CDF II Detector

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Collider Physics Workshop

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References

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   金信弘, talk at 第1回コライダー物理の研究会, 10-Feb-2001

2. "The Run 2 Physics Program of the Fermilab Tevatron Collider",
   Al. Goshaw, talk presented at KEK Physics seminar, 6 July 2001

3. http://www-cdf.fnal.gov/
   - http://www-cdf.fnal.gov/upgrades/upgrades.html(Detector)
   - http://cosmo.fnal.gov/organizationalchart/derwent/cdf_accelrrator.html
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4. "The CDF II Detector Technical Design Report",
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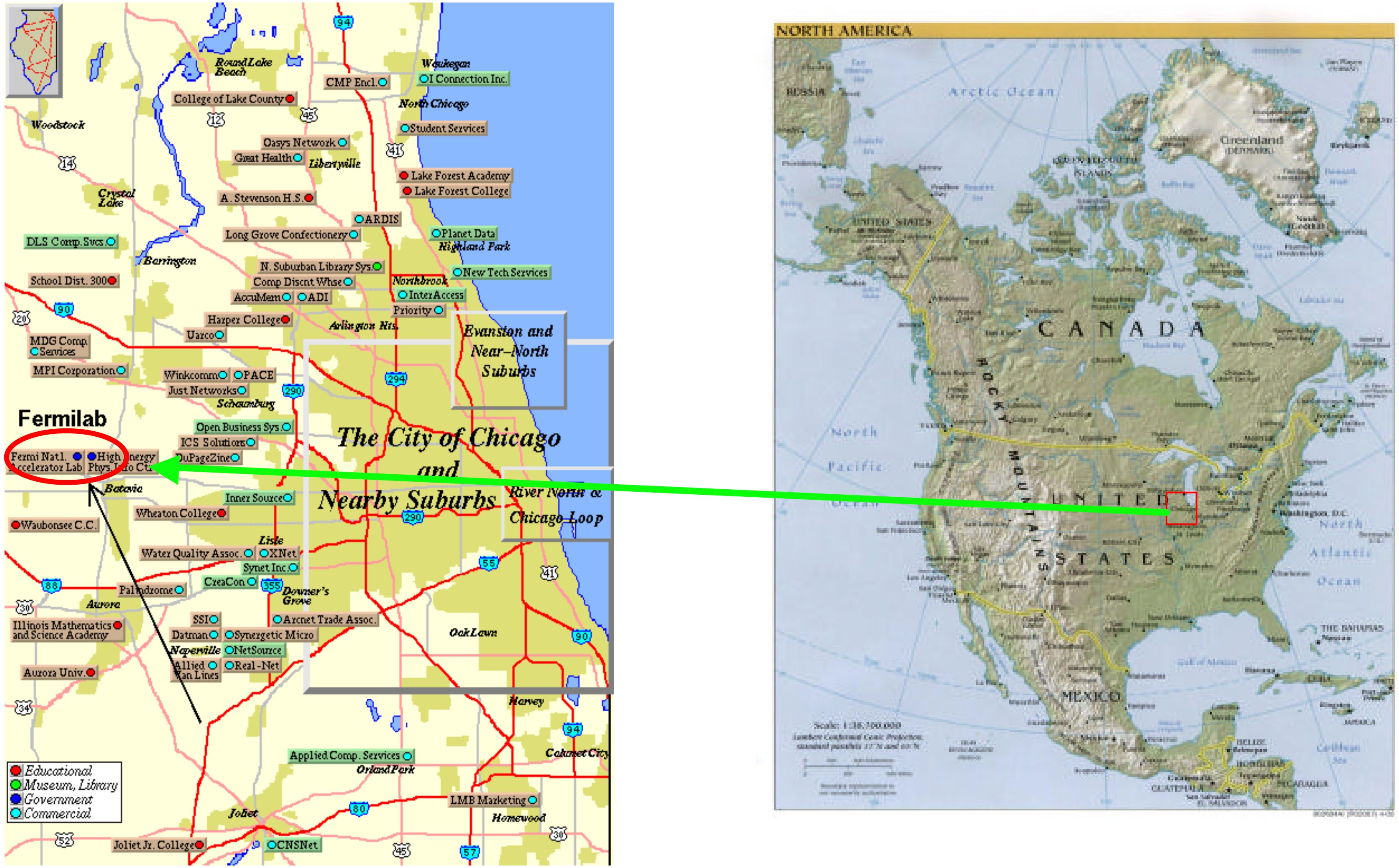
Fermilab



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Waukegan
CMP Encl.
I Connection Inc.
College of Lake County
North Chicago
Woodstock
Student Services
Oasys Network
Great Health
Libertyville
Lake Forest Academy
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A. Stevenson H.S.
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DLS Comp. Svcs.
Long Grove Confectionery
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New Tech Services
School Dist. 300
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Northbrook
AccuMem
ADI
InterAccess
Priority
Harper College
Uarco
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MDG Comp. Services
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Just Networks
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Fermilab
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The City of Chicago and Nearby Suburbs
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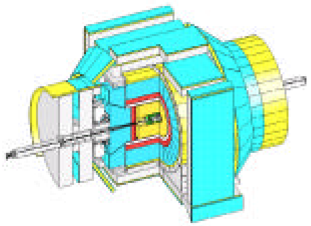
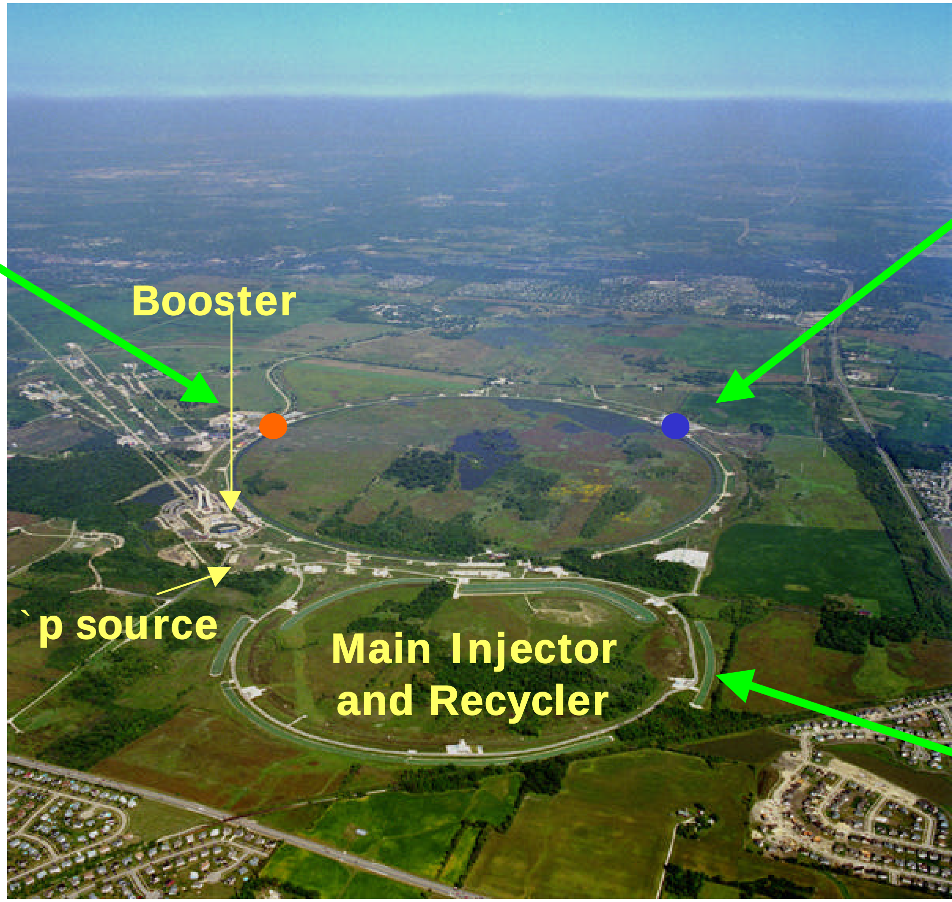
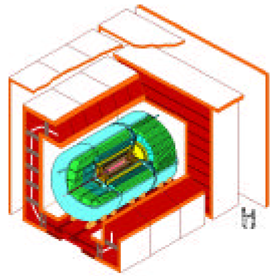
What's New at Fermilab?

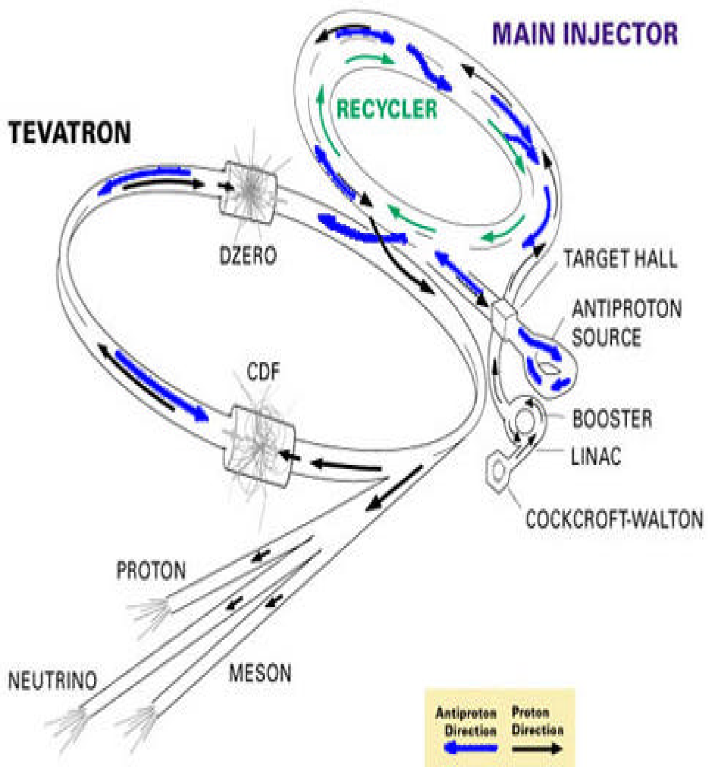




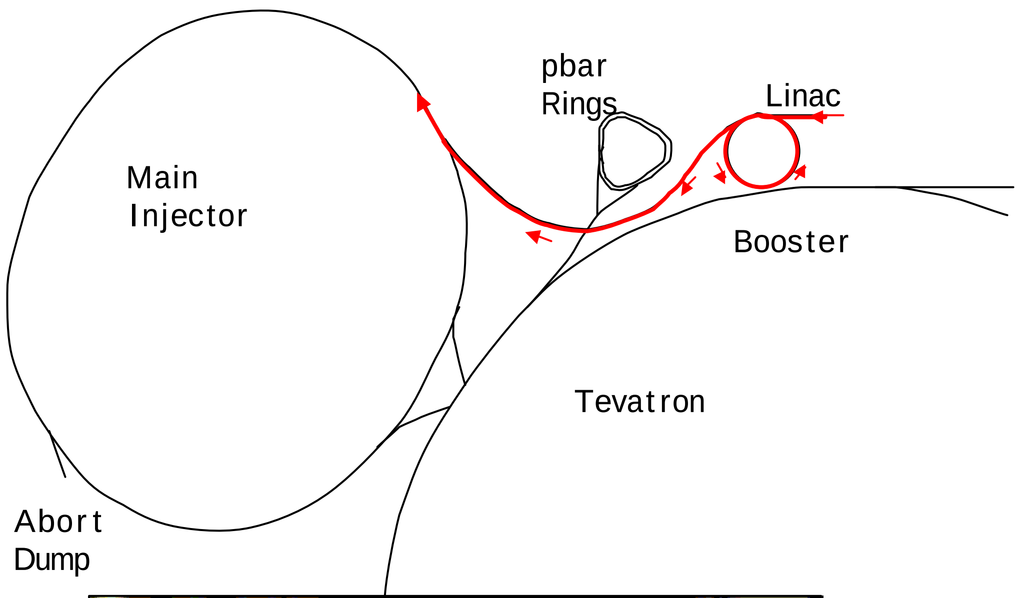


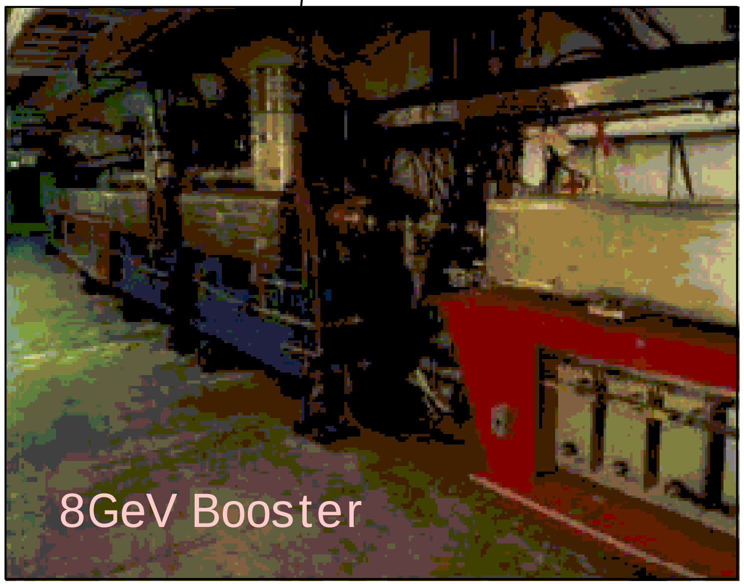
The Fermilab Accelerator Complex

- Main Injector (150 GeV proton storage ring) replaces Main Ring (the original Fermilab high energy accelerator)
- Completely revamped stochastic cooling system for pbars
- A new permanent magnet Recycler storage ring for pbars
- Higher energy collisions: 900 GeV -> 980 GeV)
- Increased number of p and pbar bunches: 6 -> 36 -> ~100

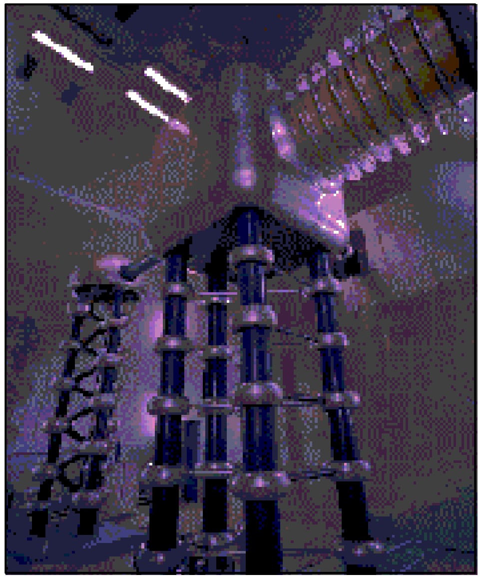


Proton Injection

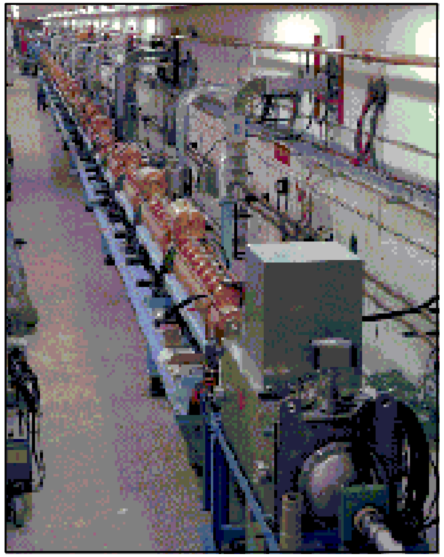




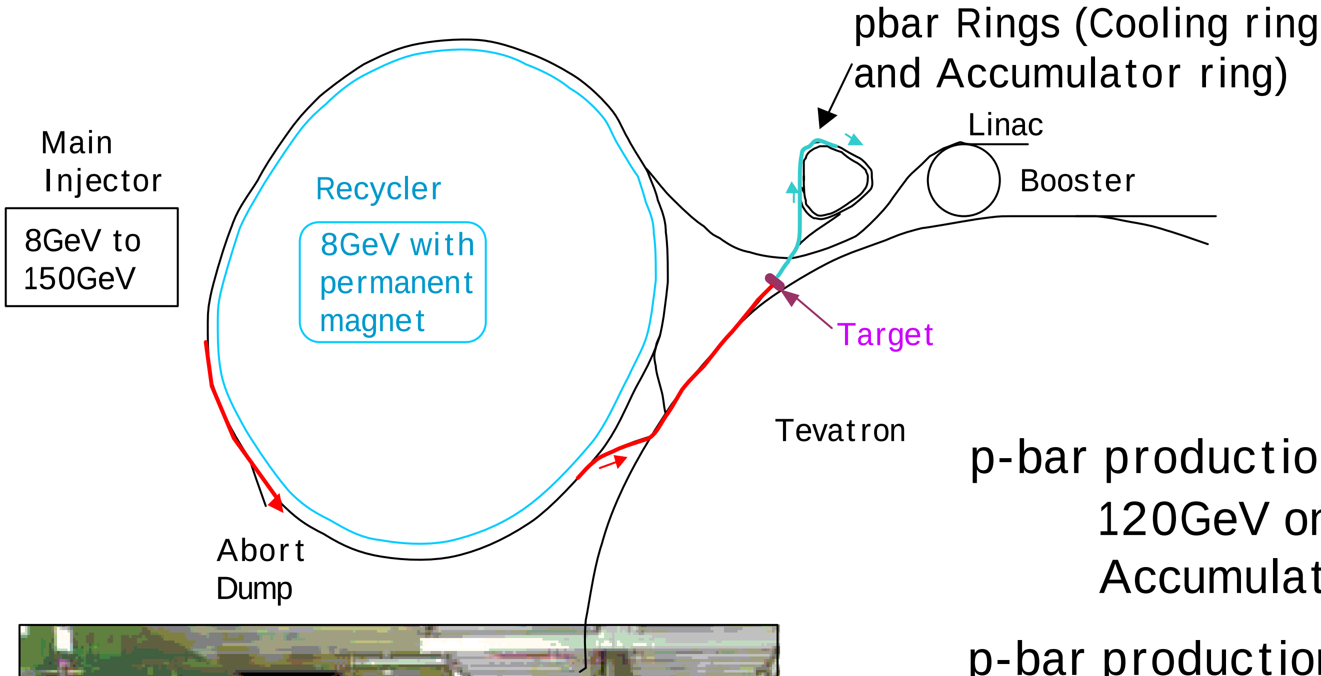
Cockroft-Walton
Preaccelerator 750KeV



400MeV Linac



P-bar accumulation



p-bar production

120GeV on target

Accumulator < 8GeV

p-bar production rate:

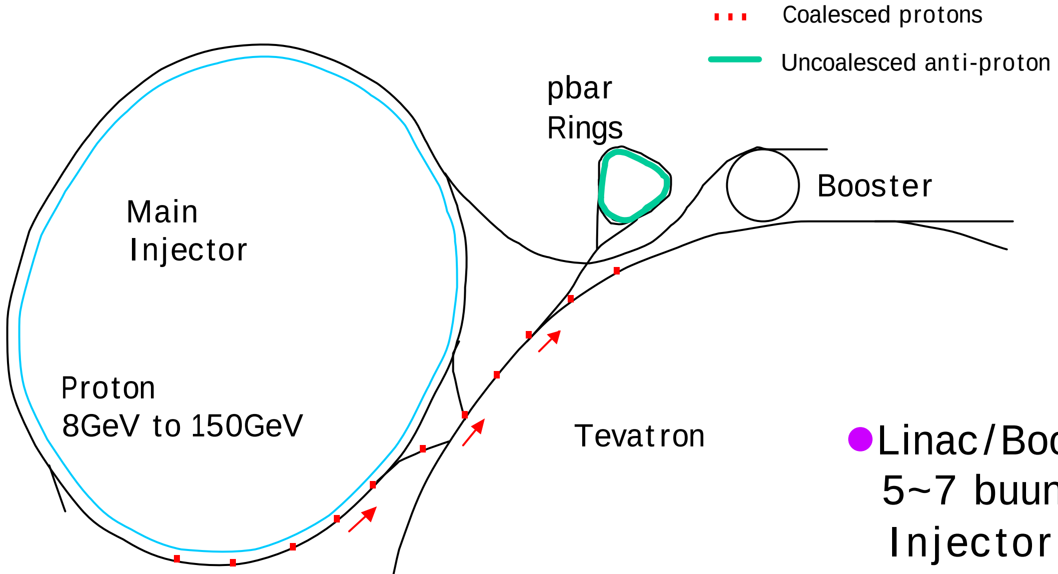
$6x10^{10}$/hr (run Ib)

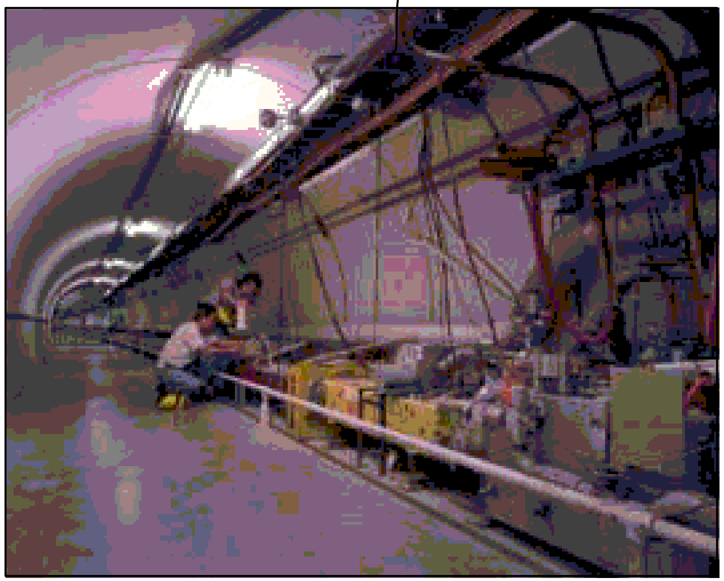
→ $1\sim2x10^{11}$/hr(run IIa)

Required: $1\sim4x10^{12}$

- More proton(x1.5) on target
- Stochastic cooling
- Recycler (use ~50% of last store)

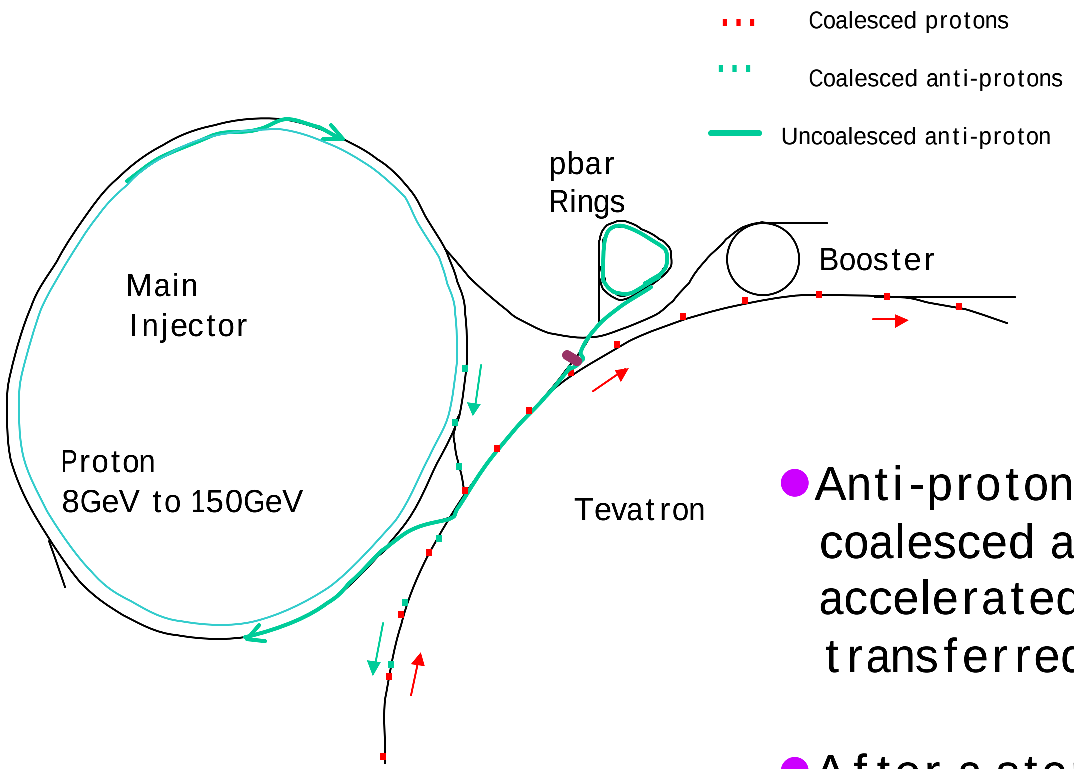
150GeV protons for Tevatron





- **Linac/Booster**
  5~7 buunches of a pulse train to Main Injector
- **Main Injector**
  Coalesce bunches into single bunch
  Accelerate to 150 GeV
- **Tevatron**
  Filled with 36 bunches

pbar to Tevatron



- Anti-protons from pbar ring are coalesced at Main Injector, accelerated to 150 GeV, then transferred to Tevatron

- After a store, remaining anti-protons are decelerated to 150 GeV, transferred to Main Injector and decelerated to 8 GeV, then stored in the recycler for next store

Tevatron parameters

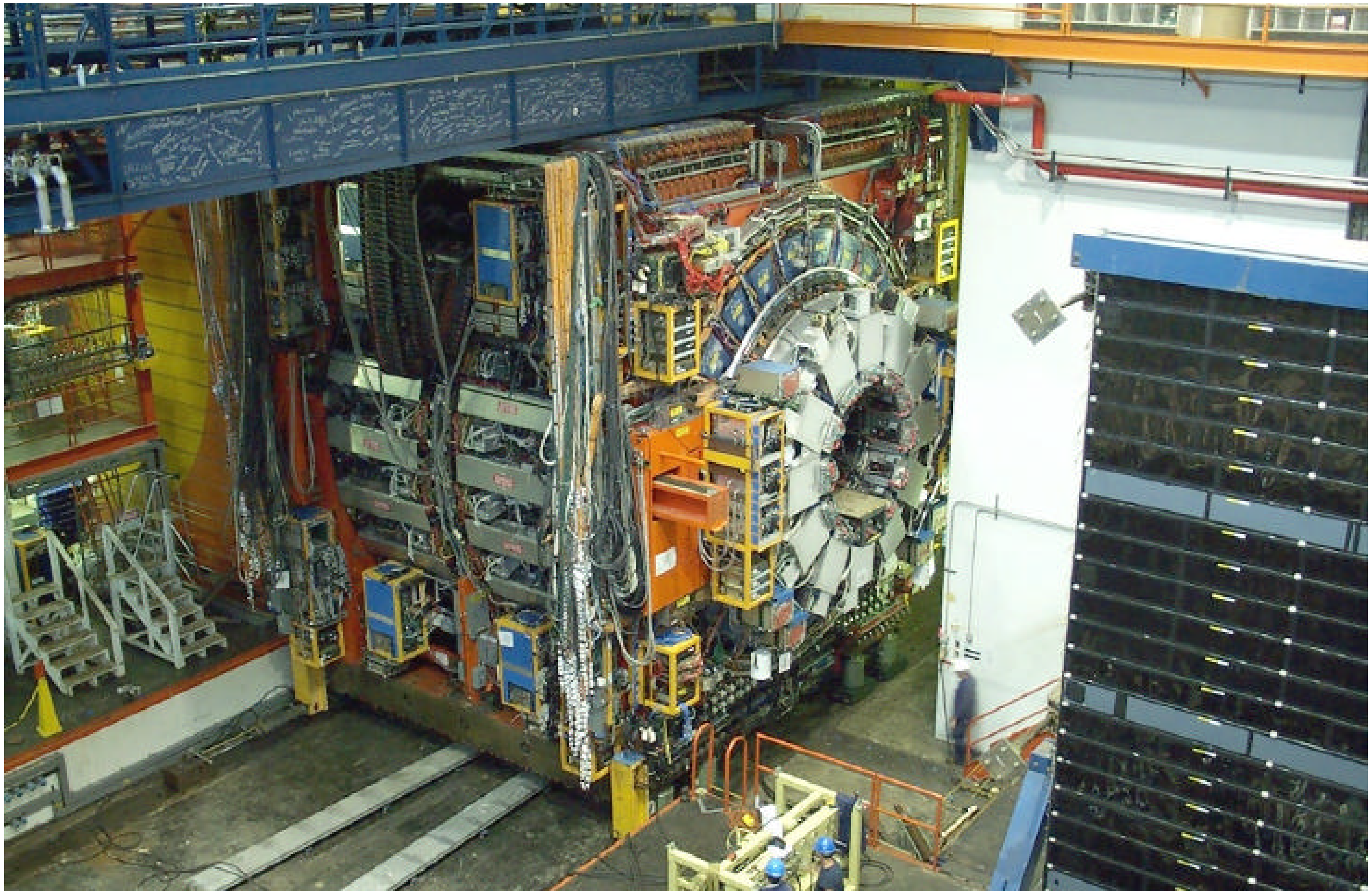
Run	Ib(1993-95)	Run IIa	Run IIa	Run IIb	unit
# of bunches	(6x6)	(36x36)	(140x103)	(140x103)	
Protons/bunch	2.3×10^{11}	2.7×10^{11}	2.7×10^{11}	2.7×10^{11}	
Anti-proton/bunch	5.5×10^{10}	3.0×10^{10}	4.0×10^{10}	1.0×10^{11}	
Total Antiprotons	3.3×10^{11}	1.1×10^{12}	4.2×10^{12}	1.1×10^{13}	
Pbar production rate	6.0×10^{10}	1.0×10^{11}	2.1×10^{11}	5.2×10^{11}	hr^{-1}
Proton emittance	23π	20π	20π	20π	mm-mrad
Antiproton emittance	13π	15π	15π	15π	mm-mrad
β^*	35	35	35	35	cm
Energy	900	1000	1000	1000	GeV
Anti-proton bunches	6	36	103	103	
Bunch length(rms)	60	37	37	37	cm
Crossing Angle	0	0	136	136	μrad
Typical Luminosity	0.16×10^{31}	0.86×10^{32}	2.1×10^{32}	5.2×10^{32}	$cm^{-2}sec^{-1}$
Integrated Luminosity	3.2	17.3	42	105	pb^{-1}/week
Bunch spacing	~3500	396	132	132	nsec
Interactions/crossing	2.5	2.3	1.9	4.8	

Tevatron status (as of 16-July-2001)

- Peak Luminosity
  - Peak L ~ $2x10^{30}$ was achieved in on June 28
  - Peak L expected by Sep. 15 ~$1x10^{31}$
  - Between June 28 and Sept. 15
    - ~ $5x10^{30}$
    - $300nb^{-1}$/store, $1500nb^{-1}$/week
    - Integrated luminosity ~$13.5pb^{-1}$
  - Peak L expected by Mid. Jan. 2002 ~$4\text{-}5x10^{31}$
  - Between Mid. Jan 2002 and June 30
    - $4.5\text{-}10pb^{-1}$/week
    - Integration Luminosity ~$190pb^{-1}$

- Shutdown schedule
  - July 8^{th}- July 16^{th} : due to helium leak casued by several quenches
  - Scheduled shutdown: Oct 8 for about 5 weeks

CDF Detector Roll-In



CDF Collaboration

North America

3 Natl. Labs
25 Universities

2 Universities

Europe

1 Research Lab
6 Universities

1 University

4 Universities

2 Research Labs

1 University

1 University

Asia

JAPAN

1 University

1 University consortium

Totals

11 countries
52 institutions
525 physicists
~ 140 students
195 theses done since 1985

Japan is a founding member of the CDF Collaboration:
Okayama U., Hiroshima U.,
KEK, Osaka City U.,
U. of Tsukuba,
and Waseda U.

Short History of CDF

- Aug. 1981 — CDF design report
- Oct. 1985 — First pp collision
- Dec. 1986 — CDF was completed
- Jan. 1987 ~ May 1987 — Test run — 0.025pb^{-1}
- Jun. 1988 ~ May 1989 — First Physics run — 4pb^{-1}

Detector upgrade

- Apr. 1992 ~ May 1993 — Run IA — 20pb^{-1}
- Dec. 1993 ~ Feb. 1996 — Run IB — 90pb^{-1}

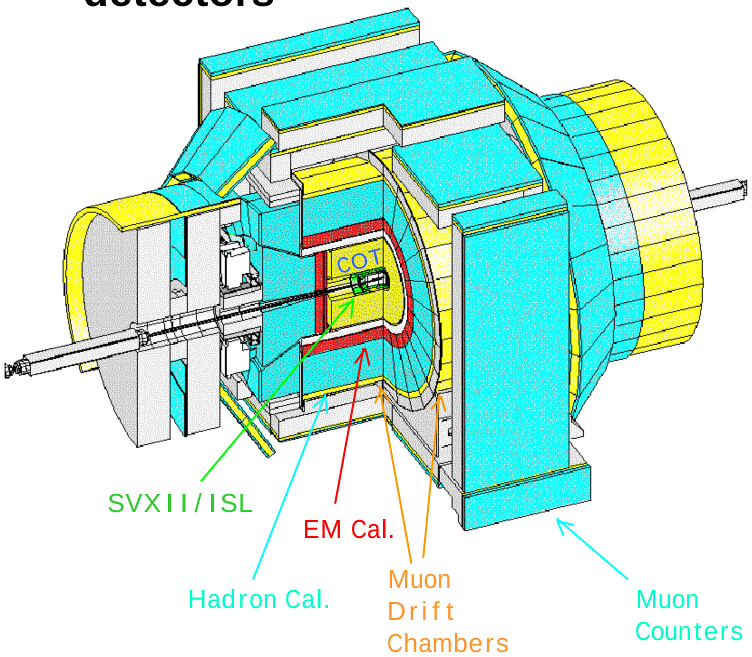
Detector/Tevatron Upgrae (1.96 TeV)

- Oct. 2000~ Aug. 2001 — Run II Commisionning
- Autum 2001 ~ — Run IIa — ~2000pb^{-1}
- 2004 ~ — Run IIb — ~15000pb^{-1}

The CDF Detector

RETAINED FROM CDF RUN I

- Solenoidal magnet (1.4T)
- Central and wall calorimeters
- Central and extension muon detectors



NEW FOR CDF RUN II

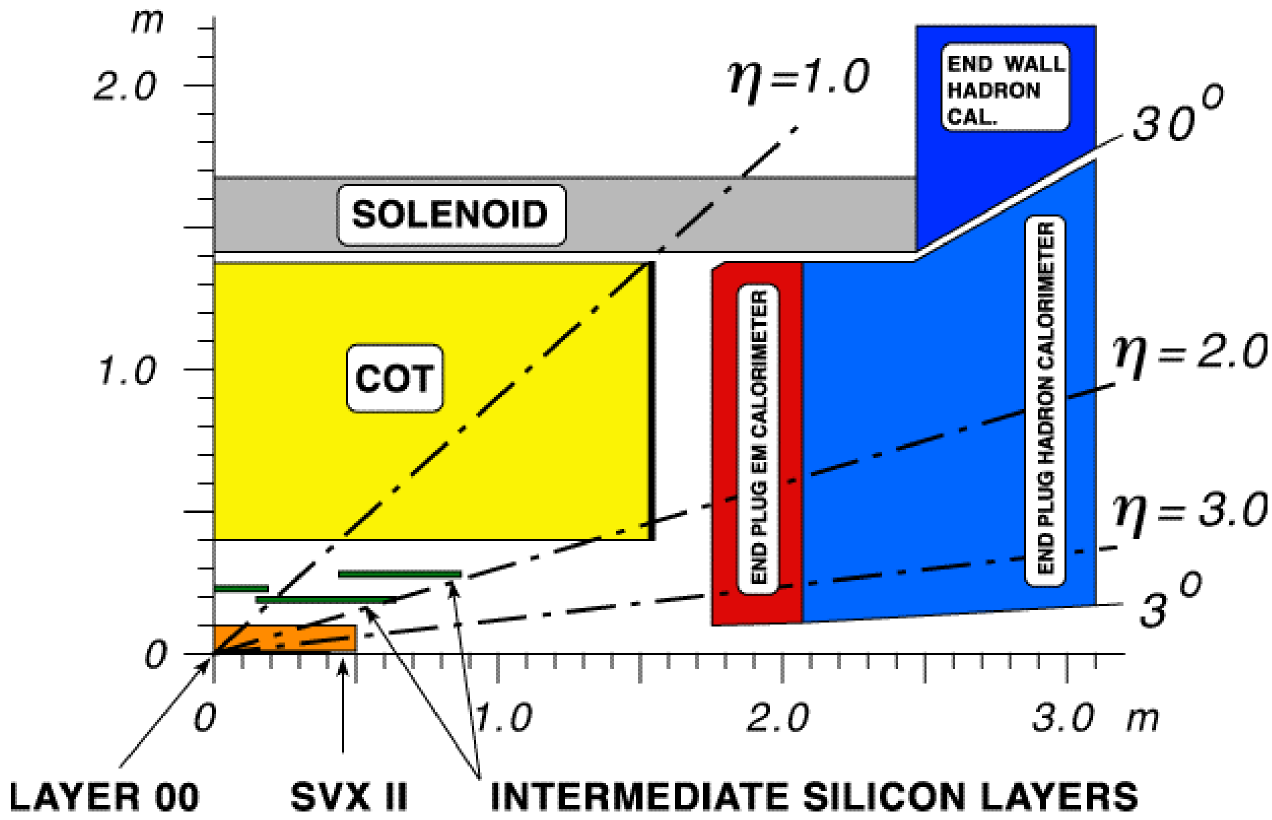
Faster detector(132ns)
Better performance

- Tracking system
  - Silicon vertex detector (SVXII)
  - Intermediate silicon layers (ISL)
  - Central outer tracker (COT)
- Scintillating tile end plug calorimeter
- Intermediate muon detectors
- Scintillator time of flight system
- Front-end electronics (132 ns)
- Trigger system (pipelined)
- DAQ system (L1, L2, L3)

Tracking detectors : COT, ISL, SVXII

COT,ISL,SVX(|η|<1.0): $dp_T / p_T^2 \sim 0.1\%$

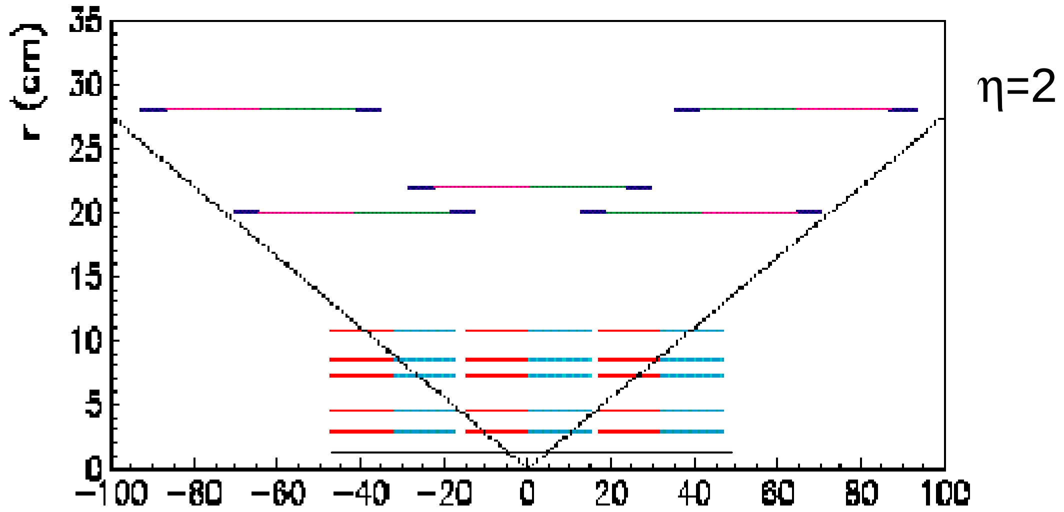
ISL,SVX(1.0<|η|<2.0): $dp_T / p_T^2 \sim 0.4\%$

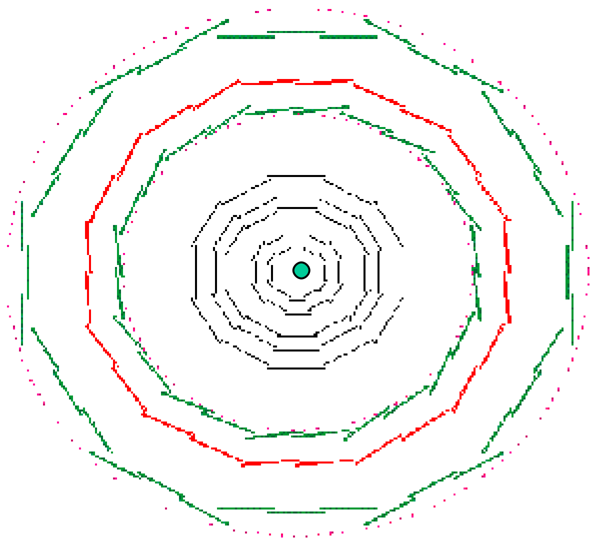


Silicon Tracking

- The silicon strip detector is a *stand-alone 3d tracking system*
- Impact parameter resolution $\sigma_d = \sqrt{a^2 + (b/P_t)^2}$ (a =7μm, b =20-30μm)
- Increase in B tagging for $t\bar{t}$:

	Run I	Run II
single tag	25%	52%
double tag	8%	28%





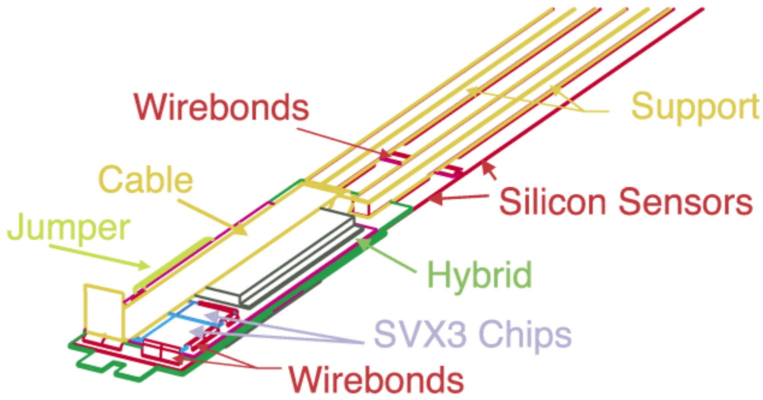
Silicon Vertex Detector(SVX II)

- Coverage: |h|<2.0
- Double sided detector: r-z readon out
- Radiation hard to survive $3fb^{-1}$ (0.5Mrad/fb^{-1} for layer0 sensor)
- 42 cell analog pipeline to store data while Level1 trigger decision.
- Readout for Level2: 6~7μsec:
  Silicon Vertex Tracker (SVT) for Level2 trigger dicision

Number of barrel	3
Number of layers/barrel	5
Number of wedges/barrel	12
Ladder length	29cm
Combined ladder length	87cm
Radius of innermost layer	2.44cm
Radius of outermost later	10.6cm
r-φ readout pitch	60~65μm
r-z readout pitch	125~141μm

(Stereo layer, 3rd & 5th, is 60mm pitch)

Resolution(radial)	12μm
Material thickness(total)	$3.5\%X_0$



Perspective view of the φ-side

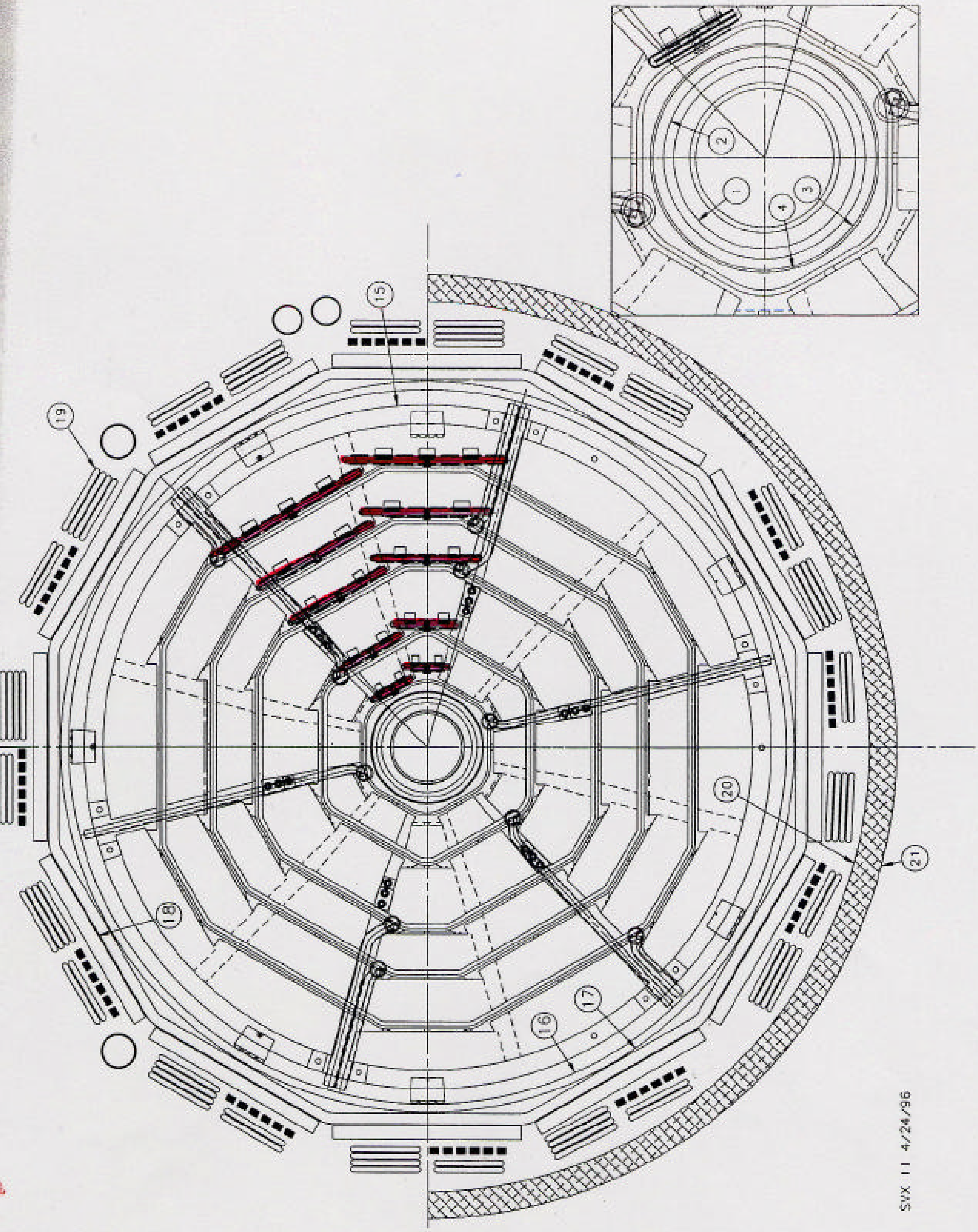
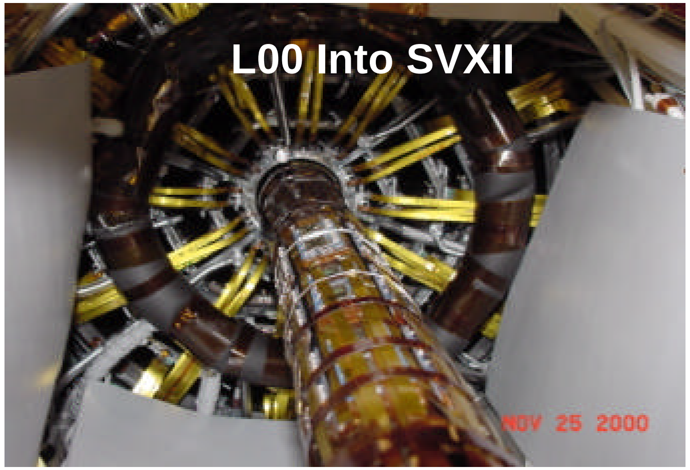
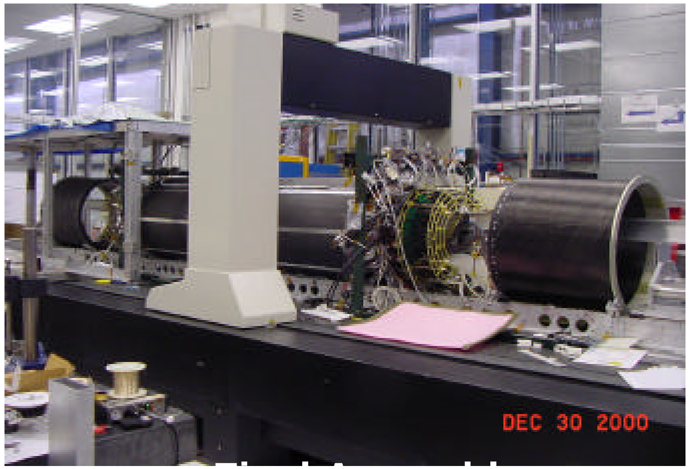
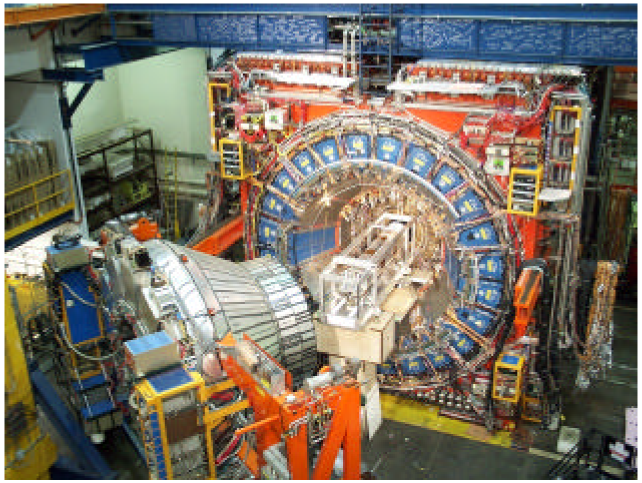


Figure 5.2: The SVX II bulkhead design

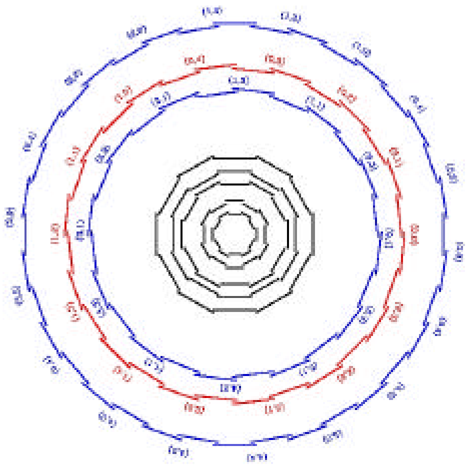
Silicon Integration and Installation

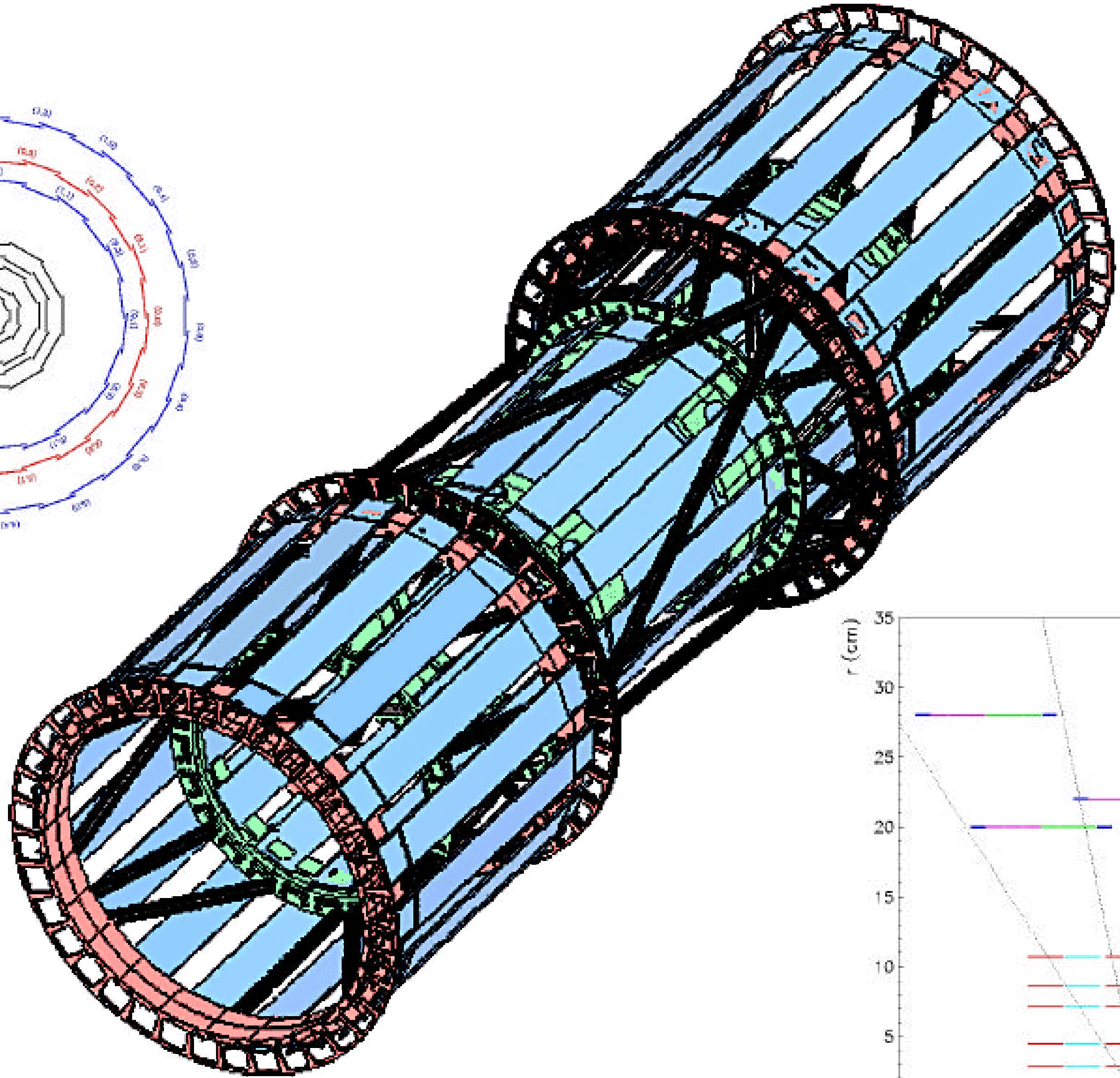


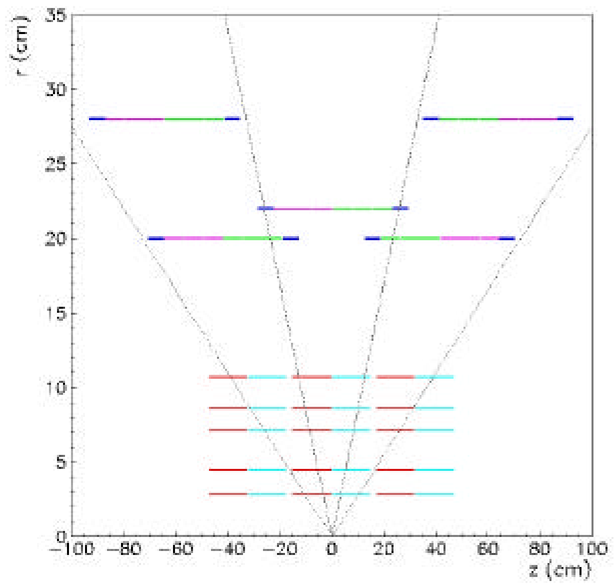




Intermediate Silicon Layer(ISL)







Intermediate Silicon Layer (ISL)

- Compare with SVXII, ISL is
  - ✓ Larger radius, Larger surface area
  - ✓ Lower ocupancy and less radiation damage

→ Simplify SVXII technology to reduce cost

ISL parameters

Radius	20 to 30cm
ηcoverage	< 2.0
Matterial/ladder	~0.5%
Total Matterial	~2%

Sensor properties

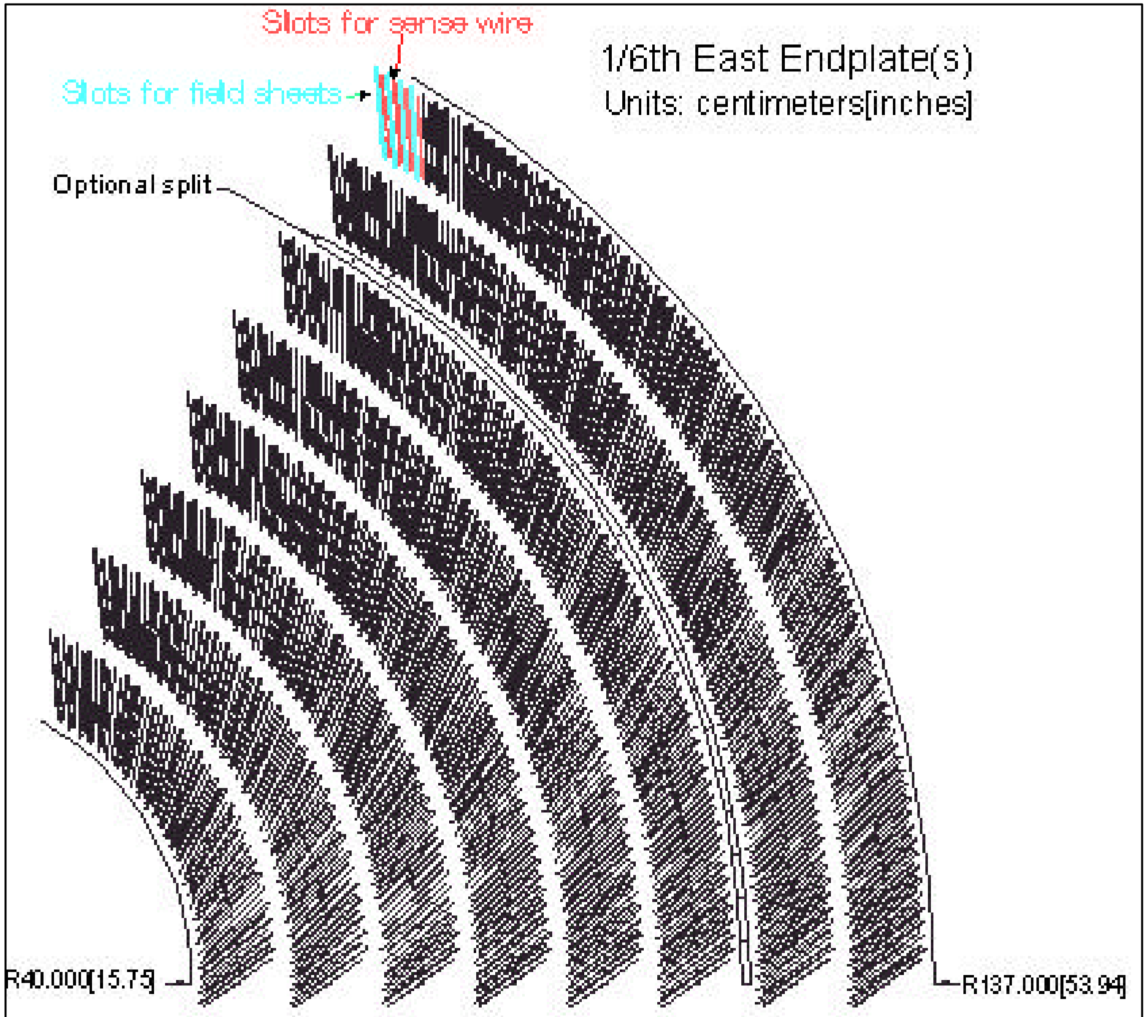
Sensor size	58mm^{W}x74mm^L
Readout strip	axial/stereo
Stereo angle	1.2^o
Strip pitch(axial)	55μm(axial), 72μm(streo)
Readout pitch	twice the strip pitch
Spacial resolution(σ)	< 16μm (axial), < 23μm(streo)

Parameters of Central Outer Tracker

Type	Drift Chamber
Max. drift time	*100nsec*
Max. drift distance	*0.88cm*
Chamber Gas	Ar-Et-CF_4(50:35:15)
Drift velocity	~100µm/nsec
Number of super layers	8 (4 axial,4 stereo)
Number of layers/SL	*12/SL*
Number of layers	96
Cells/layer	168:192:240:288:336:384:432:480
Radius at Center of SL	46:58:70:82:94:106:119:131 cm
Length of active region	310 cm
Stereo angle	3^o
Tilt angle	35^o
Radiation length	1.3%
Total number of wires	63000
Endplate load	40 tons
Expected resolution	~180µm
Two-track resolution	< 0.5cm

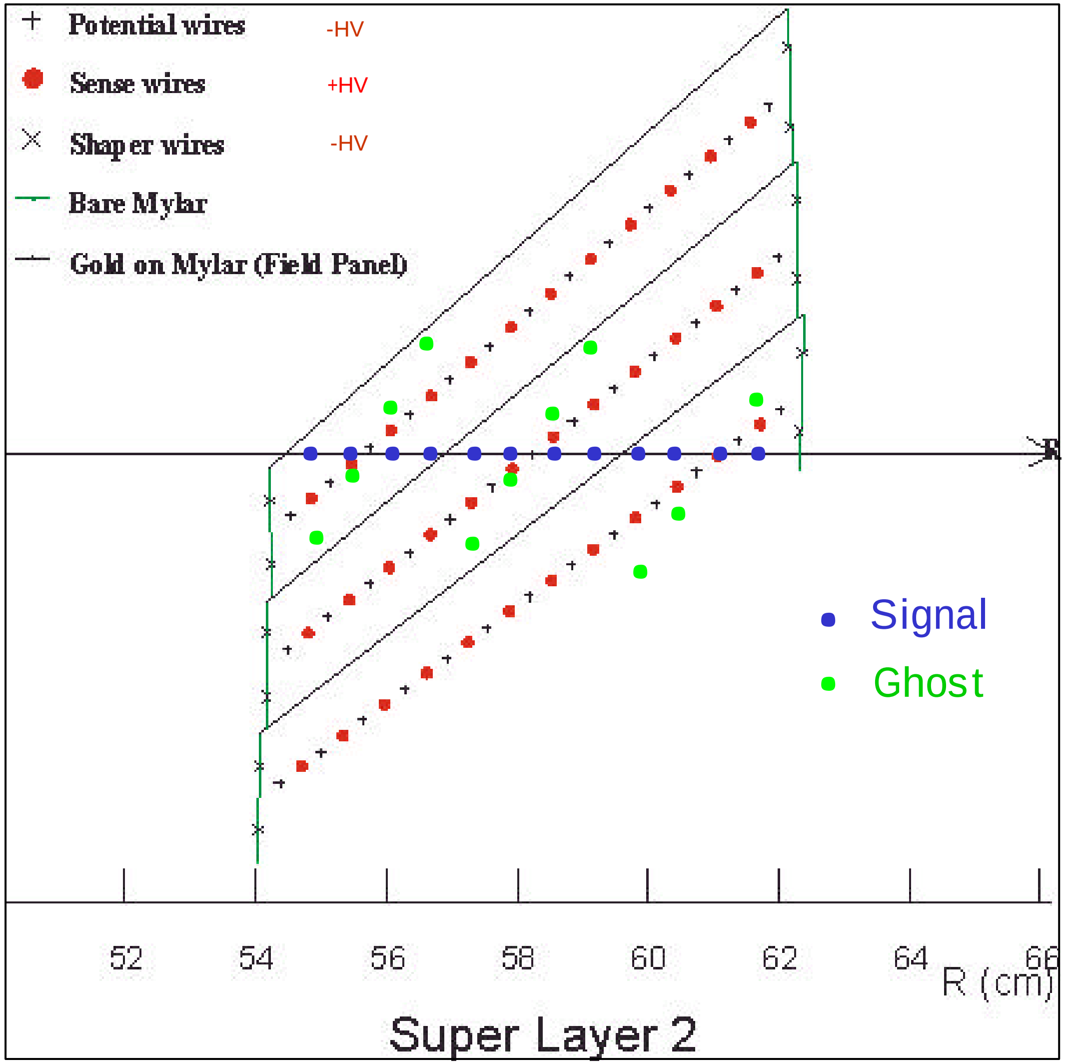
Number of layers for Tilt SL: 6 -> 12

Endplate of COT

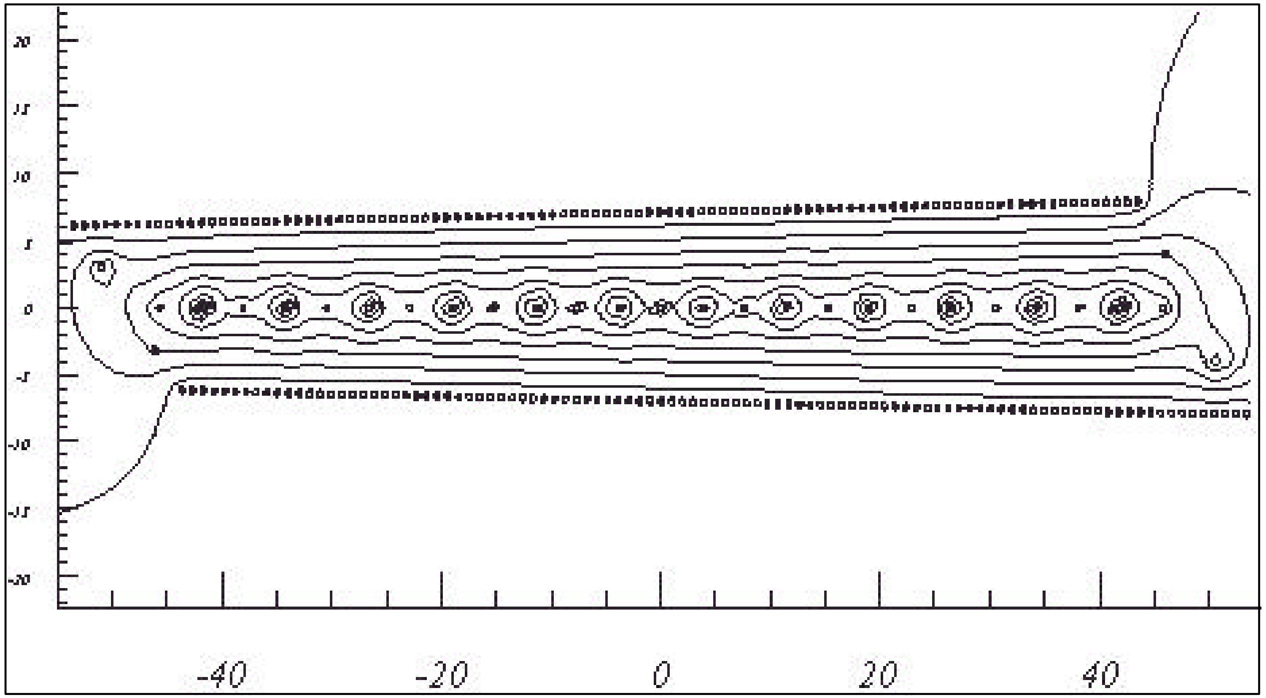


Layer #	1	2	3	4	5	6	7	8
Cells	168	192	240	288	336	384	432	480
Radius(cm)	46	58	70	82	94	106	119	131

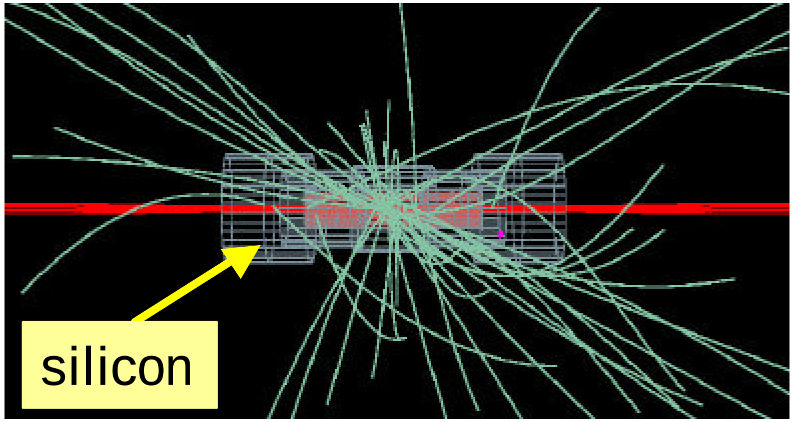
Central Outer Tracker Cell Layout



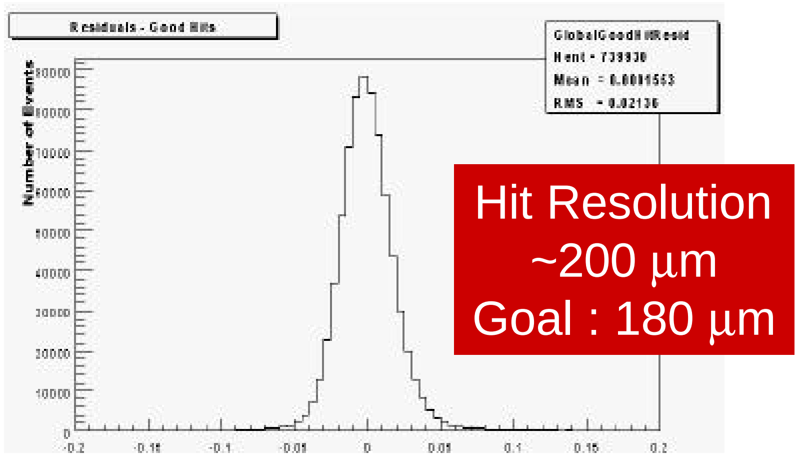
Field map of COT one cell



Tracking Performance

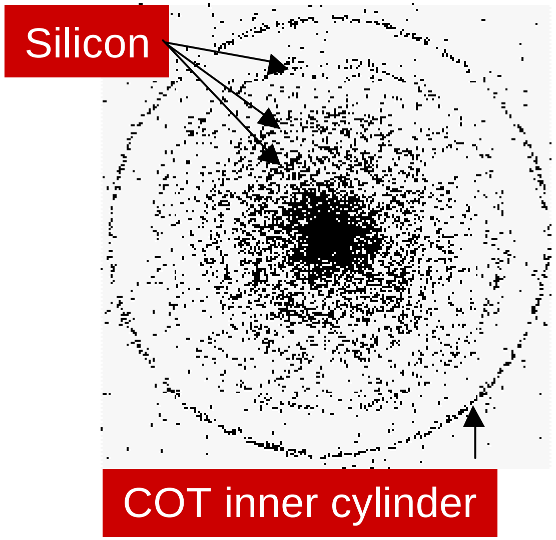


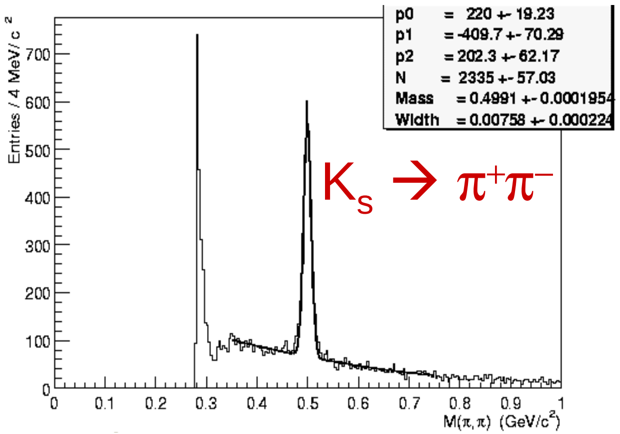
(COT tracks)

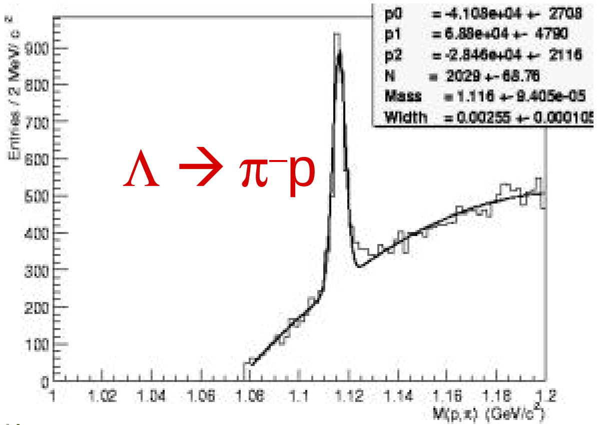


residual dist. (cm)

X-ray the detector with
g -> e+e- conversion



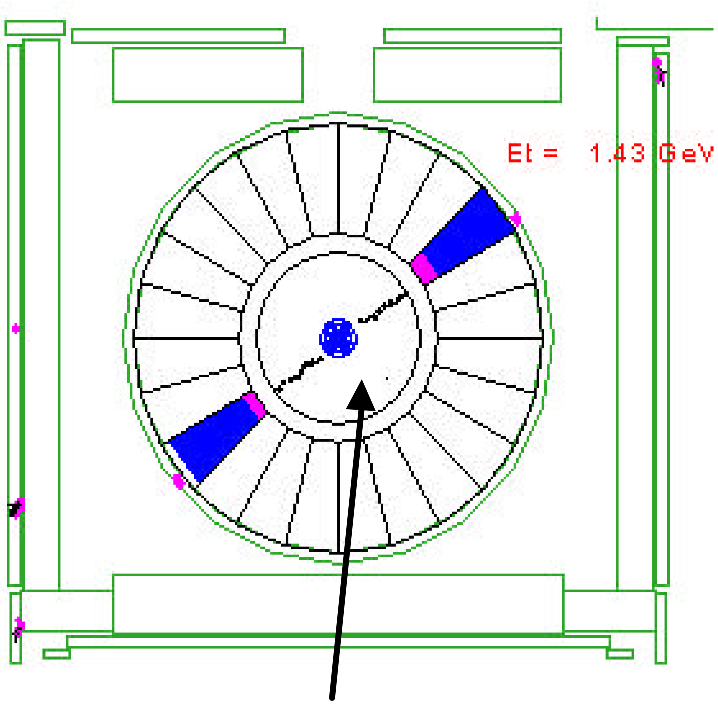




MeV/c²

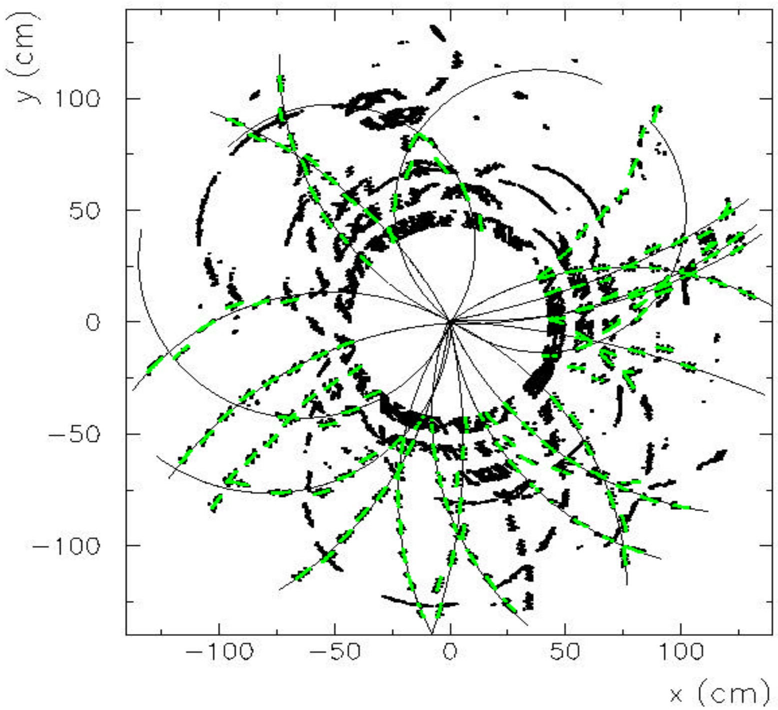
Performance of central outer tracker

Commissioning with Cosmic ray tracks



Low noise !

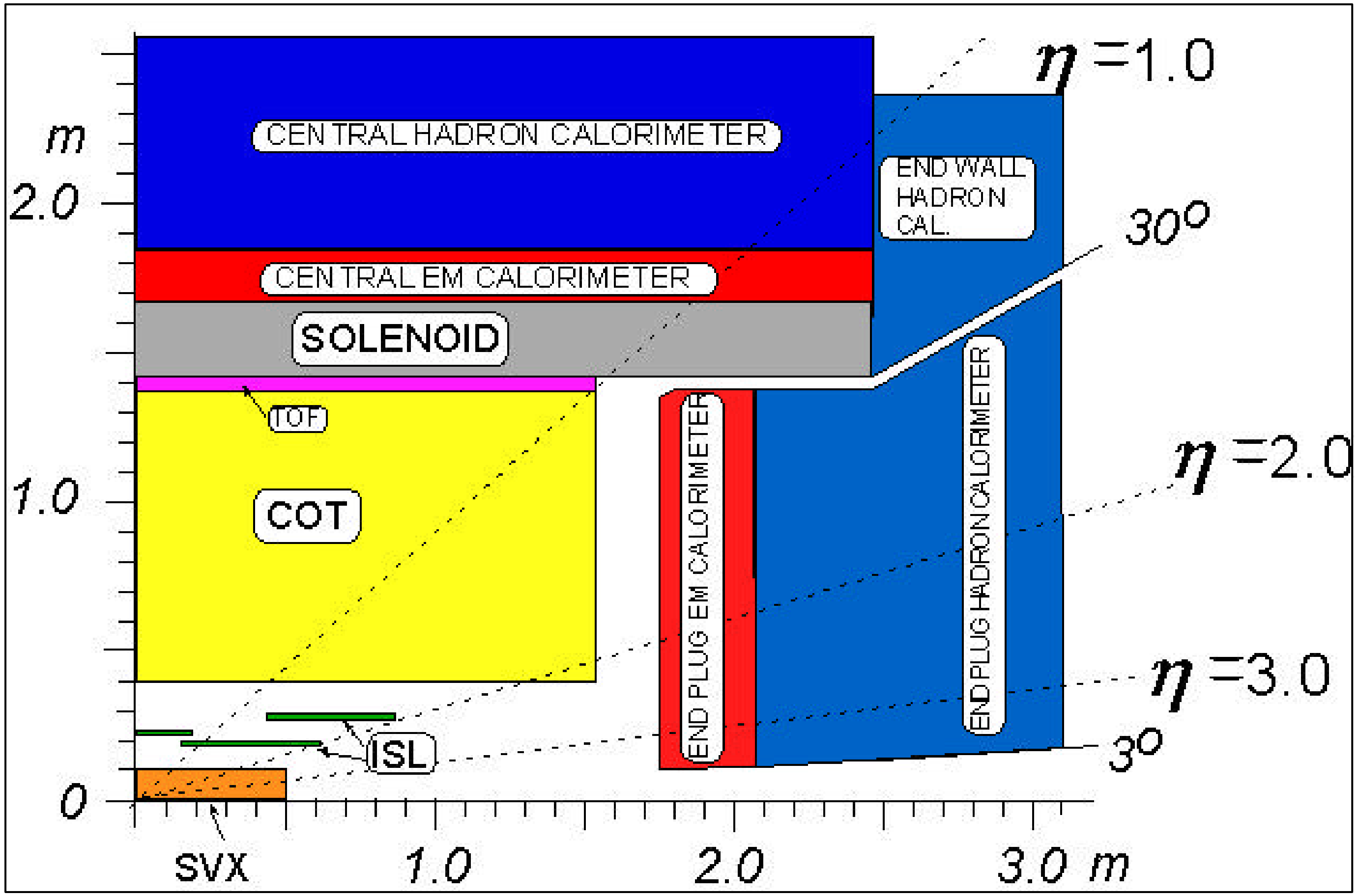
Reconstructed tracks from 1.96 TeV $p\bar{p}$ collisions



Run 2 Collisions !

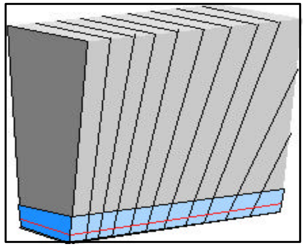
Calorimeters

Old: Central EM, Central Hadron, EndWall Hadron
New: EndPlug EM, EndPlug Hadron



Central Electromagnetic Calorimeter

Type	Scintilator/Lead sandwitch + Strip Chamber
Location	Outside coil, R=172.72cm
Segmentation(η)	10 projective towers, $\Delta\eta$=0.11
Segmentation(ϕ)	24, $\Delta\phi$=15o
Readout	Wavelength shifter and photomultiplier
Layers	20-30 lead(0.32cm), 21-31 scintillator(0.5cm)
Thickness	$18X_0$+coil($0.85X_0$)+etc, 1Labs
Energy Resolution	$13.5\%/\sqrt{E(GeV)} \oplus 2\%$



Strip Chamber

Purpose	Determine shower position and transverse development at shower maximum
Location	$5.9X_0$
Wire channels	64 / module
Strip channels	6.2cm-121.2cm: 69x1.67cm, 121.2-239.6cm: 59x2.01cm
Chamber gas	Ar/Co_2(95%/5%)
Position resolution	+- 2mm

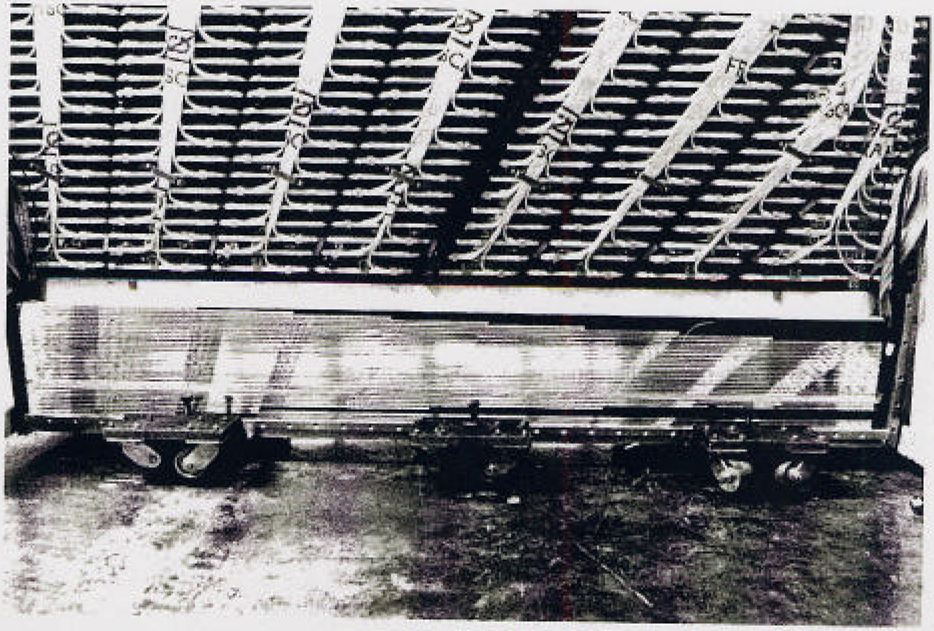


Fig. 1. Side view of the stack of lead and scintillator of the central electromagnetic calorimeter (located directly above the floor and rollers). Above the electromagnetic calorimeter is the stack of steel and scintillator, and light pipe fingers, of the hadron calorimeter in the same module. Appropriate substitution of plastic for lead allows the effective thickness in radiation lengths (total and as viewed by the strip chamber) to be nearly independent of angle.

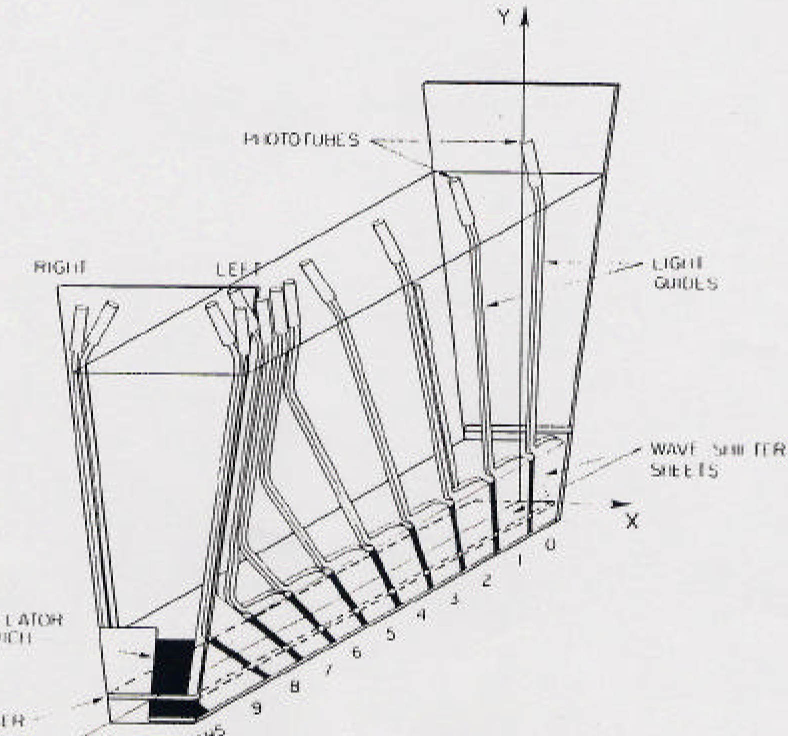
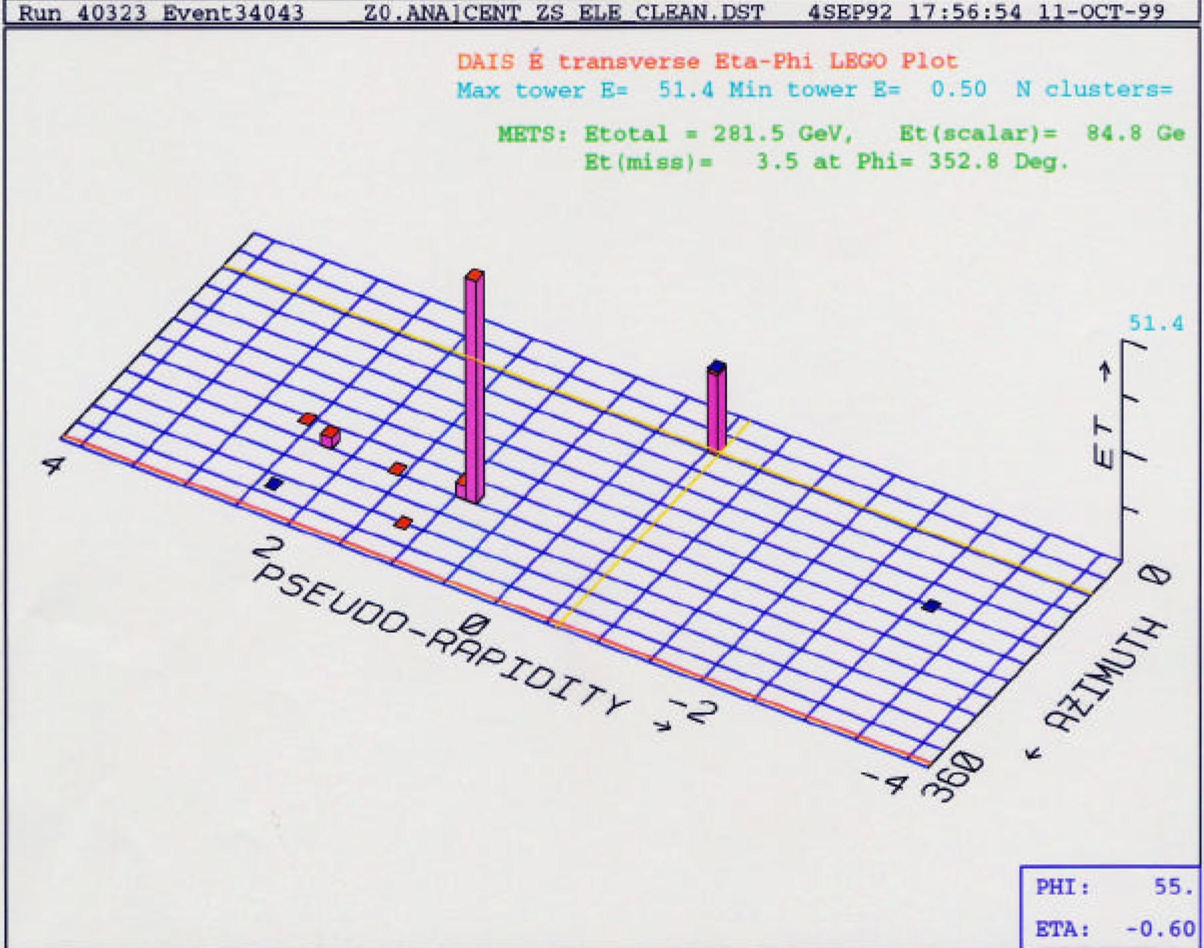
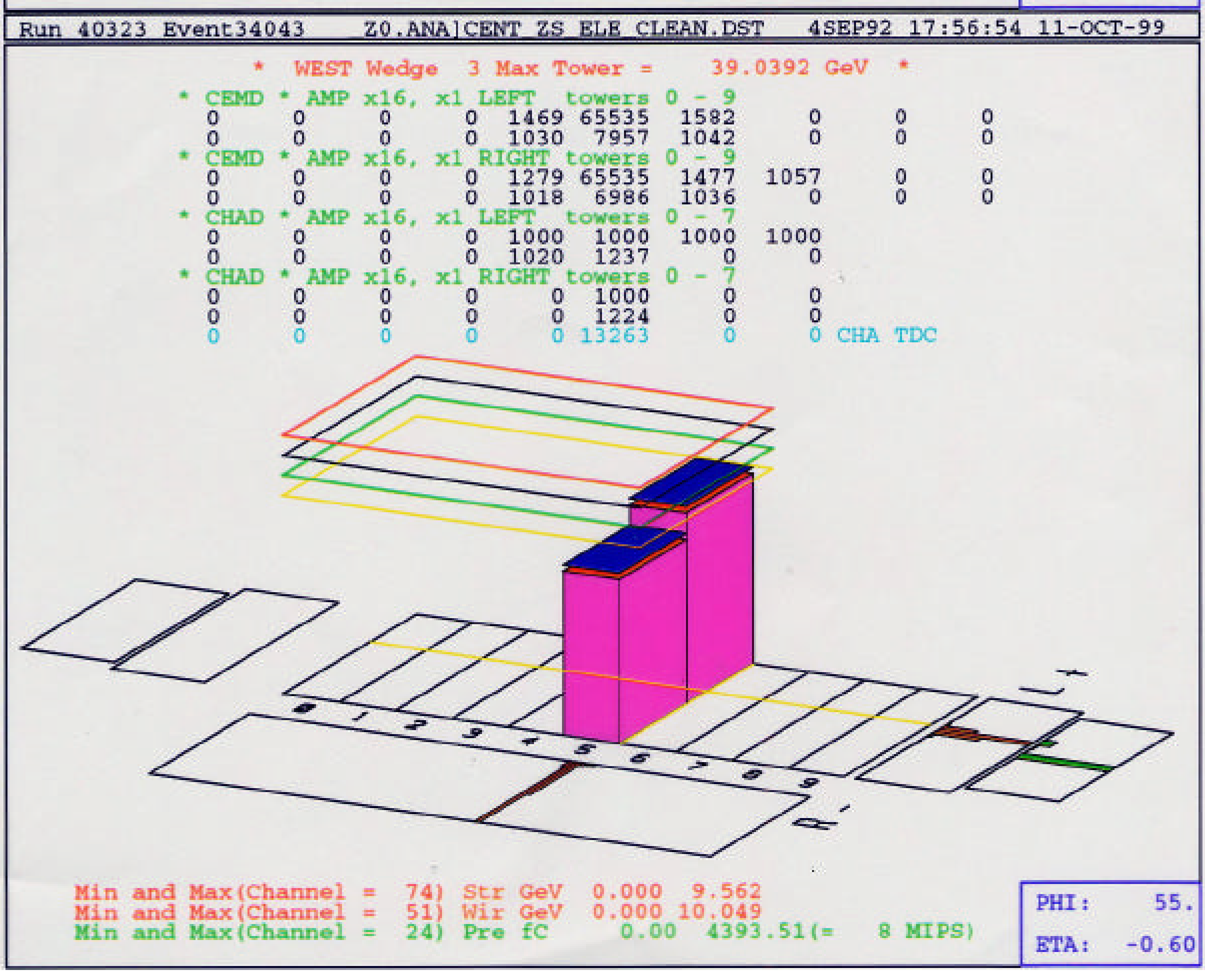


Fig. 2. Layout of the light-gathering system. The only inaccessible glue joint is the relatively robust 1 in.^{2} attachment of the folded fingers to the rods.


Run 40323 Event34043 Z0.ANA]CENT_ZS_ELE_CLEAN.DST 4SEP92 17:56:54 11-OCT-99
DAIS E transverse Eta-Phi LEGO Plot
Max tower E= 51.4 Min tower E= 0.50 N clusters=
METS: Etotal = 281.5 GeV, Et(scalar)= 84.8 Ge
Et(miss)= 3.5 at Phi= 352.8 Deg.
51.4
ET
4
2
0
-2
-4
PSEUDO-RAPIDITY
AZIMUTH
0
360
PHI: 55.
ETA: -0.60


Run 40323 Event34043 Z0.ANA]CENT_ZS_ELE_CLEAN.DST 4SEP92 17:56:54 11-OCT-99
* WEST Wedge 3 Max Tower = 39.0392 GeV *
* CEMD * AMP x16, x1 LEFT towers 0 - 9
0 0 0 0 1469 65535 1582 0 0 0
0 0 0 0 1030 7957 1042 0 0 0
* CEMD * AMP x16, x1 RIGHT towers 0 - 9
0 0 0 0 1279 65535 1477 1057 0 0
0 0 0 0 1018 6986 1036 0 0 0
* CHAD * AMP x16, x1 LEFT towers 0 - 7
0 0 0 0 1000 1000 1000 1000
0 0 0 0 1020 1237 0 0
* CHAD * AMP x16, x1 RIGHT towers 0 - 7
0 0 0 0 0 1000 0 0
0 0 0 0 0 1224 0 0
0 0 0 0 0 13263 0 0 CHA TDC
0 1 2 3 4 5 6 7 8 9
L+
R-
Min and Max(Channel = 74) Str GeV 0.000 9.562
Min and Max(Channel = 51) Wir GeV 0.000 10.049
Min and Max(Channel = 24) Pre fC 0.00 4393.51(= 8 MIPS)
PHI: 55.
ETA: -0.60

Central, EndWall Hadron Calorimeter

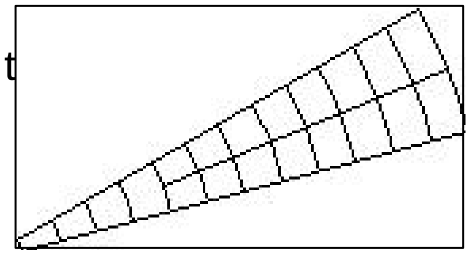
	Central	EndWall
Type	Scintilator/Fe sandwitch	
Readout	Wavelength Shifter+PMT	
$\|\eta\|$ Coverage	0~0.9	0.7~1.3
Segmentation($\Delta\eta$)	~0.1	
Segmenration($\Delta\phi$)	15^{o}	
Total Depth(λ_{abs})	4.7	4.5

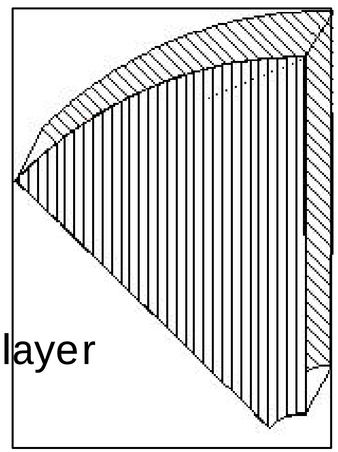
Performances by test beam

	Central	EndWall
Energy resolution	$\sim 78\% / \sqrt{E(GeV)}$	$\sim 99\% / \sqrt{E(GeV)}$
Typical position resolution at 50 GeV(cm^2)	10x5	10x5

Plug Upgrade Calorimeter (EM)

Type	Lead/Scintillator sandwitch
Readout	Wave length shifting(WLS) fibers
Coverage	1.1 < $|\eta|$ < 3.6 ($37^o < \theta < 3^o$)
Layers	23 layers of 4.5mm lead and 4mm scint
Segmentation(Dq)	$3 \sim 4^o$
Segmentation(df)	7.5^o, 15^o
Energy resolution	$16\% / \sqrt{E} \oplus 1\%$
Preshower	first layer (10mm thick scintillator)





Shower Maximum Detector

Type	Scintillator strips, 5mm width
Coverage	45^o azimuthal angle

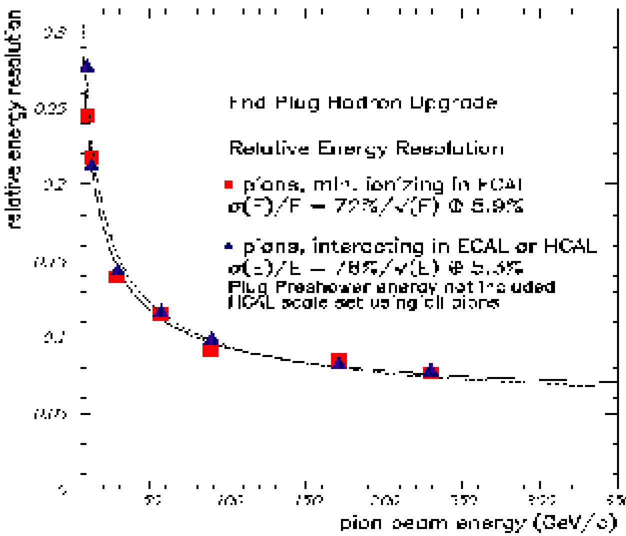
Position resolution for high energy electron
~1mm

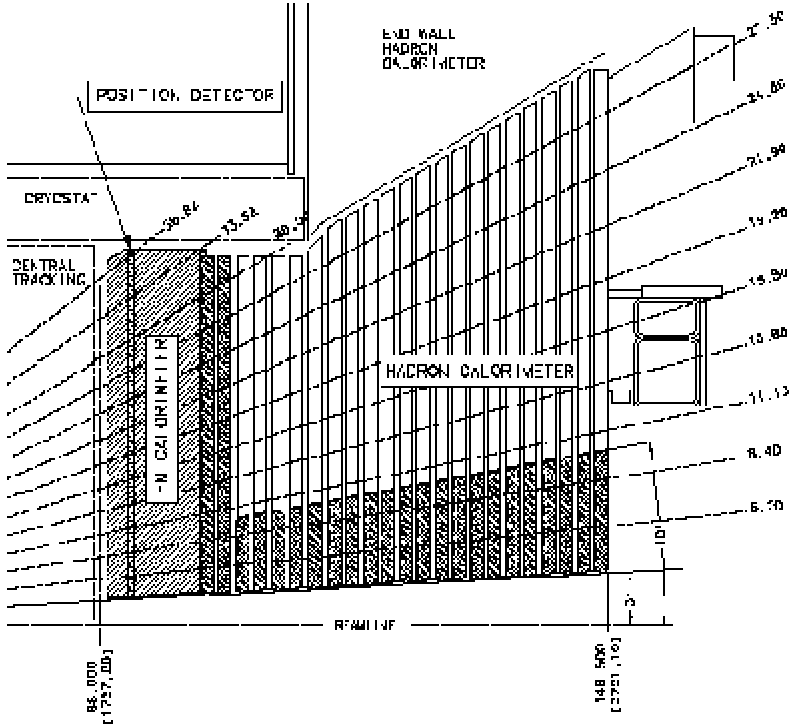
Calorimeters

- New fast, hermetic, scintillator based

Plug Calorimeter

- 21 X_o electromagnetic
- $|\eta|$ out to 3.6
- 6.6 λ_{int} hadronic
- shower max at 6 X_o





Test Beam shows good performance

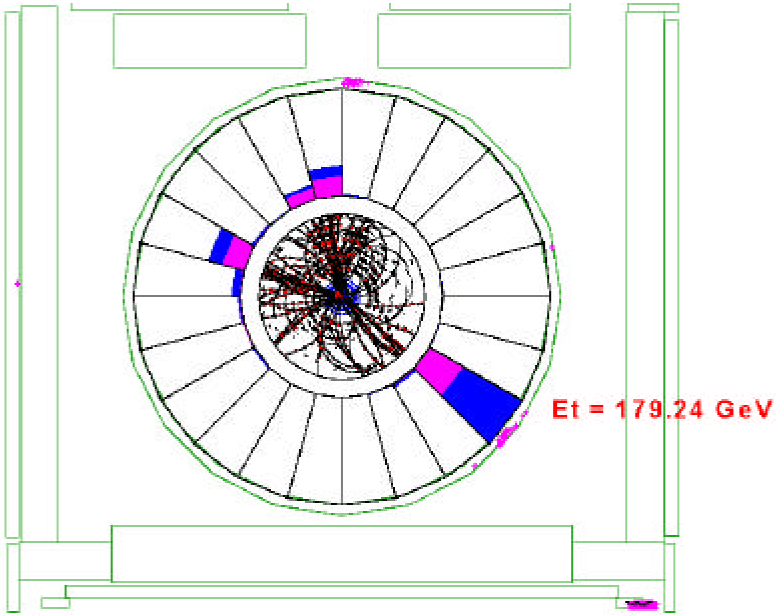
Plug Upgrade Calorimeter (Hadron)

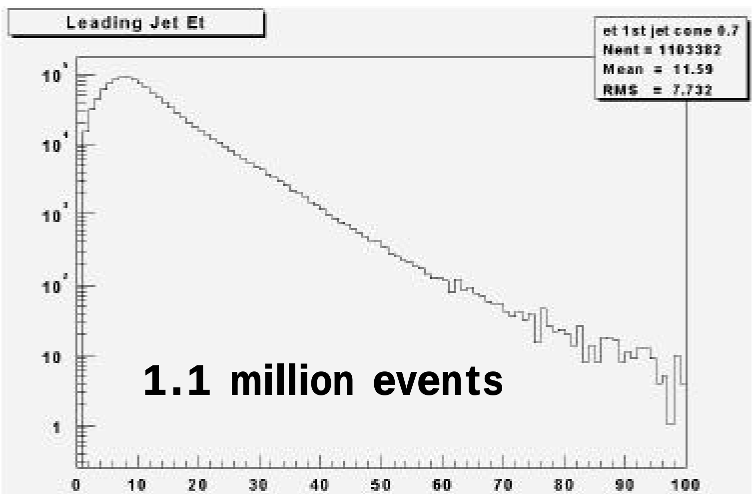
Type 23 layers of Iron/Scintillator samplig

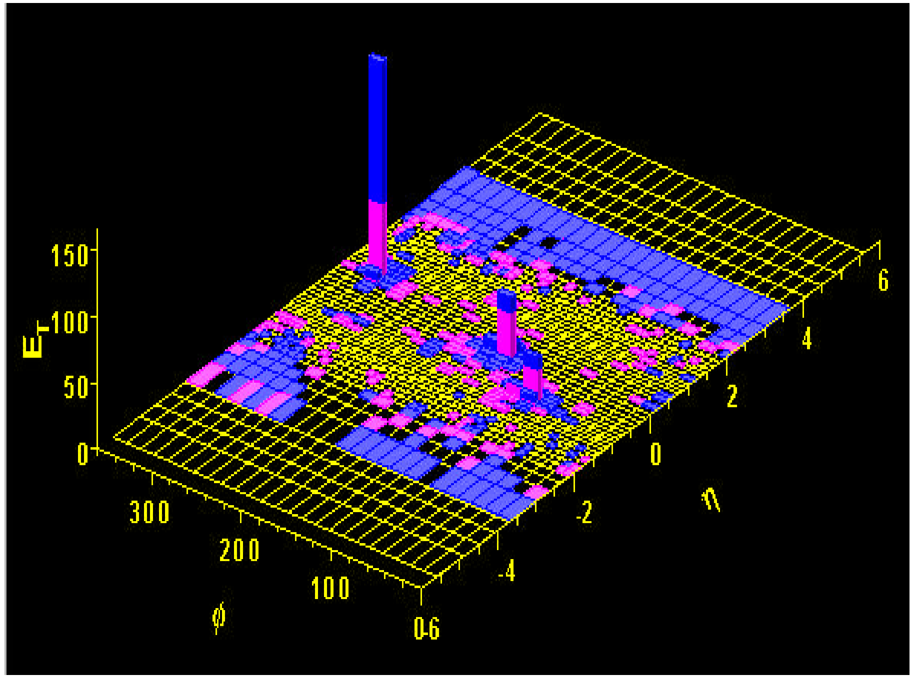
New : two layers after Plug EM Cal. and section between 3^o to 10^o.

Thickness 7 λ

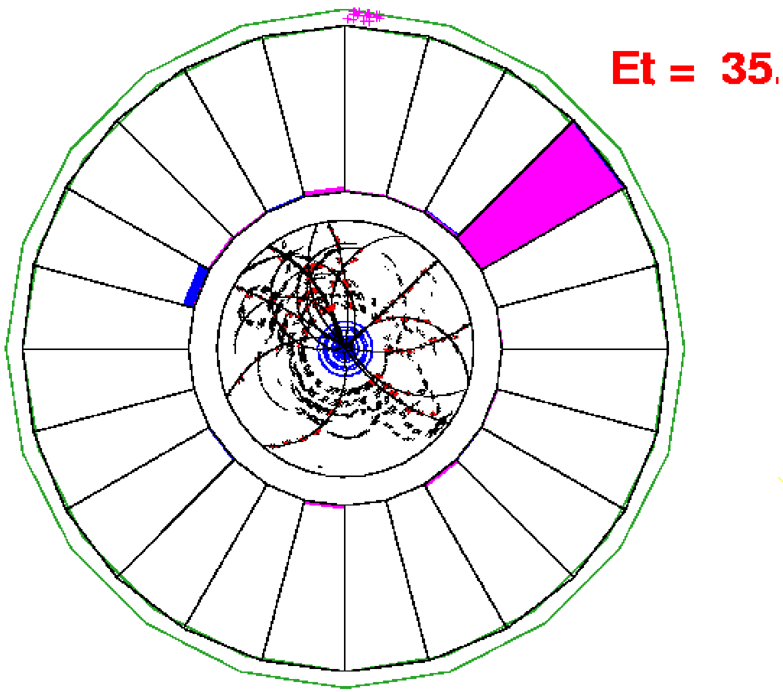
Calorimeters are performing well

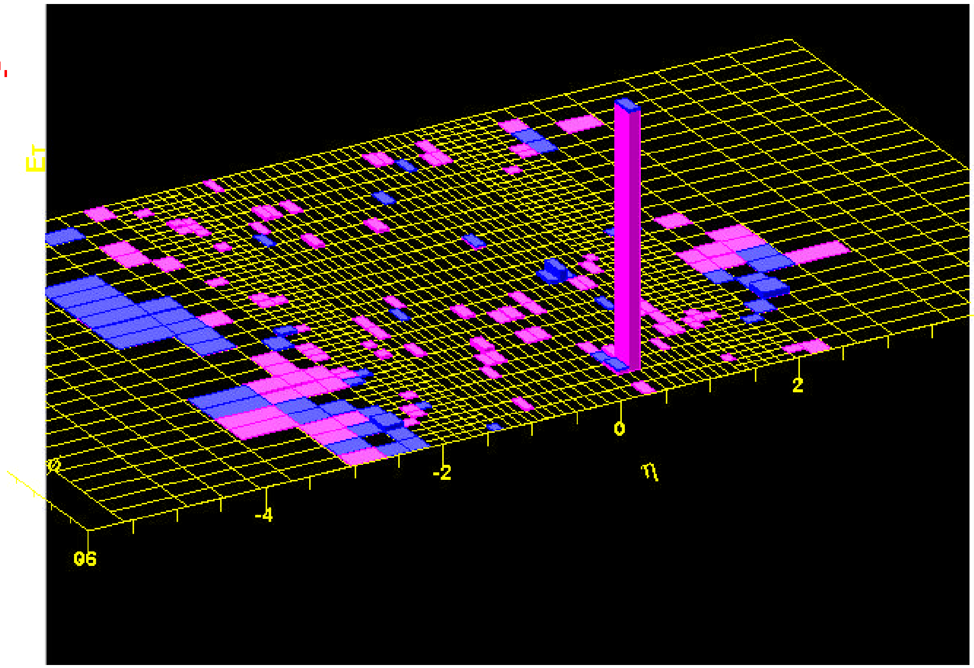






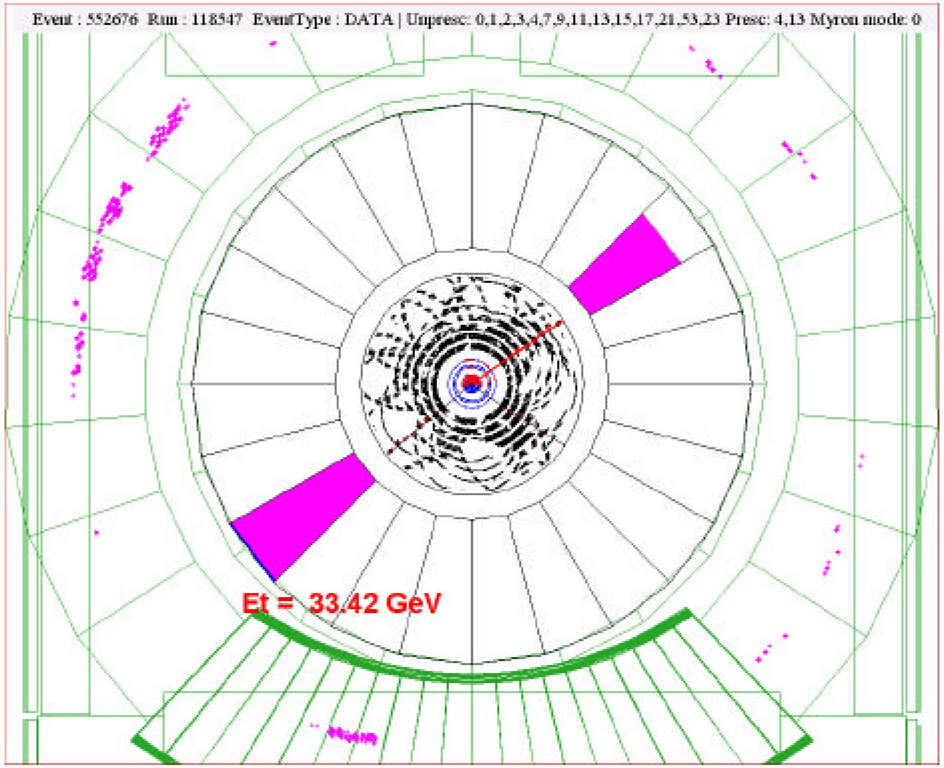
1^{st} W $\rightarrow e\nu$ Candidate

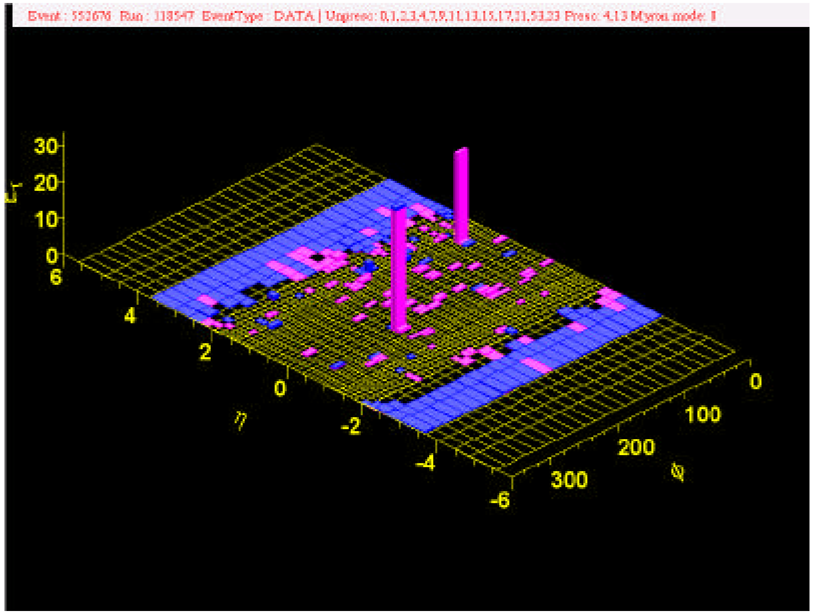




Missing E_T 38 GeV

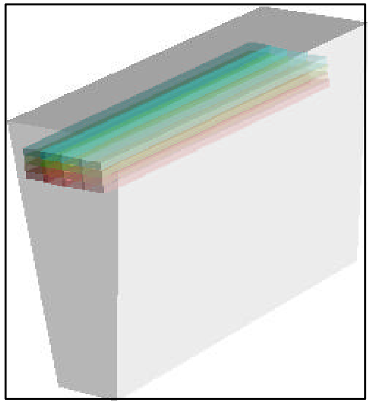
Z->ee candidate



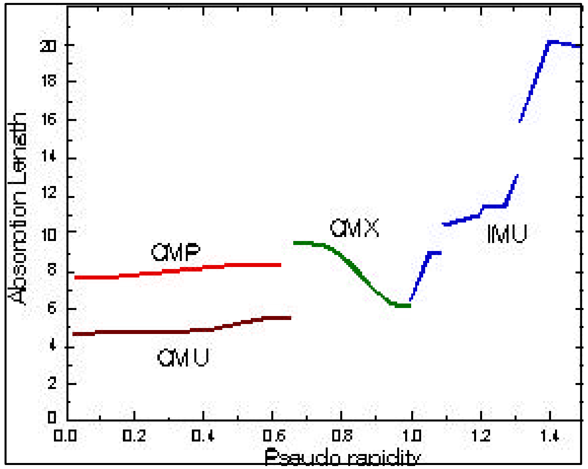


Muon Detectors

✓Momentum measurement
✓By tracking detectors in solenoid
$|\eta|<1.0$ by COT+ISL+SVX
$1<|\eta|<2$ by ISL+SVX

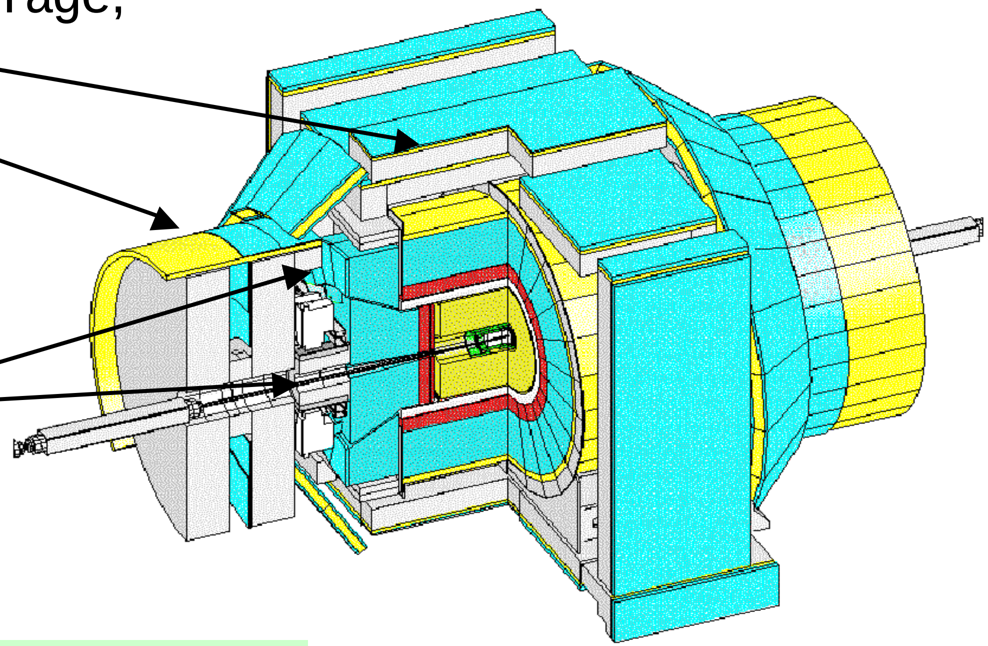


✓Muon identification
✓Identified by drift chambers and scintillation counters placed outside Hadron Calorimeter
◆CMU : $|\eta|$ < ~0.6 at the end of Central Hadron Cal.
◆CMP/CSP: $|\eta|$ < ~0.6
◆CMX/CSX: ~0.6 < $|\eta|$ < ~1.0
◆IMU: ~1.0 < $|\eta|$ < ~1.5 (for trigger) ~2.0 (for id)
✓Counter information are used for trigger and resolve off-timing hits due to long readout time of drift chambers(800~1400nsec)

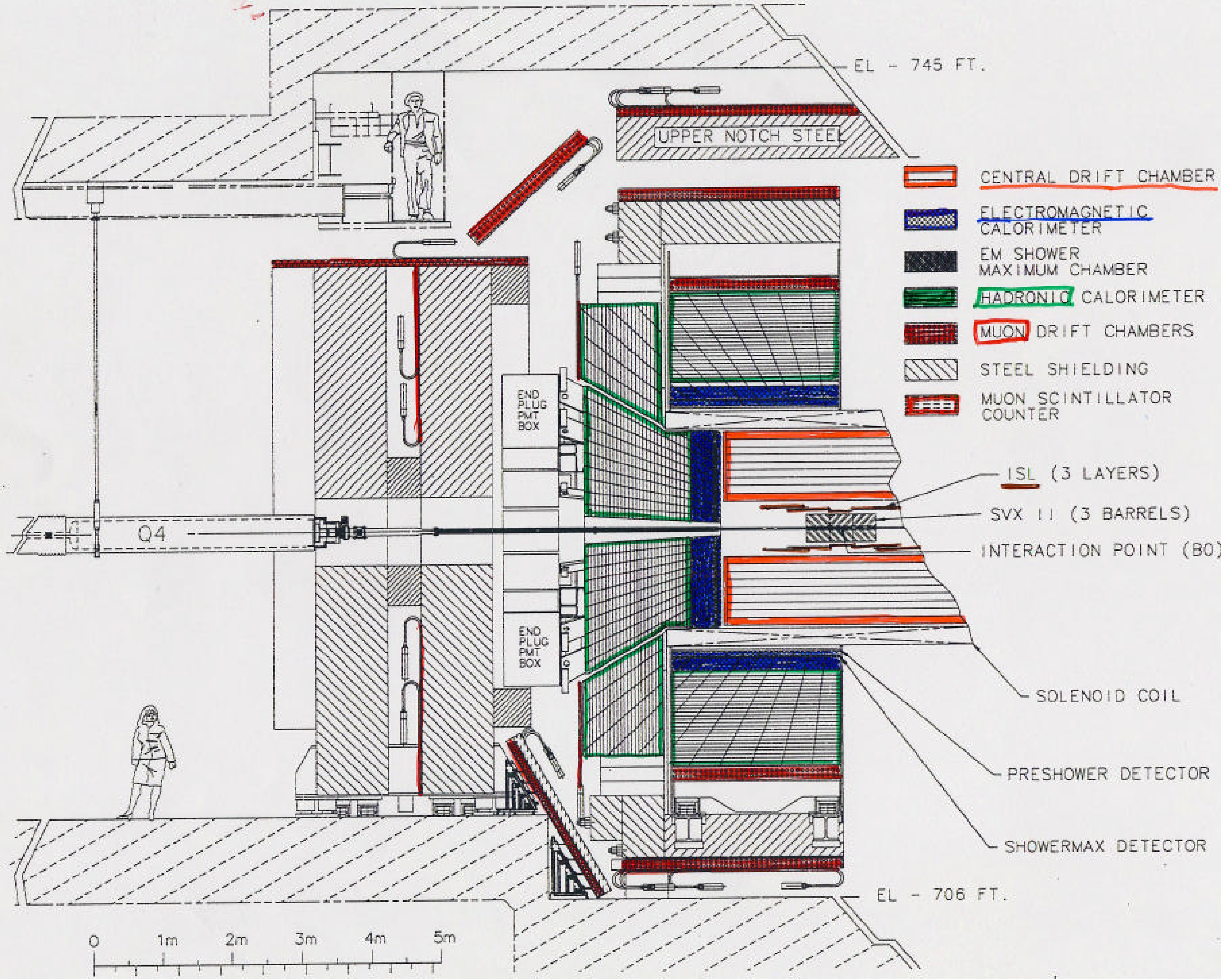


Muon Detector Upgrade

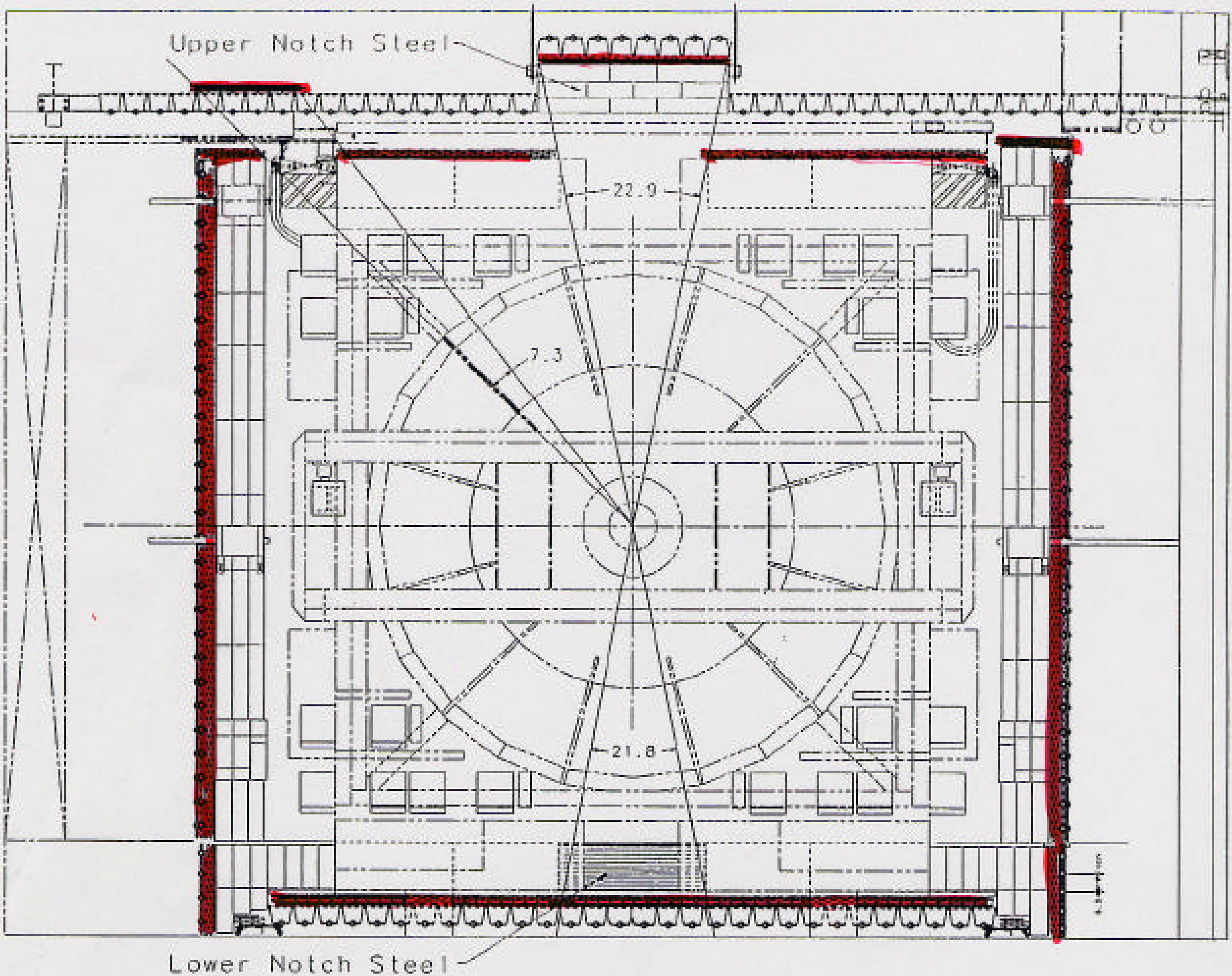
- Increase eta and phi coverage,
- Higher rate capabilities
- Better trigger shielding



CDFII total muon coverage increases by about 50%.



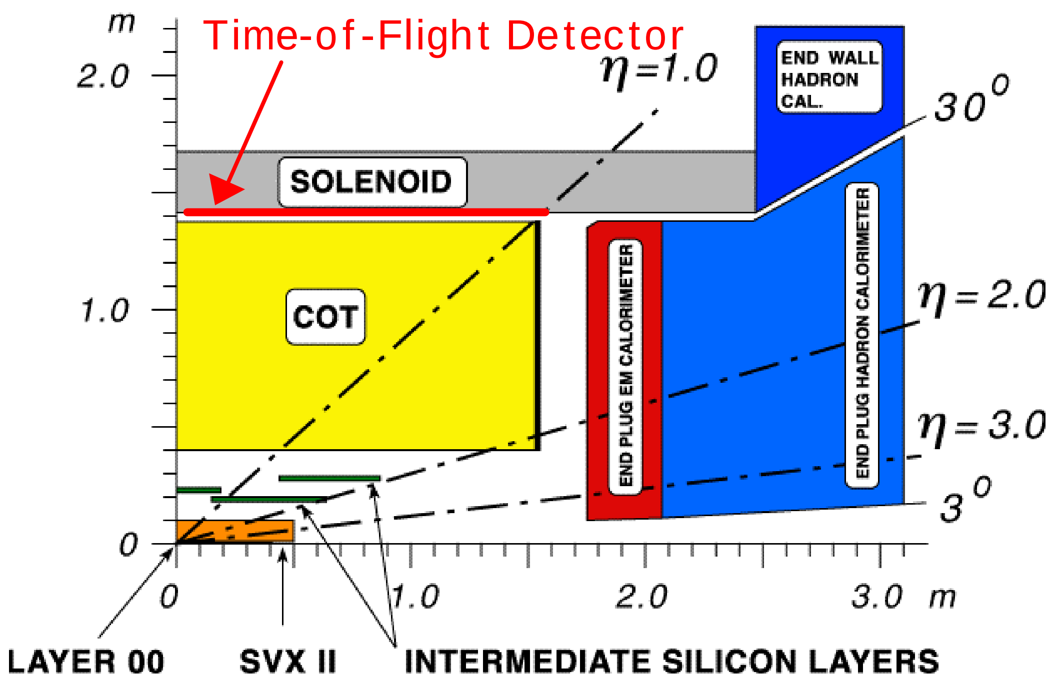
EL - 745 FT.
UPPER NOTCH STEEL
CENTRAL DRIFT CHAMBER
ELECTROMAGNETIC
CALORIMETER
EM SHOWER
MAXIMUM CHAMBER
HADRONIC CALORIMETER
MUON DRIFT CHAMBERS
STEEL SHIELDING
MUON SCINTILLATOR
COUNTER
END
PLUG
PMT
BOX
ISL (3 LAYERS)
SVX II (3 BARRELS)
INTERACTION POINT (BO)
Q4
END
PLUG
PMT
BOX
SOLENOID COIL
PRESHOWER DETECTOR
SHOWERMAX DETECTOR
EL - 706 FT.
0
1m
2m
3m
4m
5m



'igure 10.4: Configuration of the Central Muon Upgrade detector (CMP), Upgrade Scintillator (CSP) and s
absorber in Run II. On the walls the circles are the ends of PMTs. On the top and bottom the trapezoids are
ightguides viewed end-on.

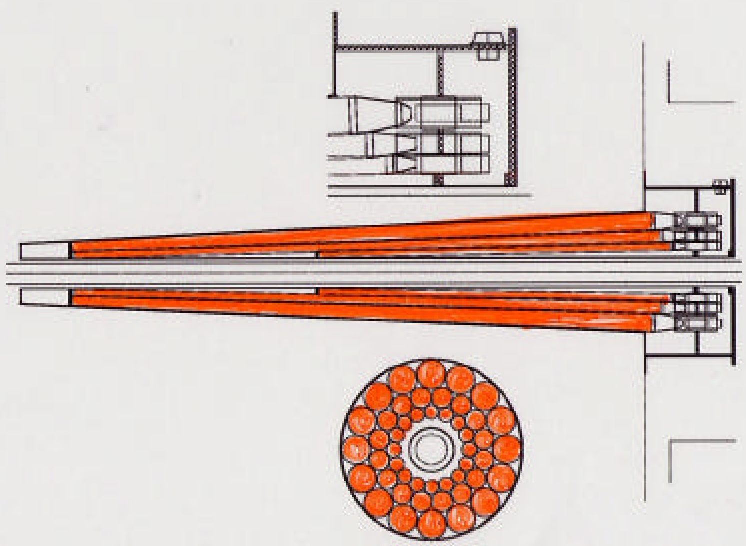
Time-of-Flight Detector

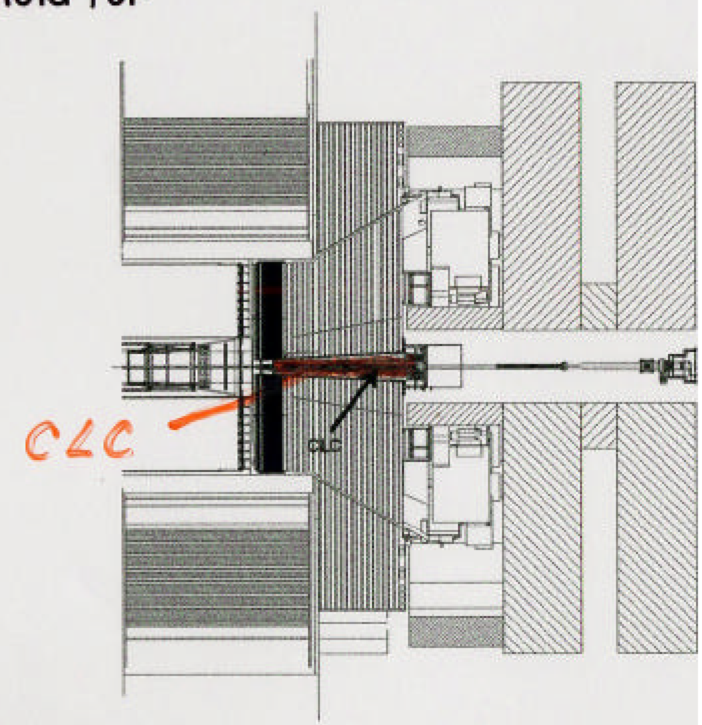
- 216 Scintillator bars(279cmx4cmx4cm) with phototubes attached to both ends.
- Between COT and Solenoid(R~138cm)
- Pseudorapidity coverage |h|<1.
- Bicron plastic scintillator BC-408 with fast rise times ~ 0.9ns
- Hamamatsu R7761, fine mesh, 19 stages PMT, to use in B=1.4T



Cherenkov Luminosity Monitor

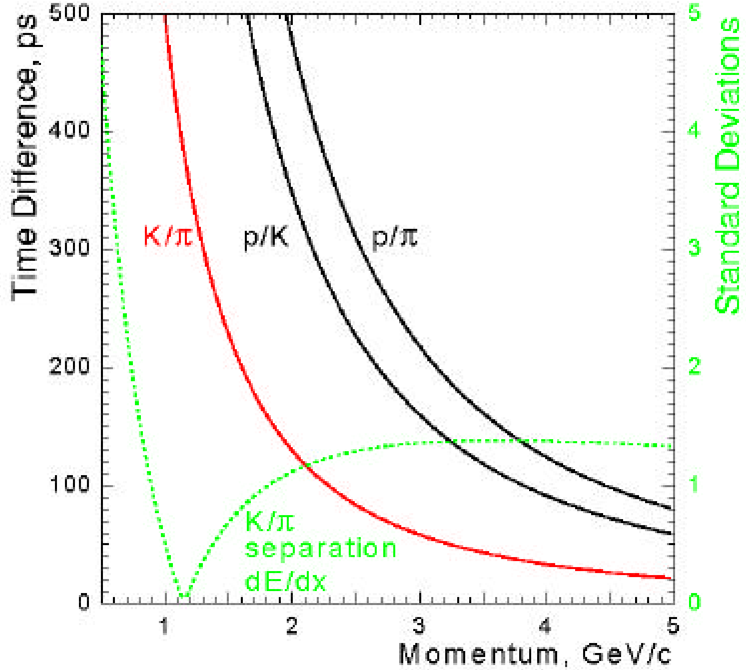
- Measures particles from inelastic $\bar{p}p$ collision
- Placed inside endplug calorimeter
- Covers $3.7 < |\eta| < 4.7$
- Conical gas-filled Cherenkov counter, readout by PMT
- Isobutane at atmospheric pressure
  - threshold: 9.3MeV/c for *e* and 2.6 GeV/c for π
  - on average, 10 particles above threshold for each $\bar{p}p$ interaction





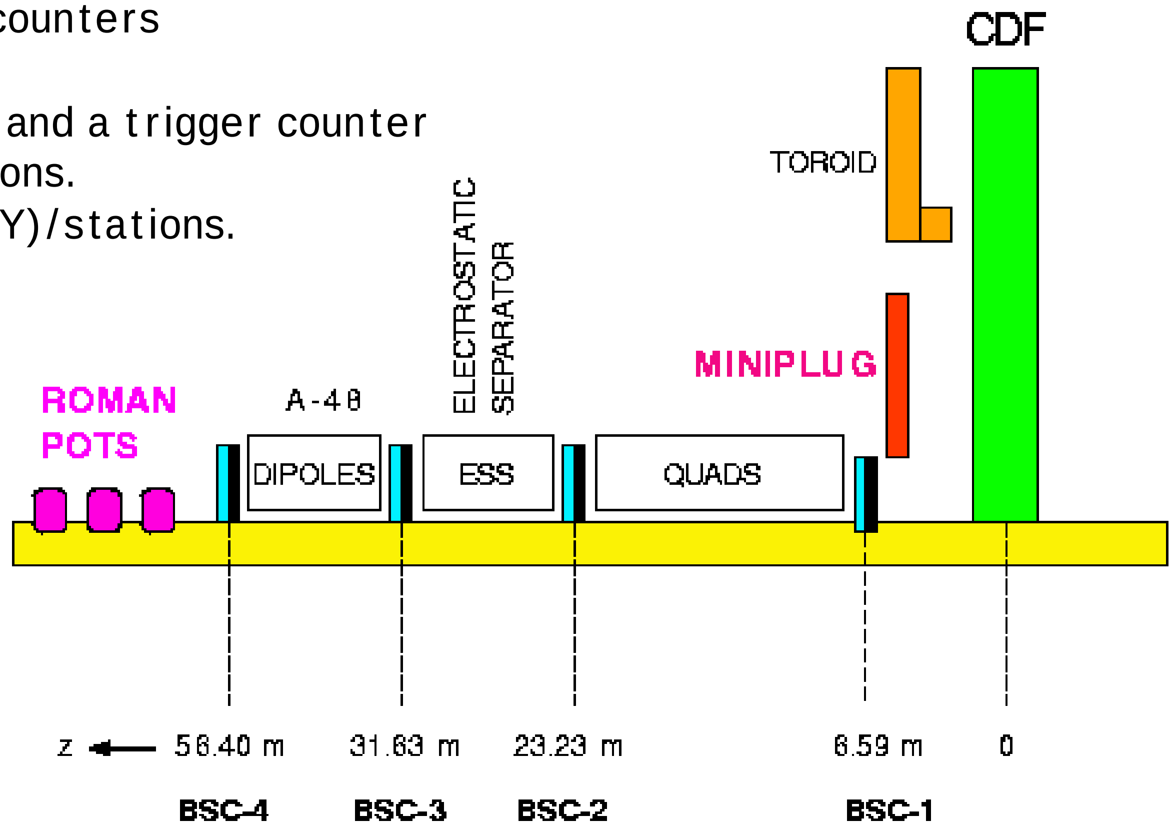
Particle ID by Time-of-Flight Detector

- For expected 100ps resolution: 2σ separation of
  - *K* and π for p<1.6 GeV/c
  - p and *K* for p<2.7 GeV/c
  - π and *p* for p<3.2 GeV/c
- Complementary to dE/dx by COT

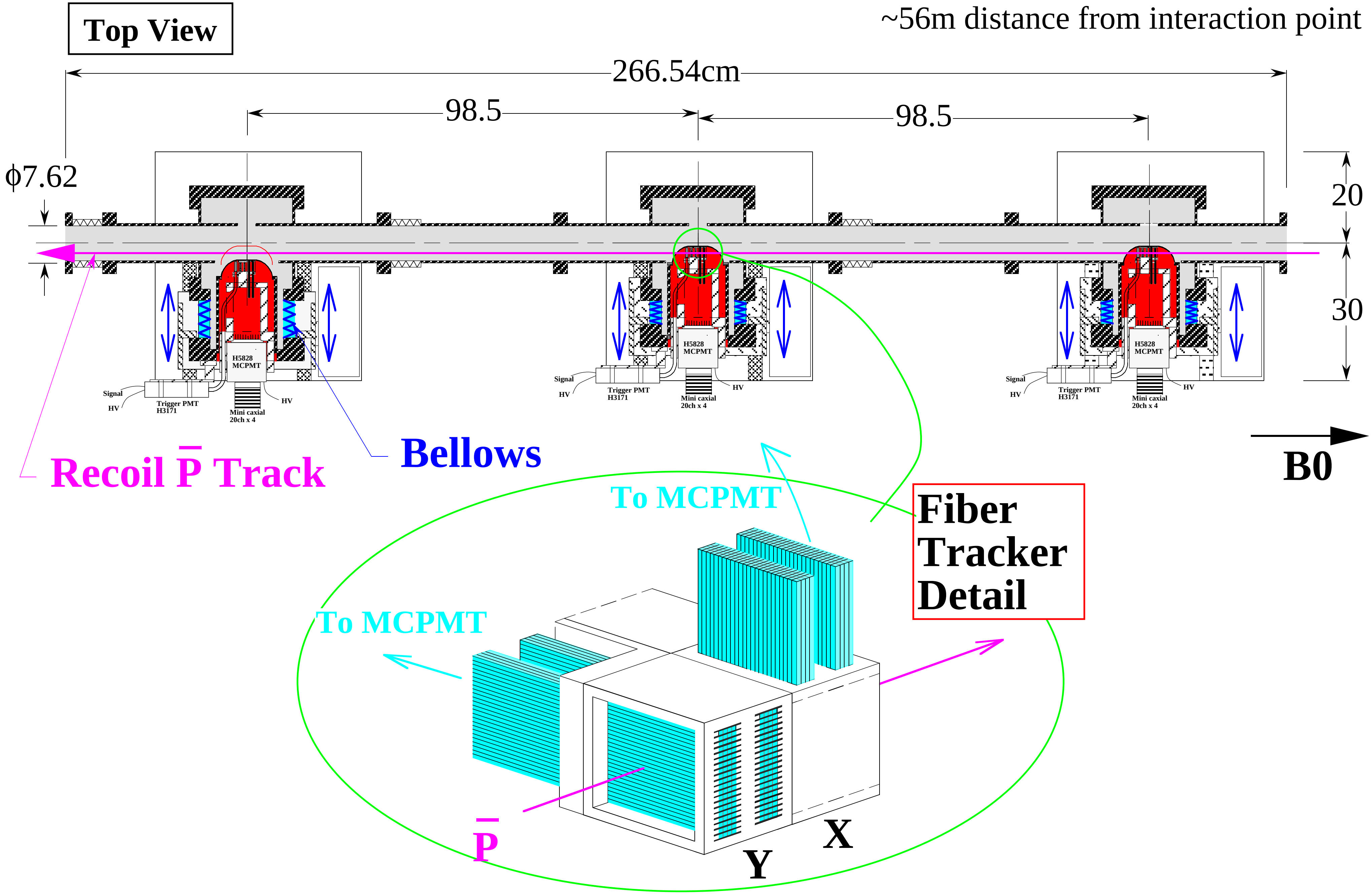


CDF forward detectors

- Miniplug
  - Lead/scintillator calorimeter to cover $3.5 < |\eta| < 5.5$
  - Placed inside the toroid magnet all the way down to the beam pipe.
- Beam Shower Counter
  - Detetct particles near beam pipe
  - For deffractive physics and for beam loss monitor
  - BSCs are scintillation counters
- Roman Pots
  - 80 scintillation fibers and a trigger counter at three readout sections.
  - Readout 40(X) and 40(Y)/stations.



Roman Pot Arrangement



Roman Pot

RUN II TRIGGER SYSTEM

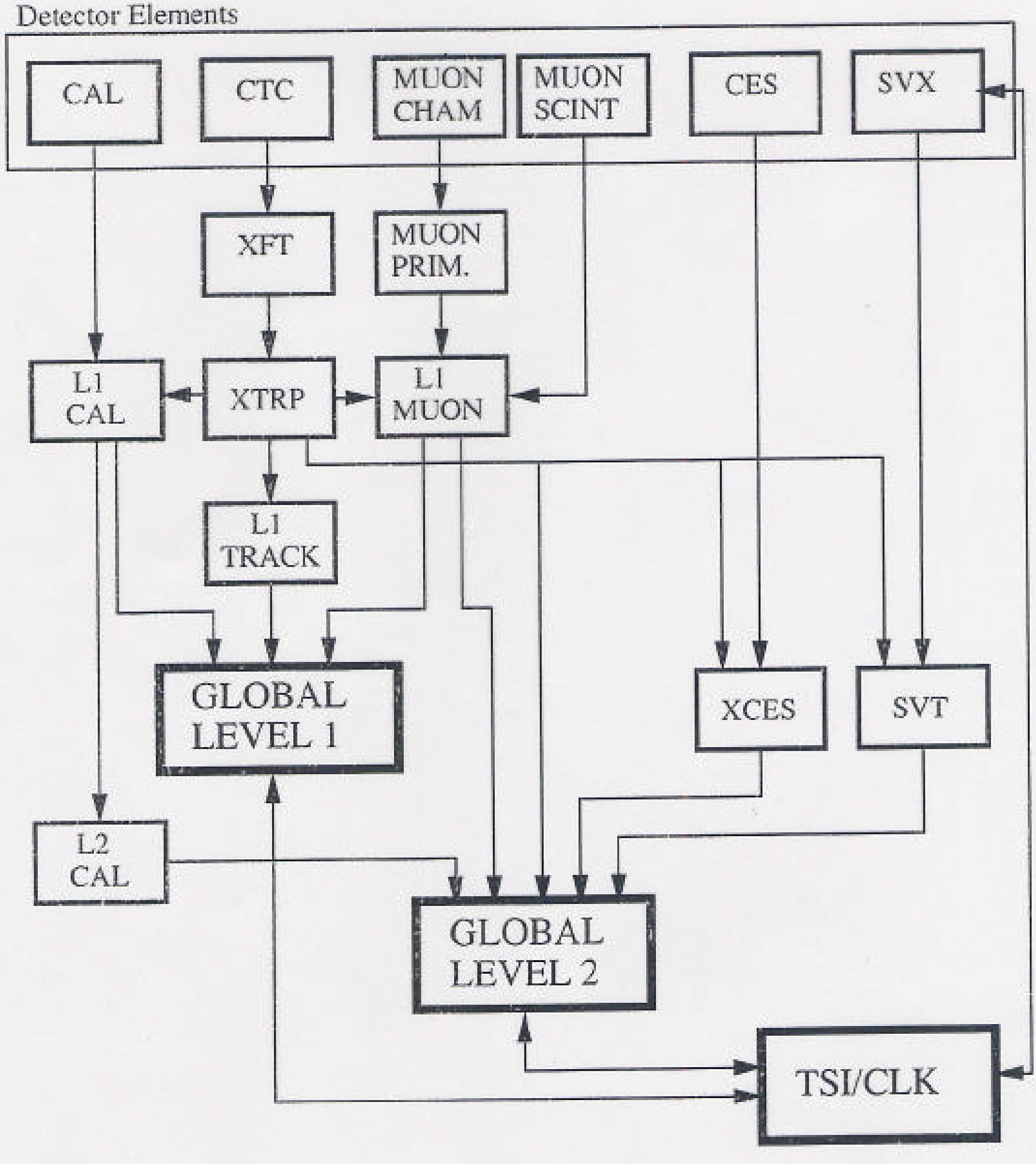
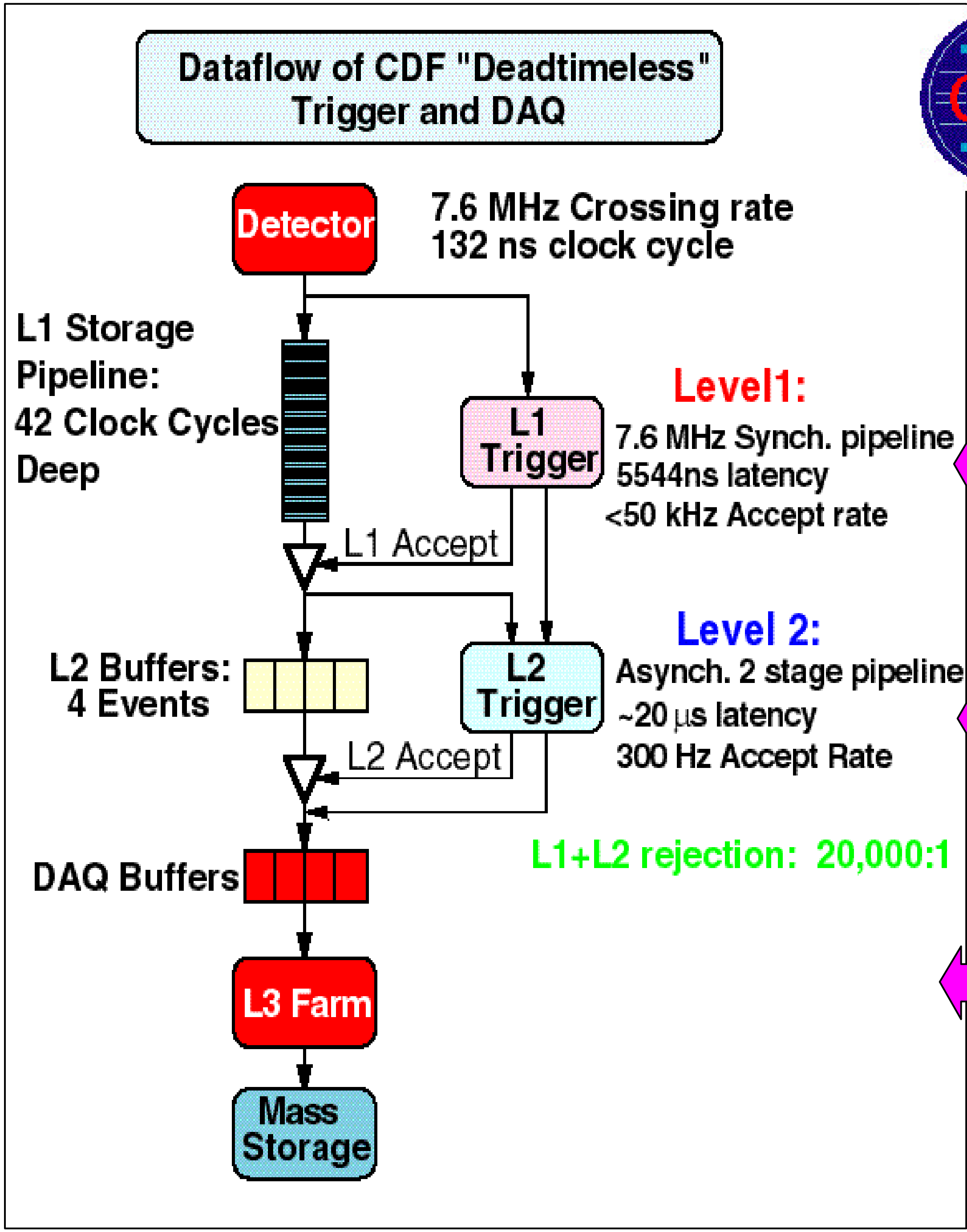


Figure 2: Block diagram of the CDF trigger upgrade. Small blocks represent trigger hardware subsystems which feed the L1 and L2 Global decision blocks. TSI/CLK provides clock and beam crossing signals. In addition the TSI distributes global trigger signals such as L1 accept, L2 accept/reject and L2 buffer number to the rest of the trigger and DAQ.

• 

Calorimeter energy
Central Tracker (Pt,f)
Muon stubs

Cal Energy-track match
E/P, EM shower max
Silicon secondary vertex
Multi object triggers

Farm of PC's running fast versions of Offline Code ➔ more sophisticated selections

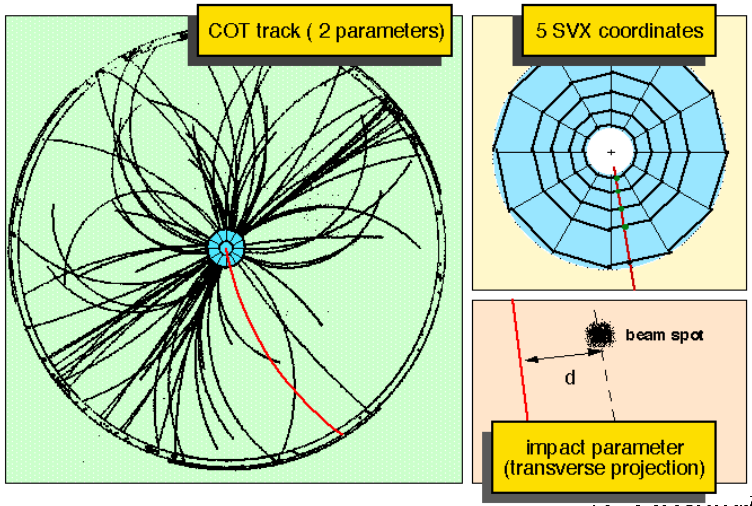
CDF Secondary Vertex Trigger

NEW for Run 2 -- level 2 impact parameter trigger

Provides access to hadronic B decays

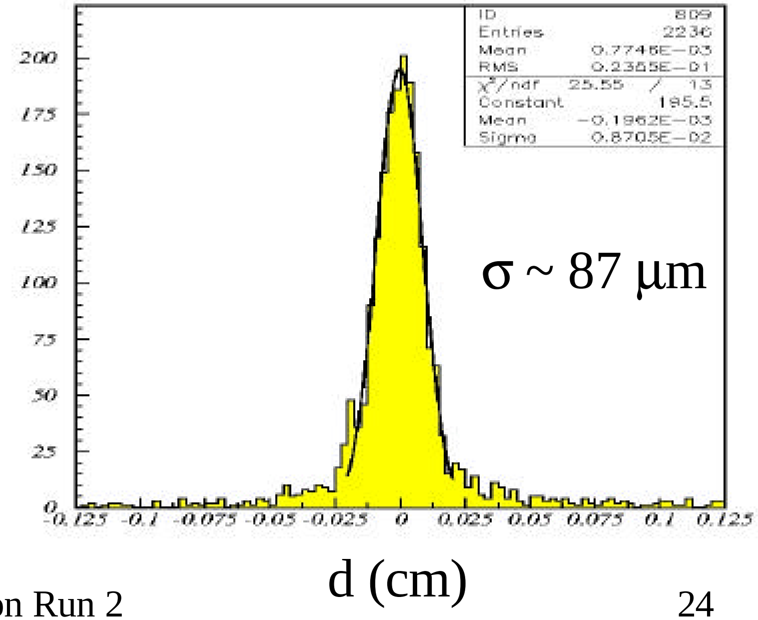
COT defines track at level 1

SVX measures impact parameter



Data from commissioning run

(no alignment or calibrations)



Summary

- CDFII upgrade is almost completed. We are making a final checkout of the detector

- New Tevatron has achieved peak luminosity ~2×10^{30}

- Physics quality data taking will start this autumn.

- First physics results of RUNII will be presented by summer 2002

- The prospect of integrated luminosity
  — ~0.2fb^{-1} by the summer 2002.
  — ~2 fb^{-1} by the end of 2003.
  — ~15 fb^{-1} by the end of 2007.
  — all at a cm energy of ~1.96 TeV

  Cf. Run1 intergated luminosity is ~0.1fb^{-1} at 1.80TeV