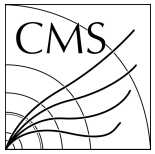
ME11 Timing and Synchronization Update

Benjamin Michlin

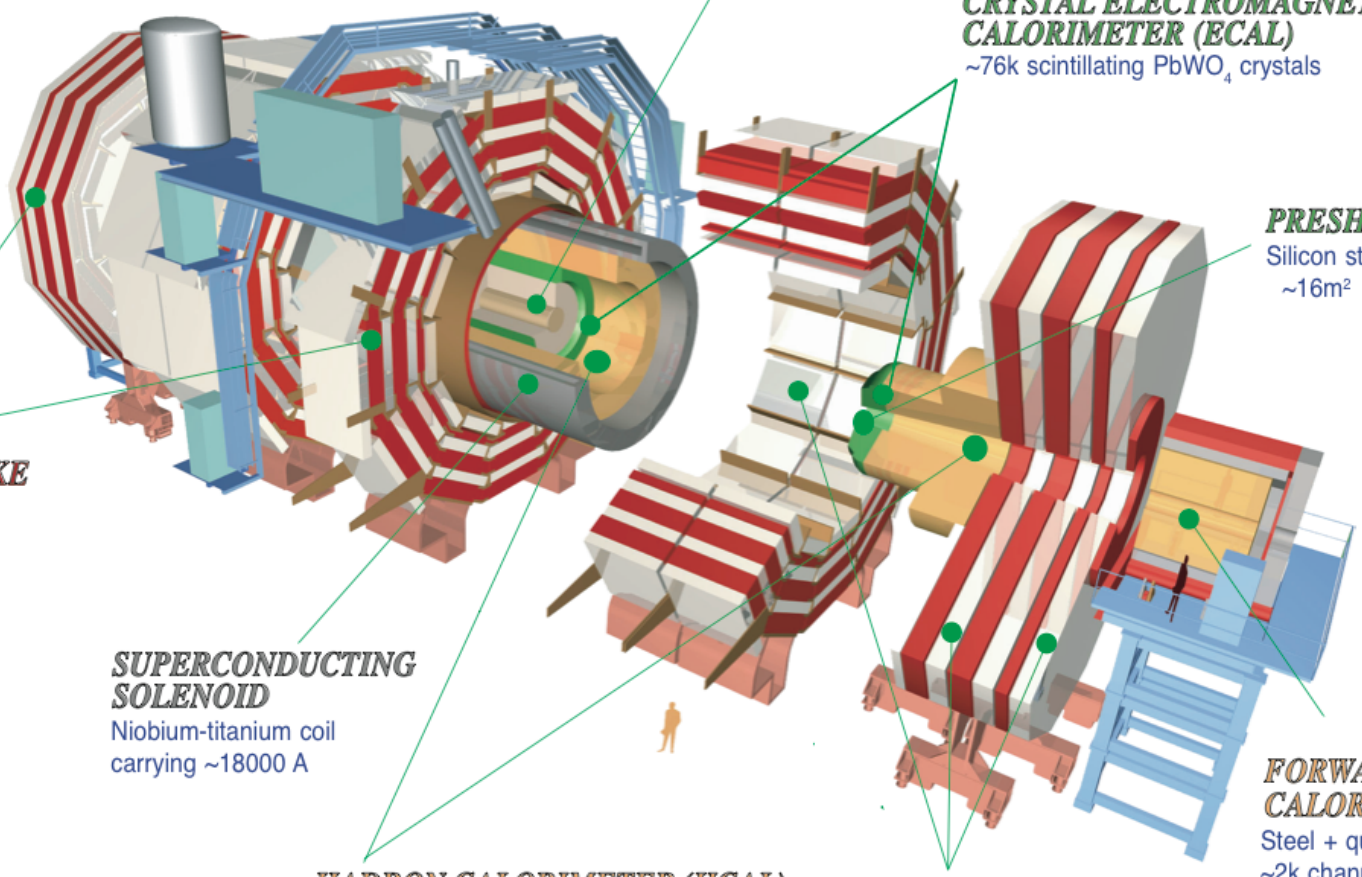


RICE

The CMS Detector and its Upgrade

CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating $PbWO_4$ crystals

PRESHOWER
Silicon strips
~16m² ~137k channels

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A

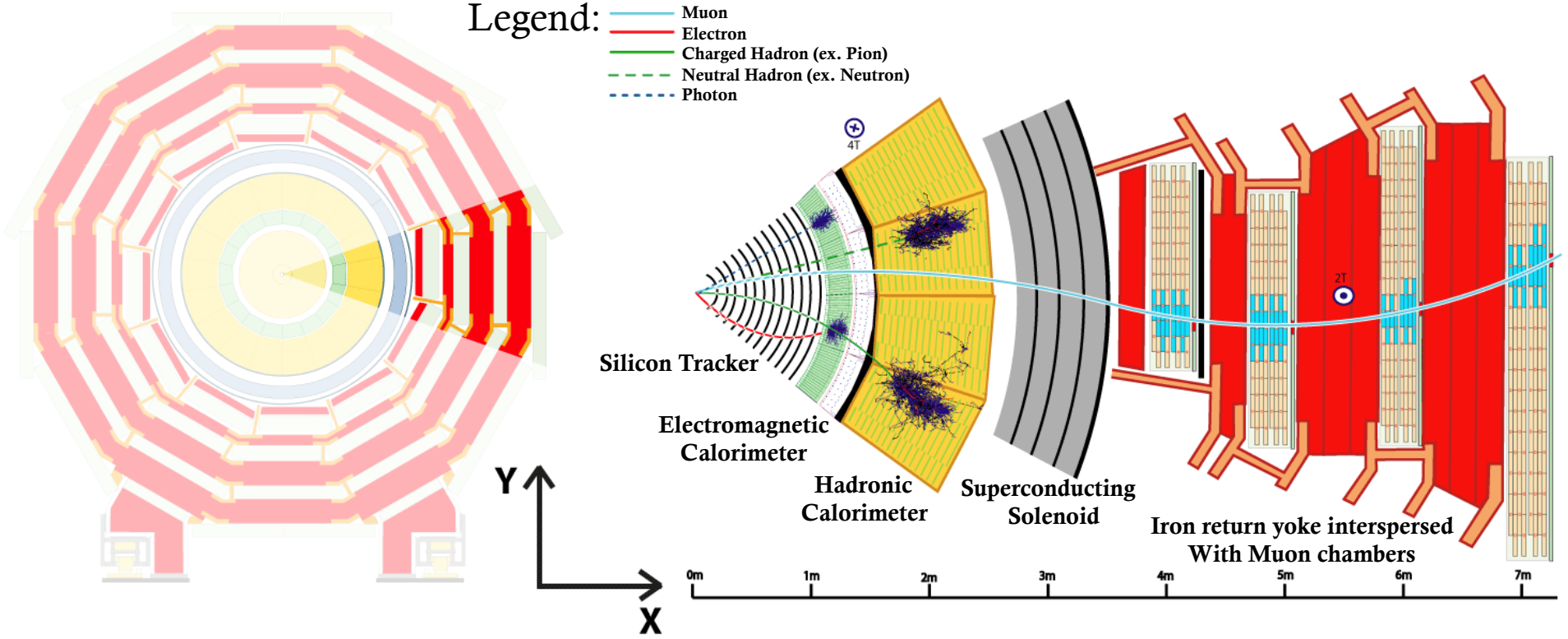
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

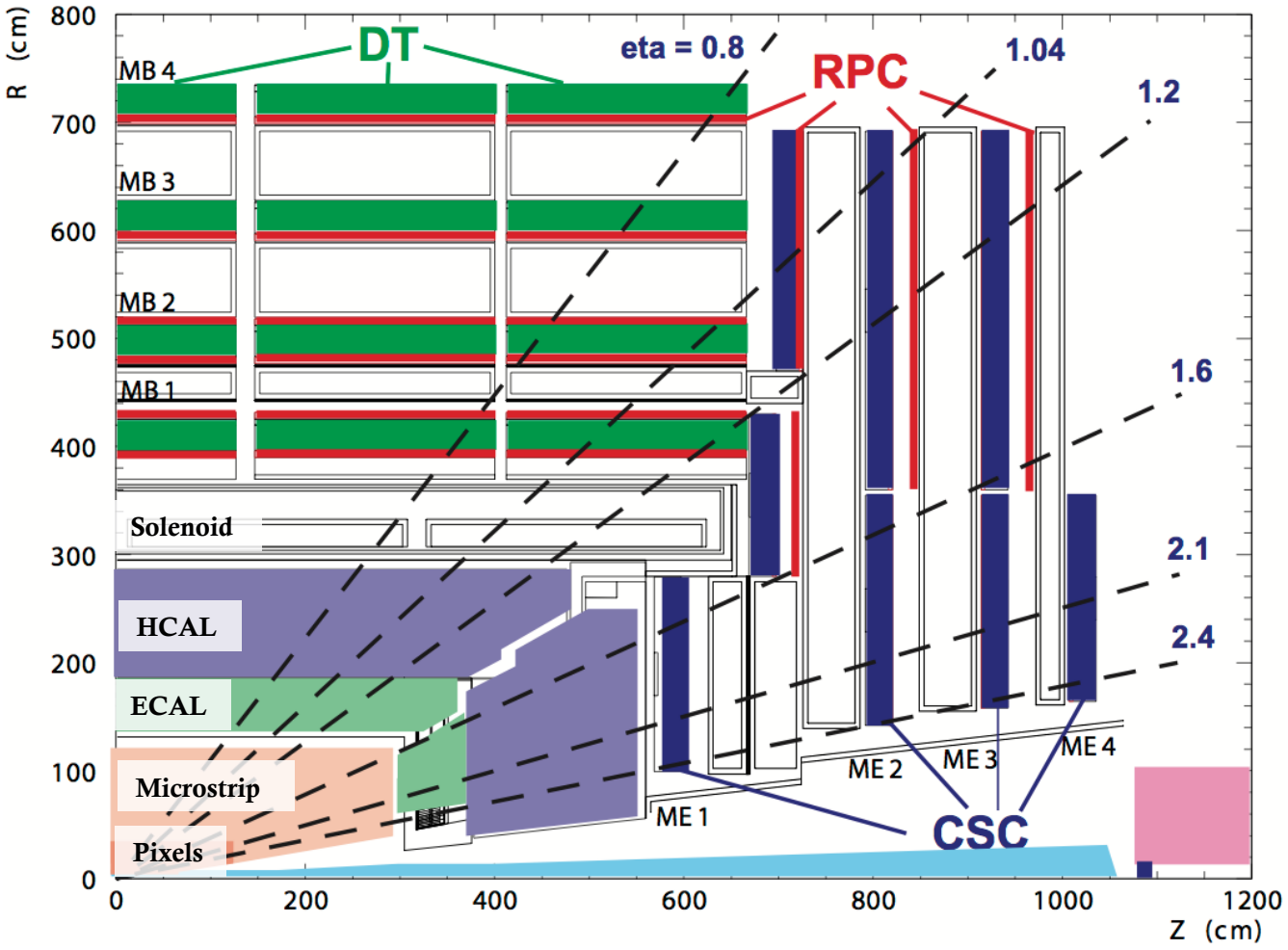
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Slice of the CMS Detector

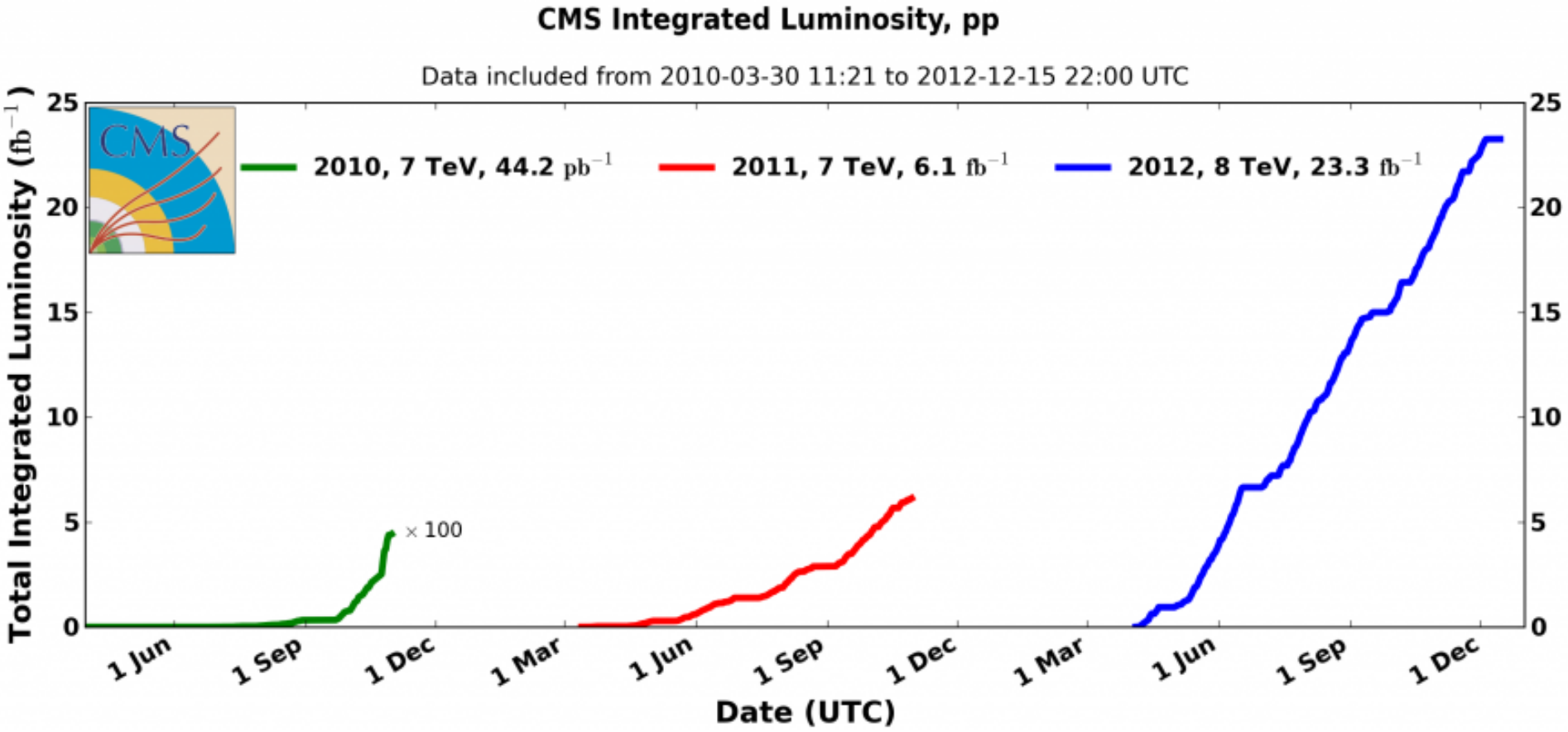


Coordinate System



- The beam axis corresponds to the z direction
- θ is the polar coordinate (with respect to the beam axis)
- ϕ is the azimuthal coordinate (with respect to the LHC plane)
- The origin is the collision point
- The pseudo-rapidity, $\eta = -\ln(\tan(\theta))$

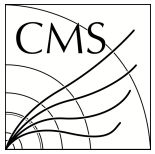
Run 1 (2010-2012)



- Center of mass energy ($\sqrt{s}$) of 7 and then 8 TeV
- With a luminosity of ~10^{34}cm^{-2}sec^{-1},
  - Corresponding to a total integrated luminosity of ~30fb^{-1} of data

Long Shutdown 1

- In 2013 the LHC entered a period known as Long Shutdown 1 (LS1).
- During LS1, the accelerator is not running so that repairs and upgrades may take place. These upgrades include improvements in order:
  - To increase the detector efficiency
  - To allow the CMS detector to function properly in a higher luminosity environment
  - To fix known problems that were discovered during the initial running period.



LHC Environment After LS1

RICE

- Luminosity increase: 10^{34} $cm^{-2}sec^{-1}$ → 2x 10^{34} $cm^{-2}sec^{-1}$
- Collision Frequency Increase: BX=50ns → BX=25ns
- Pile-up increase: 25 events/BX → 50 events/BX
- COM energy increase: 8TeV → 13TeV
- Trigger rates are expected to increase by a factor of ~6

Relevant Detector Components for this Thesis

The Level-1 (L1) Trigger

- Most collisions are "soft" collisions, meaning that there are no resulting high mass states.
- The Level-1 trigger is designed to eliminate these soft events and only keep "hard" collisions (in which there could be high mass states).
- Bunch crossing every 25ns
  - L1 must decide whether or not to keep an event every ~3 μ s
    - **L1 trigger can record a maximum of 100,000 events/sec**
  - Only partial data may be used (data from calorimeter and muon information only)

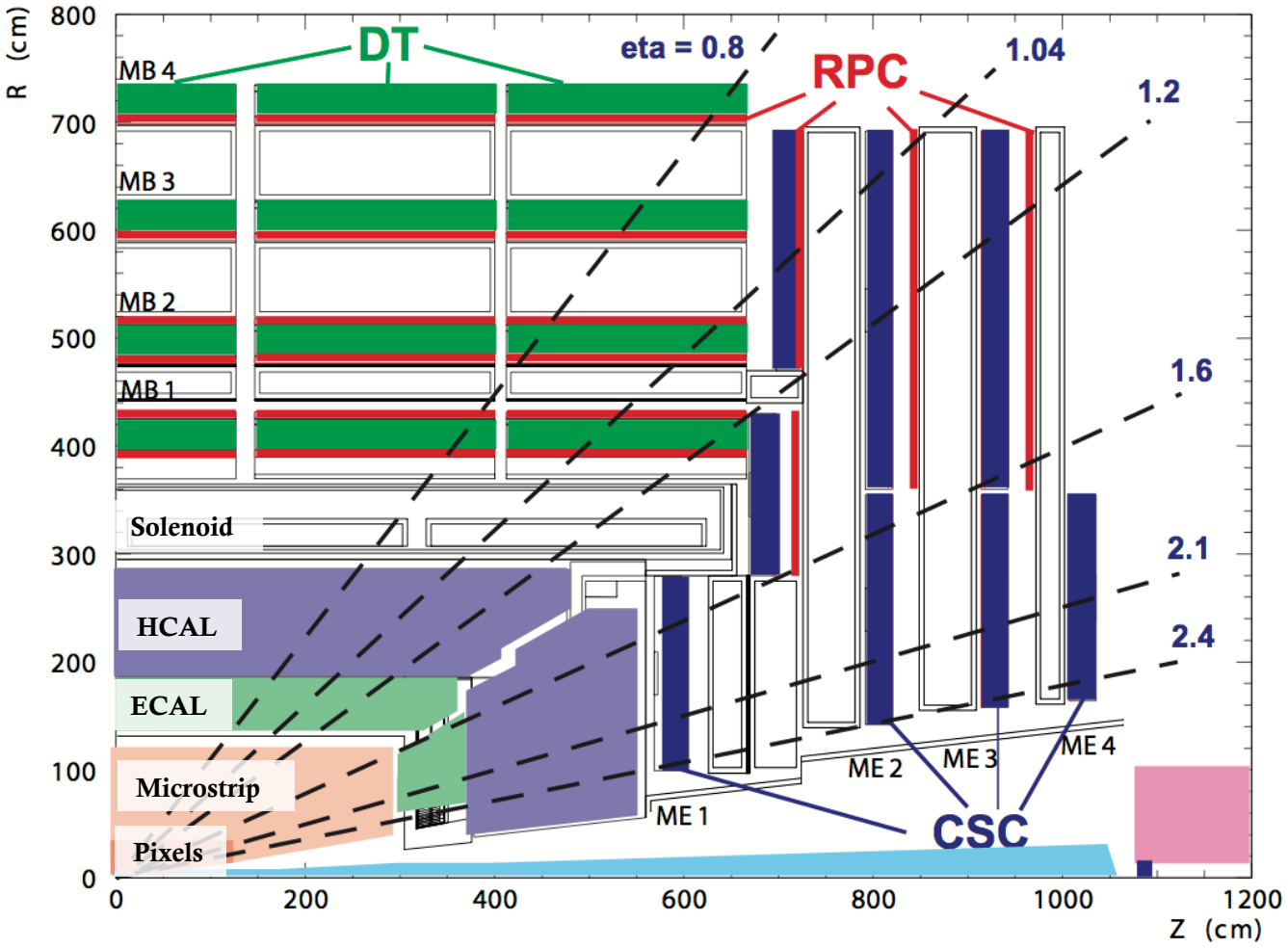
ECAL

- Used to measure the energy of particles that interact electromagnetically
  - Electromagnetic showers
- Composed of lead tungstate crystals (PbWO4) which scintillate when a charged particle enters.
  - The photons from the scintillation are then detected and an energy can be determined
- **The primary objective of the ECAL is to determine the energy of charged particles and the photon**
- There are not upgrade plans for the ECAL during LS1.

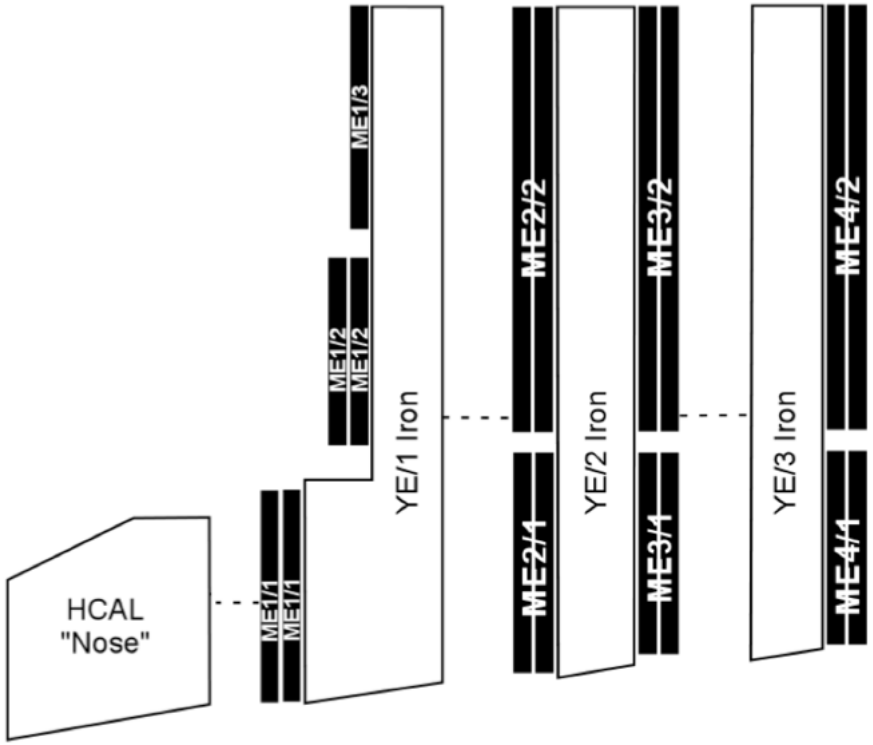
HCAL

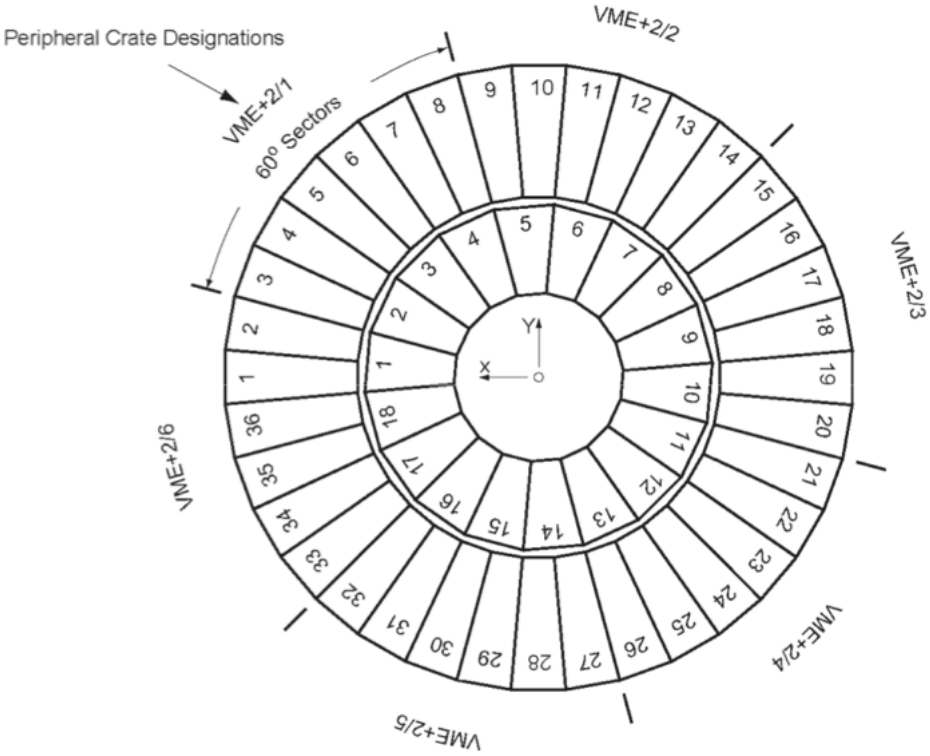
- **Primarily used to measure the energy of hadrons and jets**
  - This is accomplished by using 18 depth layers of brass and scintillator.
    - The photons from the scintillation tiles are converted via wavelength shifting (WLS) fibers, and can be used to determine the particle energy.
- Showers are sampled over ~11 interaction lengths.
- During LS1, the HCAL, barrel, endcap, and outer, (HB/HE/HO) will get improved photomultiplier tubes (PMTs) and photodetectors for more accurate energy determination.
- **During LS1, new backend electronics will be implemented in order to send enhanced information to the regional calorimeter trigger (RCT).**

Muon System

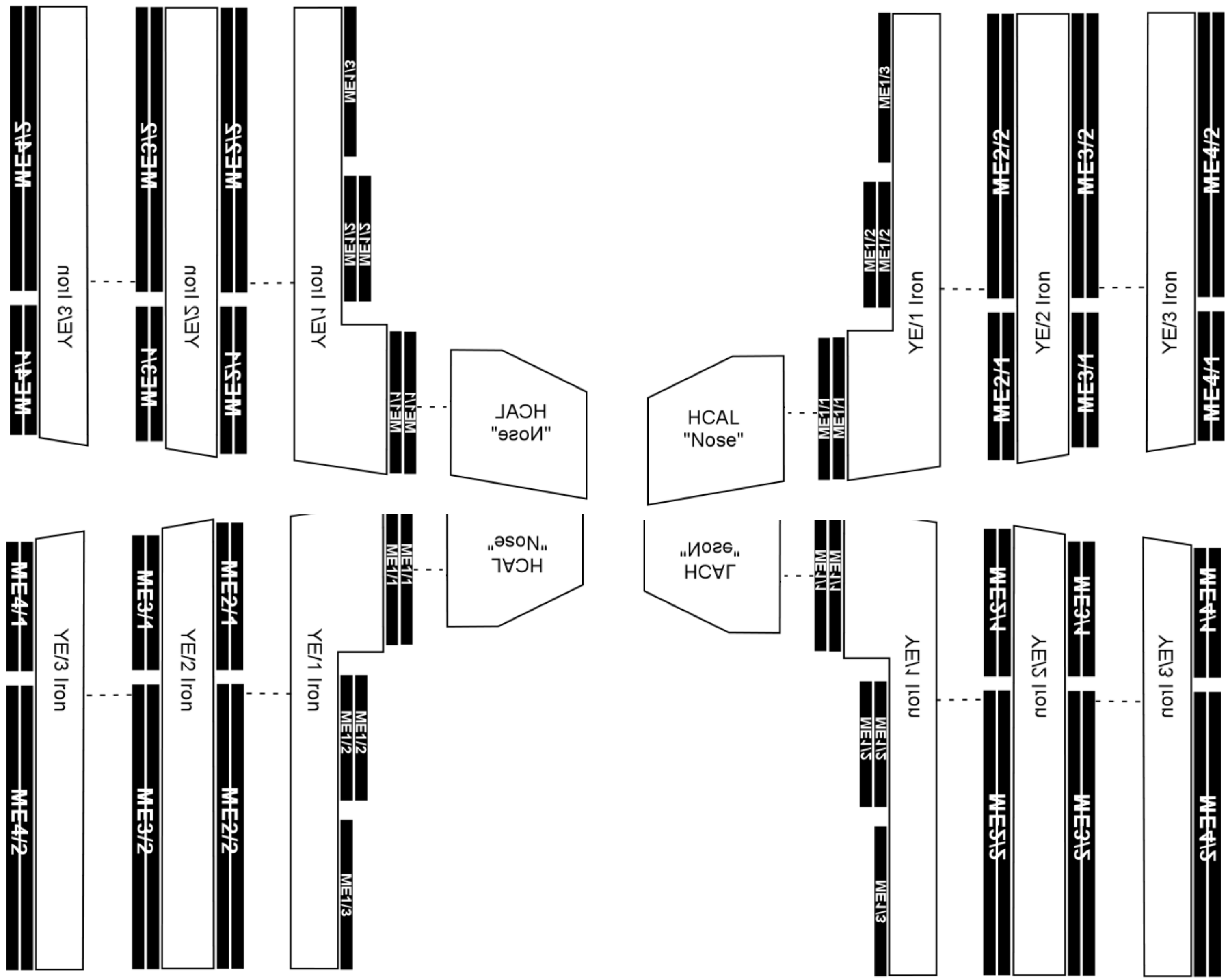

DT
RPC
eta = 0.8
1.04
1.2
1.6
2.1
2.4
MB 4
MB 3
MB 2
MB 1
Solenoid
HCAL
ECAL
Microstrip
Pixels
ME 1
ME 2
ME 3
ME 4
CSC
R (cm)
Z (cm)
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200

Cathode Strip Chambers (CSC)



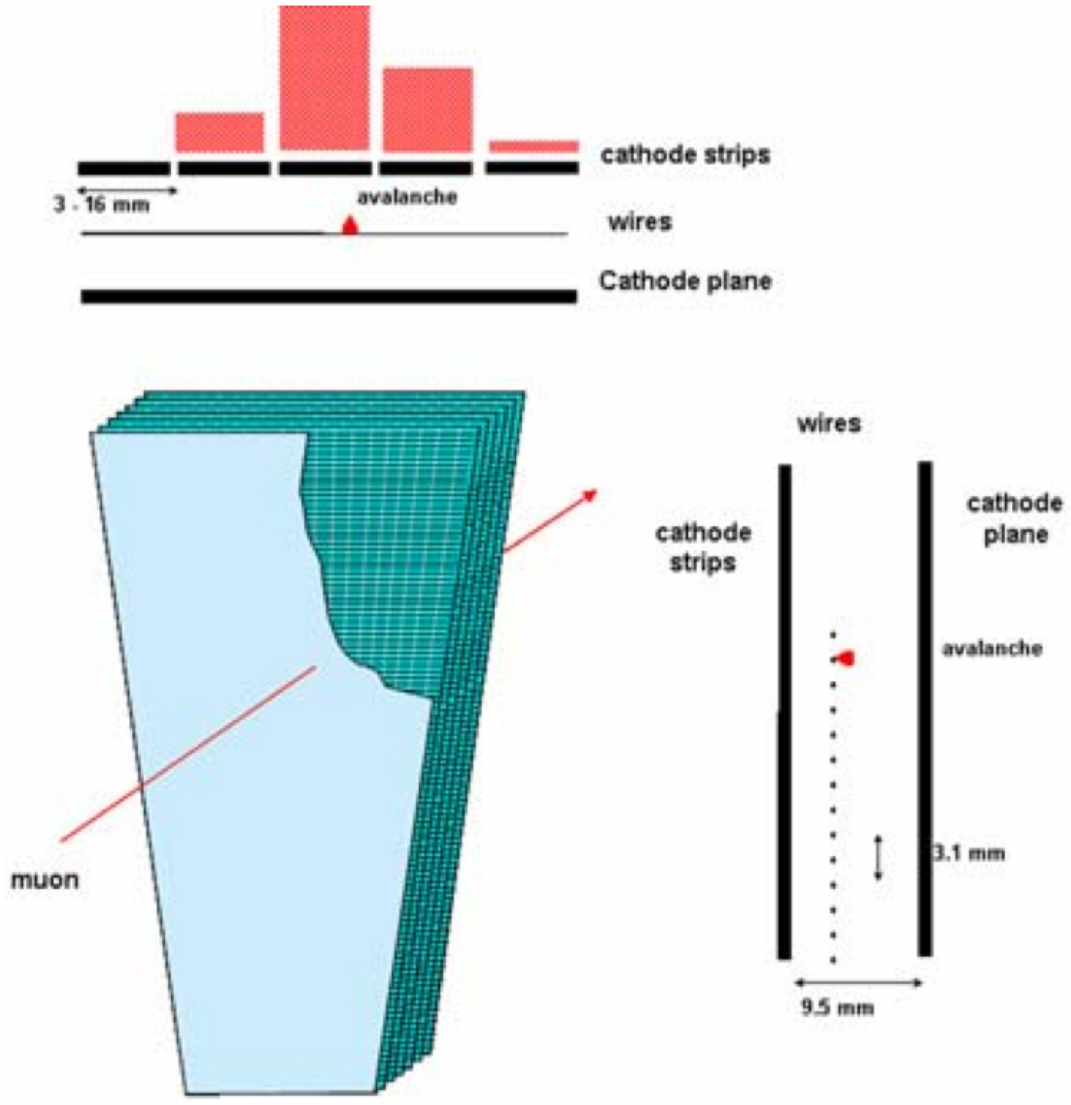


- Naming Convention: ME±<Station>/<Ring>/<Chamber>
- ME 4/2 was added as an upgrade during LS1

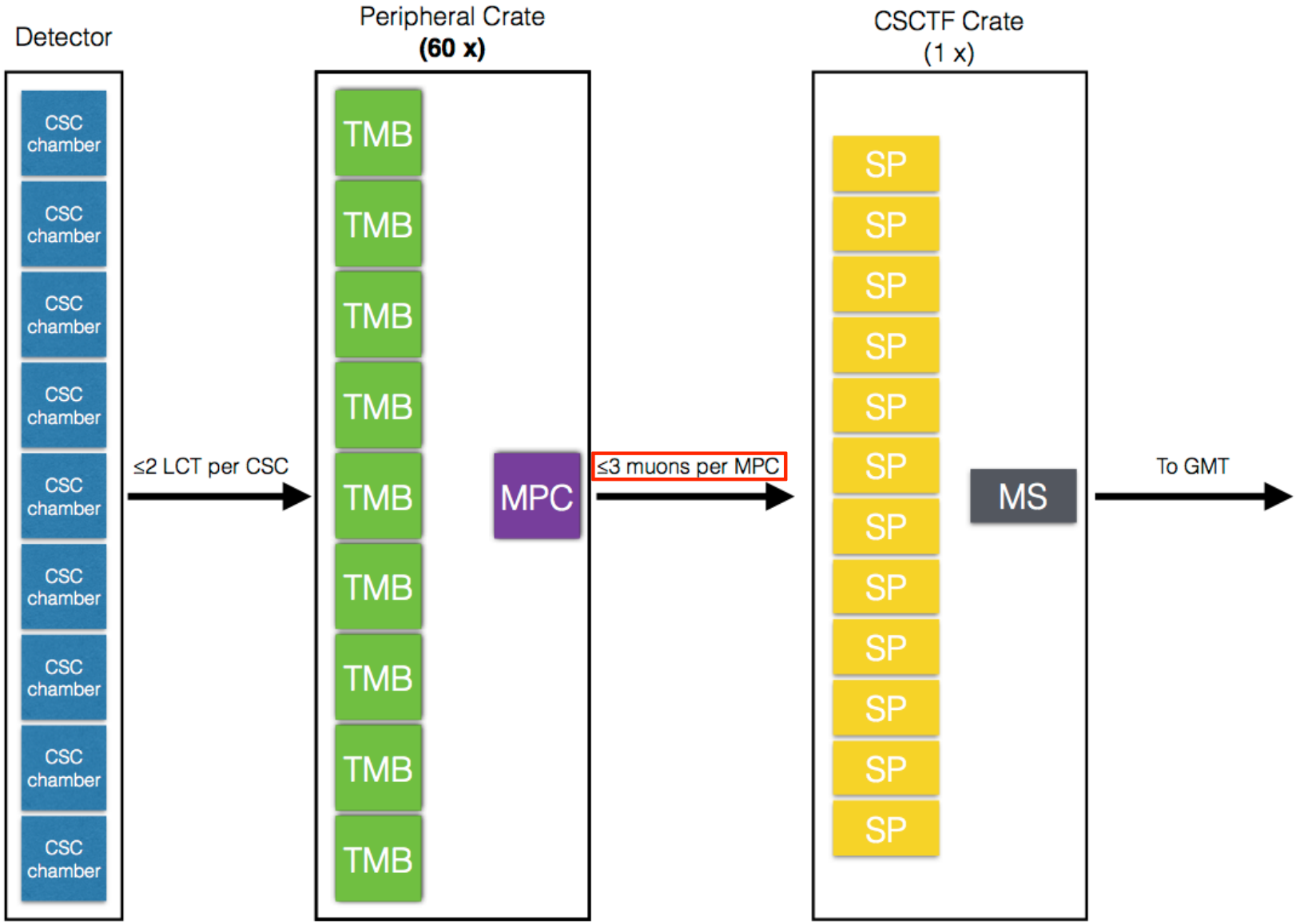

ME4/2
ME4/1
YE/3 Iron
ME3/2
ME3/1
YE/2 Iron
ME2/2
ME2/1
YE/1 Iron
ME1/3
ME1/2
ME1/1
HCAL
"Nose"

CSC Chamber

- Each chamber has 6 gaps each containing a plane of radial cathode strips and perpendicular anode wires immersed in gas.
- A muon is shown entering the CSC
- The gas becomes ionized and an electron avalanche is accumulated on the anode wires
  - A mirror charge accumulated on the cathode strips



Data Flow from CSC to GMT

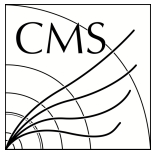


GMT Upgrade

- GMT Upgrade
  - New FPGA
  - VME→ μ -TCA
  - **Calorimeter and muon information combined**
  - More sophisticated algorithms may be used
    - Muon isolation

CSC LS1 Upgrade

- Additional ring of chambers (ME 4/2)
- Upgraded ME1/A electronics
- MPC upgrade
  - Up to 18 LCTs per MPC may be sent to SP (as opposed to the current limit of 3 LCTs per MPC)
  - **Requires new FPGA**
- CSCTF Crate: VME → μ-TCA



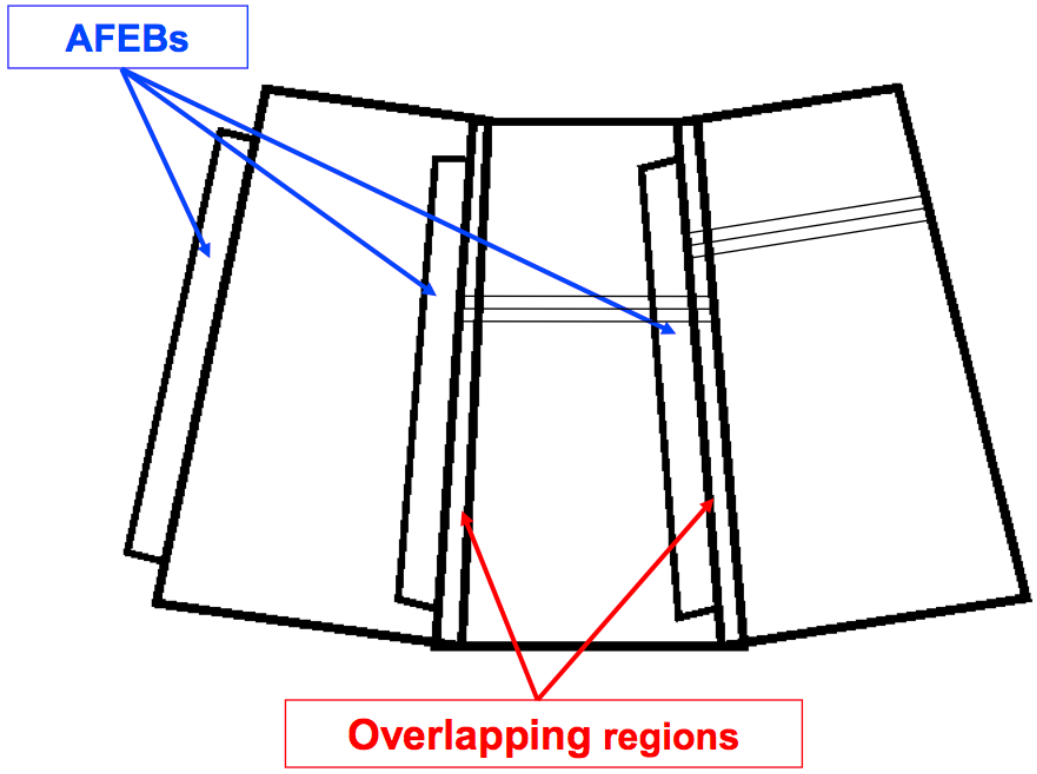
Timing

Goal

- ME11 and ME42 need a fine tuned synchronization (to make them internally consistent)
- LCTs from ME1 and ME4 must be aligned as they arrive at the CSCTF
- LCTs from same muon must arrive at CSCTF at the same bunch crossing to optimize trigger
- Need to time in chambers with beam

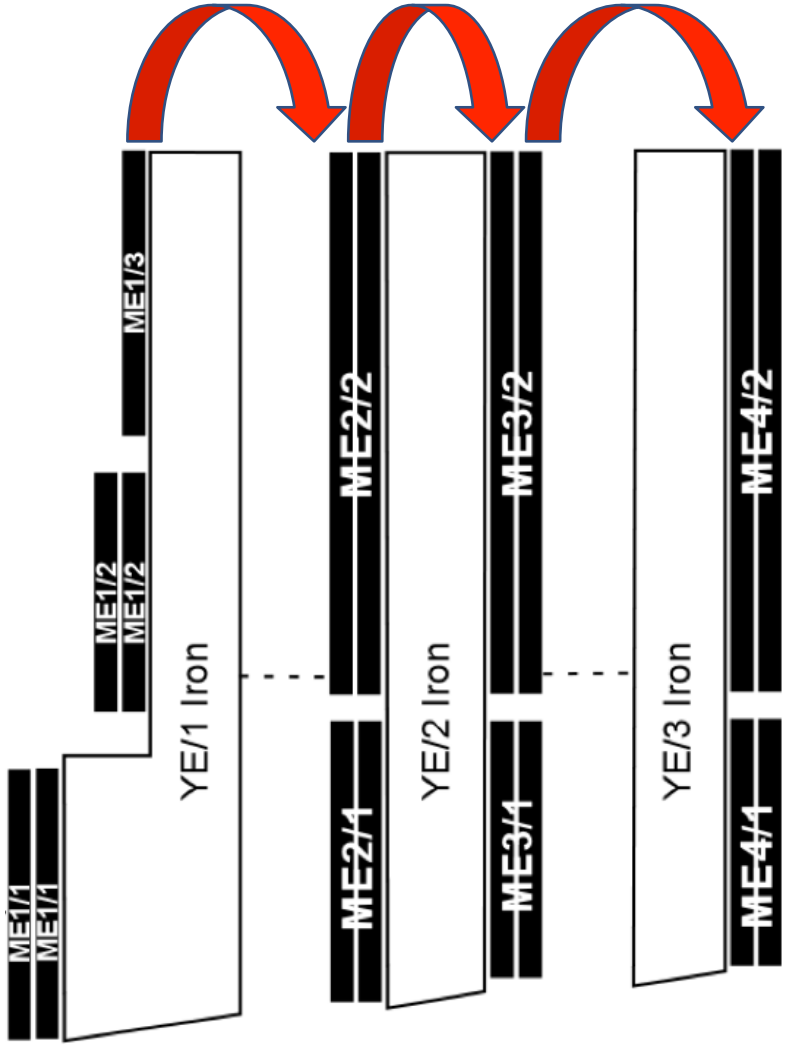
Synchronization Plan

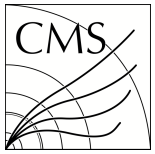
- Look at events where there are LCTs in neighboring chambers
- These LCTs are (presumably) from the same muon that passed through the overlapping regions
  - Should have the same BX timing



Synchronize Endcap

- Look for events in which LCTs are in the same sector, but different disks
  - Beam will be extremely useful
- Synchronize ME1/1 and ME4/2 using ME2 and ME3 (which should already be calibrated)





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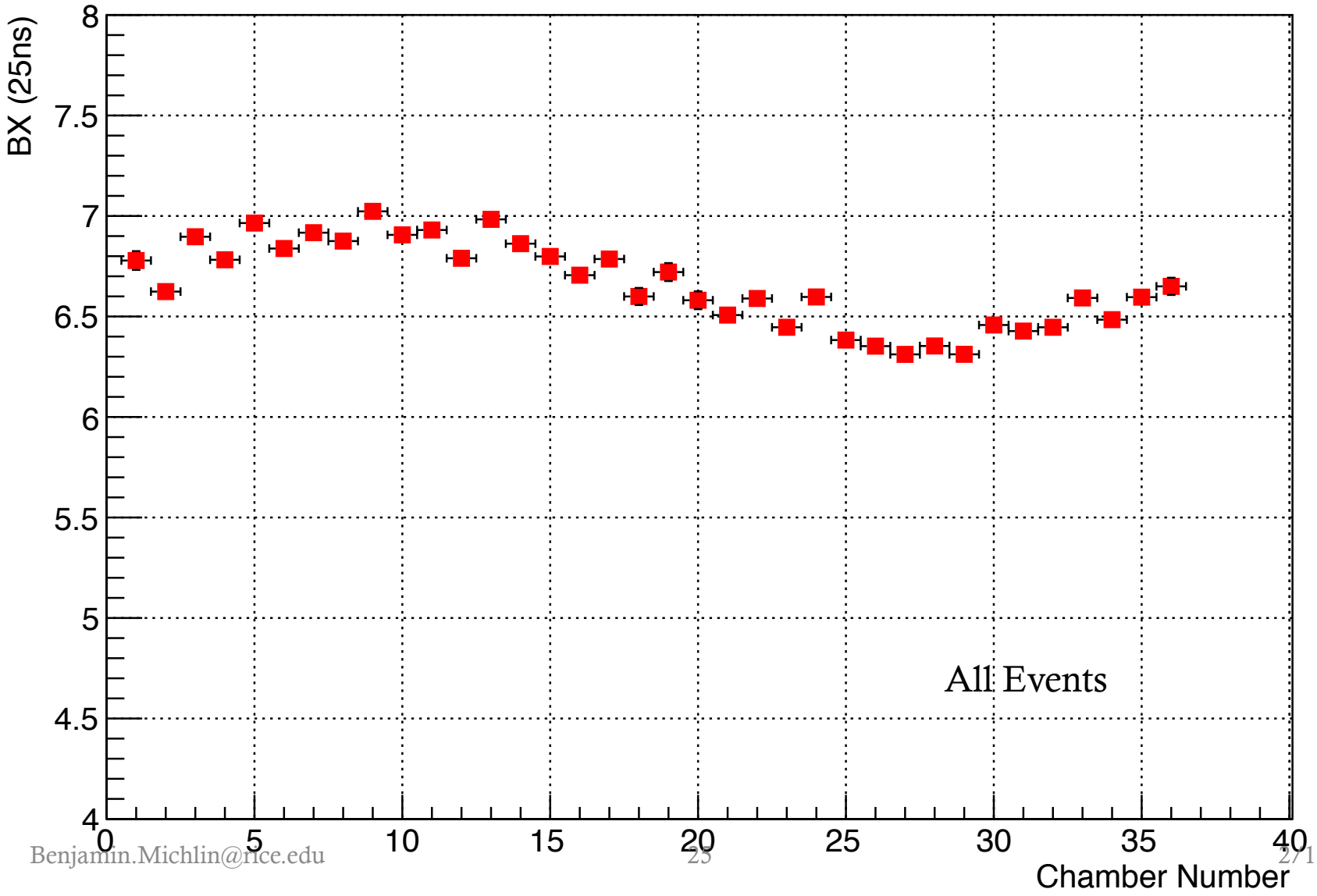
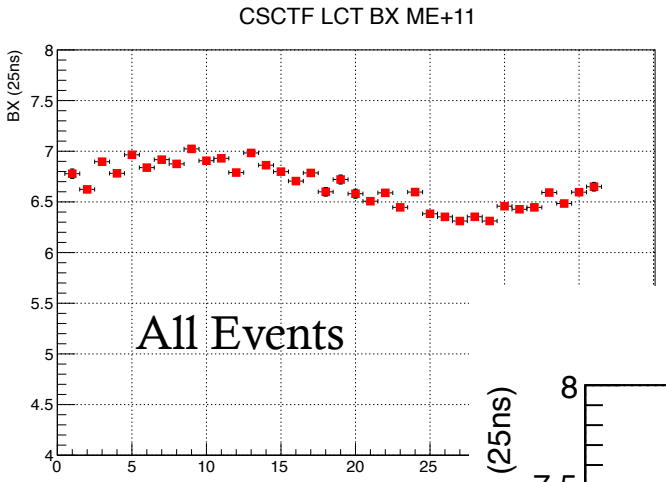
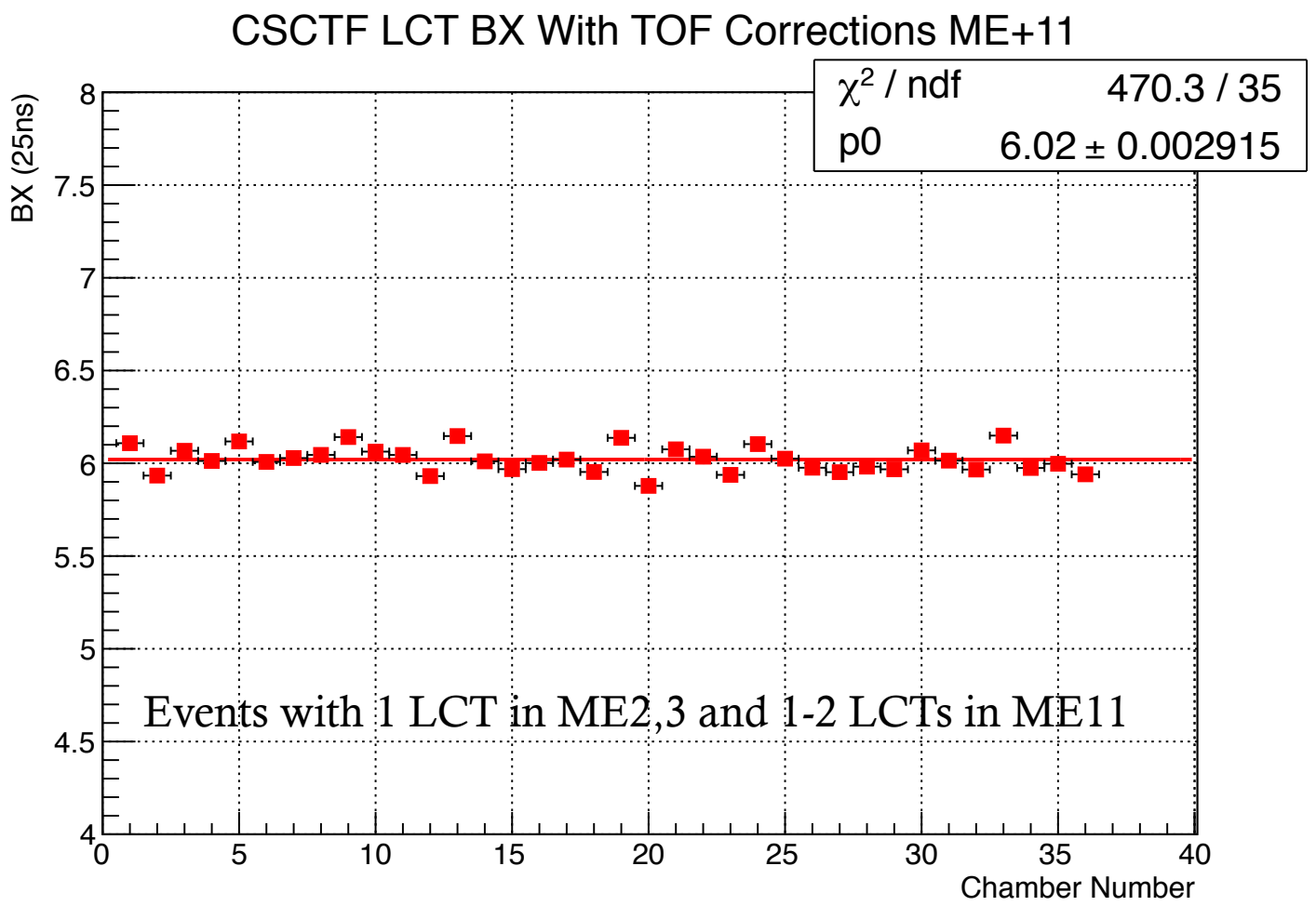
Local Run 228354

- Taken on October 25 2014
  - High statistics, ~2 million events
- Triggering on the bottom of ME2 and ME3
- Endcap was closed

Local Run 228354

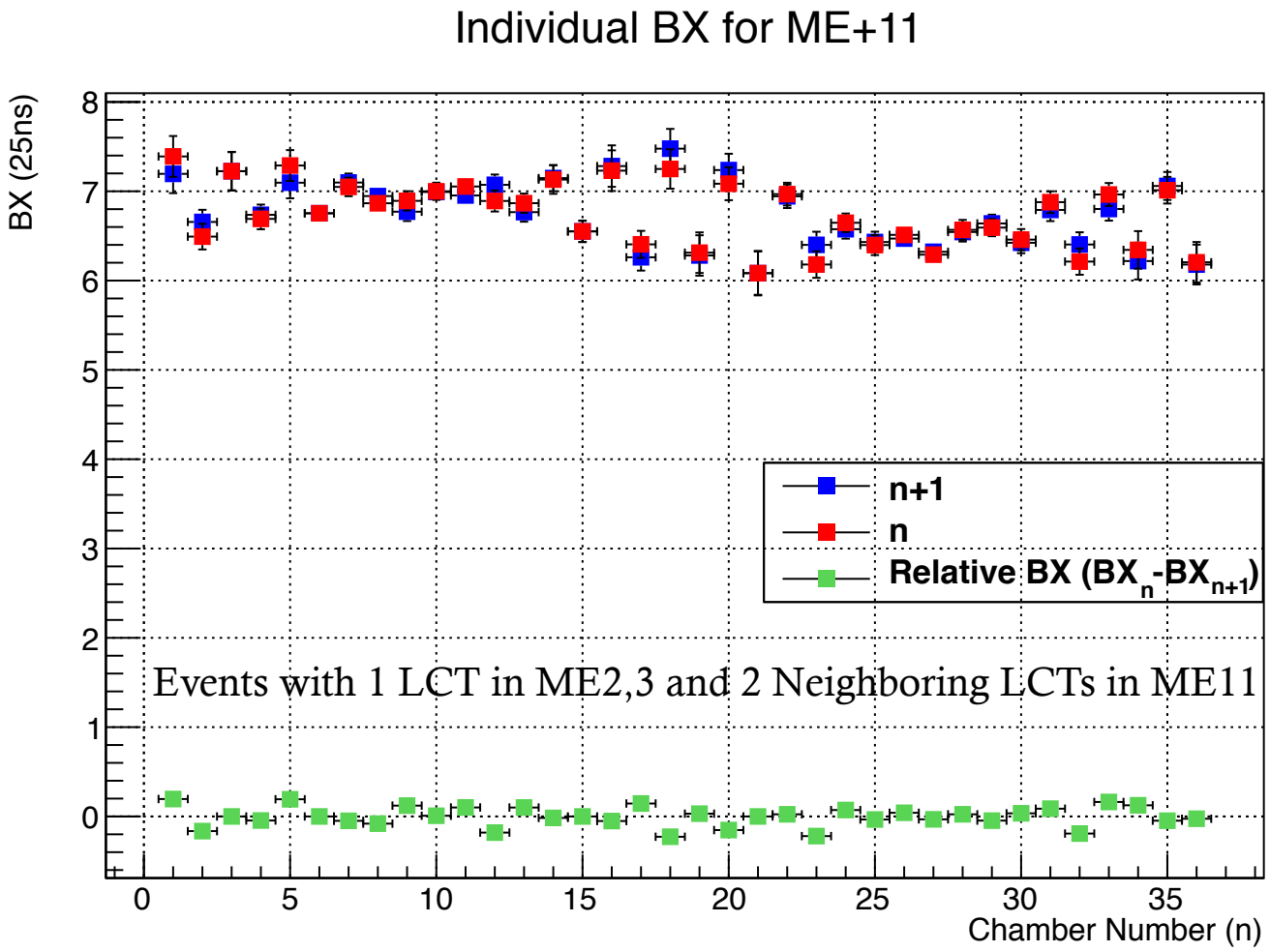






- Apply TOF corrections as described by Pieter (https://indico.cern.ch/event/343855/contribution/1/material/slides/0.pdf)

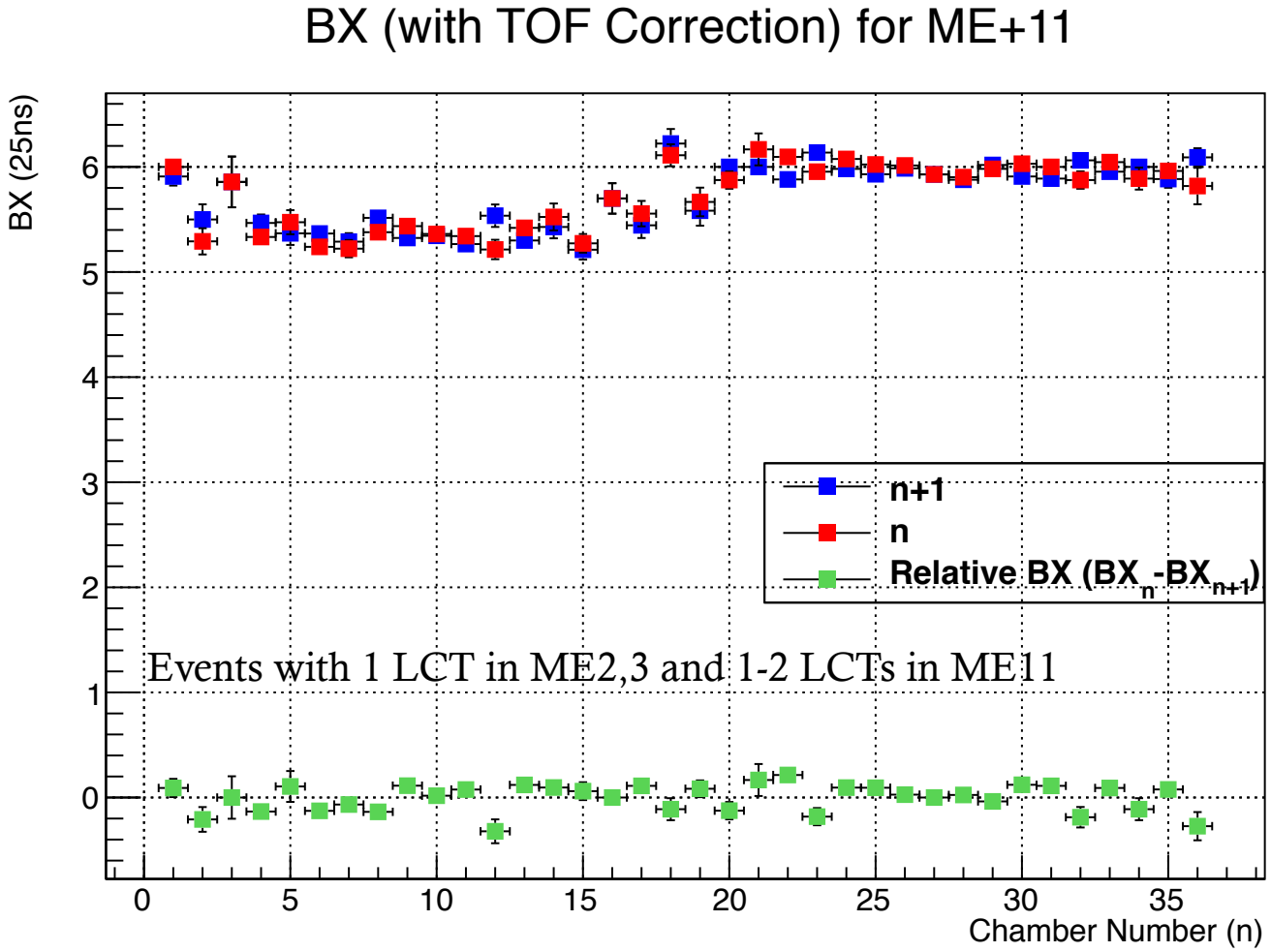
Synchronization



Neighboring chambers with NO TOF applied

- Mean BX from overlap regions
- Chamber n shows BX for overlap between chamber n and chamber n+1
- Chamber 36 wraps around
  - Chamber n is 36, chamber n+1 is 1
- Currently working on oscillations in Relative BX

Synchronization



- Mean BX from overlap regions
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- Chamber 36 wraps around
  - Chamber n is 36, chamber n+1 is 1
- Currently working on oscillations in Relative BX

Synchronization by χ^2 Minimization

$$\chi^2 = \sum_{kl} \left(\frac{\Delta_k - \Delta_l - m_{kl}}{\sigma_{kl}} \right)^2$$

- From 2009 synchronization note*:
- "*k* and *l* are labels for different chambers under study"
- "Δ is the timing shift between the two channels"
- "m is the measured BX difference"
- "σ is its measurement error"

*https://cms-csctf-sw.web.cern.ch/cms-csctf-sw/timingresult/csctf_timing.pdf

Synchronization by χ^2 Minimization

$$\chi^2 = \sum_n \left(\frac{\Delta_n - \Delta_{n+1} - m_{n,\,n+1}}{\sigma_{n,\,n+1}} \right)^2$$

- **What I did (in the spirit of the 2009 note):**
- *n* runs over chambers
- $m_{n,n+1}$ is the relative bunch crossing between chambers *n* and *n+1*
  - Green points from slide 9
- $\sigma_{n,n+1}$ is the error on $m_{n,n+1}$
  - y-errors from green points in slide 9
- Δ_n is the timing shift for chamber *n* as determined by minimization of χ^2
  - Floating parameters
  - Minimize χ^2 with 36 floating parameters (Δ)

$$\chi^2 = \sum_n \left(\frac{\Delta_n - \Delta_{n+1} - m_{n,\,n+1}}{\sigma_{n,\,n+1}} \right)^2$$

- Numerical minimization with MINUIT2
  - Identical nominal results when performing minimization via matrix equation and SVD
- Result of minimization in table.
- The corrections are the Δs
  - This is the necessary timing shift (in BX units)

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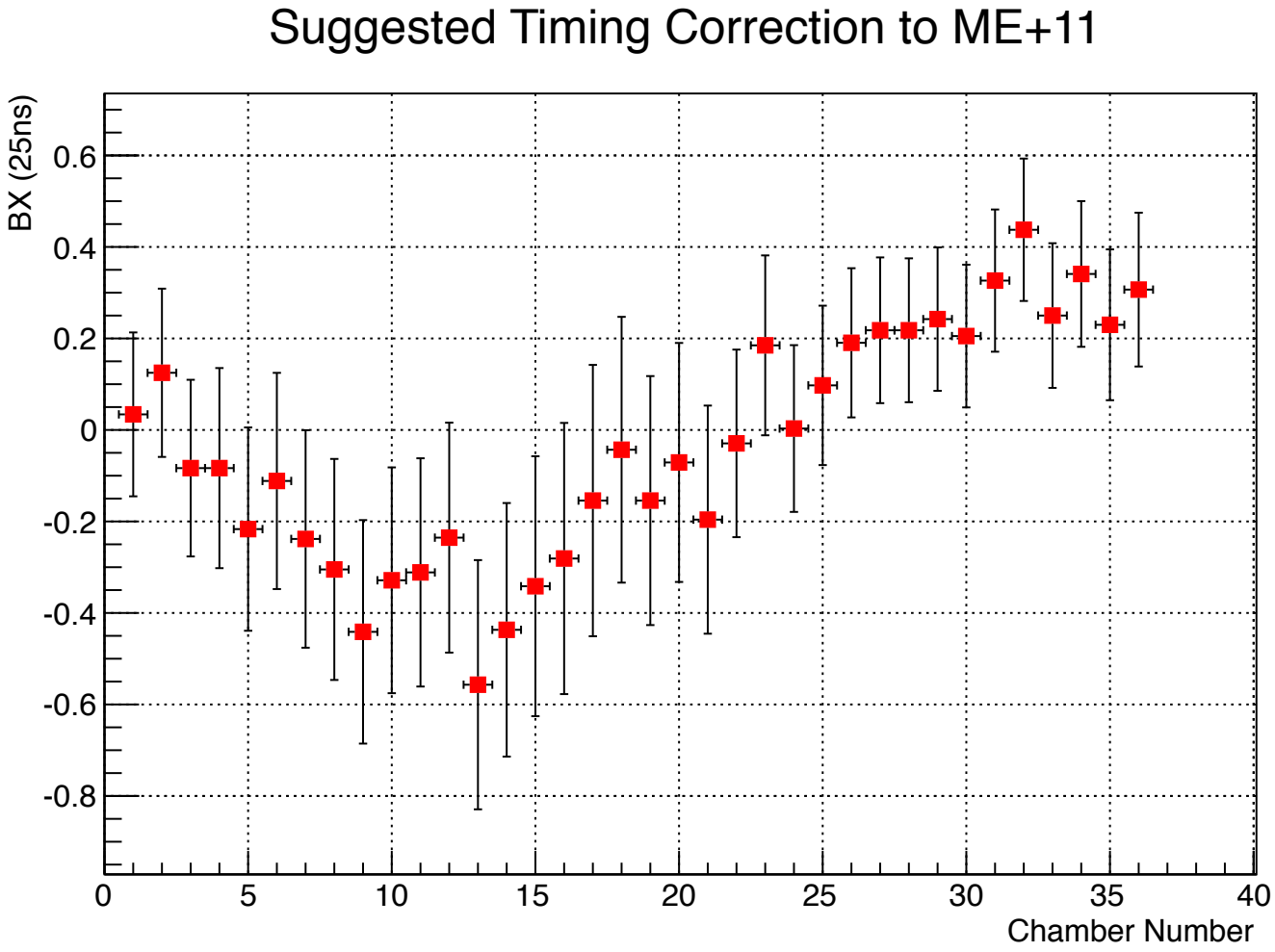
Chamber	Correction
1	0.034 +/- 0.179
2	0.124 +/- 0.183
3	-0.083 +/- 0.193
4	-0.083 +/- 0.218
5	-0.216 +/- 0.222
6	-0.111 +/- 0.236
7	-0.238 +/- 0.237
8	-0.304 +/- 0.241
9	-0.441 +/- 0.244
10	-0.328 +/- 0.246
11	-0.311 +/- 0.249
12	-0.235 +/- 0.251
13	-0.556 +/- 0.272
14	-0.436 +/- 0.277
15	-0.341 +/- 0.284
16	-0.28 +/- 0.296
17	-0.154 +/- 0.296
18	-0.043 +/- 0.29
19	-0.154 +/- 0.272
20	-0.071 +/- 0.261
21	-0.196 +/- 0.249
22	-0.029 +/- 0.204
23	0.184 +/- 0.196
24	0.003 +/- 0.182
25	0.097 +/- 0.174
26	0.19 +/- 0.163
27	0.217 +/- 0.159
28	0.217 +/- 0.157
29	0.242 +/- 0.156
30	0.205 +/- 0.155
31	0.326 +/- 0.155
32	0.437 +/- 0.155
33	0.25 +/- 0.158
34	0.34 +/- 0.159
35	0.229 +/- 0.164
36	0.306 +/- 0.168

Results from Numerical Minimization



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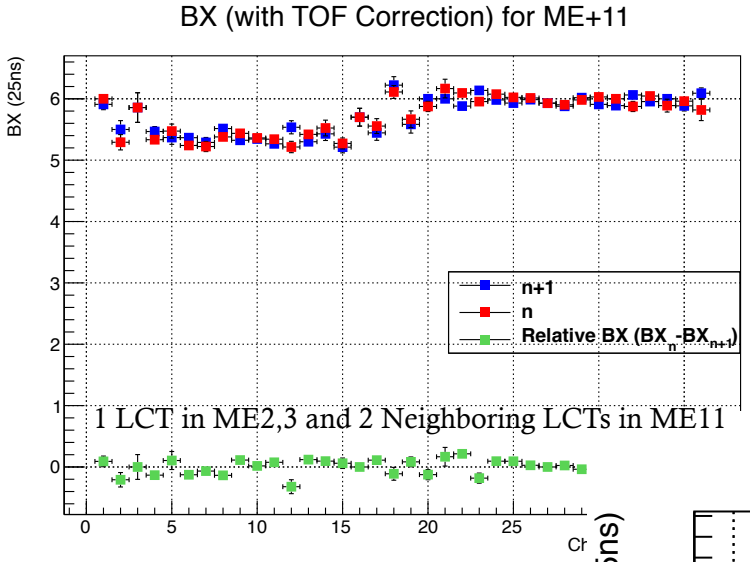
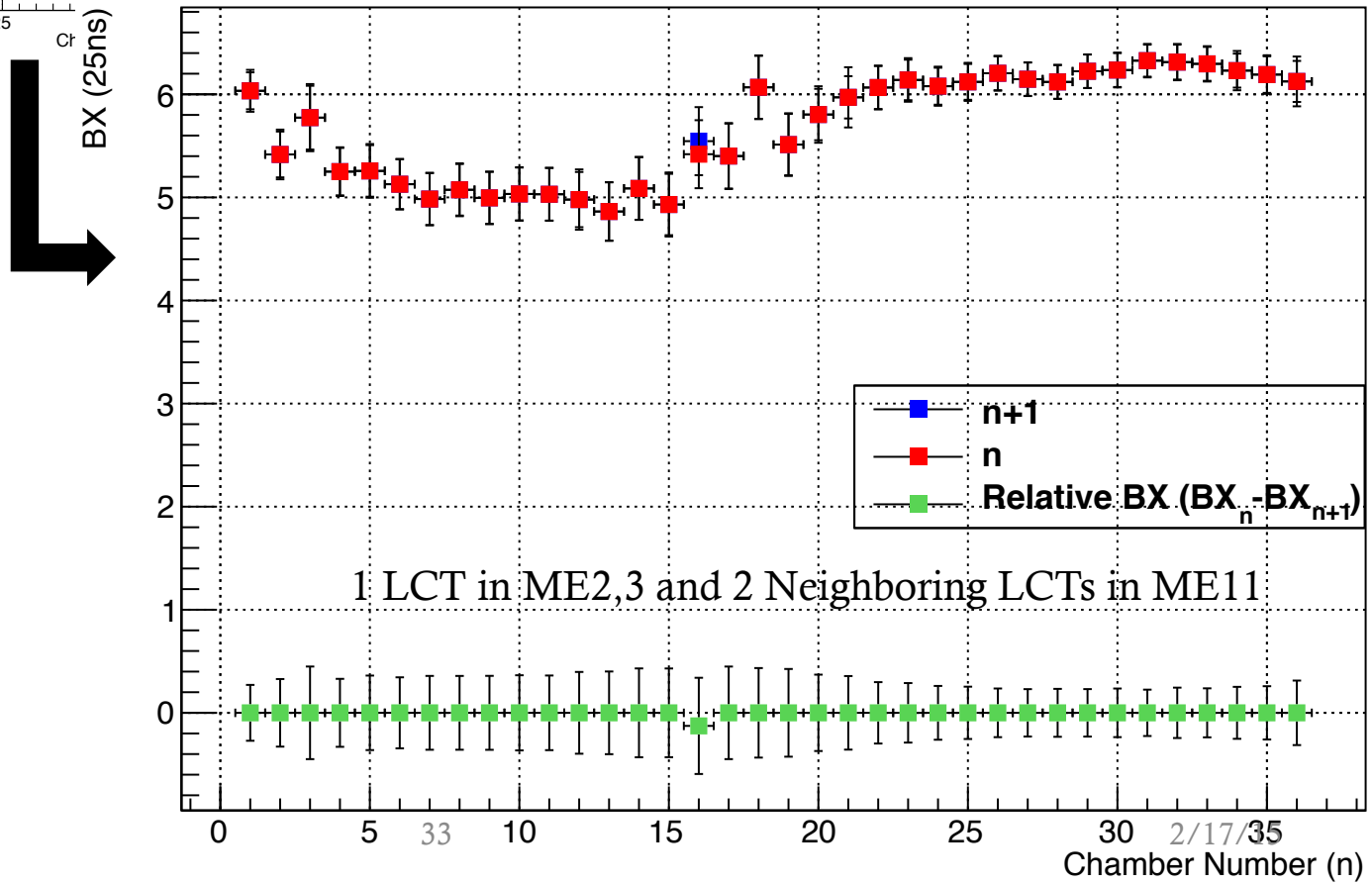
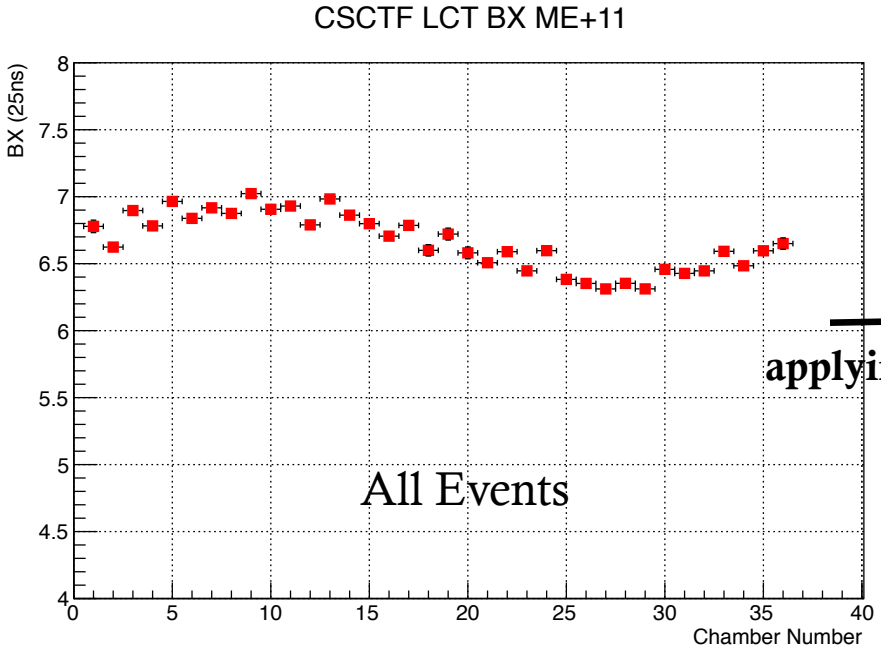


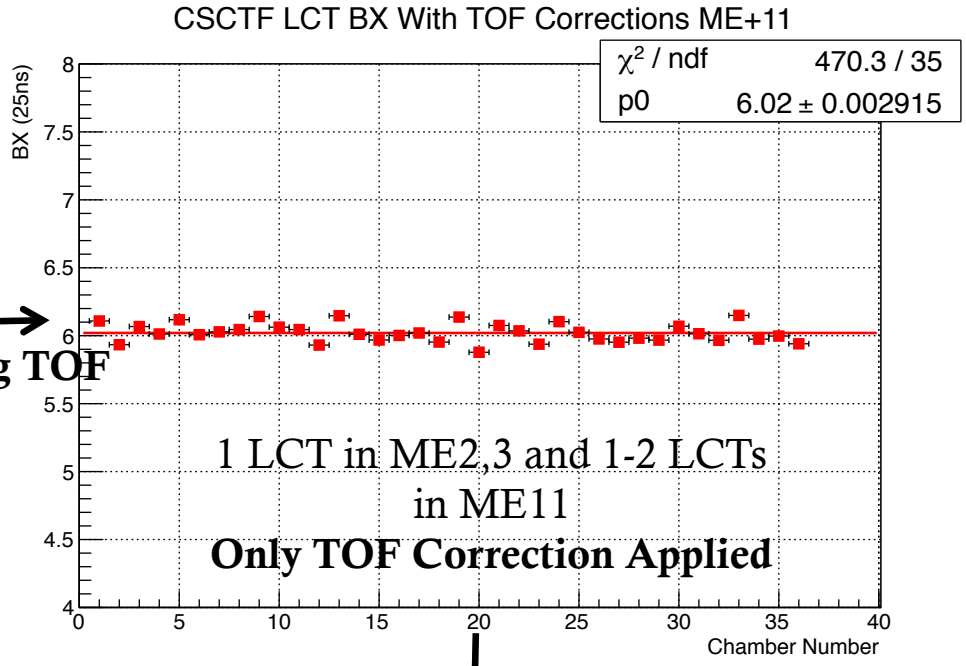
- Apply corrections from minimization
- Relative BX looks good!

BX (with ChiSquare and TOF Correction) for ME+11

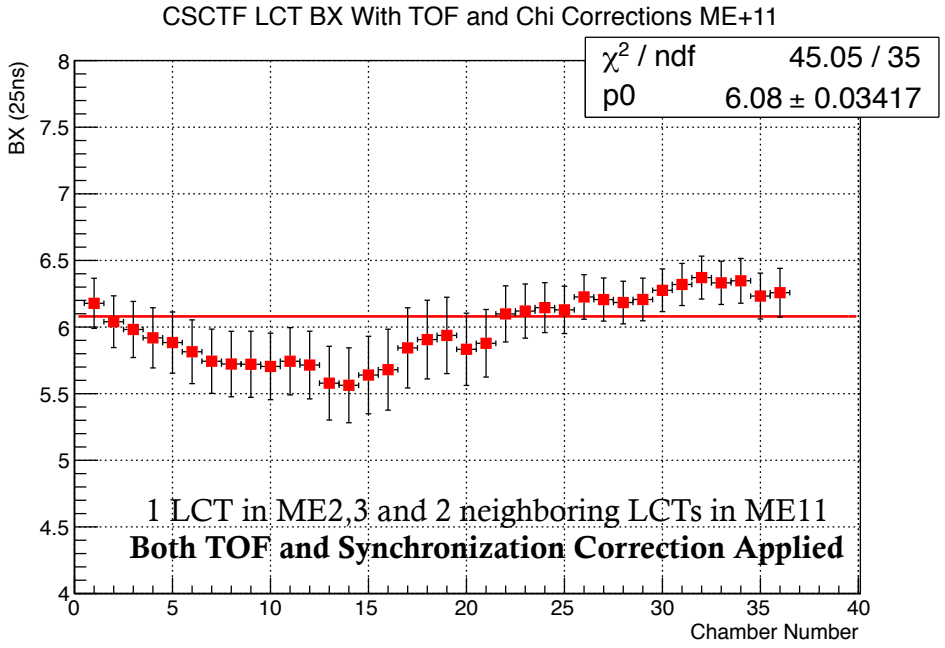




applying TOF

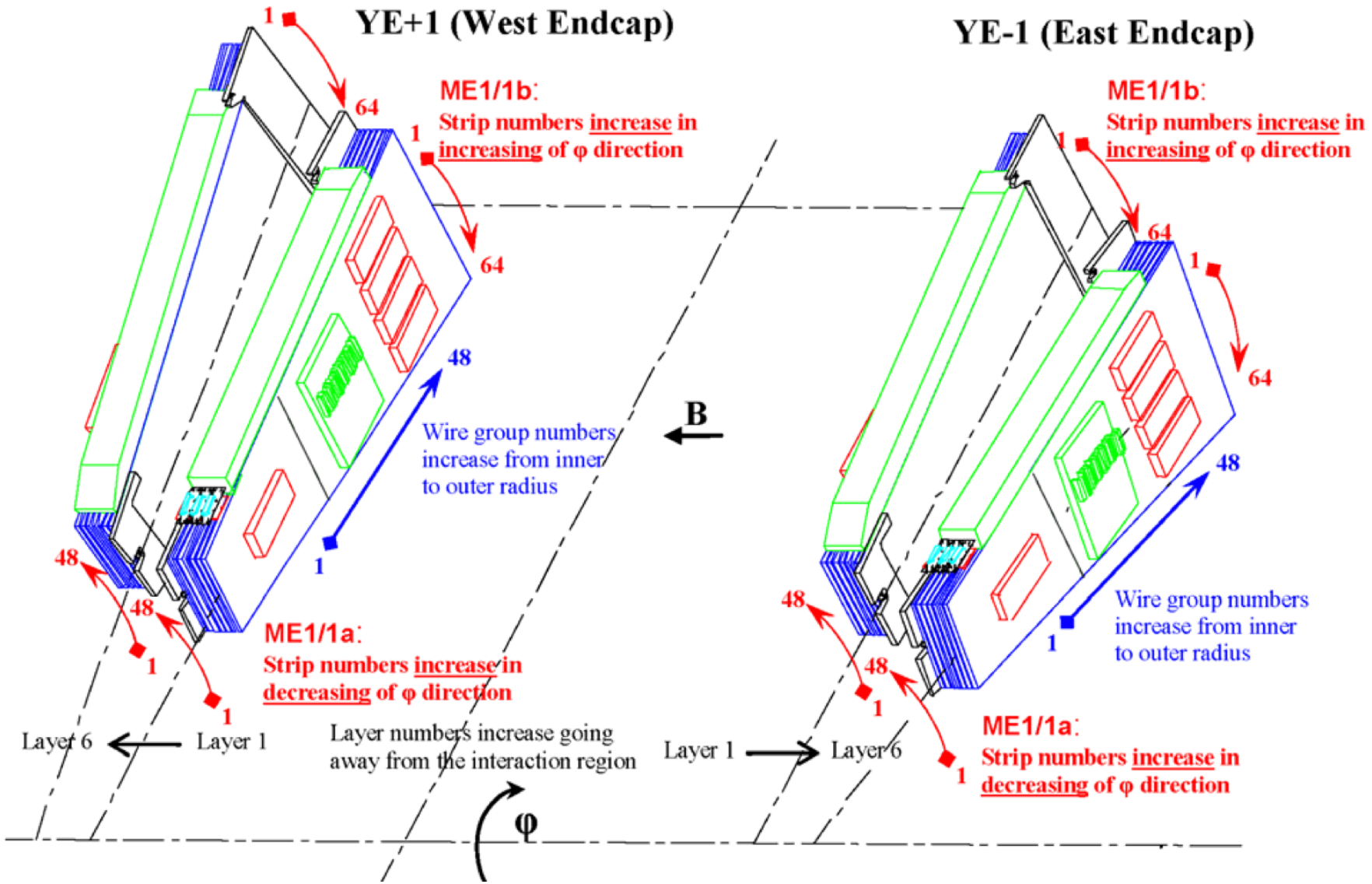


applying χ^2 corrections

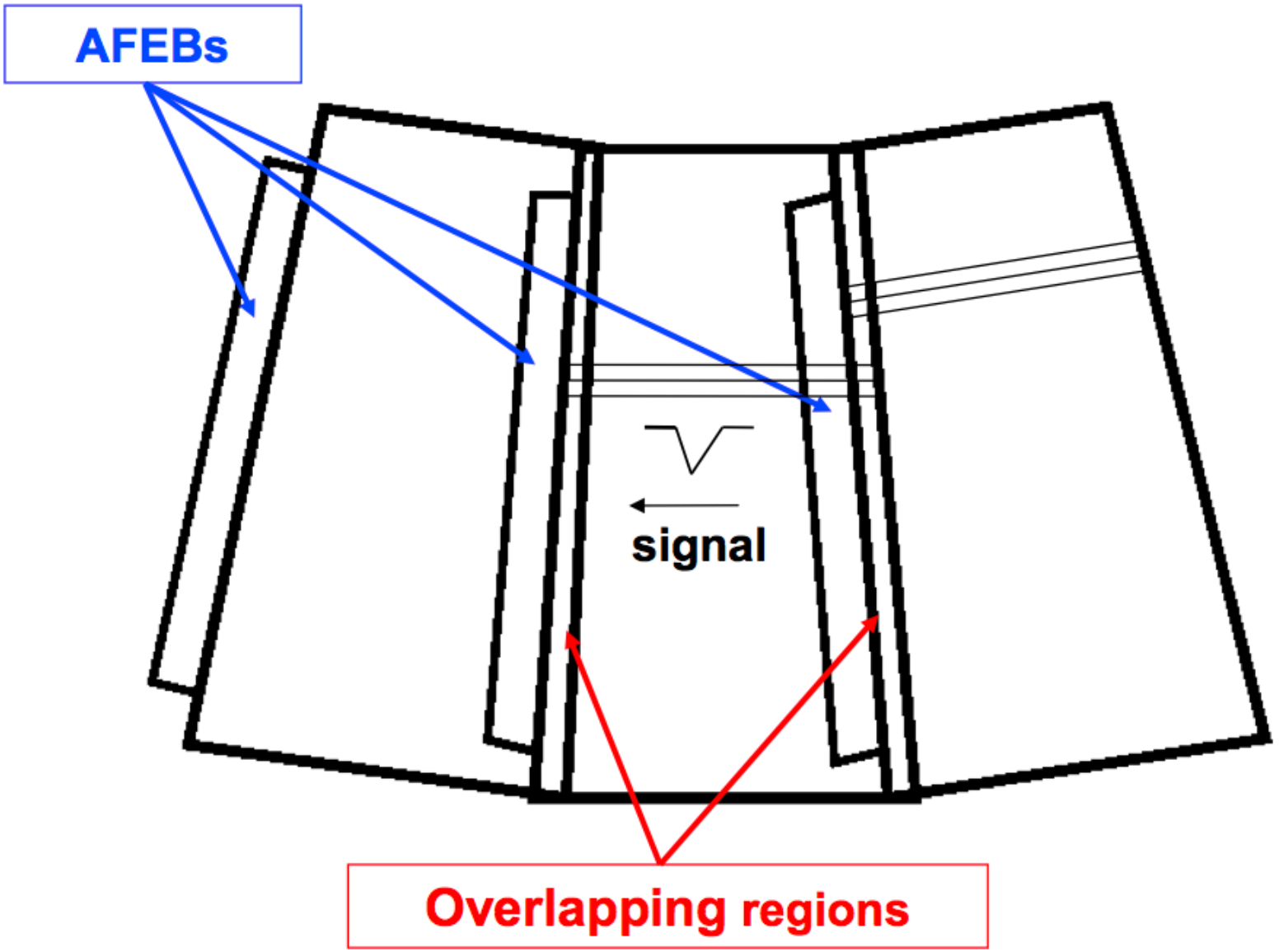


- All chambers within 1 BX
- Current work:
  - Strange behavior seen in bottom right
    - May be due to a geometric factor not yet accounted for
    - Very selective event criteria

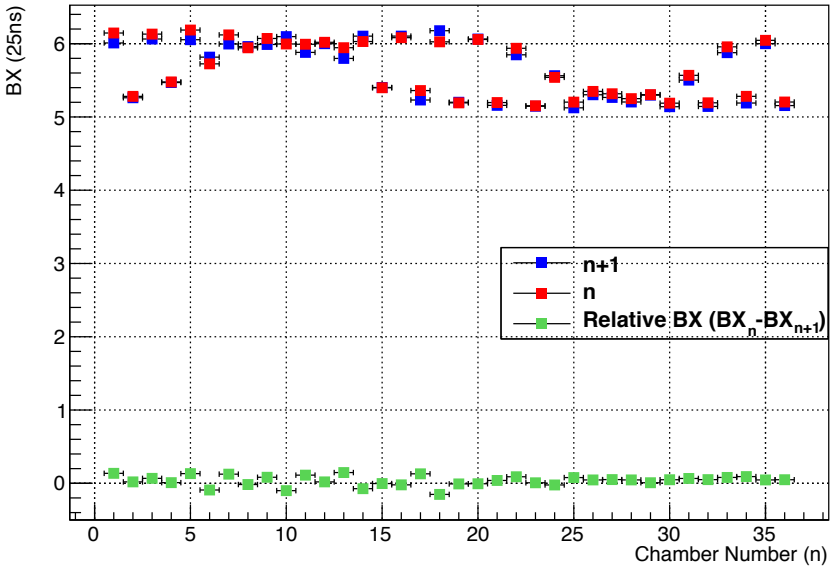
Signal Propagation

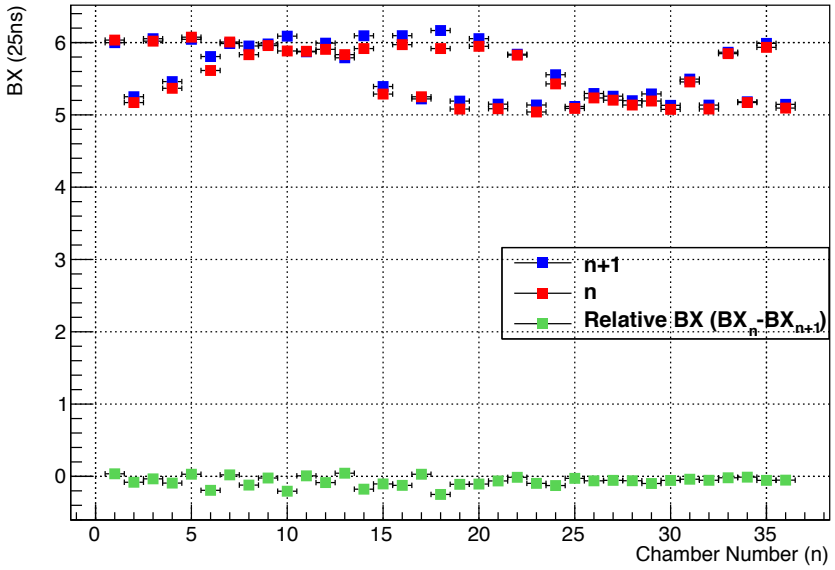


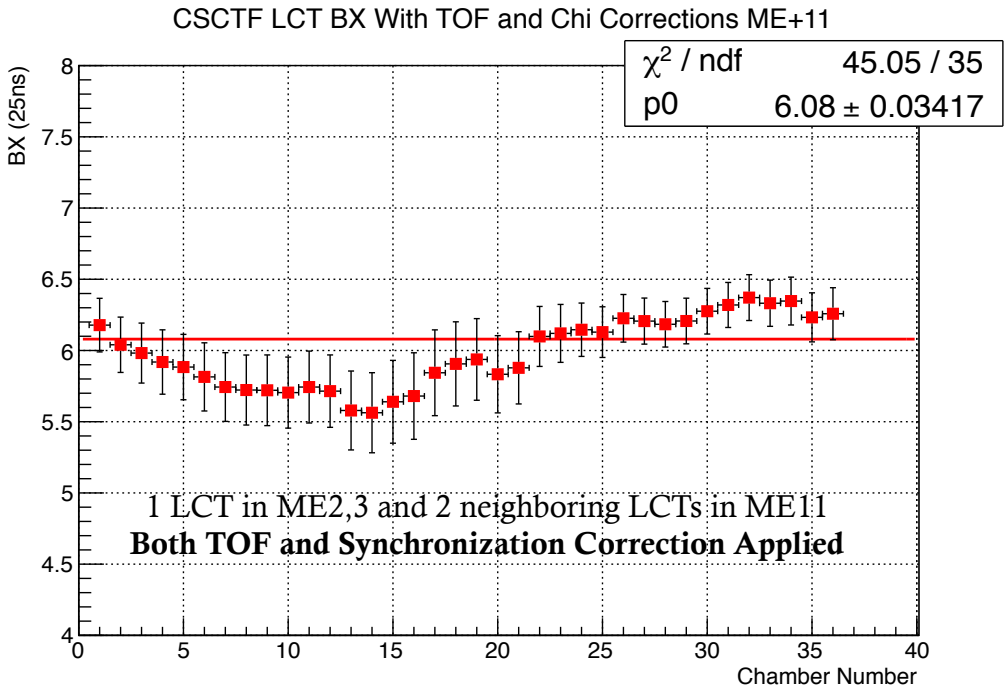
Signal Propagation

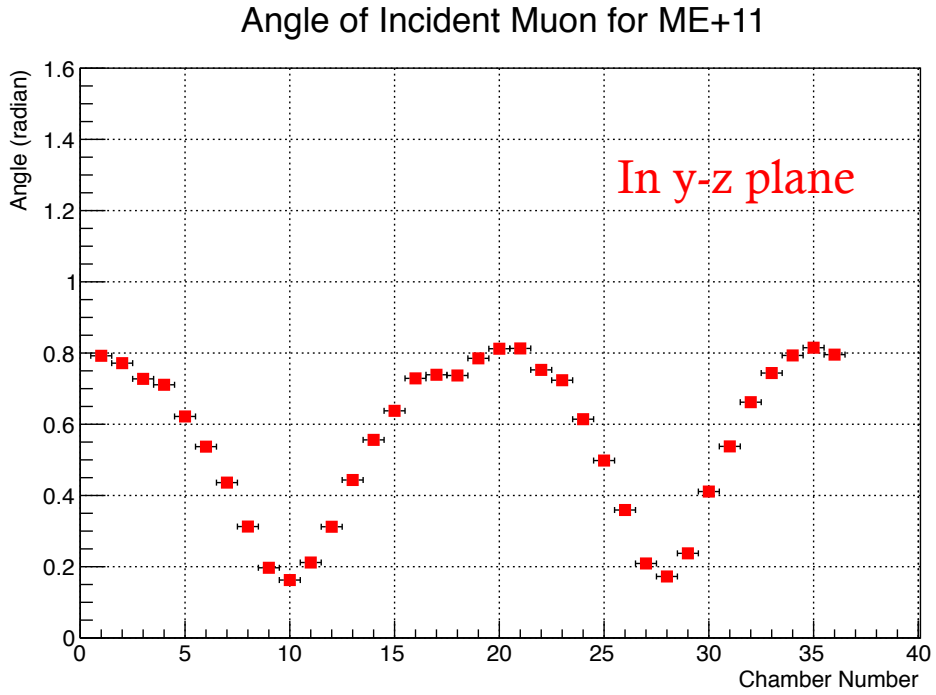


Signal Propagation







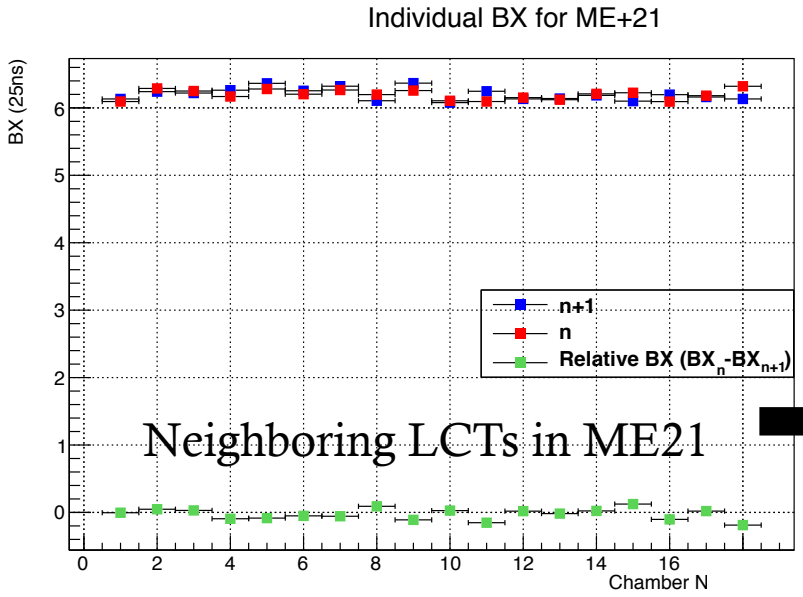


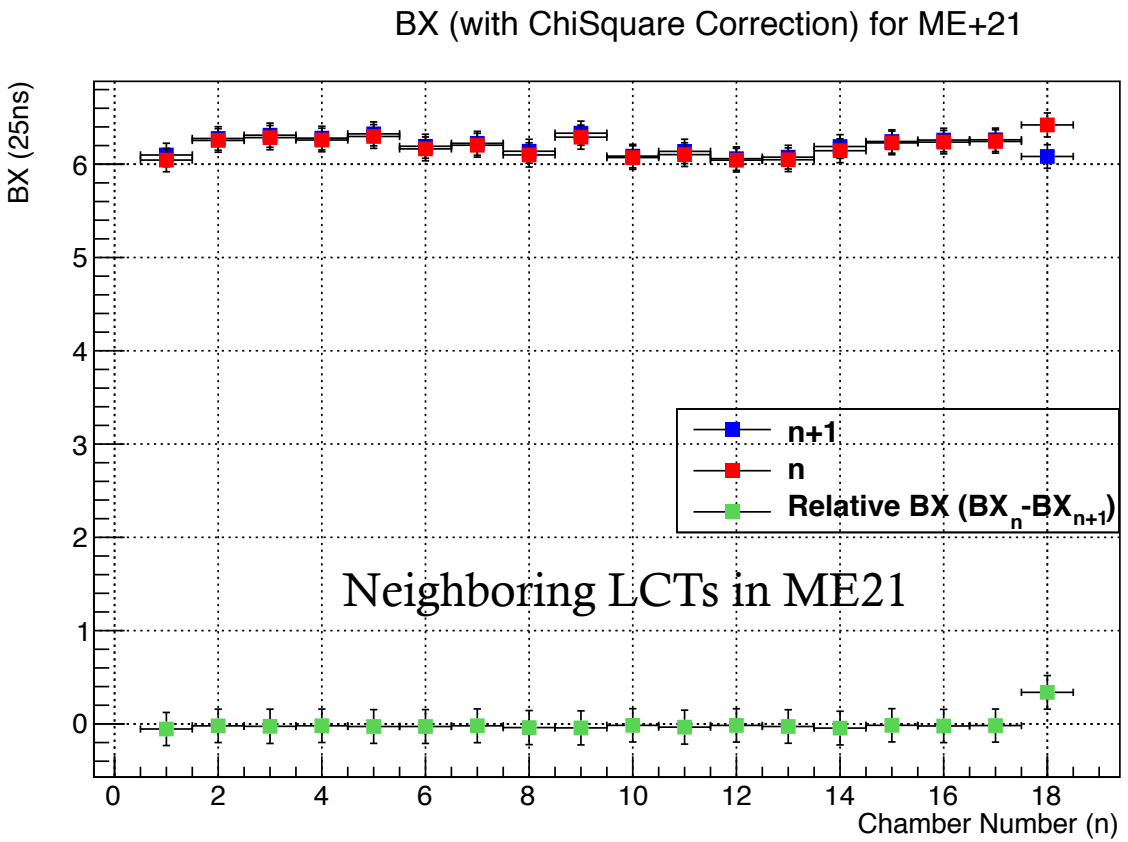
Angle of Incident Muon

- It had been suggested that strange behavior may be due to incident angle
- Horizontal chambers have higher incident angle
  - Cosmic runs
  - Features in BX should (hopefully) disappear when using beam data
- ~~Current work~~
  - ~~Apply LCT quality cuts~~

A Quick Sanity Check: Looking at ME+21 & ME+12

ME+21 From LR 227021





- Already mostly in sync
- Chi square behaves as expected and yields a more precise synchronization
- Low statistics in chamber 18

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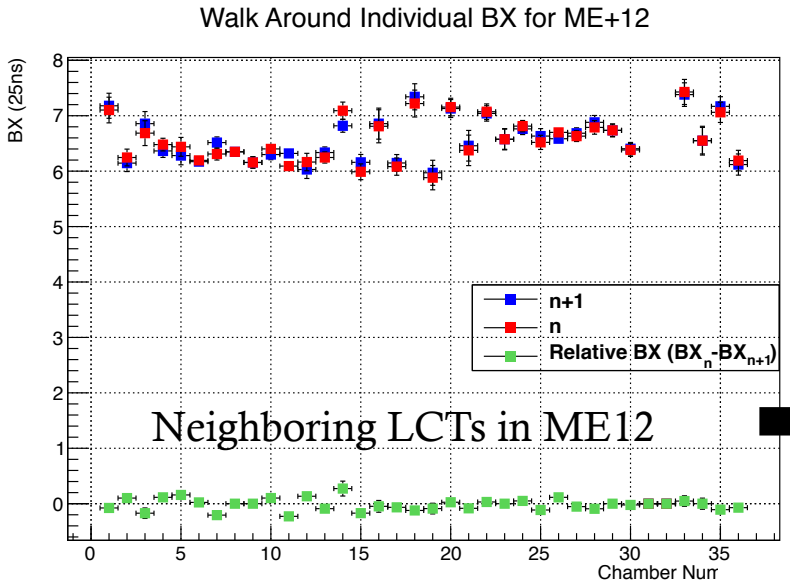
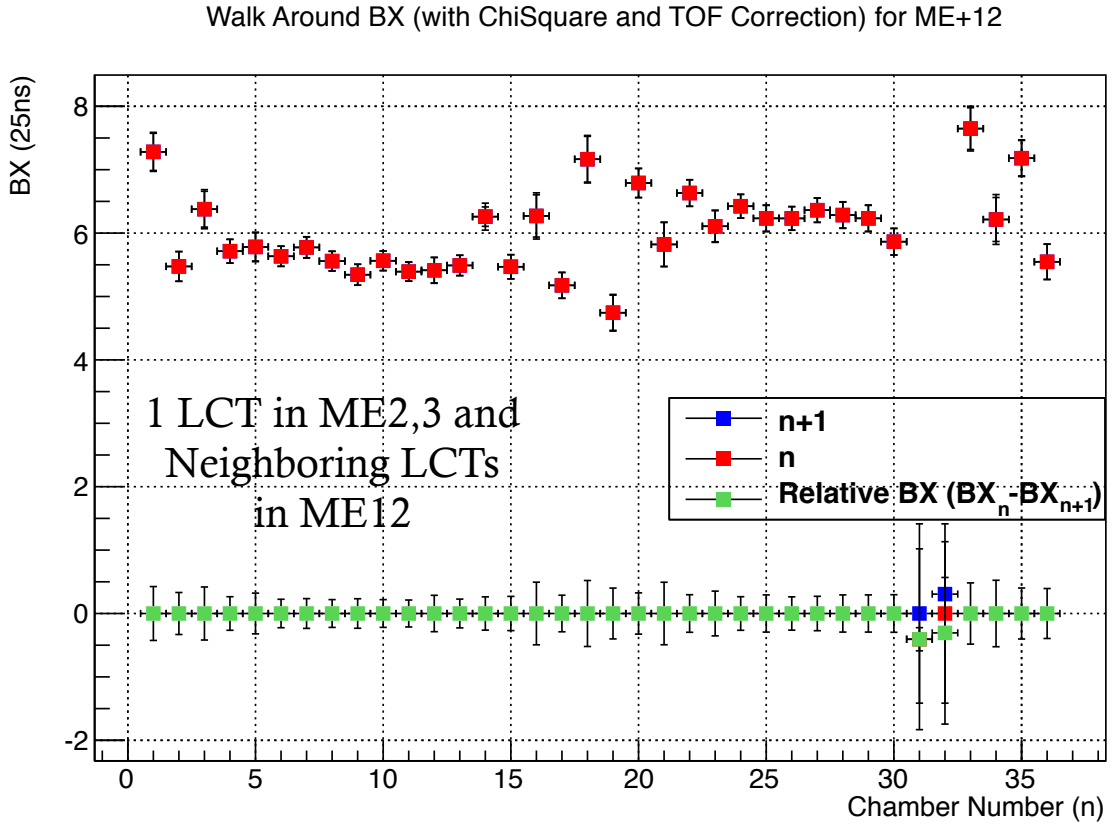


ME+12 From LR 227021

- Already mostly in sync
- Chi square behaves as expected and yields a more precise synchronization
- Low statistics in chambers 31 & 32



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Conclusions and Future Work

- Waiting for beam to avoid the incident angle and possible geometric issues
  - Beam will also be used to synchronize entire endcap
  - Time chambers to beam
- Synchronize and calibrate to other disks
- ~~ME42 needs to be done~~
  - ~~Exact same method will apply~~
- ~~Investigate signal propagation time~~
- Note in progress: DN-2014/041

2015 Stage 1 Development Calendar

Week 2 Jan 5-Jan 9 TCDS update and testing

3 Jan 12-Jan 16

4 Jan 19-Jan 23 IT network outage

5 Jan 26-Jan 30 MWGR10. MP7 test with AMAAP

6 Feb 2-Feb 6

7 Feb 9-Feb 13 CRUZET

8 Feb 16-Feb 20

9 Feb 23-Feb 27 Trigger review; Physics/upgrade week; CRAFT

10 Mar 2-Mar 6

11 Mar 9-Mar 13 First LHC beams

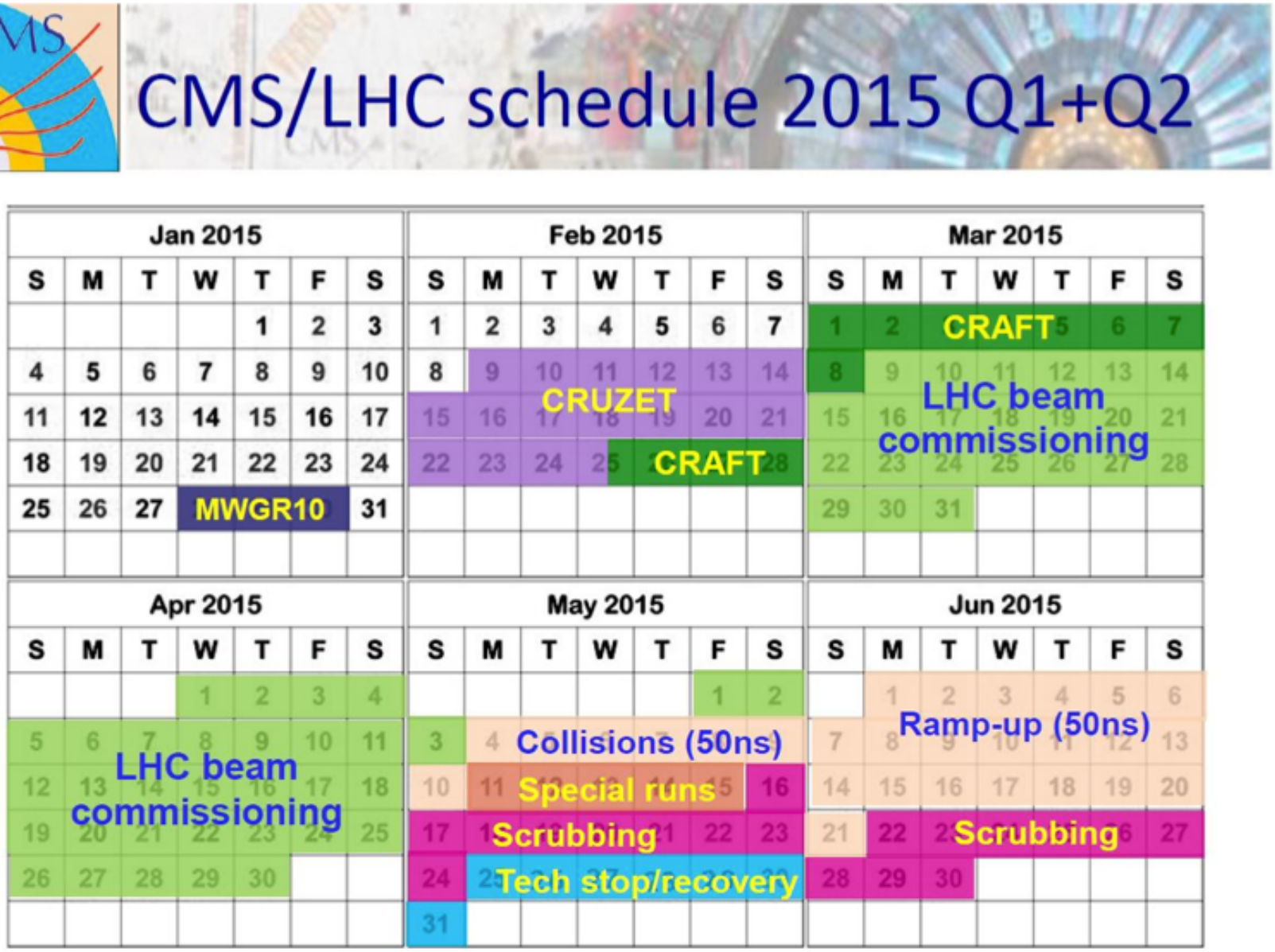
12 Mar 16-Mar 20 L1 upgrade review?

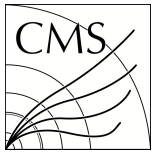
13 Mar 23-Mar 27

Collisions May 4 (wk 19)

2015 Stage 1 Development Calendar

CMS/LHC schedule 2015 Q1+Q2

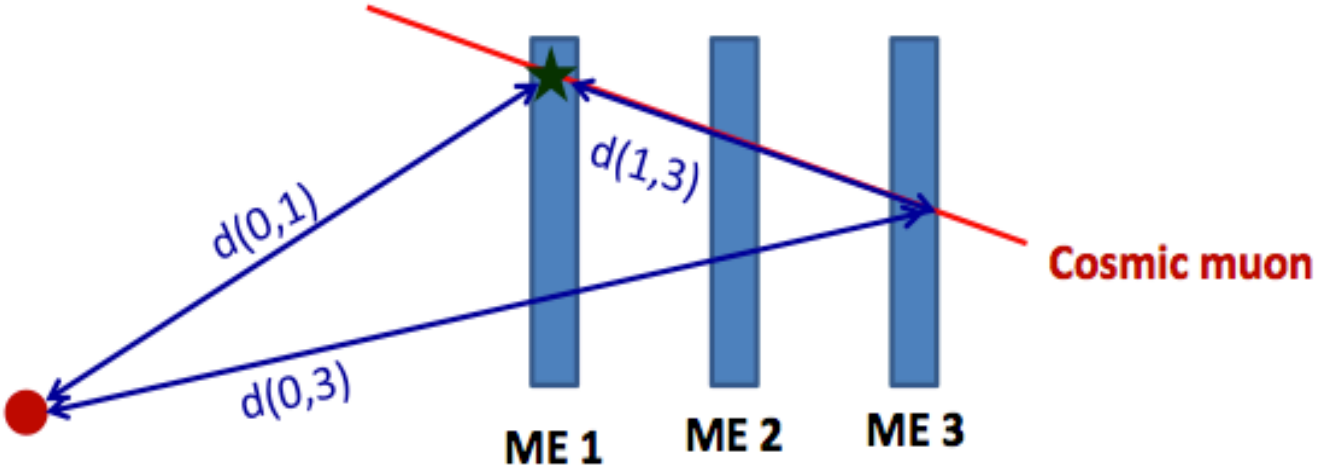




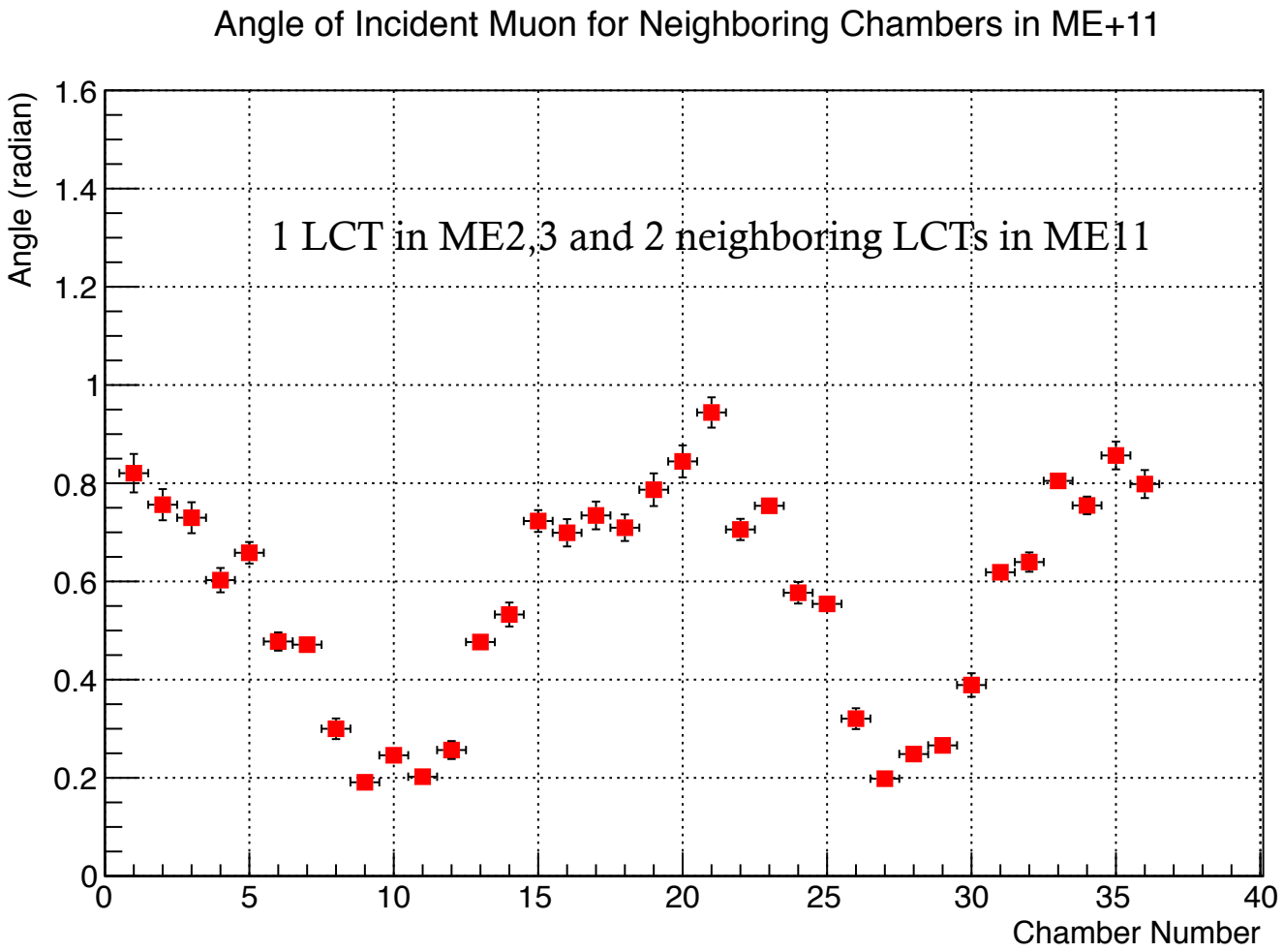
Backup

Correct time

- Using the position information of the different muons and assuming speed of light for the muon
  - Use trigger position in station 3 for muons with higher y in station 3 than station 2, trigger position in station 2 for the others
  - Time changes:
    - d(0,3)-d(0,1) is time difference in flight expected for the two hits
    - D(1,3) is the real time difference
  - For forward moving muons, both complement each other, for backward moving they counteract:
    - Forward: ALCT_Bx-d(0,2)-d(1,2)+d(0,1)
    - Backward: ALCT_Bx-d(0,3)+d(0,1)+d(1,3)

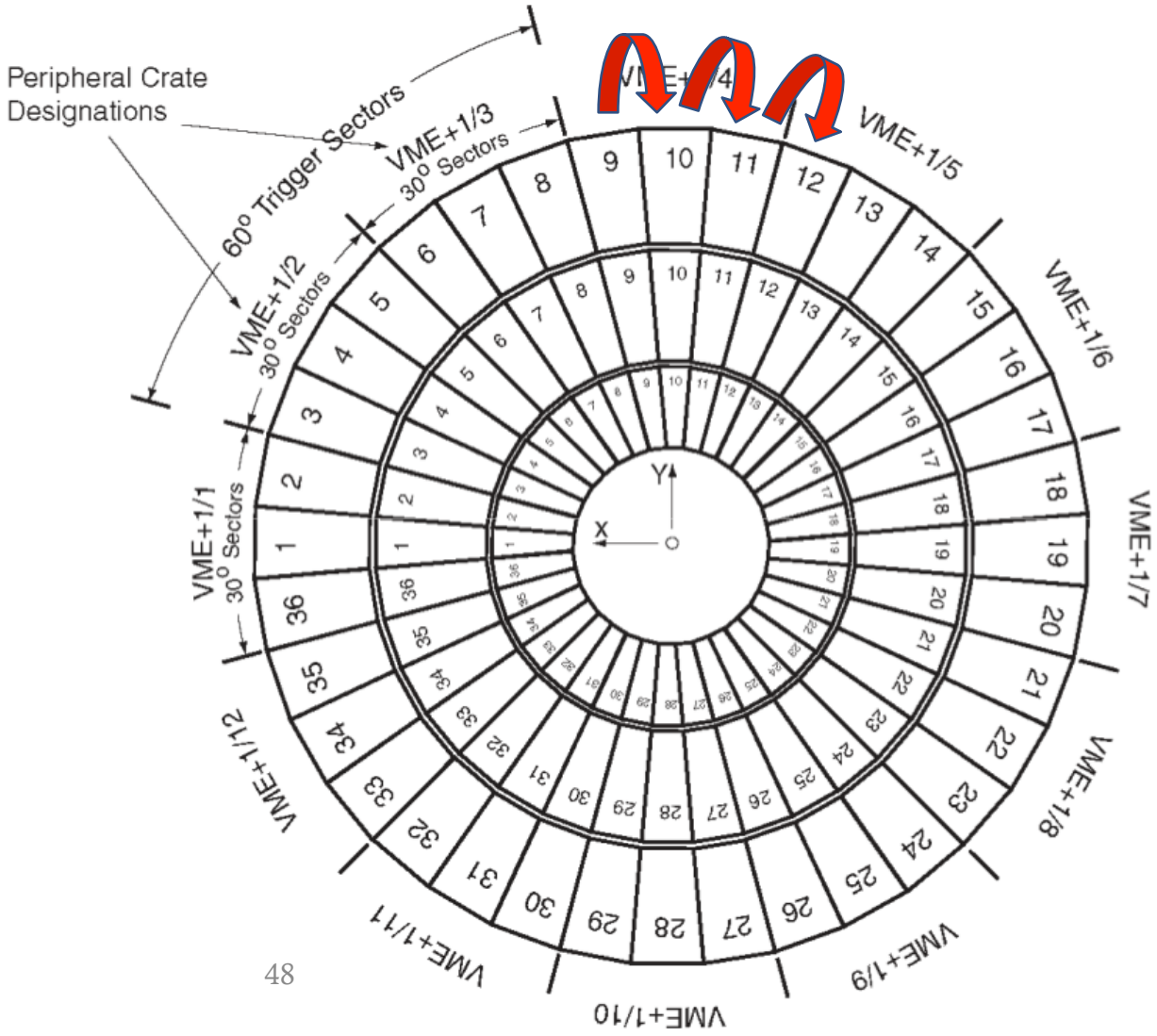


LR 228354


Angle of Incident Muon for Neighboring Chambers in ME+11
1 LCT in ME2,3 and 2 neighboring LCTs in ME11
Angle (radian)
Chamber Number
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
5
10
15
20
25
30
35
40

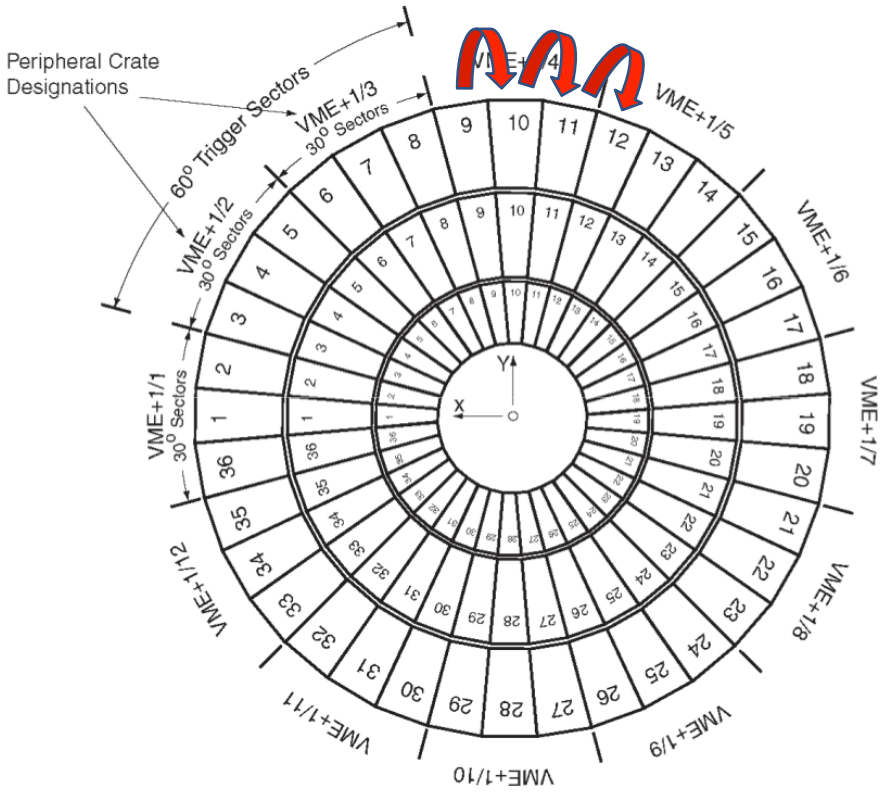
Walk-Around Rings

- Use these LCTs from neighboring chambers to "walk-around" each ring
- Synchronize each ring to itself

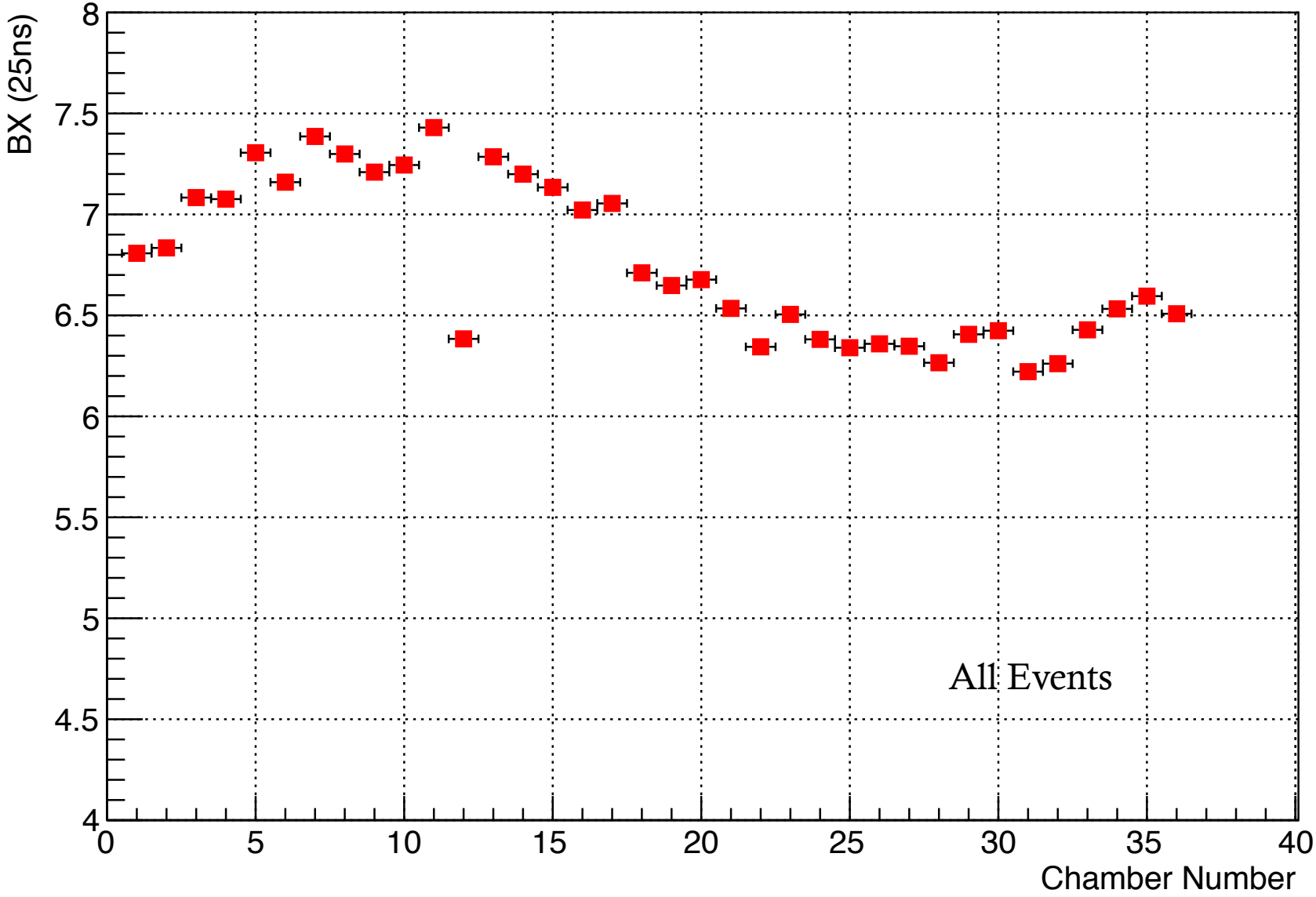


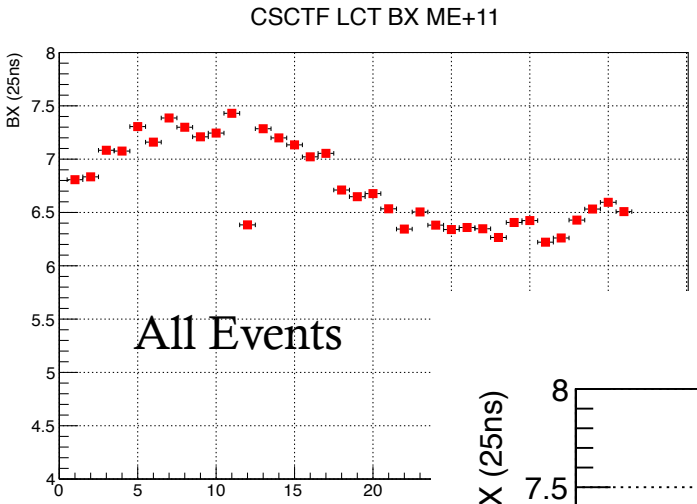
Synchronization Methods

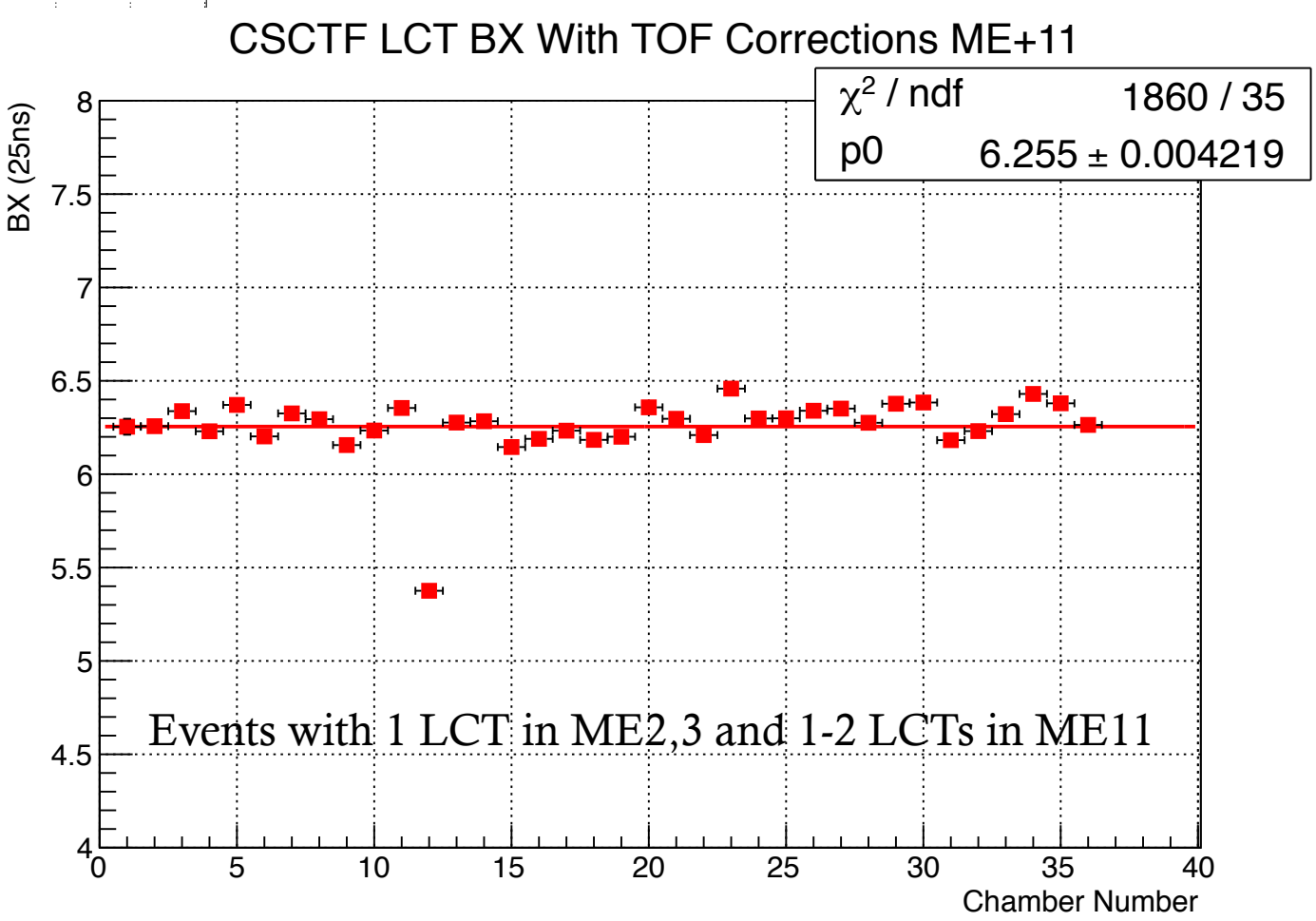
- A simple walk around (naïve method from 2009 synchronization note) does not converge.
  - "Chasing my tail"
  - 2009 note: https://cms-csctf-sw.web.cern.ch/cms-csctf-sw/timingresult/csctf_timing.pdf
- Synchronization by χ^2 minimization does work



Local Run 227021

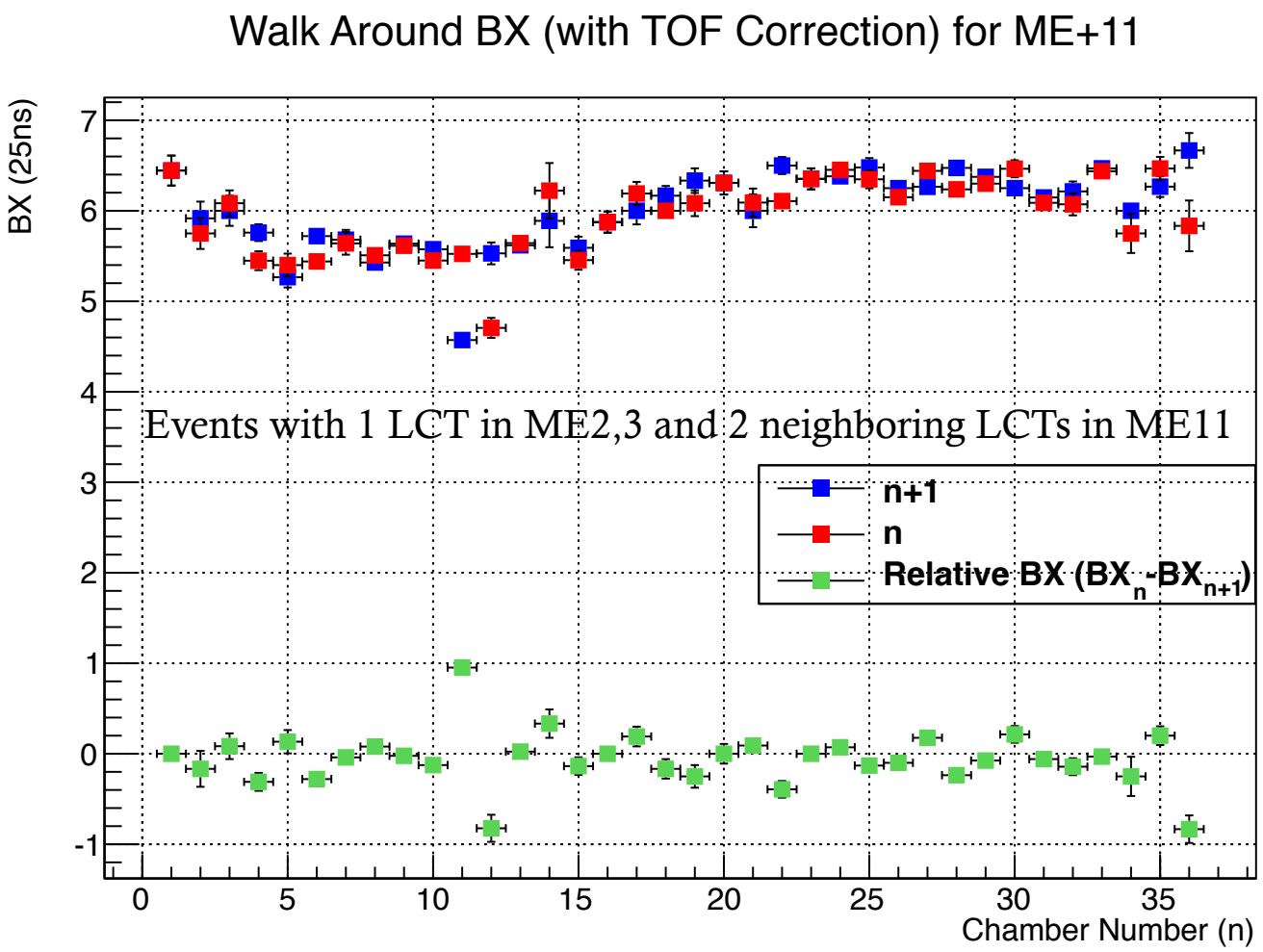






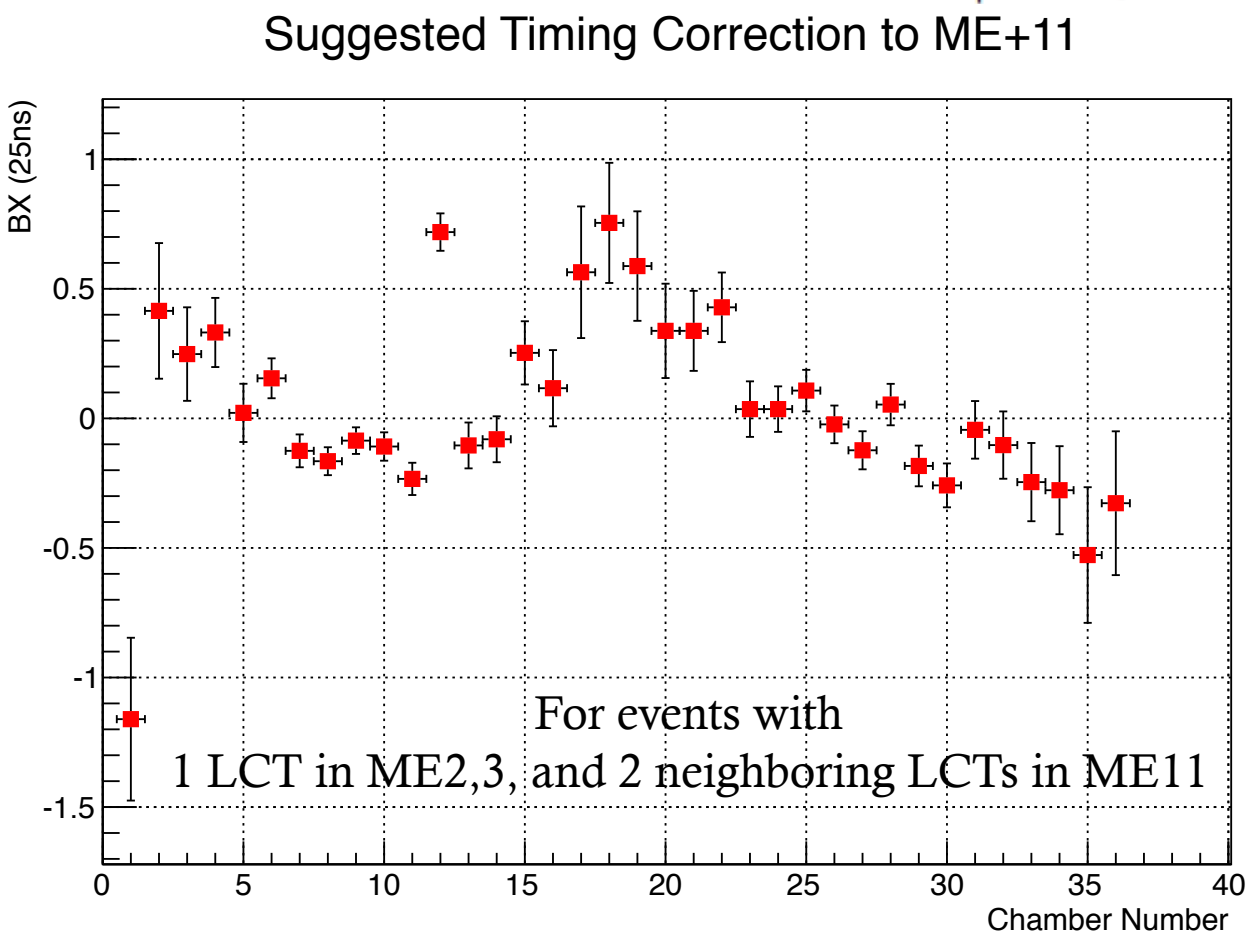
- Apply TOF corrections as described by Pieter (https://indico.cern.ch/event/343855/contribution/1/material/slides/0.pdf)

Walk Around Synchronization

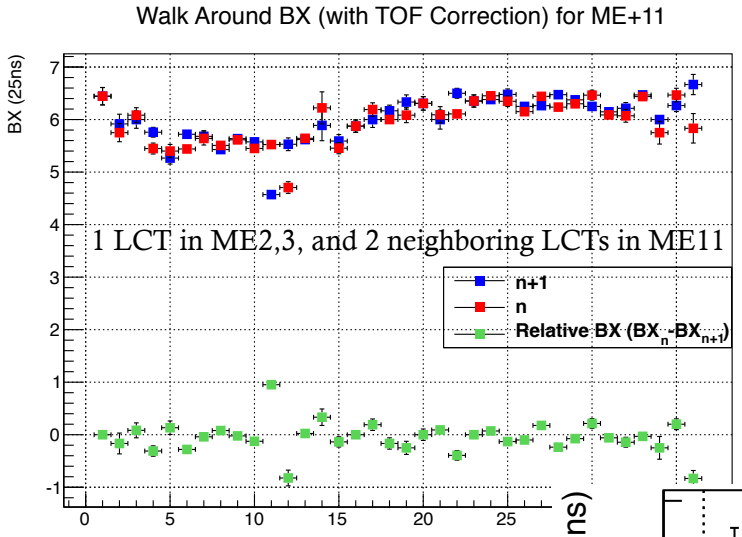


- BX from Walk-Around
- Chamber n shows BX for overlap between chamber n and chamber n+1.
- Chamber 36 wraps around.
  - Chamber n is 36, chamber n+1 is 1

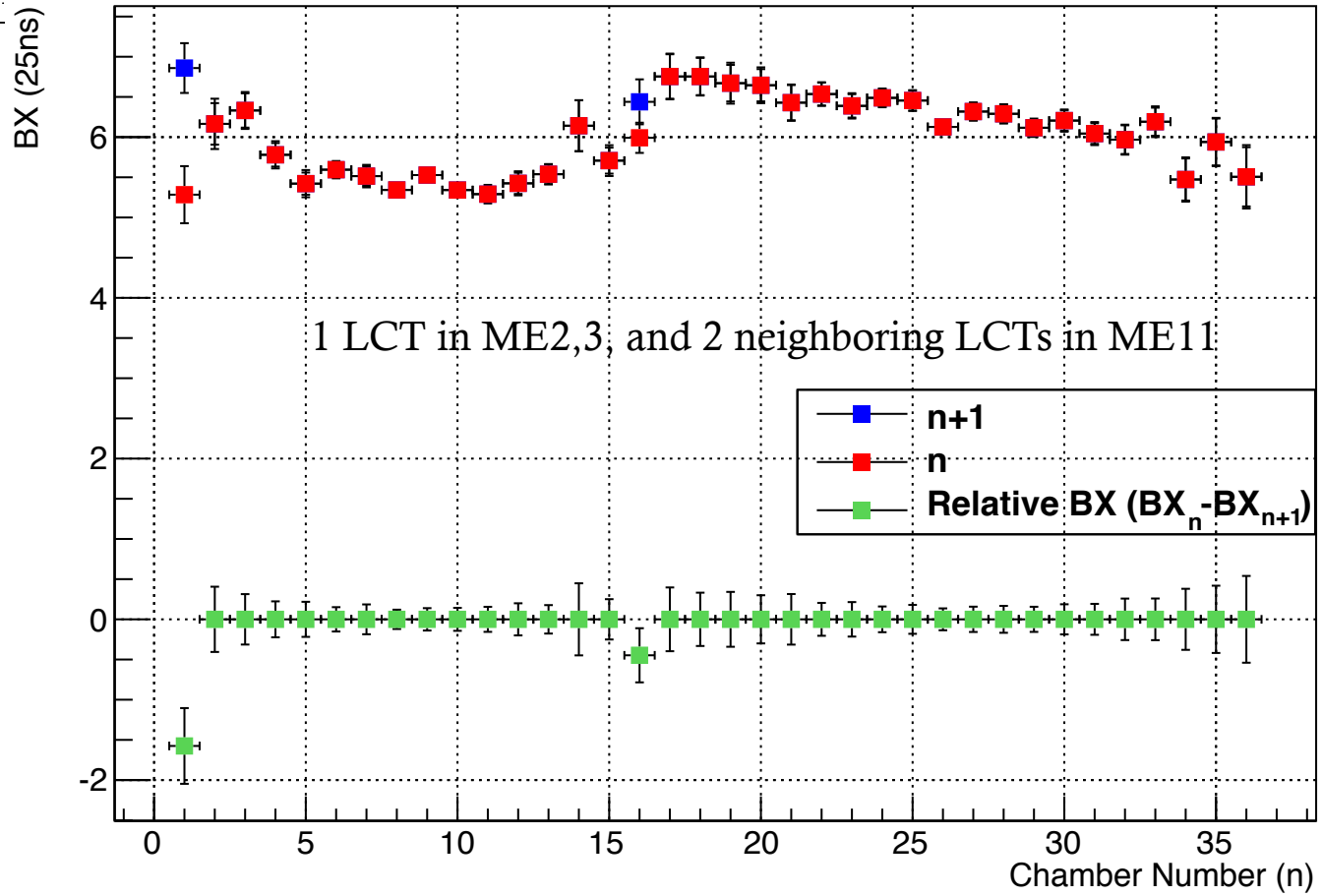
Results from Numerical Minimization



Chamber	Correction
1	-1.16 +/- 0.314
2	0.414 +/- 0.261
3	0.248 +/- 0.18
4	0.331 +/- 0.133
5	0.021 +/- 0.112
	0.154 +/- 0.076
	-0.125 +/- 0.063
	-0.165 +/- 0.053
	-0.085 +/- 0.051
	-0.108 +/- 0.054
	-0.233 +/- 0.062
	0.718 +/- 0.072
	-0.104 +/- 0.088
	-0.08 +/- 0.088
	0.252 +/- 0.121
	0.116 +/- 0.147
	0.563 +/- 0.253
	0.754 +/- 0.231
	0.587 +/- 0.211
	0.337 +/- 0.182
	0.337 +/- 0.154
	0.428 +/- 0.134
	0.035 +/- 0.107
	0.035 +/- 0.087
	0.107 +/- 0.08
	-0.023 +/- 0.072
	-0.123 +/- 0.073
	0.053 +/- 0.079
	-0.183 +/- 0.078
	-0.258 +/- 0.084
	-0.044 +/- 0.111
	-0.103 +/- 0.129
	-0.245 +/- 0.15
	-0.277 +/- 0.169
35	-0.527 +/- 0.261
36	-0.327 +/- 0.277



- Apply corrections from minimization
- Relative BX looks good!
- Bad chambers (1 & 16) are due to low statistics



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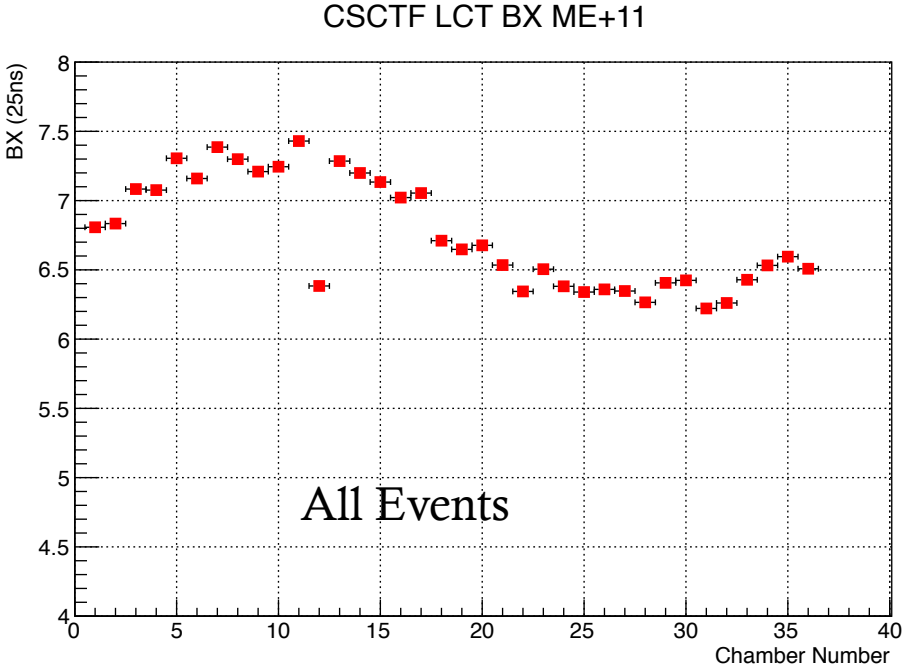
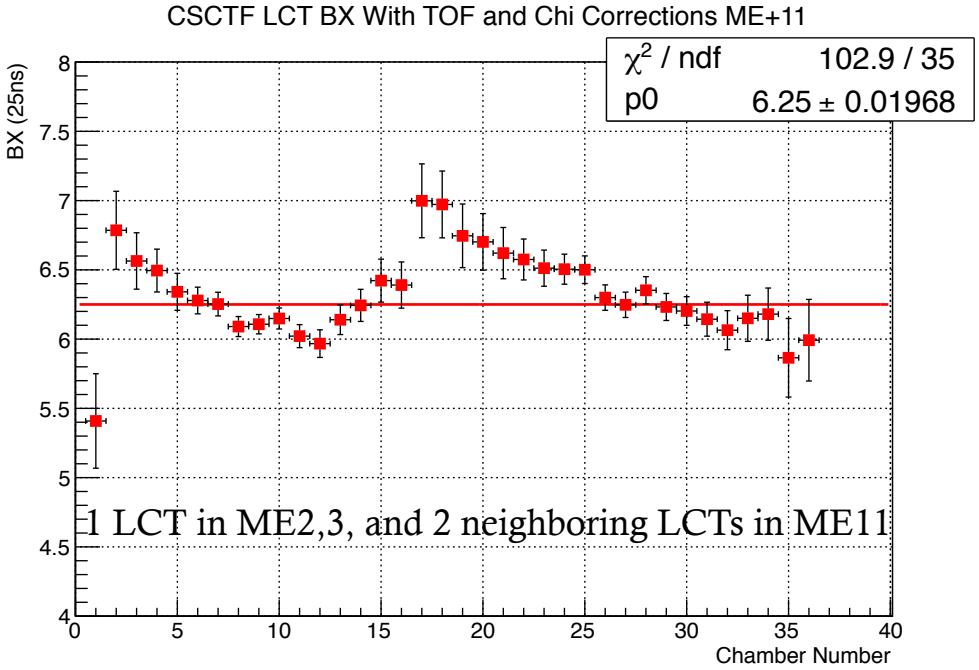
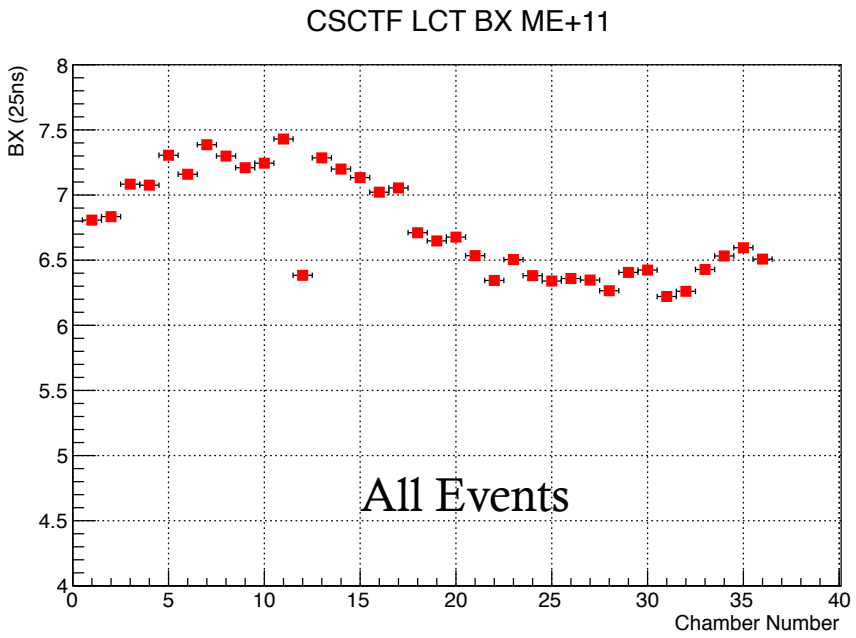
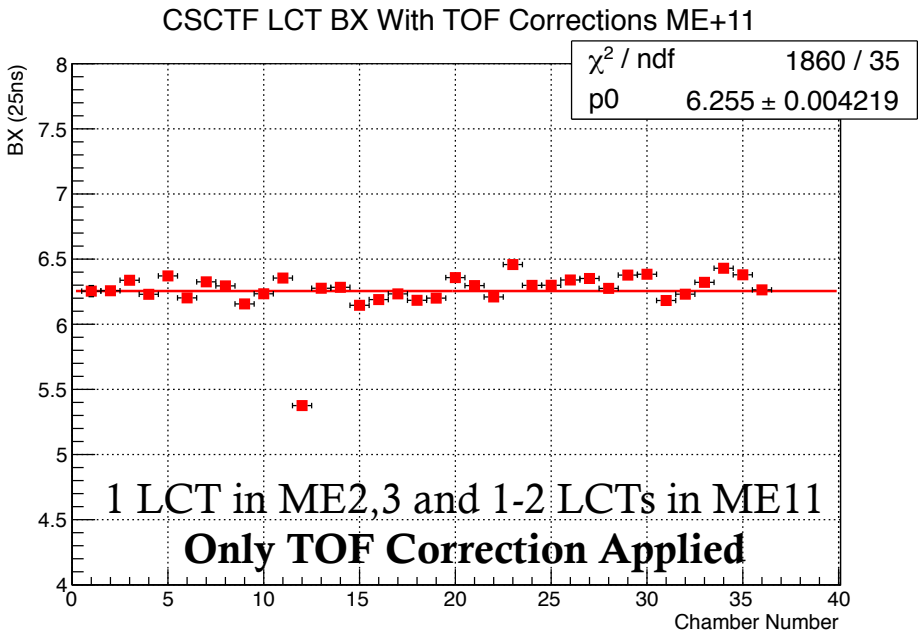
Compare Corrected BX to Original



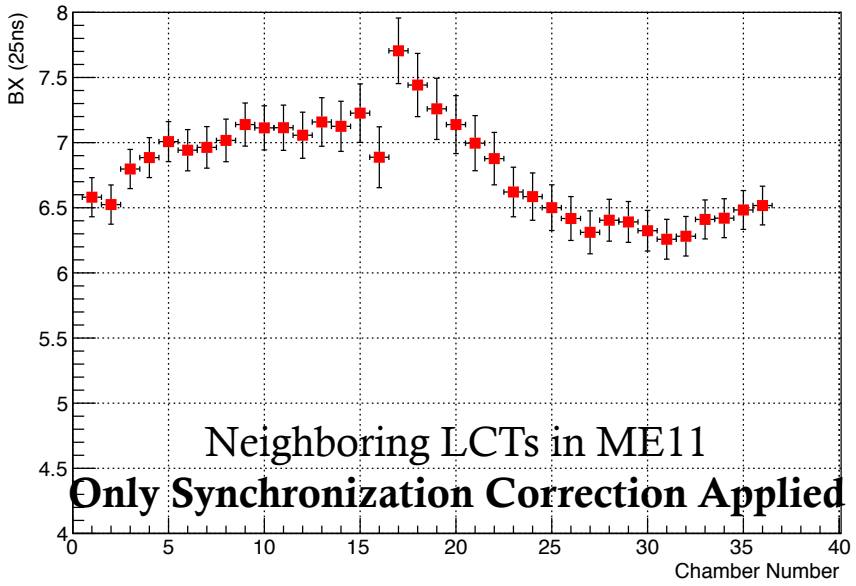


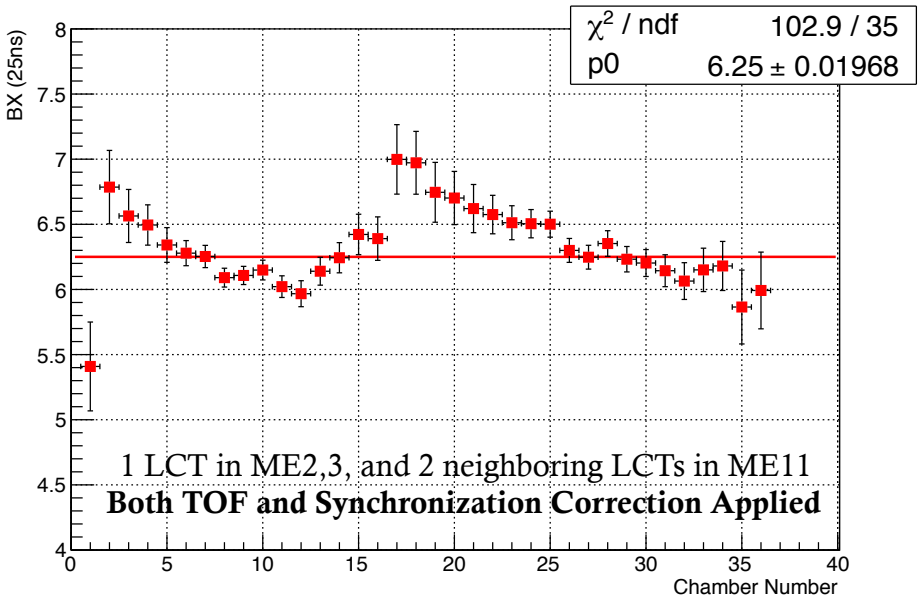
- Jumps in Right plot could be due to a geometric factor not yet accounted for
  - Very selective event criteria

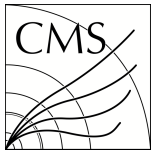




After applying χ^2 corrections



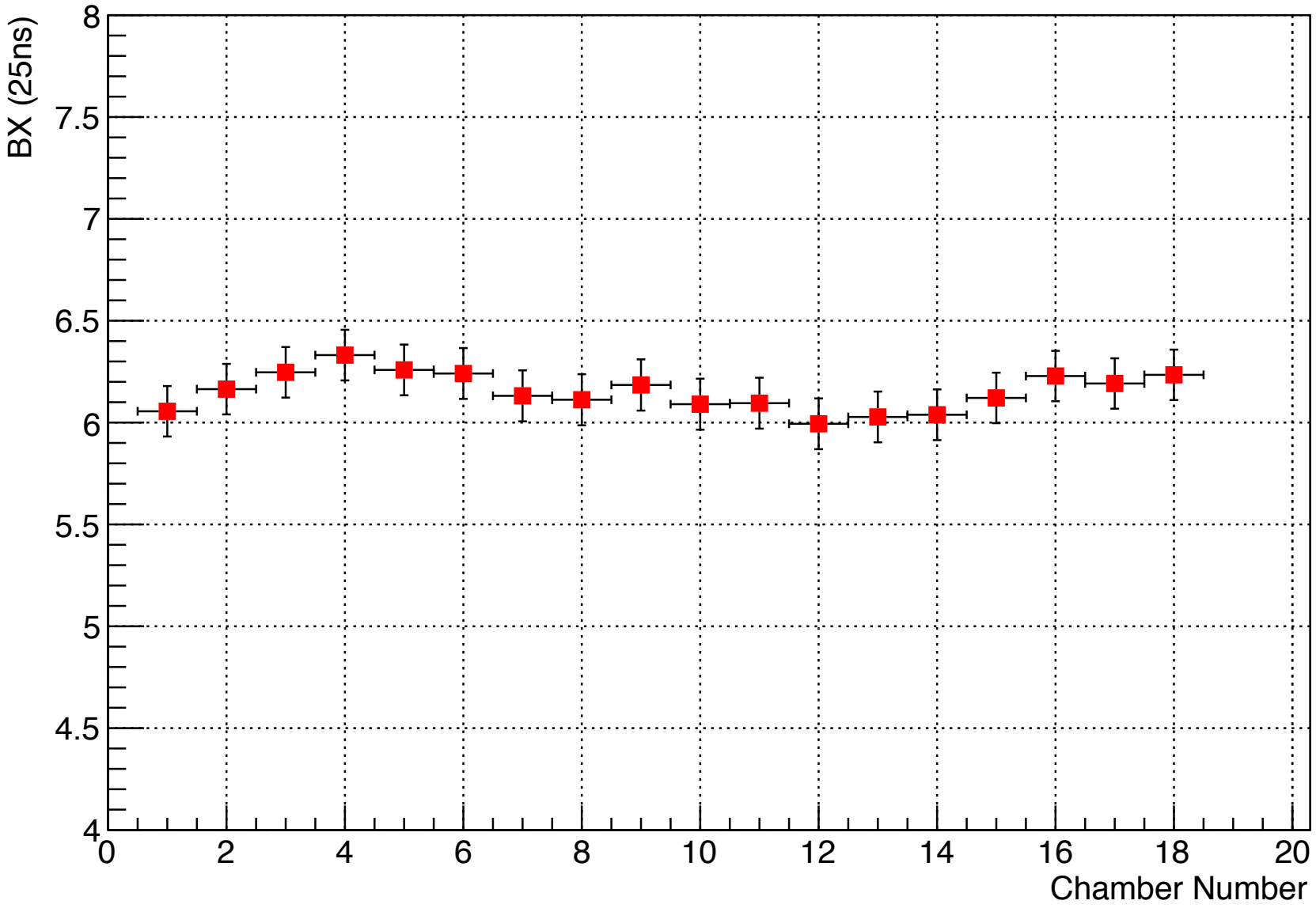


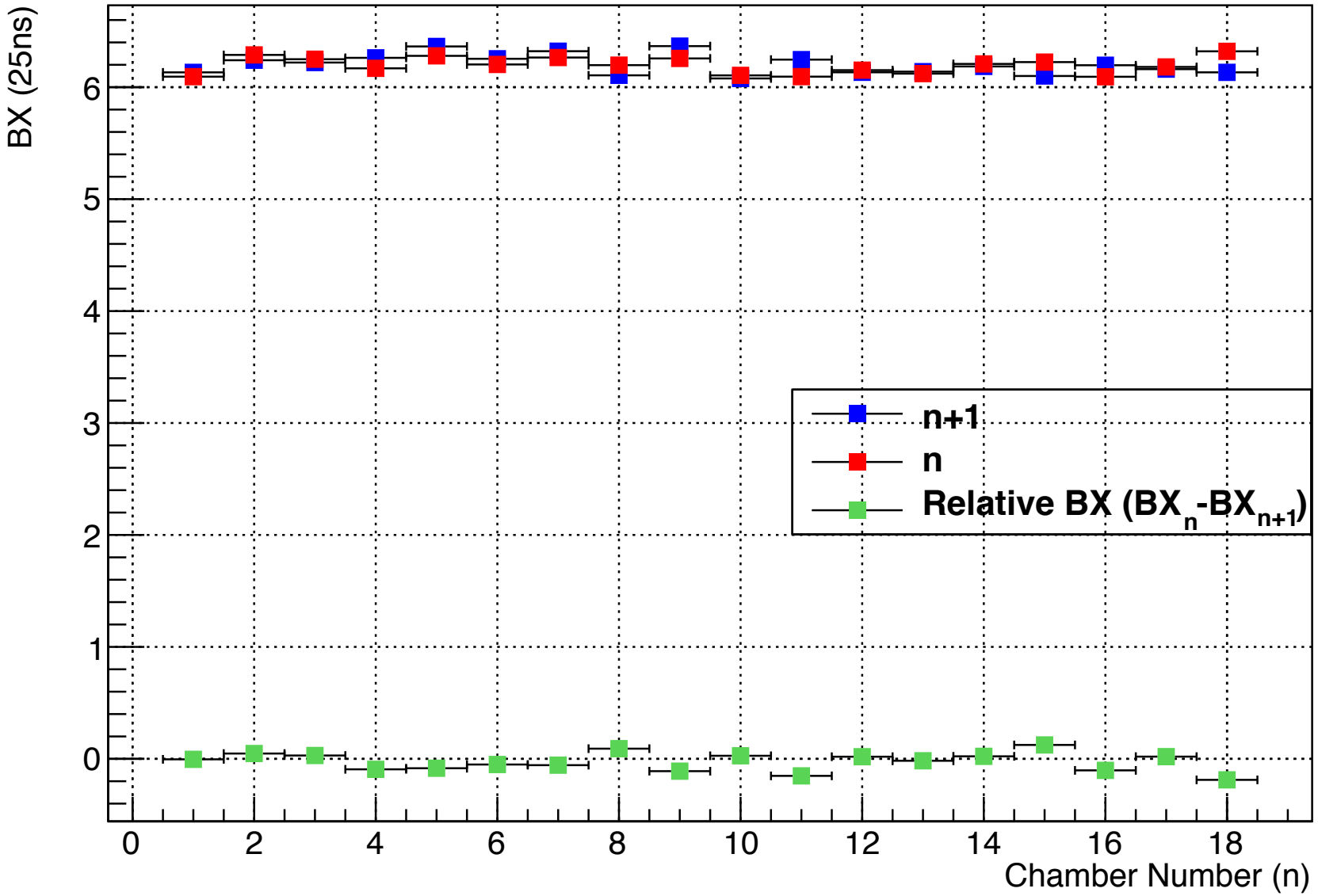


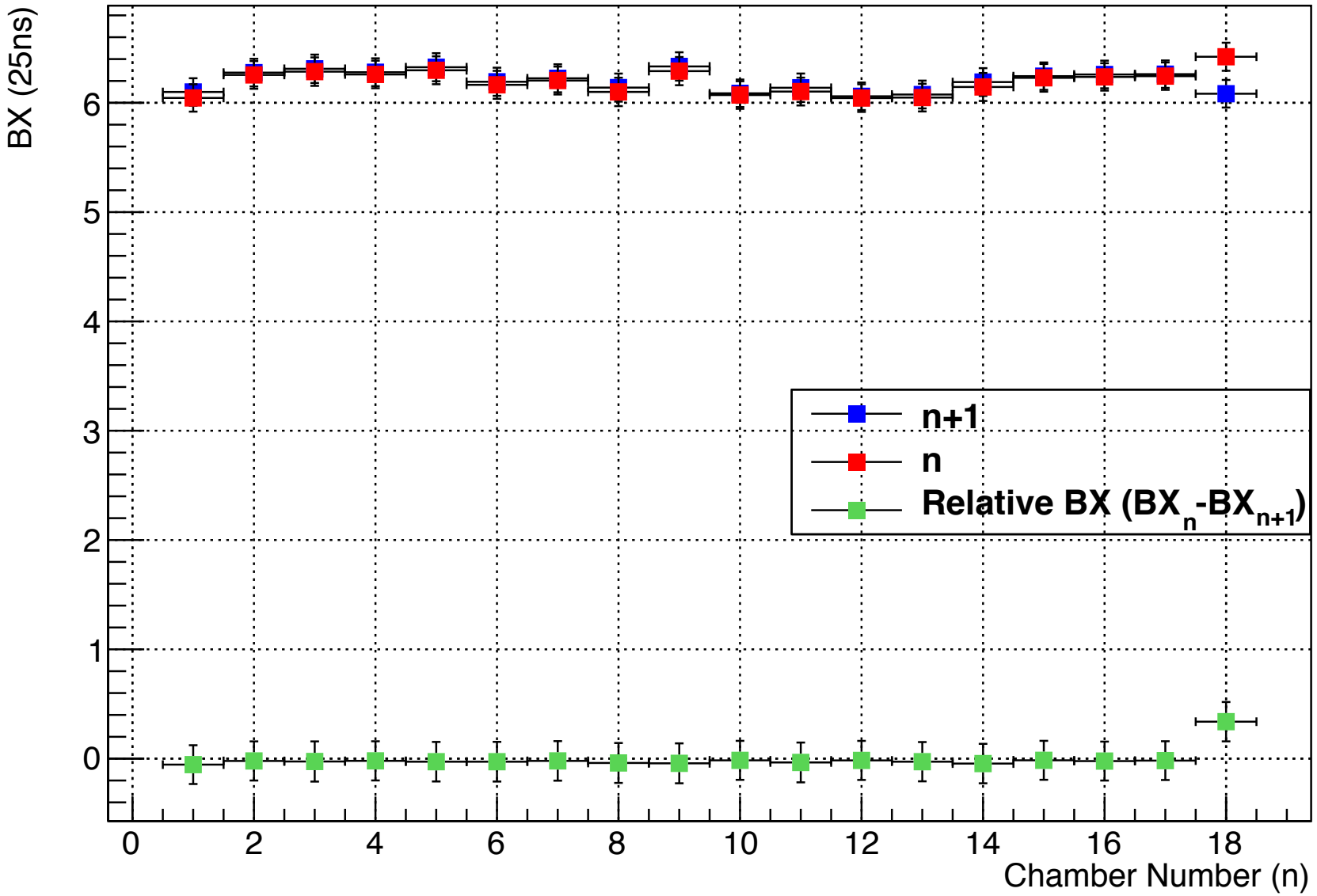
RICE

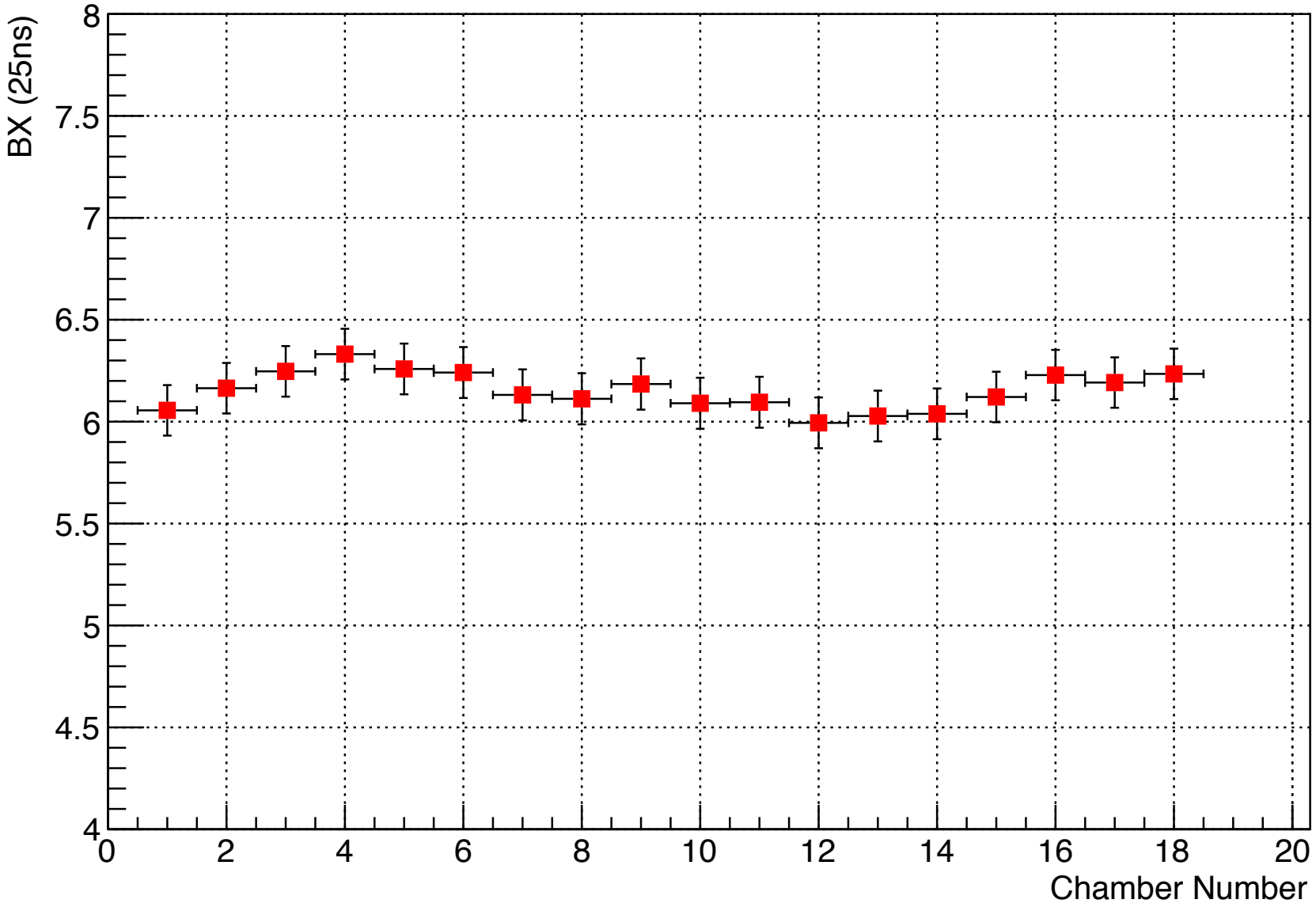
ME+21

Local Run 227021




Walk Around Individual BX for ME+21
BX (25ns)
Chamber Number (n)
n+1
n
Relative BX (BX_n-BX_n+1)
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18


Walk Around BX (with ChiSquare Correction) for ME+21
BX (25ns)
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
Chamber Number (n)
n+1
n
Relative BX (BX_n-BX_n+1)


CSCTF LCT BX With Chi Correction ME+21
BX (25ns)
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2
4
6
8
10
12
14
16
18
20
Chamber Number