Fermilab Tevatron
Collider Run II

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FNAL/Beams Division/Pbar

Fermilab Collider Run II

- Changes to the complex:
  - ⇒ Main Injector replaces the Main Ring (the original NAL high energy machine)
  - ⇒ Completely revamped stochastic cooling systems for pbars
  - ⇒ Recycler ring, first large scale permanent magnet storage ring
  - ⇒ Higher energy collisions at 980 GeV per beam
  - ⇒ Increased number of proton and pbar bunches from 6 to 36
- Significant upgrades to D0 & CDF

Run II Luminosity Goals

- Run IIa - initial phase
  - ⇒ Peak luminosity up to 2×10^{32} /cm^2/sec
  - ⇒ Switch to 103 bunches at 1×10^{32} /cm^2/sec
    - » Dependent upon successful operation of Recycler
  - ⇒ Length of Run IIa is about 2 years

- The luminosity goal for Run IIa+Run IIb is 15 fb^{-1}
  - ⇒ Increase antiproton intensity by 2-3
  - ⇒ Peak luminosity up to 5×10^{32} /cm^2/sec
  - ⇒ 103 bunch operation
  - ⇒ Length of Run IIb is about 4 years

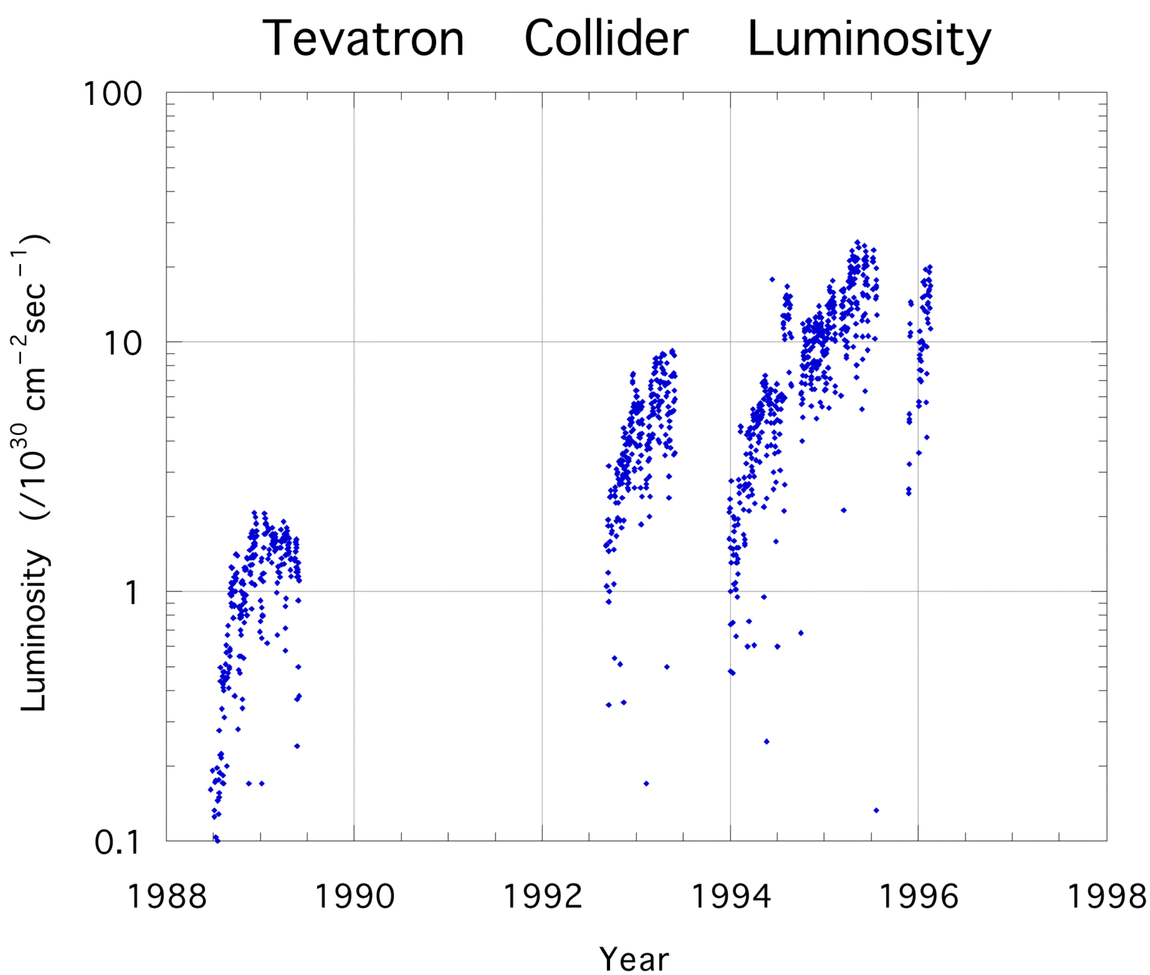
Run II Parameters

RUN	Ib (1993-95) (6x6)	Run IIa (36x36)	Run IIa (140x105)	Run IIb (140x105)	
Protons/bunch	2.3×10^{11}	2.7×10^{11}	2.7×10^{11}	2.7×10^{11}	
Antiprotons/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
$\beta*$	35	35	35	35	cm
Energy	900	1000	1000	1000	GeV
Antiproton Bunches	6	36	103	103	
Bunch length (rms)	0.60	0.37	0.37	0.37	m
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	

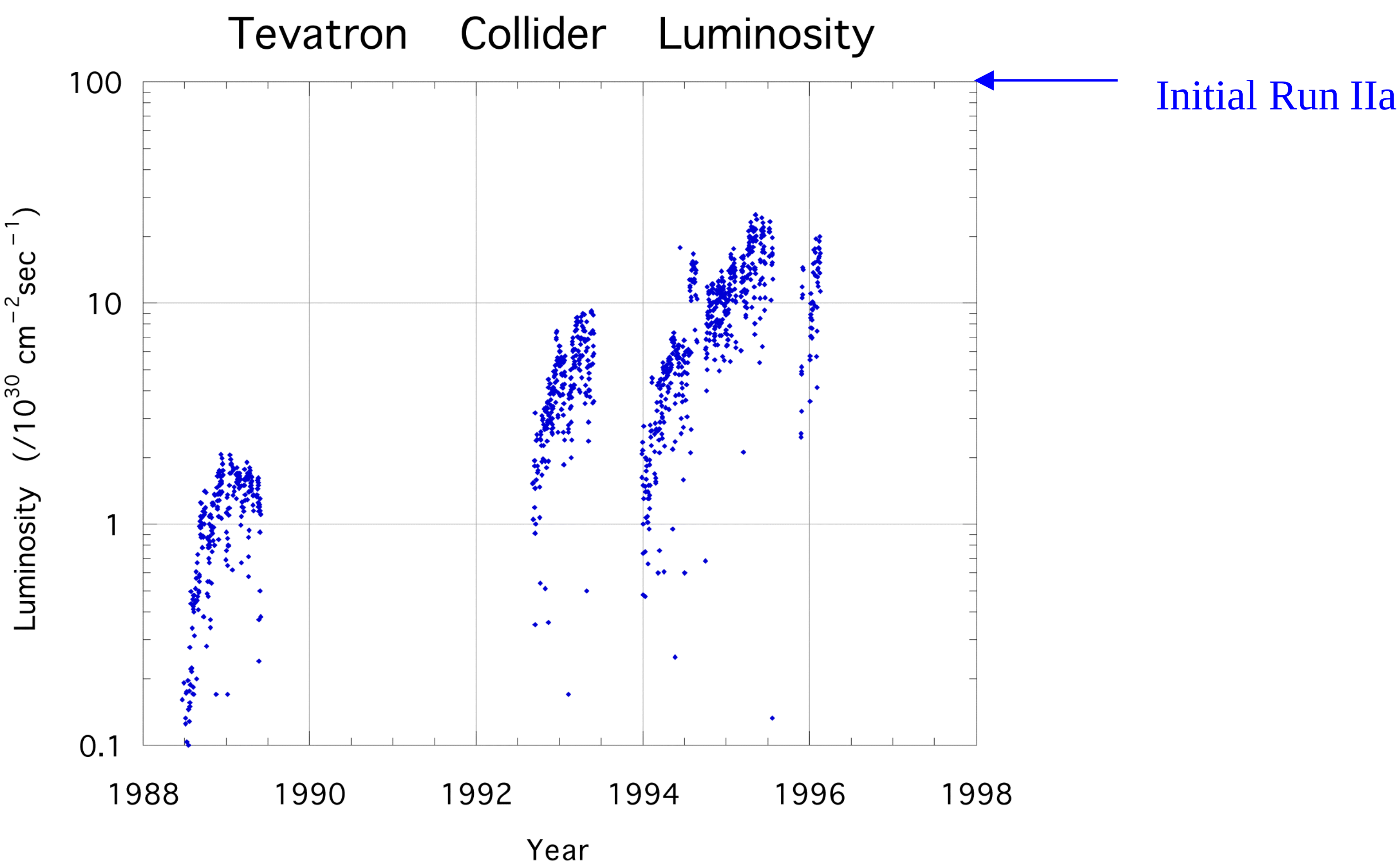
The typical luminosity at the beginning of a store has traditionally translated to integrated luminosity with a 33% duty factor. Operation with antiproton recycling may be somewhat different.

Luminosity History

Paul Derwent
5-May-01



Luminosity History



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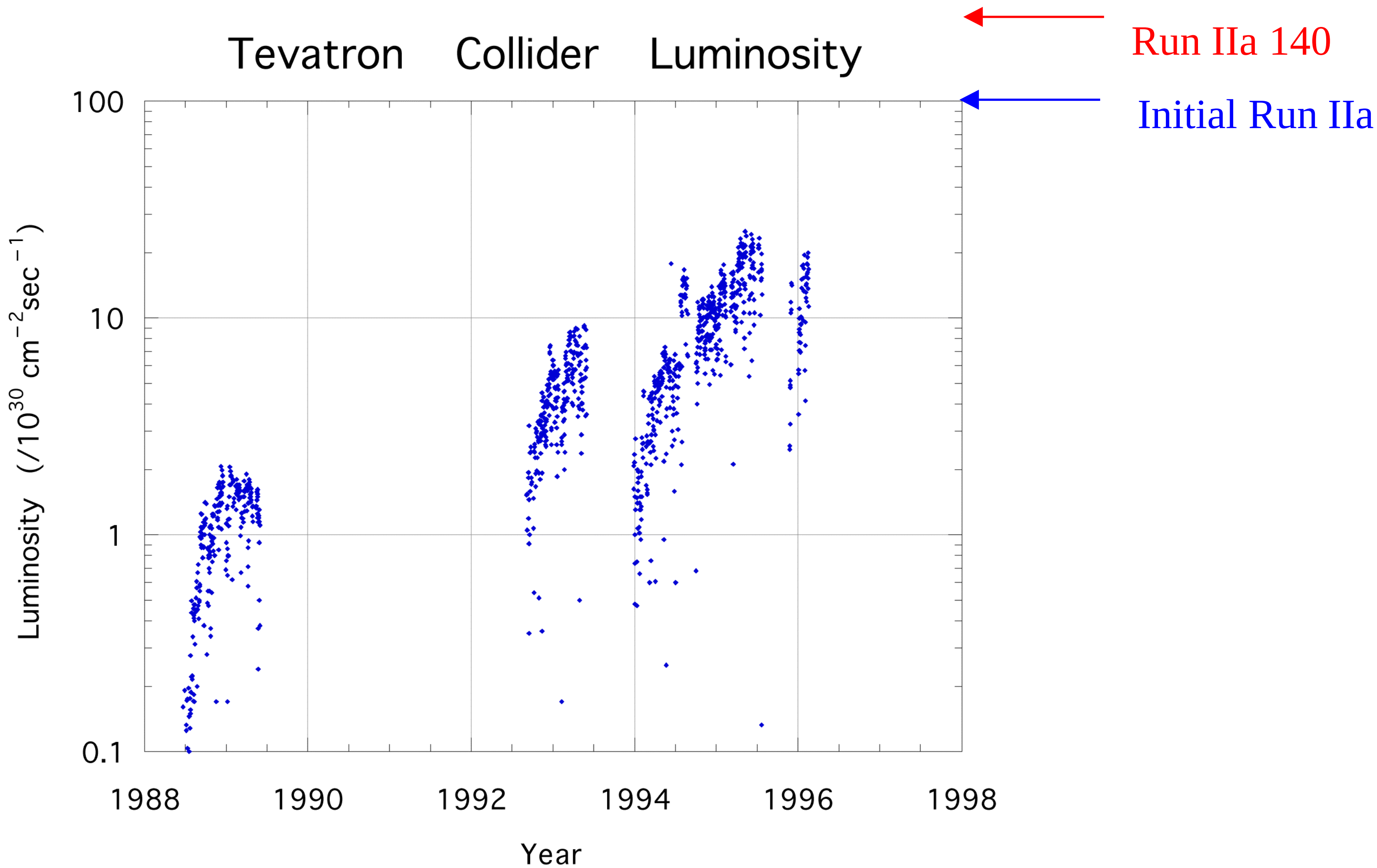

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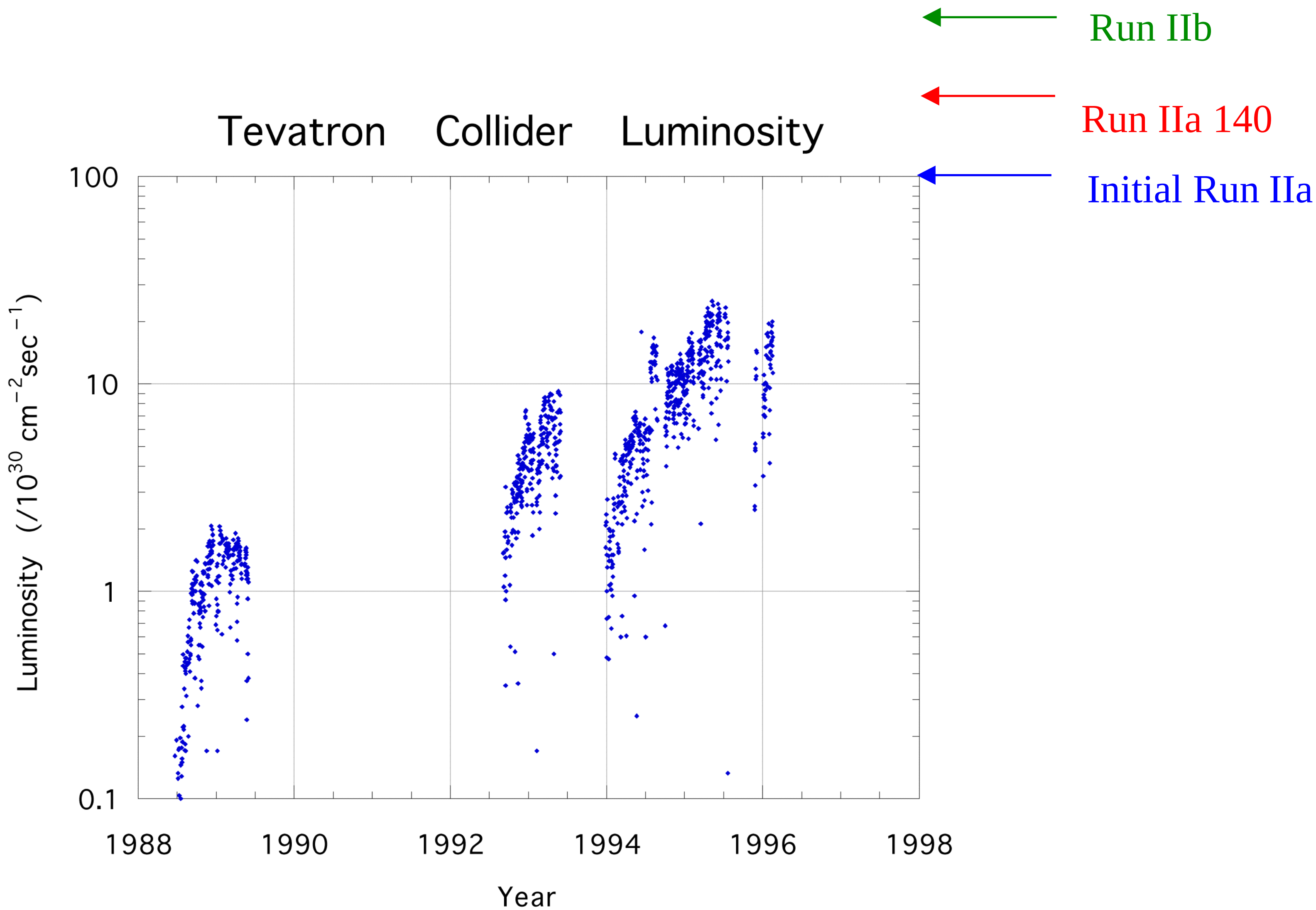

Collider
Run II

Luminosity History

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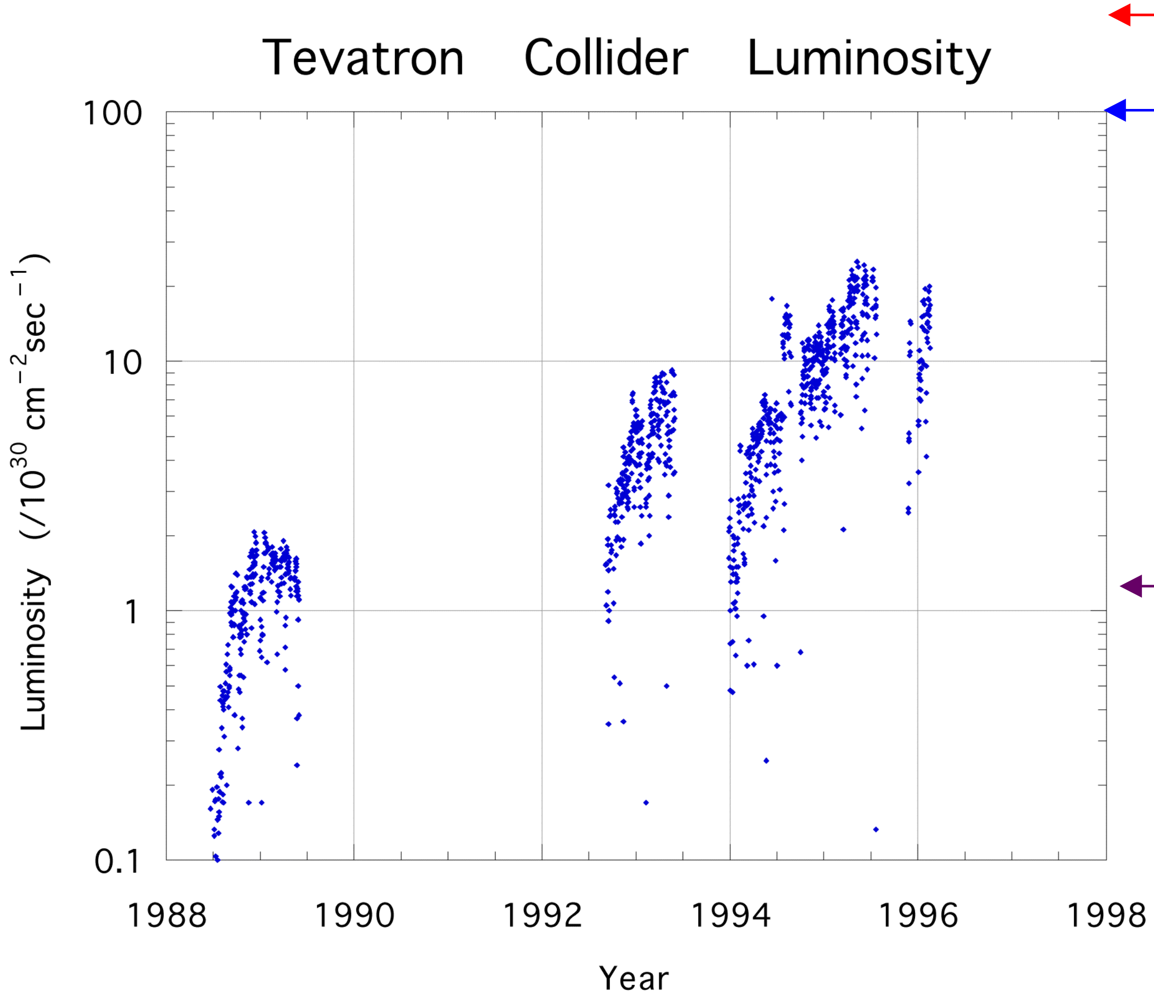
5-May-01
5

Run IIb

Run IIa 140

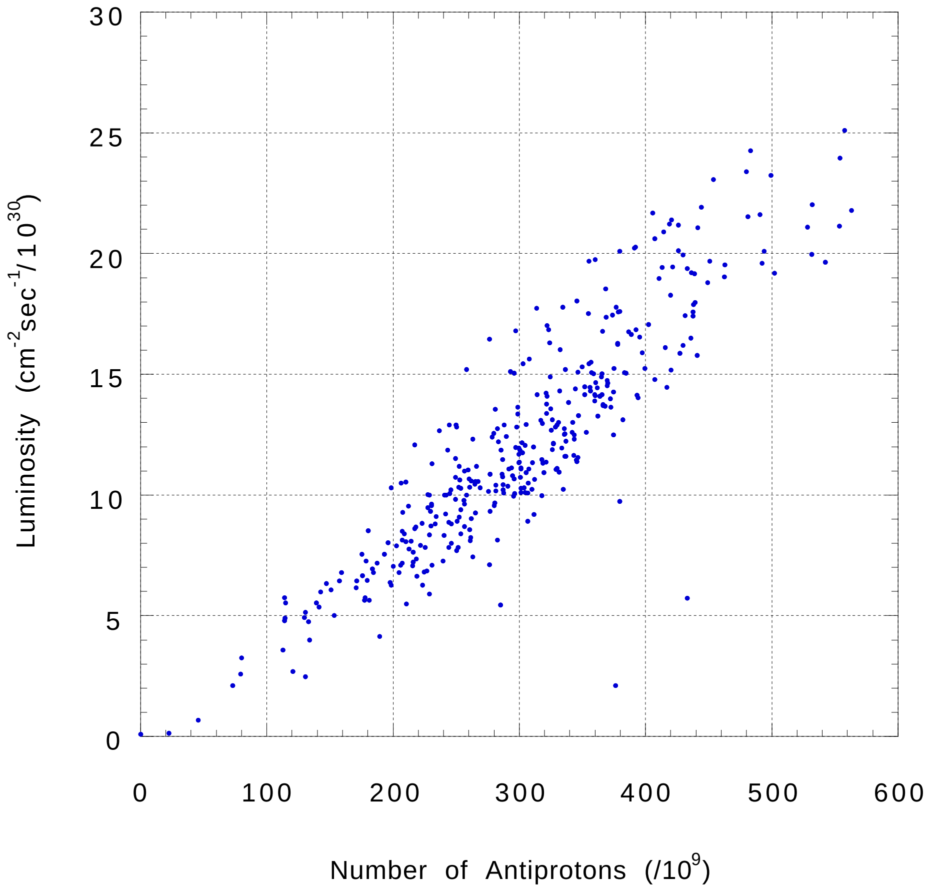
Initial Run IIa

Current Run II
peak



Luminosity Drivers

Pbars drive collider luminosity



Run II Goal: Make more pbars!

Run IIa Plan

Increase number of protons and pbars in Tevatron

⇒ Proton intensity/bunch: ~1.2x

⇒ Pbar intensity/bunch: ~0.5x

⇒ Number of bunches: 6x

Increase pbar production rate by factor of 3 over Run Ib

⇒ Decrease cycle time for protons on target	~1.6x
⇒ Increase acceptance: pbars/proton	~1.3x
⇒ Increase protons on target:	~1.5x

Run IIa plan

Integrate Recycler into operation

⇒ ‘Recycle’ pbars from Tevatron at end of store

⇒ Essential for high luminosity operation

Switch to 132 nsec operation at $1x10^{32}/cm^{-2}/sec$

⇒ When <events/crossing> ~ 5

NB: $1\ fb^{-1} = 10^{32}/cm^{2}/sec \times 10^{7}$ sec

Typical luminosity ~ 1/3 peak luminosity

Run IIb plan

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Increase the number of antiprotons in the collider by a factor of 2-3 over RunIIa

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Within a period of 2-3 years

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With a modest budget

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Without major interruption to Run IIa

Within a period of 2-3 years

With a modest budget

With a relatively small number of people

How to increase number of Pbars

- Make more:
  - ⇒ Increase proton flux on antiproton target
- Collect more:
  - ⇒ Improve collection lens performance
  - ⇒ Improve beamline apertures
- Handle more:
  - ⇒ Upgrade stochastic cooling systems
  - ⇒ Improve beam transfer efficiencies
- Utilize new storage ring:
  - ⇒ Recycler

Making more pbars

- Increase number of protons in Main Injector: ~1.8x more pbars
  - ⇒ Slip Stacking
    - » MI RF beam loading compensation
      - To keep RF voltage under control
    - » Beam sweeping at target
      - To keep target from melting
    - » Booster beam cogging
      - For alignment of 2 batches in the MI
  - ⇒ Brighter proton source
    - » Brighter ion source in linac
    - » New linac front-end acceleration stage

Slip Stacking Cartoon

1st Booster Batch injected into Main Injector
Slightly Accelerated and 2nd Booster Batch ready
2nd injected and slightly decelerated
Wait for 2 to line up with 1
Capture into 1 RF frequency

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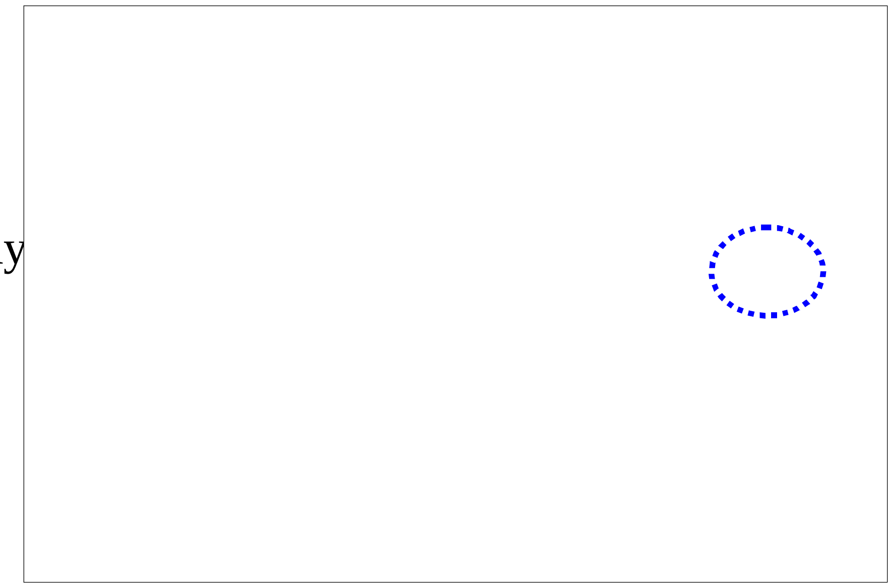

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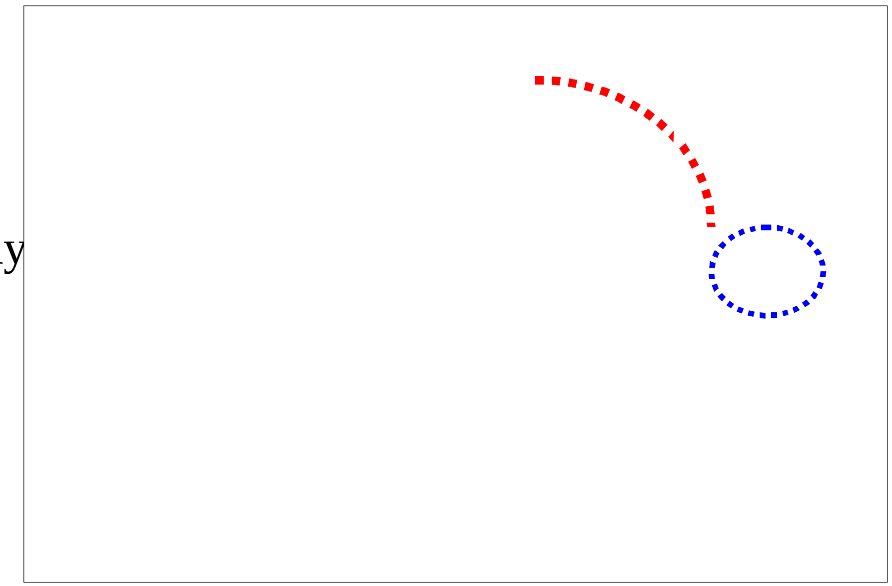

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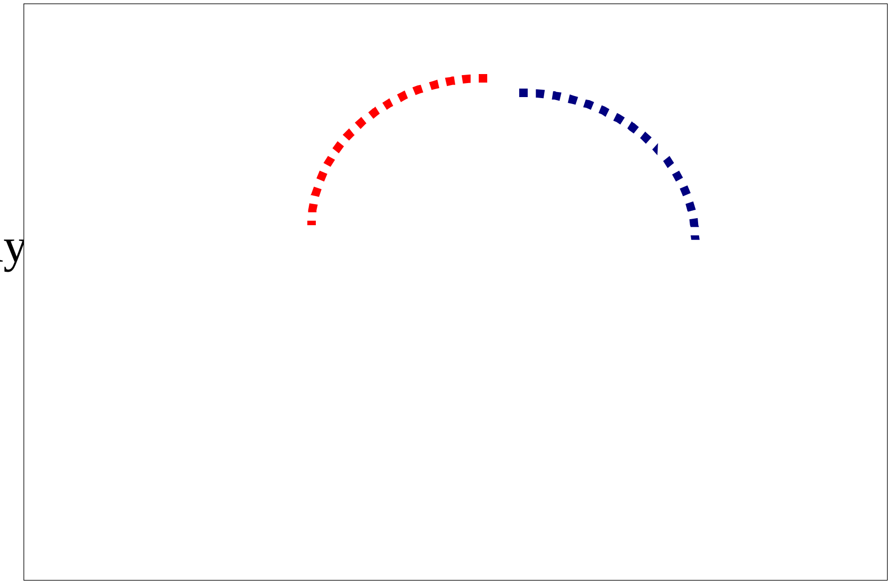

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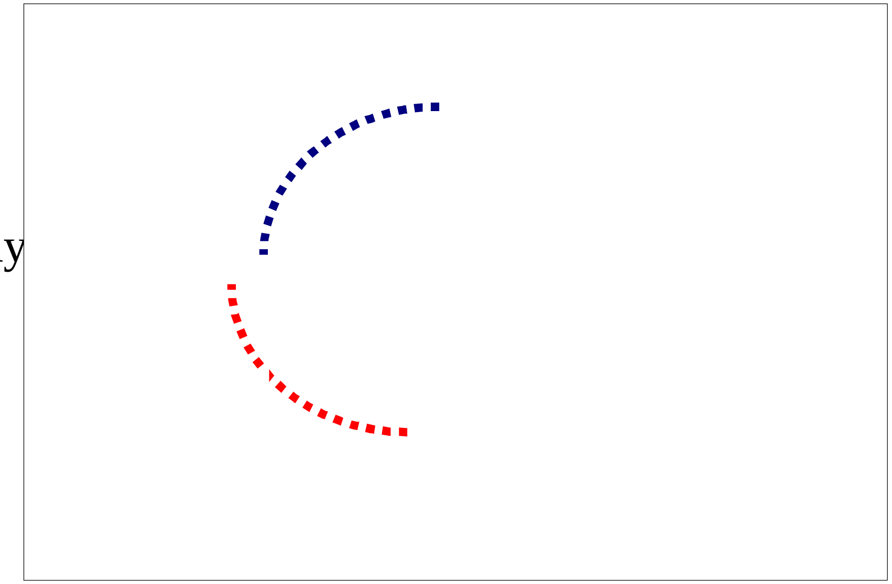

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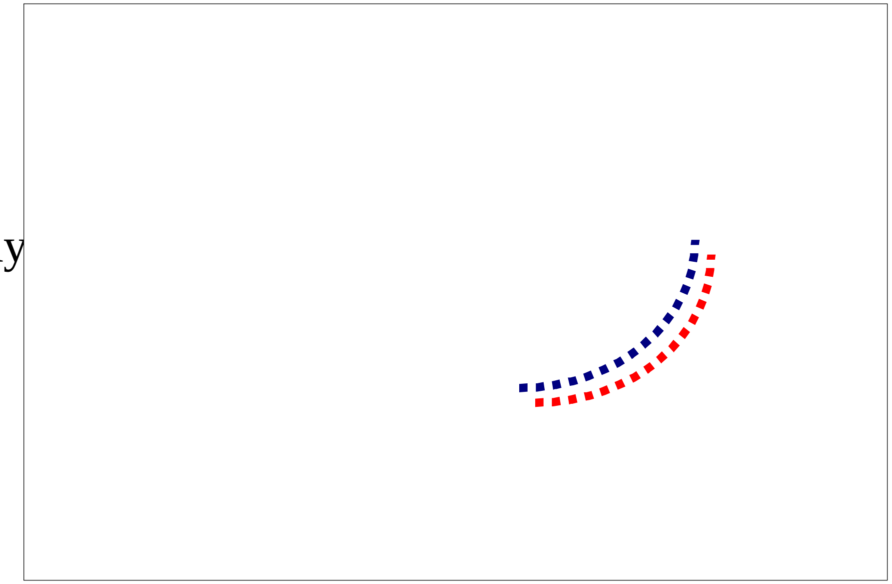

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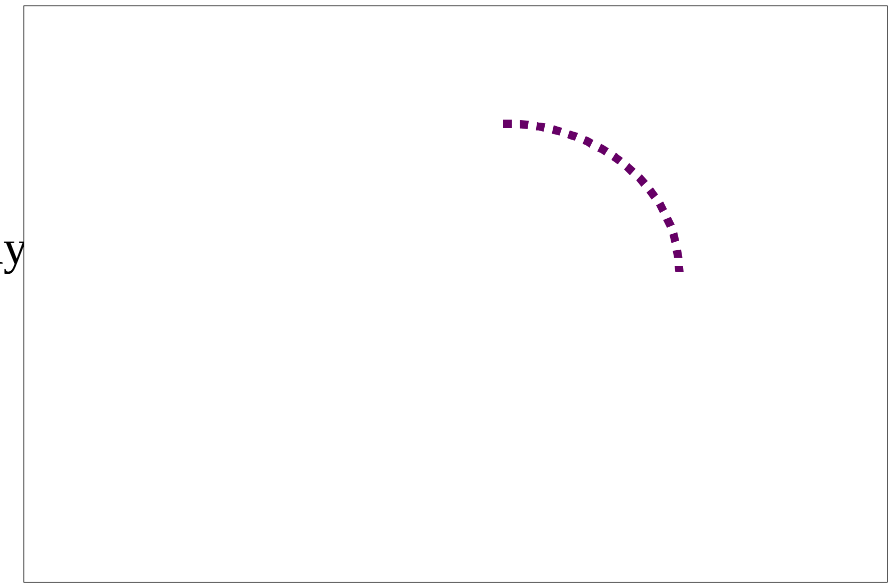
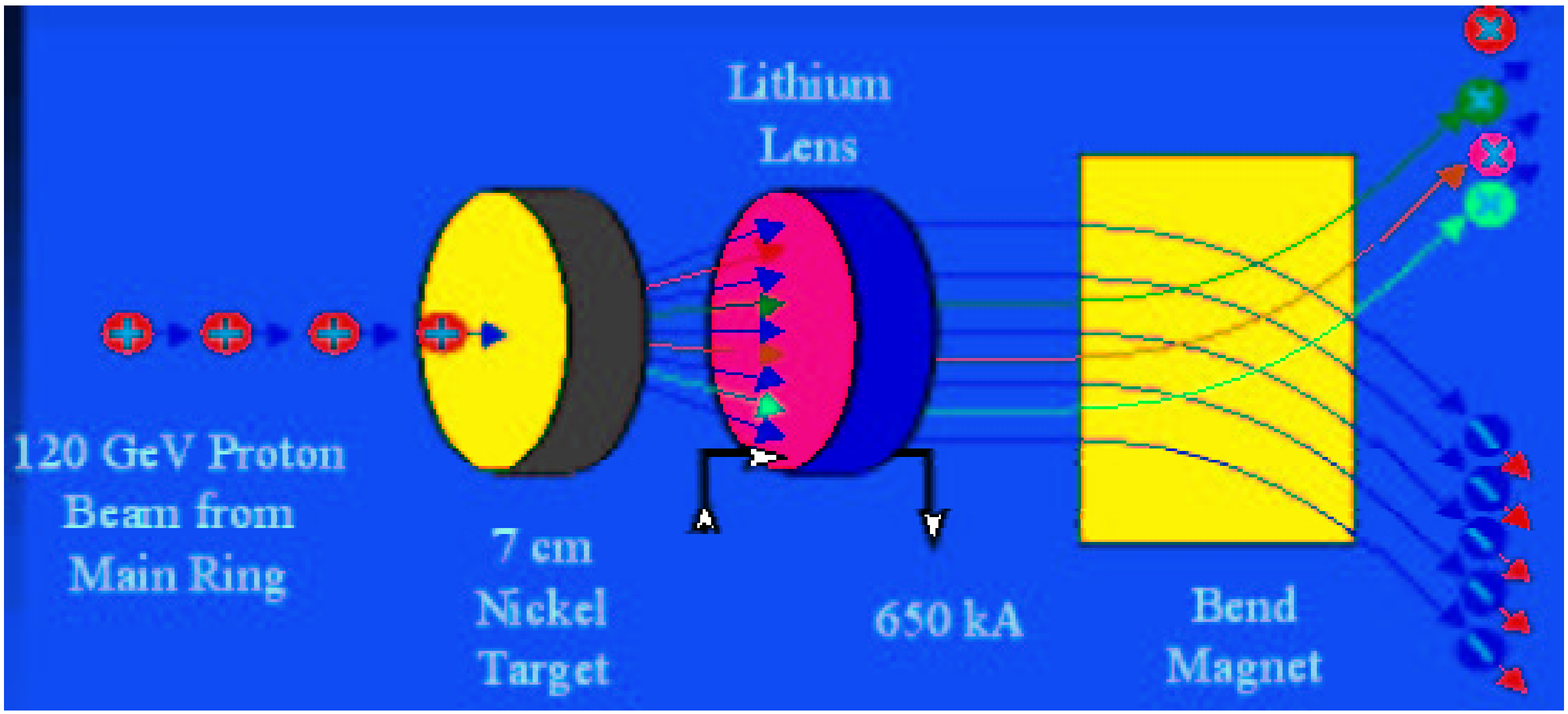
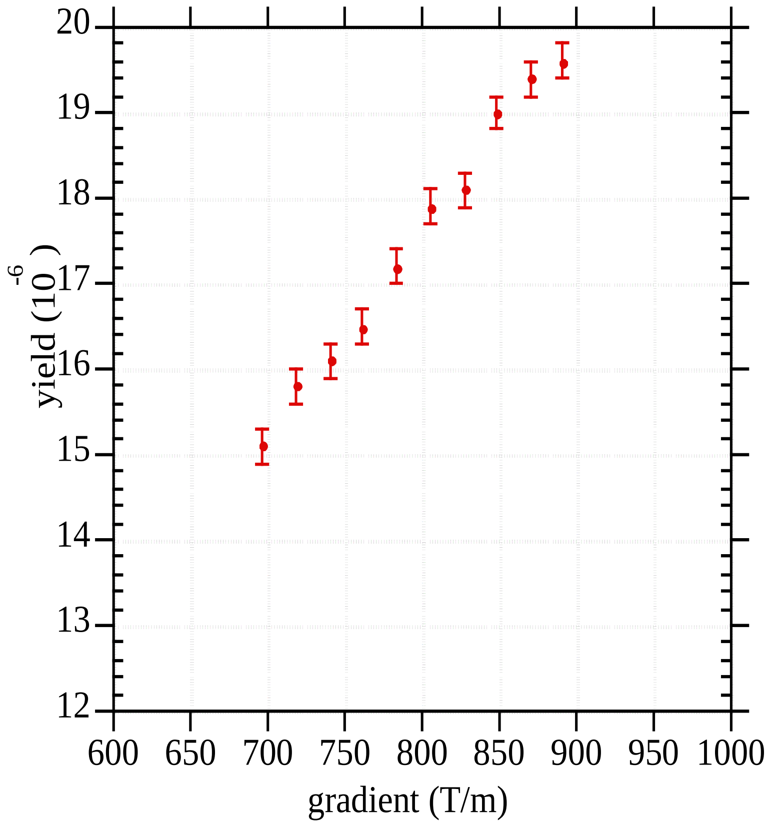


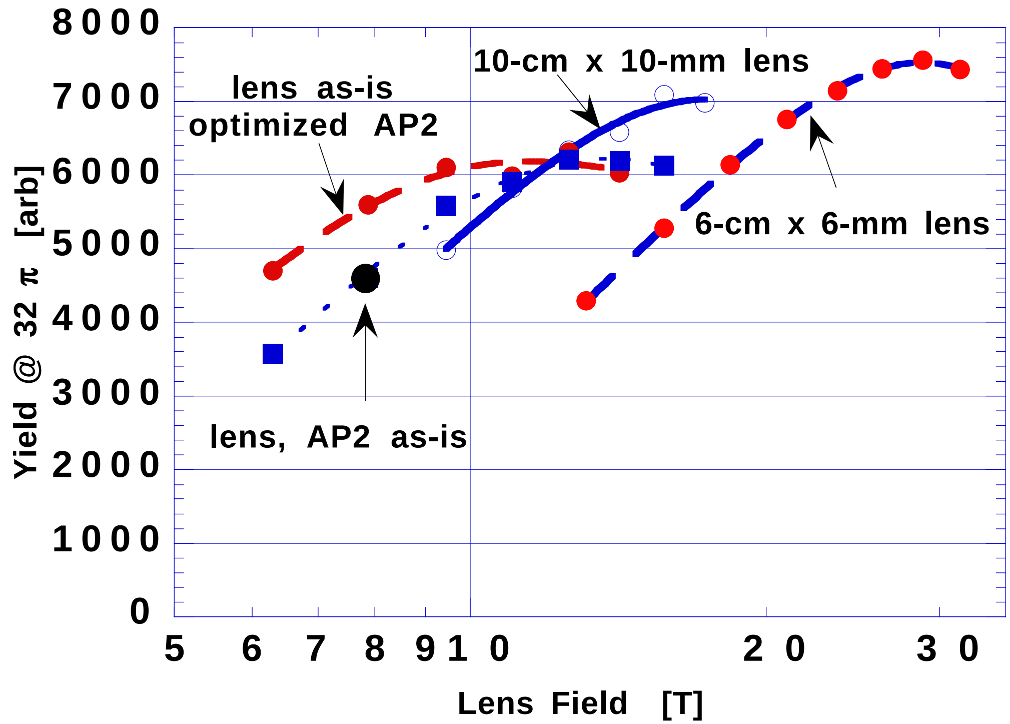
Collect more pbars



- Lithium lens: high current, radial field
- Collection efficiency depends upon lens gradient
- Upgrade goal: ~1.5x more pbars

Collect more pbars





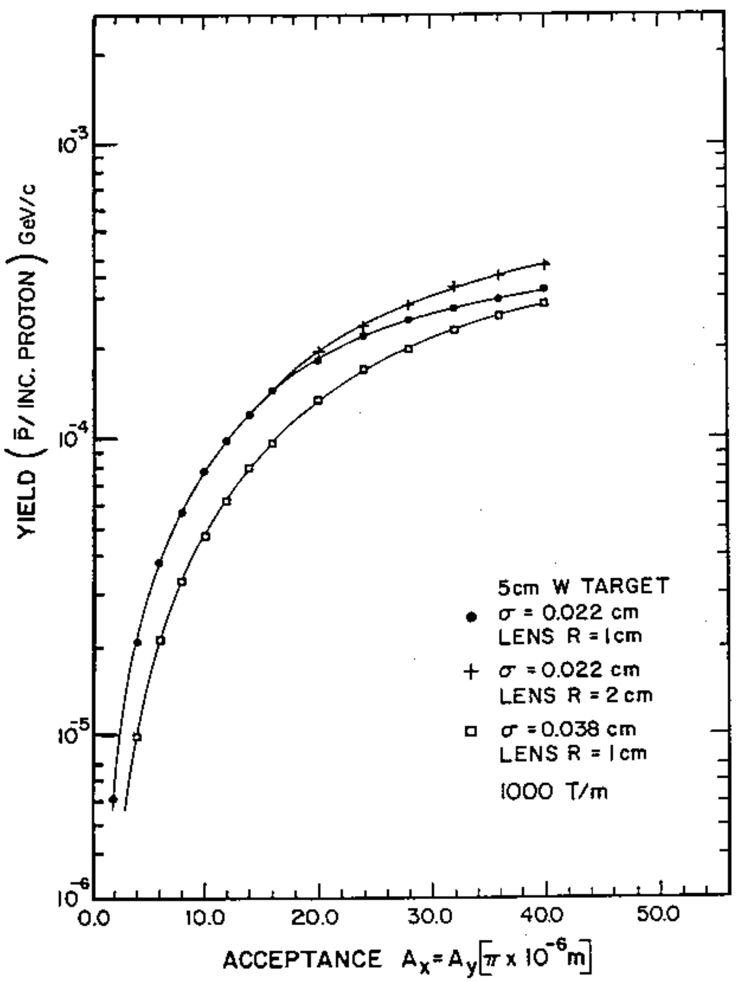
Collect more pbars

- TEV 1 design gradient was 1000 T / m
- Catastrophic failures due to component fatigue limits the present gradient to 760 T / m
- Upgrade present lens design to obtain 1000 T / m
  - ⇒ New fabrication techniques
    - » Diffusion bonding, etc.
  - ⇒ New materials
  - ⇒ Package re-design
    - » better cooling, etc.
  - ⇒ Lens parameter changes
    - » radius, etc. - **CDF P. Bussey**

Collect more pbars

- Increase aperture in regions upstream of the first stage of stochastic cooling: ~1.5x more pbars
  - ⇒ AP2 transfer line
  - ⇒ Debuncher
- The goal is to increase the aperture in both planes from 25π mm-mrad to 40 π mm-mrad
- Beam based alignment of all magnetic elements
  - ⇒ requires new instrumentation **CDF R. Hughes, B. Winer, A.Semenov**
  - ⇒ motorized quads
- Physical aperture increases
  - ⇒ such as replacing beam pipe in Debuncher dipoles with curved beam pipe

Collect more pbars

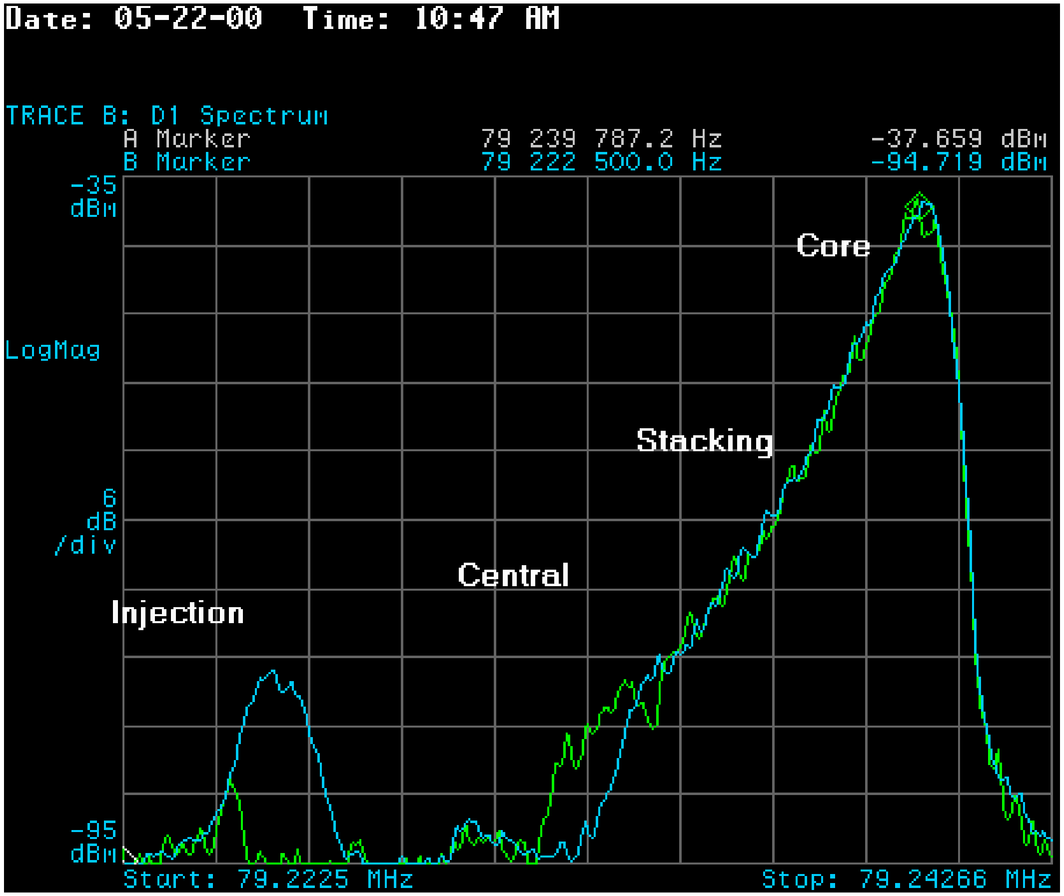


Handle more pbars

- 1.8 x 1.5 x 1.5 = 4x more pbars! (if they all work)
  - ⇒ Stochastic cooling performance:
    - » Debuncher: Run IIa upgrade looked ahead to Run Iib, modifications to hardware design
    - » Accumulator: Modifications to stacktail and core cooling
  - ⇒ Recycler cooling performance”
    - » Recycler Electron cooling
  - ⇒ Transfer performance:
    - » Transfer time ~10 minutes
    - » Transfer efficiency from Accumulator to Recycler

Handle more pbars

- Stacktail
  - ⇒ Change physical performance by changing design characteristics
  - ⇒ Change noise performance by going to L He
- Core cooling times increase: need smaller core sizes
- Transfer every ~10 minutes!



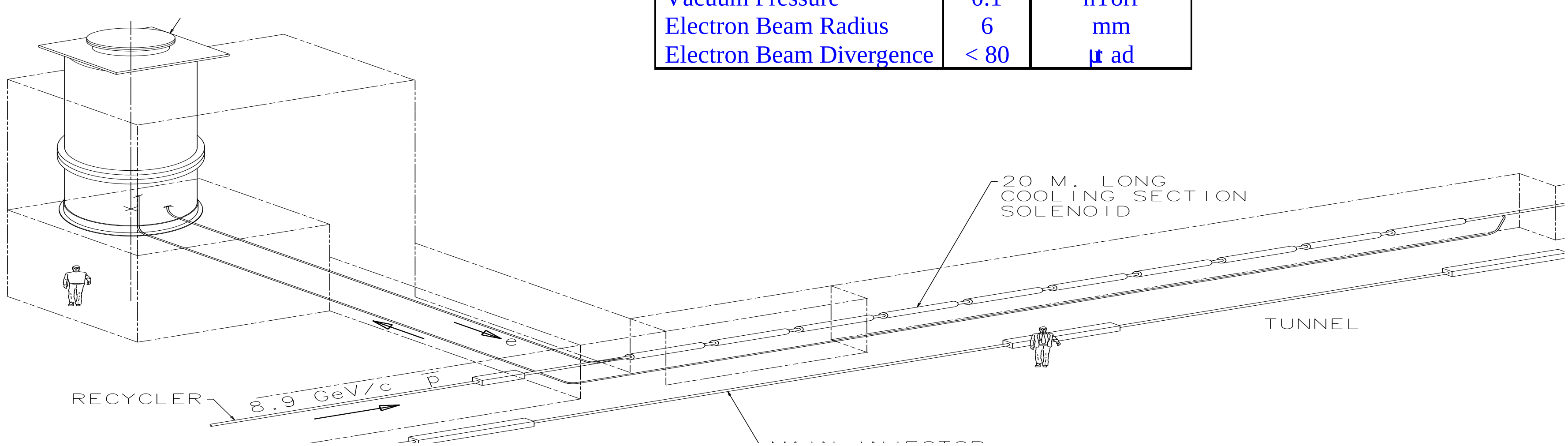
Handle more pbars

- Electron cooling in Recycler:
  - ⇒ Stochastic cooling will have problems with high densities
  - ⇒ Pbars heavier than electrons, transfer energy from heavier to lighter objects
  - ⇒ Cool and recycle high intensity pbar beams necessary for high luminosity
  - ⇒ R&D effort in progress to understand technology required for cooling 8 GeV pbars: 4.3 MeV high current electron source

Handle more pbars

Electron Cooling System Parameters

Parameter	Value	Units
Electrostatic Accelerator		
Terminal Voltage	4.3	MV
Electron Beam Current	0.5	A
Terminal Voltage Ripple	500	V (FWHM)
Cathode Radius	2.5	mm
Gun Solenoid Field	200	G
Cooling Section		
Length	20	m
Solenoid Field	50	G
Vacuum Pressure	0.1	nTorr
Electron Beam Radius	6	mm
Electron Beam Divergence	< 80	µrad



Path to Run IIb

- Increase the number of antiprotons in the collider by a factor of 2-3 over Run IIa
- More protons on the antiproton target
  - ⇒ Slip stacking (~1.8 x)
- Better antiproton collection efficiency
  - ⇒ Lithium lens Upgrade(~1.3 - 1.5 x)
  - ⇒ AP2-Debuncher aperture increases (~1.5 x)
- Handle the Increased Pbar Flux
  - ⇒ Debuncher cooling bandwidth increase
  - ⇒ Accumulator Stacktail
  - ⇒ Electron cooling in the Recycler
- Better Antiproton Transfer Efficiency

Run IIb luminosity

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