Challenges for a High-Rate TPC with MPGD Readout

Daniel M. Kaplan

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RD51 Collaboration Meeting
Bari, Italy
Oct. 8, 2010

Outline

(Varied menu!)

- Antiproton sources
- Hyperon CP violation
- A new experiment
- Issues in charmonium
- Charm mixing
- TPC options
- Summary

Antiproton Sources

- Fermilab Antiproton Source is world's most intense (and highest-energy)

Facility	$\overline{p}$ K.E. (GeV)	Stacking: Rate (10^{10}/hr)	Stacking: Duty Factor	Hours /Yr	$\overline{p}$/Yr (10^{13})
CERN AD	0.005, 0.047	–	–	3800	0.4
FNAL (Accumulator)	$\approx$3.5–8	20	15%	5550	17
~~FNAL (New Ring)~~	~~2–20?~~	~~20~~	~~90%~~	~~5550~~	~~100~~
FAIR ($\geq$2018)	2–15	3.5	90%	2780*	9

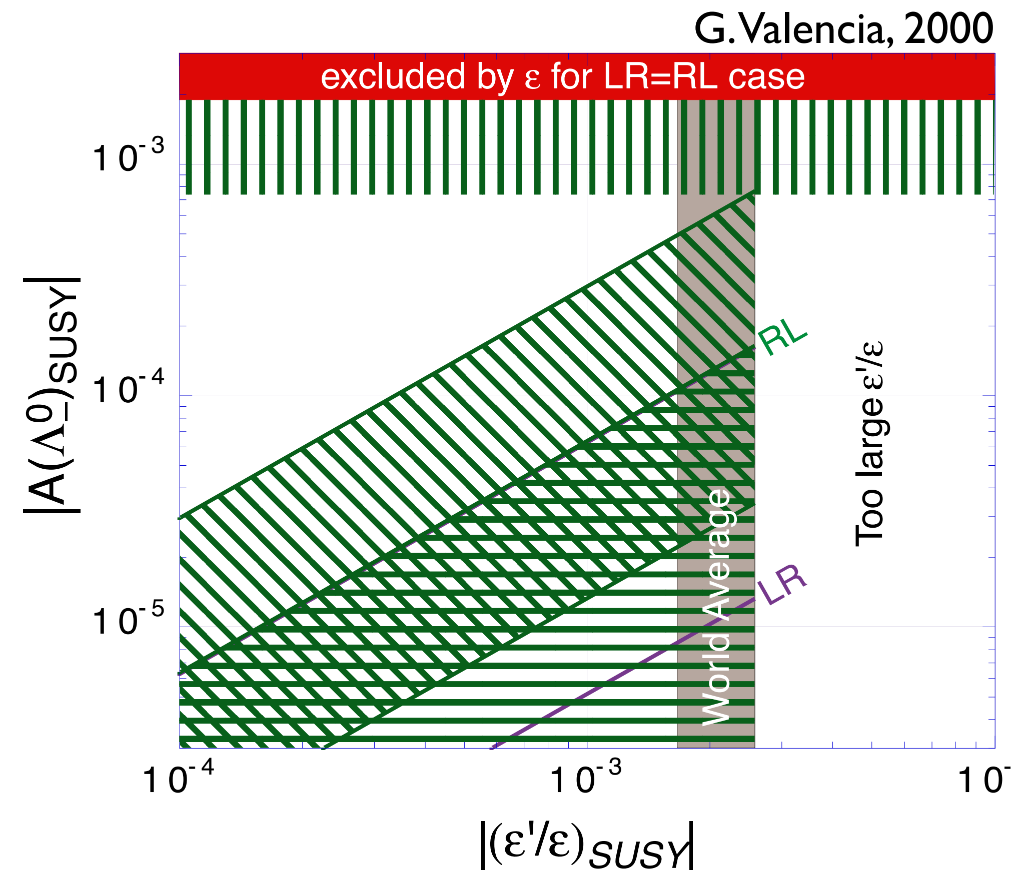
* The lower number of operating hours at FAIR compared with that at other facilities arises from medium-energy antiproton operation having to share time with other programs.

...even after FAIR@Darmstadt turns on (has yet to break ground; will take time to reach this goal)

Hyperon CP Violation

- Differently sensitive to new physics than *B* & *K* (parity-*conserving* interactions)
  - complementary to mu2e
- B Factories have shown *B* mixing & CPV dominantly SM

$\Longrightarrow$ worth looking elsewhere!



- Leading potential signals are A_Λ, $A_{\Xi\Lambda}$, B_Ξ, Δ_Ω:

$$A_\Lambda \equiv \frac{\alpha_\Lambda + \bar{\alpha}_\Lambda}{\alpha_\Lambda - \bar{\alpha}_\Lambda},\ B_\Lambda \equiv \frac{\beta_\Lambda + \bar{\beta}_\Lambda}{\beta_\Lambda - \bar{\beta}_\Lambda},\ \Delta_\Lambda \equiv \frac{\Gamma_{\Lambda\to P\pi} - \bar{\Gamma}_{\Lambda\to P\pi}}{\Gamma_{\Lambda\to P\pi} + \bar{\Gamma}_{\Lambda\to P\pi}}$$

CP-odd

- $\bar{p}$ source can produce ~10^8 $\Omega^- \bar{\Omega}^+$, & maybe ~10^{10} $\Xi^- \bar{\Xi}^+$ (transition crossing)

Hyperon CP Violation

- Theory & experiment:

Theory [Donoghue, He, Pakvasa, Valencia, et al., e.g., PRL 55, 162 (1985); PRD 34, 833 (1986); PLB 272, 411 (1991)]

- SM: $A_\Lambda \sim 10^{-5}$, $|A_{\Xi\Lambda}| < 5 \times 10^{-5}$ [J. Tandean, G. Valencia, Phys. Rev. D 67, 056001 (2003)]
- Other models: $O(10^{-3})$
  [e.g. SUSY gluonic dipole: X.-G.He et al., PRD 61, 071701 (2000)]

Experiment	Decay Mode	A_Λ	
R608 at ISR	$pp \to \Lambda X, \bar{p}p \to \bar{\Lambda} X$	-0.02 ± 0.14	[P. Chauvat et al., PL 163B (1985) 273]
DM2 at Orsay	$e^+e^- \to J/\Psi \to \Lambda\bar{\Lambda}$	0.01 ± 0.10	[M.H. Tixier et al., PL B212 (1988) 523]
PS185 at LEAR	$p\bar{p} \to \Lambda\bar{\Lambda}$	0.006 ± 0.015	[P.D. Barnes et al., NP B 56A (1997) 46]

Experiment	Decay Mode	$A_\Xi + A_\Lambda$	
E756 at Fermilab	$\Xi \to \Lambda\pi, \Lambda \to p\pi$	0.012 ± 0.014	[K.B. Luk et al., PRL 85, 4860 (2000)]
E871 at Fermilab (HyperCP)	$\Xi \to \Lambda\pi, \Lambda \to p\pi$	$(0.0 \pm 6.7) \times 10^{-4}$	[T. Holmstrom et al., PRL 93. 262001 (2004)]
		$(-6 \pm 2 \pm 2) \times 10^{-4}$	[BEACH08 preliminary]

Hyperon CP Violation

- Theory & experiment:

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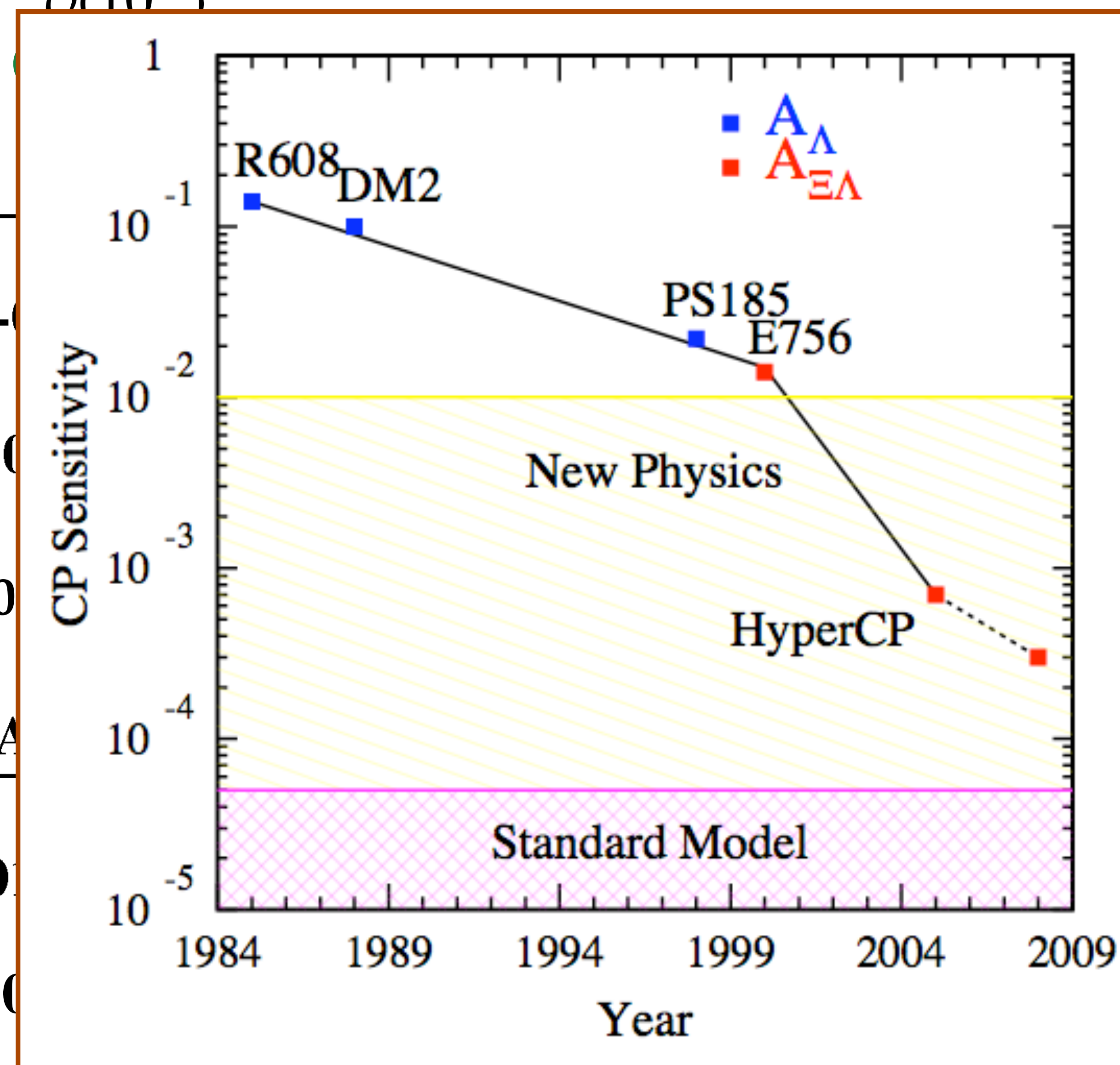
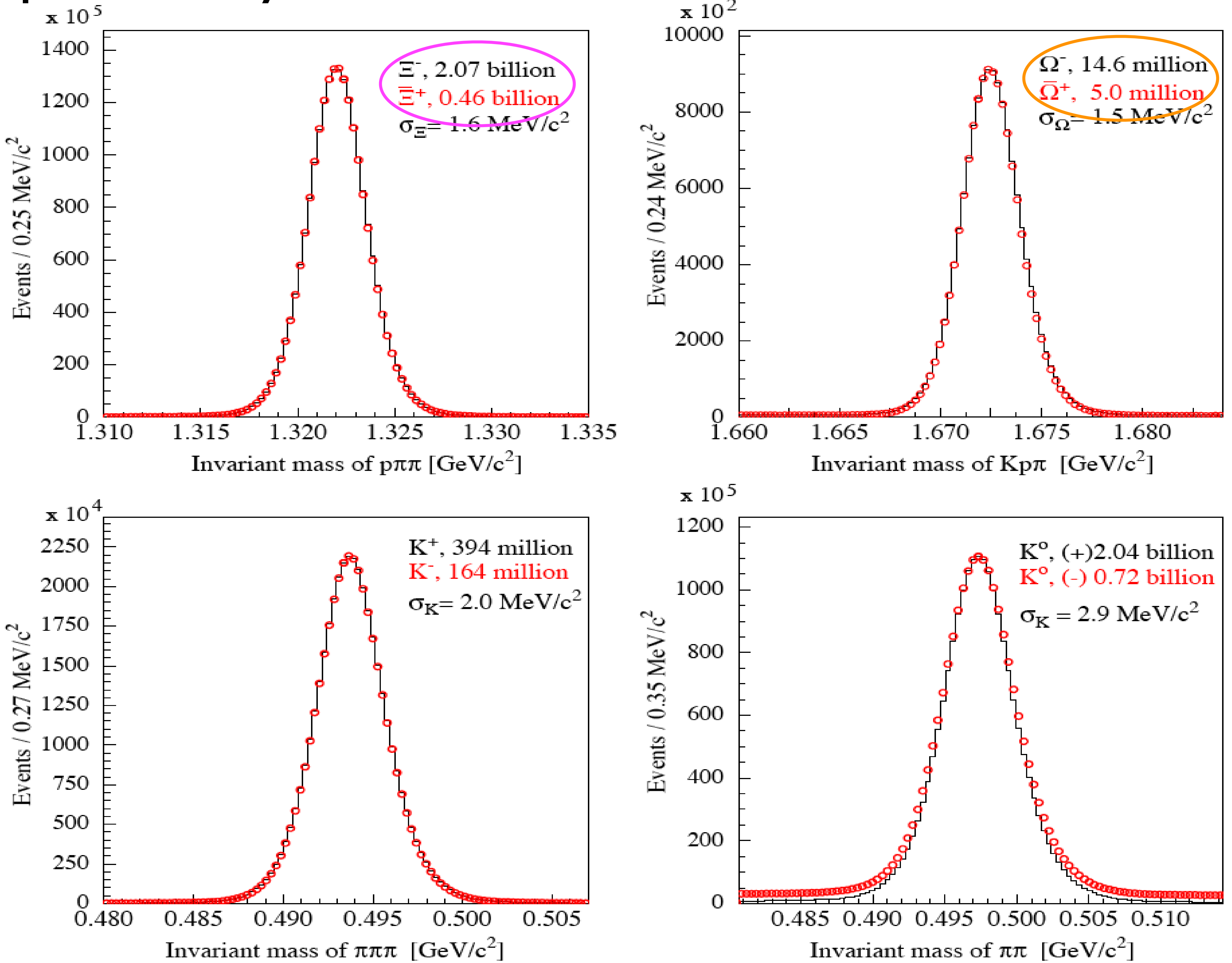


$(-6 \pm 2 \pm 2) \times 10^{-4}$ [BEACH08 preliminary]

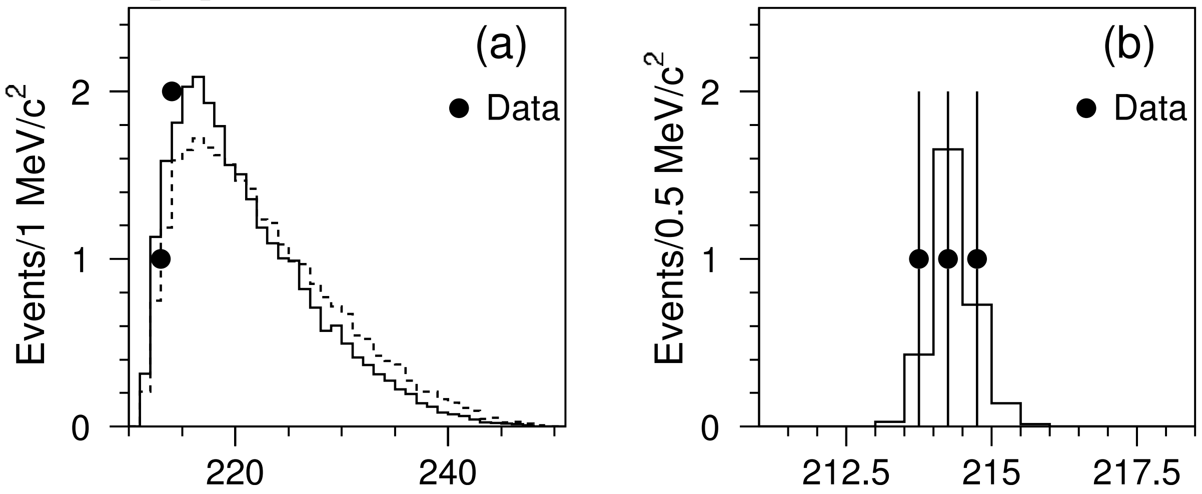
Made possible by... Enormous HyperCP Dataset



- $\bar{p}$ source can produce ~10^8 $\Omega^- \overline{\Omega}^+$/y & maybe ~$10^{10}$ $\Xi^- \overline{\Xi}^+$

HyperCP also → 10^{10} Σ^+

$\Sigma^+ \to p\mu^+\mu^-$ Decay



≈2.4σ fluctuation of SM? or

- SUSY Sgoldstino?
- SUSY light Higgs?
- other pseudo-scalar or axial-vector state?

PRL **98,** 081802 (2007) PHYSICAL REVIEW LETTERS week ending 23 FEBRUARY 2007

Does the HyperCP Evidence for the Decay $\Sigma^+ \to p\mu^+\mu^-$ Indicate a Light Pseudoscalar Higgs Boson?

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Jusak Tandean†

Departments of Mathematics, Physics, and Computer Science, University of La Verne, La Verne, California 91750, USA

G. Valencia‡

Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

(Received 2 November 2006; published 22 February 2007)

The HyperCP Collaboration has observed three events for the decay $\Sigma^+ \to p\mu^+\mu^-$ which may be interpreted as a new particle of mass 214.3 MeV. However, existing data from kaon and B-meson decays provide stringent constraints on the construction of models that support this interpretation. In this Letter we show that the "HyperCP particle" can be identified with the light pseudoscalar Higgs boson in the next-to-minimal supersymmetric standard model, the A_1^0. In this model there are regions of parameter space where the A_1^0 can satisfy all the existing constraints from kaon and B-meson decays and mediate $\Sigma^+ \to p\mu^+\mu^-$ at a level consistent with the HyperCP observation.

How Follow Up?

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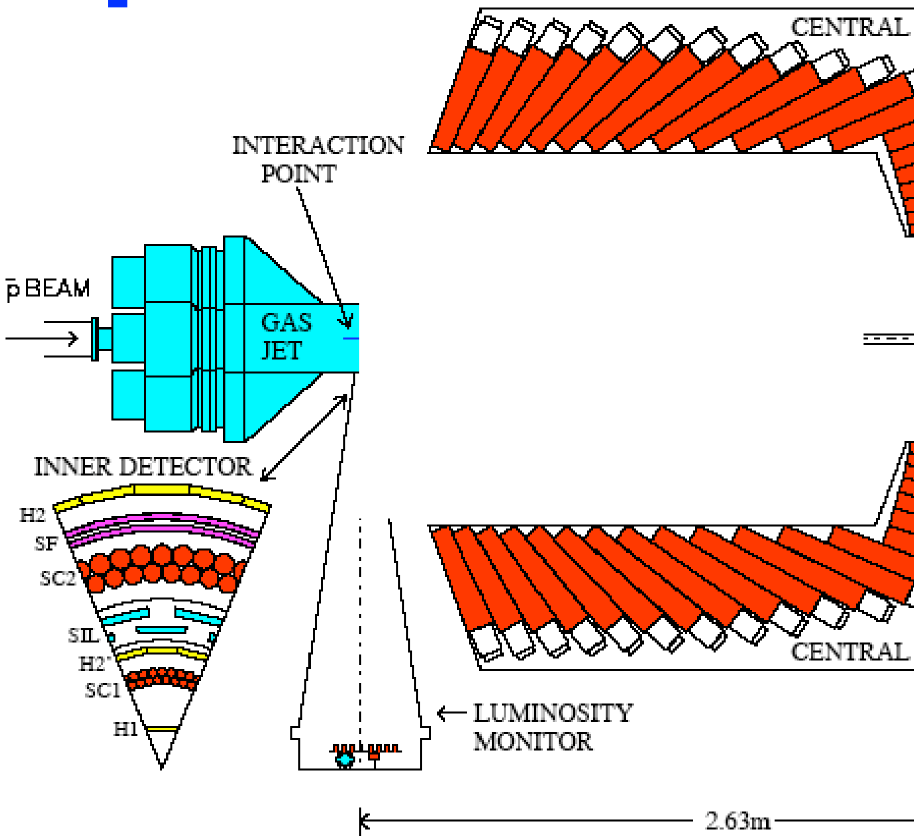
- Once Tevatron shuts down (≈2011?),
  - Reinstall E835 EM spectrometer



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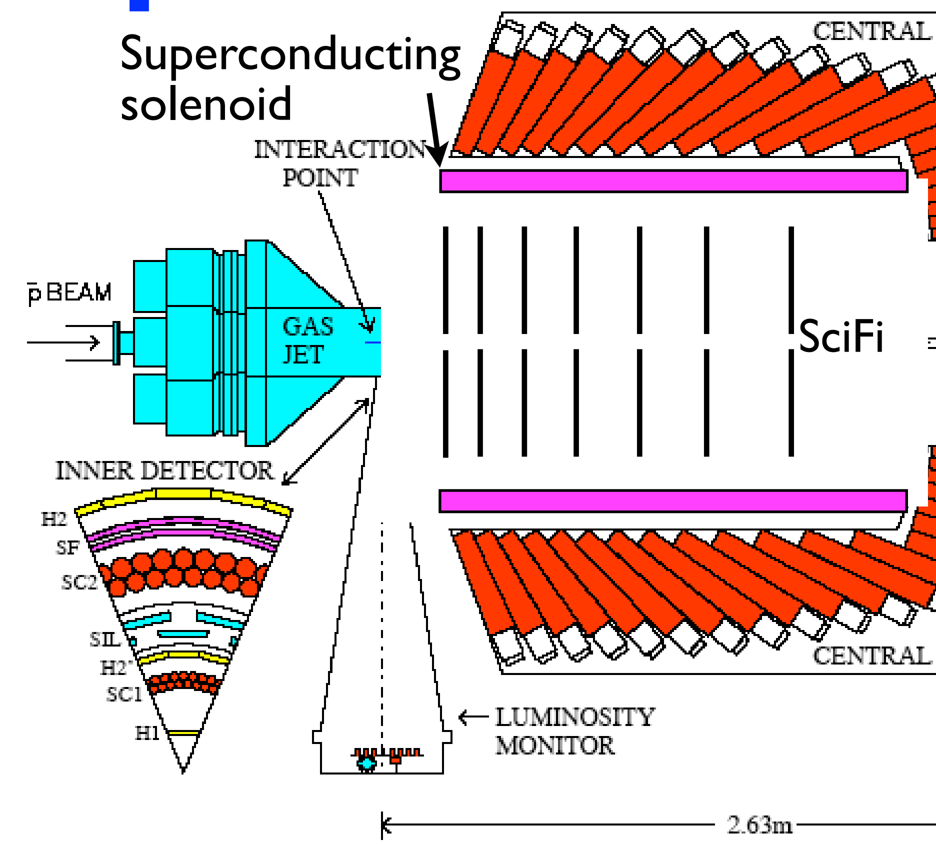
  - Add small magnetic spectrometer



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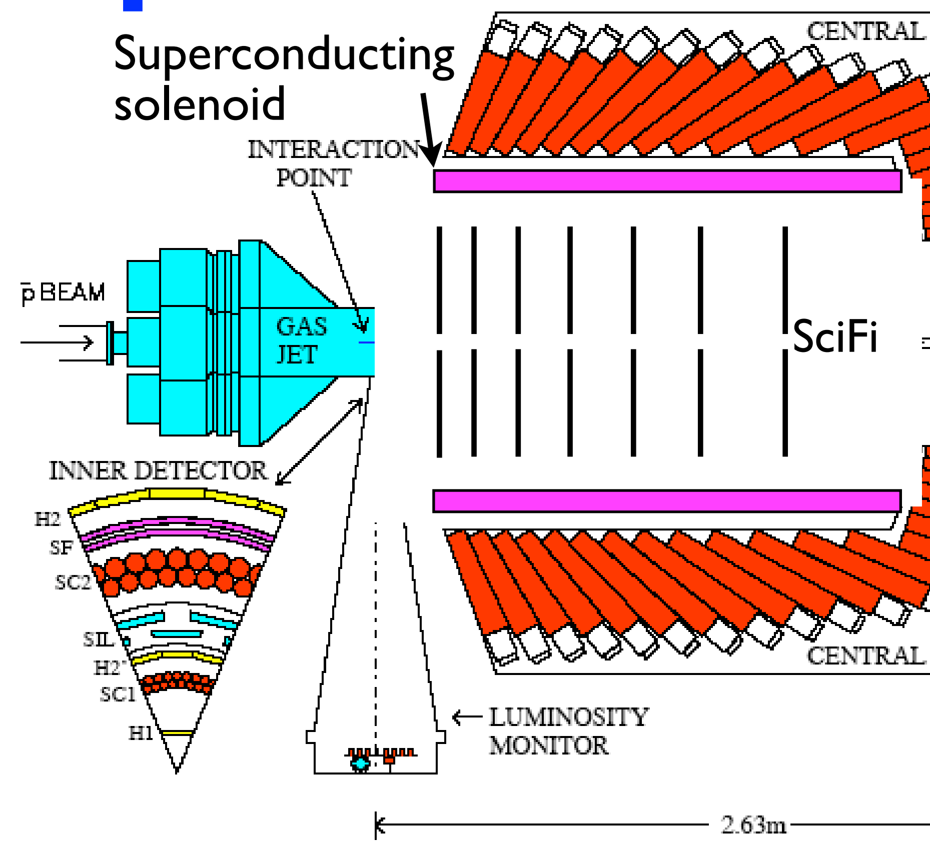
[existing BESS magnet from KEK & SciFi DAQ from DØ]



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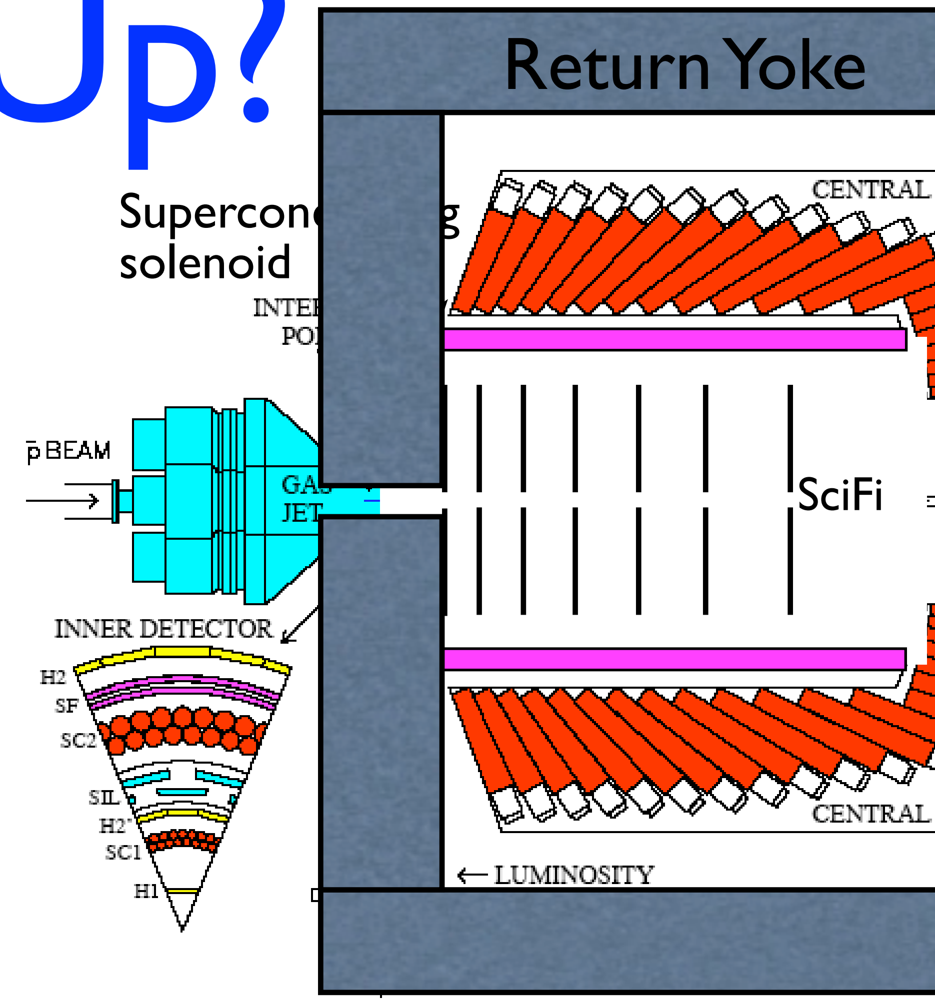

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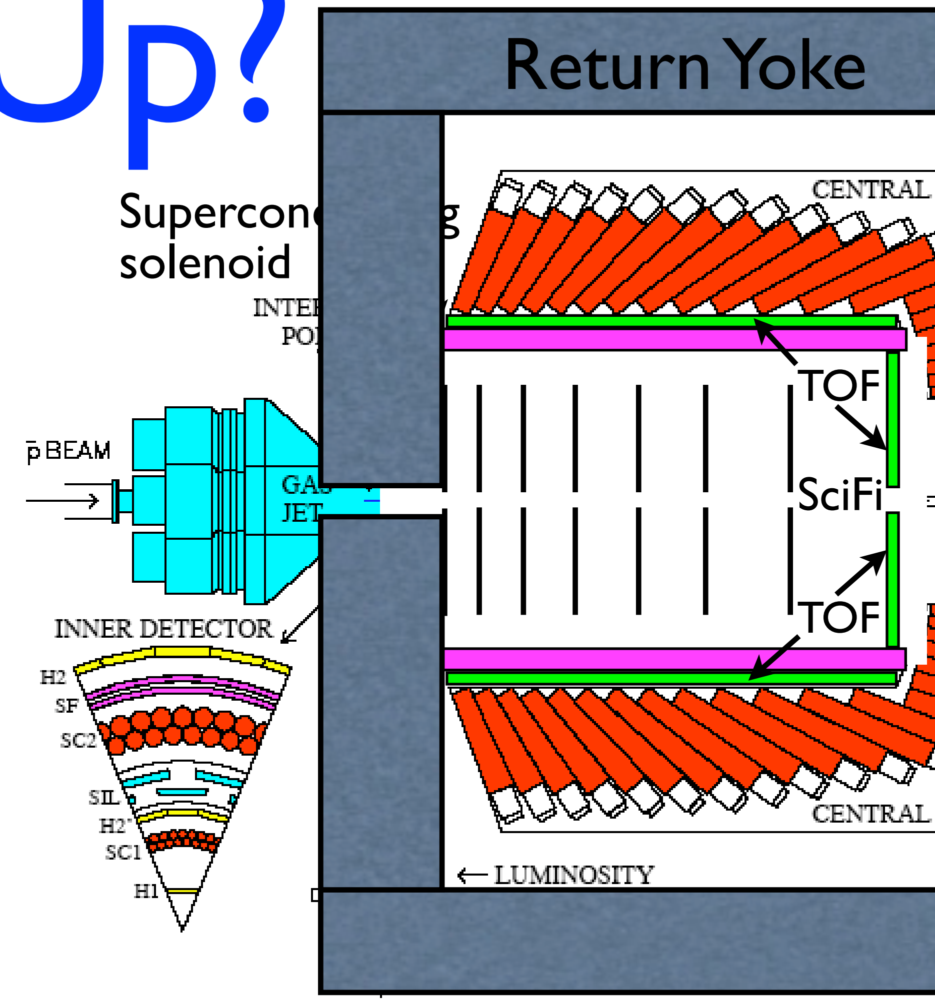

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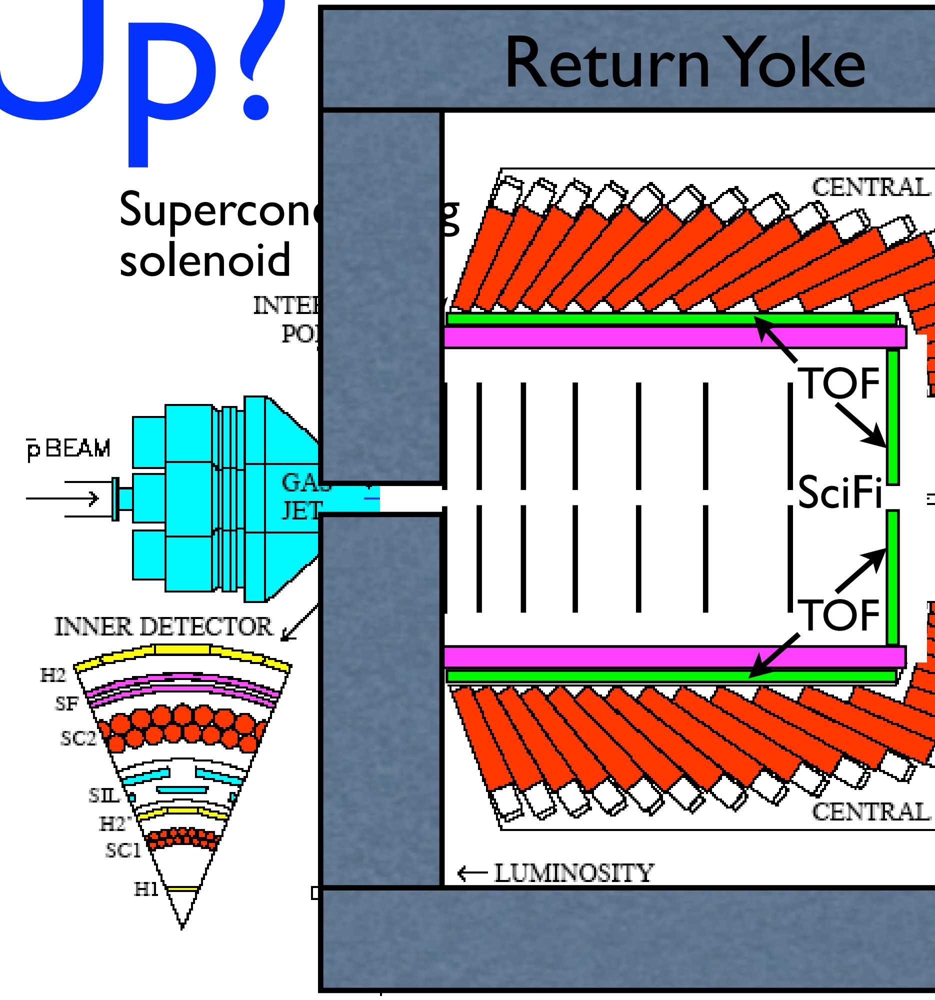

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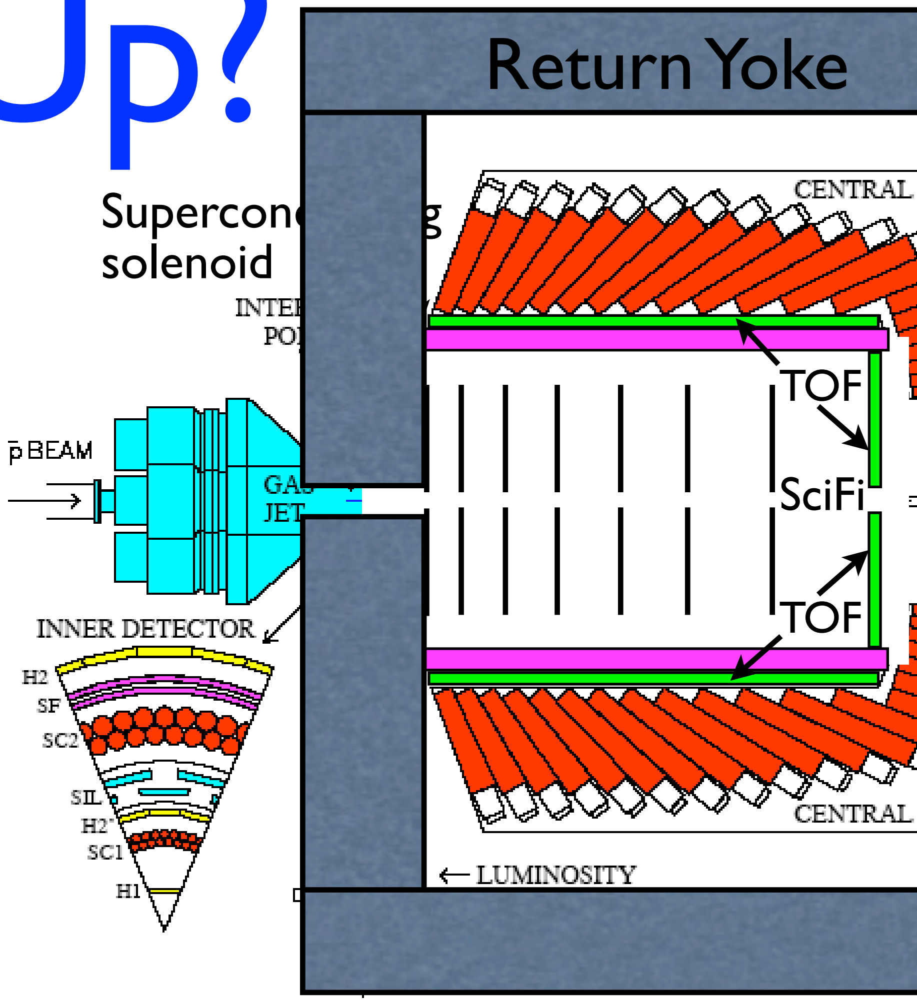

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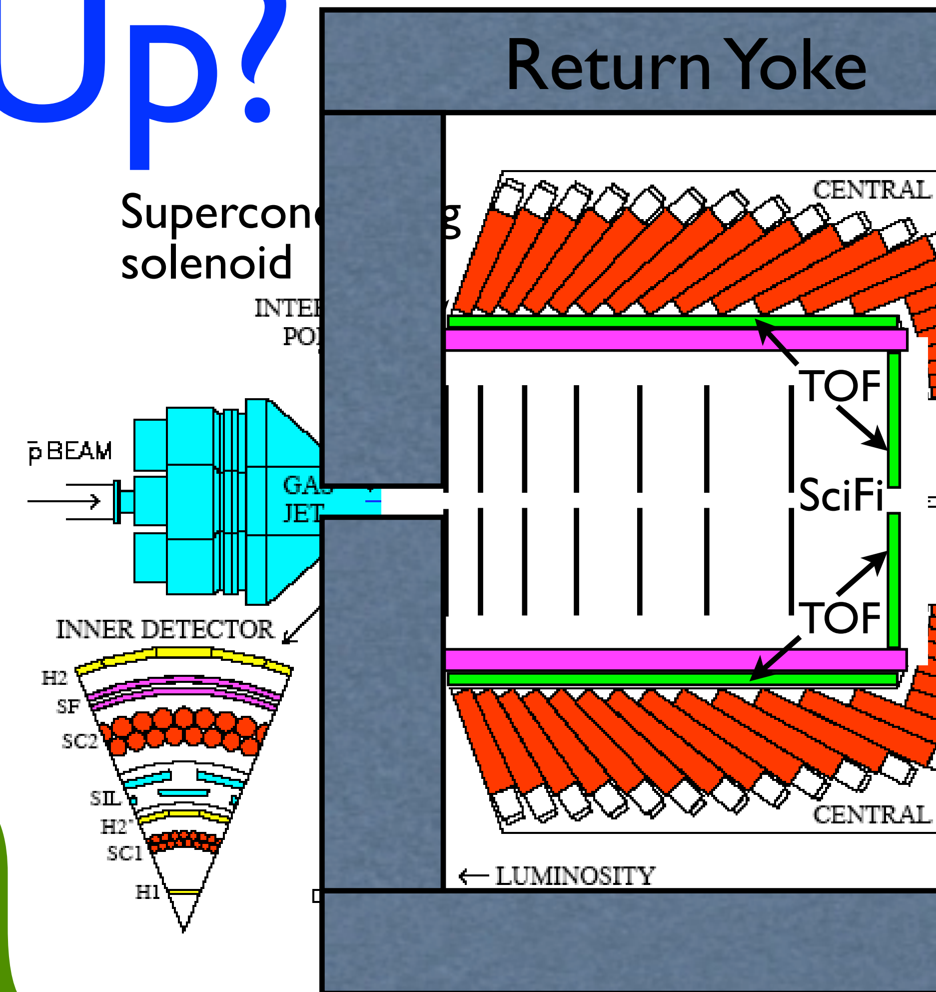

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} <$10M

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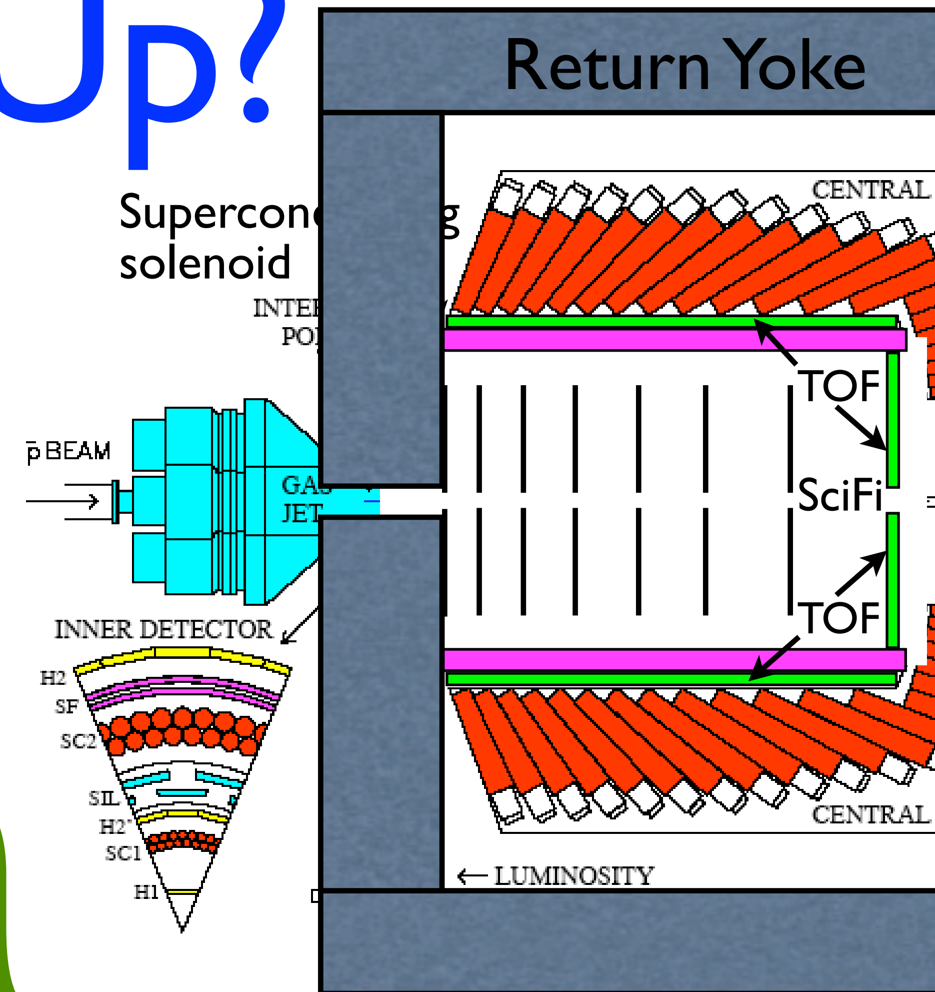

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  [existing BESS magnet from KEK & SciFi DAQ from DØ] } <$10M

  - Run $p_{\bar{p}}$ = 5.4 GeV/c ($2m_\Omega < \sqrt{s} < 2m_\Omega + m_{\pi^0}$)
    @ $\mathcal{L} \sim 10^{32}$ cm^{-2} s^{-1} (10 × E835)

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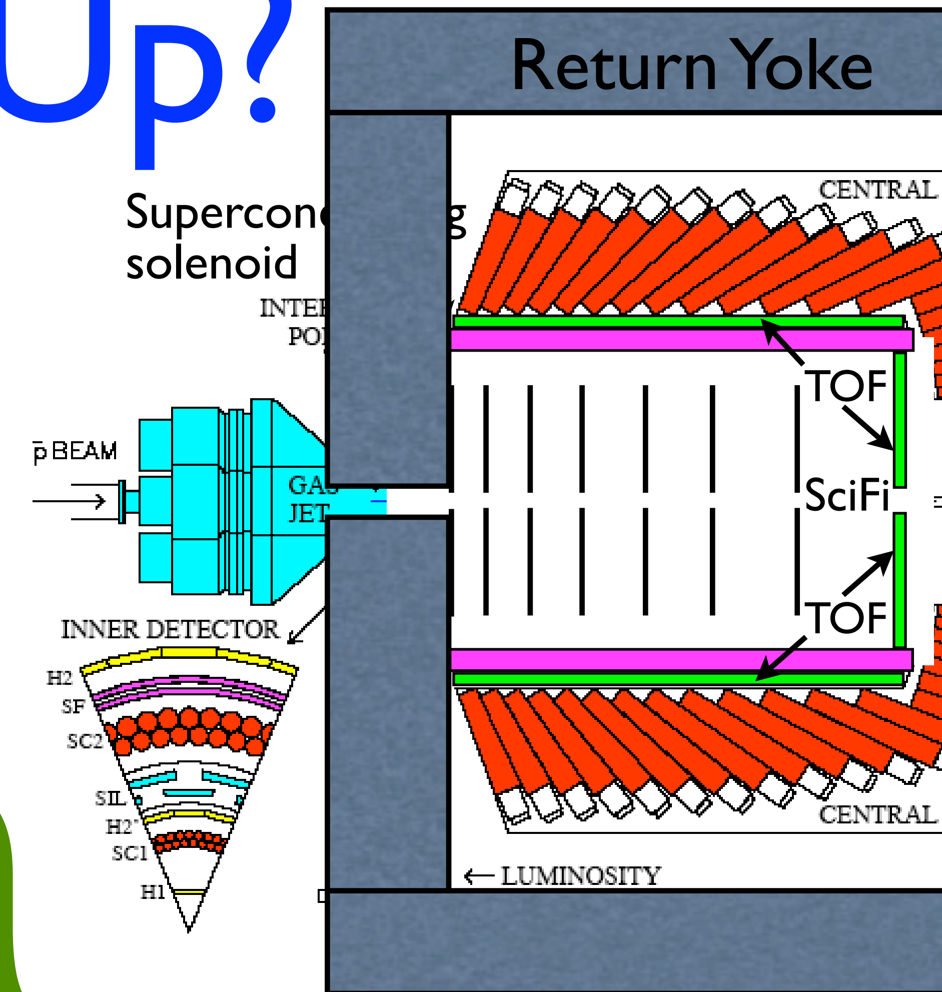

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[existing BESS magnet from KEK & SciFi DAQ from DØ]

} <$10M

➡ ~10^8 $\Omega^- \bar{\Omega}^+$/yr + ~10^{12} inclusive hyperon events!
+ number of $\Xi^- \bar{\Xi}^+$ TBD (transition crossing)

What Can This Do?

- Observe many more $\Sigma^+ \rightarrow p\mu^+\mu^-$ events and confirm or refute SUSY interpretation

- Discover or limit $\Omega^- \rightarrow \Xi^-\mu^+\mu^-$ and confirm or refute SUSY interpretation

Predicted $\mathcal{B} \sim 10^{-6}$ if P^0 real

- Discover or limit *CP* violation in $\Omega^- \rightarrow \Lambda K^-$ and $\Omega^- \rightarrow \Xi^0\pi^-$ via partial-rate asymmetries

Predicted $\Delta\mathcal{B} \sim 10^{-5}$ in SM, $\lesssim 10^{-3}$ if NP

What Else Can This Do?

- Much interest lately in new states observed in charmonium region: $X(3872)$, $X(3940)$, $Y(3940)$, $Y(4260)$, and $Z(3930)$
- $X(3872)$ of particular interest: may be the first meson-antimeson ($D^0 \overline{D}^{*0}$ + c.c.) molecule (or tetraquark or what?)

➡ need *very* precise mass & width measurement to confirm or refute

➡ $\bar{p}p \to X(3872)$ formation *ideal* for this

- Also h_c mass & width, χ_c radiative-decay angular distributions, η_c' full and radiative widths,...

Example: precision $\bar{p}p$ mass & width measurements

- Width of ψ′:
  - E835 measured
    Γ = (290 ± 25 ± 4) keV
    with 2,700 events
  - used "complementary scans" to reduce systematics

⟹ Best technique for *X*(3872) mass & (sub-MeV?) width measurement

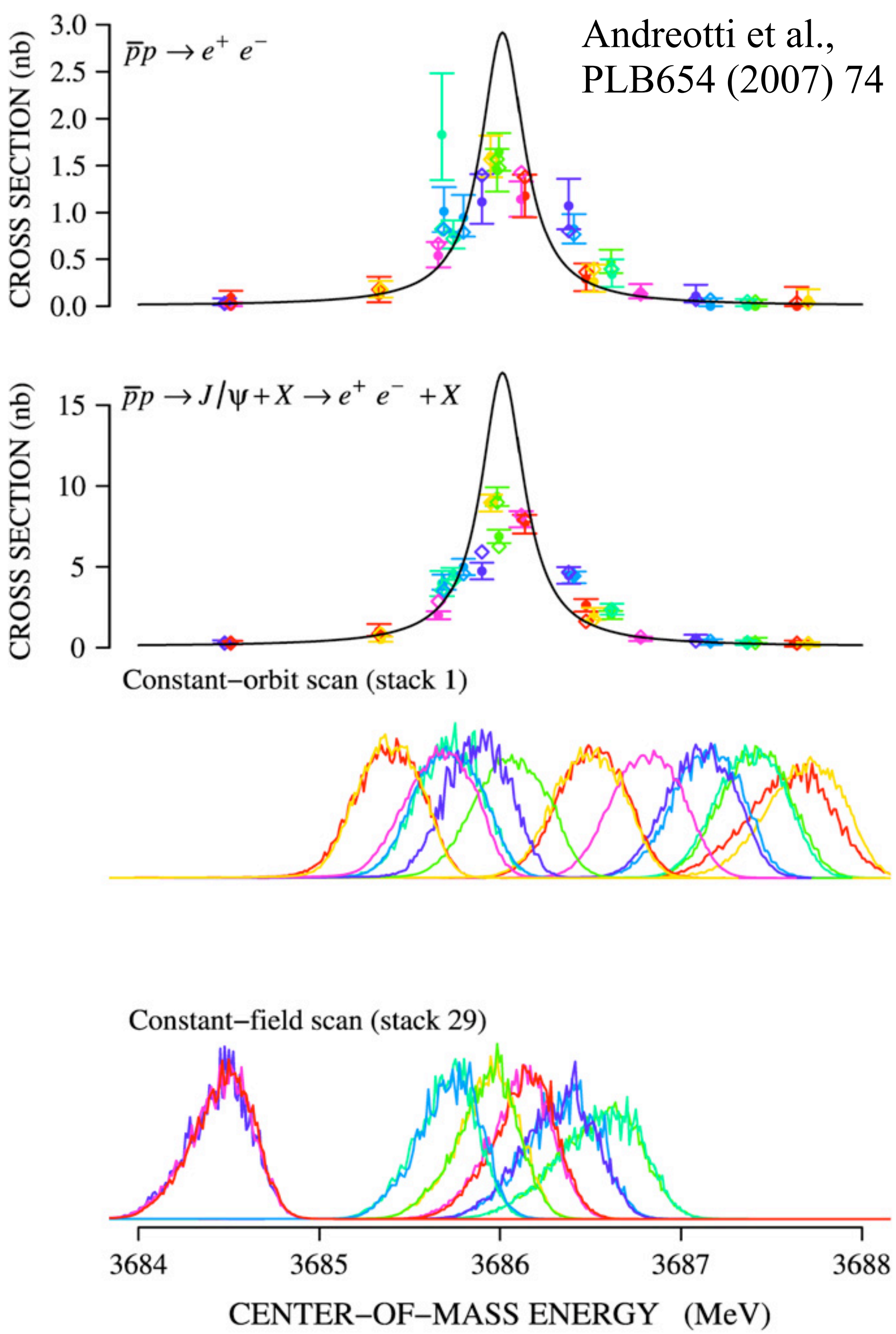


Fig. 2. $\psi(2S)$ resonance scans: the observed cross section for each channel (filled dots); the expected cross section from the fit (open diamonds); the 'bare' resonance curves σ_{BW} from the fit (solid lines). The two bottom plots show the normalized energy distributions B_i.

Charm

Charm

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

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

Eric Braaten

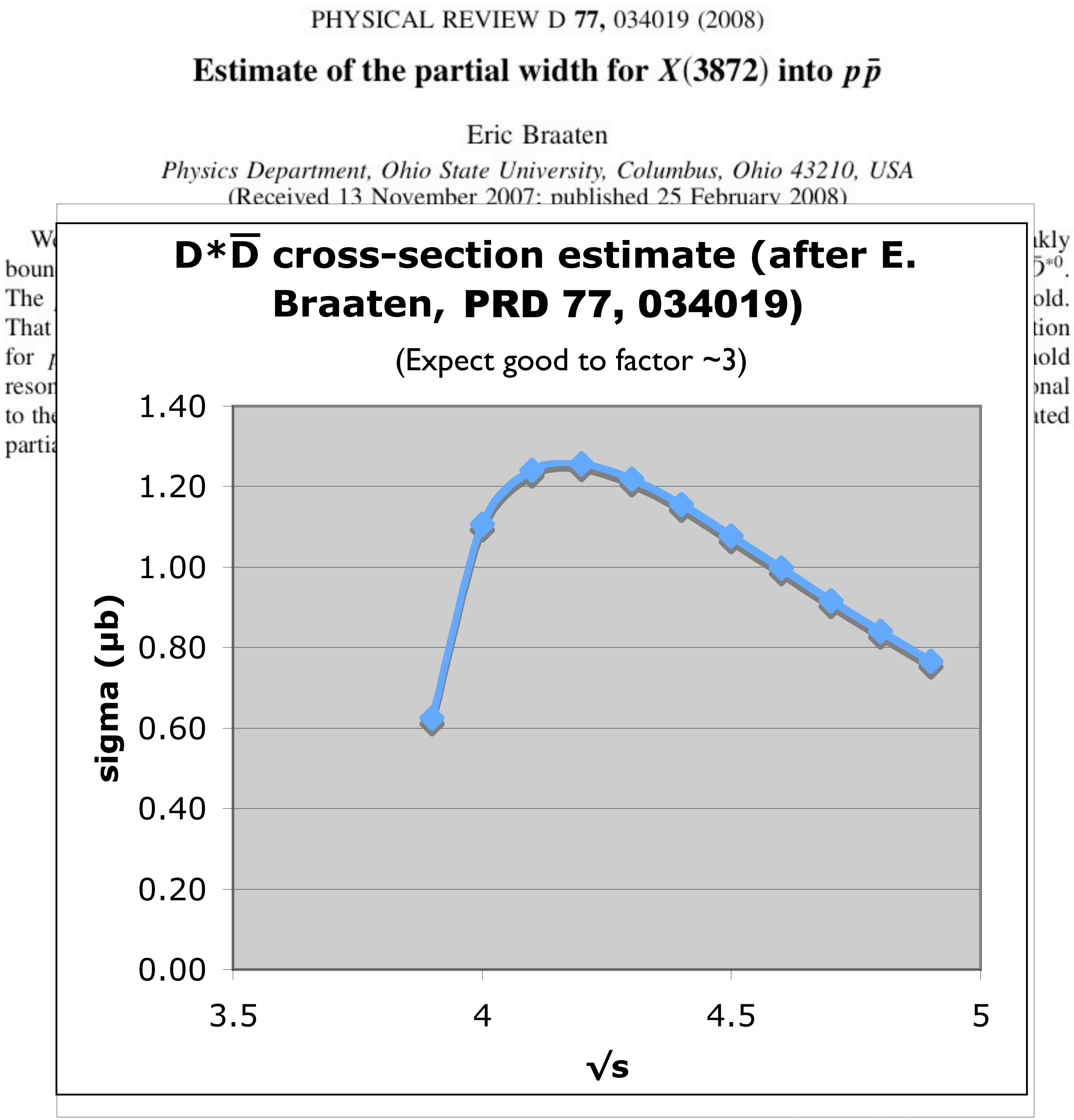
Physics Department, Ohio State University, Columbus, Ohio 43210, USA

(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}.

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

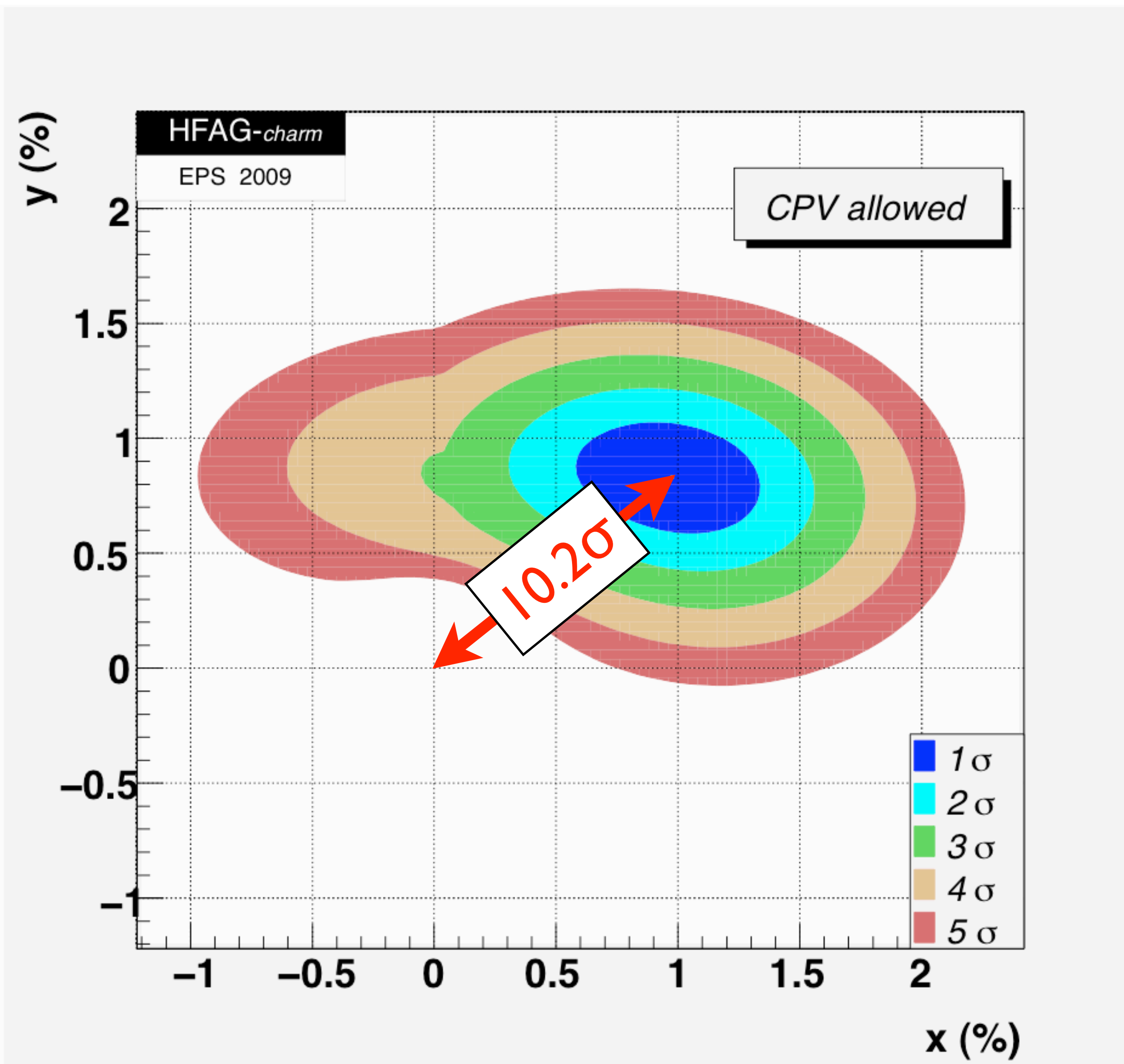
Charm



- Braaten estimate of $\overline{p}p$ $X(3872)$ coupling assuming D^*D molecule
  - extrapolates from K^*K data
- By-product is $D^{*0}\overline{D}^0$ cross section
- 1.3 μb → 5 ×10⁹/year
- Expect efficiency as at *B* factories

Charm

- *What's so exciting about charm?*
  - *D*^{0}'s mix! (*c* is only up-type quark that can)

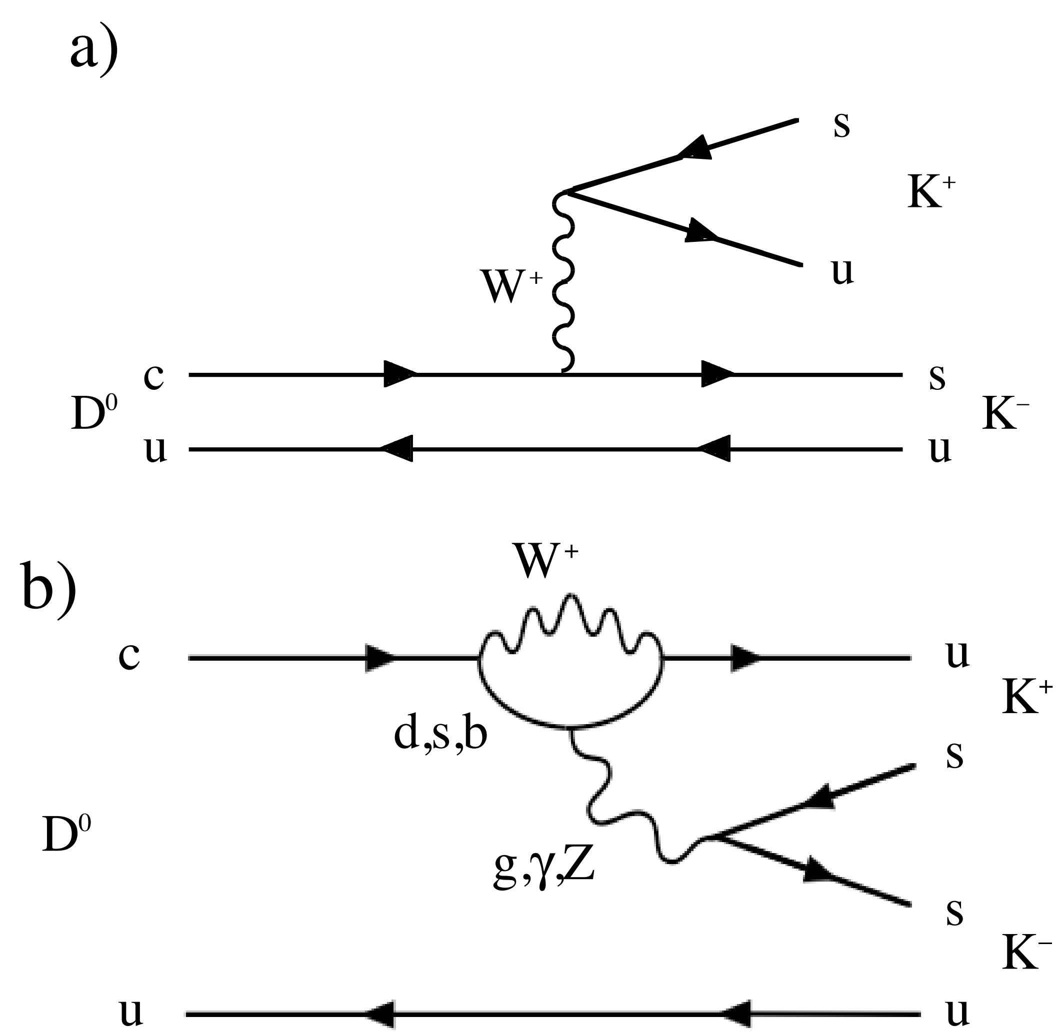


- *Big question:*
  New Physics or old?

Charm

- *What's so exciting about charm?*
  - D^0's mix! (*c* is only up-type quark that can)

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



- *Big question:* New Physics or old?

➡ key is *CP* Violation! Possible in CF, DCS only if New Physics

- *B* factories have ~10^9 open-charm events
- $\bar{p}p$ can produce ~10^{10}/y

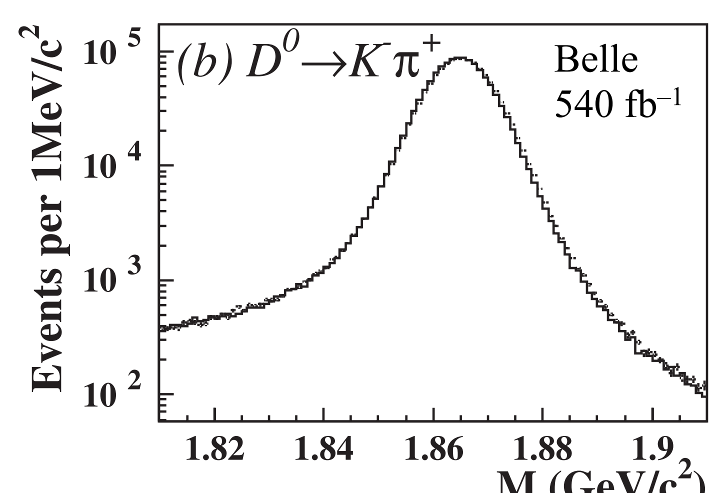
➡ world's best sensitivity to charm CPV

Charm

- Ballpark sensitivity estimate using cross section based on Braaten $\bar{p}p \to D^{*0}\bar{D}^0$ formula and assuming $\sigma \propto A^{1.0}$:

Quantity	Value	Unit
Running time	2×10^7	s/y
Duty factor	0.8*	
$\mathcal{L}$	2×10^{32}	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Target A	27	
$A^{0.29}$	2.6	(known from H.E. fixed-target)
$\sigma(\bar{p}p \to D^{*+}X)$	1.25	μb
# $D^{*\pm}$ produced	2.1×10^{10}	events/y
$\mathcal{B}(D^{*+} \to D^0\pi^+)$	0.677	
$\mathcal{B}(D^0 \to K^-\pi^+)$	0.0389	
Acceptance	0.5	(signal MC)
Efficiency	0.1	(MIPP study)
Total	2.7×10^7	events/y

- Compare with 1.22×10^6 tagged events at Belle [M. Staric et al., PRL **98**, 211803 (2007)]



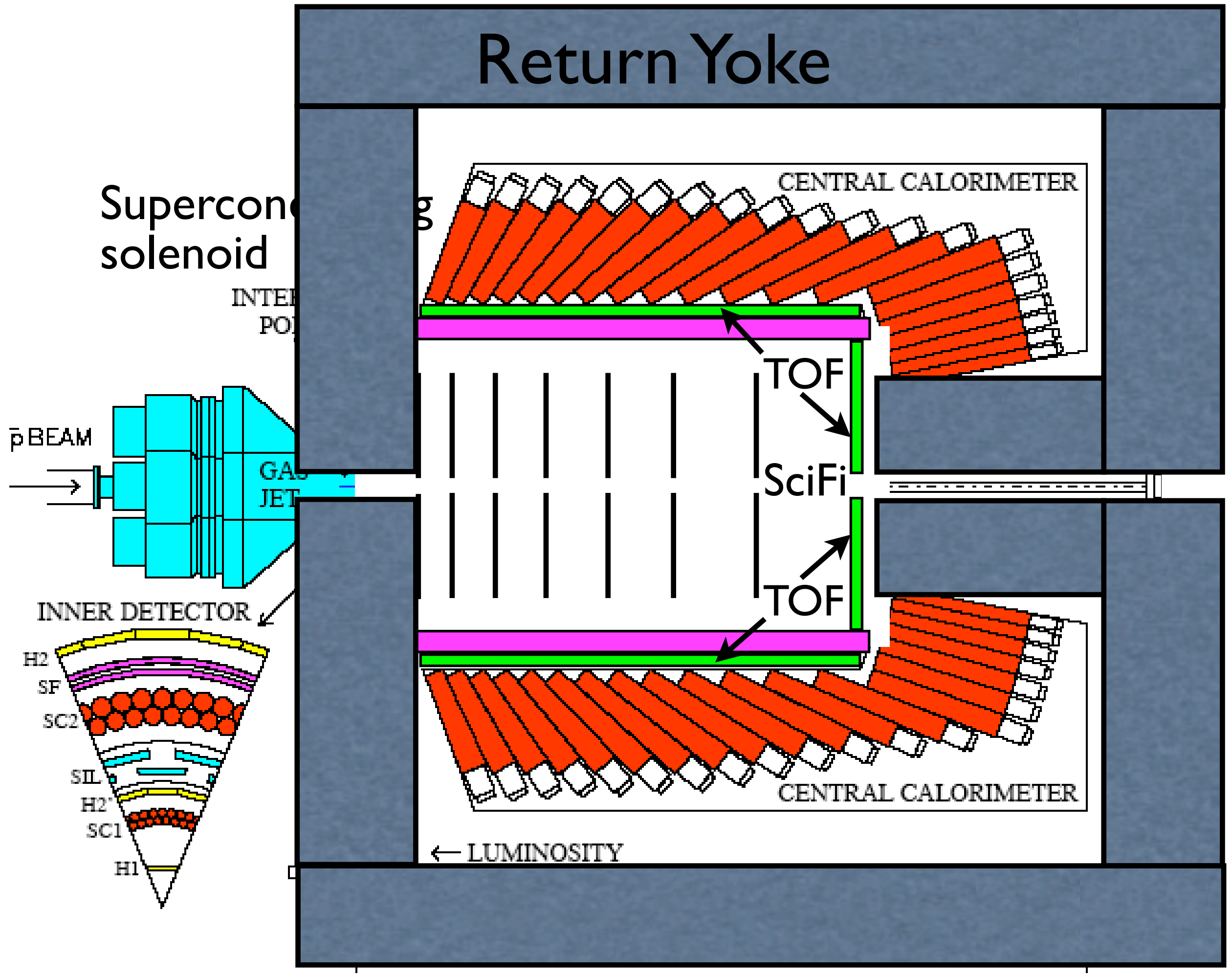
- LHC*b* will have comparable statistics but diff't systematics

High-Rate Experiment!

- Up to 50 MHz of charged particles @ 10 MHz interaction rate @ $KE_{\bar{p}}$ = 5–8 GeV

- Based on NA-48/2 KABES (tested to 70 MHz), TPC can handle this with MPGD readout (Micromegas, multi-GEM)

TPC Option 1?


Return Yoke
Supercon g
solenoid
CENTRAL CALORIMETER
TOF
SciFi
TOF
CENTRAL CALORIMETER
LUMINOSITY
p̄ BEAM
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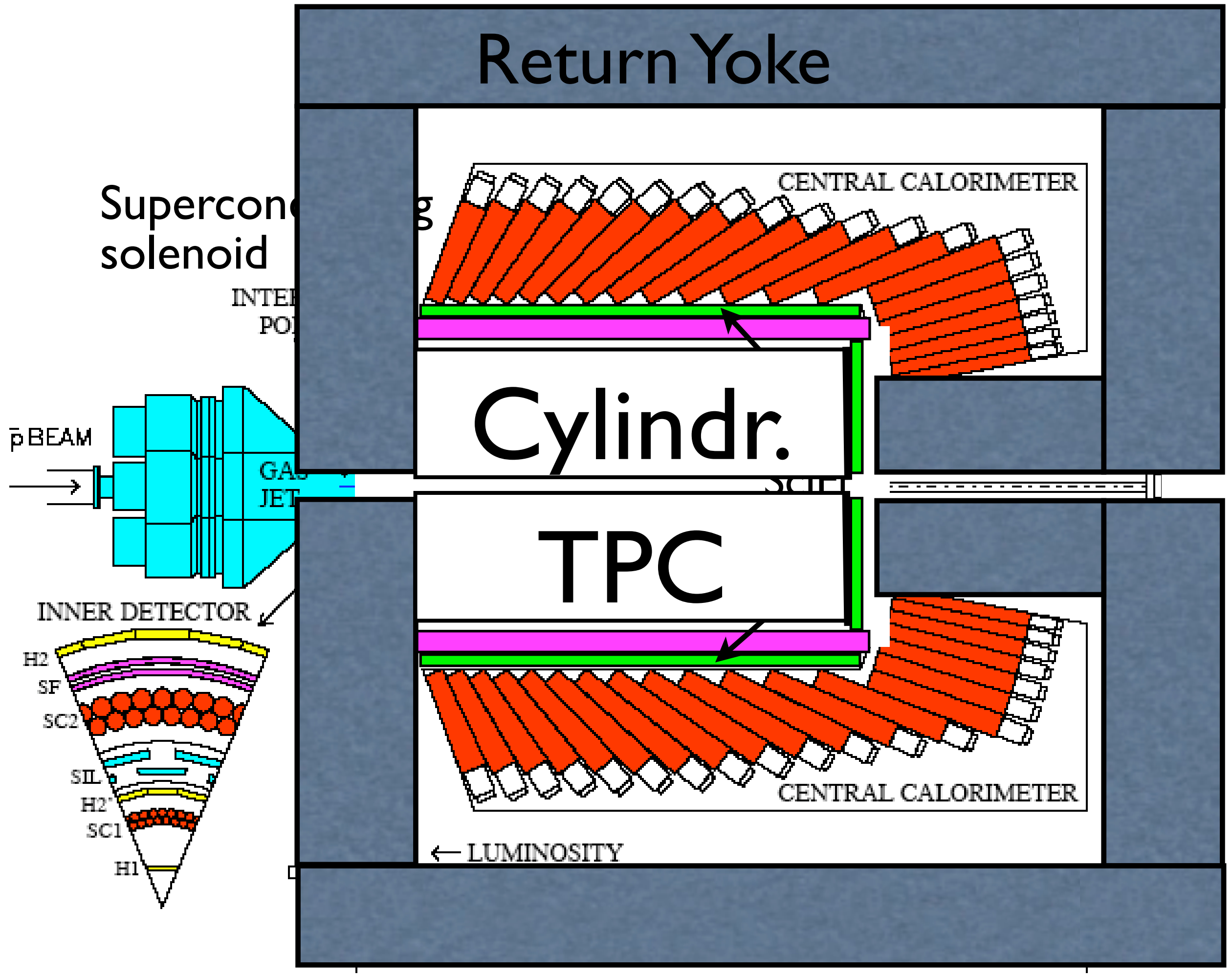
H2
SF
SC2
SIL
H2'
SC1
H1

TPC Option 1?



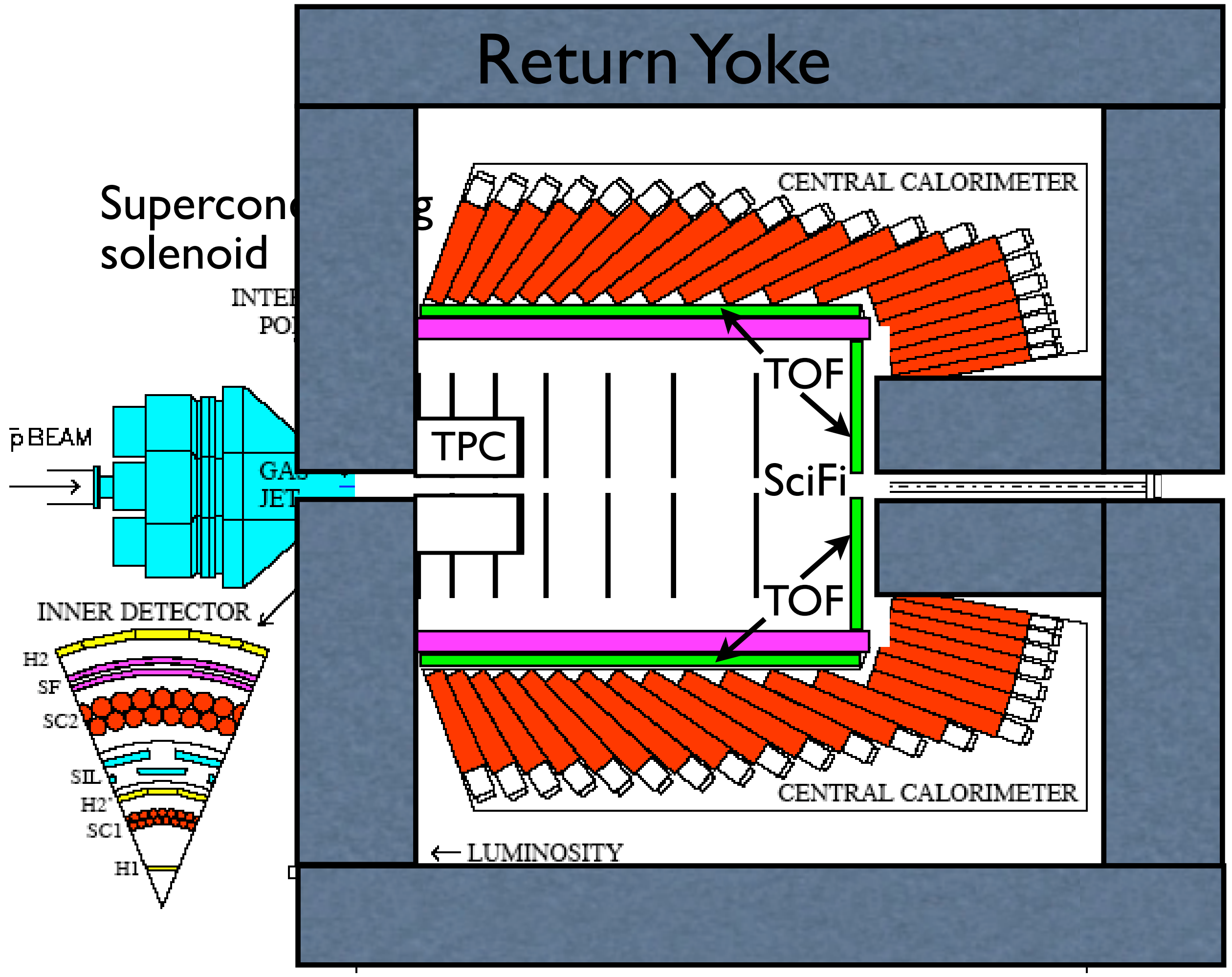
- Expected interaction rate ≈10 MHz @ 8 GeV $\bar{p}$ K.E.
- Expected track rate up to 50 MHz

$\Longrightarrow$ ≈ 1 kB per event with SciFi tracking

- TPC, L ≈ 1 m ⇒ ≈20 μs memory ⇒ ≈200 events pile-up!

$\Longrightarrow$ data per event ≈ 3 MB?!

TPC Option 2?



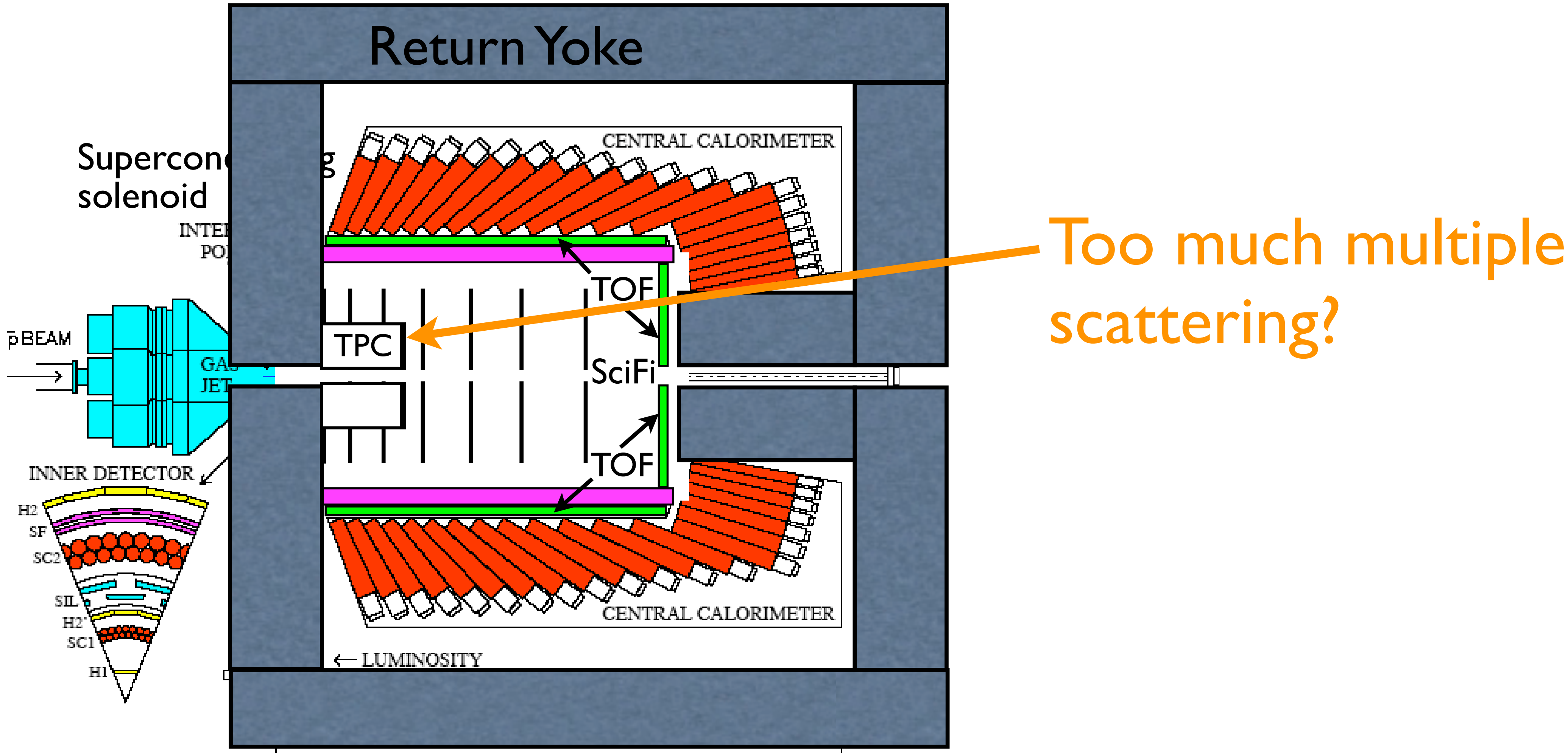
- Expected interaction rate ≈10 MHz @ 8 GeV $\bar{p}$ K.E.
- Expected track rate up to 50 MHz

⇒ ≈ 1 kB per event with SciFi tracking

- TPC, L ≈ 0.1 m ⇒ ≈2 μs memory ⇒ ≈20 events pile-up

⇒ data per event ≈ 30 kB?

TPC Option 2?



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$\Longrightarrow$ data per event ≈ 30 kB?

Data Rate

- Expect Level 1 Trigger Accept rate 100 kHz
- Pass tracker data to Level 2 Trigger
- SciFi option: needed bandwidth ≈ 100 MB/s
- TPC option 1: needed B/W ≈30 TB/s!
- TPC option 2: needed B/W ≈ 3 GB/s – OK

Summary

- Best experiment ever on hyperons, charm, and charmonia may soon be feasible at Fermilab
  - including world's most sensitive charm CPV study?
- World's best $\bar{p}$ source → simple way to broad physics program in (pre-)Project X era
- Can small high-rate TPC cost-effectively improve experiment performance?