Backgrounds at RHIC during Run24

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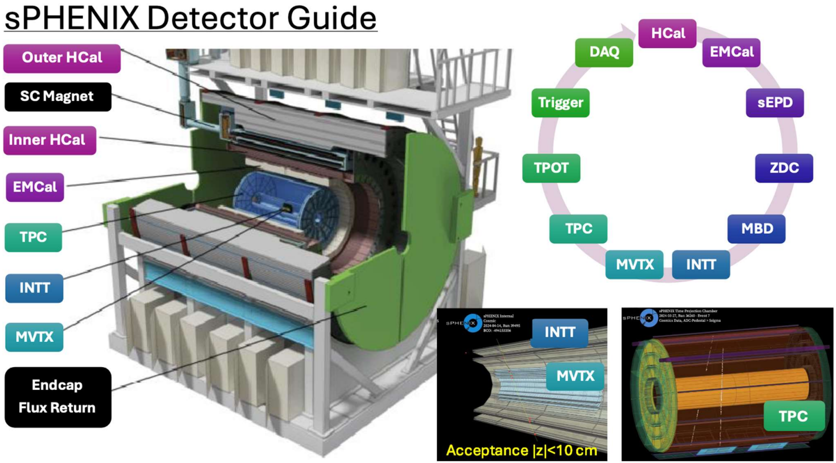
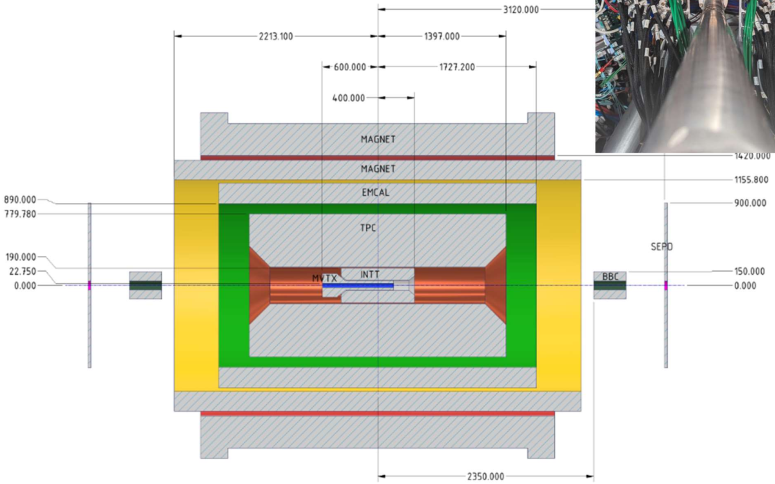
sPhenix Detector with MVTX

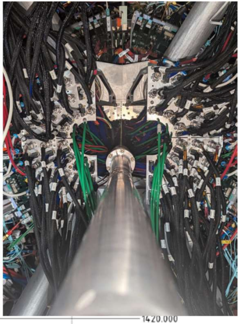
The MVTX is the detector closest to the beam pipe



From A. Drees

Location inside sPhenix





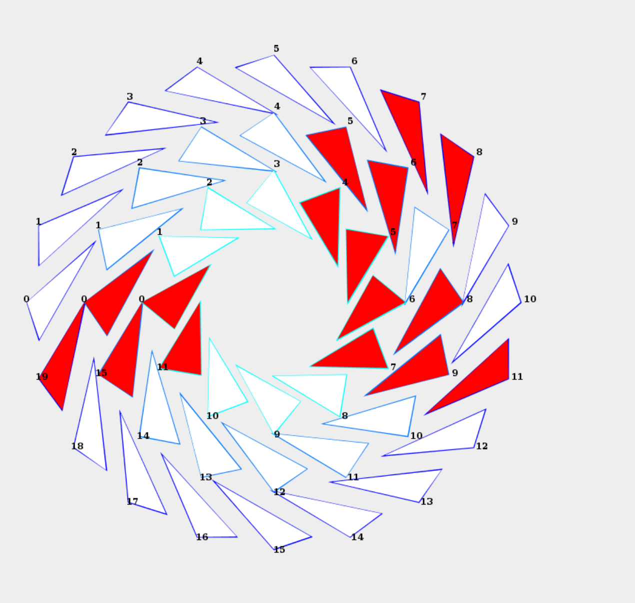
From A. Drees

The MVTX Detector Background Issue

The MVTX is at the center the sPHENIX detector.

- It was designed to operate in full-streaming mode, i.e. the system is in constant readout.
- The detector can be run in triggered mode to improve auto-recovery rate. Minimum delay is sufficient to capture real events.
- 48 staves in three layers, centered at the IP, and extends $\pm$13.5 cm. More on the geometry on the next few slide.
- If any of the staves are overloaded with charge, the entire stave will go into auto-recovery, a 20 s reboot process to reset/re-initialize that system$\Rightarrow$no data during being read out during auto-recovery.
- Primary source is yellow beam. Blue beam had significantly lower rates (56 bunches in blue had lower rates than single yellow bunch).
- Details seen in John Haggerty, sPHENIX Summary and the Run25 Plan

The MVTX detector



- MVTX auto-recovery display shown on left where red corresponds to staves in auto-recovery.
- Auto recovery process is 20s.
- Units reported to CAD are in auto-recoveries per minute. Displayed as average auto-recovery/minute.
- Simulations by sPHENIX show a single Au ion (or shower from striking the beampipe) with a longitudinal trajectory, striking the MVTX would result single/multiple MVTX staves going into auto-recovery
- Studies require MVTX to be on

MVTX geometry

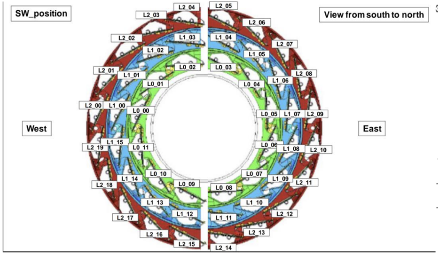
Beampipe radius	2.14 cm
Layer 0	2.4 cm
Layer 1	3.1 cm
Layer 2	3.9 cm

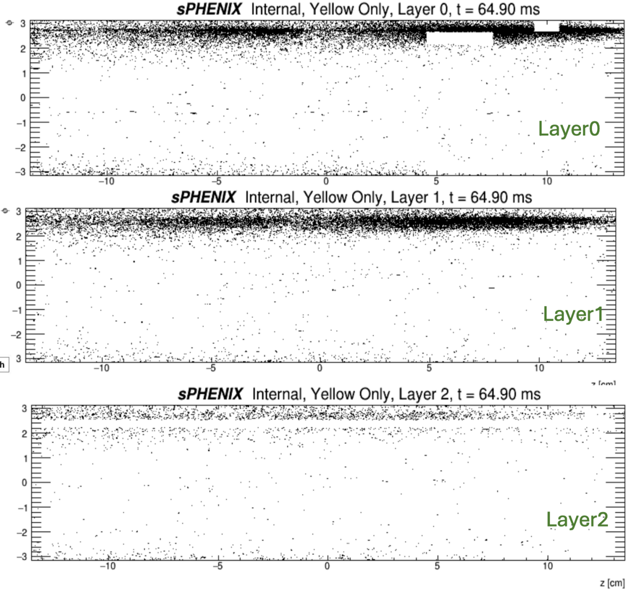
MVTX Backgrounds

No problems in proton-proton

Major background in Au+Au, even with just one bunch in the yellow ring (i.e., no collisions)

Beam backgrounds... induces auto-recoveries in MVTX

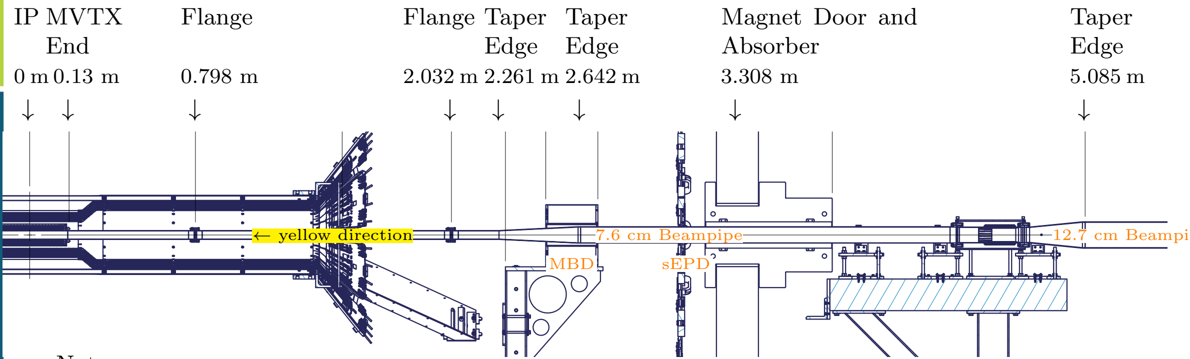




Yellow Beam Direction

From C. Dean

sPHENIX Geometry



Notes

- Opening of absorber is 12.7 cm
- The MBD and sEPD sit on the 7.6 cm beampipe (MBD on 7.62→5.4 cm taper)
- Material is beryllium to first flange, aluminum until transition from 7.62 cm to 12.7 cm.

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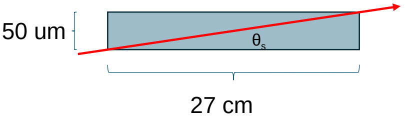
RHIC/MVTX Local Geometry

MVTX spans +/-13.5 cm around IP
Active layer is 50 um

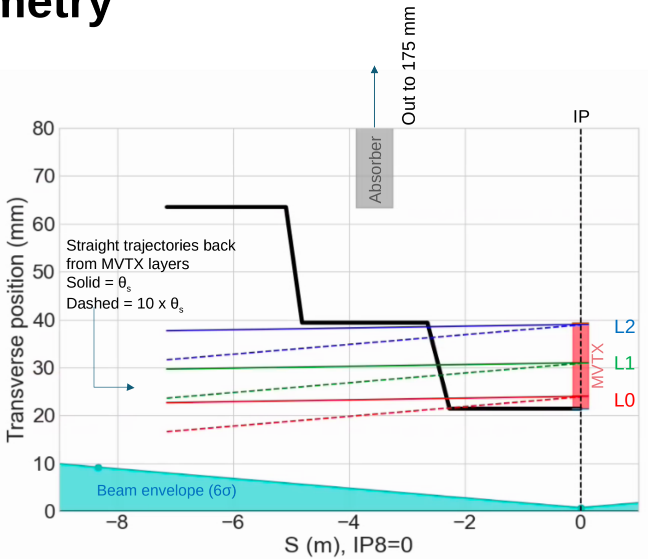
θ_s: "Skimming" angle: max angle of a trajectory that traverses the whole length of one MVTX layer: 50um/26.5cm = 0.19 mrad



Beam envelope = 6σ, no dispersion, ε=2.5 um rms,norm
No dispersion included, no crossing, nominal beam pipe

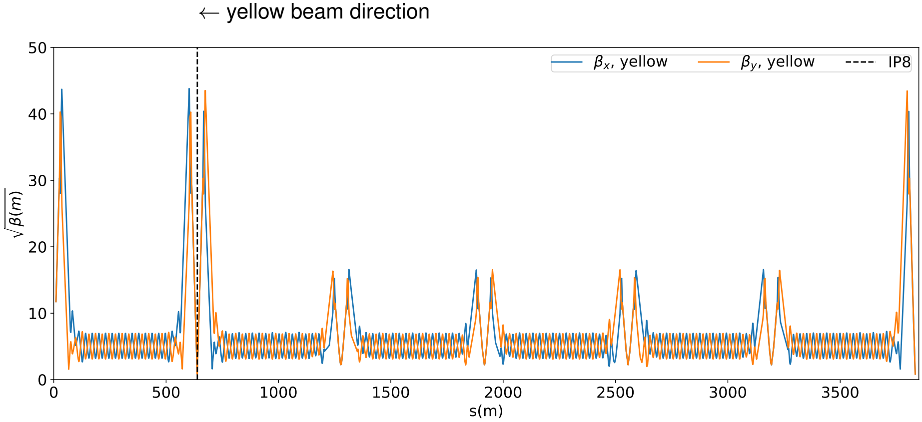
Whatever exits the pipe (doesn't need to be beam Au necessarily), probably exits at the small taper
Geometry does not exclude the larger taper, but would traverse L2->L0

Possible to load the medium pipe with absorber discs? (not *today*, obviously)



From V. Schoefer

100 GeV Au Optics, beta functions



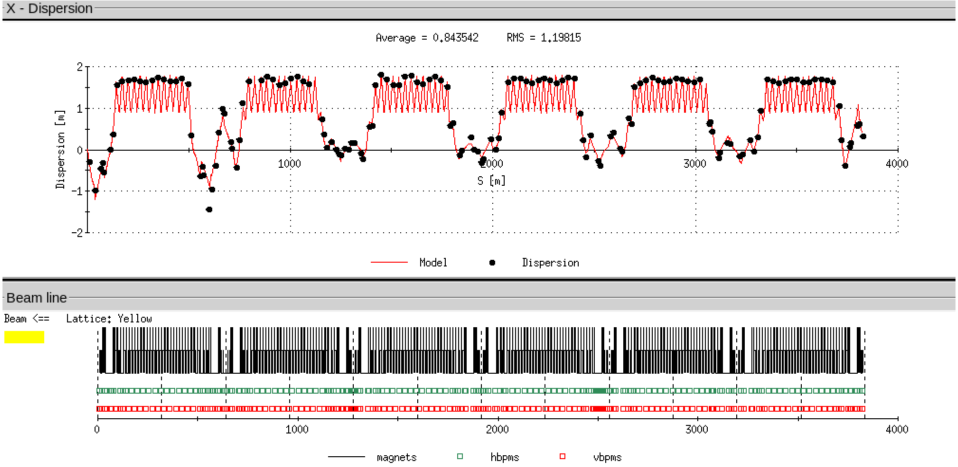
Notes:

IP	6	8	10	12	2	4
β^* (m)	0.7	0.7	5	5	5	5
β(m) (max triplets)	1918	1921	275	274	273	274

- Beam size start of store is $\varepsilon_{RMS,norm}$=2 μm
- Beam size at end of store without cooling is $\varepsilon_{RMS,norm}$=4 μm
- Beam size at end of store with cooling is $\varepsilon_{RMS,norm}$=0.8 μm

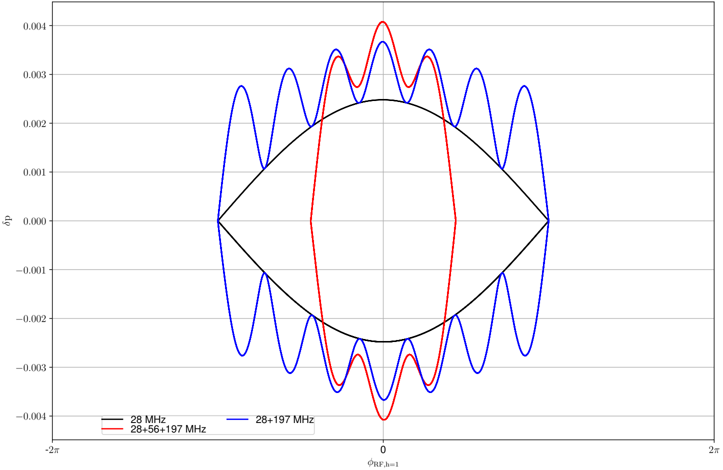
100 GeV Au Optics II, dispersion

Measured dispersion with comparison to model



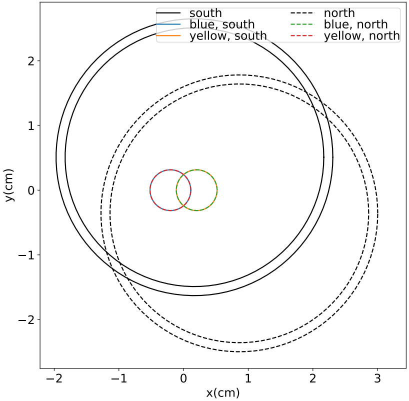
100 GeV Au RF buckets

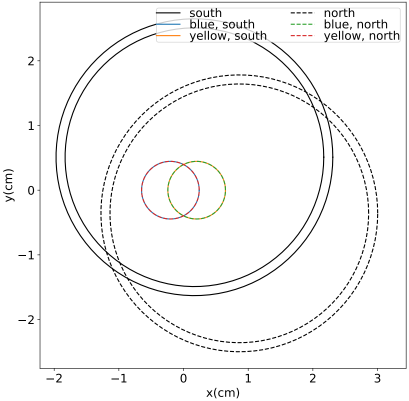
For Au the primary RF is h=360 (28 MHz system), with h=2520 (197 MHz), and the 56 MHz would be h=720.



sPHENIX beampipe with misalignments

At store+6 sigma and including misaligned beampipe, 2um beam (left) 4um beam (right)





Solid lines correspond to IP7 end of beampipe, and dashed lines correspond to IP8 section of beampipe

Notes:

- Blue is closer to the beampipe edge than yellow.
- The misalignment is parallel with the yellow beam

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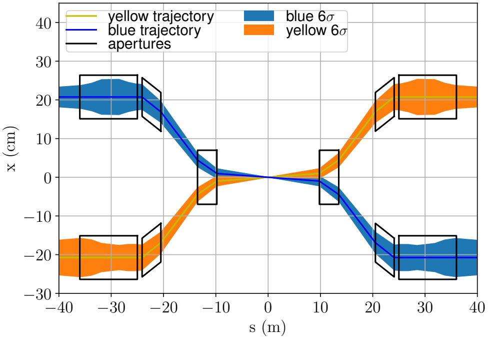
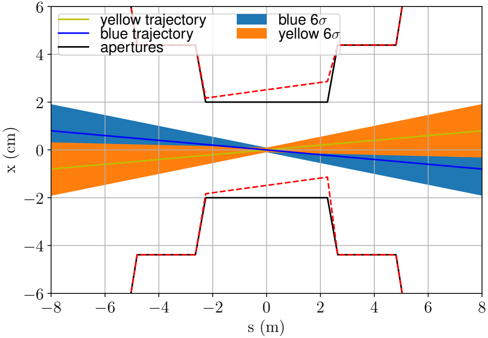
Aperture analysis with misaligned beampipe

End of store without cooling, ϵ=4 um





Notes:

- Extreme case.
- Start of store is half the size and with cooling, there's at least another factor of two.
- Only in this extreme case are we close to scraping in the triplets/DX entrance.

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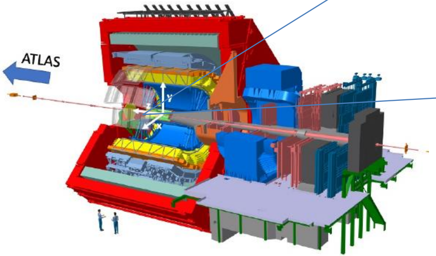
The ALICE Background, I

From R. Bruce

- **Strong background observed in ALICE from the start of the ion run**
  - Some chips of ITS fully saturated, some start getting busy, independently on if ALICE is colliding
  - Effect got worse with rising intensity in the machine
  - About 25% of inner barrel acceptance affected

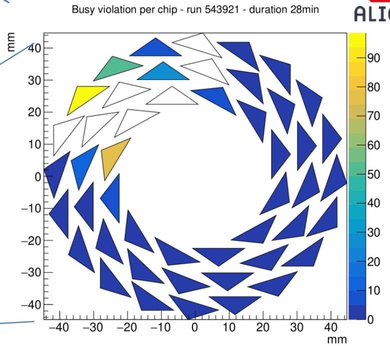
LHC Outer side

ALICE detector



LHC Inner side

Outside of the ring



ITS inner layer during 899b-fill
In white: fully saturated chips, not sending signals

Courtesy of ALICE. From talk by S. Porteboef

The ALICE Background, II

The sPHENIX MVTX detector is equivalent to the ALICE ALPIDE detector (part of Alice's Inner Tracking System).
LHC Run3 and ALICE backgrounds with Pb+Pb (notes from R. Bruce):

- Used orbit bump around IR1 to mitigate vertical dispersion caused by ATLAS crossing angle Simulations show that this bump makes 207 Pb 82+ (reaction with the crystal collimator that causes a neutron to be lost) and miss the vertical tertiary collimator nearest IP.
- Background test this orbit bump gives strong reduction of ALICE background
  - ITS no longer saturated
  - Optimum found when slightly overcompensating the ATLAS crossing angle
- Bump added to the machine configuration in physics
  - ALICE confirmed that background is now manageable even with full machine of 1240 bunches

The sPHENIX Detector

The MVTX Detector

Aperture Analysis

Comparison with MVTX Backgrounds at ALICE

MVTX background Studies

Single beam studies

12 Bunch studies

Summary

Extra Slides

Timeline of MVTX diagnostics

- 10/7, physics running (delayed approximately 5 days due to pulsed power issues)
- 10/8, sPHENIX has 6x6, reports good background status.
- 10/9, sPHENIX has 56x56, reports bad background status, found auto-recovery not enabled. Decision made to install absorber on 10/10.
- 10/10, absorber installed. sPHENIX auto-recovery signal sent to controls bad, fixed 10/11.
- 10/11, no change to sPHENIX backgrounds with absorber installed, reported no change with reduced bunch numbers from 56 to 12. MD to study their backgrounds scheduled. Meeting to discuss backgrounds at 1300. Controls produce MVTX display (Thank you to John, Seth and Wenge).
- 10/12-10/14, studies continue with a single beam (sometimes one in each ring) to diagnose issues.
- 10/15-10/21, studies with 12+ bunches in one/both rings.
- 10/11&10/14&10/18, meetings to review status of current studies. Task force formed.
- 10/21, end of RHIC run.

Baseline auto-recovery values

Beam	Number of Bunches	Average auto-recovery rate
Blue and Yellow	111x111	1.43+
Blue and Yellow	56x56	1.43
Blue	56	0.30
Yellow	56	1.23
Blue and Yellow	12x12	1.19
Blue	12	-
Yellow	12	1.20
Blue and Yellow	1x1	0.61
Blue	1	0.13
Yellow	1	0.42

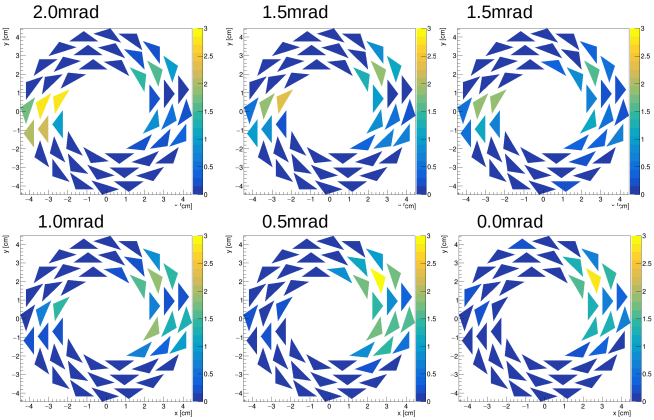
Average auto-recovery rate of 3 means all 48 staves are in constant auto recovery.

Nominal 111x111 translates to almost 50% of staves in constant auto recovery.

Single yellow studies were needed to get the majority of staves out of constant auto-recovery.

Crossing angle scan

Summary plots from C. Dean.



- Observed change in distribution of auto corrections with change in crossing angle.
- 1 mrad slightly better than rest.

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Single beam studies

Beam	Study	auto-recovery	vs. baseline
Blue and Yellow	no rebucketing	0.46	1.33
Yellow	no rebucketing	0.36	1.17
Yellow	(+) radius change	0.83	0.51
Yellow	(-) radius change	0.28	1.50
Yellow	(+) single bump (yi11-bh15)	0.65	0.65
Yellow	(-) radius change, (-) bump (yo8-bh14), 1 mrad	0.083	5.06
Yellow	above with 12 bunches	1.2	-
Yellow	Collimators moved in	0.95	-
Yellow	Collimators moved out	0.75	-

- With achieved factor of 5 improvement, decided to advance to 12 bunches.
- Radius change proved to be inconsistent.
- Attempts to improve on this final configuration were unsuccessful.

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The MVTX Detector

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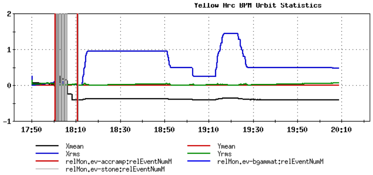
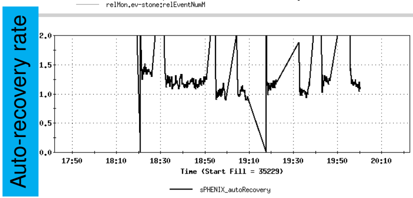
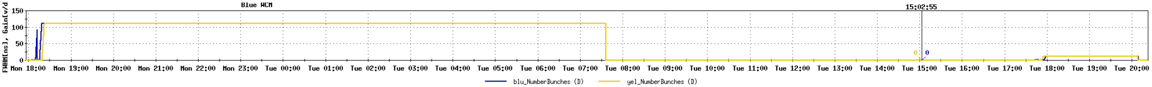
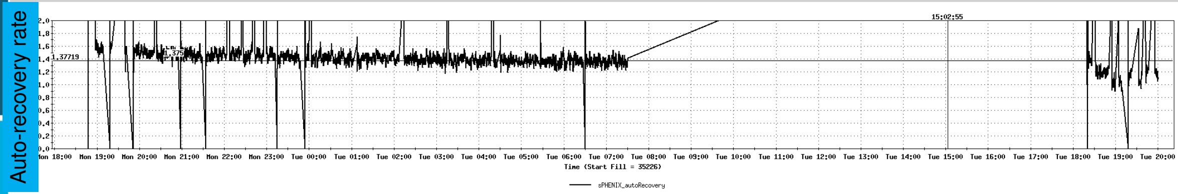
Unsqueeze of IP8

- Dedicated ramp to go into 5 m β^* at IP8 (nominal $\beta^* = 0.7$ m
- -0.4 mm yellow xarcMean ; -8 mm yo8-bh14 bump marginal improvement over 111 bunches.
- Bottom plot shows a comparison of 111x111 bunches for physics (left) with 12x12 with unsqueezed IP8 (right)
- No radial offset better (from this session).
- Switched to triggered mode after 2130.



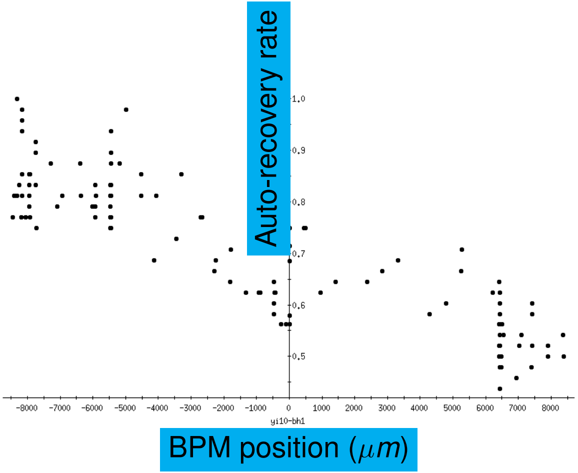






Squeeze of IP10

- Squeeze of IP10 provided marginal gains over nominal setup (30% improvement)
- Addition of a horizontal bump through the IP provided extra gains.
- A +7 mm bump is almost x2 improvement, -7 mm is almost equivalent to unsqueezed IR10 baseline.
- Takeaway: upstream squeezed IR can affect backgrounds (blue comes from the squeezed IP6)



Autorecoveries during IP6 triplet horizontal position scan

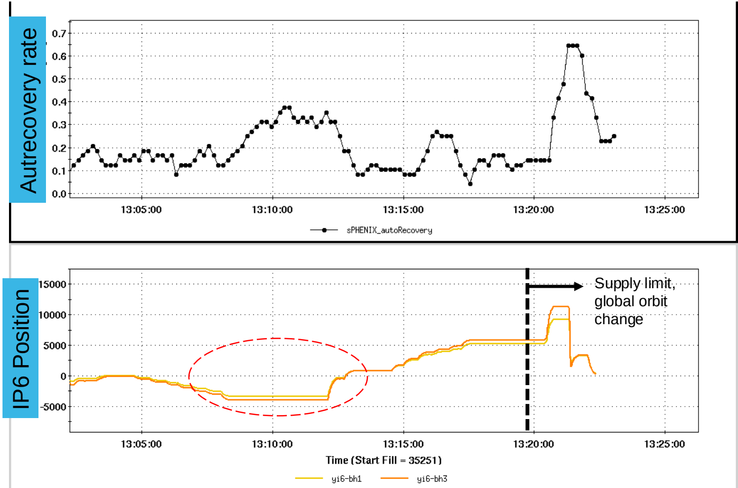
From V. Schoefer

Test was motivated by this side of IP having negative dispersion (Chuyu), this is different from the arc (10/18/2024)

Pre-fire protection bump is powered at full amplitude while this is happening

13:10: -5 mm bump in direction of dispersion, causes increase in autorecoveries (beam loss rate, not shown, goes from 5% baseline to 20% during the scraping.)

This scraping at yi6 triplet generate *something* that makes it around 5 arcs into sPHENIX MVTX.

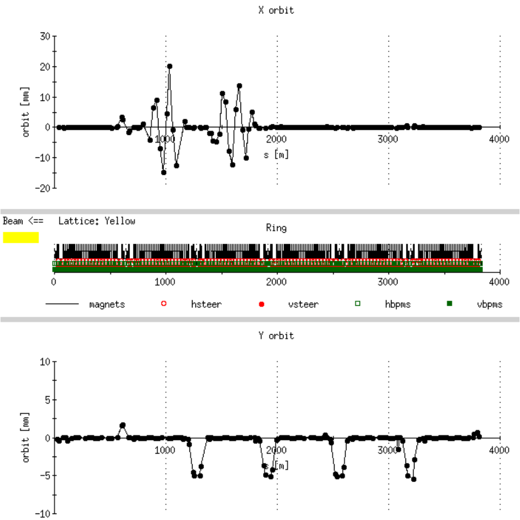


Suggests that Au interactions with matter produces a broad enough swath of phase space coordinates, including rigidity that some get scattered at least one turn *past the pre-fire bump into the MVTX.*

The point here is that our intuitions about 'what makes it' probably don't include rare, extreme combinations of phase space coordinates.

Prefire protection bump

- The prefire protection bump was used in Run16.
- In the event of a prefire of the abort kicker, particles that received a partial kick from the abort kickers would be deposited at the maximum amplitude of the bump instead of the detectors.
- This lead to a diode failure mid-run and 19.5 days of failure to replace it.
- This was tested with less than 111 bunches and low intensity.



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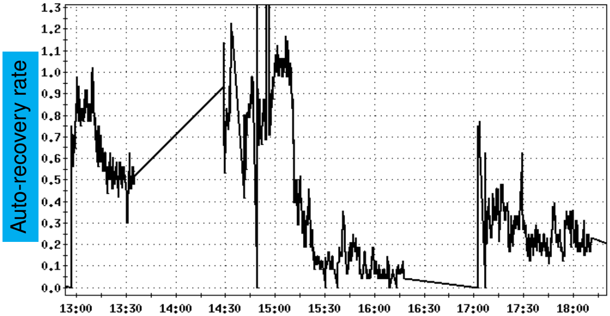
Prefire protection bump, II

- With bump and local steering were able to get MVTX to near zero auto-recoveries.
- Amplitude of prefire bump changed, found to be optimal.
- Without bump, same local steering, and 3-bumps in the arcs were not able to get to the level of the prefire protection bump (x3 higher)



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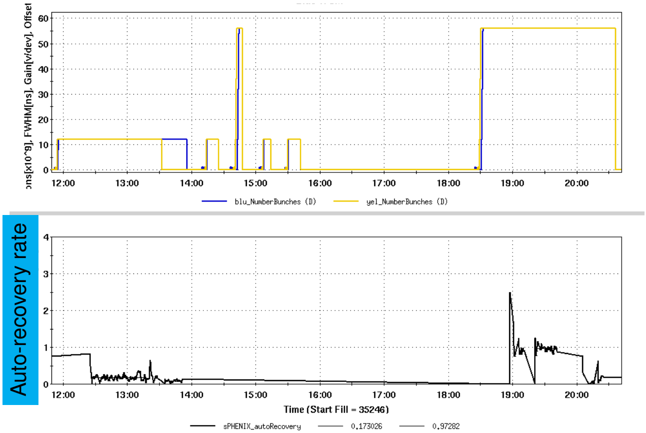
Scaling local orbit with PFP to 56 bunches



- The solution for 12 bunches was not suitable with 56 bunches.

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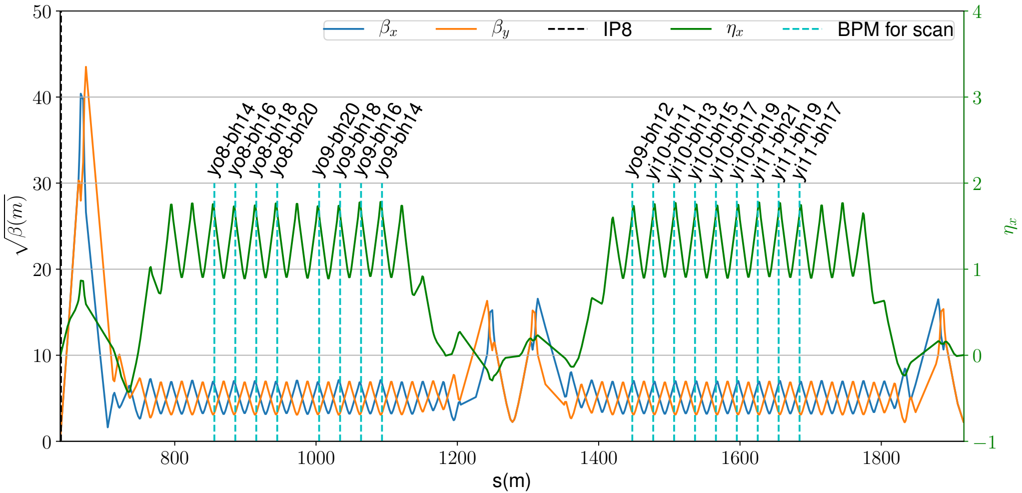
Prefire Protection bump with local steering, summary

The best results were from the prefire protection bump and local orbit steering, summarized in table below.

	Average auto-recoveries	Improvement over baseline
baseline 12 bunches (y)	1.2	-
prefire protection bump (b+y)	0.76	1.6x
prefire protection bump (y)	0.77	1.6x
prefire bump+local steering (y)	0.067	17.9x
prefire bump+local steering (b+y)	0.164	7.3x
local steering only (b+y)	0.72	1.7x
56 bunches (b+y)	0.98	1.46x (0.17x compared to 12 b+y bunches)

- Did not scale well with 56 bunches.
- Current understanding is the bump reduced the population of the high-momentum particles and the orbit steering mitigate the remaining particles from being lost on the taper/MVTX.
- Individual 3-bumps in the arcs from IP8 to IP12 had a 10-20% improvement on MVTX backgrounds depending on the phase+sign.

Scan of bumps IP8 to IP12, optics



3-bumps generated at each available horizontal BPM at ±10 mm.

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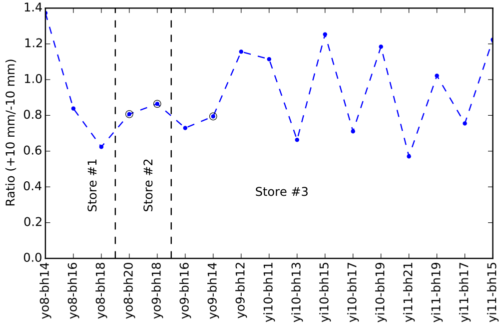
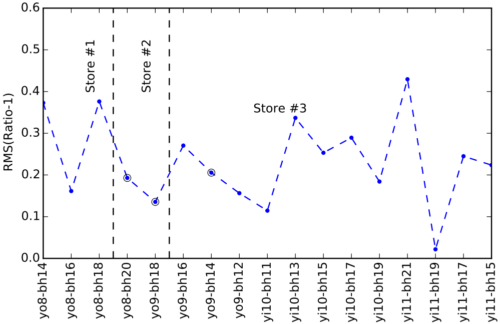
Scan of bumps IP8 to IP12, II

Ratio defined as

$$\text{Ratio} = \frac{\text{auto} - \text{recovery rate}(+10\text{mm})}{\text{auto} - \text{recovery rate}(-10\text{mm})} \quad (1)$$

RMS(Ratio-1) gives the strength of each corrector whereas the ratio gives favor to + or - polarity (+Ratio→ -bump preference)





Circled data points have data quality issues.

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sPHENIX MVTX Backgrounds studies, summary

Studies performed and their implications

Study	Summary
Yellow only studies	High backgrounds even with single bunch $\rightarrow$ prompted single yellow bunch studies
Blue only studies	Significantly lower backgrounds than with yellow, 56 bunches in blue better than single yellow bunch $\rightarrow$ primarily sourced by yellow
Unrebucketed beam	Improved auto-recoveries $\rightarrow$ affected by bucket area
Local steering (position and angle)	Significant reduction in auto-recovery rate $\rightarrow$ losses can be moved locally and redistributed
Unsqueeze of IP8	No significant change $\rightarrow$ losses not the result of local scraping in triplet or local dispersion
Squeeze of IP10	Small change in auto-recoveries with the addition of a bump at IP10 $\rightarrow$ particles can be lost at upstream squeezed IR
Bump at IP6 triplet	50% change in auto-recoveries with -5 mm bump in triplet $\rightarrow$ background affected by conditions 5 arcs away
Adjustment of global octupoles	Little to no effect $\rightarrow$ not from high betatron amplitude particle
Prefire protection bump	Significant reduction when combined with local steering and 12 bunches (did not scale to 56 bunches)$\rightarrow$ off-momentum particle
Bump scan in dispersive region	reduction in auto-recoveries $\rightarrow$ phase of prefire protection bump may not be optimal & bumps far upstream affect backgrounds

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MVTX Streaming vs Triggered Mode

MVTX – design in sPHENIX to run in streaming mode with 5-10 microsecond strobe. In that case, 100% of “big splash” events will cause an auto-recovery.

If we can run in triggered mode (which is supported), the auto-recoveries will only be if there is a “big splash” event coincident with a triggered event within ~5 microseconds.

Thus, if we run the DAQ rate at 2 kHz, one only sees 2e3 x 5e-6 = 1% of “big splash events”, and so auto-recovery rate is expected to be **100x** lower.

The sPHENIX Au+Au plan is for a DAQ rate of 15 kHz, which still should reduce the auto-recovery rate by **13x**.

This effort is completely multiplicative in benefit to any reduction in the “big splash” event rate by C-AD.

from J. Nagle

The sPHENIX Detector

The MVTX Detector

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Extra Slides

Summary

- Daily studies from its discovery to diagnose the cause of backgrounds, and mitigate its effect.
- Initial studies were done with single bunch(es) to have the staves sufficently far from saturation.
- The best achieved reduction used a combination of local steering at IP8 and the prefire protection bump, a factor of 10x reduction with 12 bunches.
- Studies indicated that the loss particle is from a large off-momentum particle.
- This solution scaled with increased intensity up to 56 bunches, not usable for sPHENIX in streaming mode.
- Operating the MVTX in triggered mode can provide a further reduction in auto-recoveries.
  - Suitable for Au+Au, not suitable for p+Au which intends to use streaming mode.

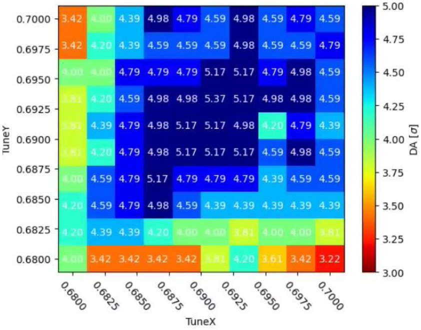
For updates, see A. Drees "sPHENIX MVTX experimental background task force"

MAC-20 Recommendation

R3 (p+p luminosity maximization for sPHENIX)
Prioritize the modeling of β^*=50 cm (and intermediate) optics aiming at achieving the desirable dynamical aperture before Run-24.

- Simulations prior to Run24 were performed with β^*=50, 60, 70, and 85 cm (85 cm being baseline) with intensities ranging from 2×10^{11} to 3×10^{11} protons/bunch.
- Simulations results shown at MAC-20 were preliminary and unintentionally had IP6 and IP8 squeezed to β^*=50 cm.
- β^*=50 cm had insufficient DA at 2×10^{11} protons/bunch.
- Prior to run, β^*=60 cm had sufficient DA at 2×10^{11} protons/bunch.

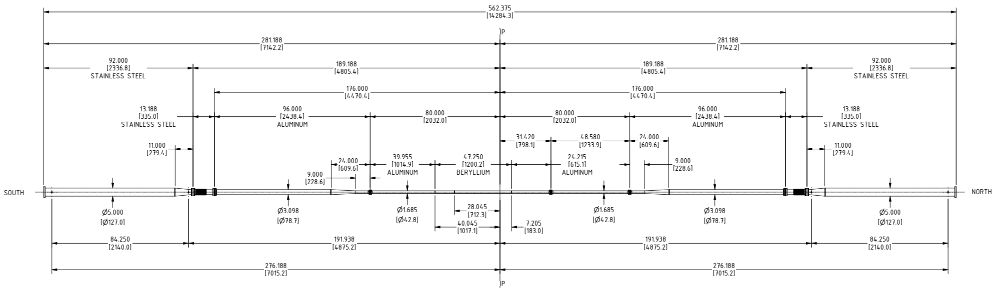
Blue-60cm-2E11-2mrad

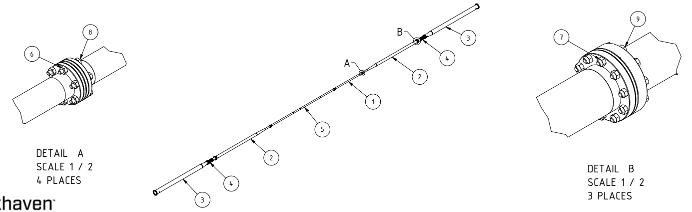


Thank you

Thank you and questions.

sPHENIX beampipe Geometry, reference





ITEM	QTY	PART NUMBER	DESCRIPTION
9	40	ANSI/ASME B18.2.1 - 5/16-18 UNC - 2, HBI	Hex Bolt - UNC (Regular Thread - Inch)
8	18	ANSI/ASME B18.2.1 - 1/4-20 UNC - 1.5, HBI	Hex Bolt - UNC (Regular Thread - Inch)
7	40	ANSI B18.2.2 - 5/16 - 18, HNI	Hex Nuts (Inch Series) Hex Nut
6	18	ANSI B18.2.2 - 1/4 - 20	Hex Nuts (Inch Series) Hex Nut
5	1	44035019 REV A	1,7 OD STAR BP ASM
4	2	42035000-03 REV C	SS, 3 in OD, BELLOWS ASM
3	2	205-0800-0273	SS, 5 in OD, BEAM PIPE
2	2	205-0800-0272	AL, 3 in OD, BEAM PIPE
1	1	205-0800-0271	AL, 1.7 in OD, BEAM PIPE

BILL OF MATERIALS

THIRD ANGLE PROJECTION

sPHENIX

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES
UPTON, NY 11973

INTERPRET IN GENERAL ACCORDANCE WITH ASME Y14.5-2009
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS ARE IN INCHES [mm]
DECIMAL TOLERANCES
X.X ± 0.05
X.XX ± 0.01
X.XXX ± 0.005

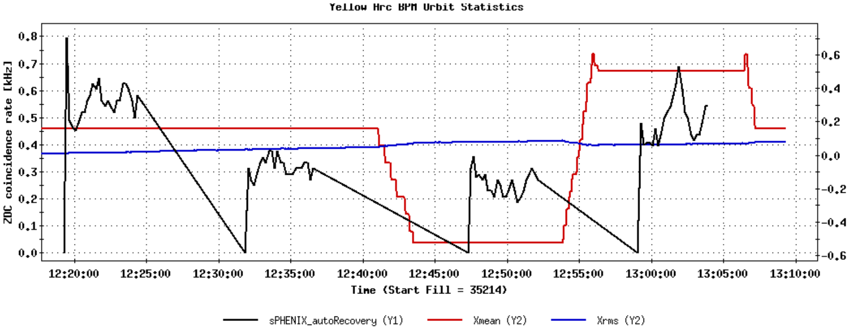
DRAWN BY:
CHECKED BY:
ENGINEER APPROVAL:
SUPERVISOR APPROVAL:
DESIGN APPROVAL:

PROJECT: Facilites
DESCRIPTION: Beam Pipe ASM
SIZE:
DRAWING NUMBER:

Brookhaven National Laboratory

Yellow only studies I

1x1 B+Y   Yellow, nominal radius   -0.5 mm   +0.5 mm



- Radius change confirmed Friday’s results
- -0.5 mm slightly better but beam losses near IR slightly higher. Orbit slightly different than Friday.
- +0.5 mm noticeably worse.
- Repeat study with 12 bunches to have a better measure of losses.
- Insert bump to see if losses can be further improved.

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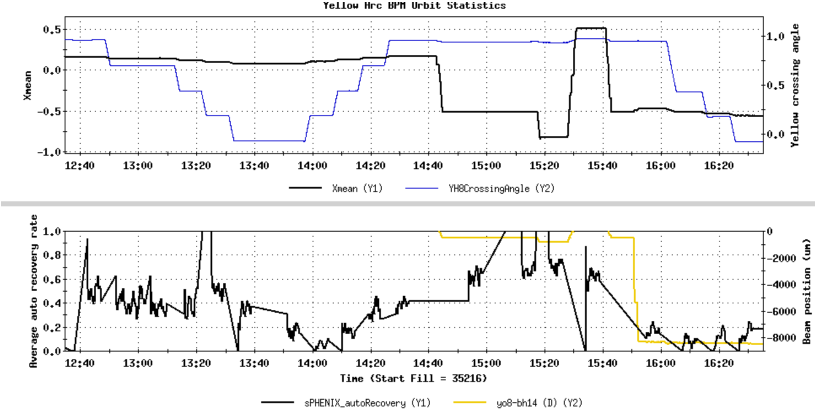
Yellow only studies II

1x1 B+Y Y crossing θ radius scan angle scan, -8 mm arc bump



- Radius change confirmed Friday's contrasted with Friday+Saturday's findings.
- sPHENIX background meeting this afternoon.
- Radius change (benign), reduced crossing angle (1 mrad) and small bump at yo8-bh14 (-8 mm) largely reduced the backgrounds.

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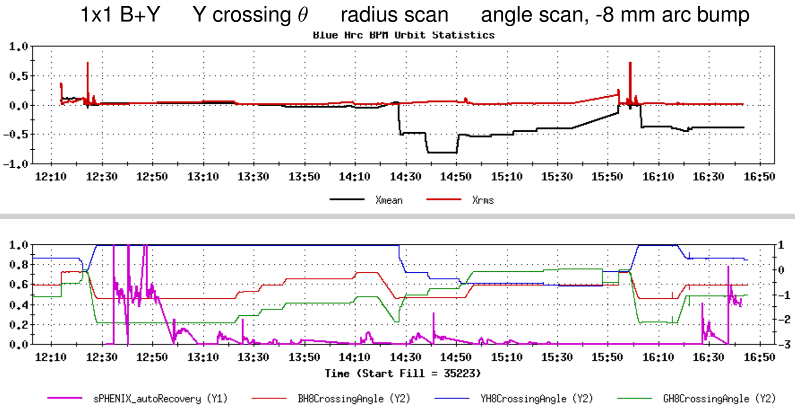
Blue only studies



- Different in radius is suitable for blue.
- Marginal change with changes in crossing angle (1 mrad is an improvement over 2)
- Configuration with -0.4 mm radius, -8 mm bump at yo8-bh14, and 1 mrad crossing angle appears optimal with both beams.

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