Introduction

Daniel M. Kaplan

ILLINOIS INSTITUTE OF TECHNOLOGY

Transforming Lives. Inventing the Future. www.iit.edu

Antiproton Physics at the Intensity Frontier

Fermilab

Nov. 18, 2011

Outline

- Lab situation
- Antiproton Sources
- Charm CPV
- A new experiment
- Conclusions

Lab Situation

- Tevatron has been surpassed in energy and shut down
- Lab budget cut, staff reduced
- Deficit cutters "driving the train" in Washington

$\Rightarrow$ To keep Lab open,

Must exploit Fermilab features that make it unique!

...and use them to do compelling physics

What makes Fermilab unique?

- Medium-energy, high-intensity neutrino beam
- Low-energy, high-intensity neutrino beam
- Long-baseline neutrino experiments

and

➡ World's best antiproton source!

➡ World’s best antiproton source!

Antiproton Sources

- Fermilab Antiproton Source is world's highest-energy
- And most intense:

Table 1: Antiproton energies and intensities at existing and future facilities.

Facility	$\overline{p}$ Kinetic Energy (GeV)	Stacking: Rate (10^{10}/hr)	Stacking: Duty Factor	Operation: Hours /Yr	Operation: $\overline{p}$/Yr (10^{13})
CERN AD	0.005 0.047	–	–	3800	0.4
Fermilab Accumulator:					
Tevatron Collider	8	>25	90%	5550	>150
proposed	$\approx$3.5–8	20	15%	5550	17
FAIR ($\gtrsim$ 2018*)	1–14	3.5	15%*	2780*	1.5

… even after (≈1G€) FAIR@Darmstadt turns on

- What compelling physics can it do?

Non-KM CP Violation

- 5 places to search for new sources of CPV:
  - Kaons
  - B mesons
  - Hyperons
  - Charm
  - Neutrinos

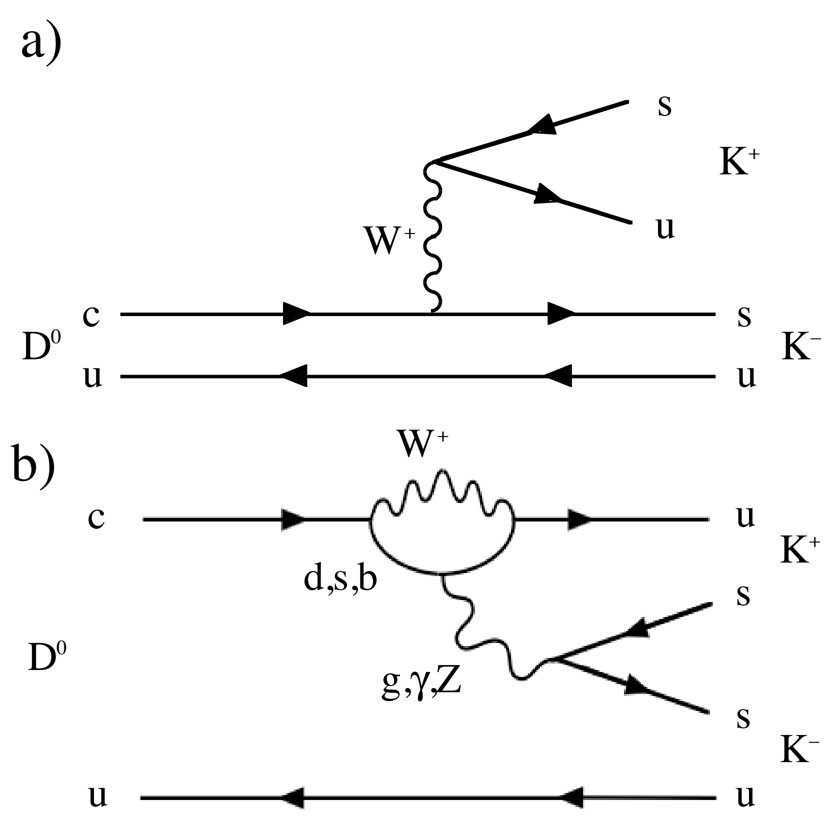
Kaons, B mesons: Years of intensive new-physics searches have so far come up empty*

Hyperons, Charm, Neutrinos: Worth looking elsewhere as well!

*except for possible DØ 3.9σ dimuon signal

Concentrate on Charm for Now

Singly Cabibbo-suppressed (CS) *D* decays have 2 competing diagrams:



- SM: Penguin– Tree interference → $\mathcal{O}(10^{-3})$ CPV in CS modes
- But only 1 SM diagram in CF, DCS modes

  ⇒ 0 CPV in SM
- But indirect CPV also possible, & mode-independent

Hot off the press!

New D^0 CPV Result

- Monday at HCP 2011, LHC*b* showed 3.5σ signal for D^0 direct CPV: (based on 1.4×10^6 tagged K^+K^-, 0.4×10^6 $\pi^+\pi^-$)
  - $A_{RAW}(f)^* = A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*+})$

    physics CP asymmetry

    Detection asymmetry of D^0

    Detection asymmetry of soft pion

    Production asymmetry

  - $\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$

    $$= [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$$

- Claim systematics ≈ cancel due to subtraction

➡ The first evidence for New Physics from LHC!

- Independent confirmation now becomes urgent

Can $\bar{p}$ expt confirm D^0 CPV?

How big is charm cross section in 8 GeV $\bar{p}p$ annihilation?

How big is charm cross section in 8 GeV $\bar{p}p$ annihilation?

PHYSICAL REVIEW D **77**, 034019 (2008)

Estimate of the partial width for $X(3872)$ into $p\bar{p}$

Eric Braaten

Physics Department, Ohio State University, Columbus, Ohio 43210, USA

(Received 13 November 2007; published 25 February 2008)

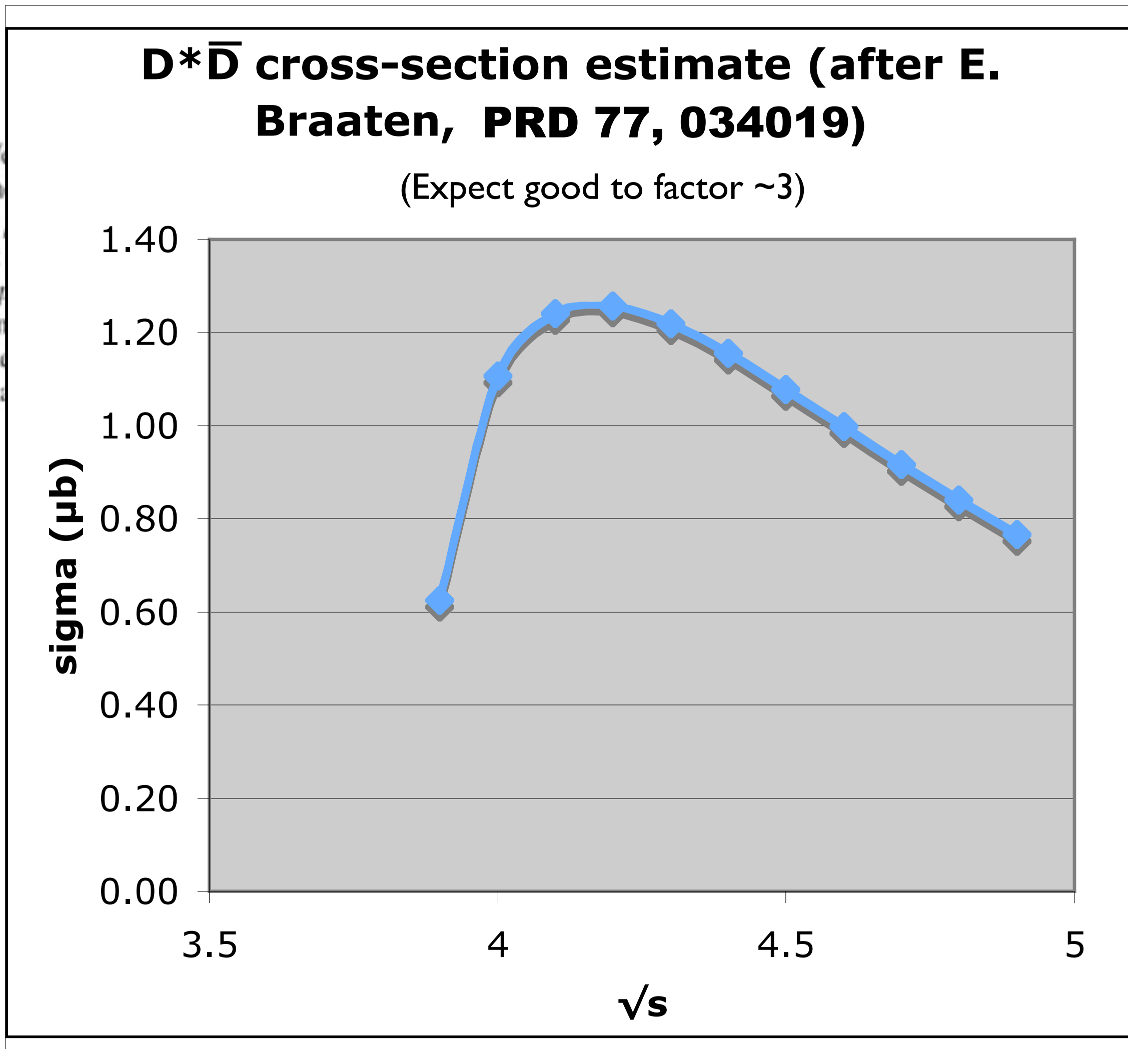
We present an estimate of the partial width of $X(3872)$ into $p\bar{p}$ under the assumption that it is a weakly bound hadronic molecule whose constituents are a superposition of the charm mesons $D^{*0}\bar{D}^0$ and $D^0\bar{D}^{*0}$. The $p\bar{p}$ partial width of X is therefore related to the cross section for $p\bar{p} \to D^{*0}\bar{D}^0$ near the threshold. That cross section at an energy well above the threshold is estimated by scaling the measured cross section for $p\bar{p} \to K^{*-}K^+$. It is extrapolated to the $D^{*0}\bar{D}^0$ threshold by taking into account the threshold resonance in the 1^{++} channel. The resulting prediction for the $p\bar{p}$ partial width of $X(3872)$ is proportional to the square root of its binding energy. For the current central value of the binding energy, the estimated partial width into $p\bar{p}$ is comparable to that of the P-wave charmonium state χ_{c1}.

- E. Braaten estimate of $\bar{p}p$ $X(3872)$ coupling assuming X is $D^*\bar{D}$ molecule
  - extrapolates from K^*K data

How big is charm cross section in 8 GeV $\bar{p}p$ annihilation?

PHYSICAL REVIEW D 77, 034019 (2008)

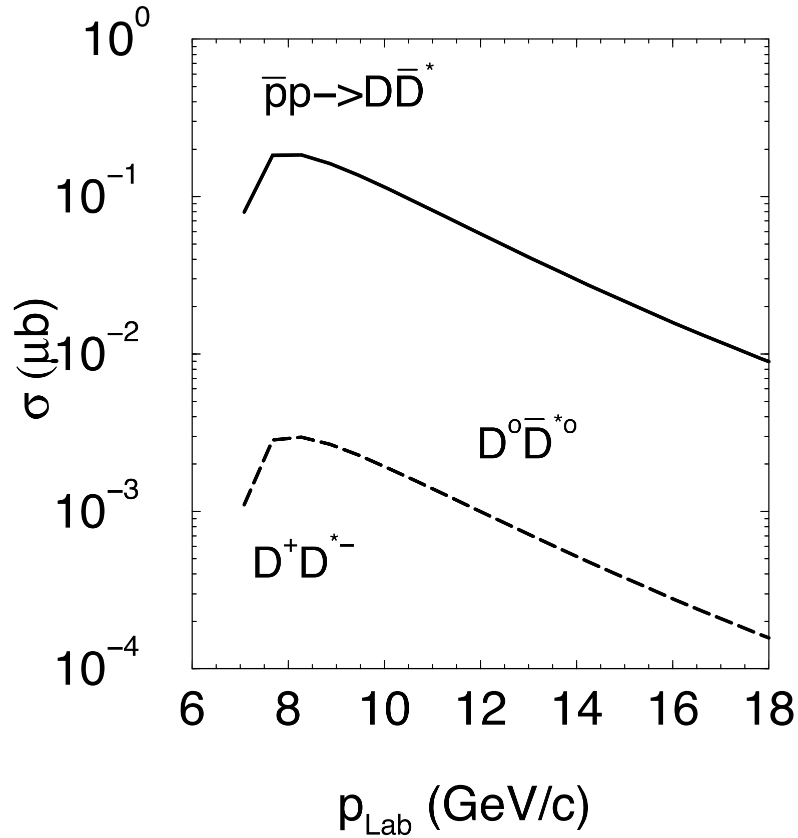
Estimate of the partial width for $X(3872)$ into $p\bar{p}$



- E. Braaten estimate of $\bar{p}p$ $X(3872)$ coupling assuming X is $D^*\bar{D}$ molecule
  - extrapolates from K^*K data
- By-product is $D^{*0}\bar{D}^0$ cross section

How big is charm cross section in 8 GeV $\bar{p}p$ annihilation?

- Another approach (Regge model)



A. I. Titov and B. Kämpfer, Phys. Rev. C **78**, 025201 (2008)

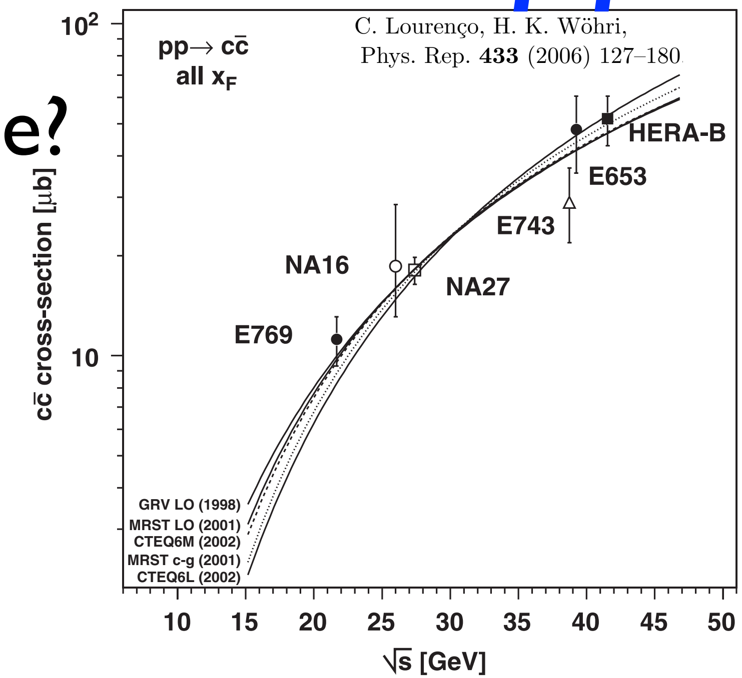
A. Titov, private communication

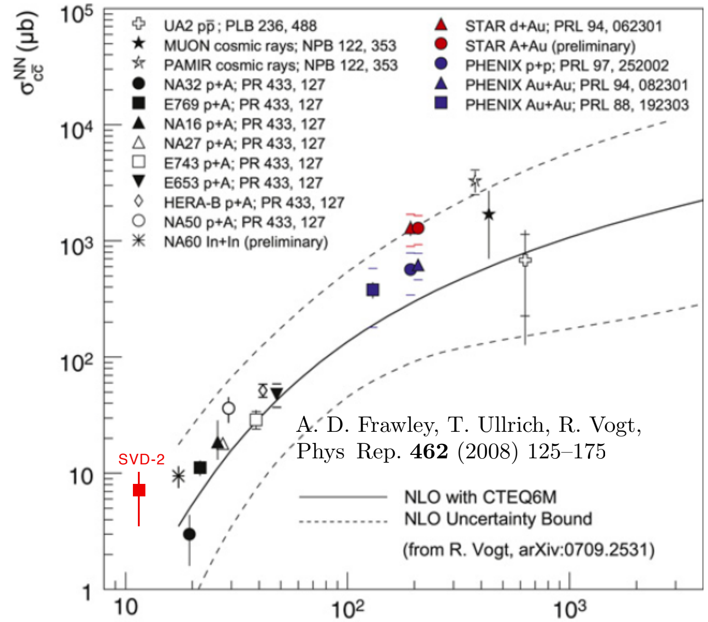
- Agreement within factor of 6

✓ not bad, considering it's low-energy QCD...

How big is charm cross section in 8 GeV $\bar{p}p$ annihilation?

- Other evidence?





REGISTRATION OF NEUTRAL CHARMED MESONS PRODUCTION AND THEIR DECAYS IN pA-INTERACTIONS AT 70 GeV WITH SVD-2 SETUP

(SVD-2 Collaboration)

A. Aleev, V. Balandin, N. Furmanec, V. Kireev, G. Lanshikov, Yu. Petukhov, T. Topuria, A. Yukaev.
Joint Institute for Nuclear Research, Dubna, Russia

E. Ardashev, A. Afonin, M. Bogolyubsky, S. Golovnia, S. Gorokhov, V. Golovkin, A. Kholodenko, A. Kiriakov, V. Konstantinov, L. Kurchaninov, G. Mitrofanov, V. Petrov, A. Pleskach, V. Riadovikov*, V. Ronjin, V. Senko, N. Shalanda, M. Soldatov, Yu. Tsyupa, A. Vorobiev, V. Yakimchuk, V. Zapolsky.
*Institute for High Energy Physics, Protvino, Russia**

S. Basiladze, S. Berezhnev, G. Bogdanova, V. Ejov, G. Ermakov, P. Ermolov, N. Grishin, Ya. Grishkevich, D. Karmanov, V. Kramarenko, A. Kubarovsky, A. Leflat, S. Lyutov, M. Merkin, V. Popov, D. Savrina, L. Tikhonova, A. Vischnevskaya, V. Volkov, A. Voronin, S. Zotkin, D. Zotkin, E. Zverev.
D.V. Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

The results of data handling for SERP-E-184 experiment obtained with 70 GeV proton beam irradiation of active target with carbon, silicon and lead plates are presented. Two-prongs neutral charmed D^0 and $\bar{D}^0$ -mesons decays were selected. Signal / background ratio is (51±17) / (38±13). Registration efficiency for mesons was defined and evaluation for charm production cross section at threshold energy is presented: $\sigma(c\bar{c}) = 7.1 \pm 2.4(stat.) \pm 1.4(syst.)$ ($\mu b/nucleon$).

- Hard to predict size of 8 GeV $\bar{p}$ cross section

⇒ Need to measure it!

$\bar{p}$ Charm Statistics

- Ballpark sensitivity estimate based on Braaten $\bar{p}p \to D^{*0}\bar{D}^0$ formula, assuming $\sigma \propto A^{1.0}$ and $\mathcal{L} = 2 \times 10^{32}$ cm^{-2} s^{-1}:

Quantity	Value	Unit
Running time	2×10^7	s/yr
Duty factor	0.8*	
$\mathcal{L}$	2×10^{32}	cm^{-2}s^{-1}
Annual integrated $\mathcal{L}$	3.2	fb^{-1}
Target A (Ti)	47.9	
$A^{0.29}$	3.1	(based on H.E. fixed-target)
$\sigma(\bar{p}p \to D^{*+} + \text{anything})$	1.25–4.5	μb
# $D^{*\pm}$ produced	(2.5–8.9) $\times 10^{10}$	events/yr
$\mathcal{B}(D^{*+} \to D^0\pi^+)$	0.677	
$\mathcal{B}(D^0 \to K^-\pi^+)$	0.0389	
Acceptance	0.45	(signal MC)
Efficiency	0.1–0.3	(MIPP & bkg MC)
Total	(0.3–3) $\times 10^8$	tagged events/yr

*Assumes ≈15% of running time is devoted to antiproton-beam stacking.

But keep in mind:
Main issue is systematics. Ours will be quite different from theirs, thus truly indep. x-check.

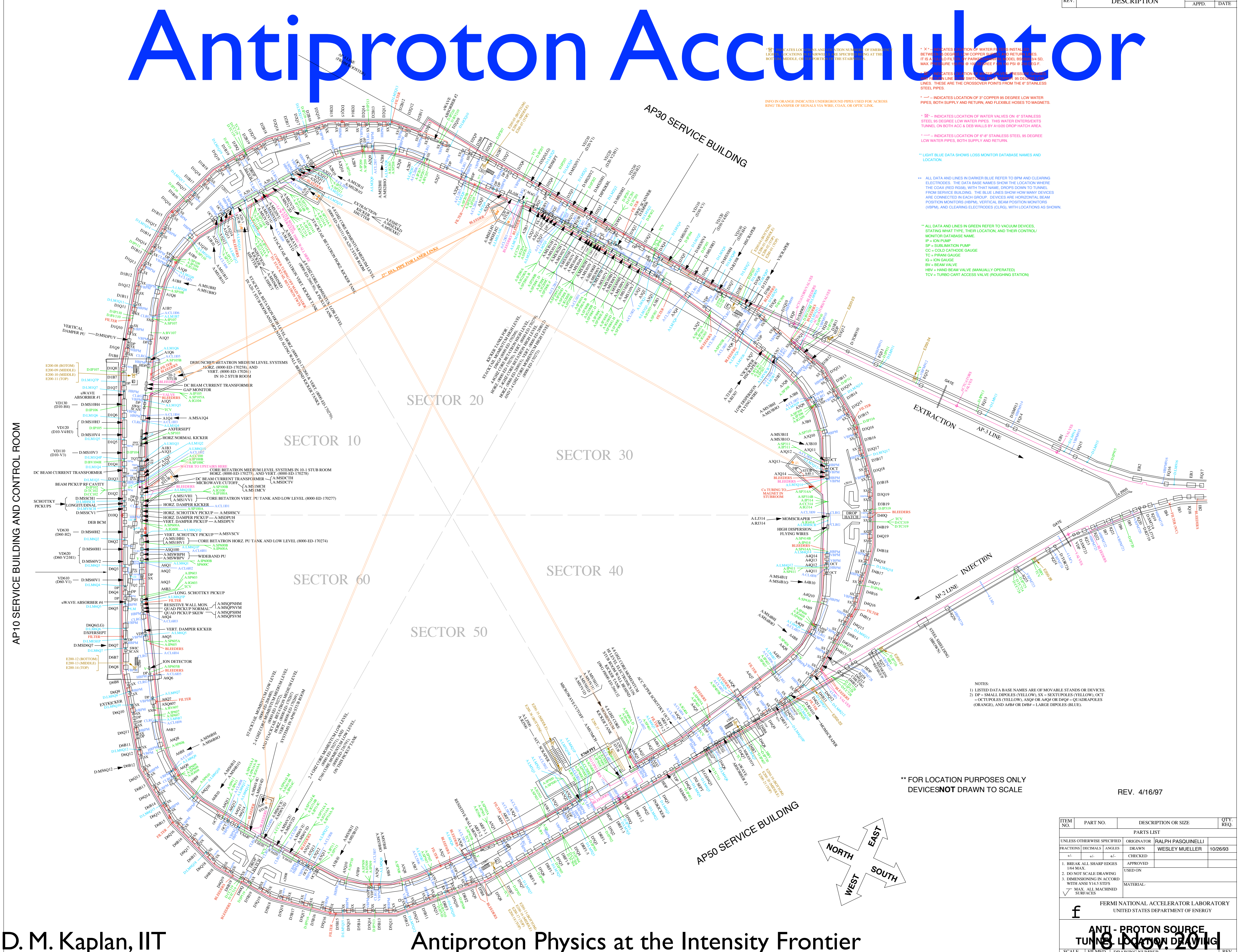
- 3–30 x 10^7 tagged $K^{\mp}\pi^{\pm}$ ⇒ 3–30 x 10^6 K^+K^-, 1–10 x 10^6 $\pi^+\pi^-$

⟹ $\delta\Delta A \approx (0.17 \text{ to } 0.10)\%$

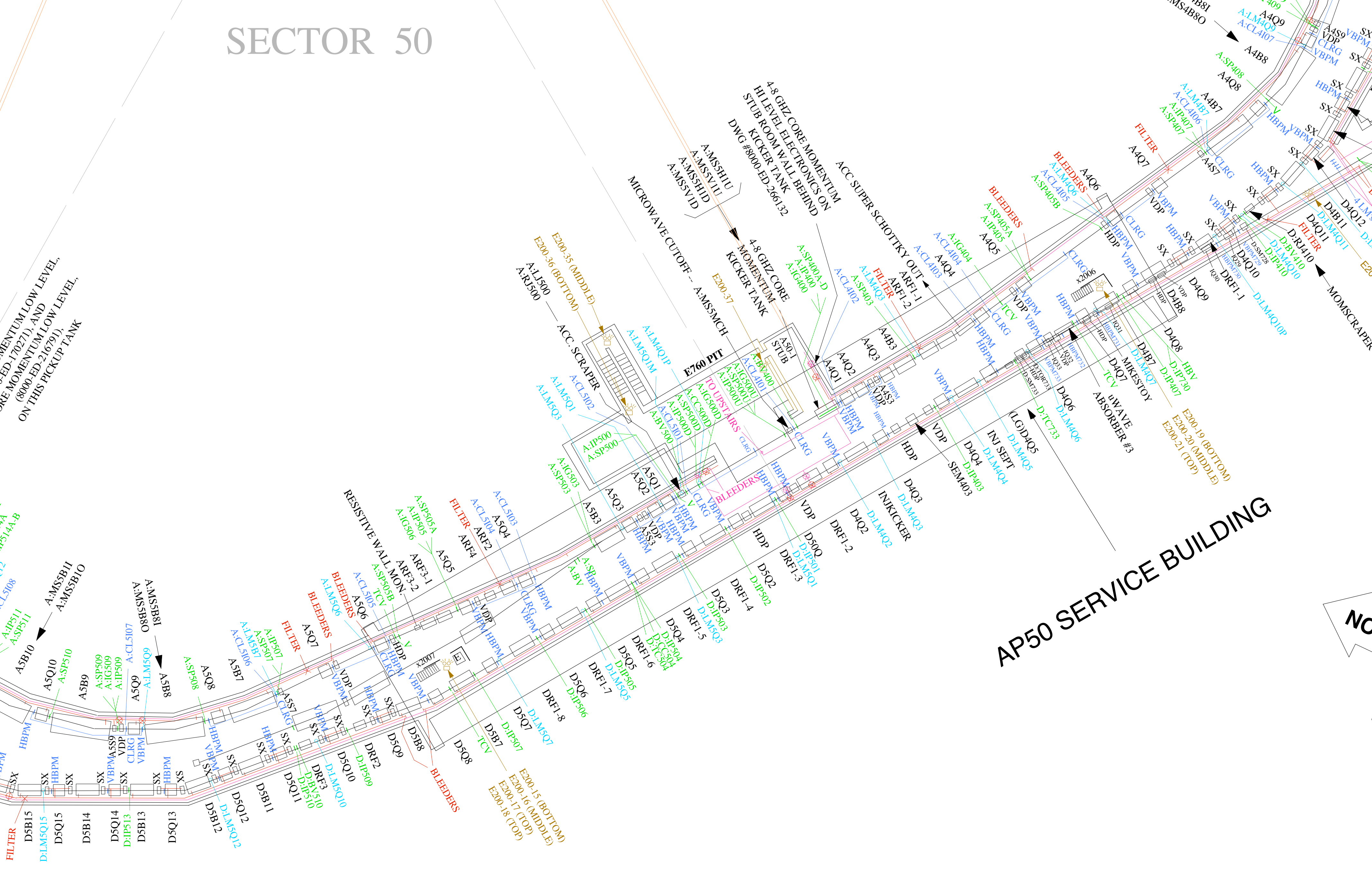
LHC*b*: $[-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$

⟹ competitive with LHC*b* *in one year of $\bar{p}$ running*

Antiproton Accumulator

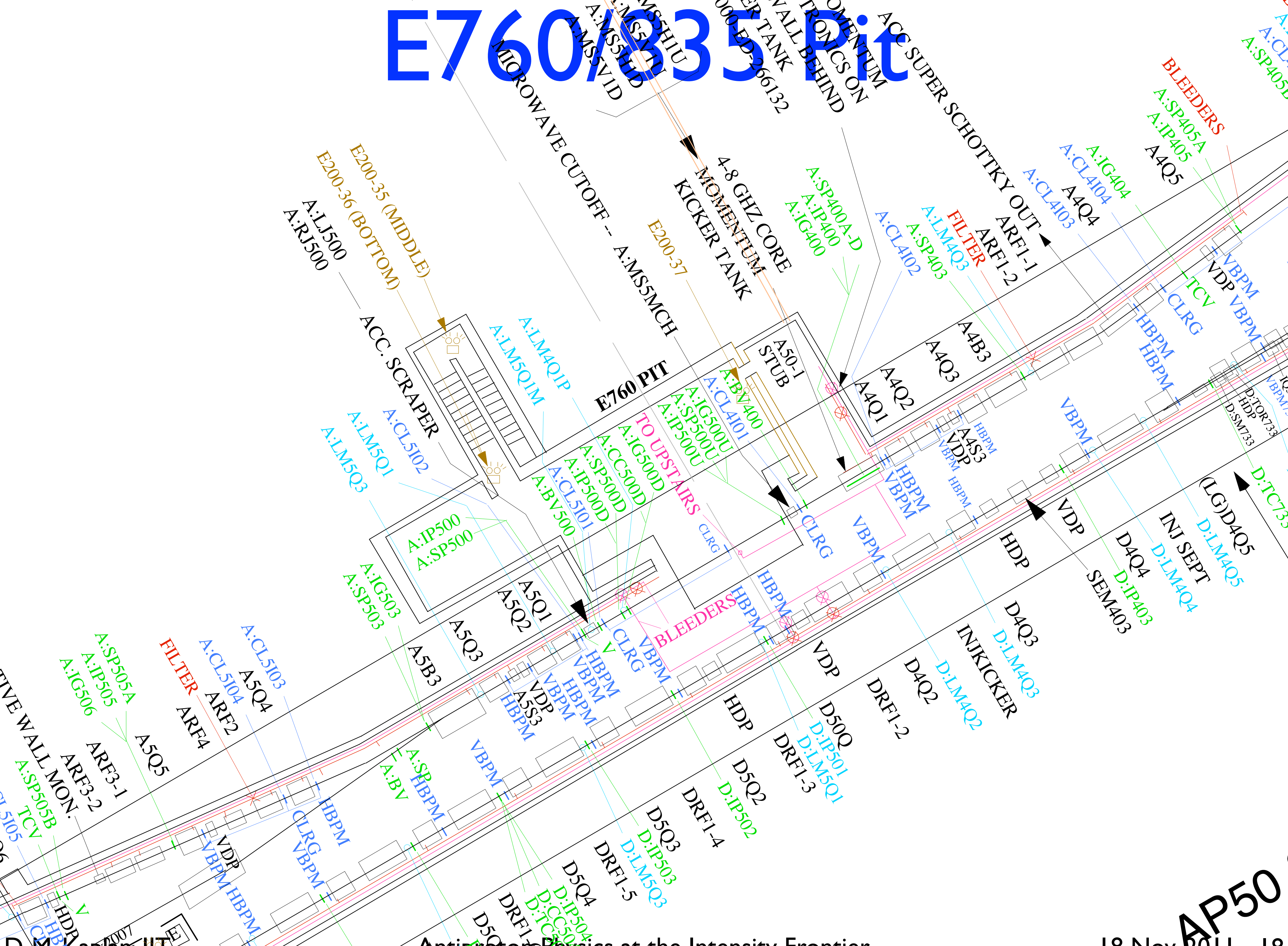


AP Sector 50

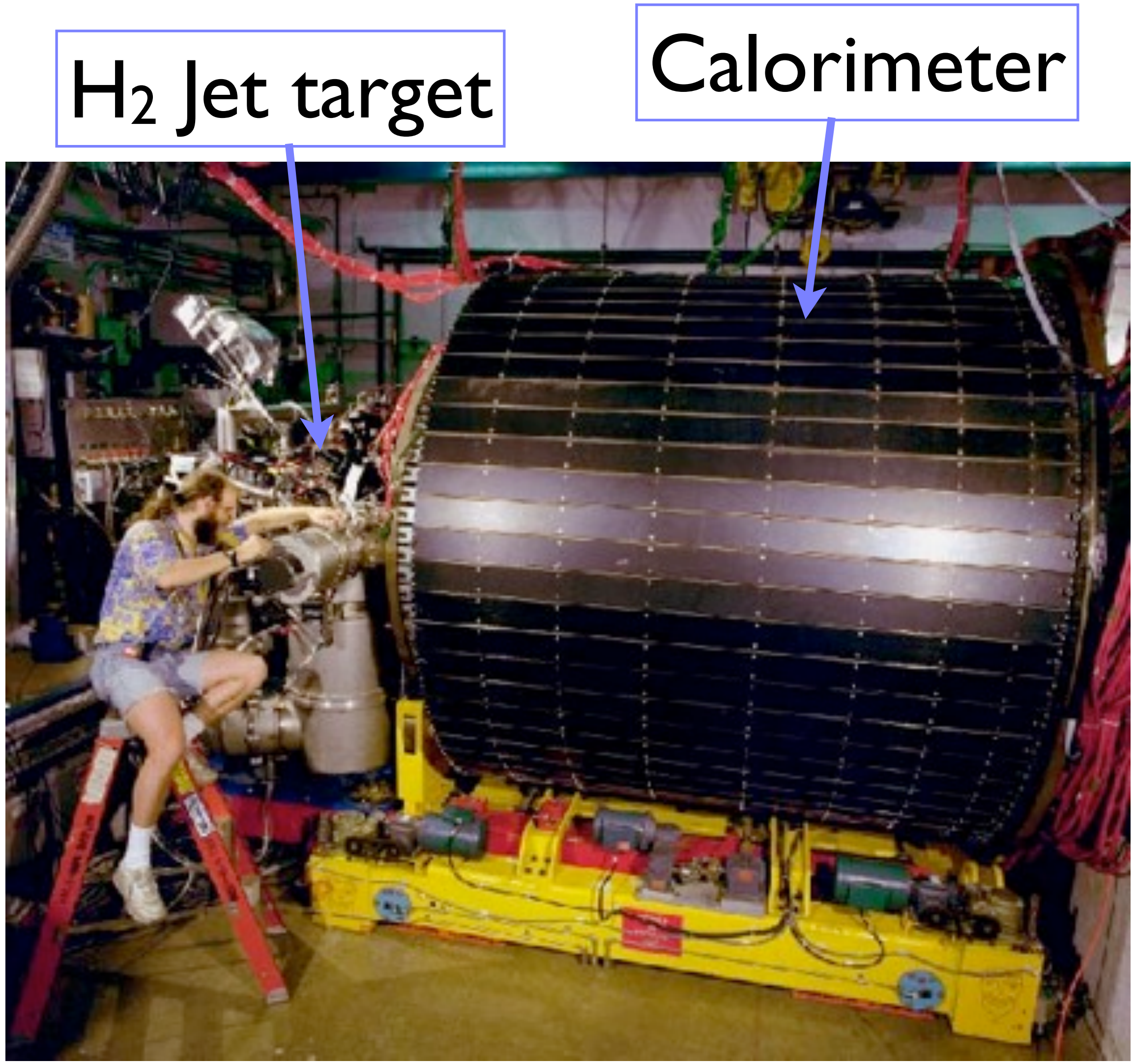


SECTOR 50
AP50 SERVICE BUILDING
E760 PIT
4-8 GHZ CORE MOMENTUM
HI LEVEL ELECTRONICS ON
STUB ROOM WALL BEHIND
KICKER TANK
DWG #8000-ED-266132
4-8 GHZ CORE
MOMENTUM
KICKER TANK
ACC SUPER SCHOTTKY OUT
MICROWAVE CUTOFF -- A:MS5MCH
ACC. SCRAPER
RESISTIVE WALL MON.
TO UPSTAIRS
BLEEDERS
FILTER
INJ SEPT
INJKICKER
MIKESTOY
uWAVE
ABSORBER #3
E200-19 (BOTTOM)
E200-20 (MIDDLE)
E200-21 (TOP)
E200-15 (BOTTOM)
E200-16 (MIDDLE)
E200-17 (TOP)
E200-18 (TOP)
E200-35 (MIDDLE)
E200-36 (BOTTOM)
E200-37

E760/835 Pit


E760 PIT
A50-1 STUB
ACC. SCRAPER
MICROWAVE CUTOFF -- A:MS5MCH
4-8 GHZ CORE MOMENTUM KICKER TANK
ACC SUPER SCHOTTKY OUT
TO UPSTAIRS
BLEEDERS
FILTER
E200-35 (MIDDLE)
E200-36 (BOTTOM)
E200-37
A:IP500
A:SP500
INJ SEPT
INJKICKER
SEM403
AP50

E760/835 in situ



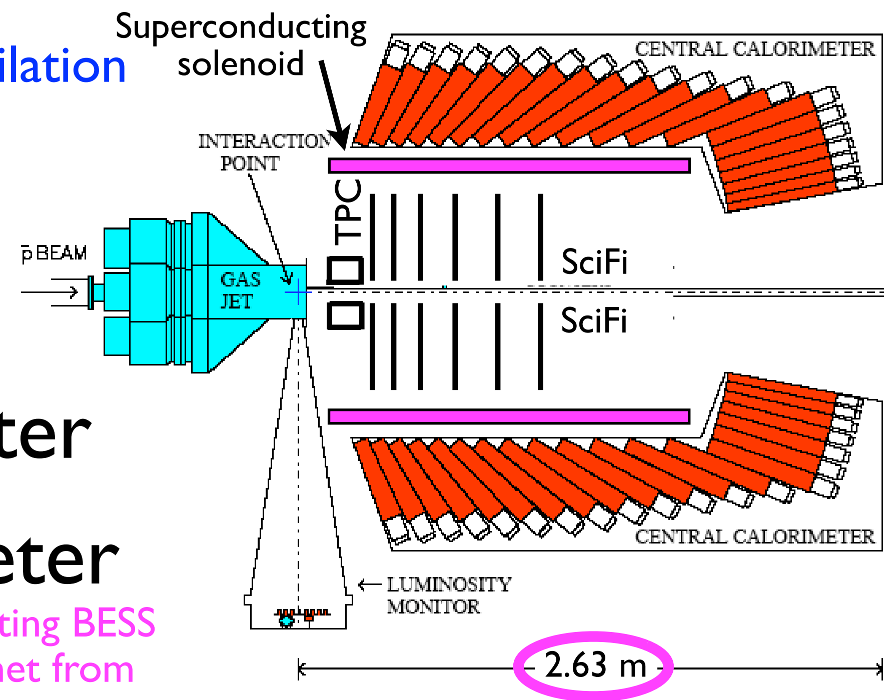
TAPAS

(The AntiProton Annihilation Specrometer)

Our proposal:

- Now that Tevatron finished,
  - Reinstall E760 barrel calorimeter
  - Add small magnetic spectrometer

[existing BESS magnet from KEK & SciFi DAQ from DØ



TAPAS

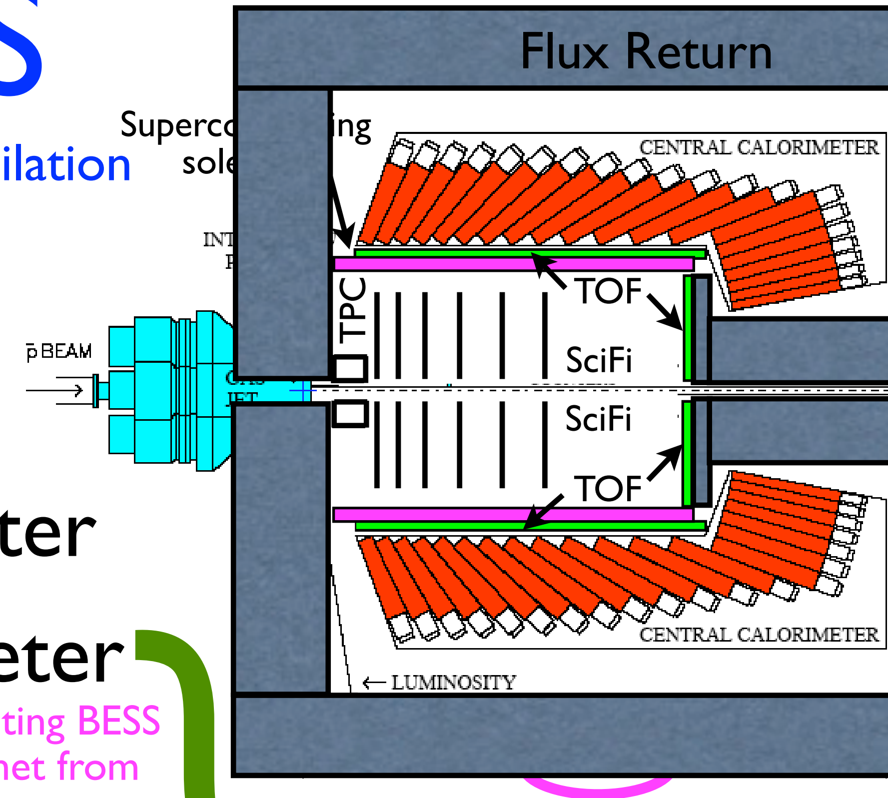
(The AntiProton Annihilation Specrometer)

Our proposal:

- Now that Tevatron finished,
  - Reinstall E760 barrel calorimeter
  - Add small magnetic spectrometer
  - Add precision TOF system
  - Add thin targets
  - Add fast trigger & DAQ systems

[existing BESS magnet from KEK & SciFi DAQ from DØ & FNAL iron]

} ≲$10M



- Take data at $\mathcal{L} = 2 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

(charm plus many other topics...)

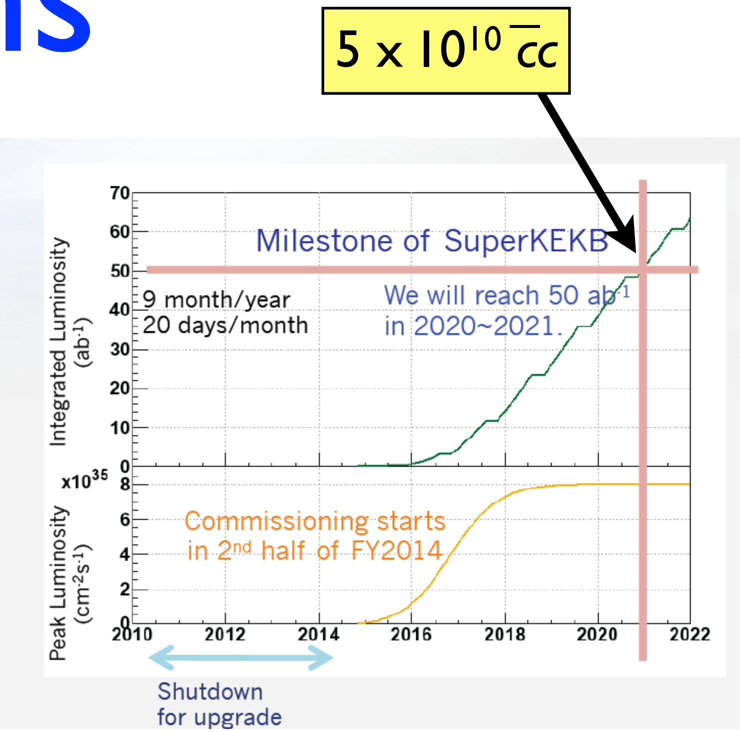
Cost Estimate

- TAPAS is *very* cost-effective (by HEP standards):

Item	Cost (k$)	Contingency (k$)
Targets	430	160
Luminosity monitor	60	20
Scintillating-fiber tracking system	1,820	610
Time-of-Flight system	500*	500
Triggering	1,390	460
Data acquisition system	490	153
Infrastructure	1,350	550
TOTALS	6,040	2,450

- Thanks to: existing calorimeter, solenoid, SciFi readout system, trigger & DAQ electronics

Conclusions



- Fermilab pbar Source can confirm or refute LHC*b* signal for charm CPV long before super B factories
- The HEP world can't wait until ≈2020 to do this
- Along with other topics to be discussed, can provide broad hadron-physics program at Fermilab while other expts under construction

  ...and while we wait for Project X