0.5$ GeV
  - dca < 2.0 cm
  - $|\eta| < 1.5$
  - $L_{CJC} > 25.0$ cm
  - $r_{Start} < 45.0$ cm
  - $p_{Link\ CJC-CST} > 0.001$
  - CST: $nHits_r >= 2$, $nHits_z >= 0$
- Requirements for hypotheses
  - $S_l, S_{i1}, S_{i2} > 2$
  - l < 1.5 cm, dl < 0.05 cm

Decay length significance Impact parameter significance

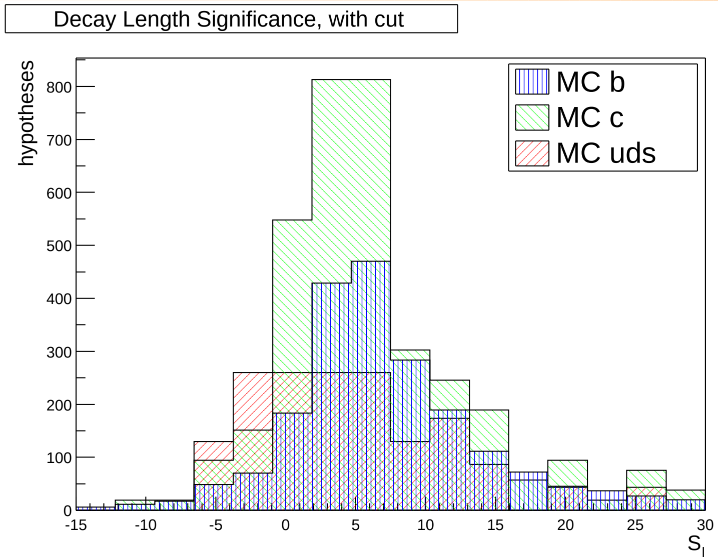


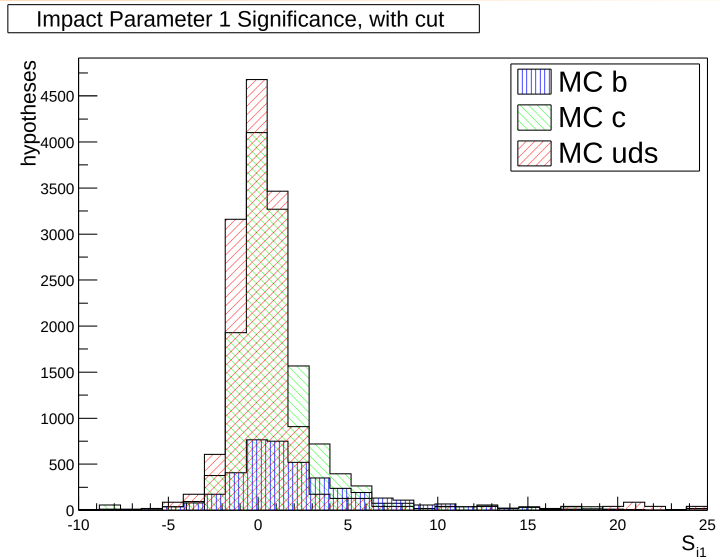


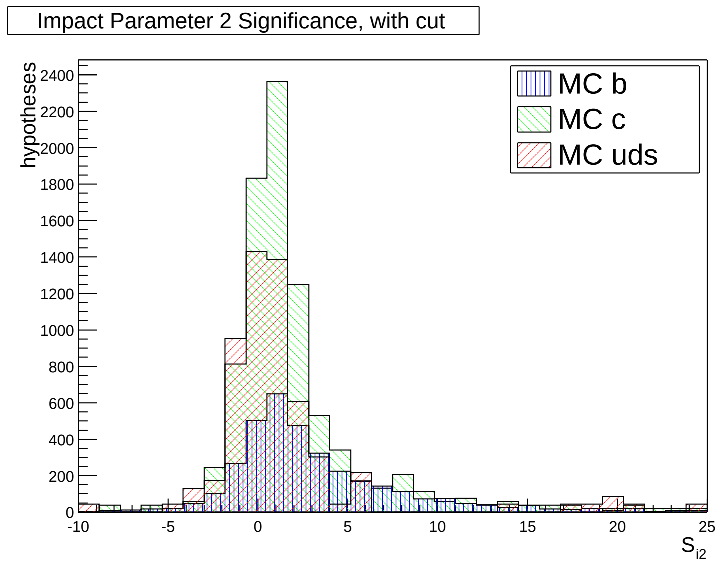
- Impact parameter 1: faster track
- Impact parameter 2: slower track



Same with cut

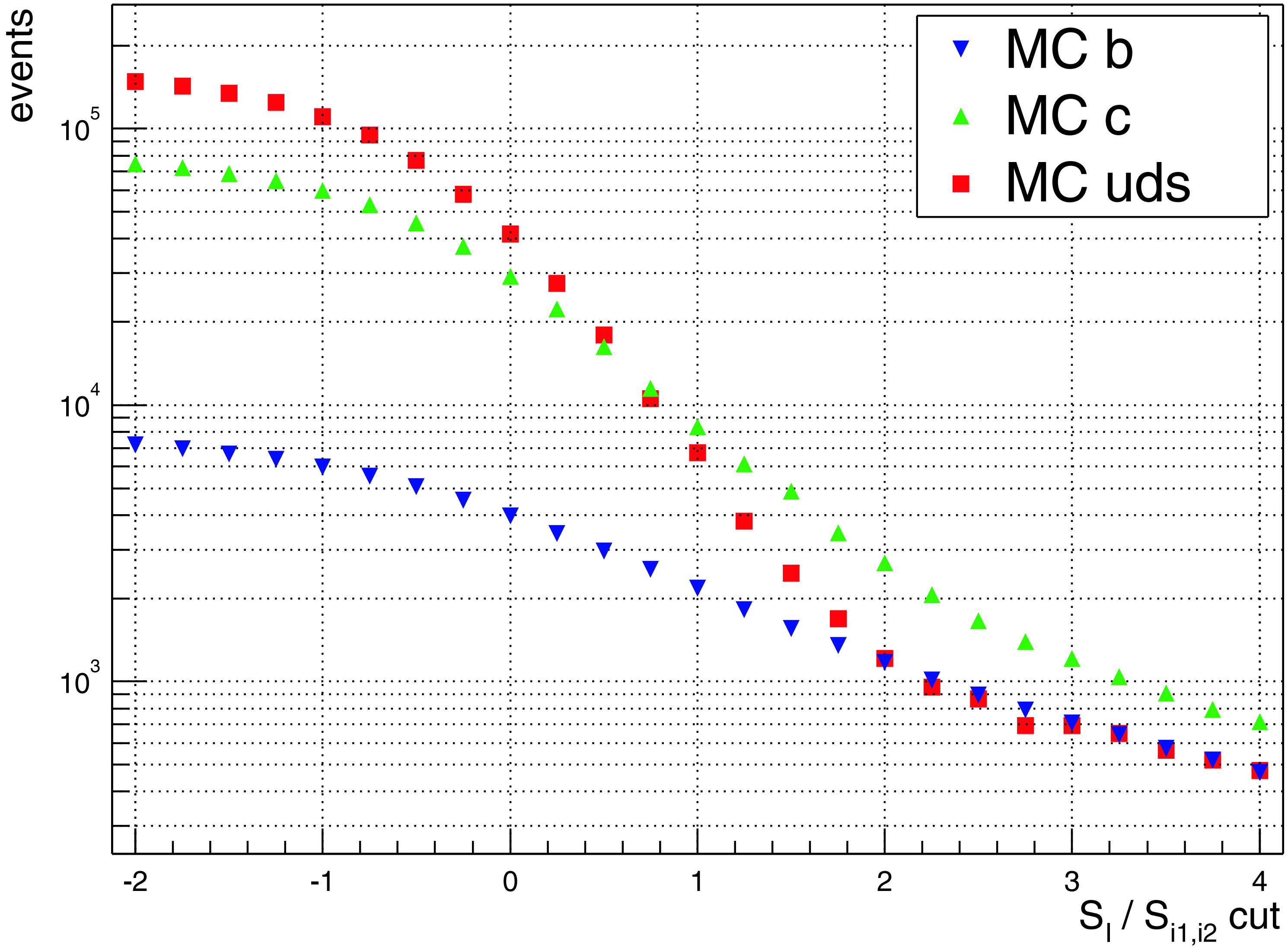






- $S_l > 2$
- $S_{i1} > 2$, $S_{i2} > 2$

Expected events in direct processes

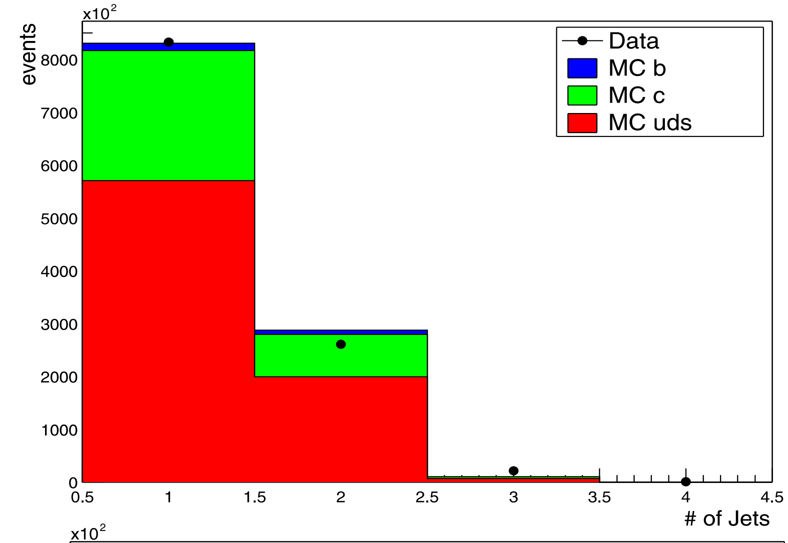


First look at data: Data set

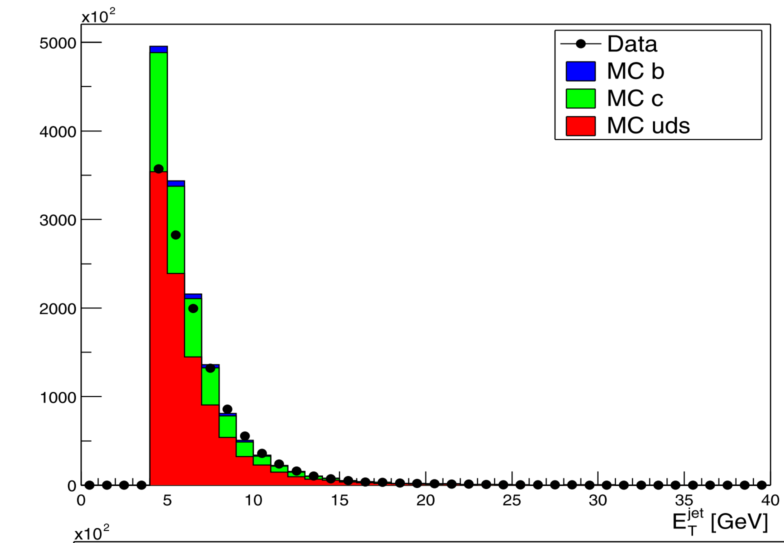
- e^+p^+ Data from 1999/2000
- Tagged photoproduction
  - Subtrigger 83
    - mean prescale factor 1.18
    - (up to now) no subtrigger efficiencies
  - ET acceptance corrected
- Good / medium run quality
- $\rightarrow$ 61.8 pb^{-1} (4.9 M events)
- Normalization of MC <−> data not yet clear; only shape!

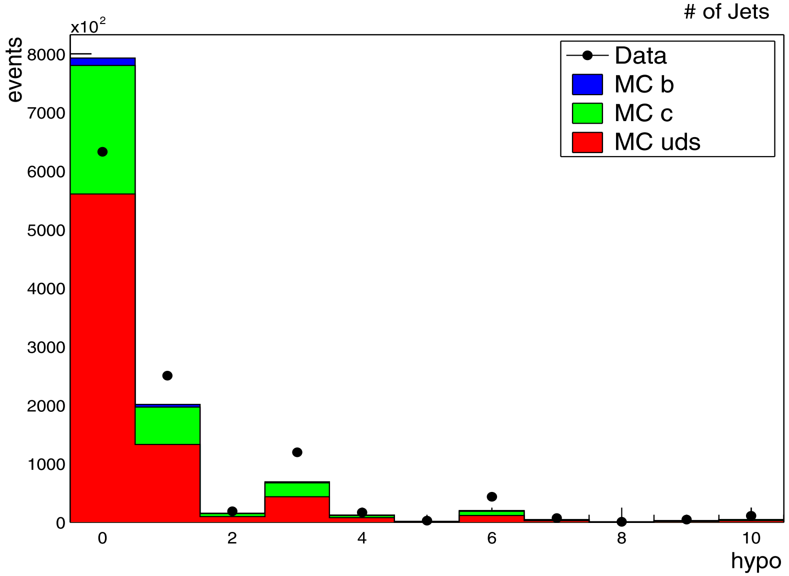
Control plots

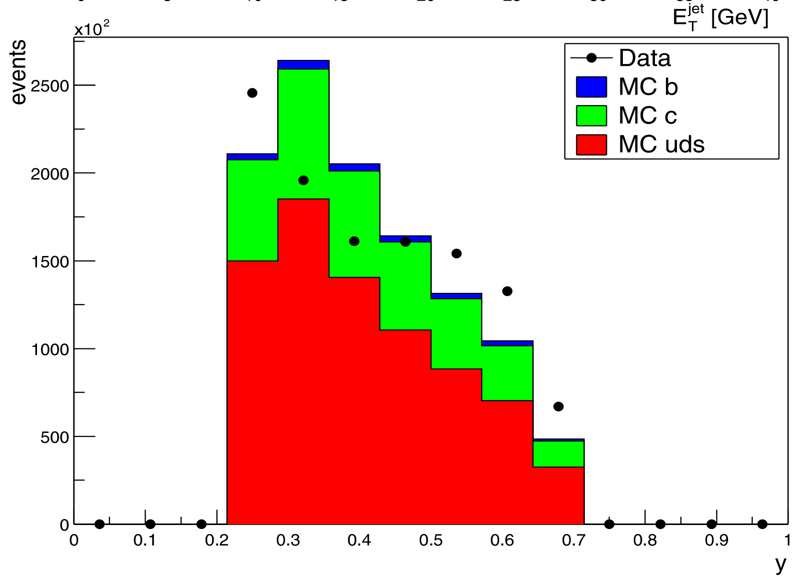
Number of jets



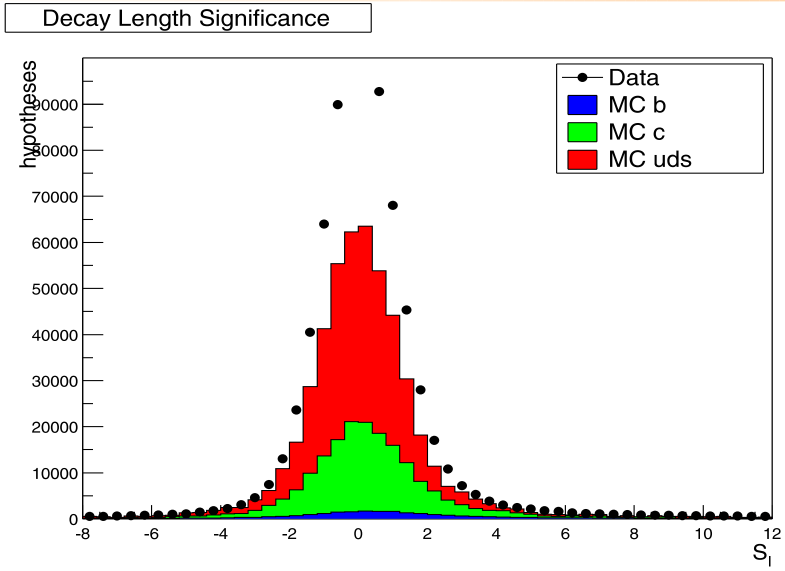
Transversal jet energy

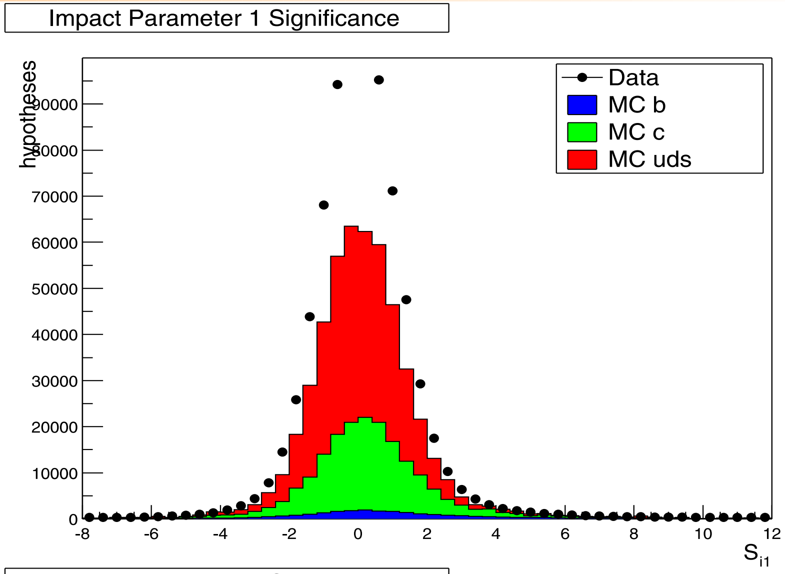


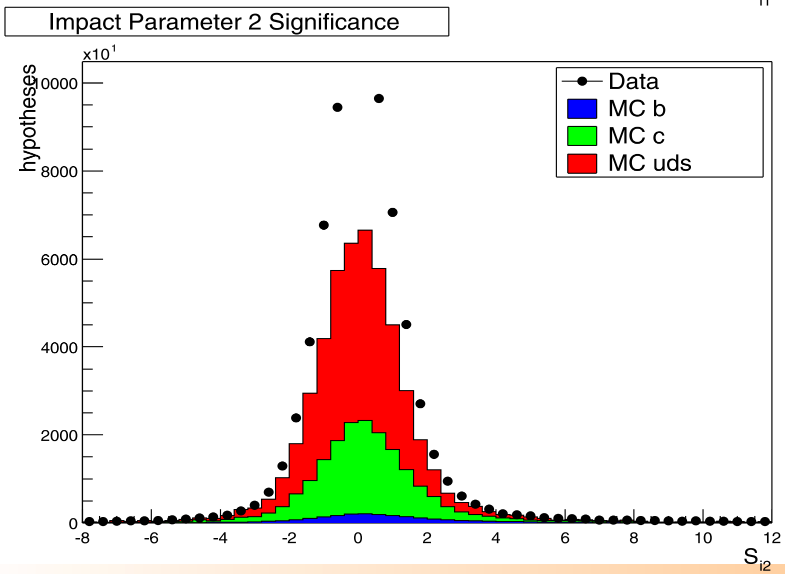




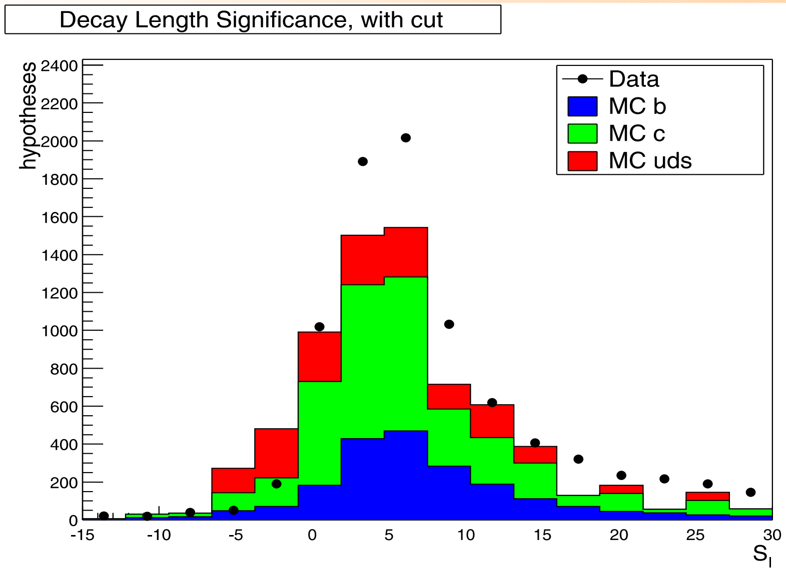
Data without cuts

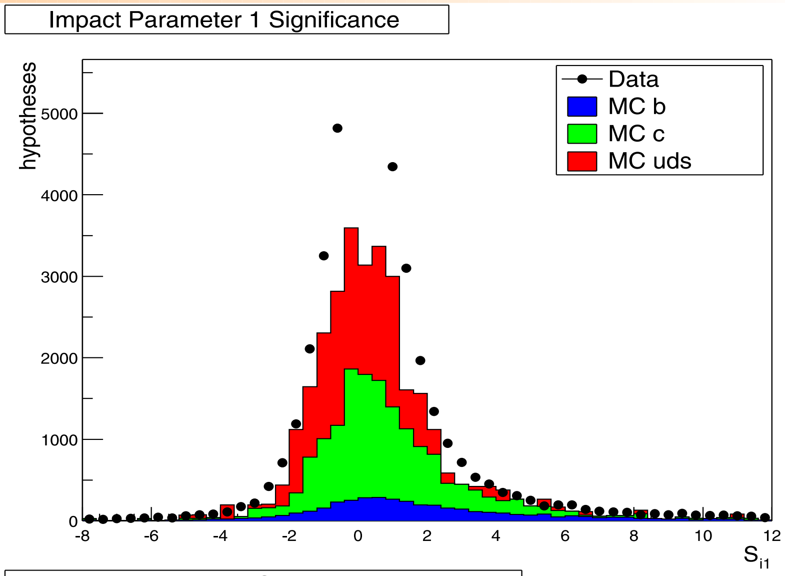


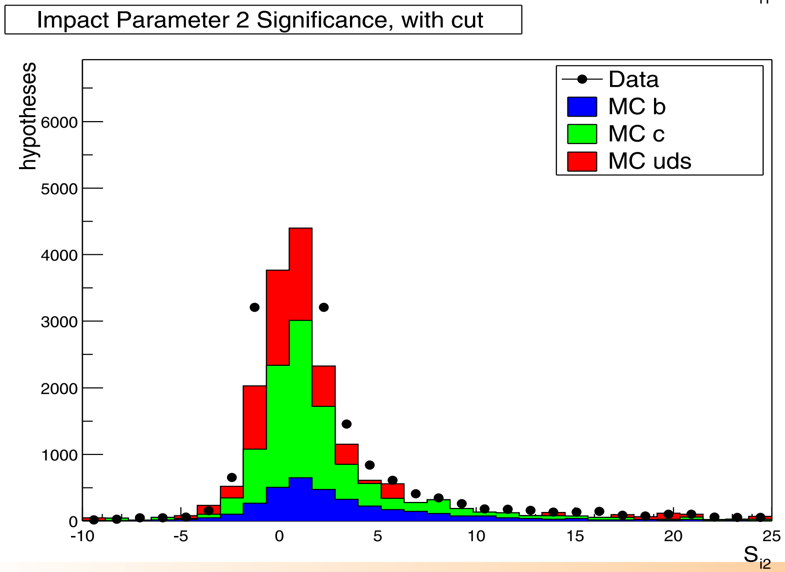




Data with cuts



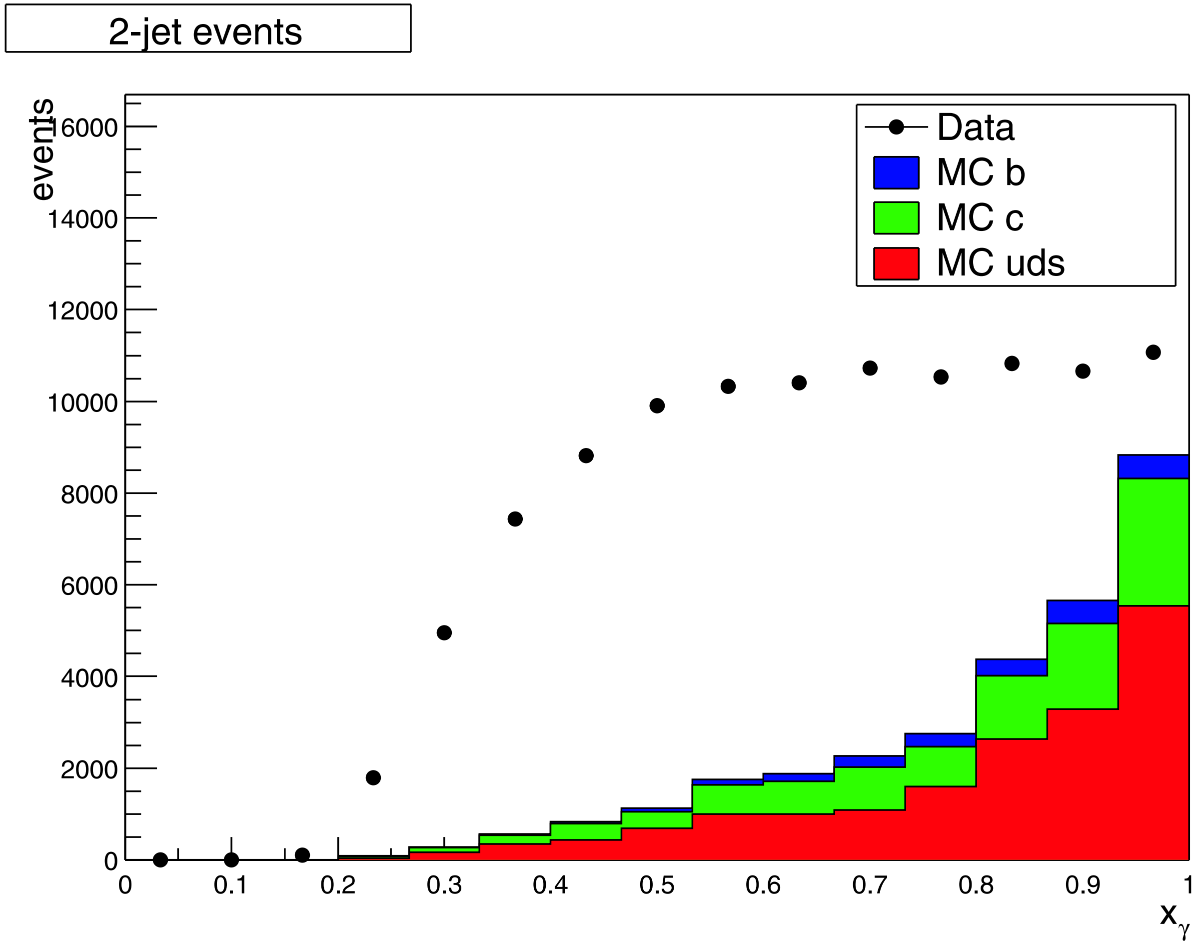




Resolved contributions?

- Look at x_γ in 2−jet events to estimate resolved part in data

$$x_\gamma = \frac{E_T^{jet1} e^{-\eta_{jet1}} + E_T^{jet2} e^{-\eta_{jet2}}}{2\, y\, E_{e'}}$$



Next steps

- Need more MC statistic
- Include resolved contributions in MC
- Determine subtrigger 83 efficiency
- Use standard background finders
- Measure differential jet cross sections
  - light quarks (measurements already exist, good cross check)
  - charmed jets
- Calculate ratios of these differential cross sections
  - Some detector inefficiencies will cancel

Summary

- Method for charm tagging with 2nd vertices seems to work also for photoproduction
- Resolved processes must be included
- Fraction for b quarks can’t be neglected

- ... but still a lot of work to do!