Design Challenges for a High-Rate TPC with MPGD Readout

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Outline

(Varied menu!)

- Antiproton sources
- New antiproton experiments
- Physics goals
- TPC options & challenges
- Summary

Antiproton Sources

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

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

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

…even after FAIR@Darmstadt turns on

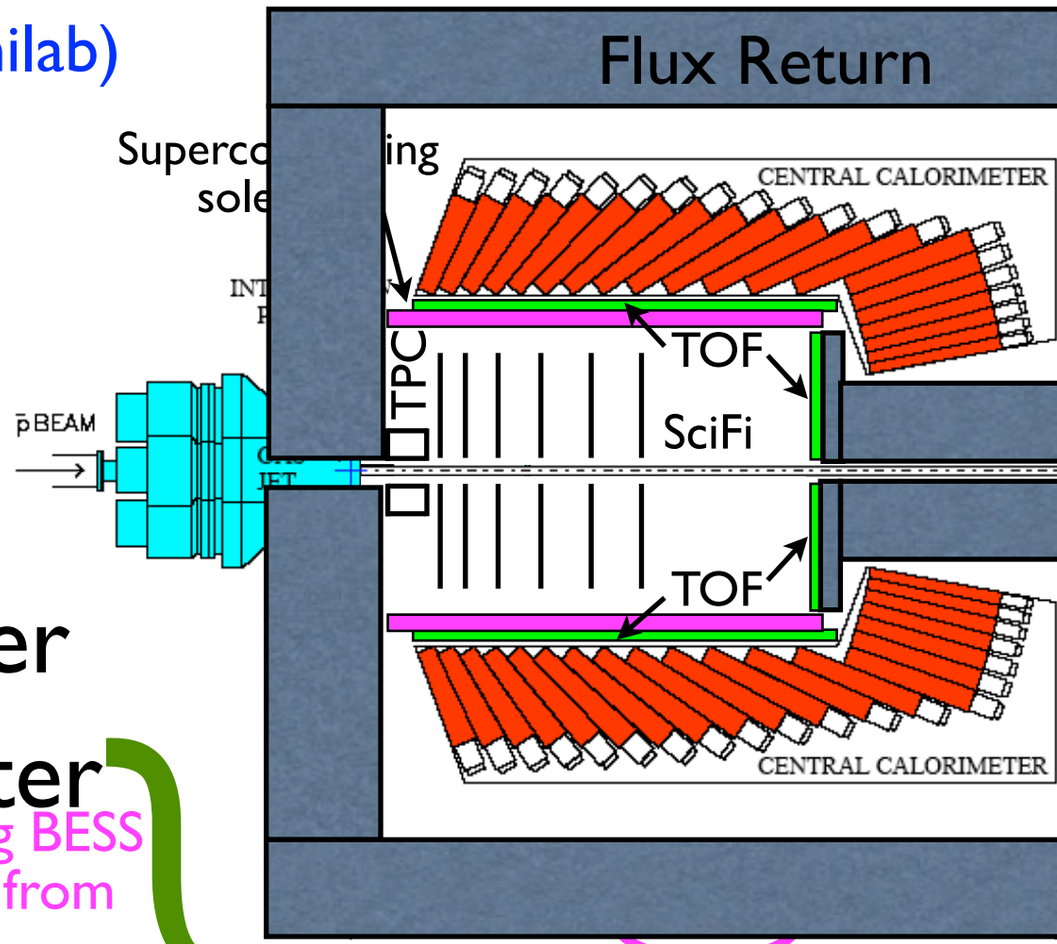
TAPAS

(The AntiProton Annihilation Specrometer at Fermilab)

Our proposal:

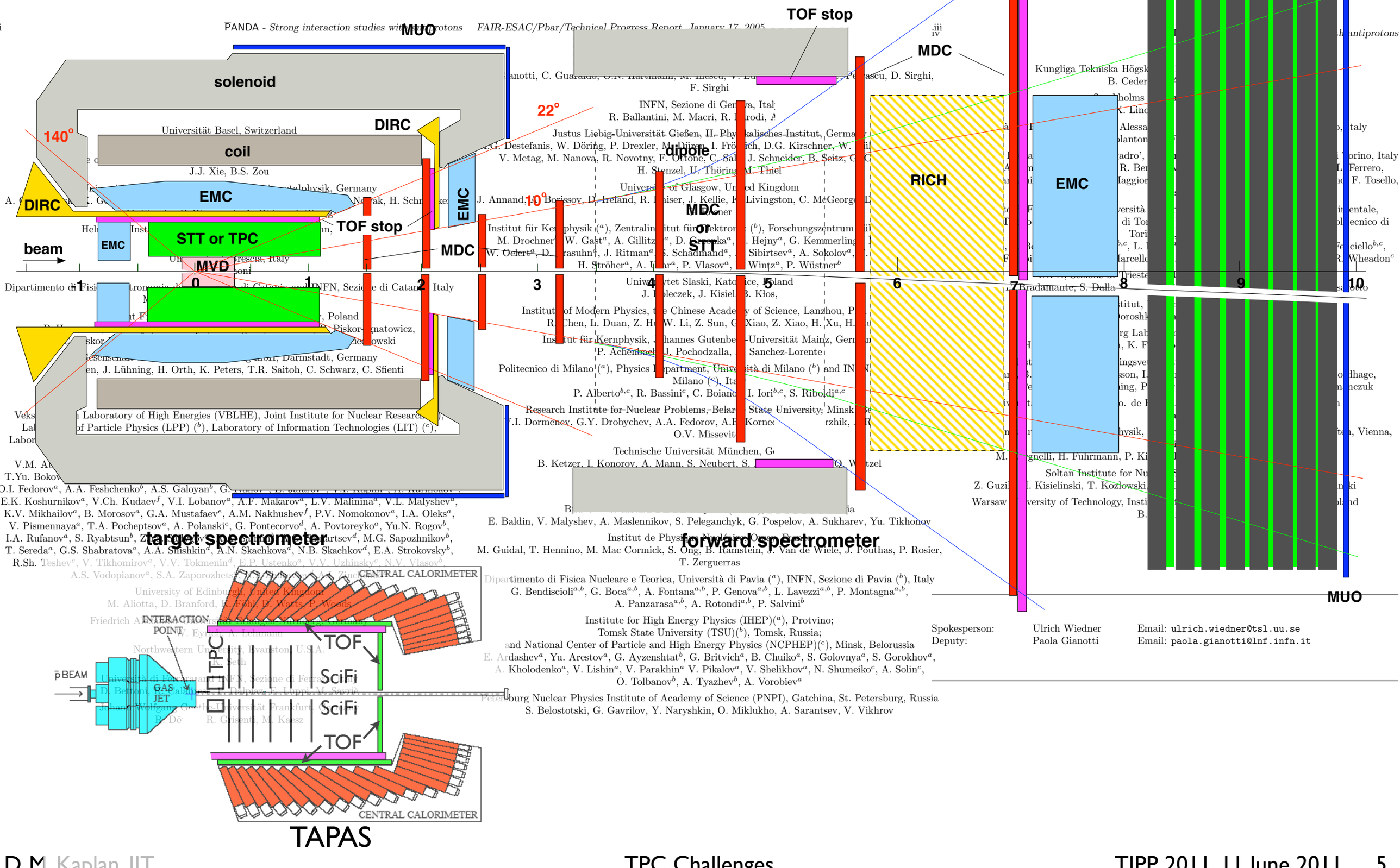
- After Tevatron finishes,
  - Reinstall E760 barrel calorimeter
  - Add small magnetic spectrometer
  - Add precision TOF system
  - Add thin targets
  - Add fast trigger & DAQ systems

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



<$10M

PANDA



TAPAS

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TAPAS Physics Case

in a nutshell:

- Hyperon CPV & rare decays
- Charmonium-like mystery states (*XYZ*...)
- Charmonium spectrum
- Charm mixing, CPV, & rare decays

} World's best exp't!

+ ($\overline{\text{P}}$ANDA) nuclear-physics topics: charmed hybrids & glueballs, nuclear effects, hypernuclei, $\bar{p}p$ Drell-Yan...

High-Rate Experiments!

- TAPAS: ≈20 to 50 MHz of charged particles
  @ 10 MHz interaction rate
  @ $KE_{\bar{p}}$ = 3.5–8 GeV

- $\overline{\text{P}}$ANDA: ≈20 to 50 MHz of charged particles
  @ (ultimately) 10 MHz interaction rate
  @ $KE_{\bar{p}}$ = 1–14 GeV

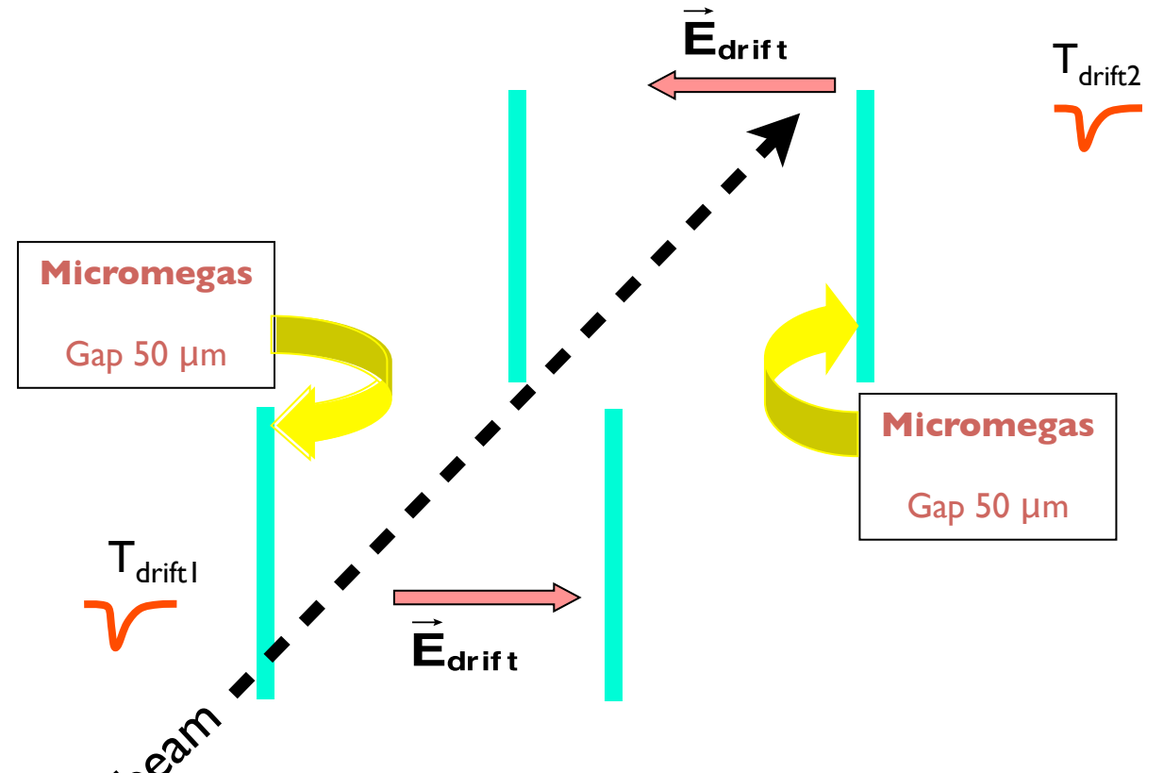
- Based on NA-48/2 KABES (tested to 70 MHz), TPC can handle this with MPGD readout (Micromegas or multi-GEM)

NA48/KABES

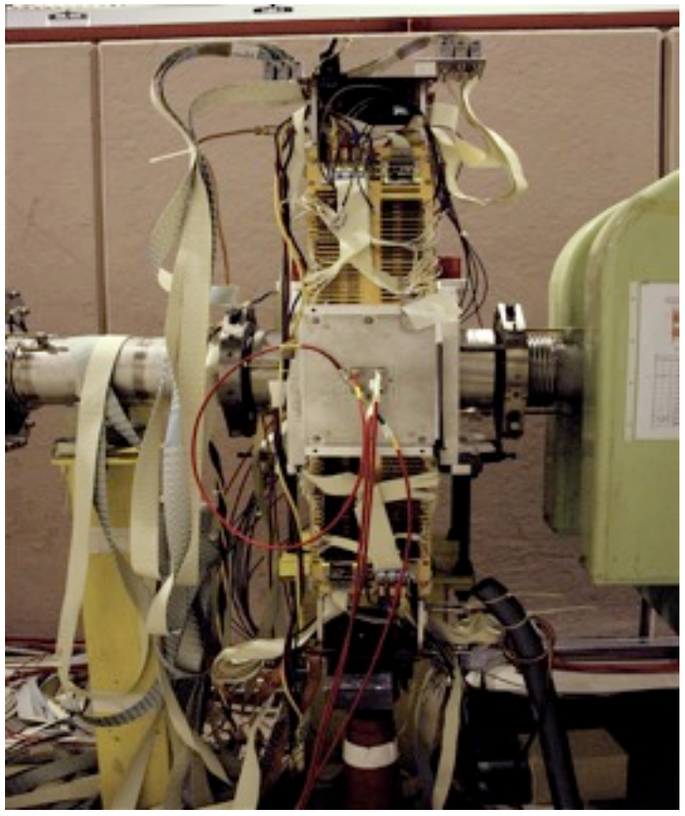
- **Principle : TPC + micromegas**
- **Flux $3x10^6/cm^2/s$ ($10^7/cm^2/s$ at hottest region)**

➡ **The charge density was about 10^3 nC/m^3**

KAon BEam Spectrometer

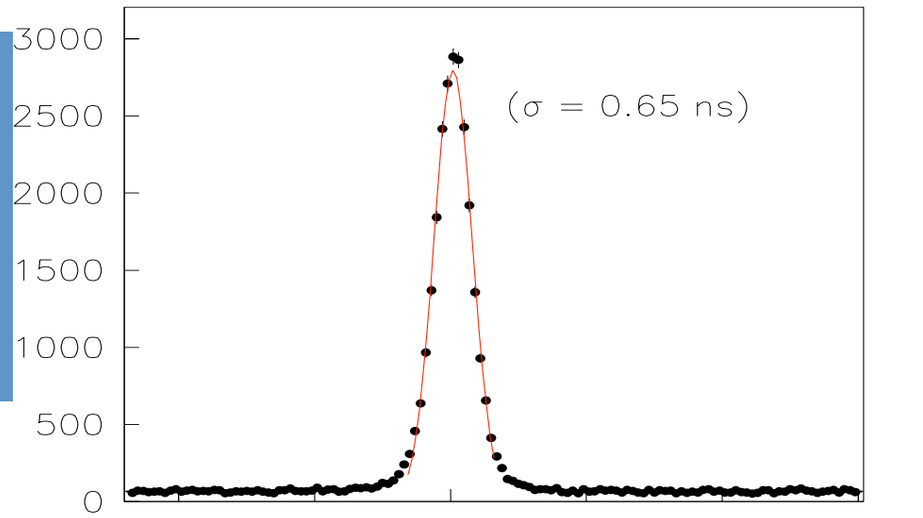


KABES in K12 (K^+ + K^-) beam line

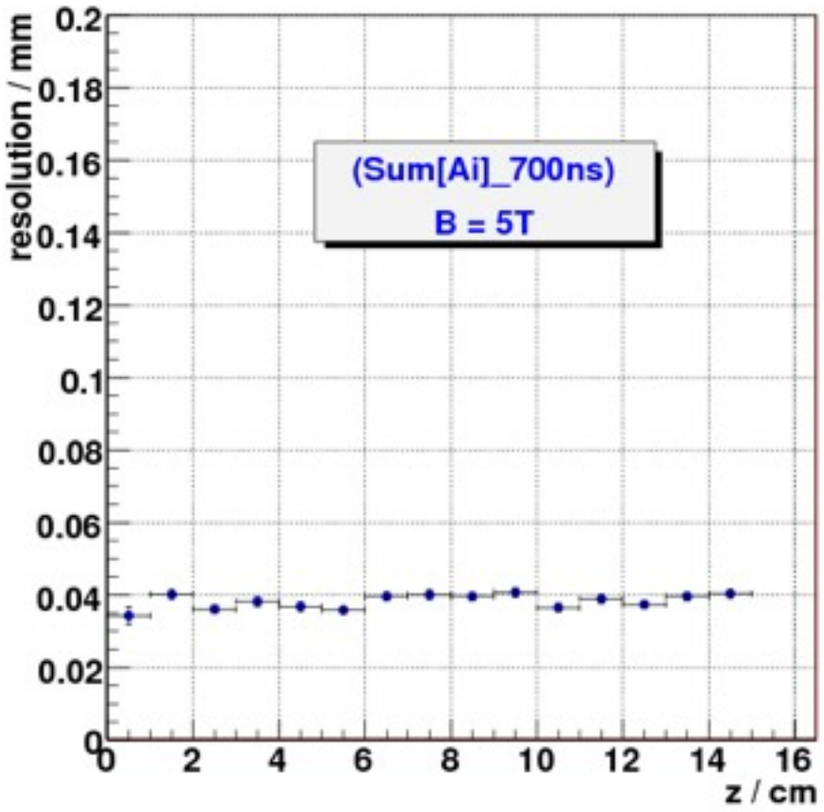


Space resolution from drift time measurement: 70 µm

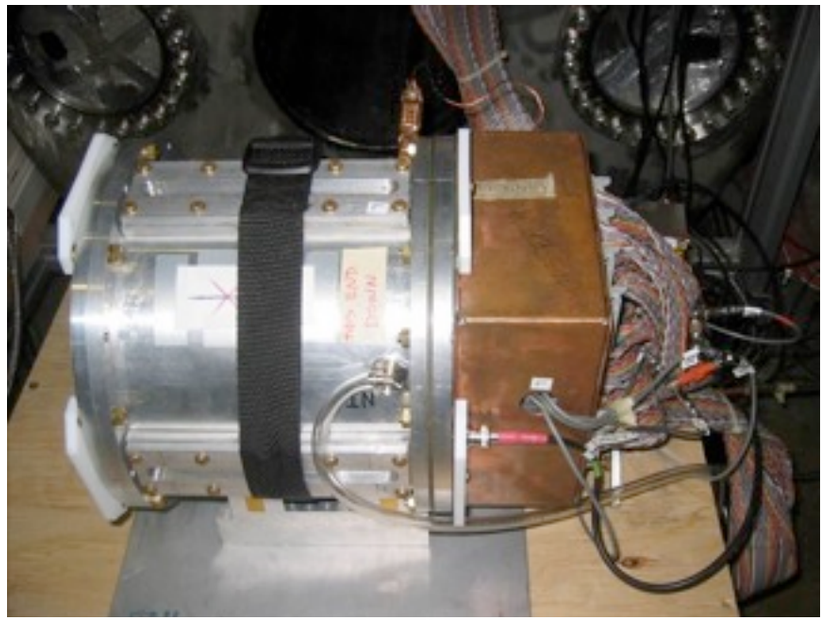
Time resolution: 0.6 ns

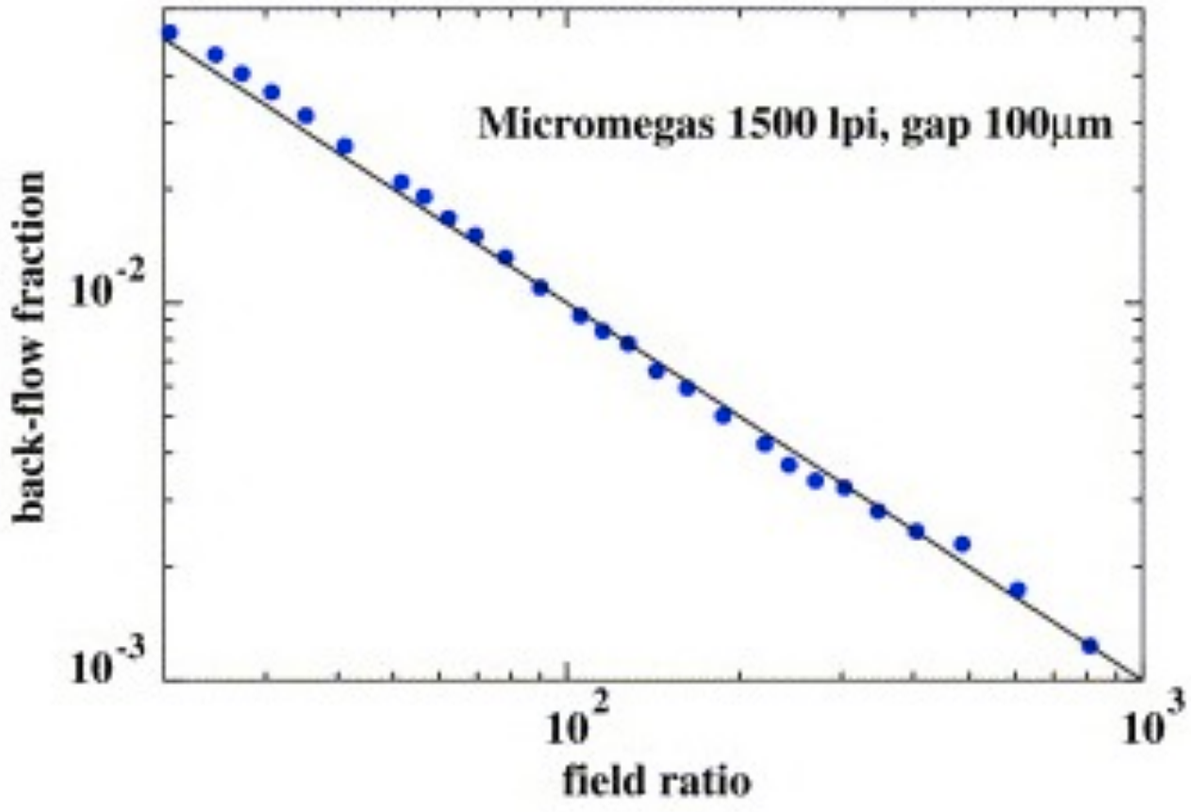


Results from Micromegas TPC R@D



M. Dixit et al., Spatial resolution
Pad size = 2 mm

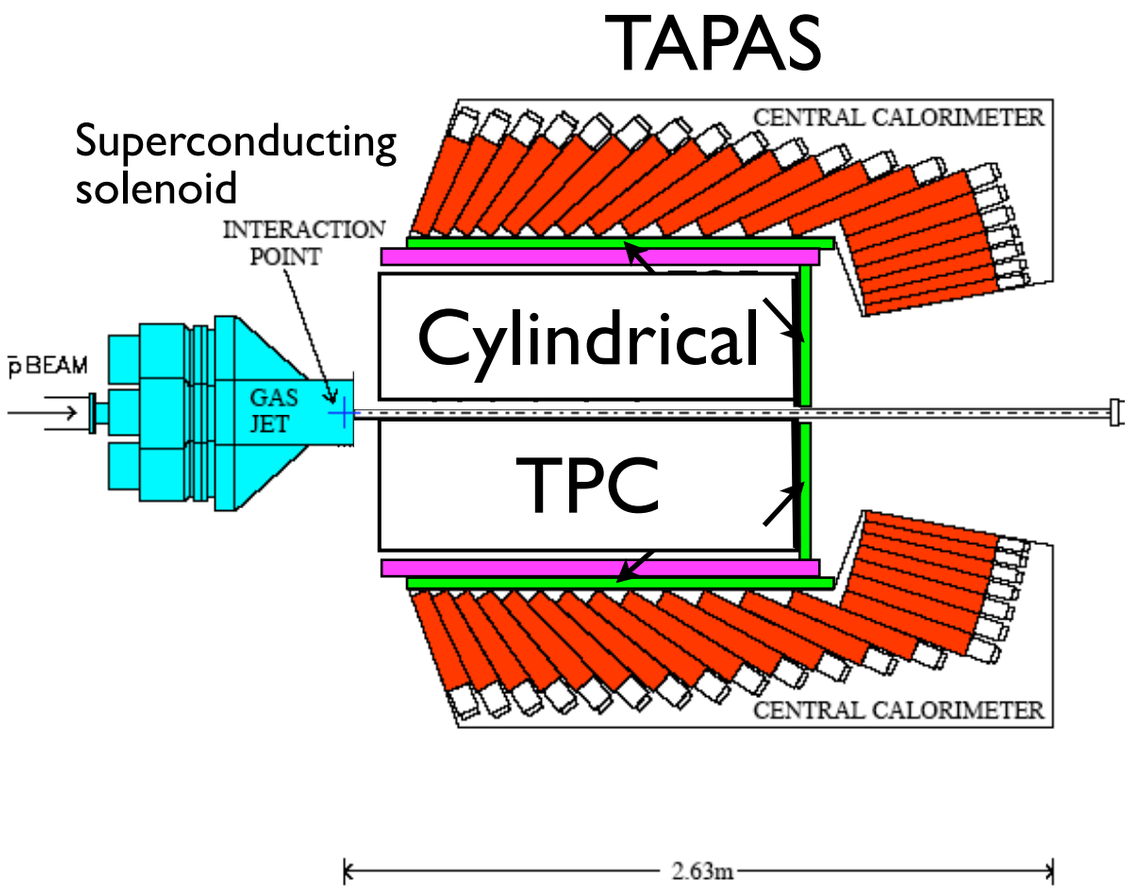




P. Colas et al., NIM-A 535 (2004) 226

With 1.5 x 4 mm^2 pads,
we expect we can have 32 pad rows
with a resolution of about 50 μm

TPC Option 1?

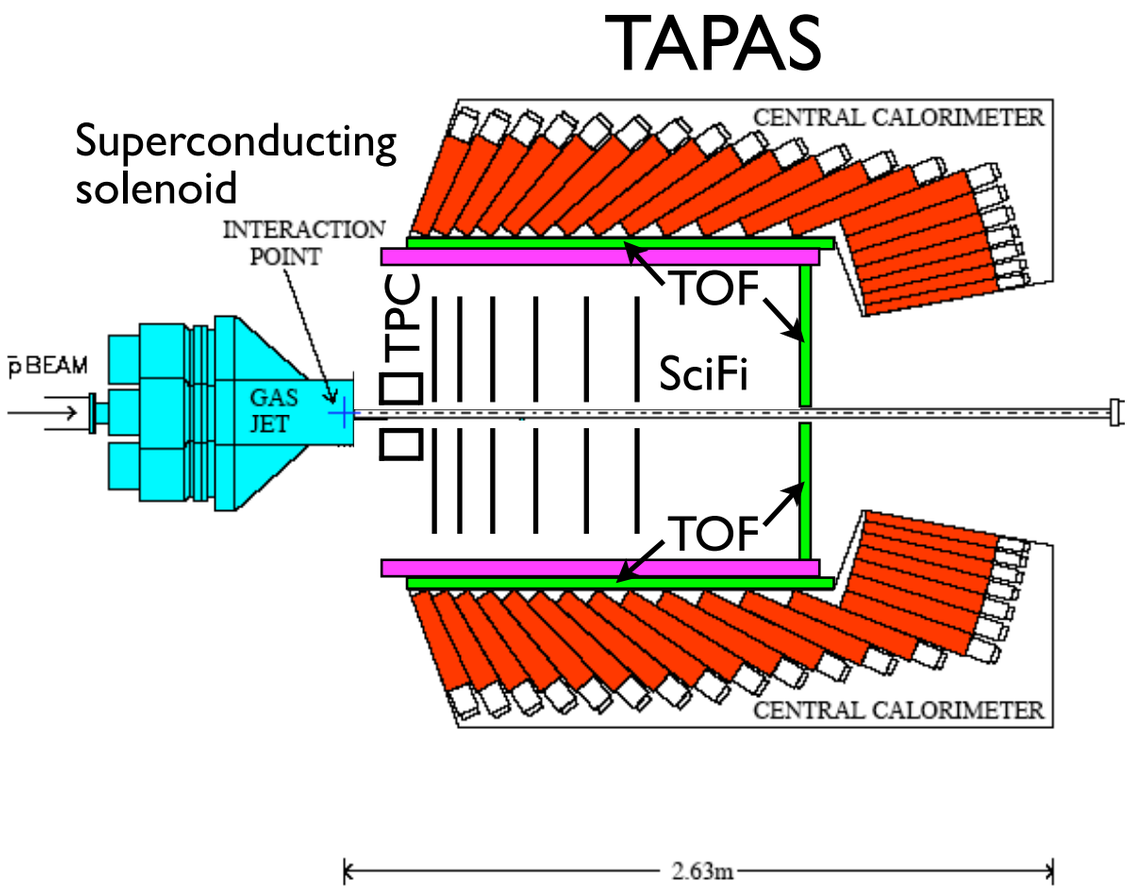


- Expected interaction rate ≈10 MHz @ 8 GeV $\bar{p}$ K.E.
- Expected track rate up to 50 MHz

  $\Longrightarrow$ ≈ 1 kB per event with SciFi tracking
- TPC, $L \approx$ 1 m $\Rightarrow$ ≈8 μs memory $\Rightarrow$ ≈80 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

  $\Longrightarrow$ ≈ 1 kB per event with SciFi tracking
- TPC, $L \approx 0.15$ m $\Rightarrow \approx 1.2$ μs memory $\Rightarrow \approx 12$ events pile-up

  $\Longrightarrow$ 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

TPC Specs

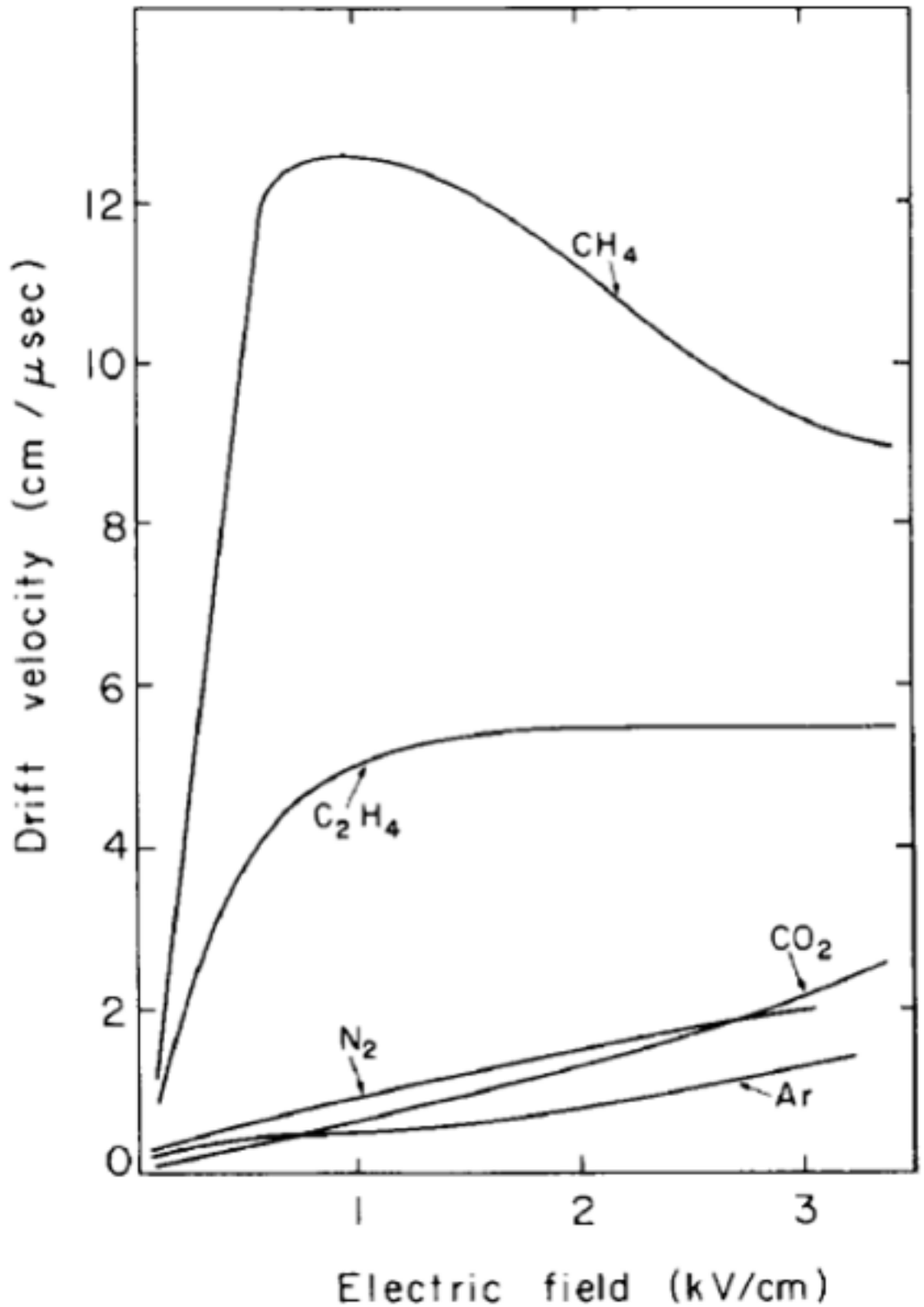
- Must minimize pile-up & space-charge effects

  $\Longrightarrow$ want high drift speed

- CH_4 @ 900 V/cm suitable

  $\longrightarrow v_{drift} \approx 12.5$ cm/μs

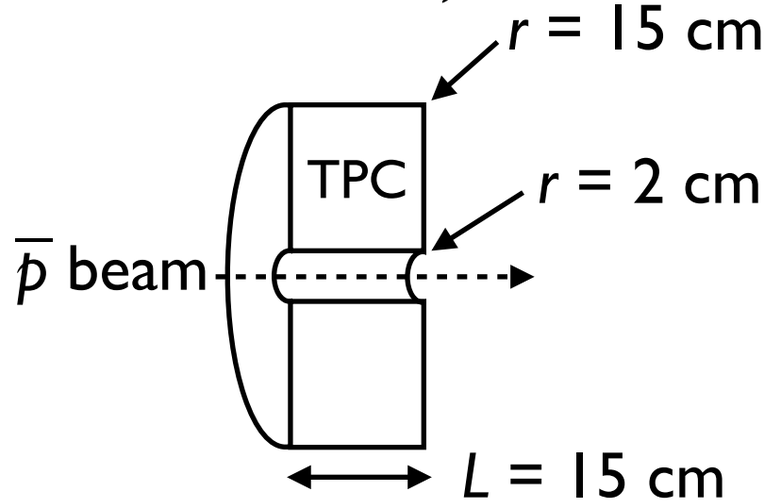
- Say
  $r_{in} = 2$ cm,
  $r_{out} = 15$ cm,
  $L = 15$ cm



Space Charge

- At high particle rate, drifting ions will perturb drift field due to space charge
- Rough (over?)estimate:
  - treat as cylinder of charge with inner radius *a*, outer radius *b*:

$$E = \frac{\rho}{2\varepsilon_0 r}\left(b^2 - a^2\right)$$



- Plausible parameter values:
  ρ = 800 nC/m^3, $r = b$ = 0.03 m, a = 0.02 m

< KABES

$\Longrightarrow E(r = 3\text{ cm}) \approx 800\,\text{V/m} = 8\,\text{V/cm}$

  - small w.r.t. 900 V/cm drift field

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?

  (For more info see http://capp.iit.edu/hep/pbar/.)