Measurement of double helicity asymmetries $\pi^{\pm}$ in production at mid-rapidity

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Motivation

- **Jaffe-Manohar Sum Rule:**

$$Proton\ Spin\ = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \boxed{\Delta G} + L_q + L_g$$

- $\Delta\Sigma$: reasonably well measured. only 30% of proton spin.

- Where is the missing part? (spin crisis)

- **Experiments to measure ΔG:**

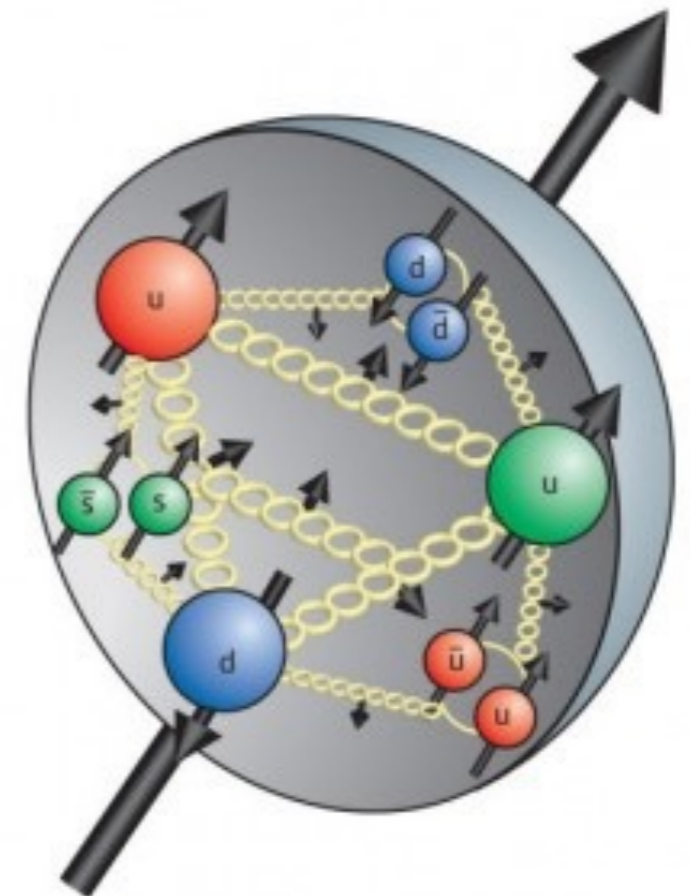- Polarized DIS and SIDIS

- Polarized p+p collisions @ RHIC:

  - PHENIX π/η/Jpsi/HFe A_{LL}:

    PRD 93 011501 (2016), PRD 91 032001 (2015), PRD 90 012007 (2014),

    PRL 103 012003 (2009) and so on.
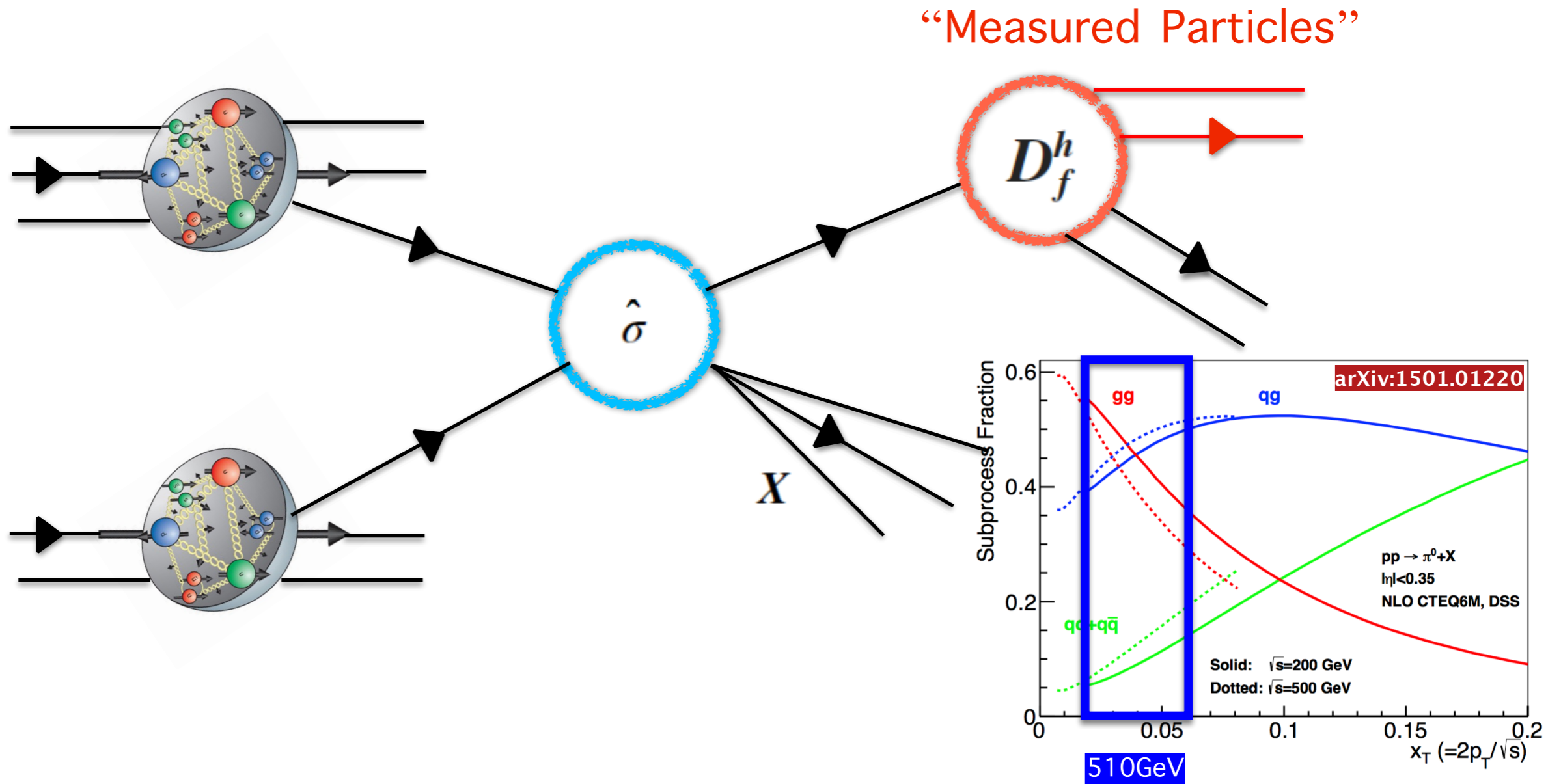
  - STAR Jet/Di-jet A_{LL}:

    PRL 115 92002 (2015), PRD 95 71103 (2017)
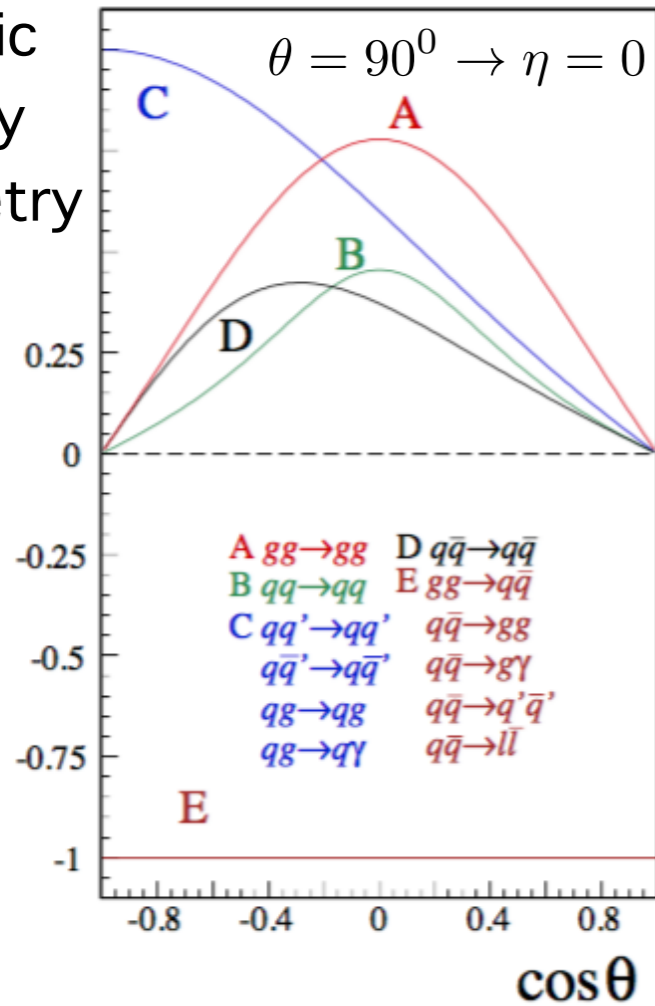
$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} = \frac{\sum_{f_1,f_2=q,\bar{q},g} \Delta f_1 \otimes \Delta f_2 \otimes \Delta\hat{\sigma}^{f_1 f_2 \to fX} \otimes D_f^h}{\sum_{f_1,f_2=q,\bar{q},g} f_1 \otimes f_2 \otimes \hat{\sigma}^{f_1 f_2 \to fX} \otimes D_f^h}$$

"Measured Particles"

D_f^h

$\hat{\sigma}$

X

arXiv:1501.01220

Subprocess Fraction

gg

qg

qq+qq̄

pp → π⁰+X
|η|<0.35
NLO CTEQ6M, DSS

Solid: √s=200 GeV
Dotted: √s=500 GeV

x_T (=2p_T/√s)

510GeV

Motivation: "Directly" access the sign of ΔG

Partonic
Helicity
Asymmetry
a_{LL}

$\theta = 90^0 \rightarrow \eta = 0$

A $gg \rightarrow gg$ D $q\bar{q} \rightarrow q\bar{q}$
B $qq \rightarrow qq$ E $gg \rightarrow q\bar{q}$
C $qq' \rightarrow qq'$ $q\bar{q} \rightarrow gg$
$q\bar{q}' \rightarrow q\bar{q}'$ $q\bar{q} \rightarrow g\gamma$
$qg \rightarrow qg$ $q\bar{q} \rightarrow q'\bar{q}'$
$qg \rightarrow q\gamma$ $q\bar{q} \rightarrow l\bar{l}$

$$A_{LL}^{\pi^+} \approx a_{gg}\Delta g\Delta g \ + \ a_{ug}\underline{\Delta u}\,\underline{\Delta g}$$
$$\phantom{A_{LL}^{\pi^+} \approx a_{gg}\Delta g\Delta g \ + \ a_{ug}} {\scriptstyle >0} \ \ {\scriptstyle >0}$$

$$A_{LL}^{\pi^-} \approx a_{gg}\Delta g\Delta g \ + \ a_{dg}\underline{\Delta d}\,\underline{\Delta g}$$
$$\phantom{A_{LL}^{\pi^-} \approx a_{gg}\Delta g\Delta g \ + \ a_{dg}} {\scriptstyle >0} \ \ {\scriptstyle <0}$$

$x(\Delta u + \Delta \bar{u})$

$x(\Delta d + \Delta \bar{d})$

Partional Helicity Asymmetry a_{LL}

PRL 113, 012001 (2014)

$\theta = 90^0 \rightarrow \eta = 0$

C
A
B
D
E

A $gg \rightarrow gg$ D $q\bar{q} \rightarrow q\bar{q}$
B $qq \rightarrow qq$ E $gg \rightarrow q\bar{q}$
C $qq' \rightarrow qq'$ $q\bar{q} \rightarrow gg$
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$qg \rightarrow qg$ $q\bar{q} \rightarrow q'\bar{q}'$
$qg \rightarrow q\gamma$ $q\bar{q} \rightarrow l\bar{l}$

$\cos\theta$
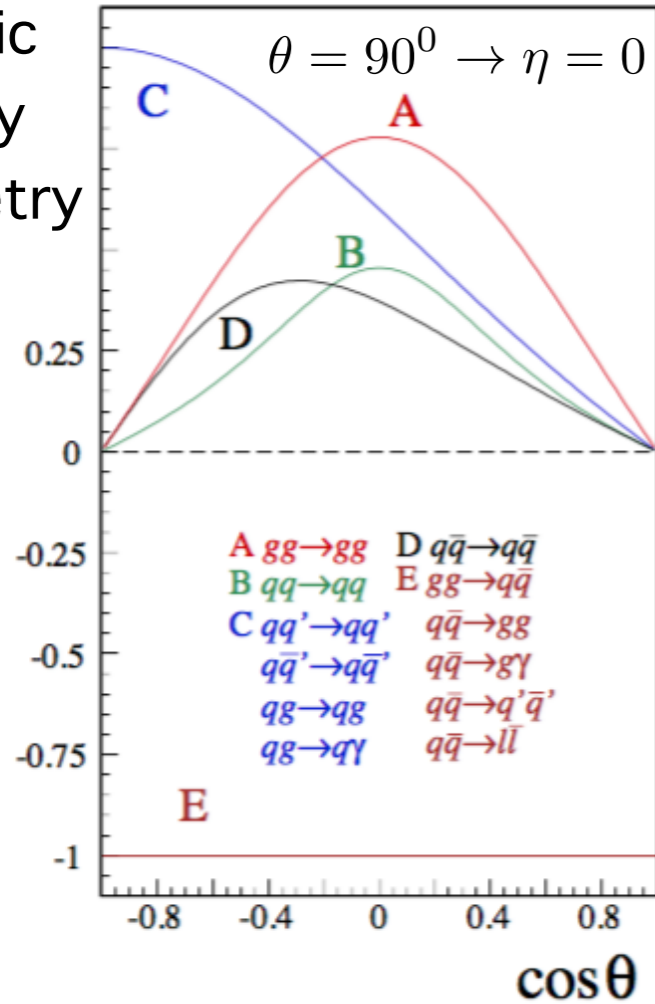
$$A_{LL}^{\pi^+} \approx a_{gg}\Delta g\Delta g + \underset{>0\ \ >0}{a_{ug}\Delta u\Delta g}$$

$$A_{LL}^{\pi^-} \approx a_{gg}\Delta g\Delta g + \underset{>0\ \ <0}{a_{dg}\Delta d\Delta g}$$

$$A_{LL}^{\pi^+} - A_{LL}^{\pi^-} > 0 \ (\text{for } \Delta g > 0)$$

Phys. Rev. D 80, 034030 (2009)

$x(\Delta u + \Delta \bar{u})$

$x(\Delta d + \Delta \bar{d})$
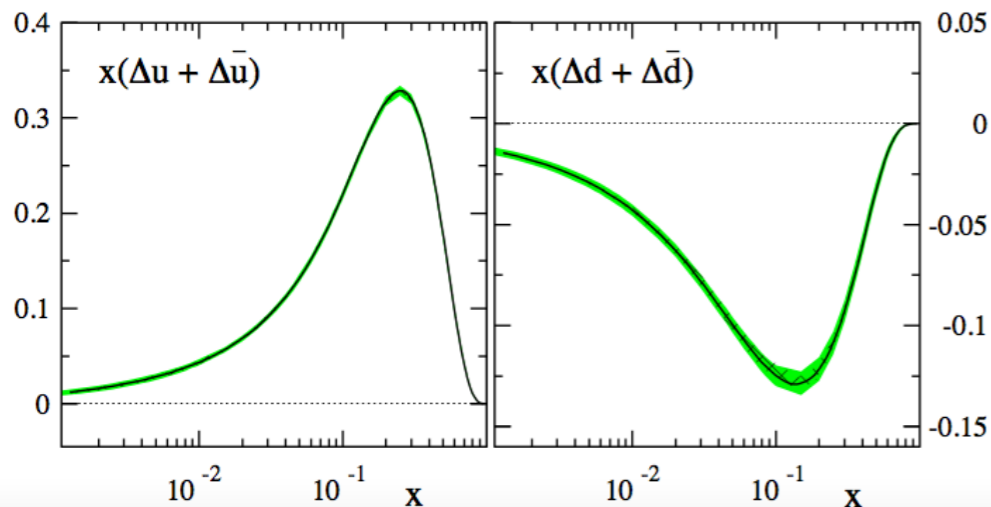
$$\Delta g > 0 \rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^-}$$

and vice versa

PRL 113, 012001 (2014)

PRD 93, 011501 (2016)

(2006~2009 RHIC)

(No RHIC)

(No RHIC)
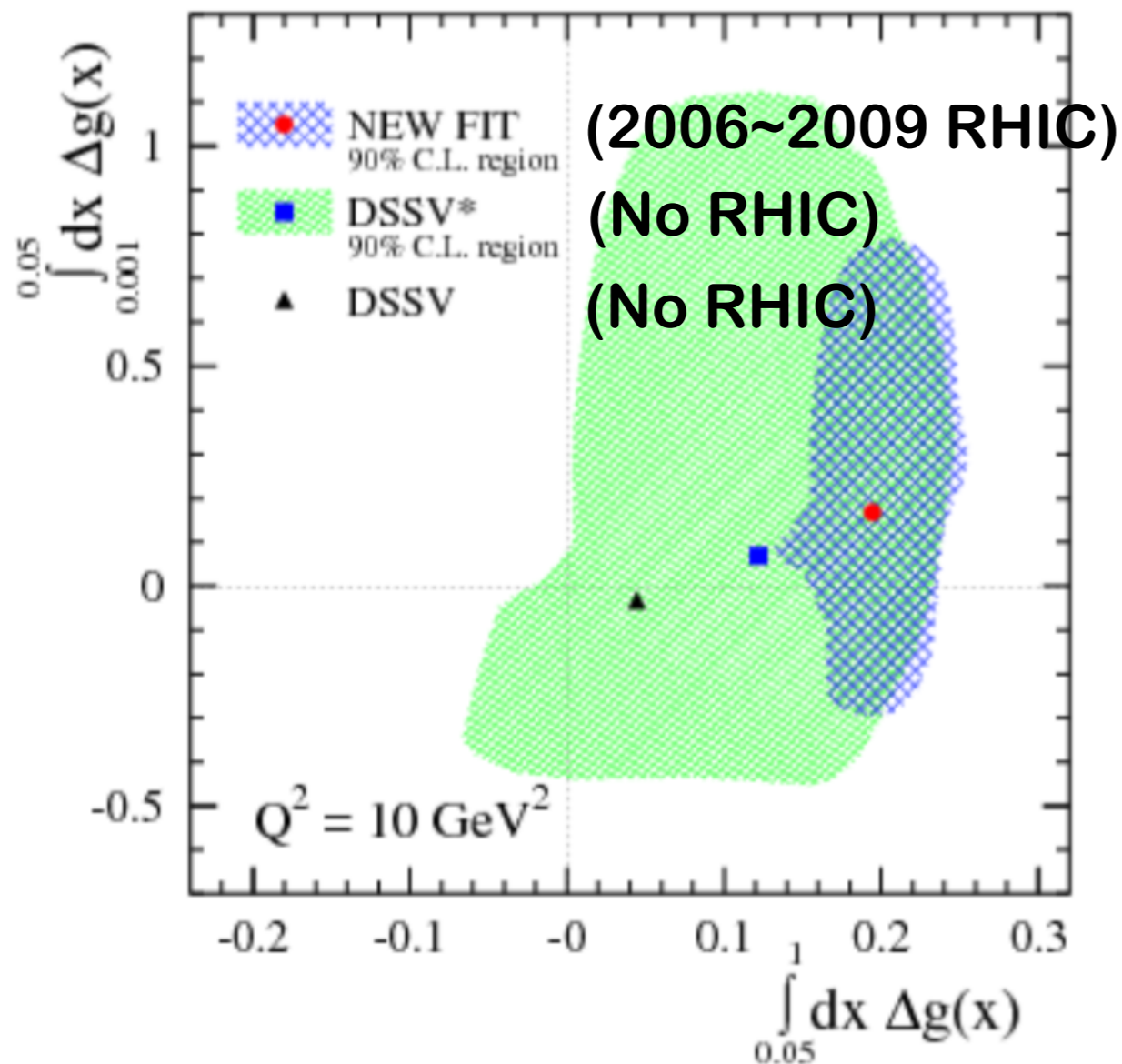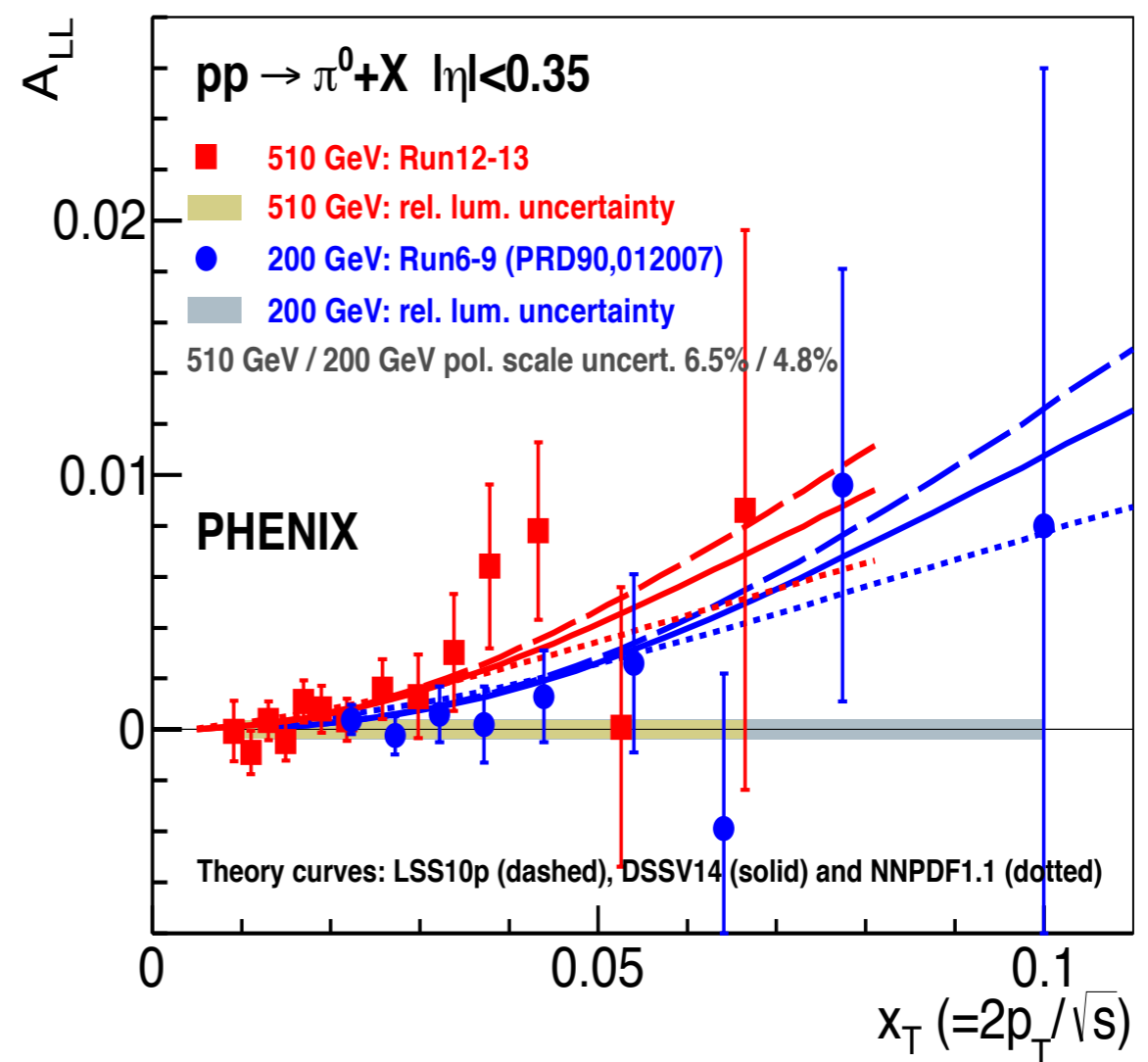
- The uncertainties have been reduced for x > 0.05 based on RHIC data up to Run-2009.
- Expanding experimental sensitivity to lower x region, x < 0.05, with PHENIX π^0 at 510 GeV.
- Showed non-zero gluon polarization via π^0 @ 510 GeV in Run-2012-2013.

$\pi^\pm$ as potential direct indicator for the sign of Δg via pion A_{LL} ordering
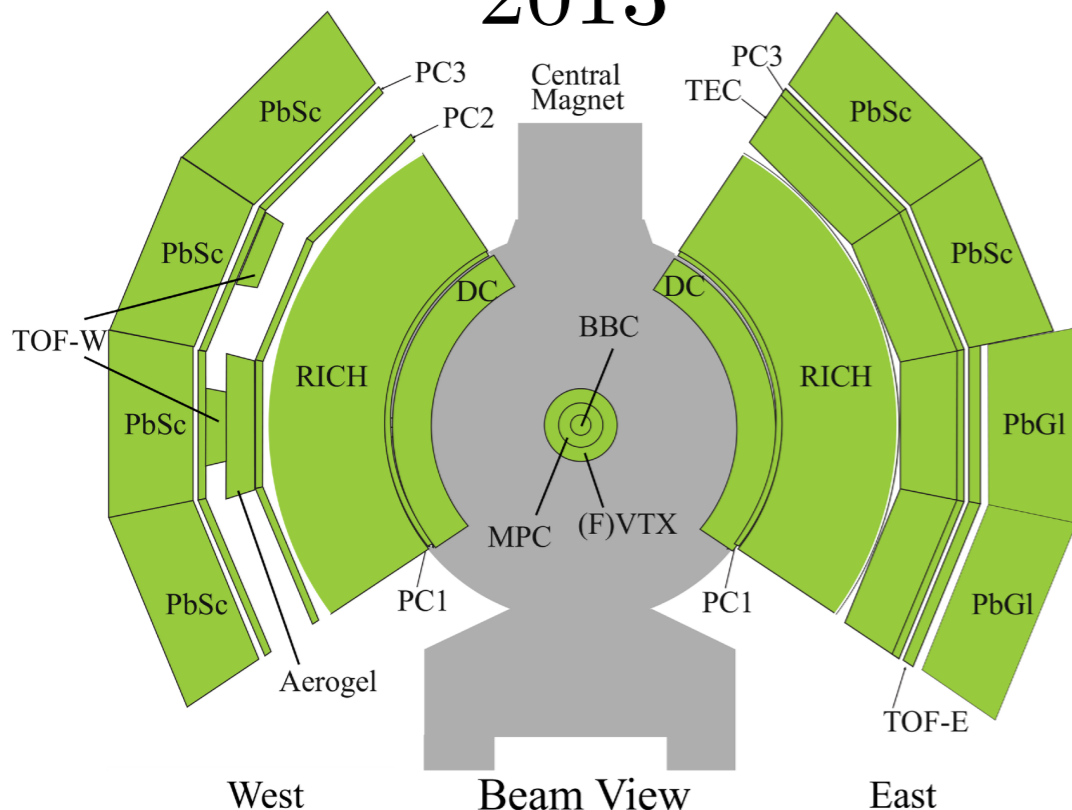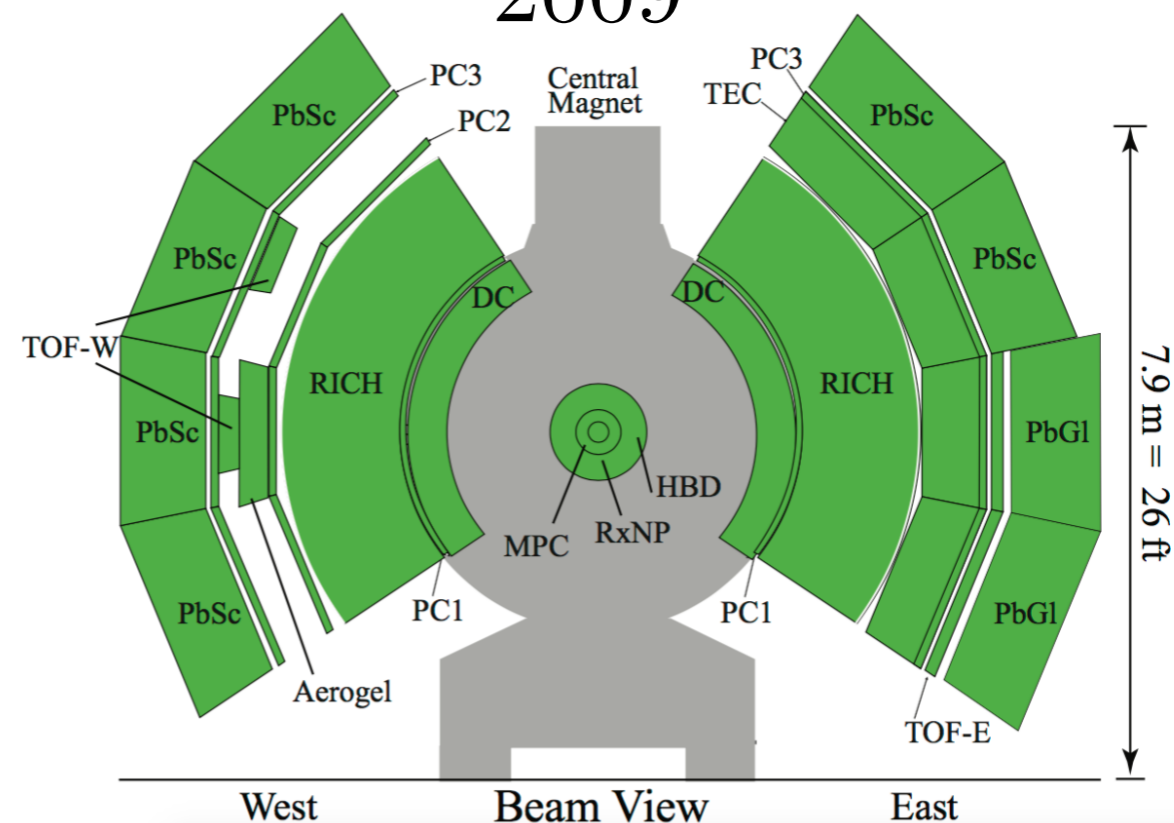
- ## Tracking
  - Drift Chamber (DC)
  - Pad Chamber (PC1/PC3)
  - Silicon Vertex Tracker (VTX) in 2013

- ## $\pi^{\pm}$ Identification
  - Ring Imaging Cherenkov Detector (RICH)
  - Electromagnetic Calorimeter (PbSc/PbGl)
  - Hadron Blider Detector (HBD) in 2009

- ## Relative Luminosity
  - Beam Beam Counter (BBC)
  - Zero Degree Calorimeter (ZDC)

- ## Acceptance
  - $|\eta| < 0.35$
  - $\Delta\phi = 2 \times \pi/2$

Polarized proton runs
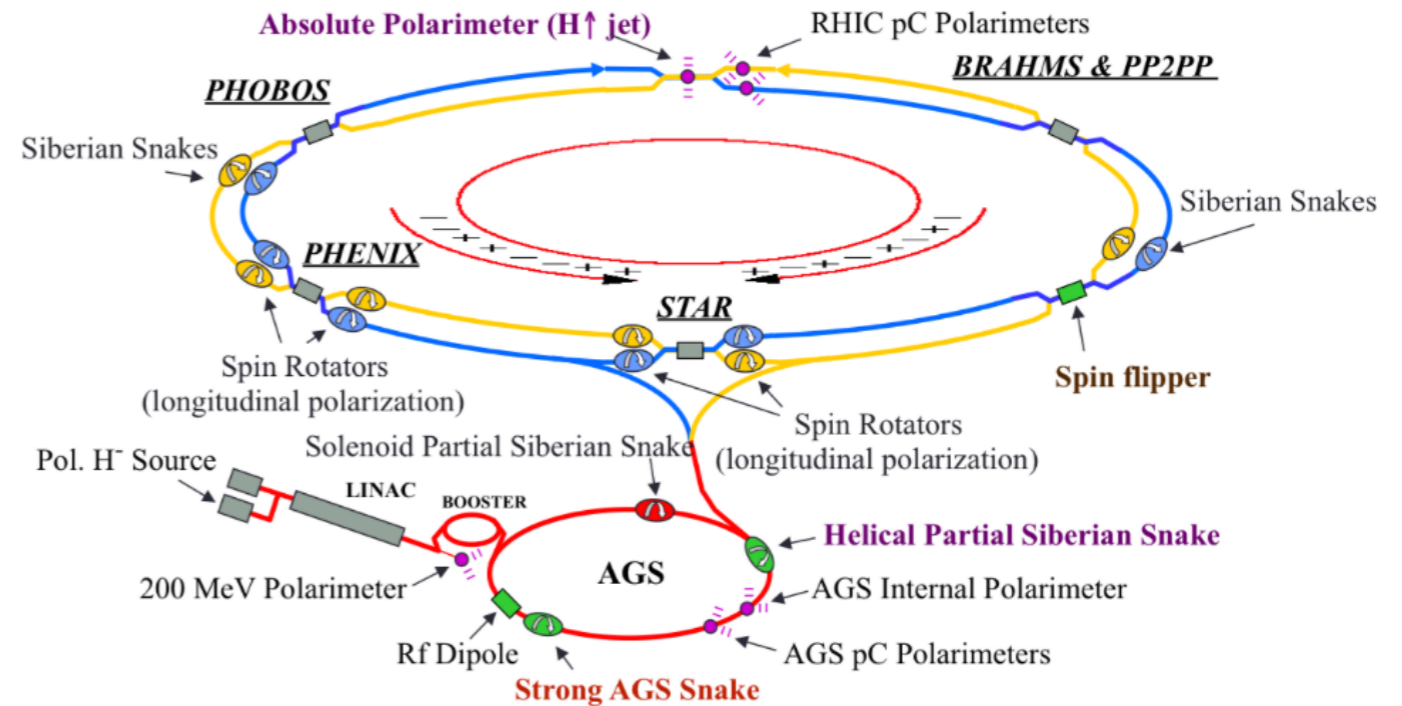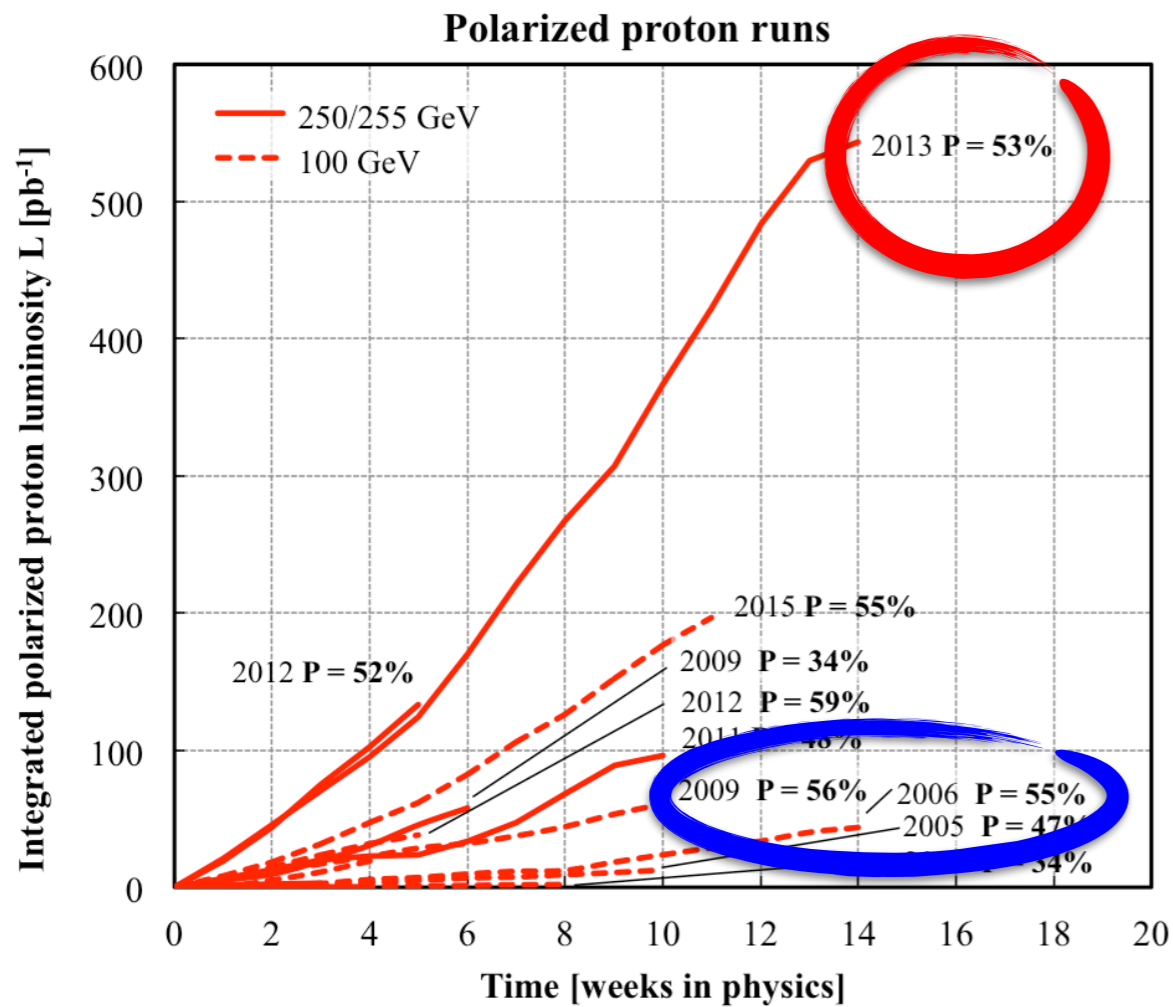
- **14** (**150**) pb^{-1} polarized p+p data available from dataset in **2009** (**2013**).

- Could improve statistical precision of A$_{LL}$ in Run-13 compared to Run-9.

- Track can be divided into two categories according to RICH response at p_T 5~15GeV/c.

  - RICH Hit: $e^{\pm}$ and $\pi^{\pm}$.

  - No RICH Hit: $K^{\pm}$ and p(-bar).

Particle	Electron	Pion	Kaon	Proton
Threshold	30MeV/c	4.7GeV/c	16GeV/c	30GeV/c
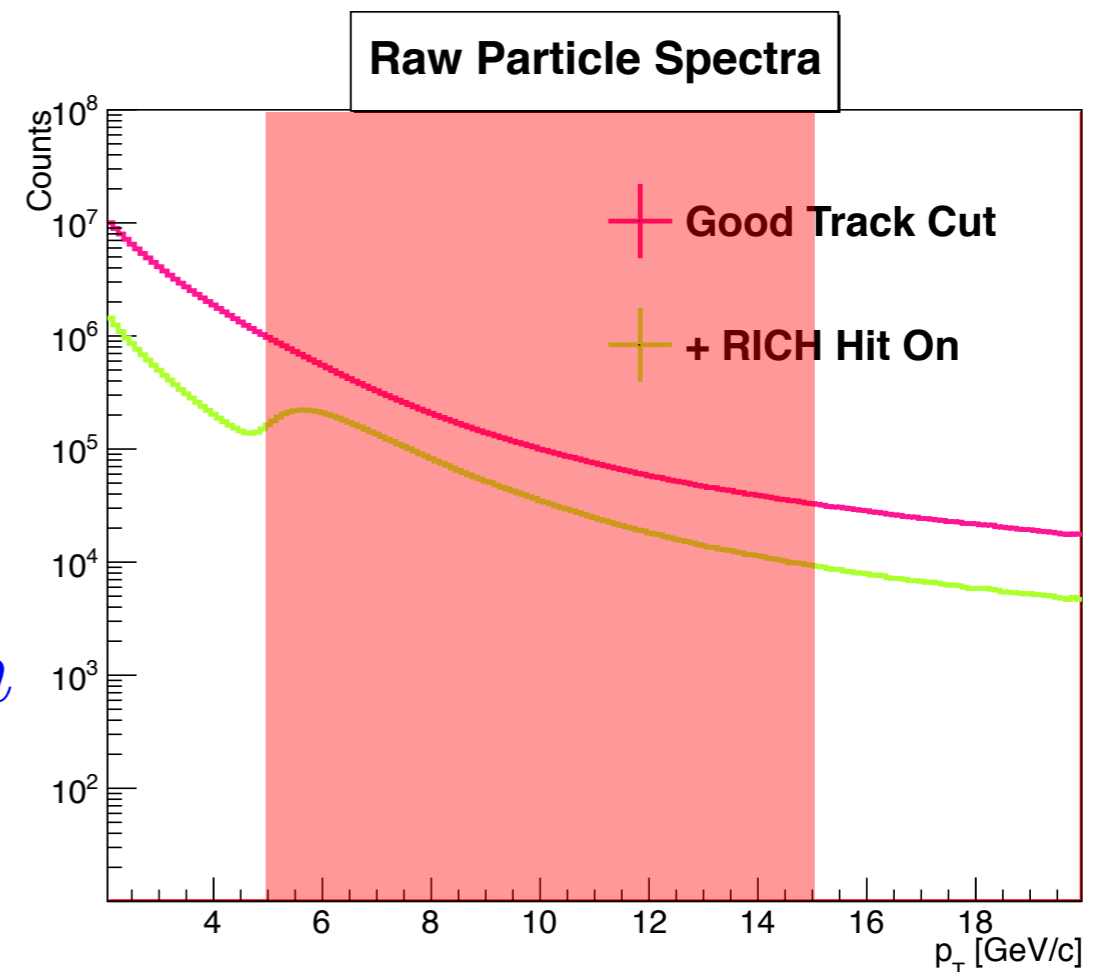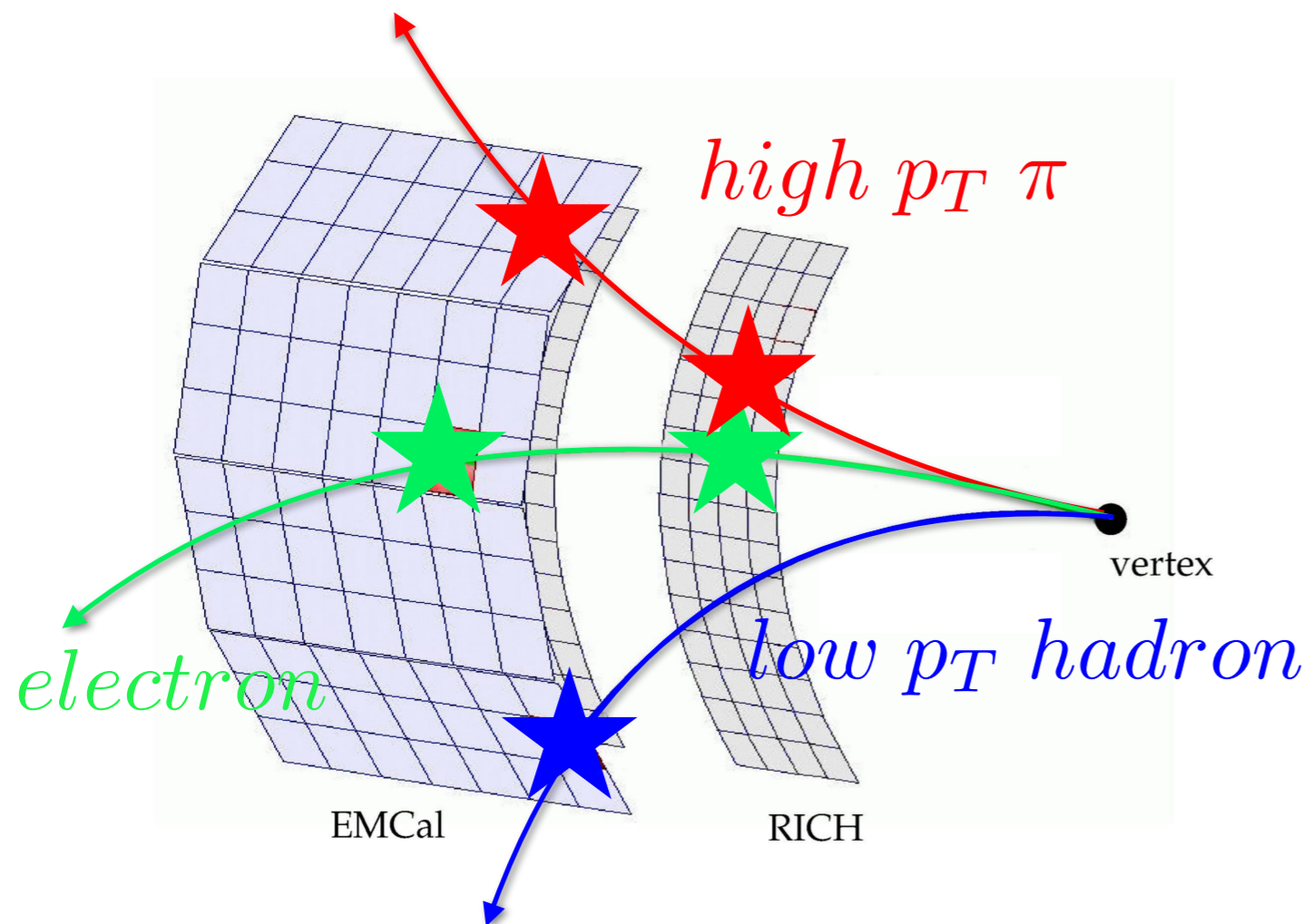
- **E/p ~ 1 : e$^{\pm}$ deposits most of their energies in the EM shower.**
- **E/p < 0.2: Conversion e$^{\pm}$s are reconstructed with higher pT.**

$\pi^{\pm}$: $5.0 < p_T < 6.0$

pion

electrons

Raw Particle Spectra

Good Track Cut

+ RICH Hit On

+ e$^{\pm}$ Rejection Cuts
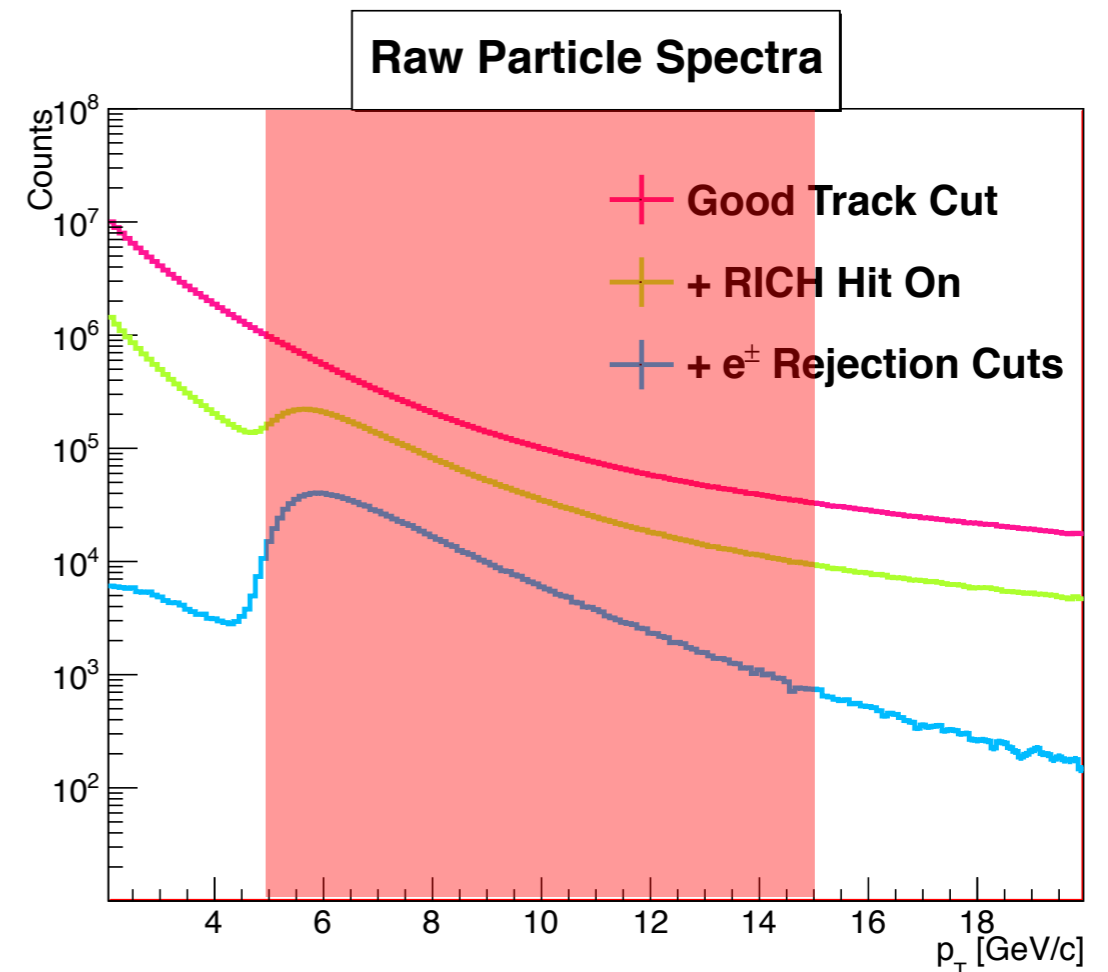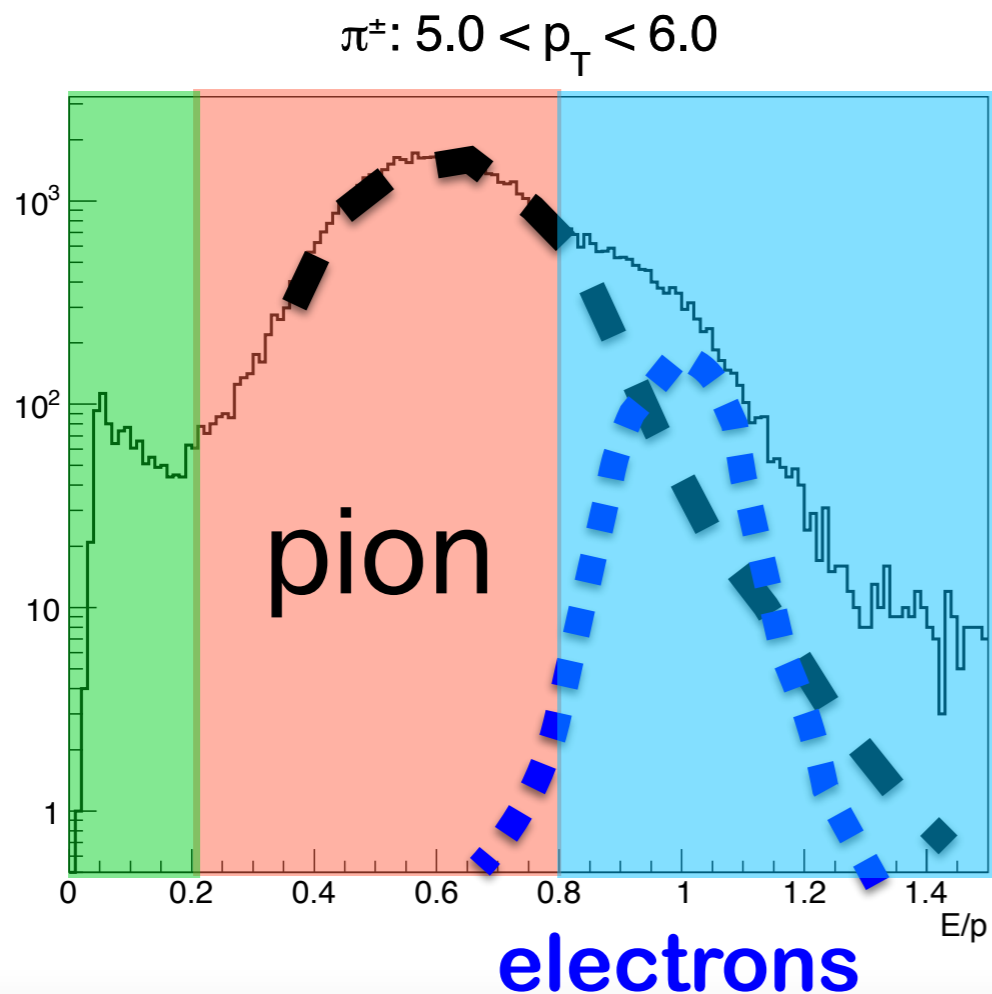
Measuring A$_{LL}$ in experiment

Same: ++   ## Opposite: +-

++   --   -+   +-
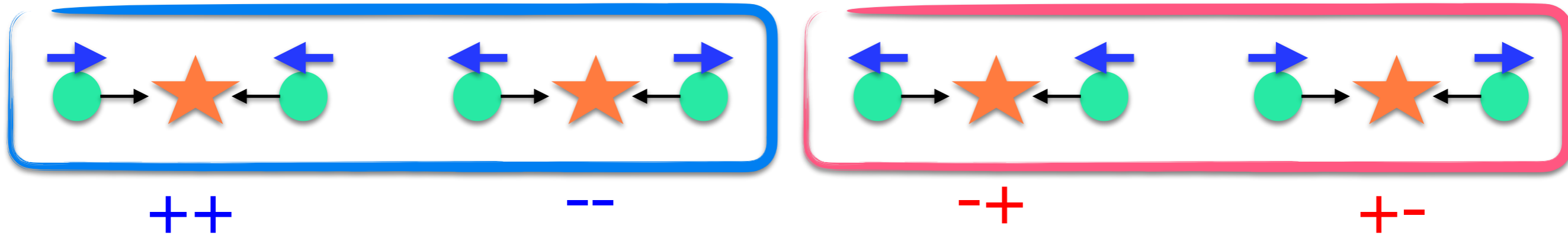
$$A_{LL}^{\pi} = \frac{d\Delta\sigma}{d\sigma} = \frac{1}{|P_B P_Y|} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

← momentum

← helicity

$$R = \frac{L_{++}}{L_{+-}}$$ by luminosity counter

$N_{++(+-)}$ pion yields in same (opposite) helicity
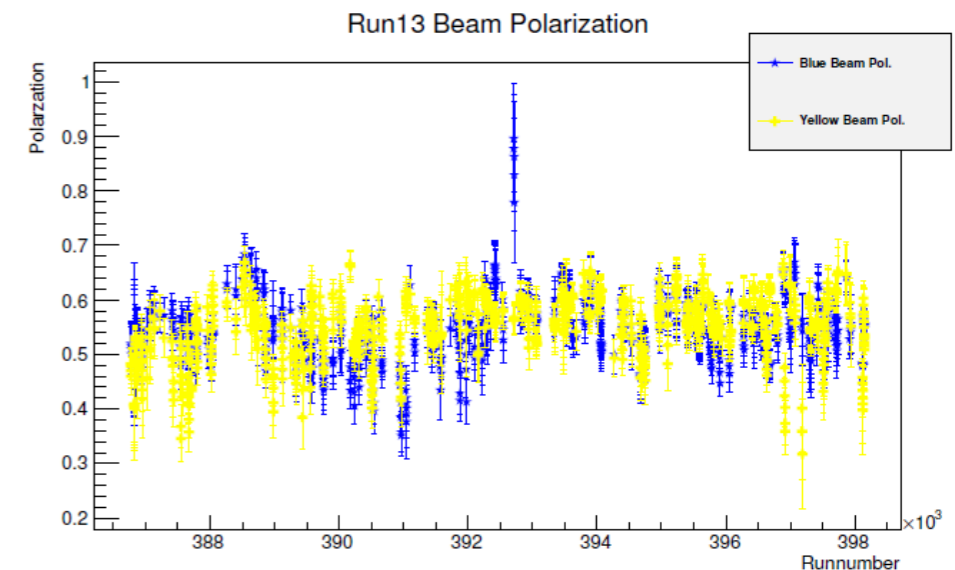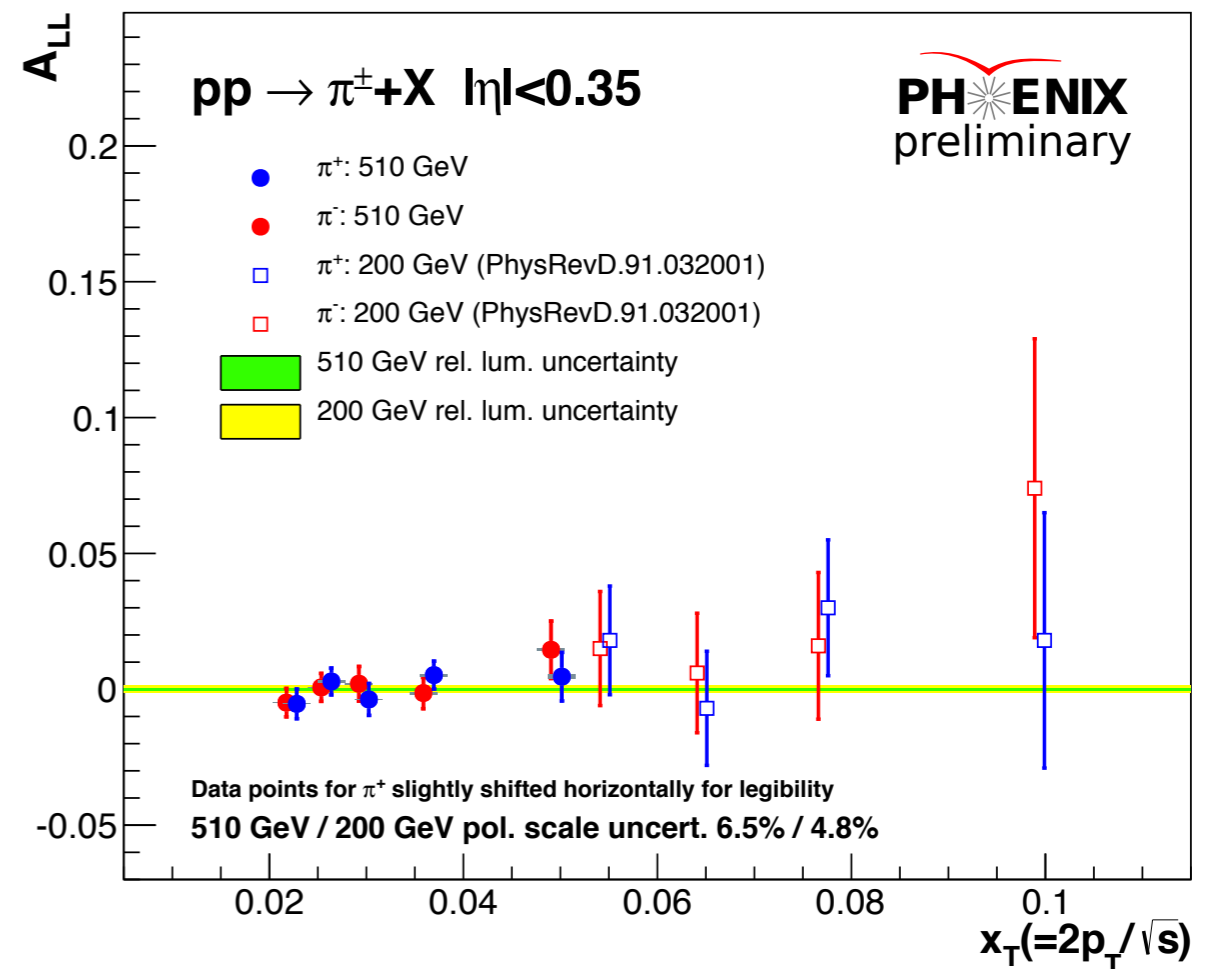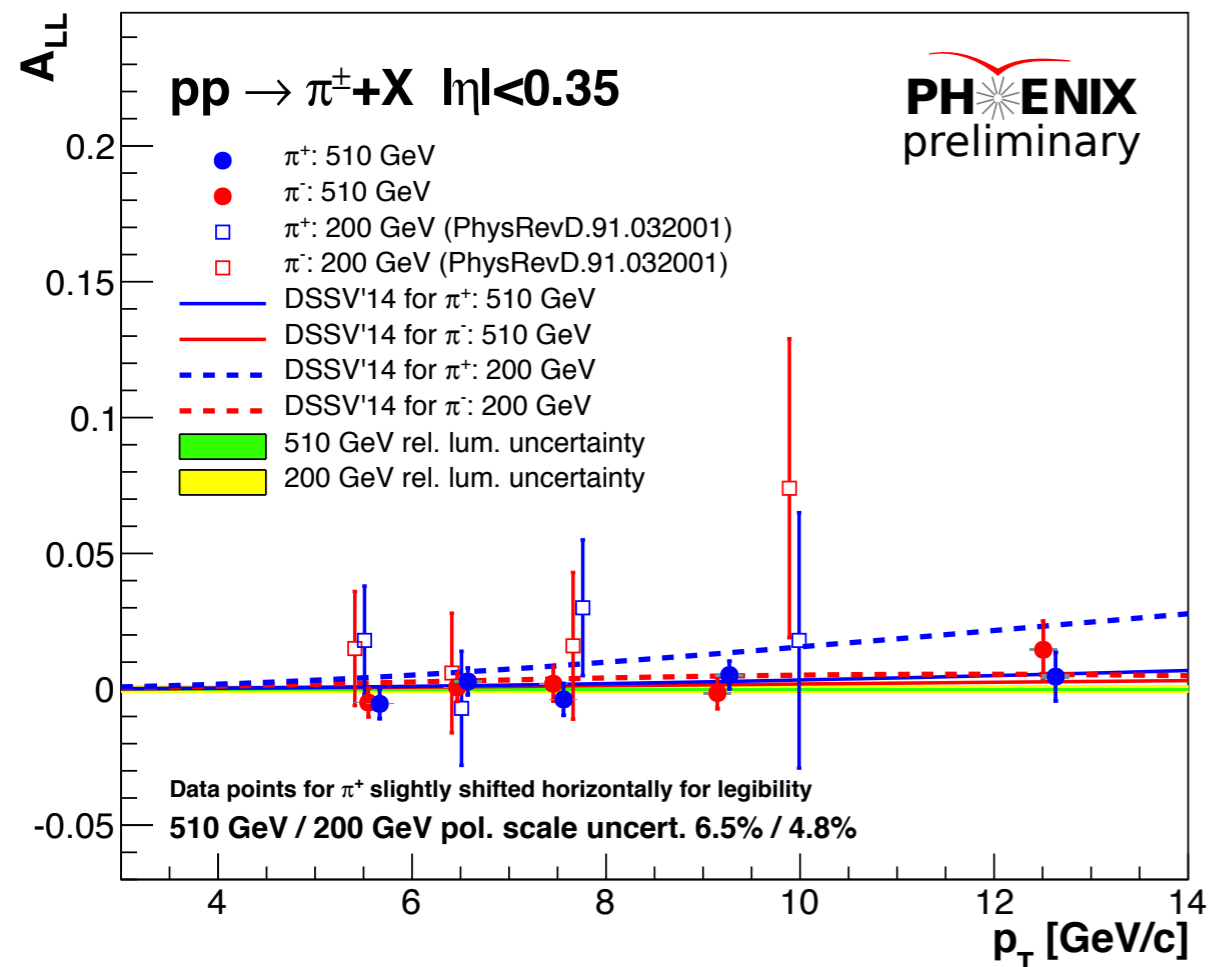
Improvement of statistical precision of $\pi^\pm$ A_{LL} in Run-13.

Expanding experimental sensitivity to lower x_T region, < 0.05, with in Run-13.

A_{LL} in $\pi^{\pm}$ and π^0 production at 510 GeV
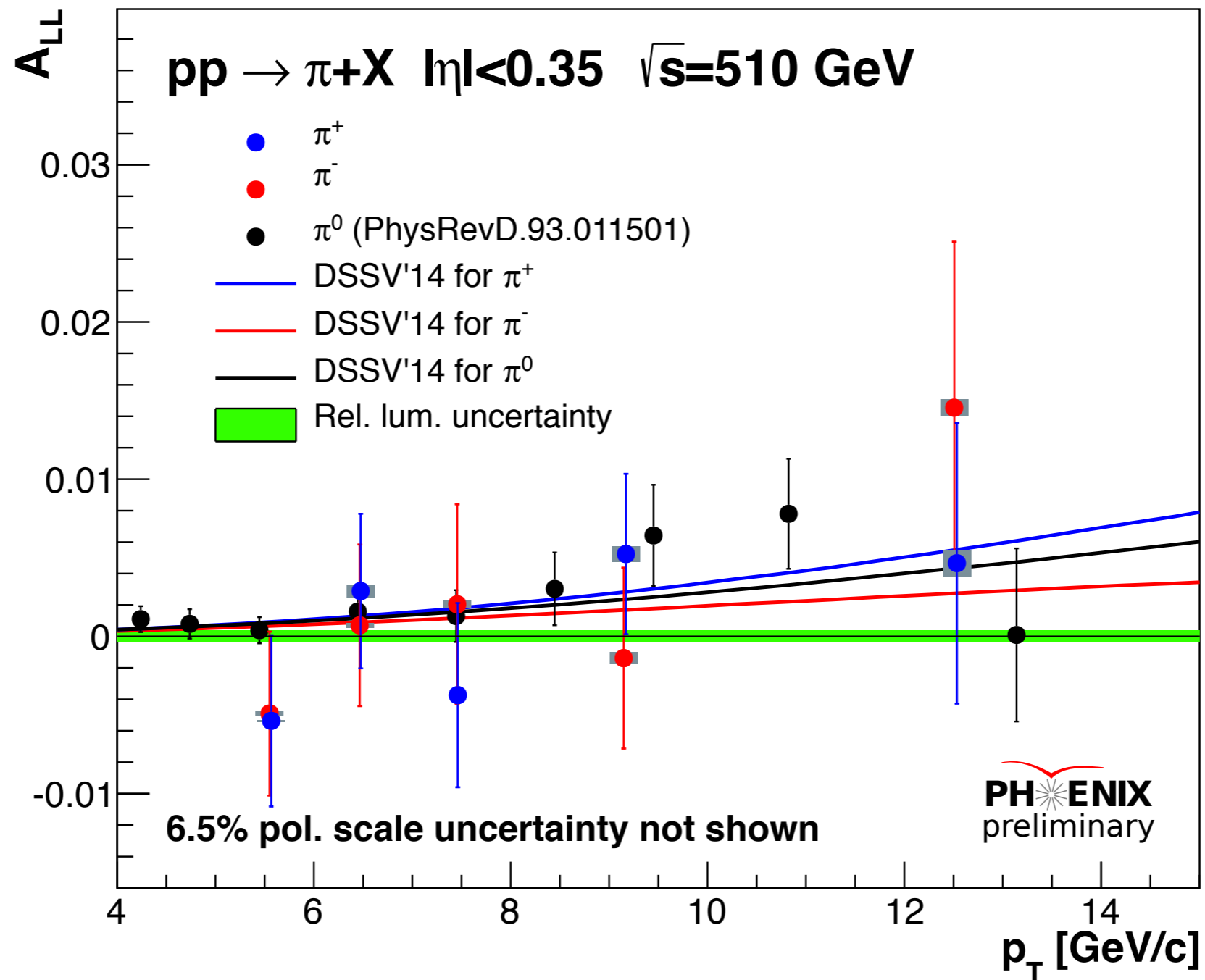
Theory curves with $\Delta G > 0$ follow measured A_{LL} within statistical uncertainty.

It looks like that the measurements are consistent with positive gluon polarization.

- **PPG request: done**

- **1st internal circulation: June 30**

- **2nd internal circulation: July 31**

- **Submission: August 15**

Summary and outlook

- A_{LL} in $\pi^{\pm}$ production can directly access to the sign of the gluon polarization.

- A_{LL} in $\pi^{\pm}$ production at 510 GeV has been measured for the first time in the world.

- As a complementary probe with improved statistics, might help to double-check the gluon polarization.

Thanks!

PHENIX Longitudinal Run

PHENIX EMCal-RICH Trigger (ERT) Set

Year	Sqrt(s) [GeV]	Int. L [pb^{-1}]	P (%)	FoM (LP^4)
2009	200	14	57	1.4
2013	510	150	55	14

	Trigger Name and Threshold [GeV]			
Year	4x4A	4x4B	4x4C	2x2E
2009	2.1	2.8	1.4	0.6
2013	4.7	5.6	3.7	2.2

- 14 (150) pb^{-1} polarized p+p data available from dataset in 2009 (2013).

- Due to the lack of hadron trigger in PHENIX, the statistical precision of the $\pi^{\pm}$ data is limited in both Run-9 and Run-13.

- Alternatively, high p_T γ triggers are used for high p_T $\pi^{\pm}$ analysis.
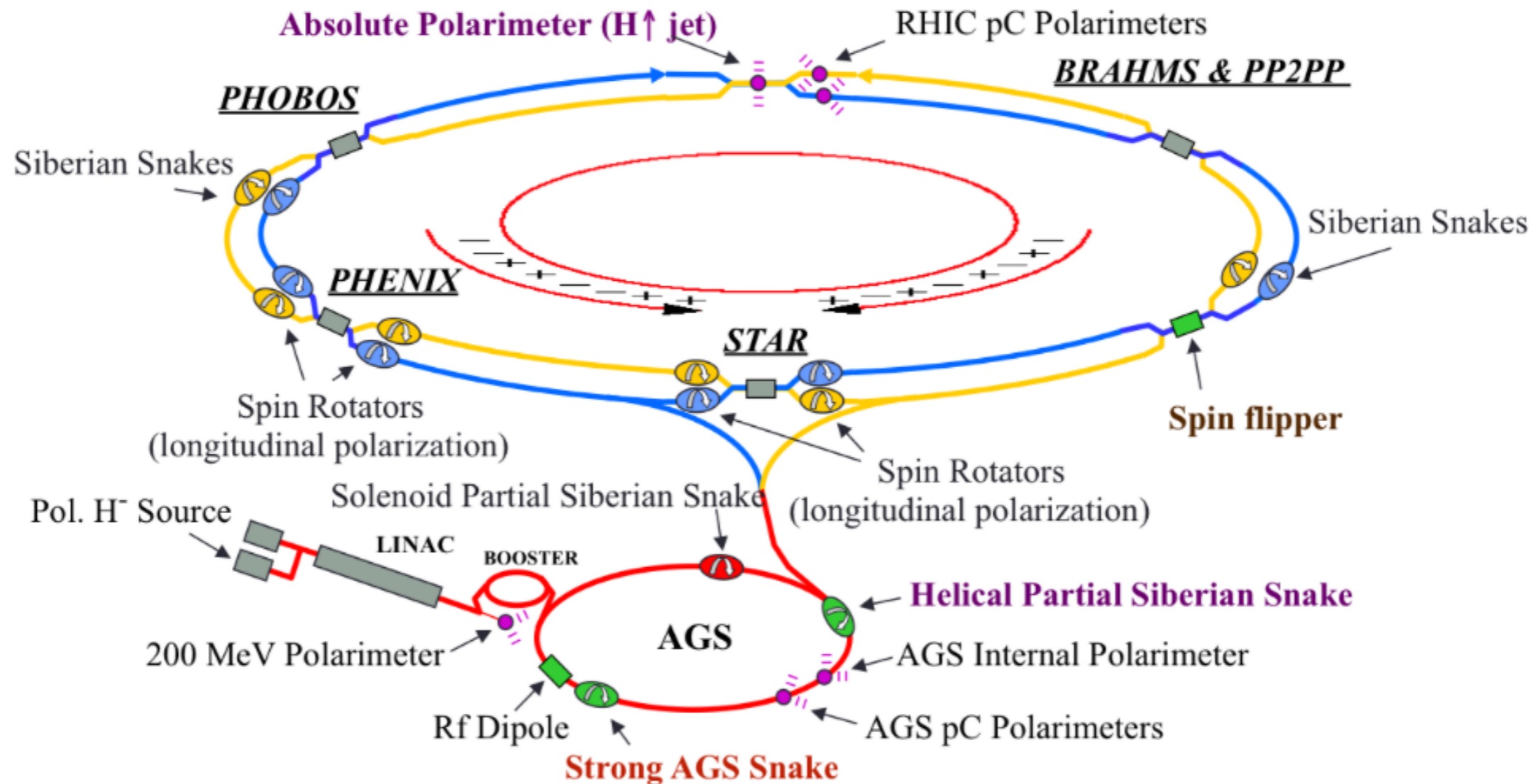
- The world's only polarized p+p collider

  - Longitudinal or transverse polarization
  - Up to $\sqrt{s}$ = 510 GeV
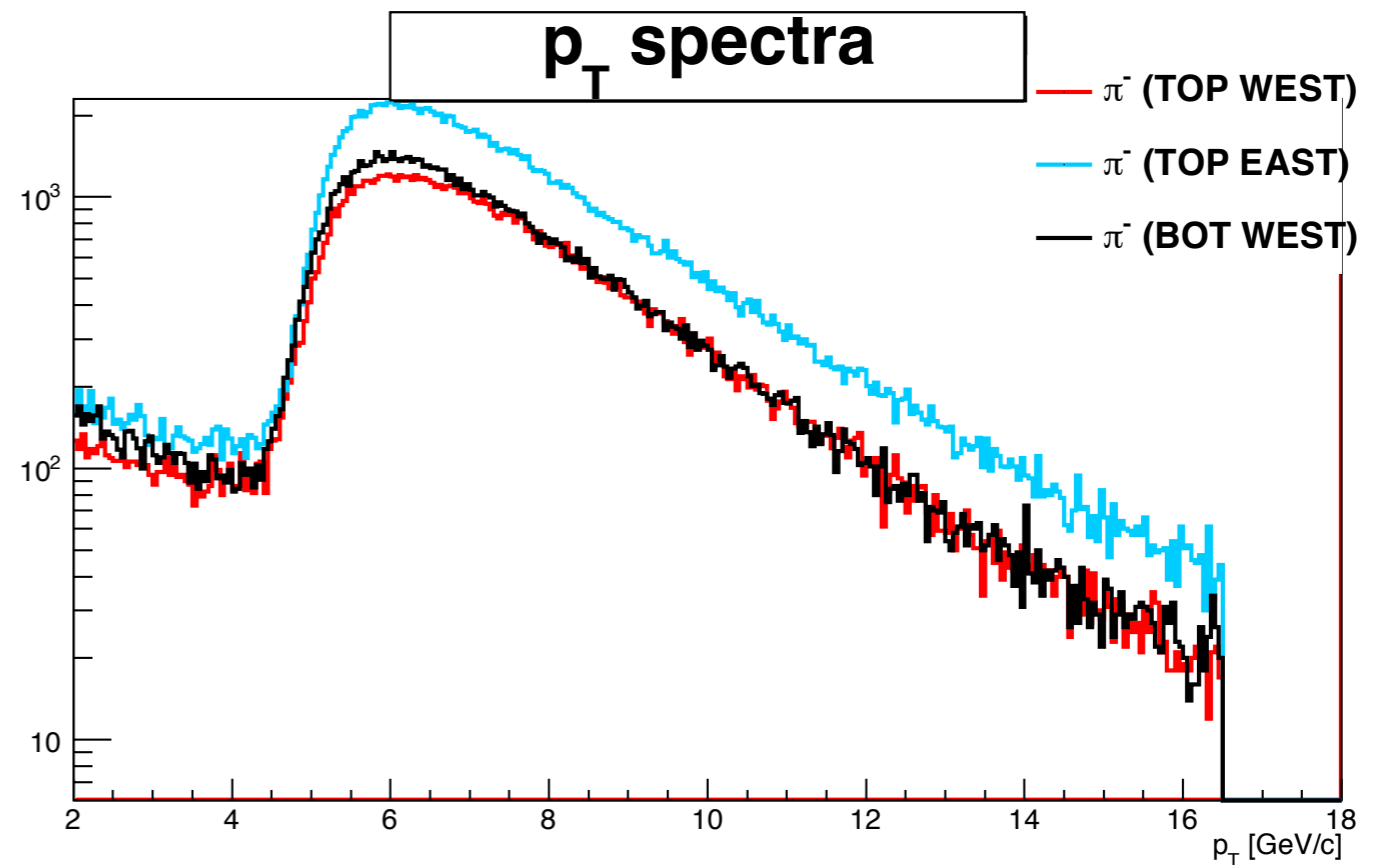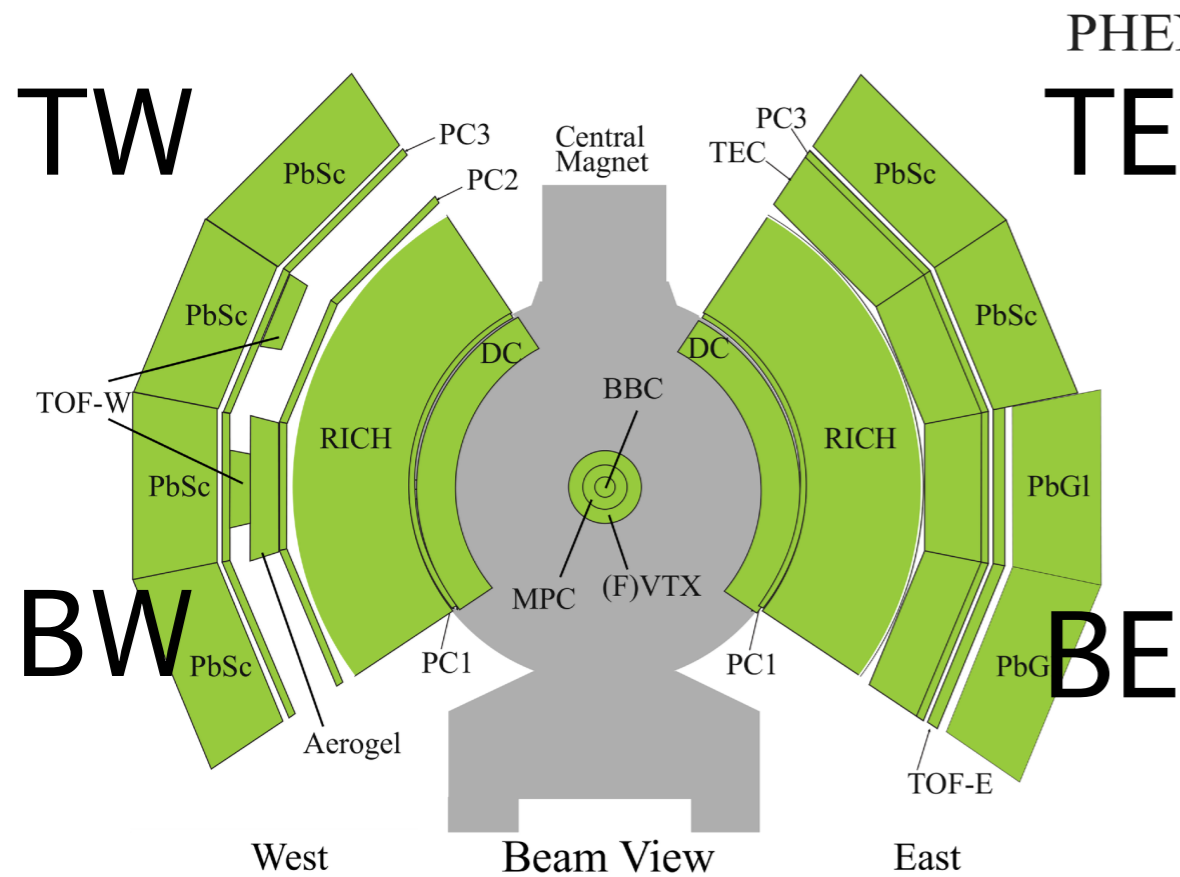
PHENIX Detector

TW

TE

BW

BE

PC3
PbSc
PC2
PbSc
TOF-W
PbSc
RICH
PbSc
Aerogel
PC1

Central
Magnet
DC
BBC
MPC (F)VTX

West   Beam View   East

PC3
TEC
PbSc
PbSc
DC
RICH
PbGl
PbG
TOF-E

p$_T$ spectra

π⁻ (TOP WEST)
π⁻ (TOP EAST)
π⁻ (BOT WEST)

p_T [GeV/c]

φ

The beam
view of DC

r

alpha_real

Real particle track

Back propagated line to BC

DC

Real beam center

pT ~ charge/alpha

alpha_reco(wrong) > alpha_real
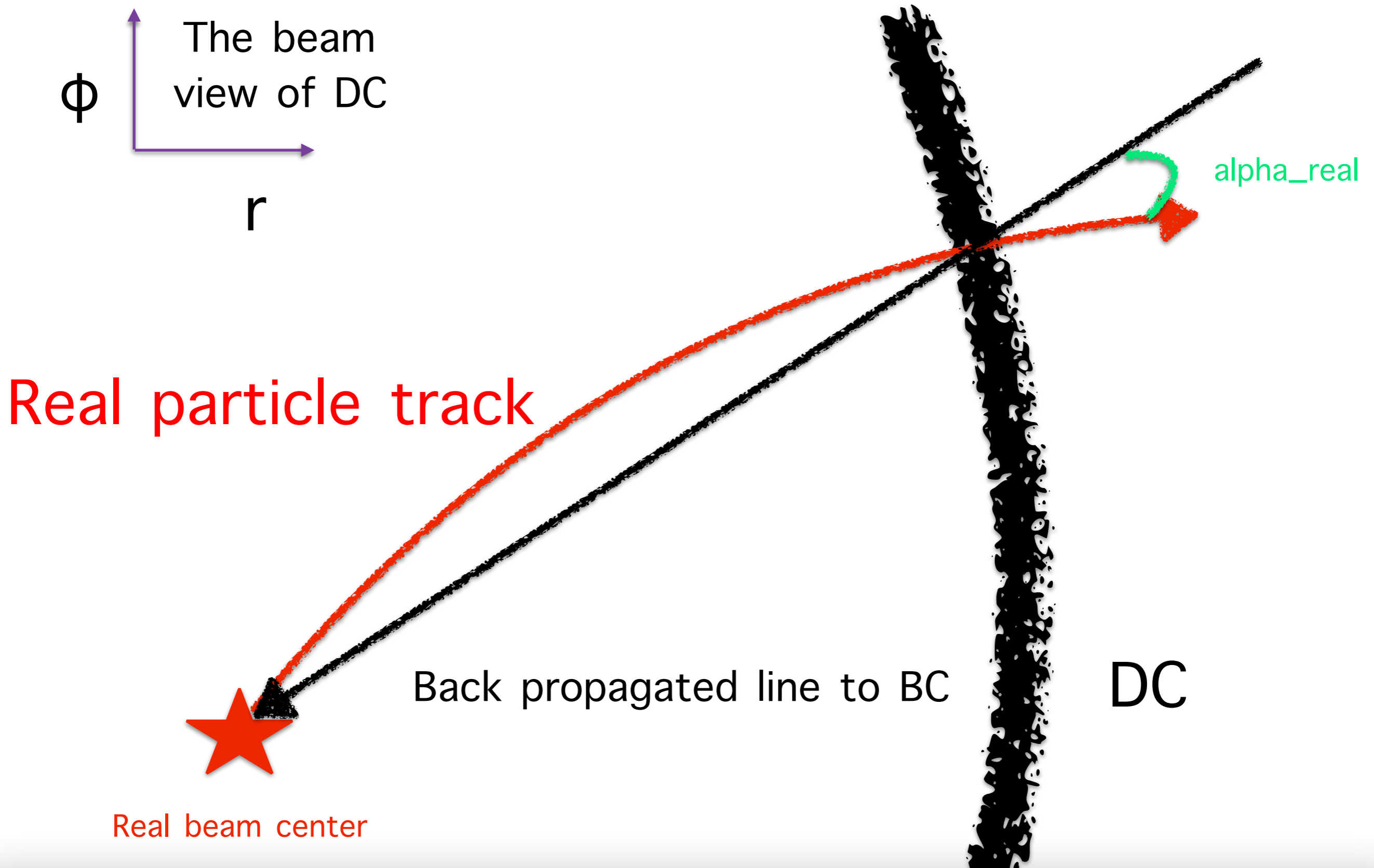
wrong beam center can decrease pT of positive track

Real particle track
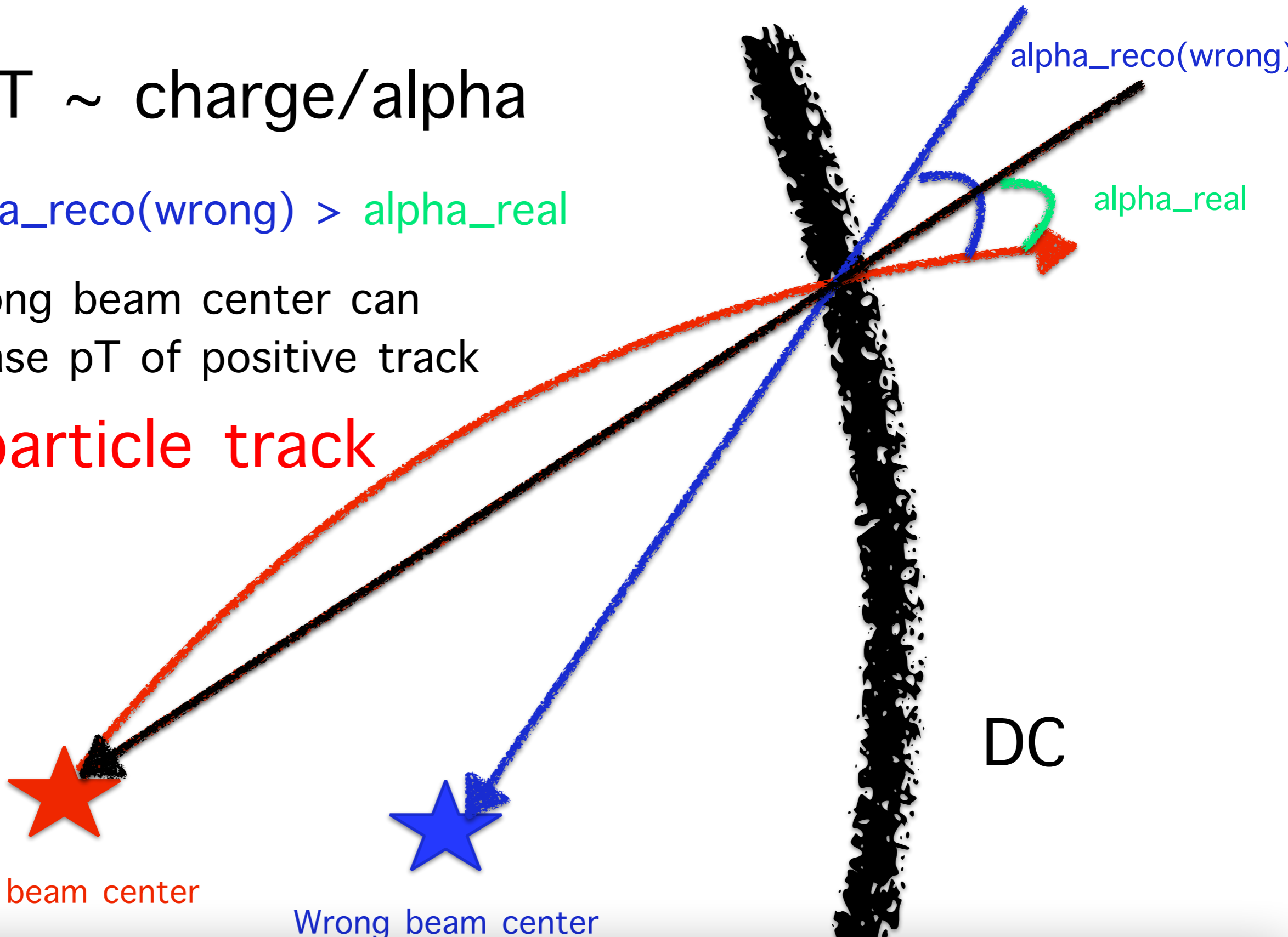
alpha_reco(wrong)

alpha_real

DC

Real beam center

Wrong beam center

pT ~ charge/alpha

alpha_reco(wrong) < alpha_real

wrong beam center can increase pT of negative track

Real particle track

alpha_reco(wrong)

alpha_real

DC

Real beam center

Wrong beam center
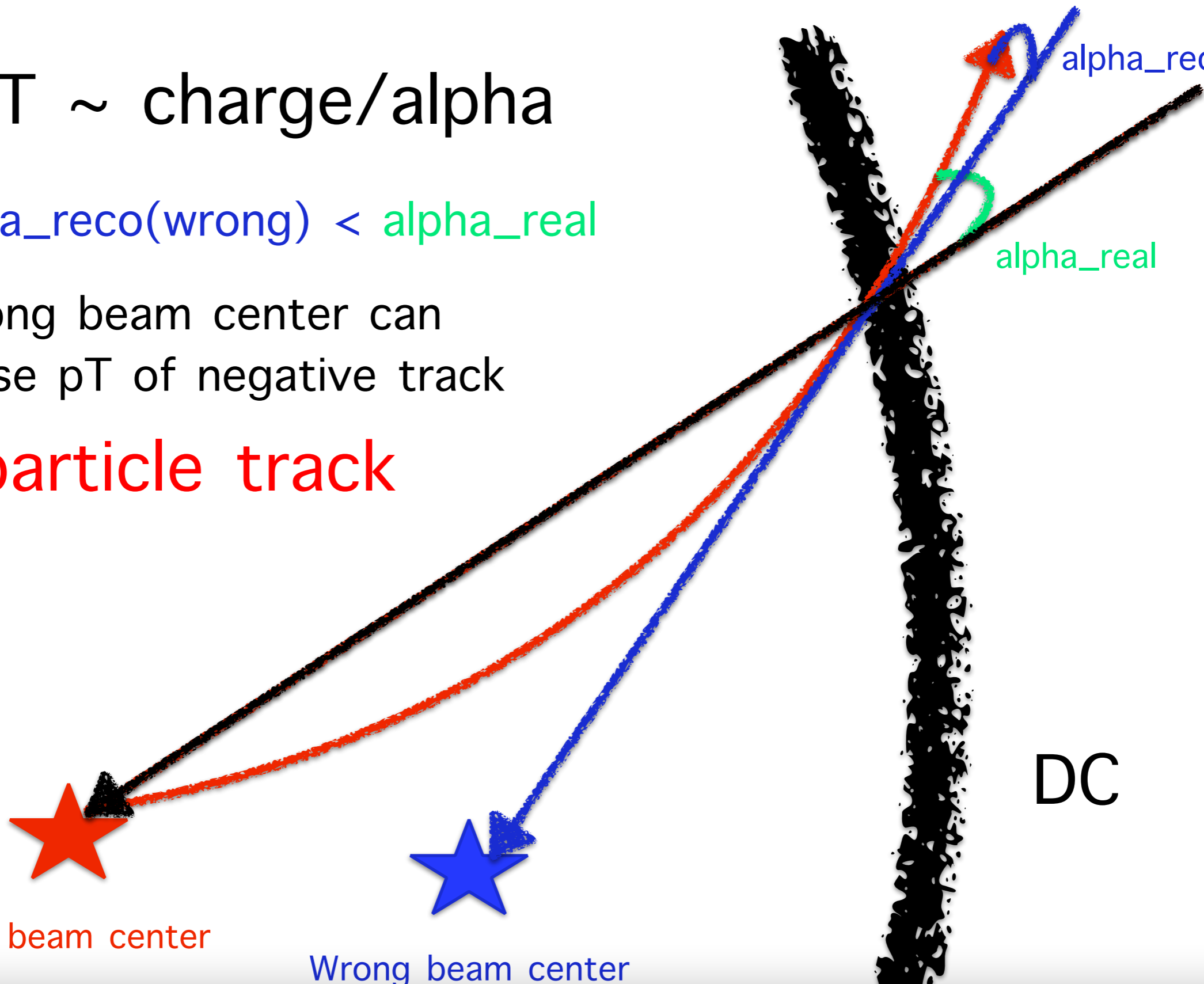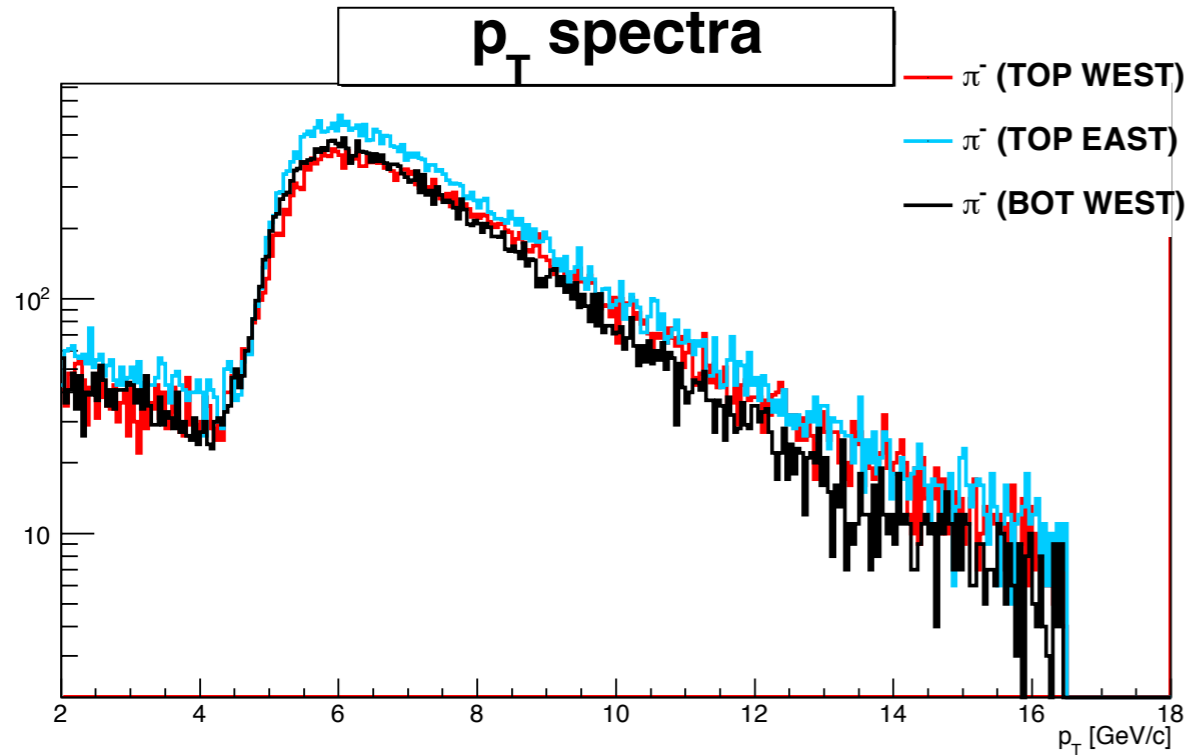
In 2012

In 2013
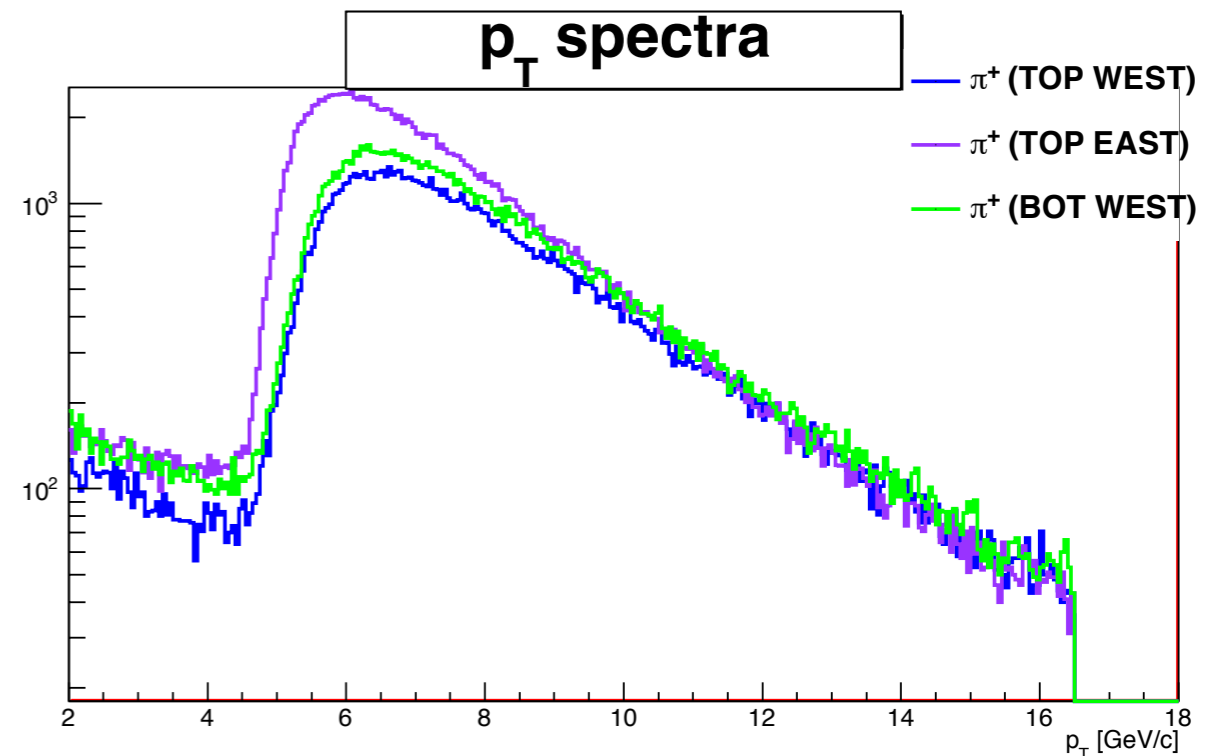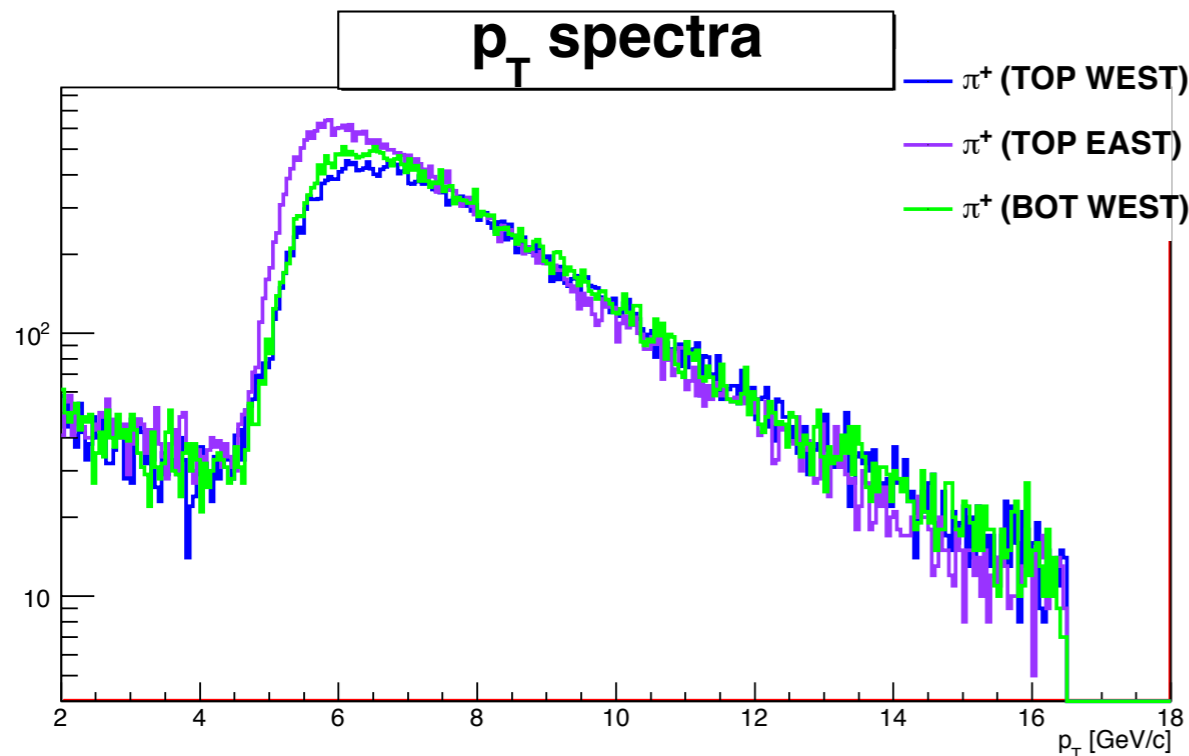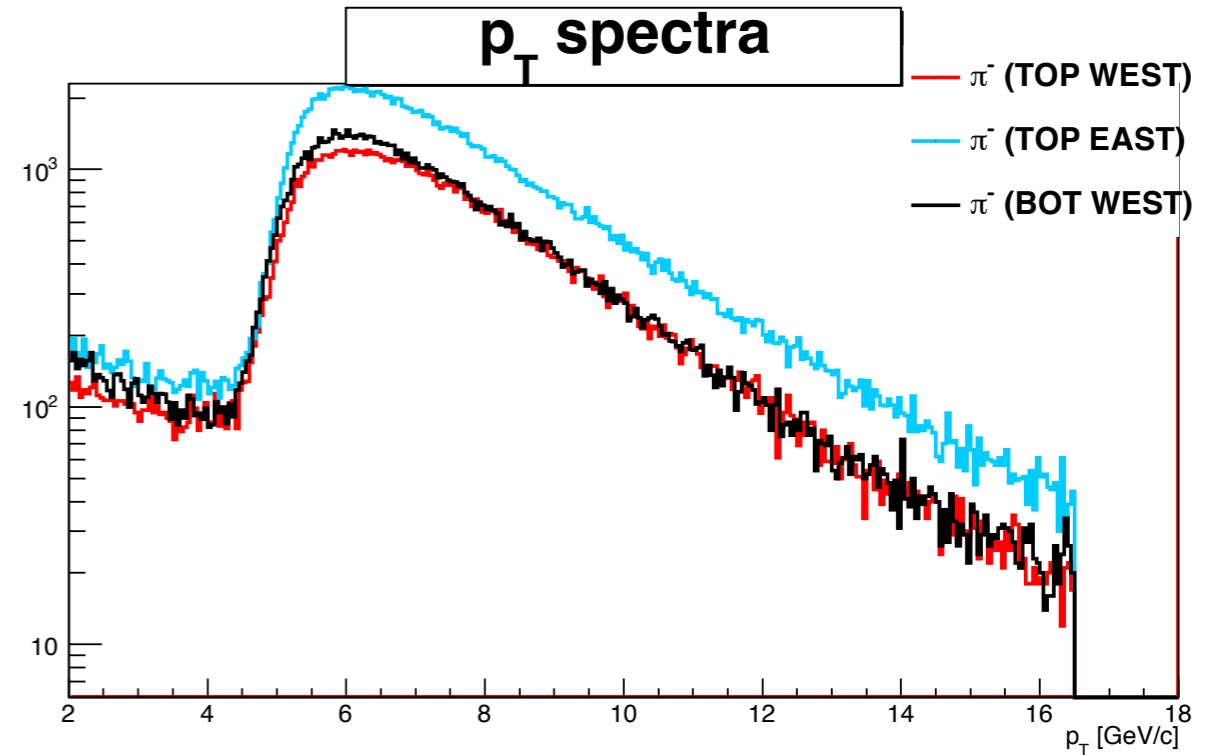
Double-check
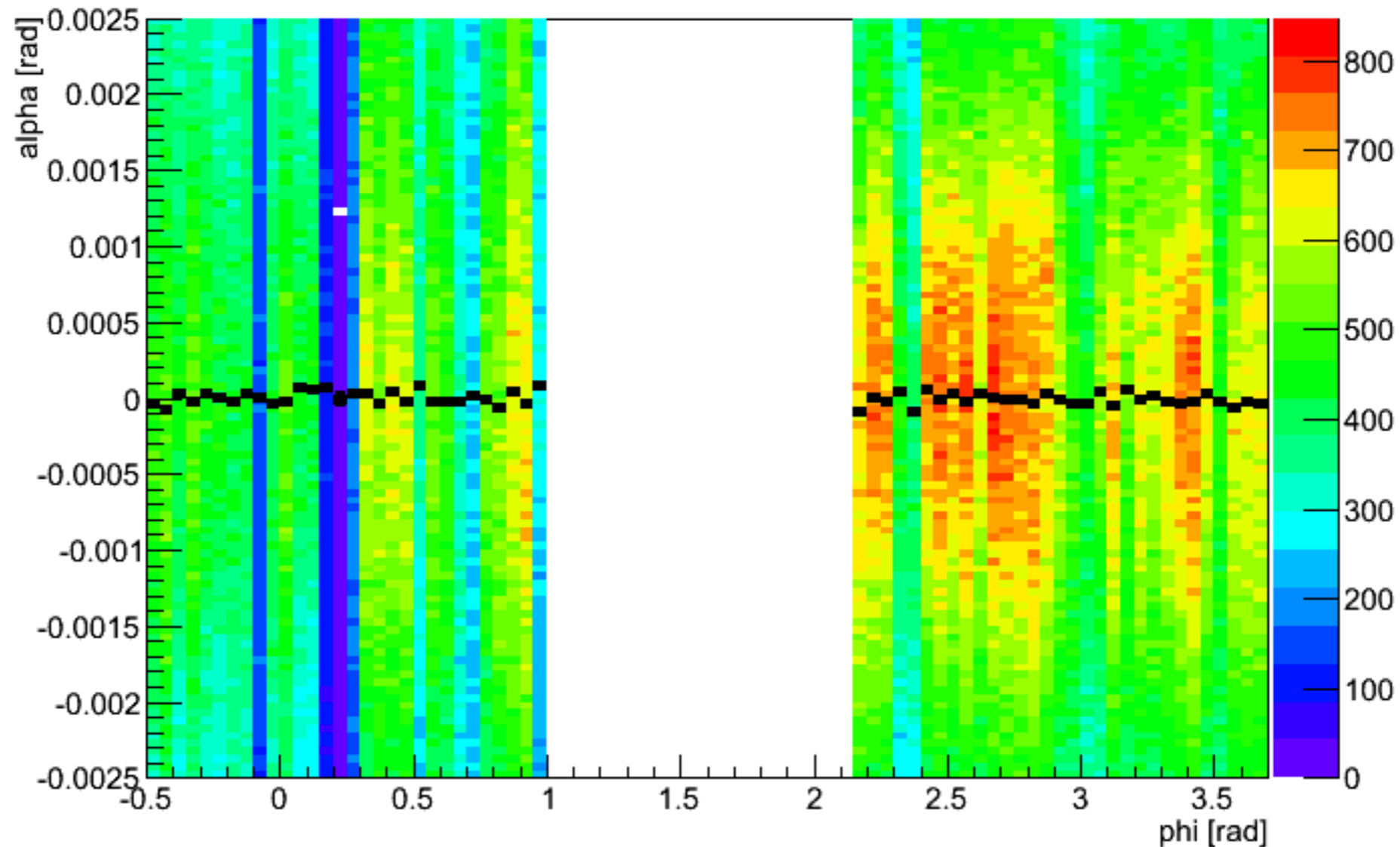
- Double checked alpha vs. phi using the same run in Ana1130.
- Alpha is almost 0. That means the beam offset calibration is acceptable.
- I looked at alpha vs. phi closely.

alpha vs phi in descending order of raw trigger rate

Name	Bit Mask	Scale Down	State	Raw Trigger Count	Raw Trigger Rate	Live Trigger Count	Live Trigger Rate
BBCLL1(>0 tubes)	0x00000001	18453	Enabled	3434784215	1017111.11	2800513371	829290.31
BBCLL1(>0 tubes) novertex	0x00000002	3989	Enabled	5563213233	1647383.25	4537432511	1343628.22
ZDCLL1wide	0x00000004	3690	Enabled	522248054	154648.52	429594384	127211.84
BBCLL1(noVtx)&(ZDCN‖ZDCS)	0x00000008	3790	Enabled	2333787041	691082.93	1919347914	568358.87
BBCLL1(>0 tubes) narrowvtx	0x00000010	500	Enabled	1718820631	508978.57	1401144806	414908.15

Raw Trigger Rate: 2787256.14

α vs φ (Run13pp510 : 391457)
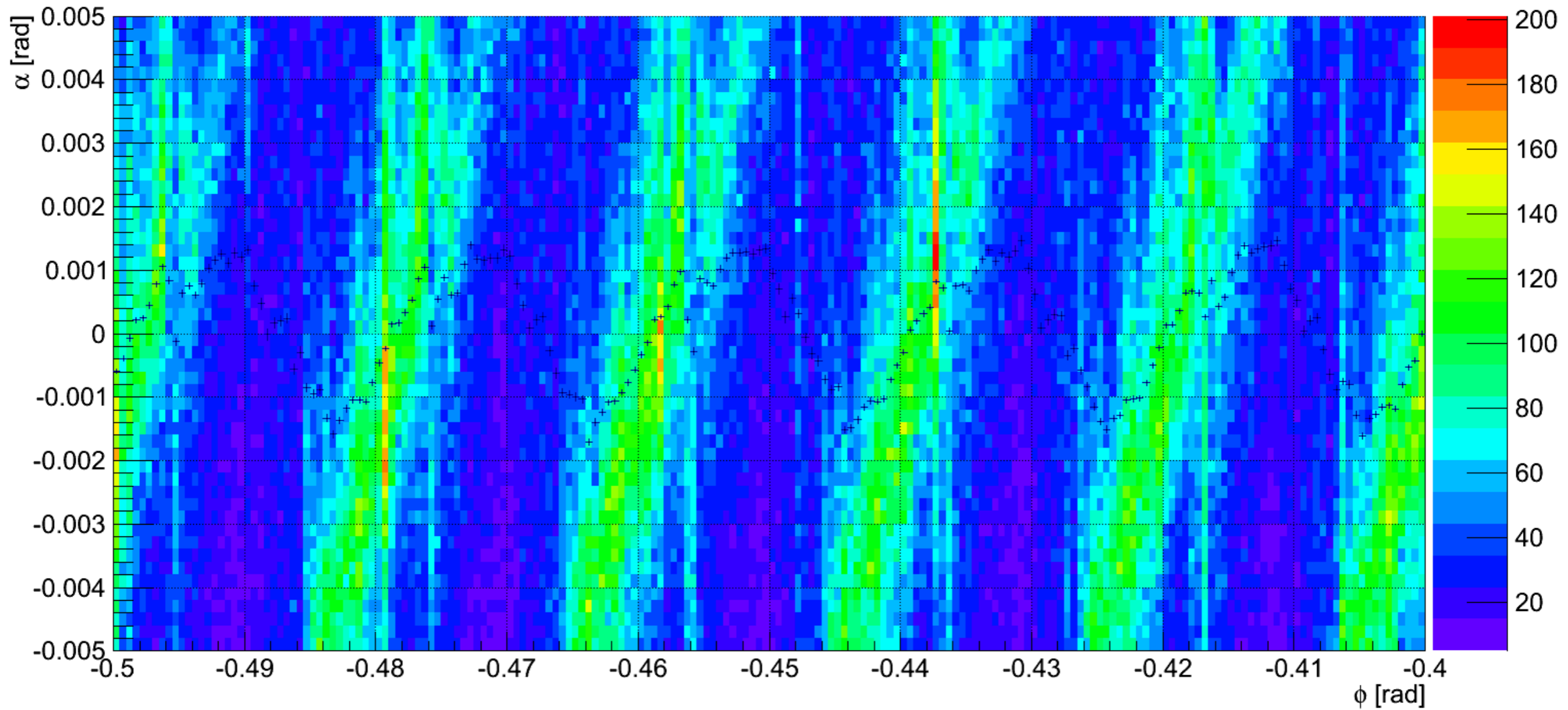
Raw Trigger Rate: 2397287.86
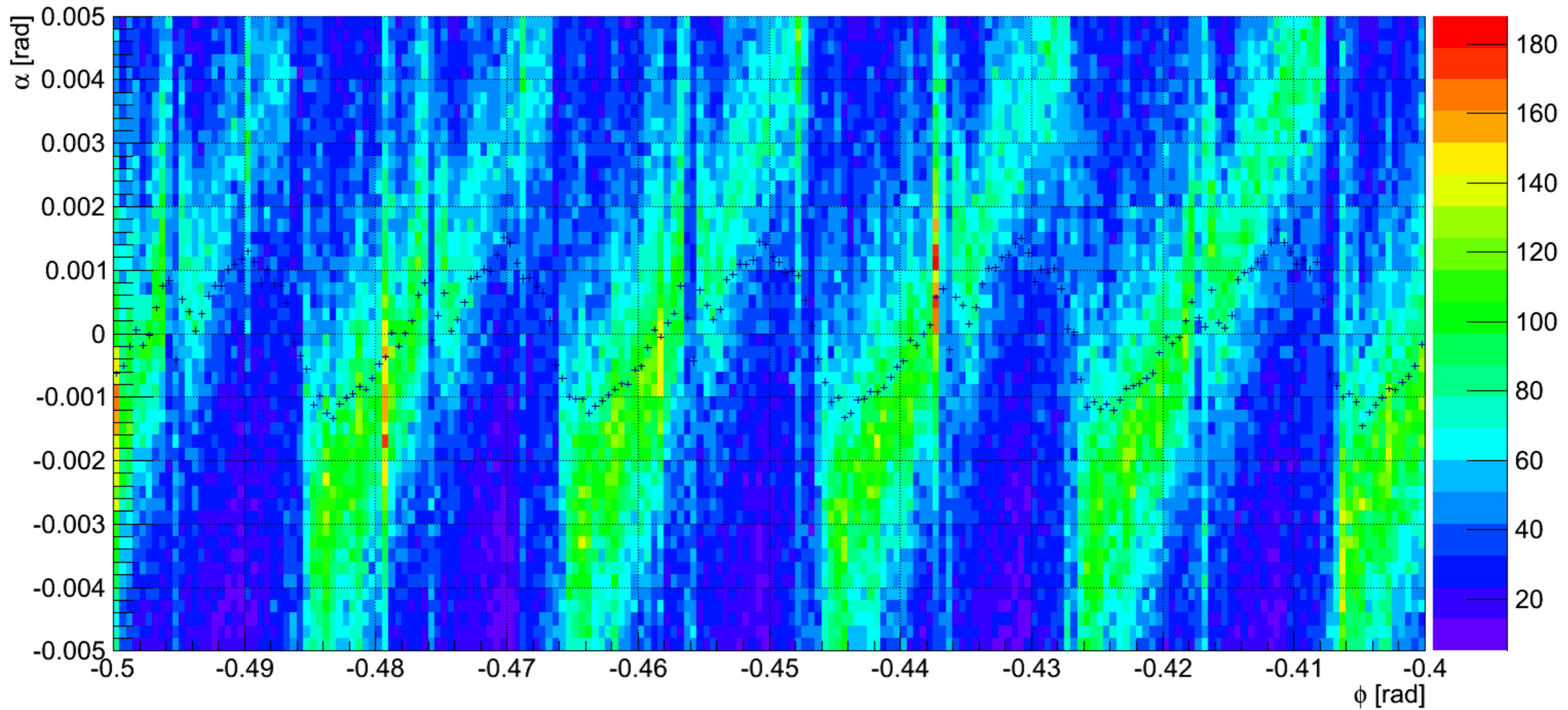

α vs φ (Run13pp510 : 393071)
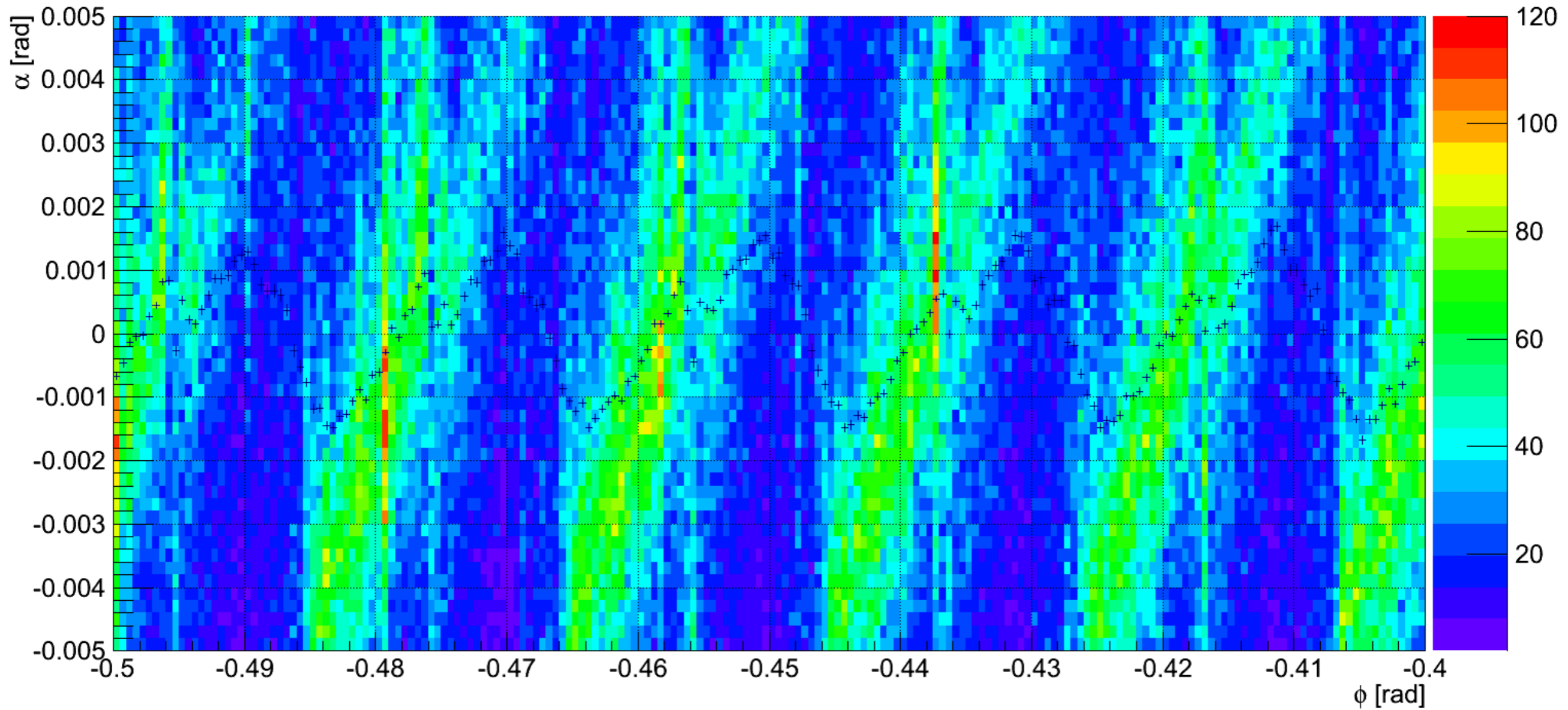
Raw Trigger Rate: 2185816.43
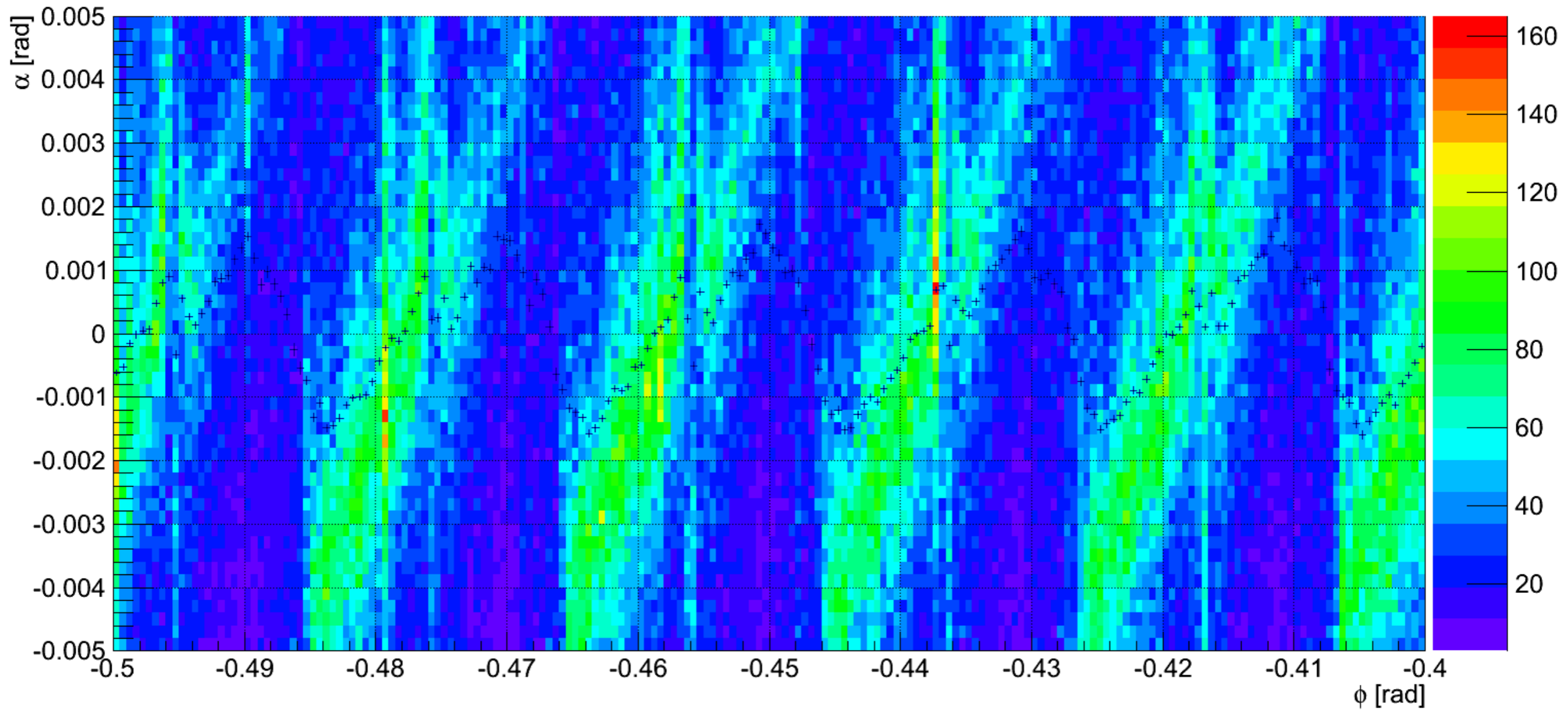

α vs φ (Run13pp510 : 394395)
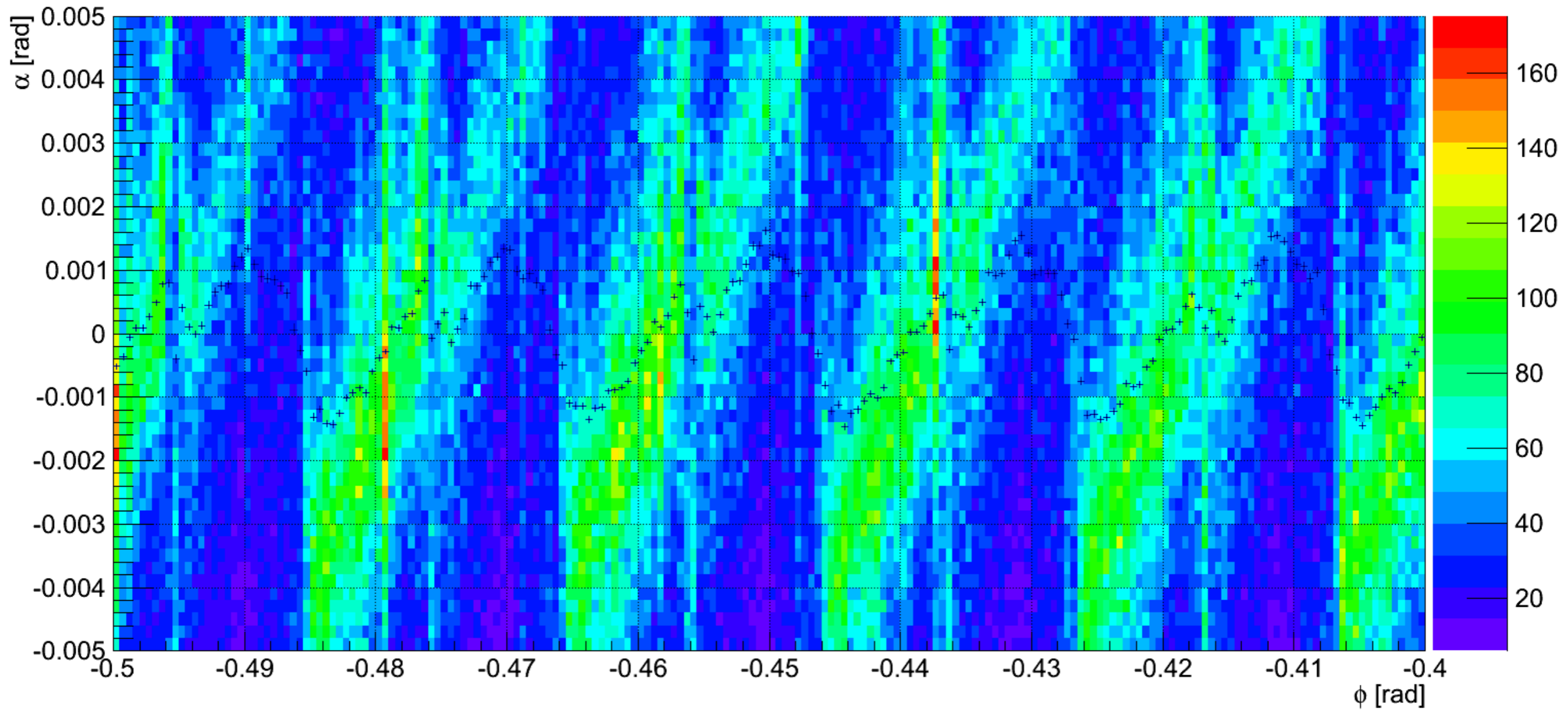
Raw Trigger Rate: 2148649.85
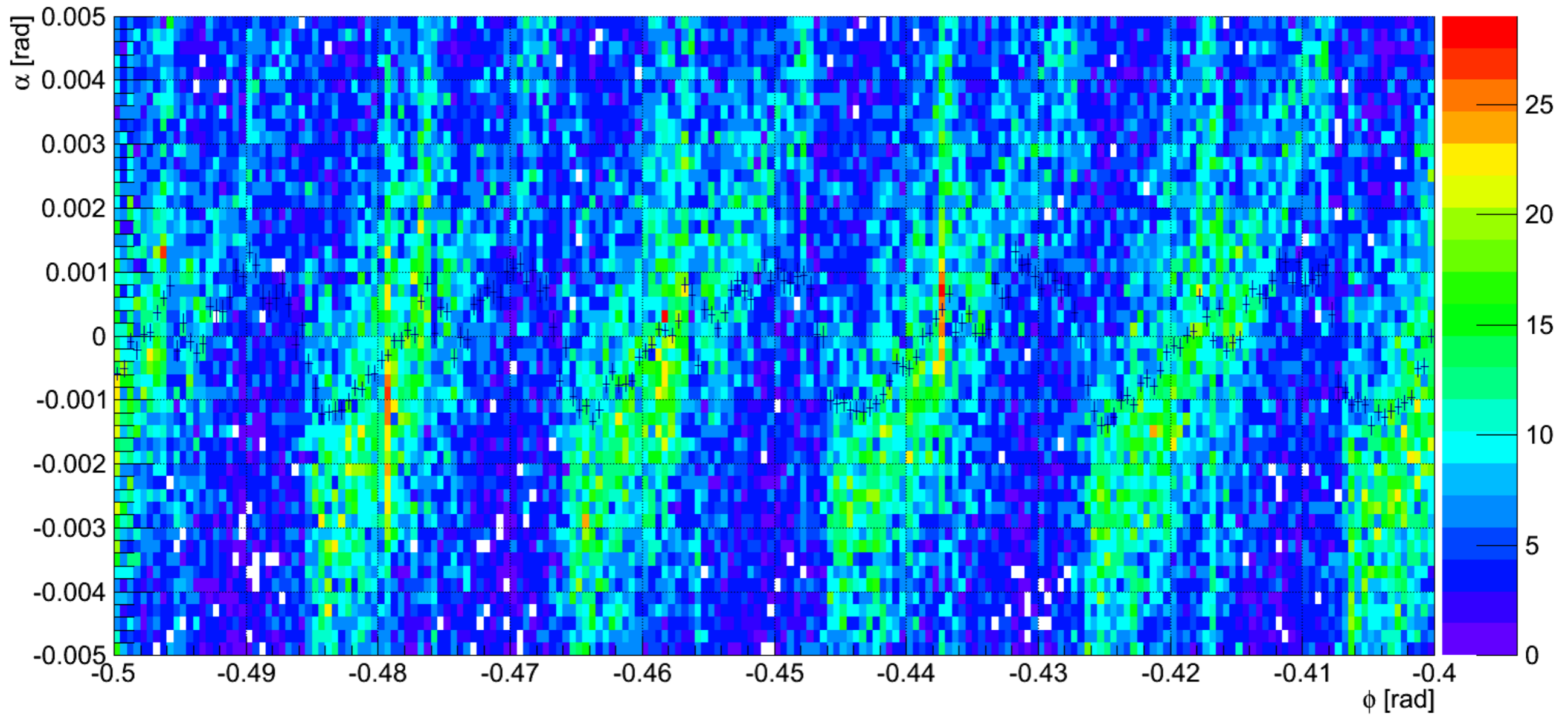

α vs φ (Run13pp510 : 388276)

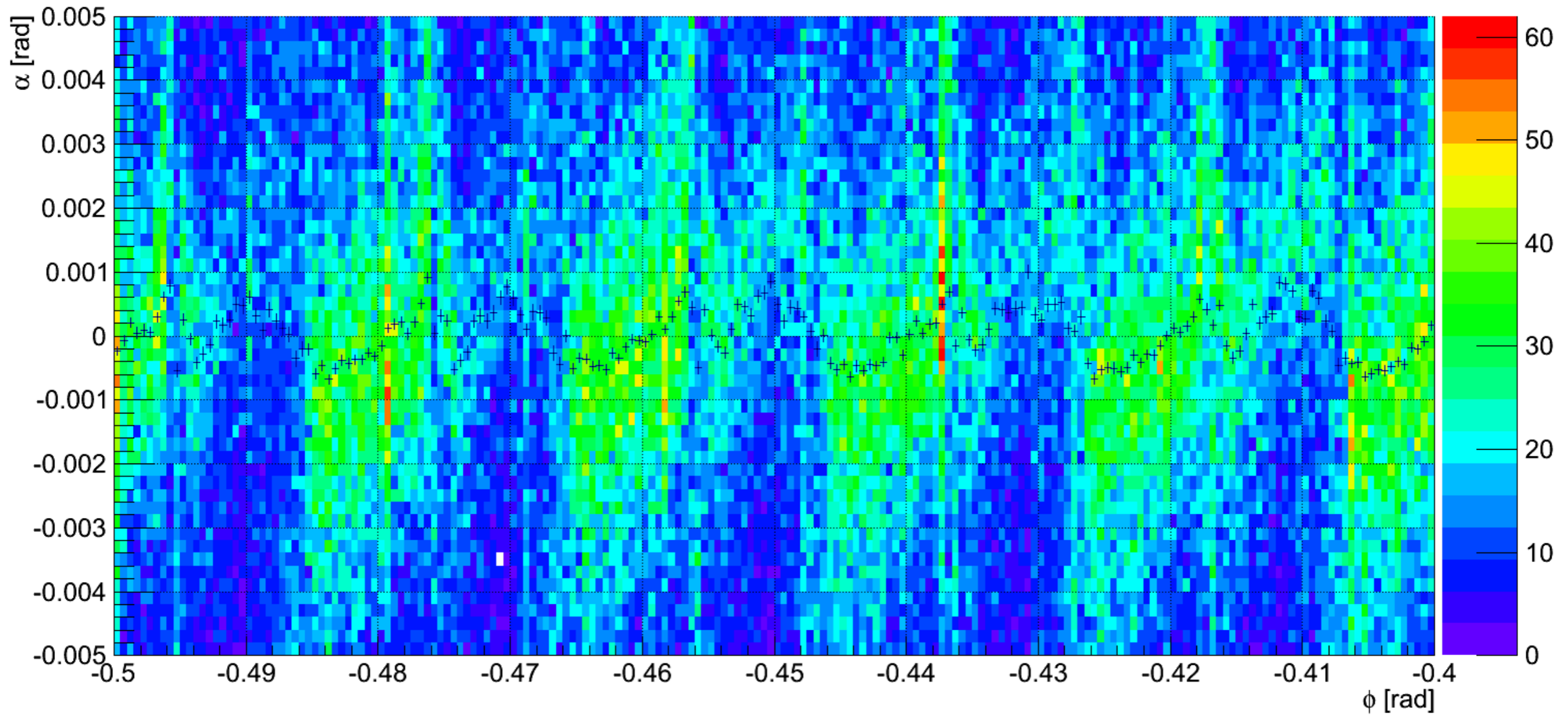# Raw Trigger Rate: 1900192.05

α vs φ (Run13pp510 : 391877)

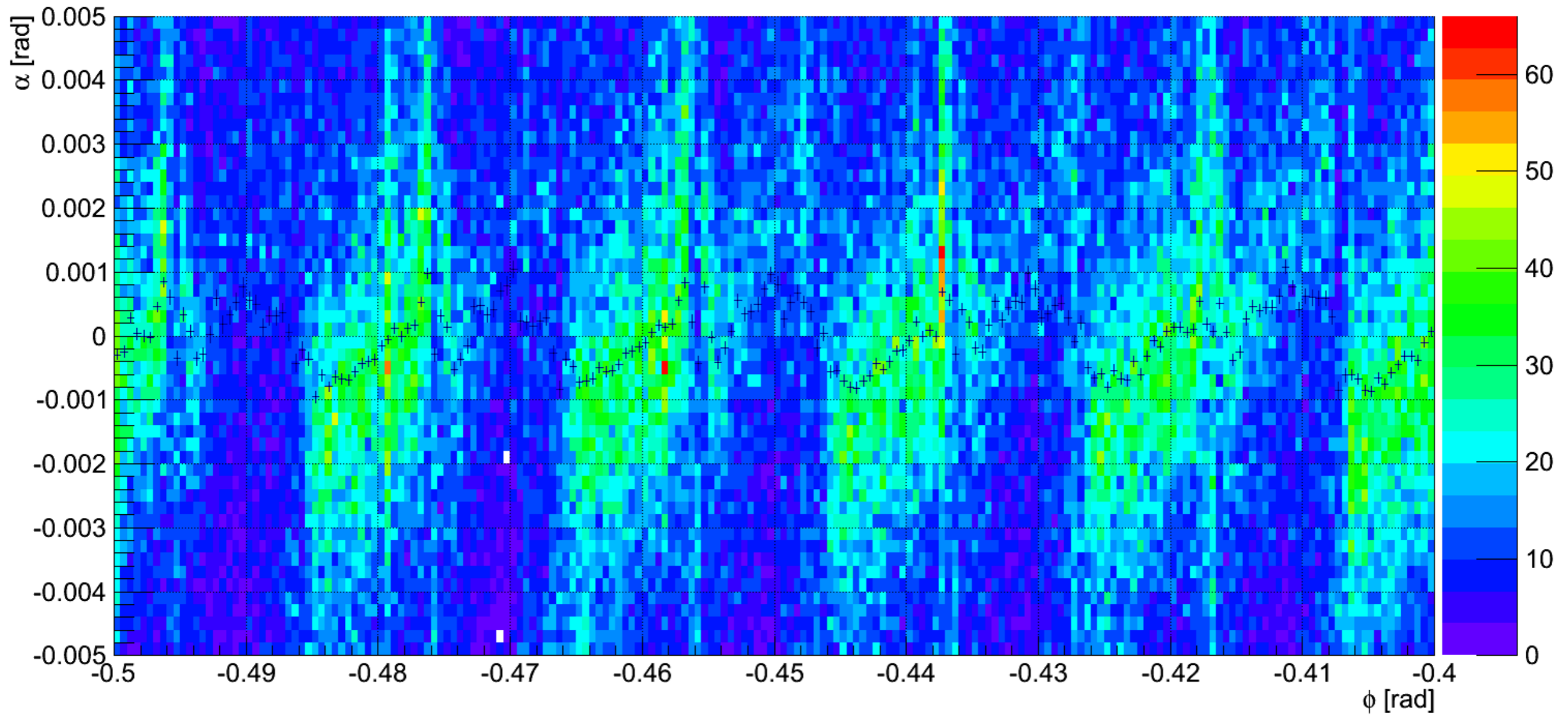# Raw Trigger Rate: 1795081.98

α vs φ (Run13pp510 : 390240)

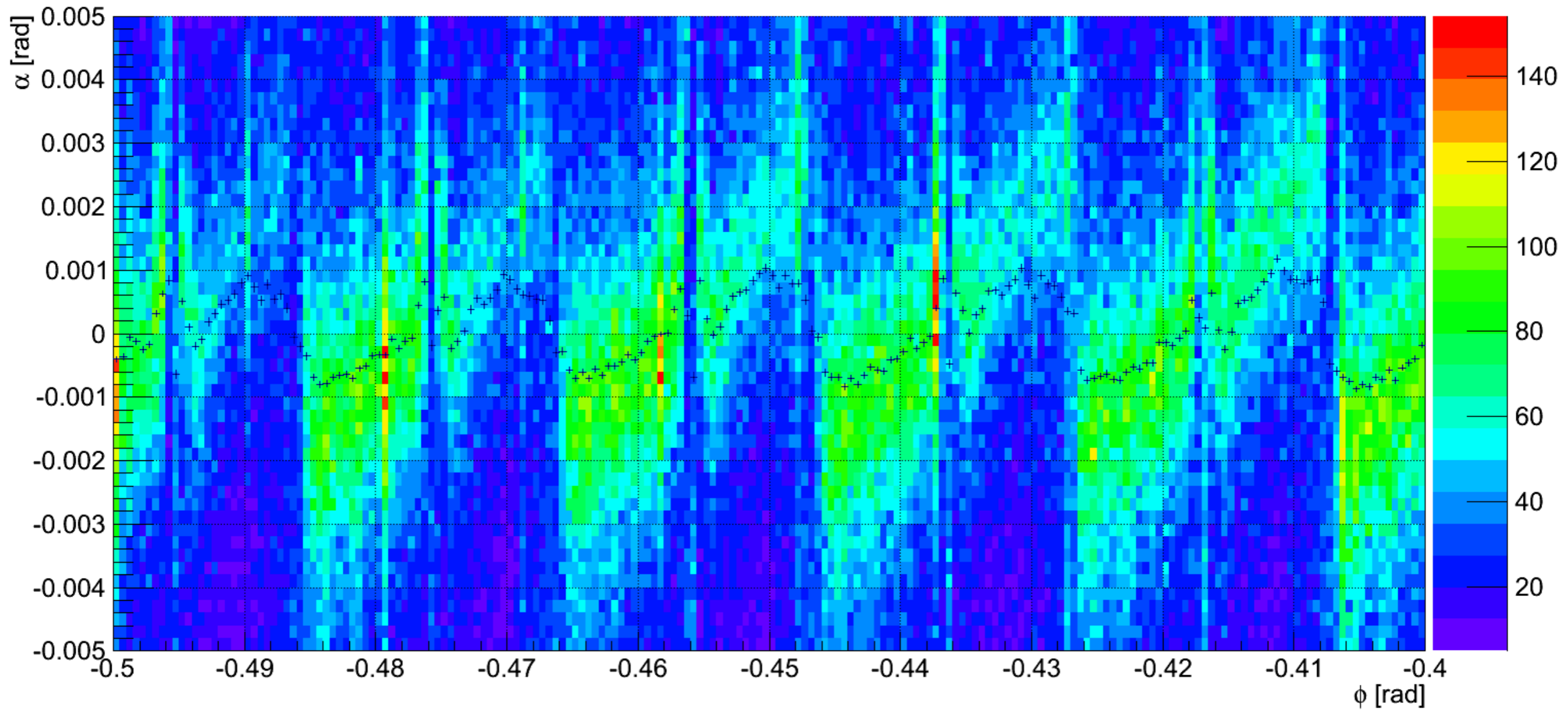# Raw Trigger Rate: 1769864.82

α vs φ (Run13pp510 : 390241)

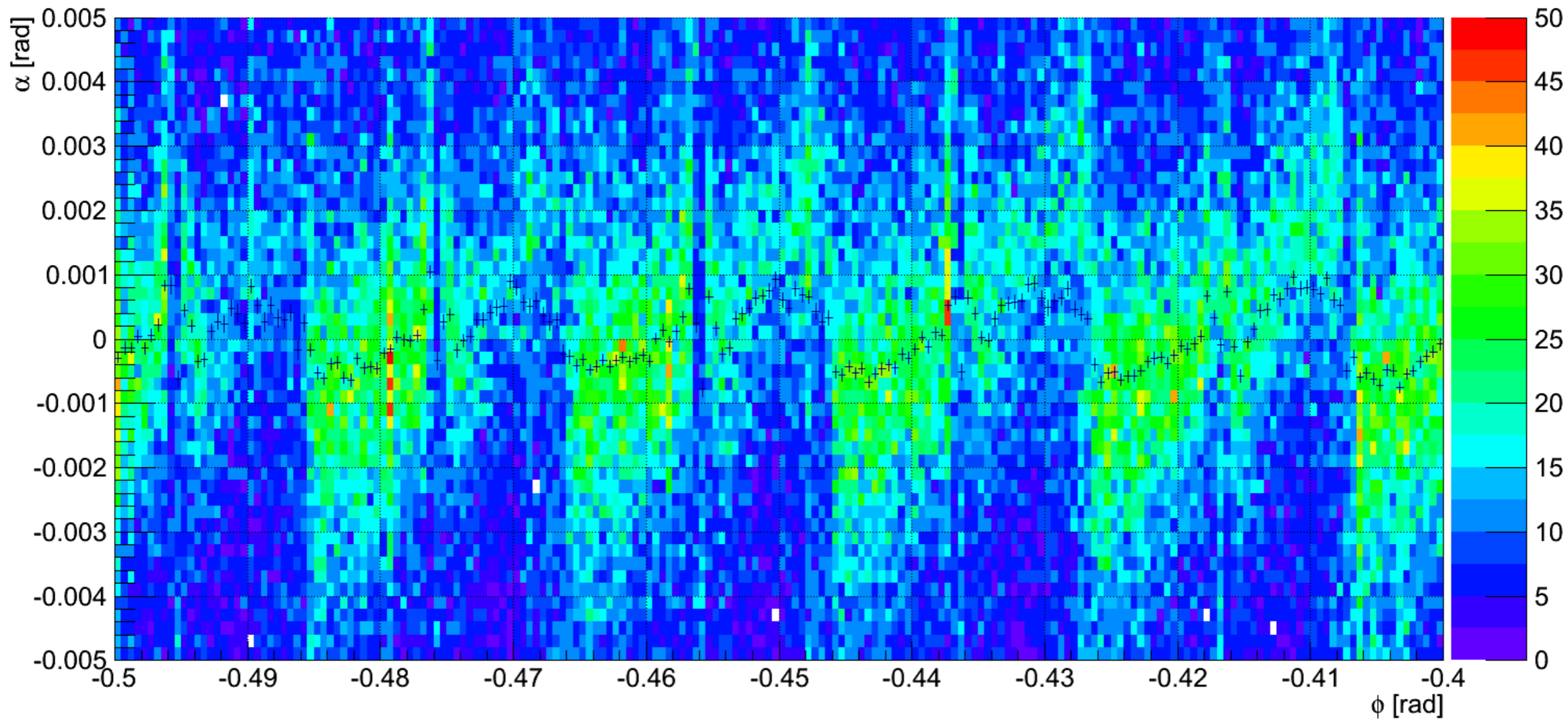# Raw Trigger Rate: 1647383.25

α vs φ (Run13pp510 : 386885)

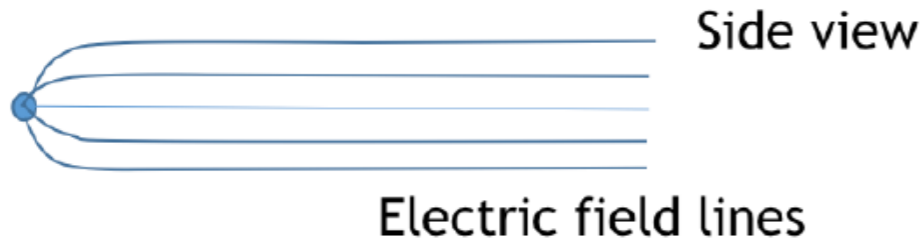# Raw Trigger Rate: 1081912.40

α vs φ (Run13pp510 : 390022)

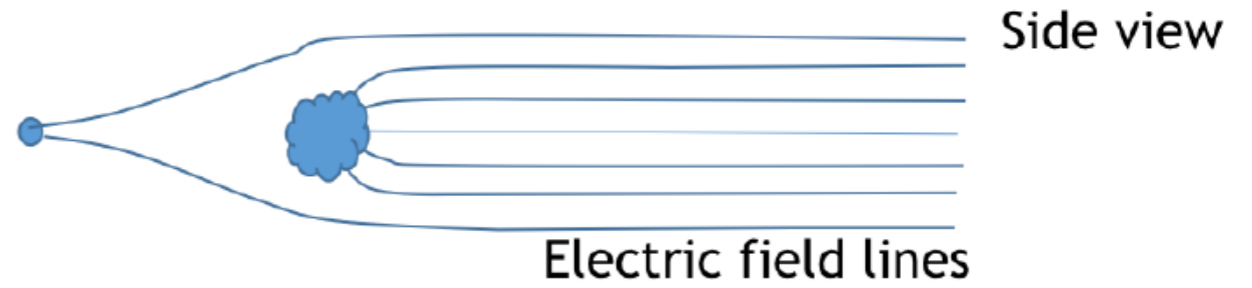# Raw Trigger Rate: 1053916.98
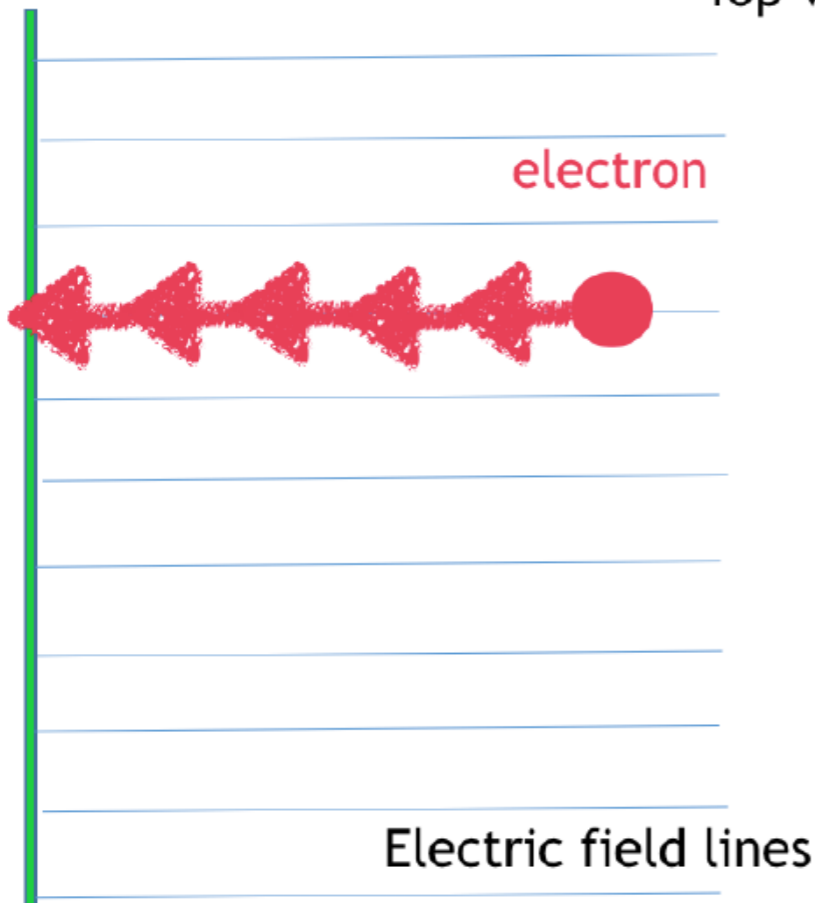

α vs φ (Run13pp510 : 390023)

NO positive ion cloud

Side view

Electric field lines

Top view

electron

Electric field lines

Anode(positively charged electrode)

Positive ion cloud

Side view

Electric field lines

Top view

electron

Distorted electric field lines

Anode(positively charged electrode)

36