The TPC in the High Luminosity Era at RHIC

(Prospects, Limitations, and Learning to Live with Middle Age)

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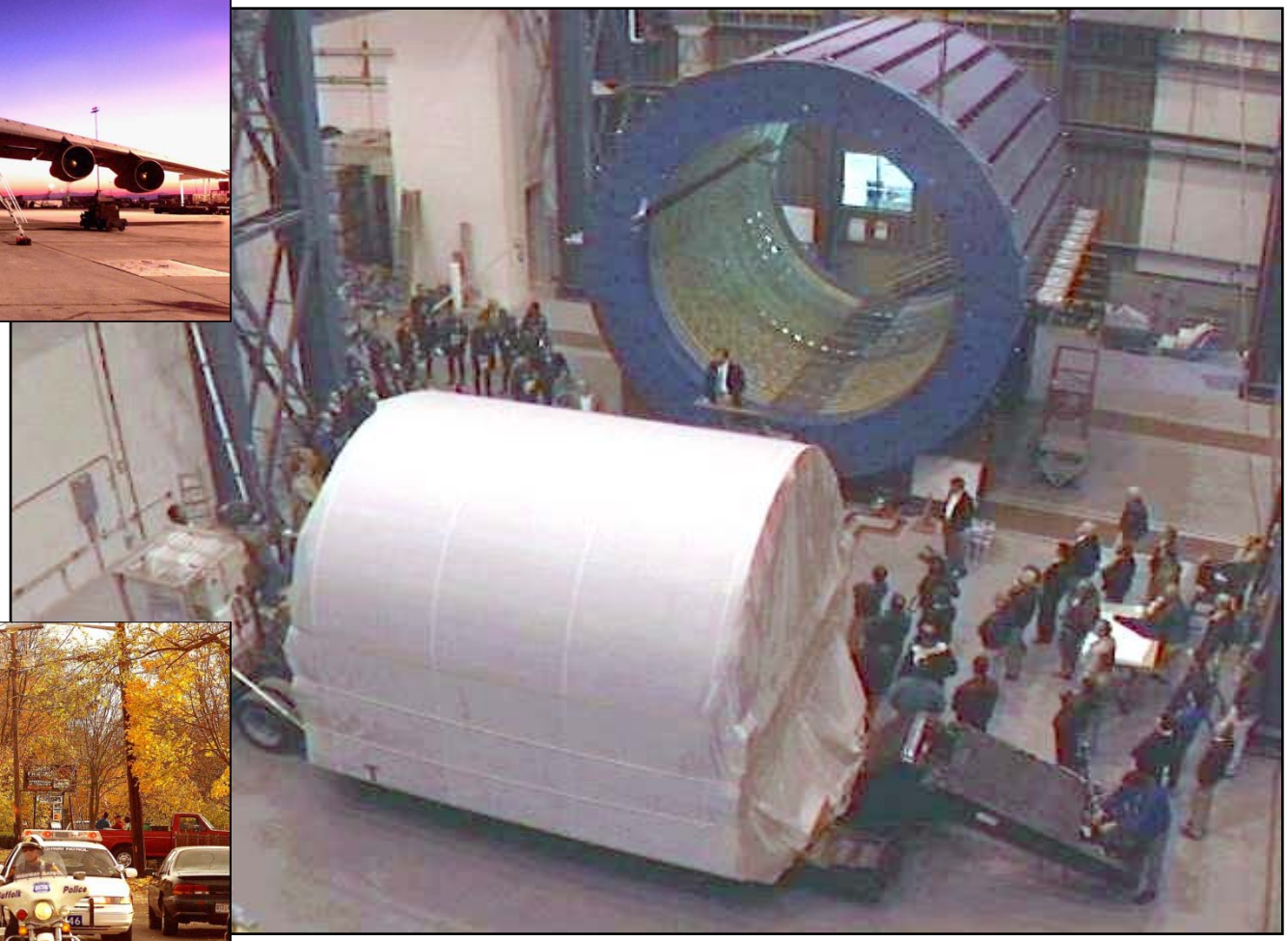
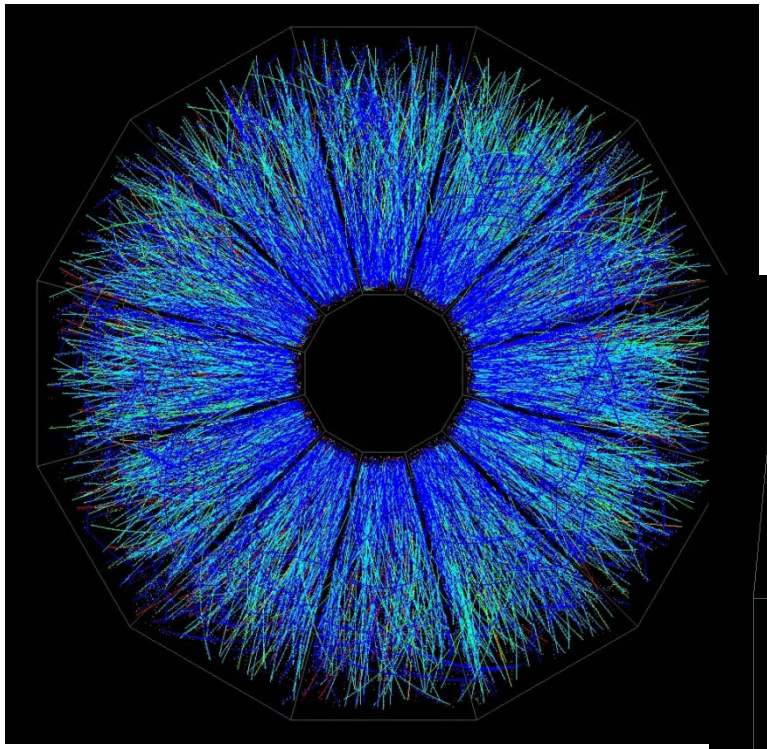
July 23rd, 2009

The TPC Flies from LBL to BNL - Nov 6, 1997

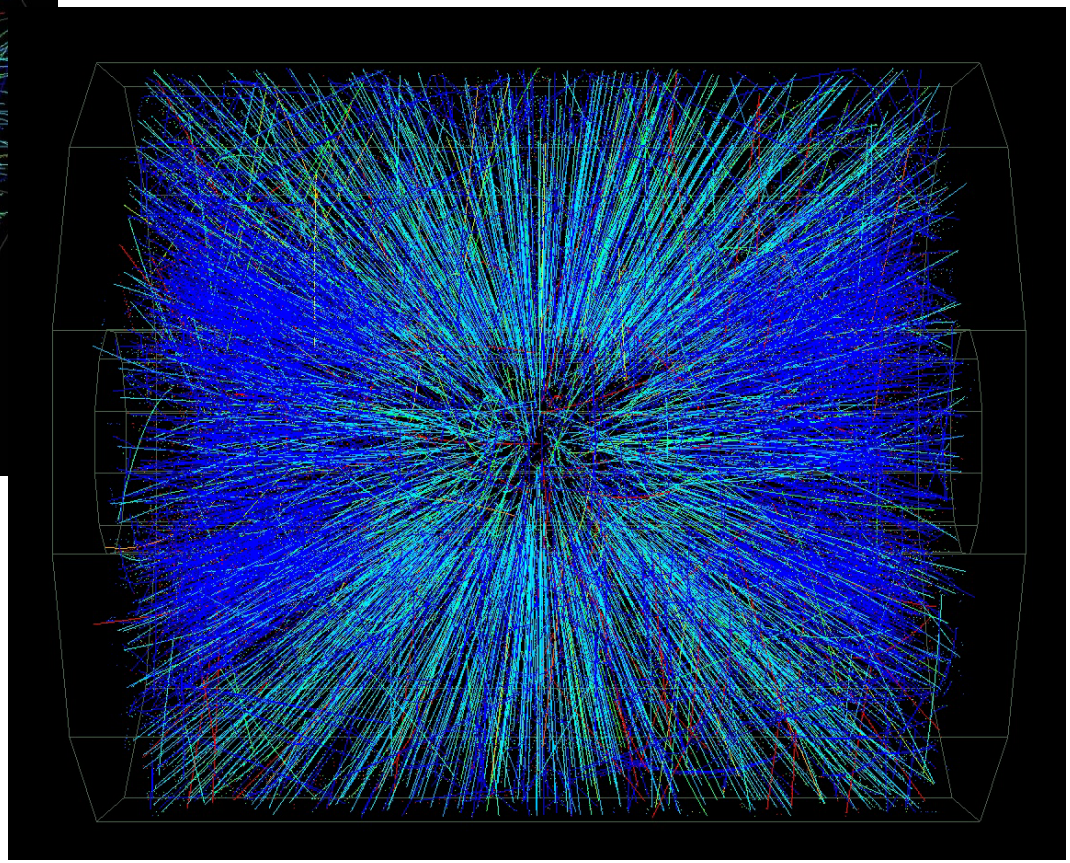


Chronologically, the TPC is a middle aged detector; yet we are hoping it will be productive for another decade.

Au on Au Event at CM Energy ~ 130 GeV*A



The STAR TPC has taken beautiful data, without a glitch, since the very first day of RHIC operations

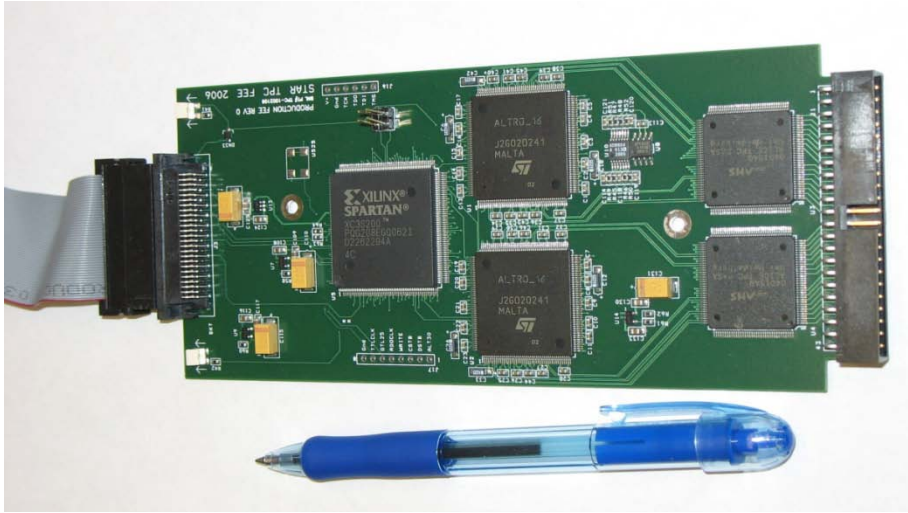


Data Taken June 25, 2000.

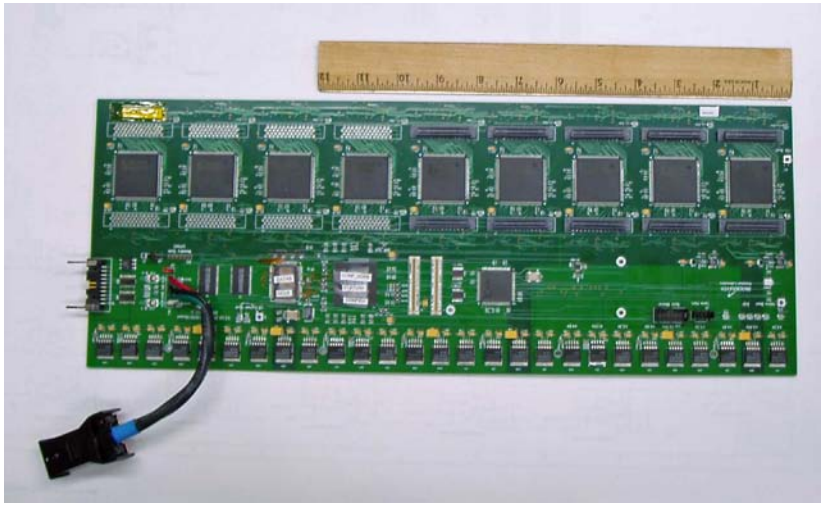
The TPX Upgrade (TPc electronics eXtended)

- **Works well**
  - **5% deadtime at 1 kHz (pp)**
  - **Max rates ~ 3 kHz**
  - **Enables high level triggers for use in high luminosity running**

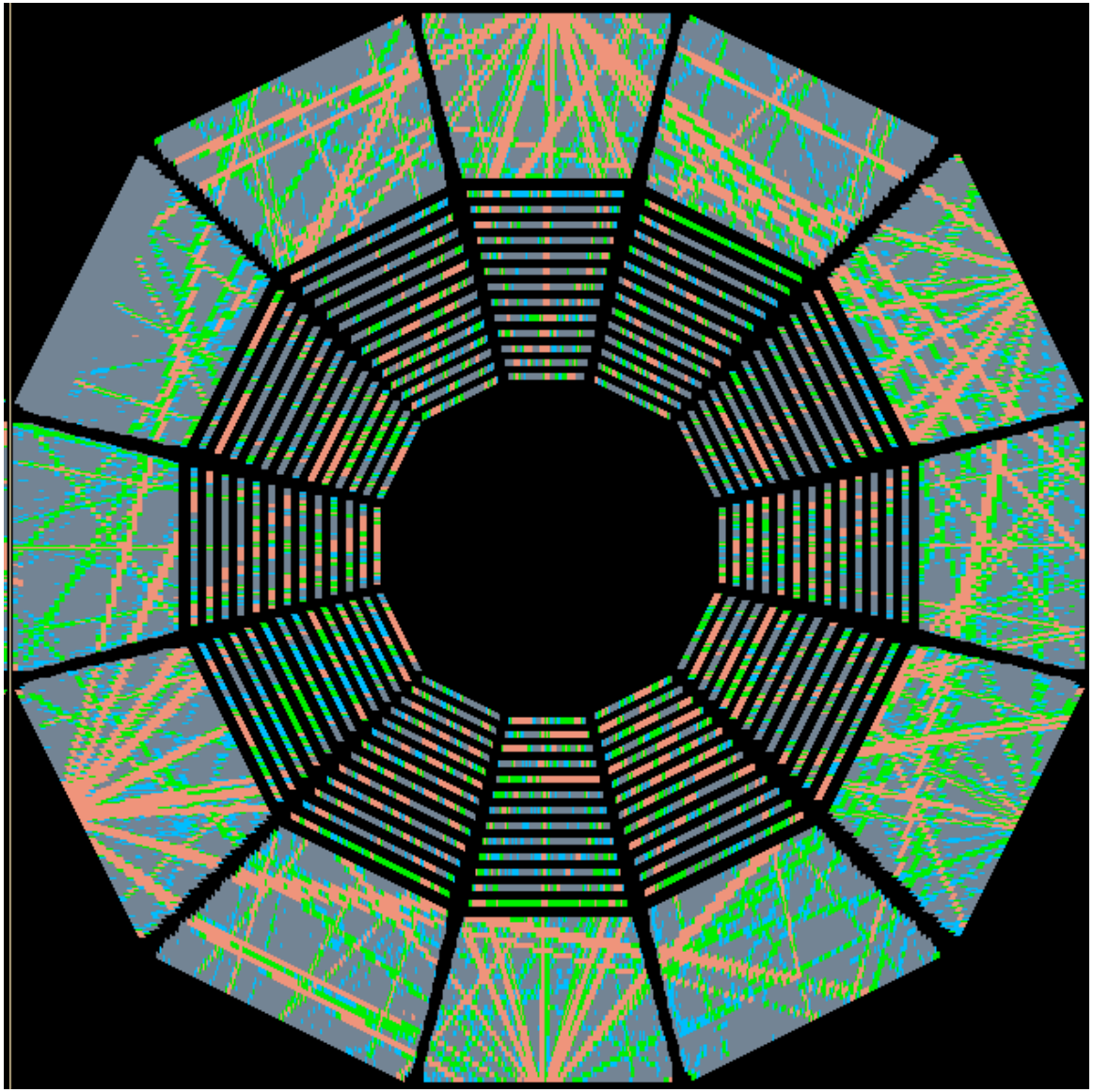
New muscle for an old detector and a tremendous success



- **Better Signal to Noise than old electronics**
  - **Old:**
    - **~30 ADC counts was the highest peak of the cluster**
    - **~1.5 ADC RMS**
    - **S/N is 30/1.5 = 20**
  - **New:**
    - **~22 ADC peak**
    - **~0.7 ADC RMS**
    - **S/N (22/0.7) = 30**

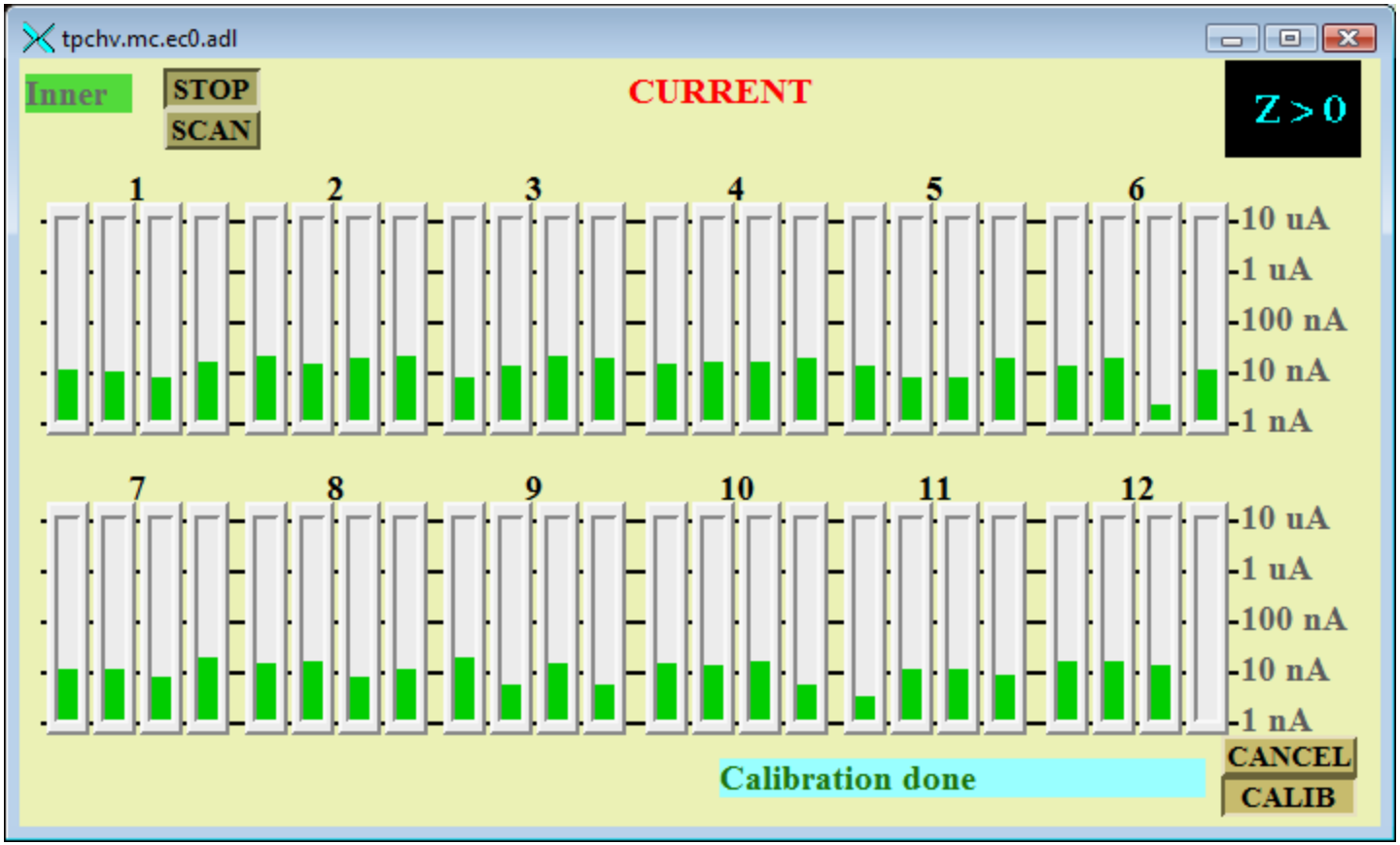


We explored new territory with pp500 in 2009



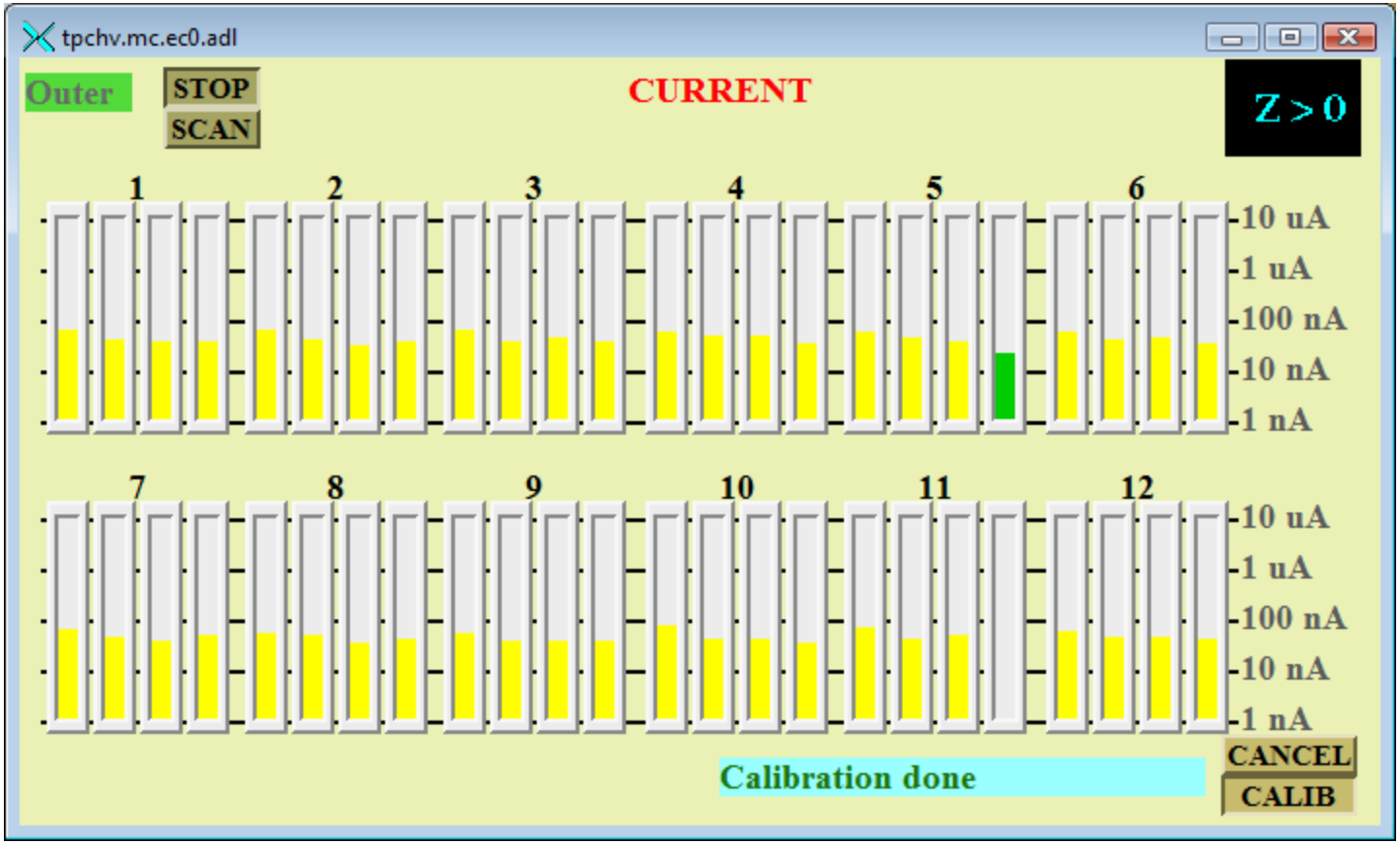
- pp500 Luminosity was up a factor of 3 compared to 2008 pp200 run (and is expected to go up 4x in coming years)
- pp500 Multiplicities are 1.25x higher than in pp200
- So we were working with more charge in the TPC than ever before … and, of course, there is a desire to go to even higher levels.
- Trigger rates can now go up a factor of 3-10x due to success of TPX

Anode Currents in Run 8



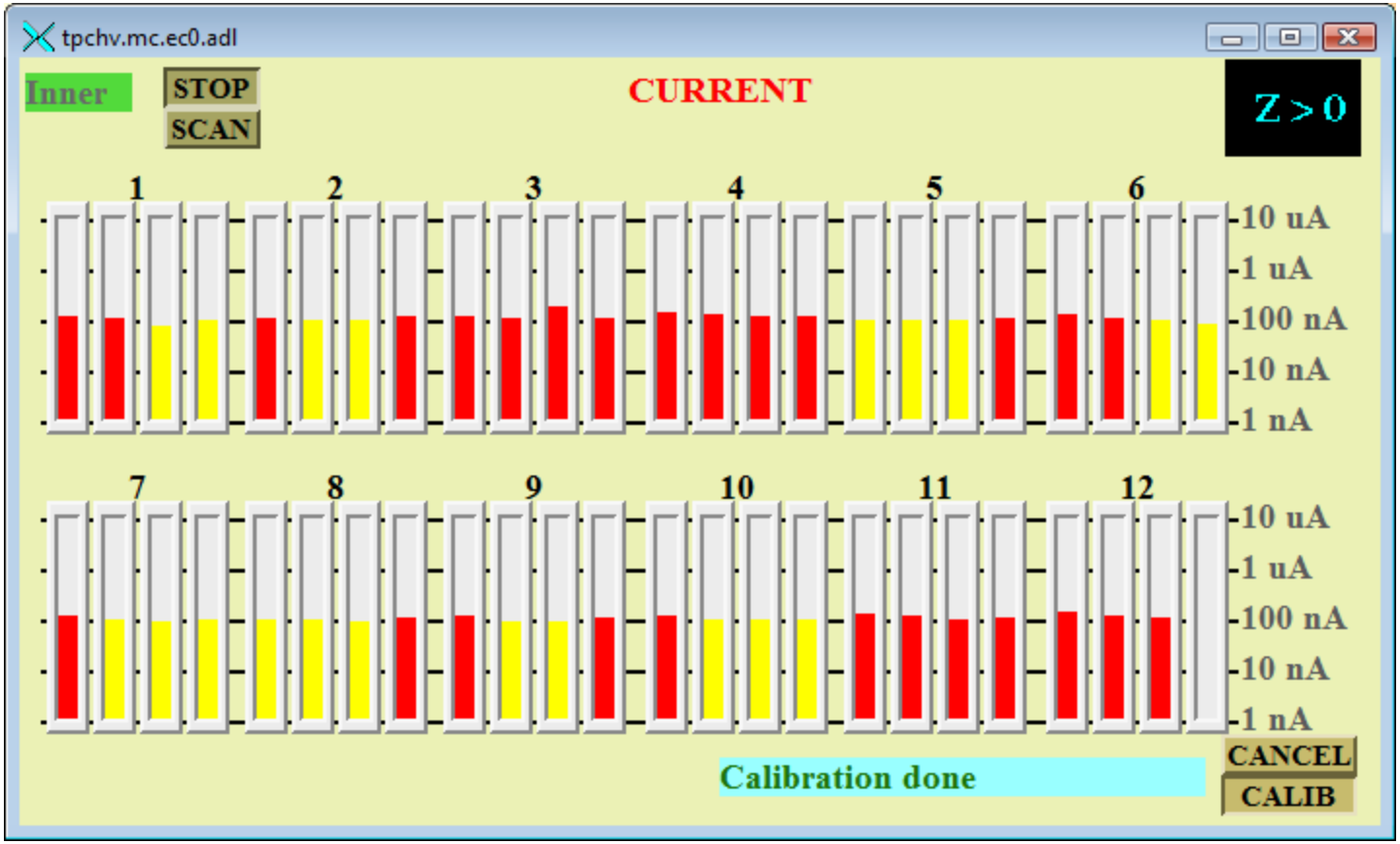
- **Our tradition has been to keep the anode currents low to avoid damage to the TPC and to avoid aging the anode wires**

Anode currents on the outer sector in Run 9



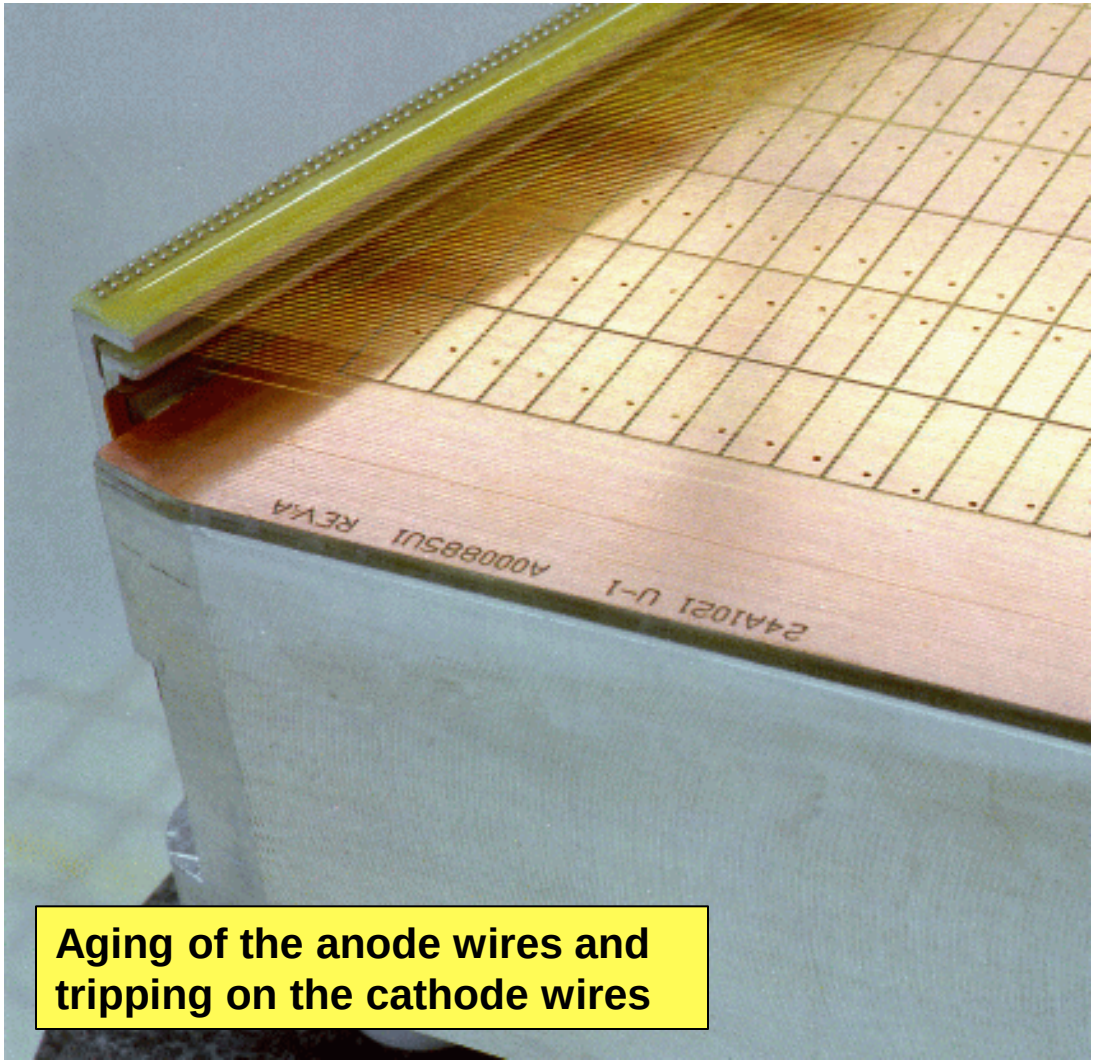
- **The charge density in the TPC ~ $1/r^2$ so the outer sectors see less load**

Inner Sector: Normal operation – pp500 Run 9



- **To be fair, the alarm limits are set at our discretion and we haven't changed the alarm limits on these screens compared to last year.**

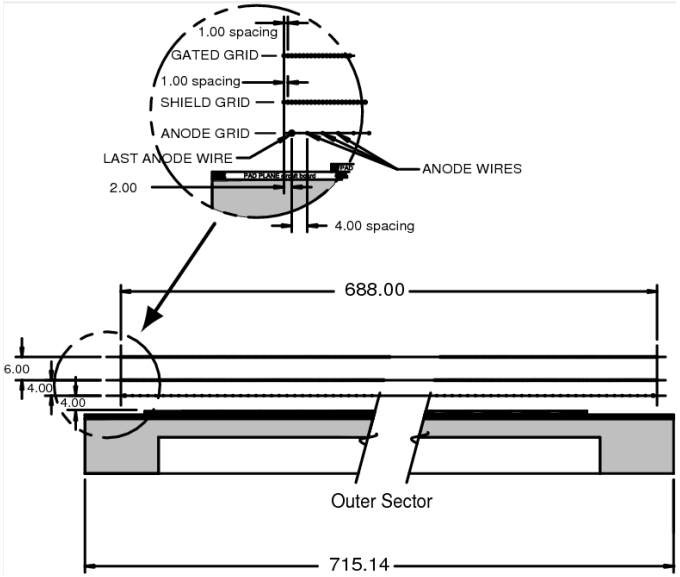
TPC Sector Detail – Aging of the Anode Wires



- **Gating Grid**
- **Ground Shield**
- **Anode**
  - **4 mm pitch, no field wires**
  - **Spacing: inner ≠ outer**
- **Pad Plane**

Sector Operation for 20:1 signal to noise

Sector	anode voltage	gas gain
inner	1170	3770 ± 10%
outer	1390	1230 ± 10%



Aging Curves – the slow predictable process

- Figure(s) of merit
  - Relative gain (G/G_0)
  - Pulse height, shape
  - vs. collected charge per unit length
- Two parameters

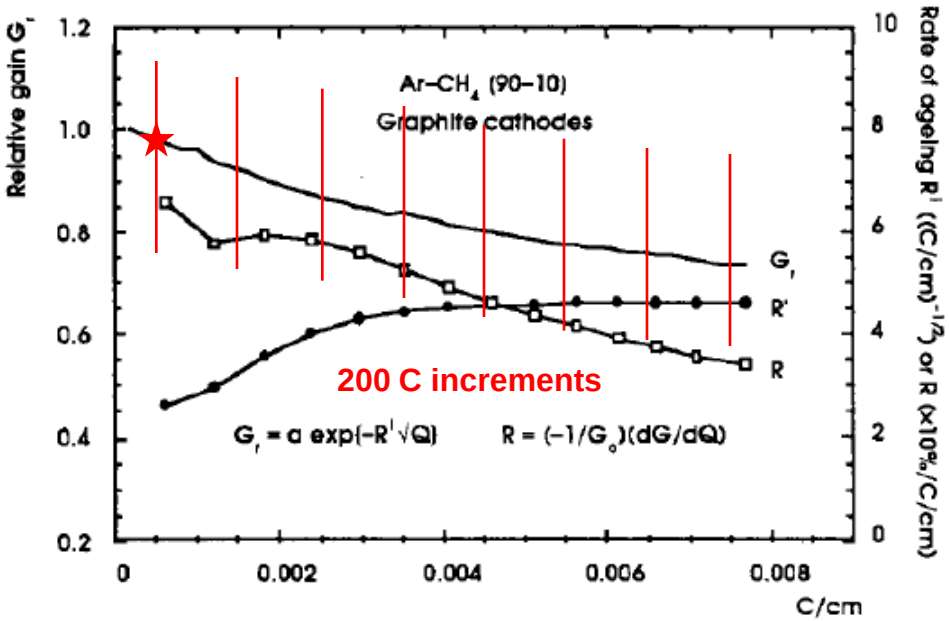
$$R = \frac{-1}{G_0}\left(\frac{dG}{dQ}\right)$$

J. Kadyk, Nucl. Instr. and Meth. **A300** (1991) 436.

$$\frac{G}{G_0} = a \cdot e^{-R'\sqrt{Q}}$$

R. Bouclier, M. Capeáns, C. Garabatos, R.D. Heuer, M. Jeanrenaud, T.C. Meyer, F. Sauli, K. Silander, Nucl. Instr. and Meth. **A346** (1994) 114.

- **During the pp500 run, STAR accumulated 10 C of charge on the inner sectors of the TPC**
  - **Approximately 1600 m of wire**
- **During the 2009 pp200 run, STAR accumulated another 12 C**
- **Prior to 2009, we estimate that STAR accumulated 40 C of charge on the inner sectors**



R. Bouclier, M. Capeáns, C. Garabatos, et al., Nucl. Instr. and Meth. **A346** (1994) 114.

Wire Aging isn't the only issue

- **Wire aging isn't the only issue with respect to predicting whether the STAR TPC will last for another 8 to 10 years**
  - **A drop in gain of 10-20% is not catastrophic, even 30% is OK on the inner sectors**

- **HV Channel tripping is important, too. (non-linear aging)**
  - **HV tripping (due to drawing too much current) is a show stopper**
  - **We cannot run if the frequency of trips exceeds the recovery time**
  - **Too many trips causes permanent damage to the TPC. For example this years pp500 run has caused 1 HV channel to fail and at least two more will not reach full voltage (out of 192).**
  - **HV trips are a non-linear form of wire aging … but are not so uniform in their characteristics and not so predictable**
  - **Presumably due to the Malter effect on the Cathode wires**

Inner Sector Trip History During pp500 Run

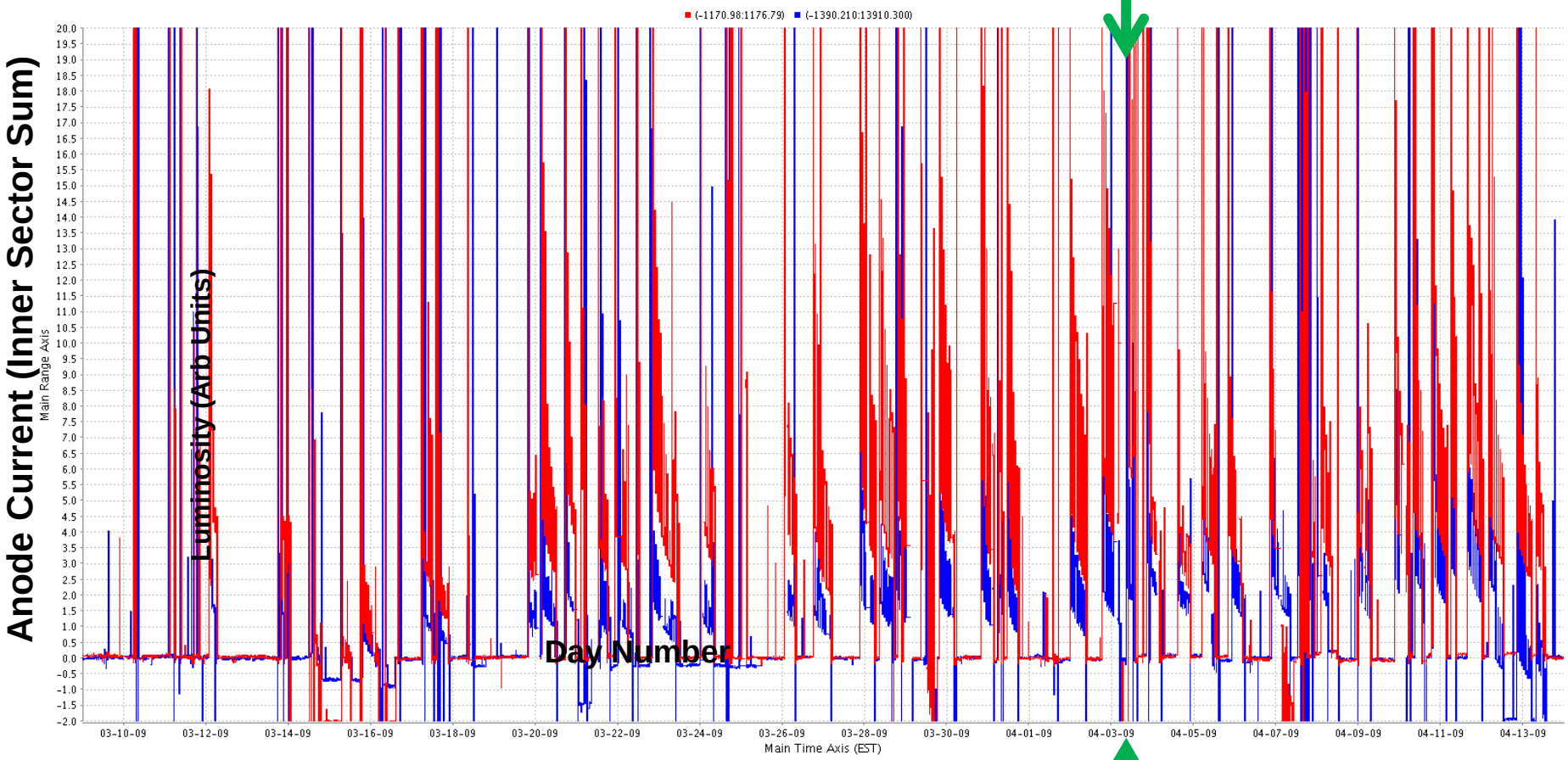
	1	2	3	4	5	6	7	8	9	10	11	12
2006	6	6	8	0	5	6	13	9	7	4	7	4
2007	3	2	2	11	1	1	7	1	2	4	2	1
2008	4	4	4	21	1	4	4	2	2	3	2	1
2009	4	1	23	131	0	1	10	0	8	3	4	3

	13	14	15	16	17	18	19	20	21	22	23	24
2006	11	9	6	7	4	15	5	9	5	11	11	9
2007	4	4	6	0	10	7	2	1	6	1	10	4
2008	1	1	5	6	6	4	0	5	5	4	1	1
2009	3	1	61	1	13	56*	2	3	0	2	5	2

* One channel disabled

Trip rate reduced by reducing the gain

Trips/day: 6, 0, 1, 0, 0, 3 6, 0, 0, 4, 6, 6, 19, 12, 7, 7,14, 8, 14, 32, 23, 17, 22, 24, 4, 4, 2, 5, 0, 1, 3, 6, 2, 0



03/10/09 **1170 V set for inner sectors** **1135 V** **04/12/09**

Trip frequency vs time for pp500 GeV

On 04/03/2009, all inner sectors voltages dropped by 35 Volts ⇒ 66% Gain

Good news and Bad News … first the good news

- **Last year, we installed new electronics (TPX). The S/N ratio for TPX is 30:1 … the spec for the original STAR TPC was 20:1**
  - **This suggests that we can lower the gain on both the inner and outer sectors by 1/3 and still achieve baseline performance.**
  - **The new voltages would be Inner: 1135 V Outer: 1345 V @ 66% gain**
- **The bad news is that the TPC inner sectors 'tripped' too often at Run 9 pp500 luminosities … (and we really hope to go to 4x $\mathcal{L}_{today}$)**
  - **Peak luminosity at the end of run 8 was $2 * 10^{31}$**
  - **Peak luminosity at the end of the pp500 engineering run was $6.6 * 10^{31}$**
- **The good news is that we lowered the voltage on the inner sectors from 1170 to 1135 volts and the performance of the anodes was stable at Run 9 pp500 luminosities.**
- **So we proceeded conservatively and ran pp200 at 1135 / 1390 V**
  - **Performance was stable at 400 Hz trigger rate in pp200 for Run 9**
  - **We will be testing both tracking and dE/dx to see if we can go even lower**

Going to higher luminosities is possible but lower gains will be required to go to 4x $\mathcal{L}_{today}$

The 2009 TPC Review – June 4-5, 2009

- **The '08 S&T review panel asked us study high luminosity running at RHIC**
  - ***"The STAR collaboration should develop a program to study possible consequences (e.g., aging) of operating the TPC in a high luminosity environment. Progress should be documented and presented at the 2009 RHIC S&T review".***
- **Nu Xu formed a panel to study the long term future of the TPC**
  - **Ron Settles (Chair, MPI-Munich), Howard Wieman (LBL), Velko Radeka (BNL), Dick Majka (Yale), Craig Woody (BNL), Chilo Garabatos (GSI)**
- **Charge to the '09 TPC Review Committee**
  - ***The [STAR] collaboration is also planning to install several new detectors whose installation will coincide, in time, with a significant increase in the luminosity of the beams at RHIC.***
  - ***These upgrades will allow the collaboration to continue to do compelling physics for many more years but the usefulness of these new detectors will depend on excellent performance from the TPC.***
  - ***Therefore, it is important to know if the TPC can meet the requirements of the experimental program in the high luminosity era at RHIC and if there are intrinsic lifetime or aging issues for the TPC that might affect how, or how long, it can run.***

TPC Lifetime Review – 2009 Action Items

- **The Committee recommends running with lower gains in all future pp running and possibly HI. Study impact on physics.**
- **Take calibration runs at the end of the 2009 run to determine aging on wires relative to the beginning of the run. Also study lower gains on the TPC sectors so we can choose a new gain setting for future running. Check Dedx and tracking quality.**

- **Build a mount for the sector insertion tool. We have a preliminary design from LBL.**
- **Remove one sector and replace it with a spare sector in the summer of 2010. Study aging on these wires. We need a laboratory in which to work and a place to test the spare sector before it goes in, and then the old one once it is removed.**

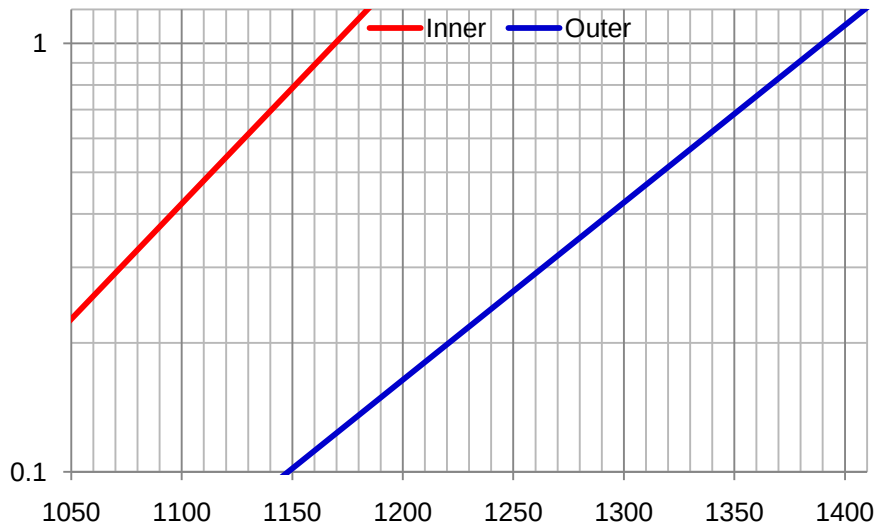
- **Instrument the MWPC cards (ie the anode wires) and study the output to determine if it is the ABDB or anode or cathode wires that are sparking.**
- **Change grounding on MWPC cards to lower the amount of stored energy on the unused anode wires on the inner sector.**

(continued)

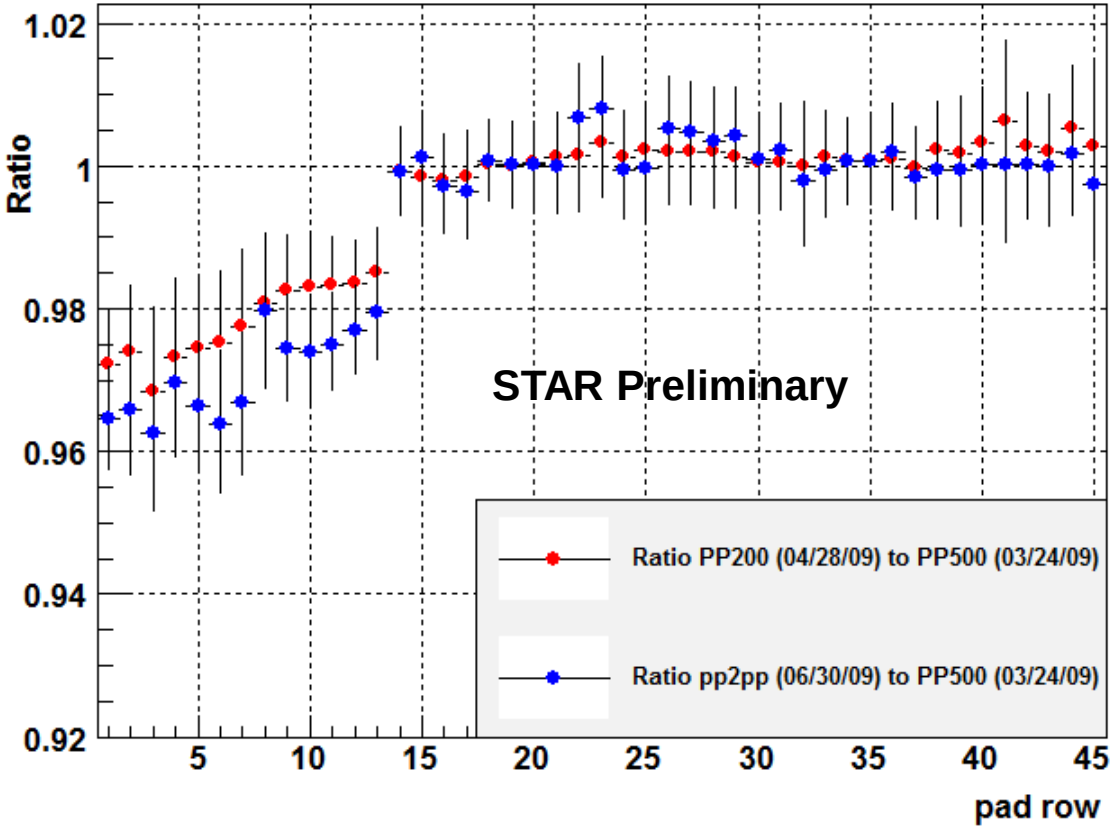
Data Taken During pp2pp Run (circa July 4th)

- **dE/dx studies & Alignment data were taken during the pp2pp physics run**
- **ΔV studies done with dedicated runs during pp2pp shifts**
- **All triggers were VPD minbias triggers**
- **About 500 K events taken at each voltage setting. 1 M at top voltage for reference.**
- **Data are too new to have results except for a quick look at full voltage gain**

Inner V	Inner Gain	Outer V	Outer Gain	Event Goal
1170	100%	1390	100%	1 M
1135	66%	1390	100%	1 M
1120	55%	1390	100%	250k
1100	42%	1390	100%	250K
1080	32%	1390	100%	250K
1060	24%	1390	100%	250K
1170	100%	1345	66%	250K
1170	100%	1325	55%	250K
1170	100%	1300	42%	250K
1170	100%	1270	32%	250K
1170	100%	1240	24%	250K



Measuring the relative gain of the TPC



10 C pp500
+12 C pp200

The Inner pad rows are affected the most

Y. Fisyak

- Low intensity calibration data taken at the beginning, middle and end of Run 9 (at 100% gain setting)
- Choose min I tracks … outer sector data normalized to 1.0
- Note: these are difficult measurements!

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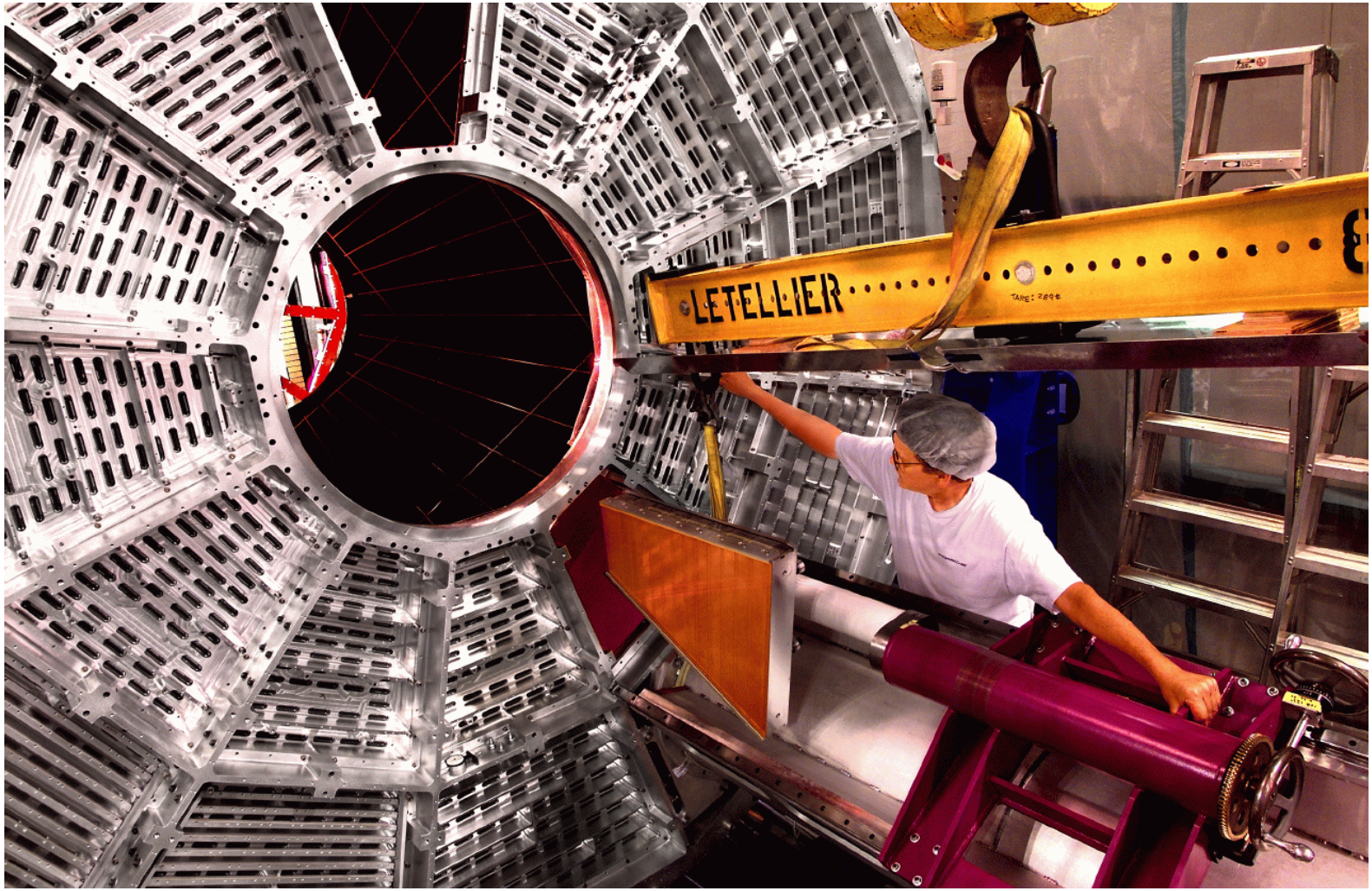
(continued)

Sector Repair is possible but not a trivial task



Sector Installation & Tooling

TPC Lifetime Review – 2009 Action Items (cont)

- **Develop mechanism to ramp Anode voltages down 100 V when not explicitly used.**
- **Add water or Alcohol to the gas. This needs R&D to determine its effect on field cages and other material surfaces (eg resistance).**
- **Create a cost and schedule for winding new Anode and Cathode (aka Ground) wires. Include a fix for grid leak, if possible. Determine availability and status of the BNL wire winding machine. Establish a laboratory in which to work.**
- **Create cost and schedule for gem readout option for inner sectors. Discuss pad plane, signal polarity, readout resolution (spatial). Note that this has never been done before for a large TPC and so requires substantial R&D.**

The full List of Presentations and the Committee Report can be found at:
http://indico.mppmu.mpg.de/indico/conferenceDisplay.py?confId=494

Winding new grids

The STAR TPC should last a long time. However, the option to replace the wire grids on the endcaps of the TPC is an extremely valuable contingency for us.

Also an opportunity to fix the grid leak problem, and to rebuild the ABDB boards which may account for some of the HV tripping

TPC Calibrations

- **Hao Qiu has done preliminary calib work for all datasets. See pp500 for example:**
  http://www.star.bnl.gov/HyperNews-star/protected/get/startpc/370.html

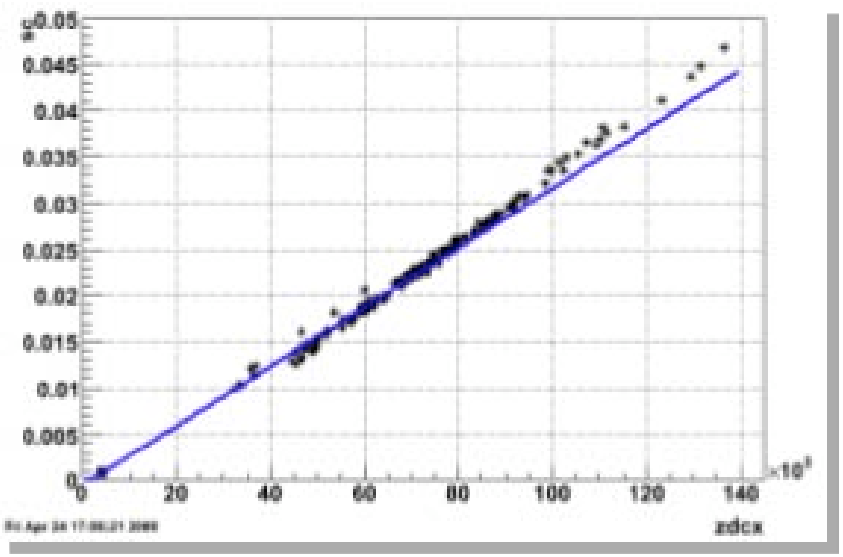
- **First order (linear) fit doesn't match data at high luminosity**
  - **Deviation corresponds to ~3 mm errors**

- **Can be improved by non-linear fit**
  - **Work in-progress (still wrestling with contributions from pileup)**

TPC Calibrations are a significant challenge in the high luminosity era at RHIC. We learn something new each year.

So far, the space charge distortions are not the largest distortion seen in the TPC … shorted rings are.

Pileup is another serious challenge but also an asset



Conclusions

- **The TPC is a beautiful detector. It is a credit to the original design that it has lasted so long and offers so many options for continued operation beyond the original specifications.**

- **The TPC has performed well in 2009**
  - **Wire (slow) aging isn't the immediate problem.**
  - **HV channel trips (fast aging) may be the greater problem … but lower gain operations has helped**
- **We are exploring new territory with high luminosity beams**
  - **We have successfully found a strategy to deal with Luminosities up to 6×10^{31} for protons**
    - **similar strategies will work for HI … but have not yet been needed**
  - **Higher luminosities will require running at lower gain for pp and HI**
  - **Critical data is in hand**
    - **needs to be evaluated for efficiency, dE/dx and p_T resolution**

- **Calibration of the TPC data is challenging, but manageable**

- **Staffing TPC Hardware and Software positions is a continuing management challenge … but a challenge that can be met.**

The TPC has a bright future. But we must proceed with caution, wisdom and care.

Backup Slides

TPC Manpower - Hardware

- **TPC Hardware**
  - **A. Lebedev (BNL), J. Thomas(LBL) – 2009 Subsystem Managers**
  - **Howard Wieman (LBNL), Dana Beavis (BNL)**
- **Gas System**
  - **Leonid Kotchenda (PNPI), Peter Kravstov (PNPI)**
- **Interlocks**
  - **Jim Thomas**
- **Water**
  - **CAD, Alexei Lebedev, Bob Soja (BNL)**
- **Slow controls & Computers**
  - **Yuri Gorbunov (Creighton) & Wayne Betts (BNL)**
- **Electronics**
  - **STSG – C. D'Agostino + Crew, Tonko Ljubicic, Jeff Landgraf, Bob Scheetz (BNL)**
- **Laser**
  - **Alexei Lebedev**

TPC Manpower - Software

- **Pad Monitor**
  - **Jo Schambach (UTA)**
- **Bad Pad/Gain file**
  - **Tonko Ljubicic, Jeff Landgraf**
- **Calibrations for Drift Velocity, dE/dx, etc.**
  - **Richard Witt (Naval Academy), Yuri Fisyak, Patricia Fachini (BNL)**
- **Calibrations for Grid leak, Space Charge, Shorts etc.**
  - **Gene Van Buren (BNL), Hao Qiu , JT, Joe Seele (MIT), Grant Webb (UK)**
  - **Na Li (IOPP Wuhan), Shusu Shi (HNU Wuhan)**
- **New Fast Tracker for Fast Offline**
  - **Hao Qiu (Lanzhou & BNL), Zhangbu Xu, Aihong Tang, Yuri Fisyak (BNL)**

TPC Manpower Issues

- **The Good News: New faces on the list**
  - **The Spokesman's office has been very good about recruiting students (esp. for calibration work)**
  - **We also need some senior faces, and people who don't rotate so fast**

- **The Bad News: Many are the same old faces … some are wearing out**
  - **After a decade, many of these folks would like to refresh and move on to new frontiers**

- **2009 TPC Review Committee Report**
  - **"An overall observation is that manpower is barely adequate to keep the detector running, and the collaboration should make every effort to increase the critical mass of sub-detector, DAQ and software experts."**
  - **"It should, however, be noted that several young people have already been added to the team. This is an excellent step in the right direction. The collaboration should be commended for this positive development, and it is urged to continue along that path."**

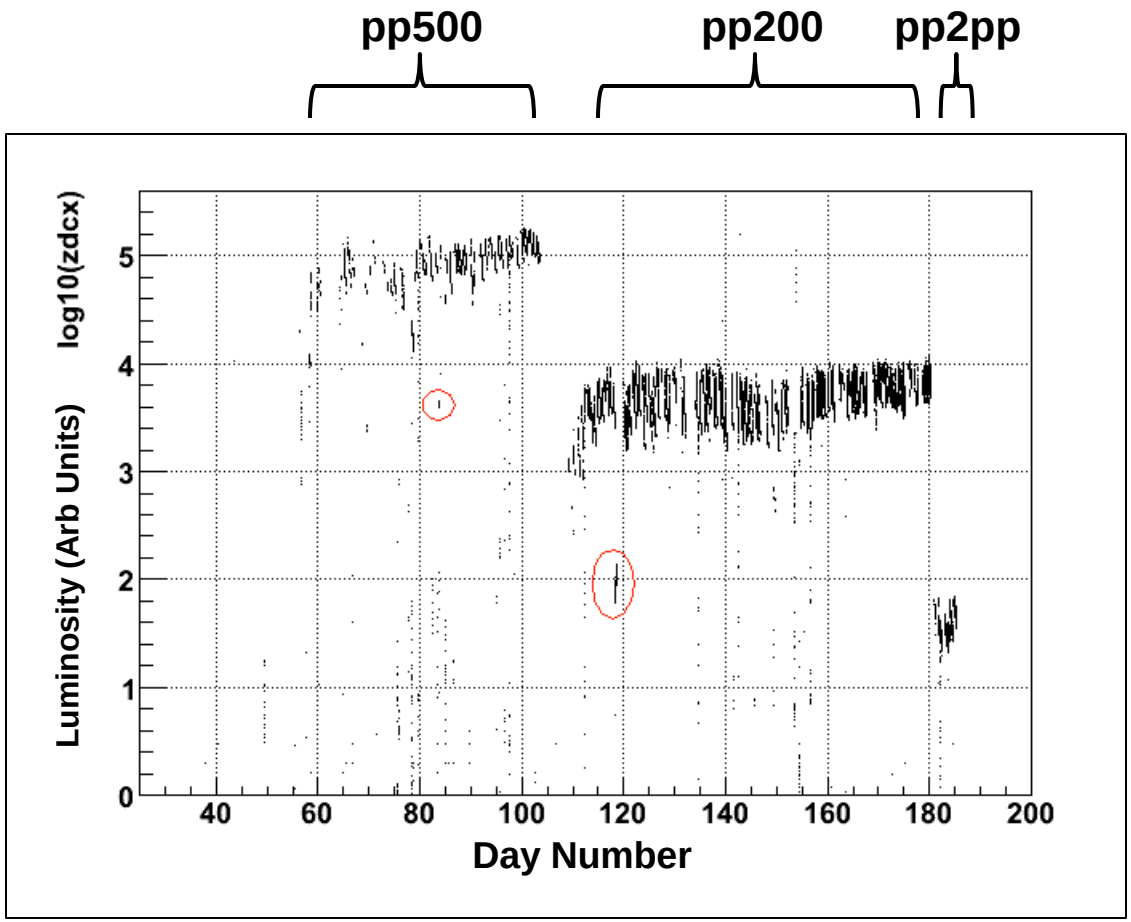
Manpower is an evolving situation: A management challenge

Accumulated Charge – Historical Data

Run	Species	Energy, GeV/nucleon	Time in Physics	Charge, Inner sect, C
Run-1 2000	Au-Au Au-Au	27.9 65.2	3 shifts 5.3 weeks	
Run-2 2001	Au-Au P-P	100 100	16 weeks	0.5*
Run-3, 2002/03	d-Au	100	10 weeks	1.28*
Run-4, 2003/04	Au-Au P-P	100 100	12 weeks 6 weeks	4.6*
Run-5, 2004/05	Cu-Cu P-P	100, 31, 11 100	8 weeks	3.0*
Run-6,2006	P-P	100, 30	13 weeks	9.0
Run-7, 2007	Au-Au	100	12.8 weeks	10.6
Run-8, 2007/08	d-Au P-P	100 100	9.0 weeks 3.4 weeks	7.7 3.4

A. Lebedev

Run 9: Luminosity as a function of time



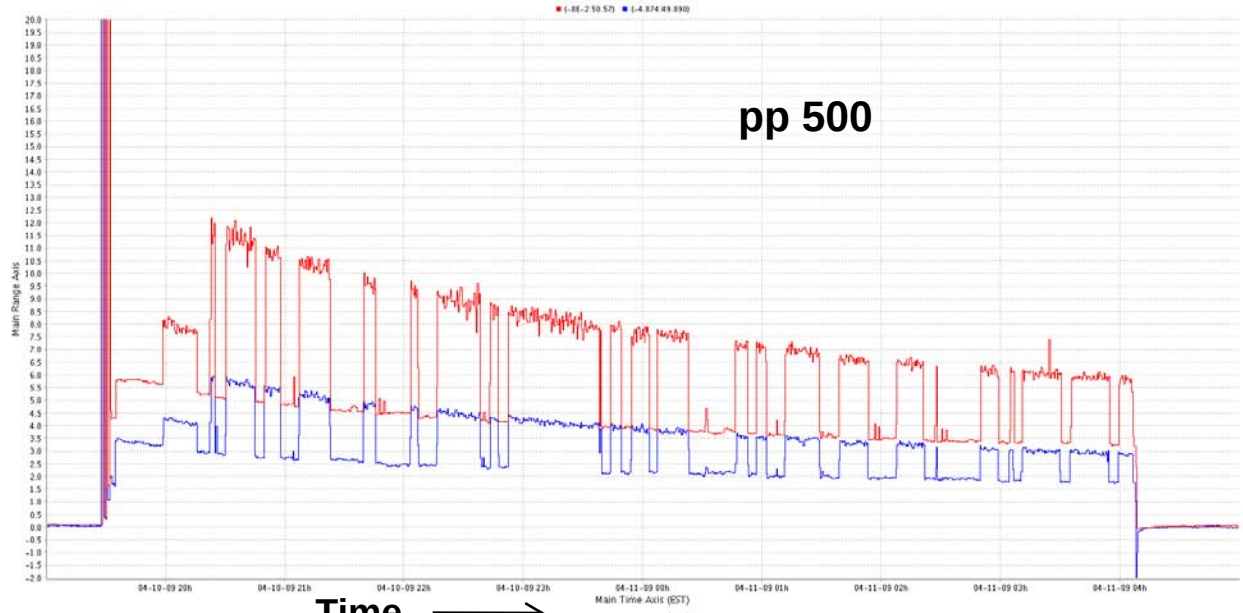
- The red circles mark two of the three “low luminosity” calibration runs
- The third low luminosity run was taken concurrently with the pp2pp running

Typical Current Draw on the Anodes

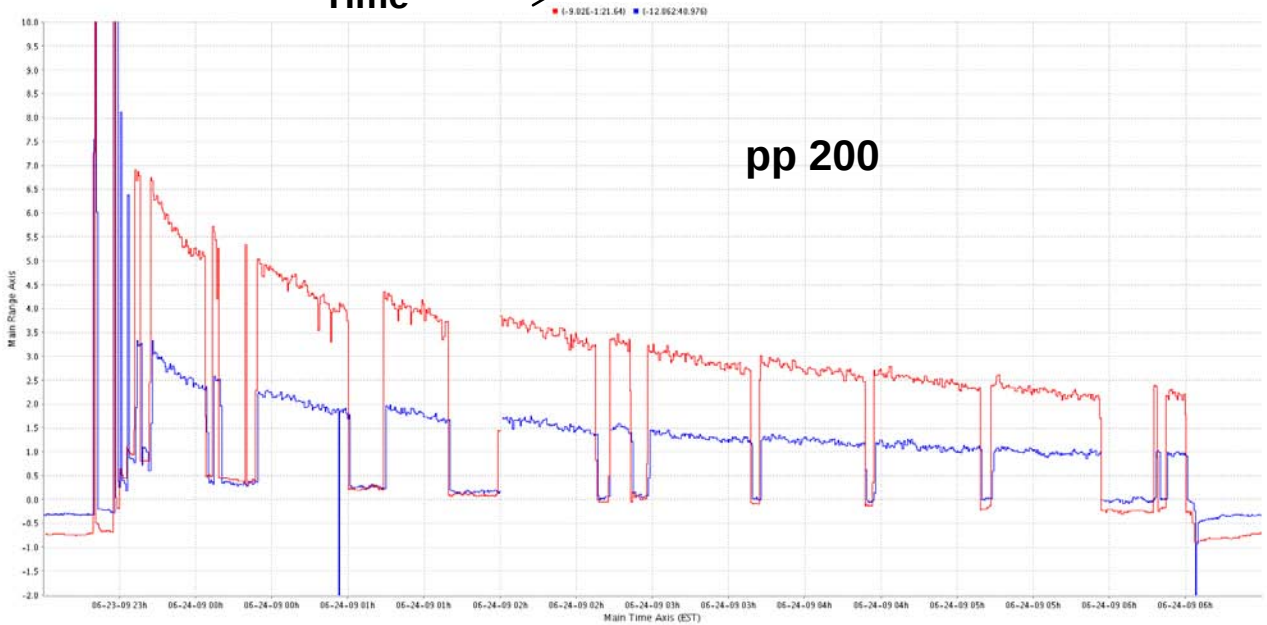
10 →

Summed Anode Current (μA)

5 →



Time →



Empirically, pp500 is ~2x pp200 or AuAu 200

Inner
Outer

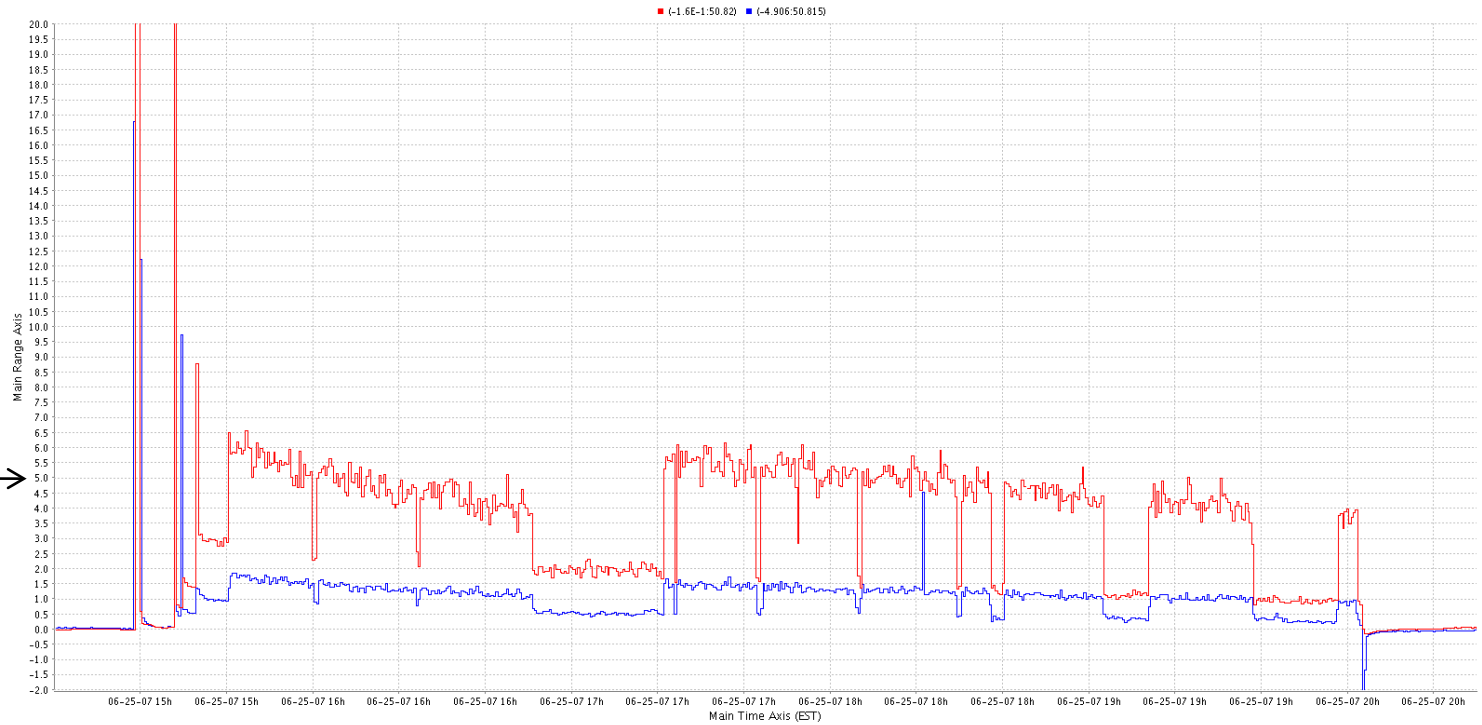
Inner
Outer

Au-Au 200 from Run 7 is similar to pp200

AuAu 200 Anode current draw

Summed Anode Current (μA)

5



Time

Beam Related Issues for TPX

- **At beam injection:**
  - **1-2 RDOs (out of 144) fail due to SEUs**
- **During running:**
  - **1 FEE (out of ~4800) fails per ~0.3-1 hr**
    - **Varies with beam luminosity i.e falls to 1 FEE per 2hr at end of fills**
    - **More often in pp500 than pp200**
- **Remedies:**
  - **At start of DAQ run we reload all FPGAs and re-download all parameters & pedestals (~15 seconds)**
  - **At FEE failure we do the same but only for that RDO**
    - **Next year we plan to auto-recover in about 1-2 seconds**
- **Lost 4 RDOs until now (out of 144)**
  - **All 4 have the same symptom**
  - **However 1 was dead before the beam started**
  - **Post-mortem analysis suggests that the EPROMS failed. They have now been repaired.**

Work Needed … but basically a happy story