μRWELL Detector R&D for EIC and Others

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KU SNU Mini-workshop @ Kyushu University

Contents

- Introduction to μRWELL
  - Working principle
  - Low and high rate μRWELL
  - Production process

- The ePIC experiment
  - Physics goal
  - Contribution plan toward GEM + μRWELL ECT

- DAMSA, LHCb?, Future collider?

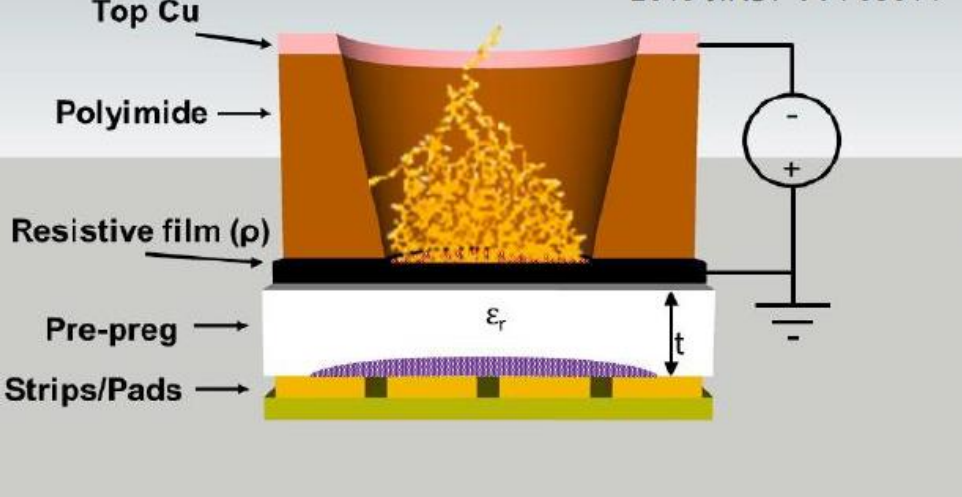
- Current R&D status

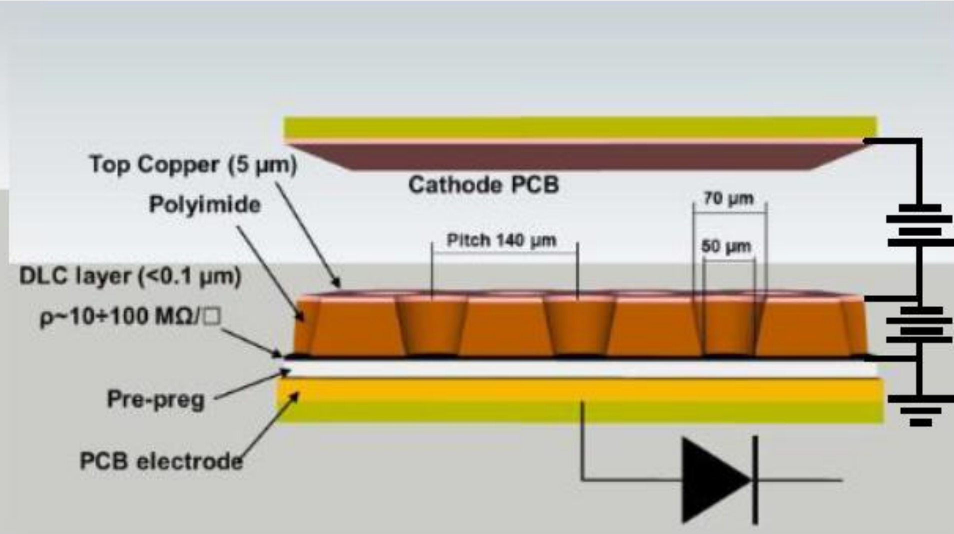
1. Introduction to μRWELL

- Micro Resistive WELL, a resistive variant of GEM
  - Resistive layer, DLC, prevents streamer from evolving discharge
  - No spatial separation between the avalanche and induction region is required

  → Self-rigidity ⇒ Simpler detector structure ⇒ Cost effective

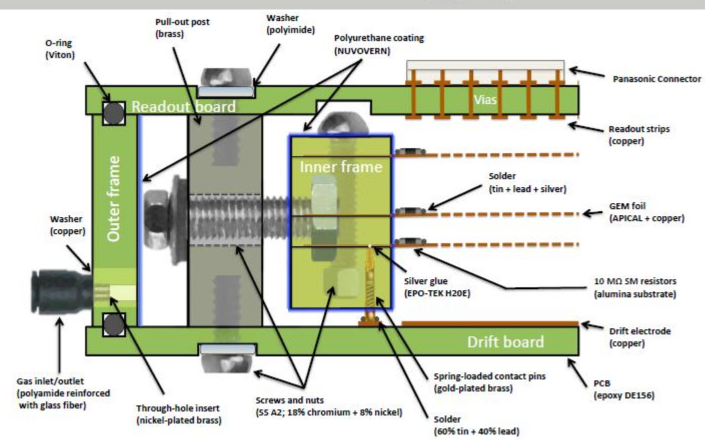
2019 *JINST* **14** P05014





- Position resolution ~ $70\mu m$

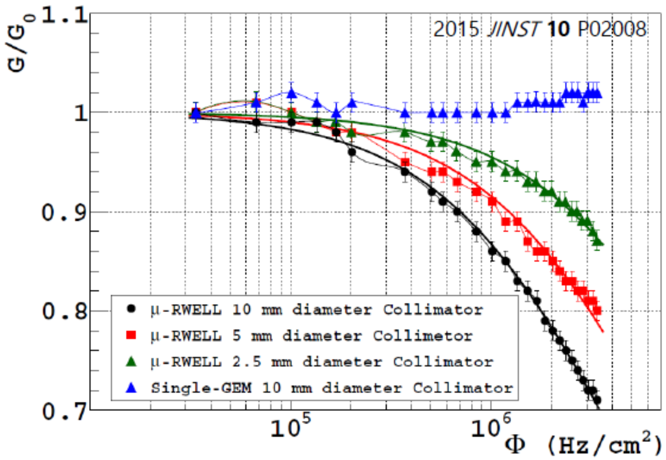
  Time resolution ~ 5-7 ns

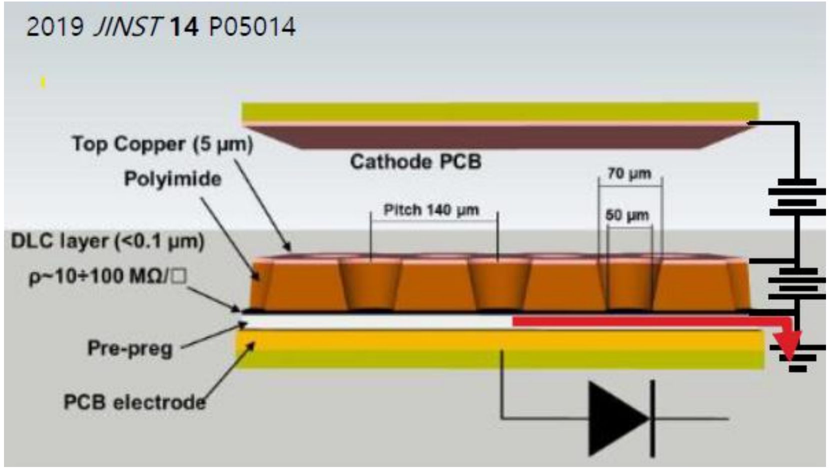


1. Introduction to μRWELL

- High rate μRWELL

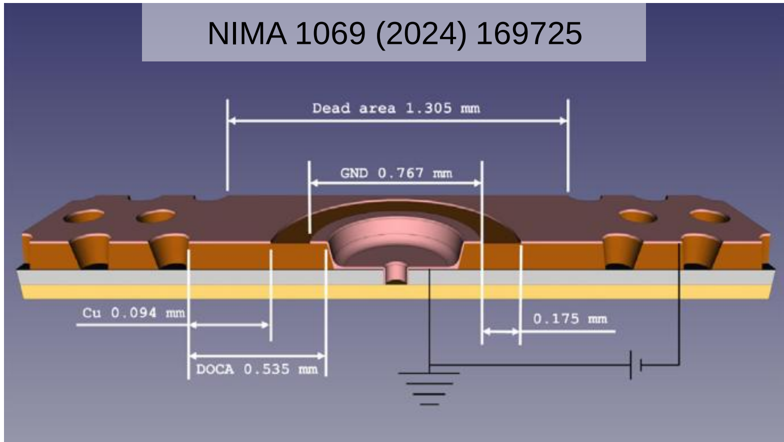
  - Rate capability of μRWELL is limited due to voltage drop occurring charge drain





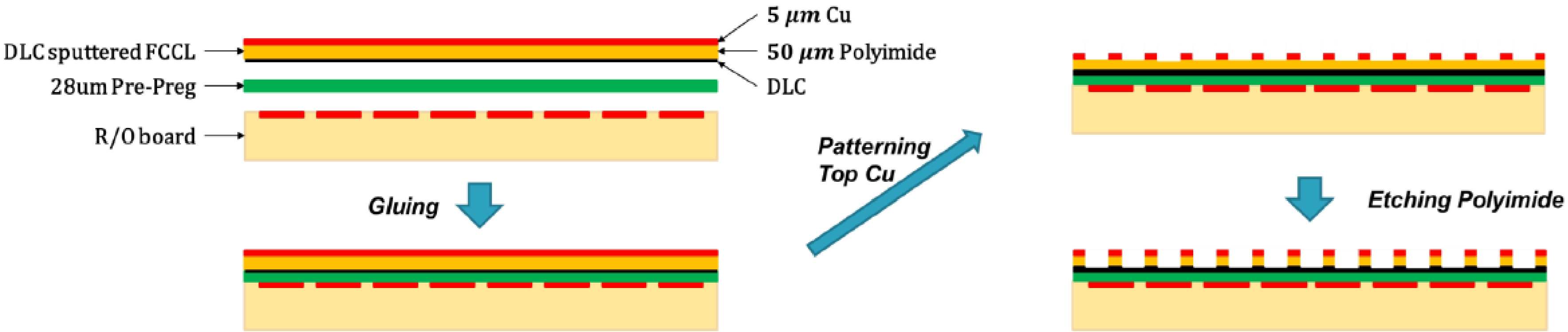
  - The rate capability can be restored through additional grounds

- ePIC, DAMSA → Low rate μRWELL
  LHCb, CLAS12 → High rate μRWELL

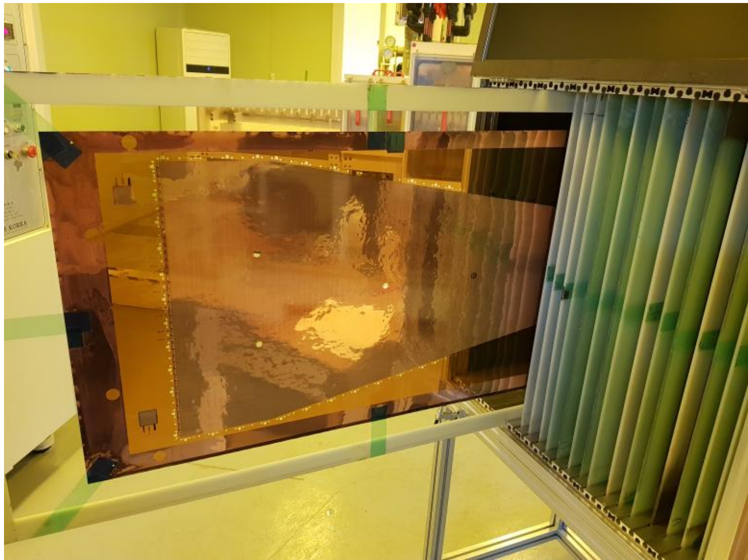


1. Introduction to μRWELL

- GEM and μRWELL share production process



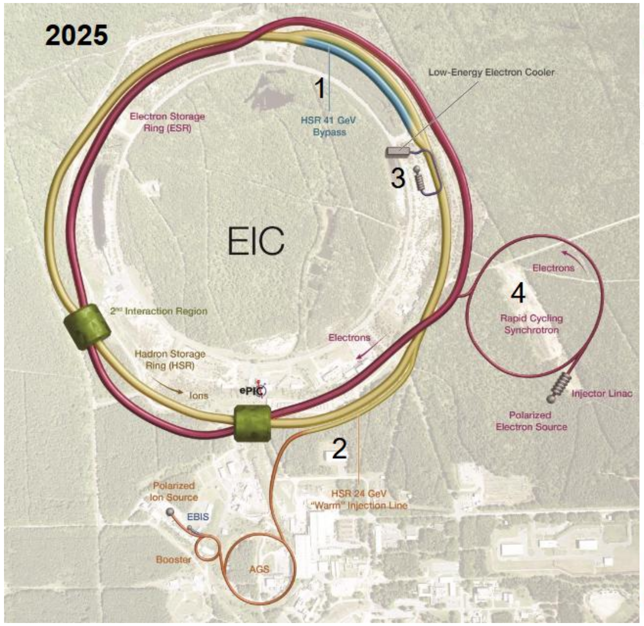
- Gluing
- Cu etching
- PI etching
- Cleaning to give HV stability

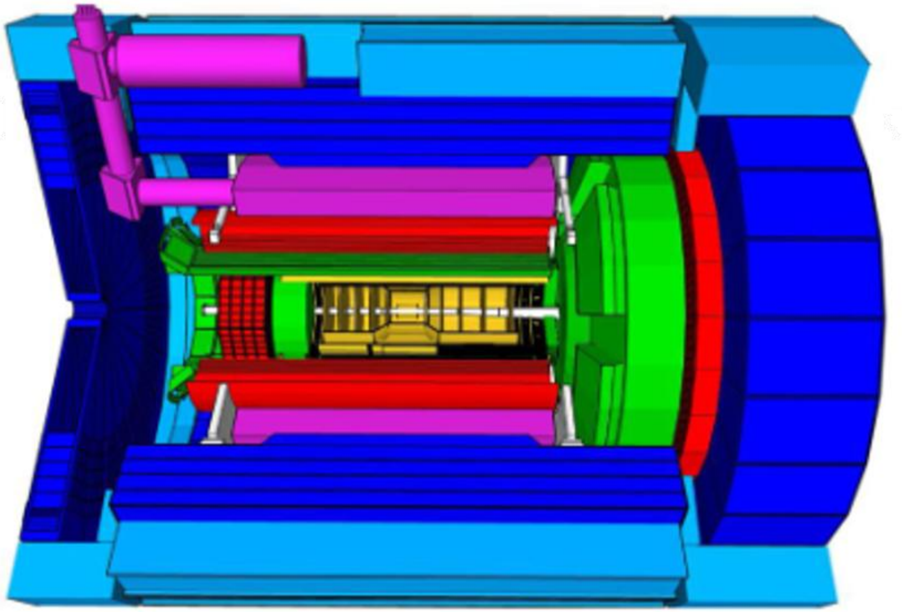


- DLC-FCCL
  - Sputtering
  - Will be done in CERN MPT
  - Looking for domestic companies as well

2. ePIC Experiment

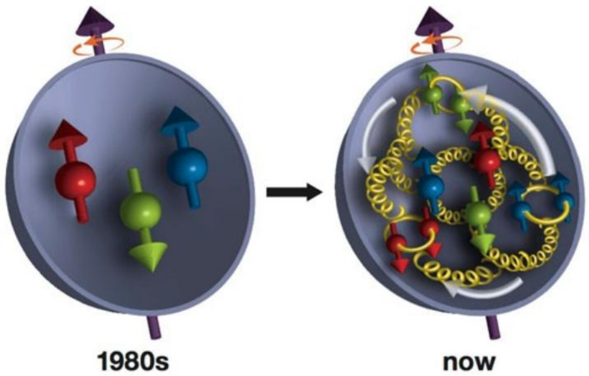
- BNL is building a new polarized electron ring around RHIC

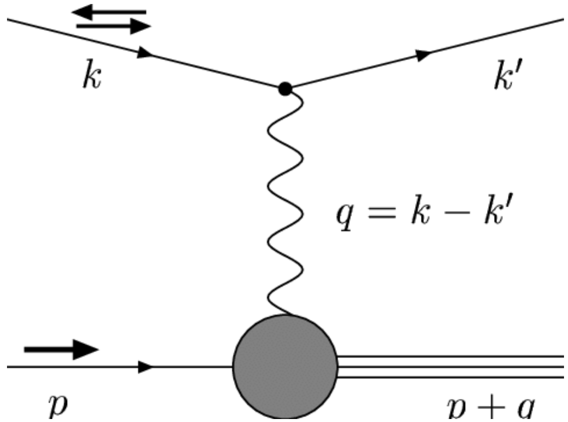




- To understand how spin and mass of proton emerge from its constituents
- To understand proton structure in higher dimension i.e. TMD and GPD
- To understand pion and kaon(?) structure
- Gluon saturation exists or not
- …

2. ePIC Experiment – Spin





- EMC experiment (Nuclear Physics B 328, 1 (1989)) revealed spin carried by quarks ($\Delta\Sigma$) was surprisingly small < 0.12

  - Series of polarized DIS and SIDIS

  → Proton Spin Crisis!

  puzzling result was termed the "proton spin crisis".[4] The problem is considered one of the important unsolved problems in physics.[5]

- Jaffe-Monohar sum rule

  - $S^p = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta G + L_z^g$

  → We should not ignore gluon and angular momentum contribution!

2. ePIC Experiment – Spin

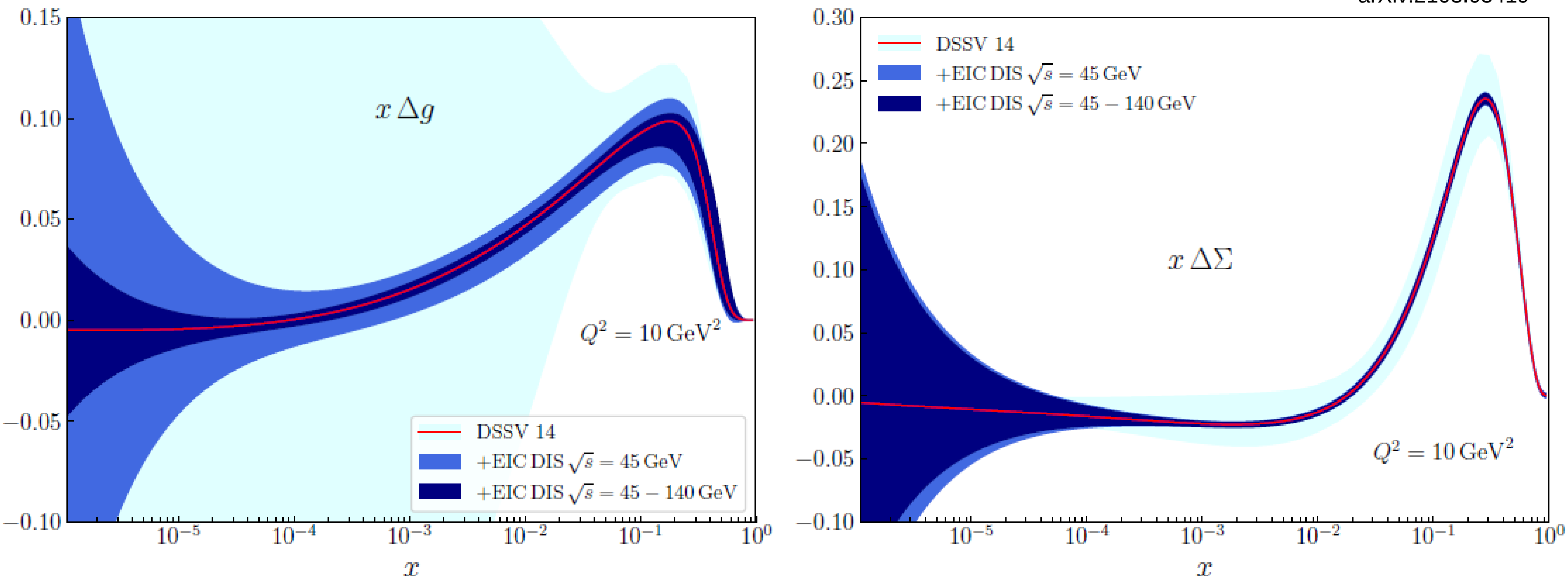
- Inclusive A_{LL}

$$\frac{1}{2}\left[\frac{d^2\sigma^{\leftrightarrows}}{dxdQ^2} - \frac{d^2\sigma^{\rightrightarrows}}{dxdQ^2}\right] \cong \frac{4\pi\alpha^2}{Q^4} y(2-y) g_1(x,Q^2)$$

, where $g_1(x,Q^2) = \frac{1}{2}\sum e_q^2[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)]$.

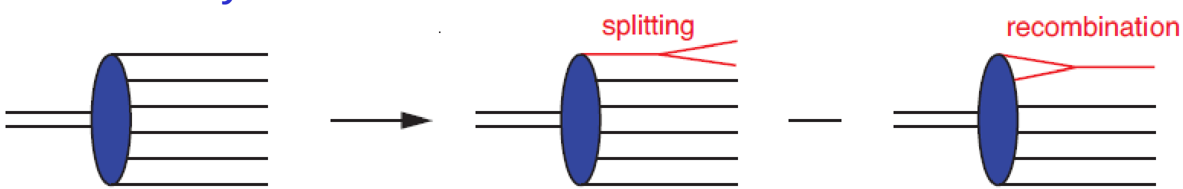
- Δg is encoded in scale violation of g_1

arXiv:2103.05419



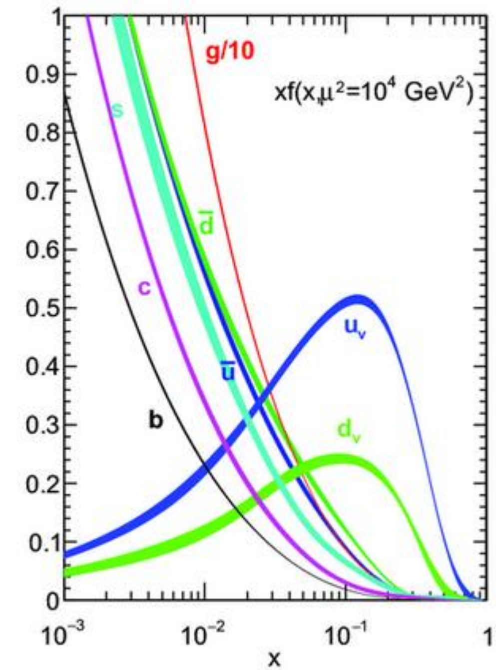
2. ePIC Experiment – Gluon Saturation

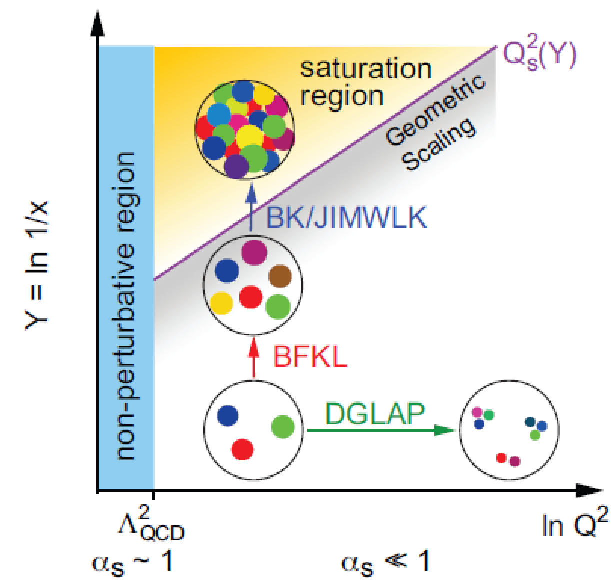
- Will gluon density continue to increase in low enough x region?
  - Probably not



- BK evolution
  - $\frac{\partial N(x,r_T)}{\partial \ln(^1/_x)} = \alpha_s K_{BFKL} \otimes N(x,r_T) - \alpha_s [N(x,r_T)]^2$

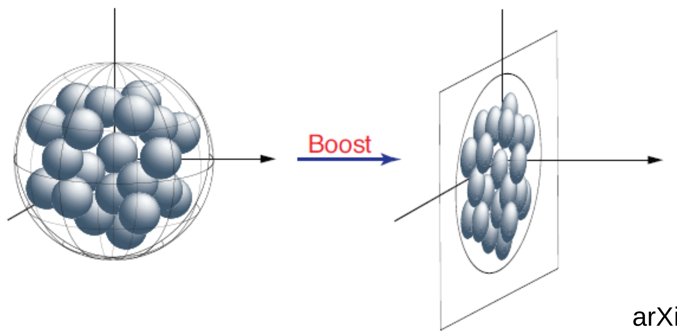
- HERA implied the existence of CGC



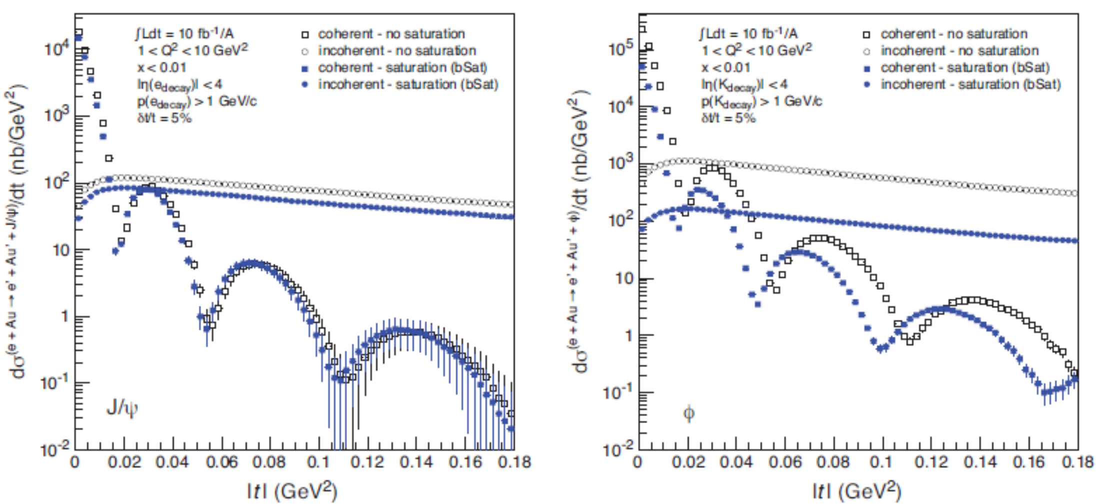


2. ePIC Experiment – Gluon Saturation

- Nuclear “Oomph” factor
  - To access CGC, we need higher beam energy or heavy ion collision
  - Gluon fields are overlapped by Lorentz contraction and higher density gluon field can be probed wo/ increasing beam energy
  - $Q_s^2(x) \sim A^{1/3}(\frac{1}{x})^{\lambda}$ where $\lambda = 0.2 - 0.3$



arXiv:1212.1701



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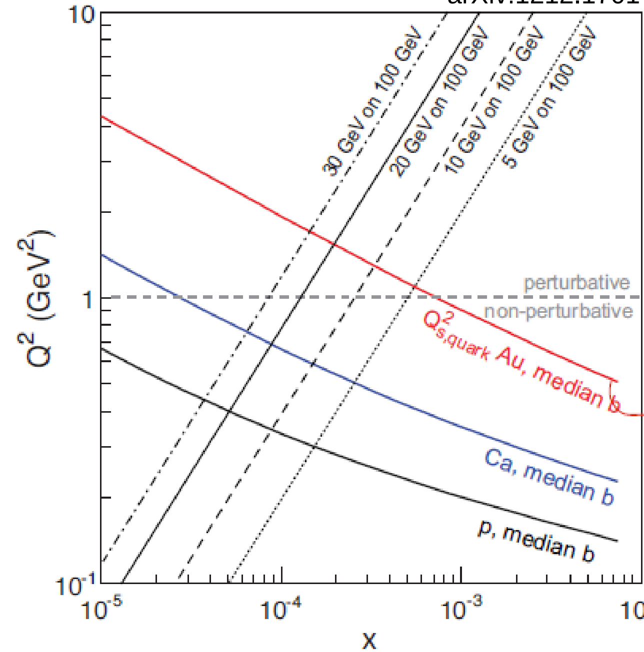
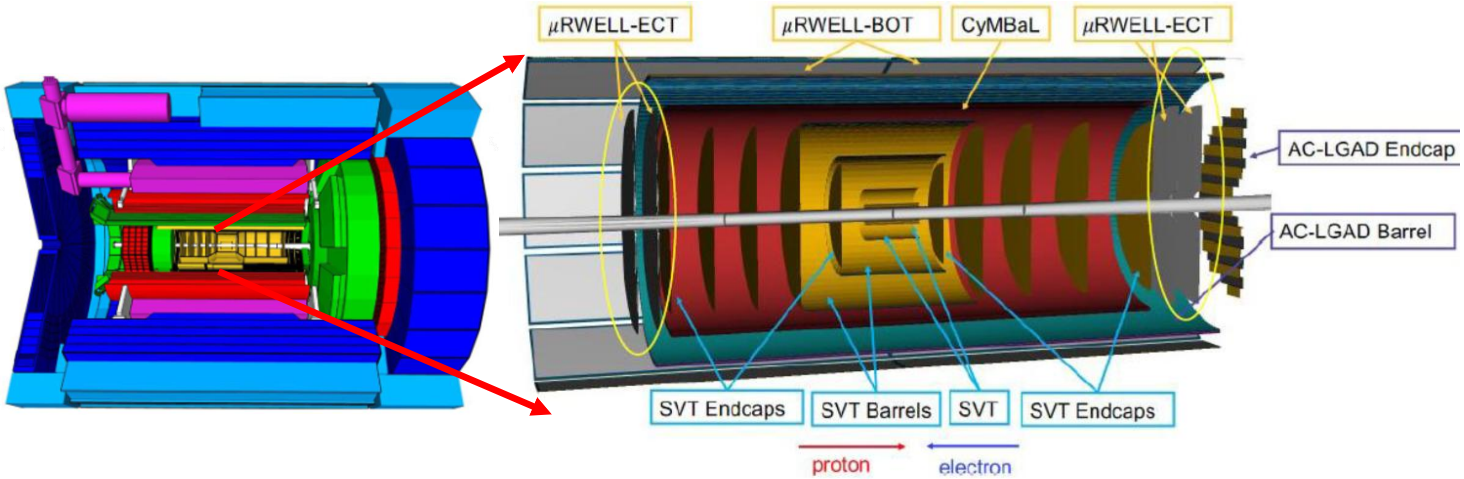
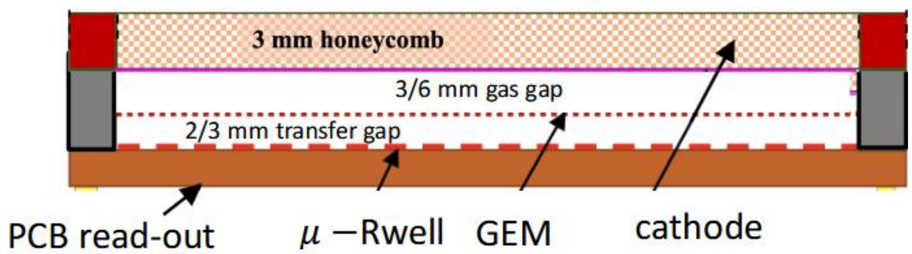
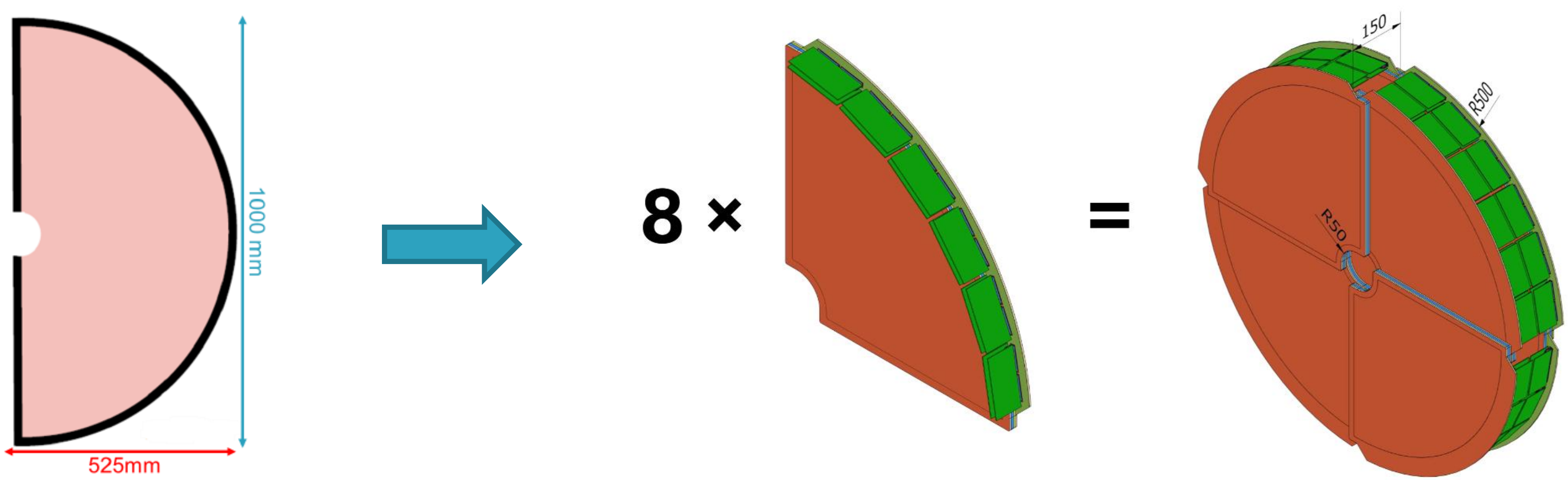


2. ePIC Experiment – ECT







2. ePIC Experiment – ECT

- “Main risk is related to CERN being the unique producer of μRWELL detector layer”

 → Korea can mitigate this risk

- In-kind contribution of GEM & μRWELL for the ECT project

 - 2.2 M USD is very likely
 - PI: Prof. Seonho Choi
 - Starter of the Korean μRWELL R&D

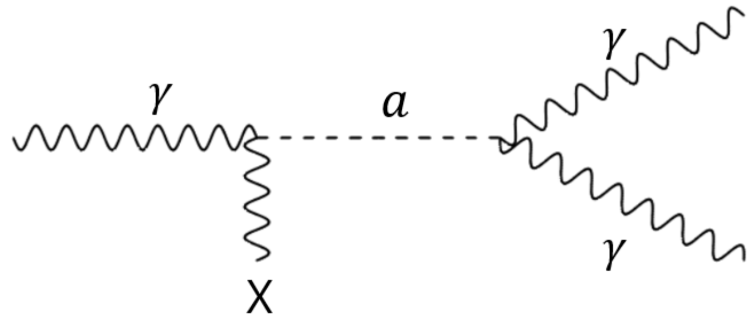
MPGD Timeline			DURATION (years)
START DATE	END DATE	DESCRIPTION	
3/1/24	12/31/24	Detectors Overall Design	<1
1/1/25	12/31/26	Pre - Production	2
1/1/27	31/12/29	Production & QA	3
1/1/30	6/1/30	Commissioning & Installation	0.5

3. DAMSA Experiment

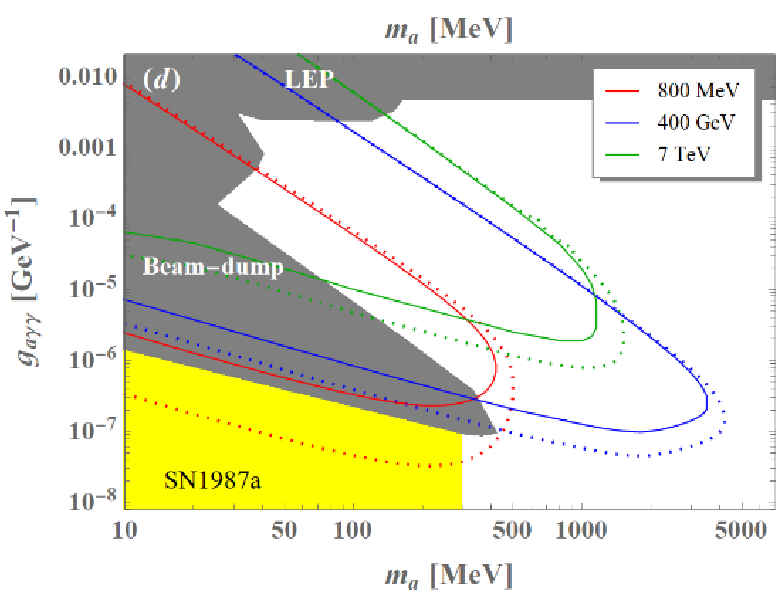
• Search for $a \to \gamma\gamma$ and $A' \to e^+e^-$ using the beam dump of Fermi Lab. PIP 2

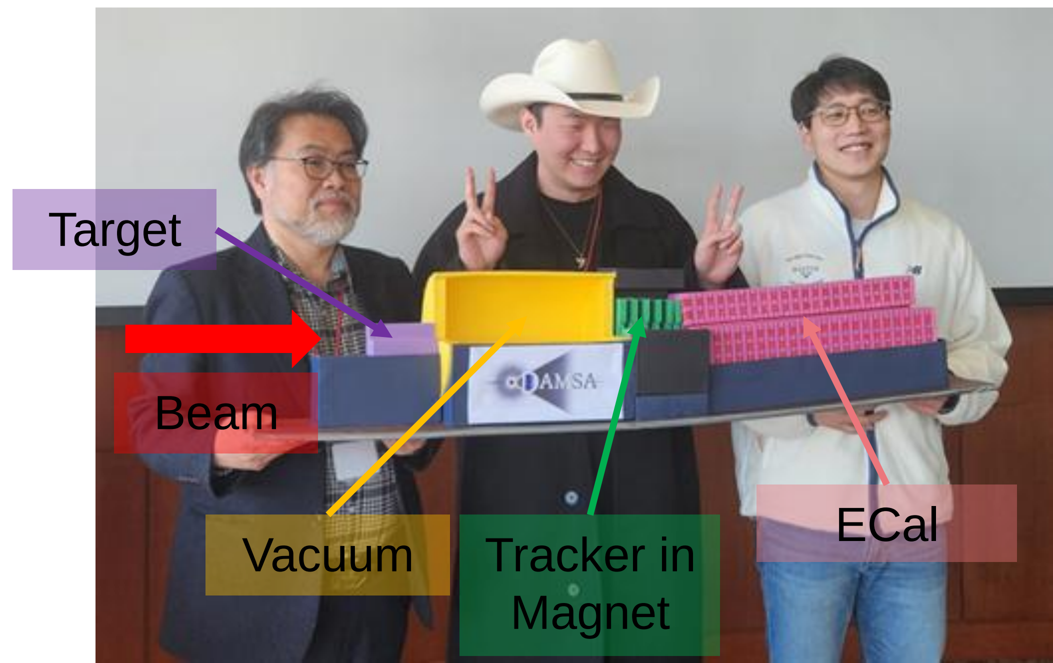
- PRD 107 L031901 2023

- μRWELL tracker with XY 128*128 capacitive sharing RO



• The key of the DAMSA experiment is to place the detector directly behind the beam dump





4. LHCb?

- LHCb will replace MWPC to (GEM +) high rate μRWELL

 - Due to limited rate capability of MWPC

- 574 chambers to cover $40\ m^2$

 - Producing all necessary μRWELL @ CERN MPT alone may not be possible

 - If LHCb chooses GRWELL as it seems to be leaning toward recently, it will be nearly impossible to complete production solely through CERN MPT


Journal of Instrumentation

SISSA

OPEN ACCESS

The μ-RWELL layouts for high particle rate

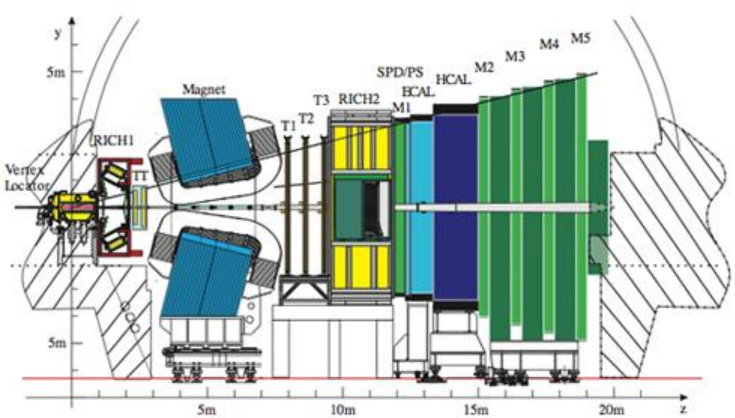
To cite this article: G. Bencivenni *et al* 2019 *JINST* 14 P05014

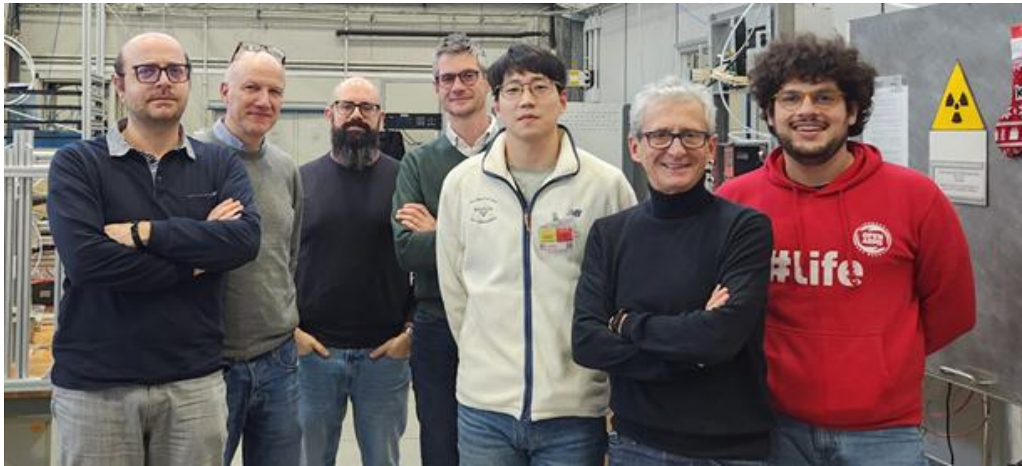
View the article online for updates and enhancements.

Recent citations

- Development of Micromegas detectors with resistive anode pads
  M. Chefdeville *et al*
- Position-Sensitive Thermal and Cold Neutron Detectors with $$_{2}^{3}{\text{He}}$$ Gas Converter (Review)
  A. P. Kashchuk and O. V. Levitskaya
- The Well (micro-Well) Electron Multiplier with the DLC anode—a key element of the robust and fast 2D-position sensitive MPGD
  A. Kashchuk *et al*

- LHCb has proposed a collaboration



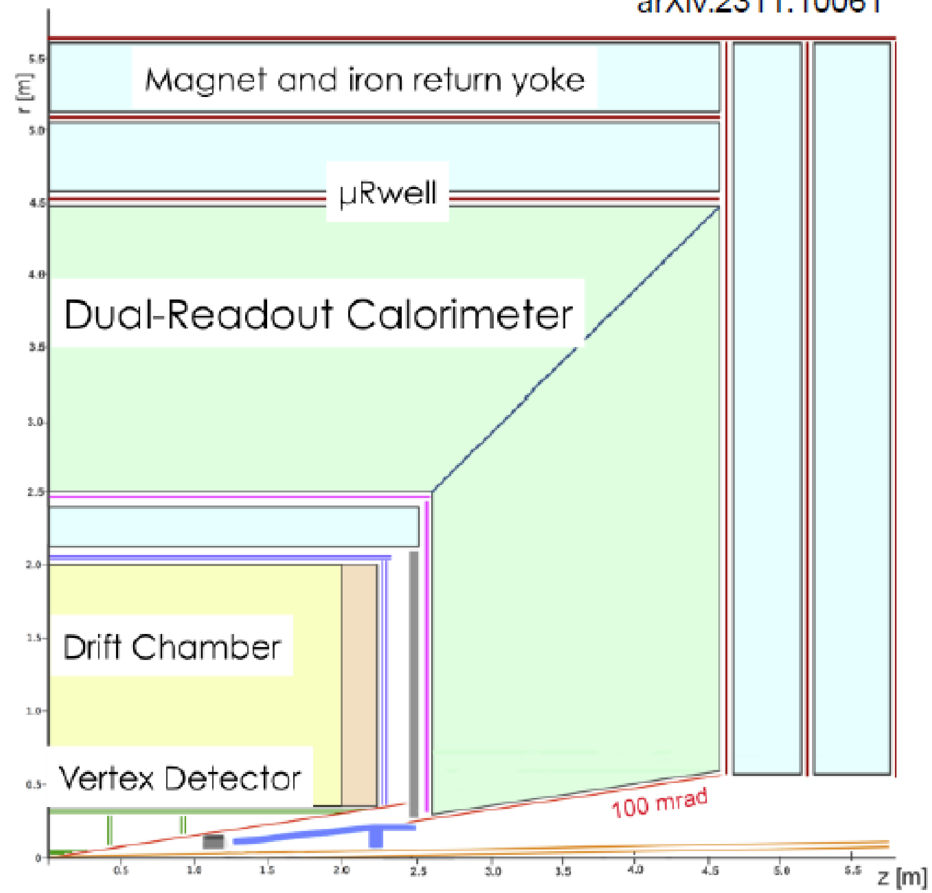


5. Future Collider?

• Not sure which collider will be realized. However, it's clear that μRWELL will be crucial in new experiment

- IDEA plan requires so many $50 \times 50cm^2$ μRWELL for pre-shower (520) and muon station (1520)

arXiv:2311.10061



6. Current Status

- Procurement for μRWELL production R&D

 - DLC-FCCL

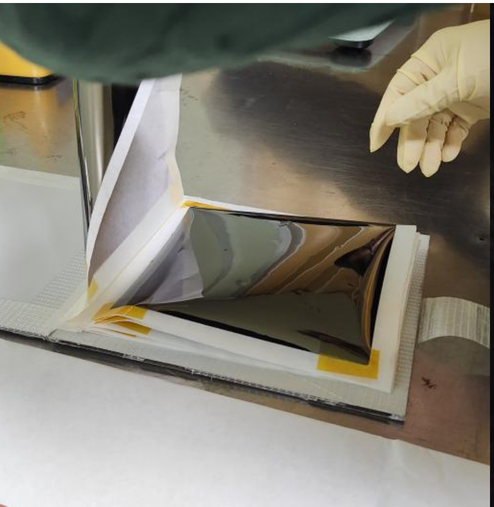
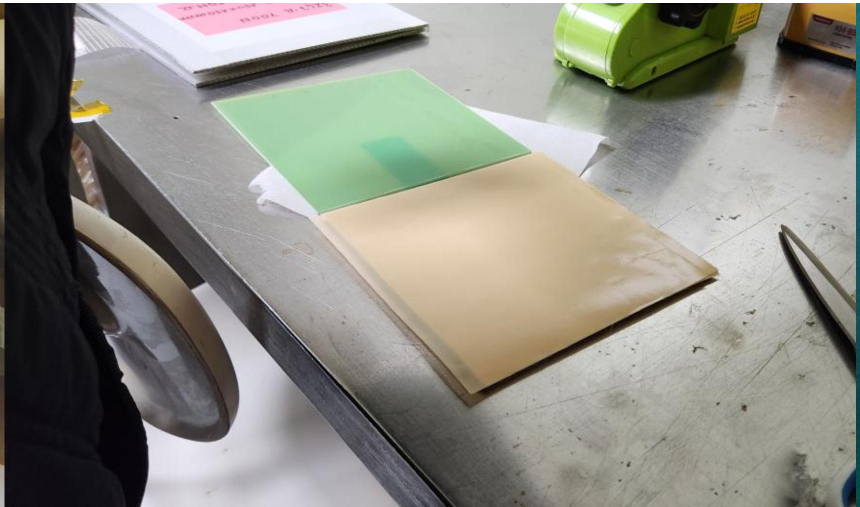
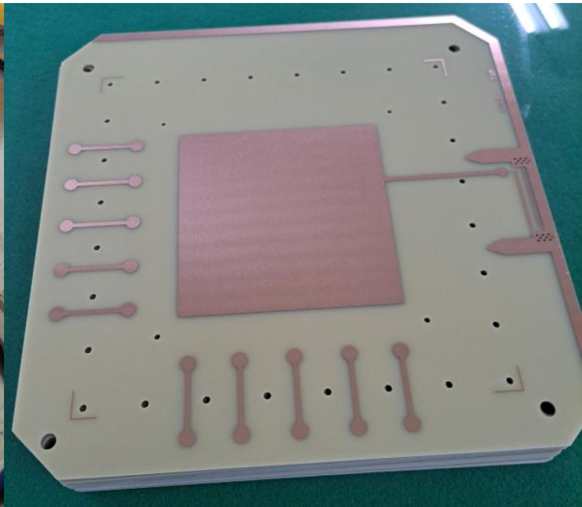
   1 XY 128*128 Ch. RO PCB

   Gas frame, o-ring, ETC were delivered from CERN MPT

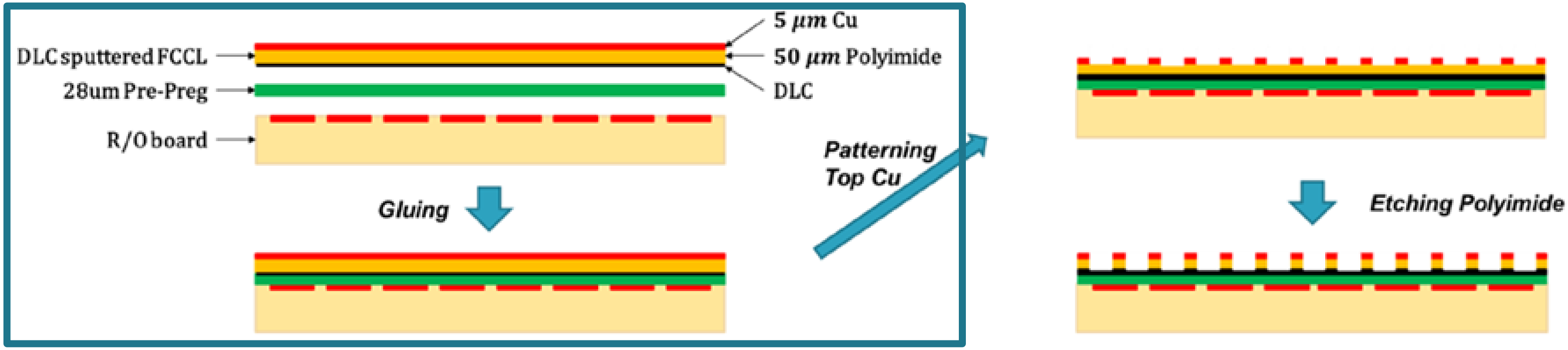
 - 1 Ch. RO PCBs for test produced in Korea

- DAQ for the R&D and DAMSA experiment

 - Purchasing SRS system with VMM3a hybrid card

6. Current Status – Gluing



- Pressing DLC FCCL, pre-preg and RO PCB at high temperature in a vacuum chamber

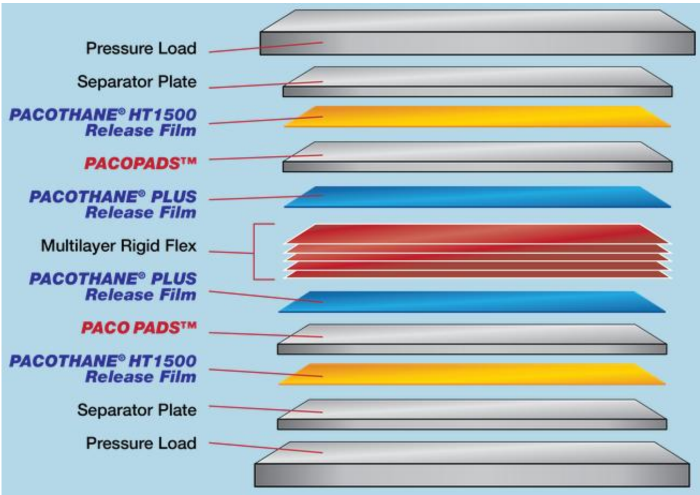
 - Common technique in PCB maker

 - Use only 7-10 bar, half of common PCB process, not to damage Cu layer

 - At such low pressure, flatness control is crucial

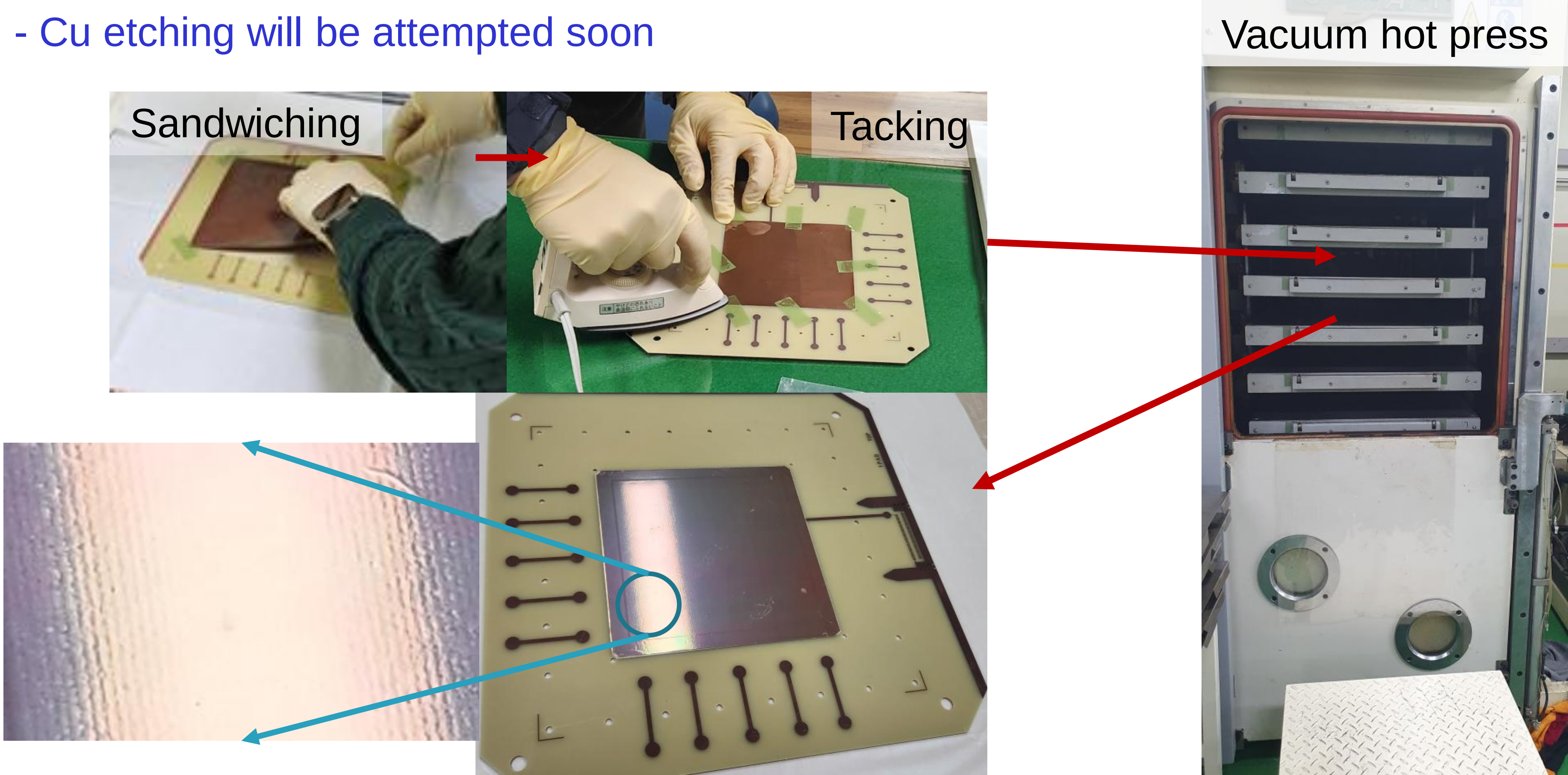
 Pressure regularization also is crucial

 ⇒ Know-how in “stack” construction is important



6. Current Status – Gluing

- The first press work attempted, evaluating results
  - Not perfect but promising result is obtained
  - Flatness seems fine, but pressure regulation was insufficient
    Glass wool pattern from Pre-Preg visible on Cu layer
    Will retry with a different pressure regulation pad
  - Cu etching will be attempted soon



Summary

- μRWELL, resistive variant of GEM, is very promising technology

 - Free from discharge & simpler structure

 - Using expertise we've accumulated during the CMS GEM project, SNU can produce μRWELL

- The ECT of the ePIC experiment is the first contribution site

 - Many fundamental nuclear physics goals will be covered by the ePIC

 - The budget for the in-kind contribution is secured

- The DAMSA experiment is the second

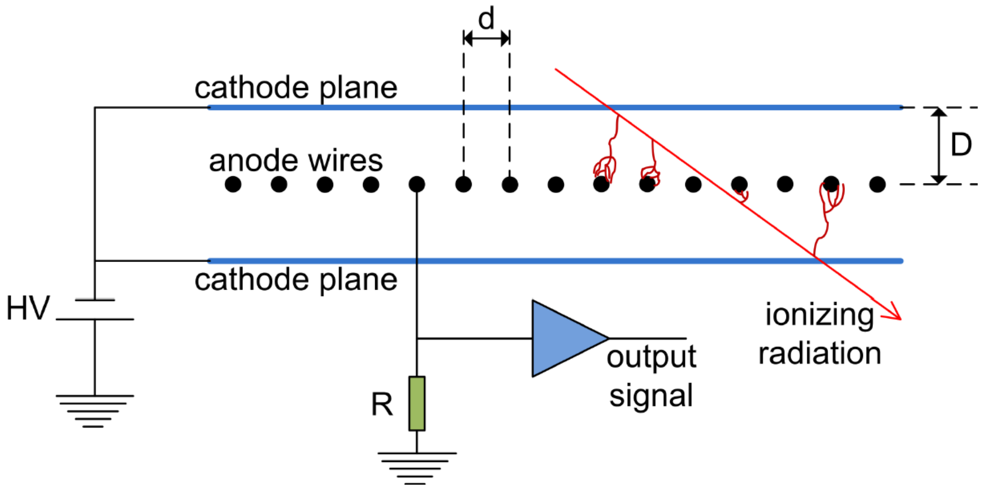
 - Hope to contribute to LHCb and future collider experiments

- Attempted the first μRWELL production step: glue process

 - Not perfect but promising result is obtained

Back Up

1. Introduction to μRWELL



- Working principle

  Ionization → Drift → Multiplication → Signal induction → Charge drain

- Limitation of MWPC

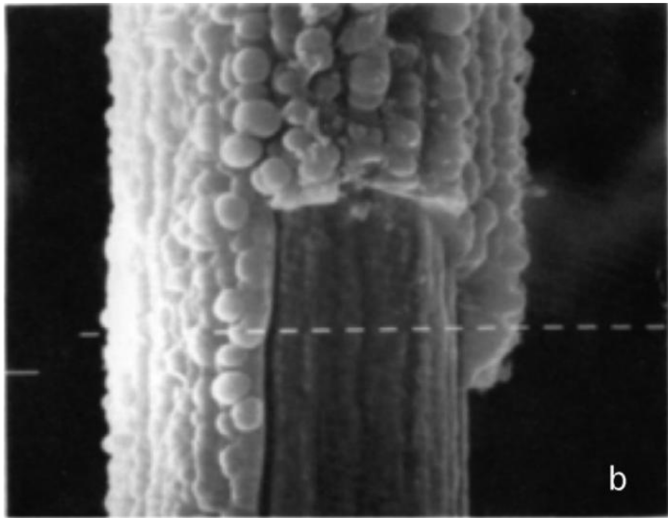
  ⇒ Mechanical complexity → lack of scalability

  Limited multi-track resolution $\sim O(10mm)$

  Not enough rate capability

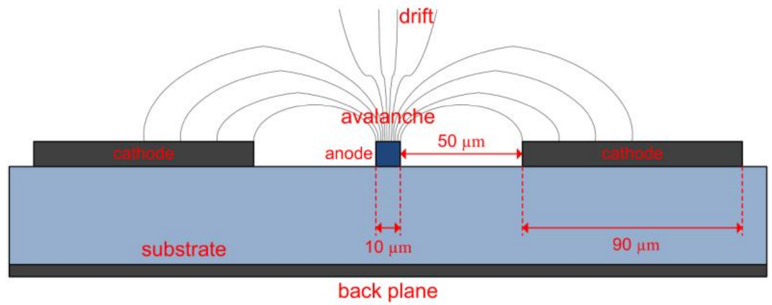
  Aging

Fabio Sauli

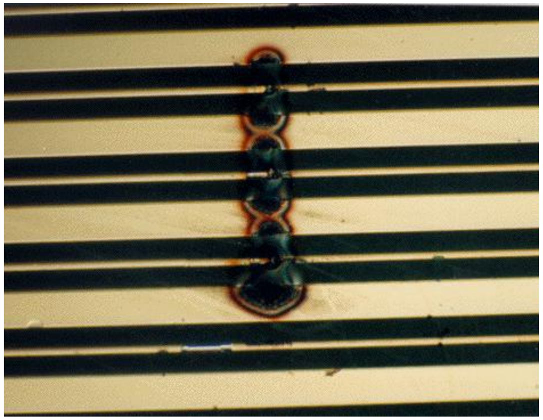


1. Introduction to μRWELL

Fabio Sauli



- Micro Strip Gaseous Counter
  - Susceptible to discharges



- Streamer formation
  - Field distortion by space charge and secondary avalanche by UV

  $\rightarrow P_{discharge} \sim e^{gain}$

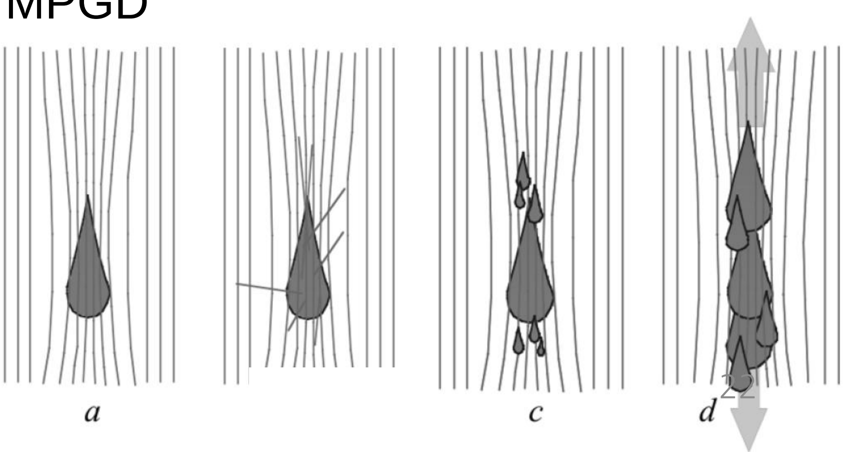
  $\Rightarrow$ Necessity of quenching gas

- For rate capability and multi-track resolution, micro patterning was the right direction to go

  $\Rightarrow$ Preventing discharges became the key of MPGD

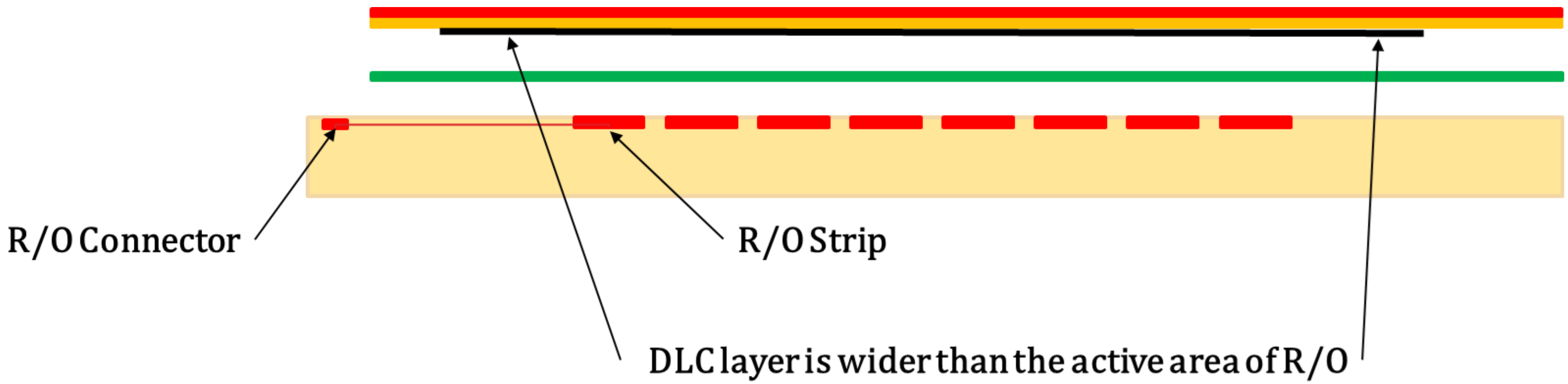
  $\rightarrow$ Step by step amplification & separation of induction and amplification region

  $\rightarrow$ Resistive layer



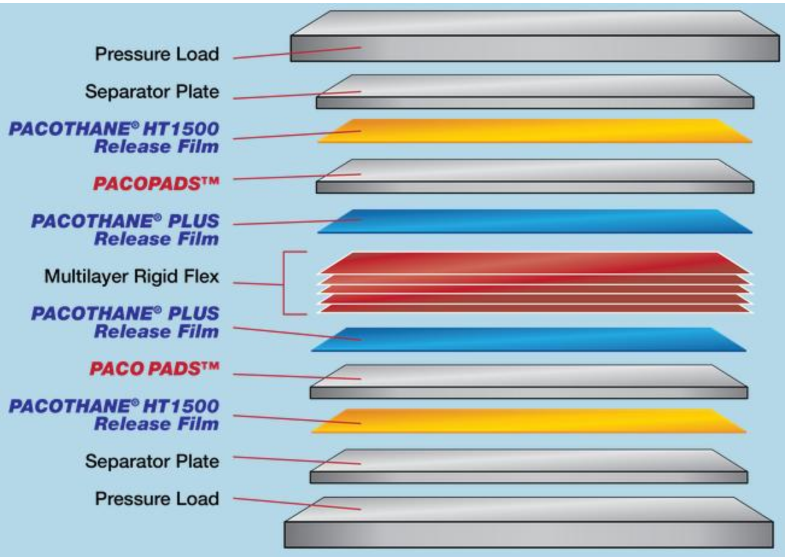
2. Production processes

• The DLC layer is formed by a sputtering process and are procured by ordering it from CERN or other suppliers



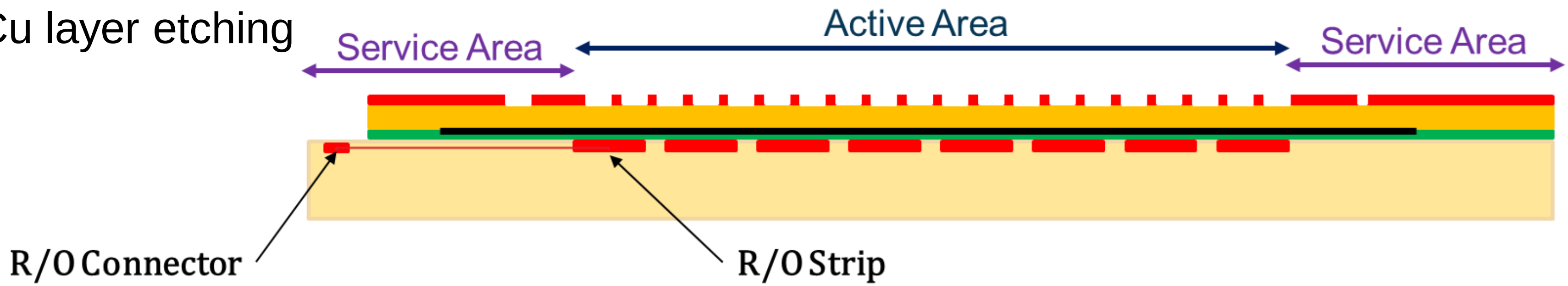
• Pressing DLC FCCL, pre-preg and RO PCB at high temperature in a vacuum chamber

- Will be done by PCB maker
- Common PCB pressing process, but requires know-how to construct “stack” to control the flatness issue

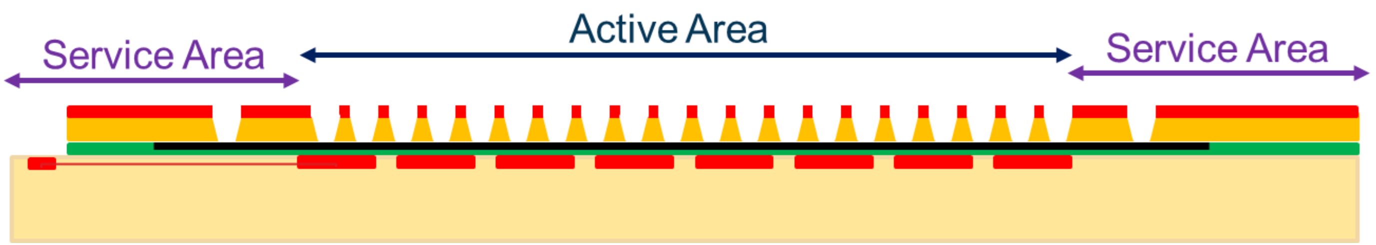


2. Production processes

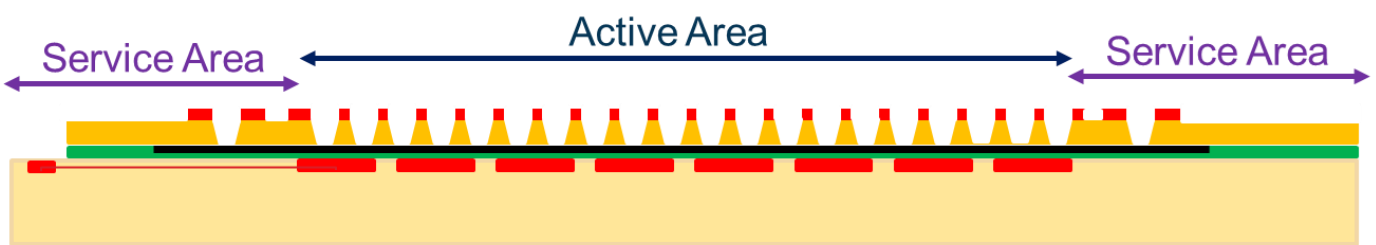
- 1st Cu layer etching



- PI layer etching
  - KOH, amine

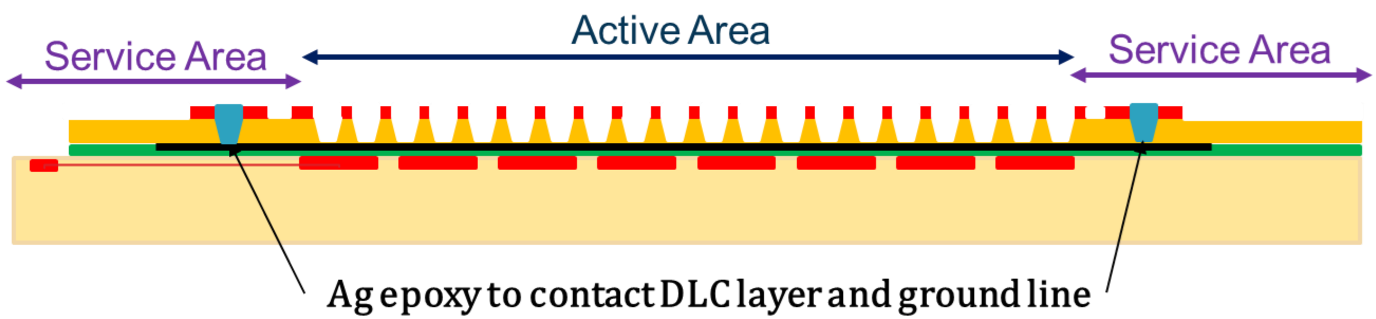


- 2nd Cu etching

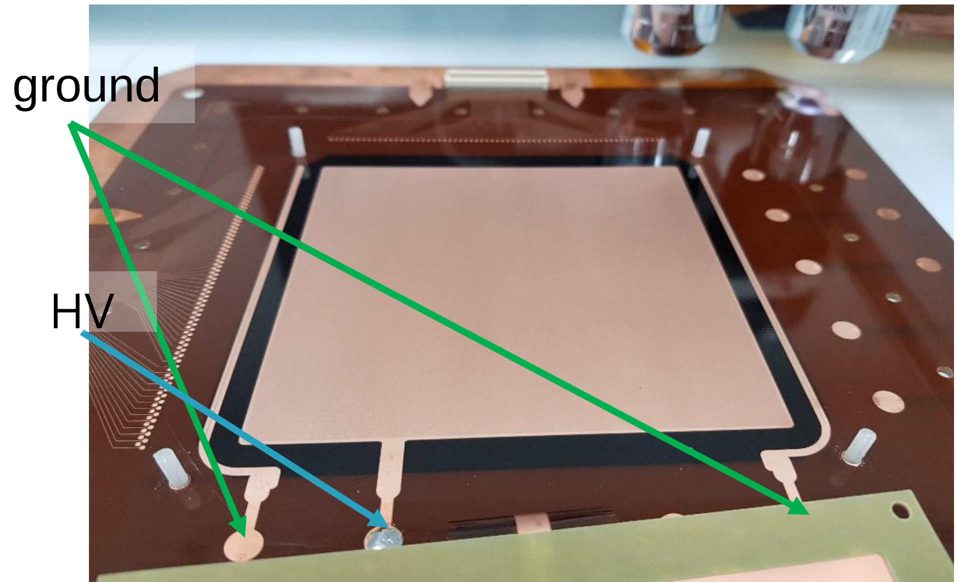


2. Production processes

- Ag epoxy pasting

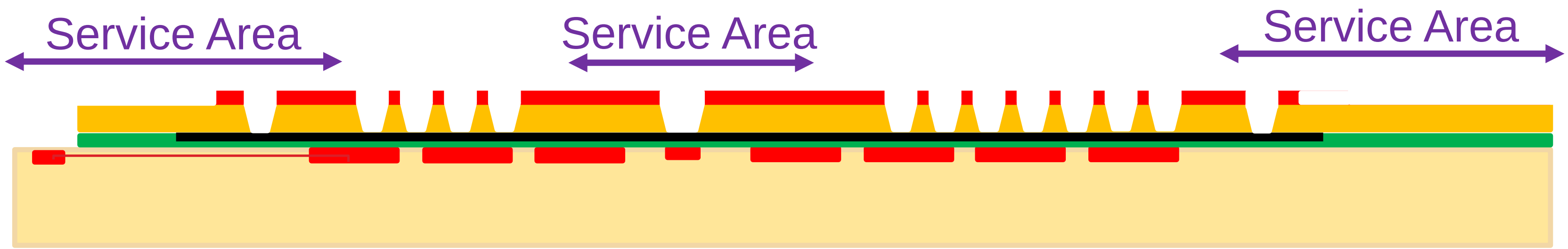


- Soldering connectors and cleaning
  - C-cleaning & E-cleaning needs lots of know-how
  - We have the know-how through KCMS GEM production

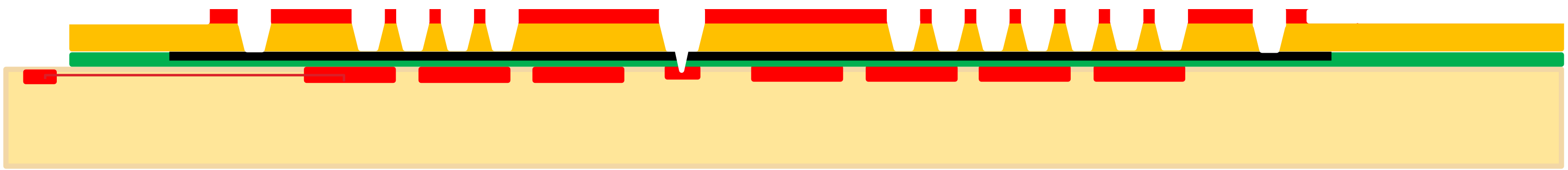


7. Introduction to high rate μRWELL

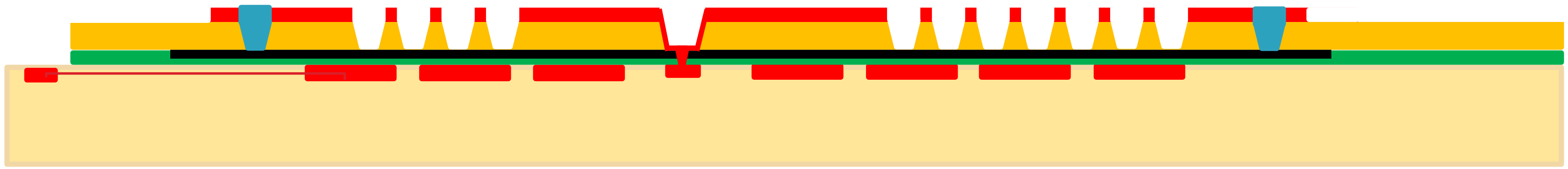
- PI etching



- Drilling (CNC)



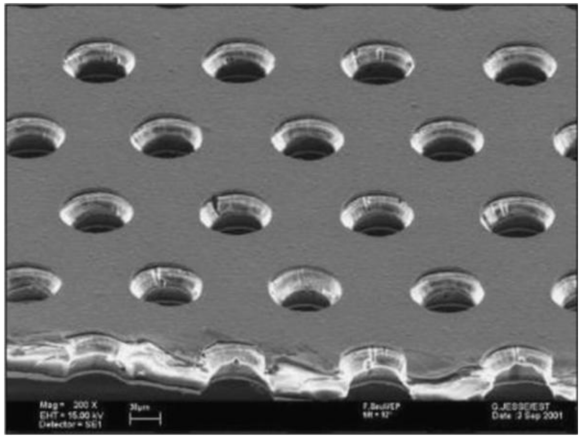
- Plating

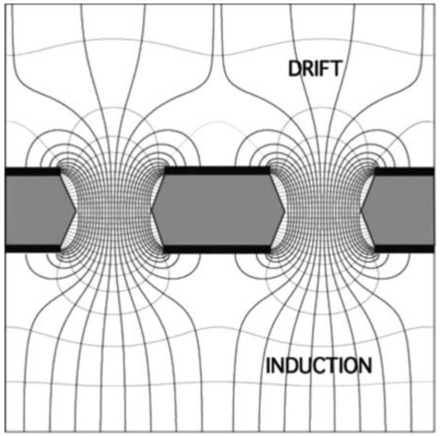


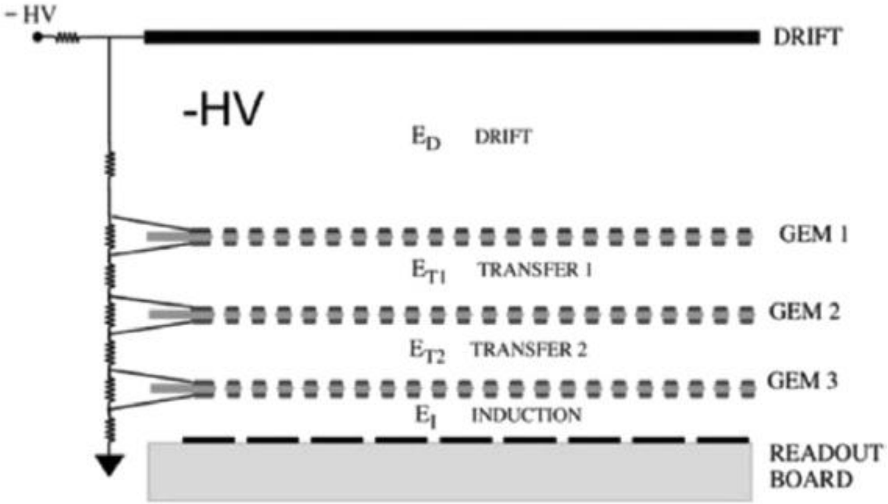
1. Introduction to μRWELL

• Gas electron multiplier

 - Step-by-step amplification & separation of induction and amplification region







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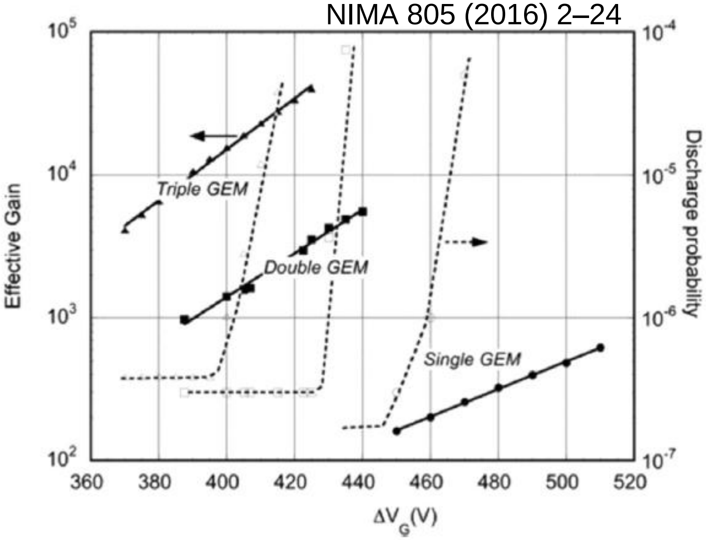


1. Introduction to μRWELL

- Advantages of GEM

  - Good position and multi-track resolution

  - Fair time resolution

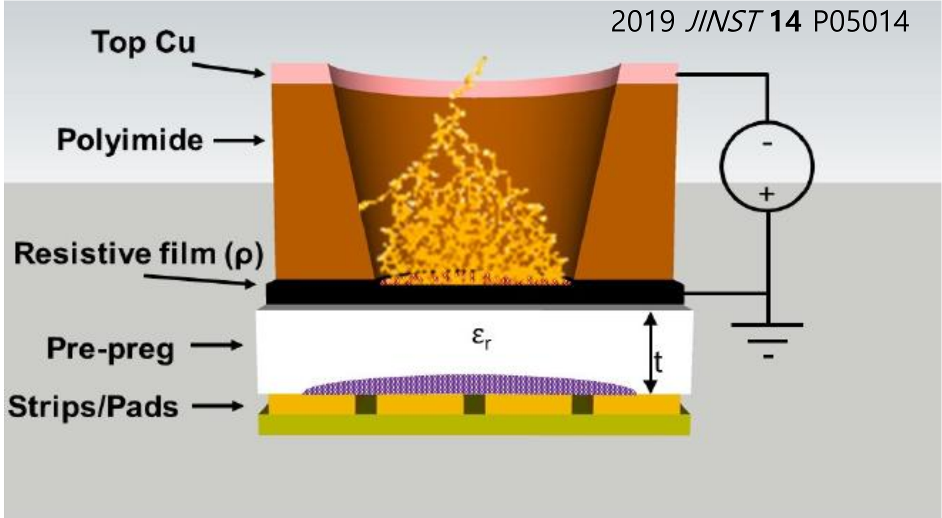
  - Extremely robust to classical aging

  - Extremely high rate capability

  → Nice detectors for high rate experiments and imaging application

1. Introduction to μRWELL

- Micro resistive well, the resistive variant of GEM
  - Resistive layer, DLC, prevents streamer from evolving discharge
  - No spatial separation between the avalanche and induction regions is required



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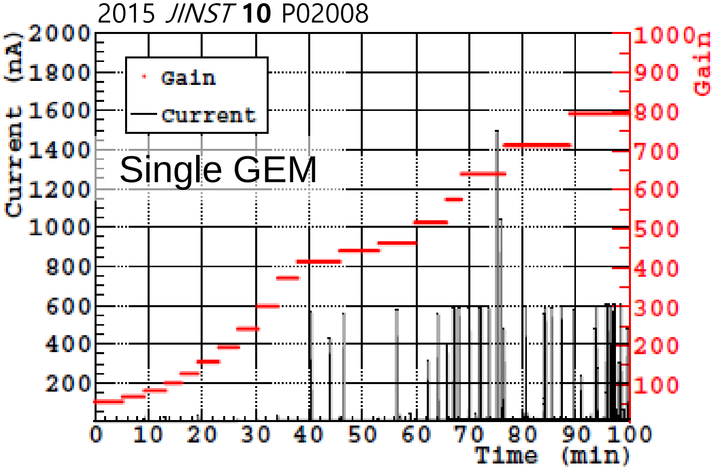
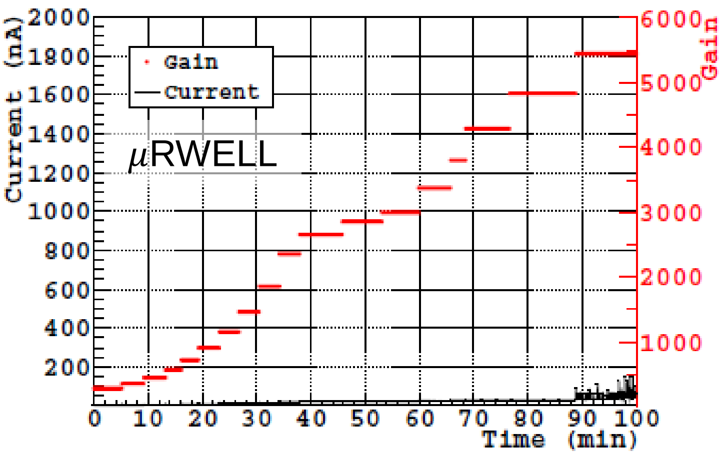


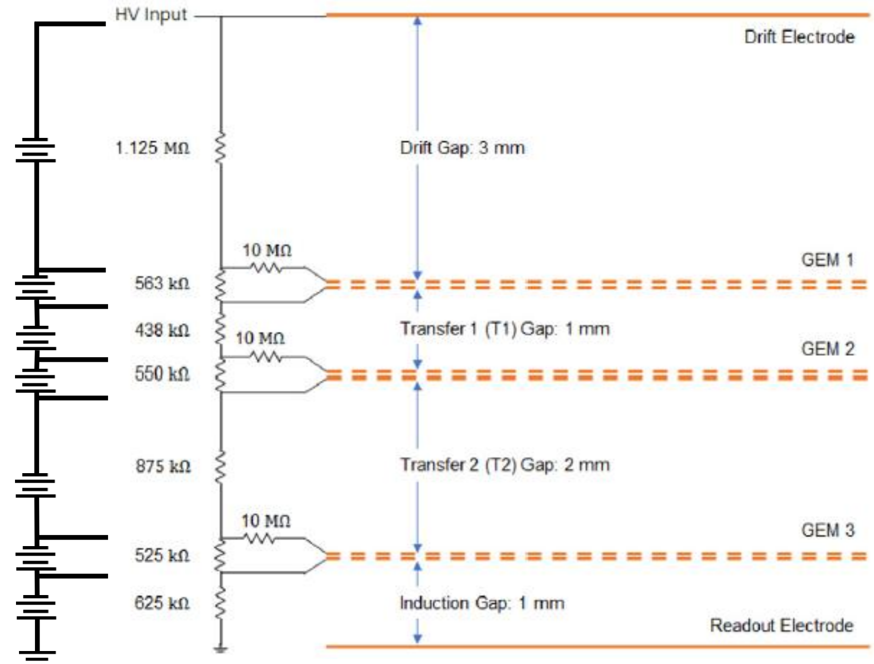


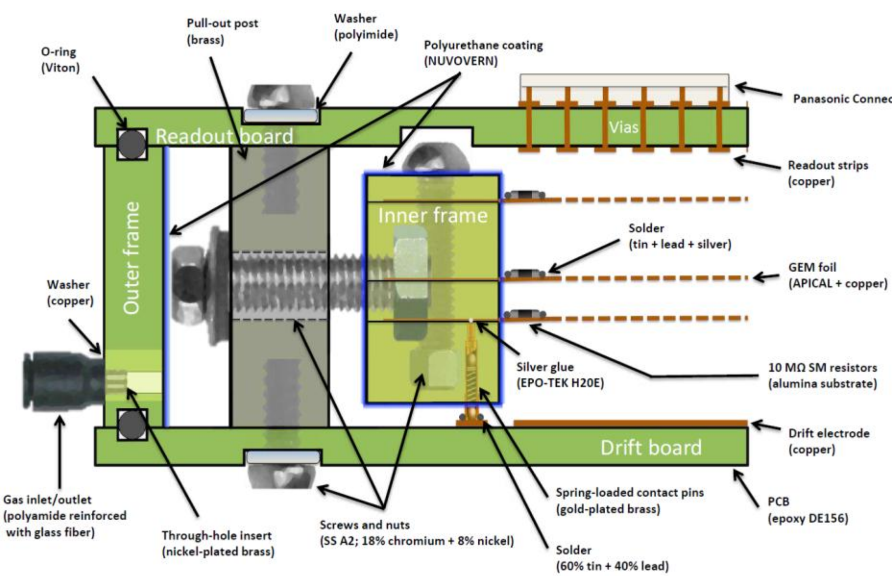
1. Introduction to μRWELL

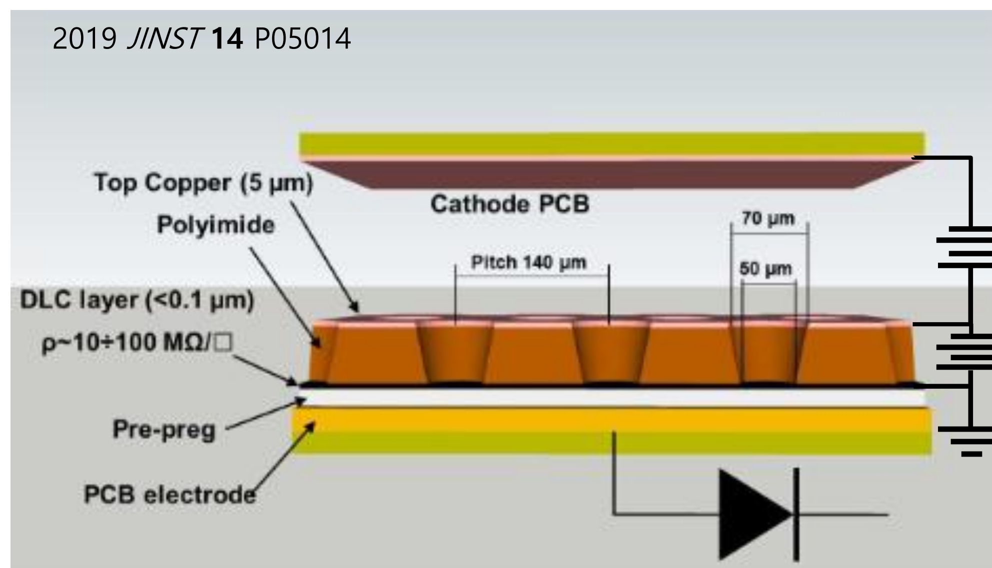
- Simpler structure and easier assembly
  - Self rigidity due to RO
  - One foil is enough
  - Simpler HV supply
  - ⇒ Cheap

A1515BTG

or



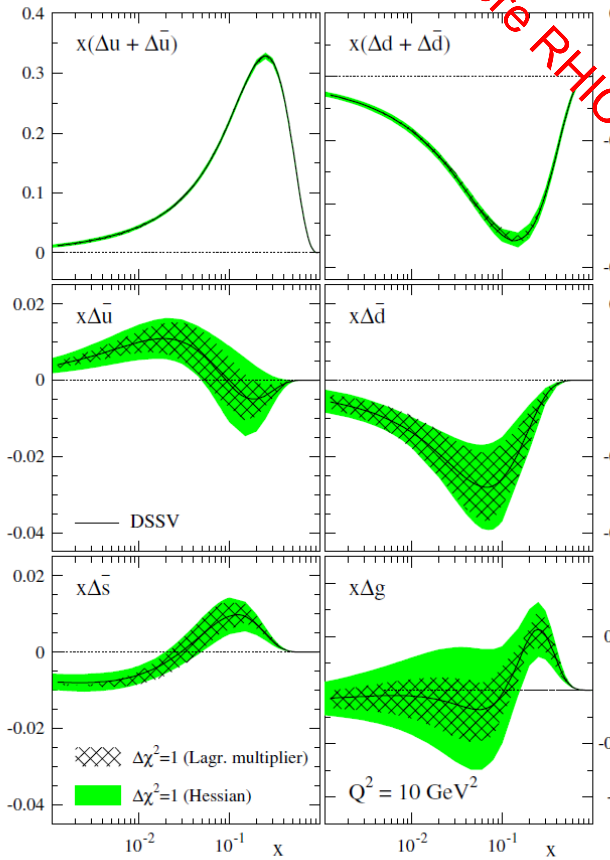




2. Proton spin structure and PHENIX experiment

Before RHIC

- RHIC spin program
  - Polarized p+p collision @ $\sqrt{s}$ = 200 and 510 GeV
  - Jet and hadron A_{LL} to constrain ΔG @ LO



Phys. Rev. D 80, 034030 (2009)

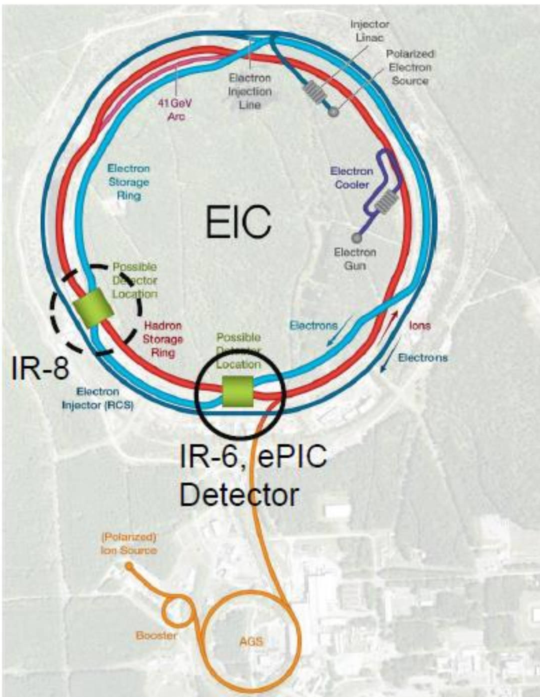
$$A_{LL}^h = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

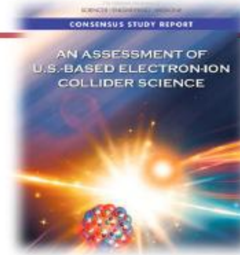
$$= \frac{\sum_{f_{a,b}=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma}_{elastic}^{a+b\to c+X} \otimes D_c^h}{\sum_{f_{a,b}=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma}_{elastic}^{a+b\to c+X} \otimes D_c^h}$$

$$= \frac{\sum_{f_{a,b}=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \hat{\sigma}_{elastic}^{a+b\to c+X} \times \hat{a}_{LL}^{a+b\to c+X} \otimes D_c^h}{\sum_{f_{a,b}=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma}_{elastic}^{a+b\to c+X} \otimes D_c^h}$$

$$\Delta f = f^{\uparrow} - f^{\downarrow}$$

EIC Scope





Project Design Goals

- High Luminosity: L= $10^{33} – 10^{34} cm^{-2} sec^{-1}$, 10 – 100 fb^{-1}/year
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: E_{cm} = 29 – 140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate a Second Interaction Region (IR)

IR-8

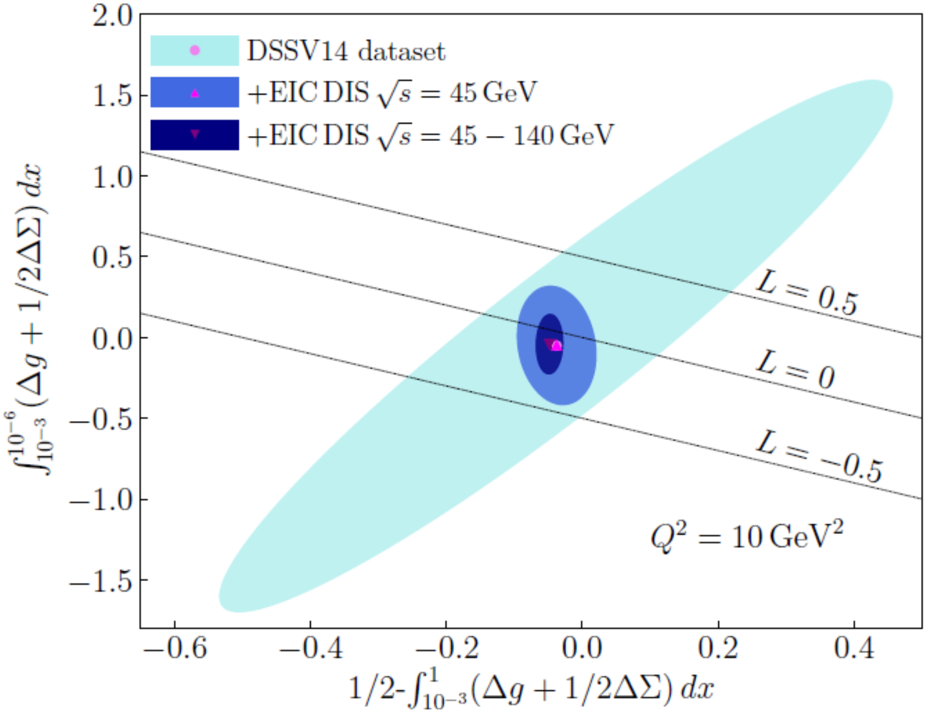
p: 41 GeV, 100 to 275 GeV	p/A beam →	← e beam	e: 5 GeV to 18 GeV

Physics programs – spin structure of proton

- OAM
  - As S_q and S_g are expected to be precise, OAM will be constrained
  - $J^q = \frac{1}{2} - J^g = \frac{1}{2}\int dx x[H^q(x, \xi = 0, t = 0) + E^q(x, \xi = 0, t = 0)]$, where H and E are GPD

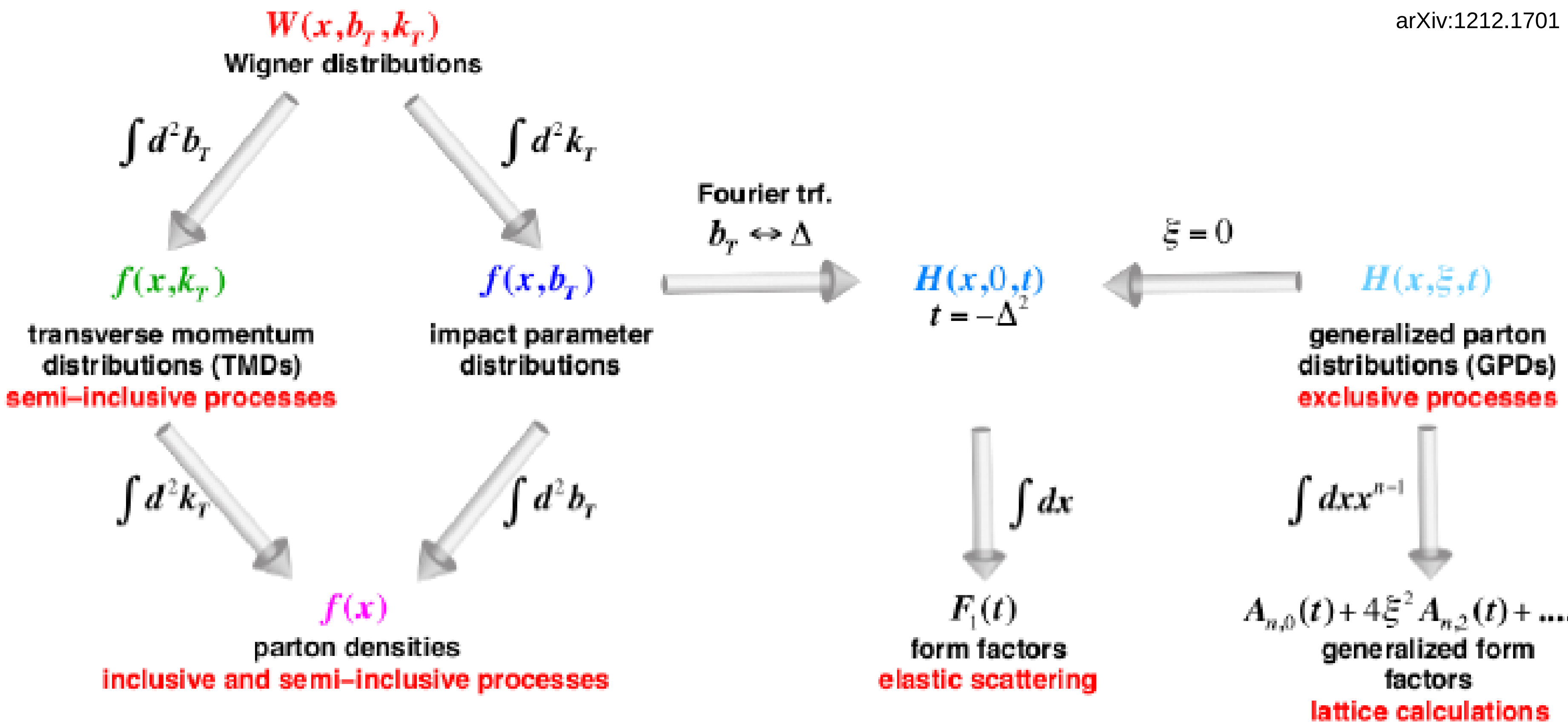
    $OAM_q = J^q - S_q$ and $OAM_g = J^g - S_g$
  - H and E are accessible at EIC and JLab via DVCS and DVMP

arXiv:2103.05419



Physics programs – Multi. D. imaging of proton

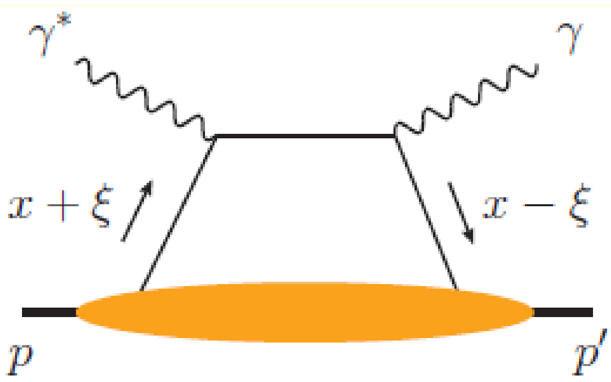
arXiv:1212.1701

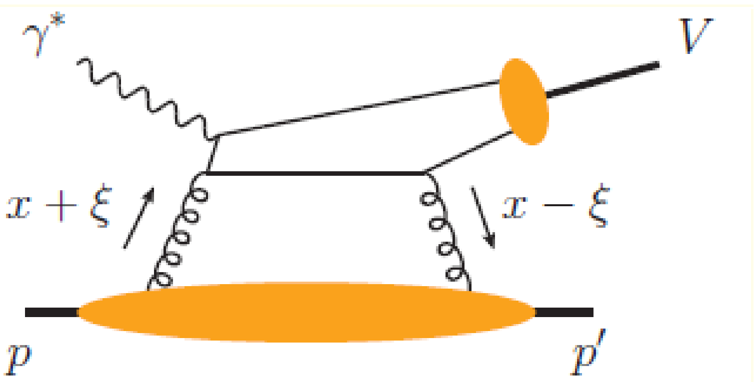


Physics programs – GPDs

- GPDs provide a connection between PDFs and form factors

- The cleanest channels to access GPDs are DVCS and DVMP
  - $x+\xi$ and $x-\xi$ are longitudinal parton momentum fractions with respect to the average proton momentum $\frac{p+p'}{2}$ before and after scattering



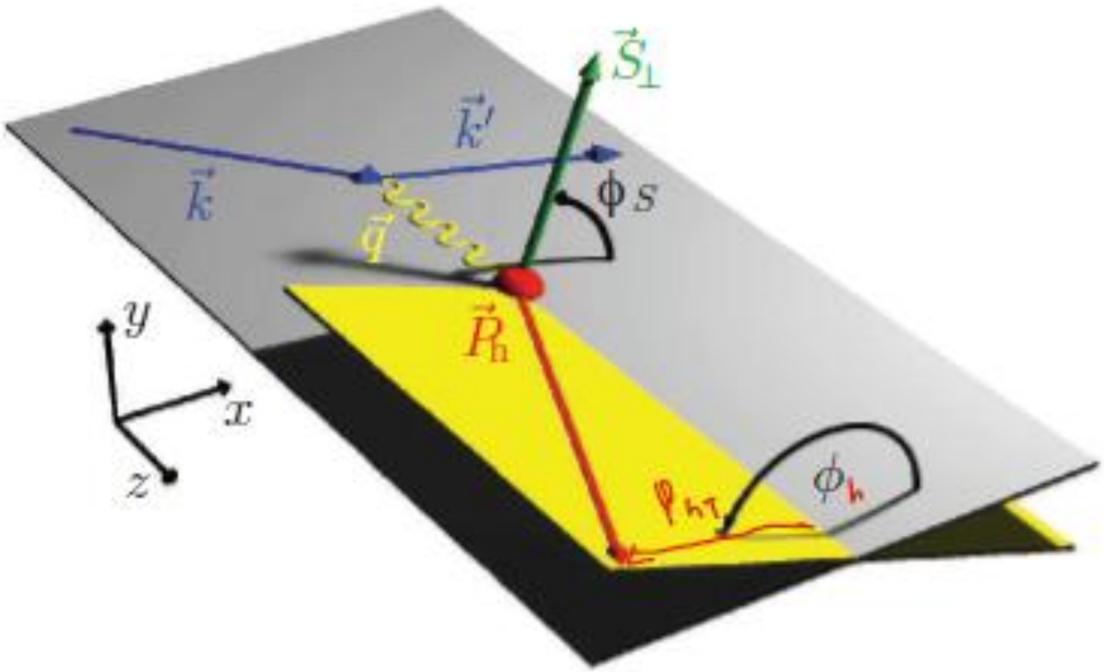


Physics programs – TMDs

- $\frac{d\sigma}{dx dy d\phi_S dz d\phi_h dP_{hT}^z} \propto F_{UU} + |S_\perp| \sin(\phi_h - \phi_S)\, F_{UT}^{\sin(\phi_h - \phi_S)} + \cdots$

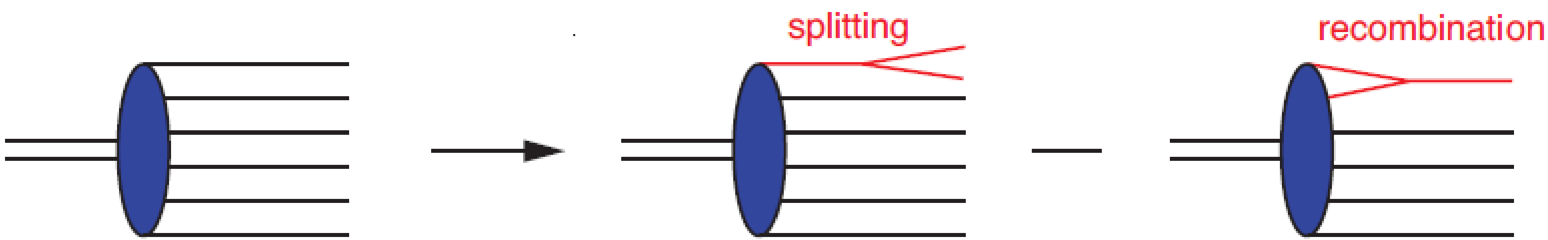
, where $F_{UT}^{\sin(\phi_h - \phi_S)} = \sum_q e_q^2 |C_V\ (Q)|^2 [R(Q;\mu_0) \otimes f_{1T}^{\perp q}(x;\mu_0) \otimes D_1^q\ (z;\mu_0)](P_T)$

, where $|C_V\ (Q)|^2$ perturbative coefficient, $R(Q;\mu_0)$ evolution factor, $f_{1T}^{\perp q}(x;\mu_0)$ Sivers TDM, and $D_1^q\ (z;\mu_0)$ unpolarized TMD FF



Physics programs – Gluon saturation

- Will gluon density continue to increase in low enough x region?
  - Probably not

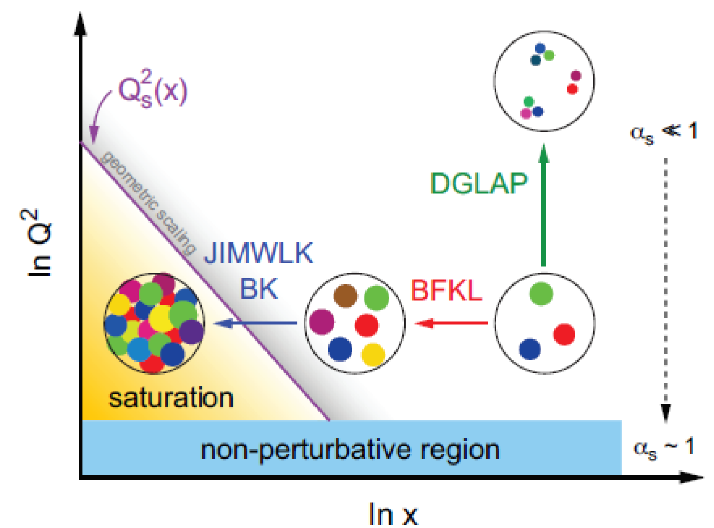


- BFKL evolution
  - The evolution eq. that allows one to construct the PDF at low-x
  - $\frac{\partial N(x,r_T)}{\partial \ln(1/x)} = \alpha_s K_{BFKL} \otimes N(x,r_T)$, where $r_T \sim 1/Q$ (transverse distance) and Fourier Tr.

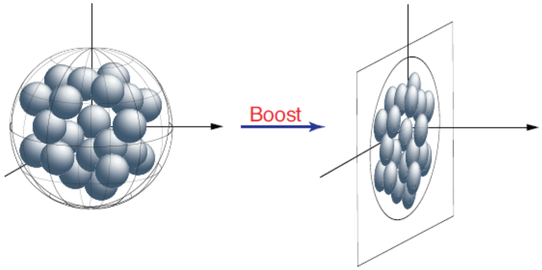
of $N(x,r_T)$ is related to gluon TMD

- BK evolution
  - $\frac{\partial N(x,r_T)}{\partial \ln(1/x)} = \alpha_s K_{BFKL} \otimes N(x,r_T) - \alpha_s [N(x,r_T)]^2$

- HERA implied the existence of CGC



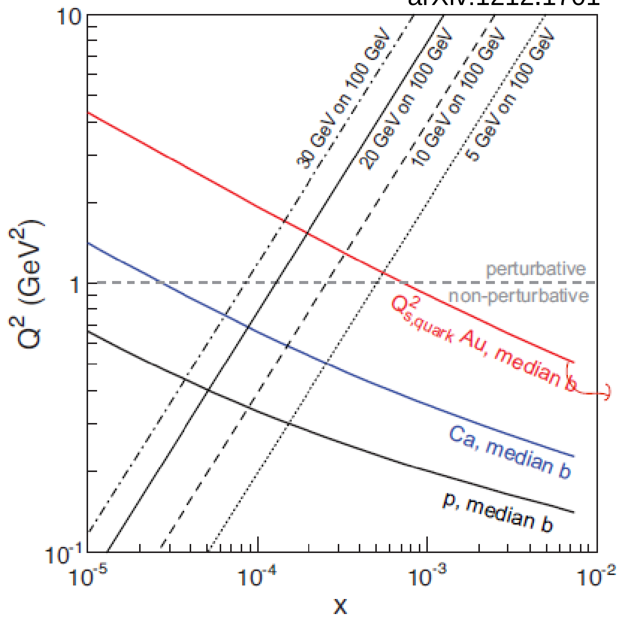
Physics programs – Gluon saturation



- Nuclear "Oomph" factor
  - To access CGC, we need higher beam energy or heavy ion collision
  - Gluon fields are overlapped by Lorentz contraction and higher density gluon field can be probed wo/ increasing beam energy
  - $Q_s^2(x) \sim A^{1/3}(\frac{1}{x})^{\lambda}$ where $\lambda = 0.2 - 0.3$

- Observables
  - Nuclear structure function
  - Di-hadron correlations
  - Diffractive events

arXiv:1212.1701



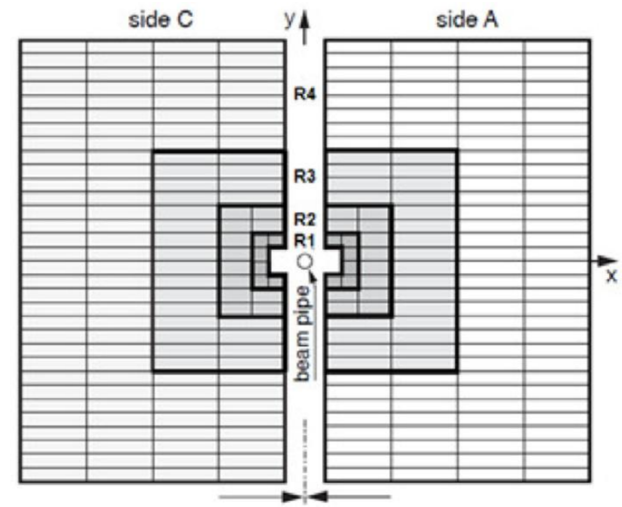
4. High rate μRWELL application – LHCb

- Replacement of MWPC to high rate μRWELL
  - Due to limited rate capability of MWPC
  - 574 chambers to cover $40\ m^2$
  - Production will start ~2027

- Recently, the leader of the LHCb upgrade suggested collaboration
  - PCB production @ Eltos, Italy
  - μRWELL @ KCMS

- CERN has transferred technologies of μRWELL production to Eltos for FCC-ee
  - However, Eltos failed in PI etching and is focusing on PCB production

- Need intensive technology R&D and mass production



Rates (kHz/cm^2)	M2	M3	M4	M5
R1	749	431	158	134
R2	74	54	23	15
R3	10	6	4	3
R4	8	2	2	2