Evaluating the 2013 e-lens lattices

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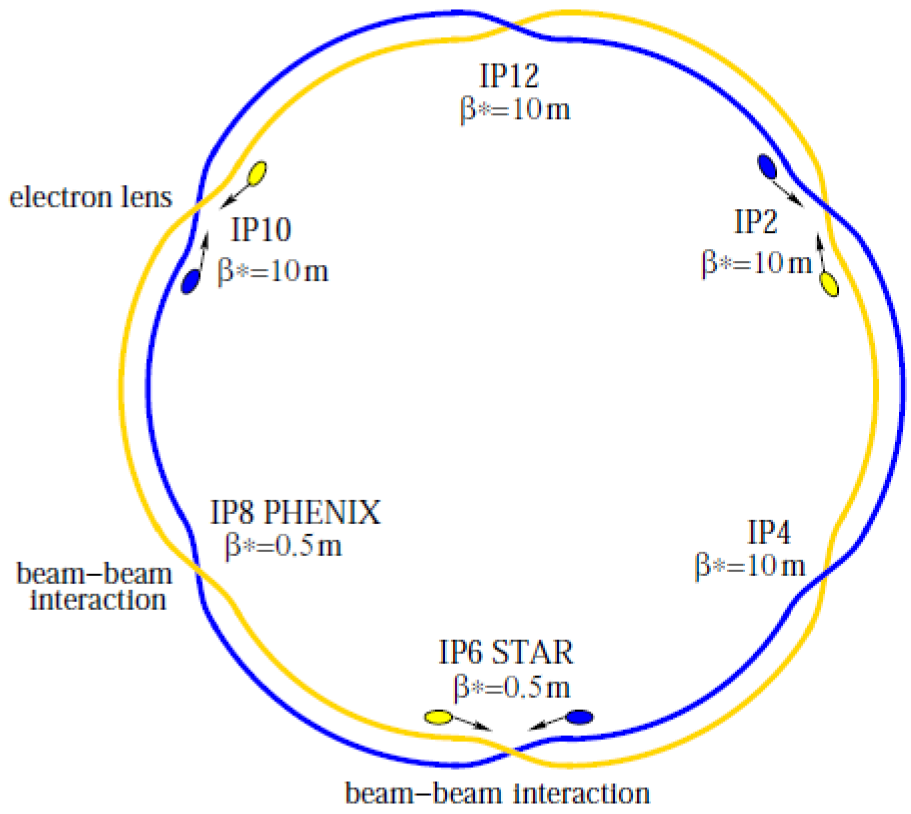
Introduction



1) To further increase RHIC luminosity in the proton collision with higher proton bunch intensities, we need to compensate the effects from beam-beam interactions.

2) Two electron lenses are being installed on either side of IP10 for beam-beam compensation.

3) To compensate beam-beam effects from IP8 with the electron lenses at IP10, we require that the phase advances between IP8 and the center of electron lenses to be k*PI, k is an integer.

4) In the 2013 RHIC proton operation, we began with the electron lattices and switched to standard lattices later.

E-lens Lattice Parameters

Blue Ring

E-lens lattices

```
------------------------------------------------------------
Optics Summary:
    Length:    3833.84518145942
    Tunes :    27.6899212445768    29.6799096834196
    Chrom1:    1.03173859169932     1.0393946808657
    Chrom2:   -1950.92336084038   -1871.07976499074
    Chrom3:   -353630.244578066   -438759.318841539
    Beta* :   0.652822933908604   0.650673711876454
    Alfa* :-0.00545758856694726-0.000369805243992121
    Etax* :-0.000686285206060382  0.0397992042448517
    Etay* :                   0                   0
  Beta_max:    2046.15664388363     2037.6490981462
```

Standard lattices

```
------------------------------------------------------------
Optics Summary:
    Length:    3833.84518145944
    Tunes :    28.6949122264153      29.684908118078
    Chrom1:   0.935787959641578    0.995060413172091
    Chrom2:    2504.90001489524     4643.19551322844
    Chrom3:    713345.912193491     53942.1017925052
    Beta* :   0.634232000521707    0.652362974195834
    Alfa* : -0.0494583214372595  0.0123041892104769
    Etax* :  0.0137689937533788  0.0348605319284078
    Etay* :                   0                    0
  Beta_max:    2127.29909711623     2038.5055217268
```

Yellow Ring

E-lens lattices

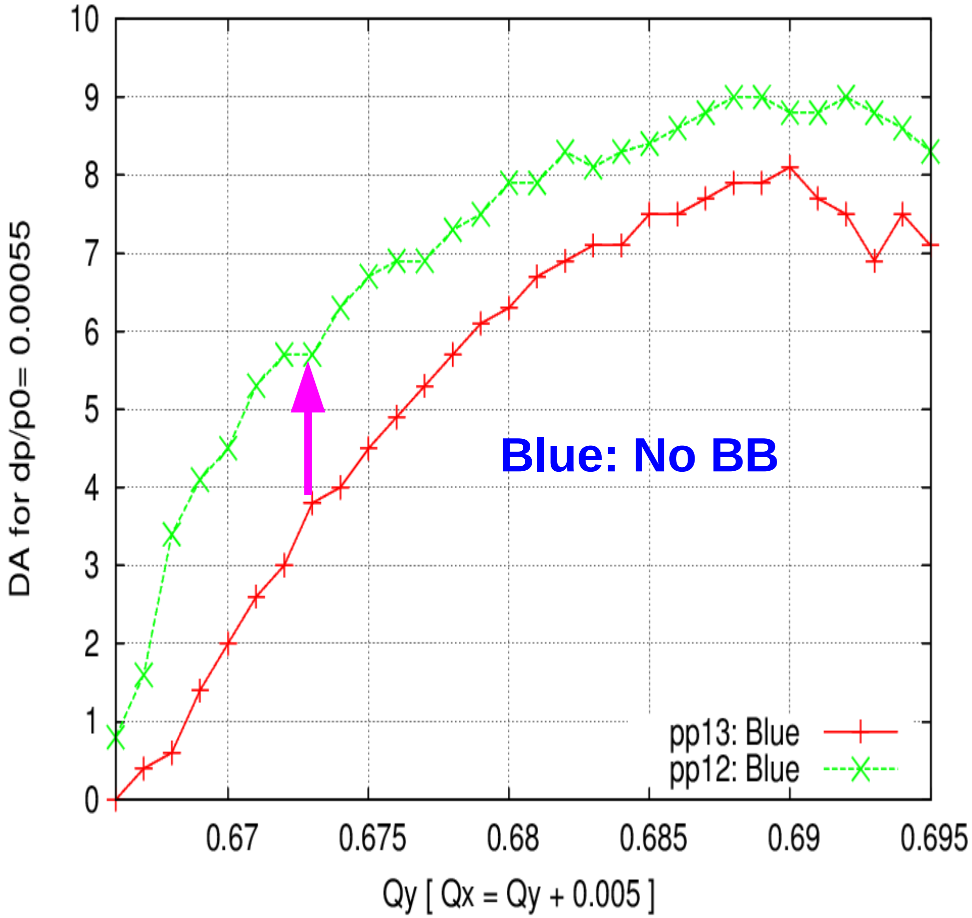
```
------------------------------------------------------------
Optics Summary:
    Length:    3833.84518145947
    Tunes :    29.6899070837287    30.6799006568637
    Chrom1:    1.00794899981578   0.961970067250213
    Chrom2:    3136.30191039929   -4634.12680338003
    Chrom3:   -91122.5357264787    423337.161161207
    Beta* :   0.659627602473874   0.658293636731087
    Alfa* : -0.0737102751130186 -0.0690678821757223
    Etax* :-0.00396062131150887-0.00762206887470051
    Etay* :                   0                   0
  Beta_max:    2060.32086590574     2051.1207309571
```

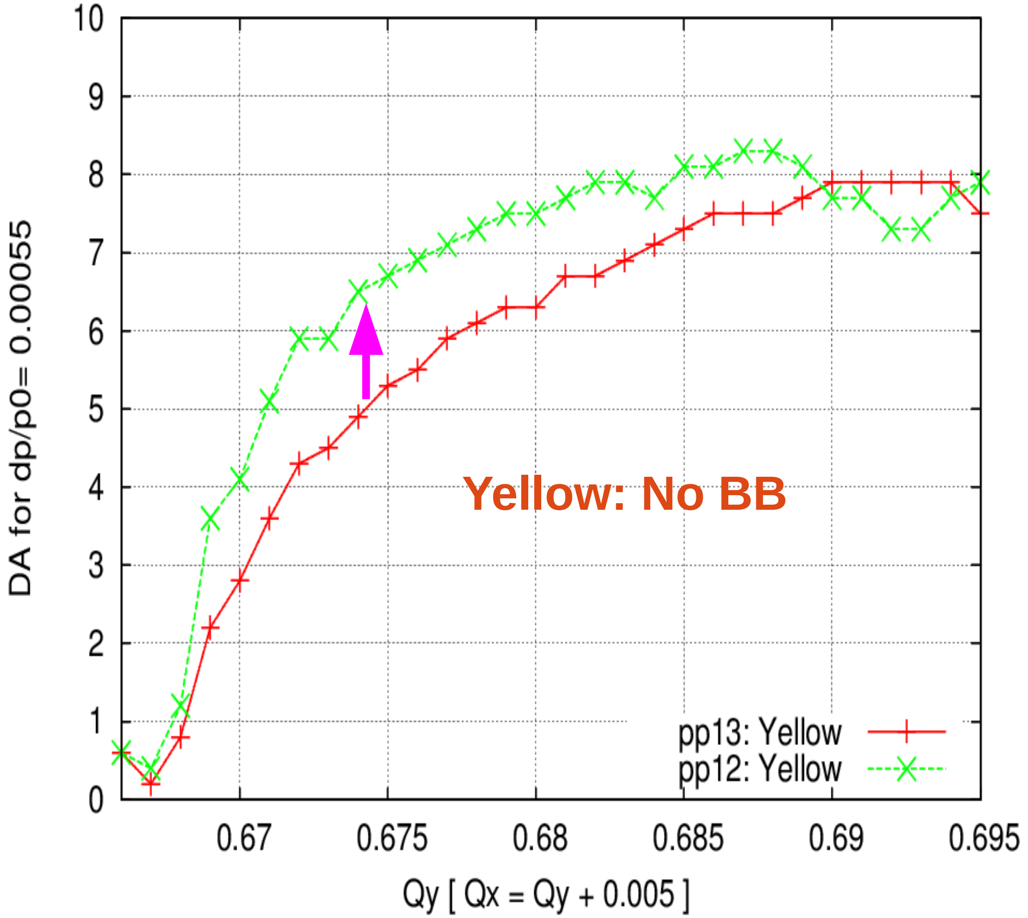
Standard lattices

```
------------------------------------------------------------
Optics Summary:
    Length:    3833.84518145947
    Tunes :    28.6949125077273     29.6849086172218
    Chrom1:   0.985539652908263    0.893284641274102
    Chrom2:   -5538.32470675412   -909.892871793922
    Chrom3:    97469.2117541732     1249310.85033292
    Beta* :     0.6411717324052   0.667036577013632
    Alfa* :-0.0257159429237676 0.00785941322926295
    Etax* :  0.0160945592338176   0.0331548918855694
    Etay* :                   0                    0
  Beta_max:    2116.59988635134     1993.81619985556
```

Integer tunes: (27. 29) for Blue e-lens lattice, (29,30) for Yellow e-lens lattice
(28, 29) for standard lattices

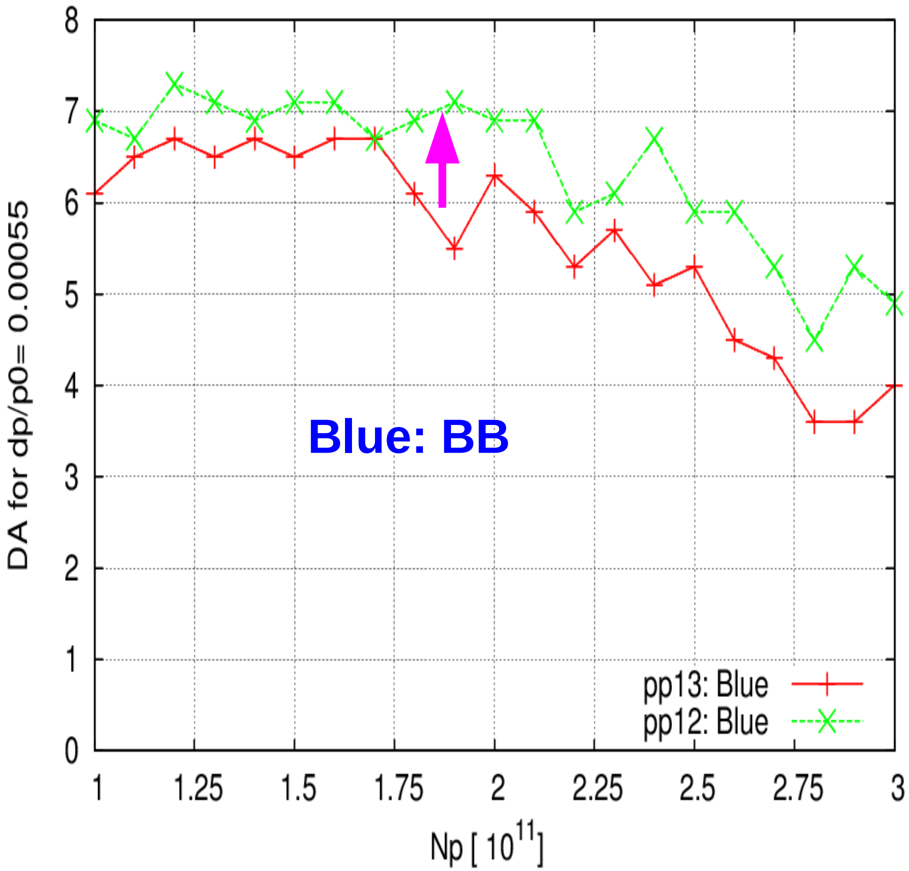
Dynamic Aperture without BB

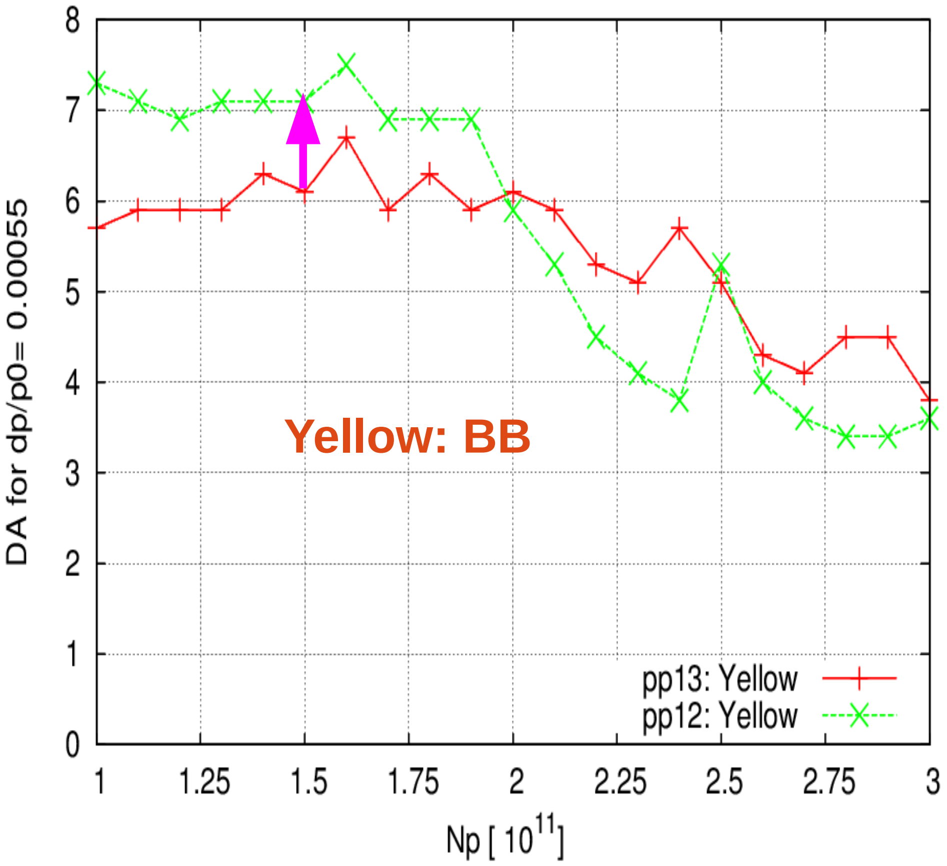




1) Dynamic apertures in the tune scan at 250~GeV, with dp/p0=0.00055.
2) DAs from standard lattices are bigger than that from e-lens lattices.
3) This means that 3Qx,y resonances are stronger for e-lens lattices
Here: IR nonlinear multipole field errors are included.

Dynamic Aperture with BB

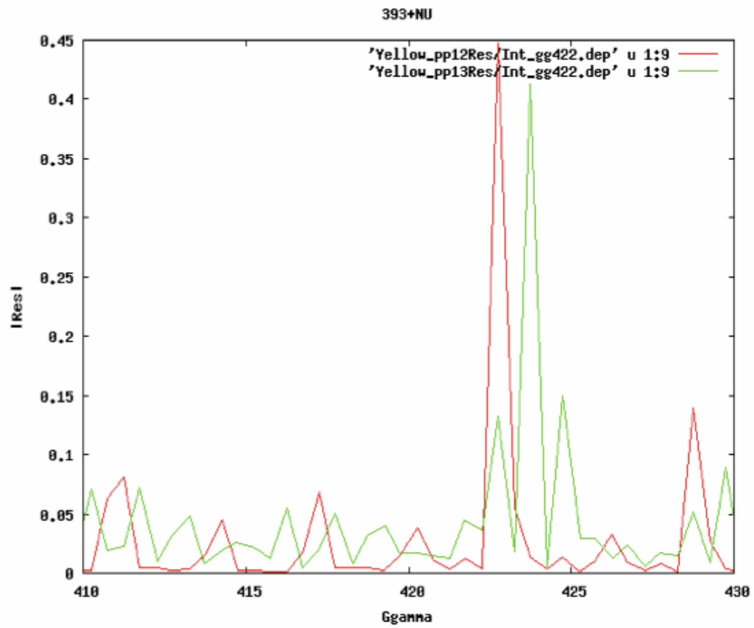


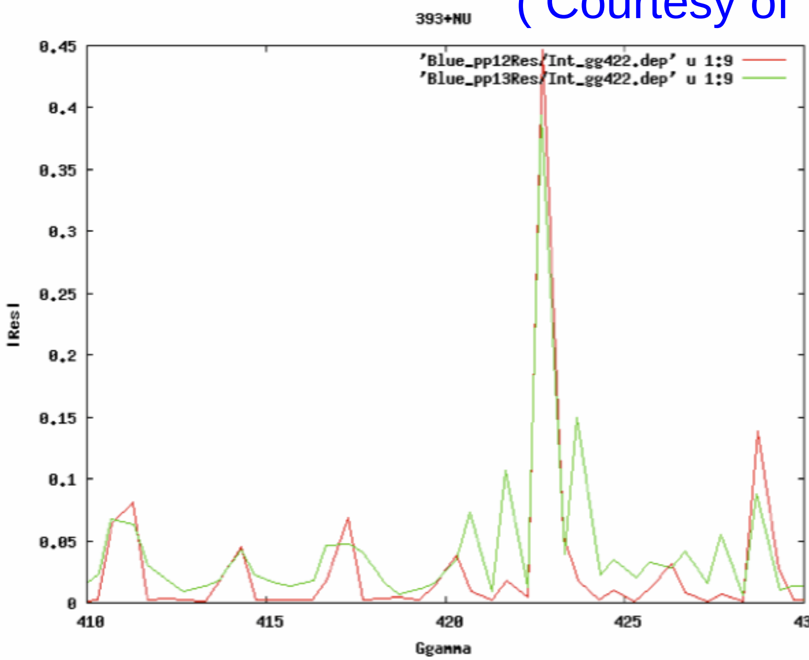


1) Dynamic apertures calculated with beam-beam interactions, with dp/p0=0.00055.
2) DAs from standard lattices are bigger than that from e-lens lattices.
3) The DA gap is bigger in the Yellow ring than in the Blue ring, in Yellow ring: ~1sigma
Here: IR nonlinear multipole field errors are included.

Spin Resonance Calculations

(Courtesy of Vahid)





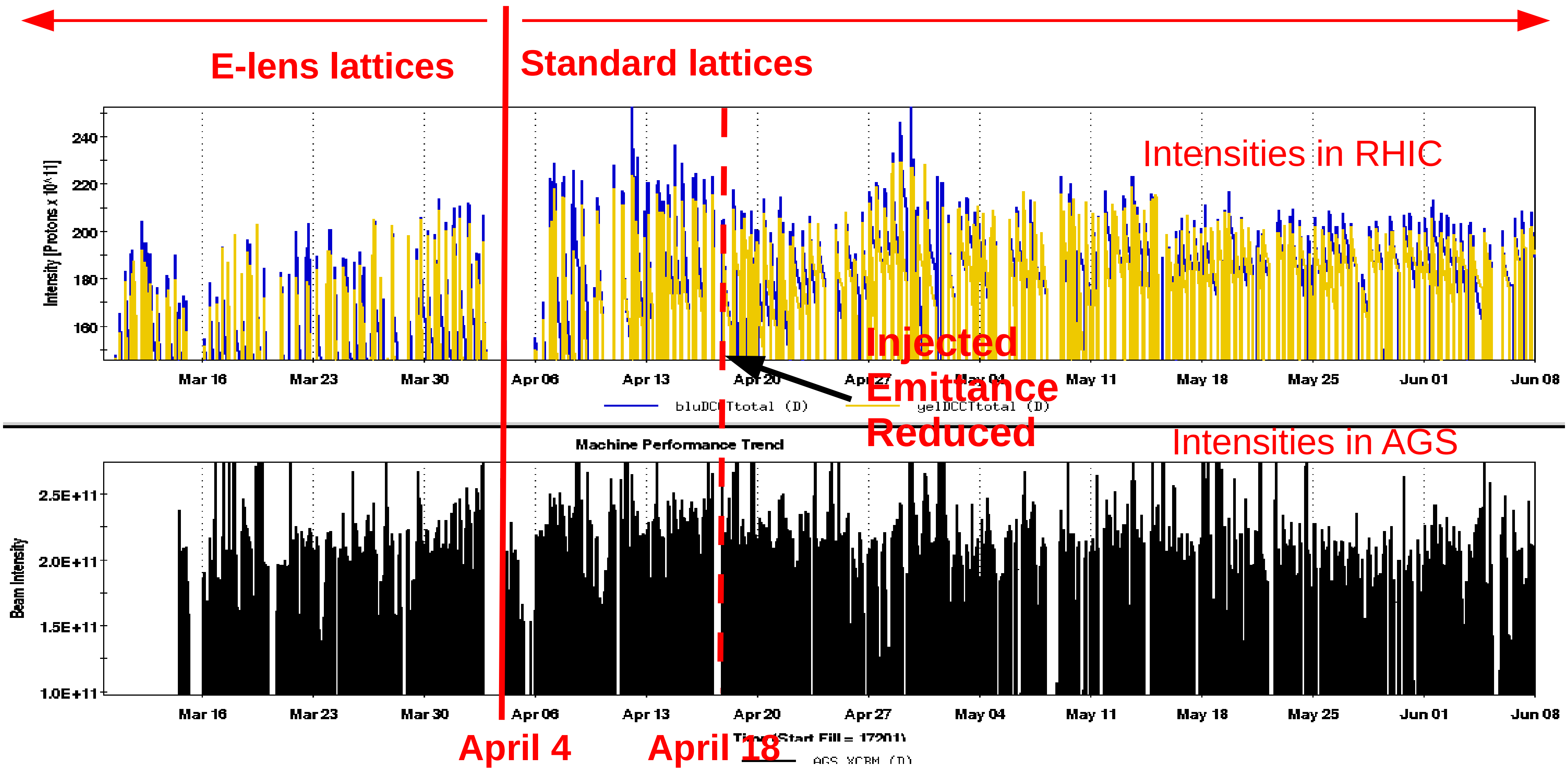
Reduced Resonances by 10 to 14%

Resonances	Blue (new-old)	Yellow (new-old)
231+NU	-0.0387	-0.0415
411-NU	-0.06134	-0.0655
393+NU	-0.05347	-0.0347

Based on simulation calculation:
e-lens lattices reduce the major spin resonances by (10-14)%, compared to standard lattices.

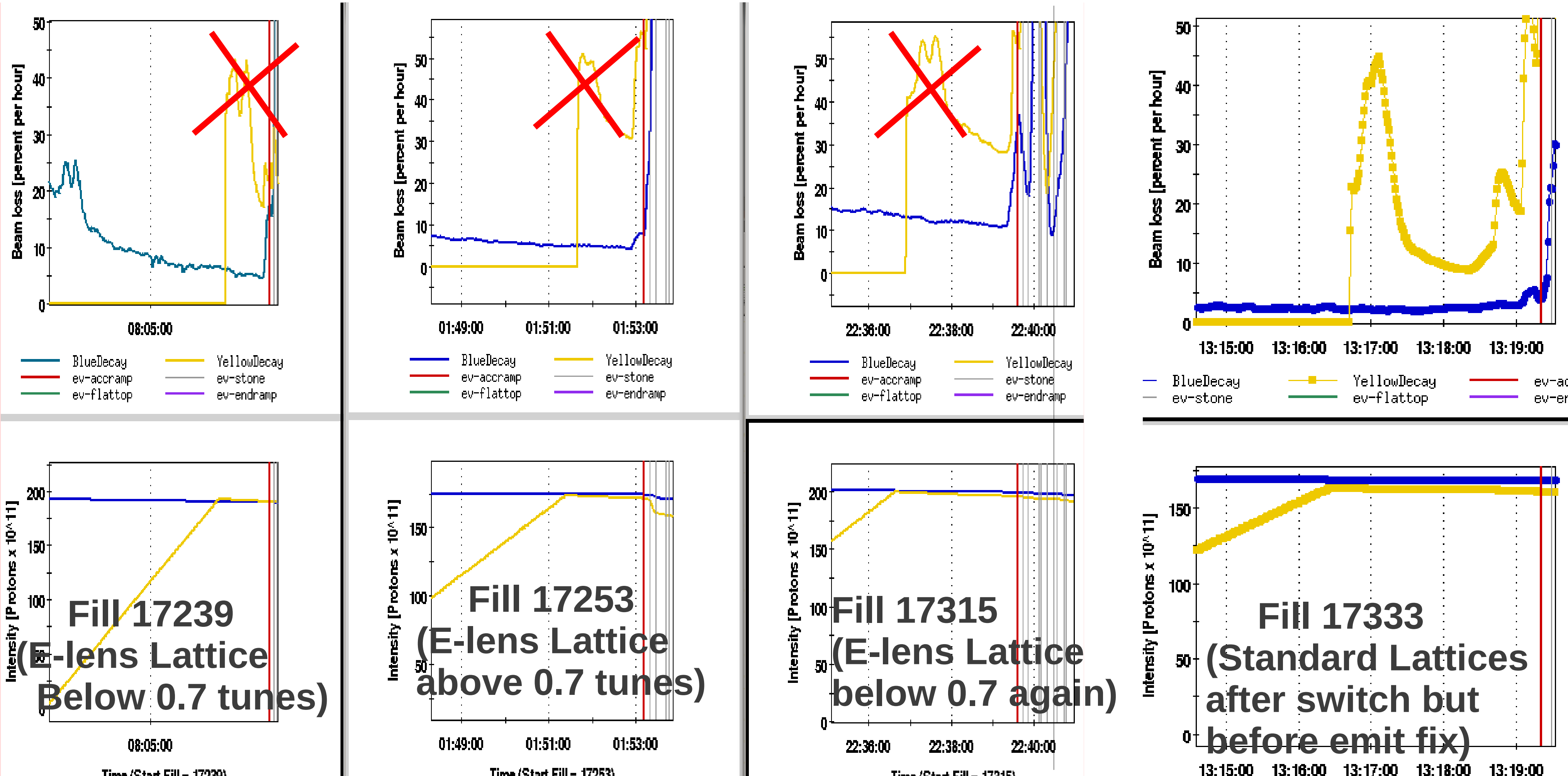
Time Line: Running with E-lens Lattices

Fill 17201 – 17322: e-lens lattices
Fill 17322 (April 4) – 17601: standard lattices
Fill 17396 (April 18) – 17601: emittances reduced below 10Pi from injection
Together with lattice switch, 197 RF voltages were reduced to 100kV from 300kV

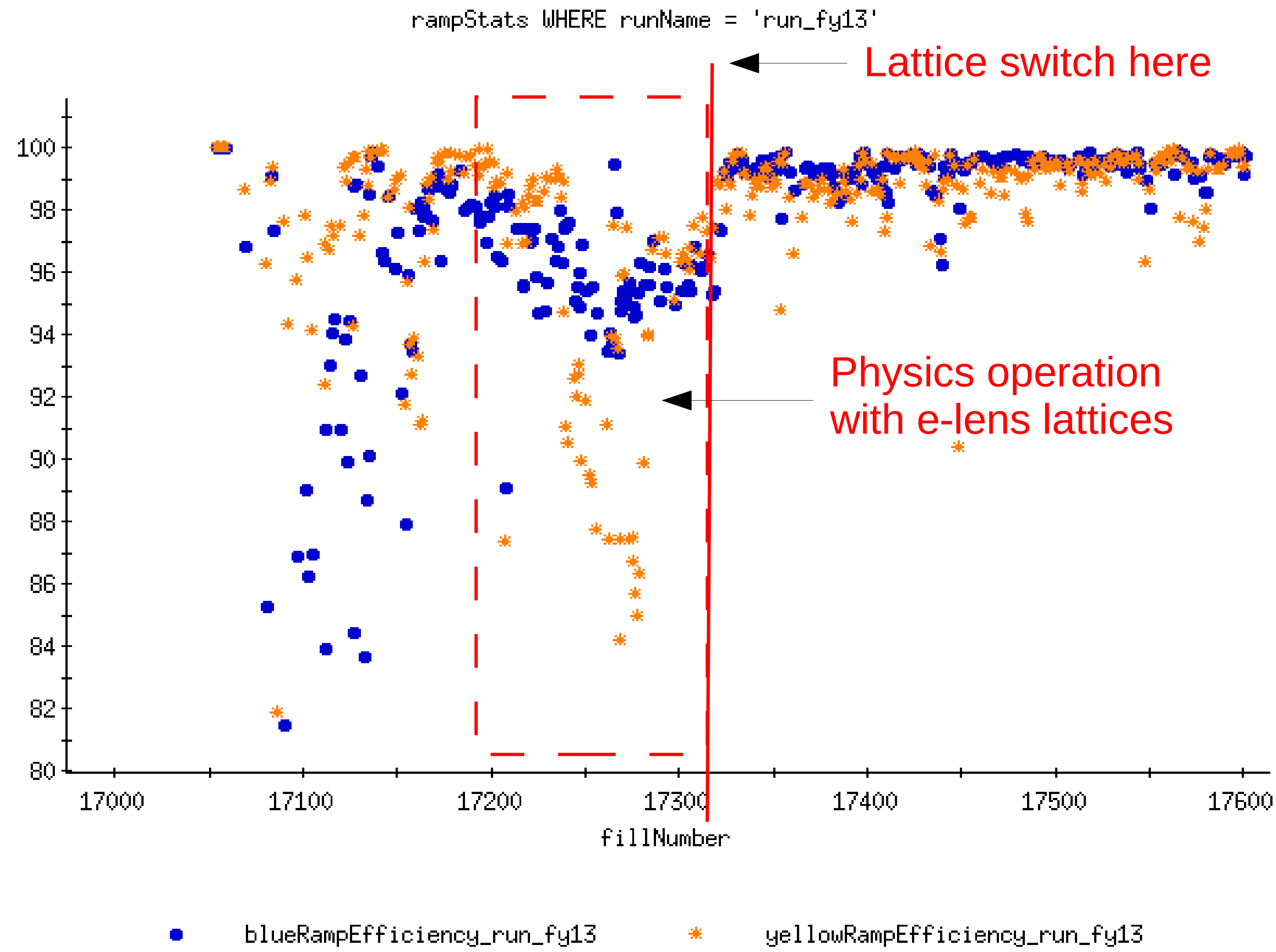


Beam Lifetime at Injection

With e-lens lattices, it was very PAINFUL to inject YELLOW beam with good lifetime:
1) We had to place injection tunes above 0.69, horizontal tunes even put to 0.698
2) Yellow tunes were then placed above 0.7 at injection from **Fill 17240**
3) Yellow tunes were put back below 0.7 from **Fill 17312** just before switch,
4) Struggled with 3Qx,y corrections at injection, but turned out not so helpful.

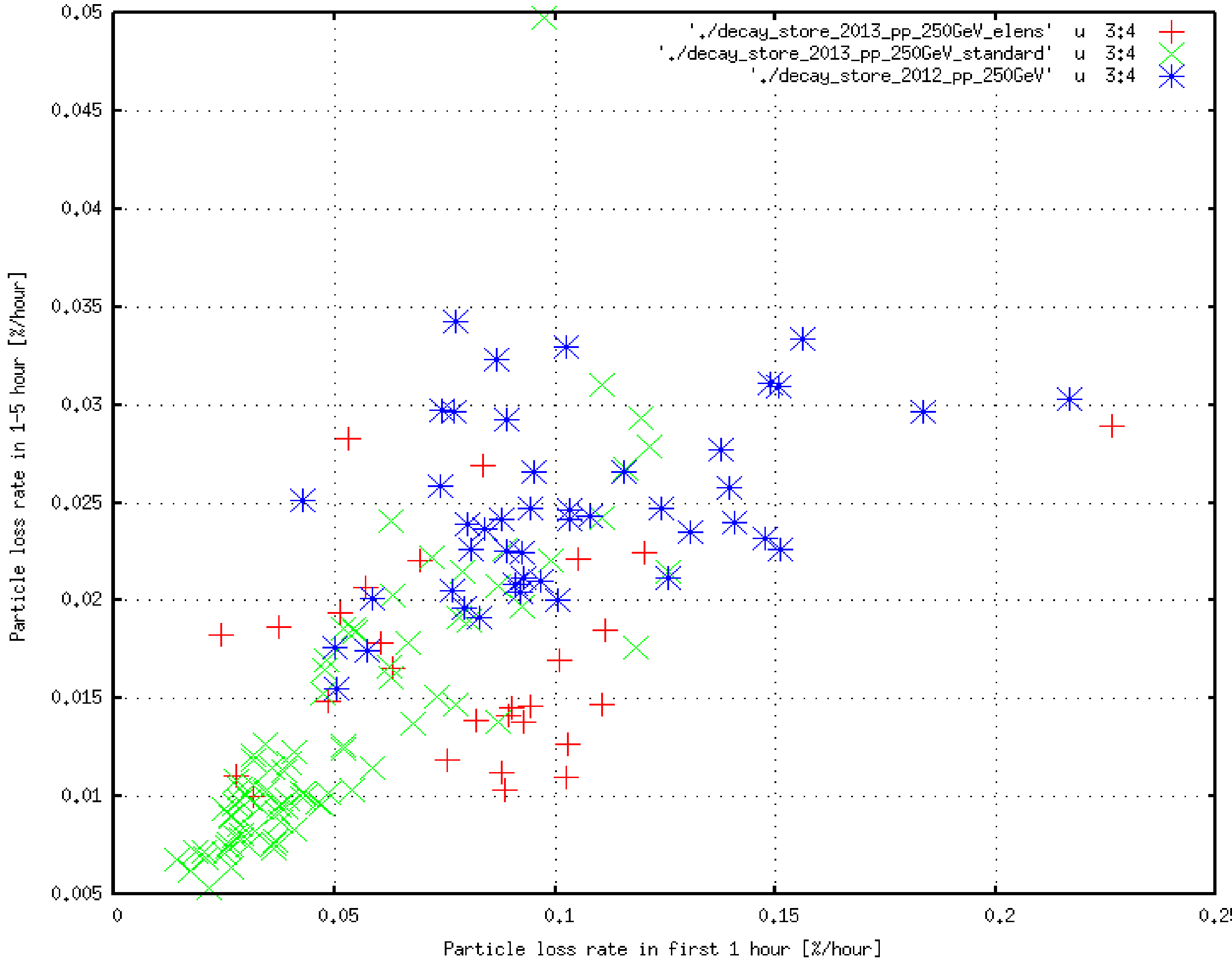


Ramp Efficiencies



Ramps with e-lens lattices gave much worse ramp efficiencies for BOTH RINGS, comparing with the late standard lattices, which also should be linked to 3Qxy RDTs.

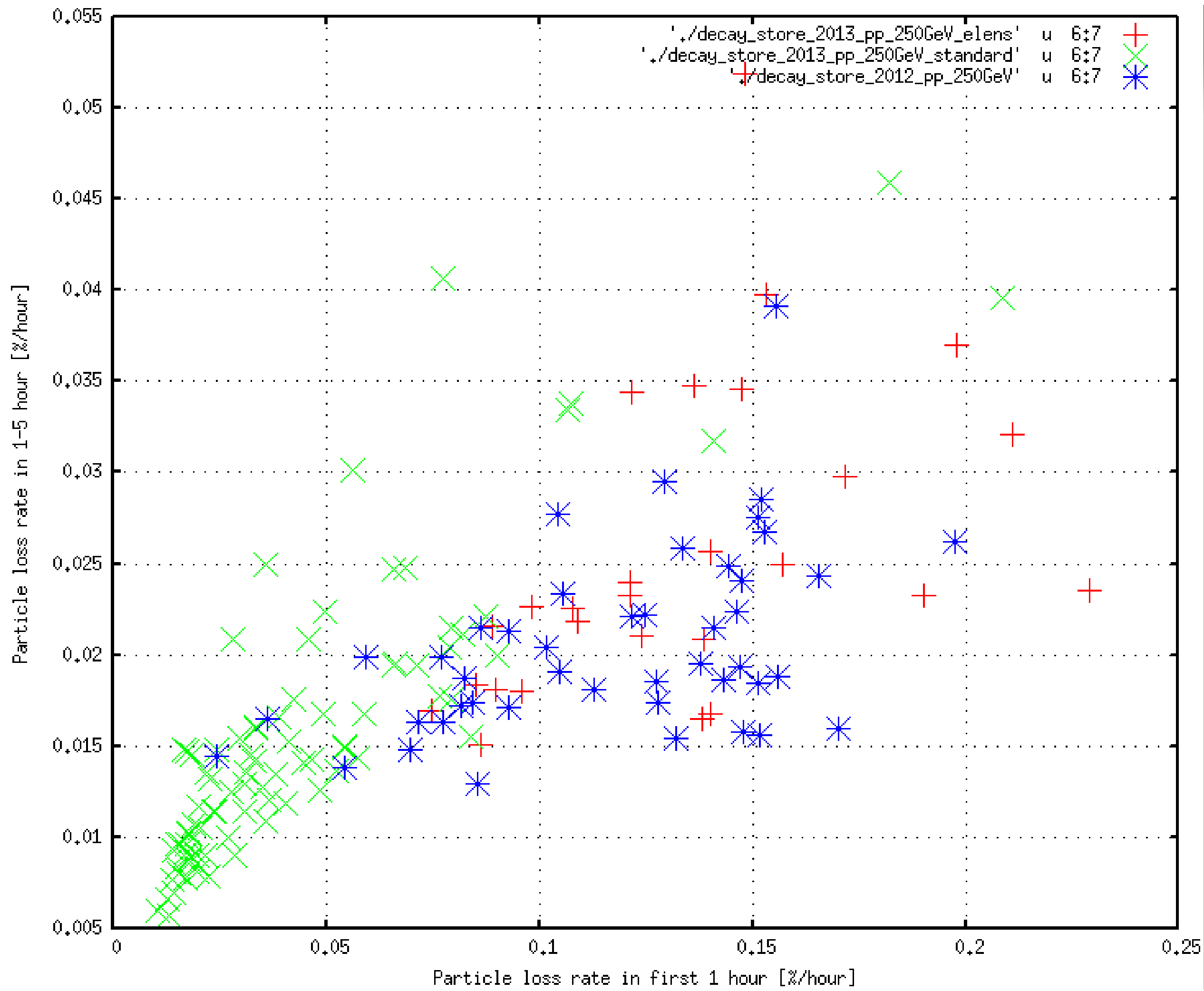
Beam Loss with Collision: Blue Ring



Only fills with store length > 6 hours are considered.

1) **In the first 1 hour**: e-lens lattices loss rates was comparable to that in2012 p-p run, but larger than 2013 standard lattices.
2) **between 1-6 hours**: e-lens lattices was better than that in 2012 p-p run.
3) NOTE: with e-lens lattices, yellow beam always had worse lifetime than blue beam.
4) NOTE: 2013 standard lattice run used 100kV instead of 300kV 197 RF cavities.

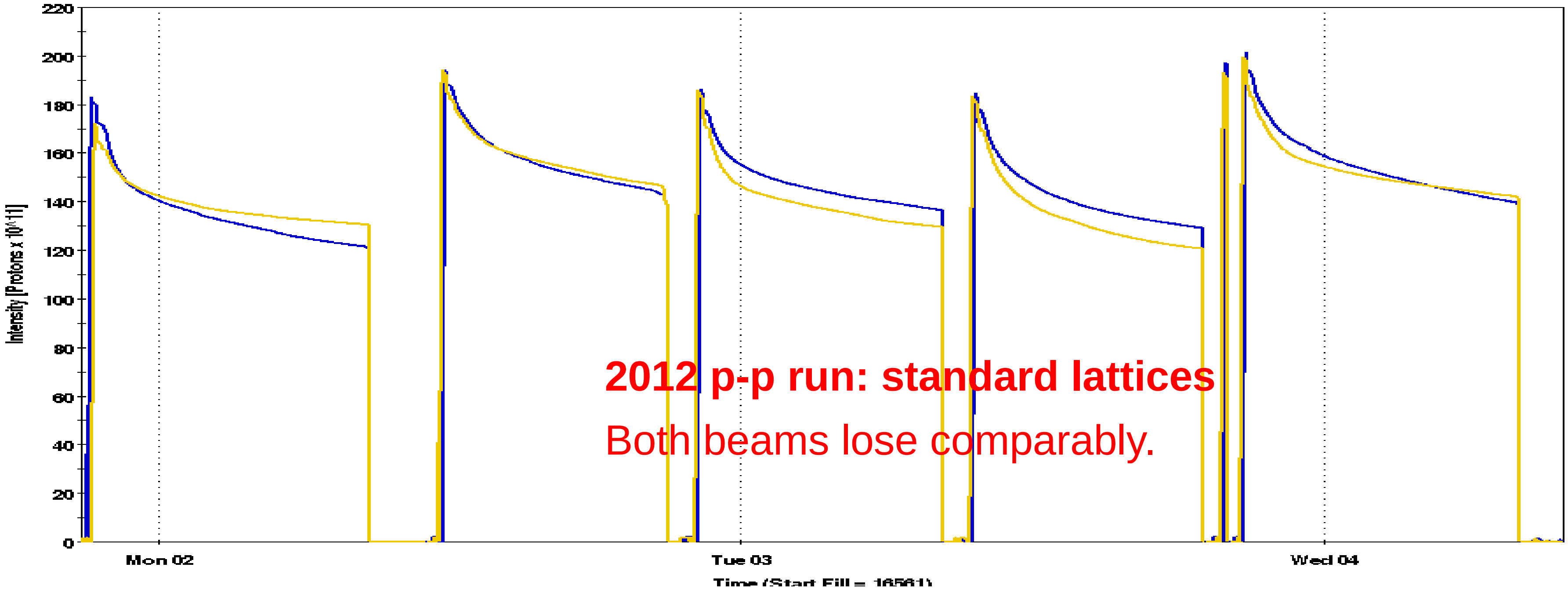
Beam Loss with Collision: Yellow Ring

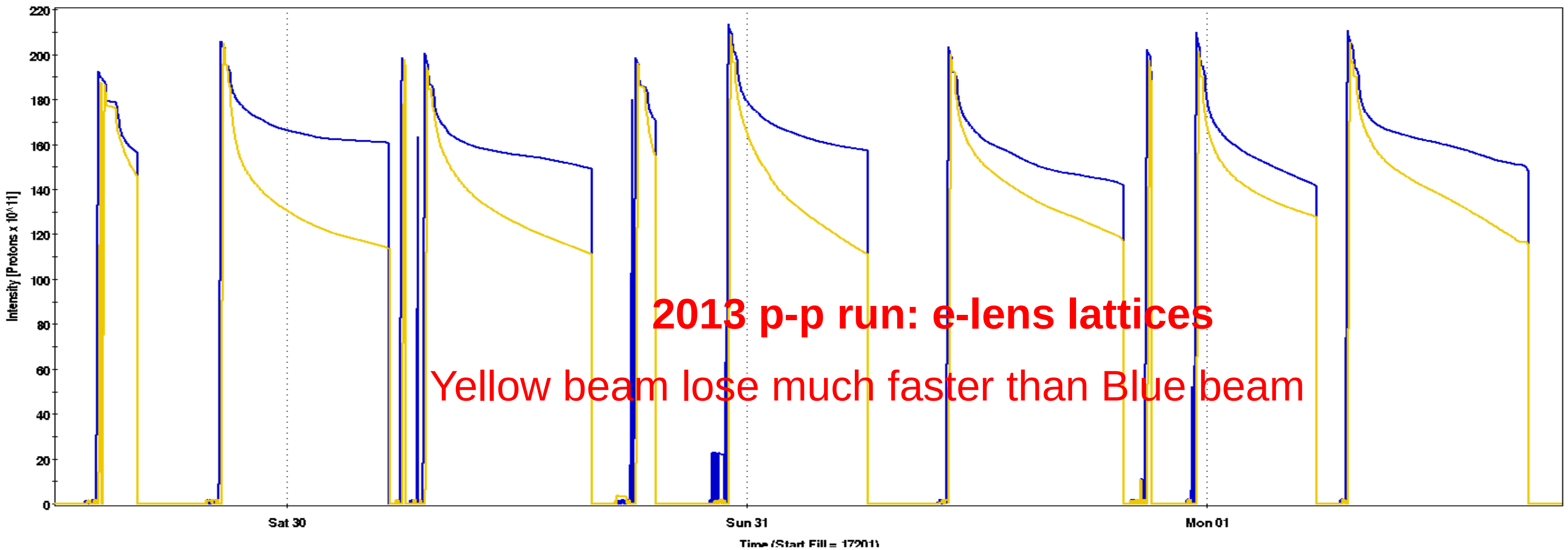


Only fills with store length > 6 hours are considered.

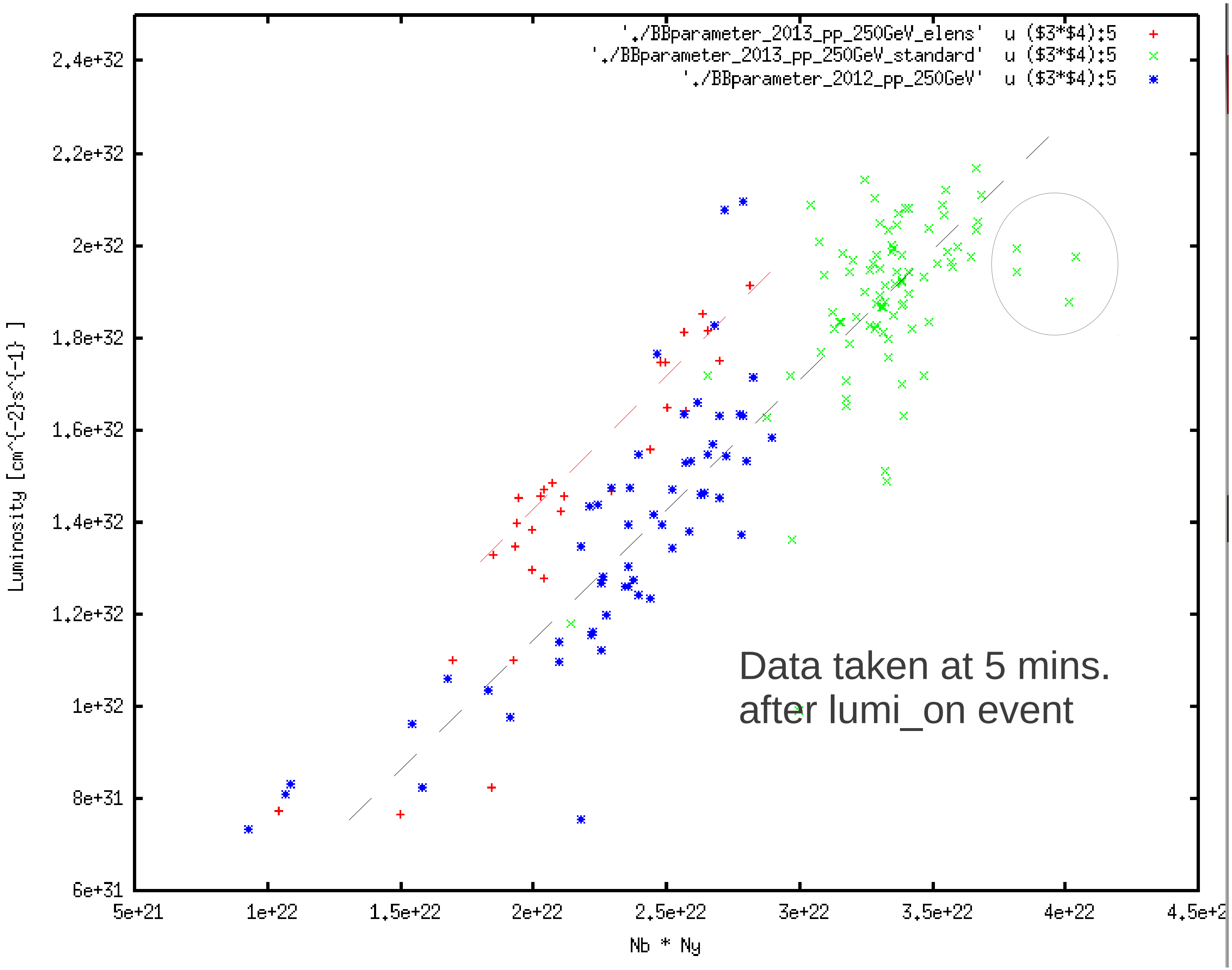
1) **In first hour**: 2013 yellow e-lens lattice gave more loss than that in 2012 p-p run.
2) **In 1-6 hours**: 2013 yellow e-lens lattice gave more loss than that in 2012 p-p run.
3) **In 2013 run**: 2013 yellow e-lens lattice gave much more loss than 2013 standard yellow latt.
4) NOTE: Due to different 197RF voltage and injected emittances,
no direct comparison between 2013 e-lens lattices and 2013 standard lattices.

2013 e-lens lattices and 2012 p-p run





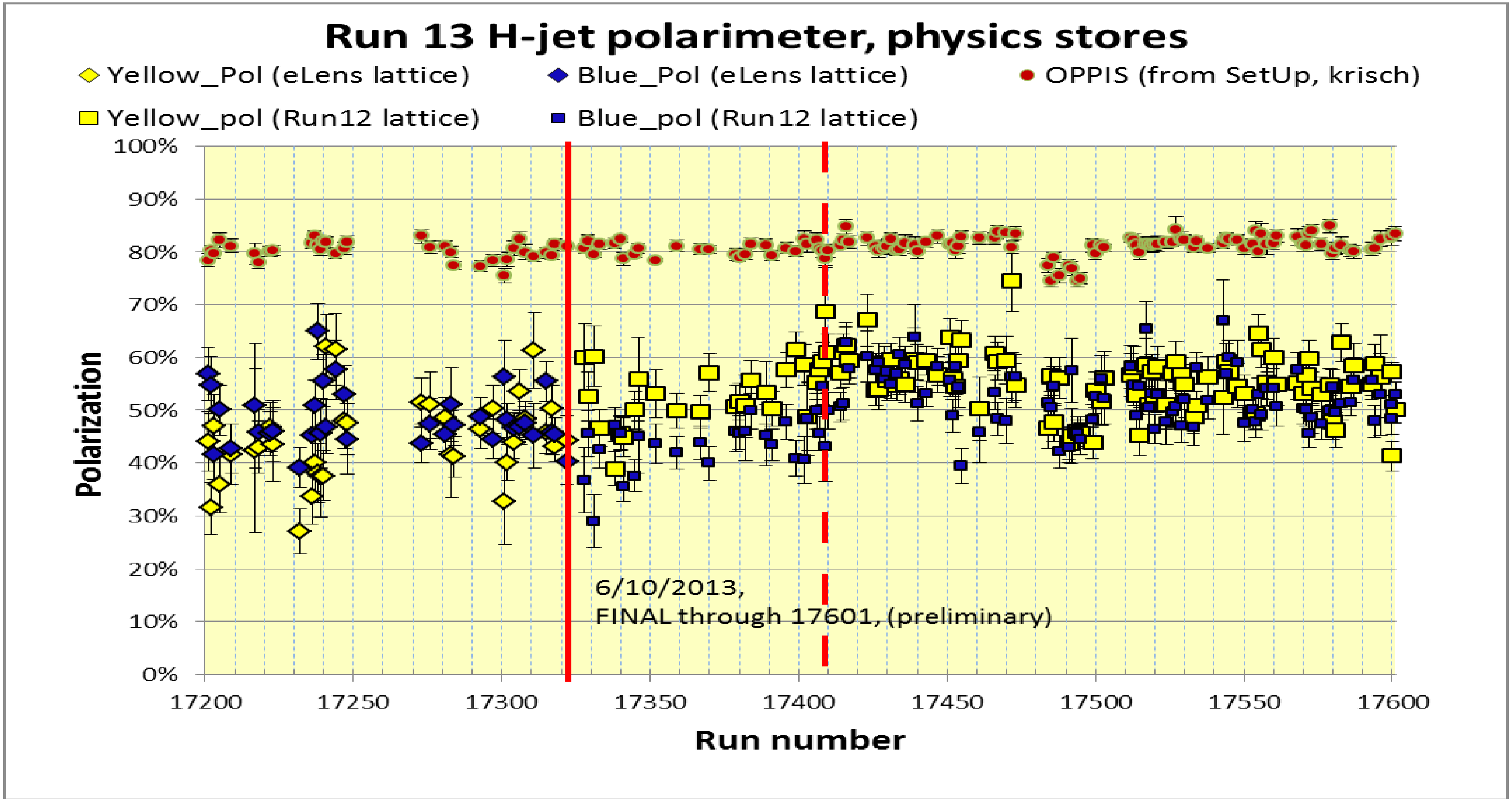
Luminosity & Intensities



1) Luminosity proportional to Np_{Blue} * Np_{Yellow}.
2) I suspect luminosity with e-lens lattices was still over-estimated.

Jet Polarization Measurements

Polarization Journey:
1) Lattice switch: April 4, Fill 17322
2) Emittance Fix: April 18, Fill 17396



Averaged Jet Measured Polarization

2013 p-p runs:

1) stores 17201-17322: e-lens lattices
   Yellow average = 44.1% ± 0.8%
   Blue average = 47.7± 0.7%

(Courtesy of Haixin)

2) stores 17323-17368: standard lattices without emittance fix
   Yellow average = 50.0% ± 0.9%
   Blue average = 42.7% ± 0.8%

3) stores 17369 – 17601 : standard lattices with emittance fix
   Yellow average = 55.1%± 0.4%
   Blue average = 51.7 %± 0.3%

Average for all fills: Yellow = 52.9% +/- 0.3%, Blue = 49.9% +/- 0.3%,

2012 p-p run: standard lattice:

(data from Wolfram's talk in NPP/PAC)

Average for all fills: Yellow = 53.5%, Blue = 50.3%

Observations:
1) **With e-lens lattices**: polarization measurements were lower than 2012 p-p run, especially much lower with the Yellow e-lens lattice with 44%. Blue polarization 47.7%.
2) **With standard lattices before emittance fix**: Yellow polarization measurements above 50%, while Blue polarization measurements were reduced from 47% to 43%.
3) **With standard lattices after emittance fix**: the Yellow measurements above 55%, slightly better than 2012 run;Blue measurements were close to 50%, comparable to 2012 run. However, in the best week of polarization, both higher than 2012 run.

Summary

1. 2013 e-lens lattices of both rings showed low beam lifetime at injection and high beam loss on ramp, which was related to their large third order resonance driving terms. The corrections at injection worked not very well.

2. With collisions, the 2013 Blue e-lens lattices gave comparable or even better beam lifetime than that from the standard Blue lattice in 2012 p-p run. However, the 2013 Yellow lattices gave more beam loss than that from standard Yellow lattice in the 2012 p-p run.

3. There was no direct comparison between 2013 e-lens lattices and 2013 standard lattices because of different 197 RF cavities used.

4. For e-lens lattices: polarization in the Blue ring was 3.5% higher than Yellow ring. For the stand lattices with emittance fix, polarization in the Yellow ring was 4.5% higher than Blue ring.

5. Without emittance fix: 2013 e-lens Blue ring lattice gave much higher polarization than the standard lattices (5% absolute value), but the 2013 e-lens Yellow ring gave much lower polarization than the standard lattice (6% absolute value).

6. For standard lattices with emittance fix: polarization in the Blue ring standard lattice increased by 9% (absolute value) and polarization in the Yellow ring standard lattice increased by 5% (absolute values). Averaged values in both rings very similar 2012 run.

Difficulties in Evaluating

Evaluating through numeric simulations:

1) straight-forward, easy to compare
2) but need good model of lattices, should include errors and noises
3) also need solid tracking tools

Evaluating through experiments or actual operation:

1) complicated, mostly not easy to draw conclusions, but it is a final evaluation
2) can't not only focus on the outputs, have to focus on the inputs to lattices
3) also need reliable and calibrated diagnosis, etc.

My personal opinions:
1) if reliable tracking results veto a lattice, we'd better not go with it.

Difficulty:
I believe tracking results but not sure if results are crucial to the actual operation
DA is crucial to operation
But resonance driving term, second order chromaticity may not be.

2) if operation shows a lattice is good, it is good (of course).

Design Future E-lens Lattices

Beam dynamics aspects:

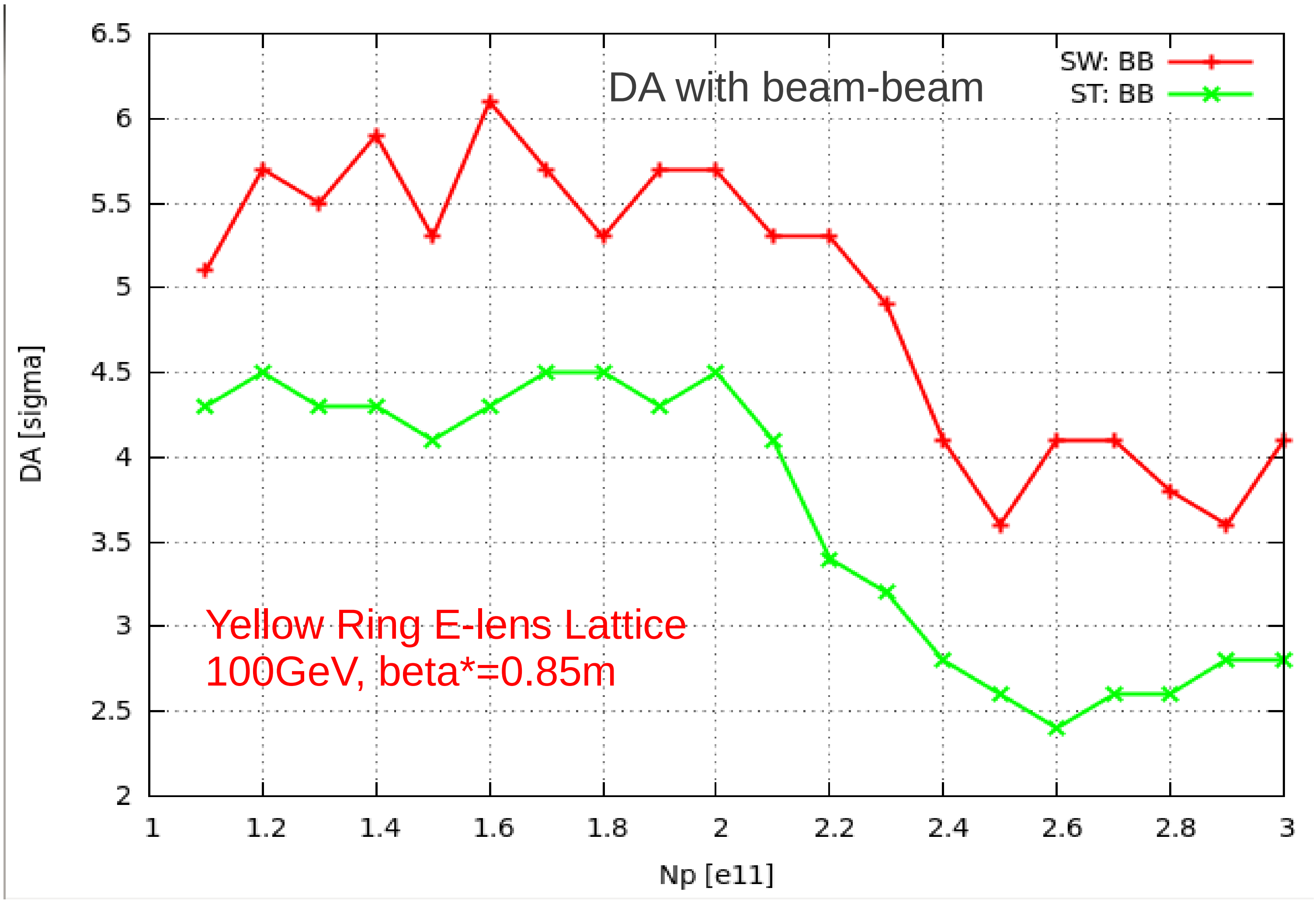
1) Linear lattice design should also takes into account nonlinear issues:
   Third order resonance driving terms, second order chromaticity, etc.
2) We have robust tracking methods and codes, and with experiences to
   determine a lattice is good or bad.
3) **Success of beam-beam compensation heavily depends on the e-lens lattices,**
   The higher dynamic aperture, the easier to achieve beam-beam compensation.

Spin dynamics aspects (only questions)**:**

1) Do we have reliable single- or multi-particle tracking methods and codes ?
2) How do (did) these codes benchmark (predicted) with the actual operation ?
3) What observables can be used to evaluate beam's (not single particles) polarization ?

A good e-lens lattice:
1) **MUST** have good dynamic aperture
2) MUST have decent polarization
3) Lack anyone of above two, the lattices can be dumped.

New Approach to E-lens Lattices



Here we also considered the phase advances between IP6 and IP8 to be 2kPi+ Pi/2, which reduces the second order chromaticities and increases dynamic aperture.