Kinematic Analysis of t-tbar events in CMS

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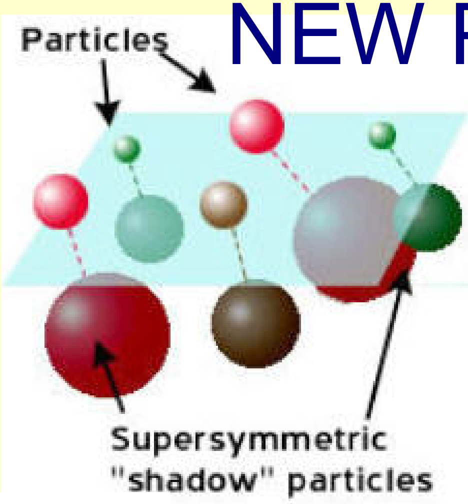
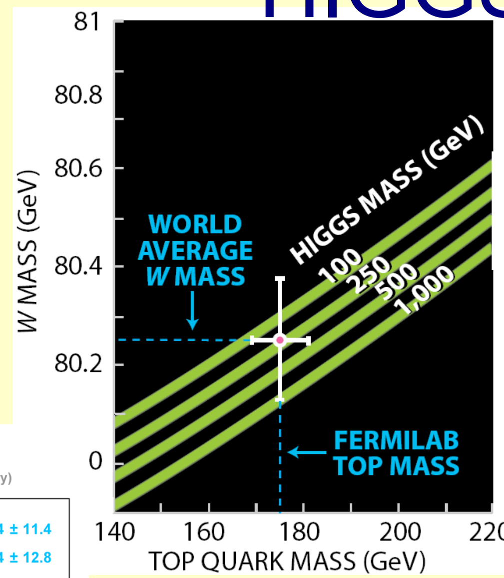
- Introduction
  - Top physics
  - LHC and CMS
  - Event reconstruction
- Analysis Techniques
- Results
- Summary (& Questions)

Why top physics?

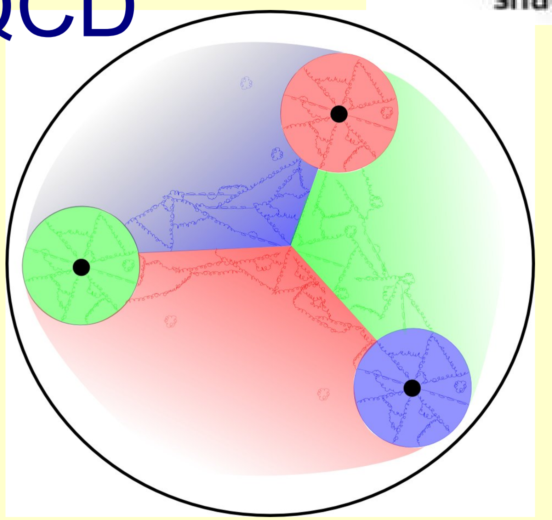
NEW PHYSICS

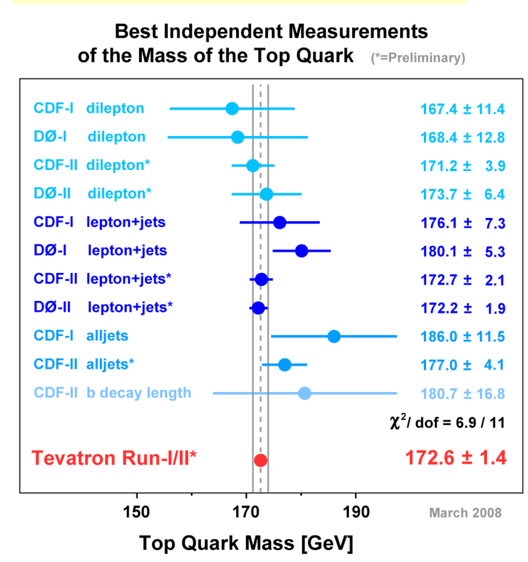


HIGGS



QCD



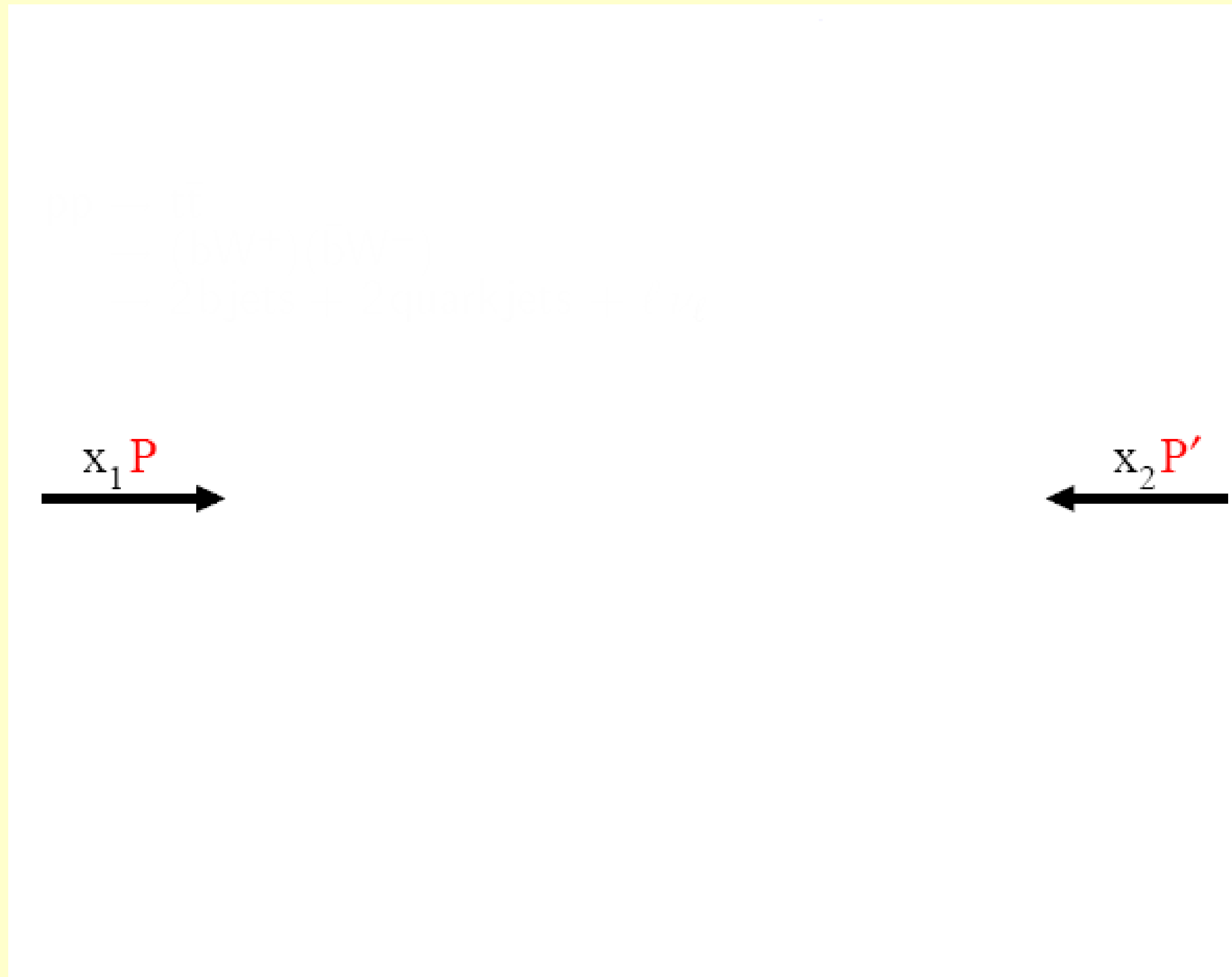


TOP MASS

The t-tbar event

- Two quarks approach IP

  momenta: x_1P and x_2P'

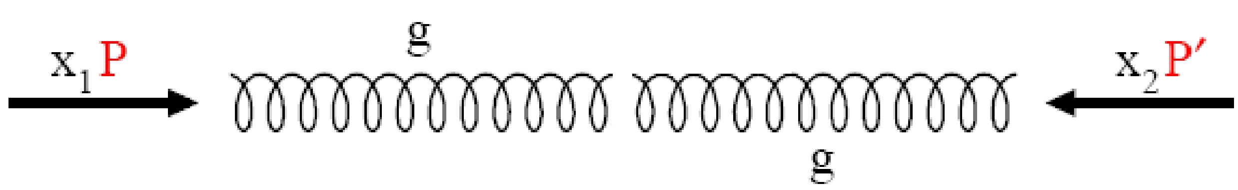


The t-tbar event

- A Gluon is radiated from each parton

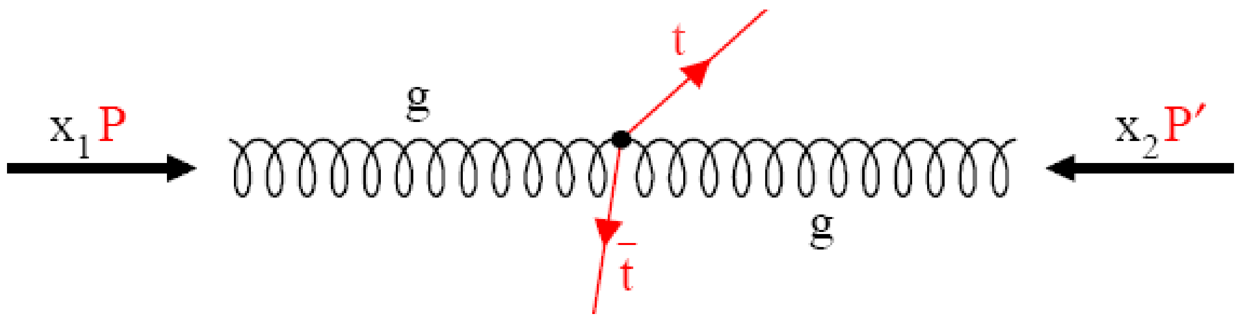
  "Gluon Fusion"

- Dominant production mechanism at LHC



The t-tbar event

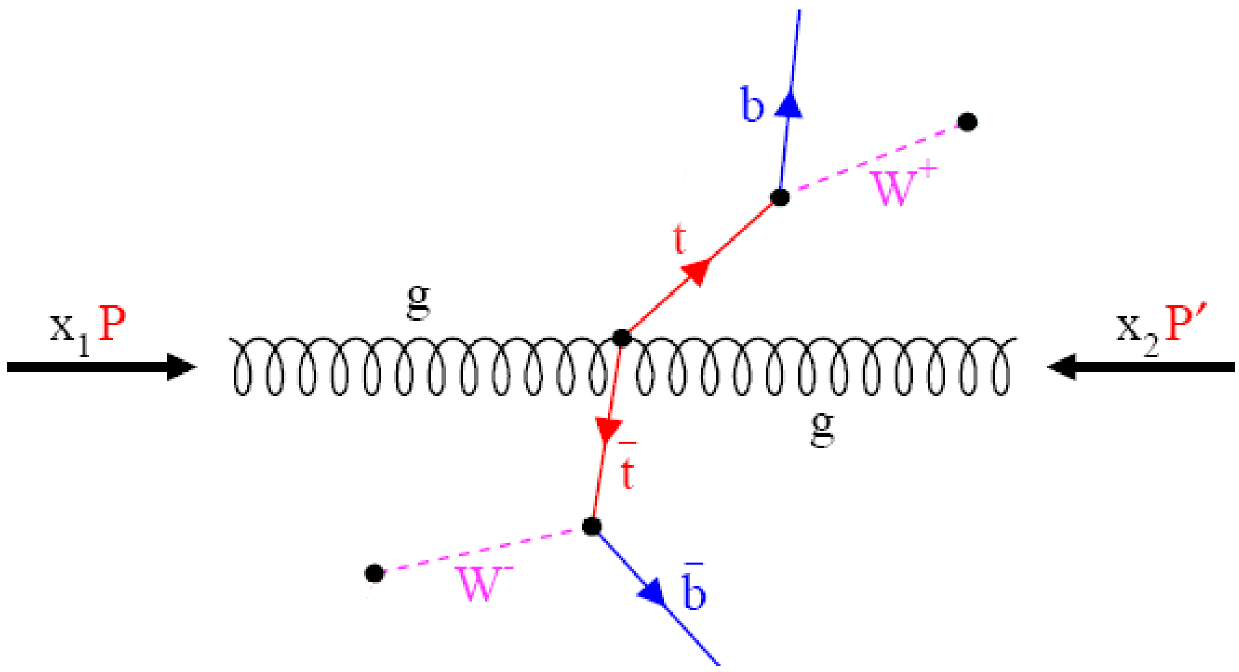
- Top pair produced in interaction



- Lifetime:
  ~ 10^{24} s

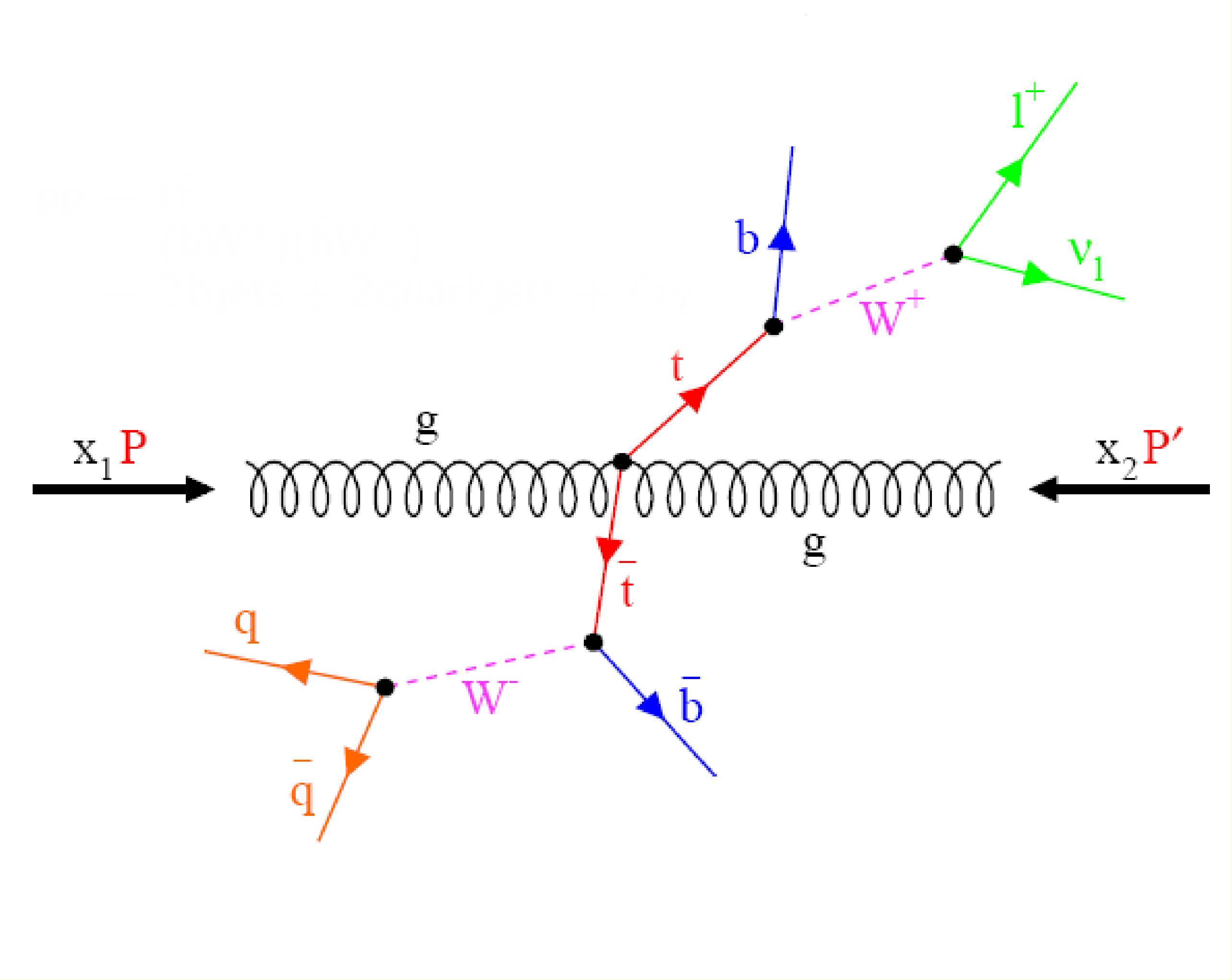
The t-tbar event

- Top particles decay to bottoms and $W^{\pm}$.
- CKM element $|V|_{tb} \sim 1$



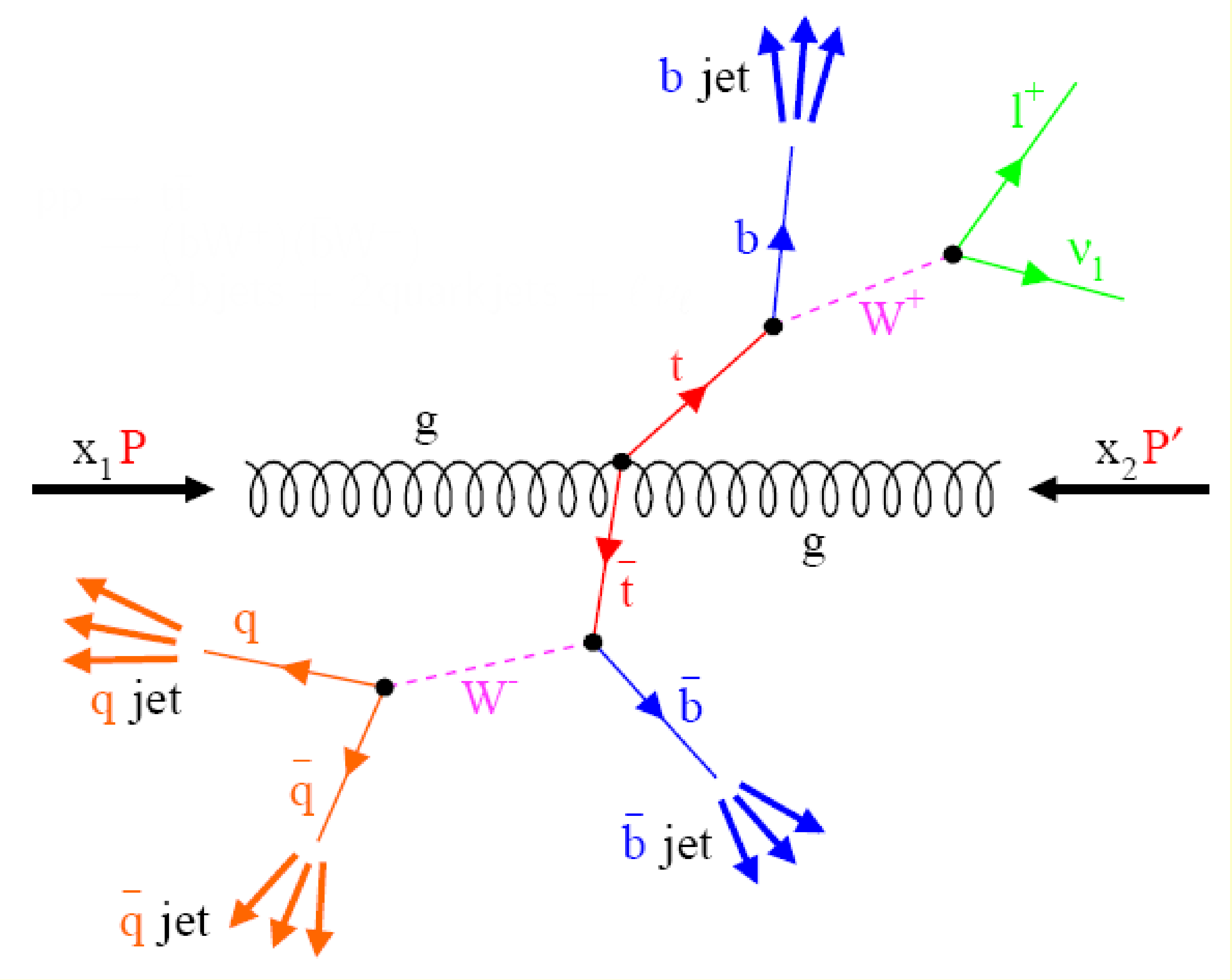
The t-tbar event

- W $^{\pm}$ decay into particle antiparticle pair.
  - Hadronically
  - Semi-Leptonic
  - Fully Leptonic



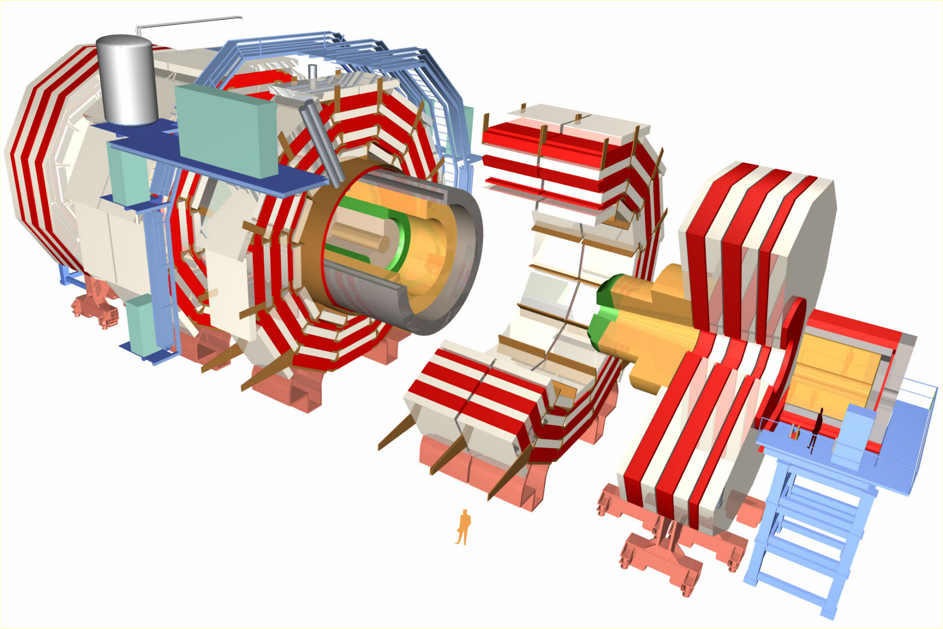
The t-tbar event

- Individual quarks cannot exist and quickly form jets



CMS

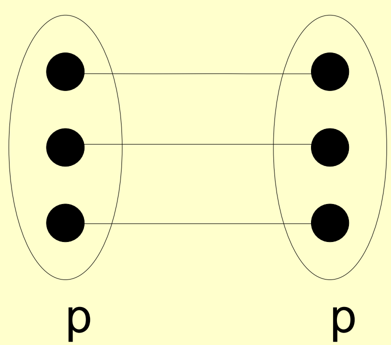
- All-purpose detector for the LHC
  - High segmentation and (almost) fully hermetic
  - High B fields
  - Relatively compact detector
  - Fast response time
  - Particle ID, momentum and energy resolution

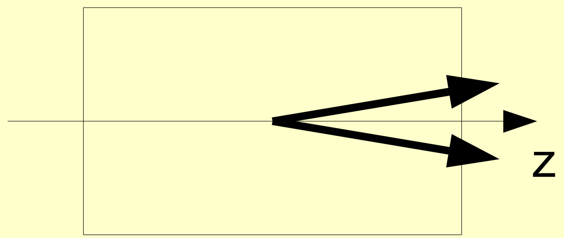


Interactions at the LHC

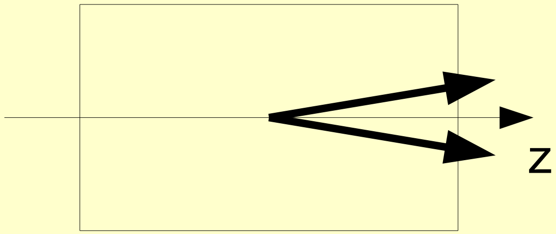
- At LHC:
  - Not fundamental particles
  - Mainly Gluon fusion interactions
  - Not a symmetric collider!

  - **Boosted system** → particles not created in rest frame!





η and ΔR



- η is a rapidity-like quantity "pseudo-rapidity"

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

- ΔR gives measure of angular separation

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

η and ΔR remove boost effects

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Event Reconstruction I

- Techniques for event reconstruction (a simplified list):
  - Particle ID
  - Jet algorithms
    - $\rightarrow$ b (and c) tagging
  - p_t and η cuts
  - Missing energy & p_t

  What was in the event?

  - Jet N & type cutting
  - **Event shape**
  - ***Angular separations***

  What event was it?

Event Reconstruction II

- Event reconstruction is very difficult!

Consider a typical top physics event:

TOP PHYSICS

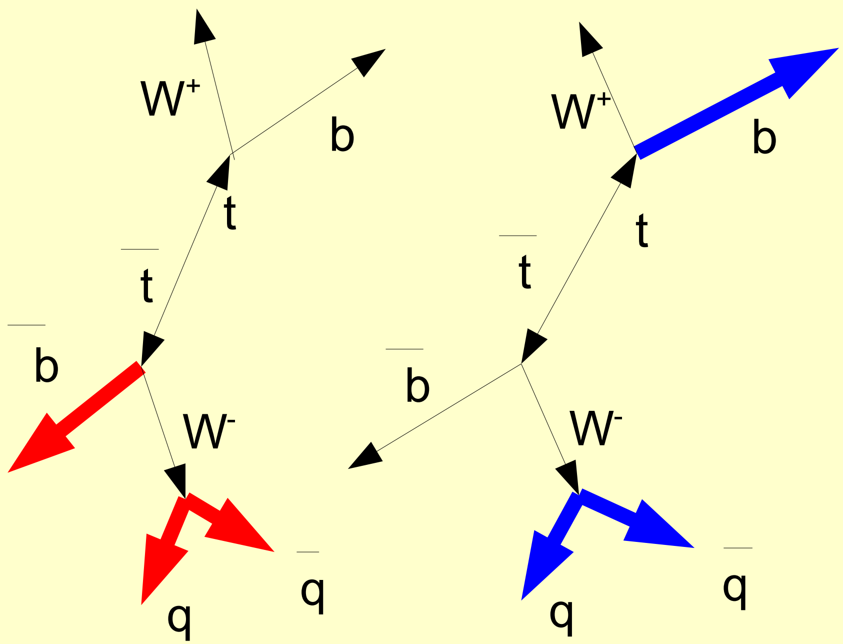
Event Reconstruction III

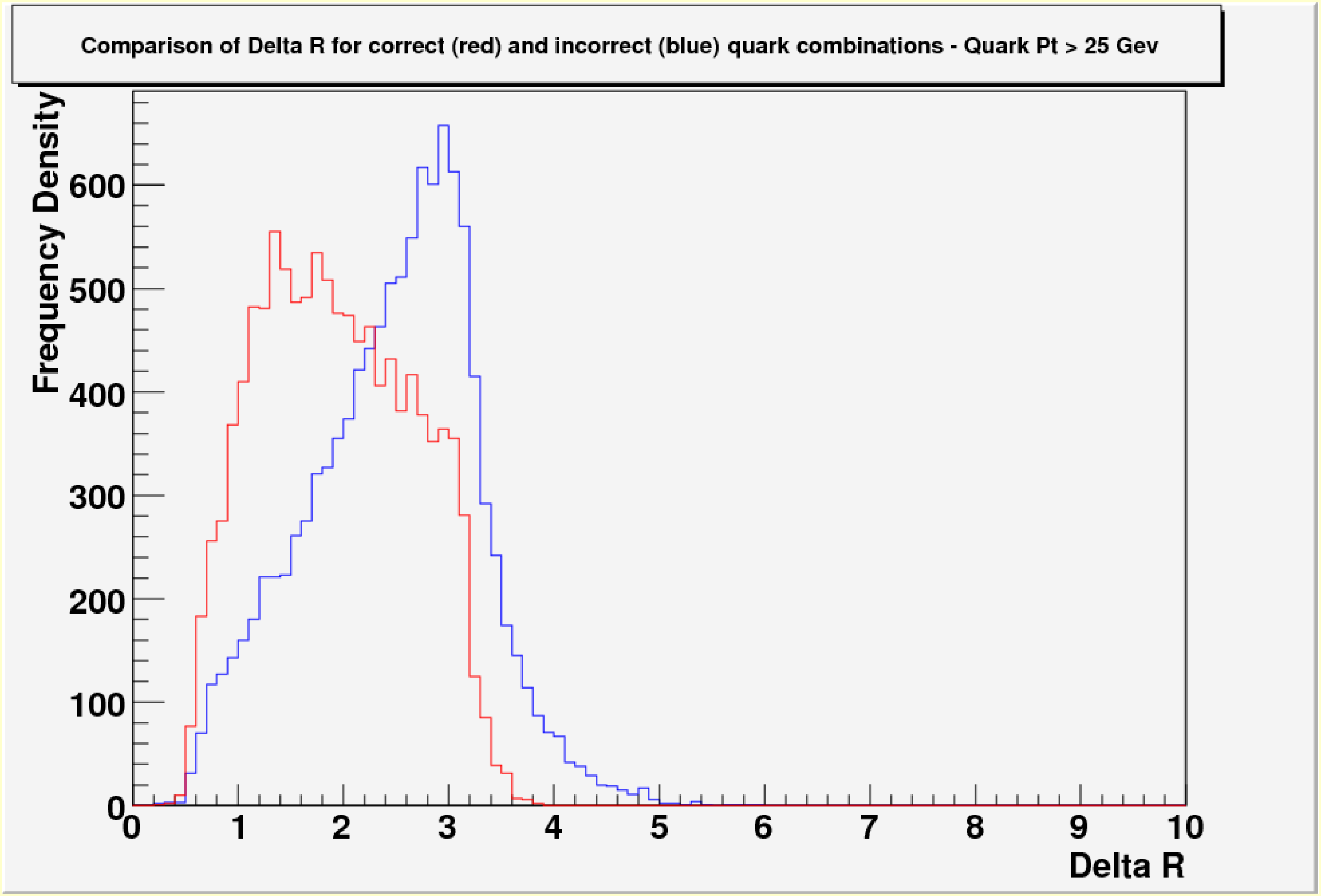
- Event reconstruction is very difficult!
  - Unknown CMS energy & position
  - Neutrino & **Combinatoric** effects
  - Detector & analysis effects

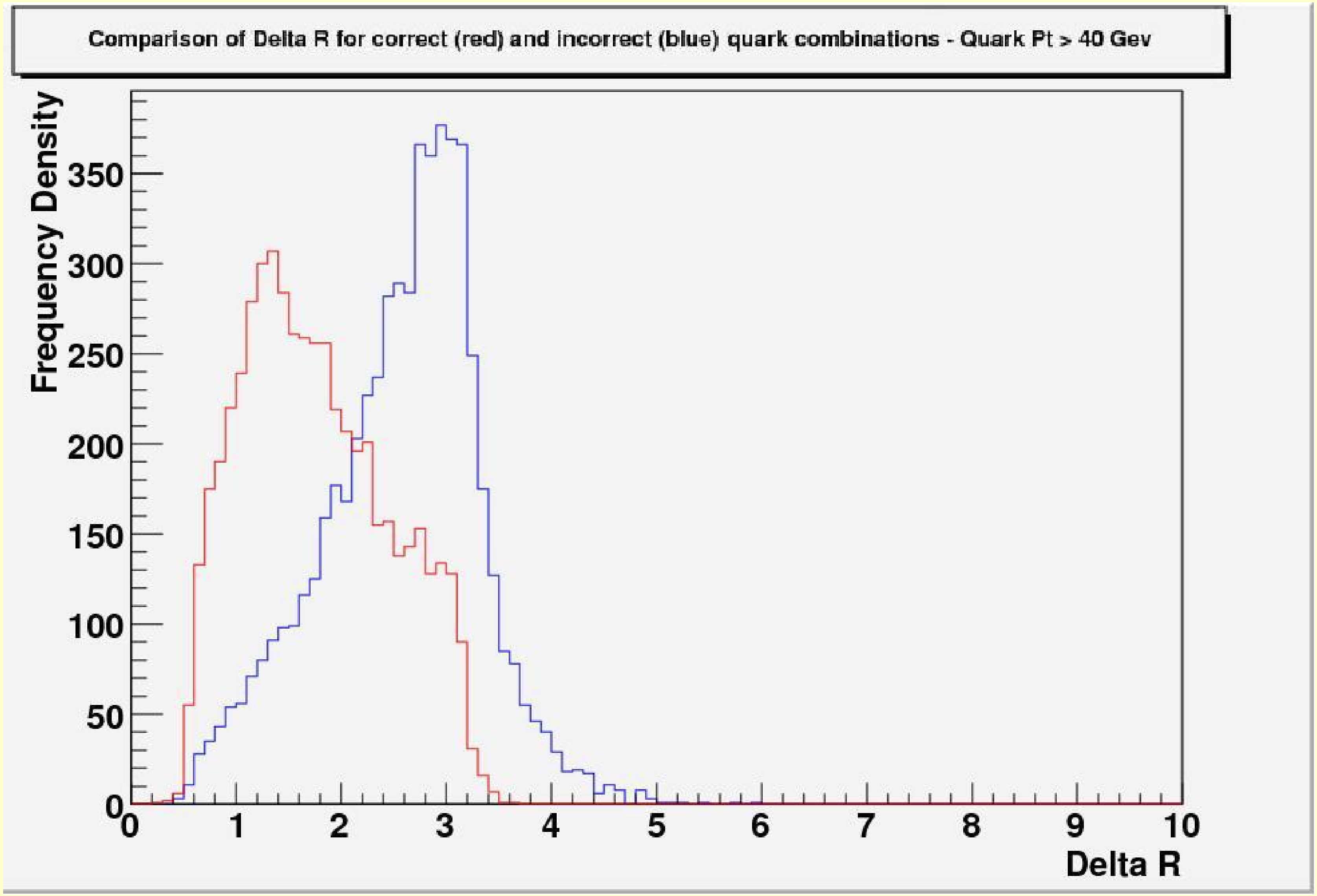
Analysis Techniques and Results

Method I : Angular Separation (ΔR)

- Look at ΔR for various particles in the event
  - for particles from same initial particle (red)
  - for same particles from different initial particles (blue)
  - Two momentum cuts (25 GeV, 40 GeV)



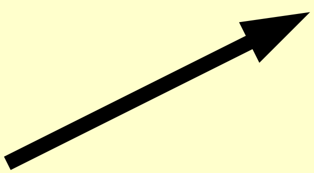

Comparison of Delta R for correct (red) and incorrect (blue) quark combinations - Quark Pt > 25 Gev
Frequency Density
0
100
200
300
400
500
600
0
1
2
3
4
5
6
7
8
9
10
Delta R


Comparison of Delta R for correct (red) and incorrect (blue) quark combinations - Quark Pt > 40 Gev
Frequency Density
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
Delta R

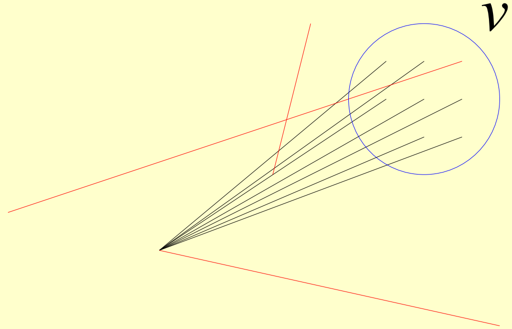
Method I : Angular Separation (ΔR)

- However, quarks are not seen in the detector system
  - Change generator to create jets, not quarks
  - Less well defined events
    → does difference still exist?

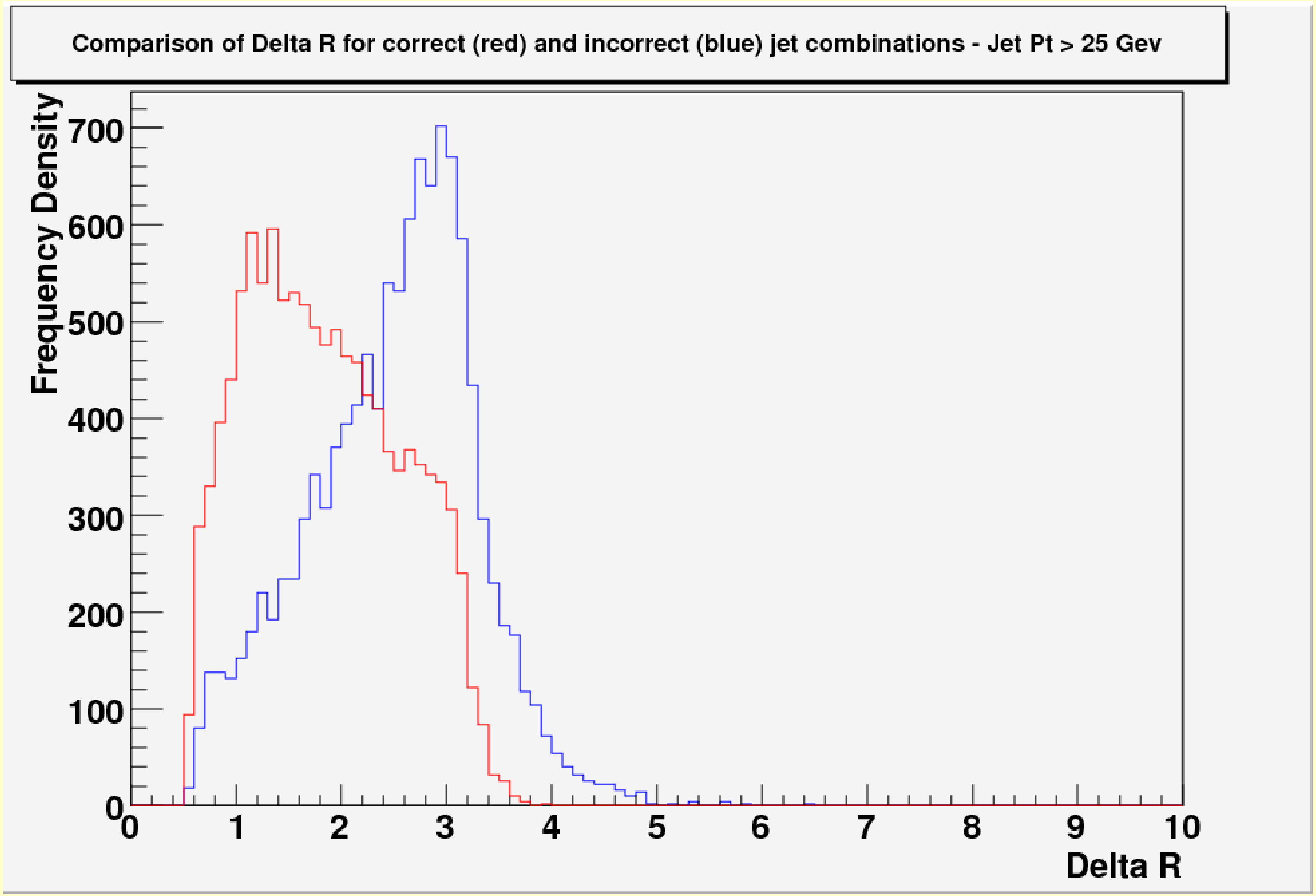
$\bar{v}=(\bar{v}_x, \bar{v}_y, \bar{v}_z)$

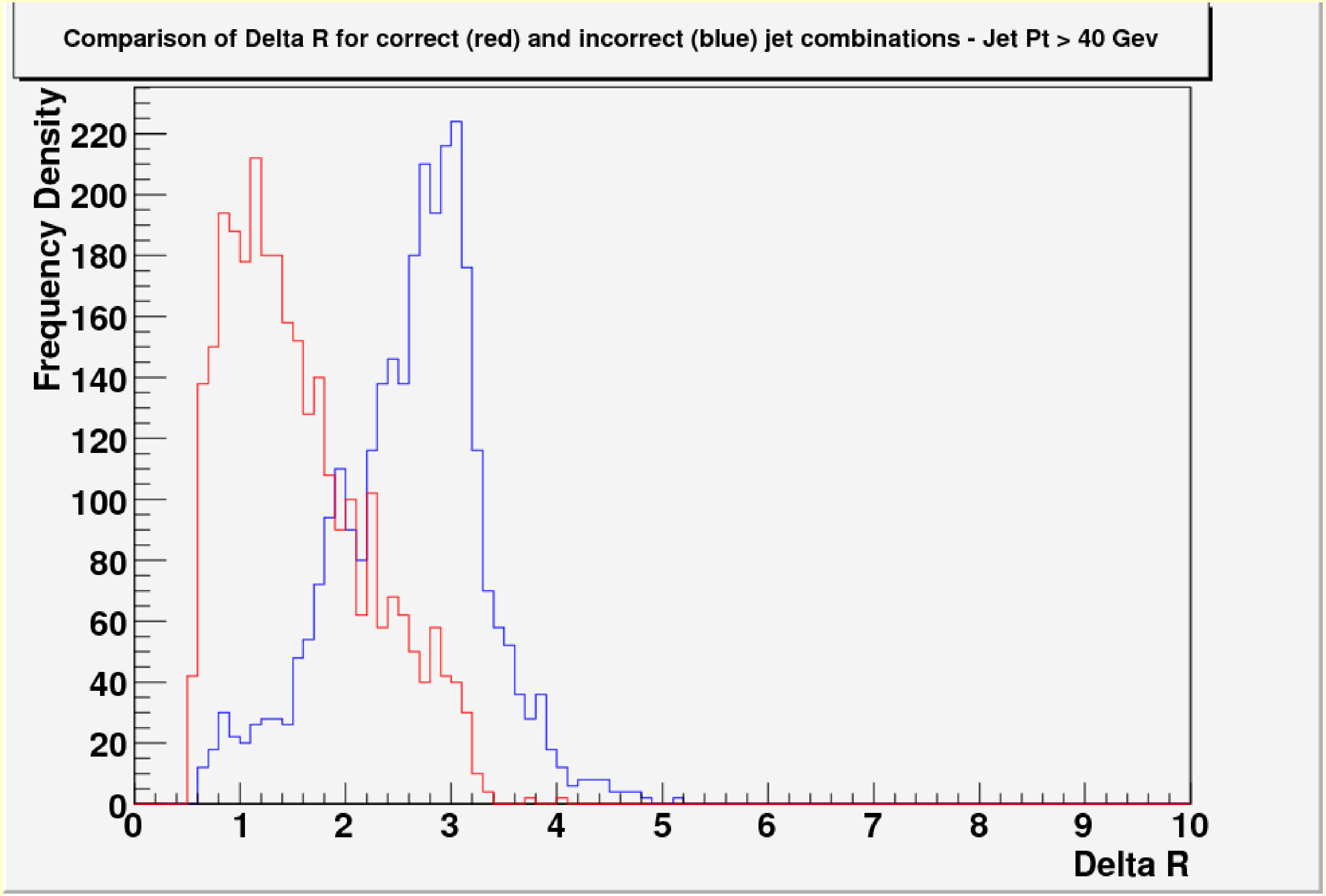


$\bar{v}'=(\bar{v}_x', \bar{v}_y', \bar{v}_z')$



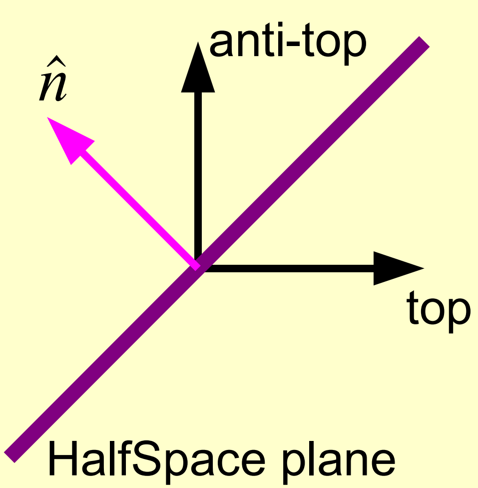
Quark events $\xrightarrow{\text{to}}$ jet events

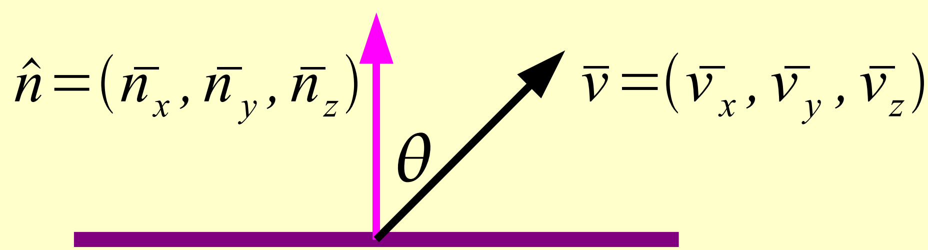

Comparison of Delta R for correct (red) and incorrect (blue) jet combinations - Jet Pt > 25 Gev
Frequency Density
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Delta R


Comparison of Delta R for correct (red) and incorrect (blue) jet combinations - Jet Pt > 40 Gev
Frequency Density
220
200
180
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
Delta R

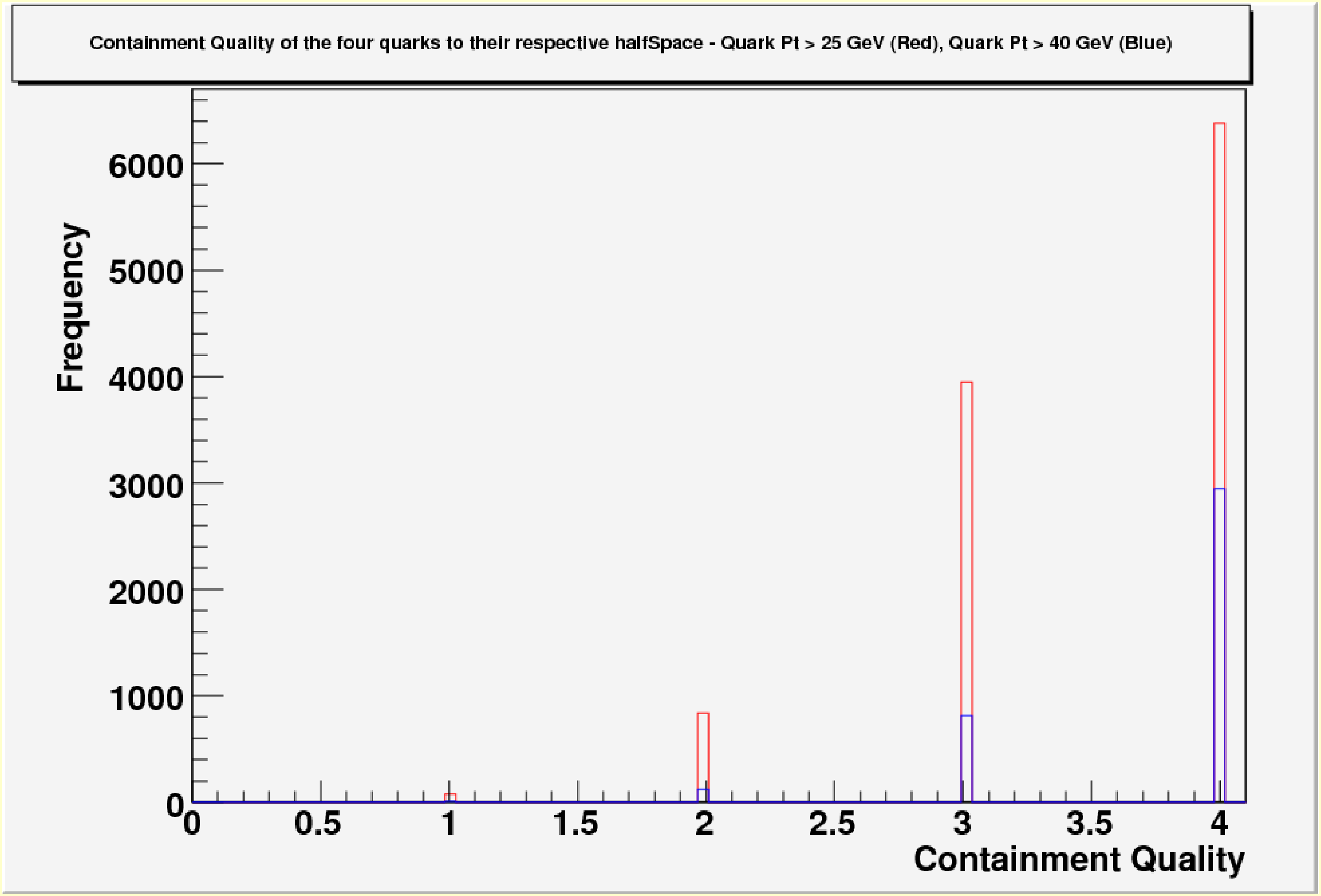
Method II : Event Shape (halfSpace)

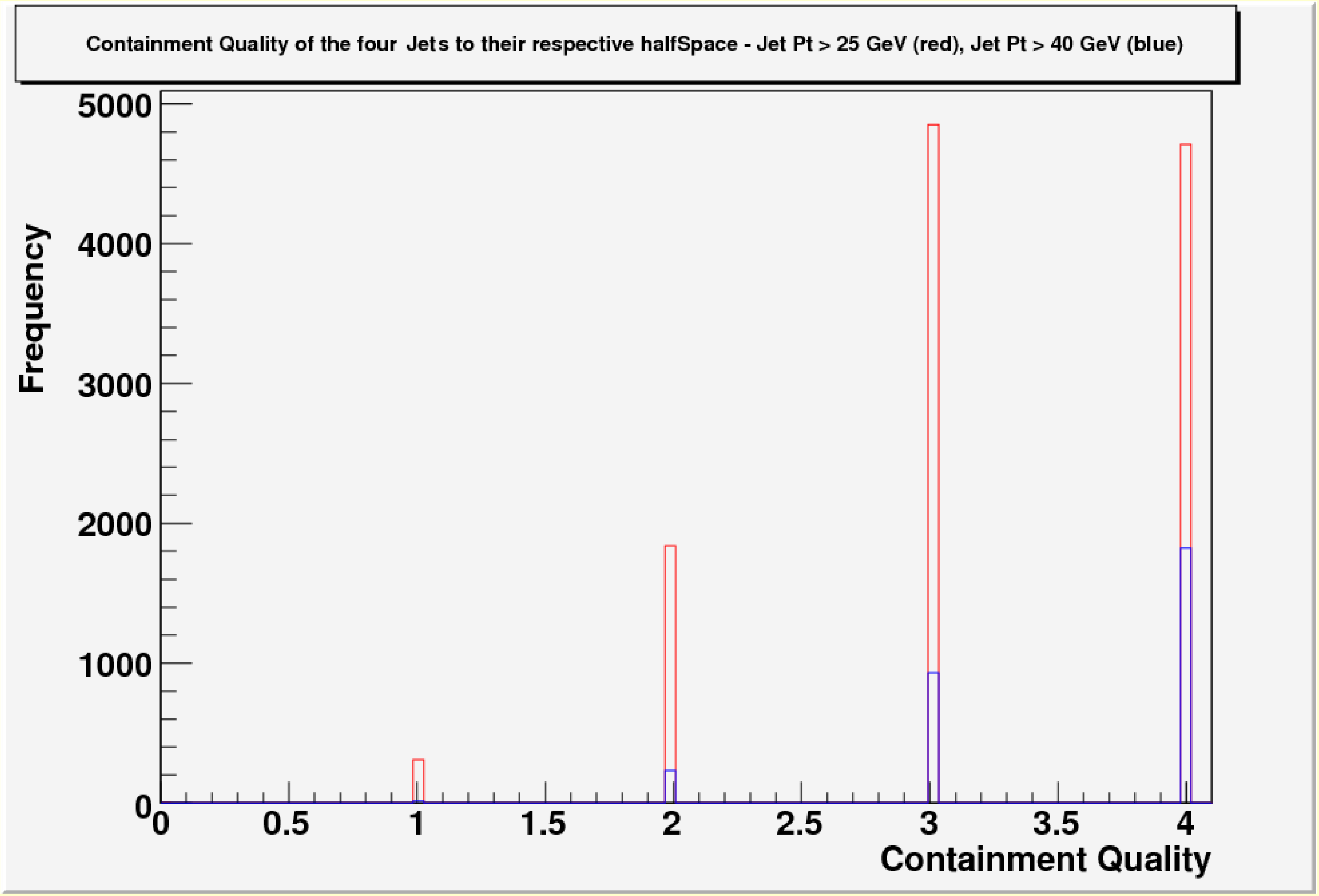
- Separate event into two halves
  - Use momentum vector of observable particles
  - Are the decays contained within the halfSpace?
    → Containment Quality





$$\left\{ \begin{array}{l} \cos(\theta = 270 \rightarrow 90) = +ve \\ \cos(\theta = 90 \rightarrow 270) = -ve \end{array} \right\}$$


Containment Quality of the four quarks to their respective halfSpace - Quark Pt > 25 GeV (Red), Quark Pt > 40 GeV (Blue)
Frequency
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Containment Quality


Containment Quality of the four Jets to their respective halfSpace - Jet Pt > 25 GeV (red), Jet Pt > 40 GeV (blue)
Frequency
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Containment Quality

Result Summary

- Angular Separation (ΔR) & Event Shape
  - Good possibility for use in event reconstruction
  - Input for likelihood function
  - Improved results for high momentum jets
    → loss of statistics
  - Improvement with further study!

Further Studies

- Improvement of cuts?
  - With consideration of detector effects and other cuts
- More halfSpace studies?
  - More halfSpace configurations, multiple spaces
  - Which particles leave the spaces under which conditions → look for correlations

Talk Summary

- Introduction
  - Top physics
  - LHC and CMS
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- Analysis Techniques
- Results
- Summary (& **Questions**)