Beamstrahlung Background in ILD@FCC-ee
(update)

8th FCC Physics Workshop

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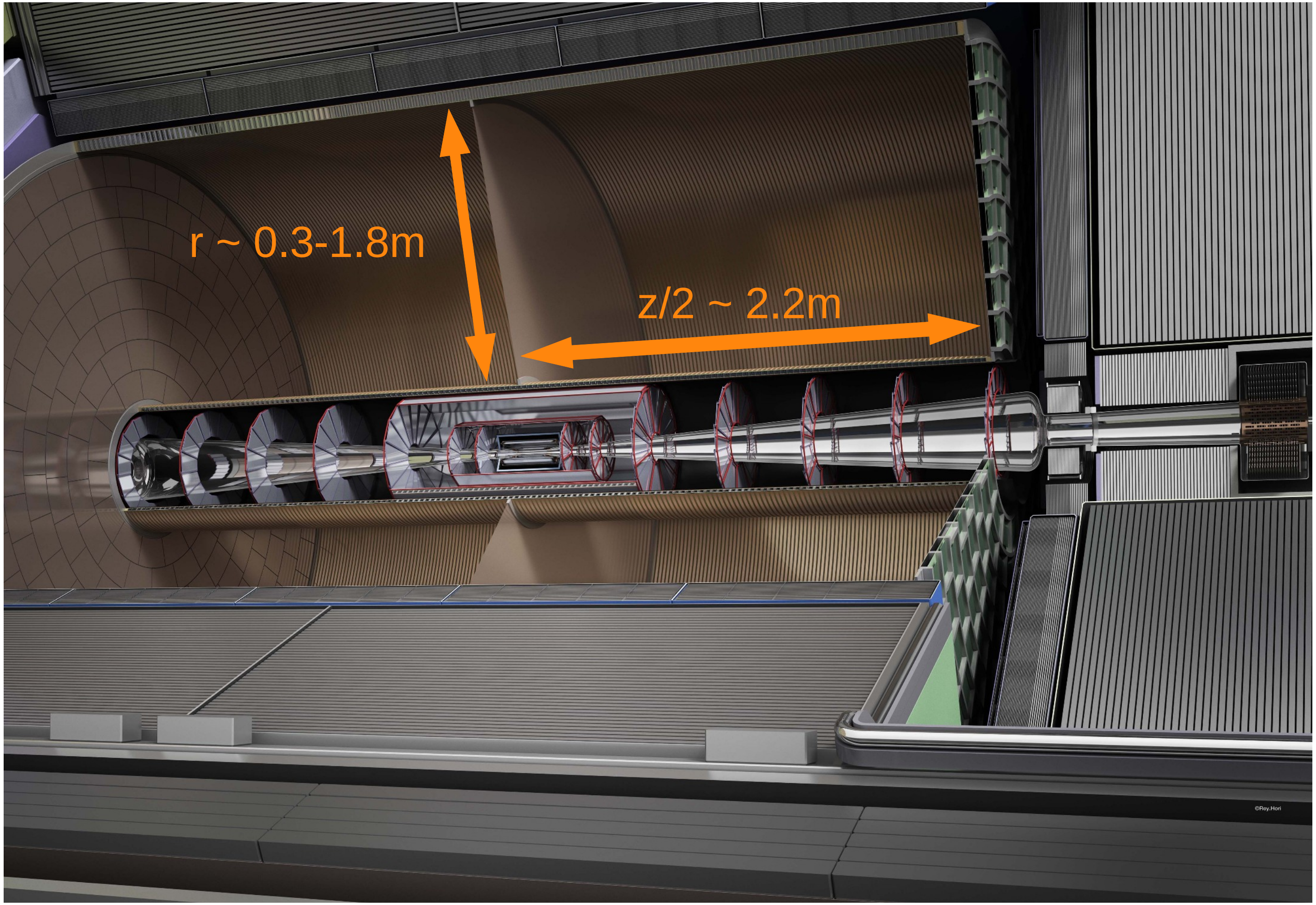
Daniel Jeans, Jenny List, Victor Schwan
victor.schwan@cern.ch

TPC of the ILD@ILC

- Hybrid tracking system
- Ions build up in TPC volume due to slow drift speed
- Primary ions and ion backflow from gas amplifier (GEM, microMegas, ...)
- Distort trajectory of ionization electrons
- May degrade momentum resolution
- Beamstrahlung expected to be major contributor

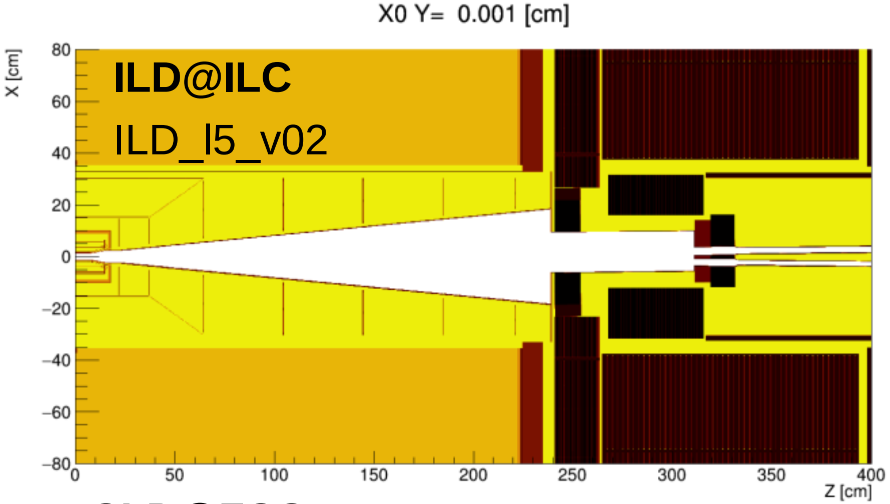


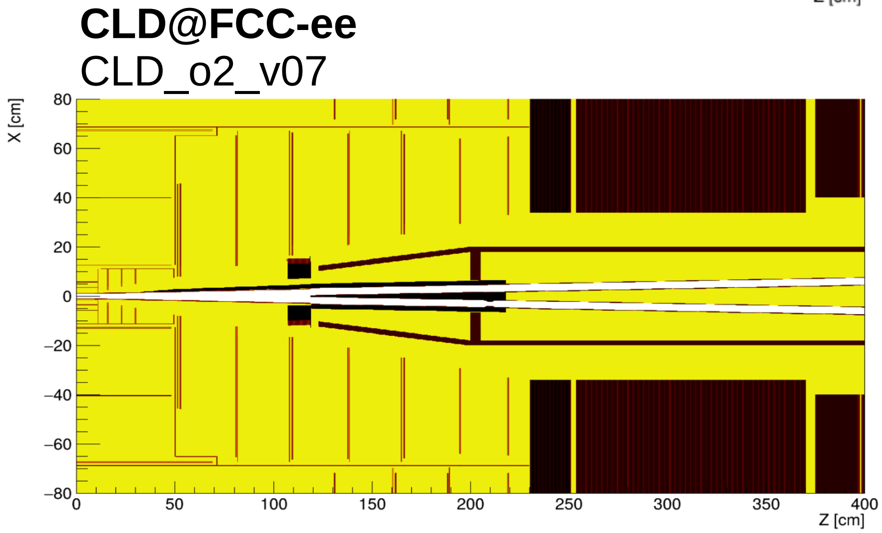
Machine-Detector-Interface: ILC vs FCC-ee

	ILC	FCC-ee
Crossing angle	14 mrad	30 mrad
L*	4.1 m	2.2 m
Detector solenoid	3.5 T	2.0 T
Add. B-fields	anti-DID (?)	- compensating - screening

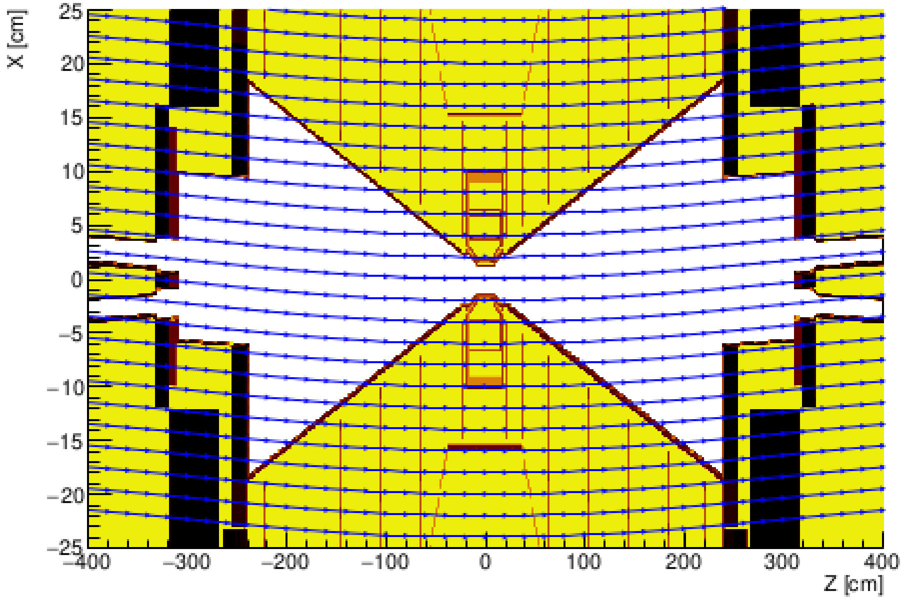
* DID = detector-integrated dipole

- Very different bunch structure, materials and fields in the forward region

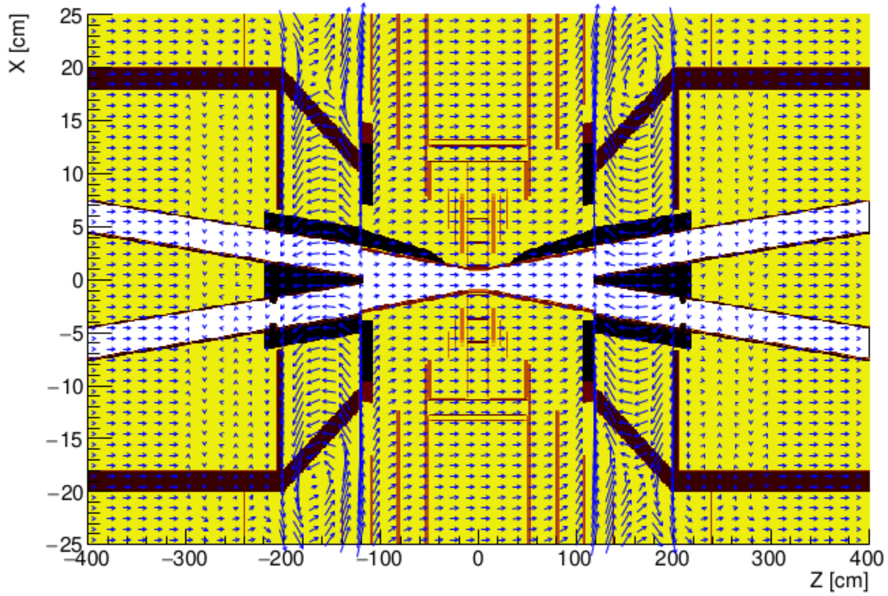




Magnetic Field Maps



ILC with anti-DID



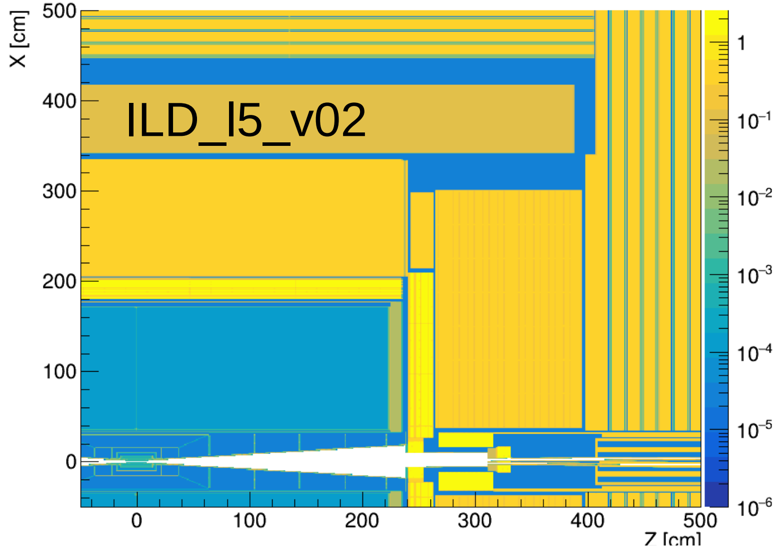
FCC-ee with compensating and screening fields

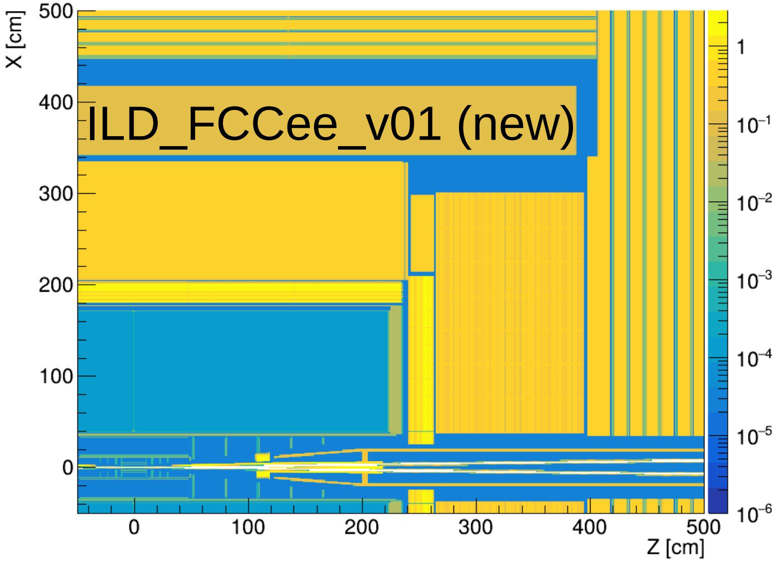
- Beamstrahlung ⇒ many, very low p_T e+e- created in bunch collisions
- Anti-DID (detector-integrated dipole) field guides low p_T particles into the outgoing beampipes

New ILD Models for FCC-ee

Recipe:

- Take ILD_l5_v02
- Remove subdetectors in cylindrical volume inside TPC
- Take subdetectors in this volume from CLD_o2_v07
  - Vertex, Inner Tracker adapted
  - Common MDI: MDI_o1_v00
- ⇨ Volume overlap of Inner Tracker (CLD) and TPC (ILD)
  - Prioritize TPC: ILD_FCCee_v01
  - Prioritize Inner Tracker: ILD_FCCee_v02





Number of Primary Ions Produced in TPC per BX

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean ± RMS		
ILD_l5_v02	3.5 (uniform)	ILC	[illegible]5 ± 19.9	14 ± 14	960 ± 150
ILD_l5_v02_2T	2.0 (uniform)	ILC	[illegible]9 ± 11.1	15 ± 11	4700 ± 300
ILD_l5_v03	3.5 (map)	ILC	[illegible].7 ± 7.9	14 ± 11	1100 ± 200
ILD_l5_v05	3.5 (map, anti-DID)	ILC	[illegible].6 ± 1.5	3.7 ± 9.7	450 ± 110
new FCCee models					
ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 ± 115	987 ± 155	111000 ± 2100
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 ± 86	823 ± 180	100000 ± 2100

Beam

D. Jeans

- Only ions originating from beamstrahlung considered

Number of Primary Ions Produced in TPC per BX

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ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9 ± 11.1	15 ± 11	4700 ± 300
ILD_l5_v03	3.5 (map)	ILC	5.7 ± 7.9	14 ± 11	1100 ± 200
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6 ± 1.5	3.7 ± 9.7	450 ± 110
new FCCee models					
ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 ± 115	987 ± 155	111000 ± 2100
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 ± 86	823 ± 180	100000 ± 2100

D. Jeans

- Only ions originating from beamstrahlung considered
- "realistic" situations : a **few 100k** → **1M** primary ions / BX
- ILC and FCC-ee are similar

  (Comparing ILC-MDI @ ILC-beam conditions with FCCee-MDI @ FCCee-beam conditions
- ILD_FCCee_v0X @ ILC show effect of missing anti-DID and close QD0 positioning

  (unrealistic situation)

Number of Primary Ions Produced with Collision Rate

- **TPC integrates over many collisions**; maximum ion drift time ~ 0.44 s

#ions ≈ primary ions/BX * BX freq * max drift time * 50%

[some ions already reached cathode]

Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	260 k	820 k	450 k
primary ions in TPC at any time	1.7×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.4	0.54	0.0025

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- Primary ion density in TPC:
  - **2500** times higher at FCC-ee-91 than ILC-250
  - **200** times higher at FCC-ee-240 than ILC-250
- expected maximum distortion due to beamstrahlung at FCC-91 is O(cm) [primary ions only, ILD_FCCee_v01]

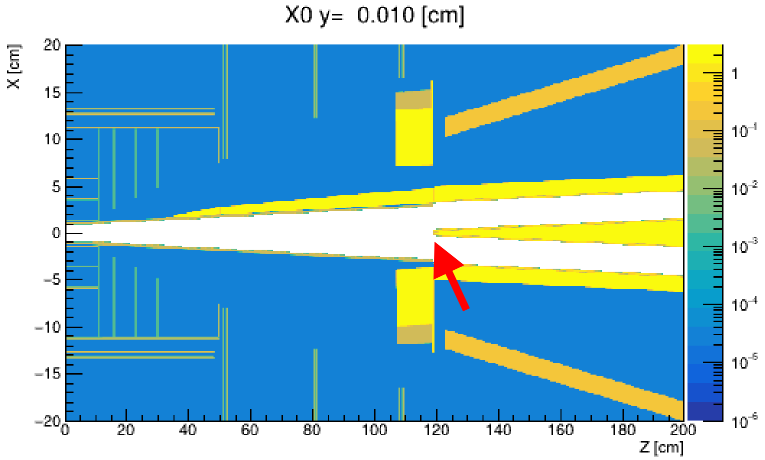
Test of Mitigation Options

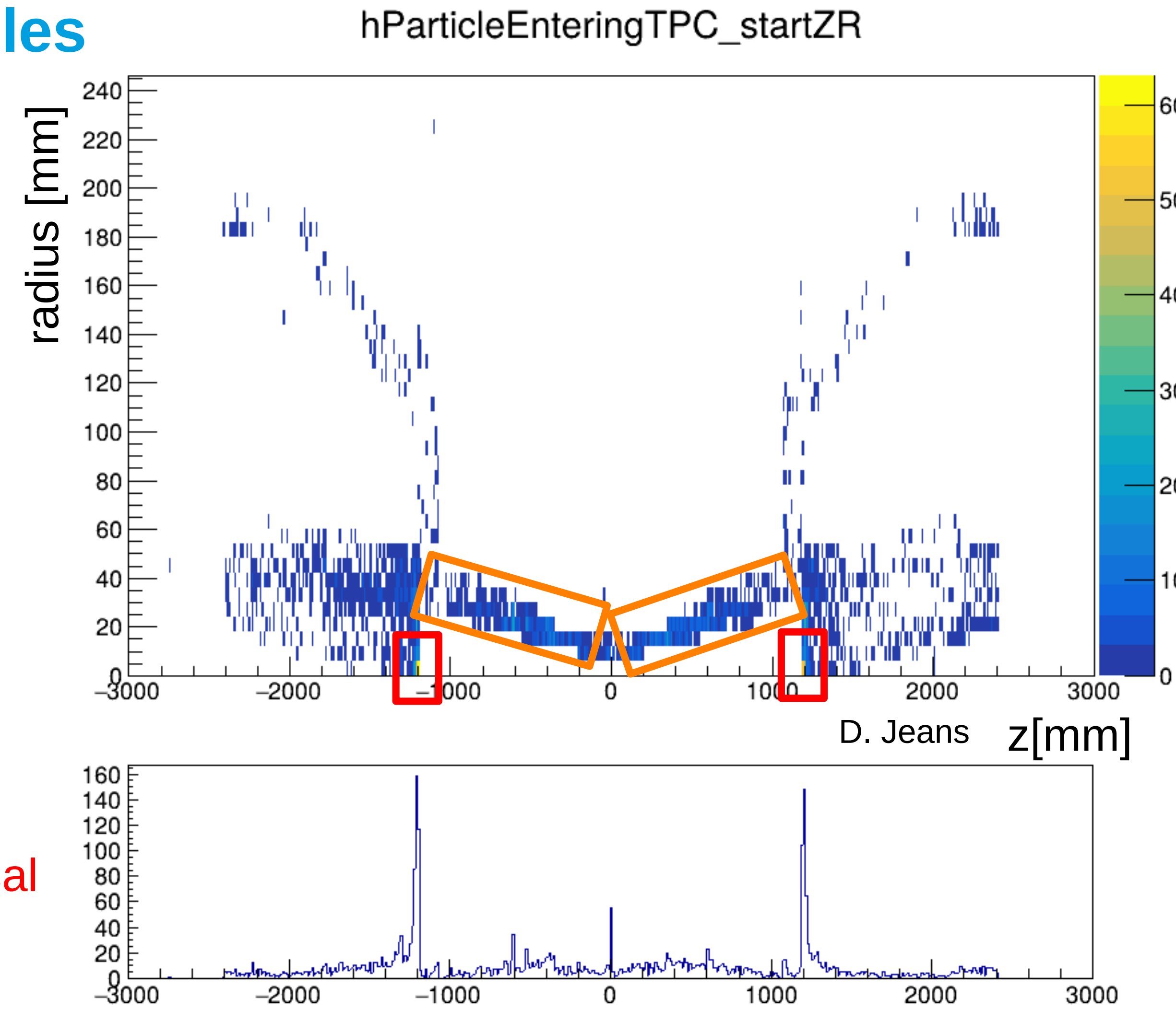
Disclaimer:

I was strongly involved in the creation of the previously shown ILD@FCCee models, but not in the following TPC studies by Daniel Jeans.

Origin of Parent Particles

ILD_FCCee_v01 model
(with field map)
MDI exactly from MDI_o1_v00



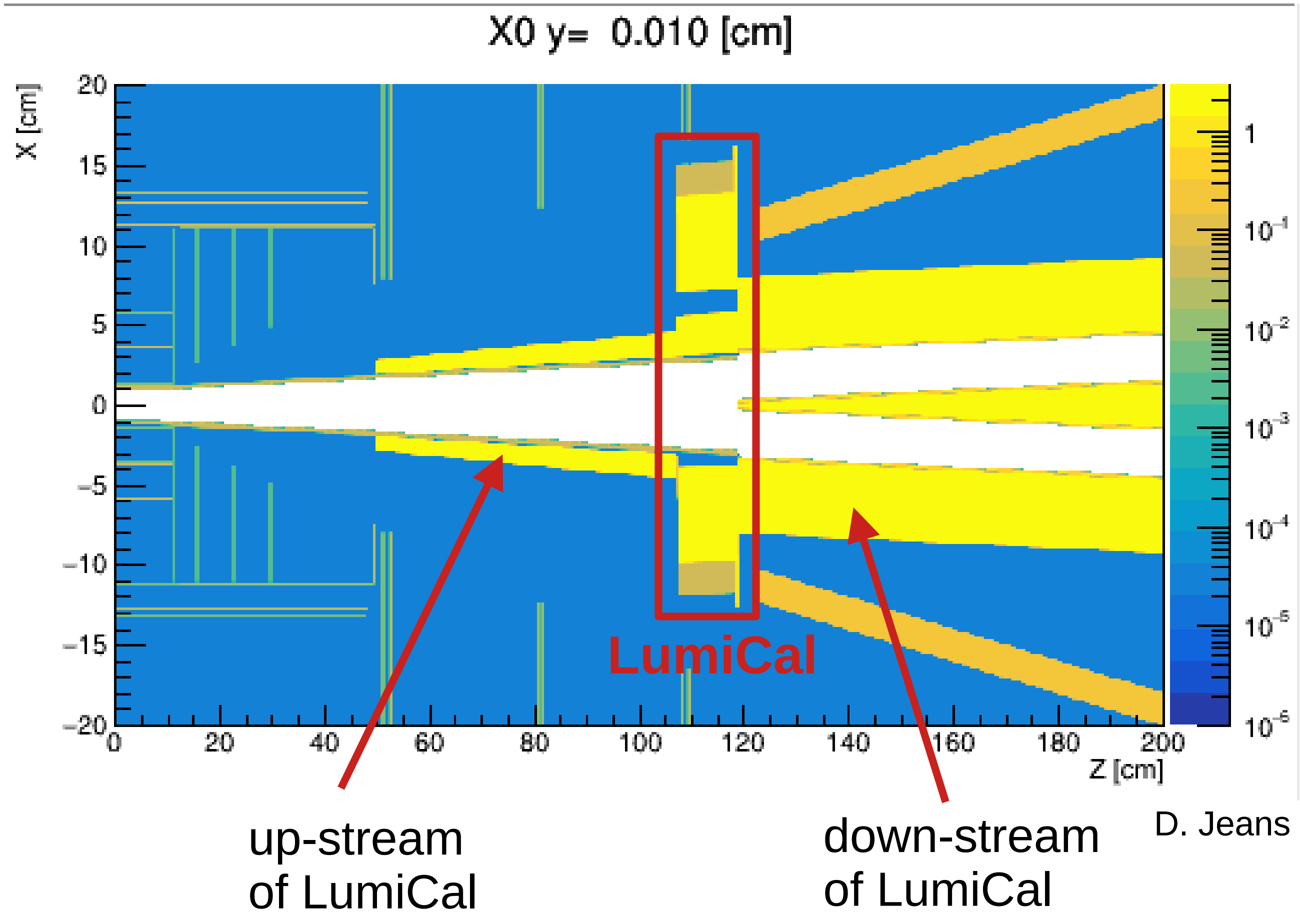


Main points of origin:

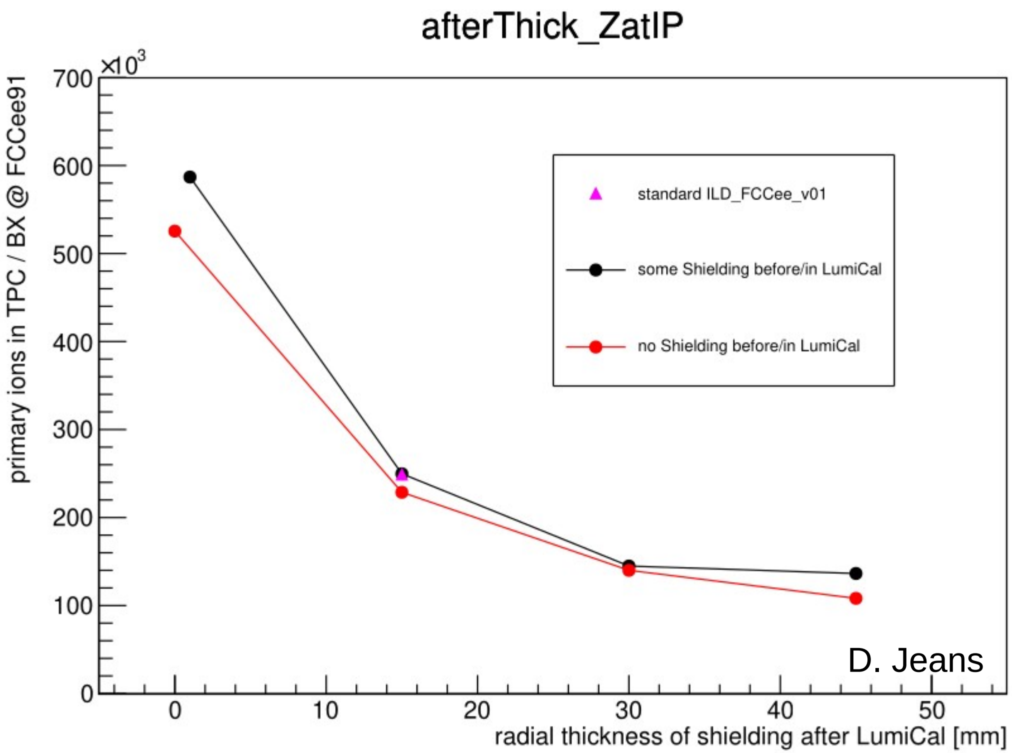
- In the plane containing the LumiCal
- inner beampipe shielding

*Shielding material: tungsten

Possible Shielding Positions



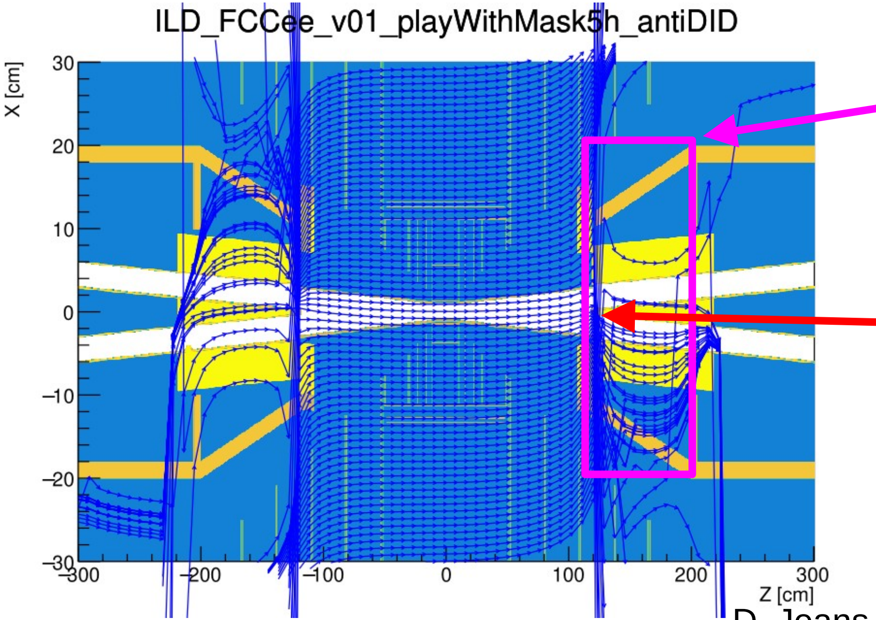
Effect of Thicker Shielding on Number of Primary Ions



"down-stream"

- up-stream shielding *before or inside* LumiCal doesn't reduce pair bg in TPC
- thicker down-stream shielding *after* LumiCal does help: e.g. increase from 15 → 30 or 45 mm

Magnetic Fields



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- compensating solenoid (–5T) ensures that integrated B_z seen by beam is 0
- limited space available
  → strong compensating magnet, limited detector solenoid
- transition between + 2T detector solenoid and – 5T compensating solenoid is essentially a magnetic wall for low p_T e^{+-}
  → steered into the shielding just behind LumiCal

- **new proposal** for alternative compensation scheme moves this strong compensating solenoid outside the detector `doi:10.18429/JACoW-IPAC2024-TUPC68`
  → more space available for compensation → relaxed limit on detector solenoid strength
- Would there be any effect on beamstrahlung backgrounds?

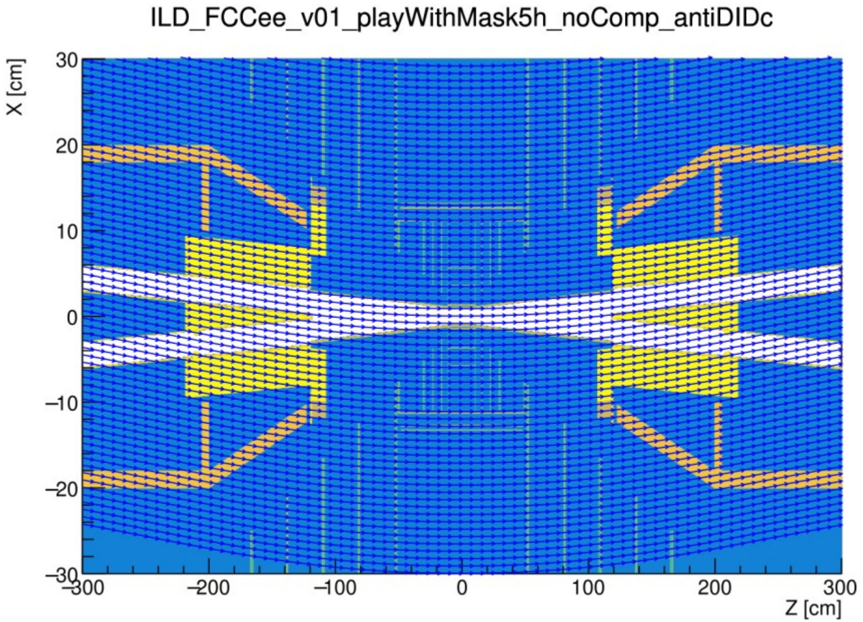
Magnetic Fields

- test removing strong compensating solenoid field
  - * also remove the “screening field” for technical reasons

- also try introducing an “anti-DID” field a la ILD@ILC
  - → small Bx to bend field lines (and therefore, low pT particles into outgoing beampipe)
  - [Daniel imagines that this will require adjustments in machine optics. He cannot judge its technical feasibility]

- optimal anti-DID strength should depend on:
  - main solenoid field, crossing angle, …

- use ILD@ILC field map for anti-DID field simple scaling of its strength



uniform solenoid + anti-DID

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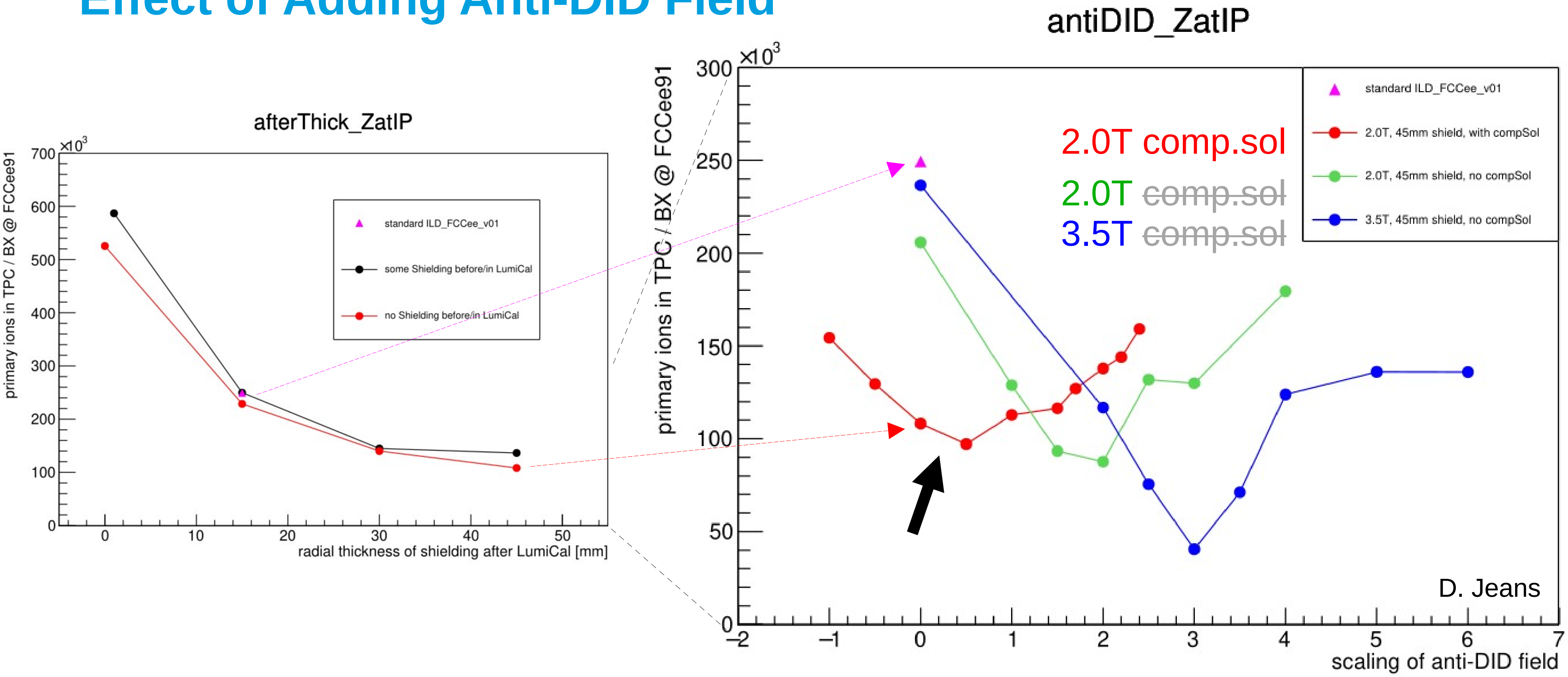
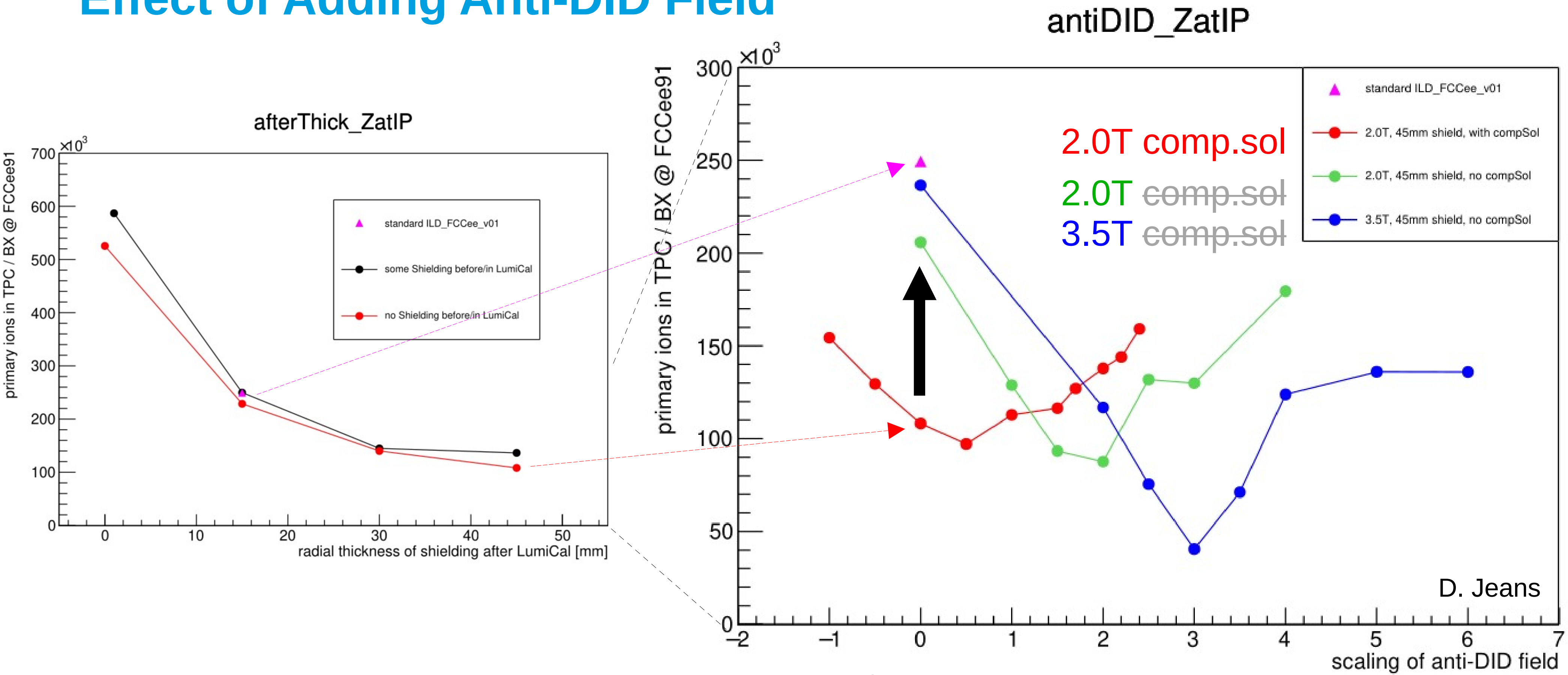
Effect of Adding Anti-DID Field



❖ with the compensating solenoid, it doesn't help much → "magnetic wall"

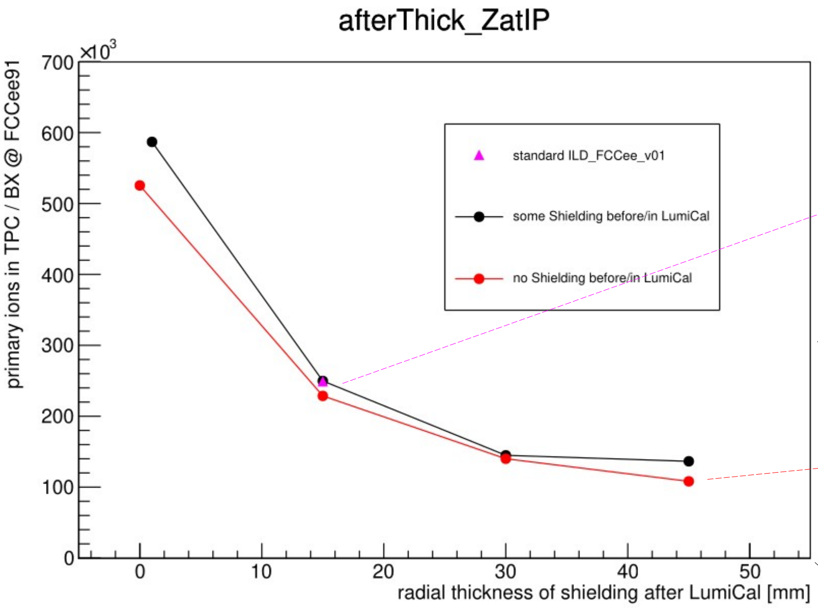
Effect of Adding Anti-DID Field

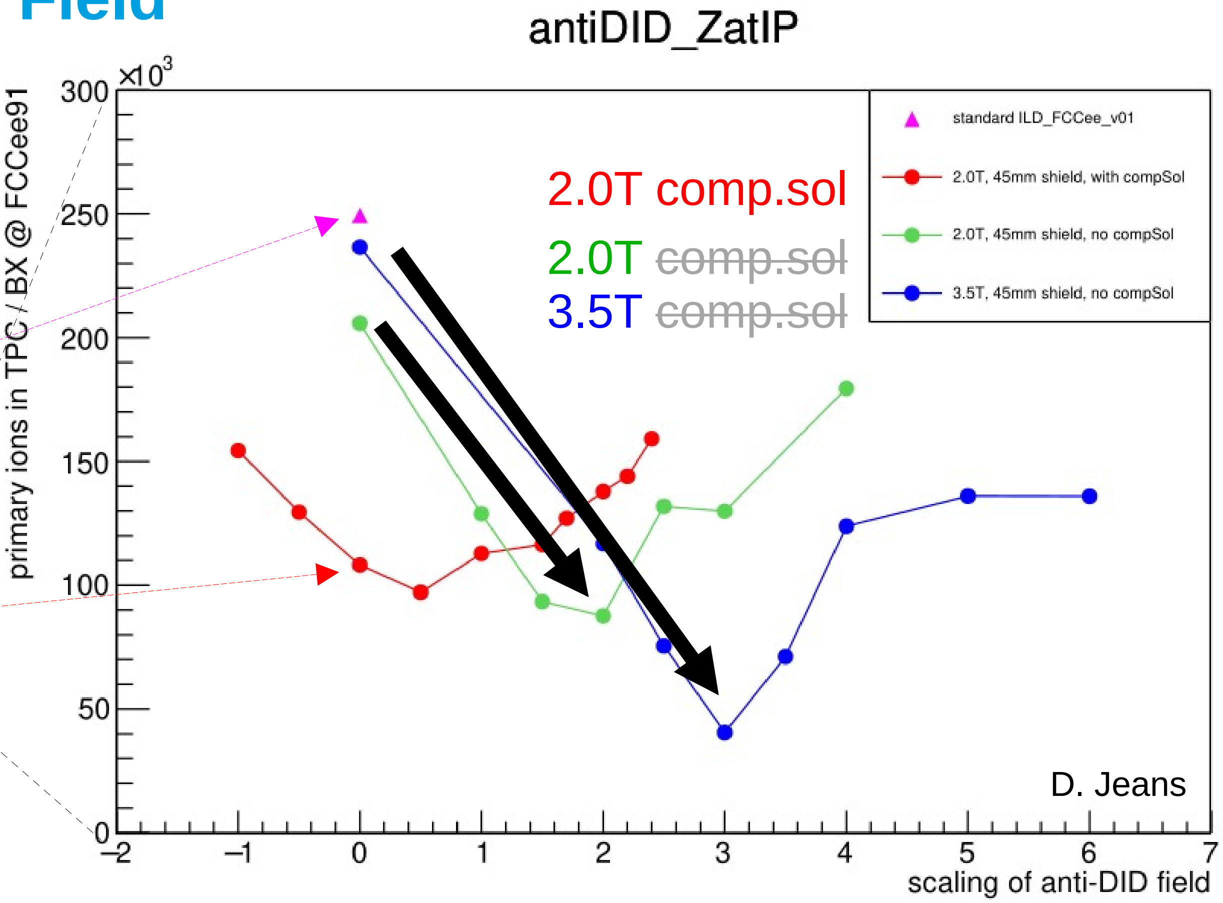


- removing compensating solenoid results in significant increase in background

  → removal of “magnetic wall”

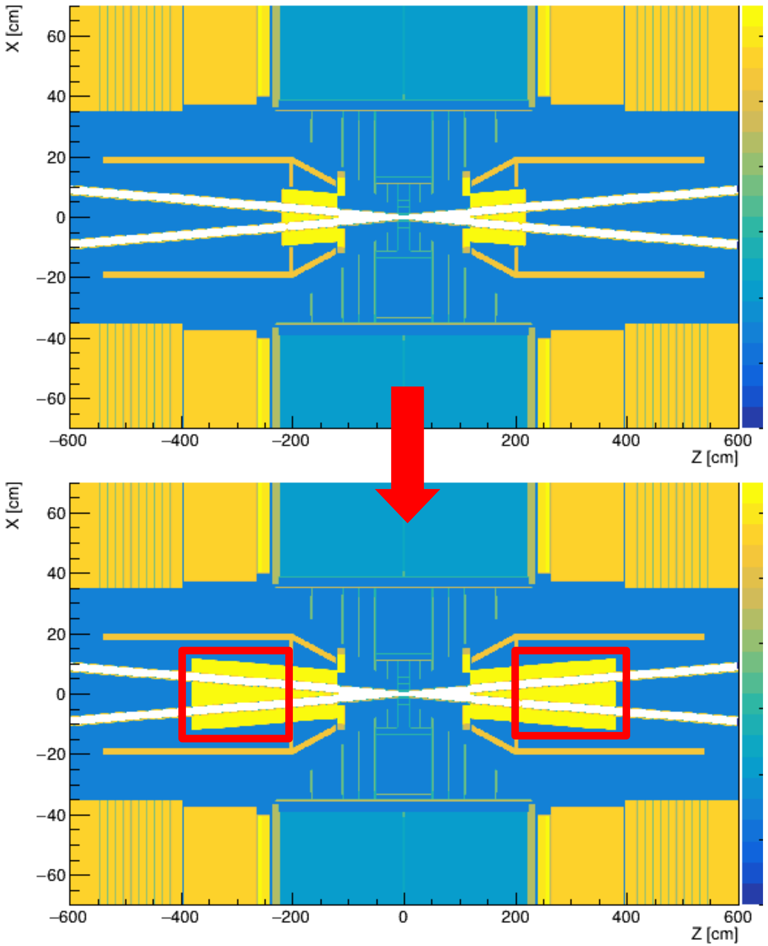
Effect of Adding Anti-DID Field

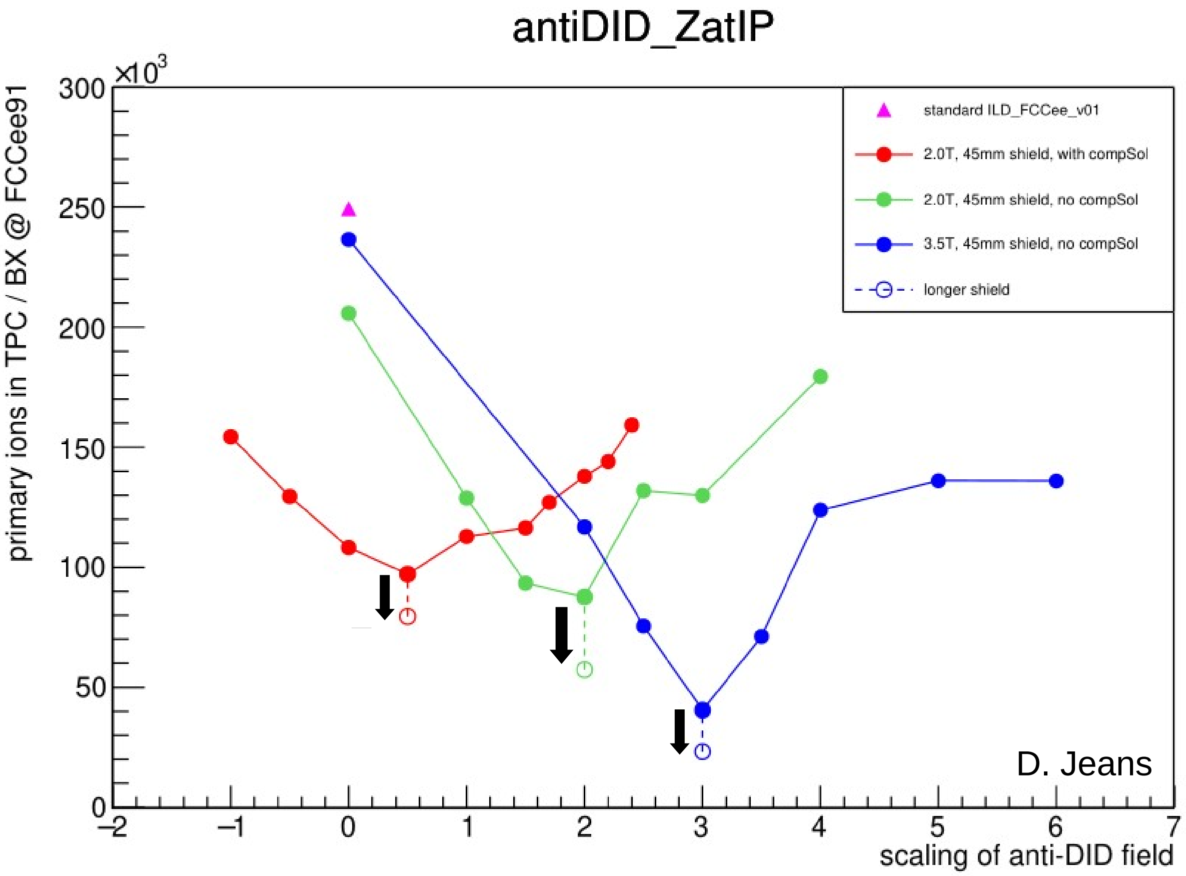




- without compensating solenoid, it reduces BG by factor ~2 @ 2T, ~6 @ 3.5T
- clear advantage of higher field (only if anti-DID available)

Extend Length of Down-Stream Shielding

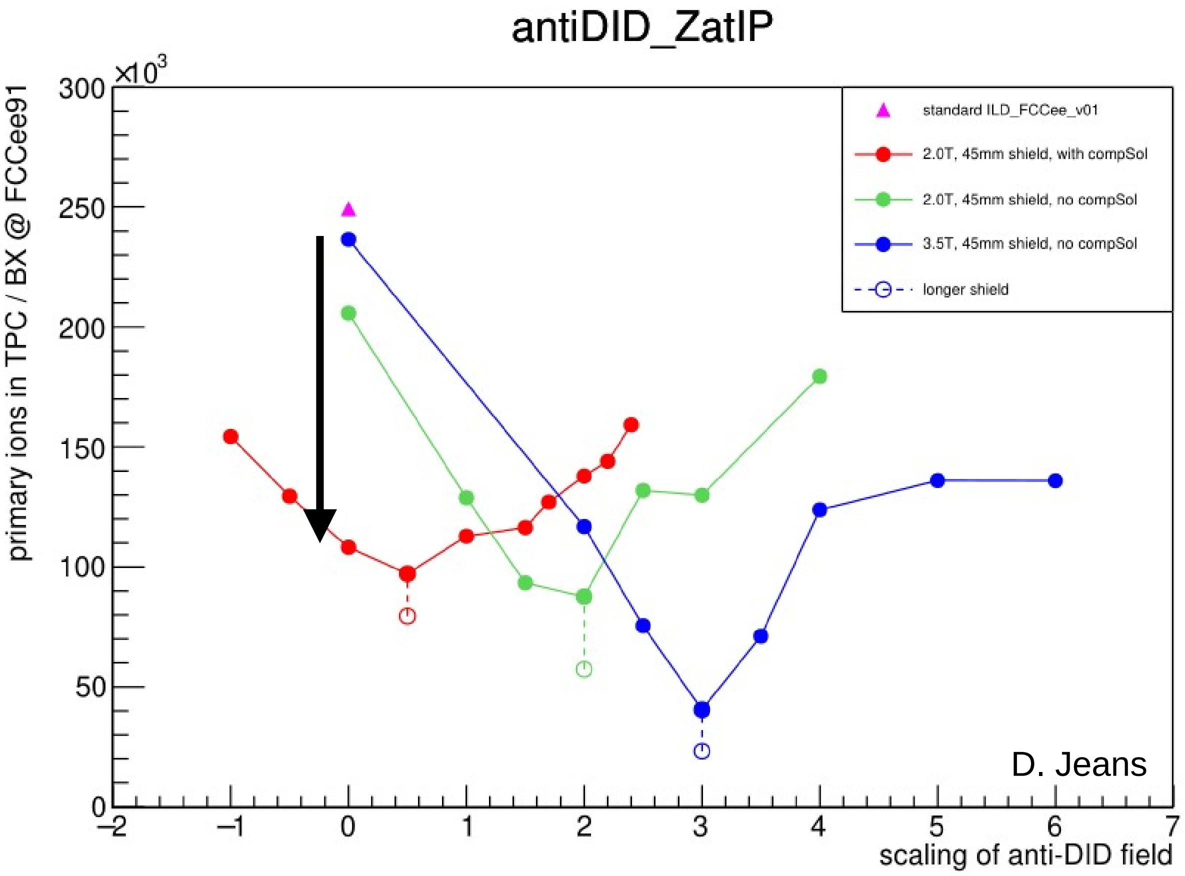




* just a toy model: eg QD0 needs space!

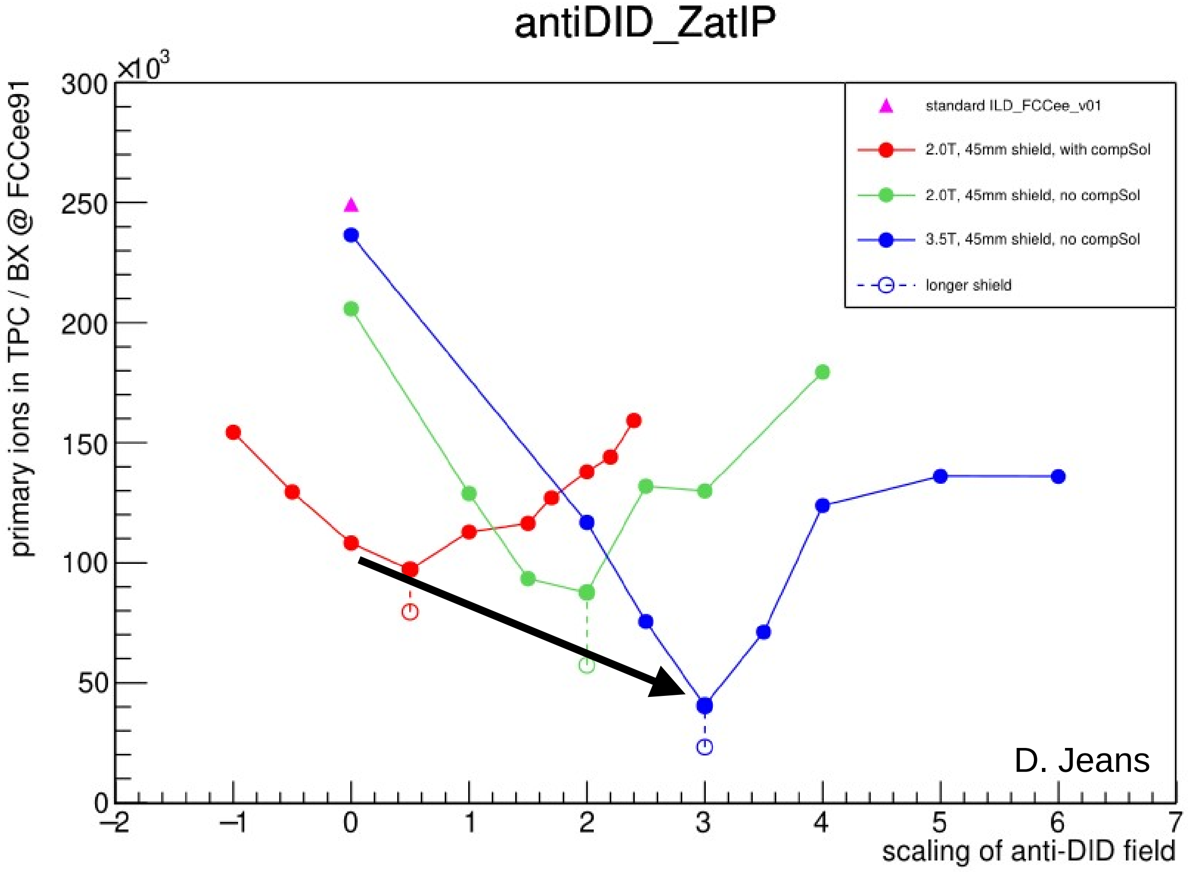
Reduces primary ions by ~ a factor 2

Summarizing Means to Reduce Beamstrahlung BG in TPC



1. **thicker** shield after LumiCal x1/2.5

Summarizing Means to Reduce Beamstrahlung BG in TPC



1. **thicker** shield after LumiCal x1/2.5

2. 2.0 → **3.5 T + anti-DID** x1/2

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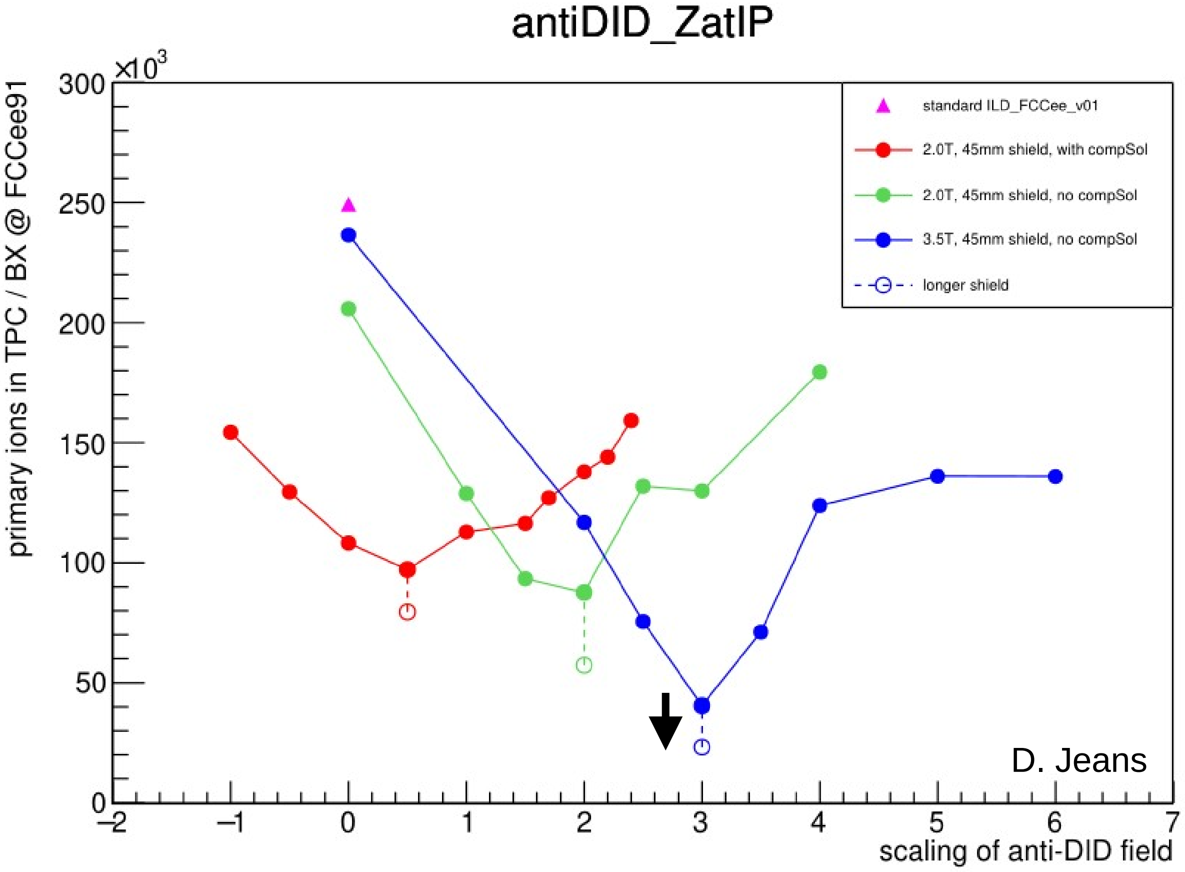

1. **thicker** shield after LumiCal x1/2.5

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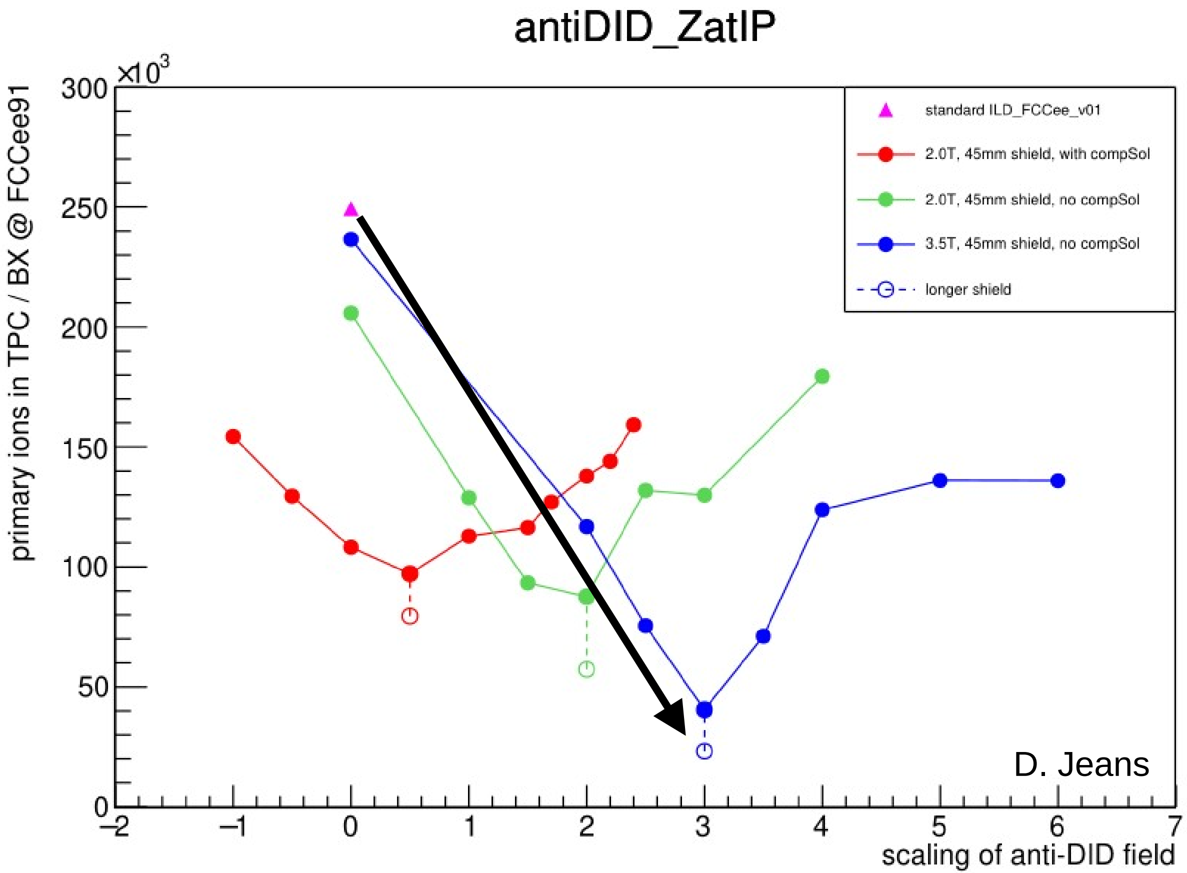
3. **longer** shield after LumiCal x1/2

Summarizing Means to Reduce Beamstrahlung BG in TPC



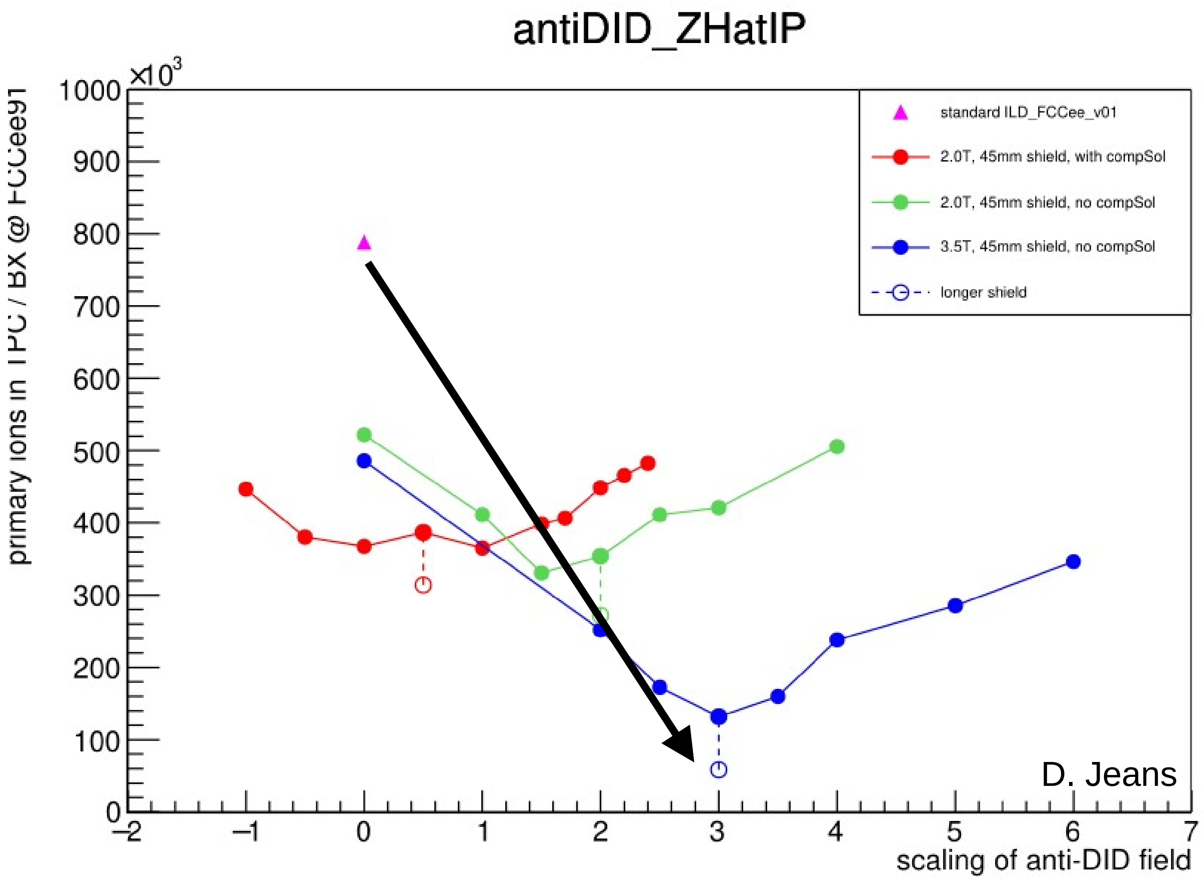
1. **thicker** shield after LumiCal x1/2.5

2. 2.0 → **3.5 T + anti-DID** x1/2

3. **longer** shield after LumiCal x1/2

overall, ~**10x** reduction in TPC BG compared to MDI_o1_v00

What About 240 GeV?



- Similar findings
- Reduction by ~ a factor of **10** seems feasible

Conclusion

Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	26~~0~~ k	82~~0~~ k	450 k
primary ions in TPC at any time	$1.7 \times 10^{\cancel{12}\ 11}$	$1.4 \times 10^{\cancel{11}\ 10}$	6.5×10^{8}
average primary ion charge density $\mathrm{nC/m^3}$	~~6.4~~0.6	~~0.54~~0.05	0.0025

*very rough estimates D. Jeans

primary ion density in TPC: ~~2500~~250 times higher at FCCee-91 than ILC-250

~~200~~ 20 times higher at FCCee-240 than ILC-250

n.b. this comparison does not consider the secondary ions created in gas amplification

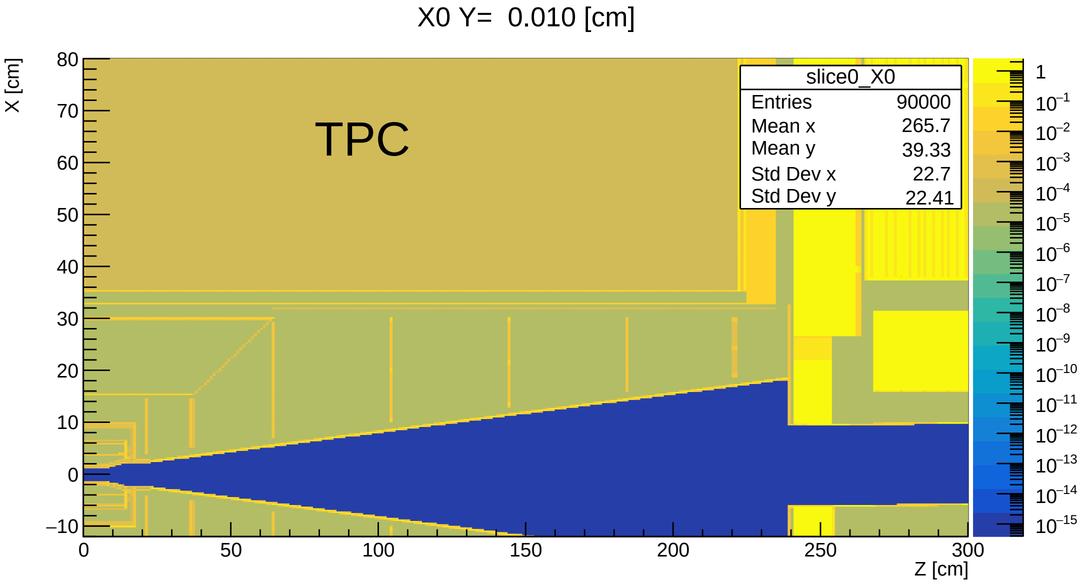
→ almost certainly worse at circular collider due to "no" gating

Thank you for your attention!

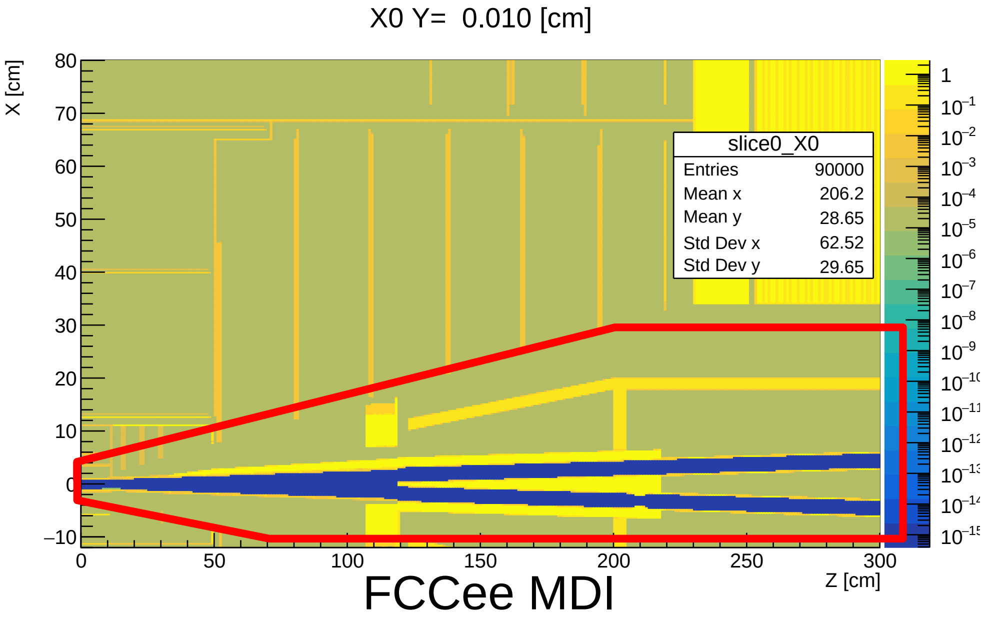
Back up

Starting Point

ILD (for ILC)
- ILC MDI
- Hybrid tracking layout



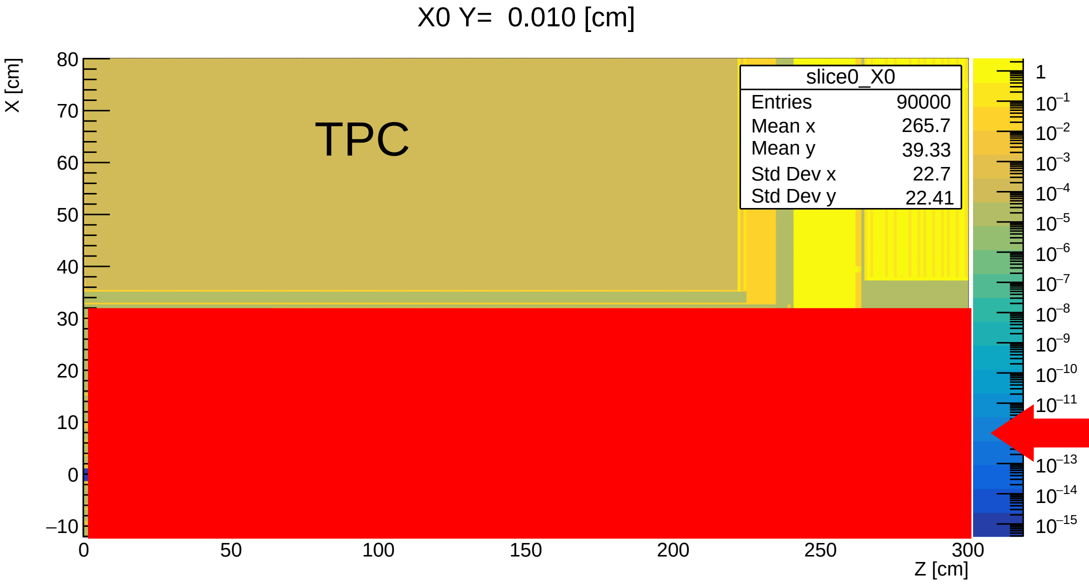
CLD (CLIC-like Detector)
- FCCee MDI
- All-silicon tracking

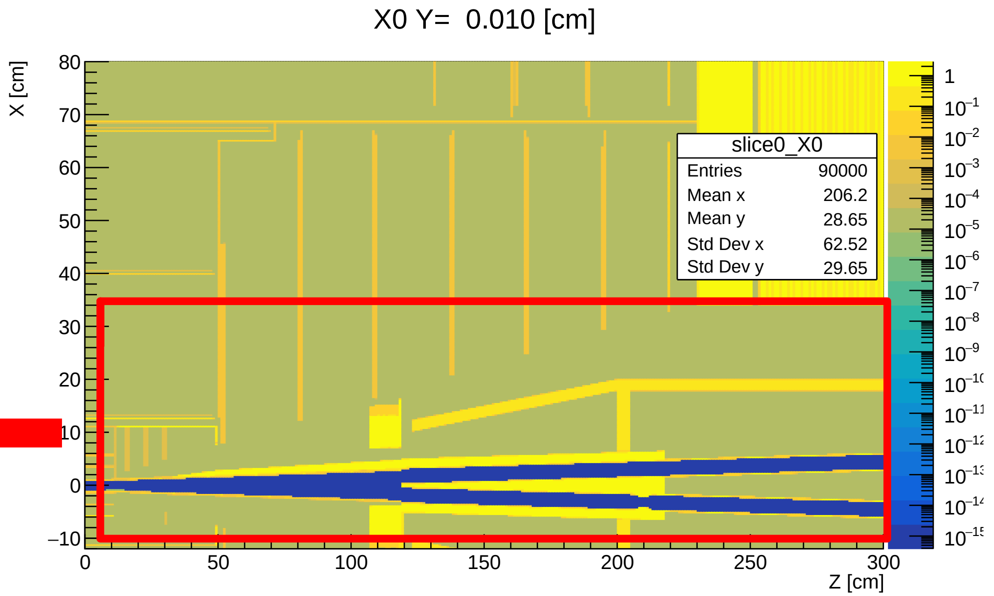


Ansatz

ILD (for ILC)
- ILC MDI
- Hybrid tracking layout

CLD (CLIC-like Detector)
- FCCee MDI
- All-silicon tracking





Ansatz:
1) Remove everything inside of the TPC from ILD
2) Replace with CLD subdetectors

Ansatz

ILD (for ILC)

- ILC MDI
- Hybrid tracking layout

CLD (CLIC-like Detector)

- FCCee MDI
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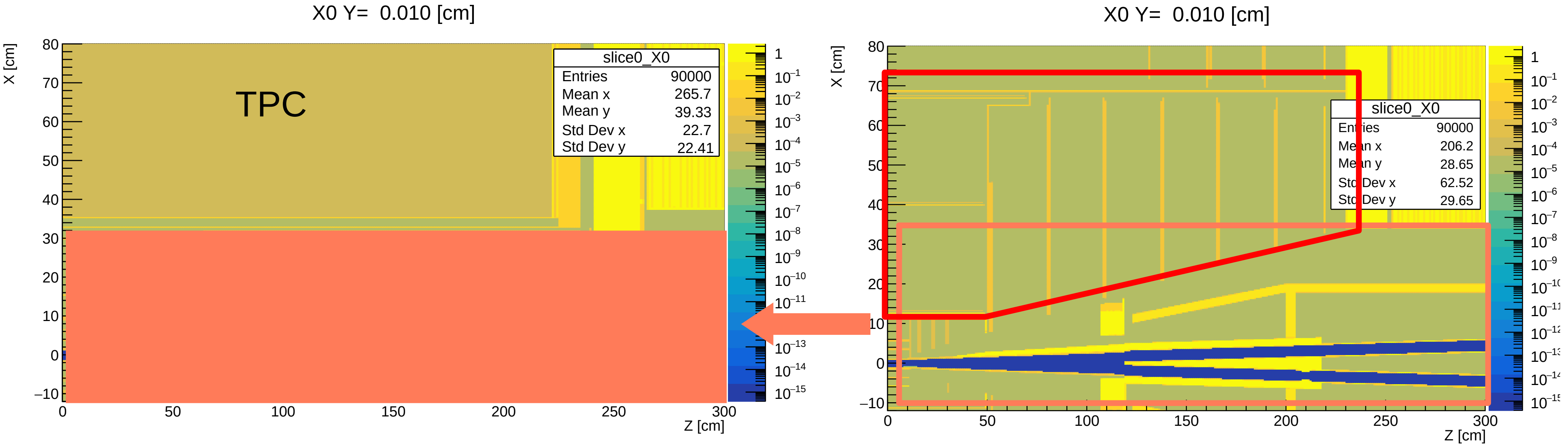


Ansatz:

1) Remove everything inside of the TPC from ILD
2) Replace with CLD subdetectors

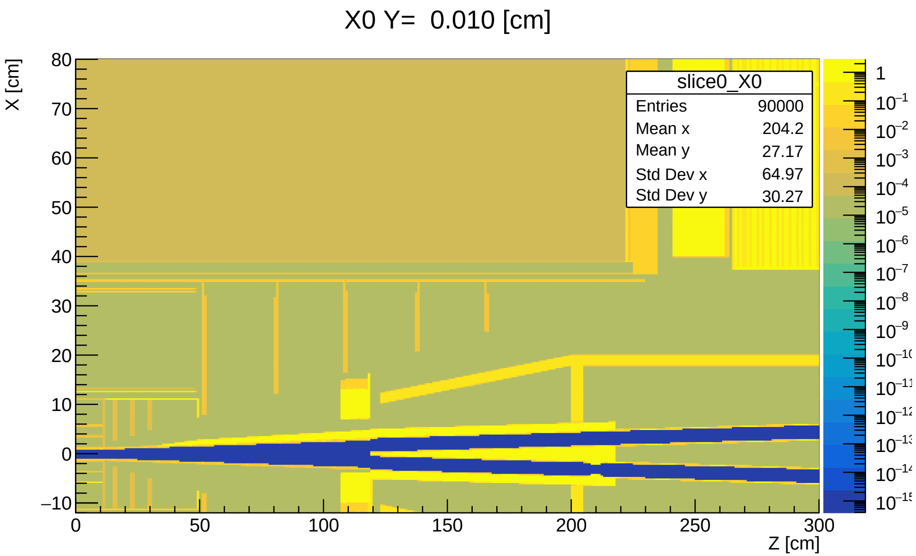
New Models or 2 Merging Strategies

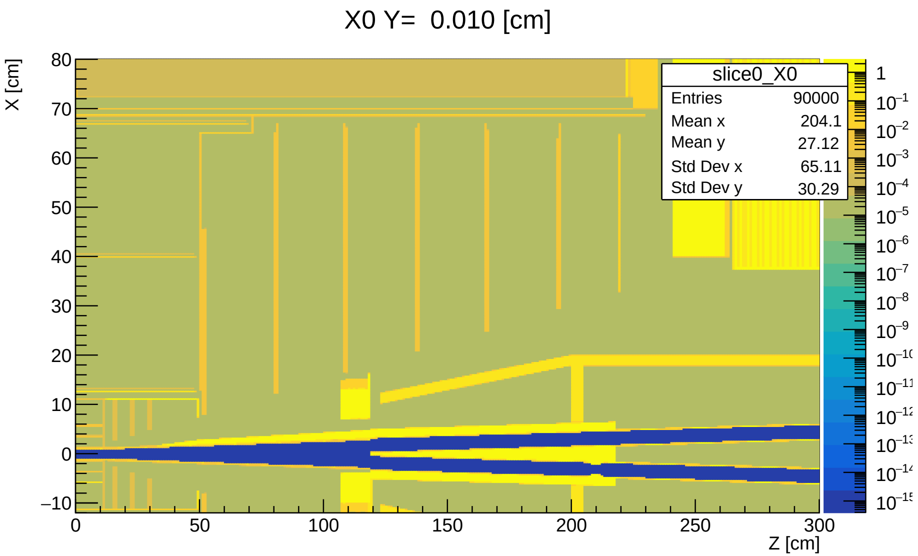
ILD for FCCee **v01** – large TPC:

- Leave TPC as large as possible
- Squeeze Inner Tracker in between TPC and Vertex Detector

ILD for FCCee **v02** – small TPC:

- Copy Inner Tracker from CLD
- Shrink TPC to accommodate the IT





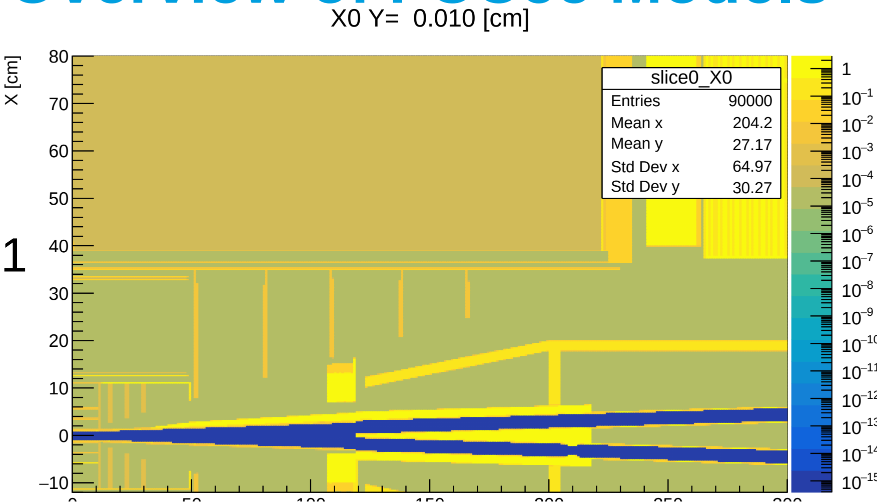
*Common MDI_o1_v00

model description source

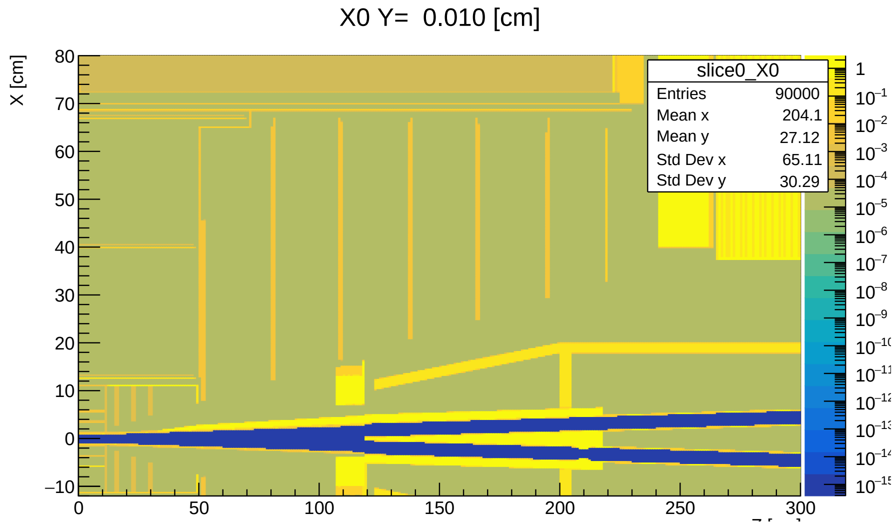
*Calorimeter and solenoid volumes were left unchanged, except for removed ECal Ring and LHCal

Overview of FCCee Models

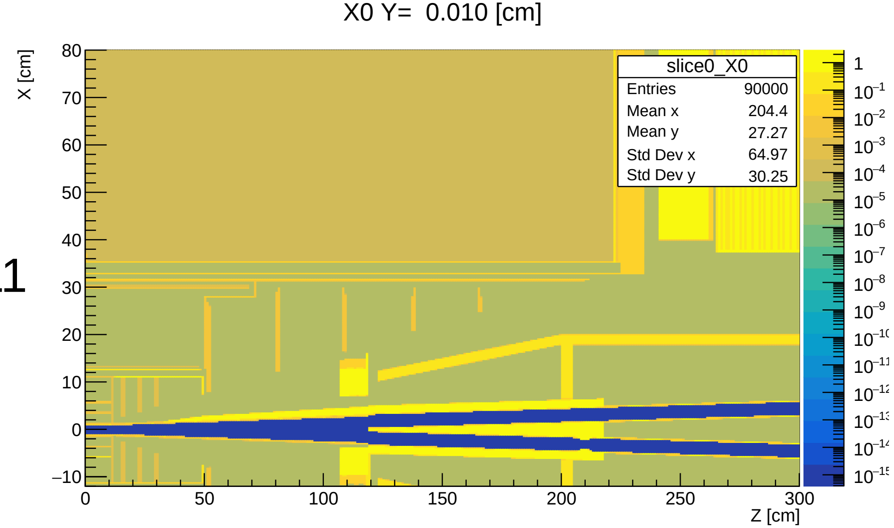
FCC1



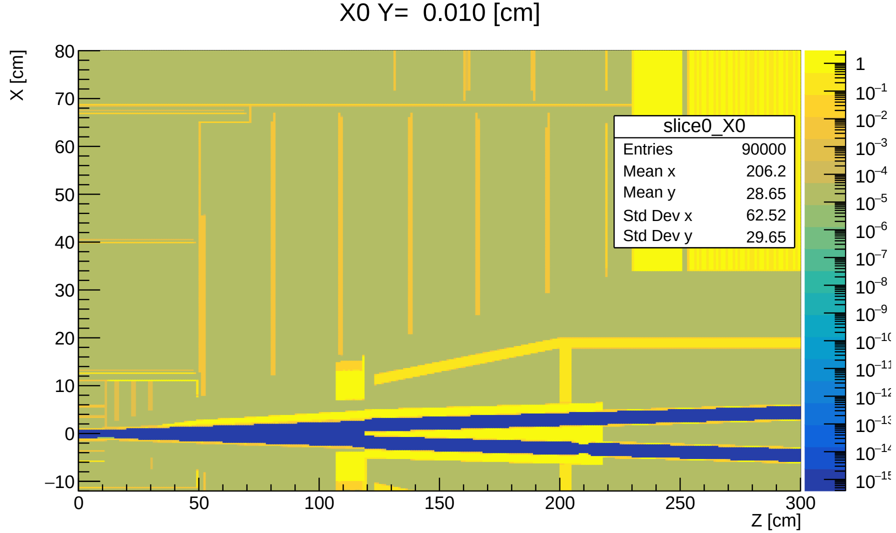
FCC2



v11

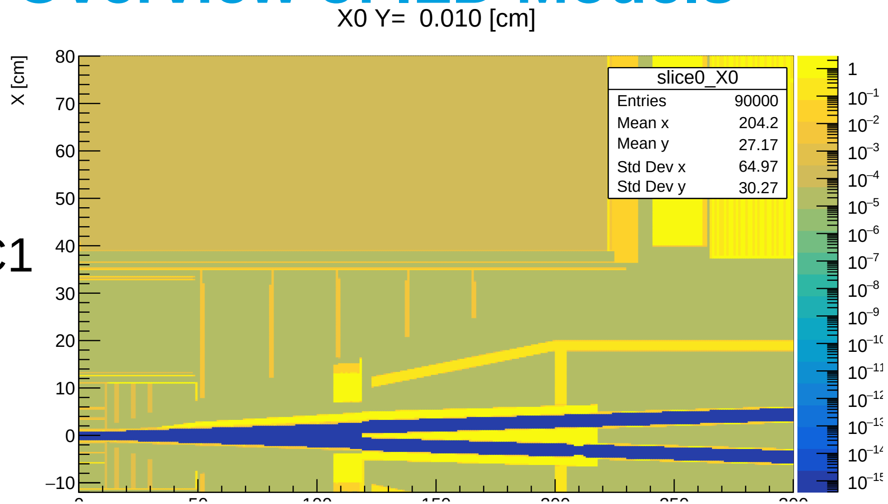


CLD

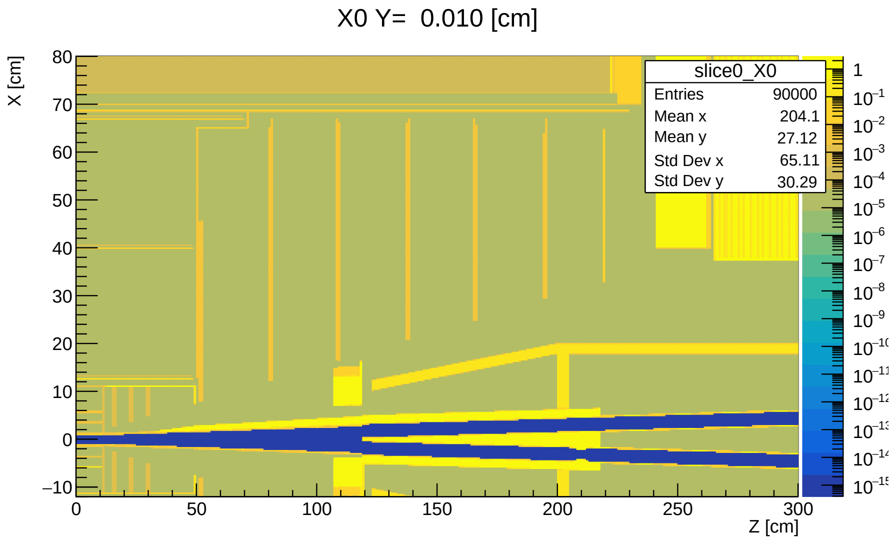


Overview of ILD Models

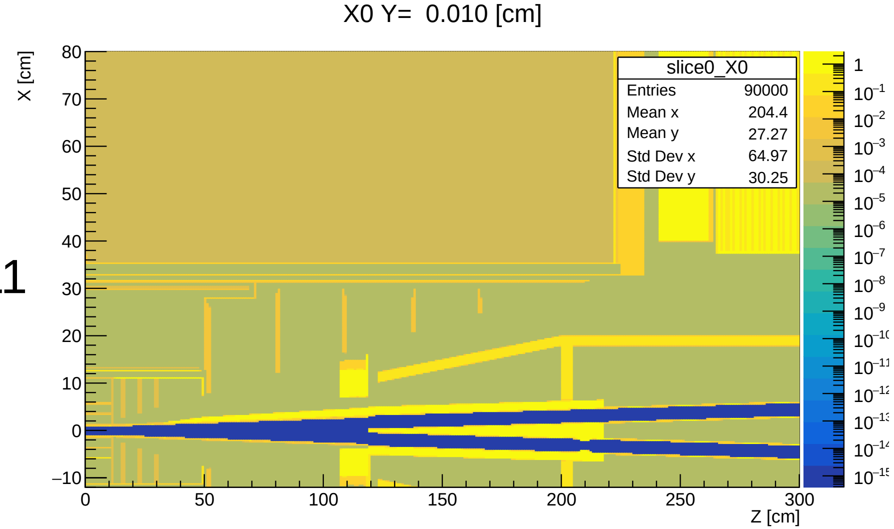
FCC1



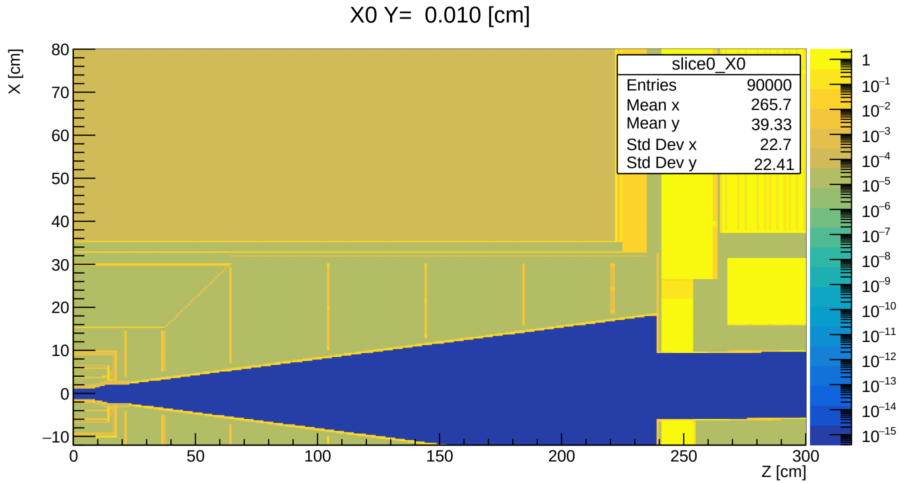
FCC2



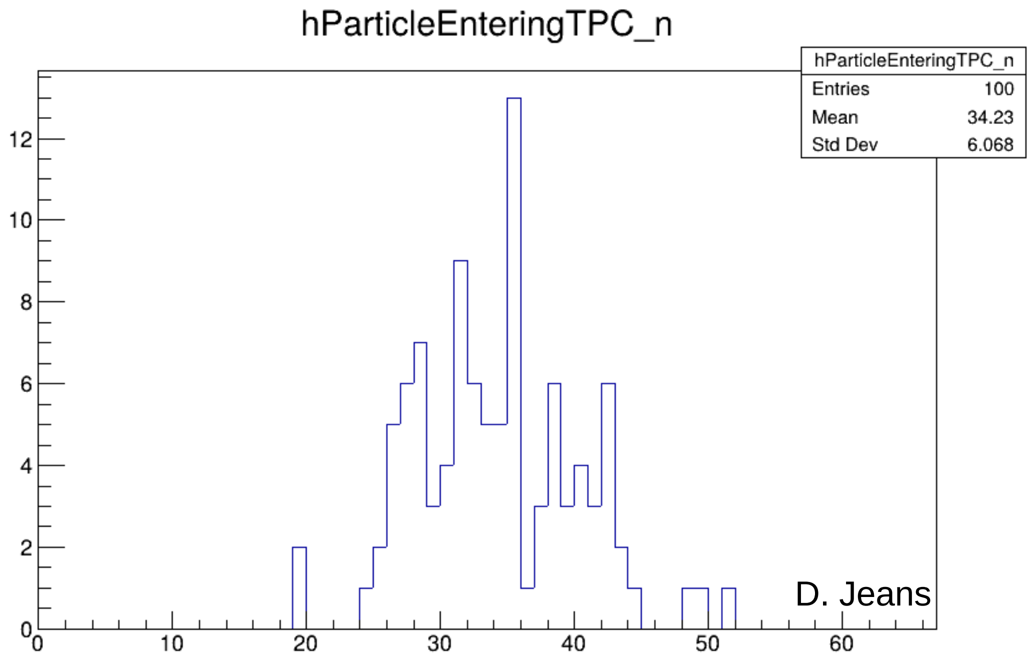
v11



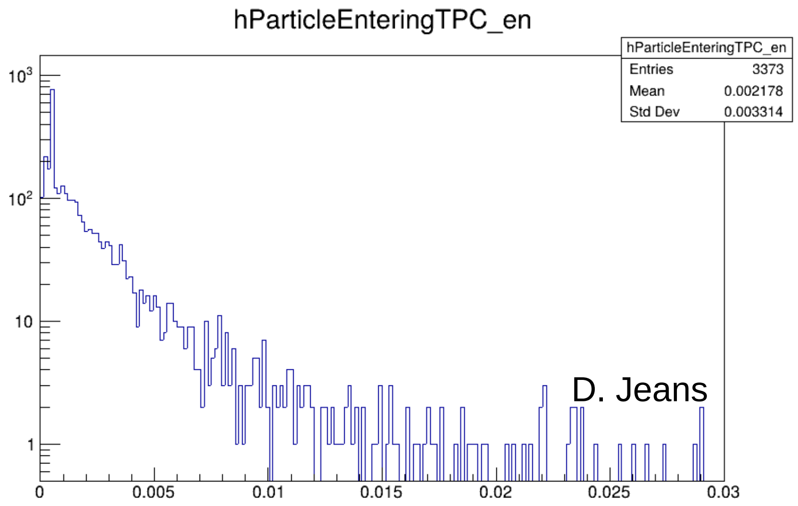
v02



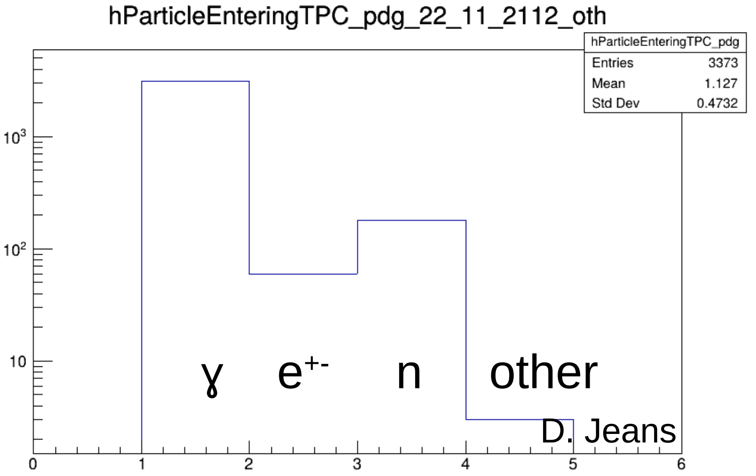
Particles Which Induce TPC Hits



#particles entering TPC / BX



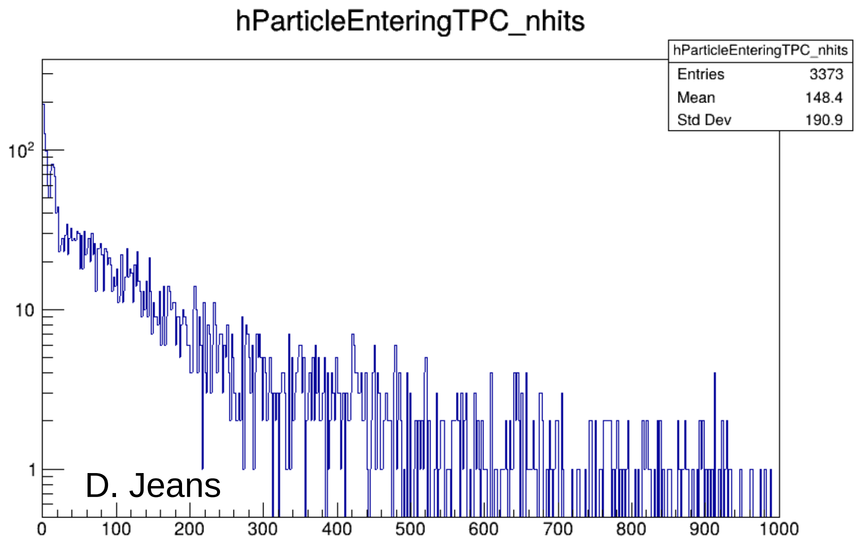
their energy [GeV]



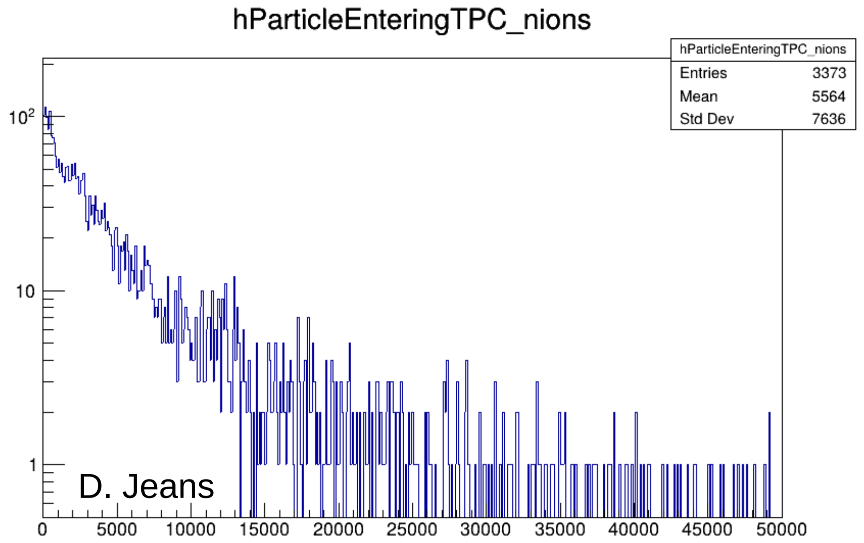
their type

ILD_FCCee_v01 model (with field map)

Particles Which Induce TPC Hits



#TPC hits induced per particle

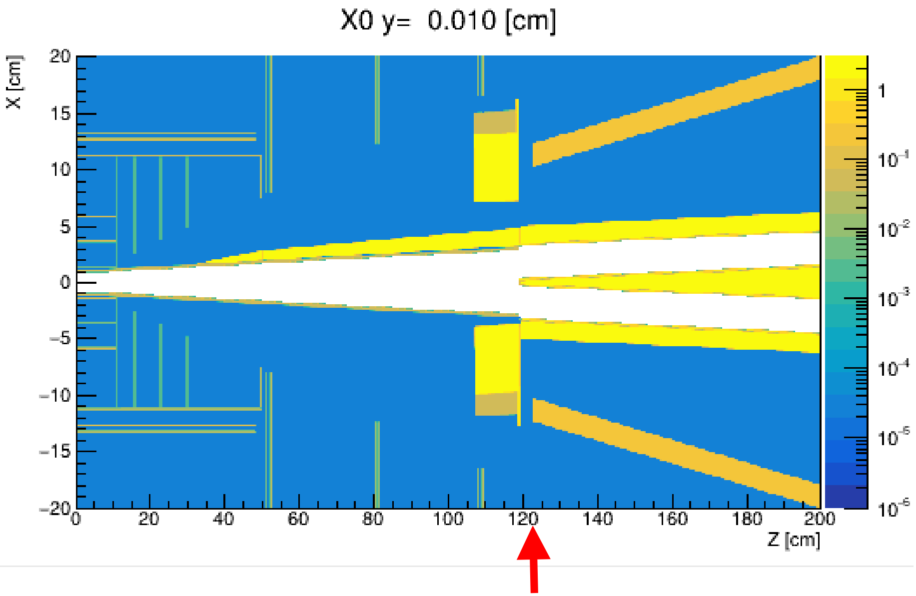


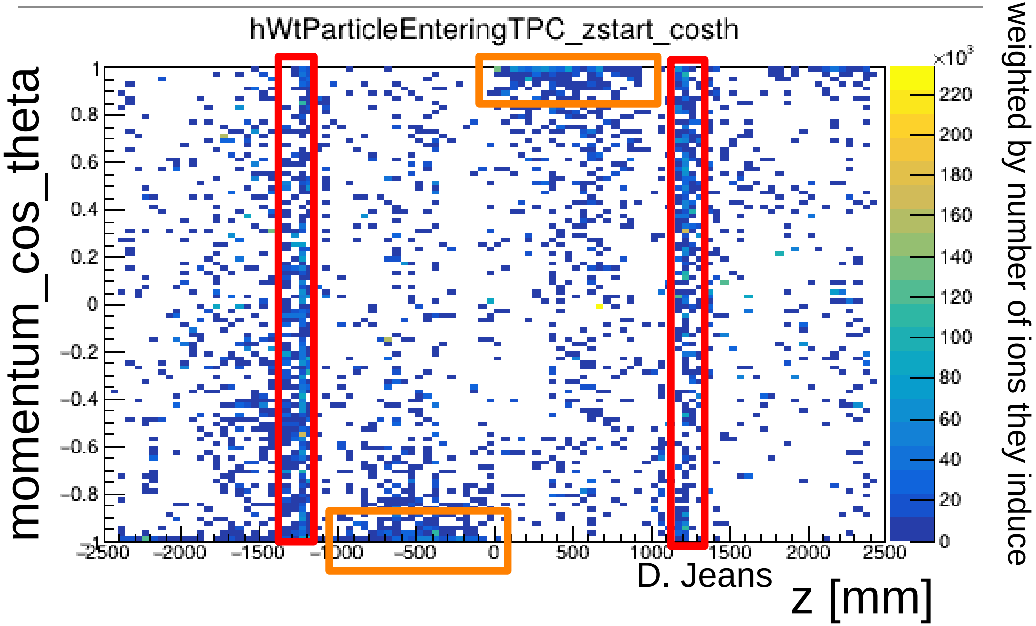
#primary ions in TPC induced per particle

Origin of Parent Particles

ILD_FCCee_v01 model (with field map)
MDI exactly from MDI_o1_v00

production point of particles entering the TPC

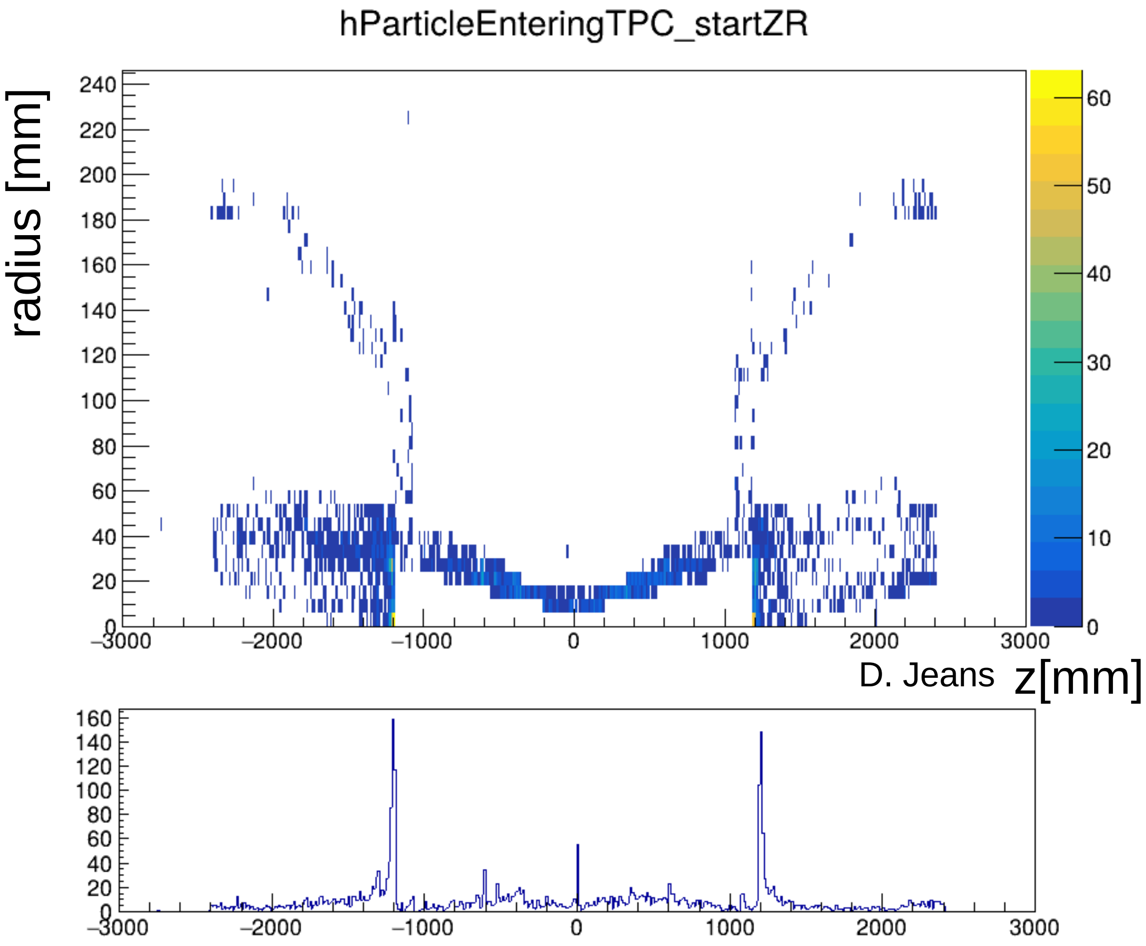




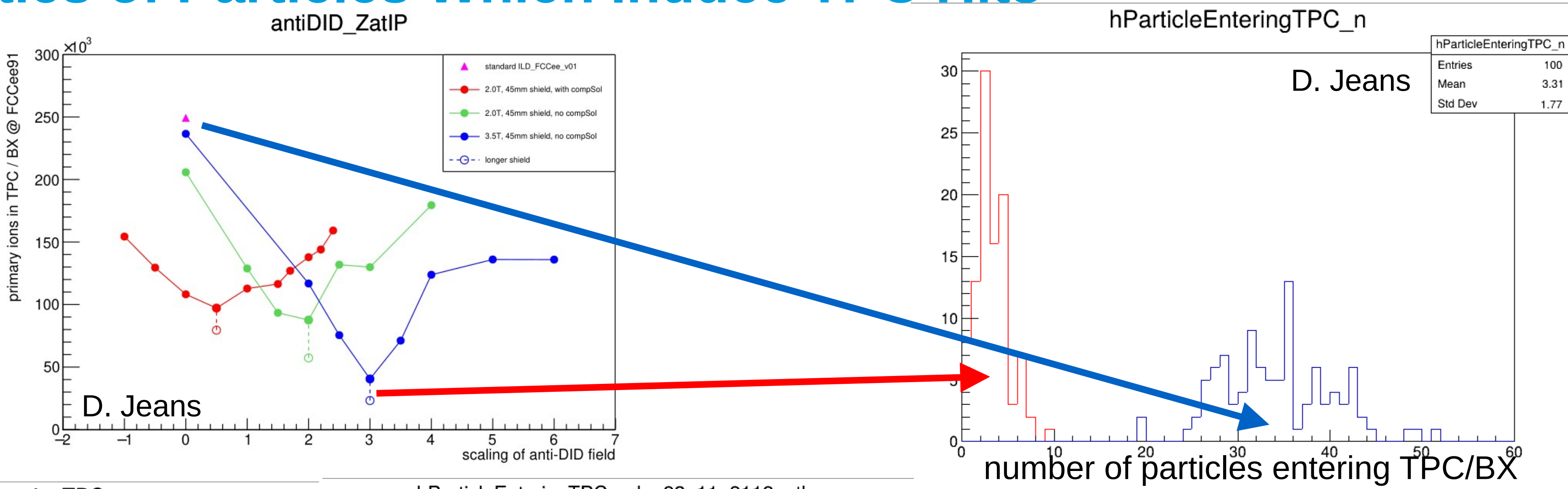
Main points of origin:

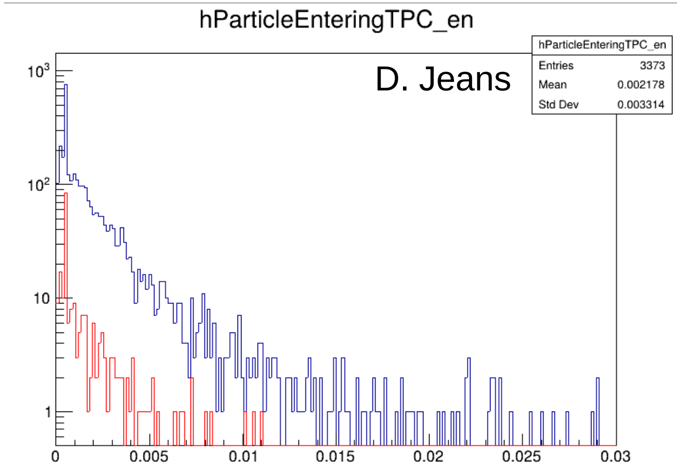
- In the plane containing the LumiCal
- inner beampipe shielding

Birthplace of Particles Entering the TPC

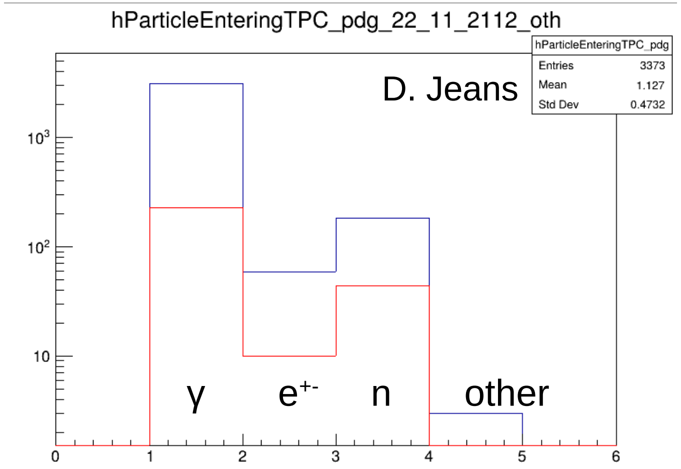


Properties of Particles Which Induce TPC Hits

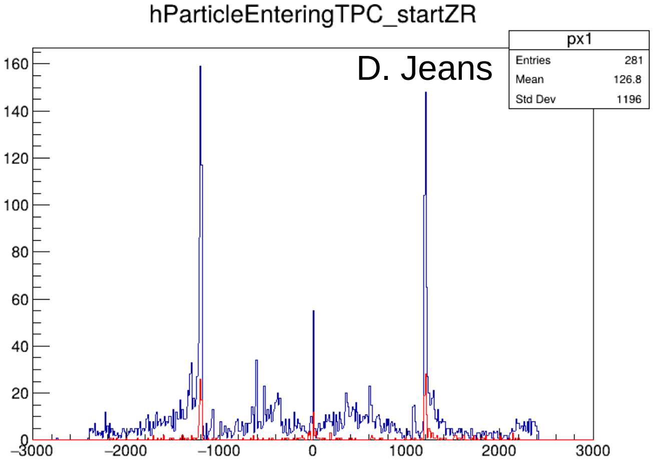




energy of particles entering TPC [GeV]



type of particles entering TPC [GeV]



Number of Primary Ions Produced with Collision Rate

- **TPC integrates over many collisions**; maximum ion drift time ~ 0.44 s
- roughly estimate number of primary ions in the TPC volume (~42 m^3) at any time, taking account of different collision rates
- number of ions ≈ primary ions/BX * BX freq * max drift time * 50%

  [some ions already reached cathode]

Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	260 k	820 k	450 k
primary ions in TPC at any time	1.7×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.4	0.54	0.0025

D. Jeans

Primary ion density in TPC:

- **2500** times higher at FCCee-91 than ILC-250
- **200** times higher at FCCee-240 than ILC-250

Gating

- Infos: https://agenda.linearcollider.org/event/7390/timetable/
- Mitigates “Ion Feedback Problem” → distortion of reconstructed tracks
- Gating foil which has GEM-like structure circa 1 cm before amplification
- Optical aperture ratio > 80%

- Goal:
  - High electron transparency in OPEN state (during train)
  - High ion blocking power in CLOSE state (during break)

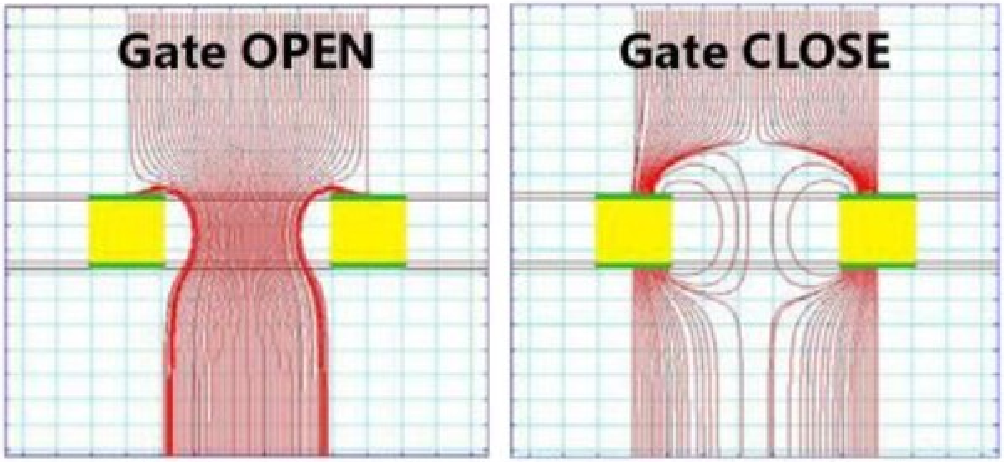


Fig 3. Electric field of gating foil

Masaru Yoshikai

CellIDEncodings: Current Situation

- Each sensor cell has a unique CellID (64 bits, partially split into 2x32 bits in LCIO for storage, always uint64_t in EDM4hep)
- For tracking: only 32 bits to enumerate the sensor, leaving 32 bits for strips / pixels on each sensor (convention from LC)
- CellIDEncoding can be used to split these into several smaller pieces
  - for ILD: **`system:5,side:-2,layer:9,module:8,sensor:8`**
  - for CLD: **`system:5,side:-2,layer:6,module:11,sensor:8`**

- Important assumption: **Only one convention for complete tracker!**
  - For now use ILD convention (need enough layer bits for TPC!)

CellIDEncodings: Food for Thought

- Now is a good time to potentially rethink some of the LC conventions
- Do we need / want CellIDEncodings that are the same for all subdetectors?
  - Just define `system:5,side:-2` and leave the distribution of remaining bits for layer, module, sensor to each subdetector?
- Are we happy with 32 bits up to the sensor, or do we need more? How many bits can we take from the 32 that are currently reserved for on-sensor ids?

The usual caveats apply:

- Available person power to actually act on any potential decision