Methods and algorithms for diboson production in hadronic final states

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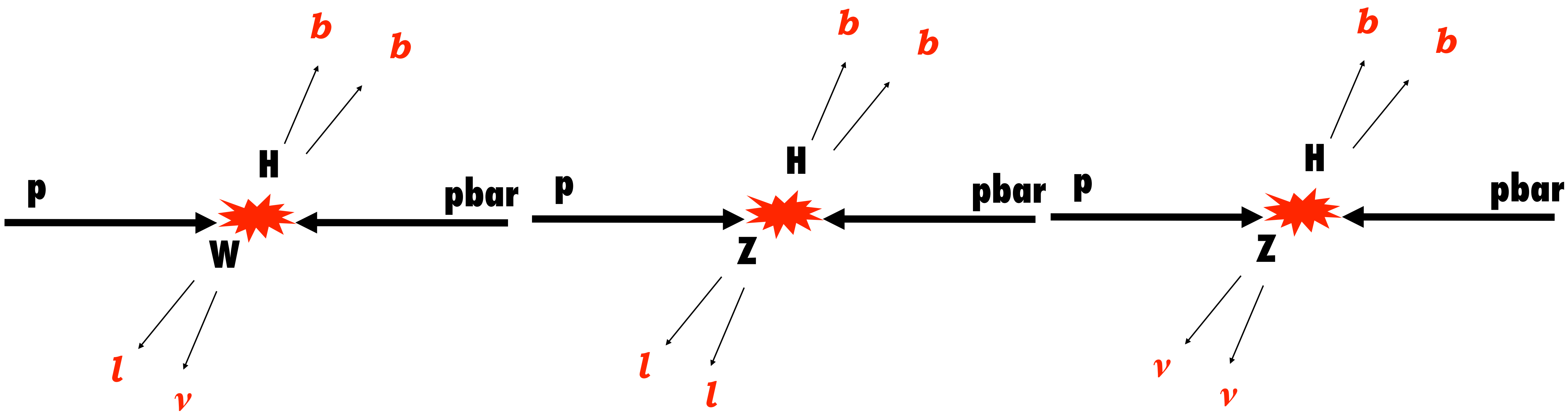
Outline

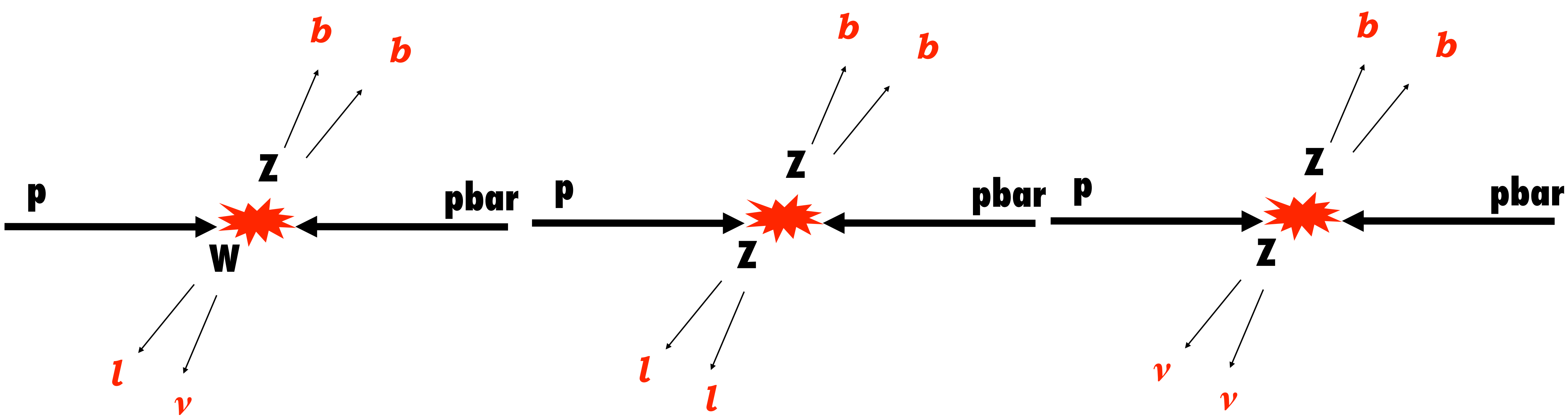
- High P_T physics with jets
- Issues
- Quark-gluon separation
- b tagging
- Conclusions

Associated Higgs



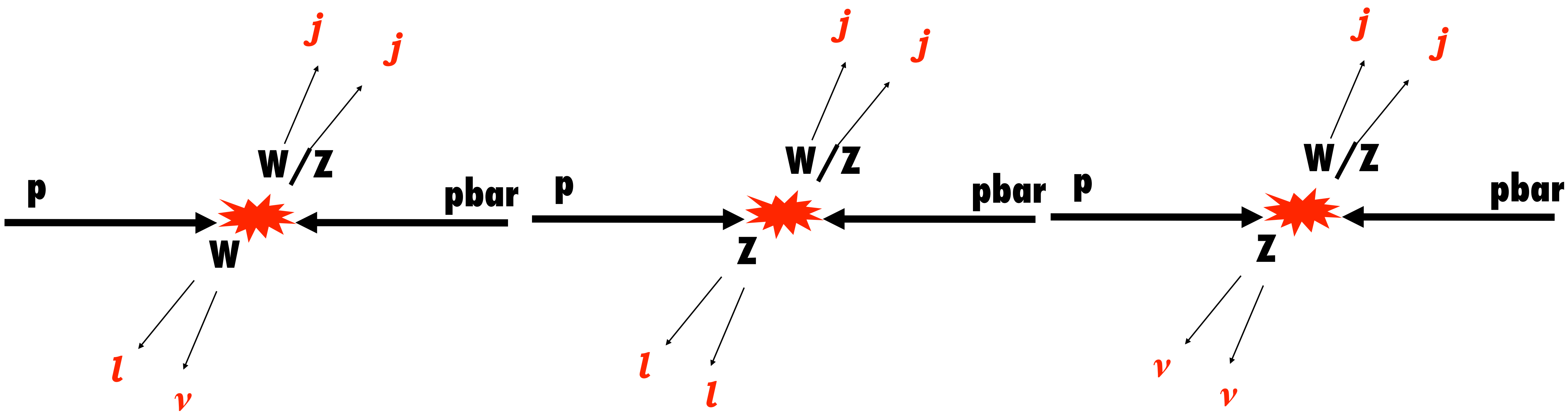
- The most promising channel for low Higgs
  - at least at the Tevatron

Dibosons



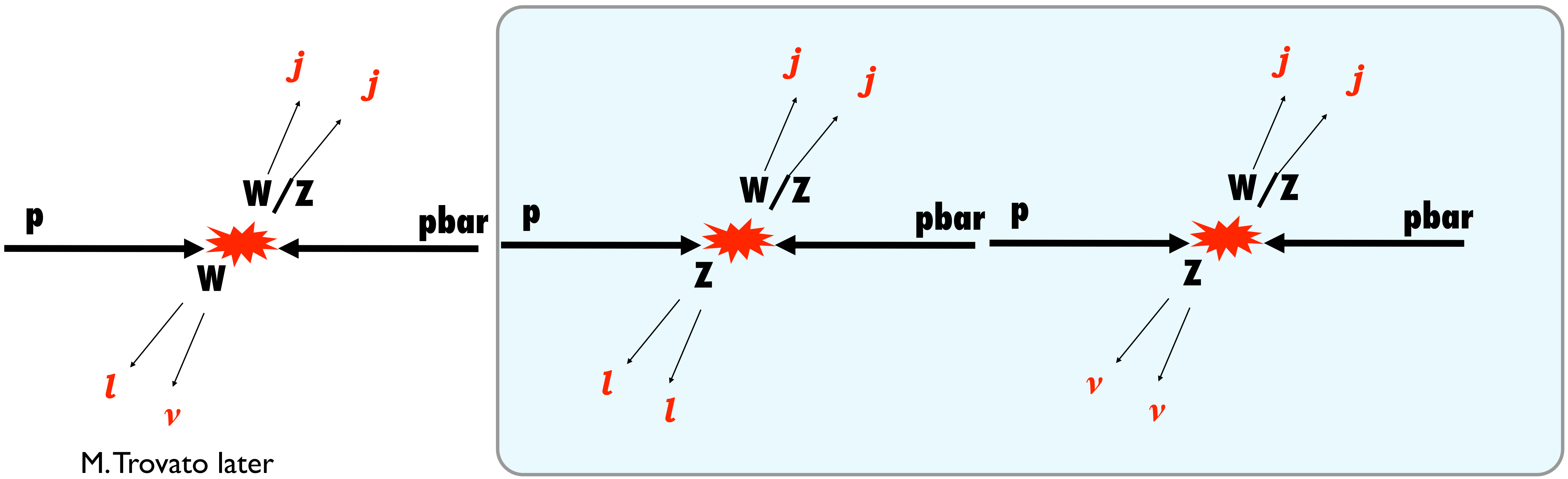
- As close as possible to the Higgs
  - calibration of tools
- The only chance to observe Z→bb

Dibosons



- One of the few (if not the only) standard candle in jet spectroscopy
- W-Z indistinguishable because of energy resolution
- Anomalous Triple Gauge Coupling study ground

Dibosons

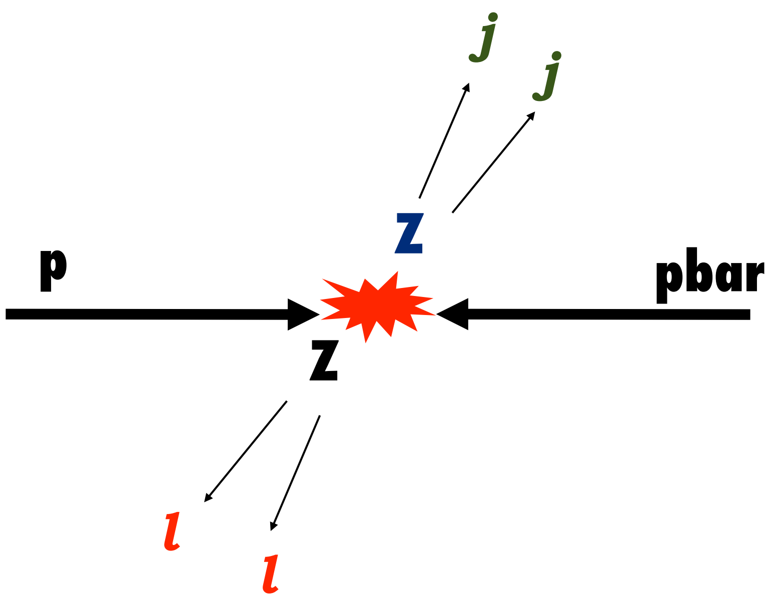


M.Trovato later

- One of the few (if not the only) standard candle in jet spectroscopy
- W-Z indistinguishable because of energy resolution
- Anomalous Triple Gauge Coupling study ground

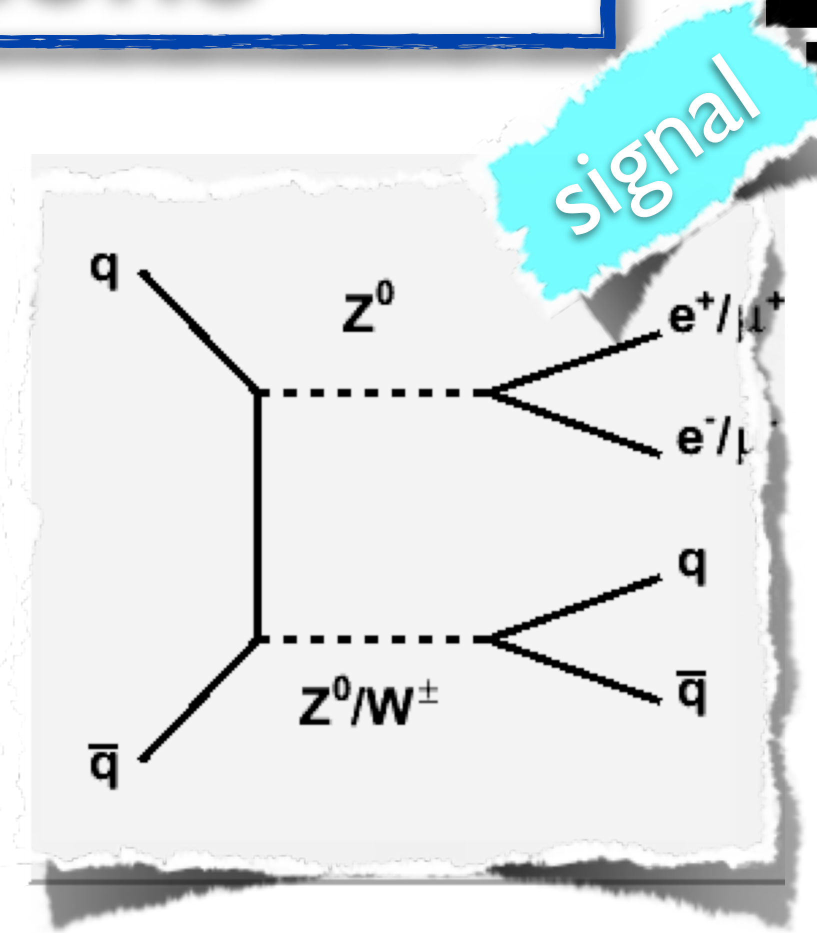
W(Z)+Z→lljj in a slide

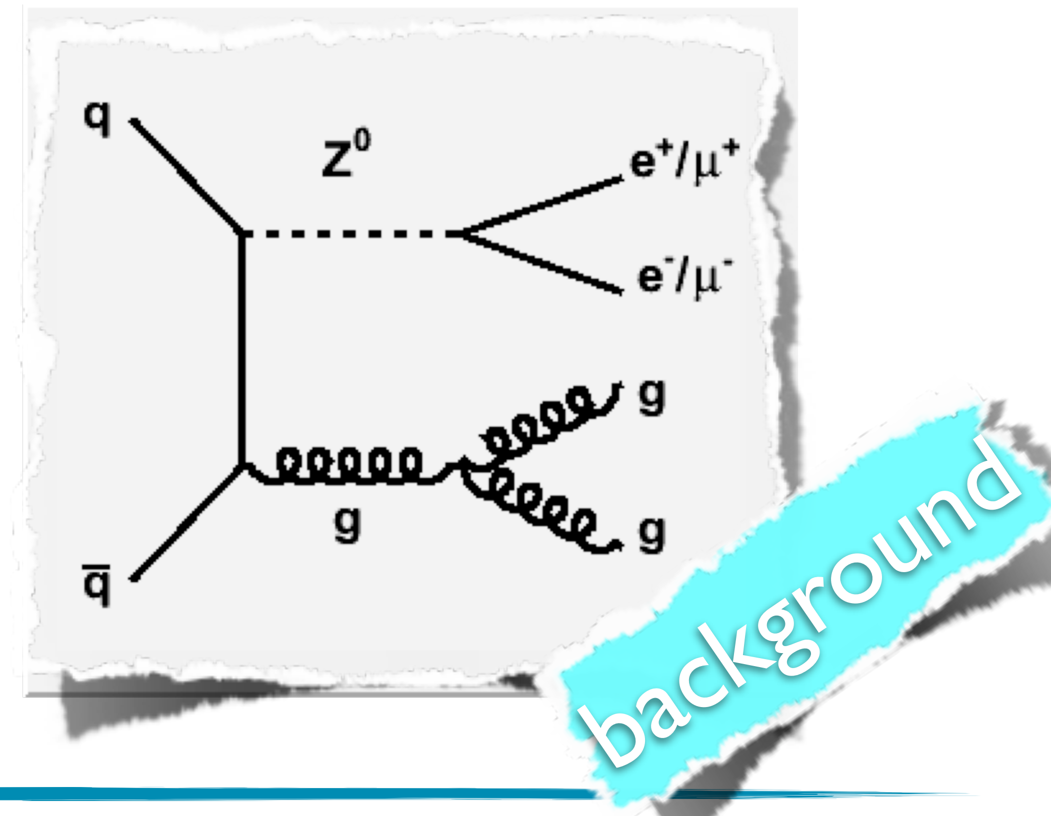
- Precursor for the cleanest VH channel
  - clean but hard
  - low xsection x BR is a killer
- Typical selection:
  - Two leptons above 20GeV
  - Two jets above 20 GeV
  - Low MET



Quarks vs gluons

- Large Z+jets background
  - lots of gluons
- Signal mostly quarks
- Separating would improve S/B a lot
- Several attempts in the past by using shape of jets





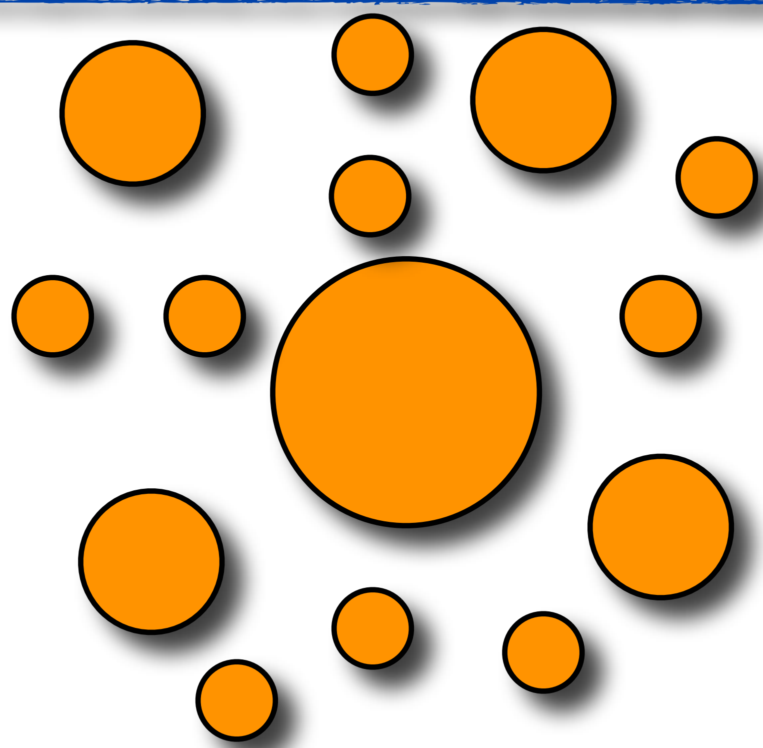
Separating quarks and gluons

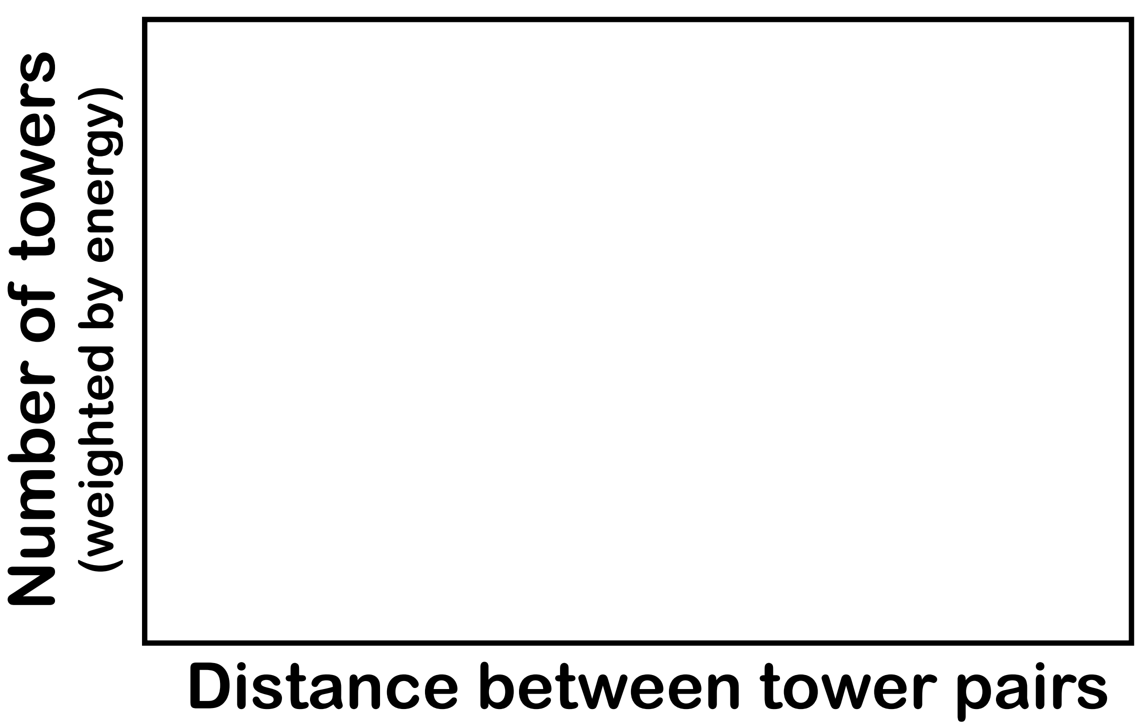
Developed by Wesley Ketchum, PhD student at UChicago

- To distinguish between quarks and gluons, look at distribution of ΔR between all pairs of towers in jet
  - Weight tower pairs by energy relevance ($E_i \times E_j \ / \ E_{tot}^2$)
  - Compare to "typical" quark and gluon jet templates by computing a likelihood (or at least likelihood-like quantity)
  - Templates from ALPGEN $Z \rightarrow ll$ + 2 parton MC
  - Construct Likelihood Ratio: LR = L (jet from quark) / L (jet from gluon)

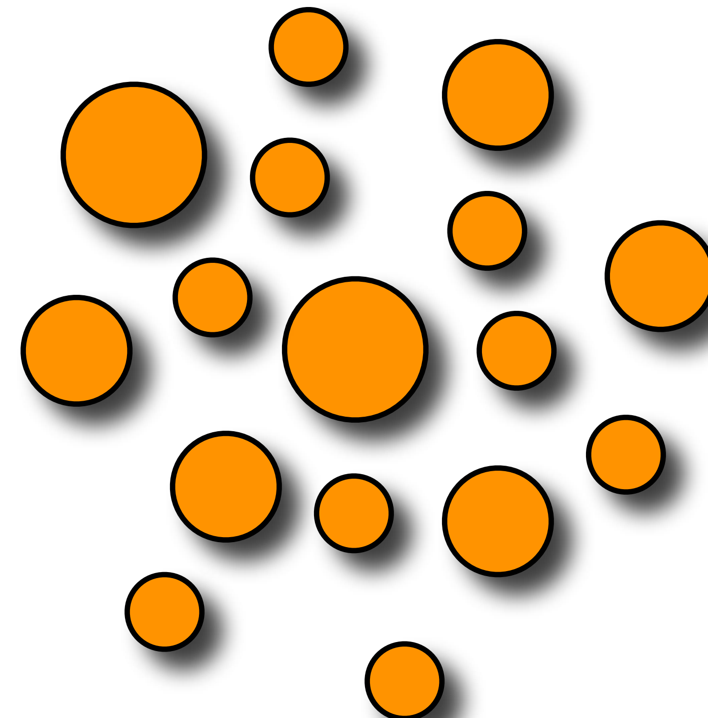
Just like two point correlation function in astrophysical observations

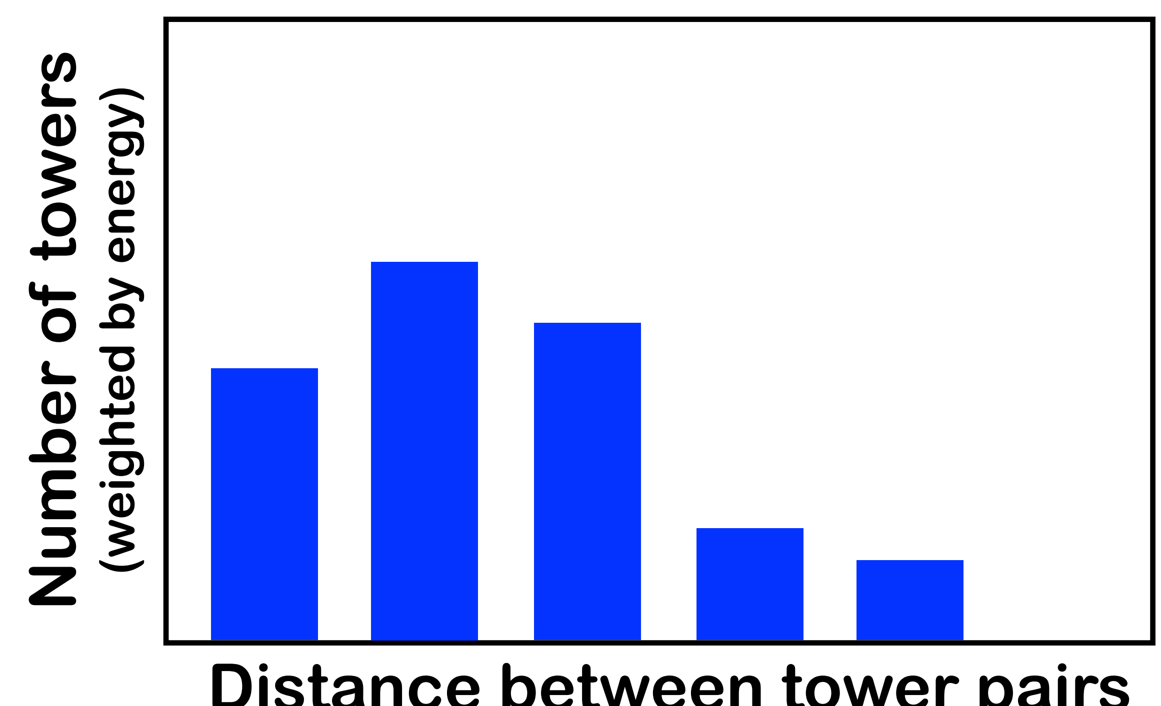
(Light) quarks





gluons





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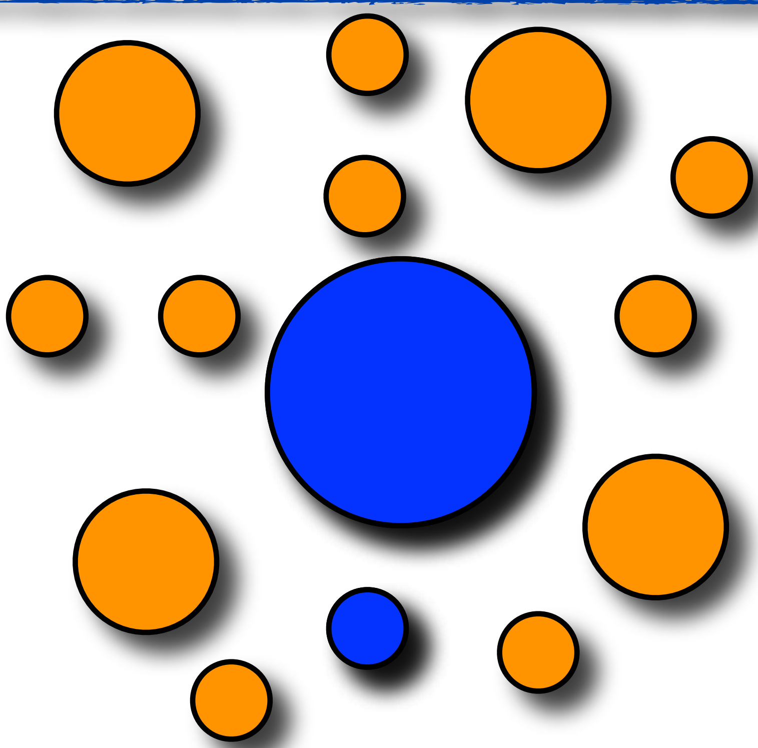

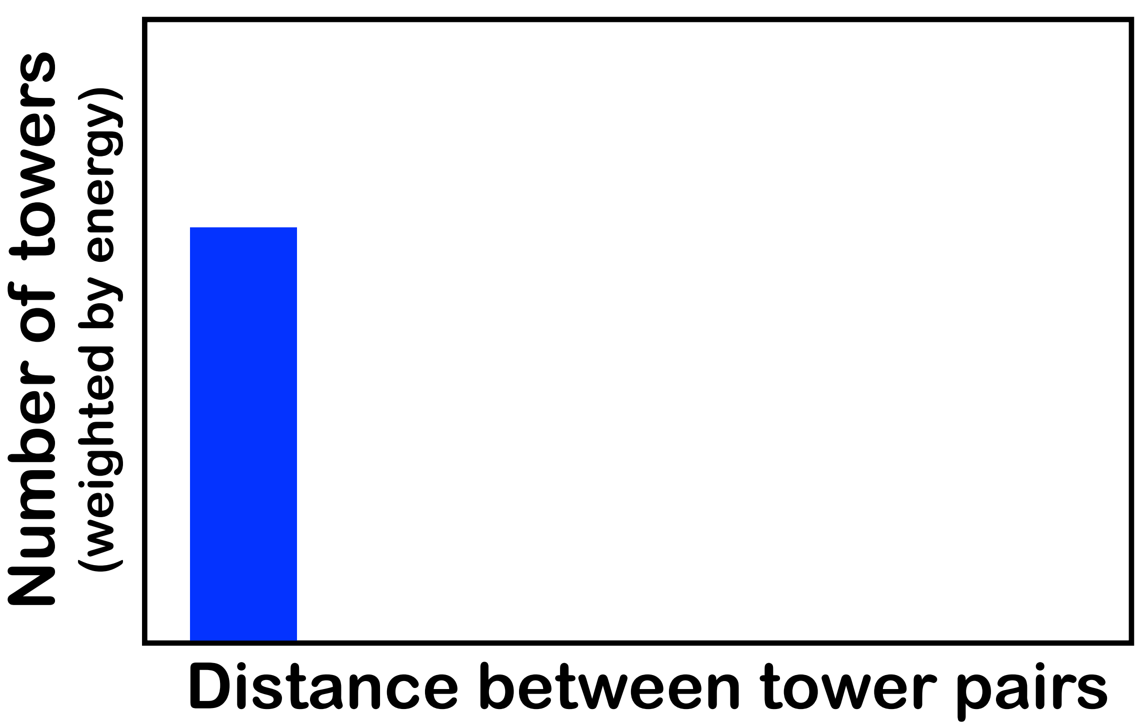

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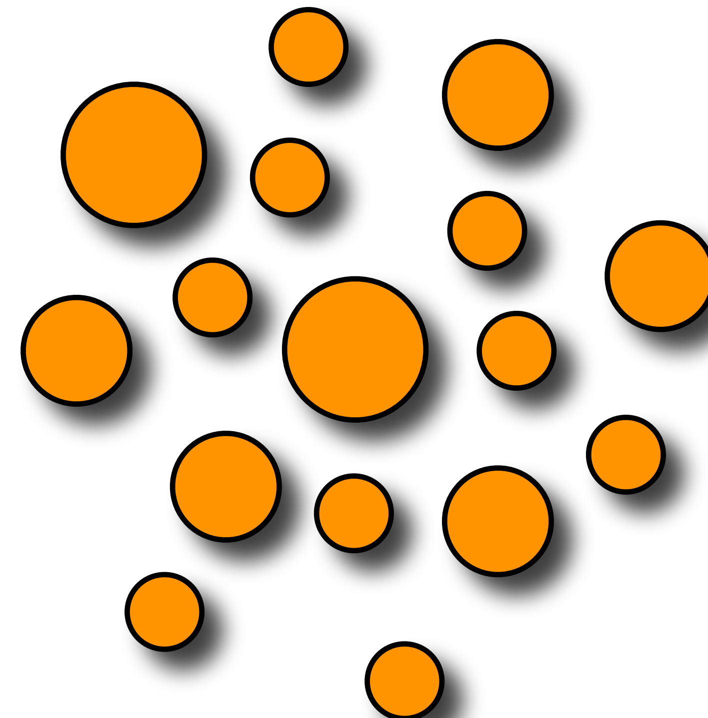

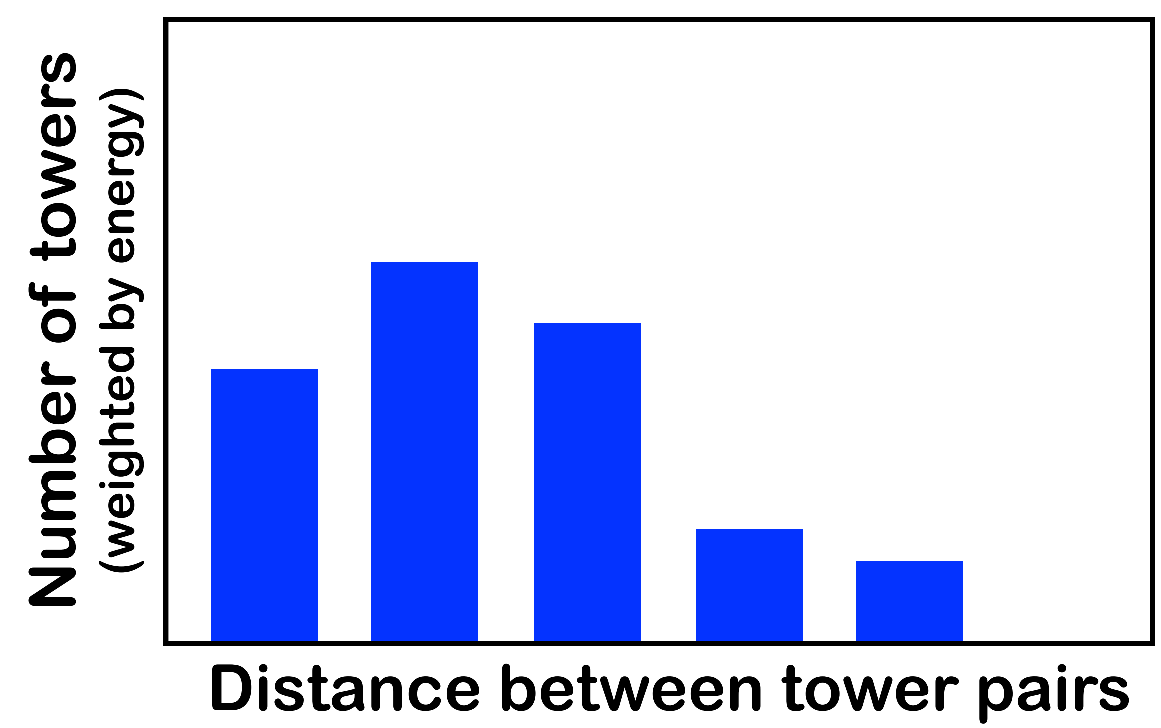

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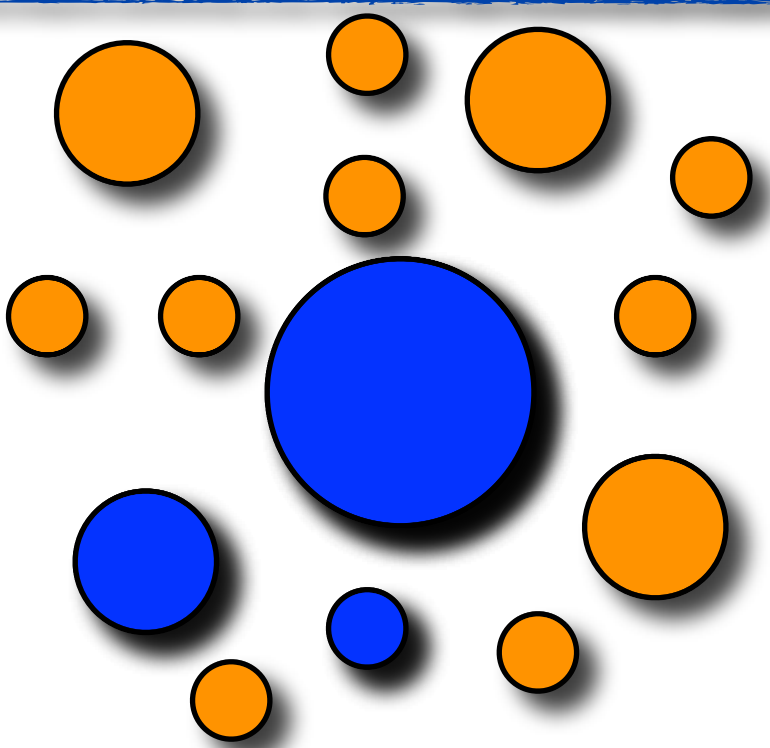
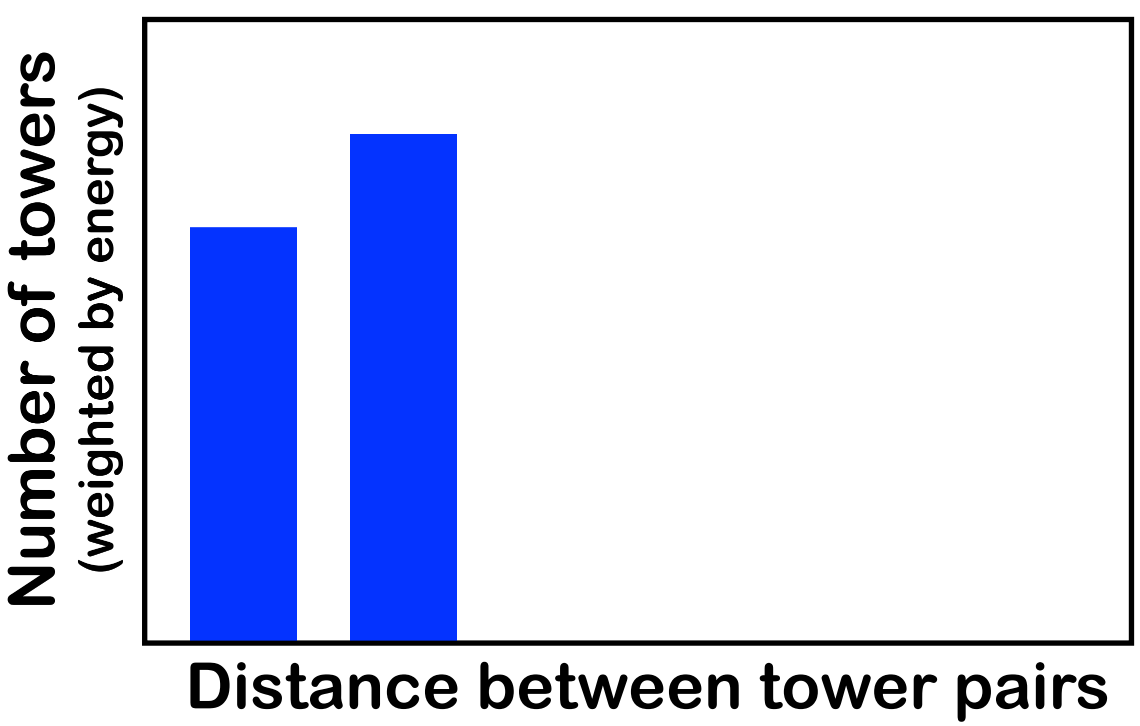
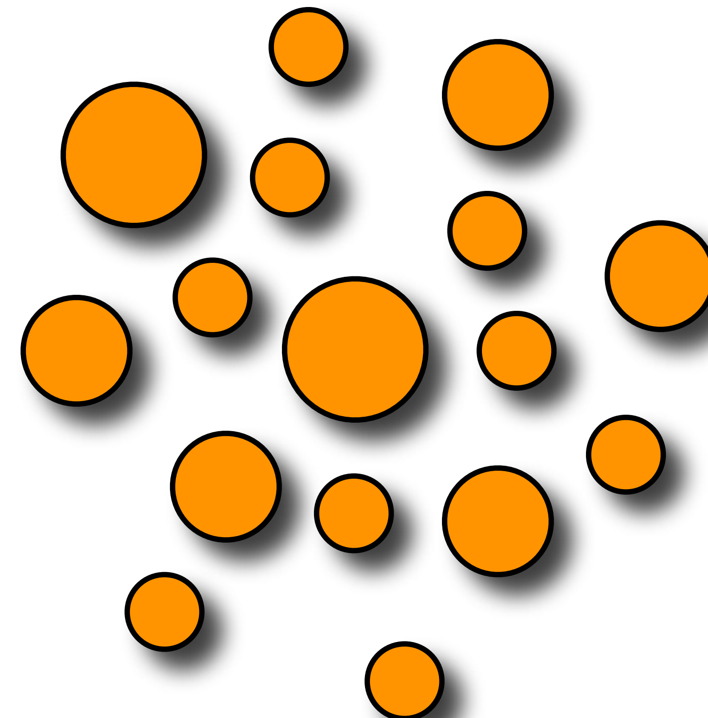
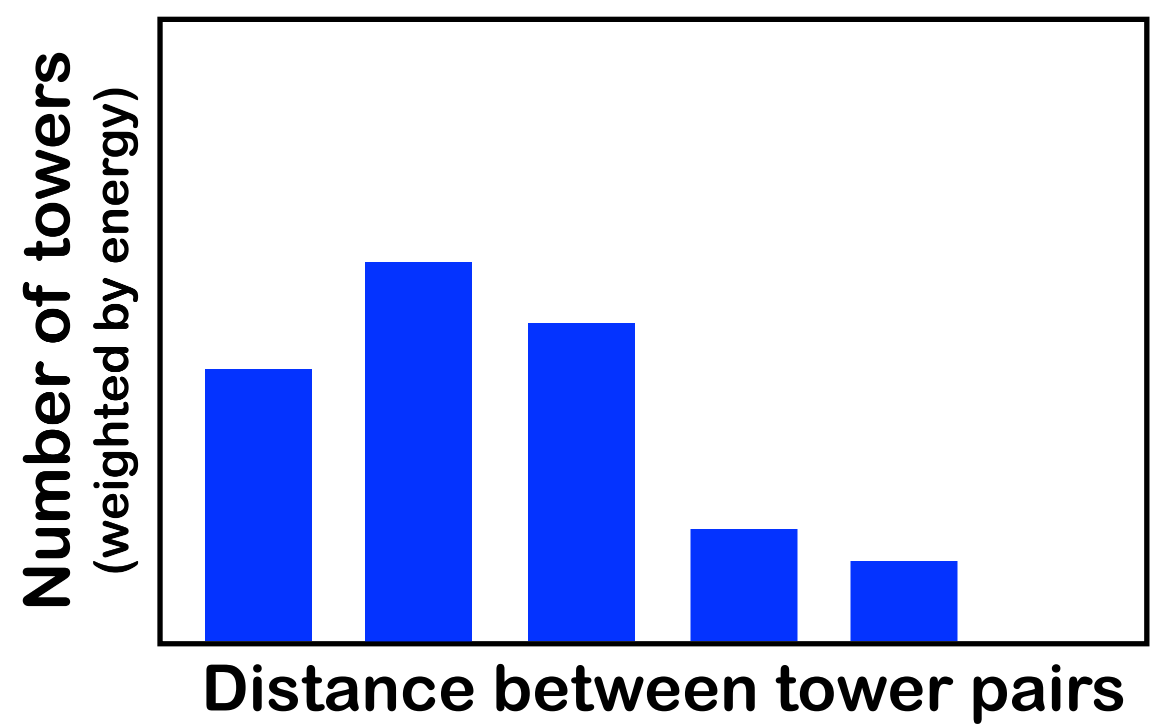


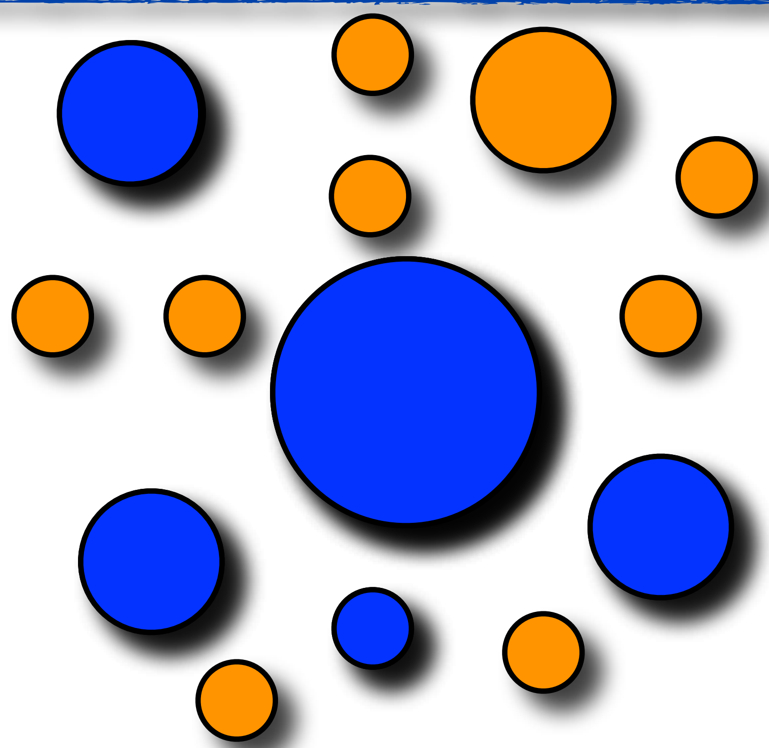


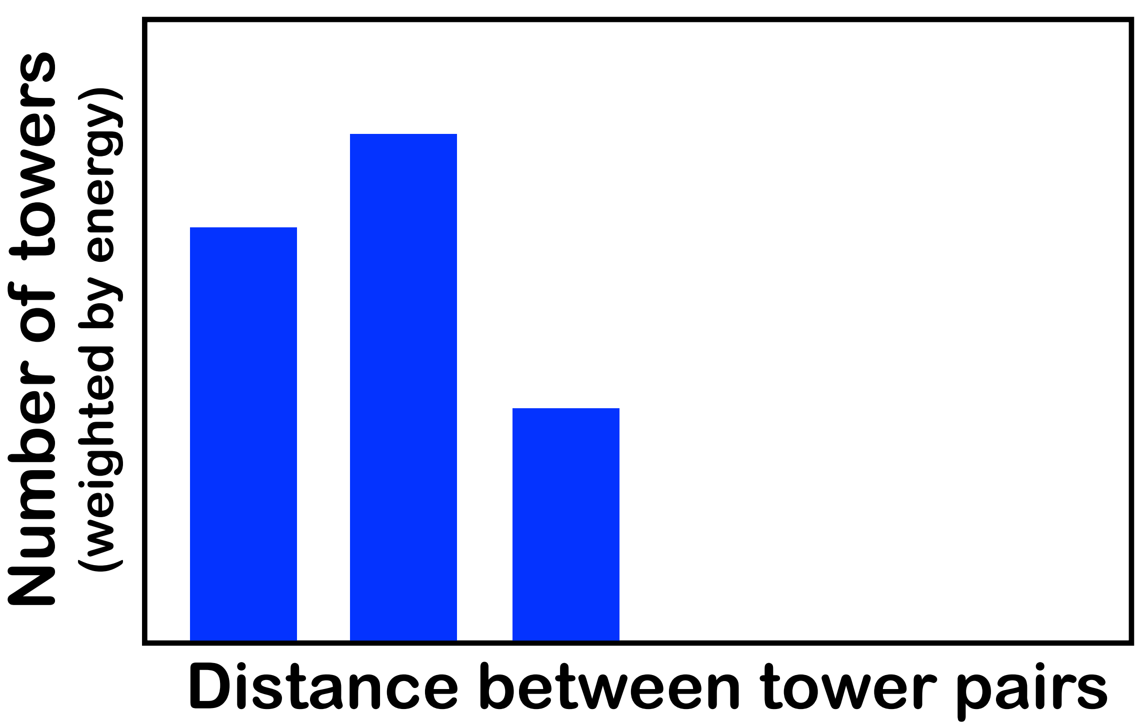
gluons



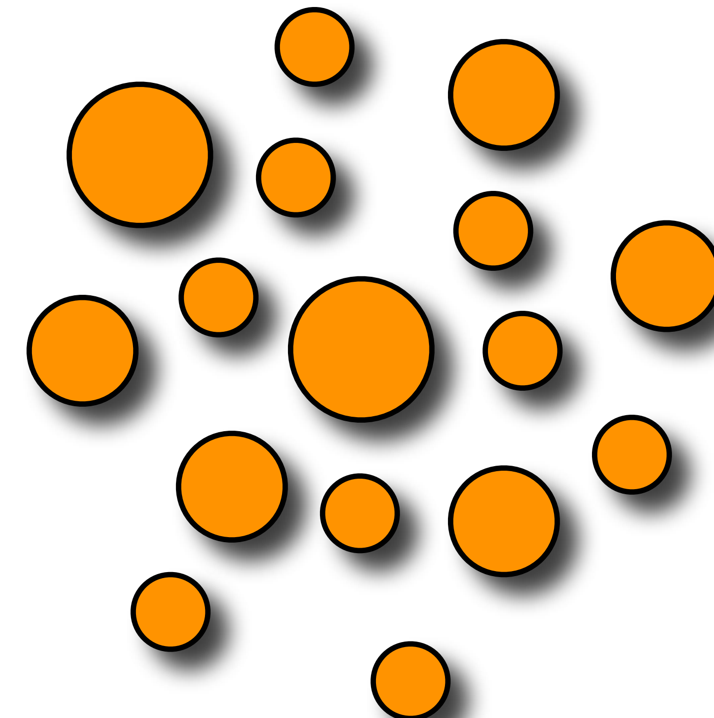


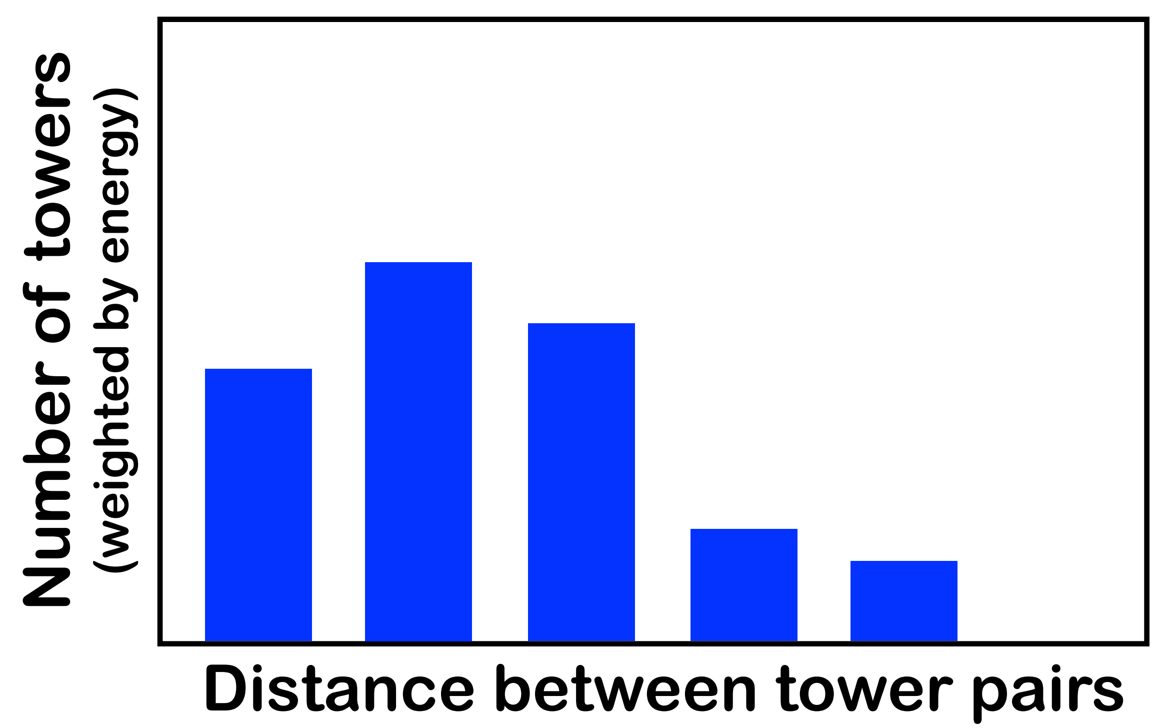
(Light) quarks





gluons





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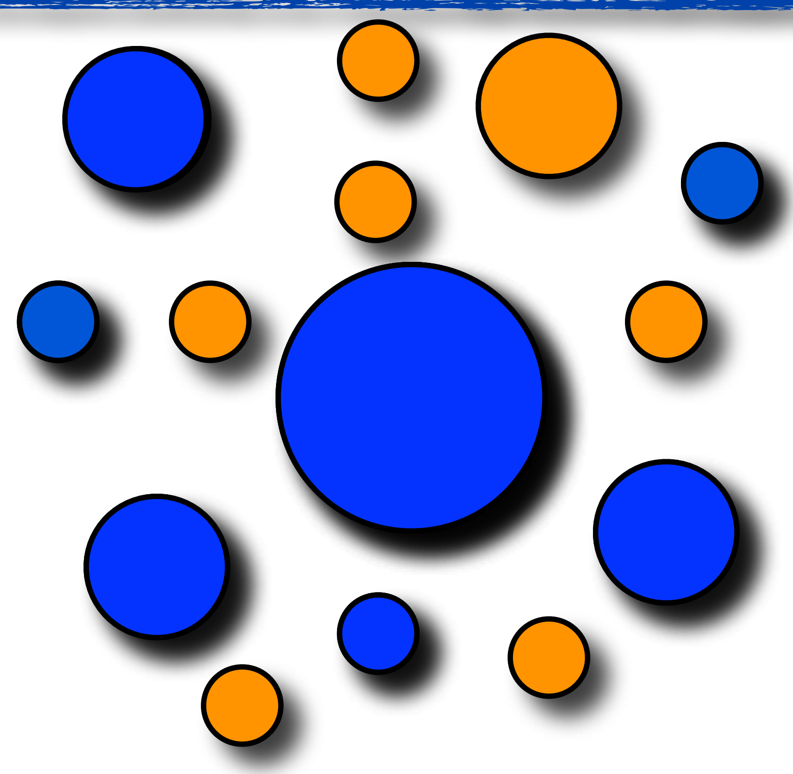
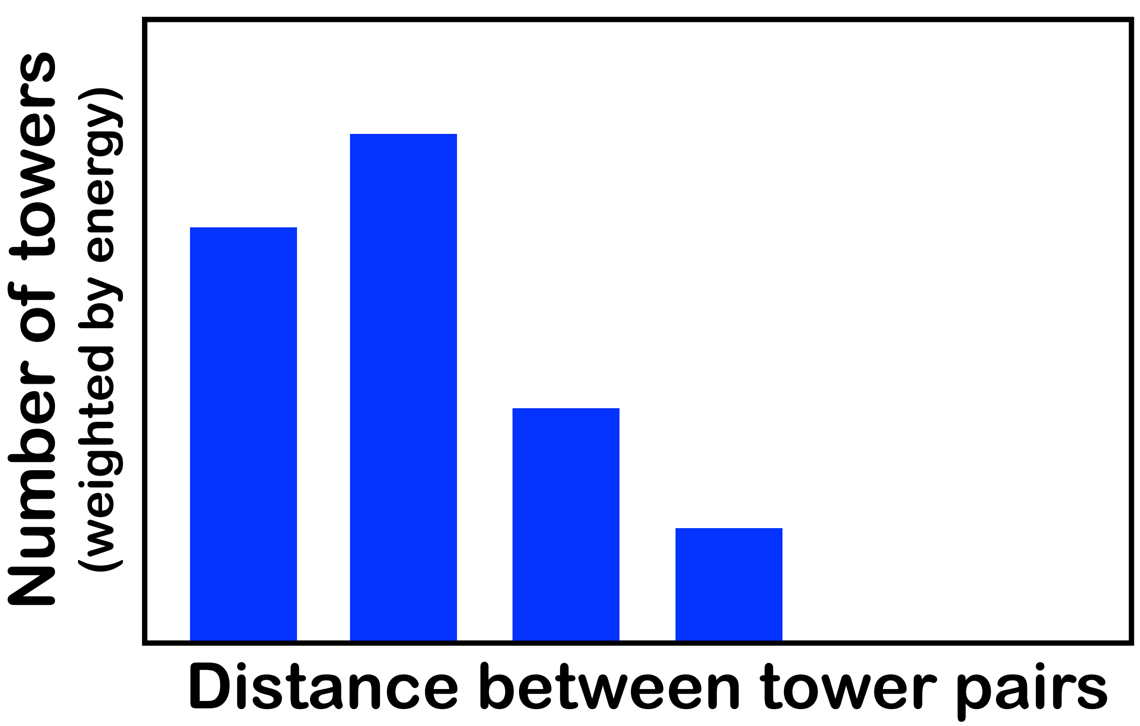
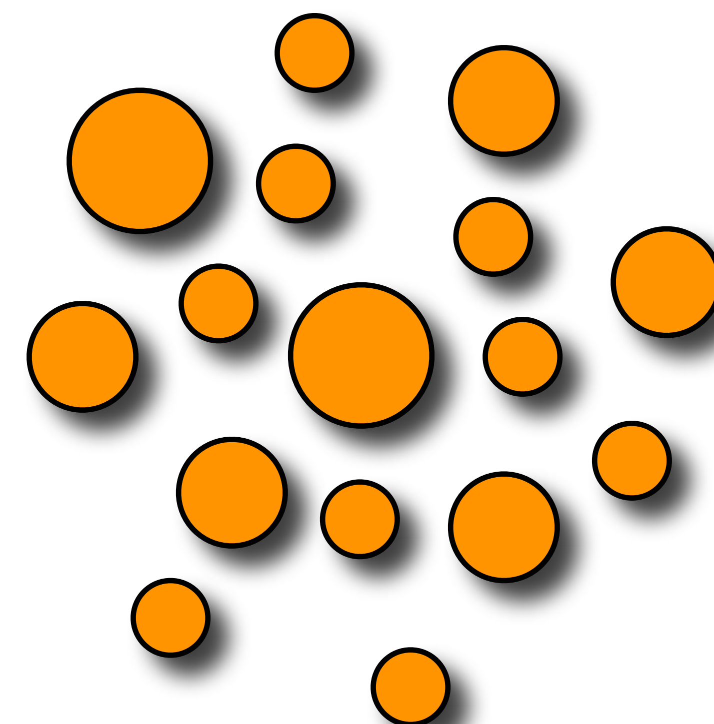
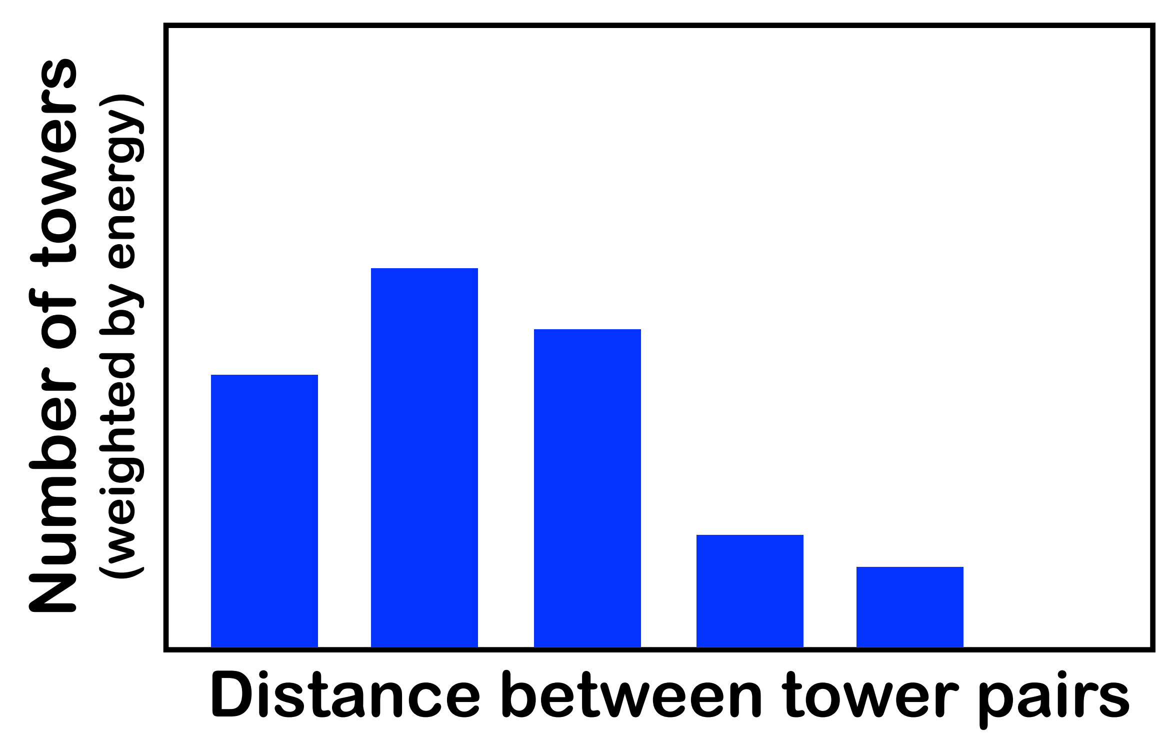




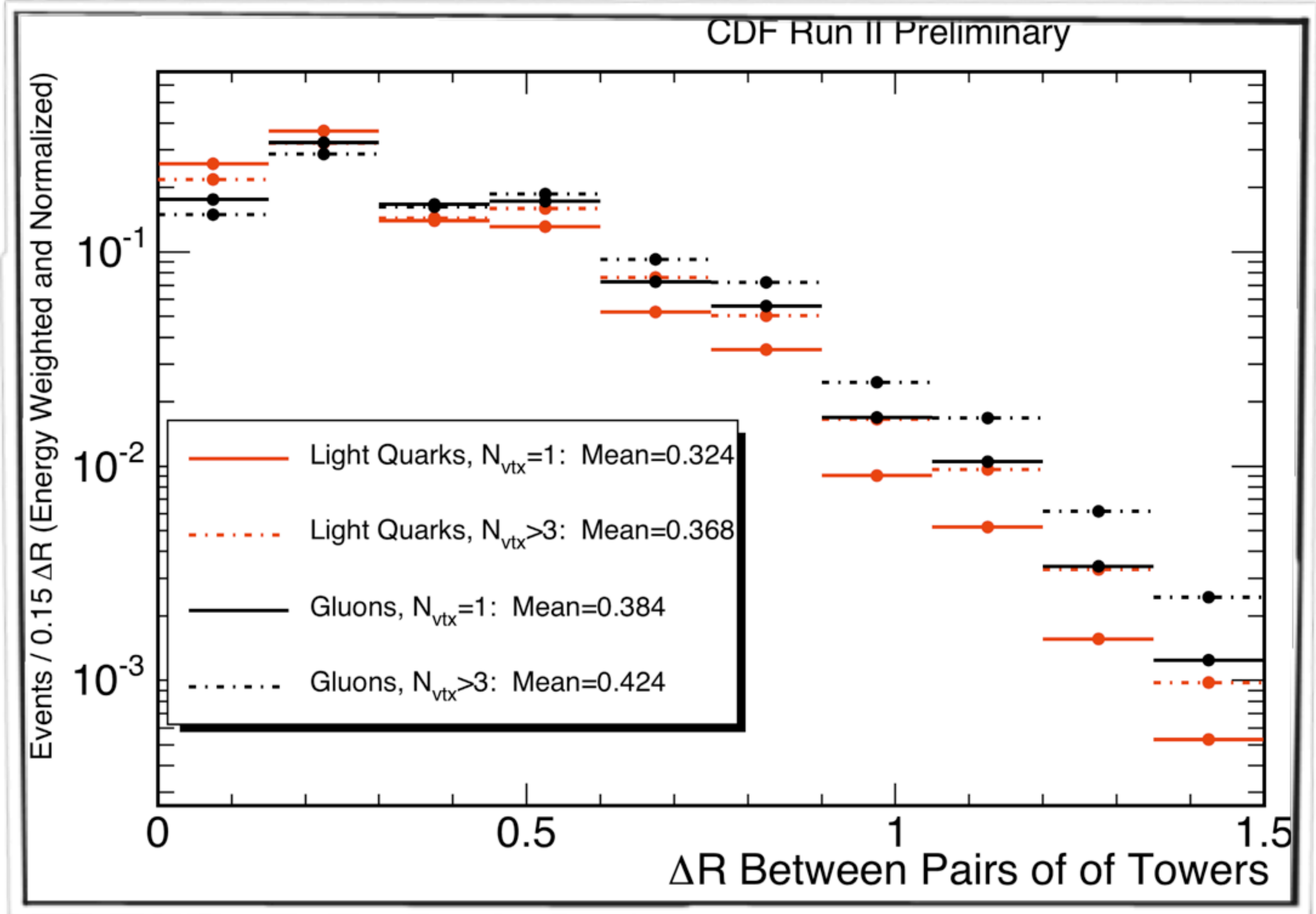
gluons





What do we see?

- The quark and gluon ΔR are very similar
- Remember the power of large numbers
  - There are ~20 towers in a jet
  - N(N-1) large

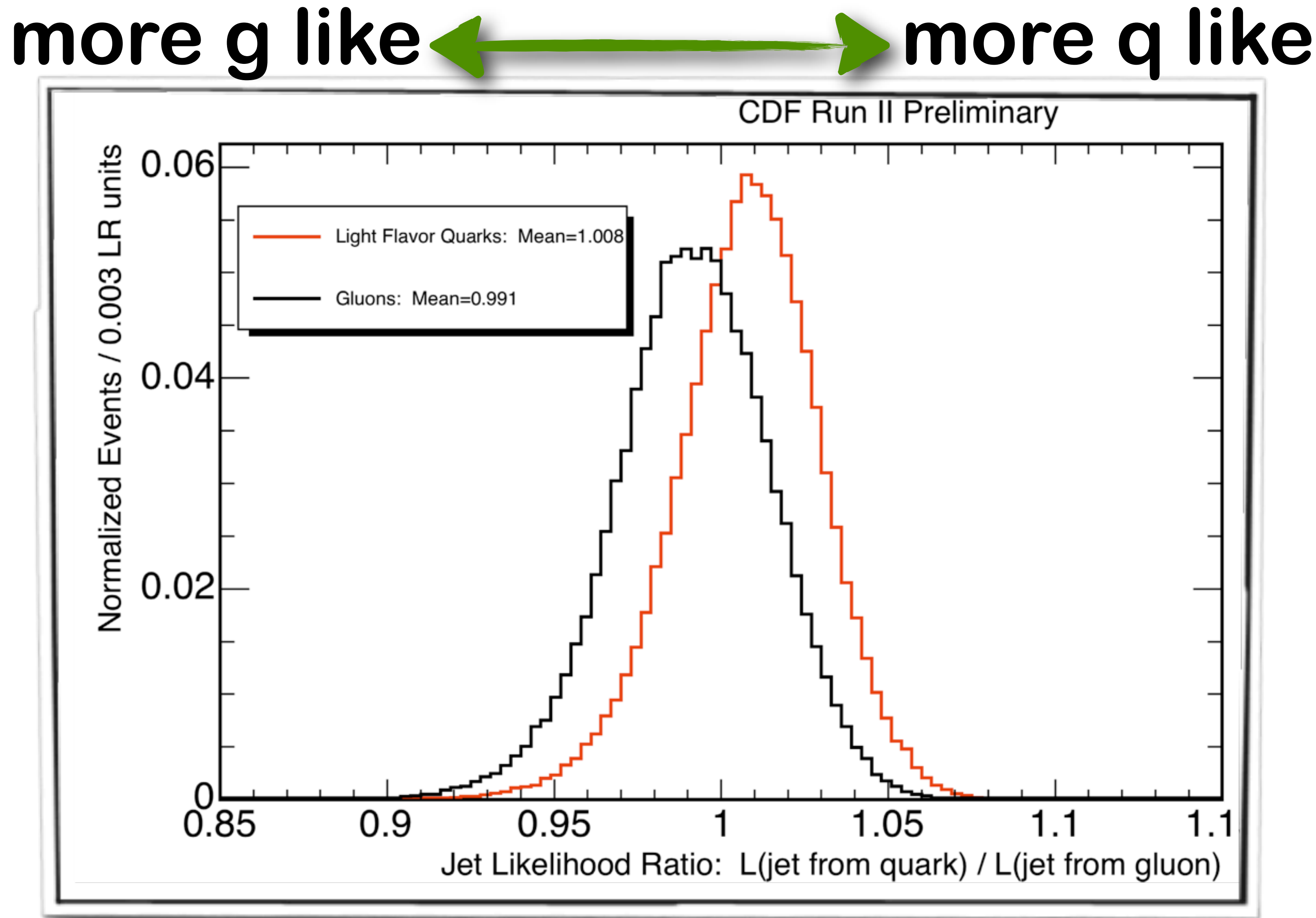


Use different templates for different number of vertices:

More interaction vertices ➜ more energy distributed throughout calorimeter ➜ jets look more spread out ➜ jets look more gluon-like

The likelihood ratio (LLR)

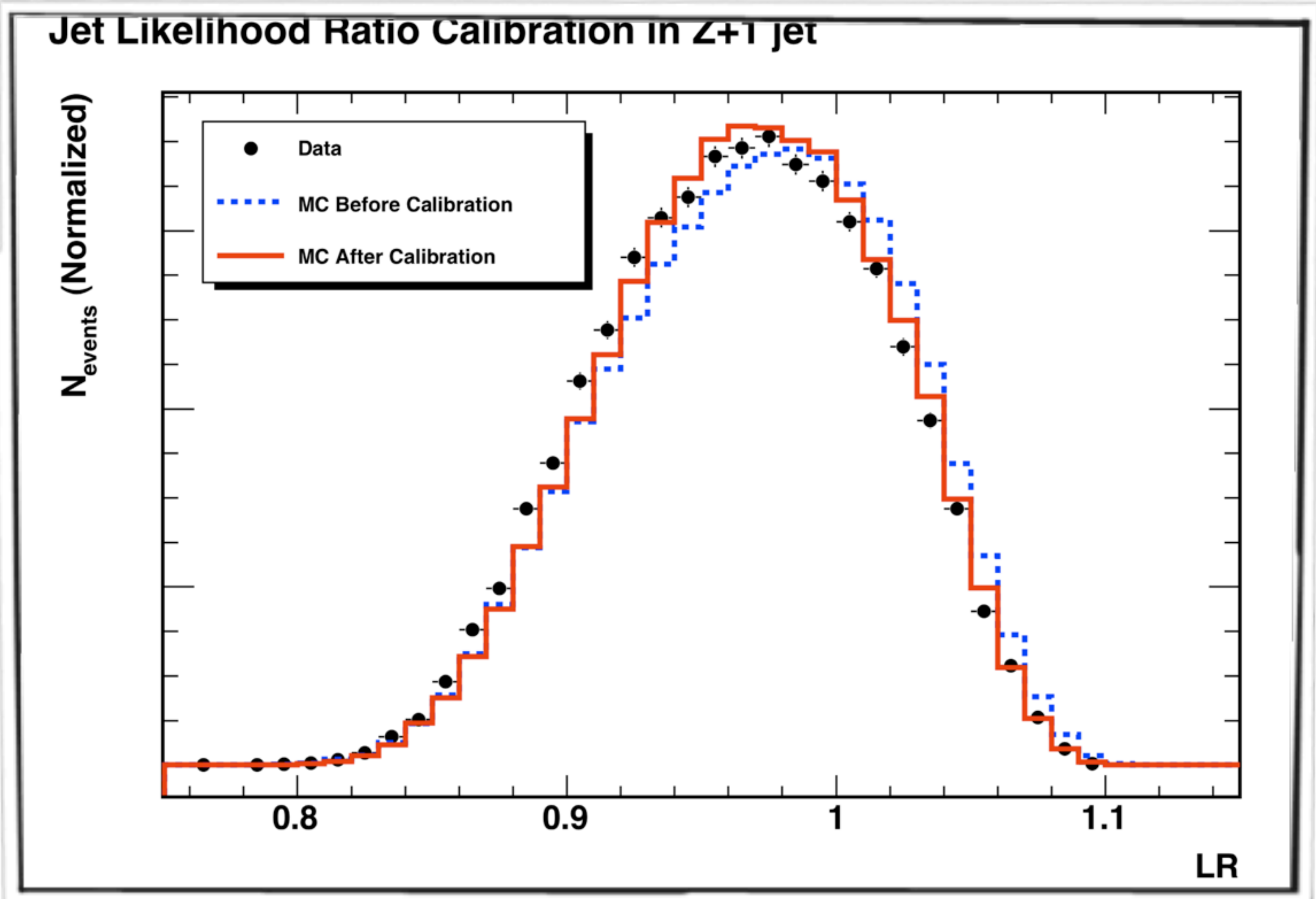
- Quarks and gluons look different enough
- Separate on a statistical basis



Not enough for a straight cut but useful in a multivariate analysis

Check in Z+1 jet

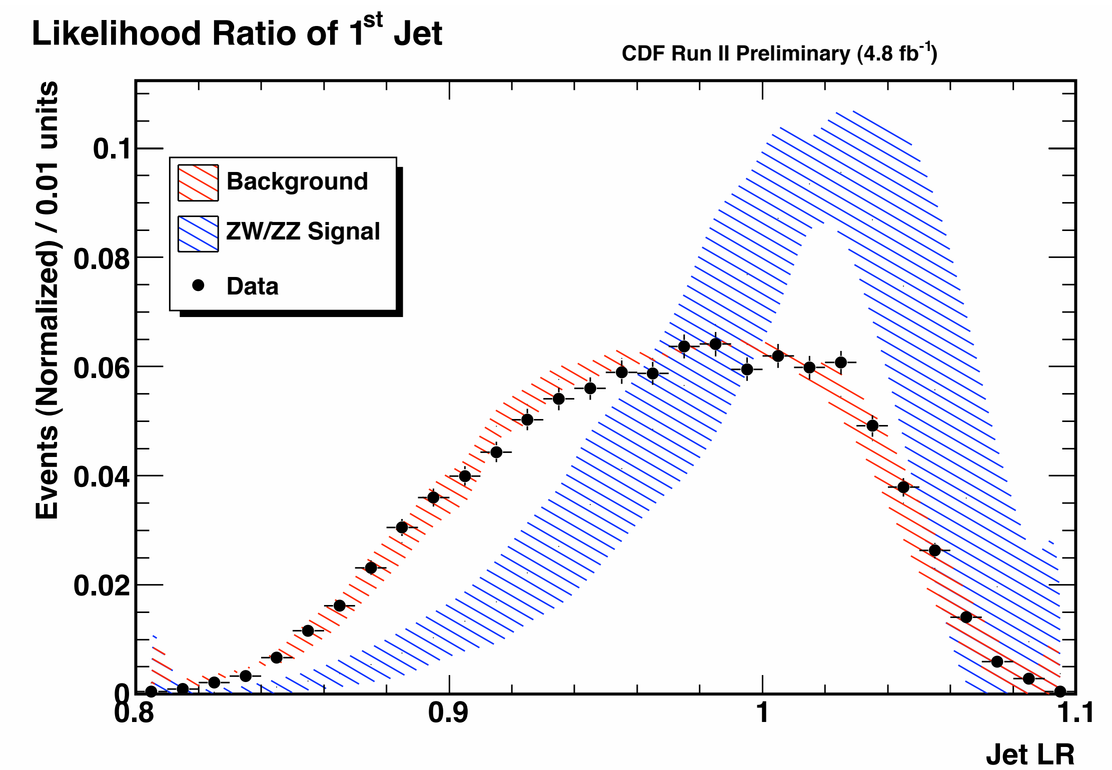
- Still not the “signal” region
  - Large stats sample
  - Check how the calibration worked
- A bit off but much better agreement
  - This final difference can be used to asses systematics

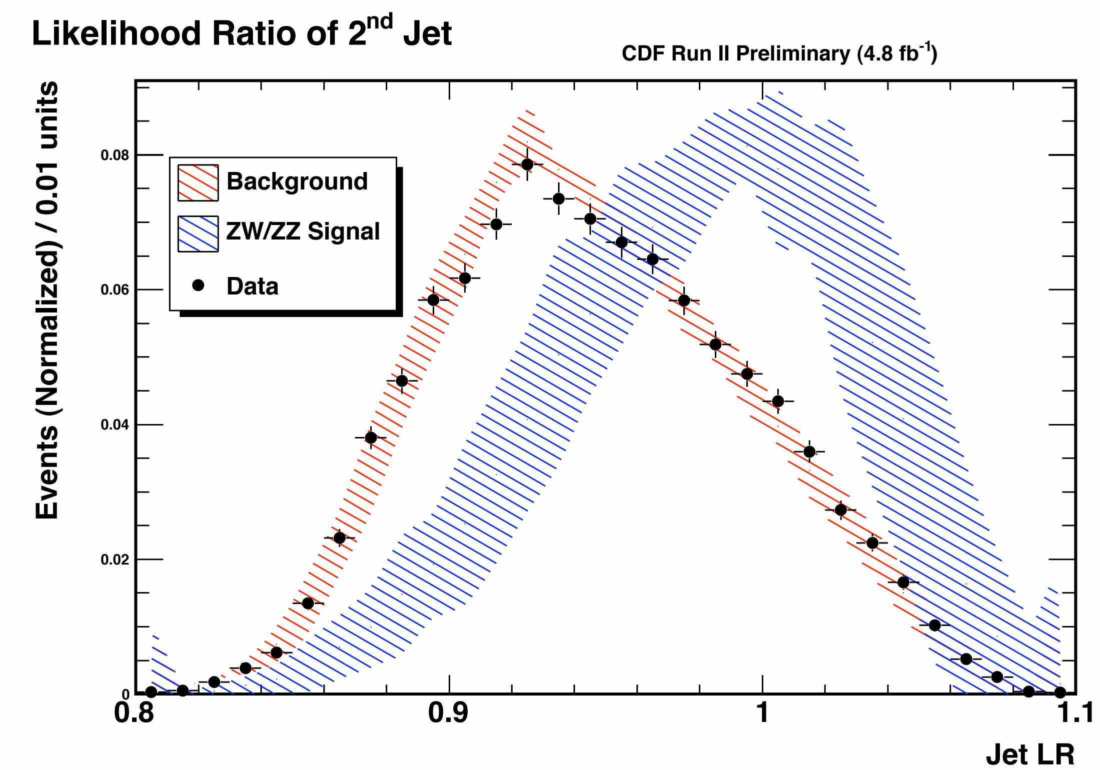


We now have a q/g separator which MC can described quite well

Finally, the Z+2 jets

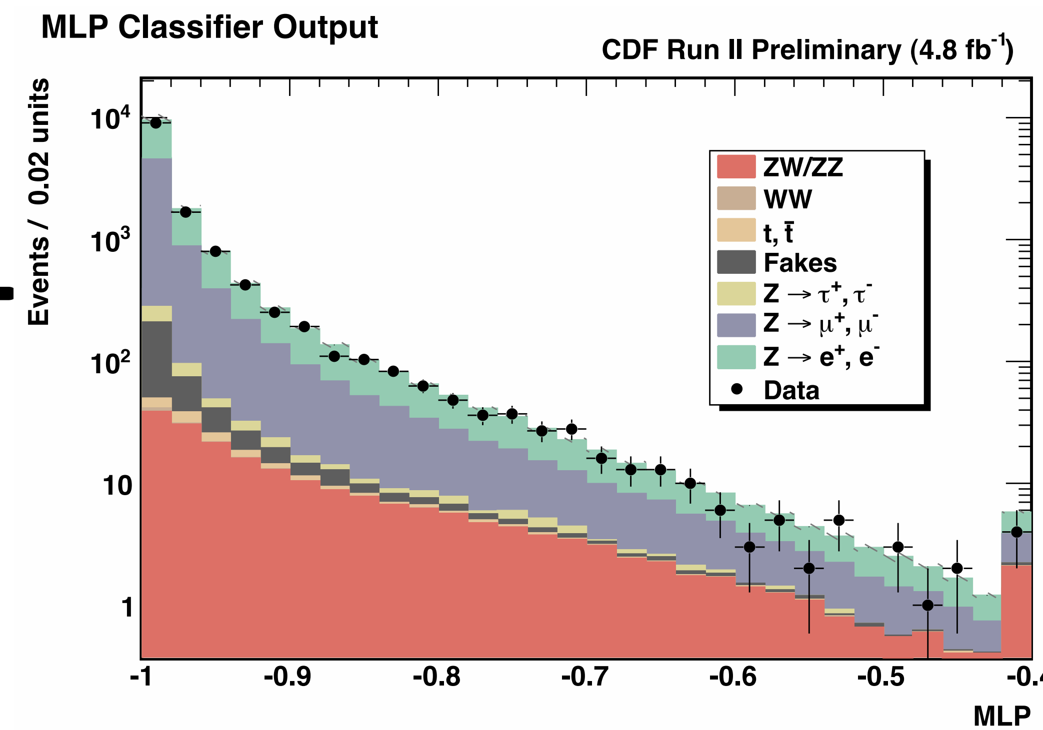
- This is our final sample of interest
  - Significant separation between quark and gluon jets
  - Can be used on a multivariate analysis
  - Double gain, because we can use it on both jets
  - Systematic band derived from Z+1jet
- Ways to improve?

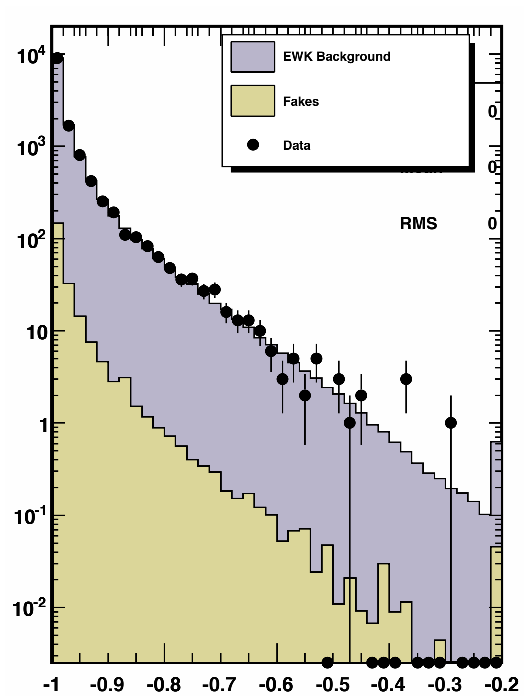


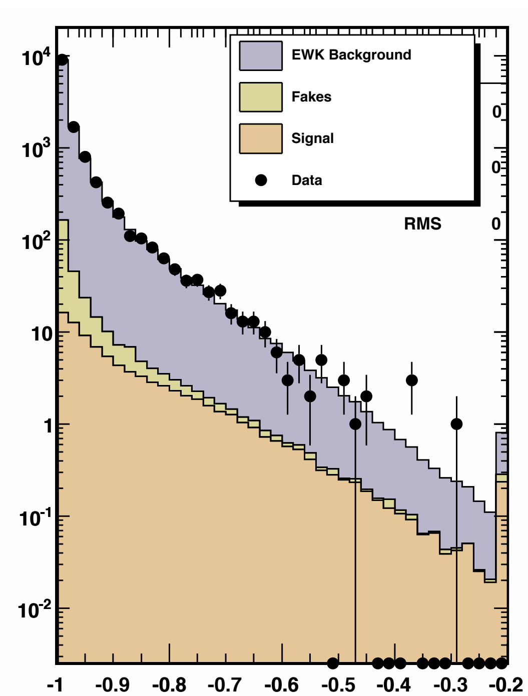


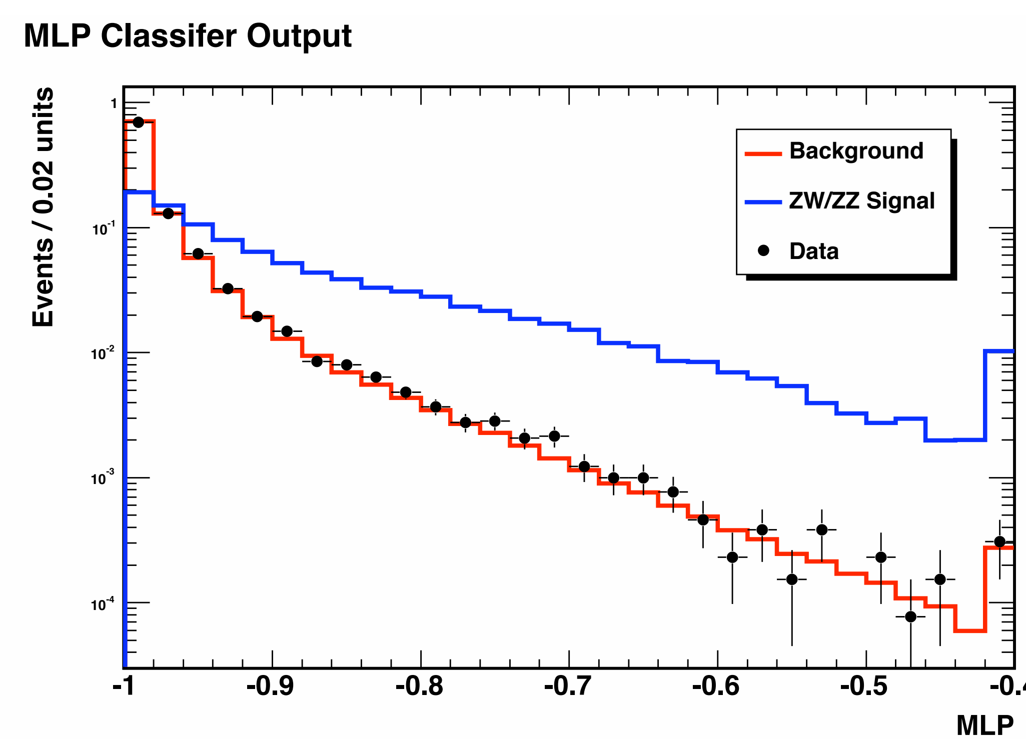
Final result

- σ_{WZ+ZZ} < 18pb at 95% CL
  - 2.4 × SM



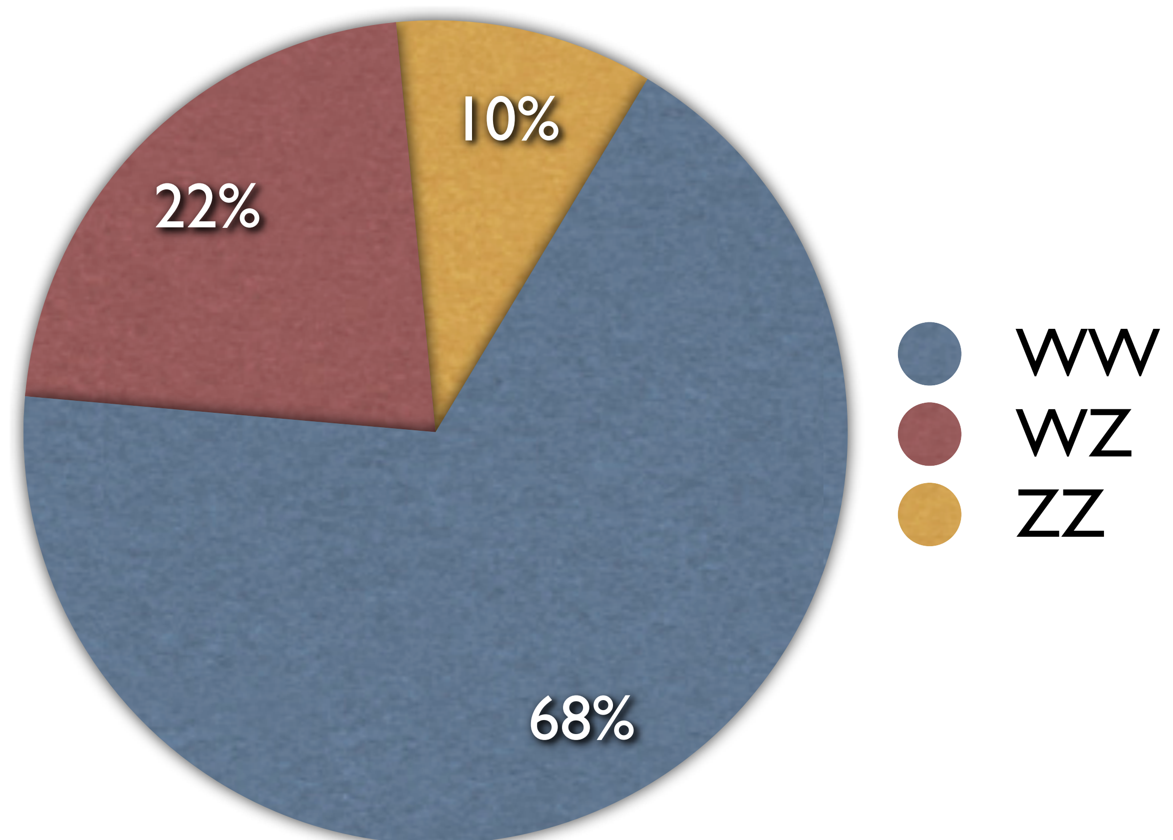






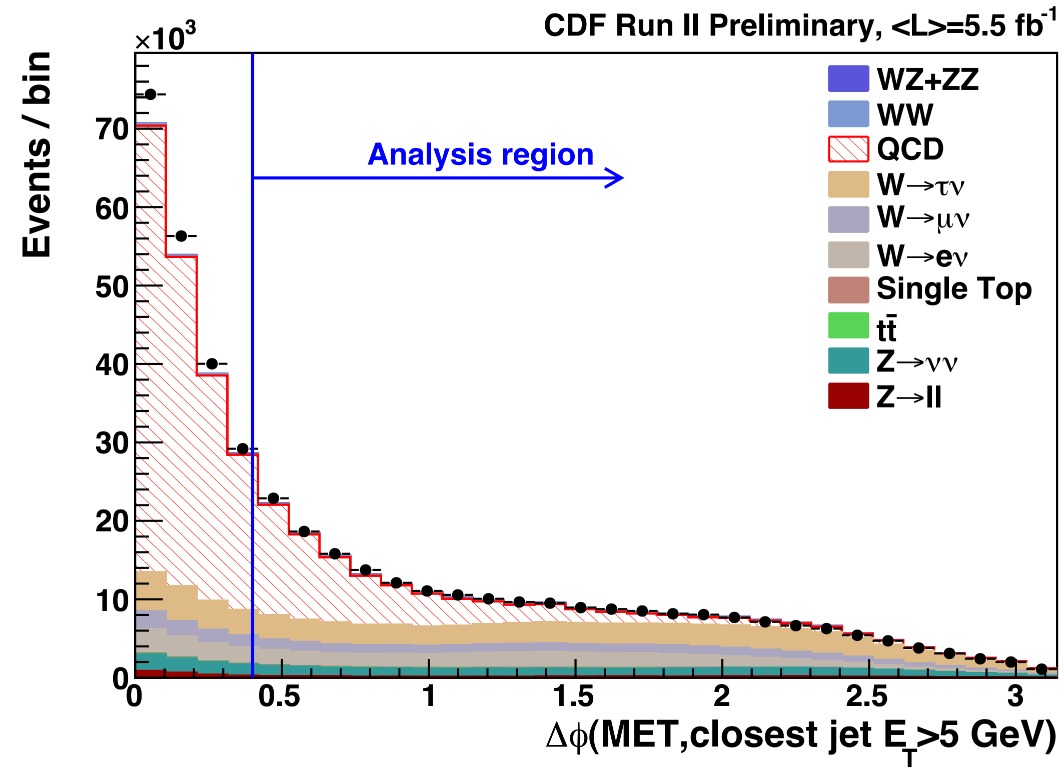
MET+jets

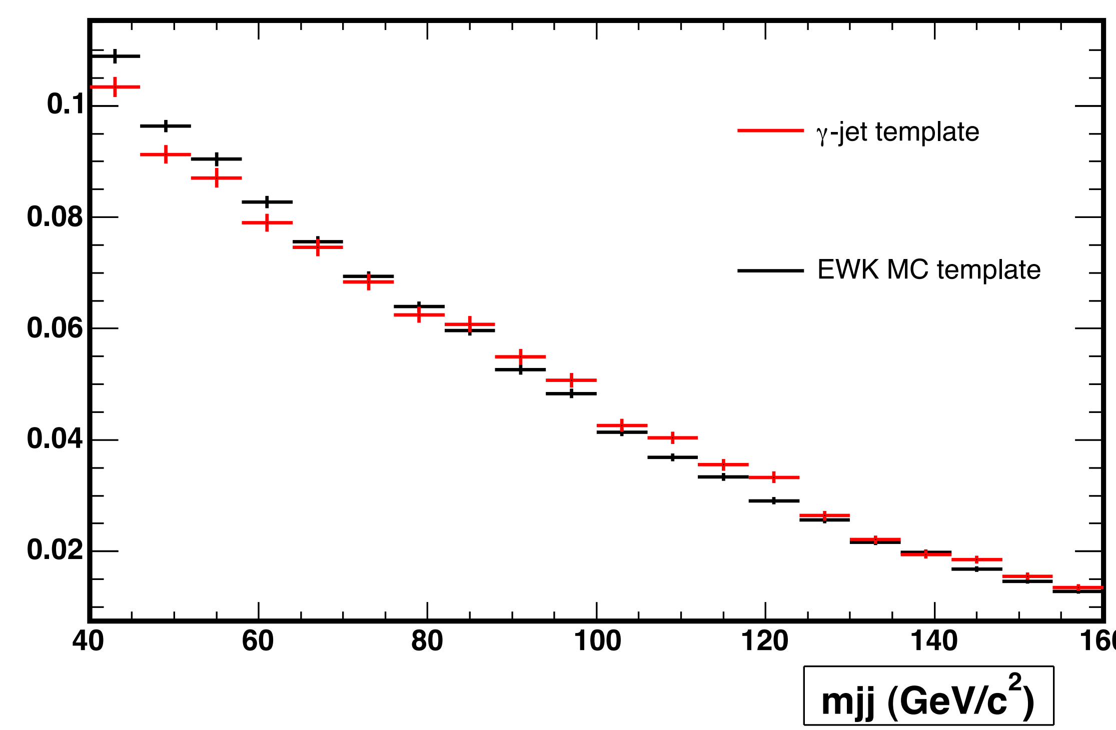
- The highest acceptance
  - it pays
- First observation of dibosons in hadronic final states
- Selection:
  - Jets ET above 25
  - MET above 60
  - +++ lots of cleaning cuts
- No btagging → WW dominates



Two big backgrounds

- QCD - multijet production
  - MET comes from mismeasurement
  - or resolution effects
- EWK - W+jets, Z+jets
  - Rely on MC model
    - ALPGEN, pythia, MadGraph, Sherpa, etc
    - none of them reproduce the CDF data completely
  - γ+jets similar production, use for systematics

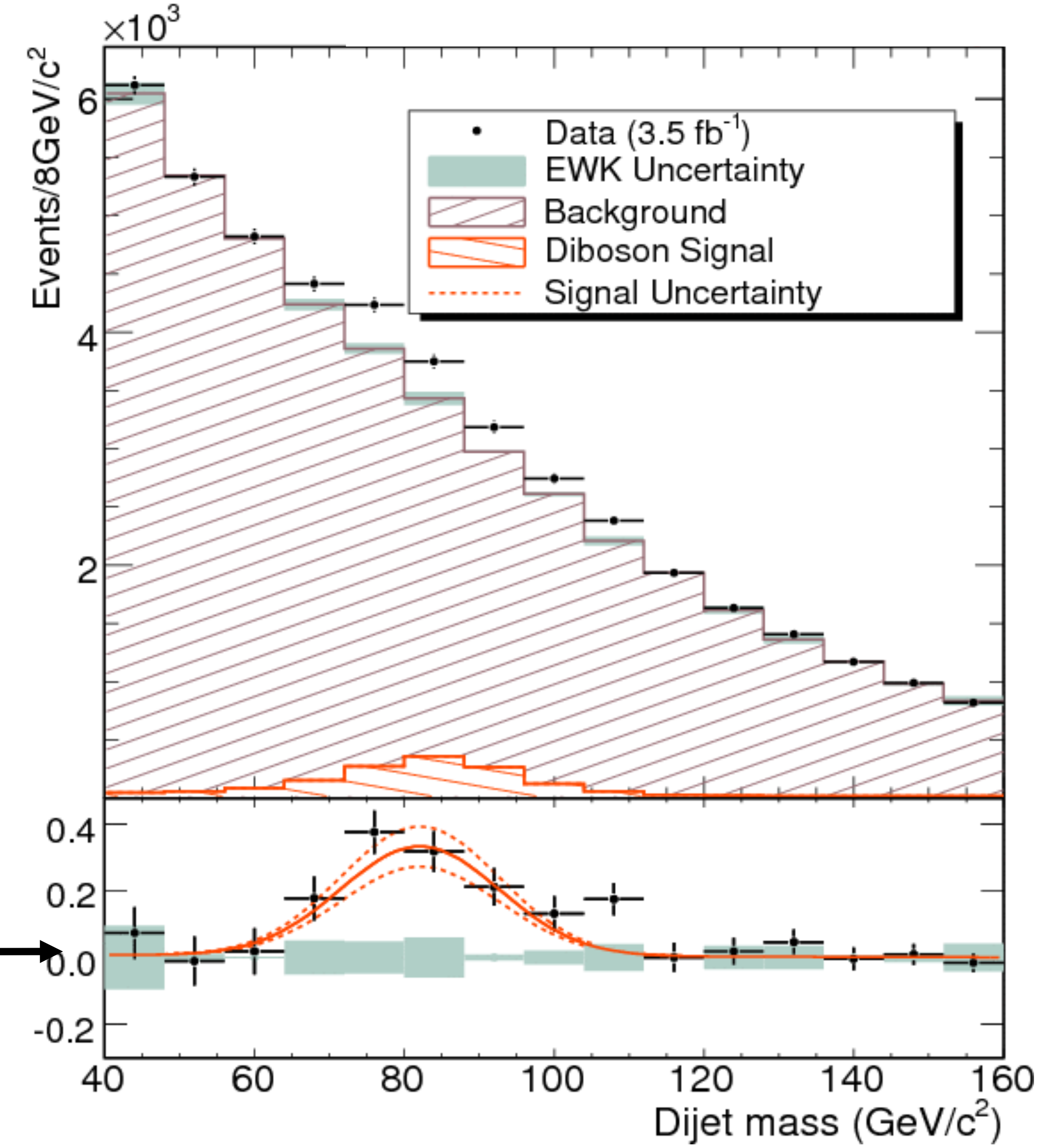




Results

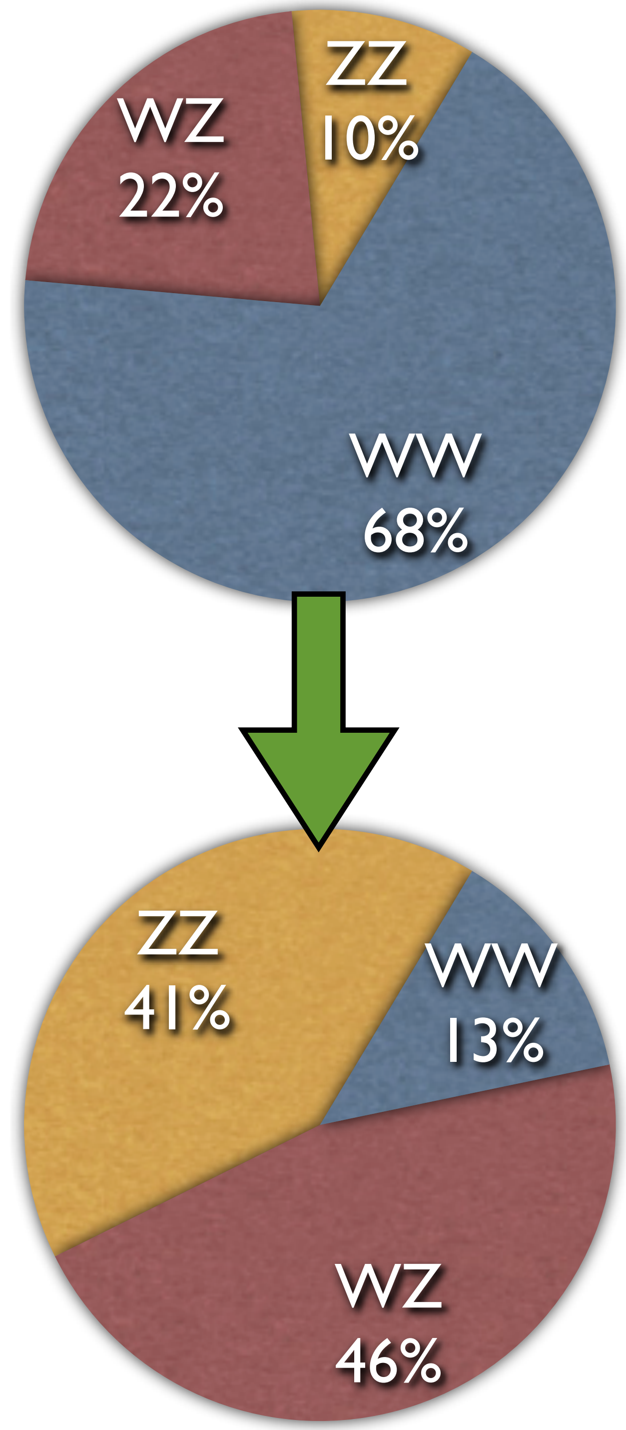
- Fit result:
  - 1516 ±239 (stat) ± 144(sys)
  - Expected 1398 ± 243

Data - background



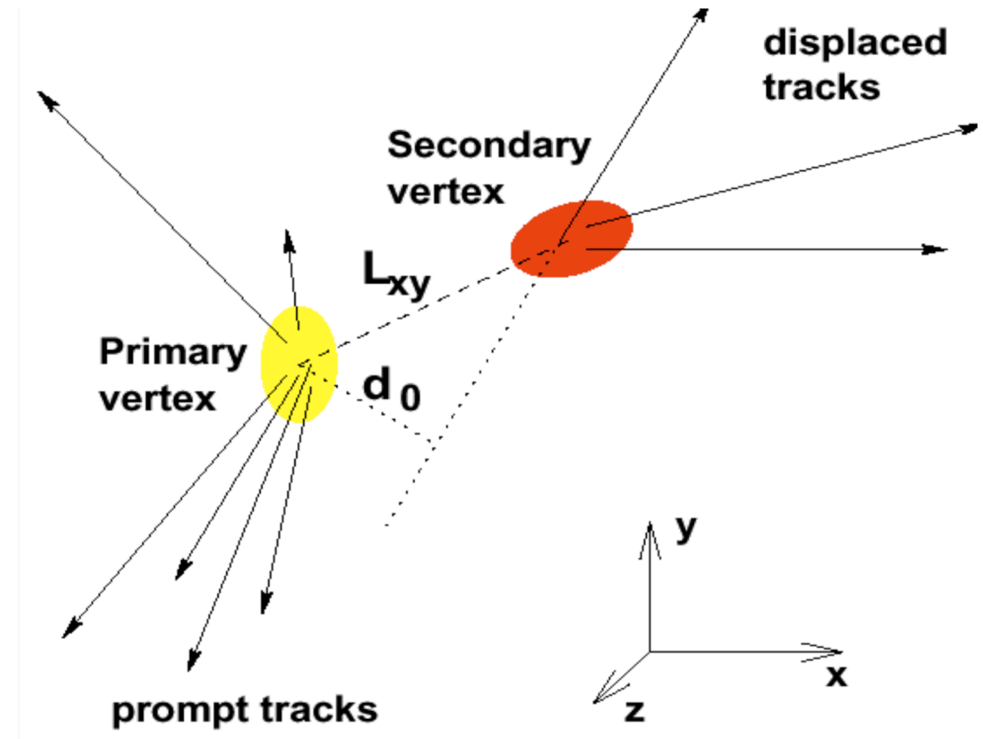
b quarks

- Why is it important?
  - H→bb
  - top physics BR(t→Wb) = 100%
  - New Physics most likely in 3'rd gen.
    - sbottom, stop decays into b+X
- Not something new
  - LEP, HERA, Run 1
- Precision vertexing
  - Silicon vertex detector



Signature of b-jets

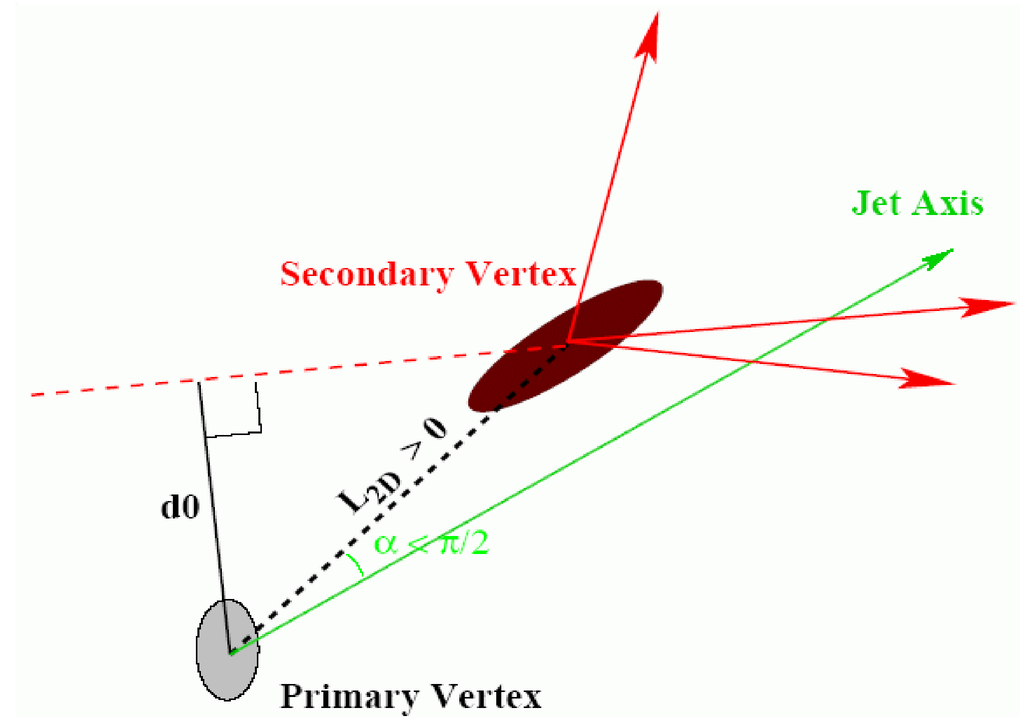
- b - long lived (!)
  - 1.5ps → cτ = 450micron
- b heavy (!)
  - 5.3GeV/c^2
- hard fragmentation
  - B hadron retains 70% of b- quark momentum



- High PT tracks
- Secondary vertices
  - Large impact parameters

A new btagger

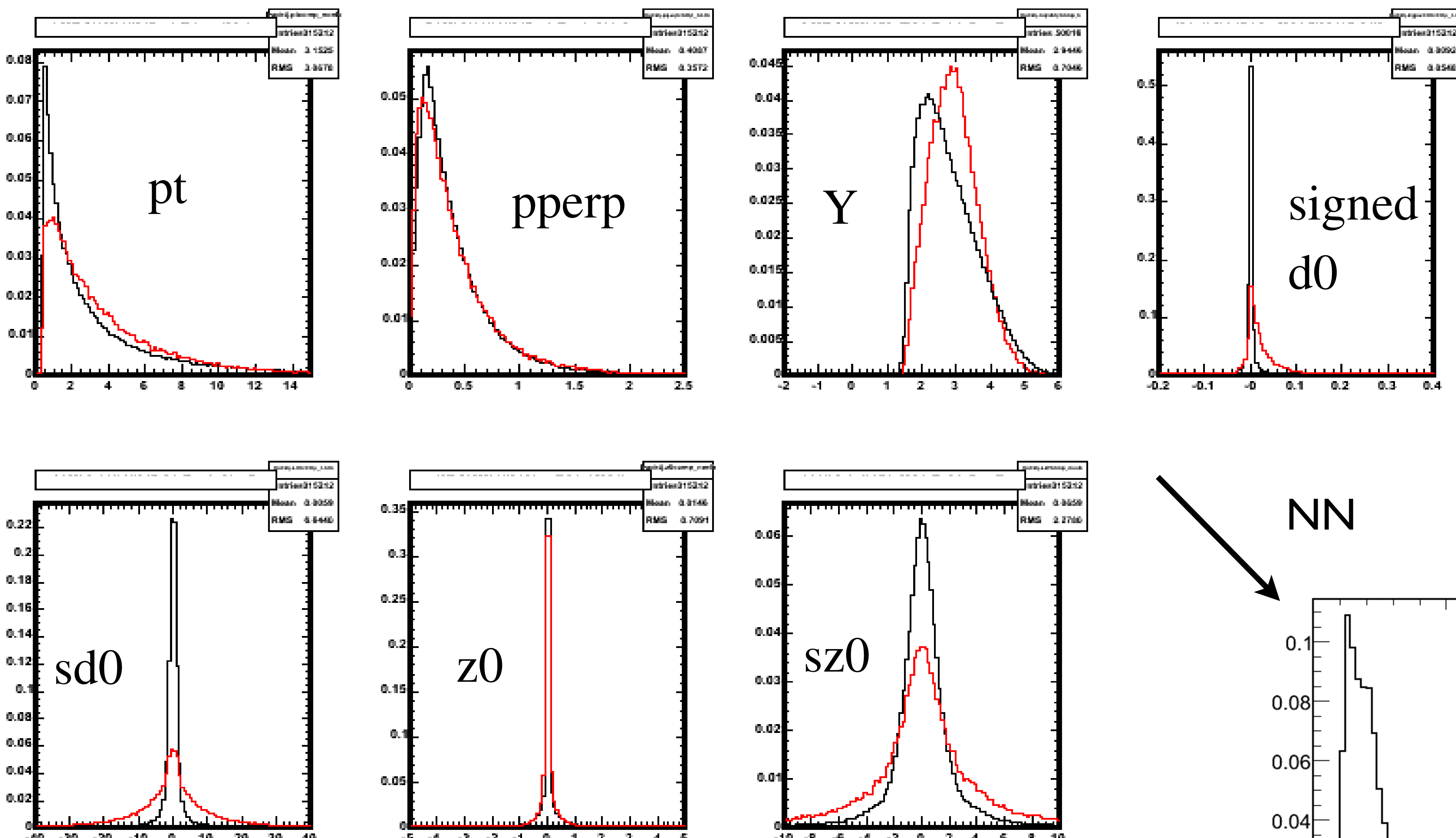
- First rank tracks
  - track displacement
    - signed impact parameter (d0) and significance for impact parameter (sd0)
    - z position wrt primary vertex and its significance
  - high B momentum
    - Track Pt
    - Momentum transverse to jet axis (pperp)
    - Rapidity wrt jet axis (Y)

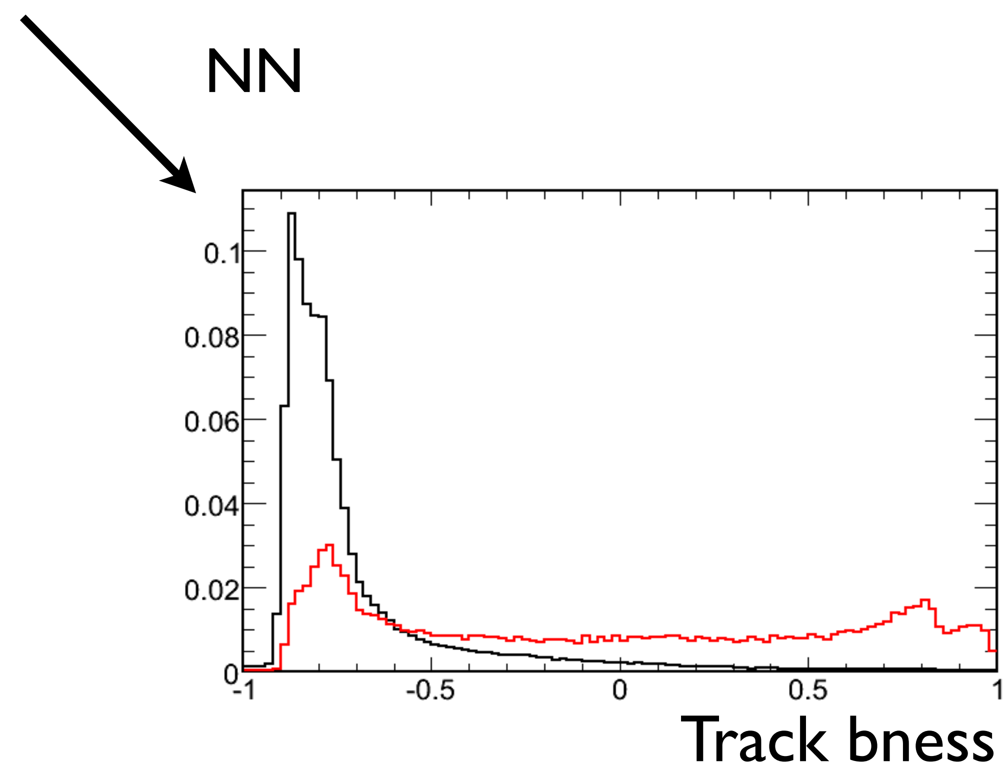


developed by John Freeman (Fermilab postdoc) and by Stephen Poprocki (Cornell PhD student)

Track bness inputs

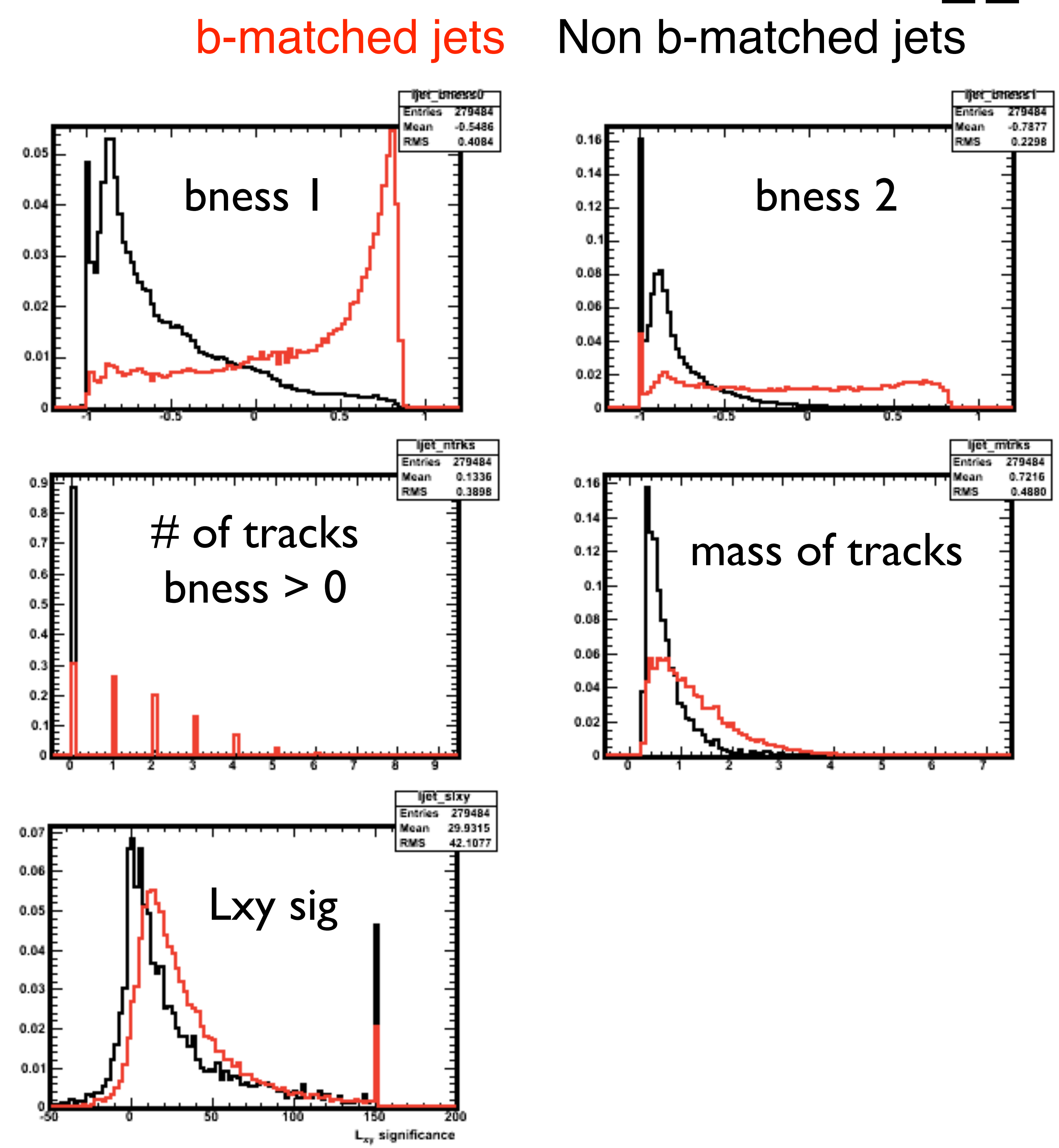
B daughters   Non-B daughters





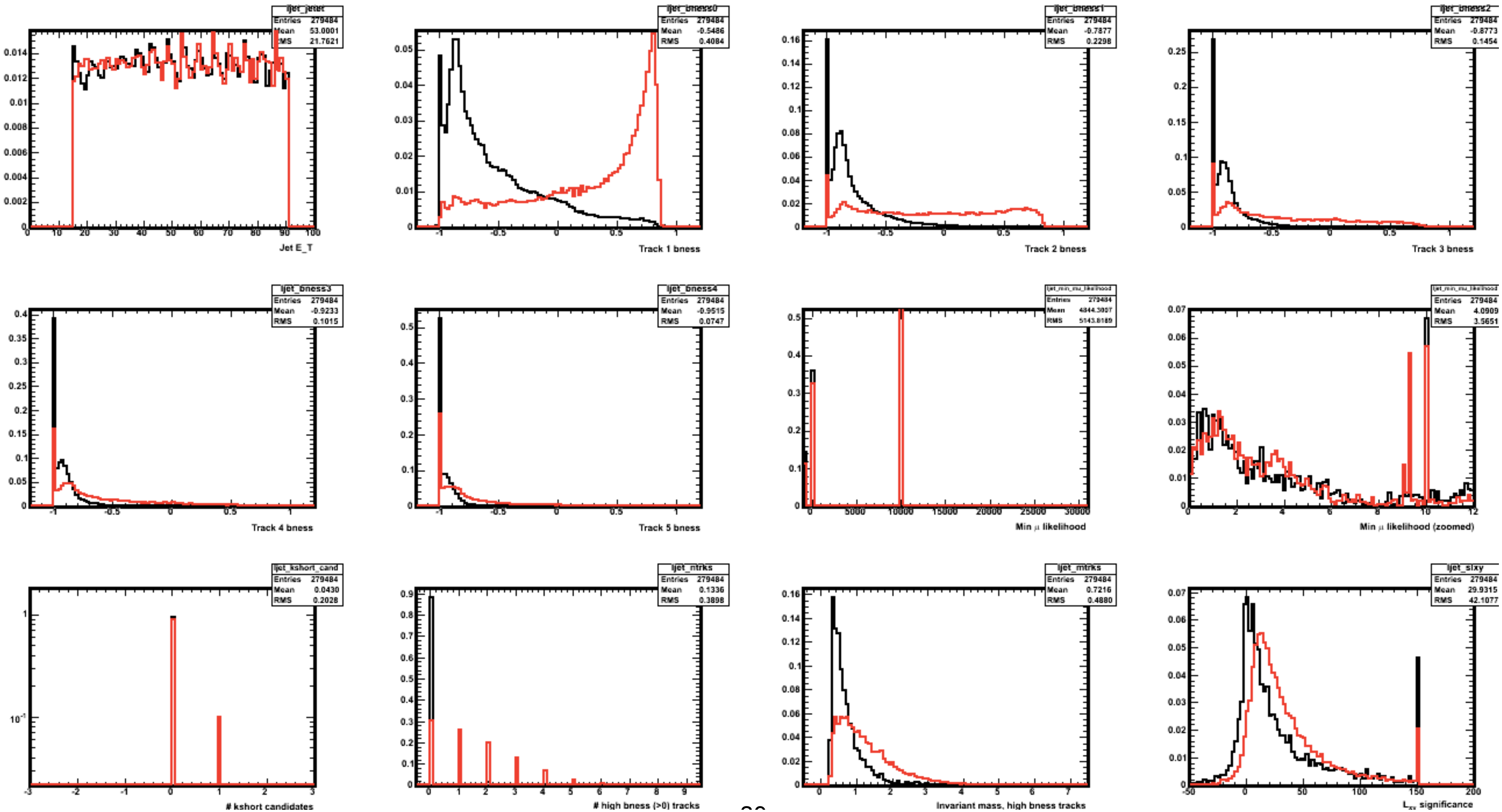
Jet bness

- Top 5 tracks bness (bness1, etc.)
- # of tracks with bness > 0
  - inv. mass of those
- Lxy significance
- Min muon likelihood form SLT
- # of KS candidates



All jet bness inputs

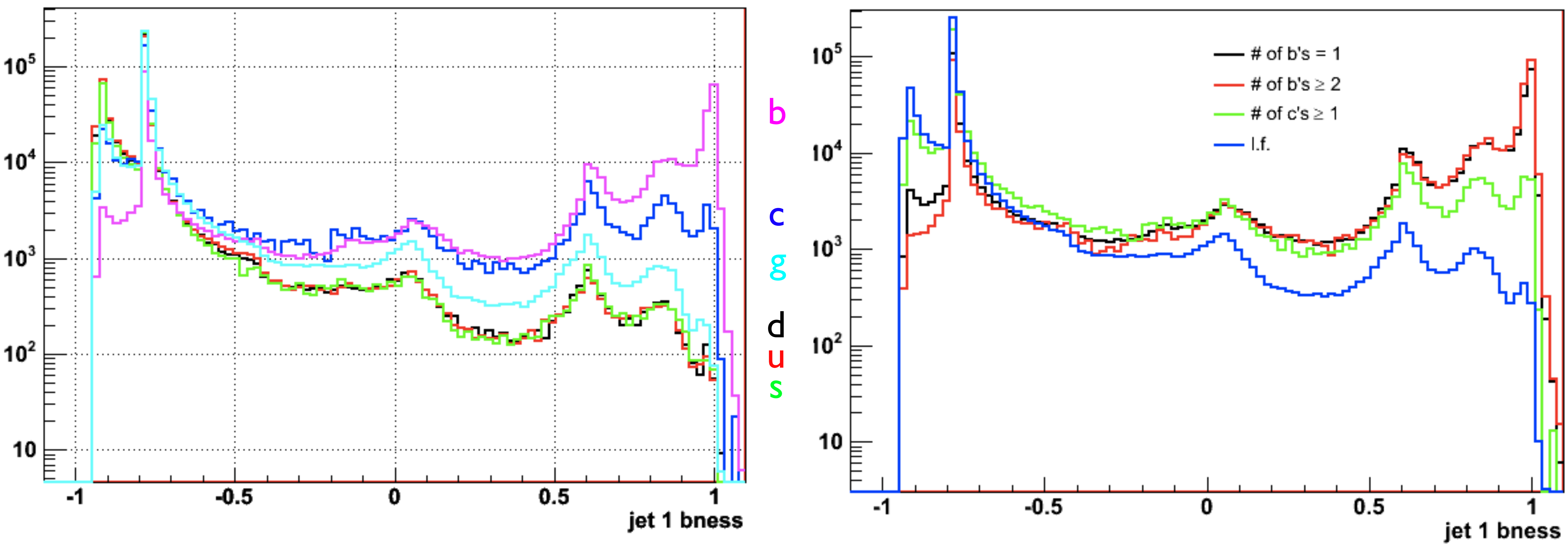
B daughters   Non-B daughters



Jet bness output

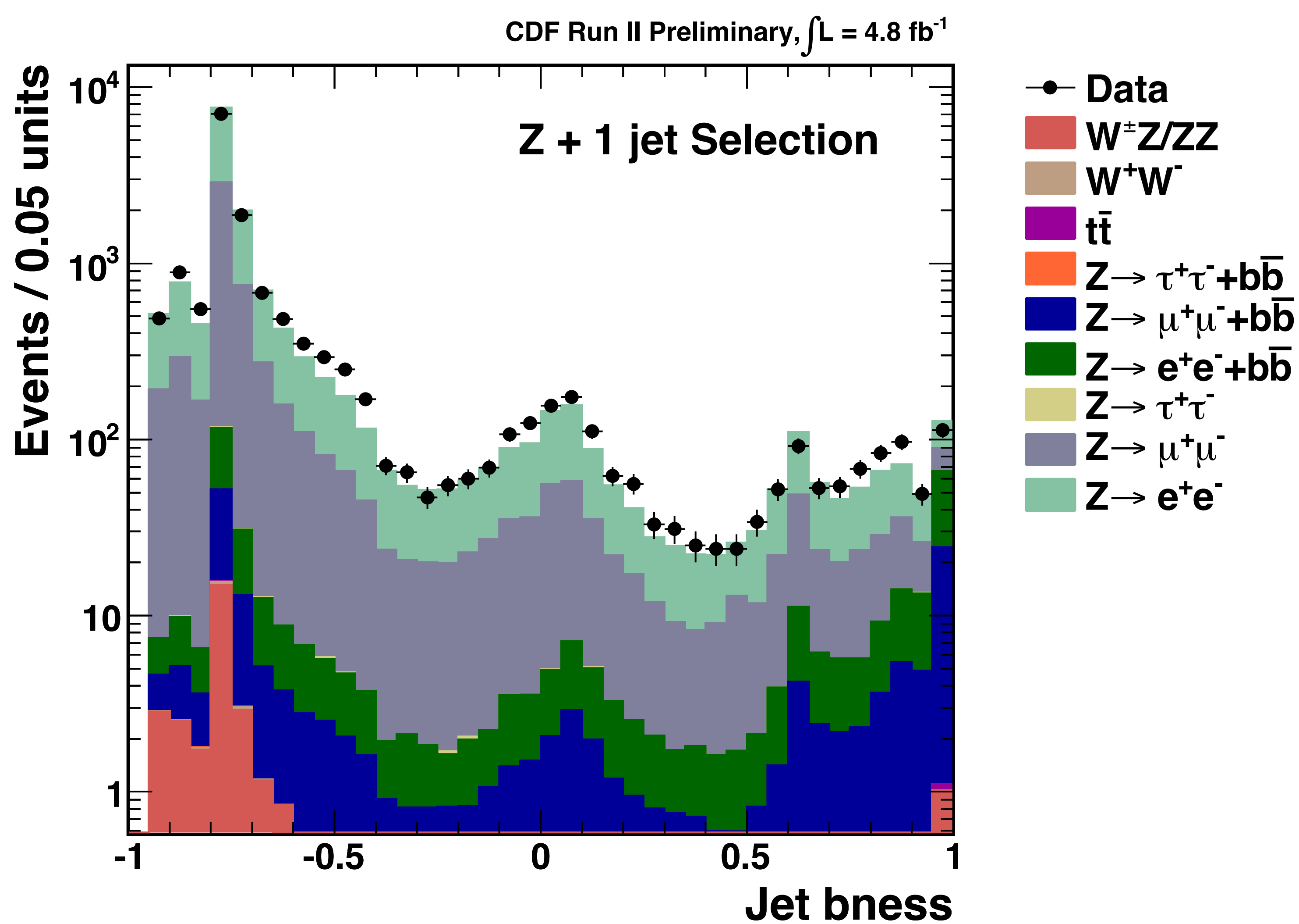
- First try: dijet MC
- Jets matched to just 1 parton (DR<0.4)
- Normalized to equal area

- Including jets matched to multiple partons
- If there is at least 1b does not seem to matter if other partons are also matched



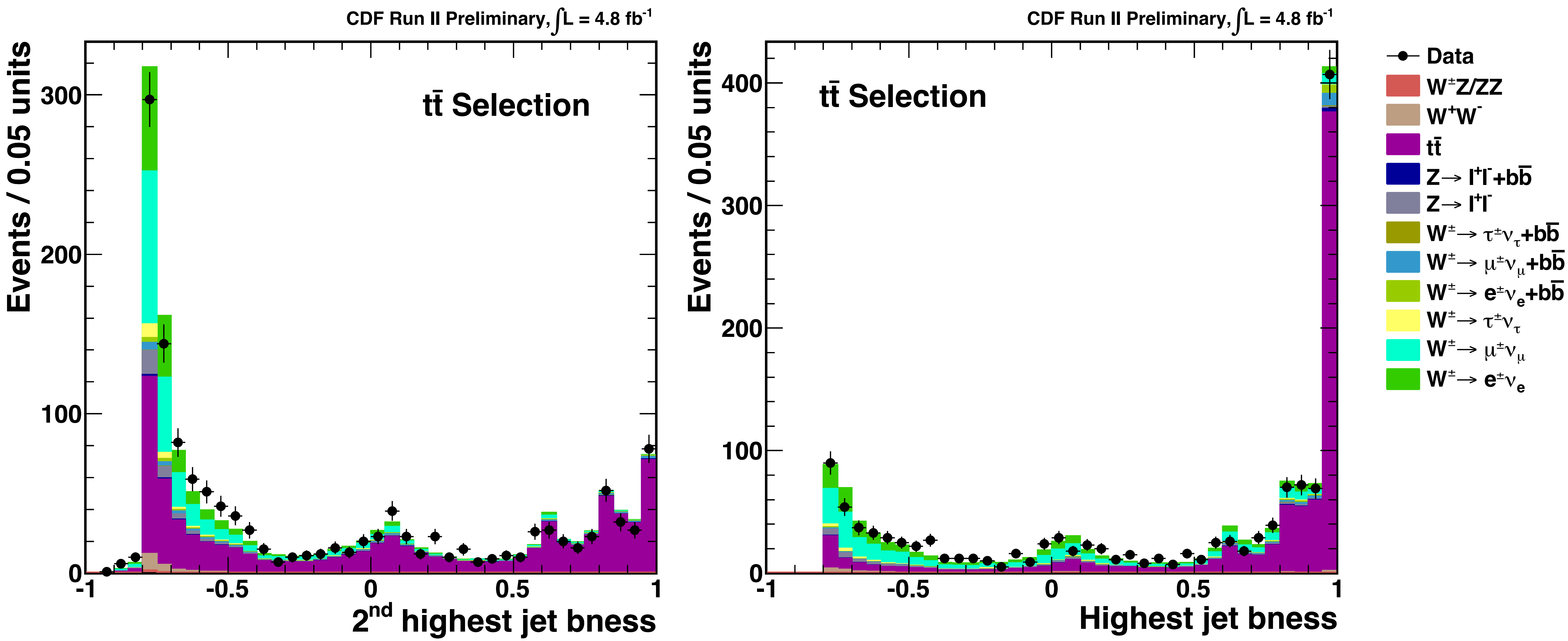
How about data

- Again, all this nice MC have to get a reality check from the data (agh!)
- Z+1jet mostly non-b jets
- used to measure the mistag rates

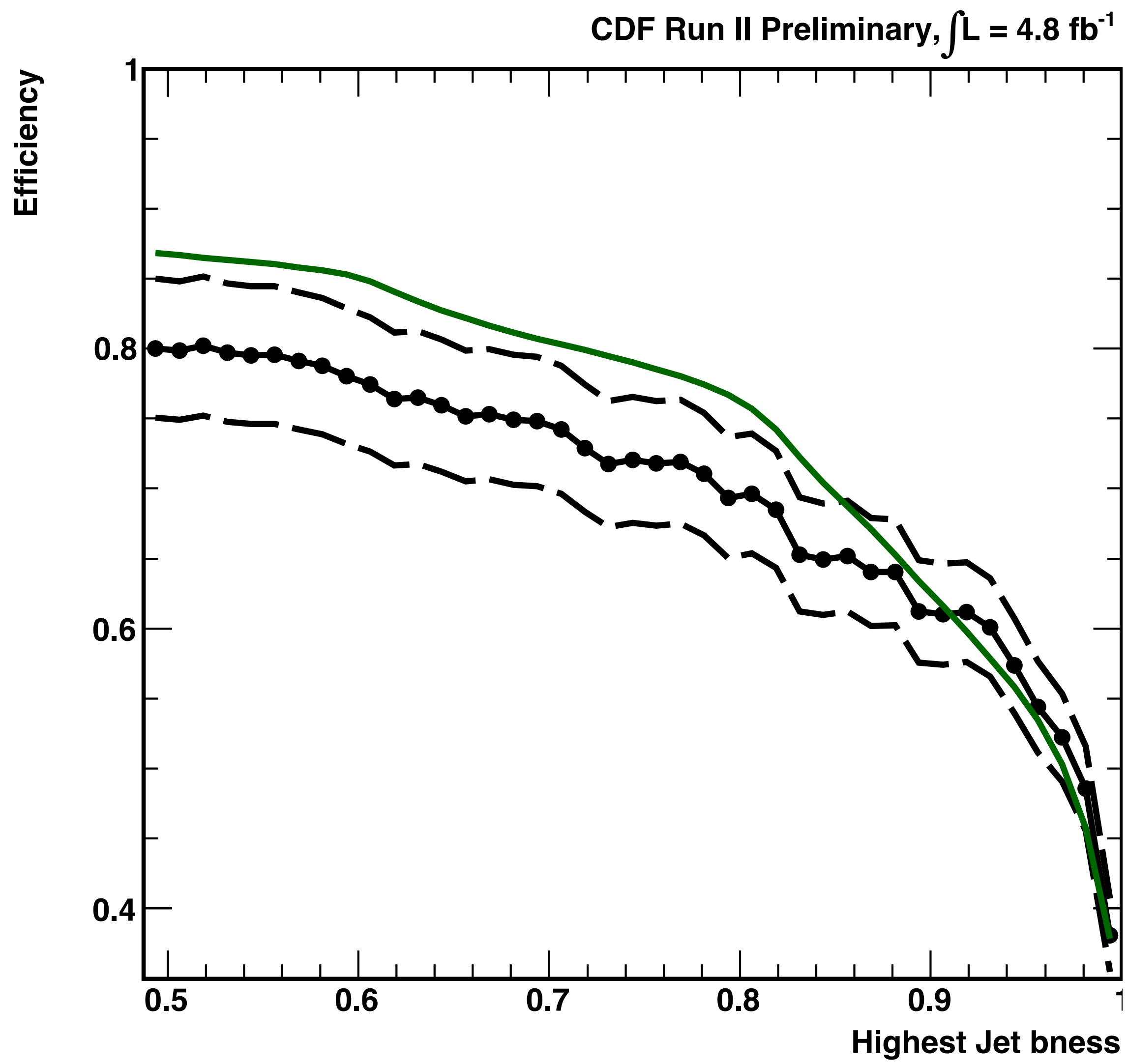


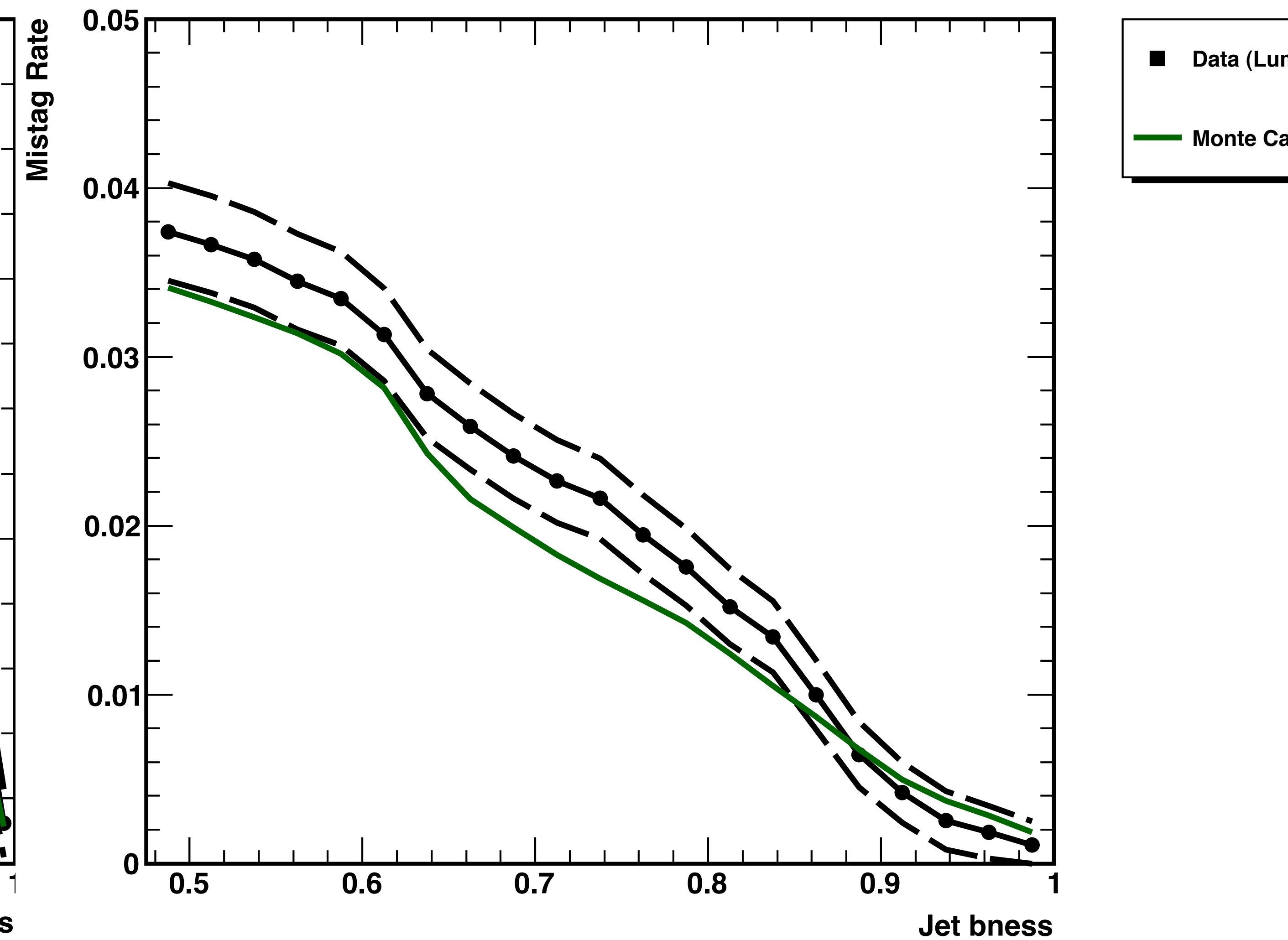
ttbar selection

- Enhanced in b
- lepton+jets ttbar with bkg. suppressing cuts
- use to measure the efficiency



Efficiencies and mistags





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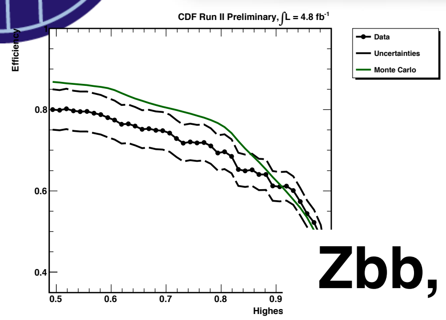
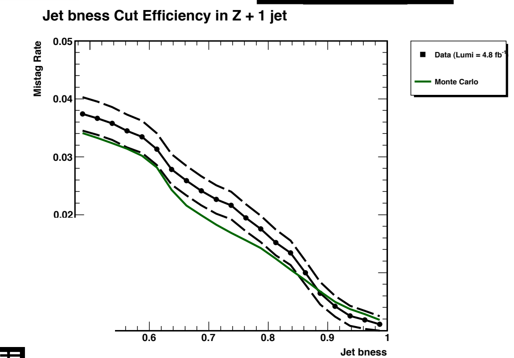
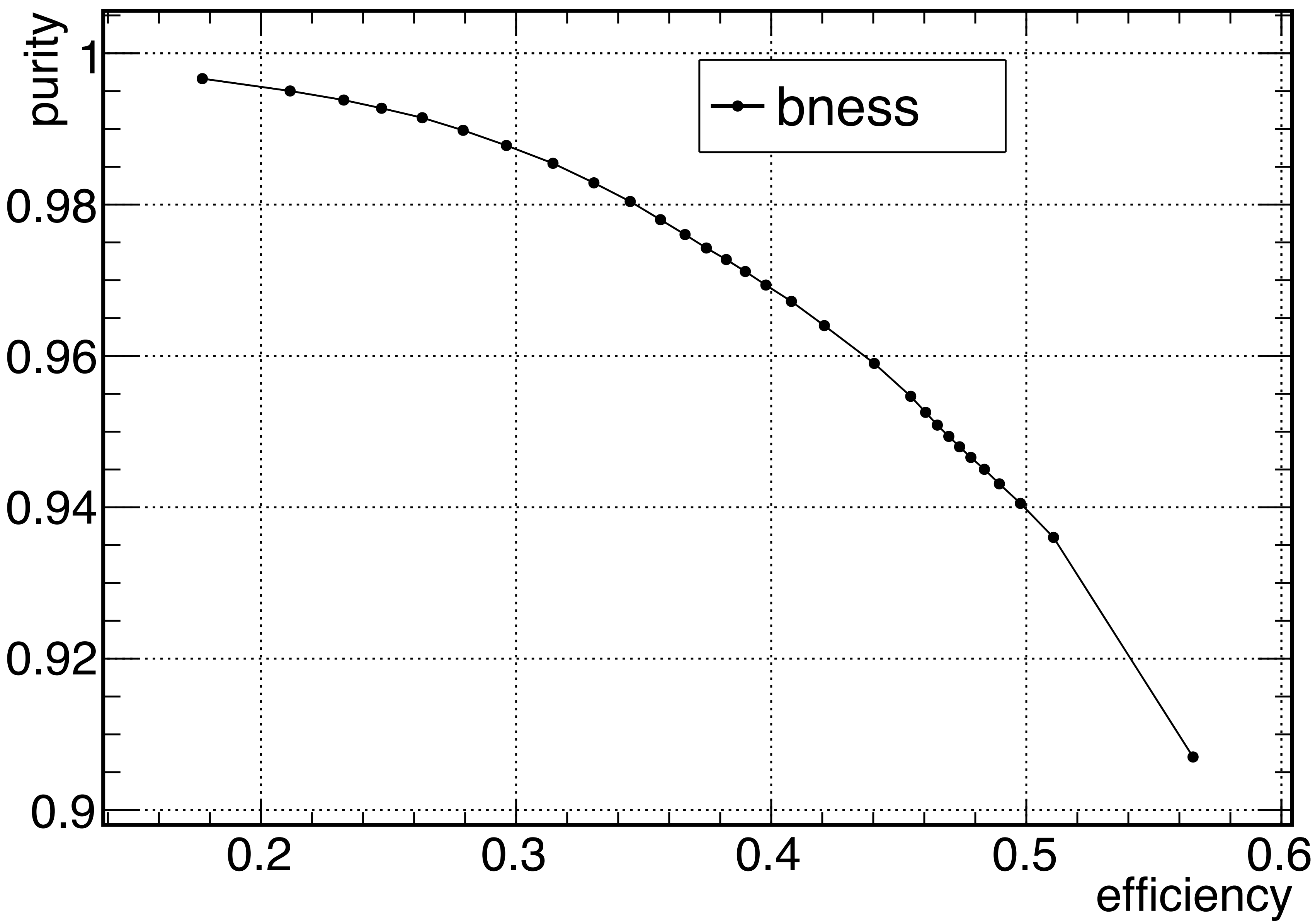




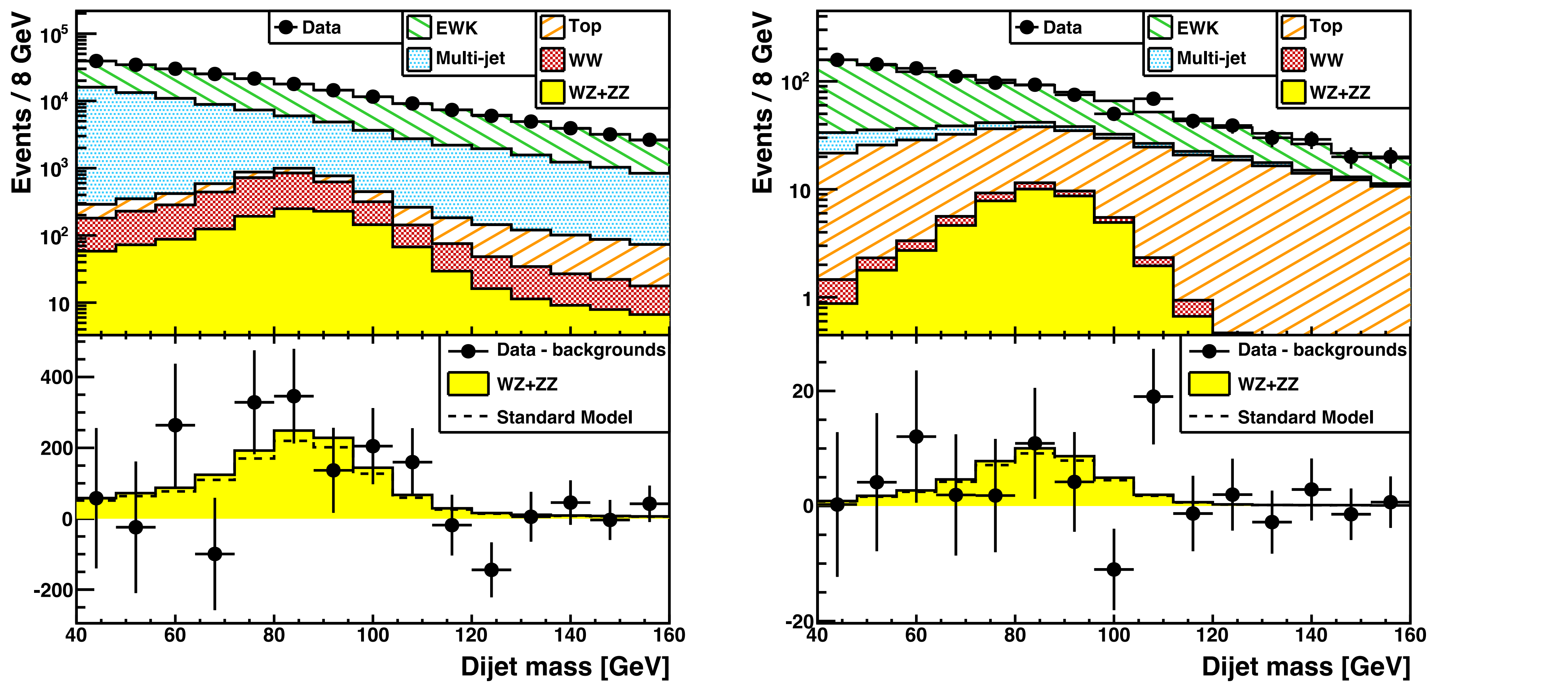
Zbb, Zqq MC



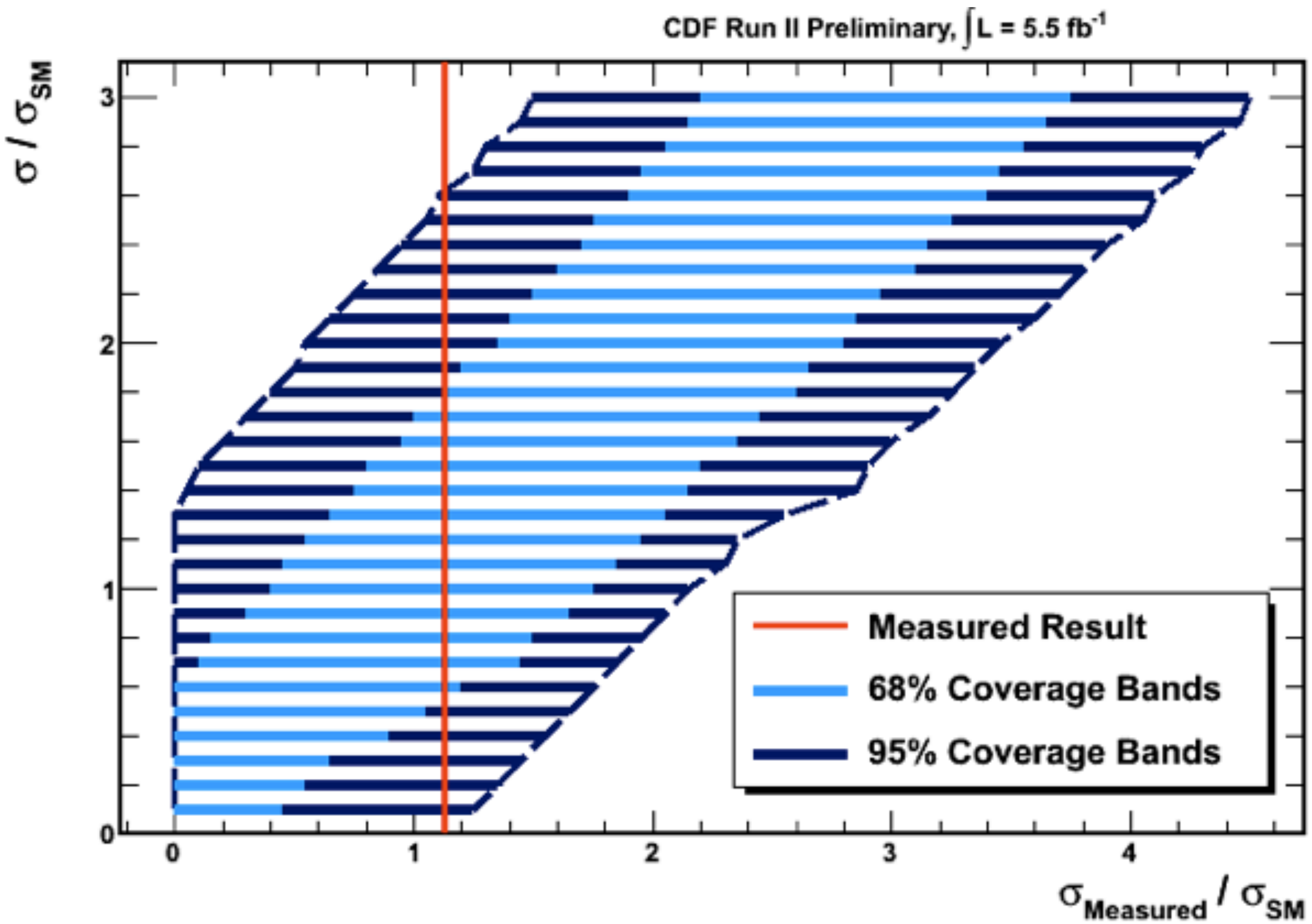
Results

- search for WZ+ZZ
  - two channels differentiated by bness
- WW constrained to theoretical cross section
- This is as close to the Higgs as it gets

Process(es)	Fit N_{events} (no-tag)	Fit N_{events} (2-tag)
EWK	$149100\ ^{+5700}_{-5200}$	$687\ ^{+52}_{-51}$
$t\bar{t}$ and single t	1700 ± 150	$312\ ^{+36}_{-42}$
Multi-jet	$76600\ ^{+5000}_{-5400}$	59.4 ± 8.0
WW	2700 ± 210	$8.3\ ^{+2.0}_{-2.2}$
WZ/ZZ	$1320\ ^{+790}_{-780}$	45 ± 26



A measurement of significance

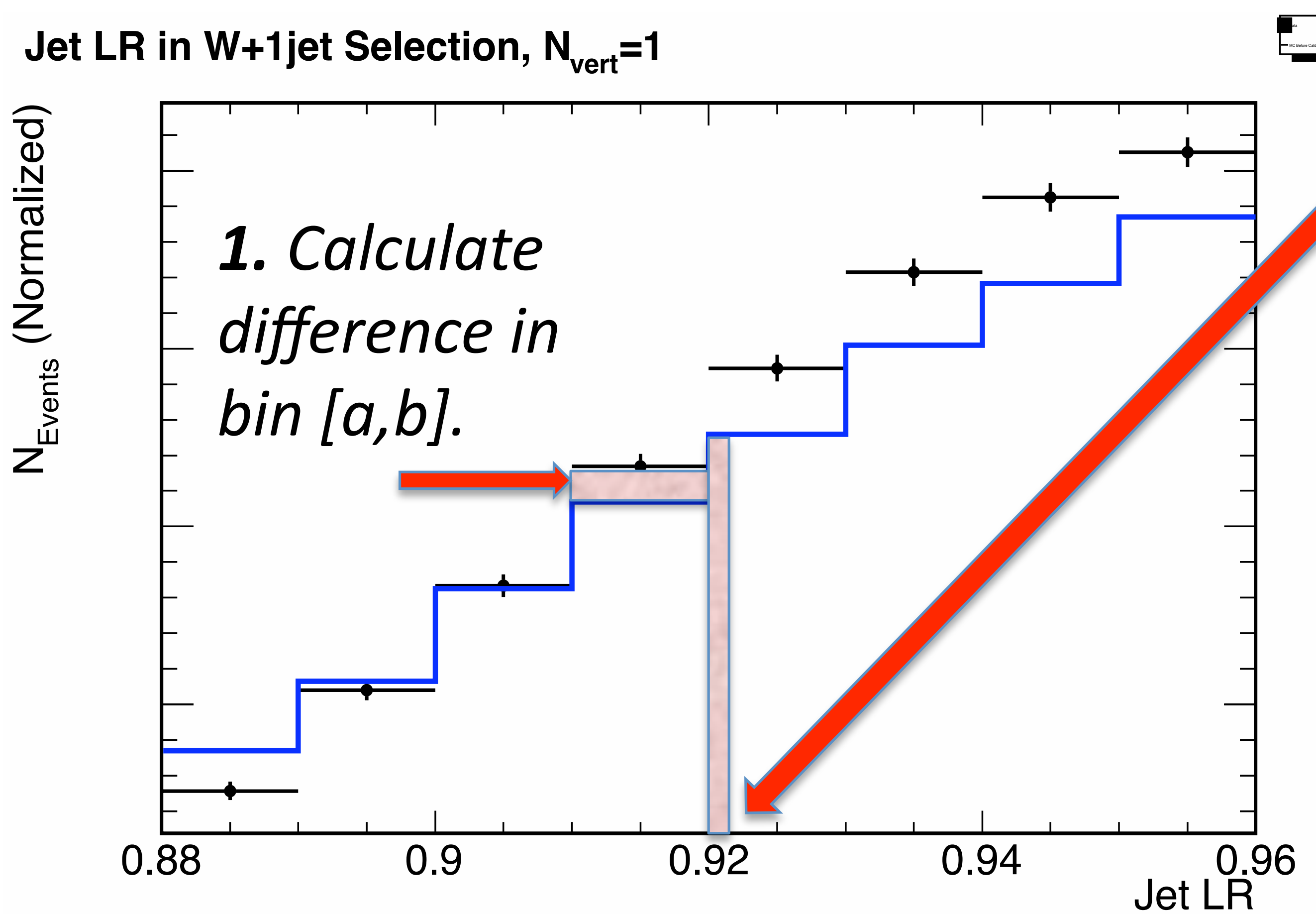


- Almost 2σ measurement

Conclusions

- To do any spectroscopy we need to prove first that we can identify the standard candles
- This is highly nontrivial because of the large backgrounds
- Any tools that we developed have to be benchmarked on them
- Dibosons in hadronic final states have been unambiguously demonstrated at CDF

- **Rescale LR in MC to match data in discrete bins**



1. *Calculate difference in bin [a,b].*

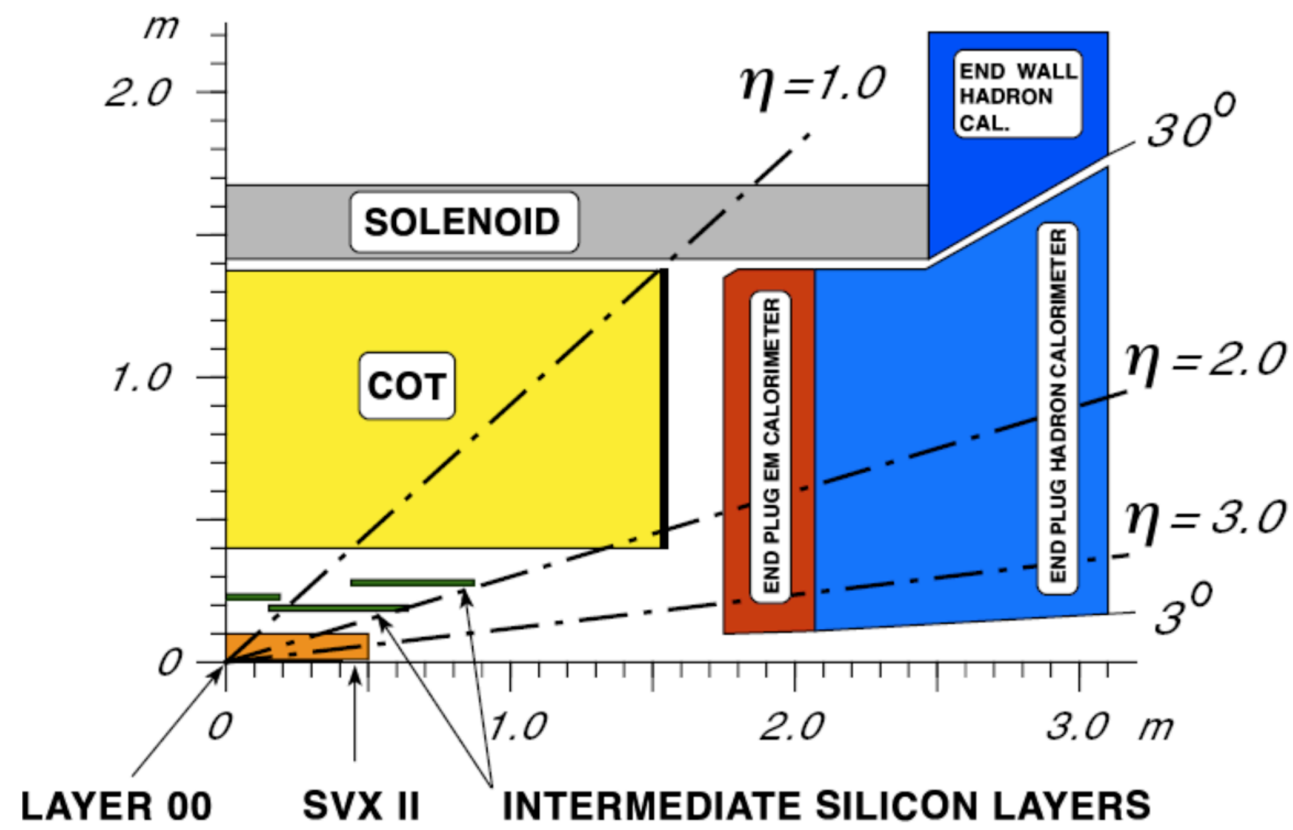
2. *Calculate bound in next bin to match that area (**b'**)*

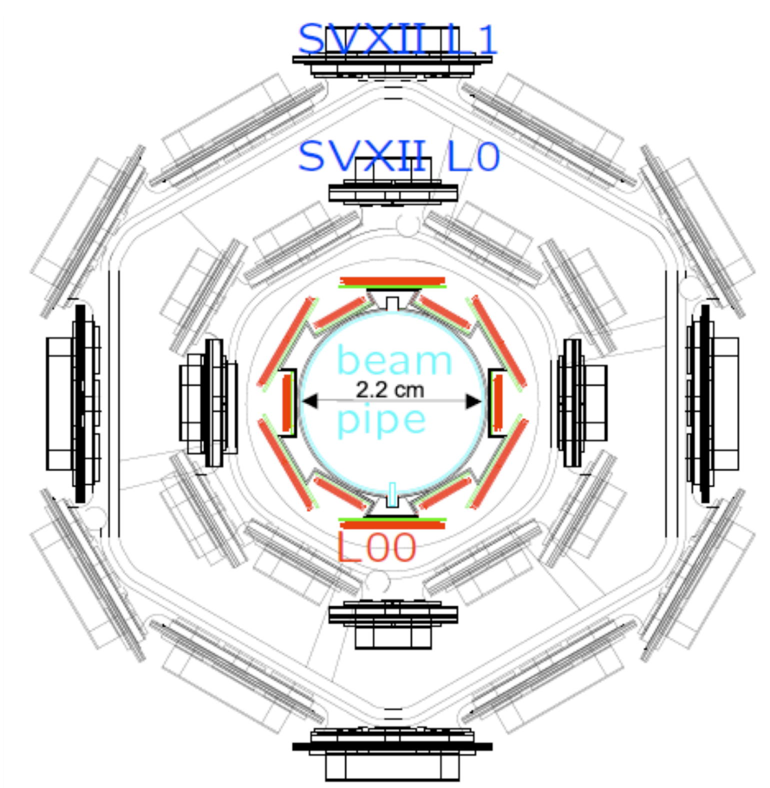
3. *Rescale value of LR in MC*

$$LR \to a + (LR - a) \times \frac{(b - a)}{(b' - a)}.$$

CDF tracking

- COT: 96 layers drift chamber
  - 4 axial 4 stereo superlayers
  - 1.4 T field
- Silicon tracker:
  - 95 cm long L00
  - 3 SVX II layers each 29cm long

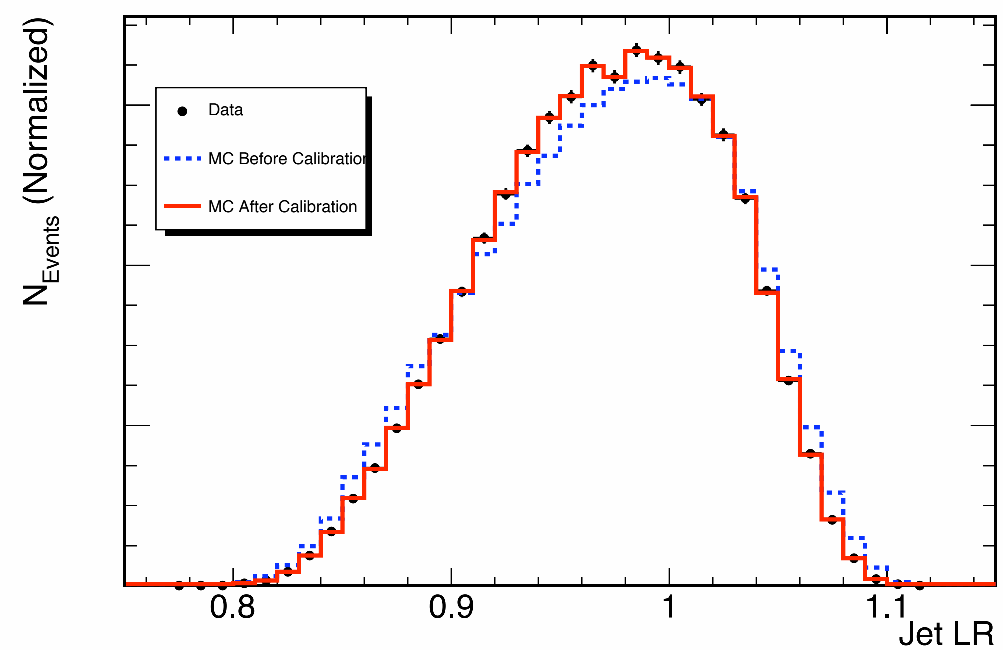




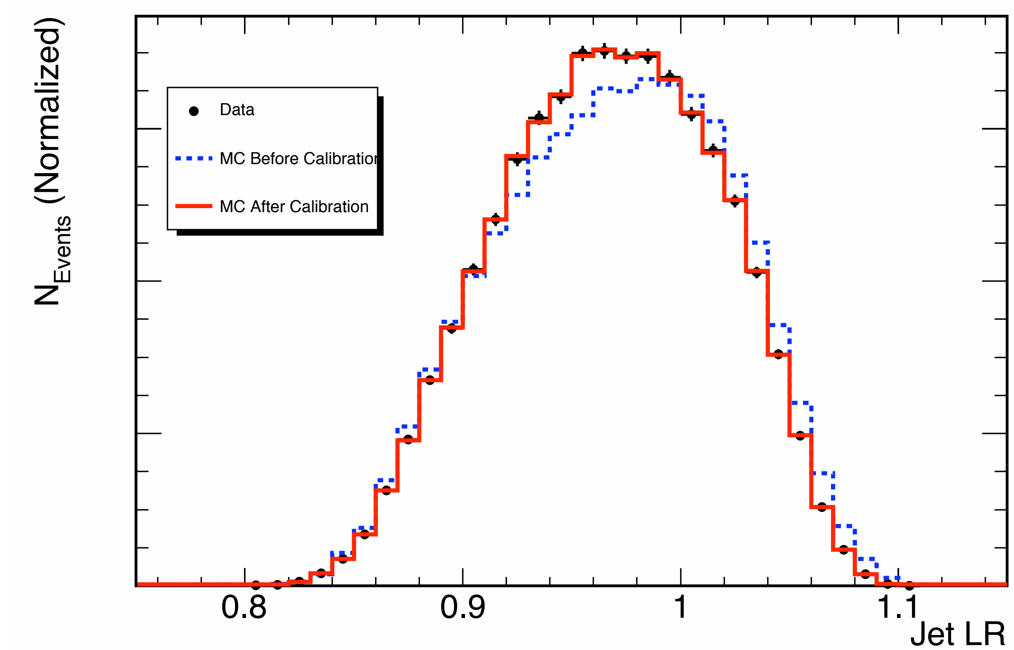
- L00 - single sided r=1.2cm
- SVX II 5 double sided layers
  - L0 rφ-rz, r=2.5cm
  - L1 rφ-rz, r=4.5cm
  - L2 rφ-1.2° stereo, r=6.5cm
  - L3 rφ-rz, r=8.5cm
  - L4 rφ-1.2° stereo, r=10.5cm
- Total sensor area 6m
- 720k electronic channels

...and vs number of vertices

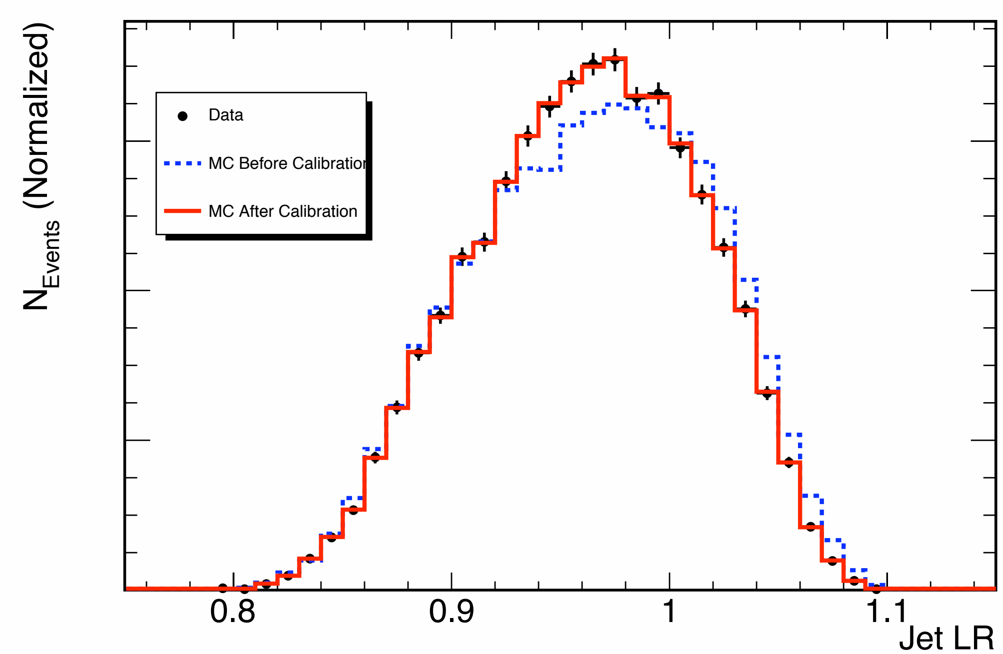
Jet LR in W+1jet Selection, N_{vert}=1



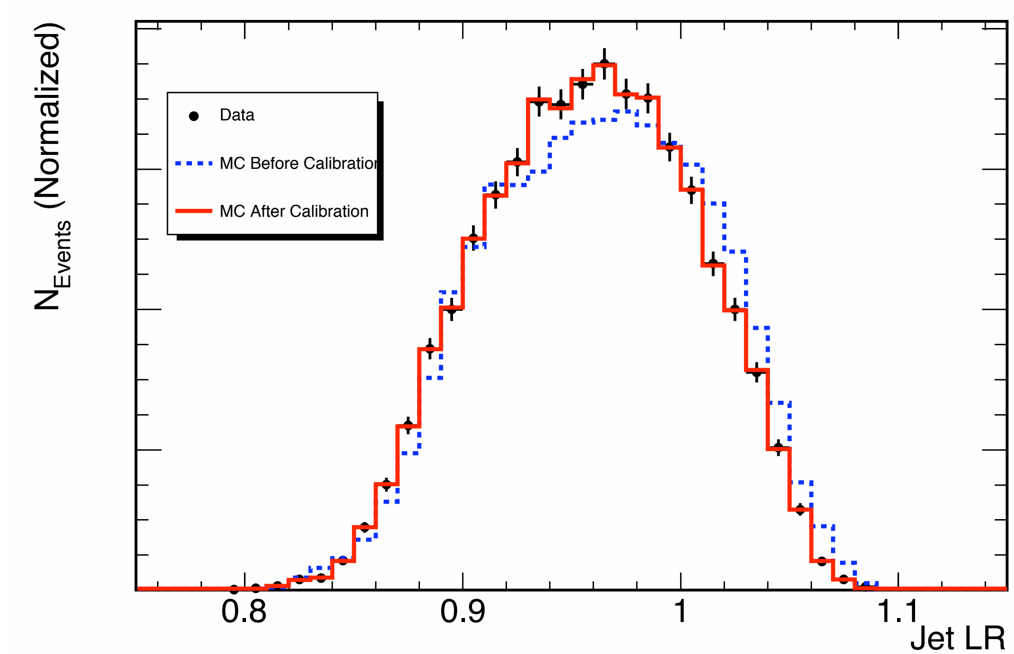
Jet LR in W+1jet Selection, N_{vert}=2



Jet LR in W+1jet Selection, N_{vert}=3

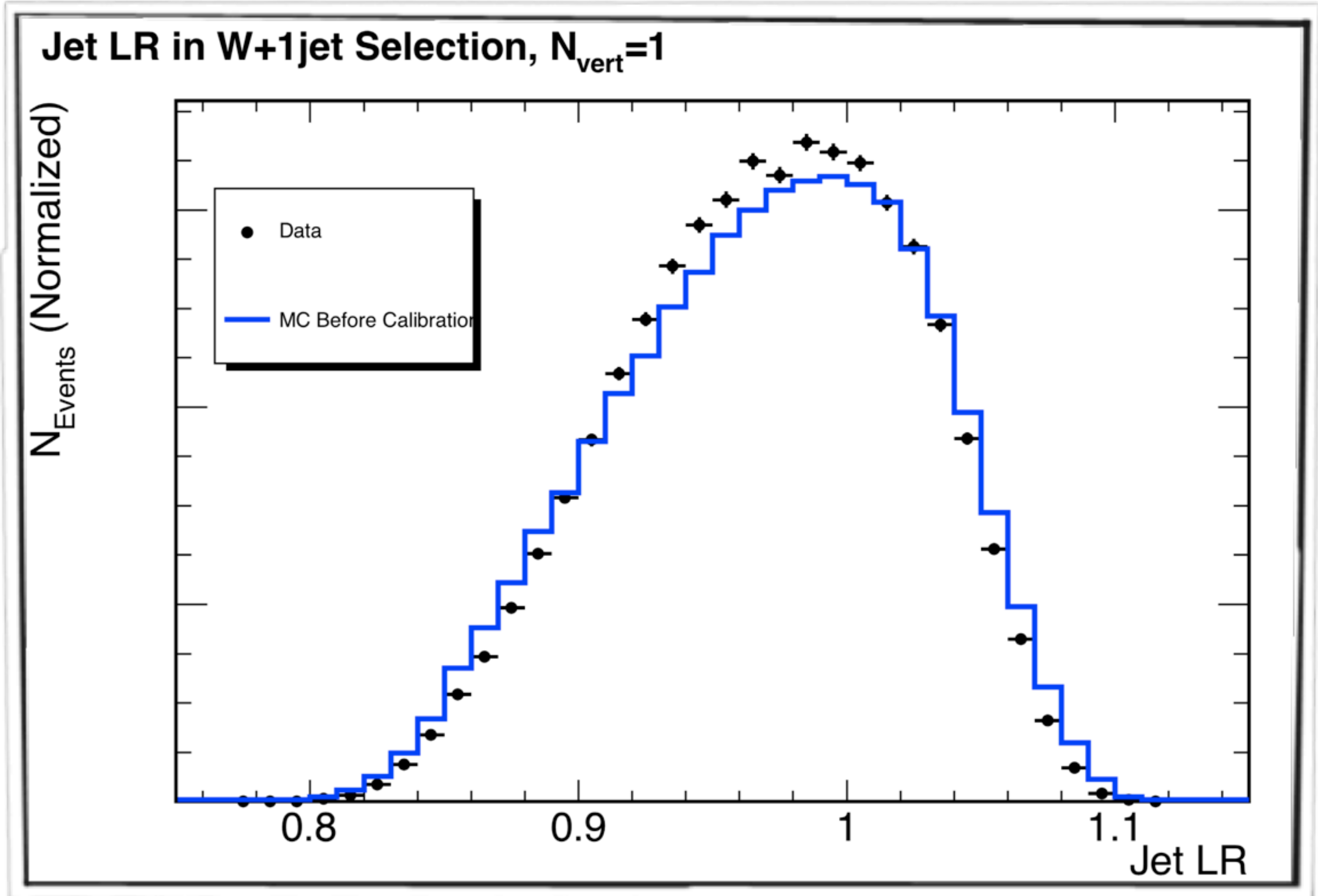


Jet LR in W+1jet Selection, $N_{vert} \geq 4$



How about data?

- Use W+jets because large stats
  - also, similar to what we are in the end looking for
- The shape looks quite good given the level of accuracy the simulation has to get right
- Still data systematically higher (more quark like)
- Strong assumption: the quark and gluon ratio is correctly described in MC

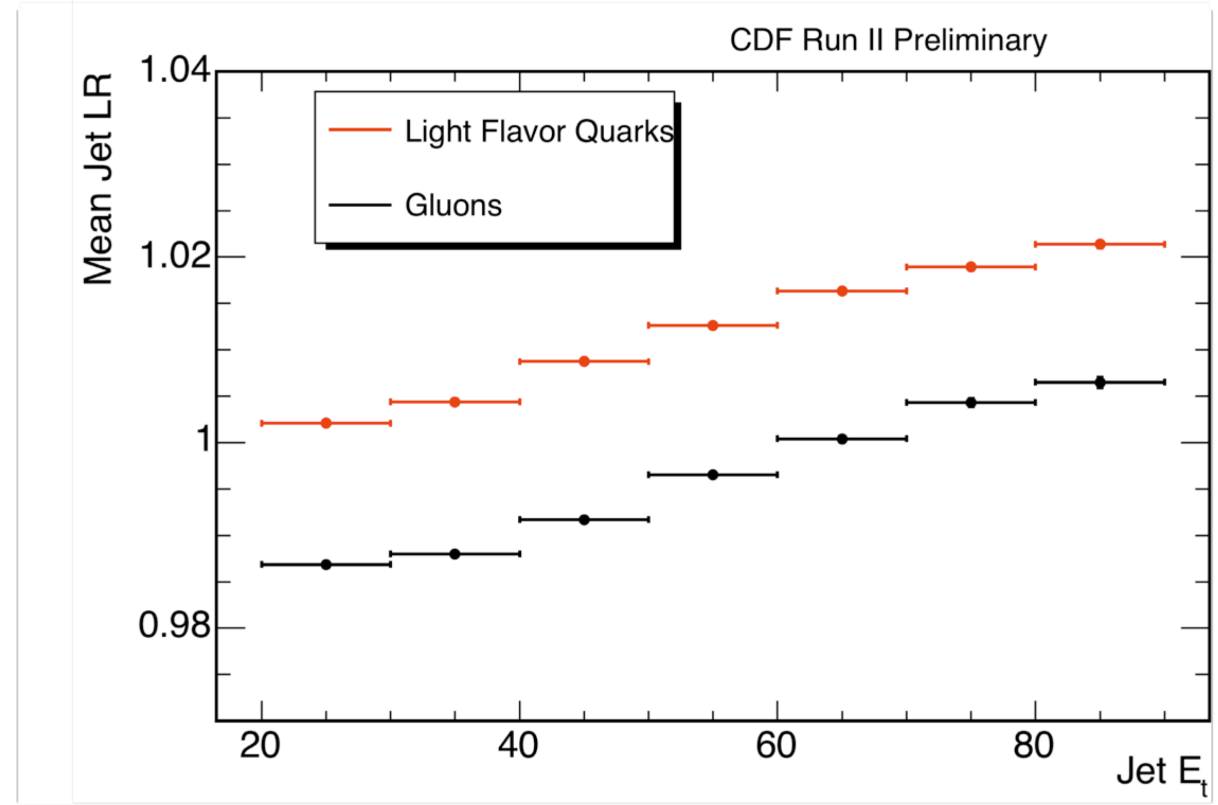


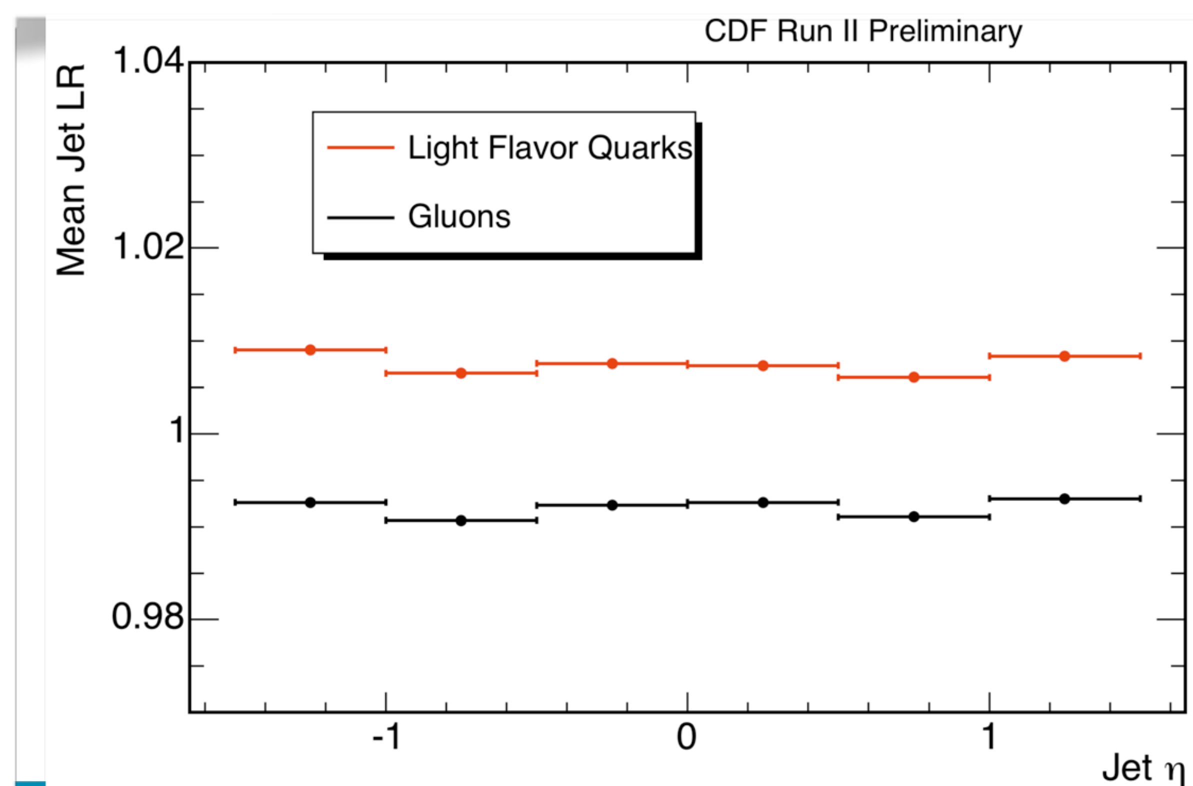
Assume all differences are due to calorimeter simulation

Calibrate based on the W+jets data

Correlations
(Is It Really True?)

- **Jet LR and E_T show strong correlation**
  - Expect jets with greater ET to be more collimated → look mre like quarks → have higher LR
  - Still see discrimination in similar ET jets
- **Jet LR looks uncorrelated with jet η**
  - Small differences possibly from different calorimeter structure inputs





Other taggers

- Soft Lepton Tagger
- Count displaced tracks
  - 3 2 sigma or 2 3 sigma
  - signed IPs against jet direction
- Jet probability
  - Joint probability for all tracks to come from a primary vertex
  - Track resolution derived from negative IP tracks
  - Use only positive IP tracks in probability calculation
- Multivariate taggers
  - CDF NN tagger
  - D0 NN tagger

Secondary vertex tagger

- Identify secondary vertices
  - Impact parameter significant
  - Fit displaced tracks (>Pt) to a common vertex
  - Prune tracks and cut on fit chi2
  - Cut on Lxy significance