ILC Technology Networkとは直接関係ないけれど、この機会を借りて...

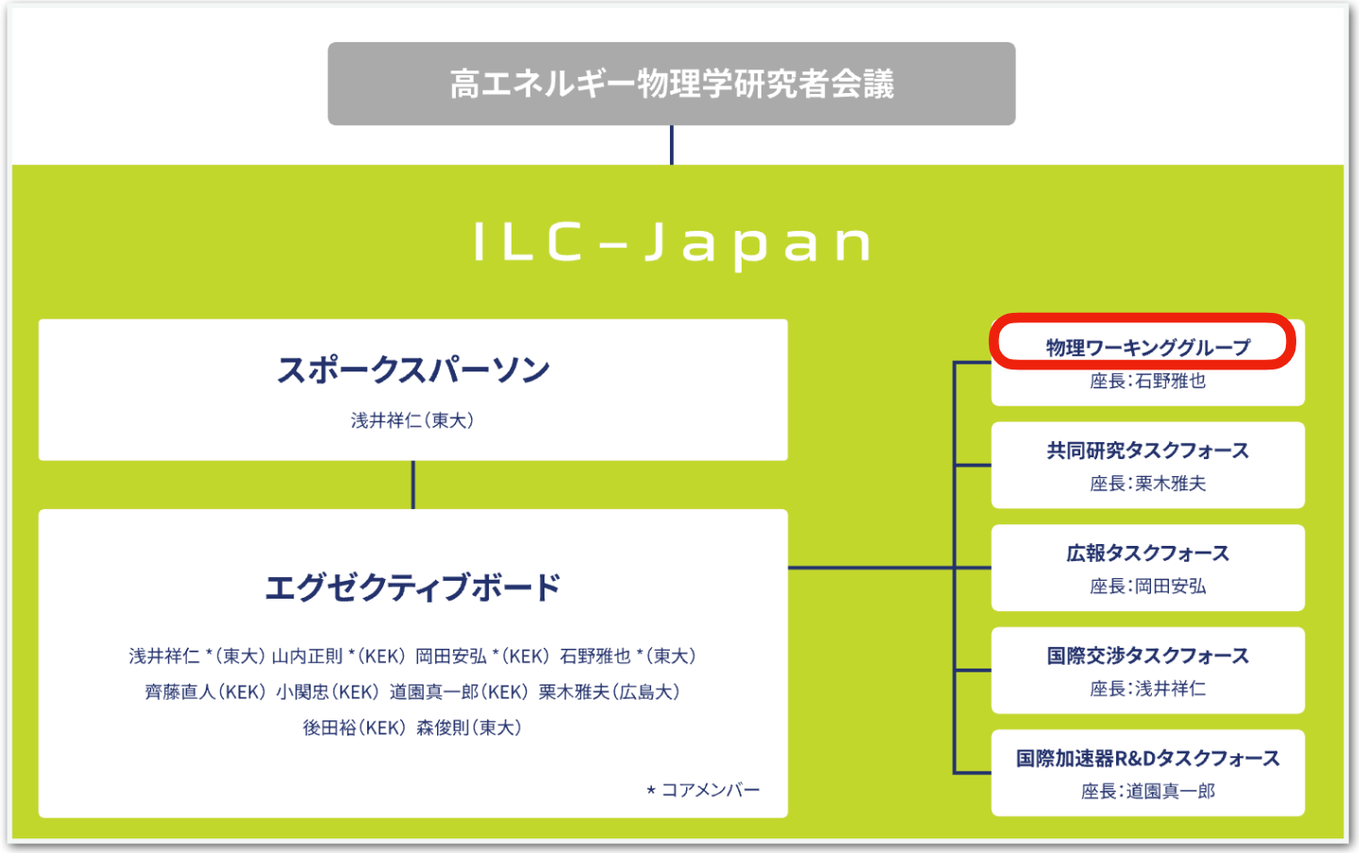
# $e^+e^-$ Linear Colliderにおける物理・検出器の研究

## 現状と提案

石野 雅也（ICEPP）

ILC物理WG

# 物理WG in ILC-Japan




（一般論としては、） $e^+e^-$ Linear Colliderをつかった物理研究の推進

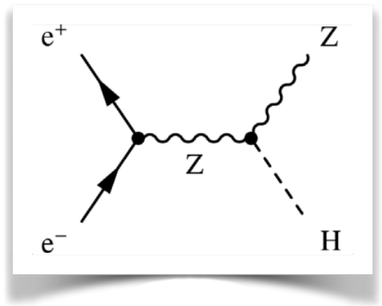
**$e^+e^-$ LCでの物理研究の再拡大、興味を持って研究に取り組む人を**
**掘り起こして協同研究の輪を広げる。そのための様々な手を打つ。**
**（scientificな観点から）**

# ILC-J物理WGとしてのスコープ

$\sqrt{s}$ = "250 GeV" → 380 GeV → 500 GeV → 1 TeV (or multi-TeV)

# $\sqrt{s}$ = 250 GeV

$\sqrt{s}$ = "250 GeV" → 380 GeV → 500 GeV → 1 TeV (or multi-TeV)




$\kappa = g_X/g_X^{SM} = 1+\Delta\kappa$
$\Delta\kappa \sim O(v^2/\Lambda^2)$

For new physics at 1 TeV
expect deviations of O(6%)

## Higgs： Precision Measurements

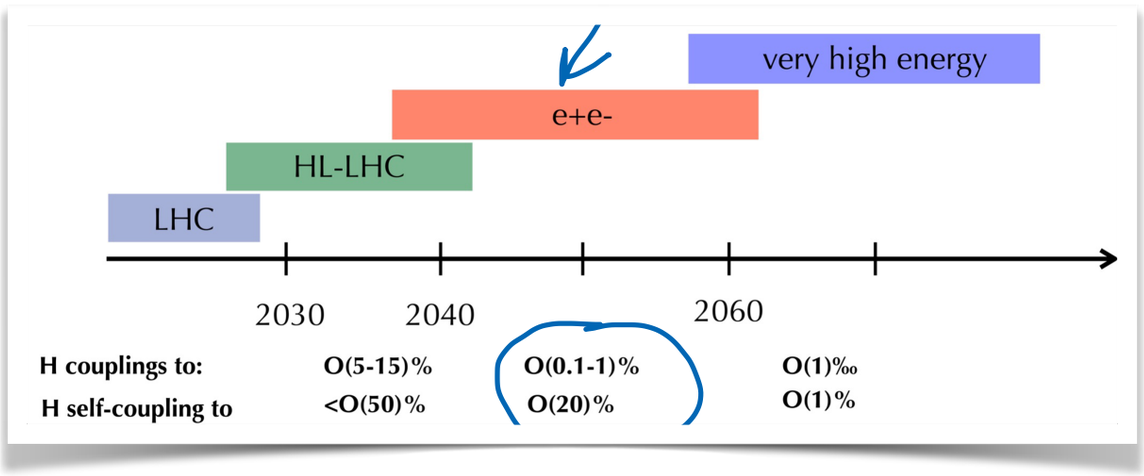
- Couplings **O(a few %)** → new Physics at **TeV Scale**
- Higgs-CP → **真空の構造** (e.g. 2HDM+singlet)
- if CPが破れている - **電弱Baryogenesisへのヒント**
  - (HHHに大きな変化(~20%))
  - ゲージ粒子との結合が**数%**変わる

**( 2017 )**

**ILC 250GeV Higgs Factory の物理意義を検証する委員会 報告書**

**( 2017 )**

高エネルギー物理学将来計画検討委員会 答申

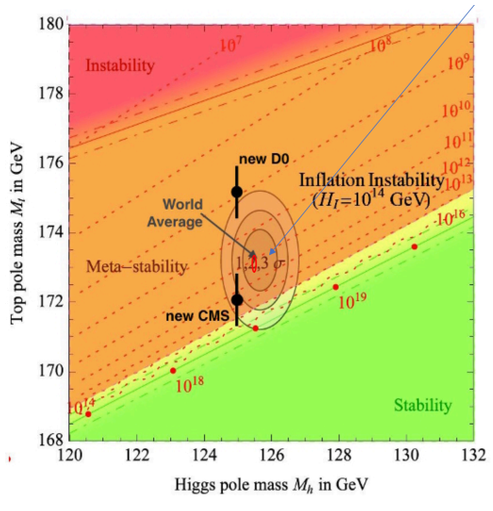


# $\sqrt{s}$ = higher higher higher ... extendability

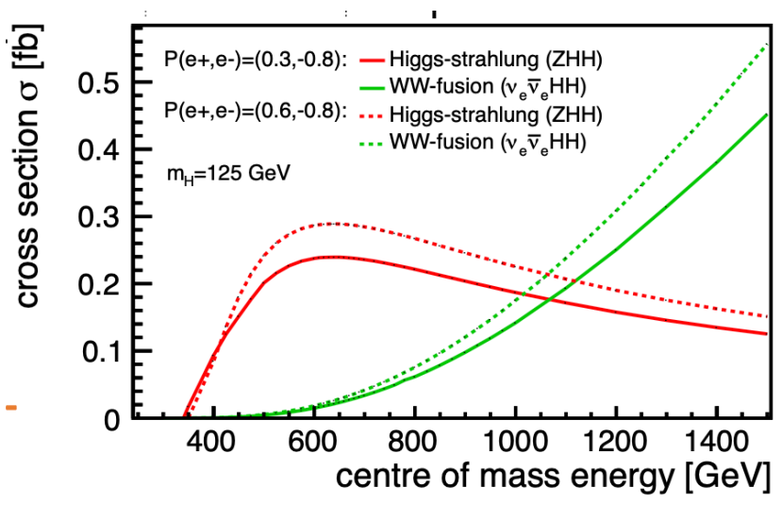
$\sqrt{s}$ = "250 GeV" → 380 GeV → 500 GeV → 1 TeV (or multi-TeV)

- Top mass → Vacuum Stability
- Higgs Self-Coupling,
- New Particle Search (ALP, LLP, EWKino/Higgsino, ...)
- 様々

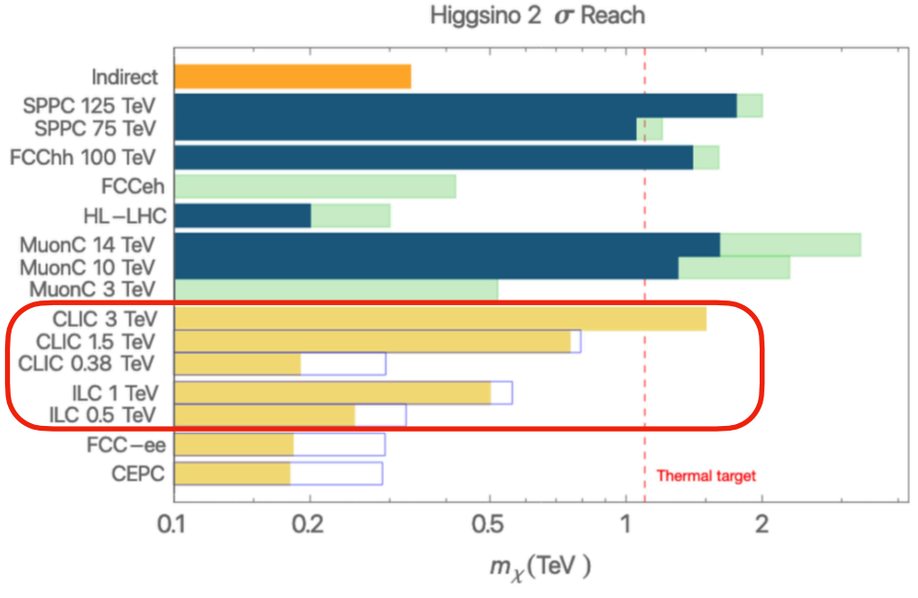
## $m_{top}$ → 真空安定性




## HHH → $\lambda_3$




## Higgsino



# ILC-J物理WG (2023/01 - 05)

東京大学 THE UNIVERSITY OF TOKYO

## コアグループ：石野・末原・Daniel・Junping・藤井 → bi-weekly

A set of Shopping List

| **Higgs Physics** | |
|---|---|
| Mass | new method other than traditional recoil mass |
| CP-violating effects in coupling to fermiions | H-->ττ |
| CP-violating effects in coupling to bosons | anomalous HZZ, HWW, HγZ couplings; benchmark |
| **Portal to dark sector & Exotic decays** | H-->bbbb; H-->bb+invisible; H-->ττττ; H-->cccc |
| **Triple Higgs coupling** | combined **single** & double Higgs analysis |
| Synergy with LHC | Total width using off-shell Higgs; BR(H-->γZ/γγ) / BF |
| H → ss | |
| | |
| **EW Precision Physics** | |
| 4-fermion interaction in μ/τ channels | benchmark models; advantage of beam polarizatior |
| Z-pole observables by radiative return events | theory uncertainties; A_f other than for electron |
| CP-violating triple gauge couplings | new analysis in WW channel |
| Z couplings to u/d-quarks | separating u/d events using charge asymmetry in F |
| | |
| **Top-quark Physics / QCD** | |
| Mass | theory & experimental systematics |
| Top-EW coupling just above tt threshold | |
| Top-Yukawa coupling below ttH threshold | quantum effect; prospects in a more model-indepen |
| Alpha_S & Jet Shapes | |

| **New Particle Searches** | |
|---|---|
| Axion like particles | |
| Long lived particles | displaced vertex; kinks; advantage of TPC |
| Light new particles with beam dump experiment | |
| SUSY EWikinos / Higgsino | |
| g-2 parameter determination with SUSY | |
| | |
| **Reconstruction tools** | |
| Flavor tagging | with machine learning |
| Tau polarization reconstruction | with impact parameters |
| Parton shower at NLO | impact to precision physics |
| Jet clustering algorithms | color-singlet clustering; machine learning |
| Particle Flow | machine learning |

## 一緒に研究をやれそうな仲間はどこにいる?

e.g. LHC, Belle, ... Colliderで物理をしている人に限る必要はないが、まずはそのあたりから声かけ

- **LHCとのSynergy**（廣瀬、野辺、増渕、Sanmay）
  - Single Higgs Productionにおける **Self-Couplingの効果**（増渕）→　2nd & 3rd meeting
- **BelleとのSynergy**（石川、中村）：探索中

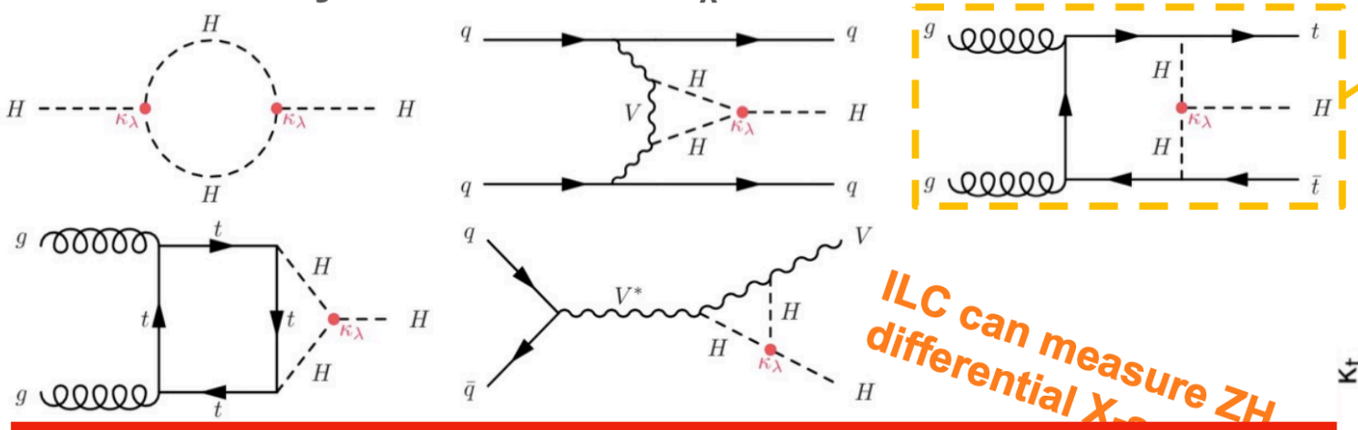
# LC250 x LHC : Self-Coupling in Single H

増渕

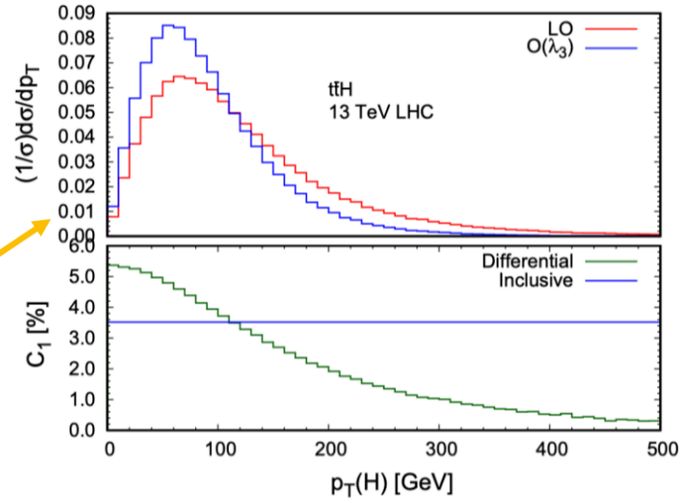
## Single Higgs can constrain $\kappa_\lambda$?

EPJC 77 (2017) 887

- Single Higgs productions also depends self-coupling contribution via NLO EW correction
  ➔ **Indirectly constraint on $\kappa_\lambda$**

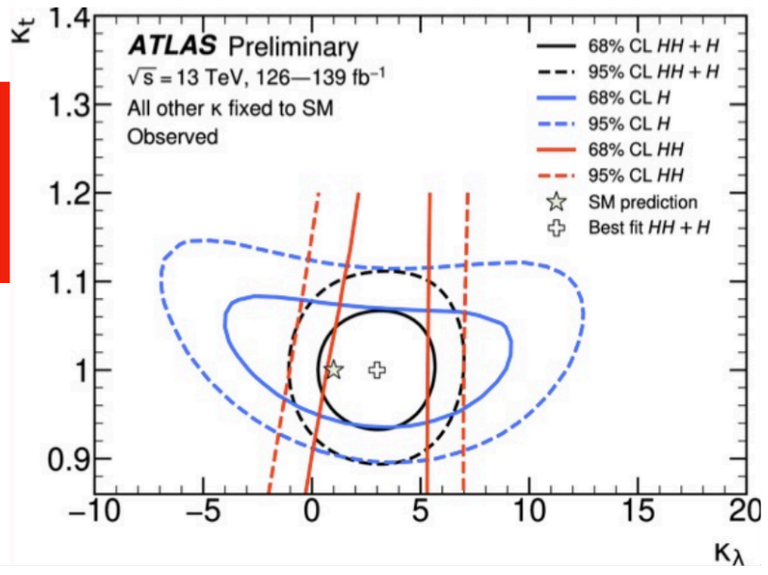



ILC can measure ZH differential X-sec!?




- **$\kappa_\lambda$ dependence by a function of Higgs $p_T$**
  **➔Precision measurement on differential cross section is crucial**

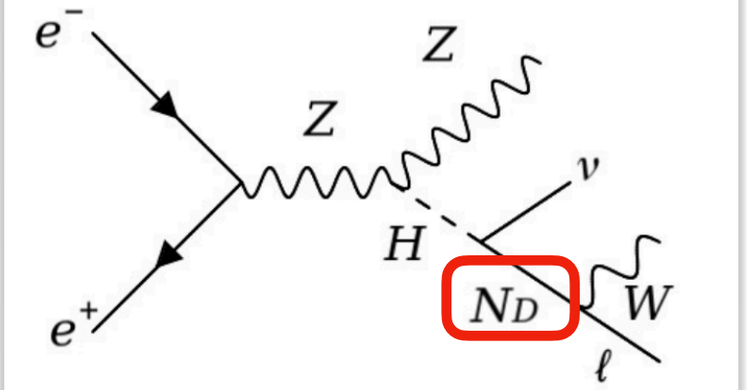
- Perform combined fit with single Higgs (STXS) and HH
  ➔ Possible to constrain other coupling parameters ($\kappa_t$) simultaneously
  ➔ ~5-10% improvement on $\kappa_\lambda$ constraint




- 微分断面積 → Higgs Self-Couplingの効果にsensitive
- ILC250では?

# 飛び込み thanks!! → quick resultの１例

| Higgs Physics | |
|---|---|
| Mass | new method other than traditional recoil mass |
| CP-violating effects in coupling to fermiions | H-->ττ |
| CP-violating effects in coupling to bosons | anomalous HZZ, HWW, HγZ couplings; benchmark models |
| Portal to dark sector & Exotic decays | H-->bbbb; H-->bb+invisible; H-->ττττ; H-->cccc |
| Triple Higgs coupling | combined single & double Higgs analysis |
| Synergy with LHC | Total width using off-shell Higgs; BR(H-->γZ/γγ) / BR(H-->ZZ*) |
| H → ss | |




- 4月： 留学生（M1）、ICEPPに到着。Simon, Junping, 石野　解析テーマ決定

- 5月中旬まで：　B.G.としての H→WW study
  - Frameworkに慣れる
  - 既存Sample利用
  - Cut Optimization, MVA training, ...
  - 並行して、信号サンプルの生成

- 5月下旬ー今：
  - 信号サンプルの解析
  - mass pointのスキャン：進行中　→　**最終結果に近づいている**

- 夏？：　**論文 submit**

# ILC-J物理WG (2023/06 - )

**コアグループ拡大：理論（北原・津村） Belle（中村） ATLAS（野辺）** ５人(石野、末原、Daniel, Junping, 藤井)

反省というか、気付きというか：

- もしかして、Higgs 250GeVの物理（将来計画答申 2017、ILC250GeVの物理意義）に納得している人の数は、そんなに多くない??
- 「Higgsの精密測定はキラーサイエンス」。。。　　そんなに共感されていない??

⇒　今一度、250GeV → 1 TeV (multi-TeV)という**全体シナリオをふまえ**、
$e^+e^-$ LCにおける**物理の魅力・売りをWGで再確認**した上で、
コミュニティーに声をかけていきたい

「ILC250の意義(2017)、Snowmass Input、等の材料を利用」

⇒　**high speed**で digestして、資料を再編集して形にする

⇒　その上で研究機関をまわったり、個人的にコンタクトをとったりしながら、
研究の輪を広げていく

⇒　phase transition!!

# テラスケール研究会 → Tera-Scale Physics and Beyond



## Workshop for Tera-Scale Physics and Beyond

Friday 23 Jun 2023, 09:30 → 17:30 Asia/Tokyo

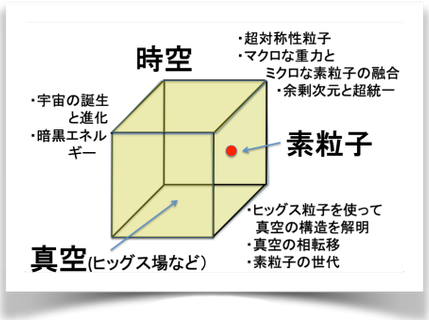
JR Kyushu Hall/JR九州ホール (JR HAKATA CITY (9F)/JR博多シティ （JR博多駅・駅ビル）(9F))

Description 本研究会は、研究拠点形成事業「ミューオン素粒子物理学の国際研究拠点形成」（リンク・リンク）の助成により開催しております。

This workshop is supported by JSPS "Core-to-Core Program" of ミューオン素粒子物理学の国際研究拠点形成（link・link）

Registration *You are registered for this event.* Check details

https://indico.cern.ch/event/1279566/timetable/?view=standard#2-experiment-status-of-run3-op




| | | |
|---|---|---|
| 09:30 → 10:00 | Registration | |
| 10:00 → 10:05 | **Welcome** | **Speaker**: Junji Tojo (Kyushu University (JP)) |
| 10:05 → 10:45 | **Experiment: Status of Run3 operation and HL-LHC upgrade (25'+15')** | **Speaker**: Tomoyuki Saito (University of Tokyo (JP)) |
| 10:45 → 11:30 | **Experiment summary: Top+SM (30+15')** | **Speaker**: Yasuyuki Horii (Nagoya University (JP)) |
| 11:30 → 12:15 | **Experiment summary: Higgs+BSM Higgs+Dihiggs (30'+15')** | **Speakers**: Minoru Hirose (Osaka University (JP)), Minoru Hirose (Osaka University) |
| 12:15 → 13:15 | Lunch! | |
| 13:15 → 13:40 | **Topical theory talk: Electroweak baryogengesis (15'+10')** | **Speaker**: Yushi Mura (Osaka Univ.) |
| 13:40 → 14:05 | **Topical theory talk: Vacuum stability (15'+10')** | **Speaker**: So Chigusa (LBNL, UC Berkeley) |
| 14:05 → 14:35 | **ILC prospect: ILC status and Higgs summary (20'+10')** | **Speakers**: Taikan Suehara (Kyushu University (JP)), Taikan Suehara (Kyushu University) |
| 14:35 → 15:00 | **Topical theory talk: Status of flavor anomalies (15'+10')** | **Speaker**: Motoi Endo (KEK) |

## 「真空と時空の構造解明」

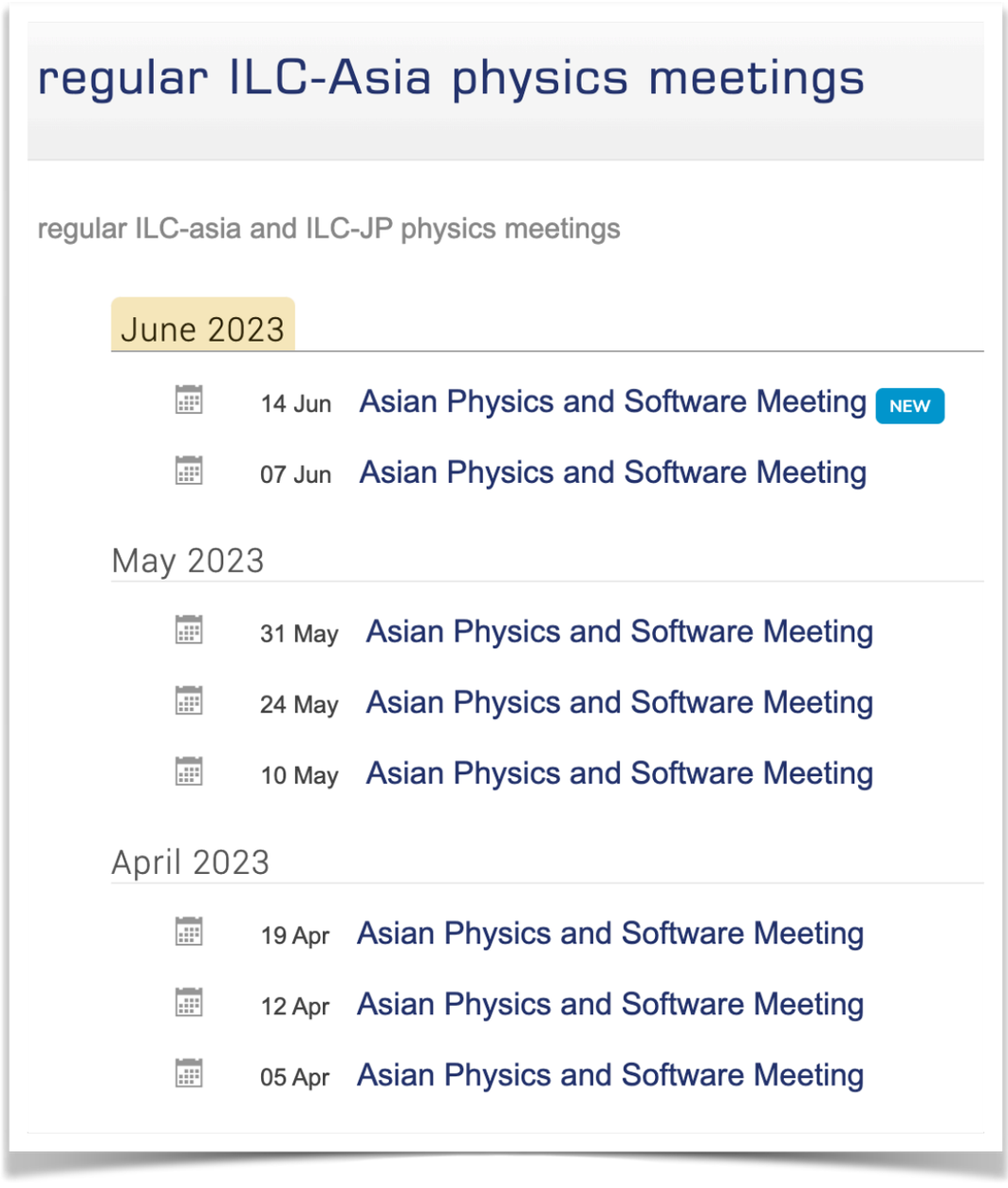
- HiggsのBig Pictureを描く：ILC x LHC
- …

| | | |
|---|---|---|
| 15:30 → 16:15 | **Experiment summary: SUSY+Exotics (30'+15')** | **Speaker**: Yuya Mino (Kyoto University (JP)) |
| 16:15 → 16:40 | **Topical theory talk: Status of WIMP Dark Matter (15'+10')** | **Speaker**: Satoshi Shirai (Kavli IPMU) |
| 16:40 → 17:05 | **Topical theory talk: Swampland, cosmological constant problem, and extra dimension (15'+10')** | **Speaker**: Yuta Hamada (KEK) |
| 17:05 → 17:15 | **Closing / Conclusions** | |

# Regular Small-Size Physics Meeting

**Weekly**
**Physics and Software meeting**

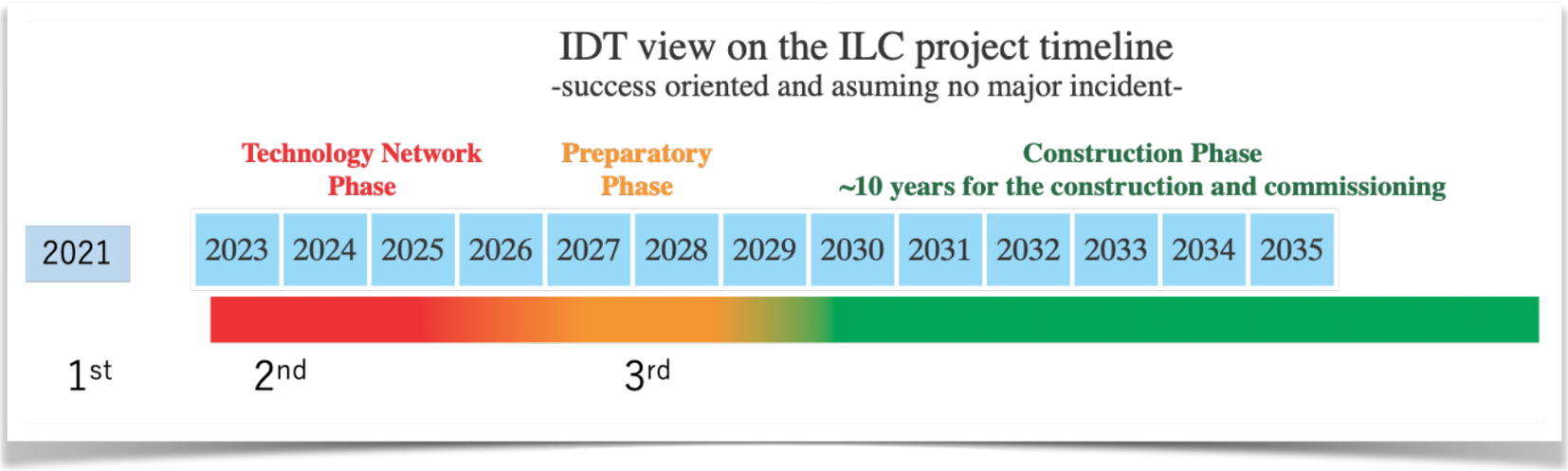
https://agenda.linearcollider.org/category/276/




**Every two months**
**ILC-J Physics WG meeting**

https://agenda.linearcollider.org/category/283/

# 検出器の開発研究




LHCの場合をふりかえると…

LHC　2000 TDR ⇒ 2008 start

HL-LHC　2017 TDR ⇒ 2029 start

- **case**: success oriented and no major incident -

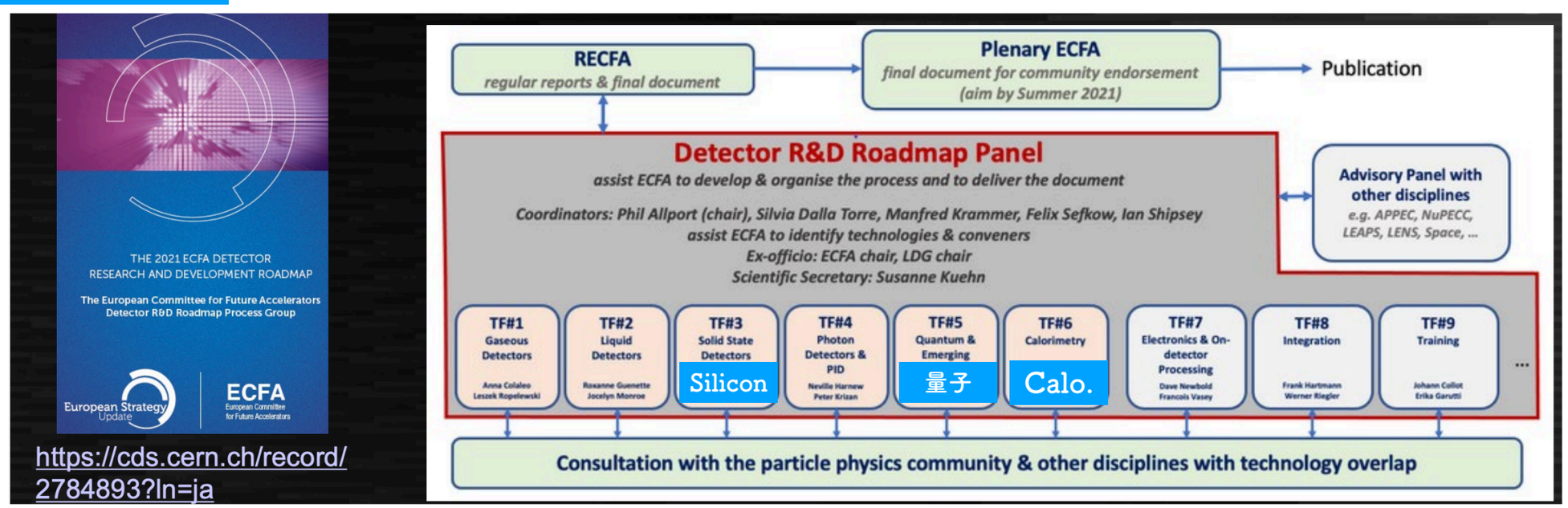
「今」：　あり余る時間があるわけでもないが、

**物理成果につながる重要なゲインがある研究に挑戦**する価値がある

（other HF → 立ち上がりタイミングの差は、そのまま検出器研究の時間的猶予の差）

## ECFA DRD

（ヨーロッパの）international R&D Framework と協力する形をとる



# 1st Workshop on ILC Technology Network and Higgs factory detector development

Saturday 21 Jan 2023, 13:00 → 16:55 Asia/Tokyo

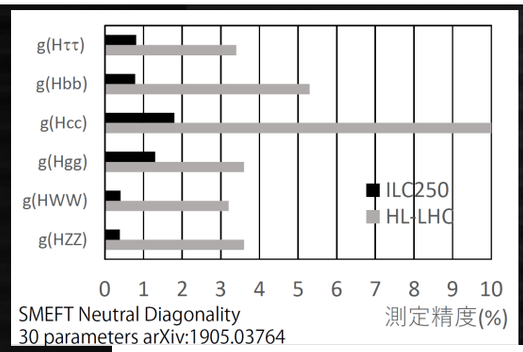
Kobayashi hall (KEK) + Zoom

東京大学 THE UNIVERSITY OF TOKYO

末原

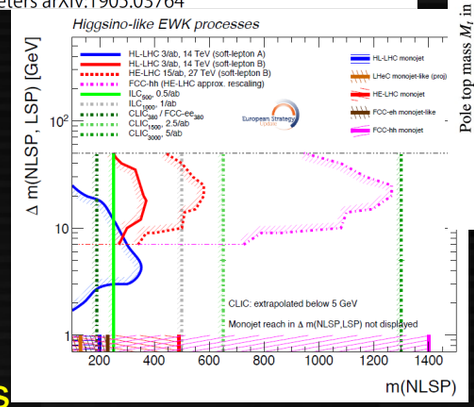
## TeV-scale new physics

- Extended Higgs sector (SUSY, composite Higgs, …)
  - Higgs couplings, SMEFT
- Direct search (SUSY, …)
  - Compressed spectrum
  - Mono-photon for WIMP
  - Long-lived etc.
- Indirect search (Z', WIMP, …)



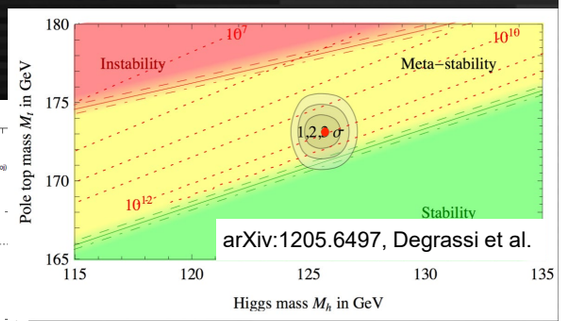

## Light new physics

- Higgs portal DM
  - Invisible/exotic decay of Higgs
- ALPs, dark photons, heavy stables
  - Fixed target, off-axis detectors



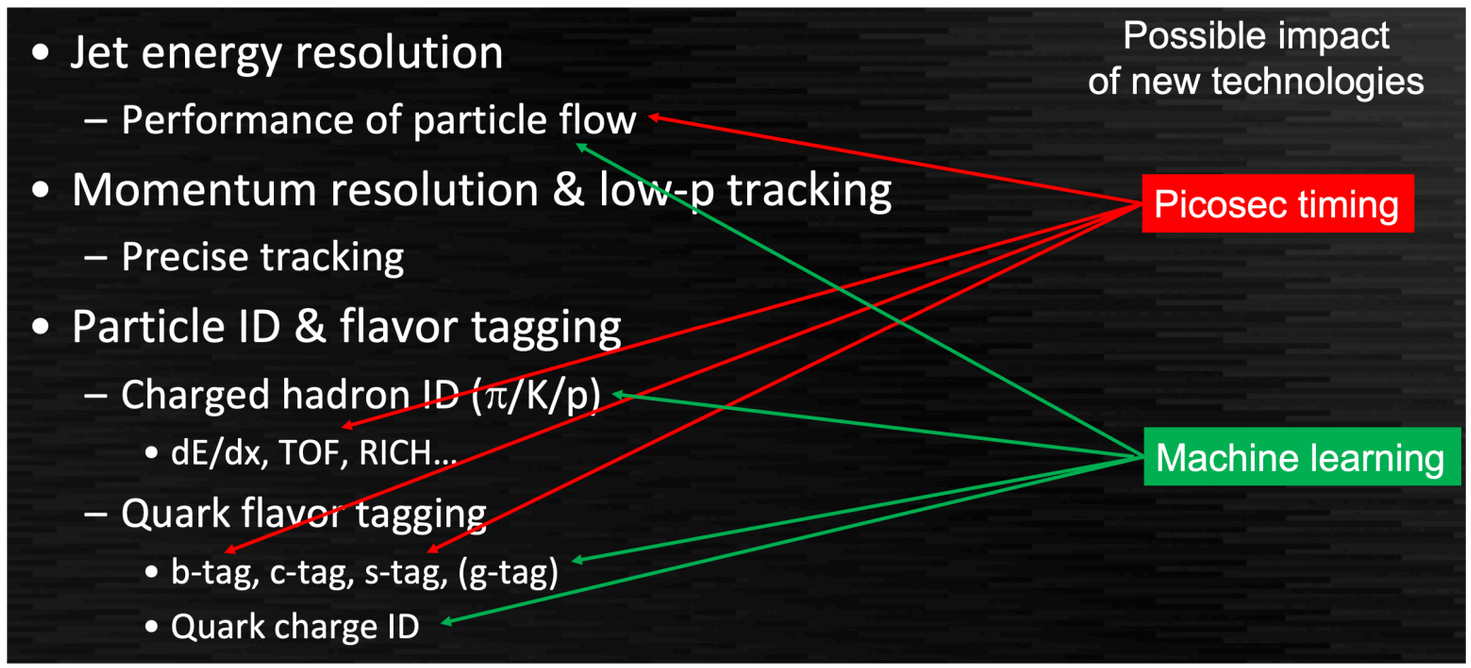

## Vacuum and spacetime

Higgs/top mass
Higgs self coupling
Higgs CP mixture




See JPS talk for details
https://kds.kek.jp/event/43097/contributions/222056/attachments/159589/204754/10pS1-04.pdf

## Key



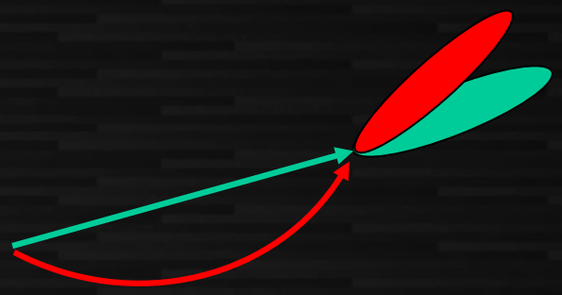

象徴的な例の１つが
Particle-Flow ⇒

# Δt & Machine-Learning ⇒ PFの性能向上

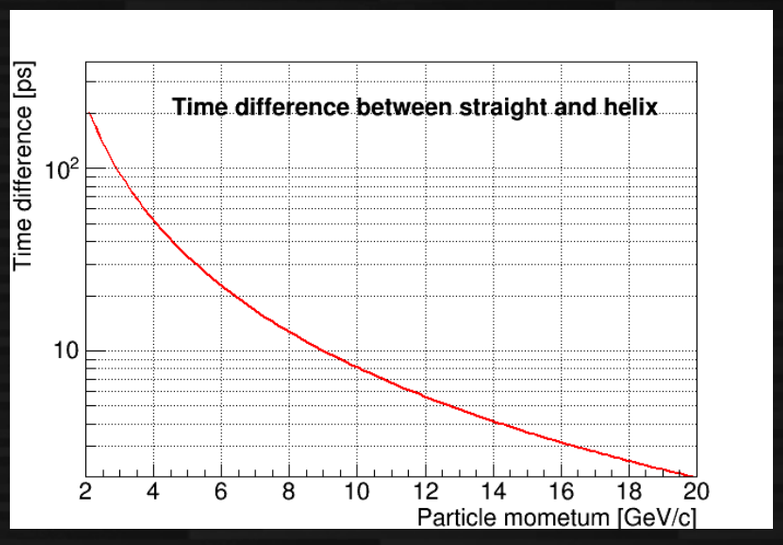
末原

## Picosec timing

5-dimensional clustering



Timing difference on charged and neutral clusters

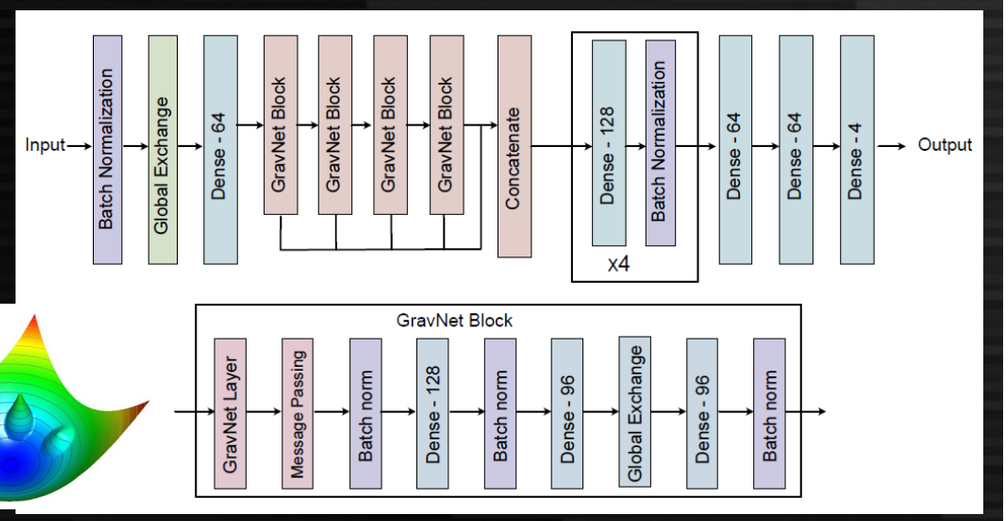



Timing resolution of EM cluster can be > 10 times higher than MIP thanks to averaging (intelligent pattern recognition necessary)

< 10 psec cluster resolution preferred

## Machine learning

- Current PFA is human-tuned → dependence on detector performance difficult to be seen
- 5D clustering with timing information
- Better performance for physics




Loss function



CMS HGCAL algorithm
Now trying to apply to ILC simulation

# KEK Energy Frontier Group からの提案 (1/21)

東京大学 THE UNIVERSITY OF TOKYO

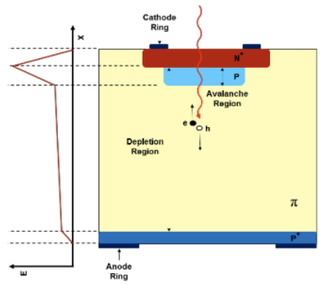
## KEK EFにおける重要な物理・専門性・優位性・国際性を総合的に考えた big picture

戸本

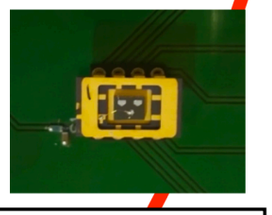
**将来実験への導入、建設、運転までを見据えたSolid state detectorの開発**

同時に、solid state detectorに不可欠な要素技術開発

- エレクトロニクス
- 機械学習
- 高磁場磁石



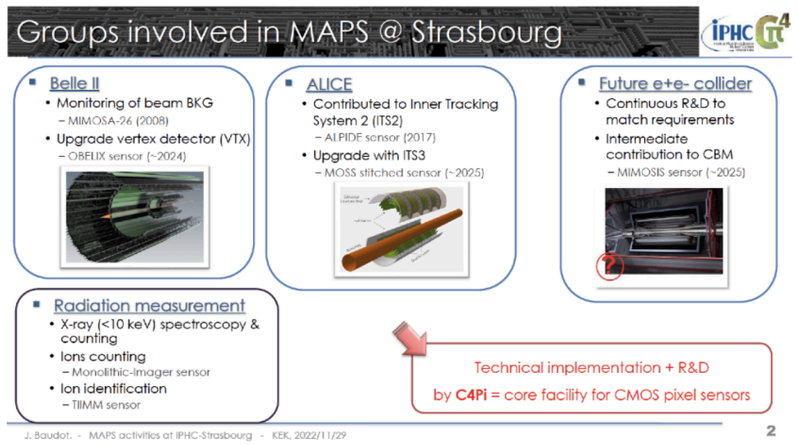

Low Gain Avalanche Diode(LGAD)



New material

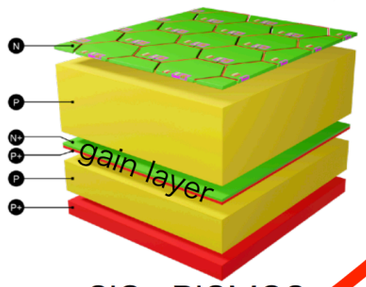
新素材、耐放射線性能が高いシリコンセンサー

radhard?




Monolithic CMOS

few $\mu$m spatial resolution




SiGe BiCMOS

Picosecond

~10 ps timing resolution

先行している欧州グループとの協同開発

- Monolithic CMOS sensor (CERN, Strasbourg)
- Pico-sec. Timing Resolution sensor (U. Geneva)

⇒ 自分たちで様々な開発ができるレベルに高める

- 最新かつmatureなtechnologyを使ったHiggs-Factoryの検出器デザインの提案 (as tracker)
- 高時間分解能 Calorimeter への応用可能性?

# KEK Energy Frontier Group からの提案 (1/21)

戸本

**Solid state detector：測定器開発センターを活用**

- Monolithic CMOS sensor with European groups
- Exploiting the properties of SiGe BiCMOS
- Explore LGAD capability
- Radiation hardness of semiconductor detectors
- R&D of the new material sensor

**Electronics：Collider Electronics Forumを活用**

- R&D for ultra high-speed date transfer (optical)
- AI on FPGA

**Machine Learning：AI Forumを活用**

- Application of AI/ML to detector operation
- Application of AI/ML to detector production and QC/QA
- Application of AI/ML to Object ID, track/vertex reconstruction

**Magnet：低温グループ、低温工学センターに協力**

- Feasibility study of the detector magnet
- Possibility of HTS

コミュニティの皆さんと進めたい

# ICEPPからの提案（1/21）

大谷

## Calorimeter Development

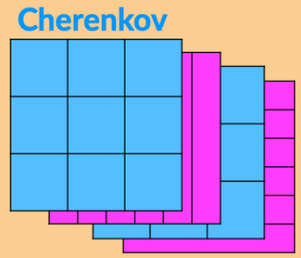
- High Granularity
- Excellent Timing Resolution O (10ps)

日米研究フレームワーク

**Dual-readout**

**Cherenkov detector**

Cherenkov radiator + UV-GasPM
- High-granularity readout
- psec timing
- Low-cost




**Scintillation detector**

SiPM-on-strip technology
- High-granularity
- low-cost

Fast timing front-end electronics

Simulation and analysis tools

Prototyping and beam test at FTBF

**Demonstrate performance of proposed calorimeter technology**

ターゲット性能に対して、可能な実装の方法は複数存在して、altenativeなアイデアもありえる
実現が必要な時期、　テクノロジーの選択に対する大きな要因

時間軸も考えながら、high-performance, robust, cost conscious なデザイン追求・demo w/ プロトタイプ

# 検出器開発に関する提案

**Solid state detector：測定器開発センターを活用**

- Monolithic CMOS sensor with European groups
- Exploiting the properties of SiGe BiCMOS
- Explore LGAD capability
- Radiation hardness of semiconductor detectors
- R&D of the new material sensor

**Electronics：Collider Electronics Forumを活用**

- R&D for ultra high-speed date transfer (optical)
- AI on FPGA

**Machine Learning：AI Forumを活用**

- Application of AI/ML to detector operation
- Application of AI/ML to detector production and QC/QA
- Application of AI/ML to Object ID, track/vertex reconstruction

**Magnet：低温グループ、低温工学センターに協力**

- Feasibility study of the detector magnet
- Possibility of HTS

**Calorimeter Development**

- High Granularity
- Excellent Timing Resolution ○ (10ps)

**Machine Learning**

**量子センサー**