Highlights of Detector/Simulation Presentations

International Workshop on the Circular Electron-Positron Collider

The University of Chicago - Michelson Center for Physics

September 16-18, 2019

Jianming Qian

University of Michigan

History

Reminder about the CEP

Kick-off on Sept. 13, 2013 - inspired by the discovery of the Higgs boson at the LHC

X. Lou

CEPC study group formed in Beijing

PreCDR, March 2015 – initial investigations; no-show stoppers, identified issues & R&D

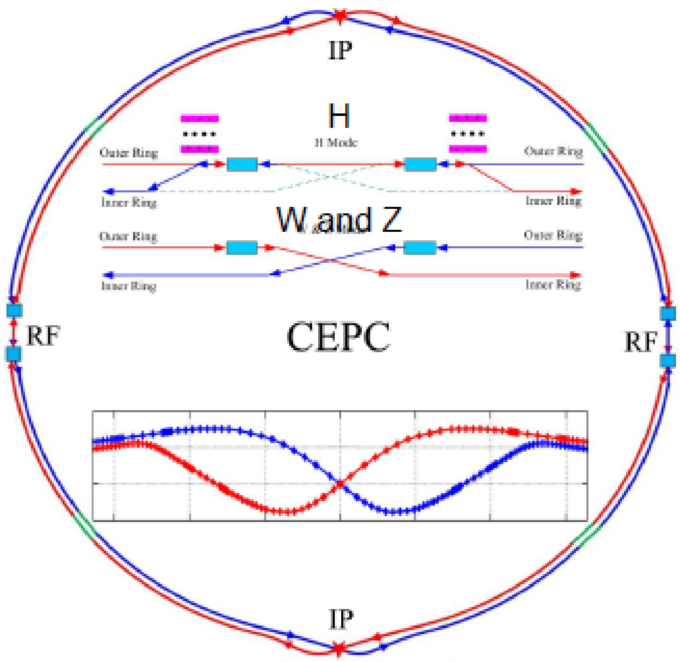
Funding, R&D, international collaboration, … – continuing effort since 2013

CDR, August-October 2018 – scientific goals well justified & aligned with intl priorities; endorsement for moving towards TDR, and …

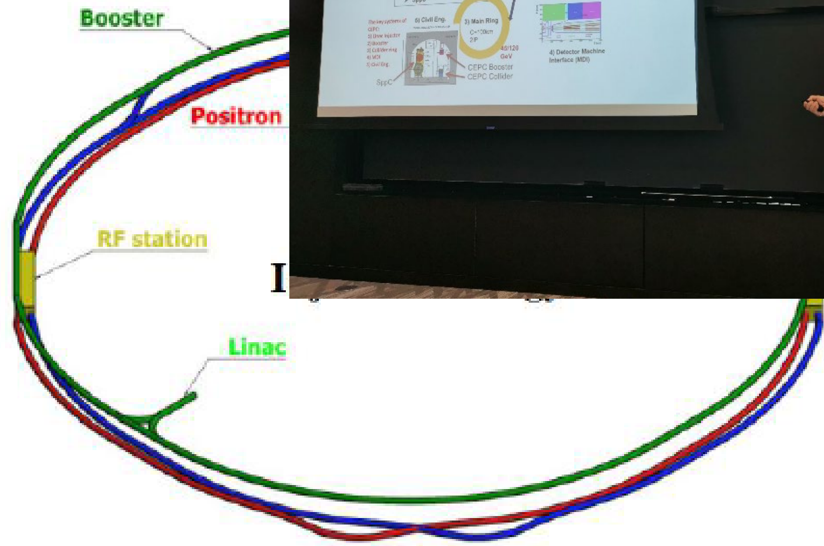
CEPC accelerator TDR, DRD, luminosity enhancement, international collaboration, …

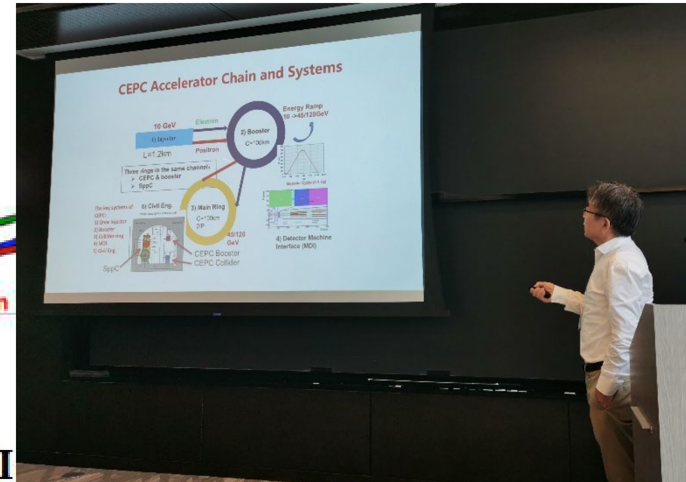
Accelerator Design and R&D

J. Gao

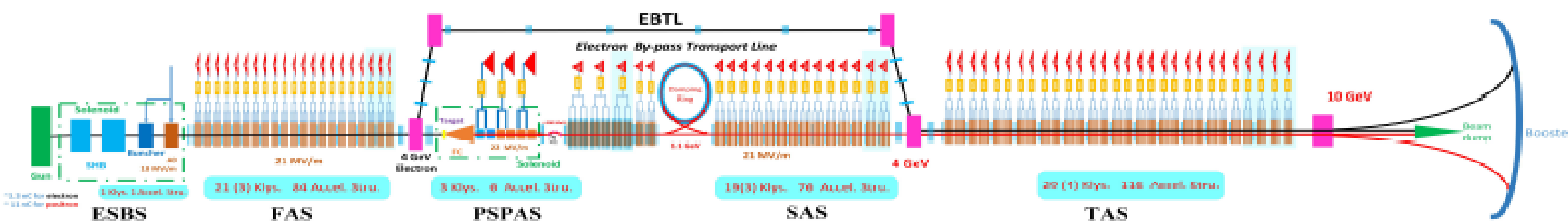


CEPC collider ring (100km)





CEPC booster ring (100km)



CEPC Linac injector (1.2km, 10GeV)

Forward Region

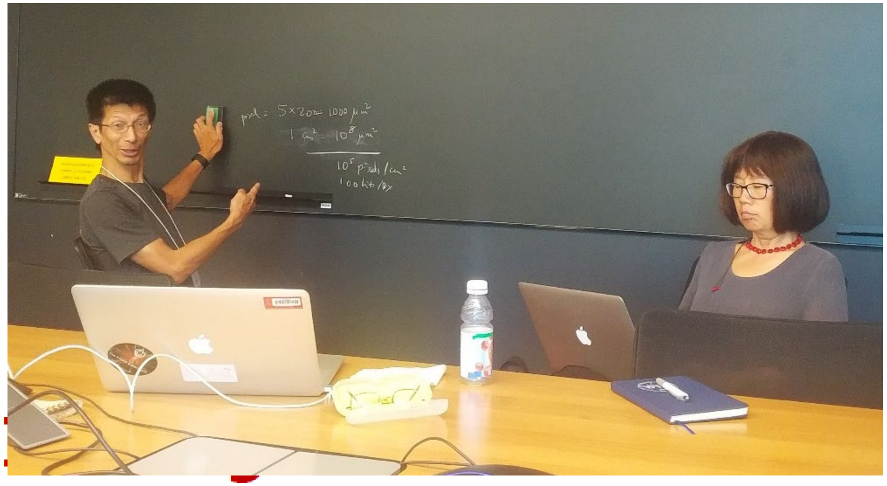
MDI issues - accelerator

Speaker: Jie Gao (Institute of High Energy Physics, China)

CEPC MDI-V1.pdf

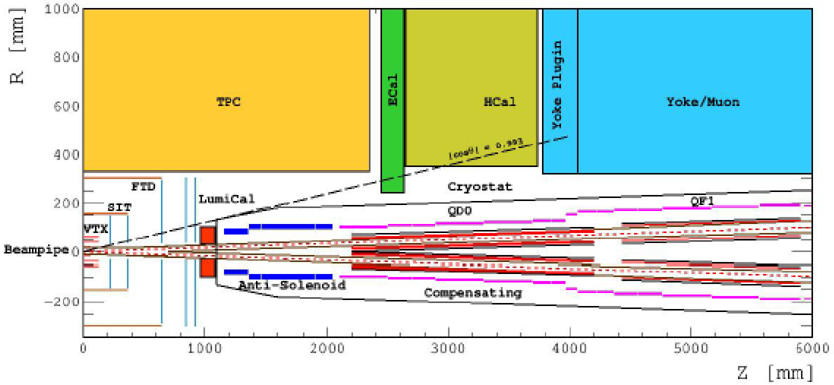
Beam induced background at IP

Speaker: Haoyu Shi (IHEP)

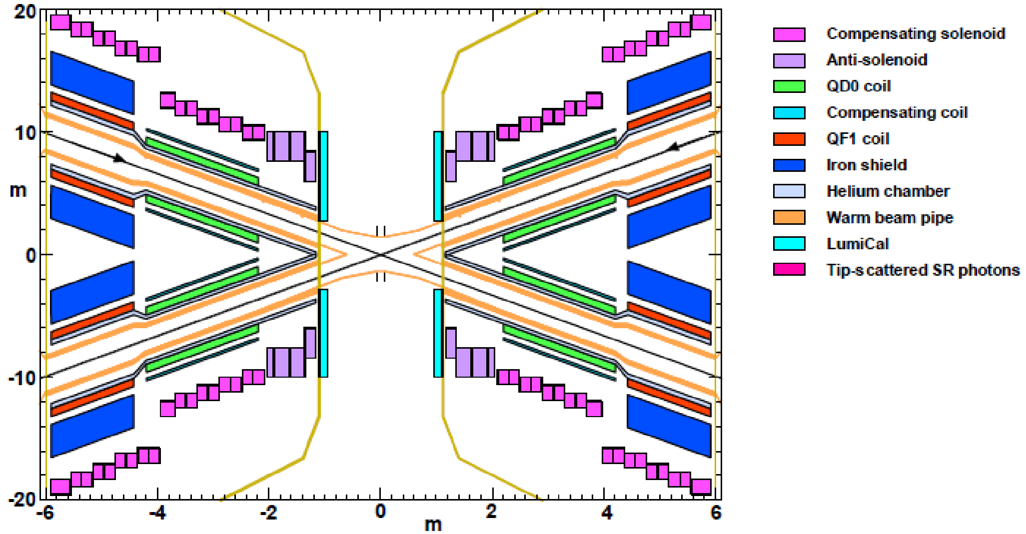


Layout and

With Detector solenoid



Without Detector solenoid
~cryostat in detail



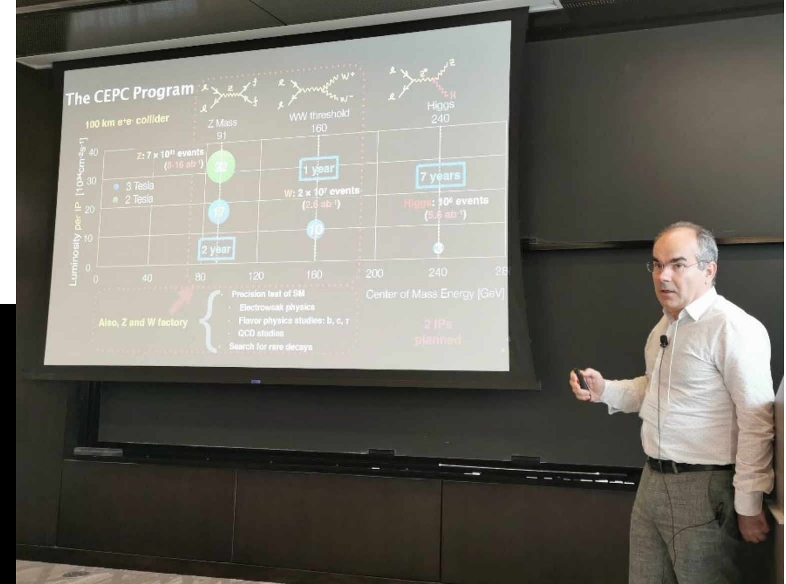
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

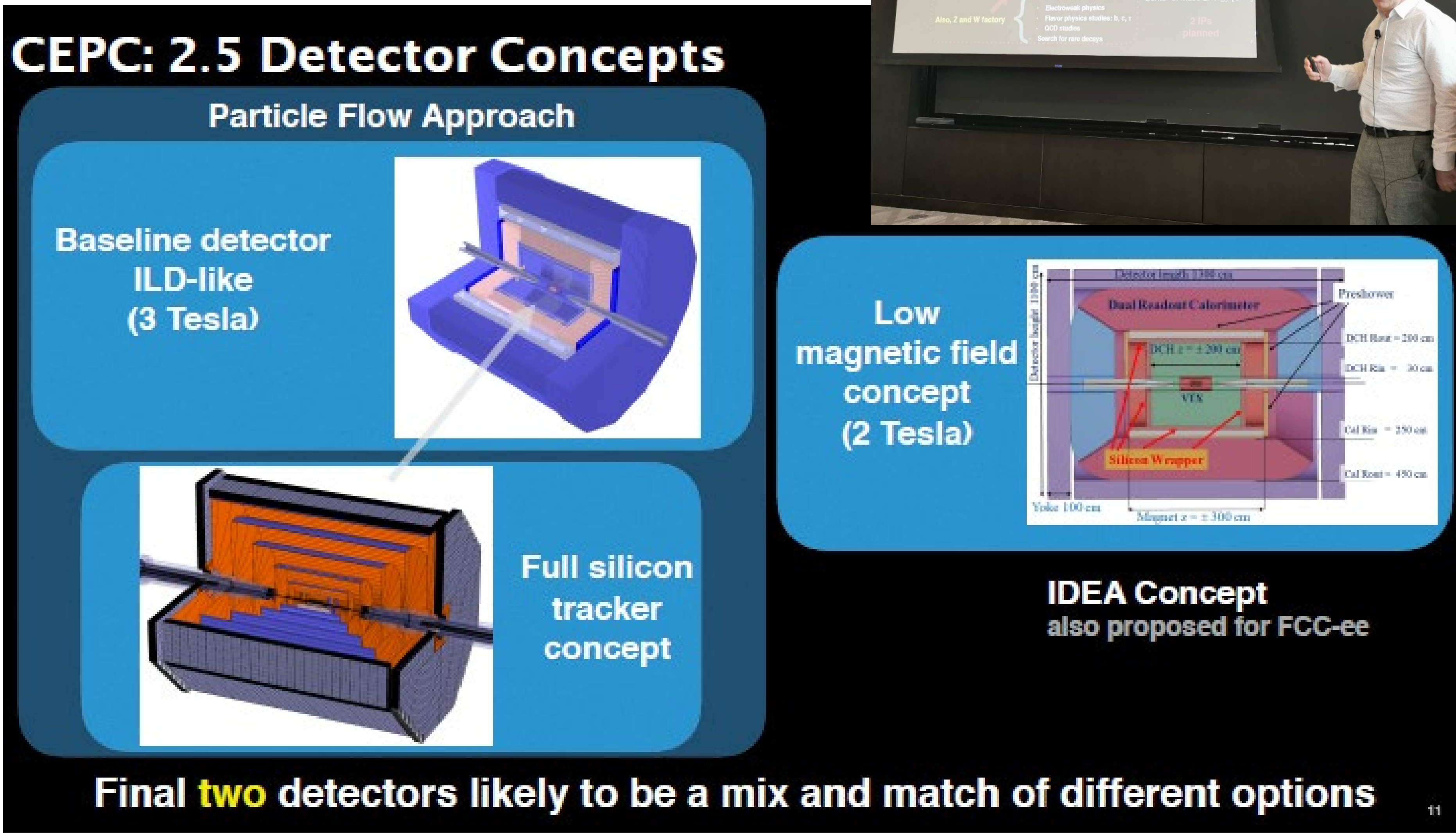
J. Gao

- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP
- The CEPC detector superconducting solenoid with 3T magnetic field and the length of 7.6m.

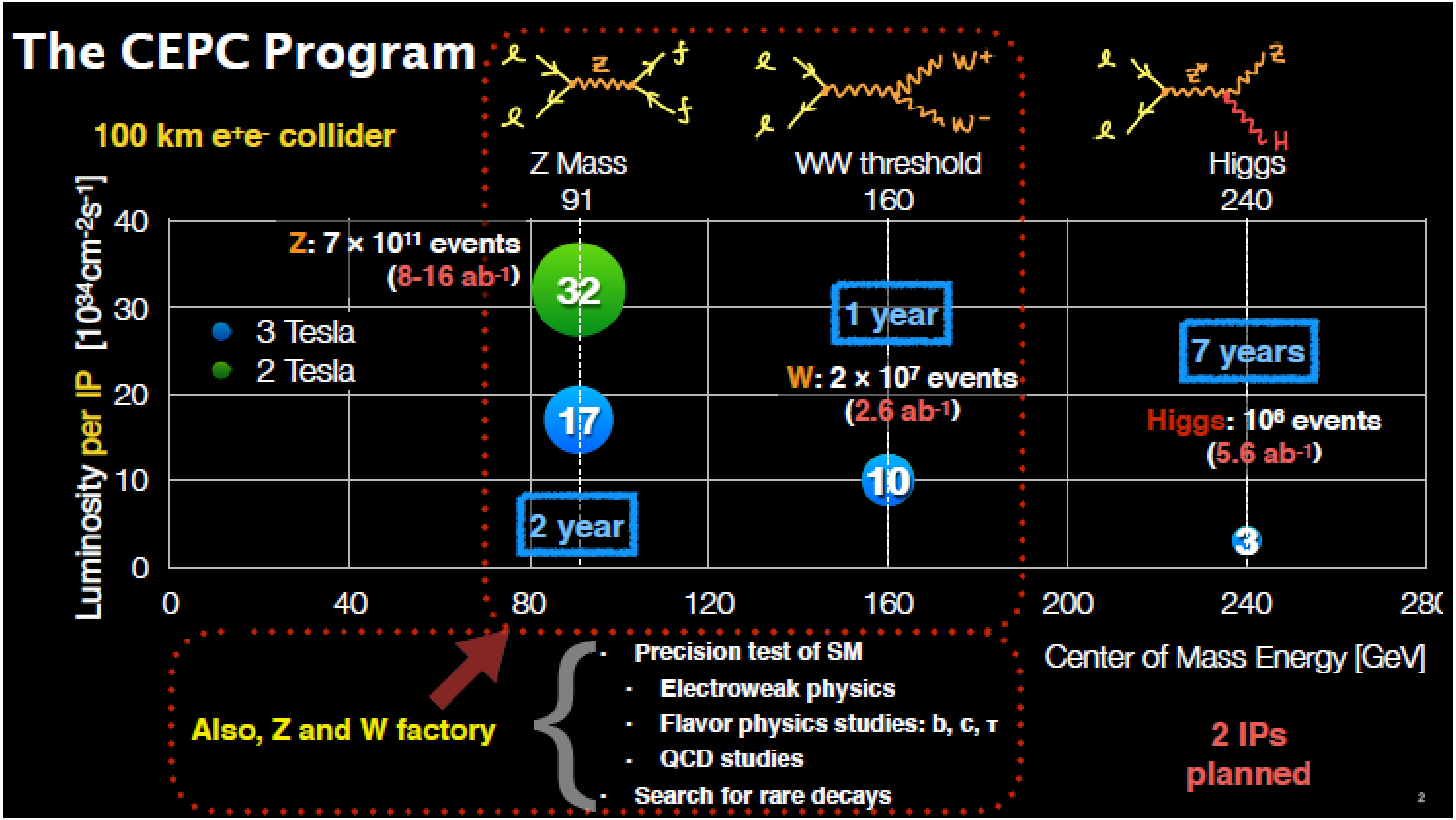
Detector Concepts

J. Guimaraes Da Costa





Rich Physics Program



J. Guimaraes Da Costa

Performance Requirements

Benchmark Physics Requirements

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta}(\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Table 3.3: Physics processes and key observables used as benchmarks for setting the requirements and the optimization of the CEPC detector.

Tracking

CEPC Tracking

Speaker: Charlie Young (SLAC National Accelerator Laboratory (U

CEPC tracking.pdf

CEPC Tracking R&D

Speakers: Paolo Giacomelli (Universita e INFN, Bologna (IT)), Pa

Tracking-R&D-CEPC... Tracking-R&D-CEPC...

CEPC Tracking - new ideas

Speaker: Wei-Ming Yao (Lawrence Berkeley National Lab. (U

cepc_tracking_chic...

Pixel detector development in China

Speaker: Qun Ouyang (Chinese Academy of Scienc

CEPC-vertex-Chicag...

Three alternative concepts

- Baseline
  - Vertex detector (VXD)
  - Main tracker: Time Projection Chamber (TPC) + inner and outer silicon tracker
- Full Silicon Tracker
  - Same vertex detector
  - Full silicon tracker
- Drift chamber
  - Similar vertex detector
  - Drift Chamber Tracker + silicon wrapper

C. Young

Momentum Resolutions

- All concepts rely on multiple layers of silicon detectors for momentum resolution, especially at outermost radius
- Thus, area of silicon is not dramatically different

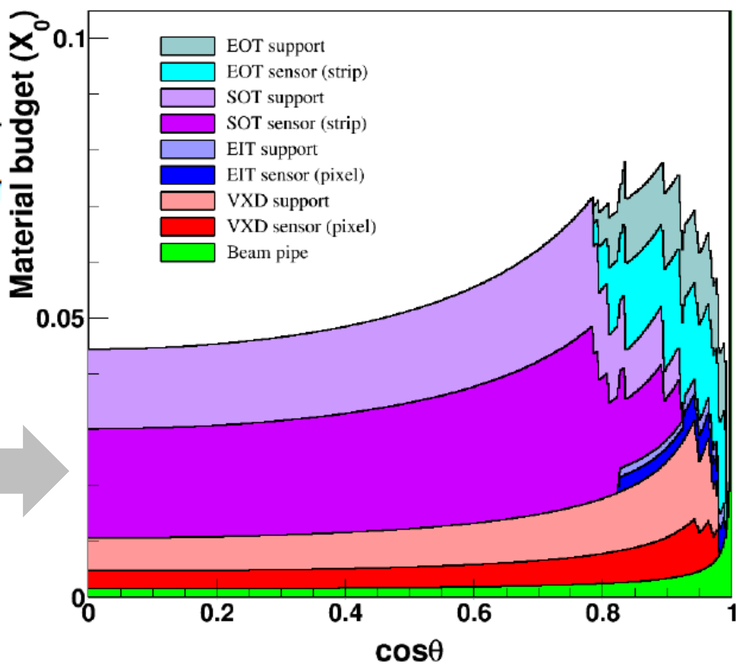
- Multiple scattering term is 1.5× to 2× of goal.
- Need to reduce (silicon) material by factor of 2 to 4.
- Historically, our initial estimates have often turned out to be under-estimates…

- Contribution from measurement uncertainty in drift concept is much too large. Remedy is likely to be m layers, which will make multiple scattering term wo

The material in tracking not only degrades the track momentum resolution, but also the EM energy resolution!

C. Young

Full silicon tracker material.
Is it realistic?

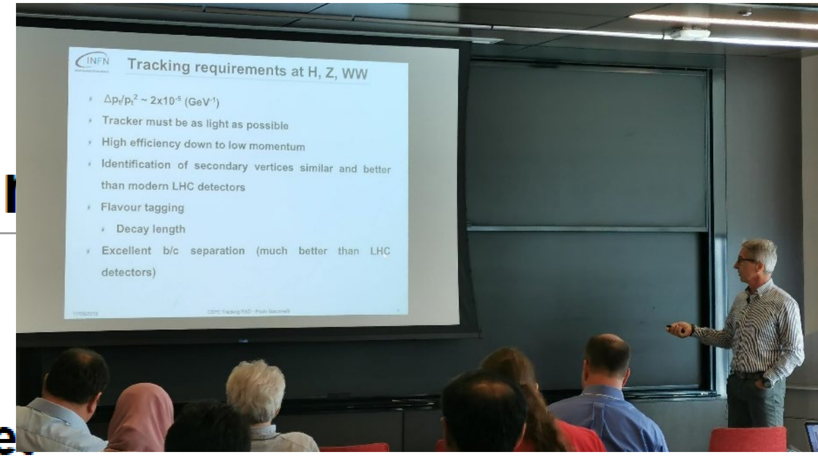


Tracking R&D

Central trackers: challen

- Silicon tracker
  - Number of layers
  - As low as possible material budge
    - Very thin detectors
- TPC
  - Ion backflow
  - Calibration and alignment
  - Low power consumption FEE ASIC (
  - Mechanical and distortion challenge
- Wire chamber
  - Very long wires, ~4m
  - New wire materials, with or without r
  - Cluster counting

17/09/2019 CEPC Tracking R&D - Paolo Giacomelli



P. Giacomelli

R&D activities

- **Initial sensor R&D targeting on**
  - *Pixel single point resolution 3- 5μm*
  - *Power consumption at the current level <100mW/cm²*
  - *Integration time 10-100μs*
  - *Time stamp of 25ns*
  - ➢ CMOS pixel sensor (CPS)-funded by MOST and IHEP
    TowerJazz CiS 0.18 μm process
  - ➢ SOI pixel sensor- funded by NSFC and IHEP
    LAPIS 0.2 μm process
- **Prototype with double-sided ladders**
  - *PLUME design concept with light structure*
  - *Verification of VTX design concept, impact parameter resolution ~5μm, and timing precision of 25-50ns*
  - *Cooling technology investigated*

Q. Ouyang

Tracking – New Ideas

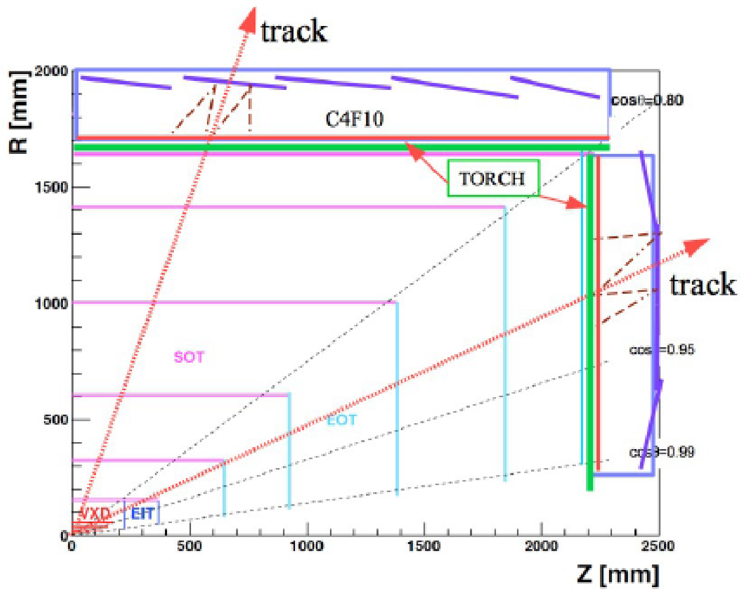
W.M. Yao

Improving FST with PID option

•To mitigate some concerns for FST:

–Limited dE/dx:

–Extra material from double sided strip layers.



•We propose:

–Replacing strip layers with HV-CMOS pixelated sensors.

–Add TORCH and RICH (C4F10) after the tracker to provide PID up to 30 GeV.

•R&D: minimize material and fast photon detection (MCP-PMT,SIPM)

•$dN/dx=2\pi\alpha(1-1/n^2)(1/\lambda_L-1/\lambda_H)\varepsilon$

•Quartz
- n=1.46
- λ=350-900 nm
- ε=0.30
- L=0.25cm(2%X0)
- N=30

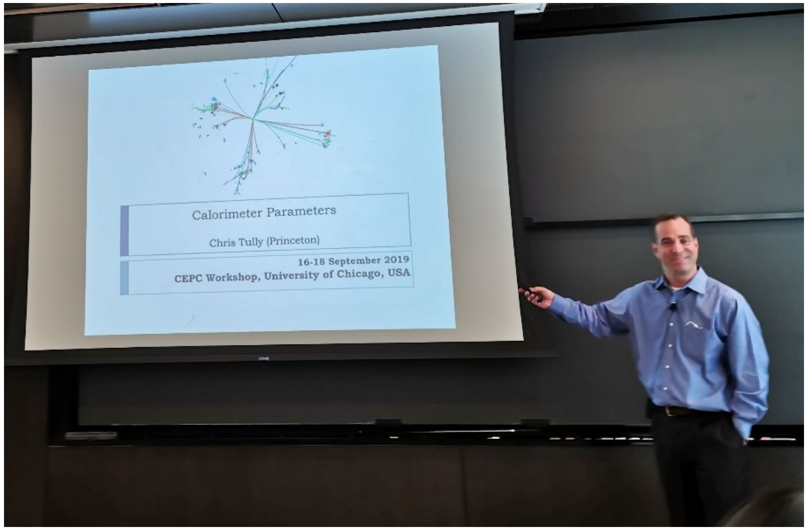
•C4F10:
- n=1.0014
- L=30 cm(1.7%X0)
- N=20

18

Limited benefits for Higgs running, but important for the flavor physics at the Z pole running.

What are viable options, can it be staged?

Calorimetry



CEPC Calorimetry
Speaker: Chris Tully (Princeton University (US))
CaloTully.pdf | CaloTully.pptx

CEPC Calorimetry R&D
Speaker: Franco Bedeschi (Universita & INFN Pisa (IT))
Bedeschi_Calorimet... | Bedeschi_Calorimet

CEPC Calorimeter - new ideas
Speaker: Sarah Eno (University of Maryland (US))
AlternativeCalorime...

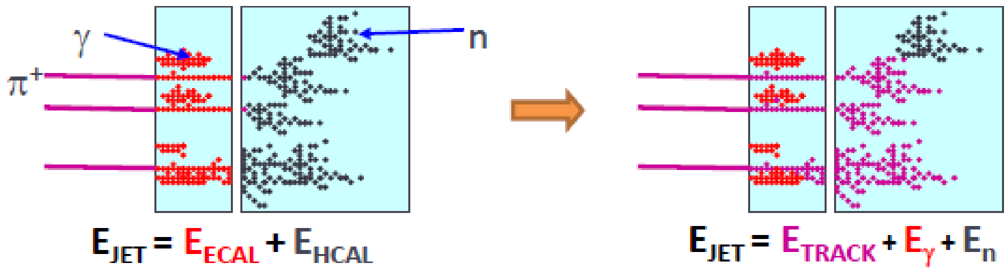
Pixel detector development in China
Speaker: Qun Ouyang (Chinese Academy of Scienc

Role of Calorimetry

- **Traditionally, Calorimetry has produced low granularity images of event energy flow with good but limited success in augmenting Particle Flow**
  - Technologies for high S/N from highly granular segmentation were limited and either power or cost prohibitive
  - Highly granular technologies often have low sampling fraction and provide stochastic noise limited input to PFA
- **Fundamentally, precision tracking is the leading instrument to PFA and Calorimetry strives to complement this information (several measures)**
  - #1: Well measured, well identified Photons/Electrons
  - #2: Electron/Pion separation
  - #3: Hadronic shower measurement and containment
  - #4: Pion/K0Long separation
  - #5: MIP calibration/Cell response uniformity

C. Tully

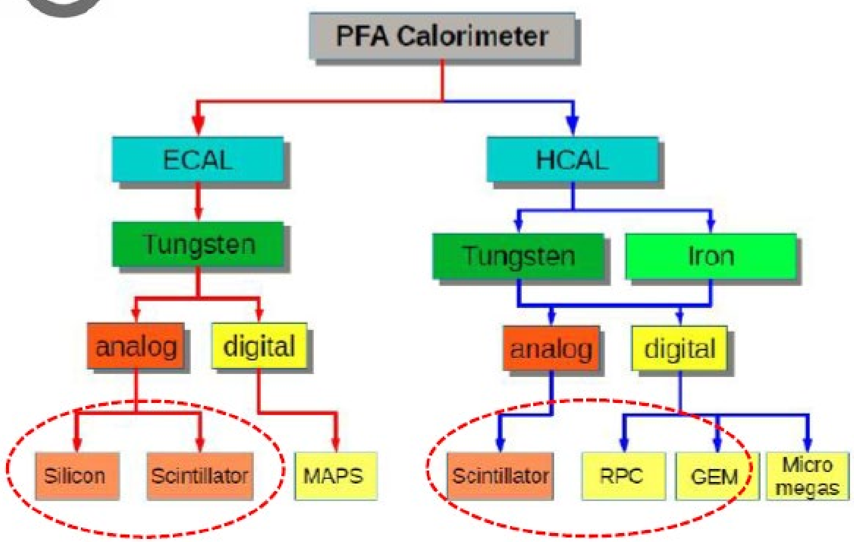
PFA Calorimetry



C. Tully

PFA Calorimeters

https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers



SiW ECAL
ScW ECAL

AHCAL: Scintillator + SiPM
SDHCAL: RPC & THGEM

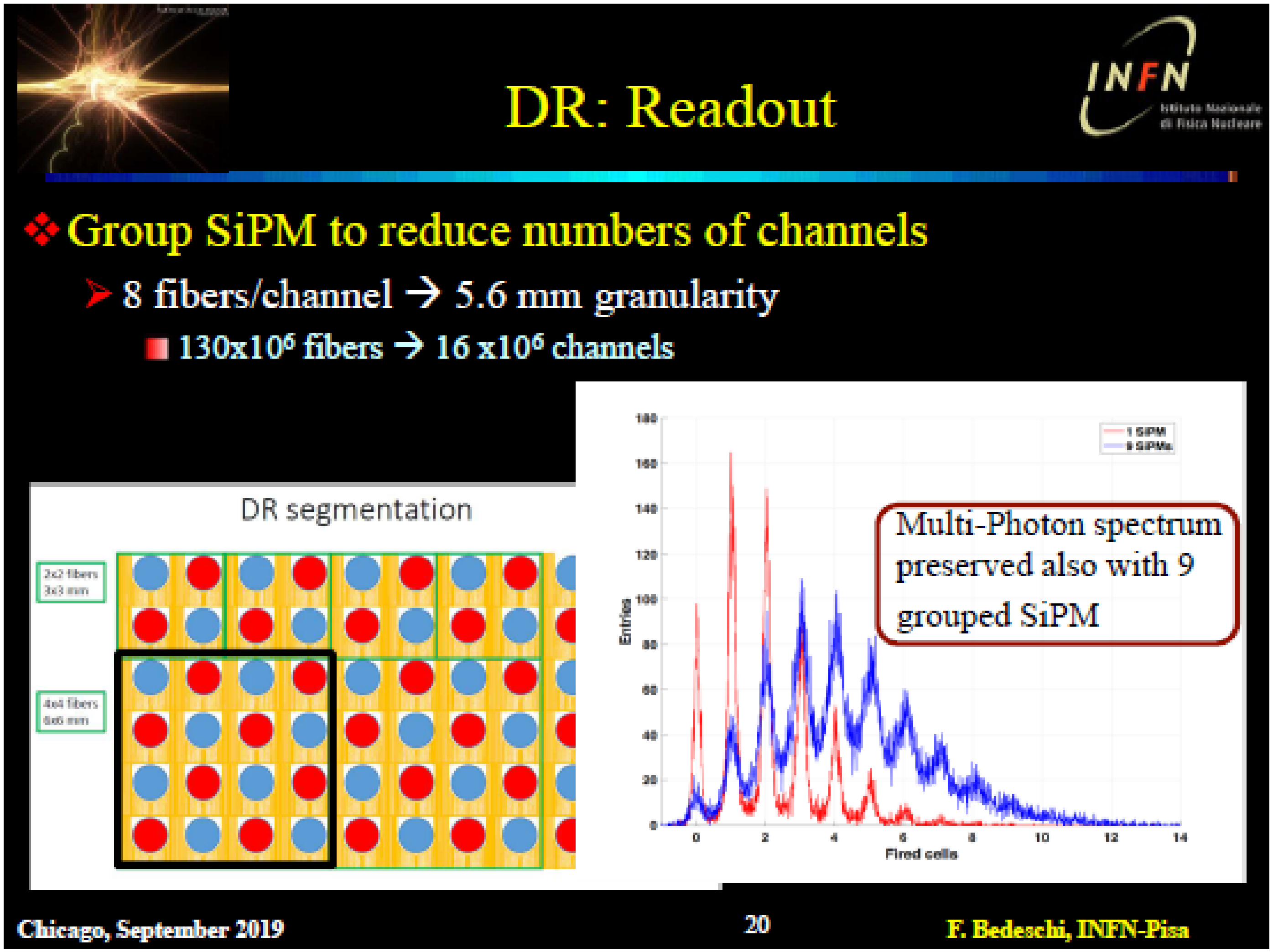
Many different options for the PFA design

Extensive R&D under CALICE umbrella

H. Yang

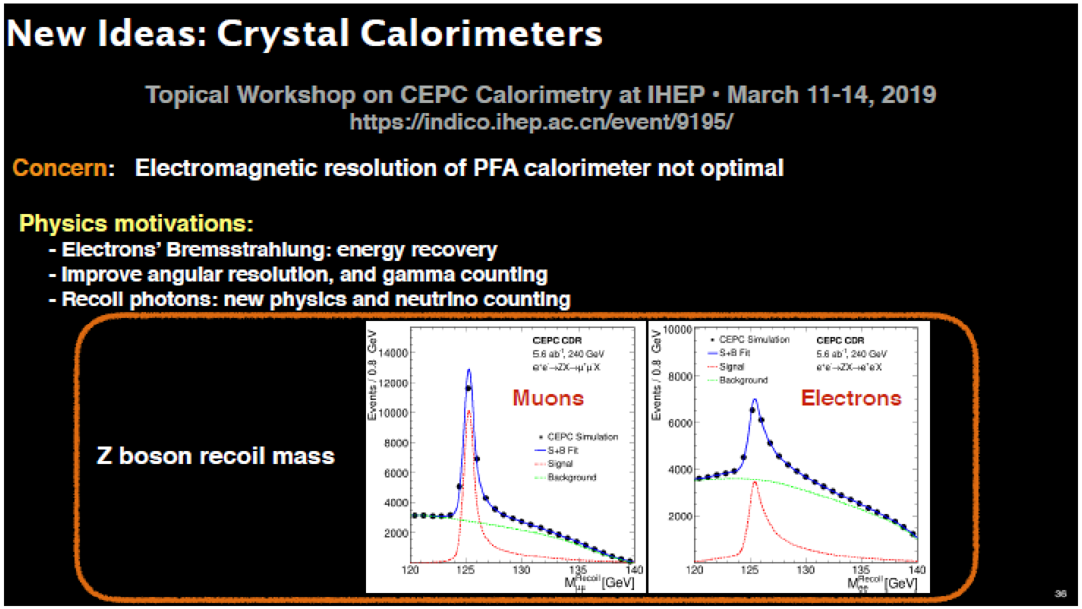
Calorimetry R&D

Cost is a major concern of a DR calorimeter



F. Bedeschi

ECAL Resolution

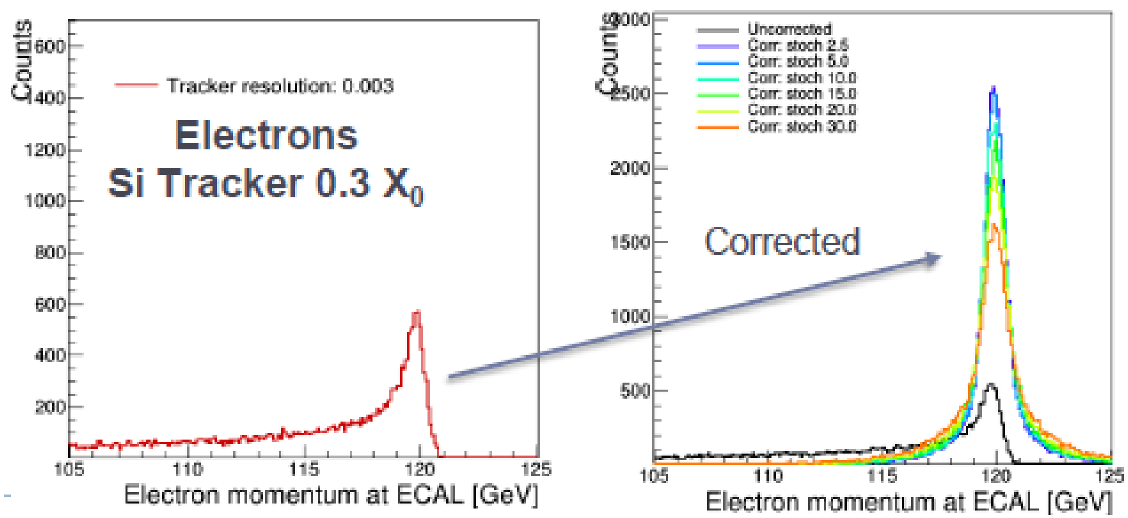


J. Costa

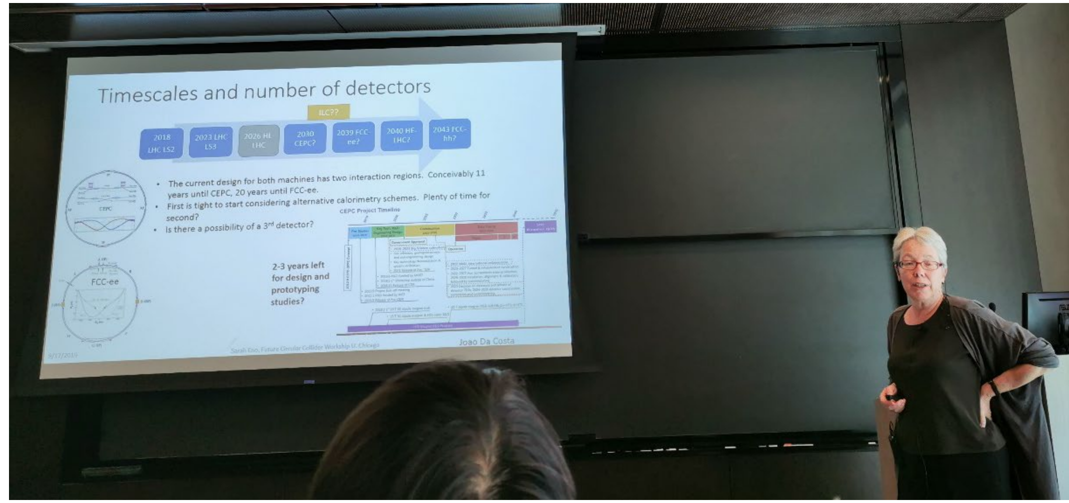
C. Tully

Good EM energy is important for the electron energy resolution.

Impact for EW and flavor physics need to be understood.



A Crystal ECAL?

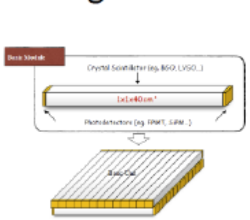


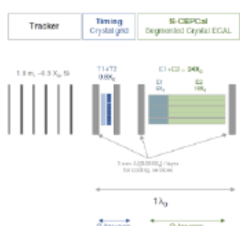
A crystal ECAL?

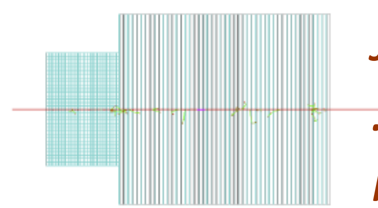
Overview: designs of crystal ECAL

S. Eno

- 3 major designs being pursued
  - Long crystal bars with optical readout at both ends (Y. Wang, et al.)
    - Use timing information for hit positions; less #channels
  - Long crystal bars with optical readout at single ends (C. Tully, et al.)
    - Less segmentation in the longitudinal direction; space for cooling
  - Thin crystal tiles with optical readout at single ends (Y. Liu, et al.)
    - Started with ultra-fine segmentation (both longitudinal and transverse)
    - Seeking trade-off between #channels and performance







Excellent EM energy resolution, what's geometry? What's its capability for PFA? How does it impact Jet energy resolution? …

Many questions to be answered.

Simulation and Analysis Tools

Machine Learning for future colliders

Speaker: Benjamin Henry Hooberman (Univ. Illinois at Urbana Champaign (US))

Chicago_FutureColli...

HepSim: A public Monte Carlo repository with physics and detector simulations

Speaker: Sergei Chekanov (Argonne National Laboratory (US))

HepSim_cepc_2019...

CEPC detector simulation

Speaker: Manqi Ruan (Chinese Academy of Sciences (CN))

1_Simulation and P...

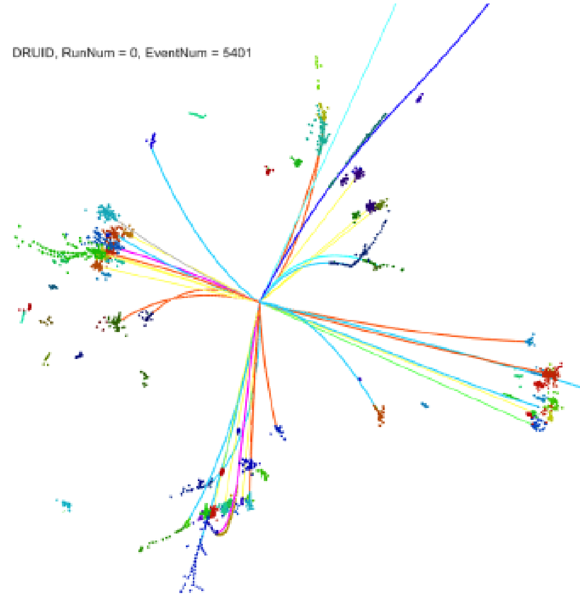
Jet algorithms and hadronic signatures for e+e- colliders

Speaker: David Miller (University of Chicago (US))

Miller_eeJetAlgorith...

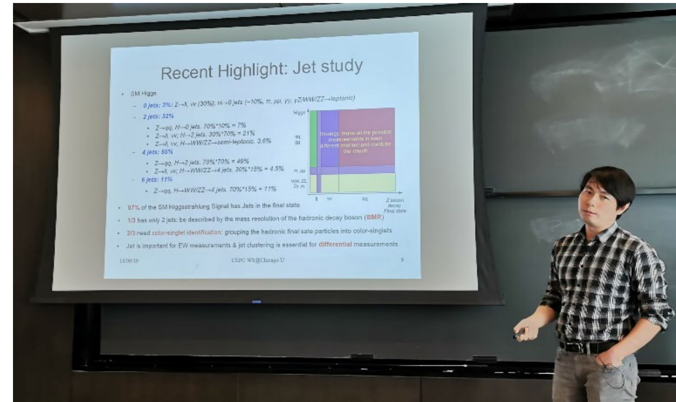
Higgs studies at 240 and 360 GeV (by vidyo)

Speaker: Kaili Zhang



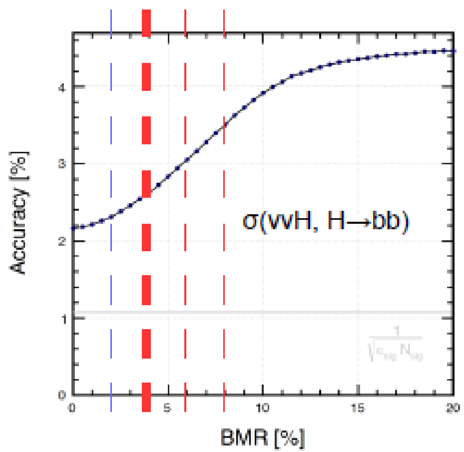
Correct classification of hadronic events into 2, 4 and 6 jets is a major part of the physics analysis!

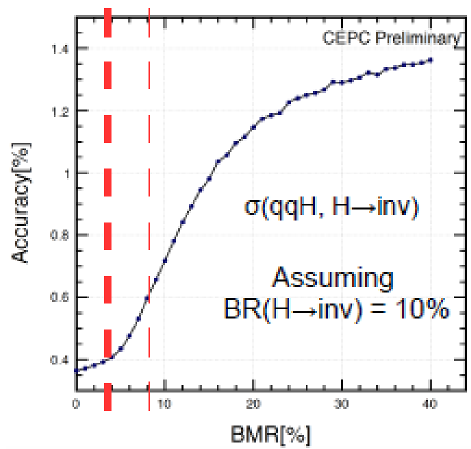
Detector Simulation

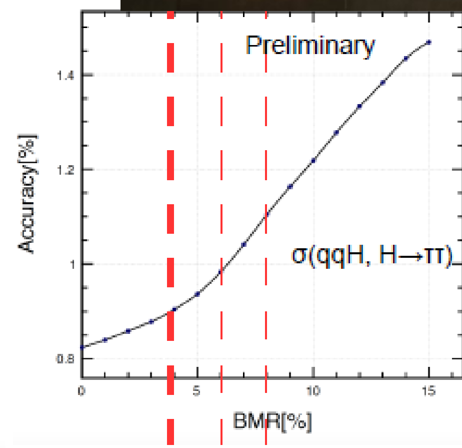


M. Ruan

Requirement from benchmark BMR < 4%







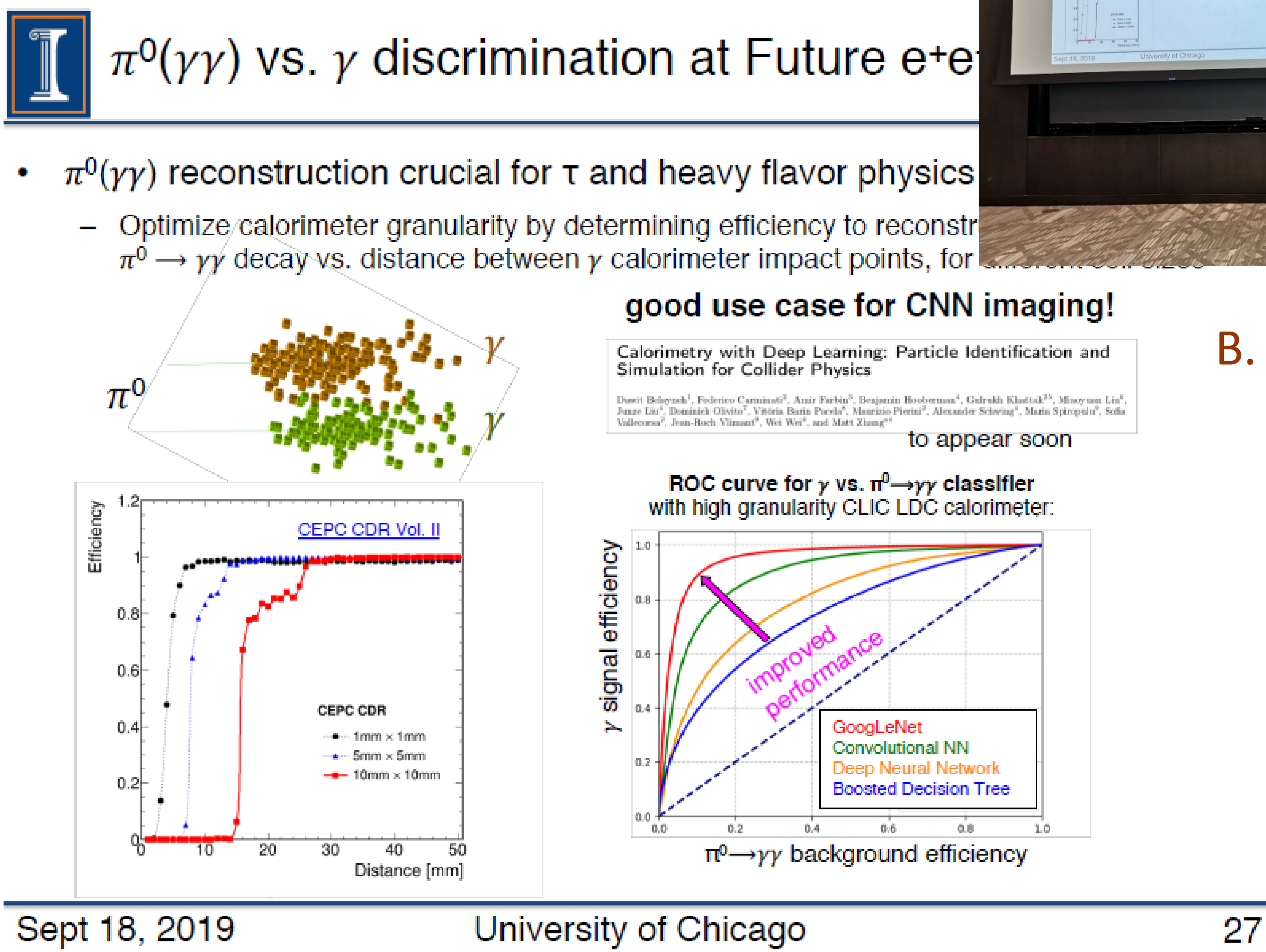
- Boson Mass Resolution: relative mass resolution of vvH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

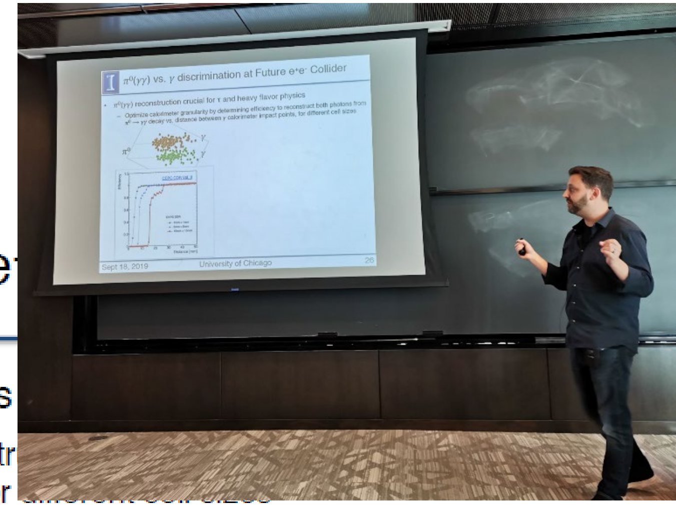
	BMR = 2%	4%	6%	8%
σ(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

18/09/19 CEPC WS@Chicago U 14

How does JER affect BMR? What is the impact of slightly degraded FPA capability? Can ML help?

Machine Learning



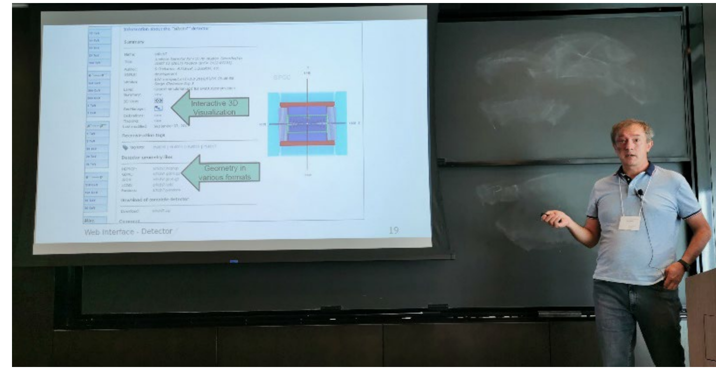


B. Hooberman

How can ML help the detector design?

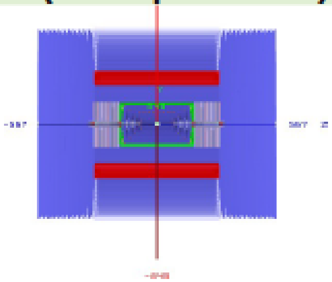
HepSim

S. Chekanov

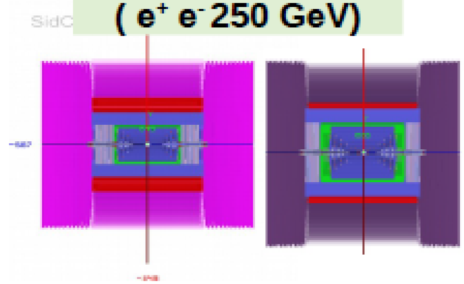


‘All-silicon’ design concepts supported in HepSim

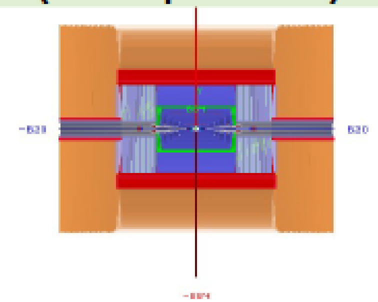
SiD (SiD LO3)
($e^+ e^-$ up to 1 TeV)



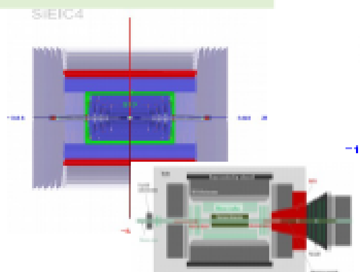
SiCPEC, SiDB
($e^+ e^-$ 250 GeV)



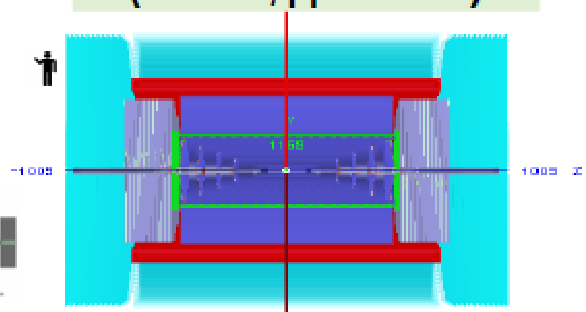
CLIC-SiD (CDR)
($e^+ e^-$ up to 3 TeV)



SiEIC, TopSide
(ep, 35-141 GeV)



SiFCC + 7 variations
(FCC-hh, pp 100 TeV)



Performance detectors:

- Physics reach studies using Geant4 simulations & full reconstruction
- Playground for various technologies and detector optimizations
- Fast turnover to modify detector & create events samples

Share similar design, but differ in sizes, calorimeter readouts etc
Interfaced with common Monte Carlo samples

Remarks

The detector concepts proposed should be viewed as starting points for discussion and optimization.

Some of the arguments for ILC-inspired designs are based on physics and knowledge long time ago. How the (non)discovery change the situation?

Should revisit the detector requirements given what we know now taking into account the cost. How will the advancements of ML techniques impact the detector design?

How can US physicists get involved and contribute?

Remarks

Physics:

Extensive studies of Higgs physics and its requirements,
but not so for Electroweak, flavor and QCD physics.
Are there unique detector requirements for those physics?

Tracking:

- What physics drives for the momentum resolution requirement beside the $H\to\mu\mu$ decay?

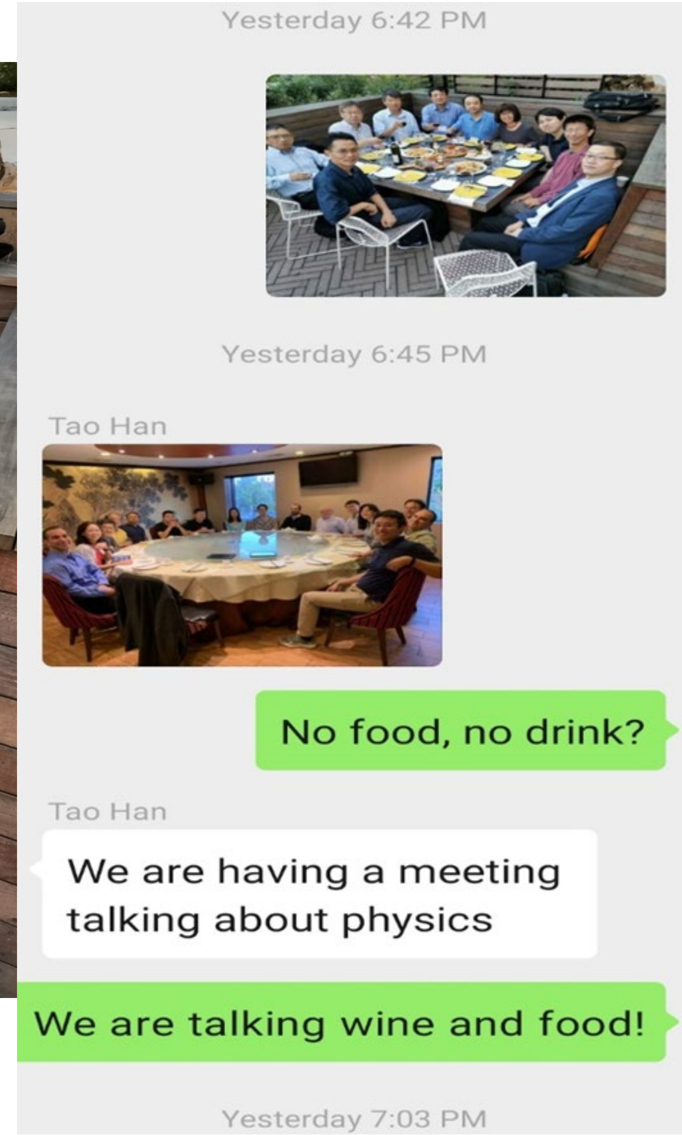
$$\Delta\left(\frac{1}{p_T}\right) \sim 2\times10^{-5}$$

  What will be the loss if the tracking volume is slightly reduced?
- Can the tracking material be controlled below 0.3X0 ? What kind of particle ID capability do we need? Can TPC handle Z pole running?

Calorimetry:

- Tradeoff between EM and jet energy resolutions: physics gains and losses?
- What kind of HCAL should a crystal ECAL be paired with?
  What is the expected jet energy resolution?
- How each option can be calibrated? Can the design be further optimized to reduce cost…

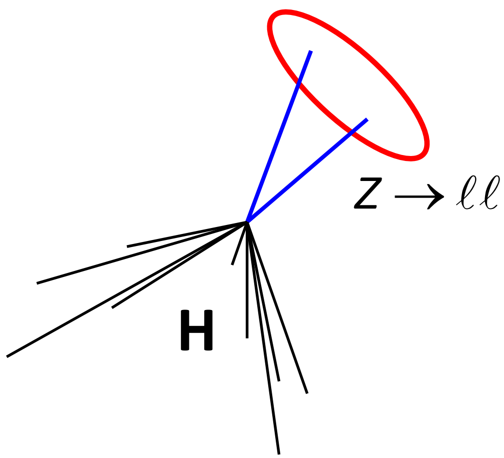

ALONTI

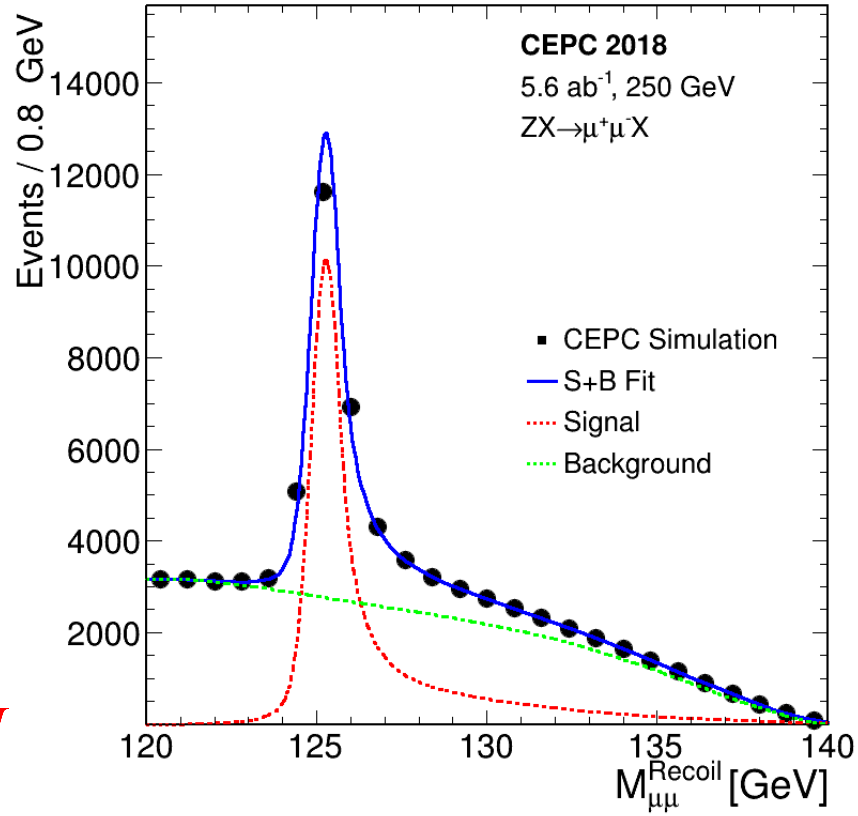

Yesterday 6:42 PM
Yesterday 6:45 PM
Tao Han
No food, no drink?
Tao Han
We are having a meeting talking about physics
We are talking wine and food!
Yesterday 7:03 PM

The End

Higgs Boson Tagging

Unique to lepton colliders, the energy and momentum of the Higgs boson in $ee \to ZH$ can be measured by looking at the Z kinematics only: $E_H = \sqrt{s} - E_Z, \quad \vec{p}_H = -\vec{p}_Z$





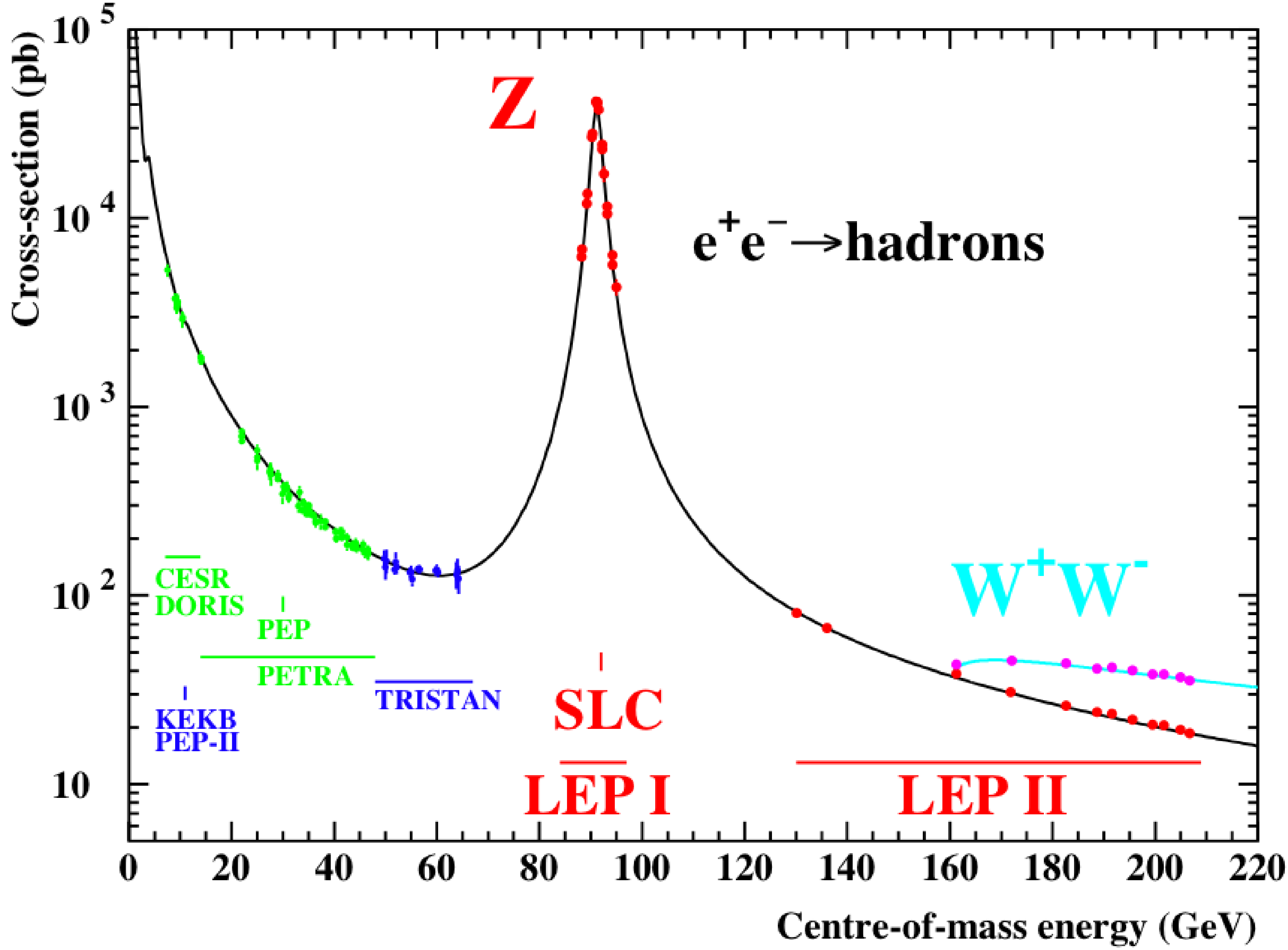
Recoil mass reconstruction:

$$m^2_{\text{recoil}} = \left(\sqrt{s} - E_Z\right)^2 - \left|\vec{p}_Z\right|^2$$

$\Rightarrow$ Identifying the Higgs boson without looking at it. Measuring $\sigma(ee \to ZH)$ independent of its decay !

LHC always measures $\sigma \times BR$, no model-independent way to distangle decay from production!

LEP



Z
$e^+e^- \rightarrow$ hadrons
W^+W^-
CESR
DORIS
PEP
PETRA
TRISTAN
KEKB
PEP-II
SLC
LEP I
LEP II
Cross-section (pb)
Centre-of-mass energy (GeV)