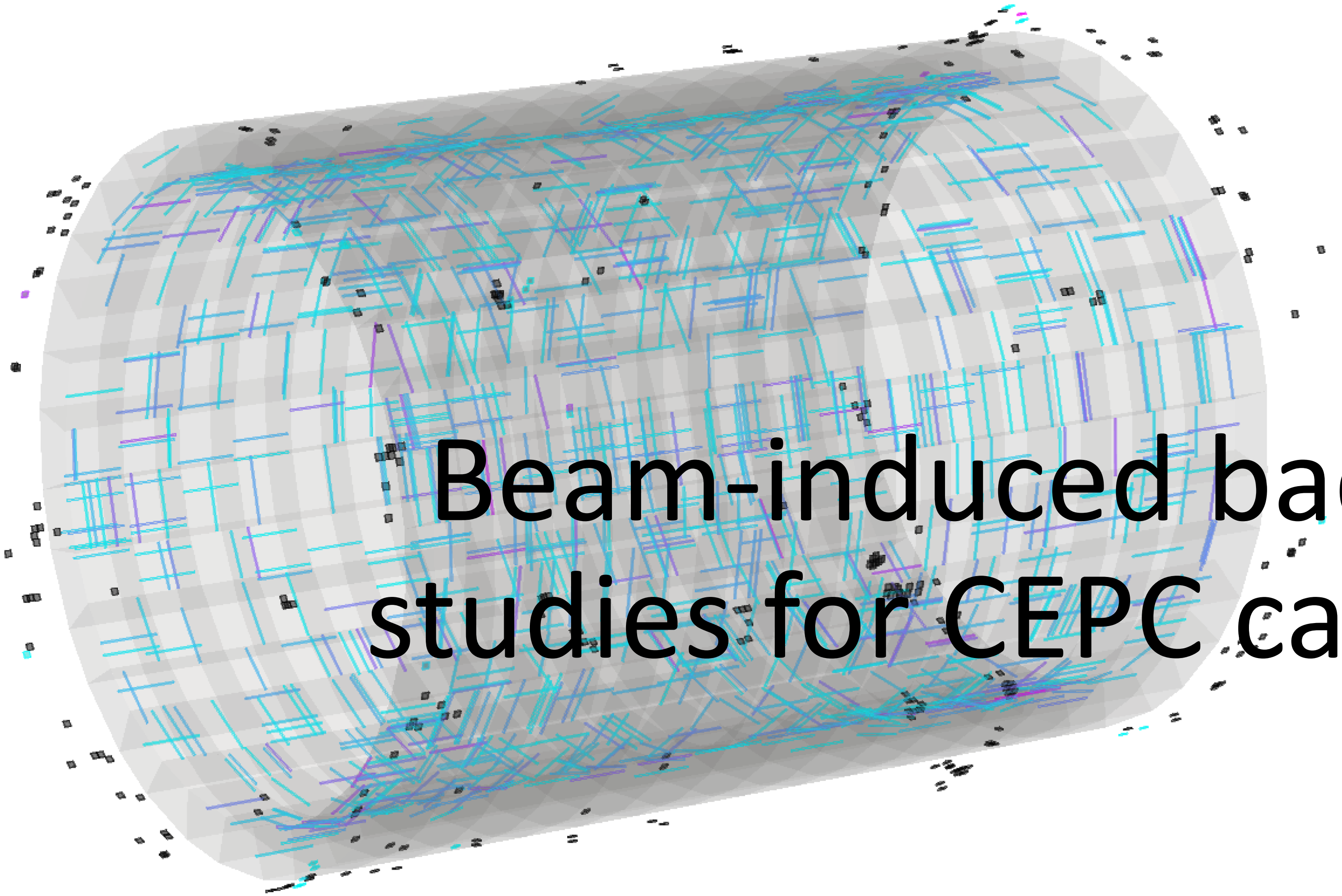

Beam-induced background studies for CEPC calorimeters

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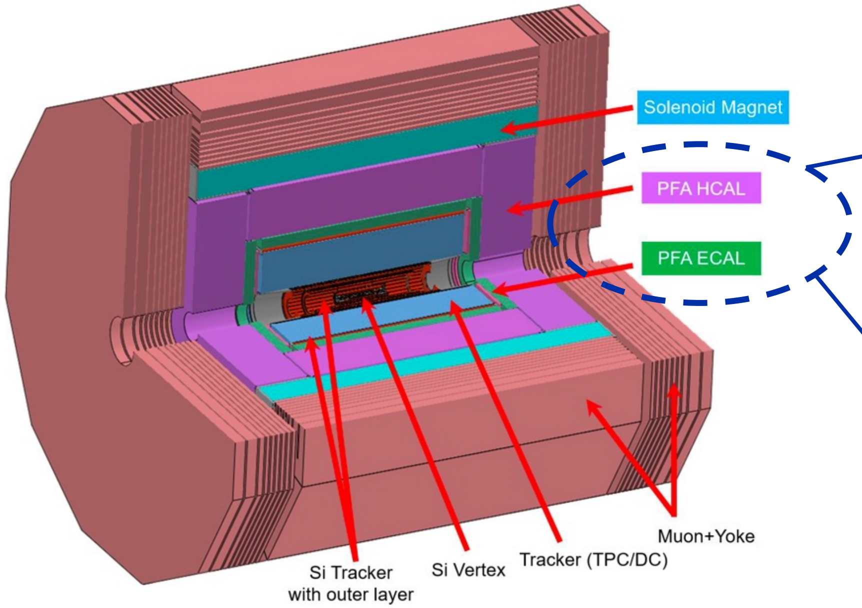
On behalf of the CEPC Ref-TDR ECAL working group

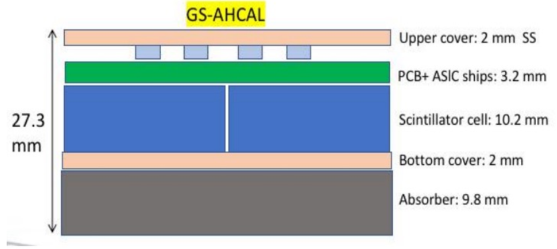
2024.10.23

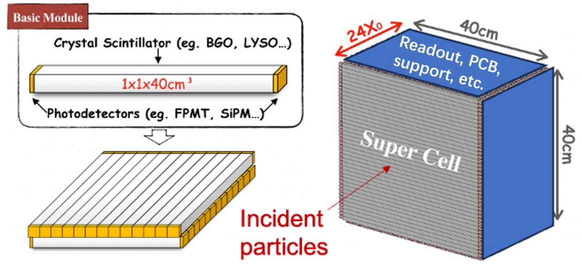
The 2024 international workshop on the high energy Circular Electron Positron Collider

Introduction

- Particle Flow Approach(PFA) calorimeter in CEPC Ref-TDR design:
  - Physics target: boson mass resolution $3\sim4\%$.
  - Homogeneous crystal ECAL + Scintillating glass HCAL
- Proper estimation of level and distribution of the beam-induced background in the calorimeter:
  - Crucial input for the design and optimization of electronics and trigger system.
  - Impact on the performance of detector design.
  - Develop methods to mitigate beam-induced background.







Source of beam-induced backgrounds

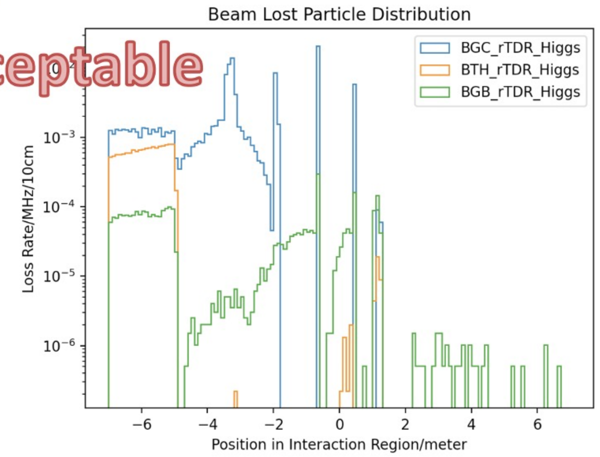
- This talk focus on beam-induced backgrounds in Higgs mode:
  - Based on the 50-MW design of CEPC Accelerator TDR, 355ns/bunch crossing.
  - Beam loss rate in Z-pole is under optimization.
  - W and top mode will be delivered in the future.

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	50			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	29.52	5.98	1.23
Bunch number	446	13104	2162	58
Bunch spacing (ns)	355 (53% gap)	23 (10% gap)	154	2714 (53% gap)
Bunch population (10^{11})	1.3	2.14	1.35	2.0
Beam current (mA)	27.8	1340.9	140.2	5.5
Phase advance of arc FODO (°)	90	60	60	90
Momentum compaction (10^{-5})	0.71	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune ν_x/ν_y	445/445	317/317	317/317	445/445
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.7/10.6	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.15	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.5	1.05/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.0045/0.13	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.1	0.7	10
RF frequency (MHz)	650			
Longitudinal tune ν_s	0.049	0.032	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	40/40	90/930	60/195	81/23
Beam lifetime requirement (min)	20	81	25	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	8.3	192	26.7	0.8

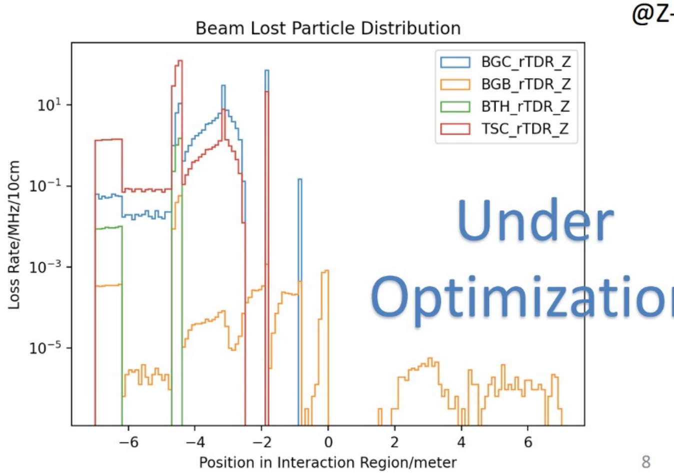
*CEPC Accelerator TDR

@Higgs

Acceptable



@Z-pole



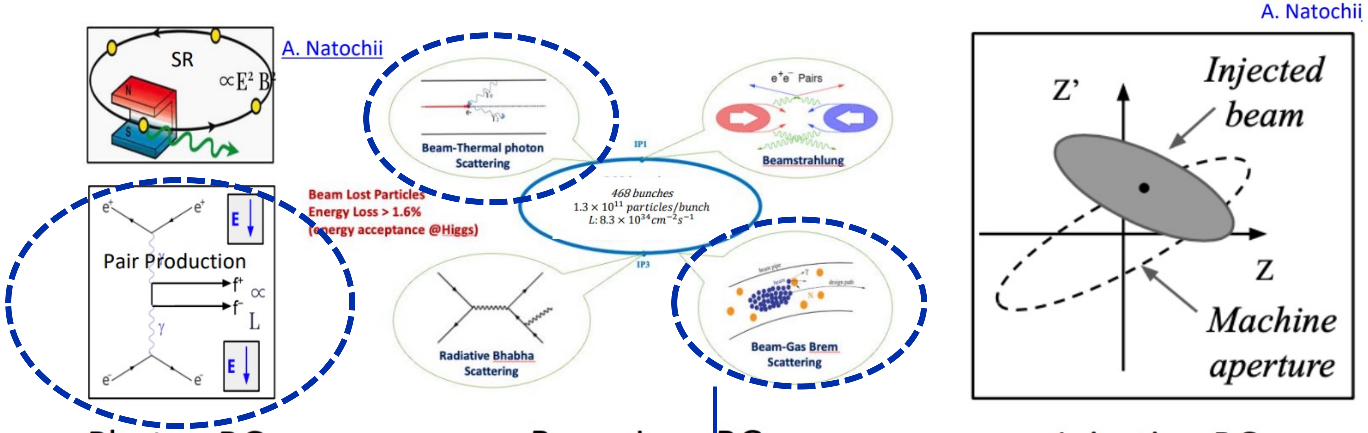
Under Optimization

*from Haoyu Shi

Source of beam-induced backgrounds in Higgs mode

✓ Pair production, Beam-Thermal Photon and Beam-Gas Scattering(Elastic/inelastic).

- Injection and synchrotron radiation will be considered in the future.
- Multi turn Bremsstrahlung and radiative bhabha have basically been shielded outside the interaction region with collimators.



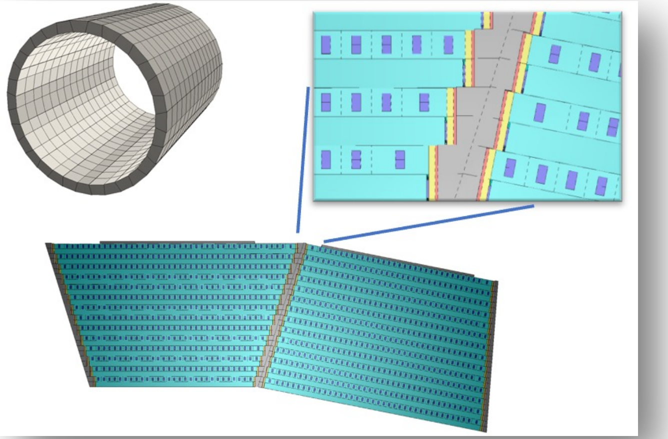
Photon BG | Beam Loss BG | Injection BG

Beam-induced backgrounds		50MW Higgs 355ns/BX
Luminosity Related	Pair production	~1300/BX
Single beam	Beam-Thermal Photon	~0.36 MHz
	Beam-Gas Bremsstrahlung	~0.04 MHz
	Beam-Gas Coulomb	~0.24 MHz

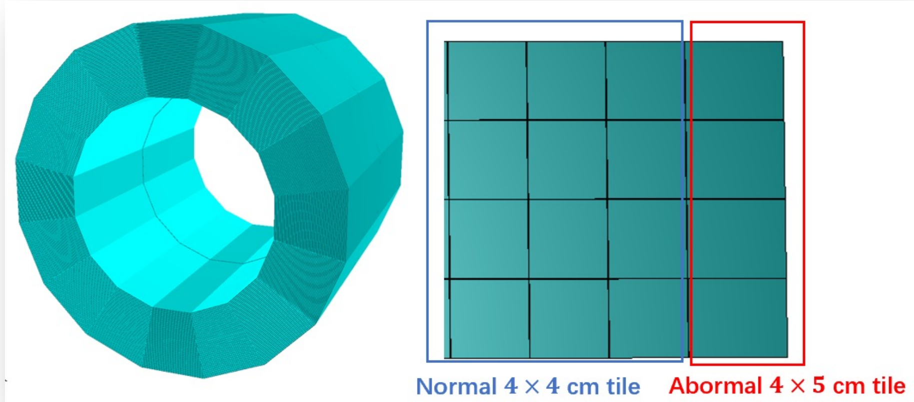
Simulation of CEPC calorimeters

- A realistic crystal ECAL and glass HCAL geometry has been implemented with DD4HEP.
- Following latest mechanical design.
- Taking wrapping, electronic boards, cooling and mechanical supporting into material budget.

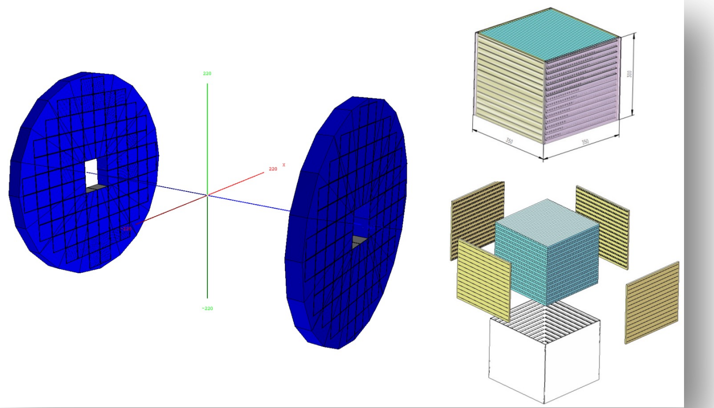
ECAL Barrel



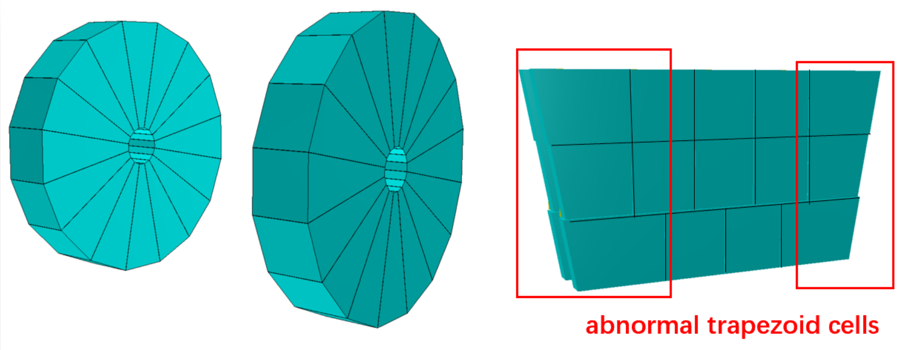
HCAL Barrel



ECAL Endcap

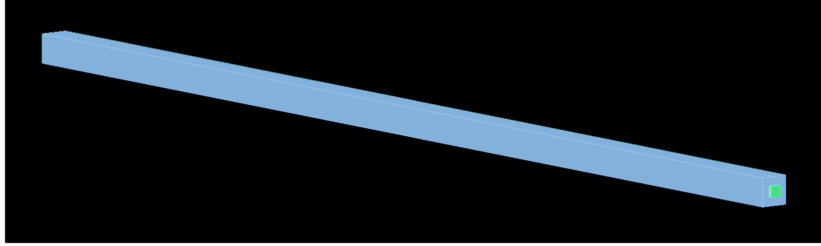


HCAL Endcap

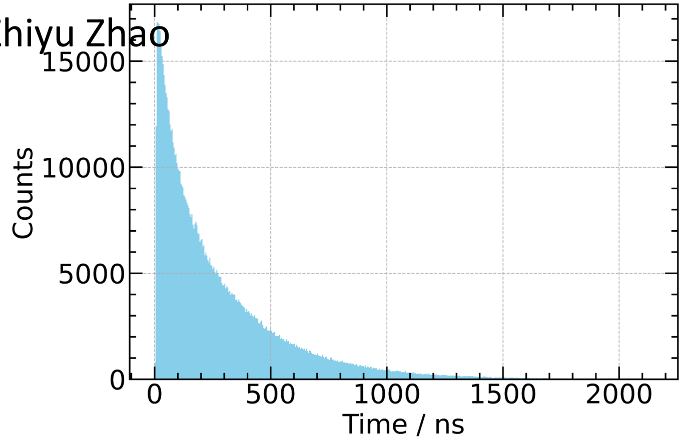


Digitization of CEPC calorimeters

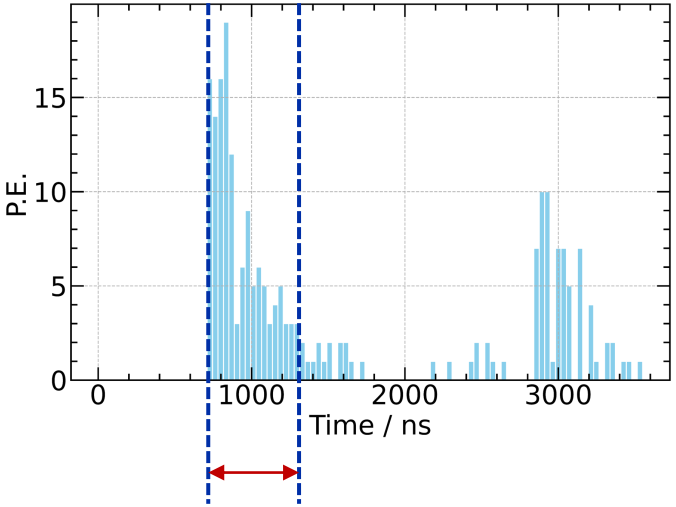
- ECAL:
  - $E_{hit} \rightarrow N_{p.e.}$: $N_{p.e.} = \frac{E_{hit}[GeV]}{E_{mip}[GeV/MIP]} \times LY$
    - Effective light yield: 200 p.e./MIP.
  - $Time_{p.e.}$: for study of pile-up
    - time of photoelectron arriving at SiPM is obtained from Geant4 optical simulation.
    - considering scintillation decay time($\tau = 300ns$ for BGO) and transmission.
  - Time window: only readout the photoelectron within the time window.
  - Threshold: 0.1 mip
- HCAL:
  - Effective light yield: 80 p.e./MIP
  - Threshold: 0.1 mip



*by Zhiyu Zhao



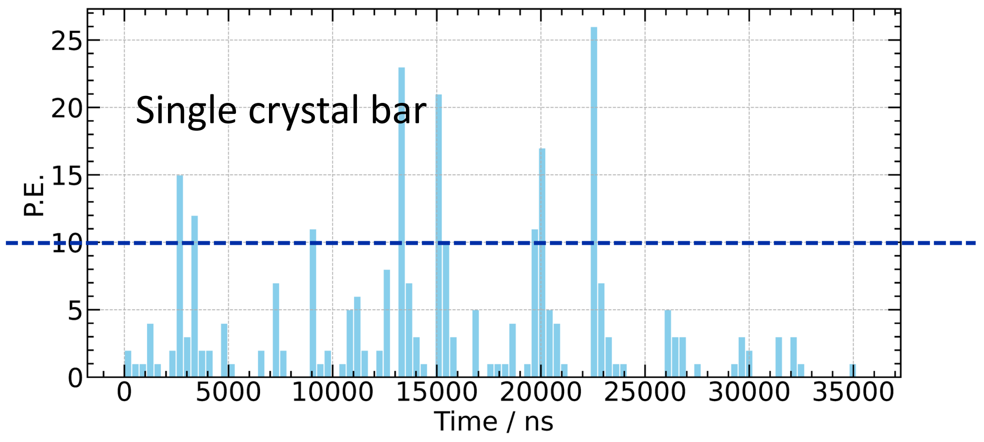
Single crystal bar



600ns time window

Count rate

- For each bar: Count rate [Hz] = Times over threshold [times] / Total time [s]
  - e.g., count rate = 8/35500ns = 225 KHz, assuming each bin stands for one time window.
- Count rate is a key parameter in determining the design of ASIC and estimation of data size.



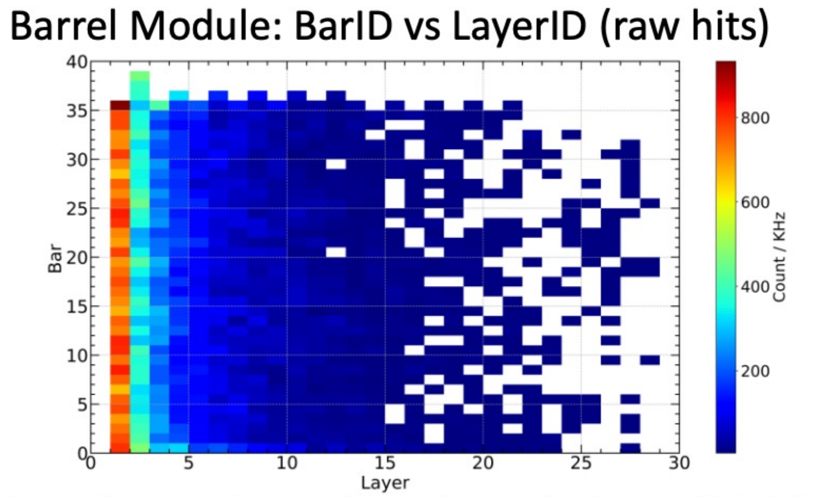
Count rate 600ns time window w/ 0.1mip threshold		Mean	Maximum
ECAL	Barrel	6.8 khz	211 khz
	Endcap	13.86 khz	333 khz
HCAL	Barrel	0.24 khz	6.2 khz
	Endcap	1.45 khz	46.3 khz

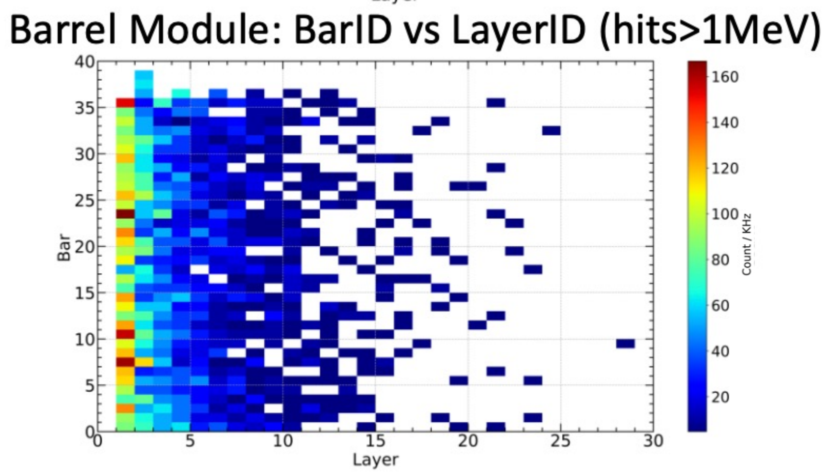
Count rate 200-300 kHz with 0.1 MIP threshold for ECAL
<50 kHz with 0.1 MIP threshold for HCAL

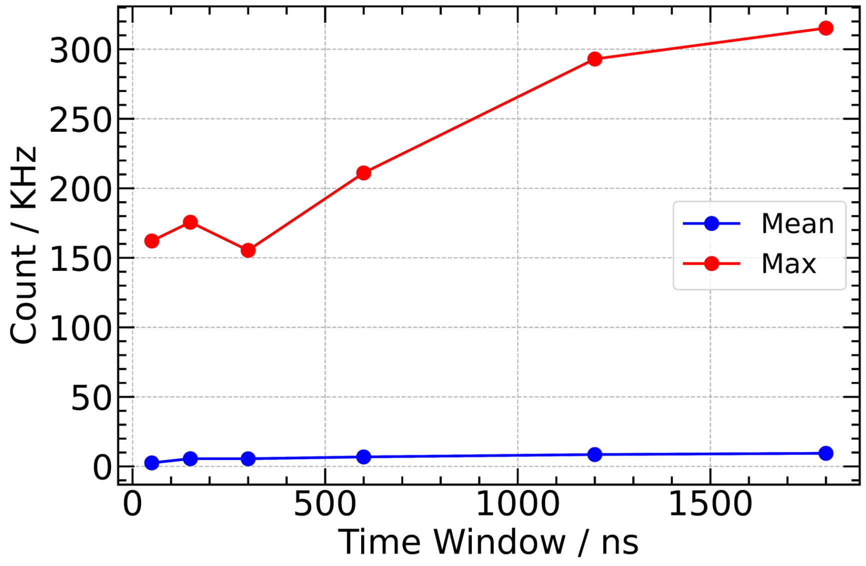
*need more check

Count rate

- Crystal bar with high count rate is mainly concentrated in the first few layers of the ECAL.
- Count rate vs time window.







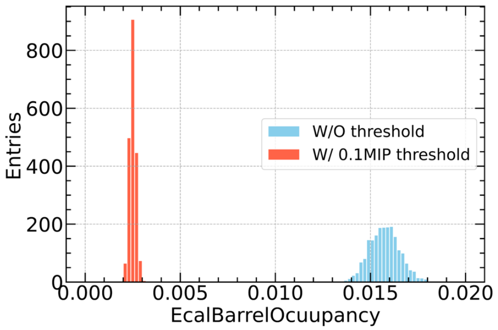
Dealing with the first few layers and time window are potential solutions

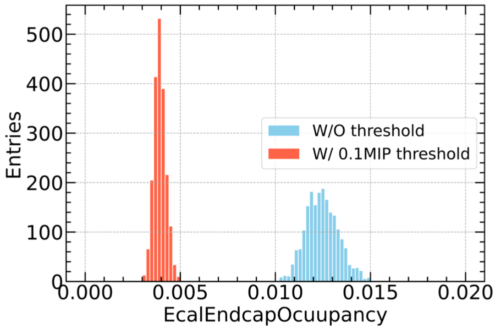
Occupancy

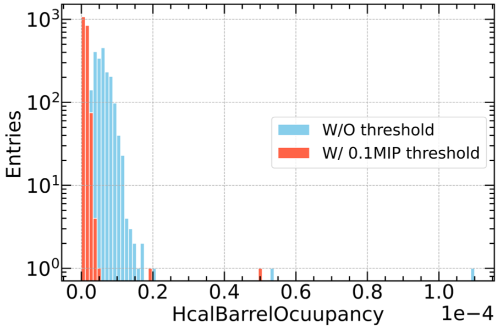
- Occupancy = fired cells / all cells (per 355ns).
- The occupancy is a key parameter for trigger system.

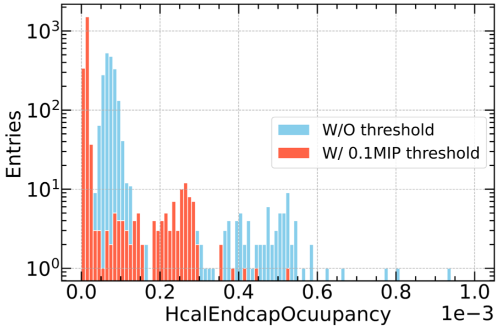
Occupancy		W/O Threshold		W/ 0.1MIP Threshold	
		Mean	Maximum	Mean	Maximum
ECAL	Barrel	$1.58e^{-2}$	$1.87e^{-2}$	$2.50e^{-3}$	$3.99e^{-3}$
	Endcap	$1.25e^{-2}$	$1.72e^{-2}$	$3.94e^{-3}$	$7.93e^{-3}$
HCAL	Barrel	$5.86e^{-6}$	$1.09e^{-4}$	$1.13e^{-6}$	$5.02e^{-5}$
	Endcap	$9.11e^{-5}$	$9.38e^{-4}$	$2.36e^{-5}$	$5.28e^{-4}$

Occupancy 10^{-3} level with 0.1 MIP threshold for ECAL
< 10^{-4} with 0.1 MIP threshold for HCAL



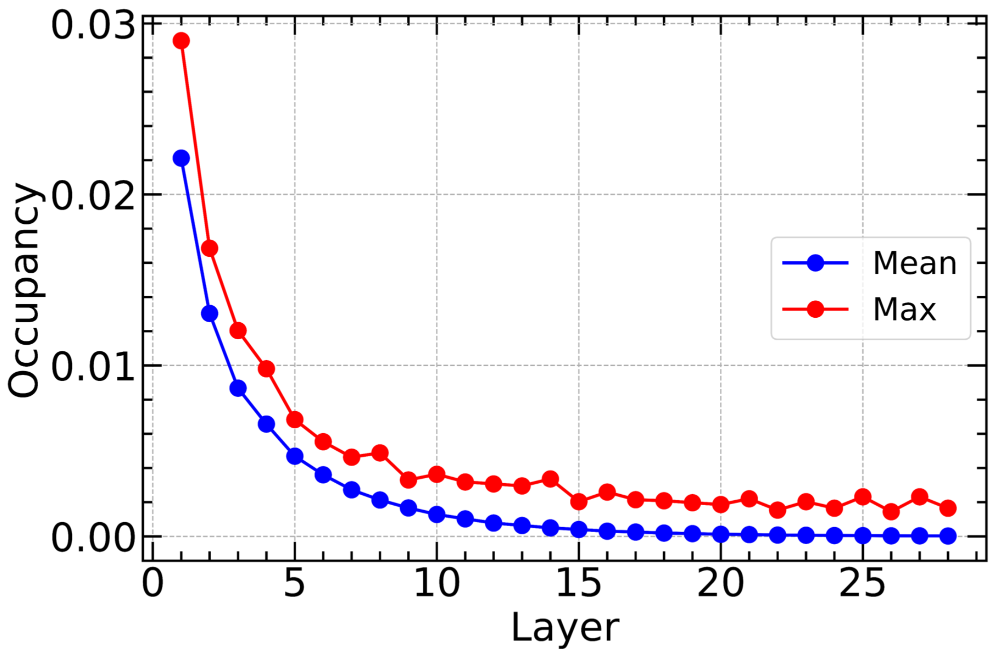






Occupancy

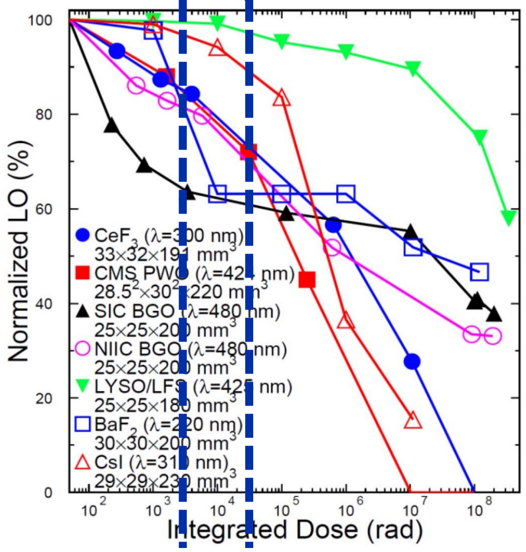
- Occupancy = fired cells / all cells (in one bunch cross).
- The occupancy is a key parameter, will influence the trigger system, signal-to-noise ratio and energy measurement.
- The distribution of occupancy in ECAL Barrel.



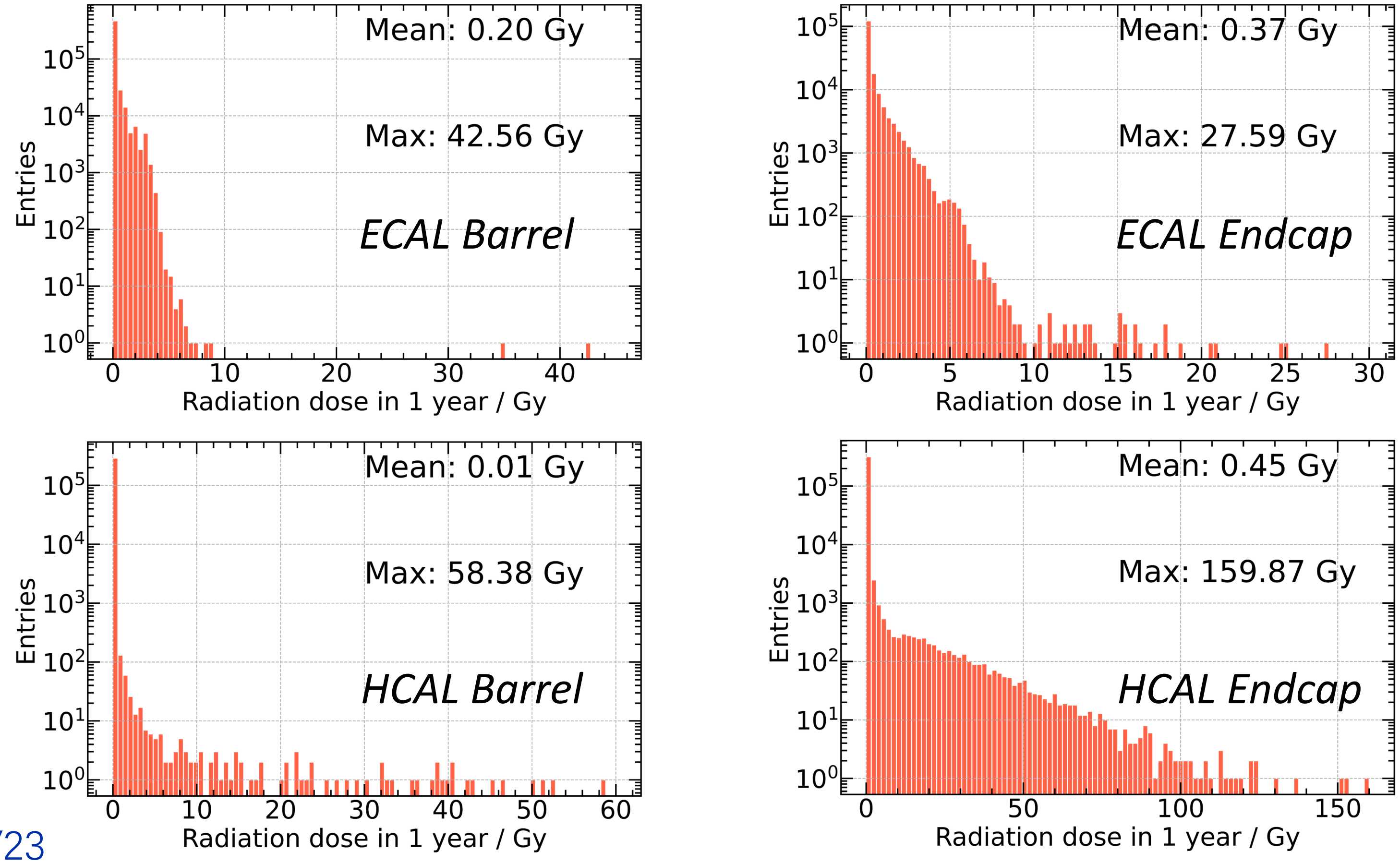
Occupancy in the first few layers (1-3%) are bigger than other layers
remove it in reconstruction is potential way

*F. Yang, L. Zhang and R. -Y. Zhu, "Gamma-Ray Induced Radiation Damage Up to 340 Mrad in Various Scintillation Crystals,"

Total ionizing dose



- Total ionizing dose(TID):
  - for each cell: accumulated energy / mass [Gy], assuming 3600 hours in one year.
  - radiation damage in crystal and glass, light output degradation.



TID in single cell up to 100 Gy/year in Higgs mode

Conclusion

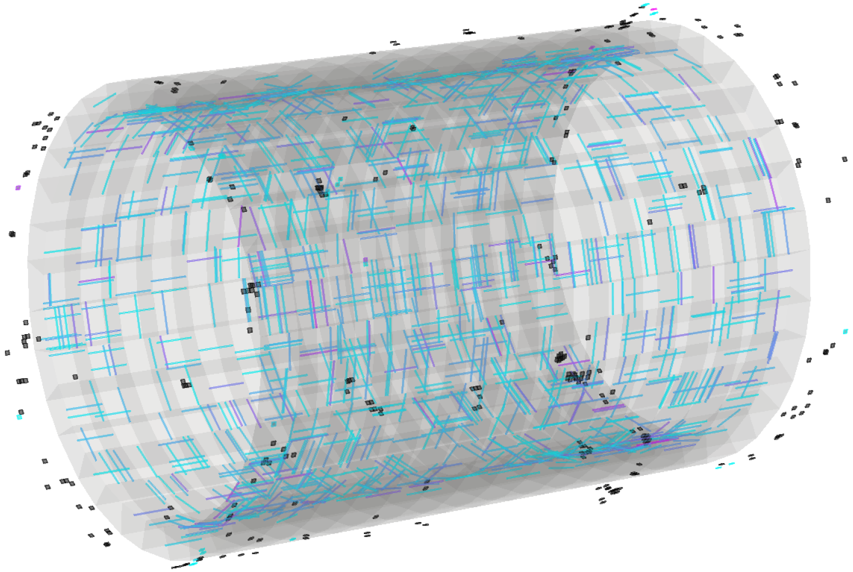
- Beam-induced background studies for CEPC calorimeters:
  - crucial for the design and optimization of the electronics, triggering, and hardware.
- Beam-induced background under the Higgs mode:
  - levels and distributions of counting rate, occupancy, and total ionizing dose (TID).
  - very preliminary results on the energy resolution of the crystal ECAL under background conditions. will deliver soon.
- Next step:
  - investigate the beam background under Z, W, and top modes.
  - exploring potential methods to reduce the Beam-induced background.

Thanks!

backup

Event display

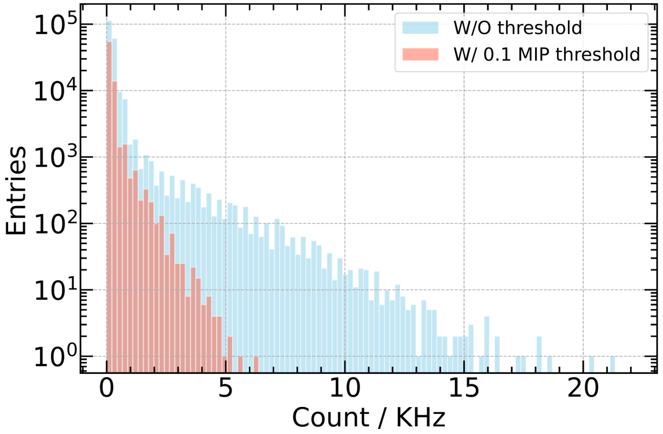
- Full simulation of CEPC Ref-TDR detector.
- With 0.1mip threshold for ECAL and HCAL.
- Energy response of beam-induced backgrounds in calorimeter barrel.
  - ECAL: long bar
  - HCAL: small cube
- Mainly concentrated in the first few layers of the ECAL.
- HCAL is better than ECAL.



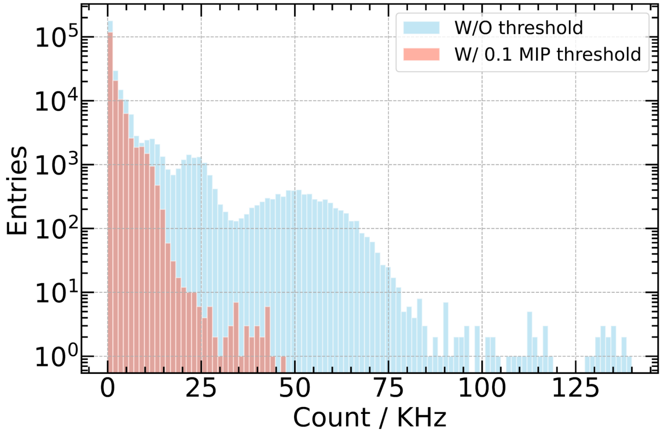
1 bunch

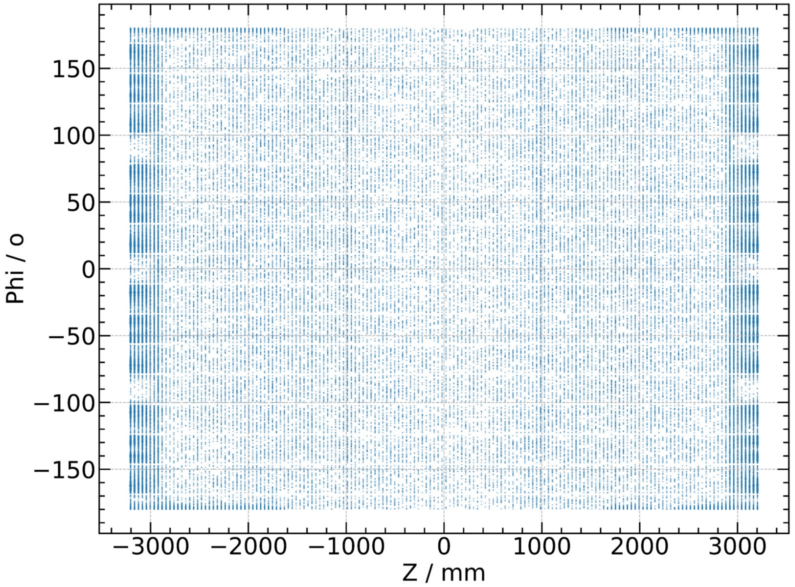
Count rate of HCAL

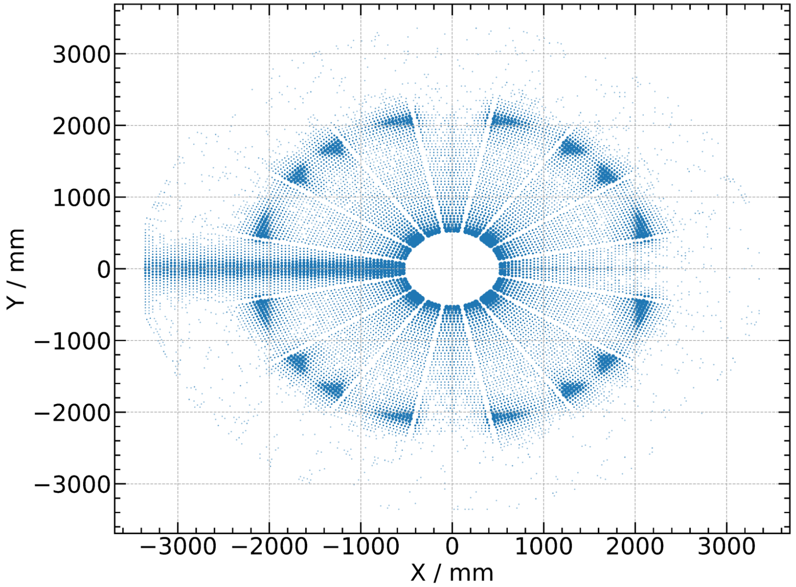
barrel



endcap







Energy resolution

- very preliminary results