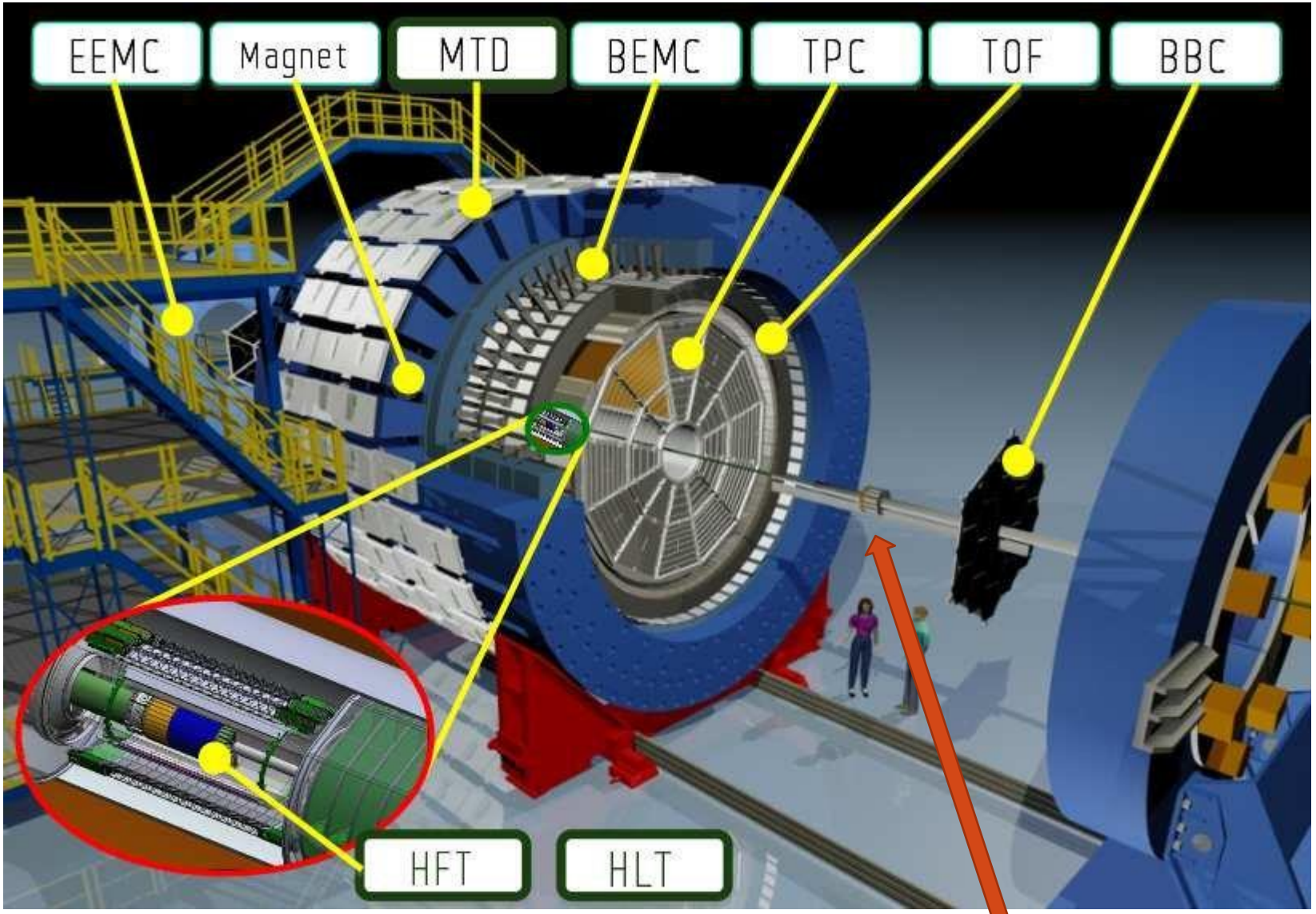
STAR Zero Degree Calorimeter

Jan Vanek

Zimní škola FJFI 2020, Bílý Potok

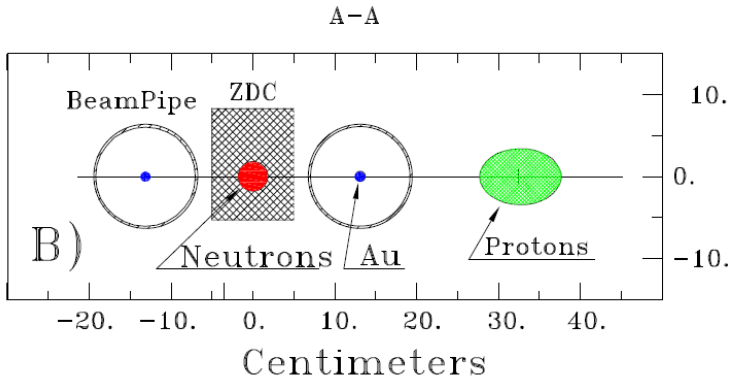
17. 01. 2020

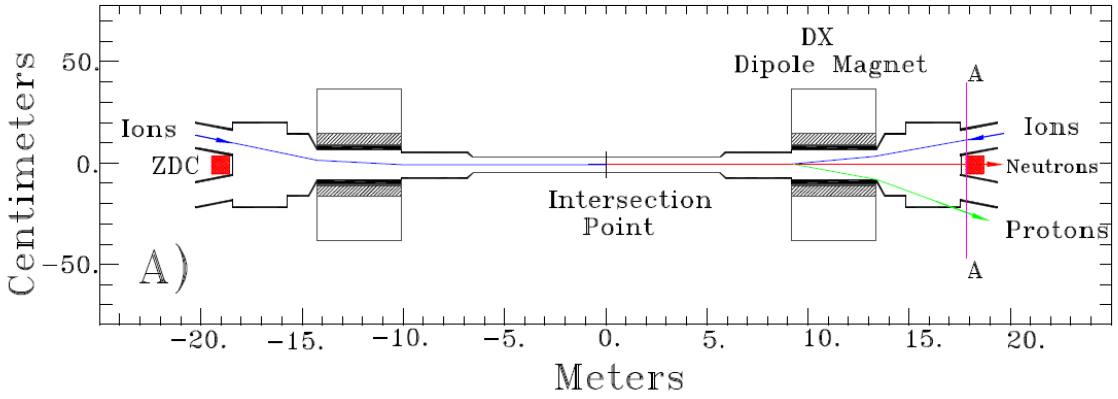
STAR DETECTOR



WHERE IS ZERO-DEGREE CALORIMETER?

- **In RHIC tunnel, 18 m from center of the STAR detector**
  - **East (ZDC-E)**
  - **West (ZDC-W)**
- **Between RHIC beam pipes**





Nucl.Instrum.Meth.A470:488-499,2001

WHERE IS ZERO-DEGREE CALORIMETER?

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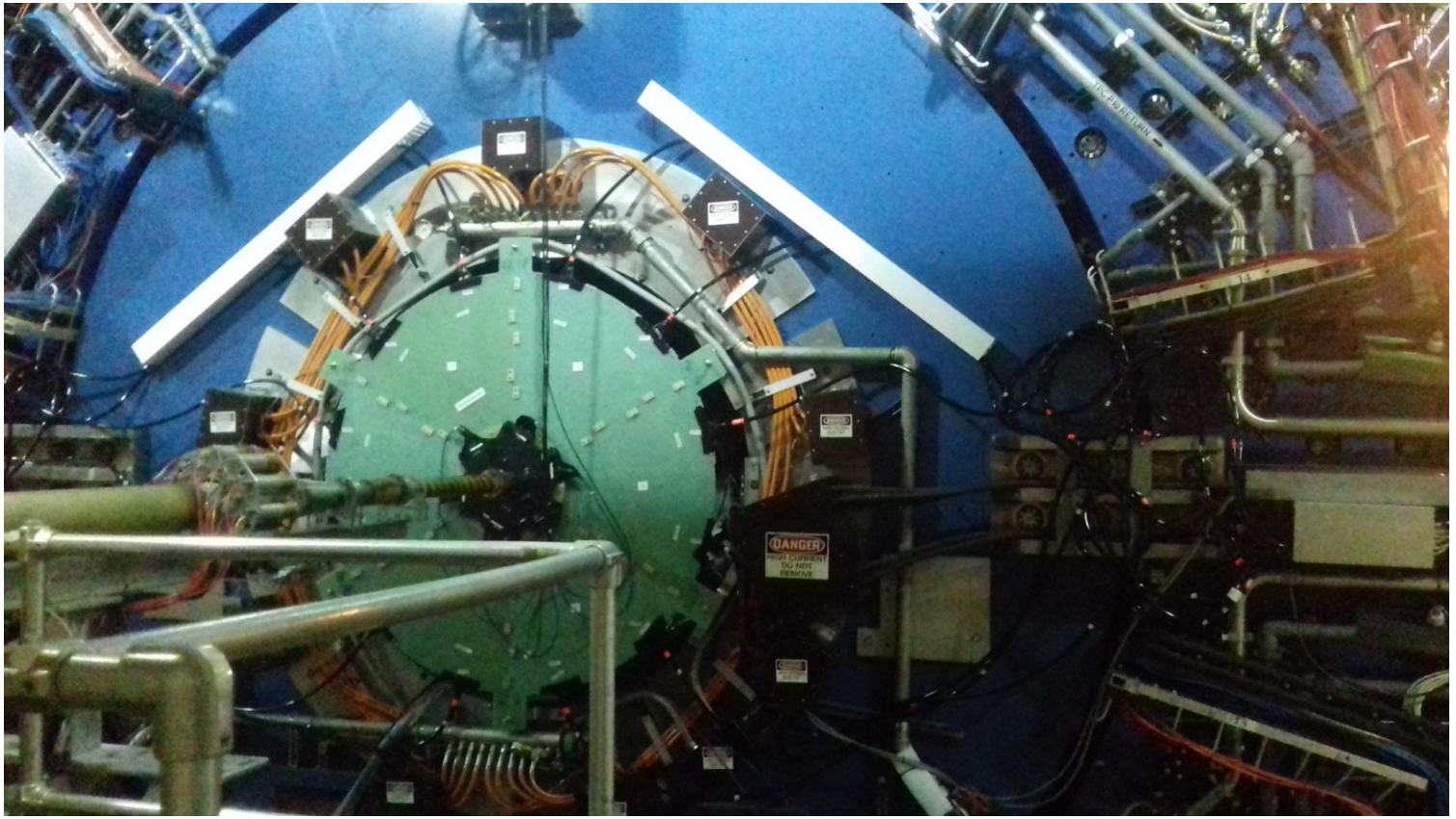
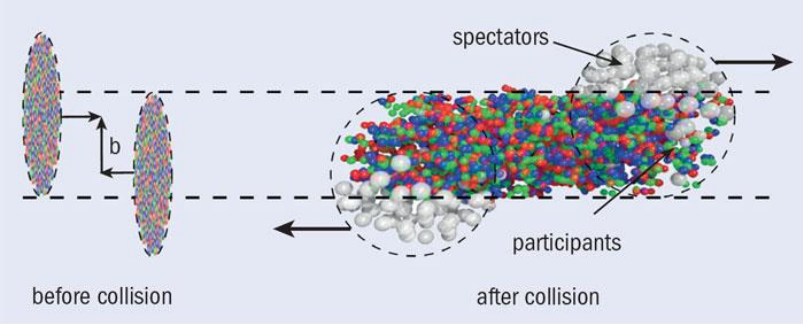
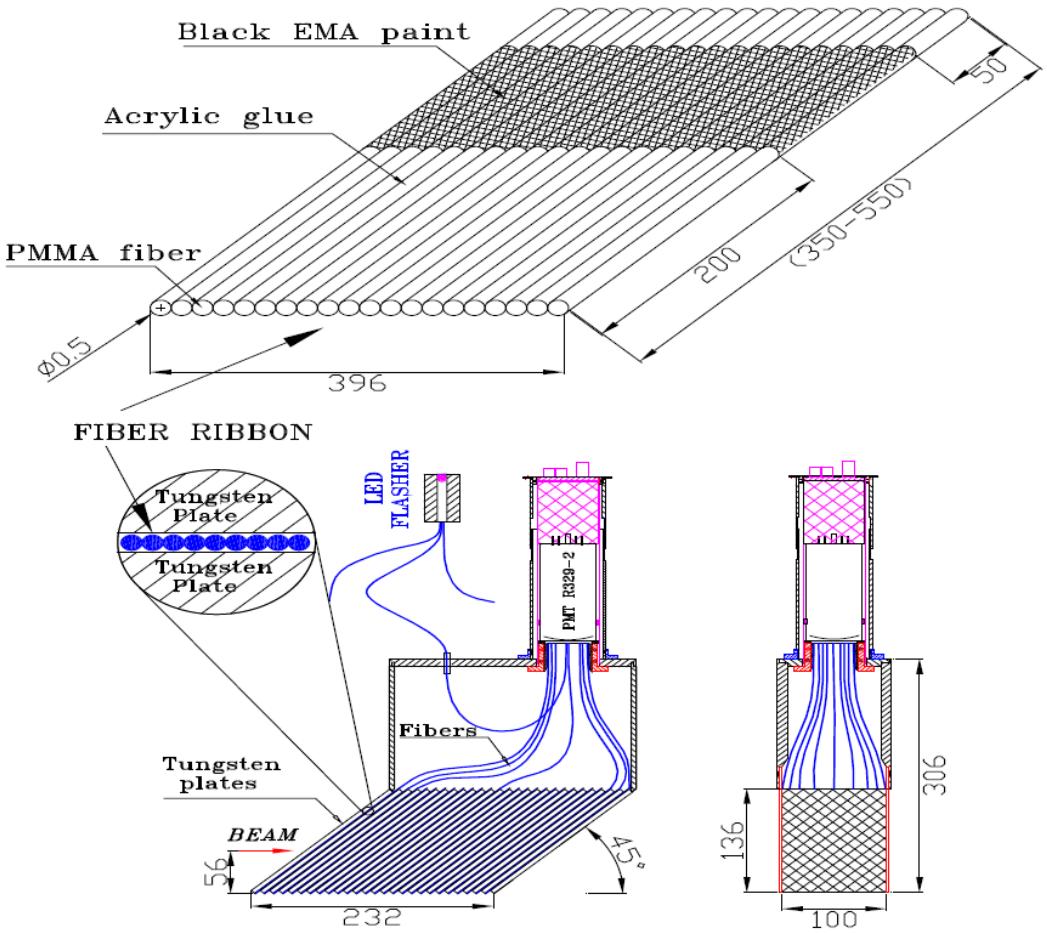


HOW DOES ZDC WORK AND LOOK LIKE?

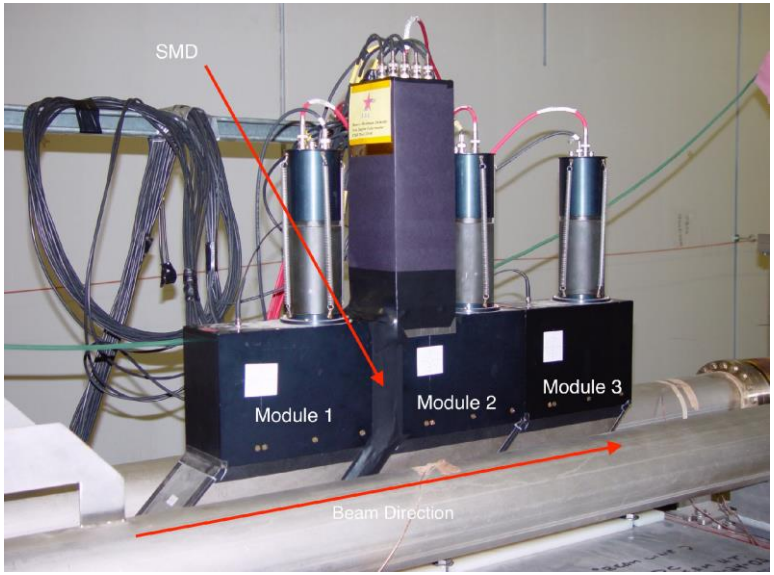


- **Detection of spectator neutrons after collision of nuclei in RHIC**
- **Conversion of ultra-relativistic neutrons in tungsten**
  - **Shower of charged particles**
- **Cherenkov light in PMMA fibers**
  - **Charged particles faster than light (in PMMA)**
- **Light collected by PMTs**
  - **Amount of light proportional to deposited energy**
- **ZDC = 6 identical modules**
  - **3 east, 3 west**



Nucl.Instrum.Meth.A470:488-499,2001

HOW DOES ZDC LOOK LIKE?



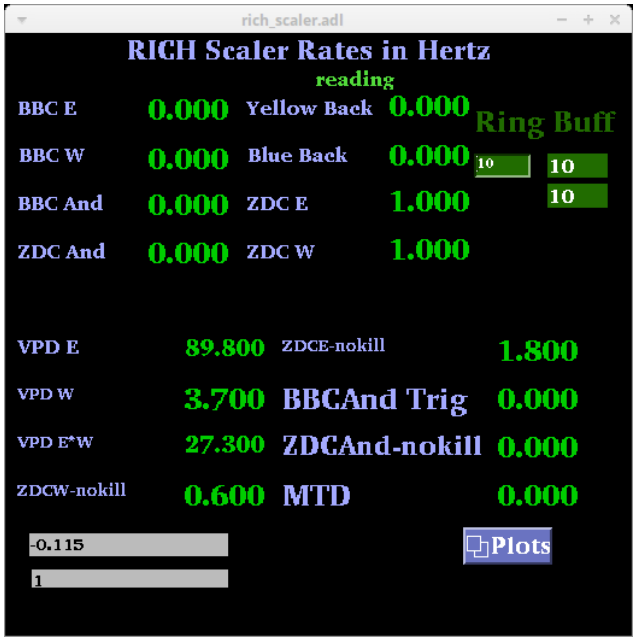
NUCL SCI TECH (2016) 27: 126

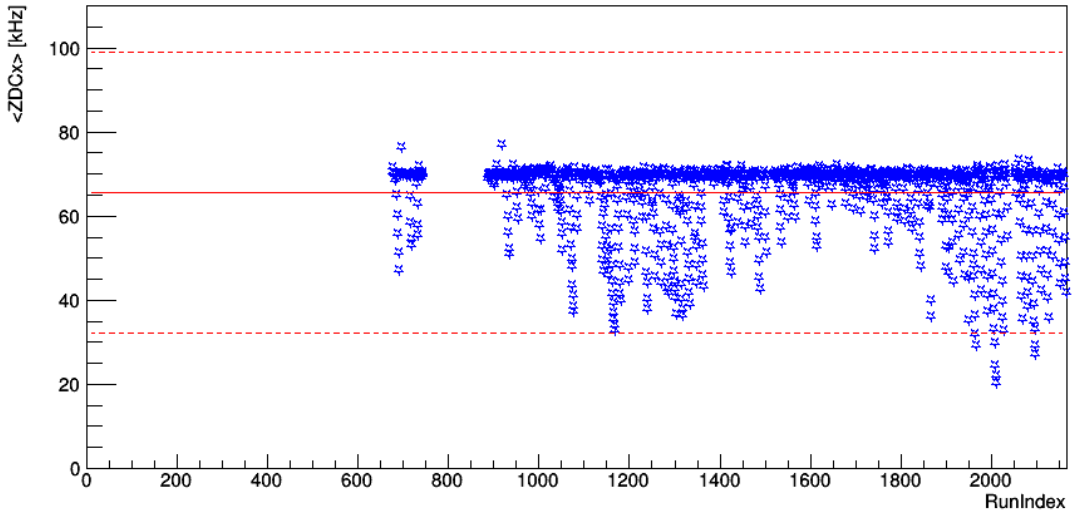
HOW CAN BE ZDC USED?

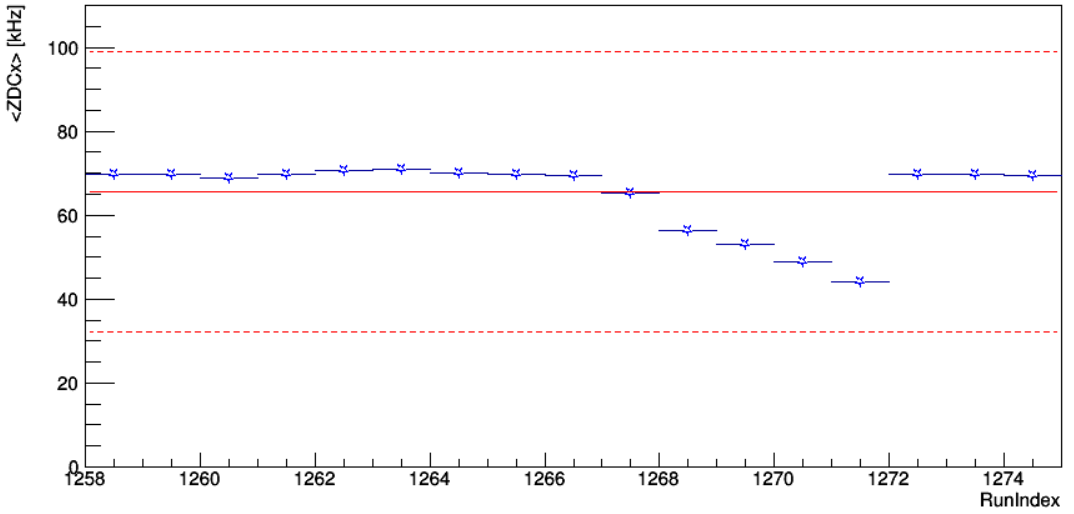
1. **RHIC monitoring**
   - **Measurement of luminosity**
     - **ZDC detection rates (east, west, AND)**
   - **Used while steering beams for collisions at STAR**
2. **Trigger**
   - **Decide if a good A+A collision occurred and give signal to other detectors to read out signal**
3. **Collision centrality determination**
   - **Number of spectator neutrons is inversely proportional to collision centrality**
     - **More central collision – less spectator neutrons and vice versa**
   - **Not used at STAR at the moment**
4. **Pileup correction**
   - **Correction of charge particle multiplicity in TPC**

HOW LARGE ARE ZDC RATES AT STAR?

- **Example for Run16 Au+Au@200GeV**
- **Typical measured rate is 70 kHz for Run16**
- **RHIC also monitors BBC and VPD rates**







HOW DOES ZDC TRIGGER STAR?

previous run #21013011 | next run #21013013

Information for run: 21013012

Run Log
Back to Calender

Trigger Info | Run Info | Thresholds

All Details | No Details | main | Requirements | Detectors | Overlaps | PS Setup | Emulation

name	daqid	offline id	ps	expected rate	scaler rate	evts	tape rate	stream		
minbias (history)	1	710010	1.0000	3.00K	1.06K	619.47K	0.0000	physics	more	
minbias (history) --> Requirements:	+TOFmult0 +EPD-TAC +EPD-E +EPD-W -Laser-protection	or	+TOFmult0 +VPD-TAC +VPD-E +VPD-W -Laser-protection	or	+ZDC-TAC +ZDC-E +ZDC-W -Laser-protection	L1: Accept	L2: l2-emc-ped	L4: Accept	more	hide
minbias_withetof (history)	2	710018	1.0000	3.00K	1.06K	510.08K	0.0000	physics	more	
minbias_withetof (history) --> Requirements:	+TOFmult0 +EPD-TAC +EPD-E +EPD-W -Laser-protection	or	+TOFmult0 +VPD-TAC +VPD-E +VPD-W -Laser-protection	or	+ZDC-TAC +ZDC-E +ZDC-W -Laser-protection	L1: Accept	L2: Accept	L4: Accept	more	hide
minbias_gmt (history)	4	710019	60.00	50.00	1.05K	10.32K	0.0000	physics	more	
minbias-hlt70 (history)	12	710012	emulated			114.26K	0.0000	physics	more	
minbias-hlt150 (history)	13	710013	emulated			197.65K	0.0000	physics	more	
minbias-allvtx (history)	14	710014	emulated			248.29K	0.0000	physics	more	
minbias-sendvtxt (history)	15	16	emulated			249.90K	0.0000	physics	more	
bbc-tof0 (history)	16	710814	2.00K	5.00	8.30K	1.98K	0.0000	physics	more	
bbc (history)	17	710801	30.00K	26.67	8.89K	142.00	0.0000	physics	more	
bbc-tac (history)	18	710802	16.00K	50.00	771.69	22.00	0.0000	physics	more	
bbc-tac-tofmult0 (history)	19	710803	2.00K	400.00	563.70	136.00	0.0000	physics	more	
epd (history)	20	710824	500.00	1.60K	11.31K	12.15K	0.0000	physics	more	
epd-tac-nocut (history)	21	710833	22.00K	0.0727	831.18	31.00	0.0000	physics	more	
epd-tac (history)	22	710825	50.00	32.00	831.18	13.12K	0.0000	physics	more	
epd-tac-tofmult0 (history)	23	710826	50.00	16.00K	625.45	10.56K	0.0000	physics	more	
vpd (history)	24	710807	50.00	20.00	1.61K	12.34K	0.0000	physics	more	
vpd-tac (history)	25	710808	50.00	14.00	588.95	5.66K	0.0000	physics	more	
vpd-tac-tofmult0 (history)	26	710809	50.00	14.00	539.46	5.50K	0.0000	physics	more	
zdc (history)	27	710810	300.00	0.2333	11.75	4.00	0.0000	physics	more	
zdc-tac (history)	28	710811	20.00	3.50	11.75	41.00	0.0000	physics	more	
zdc-tac-tofmult0 (history)	29	710812	20.00	3.50	6.50	39.00	0.0000	physics	more	
mb_epdcomponent (history)	34	710015	1.0000	7.00M	625.45	527.83K	0.0000	physics	more	
mb_vpdcomponent (history)	35	710006	1.0000	700.00	539.46	275.06K	0.0000	physics	more	
mb_zdccomponent (history)	36	710007	1.0000	90.00	11.75	784.00	0.0000	physics	more	
testLaserFire (history)	54	55	1000.00M	0.0000	0.0000	1.0000	0.0000	physics	more	
testLaserProtect (history)	55	56	1000.00M	0.0000	0.0000	1.0000	0.0000	physics	more	
zerobias (history)	59	9300	9.34M	1.0000	9.34M	1.73K	0.0000	zerobias	more	

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minbias (history)	1	710010	1.0000	3.00K	1.06K	619.47K	0.0000	physics	more	
minbias (history) --> Requirements:	+TOFmult0 +EPD-TAC +EPD-E +EPD-W -Laser-protection	or	+TOFmult0 +VPD-TAC +VPD-E +VPD-W -Laser-protection	or	+ZDC-TAC +ZDC-E +ZDC-W -Laser-protection	L1: Accept	L2: l2-emc-ped	L4: Accept	more	hide
minbias_withetof (history)	2	710018	1.0000	3.00K	1.06K	510.08K	0.0000	physics	more	
minbias_withetof (history) --> Requirements:	+TOFmult0 +EPD-TAC +EPD-E +EPD-W -Laser-protection	or	+TOFmult0 +VPD-TAC +VPD-E +VPD-W -Laser-protection	or	+ZDC-TAC +ZDC-E +ZDC-W -Laser-protection	L1: Accept	L2: Accept	L4: Accept	more	hide
minbias_mtd (history)	4	710019	60.00	50.00	1.05K	10.32K	0.0000	physics	more	
minbias-hlt70 (history)	12	710012	emulated			114.26K	0.0000	physics	more	
epd-tac-tofmult0 (history)	23	710826	50.00	16.00K	625.45	10.56K	0.0000	physics	more	
vpd (history)	24	710807	50.00	20.00	1.61K	12.34K	0.0000	physics	more	
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zdc (history)	27	710810	300.00	0.2333	11.75	4.00	0.0000	physics	more	
zdc-tac (history)	28	710811	20.00	3.50	11.75	41.00	0.0000	physics	more	
zdc-tac-tofmult0 (history)	29	710812	20.00	3.50	6.50	39.00	0.0000	physics	more	
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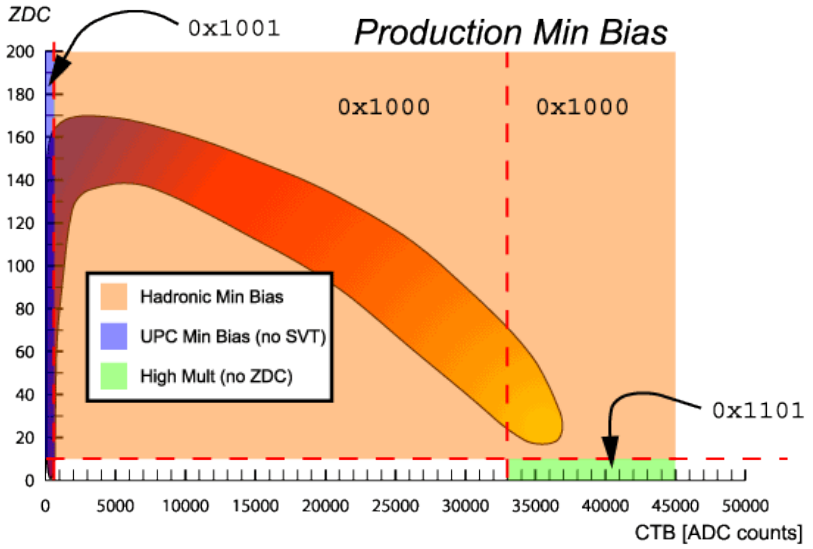
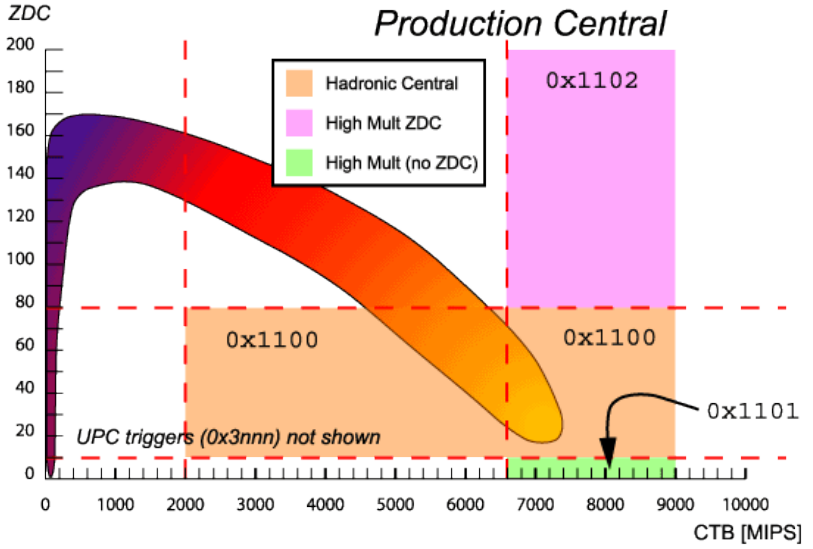
testLaserFire (history)	54	55	1000.00M	0.0000	0.0000	1.0000	0.0000	physics	more	
testLaserProtect (history)	55	56	1000.00M	0.0000	0.0000	1.0000	0.0000	physics	more	
zerobias (history)	59	9300	9.34M	1.0000	9.34M	1.73K	0.0000	zerobias	more	

HOW CAN ZDC MEASURE CENTRALITY?

- **Measurement of number of spectators of A+A collision**
- **Central collisions**
  - **Very few or no spectators**
  - **All nucleons participate in collision**
  - **High particle multiplicity in STAR detector**
- **Mid-central**
  - **Destruction of bounds between spectators**
  - **Increasing number of spectators with decreasing centrality**
  - **Opposite trend for charged particles in STAR**
- **Peripheral**
  - **Nuclei nearly intact, but excited**
  - **Emission of single or a few neutrons**
  - **Low multiplicity in both ZDC and STAR**

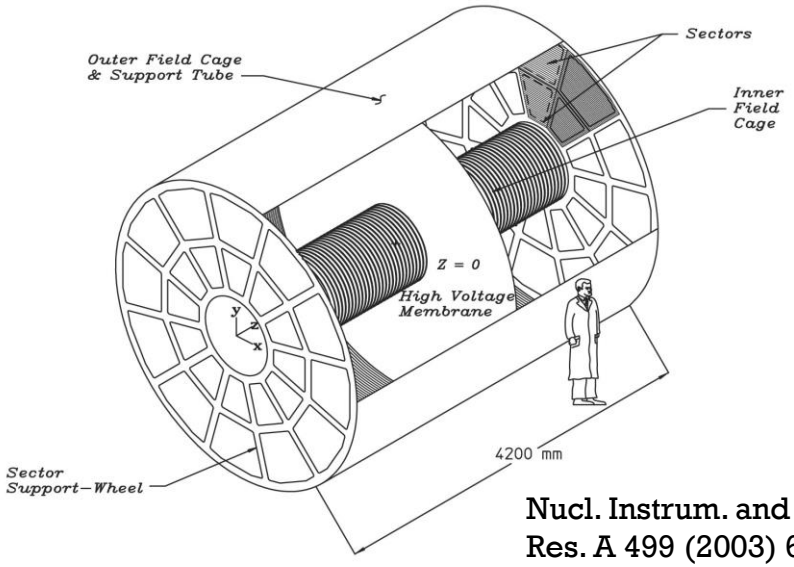




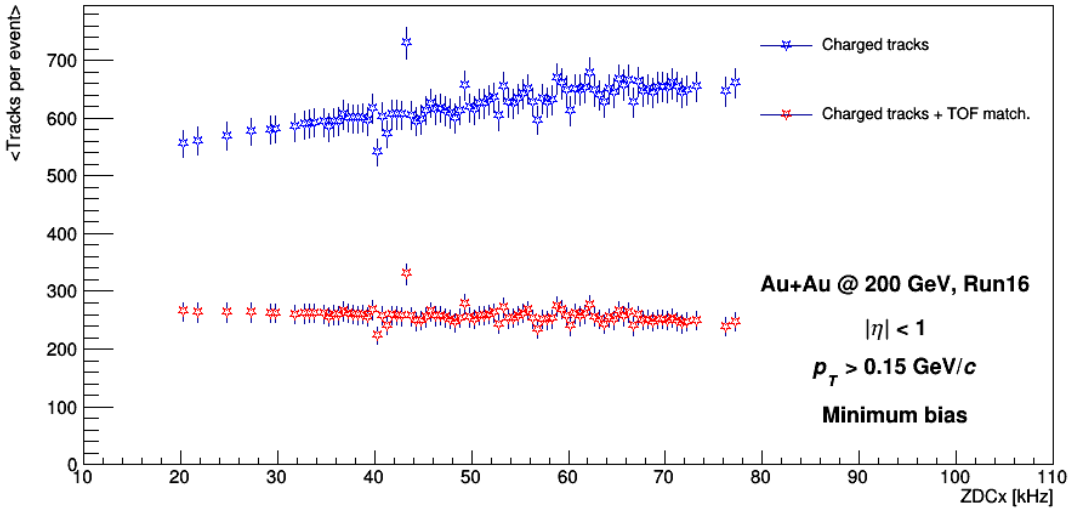
STAR trigger group (accessed on 01/17/20): https://www.star.bnl.gov/public/trg/

HOW TO DEAL WITH PILEUP USING ZDC?

- **Number of charged tracks in TPC increases with collision rate**
  - **TPC is slow detector**
- **How slow?**
  - **Highest drift velocity of electrons = 5.5 cm/μs**
  - **TPC length = 420 cm**
  - **Readout frequency max. approx. 26 kHz**
- **More important for small systems (d+Au, p+Au)**
  - **Collision rates up to 1.2 MHz (d+Au)**



Nucl. Instrum. and Meth. in Phys. Res. A 499 (2003) 659



HOW TO PREPARE ZDC FOR NEW RUN?

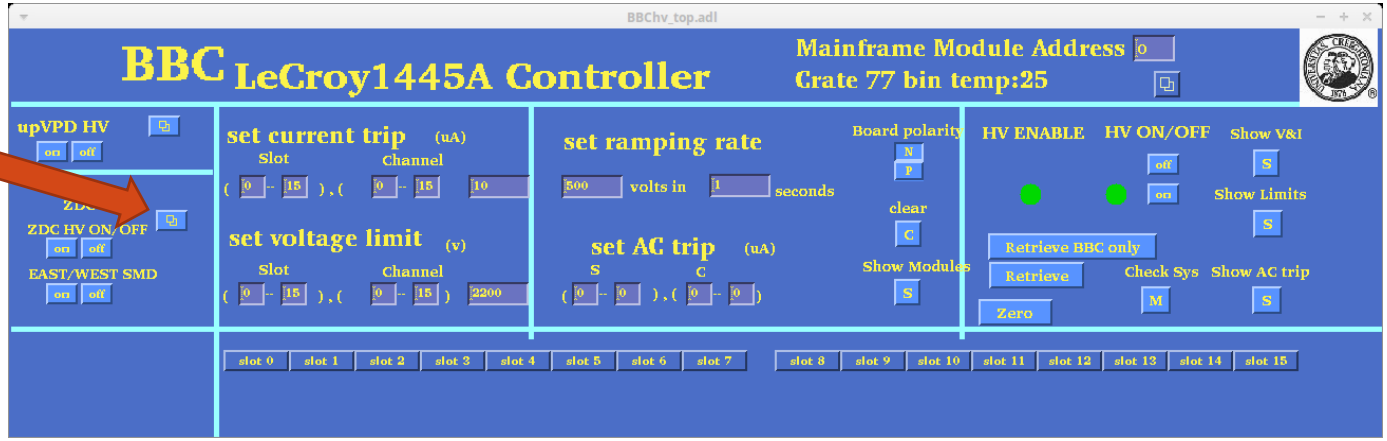
- **Part of service task of PhD. students from FNSPE and NPI**
  - **Lukas Kramarik, Jan Vanek, (Miro Simko)**

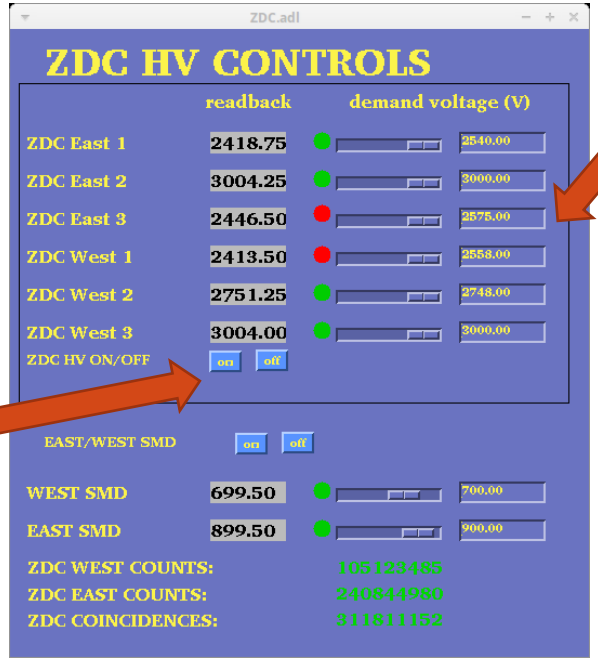
1. **Check ZDC high voltage (HV) and electronics**
   - **All photomultipliers (PMTs) are working?**
   - **Do we see signal from the PMTs?**
   - **Is the electronics working?**

2. **Calibrate ZDC gain by adjusting HV**
   - **Gain of each ZDC tower**
     - **Balance between towers of ZDC**
   - **Single neutron peak (SNP)**
     - **Balance between east and west ZDC module**

HOW TO CHECK AND CONTROL ZDC HV?

1. Press this





2. Then press this
   - Automatically loads HV for all PMTs

3. Adjust the HV here if needed

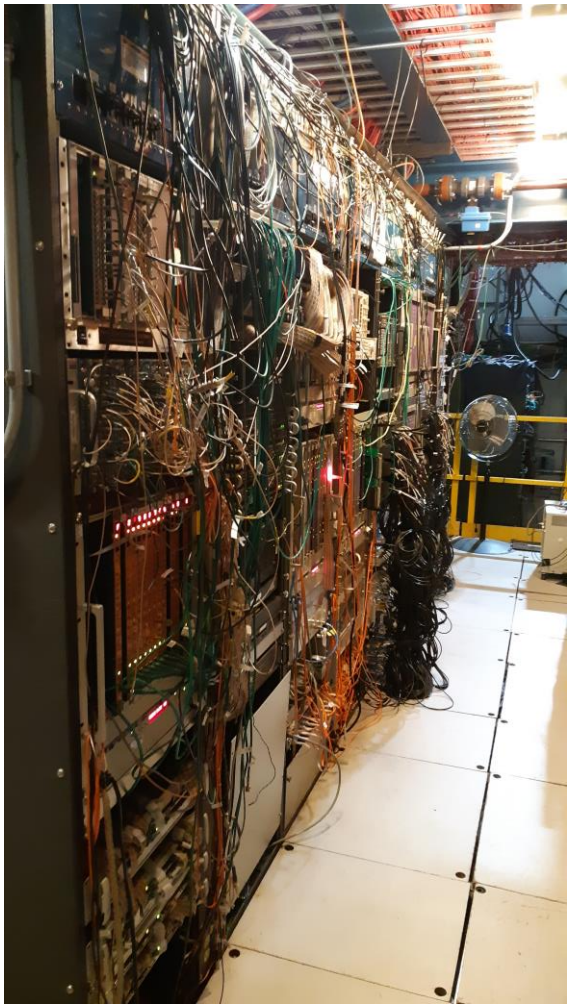
4. Connect output from individual PMTs to oscilloscope and hope that you will see a signal

HOW TO CHECK ZDC ELECTRONICS

- **Expectation:**
  - **STAR is a 21st century, state-of-the-art experiment a has the most modern and sophisticated electronics. It will for sure look something like this:**

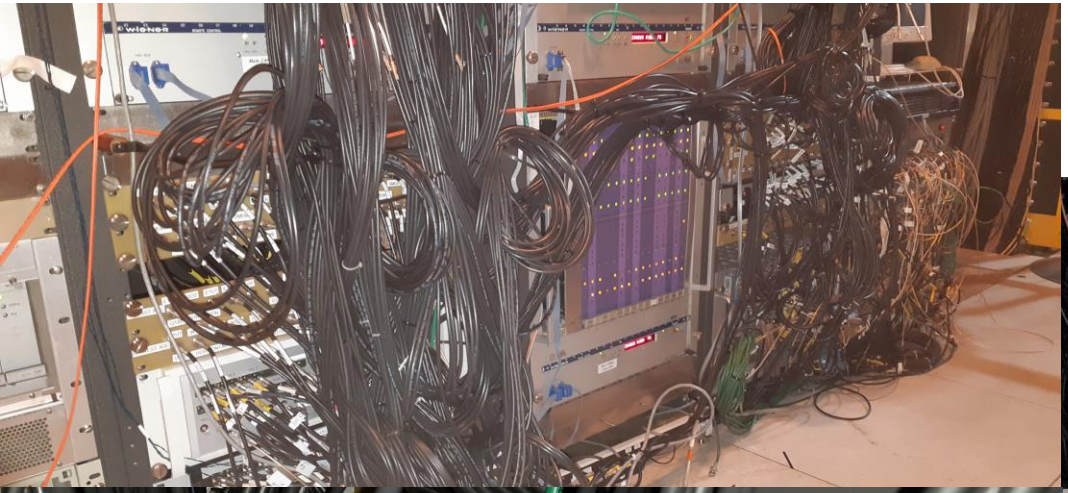
HOW TO CHECK ZDC ELECTRONICS

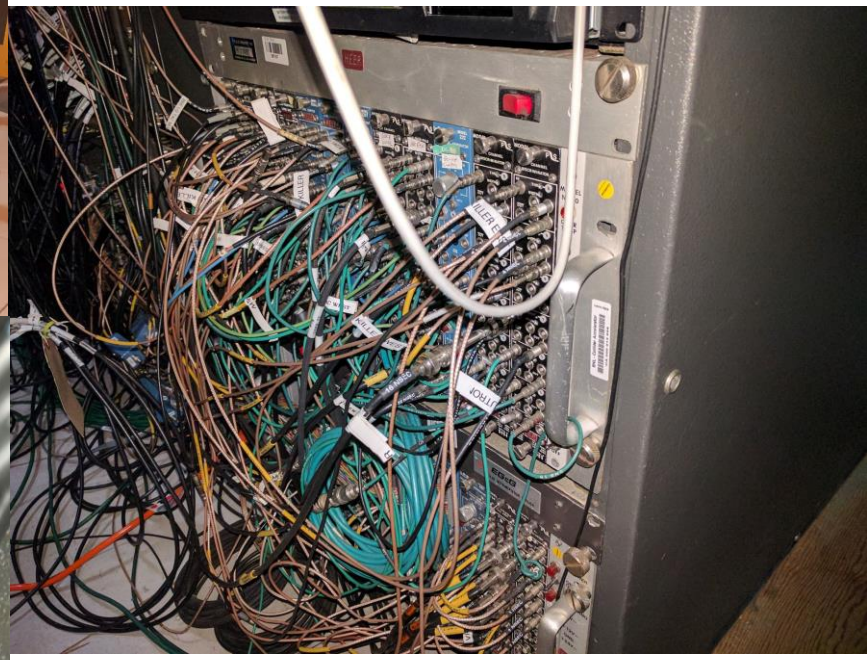
- **Reality:**
  - **STAR is a 21st century, state-of-the-art experiment, but now has often quite outdated and old electronics and it actually, it looks like this:**

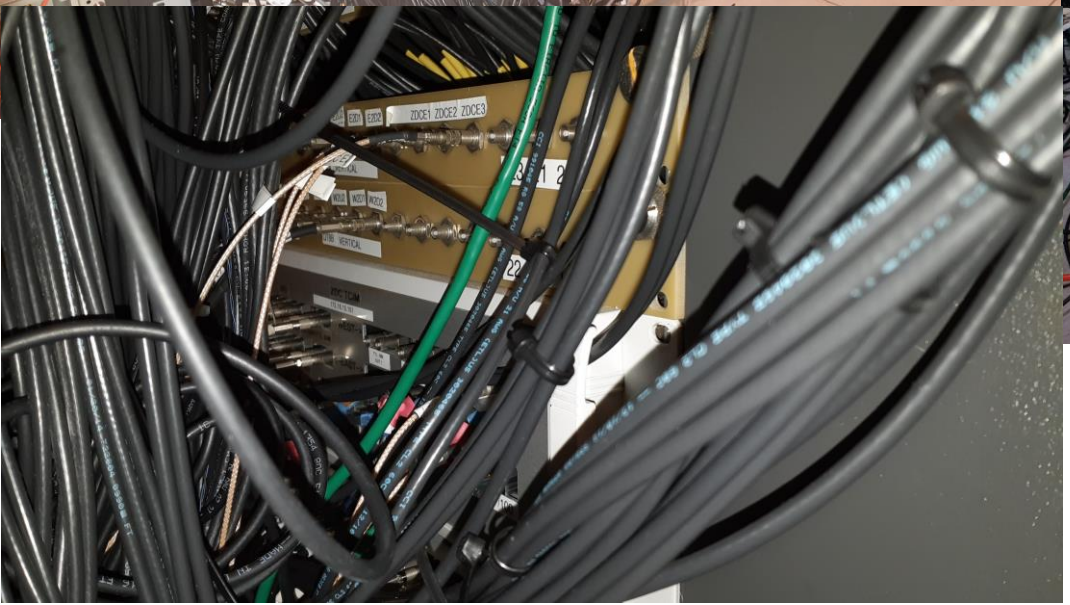


HOW TO CHECK ZDC ELECTRONICS

- **Check that signal goes through the whole electronics**
  - **Connect pulser (small frequency generator) to various places of the read-out electronics circuit**

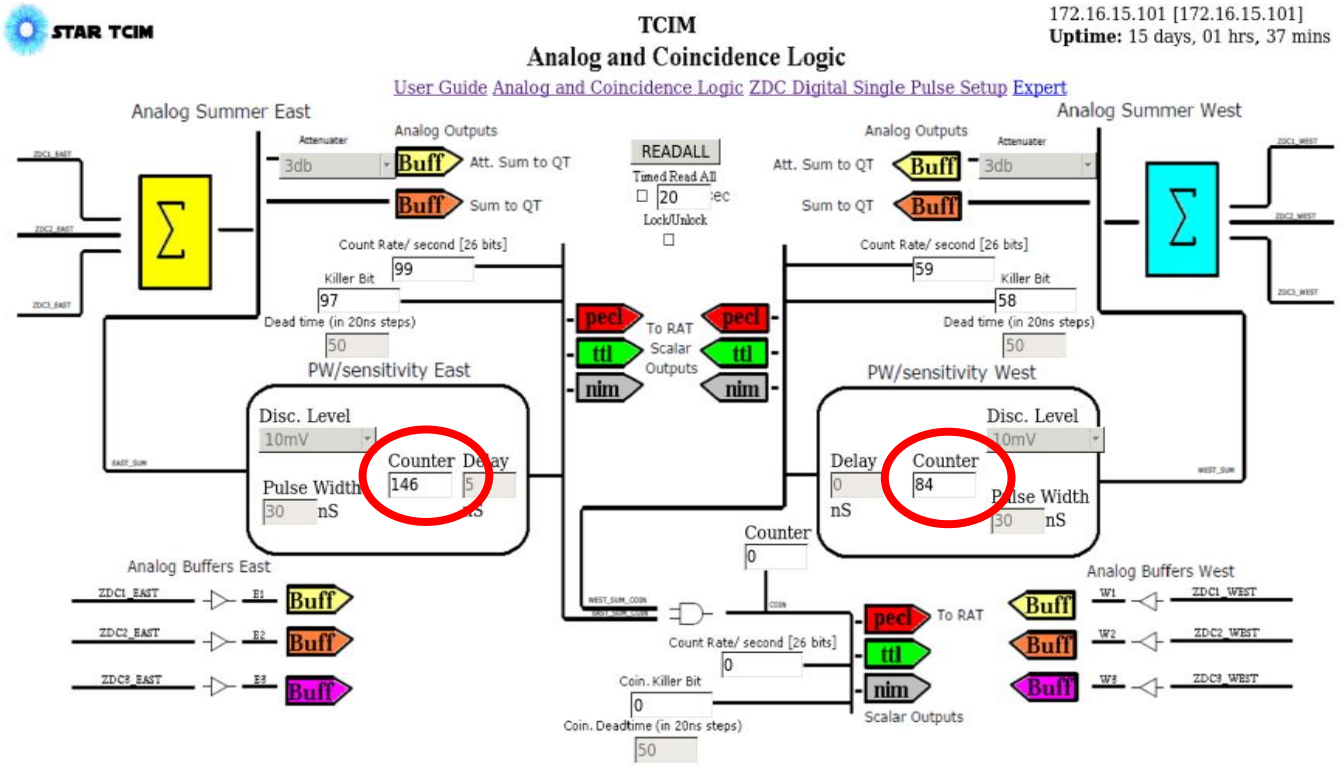


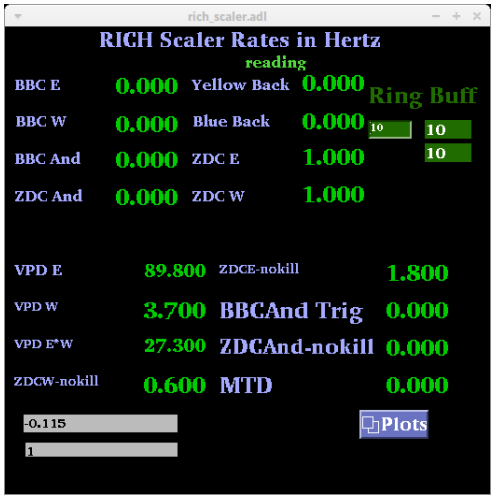




HOW TO CHECK ZDC ELECTRONICS

- **Check that the electronics works**
  - **Connect pulser to input to the electronics so that it simulates coincidence between ZDC-E and ZDC-W**
    - **ZDC-AND at the same rate as on single towers**
    - **RICH scalers show the correct rates (information for RHIC)**

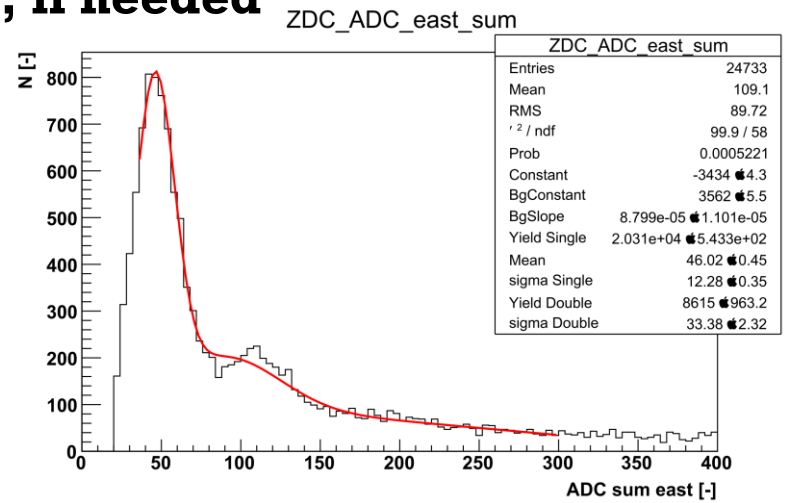




HOW TO CALIBRATE ZDC?

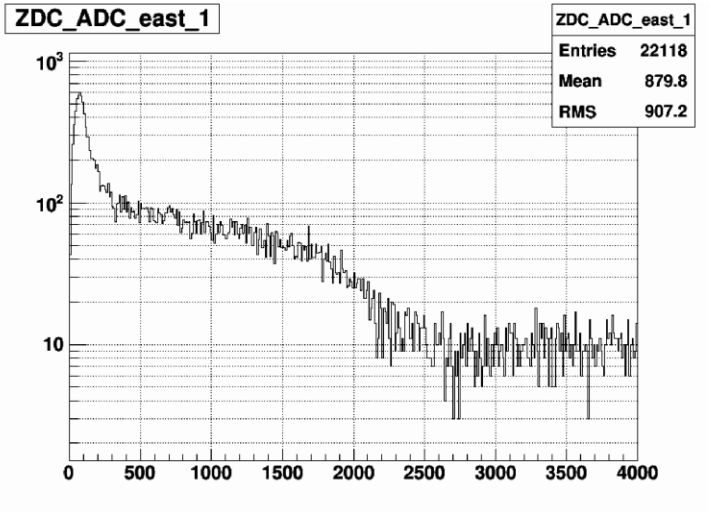
- **The ADC value is proportional to energy deposited in the ZDC and HV applied to the PMTs**
  - **Energy deposition given by energy of neutron – fixed (100 GeV)**
  - **Need to set HV so that:**
    - **The total gain is sufficient for electronics**
    - **ZDC-E and ZDC-W have the same total ADC value for SNP**
    - **Individual towers have to have ADC values in ratio of 6:3:1**

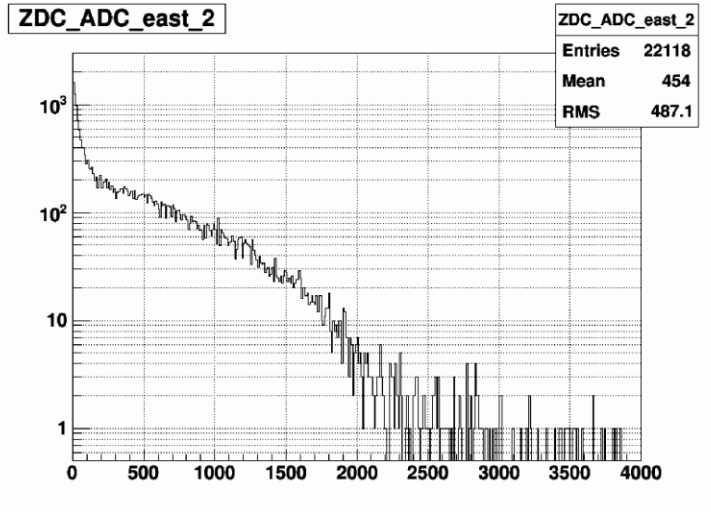
1. **Request dedicated run to collect data for calibration**
2. **Compare ADC values for individual towers**
3. **Fit total ZDC-E and ZDC-W ADC sum to determine position and width of the SNP and double neutron peak**
4. **Compare total ADC values for ZDC-E and ZDC-W**
5. **Adjust voltages and repeat, if needed**

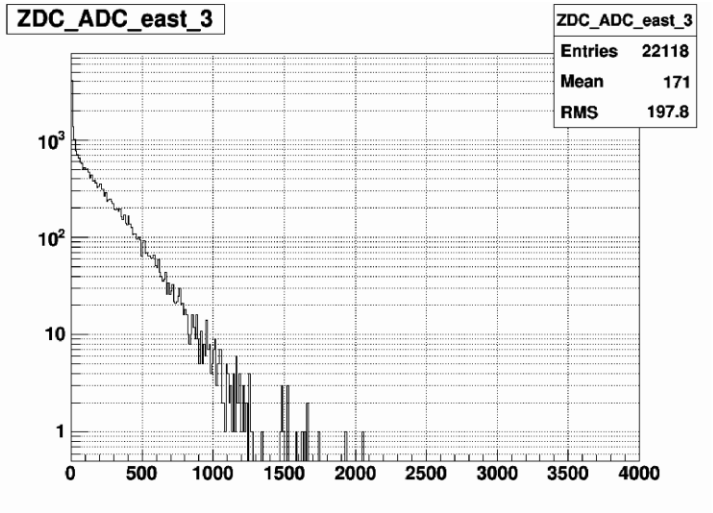


HOW TO CALIBRATE ZDC?

- **Single tower ADC distributions for ZDC-E**







HOW TO REPAIR ZDC IF IT GOES WRONG?

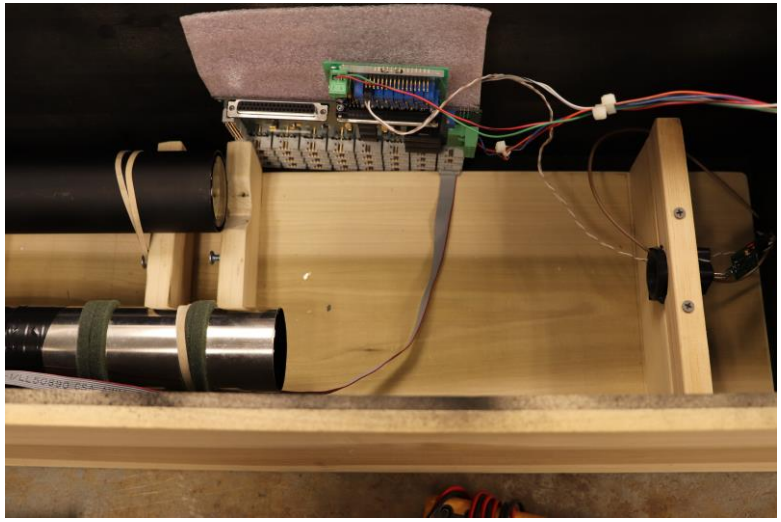
- **What can go wrong?**
  - **Anything (everything?)**
  - **ZDC has been designed and built 20 years ago and it was intended for much lower luminosities for much shorter time**
  - **Current issues:**
    - **PMTs: vacuum, magnetic field protection, radiation damage, connectors (HV, LV)**
      - **Slowly rising required operating voltage – reaching/at maximum**
    - **PMMA fibers: mostly radiation damage – loss of transparency – lower light gain**
      - **Would require new ZDC from scratch**
  - **Potential issues**
    - **Cables: cables going from/to ZDC to/from STAR, optical ling from ZDC electronic to RHIC**
    - **Electronics: replacement?**

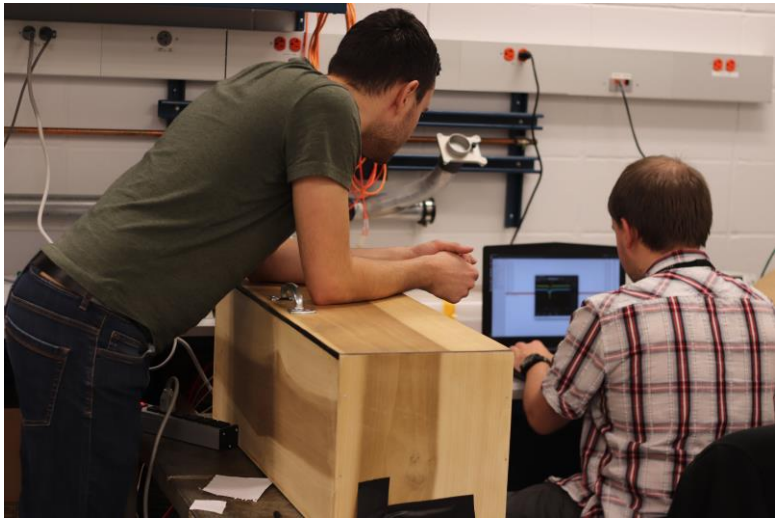
HOW TO REPLACE ZDC PMTs?

- **Get a new/used replacement PMTs**
  - **New – ideal but quite expensive and have to match specification**
  - **Used – free, BNL/STAR has many, many used parts, but usually are old**
- **About 100 PMTs from BRAHMS is/was available**
  - **In 2018 we decided to use the opportunity to replace bad PMTs in ZDC**

HOW TO SELECT REPLACEMENT PMTs?

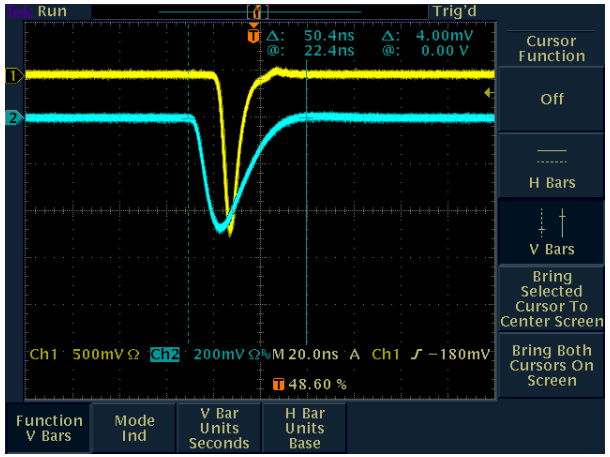
- **Replace just bad PMTs?**
  - **Find the same type and compare performance**
- **Replace all 6 PMTs with a different type?**
- **Check of performance**
  - **Signal pulse height vs. light**
    - **Gain and its linearity**
  - **Pulse rise time**
  - **After-pulsing**





HOW DID WE SELECT REPLACEMENT PMTs?

- **Measured gain of all replacement and ZDC PMTs**
- **Selected candidates**
  - **High gain PMTs with reasonably low after-pulsing**



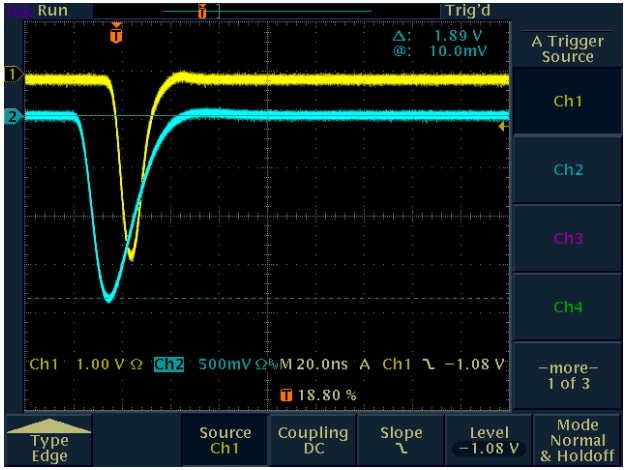
box	type	ID	Pulse height [mV]	Pulse width [ns]	Ref. pulse height [mV]	Ref. pulse width [ns]	Tim diff. between ref. and tested [ns]	Time diff., signal and after peak [ns]	After-pulse height [mV]	note	Supply volage [V]
5		AA935	232	47,8	1360	28	-7,6	274	minor		2500
5	H2431-01	AA1802	132		1440	29,2		274	minor		2500
5		AA2001	336	42,4	1440				no after-peak		2500
5	H2431-01	AA1976	184		1440						2500
5		AA1199	1030	47,6	1530			231	minor?		2500
5		AA1694	212		1530						2500
5		AA1975	424	48,6	1540			232	medium		2500
5		AA1987			1540					bad	2500
9	H2431	AA1988			1540					bad	2500
9	H2431	AA1261	320	50	1460		-10				2500
9	H2431	AA762	156		1460						2500
9	H2431	AA1280	164		1460						2500
12		BB1			1460						2500
12		AA1683	288		1460			236	medium		2500
12		AA884	100		1460						2500
12		AA852	212		1540						2500
12		AA2091	280		1540				0.86 (bad enough)		2500
12		AA1444	228		1590						2500
12	H1161	old ZDC right 2	1150	50	1590		12,4	500			2500
12		BB2	156		1590						2500
12		AA1954	470		1590			224			2500
12		BB3	156		1590						2500
12		AA1805	276		1640						2500
6		AA1353	240		1640						2500
6		AA1078	144		1640						2500
6		AA1031	84		1640						2500
6		AA1150	148		1640						2500
6		AA1327	356		1640				medium-large		2500
6		AA1482	264		1640				large		2500
6		AA1139	176		1640				medium		2500
6		AA1115	272		1640				large		2500
6		AA879	280		1640				medium-large		2500
6		AA1269	236		1640				medium-large		2500
6		AA831	104		1640						2500
6		AA1073	424		1640				large		2500
6		AA908	120		1640						2500
14		AA2316	196		1550						2500
14		AA2095	124		1550						2500
14	H2431-02	AA1693	108		1550						2500
14		AA2931	164		1550						2500
14		AA2828	408		1550				medium		2500
14		AA2907	216		1550						2500
14		AA2914	300		1550						2500
14		AA2909	740		1550				medium		2500
14		AA1779	132		1550						2500
14		AA1783	348		1550						2500
14		AA819	76		1550						2500
14	H1161	RB2950	770		1550				medium		2500
14	H1161	RB3199	960		1550				small		2500
14	h1161	RB3205	690		1550						2500
14	H1161	RC2198	1280		1550				large		2500
14	H1161	RC1975	1420		1550				large		2500
14	H1161	RC2141	1340		1550			500			2500
14	H1161	RB3111	490		1550						2500
14	H1161	RB3207	680		1550						2500
11	H1161	RB3100	880		1550						2500
11	H1161	RB3256	510		1550						2500
11	H1161	RB2937	1230		1550				large	V-characteristic -> sheet 2	2500
11	H1161	RB4329	1000		1550						2500
11	H1161	RB3304			1550					bad HV connector	2500
11	H1161	RB3306	1210		1550						2500
11	H1161	ZC5021	1740		1550				large		2500
11	H1161	ZC5072	256		1550						2500
11	H1161	ZC4668	470		1550						2500
11	H1161	ZC5451	350		1550						2500
11	H1161	ZC4827	770		1550						2500
11	H1161	RB3156	550		1550						2500
11	H1161	RB3112	470		1550						2500
11	H1161	RB3234	560		1550						2500
11	H1161	RB3140	1010		1550				medium		2500
11	H6410	RC7834	570		1550					bad, no fig	2500
11	H6410	RC7835	580		1550		10		medium	2,4 kV	2400
11	H6410	RC7828	580		1550						2400
11	H6410	RC7832			1550					bad	2400
11	H6410	RC7833	800		1550						2400
11	H6410	RC7836	850		1550						2400
11	H6410	RC7814	248		1550						2400
11	H6410	RC7838			1550					bad data connector	2400
11	H6410	RC7837	980		1550						2400
11	H6410	RC7839			1550					bad	2400
11	H6410	RC7799	800		1550						2400
11	H6410	RC7841			1550					bad	2400
11	H6410	RC7827			1550					bad	2400
	H1161 ?	ZDC old 1	788	49,4	1250	27,4	13,2	642	6,2		2500
	H1161 ?	ZDC old 2	668	50,6	1300	27,4	12,4	556	2,7		2500
		Average	495,6052632								

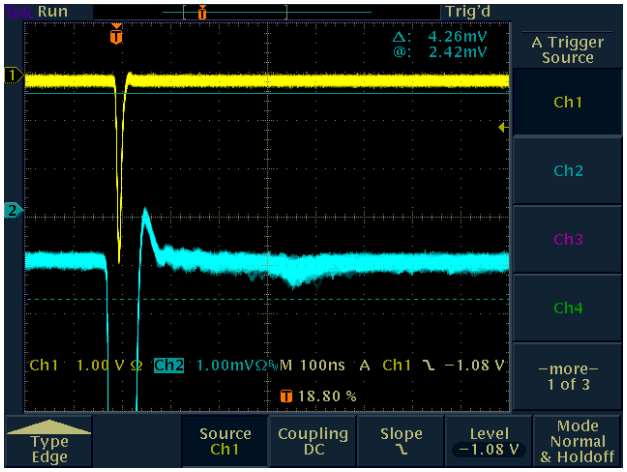
HOW DID WE TEST REPLACEMENT PMTs?

- **After-pulsing and gain linearity test**
- **Variable light input**
  - **Voltage applied to diode**
- **Same applied voltage**
  - **U = 2.6 kV**

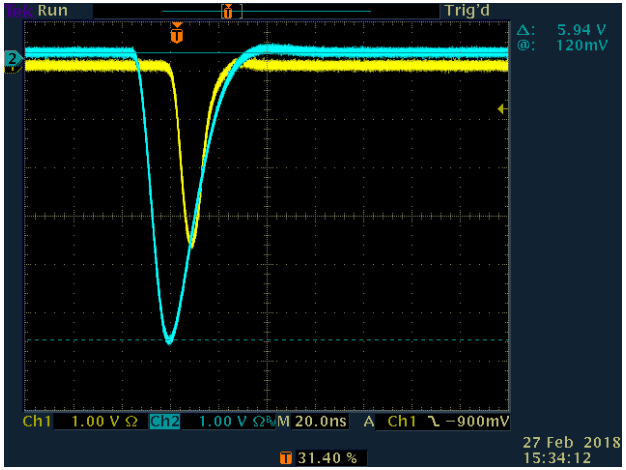
- **Old PMT**
  - **Low after-pulsing**
  - **Low gain**
- **Replacement PMT**
  - **Low after-pulsing**
  - **Good gain**

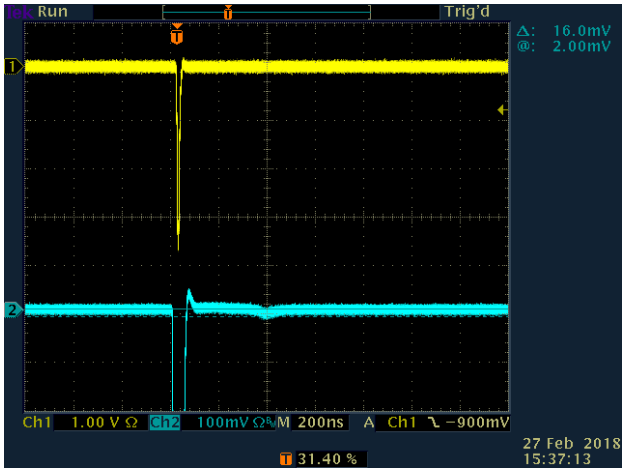
Old ZDC-W 3





Replacement H2431-50





HOW DID WE REPLACE PMTs?

- **Selected 2 replacement PMTs**
- **PMTs in ZDC-E-1 and ZDC-W-1 stayed in place**
  - **Good gain and low after-pulsing**
- **Tower ZDC-E-2 got PMT from ZDC-E-3**
  - **Both ZDC-E-2 and ZDC-E-3 were not good, but only 2 good replacement PMTs were available**
- **Towers ZDC-E-3 and ZDC-W-3 got replacement PMTs**

	N	PMT	Voltage 2016 [V]
Final voltages for run 2018			
East:	1	same	2444
	2	swapped from E3	2633
	3	new AA1783	2329
West:	1	same	2431
	2	same	3072
	3	new H2431-50	2101

THANK YOU FOR ATTENTION

BACKUP

TOF MATCHING EFFICIENCY

- **Pion TOF matching efficiency for Run16 Au+Au@200GeV**