DPG conference in Bonn

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Analysis of a Multi-Muon Signal at Collider and Fixed-Target Experiments

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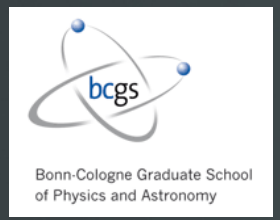

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Introduction

- Study of multi-muon events produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\ TeV$; T. Aaltonen *et al.*, arXiv:0810.5357v2 [hep-ex]
- Measurement recorded by CDFII detector
- Data set acquired with a dedicated dimuon trigger
  → integrated luminosity up to 2100 pb^{-1}

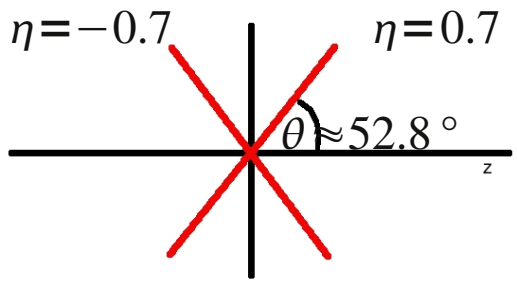
- Claim: Significant sample of events cannot be explained by known QCD production

Introduction – Data Set

- Selection criteria for the data set:
- At least two CMUP muons
- Initial muons fulfill: $p_T \geq 3\,GeV/c \qquad |\eta| \leq 0.7$

$$5\,GeV/c^2 < m_{\mu\mu} = |p_1 + p_2| \leq 80\,GeV/c^2$$

- Initial muons: The two CMUP myons with highest transverse momentum p_T



- Integrated luminosity of 742 pb^{-1}:

→ 743006 events

Introduction – Ghost Events

- Tight SVX selection: Initial muons are created within the beam pipe (radius of 15 mm)

- Measured efficiency for tight SVX: 0.1930 ± 0.0004
- If all 743006 events are from known QCD production:
  → expected efficiency for tight SVX: 0.244 ± 0.002

$$743006 - \frac{143743}{0.244} = 743006 - 589111 = 153895$$

Type	Total	Tight SVX
All	743006	143743
QCD	589111 ± 4829	143743
Ghost	153895 ± 4829	0

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Ghost Events – Ordinary Sources

- 69000 ghost events from ordinary sources, e.g. muon decays of particles with a lifetime longer than that of heavy flavors (K and π mesons) → in-flight-decays
  → Corrected ghost events: 153895 – 69000 = 84895

- At the moment we cannot exclude, that all ghost events can be accounted by ordinary sources (e.g. large uncertainty of in-flight-decay prediction)
  → significant number of additional real muons? Yes!

- Cuts on additional muons: $p_T \geq 2\,GeV/c \quad |\eta| \leq 1.1$

Ghost Events – Impact Parameter

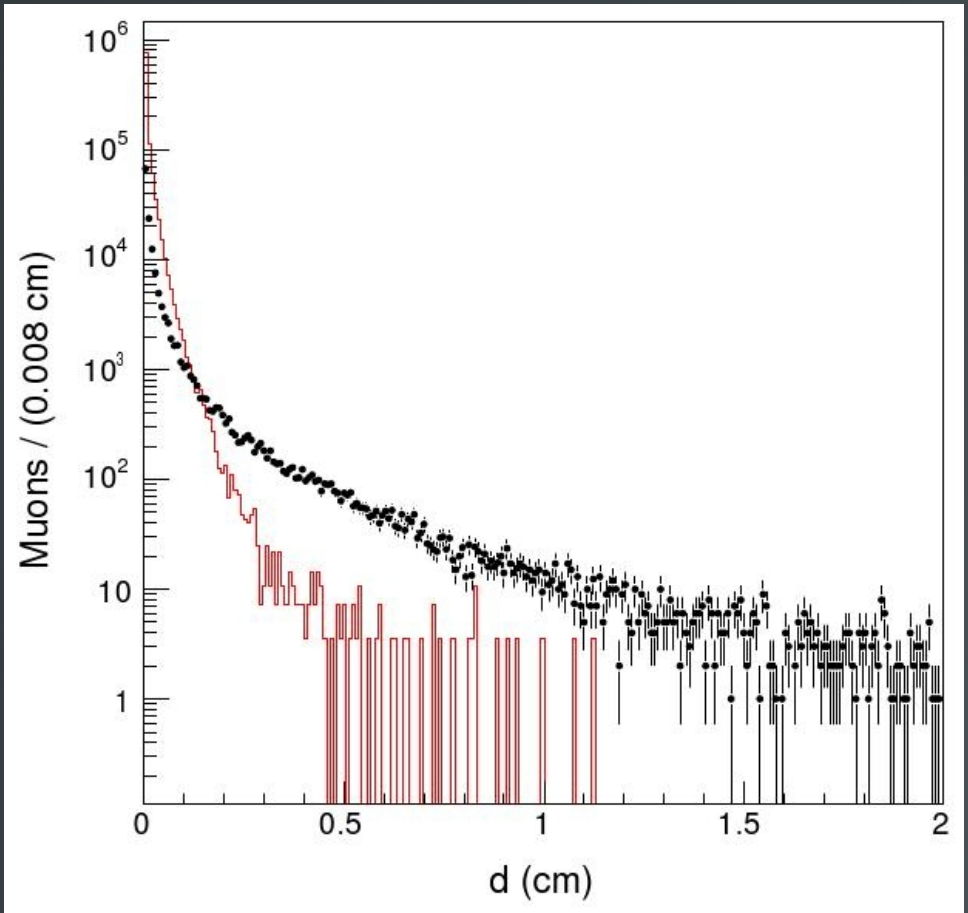
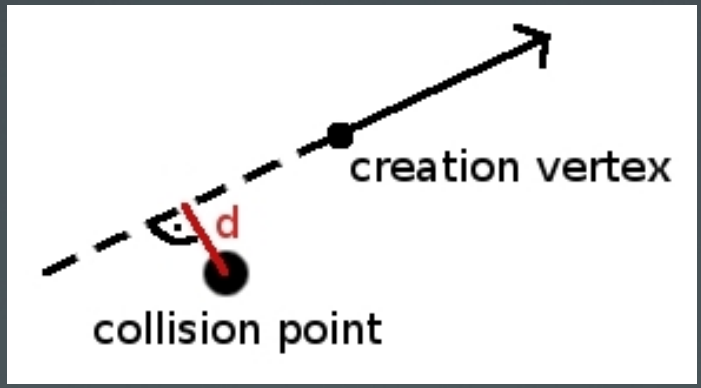


Figure 7 from arXiv:0810.5357v2 [hep-ex]

- Impact parameter distribution of initial muons (including fake ones) in ghost events (black) and QCD events (red)



Ghost Events – Muon Multiplicity

- Integrated luminosity of $2100\,pb^{-1}$
- Sign-coded multiplicity distribution of additional muons found in 36.8° cones around the direction of initial muons
- An additional muon with opposite (same) sign charge increases multiplicity by 1 (10)

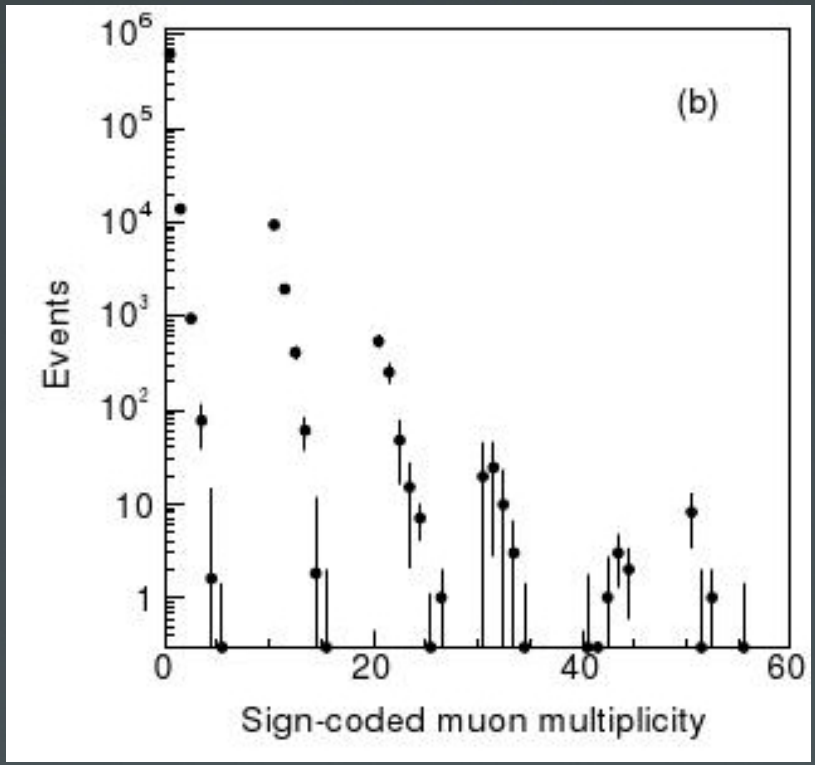
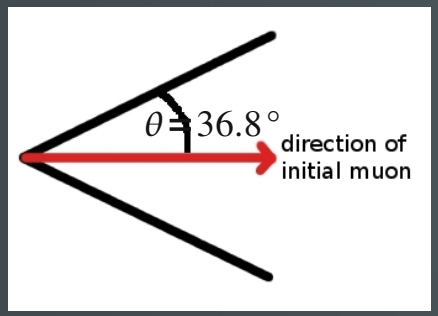


Figure 22b from arXiv:0810.5357v2 [hep-ex]



Ghost Events - Summary

- There are 84895 ± 4829 ghost events with an integrated luminosity of 742 pb^{-1}:

$$\sigma^{CDFII}_{p\bar{p}\to ghosts} = \frac{84895 \pm 4829}{742}\, pb \approx (114.41 \pm 6.51)\, pb$$

- Comparable with:

$$\sigma^{CDFII}_{p\bar{p}\to b\bar{b}\to \mu\mu} = \frac{221564 \pm 11615}{742}\, pb \approx (298.60 \pm 15.65)\, pb$$

→ Can we find ghost events in other experiments?

- Simulation in Herwig++

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Simulation – Model

- Simulation of the ghost events with the following process:

$$g\,g/q\,\bar{q}\rightarrow XX$$

- Differential cross section:

$$\frac{d\,\sigma^{Simu}_{g\,g/q\,\bar{q}\rightarrow XX}}{d\cos\theta}=\tilde{N}\cdot\frac{\beta}{\hat{s}}=\tilde{N}\cdot\frac{\sqrt{1-\frac{4\,m_X^2}{\hat{s}}}}{\hat{s}}$$

$\tilde{N}$: constant $\hat{s}$: squared center of mass energy

m_X: mass of X-particle

Simulation – Model

- X-particle:
- Neutral electric charge
- Average decay length $\gamma \tau_X v \geq 15\,mm$
- Decay in four elementary particles (at least one muon)
- Majorana particle (it is its own antiparticle)

- Free parameters: decay modes, branching ratios, $c\tau_X$ and m_X

- Set lifetime of the X-particle: $c\tau_X = 20\,mm$
- It influences the impact parameter distribution, but no other distributions!

Simulation – Set Parameters

- Decay modes of X-particle:
- 1-myon: $X \to \mu^- \bar{\nu}_\mu u \bar{d}$ or $X \to \mu^+ \nu_\mu \bar{u} d$
- 2-myon: $X \to \mu^- \mu^+ u \bar{u}$ or $X \to \mu^- \mu^+ d \bar{d}$
- 4-myon: $X \to \mu^- \mu^+ \mu^- \mu^+$

- Compare the simulation with the measurement:
- Set mass: $m_X = 1.8\, GeV/c^2$
- Set branching ratios: $w_1 = 0.9109$ $w_2 = 0.0752$ $w_4 = 0.0139$

Simulation – Expected Ghost Events

- Investigation of experiments with a muon detector with sufficient coverage and a data set with high integrated luminosity
- UA1, ZEUS, H1, E605, E772, E789 and E866

- E789 has a vertex detector!
- Data set with integrated luminosity of $(17.52 \pm 1.92)\, pb^{-1}$; D. M. Jansen *et al.*, PRL **74**, 3118 (1995)
- Opposite sign (OS) charged dimuons fulfill:

$$2\,GeV/c^2 \leq m_{\mu\mu} \leq 6\,GeV/c^2 \qquad 3.506 \leq \eta \leq 4.605$$

- Number of expected OS ghost events is appox. 78.7 ± 9.8

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Outlook & Summary

- Expect measurable number of ghost events at fixed target experiments (low mass of X-particles)

- D0 did not see any ghosts; Mark Williams, for the D0 Collaboration, arXiv:0906.2969v1 [hep-ex]!
- Results of fixed target experiments can be explained by the Standard Model?!
- Did the CDFII detector only see ghosts?

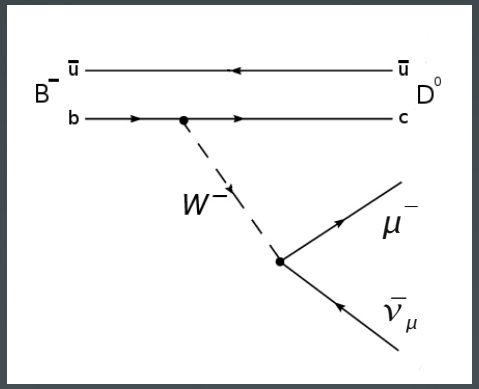
- Work on model for better reproduction of the CDFII measurement, e.g. Breit-Wigner resonance

The End

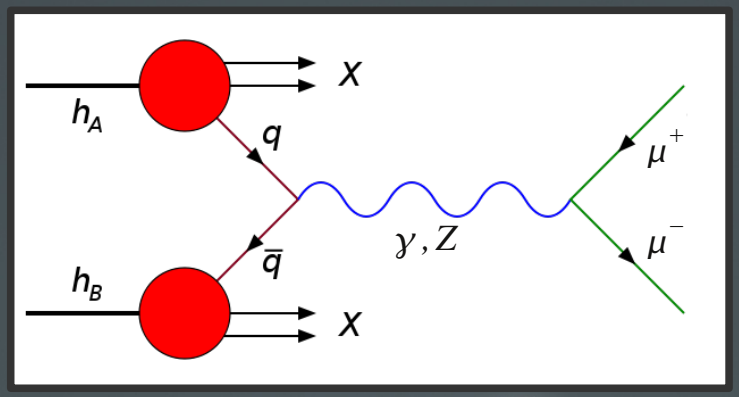
Thank you for your attention!

Backup – Introduction – QCD Production

- QCD production (dominant sources for initial muons):
- Semileptonic decays of bottom and charmed hadrons
- Prompt decays of quarkonia
- Drell-Yan production
- (Fake) muons mimicked by prompt hadrons or hadrons arising from heavy flavor decays



wikipedia.org; modified



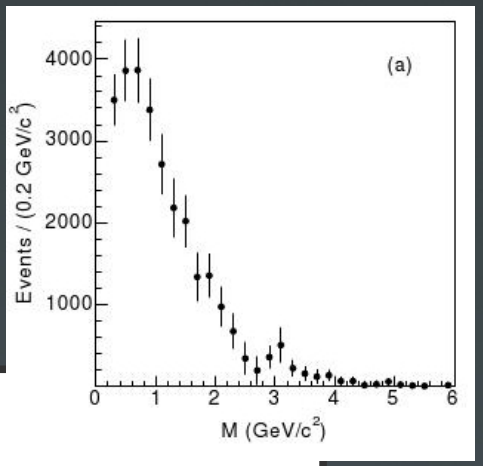
wikipedia.org; modified

Backup - Ghost Events – Ordinary Sources

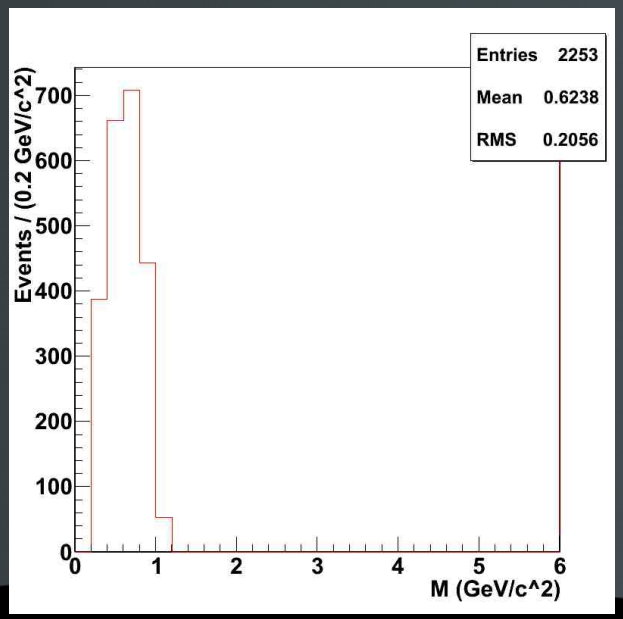
- Ordinary sources for ghost events:
- (a) Semileptonic decays of hadrons with an unexpectedly large Lorentz boost
- (b) Muon decays of particles with a lifetime longer than that of heavy flavors (K and π mesons) → in-flight-decays
- (c) Fake muons from decays of K_S^0 mesons and hyperons
- (d) Secondary interactions of prompt (hadronic) tracks that occur in the detector volume

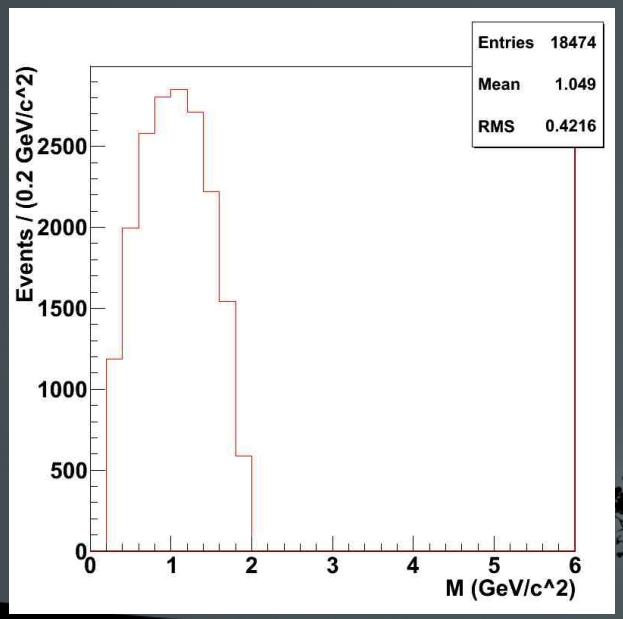
- Hyperon: baryon containing one or more strange quark, but no charm or bottom quarks

Backup – Simulation – Set Parameters



- <u>What is the mass of the X-particle?</u>
- Use the invariant mass distribution of all muons contained in the 27990 36.8° cones with at least one additional muon
- Compare with simulated distributions for pure 2- and 4-myon decay for different masses → $m_X = 1.8\,GeV/c^2$





Backup – Simulation – Set Parameters

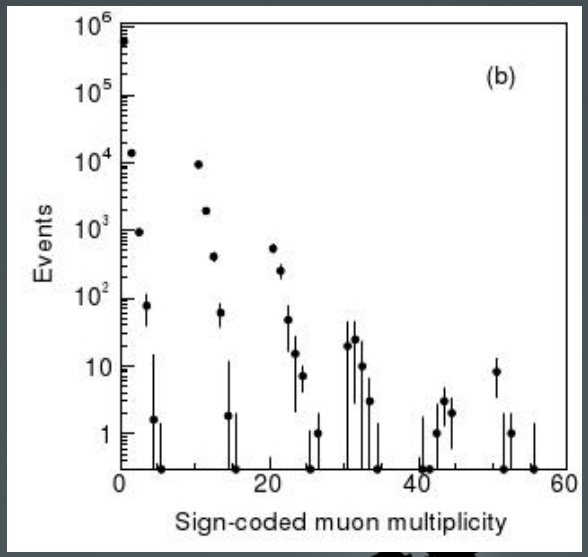
- What are the branching ratios for the decay modes of the X-particle?
- Use sign-coded multiplicity distribution of additional muons found in 36.8° cones around the direction of initial muons

- Cones with 0, 1, 2 and 3 additional muons:

$$\frac{1}{0}:\frac{23192}{620307}\approx 0.0374$$

$$\frac{2}{0}:\frac{3421}{620307}\approx 0.0055$$

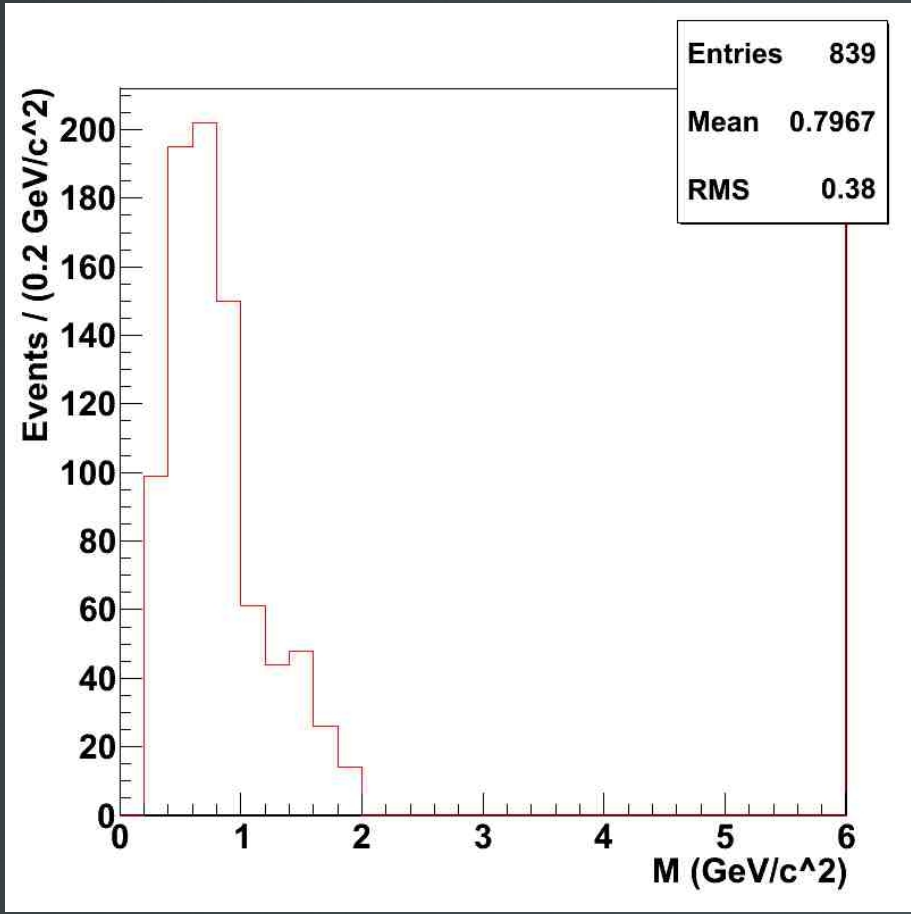
$$\frac{3}{0}:\frac{756}{620307}\approx 0.0012$$

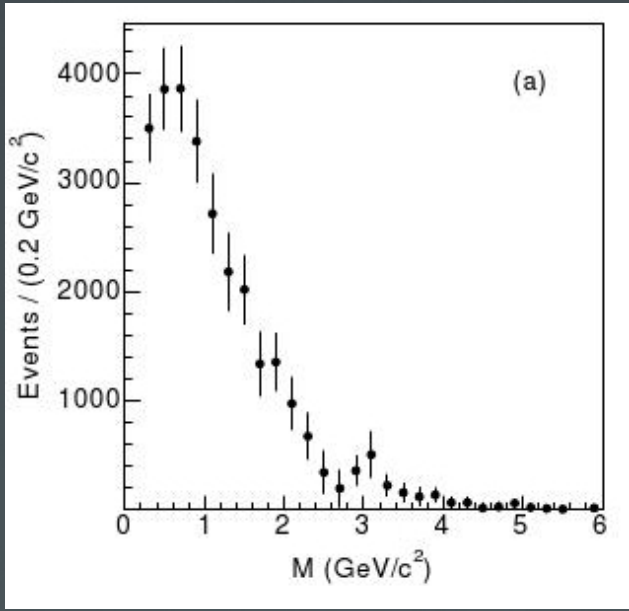


- Branching ratios: $w_1 = 0.9109 \quad w_2 = 0.0752 \quad w_4 = 0.0139$

Backup – Simulation – Set Parameters

- Simulated invariant mass distribution of all muons contained in the 36.8° cones with at least one additional muon





Backup – Simulation – Set Parameters

- Simulated sign-coded multiplicity distribution of additional muons found in 36.8° cones around the direction of initial muons