ALEPH gluon anomaly study

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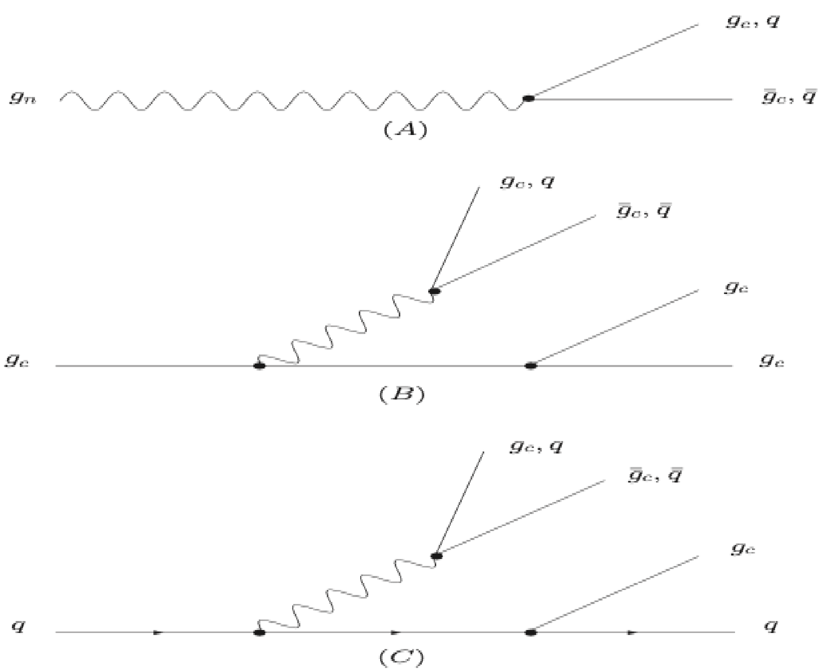
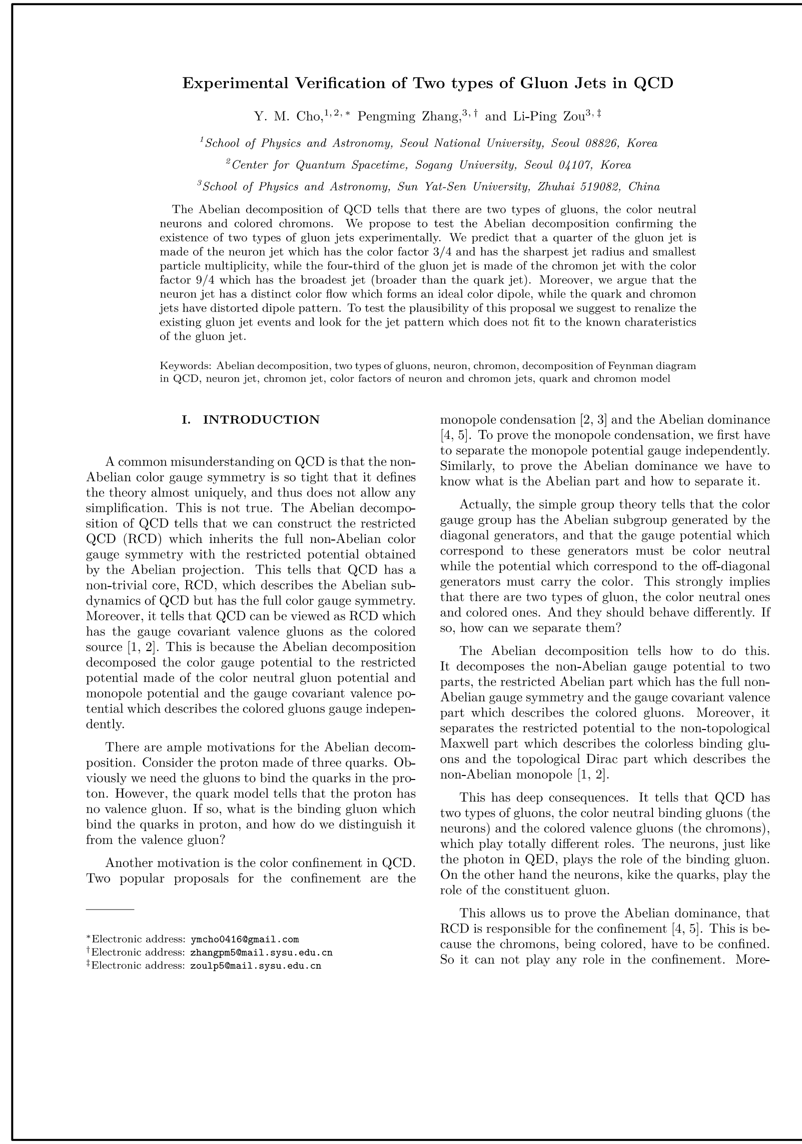
Inkyu Park, Youngkwon Jo et. al.

University of Seoul

Motivation

- **"Experimental verification of Two types of Gluon Jets in QCD"**
  - Y.M. Cho et al.





Experimental Verification of Two types of Gluon Jets in QCD

Y. M. Cho,[1,2,*] Pengming Zhang,[3,†] and Li-Ping Zou[3,‡]

[1]School of Physics and Astronomy, Seoul National University, Seoul 08826, Korea

[2]Center for Quantum Spacetime, Sogang University, Seoul 04107, Korea

[3]School of Physics and Astronomy, Sun Yat-Sen University, Zhuhai 519082, China

The Abelian decomposition of QCD tells that there are two types of gluons, the color neutral neurons and colored chromons. We propose to test the Abelian decomposition confirming the existence of two types of gluon jets experimentally. We predict that a quarter of the gluon jet is made of the neuron jet which has the color factor 3/4 and has the sharpest jet radius and smallest particle multiplicity, while the four-third of the gluon jet is made of the chromon jet with the color factor 9/4 which has the broadest jet (broader than the quark jet). Moreover, we argue that the neuron jet has a distinct color flow which forms an ideal color dipole, while the quark and chromon jets have distorted dipole pattern. To test the plausibility of this proposal we suggest to renalize the existing gluon jet events and look for the jet pattern which does not fit to the known charateristics of the gluon jet.

Keywords: Abelian decomposition, two types of gluons, neuron, chromon, decomposition of Feynman diagram in QCD, neuron jet, chromon jet, color factors of neuron and chromon jets, quark and chromon model

I. INTRODUCTION

A common misunderstanding on QCD is that the non-Abelian color gauge symmetry is so tight that it defines the theory almost uniquely, and thus does not allow any simplification. This is not true. The Abelian decomposition of QCD tells that we can construct the restricted QCD (RCD) which inherits the full non-Abelian color gauge symmetry with the restricted potential obtained by the Abelian projection. This tells that QCD has a non-trivial core, RCD, which describes the Abelian subdynamics of QCD but has the full color gauge symmetry. Moreover, it tells that QCD can be viewed as RCD which has the gauge covariant valence gluons as the colored source [1, 2]. This is because the Abelian decomposition decomposed the color gauge potential to the restricted potential made of the color neutral gluon potential and monopole potential and the gauge covariant valence potential which describes the colored gluons gauge independently.

There are ample motivations for the Abelian decomposition. Consider the proton made of three quarks. Obviously we need the gluons to bind the quarks in the proton. However, the quark model tells that the proton has no valence gluon. If so, what is the binding gluon which bind the quarks in proton, and how do we distinguish it from the valence gluon?

Another motivation is the color confinement in QCD. Two popular proposals for the confinement are the monopole condensation [2, 3] and the Abelian dominance [4, 5]. To prove the monopole condensation, we first have to separate the monopole potential gauge independently. Similarly, to prove the Abelian dominance we have to know what is the Abelian part and how to separate it.

Actually, the simple group theory tells that the color gauge group has the Abelian subgroup generated by the diagonal generators, and that the gauge potential which correspond to these generators must be color neutral while the potential which correspond to the off-diagonal generators must carry the color. This strongly implies that there are two types of gluon, the color neutral ones and colored ones. And they should behave differently. If so, how can we separate them?

The Abelian decomposition tells how to do this. It decomposes the non-Abelian gauge potential to two parts, the restricted Abelian part which has the full non-Abelian gauge symmetry and the gauge covariant valence part which describes the colored gluons. Moreover, it separates the restricted potential to the non-topological Maxwell part which describes the colorless binding gluons and the topological Dirac part which describes the non-Abelian monopole [1, 2].

This has deep consequences. It tells that QCD has two types of gluons, the color neutral binding gluons (the neurons) and the colored valence gluons (the chromons), which play totally different roles. The neurons, just like the photon in QED, plays the role of the binding gluon. On the other hand the neurons, kike the quarks, play the role of the constituent gluon.

This allows us to prove the Abelian dominance, that RCD is responsible for the confinement [4, 5]. This is because the chromons, being colored, have to be confined. So it can not play any role in the confinement. More-

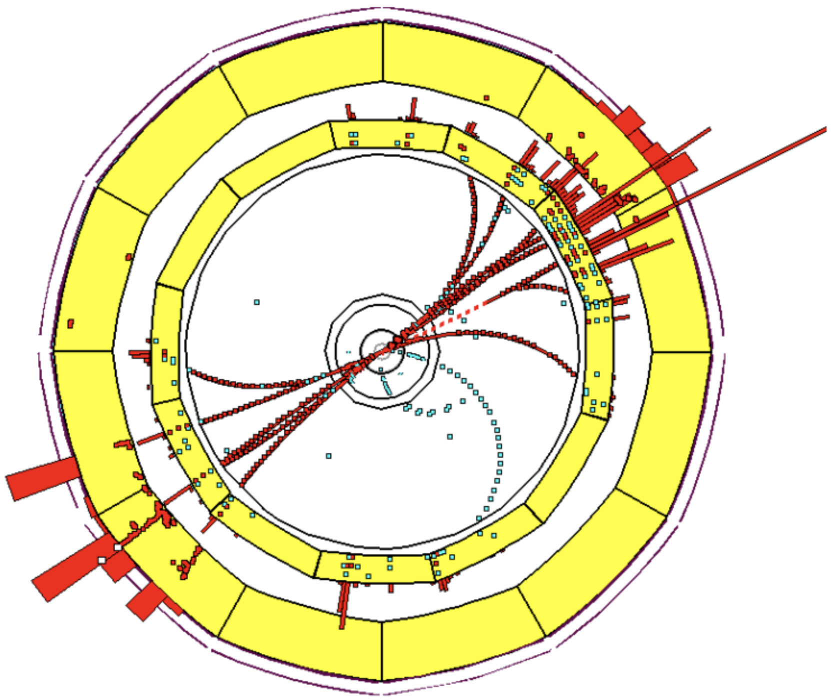
*Electronic address: ymcho0416@gmail.com
†Electronic address: zhangpm5@mail.sysu.edu.cn
‡Electronic address: zoulp5@mail.sysu.edu.cn

Gluon jet study @ LEP1

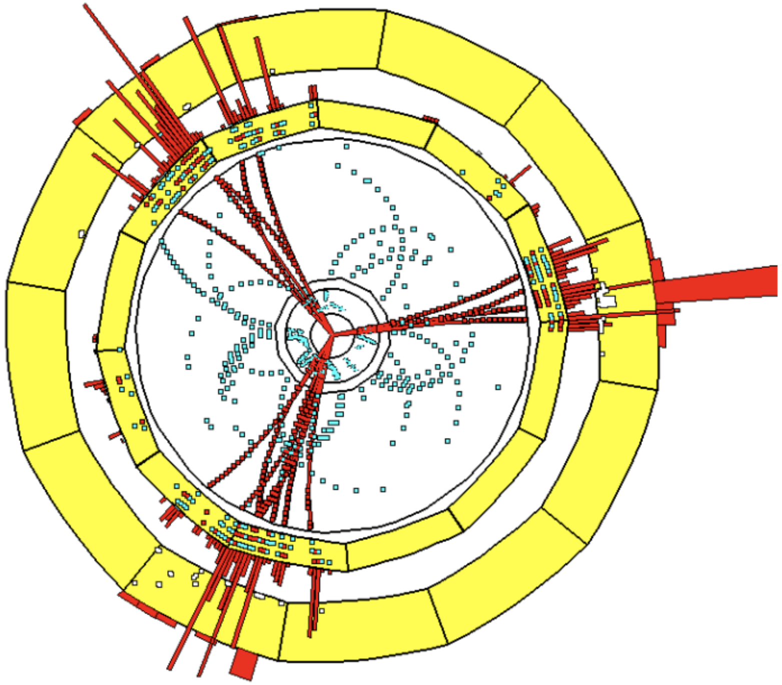
- **LEP1 : Z0 peak energy**
  - $e^+ + e^- \rightarrow (\gamma, Z^0) \rightarrow q\bar{q}$
    - ✓ $\sqrt{s} = 91\ GeV$
      - – Z mass
  - Pros and Cons
    - ✓ Pros: No initial state color → clean jets
      - – up to 90% purity!
    - ✓ Cons: difficult to access LEP data
      - – ALEPH, DELPHI, L3, OPAL

"But! You've got a friend"

ALEPH 2-jet vs 3-jet events

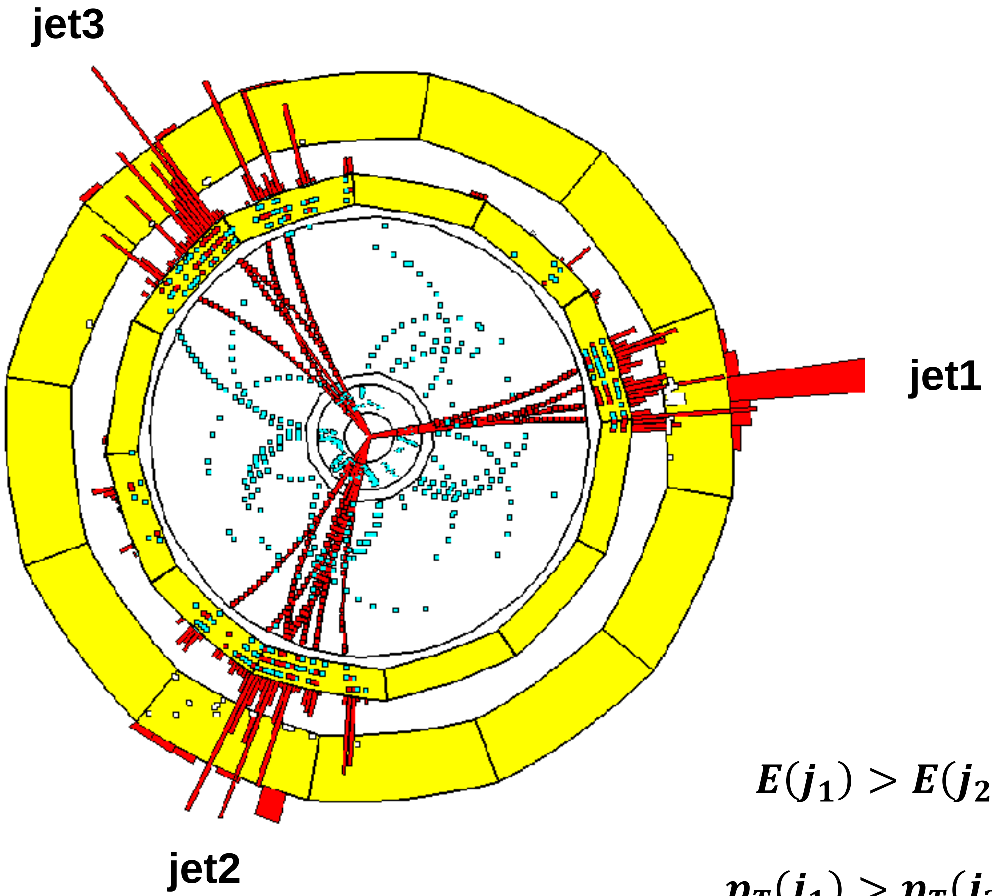


$e^+ + e^- \rightarrow q\bar{q}$



$e^+ + e^- \rightarrow q\bar{q}g$

$$e^{+} + e^{-} \rightarrow q\bar{q}g$$

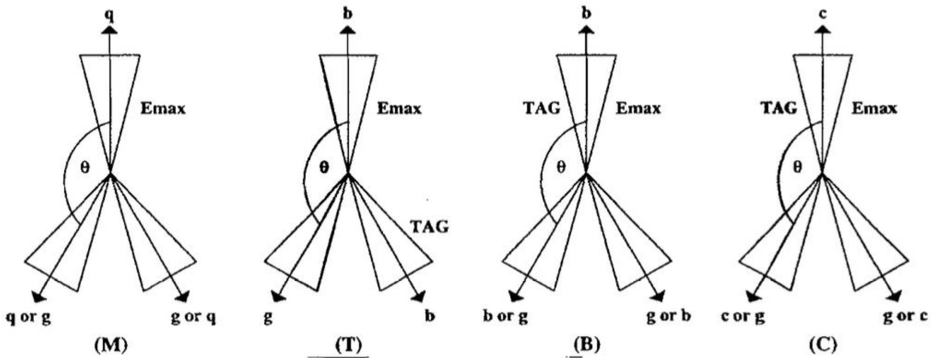


$$E(j_1) > E(j_2) > E(j_3)$$

$$p_T(j_1) > p_T(j_2) > p_T(j_3)$$

ALEPH study on gluon jets

- "Quark and Gluon jet properties in symmetric three-jet events"
  - **ALEPH 1996**
    - ✓ Phys. Lett. B 384, 353-364



Sample	Number of jets	*uds*	*c*	*b*	*g*
M (J2 and J3)	45280	31.4	8.8	11.3	48.5
T (J2 or J3)	2071	6.1	1.7	2.2	90.0
B (J2 and J3)	872	2.5	3.0	44.5	50.0
C (J2 and J3)	40	0	35	15	50

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ELSEVIER
19 September 1996
PHYSICS LETTERS B
Physics Letters B 384 (1996) 353–364

Quark and gluon jet properties in symmetric three-jet events

ALEPH Collaboration

D. Buskulic[a], D. Casper[a], I. De Bonis[a], D. Decamp[a], P. Ghez[a], C. Goy[a], J.-P. Lees[a], A. Lucotte[a], M.-N. Minard[a], P. Odier[a], B. Pietrzyk[a], M. Chmeissani[b], J.M. Crespo[b], I. Efthymiopoulos[b], E. Fernandez[b], M. Fernandez-Bosman[b], Ll. Garrido[b,15], A. Juste[b], M. Martinez[b], S. Orteu[b], A. Pacheco[b], C. Padilla[b], F. Palla[b], A. Pascual[b], J.A. Perlas[b], I. Riu[b], F. Sanchez[b], F. Teubert[b], A. Colaleo[c], D. Creanza[c], M. de Palma[c], A. Farilla[c], G. Gelao[c], M. Girone[c], G. Iaselli[c], G. Maggi[c,3], M. Maggi[c], N. Marinelli[c], S. Natali[c], S. Nuzzo[c], A. Ranieri[c], G. Raso[c], F. Romano[c], F. Ruggieri[c], G. Selvaggi[c], L. Silvestris[c], P. Tempesta[c], G. Zito[c], X. Huang[d], J. Lin[d], Q. Ouyang[d], T. Wang[d], Y. Xie[d], R. Xu[d], S. Xue[d], J. Zhang[d], L. Zhang[d], W. Zhao[d], R. Alemany[e], A.O. Bazarko[e], G. Bonvicini[e,23], M. Cattaneo[e], P. Comas[e], P. Coyle[e], H. Drevermann[e], R.W. Forty[e], M. Frank[e], R. Hagelberg[e], J. Harvey[e], R. Jacobsen[e,24], P. Janot[e], B. Jost[e], E. Kneringer[e], J. Knobloch[e], I. Lehraus[e], E.B. Martin[e], P. Mato[e], A. Minten[e], R. Miquel[e], Ll.M. Mir[e,2], L. Moneta[e], T. Oest[e], P. Palazzi[e], J.R. Pater[e,27], J.-F. Pusztaszeri[e], F. Ranjard[e], P. Rensing[e], L. Rolandi[e], D. Schlatter[e], M. Schmelling[e], O. Schneider[e], W. Tejessy[e], I.R. Tomalin[e], A. Venturi[e], H. Wachsmuth[e], T. Wildish[e], W. Witzeling[e], J. Wotschack[e], Z. Ajaltouni[f], A. Barrès[f], C. Boyer[f], A. Falvard[f], P. Gay[f], C. Guicheney[f], P. Henrard[f], J. Jousset[f], B. Michel[f], S. Monteil[f], J-C. Montret[f], D. Pallin[f], P. Perret[f], F. Podlyski[f], J. Proriol[f], J.-M. Rossignol[f], T. Fearnley[g], J.B. Hansen[g], J.D. Hansen[g], J.R. Hansen[g], P.H. Hansen[g], B.S. Nilsson[g], A. Wäänänen[g], A. Kyriakis[h], C. Markou[h], E. Simopoulou[h], I. Siotis[h], A. Vayaki[h], K. Zachariadou[h], A. Blondel[i,21], G. Bonneaud[i], J.C. Brient[i], P. Bourdon[i], A. Rougé[i], M. Rumpf[i], R. Tanaka[i], A. Valassi[i,6], M. Verderi[i], H. Videau[i,21], D.J. Candlin[j], M.I. Parsons[j], E. Focardi[k], G. Parrini[k], M. Corden[ℓ], M. Delfino[ℓ,12], C. Georgiopoulos[ℓ], D.E. Jaffe[ℓ], A. Antonelli[m], G. Bencivenni[m], G. Bologna[m,4], F. Bossi[m], P. Campana[m], G. Capon[m], V. Chiarella[m], G. Felici[m], P. Laurelli[m], G. Mannocchi[m,5], F. Murtas[m], G.P. Murtas[m], L. Passalacqua[m], M. Pepe-Altarelli[m], L. Curtis[n], S.J. Dorris[n], A.W. Halley[n], I.G. Knowles[n], J.G. Lynch[n], V. O'Shea[n], C. Raine[n], P. Reeves[n], J.M. Scarr[n], K. Smith[n], A.S. Thompson[n], F. Thomson[n], S. Thorn[n], R.M. Turnbull[n], U. Becker[o], O. Braun[o], C. Geweniger[o], G. Graefe[o], P. Hanke[o], V. Hepp[o], E.E. Kluge[o], A. Putzer[o], B. Rensch[o], M. Schmidt[o], J. Sommer[o], H. Stenzel[o], K. Tittel[o], S. Werner[o], M. Wunsch[o], D. Abbaneo[p], R. Beuselinck[p], D.M. Binnie[p], W. Cameron[p], D.J. Colling[p],

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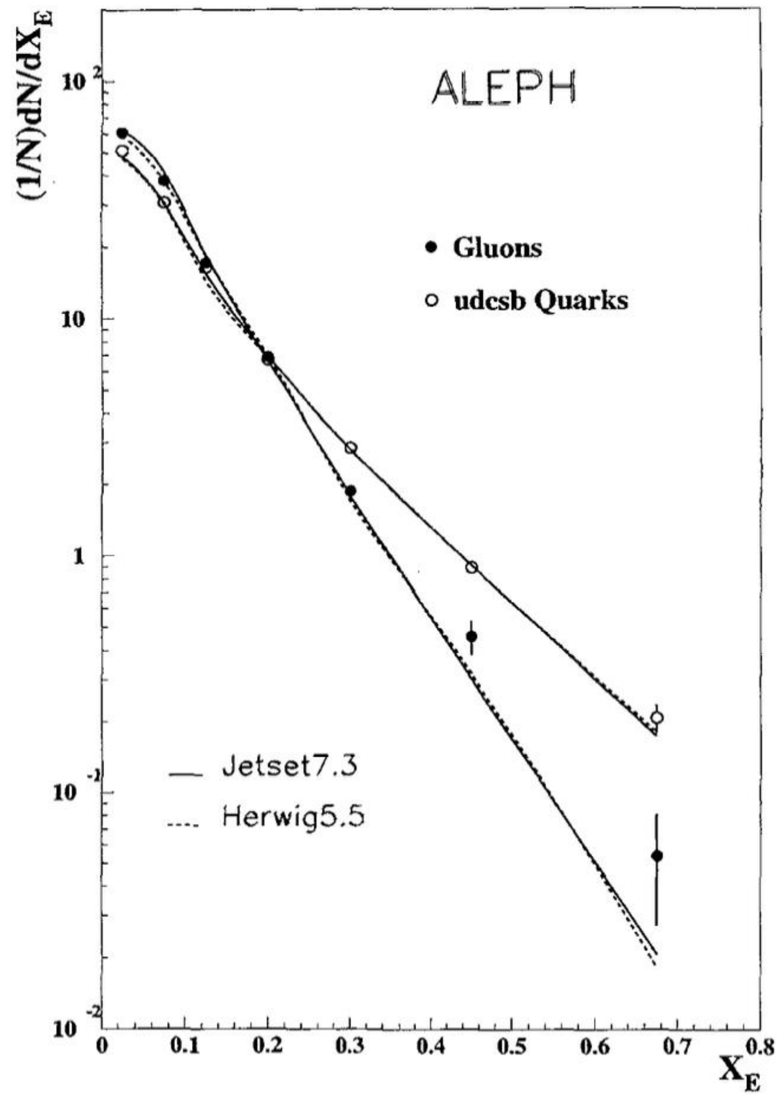
X_E

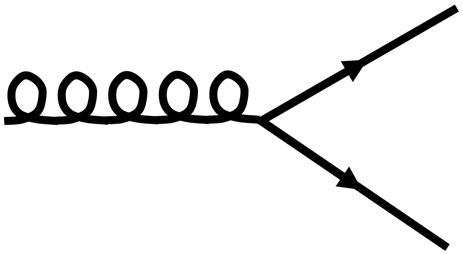
- Fragmentation function
  - like Björken x
    - ✓ $X_E = \frac{E_p}{E_j}$
    - $\frac{1}{N}\frac{dN}{dX_E}$ as a function of X_E
      - Gluons are softer
      - Quarks are harder
    - ✓ charged, neutral, all tracks



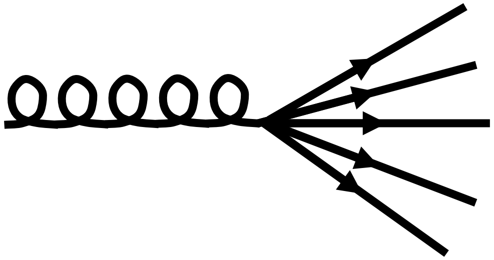
ALEPH gluons

What if?

- if
  - Color neutral gluons → few chunks



  - Colored gluons → many fragments

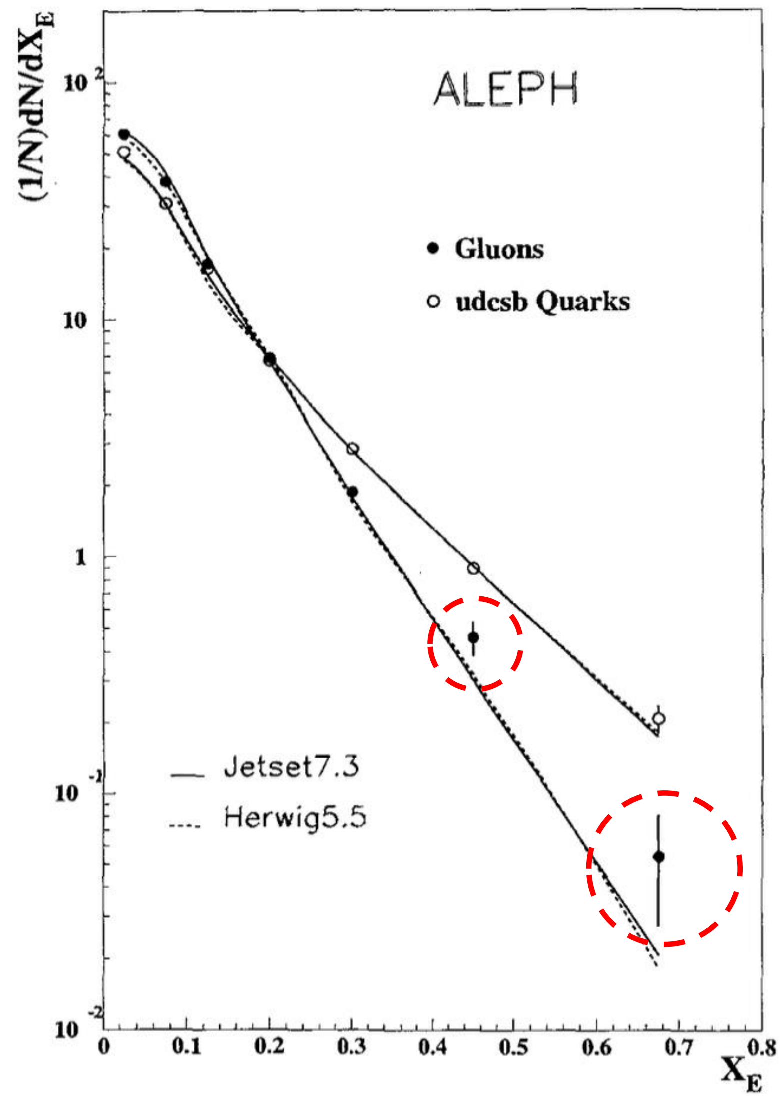


then

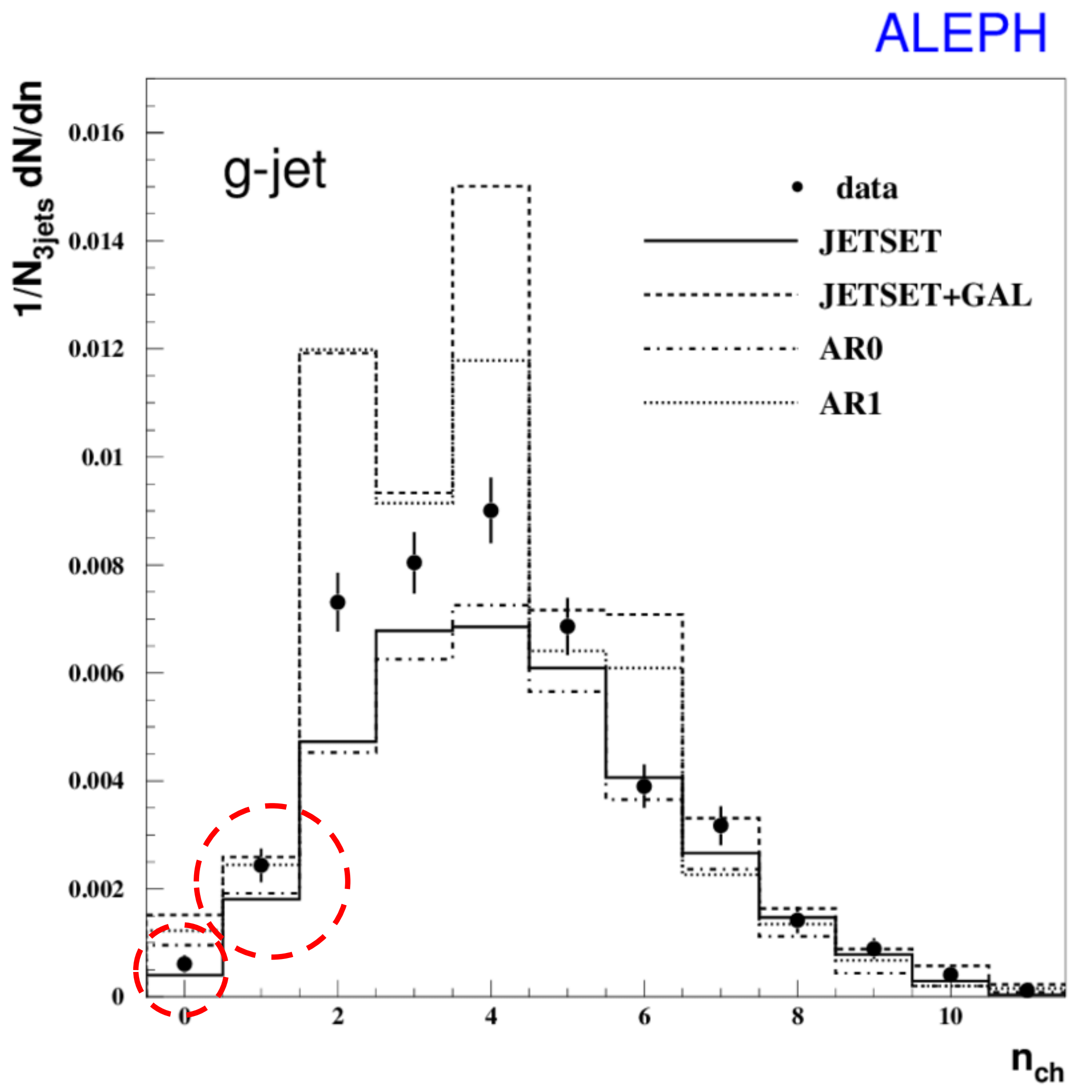
- **then**
  - **lose color neutral gluons**
    - ✓ **may not be reconstructed as jets**
      - **need to save those jets**
  - **show an excess in the small number of tracks**
    - ✓ **check this easily by seeing # of track of jets**
  - **Jet shapes can be differents**
    - ✓ **narrow jet (neurons) .vs. broad jet (chromons)**
  - **Energy shares of tracks**
    - ✓ **high share (neurons) .vs. low share (chromons)**

Expectation

- Neurons
  - few end products
    - ✓ excess in high X_E
- Chromons
  - many end products
    - ✓ excess in low X_E
- ALEPH already saw it?



nch



The charged multiplicity distribution of anti-b tagged gluon jets with a rapidity gap in $0 \le y \le 1.5$.

Reanalyzing ALEPH gluons

Event selection

- **Basic ALEPH event selections**
  - **S1 : Hadronic event selection**
    - ✓ $N_{trk} \geq 13, \quad N_{chg} \geq 5, \quad \Sigma E_{chg} \geq 15\ \mathrm{GeV}$
  - **S2 : 3-jet event selection**
    - ✓ $N_{jets} = 3 \quad (E_j > 10\ \mathrm{GeV})$
  - **S3 : 3-jet geometry selection**
    - ✓ $\theta_{12}, \theta_{13}, \theta_{23}$
      - $\theta_{12}, \theta_{13} = 150° \pm 7.5°$ **(ALEPH)**
      - $\theta_{12}, \theta_{13} = 150° \pm 15°$ **(Ana1)**
      - $\theta_{12}, \theta_{13} > 120°\ \&\ 30° < \theta_{23} < 90°$ **(Ana2)**
  - **S4 : b-jet tagging**
    - ✓ Only one of J2 and J3 must be a b-jet

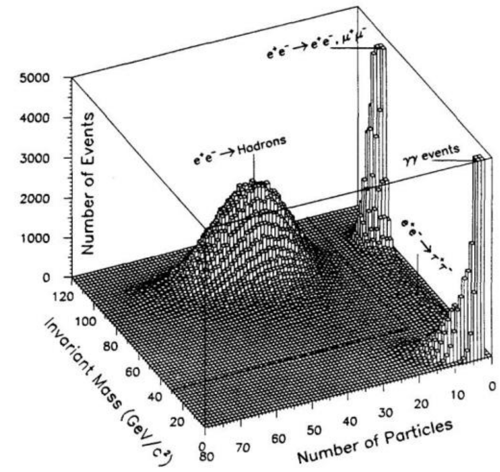
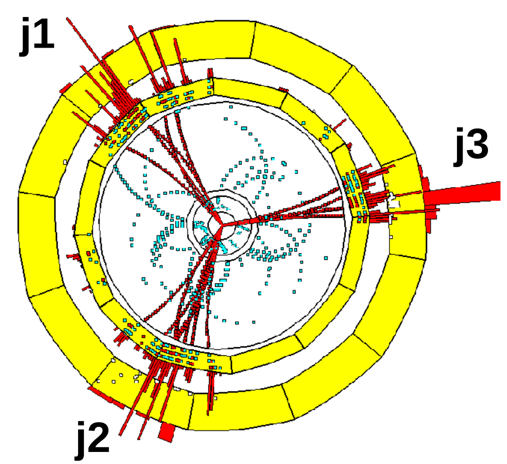
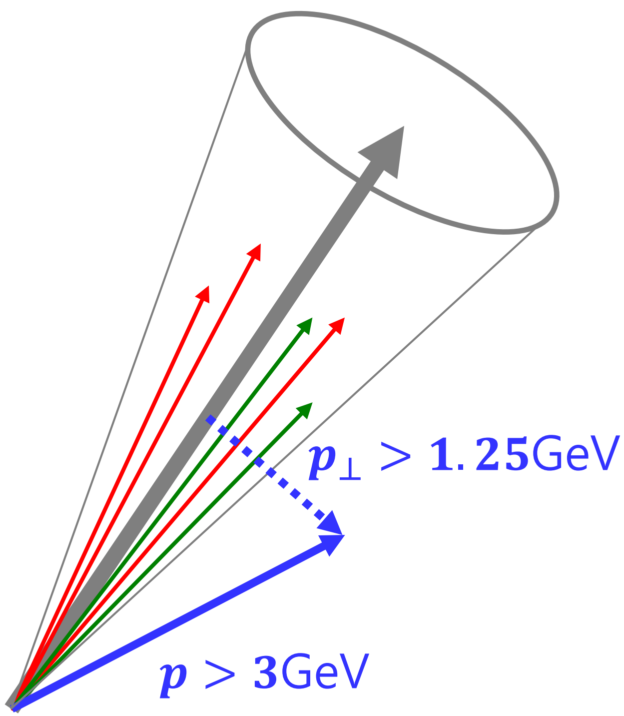


Figure 25: Invariant mass versus number of particles for all the events with at least two charged particle tracks, from part of the 1992 ALEPH data. The two low-multiplicity peaks have been truncated.



b-tagging

- **lepton $p > 3\text{GeV}$**
- **lepton $p_\perp > 1.25\text{GeV}$**



4.2.2. The B sample: Lepton tag

The presence of a high transverse momentum ($P_\perp$) lepton has been widely used in the tagging of heavy flavour events and a standard lepton selection definition [15] exists within the ALEPH collaboration. Electrons and positrons were selected using the dE/dx capabilities of the TPC and estimators based on the shape of the energy depositions in the ECAL. Muons were selected according to digital hit information recorded by the HCAL and the muon chambers. The minimum momentum of any selected lepton was 3 GeV/c. In turn, the momentum of each selected lepton was removed from its jet and its $P_\perp$ was calculated with respect to the resulting jet axis. This is known as the exclusive transverse momentum ($P_\perp^{\text{excl}}$) of the lepton.

The B sample was selected by requiring the presence of a lepton with $P_\perp^{\text{excl}} > 1.25$ GeV/c in the highest energy jet. According to Jetset the flavour composition of this sample was: $88.9 \pm 1.2\%$ b, $6.1 \pm 1.1\%$ c and 5% uds. The errors on these coefficients are mainly systematic. They arise primarily from the uncertainties in the Monte Carlo simulation of the b and c fragmentation, lepton decay spectra and are estimated as in [16].

Event selections

- **ALEPH (1992-1994) : $\theta_{12}, \theta_{13} = 150° \pm 7.5°$**

Selection(E>10)	Data(EeGenKT5)	MC(EeGenKT5)	MCgen(EeGenKT5)
S0: *Total*	2455515	973769	973769
S1: $N_t >= 13$, $N_c >= 5$, $\sum E_c >= 15$ GeV	2435374	767769	971683
S2: Number of jets($E > 10$) == 3	339232	115581	107495
S3: $142.5 < ang_{j1j2}, ang_{j1j3} < 157.5$	22336	7943	8769
S4: only one btag in 2nd/3rd jets	2567	911	1109

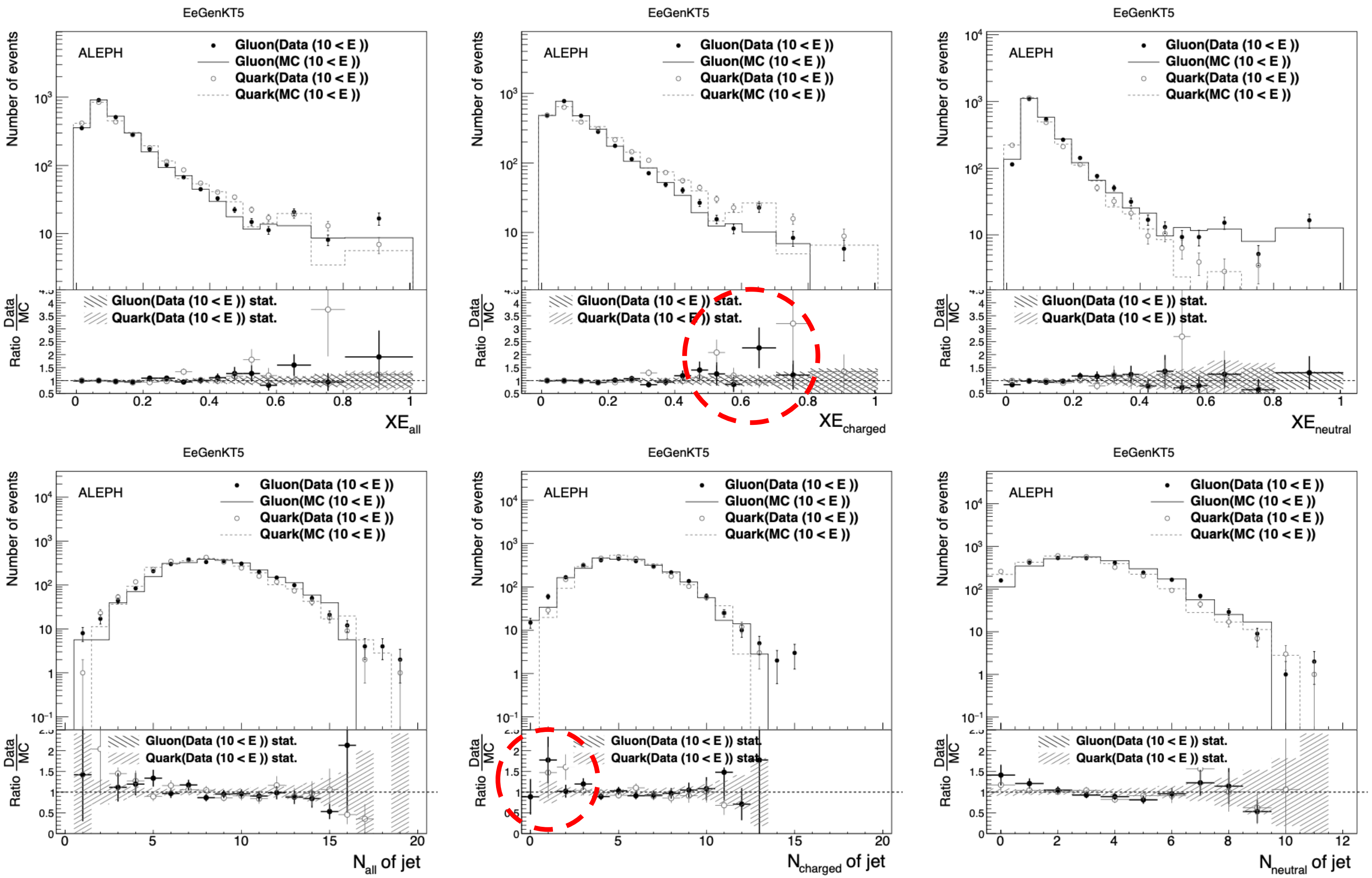
- **Ana1 (1992-1994) : $\theta_{12}, \theta_{13} = 150° \pm 15°$**

Selection(E>10)	Data(EeGenKT5)	MC(EeGenKT5)	MCgen(EeGenKT5)
S0: *Total*	2455515	973769	973769
S1: $N_t >= 13$, $N_c >= 5$, $\sum E_c >= 15$ GeV	2435374	767769	971683
S2: Number of jets($E > 10$) == 3	339232	115581	107495
S3: $135 < ang_{j1j2}, ang_{j1j3} < 165$	1100124	35082	39276
S4: only one btag in 2nd/3rd jets	11860	3982	4756

- **Ana2 (1991-1995) : $\theta_{12}, \theta_{13} > 120° \,\&\, 30° < \theta_{23} < 90°$**

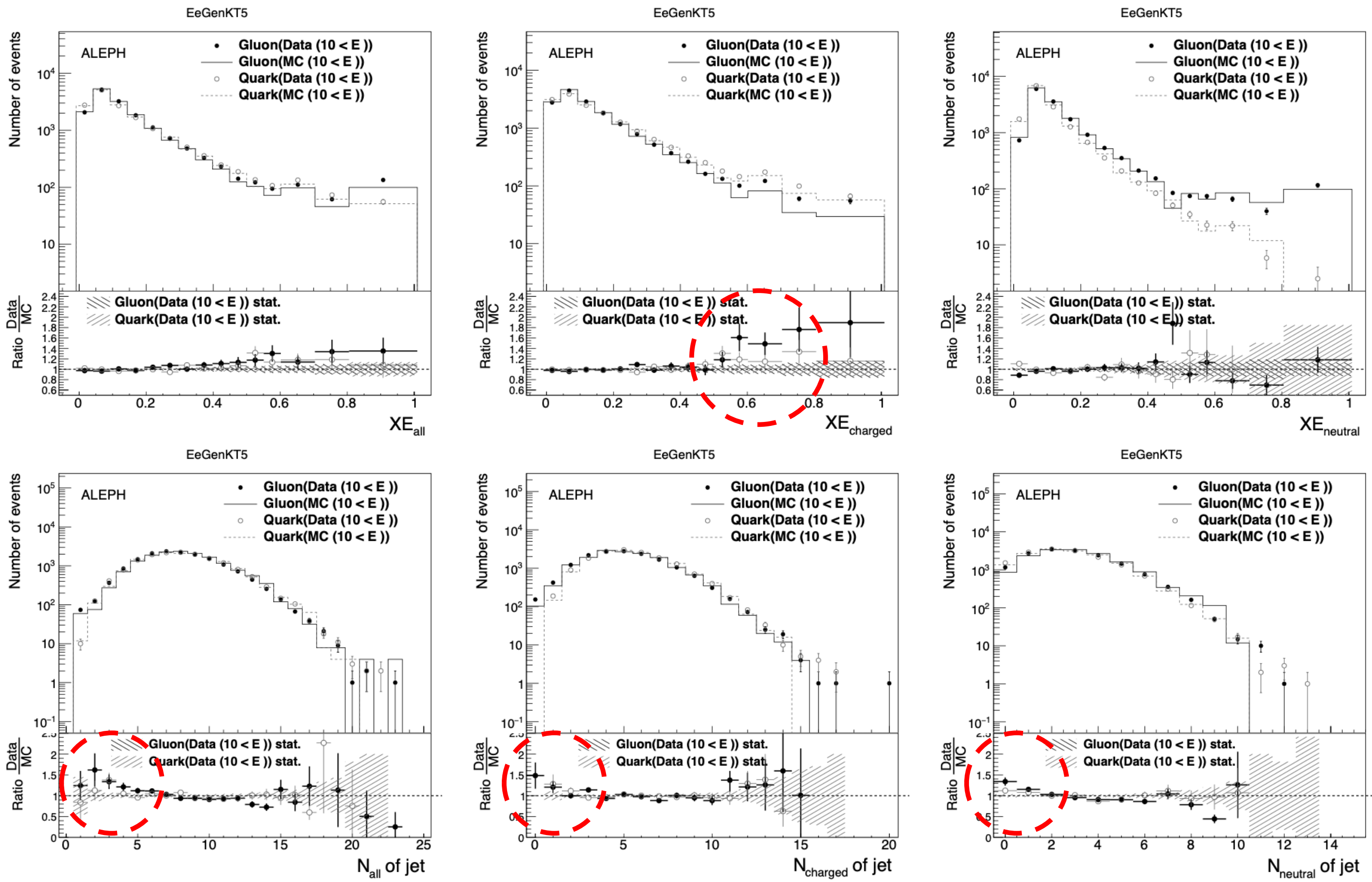
Selection(E>10)	Data(EeGenKT5)	MC(EeGenKT5)	MCgen(EeGenKT5)
S0: Total	3281123	973769	973769
S1: $N_t >= 13$, $N_c >= 5$, $\sum E_c >= 15$ GeV	3254128	767769	971683
S2: Number of jets($E > 10$) == 3	453885	115581	107495
S3: $120 < ang_{j1j2}, ang_{j1j3} AND 30 < ang_{j2j3} < 90$	305116	78235	84308
S4: only one btag in 2nd/3rd jets	36632	9218	10177

ALEPH analysis revisited



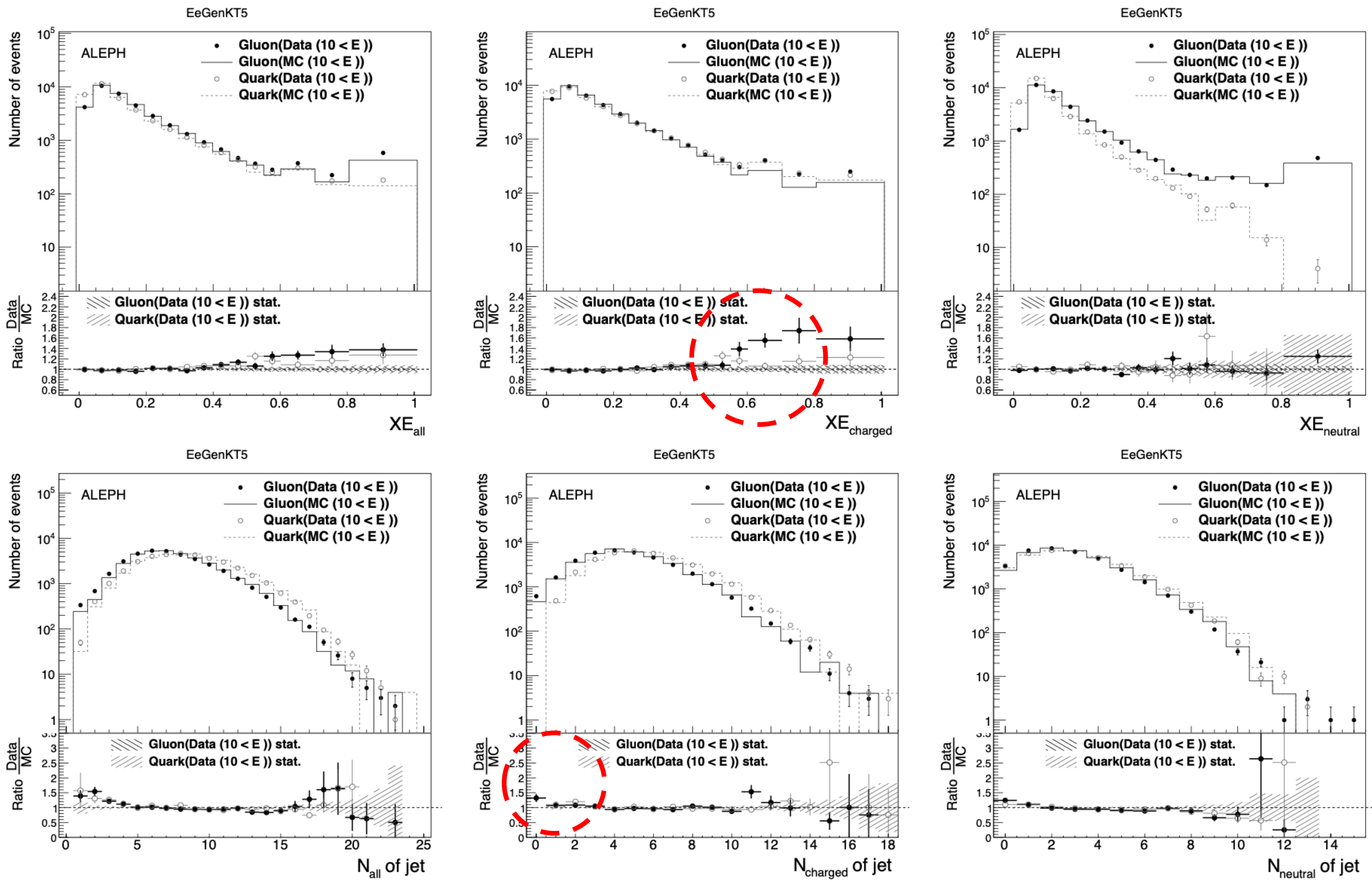
There is no noticeable tendency to exceed

Analysis 1



Data excess appears

Analysis 2



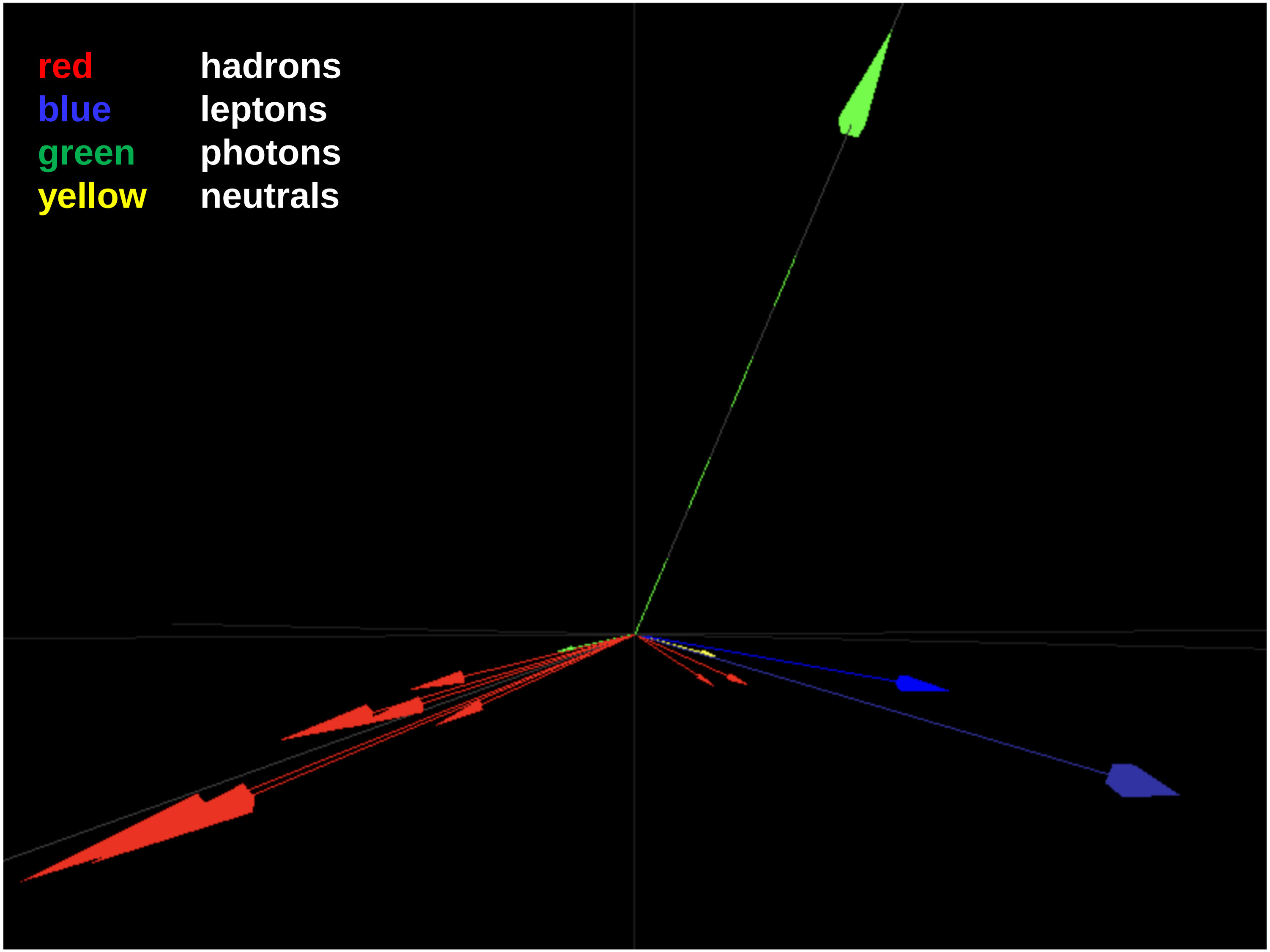
Data excess appears

Our obsevations & implications

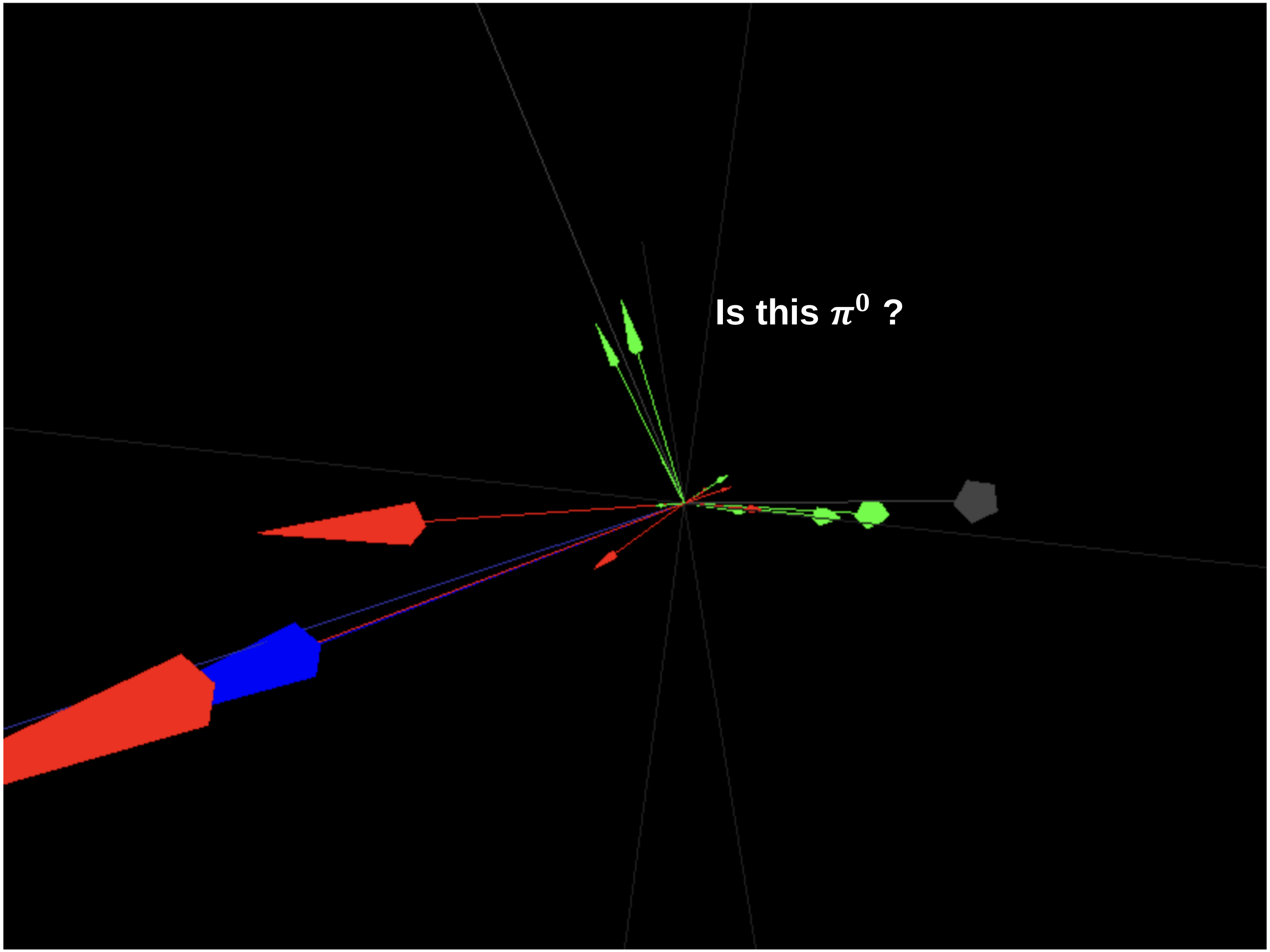
- **Data excesses in gluon jets**
  - X_E
    - ✓ Compared to MC, there are more charged tracks in t he data that take a large energy share.
  - N_{chg}
    - ✓ Compared to MC, more gluon-like jets without a cha rged track are found in the data.
- **Implications**
  - **It is unclear whether this is simply MC's fault or if there is any gluon anomaly in the data.**
    - ✓ MC tuning for fragmentations is required.
    - ✓ Can this be natually explained by Cho-gluon theory?

Jo’s Event display
for
gluons without a charged track

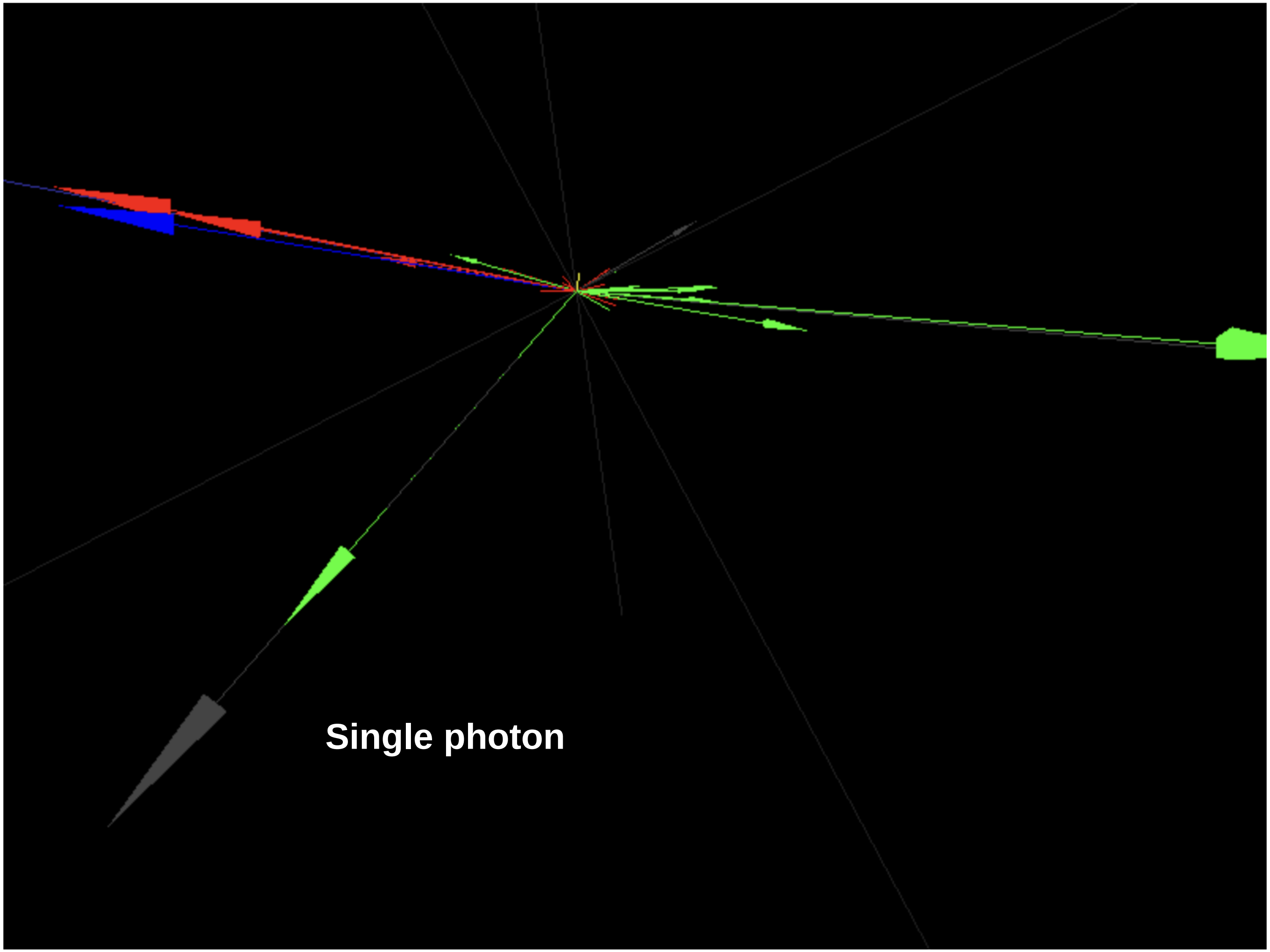
EventNo:3599, RunNo:10638



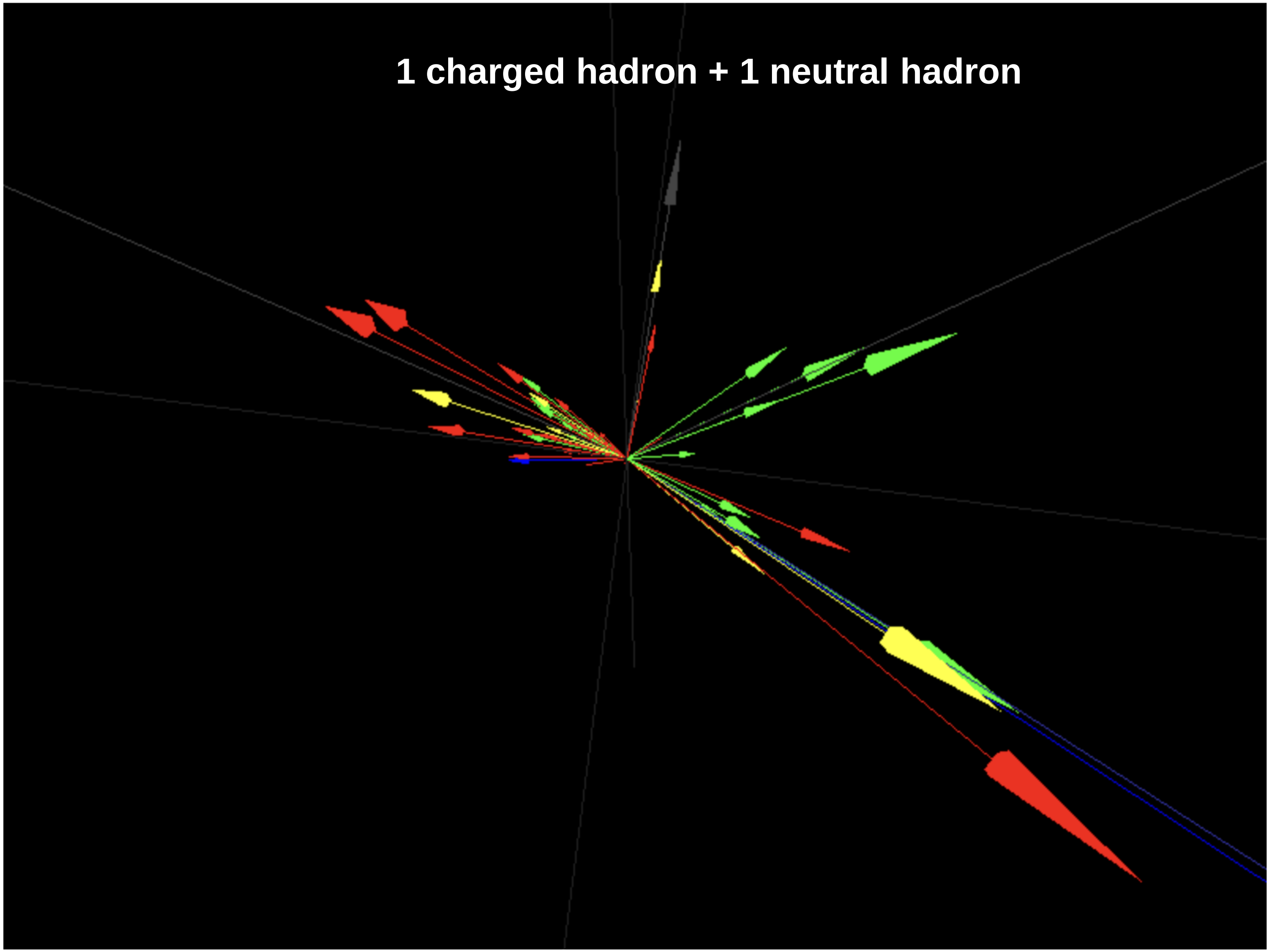
EventNo:4968, RunNo:12515



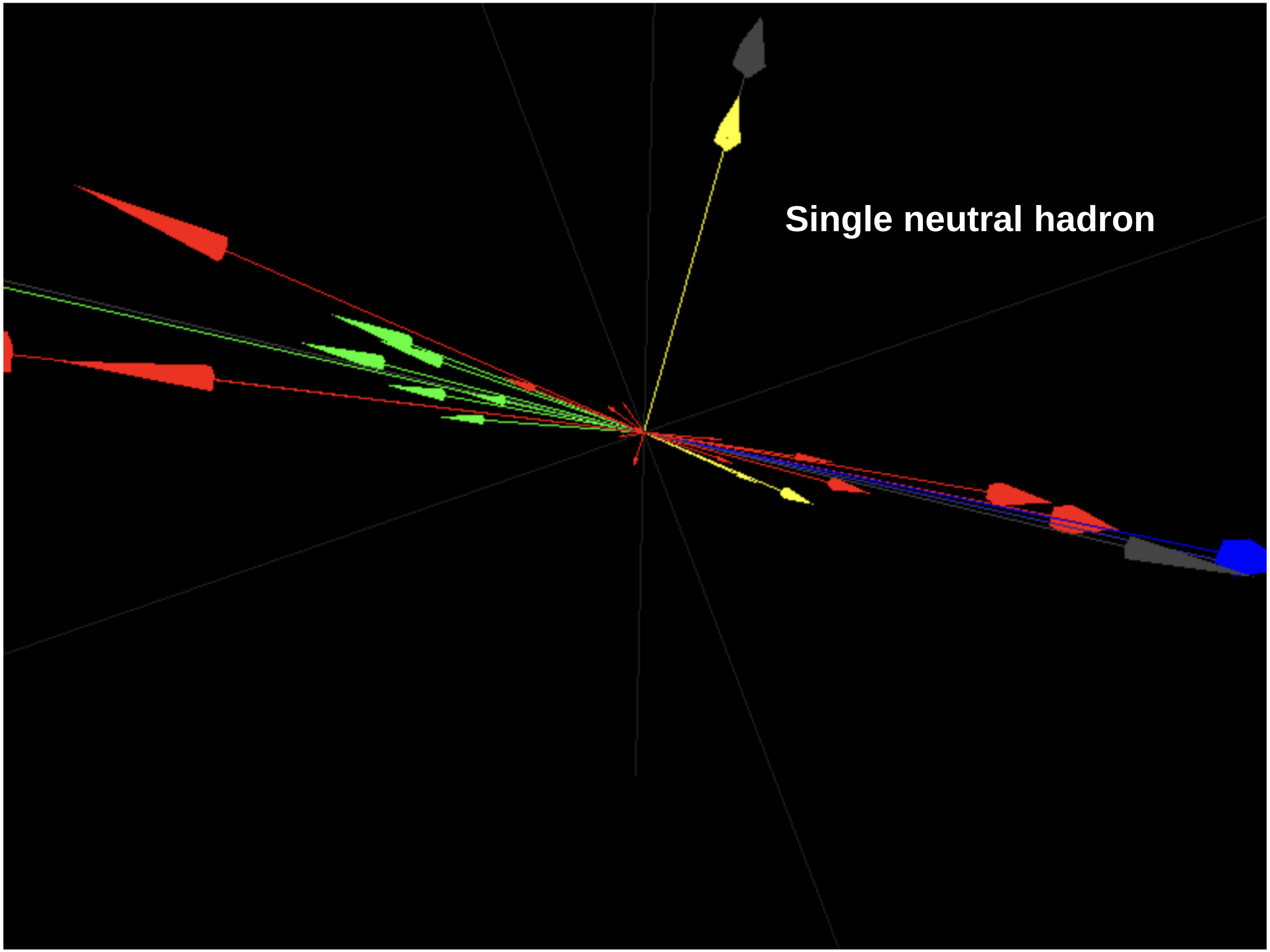
EventNo:1465, RunNo:12712



EventNo:2092, RunNo:12728

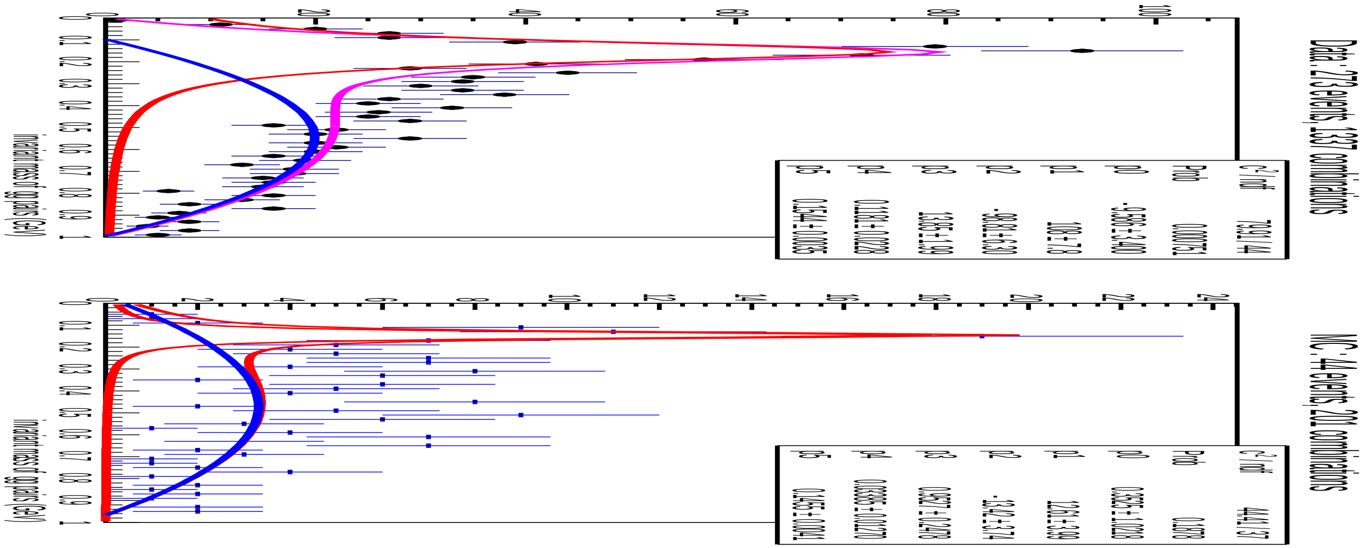


EventNo:1863, RunNo:22560



gluons without a charged track

- **two photon mass**



- **such gluons have pi0, however no notice able difference is found**

Conclusions

- **We followed ALPEH's previous analysis.**
  - Similar results were obtained.
- **We applied looser requirements than ALEPH to find any unusual gluons.**
  - There are more gluons with charged tracks with a large en ergy share in the data compared to MC
  - Neutral gluons, which do not have a charged track, are mo re abundant in the data.
- **Although we cannot directly say whether Cho-gluons exist, there are several aspects of the gluons in data that cannot be explained by current standard MC.**
  - A more in-depth study of the Gluon Anomaly is needed, su ch as using a different jet algorithm or changing the defini tion of a jet.
  - MC research at the generator level is also necessary for unf olded analysis.