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# Flavour tagging performance analysis for vertex detectors

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on behalf of the LCFI collaboration

# Introduction: aim of the studies presented

- physics studies performed in the context of R&D work of the LCFI collaboration
- aim at providing a guideline for vertex detector design, e.g.
  - How close to the interaction point does the inner layer need to be?
  - Which layer thickness should be aimed at? (multiple scattering)
  - How many layers are needed?
- to answer these questions study e.g.
  - impact parameter resolution
  - vertex charge reconstruction
  - specific physics channels expected to be sensitive (future)
- need to be sure to use all available information that might depend on detector design → develop existing flavour tagging tools further

# Software tools

- Java analysis studio, version 3 (JAS3), by T. Johnson

  http://jas.freehep.org/jas3/index.html

  - object oriented software being developed at SLAC
  - expected to provide access to a broad variety of tools via a standardised user-interface in the future

- Simulation a Grande Vitesse (SGV) version 2.31 by M. Berggren

  http://berggren.home.cern.ch/berggren/sgv.html

  - flexible, well-tested fast simulation, originated from DELPHI
  - interfaced to PYTHIA version 6.1.52
  - JADE algorithm (y-cut 0.04) for jet finding
  - includes (thanks to V. Adler) flavour-tagging code by R. Hawkings as used in BRAHMS
  - vertex finding: ZVTOP by D. Jackson

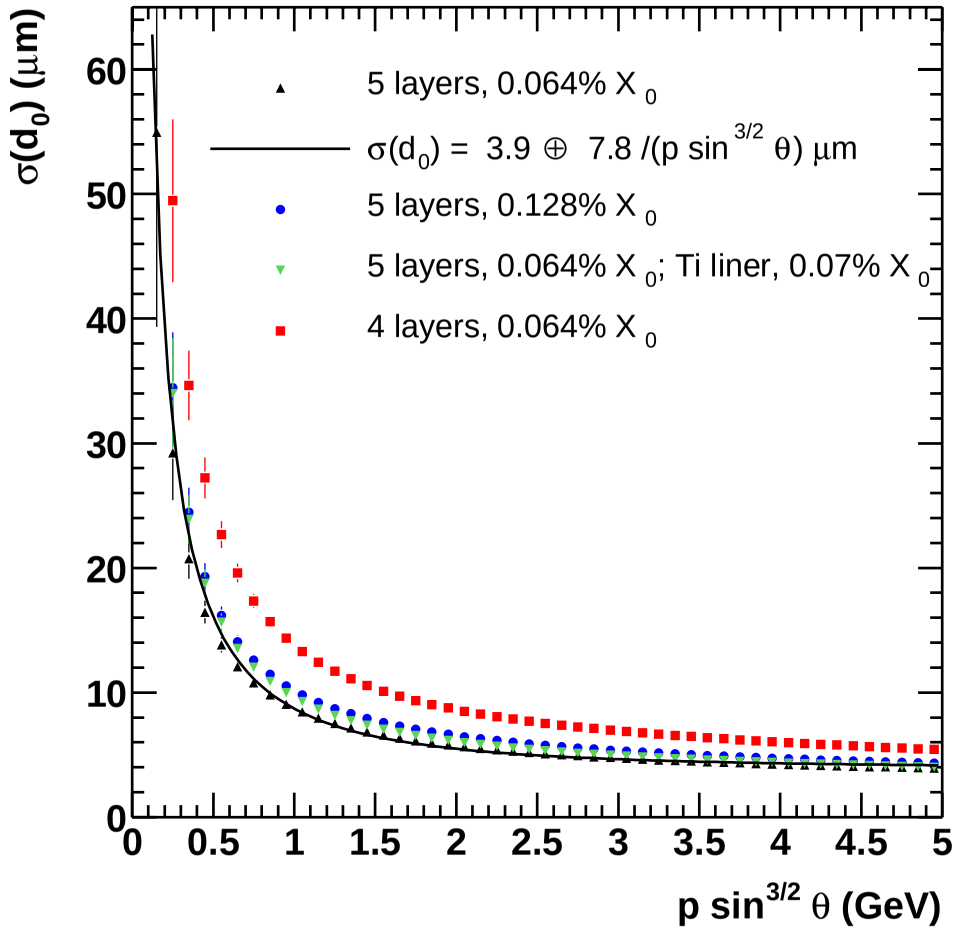
# Impact parameter resolution

**study based on single pions, generated using SGV**

**impact parameter in Rφ at track perigee**

**detector geometries:**

- ▲ **standard detector: 5 layers (each 0.064 % $X_0$) at radii 15 mm to 60 mm**
- ● **double layer thickness**
- ▼ **beam-pipe with Ti-liner (0.07 % $X_0$)**
- ■ **4 layers at radii 25 mm to 60 mm**



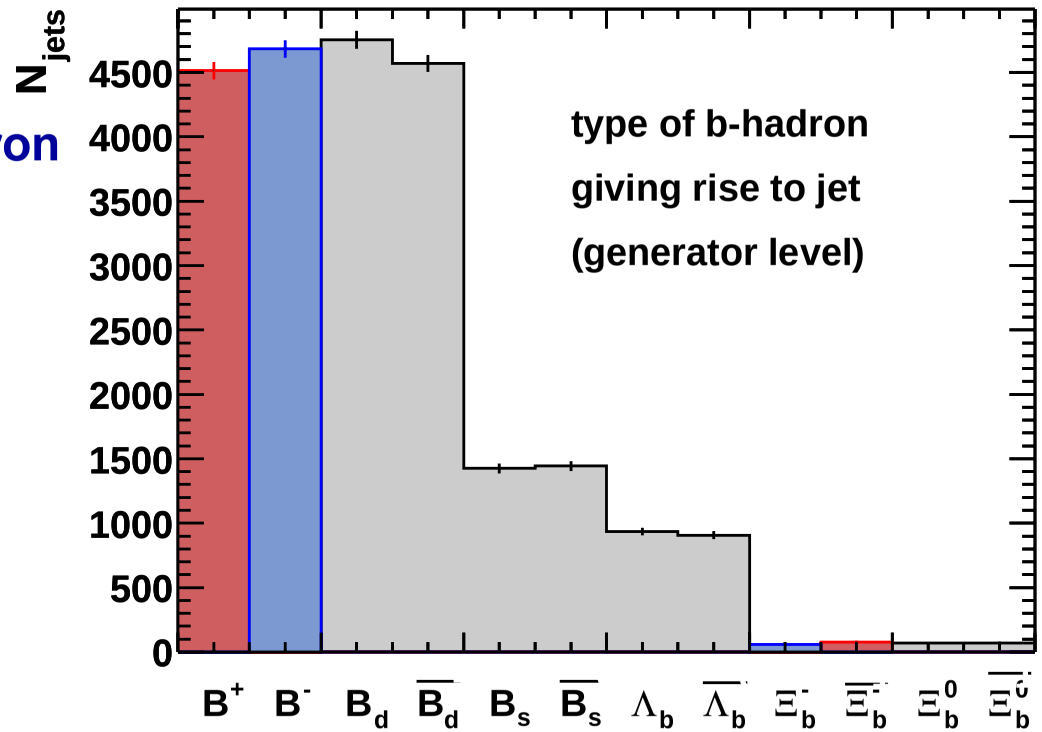

- ➢ **increasing material budget has moderate effect, but**
- ➢ **performance strongly suffers when beam-pipe radius is increased**

# Vertex charge study: introduction

**preliminary results from an SGV-based study**

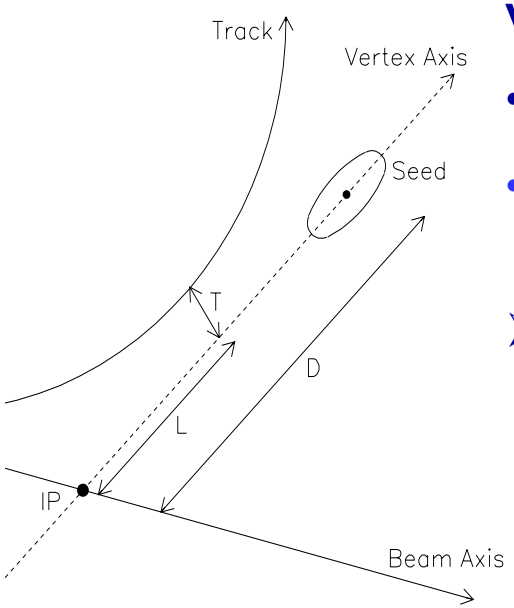
- **Motivation: discern charged b jets ( $Q_{Vtx} = -1$ ) from charged b-bar jets ( $Q_{Vtx} = +1$ )**
- **study monoenergetic jets from $e^+e^- \rightarrow \gamma Z \rightarrow b\bar{b}$ at $E_{CM} = 200$ GeV :**
  **13600 events with exactly 2 jets with $\cos\angle(\vec{p}_{J1}, \vec{p}_{J2}) < -0.95$ found within thrust angle range $20^\circ < \theta < 160^\circ$**

- **determine generator level type of jet (b or b-bar ) by searching for MC B-hadron close to jet $\cos\angle(\vec{p}_B, \vec{p}_J) > 0.95$ and finding corresponding charge**
  → **B-hadron successfully identified for 23500 jets**
- **at generator level, 40 % of these jets stem from charged hadrons**

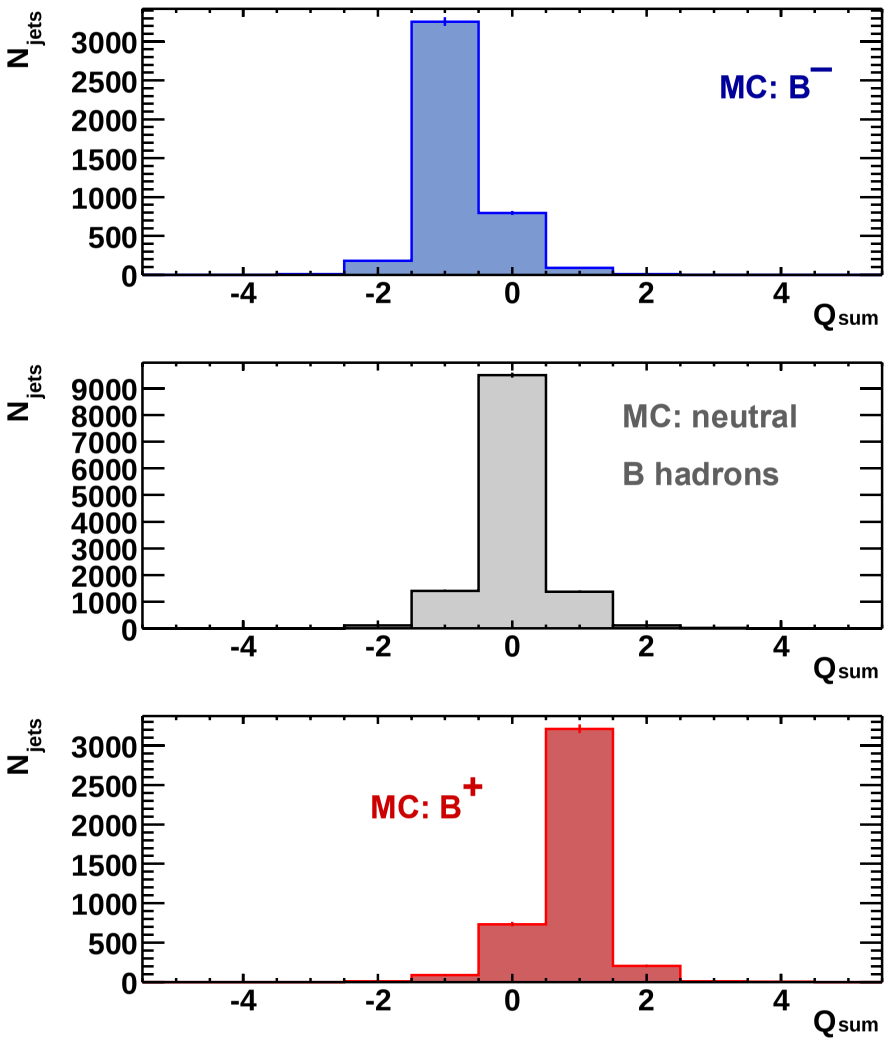


# Vertex charge reconstruction

- run ZVTOP to find vertex candidates, require tracks have $d_0 < 0.3$ (1.0) cm
- seed vertex: candidate furthest from IP
- assign tracks to seed, which at point of closest approach to the vertex axis have:
  - $T < 1$ mm
  - $0.3 < L/D < 2.5$




- add up charges of tracks assigned to seed to give $Q_{sum}$

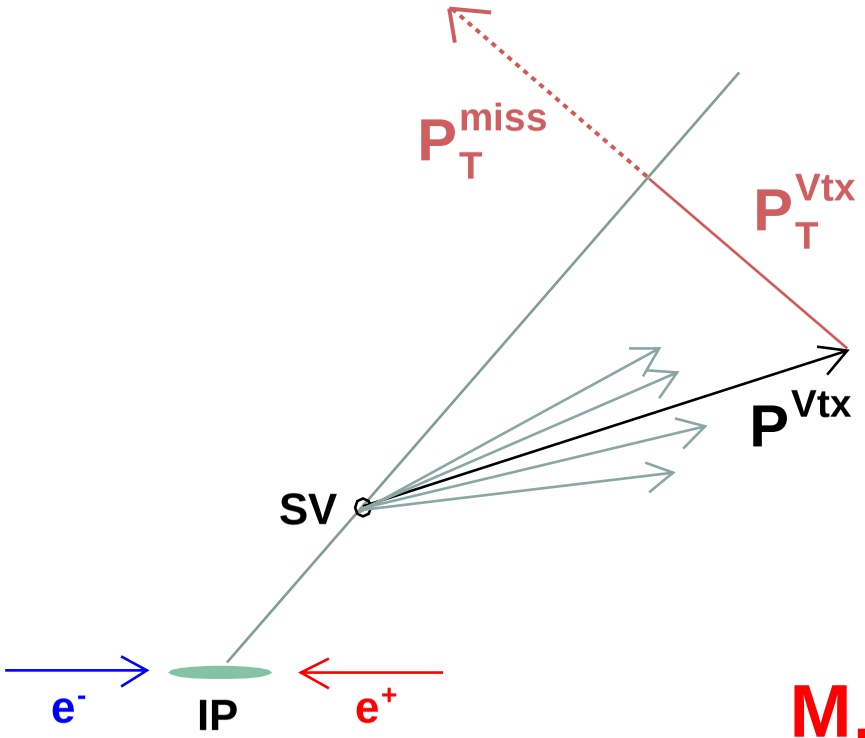



- reconstructed vertex charge

$$Q_{Vtx,r} = \begin{cases} +1 \text{ for } Q_{sum} = +1 \text{ or } +2 \\ -1 \text{ for } Q_{sum} = -1 \text{ or } -2 \end{cases}$$

# Vertex charge: b-tagging

- in physics events, jet-flavour tagging required
- in this preliminary study, the 'Pt corrected vertex mass', $M_{Pt}$ , is used as tag-parameter:




- sum up four-momenta of tracks assigned to seed: find $P_{Vtx}$ and vertex mass
- apply kinematic correction to partially recover effect of missing neutral particles:

$$M_{Pt} = \sqrt{M_{Vtx}^2 + |P_T^{Vtx}|^2} + |P_T^{Vtx}|$$

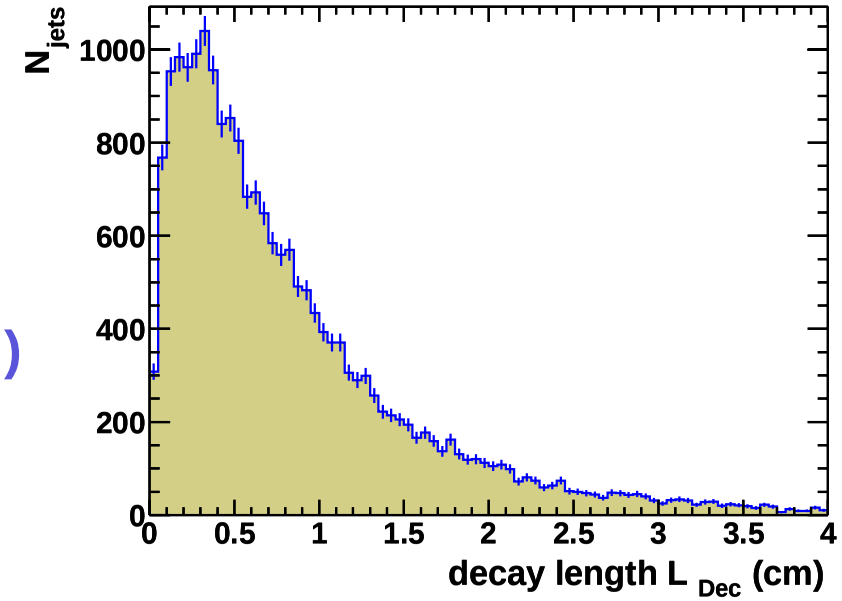
# Vertex charge: efficiency, purity

efficiency $\in_b (M_{Pt,\,cut}) = \dfrac{N(M_{Pt,\,cut})}{N_{tot}}$ with

$N(M_{Pt,\,cut})$ : # (jets) with $L_{Dec} > 300\ \mu m$ and

$M_{Pt,\,cut} < M_{Pt}$ ( < 5.5 GeV )

$N_{tot}$ : # (jets) in event selection cuts

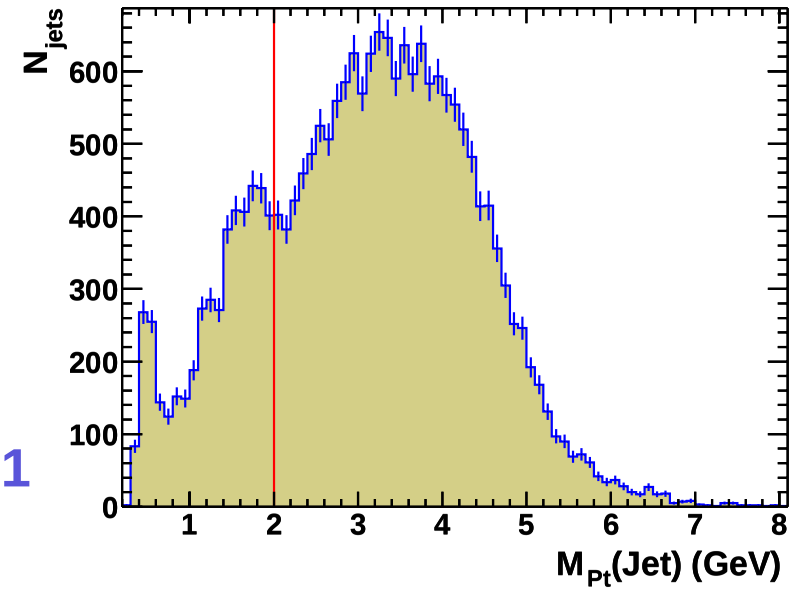



Purity for discerning b from b-bar:

$$\Pi(b) = N_{b,\,r=g} / N(M_{Pt,\,cut})$$

$N_{b,\,r=g}$ : # (jets) from b-quark with $Q_{Vtx} = -1$

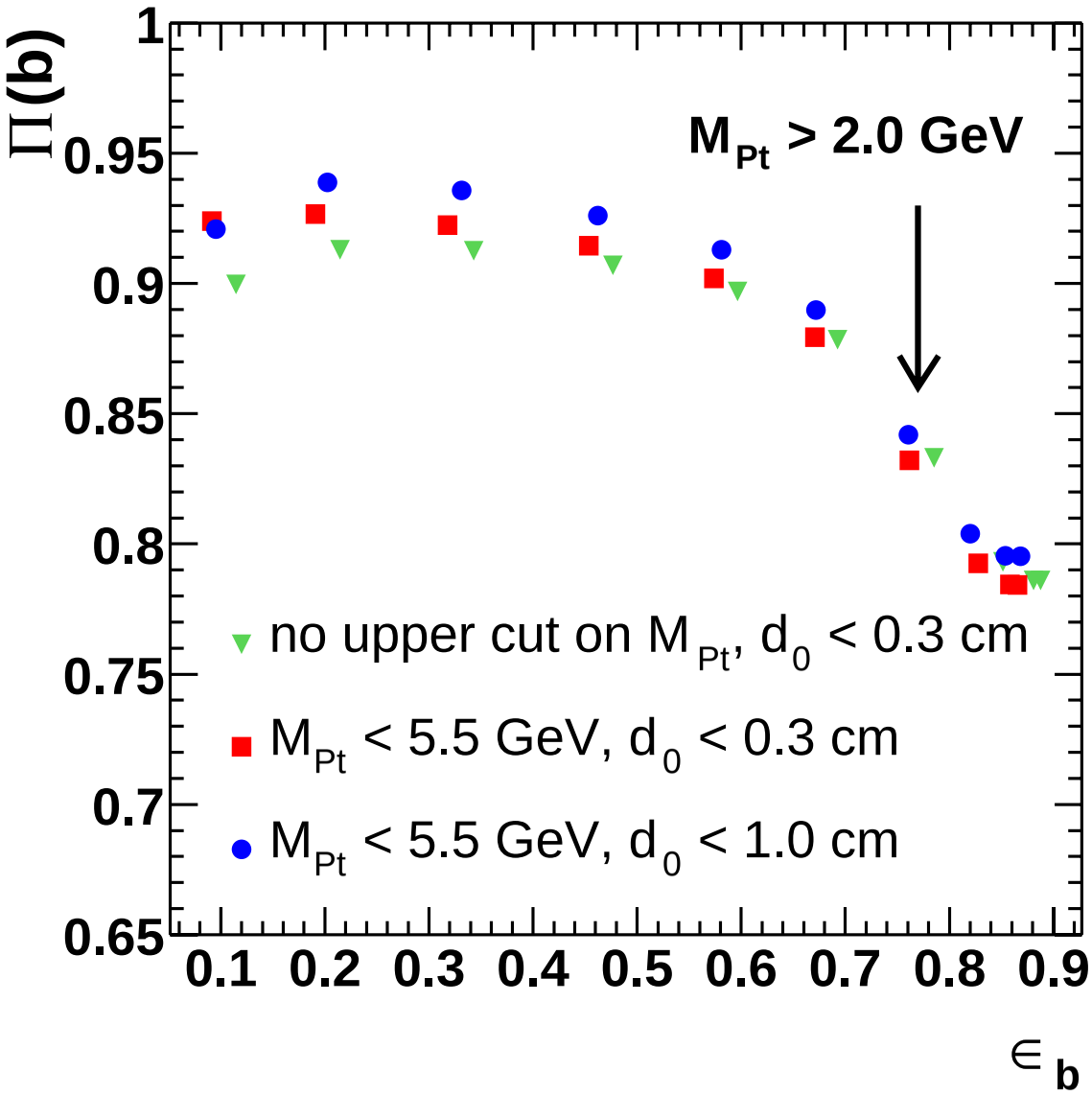
+ # (jets) from b-bar quark with $Q_{Vtx} = +1$



# Vertex charge: results

standard detector geometry, different versions of tagging and of track assignment:

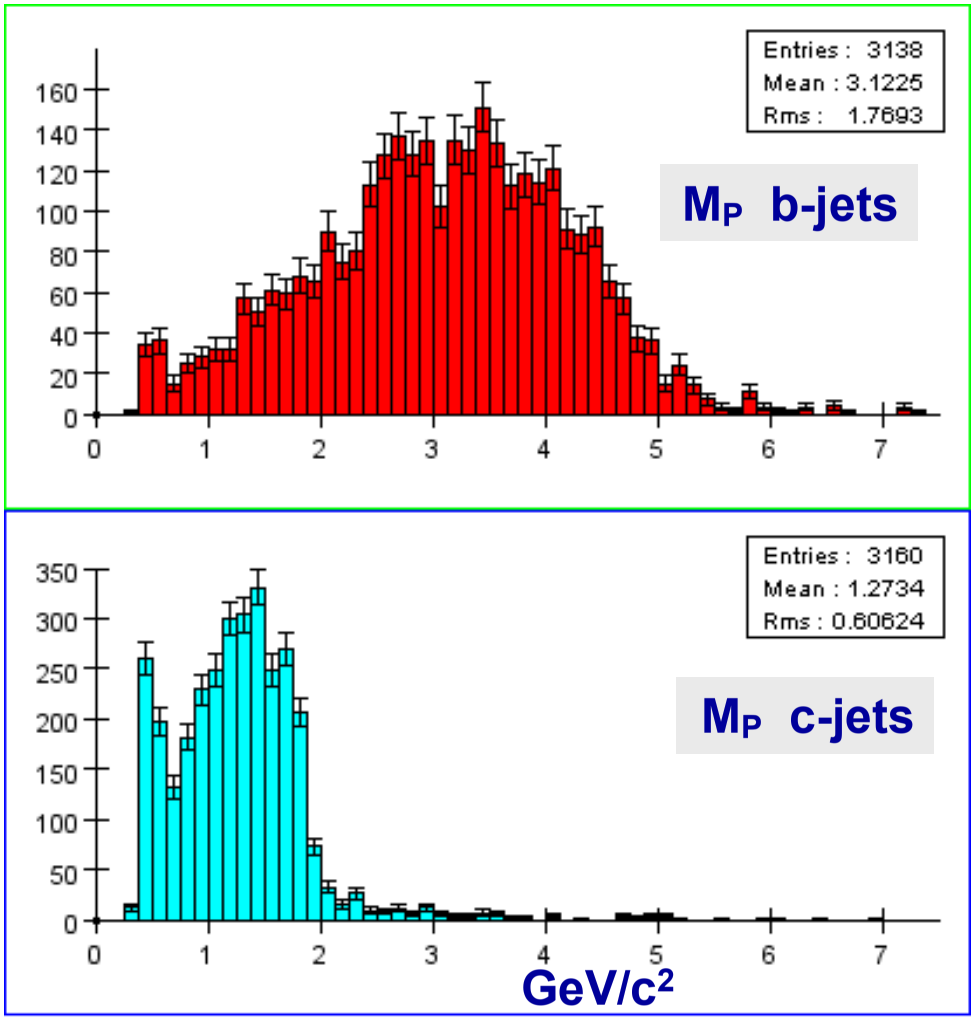
tagging and track assignment need to be optimised before detector geometries can be compared



# Explicit use of neutral information

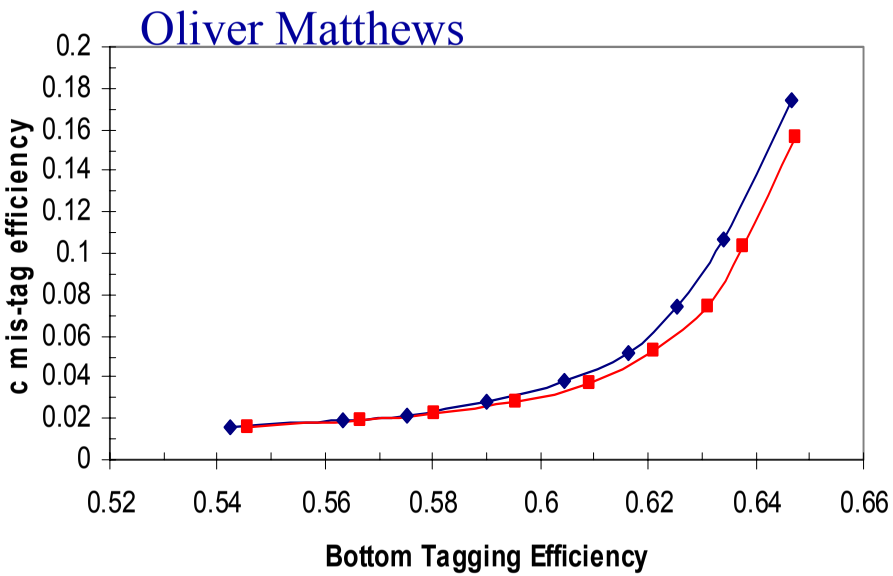
**preliminary feasibility study based on JAS3, neural-net approach**

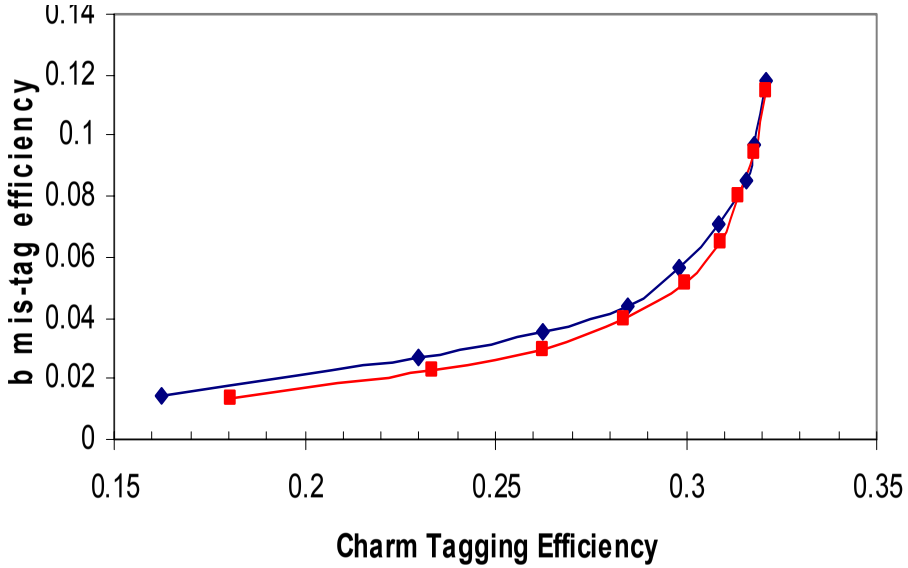
**Can non-vertex information, e.g. calorimeter, aid the performance ?**




- $Z^0 \rightarrow b\bar{b}, c\bar{c}$ events
- SiD detector simulation
- Java version of ZVTOP (by W. Walkowiak)
- use Neural Network (cjnn by S. Pathak) with vertex- and neutral information as input
- neutral information: highest energy $\pi^0$ in jet, using MC truth

# Using neutral information: results




**two neural networks compared:**

- 2 Inputs
  - $M_{PT}$ (Vertex)
  - Momentum (Vertex)
- 4 Inputs
  - $M_{PT}$ (Vertex + $\pi^0$)
  - Energy of $\pi^0$

**effect of adding highest energy $\pi^0$ information:**

- 1% increase in b-tag efficiency
- relative reduction of b-jet background to c-tag by 10-25%

# Summary

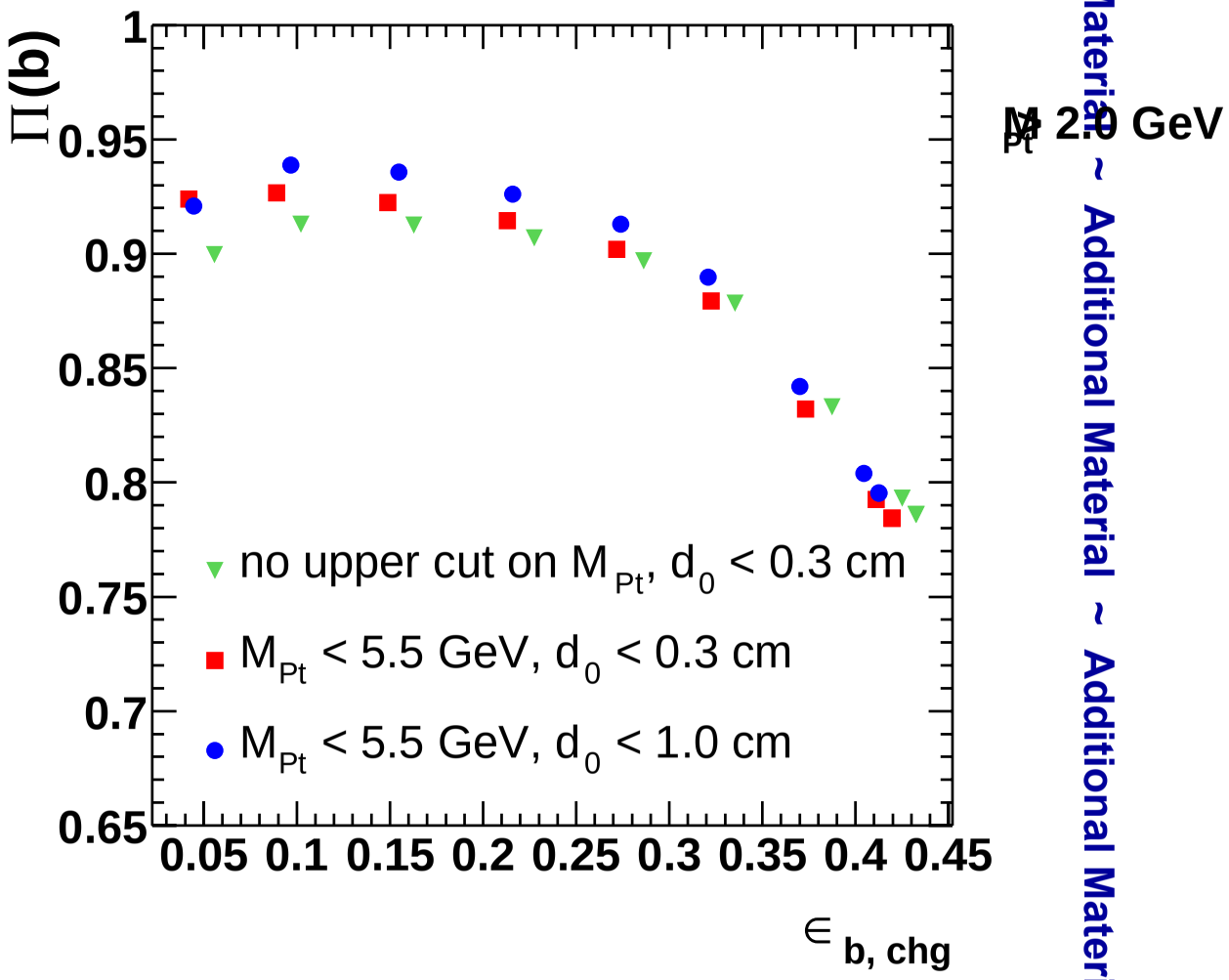
- impact parameter resolution degrades considerably with increasing beam-pipe radius

- study of vertex charge reconstruction in terms of purity vs efficiency shows dependence on methods to assign tracks to seed vertex and on jet flavour-tagging
  → these algorithms need to be optimised before effect of varying the detector geometry can be studied

- preliminary neural network study: adding highest energy $\pi^0$ information may improve b-tag efficiency and c-tag purity

# Vertex Charge: Modified Efficiency Definition

- purity based only on jets with reconstructed vertex charge < > 0
- when taking only these jets into account in the definition of efficiency (cf. plot), efficiencies considerably lower (large number of neutrals)

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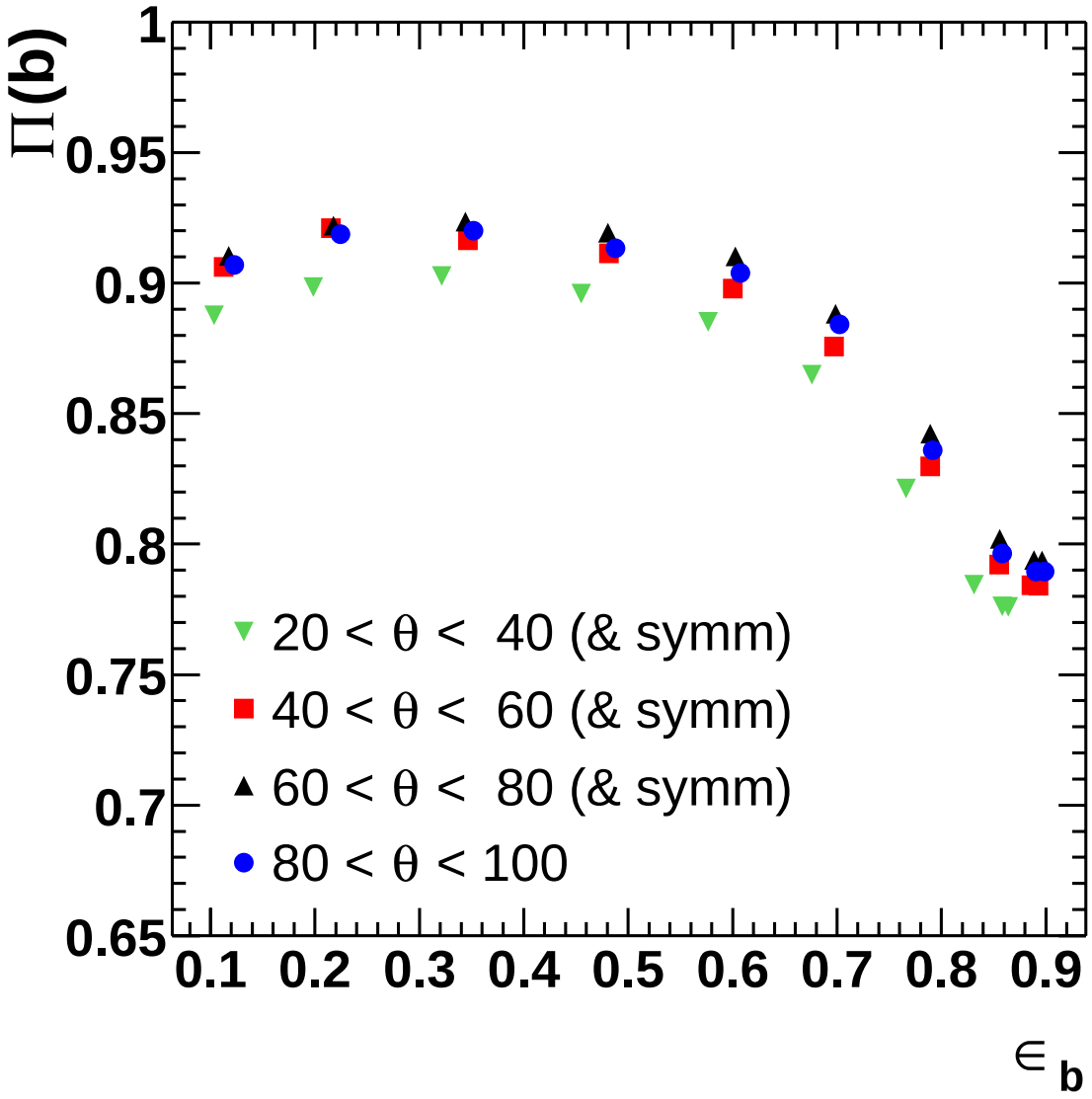
# Vertex Charge: Angular Dependence




purity plotted in ranges of thrust angle shows effect of loosing tracks at the edge of the detector

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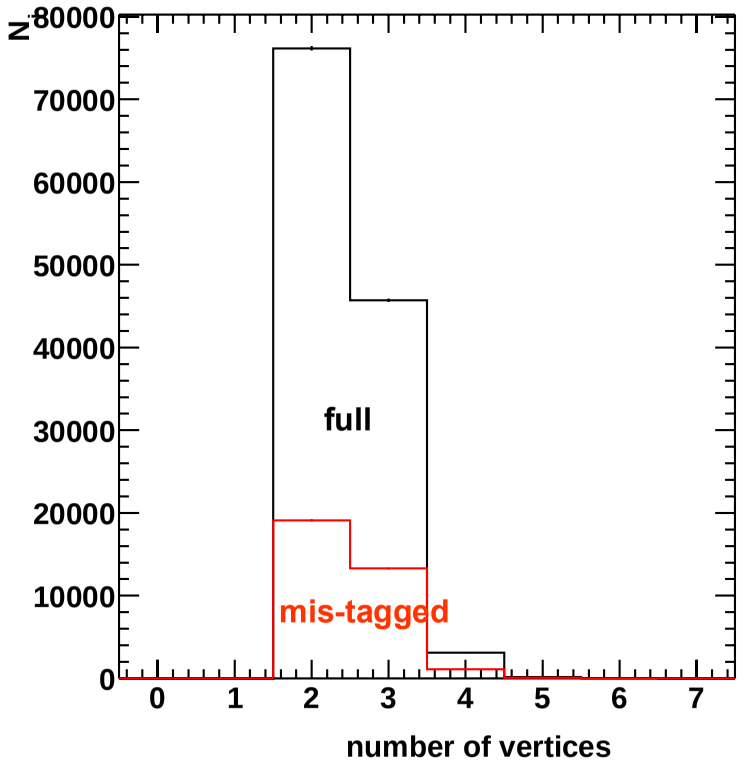
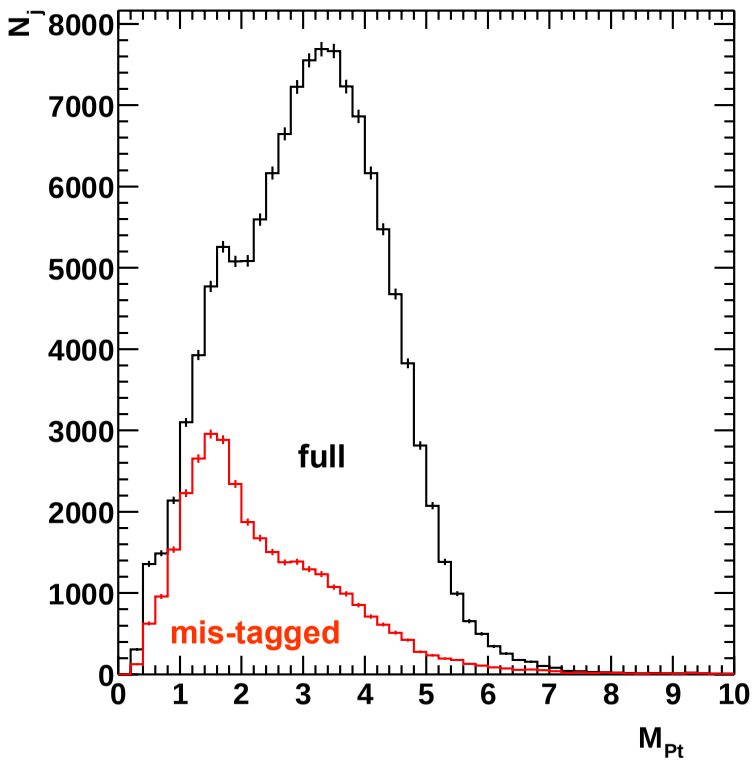
# Vertex Charge: Possible Improvements

**Compare mis-tagged jets to full sample:**




- mis-tagged jets more likely to be found in jets with low Pt-corrected mass
- might gain from running track assignment for primary vertex-associated tracks

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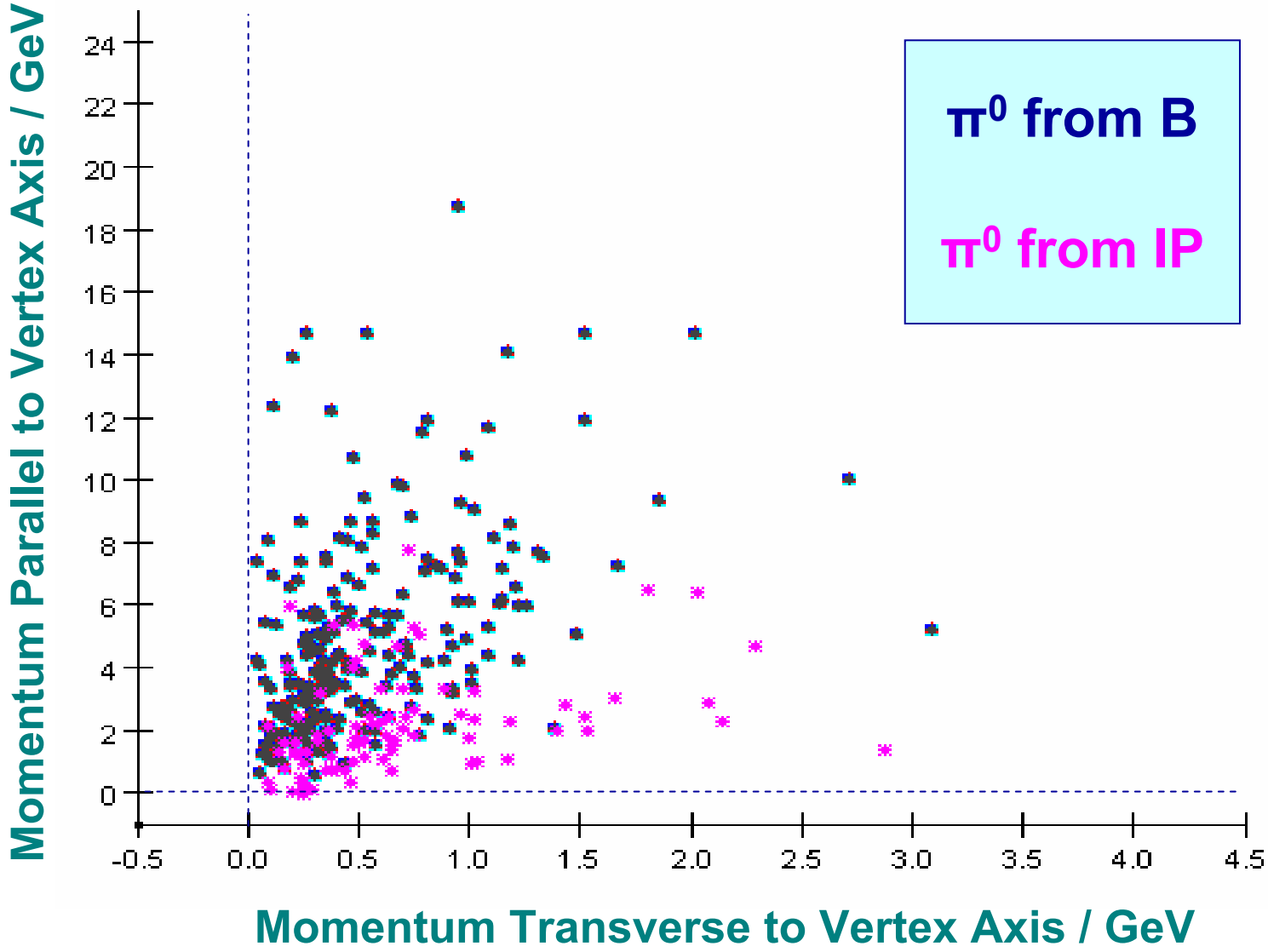
# Using neutral information: kinematics

**Kinematic properties of the highest energy $\pi^0$ from 45 GeV jets:**

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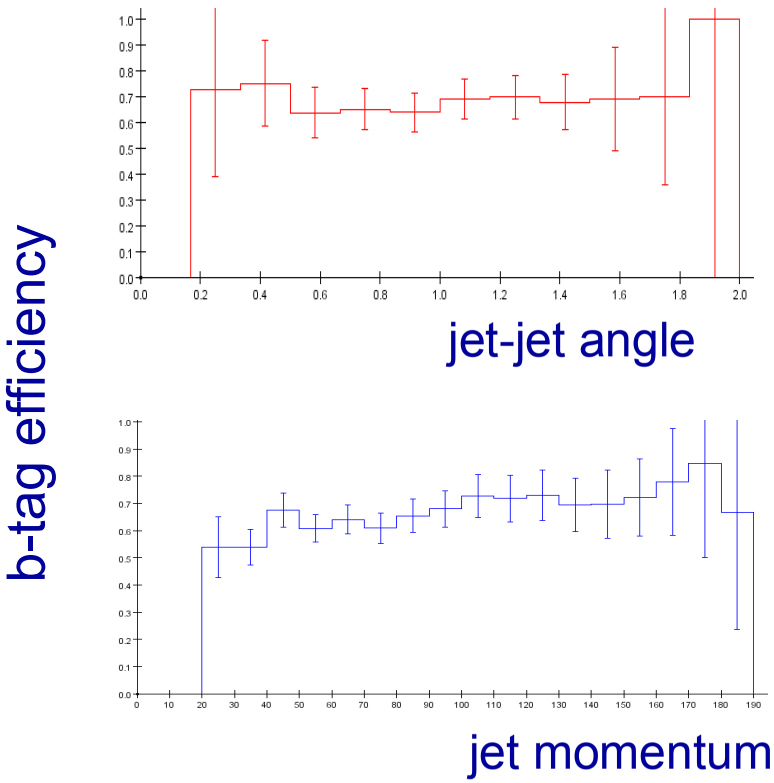
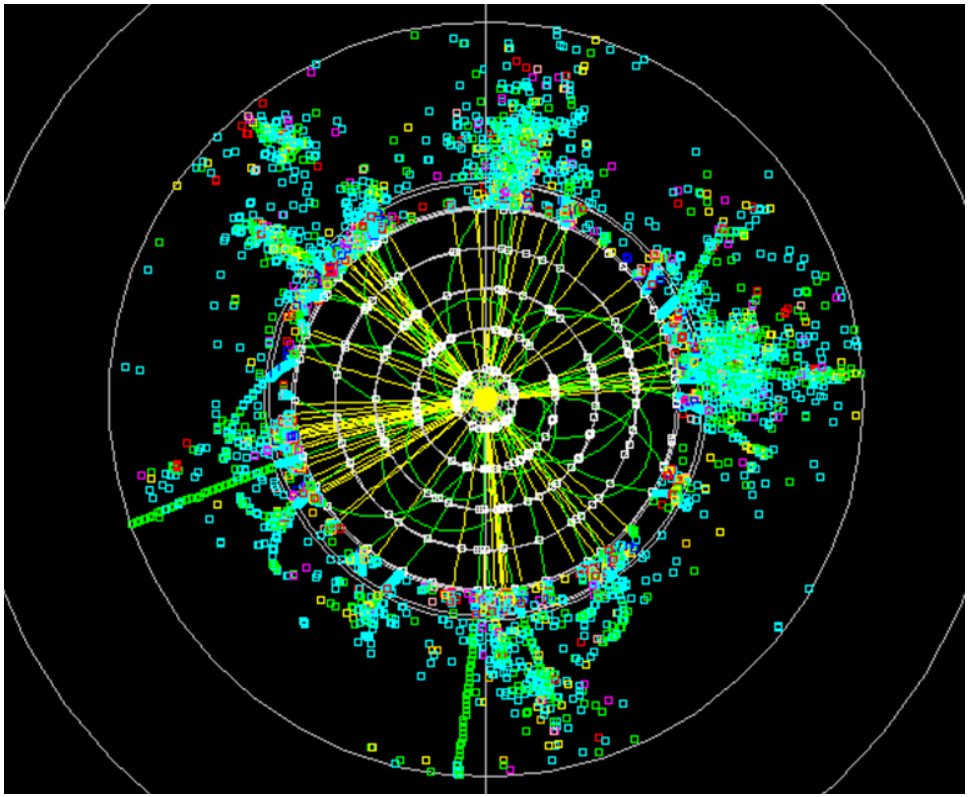
# b-tag efficiency in multijet events

Suzannah Merchant

**Zhh events**



**dependence of b-tag efficiency on energy more significant than dependence on angle between jets**

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