The Muon Telescope Detector

W.J. Llope, Rice University

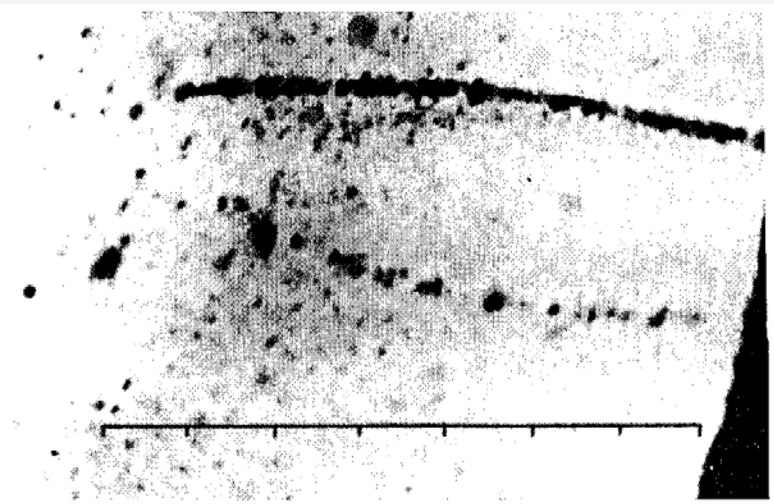
Outline:

- A (brief) physics introduction
- Prototype systems
- Mechanical aspects of final detectors
- Final detectors in Run-11
- Full System design & installation
- Run-12 installation and early results
- Project timeline

Wikipedia: "Muons were discovered by Carl D. Anderson & Seth Neddermeyer at Caltech in 1936"

"Who ordered that?!?" – I.I. Rabi in 1937

Actually seems to have been first observed in a cloud chamber in Rostock Germany in 1933!



"The other double trace of the same type (figure 5) shows closely together the thin trace of an electron of 37 MeV, and a much more strongly ionizing positive particle whith a much larger bending radius. The nature of this particle is unknown; for a proton it does not ionize enough and for a positive electron the ionization is too strong. The present double trace is probably a segment from a "shower" of particles as they have been observed by Blackett and Occhialini, i.e. the result of a nuclear explosion".

Kunze, P., Z. Phys. 83, (1933) 1

STAR-MTD "Basic Idea"

With a large area muon detector at mid-rapidity…

Physics:

- di-muon pairs from QGP thermal radiation, quarkonia, light vector mesons, resonances in QGP, and Drell-Yan production
  excellent mass resolution would separate different upsilon states

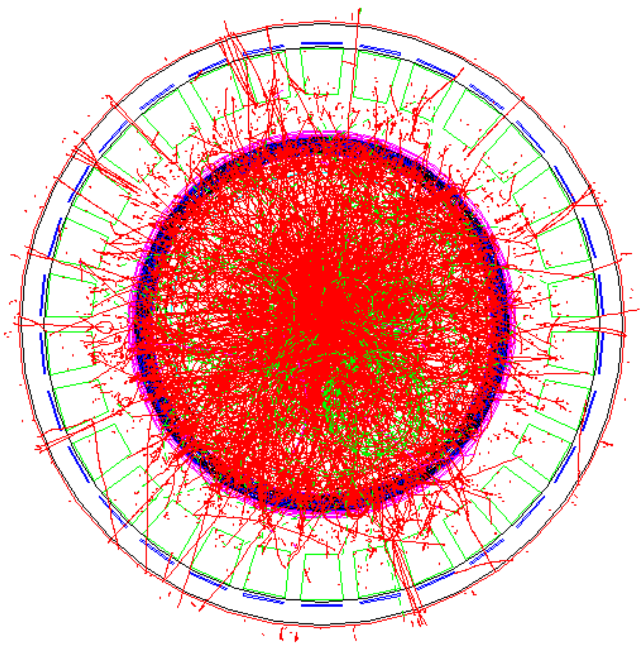
- single muons from the semi-leptonic decays of heavy flavor hadrons… e+muon correlation to distinguish heavy flavor production from initial lepton pair production

- advantages over electrons:
  - no γ conversion
  - much less Dalitz decay contribution
  - less affected by radiative losses in the detector materials

How could this be achieved?

- Hadron shielding is magnet backlegs and BEMC (~$7X_0$)
- Precise timing! start from upVPD, fast TOF hit + fast MTD hit, TPC + HFT matching
- Low-level trigger capability for low to high p_T J/ψ in central Au+Au collisions

Conceptual Design of the STAR-MTD

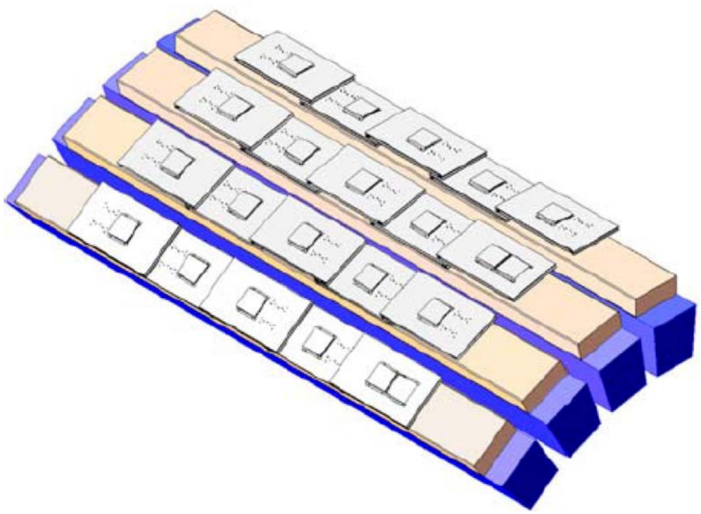


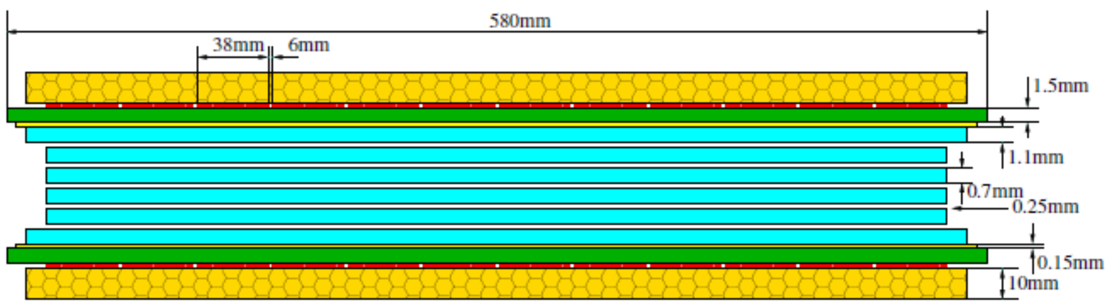
Multi-gap Resistive Plate Chamber (MRPC):
- gas detector, avalanche mode
- Inexpensive, eay to build, but precise timing

The detectors cover the steel magnet backlegs and leave the φ-gaps uncovered.
- Acceptance: ~45% at $|\eta|<0.5$

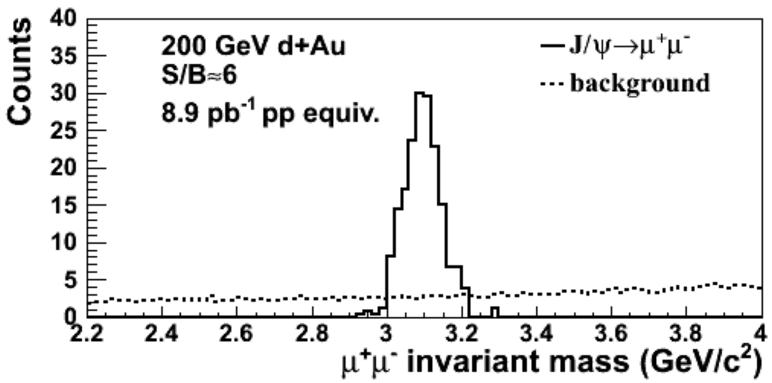
118 modules, 1416 readout strips, 2832 channels

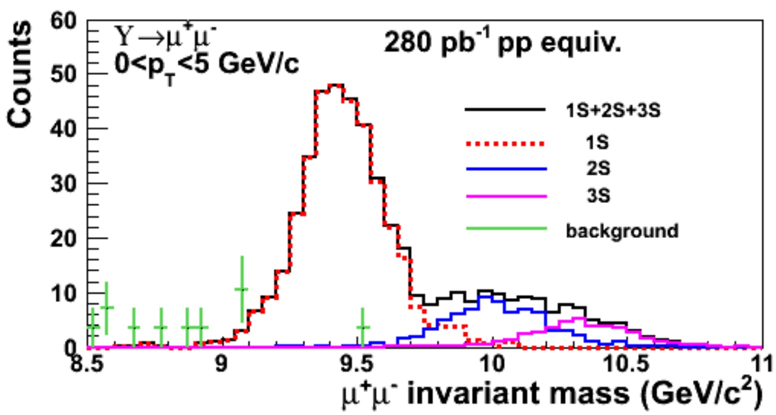
Proven detector technologies
- MRPC detectors & STAR-TOF electronics





High Mass Di-muon Capabilities





1. J/ψ: S/B=6 in d+Au and S/B=2 in central Au+Au
2. With HFT, study B→J/ψ+X; J/ψ→μμ using displaced vertices
3. Excellent mass resolution: separate different upsilon states

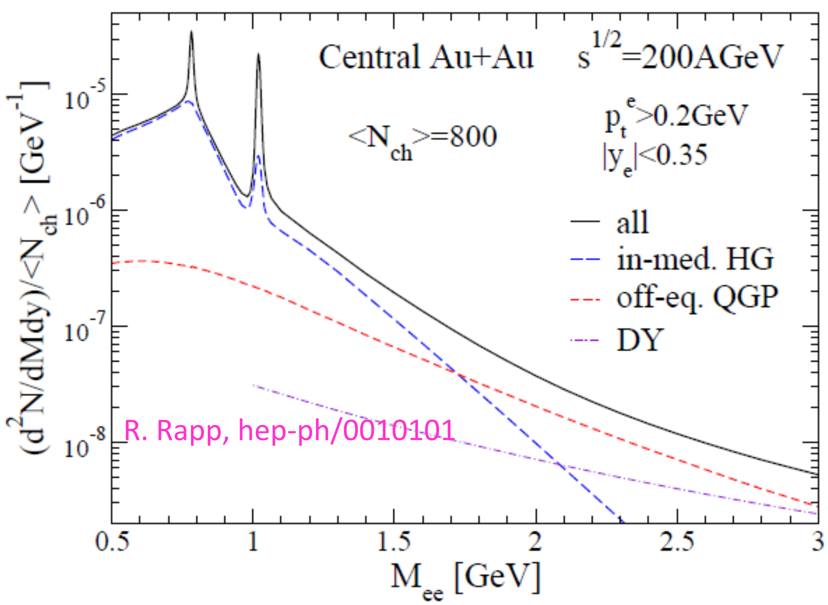
Heavy flavor collectivity and color screening, quarkonia production mechanisms:
J/ψ R_{AA} and v_2; upsilon R_{AA} …

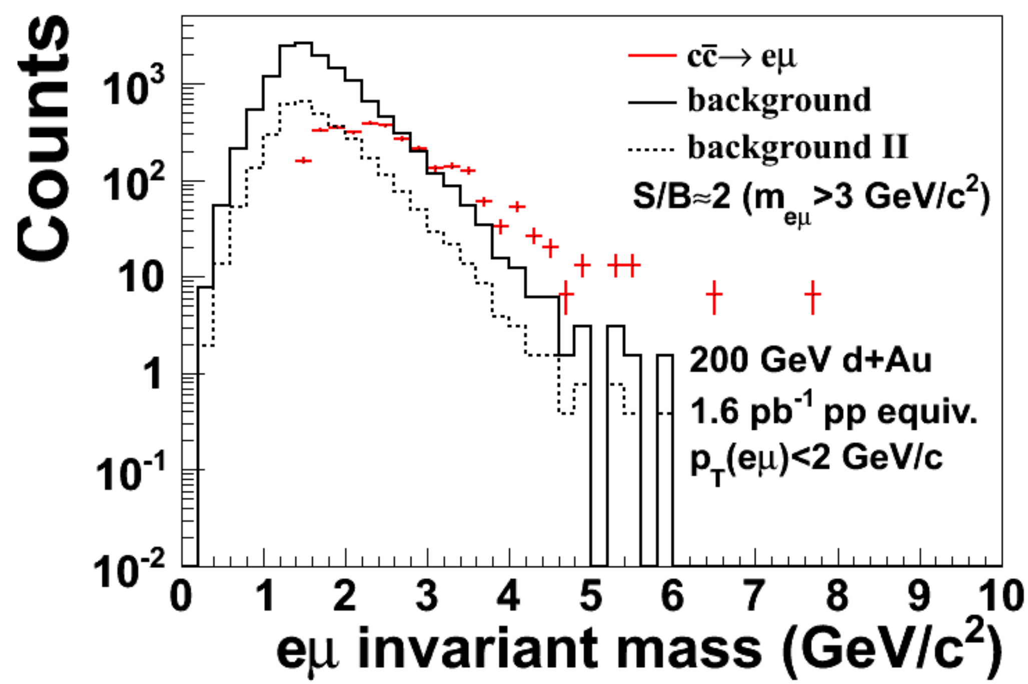
Z. Xu, BNL LDRD 07-007; L. Ruan et al., Journal of Physics G: Nucl. Part. Phys. 36 (2009) 095001

Quarkonium dissociation temperatures – Digal, Karsch, Satz

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

Distinguish Heavy Flavor and Initial Lepton Pair Production: e-muon Correlation





eμ correlation simulation with Muon Telescope Detector at STAR from ccbar:

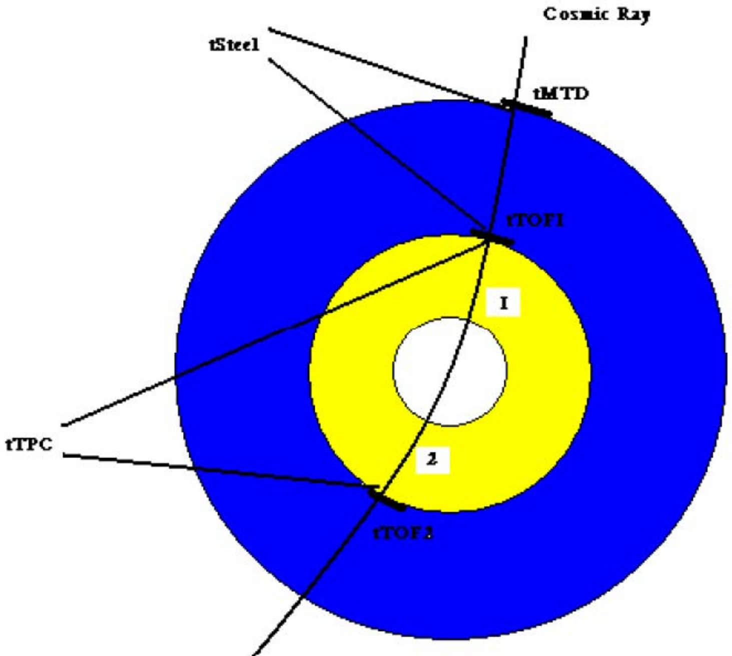
- S/B=2 (M_{eu}>3 GeV/c2 and $p_T(e\mu)$<2 GeV/c)
- S/B=8 with electron pairing and tof association

The Details for the R&D Modules

Conditions	Modules and readout
Cosmic ray and Fermi-lab T963 beam tests	**double stacks,** **module size:** 87(z)×17(ϕ) cm^2, Performance: 60 ps, ~0.6 cm at HV ± 6.3 kV
Run 7: Au+Au **Run 8: p+p, d+Au**	**double stacks, 2 modules in a tray,** **module size:** 87(z)×17(ϕ) cm^2, Readout: trigger electronics, Time resolution: 300 ps
Run 9: p+p **Run 10: Au+Au, cosmic ray**	**double stacks, 3 modules in a tray,** **module size:** 87(z)×17(ϕ) cm^2, Readout: TOF electronics; trigger electronics for trigger purpose.
Run 11	**single stack, 1 module in a tray, module size:** 87(z)×52(ϕ) cm^2, Readout: TOF electronics; trigger electronics for trigger purpose, Cosmic ray test performance: <100 ps

R&D from 2007 to 2011 led to a final design.

Run 10 Performance: Time and Spatial Resolution



Cosmic ray trigger

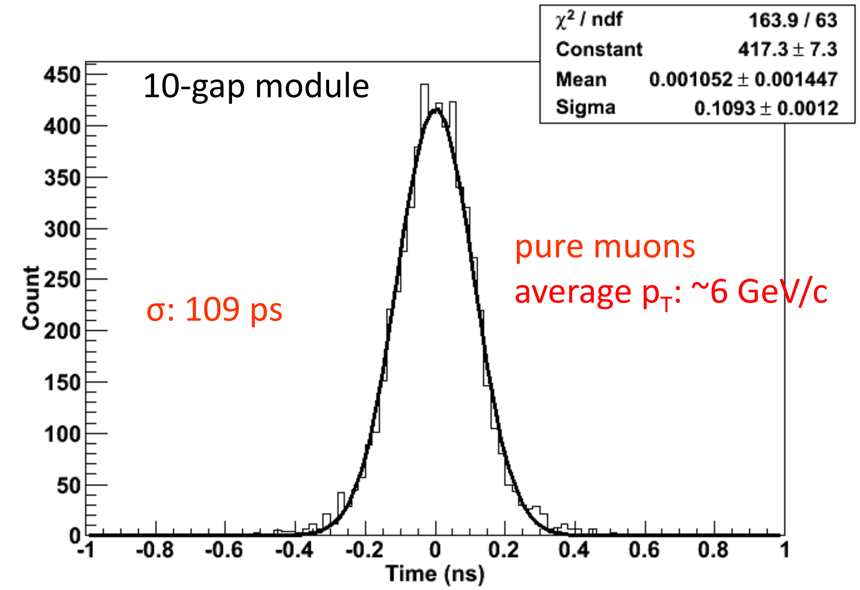
Total resolution: 109 ps

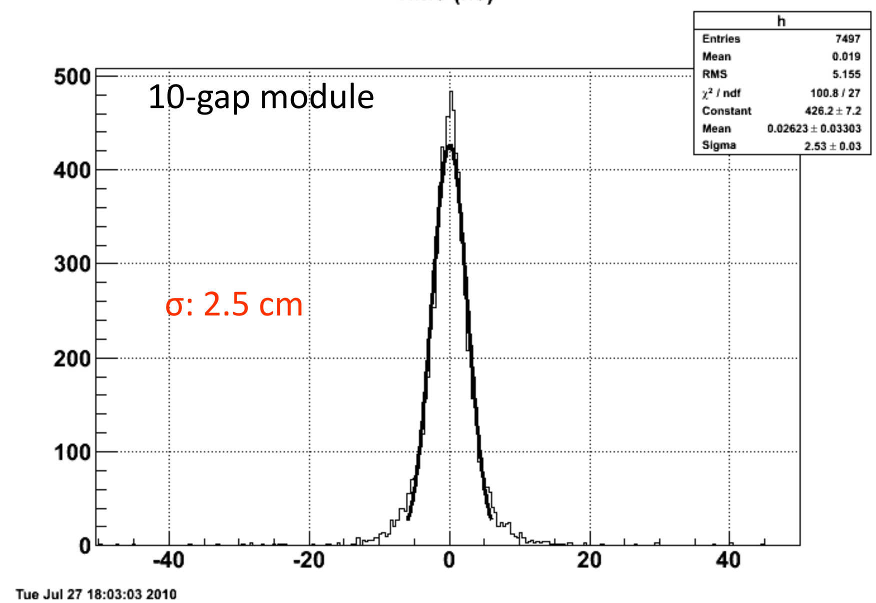
Start resolution (2 TOF hits): 46 ps

Multiple scattering: 25 ps

MTD intrinsic resolution: 96 ps

System spatial resolution: 2.5 cm, dominated by multiple scattering





Mechanical Design, Fabrication, and Installation

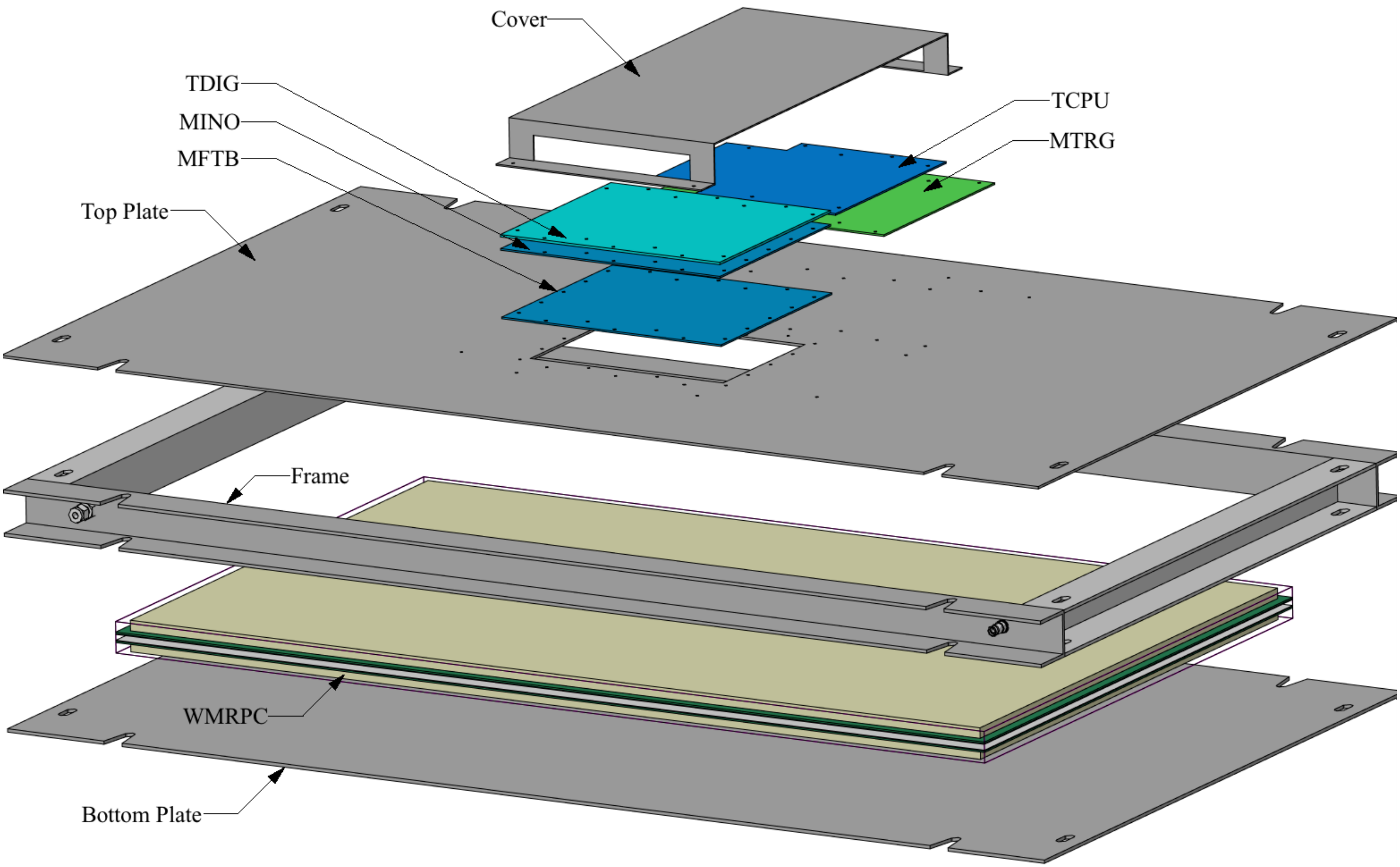
System	MRPCs	"Tray" Design	Electronics	Installation
STAR TOF	excellent	complicated	new & complicated	simple
STAR MTD	excellent	simple	commodity	complicated

Outline:

- MTD "tray" mechanical design
- MTD11 prototype assembly
- MTD11 testing
- MTD9 and MTD11 in STAR
- Run-12 installation
- Full System design and installation

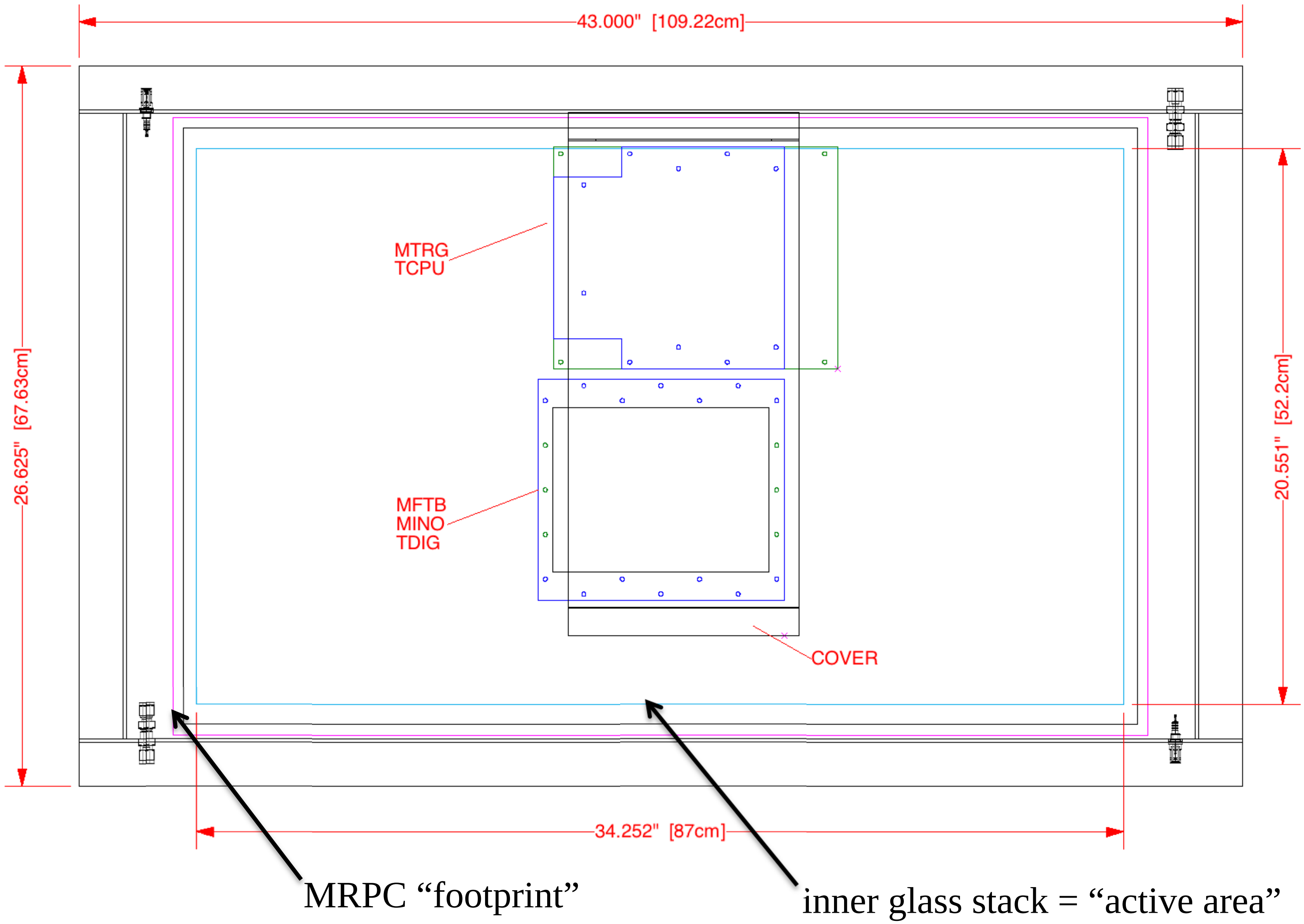
"MTD9" is the older run-9/10 prototype
"MTD11" are new prototypes for run-11

MTD11 Tray Design (Exploded View)



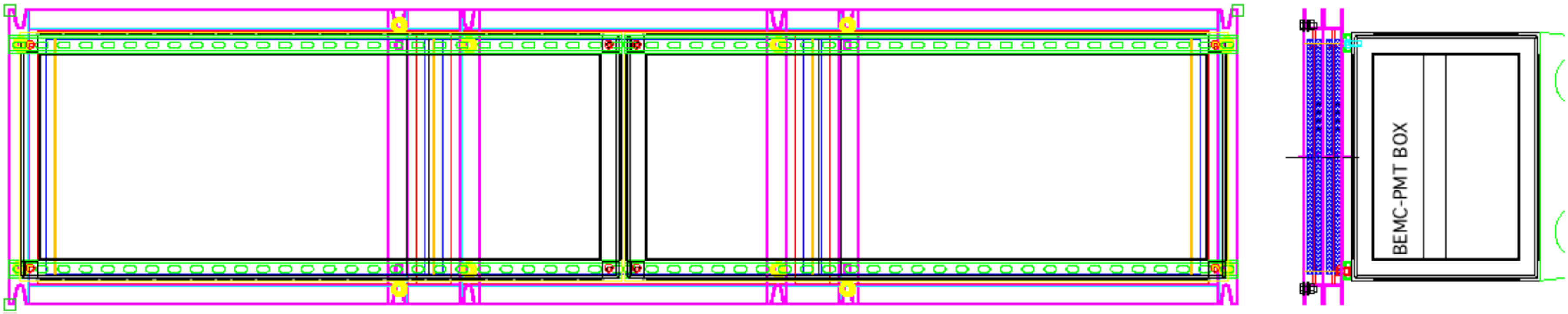
The MTD11 tray design is “final” for the full system

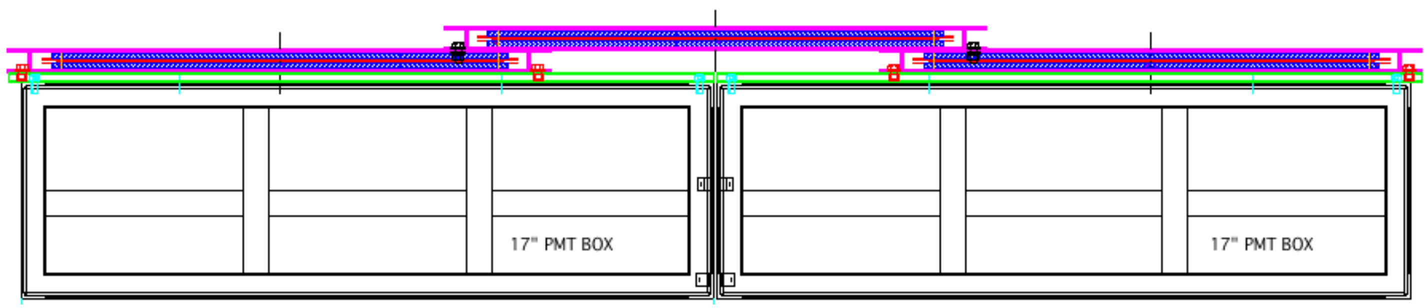
MTD11 Tray Design (Top View)



Initial Design for MTD11 Stacking in STAR

The three MTD11 Trays mount directly onto BEMC PMT boxes
The Trays overlap so that the MRPC active regions meet end-to-end in “Z”



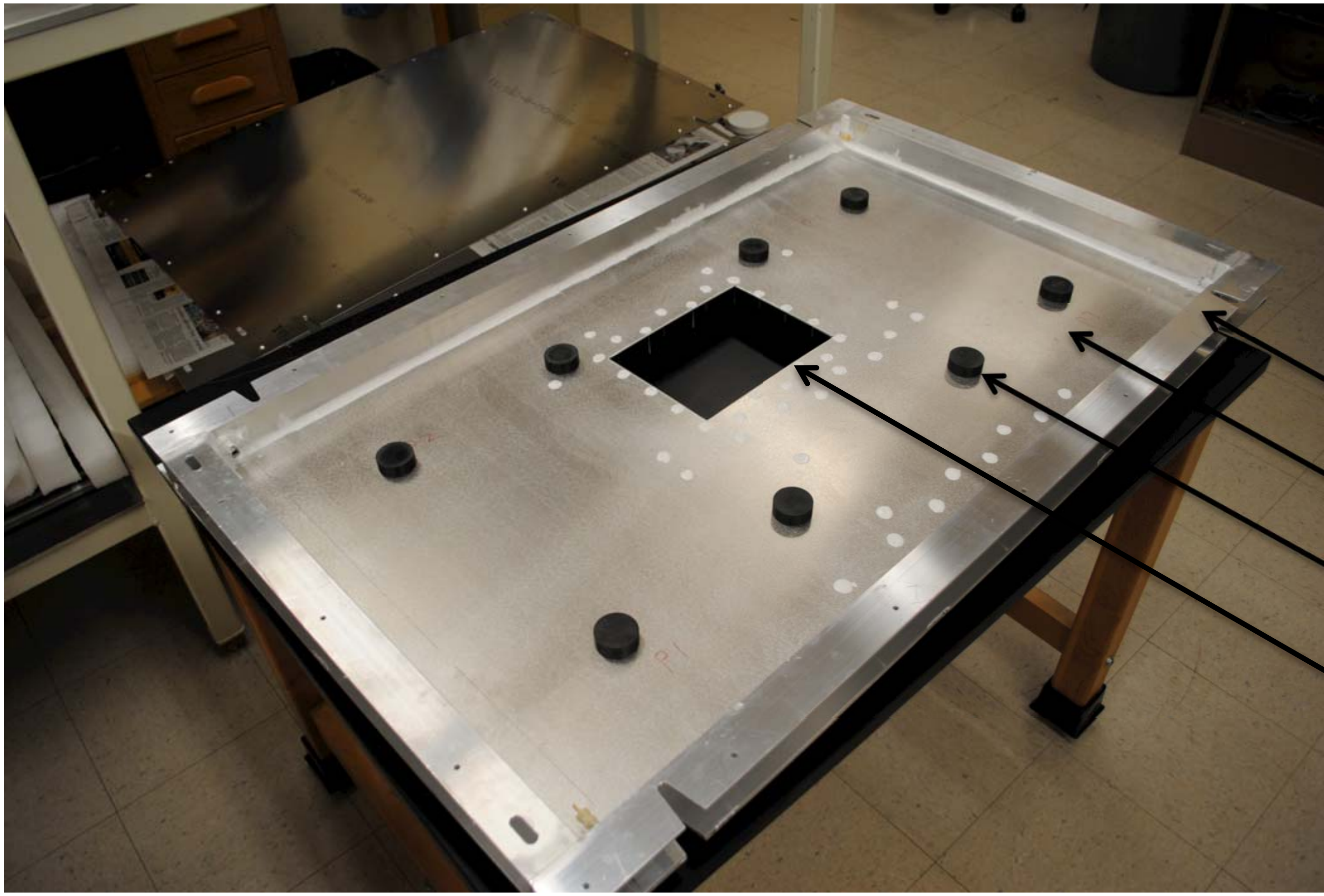


lower row of trays bolt to unistrut on the BEMC PMT boxes
upper row of trays bolt to the lower row of trays

this won’t work for the full system – more on this later in this talk…

MTD11 Tray Assembly

Tray "top" (holds electronics) is complicated… Fabricated at Oaks Precision in Houston
Delivered to UT-Austin in the back seat of my car



Top and frame (upside down)

frame

underside of top

upper spacer

"big hole" (covered by MFTB)

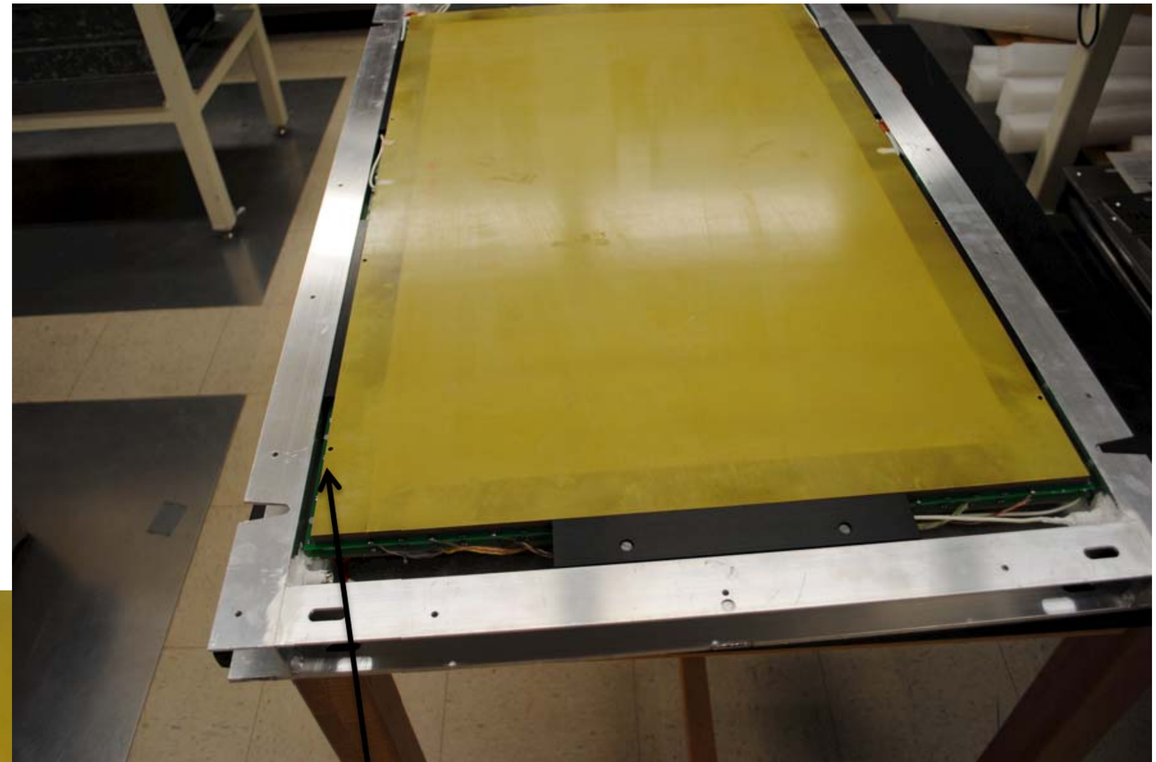
top tack-welded to (welded) frame, sealed with DC730 freon-resistant sealant
bottom bolts to frame in countersunk holes, also sealed with DC730

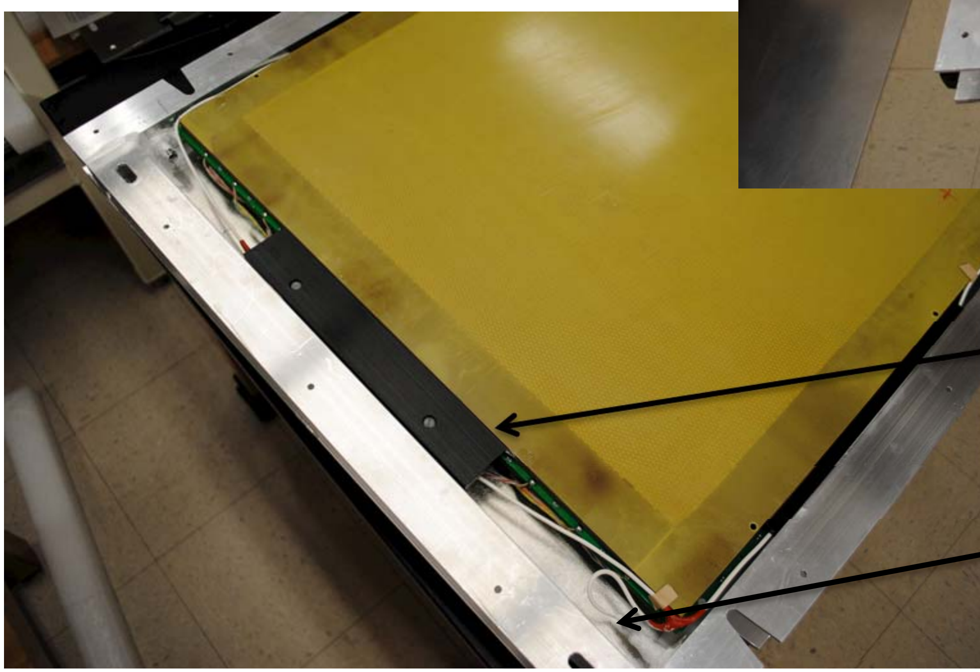
MTD11 Tray Assembly

MRPCs inside the tray…

bottom of MRPC is flush with the bottom of the tray

correct upper spacer thickness is thus important!

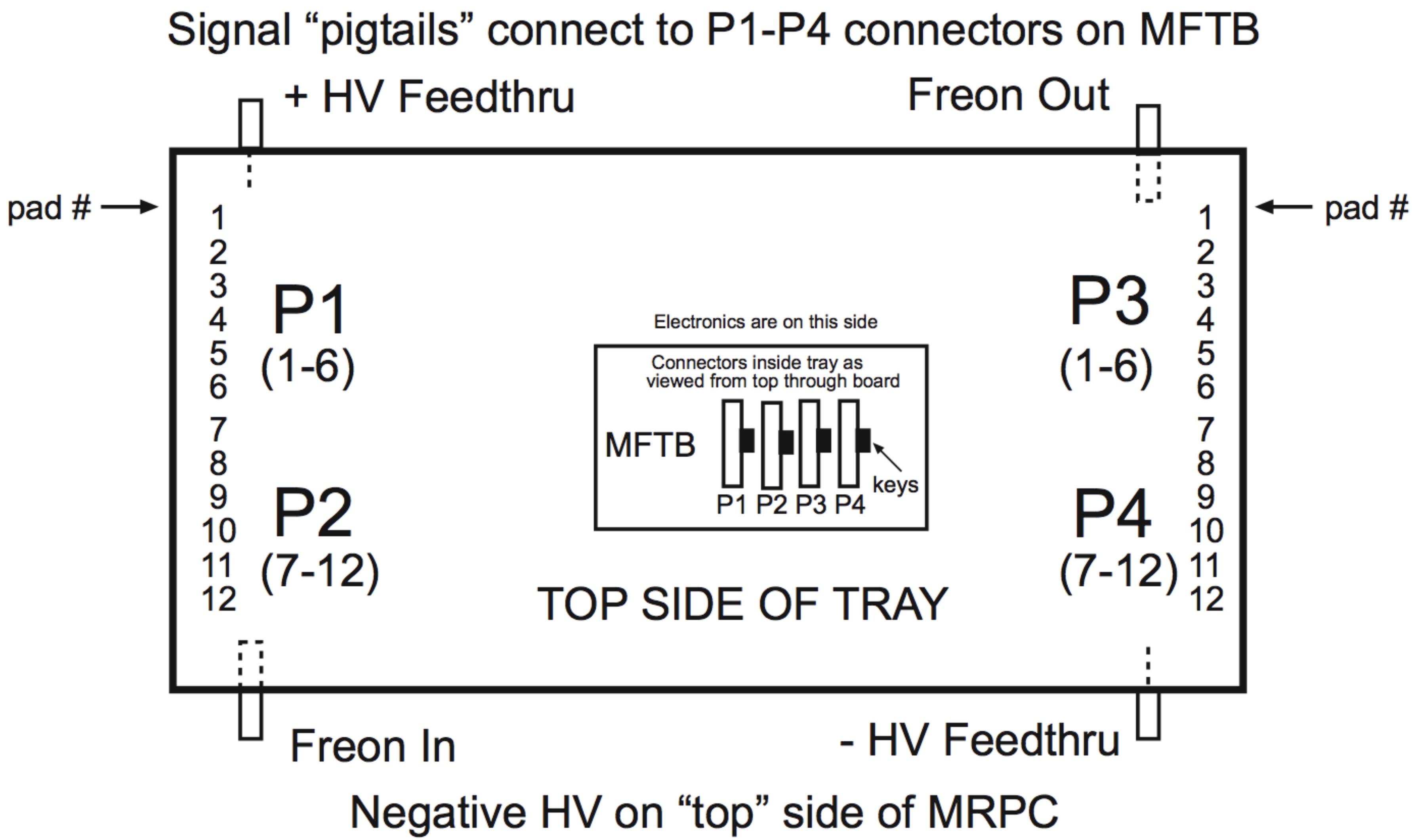




side spacers hold MRPC laterally w.r.t. the frame…

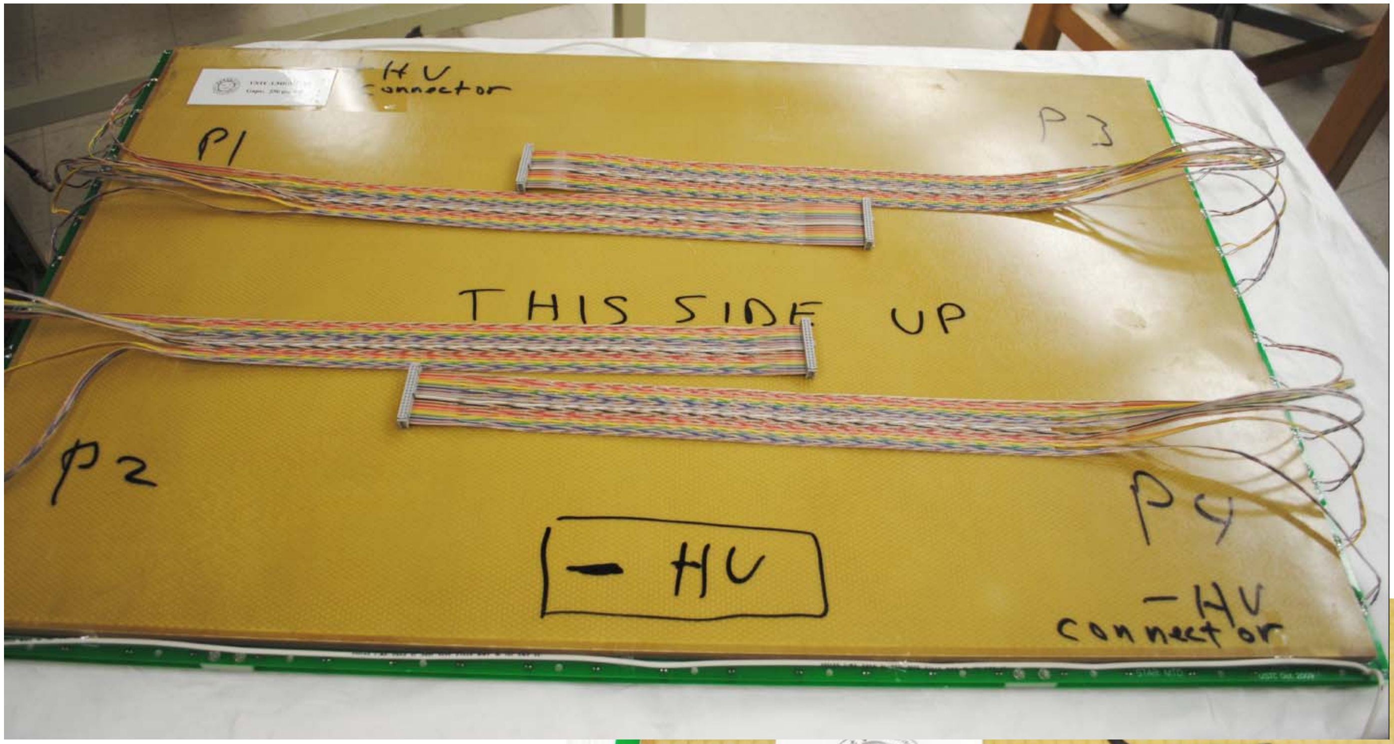
HV wiring connected to bulkhead connector

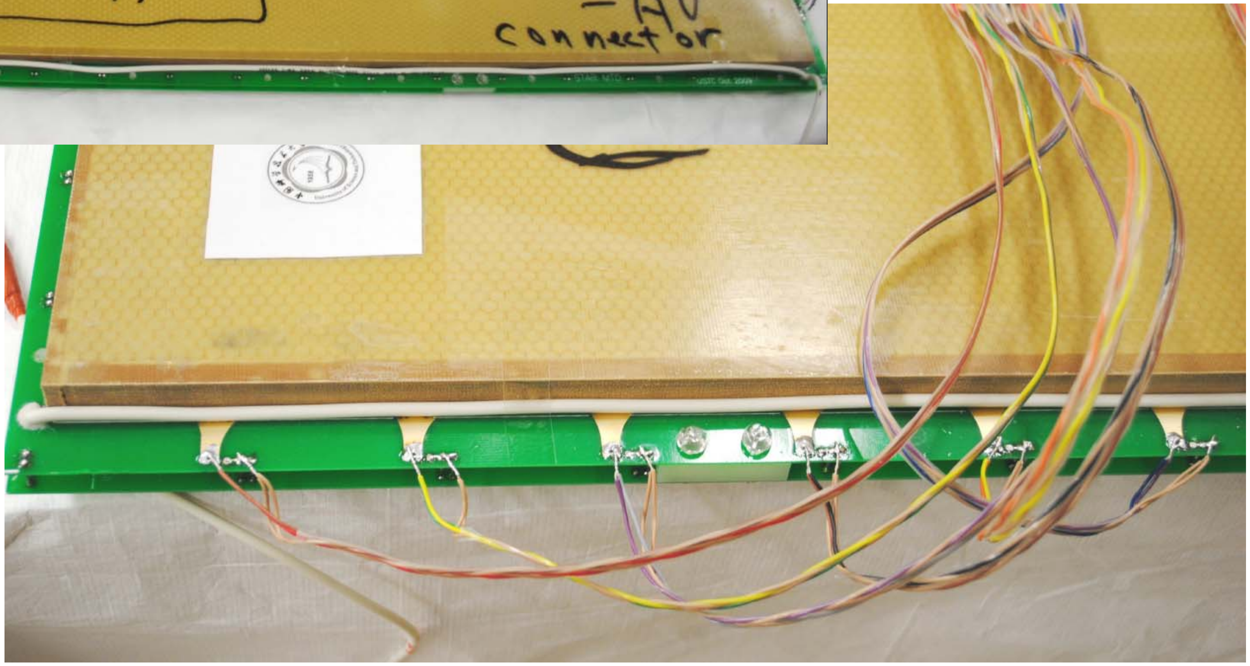
MTD11 Tray Assembly (Connections Schematic)



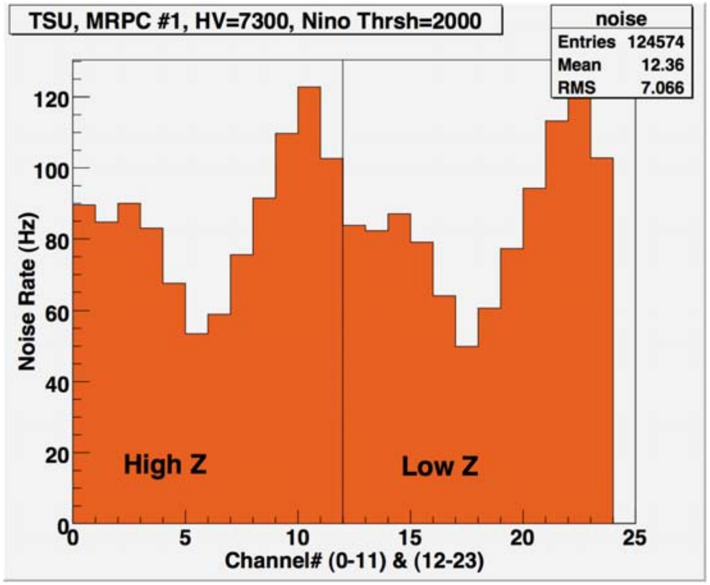
UT will make the signal pigtails and ship them to China/India…

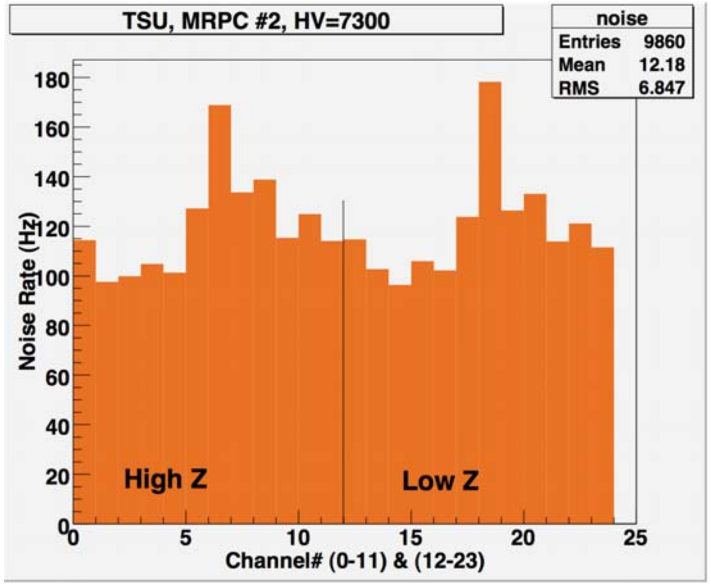
MTD11 Tray Assembly

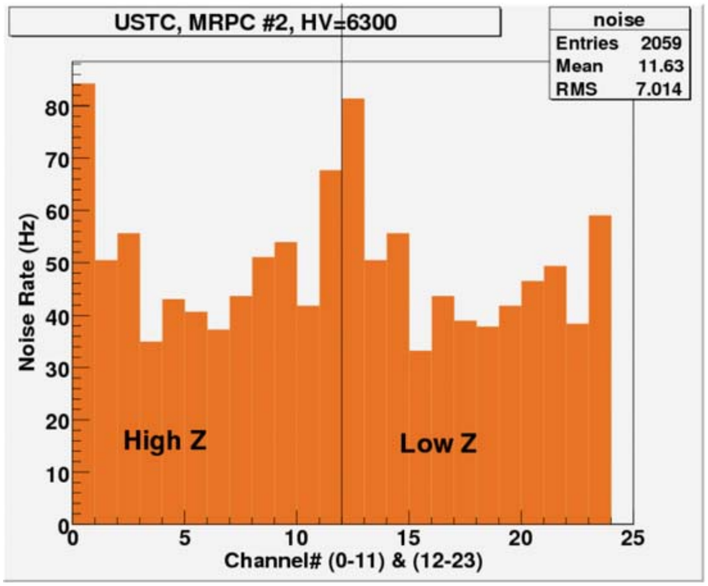




MTD11 Test Results at UT-Austin – Hit patterns





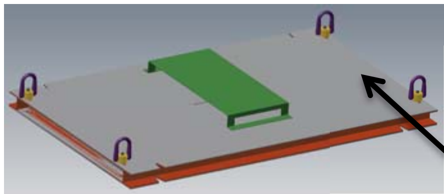


Untriggered cosmics
freon-only
6×250μm gaps: HV = ±7300V
5×250μm gaps: HV = ±6300V
Read-out via full chain of final electronics

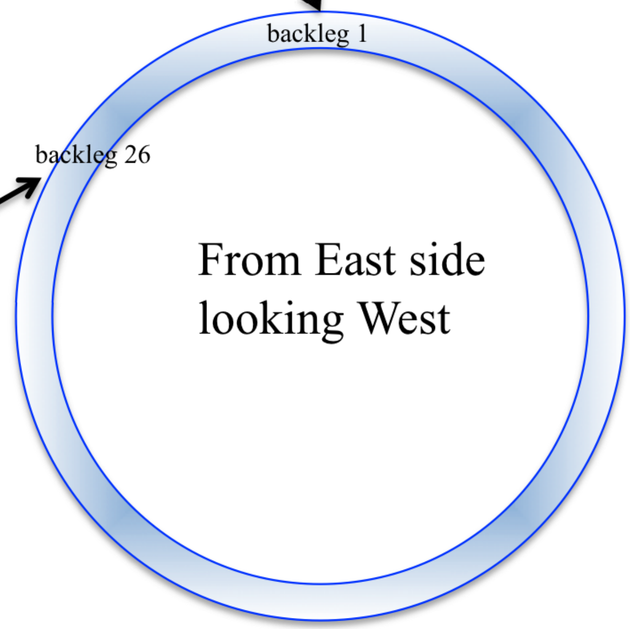
➔ reasonable noise rates…
(strip area = 331 cm^2, so <0.5 Hz/cm^2)
➔ no dead channels…

MTD9 and MTD11 Trays at BNL, December 2010

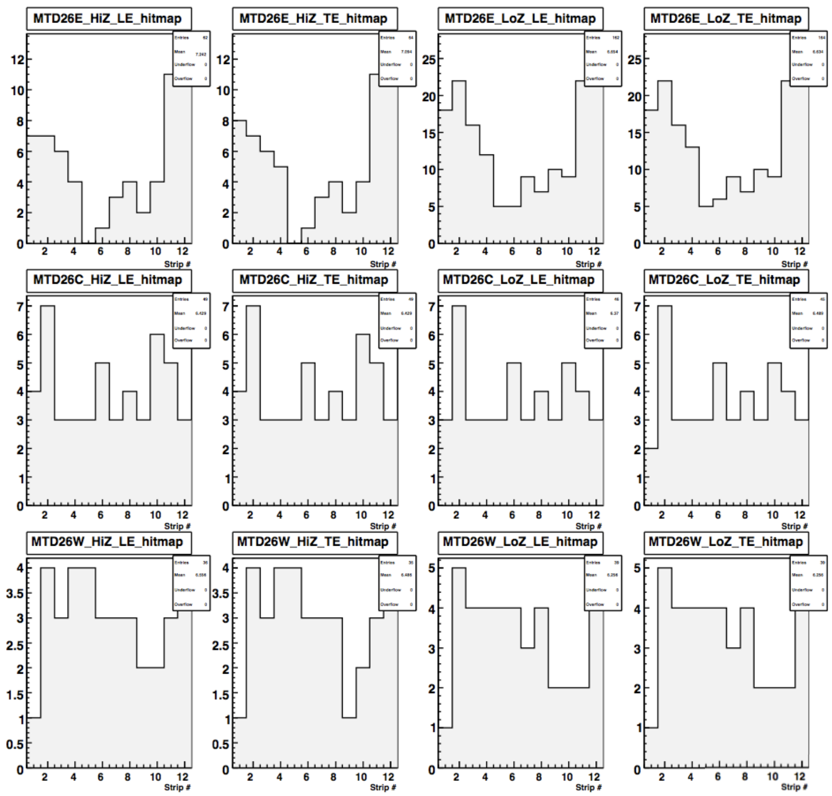
MTD9 & MTD THUB



Three MTD11 trays (craned into place)



Run 11 Online hit patterns (untriggered) and HV information



online hit patterns look reasonable

(3 MTD11 trays × 2 strip ends × 2 signal edges)

low rate per 1M events because

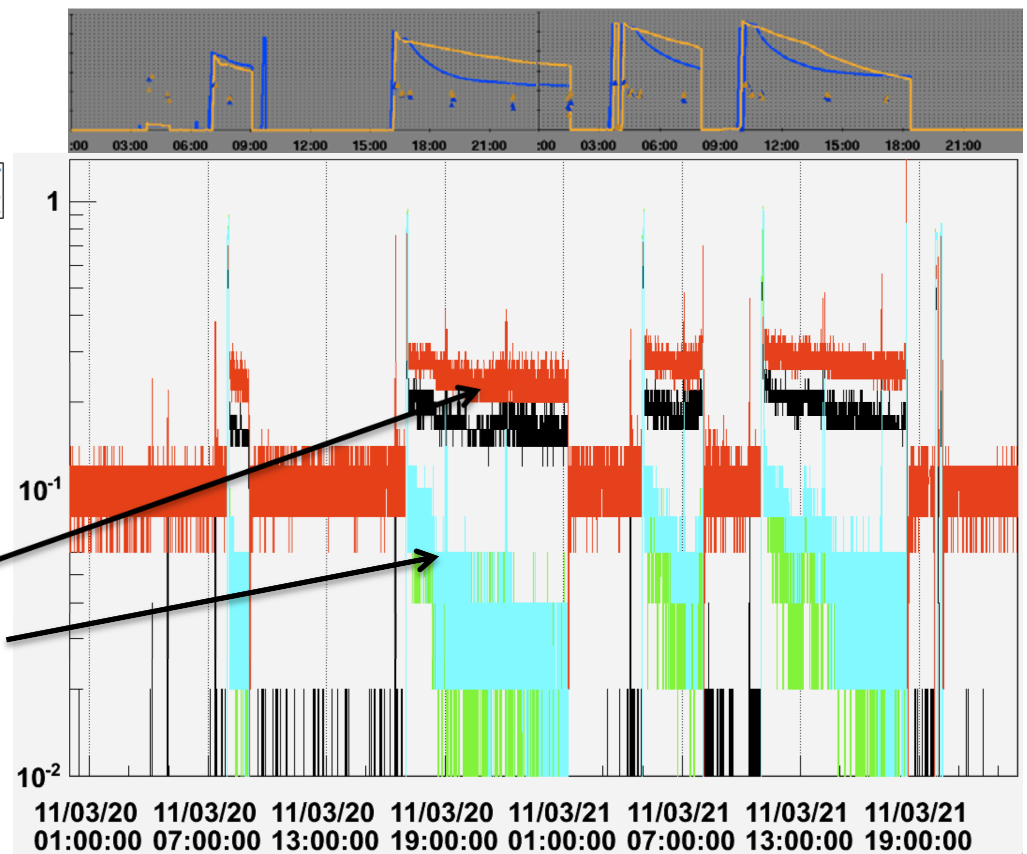
- this is p+p… ($\sqrt{s_{NN}}$ = 500 GeV)
- MTD11 trigger available late in the run

data analysis still underway

HV monitoring

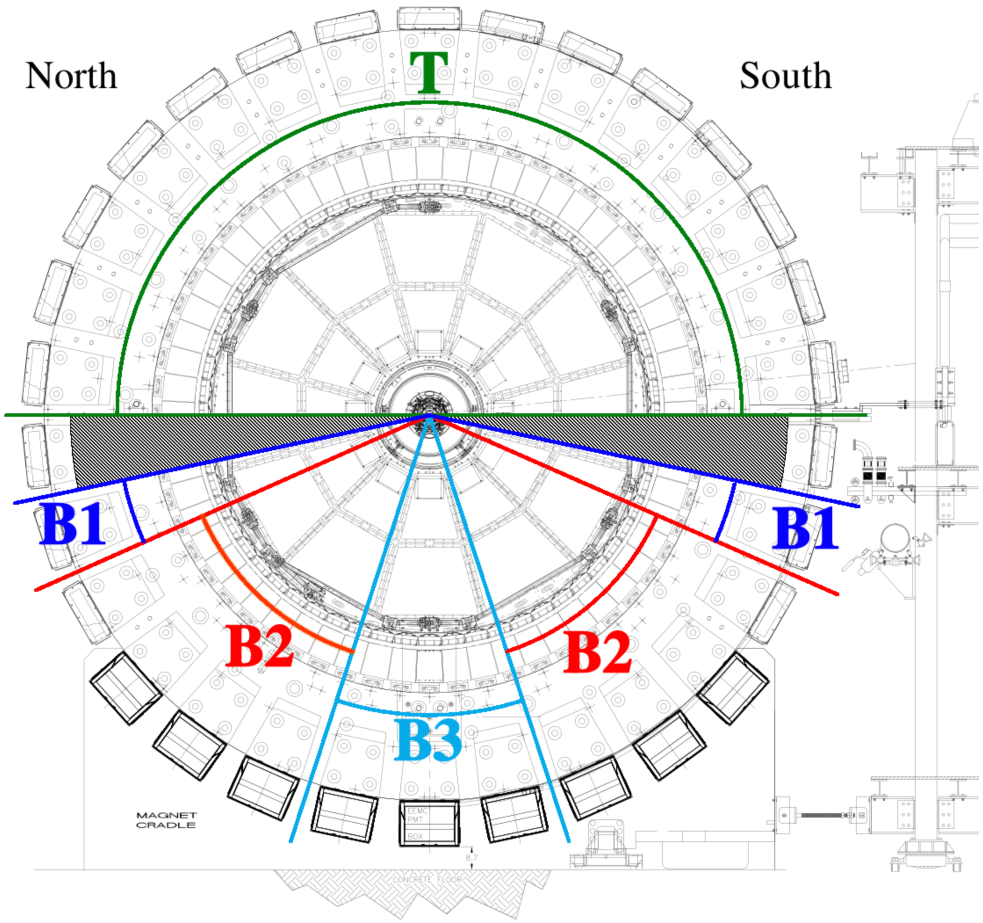
line 1: 6×250 μm gap MTD11 trays, ±7200V

line 2: 5×250 μm gap MTD11 tray+MTD9, ±6200V

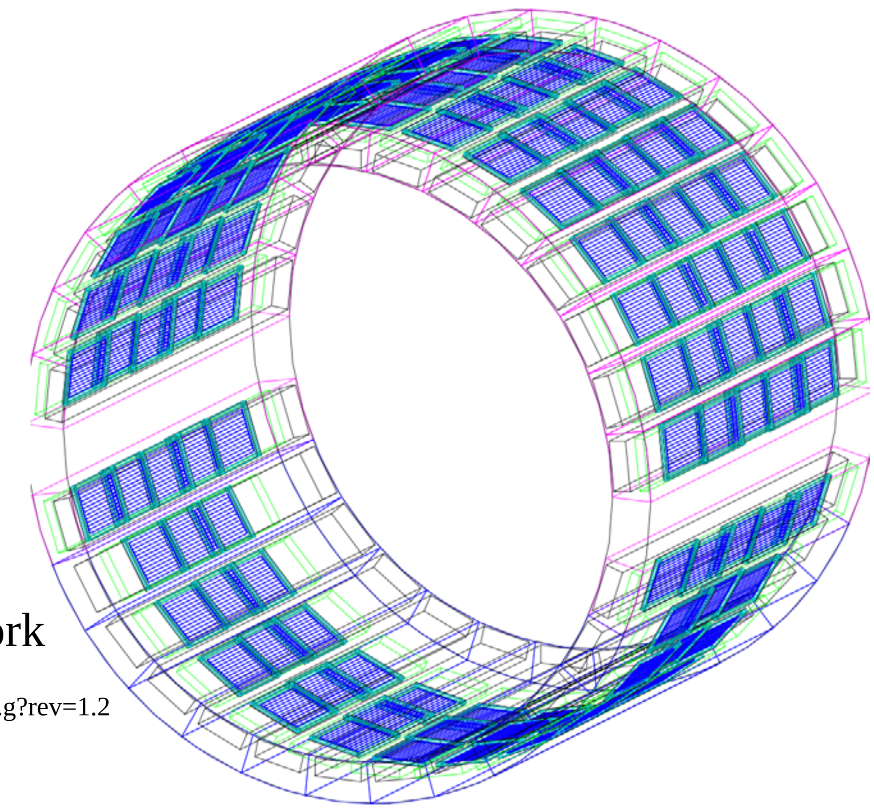


Geometry of the Full System

also see http://wjllope.rice.edu/~MTD/MTDintegration.pdf



15 “5-packs” over the top
2 “5-packs” just under equator
11 “3-packs” below
…**118 MTD trays total**
…N/S & E/W symmetric



implemented in STAR geant simulations framework

http://www.star.bnl.gov/cgi-bin/protected/cvsweb.cgi/pams/geometry/mutdgeo/mutdgeo4.g?rev=1.2

Full System Installation Scheme

The mounting scheme for the MTD full system trays is actually a difficult problem!

MTD trays must mount on top of BEMC PMT boxes…

access to these some number of these boxes is needed during every shutdown to repair BEMC channels
typically this work is done by laying down on neighboring PMT boxes
this implies that 2-3 backlegs of MTD trays would need to be removed to access a single BEMC box!

Scheme used in Run-11 worked, and was the simplest possible for us,
but it would be a nightmare for a full system…

tray positioning is a little too sloppy because of imprecise positioning of unistrut nuts
difficult to install the upper layer of trays onto lower layer of trays…
too much work for STSG (Bob Soja and his expert technicians) to remove/reinstall MTD trays
too much cabling (dis)connecting & stresses on MTD modules – increased failures & gas leaks?

There is another problem too - how do *we* get access to a random tray on top of STAR?

one cannot simply walk on the MTD layer like one can walk on the PMT boxes
how do we replace a cable or sniff for gas leaks on a random tray when everything is installed?!?

And yet another problem are obstructions hanging from the boxes below STAR…

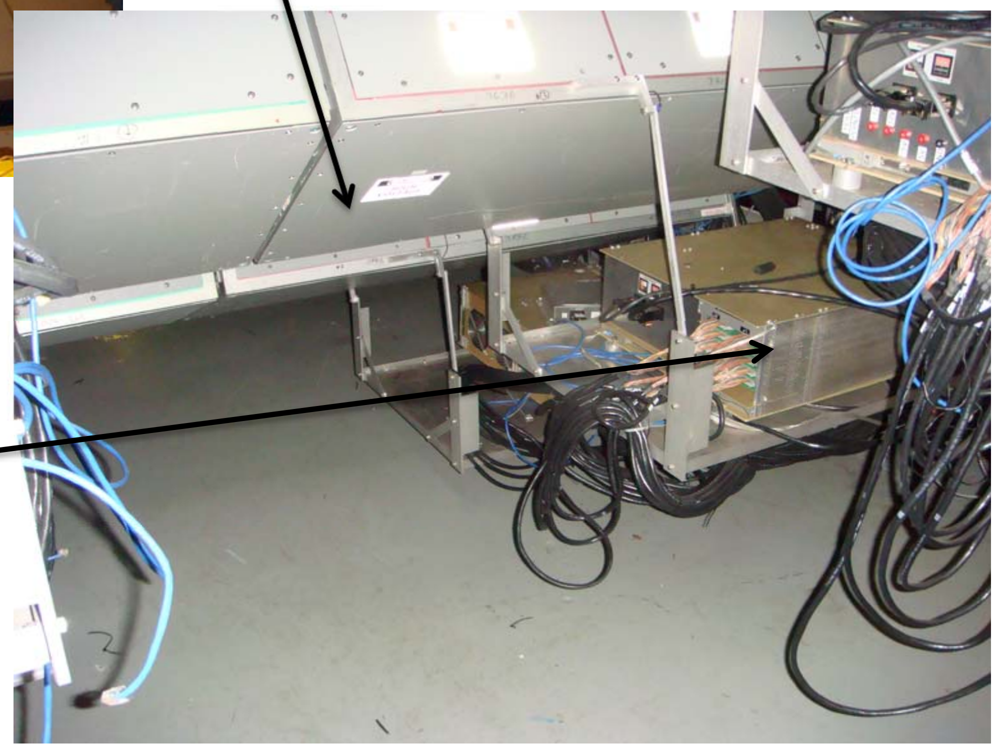
This is clearly going to be the hardest part of the total system design….

Full System Installation Scheme

above STAR

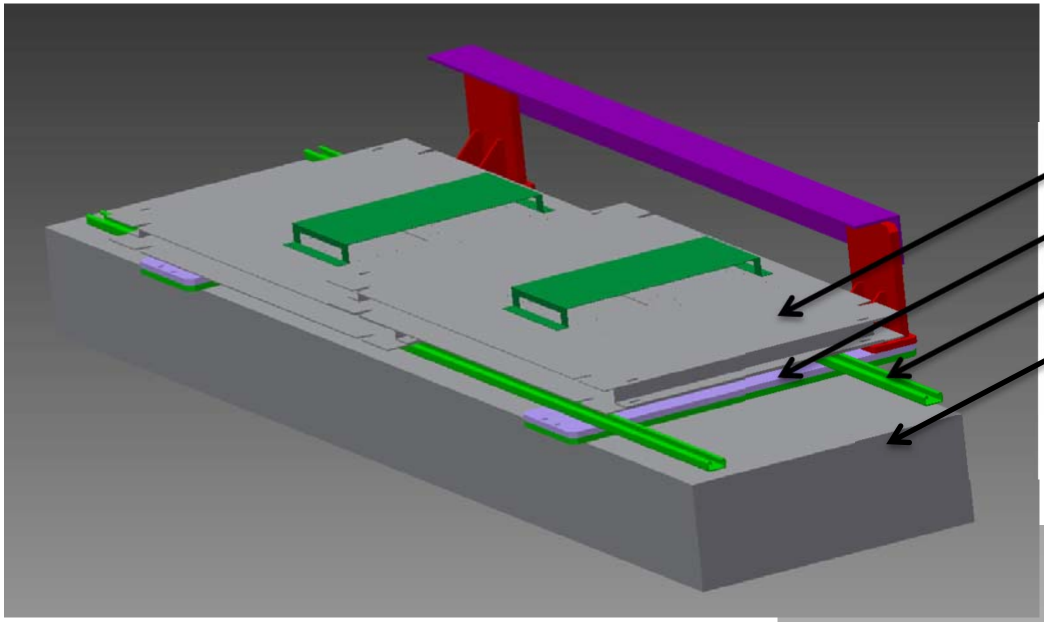
BEMC PMT boxes

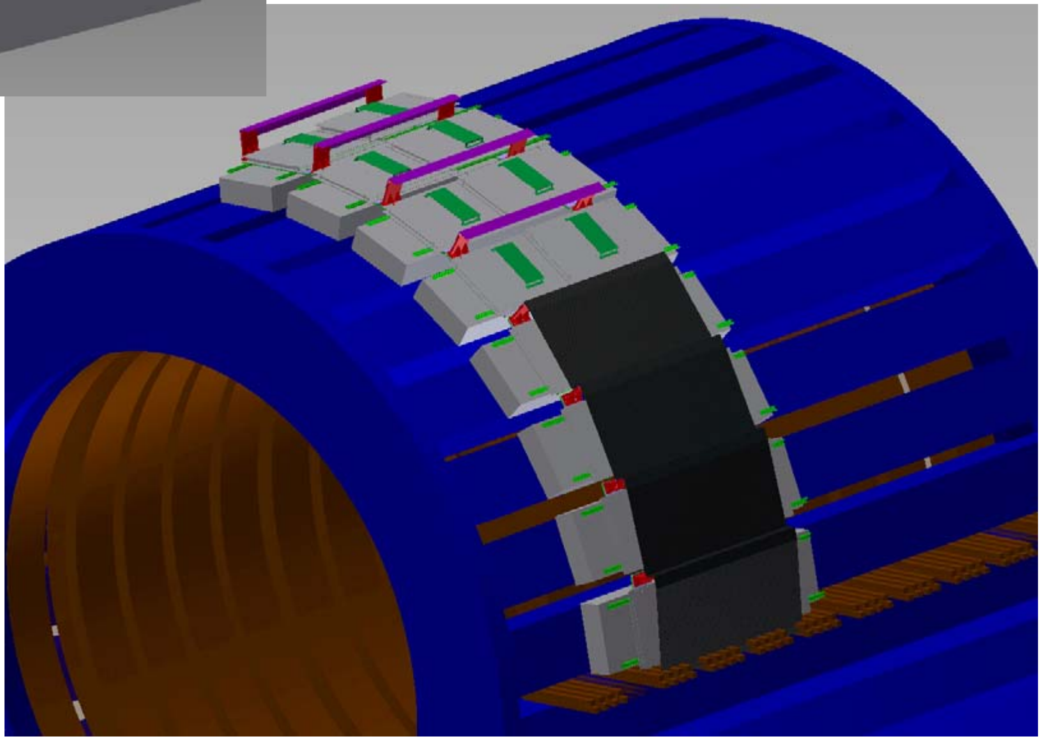
below STAR



BEMC crates

Full System Installation Scheme

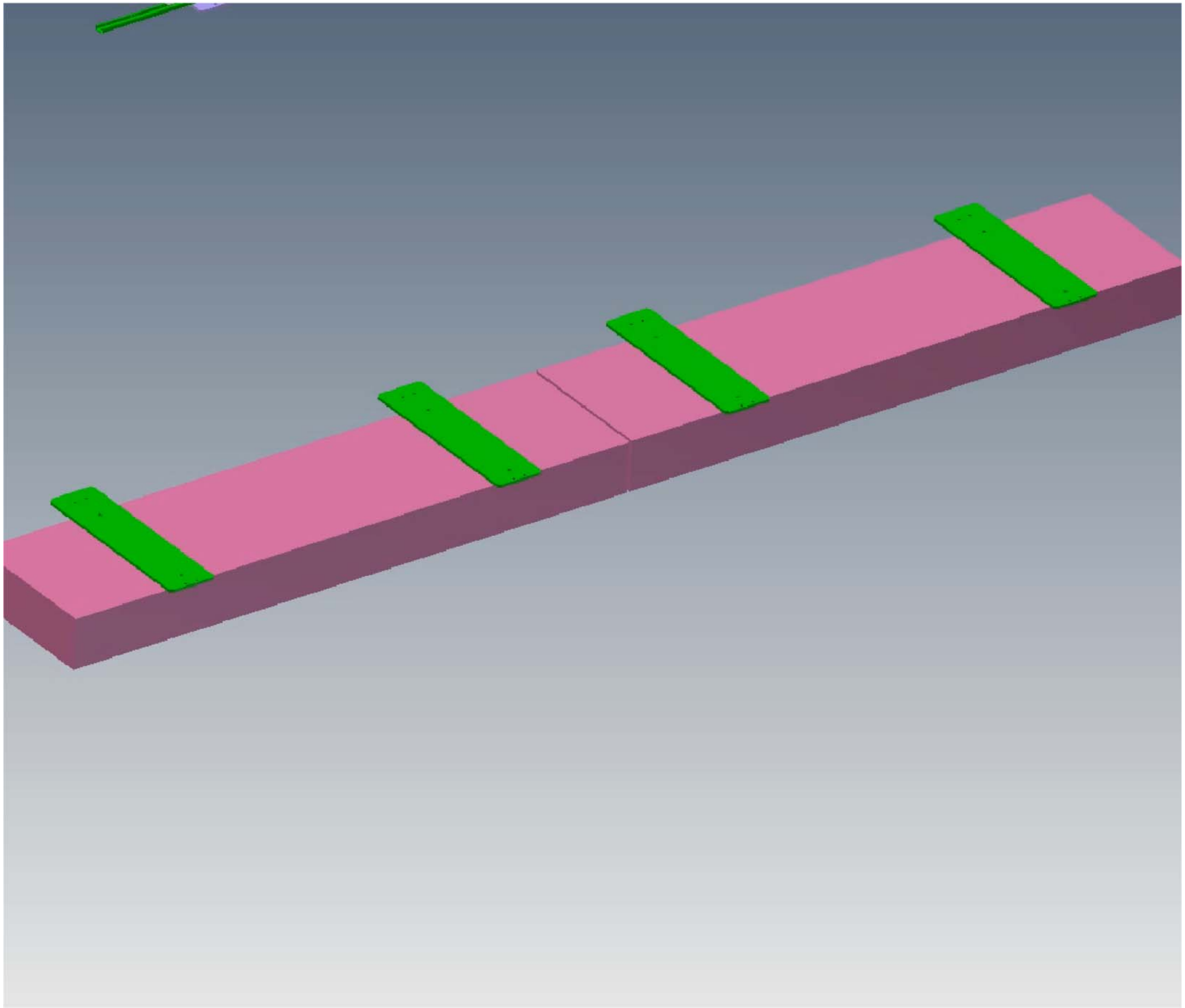




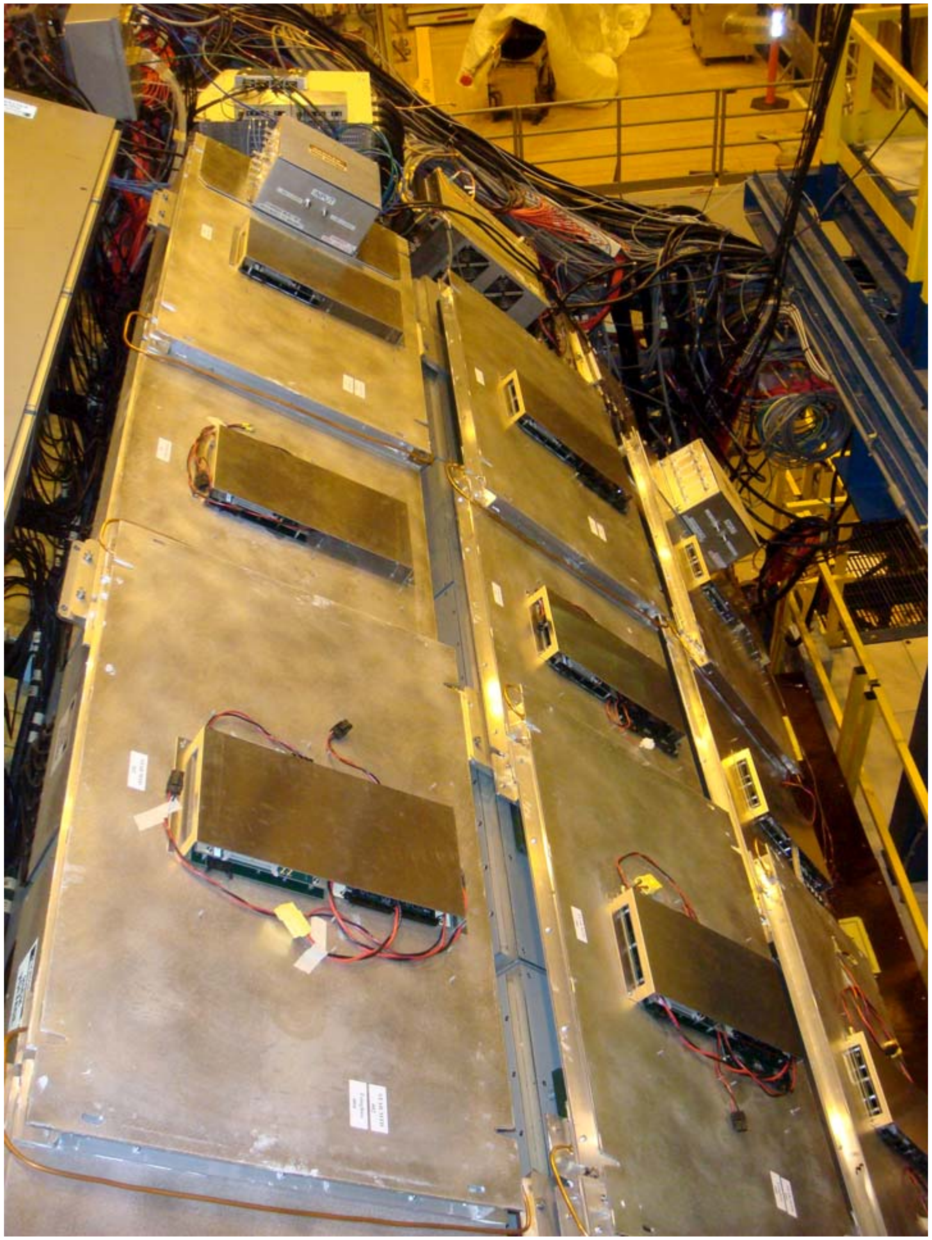
Two PMT boxes per backleg
one "2 pack" on each PMT box
5th MTD tray joins two "2 packs"

Full System Installation Scheme (Above STAR case)

movie:



Run-12 Installation



Three backlegs installed by STSG

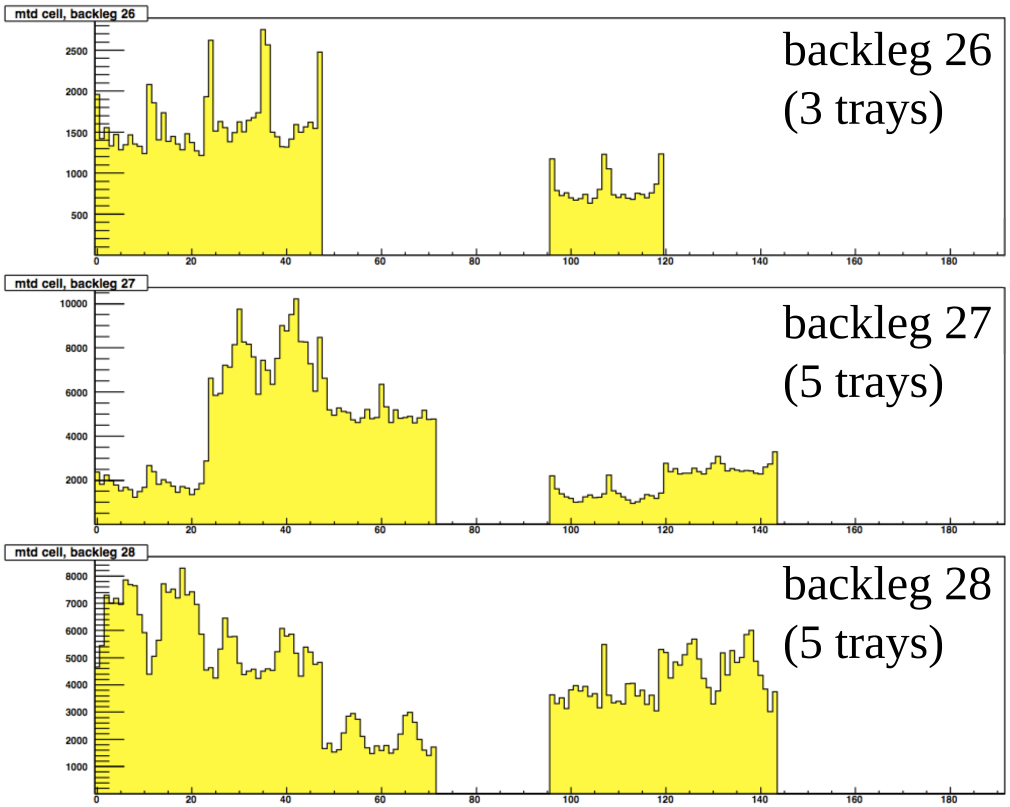
Now fully cabled up...
Tested through STAR DAQ...

gas leaks found and fixed...
HV & LV systems ready...
noise data taken...

connected to L0 trigger
will develop VPD+MTD triggers
throughout Run-12

Run-12 Installation

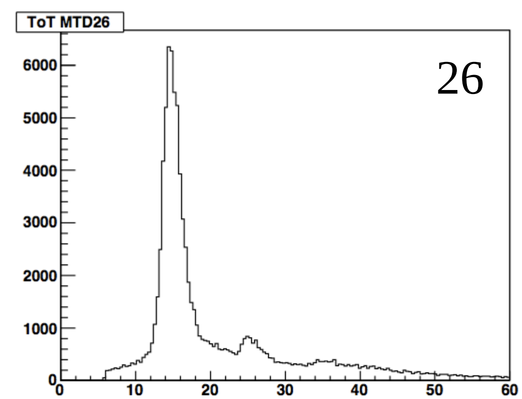
First Noise Rates & ToT distributions from Run-12 trays



channels are numbered TOF-style…
gas quality is still improving…

No bad channels

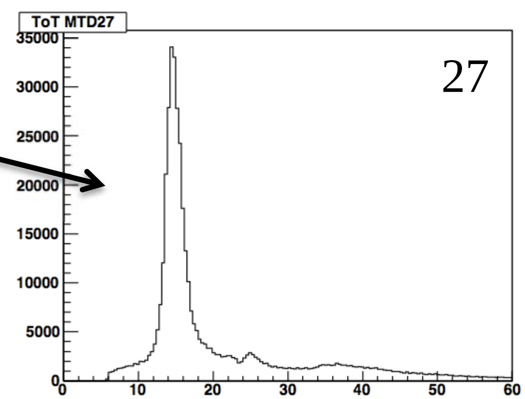
Noise rates averages very reasonable (<1 Hz/cm^2)

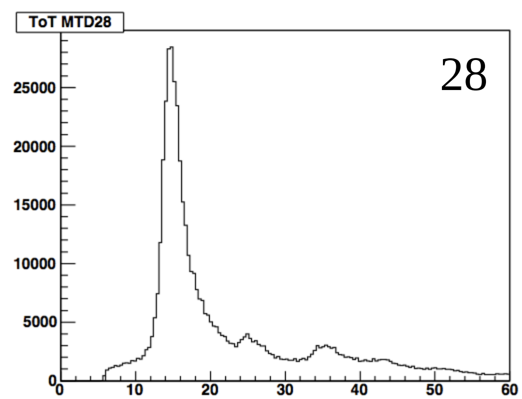


Time-over-Threshold plots

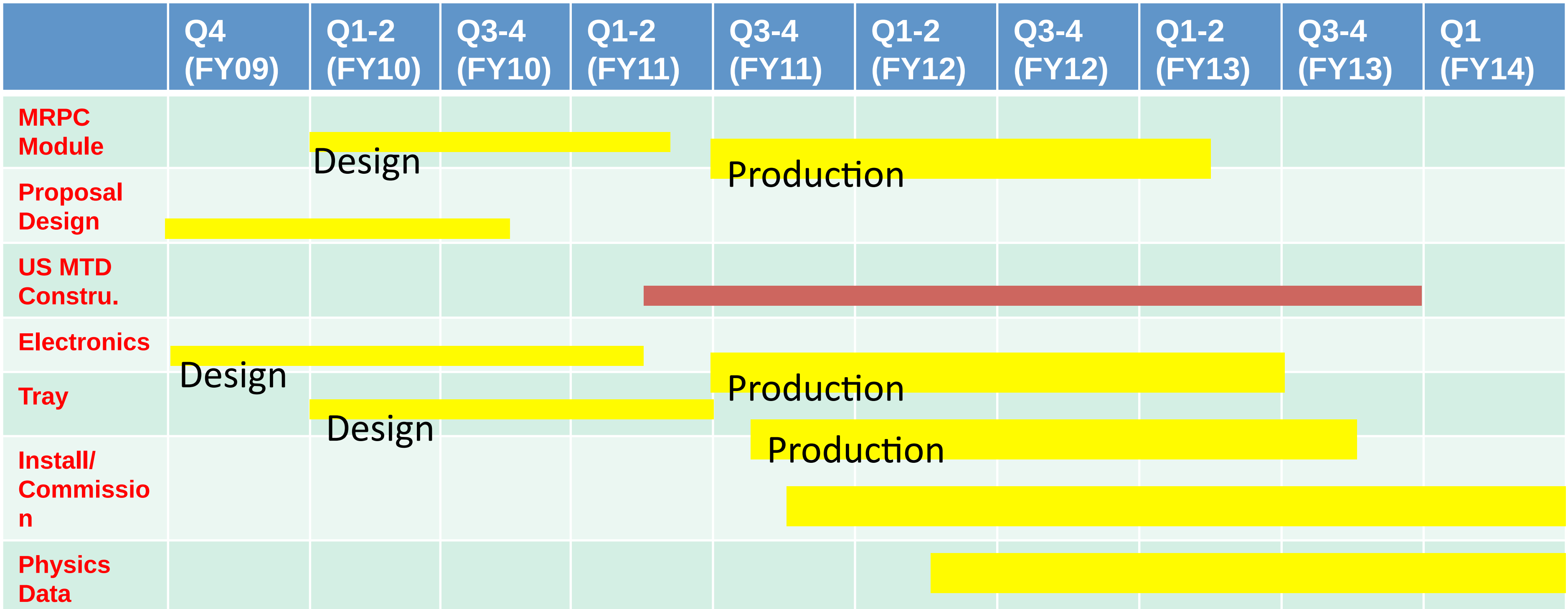
big avalanche peak

low streamer percentage





MTD Schedule



10% installation for Run12, 43% for Run13, 80% for Run 14.
Finish the project by Mar, 2014

MTD institutions: Brookhaven National Laboratory, University of California, Berkeley, University of California-Davis, Rice University, University of Science & Technology of China, Texas A&M University, University of Texas-Austin, Tsinghua University, Variable Energy Cyclotron Centre

US institutions: the electronics, the assembly of the trays and the operation of the detector

Chinese and Indian institutions: the fabrication of the MRPC modules

Summary and Conclusions

MTD will advance our knowledge of the Quark Gluon Plasma…

- low-level trigger capability — for low to high p_T J/ψ in central Au+Au collisions
- excellent mass resolution — separate different upsilon states
- e+muon correlation — distinguish heavy flavor production from initial lepton pair production
- complementary to dielectrons — different background contributions
- rare decay and exotics …

All MTD prototypes and final tray installations have been successful so far…

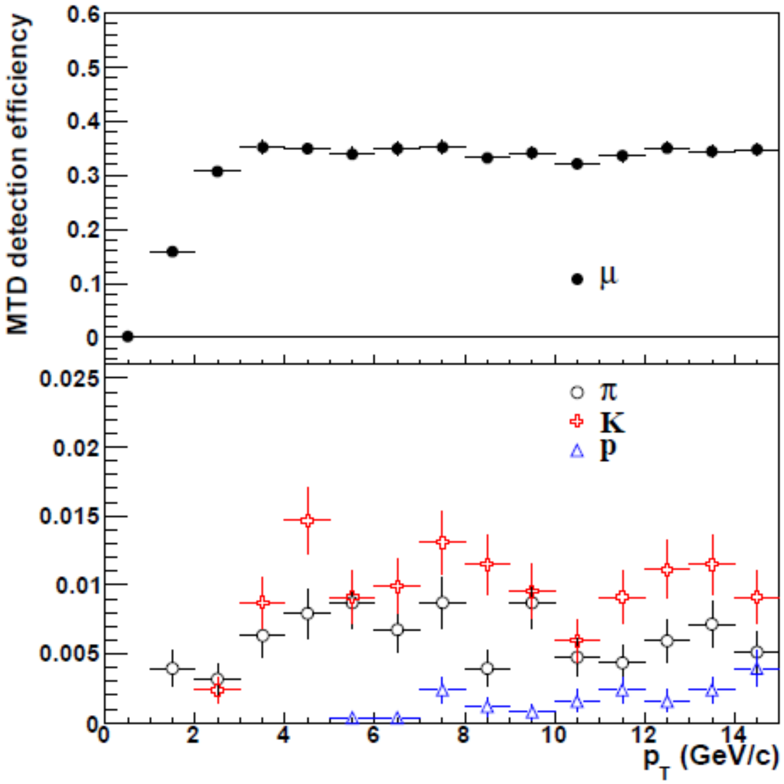
- Fabricated trays and MRPCs fit together nicely, Bench test results look very good.
- Hit patterns and noise rates in STAR are reasonable.
- “Final” detectors installed on-time for Runs 11 and 12.
- Collected untriggered data throughout Run-11, some triggered data at the end.
- Looking forward to resolution results & add’l development of timing triggers

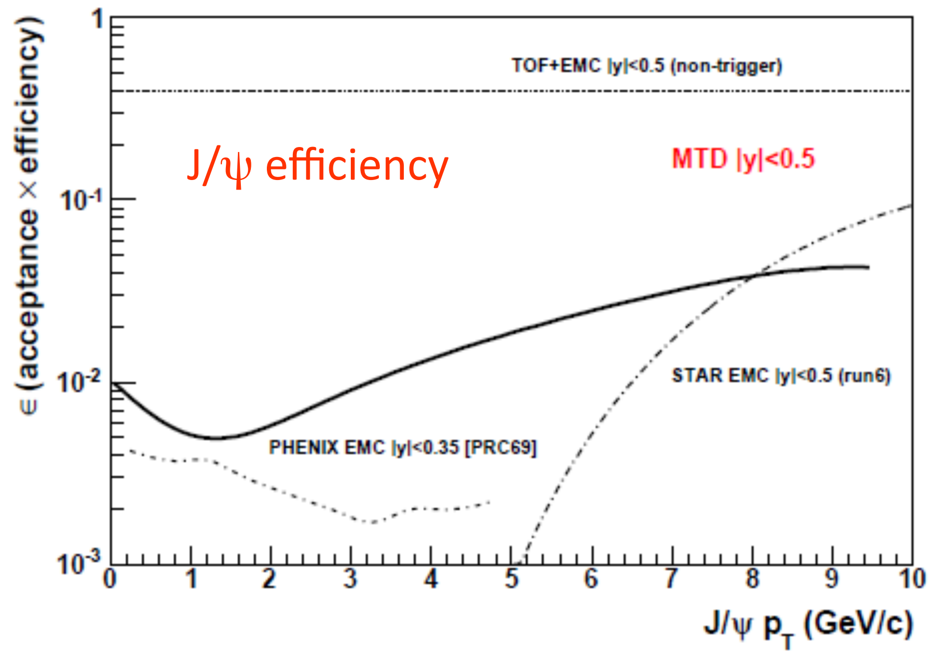
Successful Run-12 installation (13 trays) using new mounting scheme.
The critical issues in terms of system design involve optimizing some installation details..
~40% coverage for next run, remaining MTD detectors installed before Run-15.

धन्यवाद।

backup

Single Muon and J/ψ Efficiency

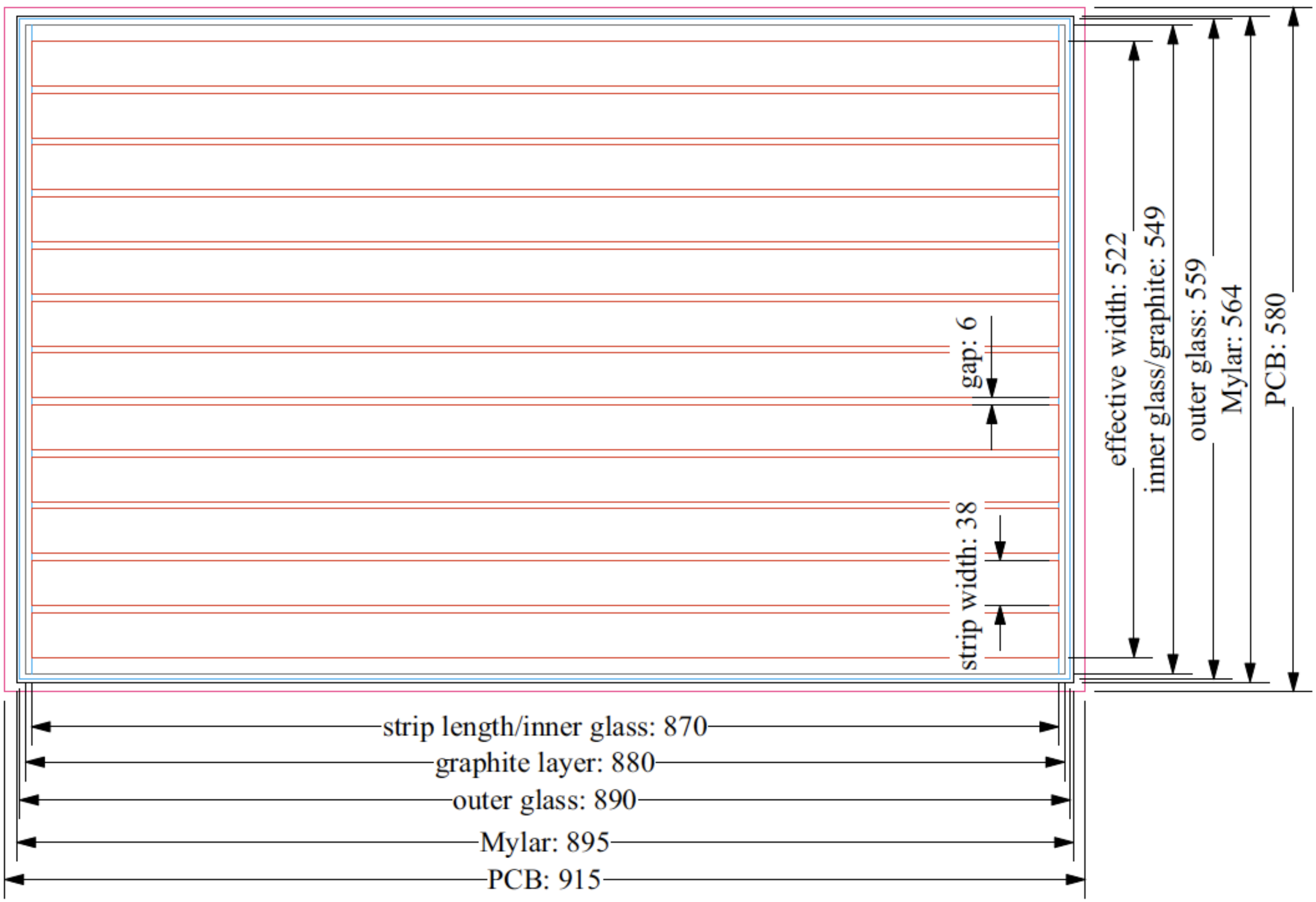




1. muon efficiency at |η|<0.5: 36%, pion efficiency: 0.5-1% at p_T>2 GeV/c
2. muon-to-pion enhancement factor: 50-100
3. muon-to-hadron enhancement factor: 100-1000 including track matching, tof and dE/dx
4. dimuon trigger enhancement factor from online trigger: 40-200 in central Au+Au collisions

Assumed MRPC Dimensions for MTD11 Prototypes

USTC Prototype
Outer (PCB) 58.0cm x 91.5cm ← Tsinghua MRPCs were 93cm long… Prefer 91.5cm
Active (Pads) 52.2cm x 87.0cm Height = 3cm Weight = 13kg (29lbs)

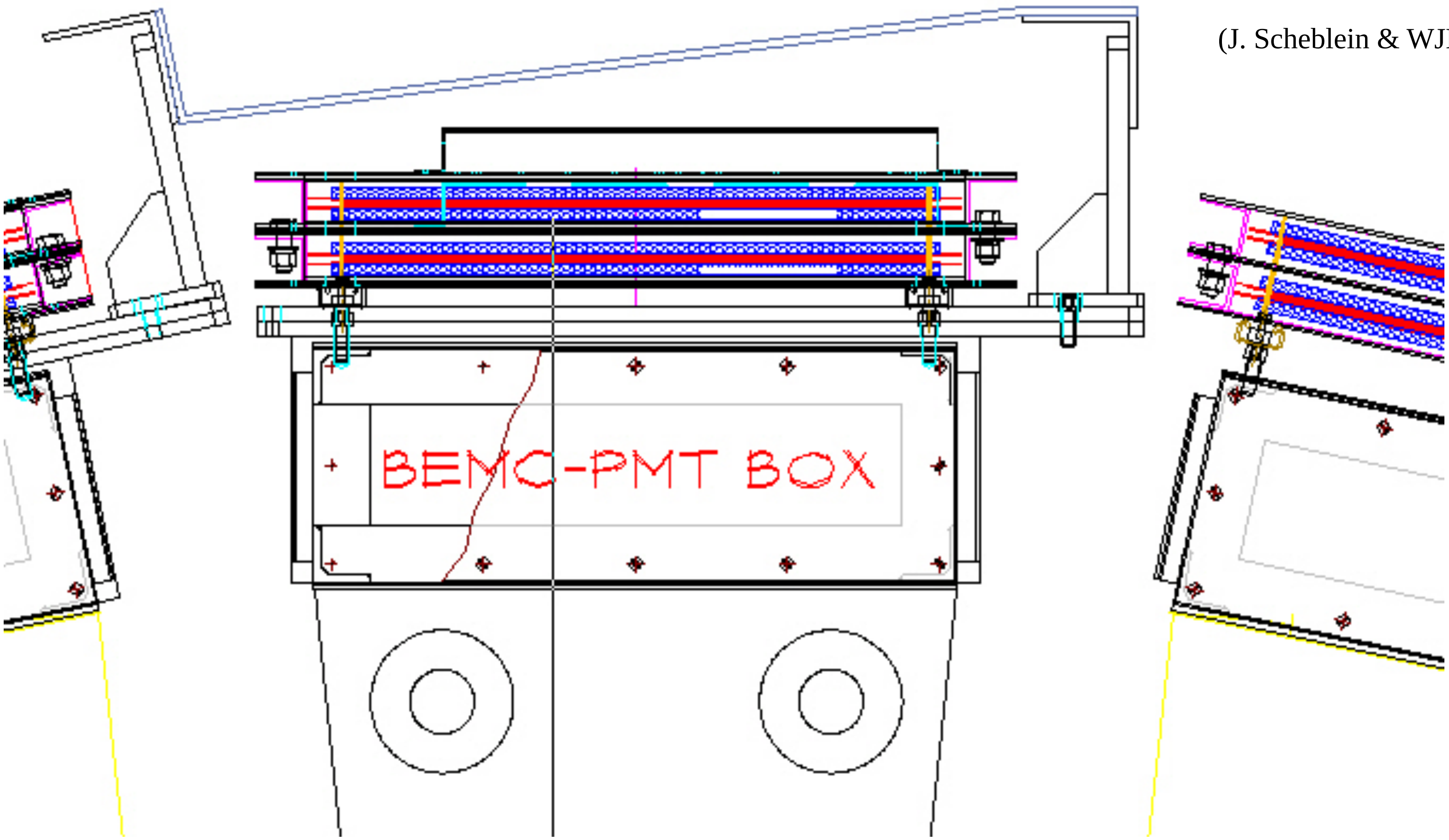


Full System Installation Scheme

new approach: Make mounting more complicated to make integration easier…

- unistrut mounts to two layers of "cross-pieces"
- use available space between backlegs
- install "diamond plate" covers over the top (heat retension?)

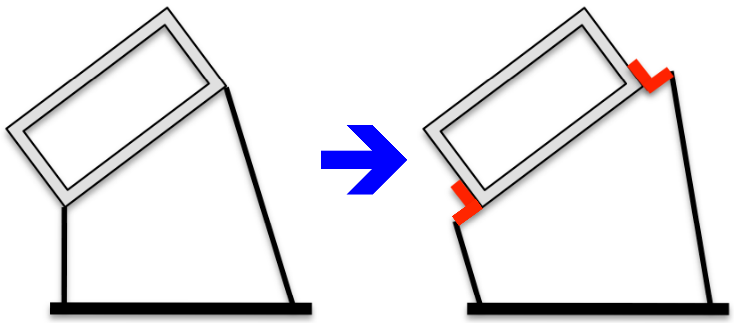
(J. Scheblein & WJL)

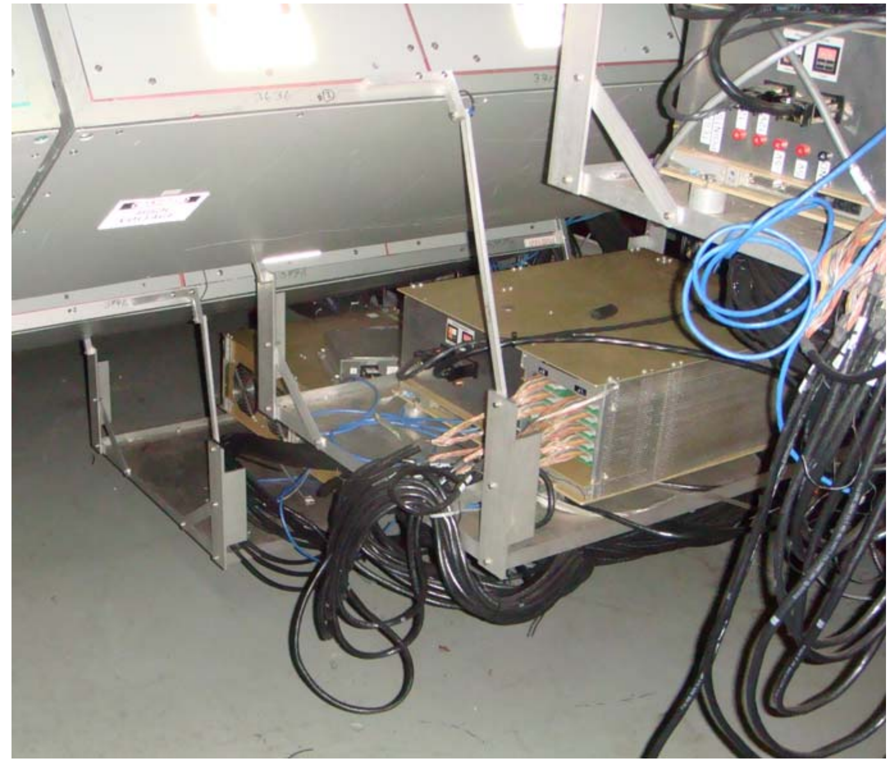


Full System Installation Scheme (Below STAR case)

Under STAR…
not a lot of room down there
not enough slack in BEMC cabling
to move these crates

only viable option known is to
"widen the hangars"





Other items:
fittings and fixtures should be plug and play (limit # of small nuts/bolts)
allow for "foam" filler pieces between PMT boxes

locate local tray testing and storage area
locate space and define fixtures for 2-pack assembly in the AB/WAH