Toward the design of the TPC at future colliders

(D_RD_28)

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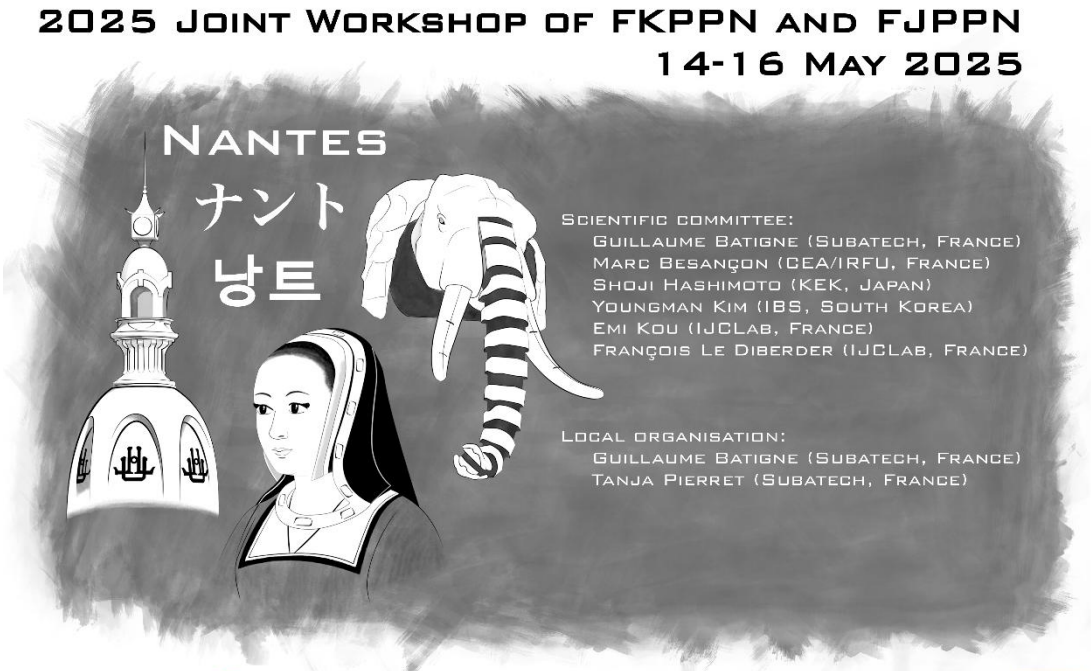
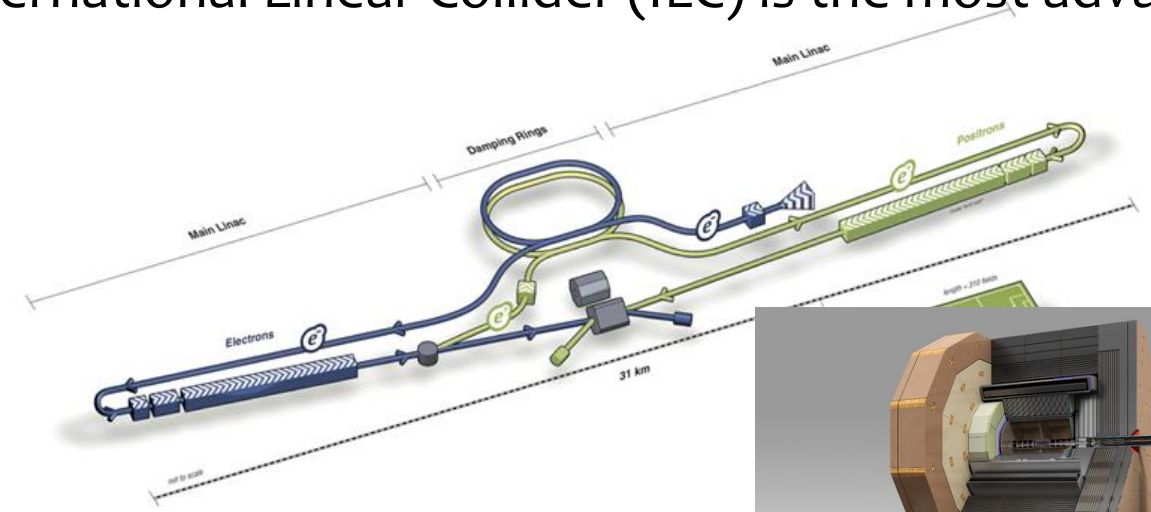
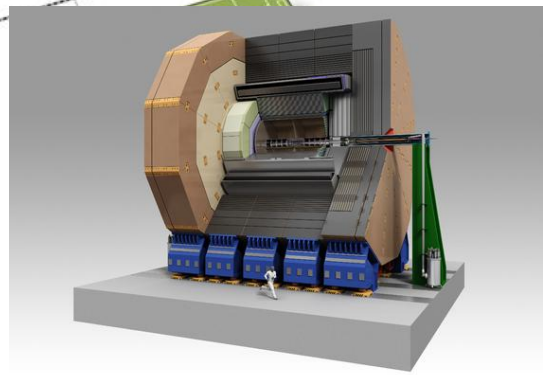


International Linear Collider

- International Linear Collider (ILC) is the most advanced project for the future Higgs factory.



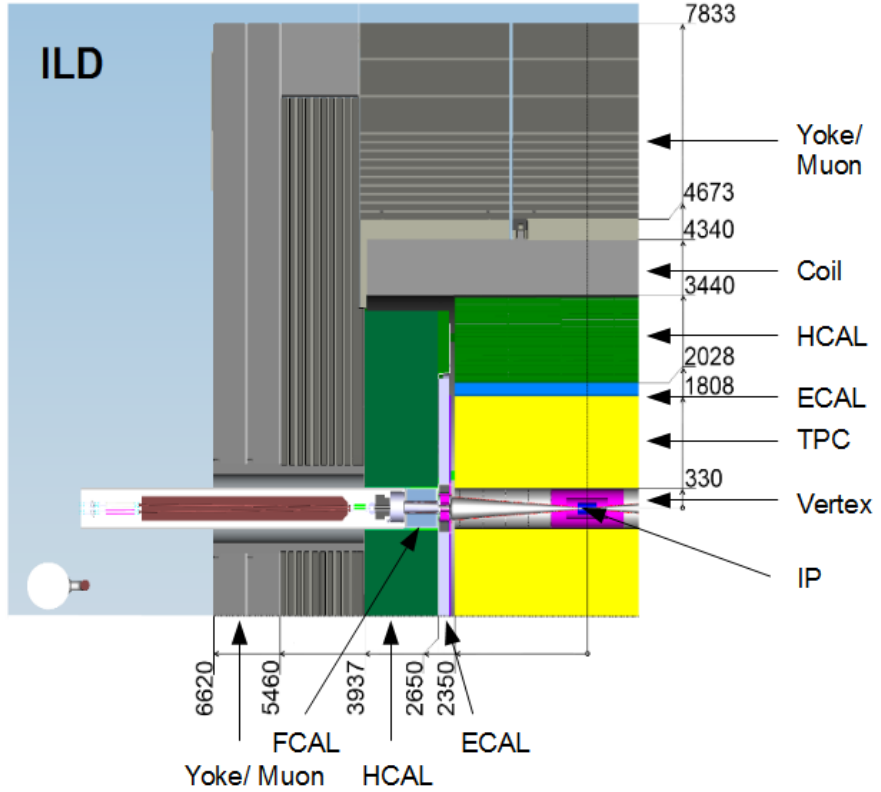


- ✓ Start at 250 GeV and upgradable to ~ 1 TeV
- ✓ 2 detector concepts (2 experiments) are currently considered.

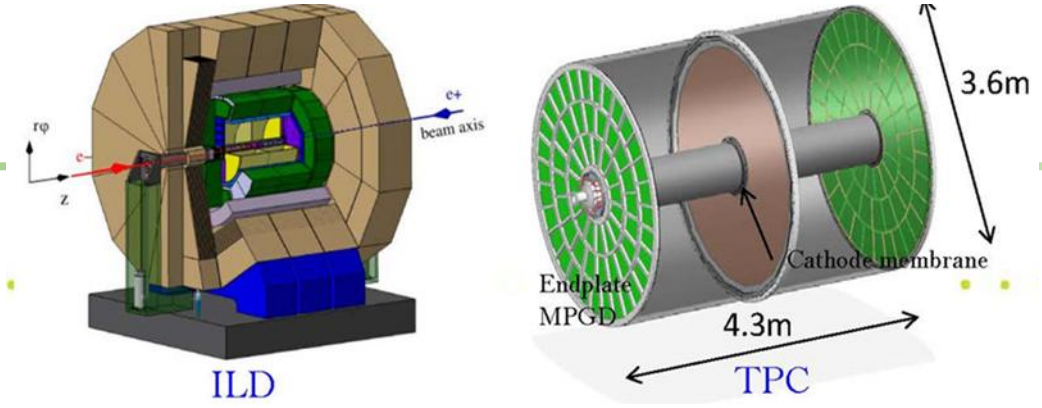
- International Large Detector (ILD) is one of the detector concepts for the ILC.

Requirements for the ILD

- momentum resolution: $\delta(1/P_T) \leq 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$
- impact parameters: $\sigma(r\phi) \leq 5\ \mu m$
- jet energy resolution: $\frac{\sigma_E}{E} \sim 3 - 4\ \%$



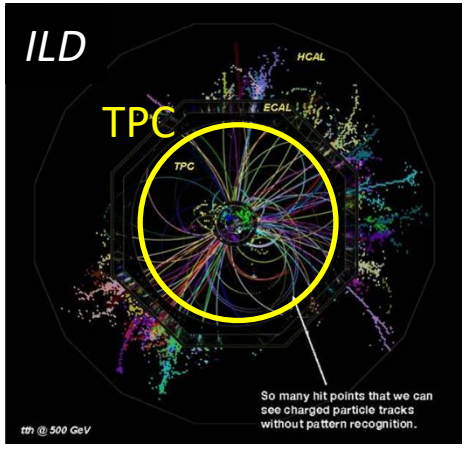
ILD Tracker (ILD-TPC)



- Time Projection Chamber (TPC) is considered to be used for the central tracker for the ILD.

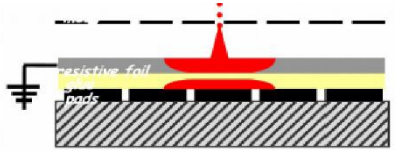
Gaseous TPC + MPGD readout

- Low material budget
- > 200 3D hit points → continuous tracking



Readout options

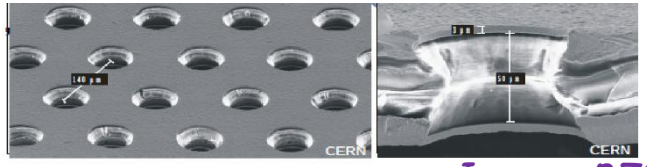
MicroMegas (MM)



using resistive anode to spread charge

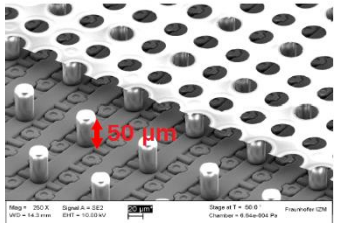
France

Gas Electron Multiplier (GEM)



Japan, DESY

pad readout



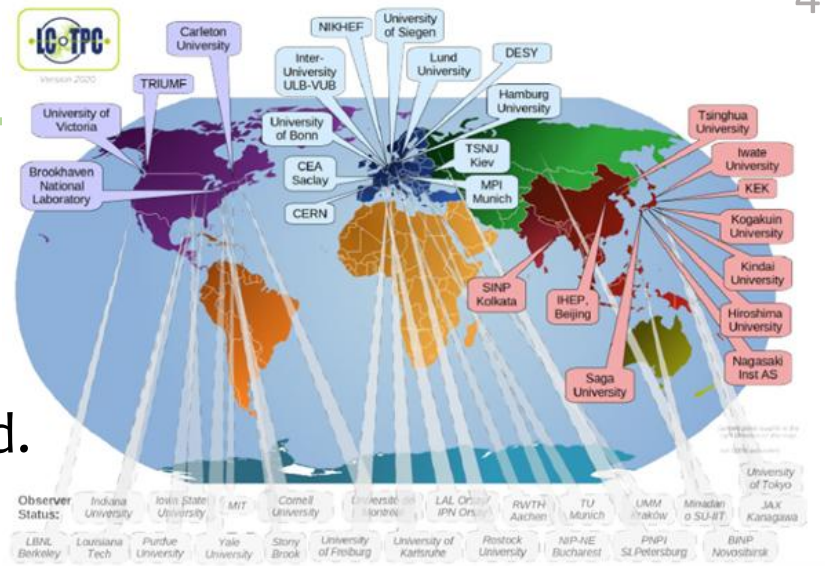
MM+Pixel readout have been studied within LCTPC collaboration.

Requirements for ILD-TPC (TDR in 3.5 T)

- $\delta(1/P_T) \leq 9 \times 10^{-5}$ GeV^{-1} (TPC only)
- $\sigma_{r\phi} \leq 100\ \mu m$ (overall)
- $\sigma_z \leq 0.4 - 1.4\ mm$ (for zero – full drift)
- 2-hit resolution in $r\phi \sim 2\ mm$
- 2-hit resolution in $rz \sim 6\ mm$
- dE/dx resolution ~ 5 %

R&D for ILD-TPC within TYL projects

- ILD-TPC has been developed by the LCTPC collaboration.
- We, France-Japan team, have made significant achievements within the series of the TYL projects.



D_RD_2 : The feasibility of a MPGD TPC for the LC was demonstrated.

- ✓ ILD detector baseline document was completed in March 2013.

D_RD_9: Main issues towards final design were pushed forward with Large Prototype of the TPC.

- ✓ Performed first test beam experiment of the large -aperture GEM-like gating device
- ✓ Studied key issues of the engineering design: CO2 cooling, track distortions, etc.

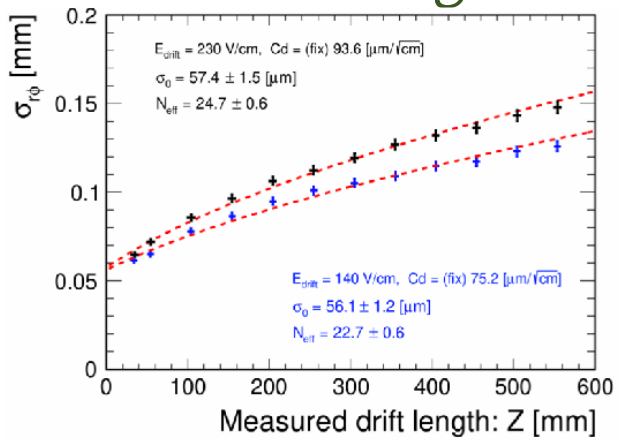
D_RD_18: Issues related to technology choice for the ILD TPC were addressed.

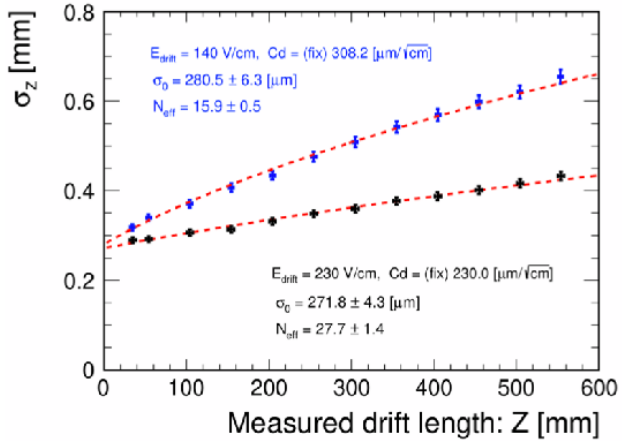
- ✓ Mitigation of ExB effects at design level (field distortions)
- ✓ Design optimization of the GEM-like gating device
- ✓ Position and dE/dx resolution of the Large Prototype
- ✓ GEM gain uniformity and minimization of the GEM discharge
- ✓ 2-phase CO2 cooling

Spatial resolution in $\sigma_{r\phi}$ and σ_z

Spatial resolutions were measured with LP test beam data and extrapolated to the ILD case.

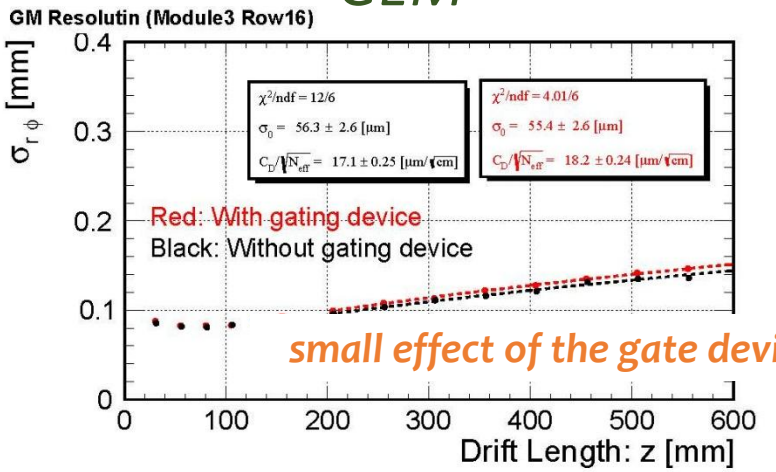
Micromegas

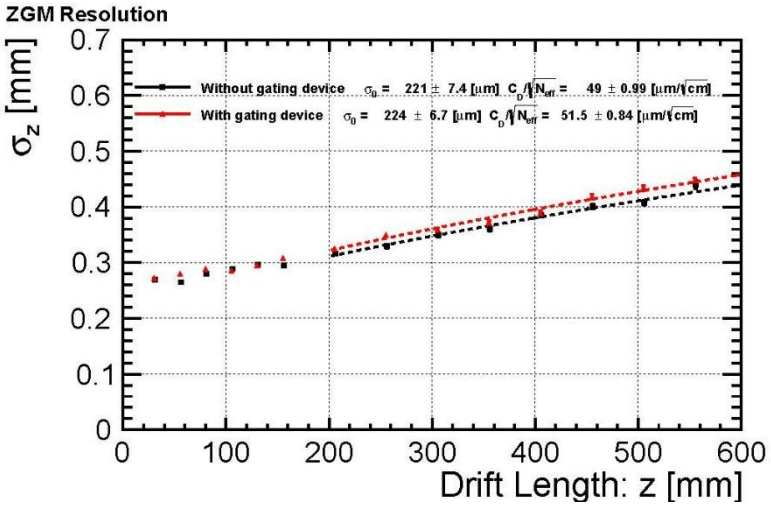


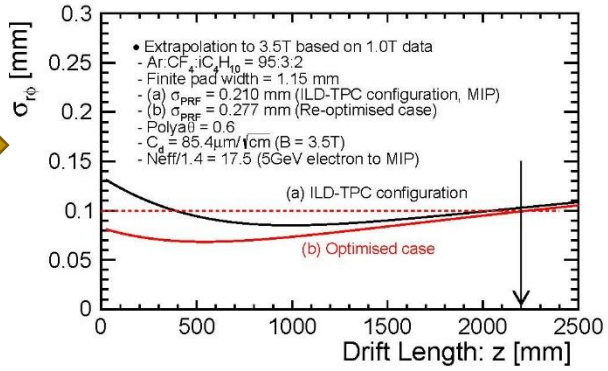


Extrapolation to a magnetic field of 3.5 T and 2.35 m drift length yields to a maximum **100 μm** over the full drift length

GEM







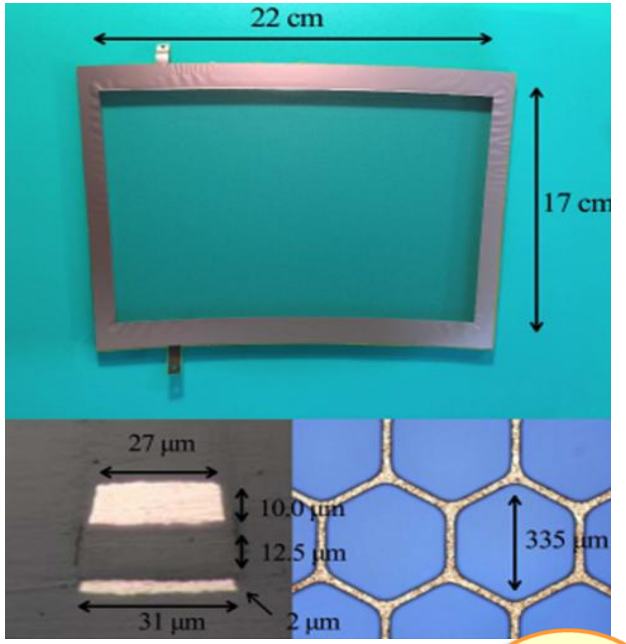
The target spatial resolution of 100 μm can be achieved over the full drift length of the ILD-TPC

σ_z at the full drift length is estimated to be **~800 μm** assuming that it is independent of the B field.

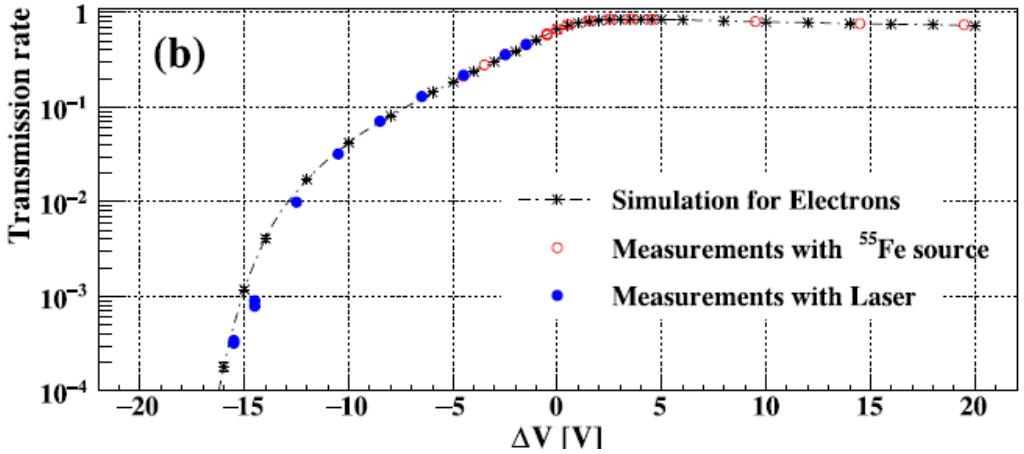
Both modules meet the ILD-TPC requirements.

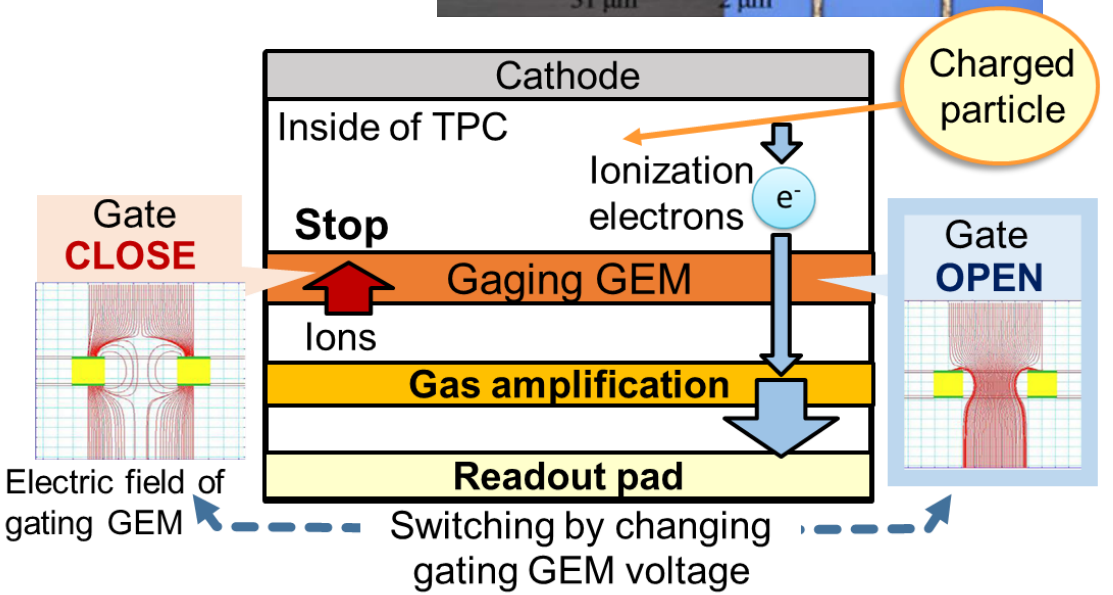
Gating GEM

- The gating foil is a thin electrode foil in which GEM-like structure having hexagonal holes with narrow rims.
- It has been manufactured using flexible printed circuit production technology by Fujikura Ltd in Japan.
- The optical aperture ratio is ~ 82 %.
- The gate is opened and closed by changing the polarity and height of the output pulse.



Transmission rate measured with GEM module

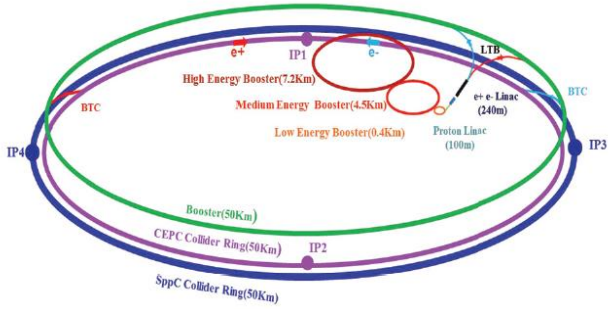


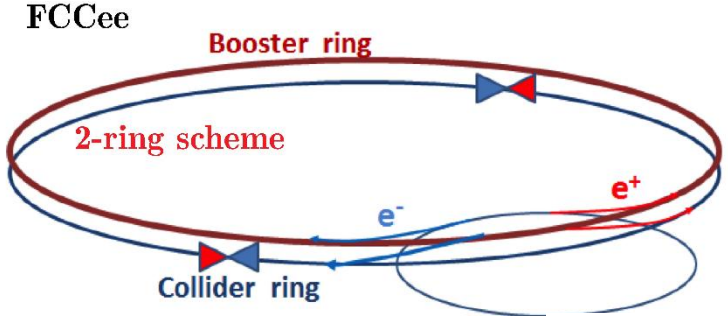


- ✓ Electron transmission rate : > 80%
- ✓ Electron blocking power : O(10^{-4}) → expect much better for ion.
- ✓ Consistent results have been obtained with MM.

Background of D_RD_28 project

- The ILC is the most mature project for the future Higgs factory.
  → We will continue to develop the ILD-TPC for coming engineering design phase.
  Recently, linear collider at CERN has been discussed in the framework of "LC Vision"
  https://agenda.linearcollider.org/event/10624/overview
- Circular colliders such as the Circular Electron Positron Collider (CEPC) and the Future Circular Collider (FCCee) have been proposed as the Higgs Factory (and for EW/top physics).





Luminosity (10^{34} cm^{-2}s^{-1})

	Z (91GeV)	H (240GeV)
ILC	0.2	1.4

- ✓ Energy range : 90-350 GeV
- ✓ Continuous bunch structure.
- ✓ Luminosity increases at low energy operation
  The condition at Z-pole is critical for the TPC performance.

	FCCee-Z	FCCee-H	CEPC-Z	CEPC-H
$\sqrt{s}$ (GeV)	90	240	90	240
L (10^{34}cm^{-2}s^{-1})	**200**	**7**	**191.7**	**8.3**
# bunches	16640	328	19918	415
Total RF voltage (GV)	0.1	2.0	0.12	2.2
Bunch intensity (10^{11})	1.7	1.8	1.4	1.4
Lumi lifetime (min)	68	38	80	20
SR Power (MW)	50	50	50	50

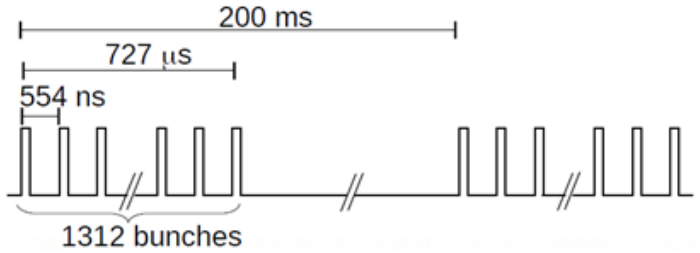
Goal of D_RD_28

- Circular colliders such as the Circular Electron Positron Collider (CEPC) and the Future Circular Collider (FCCee) have been proposed as the Higgs Factory.
- The operating conditions are absolutely different from ones for a linear collider.

  Bunch crossing

  ILC: certain time intervals

  CC : extremely high frequency



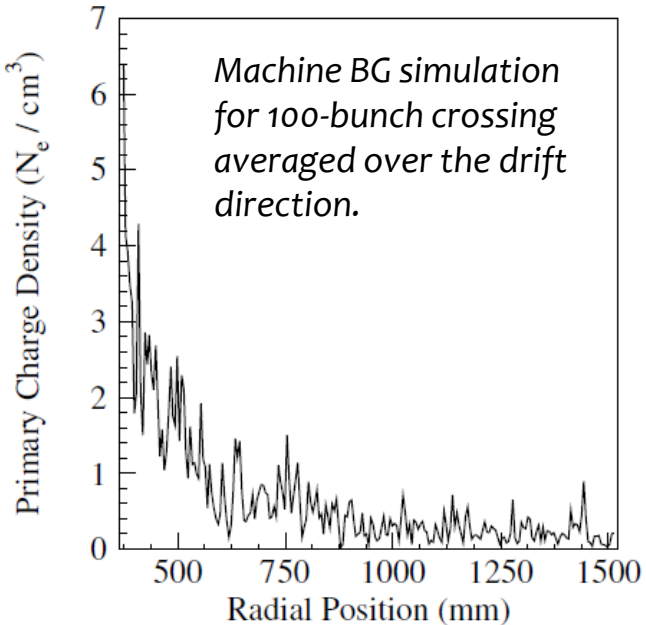
To explore the use of TPC designed for the ILC, in a circular collider

We have studied the issues …

- ✓ Impact for the degradation of spatial resolution caused by the field distortion.
- ✓ Modifying the design of readout module to suppress the IBF without the gating device.
- ✓ Development of efficient cooling system without power pulsing.

Field distortion by positive ions

- In high-rate running at the circular collider, distortion in the drift volume is a significant issue, which is caused by
  - a large amount of the primary ions from ionization of the tracks from both Z-pole events and the machine background
  - the backflowing ions generated in amplification.
    ← This issue is common to all the amplification devices.
    (gating device does not work with continuous beam)
- It is necessary to evaluate how much it affects the tracking performance and eventually the momentum resolution.



Note:

At the ILC, primary charge density is assumed to be 1-5 ions/cm³ resulting in the distortion of < 5um.

A. Vogel, 10.3204/DESY-THESIS-2008-036

Estimation of TPC distortion at Z-pole run

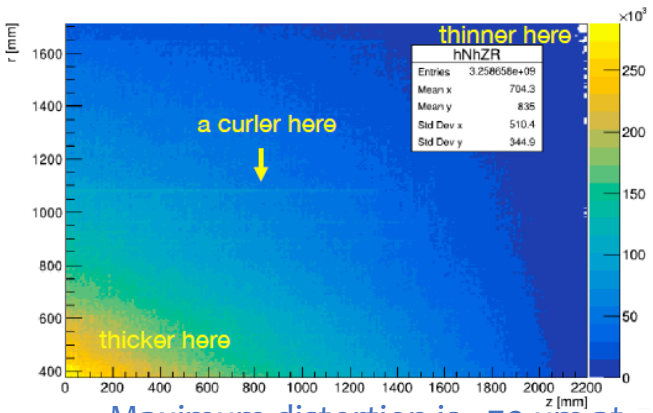
- Both French and Japanese teams have conducted the simulation study for the TPC operated at Z-pole experiment.
- In addition, correction of the track distortion using well known tracks (such as Z→μμ) is another subject to be considered, and it should be also investigated in the simulation study.

Study for Z-pole run with toy. by K. Fujii and D. Jeans from Japanese group.

Z-pole 50 Hz → 22k events in the 0.44 s time frame.

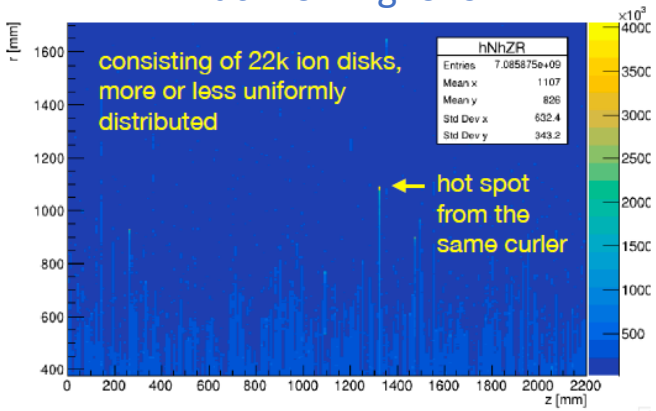
TPC size
r_{in} = 375 mm, r_{out} = 1720 mm, length = 2200 mm
B field 2 T
Ion drift velocity v_{ion}=5 m/s

Primary ions



Maximum distortion is ~70 um at the innermost region

Backflowing ions



Maximum distortion is ~160 um at the innermost region

- Further study is needed with full simulation in ILD/TPC condition.
- We may learn experience in ALICE experiment (50kHz, Pb-Pb collision) where the TPC is used for tracking.

  Evaluation of the track distortion and it's correction method.

Field distortion from beam background

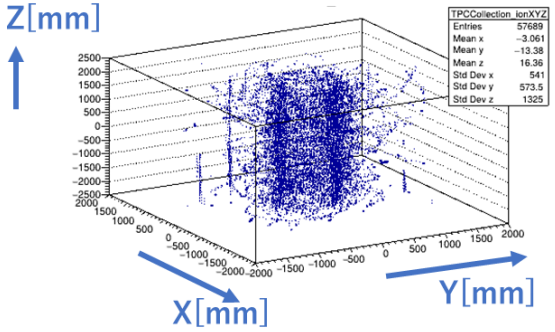
Simulation of 3D charge distribution is used for evaluating precise electric distortion.

- Space charge distribution is calculated. (Poison's equation)
- The movement of ionized electrons is traced. (Langevin equation)

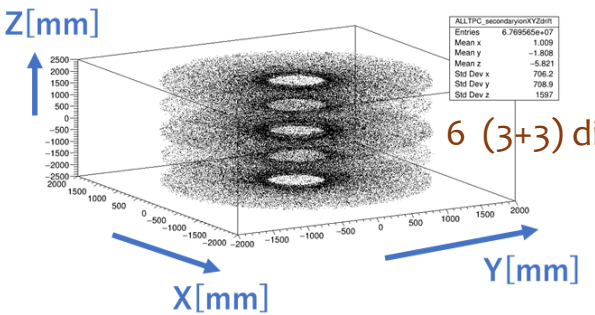
K. Watanabe
D. Jeans

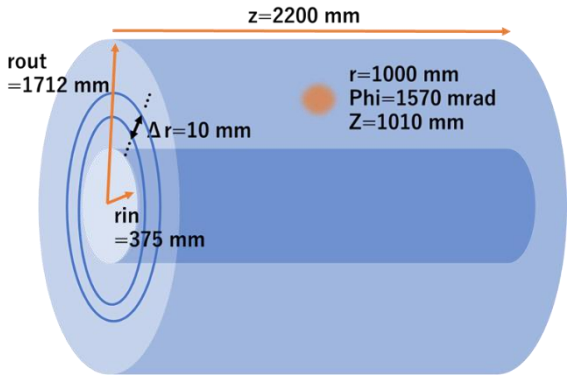
Primary and secondary ion distribution in 3 bunch crossing

Primary ion distribution



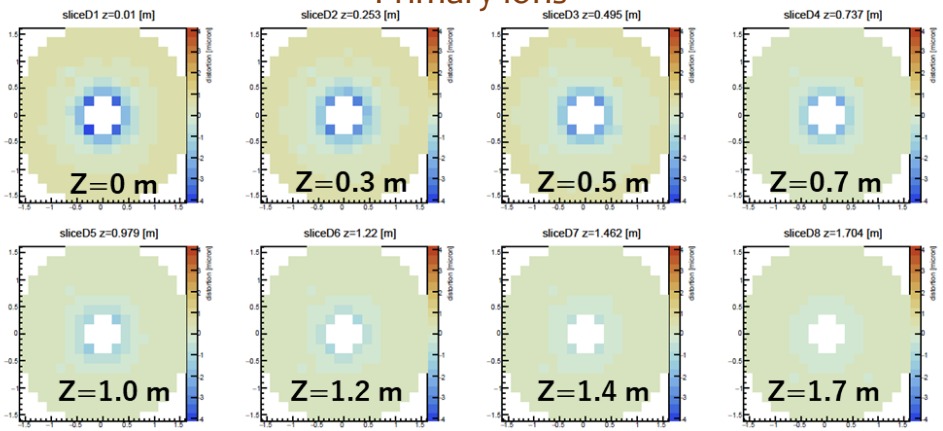
Secondary ion distribution (Ion disk) IBF=1



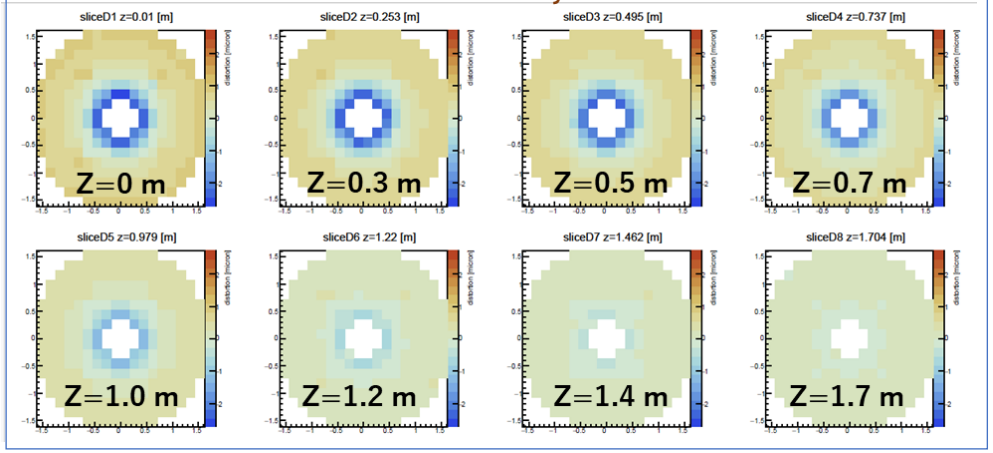


Electron arrival position deviation($\Delta r\phi$)

Primary ions



Secondary ions



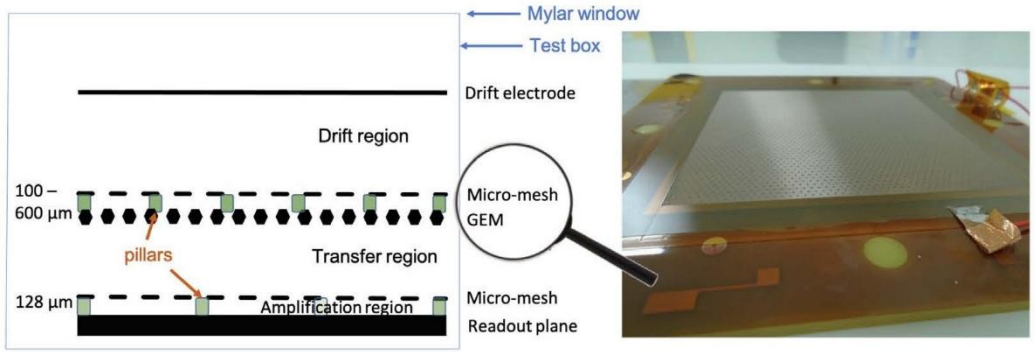
Now verifying the results and trying to understanding the systematics in the simulation

Suppress the IBF without gating

It is absolutely difficult to use an active gating system for the circular machine.

Possible ideas :

- Hybrid Micromegas + GEM Structure
  A combination of GEM and Micromegas, which allows for electron amplification while suppressing ion feedback.



Suppressed the IBF by a factor of 10 compared to single Micromegas configuration

NIMA 1051 (2023) 168134.

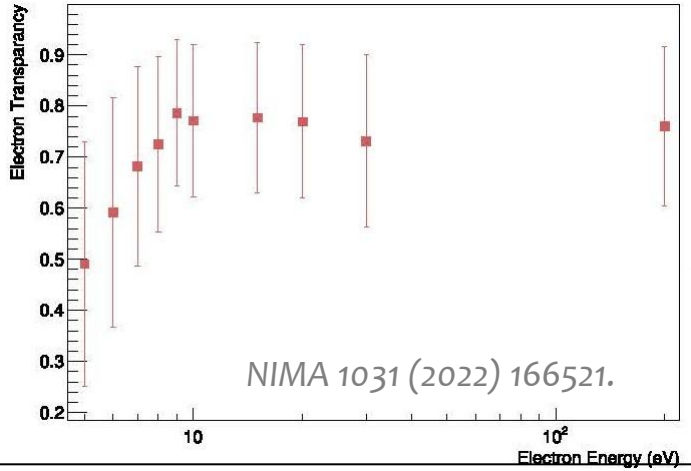
- Ion-trapping Coating / membrane
  Special surface treatments that restrict ion movement using specific materials.
- Optimizing gas
  Mixed gas to suppress the ion backflowing. (currently using T2K gas, Ar+CF4+iC4H10(95:3:2))

Invesitigating the static gating

Graphene might be useful.

- ✓ A single layer of SP2 hybridized carbon atoms arranged in honeycomb lattice with pore size ~ 0.06 nm.
- ✓ Transparent to electrons, but impermeable to ions.
- ✓ Can separate different gas volume in the same detector.
- ✓ Mechanically strong.

The transmission coefficient of 5 eV electrons to monolayer graphene is 40-50%



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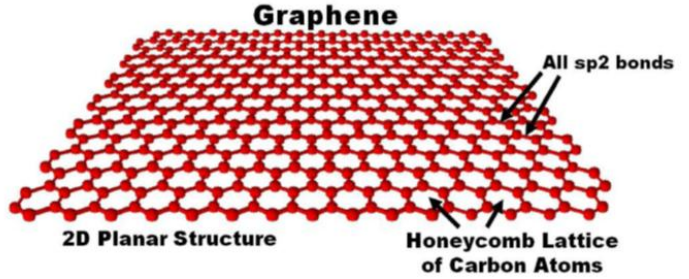
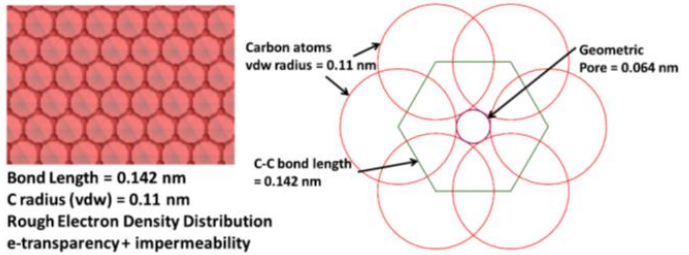




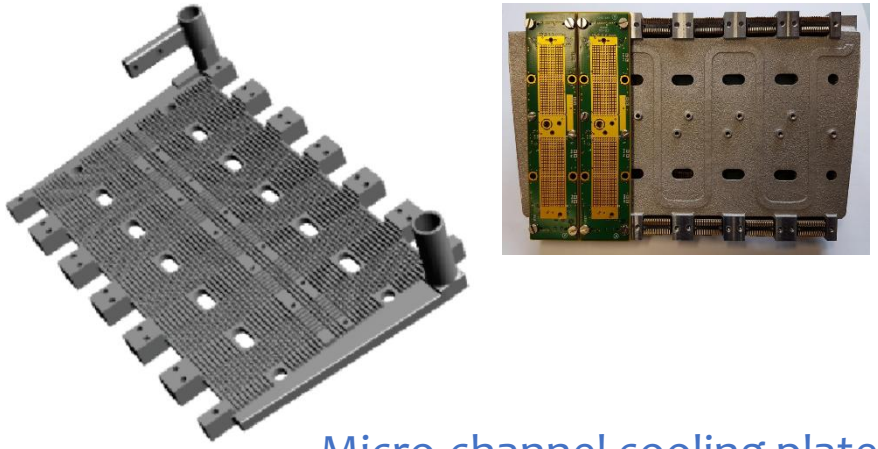
CARBON 62 (2013) 1.

- French team has examined Graphene coating technology using two MM bulk samples
- We have found that an intermediate conductive structure smaller holes, ideally ≤ 1μm, may be necessary to achieve high-quality graphene transfer.

  ⇨ will test Nano-Channel Plate (NCP)
  - NCP mounted on Micromegas
  - Coating graphene on NCP

Cooling system without power pulsing

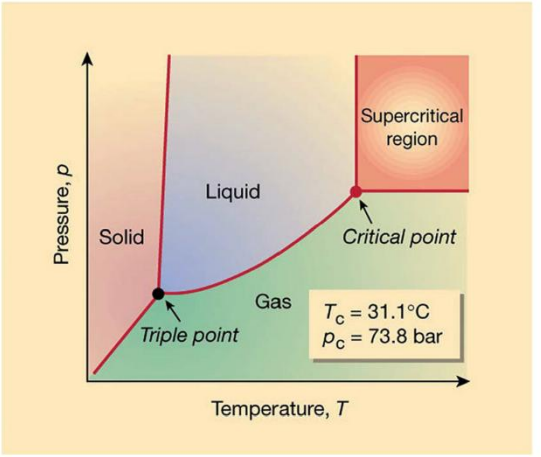
- Since power pulsing cannot be used in a circular machine, the requirement for reducing power consumption in the readout system becomes more critical.
- A new cooling system for the readout is also needed to be studied.
  - ✓ French team has tested the 3D-printed 2-Phase CO2 cooling plate in DESY using the KEK closed-loop compressor so far.
- Both teams will address the cooling issue continuing to develop the studies.
- We have been considering the use of supercritical CO2 cooling.



Micro-channel cooling plate using 3D printing technology

Supercritical CO2 cooling

- ✓ Operating Pressure : > 7.38 MPa.
- ✓ Fluid state : Single-phase, uniform flow.
- ✓ Stable and easy to control compared to 2-phase CO2 cooling.
- ✓ Simple and compact equipment design.



Applied Thermal Engineering 125 (2017) 799

Member and Fundings

FJPPL (TYL) application 2025

Fiscal year April 1st 2025 – March 31th 2026

ID:	Title: Toward the design of the TPC at future colliders					
	French Group			Japanese Group		
	name (Family name, First name)	title	lab.	name (Family name, First name)	title	lab.
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	GIOMATARIS, Ioannis	Dr.	IRFU/CEA	JEANS, Daniel	Dr.	IPNS/KEK
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	TUCHMING, Boris	Dr.	IRFU/CEA	KATO, Yukihiro	Dr.	Kinki Univ.
				WATANABE, Takashi	Dr.	Kogakuin Univ.
				WATANABE, Kanako	Ms.	Iwate Univ.
				OIKAWA, Kouhei	Mr.	Iwate Univ.
				SUGAWARA, Ryuki	Mr.	Iwate Univ.
				NAKAJIMA, Jurina	Ms.	Sokendai/KEK

Funding Request from France

Description	€/unit	nb of units	total (€)	requested to
Visit to Japan	150/day	10 days	1,500	IRFU/CEA
Travel	1000	1 travel	1,000	IRFU/CEA
Total			2,500	

Funding Request from Japan

Description	k¥/Unit	nb of units	total (k¥)	requested to
Visit to France	20/day	20 days	400	KEK
Travel	300	2 travels	600	KEK
Total			1,000	

Additional Funding from France			Additional Funding from Japan		
provided by/requested to[4]	Type	€	provided by/requested to	Type	k¥
IRFU/CEA	consumable	10,000	Iwate	consumable	300
Total		10,000	Total		300

- ✓ 1 or 2 French team members will visit Iwate for discussing the simulation studies and the preparation of the equipment.
- ✓ Two Saclay visits by 2 Japanese members are planned to join the test for measuring electron transmission and discuss the simulation studies as well.
- ✓ A part of the consumable supplies and travel expenses for this research will be covered from the respective resources.

Summary

- A series of French-Japan joint R&D (*D_RD_2*, *D_RD_9*, *D_RD_18*) has successfully achieved many significant results.
  R&D of GEM-like gating device and cooling system.
  Understanding the performance of MM/GEM module using test beam data.
- In 2023, D_RD_28 was initiated to explore the use of the TPC in the Higgs Factory, which includes a circular collider.
- We proceed with R&D on the following items based on the results we have achieved so far.
  - Evaluating field distortion by ions resulting in track distortion
    → see the distortion with more precise simulation
  - Developing correction method for track distortions
  - Modifying the design of the readout module to suppress the IBF
    → test static gating device with graphene/NCP
  - Improving cooling system
    → consider S-CO2 cooling