Challenges to DØ in the new Millennium

and its response:

UPGRADE !

(Trigger)

Manuel I. Martin (DØ Collaboration)

Notes about this web version of the presentation(s).

This is the result of the fusion of three separated talks (to be) given at RAL (England), IFAE (Barcelona, Spain) and U. of Zaragoza (Zaragoza, Spain).

Although the emphasis at each presentation is different, there is enough common ground to justify the merging of all three talks into a single document.

The presentations emphasis are:

At RAL	DØ Upgrade and New Trigger
At IFAE	DØ Collaboration and my personal contributions to it.
U. Of Zaragoza	Physics at DØ, Triggers

Manuel I. Martín

BACK HOME !

Born in Cáceres

Grew up in Barcelona

Educated in Barcelona

Started Ph.D. in 1966 (U. of Barcelona, España / Stevens Institute of Technology, NJ)

Finished Ph.D. in 1996 (U. of Zaragoza, España / Northwestern, Il)

Member of DØ since 1985

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Web sites:

http://d0server1.fnal.gov/users/manuel/

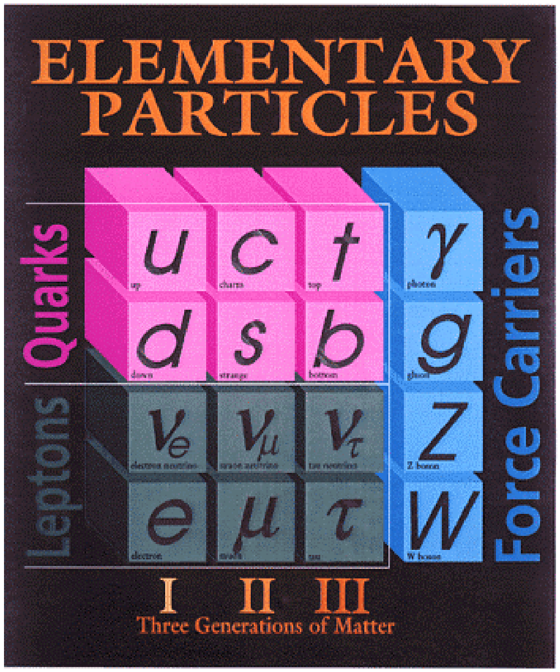
http://d0server1.fnal.gov/projects/Col_Broadcaster/Architecture/

OUTLINE

- DØ
  - The Collaboration
  - Run I
- Challenges
  - Physics
- Responses
  - Accelerator upgrade
  - Detector Upgrade
  - New Trigger System
- Summary

DØ

Physics’ Challenges



$SM \equiv SU(3) \times SU(2) \times U(1)$

Great !!

But too many arbitrary parameters:

- 6 quark masses
- 6 lepton masses
- 4 quark mixing matrix parameters
- 4 lepton mixing matrix parameters
- 3 force coupling `constants’
- 2 Higgs parameters (m_H , $\sin^2\theta_W$),
- 1 phase for strong interaction CP violation

SM does not give force unification. How to get gravity into the picture?

The Higgs mechanism is artificial.

Inserted in *ad hoc* manner to reproduce the observed massive *W* and *Z* .

etc.

The DØ Collaboration

500 scientists and engineers

60 institutions

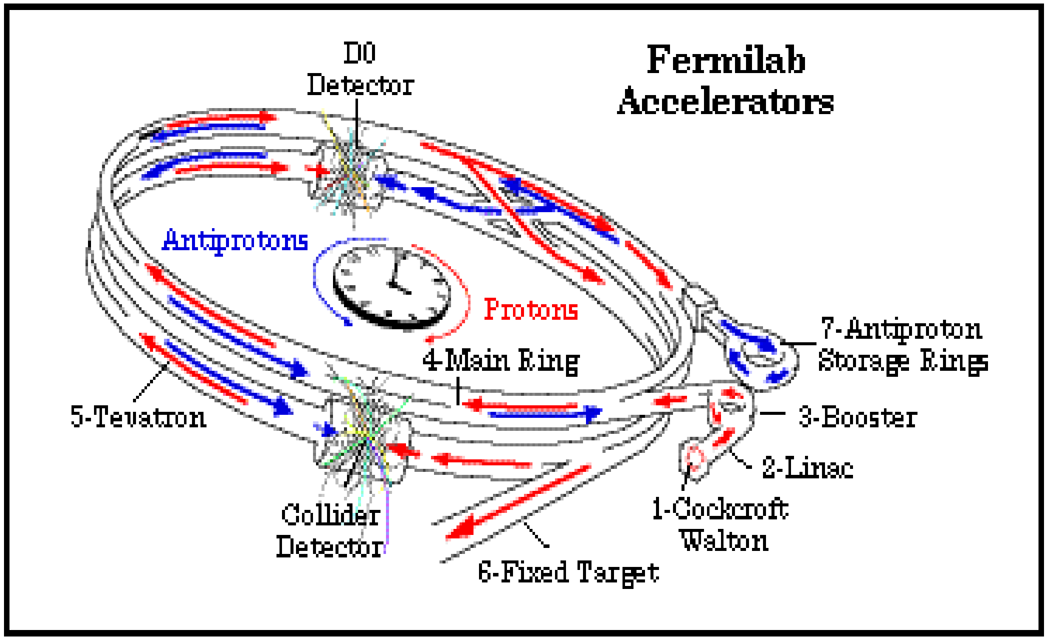
16 countries

110+ Ph.D. dissertations

80+ papers

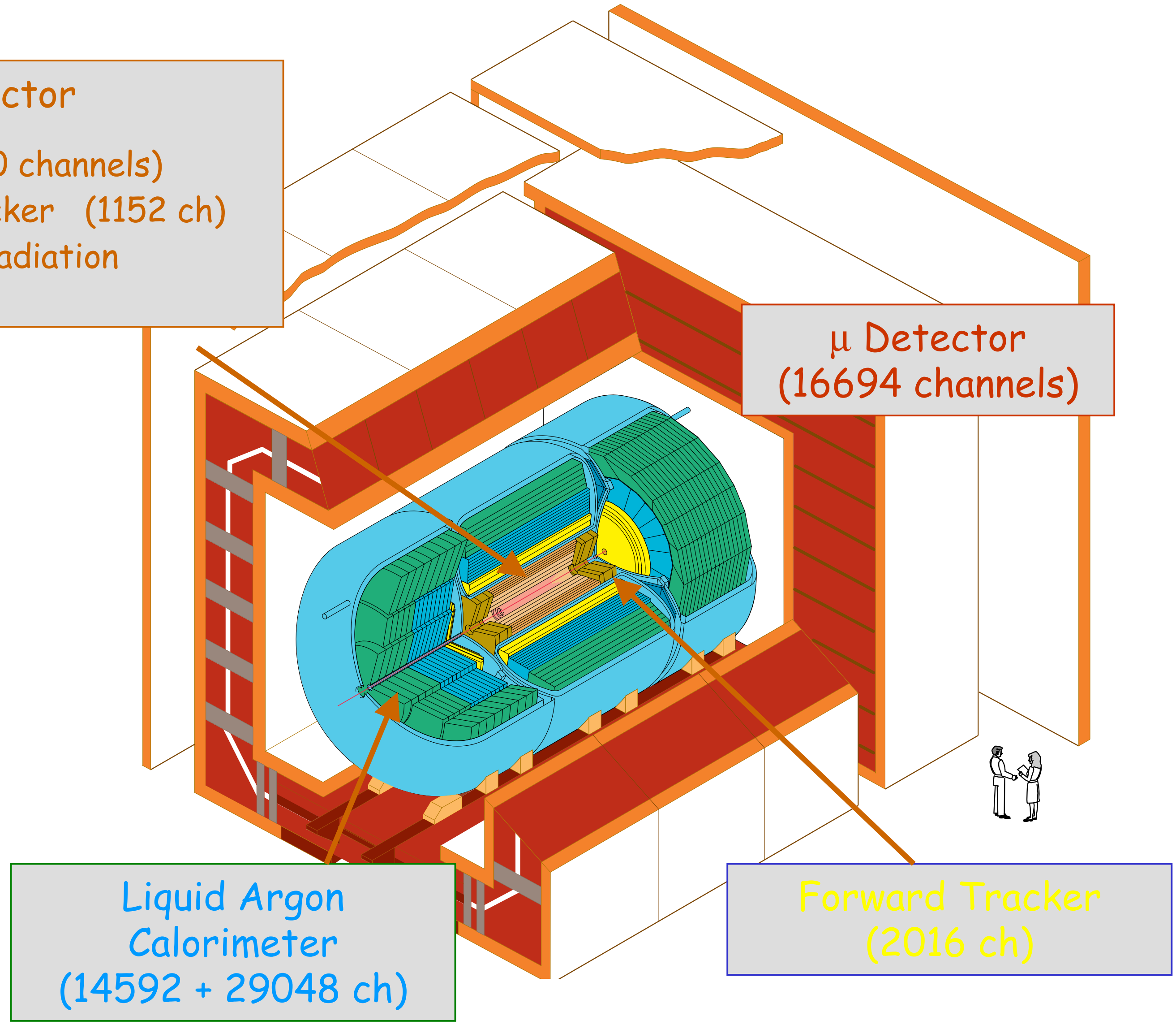
The Tevatron Runs 0 I

The Tevatron



- Proton – anti-proton Collider
  - Center of Mass Energy $\sqrt{s}$ = 1.8 TeV
  - Partons inside proton interact: quarks and gluons
- Characteristics
  - Organized in bunches (6 on 6)
  - Bunch crossing 3.5 μs
  - Peak luminosity L = 2 10^{31} cm^{-2} s^{-1}

- Two Collider experiments, CDF and DØ
  - Run Ia: 1992 – 1993; CDF and DØ, L = ~20 pb^{-1}
  - Run Ib: 1994 – 1996; CDF and DØ, L = ~120 pb^{-1}

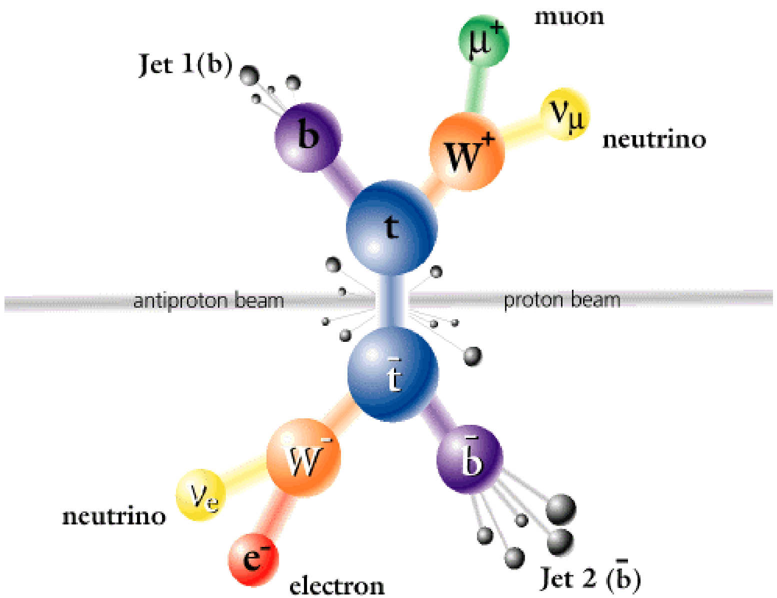


The DØ Detector for Run I

Some Studies at DØ (Run I)

- ✓ Top discovery
- ✓ Top mass
- ✓ W mass, W width, W and Z Pt spectra
- ✓ ……
- ✓ Angular distribution of the lepton in the W decay
- ✓ Searches for New Phenomena:
  - o SUSY
  - o All generations of Leptoquark pairs
  - o Bottom Squarks
  - o High Mass Photon Pairs
  - o Quark Compositeness
  - o Top Quark Decays to Charged Higgs Boson

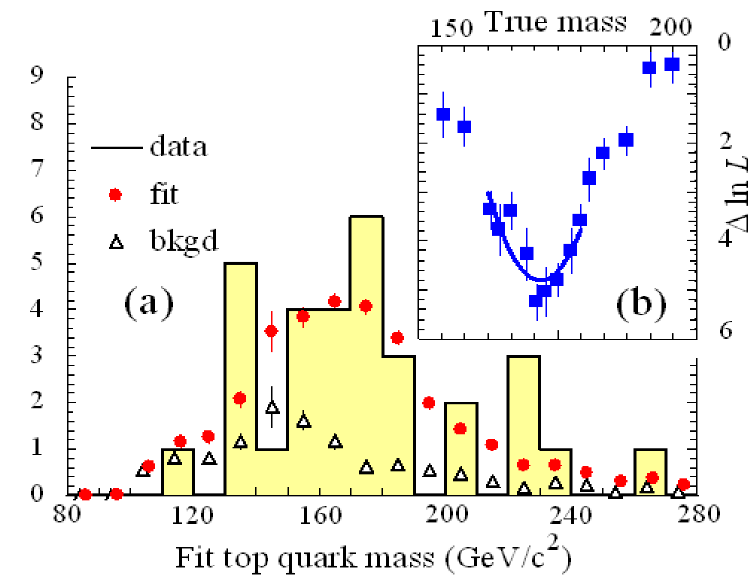
Top Discovery



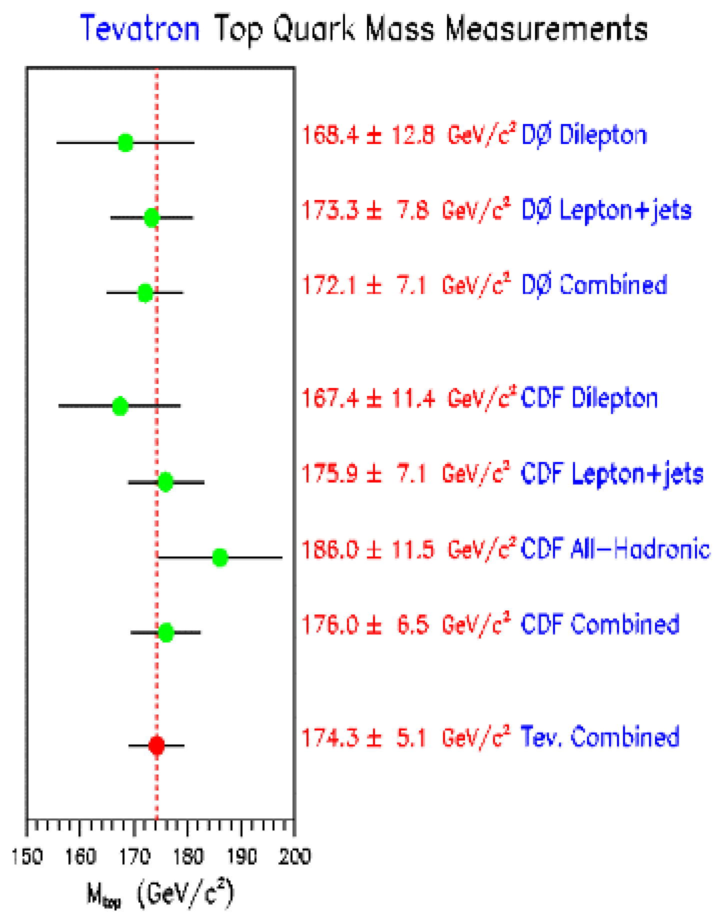
M_t = 172.0 ± 7.1GeV (DØ)

M_t = 174.3 ± 5.1GeV (TEV)

The mass reconstructed for the top-candidate events with one lepton, four jets and missing transverse momentum . The inset shows the quality of the likelihood fit as a function of top mass, with the best value of 173 GeV being at the minimum.

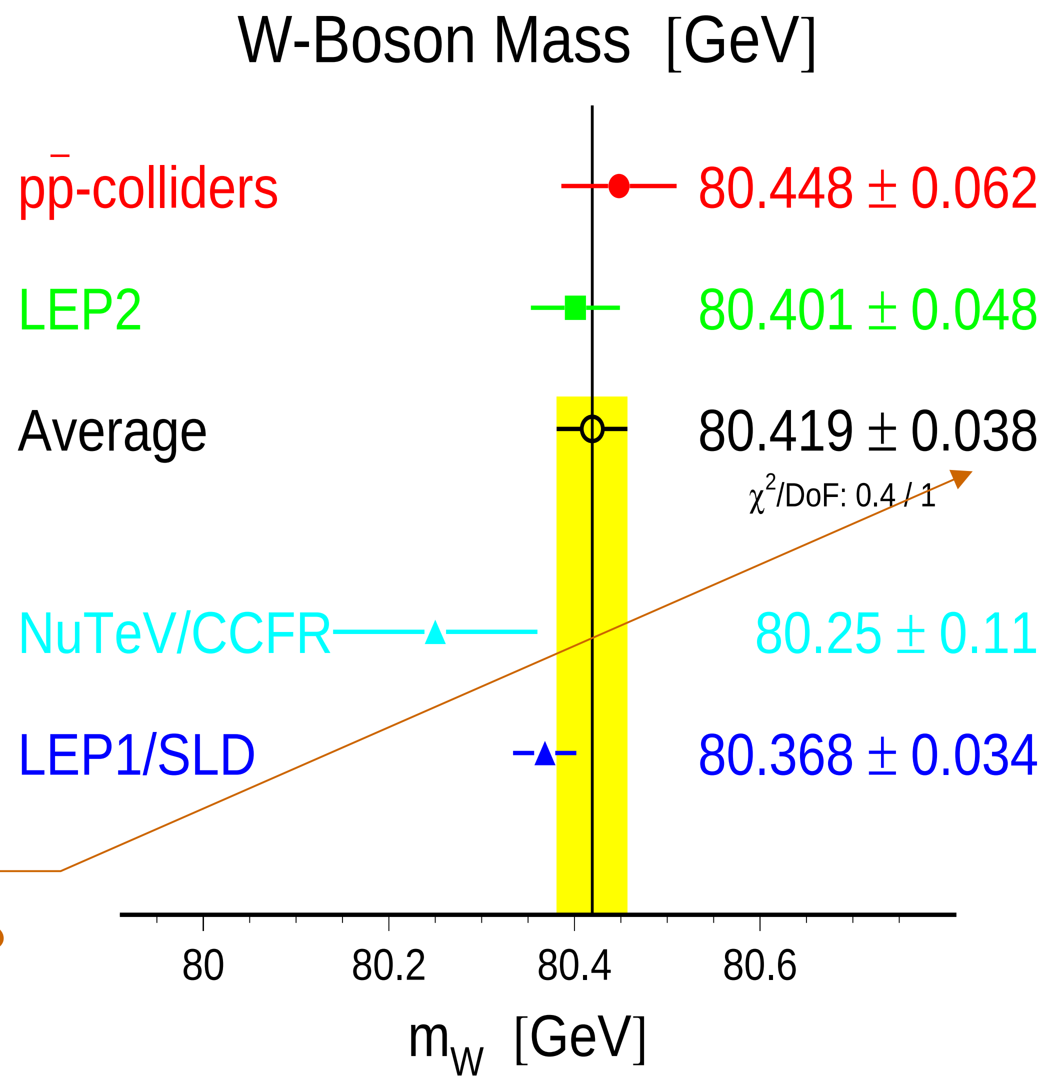


Top Mass measurements



W mass

Important to set limits to the Higgs mass

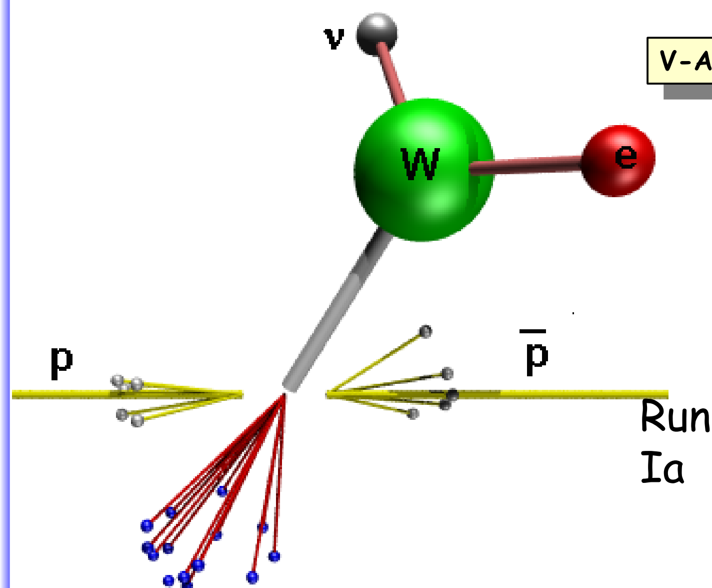


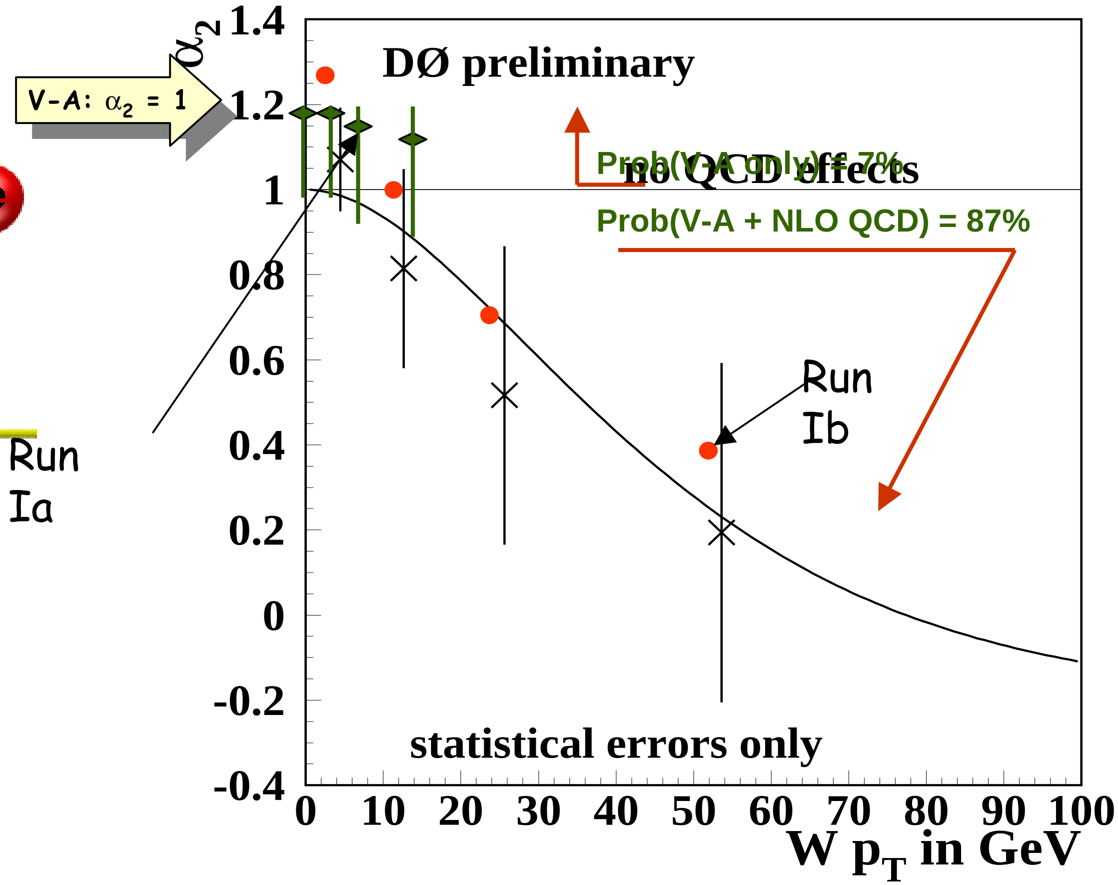
Incredibly small error

Can we do better?

W Decay Distribution → α_2

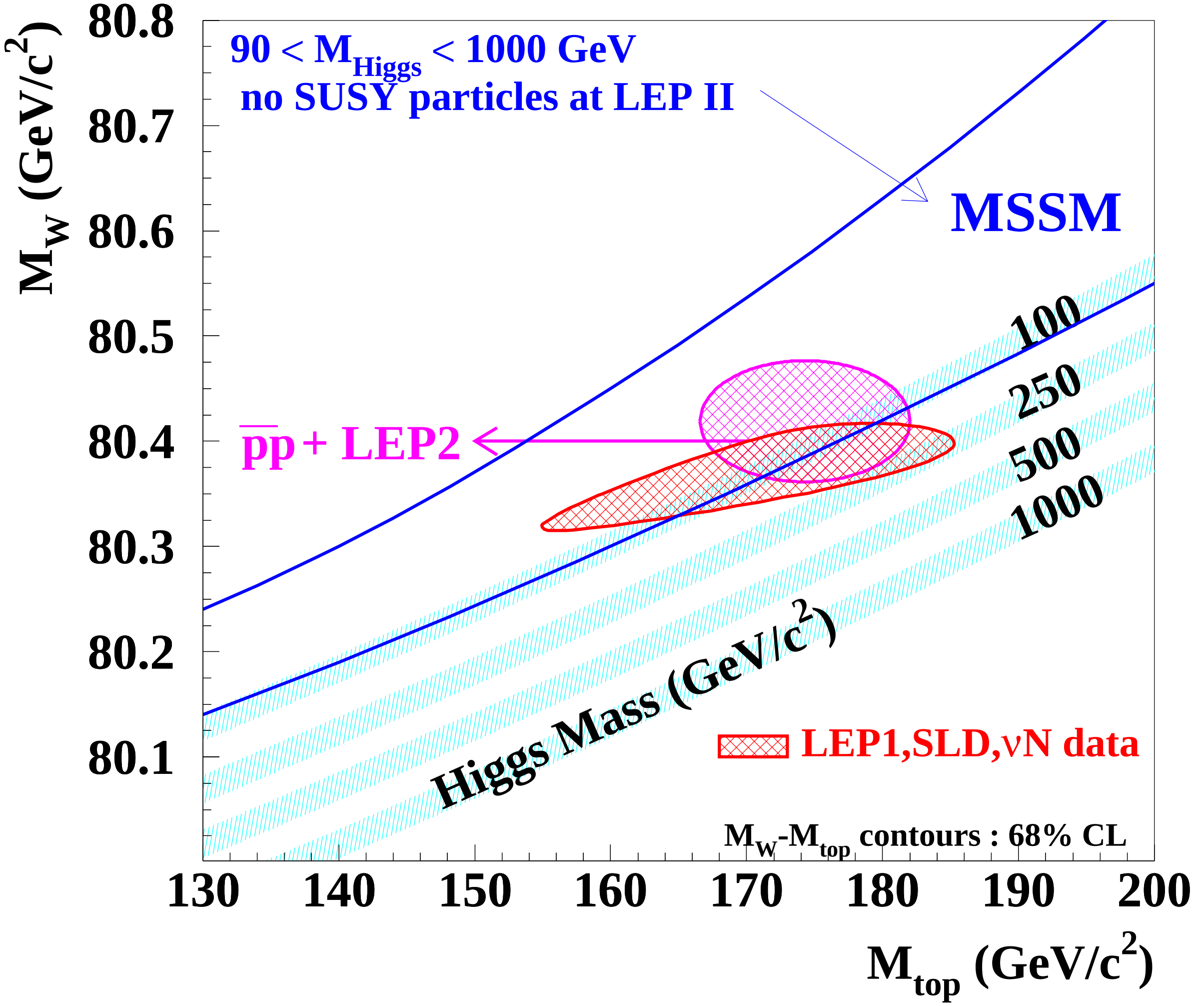
$$\frac{d\sigma}{d\cos\vartheta^*} \propto 1 + P(W)\alpha_1 \cos\vartheta^* + \alpha_2 \cos^2\vartheta^*$$





Points for Run Ia show
95% confident level

The search for the Higgs .....



PHYSICS' CHALLENGES

Physics' Challenges

HIGGS ....

SUSY (in the most general form has 124 free parameters)

So

SUGRA, GMSB, AMSB, ..., DSB

Super Gravity, Gauge Mediated Susy Breaking, Anomaly Meditated Susy Breaking, ..., Dynamic Symmetry Breaking

Compositeness ....

Strings, Branes, ...

Multidimensionality ....

In any case we are hopeful of new physics !

If EW theory is to be consistent up to energy scale Λ ...

From perturbative analysis

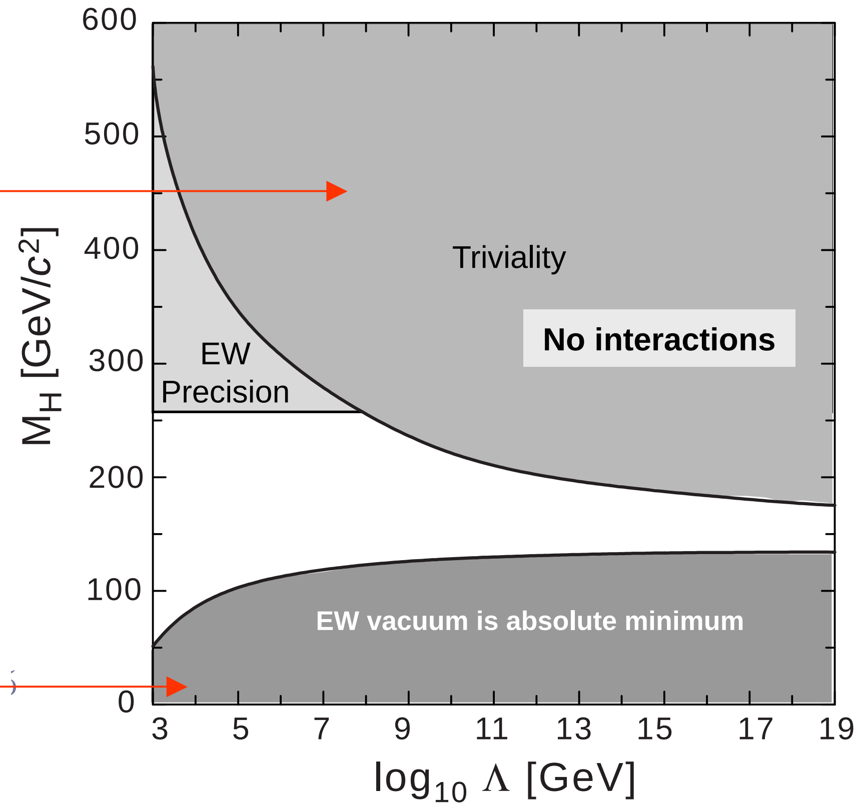
$$\Lambda \leq M_H \exp\left(\frac{4\pi^2 v^2}{3M_H^2}\right)$$

From quantum corrections to classical potential
$V(\varphi^\dagger\varphi) = \mu^2(\varphi^\dagger\varphi) + |\lambda| (\varphi^\dagger\varphi)^2$
with $\langle\varphi\rangle_0 \neq 0$

$$M_H^2 > \frac{3G_F\sqrt{2}}{8\pi^2}\left(2M_W^4 + M_Z^4 - 4m_t^4\right)\log\left(\frac{\Lambda^2}{v^2}\right)$$

$$v = \left(G_F\sqrt{2}\right)^{-1/2} \approx 246\,GeV$$

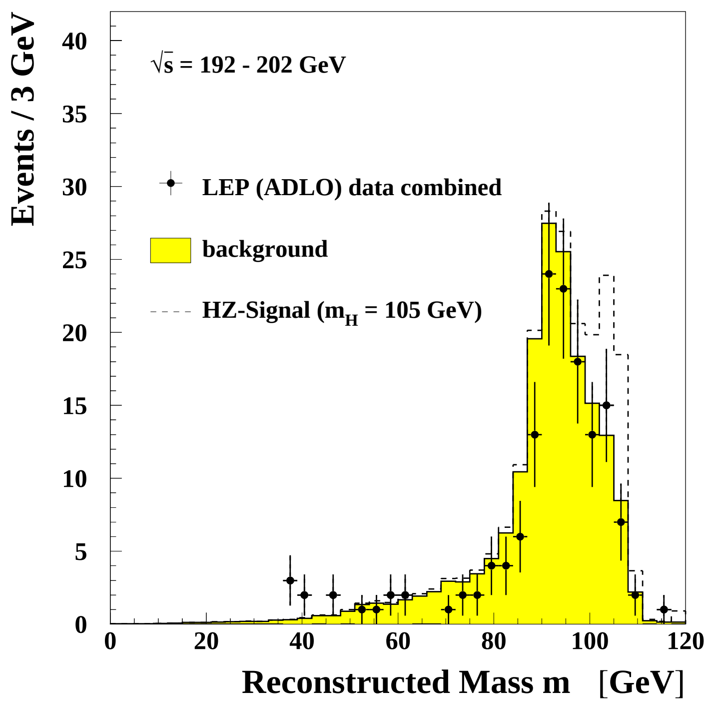
Is √2 times the vacuum expectation value of the Higgs field



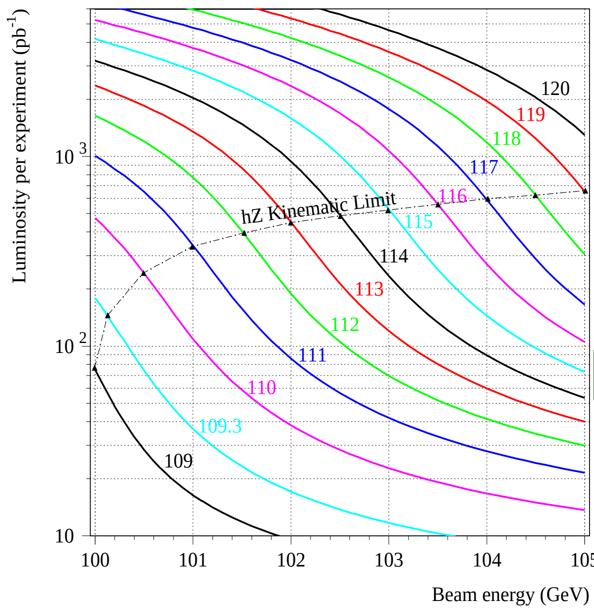
As per Chris Quigg

$\Lambda \Rightarrow 10^{16}$; $145 \leq M_H \leq 170$ GeV/c^2

THE HIGGS STILL AT LARGE ...



LEP Electroweak WG
Moriond 3/14/2000



combined limit:

$M_H > 107.7$ GeV/c^2

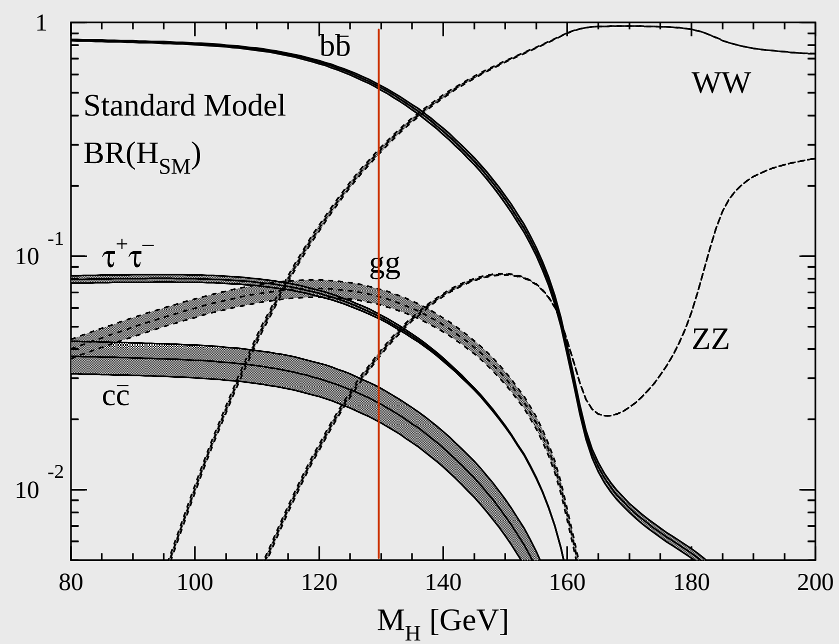
Ultimate LEP Sensitivity:

Exclusion at 95% CL

$M_H < 114 - 115.5$ GeV/c^2

P. Janot
Chamonix-2000

HIGGS DECAYS in the SM



Branching ratios of the SM Higgs obtained with HDECAY and QCD corrections beyond leading order.

Error bands include uncertainties in α_s, M_b, M_c and M_t

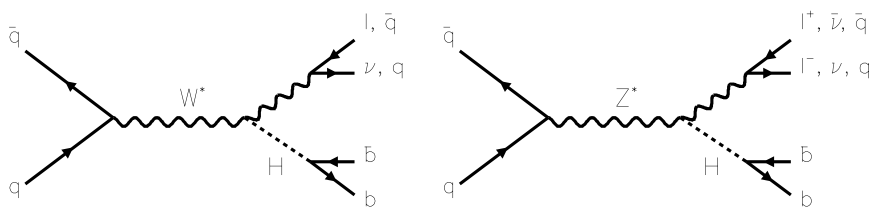
For $m_H > 130 GeV/c^2$ the mode $H \rightarrow WW$ dominates with WW final states $l^{\pm} l^{\pm} jj$ *and* $l^+ l^- \nu \bar{\nu}$

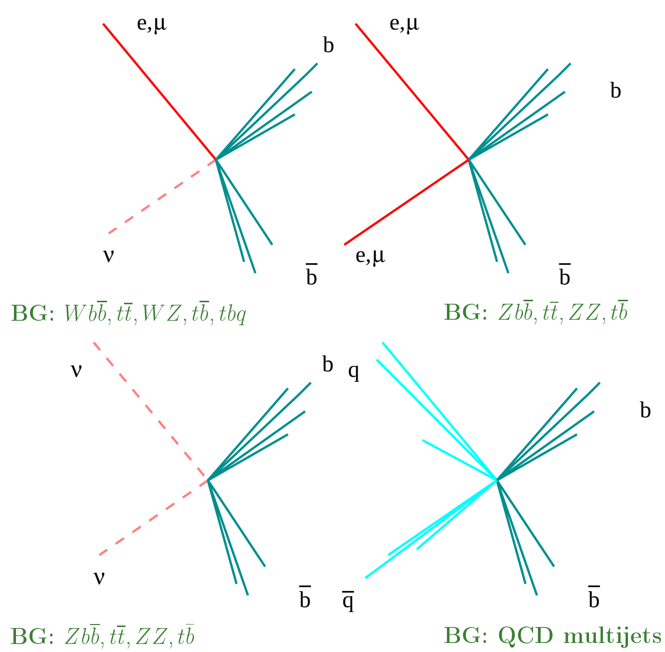
For $m_H < 130 GeV/c^2$ the mode $H \rightarrow bb$ dominates with final states WH/ZH $\rightarrow$ $q\bar{q}b\bar{b}$, $l^{\pm} \nu b\bar{b}$, $l^+ l^- b\bar{b}$ *and* $\nu\bar{\nu} b \bar{b}$

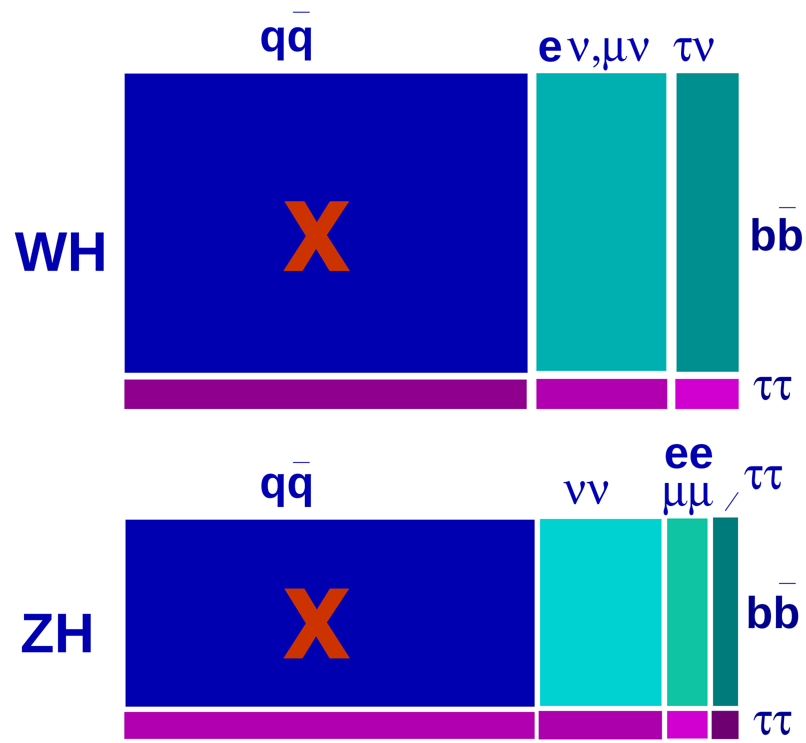
We need b tagging!

Higgs signatures if $M_H<130$GeV/c^2

(Strahlung of W/Z Bosons)

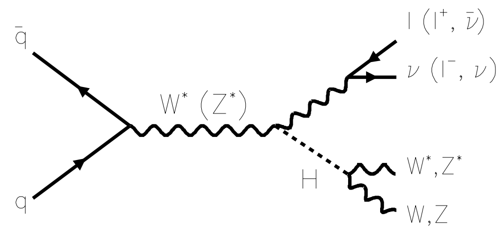




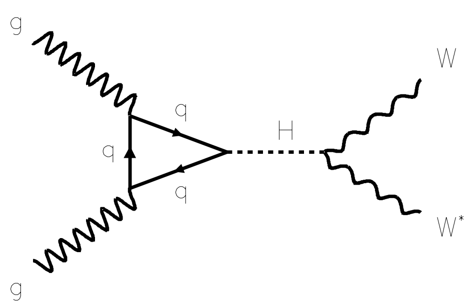


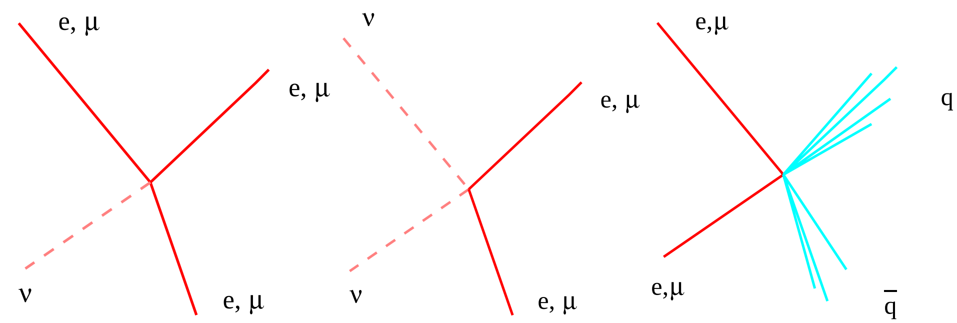
Higgs signatures if M_H>130GeV/c²

Higgs Strahlung off W/Z Bosons



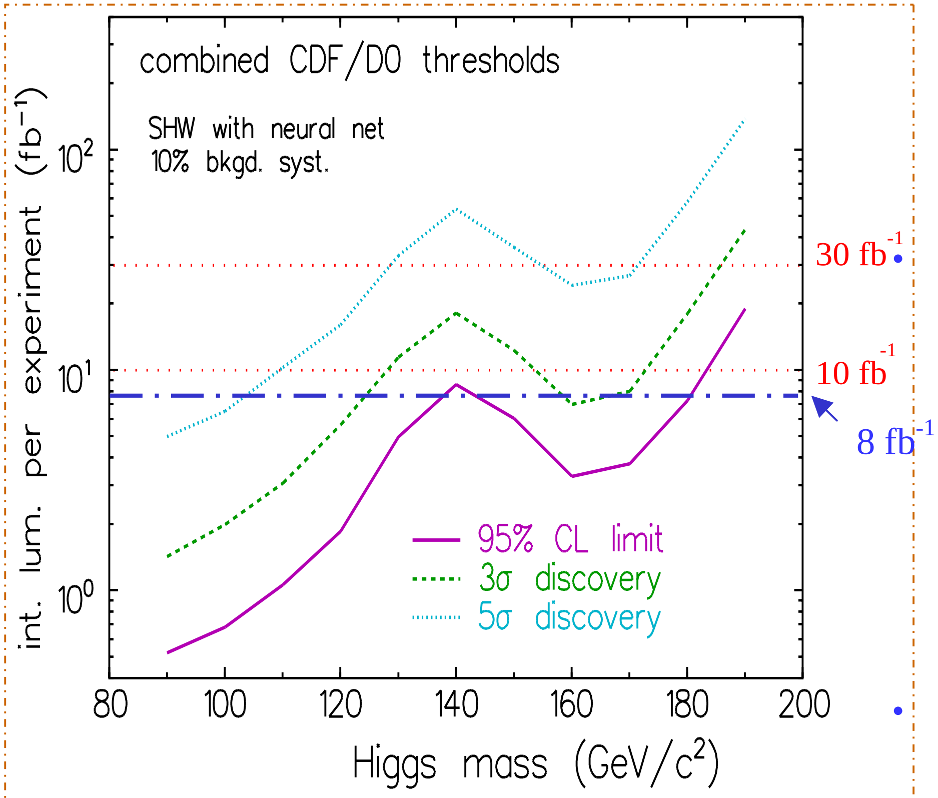
Gluon-Gluon Fusion $gg \to H$





BG: WZ, WW, ZZ $WW, t\bar{t}, WZ, ZZ$ $WW, WZ, ZZ, t\bar{t}, W/Zjj$

THINKING ABOUT THE HIGGS

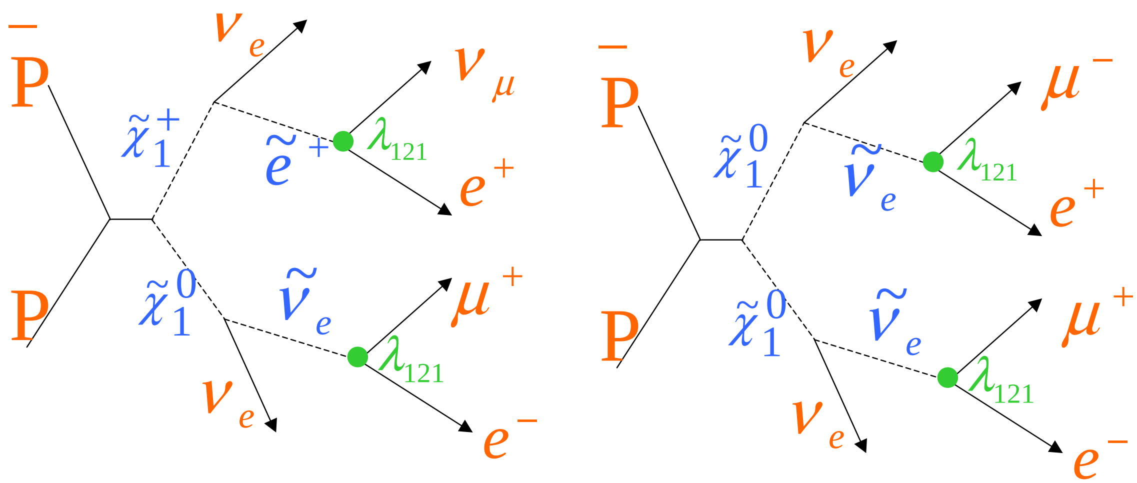


- Present SM Higgs Mass limits (95% CL):
  - M_H > 107.7 GeV (direct)
  - M_H < 188 GeV (indirect)
- With ~20 fb^{-1}, we have good sensitivity for SM Higgs:
  - 5+ s.d. discovery for m_H <125 GeV
  - 3+ s.d. discovery for m_H < 180 GeV
  - Exclude SM at 95% CL if there is no sign of the Higgs in Run 2b
- But failure or success is strongly dependent on the integrated luminosity we can achieve in Run 2b
- And our capacity to …

Examples of Interesting Final States

R-Parity Violation in SUSY

Lepton number violation at vertices λ_{121}



3 and 4 leptons FS

.... handle interesting signatures

$jets + \not{E}$

$bb + \not{E}$

$ll + jets + \not{E}$

???

$bb + ll + \not{E}$

$\gamma\gamma + \not{E}$

$\gamma + ll + \not{E}$

???

single jet

???

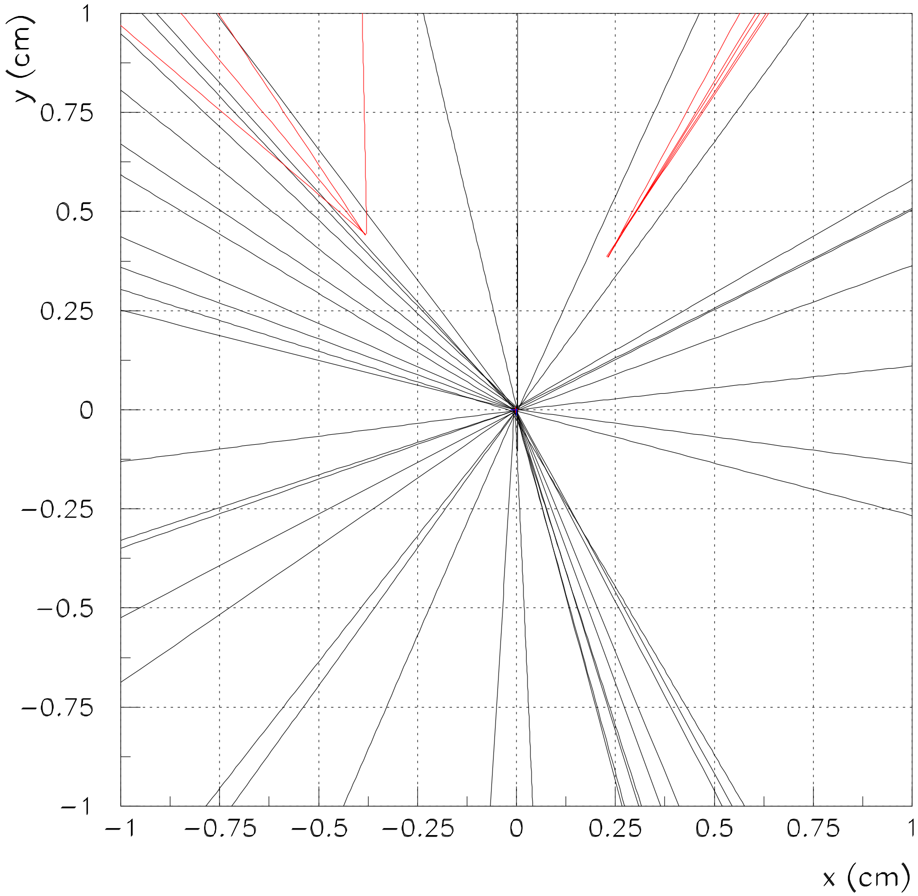
$\gamma + jets + \not{E}$

$jets + lll + \not{E}$

That are all over the map.

Then we will be able to reach $\Rightarrow$

b Tagging



- b hadrons have a life time of the order of 1.56ps
- At the Tevatron they are boosted with decay lengths of the order of 3mm

With good tracking the, secondary vertices can be found and the invariant mass of the tracks associated with the jet and its impact parameter can be used to distinguish bs from cs and light hadrons.

OUR GOALS (CHALLENGES)

–SUSY or other physics beyond the SM

–Higgs boson

Without forgetting bread and water Physics

- Precision measurements of m_W, $m_t \Rightarrow m_H$ (indirect)
- CP violation in B decays
- Detailed study of top quark properties
- New particle searches
- QCD studies (low and high Q^2)
- etc. etc.

RESPONSES

ACCELERATOR RESPONSE

The Accelerator Response

Events' rates 3.5µs → 396ns → 132ns

Peak Luminosity ($cm^{-2}\ s^{-1}$)

10^{31} → 10^{32} → $5x10^{32}$

Energy at cm

1.8 TeV → 2.0 TeV

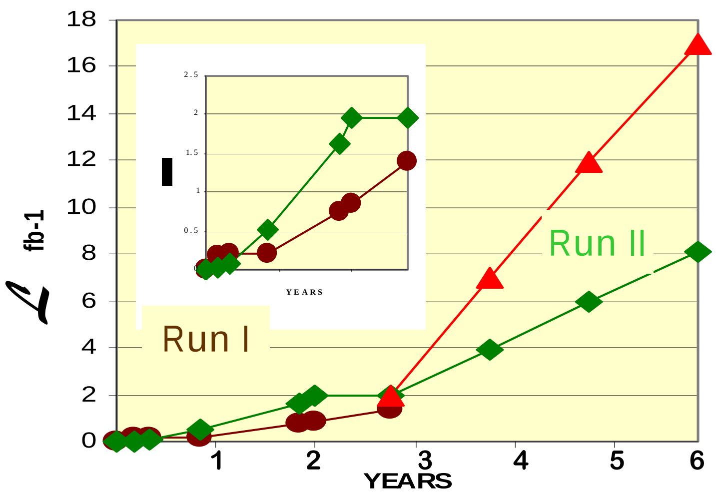
Integrated Luminosity

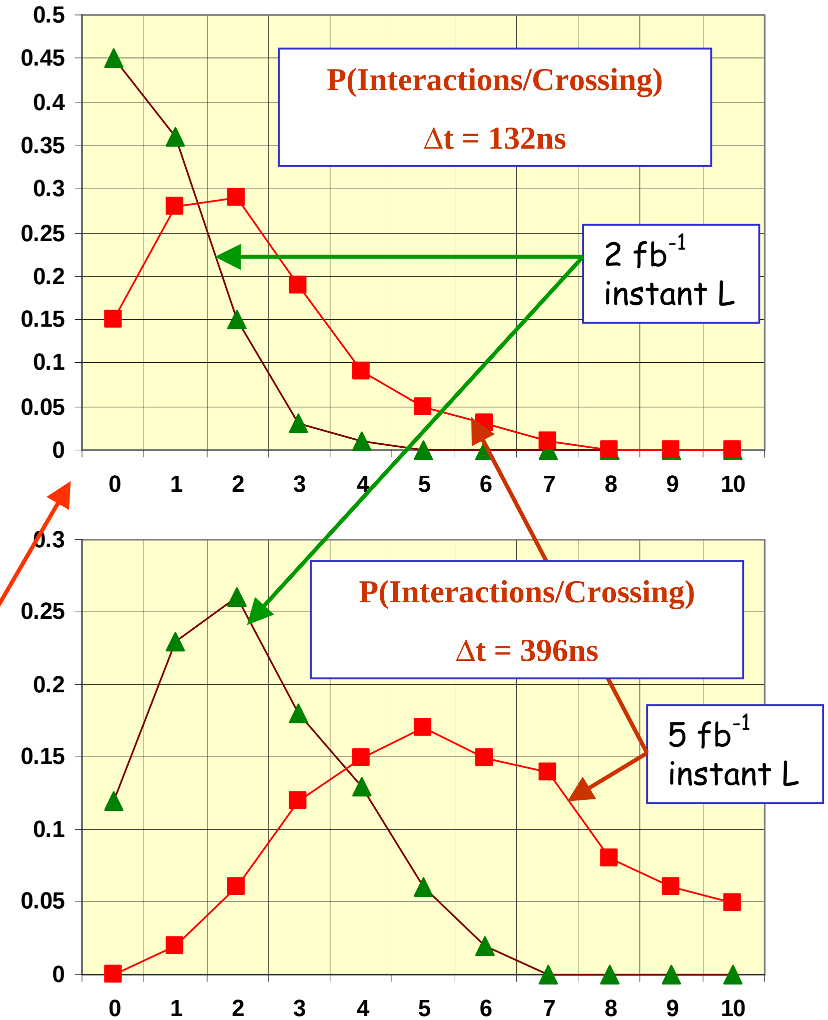
120 pb^{-1} → 2fb^{-1} → 8(30?) fb^{-1}

Interactions/event

1-2 → 3-6 → 2-4

Challenges from the Accelerator





GOOD

and

Challenging

DØ

RESPONSE

DØ UPGRADE

to be able to operate with small dead times at the new instant luminosity ($L = 2(5)\ 10^{32} cm^{-2} s^{-1}$) **and new crossing times** (Δt = 132ns) **and be responsive to the challenges of the realities of the new Physics world** **or DIE**

- A totally new Tracker System
  - An inner Si Vertex Detector
  - An outer Scintillating Fiber Detector
  - Imbedded in a 2 Tesla magnetic field
- Upgrade the μ-detector
  - Faster electronics and faster gas mixture
  - Addition of shielding material
- Upgrade the electronics of the Calorimeter with faster elements
- Add PreShower Detectors both in the Central and Forward Regions
- Design a new Trigger System
- New Algorithms, etc. etc.

DØ

RESPONSE

ALGORITHMS

NEW (almost) WAYS TO LOOK AT OLD THINGS

New Search Algorithms

- Sherlock

Reviving Old (old for non physicists) Searching Methods

- Neural Networks
- Others ?

Emphasizing Proven Analysis Methodology

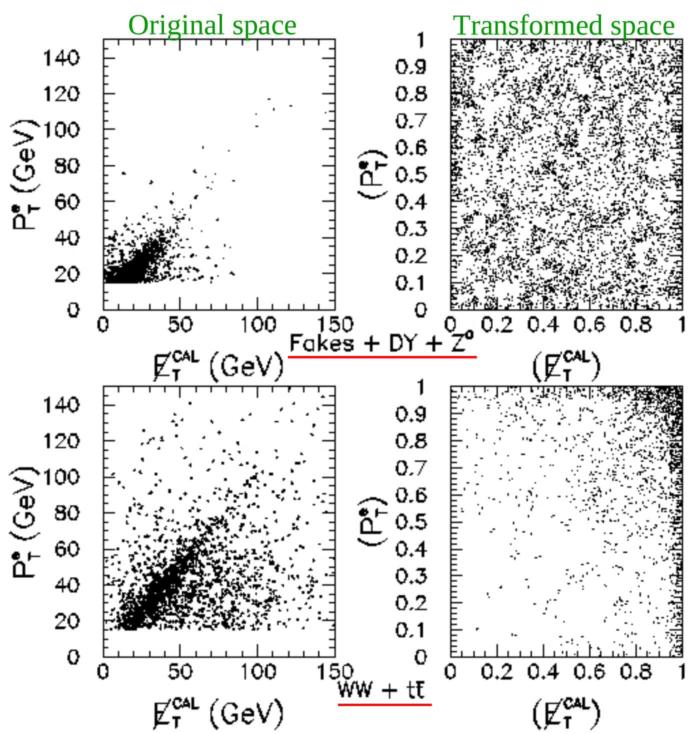
- Bayesian Analysis

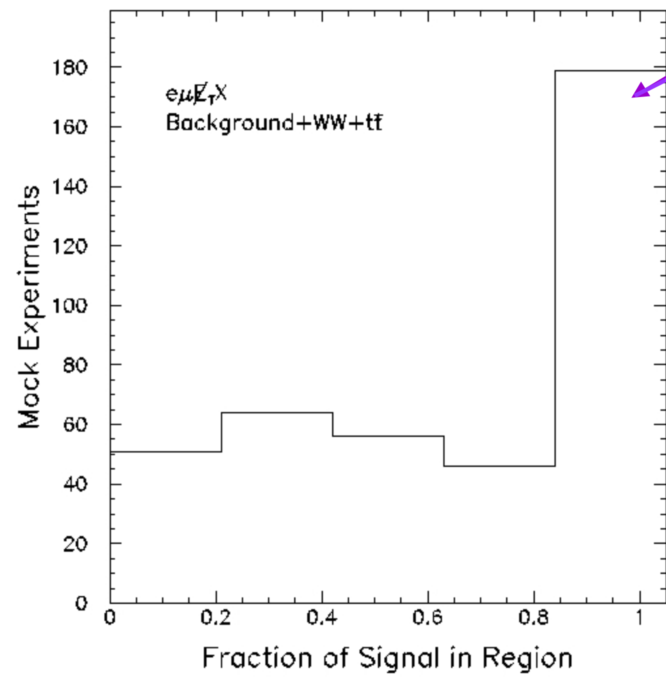
SHERLOCK (a generic search)

Strategy: use exclusive final states to define a multidimensional region

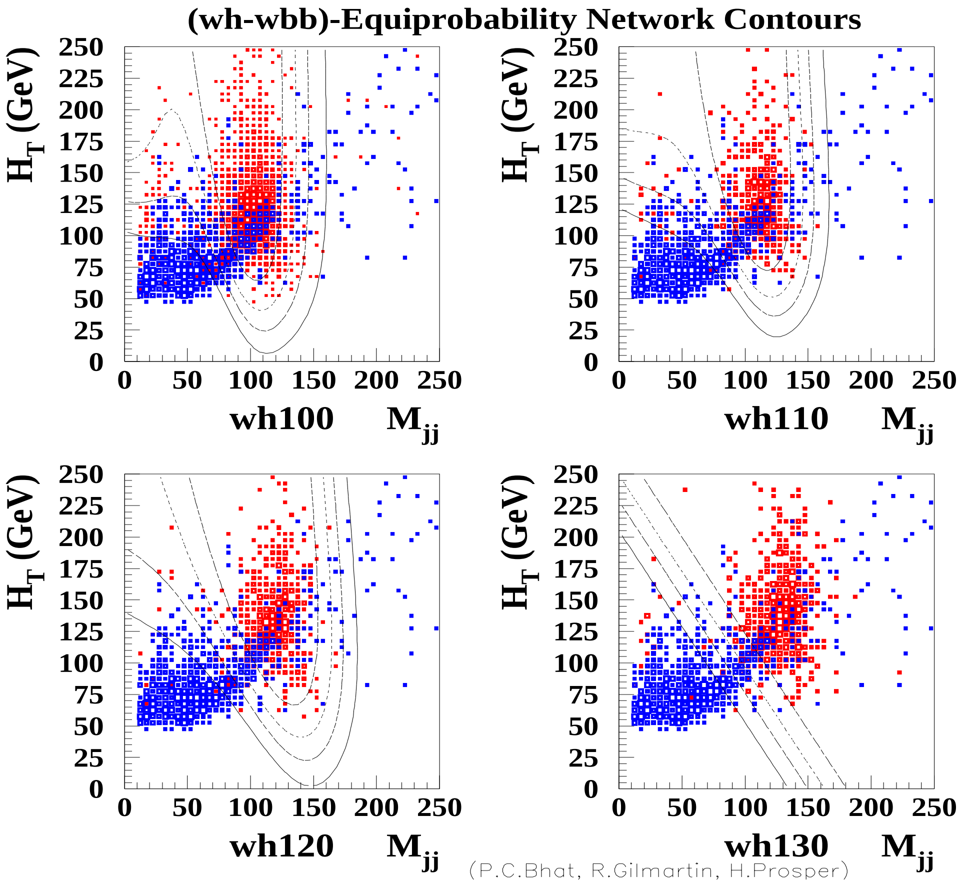
Example: assuming some standard objects e, μ, γ, etc. all events which contain the same number of each of these objects belongs to same final state

45% of the time the area chosen have 80% of the signal





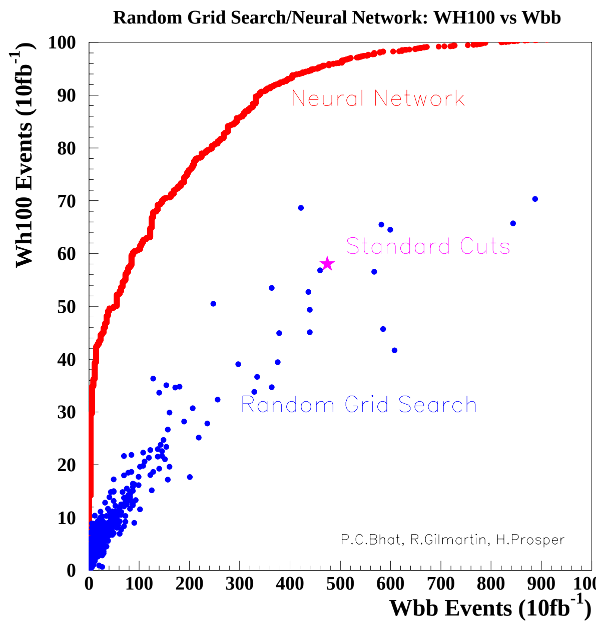
Neural Networks at Work



Neural Networks Search

<>

Complex Multivariate Search



Bayesian Analysis and Maximum Entropy Method

Probability Theory as Extended Logic

Elimination of 'paradoxes' present in the "frequentist" approach

Elimination of non-physical solutions

Provides a natural method to include a priori knowledge and to deal with systematics

Provides methodology to eliminate unwanted parameters

Takes advantage of the highly developed software using the Principle of Maximum Entropy

Methods for:

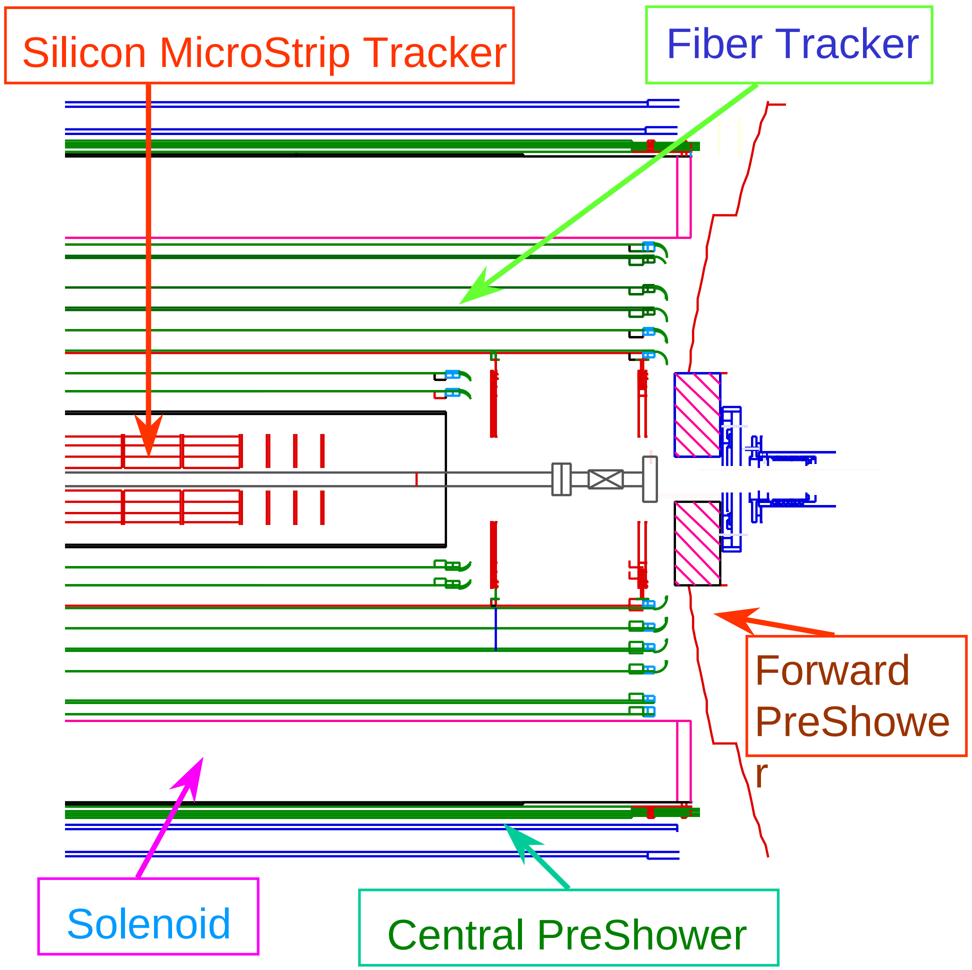
- Testing Hypothesis
- Estimating Parameters
- Shape Analysis
- Comparing and Merging Results from different Experiments

DØ

RESPONSE

NEW TRACKER

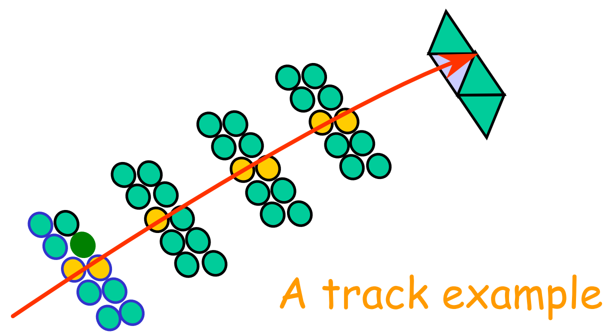
THE TRACKER FOR RUN II



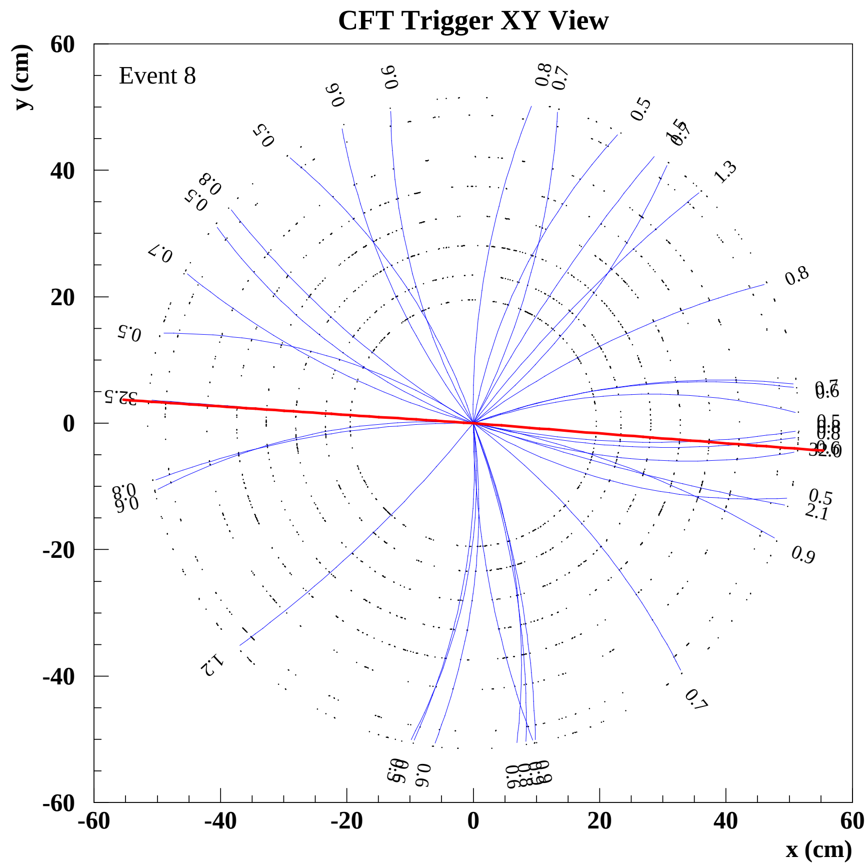
- Solenoid
  - 2T superconducting
- Fiber Tracker
  - Eight layers sci-fi ribbon doublets
  - 77,000 830 µm fibers w/ VLPC readout
- Silicon Tracker
  - Four layer barrels (double/single sided)
  - Interspersed double sided disks
  - **800,000 channels**
- PreShower
  - Central
    - Scintillator strips
    - 6,000 channels
  - Forward
    - Scintillator strips
    - 16,000 channels

Central Tracking

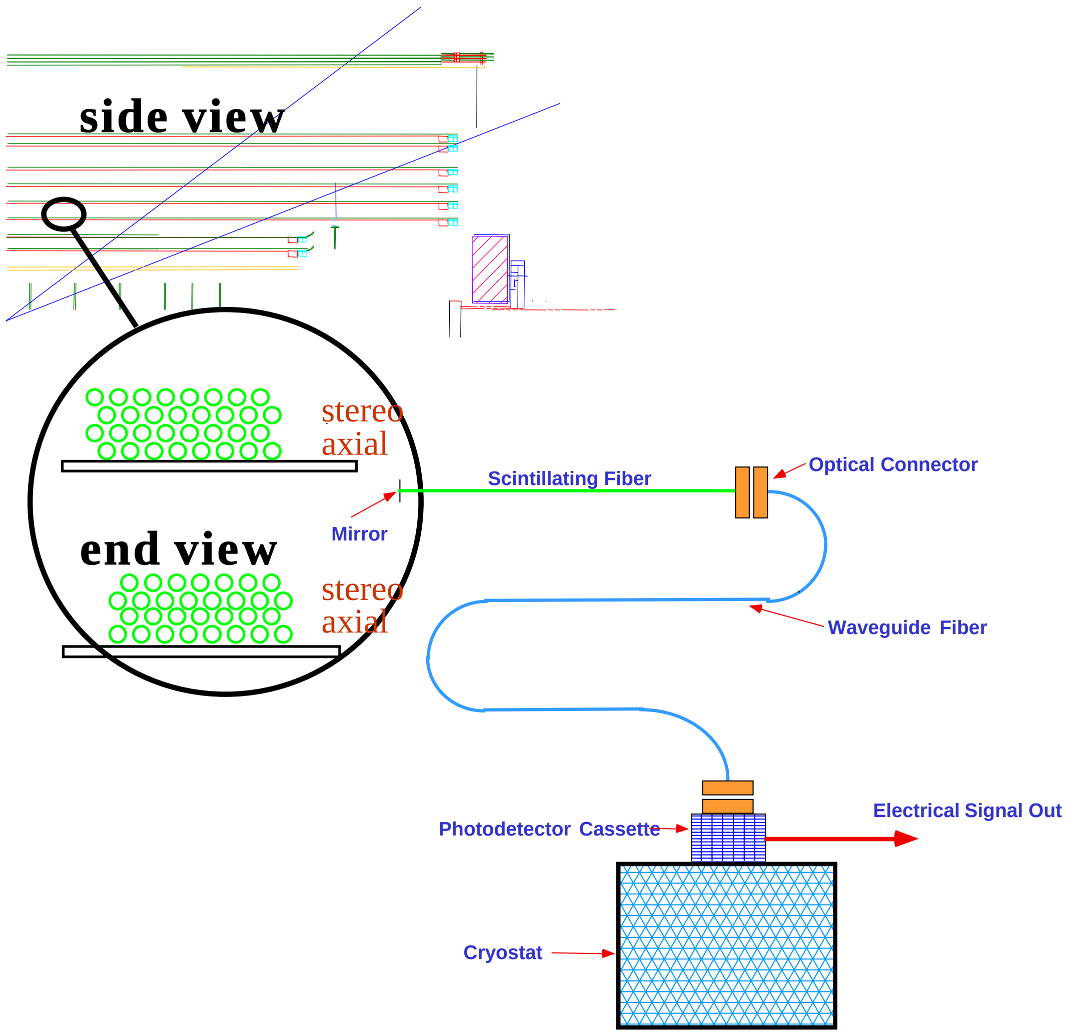
- Find tracks of particles down to Pt of 1.5 GeV
- Tag categories (incl. CPS info): track, isolated track, electron, ...



Trigger response for Z$\longrightarrow$ ee with 4 min.bias



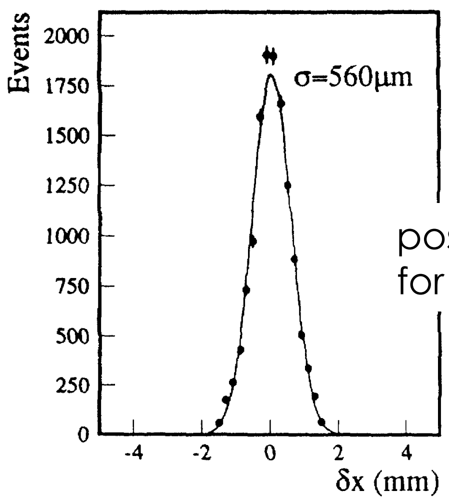
FIBER TRACKER



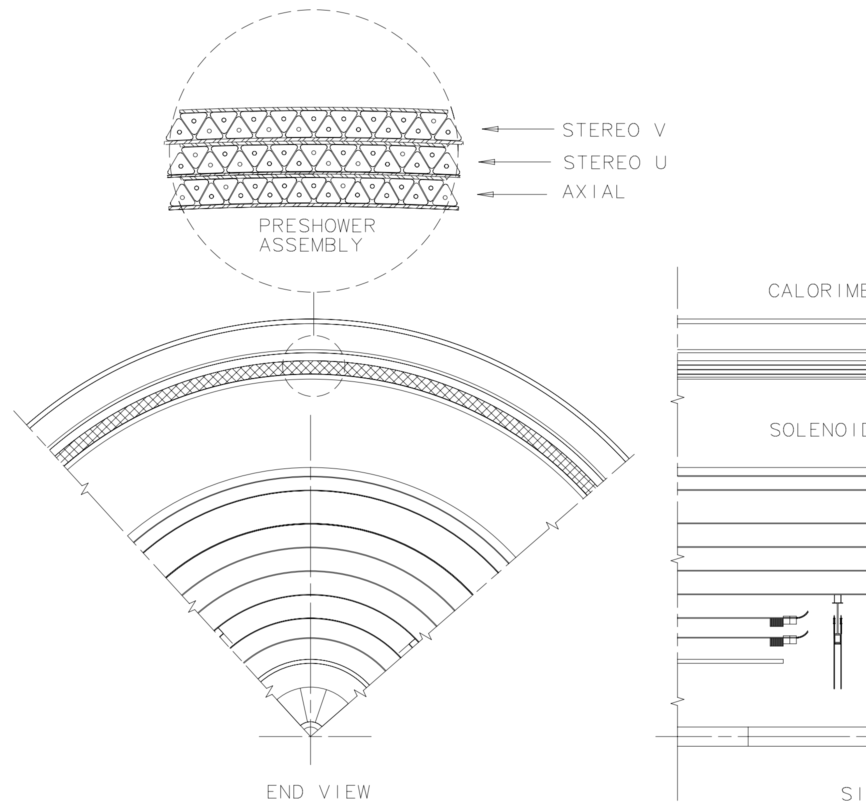
- **General**
  - Integral part of the Trigger
- **Barrels**
  - 8 carbon fiber barrels
  - 20<r<50cm
  - full coverage to η = 1.7
- **Scintillation Fibers**
  - 830mm Ø, multiclad
  - 2.6m active length
  - 10m clear waveguide to photodetector
  - rad hard (100 krad) (10yr @ 20cm @10^{32})
- **Fiber Ribbons**
  - 8 axial doublets
  - 8 stereo doublets (2° pitch)
- **Readout**
  - 77,000 channels
  - VLPC readout
  - run at low temp (9 K)
  - fast pickoff for trigger
  - SVXII readout

CENTRAL PRESHOWER

- **Specifications**
  - Partakes of the Trigger system
  - $2X_0$ preradiator (solenoid + lead) & triangular strips (axial + 20° stereo u-v) with VLPC readout
  - light yield: 20 p.e./layer for min. ionizing measured
  - Central preshower, h < 1.3
  - reduce e trig by 3-5
  - rad dose: 18 krad - ok



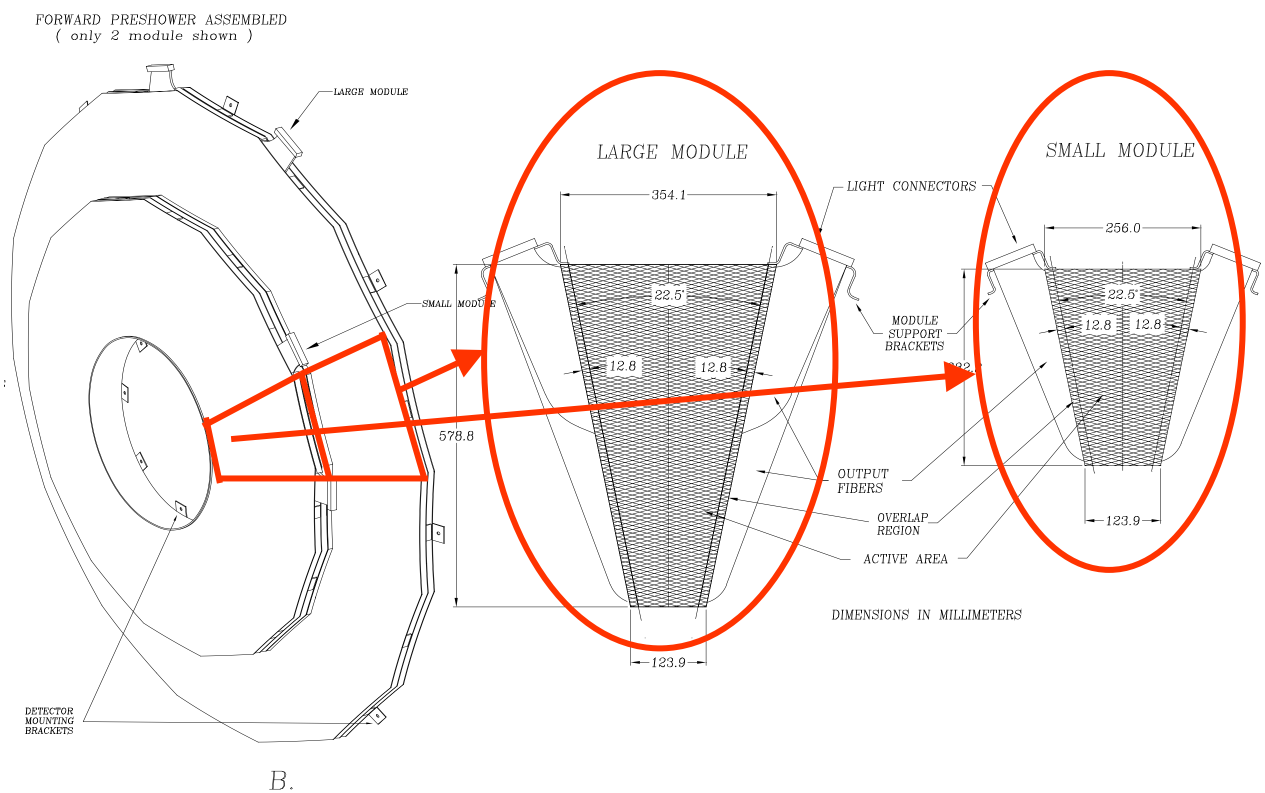
position resolution (weighted) for μ ; < 1.4 mm for 10 GeV e



7680 Axial + stereo fibers in extruded triangular strip (7 mm base width)

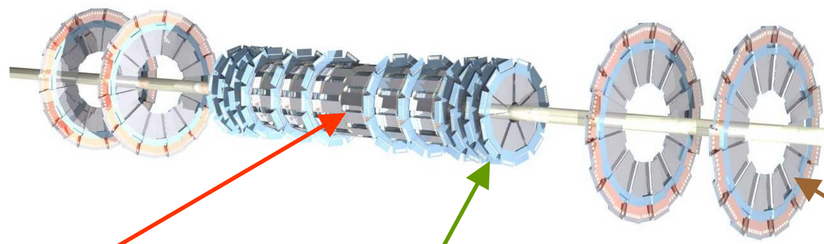
FORWARD PRESHOWER

- Specifications
  - provides trigger information in 1.4 < η < 2.5
  - uses same technology as central preshower (5mm strip base)
  - provides factor 2-4 rejection for electron trigger



2 x 8k ch, 2 sets of u-v strips with lead in between

THE SILICON MICROSTRIP TRACKER



Barrel

Four concentric “cylinders”

Single and double sided

R_{in} = 2.6cm, R_m = 9.43cm

-12.8cm < S_{inner} < 12.8cm

-38.4cm < S_{outer} < 38.4cm

F Disks

Twelve assemblies

Double sided

R_{in} = 2.57cm, R_m = 10.49cm

-54.8cm < S_{inner} < -6.4cm

6.4cm < S_{outer} < 54.8cm

H Disks

Eight assemblies

Single sided

R_{in} = 9.5cm, R_m = 26.cm

-120cm < S_{inner} < -110cm

110cm < S_{outer} < 120cm

Pitch 50μ Resolution ~ 15 μ Impact Parameter ~ 18 μ

DØ

RESPONSE

NEW TRIGGER

The Trigger ...

… a crucial part of any detector, must be designed with extreme care.

The DØ trigger must:

- reduce dead time to a minimum
- be extremely flexible
- recognize interesting signatures
- select one of ~10^6 events
- have high efficiency and high rejection

These requirements can be achieved only by a good marriage between:

- the realities imposed by the state of the art of electronics

and

- the wishes and needs of the physicists

The Trigger …
a complex design effort

Physics dictates what data to keep

Hardware dictates what data we collect

which defines what algorithms are needed.

which defines what architecture is appropriated.

which defines what hardware/technology to use.

These factors constrain the protocols for moving/filtering data and introduce timing constraints

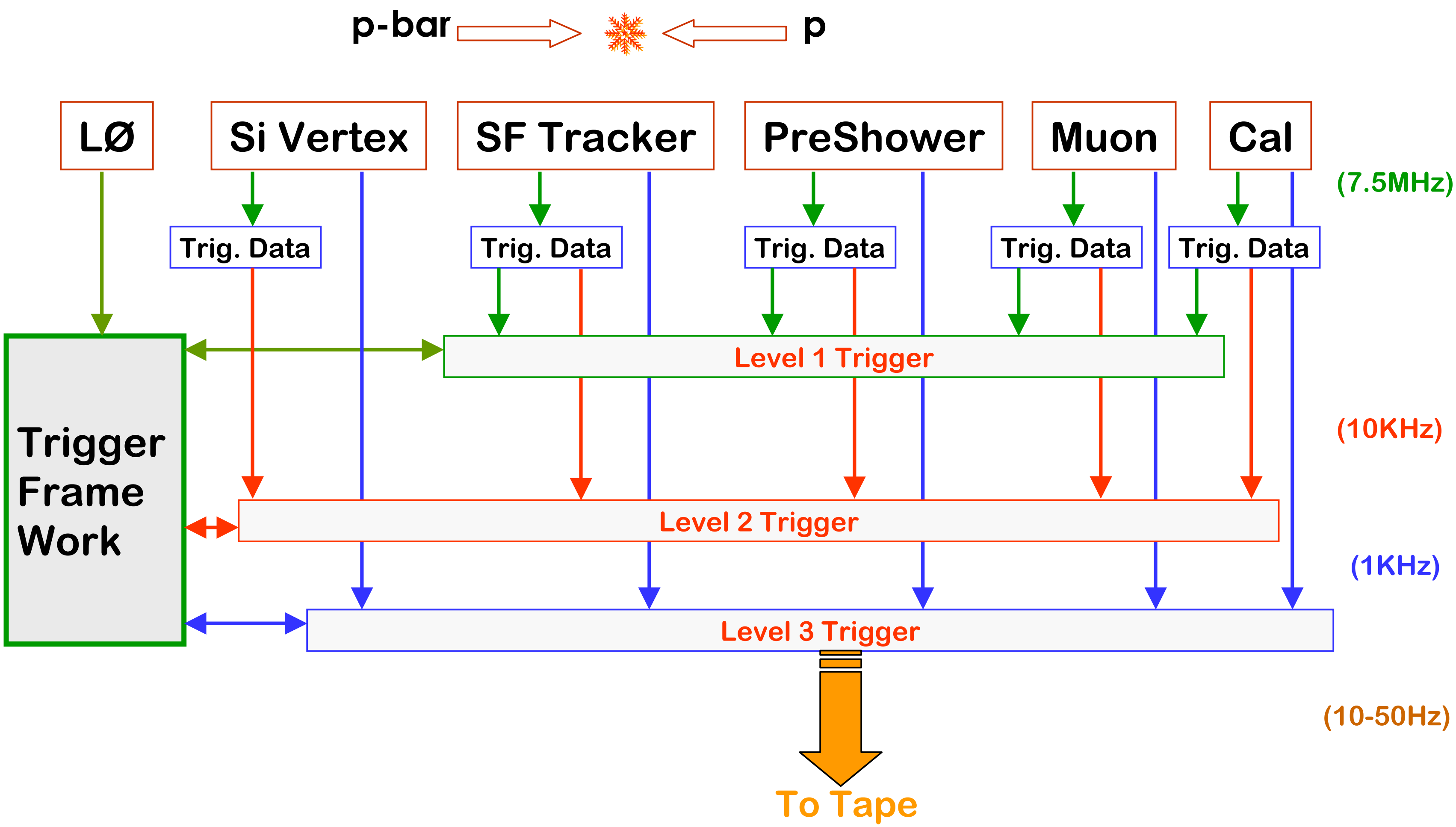
This constrains the algorithms that can be implemented.

The result is a Trigger System tailored to the type of Physics of interest

WISH LIST

Actors	Parameters		Tools
e	P_t, C, Tr., Iso		CFT, STT, PS, CAL
μ	P_t, C, Tr., Iso		CFT, μT, CAL
γ	P_t, Tr., Iso		CFT, STT, PS, CAL
Jet	ΣP_t, Tr., Iso		CFT, STT, CAL
$\not{E}$ ($\not{E}_t$)	$\not{E}$, $\Sigma\not{E}_t$, φ		CFT, STT, CAL
Vertex	Z, Δv		CFT, STT

The Trigger General Architecture

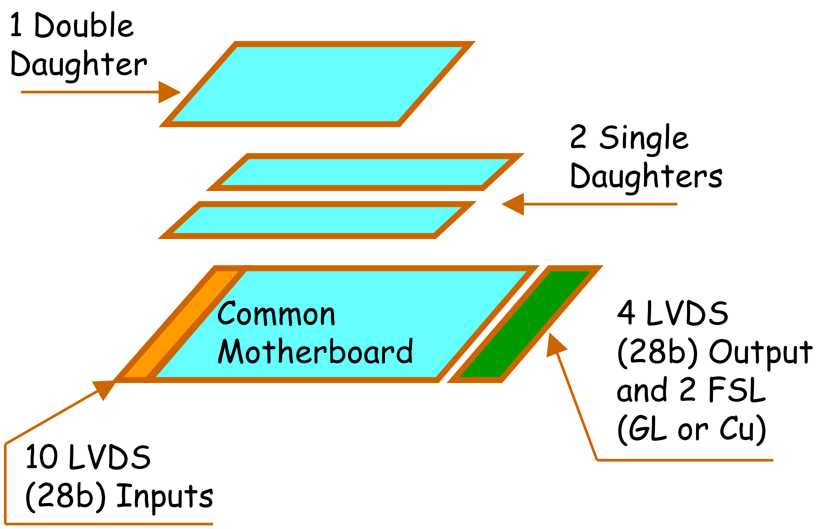


The Trigger ...

Flexibility	<>	Re programmable
Speed	<>	Fast Devices Parallel Processing
Minimum Dead Time	<>	Pipeline

Field Programmable Gate Arrays

The Trigger Hardware



- Motherboard
  - handles VME and general functions
  - holds 1 or 2 Daughterboards and a communication card
- Single Daughterboard holds 5 small/medium FPGAs
- Double Daughterboard holds one to three medium/large FPGAs

THE COMMON BLOCKS

Fig. 4. The Digital Mother Card.

Functional view of the Digital Mother Card with I/O.

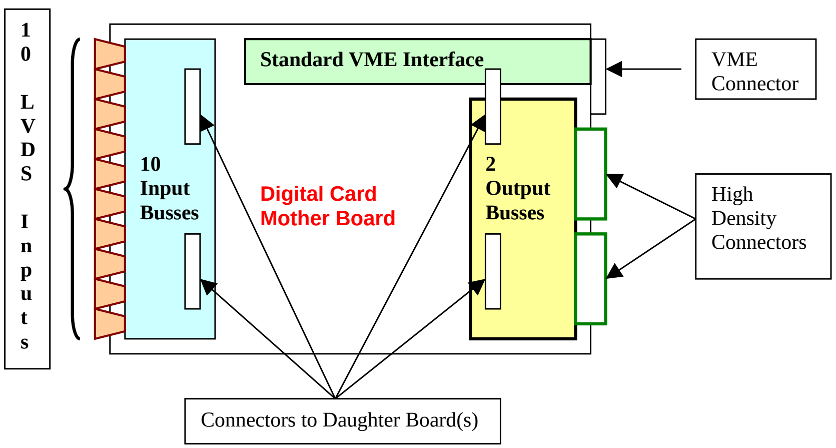
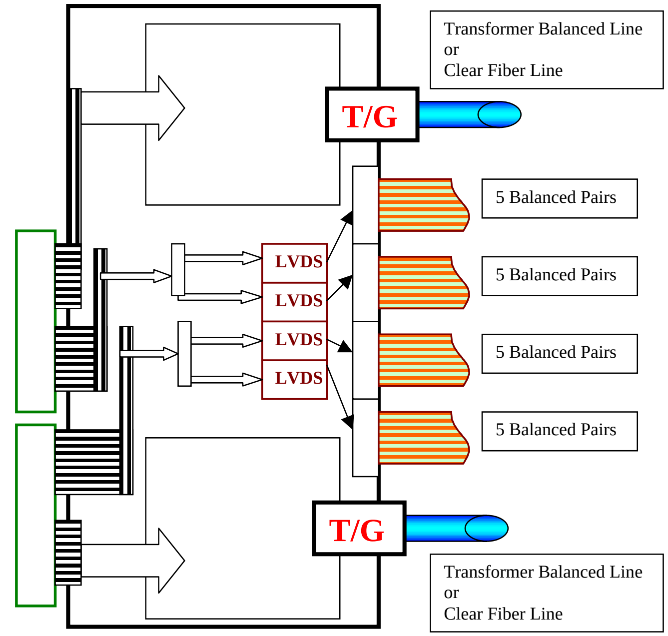


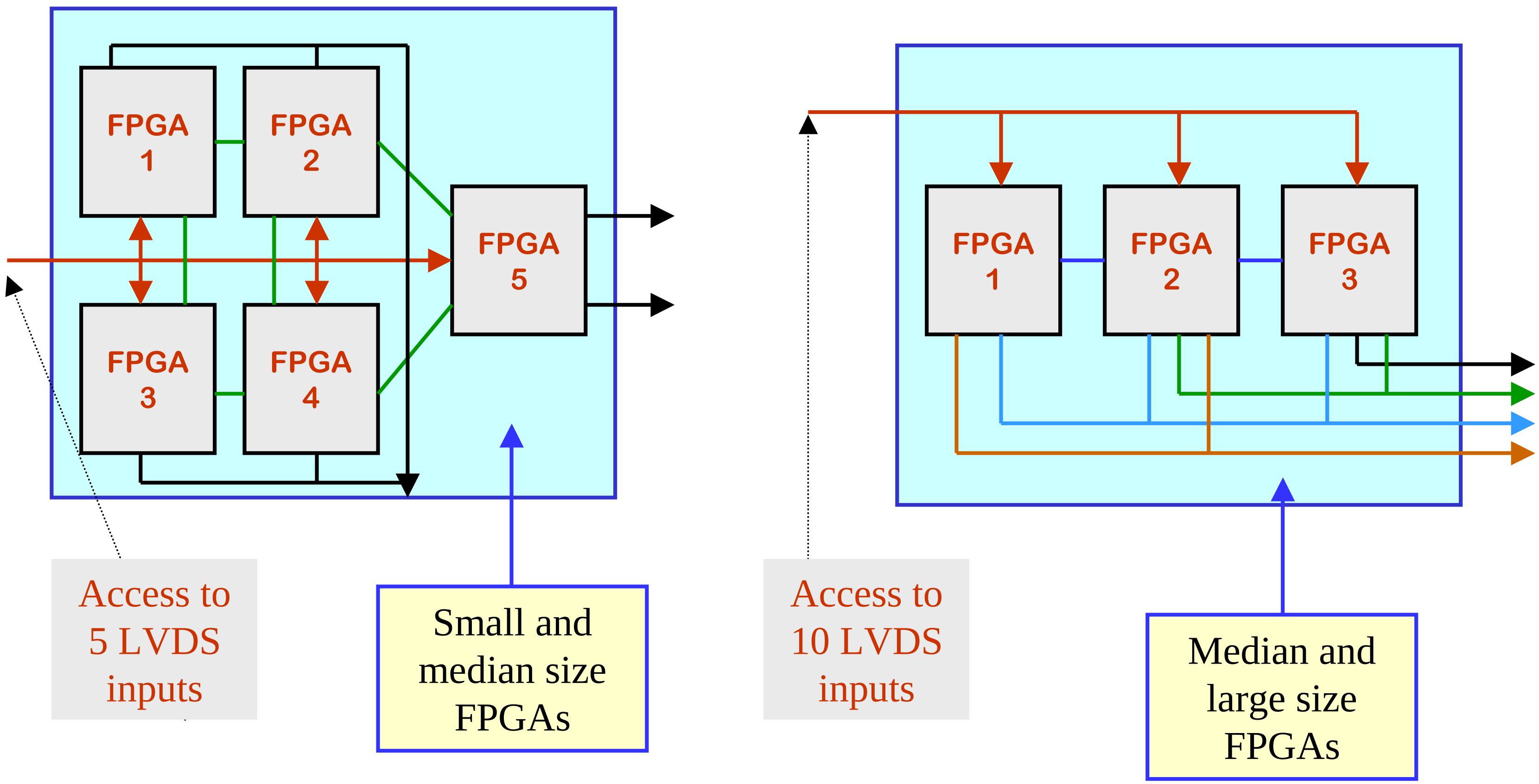
Fig. 5. The Signal Distribution Card (SDC)



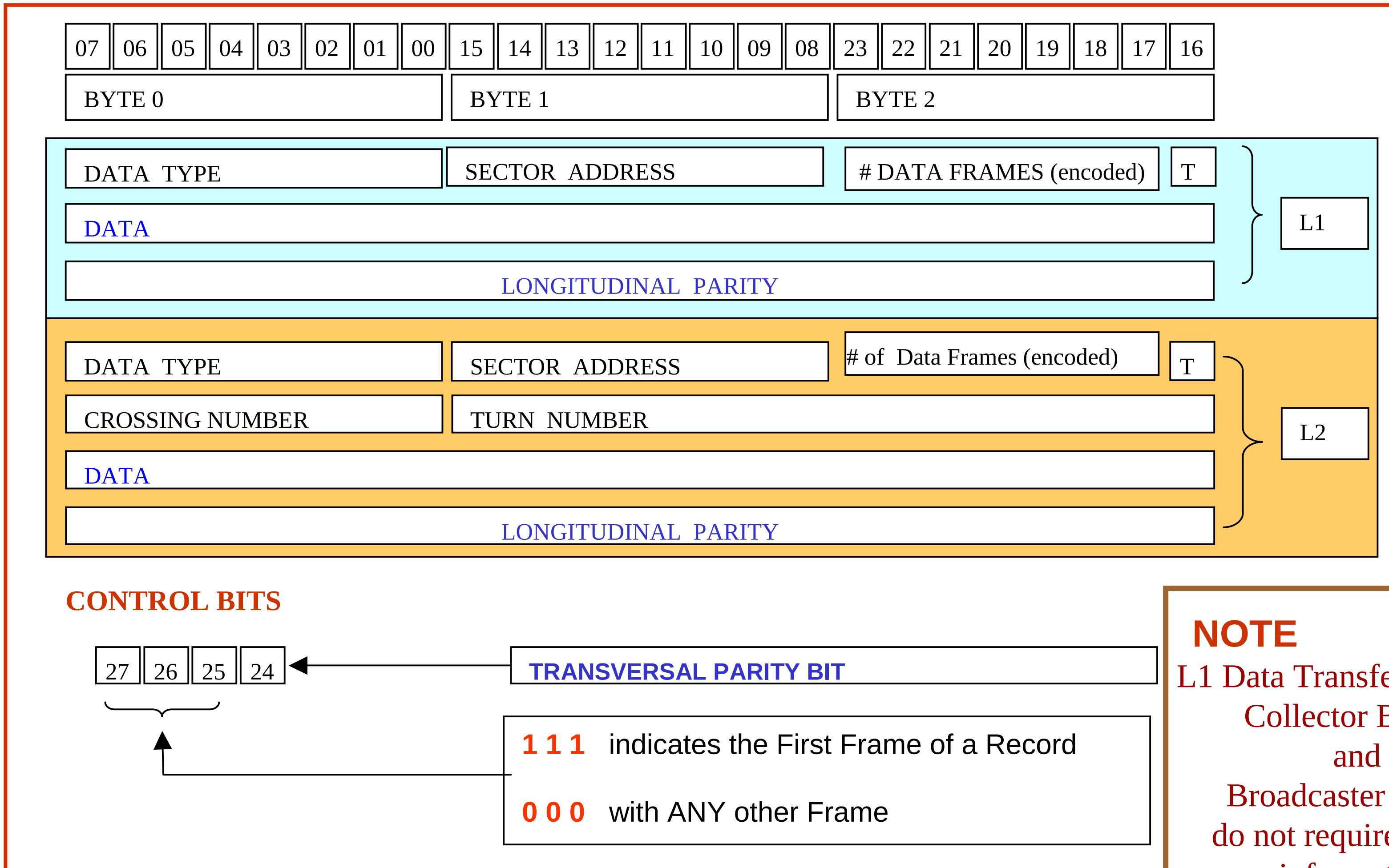
THE COMMON BLOCKS

Single Daughter Board

Double Daughter Board



Protocol for transfer of data via LVDS Links between DFE and COL and between COL and BC



NOTE

L1 Data Transfers between Collector Boards and Broadcaster Boards do not require Header information

Protocol for transfer of data via G Links

Control Bits (19 18 17 16)	Second Byte (15 14 13 12 11 10 09 08)		First Byte (07 06 05 04 03 02 01 00)		
0 0 0 1	Header Length		# of Objects		ALL G LINK (HEADER)
0 1 0 0	H Format	Obj. Format	Object Length		ALL G LINK (HEADER)
0 1 0 0	Bunch #		Data Type		ALL G LINK (HEADER)
0 1 0 0	Rotation #		Rotation #		ALL G LINK (HEADER)
0 1 0 0	Algorithm minV		Algorithm MaxV		ALL G LINK (HEADER)
0 1 0 0	Status Bits		Proc. Bits		ALL G LINK (HEADER)
0 1 0 0	SC	# Tracks Bin1	SC	# Tracks Bin 0	L2 CFT ONLY (HEADER)
0 1 0 0	SC	# Tracks Bin 3	SC	# Tracks Bin 2	L2 CFT ONLY (HEADER)
0 1 0 0	Data Type		Bunch #		TRAILER
0 0 1 0	Longitudinal Parity		Longitudinal Parity		TRAILER

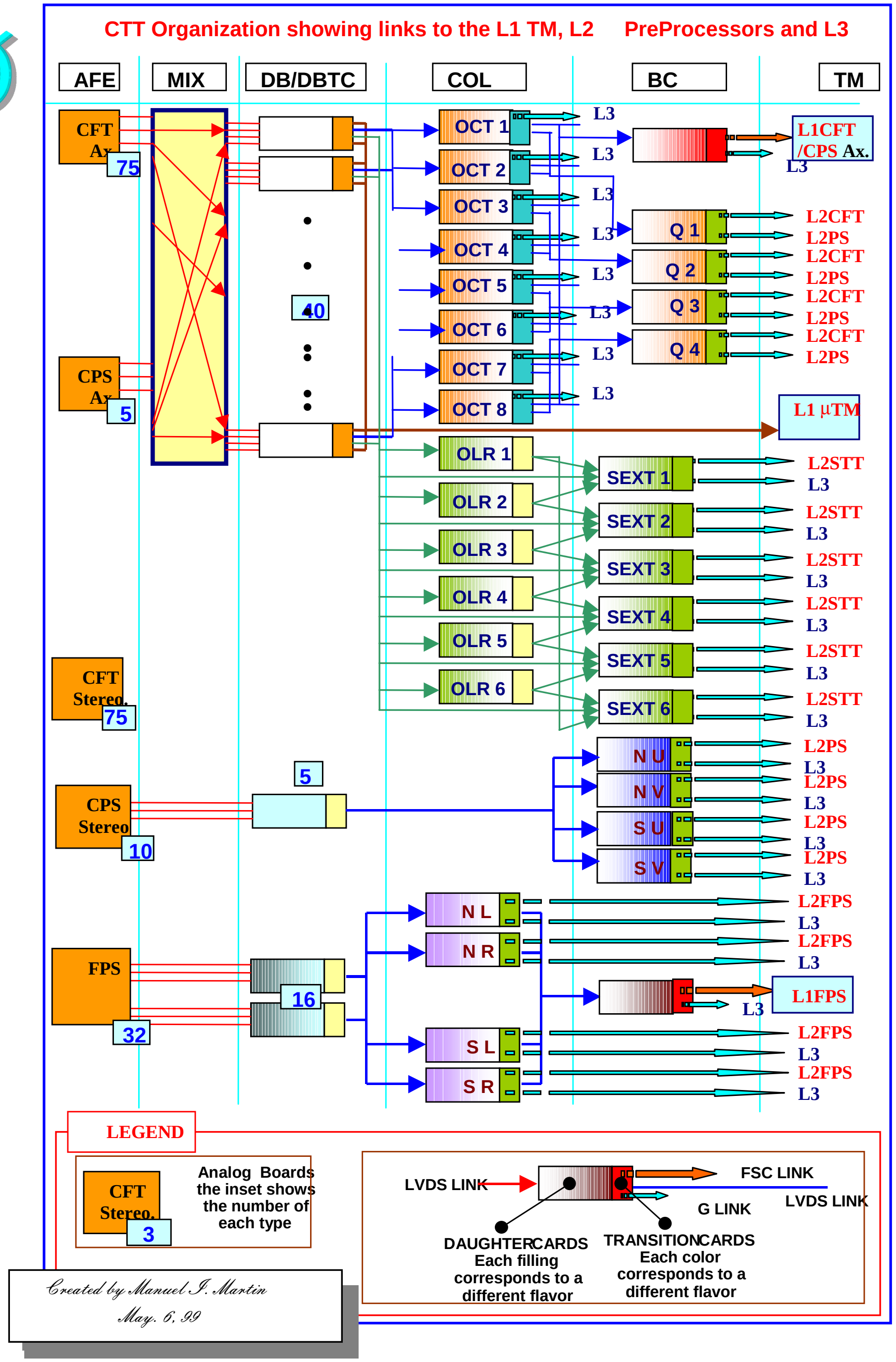


Diagram of the CTT System.

For a better view go to Manuel's Web pages at

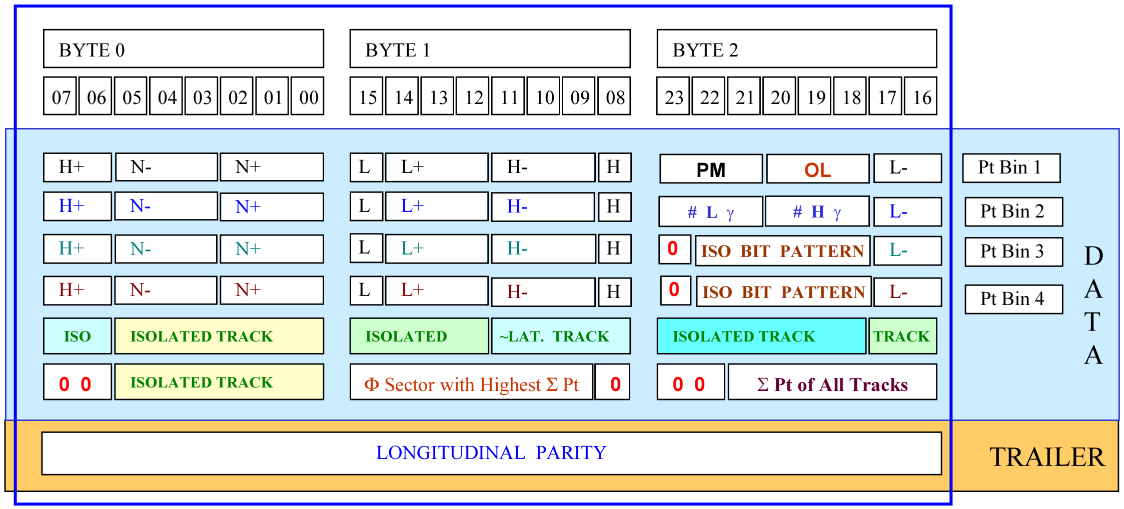
http://D0server1.fnal.gov/users/manuel/protocols/diagram.doc

GLOSARY

AFE	Analog Front End Board
MIX	Mixing Box
DB	Digital Board
DBTC	DB Transition Card
COL	Collector Board
BC	BroadCaster Board
TM	Trigger Manager
OCT	COL serving an Octant
Qx	BC serving Quadrant x
OLR	COL serving the Overlapping Regions of the SI match
SEXT	BC covering a Sextant
N/Sx	board serving the North/South side
xU/V	Refers to the U V orientation of the PS strips

ration)

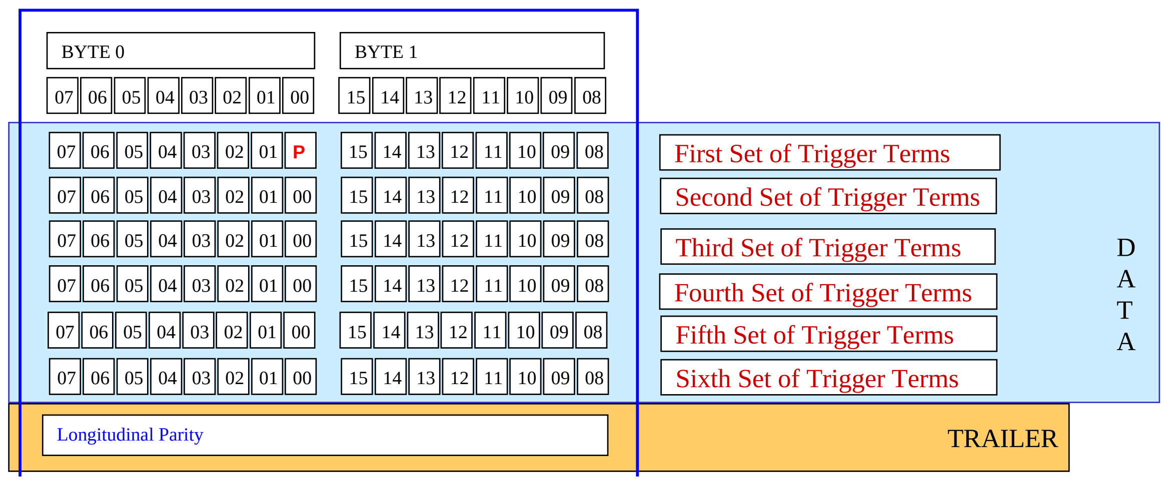
L1 CFT AND CPS TRIGGER'S DATA



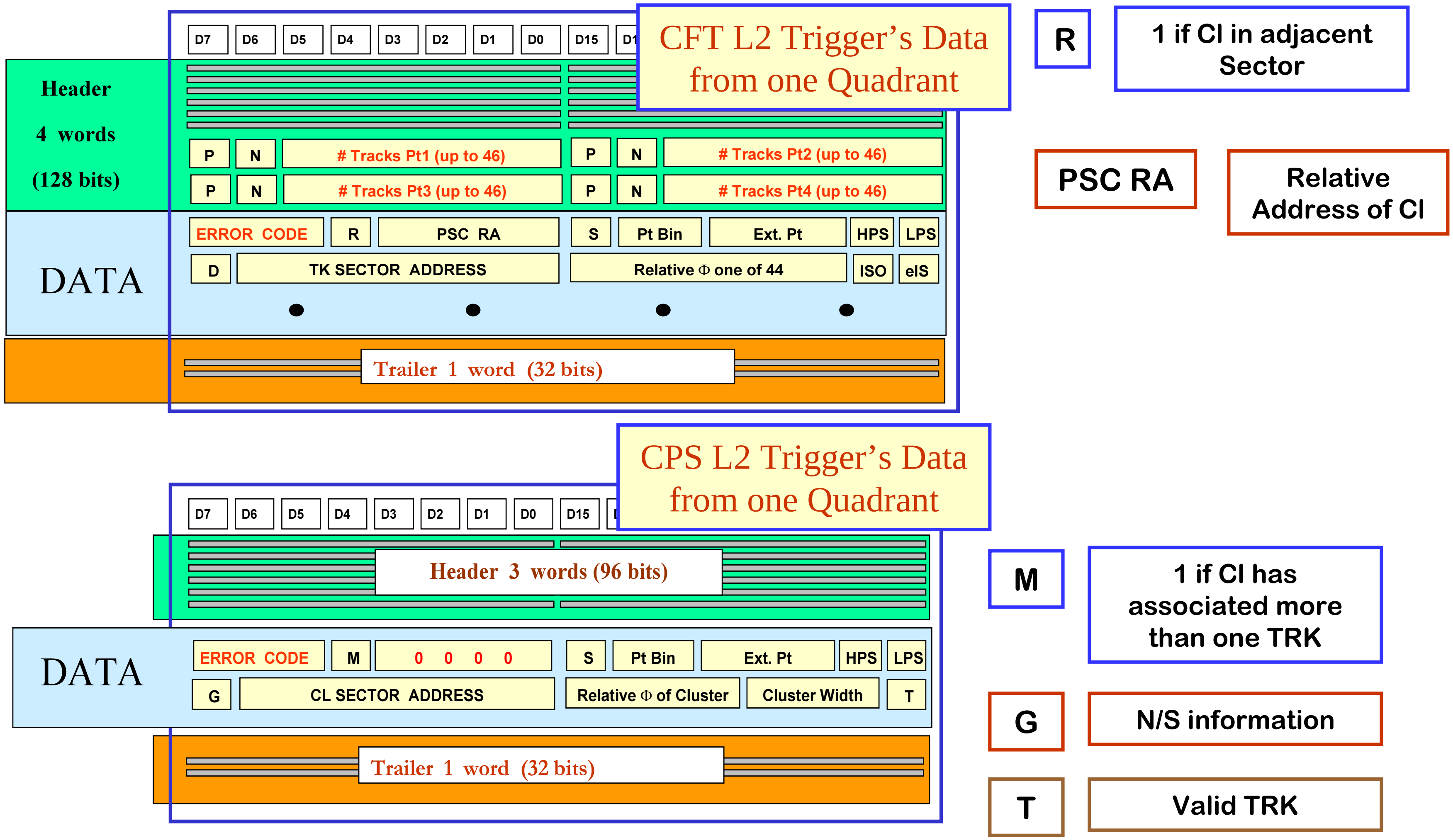
Information provided to the CTT (Central Trigger Term generator)

96 Possible Trigger Terms are generated in the CTT.

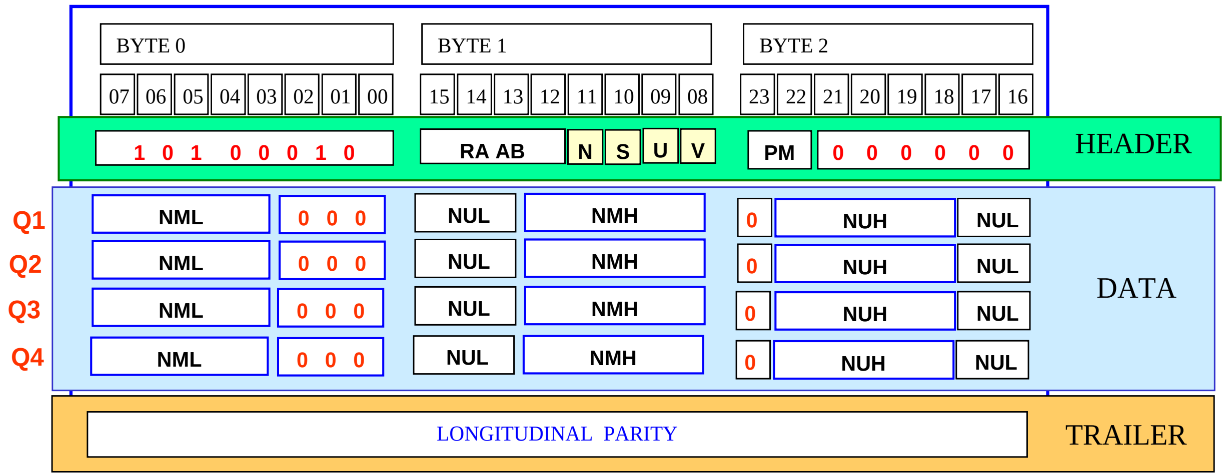
32 of these are selected to go to the Trigger Framework



L2 CFT AND CPS TRIGGER'S DATA



FPS L1 AND L2 TRIGGER'S DATA



NXY Number of

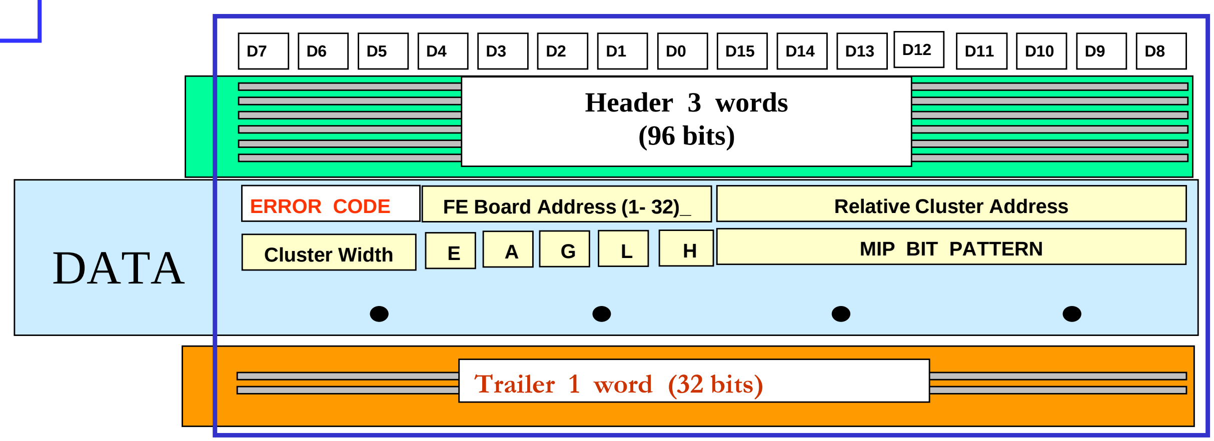
L Low energy Cluster

H High energy Cluster

M Matched with Mip Cl

U Unmatched

E	Electron candidate
A	U/V information
G	N/S information
H	Cluster Energy information
L	



L1 TRIGGER

- Number of particles identified by
  - Type … e, μ, γ
  - Pt range … 1.5GeV to 3Gev, 3Gev to 5GeV, 5 to 10 GeV, 10GeV and up
  - ϕ … Octant, Quadrant, Central, North, South
  - Isolation
- Jets identified by
  - ΣPt
  - ϕ … Octant, Quadrant, Central
- $\not{E}t$ with rough ϕ identification

L2 TRIGGER

- Particles identified by
  - Type … e, μ, γ
  - Pt
  - ϕ … ~6', 4.5° , Octant, Quadrant, Central, North, South
  - η
  - Isolation
- Better Jets' identification by
  - ΣPt
  - η
  - ϕ … 4.5°, Octant, Quadrant, Central
- $\not{E}$t with finer ϕ identification
  - ΣPt
  - η
  - ϕ … 4.5°, Octant, Quadrant, Central
- Primary Vertex Position and Secondary Vertex with Impact Parameter

The Trigger Protocols

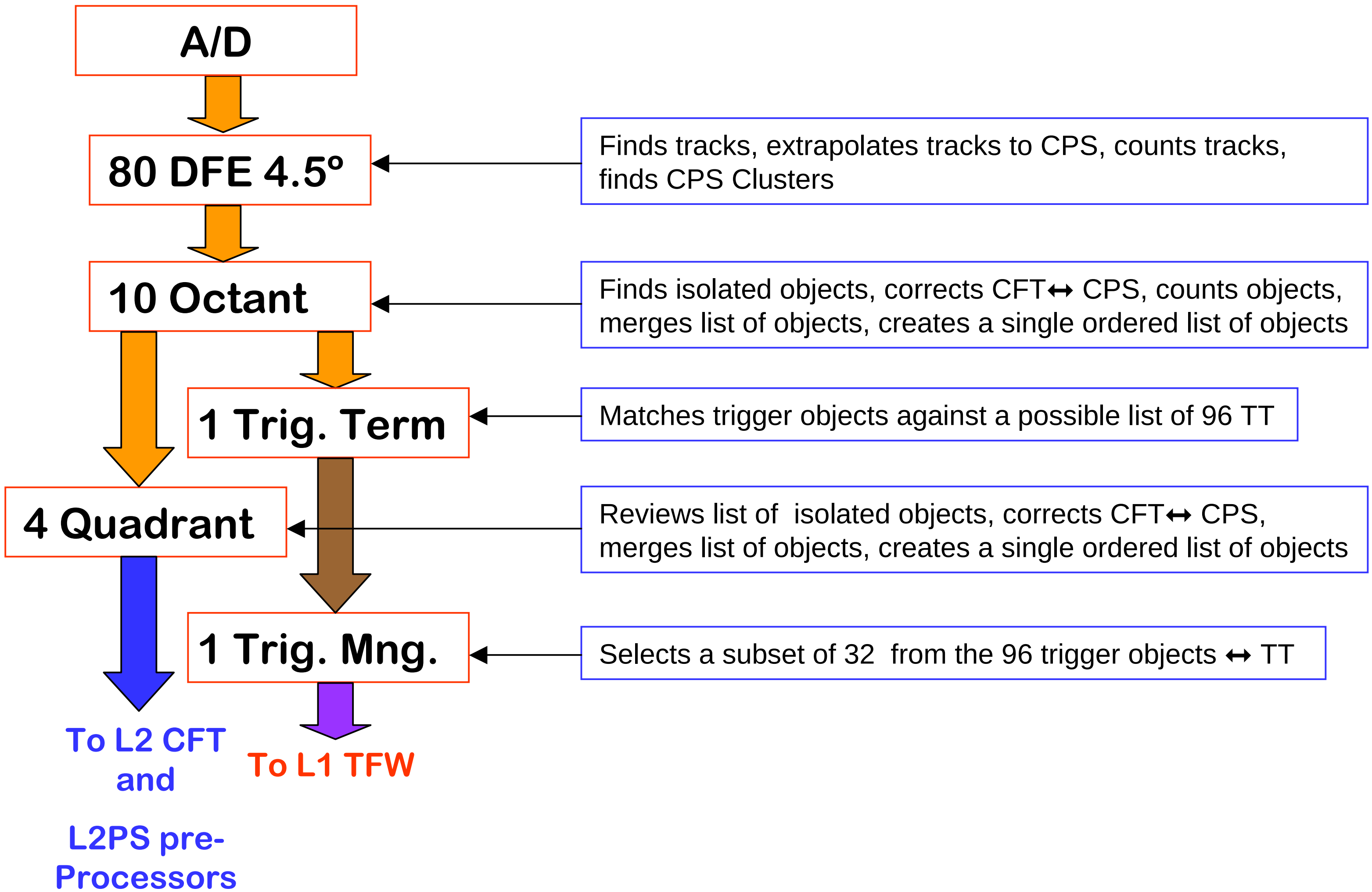
- Control data transfers between elements of the Trigger
- Assure error free transfers (max error rate tolerated 10^{-15} bit/s)**
- Matches data rates and data formats to Physics needs
- Provide the best marriage between data formats and hardware realities

Protocols used across all hardware of the DØ detector …

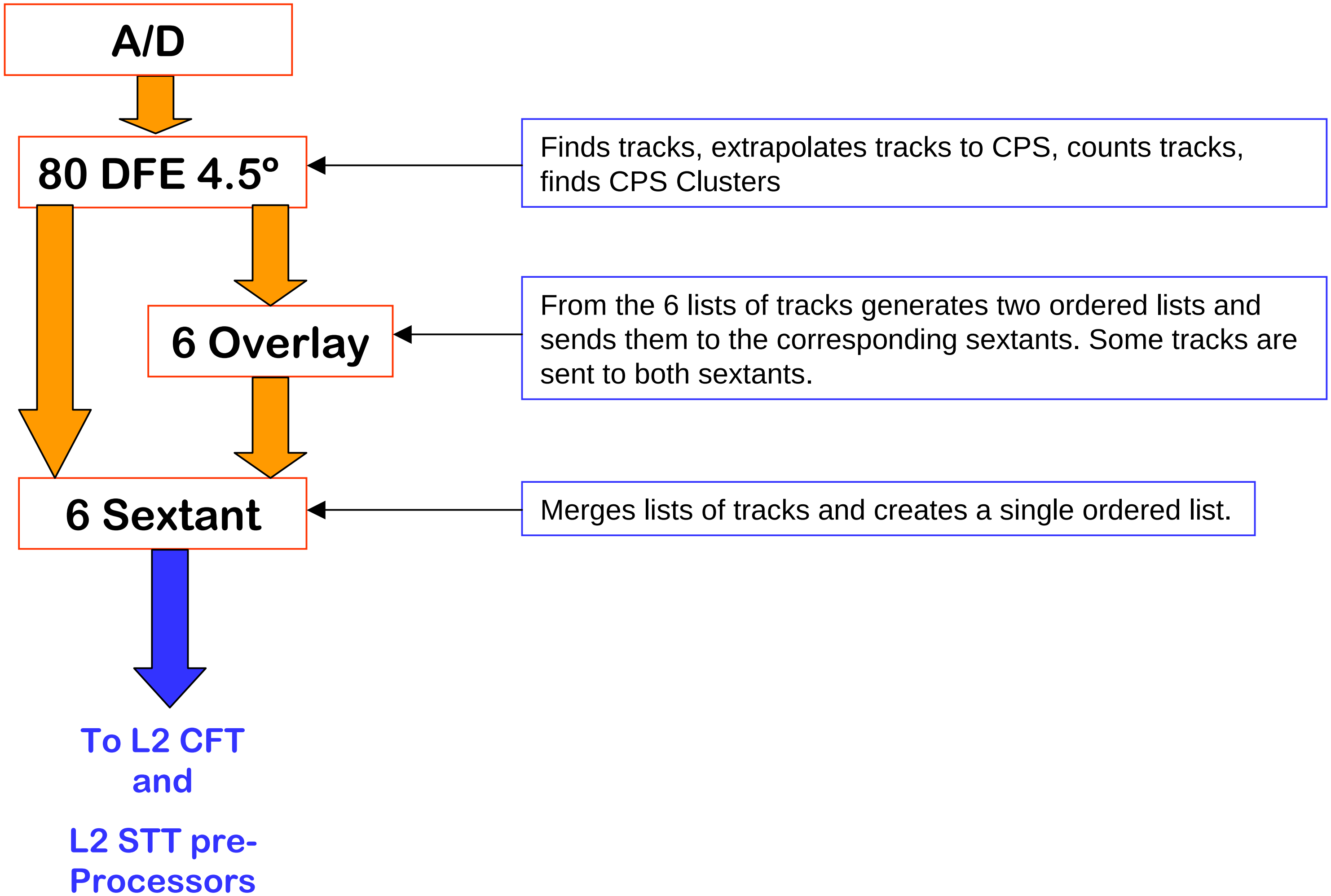
LVDS,
G Link,
FSC Link,
FPC Link

** Note.- Protocol used in the LVDS transfers reduces error rate to 10^{-24} b/s.

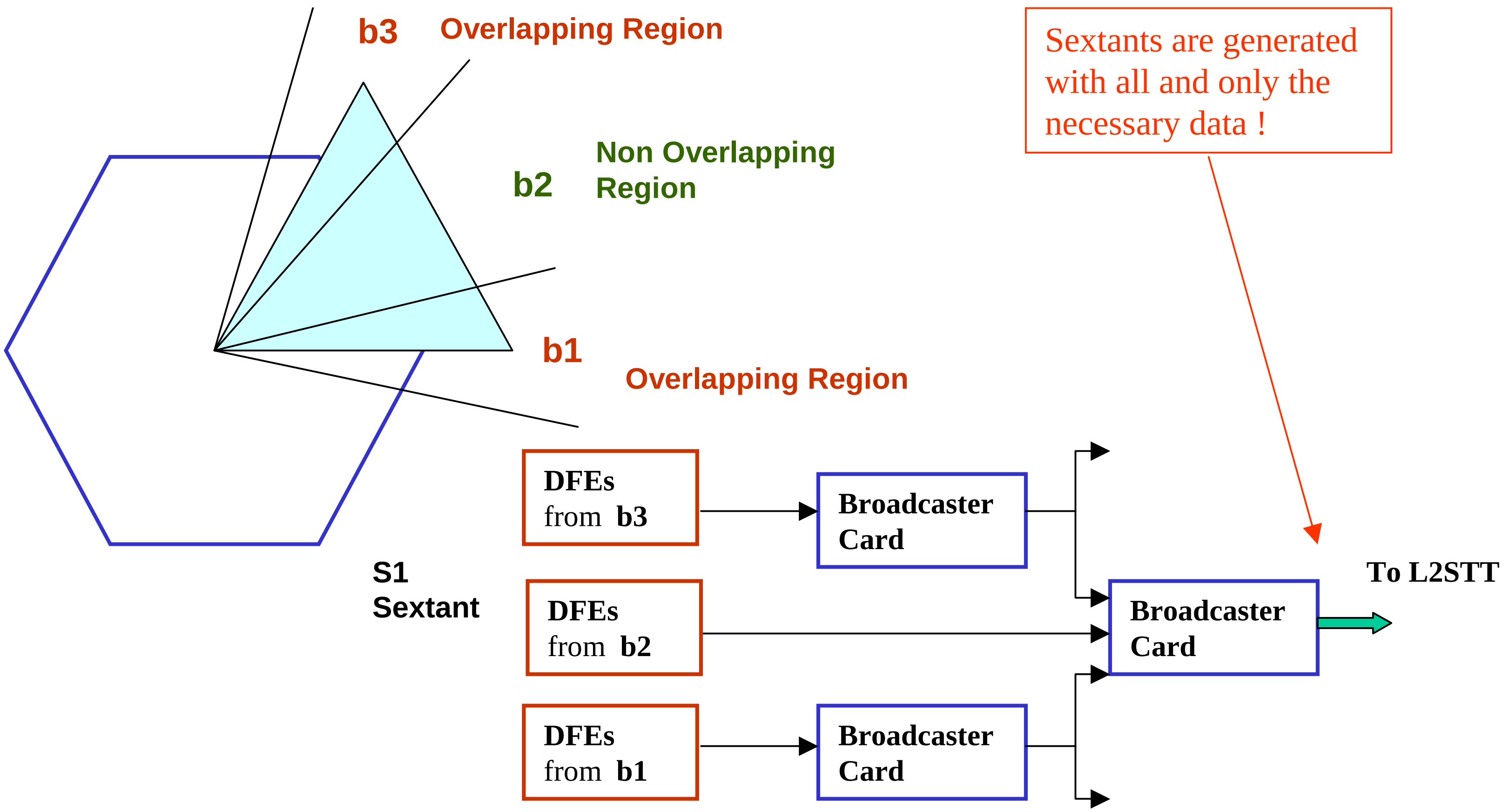
CFT and CPS Axial Trigger Architecture



CFT and Si Vertex Trigger Architecture



Organization of the STT data paths
(only one Sextant shown)



Trigger Objects

	L1					L2					
	±	Traj.	Iso	Pt		±	Traj.	Im.P.	Iso	Pt	
e	✓	✓	✓	✓	CFT, CPSA, FPS, CAL	✓	✓ ✓	✓	✓	✓ ✓	CFT, CPS, FPS, STT, CAL
μ	✓	✓		✓	CFT, MUON	✓	✓ ✓			✓ ✓	CFT, MUON
γ	na	✓	✓	✓	CFT, CPSA, FPS, CAL	na	✓ ✓		✓	✓ ✓	CFT, CPS, FPS, CAL
Jet		✓		✓	CFT		✓ ✓	✓		✓ ✓	CFT, STT, CAL
$\not{E}_t$				✓	CFT					✓ ✓	CFT, CAL

SUMMARY

RECAP

Run 1 was a success

Run 2 will be a success also with

A new Tracker

And PreShower

A central magnetic field

A upgraded m detector

Faster Calorimeter electronics

And a completely new sophisticated Trigger

Which will allow us to meet ....

OUR GOALS (CHALLENGES)

–SUSY or other physics beyond the SM

–Higgs boson

Without forgetting bread and water Physics

- Precision measurements of m_W, $m_t \Rightarrow m_H$ (indirect)
- CP violation in B decays
- Detailed study of top quark properties
- Many new particle searches
- QCD studies at high and low Q^2
- etc. etc.

BUT ....

UPGRADE ... or DIE

After 8fb^{-1}

Si Vertex Detector will require overhaul

The photon efficiency of the two inner scintillation fiber layers will be too low

DØ needs to prepare now!

New, improved Si Vertex?

Substitution of inner Sci Fibers with ….?

Other ??

New ideas? … Proposals? ….

A lot of work … not enough people

A MESSAGE TO OUR EUROPEAN COLLEAGUES

Δ¬ *ωαντσ ψου*!

DØ wants you!

- **Run II offers a broad and compelling physics program, but it’s going to take a lot of work on the detector, trigger, infrastructure software, calibration . . .**
- **We need to make sure that all our collaborators are full participants in this enterprise — and we want you to be part of it !**