Fast MRPC-TOF R&D
@ U. Tsukuba

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JSPS Grant:
“10 ps TOF detector R&D for high energy experiments” (FY 2015 – 2017, PI T. Chujo)
Members

• University of Tsukuba:
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• Tsukuba Technology University:
  – M. Inaba (pre-amp, detector design)

• JAEA:
  – H. Sako, S. Sato

• KEK:
  – K. Ozawa, K. Aoki
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5. Summary and future plans
- 6 gaps (230 micron).
- Gas mixture (non flammable mixture):
  - R134A (95%), Isobutene (5%) at 60 cc/min. or
  - R134A (90%), Isobutene (5%), SF6 (5%) at 60 cc/min.
- Operating HV: ±7.0 ~ 7.5 kV
3 Prototypes

**PH1**
- 50.9 x 53.5 cm\(^2\), 32 strips, readout at both ends.

**PH2**
- 12.5 x 53.5 cm\(^2\), 8 strips, readout at both ends.

**PH3**
- 12.7 x 53.7 cm\(^2\), 48 pads (6x2 cm\(^2\)), similar to STAR MRPC.
- PH1: worse timing resolution (>150 ps), same efficiency as PH2. Problem on uniformity of performance across the chamber. Difficulties in mechanical assembly.
- PH2: **68ps timing resolution** at optimal condition, but 90% efficiency. Solution → increase strip width.
- PH3: comparable timing resolution with PH2 (best value: 67ps), 98% efficiency.
PHENIX TOF-W:
a total of 128 MRPCs, 512 strips, and 1024 readouts. Timing resolution is 84 ps in Au + Au.
(includes the uncertainty in the start time BBC)
2. 4 Stuck MRPCs R&D w/ cosmic rays @ Tsukuba

1. Reproduce a good timing resolution 20-40 ps by 4 stuck MRPCs.
2. Optimize the parameters (# of gas gaps, gas gap width, etc.)
3. R&D for the J-PARC Heavy Ion project (30 ps TOF for hadron and muon ID) & potential use for J-PARC E16.
4. Extensive study with cosmic rays.
4 stacks MRPC in Tsukuba (2014-)

4 stacks MRPC (6 gaps x 4)
T. Nonaka (U. Tsukuba, 2015, master thesis)

Approaching to 30 ps timing resolution, importance of pre-amp gain tuning.
read out system: DRS4 evaluation board (ver. 4)
Current best & reliable value of timing resolution of this type: **47.5 ps (cosmic ray)**
Readout system (DRS4 ver.3)

T. Nonaka, Master thesis (2015, Mar.)

DRS4 evaluation board
(4ch x 3, 5 Gsa (200 ps sampling), switched capacitor array, PSI).

MRPC pulse measured by DRS4

DAQ GUI for DRS4 (T. Nonaka)
Preamplifier (M. Inaba)

Used +/- differential amplifier
- Importance of optimization of gain and impedance matching

← impedance matching dep. on pulse shape
New 4 stack prototypes in Tsukuba for ELPH test beam

165 micron, 6 gaps
148 micron, 6 gaps
128 micron, 7 gaps
104 micron, 9 gaps
90 micron, 11 gaps
90 micron, 11 gaps
Typical setup for MRPC

[Image of a typical setup for MRPC with labels for MRPC and preamplifier (M. Inaba)]
4 stuck MRPC results by cosmic rays

Shown @ JPS2016 spring meeting (K. Sato)

Gas gap width

- 165 µm
- 128 µm
- 104 µm
- 148 µm

R134a : SF₆ = 20 : 2 mL
Good signal : Streamer = 1 : 1 at the best timing resolution

(R134a : SF₆ = 50 : 5 mL
Good signal : Streamer = 97 : 1%

* 165 um MRPC: tested with beam at ELPH (2016)
Medium area MRPC prototypes

- Two types (pad and slat) PCB have been made.
- 20 cm x 30 cm PCB size
- built 4 stack MRPCs for each time, under the test with cosmic rays.
- to be tested at ELPH.
- It could be a prototype for E-16.
@ U. Tsukuba lab.
3. Signal properties (collaboration w/ SONY)

- SONY Global Manufacturing & Operations Co. (SONY GM&O)
- Modeling MRPC detector
  - Electromagnetic field cal. by solving Maxwell eq. numerically.
  - Consulting of fast signal propagation in electrodes, cables, impedance matching, and actual test.
Electromagnetic field cal. Model (SONY)

HFSS analysis, MRPC-3D model

Current generation point

50 Ω termination

Electrode

Current generation point

Electrode Cable

FEE PCB

Side view

<Time> <Frequency>

Amplitude: 1A
Rise time: 500ps
An example: proposed modifications (SONY)

Electric field near electrodes (as a function of time)

Default

Modified (Ref. conductor)

high density of electric field on the edges of electrodes ⇒ interference

Ref conductor, reduce the dispersion of electric field ⇒ small interference
Example: Pulse response

- Lager amplitude
- Reduction of reflection
- Reduction of interference between adjacent electrodes

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<th>B side</th>
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**Merit**

- Lager amplitude
- Reduction of reflection
- Reduction of interference between adjacent electrodes

**Demerit**

- Reduce electrode area
  - width 24mm⇒8mm
  - reduction of efficiency.
Proposed modification (Dec. 2015)

**Plan ①: Multi layer PCB**
- Electrodes in the different layer of PCB
- GND above electrodes
- Add current on near-by electrodes (by a different circuit)

**Plan ②: Patch structure**
- electrode pad: 24mm × 24mm
- put co-axial connector and cables on each pad

※ co-axial cable
Design considerations

– Grounding, signal reflection, impedance matching, preamp design.

– Two prototypes has been tested at ELPH beam test in Nov. 2016, together with the planed MRPC prototypes (small and medium sizes).
4. Test beam experiment in 2016 @ ELPH

GeV γ beam line @ ELPH (U. of Tohoku)
- positron beam @ 0.9 GeV
- Tested on Nov. 7-9, 2016, w/ JAEA group (GEM TPC)
4 stuck (165 um) MRPC with beams

Gas mixture and flow:
- R134a 50 ml/min
- SF6 5 ml/min (9.1%)

Best timing resolution:
- 67.4 ± 2.8 ps @ 12.0 kV

Efficiency

affected by streamers >13 kV
4 stuck (165 µm) MRPC with beams

K. Sato

Timing Resolution

MRPC Timing Resolution

a) Comparison w/ cosmic ray measurements

- Consistent with the results with cosmic

- Try 104 micron with beams (next step)

b) Comparison w/ other types (cosmic)
Medium scale MRPC:
4 stuck (165 um) MRPC with beams

Pulse shape, beam position dep.

Readout (L)          Readout (R)

Beam Position

Time (ns)

20 cm x 30 cm PCB size
4 stuck 165 micron gap width, 6 gaps/stuck
Preamp gain: 27, preamp impedance: 62 Ohm

Strongly affected by the refecion (and attenuation)!

T. Ichisawa
Medium scale MRPC: 4 stuck (165 um) MRPC with beams

- Best resolution: **76.7 ps @ 14 kV** at position “5”
- Worse resolution at the middle position “3”, due to the reflection on both ends.

**Efficiency**

- **Timing Resolution**: MRPC1 & MRPC2
- **Voltage (kV)**: 13, 13.5, 14, 14.5, 15
- **Timing Resolution (ps)**: 60, 80, 100, 120, 140, 160, 180, 200, 220, 240
- **Position (cm)**: 0, 5, 10, 15

**Efficiency (%)**

- **Voltage (kV)**: 13, 13.5, 14, 14.5, 15
- **Efficiency (%)**: 40, 50, 60, 70, 80, 90, 100

**Remarks**

- 4-stack 165um
  - position1, position2, position3, position4, position5, position6, position7

**Additional Notes**

- misalignment w.r.t. beam?
1 stuck (165 um) MRPC, pad size dep. with beams

- Expected timing resolution is 80-100 ps, but we focused on the signal shape change due to the pad shape.
- Collaboration with SONY.
1 stuck (165 um) MRPC, pad size dep. with beams

- Rise time of type2 is faster.
- The area of trigger is larger than width of type2.
- The distance to which signal run are different.
- any other reasons..?
1 stuck (165 um) MRPC, pad size dep. with beams

Timing resolution (beam spot dep.)

- **Type 1**

- **Type 2**

- Type2 was no obvious beam position dep.

- Different trend in type1. (affected by the reflection)
1 stuck (165 um) MRPC, pad size dep. with beams

**type1**

- Amp. for type1 are uncorrelated to the beam position.
- Near the reading position, amp. is higher than that for far reading position in type2.

**type2**

- Opposite to the medium scale MRPC (reflection)
- Due to the expected signal attenuation & less reflection?

\[
\text{Xaxis} = \frac{\text{amp for read1}}{\text{amp for read2}}
\]

![Diagram showing different types of MRPC and their respective amplifications at different voltages and reading positions.](image-url)
**Simulation by SONY**

**beam position dep.**

Signal arrival times are different for A and B, when beams are off center. PH are also different, due to the reflection.

### A side vs. B side

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- **A/B-1 CATHODE**
- **A/B-1 ANODE**
- **A/B-2 CATHODE**
- **A/B-2 ANODE**
- **A/B-3 CATHODE**
- **A/B-3 ANODE**

*Note: The graphs show the pulse shapes for different positions along the slat.*

- **1cm along slat**
  - **A**
  - **B**

**Pulse shape superimpose**

- **center**
- **1cm along slat**
Impedance measurements @ SONY

Connected signal cables and MRPC, TDR (differential impedance) measurement for the real prototype:

• Cable’s differential impedance: ~100 Ohm
• MRPC’s differential impedance: ~50 Ohm
→ Needed to be match!
5. Summary and future plans

- Different type of MRPCs have been built and tested with cosmic and test beam at ELPH, with the collaboration with SONY.
  - Importance of impedance matching and gain optimization for each type of MRPC (measurement).
  - For 4 stuck 165 um (104 um) MRPCs (small type): best value ~47 ps with cosmic ray, and 67 ps with beams (ELPH).
  - Need more optimization for medium scale MRPC (reflection).
  - Narrower pad (~ 1.2 cm width) has a better properties on signal shape and timing.
- **Plan in 2017:**
  - Try 104 and 90 um gap size, with “on board” differential amp for each stuck first, and then summing (SONY, M. Inaba).
  - Test on patch type, and further study on larger area MRPC.
  - ELPH test beam in late 2017.
  - Collaboration with M. Chiu (BNL) for sPHENIX fast TOF (achieved 18 ps timing resolution).
  - Garfield++ simulation?
  - Readout electronics R&D using DRS4 and prototyping.
BACKUP
Preliminary Spectrometer Design

Top View

hadron-ID ($\theta < 117^\circ$)
e-ID : $\theta < 30^\circ$
$\mu$-ID : $\theta < 25^\circ$
$20^\circ = \text{mid rapidity}$

Centrality MC + ZCAL