Synchrotron radiation background in the experiments

Francesco Collamati, Manuela Boscolo, Helmut Burkhardt

ALBA, November 2016

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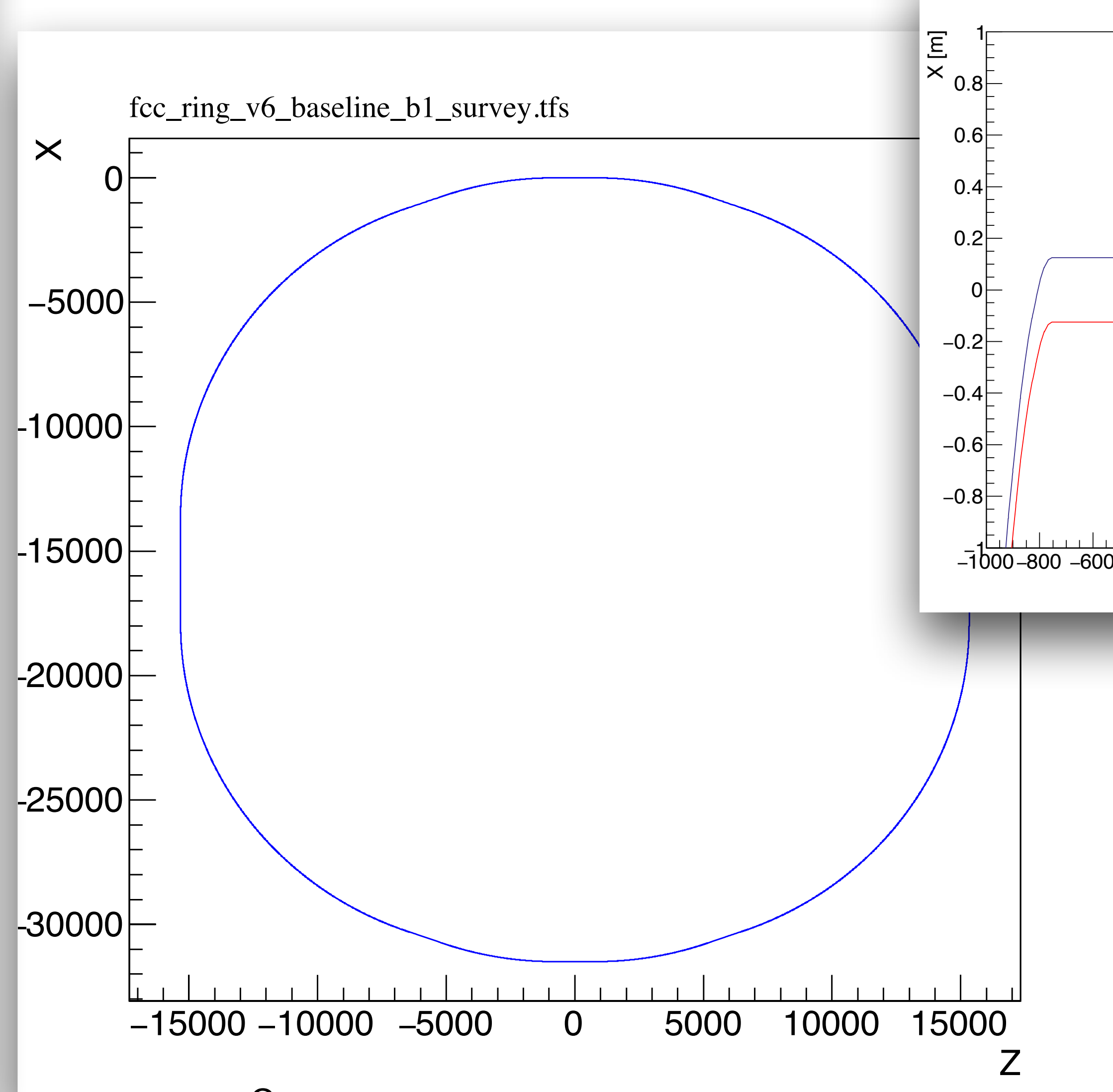
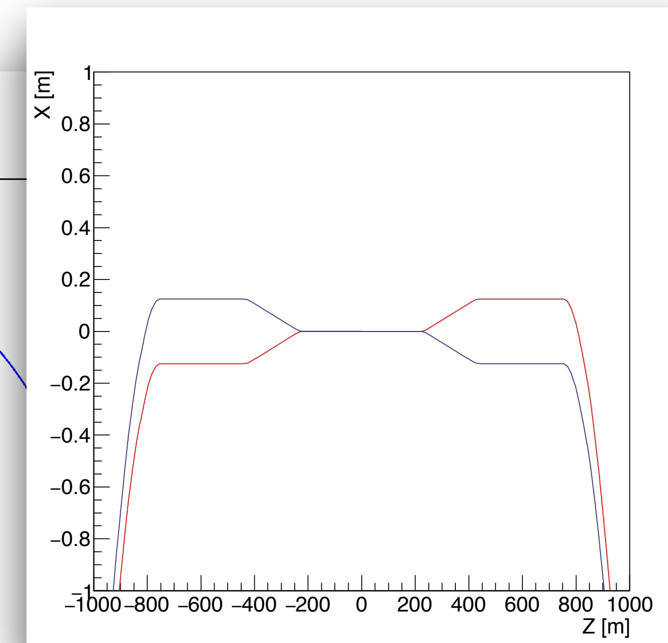
Beam parameters

```
@ NAME               %05s "TWISS"
@ TYPE               %05s "TWISS"
@ SEQUENCE           %08s "FCC_RING"
@ PARTICLE           %06s "PROTON"
@ MASS               %le           0.938272046
@ CHARGE             %le                     1
@ ENERGY             %le                 50000
@ PC                 %le      49999.9999911965
@ GAMMA              %le      53289.4486339626
@ KBUNCH             %le                 10600
@ BCURRENT           %le   4.79502351385978e-05
@ SIGE               %le                     0
@ SIGT               %le                     0
@ NPART              %le          100000000000
@ EX                 %le   4.12839700312689e-11
@ EY                 %le   4.12839700312689e-11
@ ET                 %le                     1
@ LENGTH             %le      100170.614199044
@ ALFA               %le  0.000101112451618679
@ ORBIT5             %le                    -0
@ GAMMATR            %le      99.4483723902716
@ Q1                 %le       111.3103836898
@ Q2                 %le      108.319735822487
@ DQ1                %le     0.704766620174269
@ DQ2                %le      2.53678571482396
@ DXMAX              %le      15.1732173929165
@ DYMAX              %le      14.9243069125305
@ XCOMAX             %le    0.0137550431615374
@ YCOMAX             %le    0.0137449902569815
@ BETXMAX            %le      79717.6528109933
@ BETYMAX            %le      80231.1846763345
@ XCORMS             %le  0.000356215756222975
@ YCORMS             %le  0.000359222411426776
@ DXRMS              %le      1.83029943789494
@ DYRMS              %le     0.736053497810314
@ DELTAP             %le                     0
@ SYNCH_1            %le      10.1229915726241
@ SYNCH_2            %le  0.000600932166177875
@ SYNCH_3            %le   5.73672334655025e-08
@ SYNCH_4            %le    9.2355347923506e-08
@ SYNCH_5            %le   1.16651985634425e-09
```

- 50 TeV protons
- Optics version:
    - *fcc_hh_v6_45*





Beam parameters

	FCC-hh Baseline	FCC-hh Ultimate
Luminosity L [$10^{34}cm^{-2}s^{-1}$]	5	20-30
Background events/bx	170 (34)	<1020 (204)
Bunch distance Δt [ns]	25 (5)	
Bunch charge N [10^{11}]	1 (0.2)	
Fract. of ring filled η_{fill} [%]	80	
Norm. emitt. [μm]	2.2(0.44)	
Max ξ for 2 IPs	0.01 (0.02)	0.03
IP beta-function β [m]	1.1	0.3
IP beam size σ [μm]	6.8 (3)	3.5 (1.6)
RMS bunch length σ_z [cm]	8	
Crossing angle [σ□]	12	Crab. Cav.
Turn-around time [h]	5	4

source: FCCweek16

Beam parameters

parameter	FCC-hh		SPPC	HE-LHC* (*tentative)	(HL) LHC
collision energy cms [TeV]	100		71.2	>25	14
dipole field [T]	16		20	16	8.3
circumference [km]	100		54	27	27
# IP	2 main & 2		2	2 & 2	2 & 2
beam current [A]	0.5		1.0	1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25	25
beta* [m]	1.1	0.3	0.75	0.25	(0.15) 0.55
luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	5	20 - 30	12	>25	(5) 1
events/bunch crossing	170	<1020 (204)	400	850	(135) 27
stored energy/beam [GJ]	8.4		6.6	1.2	(0.7) 0.36
synchrotr. rad. [W/m/beam]	30		58	3.6	(0.35) 0.18

source: FCCweek16

STARTING POINTS

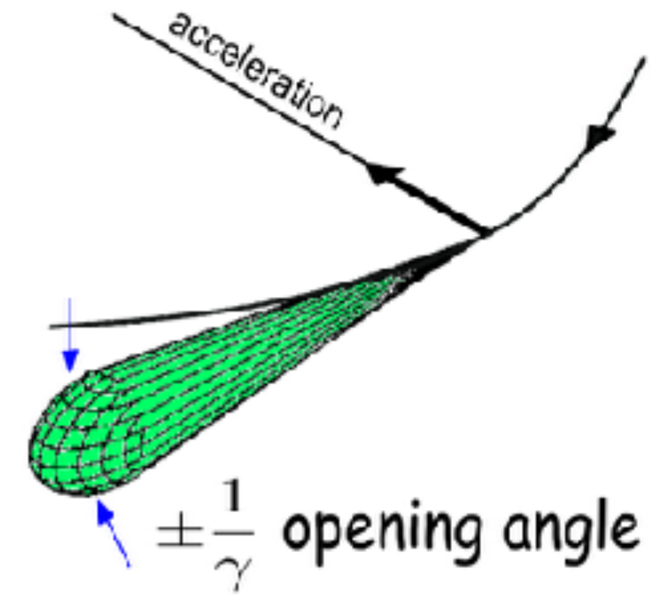
STARTING POINTS

- The synchrotron radiation **cone** is very **narrow**:

$$\gamma_p = \frac{E_p}{m_p} = \frac{50TeV}{938MeV} \sim 5 \times 10^4$$

$$\frac{1}{\gamma_p} \sim 1.9 \times 10^{-5} rad \sim 10^{-3} deg$$

$$\theta_{BEND} = 3 \times 10^{-4} rad$$



➡ We assume the SR to be “pencil beam”-like (lying on horizontal plane only)

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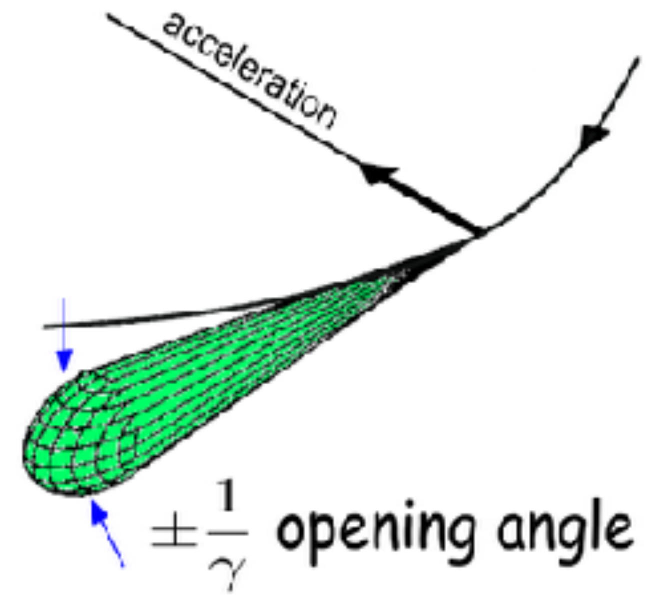

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- Critical energy in zone of interest is around **1 keV** (E_{mean}~0.3keV)

  ➡ All photons hitting the pipe are **locally absorbed** without reflection

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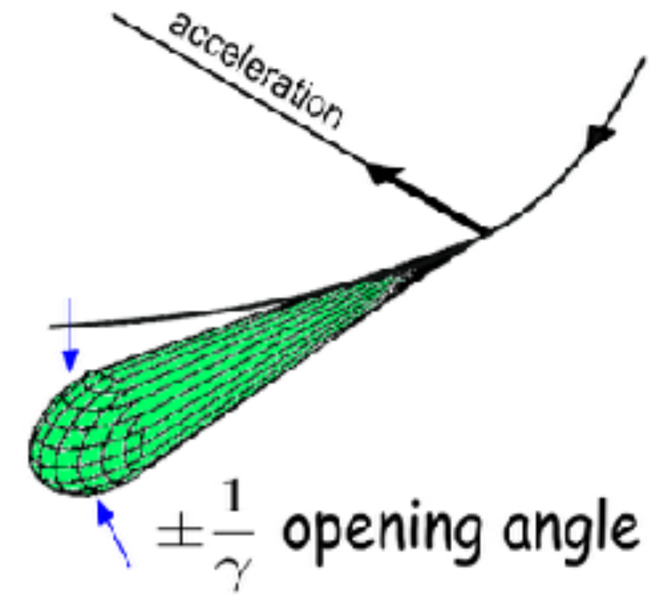

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- Critical energy in zone of interest is around **1 keV** (E_{mean}~0.3keV)

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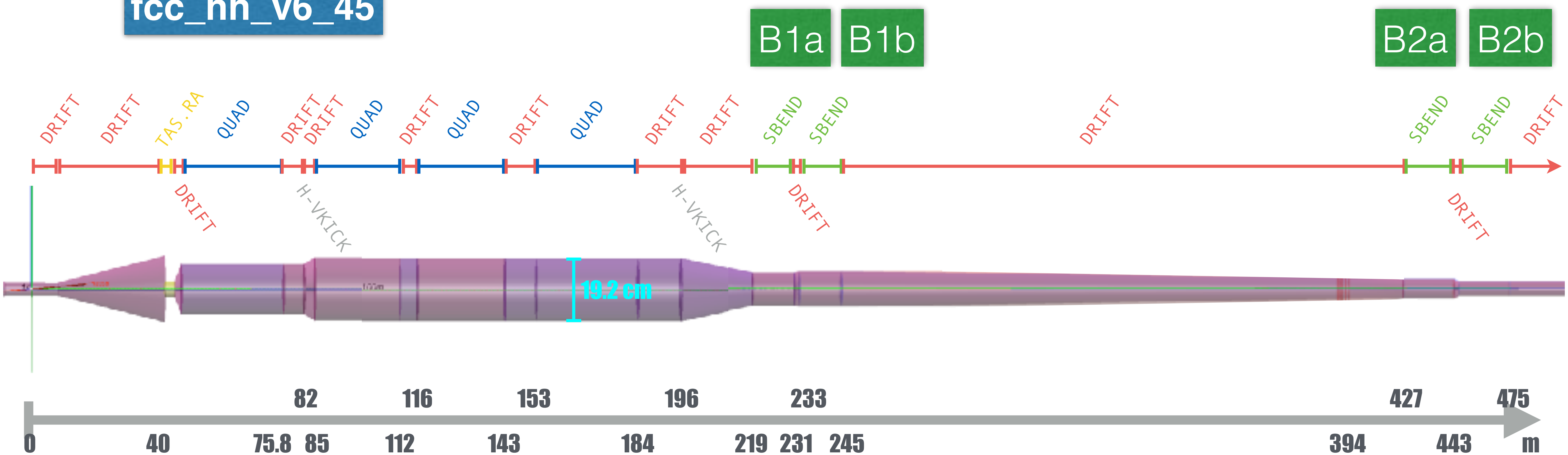
- Only particles entering the TAS can in principle reach the experiments

  ➡ We focus on particles **entering the TAS**

BEAM PIPE SCHEME FROM MADX

optics used:
fcc_hh_v6_45



- B=4.27 T
- L=12.5 m
- ϴ=-0.3 mrad
- E_C=1.146 keV
- N_γ/proton=0.1795
- P=32 W
- E_{TOT}=6.34 TeV

- B=3.56 T
- L=15 m
- ϴ=0.3 mrad
- E_C=0.95 keV
- N_γ/proton=0.1795
- P=27 W
- E_{TOT}=5.28 TeV

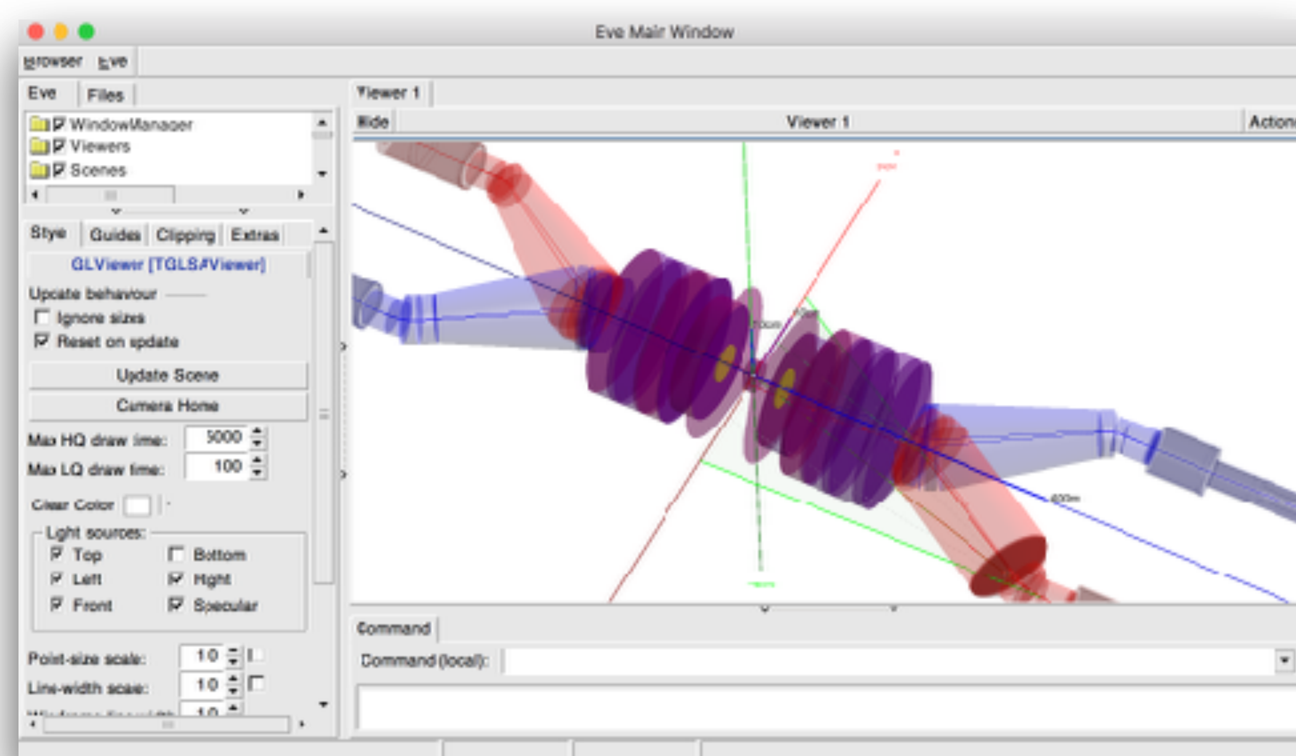
- 5486 Bends in the lattice:
  - All but 4 “strong” (~16T)
  - 4 “soft” (~4T) near the IP

First approach: MDISim

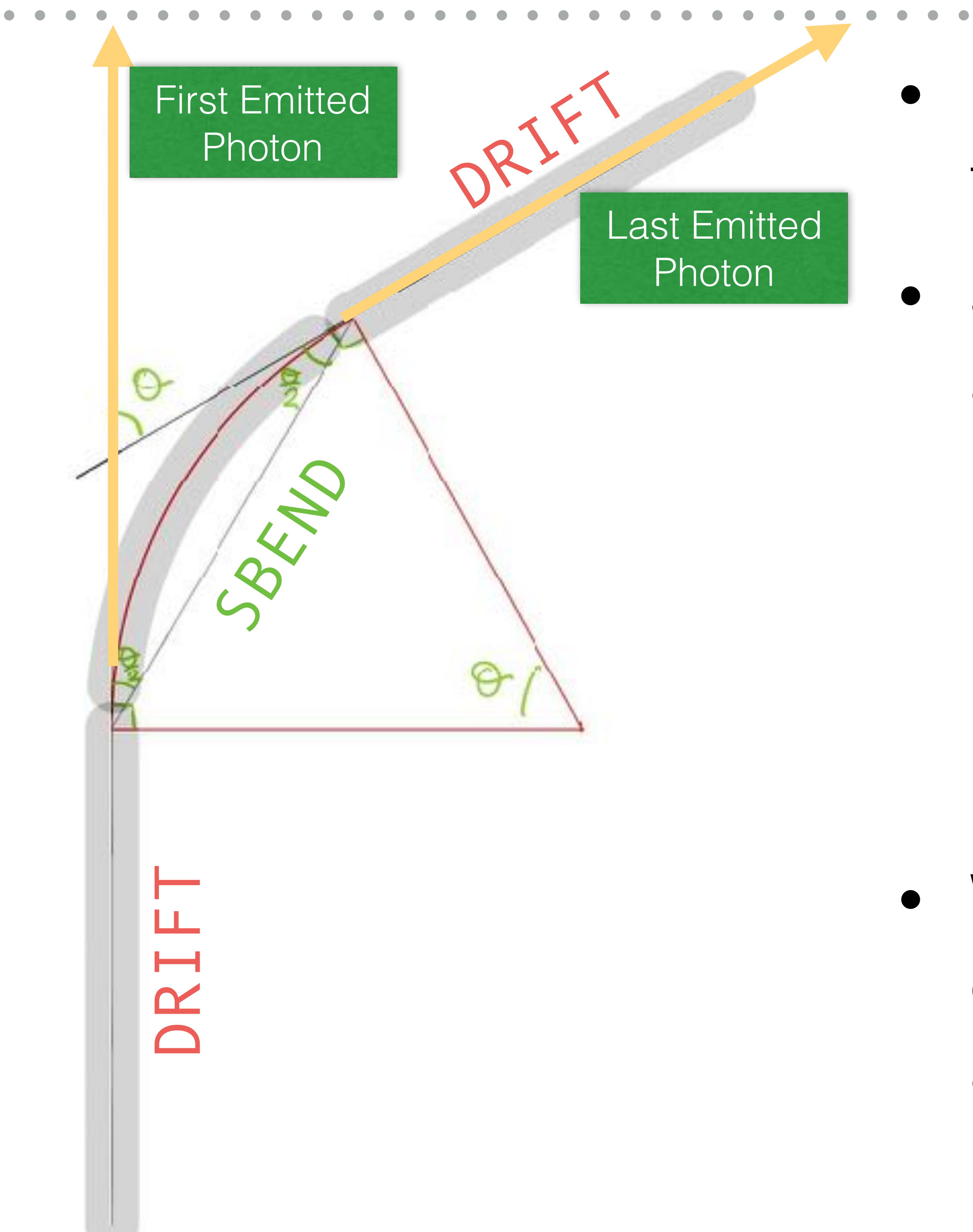
MDISim TOOLKIT

- Developed by *Helmut Burkhardt* (CERN), is a set of C++/Root classes that allow to:
    - Run Madx on the desired lattice of the FCC
    - Read Madx output, plot the lattice
    - **Calculate Synchrotron Radiation** (Power Radiated, Critical Energy..) and plot it over the geometry using Root's TEve
- Import geometry and SR in Geant4 to perform full simulation

link



PHOTON DISTRIBUTION



- Neglecting the aperture of the SR cone..
- SR Photons are emitted in an area of θ
  - same angle as the bending magnet!
  - we refer to this area as "cone"
- We assume photons are emitted isotropically in this area

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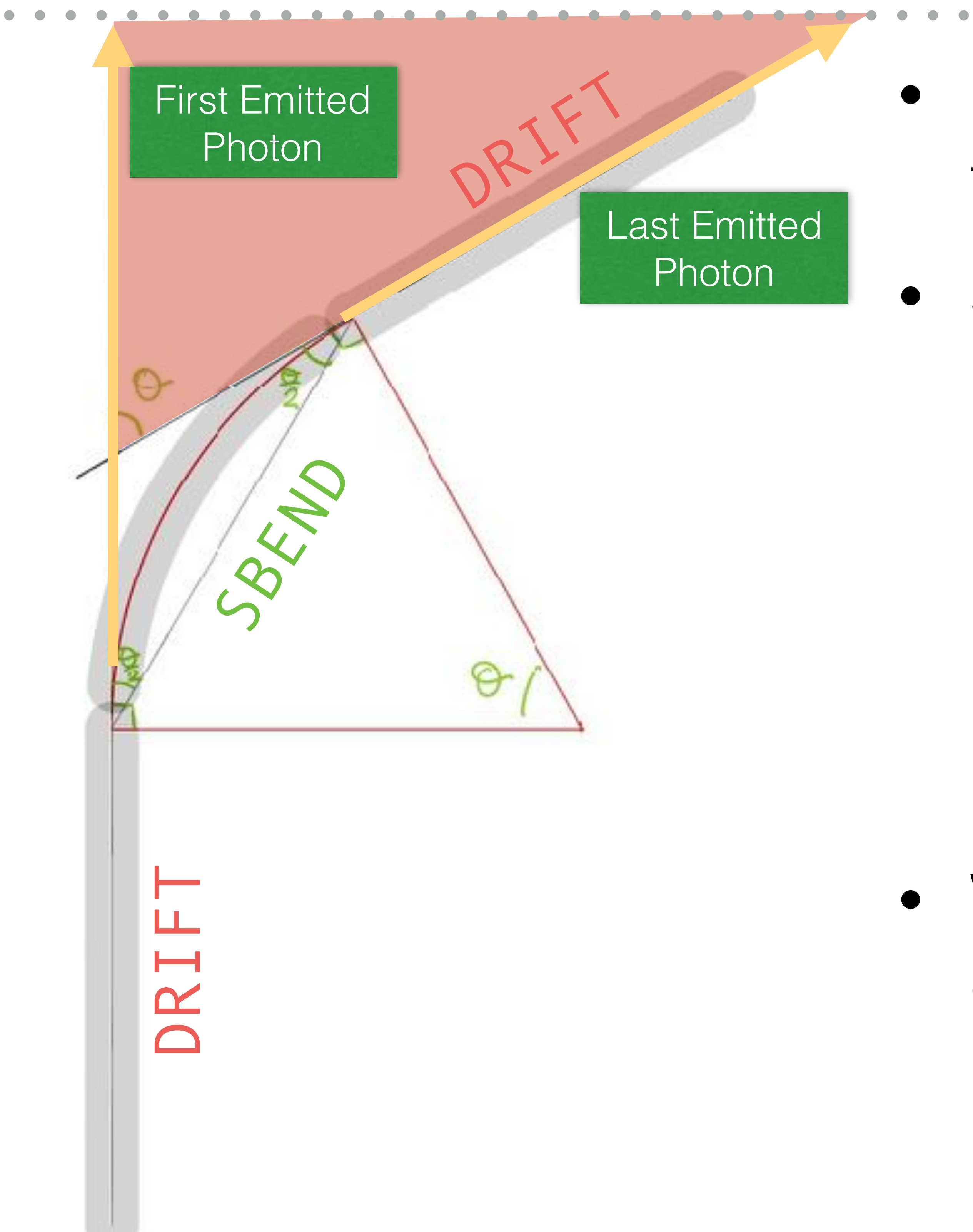

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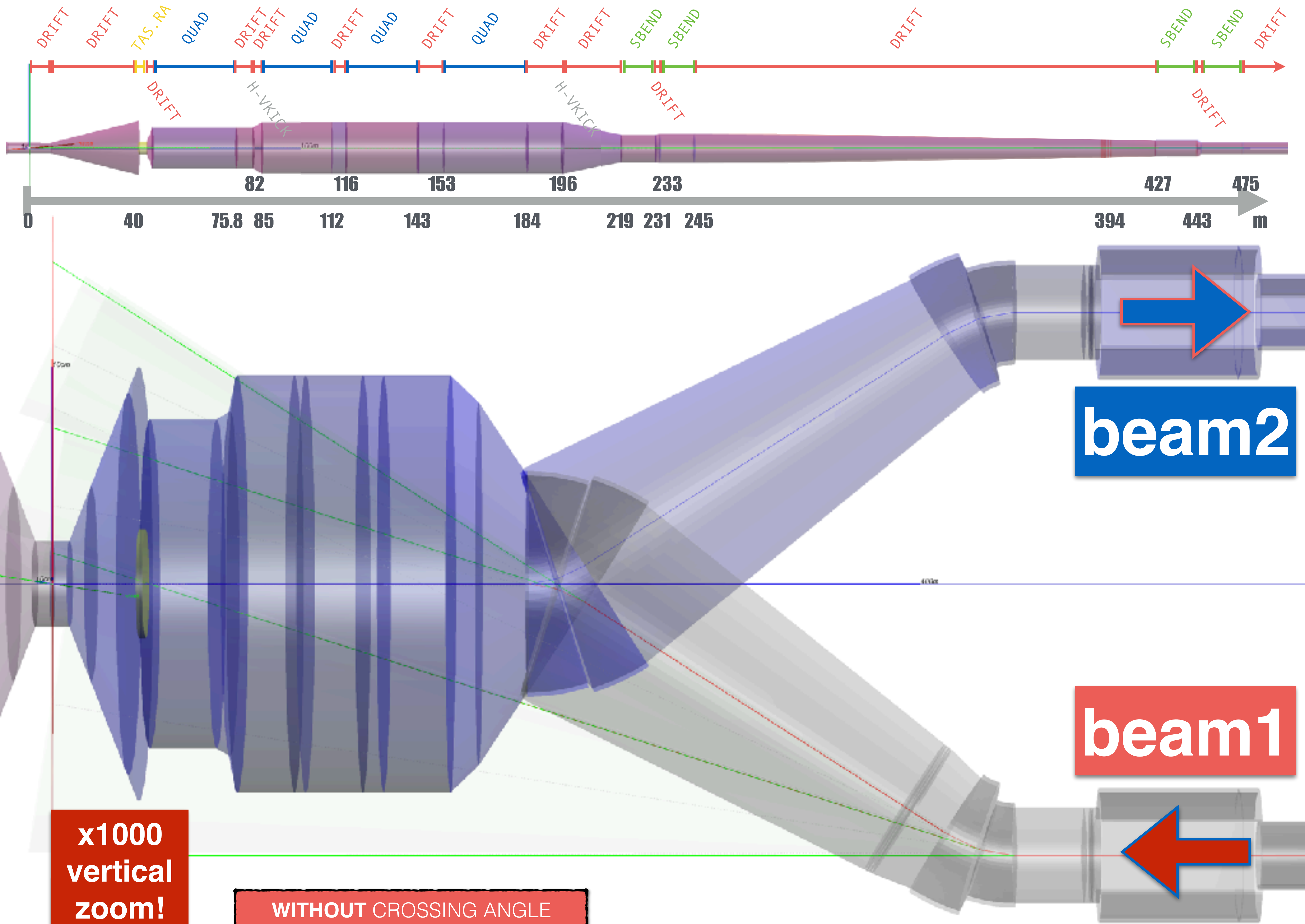
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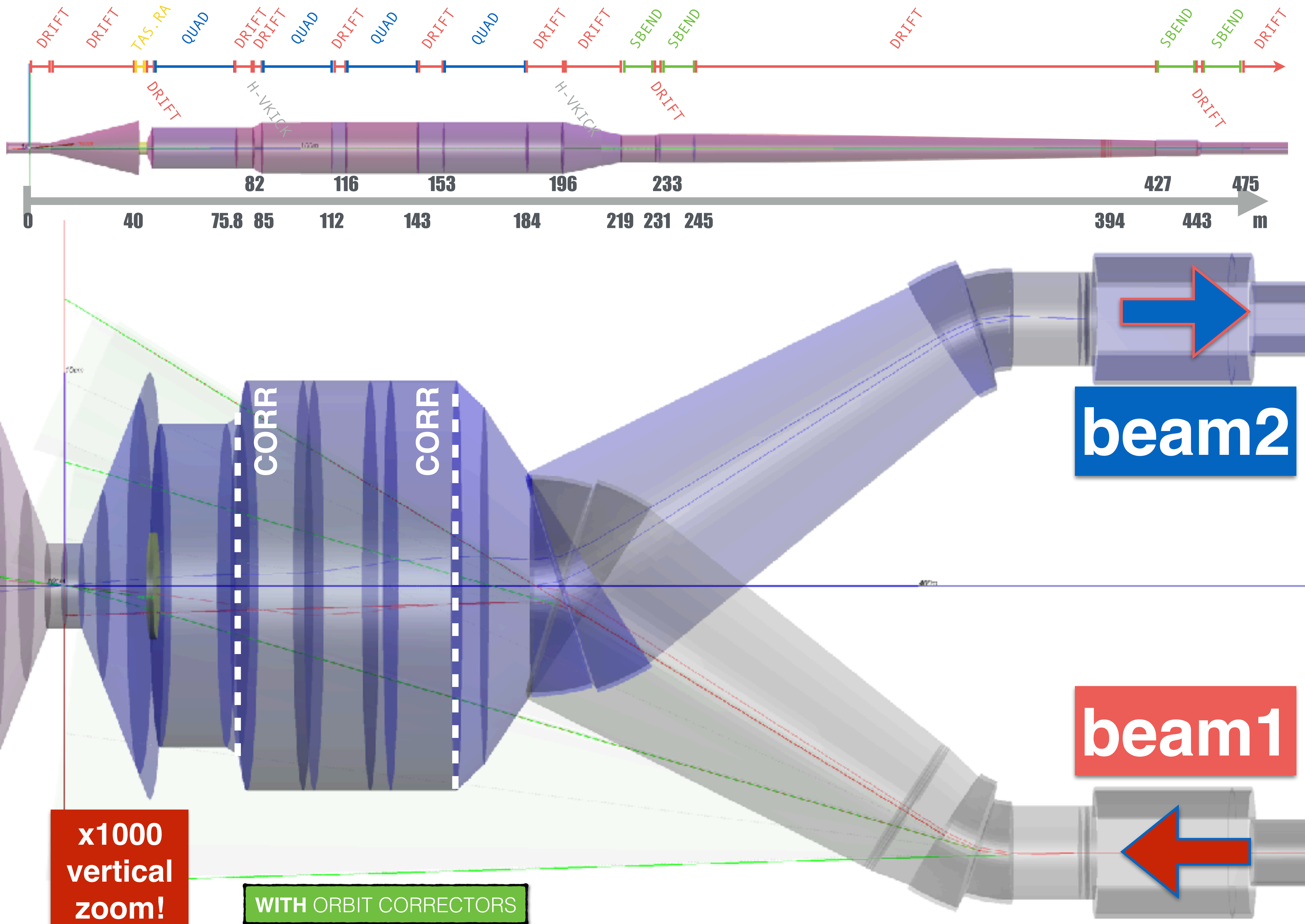
m
beam2
beam1
x1000 vertical zoom!
WITHOUT CROSSING ANGLE



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143
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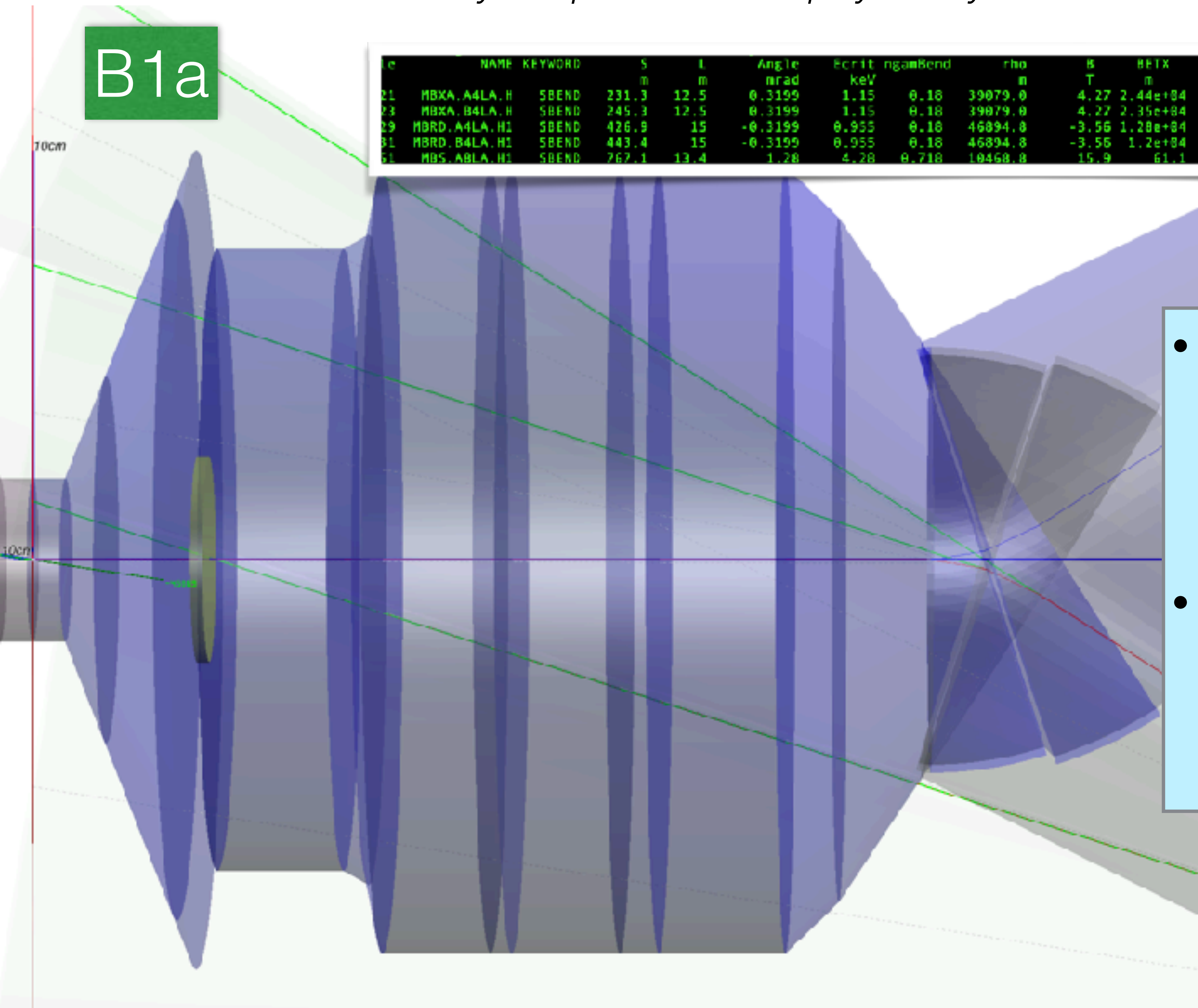
231
245
394
443
m
CORR
CORR
beam2
beam1
x1000 vertical zoom!
WITH ORBIT CORRECTORS

Solid angle evaluation

“How many SR photons can physically enter the TAS aperture?”

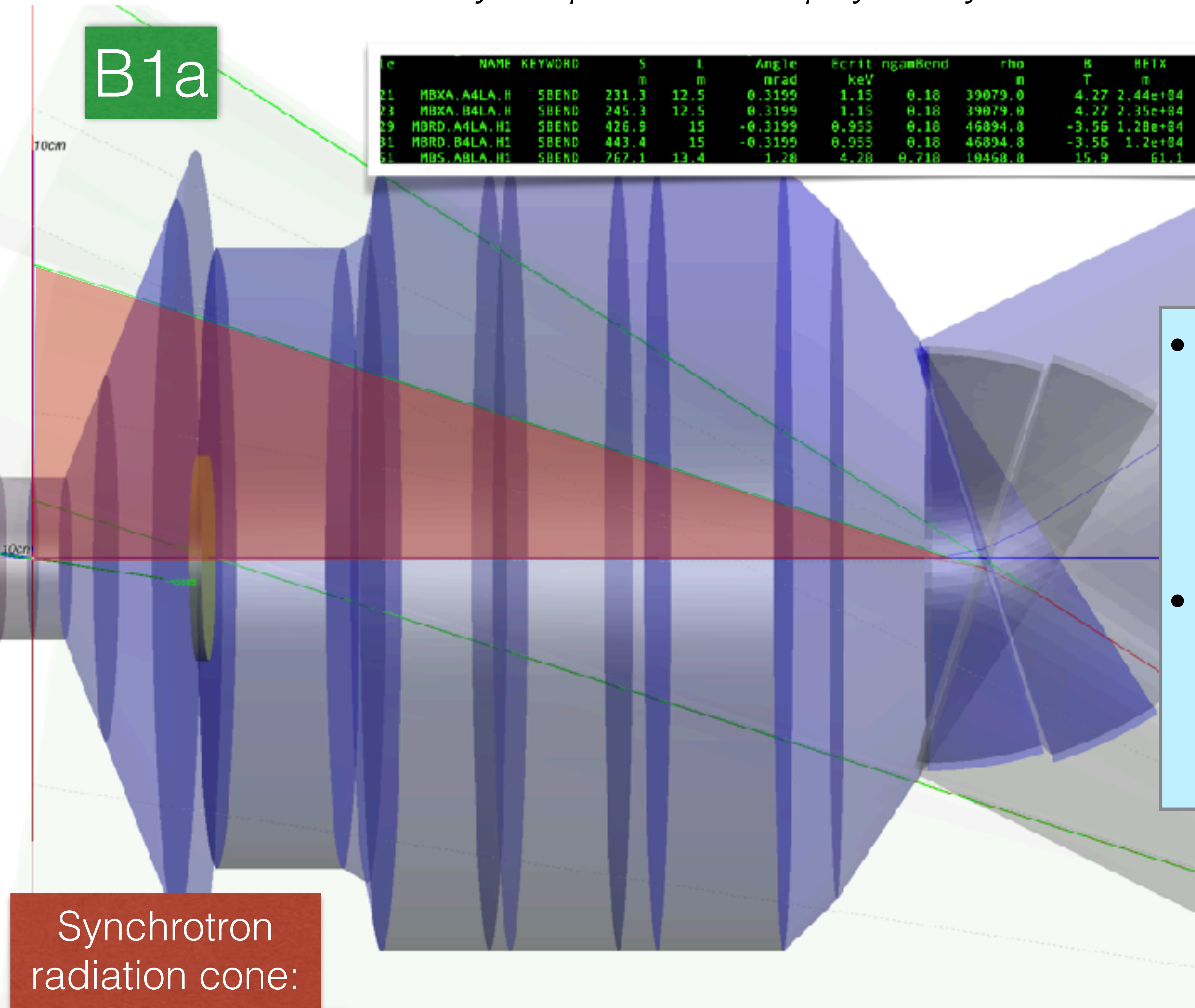


le	NAME	KEYWORD	S	L	Angle	Ecrit	ngamBend	rho	B	BETX	SIGX	divx	Power	frac>10MeV	ngam*npart	Egamtot	Em
			m	m	mrad	keV		m	T	m	mm	mrad	kW			GeV	
21	MBXA.A4LA.H	SBEND	231.3	12.5	0.3199	1.15	0.18	39079.0	4.27	2.44e+04	1	0.00141	0.0322	0	1.8e+10	6.34e+03	0.
23	MBXA.B4LA.H	SBEND	245.3	12.5	0.3199	1.15	0.18	39079.0	4.27	2.35e+04	0.984	0.00141	0.0322	0	1.8e+10	6.34e+03	0.
29	MBRD.A4LA.H1	SBEND	426.9	15	-0.3199	0.955	0.18	46894.8	-3.56	1.28e+04	0.728	0.00141	0.0268	0	1.8e+10	5.28e+03	0.
31	MBRD.B4LA.H1	SBEND	443.4	15	-0.3199	0.955	0.18	46894.8	-3.56	1.2e+04	0.705	0.00141	0.0268	0	1.8e+10	5.28e+03	0.
61	MBS.A8LA.H1	SBEND	767.1	13.4	1.28	4.28	0.718	10468.8	15.9	61.1	0.0582	0.000079	0.481	0	7.18e+10	9.46e+04	1

- MDISim gives the total SR power emitted in each element of the lattice
- From geometry the fraction of this power entering the TAS can be evaluated

Solid angle evaluation

"How many SR photons can physically enter the TAS aperture?"



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Synchrotron radiation cone: $\theta=0.3$ mrad

Solid angle evaluation

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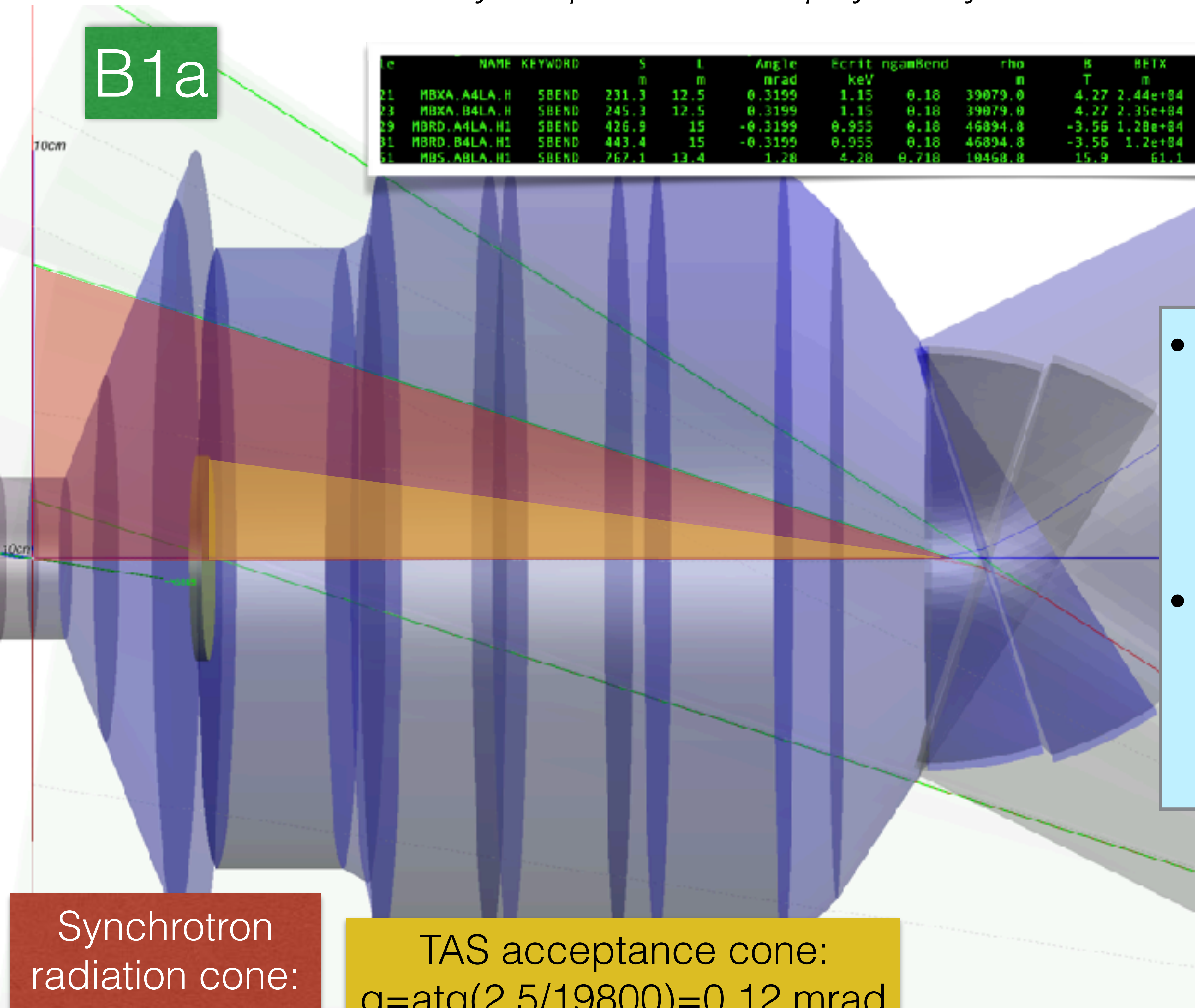

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TAS acceptance cone: $\alpha=\mathrm{atg}(2.5/19800)=0.12$ mrad

Solid angle evaluation

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B1a

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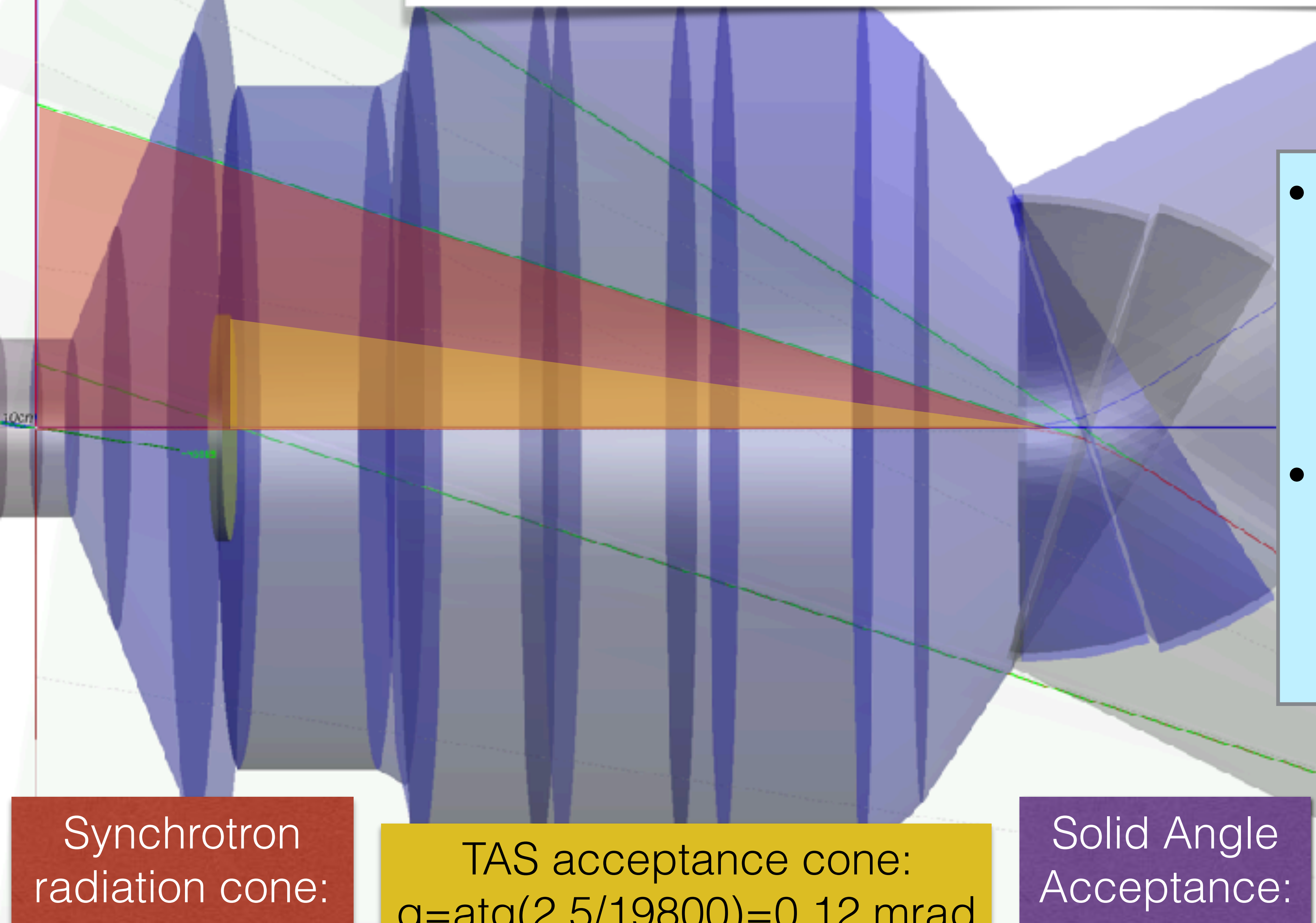

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Synchrotron radiation cone: θ=0.3 mrad

TAS acceptance cone: α=atg(2.5/19800)=0.12 mrad

Solid Angle Acceptance: f=α/θ=40%

MDISIM OUTPUT

```
iele        NAME KEYWORD      S      L     Angle   Ecrit ngamBend      rho      B      BETX    SIGX     divx   Power frac>10MeV ngam*npart Egamtot Emean
                              m      m      mrad     keV                 m      T         m      mm     mrad      kW                          GeV   keV
  21   MBXA.A4LA.H   SBEND  231.3   12.5   6.3199    1.15     0.18   39079.8   4.27 2.46e+04    1.01  0.00142  0.0322          0   1.8e+10 6.34e-03  0.353
  23   MBXA.B4LA.H   SBEND  245.3   12.5   6.3199    1.15     0.18   39079.8   4.27 2.36e+04   0.987  0.00142  0.0322          0   1.8e+10 6.34e-03  0.353
  29  MBRD.A4LA.H1   SBEND  426.9     15  -6.3199   0.955     0.18   46894.8  -3.56 1.29e+04    0.73  0.00142  0.0268          0   1.8e+10 5.28e-03  0.294
  31  MBRD.B4LA.H1   SBEND  443.4     15  -6.3199   0.955     0.18   46894.8  -3.56 1.21e+04   0.707  0.00142  0.0268          0   1.8e+10 5.28e-03  0.294
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```
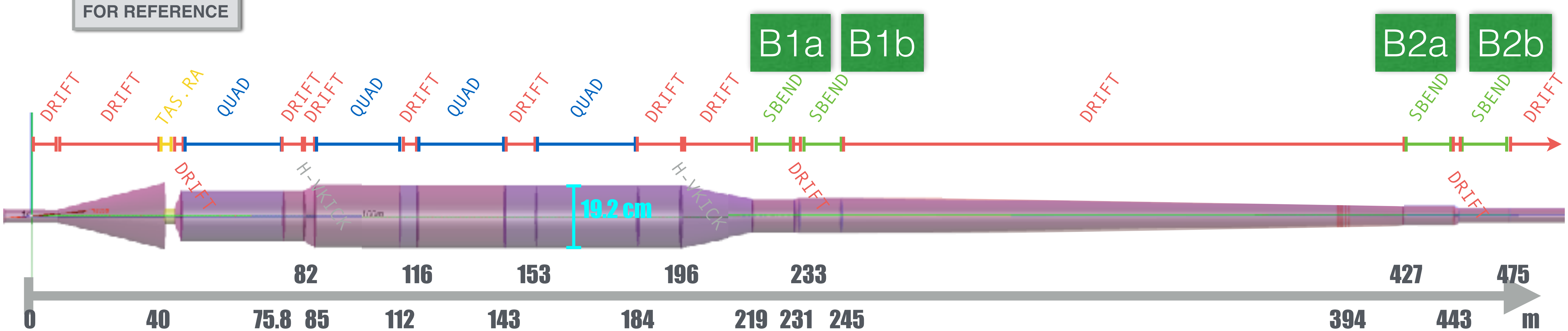

						WITHOUT Crossing Angle			WITH Crossing Angle		
el.	S (m)	B (T)	E_{crit} (keV)	$N_{\gamma TOT}$ (J)	P (W)	f_{TAS} (%)	E_{TAS} (J)	P_{TAS} (W)	f_{TAS} (%)	E_{TAS} (J)	P_{TAS} (W)
B1a	231	-4,3	1,146	1,8E+10	32	40	4,0E-07	12,8	77,0	7,7E-07	24,6
B1b	235	-4,3	1,146	1,8E+10	32	0	—	—	—	—	—
B2a	427	3,6	0,955	1,8E+10	27	15,3	1,3E-07	4,1	8,0	6,8E-08	1,2
B2b	443	3,6	0,955	1,8E+10	27	0	—	—	—	—	—
B3	767	15,9	4,279	7,2E+10	480	—	TOT	17W	–	TOT	26W

FOR REFERENCE



MDISIM OUTPUT

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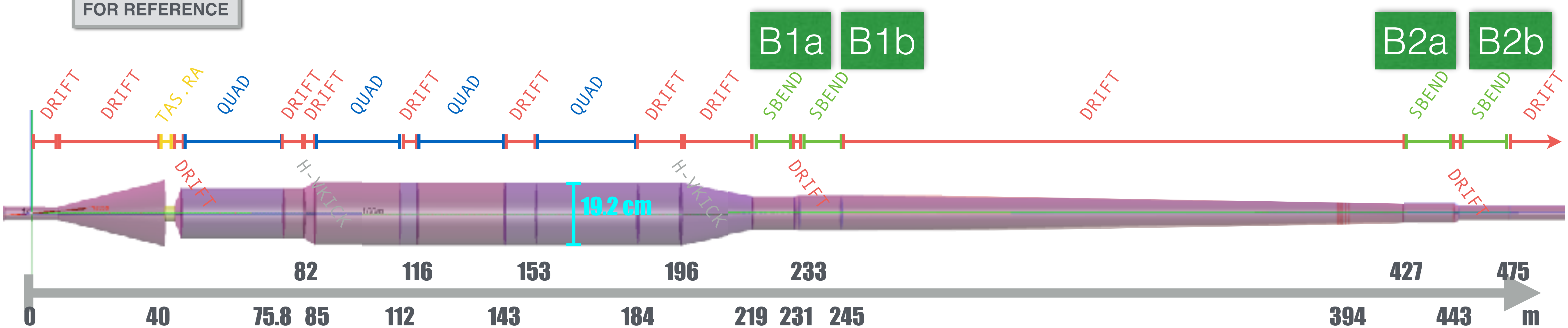
29	MBRD.A4LA.H1	SBEND	426.9	15	-6.3199	0.955	0.18	46894.8	-3.56	1.29e+04	0.73	0.00142	0.0268	0	1.8e+10	5.28e-03	0.294
31	MBRD.B4LA.H1	SBEND	443.4	15	-6.3199	0.955	0.18	46894.8	-3.56	1.21e+04	0.707	0.00142	0.0268	0	1.8e+10	5.28e-03	0.294
51	MBS.A8LA.H1	SBEND	767.1	13.4	1.28	4.28	0.718	10468.8	15.9	61.1	0.0502	0.000877	0.481	0	7.18e+10	9.46e-04	1.32

						WITHOUT Crossing Angle			WITH Crossing Angle		
el.	S (m)	B (T)	E_{crit} (keV)	$N_{\gamma TOT}$ (J)	P (W)	f_{TAS} (%)	E_{TAS} (J)	P_{TAS} (W)	f_{TAS} (%)	E_{TAS} (J)	P_{TAS} (W)
B1a	231	-4,3	1,146	1,8E+10	32	40	4,0E-07	12,8	77,0	7,7E-07	24,6
B1b	235	-4,3	1,146	1,8E+10	32	0	—	—	—	—	—
B2a	427	3,6	0,955	1,8E+10	27	15,3	1,3E-07	4,1	8,0	6,8E-08	1,2
B2b	443	3,6	0,955	1,8E+10	27	0	—	—	—	—	—
B3	767	15,9	4,279	7,2E+10	480	—	TOT	17W	–	TOT	26W

FOR REFERENCE



F. Collamati - EuroCirCol meeting - 7-9 November 2016 - ALBA Synchrotron

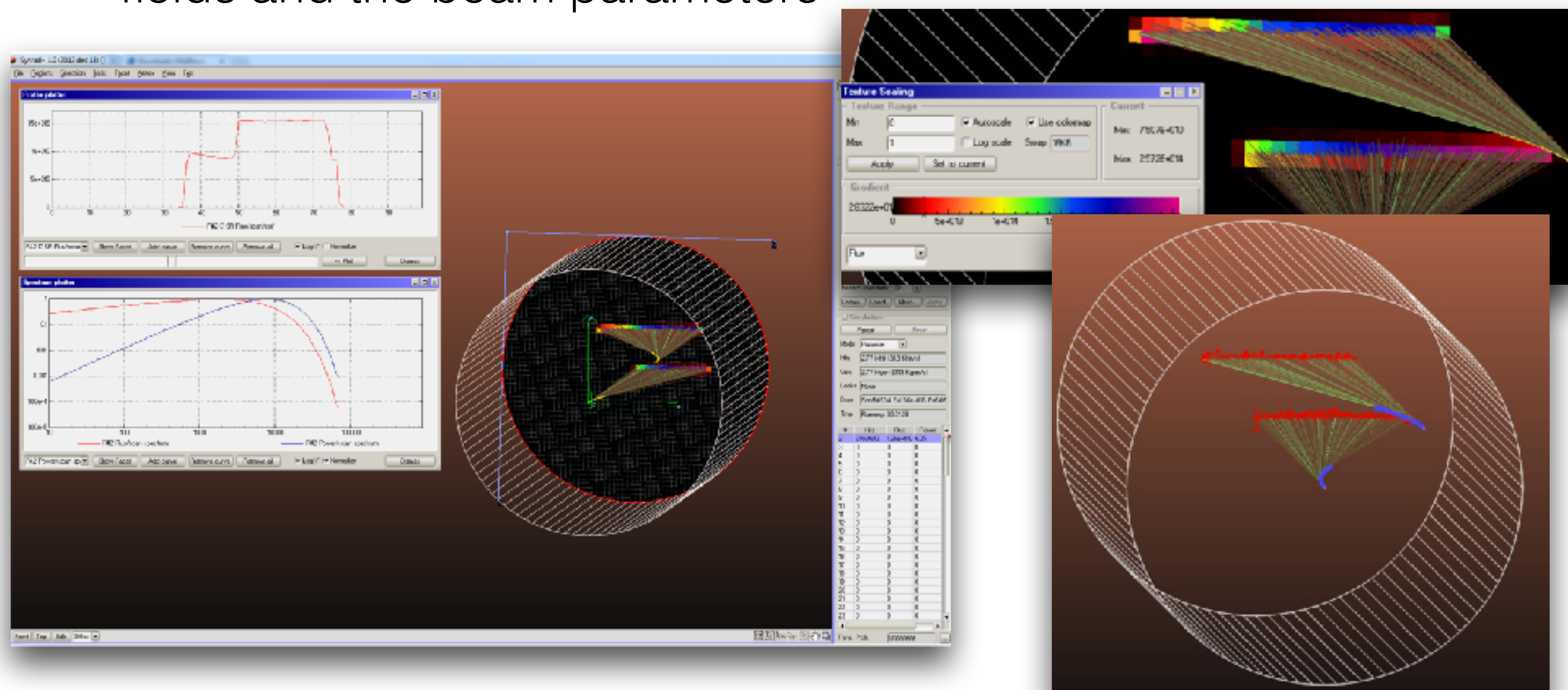
Second approach: SynRad

Synrad Software

- Synrad is a software developed by *Roberto Kersevan* able to **generate** and **trace photons** to calculate flux and power distribution on a surface caused by Synchrotron radiation

link

- Needs as input the geometry (in CAD-like format), the magnetic fields and the beam parameters



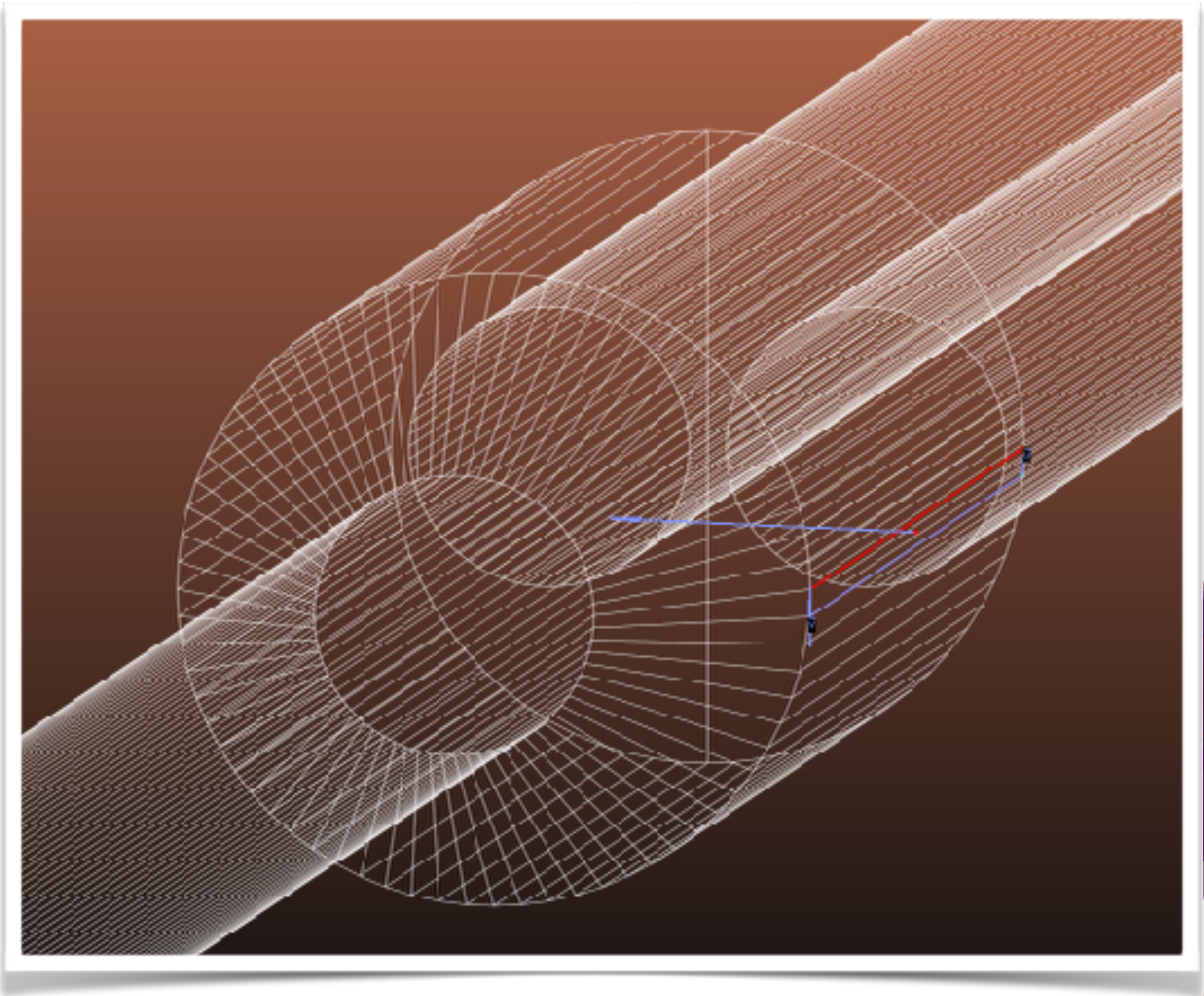
Synrad Simulation

- Roberto Kersevan used the Madx output files (run with MDISim) to:
  - **create the beam**, taking position, displacement, emittance, coupling and all the relevant parameters
  - **create the geometry**, using the apertures provided in the Madx optics file and joining them with the ones added "by hand" (eg for TAS)

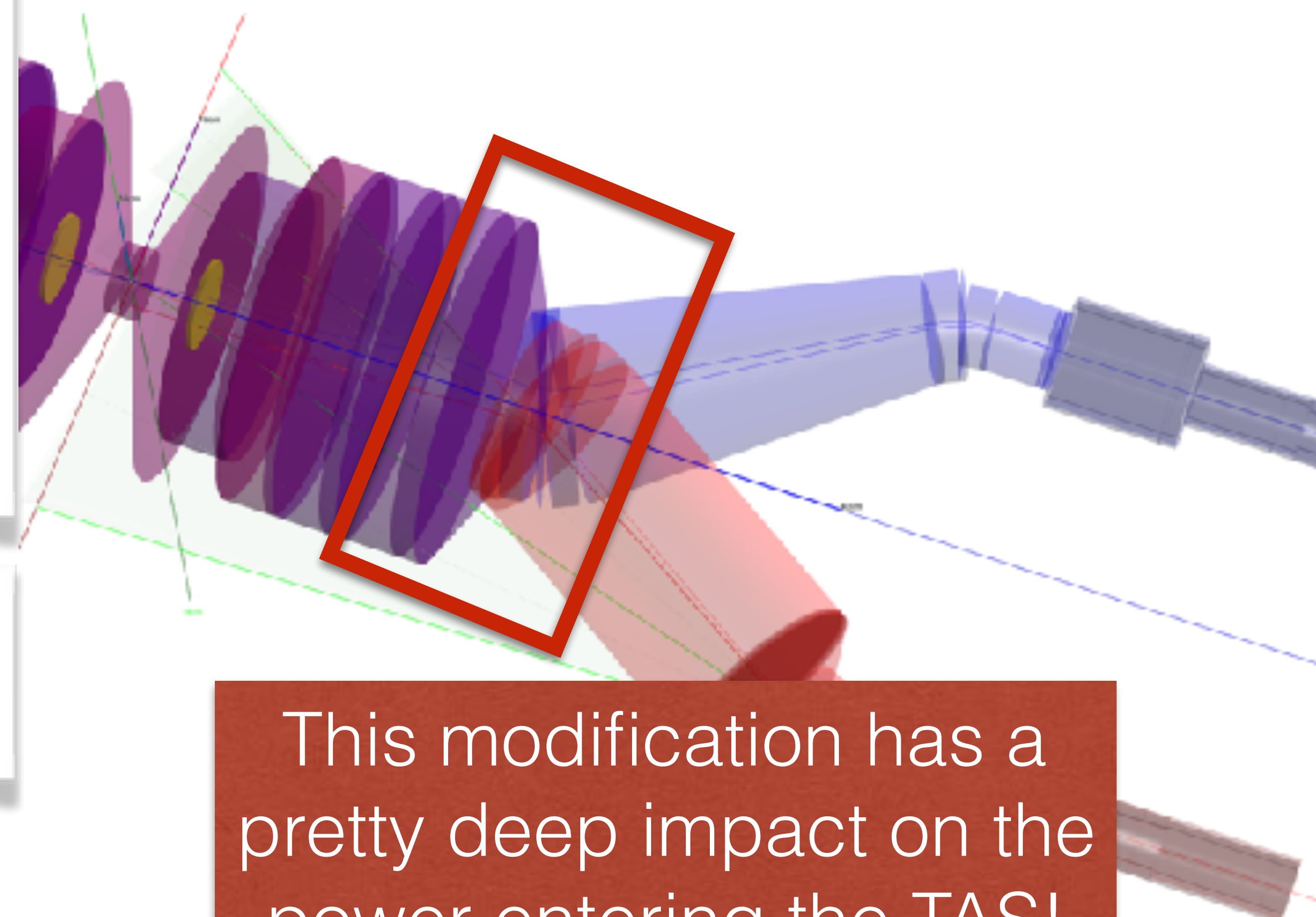
  ➡ he added to the geometry some elements not included in the optics file to resolve some "unrealistic" configurations originating from the mere optics files

    ➡ recombination chamber, beam pipe size discontinuities…

R. Kersevan modifications to the geometry



For recombination chamber and beam pipe size he used as reference LHC, making a sort of "projection"

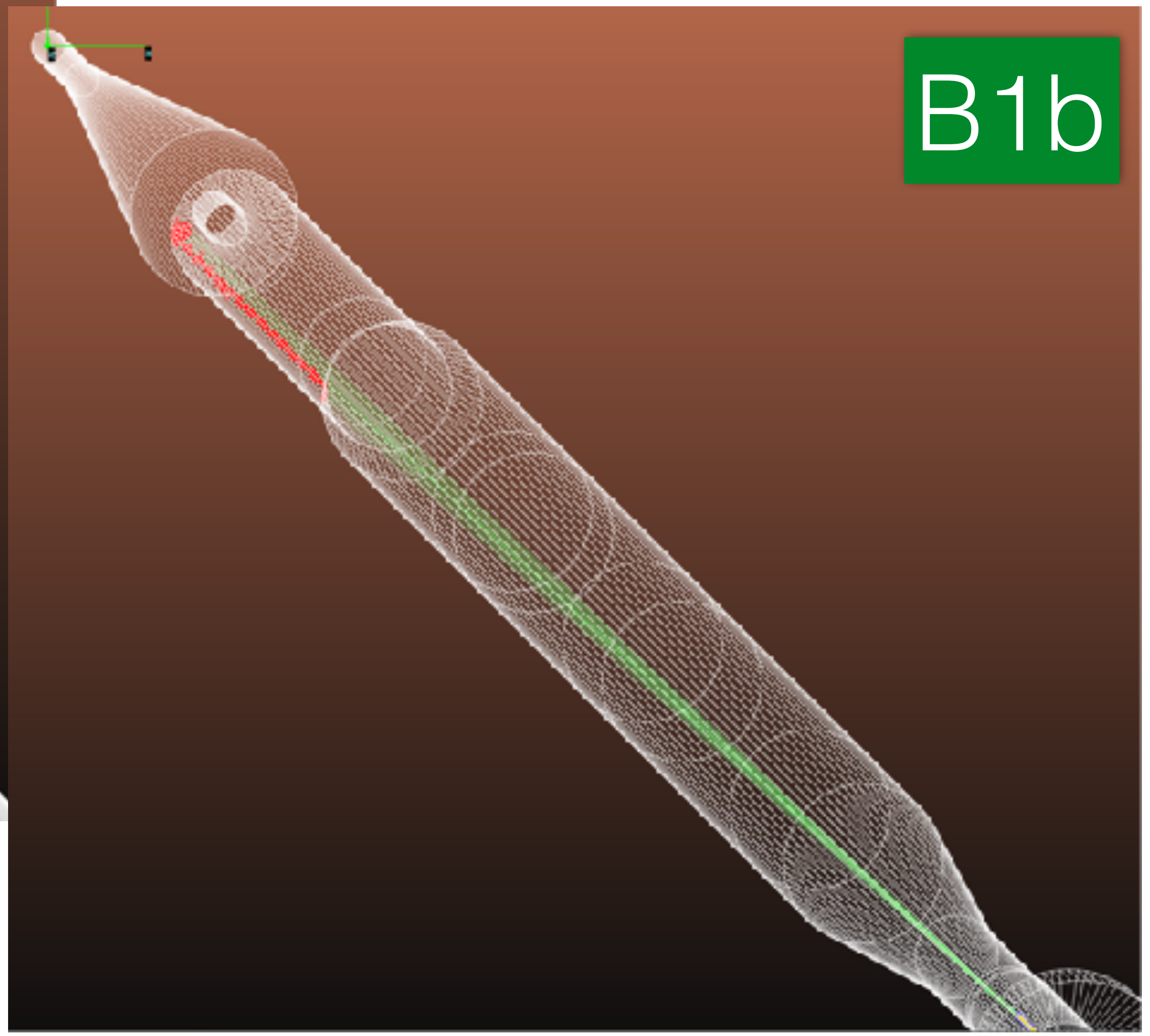


This modification has a pretty deep impact on the power entering the TAS!

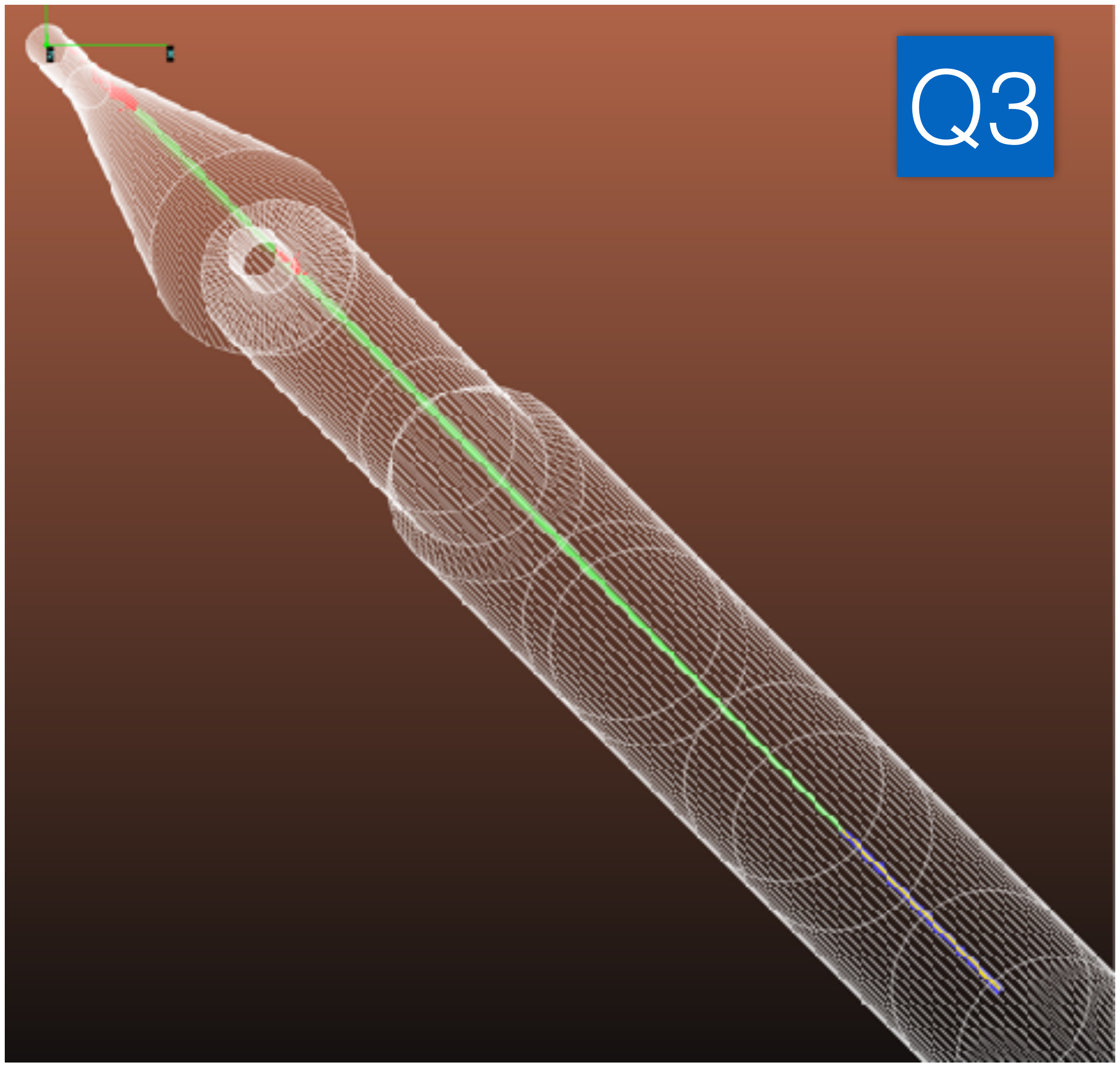
- So I evaluated with SynRad the **power entering the TAS** from the various magnetic elements in both cases *with* and *without* the *Crossing Angle*

here showing

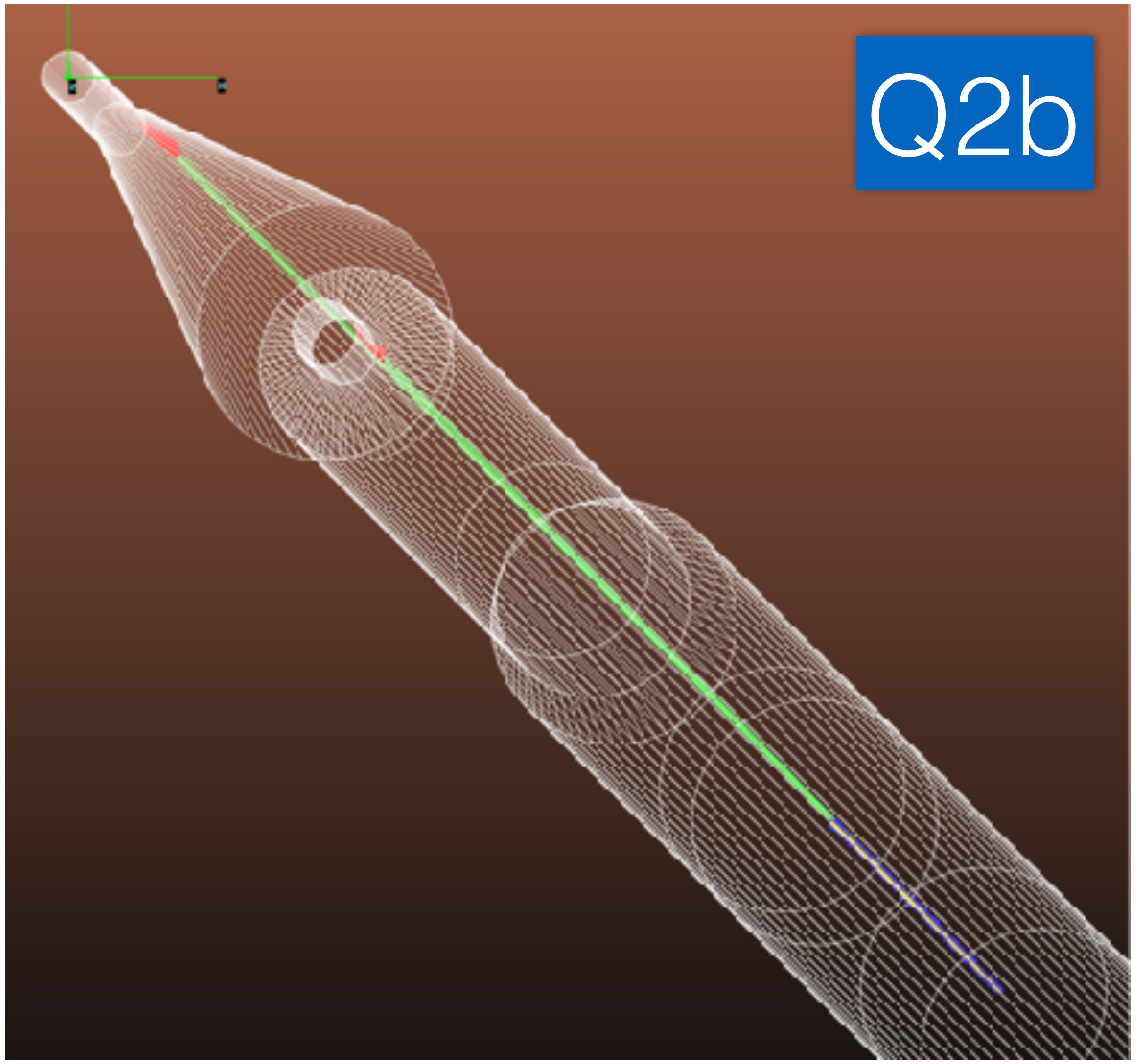
No Crossing Angle



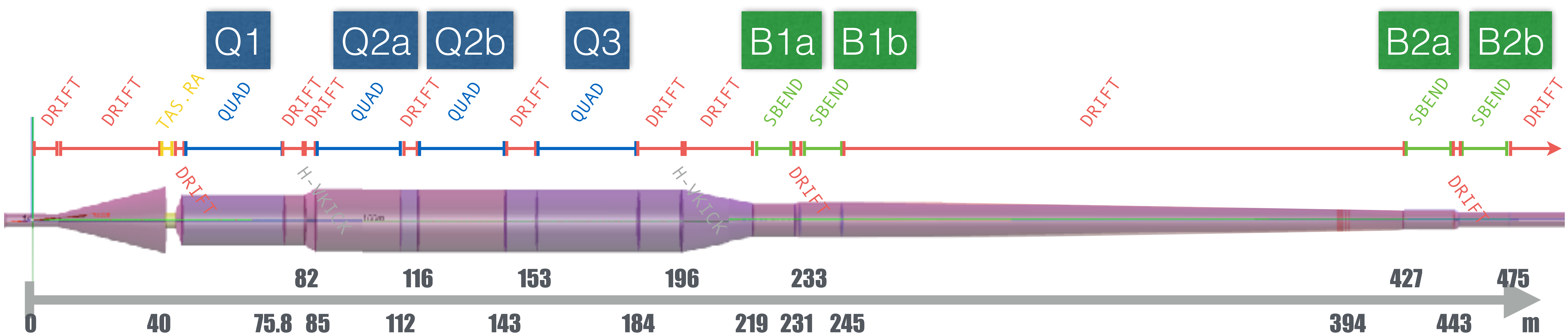
- Being a Monte Carlo program, Synrad is able to simulate even the contribution to Synchrotron Radiation due to **quadrupoles**!



here showing
With Crossing Angle



Power (W)	No Crossing Angle		Crossing Angle	
	MDISim	SynRad	MDISim	SynRad
B2b	0	0	0	0
B2a	4,1	0,08	1,2	1E-03
B1b	0	0	0	4E-05
B1a	12,8	5,02	24,6	5,75
Q3	—	0	—	1,24
Q2b	—	0,139	—	2,19
Q2a	—	0	—	1E-04
Q1	—	0,0113	—	e-6
TOT	**16,9**	**5,3**	**25,8**	**9,2**



Summarizing the two approaches

- **MDISim**
  - Pros:
    - very fast and flexible tool (e.g. in case of new optics/geometry…)
    - easy interface with Geant4 for full simulation
  - Cons:
    - Solid angle evaluation suffers of substantial uncertainties due to graphical technique adopted
    - no quadrupoles
- **SynRad**:
  - Pros:
    - very precise and accurate simulation
    - quadrupoles
  - Cons:
    - requires great work to build geometry
    - not flexible (e.g. in case of new optics/geometry…)

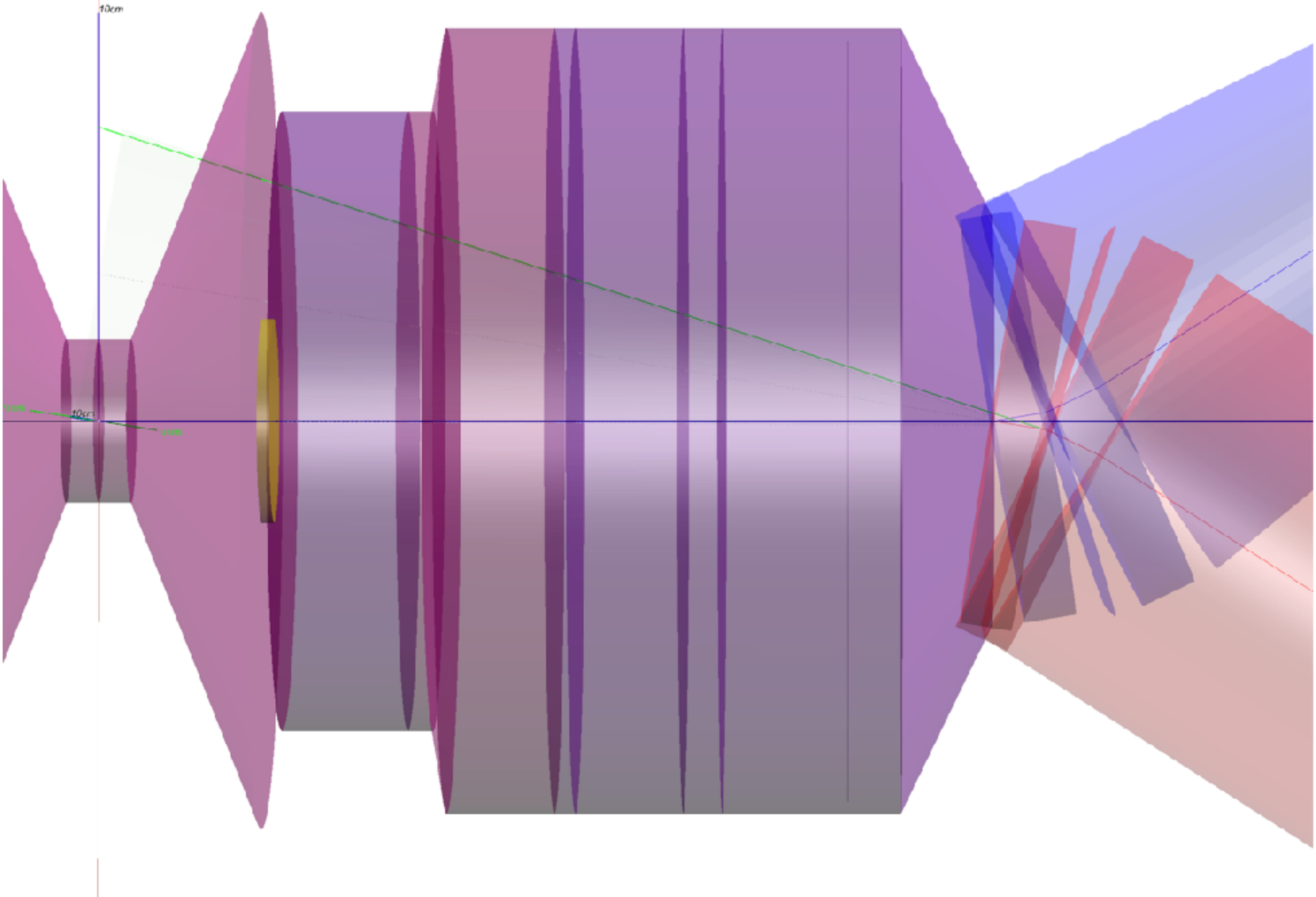
Conclusions

- **Synchrotron Radiation** emitted in the last bends (500m from the IP) **is not an issue**:
  - The emitted Power is IN TOTAL ~100 W (=upper limit in all beam conditions)
  - The **fraction** of this power **entering the TAS** is **~10 W with/without crossing angle**
  - Orbit correctors contribute for ~ W (~10x lower than bends)
  - The emitted photons, even if numerous (**$\sim 10^{10}$** per bunch), have a **critical energy** of **1keV**
  - They are **safely stopped** within the pipe (no full simulation needed!)
  - even in a **non-collision scheme** (beam separation at IP) we can use as a reference (extreme) value the **100 W limit ➜ safe limit**

backup

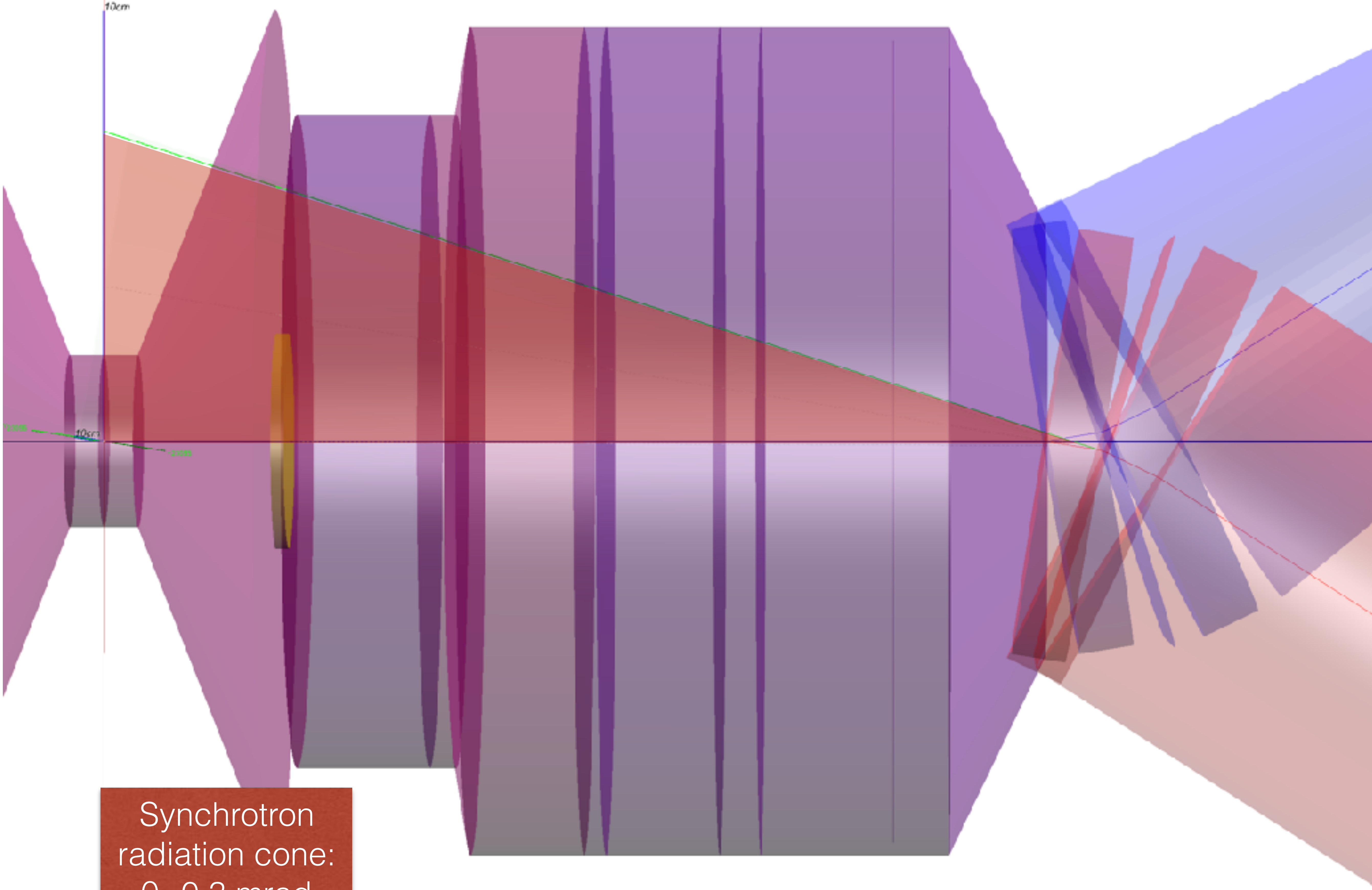
WITHOUT CROSSING ANGLE

B1a



WITHOUT CROSSING ANGLE

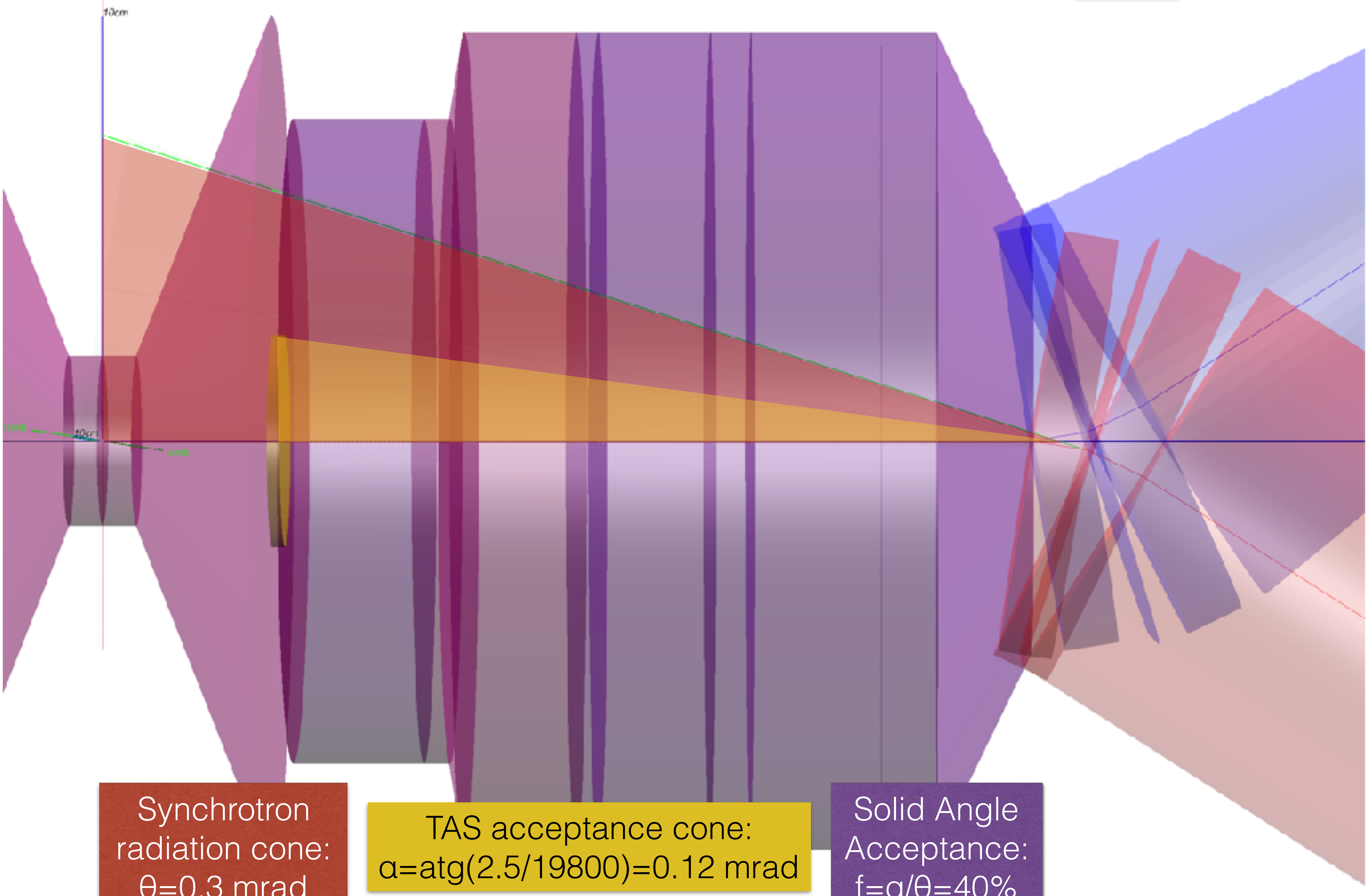
B1a



Synchrotron radiation cone: θ=0.3 mrad

WITHOUT CROSSING ANGLE

B1a



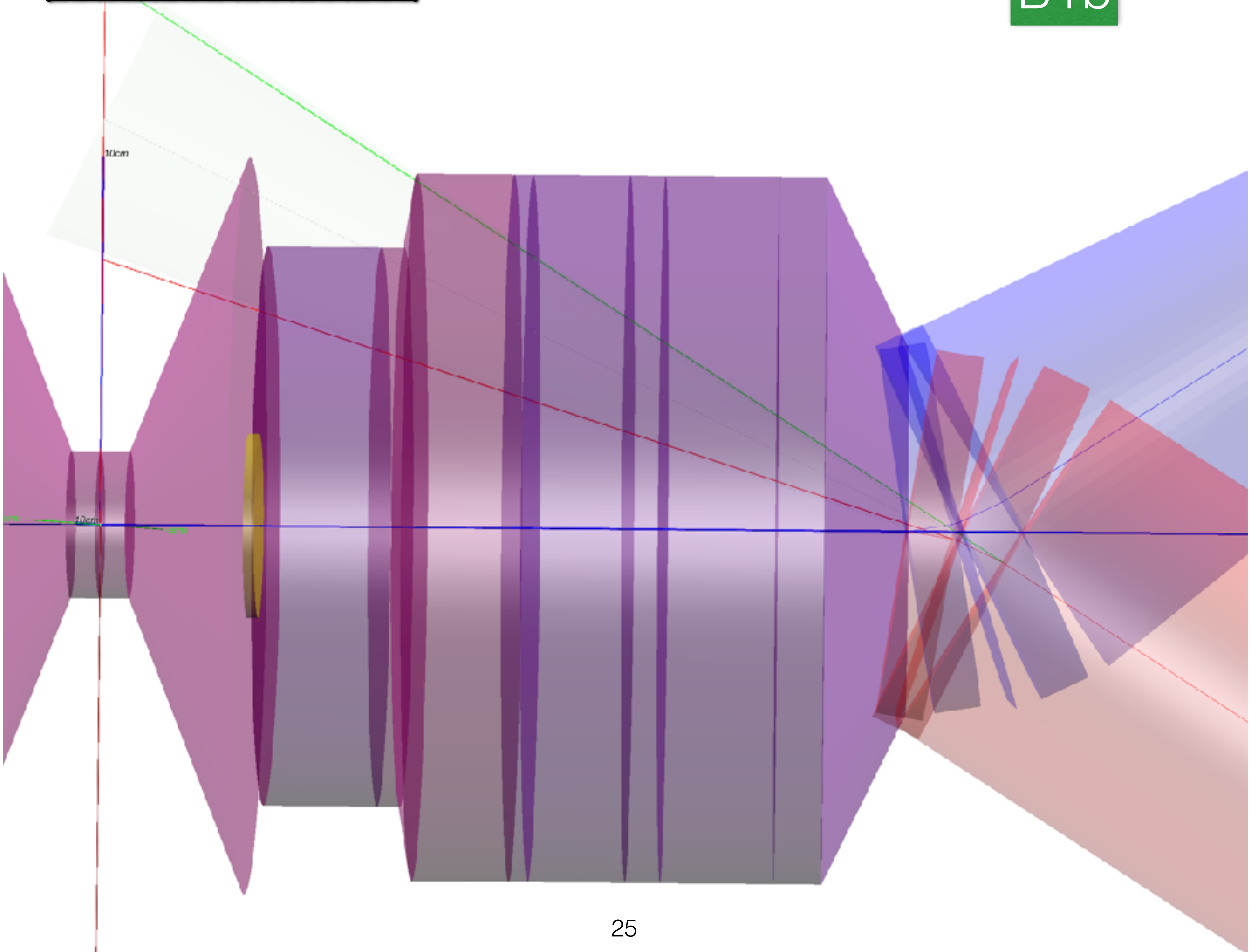
Synchrotron radiation cone:
θ=0.3 mrad

TAS acceptance cone:
α=atg(2.5/19800)=0.12 mrad

Solid Angle Acceptance:
f=α/θ=40%

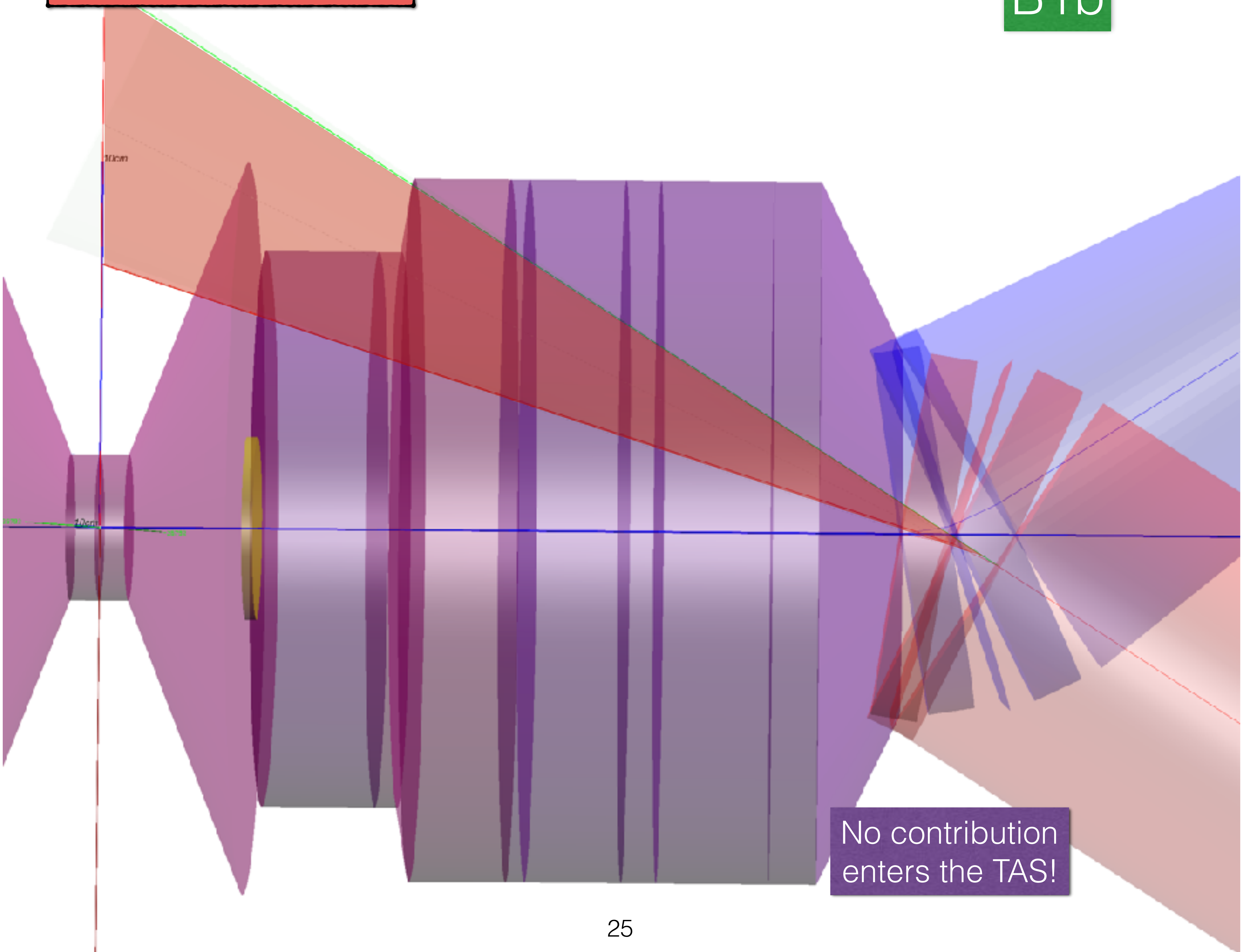
WITHOUT CROSSING ANGLE

B1b



WITHOUT CROSSING ANGLE

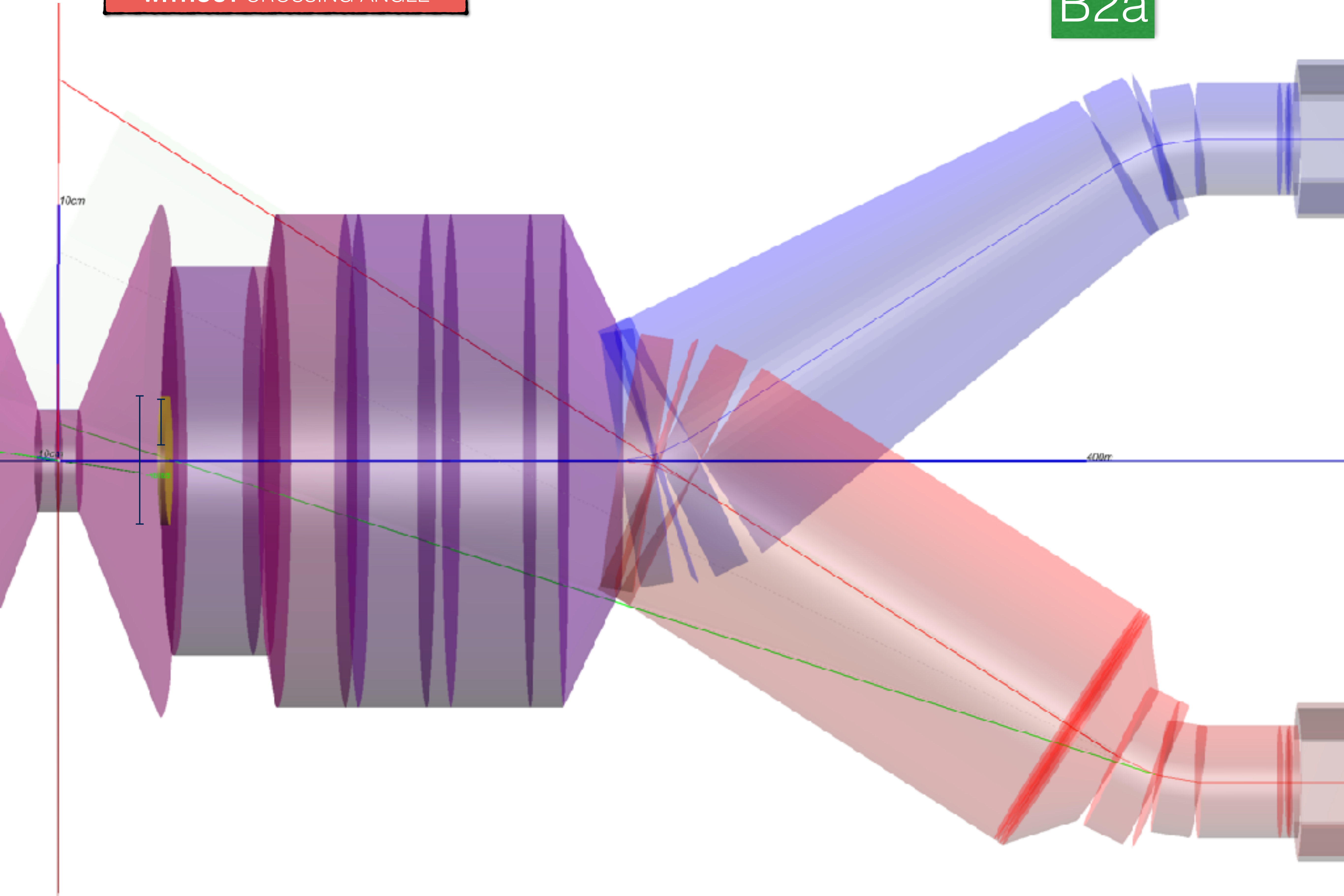
B1b



No contribution enters the TAS!

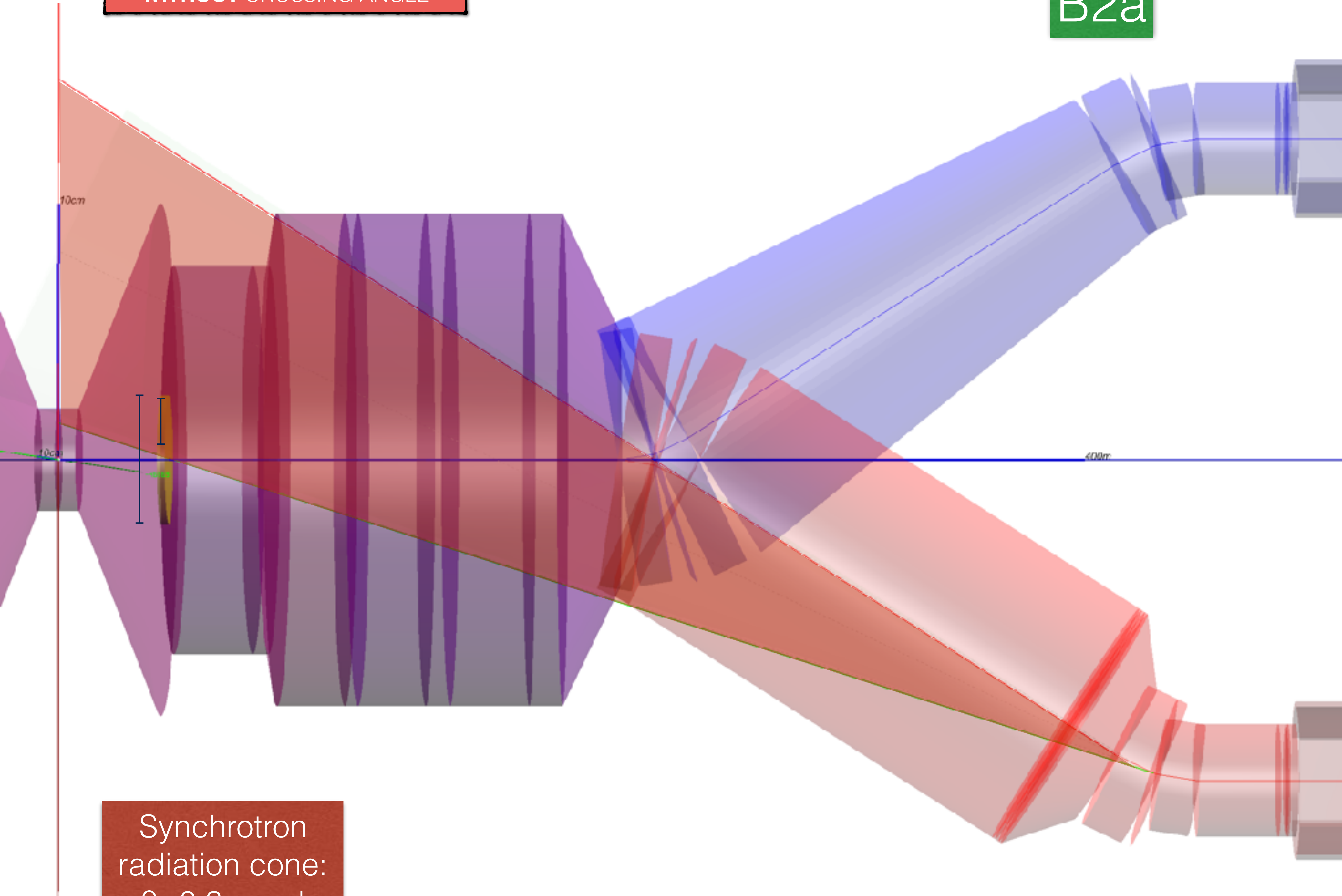
WITHOUT CROSSING ANGLE

B2a



WITHOUT CROSSING ANGLE

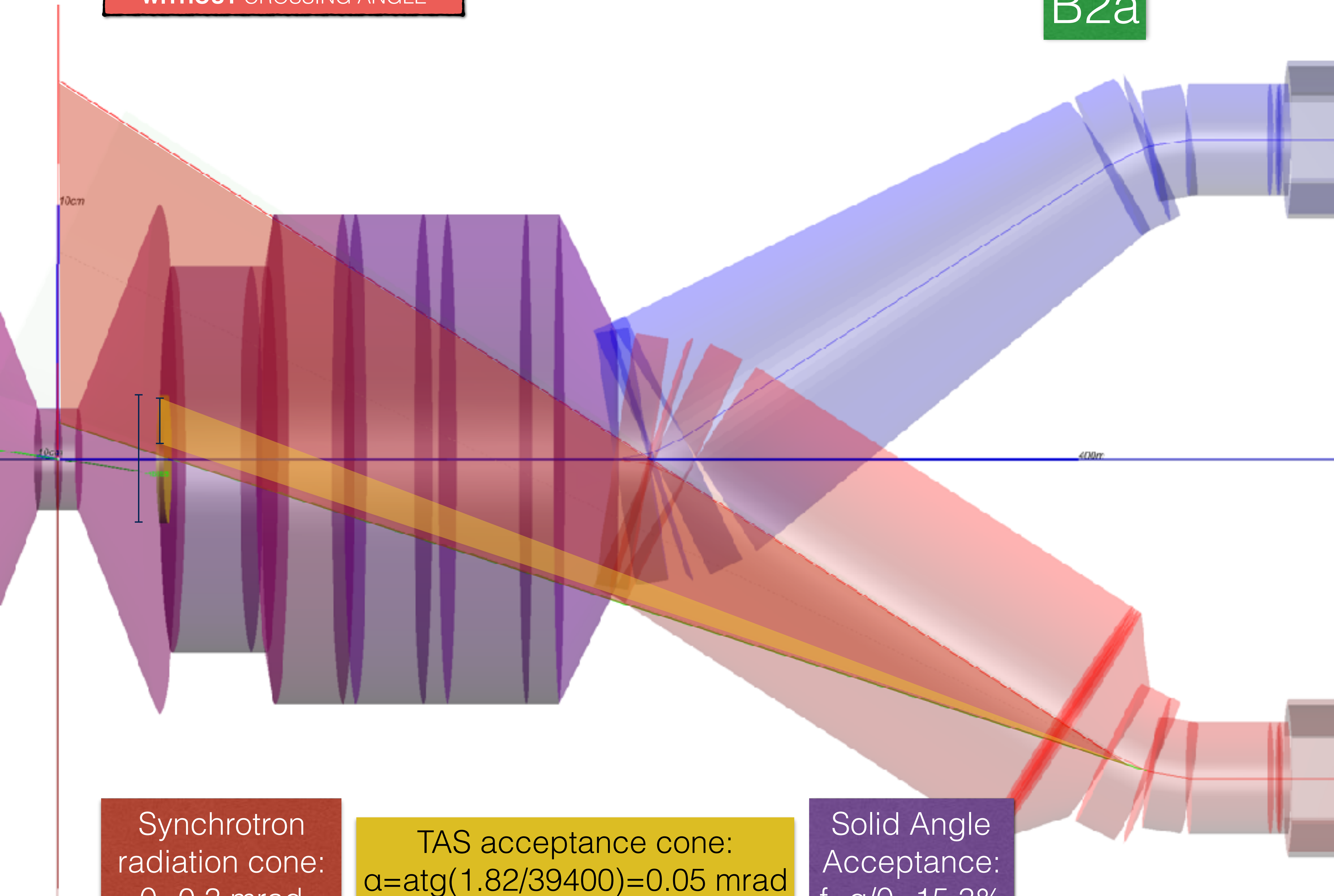
B2a



Synchrotron radiation cone: θ=0.3 mrad

WITHOUT CROSSING ANGLE

B2a



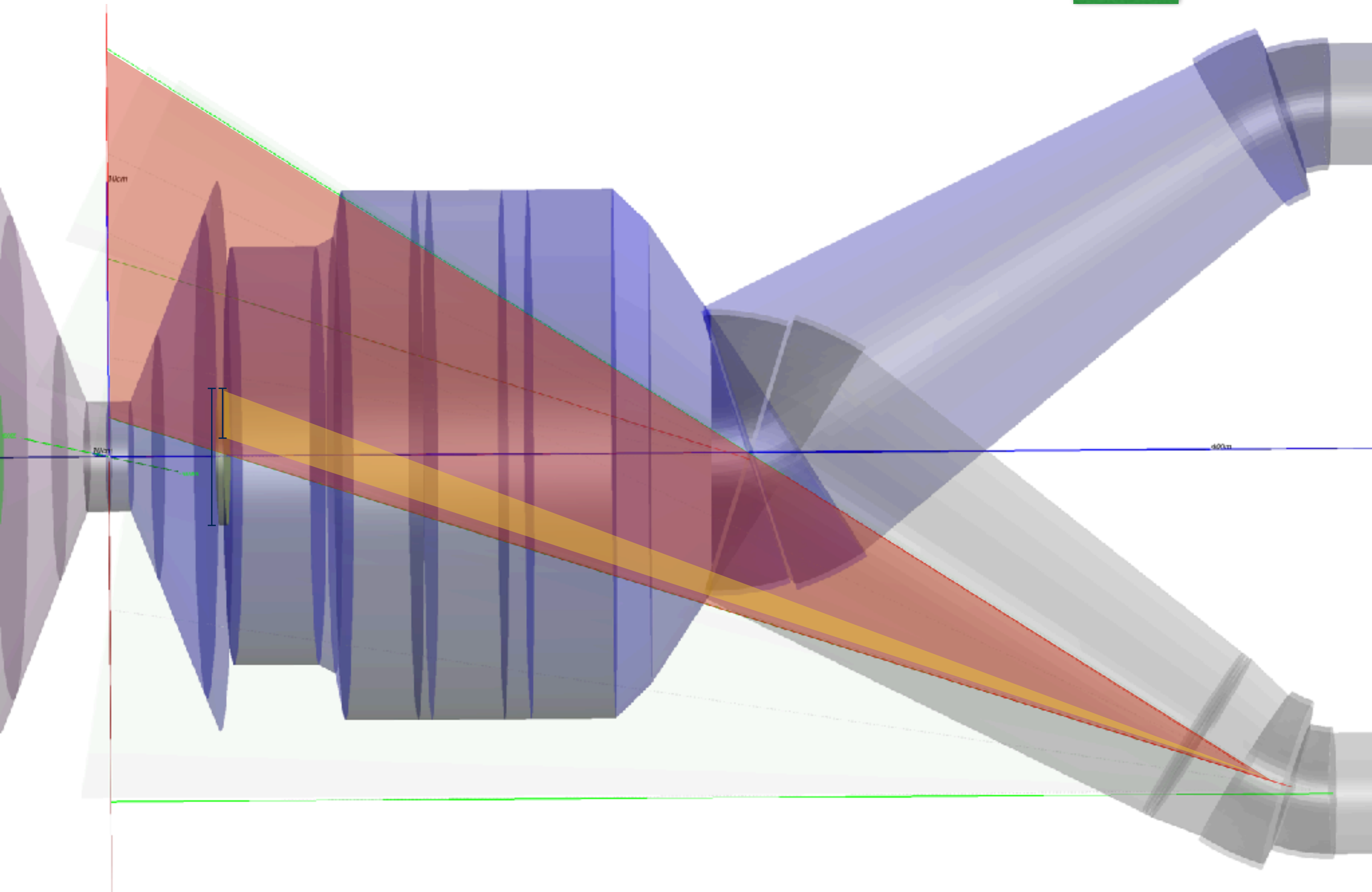
Synchrotron radiation cone: θ=0.3 mrad

TAS acceptance cone: α=atg(1.82/39400)=0.05 mrad

Solid Angle Acceptance: f=α/θ=15.3%

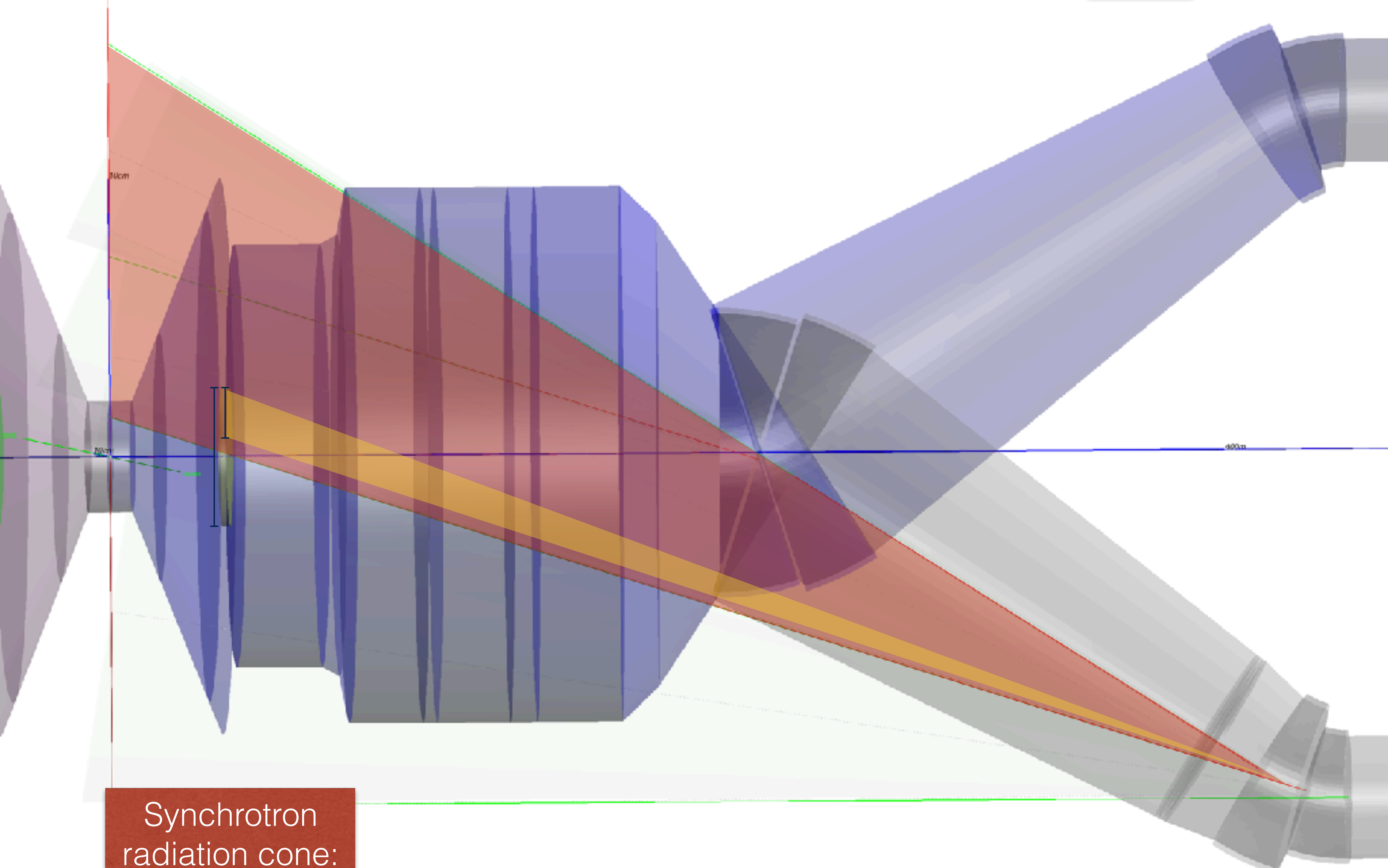
WITHOUT CROSSING ANGLE

B2a



WITHOUT CROSSING ANGLE

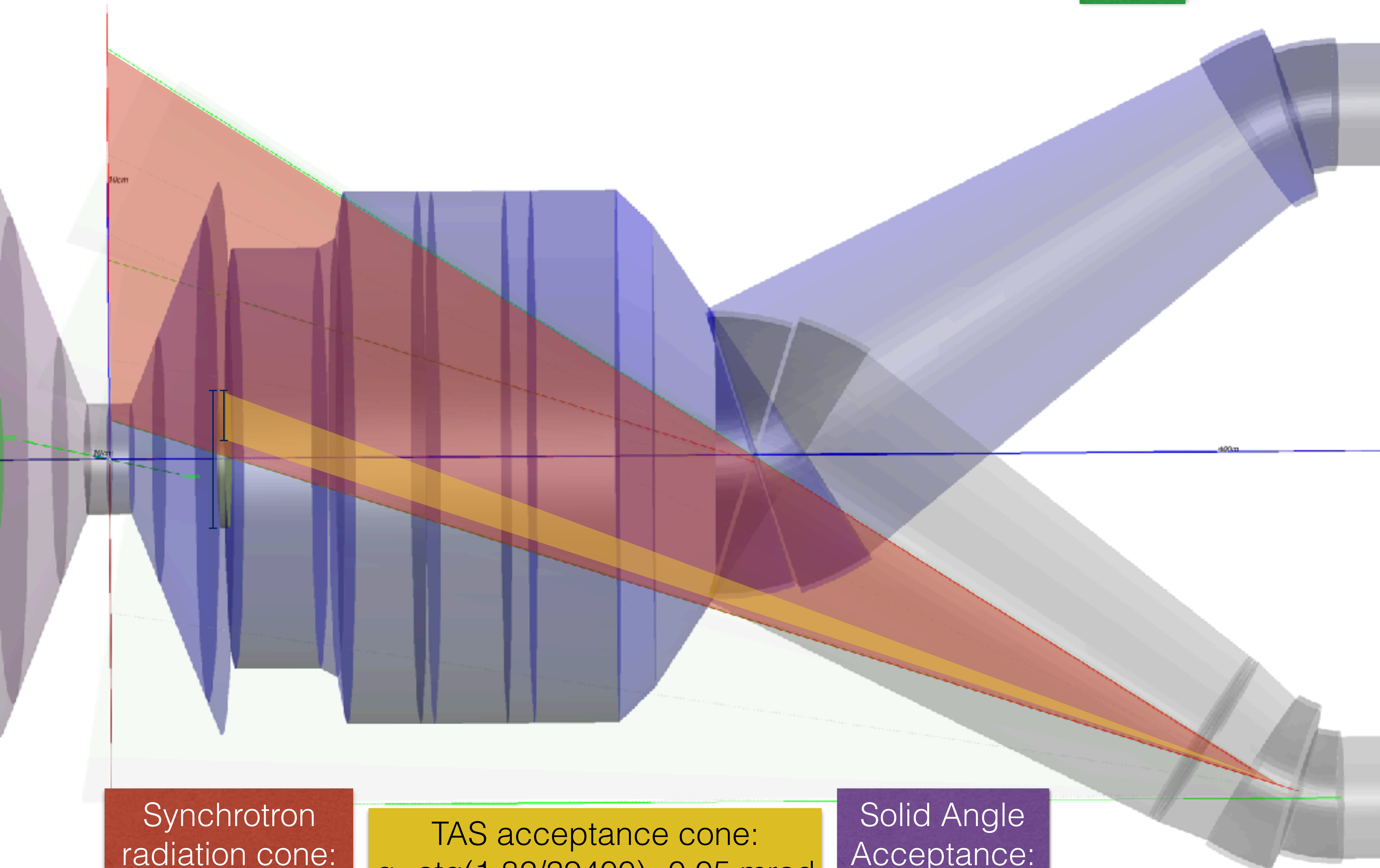
B2a



Synchrotron radiation cone: θ=0.3 mrad

WITHOUT CROSSING ANGLE

B2a



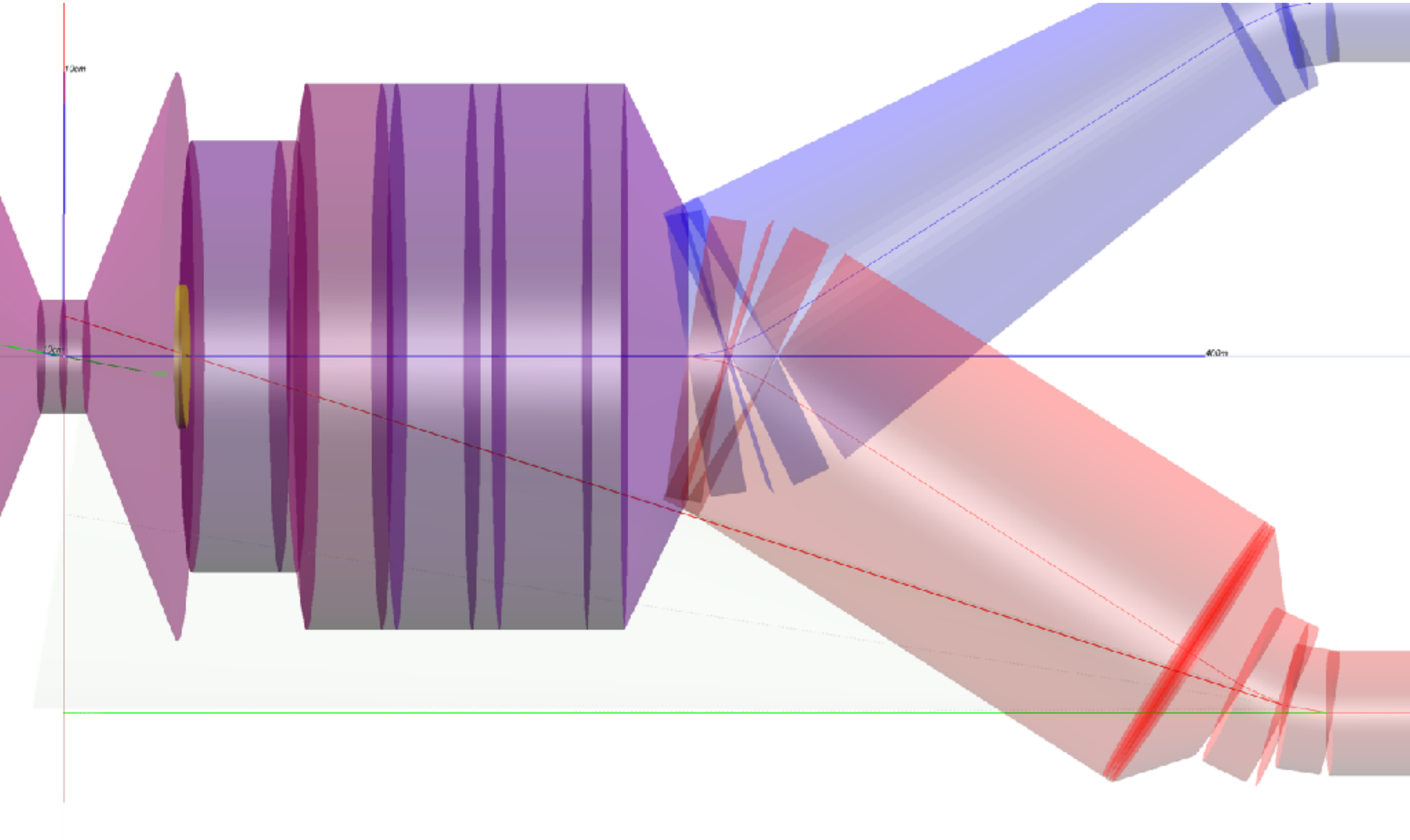
Synchrotron radiation cone: θ=0.3 mrad

TAS acceptance cone: α=atg(1.82/39400)=0.05 mrad

Solid Angle Acceptance: f=α/θ=15.3%

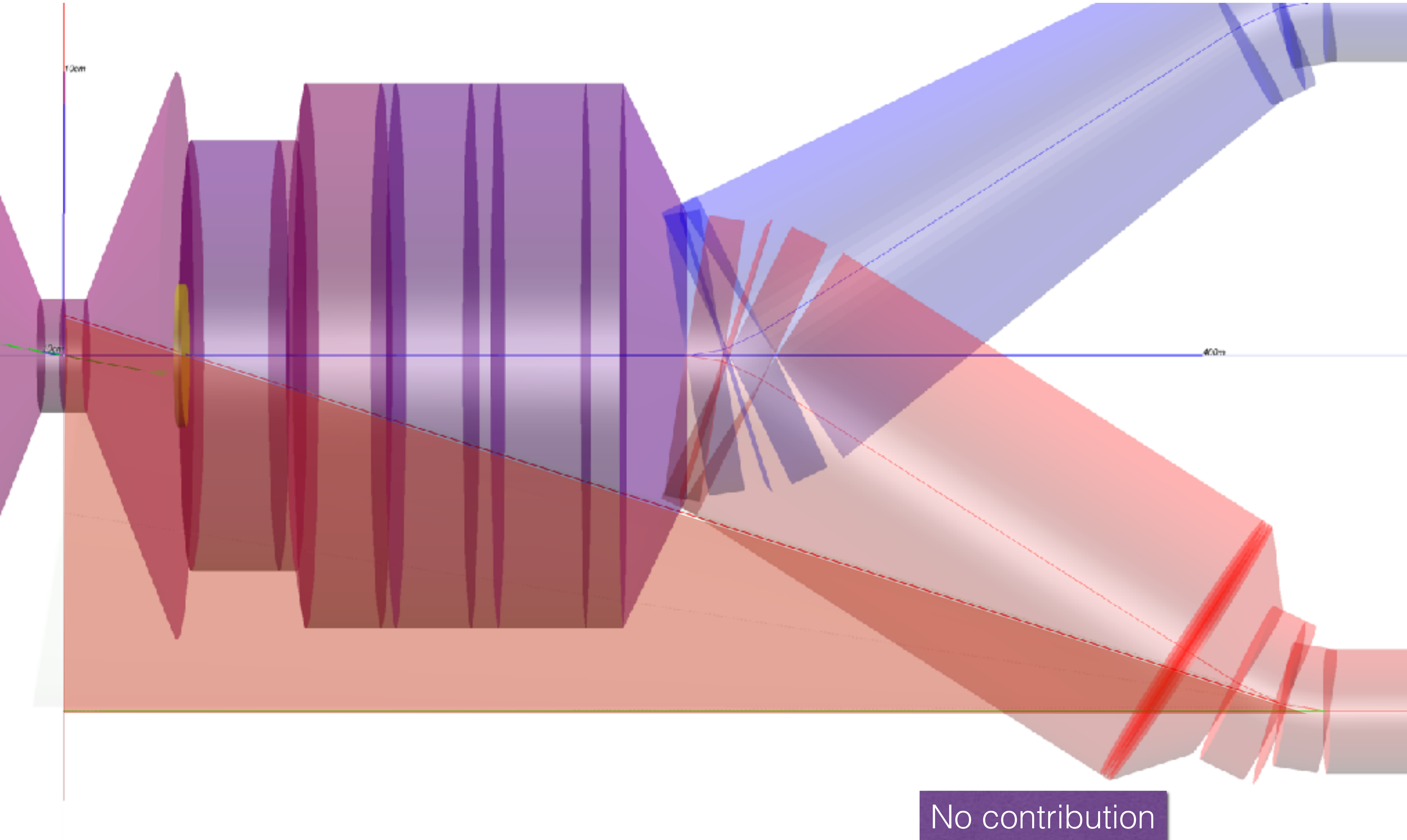
WITHOUT CROSSING ANGLE

B2b

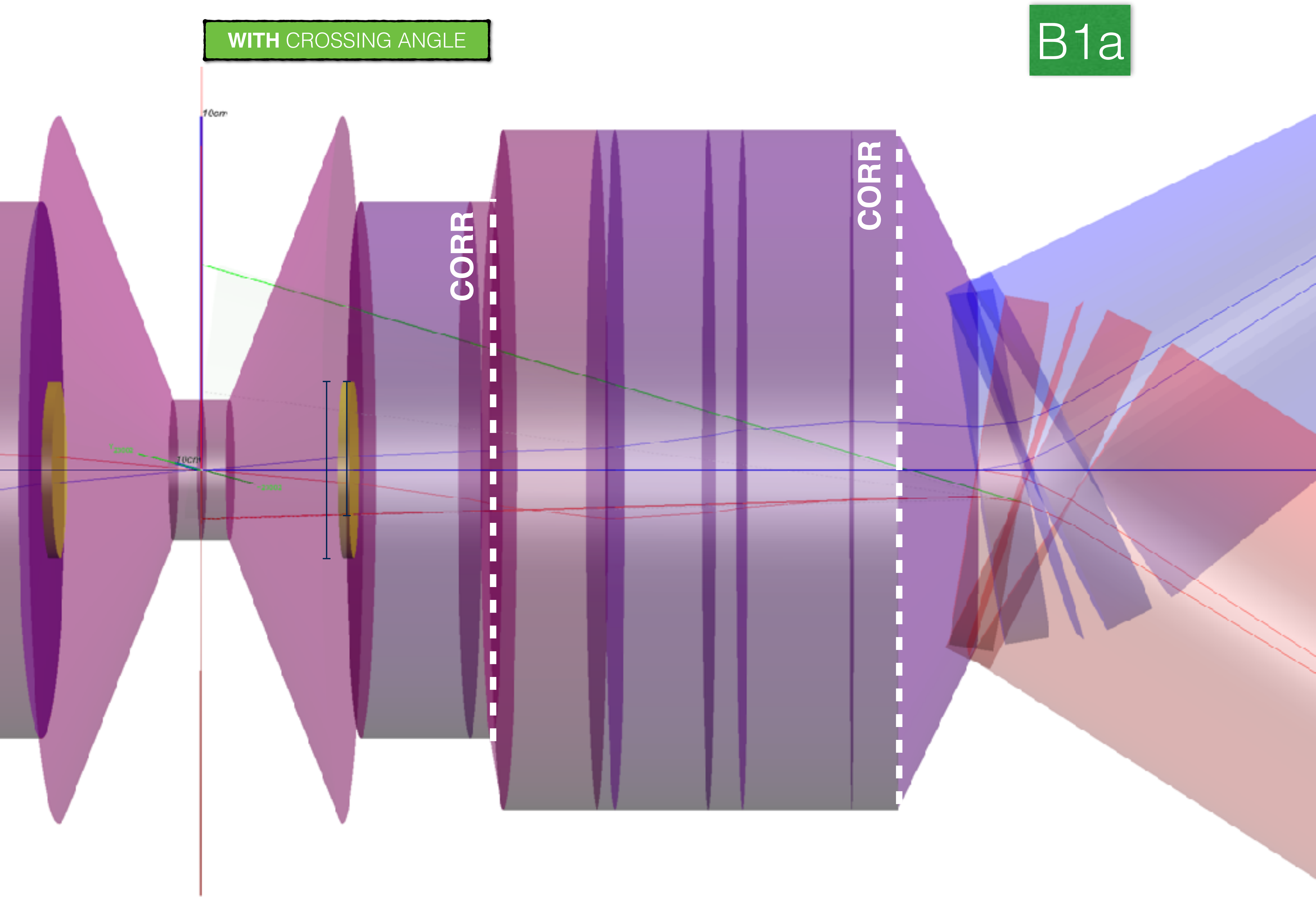


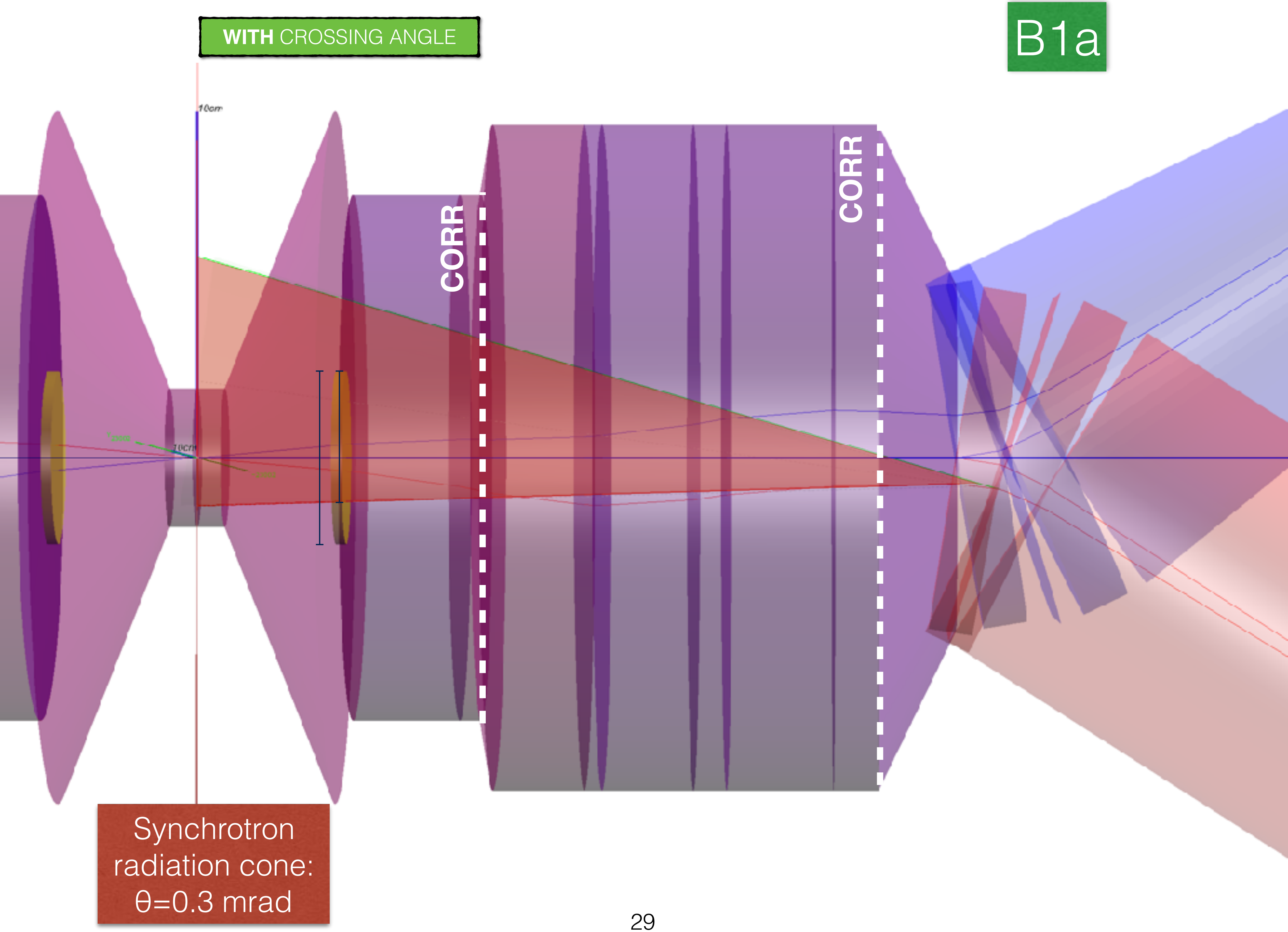
WITHOUT CROSSING ANGLE

B2b



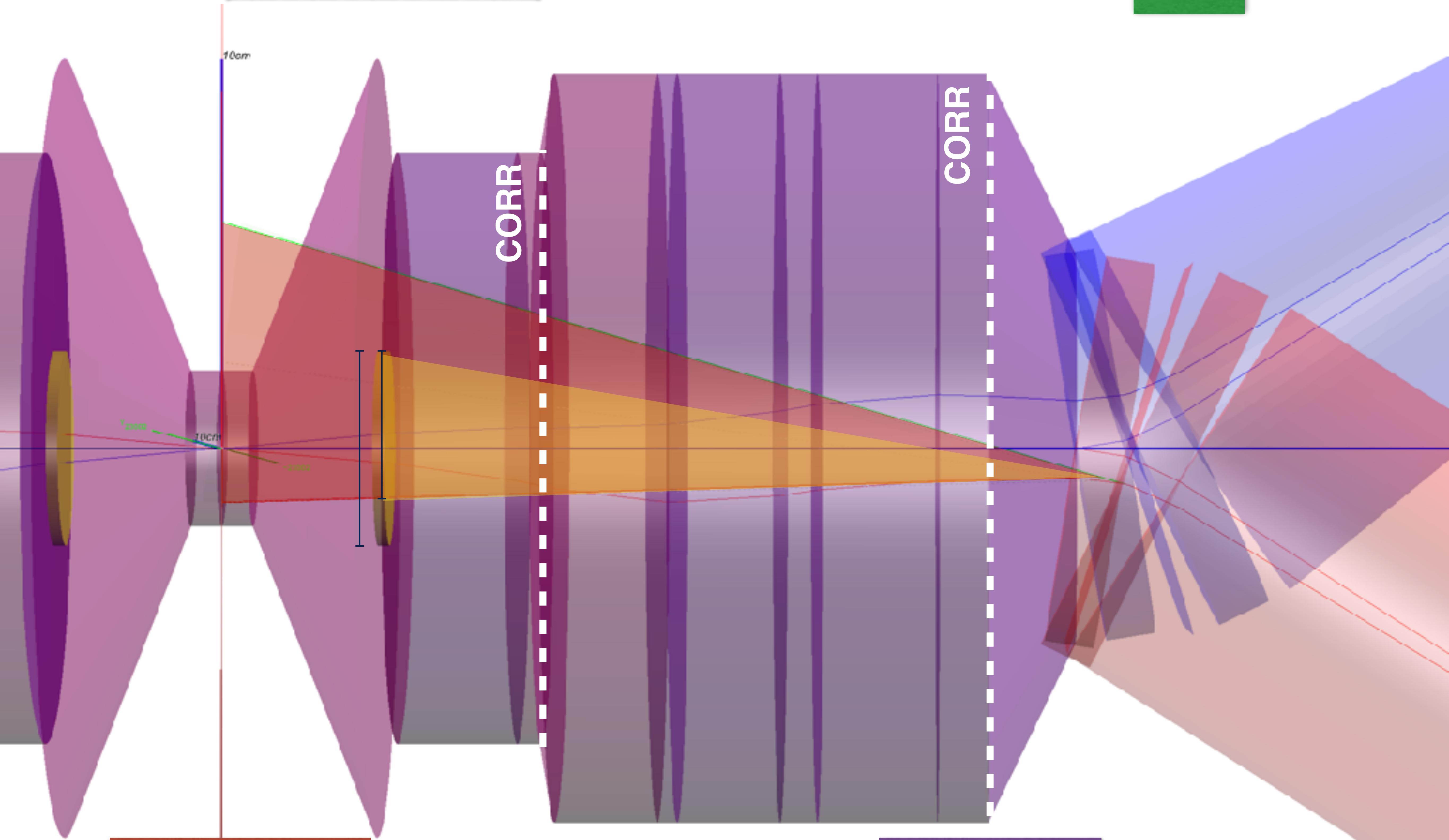
No contribution enters the TAS!


WITH CROSSING ANGLE
B1a
10cm
CORR
CORR


WITH CROSSING ANGLE
B1a
10cm
CORR
CORR
Synchrotron
radiation cone:
θ=0.3 mrad

WITH CROSSING ANGLE

B1a



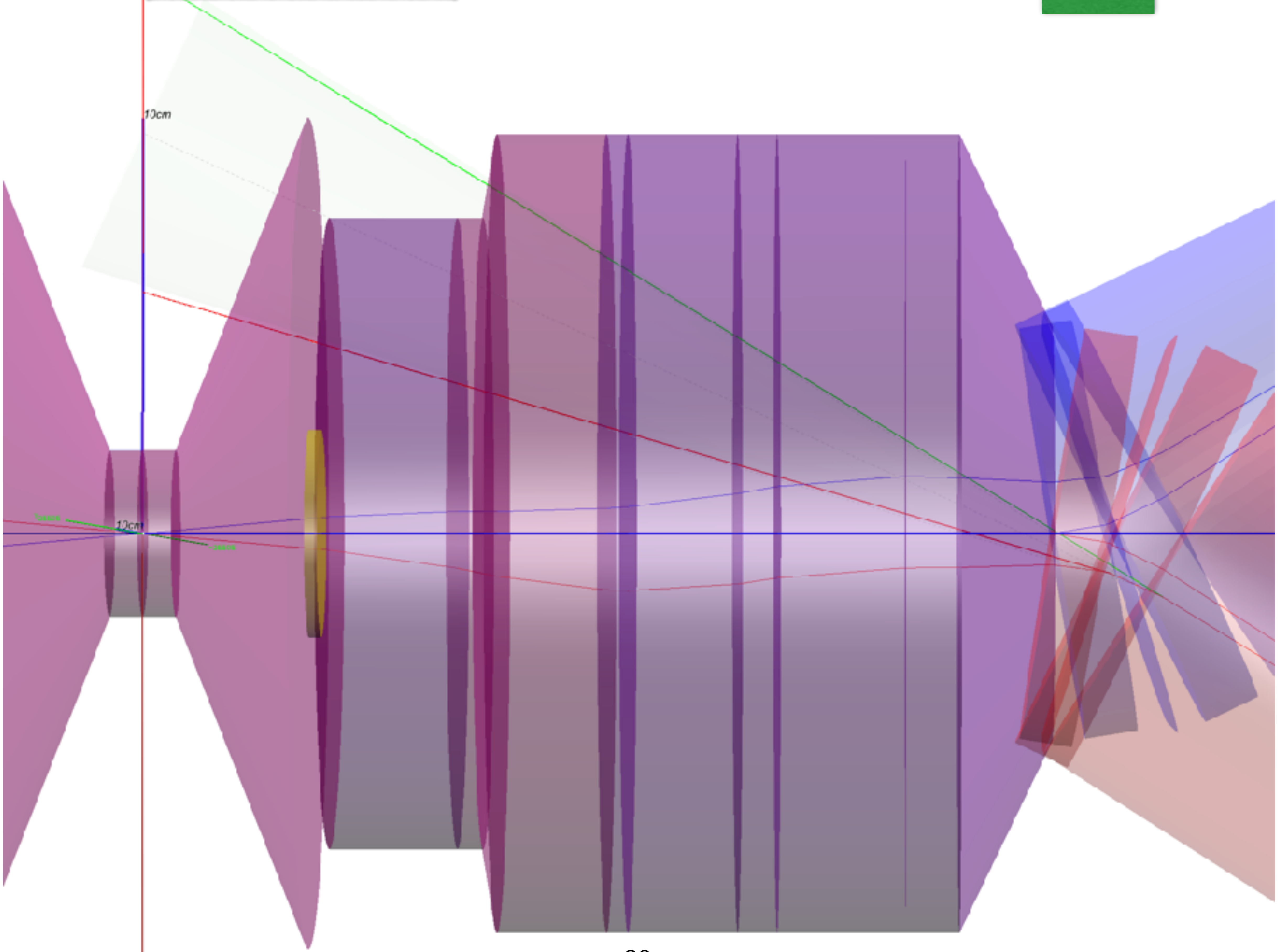
Synchrotron radiation cone: θ=0.3 mrad

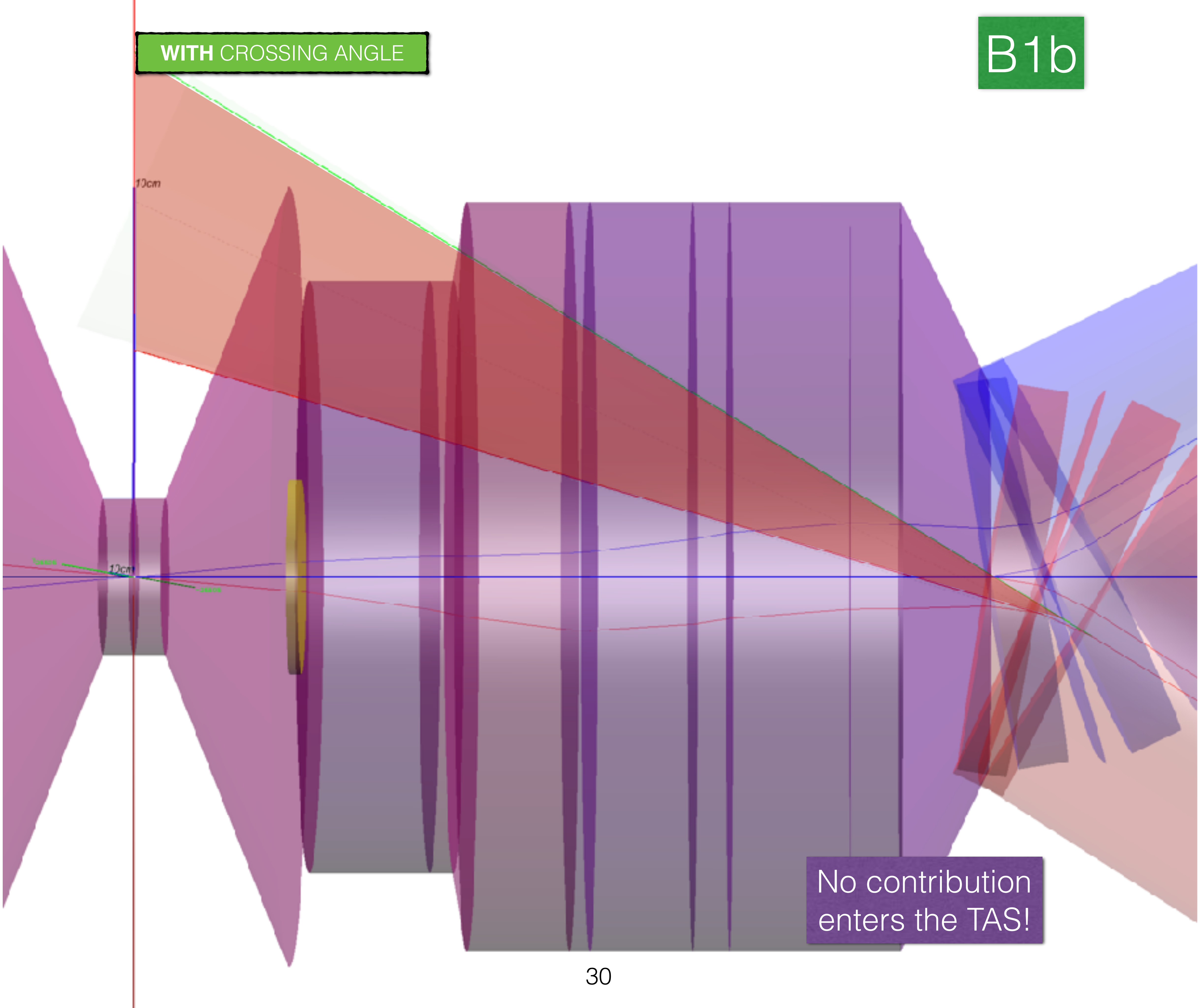
TAS acceptance cone: α=atg(4.6/19800)=0.23 mrad

Solid Angle Acceptance: f=α/θ=77%

WITH CROSSING ANGLE

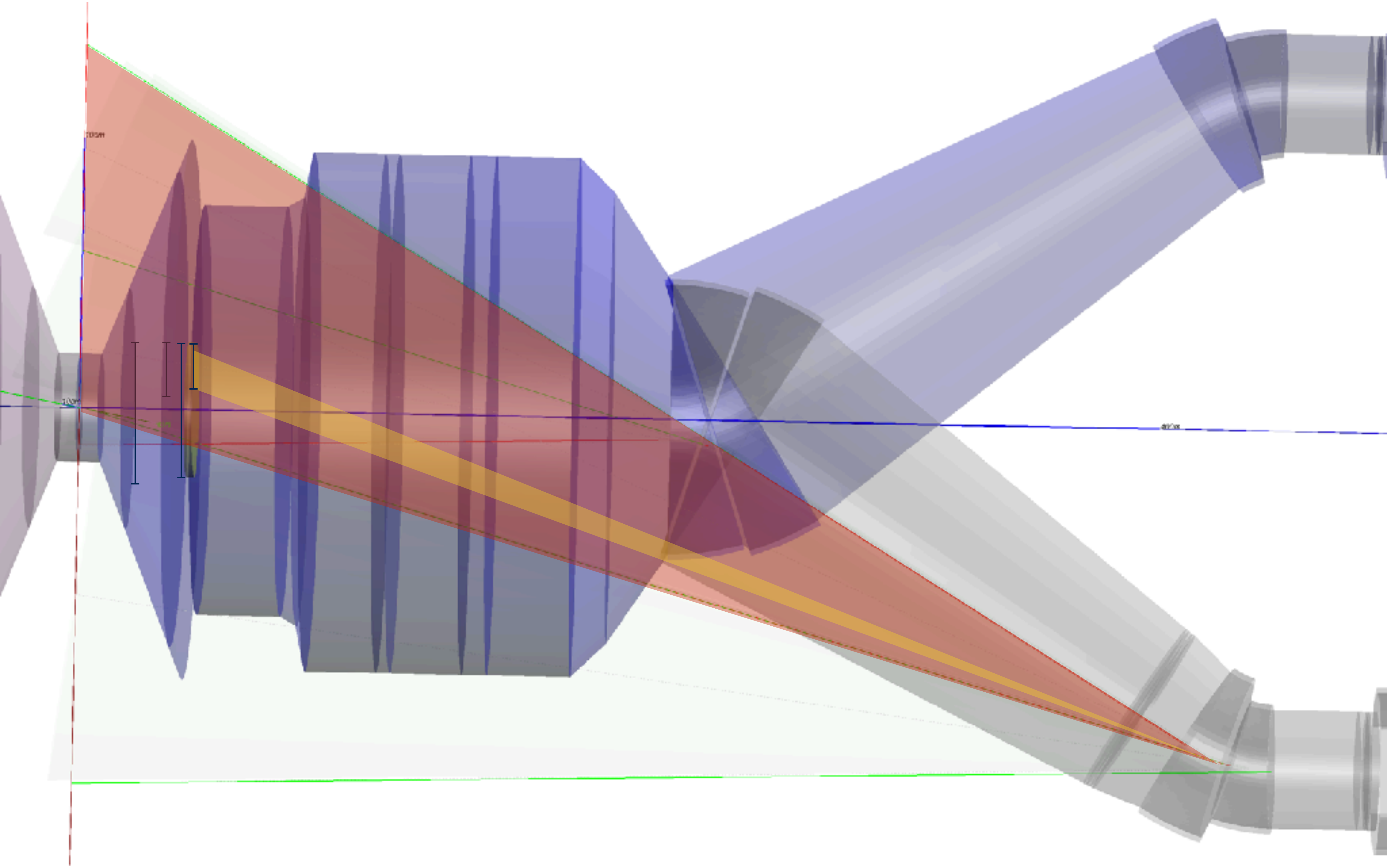
B1b




WITH CROSSING ANGLE
B1b
10cm
No contribution enters the TAS!

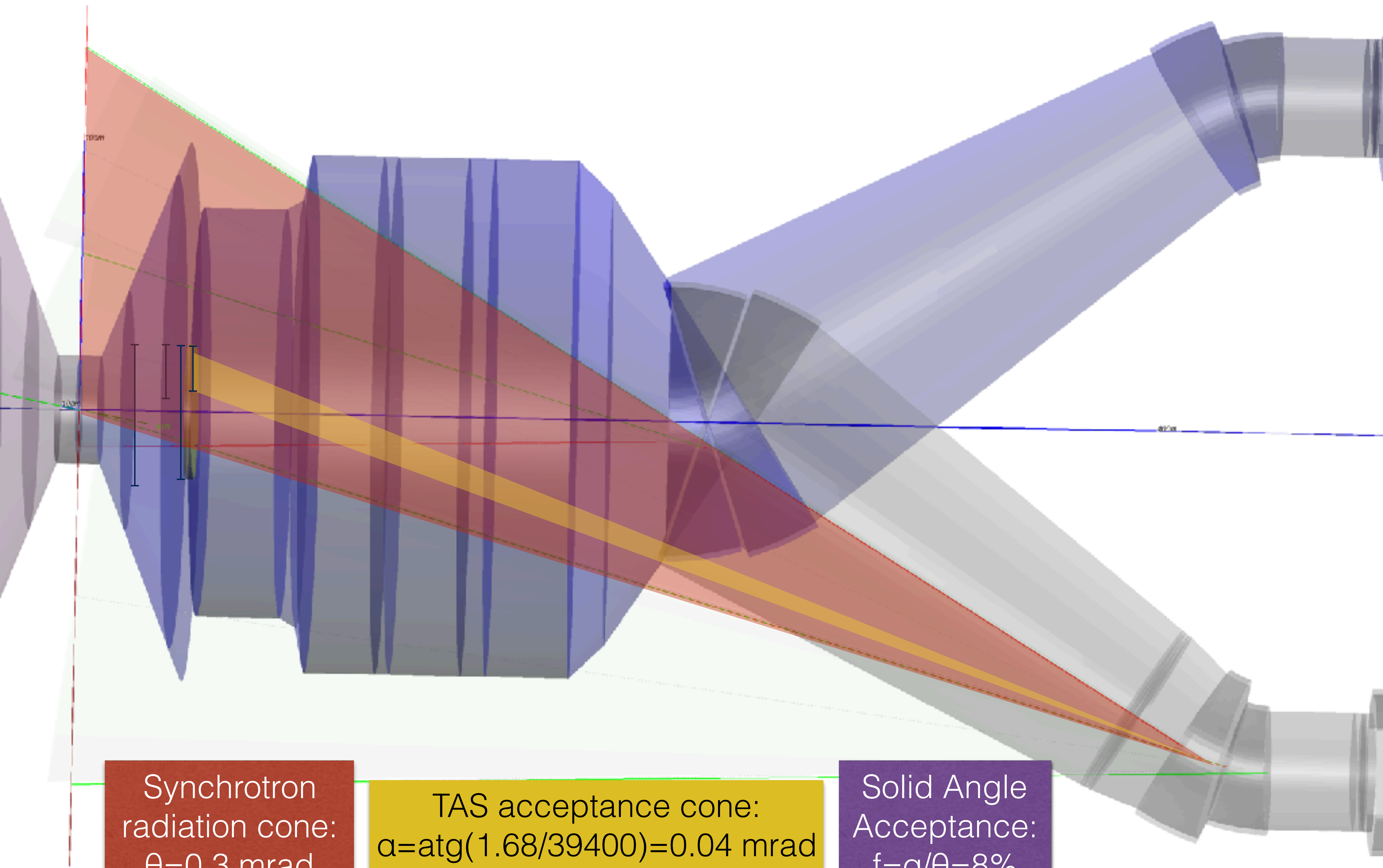
WITH CROSSING ANGLE

B2a



WITH CROSSING ANGLE

B2a



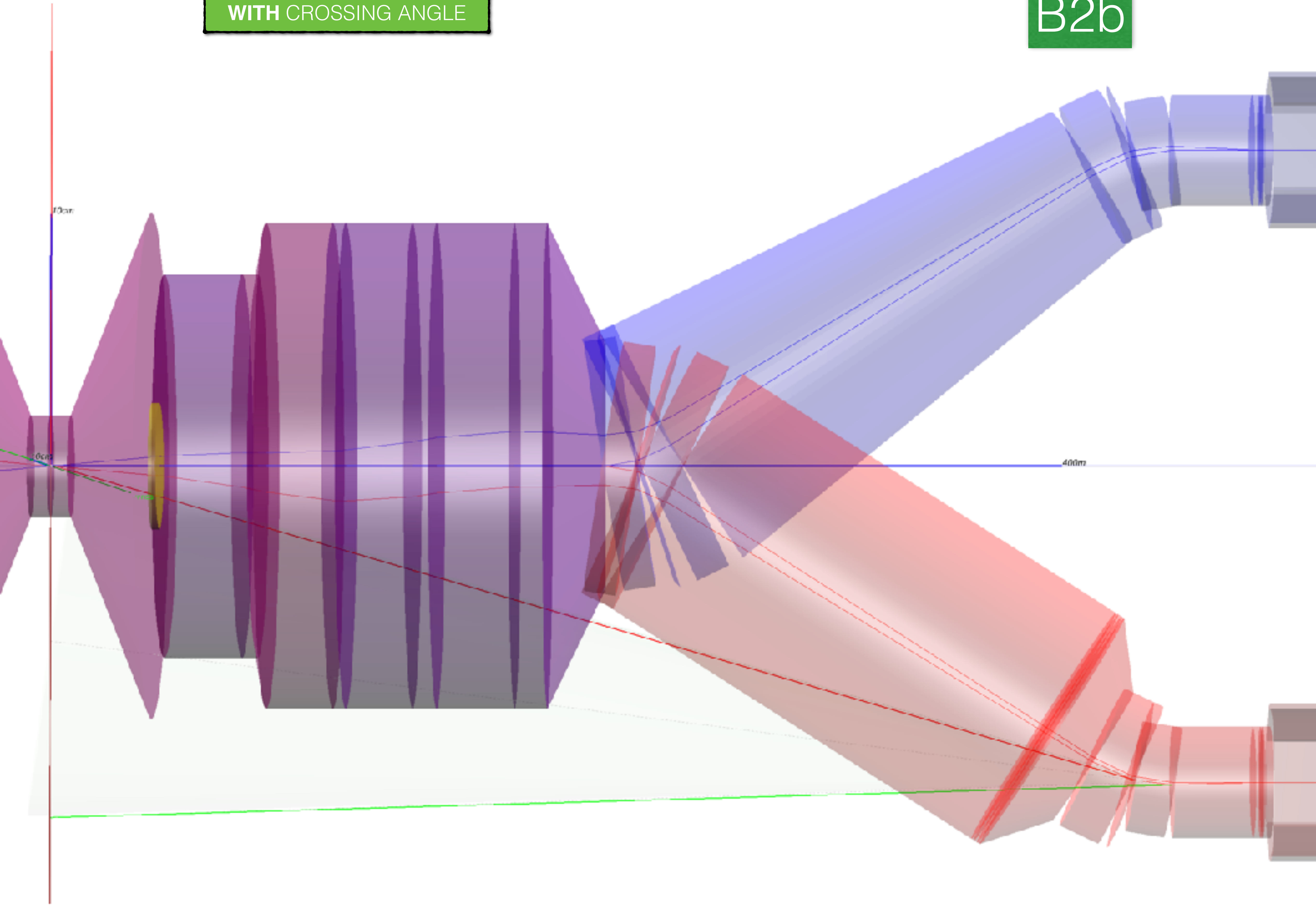
Synchrotron radiation cone: $\theta=0.3$ mrad

TAS acceptance cone: $\alpha=atg(1.68/39400)=0.04$ mrad

Solid Angle Acceptance: $f=\alpha/\theta=8\%$

WITH CROSSING ANGLE

B2b



WITH CROSSING ANGLE

B2b