CERN MCP-TOF Results

A. Lehmann, M. Böhm, M. Pfaffinger, F. Uhlig

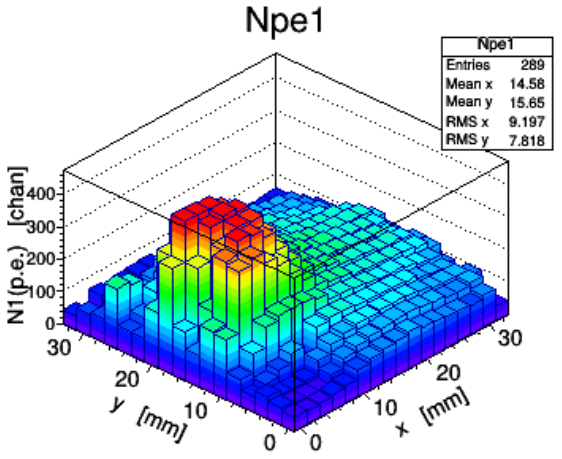
- Readout tests with several SiPMs per SciTil
- CERN MCP-TOF setup
- TOF resolutions
- From TOF resolutions to counter resolutions
- Counter resolutions
- Summary

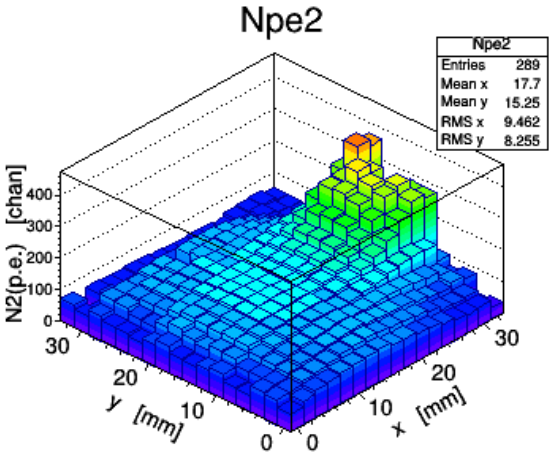
Tests with 2/3/4 SiPMs/SciTil Side

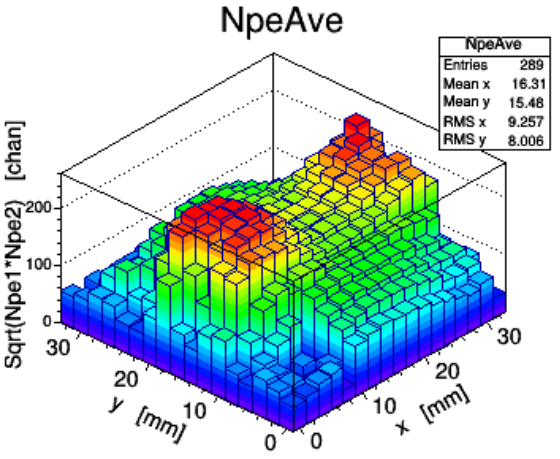
- Setup
  - BC418 scintillator wrapped with aluminum foil
  - 2 – 4 serial 3x3 mm^2 SiPMs per side of 30x30x5 mm^3 SciTil
  - KETEK PM3375TPSB0 with 75 µm pixels
  - Readout with VME DAQ
- Time Resolutions
  - 1 SciTil (center): **>120 ps** (for Hamamatsu SiPMs)
  - 2 SciTils (outside): 82 ps
  - 2 SciTils (center): 80 ps
  - 3 SciTils: 66 ps
  - 4 SciTils: **55 ps**

Pulse Heights with 2 SiPMs/side

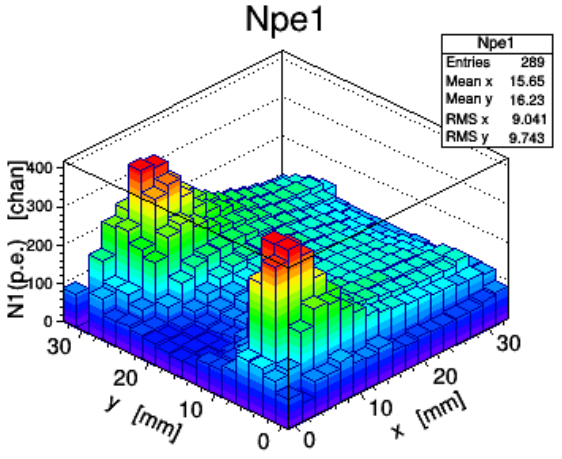
2 SiPMs (center)

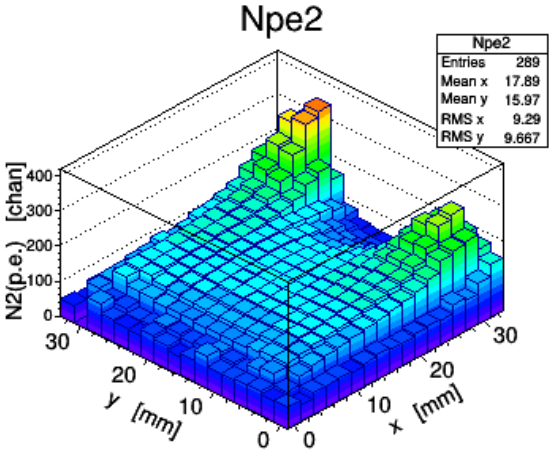


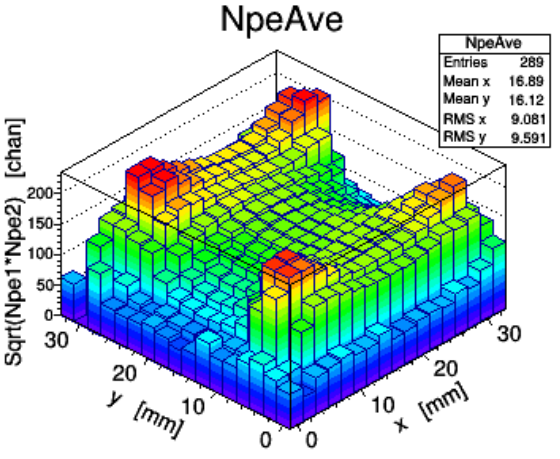




2 SiPMs (outside)



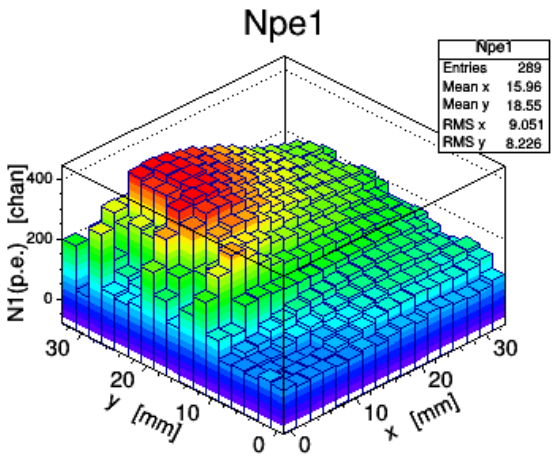


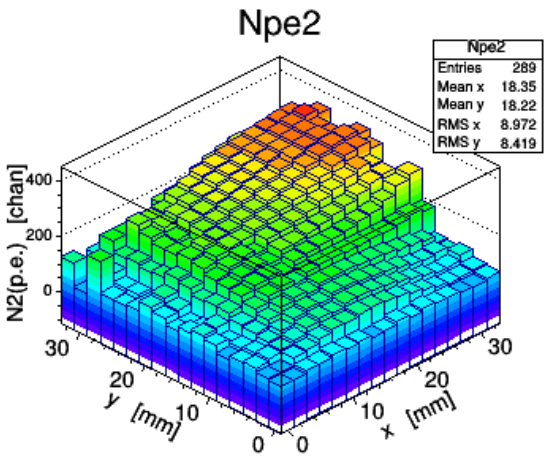


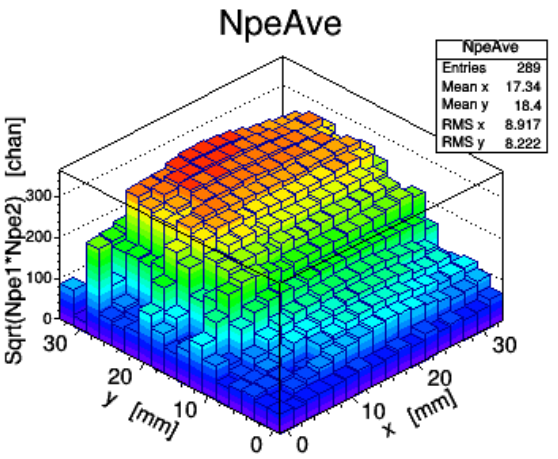
- Pulse height distributions depend heavily on SiPM placement
- No homogeneous pulse height distributions

Pulse Heights with 3/4 SiPMs/side

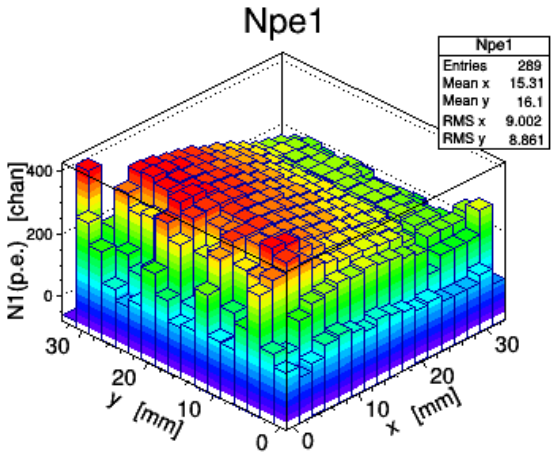
3 SiPMs (left)

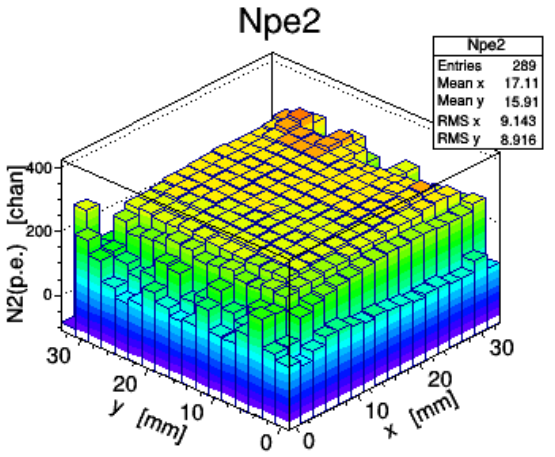


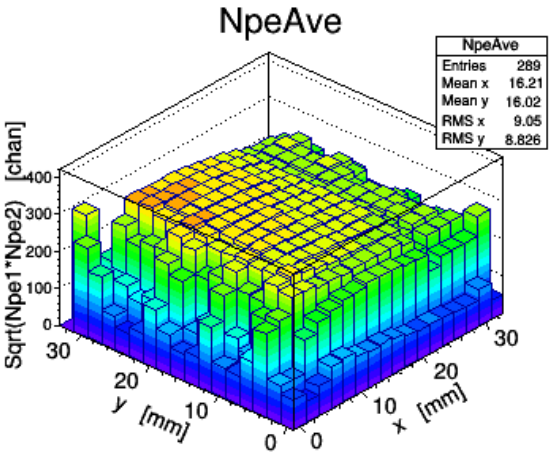




4 SiPMs (center)



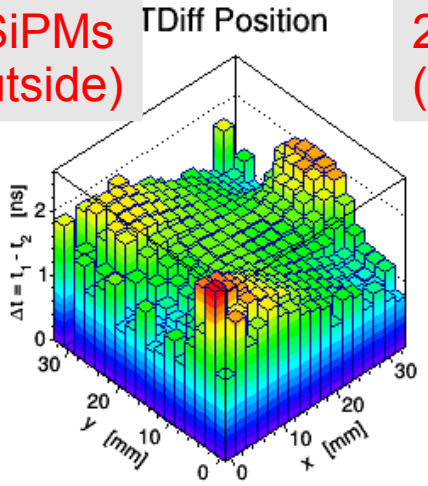




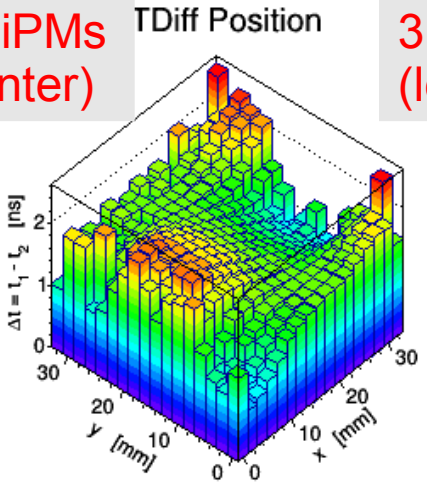
- Pulse height distributions are getting more homogeneous with increasing number of SiPMs/side

Time Resolution with 2/3/4 SiPMs

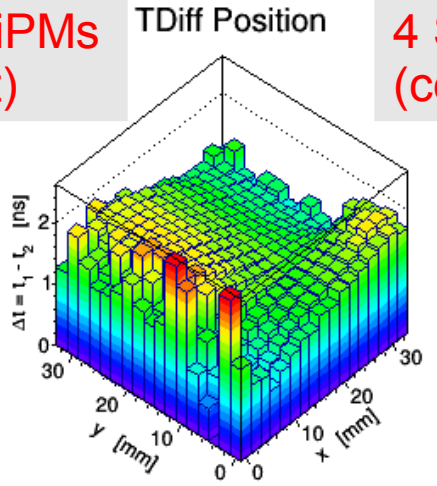
2 SiPMs (outside)



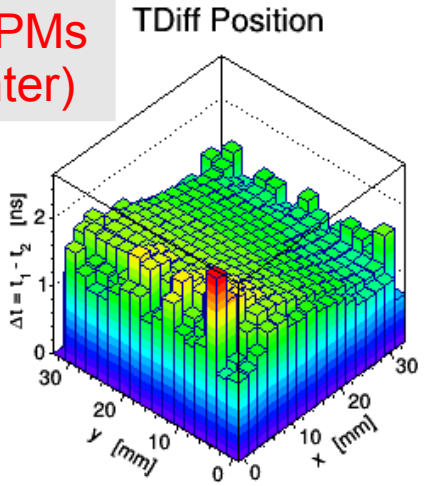
2 SiPMs (center)

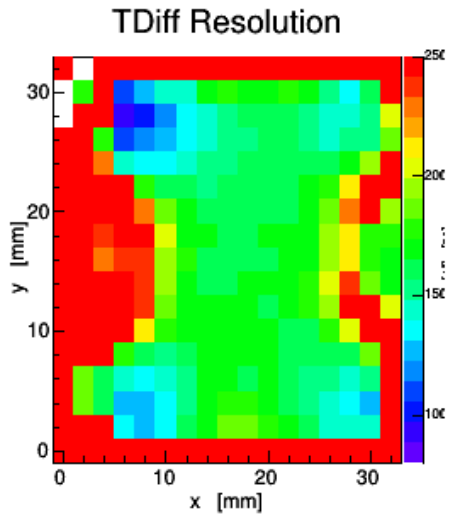


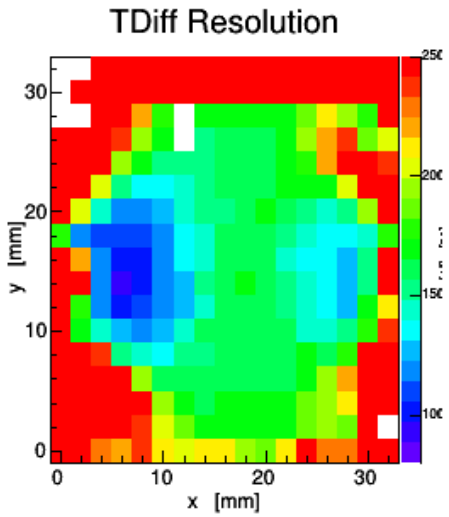
3 SiPMs (left)

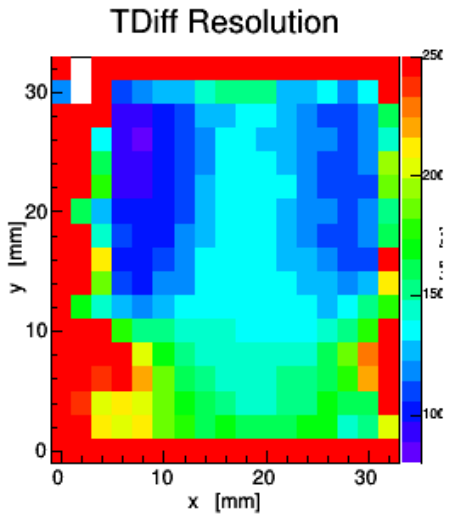


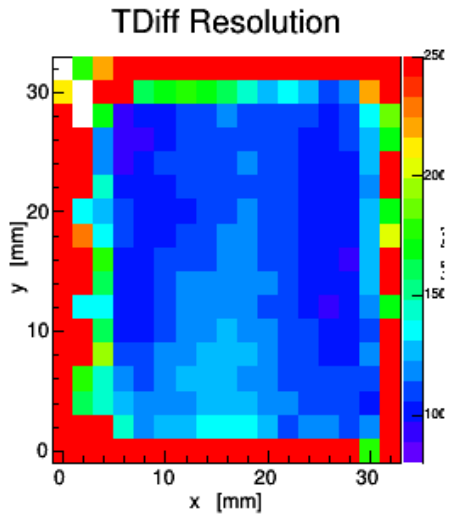
4 SiPMs (center)





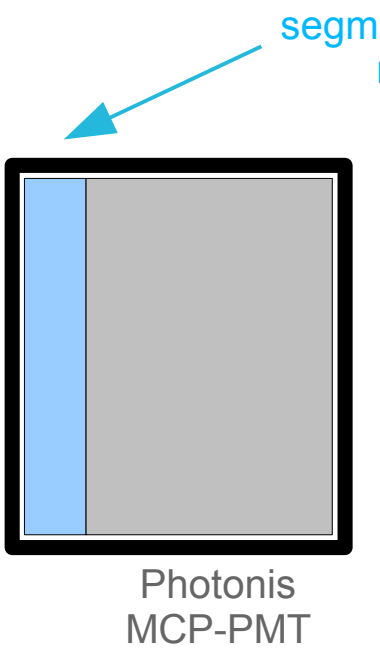


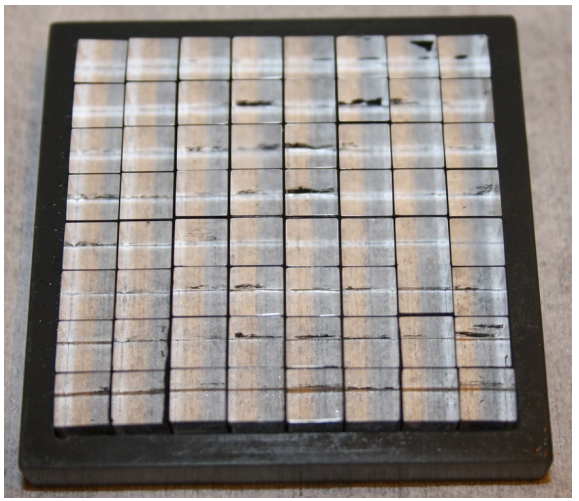




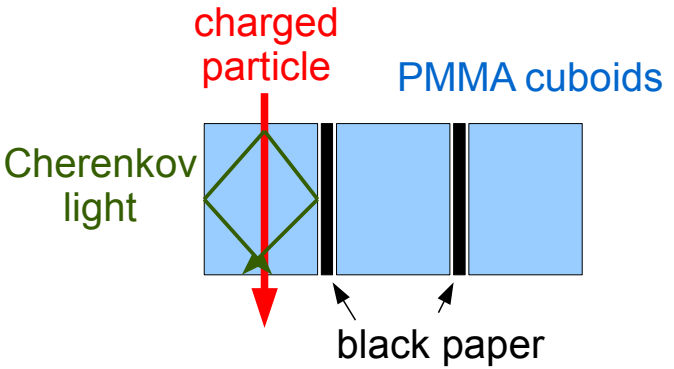
- Distribution of time resolution depends heavily on SiPM placements
- Best and most homogeneous time resolutions with 4 SiPMs/side

MCP-PMT Setup with Radiator





CERN run June/July 2015



- Segmented PMMA radiator coupled directly to Photonis XP85012/XP85112
  - Each PMMA segment matches MCP anode pixel (8x8 pixel, 6x6 mm^2 each)
  - Particle beam perpendicular to radiator directly through MCP-PMT
- Readout of 64 anode pixels and 1 MCPout (sum of all anodes) with Padiwa frontend boards and TRB DAQ

SciTil Setup

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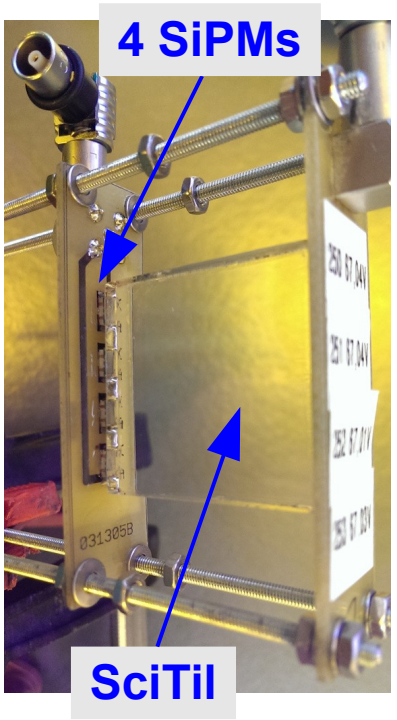
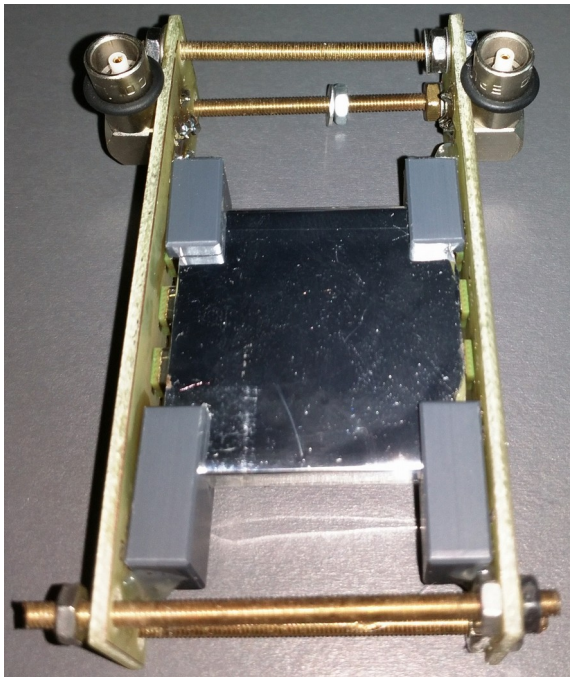
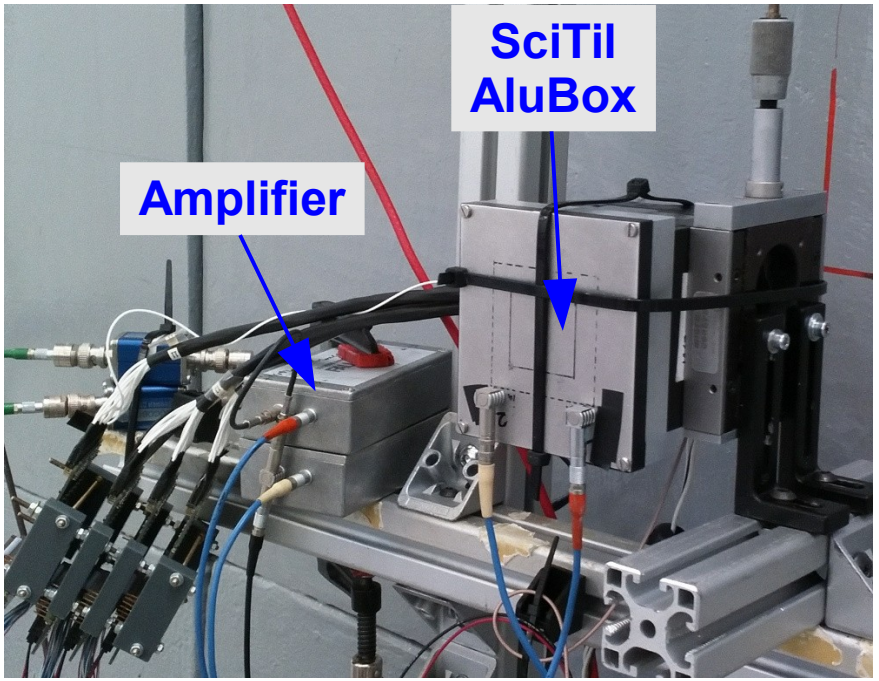




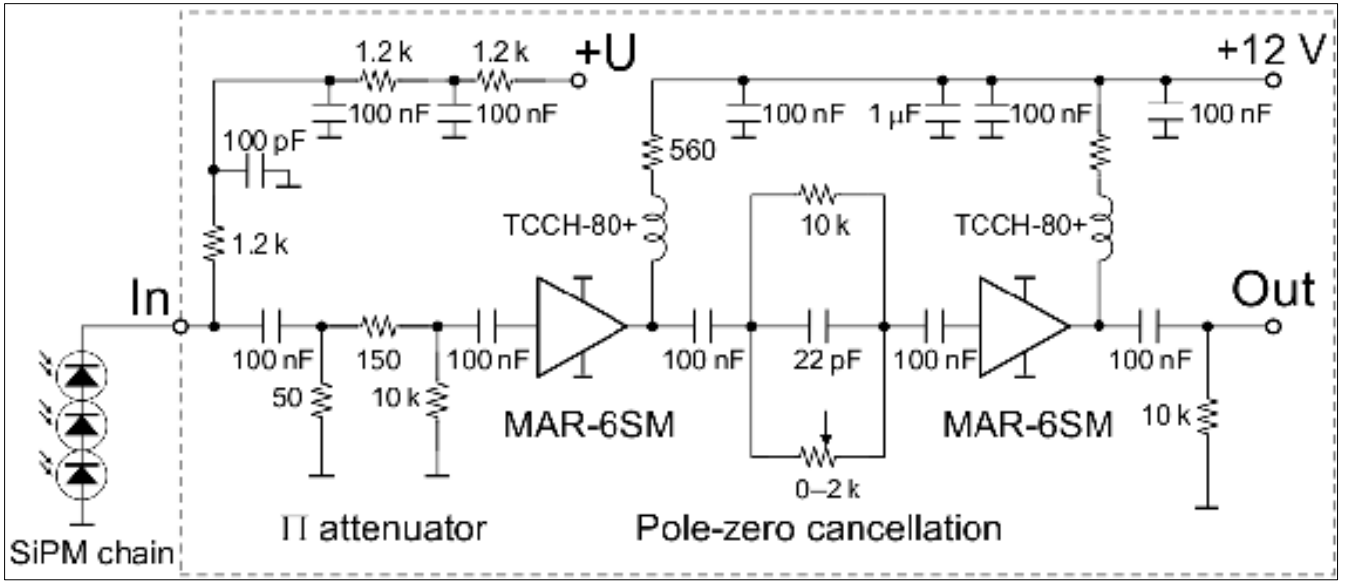


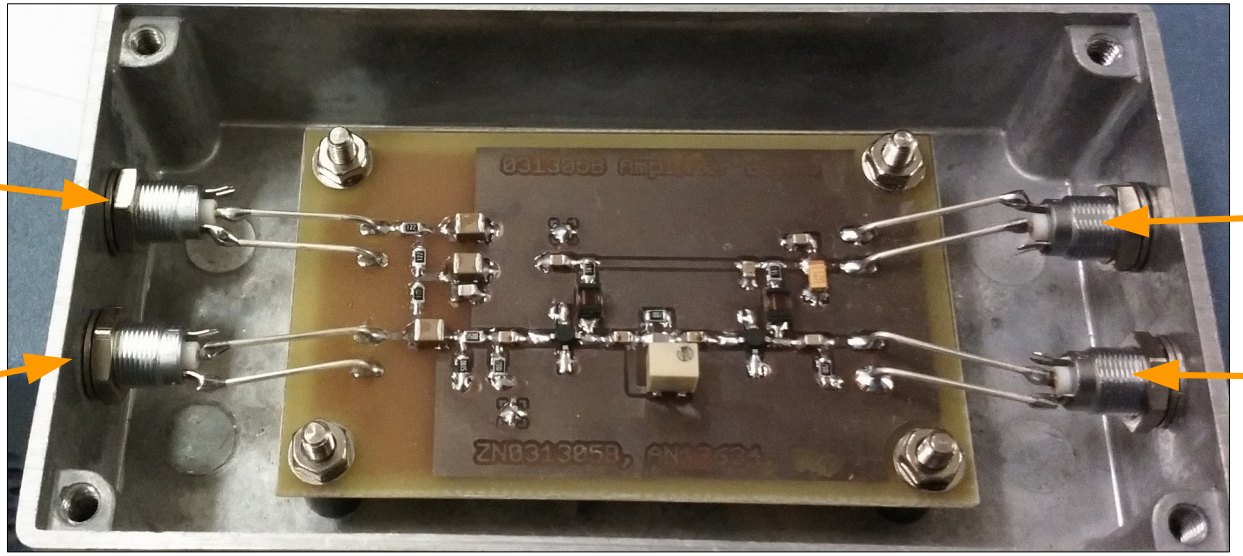
- SciTils (BC418, 30x30x5 mm^3 and 30x50x5 mm^3)
  - Wrapped in aluminum foil
  - Read out at 2 sides with 4 SiPMs (KETEK, 3x3 mm^2) connected in series
  - SciTil + SiPM readout boards packed in light tight alubox
- Raw signals fed through amplifiers and given to Padiwa frontend boards

SciTil Amplifier Layout

CERN run June/July 2015

P. Cattaneo et al.,
arXiv: 1402.1401v1





SiPM Voltage
+U

To SiPM
In

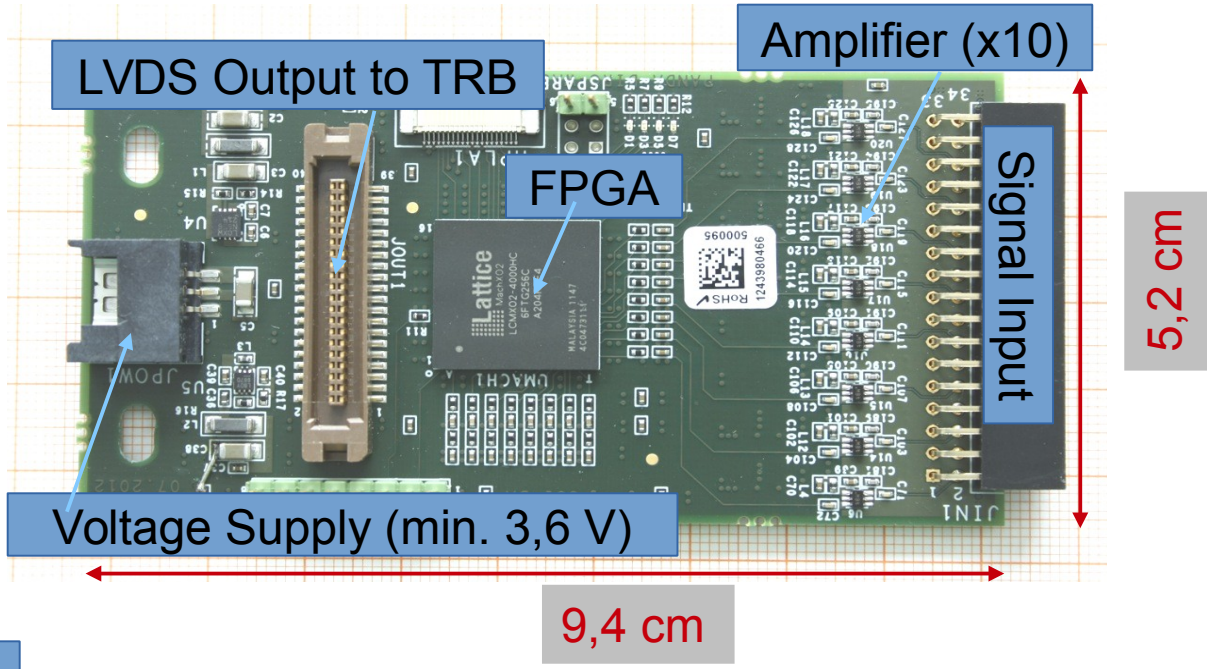
Amplifier
+12 V

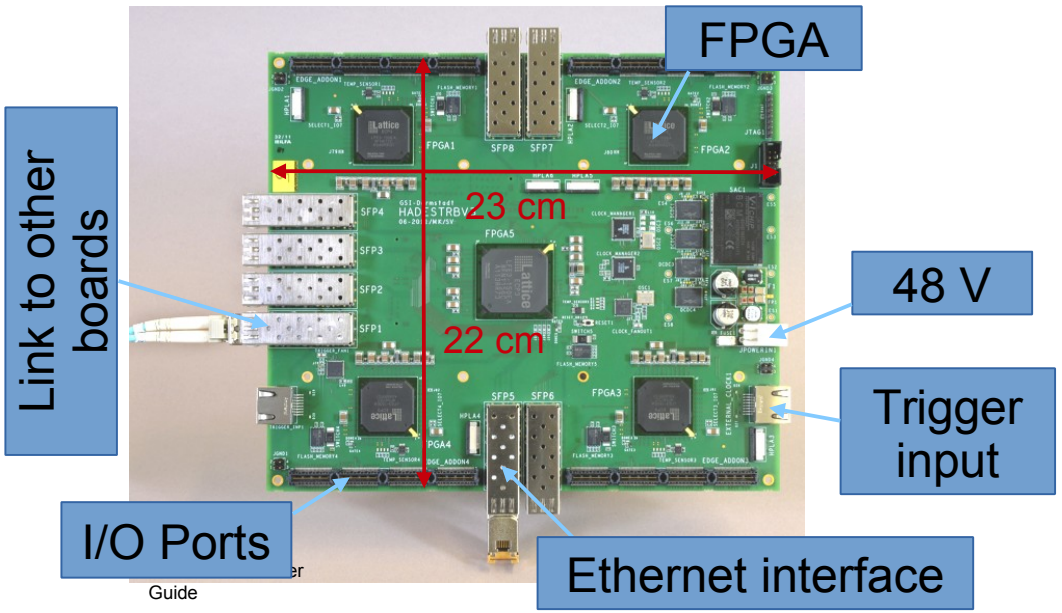
From SiPM
Out

MCP-TOF Readout

CERN run June/July 2015

- Padiwa
  - 16 channels input, LVDS output
  - Discriminator threshold selection and other settings via TRBv3 board

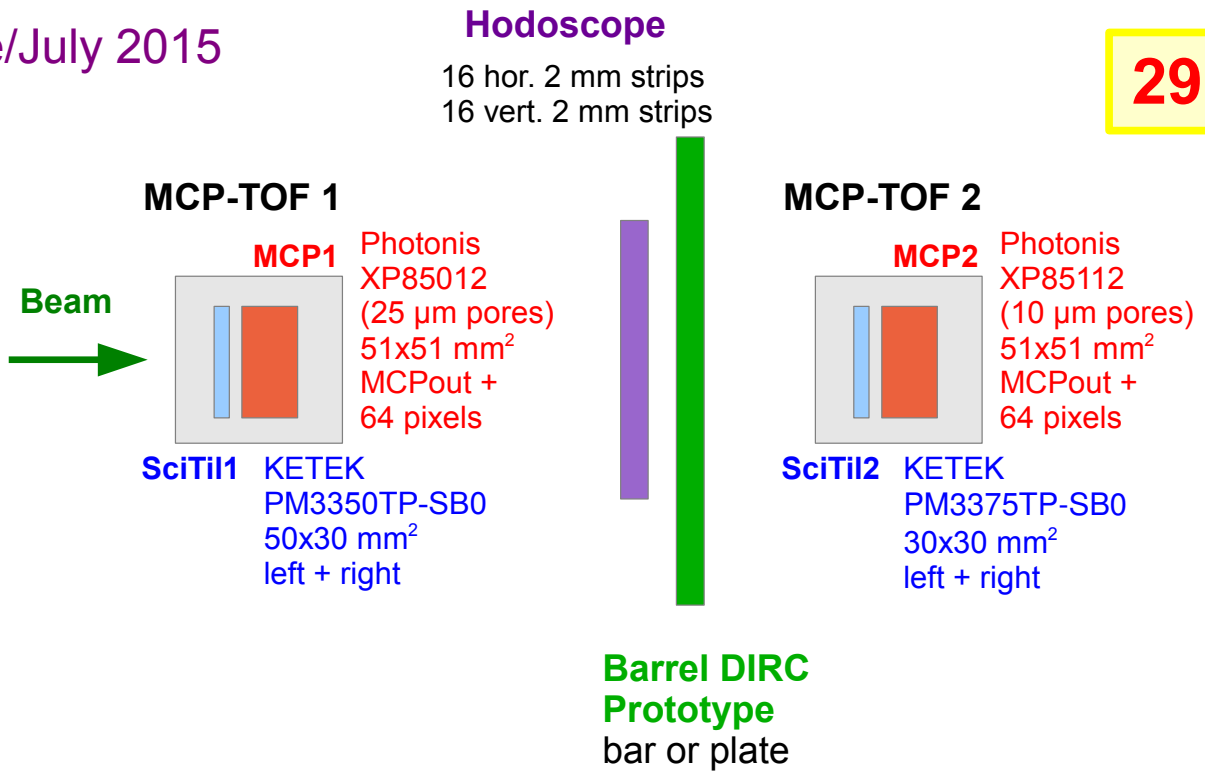




- TRBv3
  - FPGA based TDC and trigger board with 256 TDC channels per board
  - Up to 3.6 ps time resolution possible (~10 ps with 256 channels)

MCP-TOF Setup

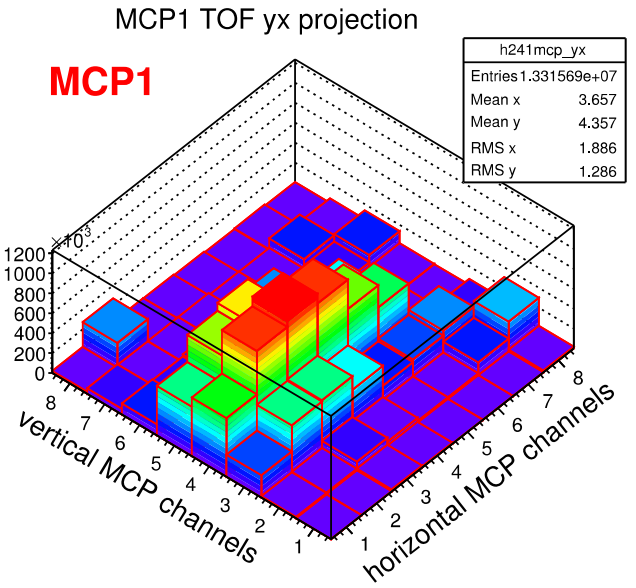
CERN run June/July 2015

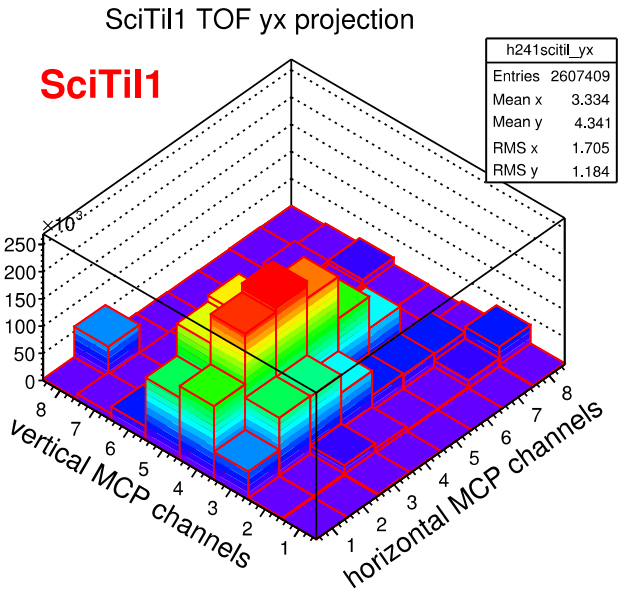


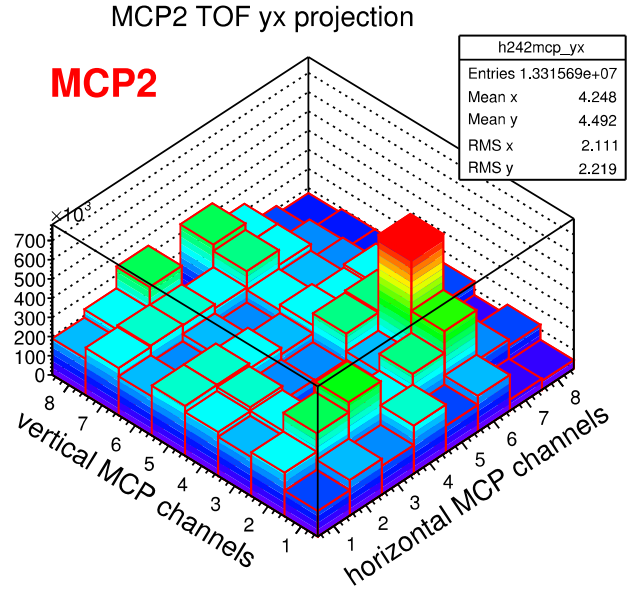
- In both MCP-TOF stations 1 SciTil and 1 MCP counter each
  - MCP-TOF1 (MCP-out, SciTil_l, SciTil_r) at one Padiwa (no reftime needed)
  - MCP-TOF2 (MCP-out, SciTil_l, SciTil_r) at one Padiwa (no reftime needed)
  - **2 different TRB-boards** for MCP-TOF1 and MCP-TOF2 **(reftime necessary)**
  - Additional setup with all MCP-out and SciTil signals at **1 TRB + aircell cables (no reftime)**
- 6 TOF infos → determination of time resolution for each counter possible

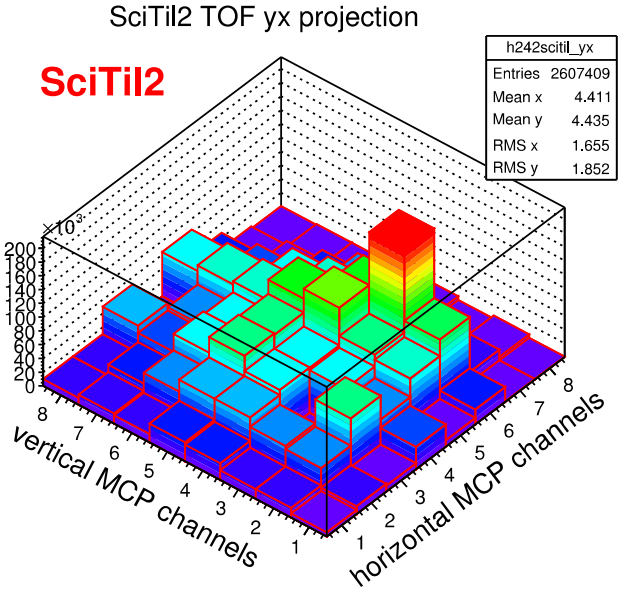
Beam Profiles (at 2 GeV/c)

- Plots show beam profiles at TOF1 and TOF2 (not perfect because of cross talk among MCP pixels)
- Narrow beam spot at TOF station 1
- Wide beam spot at TOF station 2
- At TOF station 2 narrow sized SciTil (30x30 mm^2) is visible in MCP area of 51x51 mm^2]





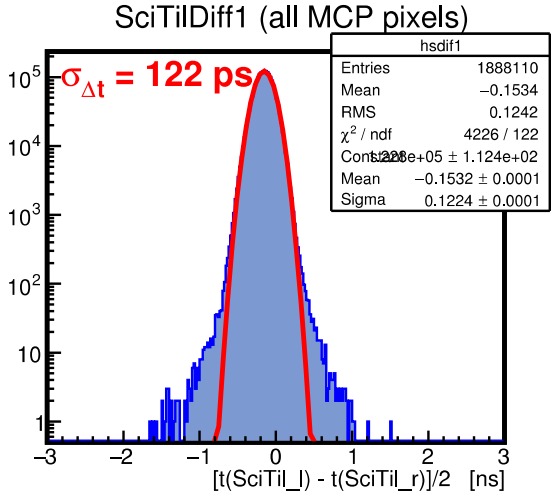


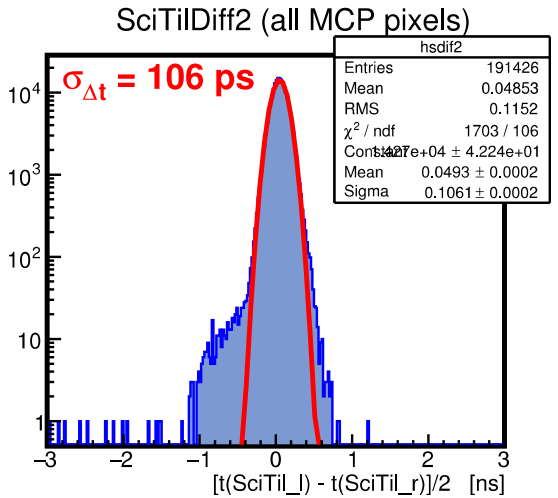


SciTil Time Difference (at 2 GeV/c)

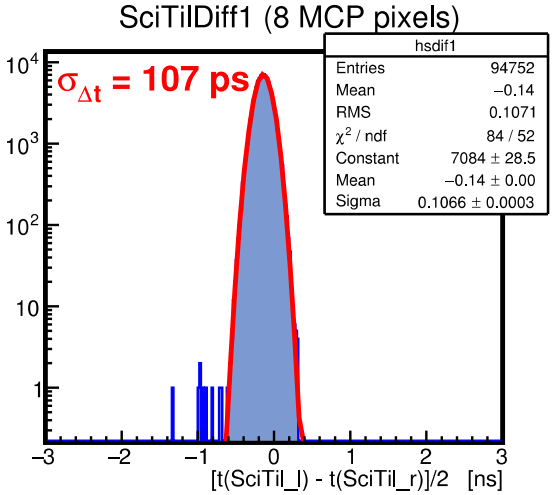
Time difference
Δt = (SciTil_left - SciTil_right) / 2

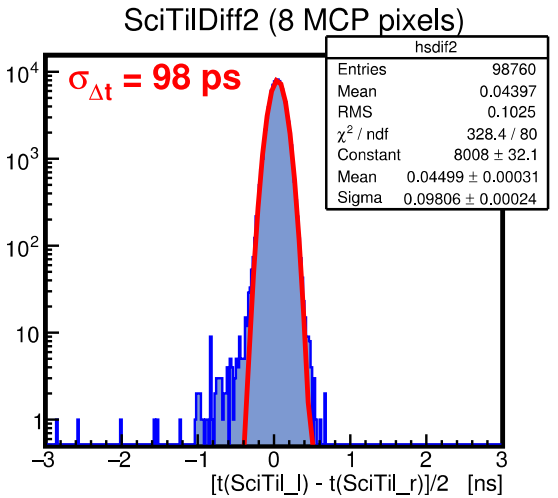
all 64 MCP pixels



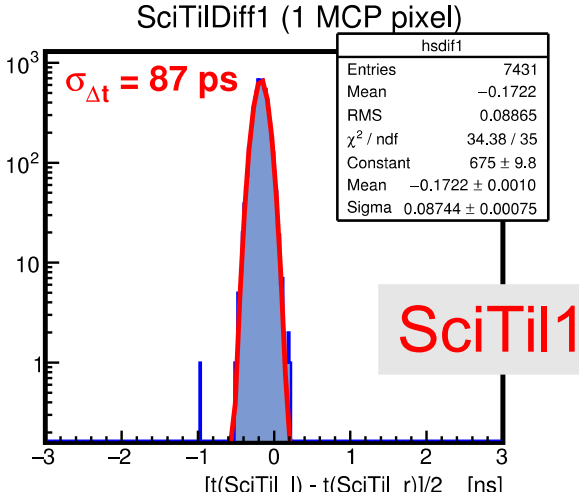


pixels (2-5)/(4+5)

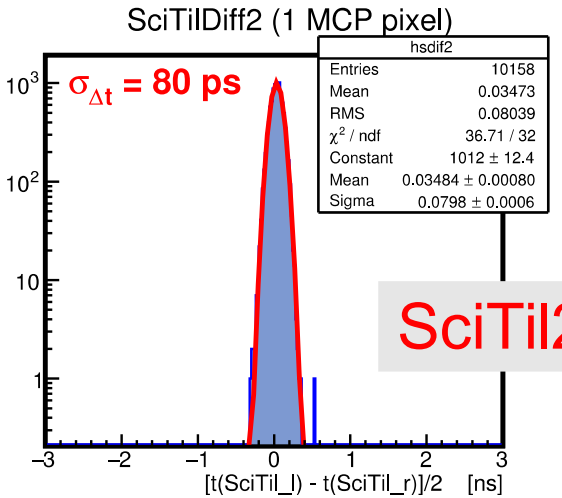




pixel 4/4



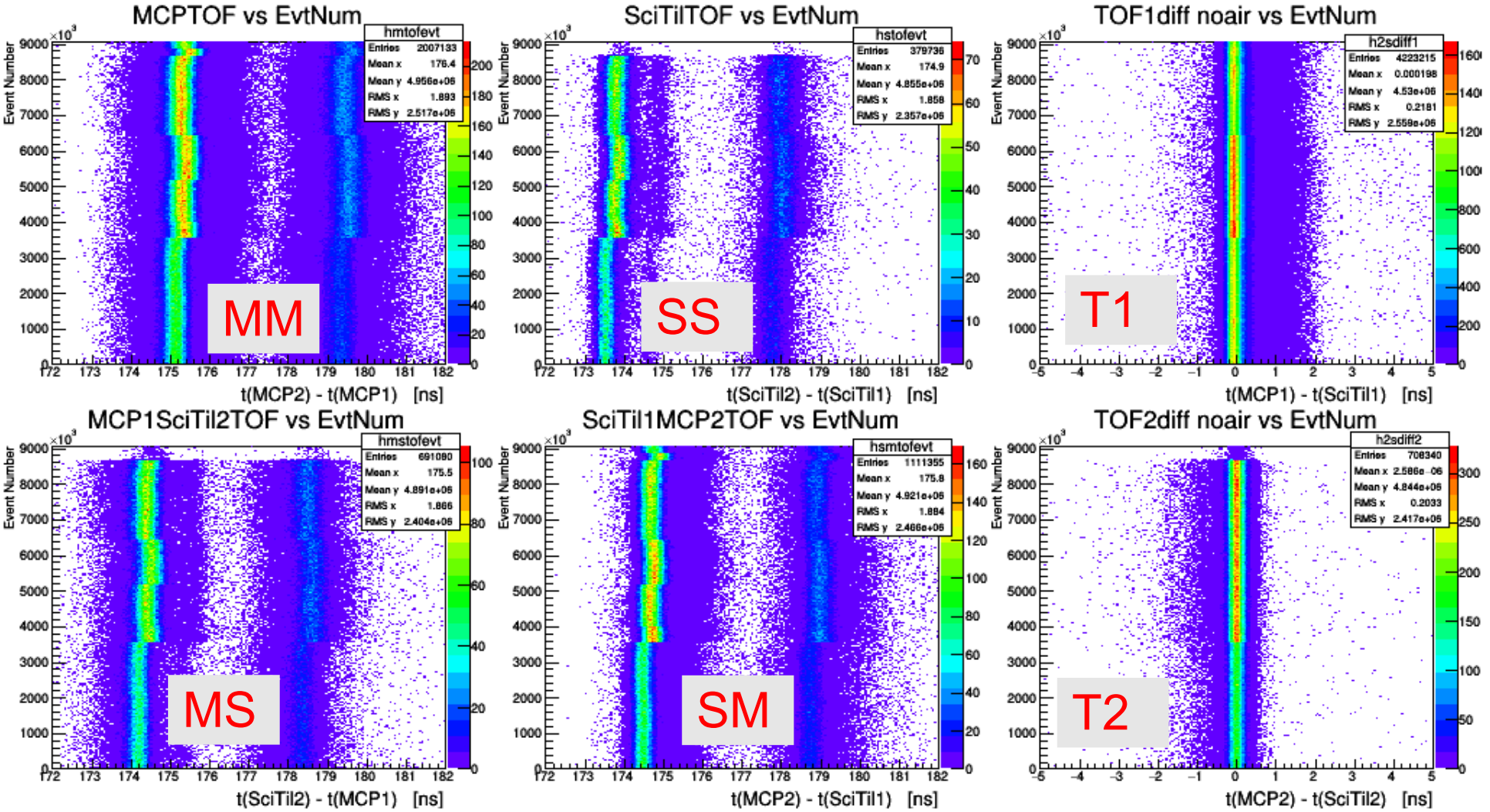
SciTil1



SciTil2

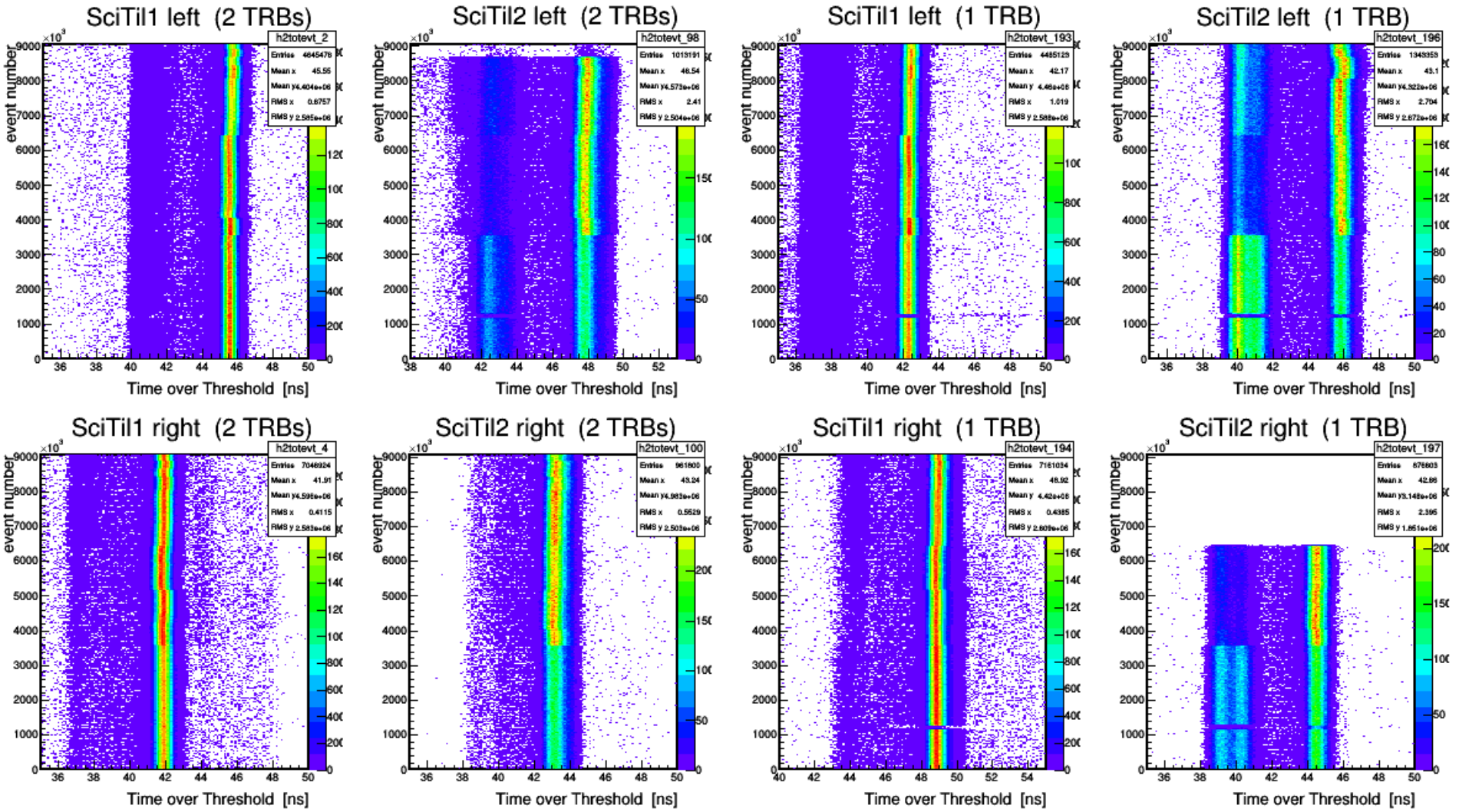
- SciTil 2 (30x30 mm^2) with better time resolution than SciTil 1 (50x30 mm^2)
- Time resolution with 1 MCP pixel (narrow) better than with all pixels (wide)

TOF vs EventNumber (at 3 GeV/c)



- All 3 GeV/c data used, but different TRB boards for TOF1 and TOF2
- TOF position is not stable over time → correction needed

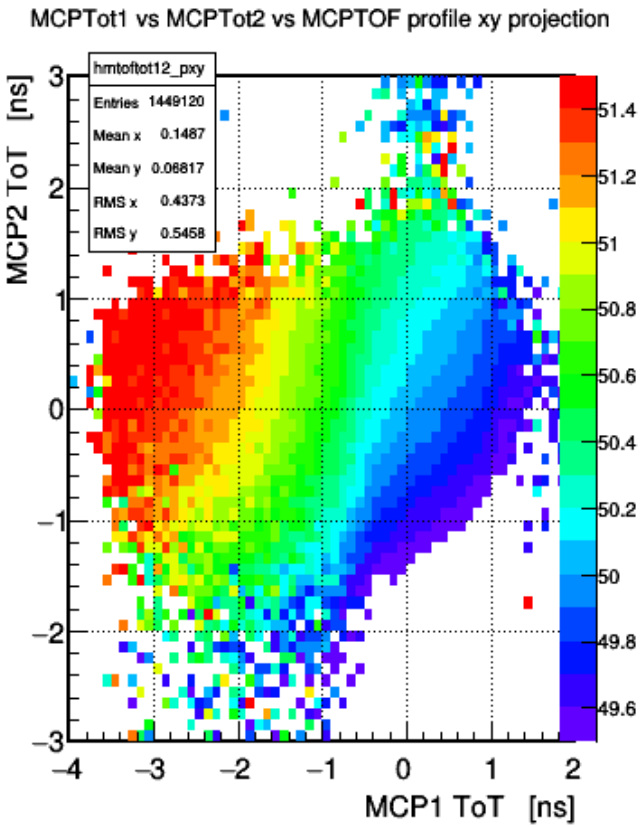
ToT vs EventNumber (at 3 GeV/c)



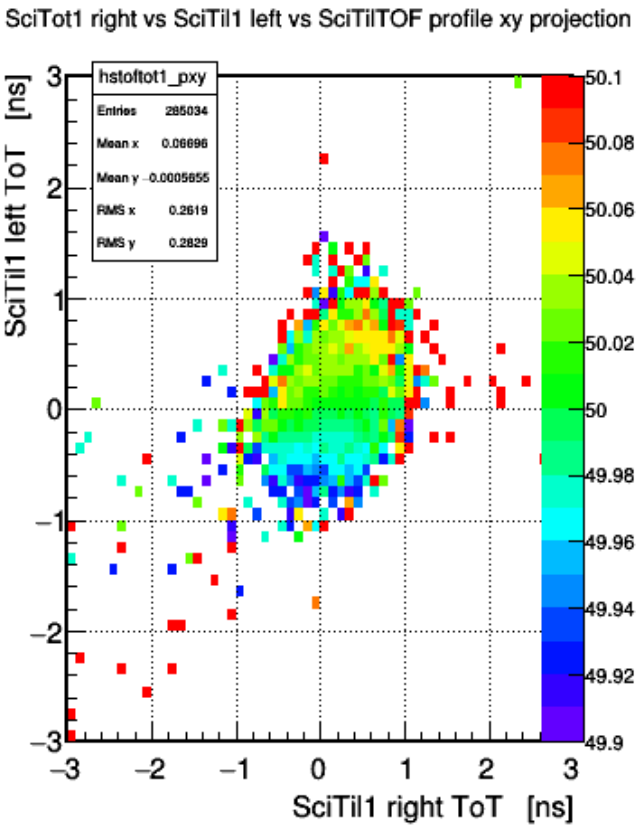
- All 3 GeV/c data used, with 2 TRBs and 1 TRB + long aircell cables
- ToT position is slightly instable over time → correction applied

TOF vs ToT1 vs ToT2 (at 3 GeV/c)

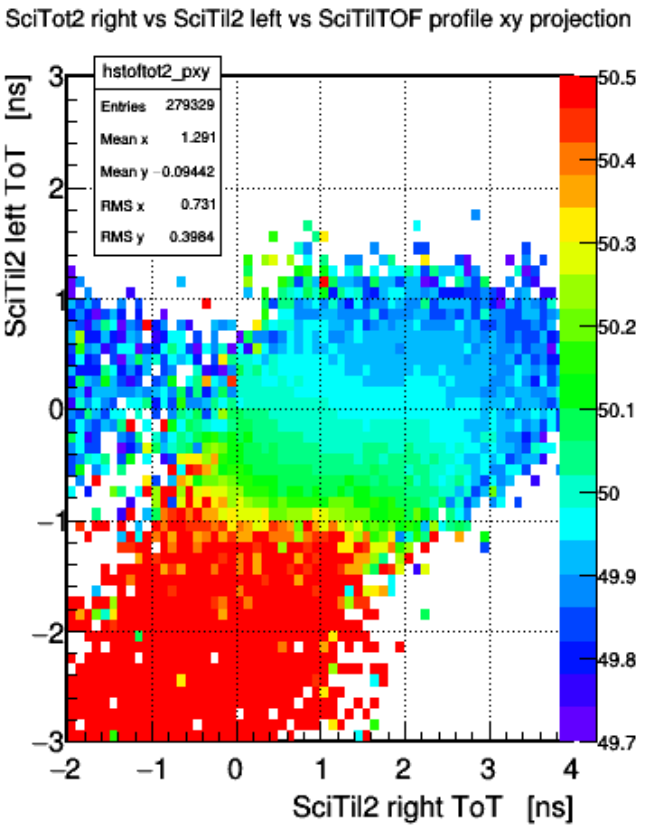
MCP1 vs MCP2



SciTi1 (left vs right)



SciTi2 (left vs right)



- 2D time walk correction
- All 3 GeV/c data, with 1 TRB + long aircell cables
- 2D profile histos using ToT show time walk effects → TOF correction

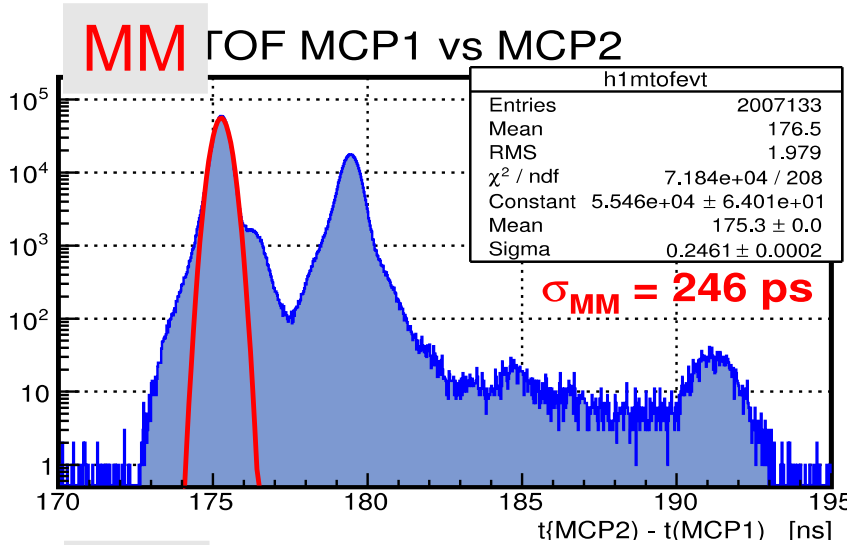
Corrections Applied to TOF Analysis

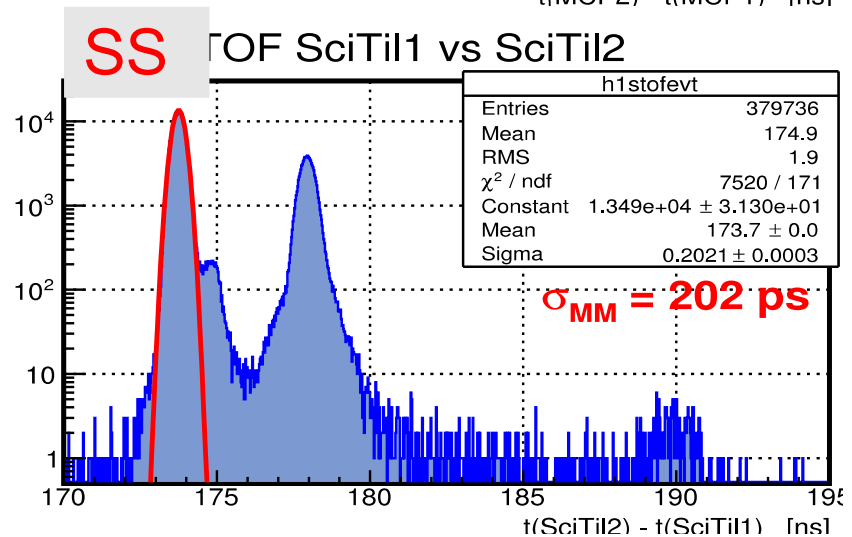
- Time of Flight (TOF)
  - Create 2D histo TOF vs EventNumber
  - Determine TOF positions after ~10k Events using TProfile
  - → event wise correction of TOF (t2 – t1) position
- Time over Threshold (ToT)
  - Create 2D histo ToT vs EventNumber
  - Determine ToT position after ~10k Events using TProfile
  - → event wise correction of ToT1 and ToT2
- Time Walk of corrected TOF and ToT1 and ToT2
  - Create 3D histo from TOF vs ToT1 vs ToT2
  - TProfile2D gives TOF position dependent on ToT1 and ToT2
  - → event wise TOF correction

Corrected TOF Resolution (3 GeV/c)

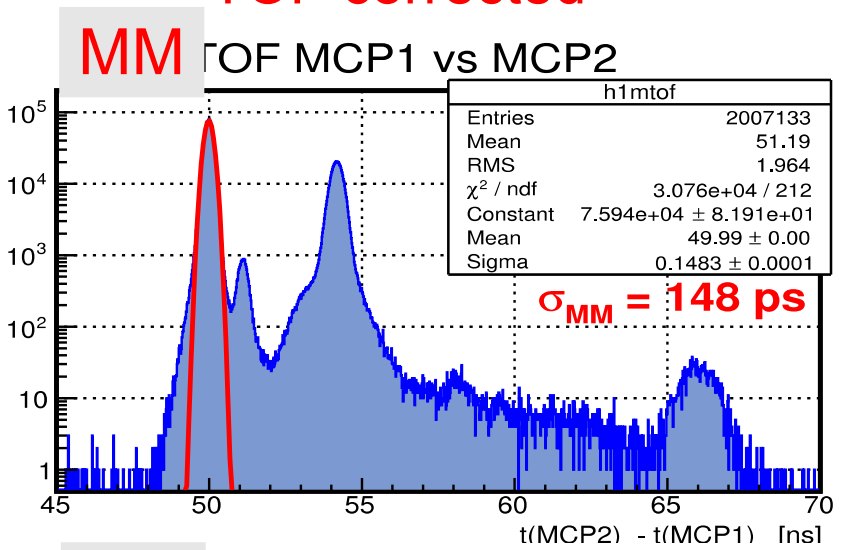
Readout with 2 TRB boards

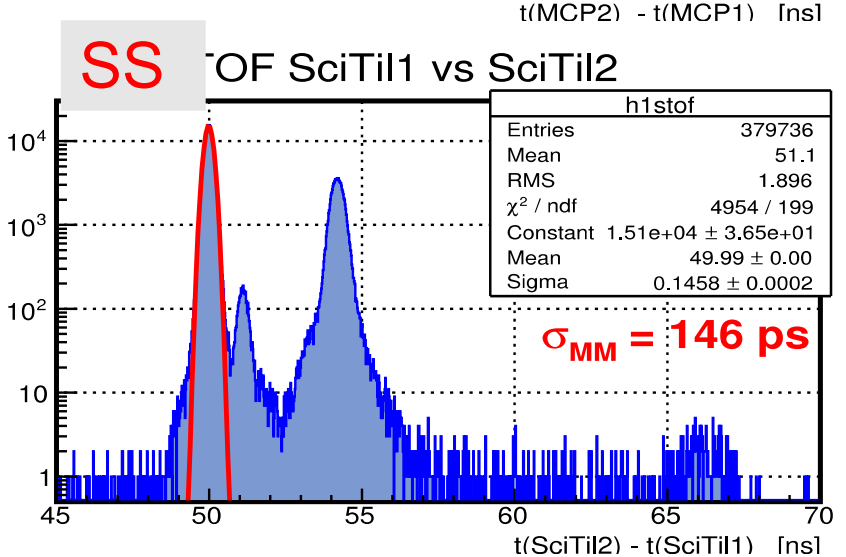
TOF uncorrected





TOF corrected



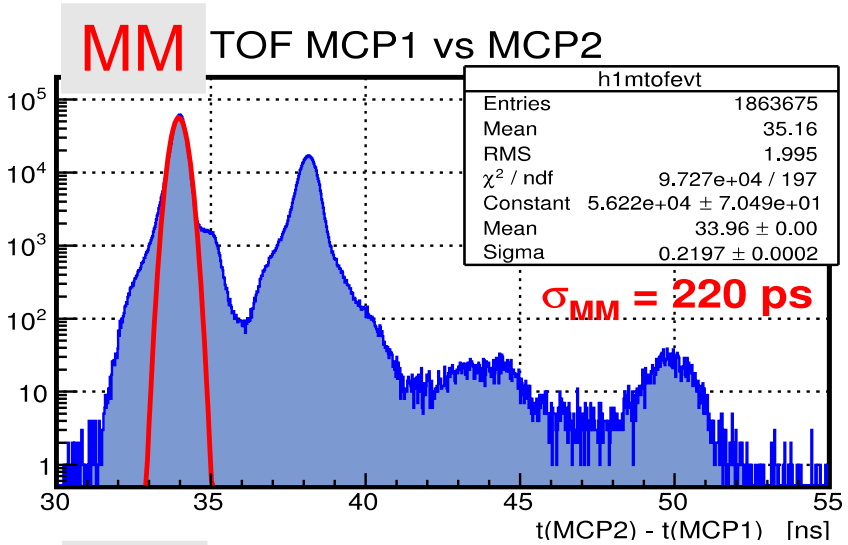


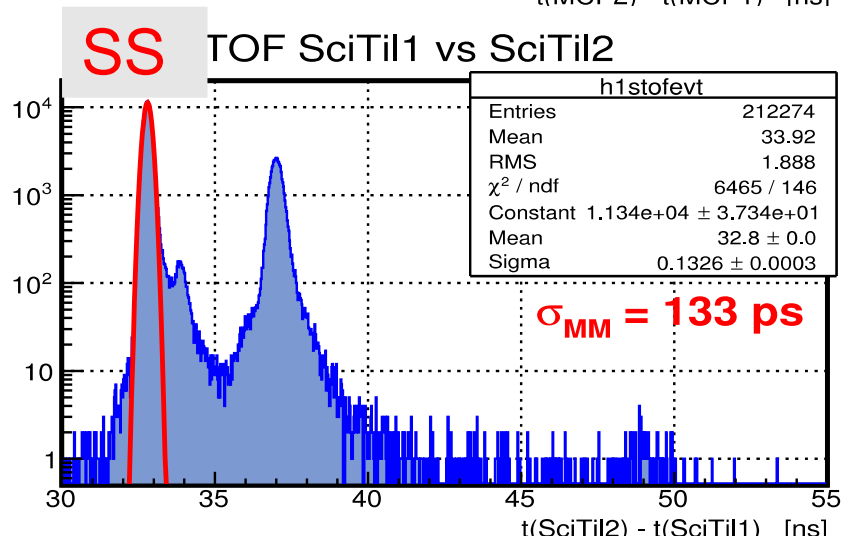
- Significantly improved TOF resolution after corrections

Corrected TOF Resolution (3 GeV/c)

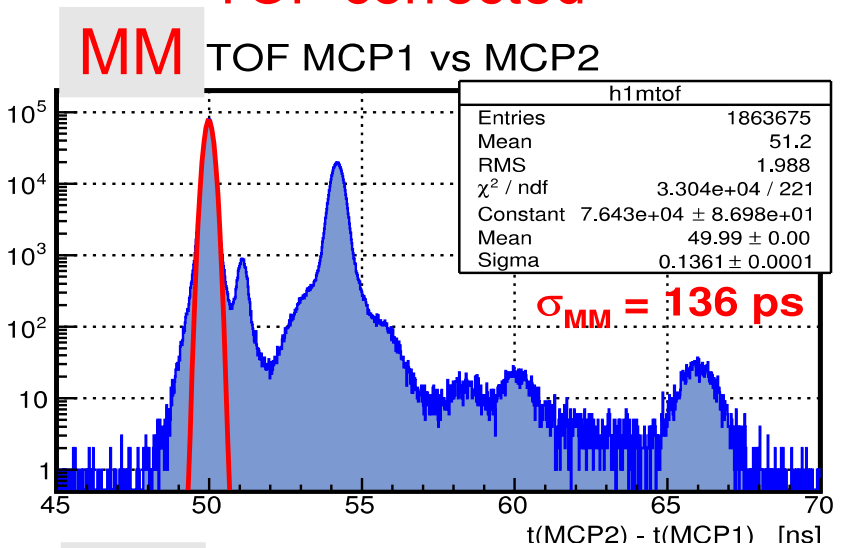
Readout with 1 TRB board
+ long aircell cables

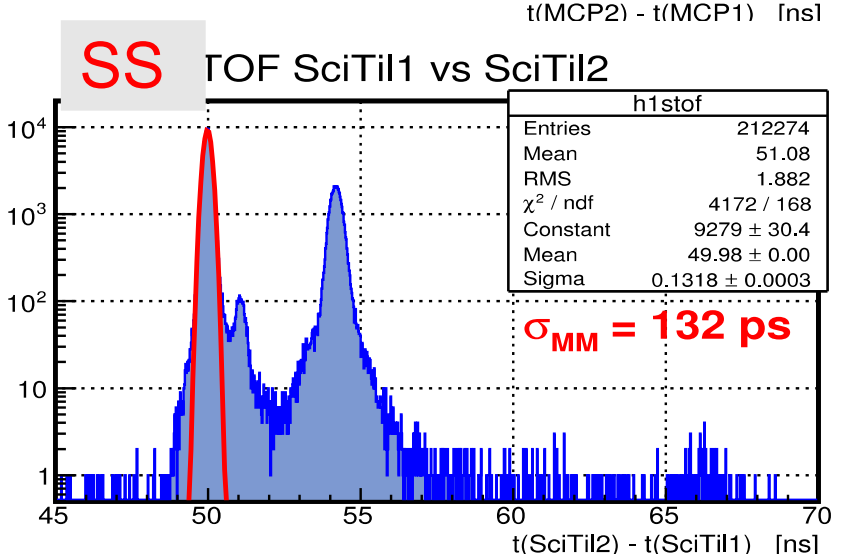
TOF uncorrected





TOF corrected

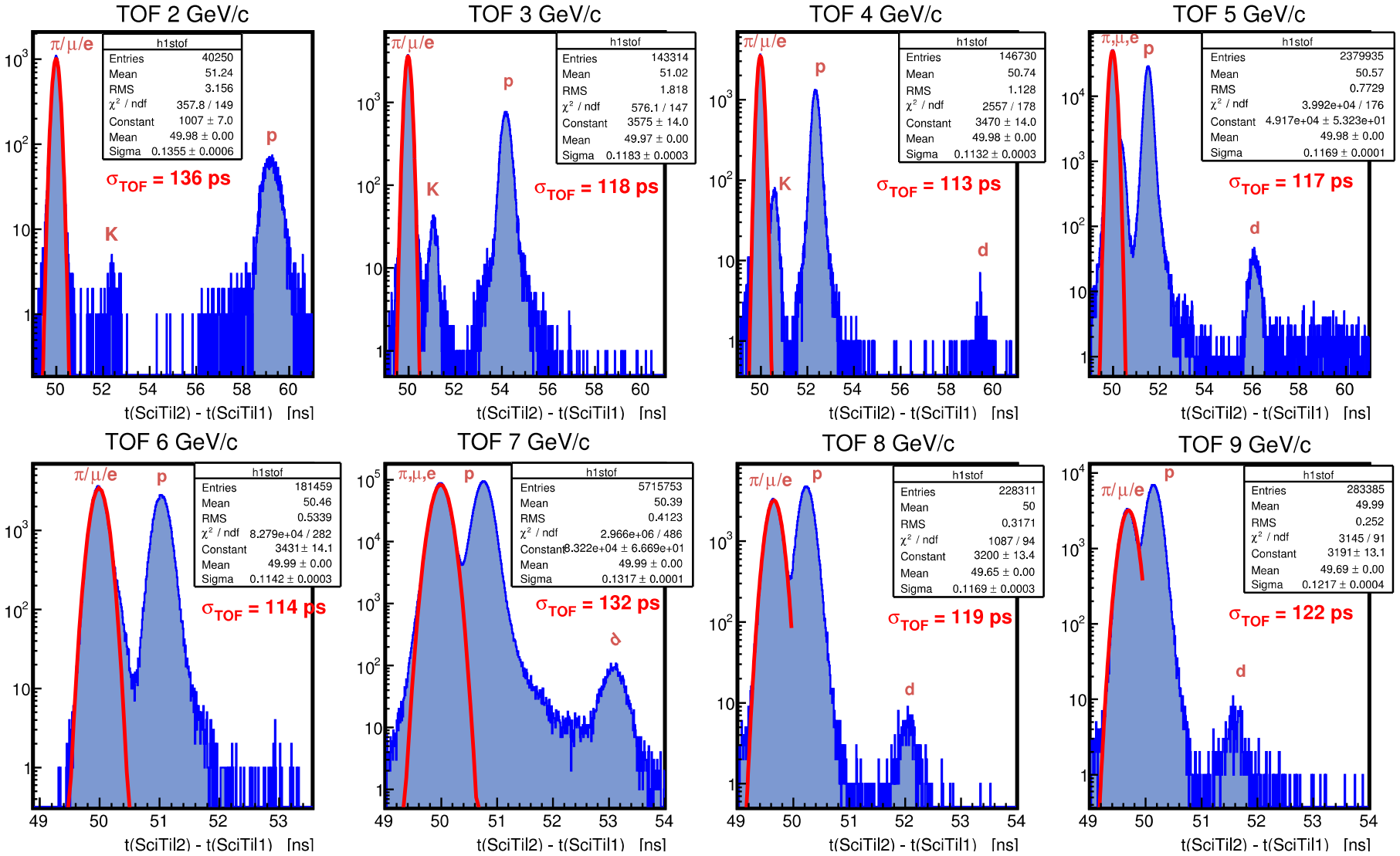




- TOF resolutions with aircell cables and 1 TRB better than with 2 TRBs

SciTil TOF and PID at 2 – 9 GeV/c

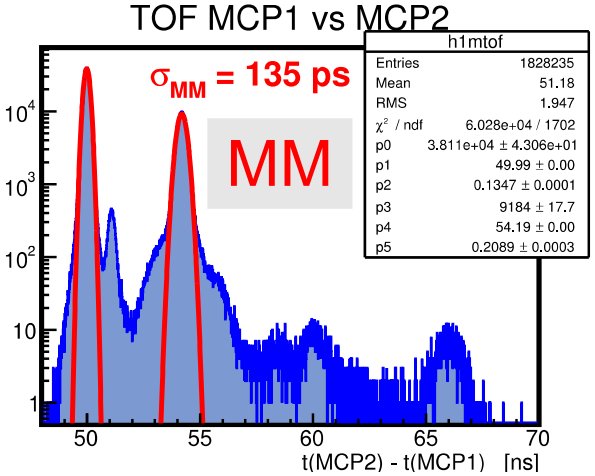
Readout with 1 TRB board
+ long aircell cables

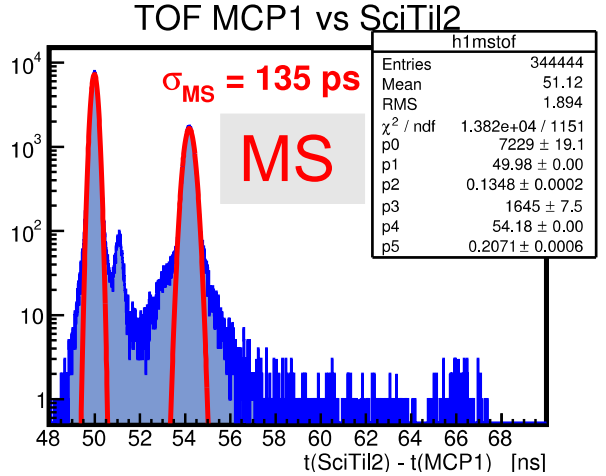


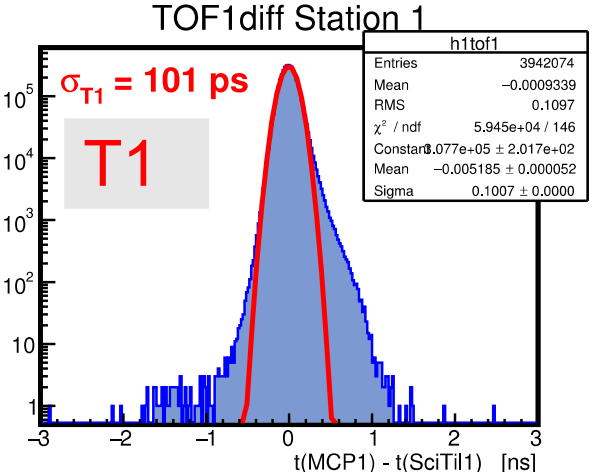
- "corrected" TOF = (SciTil2_l + SciTil2_r)/2 – (SciTil1_l + SciTil1_r)/2
- Pions and protons clearly separable up to 10 GeV/c, pions/kaons up to 4 GeV/c

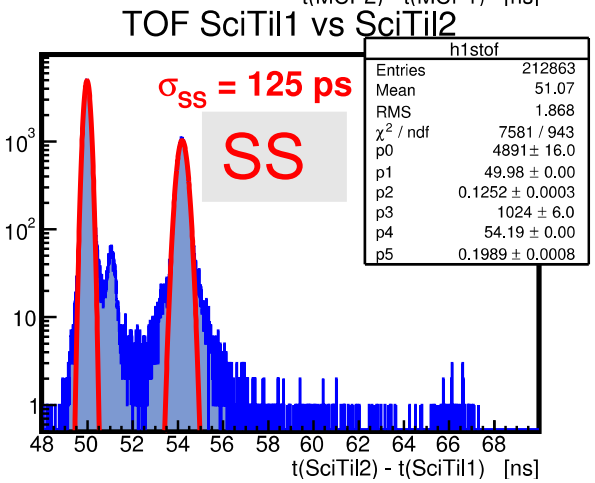
TOF Fits (3 GeV/c, all MCP Pixels)

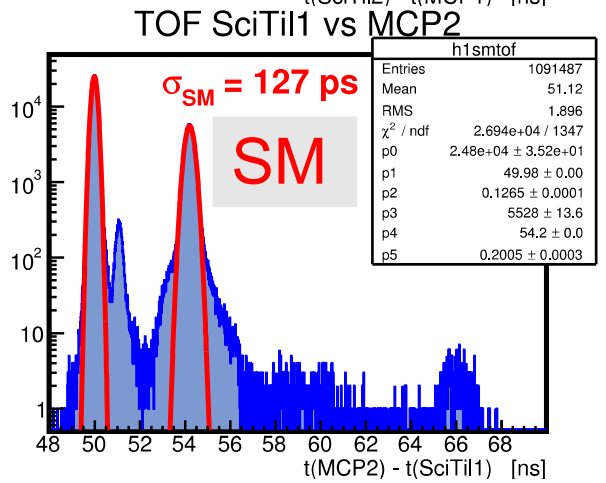
Readout with 1 TRB board
+ long aircell cables

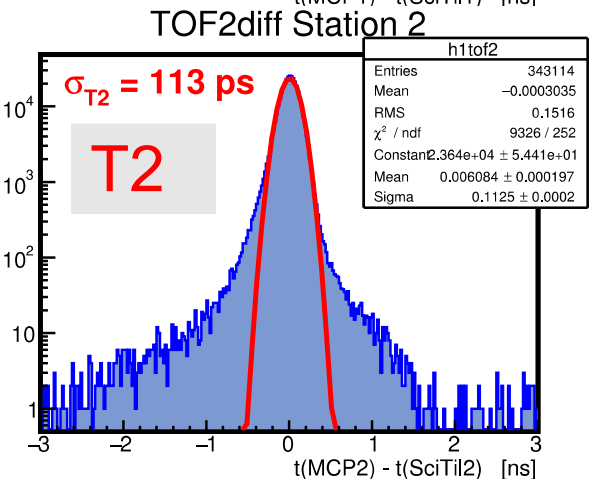








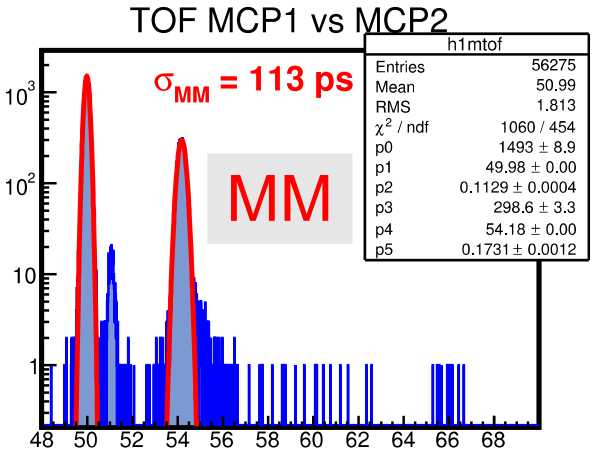


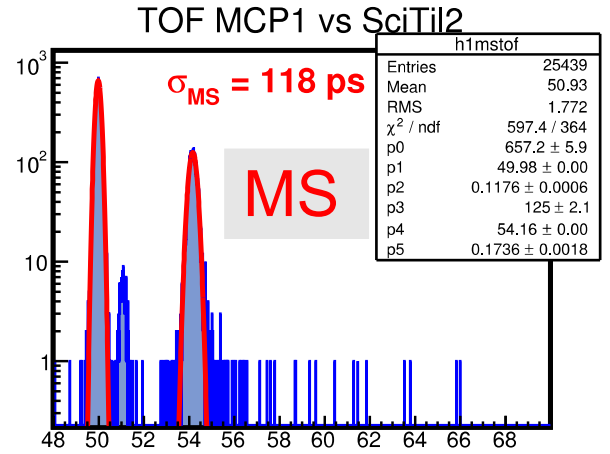


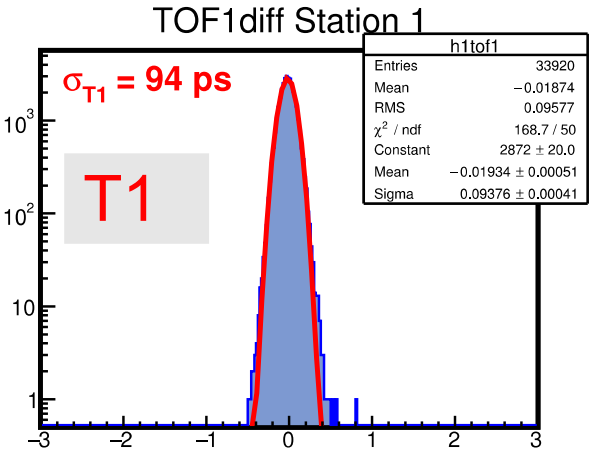
- Corrected TOF distributions of all MCP pixels (MCPout signal)
- Moderate resolutions for all 6 counter combinations

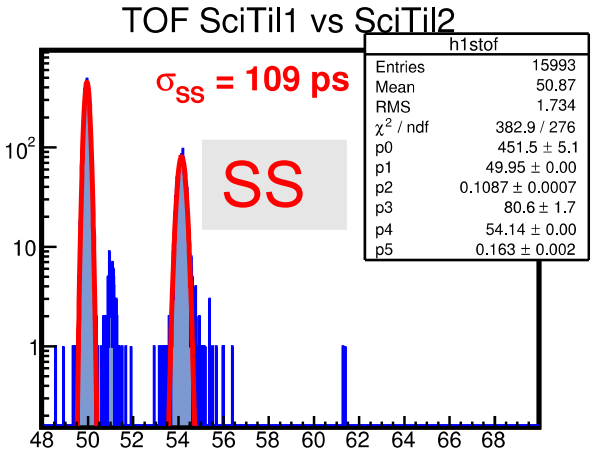
TOF Fits (3 GeV/c, one MCP Pixel)

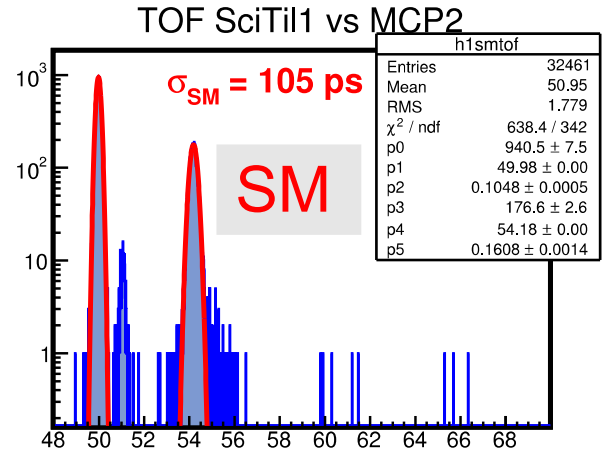
Readout with 1 TRB board
+ long aircell cables

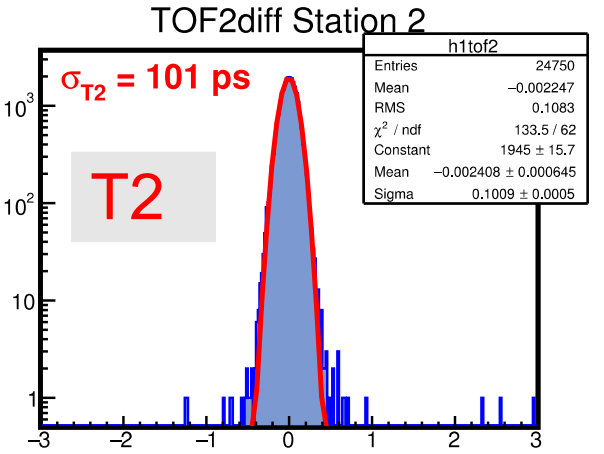












- Corrected TOF distributions (both MCPout signals with trigger on px 4/4)
- better resolutions than with all pixels for the 6 counter combinations
- A lot less statistics but also less background

Determination of Time Resolutions

$$\sigma_{MM} = TOFres(MCP\,2 - MCP\,1)$$
$$\sigma_{SS} = TOFres(SciTil\,2 - SciTil\,1)$$
$$\sigma_{SM} = TOFres(MCP\,2 - SciTil\,1)$$
$$\sigma_{MS} = TOFres(SciTil\,2 - MCP\,1)$$
$$\sigma_{T1} = TOFres(MCP\,1 - SciTil\,1)$$
$$\sigma_{T2} = TOFres(MCP\,2 - SciTil\,2)$$

$$\sigma_{M1} = TimeRes(MCP\,1)$$
$$\sigma_{M2} = TimeRes(MCP\,2)$$
$$\sigma_{S1} = TimeRes(SciTil\,1)$$
$$\sigma_{S2} = TimeRes(SciTil\,2)$$
$$\sigma_{beam} = TimeRes(Beam, Clock, \ldots)$$

$$\sigma^2_{MM} = \sigma^2_{M1} + \sigma^2_{M2} + \sigma^2_{beam}$$
$$\sigma^2_{SS} = \sigma^2_{S1} + \sigma^2_{S2} + \sigma^2_{beam}$$
$$\sigma^2_{MS} = \sigma^2_{M1} + \sigma^2_{S2} + \sigma^2_{beam}$$
$$\sigma^2_{SM} = \sigma^2_{S1} + \sigma^2_{M2} + \sigma^2_{beam}$$
$$\sigma^2_{T1} = \sigma^2_{M1} + \sigma^2_{S1}$$
$$\sigma^2_{T2} = \sigma^2_{M2} + \sigma^2_{S2}$$

- 6 measured TOF resolutions
- 4 counter + 1 “beam” resolutions
- 6 equations, 5 unknowns
  - Create 6 bin histogram with individual TOF resolutions
  - ROOT least square using Minuit
- → **Resolution of each counter**

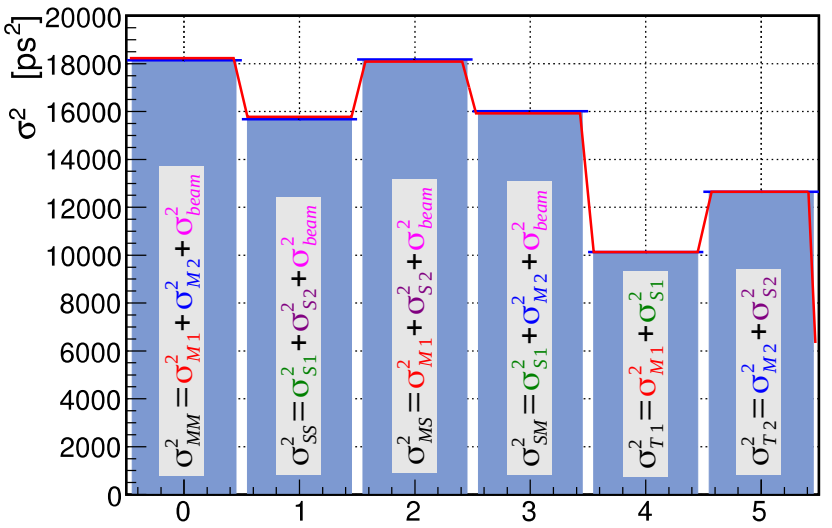
Obtain Counter Time Resolutions

- 6 TOF values and 5 unknown counters
- Solve with ROOT least square fit (Minuit)
- Create 6 bin histogram with TOF values of different combinations put to one bin each
- Define a function which contains all counter resolutions as free parameters
- Use ROOT Fit method

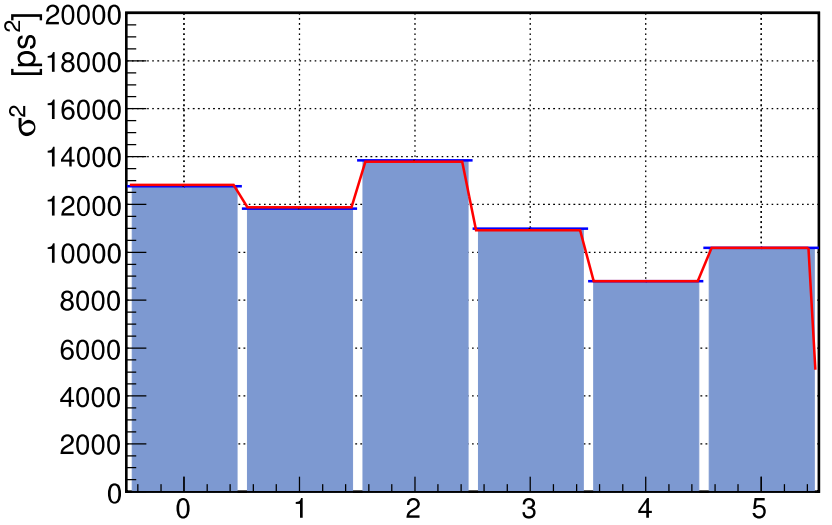
```
Double_t LinEq(Double_t *x, Double_t *par)
{
 Double_t xval = 0.;
 if (x[0] < 0.5)       // MCP2 - MCP1
   xval = par[0] + par[2] + par[4];
 else if (x[0] < 1.5)  // SciTil2 - SciTil1
   xval = par[1] + par[3] + par[4];
 else if (x[0] < 2.5)  // SciTil2 - MCP1
   xval = par[0] + par[3] + par[4];
 else if (x[0] < 3.5)  // MCP2 - SciTil1
   xval = par[1] + par[2] + par[4];
 else if (x[0] < 4.5)  // MCP1 - SciTil1
   xval = par[0] + par[1];
 else if (x[0] < 5.5)  // MCP2 - SciTil2
   xval = par[2] + par[3];

  return xval;
}
```

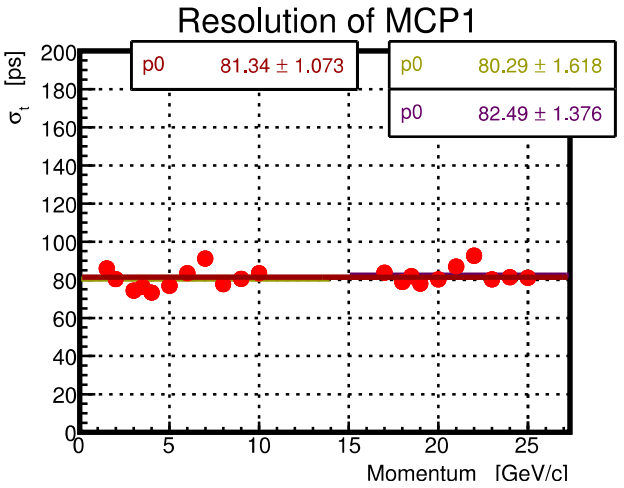
Pions 3 GeV/c all MCP pixels

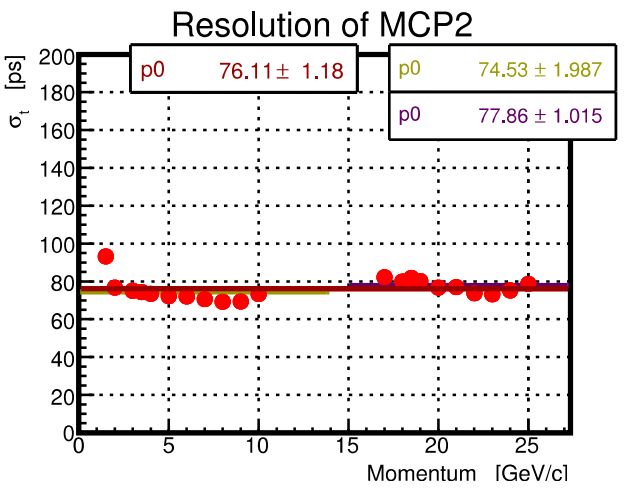


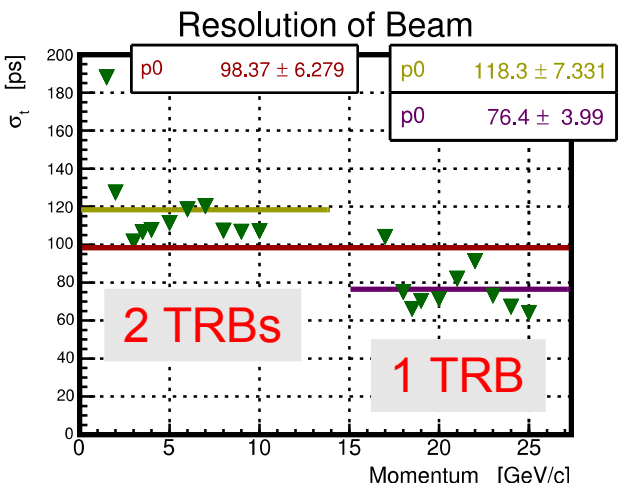
Pions 3 GeV/c one central MCP pixel (4/4)

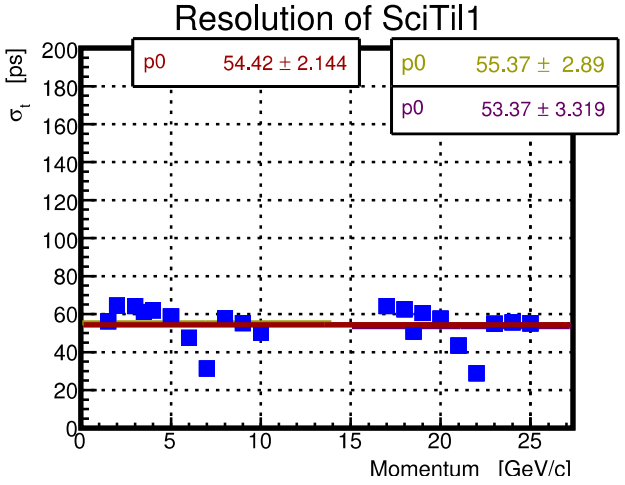


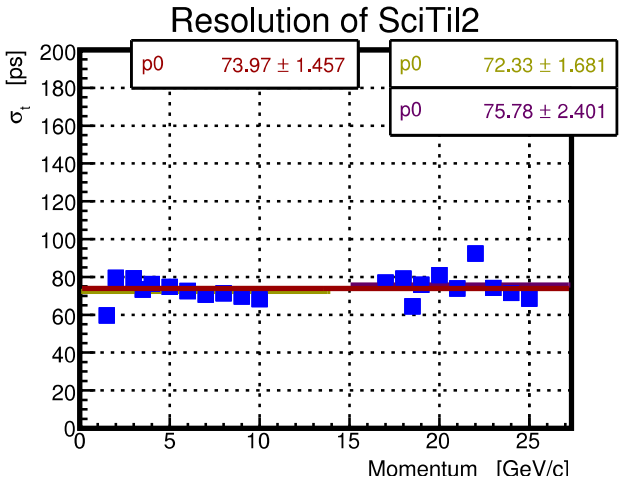
Counter Resolutions (all Momenta)









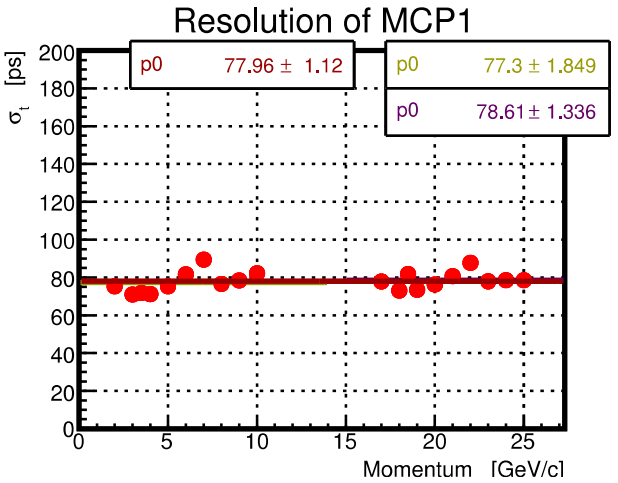


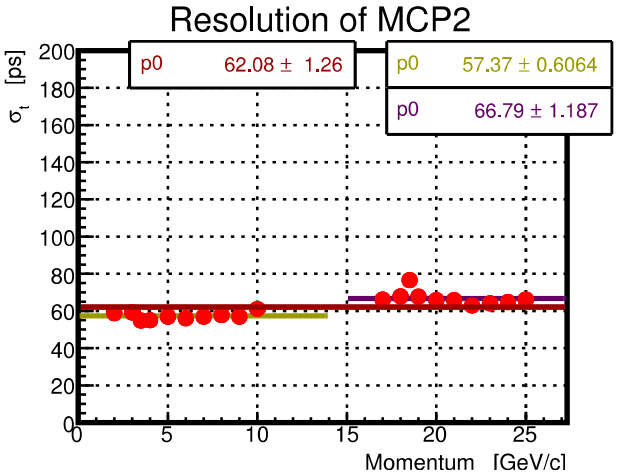
All MCP pixels

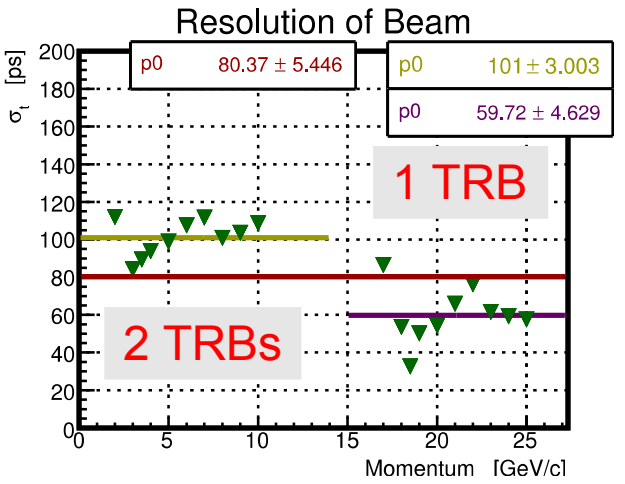
$$\sigma_{M1} = (81 \pm 1)\,ps$$
$$\sigma_{M2} = (76 \pm 1)\,ps$$
$$\sigma_{S1} = (54 \pm 2)\,ps$$
$$\sigma_{S2} = (74 \pm 2)\,ps$$
$$\sigma_{beam,\,2\,TRBs} = (118 \pm 7)\,ps$$
$$\sigma_{beam,\,1\,TRB} = (76 \pm 4)\,ps$$

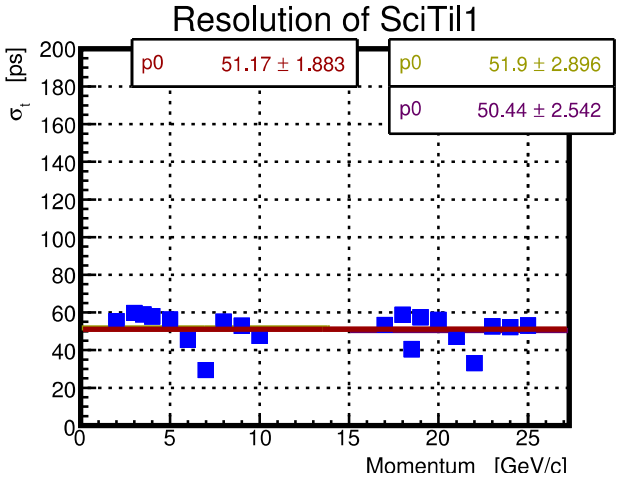
- Different resolutions for σ_{beam} with 2 TRBs and with 1 TRB
- Counter resolutions roughly independent of TRB setup

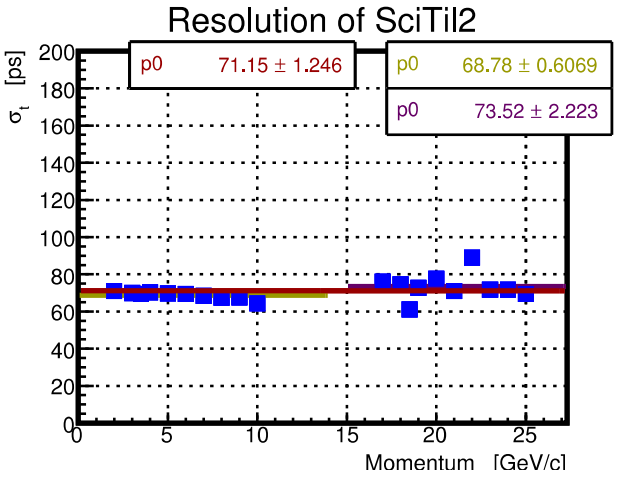
Counter Resolutions (all Momenta)











$$\sigma_{M1} = (78 \pm 1)\,ps$$
$$\sigma_{M2} = (62 \pm 1)\,ps$$
$$\sigma_{S1} = (51 \pm 2)\,ps$$
$$\sigma_{S2} = (71 \pm 2)\,ps$$
$$\sigma_{beam,\,2\,TRBs} = (101 \pm 3)\,ps$$
$$\sigma_{beam,\,1\,TRB} = (60 \pm 5)\,ps$$

One MCP pixel (4/4)

- Different resolutions for σ_{beam} with 2 TRBs and with 1 TRB → reftime!
- Counter resolutions slightly better than for readout of all pixels

Summary

- Best SciTil time resolution homogeneity across surface reached with 4 SiPMs/side
- Analysis of all MCP-TOF data of June/July 2015 CERN run
- TOF and ToT data show slight jumps over time
- Kaons separable from pions up to ~5 GeV/c
- Pions and protons separable up to 10 GeV/c
- The measured TOF combinations of the 4 used counters are a powerful tool to determine the time resolution of each counter
  - MCP time resolutions between 60 and 80 ps
  - **SciTil time resolutions between 50 and 70 ps**
    - **measured in a real experiment, not in the lab!**
    - **resolution kept constant over ~2.5 weeks**