Measurement of double helicity asymmetries in $\pi^{\pm}$ production in PHENIX

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Motivation

- **Jaffe-Manohar Sum Rule:**

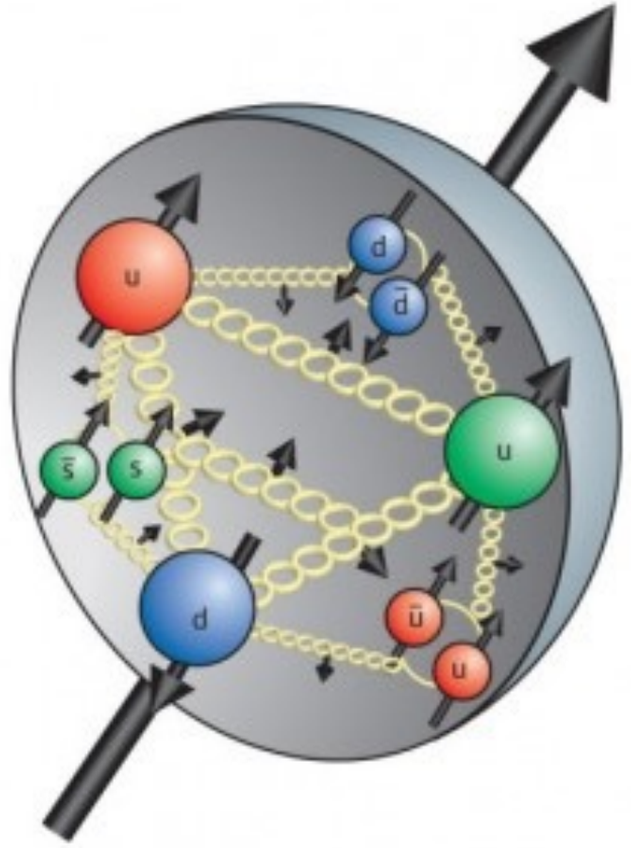
$$Proton\ Spin\ = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \boxed{\Delta G} + L_q + L_g$$

  - ΔΣ: 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}:

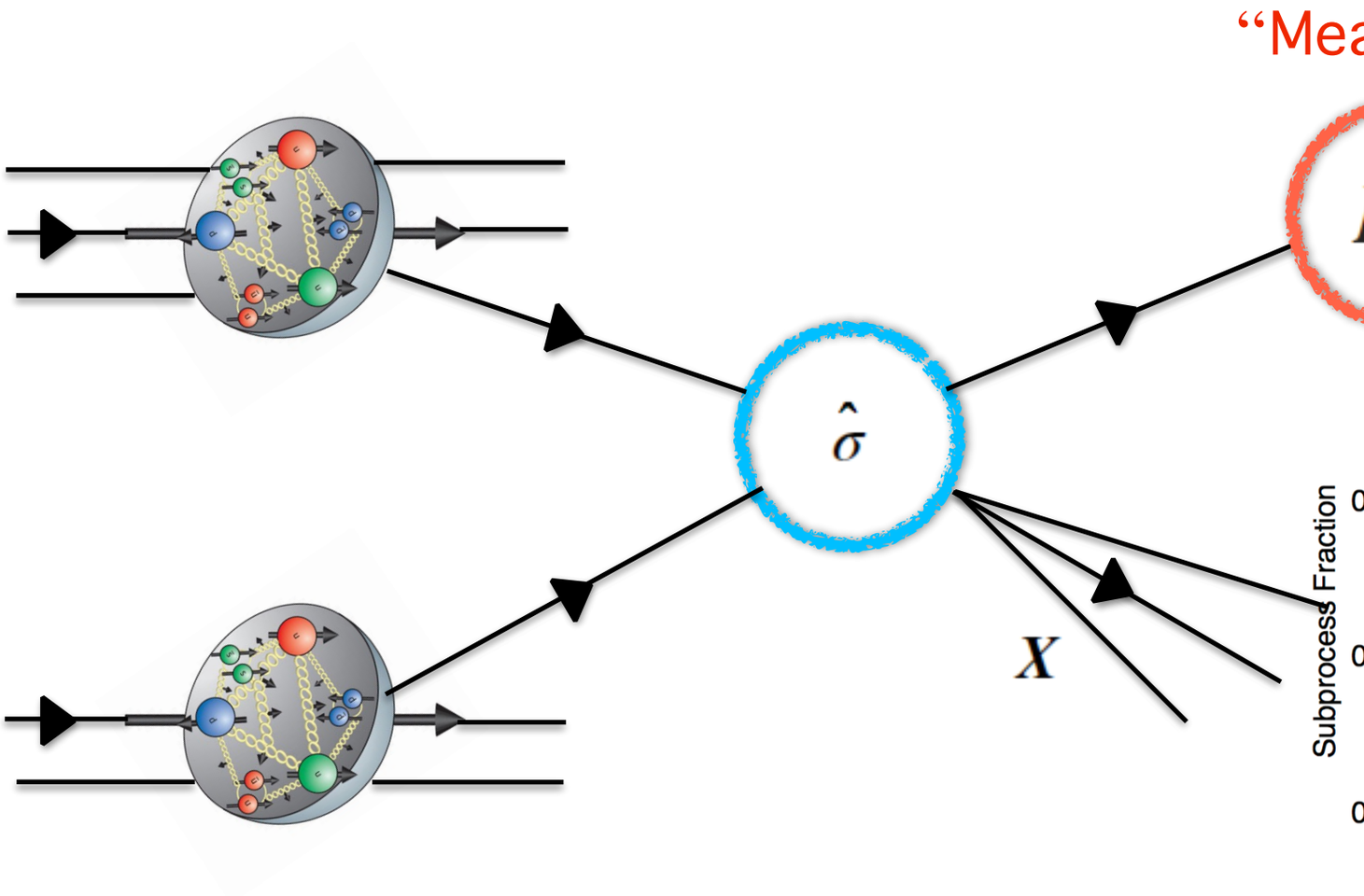
      PRD 93 011501 (2016), PRD 91 032001 (2015), PRD 90 012007 (2014), PRL 103 012003 (2009) and so on.
    - STAR Jet/Di-jet A_{LL}:

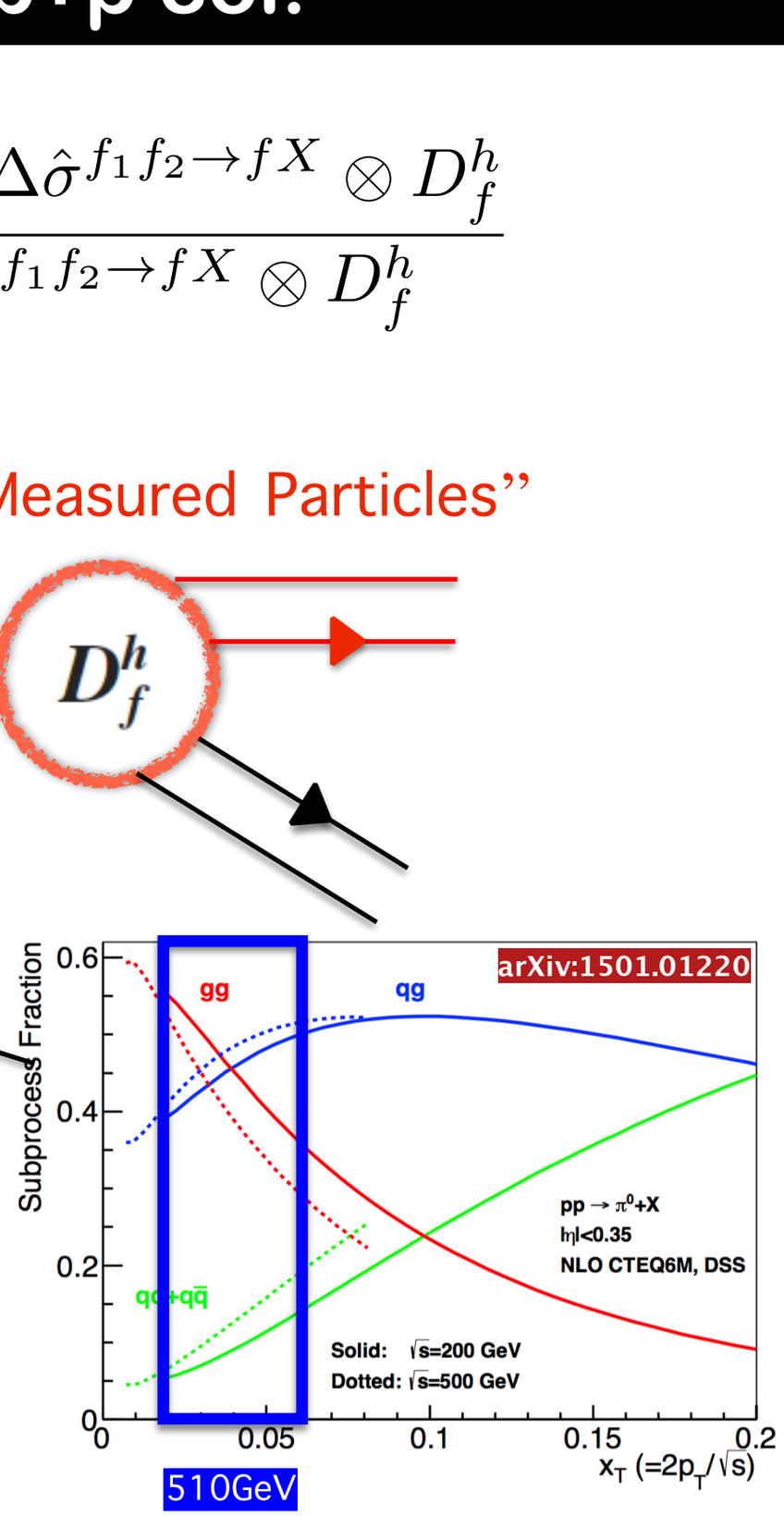
      PRL 115 92002 (2015), PRD 95 71103 (2017)



Motivation: Accessing ΔG via A_{LL} in p+p col.

$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} = \frac{\sum_{f_1,f_2=q,\bar{q},g} \Delta f_1 \otimes \Delta f_2 \otimes \Delta\hat{\sigma}^{f_1 f_2 \to f X} \otimes D_f^h}{\sum_{f_1,f_2=q,\bar{q},g} f_1 \otimes f_2 \otimes \hat{\sigma}^{f_1 f_2 \to f X} \otimes D_f^h}$$

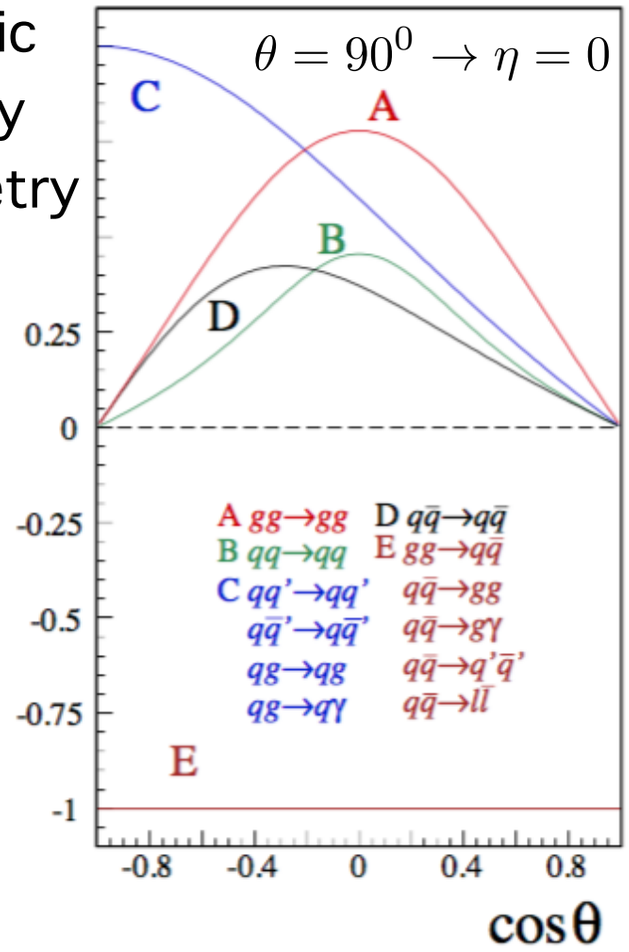




Motivation: “Directly” access the sign of ΔG

Partonic Helicity Asymmetry a_{LL}

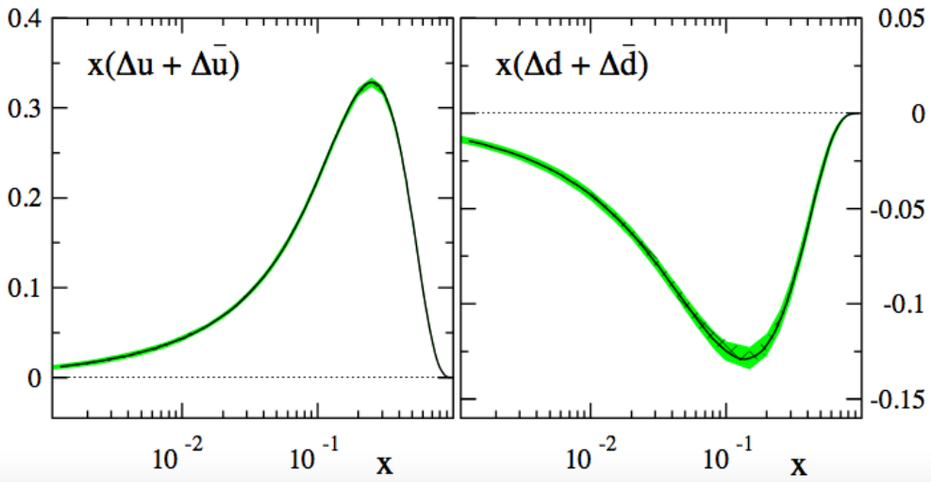
PRL 113, 012001 (2014)



$$A_{LL}^{\pi^+} \approx a_{gg}\Delta g\Delta g + \underbrace{a_{ug}}_{>0}\underbrace{\Delta u}_{>0}\Delta g$$

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

Phys. Rev. D 80, 034030 (2009)



Motivation: "Directly" access the sign of ΔG

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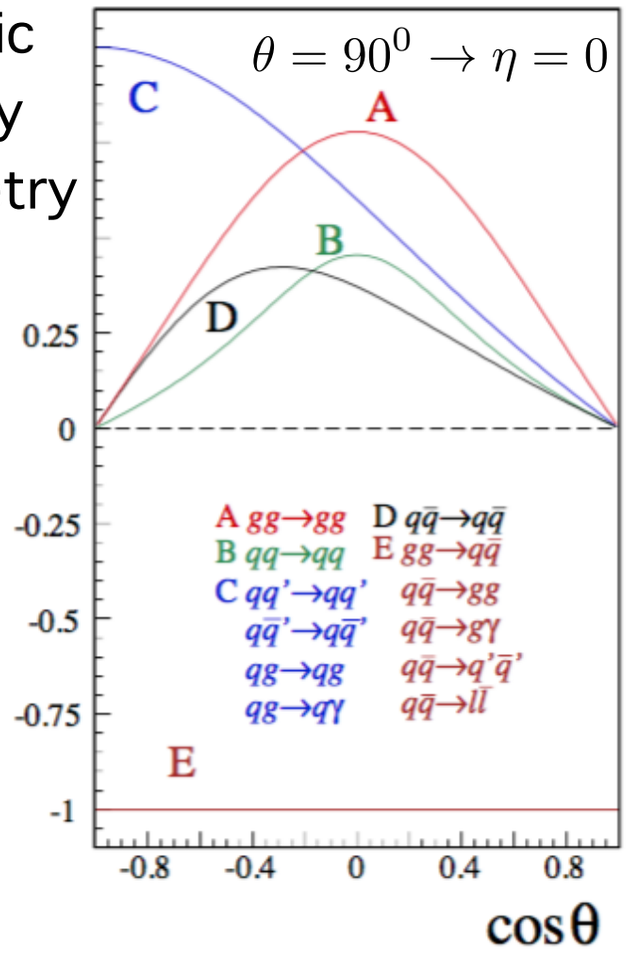
PRL 113, 012001 (2014)



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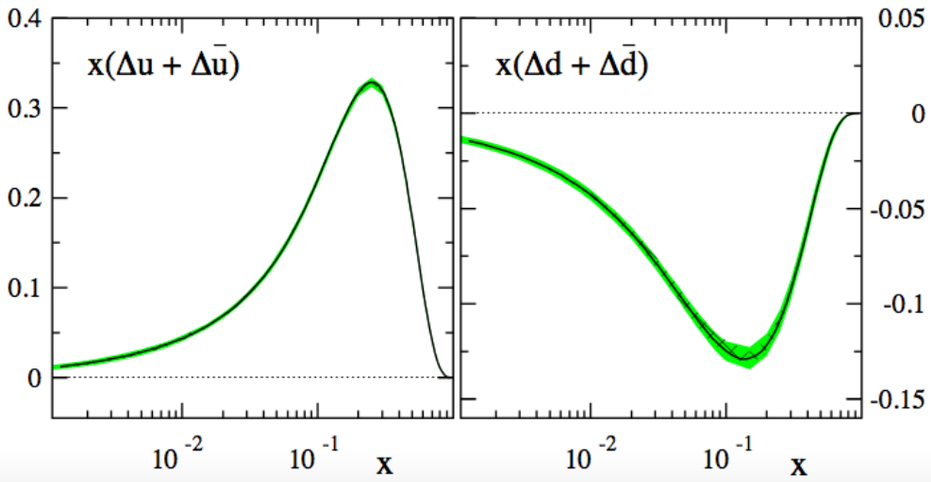


$$\left.\begin{aligned} A_{LL}^{\pi^+} &\approx a_{gg}\Delta g\Delta g + \underbrace{a_{ug}}_{>0}\underbrace{\Delta u}_{>0}\Delta g \\ A_{LL}^{\pi^-} &\approx a_{gg}\Delta g\Delta g + \underbrace{a_{dg}}_{>0}\underbrace{\Delta d}_{<0}\Delta g \end{aligned}\right\} \rightarrow$$

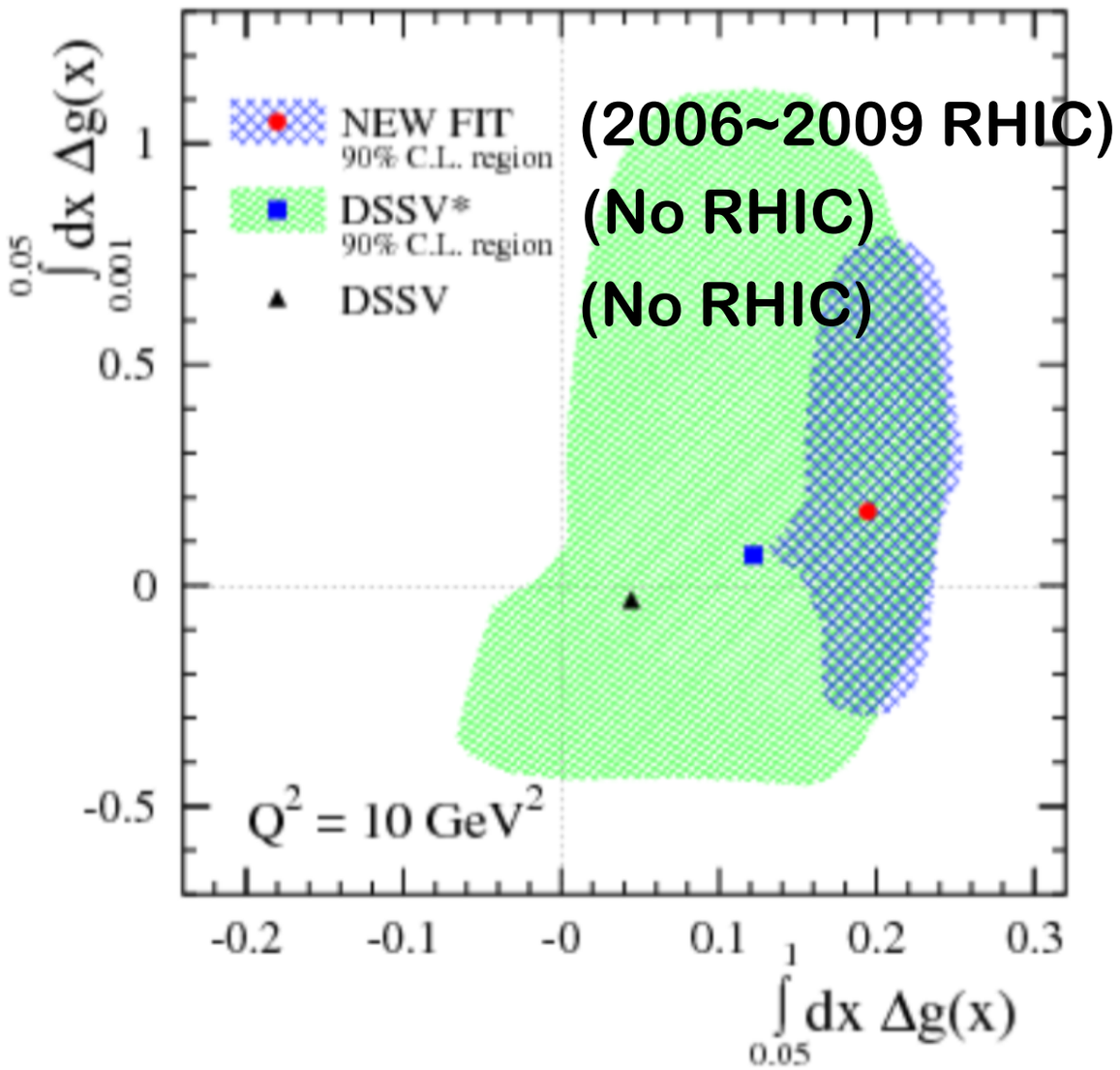
$$A_{LL}^{\pi^+} - A_{LL}^{\pi^-} > 0 \text{ (for } \Delta g > 0)$$

$$\Delta g > 0 \rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^-}$$

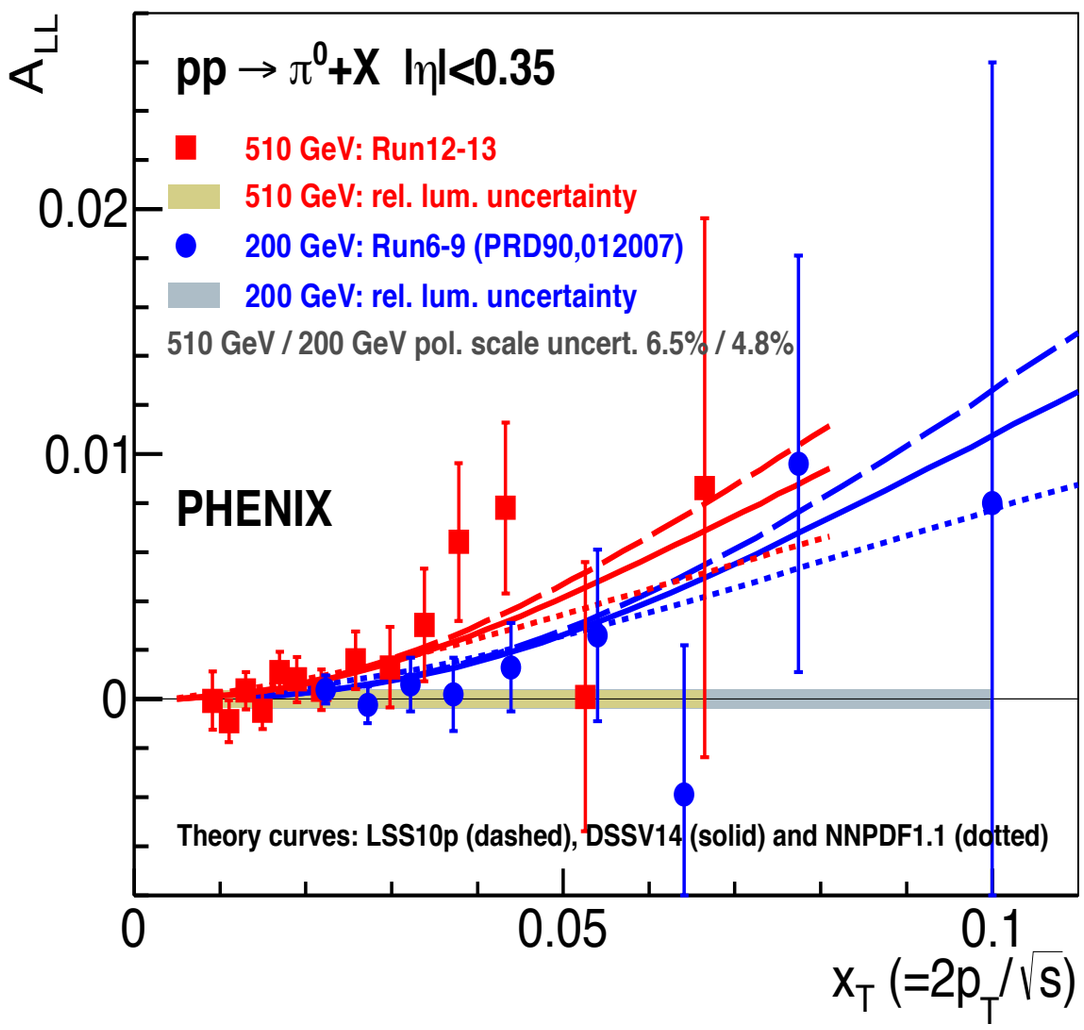
and vice versa

Current understanding

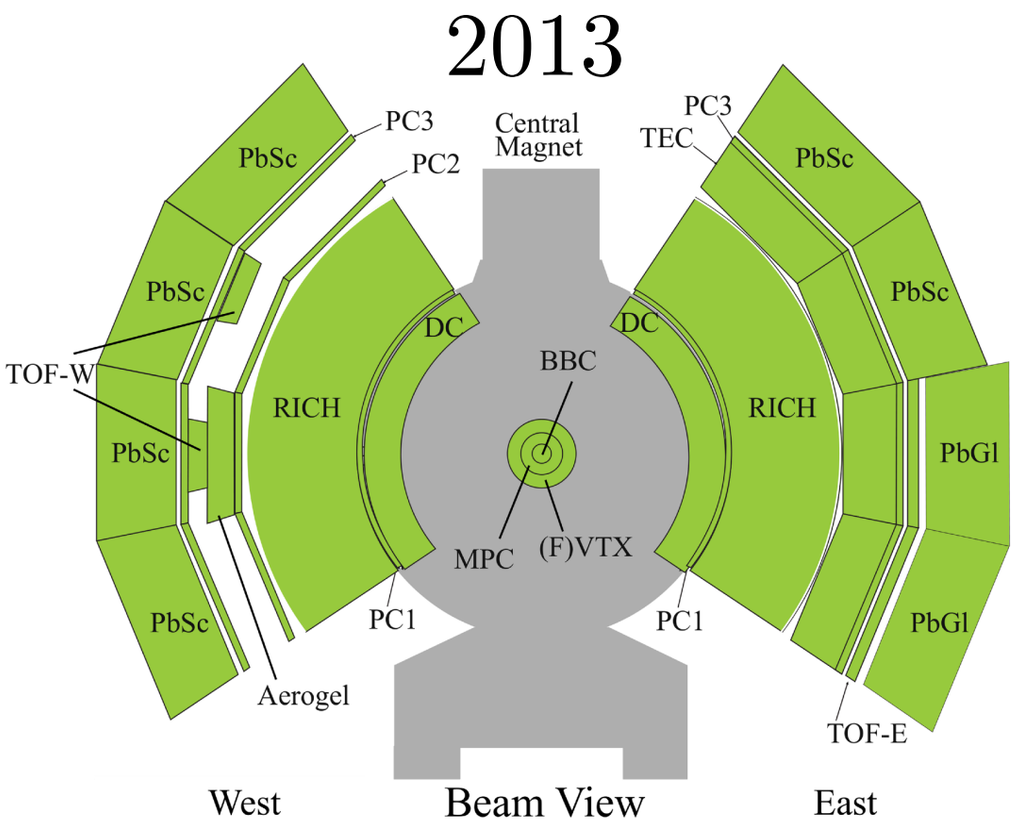
PRL 113, 012001 (2014)

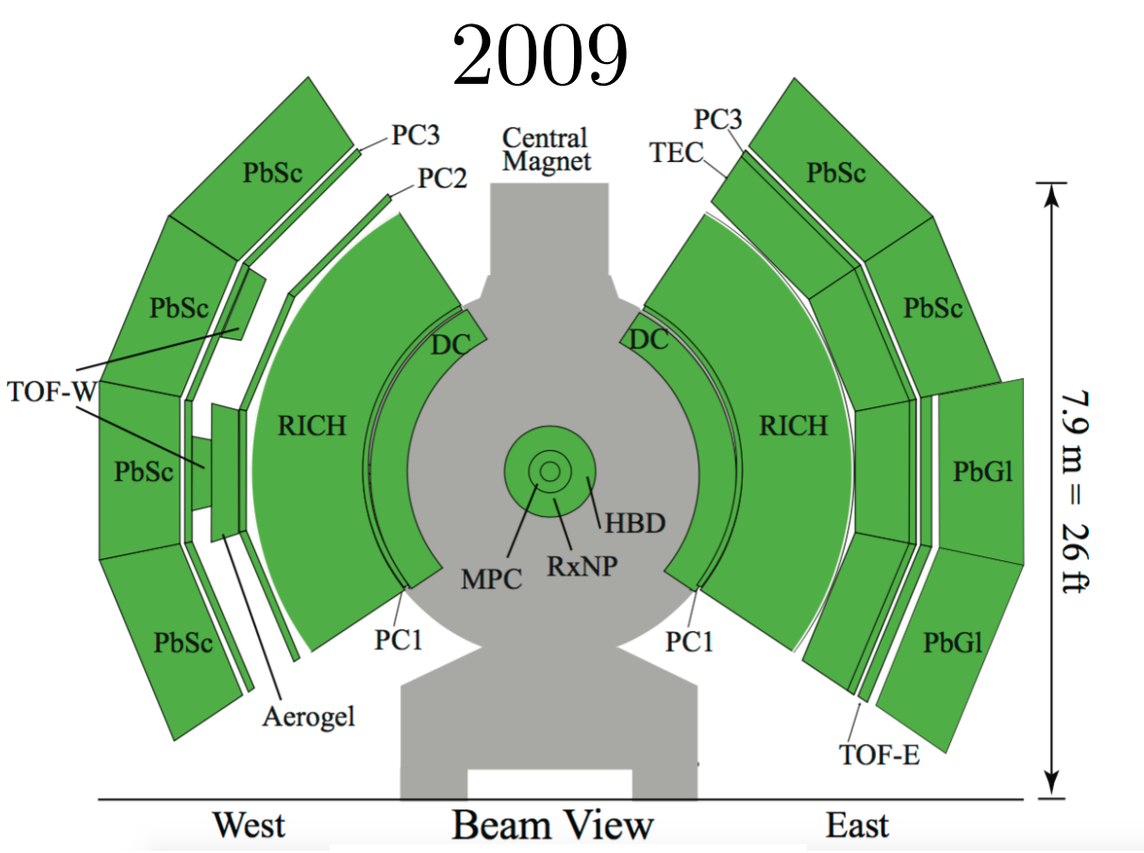


PRD 93, 011501 (2016)



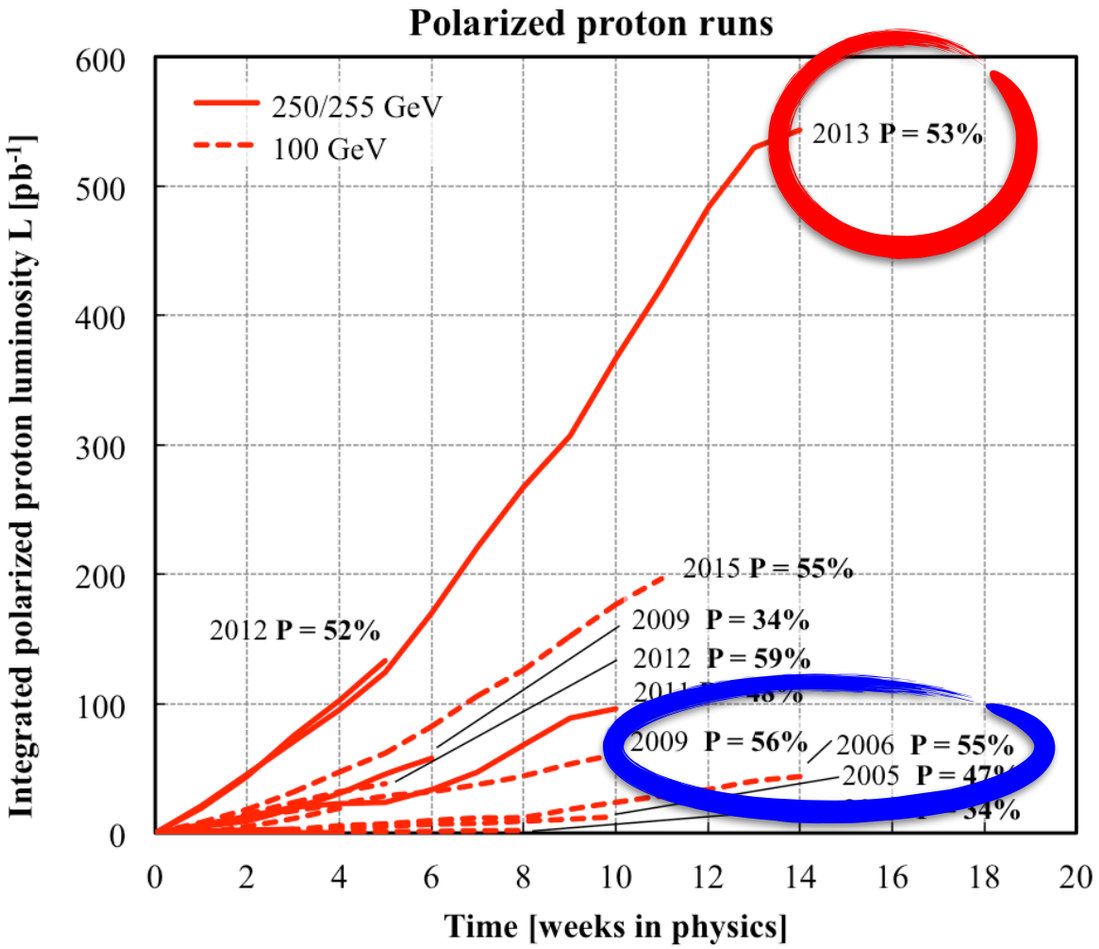
- The uncertainties have been reduced for x > 0.05 based on RHIC data up to Run-2009.
- Expanding experimental sensitivity to lower x region, x < 0.05, with PHENIX π^0 at 510 GeV.
- Showed non-zero gluon polarization via π0 @ 510 GeV in Run-2012-2013.

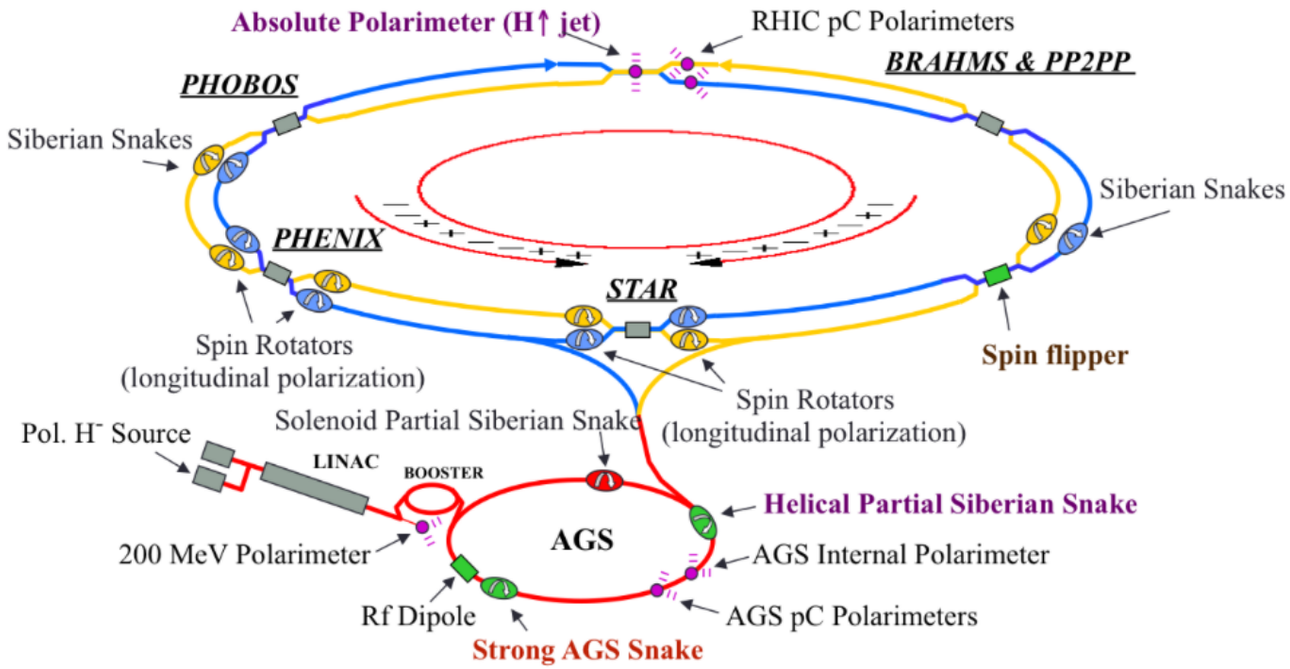




- Tracking
  - Drift Chamber (DC)
  - Pad Chamber (PC1/PC3)
  - Silicon Vertex Tracker (VTX) in 2013
- $\pi^{\pm}$ Identification
  - Ring Imaging Cherenkov Detector (RICH)
  - Electromagnetic Calorimeter (PbSc/PbGl)
  - Hadron Blider Detector (HBD) in 2009
- Relative Luminosity
  - Beam Beam Counter (BBC)
  - Zero Degree Calorimeter (ZDC)
- Acceptance
  - $|\eta|<0.35$
  - $\Delta\phi = 2 \times \pi/2$

Data recoding @ PHENIX





- **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.**

Data recoding and trigger set in Run-9 and Run-13

PHENIX Longitudinal Run

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

PHENIX EMCal-RICH Trigger (ERT) Set

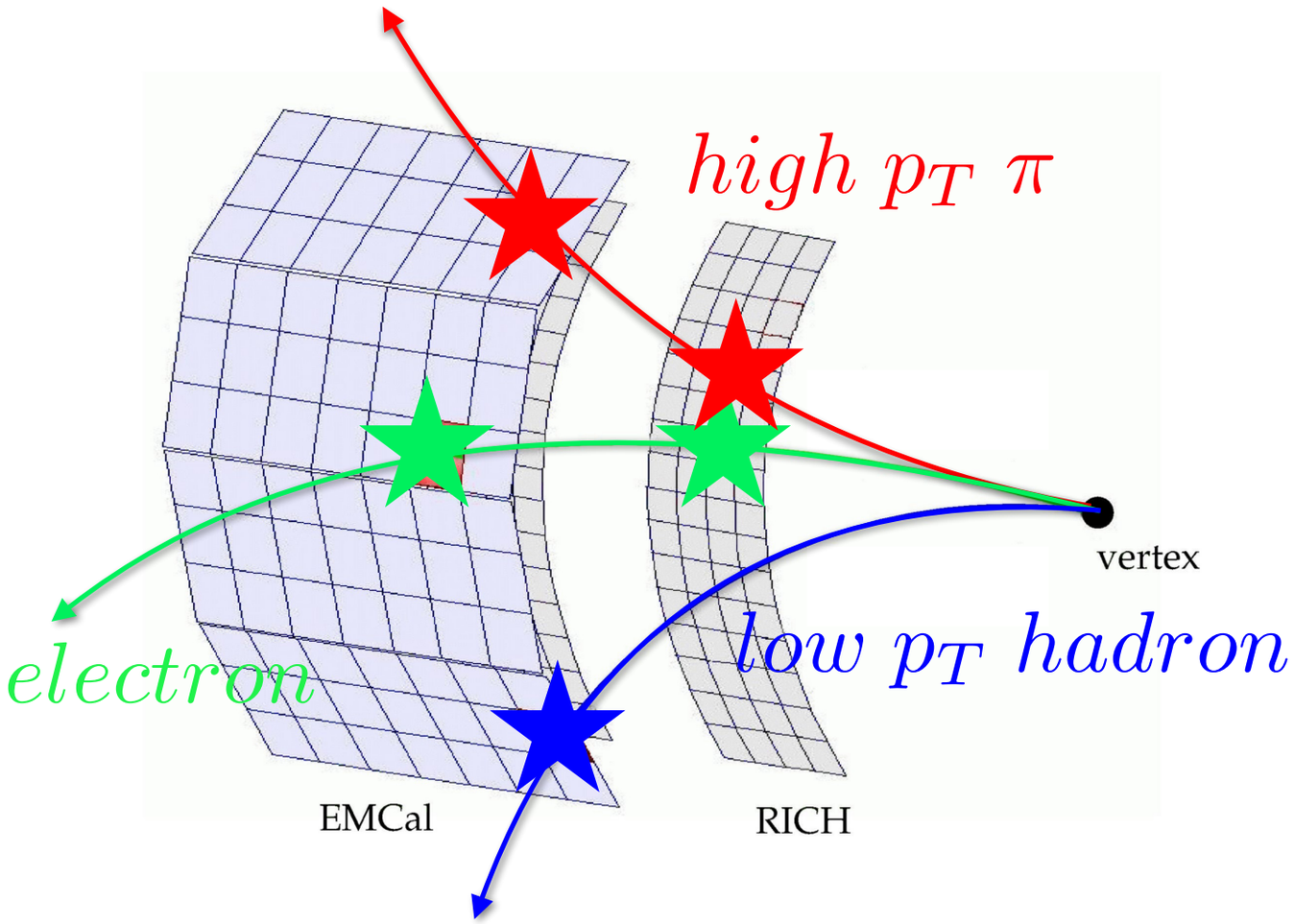
	Trigger Name and Threshold [GeV]			
Year	*4x4A*	*4x4B*	*4x4C*	*2x2E*
2009	*2.1*	*2.8*	*1.4*	*0.6*
2013	*4.7*	*5.6*	*3.7*	*2.2*

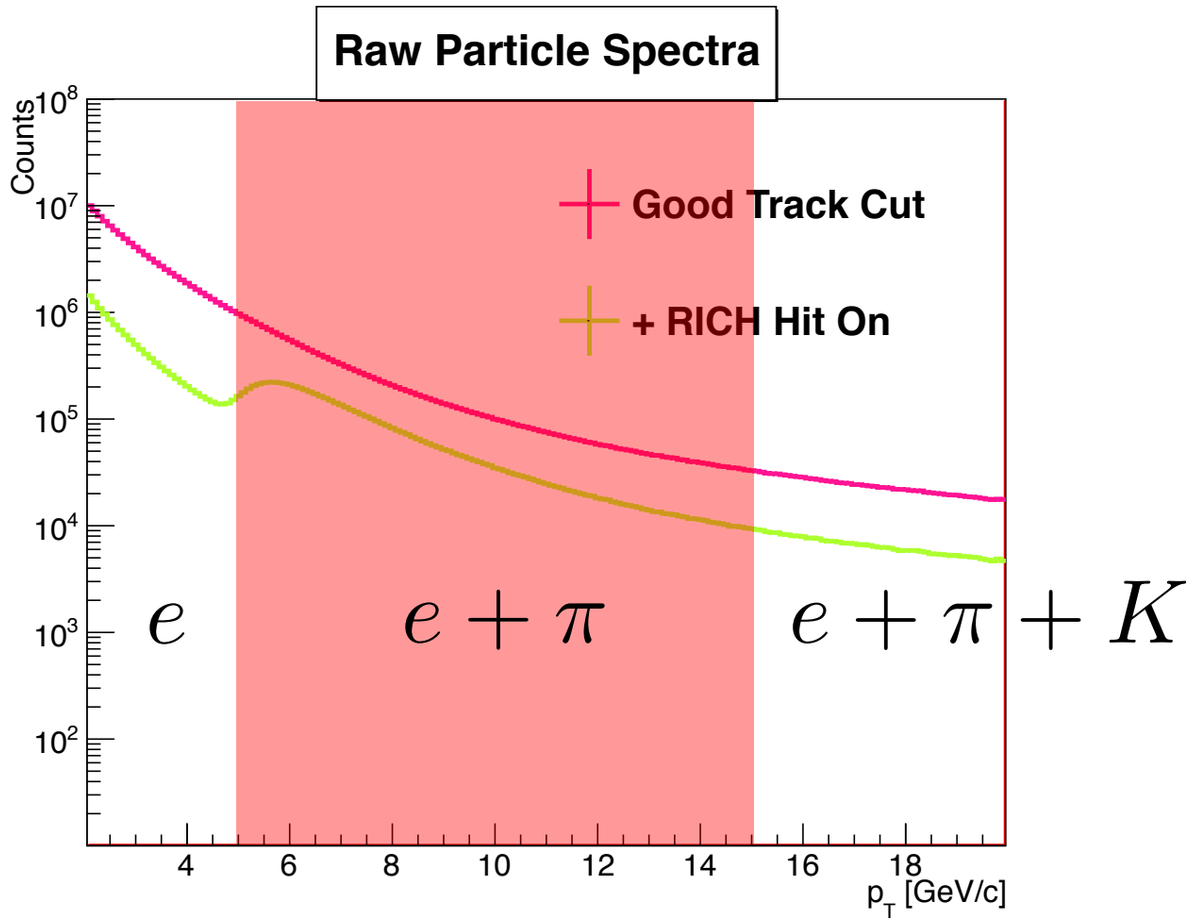
- Due to the lack of hadron trigger in PHENIX, the statistical precision of the $\pi^{\pm}$ data is limited in both Run-9 and Run-13.
- Alternatively, high p_T γ triggers are used for high p_T $\pi^{\pm}$ analysis.

Particle ($\pi^{\pm}$) ID and background sources

- 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).

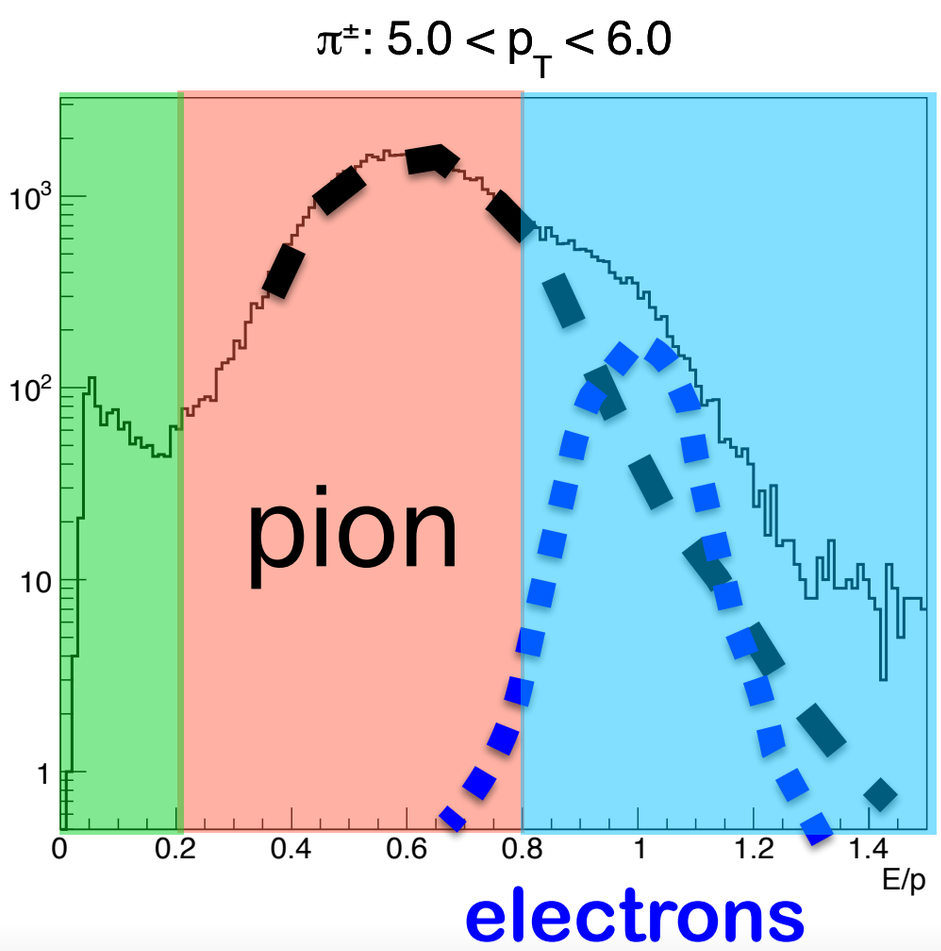
Particle	*Electron*	*Pion*	Kaon	*Proton*
Threshold	*30MeV/c*	*4.7GeV/c*	*16GeV/c*	*30GeV/c*

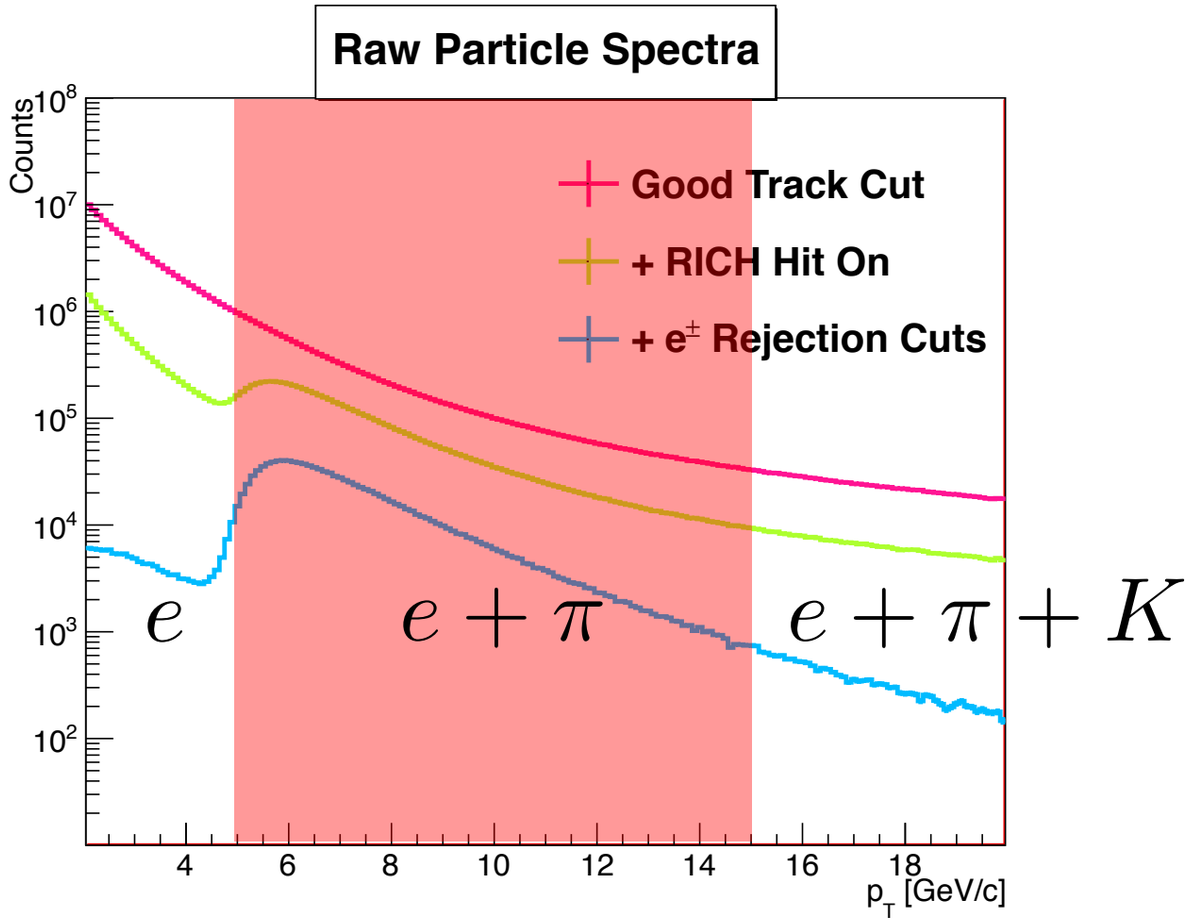




Particle ($\pi^{\pm}$) ID and background sources

- **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.**

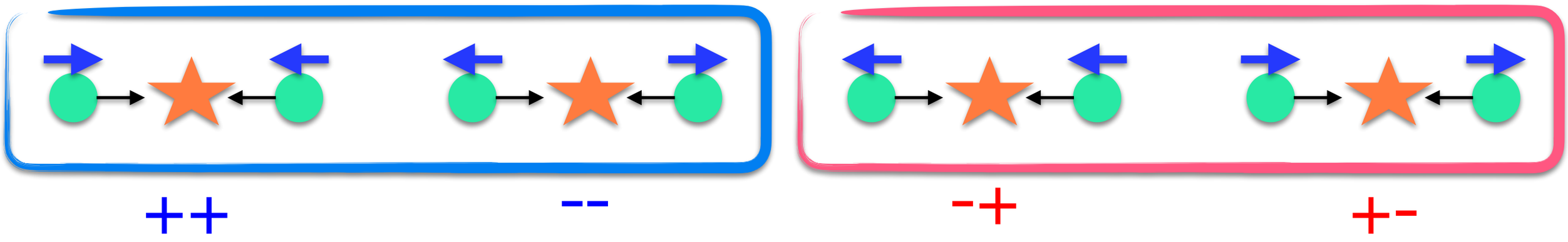




Measuring A_{LL} in experiment

Same: ++

Opposite: +-



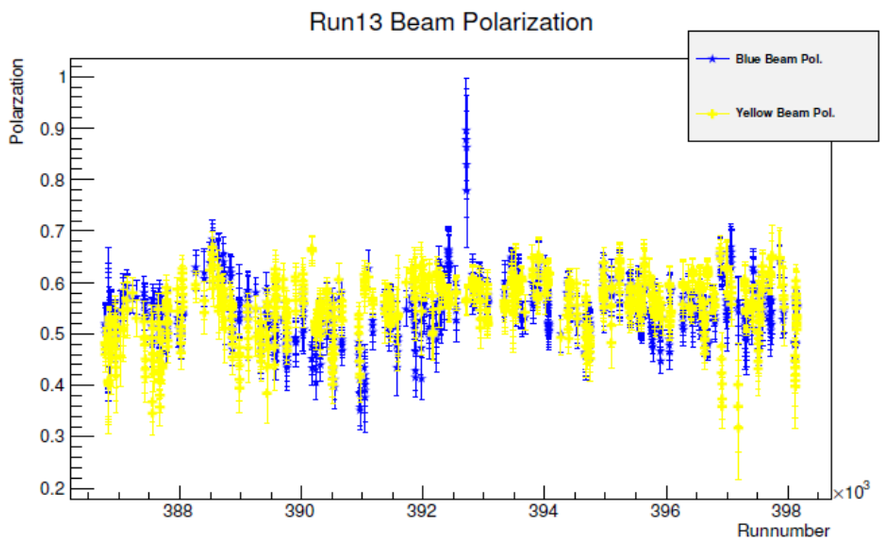
momentum

spin

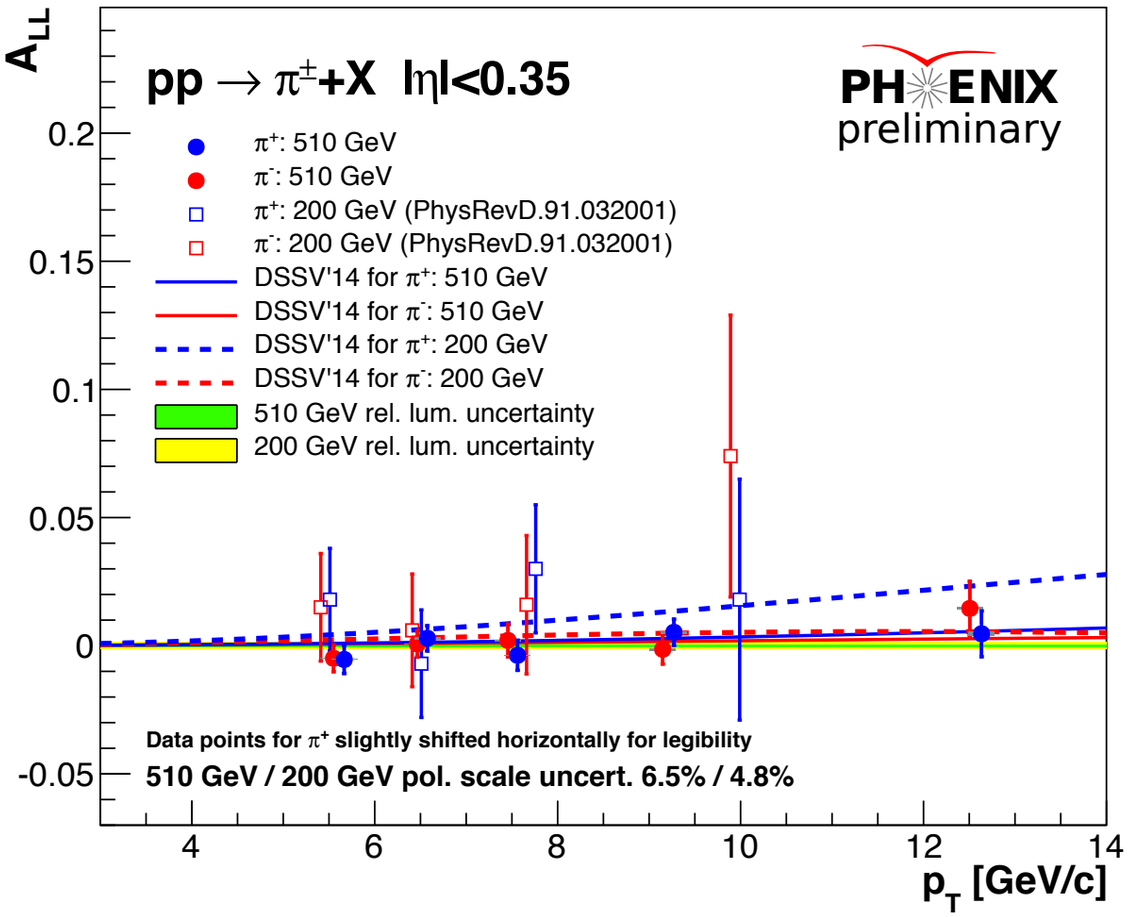
$$A_{LL}^{\pi} = \frac{d\Delta\sigma}{d\sigma} = \frac{1}{|P_B P_Y|} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

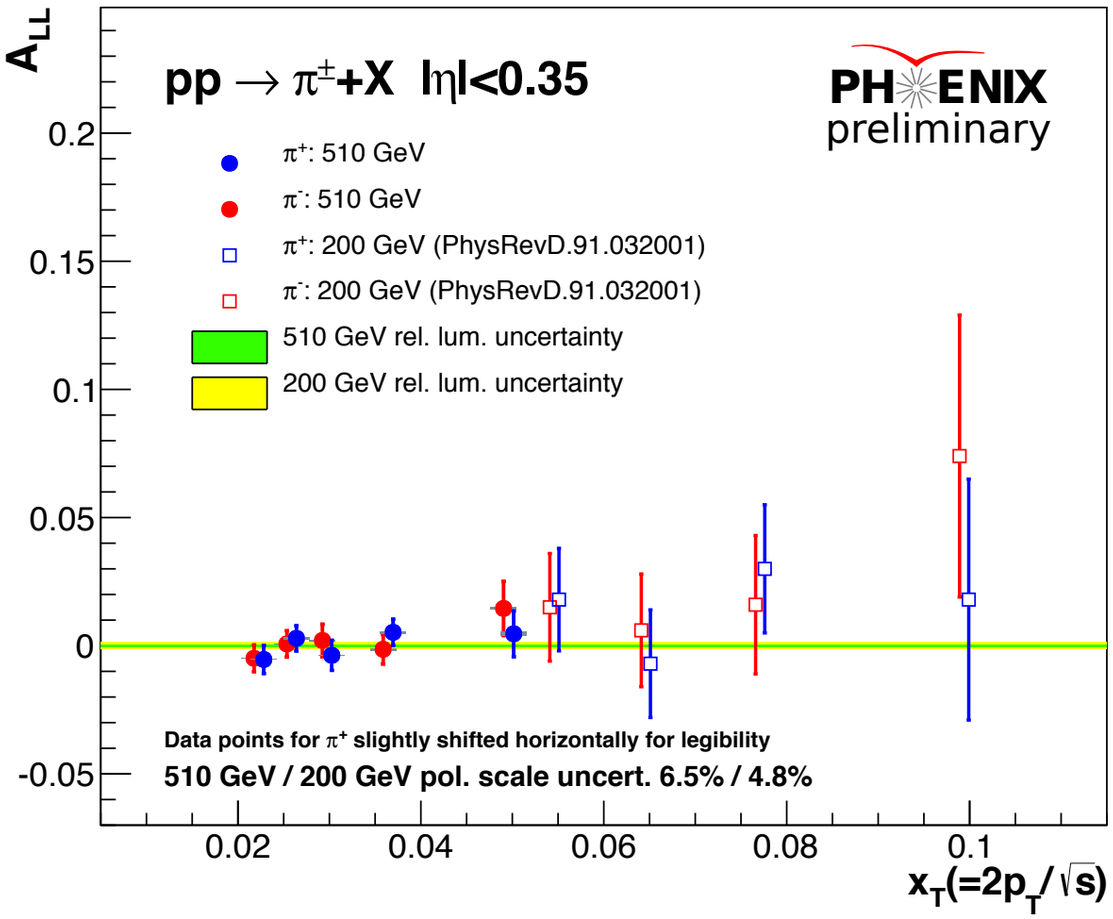
$$R = \frac{L_{++}}{L_{+-}}$$ by luminosity counter

$N_{++(+-)}$ pion yields in same (opposite) helicity



A_{LL} in $\pi^{\pm}$ production at 510 GeV and 200 GeV

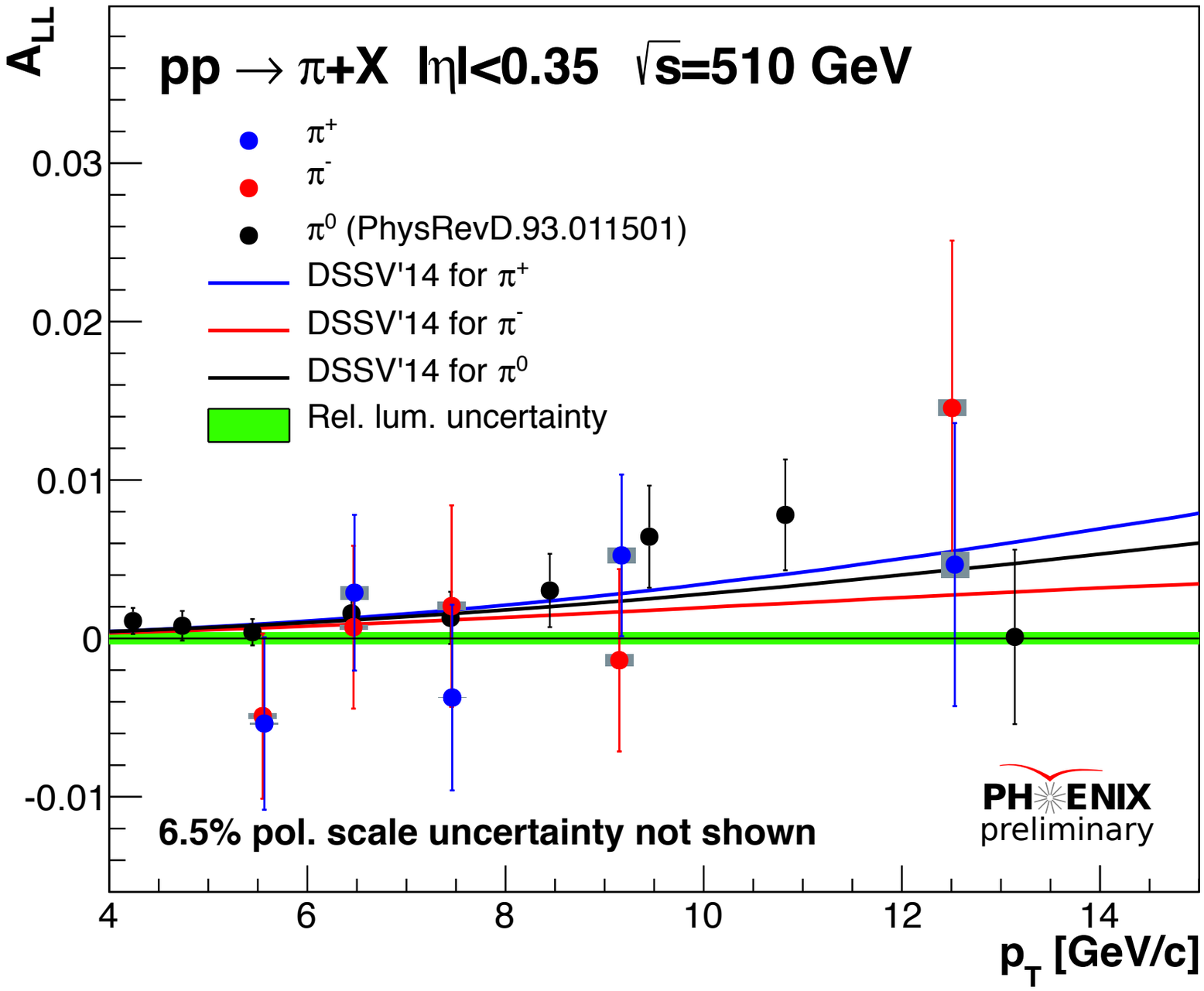




Improvement of statistical precision of $\pi^{\pm}$ A_{LL} in Run-13.

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.

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!

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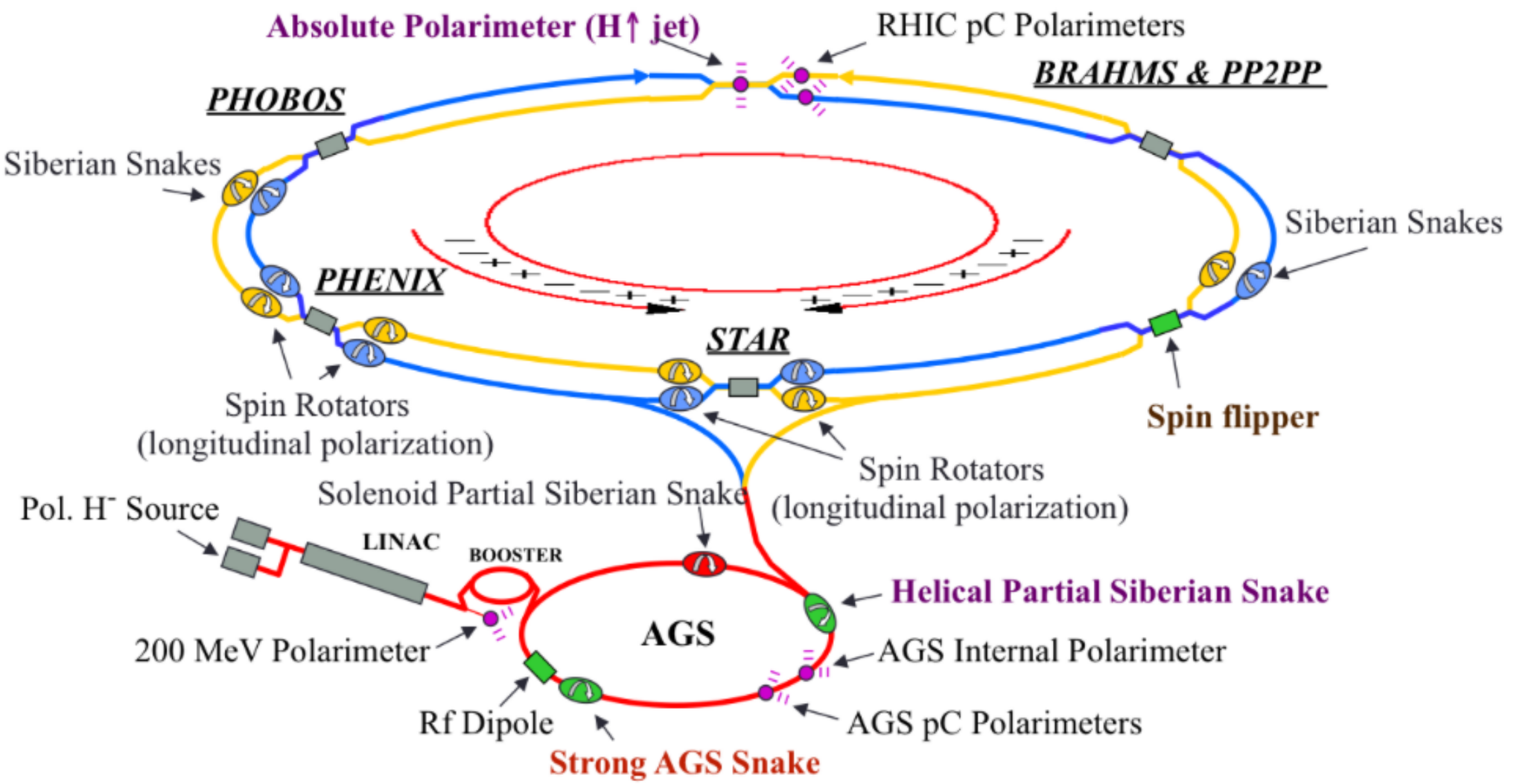
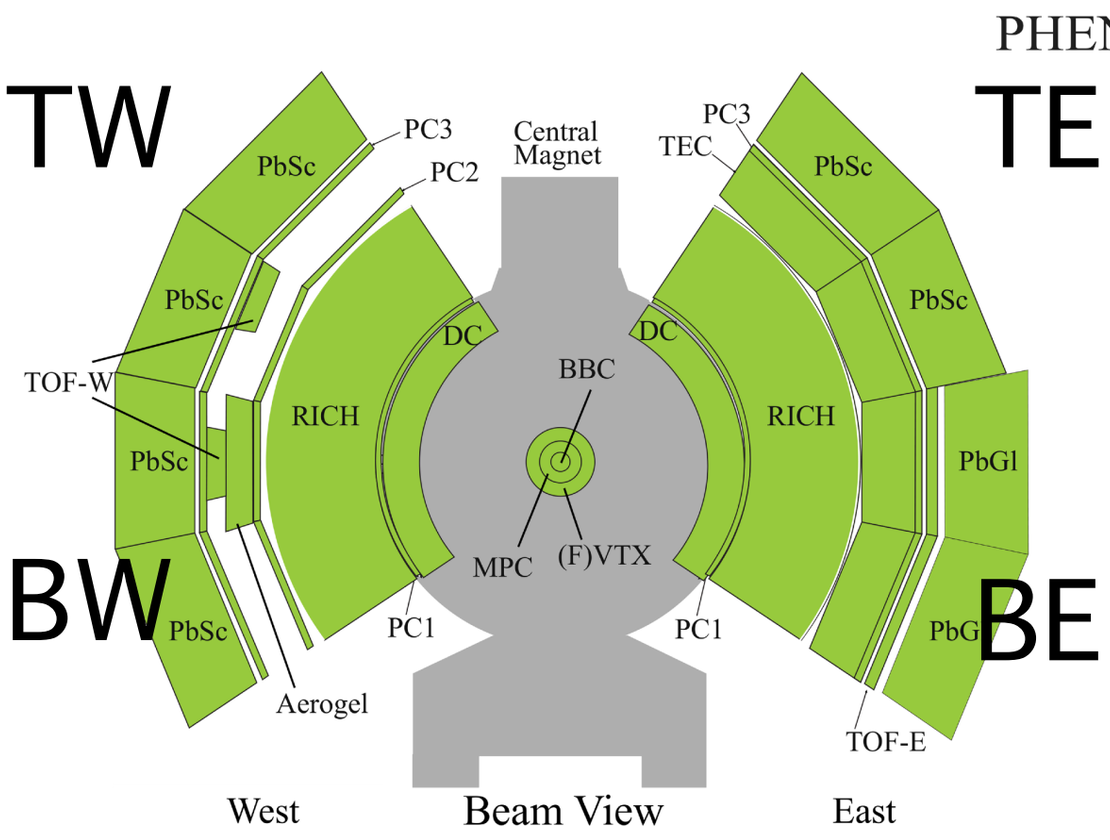
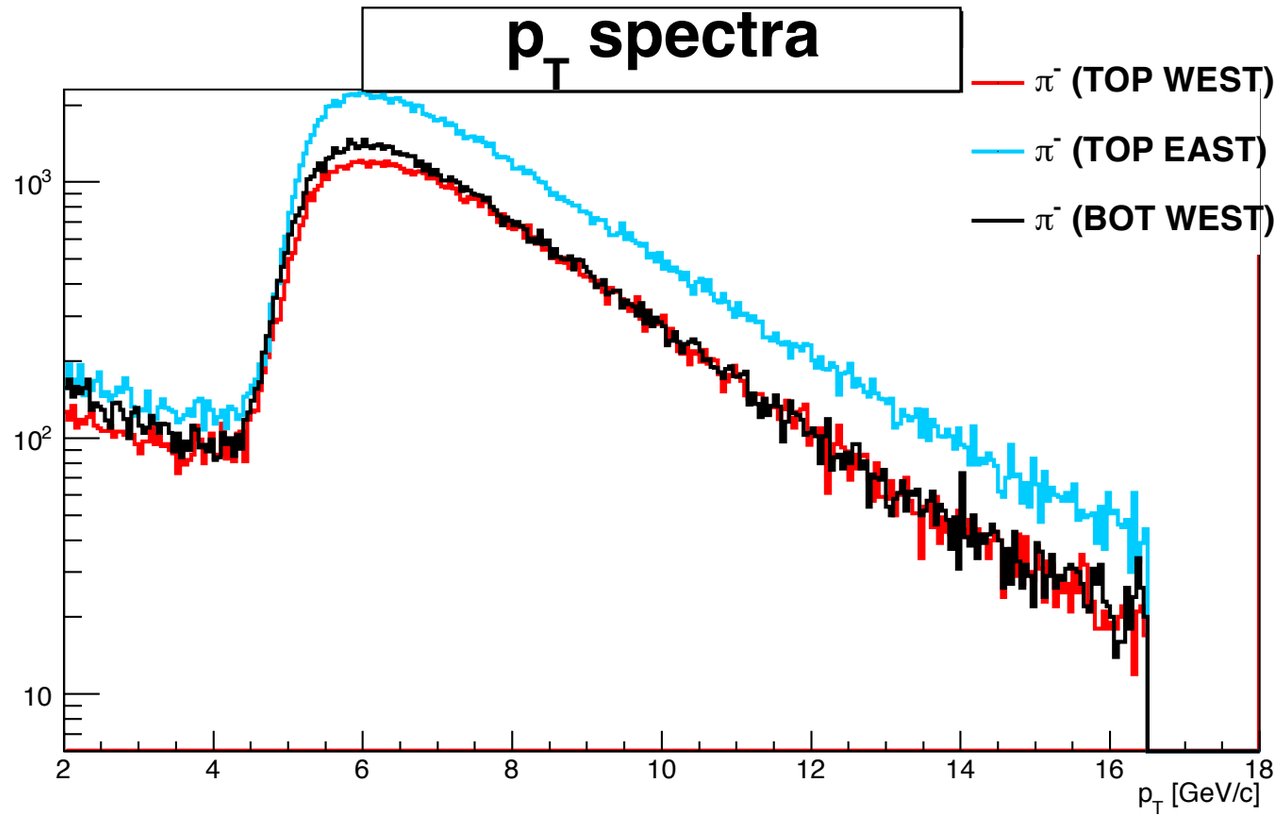
RHIC



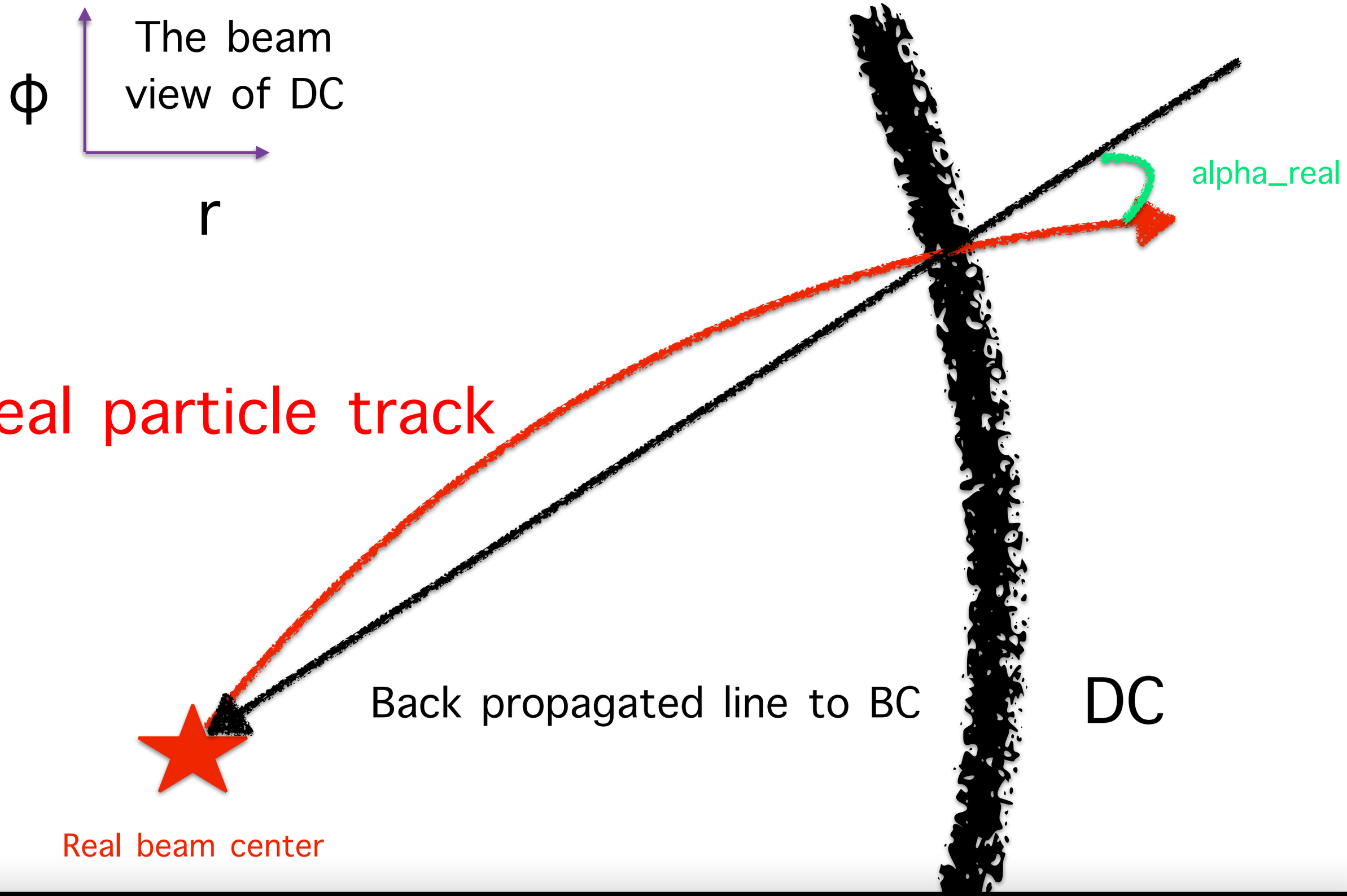
- The world's only polarized p+p collider
  - Longitudinal or transverse polarization
  - Up to $\sqrt{s}$ = 510 GeV

Momentum Issue





Example: with correct beam offset



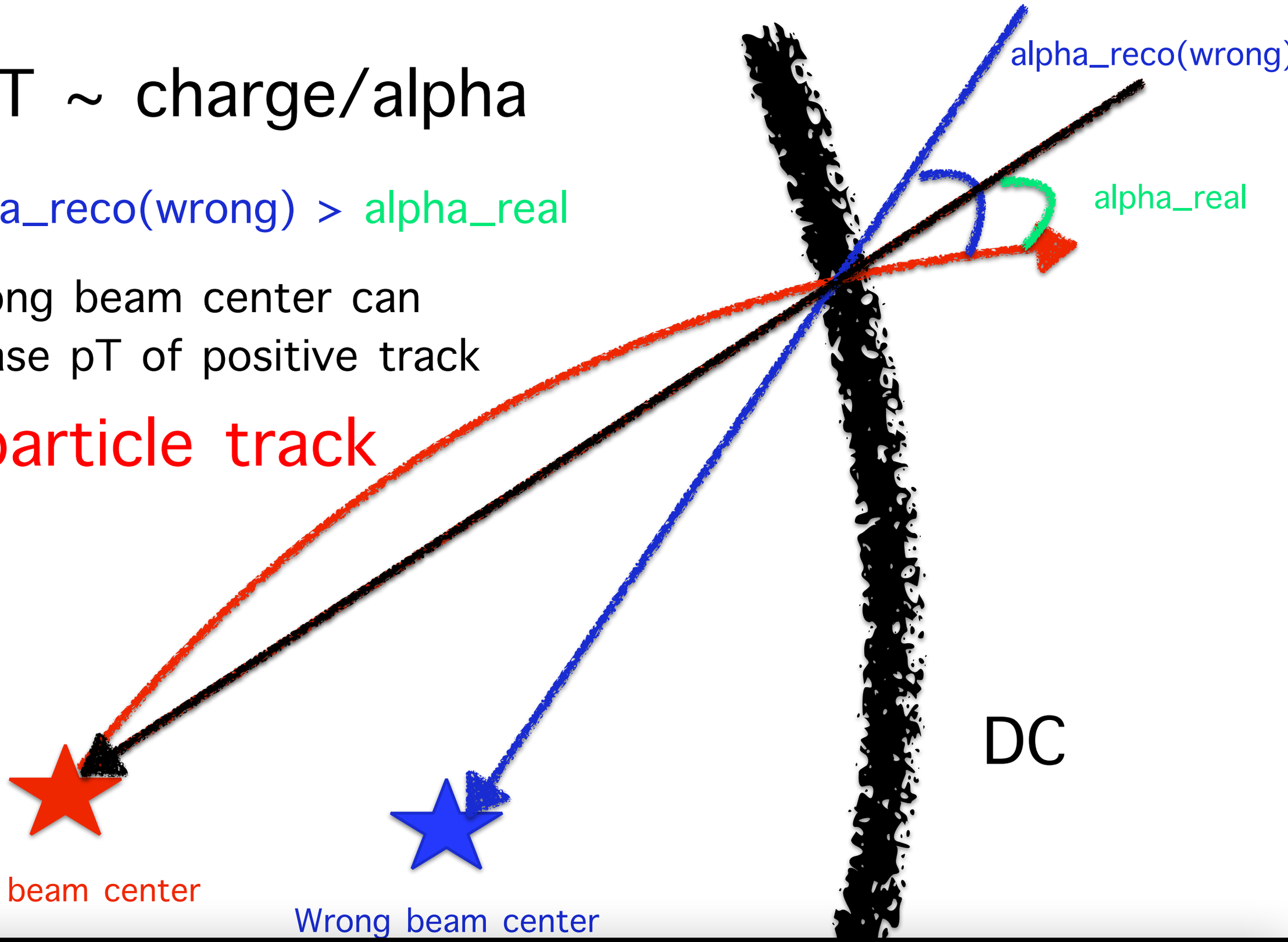
Example: with wrong beam offset

pT ~ charge/alpha

alpha_reco(wrong) > alpha_real

wrong beam center can
decrease pT of positive track

Real particle track



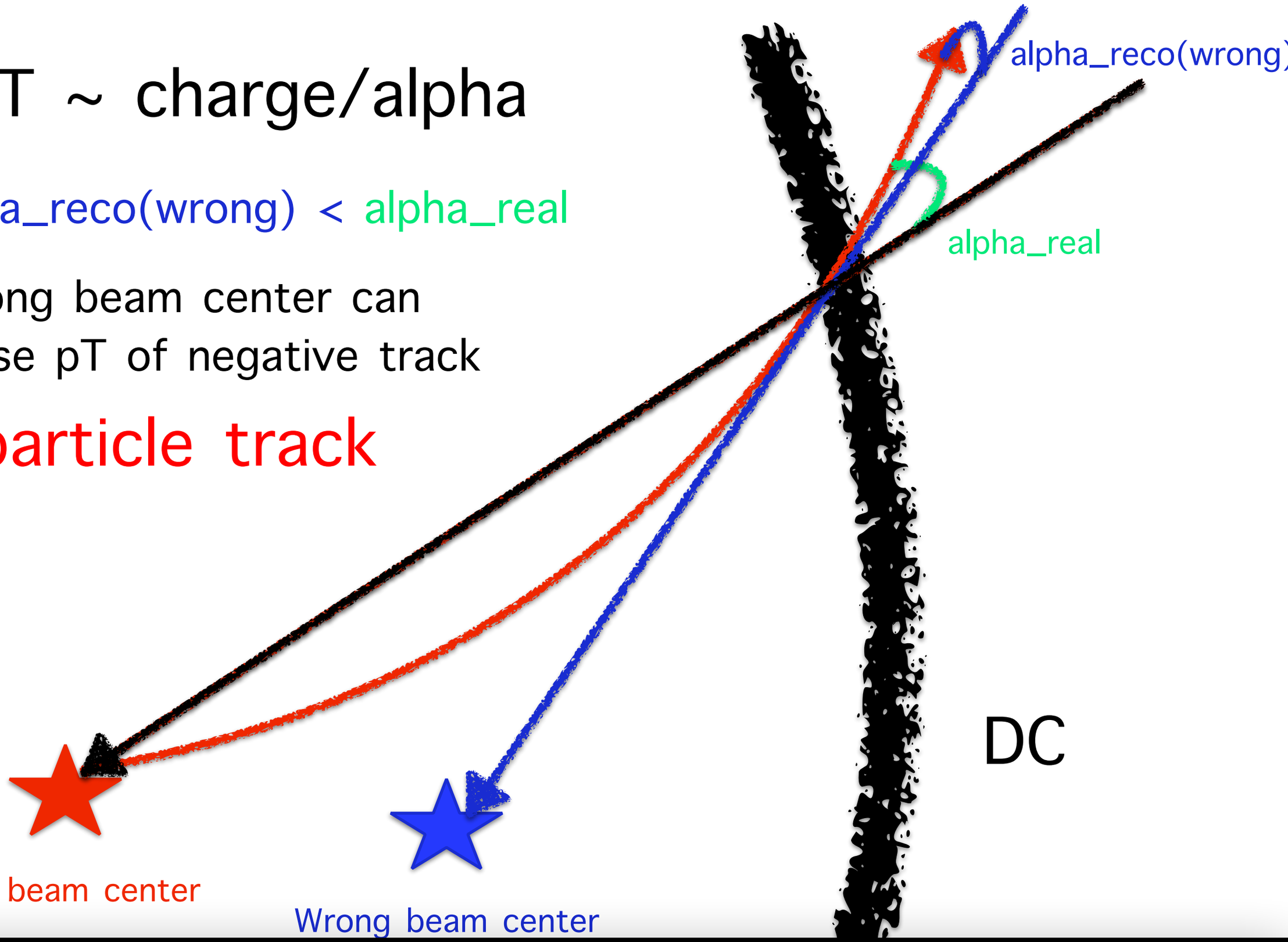
Example: with wrong beam offset

pT ~ charge/alpha

alpha_reco(wrong) < alpha_real

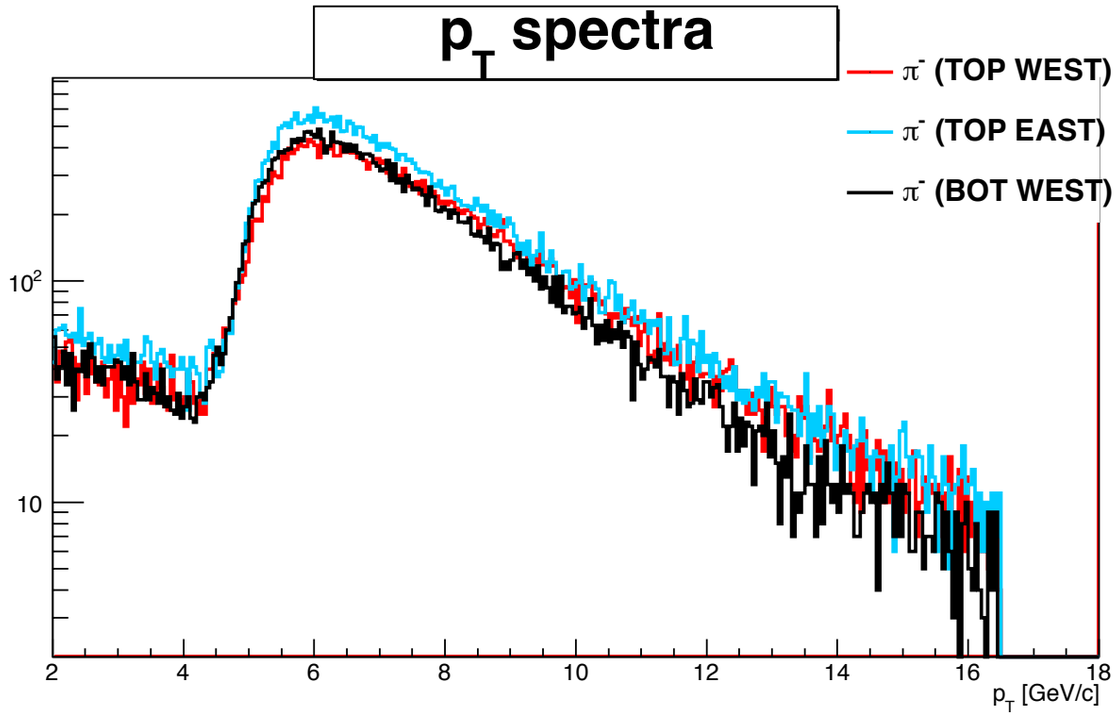
wrong beam center can
increase pT of negative track

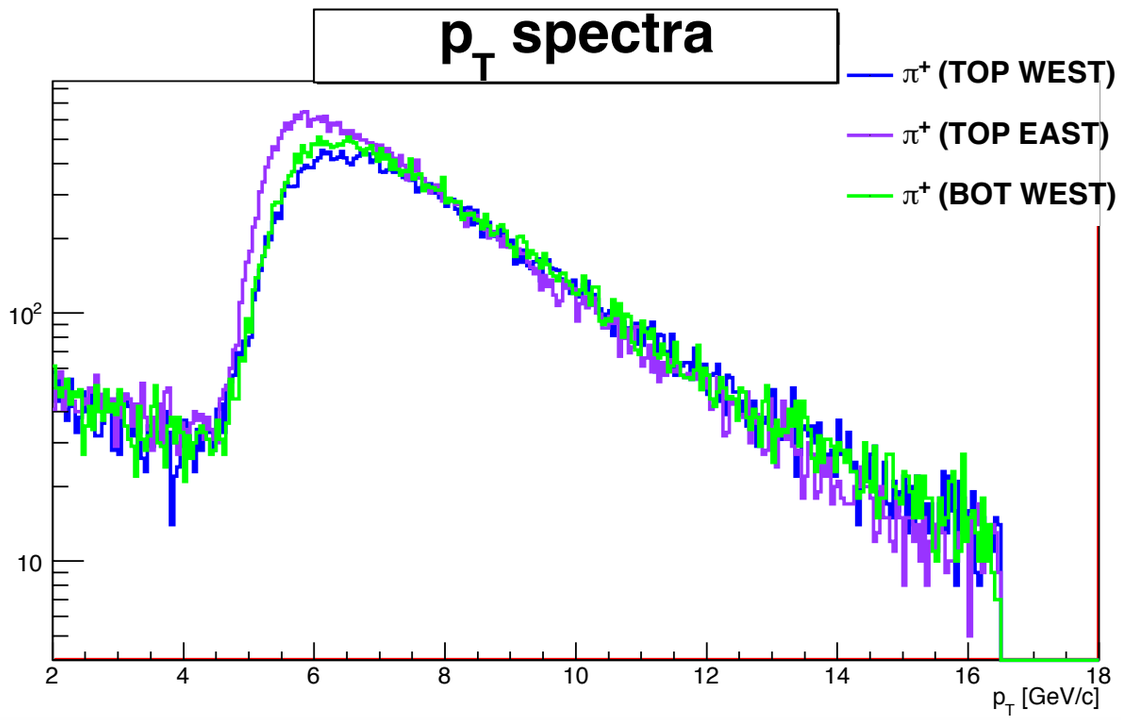
Real particle track



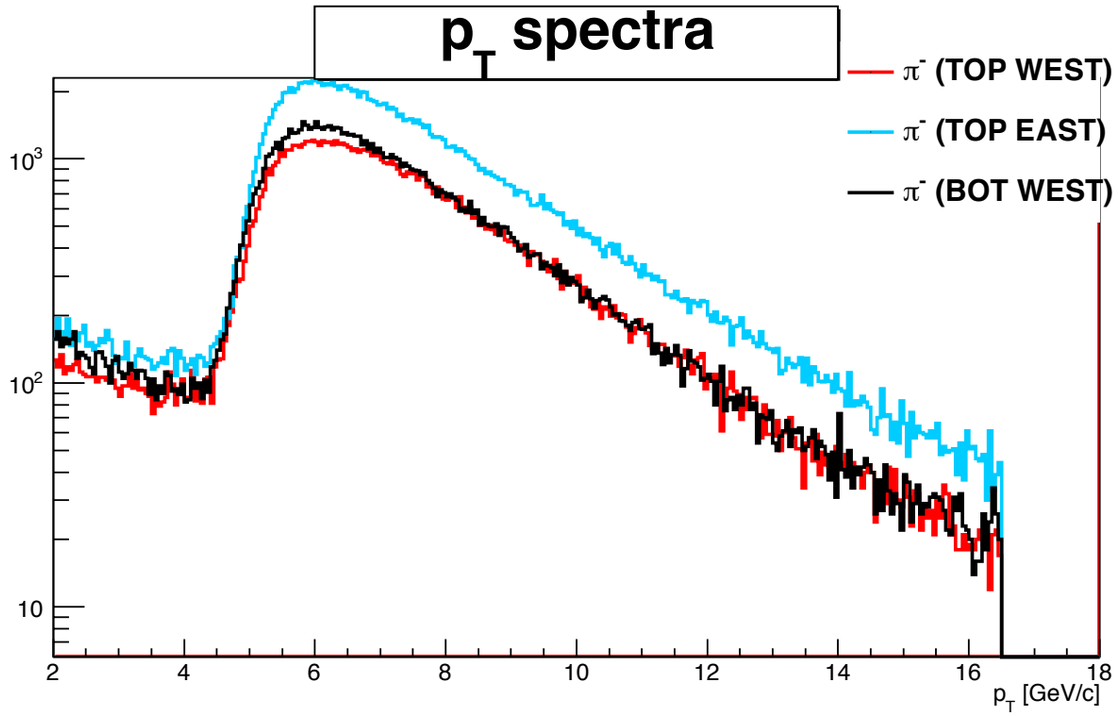
Raw pT Spectra at 510 GeV in 2012 and 2013

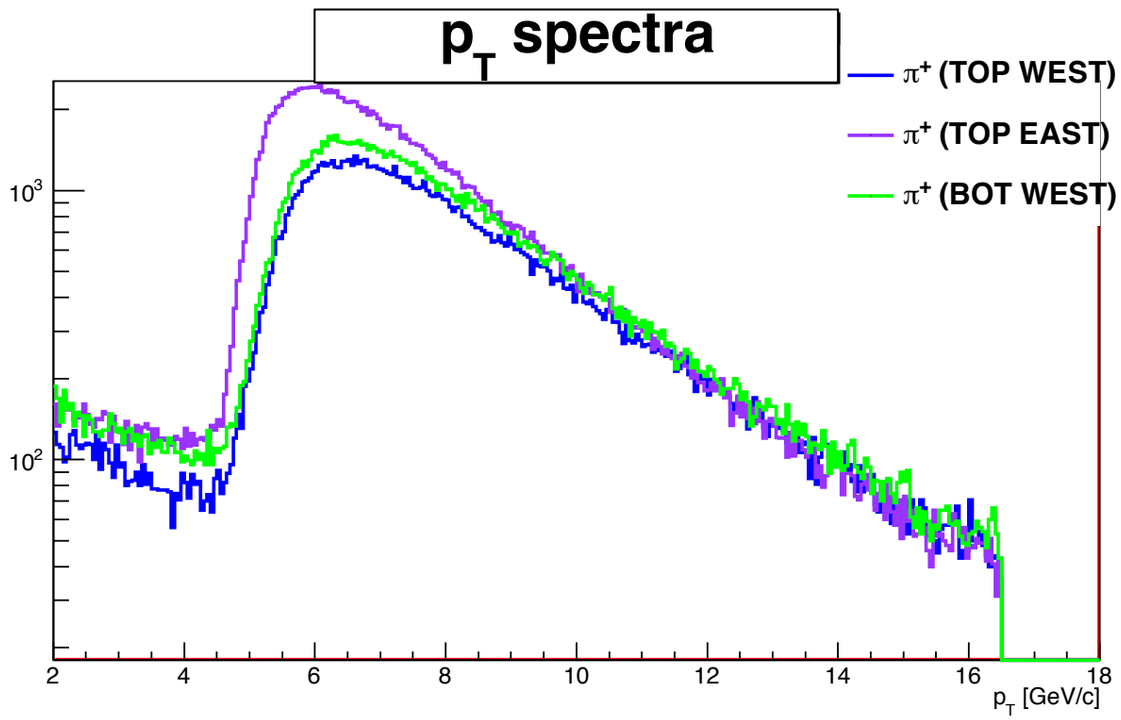
In 2012



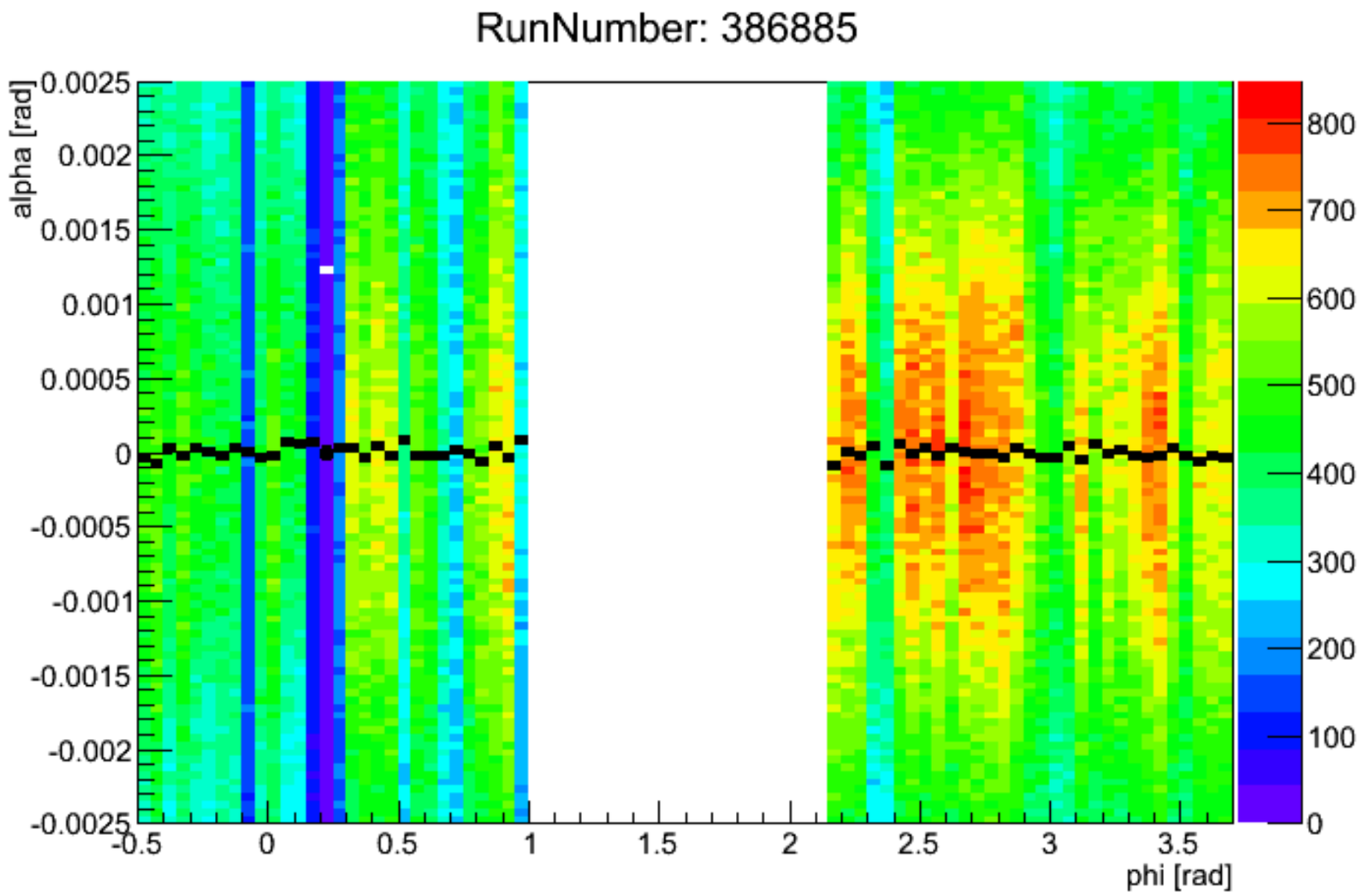


In 2013





Double-check

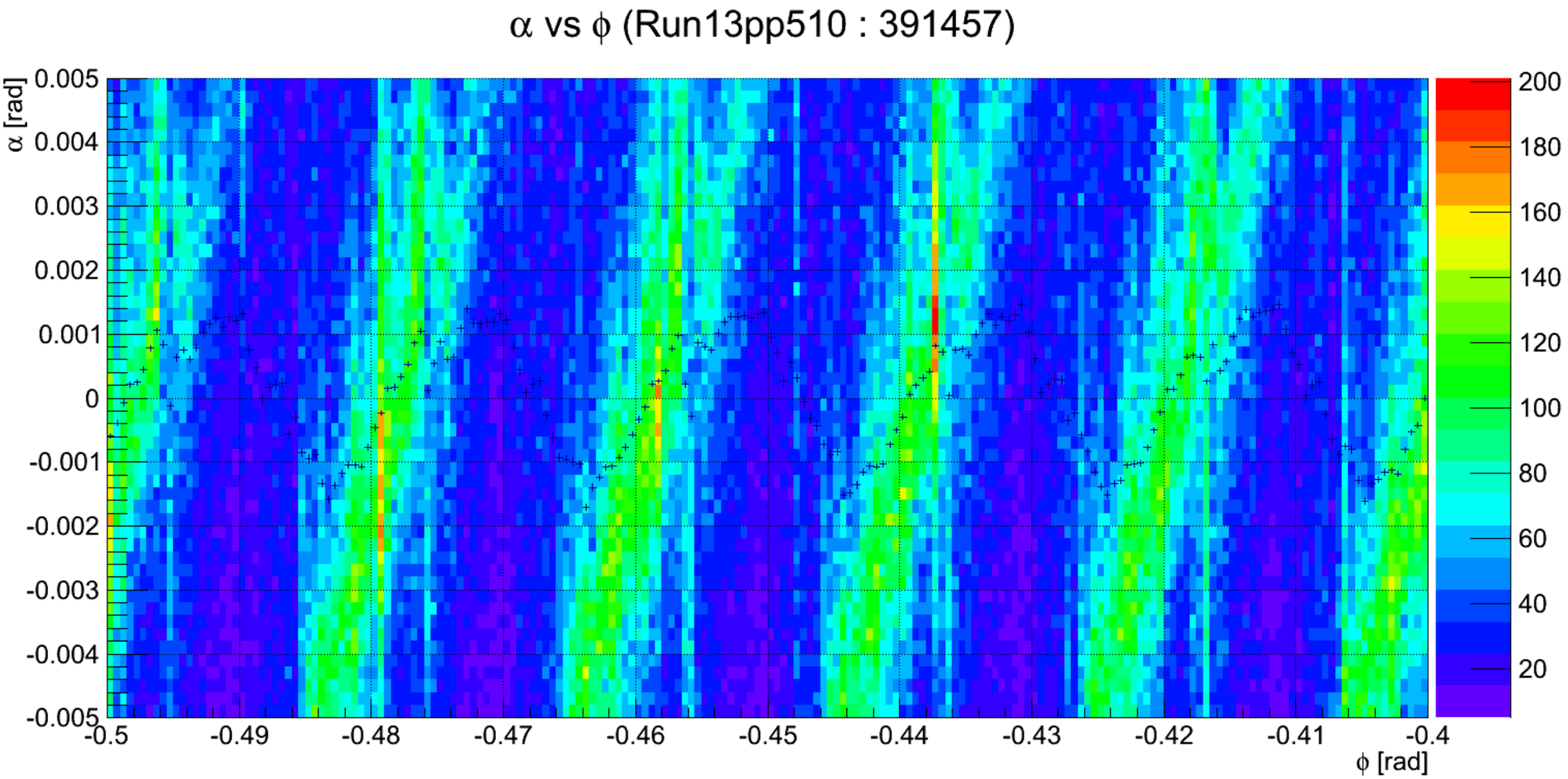


- Double checked alpha vs. phi using the same run in Ana1130.
- Alpha is almost 0. That means the beam offset calibration is acceptable.
- I looked at alpha vs. phi closely.

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



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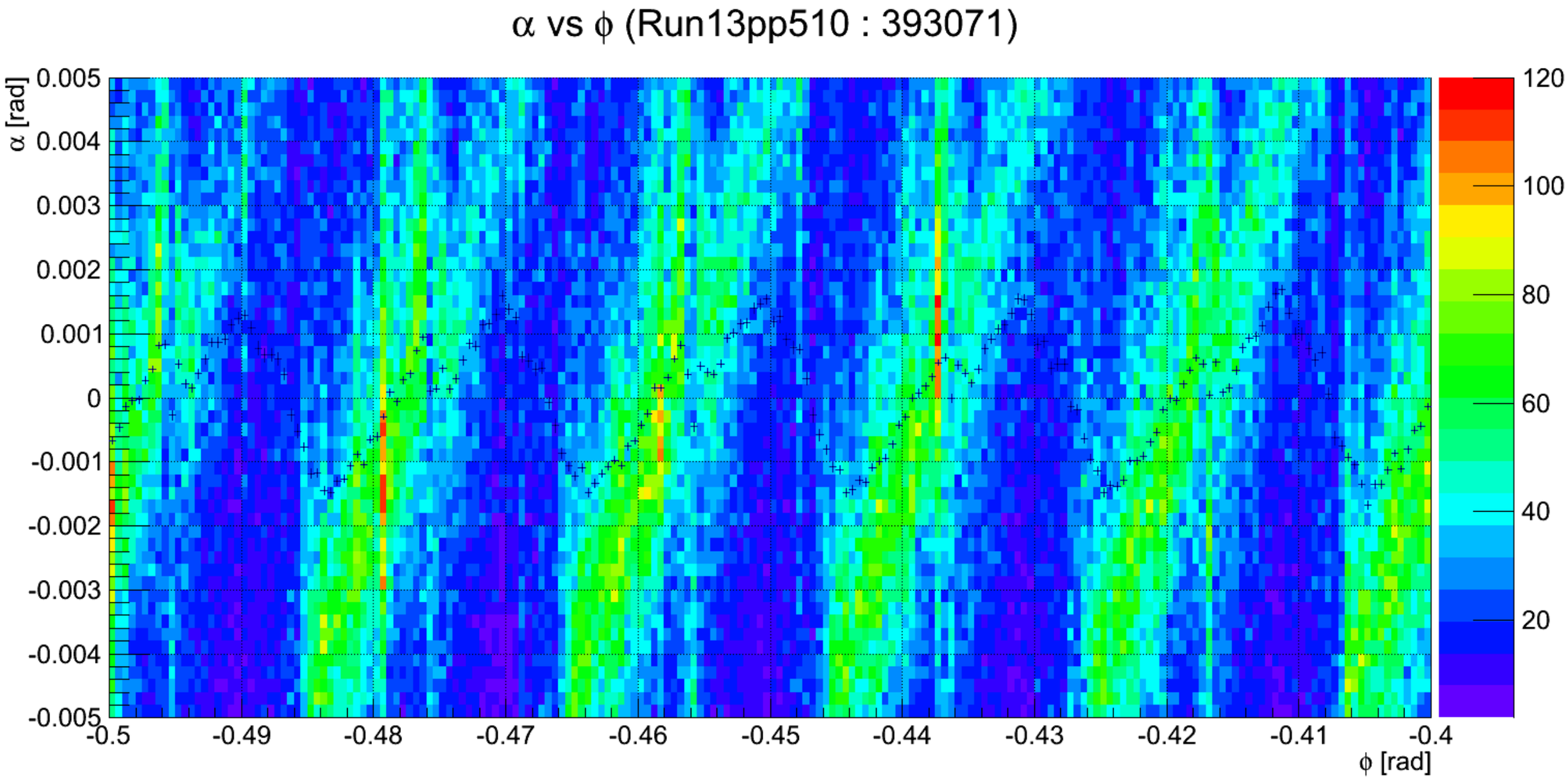
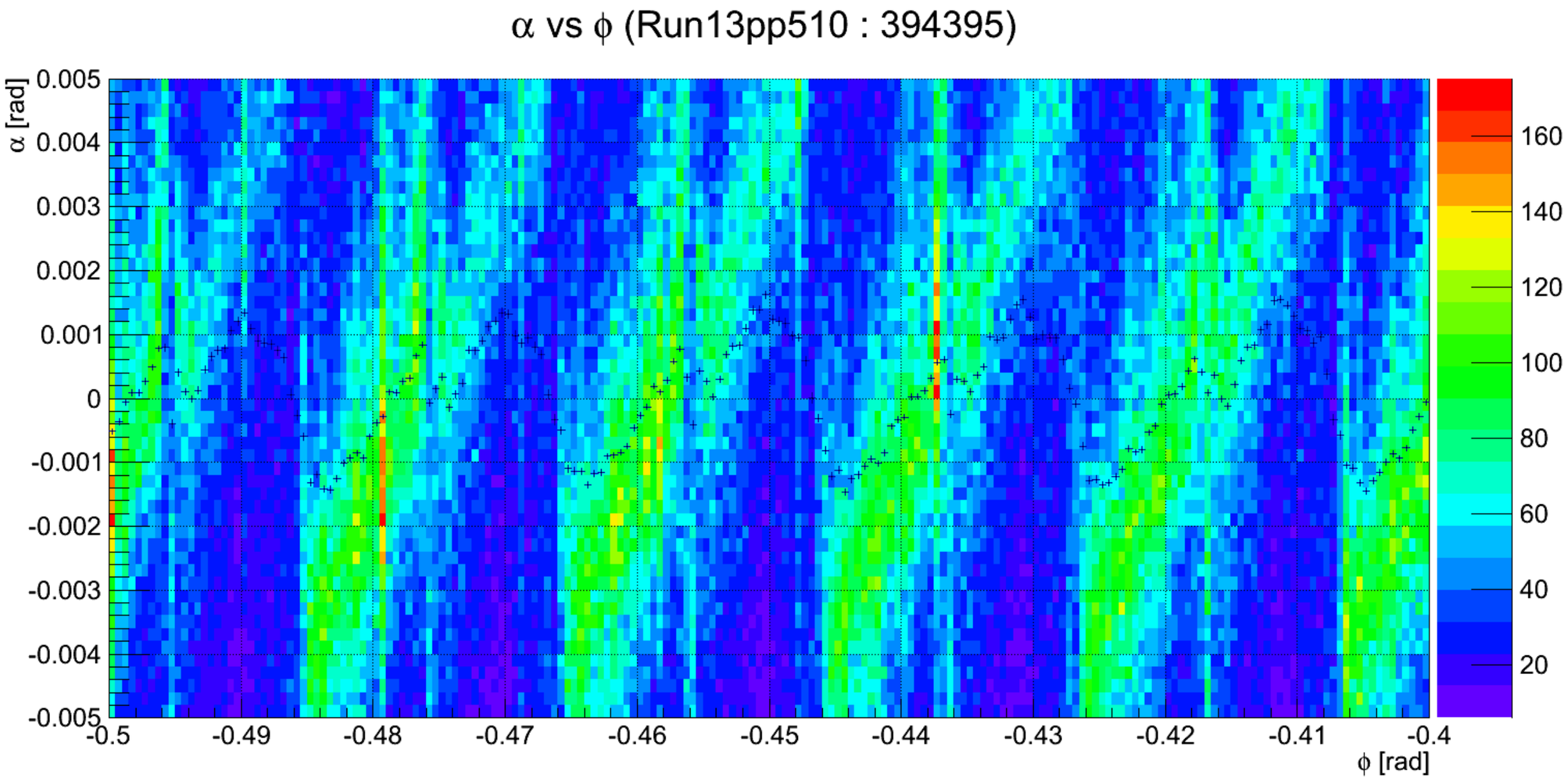
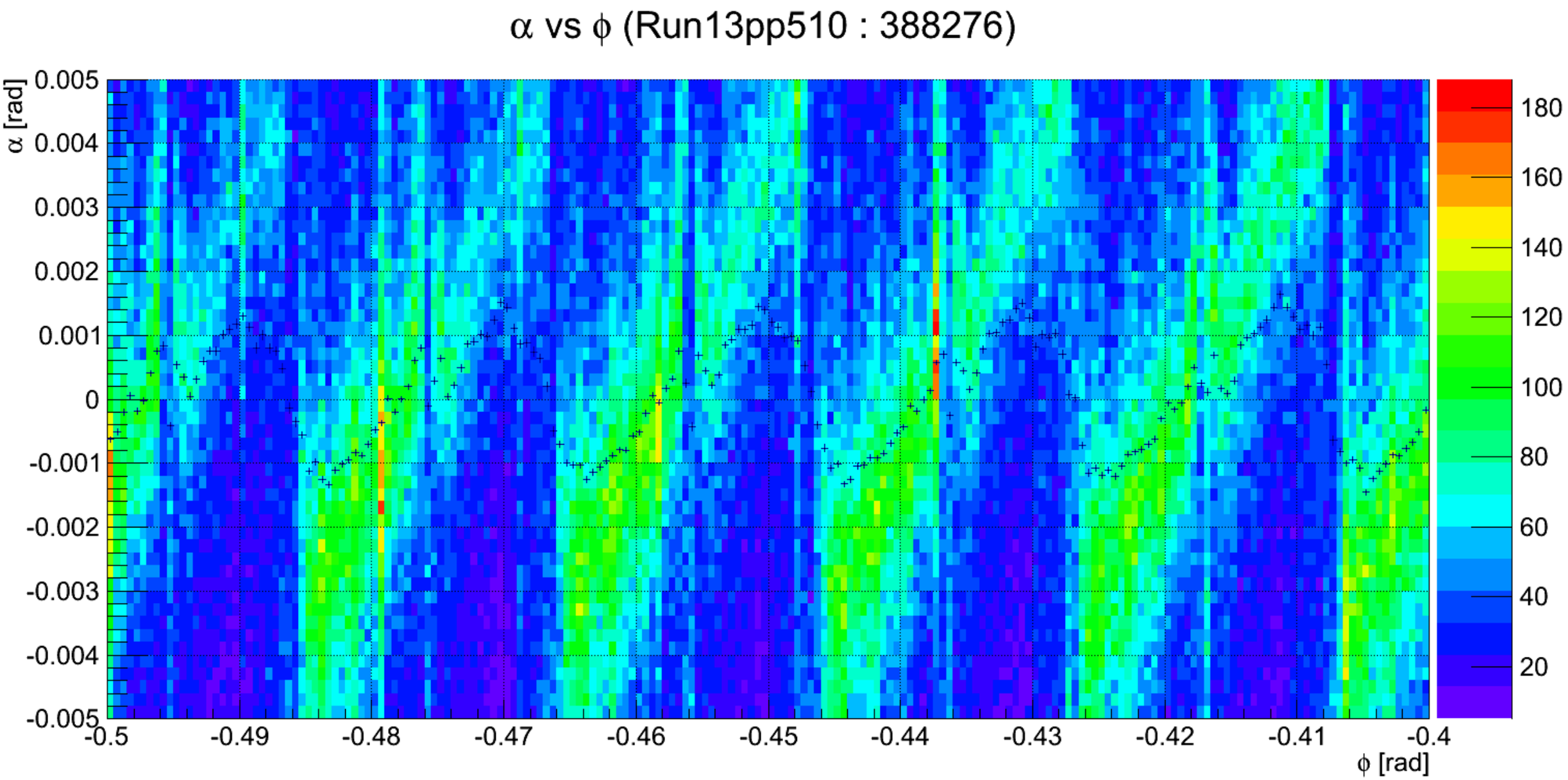


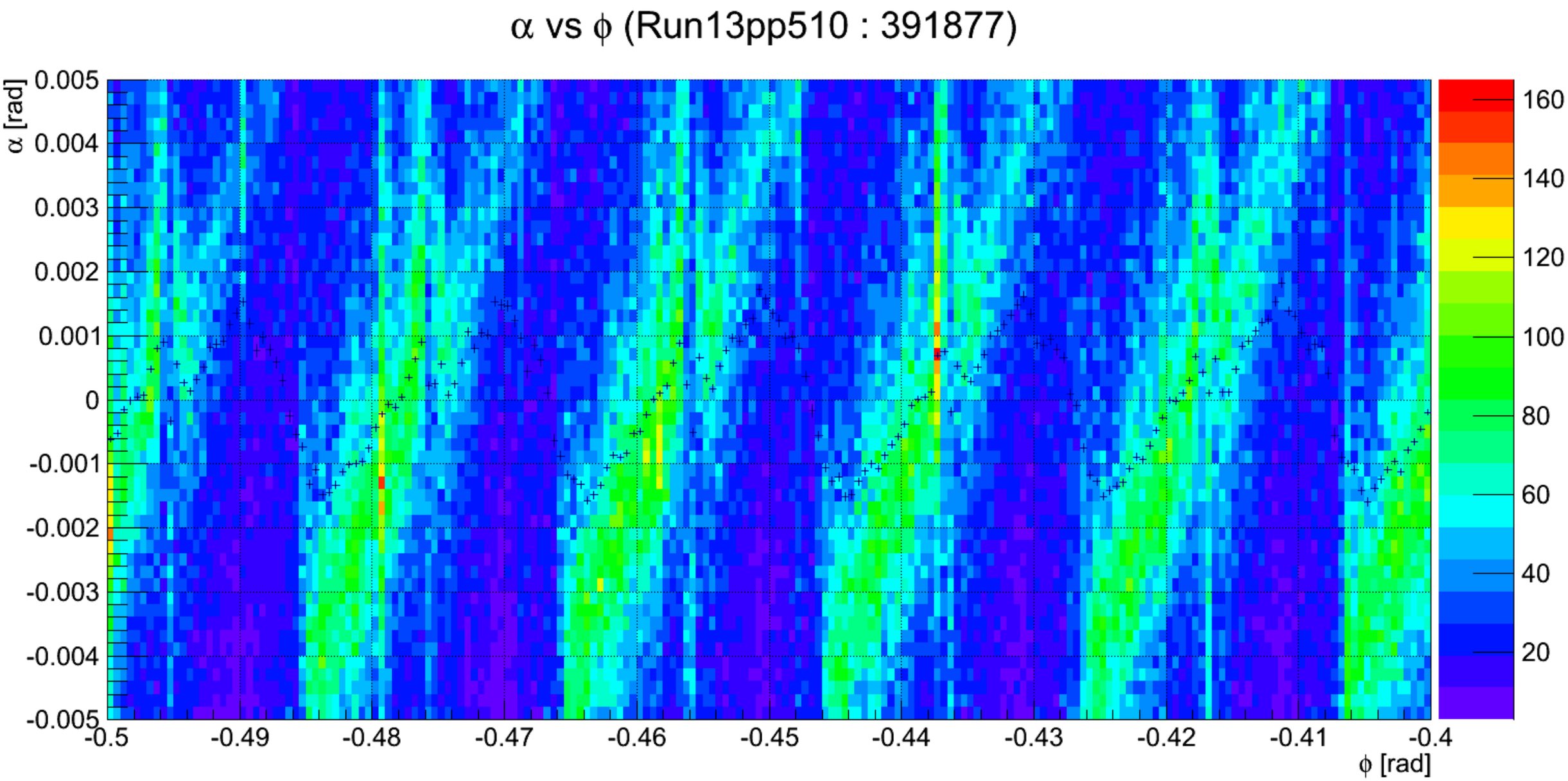
Raw Trigger Rate: 2185816.43



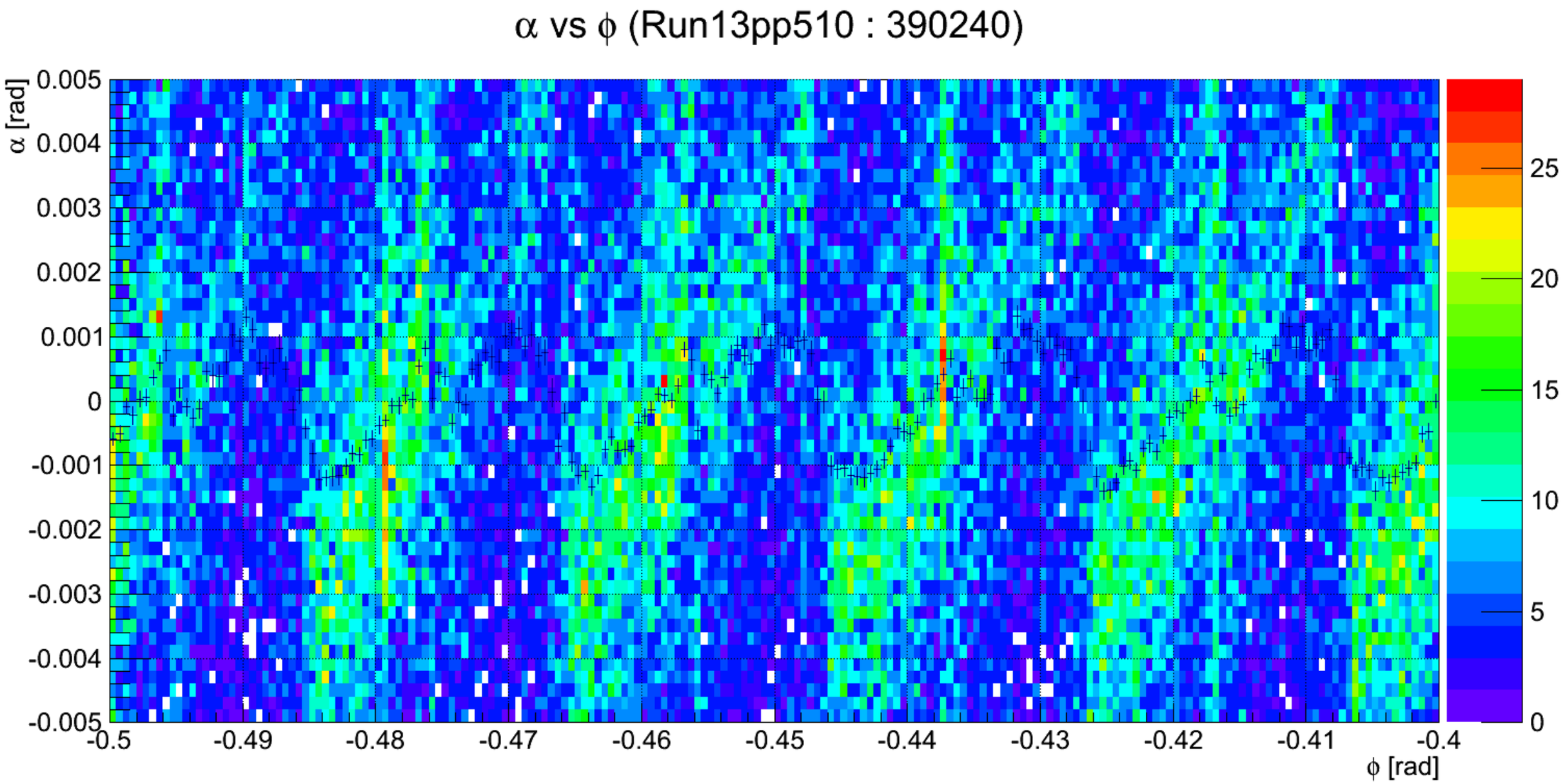
Raw Trigger Rate: 2148649.85



Raw Trigger Rate: 1900192.05



Raw Trigger Rate: 1795081.98



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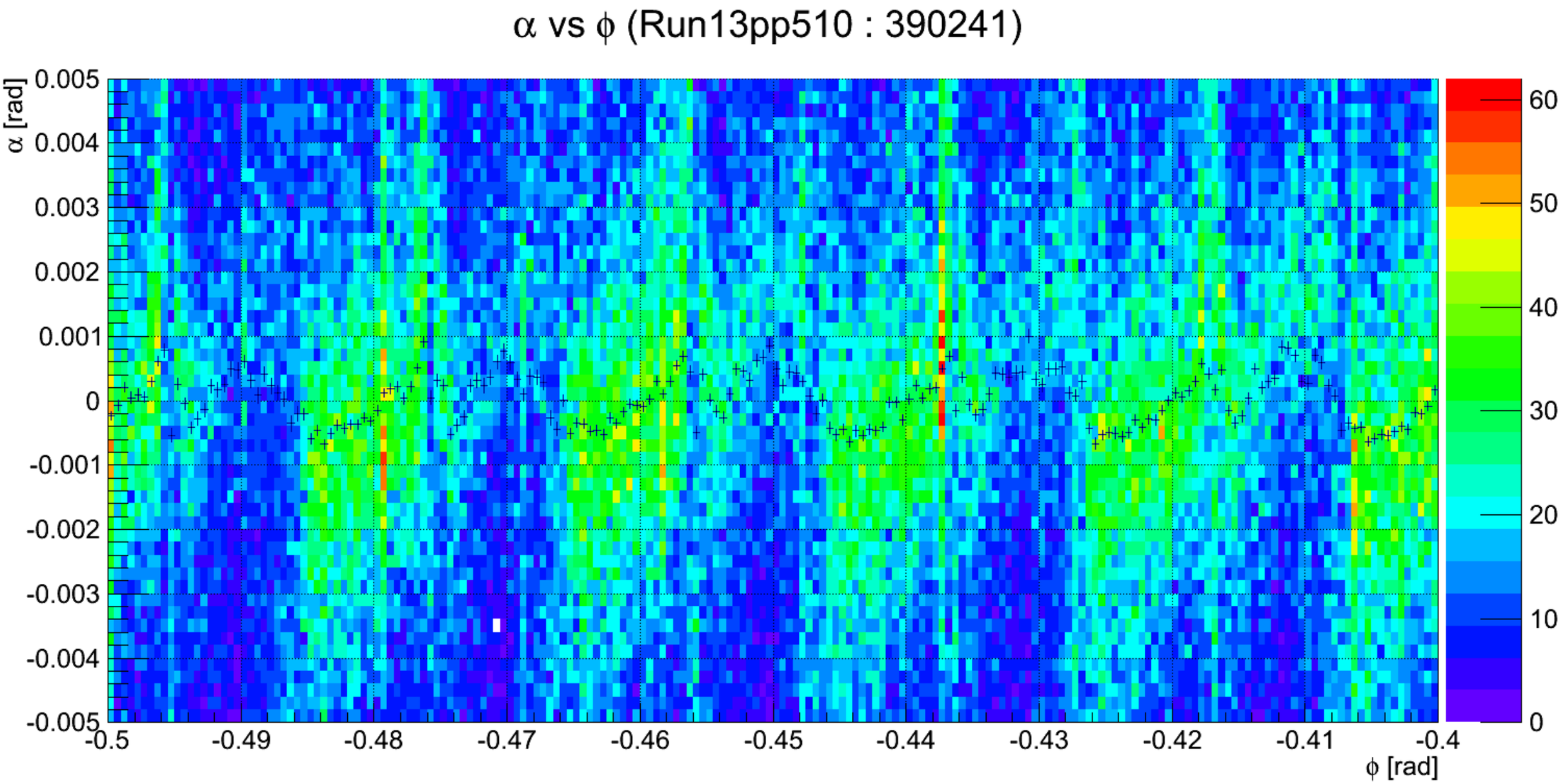

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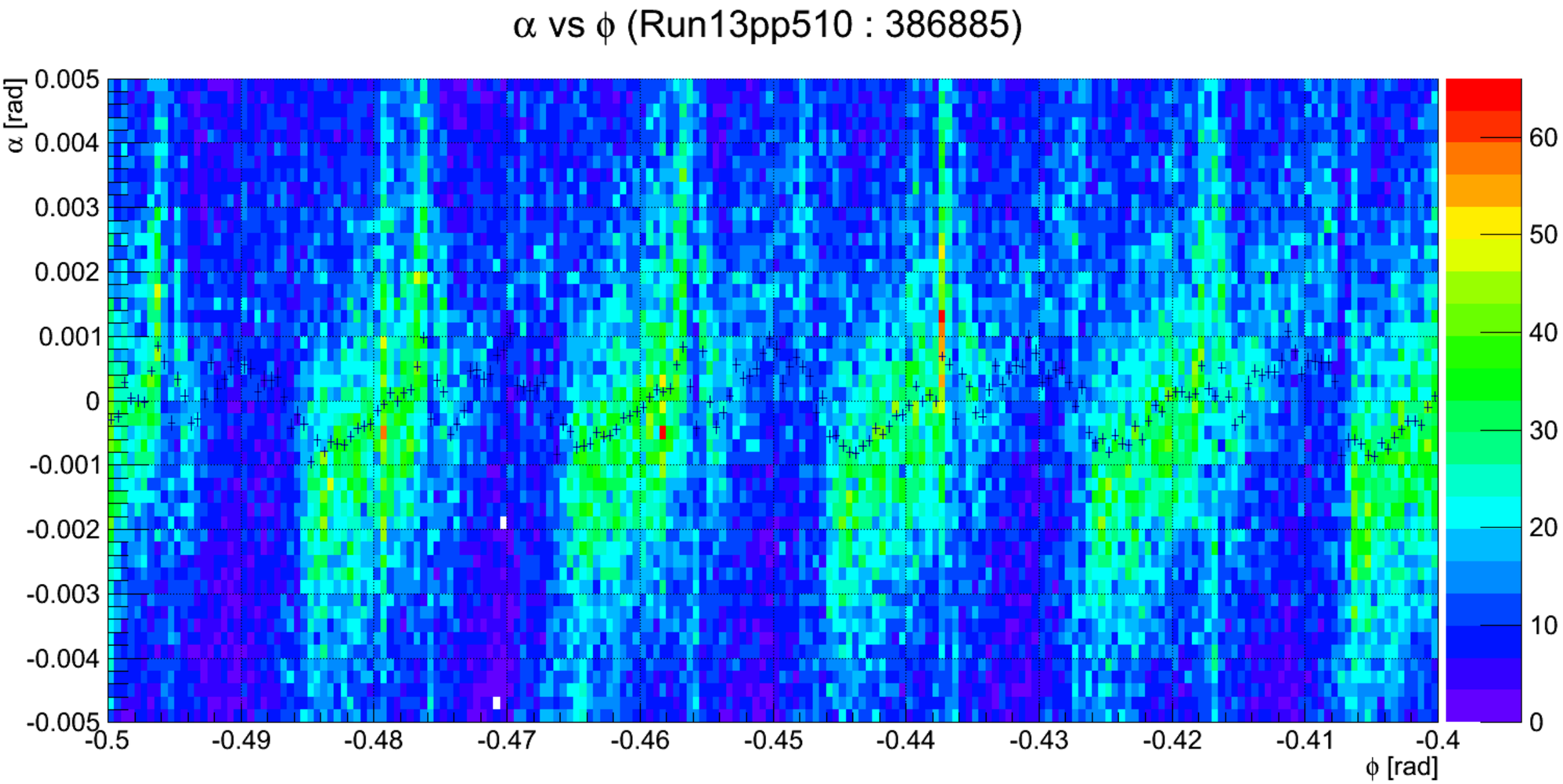

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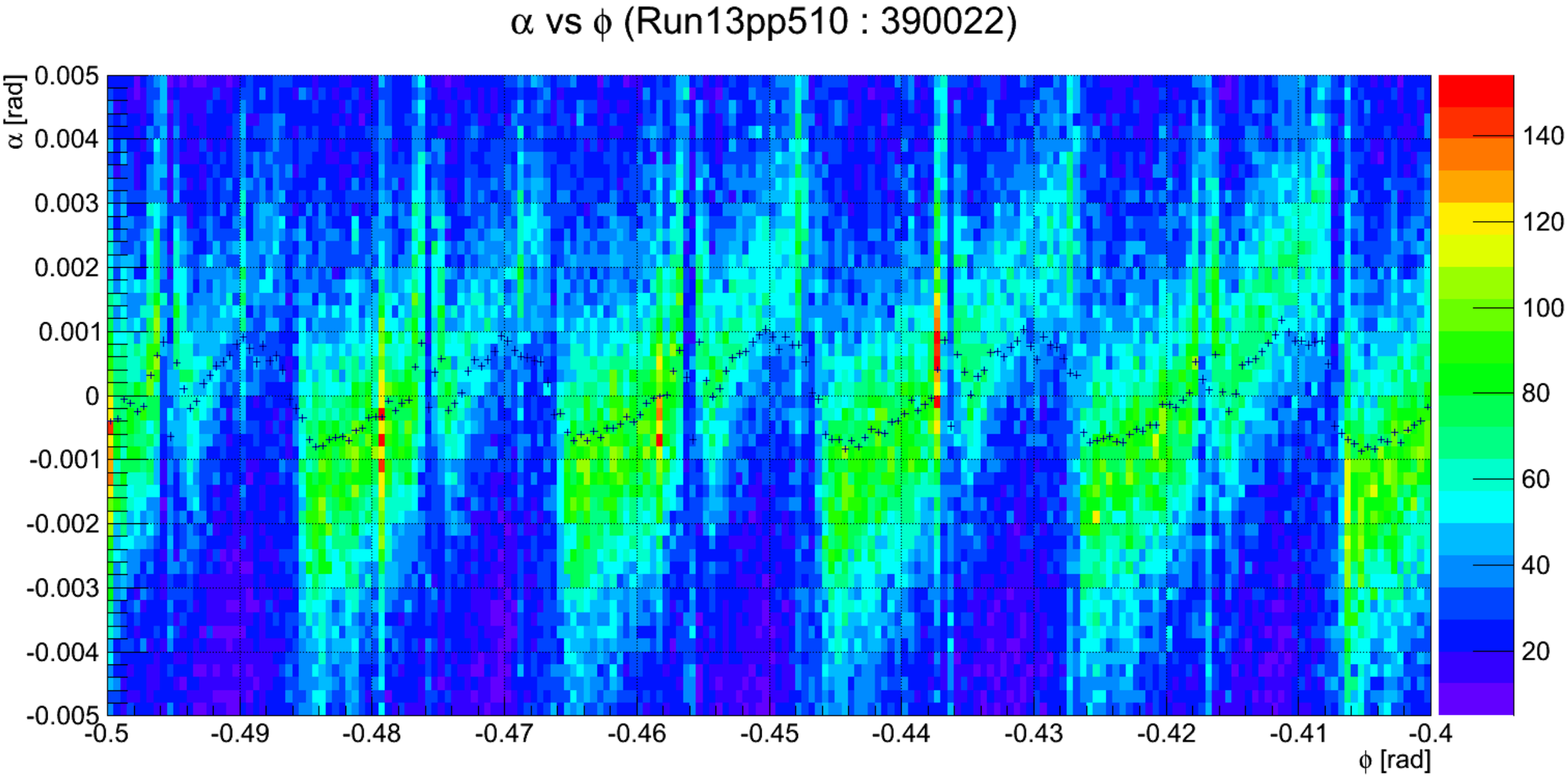
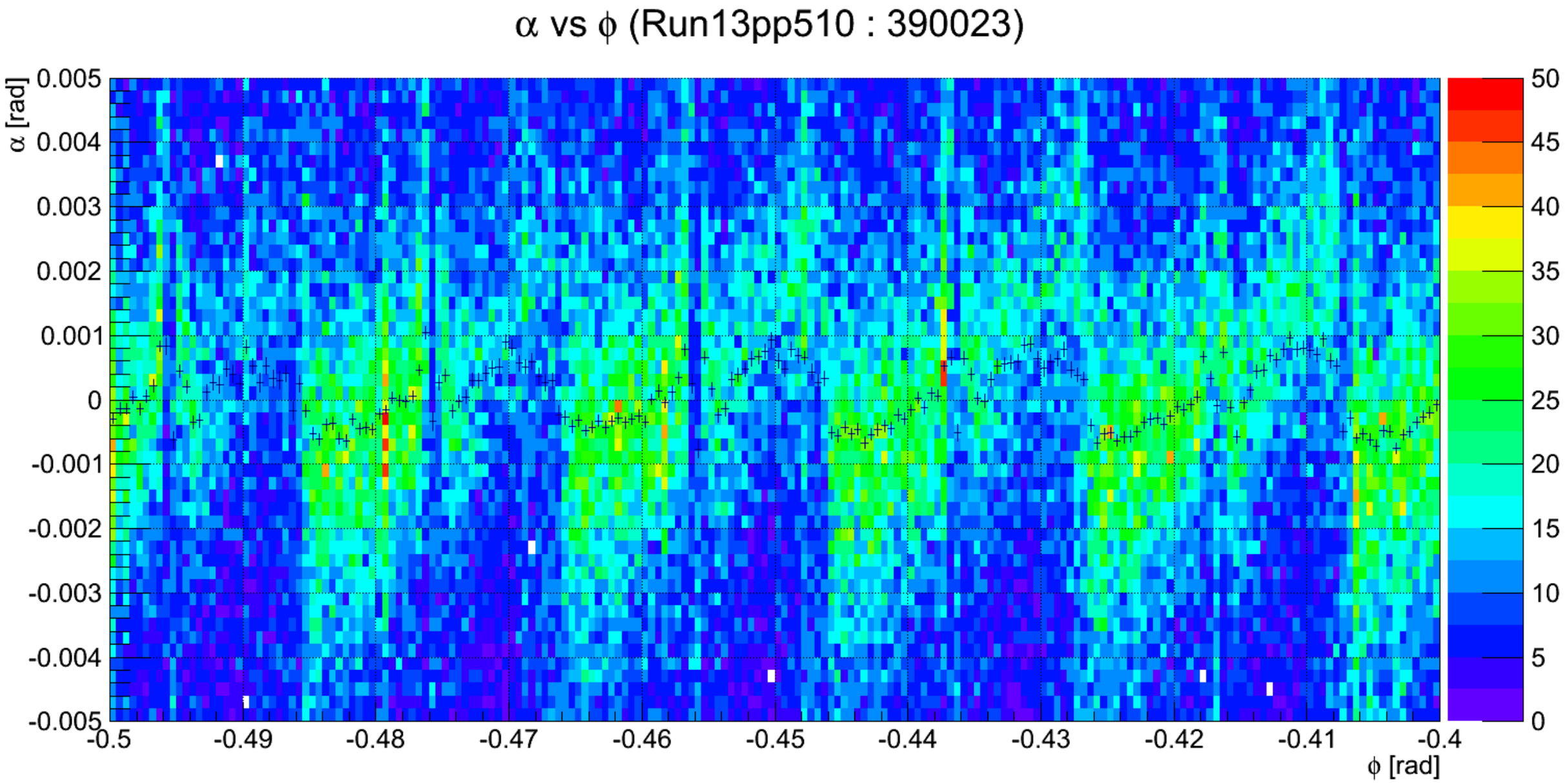
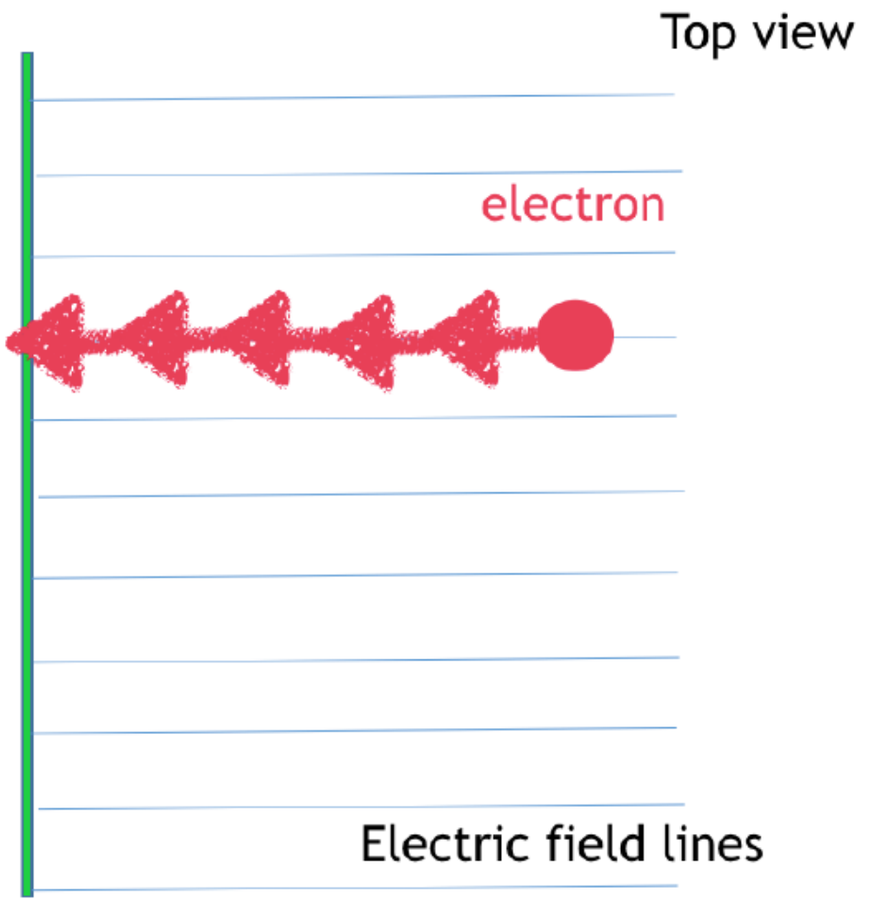


Raw Trigger Rate: 1053916.98



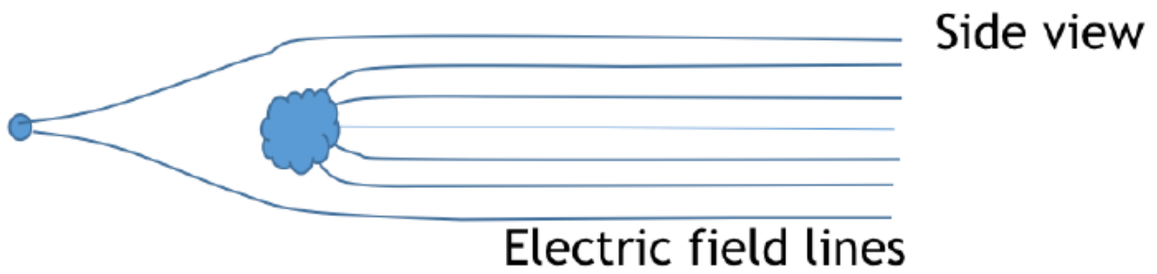
Wrong Drift Time

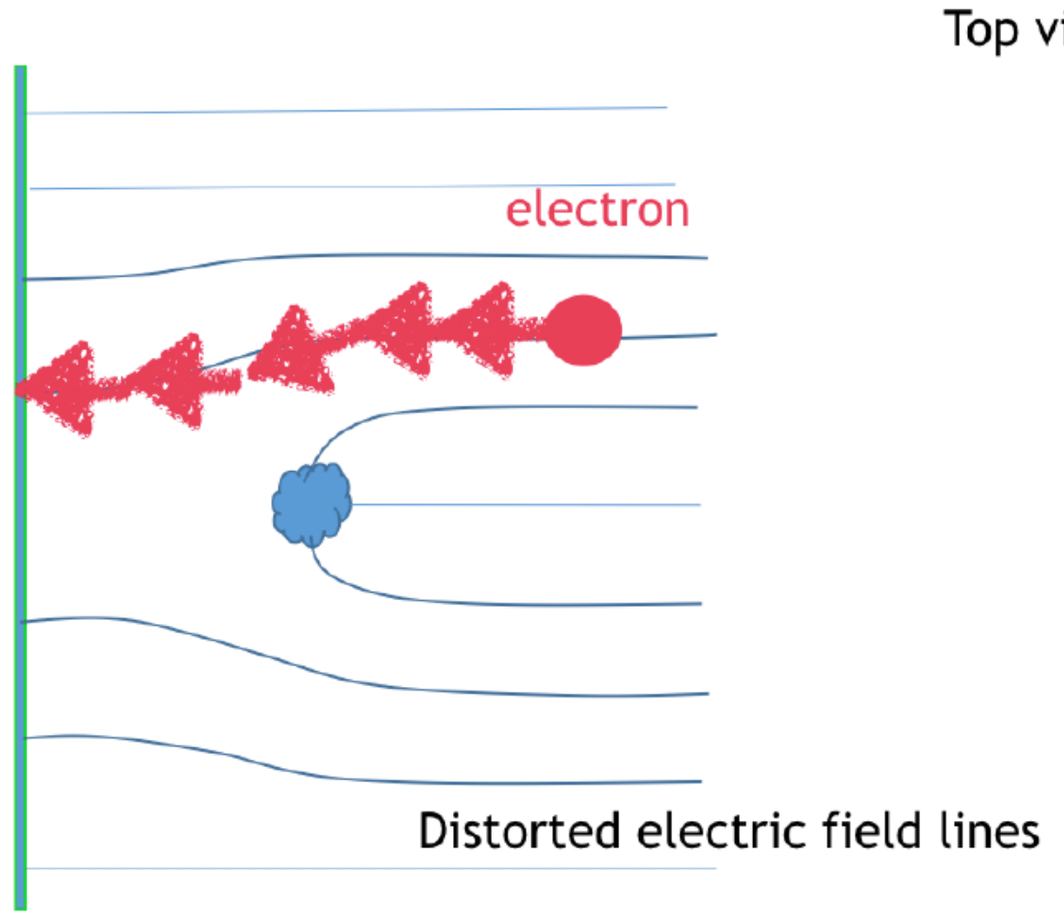
NO positive ion cloud



Anode(positively charged electrode)

Positive ion cloud





Anode(positively charged electrode)