Status of the CDF Experiment

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(on behalf of the CDF collaboration)

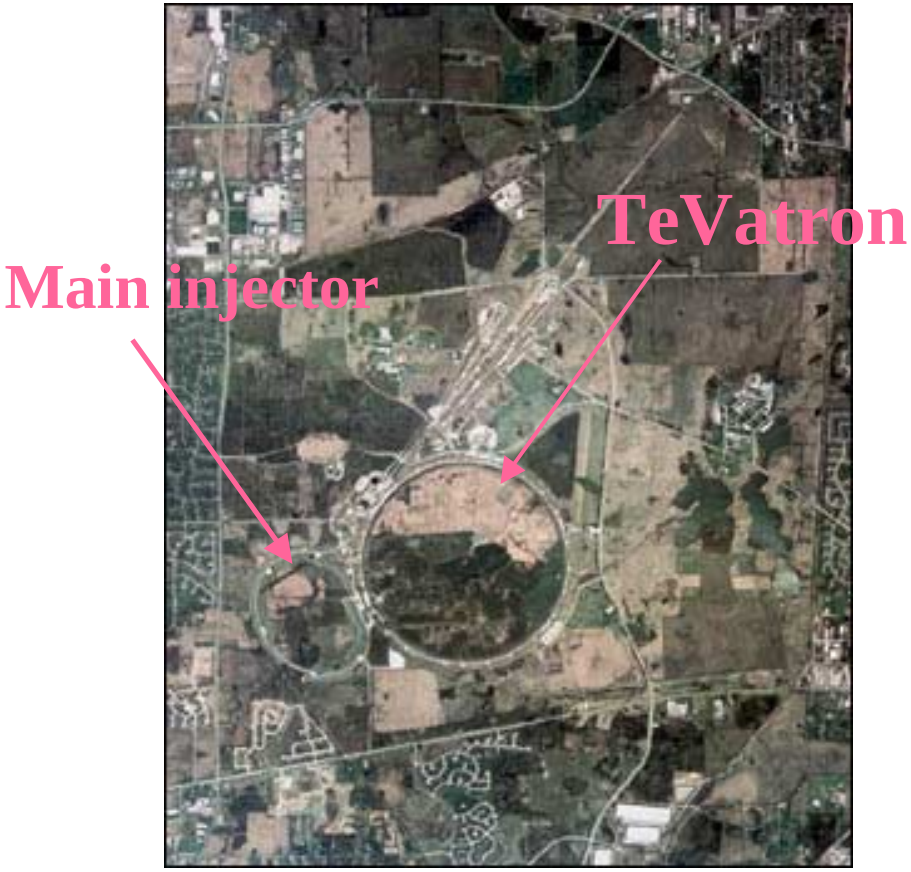
DESY, April 2002

Outline of the talk

- Accelerator and detector upgrades
- Preliminary results from first data ~ 4-8 pb^{-1}
  - Tracking
  - Calorimeter system
  - Muon system
  - Trigger
- Perspectives for (some) Searches
  - top-quark sector, new U(1) gauge bosons, Run I anomalies, Higgs

Tevatron Run II

Accelerator configuration



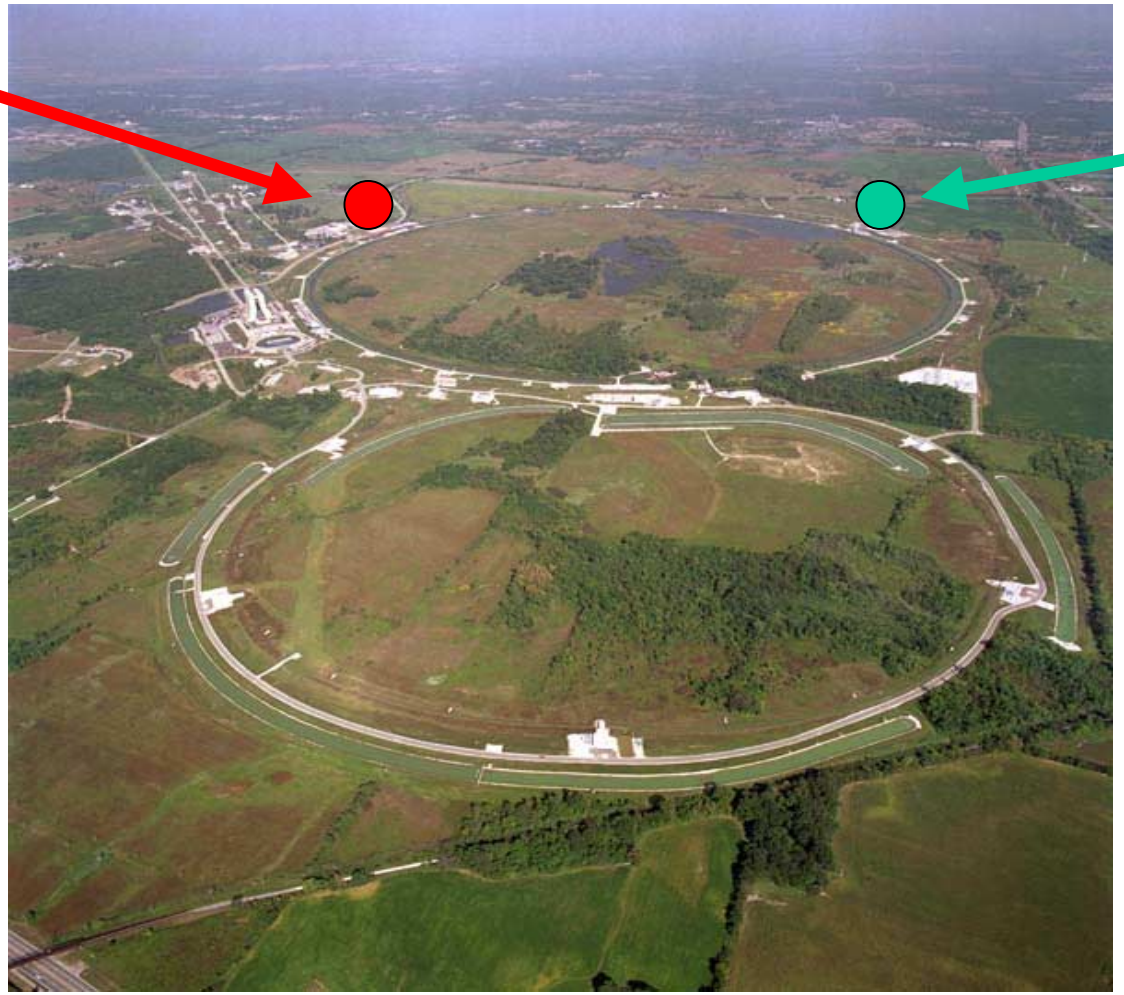
- **Run IIa:**
  - **started officially in March**
  - **until end of 2004**
  - **Goal: L=1 fb^{-1} /year=>2fb^{-1}**
  - **200 pb^{-1} by end of 2002**
- **Run IIb:**
  - **2004 until LHC**
  - **Goal: L=5 fb^{-1} /year=>15 fb^{-1}**
- **Increased collision rate: operation at p p crossing times of 396 ns(IIa) or 132 ns (IIb).**
- **Increased CMS energy: $\sqrt{s}$ = 2.0 TeV**
- **Peak Luminosity:**
  - **Run IIa: 2x10^{32} cm^{-2} s^{-1}**
  - **Run IIb: 2x10^{32} cm^{-2} s^{-1}**
  - **so far achieved: 2x10^{31} cm^{-2} s^{-1}**

The Tevatron

CDF

525 people

13 countries



D0

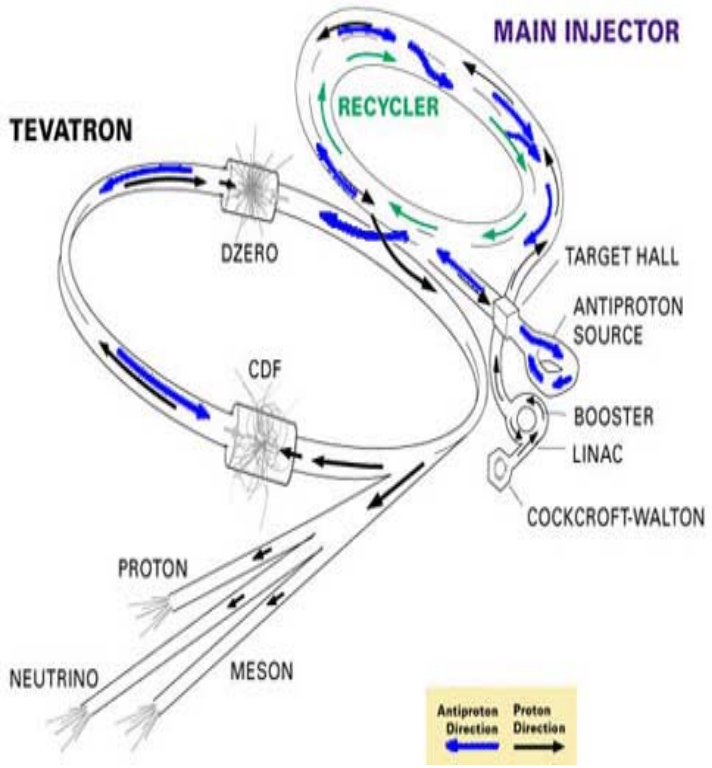
580 people

17 countries

p-$\bar{p}$ collisions at sqrt(s) = 2.0 TeV

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



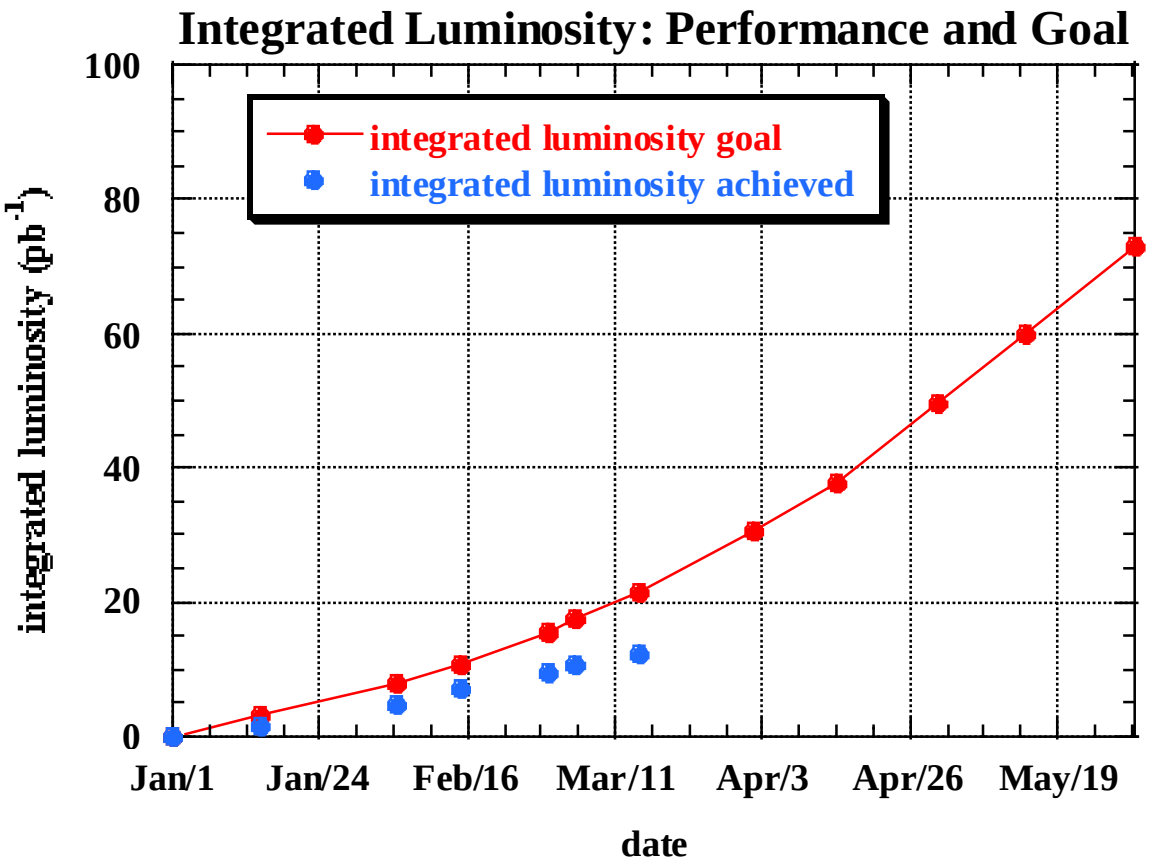
Run 1 vs Run 2

	Run 1	Run 2
Date	1992 – 1996	2001 - 2007
Integrated Luminosity	110 pb^{-1}	$2fb^{-1}$ -> 15 fb^{-1}
c.m. energy	1.8 TeV	2 TeV
Luminosity	2×10^{31} cm^{-2} s^{-1}	2×10^{32} cm^{-2} s^{-1}
Bunch spacing	3.5 μs	396/132 ns

Tevatron Projections

- Run IIa:
  - started officially March 2001:
    - $\int L\,dt$ ~25 pb^{-1} up to now / spec L=1.4x10^{31} $cm^{-2}s^{-1}$
    - $\int L\,dt$ ~200 pb^{-1} by end of 2002 / spec L=2x10^{32} $cm^{-2}s^{-1}$
  - $\int L\,dt$ ~2 fb^{-1} by end of 2004
- Run IIb:
  - $\int L\,dt$ ~15 fb^{-1} by end of 2007
- all at a cm energy of ~ 1.96 TeV
- Proposals to extend Run 2 data to 20-30 fb^{-1}
  - Upgrade of linac could provide 50% more protons

Integrated Luminosity Performance and Goal



TeVatron performance not ideal yet but accelerator division have worked out detailed studies schedule to improve this!

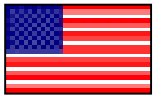
Tevatron Physics Potential
Run 2 vs Run 1

Process $p\bar{p} \rightarrow X\,Y$	Mass Y GeV/c^2	Production sensitivity increase
$t\,\bar{t}$	175	1.4 x 200
W H	120	1.2 x 200
q q	300	1.8 x 200
g g	300	2.1 x 200

Sensitivity increase of Run 2 vs Run 1 200 - 400

CDF Collaboration

North America



3 Natl. Labs
25 Universities

2 Universities

Europe

1 Research Lab
6 Universities

1 University

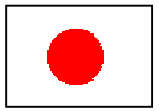
4 Universities

2 Research Labs

1 University

1 University

Asia



4 Universities
1 Research Lab

1 University

3 Universities

Totals

11 countries

55 institutions

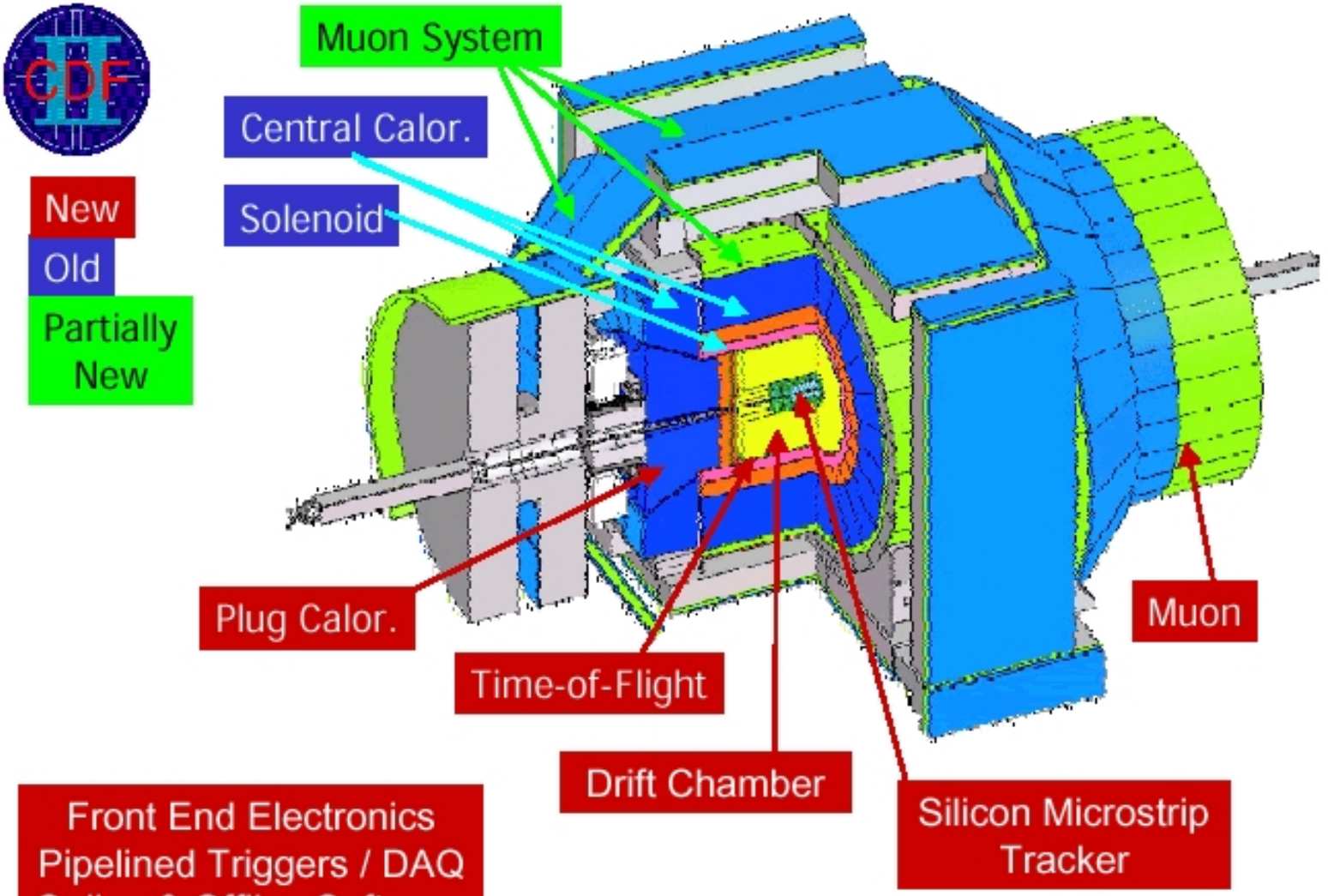
525 physicists

Experiment status and plans

- Since operation start-up in the collision hall in March 2001, the CDF detector has been commissioned using ~ 20 pb^{-1} of data provided by the Tevatron (utilized about 4 to 8).
- Most detector components are ready for physics quality data.
- Goal is first physics results by summer-fall 2002

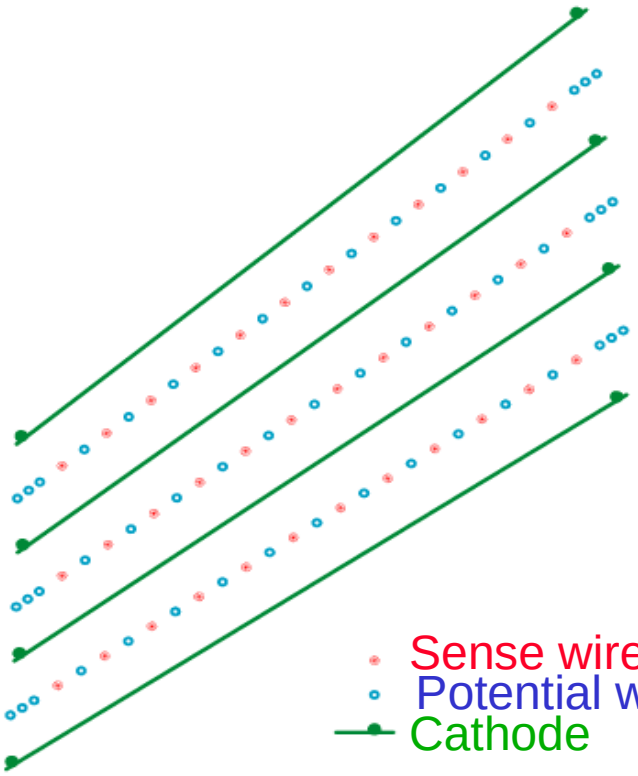
Detector roll-in February 2001

CDF


CDF
New
Old
Partially New
Muon System
Central Calor.
Solenoid
Plug Calor.
Time-of-Flight
Drift Chamber
Silicon Microstrip Tracker
Muon
Front End Electronics
Pipelined Triggers / DAQ
Online & Offline Software

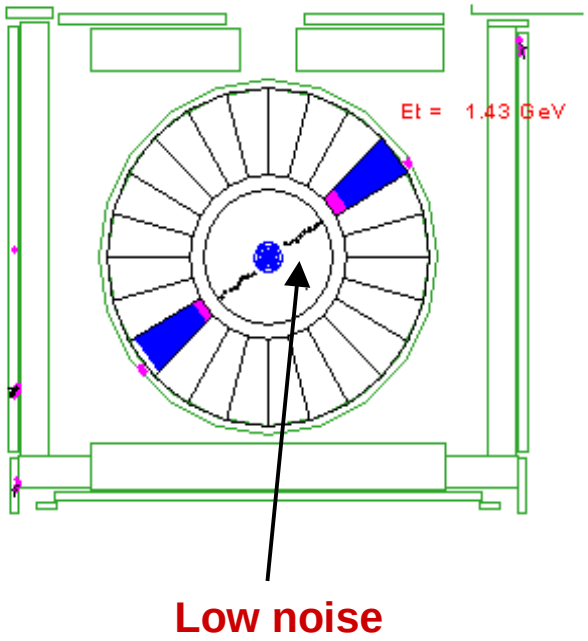
Central Outer Tracker Upgrade

96 wire planes
8 superlayers
50% are 3° stereo
~1.0 cm drift cells
30,240 sense wires



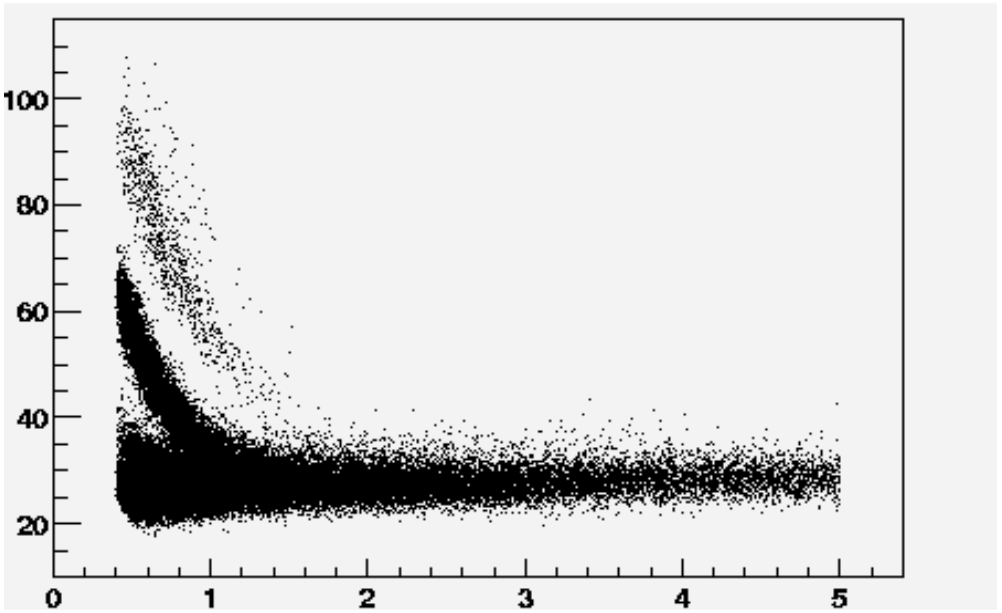
COT performance

Cosmic ray tracks



COT wires

96 pulse height measurements
dE/dx measured from pulse width
via new ASD + TDC electronics

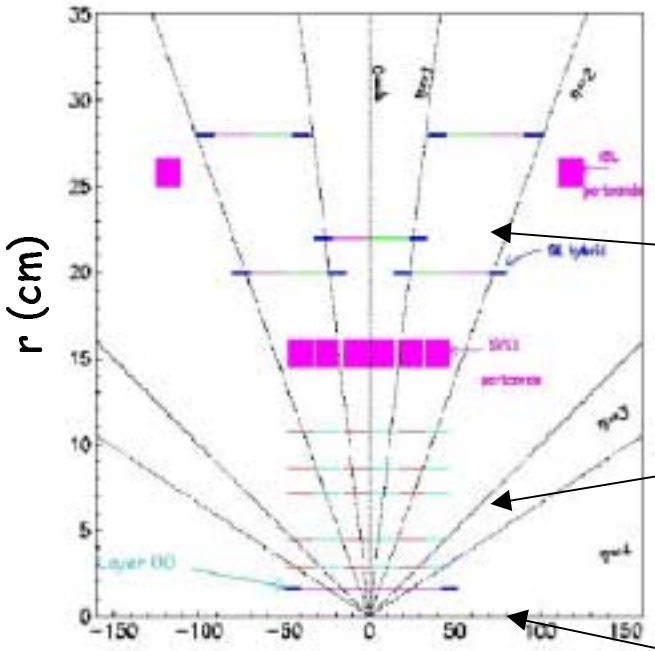


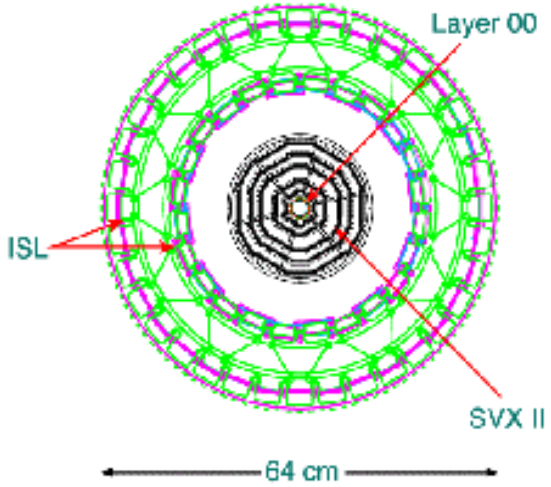
COT performing very well: ready for physics!

Silicon Detector Upgrade

- The silicon strip detector is a stand-alone 3d tracking system
- A six layer vertex detector with impact parameter resolution

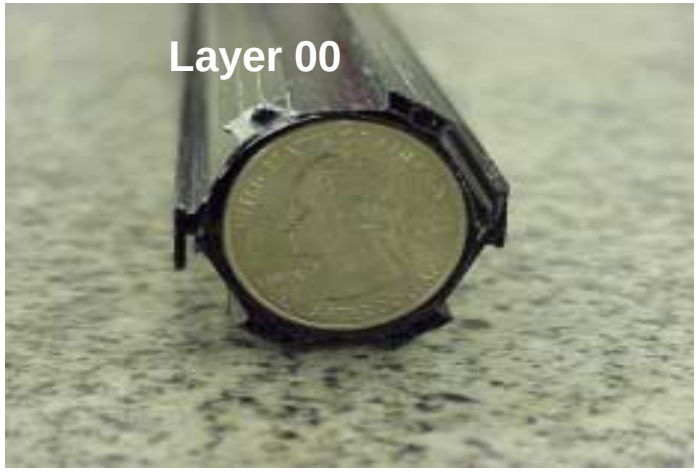
  $\sigma_d = \sqrt{a^2 + (b/P_t)^2}$ (a =7μm, b =20-30μm)
- Intermediate silicon layers for extrapolation to central outer tracker and forward tracking up to η=2



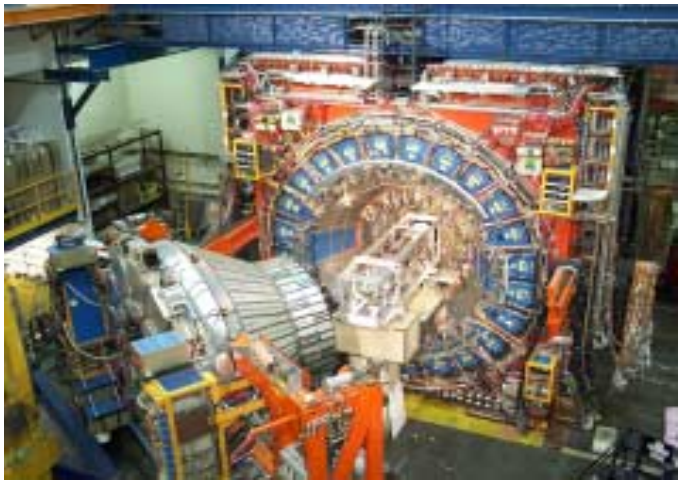


- 720000 readout channels!!!
- about 6m^2 of Si in total

Installation of the Silicon Detectors



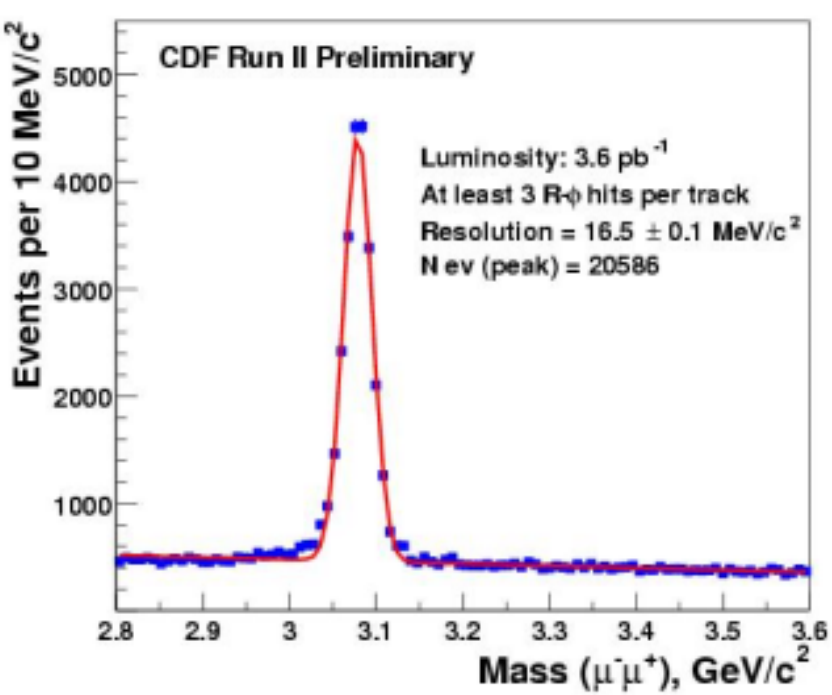
Installation inside CDF

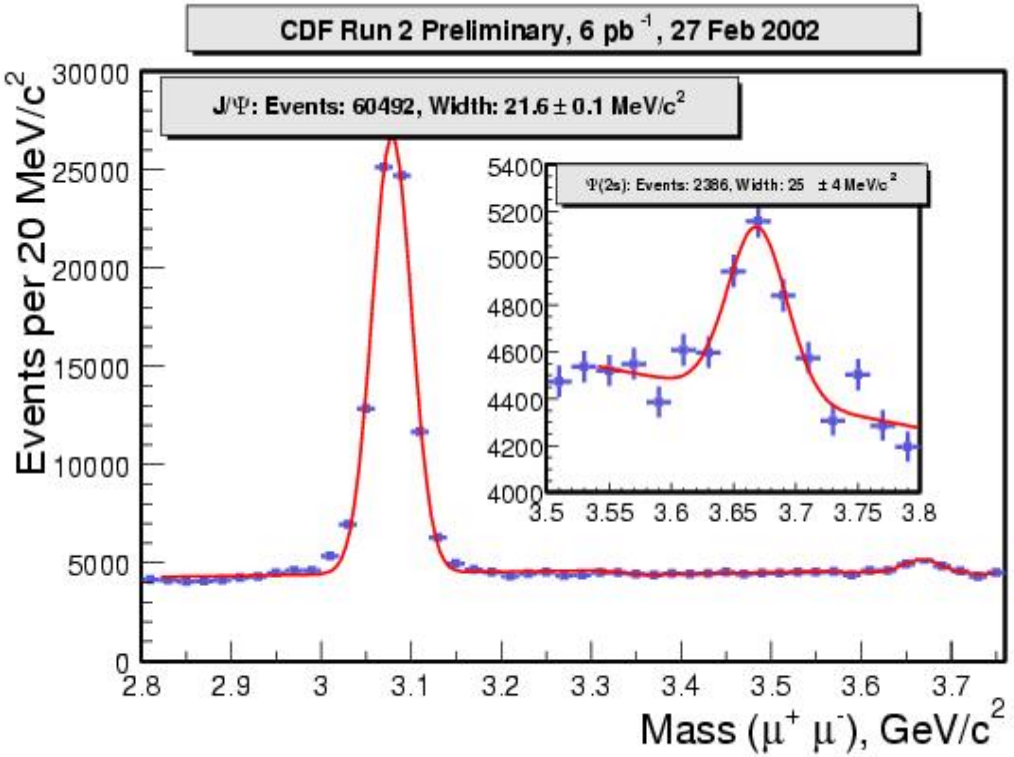


SVXII+L00 94% integrated and working

ISL cooling pipes blocked -> free with Laser in summer shutdown

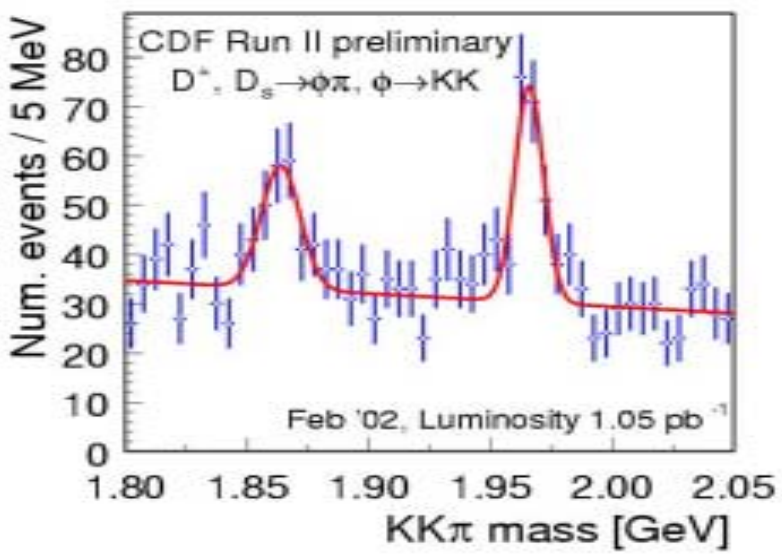
Tracking data: J/ψ resolution

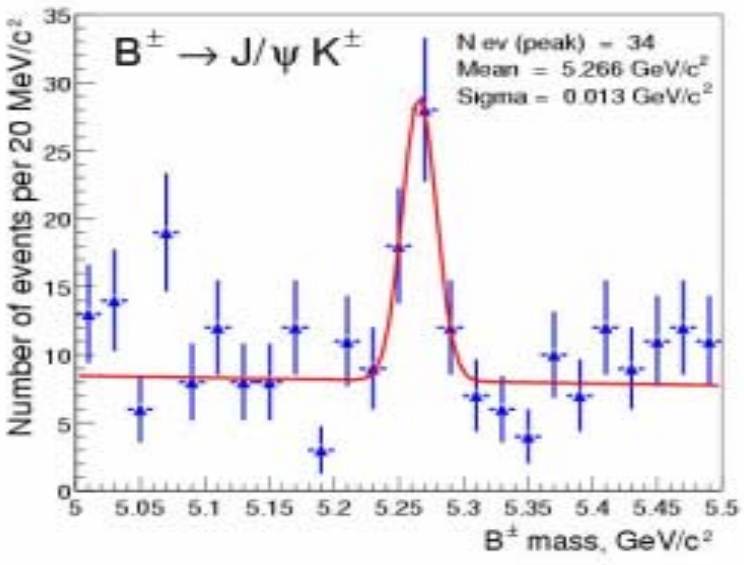




- Resolution improved from 22 MeV to 16.5 MeV
- further improvement expected with better internal alignment

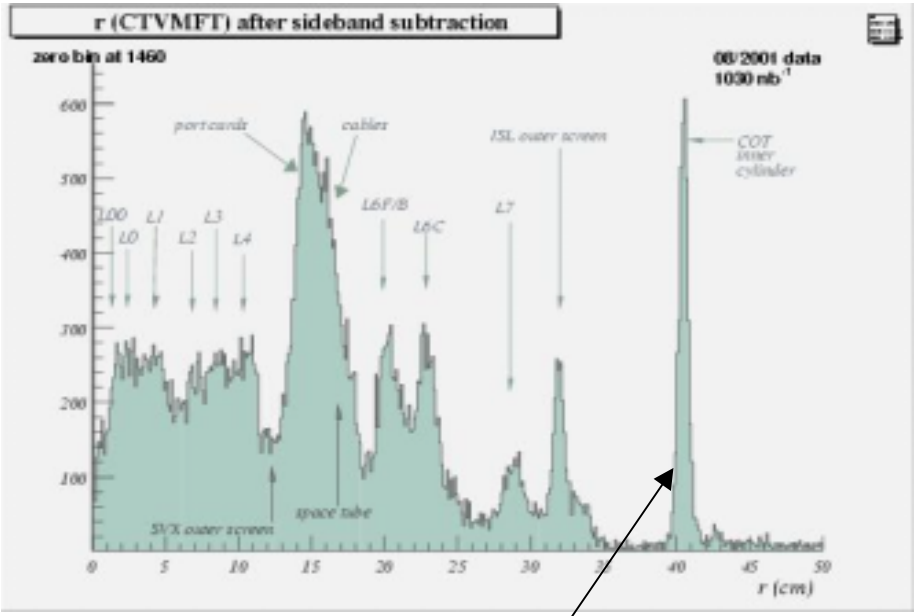
Tracking: B and D Mesons



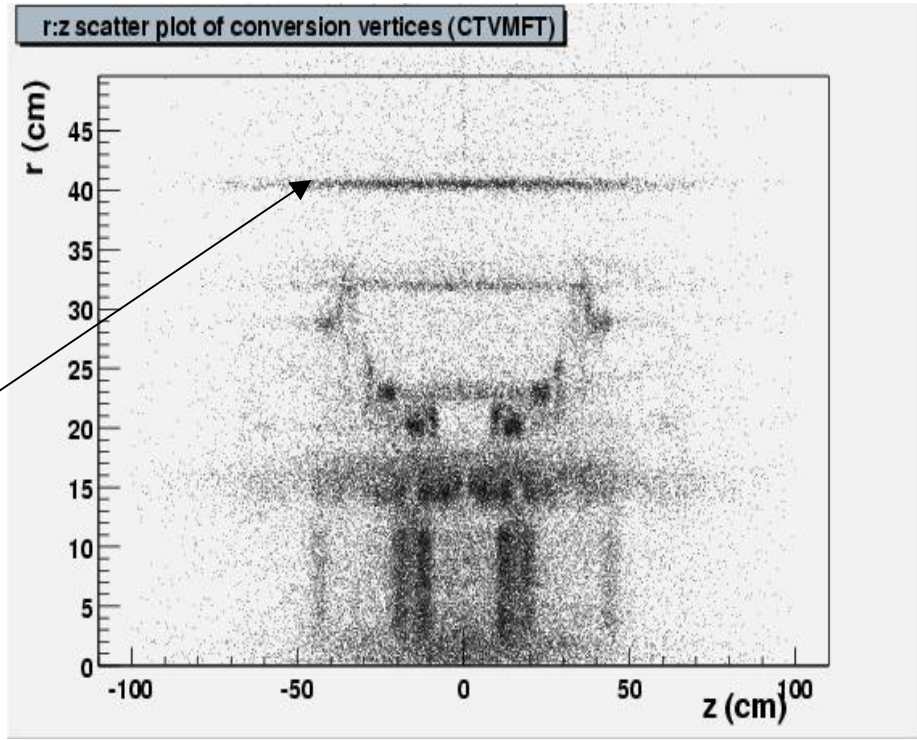


- Clear signals of D^+, D_s and $B^\pm$ using the COT and Si tracking
- COT calibration, Si alignment and tracking algorithms are progressing rapidly

X-Raying the material



Photon conversions (e^+e^- pairs) reconstructed with COT ==> X-ray of material

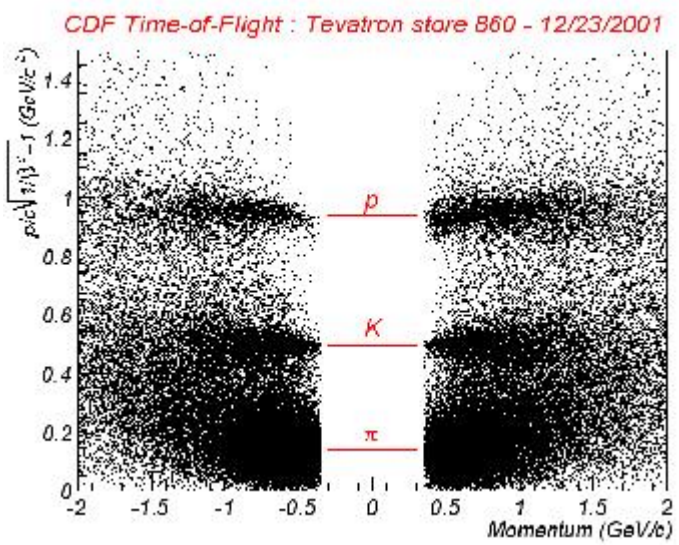


COT inner cylinder

A lot of material (cables, portcards, etc.) well understood: vital for simulation!

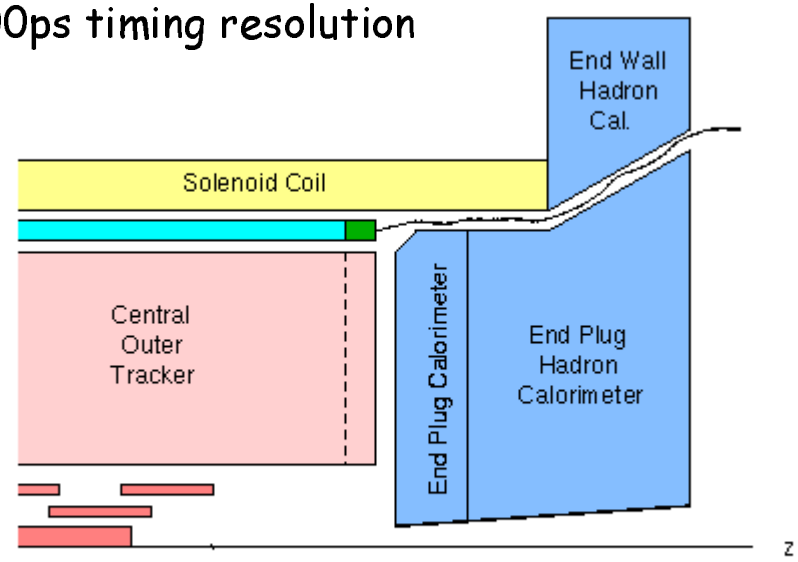
Time Of Flight System

- New detector between coil and tracking chamber
- measure TOF of charged particles with 100 ps precision



TOF scintillator bars

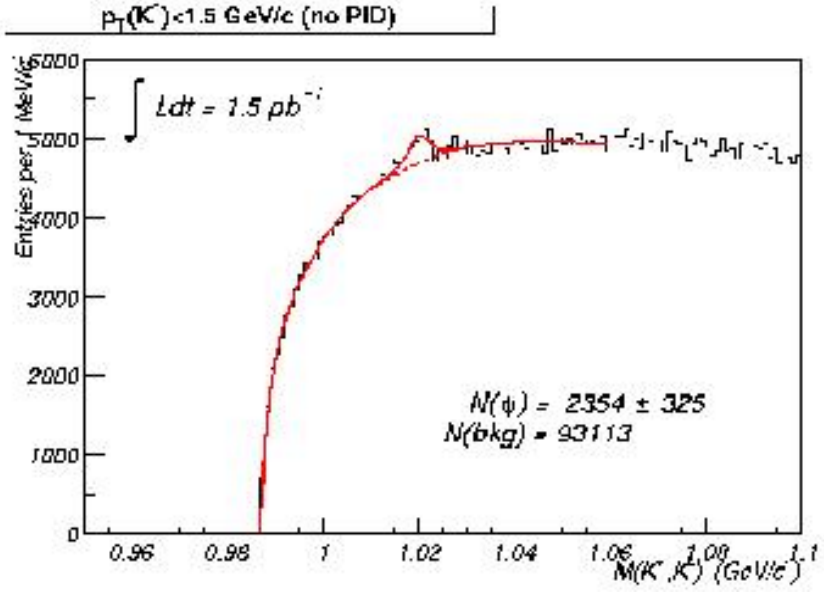
- 216 x 2 PMT channels
  100ps timing resolution

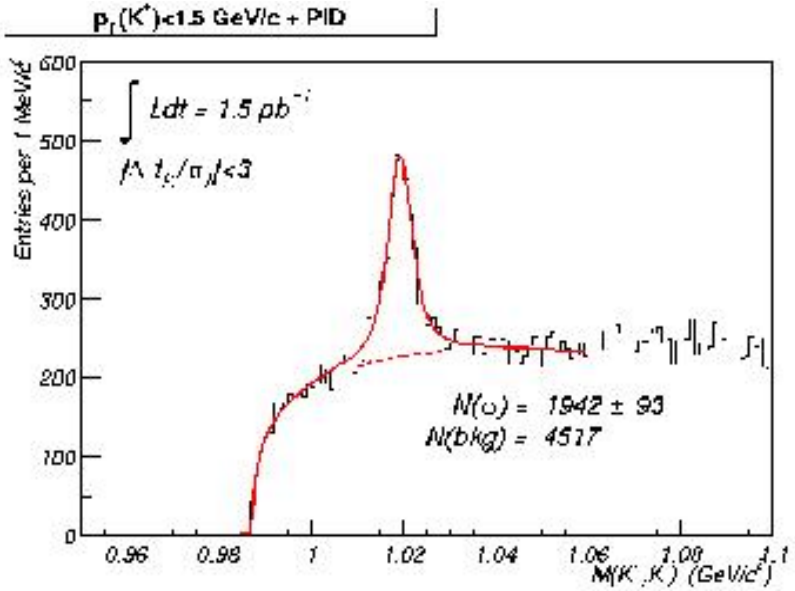


Final calibrations in progress but
150 ps esolution achieved already!

Particle Identification: TOF

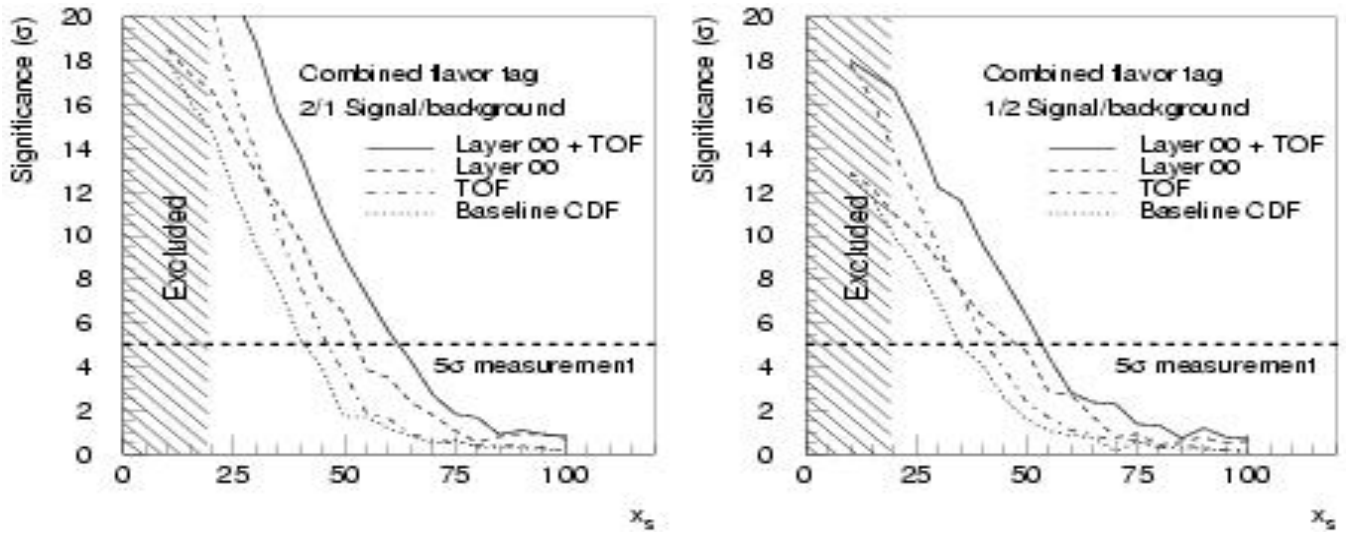
Φ->KK reconstruction: S/B improves from 1/50 to 1/2 when using TOF for Particle ID!!!





Impact on B-physics: TOF

- Physics associated with B-meson, in particular B_s^0 mixing (unitary triangle verification)
- With L00 and TOF discovery reach/exclusion limits improved by >= 30%



- Also already proven to be useful e.g. for rejection of cosmic rays

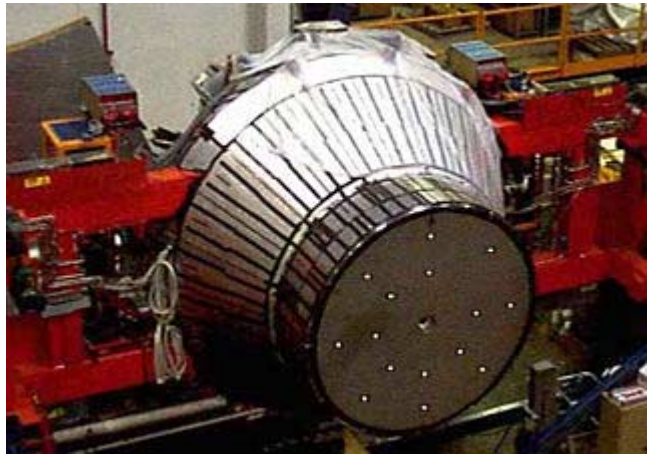
Calorimeter Upgrades

Central calorimeters retained from Run 1 with new readout electronics

- $|\eta|$ out to 1.0
- EM and hadronic towers with segmentation: $\phi \times \eta = 15^0 \times 0.11$
- Drift chamber at maximum of shower in EM Calorimeter ("ShowerMax")

New scintillator based **plug calorimeter**

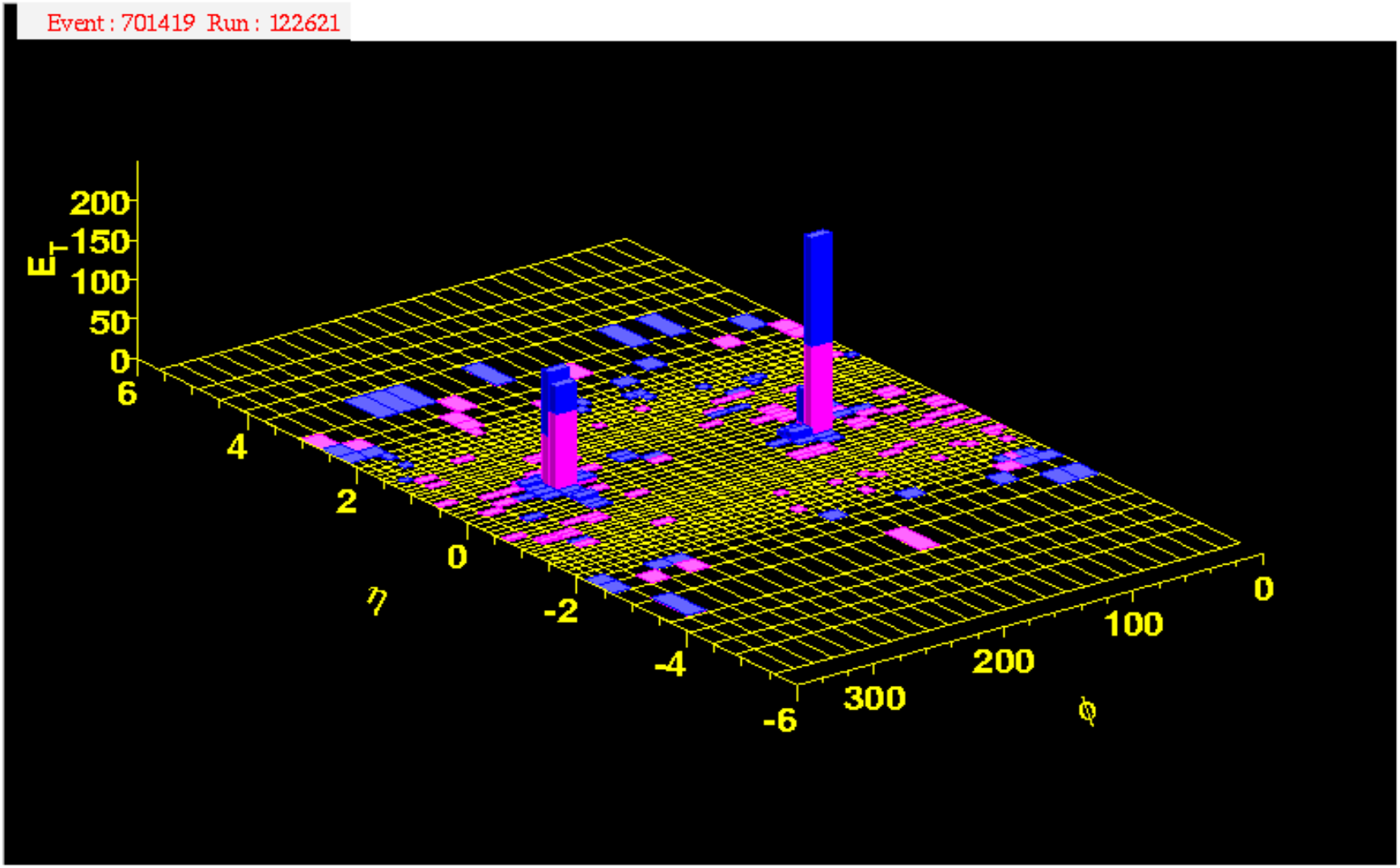
- $|\eta|$ out to 3.6
- EM, hadronic
- ShowerMax
- central calorimeter η-ϕ-segmentation maintained as far as possible.



New **MiniPlug**

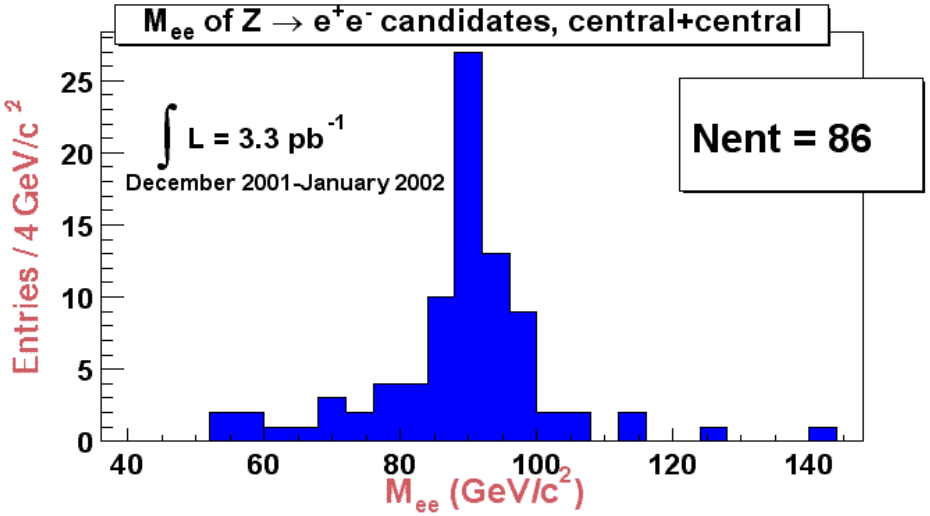
- $|\eta|$ out to 5.5
- diffractive physics/forward jets

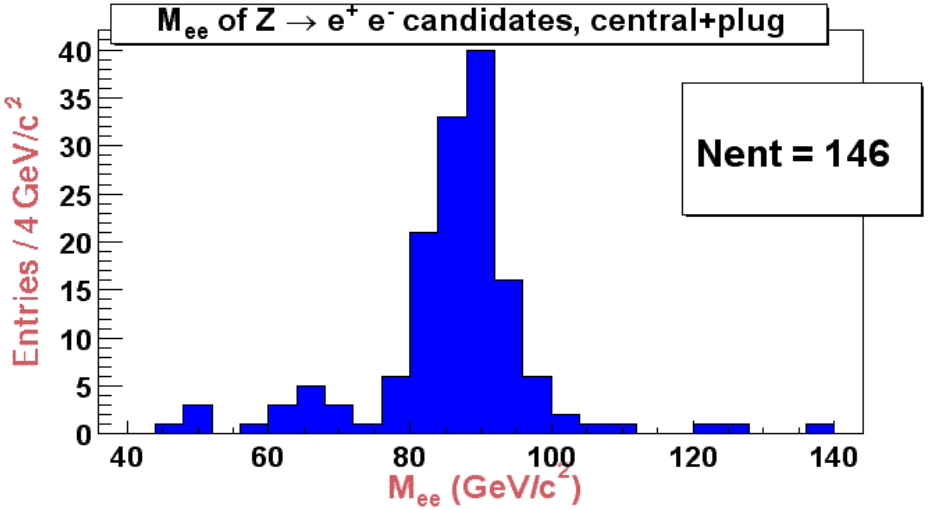
Dijet Event with E_t~400 GeV



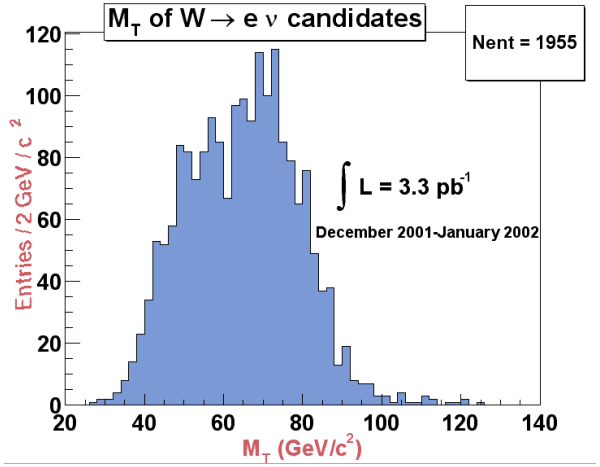
High Pt Electrons

Z -> e^+ e^- invariant mass





W -> e ν transverse mass

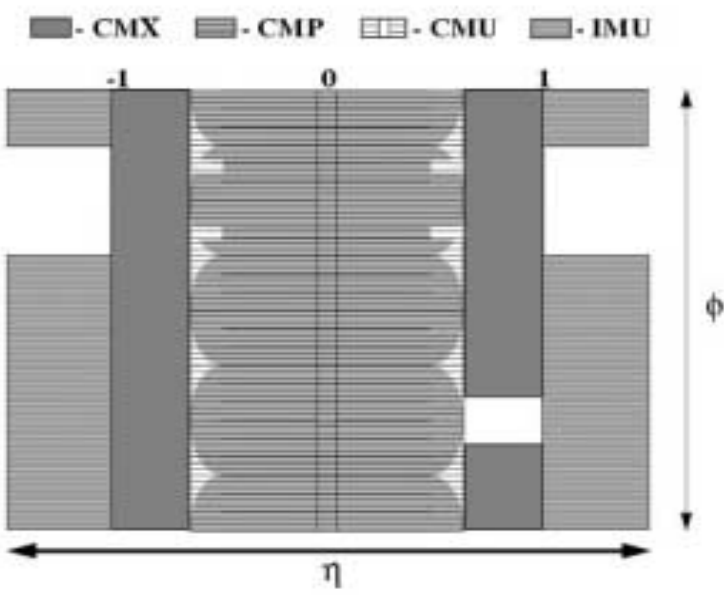


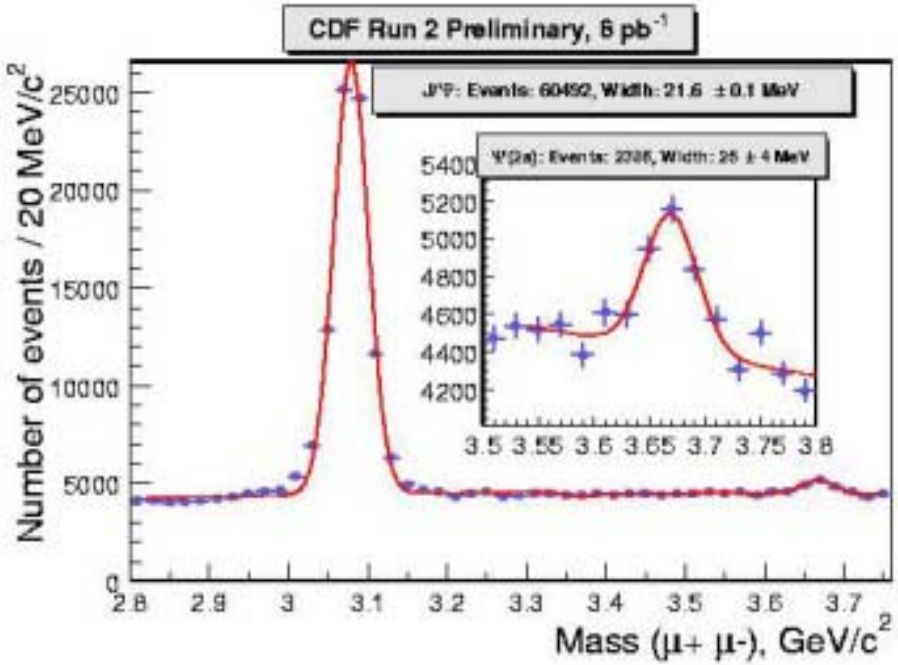
EM Calibration in good shape in both central and new plug Calorimeters

Muon System Upgrade

"Old" Run 1 central muon detectors retained but new readout electronics

"New" extension (CMX) and intermediate (IMU) muon chambers will extend muon coverage from $|\eta|$ = 0.6 to 1.6 (for $|\eta| > 1.0$ use Si tracking)

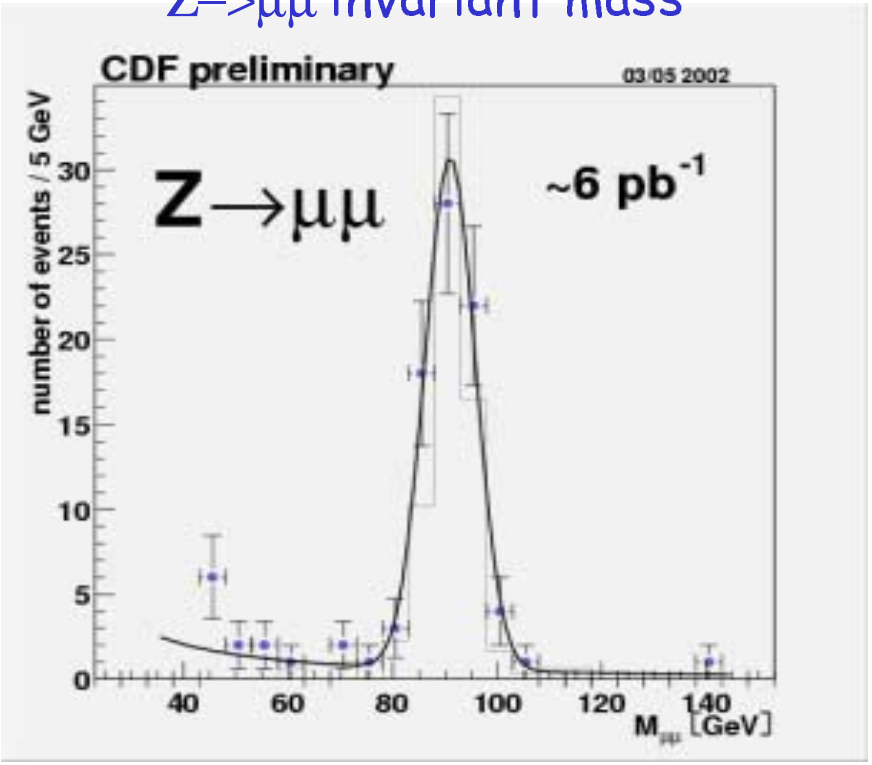




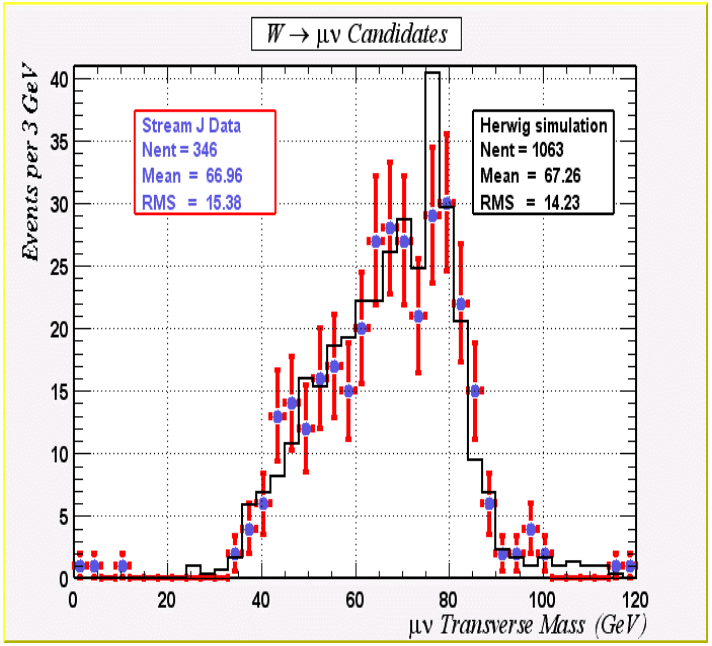
More than 60000 J/Ψ mesons in μ channel

More Muon Data

Z–>μμ invariant mass

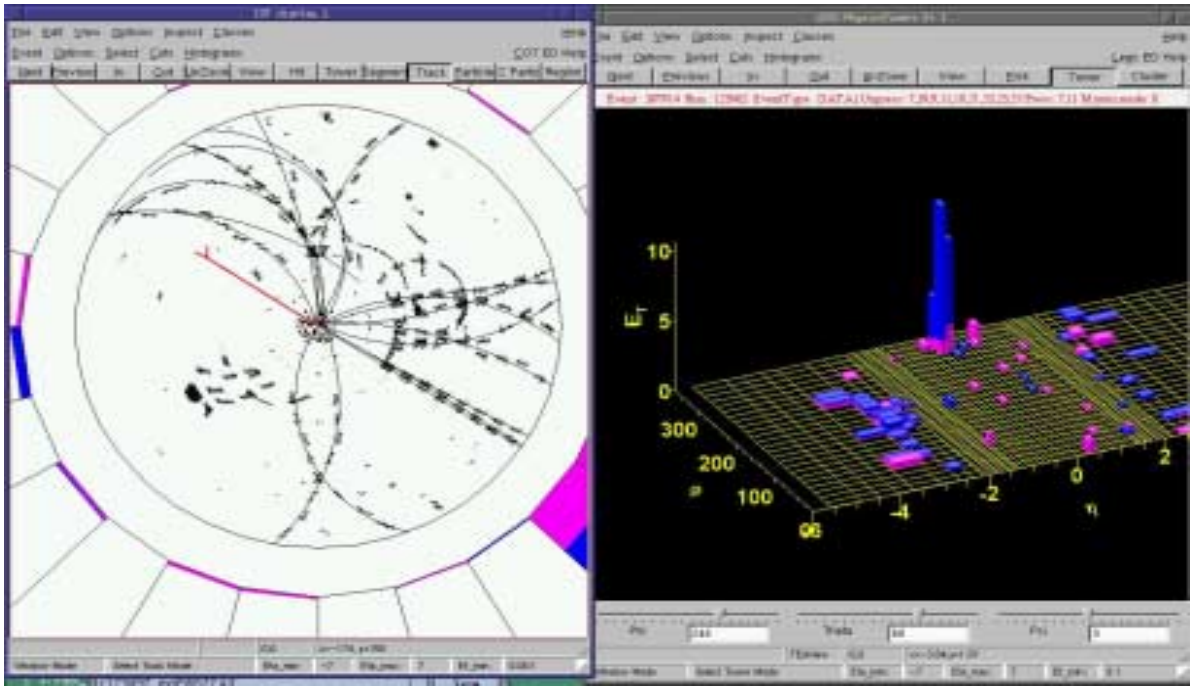


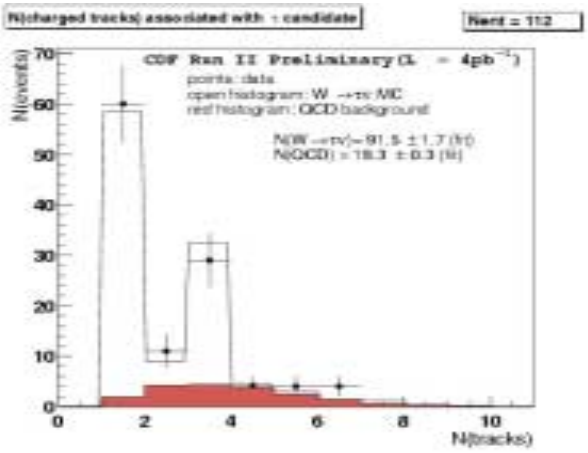
- W -> μ ν transverse mass

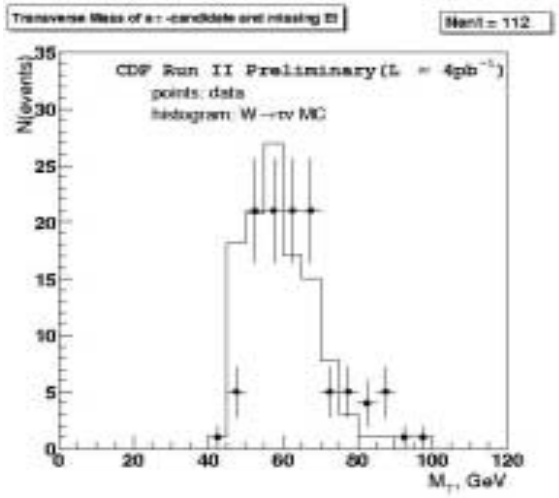


Muon System and reconstruction performing well

First τ signals





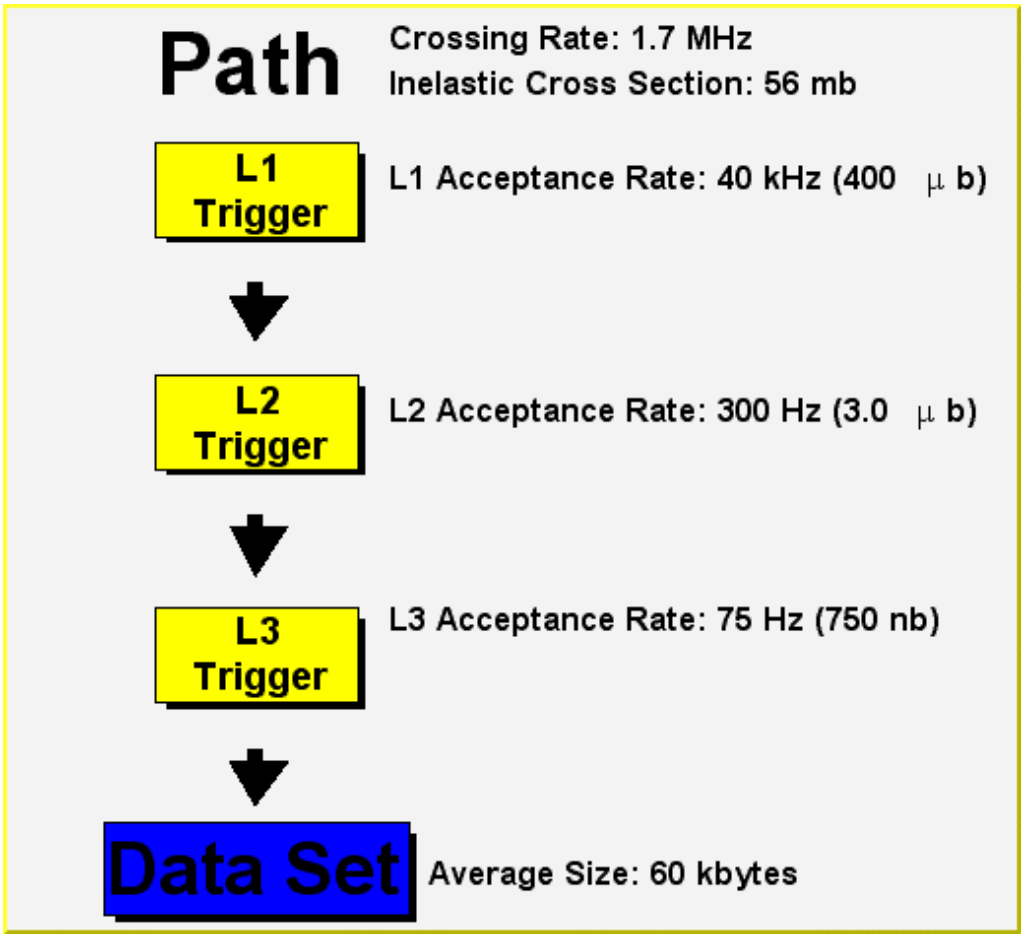


Clear W–>τν signal already with 4 pb^{-1}

τ-ID important for SUSY at high tanβ

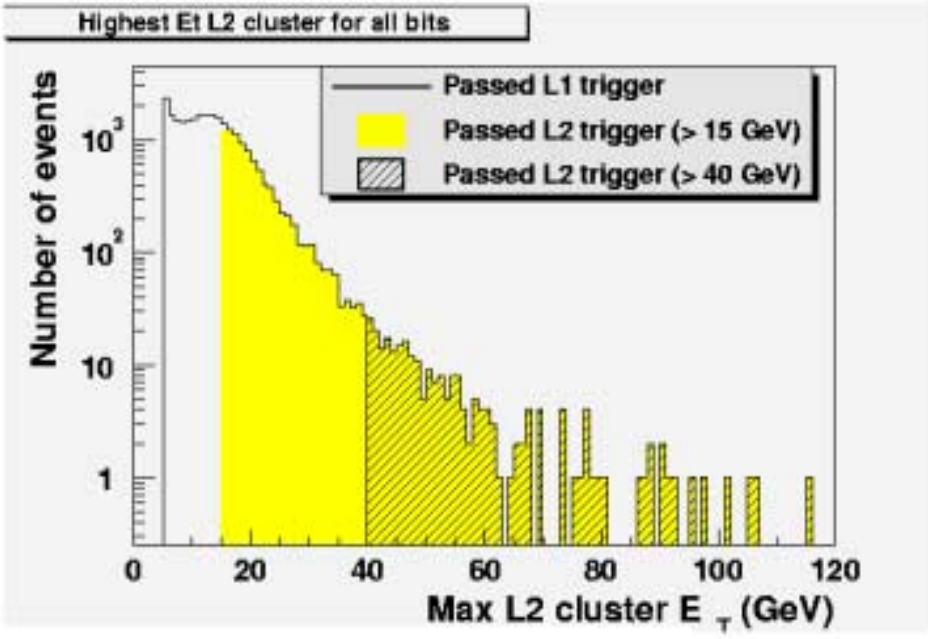
Trigger system

- **Level 1:**
  - **Calorimeter:**
    - **single towers: jets, electrons,...**
    - **Global triggers : MET, SumEt,...**
  - **eXtremly Fast Tracker (PT>1.5 GeV)**
  - **Muons**
- **Level 2:**
  - **Calorimeter clustering**
  - **Silicon Vertex Tracker**
- **Level 3:**
  - **offline-like reconstruction**



Calorimeter Trigger

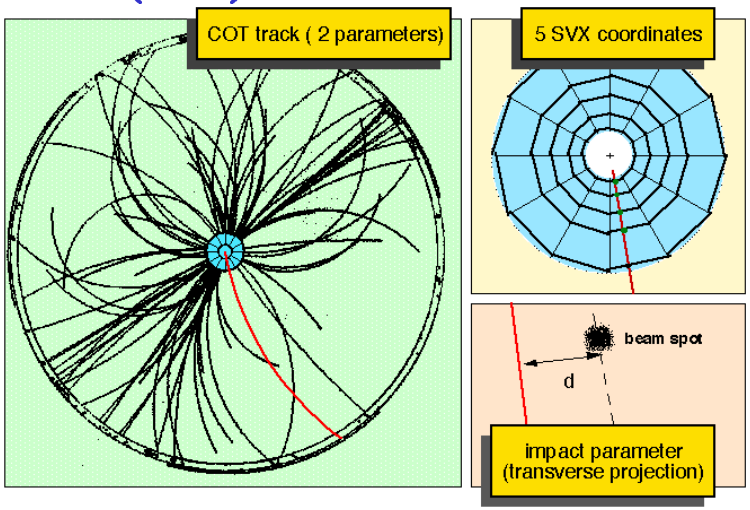
- E.g. Jets:
  - Single Tower trigger at L1
  - Tower clustering at L2
  - Jet Algorithm at L3
  - Inclusive jets prescaled for Et<100 GeV
- all Calorimeter triggers ready for physics

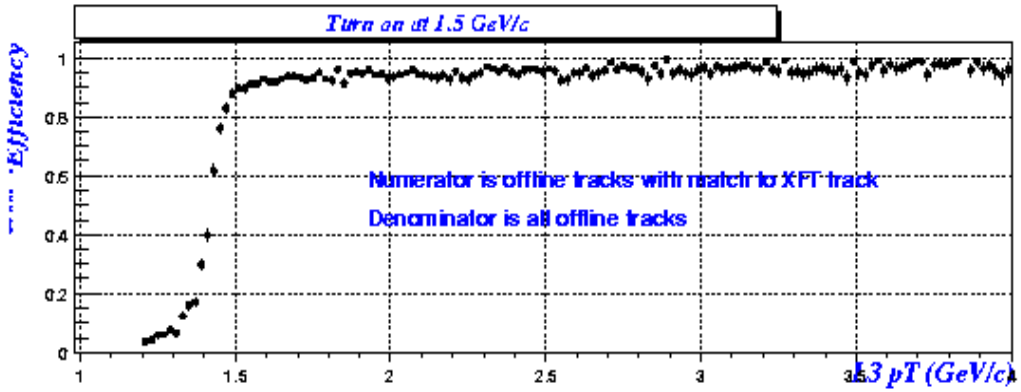


XFT and SVT trigger status

COT defines track momentum cut at level 1 (XFT)

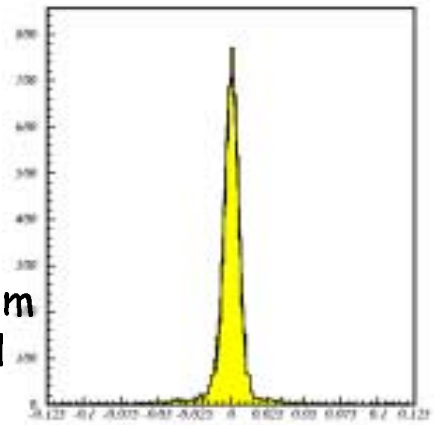
SVX measures impact parameter cut at level 2 (SVT)





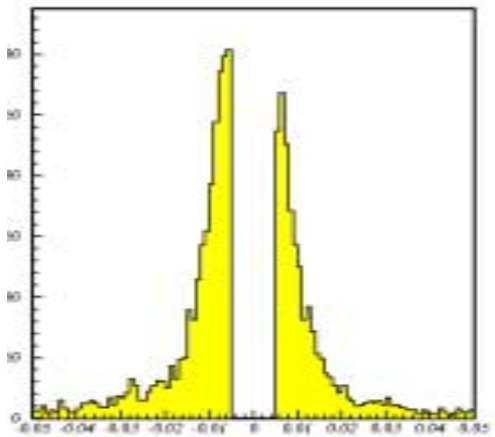
d_o (cm)

SVT impact parameter



σ= 48 μm including beam spot spread

SVT impact parameter cut at 50 μm

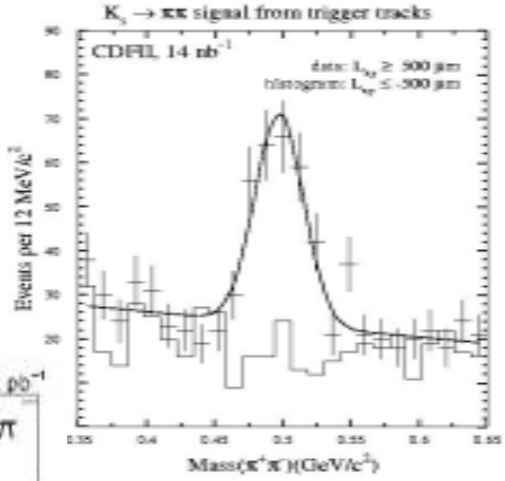


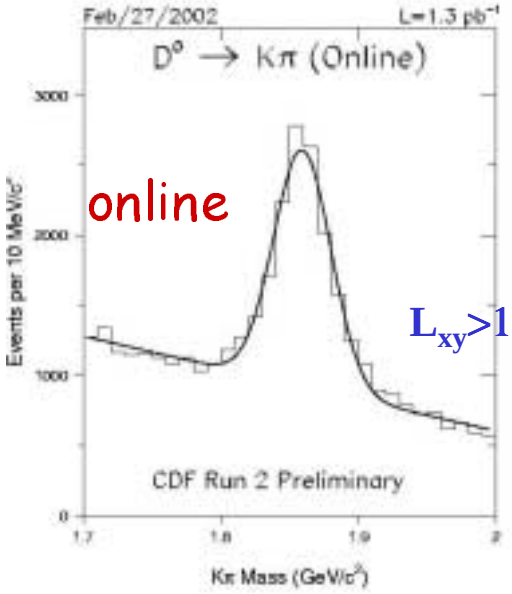
d_o (cm)

Using SVT Trigger

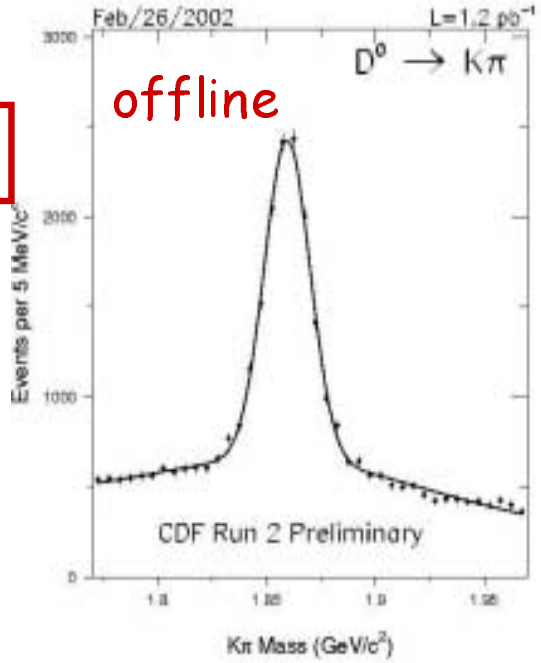
- trigger on large impact parameter at L2 (using XFT and SVX)
- only way to trigger hadronic B-decays (B->ππ): 2 tracks with d_0>100 μm
- SVT trigger running successful since October 2001

$K_s \rightarrow \pi\pi$





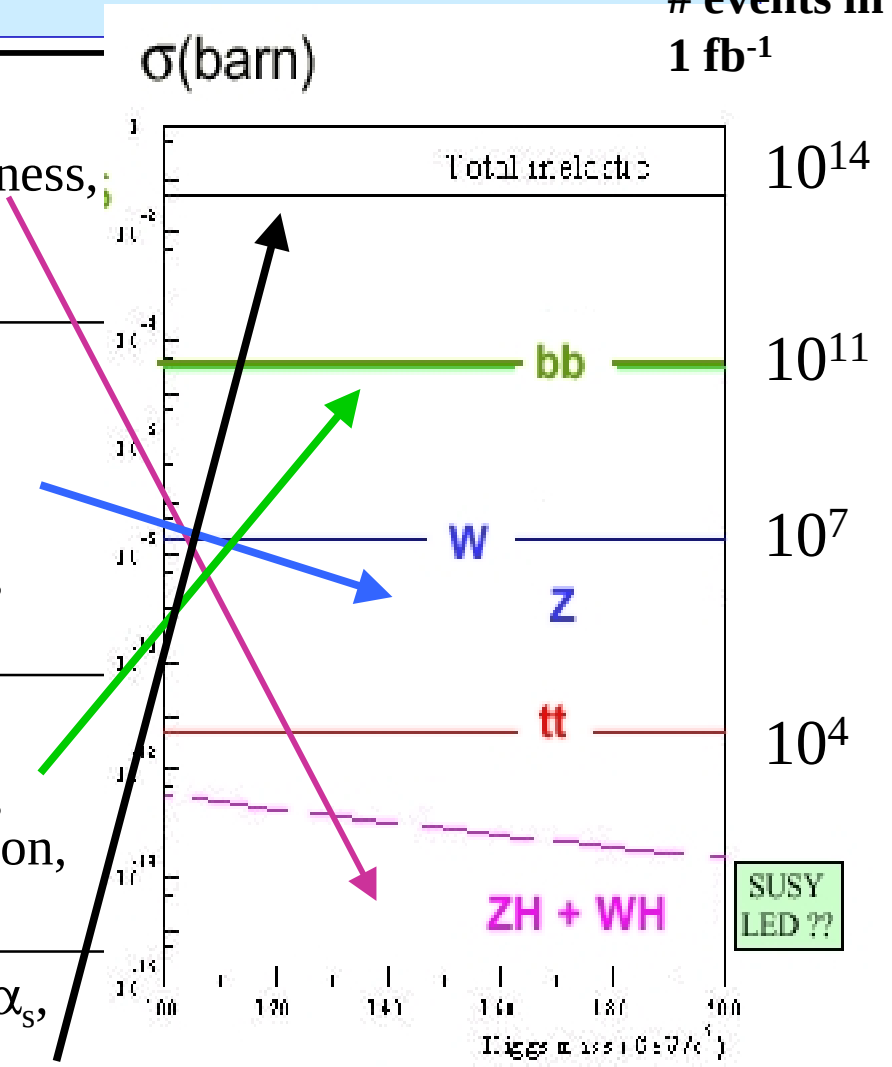
$D^0 \rightarrow K\pi$



Triggering about 8 D^0/nb^{-1}: huge sample for charm physics

Physics potential of Run 2

Searches	**Higgs** SUSY, compositeness, leptoquarks etc.
Electroweak	**W**: mass, width, gauge couplings **Top**: mass, cross-section, branching ratios
Heavy flavour	**Lifetimes,** cross-section, B_c, Λ_B, B_s studies, CP violation, $\mathbf{x_s}$
QCD	Jet cross-section, α_s, multijet events



 # events in 1 fb^{-1}

10^{14}

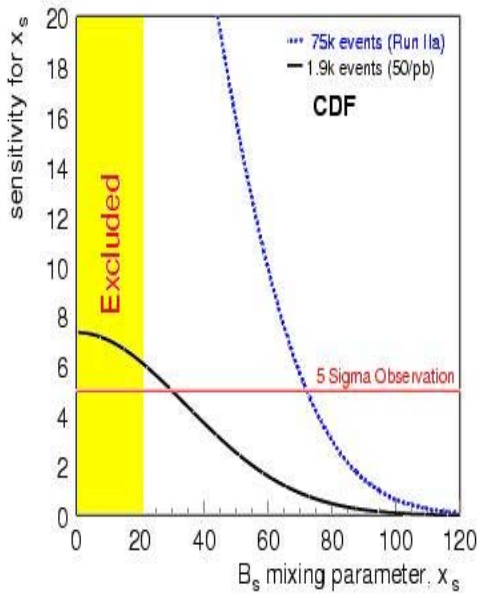
10^{11}

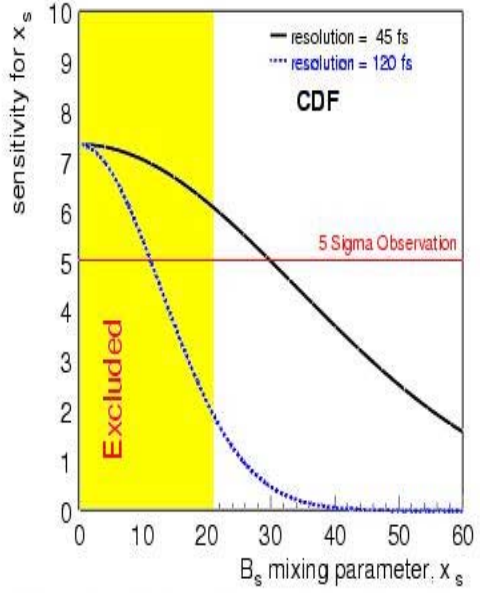
10^{7}

10^{4}

Beauty at CDF II

- B-physics greatly profits from Run II upgrades
  - SVT trigger: trigger on hadronic B decays
  - Silicon tracking (decay length, secondary vertex)
  - TOF: particle ID (π-/K-separation)
  - COT: dE/dx for particle ID
- highlight B_s mixing: reach up to x_s=30 for only 50 pb^{-1}



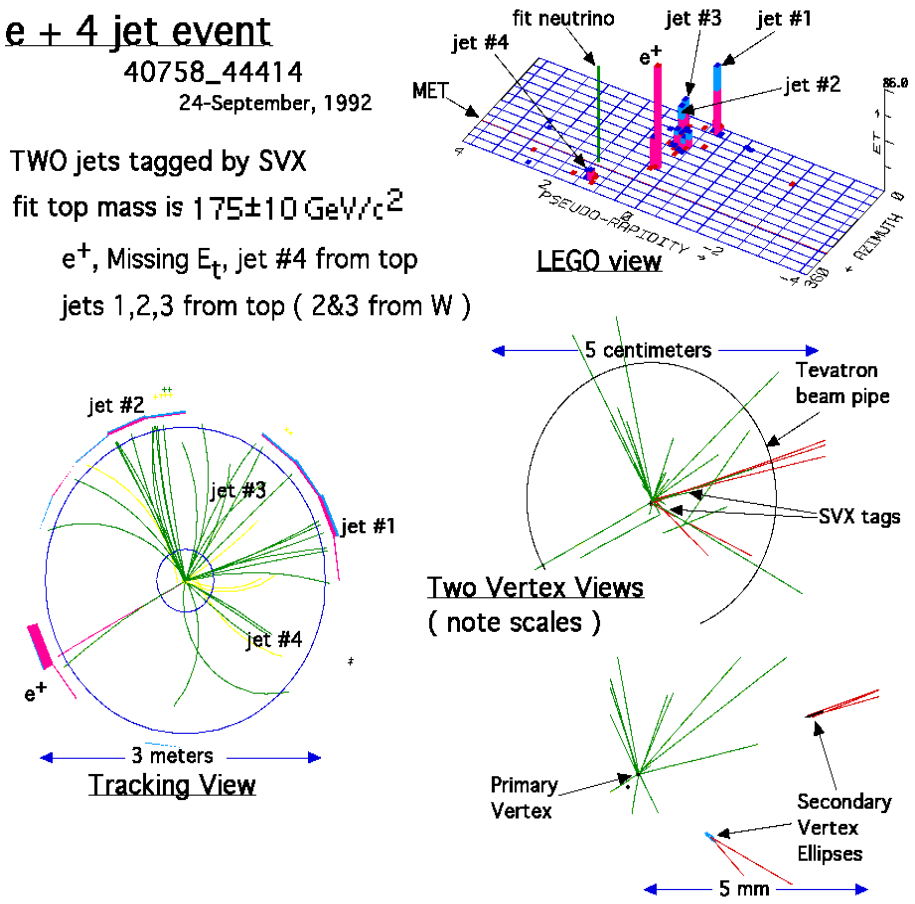


Reach varies between 11 - 30

$N(B_s)$ = 75k, 1.9k
εD^2 = 11.3%
σ_t = 45 fs, 120 fs
S/B = 1 : 2 – 2 : 1

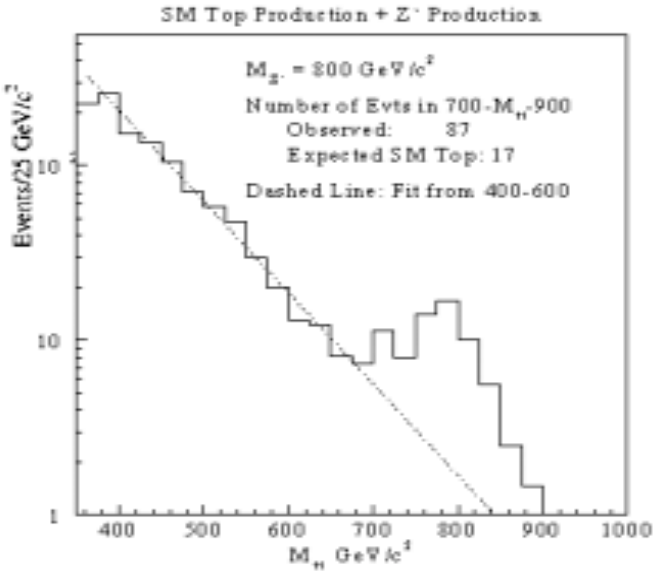
Top Physics in Run II

- Discovery (Run I) -> precision (Run II)
- B detection efficiency will be improved in Run 2
- more efficient triggering in all-hadronic mode with level 2 displaced vertex triggers
- Increased acceptance for leptons due to ISL at high η
- 13000 top events in 2 fb^{-1} (only about 100 used in Run I)

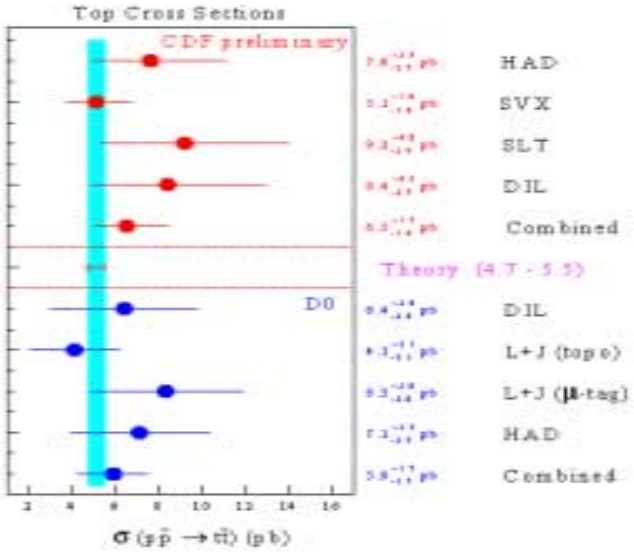


New Physics in Top Sector(1)

- new particle X-> t t



- production cross-section: agreeing with SM?

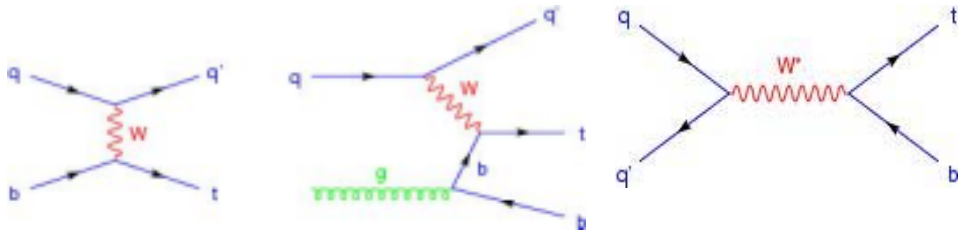


Uncertainty	Run 1	Run 2a	Run 2b	LHC
Statistical	16	3	0.7	0.4
Systematic	20	6	5	5 (~ *Lum*)

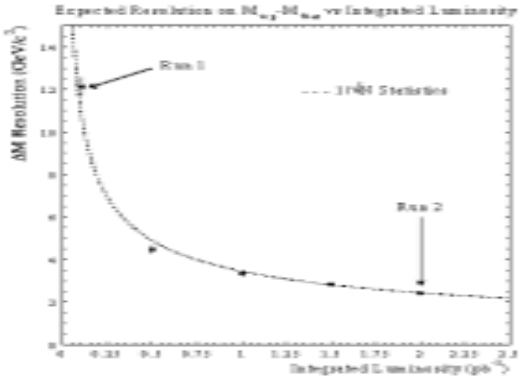
New Physics in Top Sector(2)

- **Rare decays:**
  - t -> W s BR ~ 10^{-3}
  - t -> W d BR ~ 5 x 10^{-5}
  - t -> g c,u BR ~ 10^{-8}
  - t -> Z c,u BR ~ 10^{-12}
- Righthanded W
  - F=0.11+-0.15+-0.06
- W polarisation
  - F=0.97+-0.37+-0.12
- M(t)-M(t)=0?

- single top => V_{tb}
  - Run I: σ<13.5 pb @95%CL



	Run 1	Run 2a	Run 2b	LHC
σ(single top)	–	~ 20	~ 8	~ 5 (lum)
$\Gamma(t \to Wb)$	–	~ 25	~ 10	~ 10
$\lvert V_{tb}\rvert$	–	~ 12	~ 5	~ 5



Higgs Hunting at the Tevatron

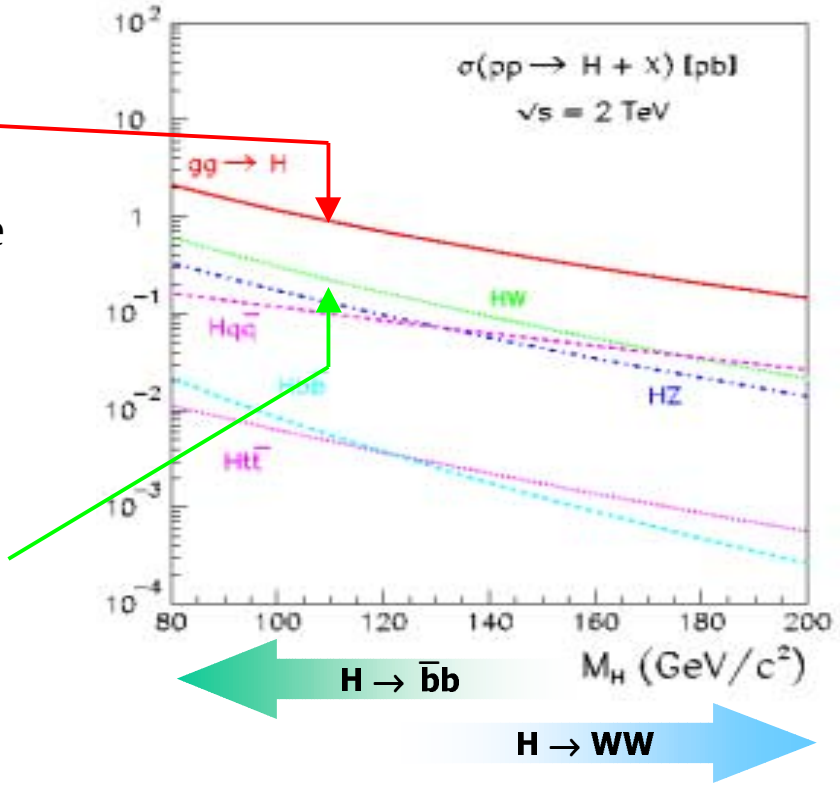
- Inclusive Higgs cross section is quite high: ~ 1pb
  - for masses below ~ 140 GeV, the dominant decay is H → bb
  - at higher masses, can use inclusive production plus WW* decays
- the best channel below ~ 140 GeV is

associated production of H plus a W or Z

  - leptonic decays of W/Z help give the needed background rejection
  - cross section ~ 0.2 pb

– vital ingredients:

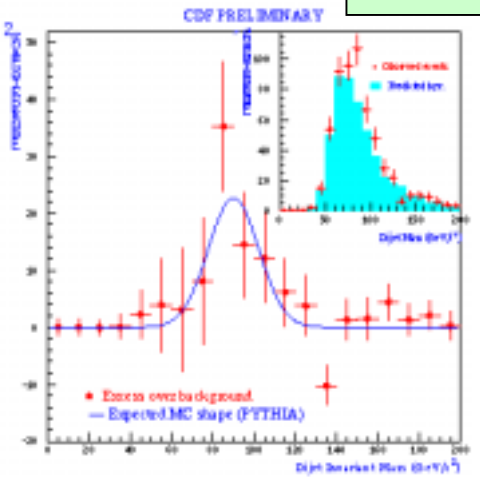
  - mass resolutions (jet energies)
  - b-tagging
  - understanding of BG
  - clever analysis (NN,etc.)



Dominant decay mode

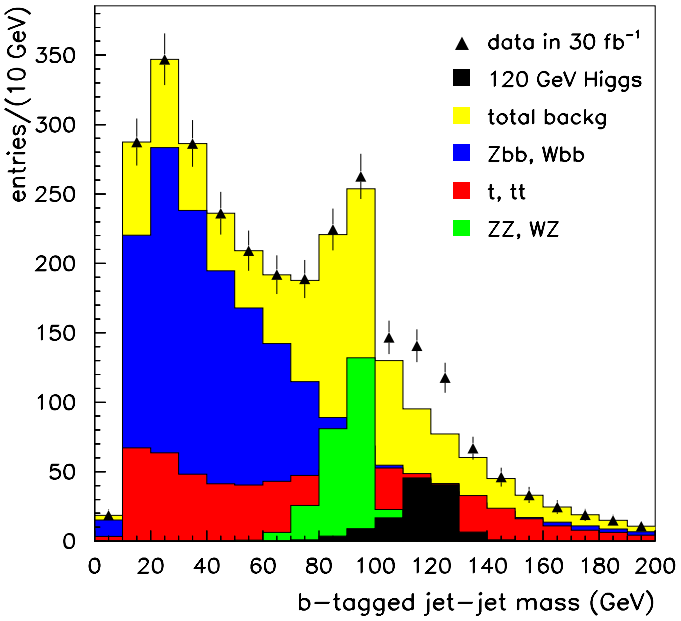
Higgs Search

Find a signal

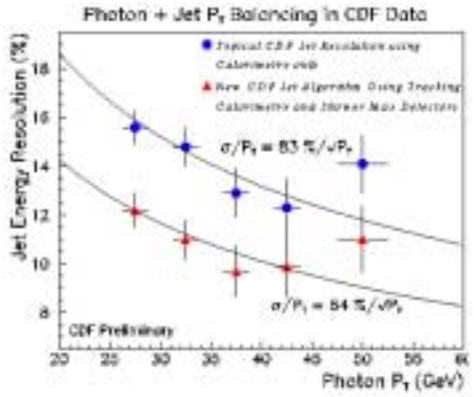


CDF Run I
Z -> b b
data

120 GeV Higgs for 30 fb^{-1}



Develop new jet measurements
to improve the di-jet mass resolution

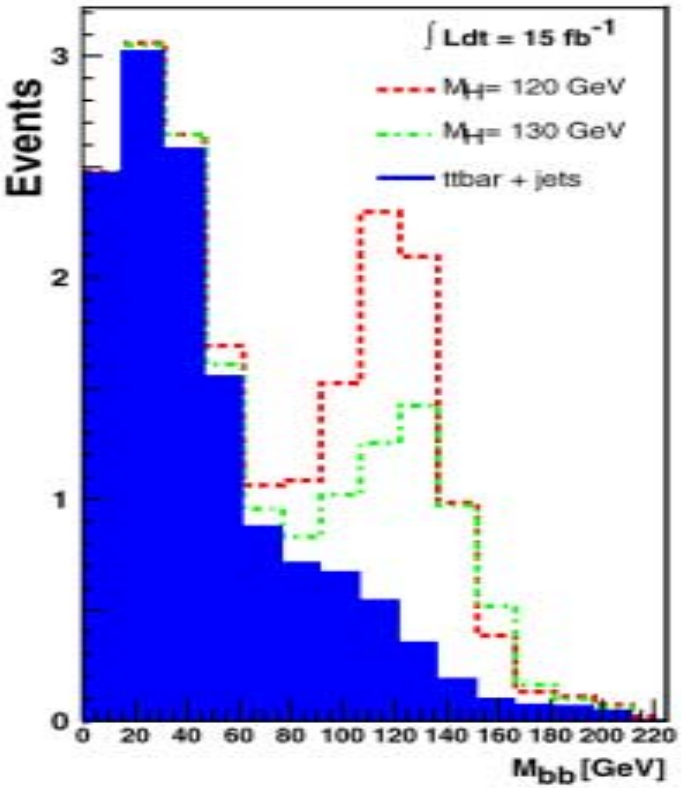


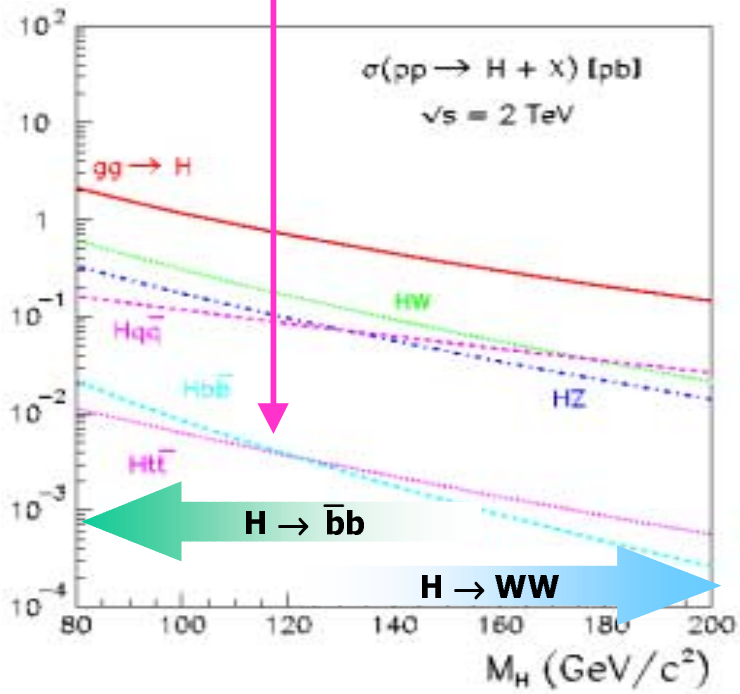
CDF jet
studies

D0 Higgs
simulation

Associated production $\bar{t}t$ + Higgs

- Cross section very low (few fb) but signal:background good
- Major background is tt + jets
- Signal at the few event level:



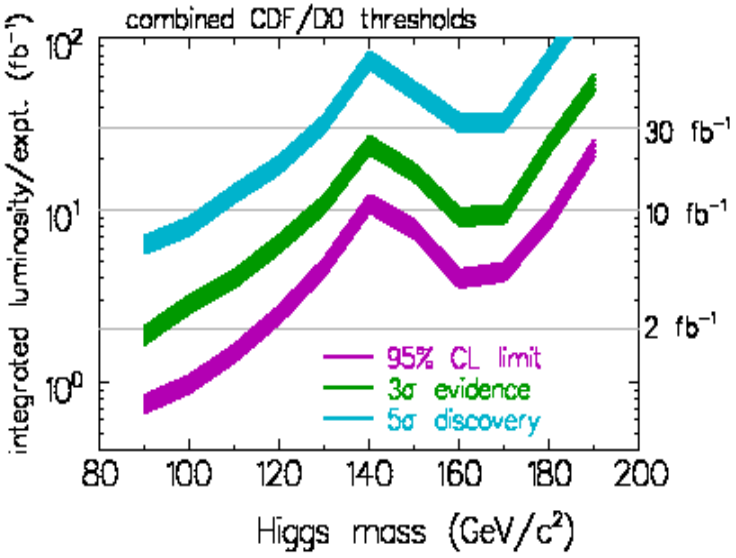


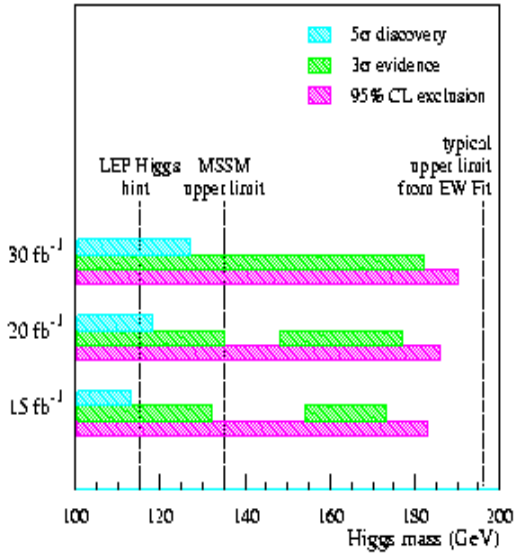
Higgs Discovery Prospects in Tevatron Run 2

- Can exclude a SM-like Higgs with mass up to ~ 180 GeV/c^2 with 15 fb^{-1} of data at 95%CL

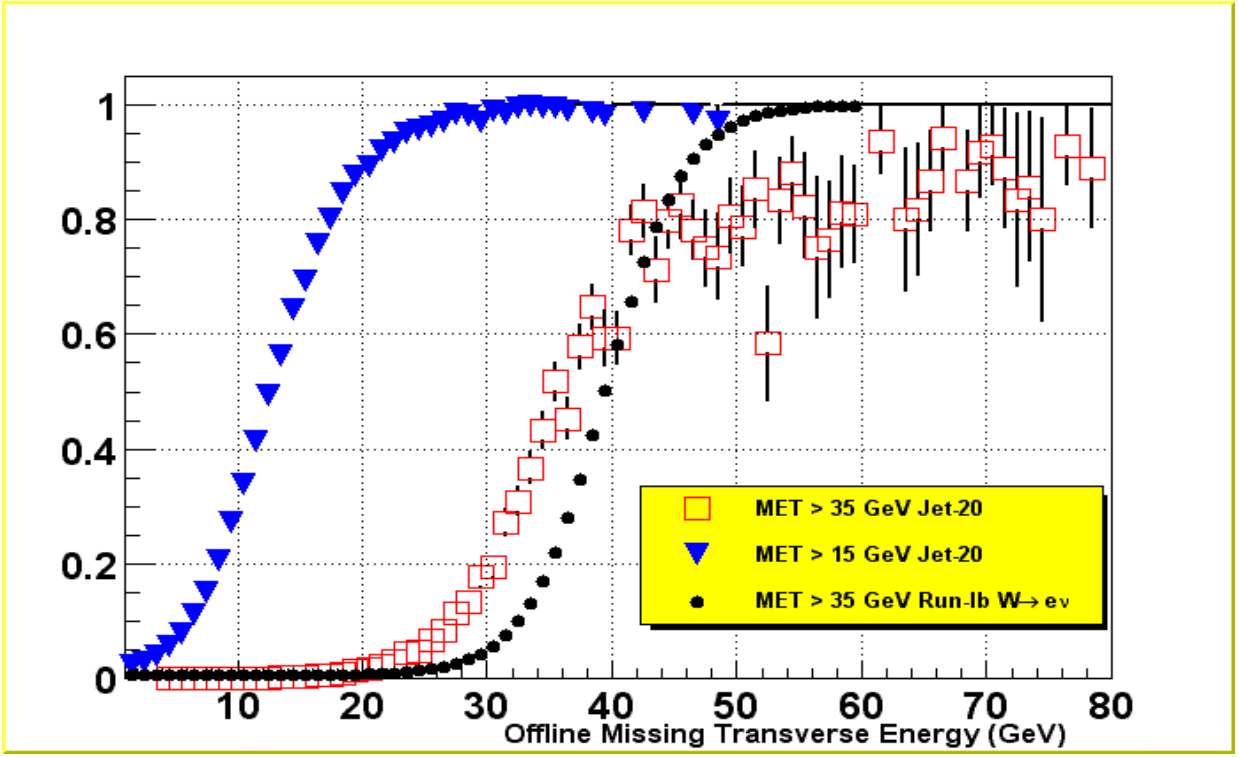
- Important to push integrated luminosities to ~ 30 fb^{-1} for discoveries
  - 3 sigma evidence to ~ 180 GeV/c^2
  - 5 sigma discovery to ~125 GeV/c^2

- Maybe pessimistic since working seriously with often gives much better results than anticipated in workshops





Getting ready for the Higgs

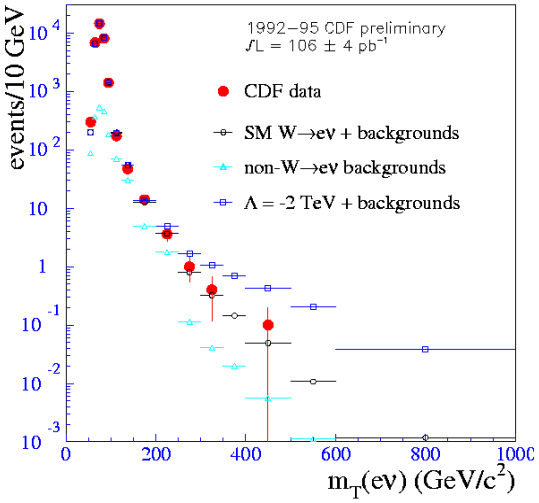


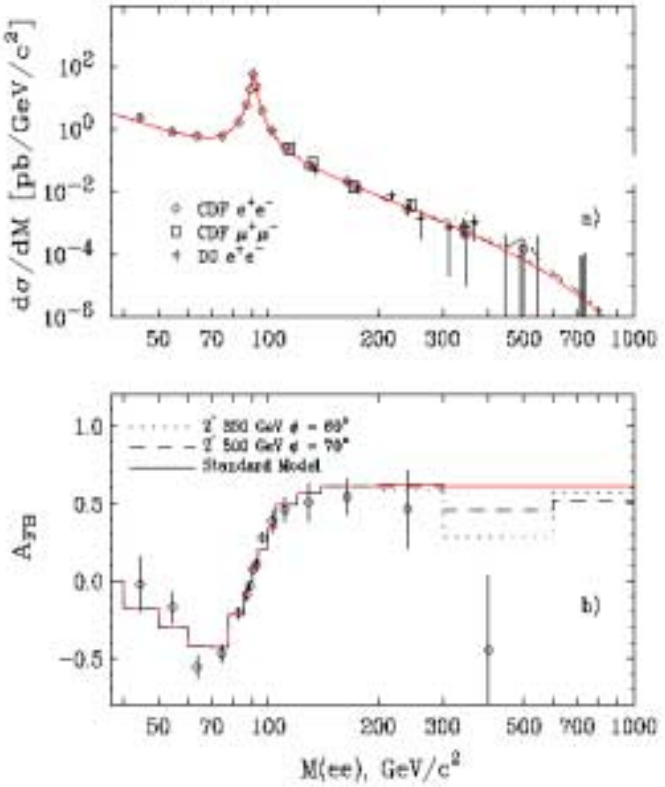
- Trigger strategies
  - SVT to select a sample enriched in heavy flavors
  - qqbb, MET + bb

Improved triggering on Met
==> efficiency improved by 40% e.g. for (typical) 40 GeV offline cut

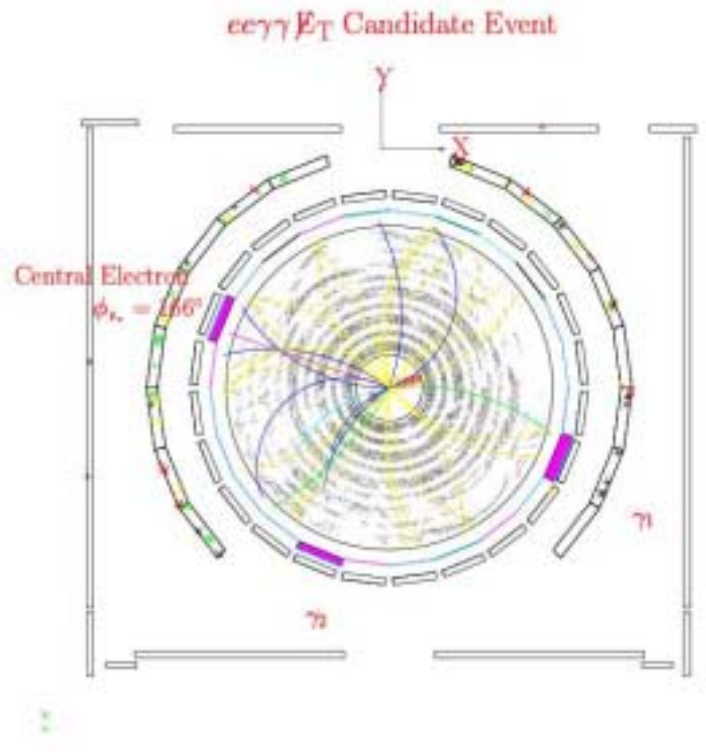
Beyond the Standard Model
New U(1) Gauge Bosons

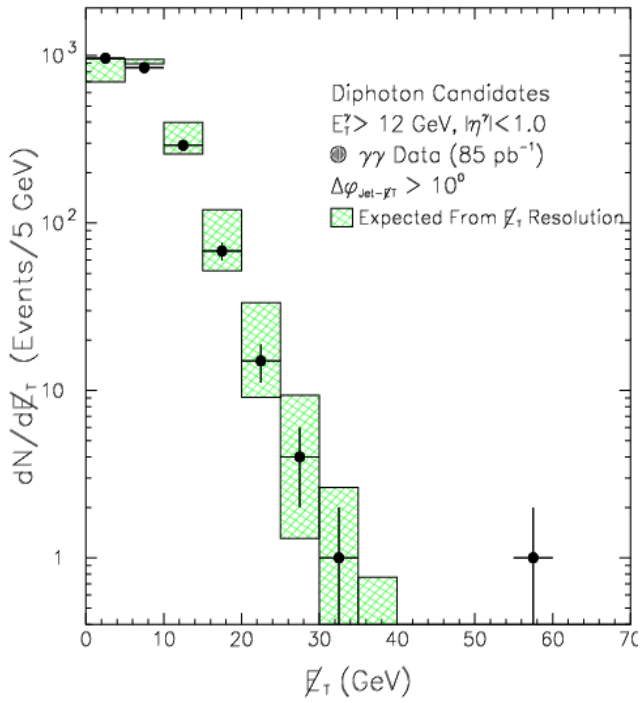
- Search for new W′ and Z′ bosons (CDF Run 1)
  - $M_{Z'} > 690$ GeV/c^2
  - $M_{W'} > 786$ GeV/c^2
- Run 2 projections:
  - $M_V >$ ~ 1 TeV (for SM couplings)





Run I anomalies: Photons



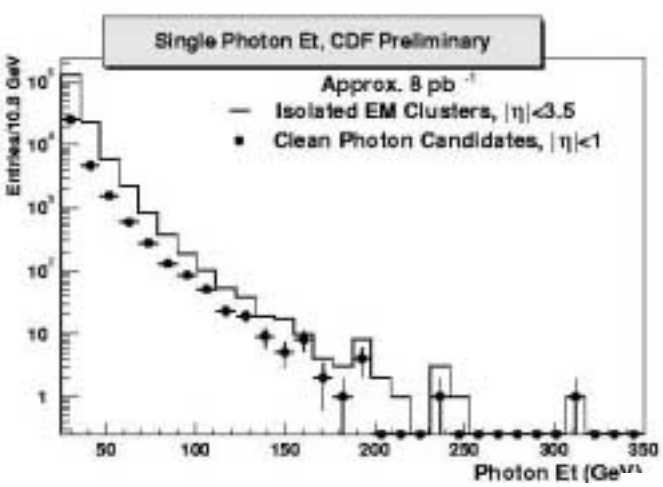


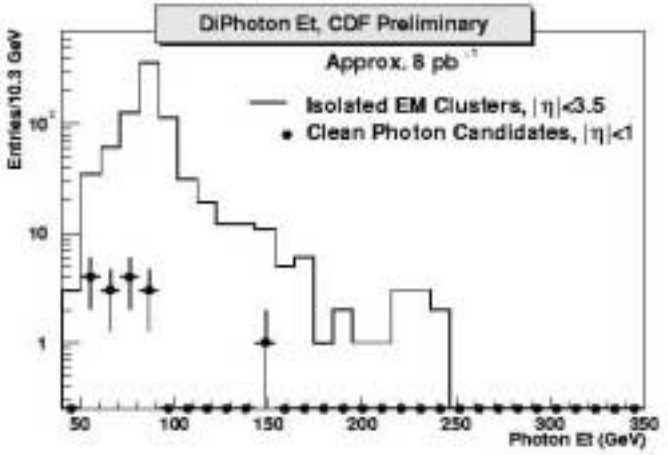
SM expectation for this event: 10^{-6}

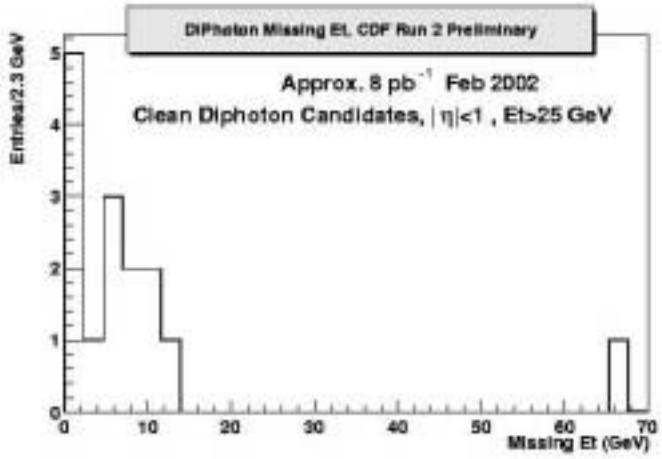
any such new event would be exciting!

Follow up on run I anomalies

Photons







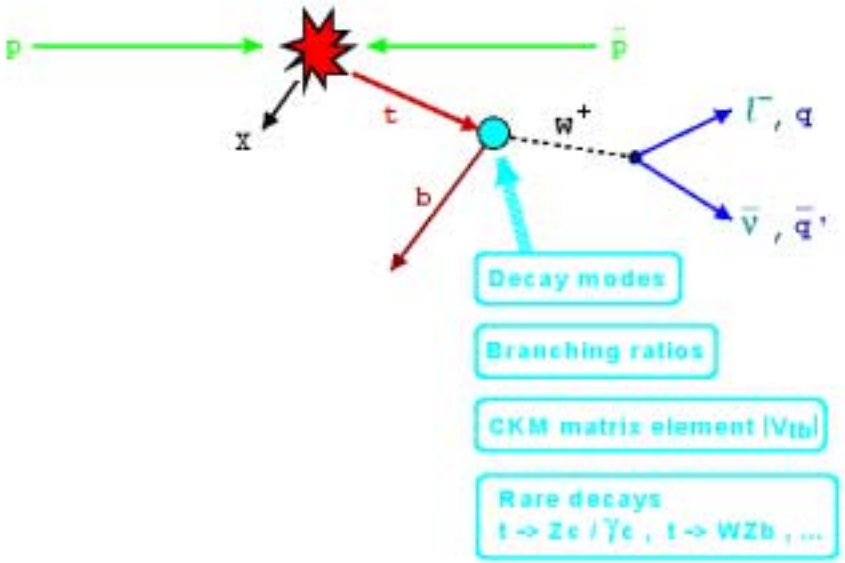
Event at high Et appears to be a simple diphoton event with a jet pointing at a crack, causing the met.
There are no electrons or muons in the event :-(

Conclusions

- Run II started:
  - Tevatron inst. luminosity still factor 10 lower than goal
  - summer shutdown for six weeks to upgrade recycler
  - achieve design luminosity end of 2002
  - CDF detector and trigger mostly ready for physics
    - first physics signals: Z, W, J/psi, ...
  - ISL cooling problem will be solved in summer shutdown
- physics programme:
  - first 200 pb^{-1} by end of this year: run I anomalies, B_s mixing, obtain good understanding of detector
  - Run IIa: precision top and W, precision B-physics, many searches (SUSY, LED, the unexpected,...)
  - Run IIb: SM (and SUSY) Higgs, higher precision/sensitivity, follow up on previous discoveries hopefully!!!!)

Properties of the Top Quark

- Mass ~ 175 GeV/c^2
- Γ ~ 1.5 GeV
- $\tau \sim 4 \times 10^{-25} < (\Lambda_{QCD})^{-1} \sim 10^{-23}$
  => free top decay
- Spin = $\frac{1}{2}$
- couplings = +2/3e , color triplet, weak $(T_3)_L$
- BR for t->Wb=99.9% (in SM)
  σ_{ttbar}~6 pb

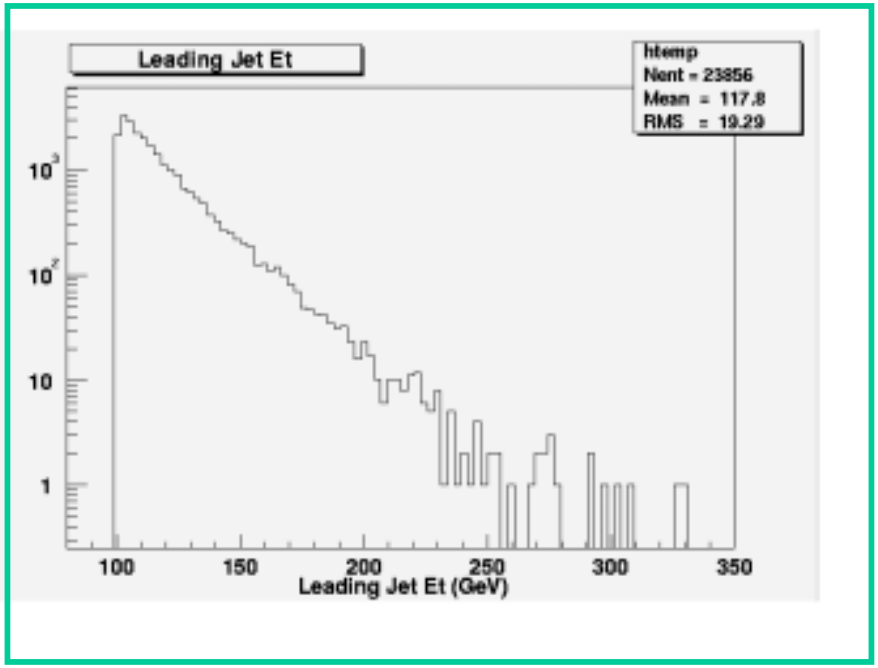


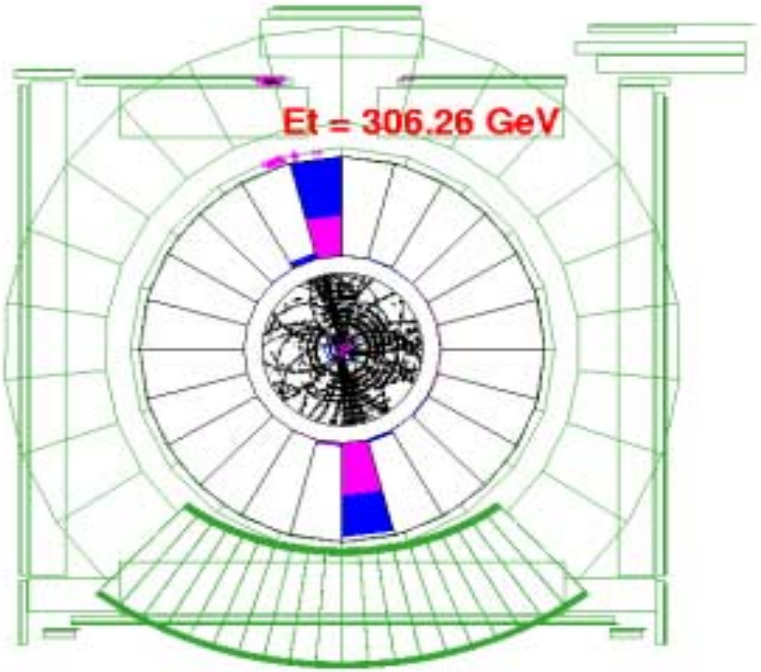
Summary of Projected Top Quark Measurements

Top quark Property	Run 1 measurement	Precision			
		Run 1	Run 2a	Run 2b	LHC
Mass (CDF + DØ)	$174.3 \pm 3.3 \pm 3.9\,\mathrm{GeV/c^2}$	2.9%	1.2%	1.0%	1%
$\sigma_{t\bar{t}}$	$6.5^{+1.7}_{-1.4}$ pb	25%	10%	5%	5%
W helicity, F_0	$0.91 \pm 0.37 \pm 0.13$	0.4	0.09	0.04	0.01
W helicity, F_+	$0.11 \pm 0.15 \pm 0.06$	0.15	0.03	0.01	0.003
$R \equiv \frac{B(t\to Wb)}{B(t\to Wq)}$	$0.94^{+0.31}_{-0.24}$	30%	4.5%	0.8%	0.2%
	> 0.61 at 90% C.L.				
$\lvert V_{tb}\rvert$	$0.96^{+0.16}_{-0.12}$ (3-gen.)				
	> 0.051 at 90% C.L.	> 0.05	> 0.25	> 0.50	> 0.90
σ(single top)	< 18.6 pb	–	20%	8%	5%
$\Gamma(t \to Wb)$	–	–	25%	10%	10%
$\lvert V_{tb}\rvert$	–	–	12%	5%	5%
BR($t \to \gamma q$) 95% CL	0.03	0.03	2×10^{-3}	2×10^{-4}	2×10^{-5}
BR($t \to Zq$) 95% CL	0.30	0.30	0.02	2×10^{-3}	2×10^{-4}

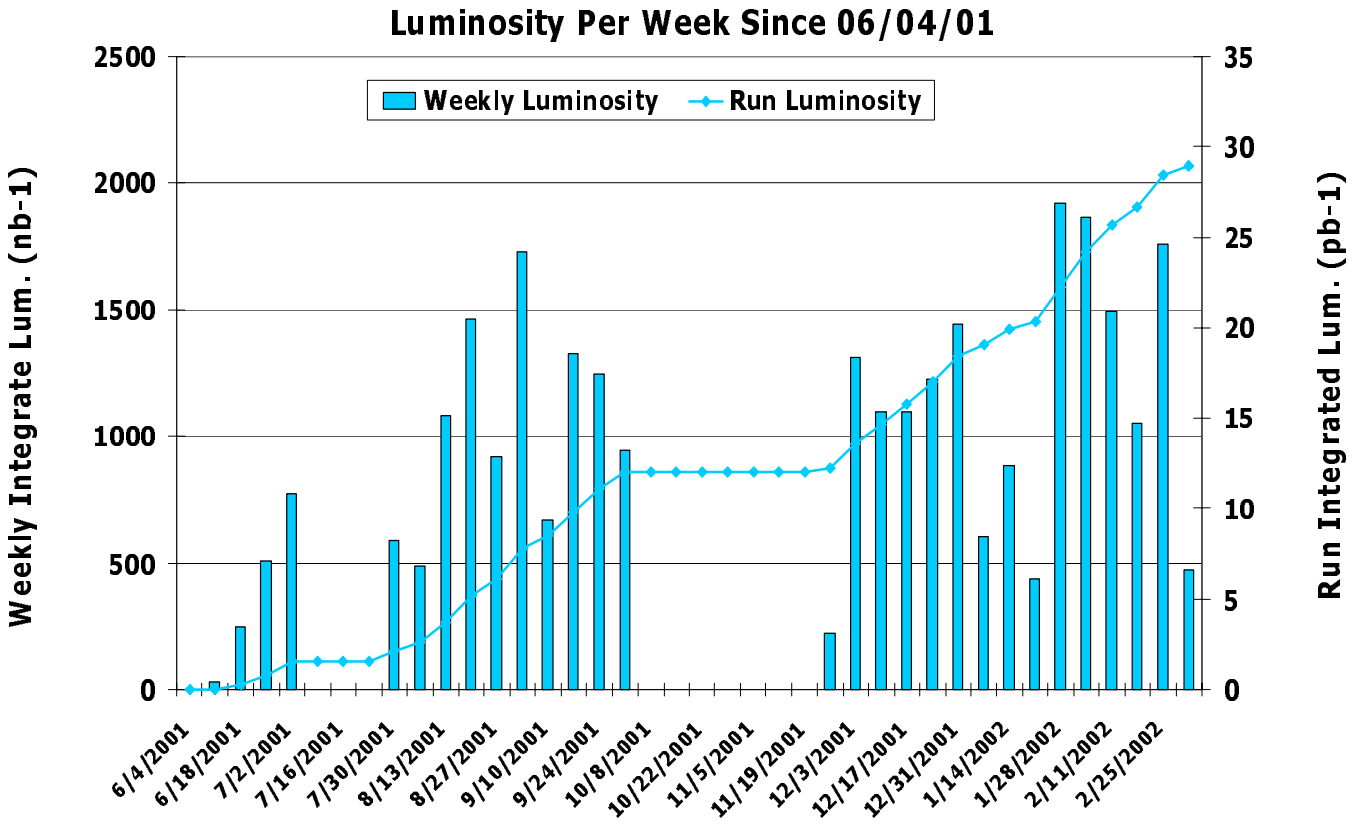
Calorimeter: Jets

- Jets being selected on-line and are reconstructed offline. Algorithms are in place and well advanced



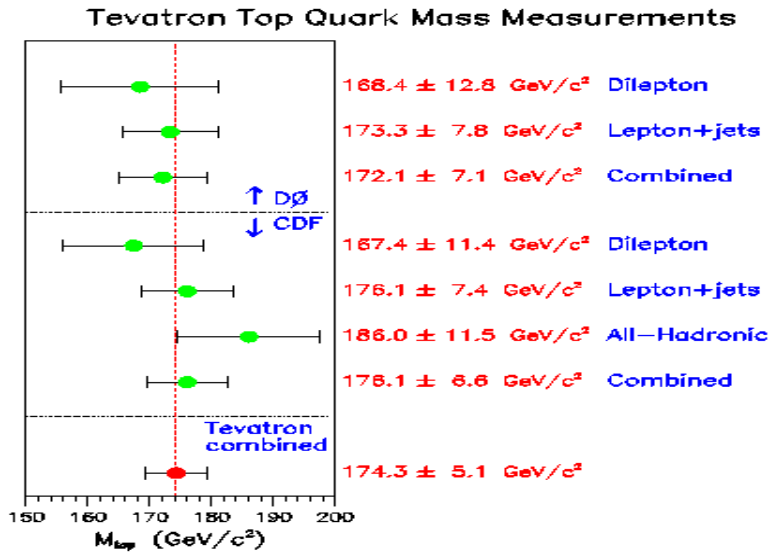


Integrated Luminosity History



Top mass in Run 1 -> 2

- Combine 3 CDF and 2 D0 top decay channels
- Measurement comparable to precision of b quark mass, and significantly better than Run 1 projections.



$M_t = 174.3 \pm 5.1$ GeV/c^2

$M_t / M_b = 36 \pm 2$

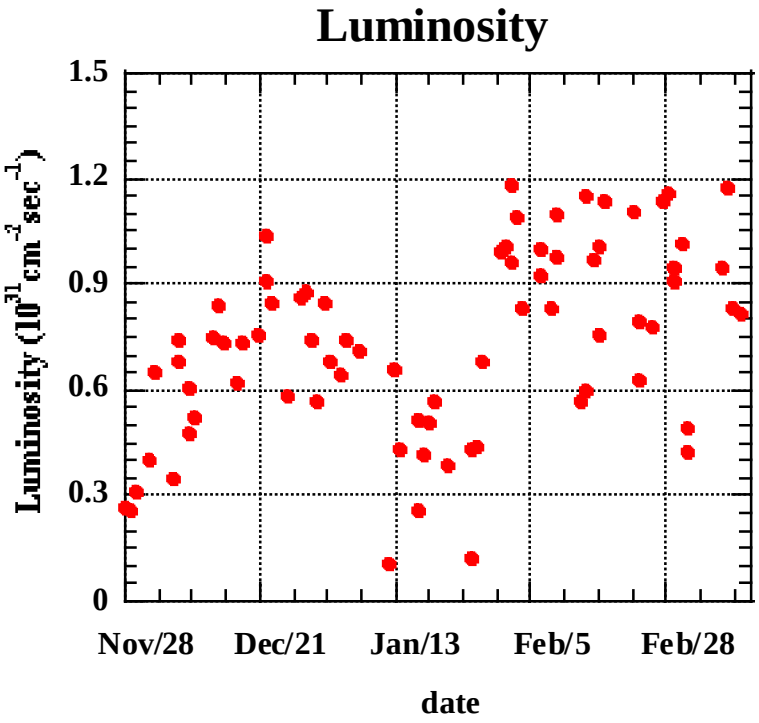
$M_t \sim$ scale of EWSB $= (2\sqrt{2}\, G_F)^{-1/2}$

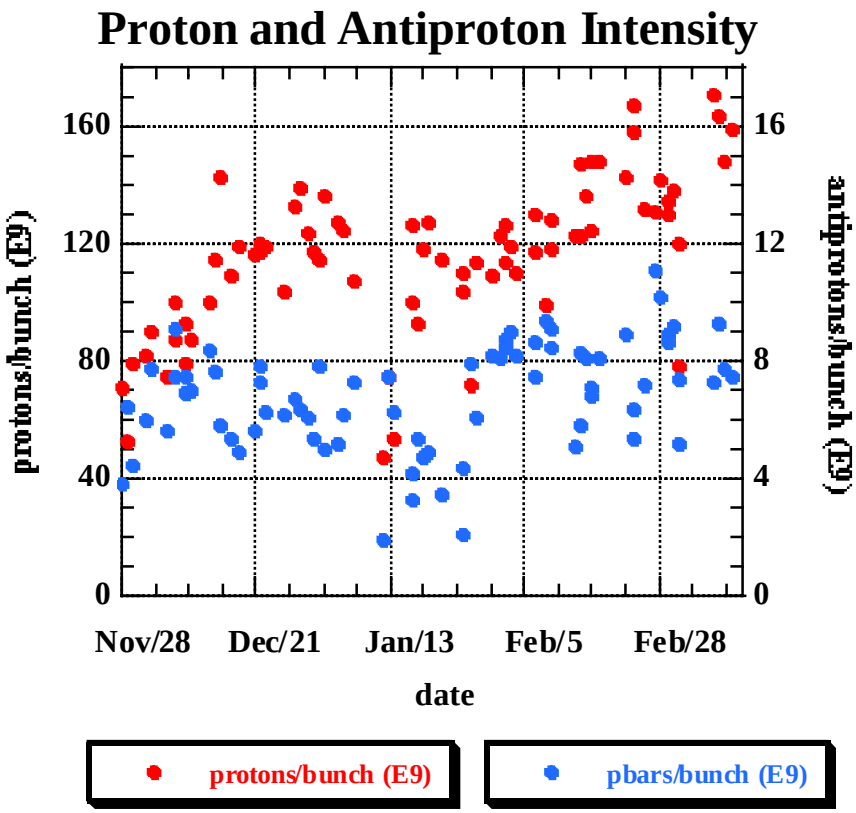
$= 175$ GeV/c^2

In Run 2 projections are

$\delta M_t \sim 3\ (\sim 2)$ GeV/c^2 with 2 (> 10) fb^{-1} for (CDF or D0)

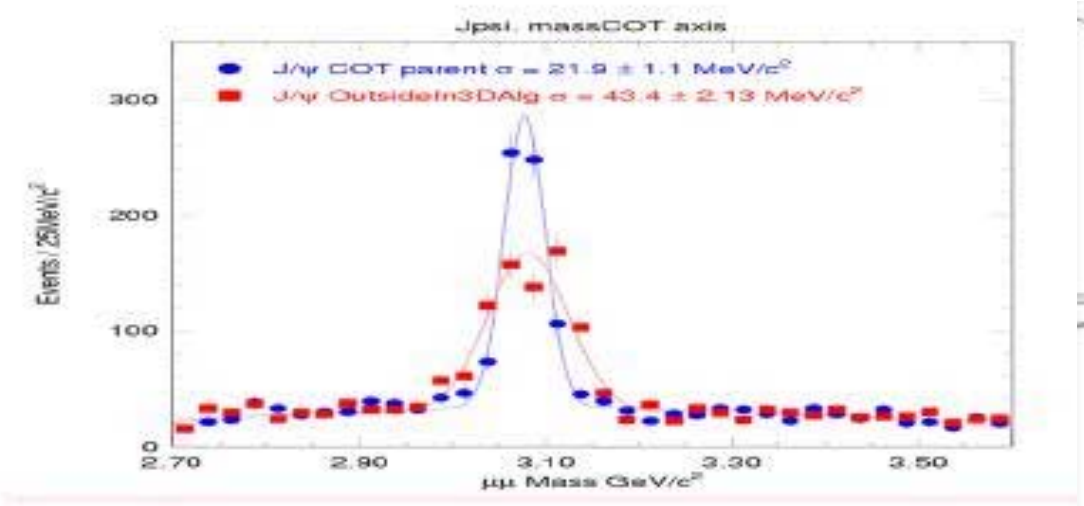
Peak Luminosity and Intensity

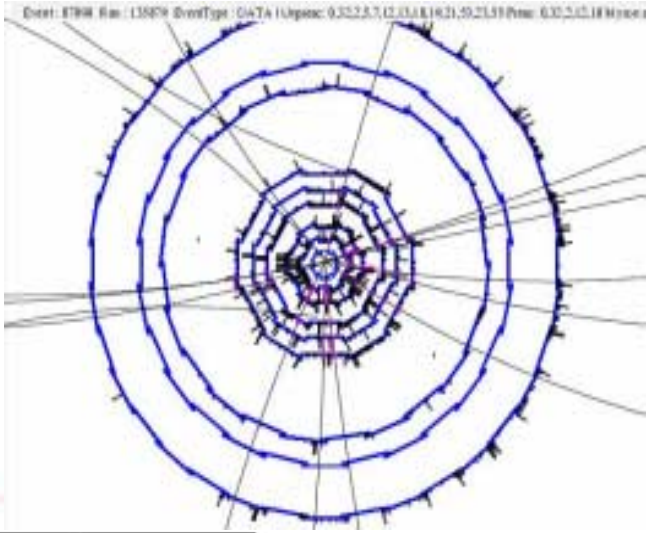




Both Luminosity and intensity are improving!

Tracking data: J/ψ resolution





	Alignment	N(J/ψ)	σ(J/ψ)	ΔZ	S/B
COT	10.2	24409	22 MeV	800μ	1.62
+SVX rphi	10.2	10569	17 MeV	240μ	2.83
+3 Z hits	10.2	3288	16 MeV	160μ	4.28

*Pre-shutdown data with 4.3.0int1

*Latest runs 138021 gives r-phi si coverage for Jpsi 70%