Muon Reconstraction at the CMS Experiment

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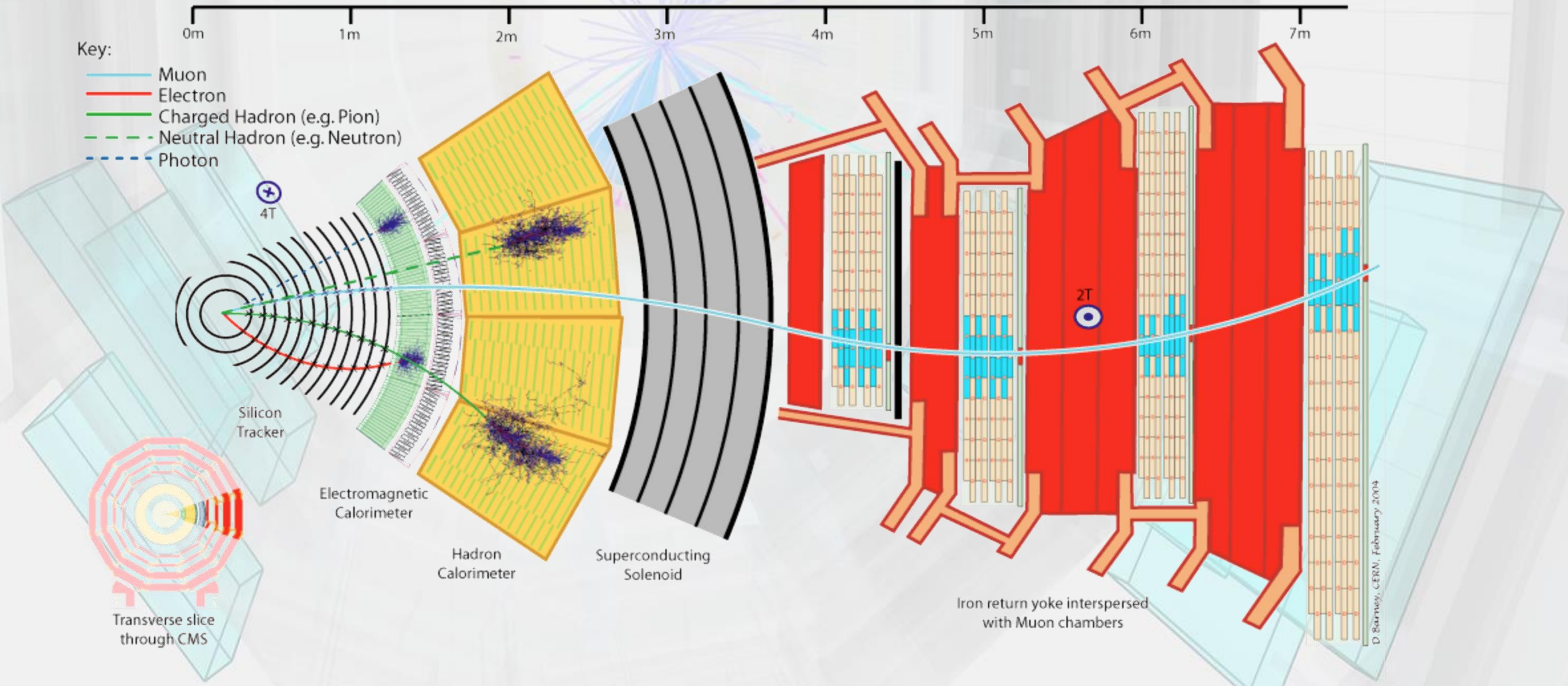
S. Shmatov and N. Voytishin,

Dubna, 2 April 2024

The Conference of Nuclear Physics Section of the Physical Sciences
Department of the Russian Academy of Sciences

Tracking at CMS: Tasks and Challenges



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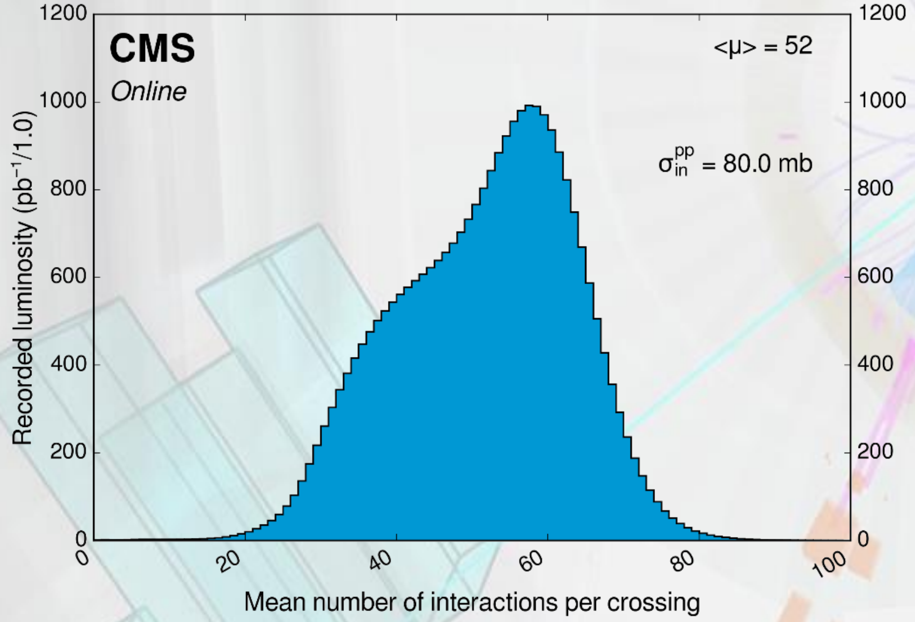

Conditions: $L_{inst} \sim 2 \times 10^{34}\ cm^{-2}s^{-1}$

- Bunch crossing (BX) every **25 ns**
- up to **80** pp-collisions per BX
- ~ **30** charged particles per pp-collision

up to **2400** charged particles per BX or $\mathbf{10^{11}}$ per second

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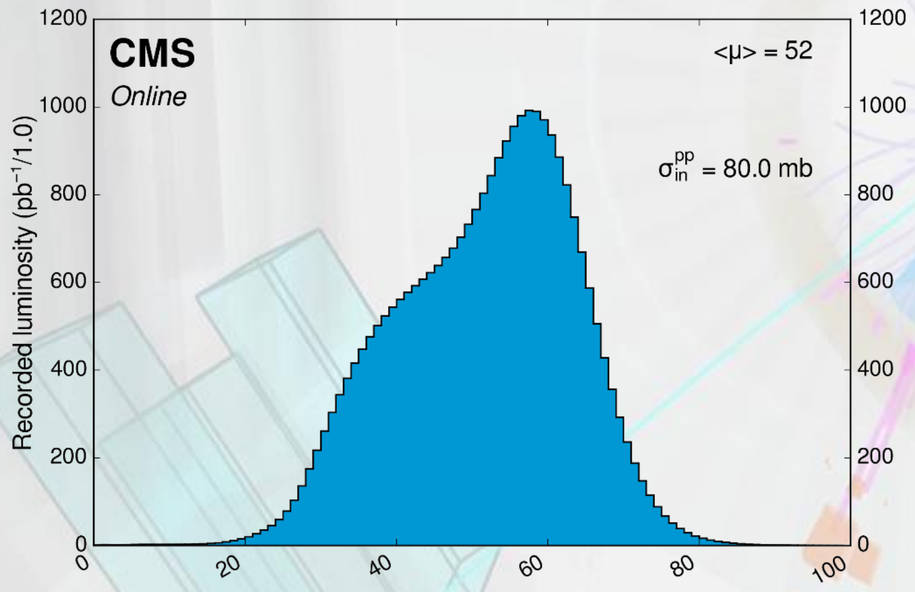

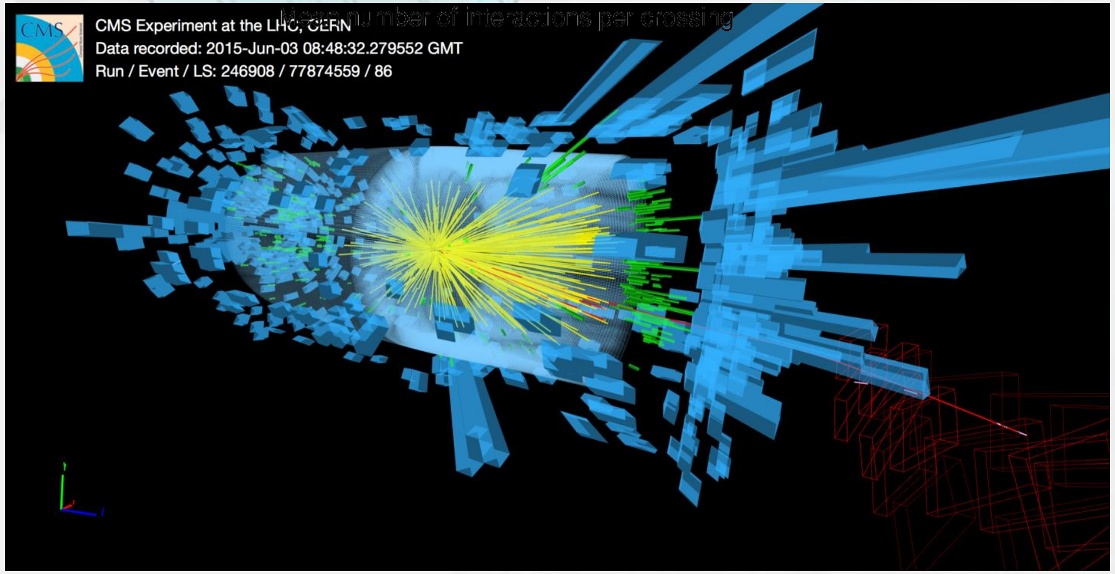

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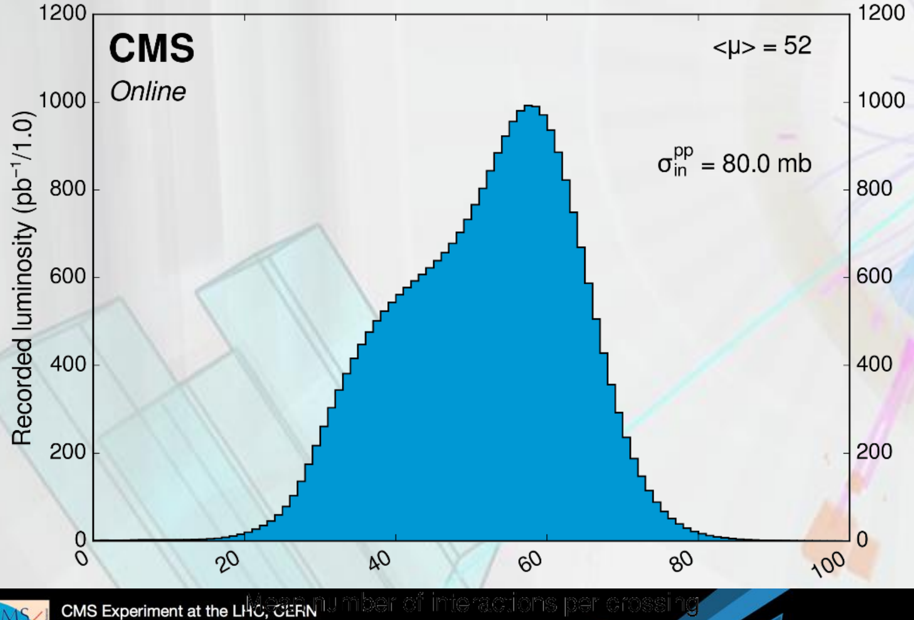

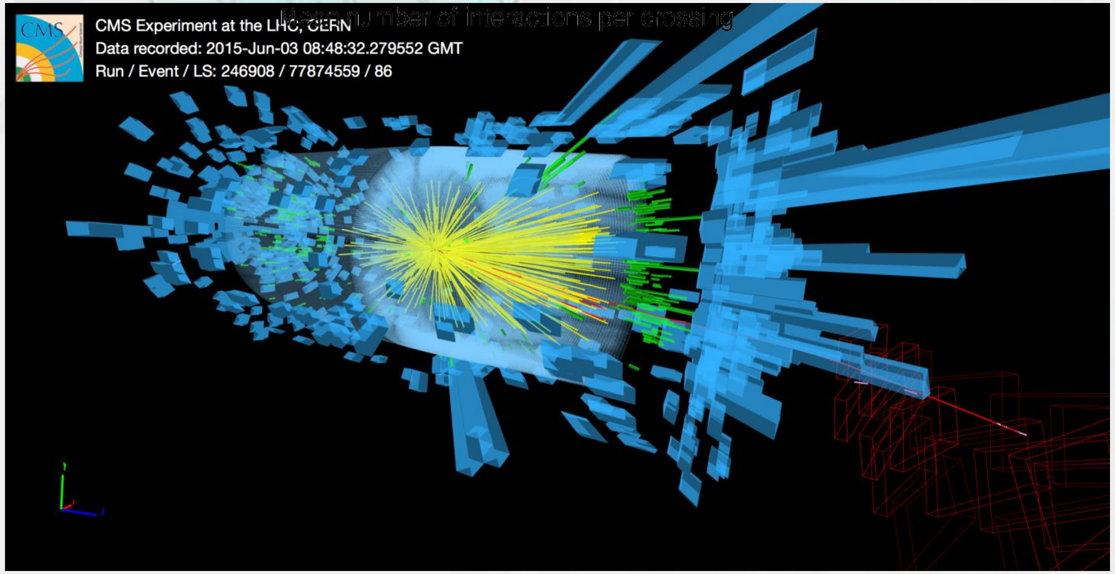

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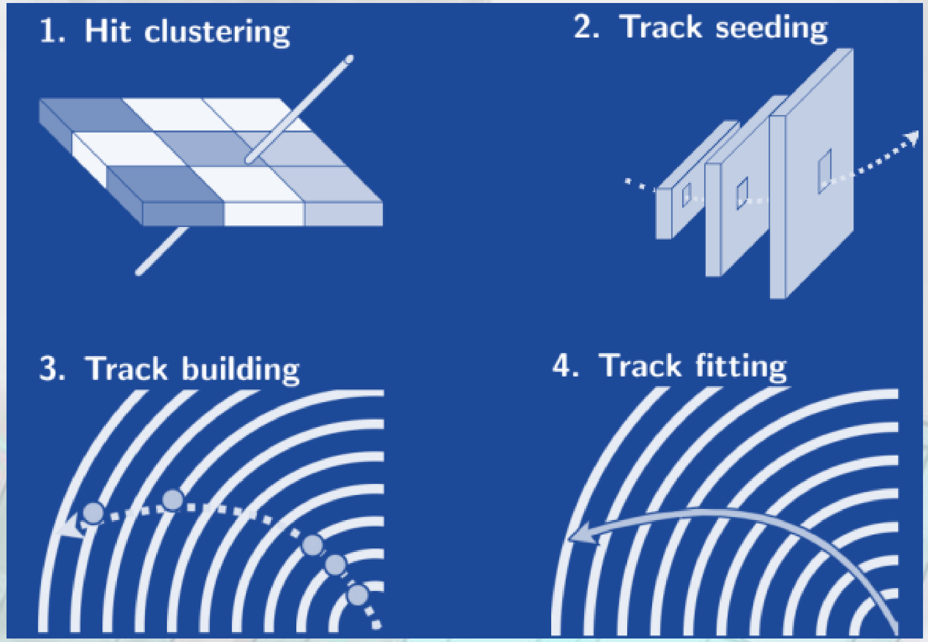
Requirements: fast and accurate

- High efficiency
- Low fake rate
- Precise track parameters
- Quickly!

Tracks Reconstruction. Muon Case

Common steps of reconstruction:

1. **Clustering and Seeding** – using combination of hits to provide track candidate
2. **Track building** – adding compatible hits to predicted trajectory. Updating parameters
3. **Final fit** – adding vertex, taking into account detector defects, smoothing trajectory, final estimation of parameters and uncertainties



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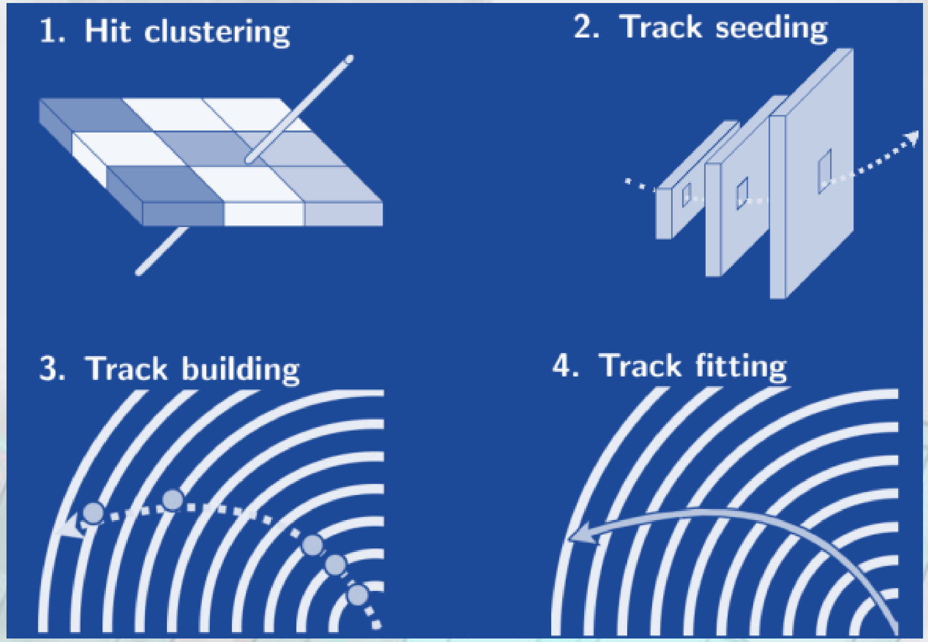

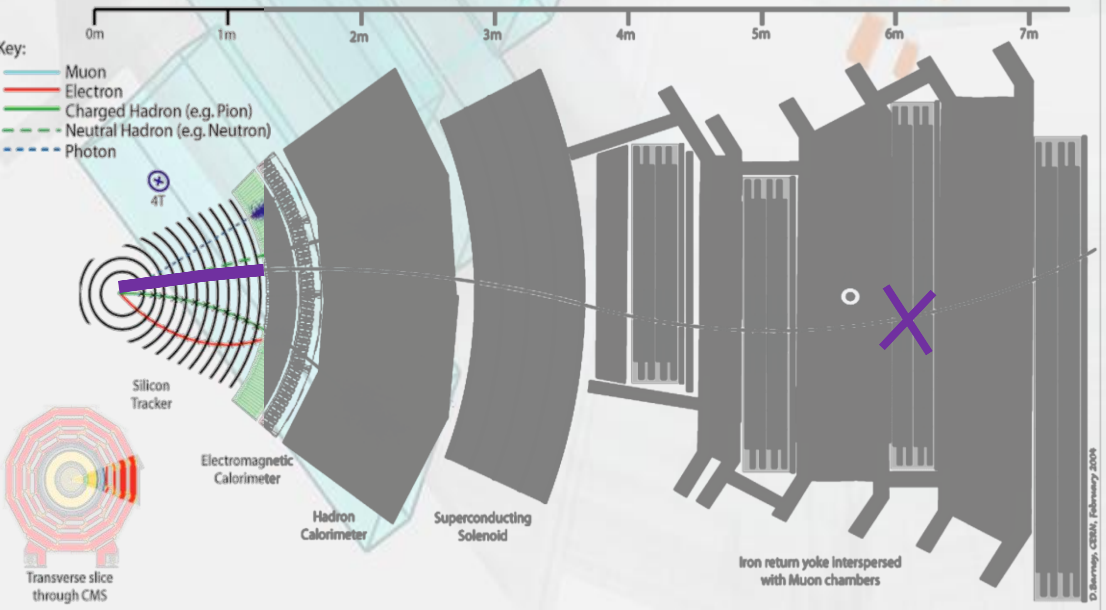

Muon reconstruction algorithms:

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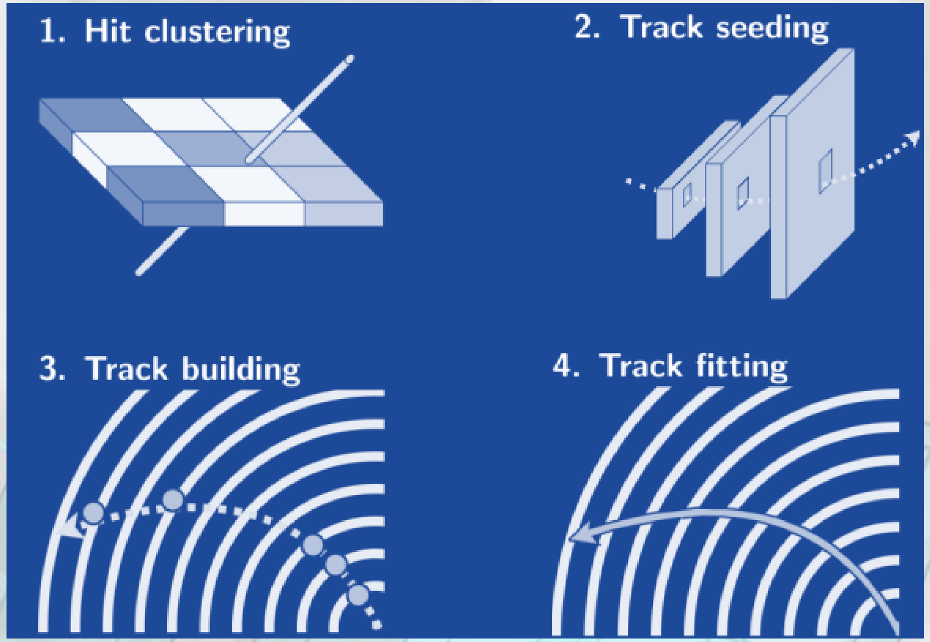

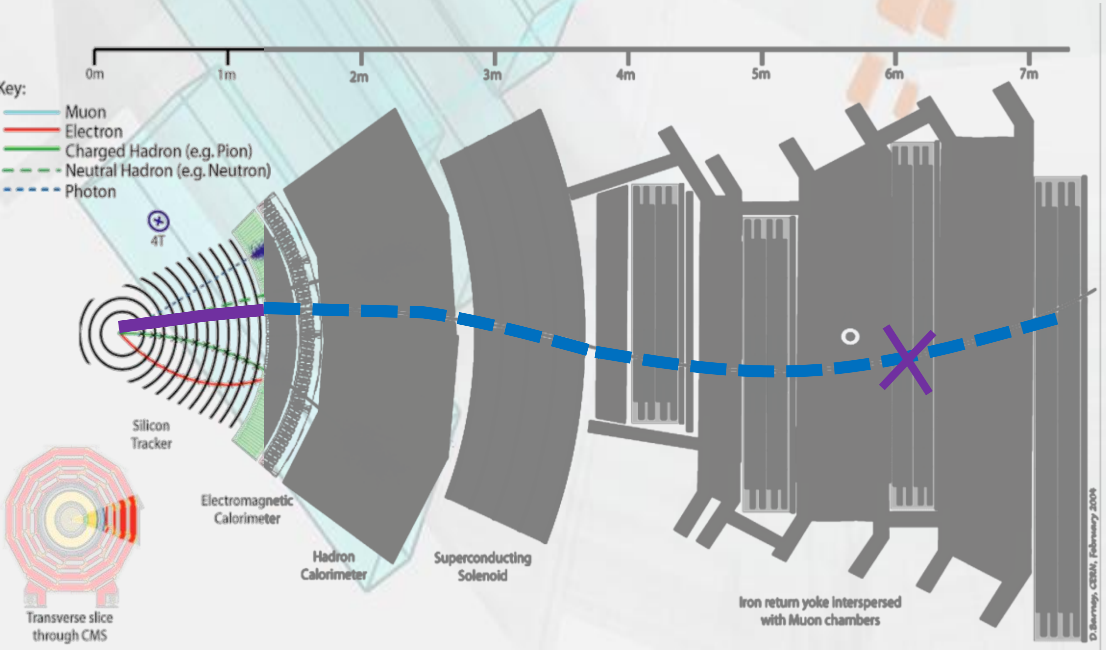

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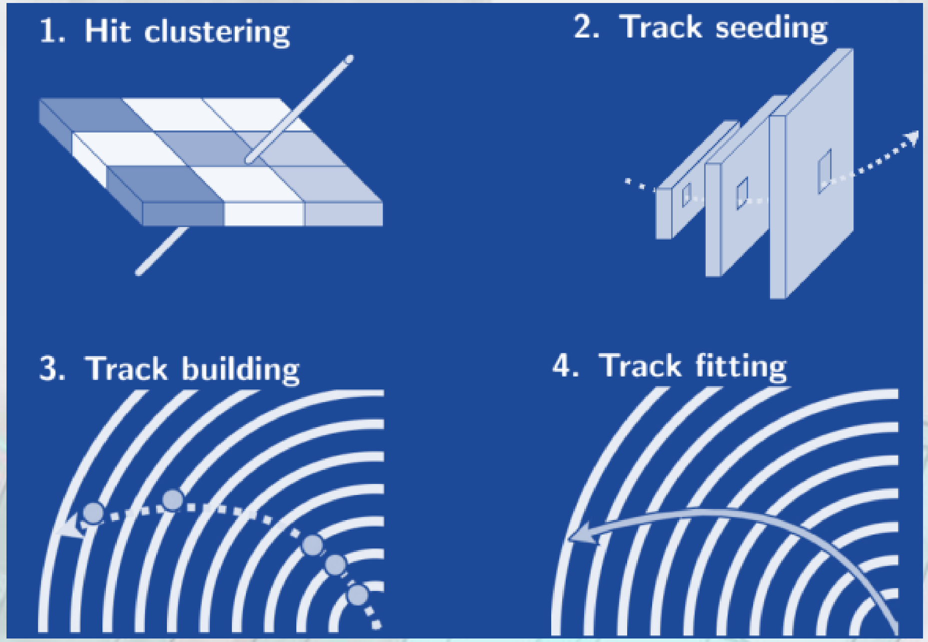

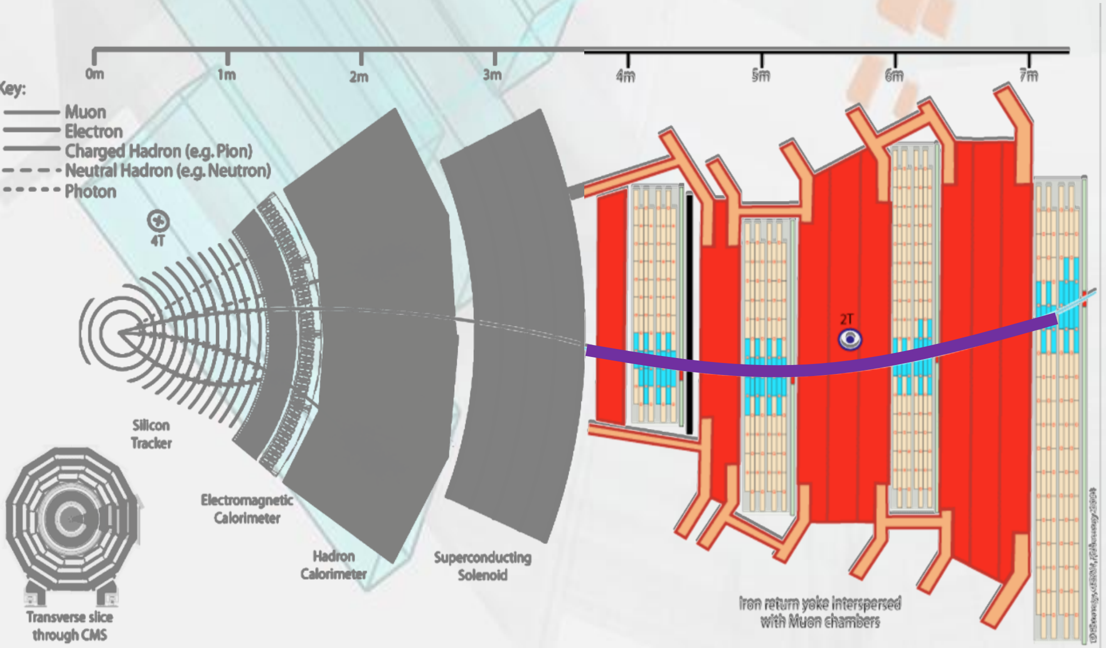

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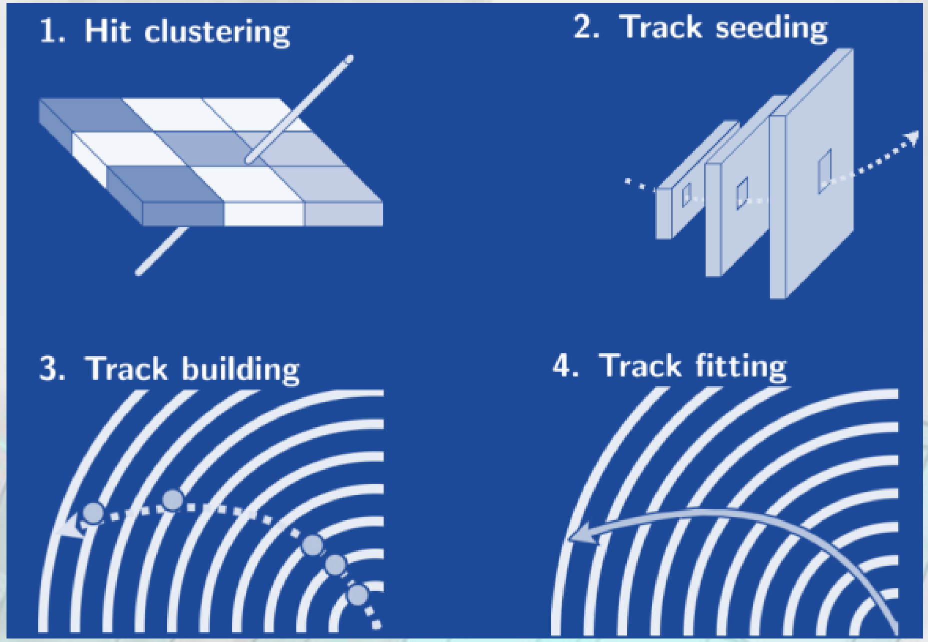

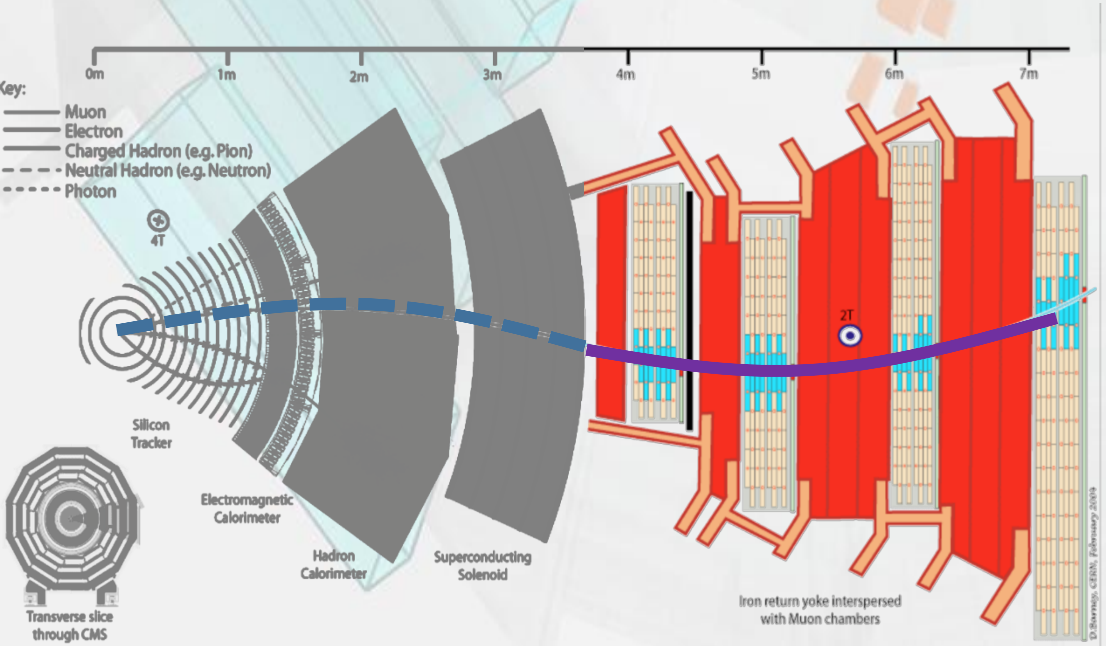

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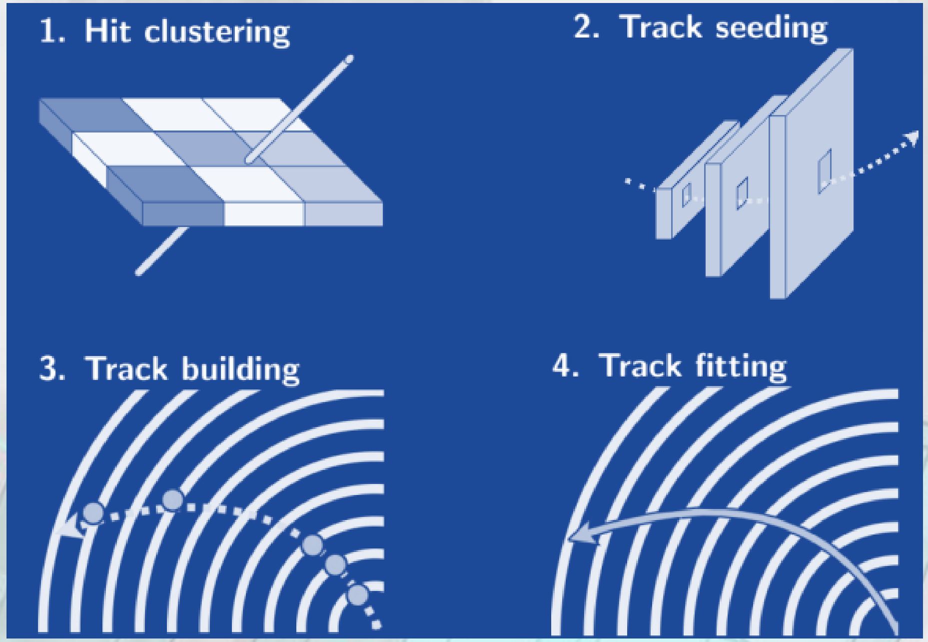

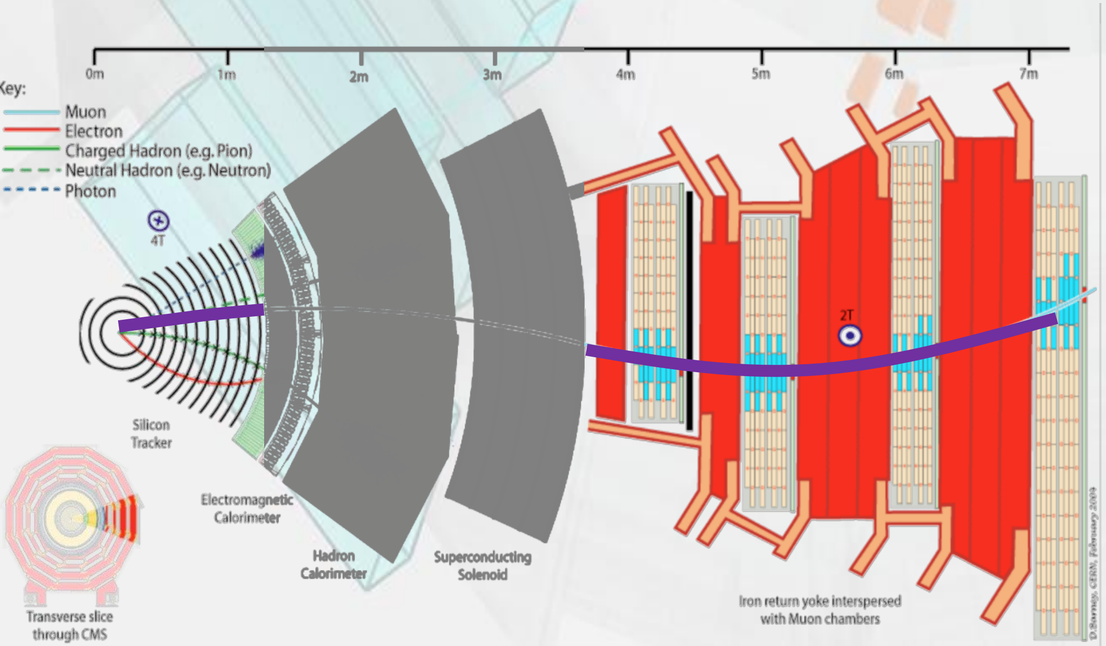

Muon reconstruction algorithms:

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- **Global**– muon chambers and silicon tracker

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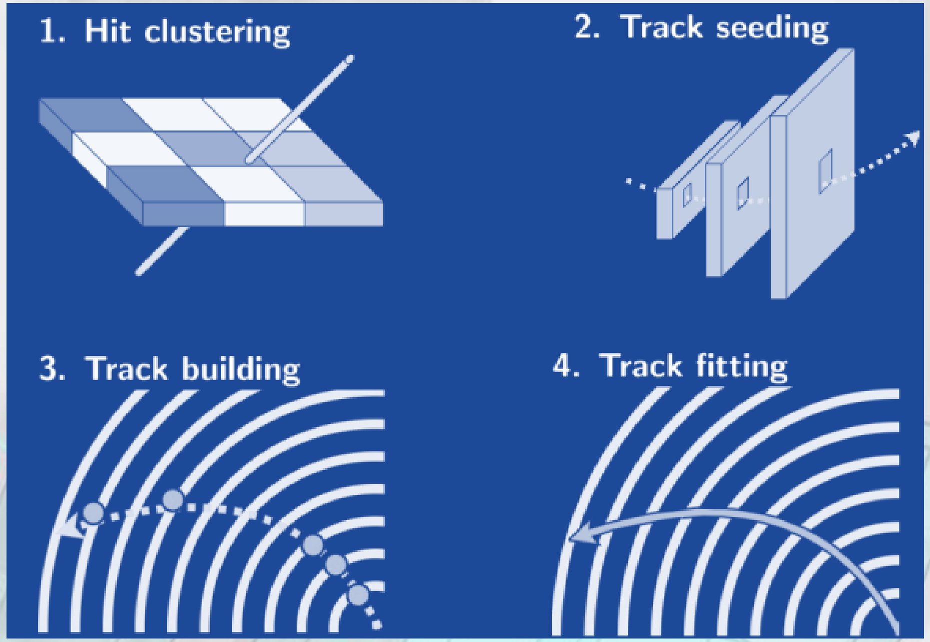

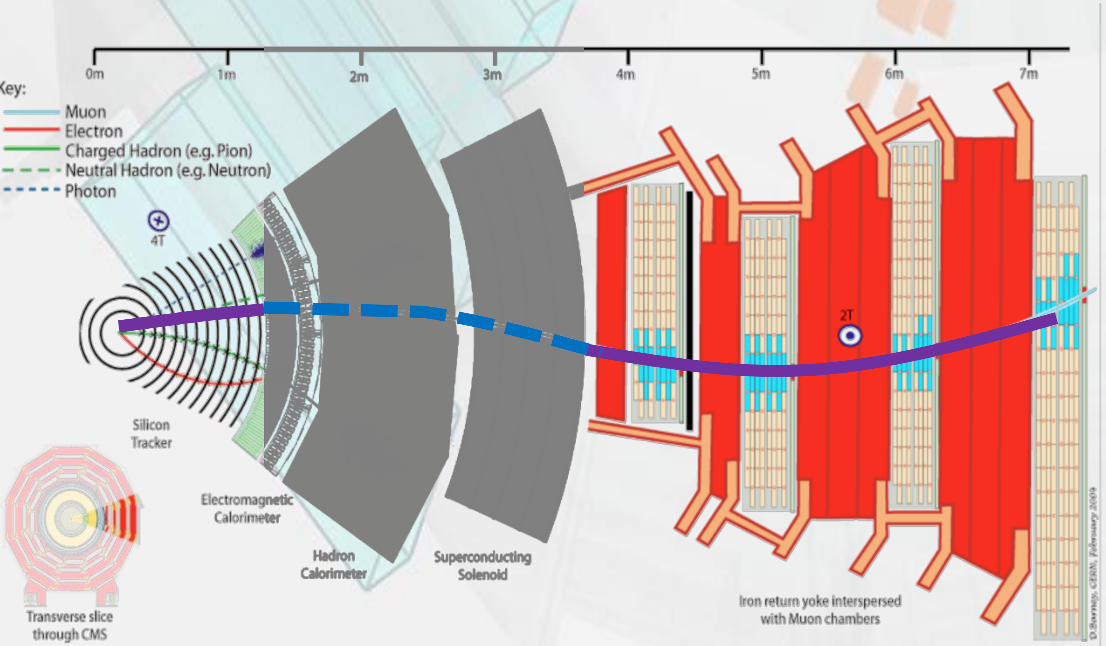

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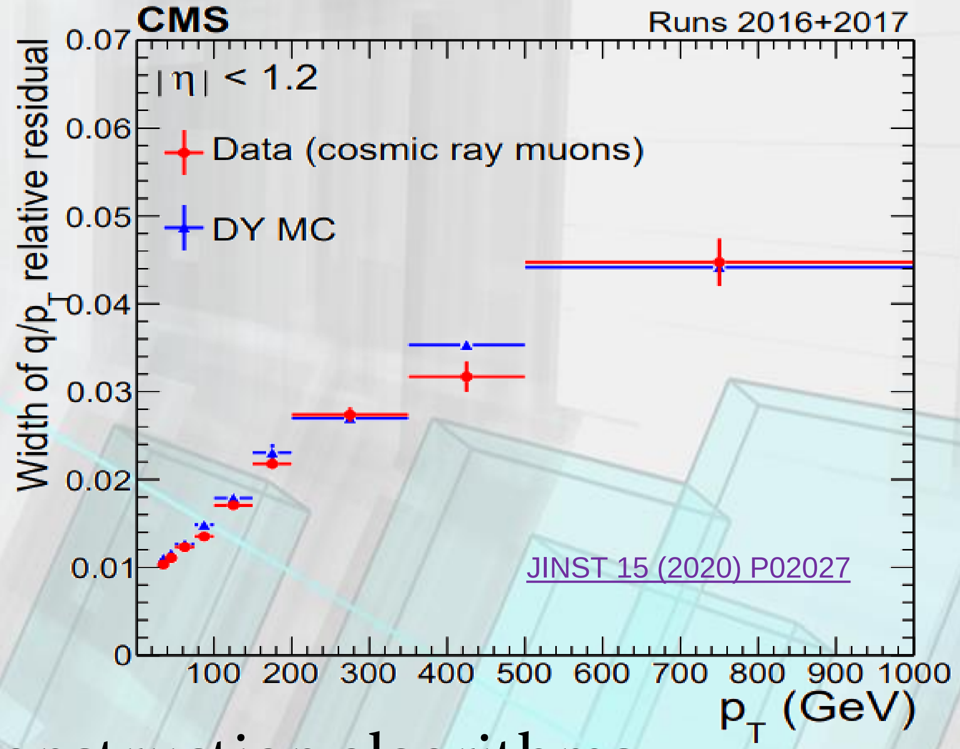

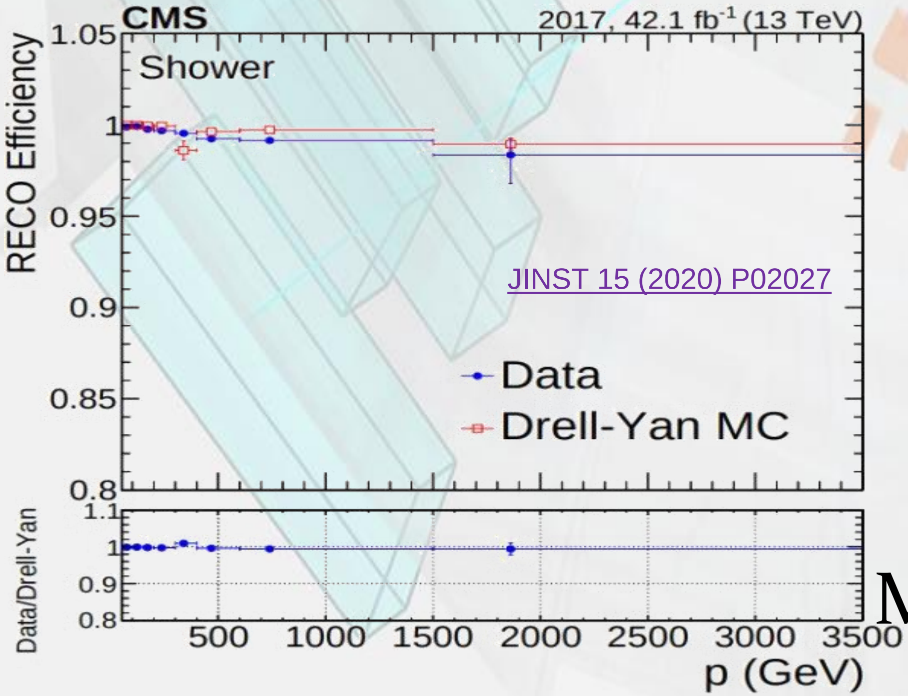

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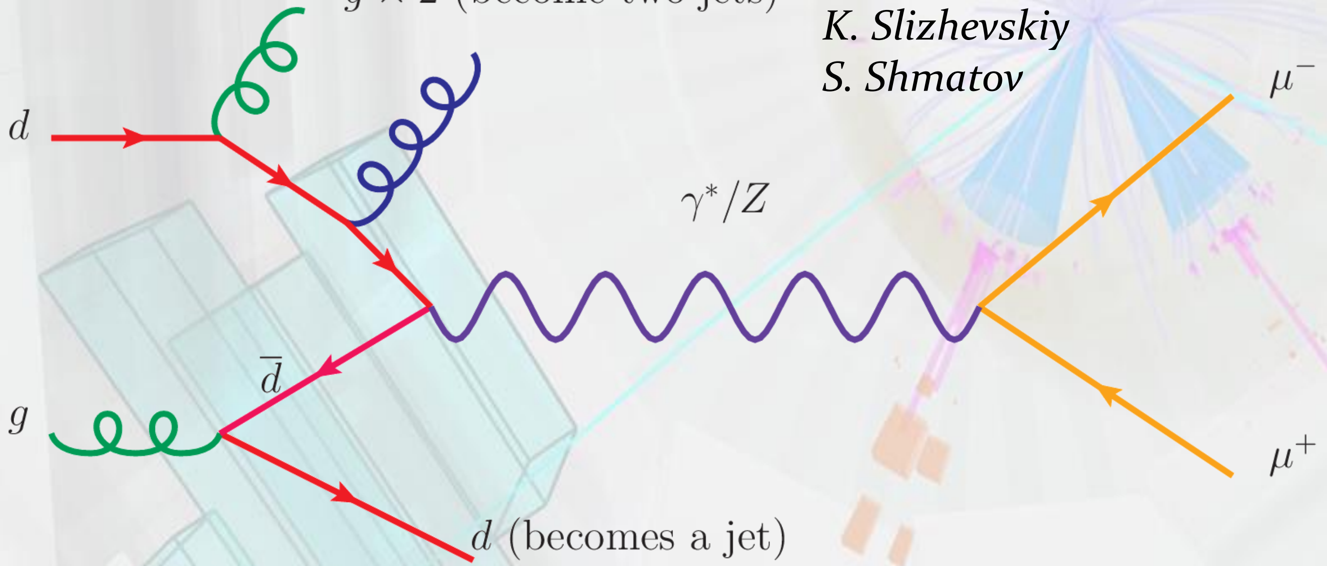
Muon reconstruction efficiency ~99%

Muon momentum resolution ~98% (p_T<200 GeV/c)

How to Find the Right Muon. Isolation

See “New Physics” reports :
Y. Korsakov
K. Slizhevskiy
S. Shmatov



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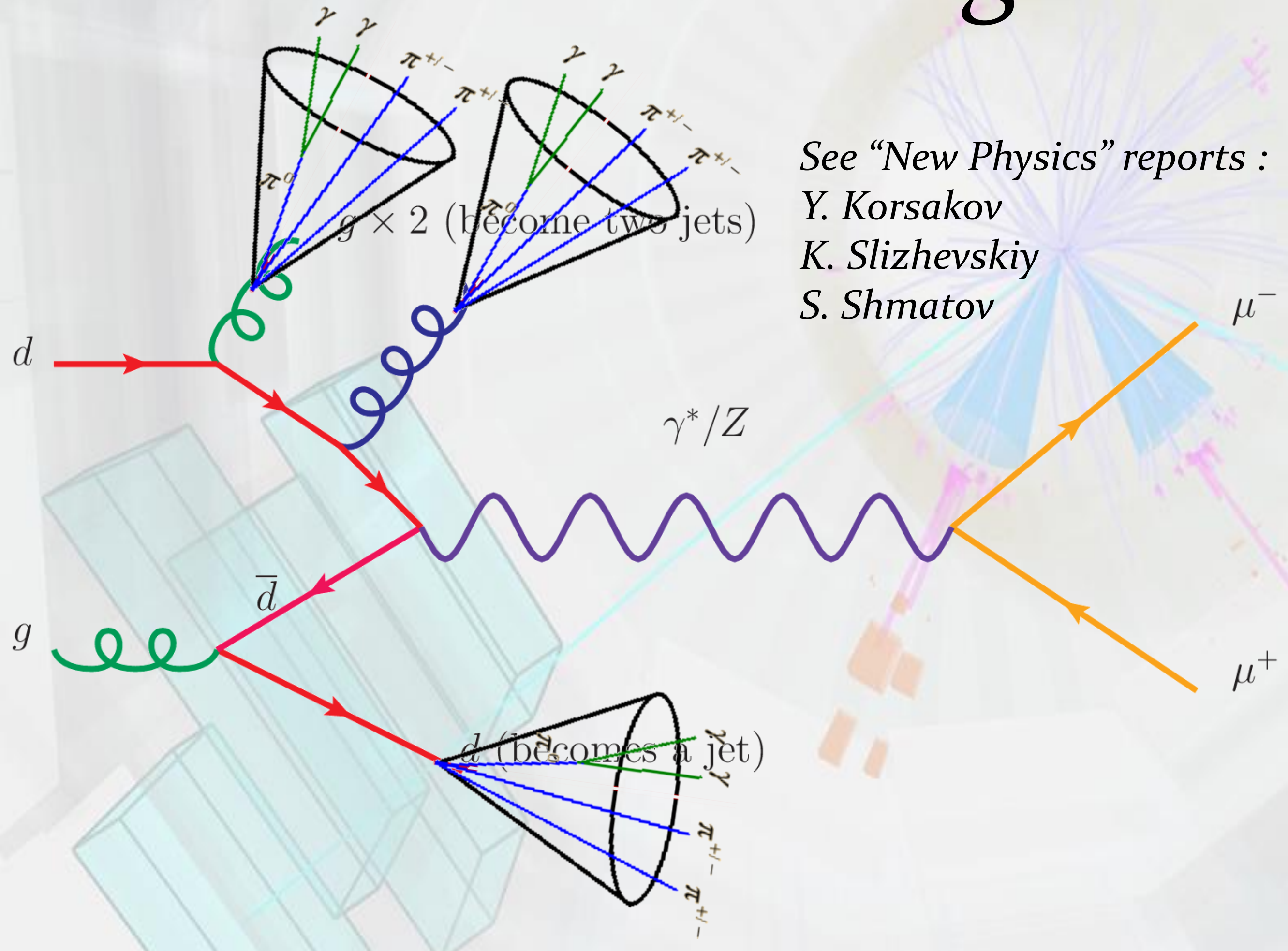

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We need to distinguish signal muons. How?

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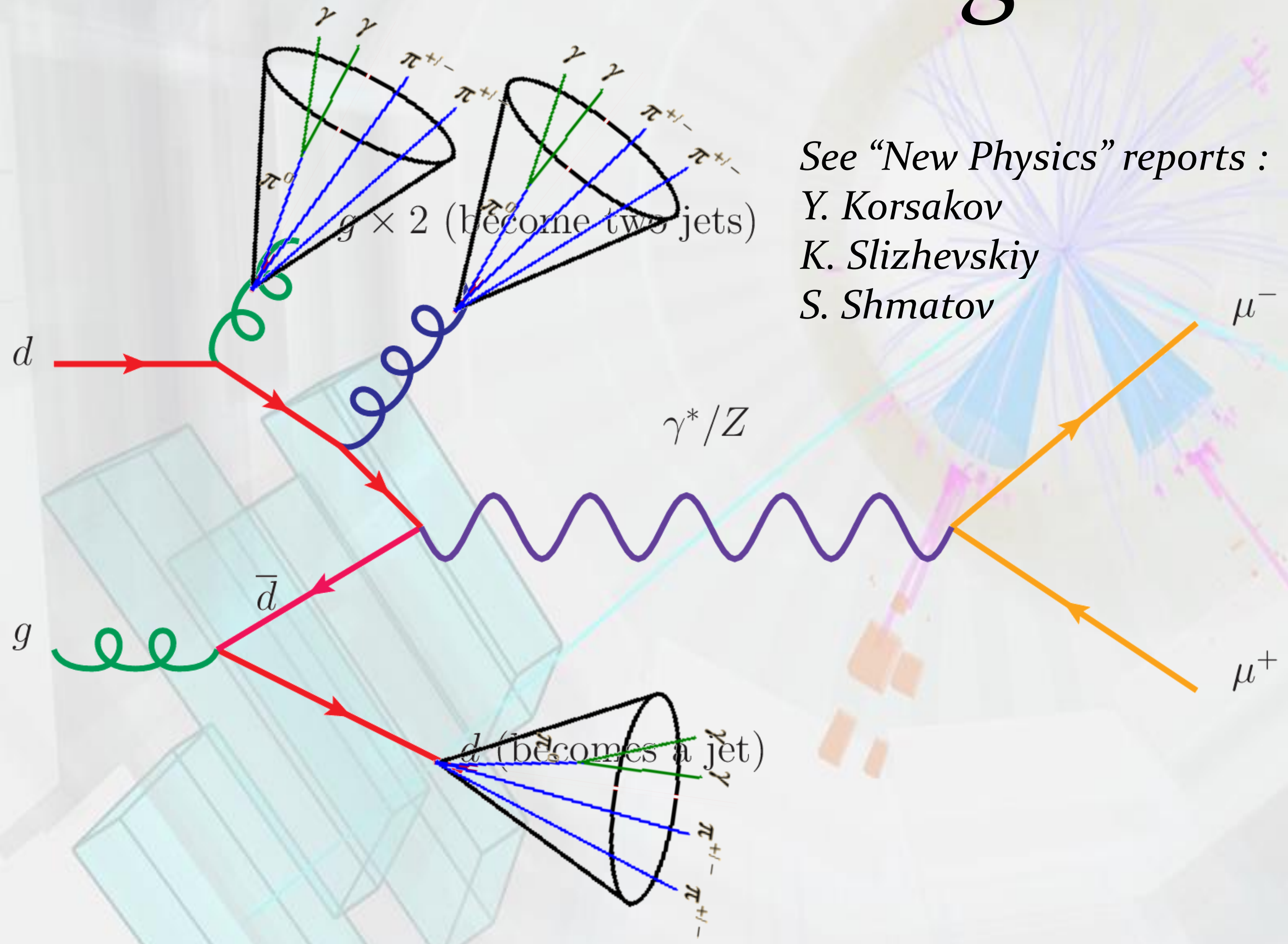

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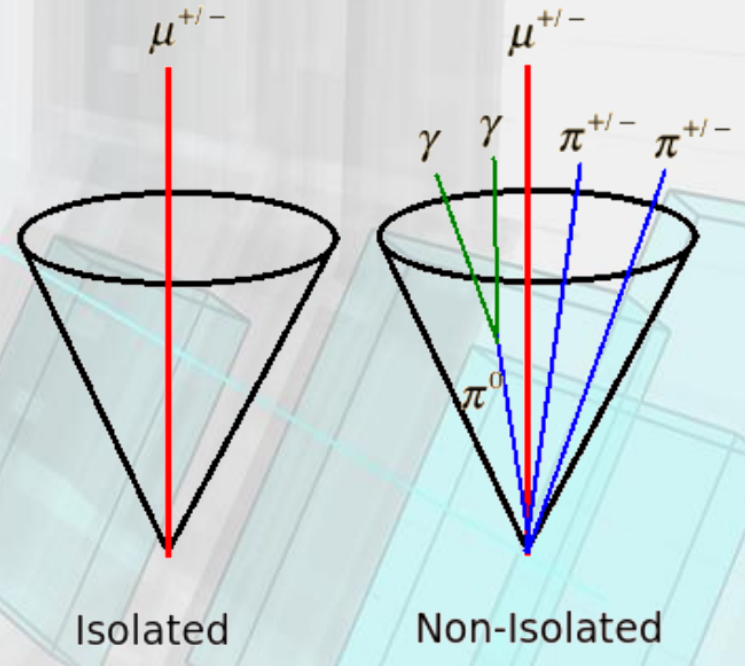

- **Tracker isolation** – only silicon tracker is used
- **Combined isolation** – silicon tracker and calorimeters are used
- **Particle flow isolation** – all subdetectors are used

$$\Delta R = \sqrt{\Delta\varphi^2 + \Delta\eta^2} < 0.4$$

$$\frac{\sum p_T^{\Delta R} - p_T^{\mu}}{\sum p_T^{\Delta R}} < 0.15$$

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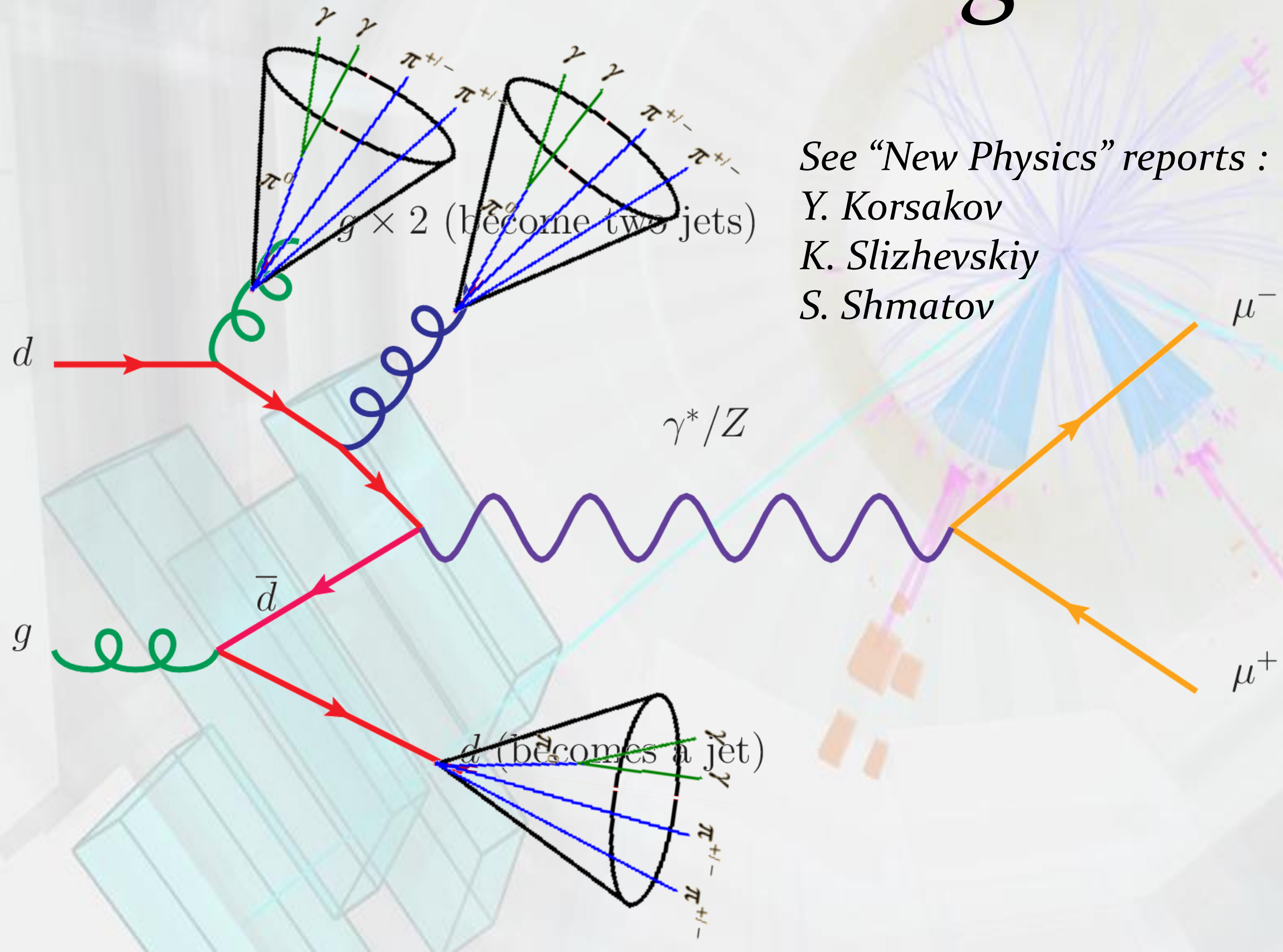

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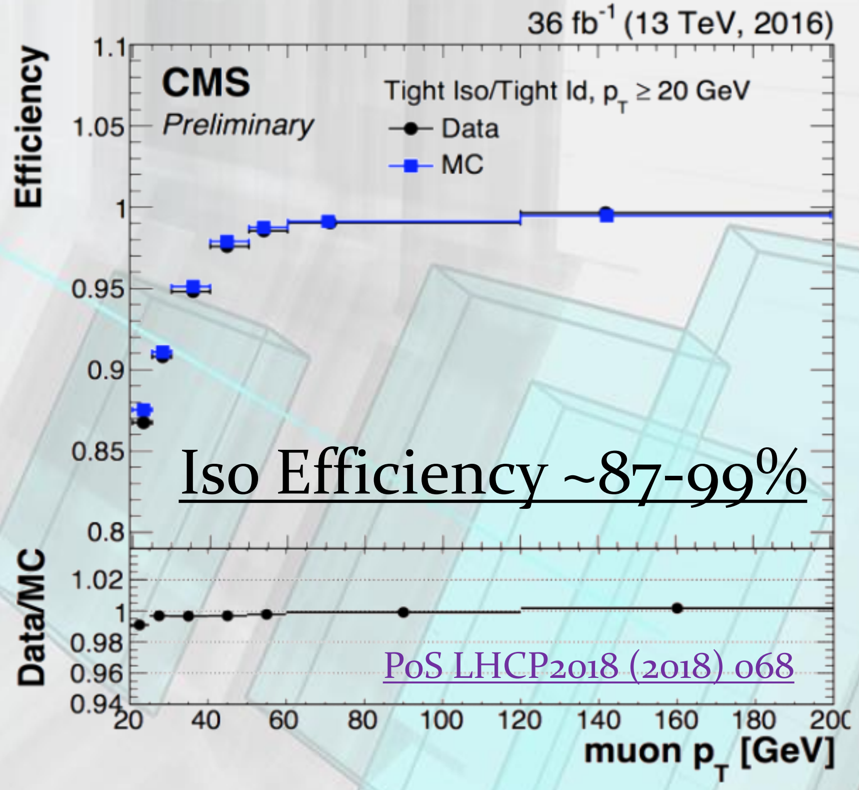

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PoS LHCP2018 (2018) 068

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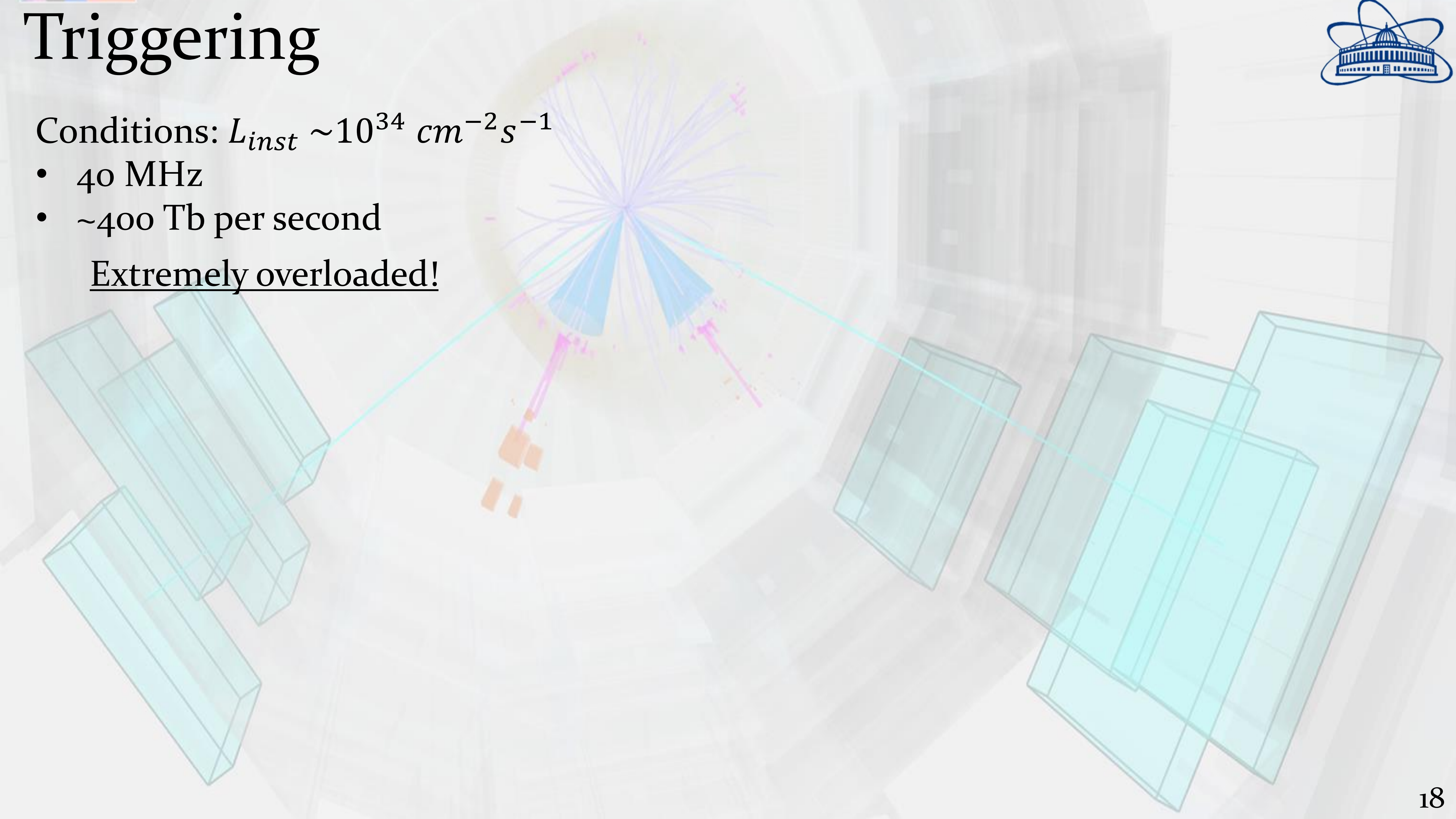
Triggering

Conditions: $L_{inst} \sim 10^{34}\ cm^{-2}s^{-1}$

- 40 MHz
- ~400 Tb per second

Extremely overloaded!



Triggering

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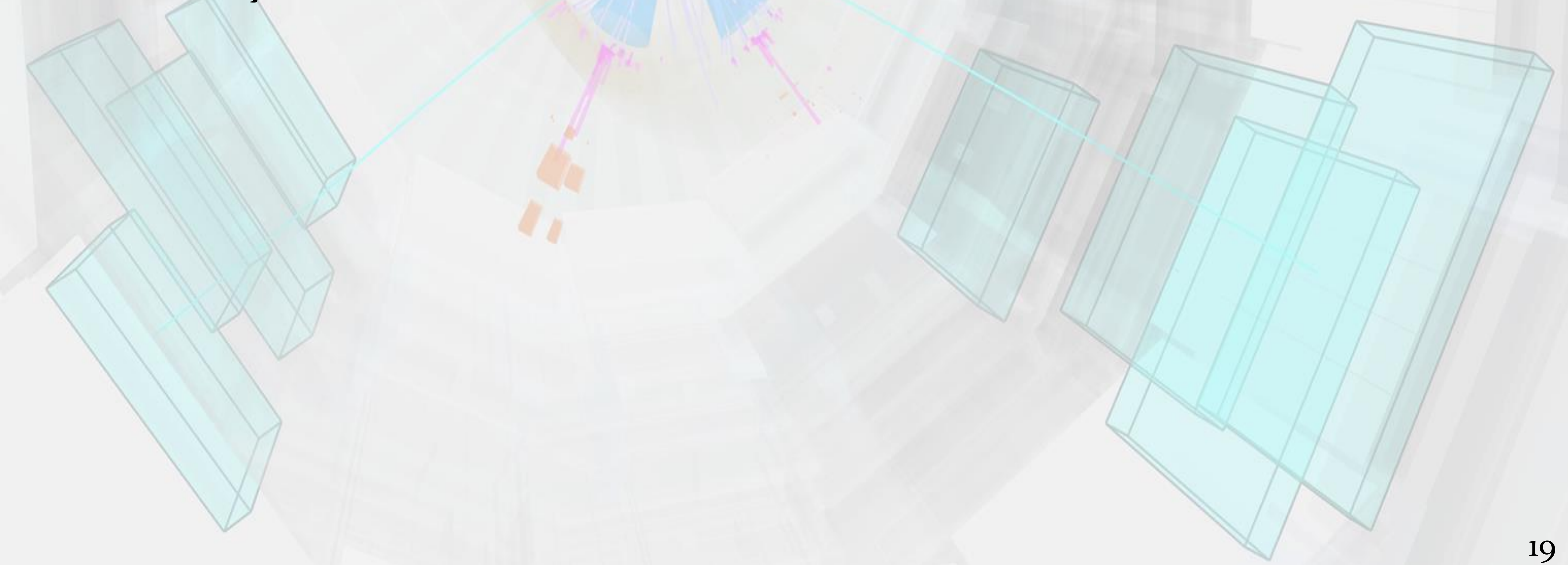
Requirements: few but interesting & quality

- High efficiency
- High purity
- Computing economy



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Level 1 Trigger (L1)

Hardware

Local trigger – collect signals from muon stations

↑

Regional trigger – rank objects in one detector subsystem

↑

Global trigger– make decision, form data stream

30 kHz

High Level Trigger (HLT)

Software

Use information from silicon tracker

↑

Vertex snap

↑

Apply Isolation criteria

↑

Fitting

↑

Make a decision

100 Hz / 100 Mb/s

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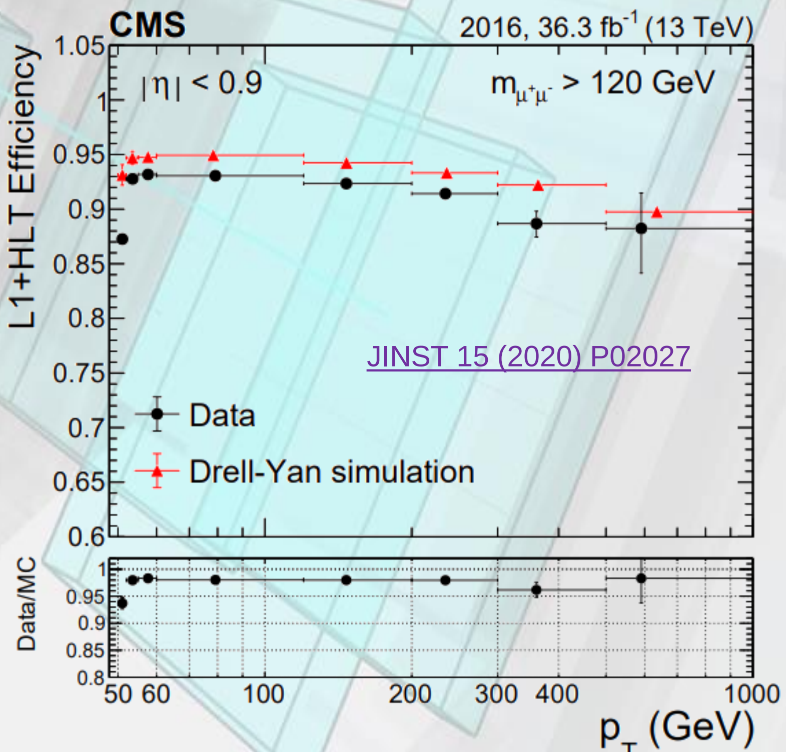
Trigger Efficiency ~93-98%



Muon Identification

Electroweak precision measurements requires high quality muon tracks.
Special Identification algorithms are used

Tight Muon

The candidate is reconstructed as a Global Muon	
χ^2/ndof of the global-muon track fit < 10	To suppress hadronic punch-through and muons from decays in flight
At least one muon chamber hit included in the global-muon track fit	
Muon segments in at least two muon stations	To suppress accidental track-to-segment matches
Its tracker track has transverse impact parameter d_{xy} < 2 mm w.r.t. the primary vertex, d_z < 5 mm	To suppress cosmic muons and further suppress muons from decays in flight and tracks from pileup
Number of pixel hits > 0. number of tracker layers with hits >5	To guarantee a good p_T measurement, for which some minimal number of measurement points in the tracker is needed

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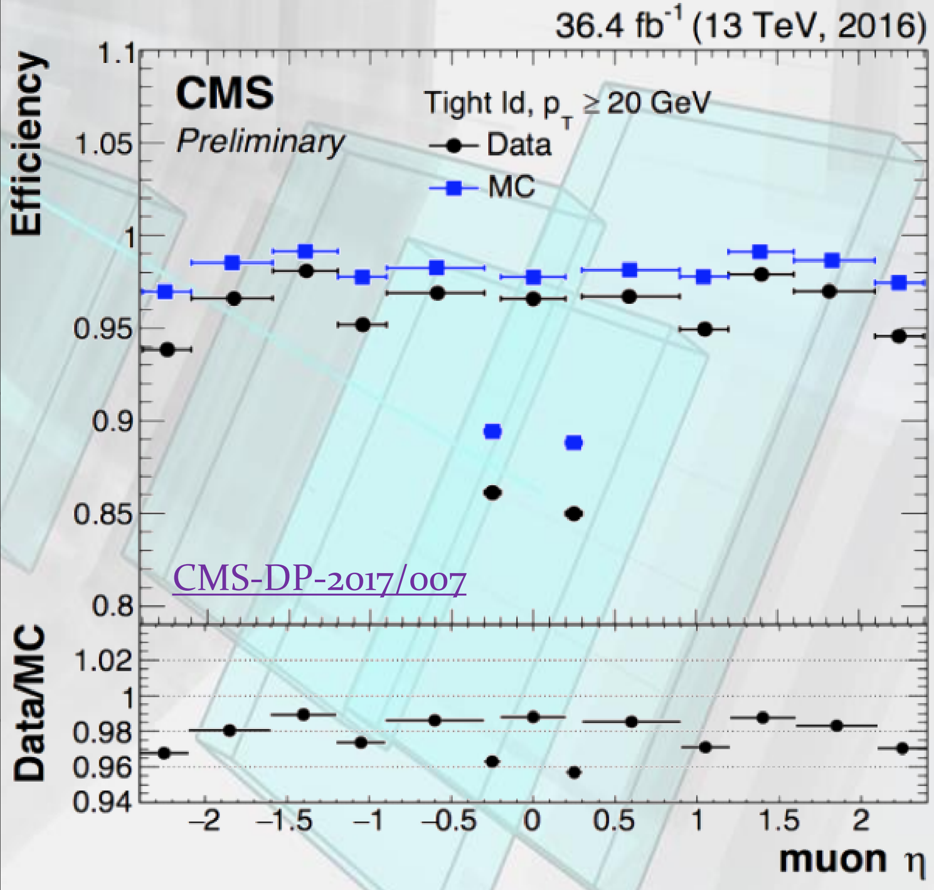
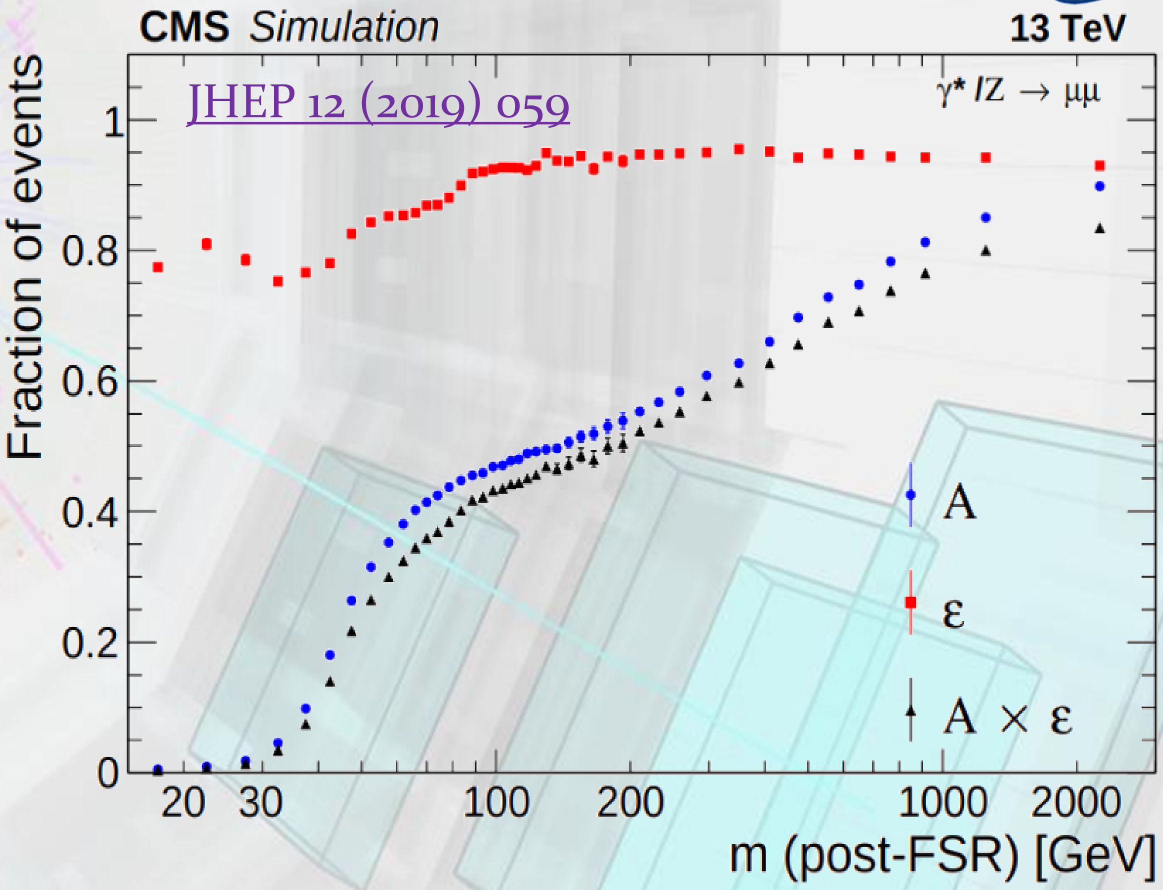
Identification efficiency >95%!



Conclusions

Existing methods of muon tracks registration, its parameters measurement and background suppression demonstrate high efficiency and accuracy, and allow us to successfully perform precision measurements with muons



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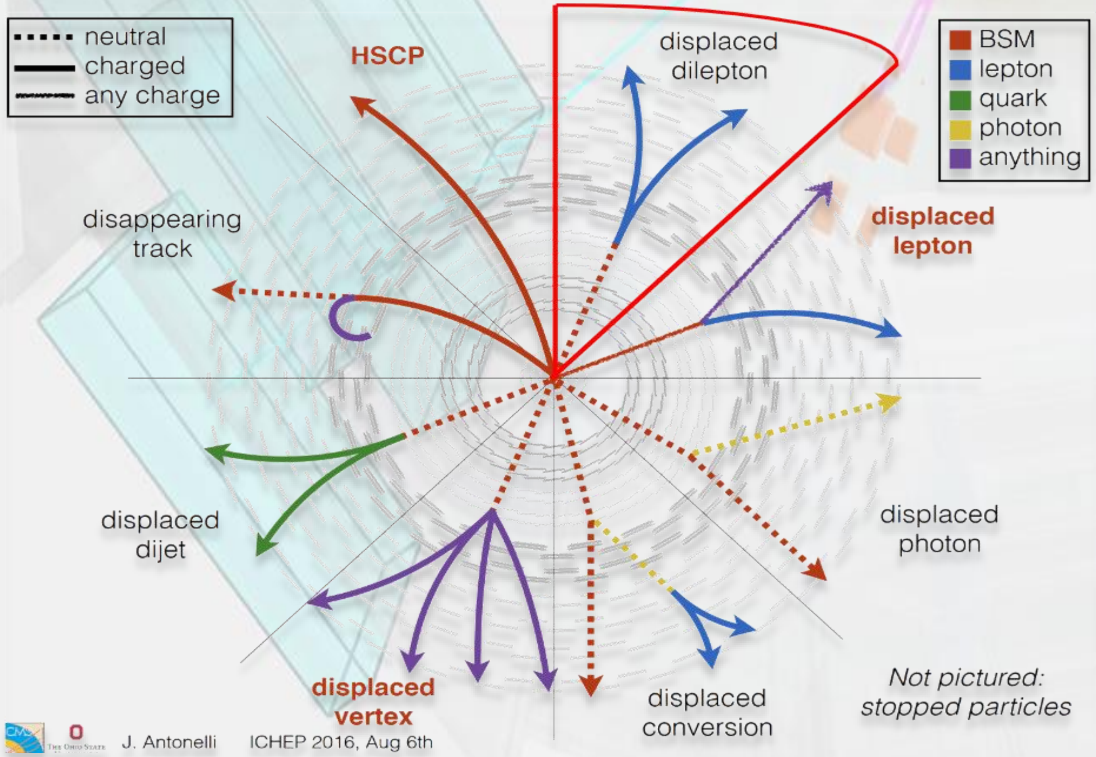
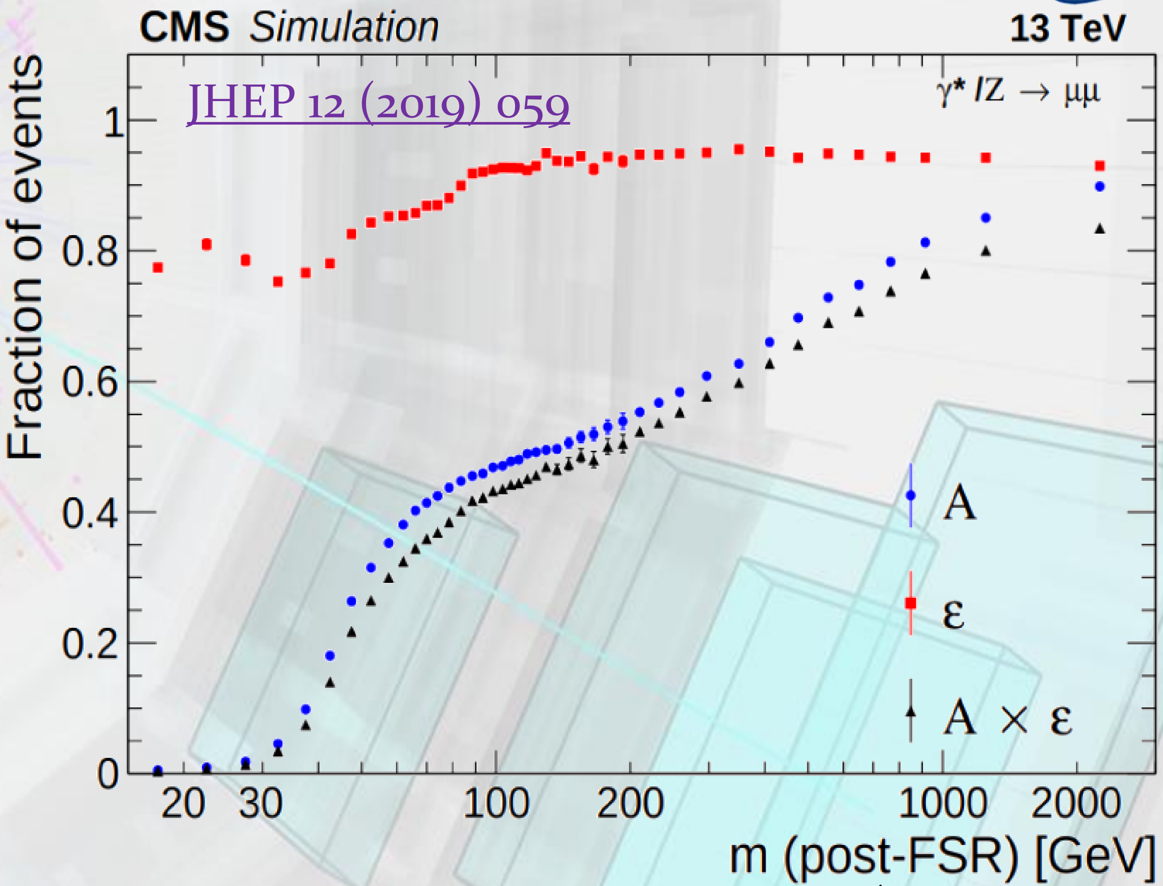
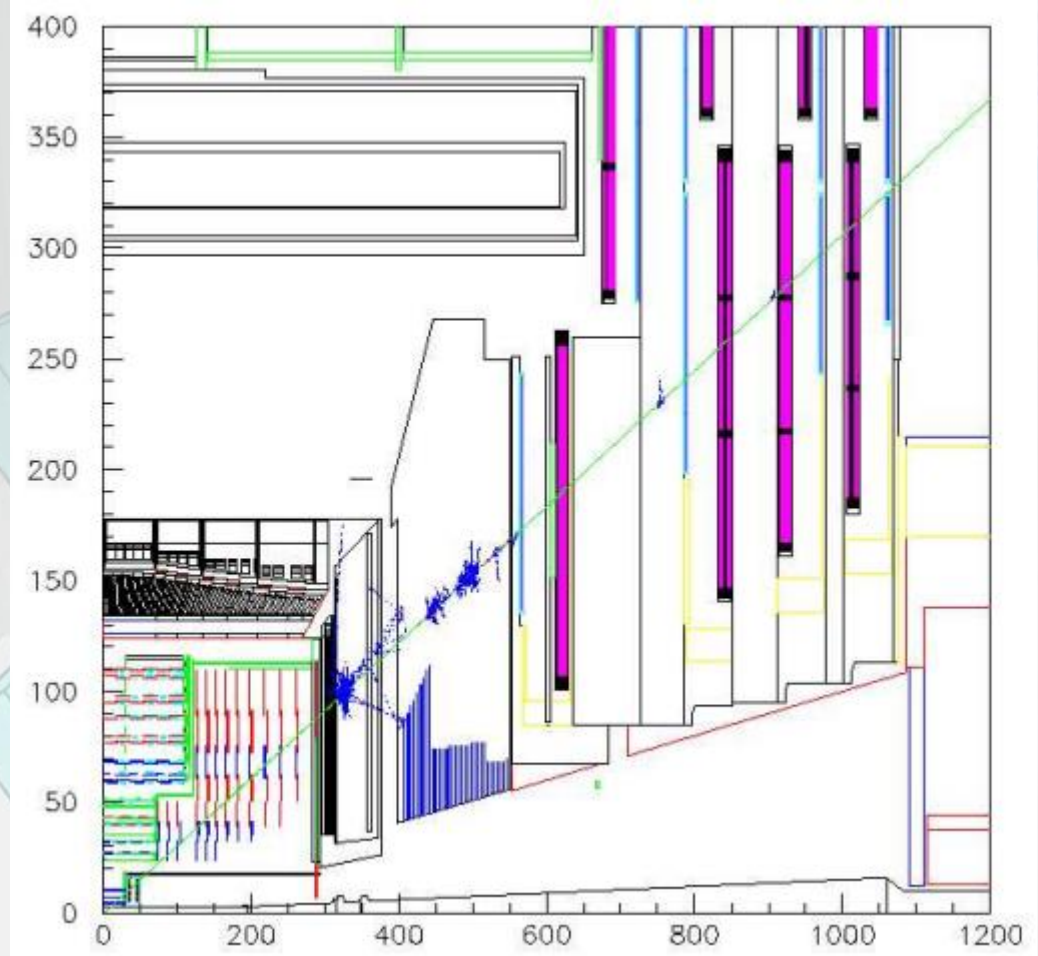




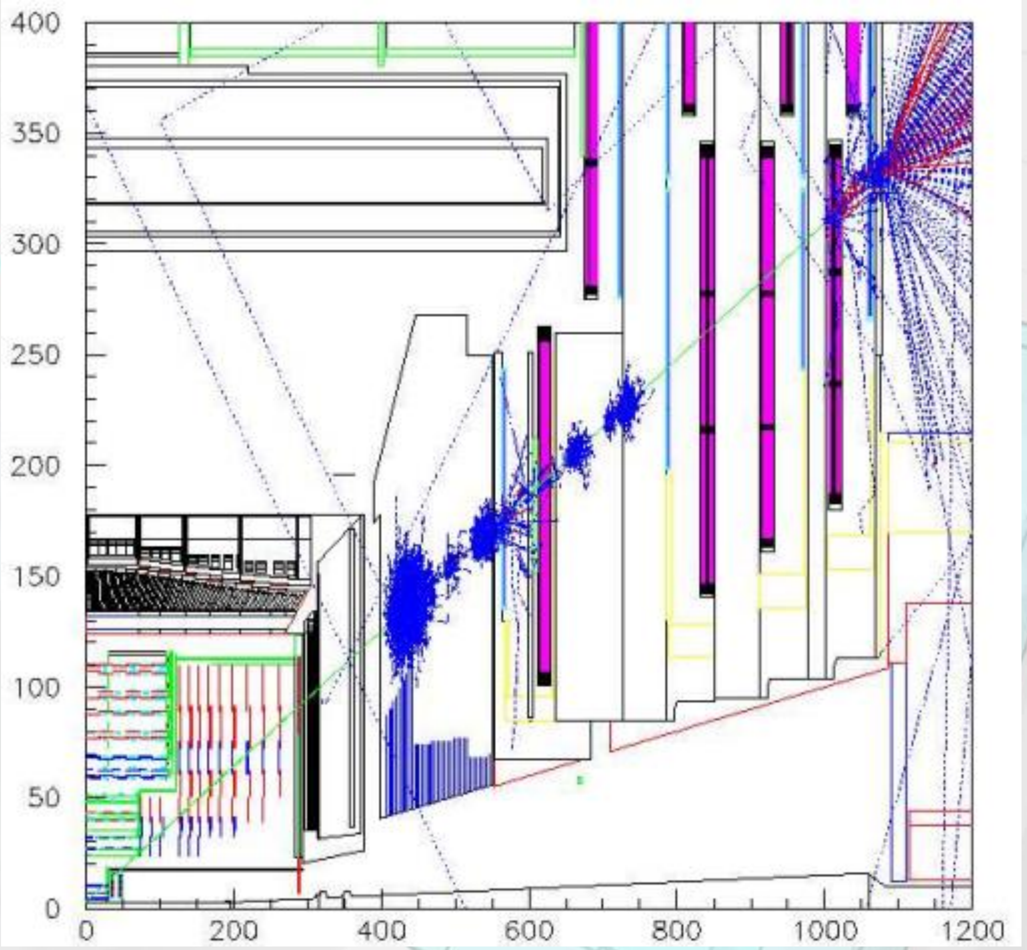
New technics and algorithms (mkFIT , DNN etc.) are coming (JINST 19 (2024) P02031). New registration methods for exotic experimental signatures are under the process or already applied (JHEP 03 (2022) 16025)

Backup

High p_T Muon Event

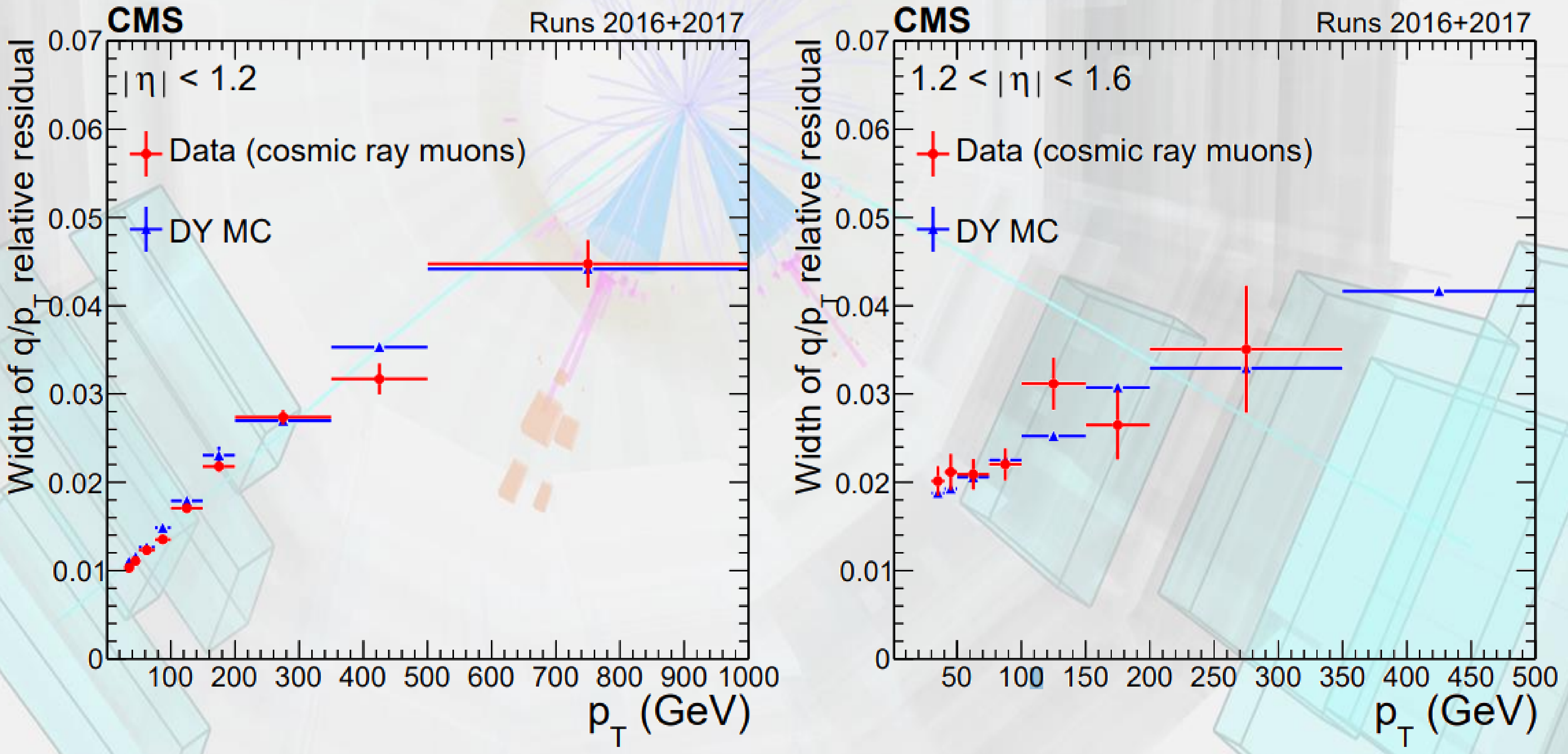


p_T=100 GeV/c



p_T=1000 GeV/c

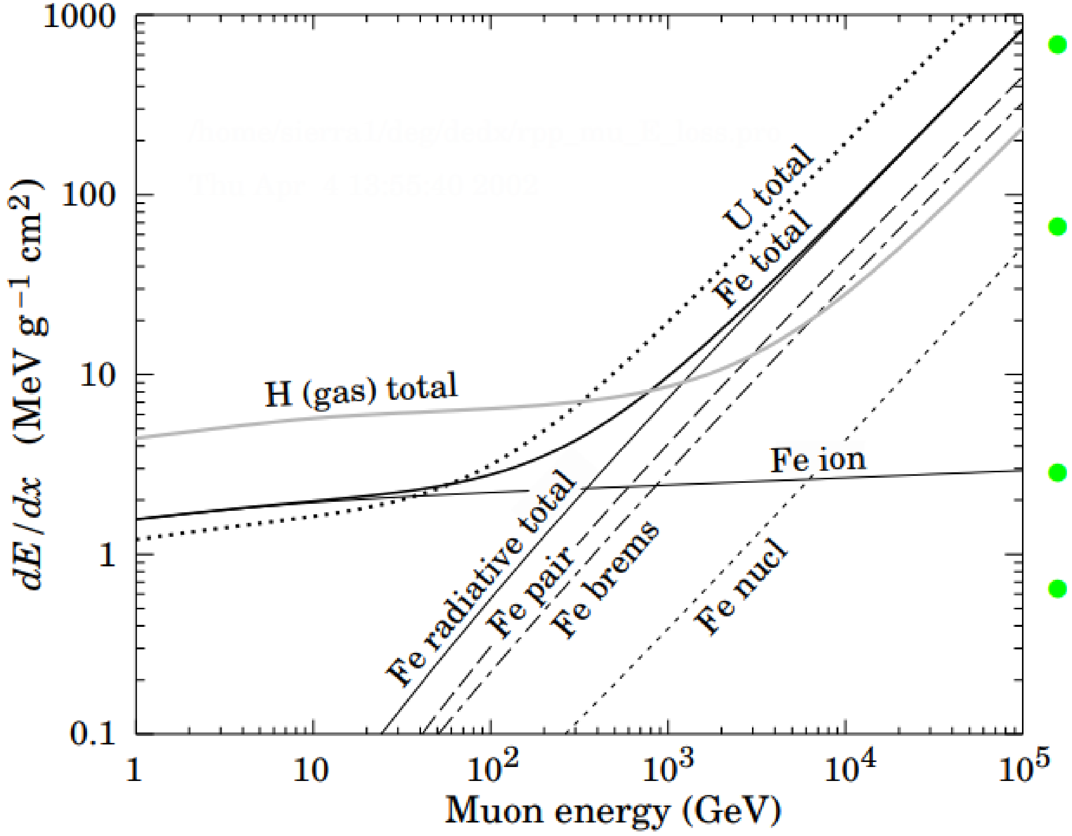
Muon p_T Resolution



$$R_{\text{cosmic}}(q/p_{\text{T}}) = \frac{(q/p_{\text{T}})^{\text{Upper}} - (q/p_{\text{T}})^{\text{Lower}}}{\sqrt{2}(q/p_{\text{T}})^{\text{Lower}}},$$

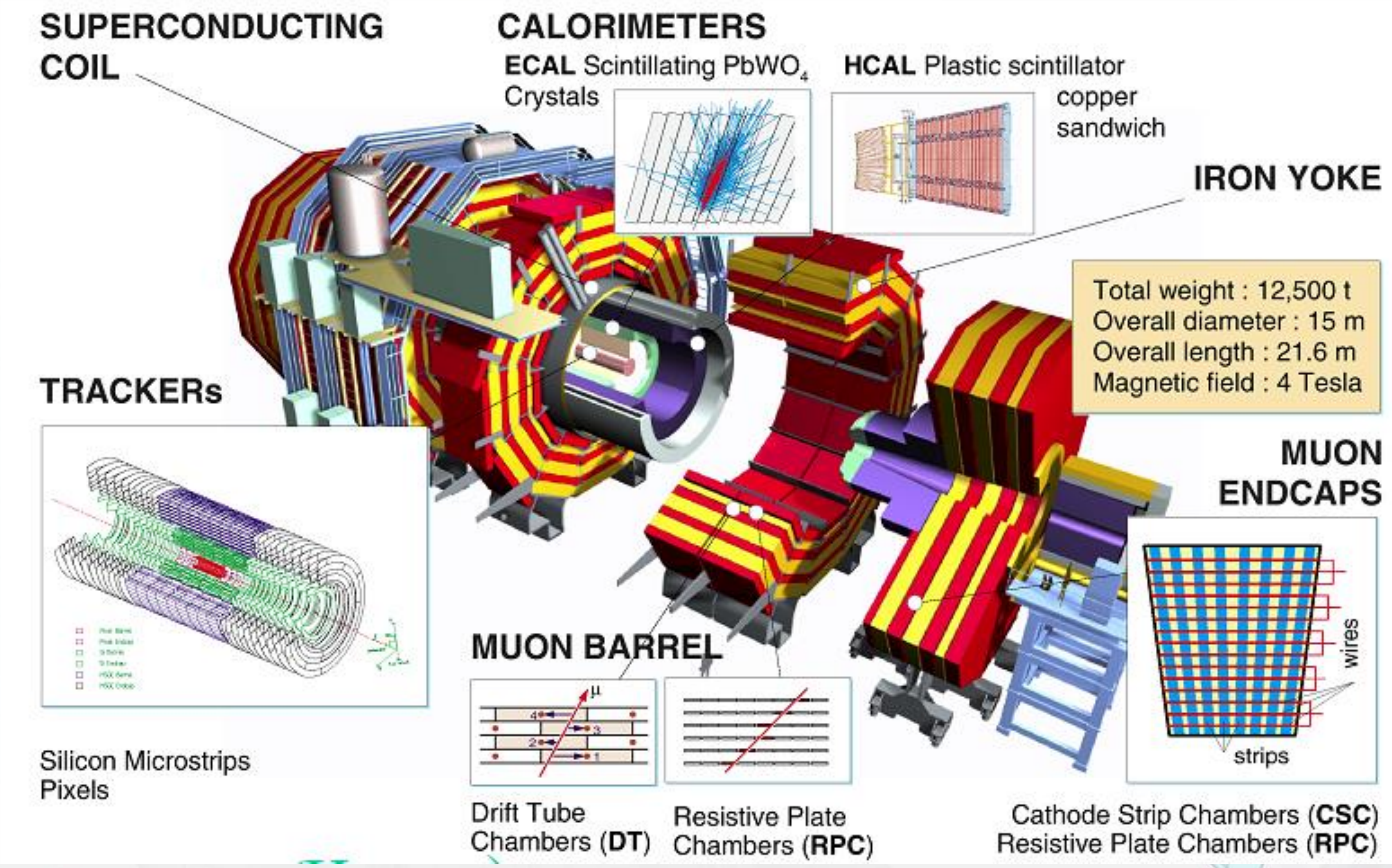
Muon Energy Loss

PDG(Eur.Phys.J.C15:163-173,2000)



- Ionization losses: $dE/dx \approx 2$ GeV/m of iron
- Radiative losses (e^+e^- pair production, bremsstrahlung): dE/dx rise linearly with E
- $E_{crit.} \approx 350$ GeV for iron
- e^+e^- pair production gives larger contribution than bremsstrahlung to dE/dx

CMS



SUPERCONDUCTING COIL
CALORIMETERS
ECAL Scintillating $PbWO_4$ Crystals
HCAL Plastic scintillator copper sandwich
IRON YOKE
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
TRACKERs
MUON ENDCAPS
wires
strips
MUON BARREL
μ
Silicon Microstrips
Pixels
Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)
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