beam parameters @ 250 GeV

implications for
physics and detectors

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we are now considering energy staging of ILC

250 GeV Higgs factory

→ luminosity and/or energy upgrades

→ 500 GeV

→ ...

current ILC design optimised for 500 GeV

250 GeV phase will have greater weight in the

- project approval process
- first ~10 years' operation

revisiting parameters for 250 GeV ILC machine

→ can we get more physics output from ILC-250 ?

→ can we get higher instantaneous luminosity at 250 GeV ?

outline

- alternative parameter sets for 250 GeV ILC
- effect on luminosity spectrum
- effect on a physics measurement
- effect on detector backgrounds

reminder for accelerator non-experts

ILC beams focussed into a very thin ellipse @ IP : σ_X , σ_Y

Luminosity ~ 1 / (σ_X σ_Y)

As beams pass through each other,

e+, e- are affected by EM field of opposing bunch

"disruption parameter" ~ 1 / ($\sigma_X + \sigma_Y$)

disruption gives rise to beamstrahlung,

less clean luminosity spectrum

Very flat beams can give

Small (σ_X σ_Y) → high luminosity

Large ($\sigma_X + \sigma_Y$) → modest disruption

Beam characterised by "emittance"

Spatial spread x Angular spread ~ constant, determined by damping rings

β^* characterises how much is in the Spatial vs. Angular spread at the IP

beam size at IP $\sigma \sim \sqrt{(\text{emittance} \times \beta^*)}$, individually for (x, y)

K. Yokoya has suggested ways to increase luminosity at 250 GeV

start from TDR parameters	**TDR**	**"Set 2"**
+ horizontal emittance → reduce by 2	**TDR+ε_x**	**"Set 4"**
[requires mode aggressive damping ring design]		
+ horizontal beta* → reduce by sqrt(2)	**TDR+ε_x/β_x**	**"Set 15"**
[beam size @ IP ~ sqrt (emittance x beta*)]		
+ vertical beta* → increase by sqrt(2)	**TDR+$\varepsilon_x/\beta_x/\beta_y$**	**"Set 16"**
[mitigate growth of disruption parameter]		

...all other parameters unchanged

movie 1 , movie 2, movie 3 of simulated bunch crossings (CAIN) bunches are smaller in the x-direction

→ interact more strongly with each other

→ more luminosity

→ more beamstrahlung

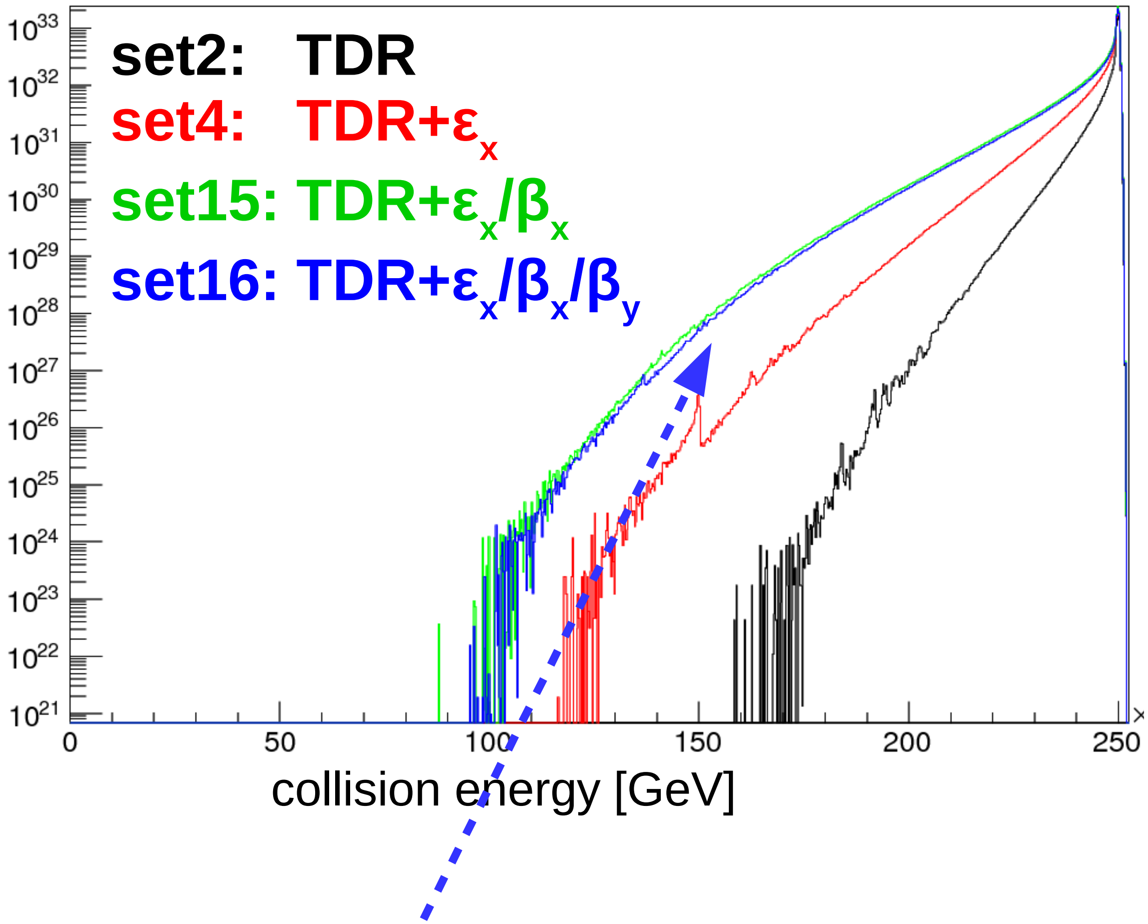
→ larger energy spread of collisions

→ more detector backgrounds

in this talk, we'll look at the effect on

the physics and detector

Luminosity spectra of different parameter sets

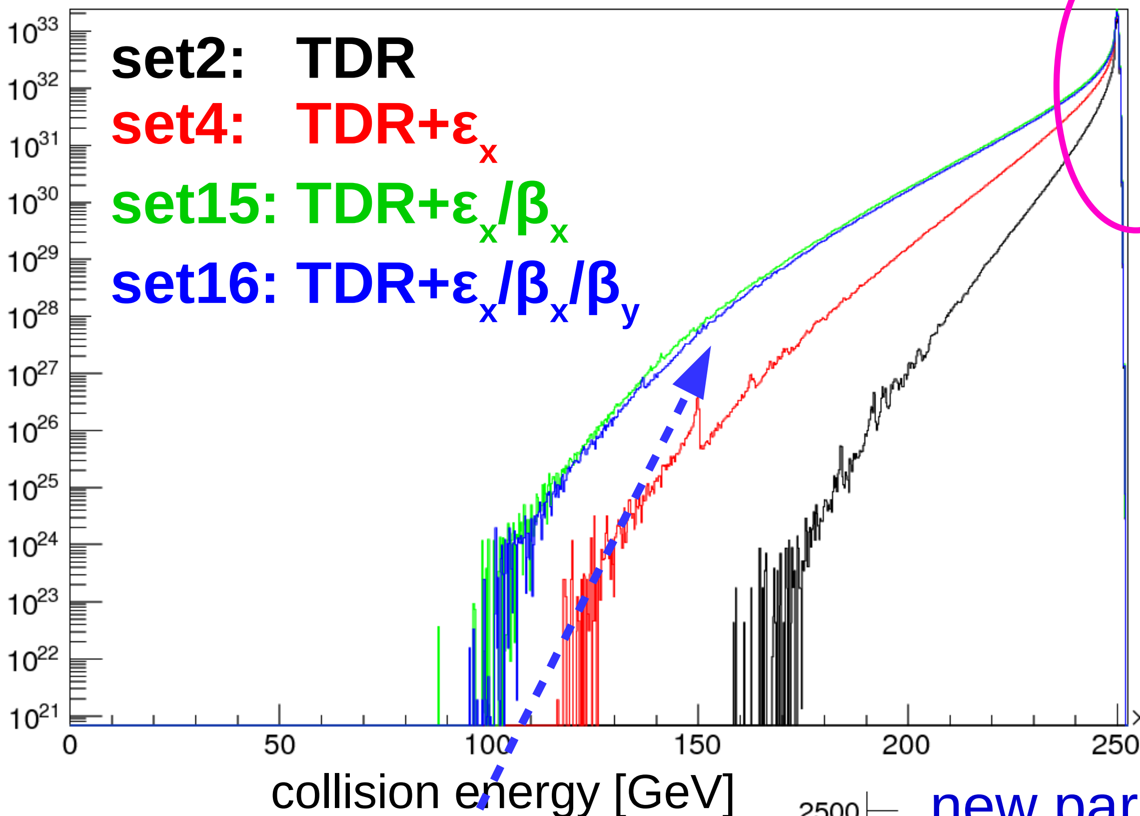


calculated by CAIN v2.4.3

with initial beam energy spread
e– beam: 0.19 %
e+ beam: 0.152 %

new parameters:
larger tails due to increased beamstrahlung

Luminosity spectra of different parameter sets



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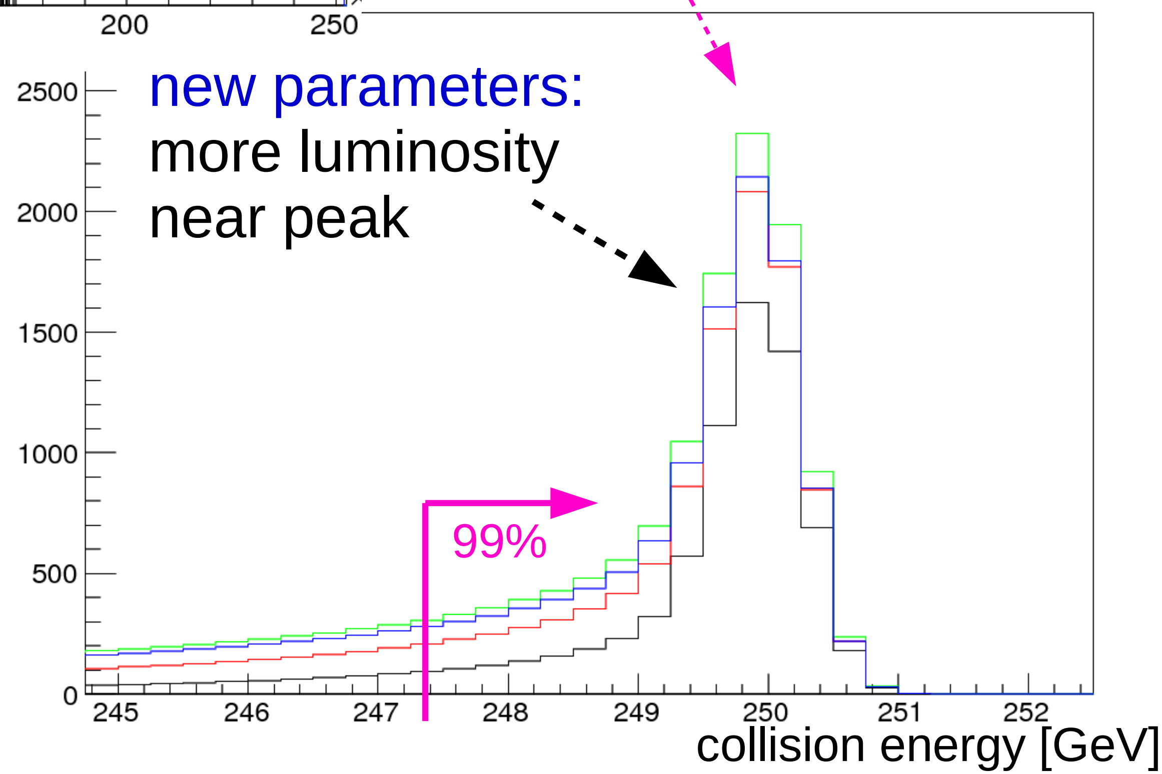


Luminosities for different beam parameters at 250 GeV

$[cm^{-2}s^{-1}]$	**all energies**	**>90%**	**>95%** of nominal energy	**>99%**
TDR	8.08e+33	8.08e+33	7.99e+33	6.97e+33
TDR+ε_x	1.37e+34 **x1.69**	1.35e+34 **x1.68**	1.29e+34 **x1.62**	9.90e+33 **x1.41**
TDR+ε_x/β_x	1.97e+34 **x2.44**	1.90e+34 **x2.35**	1.72e+34 **x2.15**	1.18e+34 **x1.69**
TDR+$\varepsilon_x/\beta_x/\beta_y$	1.80e+34 **x2.23**	1.73e+34 **x2.15**	1.57e+34 **x1.97**	1.08e+34 **x1.55**

enhancement with respect to TDR

70 ~ 140 % enhancement over full energy range

40 ~ 70 % enhancement > 99% of nominal energy

Effect on physics

250 GeV running focussed on Higgs physics

the analysis most sensitive to
knowledge of the collision energy is probably
Higgs mass measurement in recoil analysis $e^+ e^- \rightarrow H\,Z$

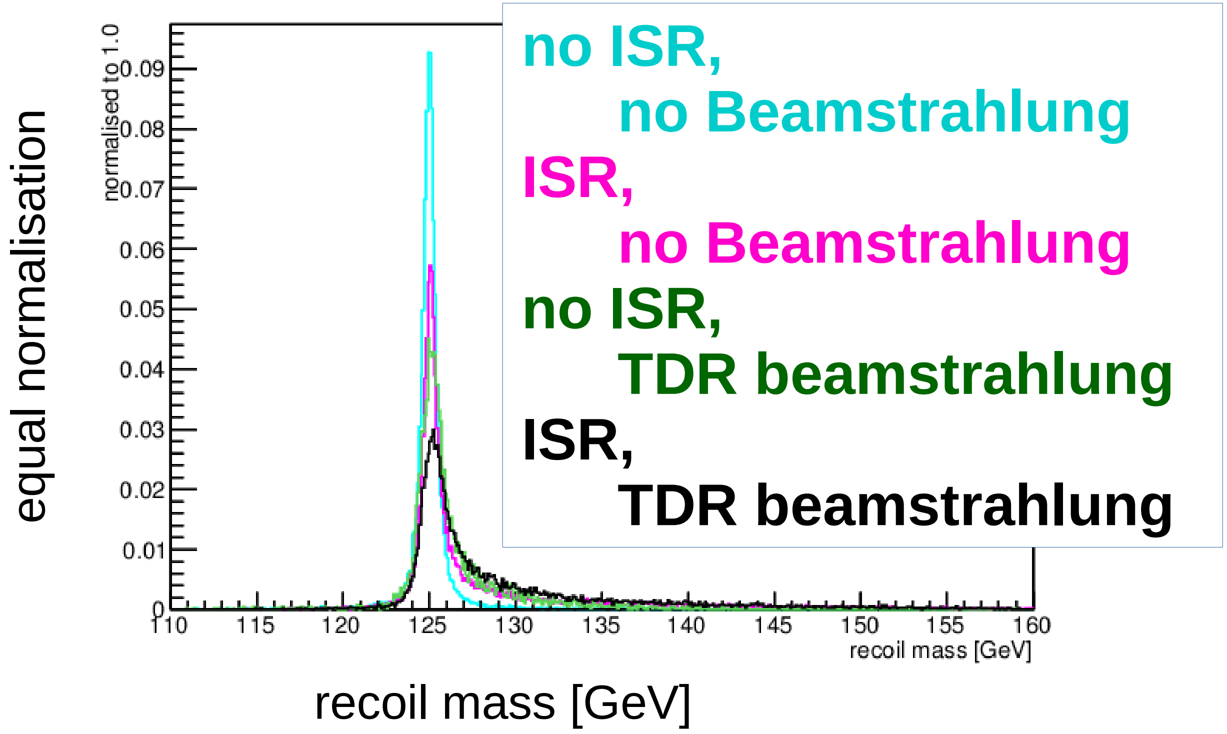
measured Z momentum and
assumed (nominal) centre-of-mass energy and frame
are used to indirectly reconstruct Higgs 4-momentum

Z decay to muons is most precisely measured
therefore most sensitive to luminosity spectrum

use WHIZARD2 to generate
$e^+ e^- \rightarrow \mu\,\mu\,H\,;\,H \rightarrow 4\,\nu$
at 250 GeV with different beam energy spectra (from CAIN)

fully simulate & reconstruct events in
ILD_l1_v01 model (ilcsoft v01-19-01)

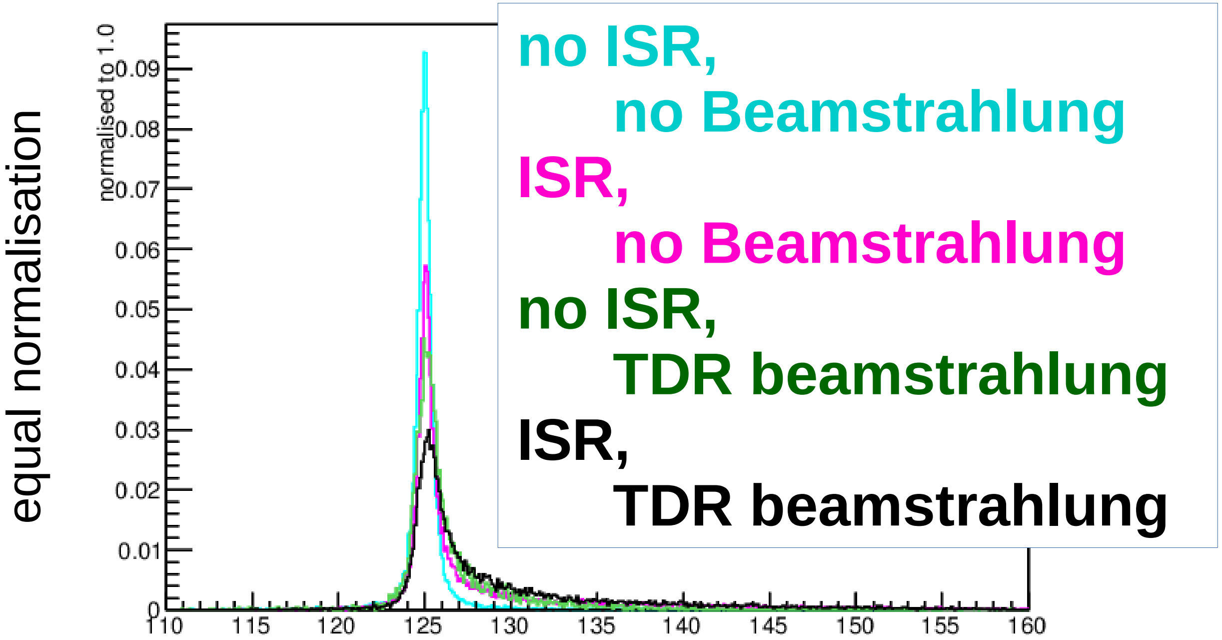
recoil mass distributions: after full simulation and reconstruction



width of **"perfect" no-ISR no-BS** case is due to detector resolution

effects of **ISR** and **beamstrahlung** on peak are of similar size

recoil mass distributions: after full simulation and reconstruction



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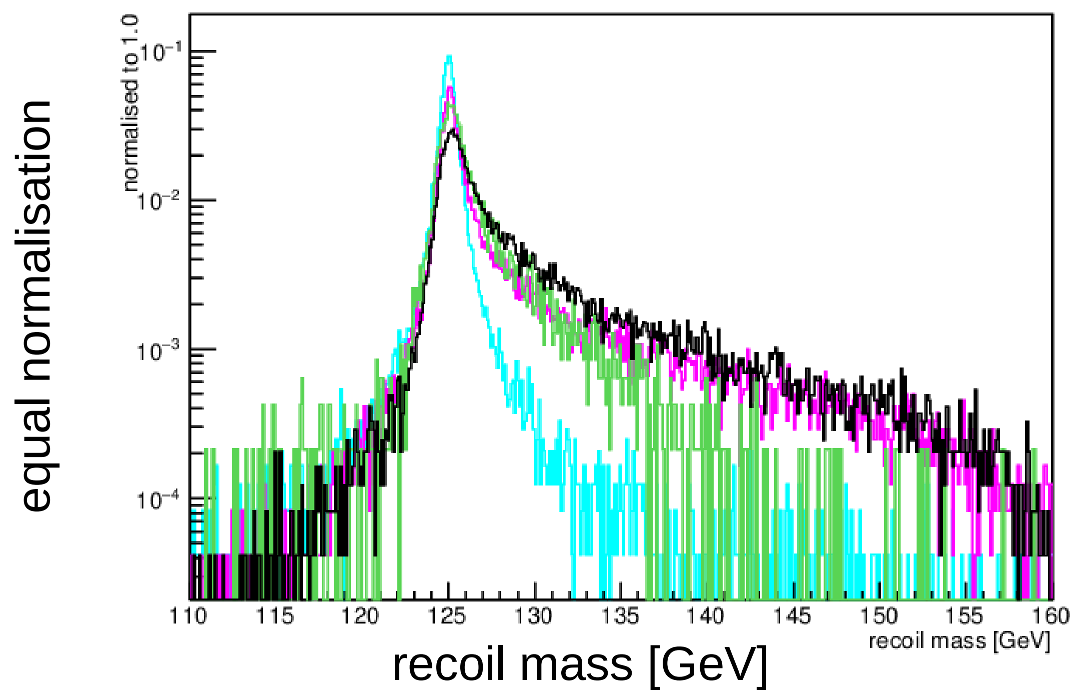
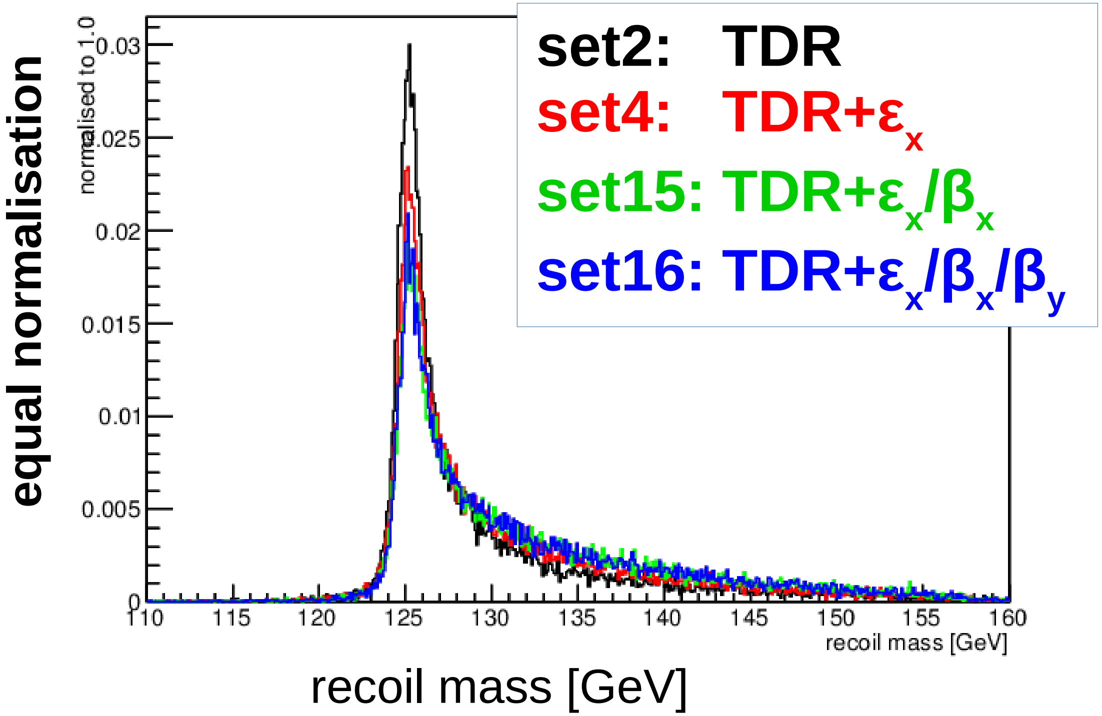


recoil mass distributions: after full simulation and reconstruction

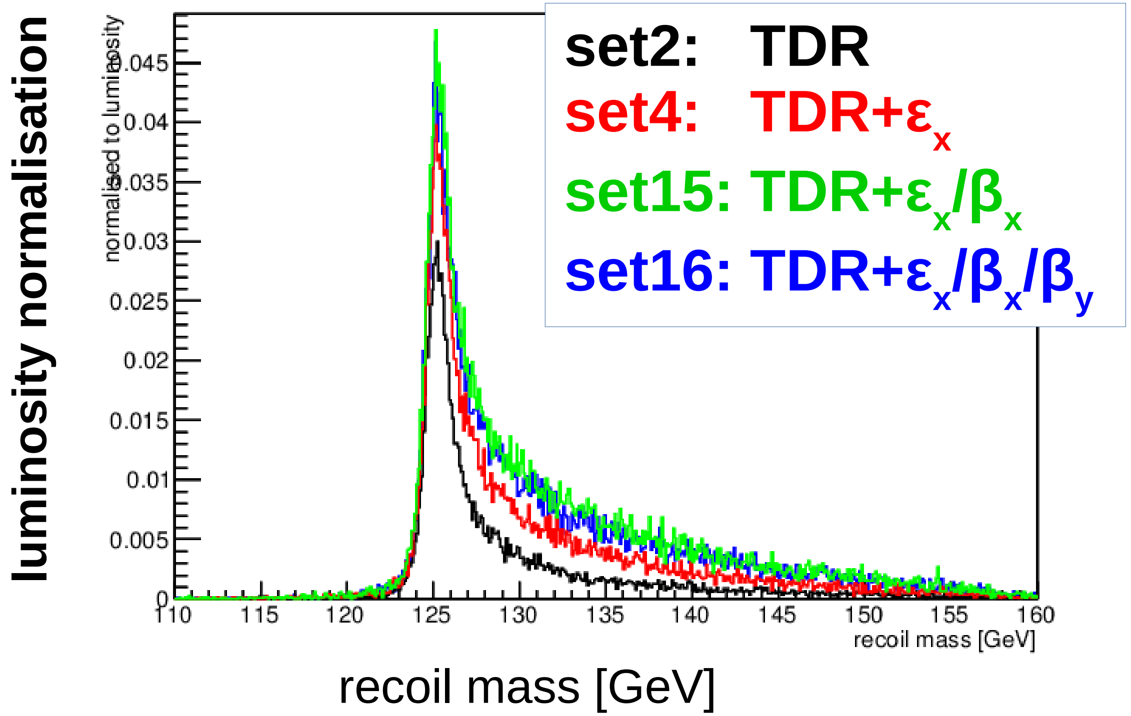
compare different ILC250 beam parameter sets



new parameter sets: smaller fraction of events in peak, more in upper tail

recoil mass distributions: after full simulation and reconstruction

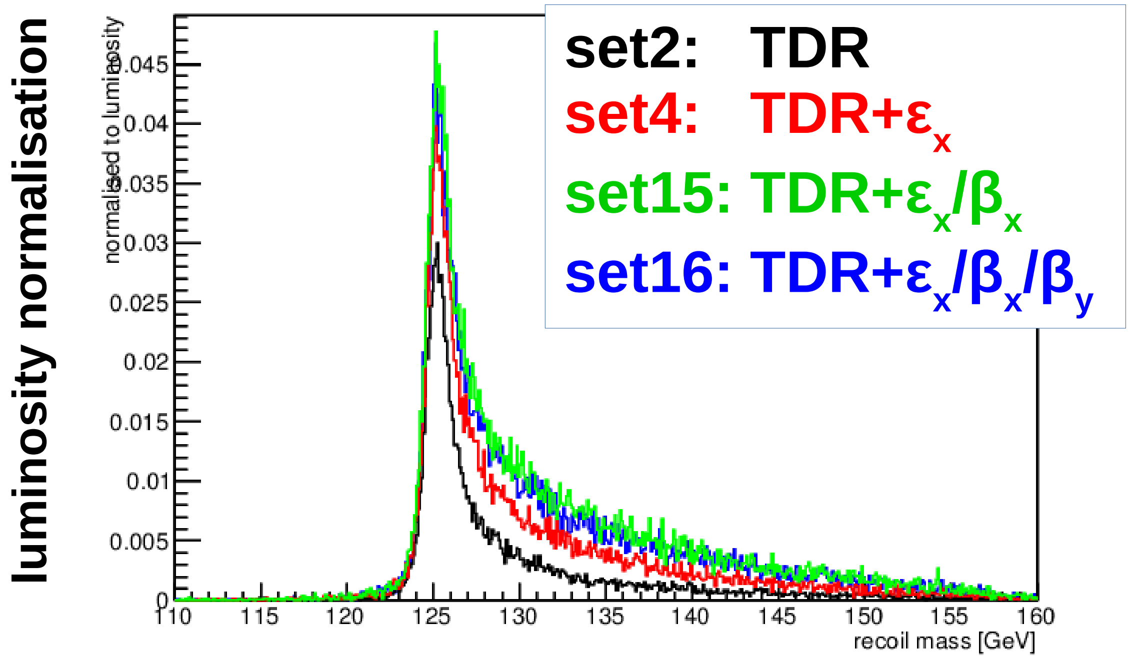
compare different ILC250 beam parameter sets



weighted by luminosity, new parameter sets give more events in peak (and many more in tail)

recoil mass distributions: after full simulation and reconstruction

compare different ILC250 beam parameter sets



recoil mass [GeV]

weighted by luminosity, new parameter sets give more events in peak (and many more in tail)

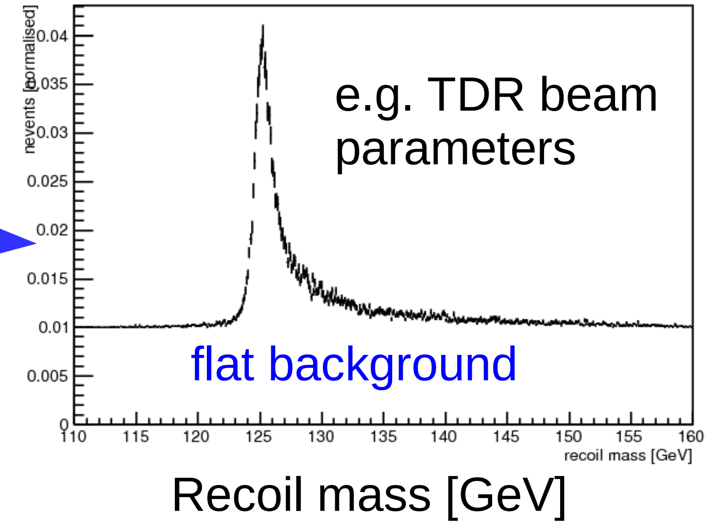
which is “better”,
and by how much ?

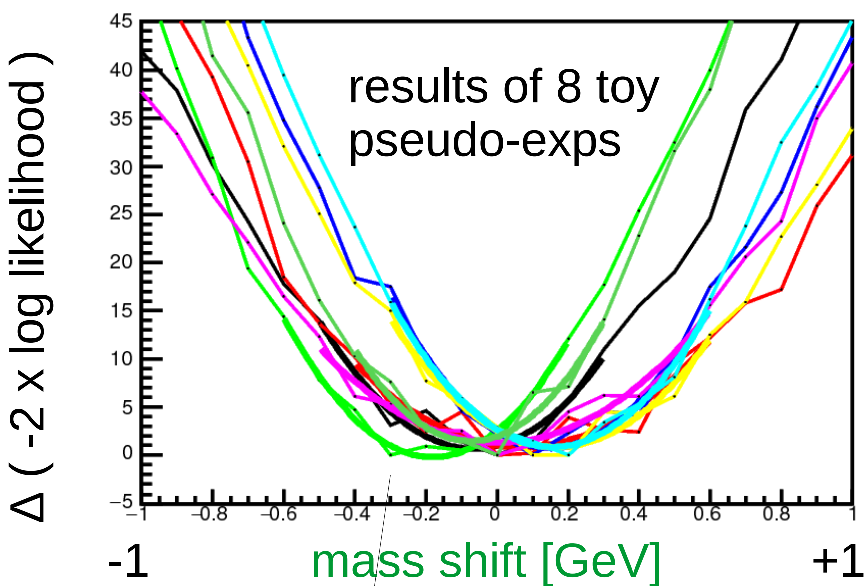
For Higgs **mass** measurement, narrow and tall peak better
→ events in tail ~useless
For other Higgs properties, events in tail useful → less sensitive

simple mass analysis

assume reconstructed signal shape
+ flat background

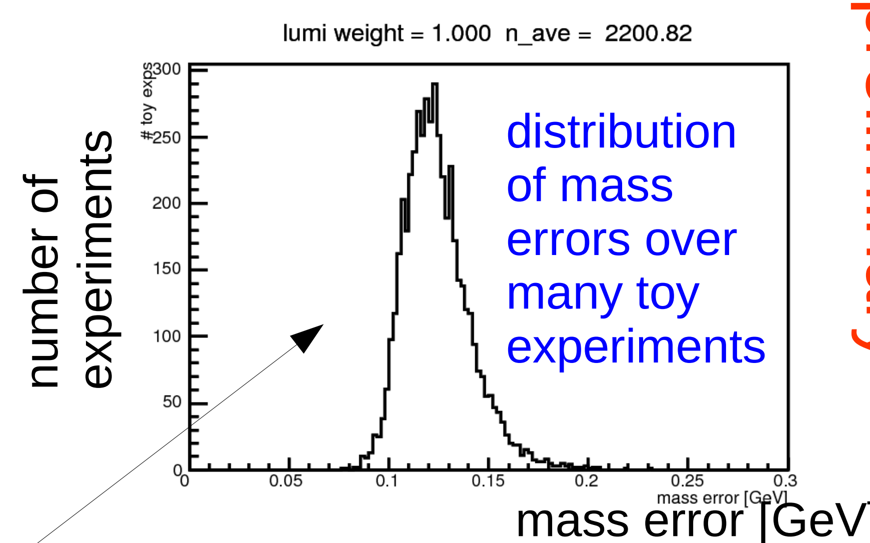
use as template for Toy MC experiments
fit data of each experiment with
shifted signal peak + flat background

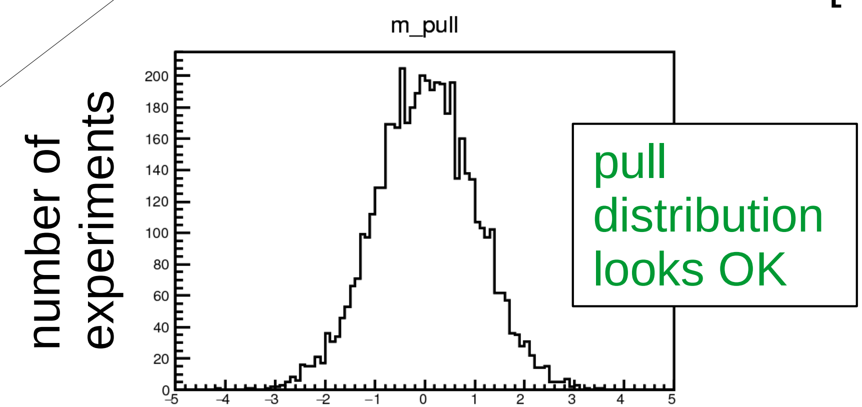




fit curves to parabola near minimum
→ extract mass and error

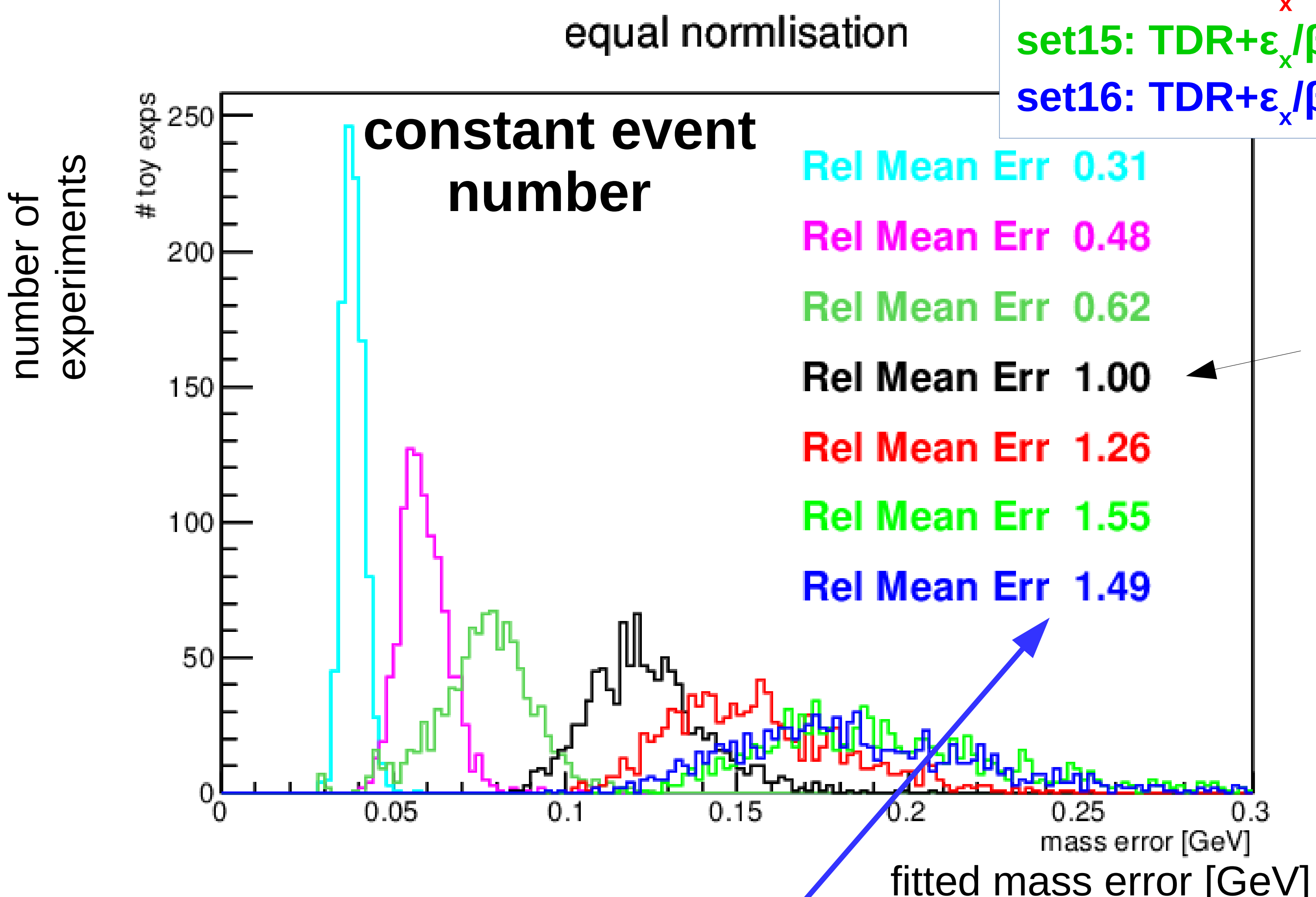
preliminary





expected mass measurement errors using different beam spectra

no ISR, no Beamstrahlung
ISR, no Beamstrahlung
no ISR, TDR beamstrahlung
set2: TDR
set4: TDR+ε_x
set15: TDR+ε_x/β_x
set16: TDR+$\varepsilon_x/\beta_x/\beta_y$

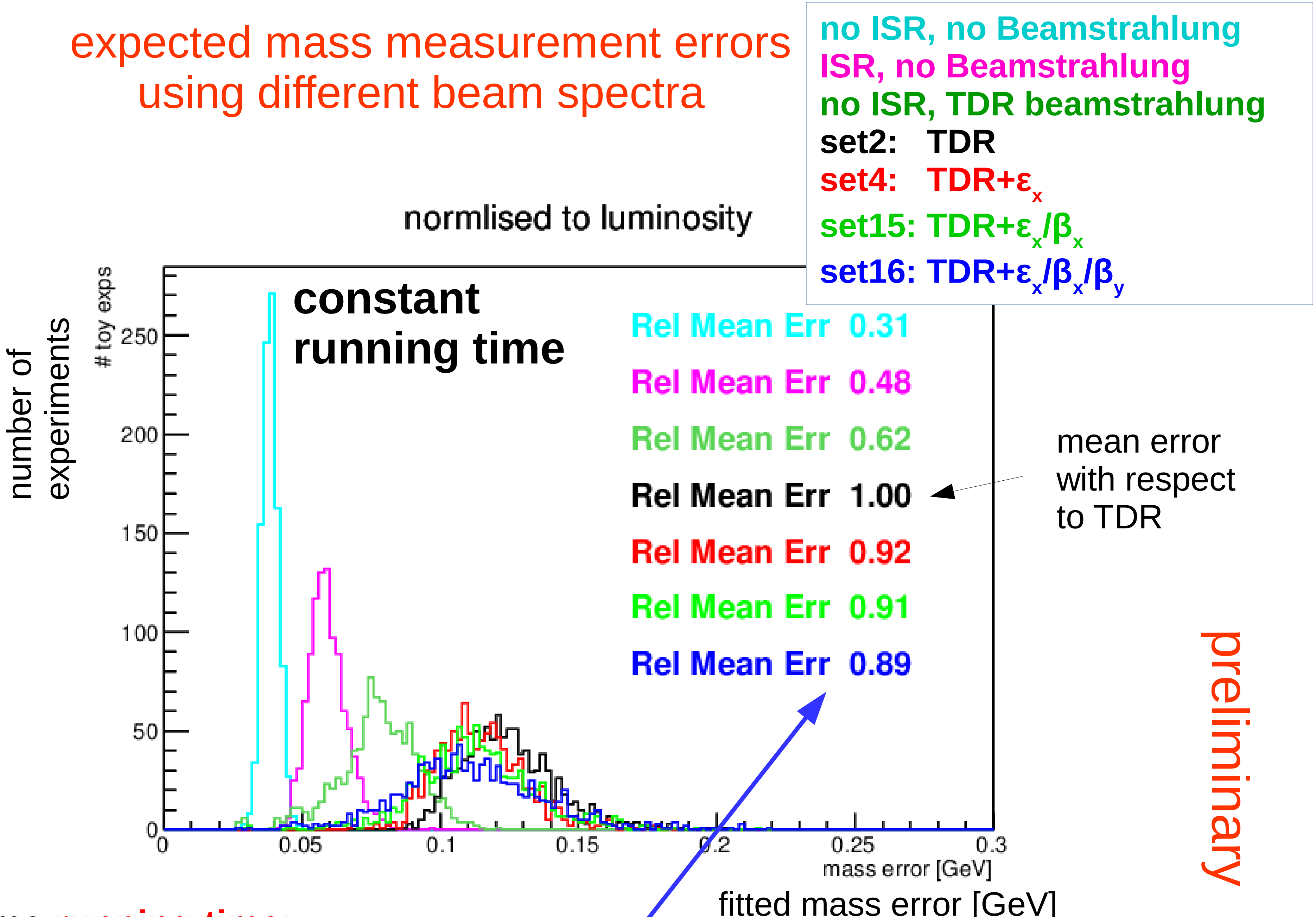


mean error with respect to TDR

preliminary

with same **number of events**:
new spectra less powerful,
mass resolution degrades by 25 ~ 55% compared to TDR

expected mass measurement errors using different beam spectra



with same **running time**:
higher lumi more than compensates,
mass resolution improves by ~10%
compared to TDR

Higgs mass measurement in
recoil against $Z \to \mu\mu$ especially sensitive
to energy spectrum

other Higgs analyses at 250 GeV
should gain more than this 10% factor

e.g. hadronic recoil analysis:
peak smeared by jet energy resolution, so
should be less sensitive to beamstrahlung

Higgs branching ratio measurements:
total number of Higgs more important than
number in peak

These higher-lumi 250 GeV beam parameters
seem beneficial for Higgs measurements

detector backgrounds

the more violent bunch-bunch interactions
of higher-lumi parameter sets
produce more low energy e+e- pairs
"incoherent pairs"

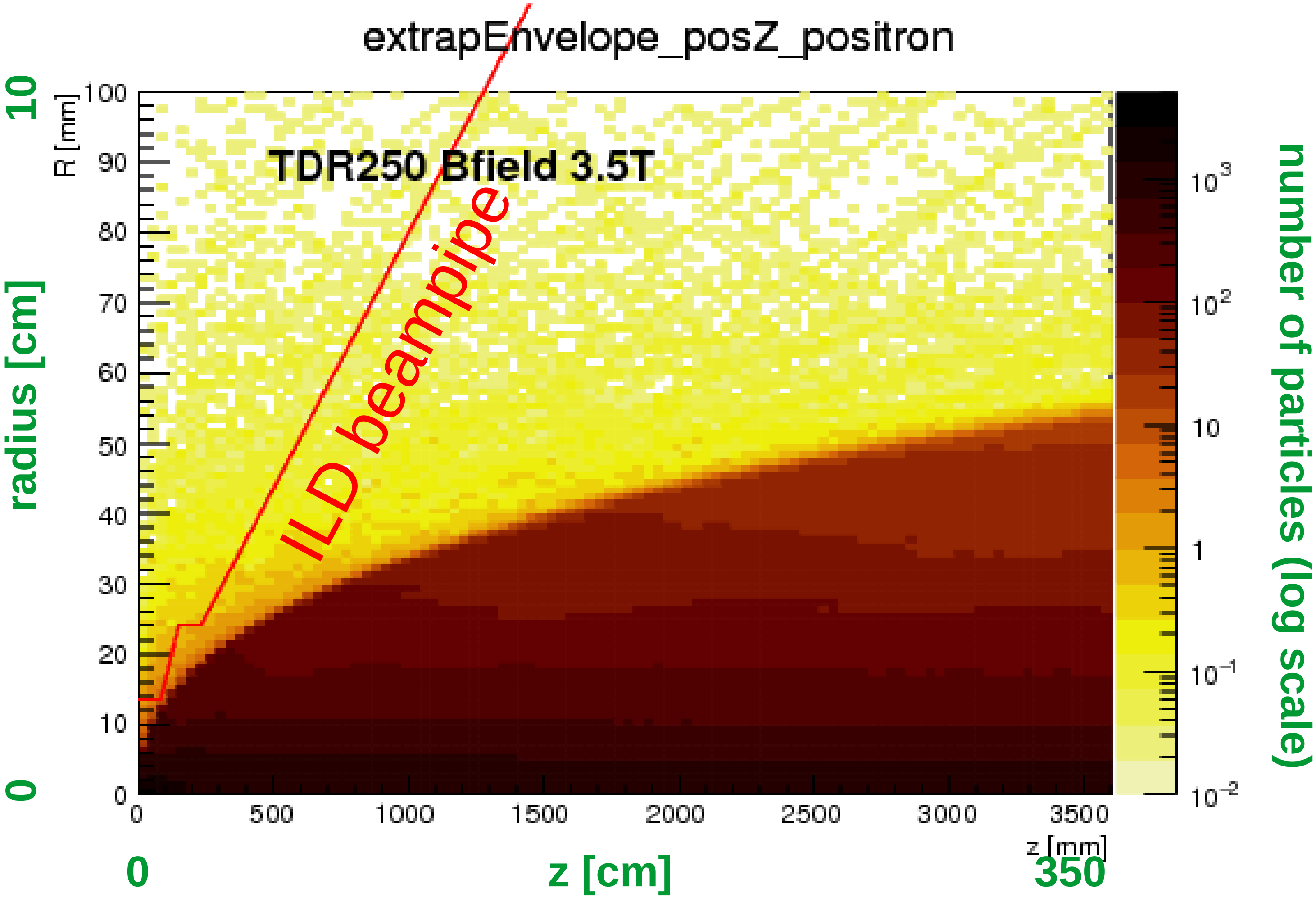
these are mostly kept within the beampipe
by the experiments' solenoidal field,
but some fraction can hit
beampipe and inner detectors

many will hit the forward calorimeters,
some will be reflected back
(not considered in this study)

use CAIN to simulate number & spectrum of pairs
extrapolate in uniform 3.5T solenoidal B-field
(set anti-DID & crossing angle to zero)

Distribution of incoherent pairs around beampipe

simple extrapolation in uniform 3.5T field, no beam crossing,
no material interactions, no backscatter from e.g. FCAL



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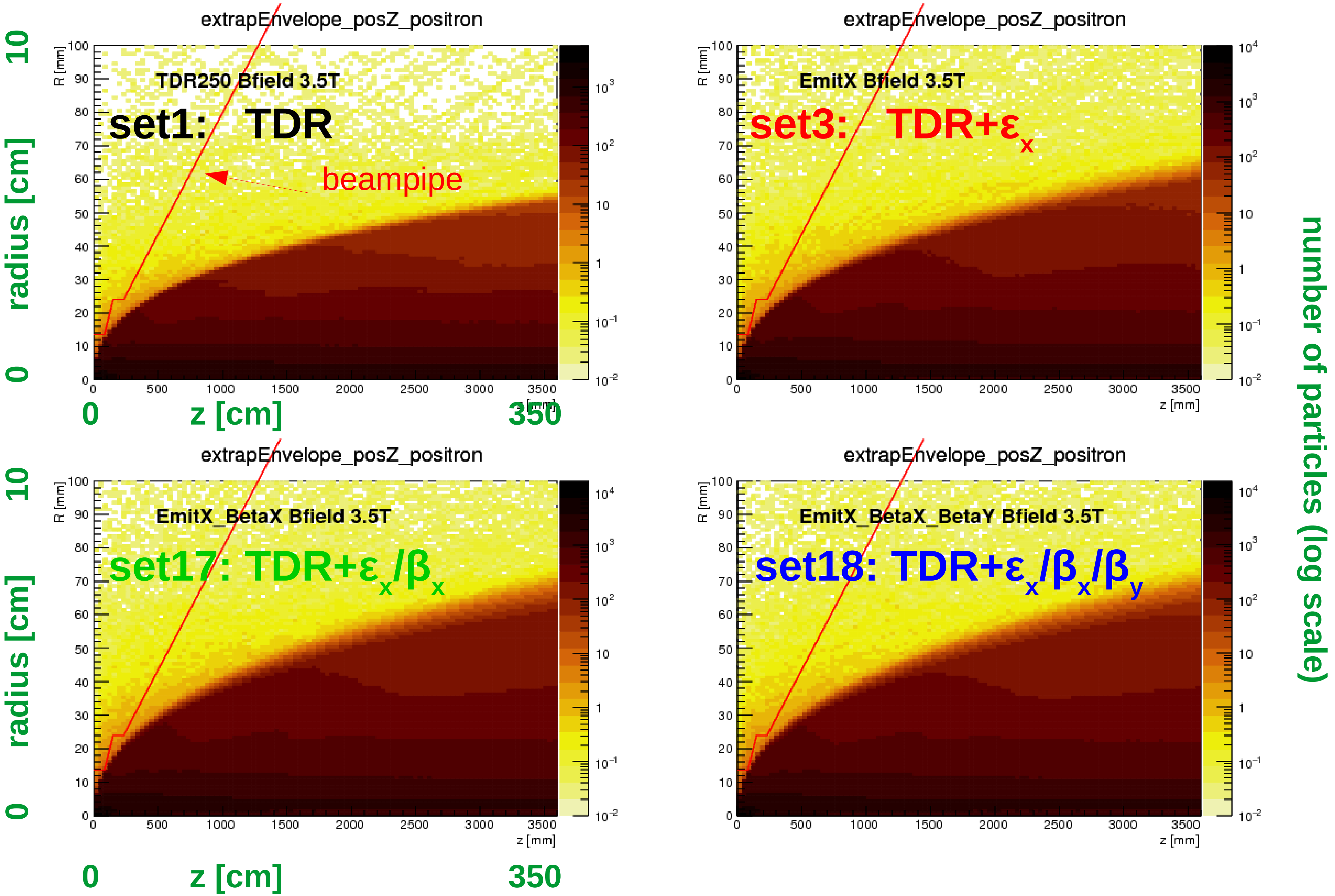
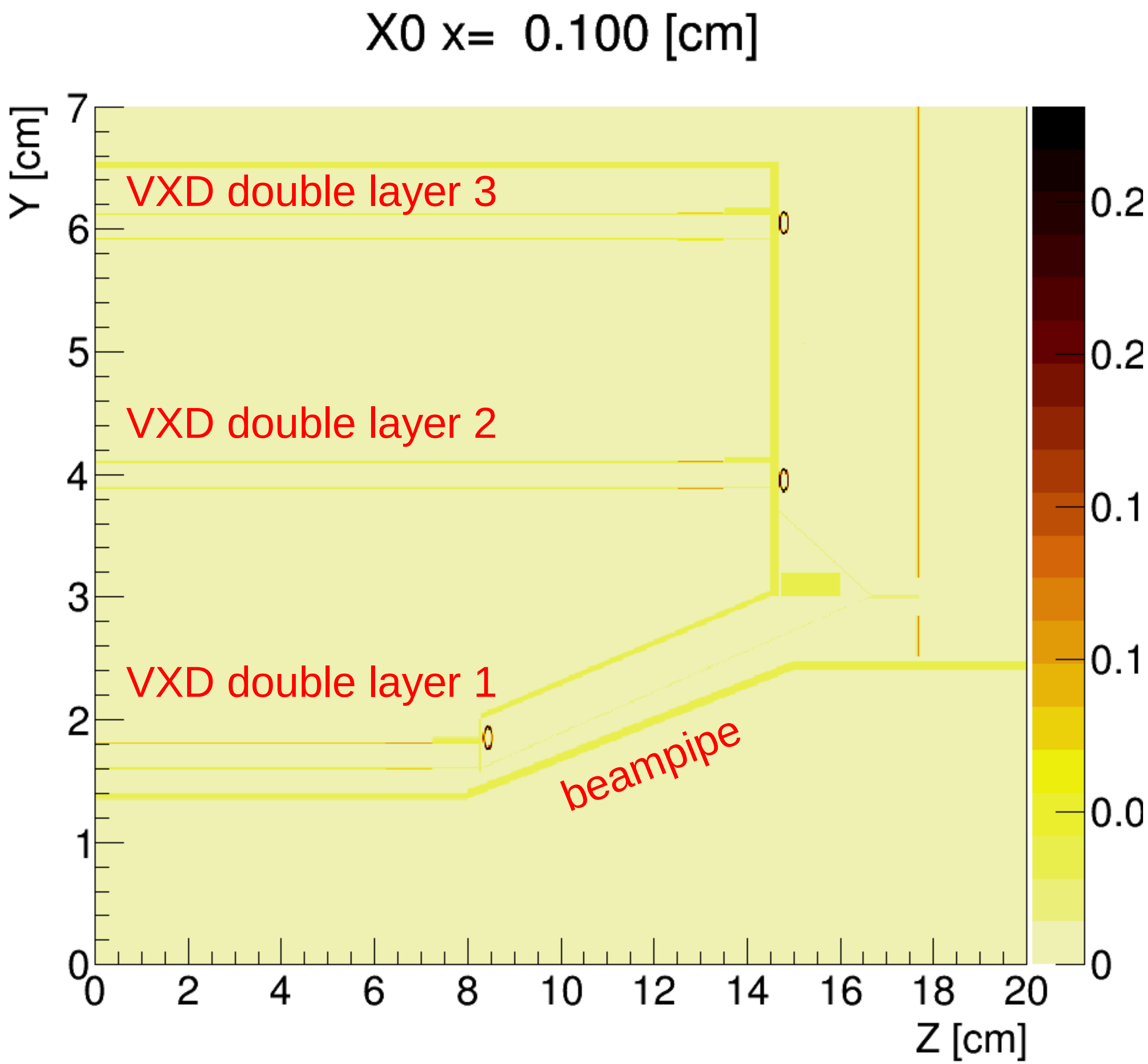
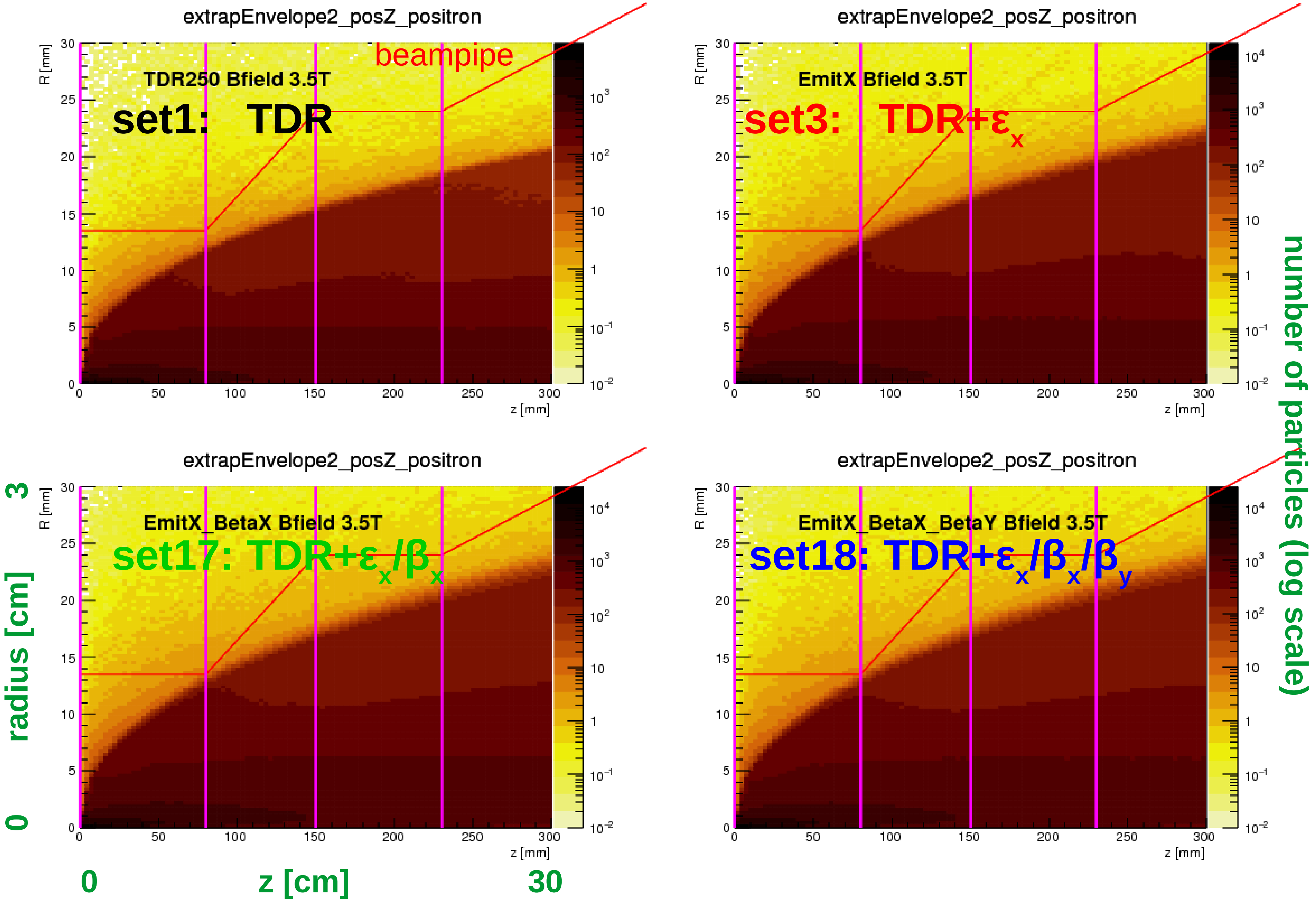


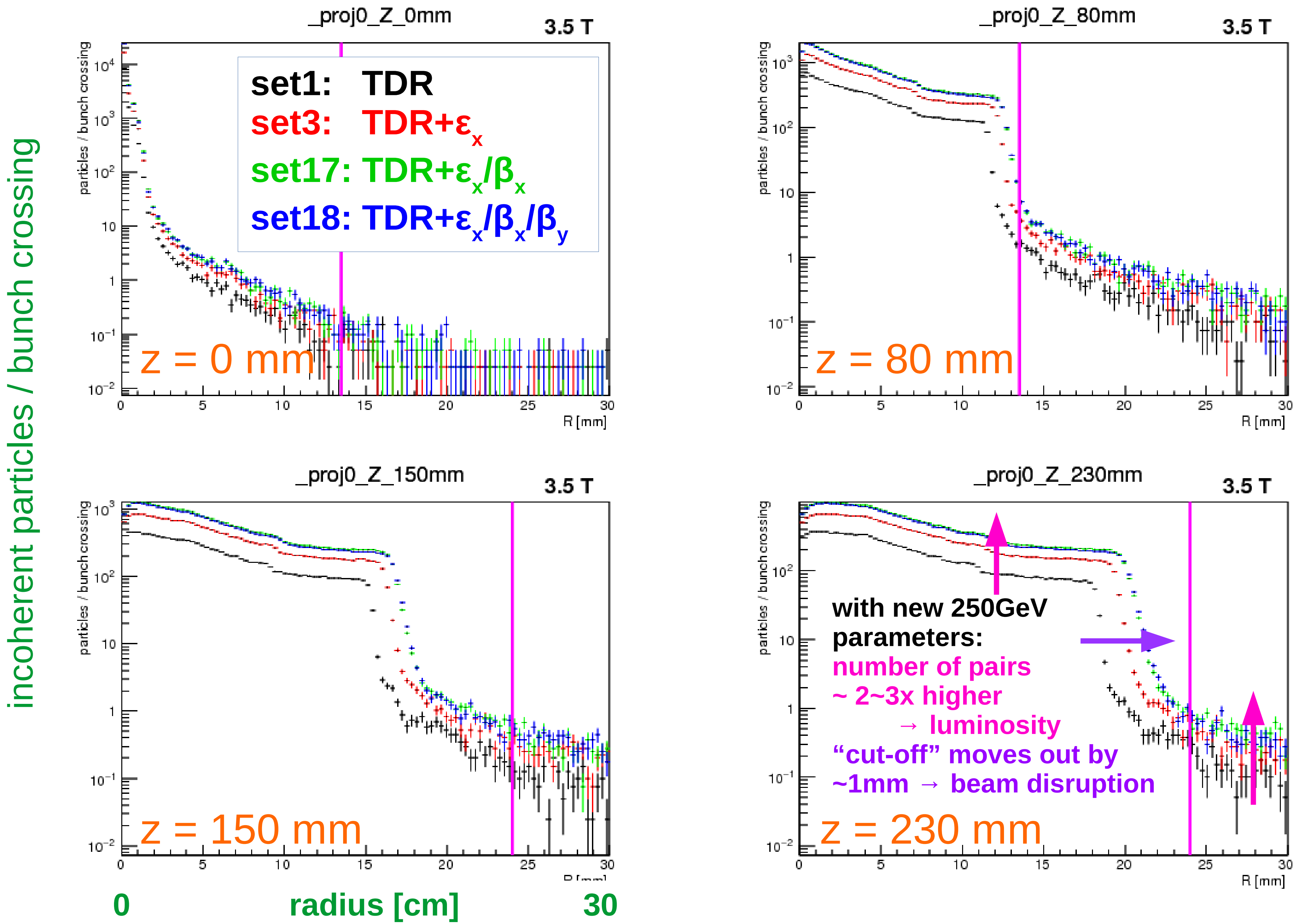
beampipe design in central region of ILD



zoom into central region



same distributions, sliced along pink lines



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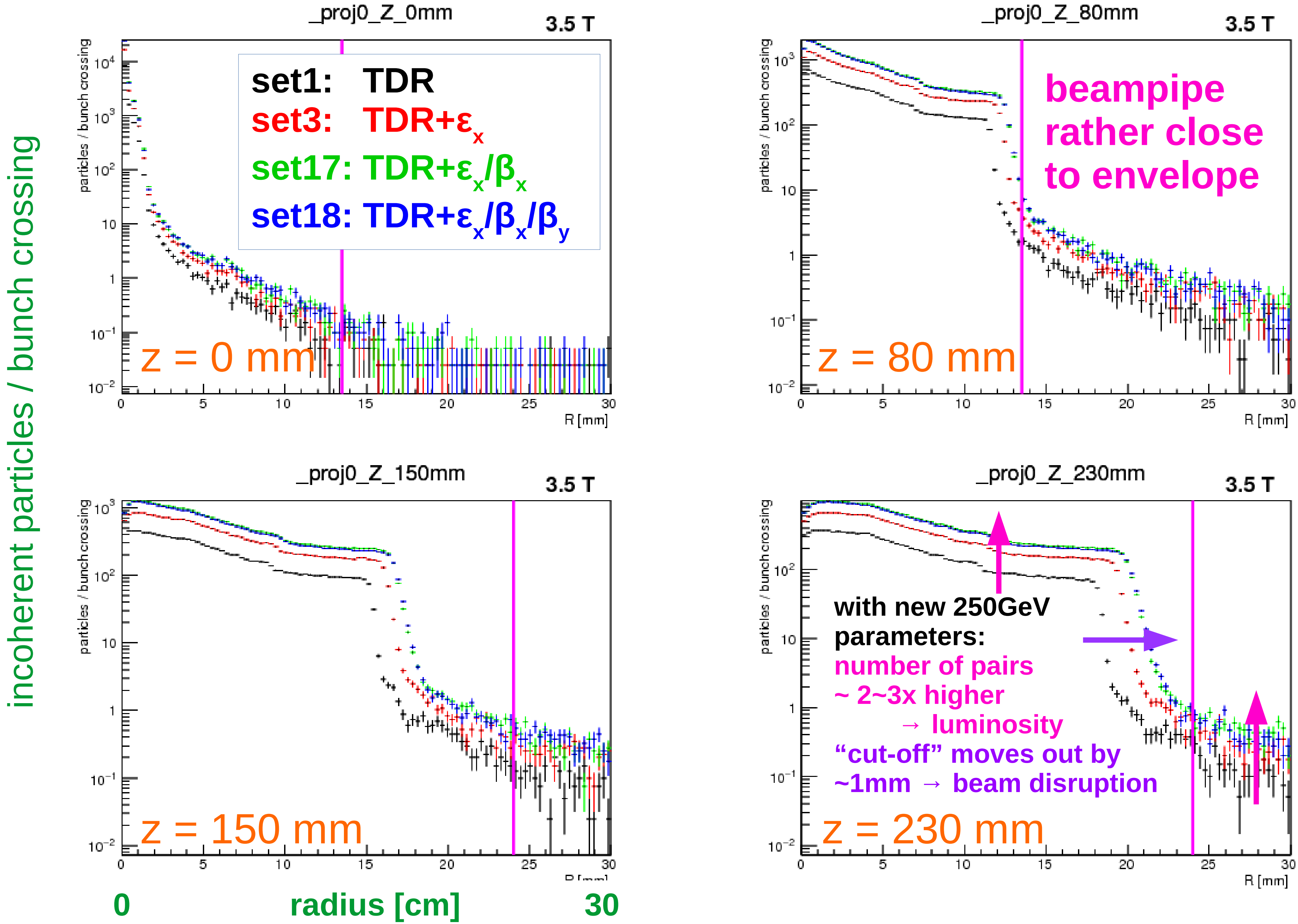
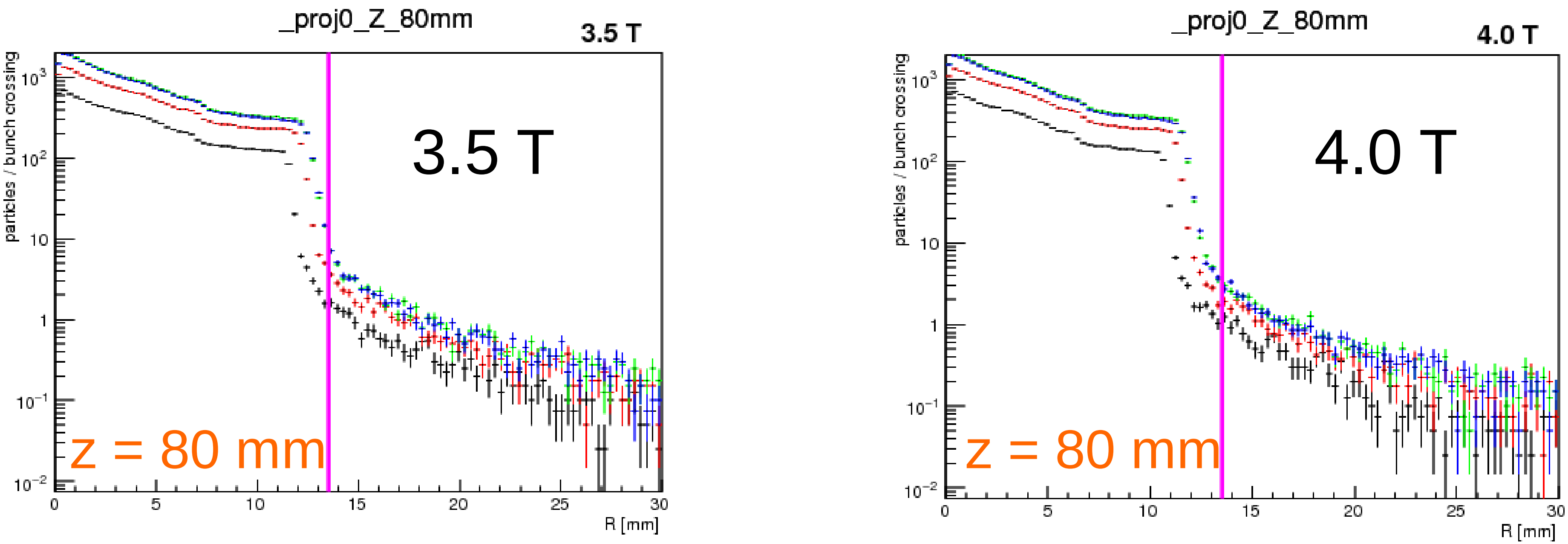


situation improved by

→ larger beam pipe design

→ increased magnetic field: 3.5 T → 4.0 T

incoherent particles / bunch crossing



in current ILD design, ILD solenoid can reach 4.0 T

but is operated at 3.5 T (at least at 250 GeV)

but higher field has trade-offs:

reduced low p_T track finding efficiency

worse vertex charge measurement

Compare new 250 GeV parameter sets with TDR250:

– “envelope” of incoherent pairs grows by O(1 mm)
→ increase size of beampipe ?
→ increase magnetic field ?

– direct incoherent pair backgrounds in e.g. VTX
increase by factor 2-3 compared to TDR250 parameters

– additional contribution from backscattered particles
e.g. from beamcal
→ would expect similar enhancement, but
requires full simulation with realistic B-field

Summary

effects of proposed new 250 GeV beam parameters

smaller bunches than TDR

→ higher luminosity +40~70% at E_{COM} > 0.99 x 250 GeV

→ more bunch disruption, beamstrahlung, backgrounds

promising for physics

despite less clean luminosity spectrum,

statistical error on Higgs mass from H + (Z→μμ)

improves by ~10%

expect more significant improvements for

other Higgs measurements

has implications for detector

→ 2-3 x more incoherent pairs than TDR–250

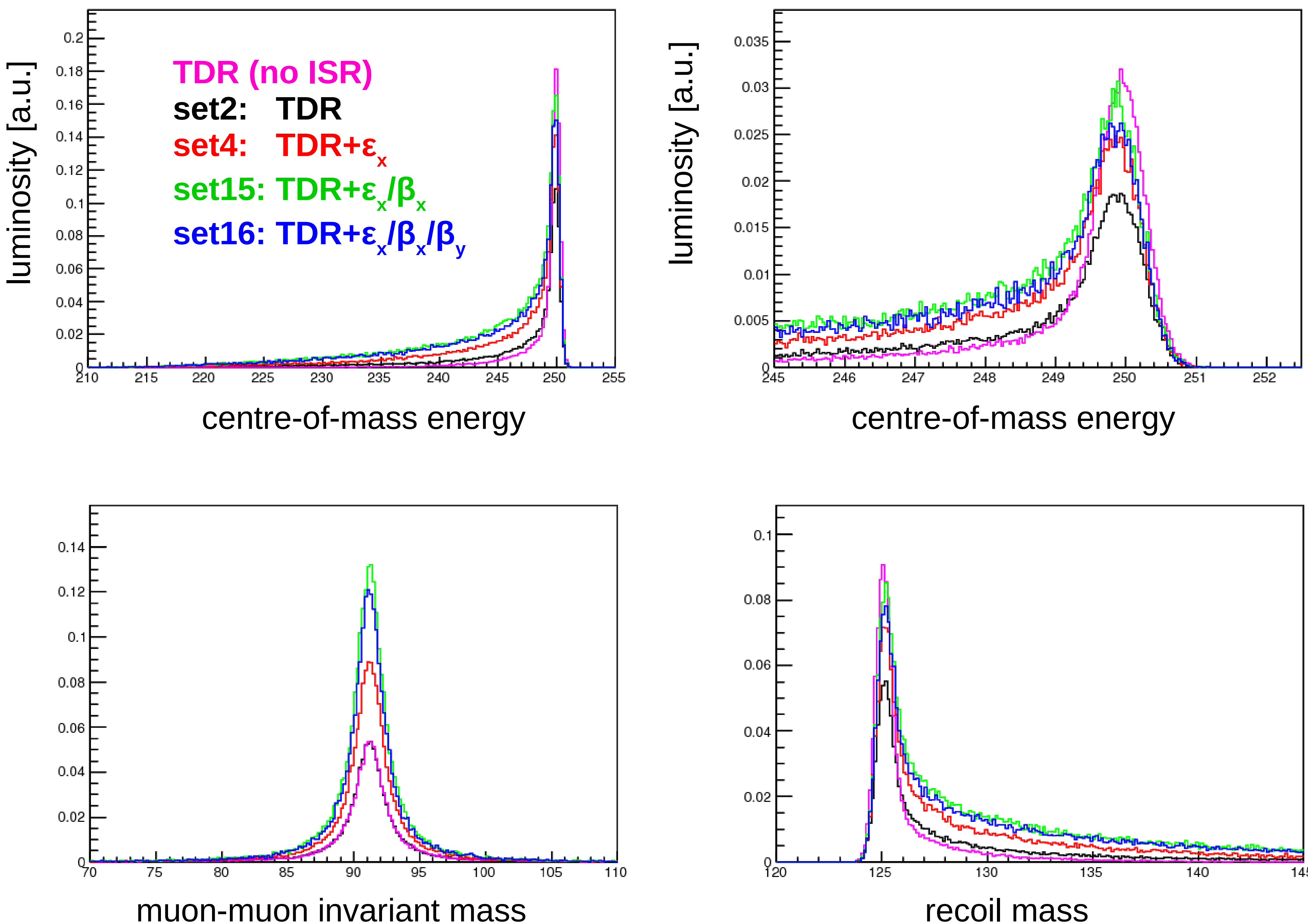
higher backgrounds in vertex detector

→ pair envelope grows by O(1mm)

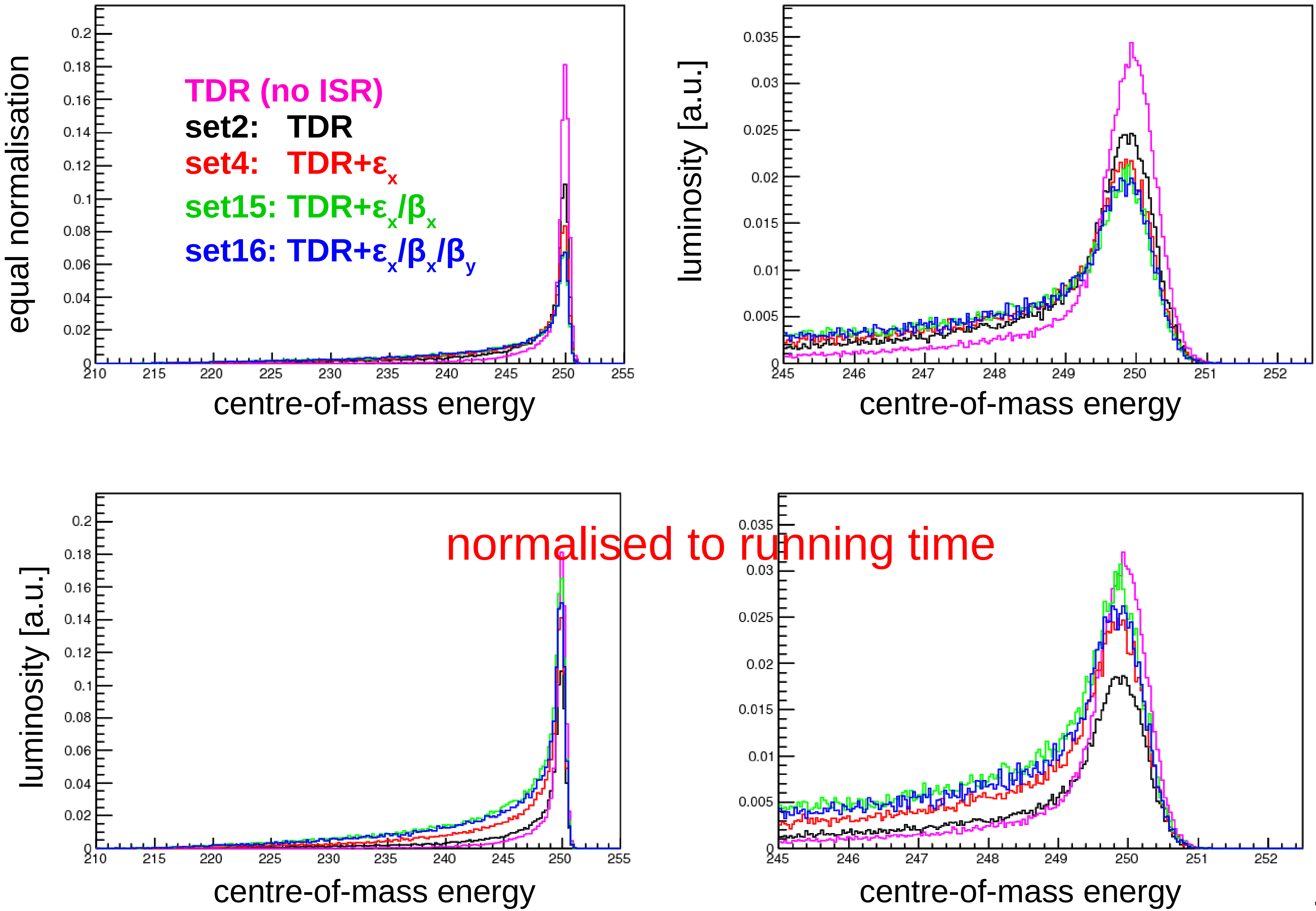
larger beam pipe, higher B-field ?

backup

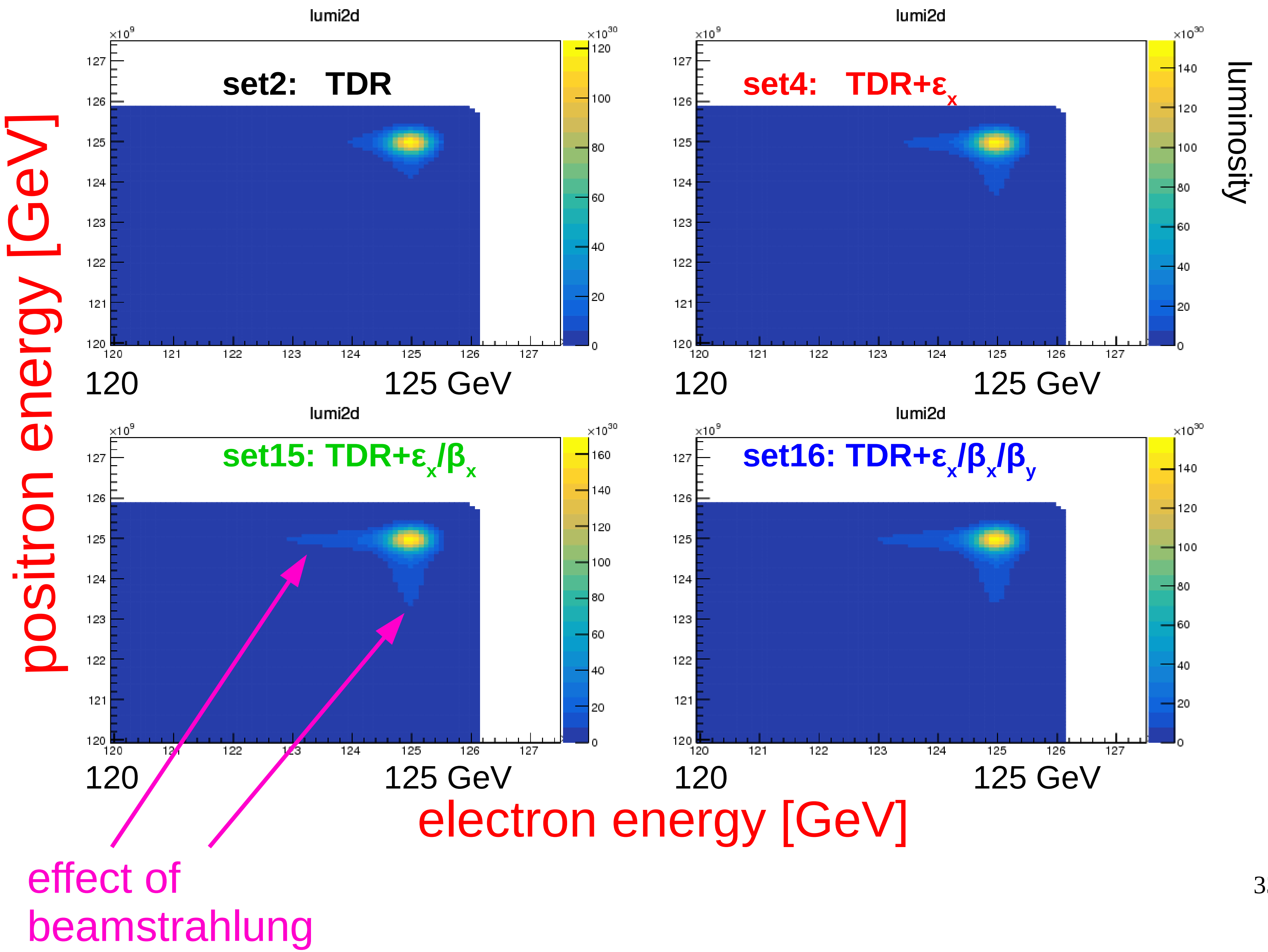
at generator level



at generator level

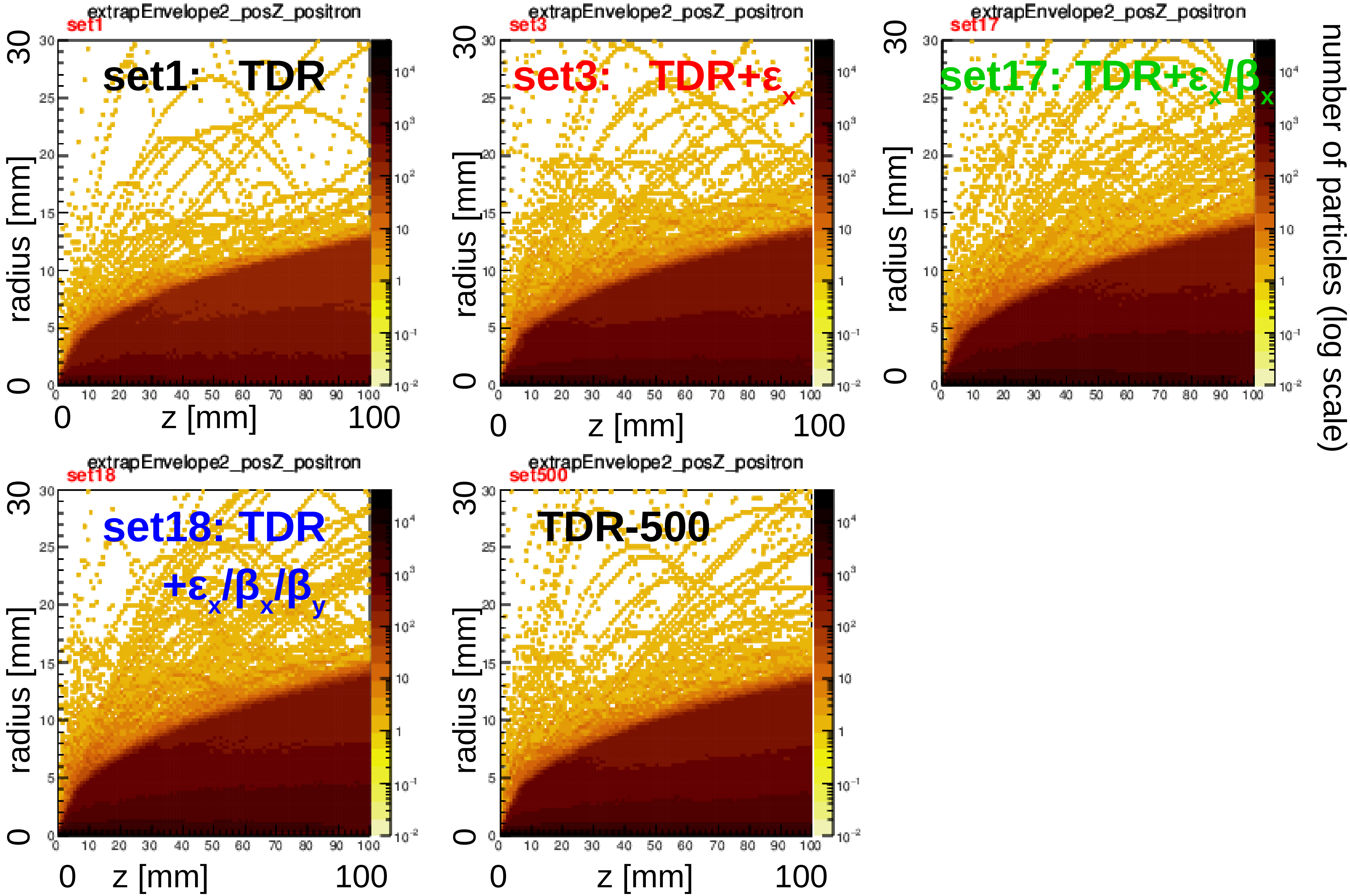


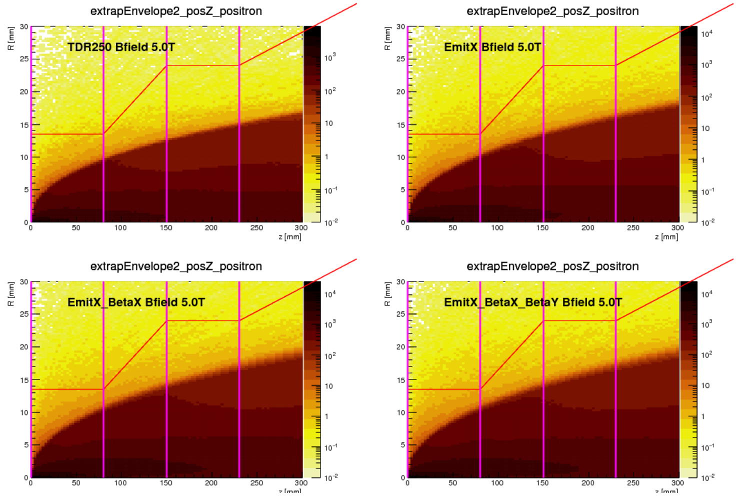
2-d luminosity spectra (CAIN 2.4.3)

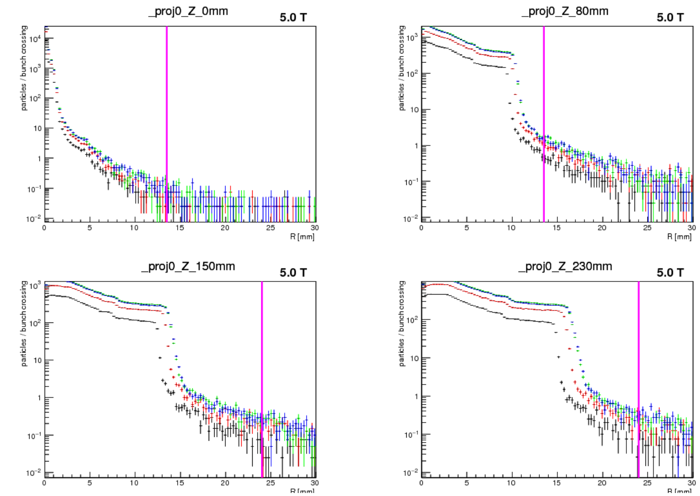


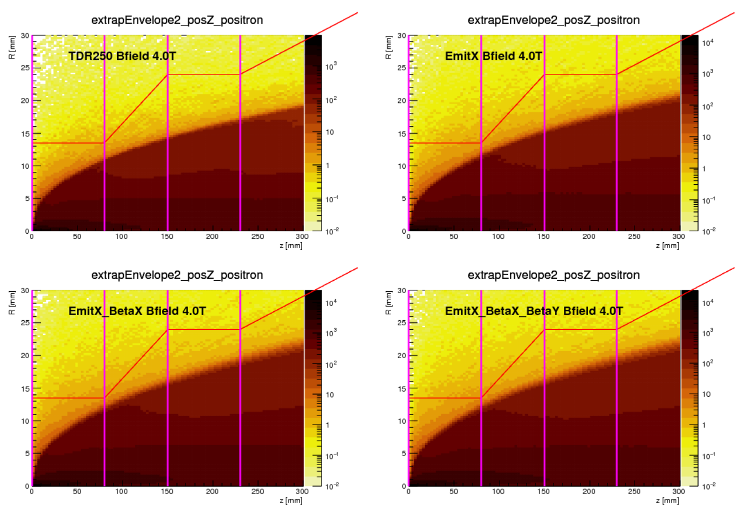
Distribution of incoherent pairs around beampipe

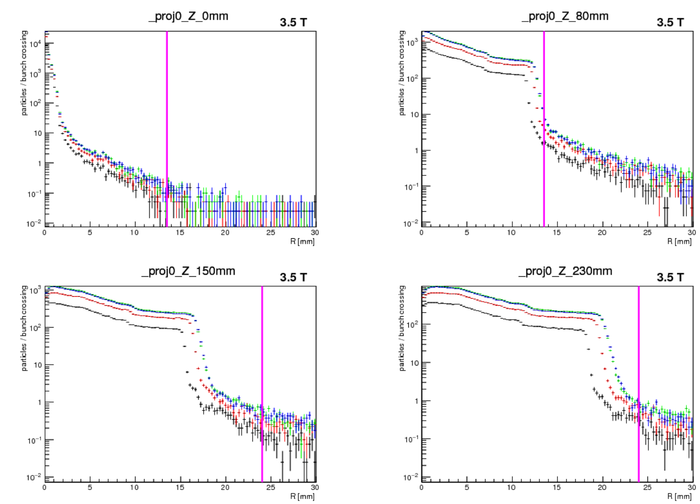
simple extrapolation in uniform 3.5T field, no beam crossing,
no material interactions, no backscatter from e.g. FCAL




extrapEnvelope2_posZ_positron
TDR250 Bfield 5.0T
extrapEnvelope2_posZ_positron
EmitX Bfield 5.0T
extrapEnvelope2_posZ_positron
EmitX_BetaX Bfield 5.0T
extrapEnvelope2_posZ_positron
EmitX_BetaX_BetaY Bfield 5.0T
R [mm]
z [mm]


_proj0_Z_0mm
5.0 T
_proj0_Z_80mm
5.0 T
_proj0_Z_150mm
5.0 T
_proj0_Z_230mm
5.0 T
particles / bunch crossing
R [mm]

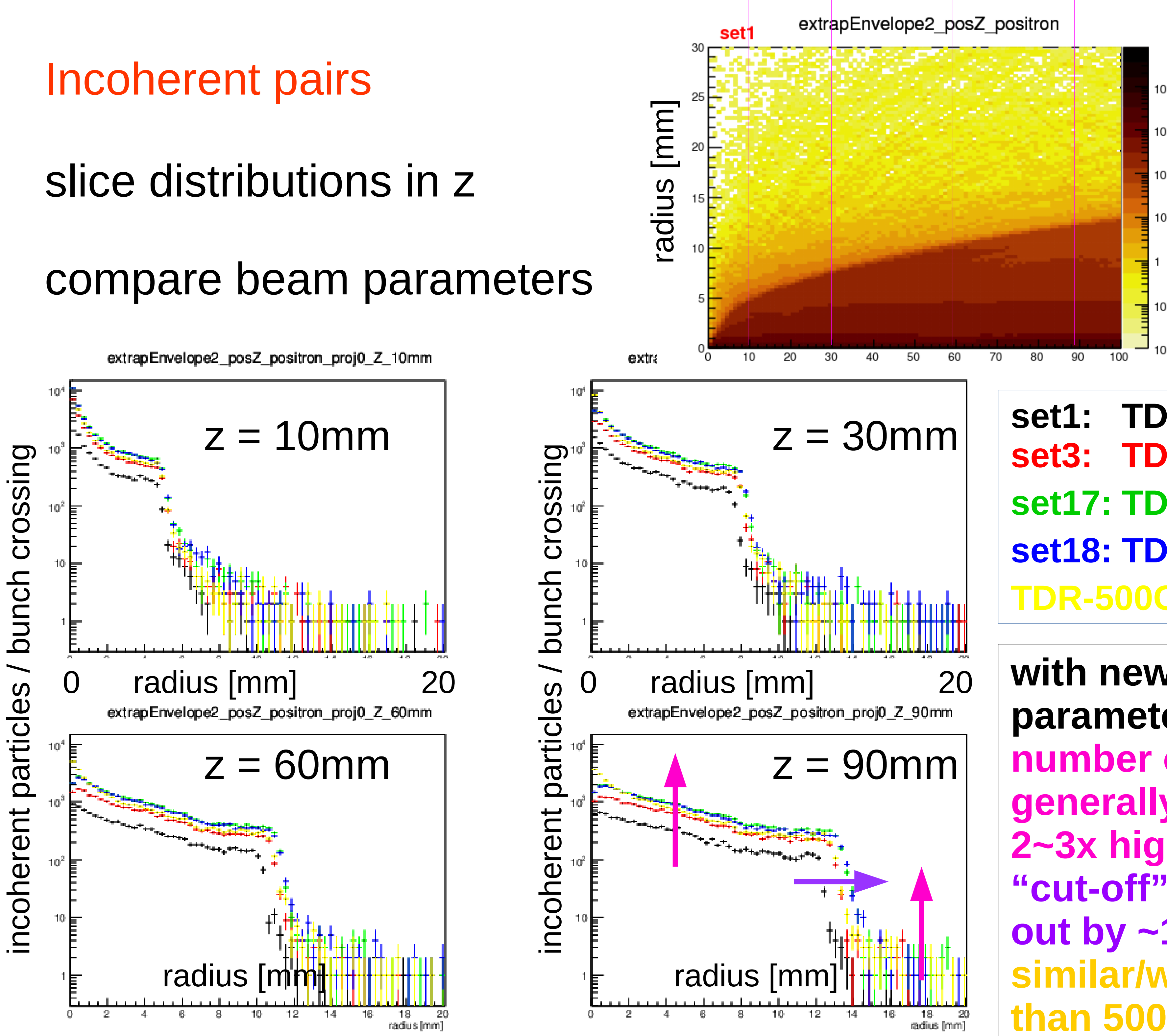

extrapEnvelope2_posZ_positron
TDR250 Bfield 4.0T
extrapEnvelope2_posZ_positron
EmitX Bfield 4.0T
extrapEnvelope2_posZ_positron
EmitX_BetaX Bfield 4.0T
extrapEnvelope2_posZ_positron
EmitX_BetaX_BetaY Bfield 4.0T
R [mm]
z [mm]


_proj0_Z_0mm
3.5 T
_proj0_Z_80mm
3.5 T
_proj0_Z_150mm
3.5 T
_proj0_Z_230mm
3.5 T
particles / bunch crossing
R [mm]

Incoherent pairs

slice distributions in z

compare beam parameters

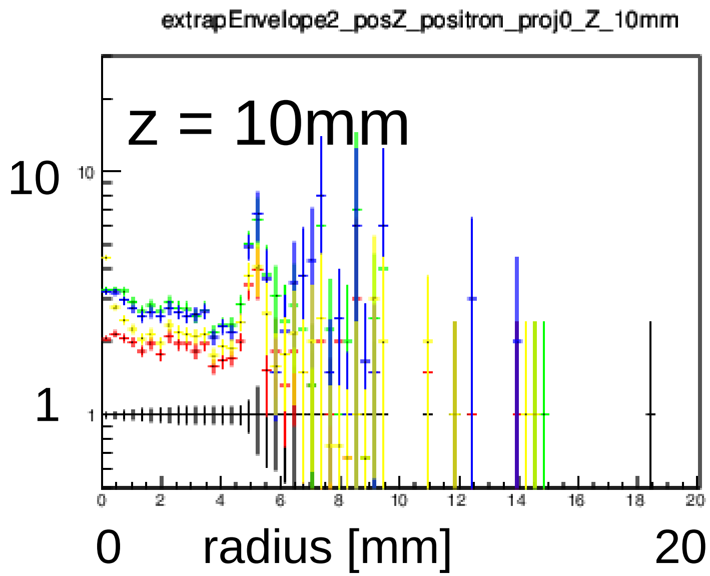


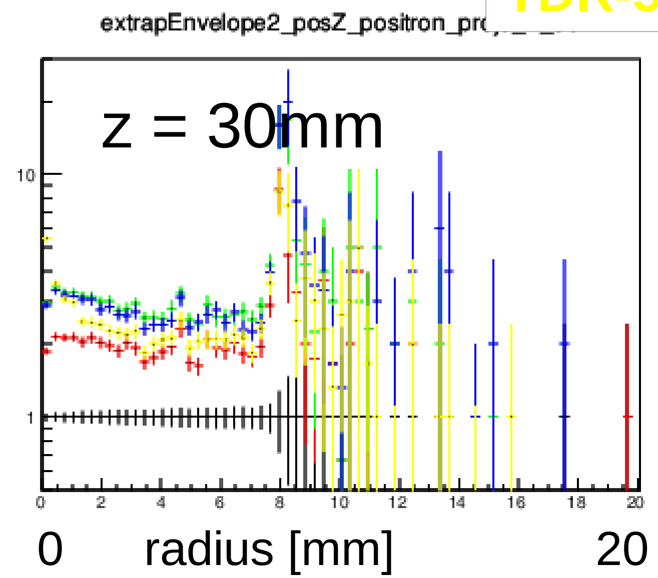
set1: TDR
set3: TDR+ε_x
set17: TDR+ε_x/β_x
set18: TDR+$\varepsilon_x/\beta_x/\beta_y$
TDR-500C

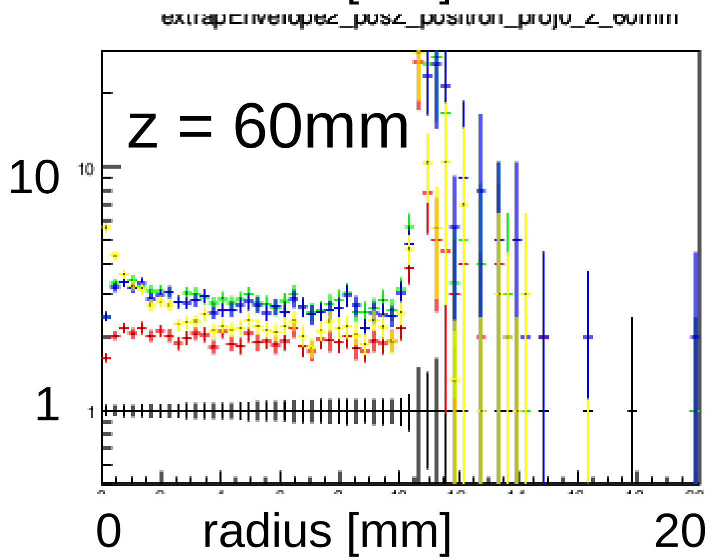
with new 250GeV parameters:
number of pairs generally 2~3x higher
"cut-off" moves out by ~1mm
similar/worse than 500 GeV

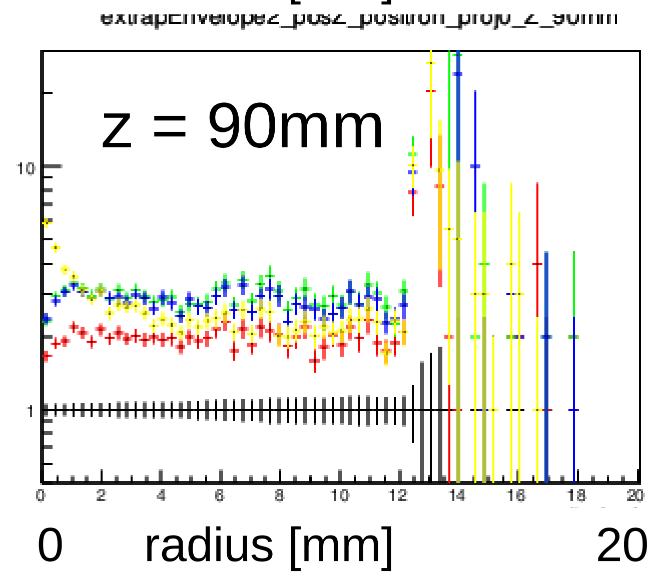
pair backgrounds: ratio to TDR

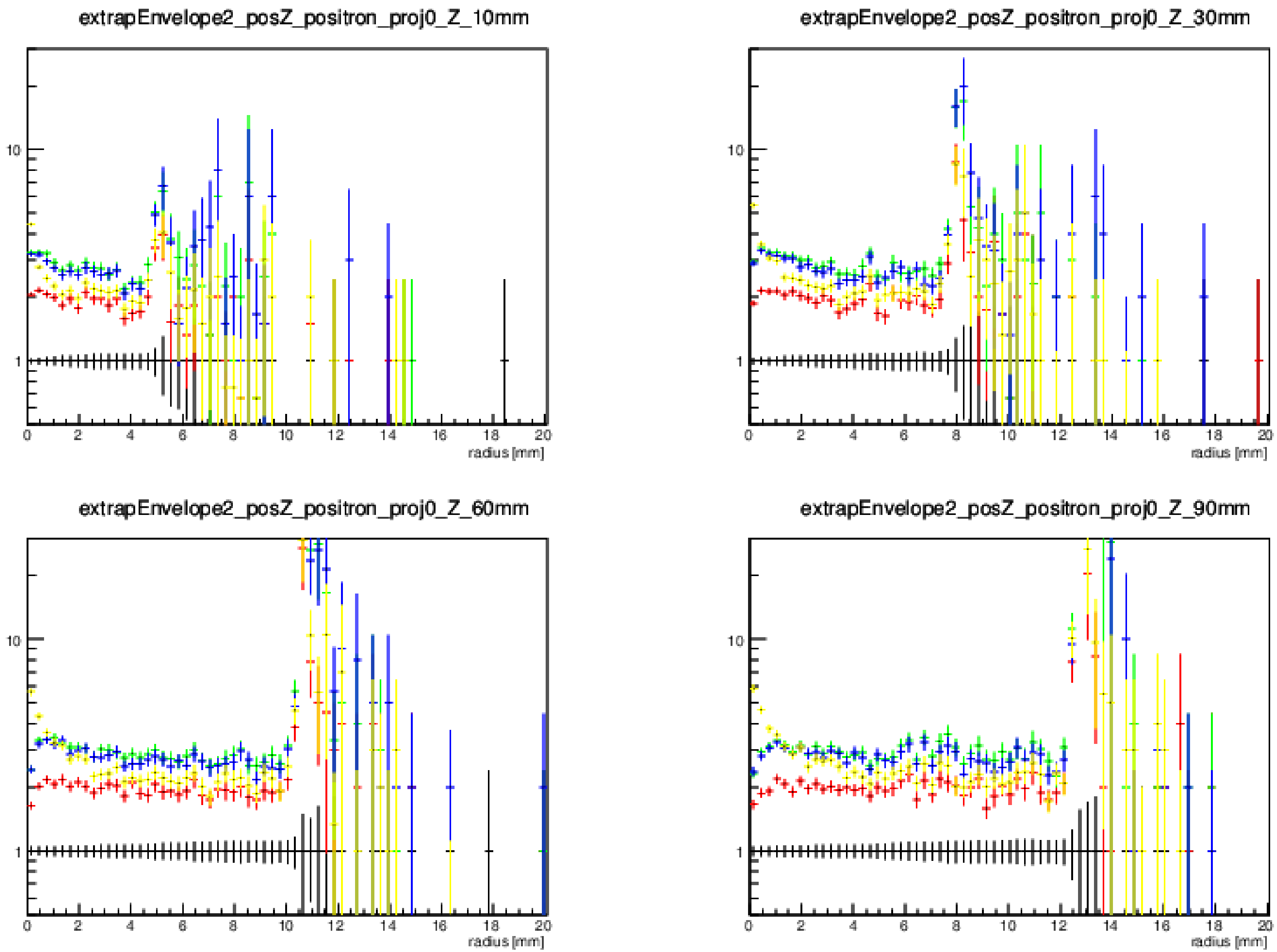
set1: TDR
set3: TDR+ε_x
set17: TDR+ε_x/β_x
set18: TDR+$\varepsilon_x/\beta_x/\beta_y$
TDR-500





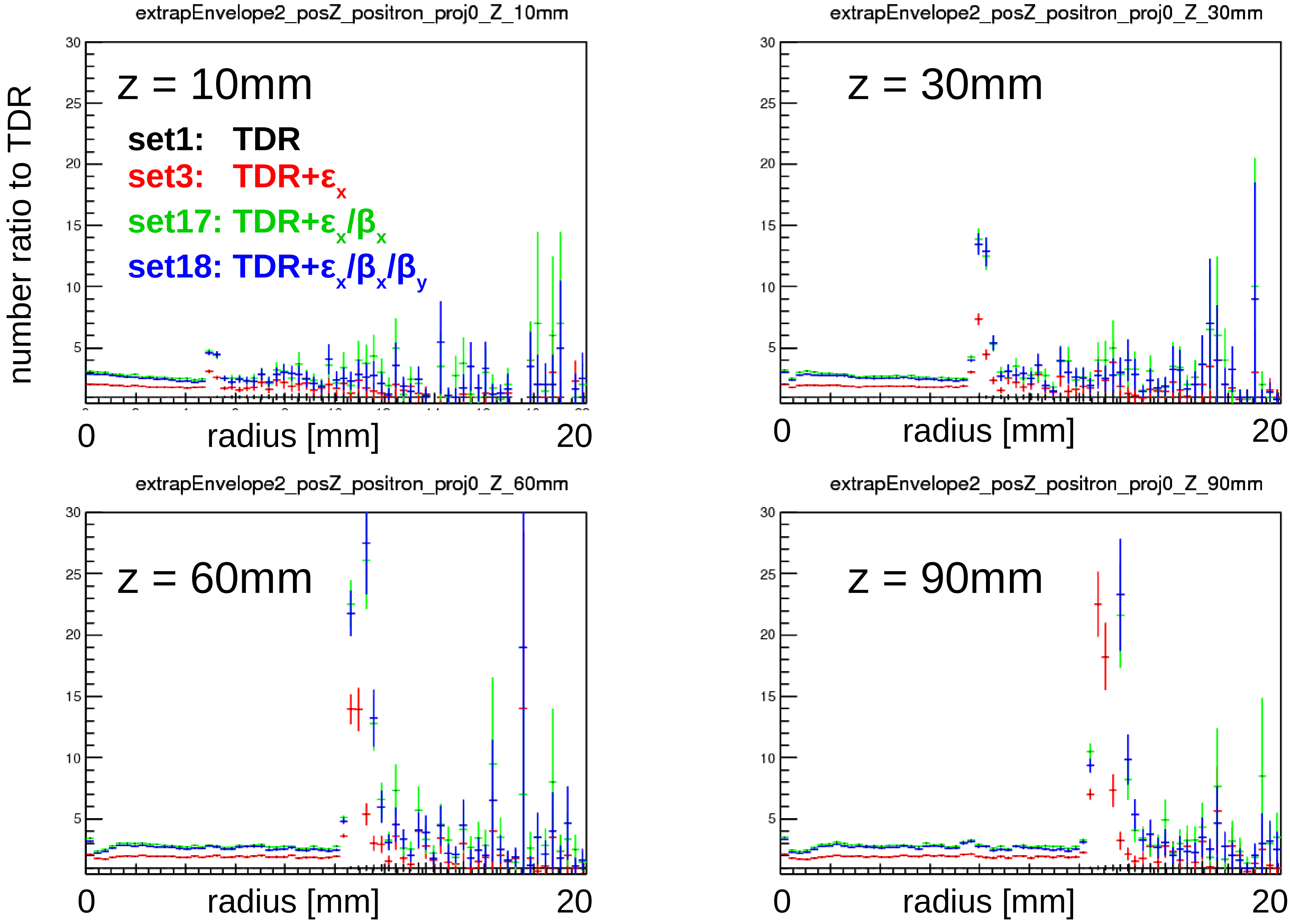




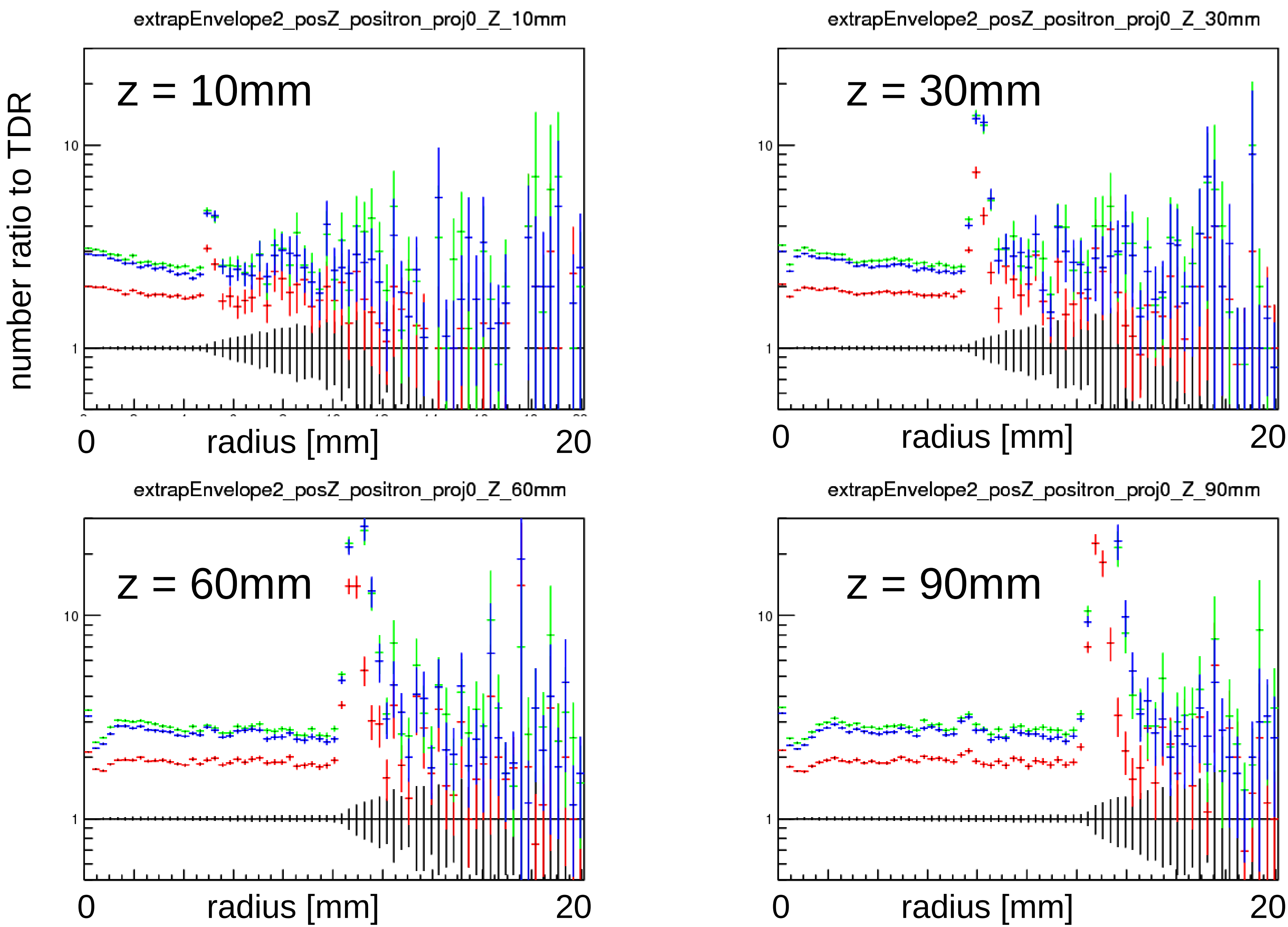


extrapEnvelope2_posZ_positron_proj0_Z_10mm
extrapEnvelope2_posZ_positron_proj0_Z_30mm
extrapEnvelope2_posZ_positron_proj0_Z_60mm
extrapEnvelope2_posZ_positron_proj0_Z_90mm
10
1
0
2
4
6
8
10
12
14
16
18
20
radius [mm]

incoherent pair distribution: ratio to TDR beam parameters



incoherent pair distribution: ratio to TDR beam parameters



TDR (Combined TDR_machine_parameters_stamp.pdf and L study parameters 16-02-2012.xlsx

		Baseline						**1TeV**		New
							Full Power	A1	B1b	Param
Ecm	GeV	200	230	250	350	500	500	1000	1000	250
N	e10	2.0	2.0	2.0	2.0	2.0	2.0	1.737	1.737	2.0
Collision frequency	Hz	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	5.0
Electron linac rep rate	Hz	10.0	10.0	10.0	5.0	5.0	5.0	4.0	4.0	5.0
Nb		1312	1312	1312	1312	1312	2625	2450	2450	1312
Bunch separation	ns	554	554	554	554	554	366	366	366	554
Beam current	mA	5.78	5.78	5.78	5.78	5.78	8.75	7.60	7.60	5.78
PB	MW	4.2	4.8	5.3	7.4	10.5	21.0	27.3	27.3	5.3
sigz	mm	0.3	0.3	0.3	0.3	0.3	0.3	0.25	0.225	0.3
sige(e-)	%	0.206	0.193	0.188	0.156	0.124	0.124	0.083	0.085	0.188
sige(e+)	%	0.187	0.163	0.15	0.1	0.07	0.07	0.043	0.047	0.15
enx	μm	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	5.00
eny	nm	35.0	35.0	35.0	35.0	35.0	35.0	30.0	30.0	35.0
electron polarization	%	80	80	80	80	80	80	80	80	80
positron polarization	%	31	31	31	29	22	22	30	30	31
betax	mm	16.0	14.0	13.0	16.0	11.0	11.0	22.6	11.0	13.0
betay	mm	0.34	0.38	0.41	0.34	0.48	0.48	0.25	0.23	0.41
sigx	nm	904.2	788.7	729.0	683.5	474.2	474.2	480.6	335.3	515.5
sigy	nm	7.80	7.69	7.66	5.89	5.86	5.86	2.77	2.63	7.66
theta_x	μr	56.5	56.3	56.1	42.7	43.1	43.1	21.3	30.5	39.7
theta_y	μr	22.9	20.2	18.7	17.3	12.2	12.2	11.1	11.7	18.7
Dx		0.21	0.24	0.26	0.21	0.30	0.30	0.11	0.20	0.51
Dy		24.3	24.5	24.5	24.3	24.6	24.6	18.7	25.4	34.5
Upsilon (average)		0.013	0.017	0.020	0.030	0.062	0.062	0.128	0.203	0.028
Ngamma (formula)		0.95	1.08	1.16	1.23	1.72	1.72	1.43	1.97	1.62
deltaB (formula)	%	0.510	0.749	0.935	1.416	3.651	3.651	5.330	10.19	1.772
HDx		1.05	1.15	1.18	1.10	1.31	1.29	1.01	1.04	1.77
HDy		4.52	5.03	5.36	4.52	6.07	6.07	3.55	4.03	6.10
HD		1.69	1.84	1.90	1.73	2.09	2.07	1.53	1.62	2.43
Lgeo	1.0E+34	0.296	0.344	0.374	0.518	0.751	1.504	1.768	2.672	0.529
L (formula, no waist shift)	1.0E+34	0.501	0.632	0.712	0.896	1.567	3.117	2.706	4.337	1.285
L (simulation, waist shift)	1.0E+34	0.59	0.73	0.82	1.03	1.79	3.6	3.02	5.11	