RPC/MRPC development for Muon system @USTC

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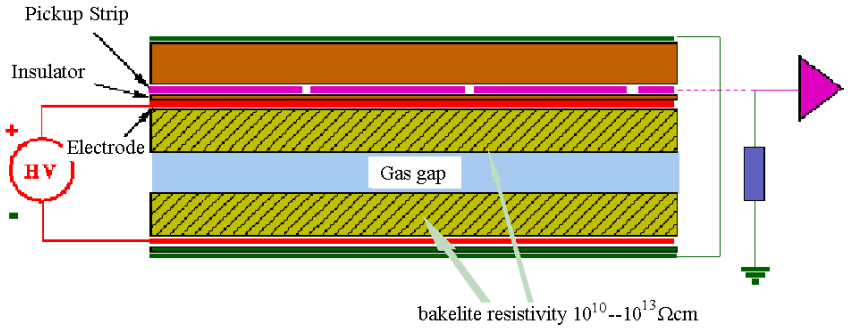
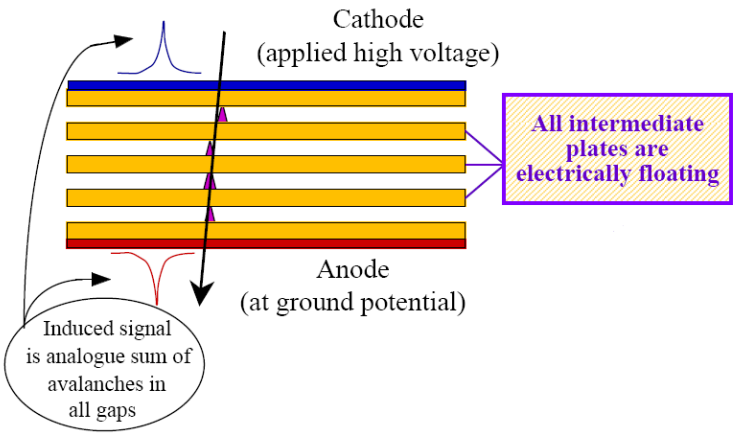
Outline

- Introduction
- The Muon Telescope Detector (MTD)@STAR
  - MRPC R&D for STAR-MTD
  - Performance of STAR MTD
- Thin gap RPC for ATLAS Phase-II upgrade
  - Motivation
  - R&D status
- Summary

RPC & MRPPC



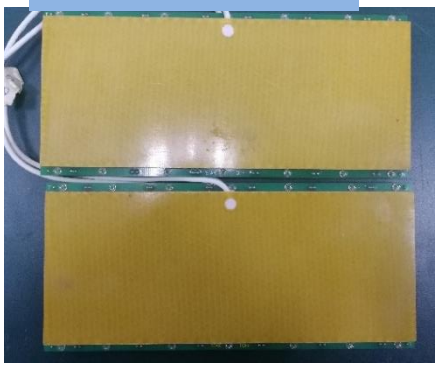


	RPC	MRPC
Gap Numb.	1 or 2	n
Gap size	~ 2 mm	~ 200 µm
Electrode	Bakelite or glass	glass
Mode	Streamer or Avalanche	avalanche
Time resolution	~ 1 ns	~ 50 ps
Advantage	Low cost	High time resolution
Usage	Muon	TOF

MRPC R&D and production at USTC

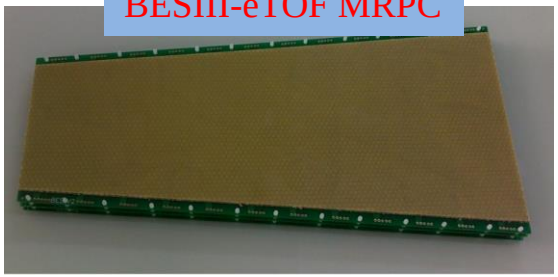
- We have developed the TOF system for STAR, the eTOF for BESIII and the MTD system for STAR with MRPC.
- We are developing the TOF system for CBM.
- More than 1350 / 46 m^2 MRPC have been produced.

STAR-TOF MRPC



STAR-MTD MRPC

BESIII-eTOF MRPC

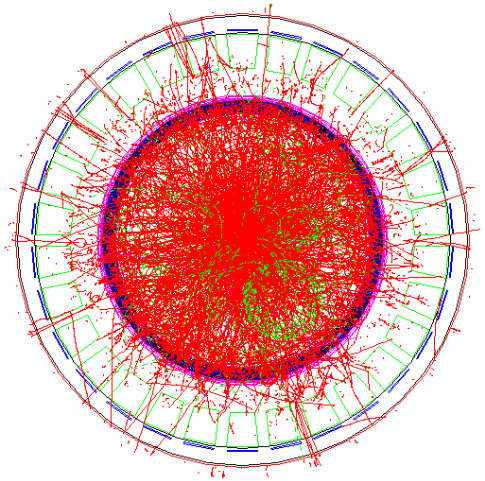


- STAR-TOF 1210 MRPC production(1/3). Time resolution < 80 ps
- STAR-MTD 59 MRPC production(1/2). System time resolution~120 ps
  Position resolution~1 cm
- BESIII-eTOF 80 MRPC production(100%). System time resolution~60 ps

The MTD at STAR

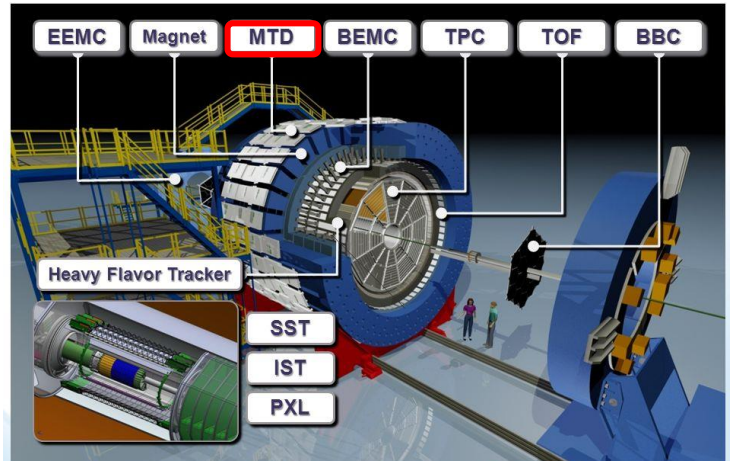
A large area of Muon Telescope Detector (MTD) at mid-rapidity, **allows for the detection of**,

- **di-muon pairs** from QGP thermal radiation, quarkonia, light vector mesons, possible correlations of quarks and gluons as resonances in QGP, and Drell-Yan production
- **single muons** from the semi-leptonic decays of heavy flavor hadrons
- advantages over electrons: no γ conversion, much less Dalitz decay contribution, less affected by radiative losse in the detector materials, trigger capability in Au+Au



A novel proposal: **single layer detector**

- Iron bars as absorber
- Muon ID by combining,
  - ✓ 2d position ➔ Track matching
  - ✓ Time measure ➔ Time matching
  - ✓ Energy loss in TPC
- Cost-effective for large area



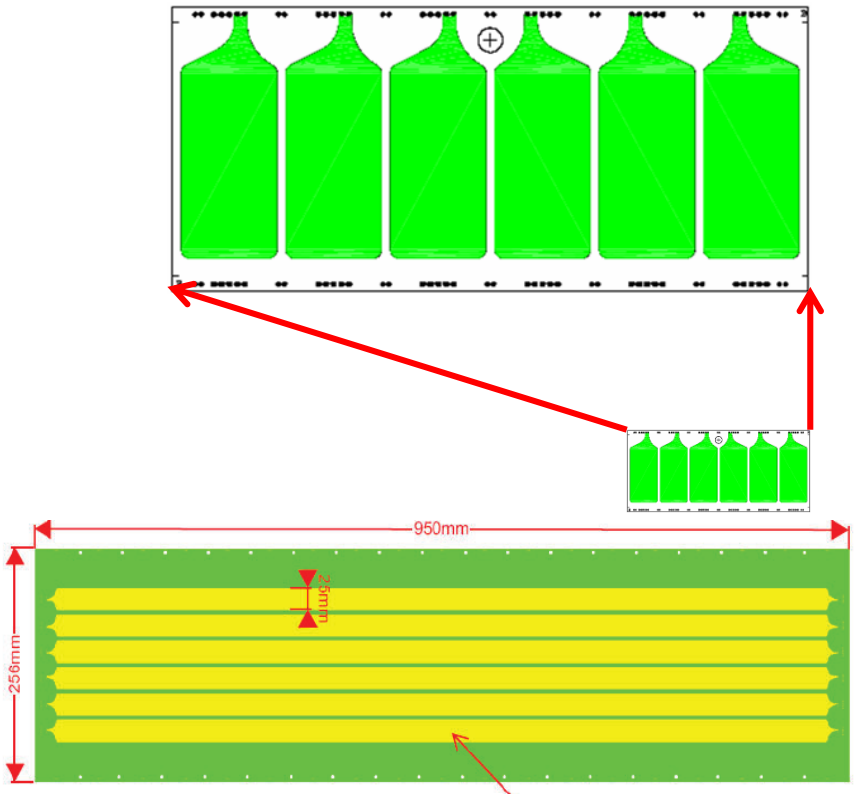
Z. Xu, BNL LDRD 07-007;
L. Ruan et al., Journal of Physics G: Nucl. Part. Phys. 36 (2009) 095001

MRPC with long readout strips (LMRPC)

- The Multi-gap Resistive Plate Chamber (MRPC)
  - ✓ Very good time resolution
  - ✓ High efficiency
  - ✓ magnet field resistant
  - ✓ Used for STAR TOF successfully
  - ✓ Flexible readout pattern
  - ✓ Cost effective for large area coverage

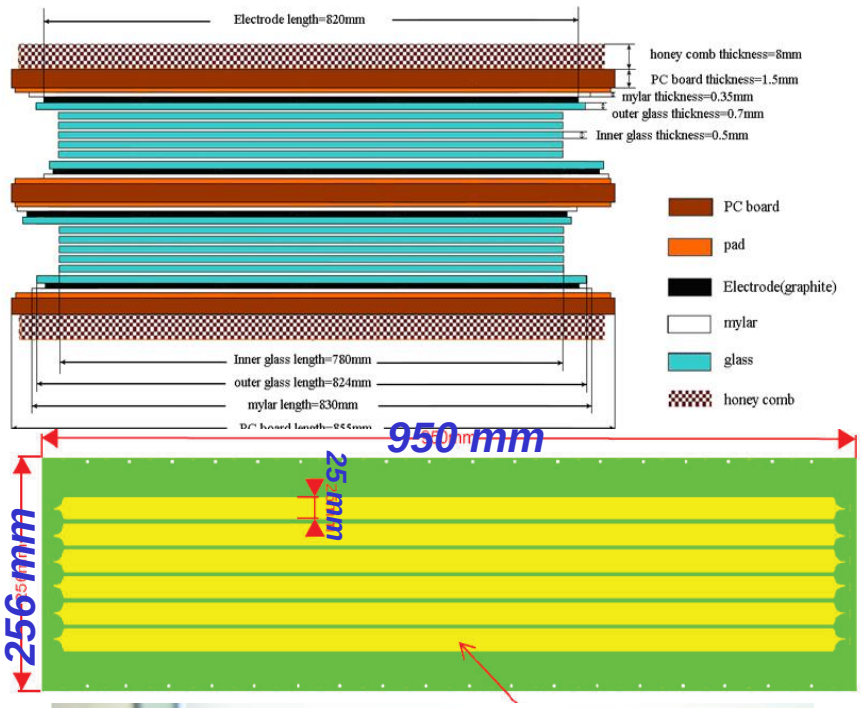
➔ Long readout strip for MTD

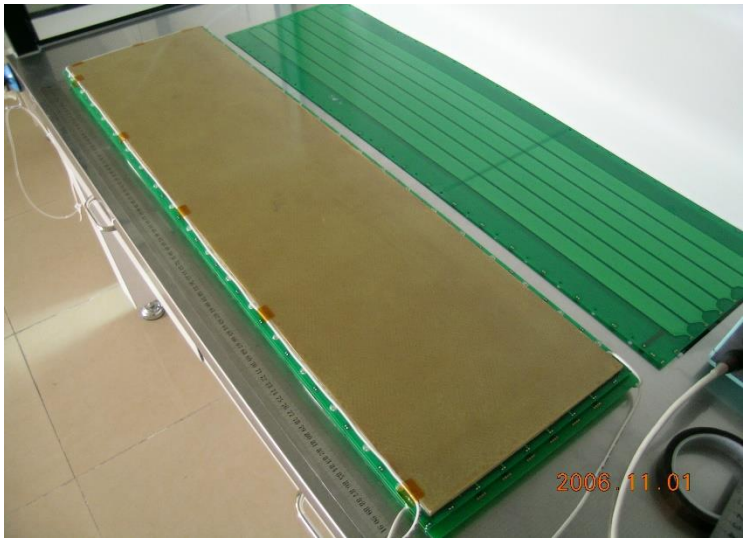
- ➢ Muon multiplicity is low
- ➢ Save electronics channels
- ➢ Signals read out from two-ends
  - — Mean time for timing
  - — Time difference for position

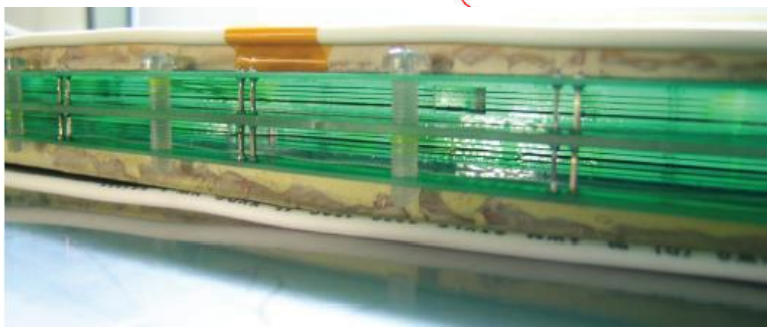


First LMRPC prototype

- Constructed in 2006 at USTC
  - Size: 950 x 256 mm^2
  - Read out strip: 25 mm x 870mm
  - Active area: 870 x 170 mm^2
  - Gas gaps: 0.25 mm x 10, in 2 stacks





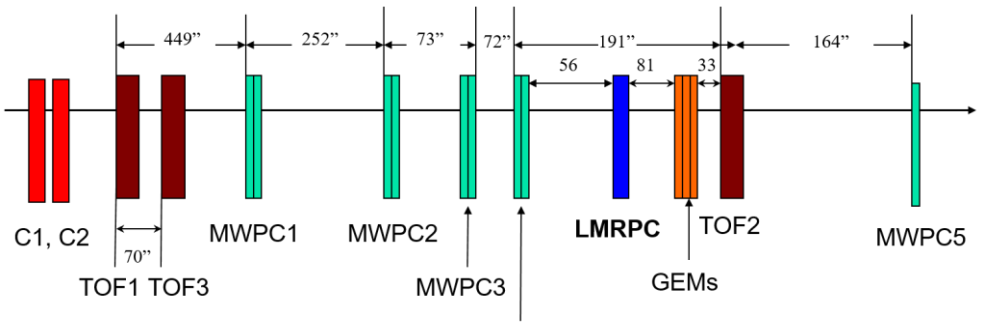


Y. Sun et al., NIMA 593 (2008) 430

Performance of the prototype LMRPC

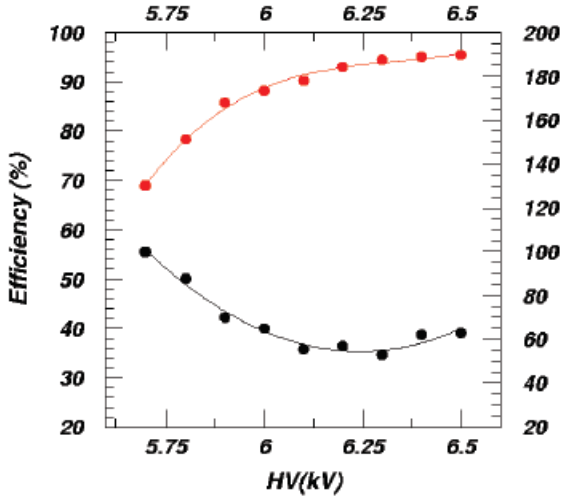
- **Tested with cosmic ray & beam**
  - Working HV: ±6300V
  - time resolution: ~60 ps
  - spatial resolution: ~1cm
  - efficiency: >95%
- **Performance comparable to TOF**

Beam test setup @ Fermi Lab

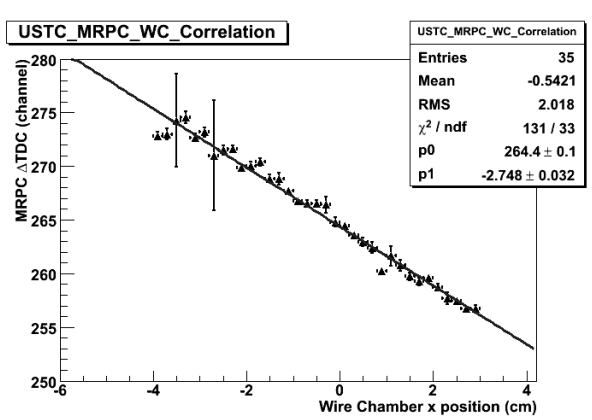


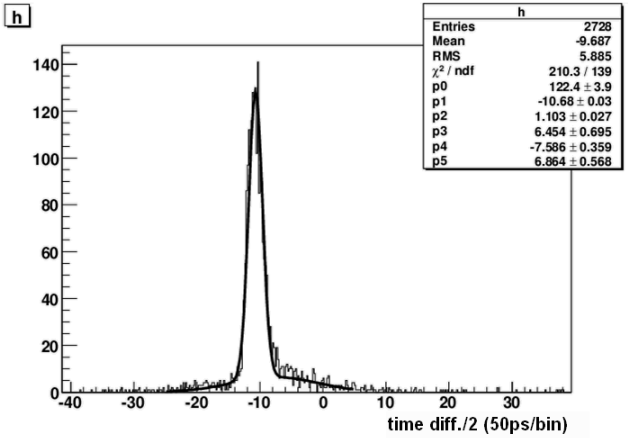
Beam Energy: 32 GeV

Cosmic ray test plateau

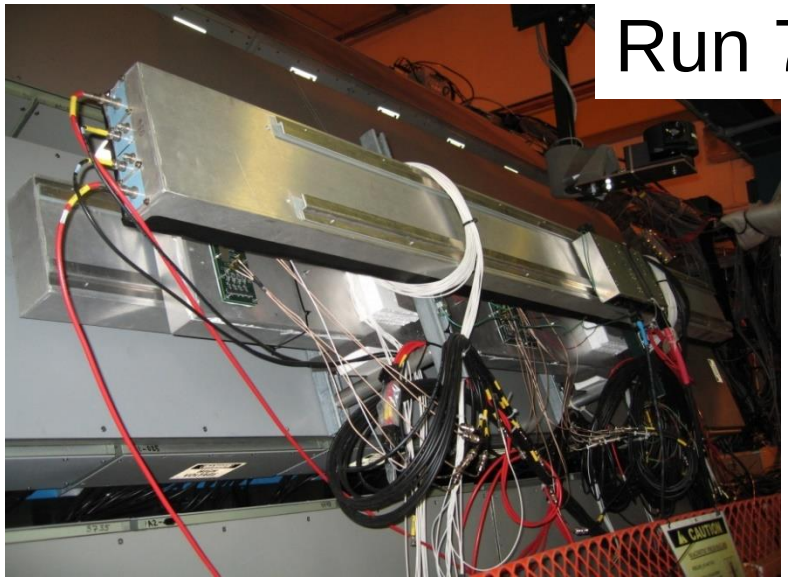


Spatial resolution

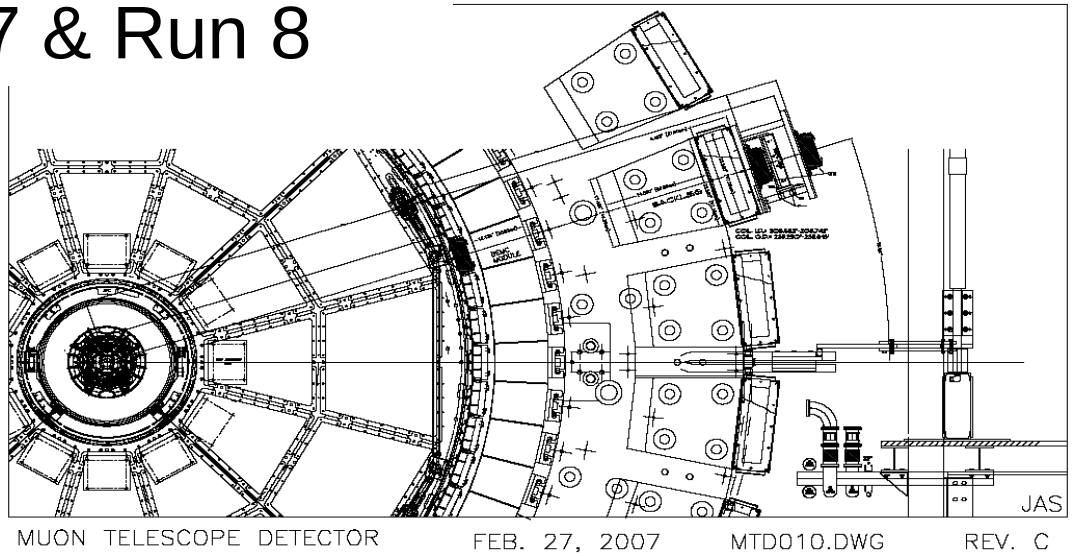


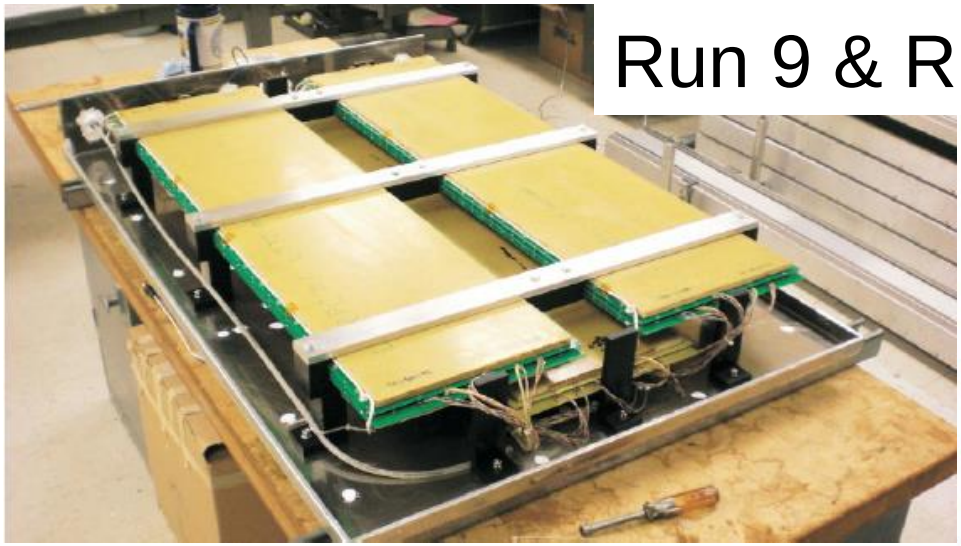


Prototypes running in STAR



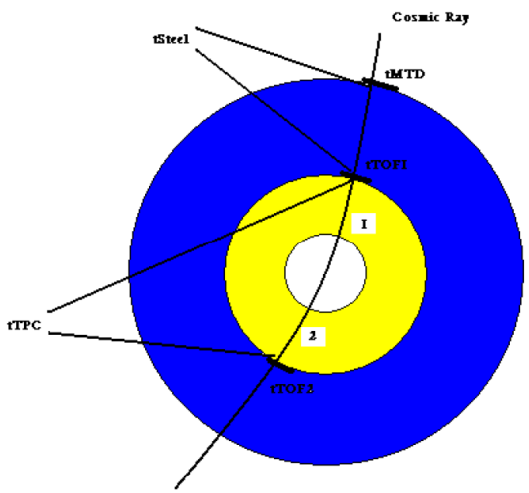
Run 7 & Run 8

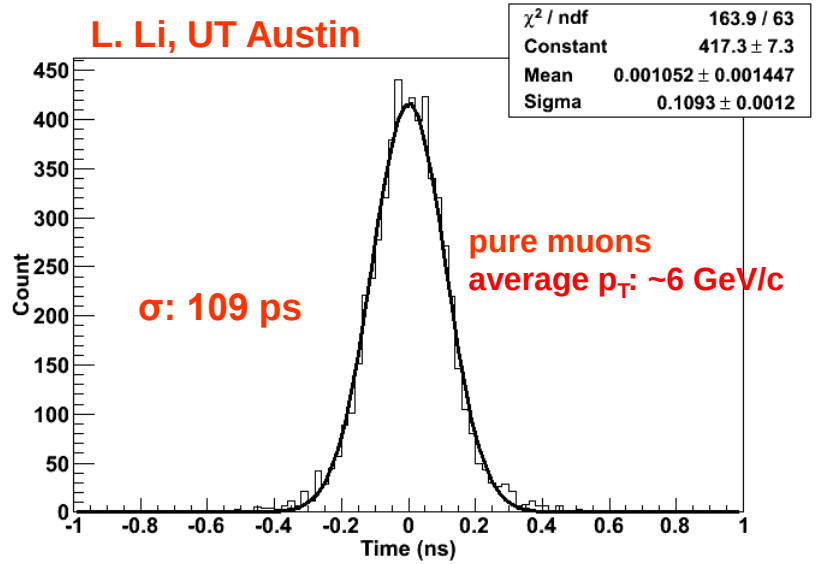




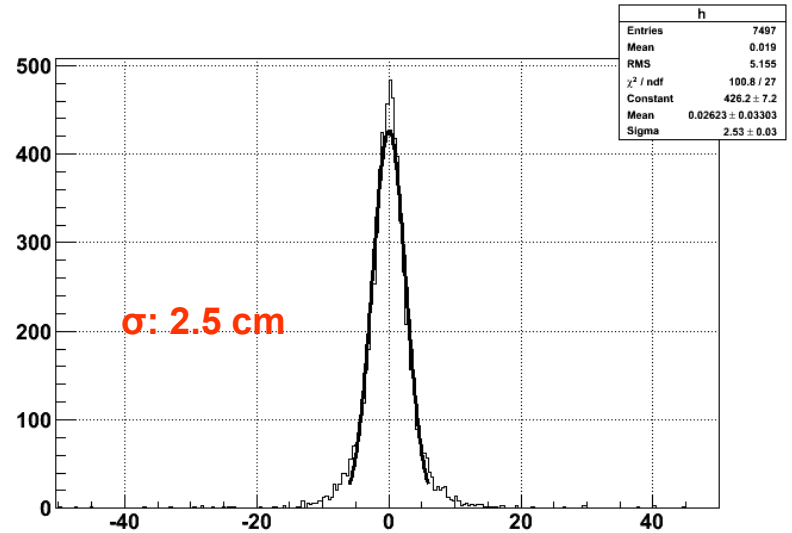
Run 9 & Run 10

Run10 performance with cosmic ray





- **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**

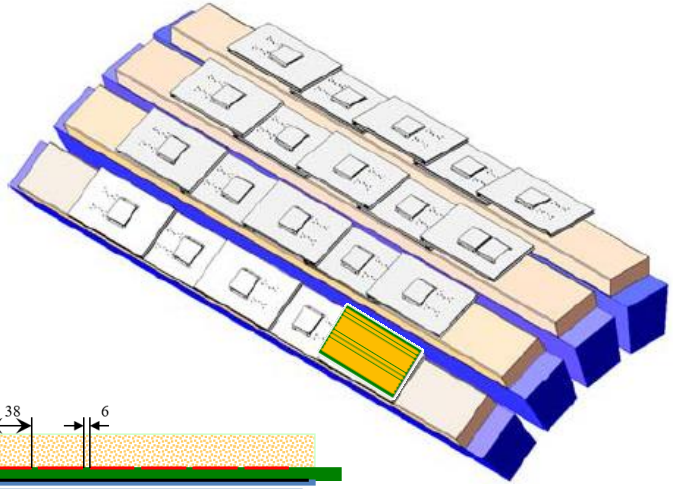


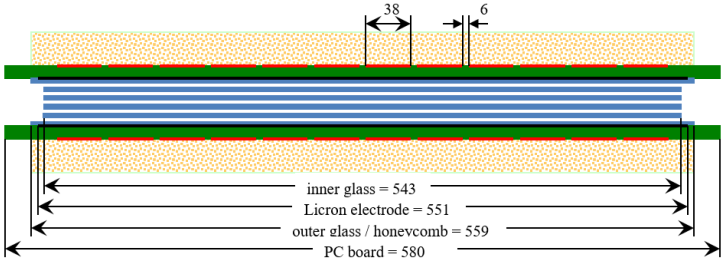
MTD system requirements

- **Time resolution less than 100 ps, spatial resolution ~ 1 cm.**
- **The mechanics design must allow a convenient replacement of individual MTD box and access to the BEMC box.**
- **The system must be able to operate in the fringe field from 0.5 Tesla STAR magnet field.**
- **The system must operate at low noise rate. The total noise rate should be less than 0.5 M Hz, 1 Hz/cm^2.**
- **The system must be safe, meet all BNL safely requirements.**
- **The system must not impair the performance of other STAR detectors.**

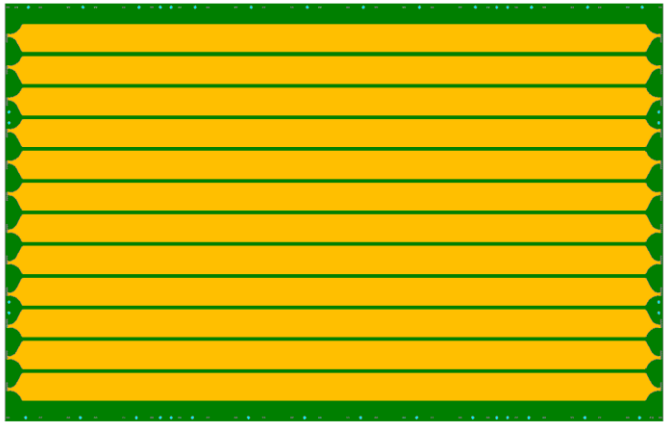
Final design for construction

- A module with one LMRPC covers the whole iron bars and leave the gaps in-between uncovered.
- Acceptance: 45% at $|\eta|<0.5$
- In total, 122 modules, 1464 readout strips, 2928 readout channels

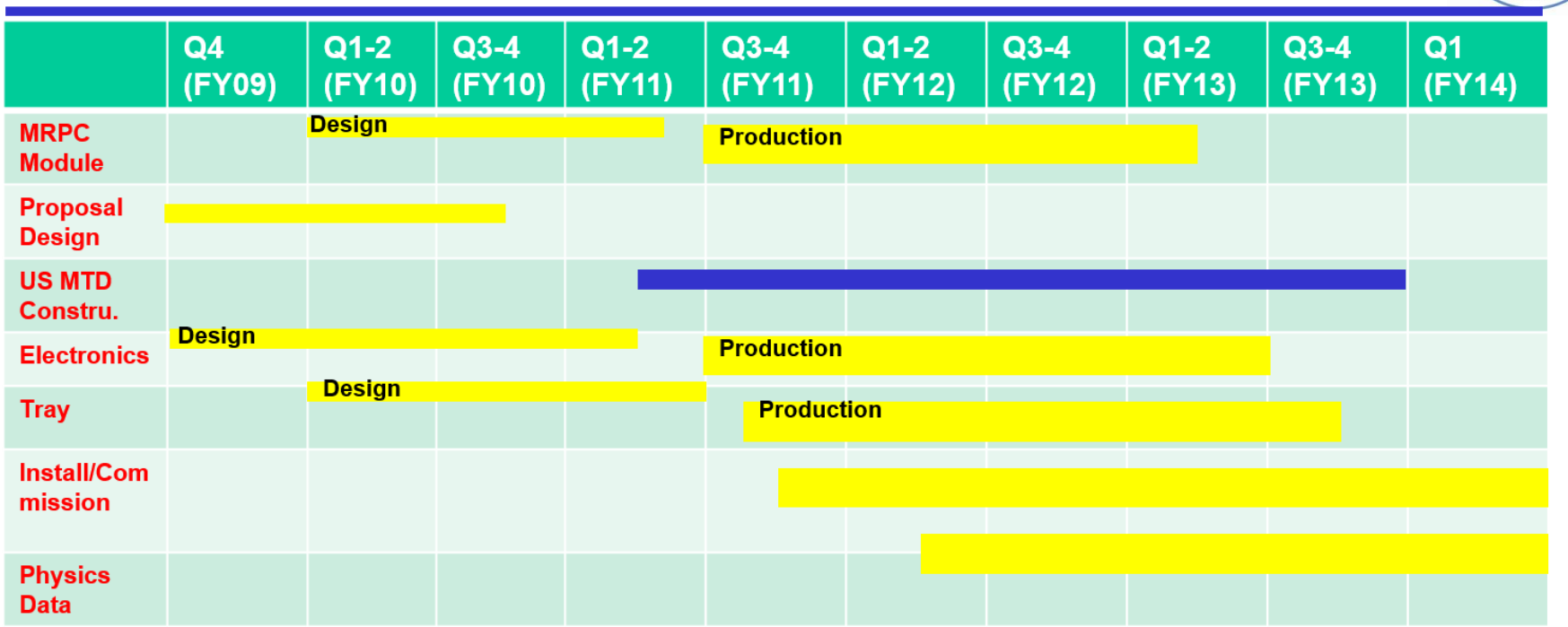




- LMRPC final design
  - Size: 915 x 580 mm^2
  - Read out strip: 38 mm x 870mm x 12
  - Active area: 870 x 522 mm^2
  - Gas gaps: 0.25 mm x 5



MTD construction and installation



The project approved and funded in May 2011: 10% installation for Run12, 43% (63%) for Run13, 80% (96%-100%) for Run 14. Finished 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

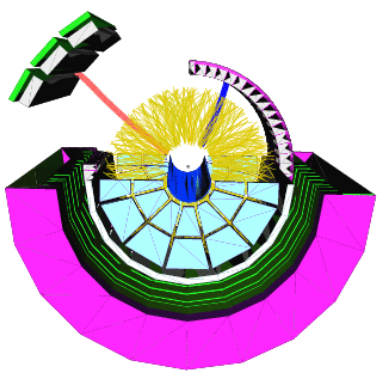
US institutions: the electronics, the assembly of the trays and the operation of the detector

Chinese and Indian institutions: the fabrication of the MRPC modules

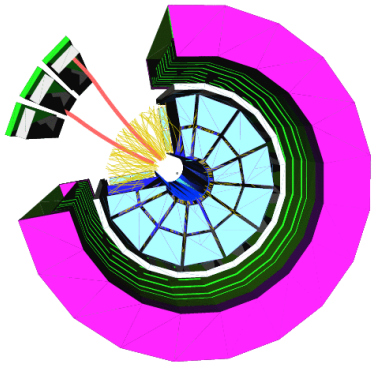
MTD performance from Run12

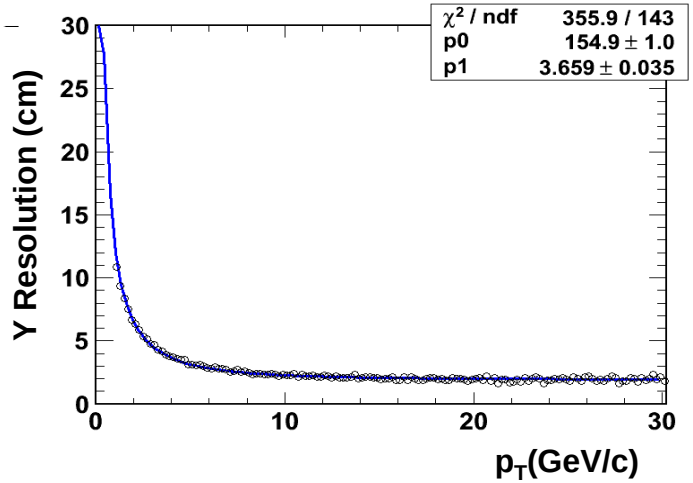
For Run 12, 13 trays on three backlegs installed.

e-muon



di-muon



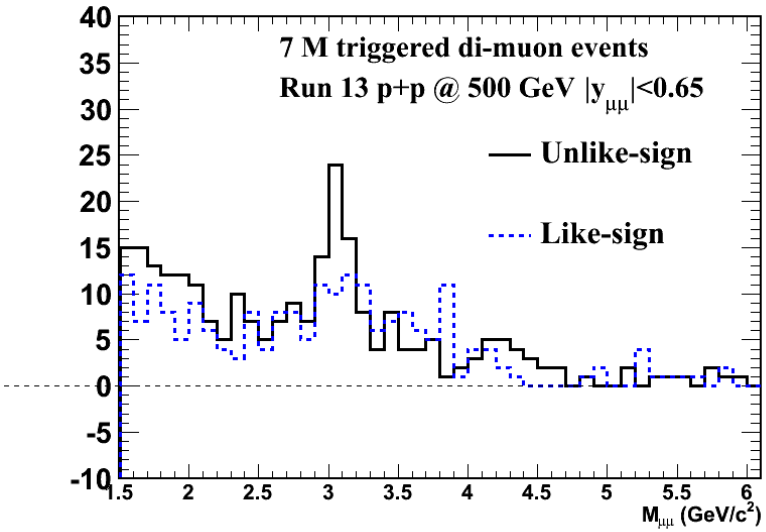


Commissioned e-muon (coincidence of single MTD hit and BEMC energy deposition above a certain threshold) and di-muon triggers, event display for Cu+Au collisions shown above.

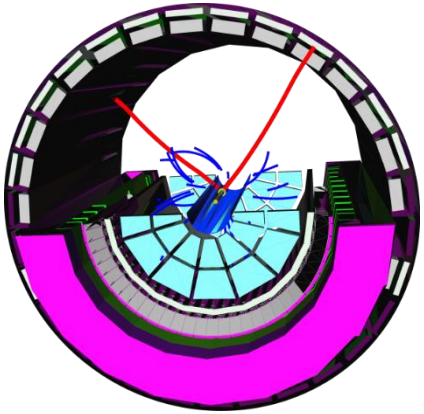
Intrinsic timing and spatial resolution: < 100 ps and 1~2 cm, respectively.

MTD performance from Run13

75 trays installed for Run 13.



J/ψ signals observed in p+p 510 GeV collisions



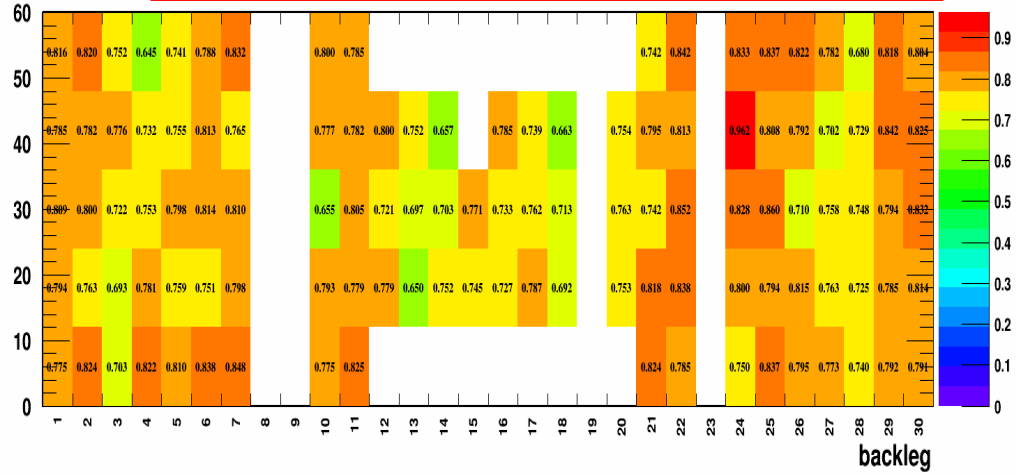
Event display for J/ψ event in p+p 510 GeV collisions

Trigger algorithm in place on May 9th. Single-muon, di-muon, electron-muon triggers were commissioned on May 10th.

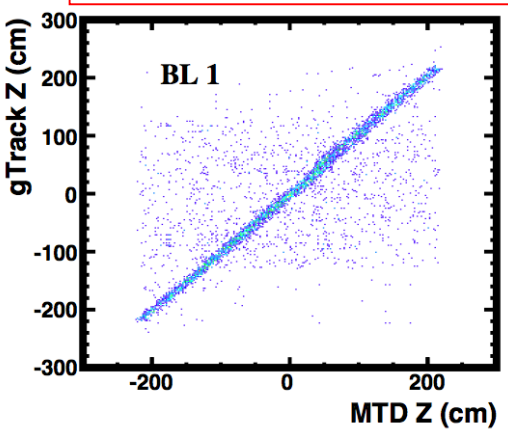
MTD performance from Run14

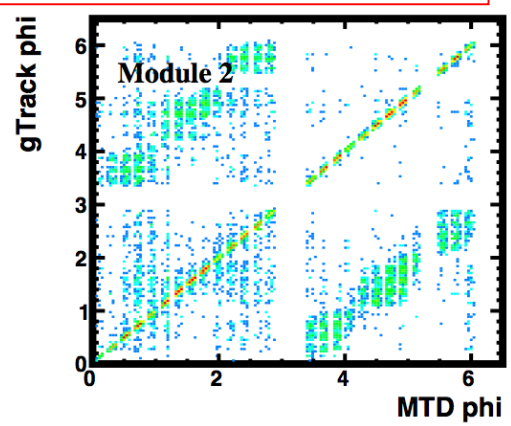
Installation finished by April.

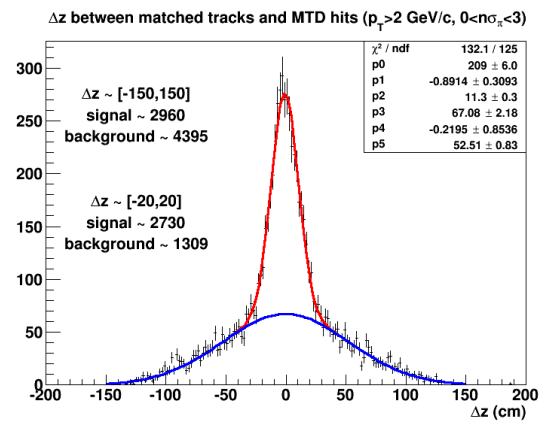
MTD matching efficiency: 65-85%.



MTD hits can be matched with the TPC tracks.

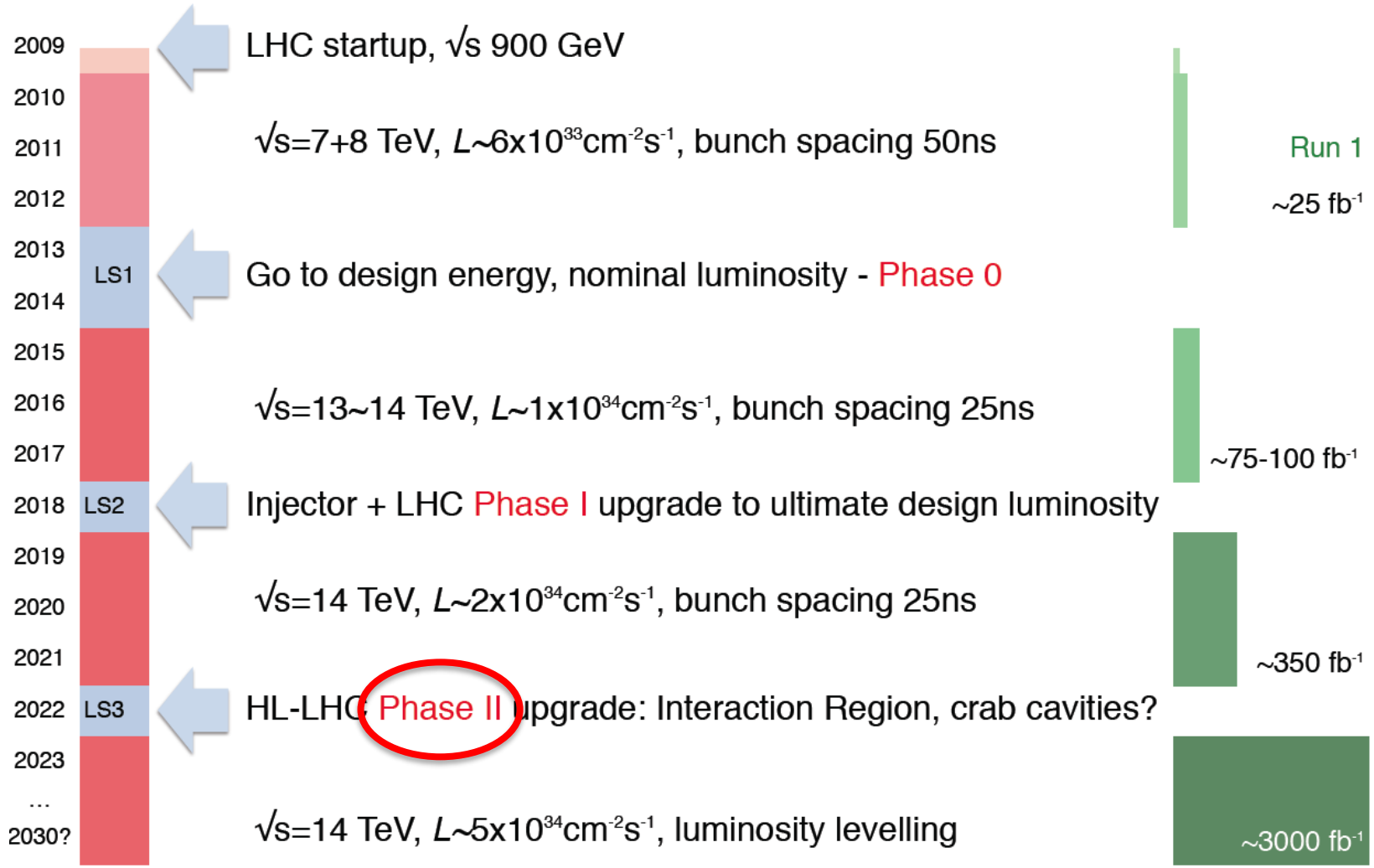






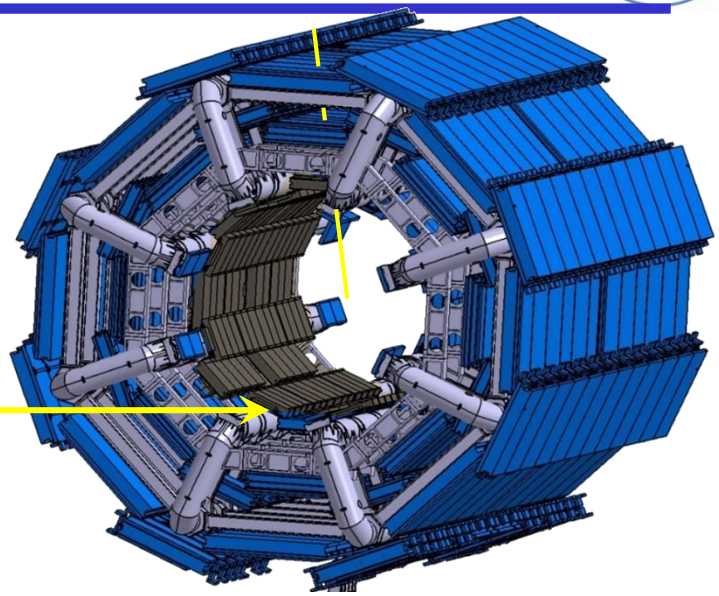
Position resolution for muon at $p_T > 2$ GeV/c is about 11 cm, dominated by multiple-scattering effect.

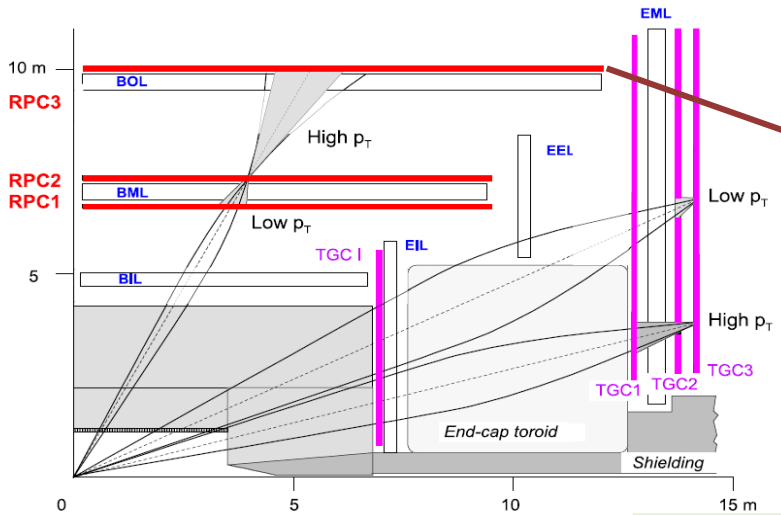
RPC R&D for ATLAS Phase-II upgrade

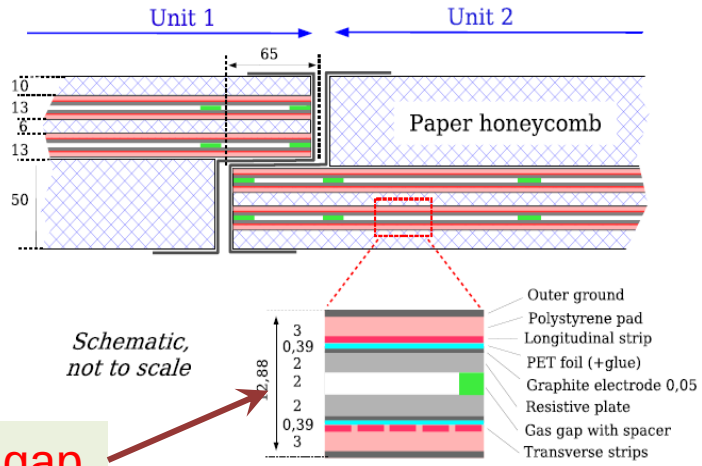


Current ATLAS RPC muon trigger system

- 6 layers RPC (BM and BO), measure η&ϕ position on each layer.
- OUTER LAYER (BO) for High p_T trigger
- MIDDLE LAYER (BM) for Low p_T trigger
- NO RPC on INNER LAYER (BI)







Traditional 2 mm gas gap

The main problems of current RPC

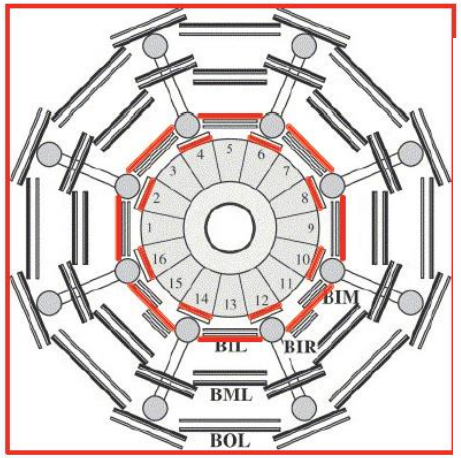
- **Longevity:**
  - Designed for work under 1×10^{34} $cm^{-2}s^{-1}$@14TeV for 10 years, corresponding to integrate charge of 0.3 C/cm^2
  - Reach the life time at HL-LHC
  - Can only work under lower voltage with detection efficiency lost of 15%-35%

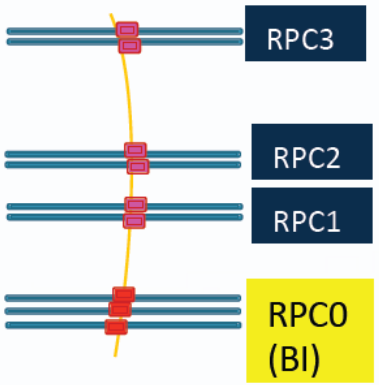
$L=7\times10^{34}cm^{-2}s^{-1}$@14TeV

Sector Φ Id.	RPC unit Id. along Z direction -6.2	-6.1	-5.0	-4.0	-3.2	-3.1	-2.2	-2.1	-1.2	-1.1	1.1	1.2	2.1	2.2	3.1	3.2	4.0	5.0	6.1	6.2	Average
01.01	342	280	301	225	145	114	128	101		61	61	71	113	122	127	136	214	276	269	285	180
01.02	293	281	303	218	159	133	129	143		76	71	75	127	143	140	148	215	295	278	297	188
2	168	204	188	138	109	90	77	63	55	56	45	48	61	79	94	104	140	207	196	152	115
03.01	297	296	281	198	148	128	119	119	68	67	65	71	131	125	114	125	207	329	268	290	177
03.02	300	243	277	210	151	129	155	122	85	75	75	70	122	127	152	132	207	315	243	299	179
4	112	166	158	151	101	83	65	77	41	53	46	41	73	68	92	108	160	196	175	112	101
05.01	171	173	263	138	105	102	140	127	68	60	60	69	124	177	102	137	185	290	173	171	149
05.02	227	198	237	158	109	105	136	143	77	61	63	71	111	136	108	141	200	267	255	282	159
6	175	186	208	163	105	95	90	95	77	59	52	59	84	81	106	124	189	200	227	167	131
07.01	305	263	288	191	154	129	131	114		76	78		122	139	124	148	185	261	268	305	183
07.02	327	258	216	203	141	112	129	108		74	77		105	114	112	152	184	278	276	279	175
8	146	196	195	161	103	85	80	70	50	57	54	54	67	74	85	108	168	196	194	156	118
09.01	319	246	301	206	155	117	149	119		46	64		106	134	124	135	197	283	262	297	181
09.02	347	258	287	205	143	95	107	103		58	67		99	112	95	137	188	285	265	292	174
10	174	201	207	147	99	86	68	71	46	43	41	50	64	69	80	103	148	193	201	170	115
11.01	308	244	237	157	97	84	81	87		40	43		83	94	92	94	148	227	215	278	132
11.02	196	193	157	105	78	66	55	57		33	31		50	62	58	71	98	151	160	185	98
12						80	81	66	51	36	36	51	75	87	80						64
13.01	291	278	253		140	102	96	84	43	41	47	50	87	95	99	123		249	263	319	149
13.02	299	264	262		104	97	105	86	49	48	50	56	93	103	97	110		252	227	294	146
14						142	68	64	52	41	40	49	63	68	136						76
15.01	196	221	148	113	76	71	67	49		38	36		50	59	86	87	104	156	173	196	104
15.02	183	159	246	164	116	98	103	75		44	43		75	106	112	107	158	248	159	183	133
16	173	214	216	173	108	89	54	75	56	59	50	50	77	54	87	103	177	209	208	154	124
Average	229	223	234	167	118	101	96	88	56	52	51	56	86	97	103	118	171	240	221	221	137

- **The rate capability:**
  - Under HL-LHC, the extrapolated rate on RPC will be an order of magnitude higher, ~300Hz/cm^2

- **Basic solution:**
  - Add 3 BI RPC layers
  - Rate: ~ kHz/cm^2, work 10 years for HL-LHC
  - With higher spatial and time resolution for muon tracking and bunch crossing ID
  - Close most of the acceptance holes





The basic requirements

- Higher rate capability: ~ kHz/cm^2
- Longer longevity: 10 years of HL-LHC
- Higher spatial resolution: ~ mm
- Higher time resolution: ~0.5ns

Current RPC detector:

- Charge: 30 pC/count
- Rate capability: ~ 100 Hz/cm^2
- Time resolution: 1.1 ns
- Strip pitch: 26-35 mm
- 2 mm gas gap, with avalanche mode

By reducing the charges generated each count, the rate capability and longevity can be improved, and also the timing and spatial performances.

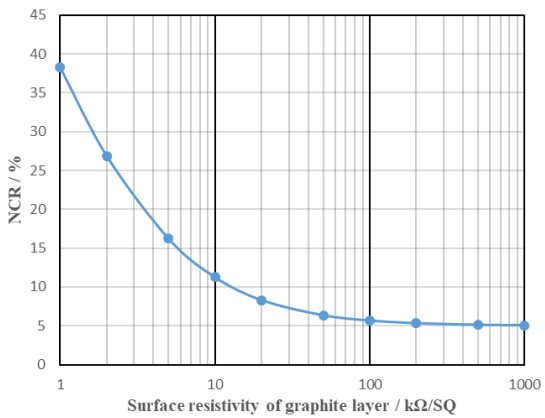
The avalanche will be limited with reduced develop distance, i.e., the gap size, the lost in gas multiplier will be compensated by FEE amplifier.

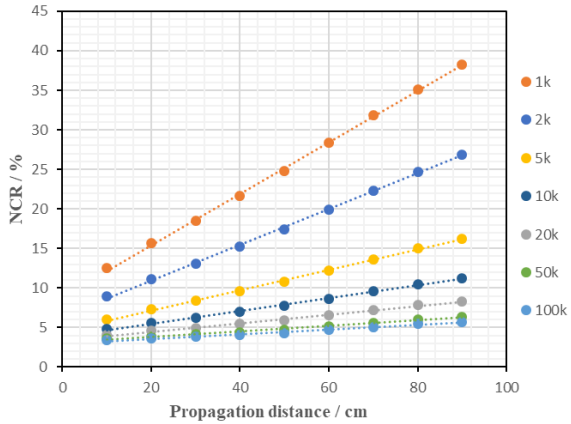
Main challenges

- More sensitive, high signal-to-noise ratio, fast, low power consumption Front End Electronics
- New materials for a thinner and more rigid chamber structure
- Increasing the signal-to-noise ratio by optimizing the gas gap and readout panel structure
- Optimizing the detector parameters for maximizing spatial and time resolution, thus momentum resolution, and track-to-track separation.
- Looking for new environment friendly gas mixture.

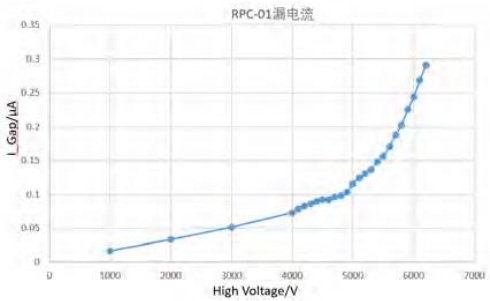
The progresses on thin gap RPC

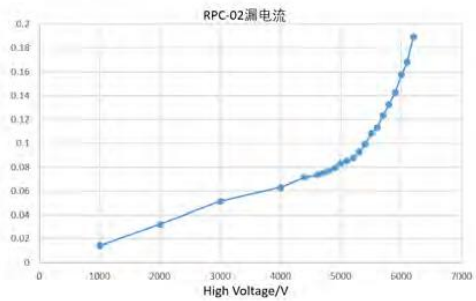
- The cluster size was simulated in the PCB Studio of Computer Simulation Technology Suite (CTS).

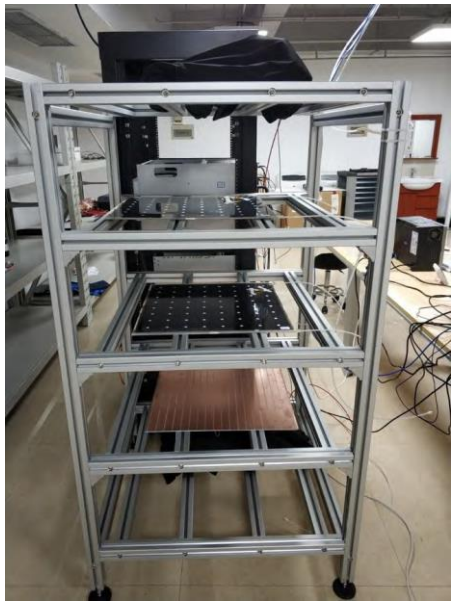




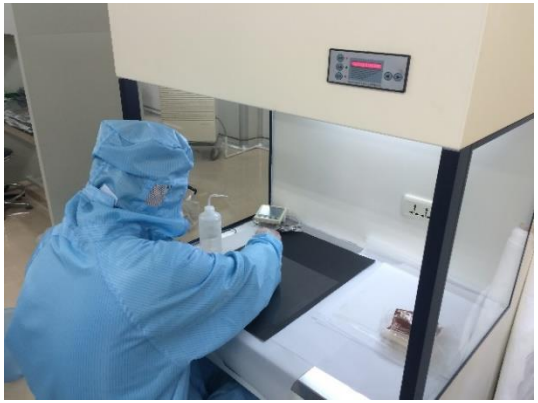
- Gas gap (1 mm) cosmic ray test started.







Summary



- R&D, design, mass production, QC&QA capability on MRPC.
- Several TOF, Muon systems have been built successfully.
- R&D on Thin gap RPC for ATLAS Phase-II upgrade on going.
- Hope that we can make real contributions to ILC.

Thank You !