Searches for Techniparticles at DØ

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- Technicolor Physics
  - Electroweak Symmetry Breaking
  - Previous Searches
- Current Searches at DØ:
  - b-tagging
  - $W \pi_T \rightarrow e \nu b \bar{b}/\bar{c}$
    - Event selection and Optimization
    - Cross Section Limits
  - $\rho_T/\omega_T \rightarrow e^+e^-$

Mechanism of electroweak symmetry breaking

- We observe *from experiment* that quarks and leptons obey gauge symmetries:
  - SU(3) strong force
    - binds quarks into protons and neutrons
  - U(1) electromagnetic force
    - atomic bound states
  - $SU(2)_L$ weak force
    - β decay

– The "problem" of particle's mass

- Adding mass terms for fermions and Gauge bosons in the standard model Lagrangian breaks gauge invariance and renormalization of the Standard Model.
  - $W_L W_L$ violate unitarity ($\sigma(WW) \sim s$)

Mechanism of electroweak symmetry breaking (2) Technicolor

- Analogy with QCD:
  - QCD predicts masses for W and Z bosons:
    - When QCD coupling constant becomes large, strong interaction binds quark anti-quark pairs.
    - $\langle Q_L Q_R \rangle \neq 0$ condensate breaks chiral symmetry $\Rightarrow$ Formations of Goldstone bosons
    - Coupling of the condensates with unbroken electroweak gauge fields provide mass terms for W and Z. (Goldstone bosons are eaten)
    - W, Z masses are underestimated by 4 order of magnitude
    - M_W/M_Z is correct!

- Technicolor (TC - first introduced by Weinberg and Susskind):
  - New stronger dynamics $SU(N_{TC})$
  - N^2_{TC} - 1 new gauge bosons: technigluons
  - Physical spectrum for TC condensates consists of technimesons, composed by QQ and technibarions made of N_{TC} techniquarks
  - TC is scaled to give the correct value for W and Z masses

$$\frac{F_{TC}}{f_\pi} \approx 2500$$

Low Scale Technicolor Models

- Large numbers of technifermions are the natural choice for several Technicolor Models
  - Walking Technicolor
    - Evade large flavor changing neutral current
  - Topcolor-assisted Technicolor
    - Many technifermions are needed to generate hard masses for quarks and leptons
  - **Technicolor Straw Man Model (TCSM):** K. Lane, S. Mrenna hep-ph/02110299
    - Set the scale for calculating lowest-lying bound state of lightest technifermion doublets
    - color singlet vector mesons (200 – 400 GeV)
      - produced in pp collisions
        - Decays:

$\omega_T \to \gamma\pi_T$	$\rho_T \to \pi_T\,\pi_T$	$\rho_T \to \pi_T\,\pi_T$
$\to \gamma Z$	$\to W\pi_T\,,\ Z\pi_T$	$\to W\pi_T, Z\pi_T$
$\to 3\pi_T$	$\to WW$	$\to WZ$
$\to f\,f, g\,g$	$\to f\,f, g\,g$	

    - color-singlet scalar mesons
      - lightest technihadrons $\pi_T^{0}\ \pi_T^{+/-}$
        - Decays: $\pi_T \to ff, gg\ (\pi_T^{0} \to bb,\ \pi_T^{+/-} \to bc$ dominate)

Previous Searches

- TCSM Parameters:
  - **N_D** : number of technifermion doublets
  - **$Q_D = Q_U - 1$** : technifermion charge
  - **$\sin\chi$** : mixing angle
  - **M_V** : mass parameter (it controls technifermions coupling and decay mode)
- Previous searches

CDF RunI

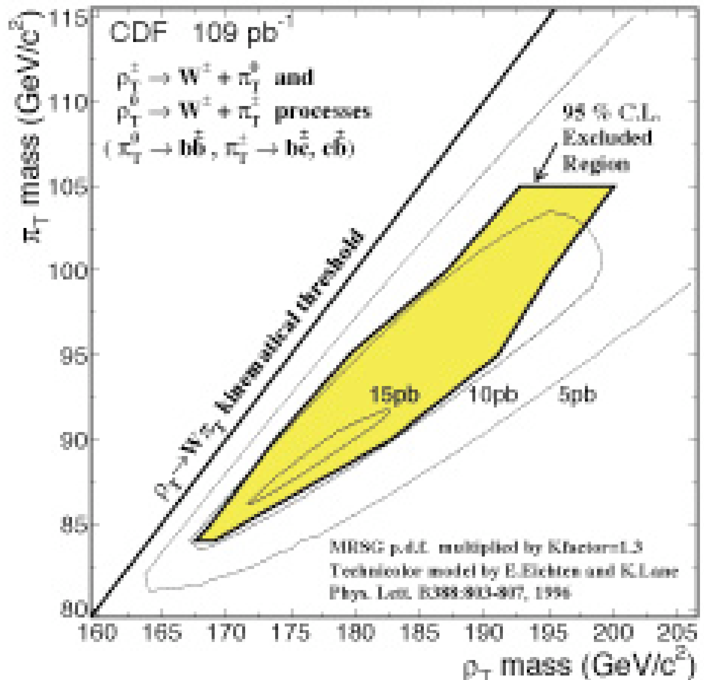
- $W\pi_T$ and $\omega_T \to \gamma\pi_T$
- $M_V = 100$

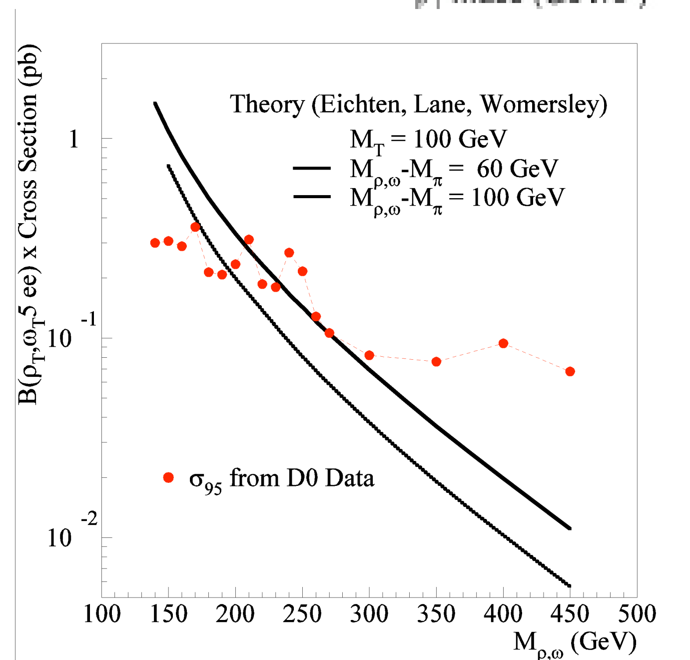
DØ RunI

- $\rho_T/\omega_T \to ee$
- $M_T = M_V = 100$ to 400
- $M(\rho_T/\omega_T) - M(\pi_T) = 60, 100$ GeV
  - $M_V = 100$ GeV $\Rightarrow$ $W\pi_T$ channel open

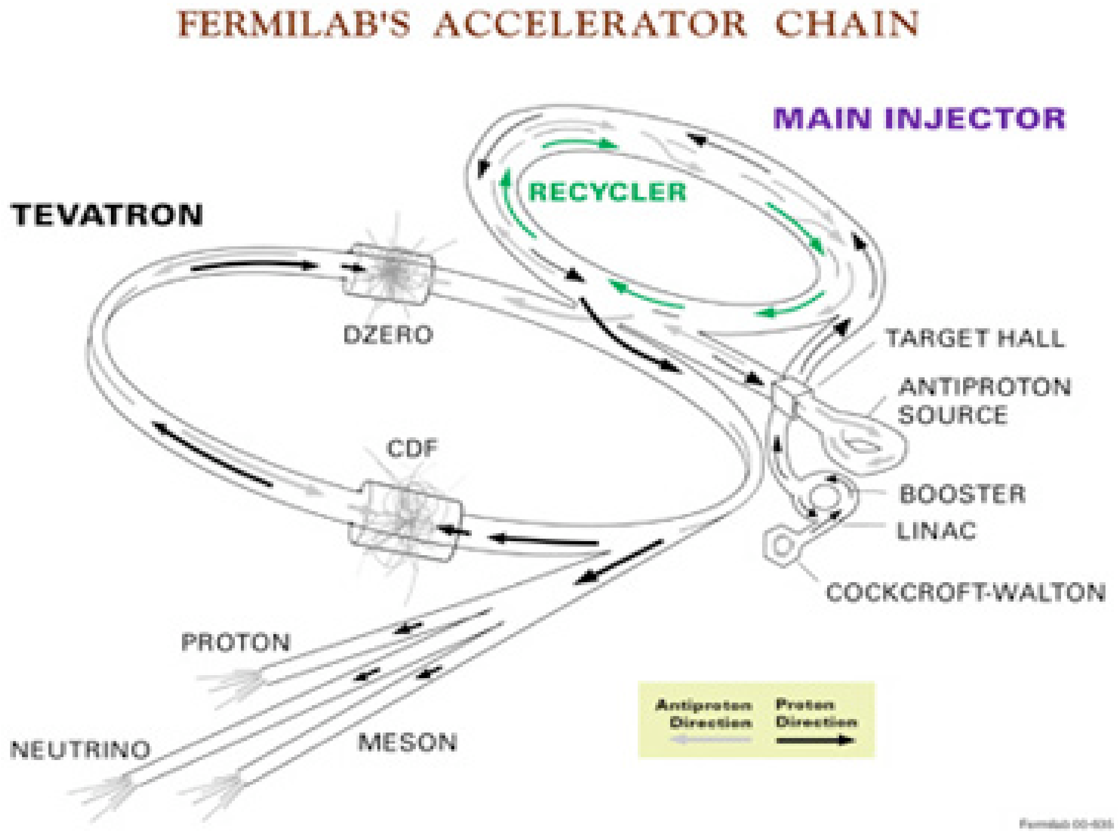
LEP

- $\rho_T \to WW$, $\rho_T \to \pi_T W$ (DELPHI)
- $M(\pi_T) = 105$ GeV $M(\rho_T) = 200$ GeV is excluded for some TCSM parameters





Tevatron RunII



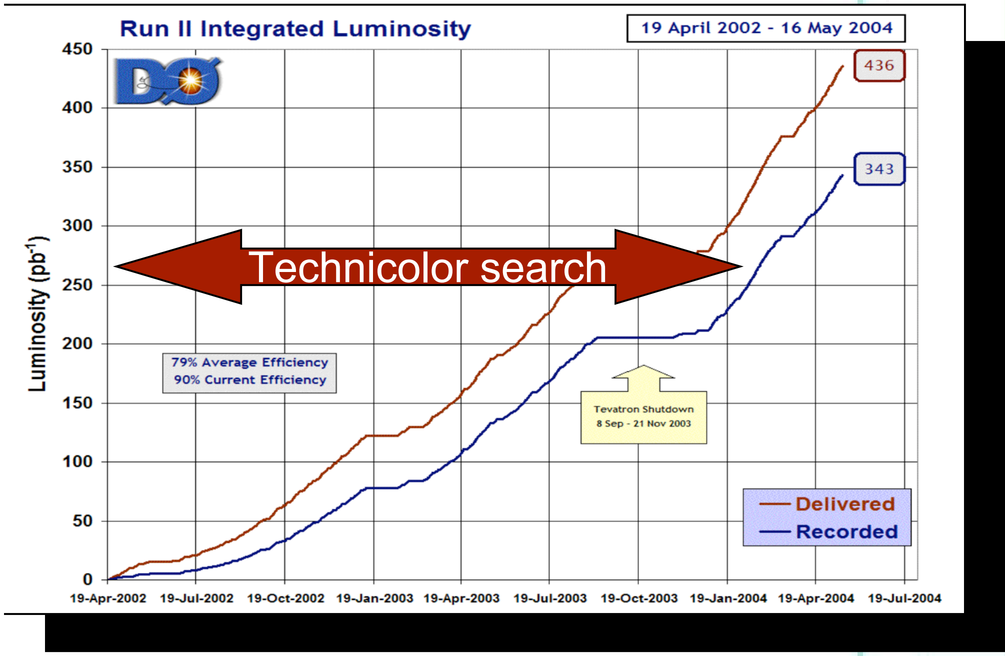
	Run I	Run IIa
Bunches in Turn	6 × 6	36 × 36
√s (TeV)	1.8	1.96
Typical L ($cm^{-2}s^{-1}$)	1.6×10^{30}	9×10^{31}
∫ Ldt (pb^{-1}/week)	3	17
Bunch crossing (ns)	3500	396

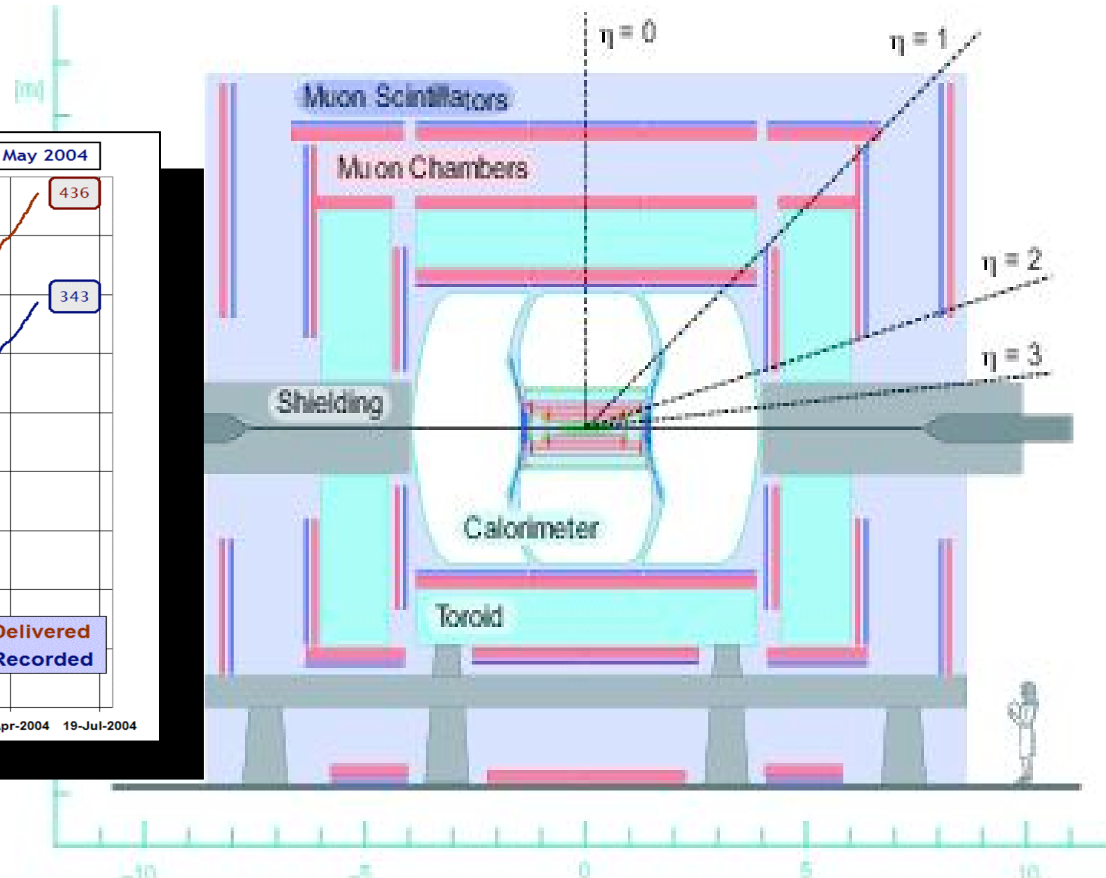
To reach higher masses with the same energy→ higher luminosity

Increase in number of antiprotons → the key for higher luminosity

Expected peak luminosity → $3 \cdot 10^{32}$ $cm^{-2}sec^{-1}$ by 2007

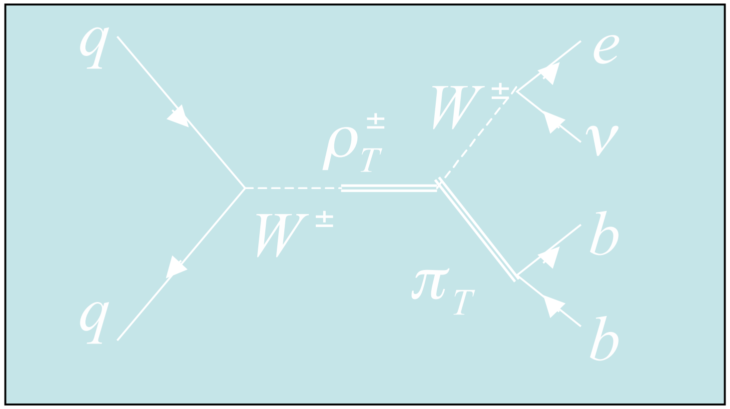
DØ RunII

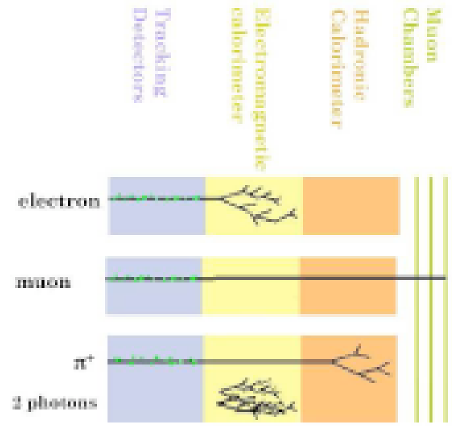




- Data collected with the DØ detector at the Fermilab Tevatron operating at $\sqrt{s}$ = 1.96 GeV up to April 2004
- Total $\int \mathcal{L}\, dt$ = 238 pb^{-1}

$W\pi_T$ Events Selection





One isolated electron

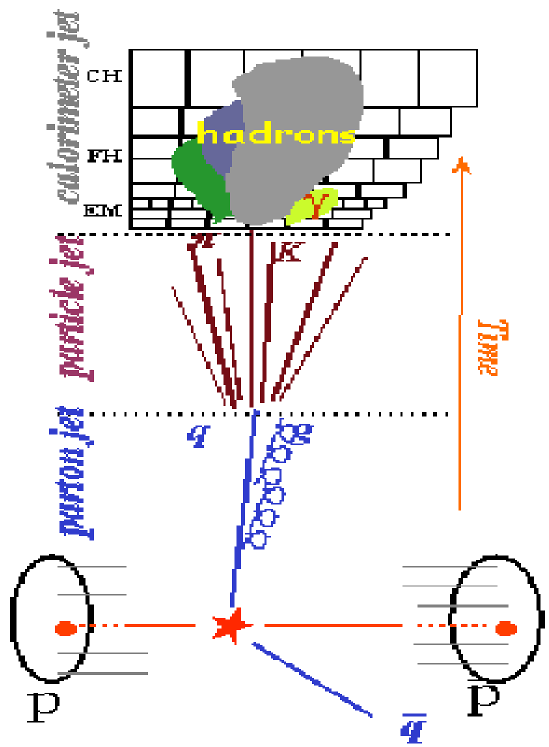
- veto on the presence of another electrons suppress Z contaminat

Missing E_T > 20 GeV

- eliminates multi-jets (QCD)

Two calorimeter jets

- Veto on a third jet, suppresses tt background
- At least one jet has to be associated with a Secondary Vertex (b-tagging)



ν 's don't interact with the D0 detector: its presence is then detect by the energy imbalance in the event

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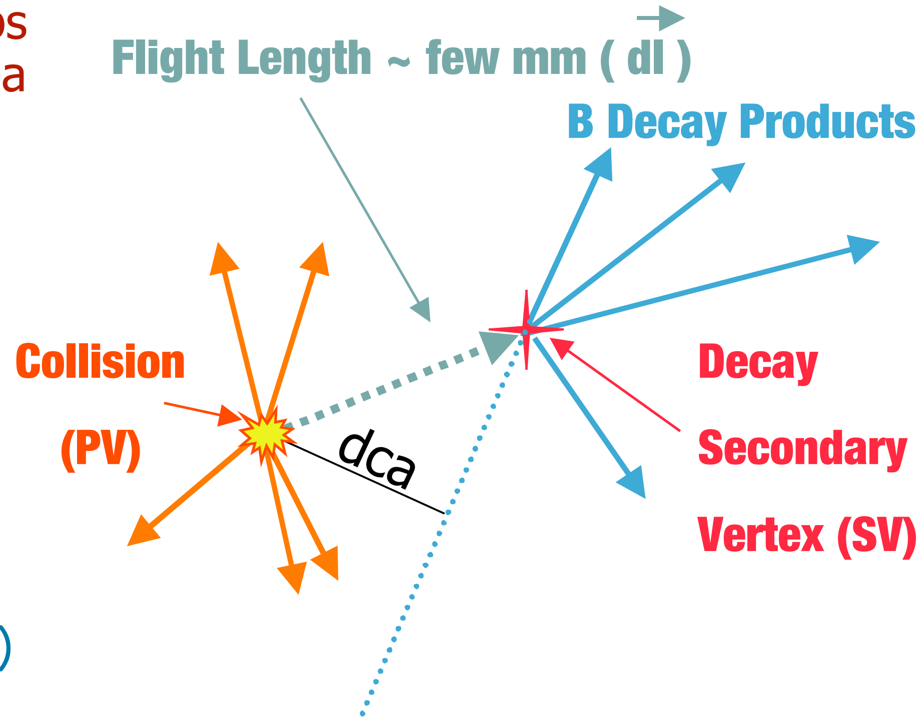
b-quark Jet Identification
b-tagging

- Descriptions of b-tagging algorithms:
  - Secondary Vertex Algorithm (SVT)
- Discrimination between signal and background
- Methods to evaluate efficiency and fake rate from DATA

b-tagging (1)

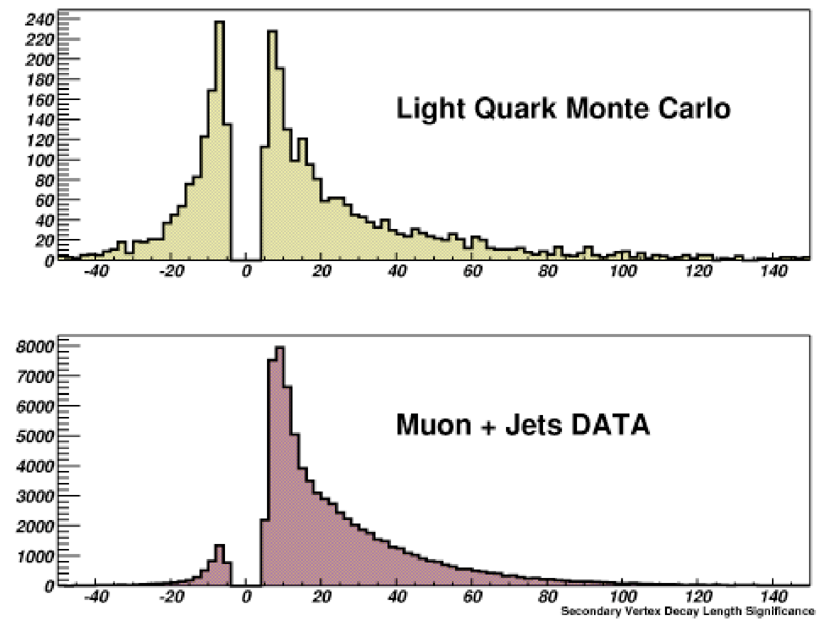
- b-hadrons lifetime is of the order of 1.6 ps corresponding to to a decay of 3 mm for a 40 GeV/c momenum
- the distance of closest approach (dca) of tracks coming from b-decays are of the scale 400 μm
- Light quark fragmentation creates tracks with dca much closer to zero.
  - Smearing due to detector resolution, multiple scattering, decays in flight (i.e. $K^0_s \rightarrow \pi^+ \pi^-$)
- Secondary Vertex Tagger algorithm (SVT) fits track with high dca to the b-hadron decay vertex.
  - Tracks with different quality requirement can be chosen in order to form the SV
  - After SV is fitted the Decay Length Significance (dls) of the vertex is a powerful discriminator between fake and real SV
    - Negative dls is unphysical



$$dls = \frac{\vec{dl} \cdot \vec{p}(SV) \cdot |\vec{dl}|}{|\vec{dl} \cdot \vec{p}(SV)| \cdot \sigma_{dl}}$$

b-tagging (2)
Decay Length Significance

- When a SV is found inside calorimeter jet, the jet is considered as b-tagged
  - dls > 0: positive tagging
  - dls <0: negative tagging
- Jets with an embedded muon (Muon Jets) are used for their high b-content
  - 40% of the time a b decay produces a muon
  - High asymmetry in SV dls indicates the presence of heavy flavor
- From Monte Carlo light quark: dls distribution is not symmetric
  - Spurious presence of tracks coming from decay in flight or γ conversion
  - Pure Negative tag cannot be used in order to estimate Mistag Rate



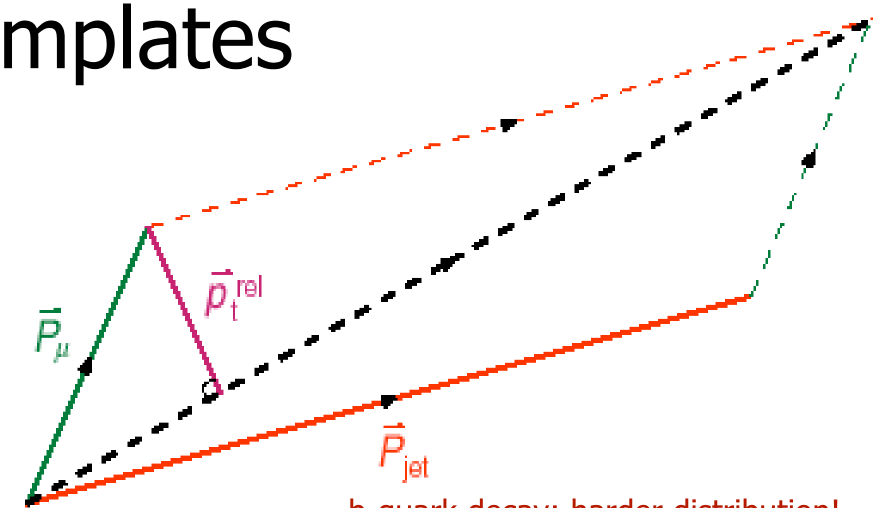
b-tagging efficiency (1)

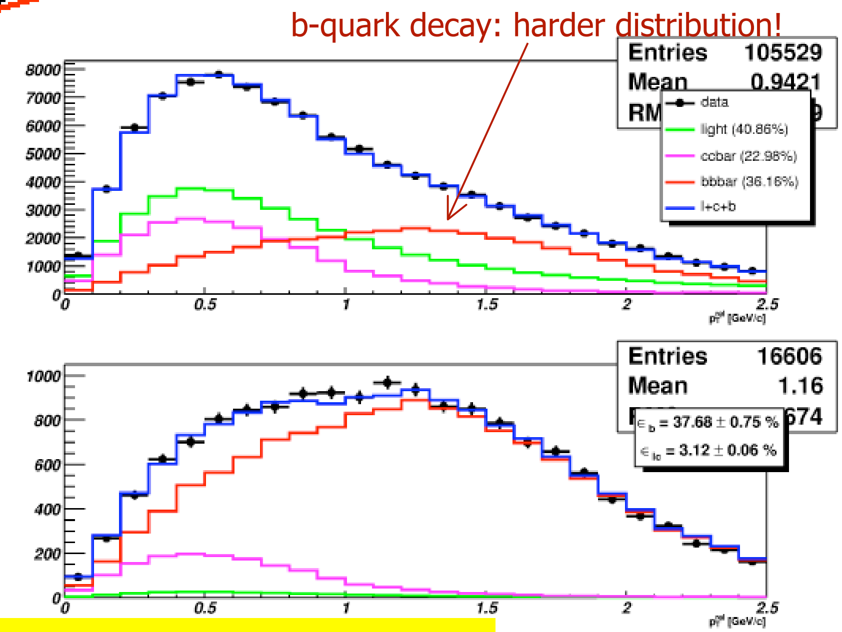
p_T^{rel} templates

b-tagging efficiency is estimated from Muon Jets

Due to the higher b quark mass the muon coming from b-decay has higher p_T^{rel}

Fitting p_T^{rel} distribution of the Muon Jets sample before and after applying SVT with MC templates





$$\varepsilon_{b\text{-tagging}} = (N_{\text{tagged jets}} \cdot f^b_{\text{tagged jets}}) / (N_{\text{jets}} \cdot f^b_{\text{jets}})$$

b-tagging efficiency (2)

system 8

$$n = n_b + n_{cl}$$
$$p = p_b + p_{cl}$$
$$n^{\mu} = \varepsilon^{\mu} n_b + r^{\mu} n_{cl}$$
$$p^{\mu} = \varepsilon^{\mu} p_b + r^{\mu} p_{cl}$$
$$n^{SVT} = \varepsilon^{SVT} n_b + r^{SVT} n_{cl}$$
$$p^{SVT} = \beta \ \varepsilon^{SVT} p_b + \alpha \ r^{SVT} p_{cl}$$
$$n_{all} = k_b \ \varepsilon^{SVT} \ \varepsilon^{\mu} n_b + k_{cl} \ r^{SVT} \ r^{\mu} n_{cl}$$
$$p_{all} = k_b \ \beta \ \varepsilon^{SVT} \ \varepsilon^{\mu} p_b + k_{cl} \ \alpha \ r^{SVT} \ r^{\mu} p_{cl}$$

$\varepsilon \ (\ r \ ) =$ *efficiency for tagging b(light) quarks*

$\alpha \ , \ \beta =$ *efficiency correlation for the two samples*

$k_{b \ (cl)} =$ *taggers correlations*

- Relies on **2 taggers** (track based and muon p_T^{rel}) and **2 samples** (n, p with different b-content)
- Allows to solve **8 equations** with **8 unknowns**:
- Assumes b-tagging efficiency is the same in the two sample (β~1 checked from MC)
- Same b-tagging efficiency with α= 1+/-0.3 (negligible systematics).
- small correlation between the two taggers $\mathbf{k_b}$ and $\mathbf{k_{cl}}$ ~1.
- Analytically solvable

b-tagging efficiency (3)

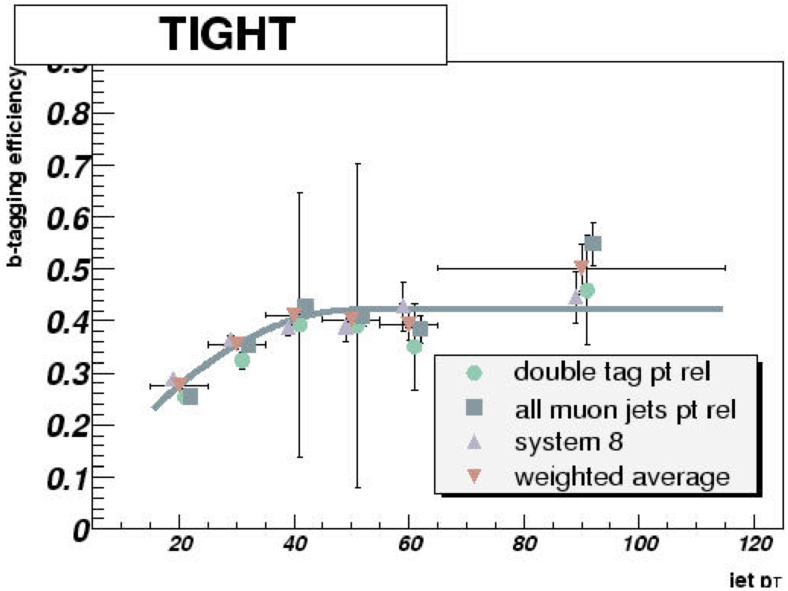
•b-tagging efficiency depends upon the track quality and track activity around the jet and therefore upon its energy and direction.

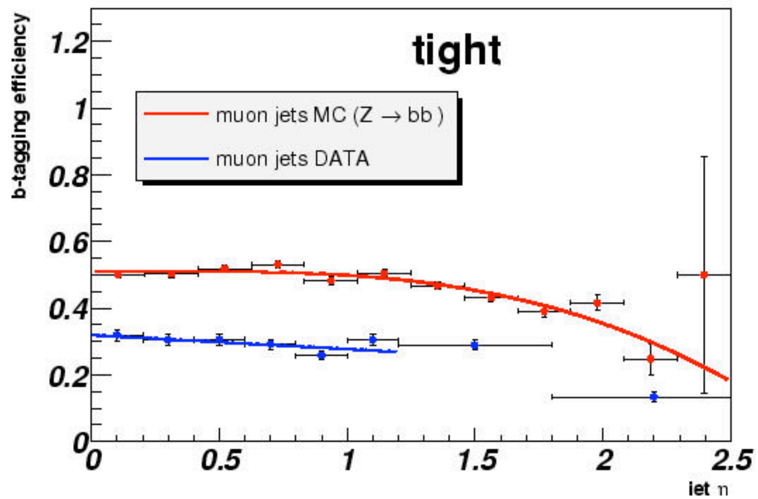
•Methods require high statistics and therefore errors in some pt or η can be quite big

• 3 Vertex definitions are defined

- MEDIUM, TIGHT, LOOSE
- (different cuts on track p_T, χ^2, # of detector hits, etc.)

• Monte Carlo and Data performance are not the same, efficiency is then scaled.

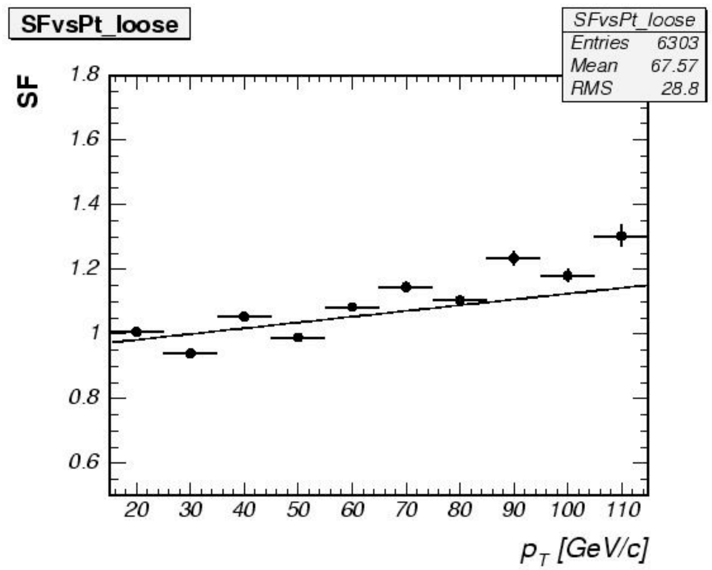


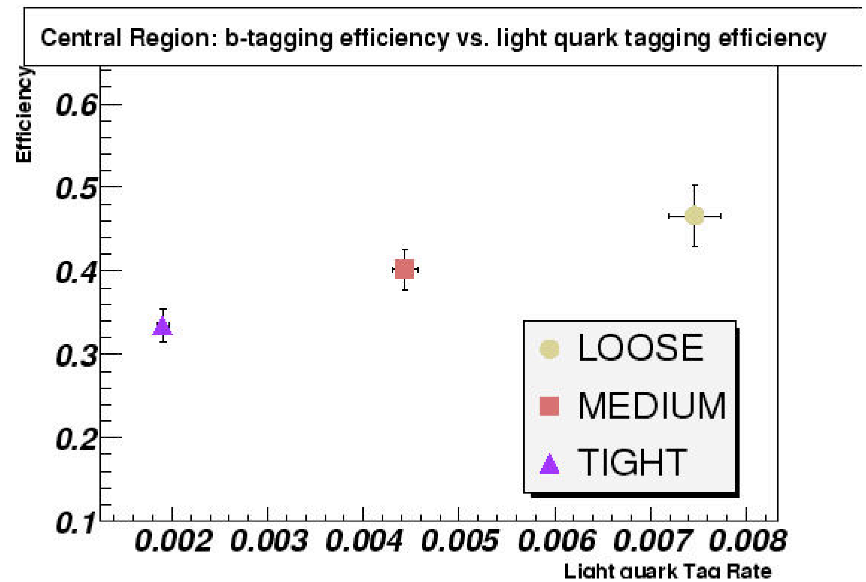


Light Quark Tag Rate Estimation

- Light Quark tagging rate is mainly due to resolution effects in the detector.
- Estimation is based on the negative tag rate in DATA content depleted in heavy flavors: MULTIJET EVENTS
- correction from MC QCD
  - Take into account of HF contributions to the neg tag rate (SF_{hf})
  - Asymmetry present in light quark DLS distribution mainly due to decays in flight, interactions with material and fakes (SF_{ll})

$$\varepsilon_{light} = \varepsilon_{data}^{negative}(E_T, \eta)\, SF_{hf}\, SF_{ll}$$





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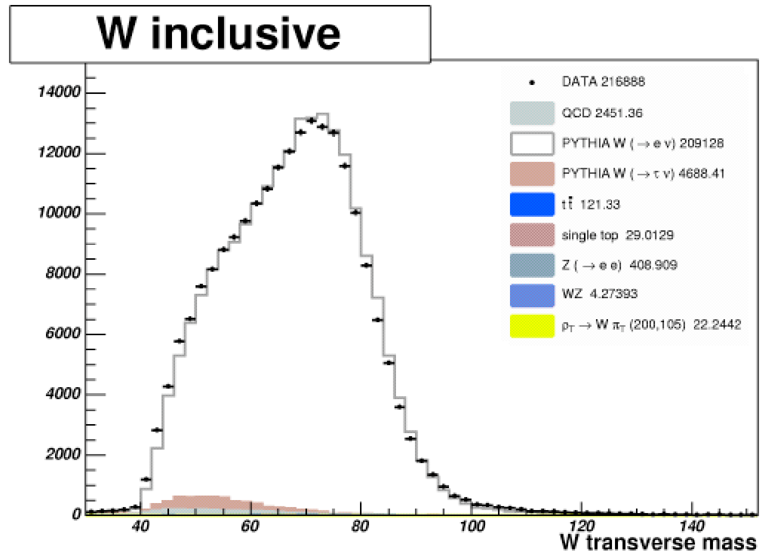
W π_T Luminosity Determination

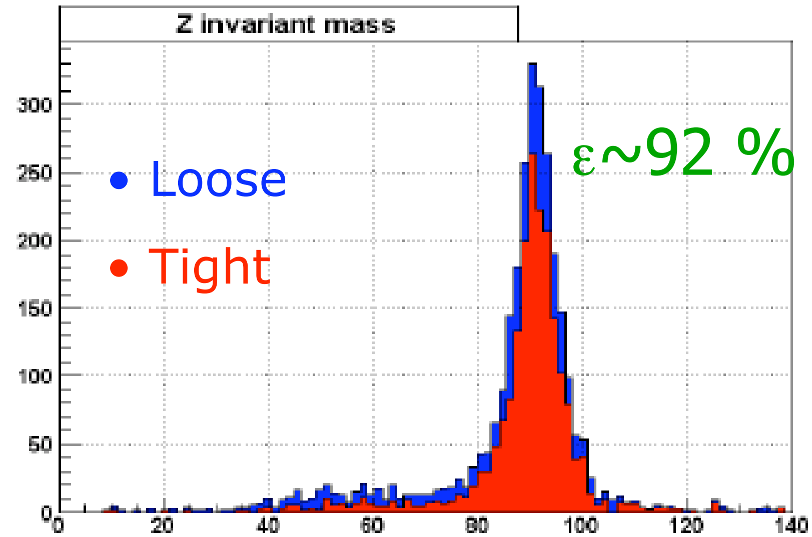
- We request one tight electron and missing energy in the calorimeter
  - signal of W boson production
- We normalize the data sample to the physics processes we expect to give the same signature
- From the cross section of these processes we then get the Luminosity:
  - $L = (N)/(\Sigma\, \sigma_i \cdot B_i \cdot \varepsilon_{cut}^{i})$
    - N = # DATA events
    - $\sigma \cdot B$ = cross section times branching ratio
    - ε_{cut} = cut eff
  - $L = 238\ pb^{-1}$

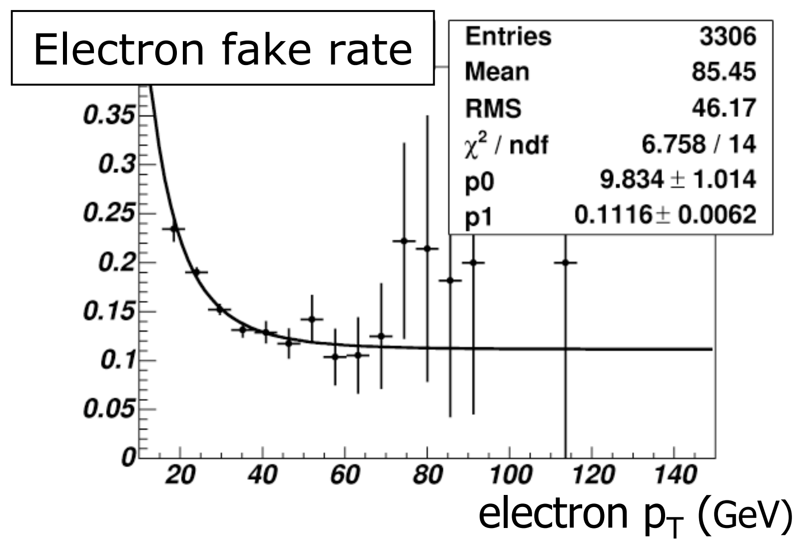


- $W \to e\,\nu$, $W \to \tau\,\nu$
- $tt \to l\nu l\ \nu bb$, $l\nu jjbb$
- $WZ \to e\ \nu bb$
- single top
- $W \to e\,\nu$, $W \to \tau\,\nu$
- $Zbb \to eebb$, $Z \to ee$

Multijet Background (QCD)

- Part of the instrumental background is due to hadronic jets faking the electron signature
- This specific background is estimated from data
- Tight electron is a calorimeter electron (Loose) with a matched track.
- In the Z mass peak Loose electrons are real electrons
- Loose electrons produced back to back with hadronic jets (in dijet samples are considered fakes

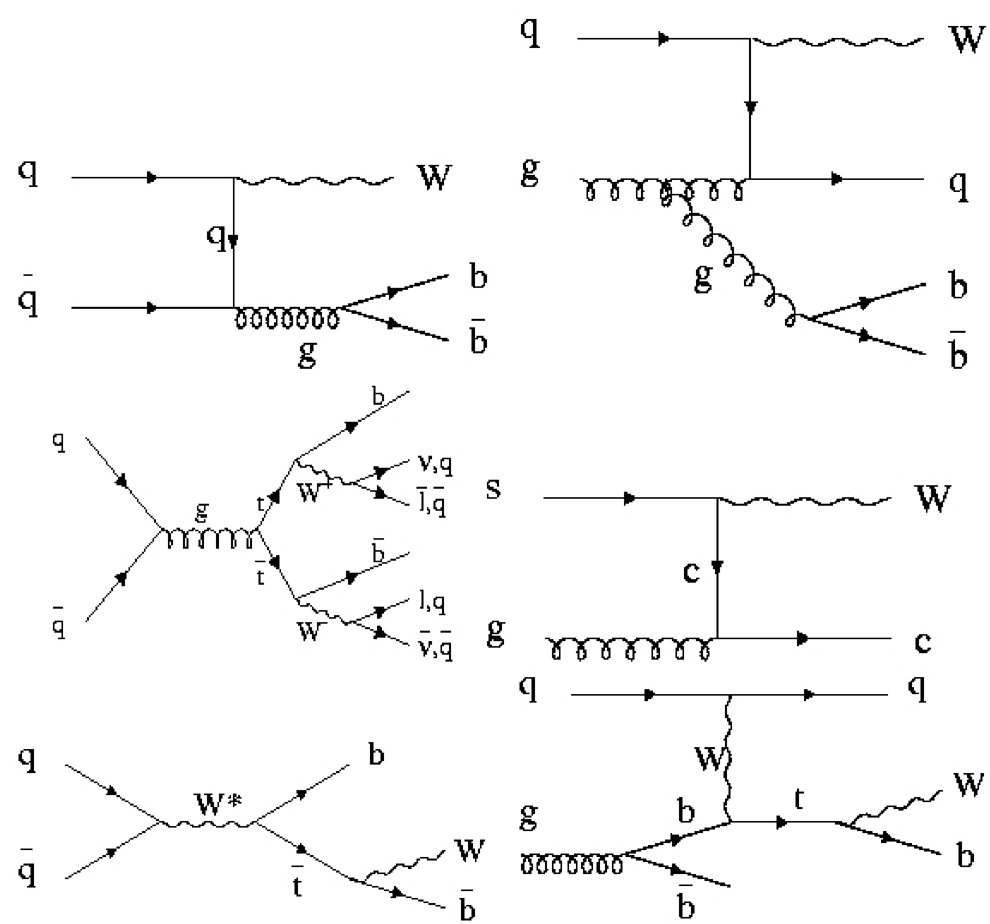




fake rate ~16 %

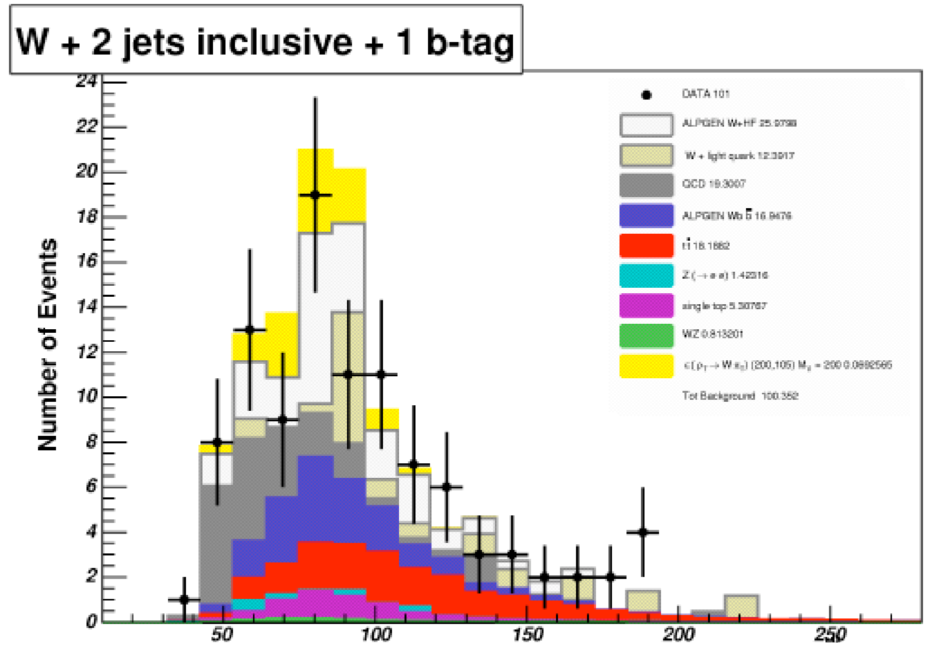
Technicolor Optimization

- Event selection:
  - one electron
  - missing transverse energy
  - 2 jets
    - one jet b-tagged
- Many physics processes have or can fake this signature:
  - W + light quark jets
    - one of the jet is mistagged as b-jets
  - W + heavy flavored jets
    - Wcc, Wbb, Wc, Wbbj
  - Top quark production
    - Single top
    - tt with not reconstructed jets

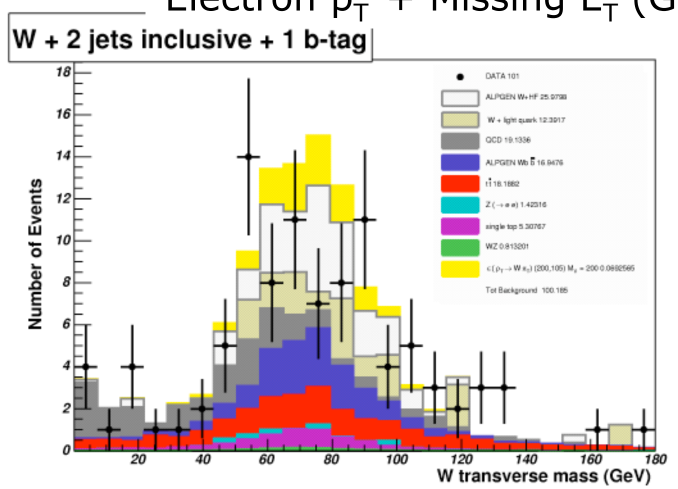


b-tagged signal estimation

- W/Z boson background produced together with heavy flavored jets and top quark production are estimated from Monte Carlo simulated events
  - To each jet is associated the quark that originated it
  - tagging probability function depending on p_T and η
- W + light quark jets is estimated from data:
  - after QCD subtraction all jets are considered originated from light quarks
- Calorimeter quantities are used to discriminate signal versus background



Electron p_T + Missing E_T (GeV) E_T^W



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$E_T^W > 65$ GeV

W transverse mass > 30 GeV

Data	74

Sources of Background

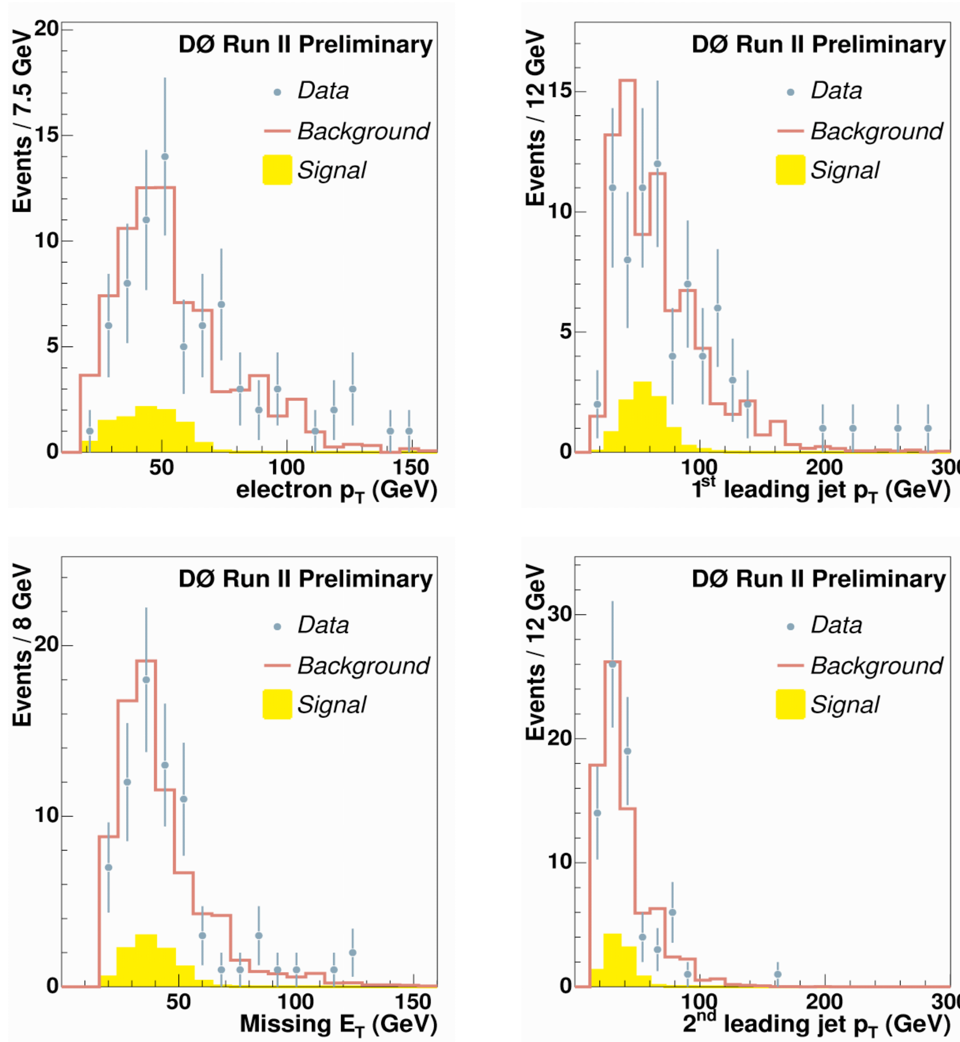
Physics Background

tt	15
Single top	4
W+ Heavy Flavors	33
WZ	1
Z→ee	2
total	55

Instrumental Background

QCD	7
W + light quarks	11
Tot Backd	73 ± 19

Expected Signal	9.1 ± 1.3



$M(\pi_T)$ = 105 GeV $M(\rho_T)$=200 GeV
M_V=200 GeV :

- $W\pi_T^{+/-}$ ~ 3.7 pb
- $W\pi_T^{0}$ ~ 2.9 pb

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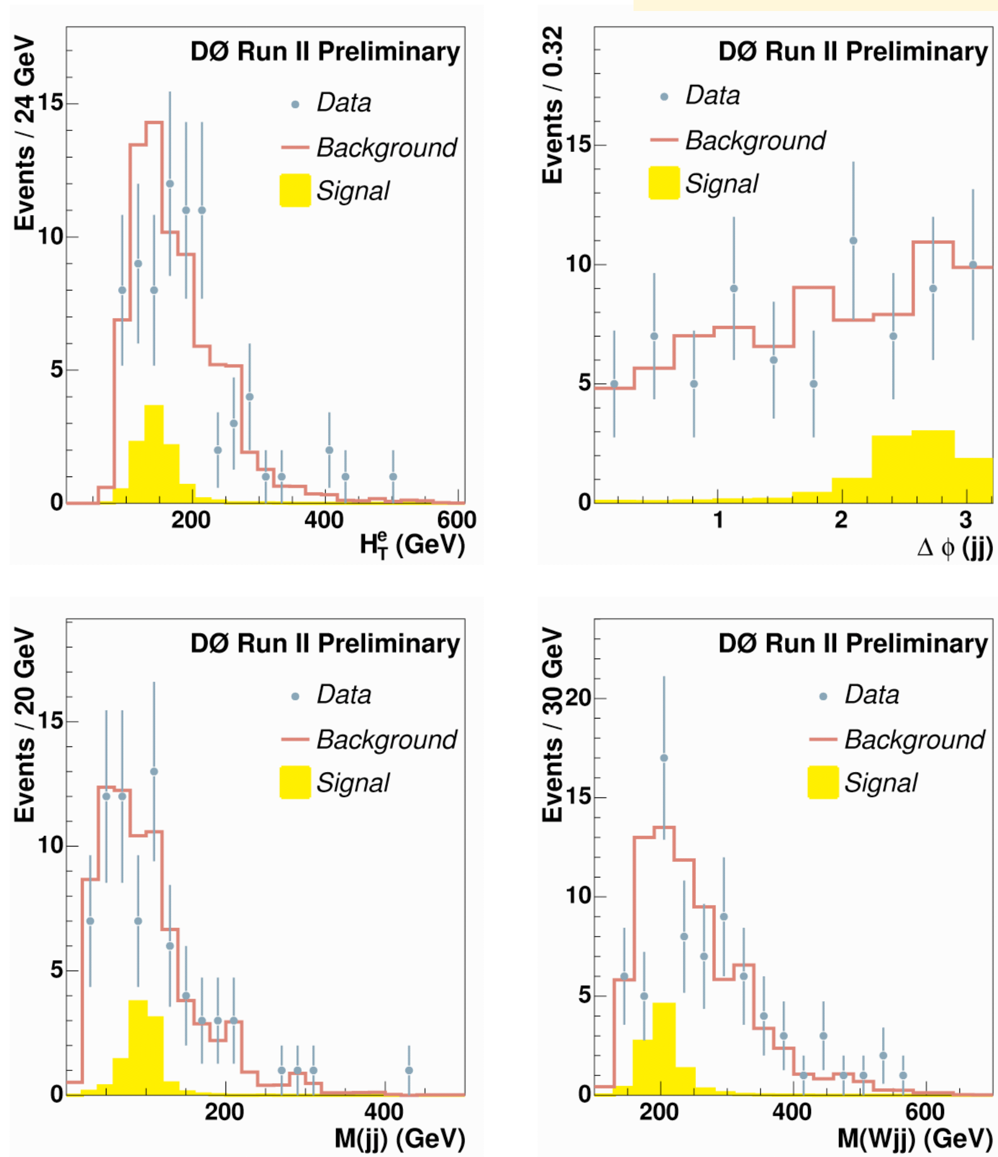
$W\pi_T$ Optimization

$\int \mathcal{L}\, dt = 238\ pb^{-1}$

- H_T^e (electron p_T + Σ jet p_T)
- $p_T(jj)$ (p_T of the dijet system)
- $\Delta\phi(jj)$
- M(jj) (invariant mass of the dijet system)
- M(Wjj) (invariant mass of the W + dijet system)



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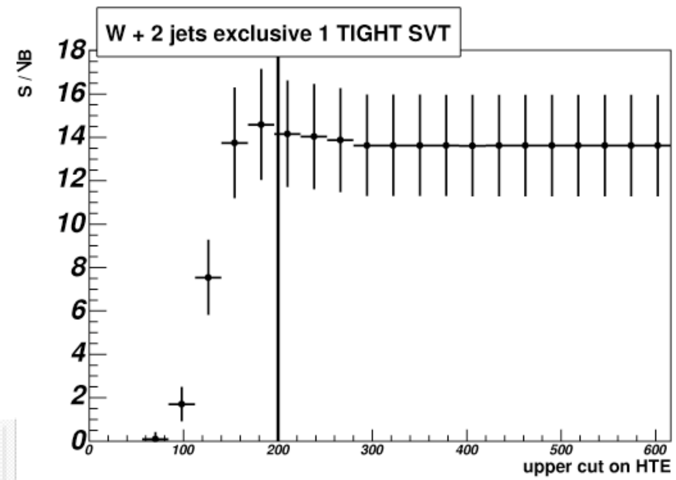
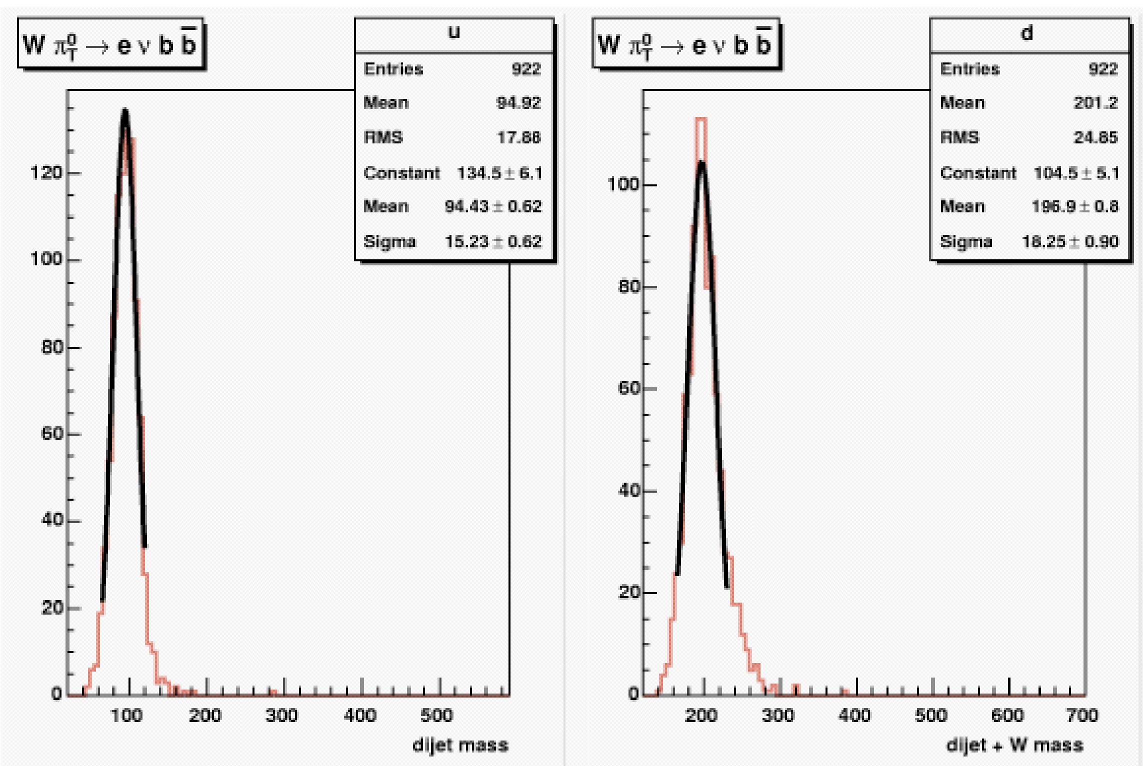
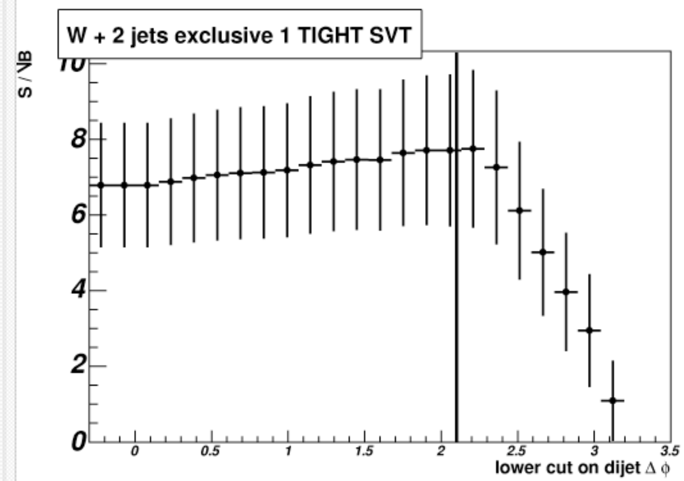
Cuts Optimization

Cuts are optimized according to S/√B

Mass window is 2 σ on the fully simulated technimeson mass peaks







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$W\pi_T$ Cross Section Limit

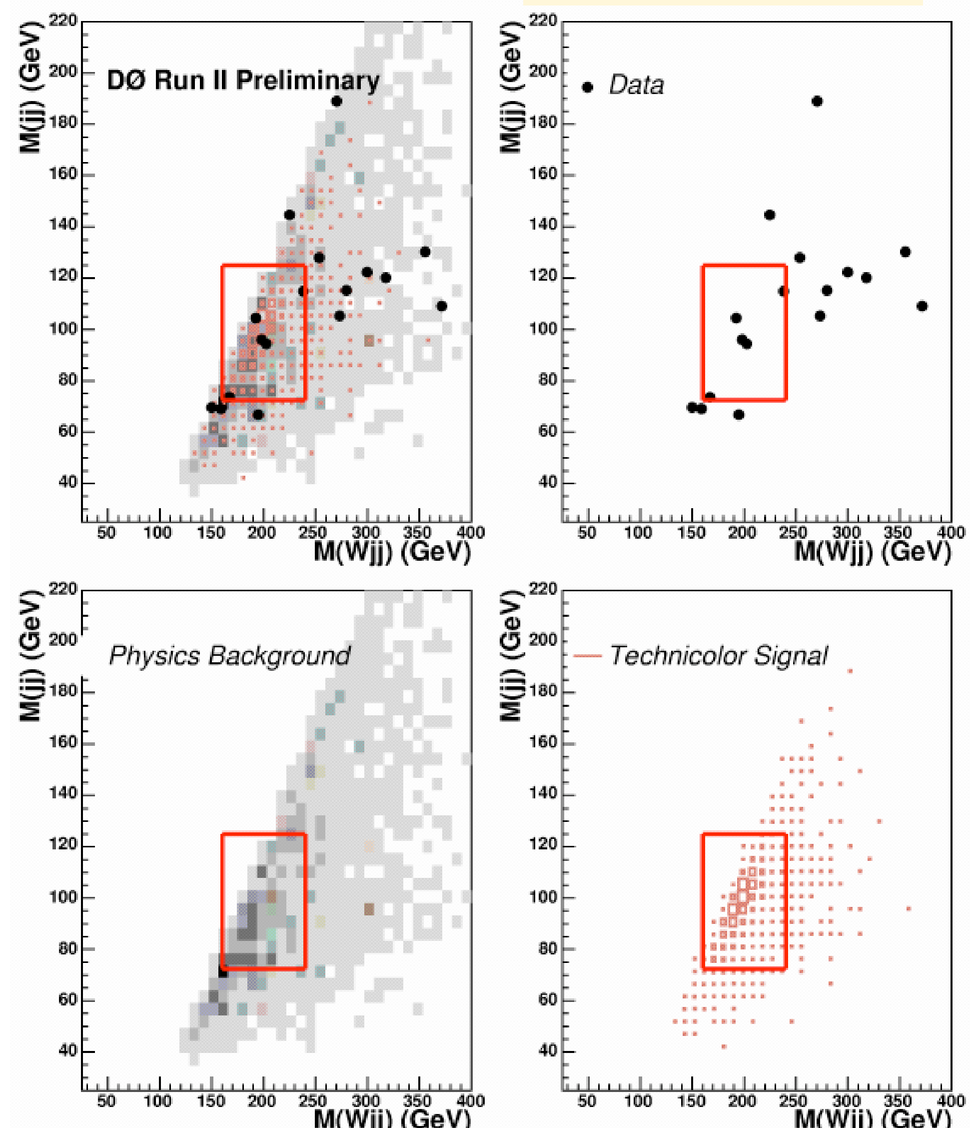
$\int \mathcal{L}\, dt = 238\ \text{pb}^{-1}$

- $\Delta\phi(jj) > 2.2$
- $p_T(jj) > 75$ GeV
- $H_T^e < 200$ GeV
- Mass Window

	data	background	signal
Baseline + $\Delta\phi$	28	28.3±7.1	7.5±1.1
+ $p_T(jj)$	22	24.7±6.2	7.4±1.1
+ H_T^e	17	18.3±4.6	7.2±1.1
+ mass window	4	6.6±1.6	6.2±0.9

Cross section 95% C.L.

upper limit 6.4 pb



Systematic errors Table

Sources of systematic errors:

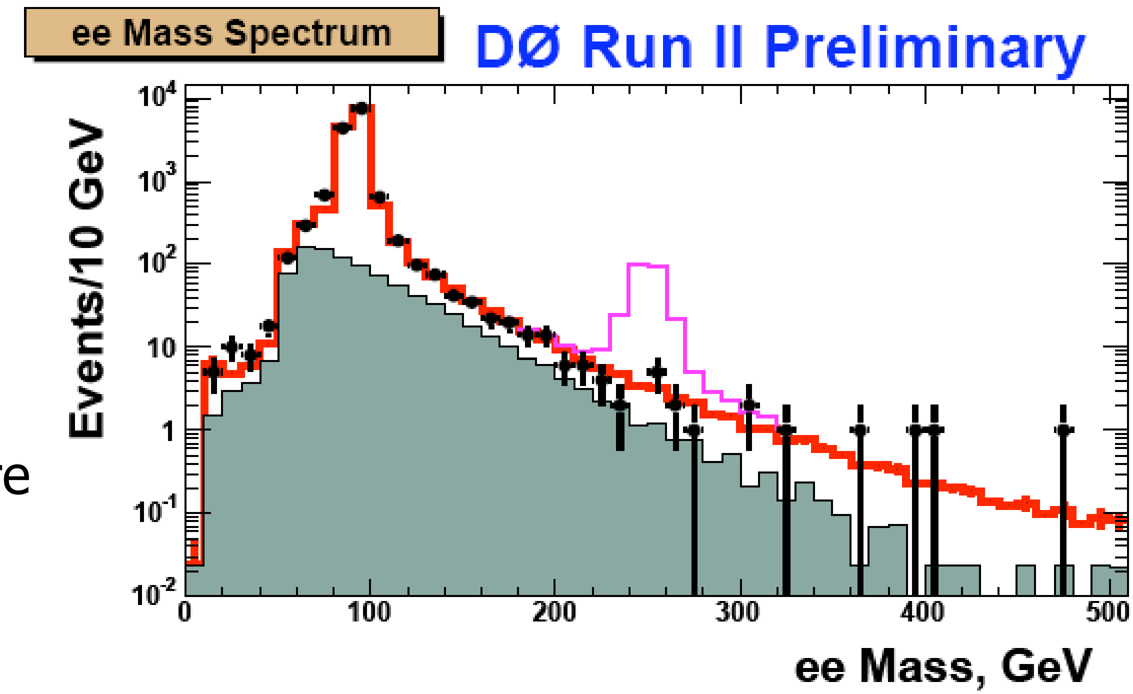
- Jet Energy Scale
  - Correction to the sampling calorimeter measurement
- b-tagging efficiency
- electron ID efficiency
- Total Systematic Errors

Background	Signal
21 %	9 %
8 %	8 %
5 %	5 %
25 %	15 %

$\omega_T/\rho_T \rightarrow e^+e^-$

$\int \mathcal{L}\, dt = 200\ pb^{-1}$

- Events with 2 high p_T electrons are selected
- Background
  - Drell-Yan production
  - QCD
- Search for $\rho_T/\omega_T \rightarrow e^+e^-$ as a bump/excess at high dielectron mass
- Intrinsic widths of ρ_T,ω_T are about 0.5 GeV
  - Thus resonance width dominated by detector resolution



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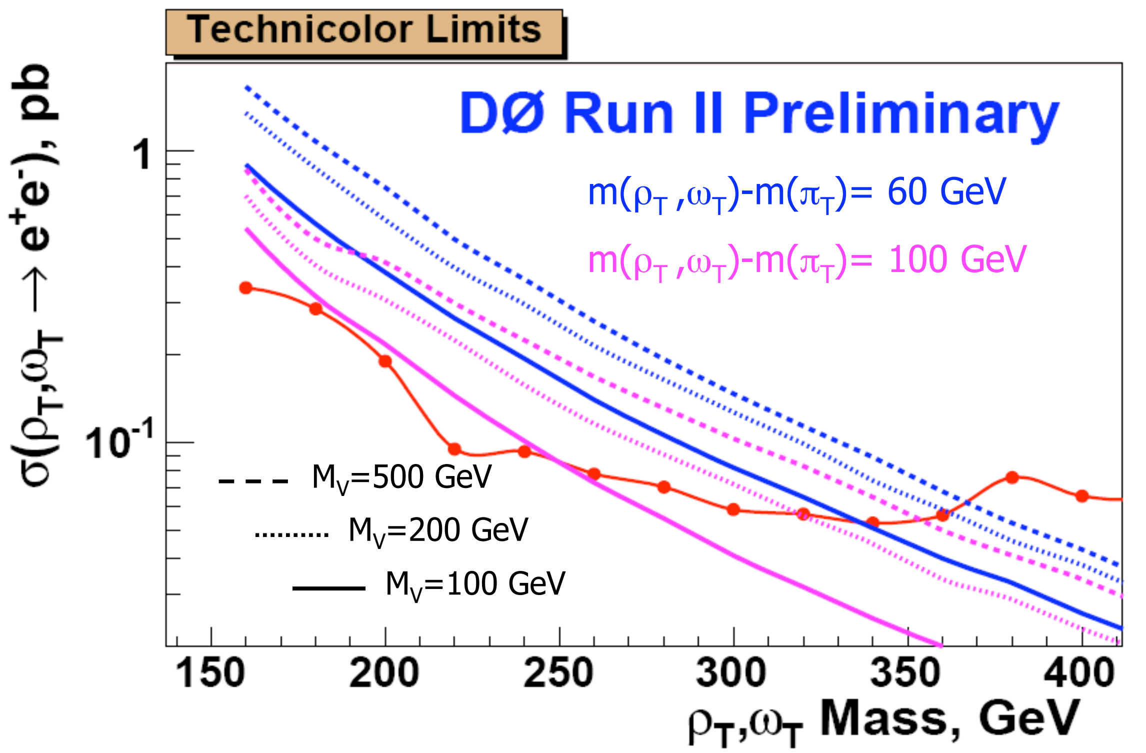
$\omega_T/\rho_T \rightarrow e^+e^-$ Limits

$\int \mathcal{L}\,dt$ = 200 pb^{-1}

- 95% C.L.
  - $m(\rho_T, \omega_T) - m(\pi_T) = 60$GeV
    - $m(\rho_T, \omega_T) > 367$ GeV for M_V = 500 GeV
    - $m(\rho_T, \omega_T) > 340$ GeV for M_V = 100 GeV
  - $m(\rho_T, \omega_T) - m(\pi_T) = 100$ GeV
    - $m(\rho_T, \omega_T) > 355$ GeV for M_V = 500 GeV
    - $m(\rho_T, \omega_T) > 240$ GeV for M_V = 100 GeV



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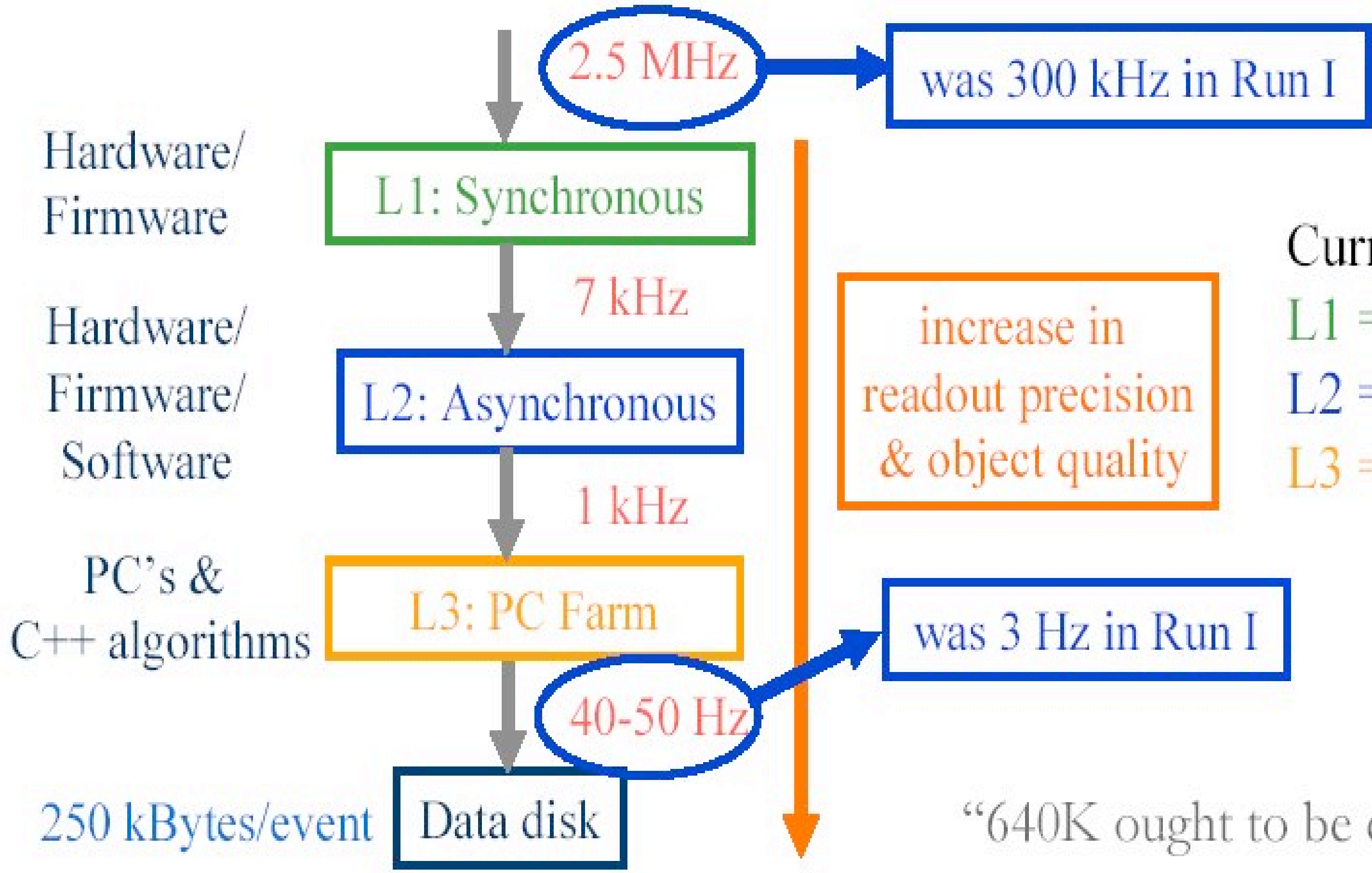
Summary

- DØ has begun to search for Technicolor particles in the W+2 jets channel
  - New b-tagging capability respect to RunI
  - No evidence were found for the π_T, ρ_T mass combination considered
- $\rho_T/\omega_T \rightarrow$ ee analysis
  - Most restrictive constraints on dilepton technicolor decays to date
- Outlook:
  - Almost twice more luminosity available for these analysis
  - Add μ channels soon

Trigger



Current Run-II rates:

L1 = 1.5-2.0 kHz

L2 = 500-900 Hz

L3 = 30-50 Hz

"640K ought to be enough for anybody."

-- *Bill Gates, 1981.*

b-tagging Systematic Errors

error	Loose	Medium	Tight
$p_T^{rel}(\mu)$	1.8	2.5	1.7
β	0.71	0.65	0.8
α	0.1	0.1	0.4
K_b	1.29	1.07	0.84
K_{cl}	0.2	0.2	0.01
Tot error	2.33	2.80	2.10
previous	5.7	7.3	8.0