Future plan of dilepton measurement
レプトン対測定の将来計画

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Hiroshima University

Heavy Ion Pub @ Kyoto

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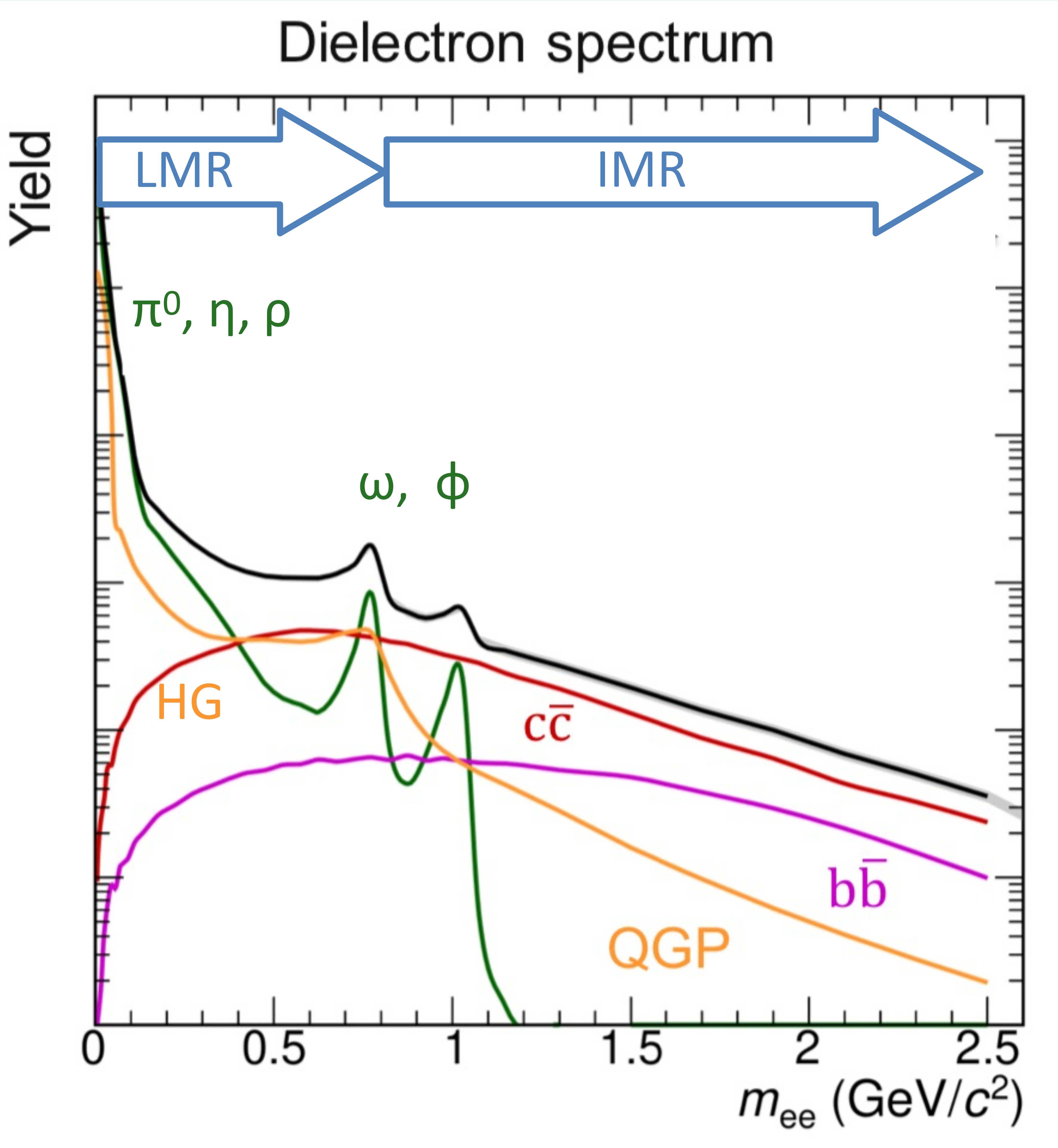
Dilepton measurement in HIC



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  - Carry the information w/o final-state interactions

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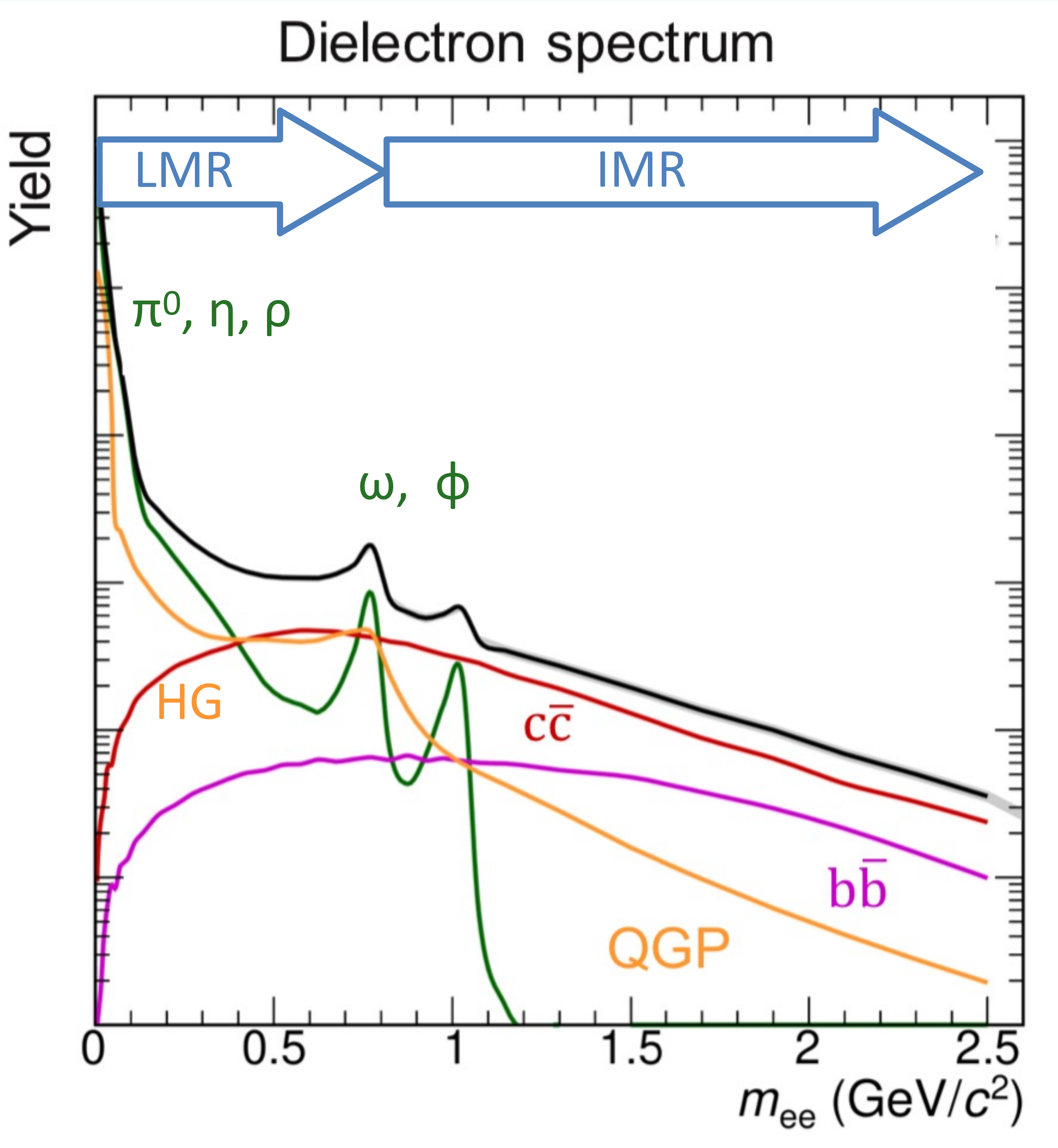

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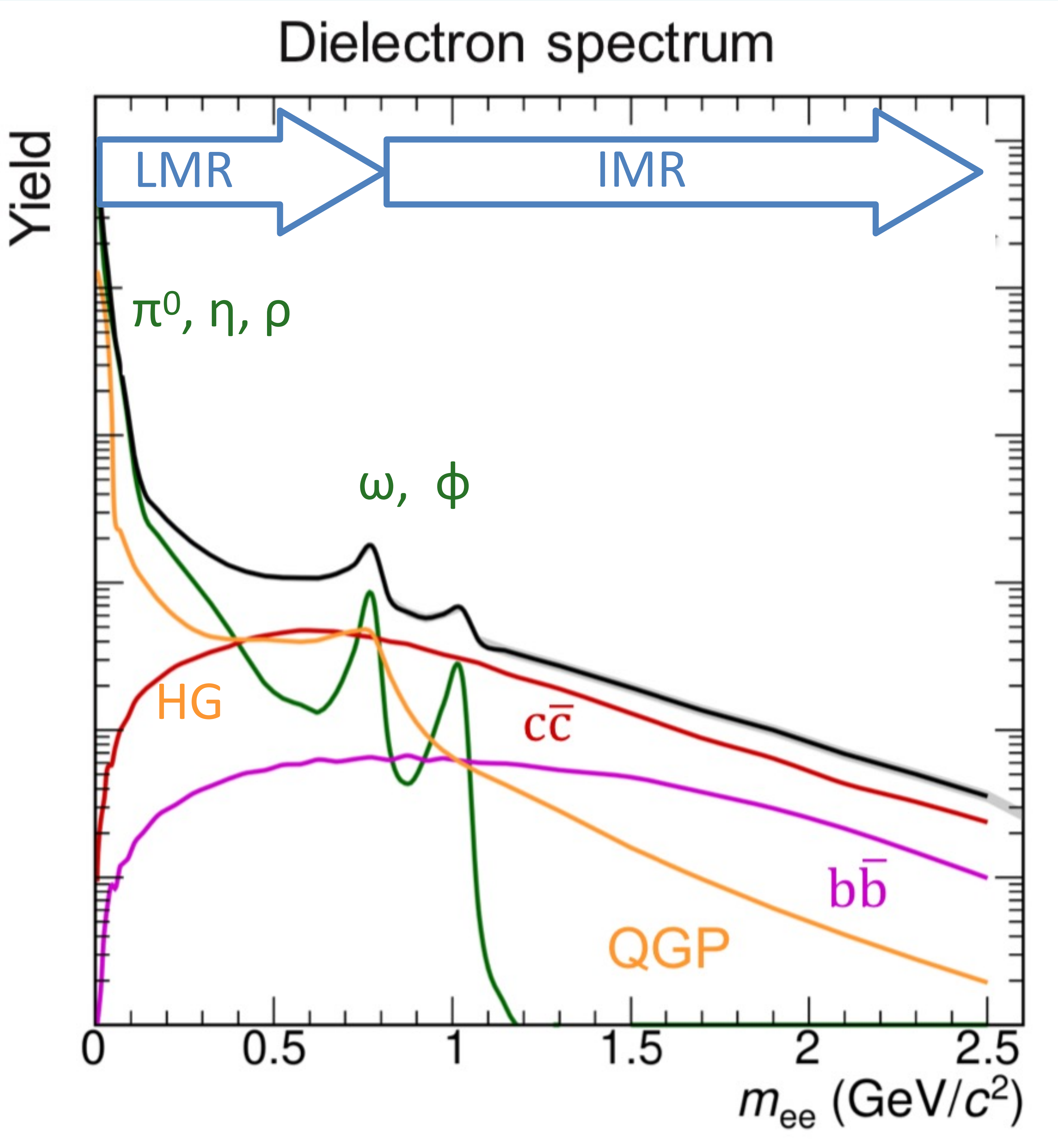

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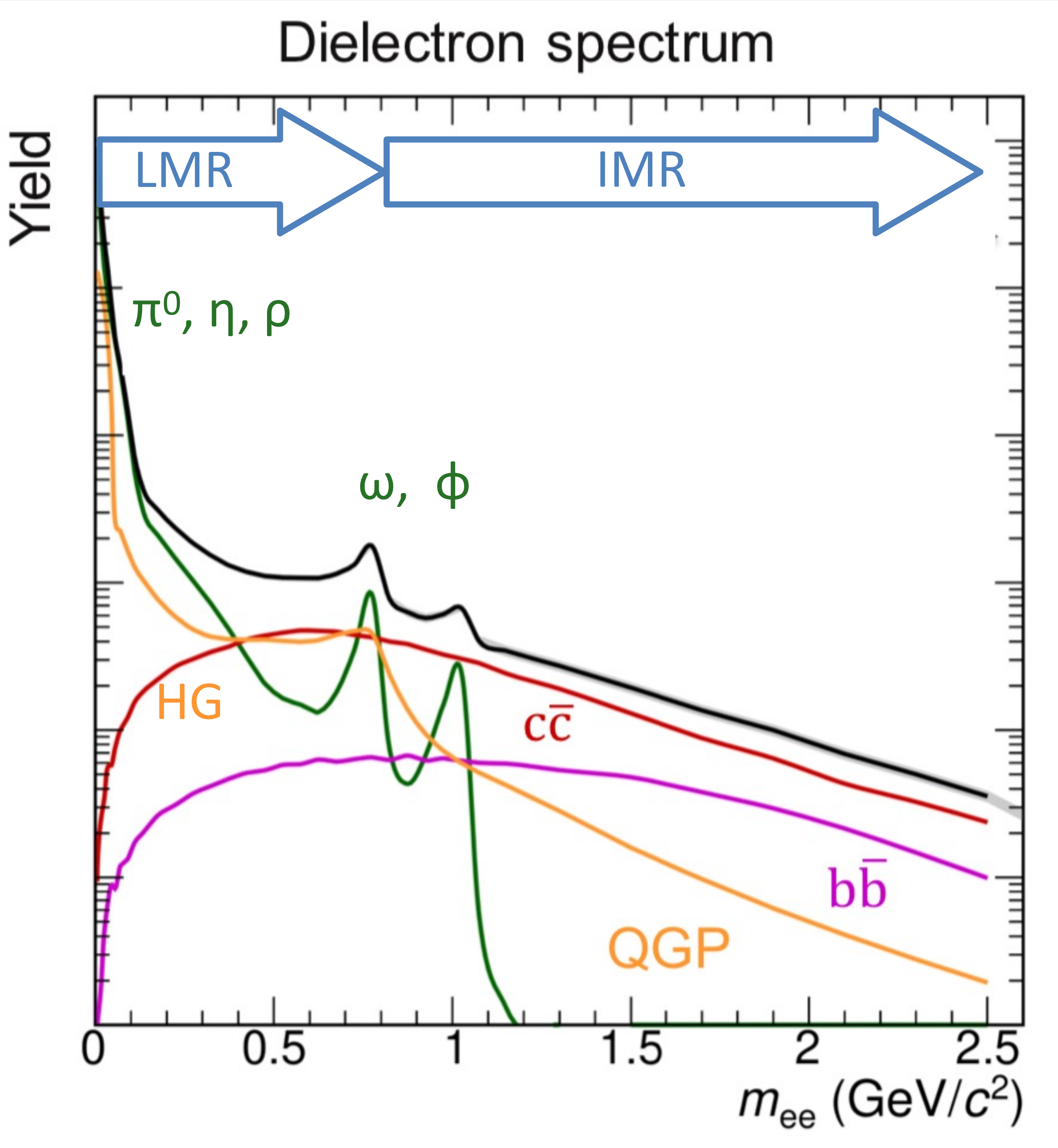

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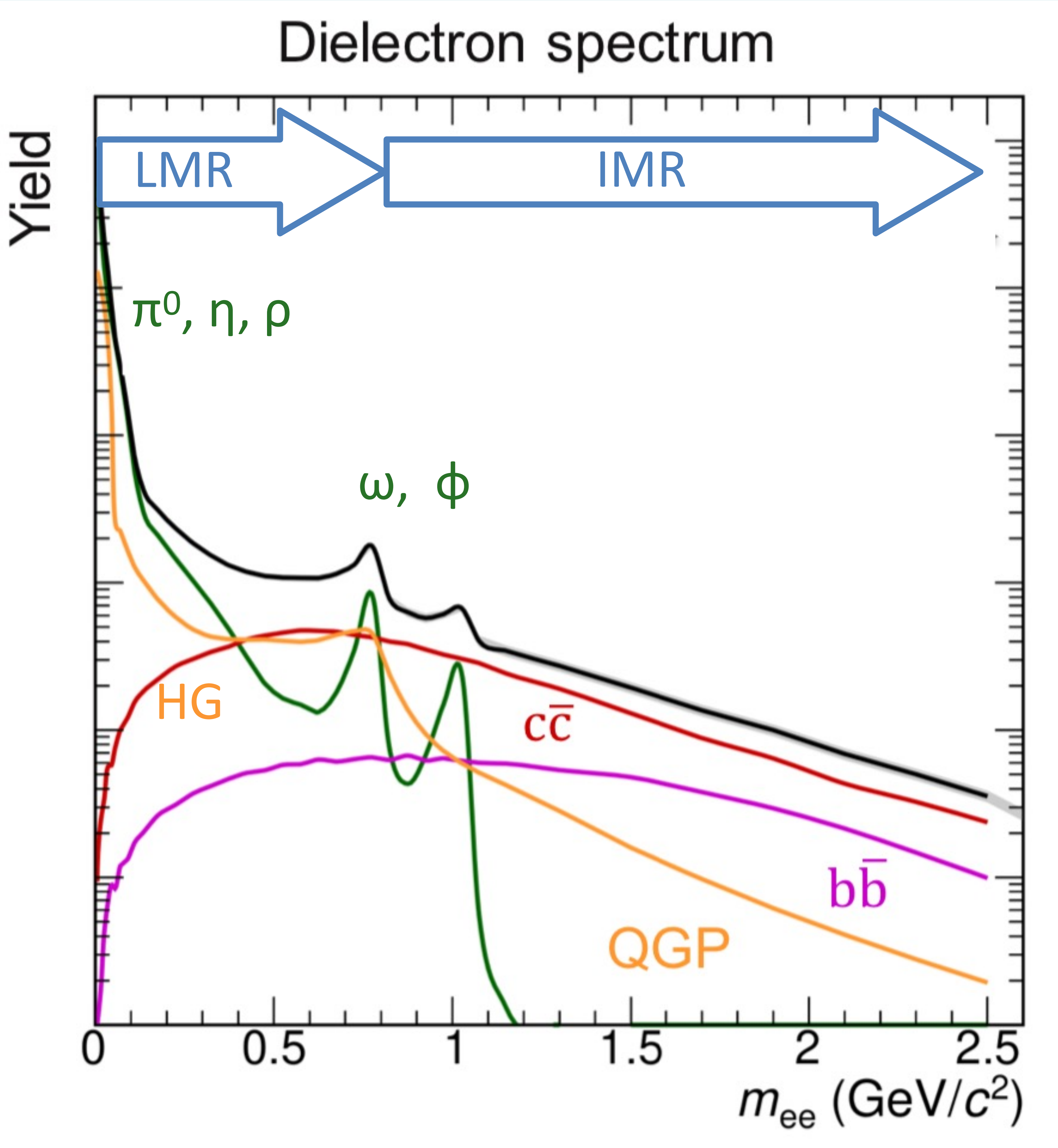

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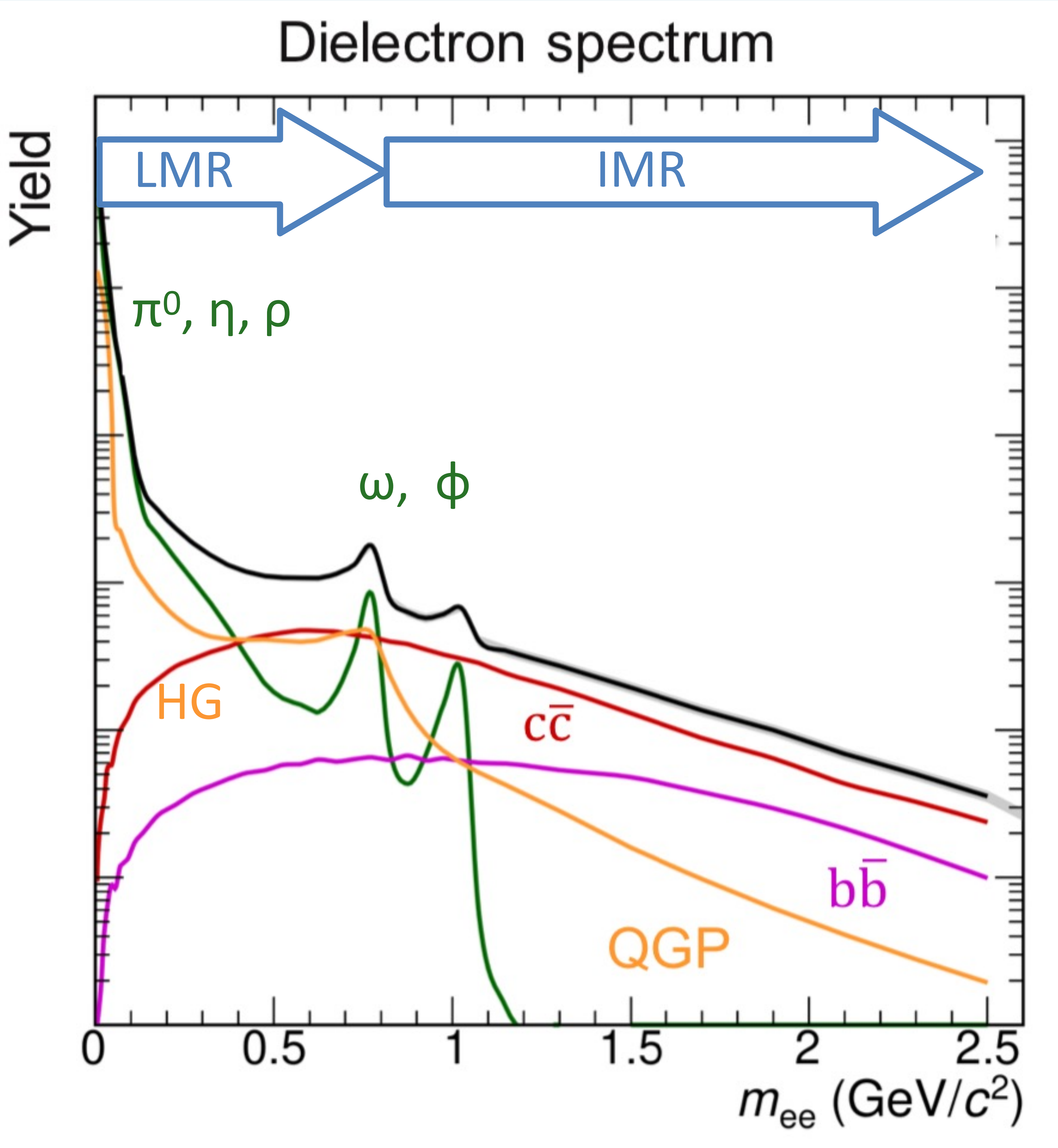

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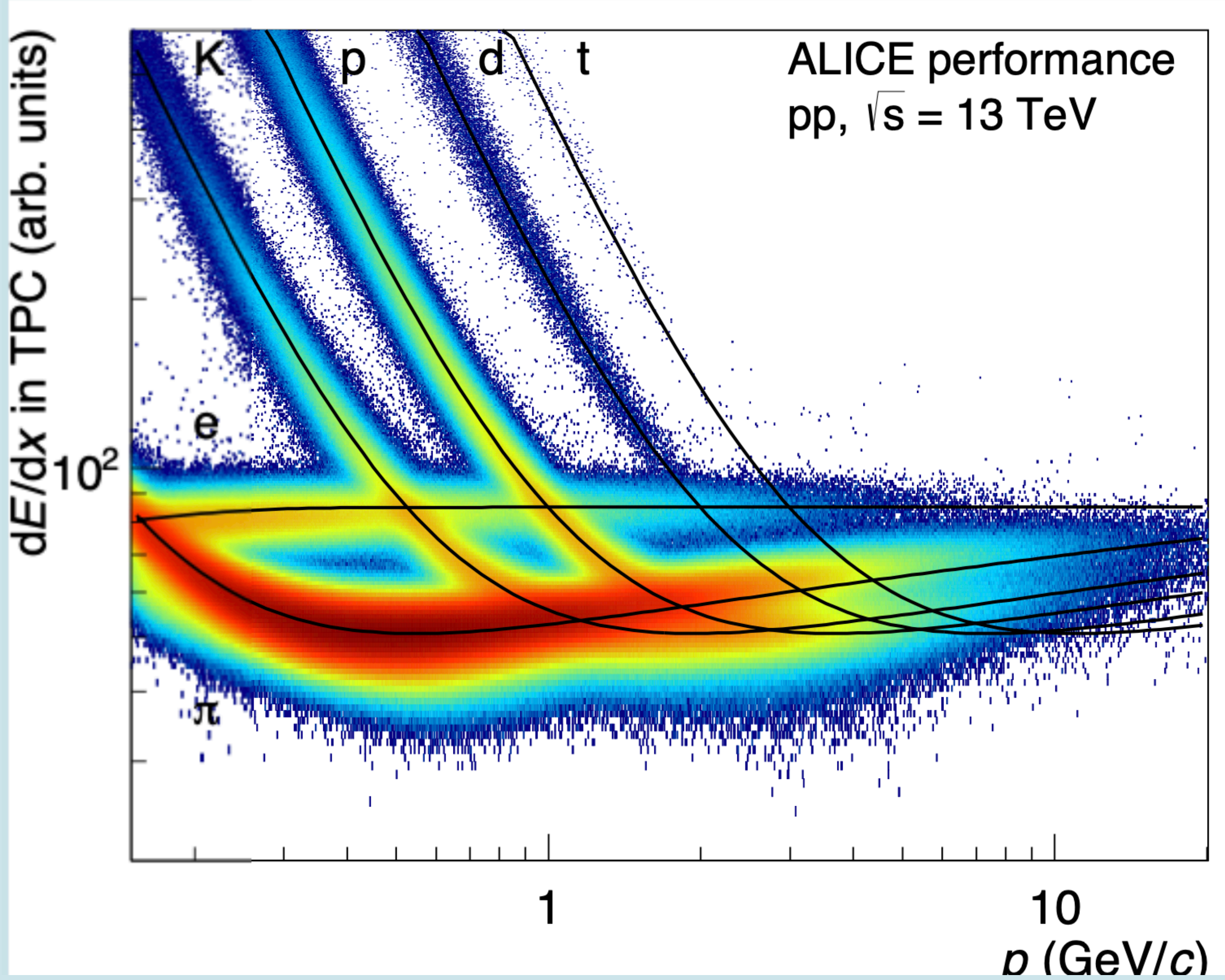
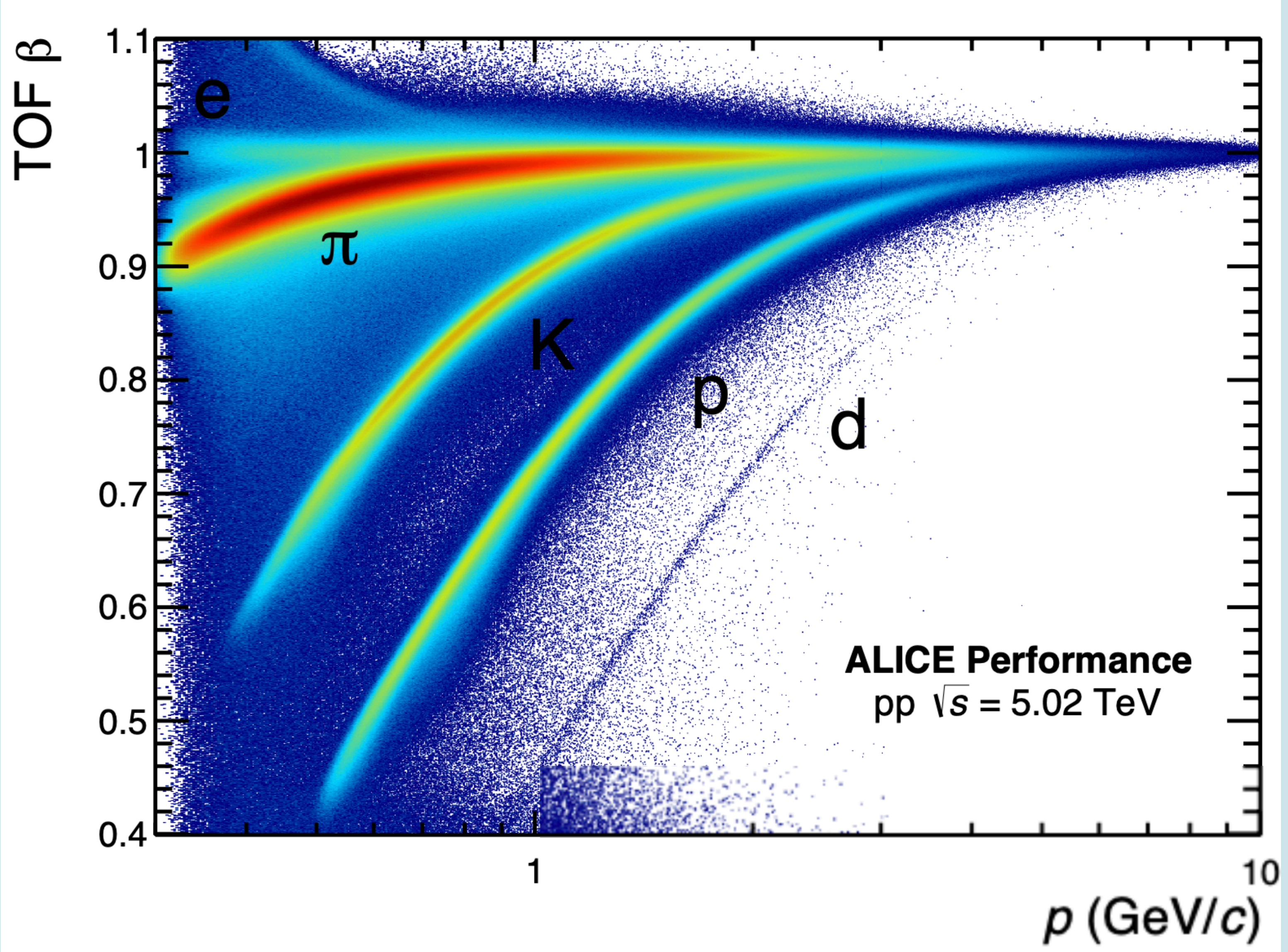
Experimental technique electron identification

- All techniques use mass information for identification
  - e.g. dE/dx, time-of-flight, and so on





Experimental technique
electron identification

- All techniques use mass information for identification
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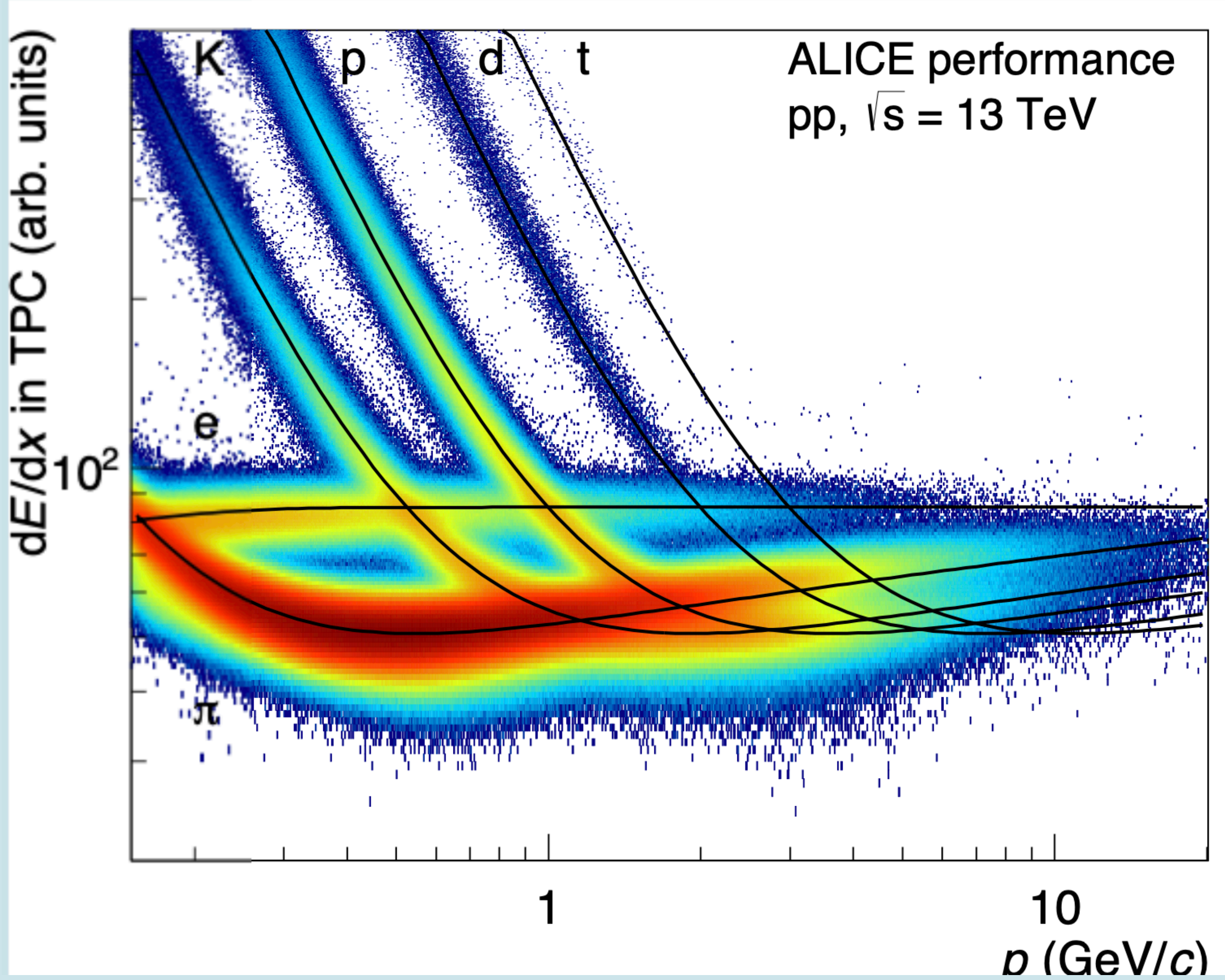
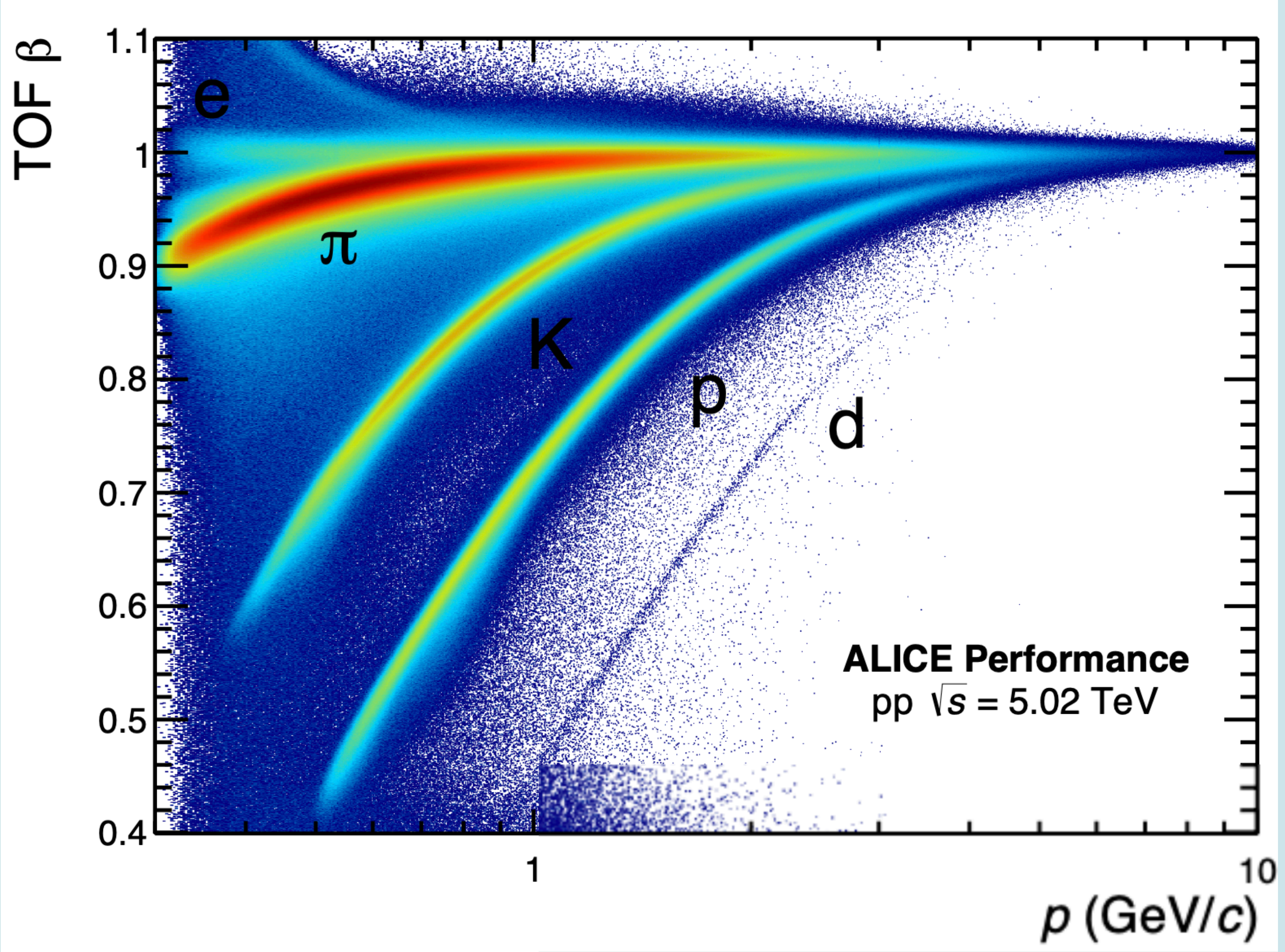
- Unfortunately, muon mass is almost the same as the pion mass
  - μ=105MeV/c^2, π=139MeV/c^2





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  - Stable lepton with much higher mass than electron

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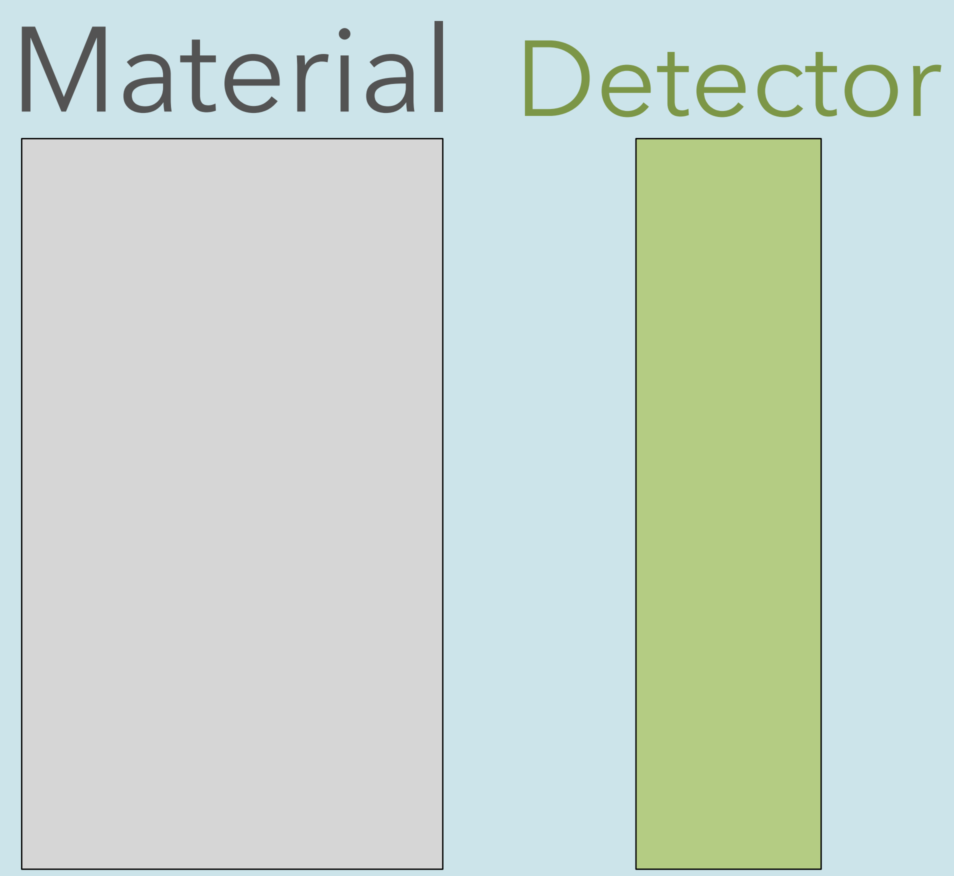

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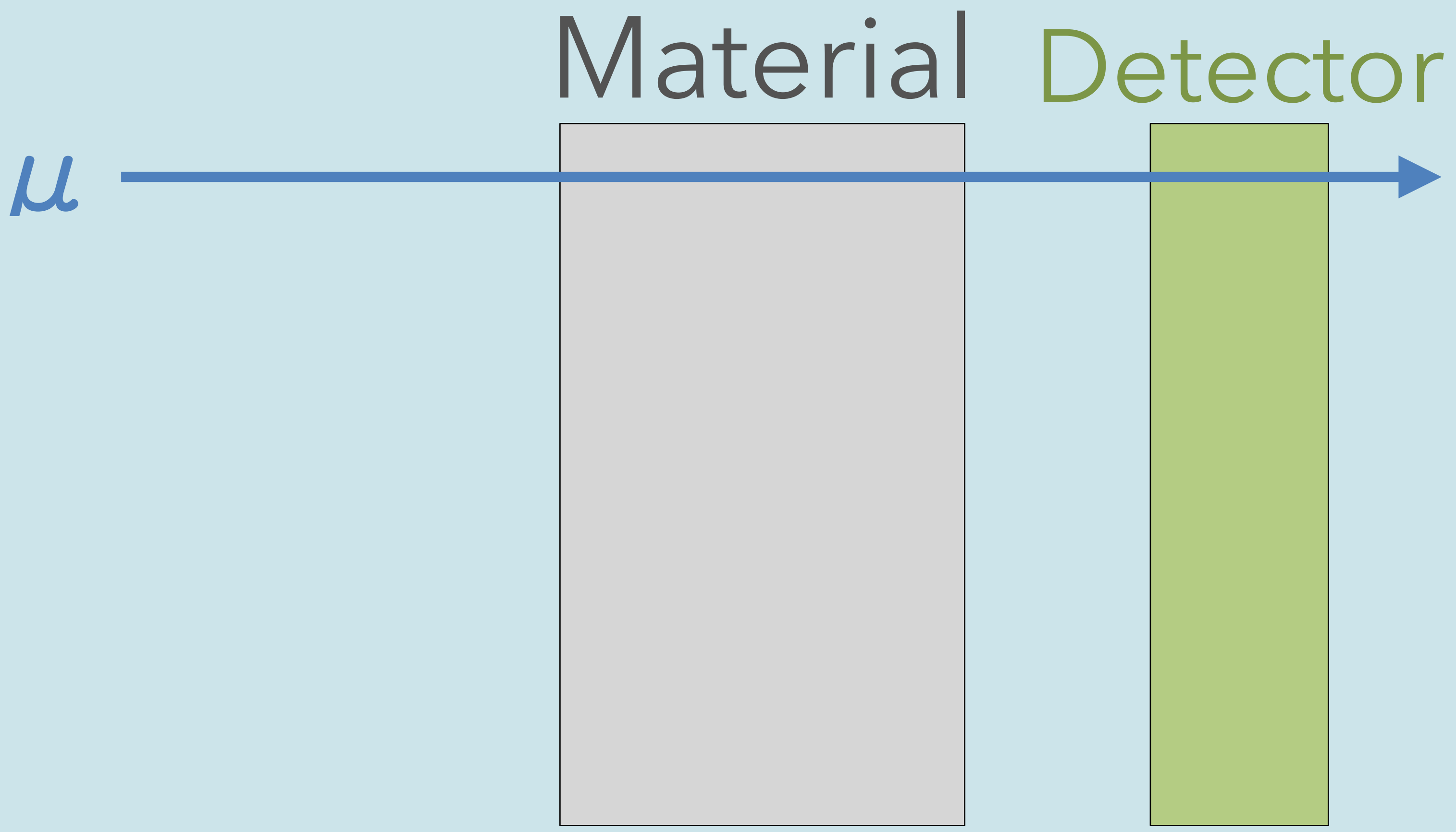

Penetrate (achieving a detector)

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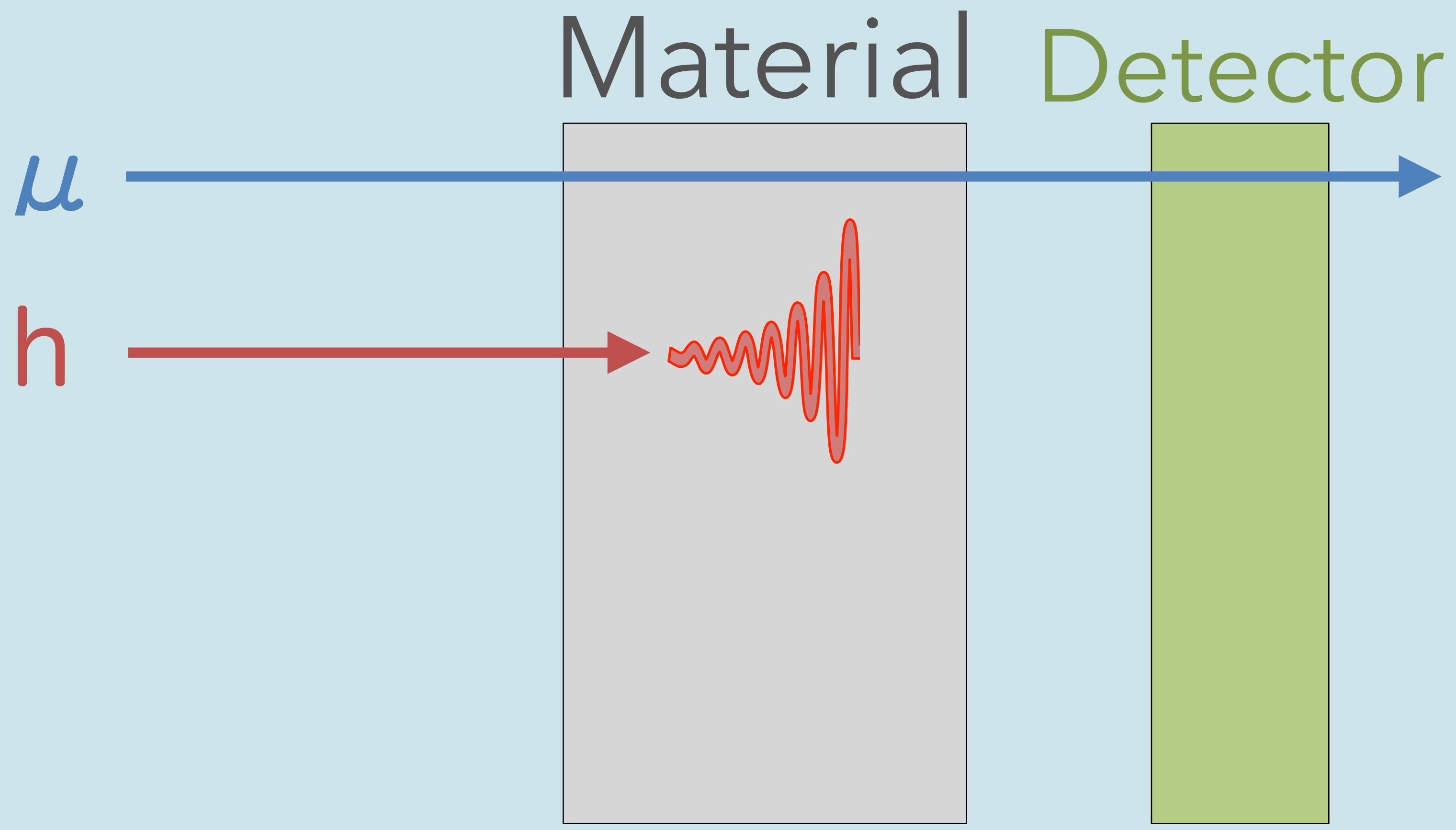

Penetrate (achieving a detector)

Stopped by the hadron shower

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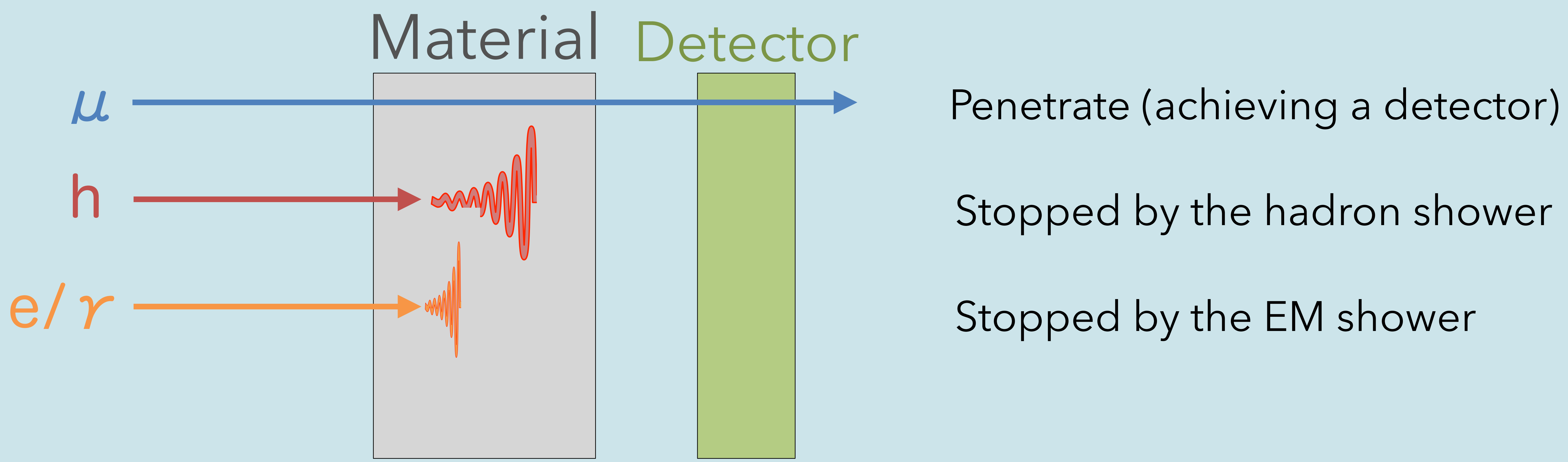

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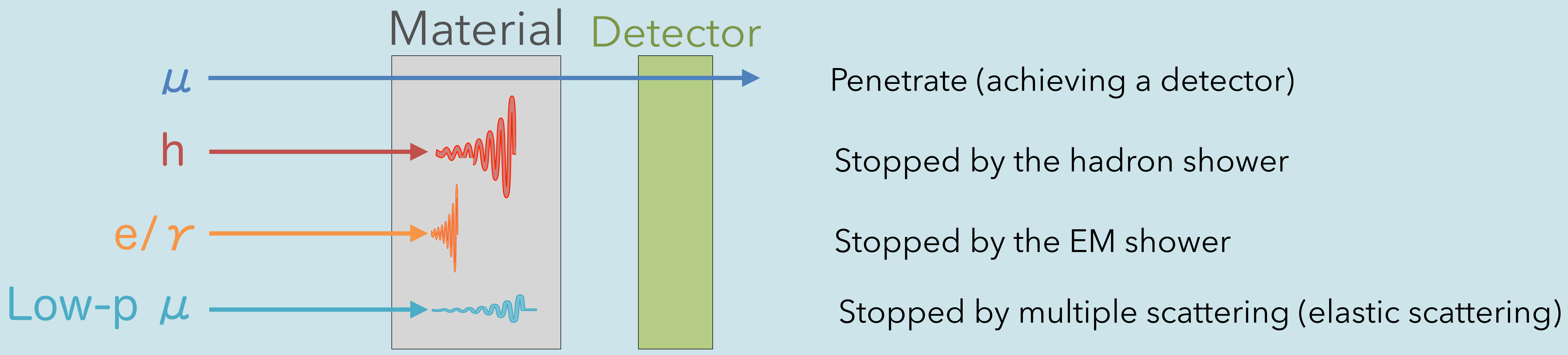

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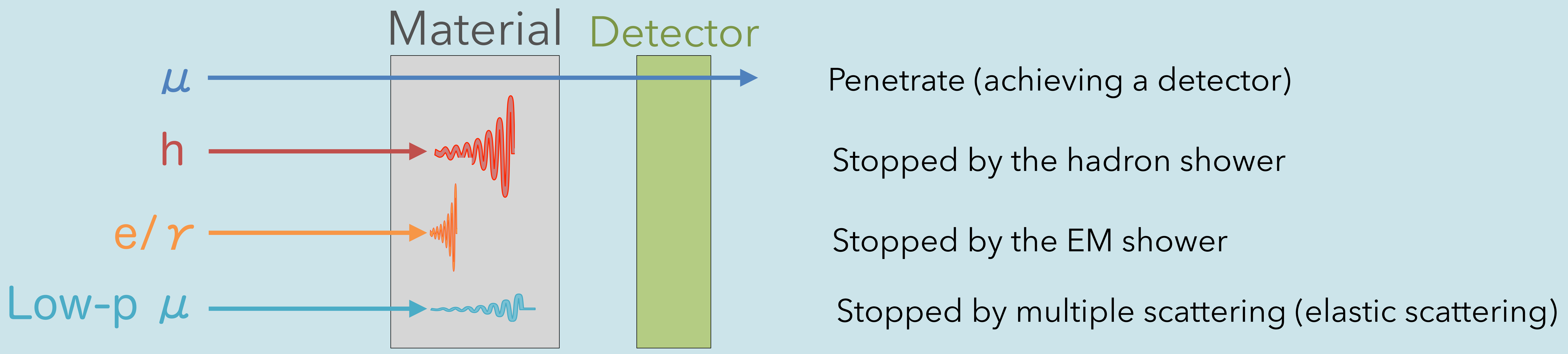
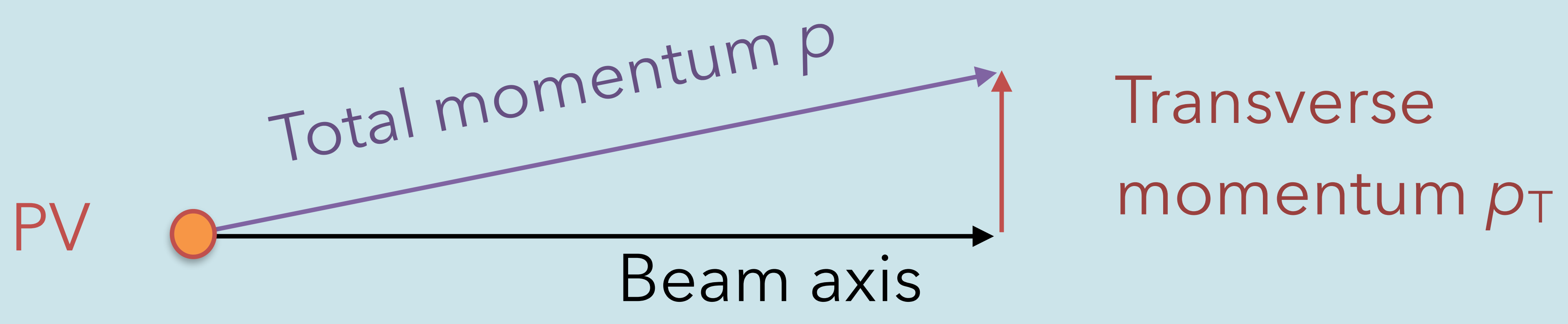


- Low-p_T muon is measured in forward rapidity (Lab-frame)
  - Satisfy large total momentum and low-p_T

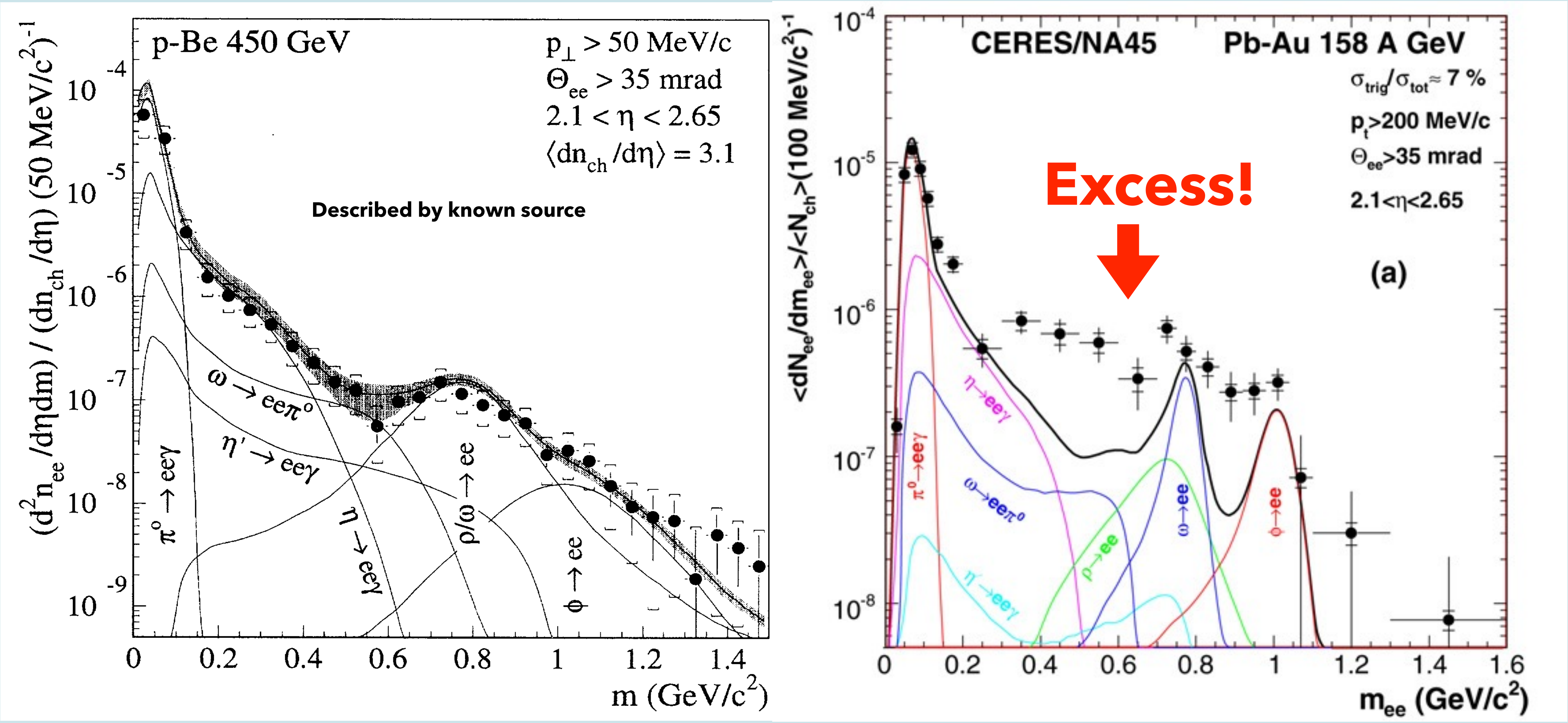


e.g. p~5GeV/c → p_T~0.5GeV/c @ η=3.0

1990s - 2010s

Results from SPS: CERES dielectron measurement

- CERES collaboration observed the enhancement in LMR in A-A collisions, not in pp via dielectron
  - Low mass vector meson mass modification due to Chiral symmetry restoration (CSR)?
  - Dropping? or Broadening?



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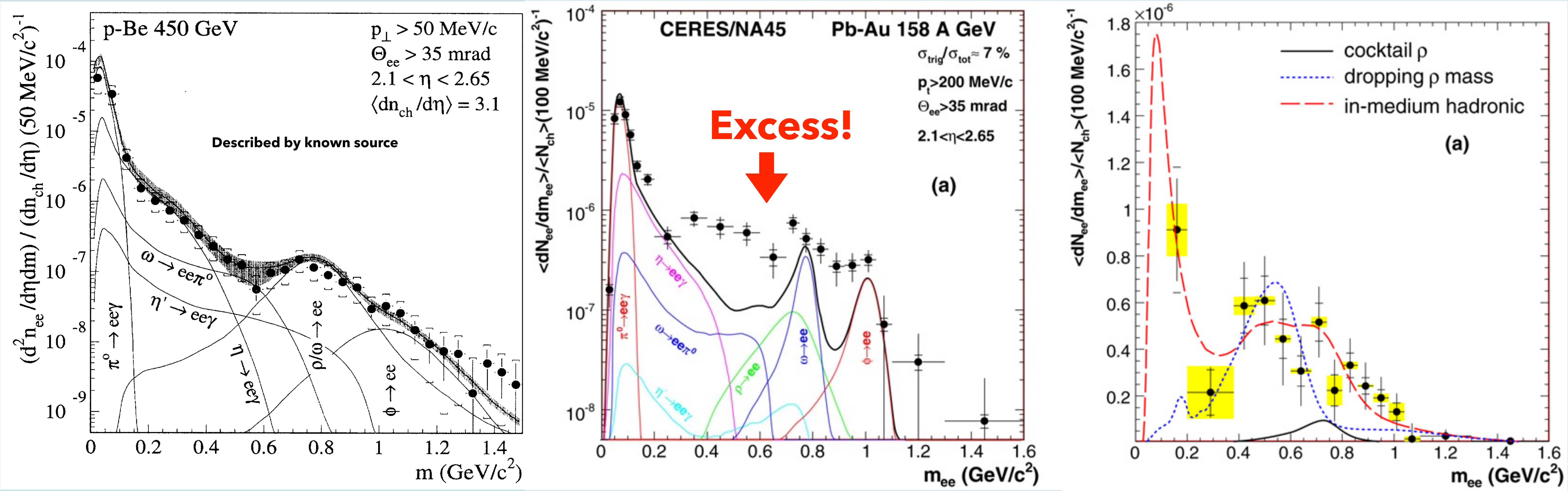
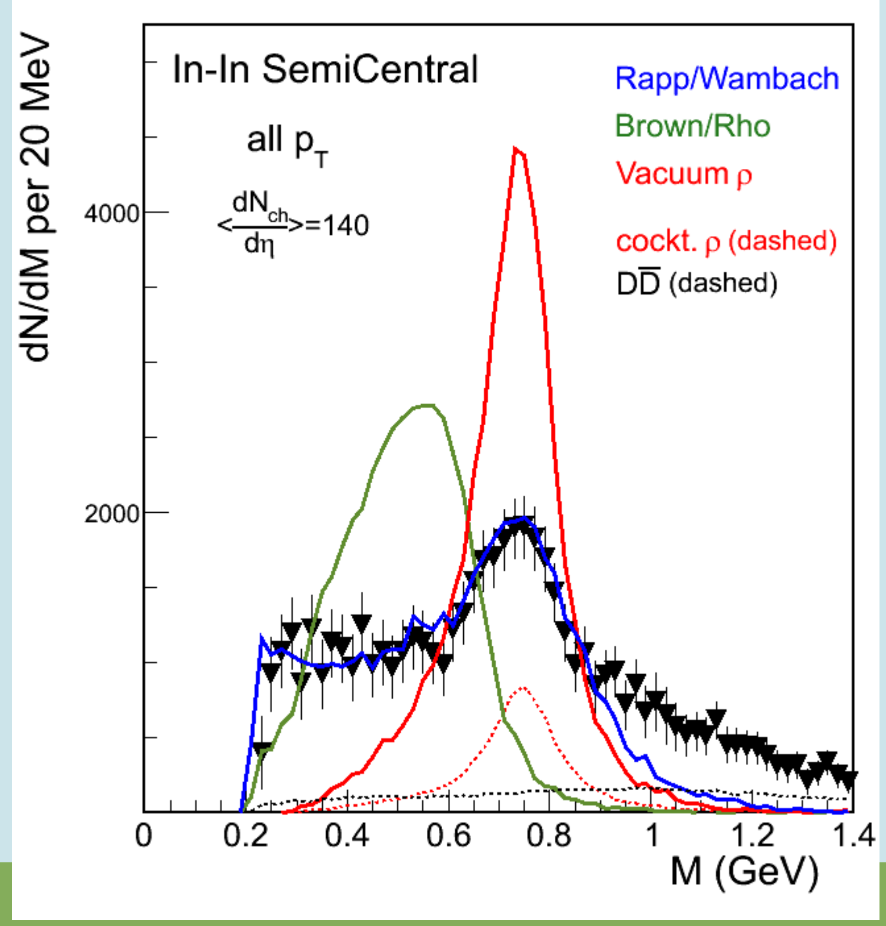
  - Dropping? or Broadening?
- Resolution and statistics accuracy was insufficient to determine the source
  - Combinatorial background electrons from π^0 Dalitz decay and γ conversion were huge



Results from SPS: NA60 dimuon measurement

- Clear excess was observed with high-quality data
  - Ruled out the dropping mass
    - Underestimate 0.6 - 0.8 GeV/c^2, overestimate 0.2 - 0.6 GeV/c^2



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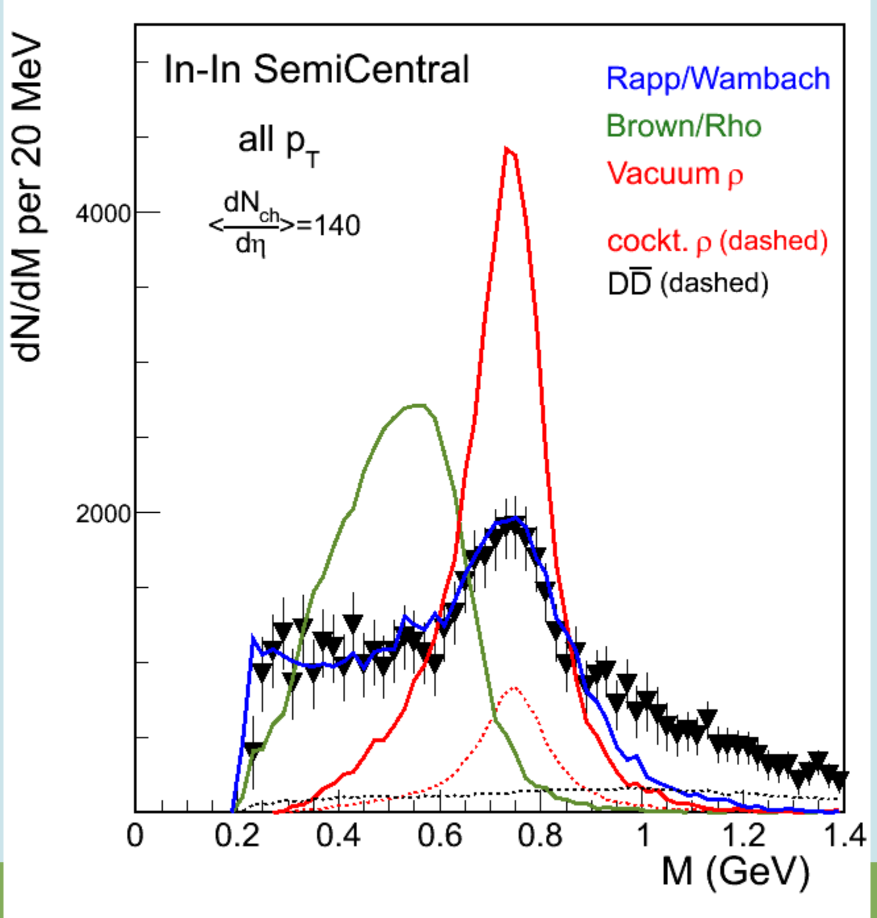

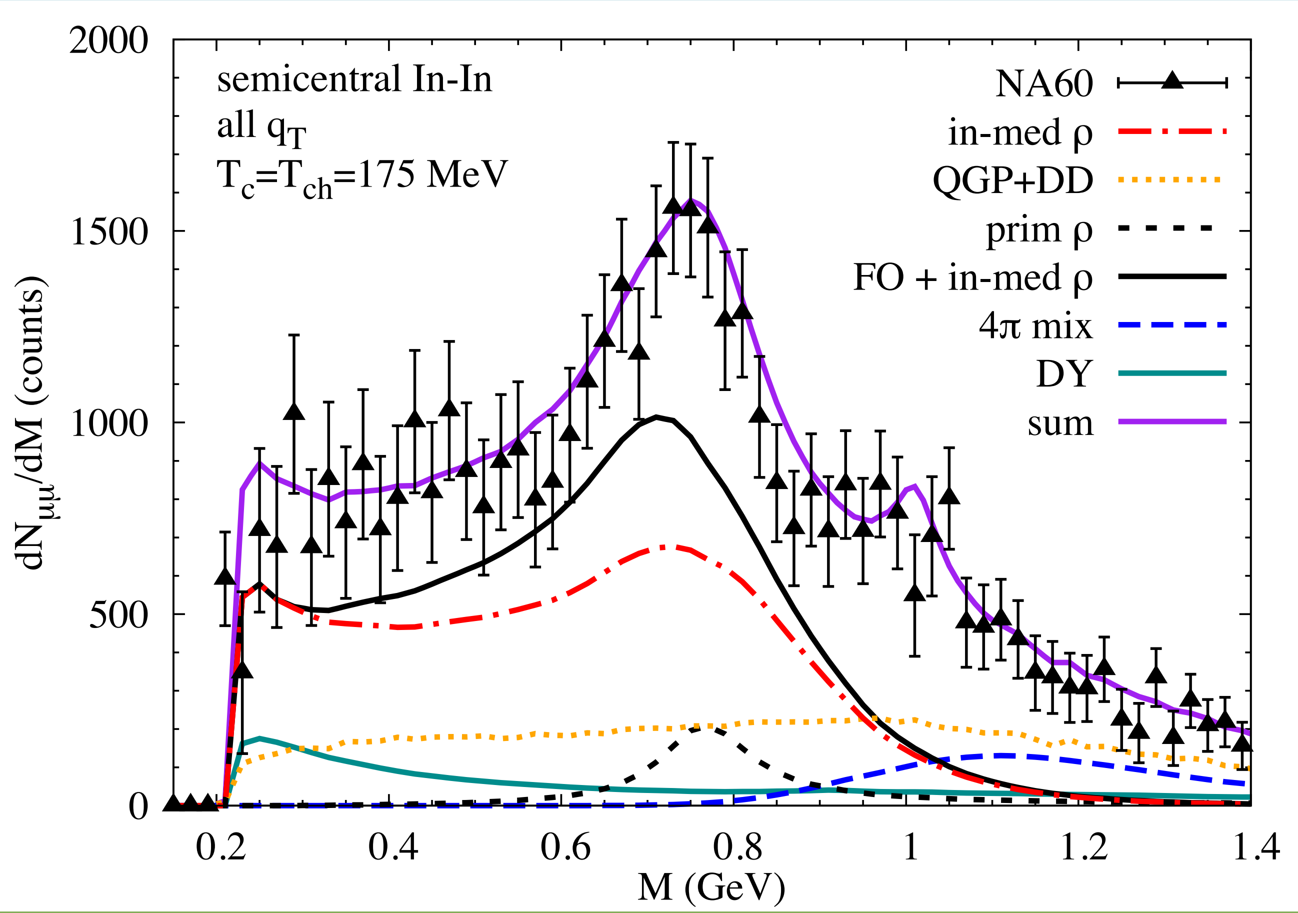

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  - Excess data in LMR could be described by the hadronic matter effect
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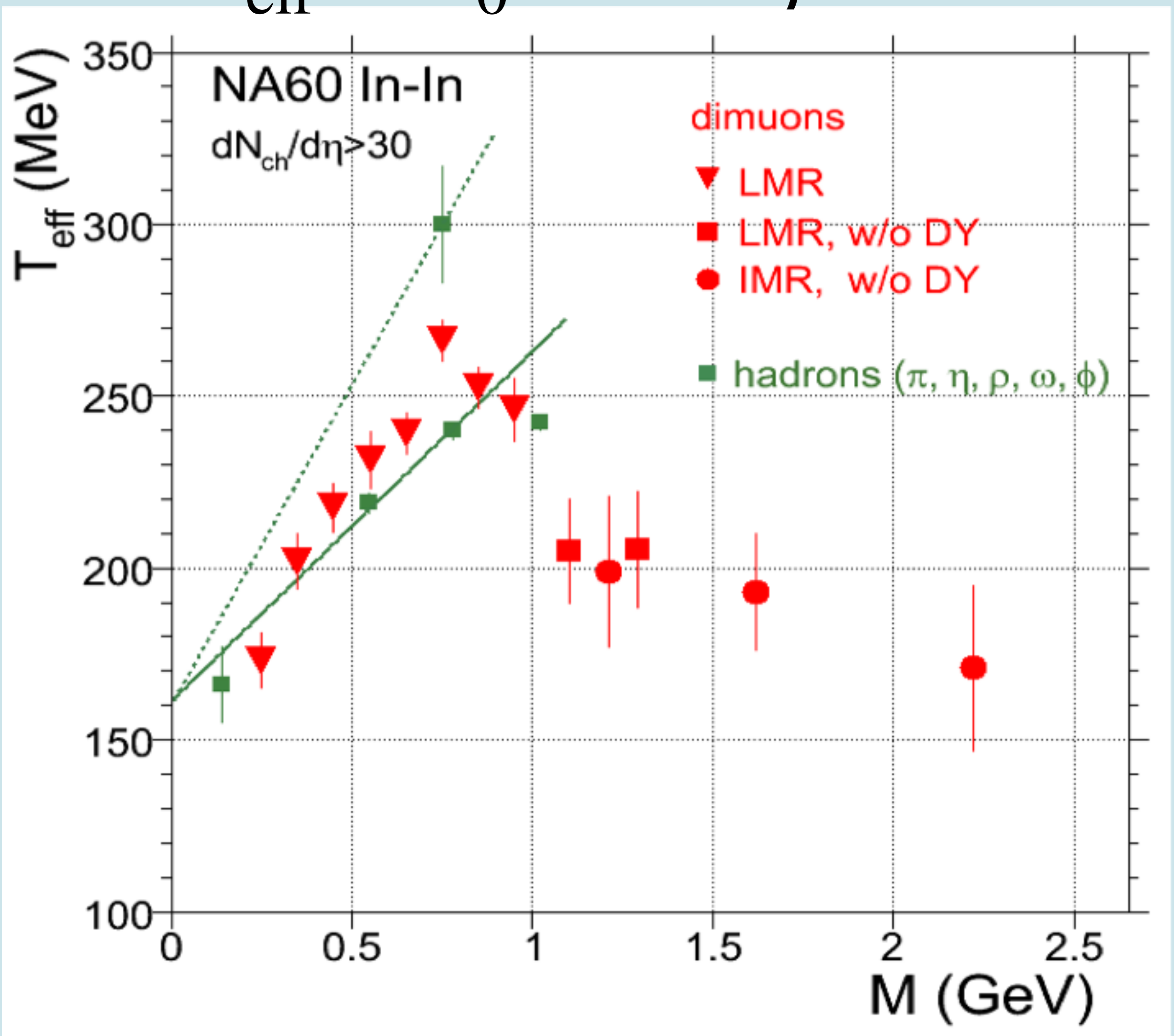
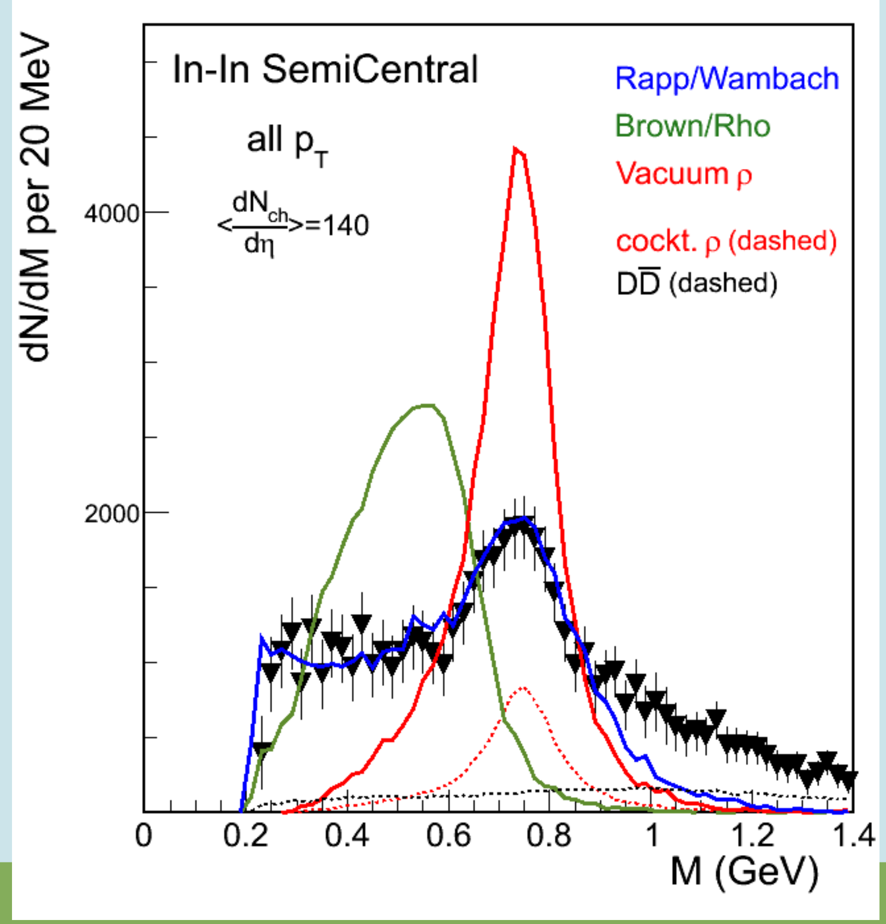
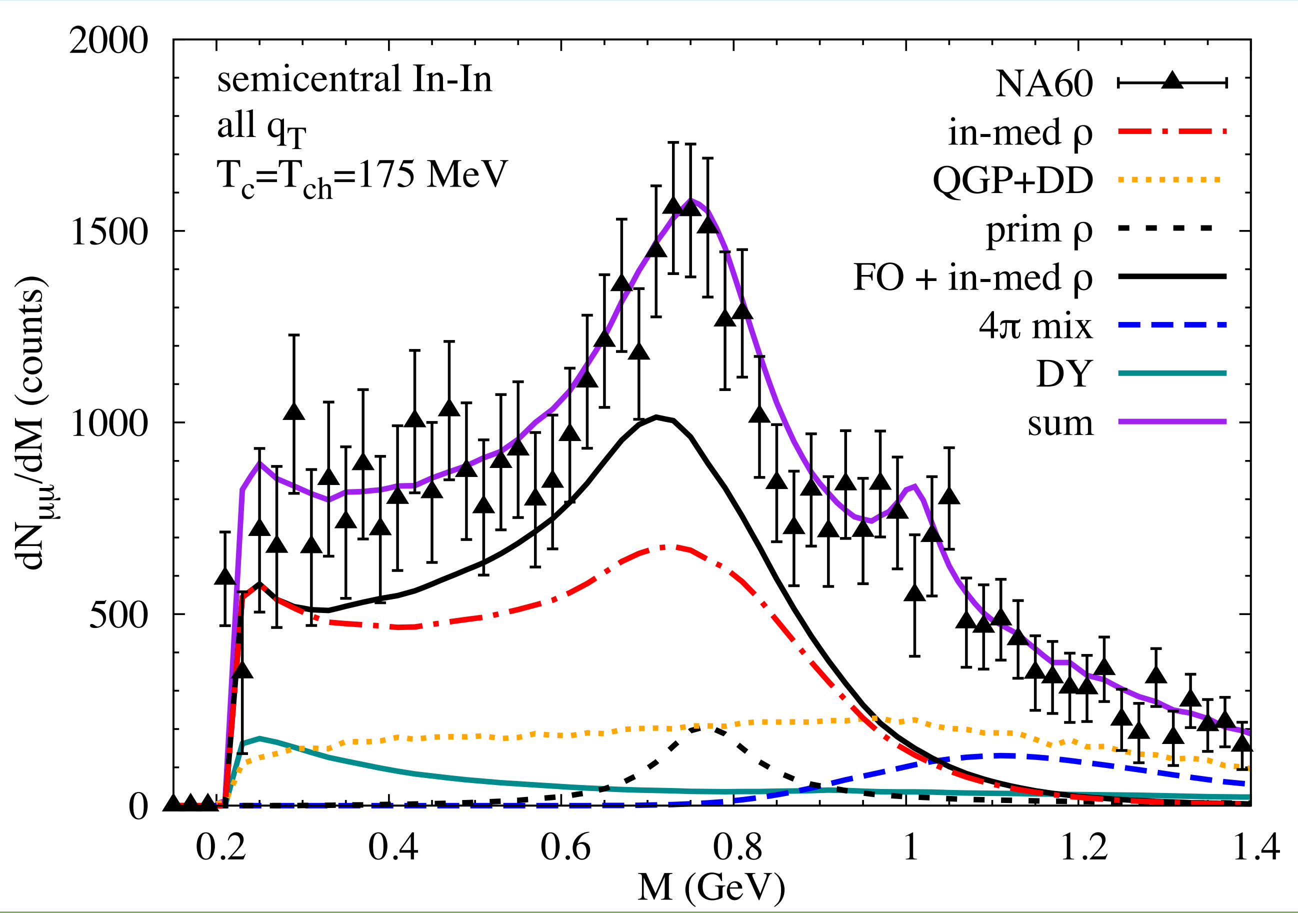
- Excess data at IMR was explained by thermal radiation
  - qqbar→$\mu\mu$

$$T_{\mathrm{eff}} = T_0 + m < \beta >^2$$







- Excess below 1 GeV/c²
  - Consistent with other hadrons
  - Late-stage emission after the occurrence of radial flow
- Excess above 1 GeV/c²
  - No mass dependence
  - Early-stage emission before the occurrence of radial flow

RHIC results
dielectron measurement

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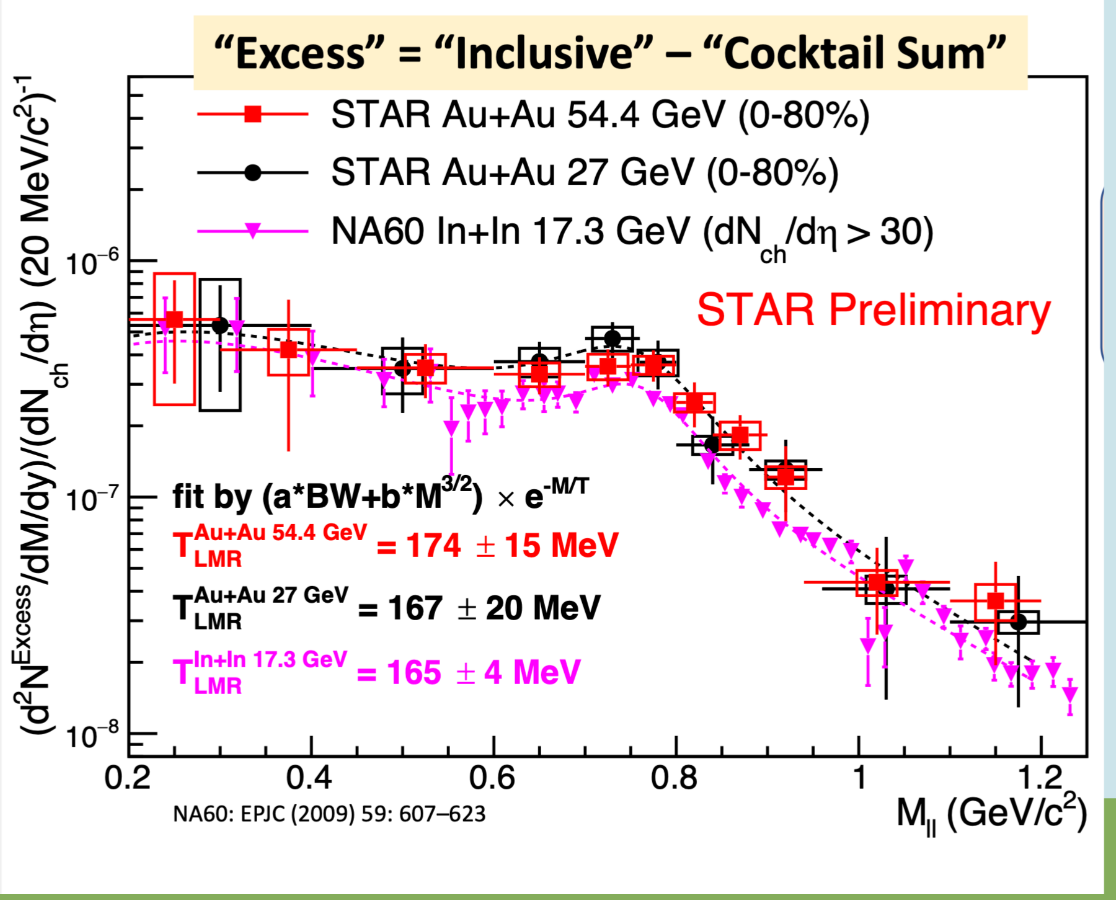
Beam Enegy Scan between SPS and top RHIC



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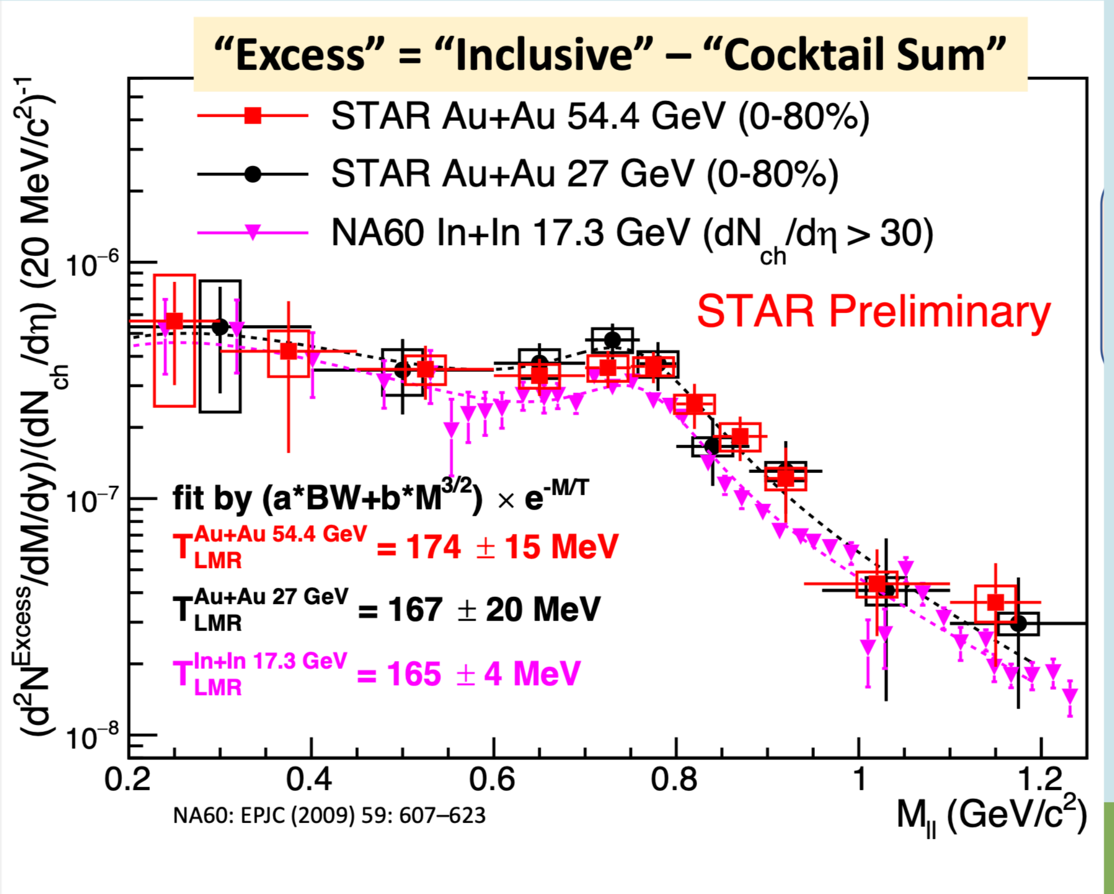

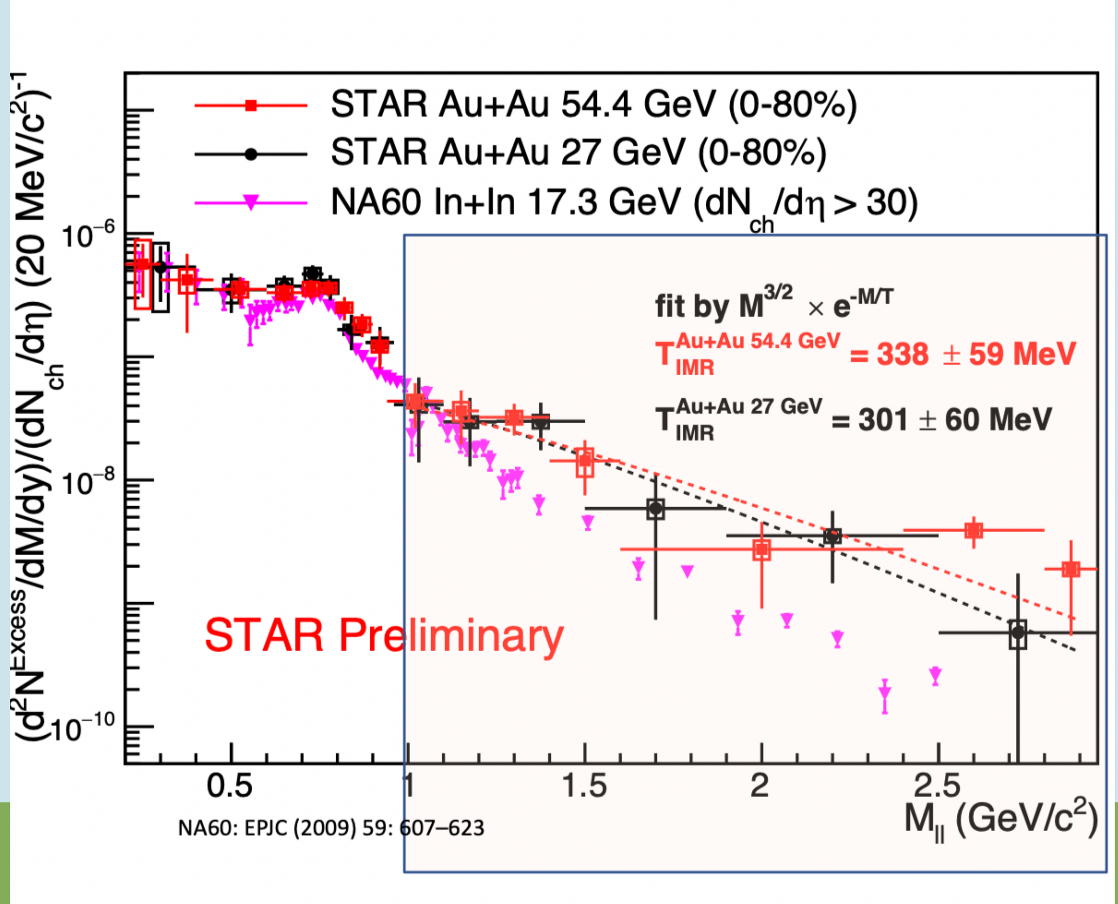

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- The same trend as SPS was seen in the collision energy of the RHIC BES program
  - Same temperature in LMR = the same temperature at late stage
  - Higher temperature in IMR = higher temperature at early stage
- Enhancement has been measured at top energy $\sqrt{s_{NN}}$ = 200 GeV (MB: 2.4M Evts)
  - Large uncertainties due to the huge combinatorics @ LMR and HF contributions @ IMR

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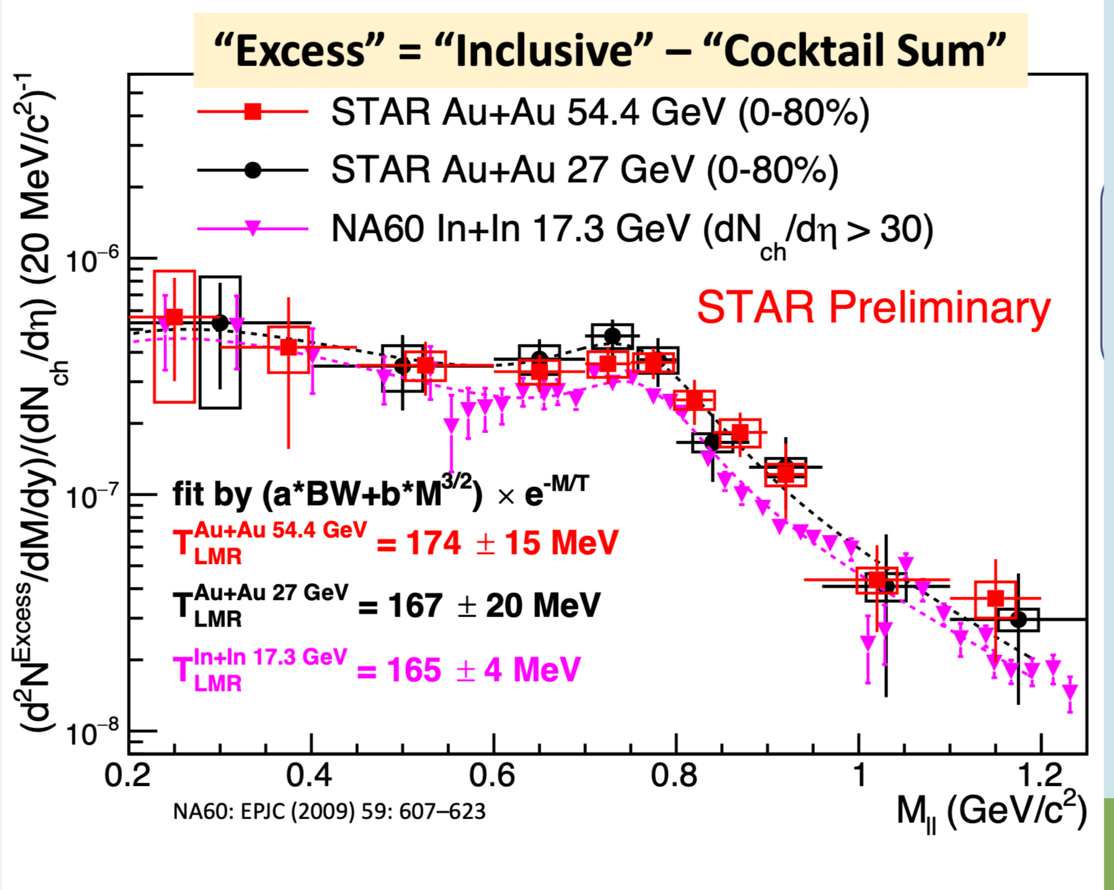
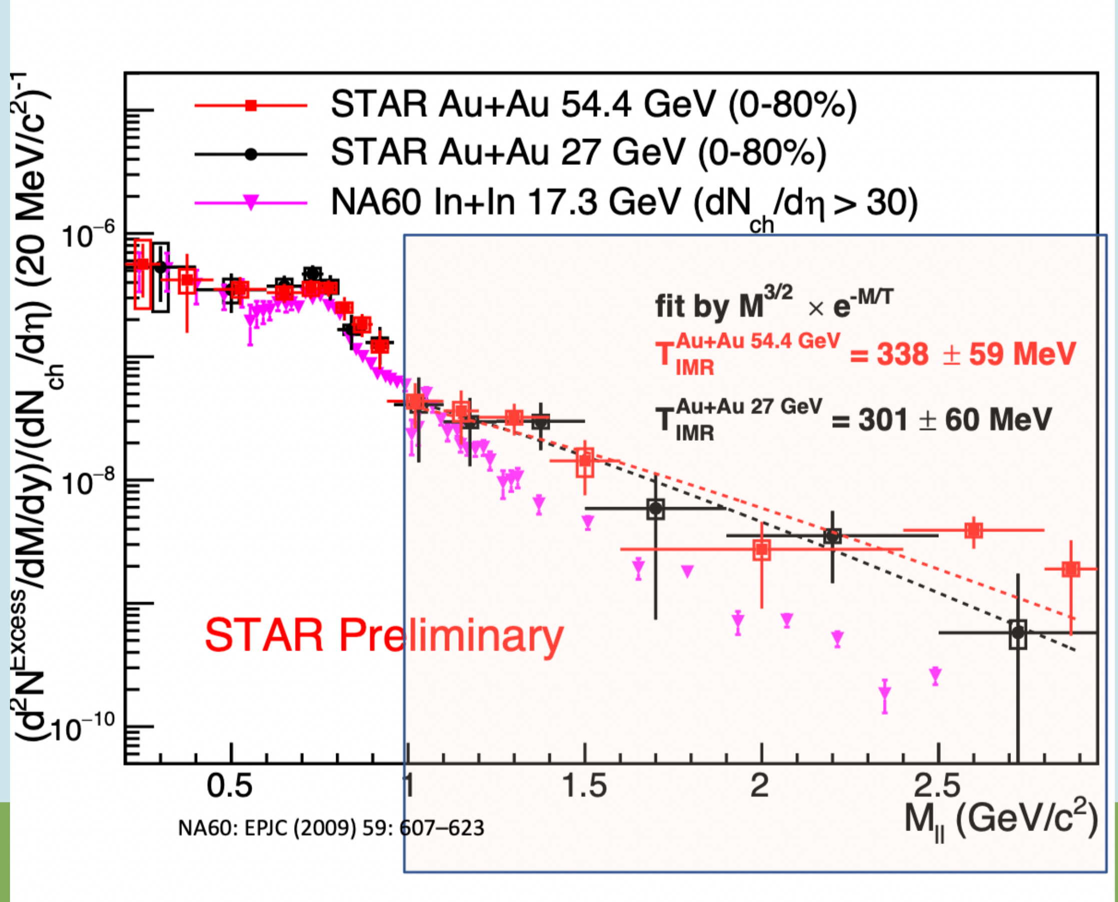
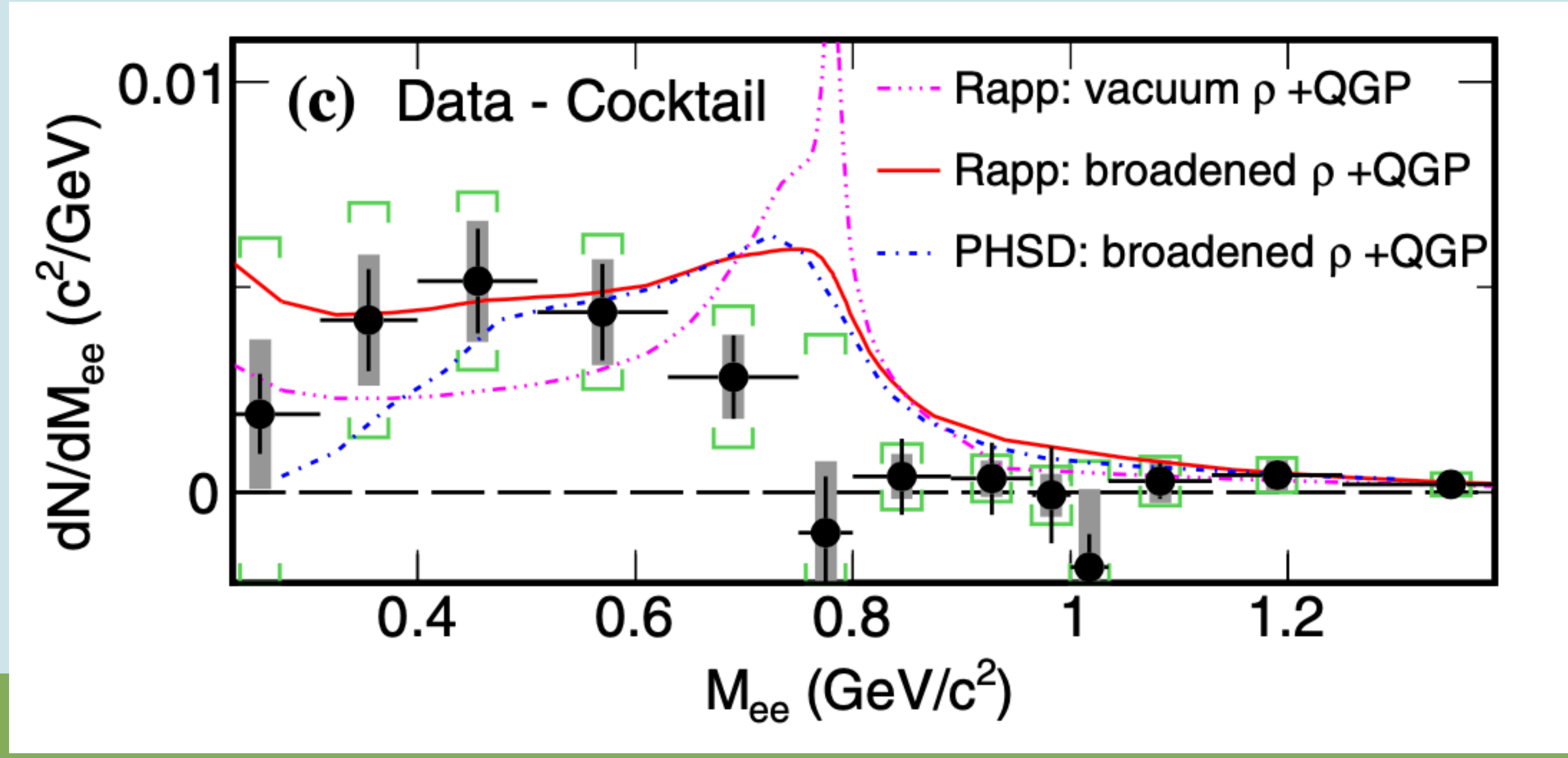




Top RHIC energy √sNN = 200 GeV (MB)



LHC results
Dielectron and dimuon measurement

- Dielectron spectrum seems to have enhancement at LMR (0-10%: 65M Evts)
  - No conclusion due to insufficient accuracy
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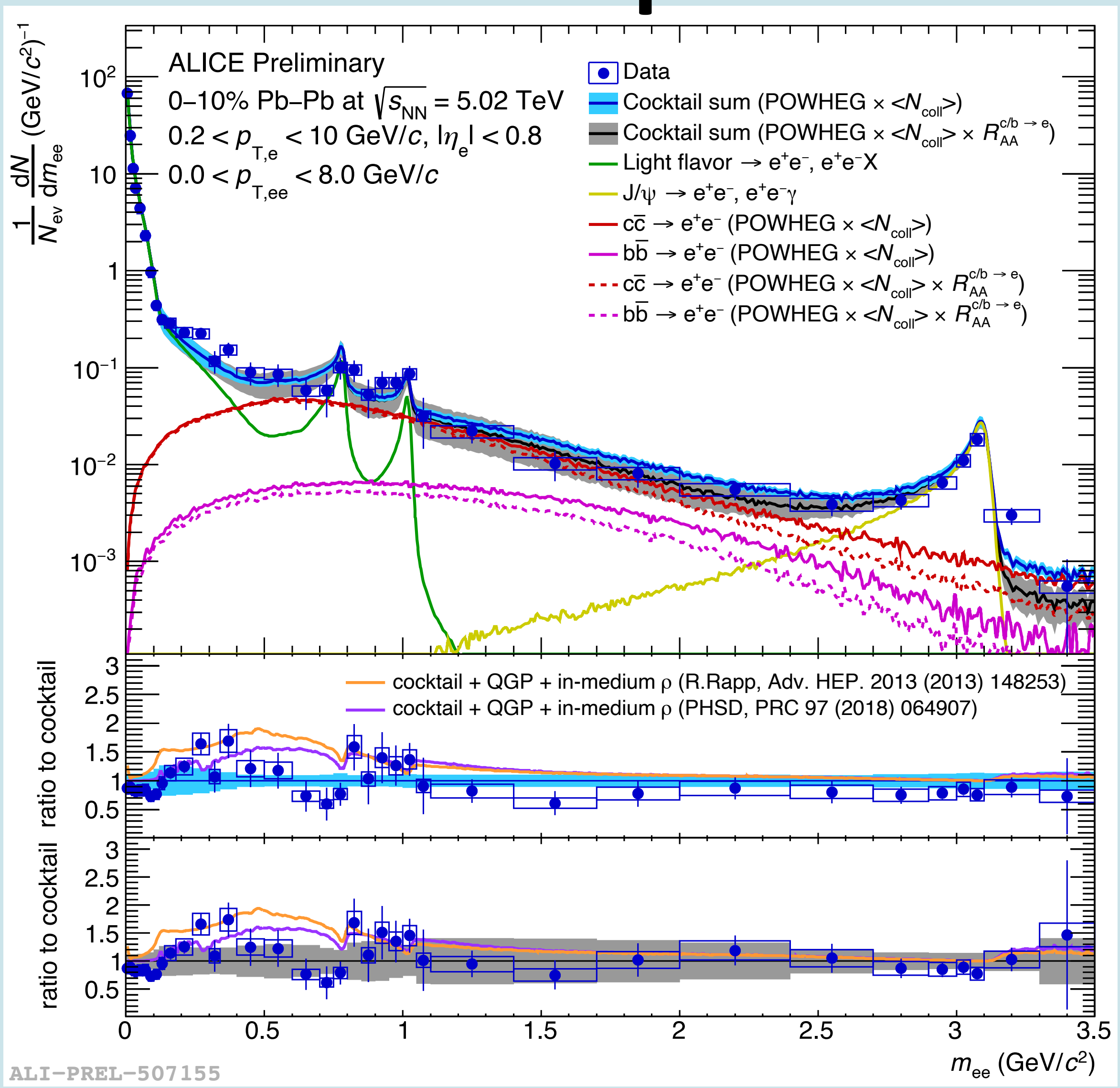
  - More contribution from HF w.r.t. the previous experiments

Dielectron spectrum



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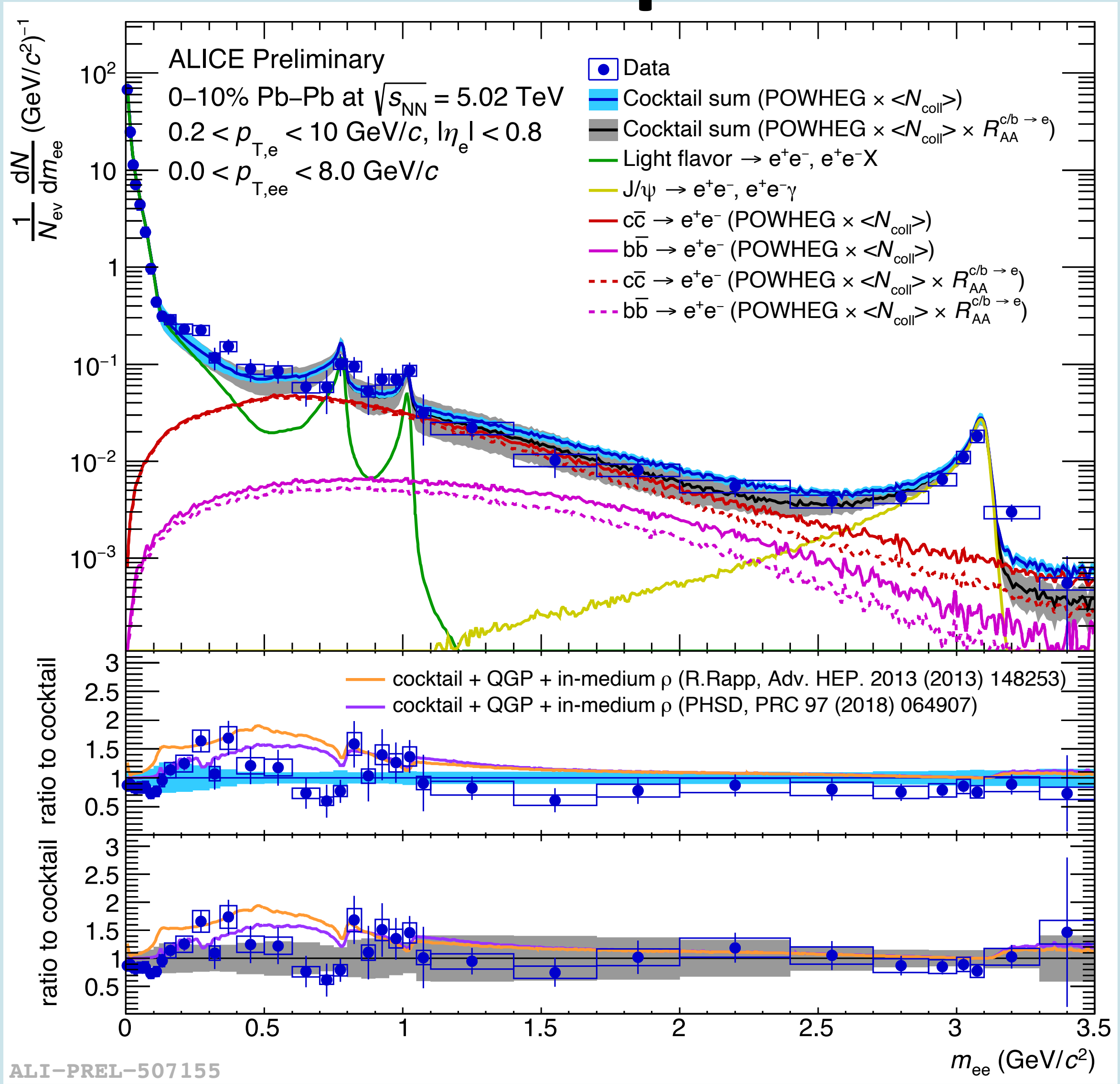
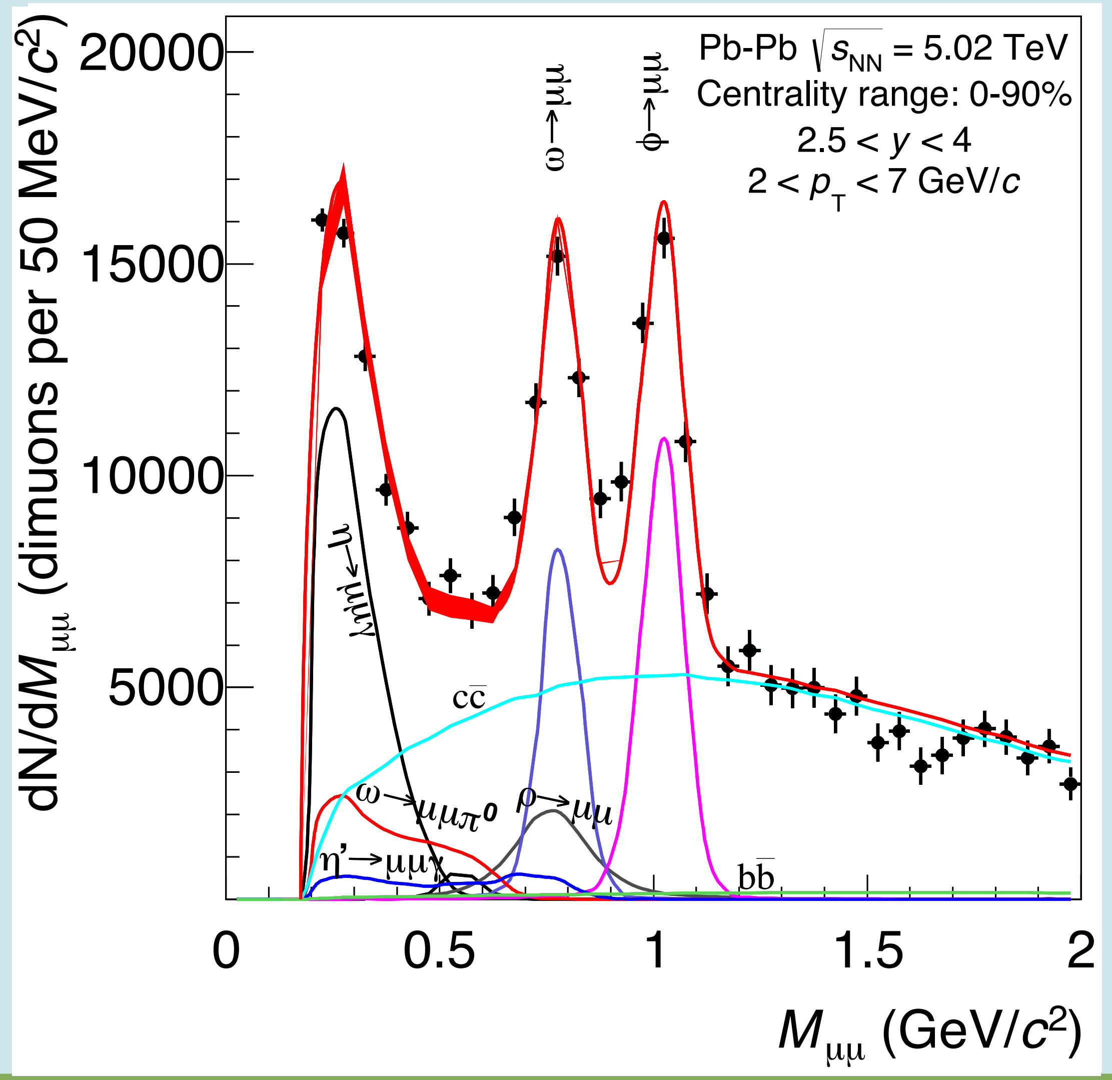
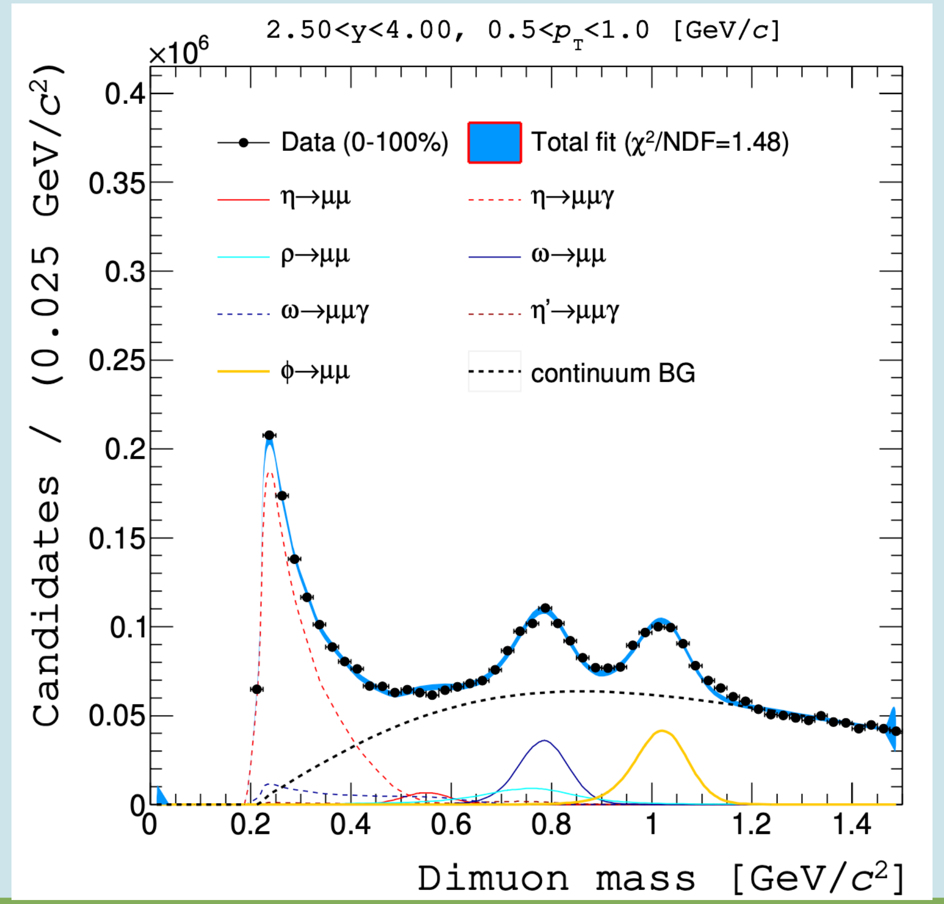


Dimuon spectrum



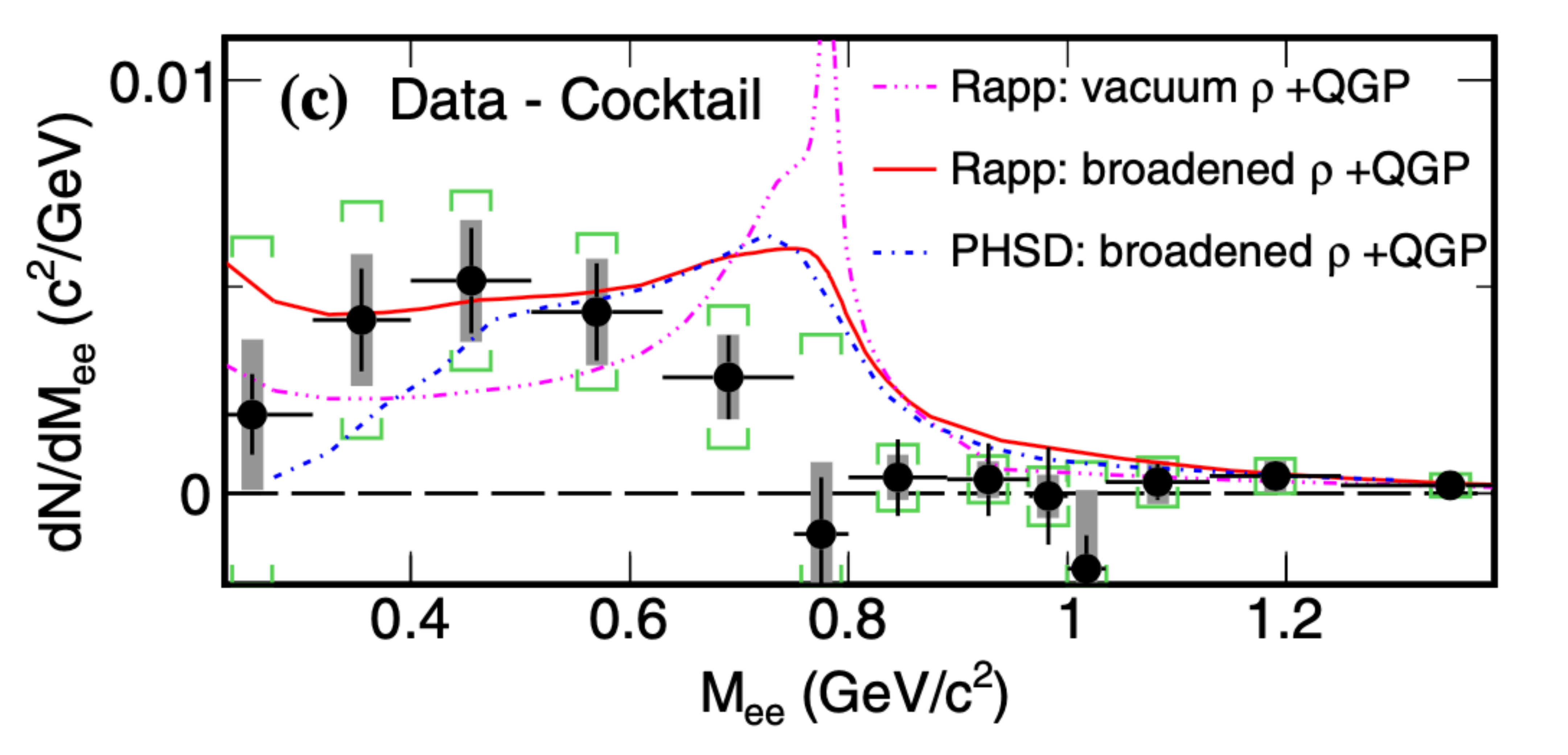
w/o trigger threshold



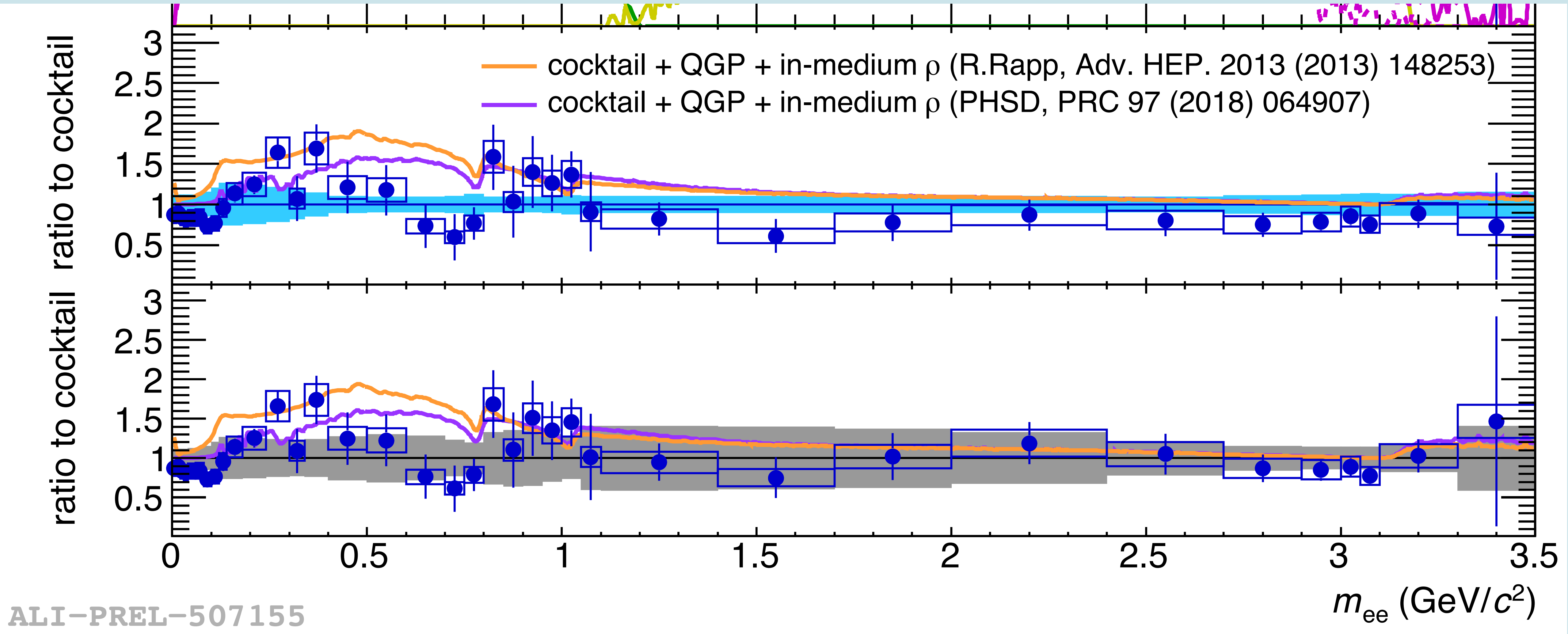
- Dimuon spectrum cannot access LMR and IMR
  - Insufficient mass resolution due to multiple scattering
  - Inaccessible low p_T region due to trigger operation
    - down to p_T~0.5 GeV/c w/o trigger threshold
  - Inaccessible estimation of HF contribution

Focus on LMR results at RHIC and LHC

Top RHIC energy $\sqrt{s_{NN}}$ = 200 GeV (MB)



Top LHC energy $\sqrt{s_{NN}}$ = 5.02 TeV (0-10%)



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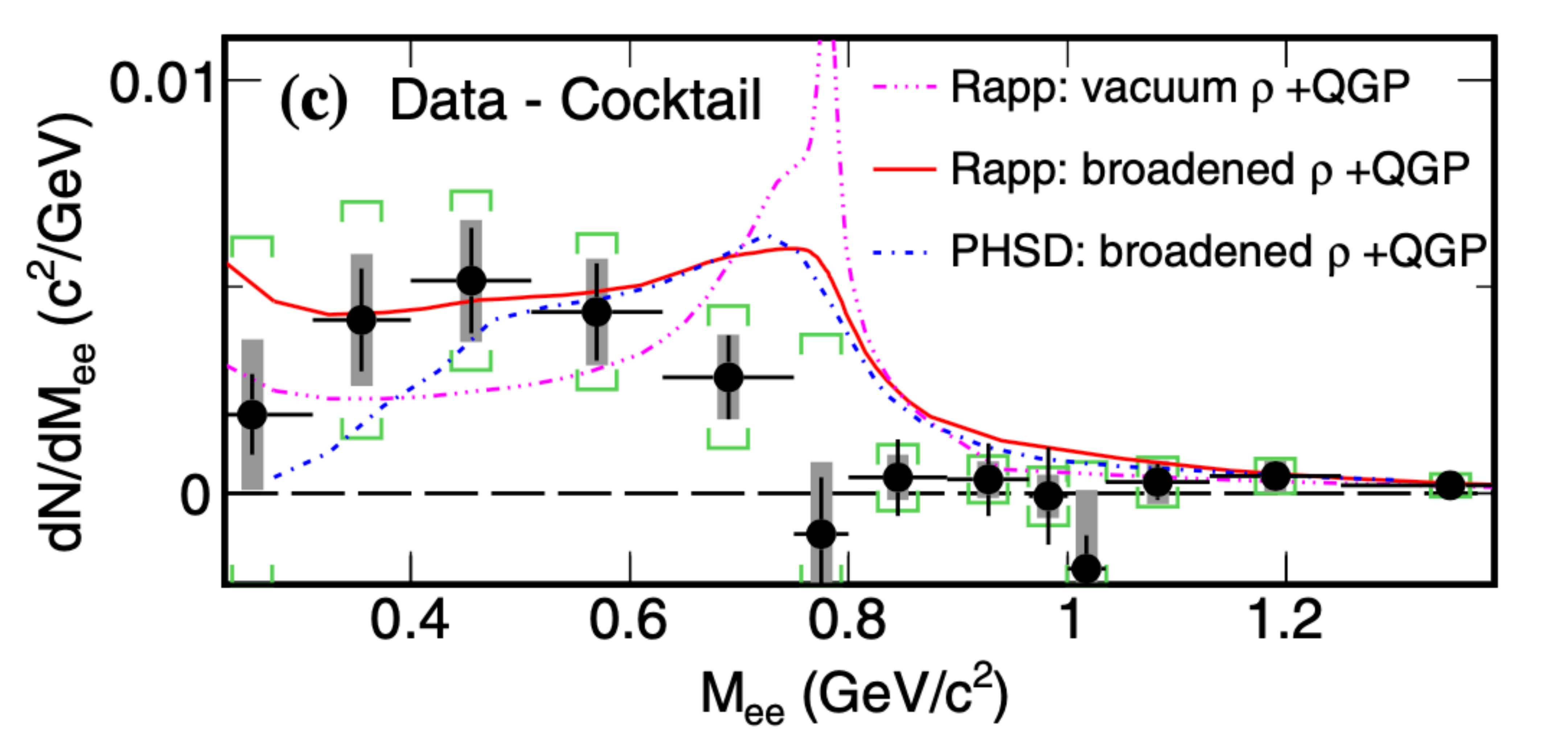

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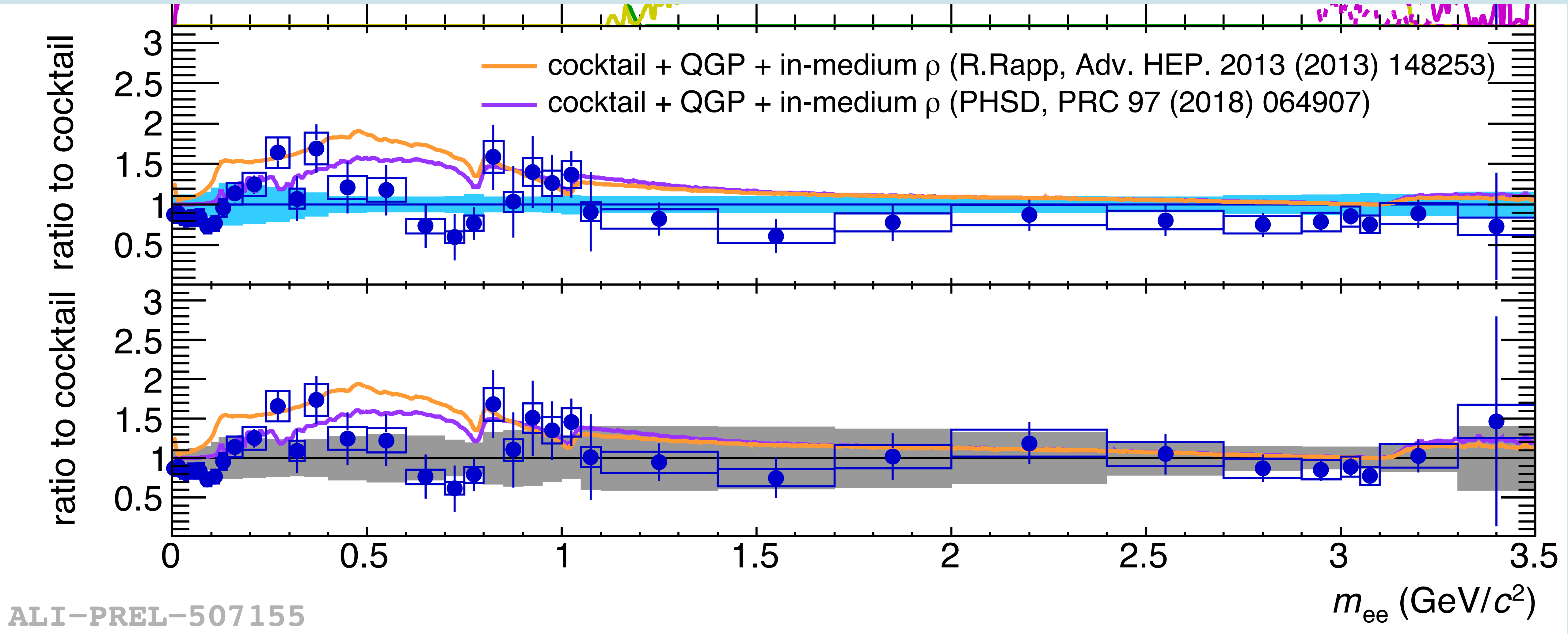

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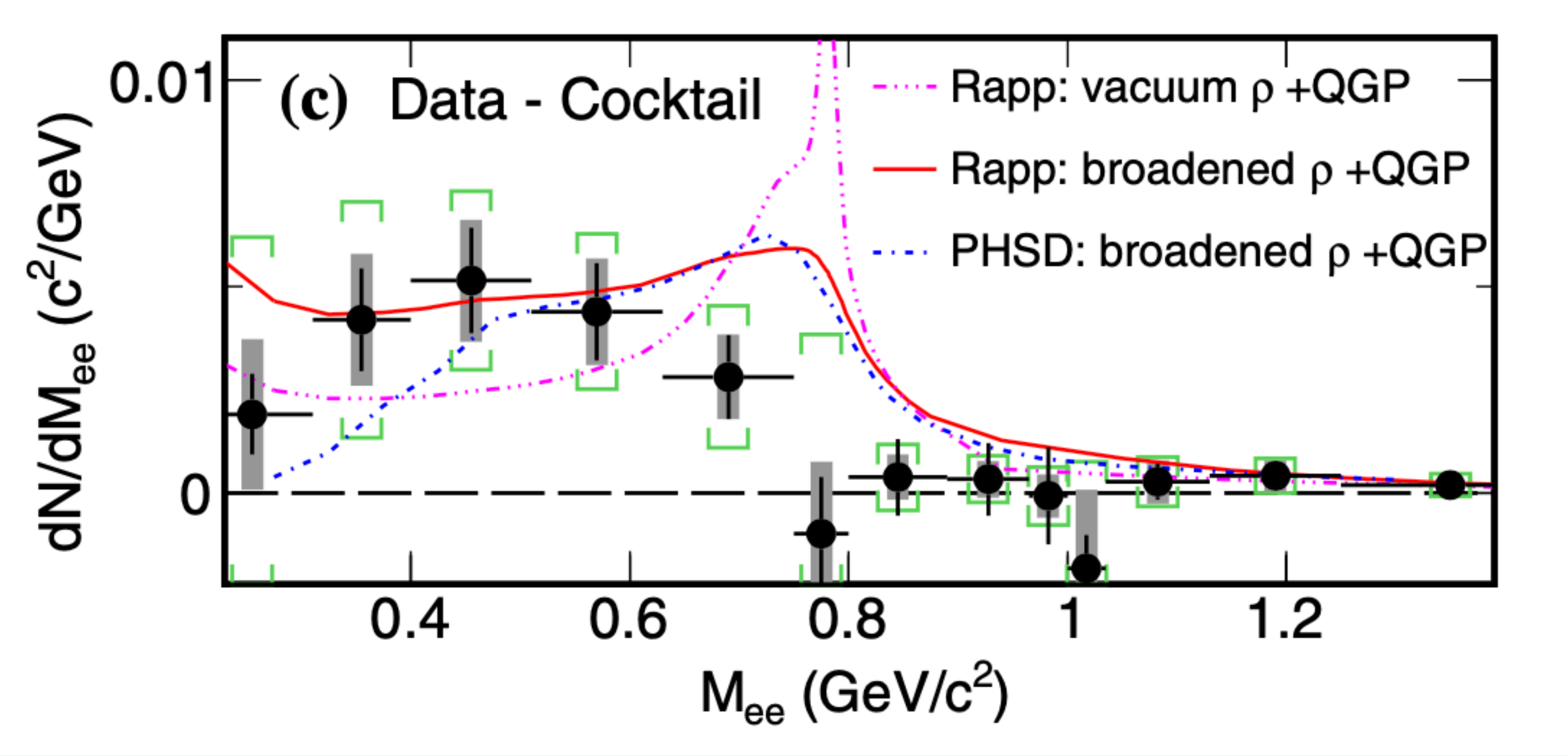

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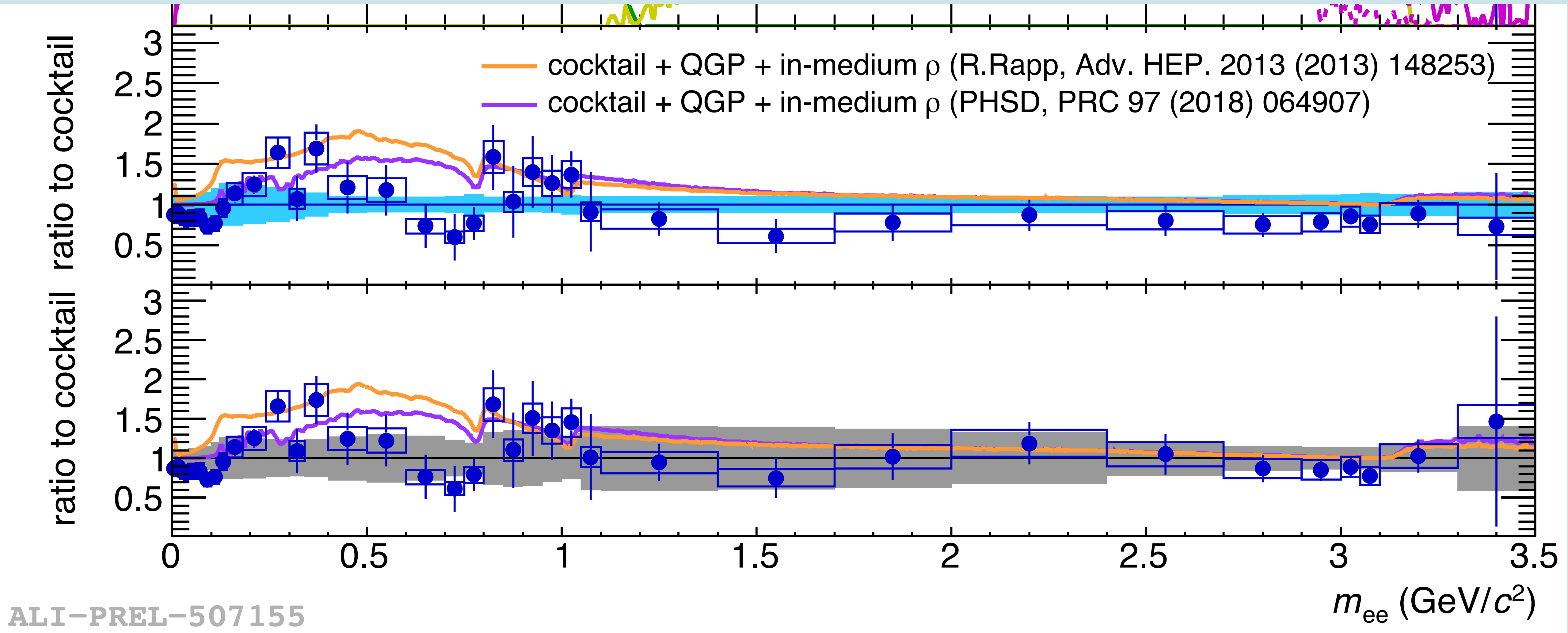

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  - Need more precise measurement
- Thermal dilepton cannot be accessed due to huge HF contributions
- Much more statistics, reduction of combinatorics, and HF lepton rejection are necesary

What learned?

- At SPS and RHIC BES energy ($\sqrt{s_{NN}}$ ~ 17 - 55 GeV), the LMR excess (broadening) could be explained by hadronic matter effects
  - Mass modification at LMR was discovered, but it did not indicate CSR necessarily
    - Ruled out mass dropping scenario at these energies
  - Thermal dilepton was measured and they are above Tc ~ 170 MeV
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- Improvement of detection technology/method is essential
  - Improvement of vertex detector to determine leptons from HF DCA at low p_T
  - Improve statistics and/or dimuon measurement to reduce combinatorial background effects

2020s

HI program at LHC (ALICE 2) 2022 ~

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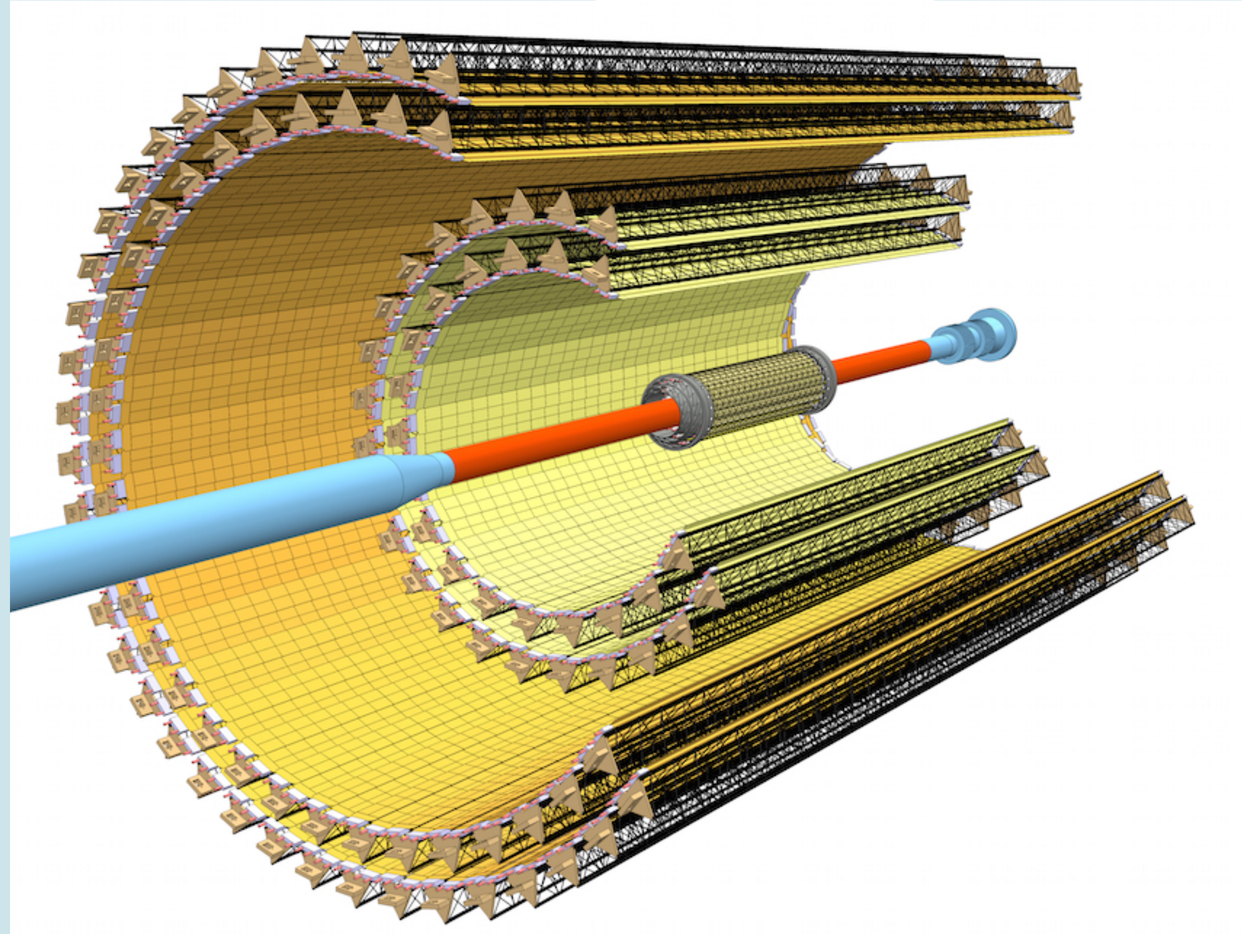
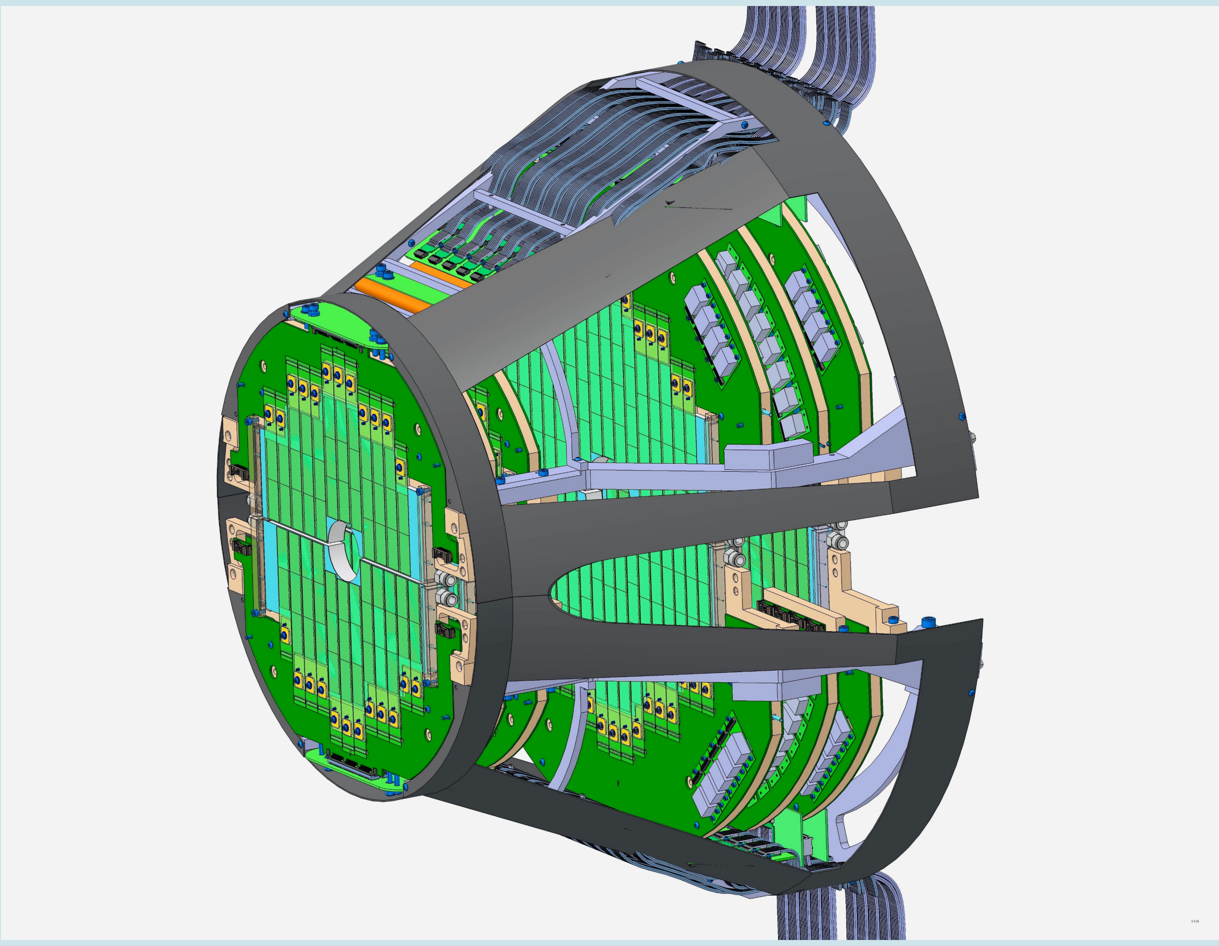
  - Fwd-rapidity ($2.5\eta<3.6$) : DCA_{xy}@1GeV/c N/A → 80 μm
    - Better opening angle resolution

Mid-rapidity



Forward rapidity



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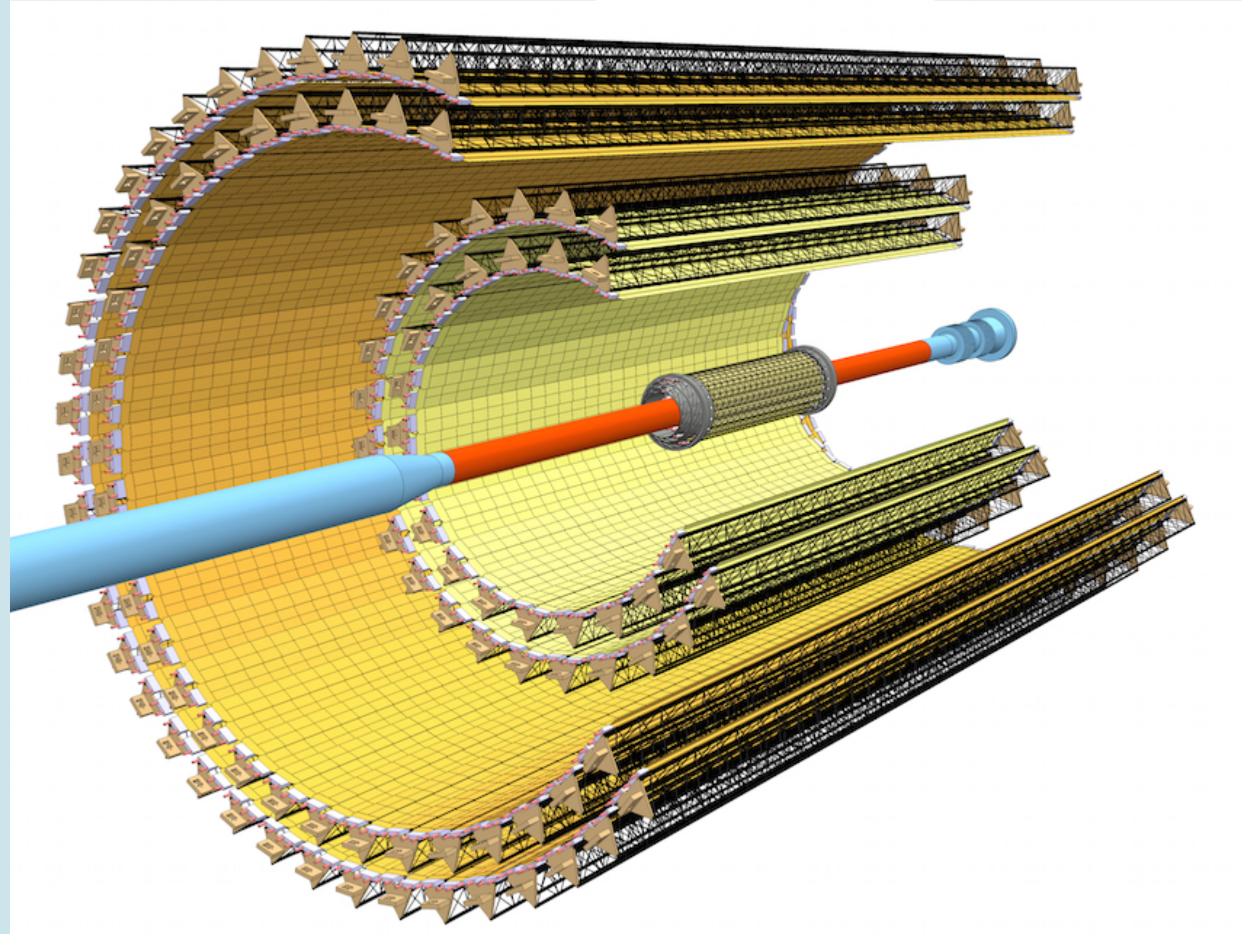
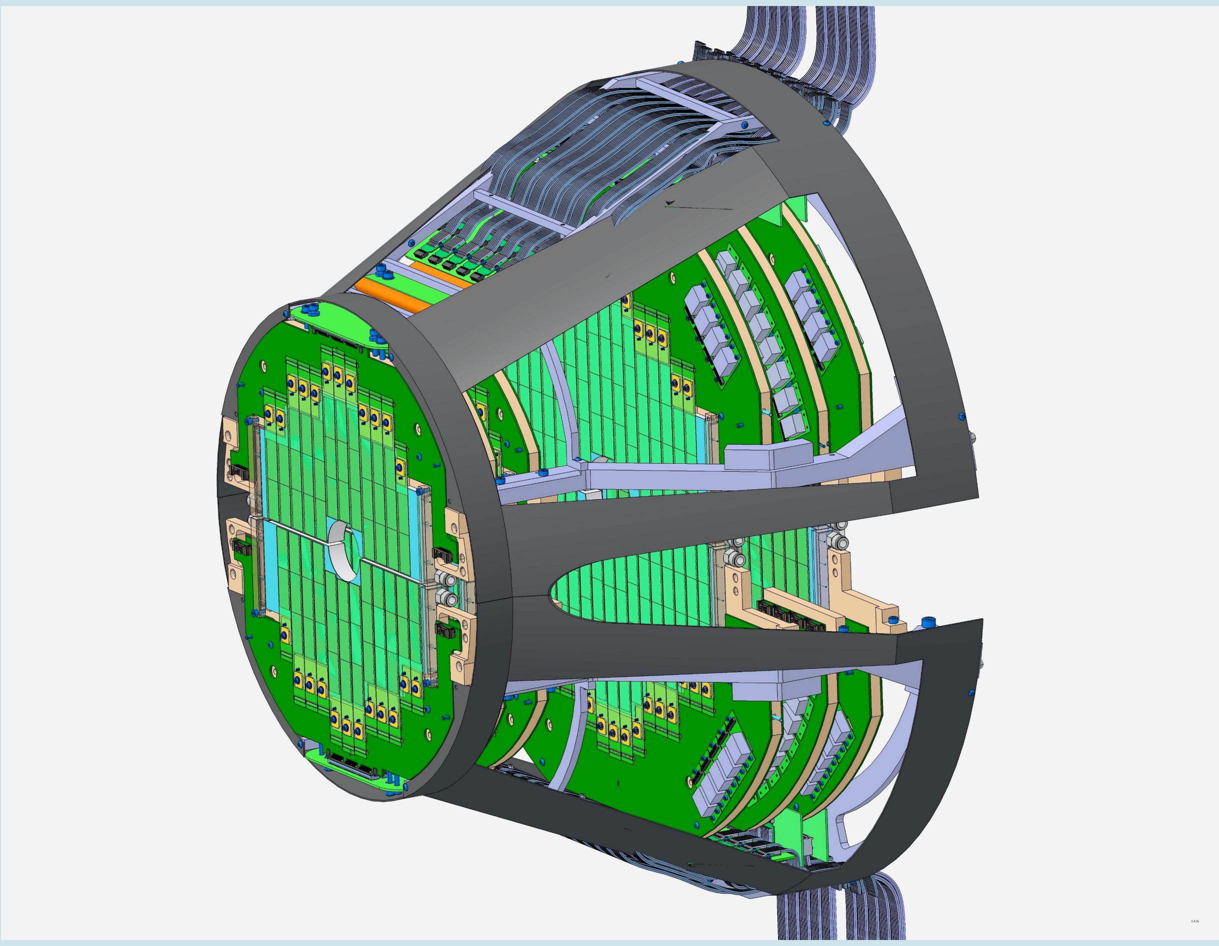
  - Fwd-rapidity ($2.5\eta<3.6$) : DCA_{xy}@1GeV/c N/A → 80 μm
    - Better opening angle resolution
- It will record all HI collisions with a 50 kHz interaction rate
  - 100 times larger statistics for MB and 10 times larger statistics 0-10% centrality

Mid-rapidity

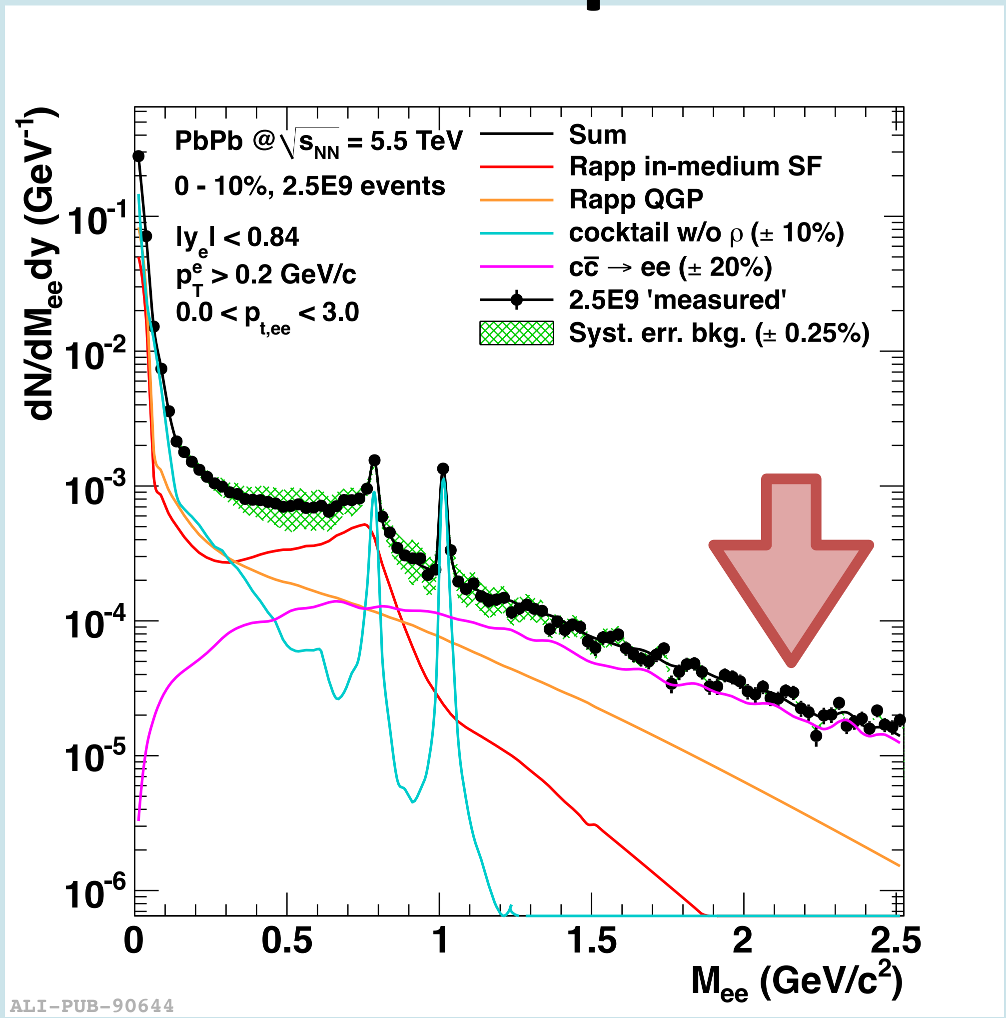


Forward rapidity



Expected performance of ALICE 2

Dielectron spectrum



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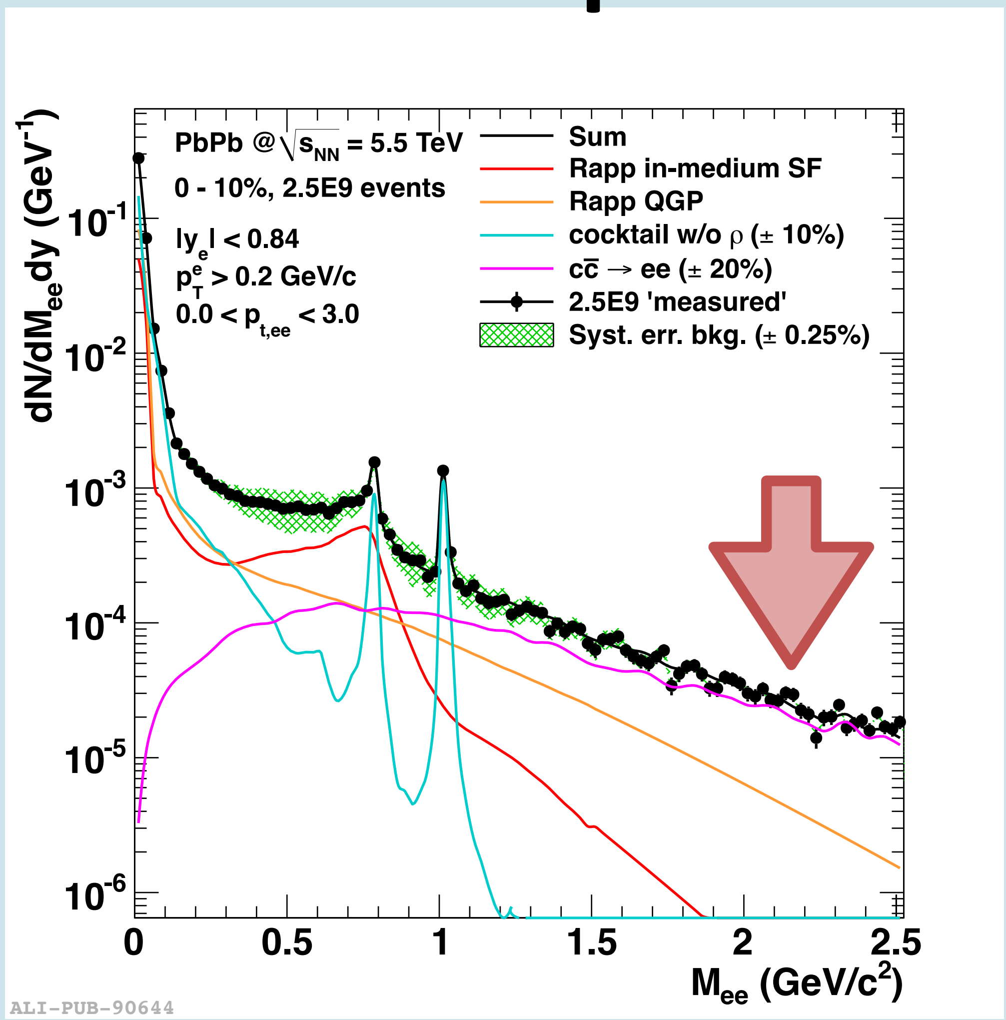
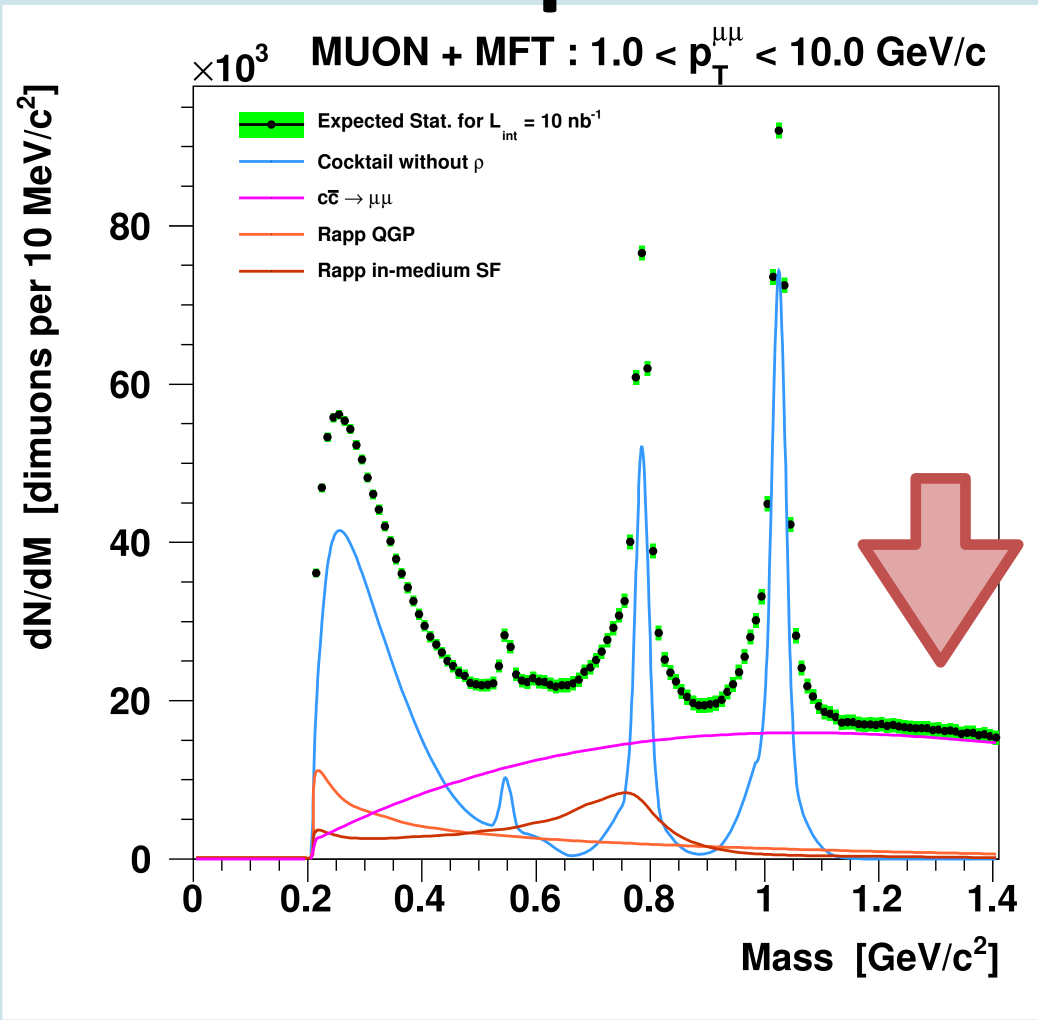


Dimuon spectrum



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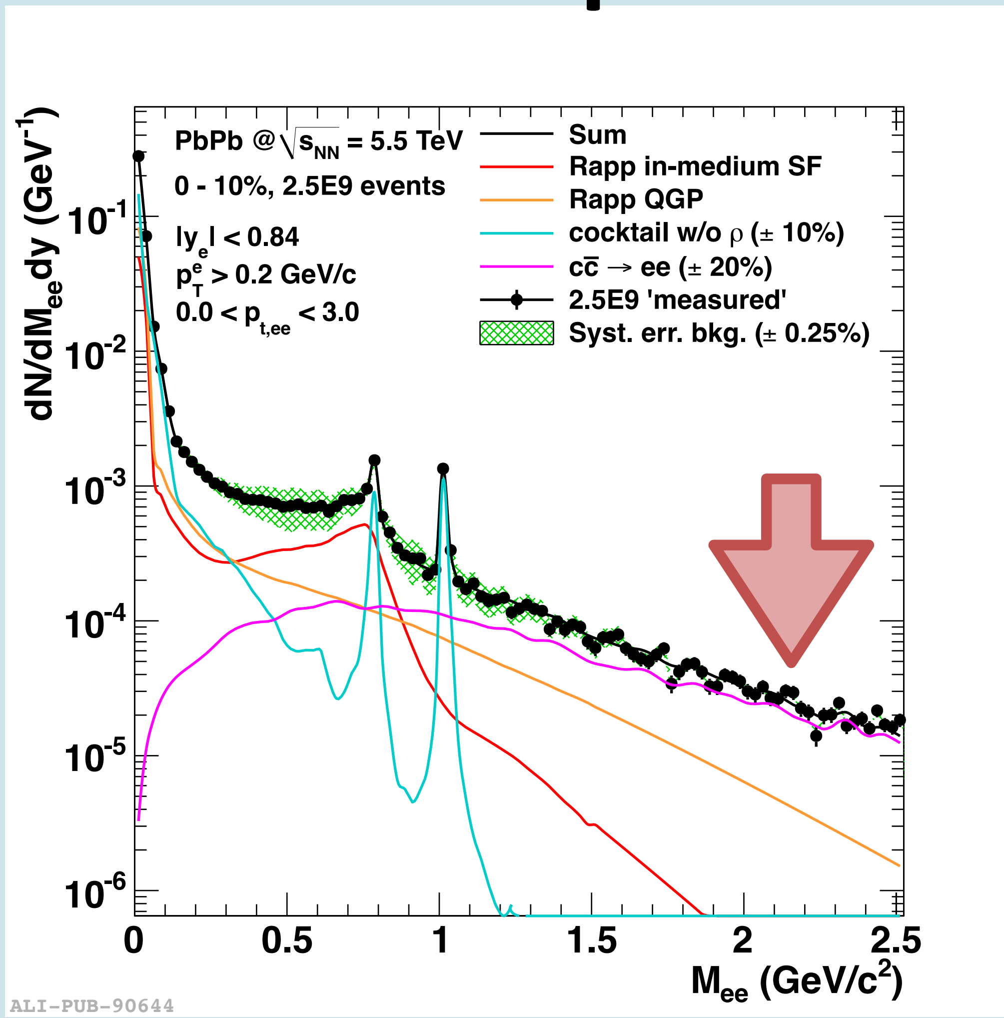

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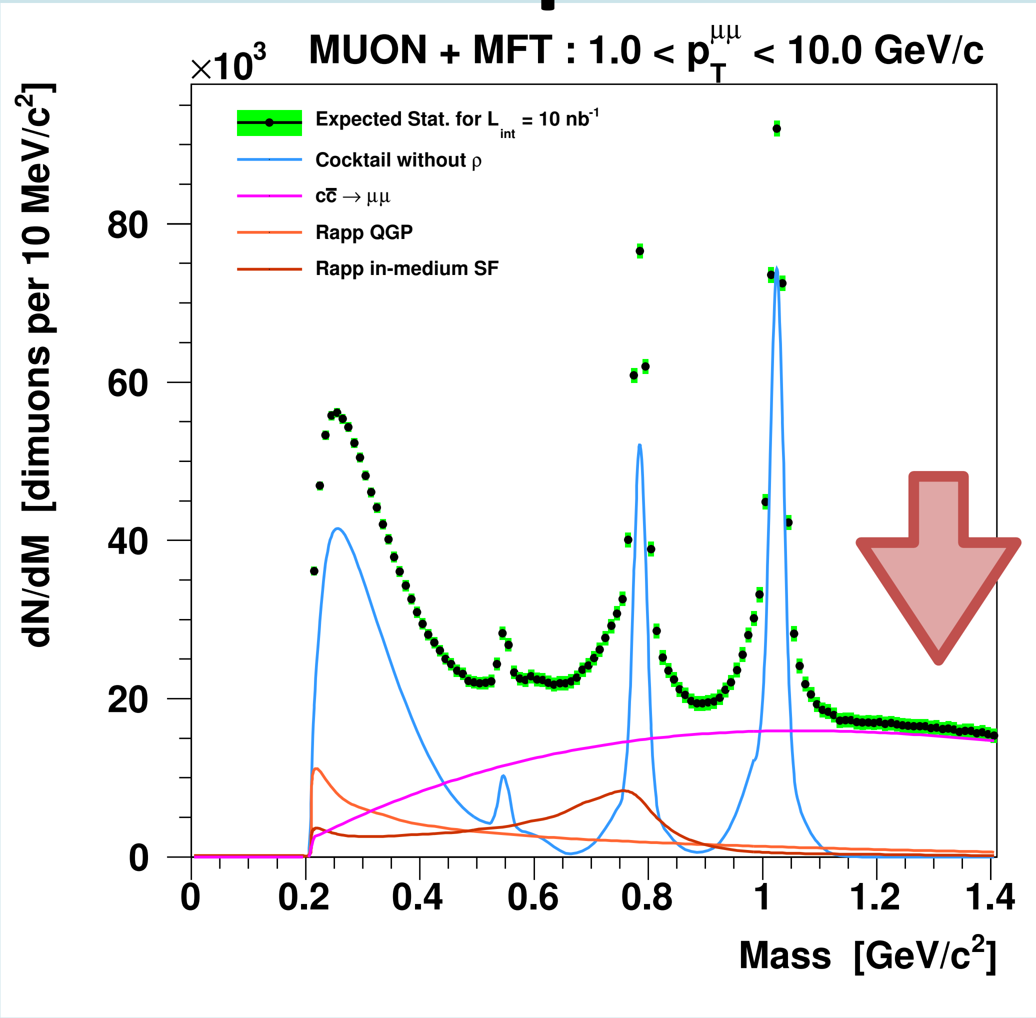

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  - Down to p_T ~ 1 GeV/c thanks to new read-out system
- Mass modification at LMR will be measured, but thermal radiation and chiral mixing will be still tough due to HF

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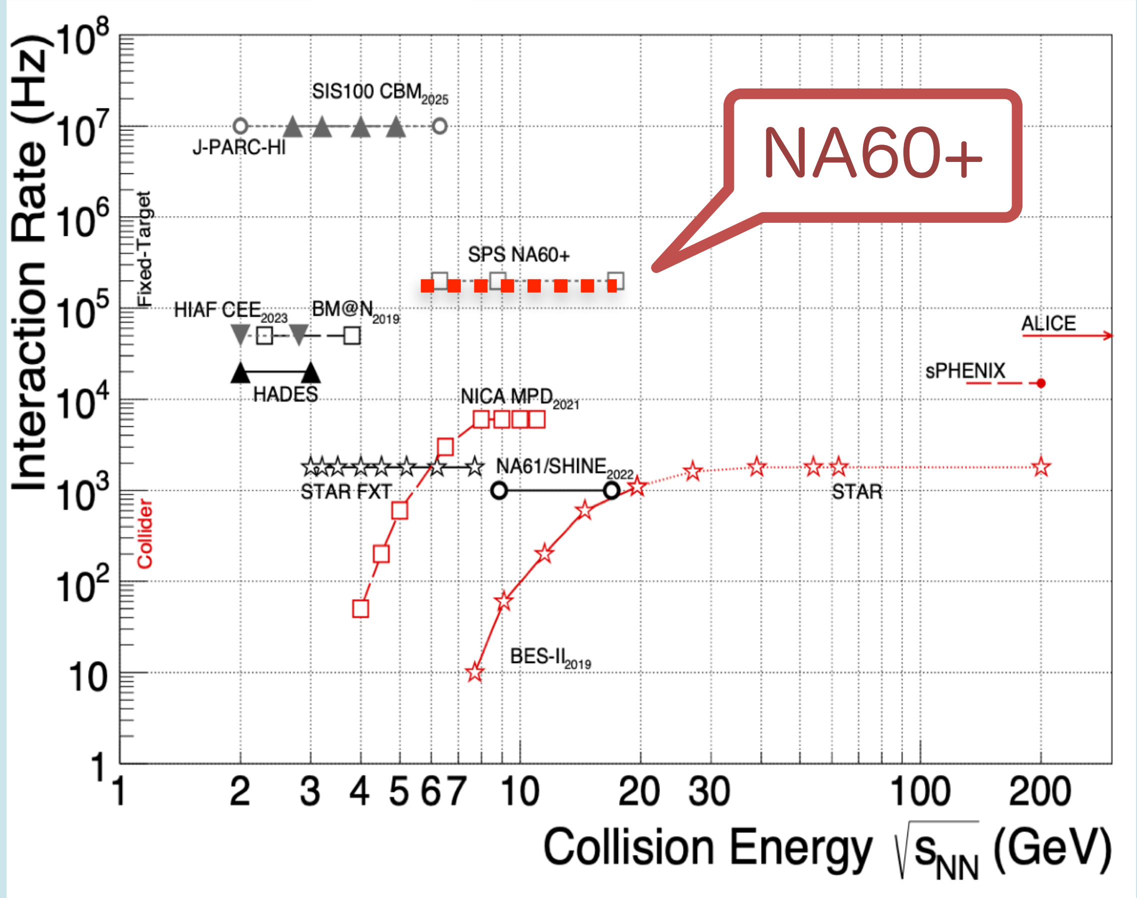

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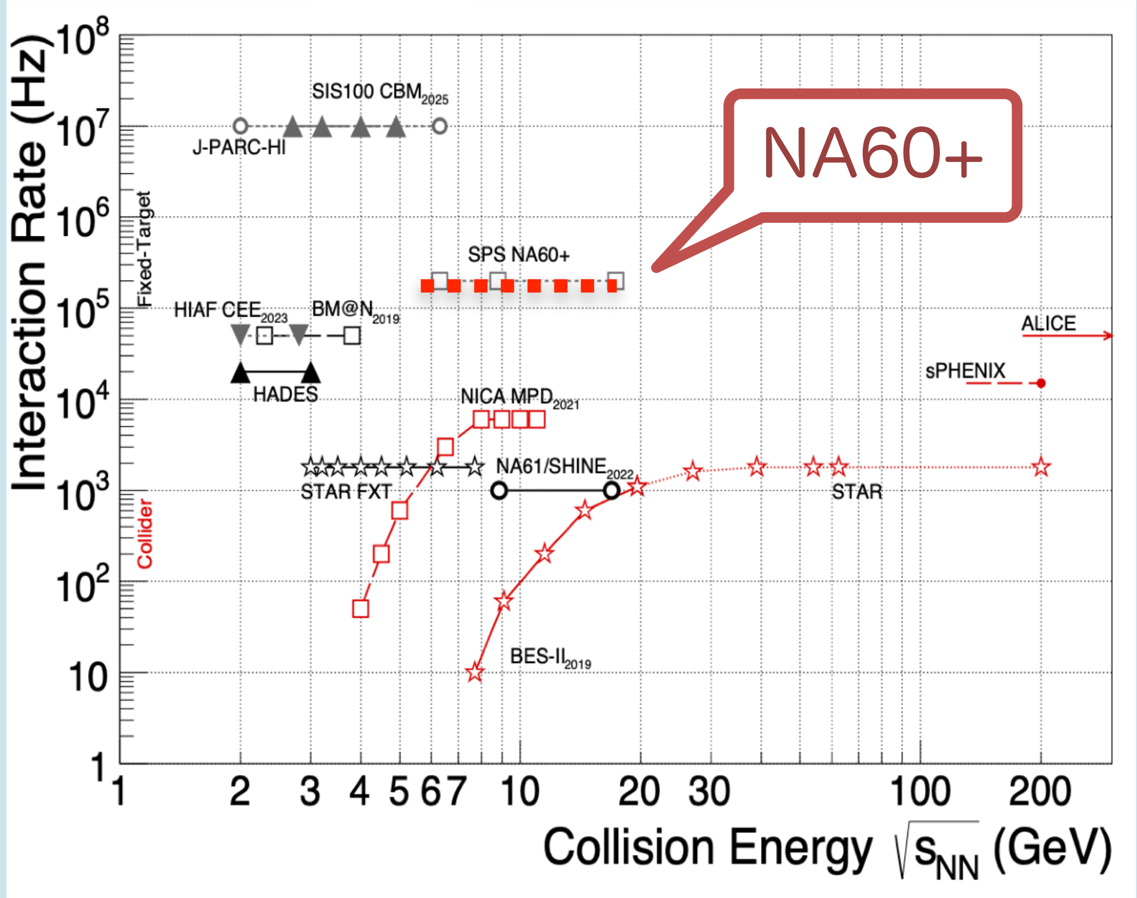
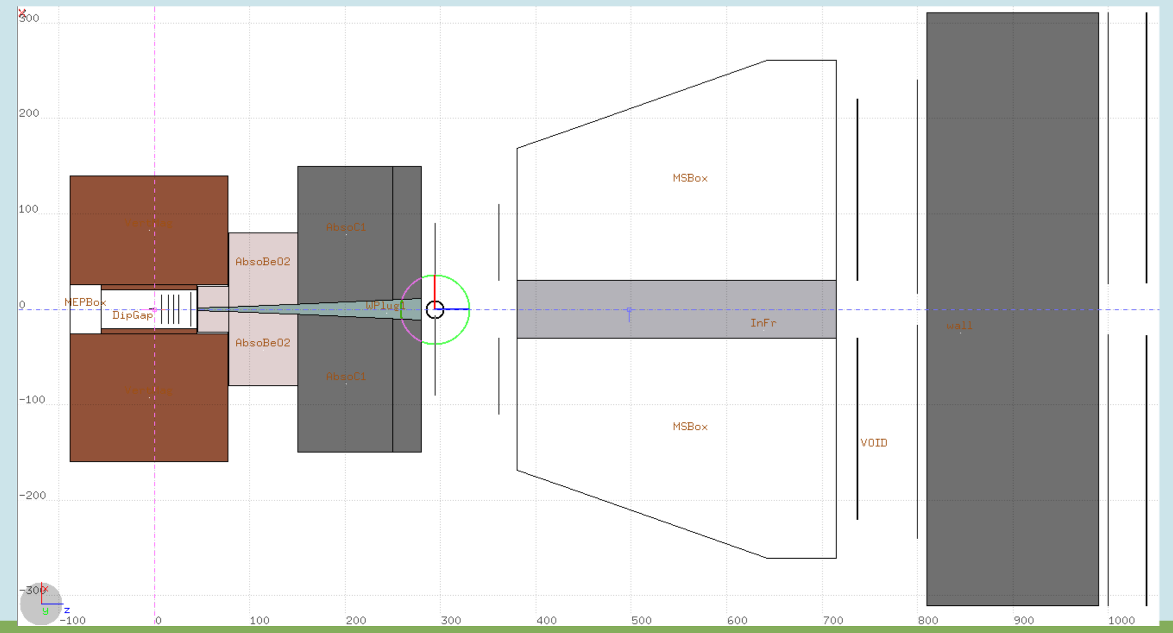


Low energy setup
$\sqrt{s_{NN}}$ = 6 - 9 GeV
Absorber = 1.3 m



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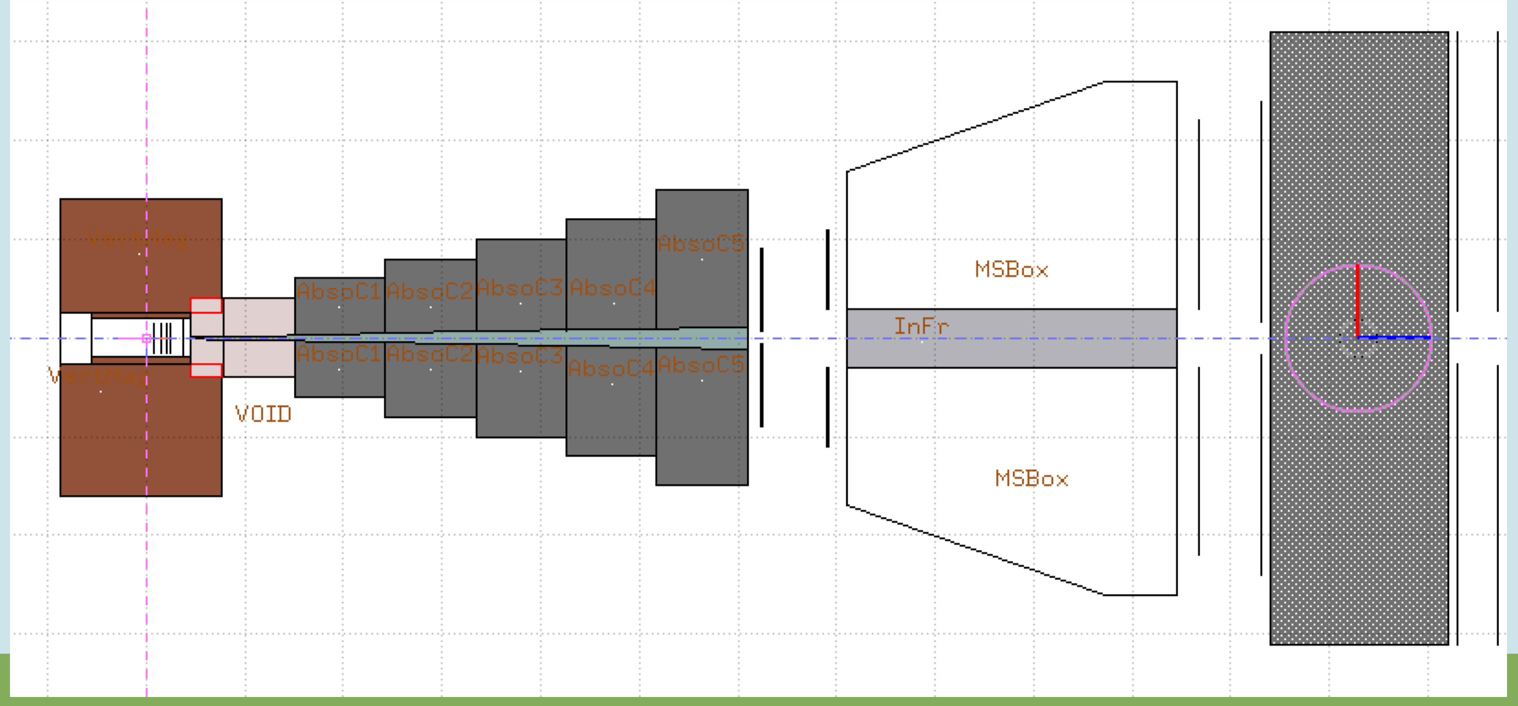

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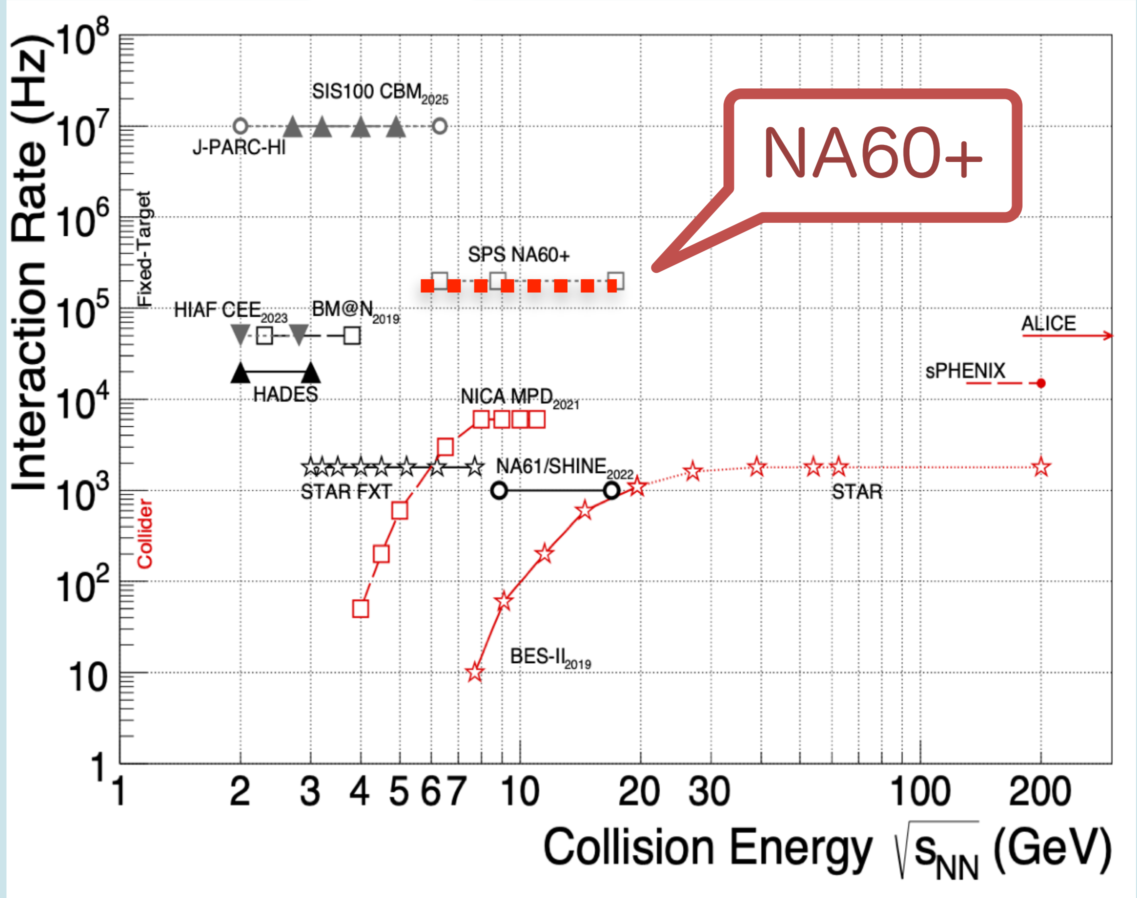
- Muon reconstruction performance and statistics will be improved
  - x 10 - 100 statistics of NA60



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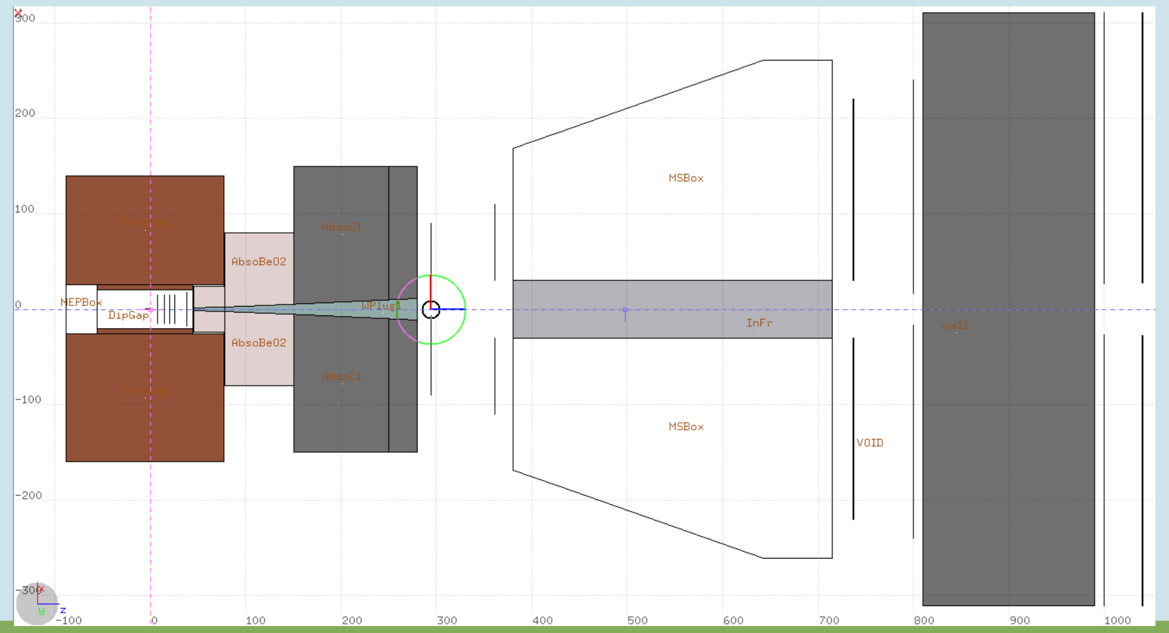

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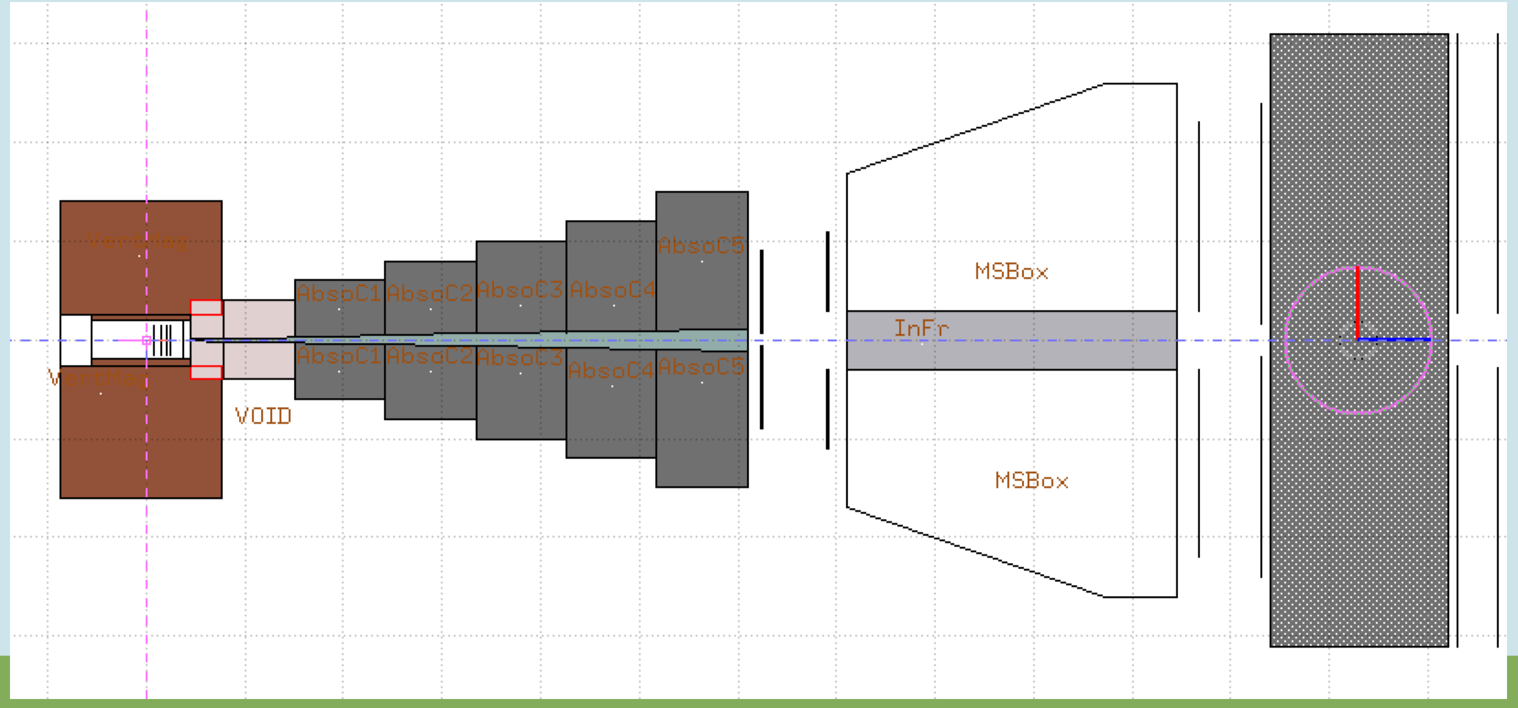

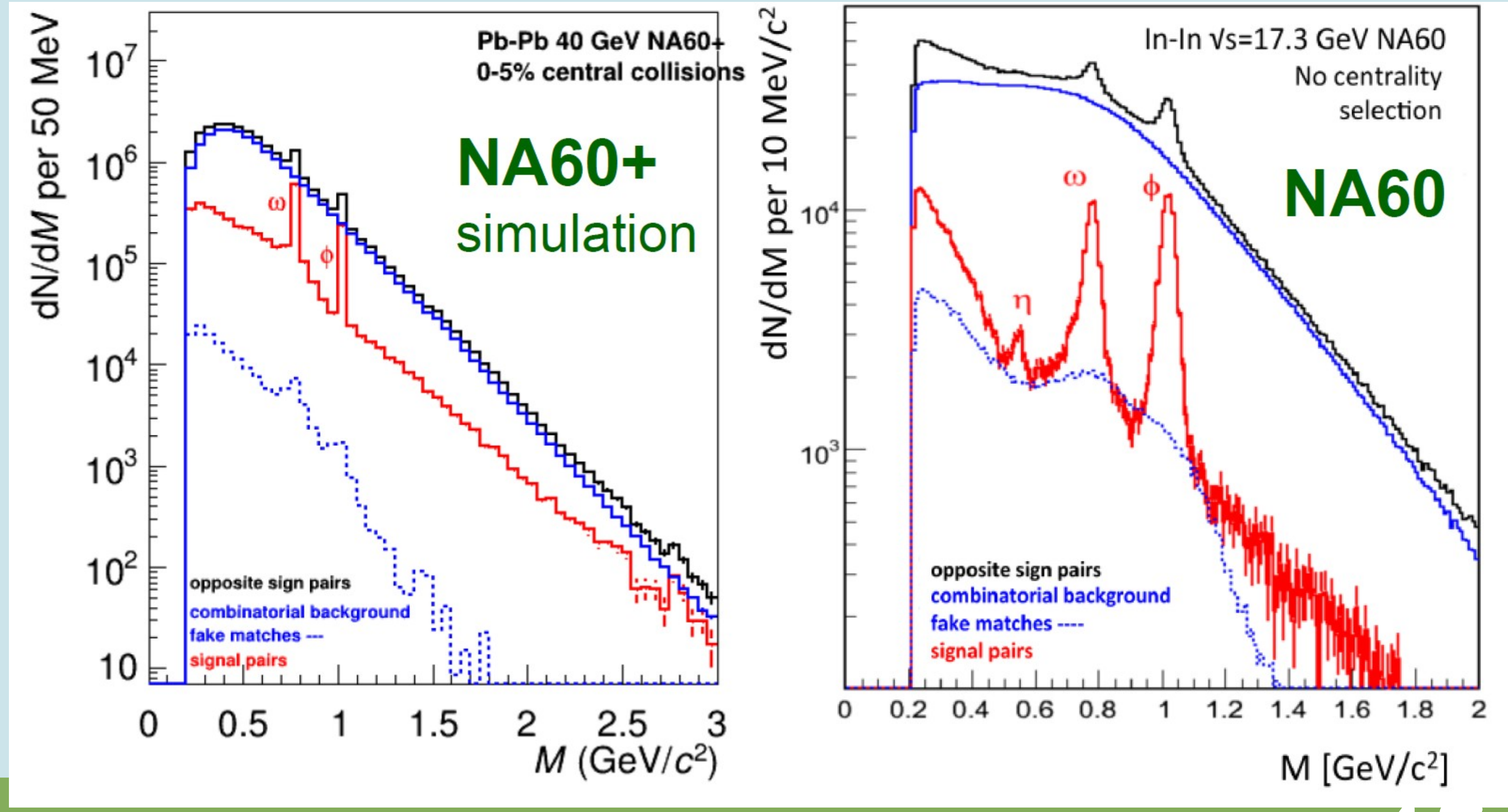

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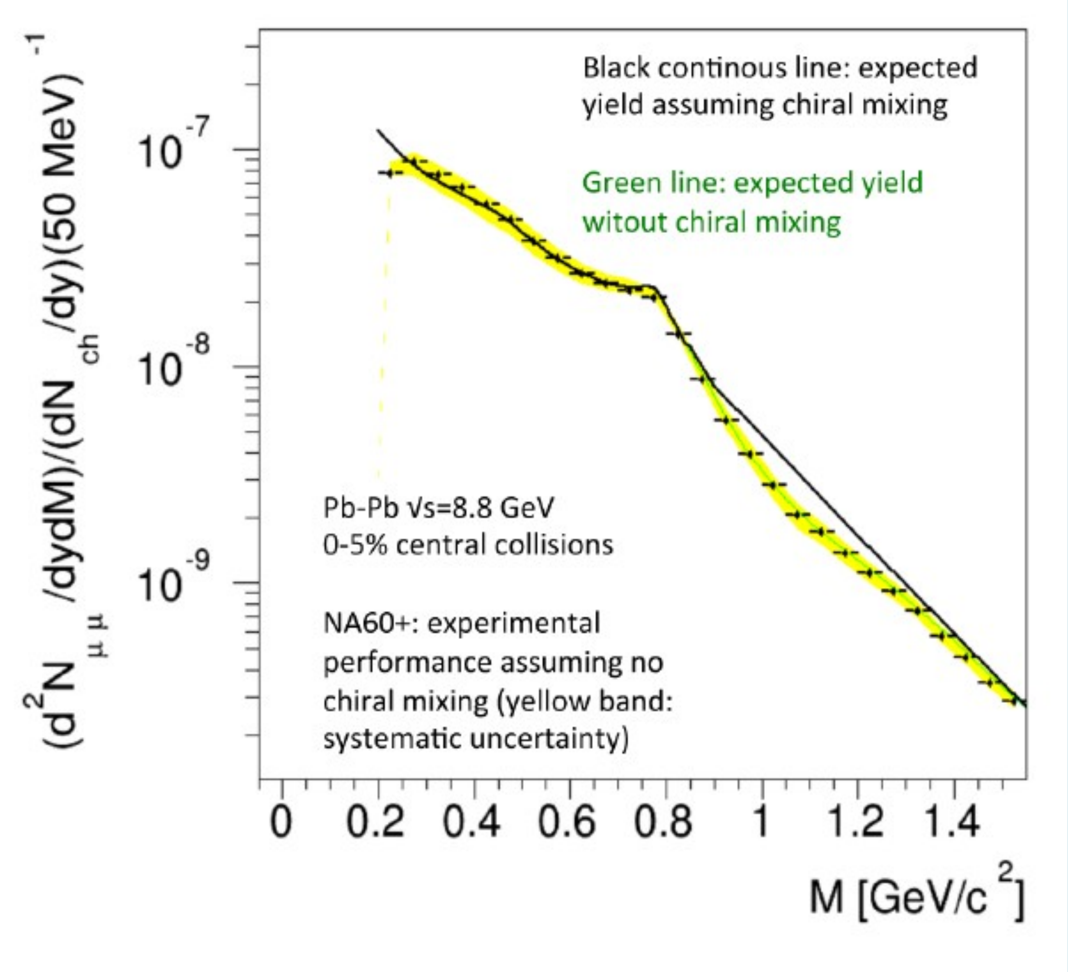

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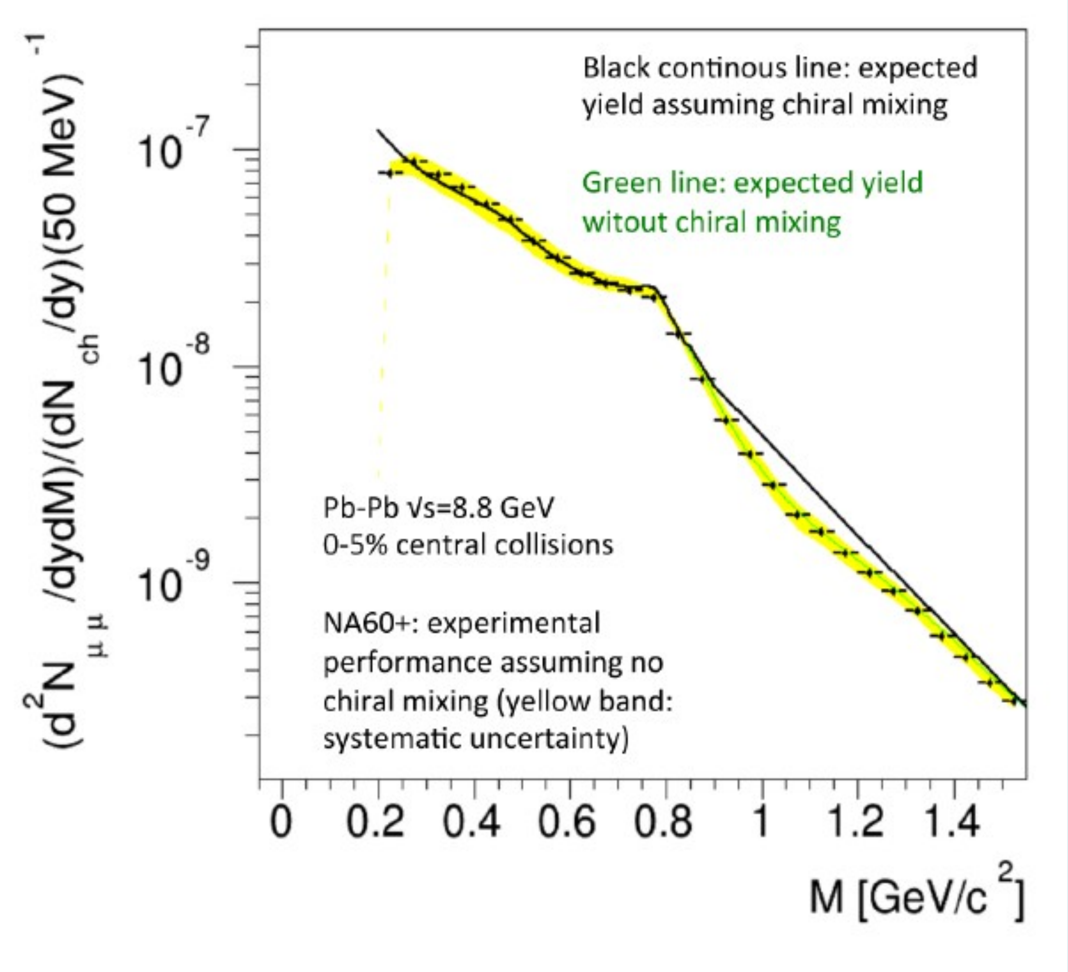

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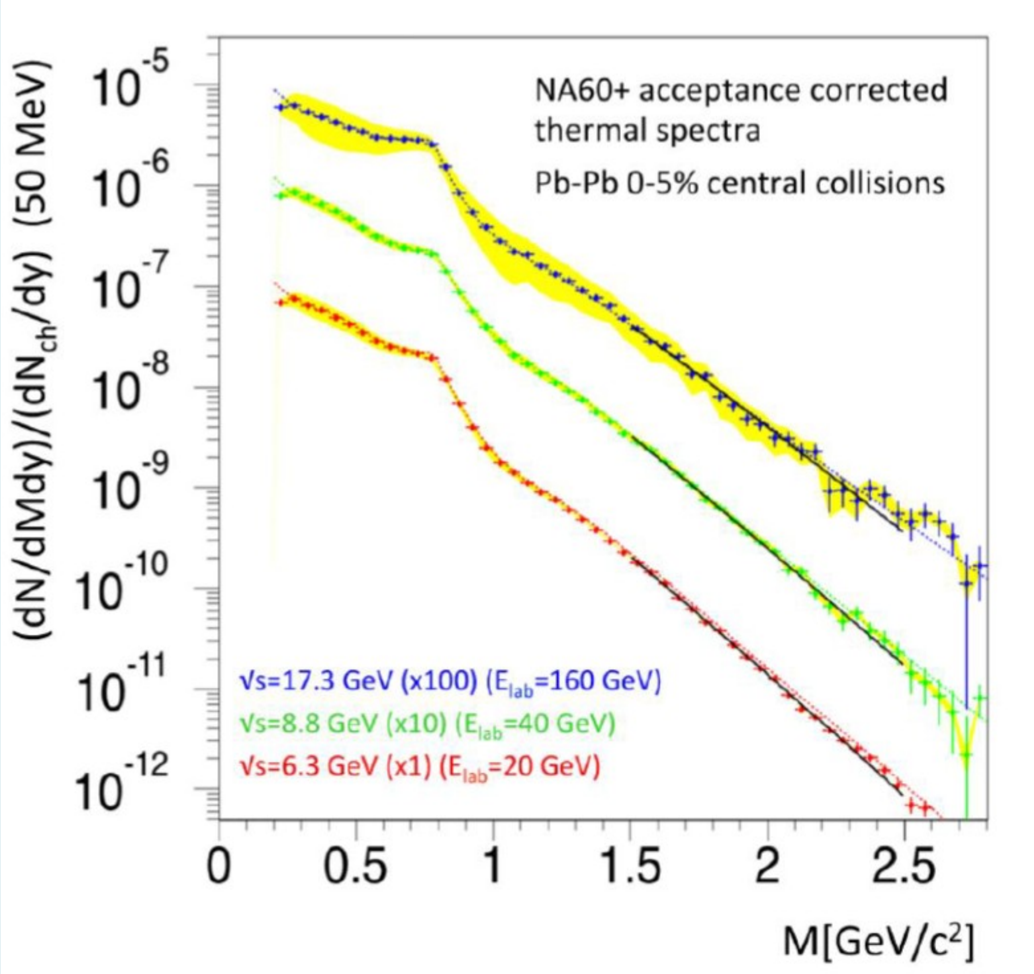

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  - Charmonia (J/ψ, ψ(2S)) measurement

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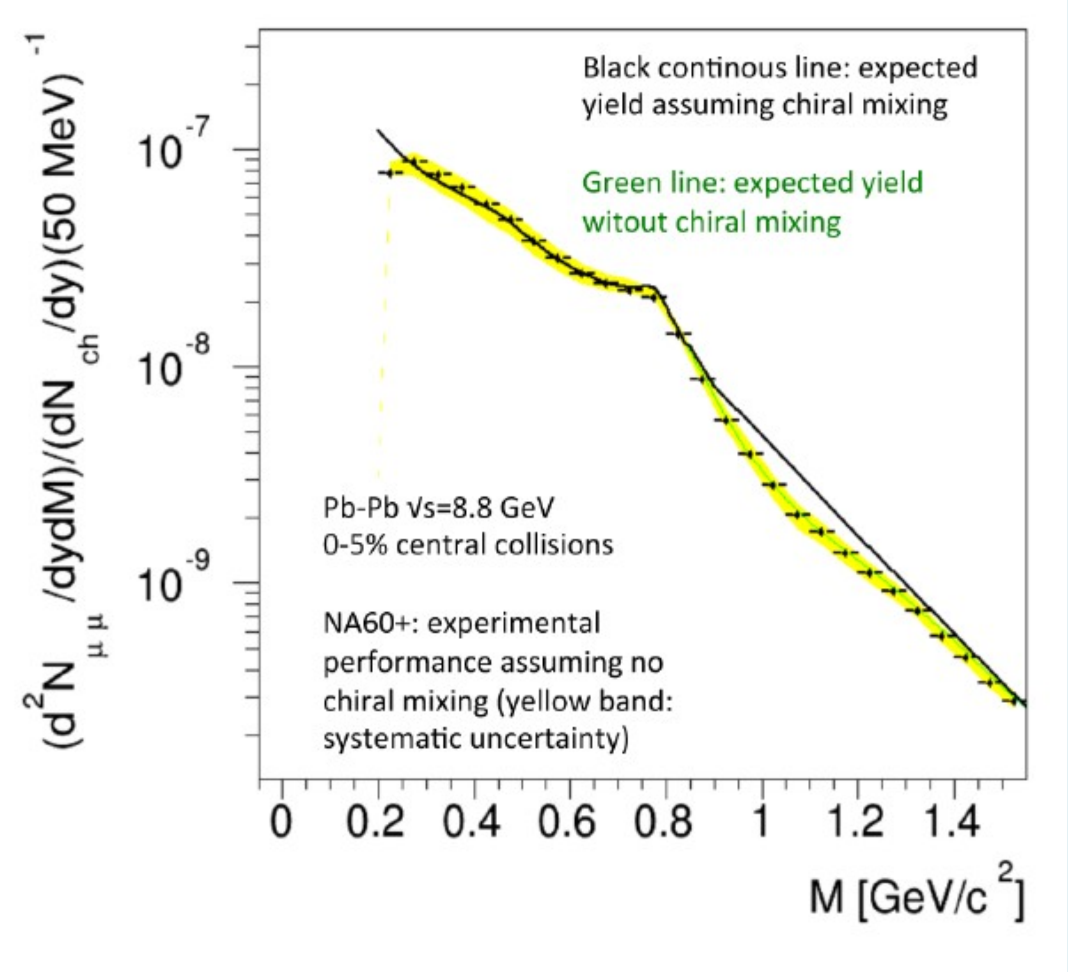

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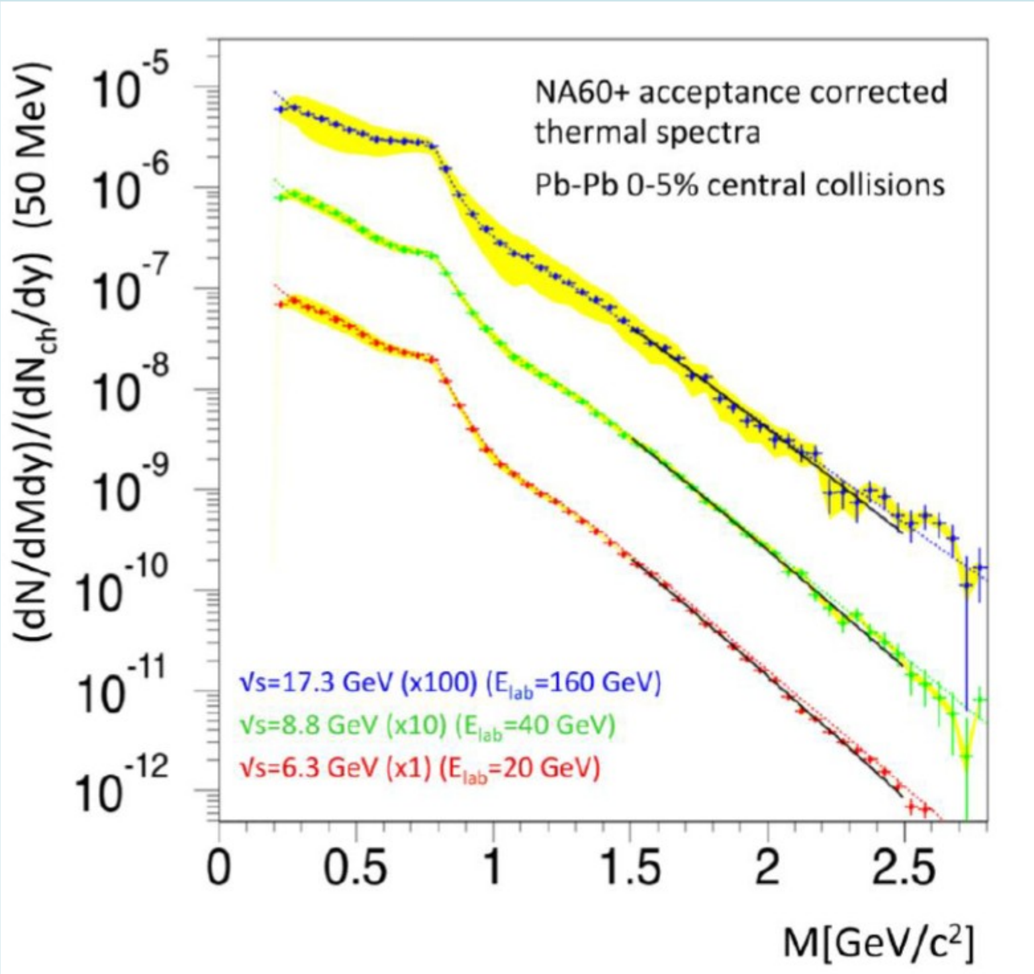
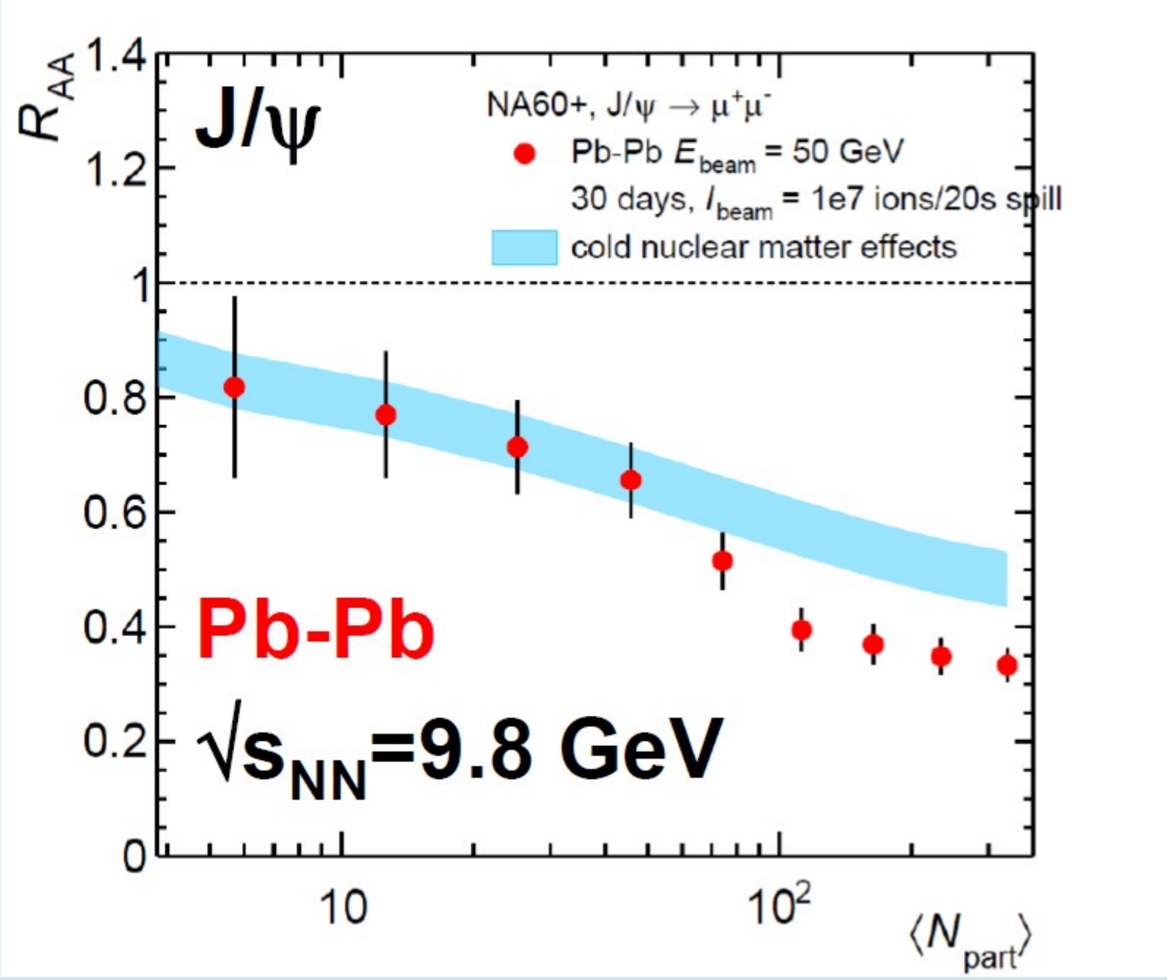


Charmonia measurement



Fixed target program at LHC (AFTER) 2027 ~

- Fixed target mode with TeV beams
- Several methods of placing target

Technical Solution	Beam type	Target type	θ_{target} (cm^{-2})	$\mathcal{L}$ ($\text{cm}^{-2}.\text{s}^{-1}$)	$\mathcal{L}_{\text{int}}$ (pb^{-1}/year)
Gas-Jet Target	p	$H\uparrow$	1.2×10^{12}	4.3×10^{30}	43
	p	H_2	10^{15} - 10^{16}	3.6×10^{33} - 3.6×10^{34}	36×10^{3} - 36×10^{4}
	Pb	$H\uparrow$	1.2×10^{12}	5.6×10^{26}	0.56×10^{-3}
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Storage-Cell Target	p	$H\uparrow$	2.5×10^{14}	9.2×10^{32}	9200
	p	Xe	6.4×10^{13}	2.3×10^{32}	2300
	Pb	$H\uparrow$	2.5×10^{14}	1.2×10^{29}	0.120
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- Energy range on a fixed target
  - 7 TeV proton beam
    - $\sqrt{s} = \sqrt{2m_N E_p} = 115$ GeV
    - $y_{c.m.s.} = 0 \rightarrow y_{lab} = 4.8$ ($\gamma \sim 60$)
  - 2.76 TeV Pb beam
    - $\sqrt{s_{NN}} = \sqrt{2m_N E_{Pb}} = 72$ GeV
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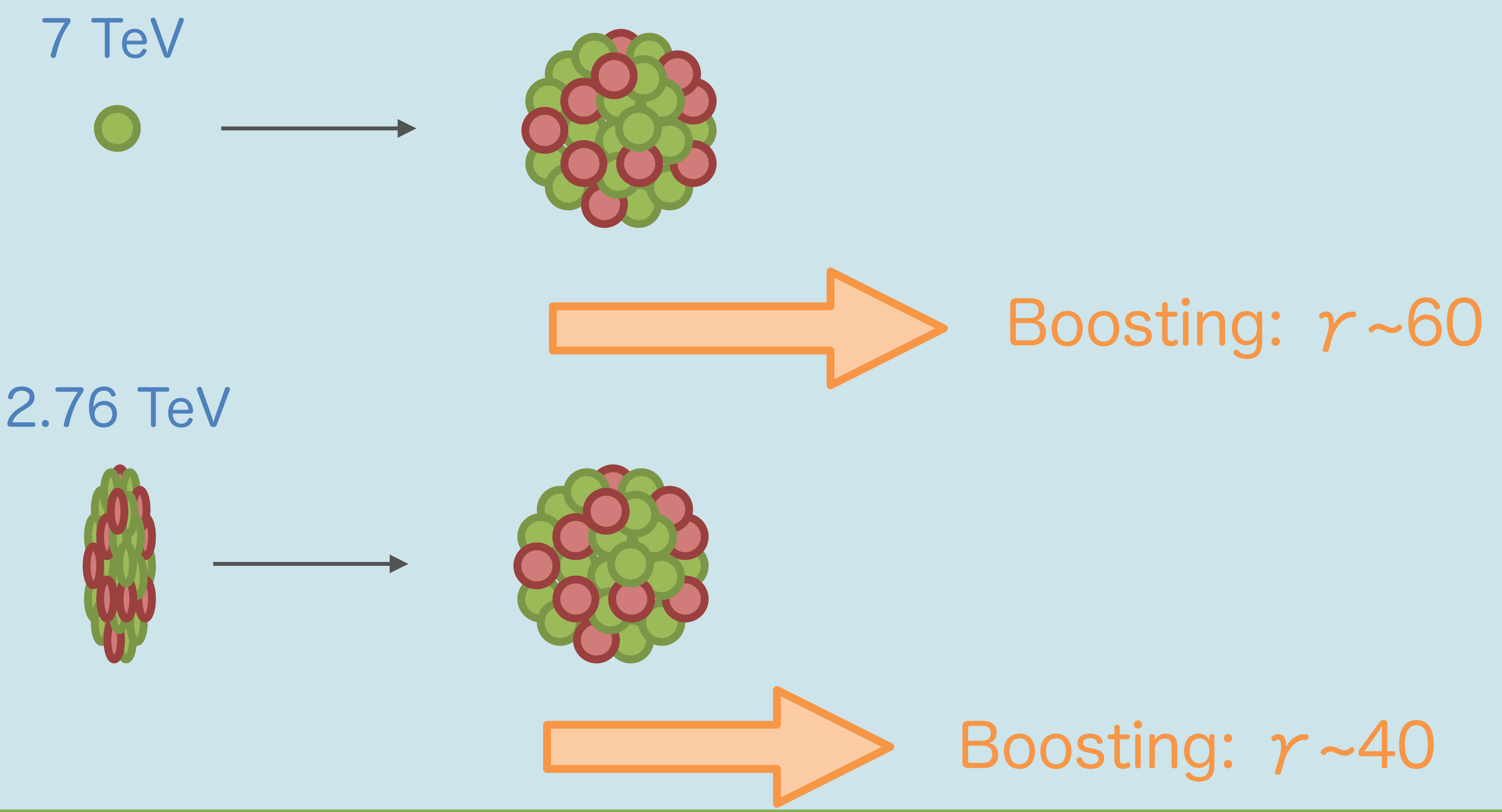

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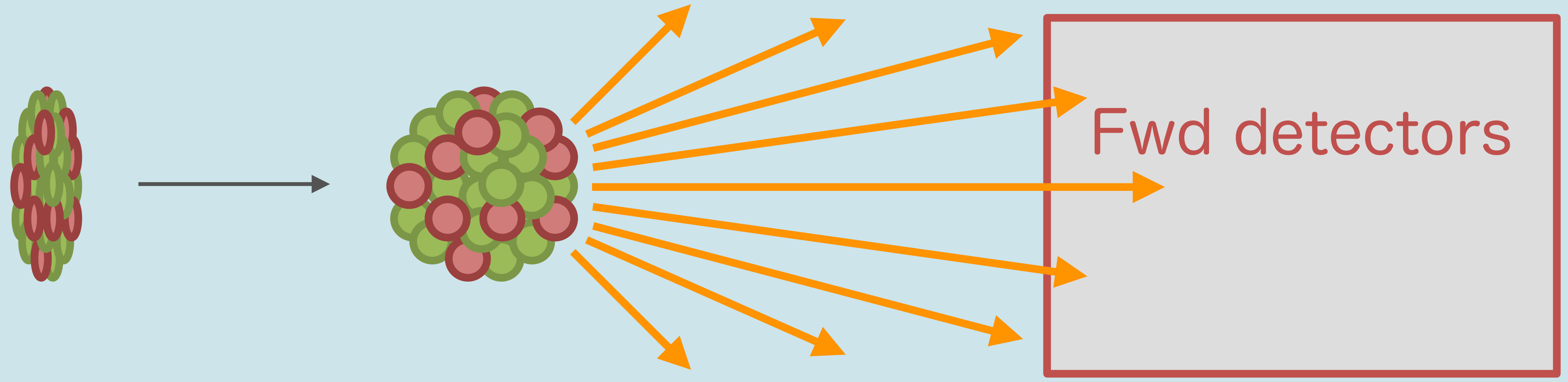

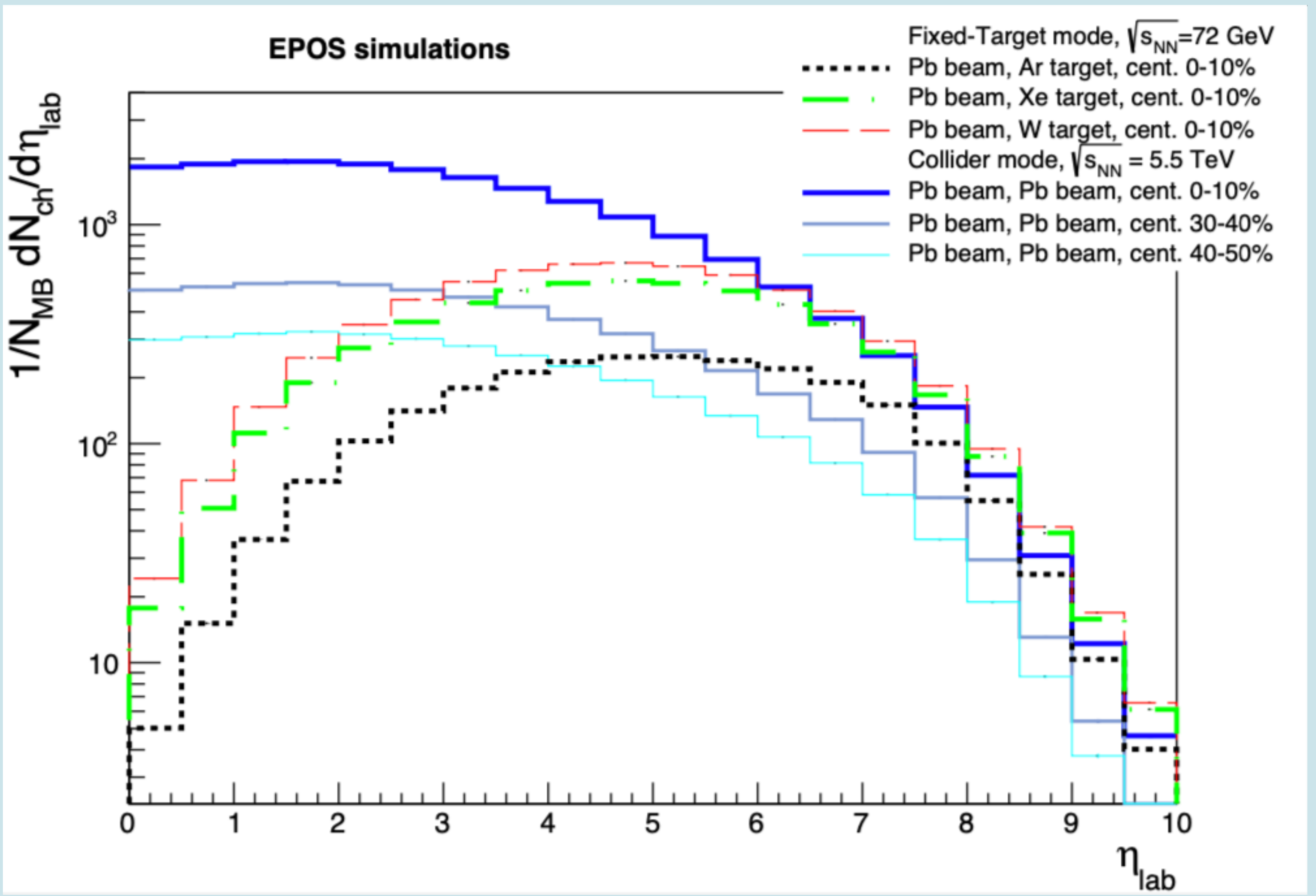

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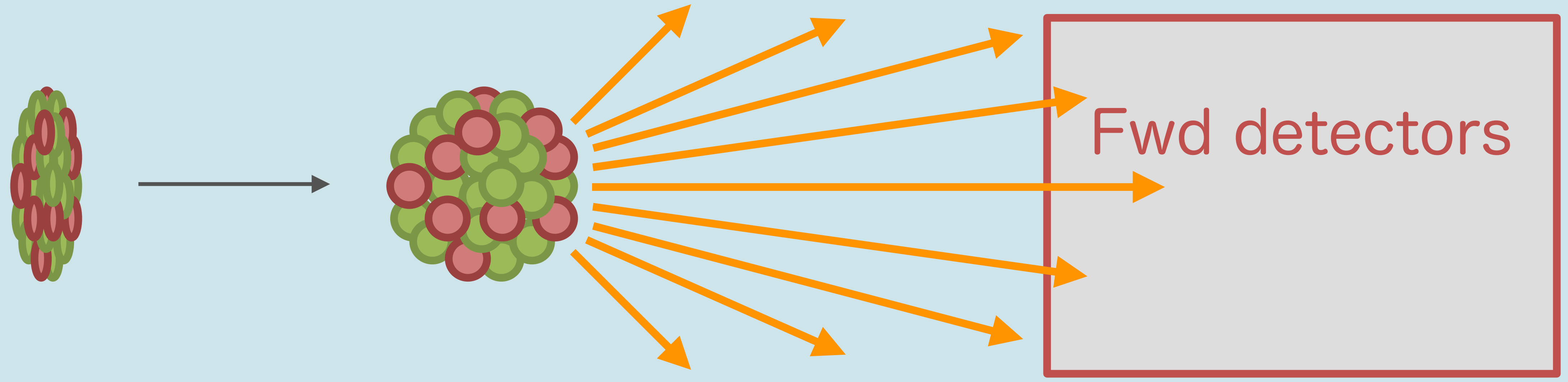
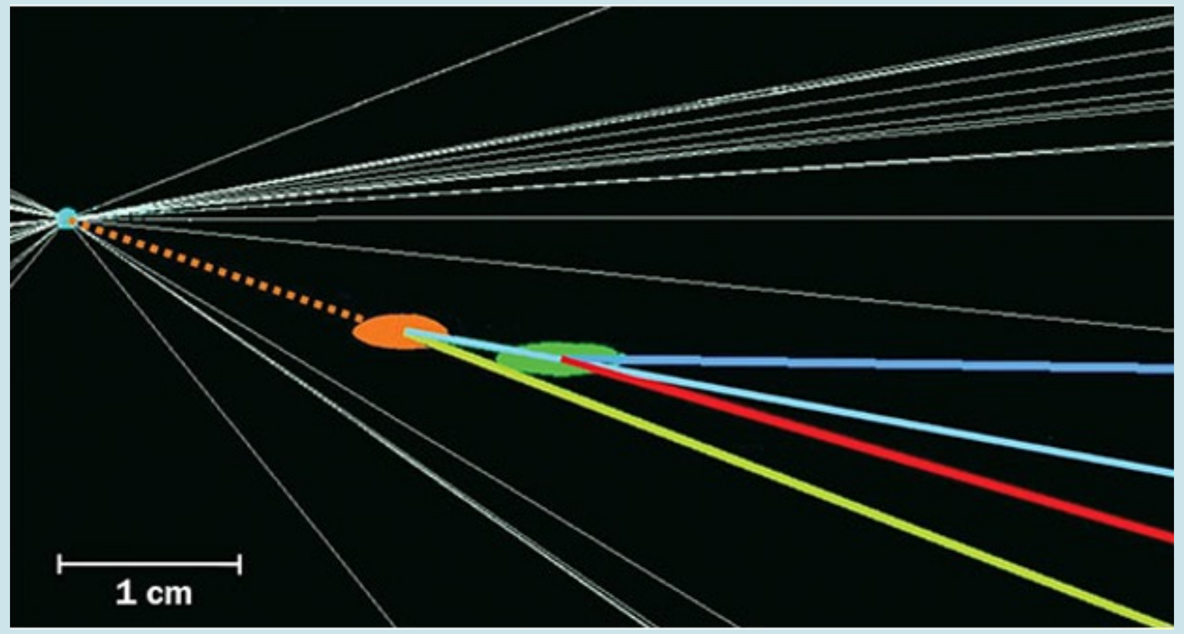
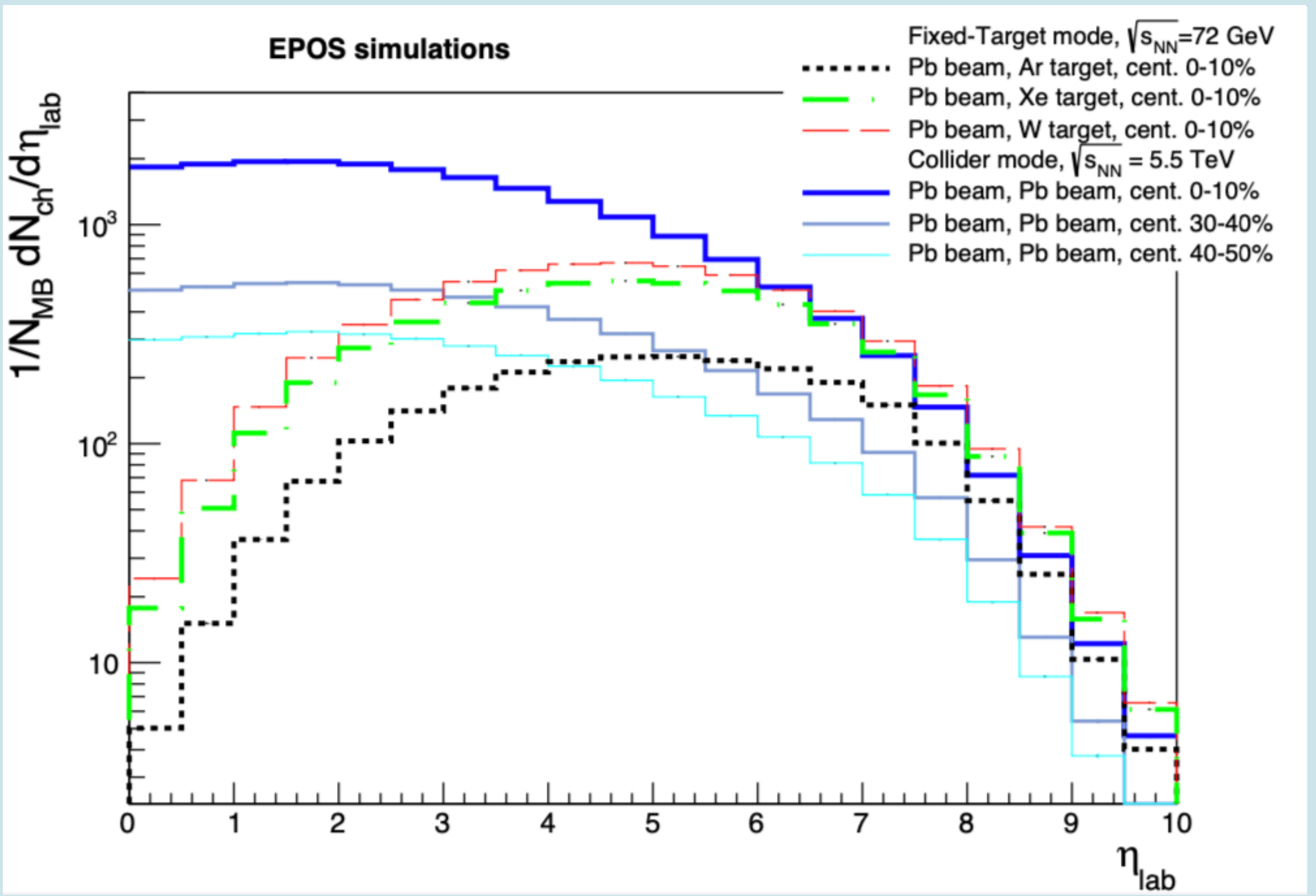


Event display of LHCb





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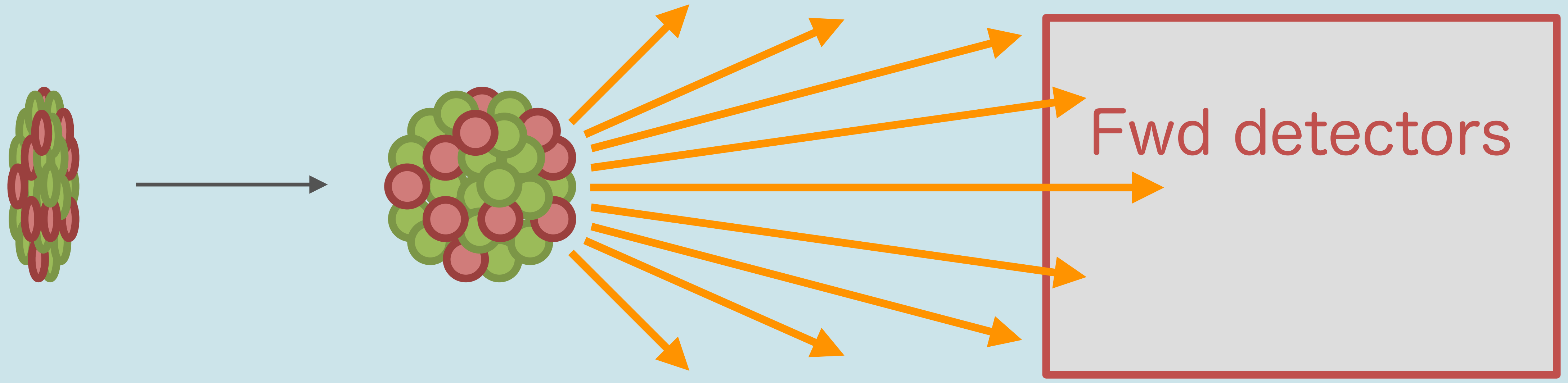

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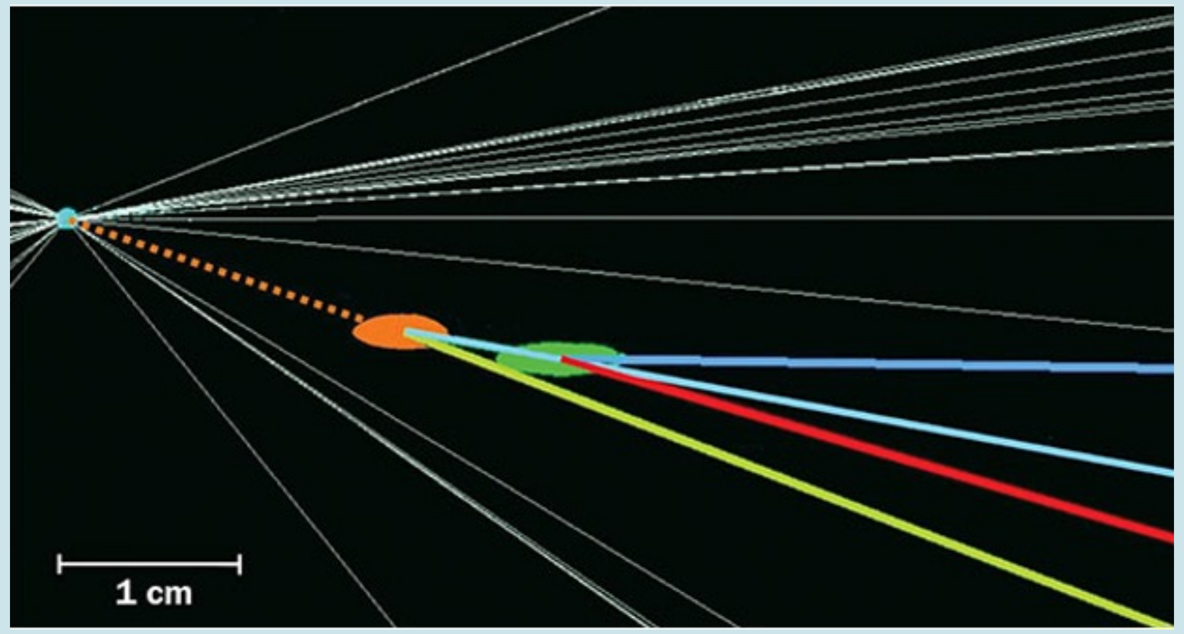

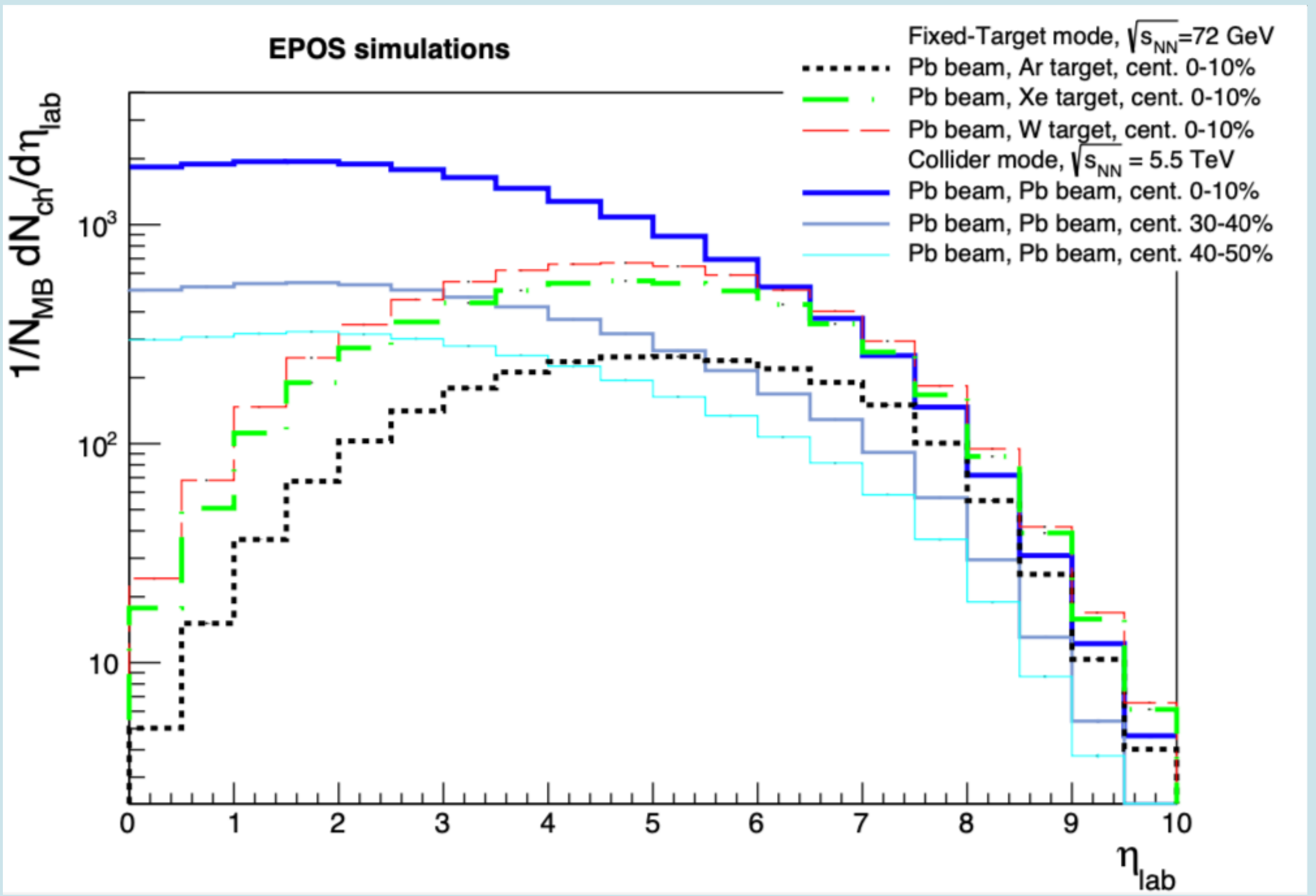

- LMR and IMR dimuon performance evaluation has not been started
  - Very interesting results can be expected

2030s

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  - Based on Si sensor detectors covering $|\eta| < 4$
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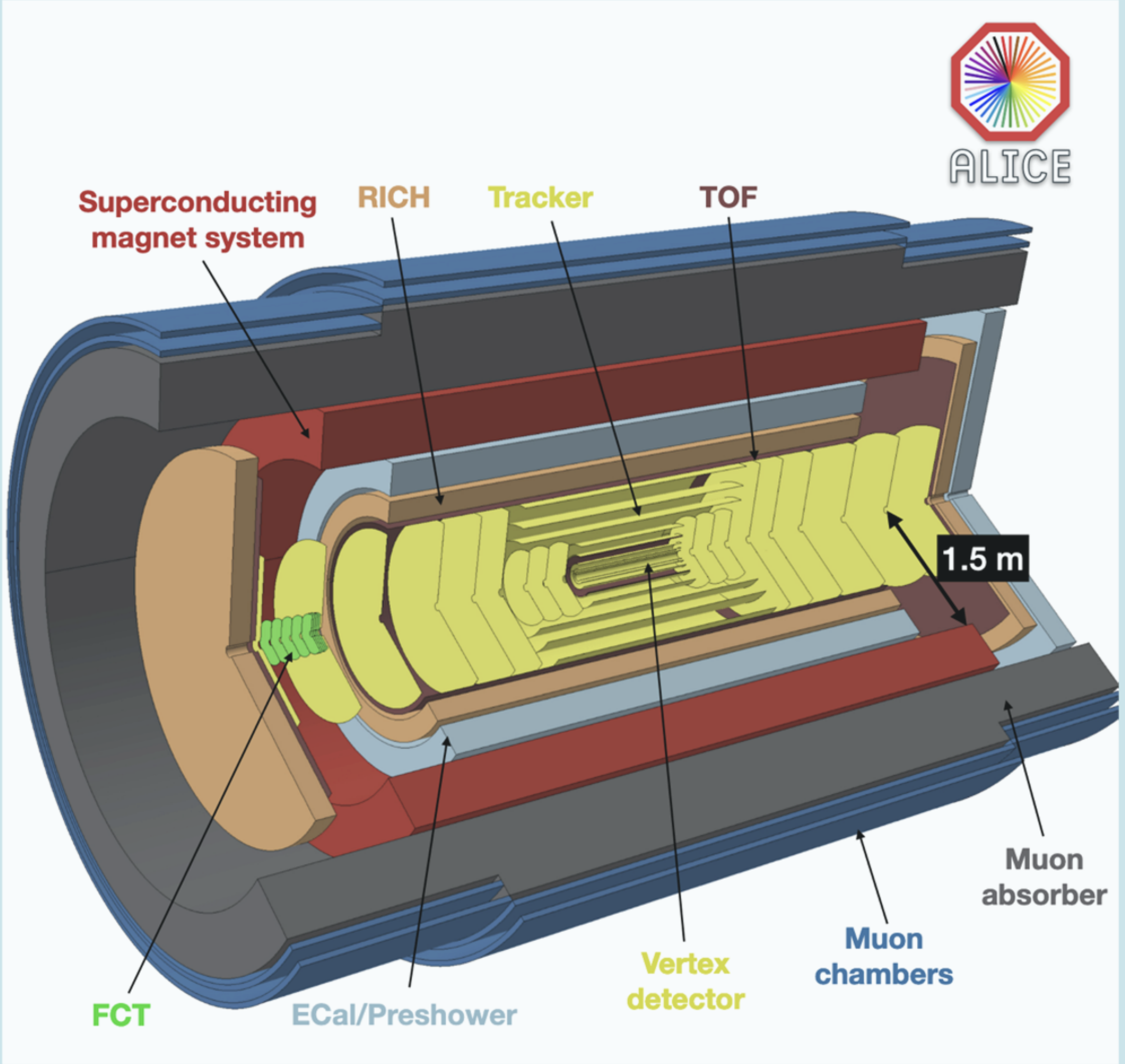

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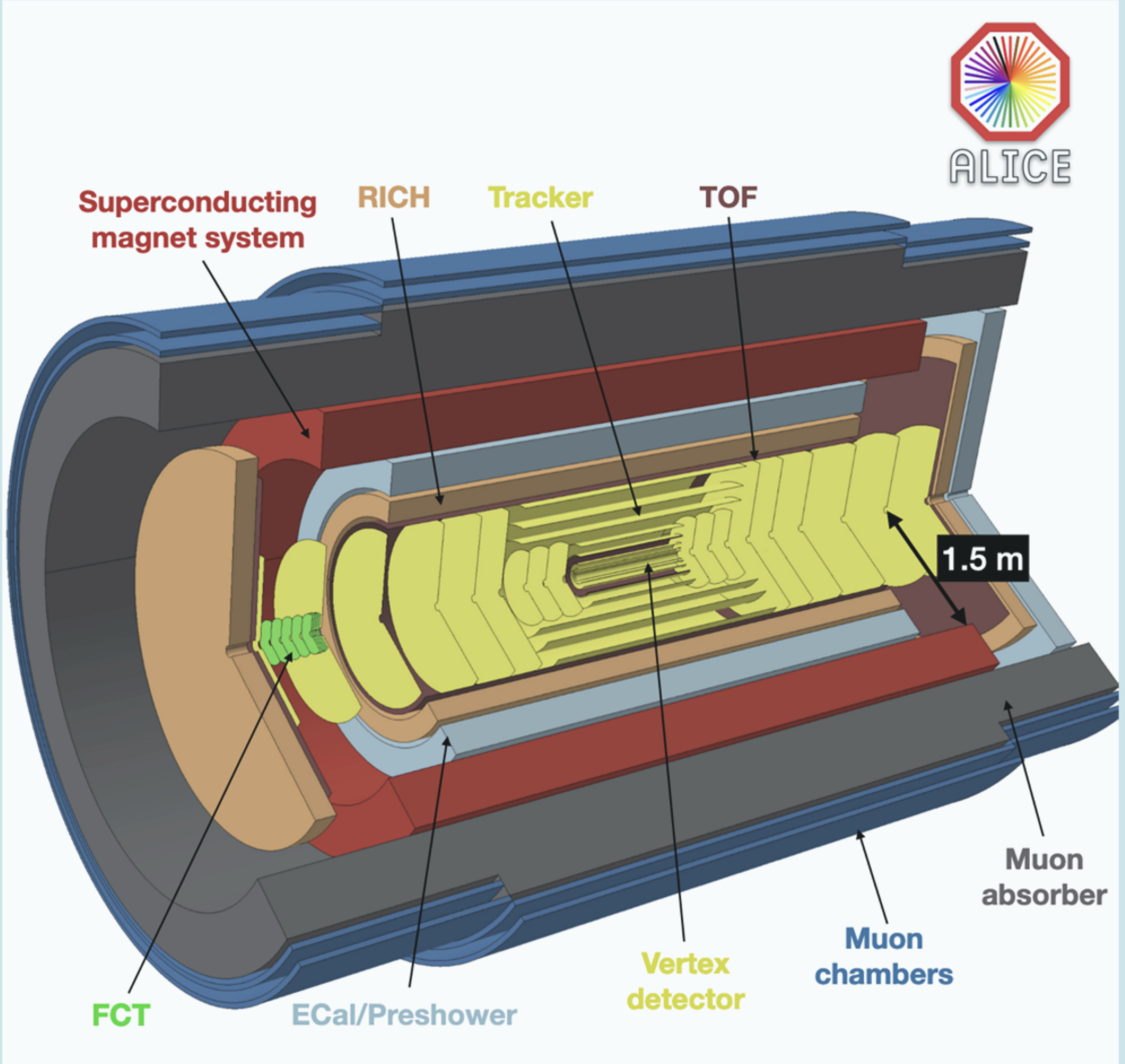

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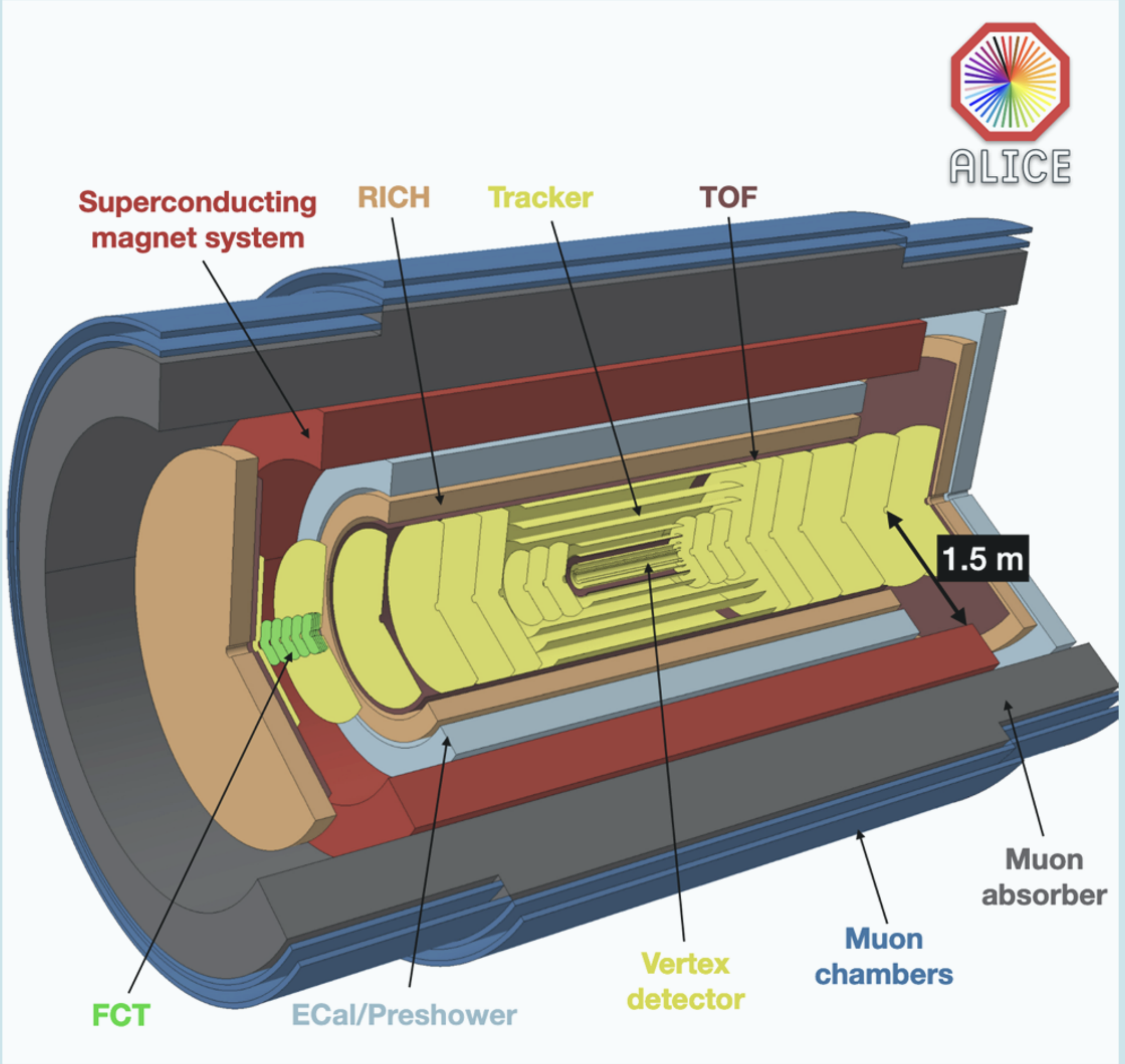

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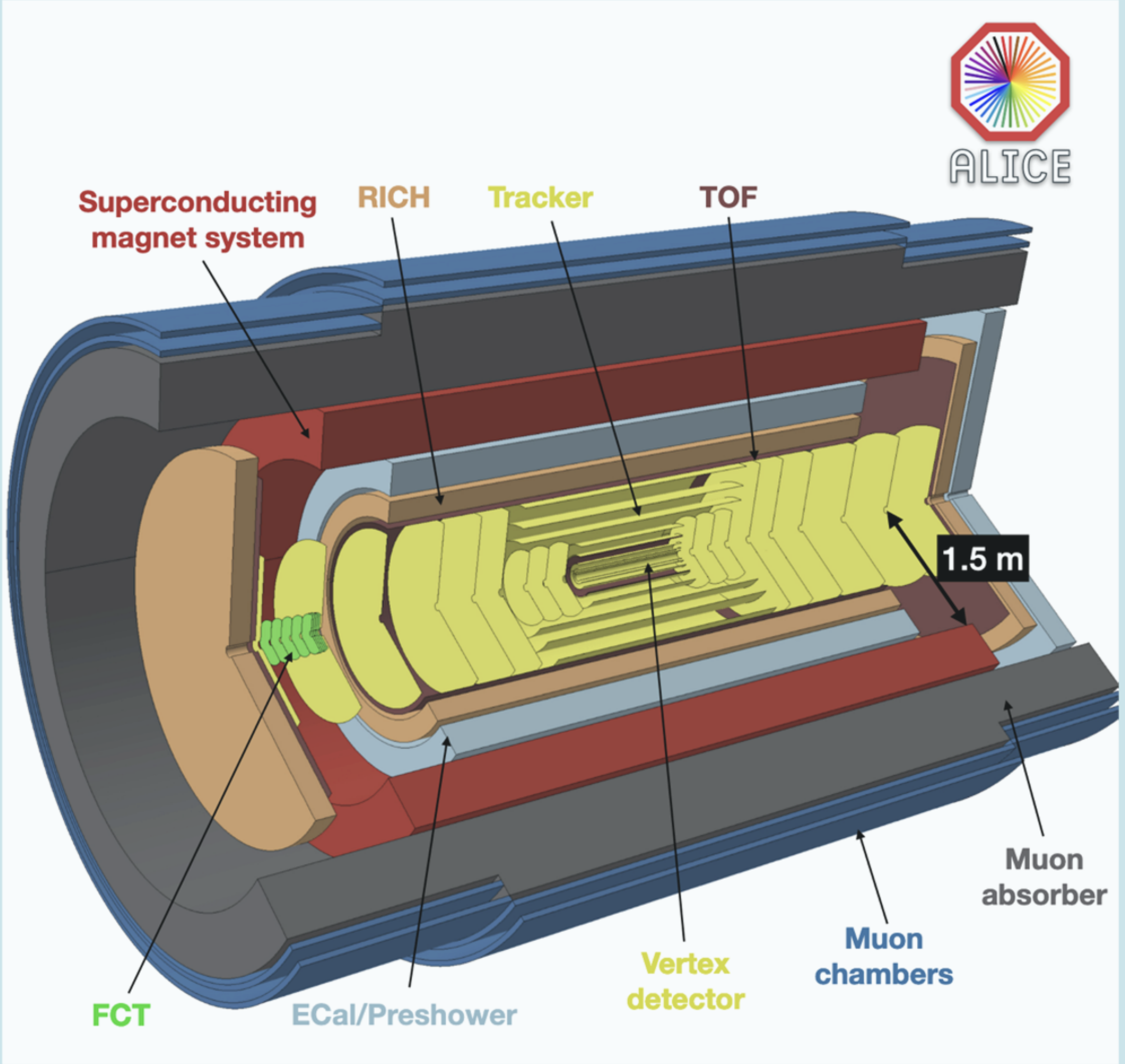

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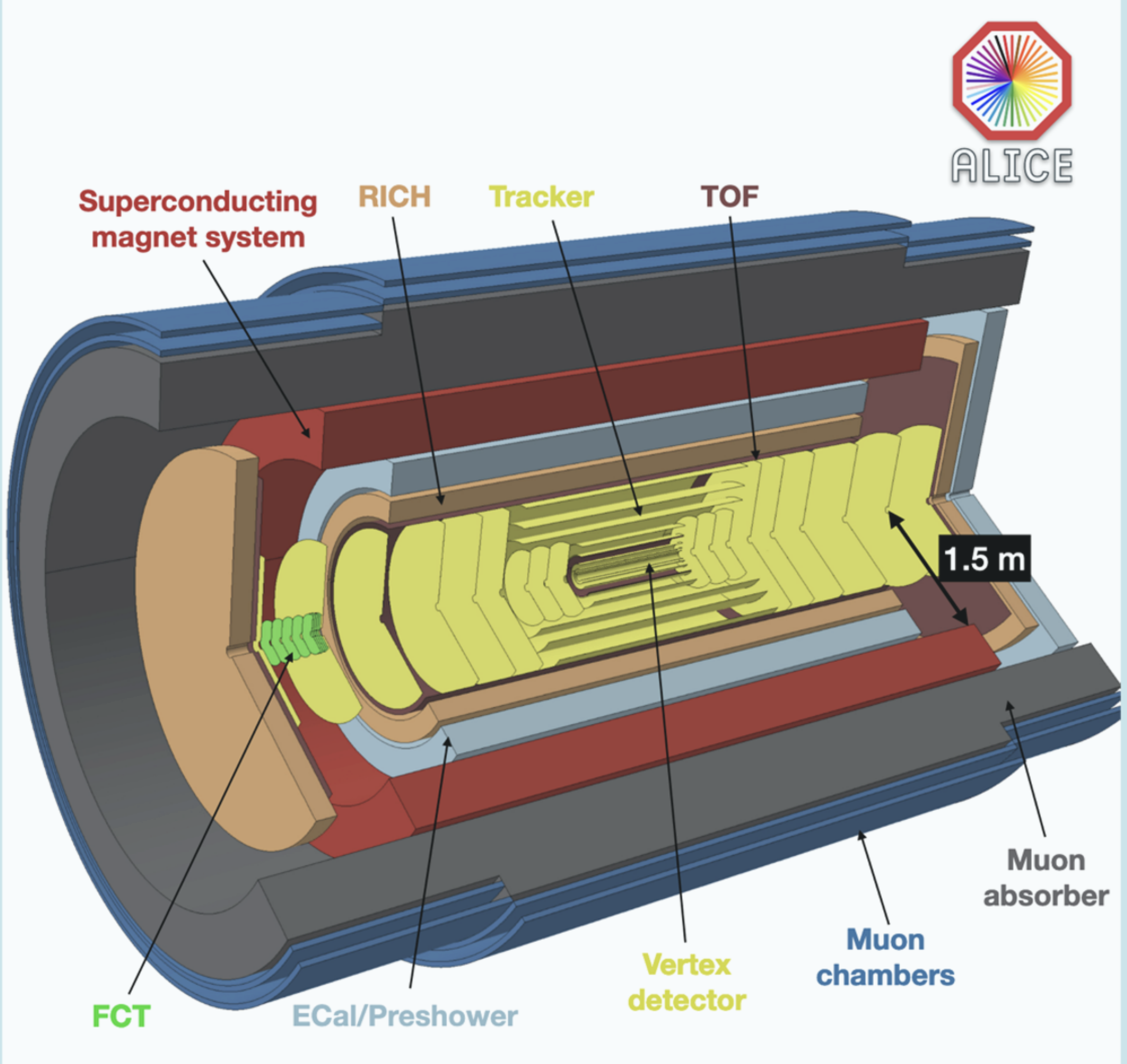
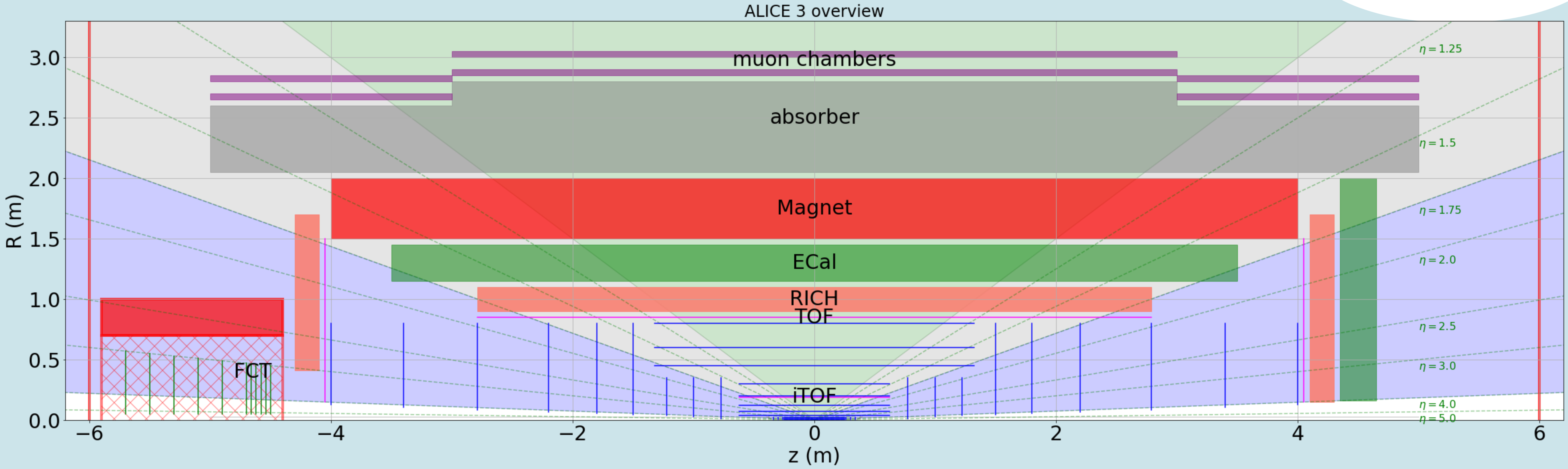
    - Get large statistics



Detector geometry



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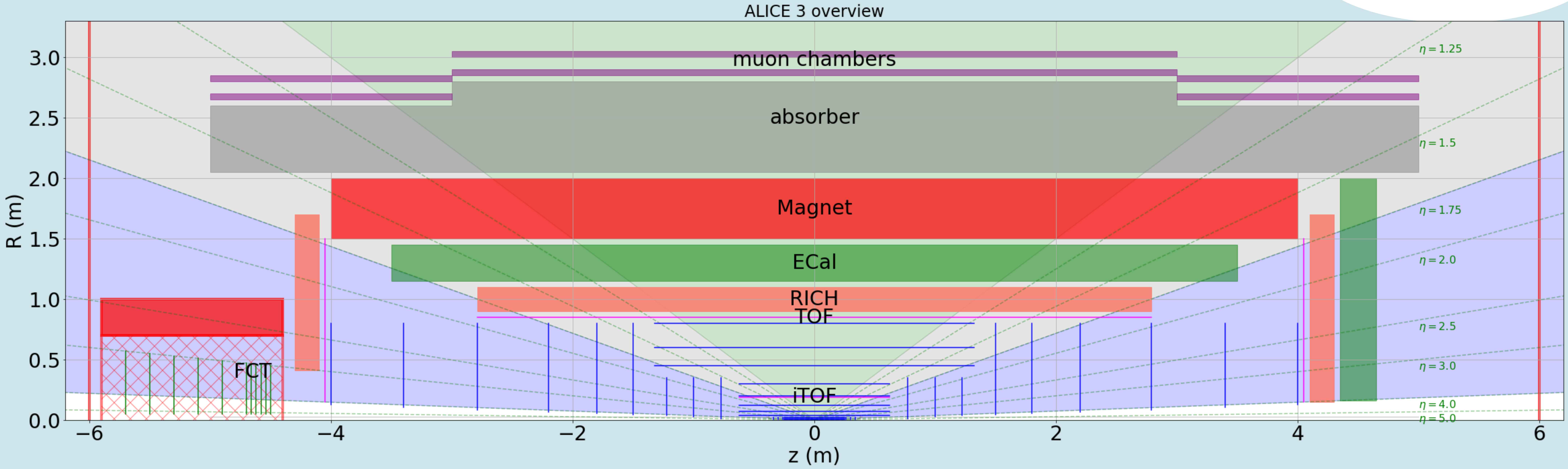

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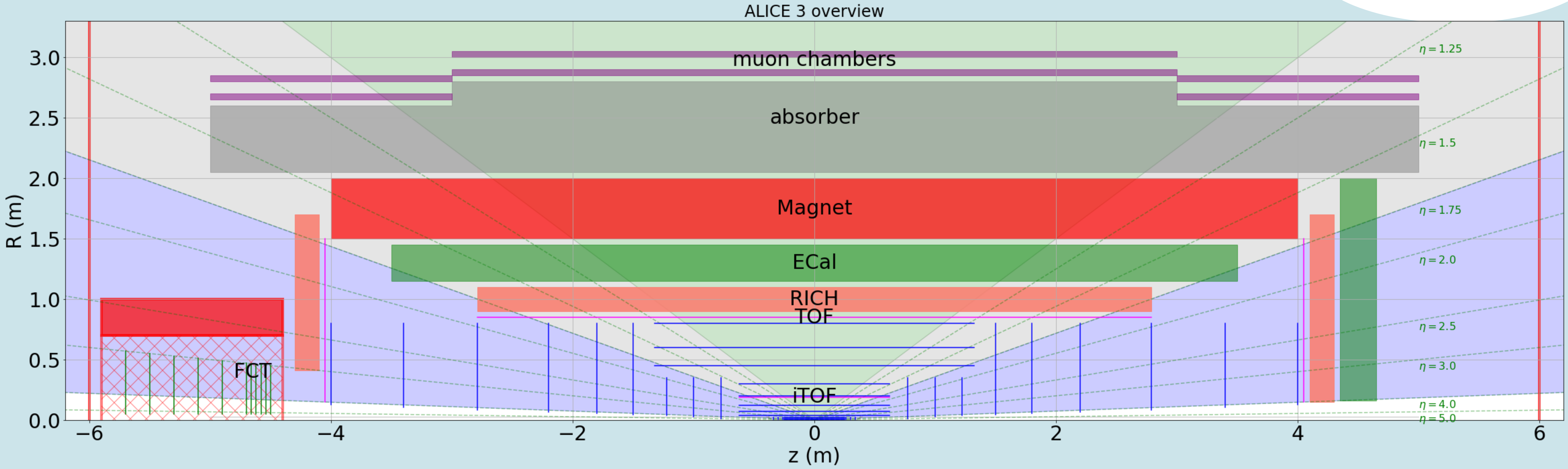

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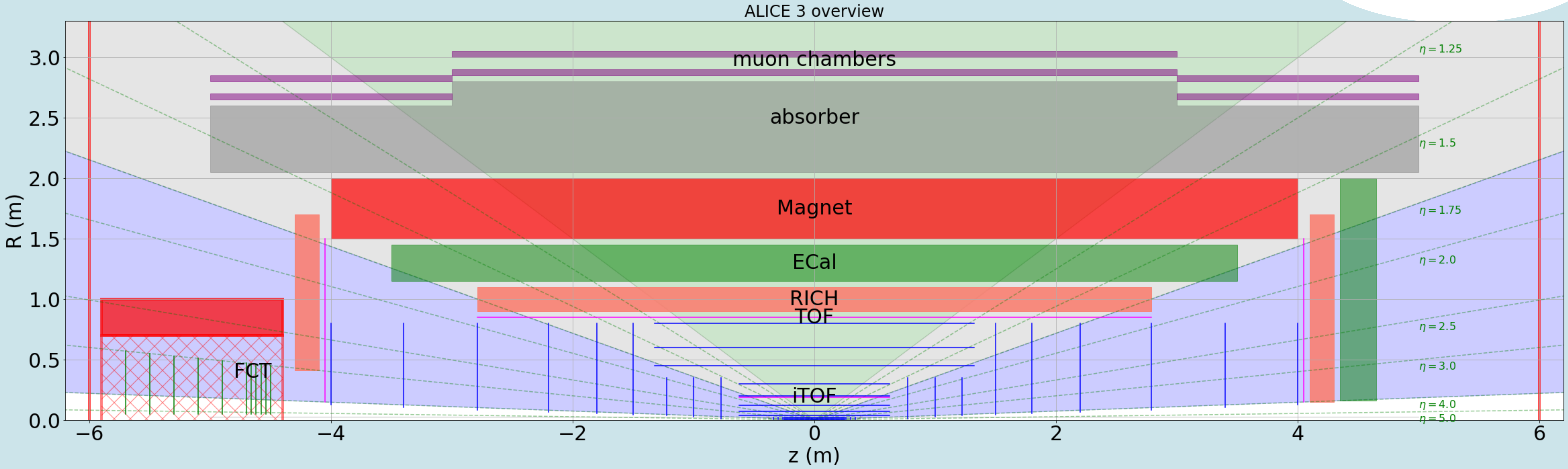

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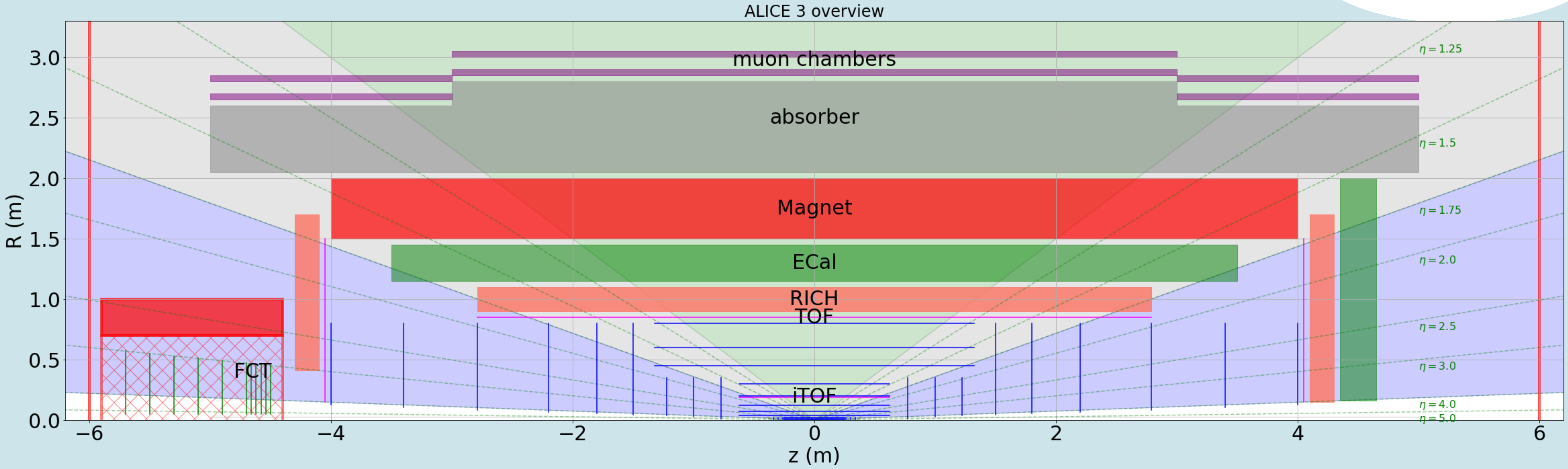

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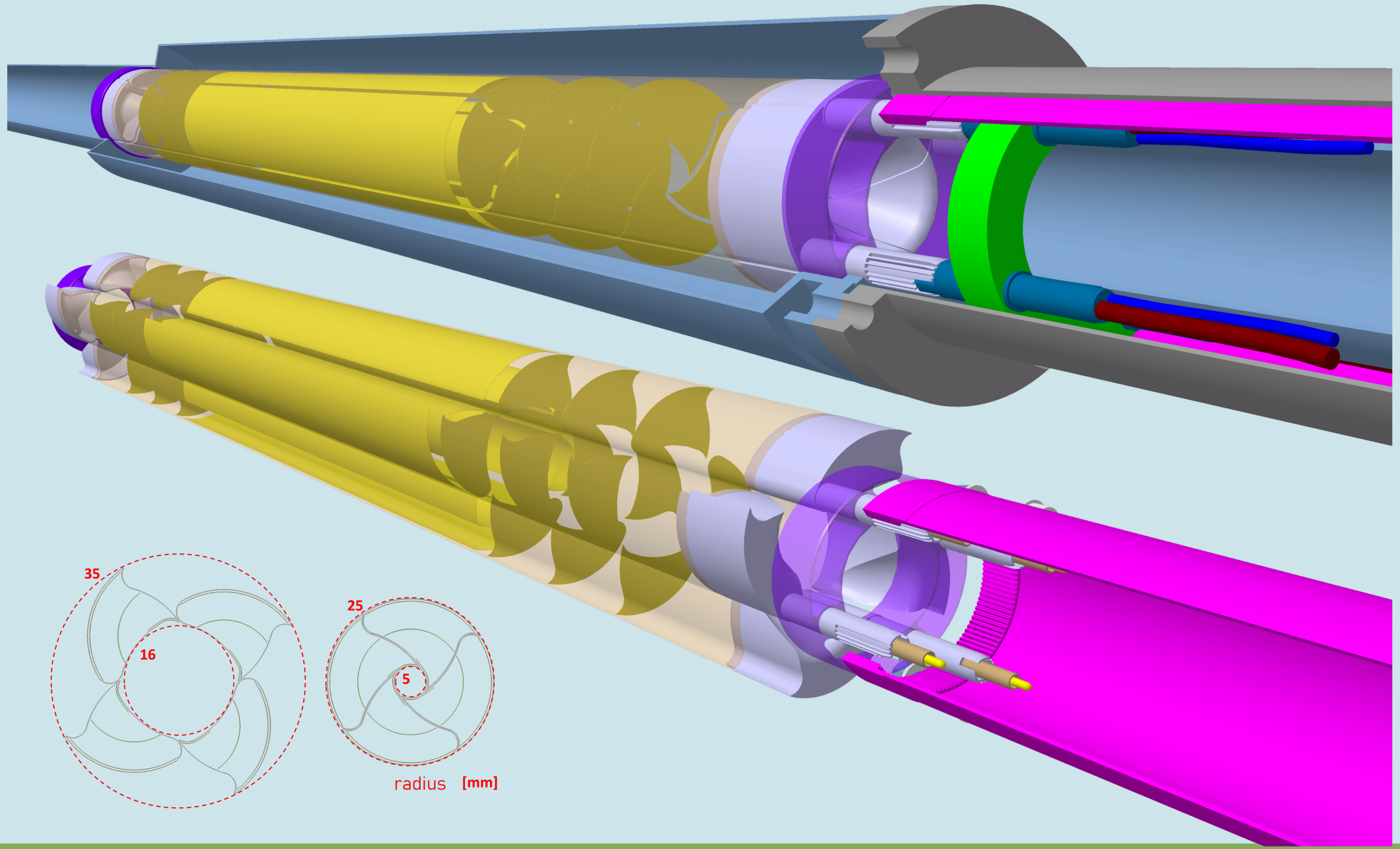
Precise vertex and track reconstruction

- The innermost 3 layers and 3 disks will be installed inside the beam pipe



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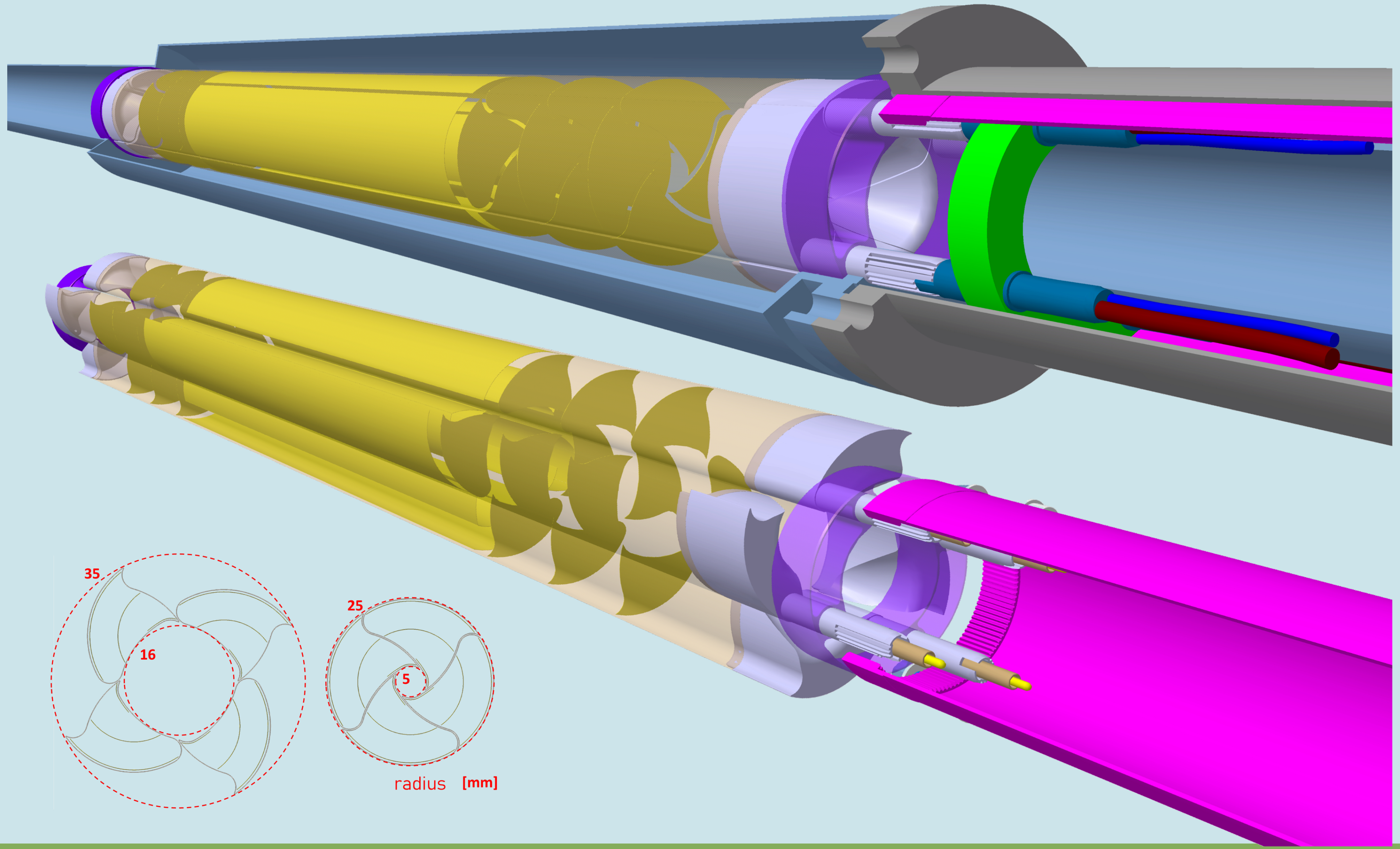

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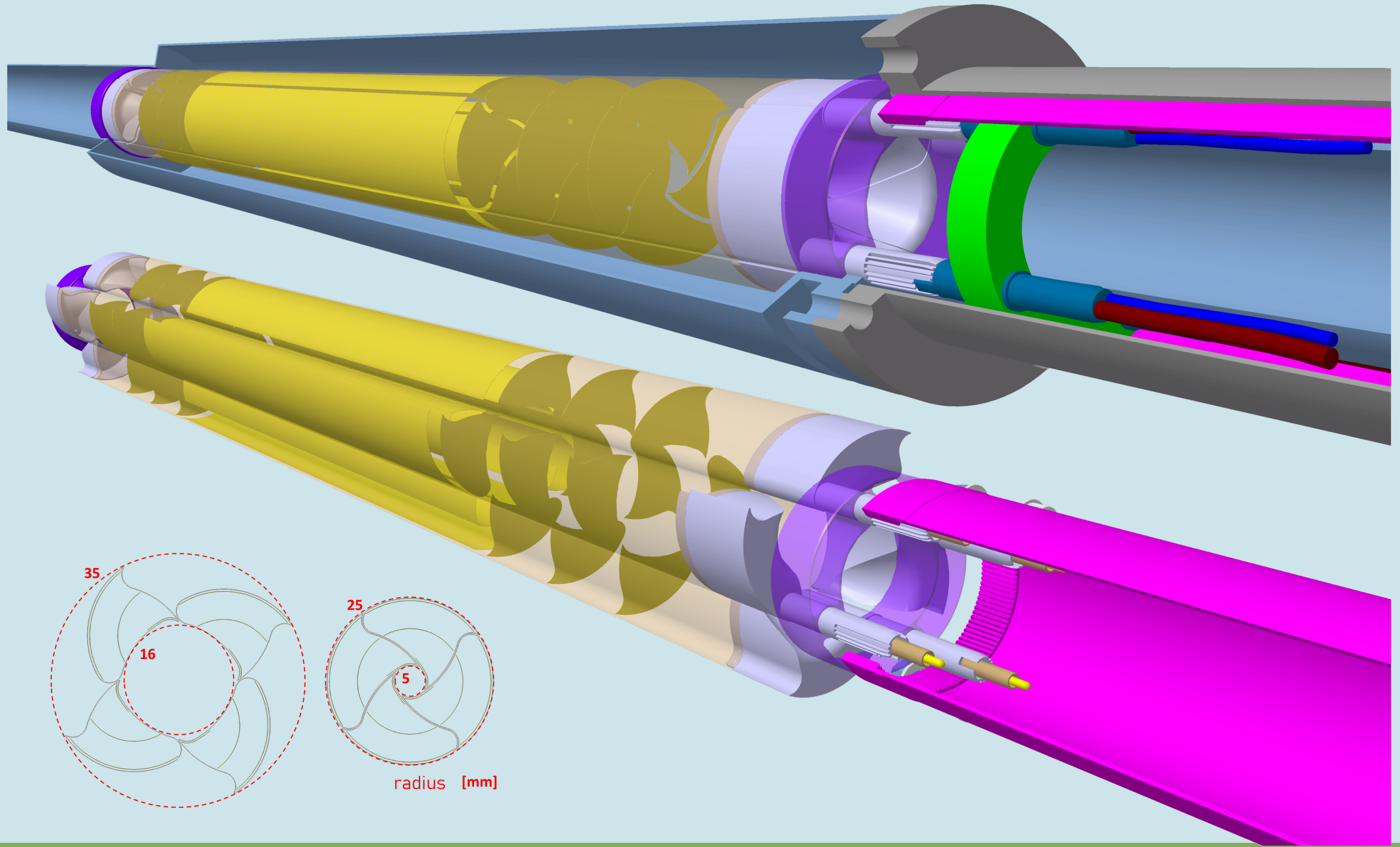
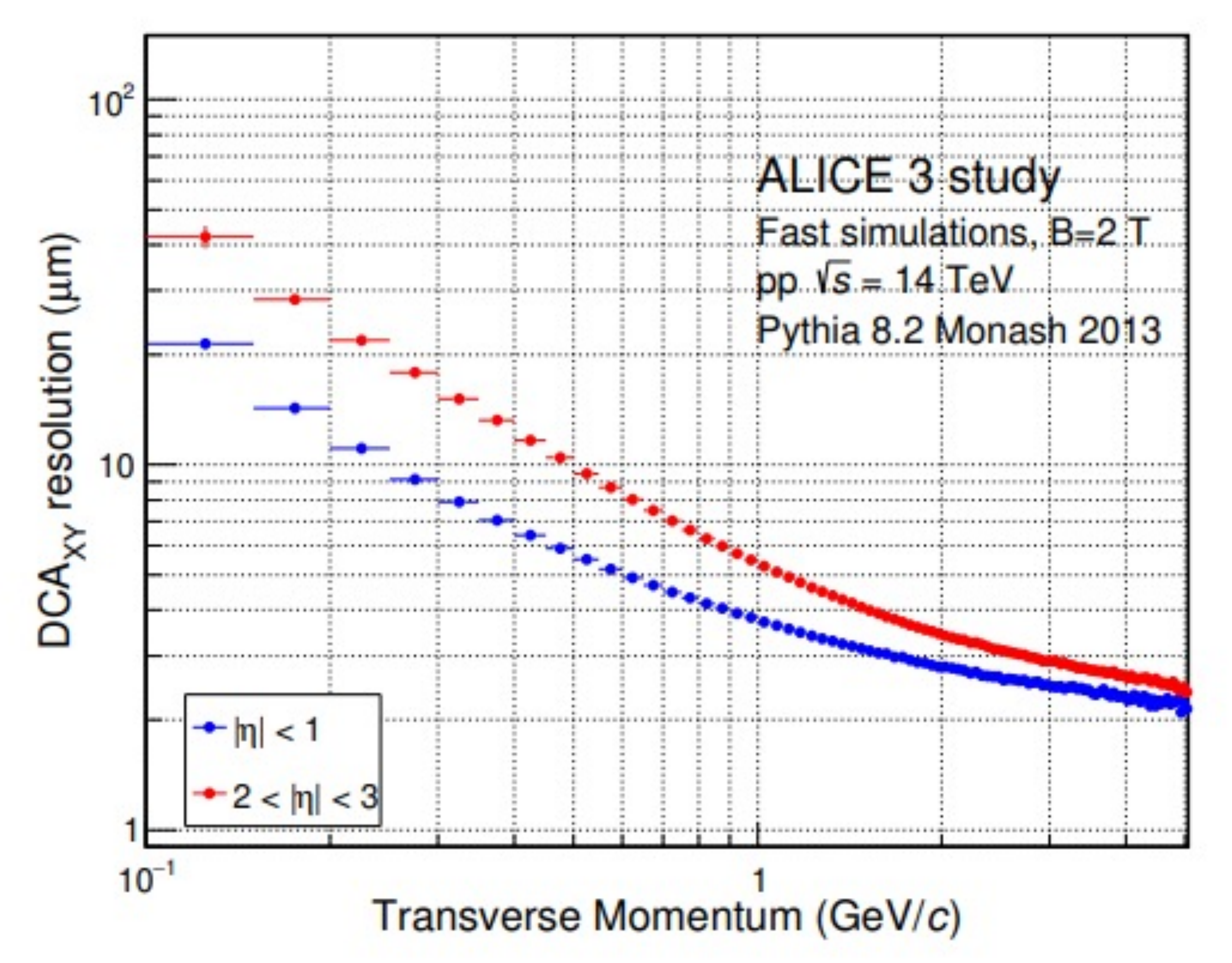
  - Retractable detector design: R_{min} = 5 mm (beam injection) → 1.5 mm (physics run)
  - Pixel pitch: 5 μm (ALICE 2: ~30μm)
  - $DCA_{xy\ \&\ z}$ resolution: ~ 4μm @ 1GeV/c (ALICE 2: 25μm)

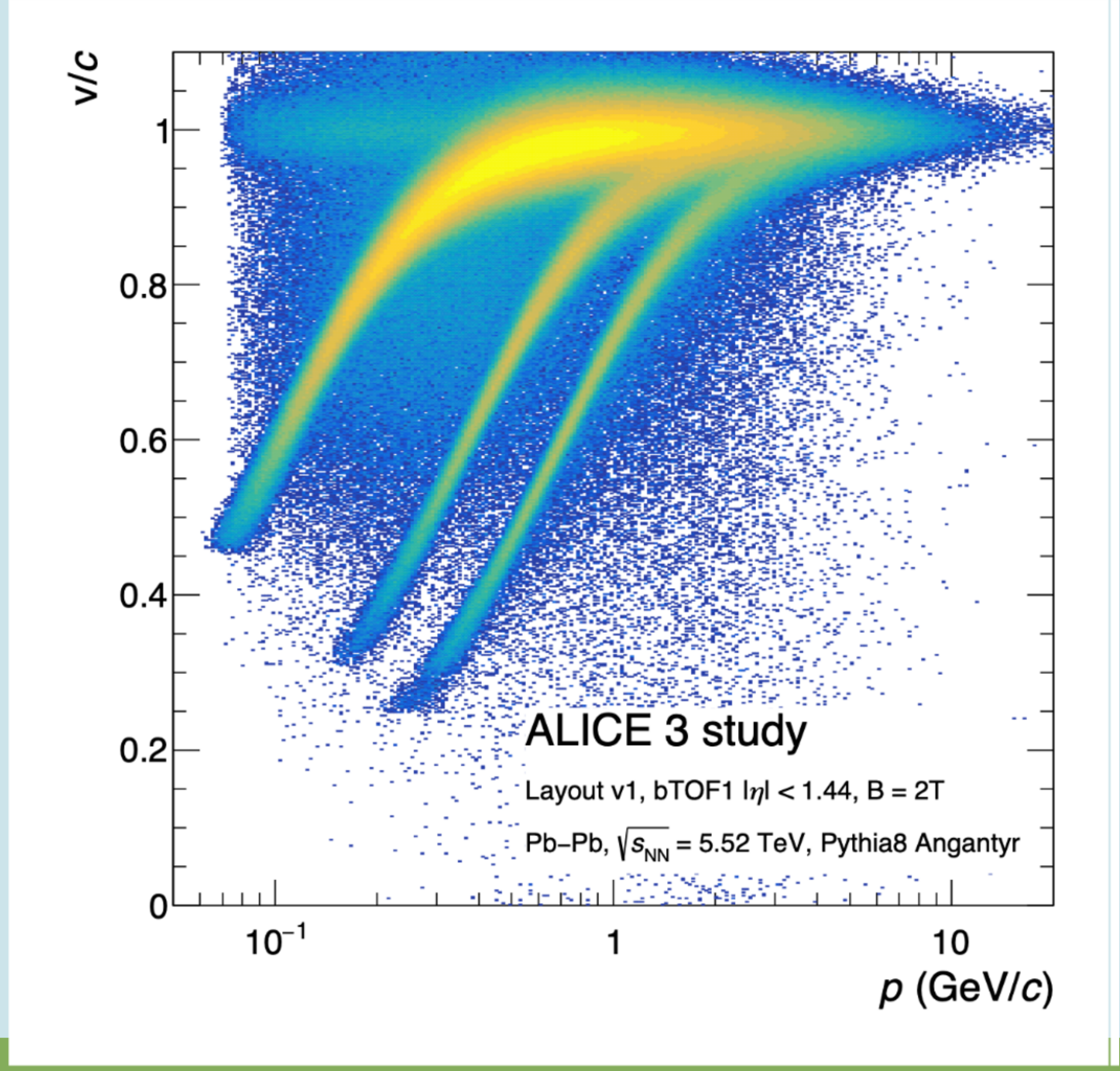




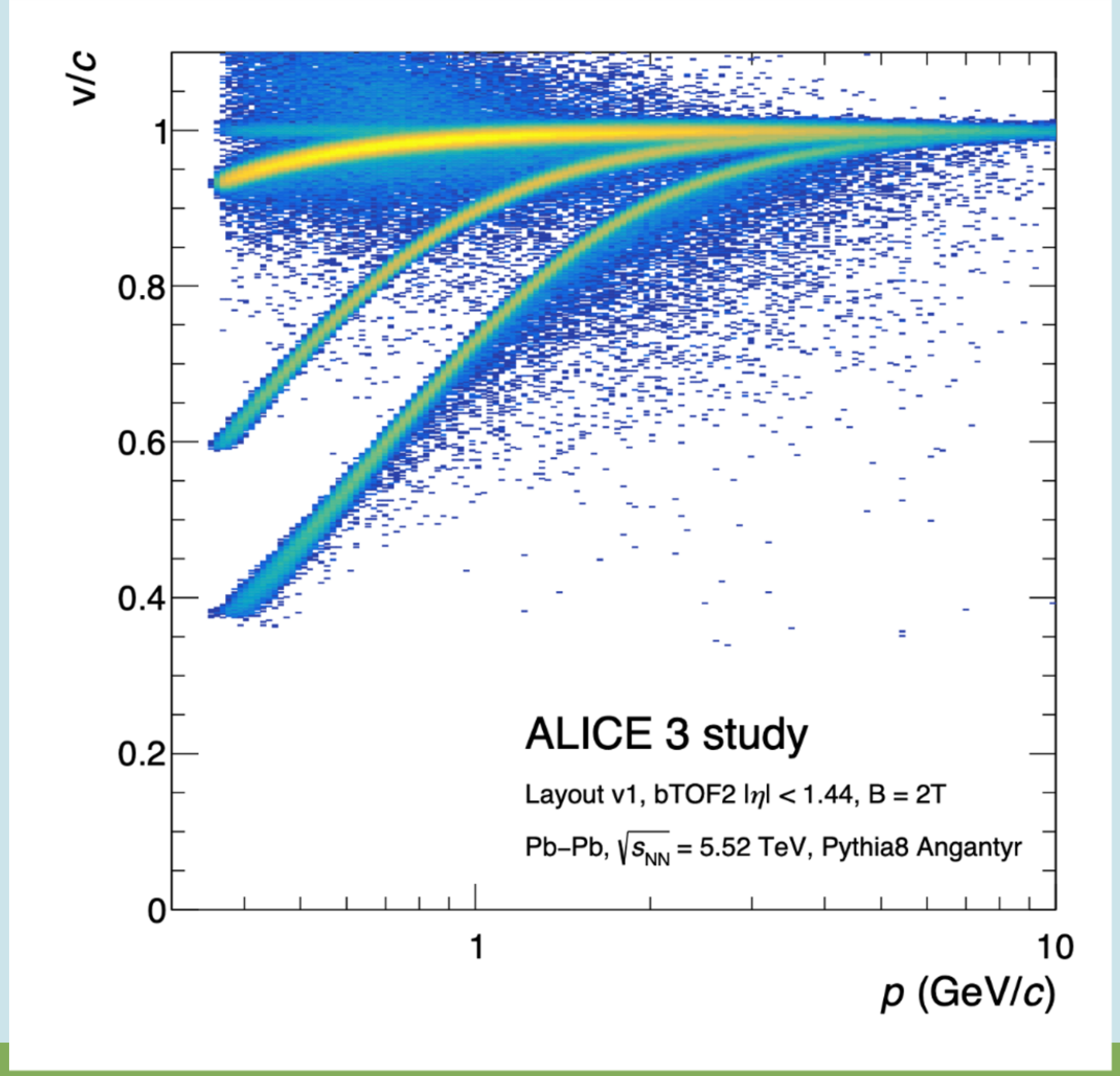
Particle identification

- Electron will be identified with outer and inner TOF and RICH
  - Up to 1.5 GeV/c with RICH and down to 0.06 GeV/c with inner TOF

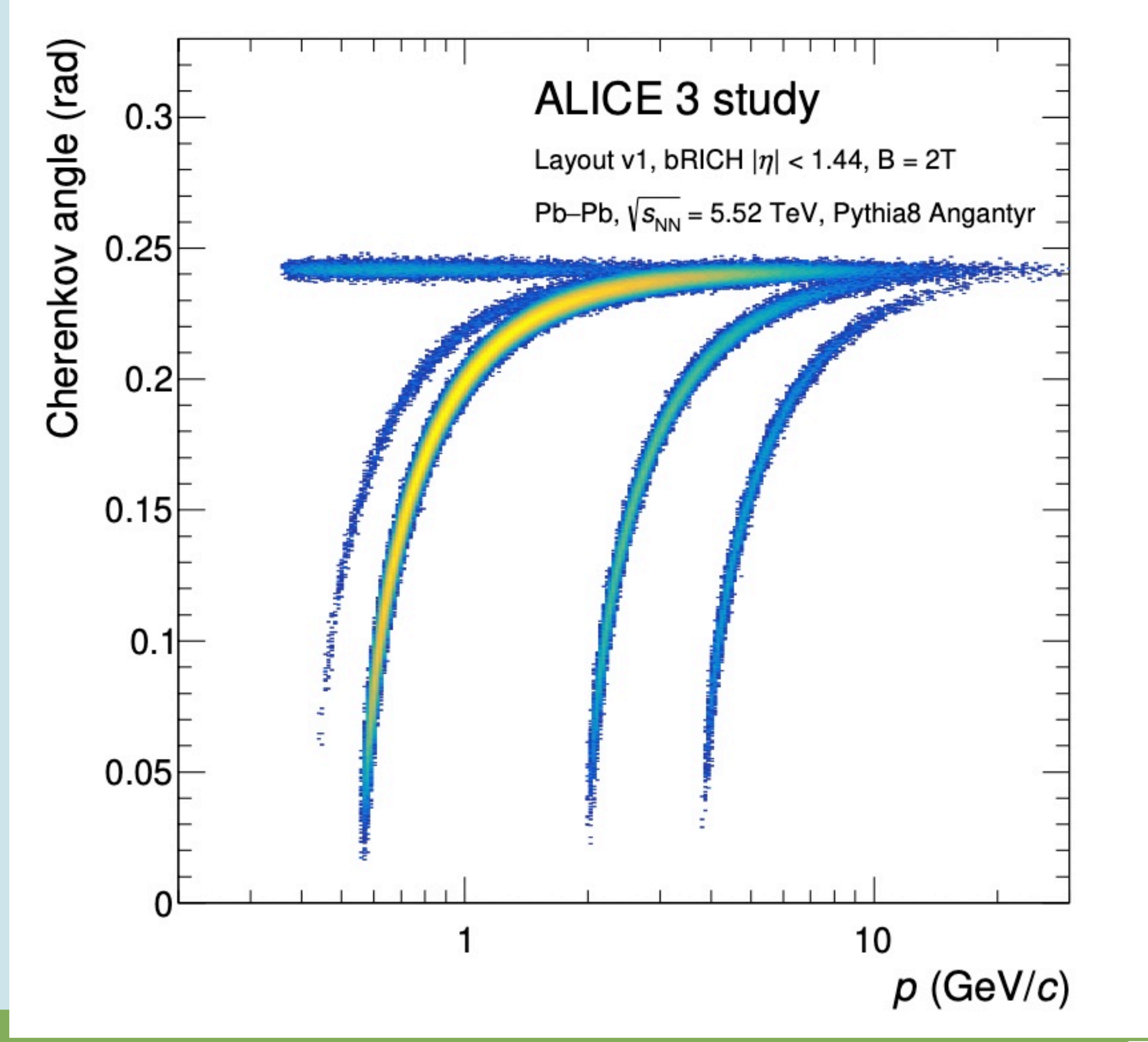
Inner TOF (20 cm)



Outer TOF (85 cm)



RICH Cherenkov angle



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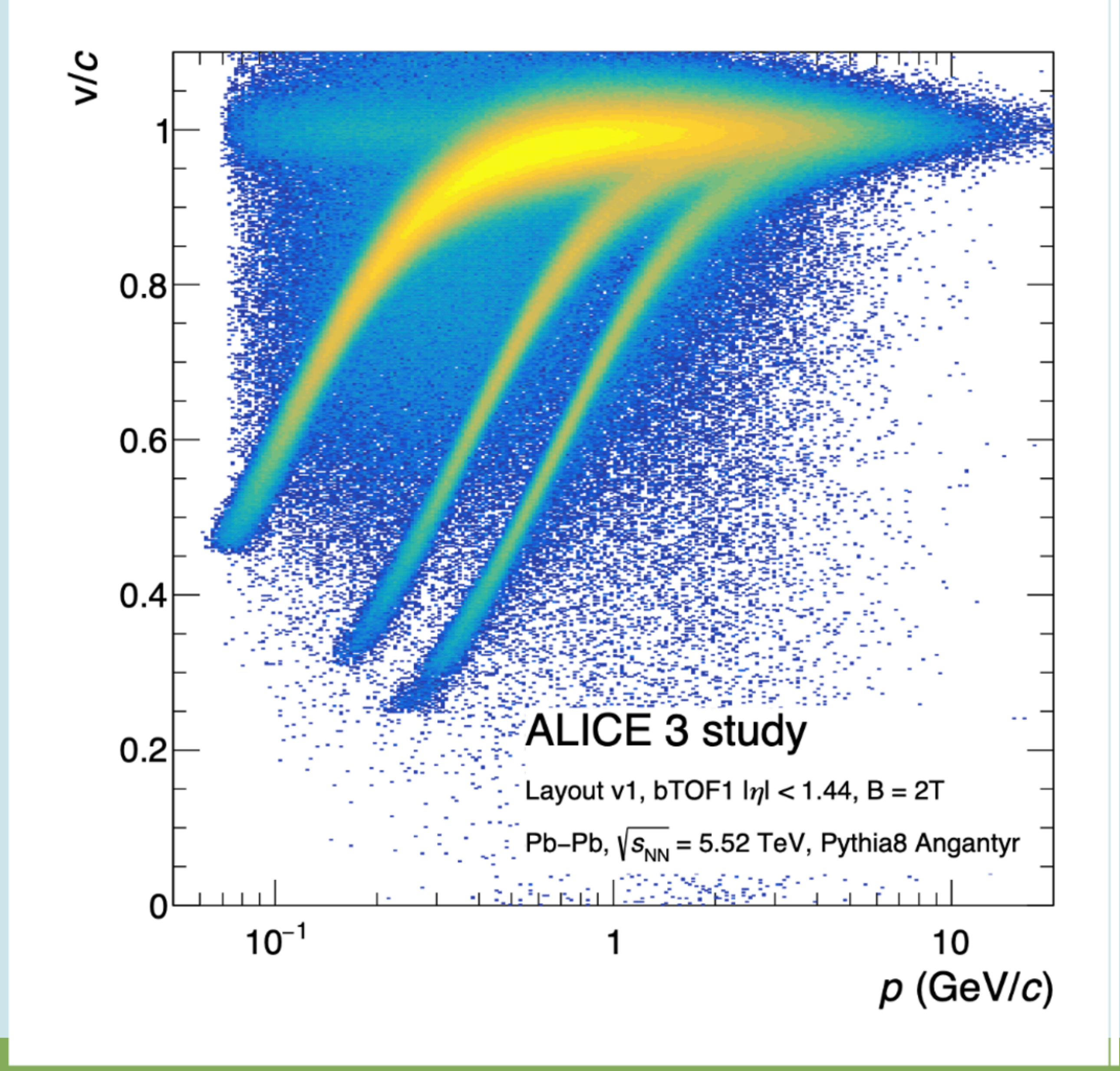
  - Up to 1.5 GeV/c with RICH and down to 0.06 GeV/c with inner TOF
- Muon will be identified with RICH and Muon identifier
  - Up to ~1.5 GeV/c with RICH and over > 1.5 GeV/c with Muon identifier

Inner TOF (20 cm)



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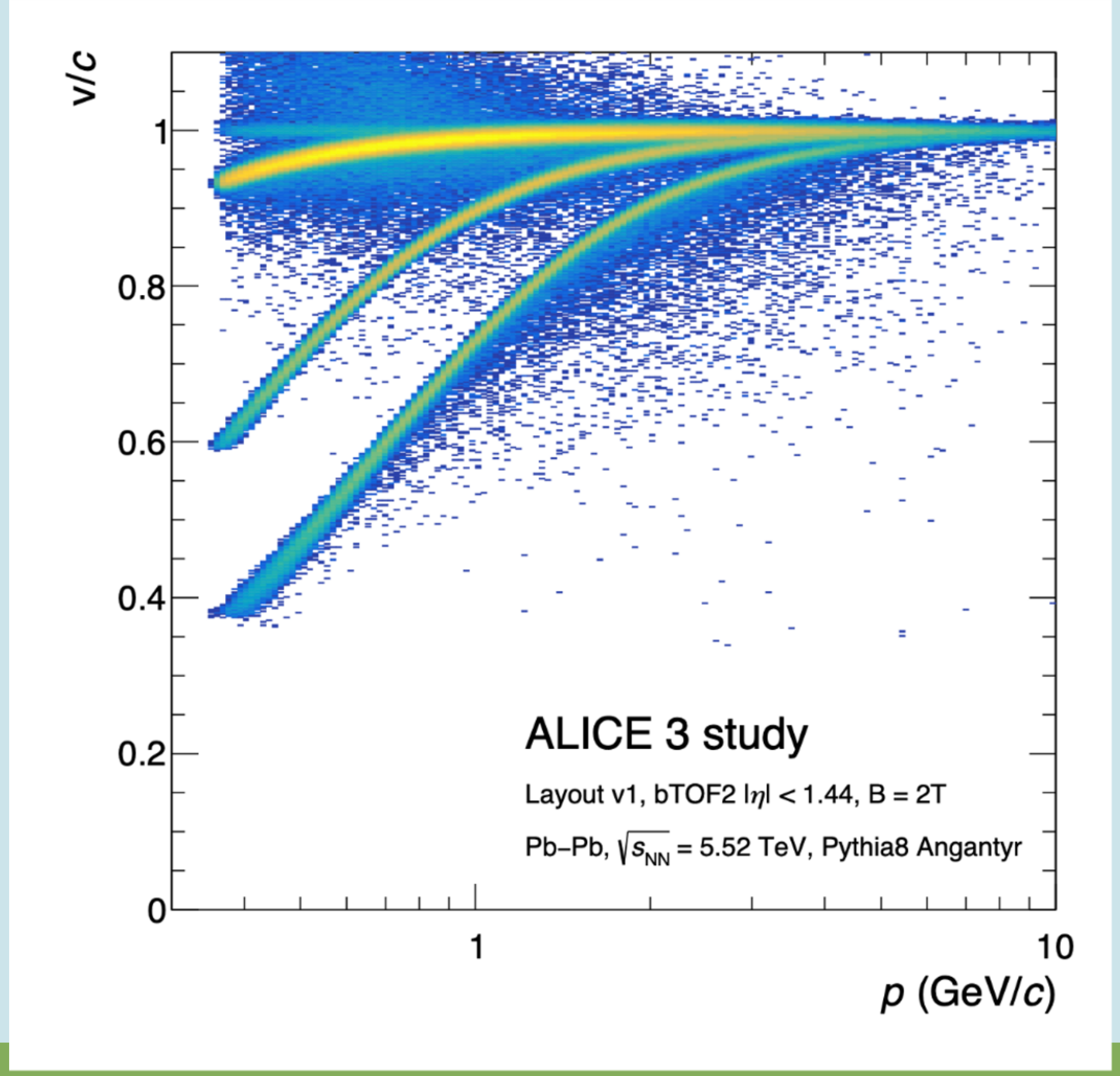

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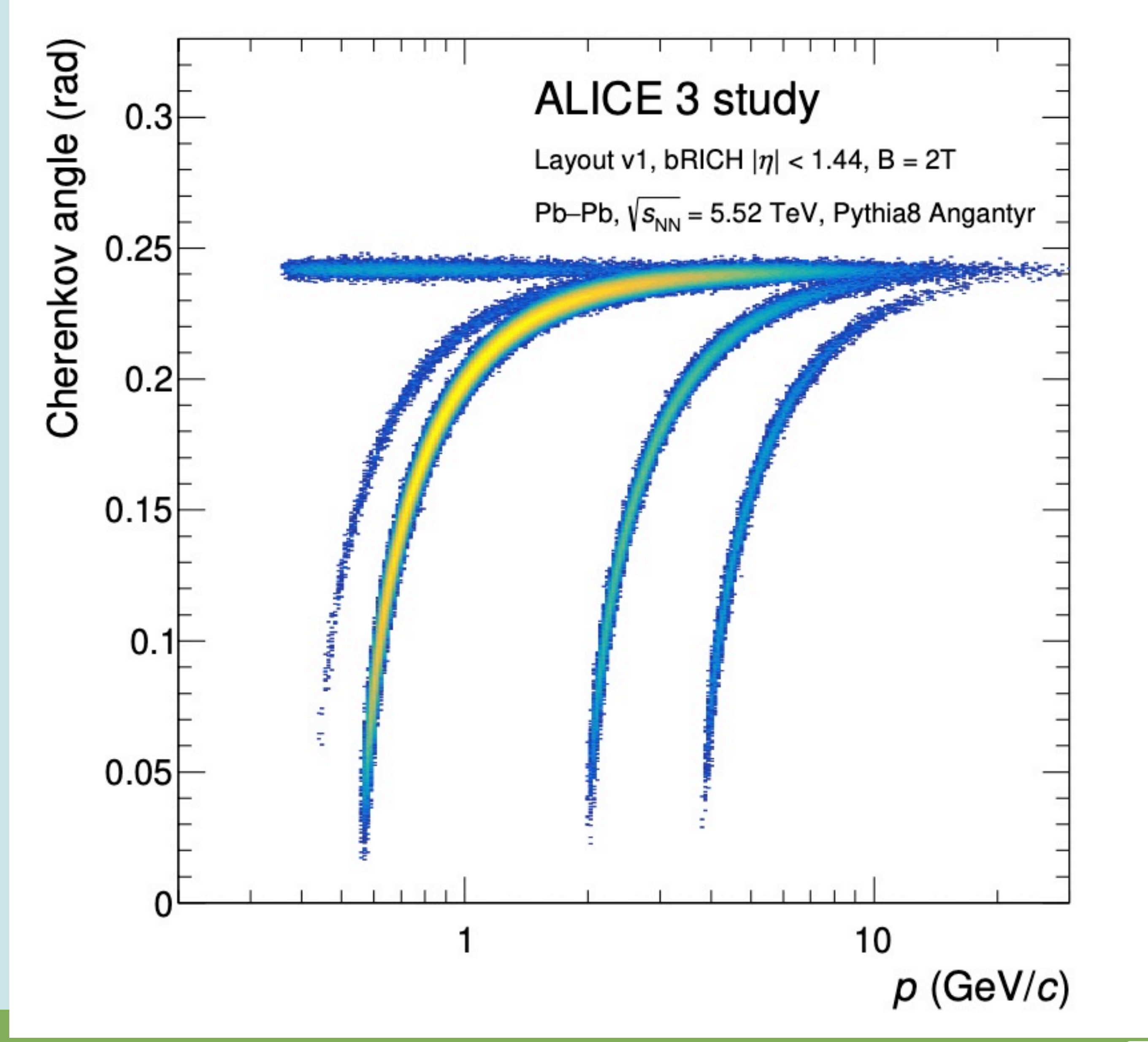

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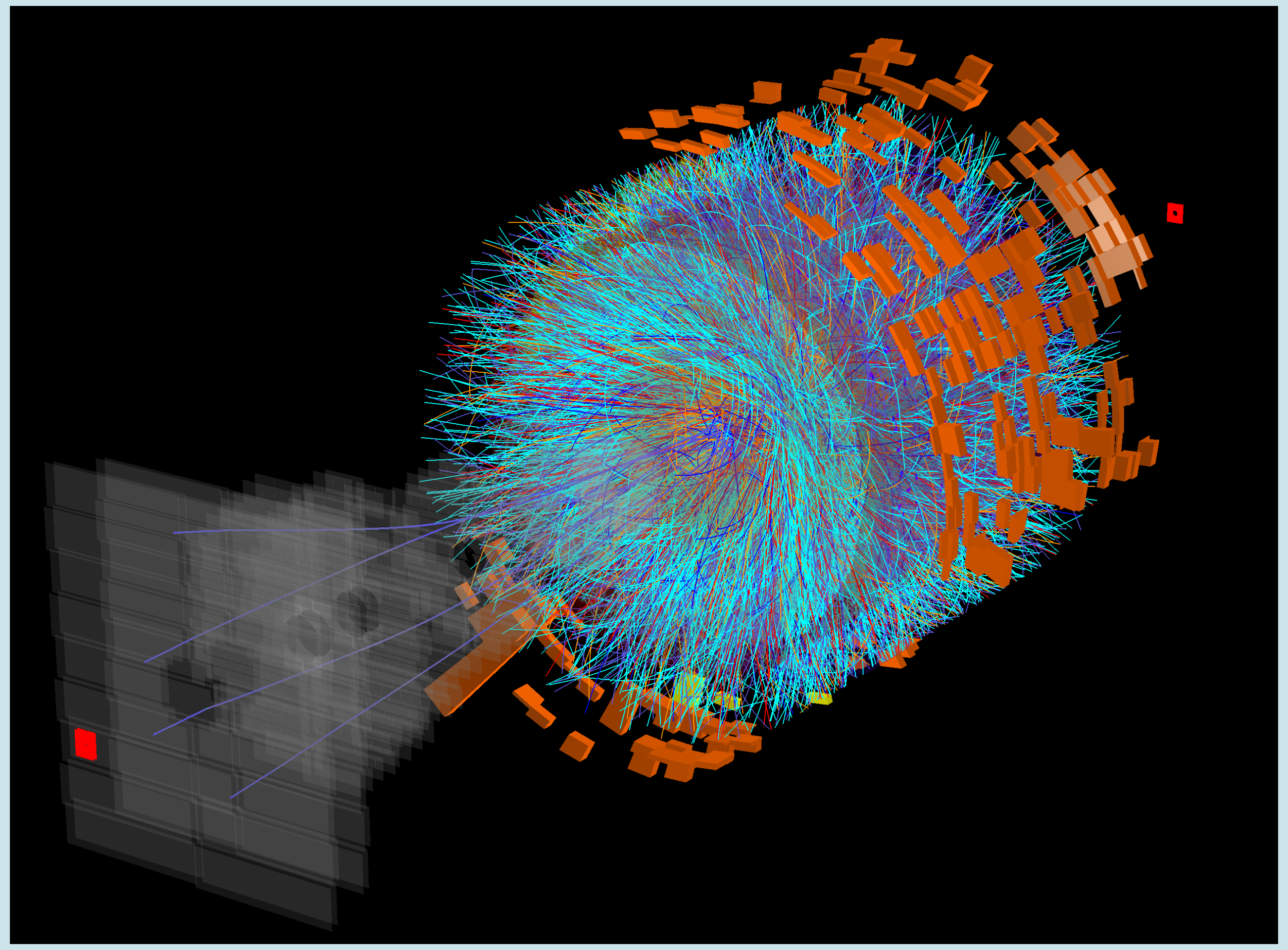

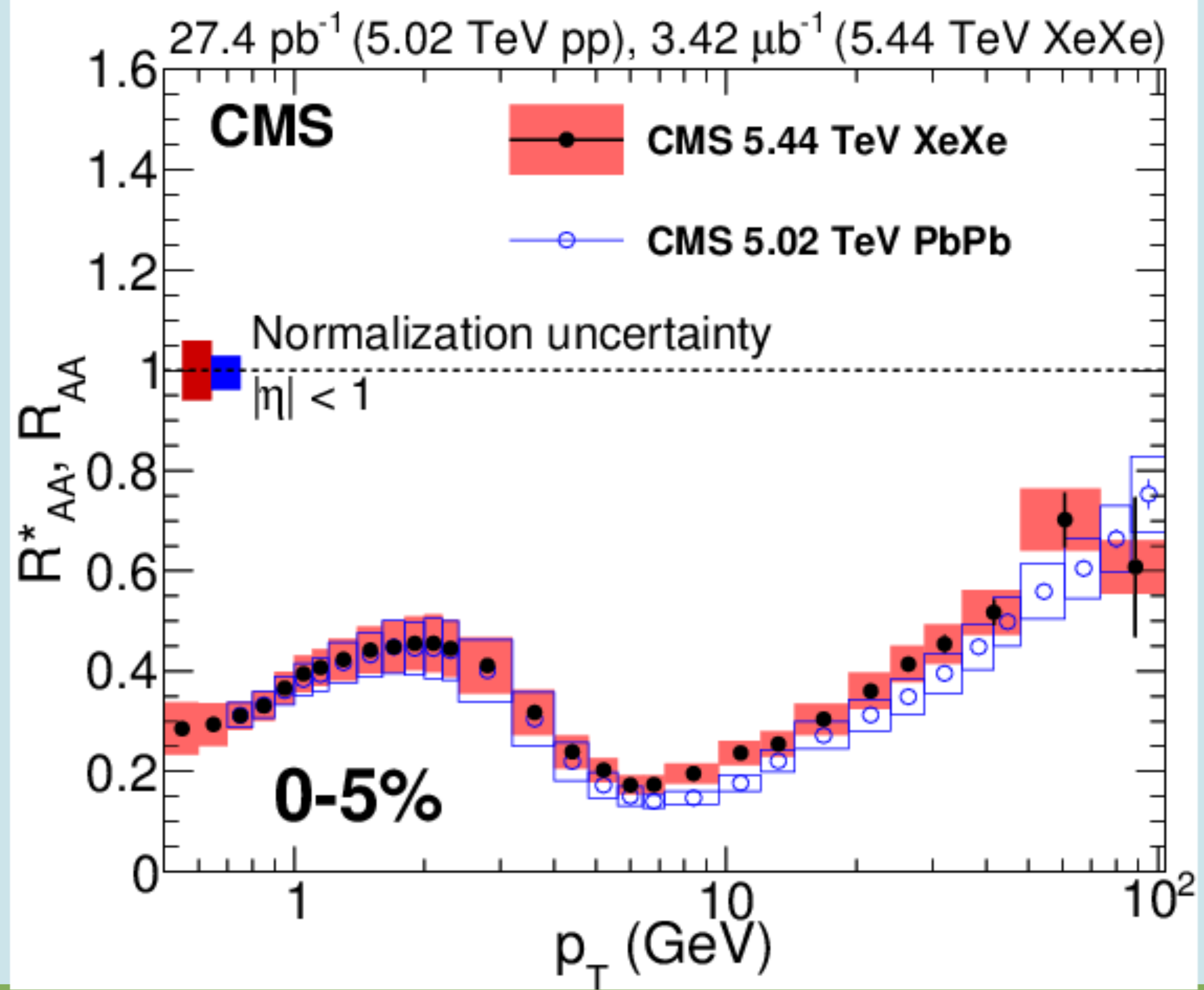

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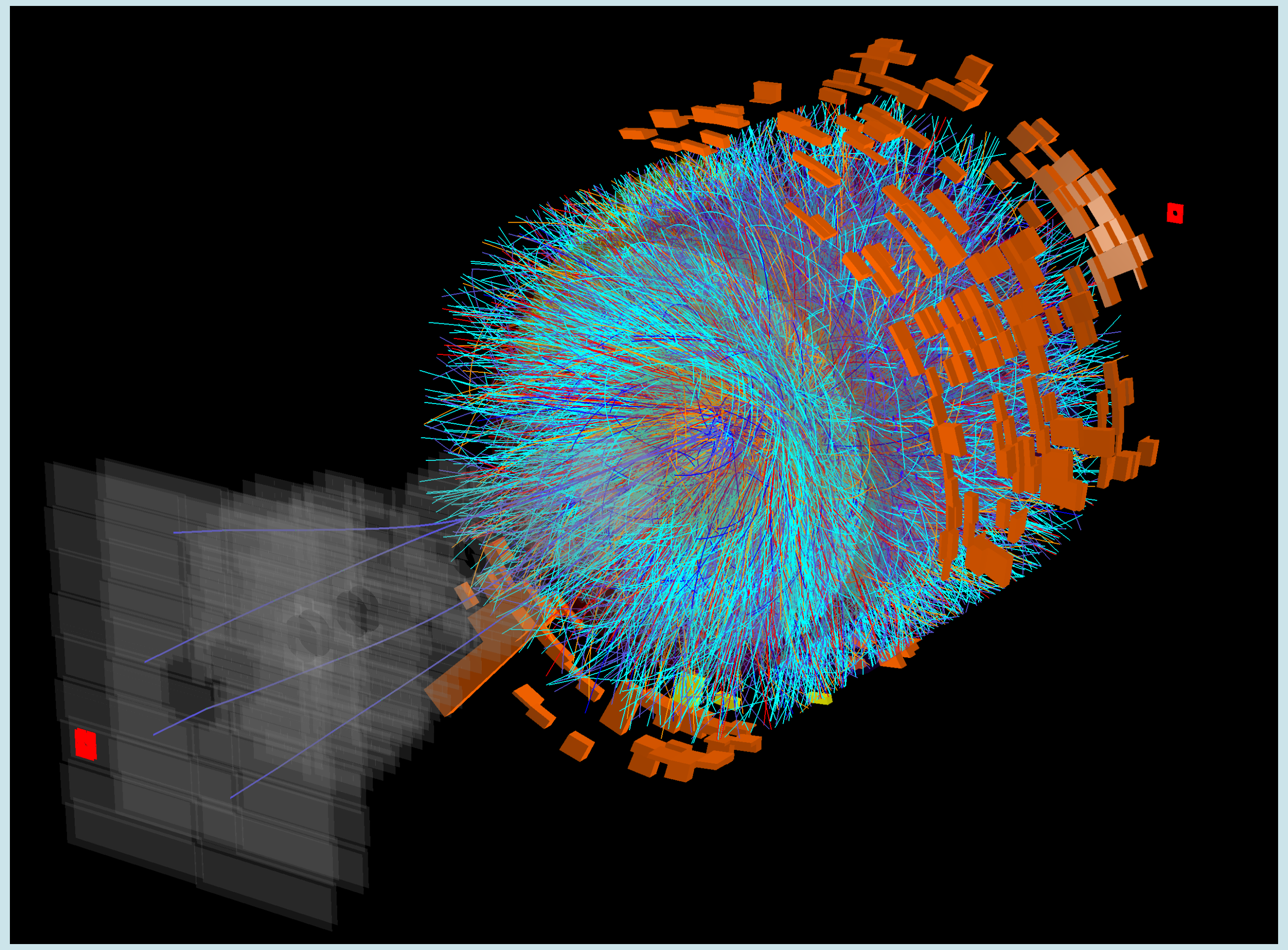
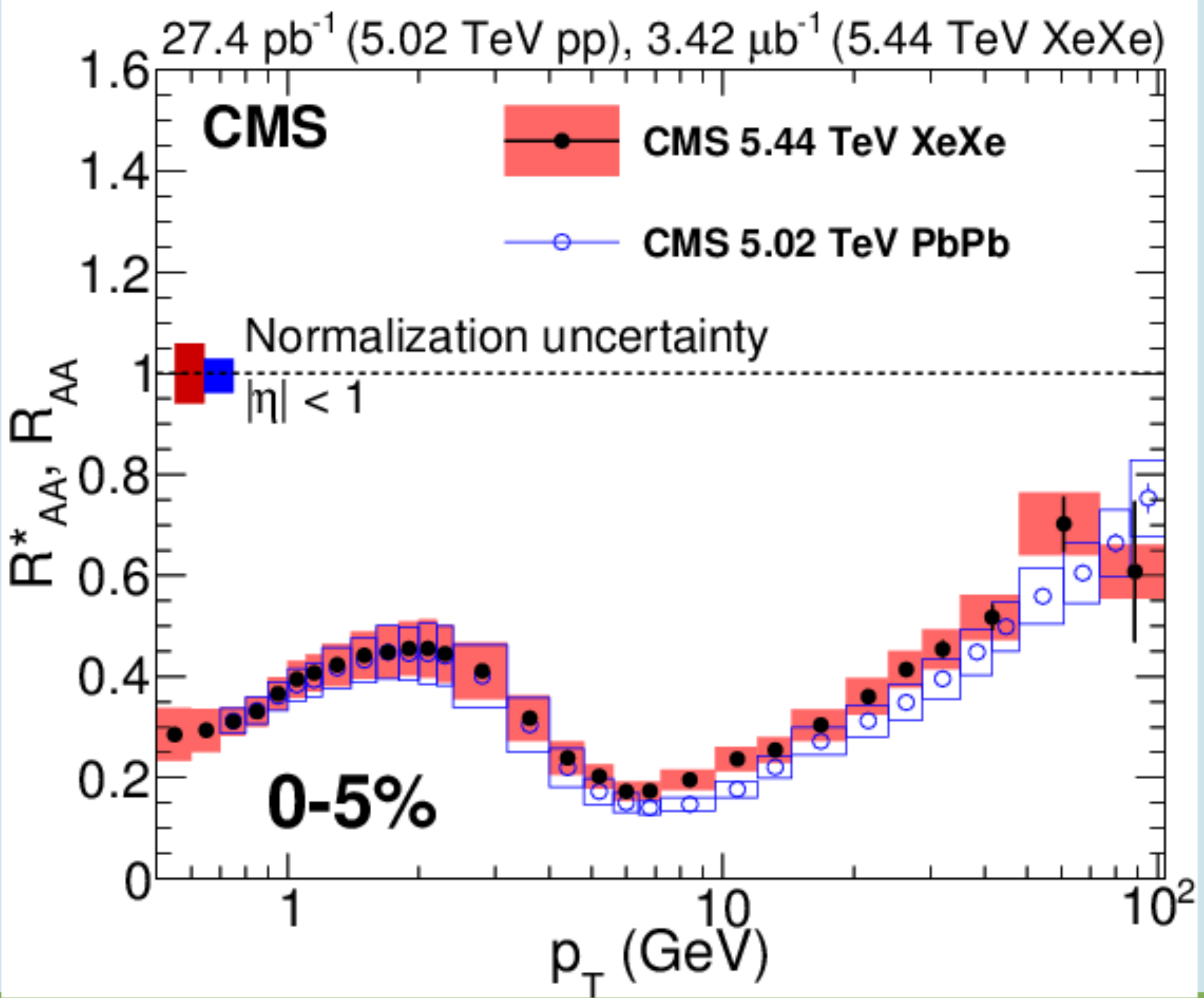
  - Achieve higher luminosity, e.g. L_{XeXe} ~ 4 - 5 x L_{PbPb}



Quantity	pp	O–O	Ar–Ar	Ca–Ca	Kr–Kr	In–In	Xe–Xe	Pb–Pb
$\sqrt{s_{NN}}$ (TeV)	14.00	7.00	6.30	7.00	6.46	5.97	5.86	5.52
L_{AA} ($cm^{-2}s^{-1}$)	$3.0 \cdot 10^{32}$	$1.5 \cdot 10^{30}$	$3.2 \cdot 10^{29}$	$2.8 \cdot 10^{29}$	$8.5 \cdot 10^{28}$	$5.0 \cdot 10^{28}$	$3.3 \cdot 10^{28}$	$1.2 \cdot 10^{28}$
$\langle L_{AA} \rangle$ ($cm^{-2}s^{-1}$)	$3.0 \cdot 10^{32}$	$9.5 \cdot 10^{29}$	$2.0 \cdot 10^{29}$	$1.9 \cdot 10^{29}$	$5.0 \cdot 10^{28}$	$2.3 \cdot 10^{28}$	$1.6 \cdot 10^{28}$	$3.3 \cdot 10^{27}$
$\mathscr{L}^{month}_{AA}$ (nb^{-1})	$5.1 \cdot 10^{5}$	$1.6 \cdot 10^{3}$	$3.4 \cdot 10^{2}$	$3.1 \cdot 10^{2}$	$8.4 \cdot 10^{1}$	$3.9 \cdot 10^{1}$	$2.6 \cdot 10^{1}$	5.6
$\mathscr{L}^{month}_{NN}$ (pb^{-1})	505	409	550	500	510	512	434	242
R_{max} (kHz)	24 000	2169	821	734	344	260	187	93
μ	1.2	0.21	0.08	0.07	0.03	0.03	0.02	0.01
$dN_{ch}/d\eta$ (MB)	7	70	151	152	275	400	434	682



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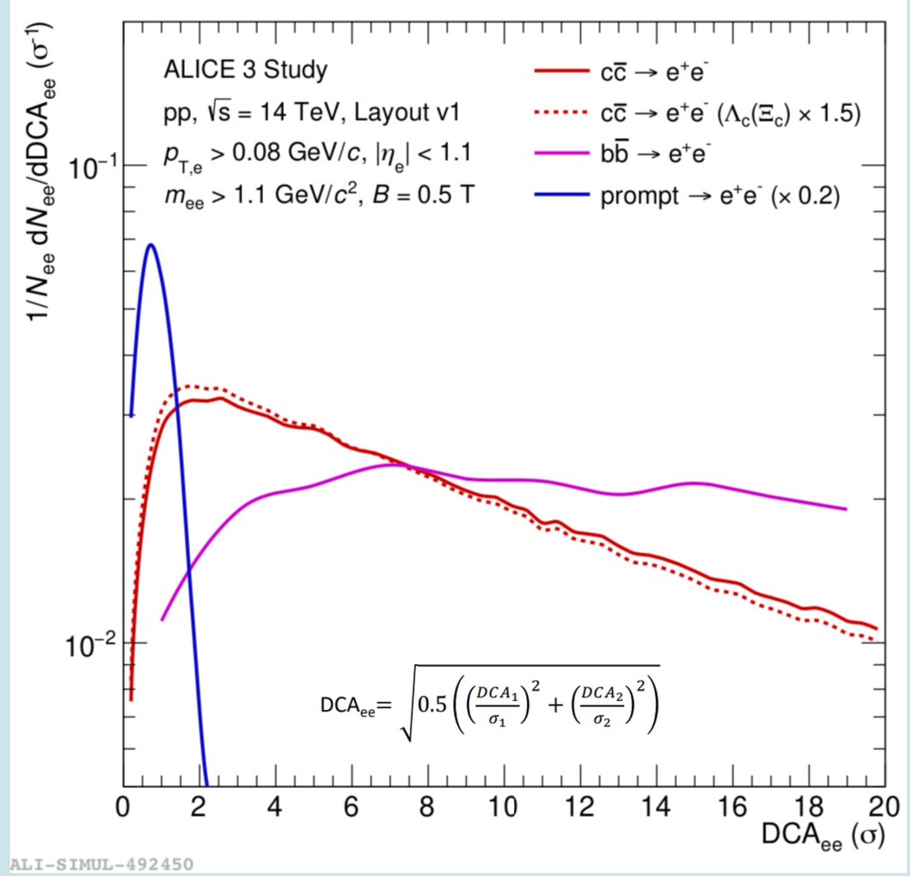
- Performance evaluation of dielectron is in progress
  - Rejection of 94% ccbar with keeping 73% of prompt pairs (17% with ALICE 2)

Pair DCA



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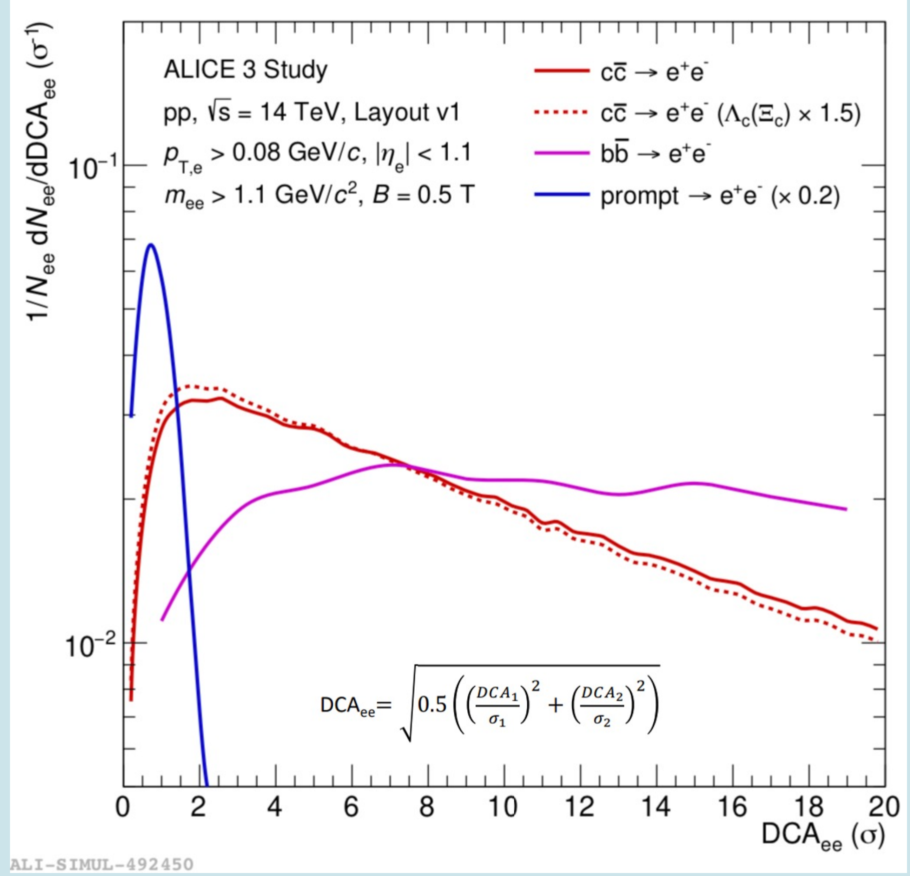

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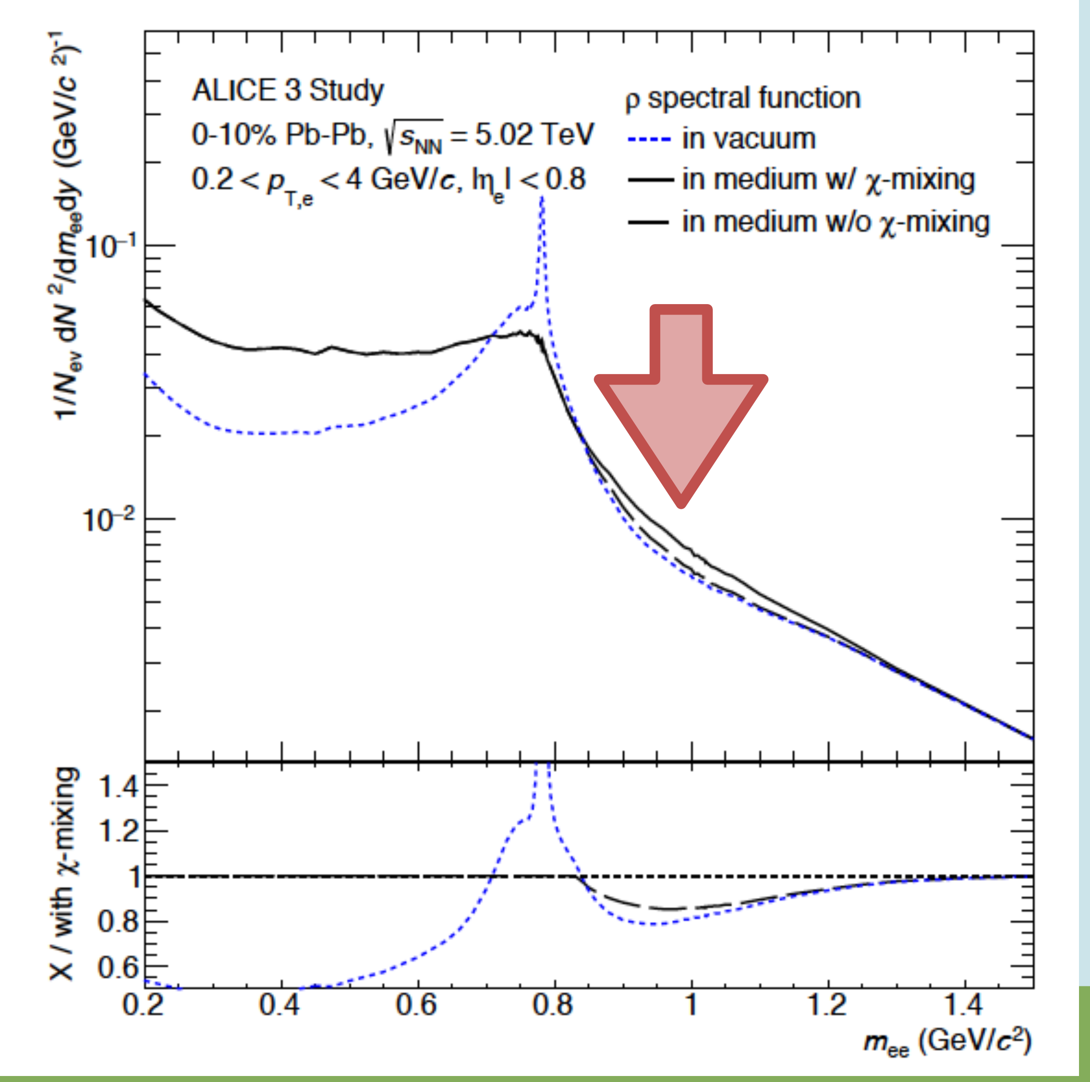
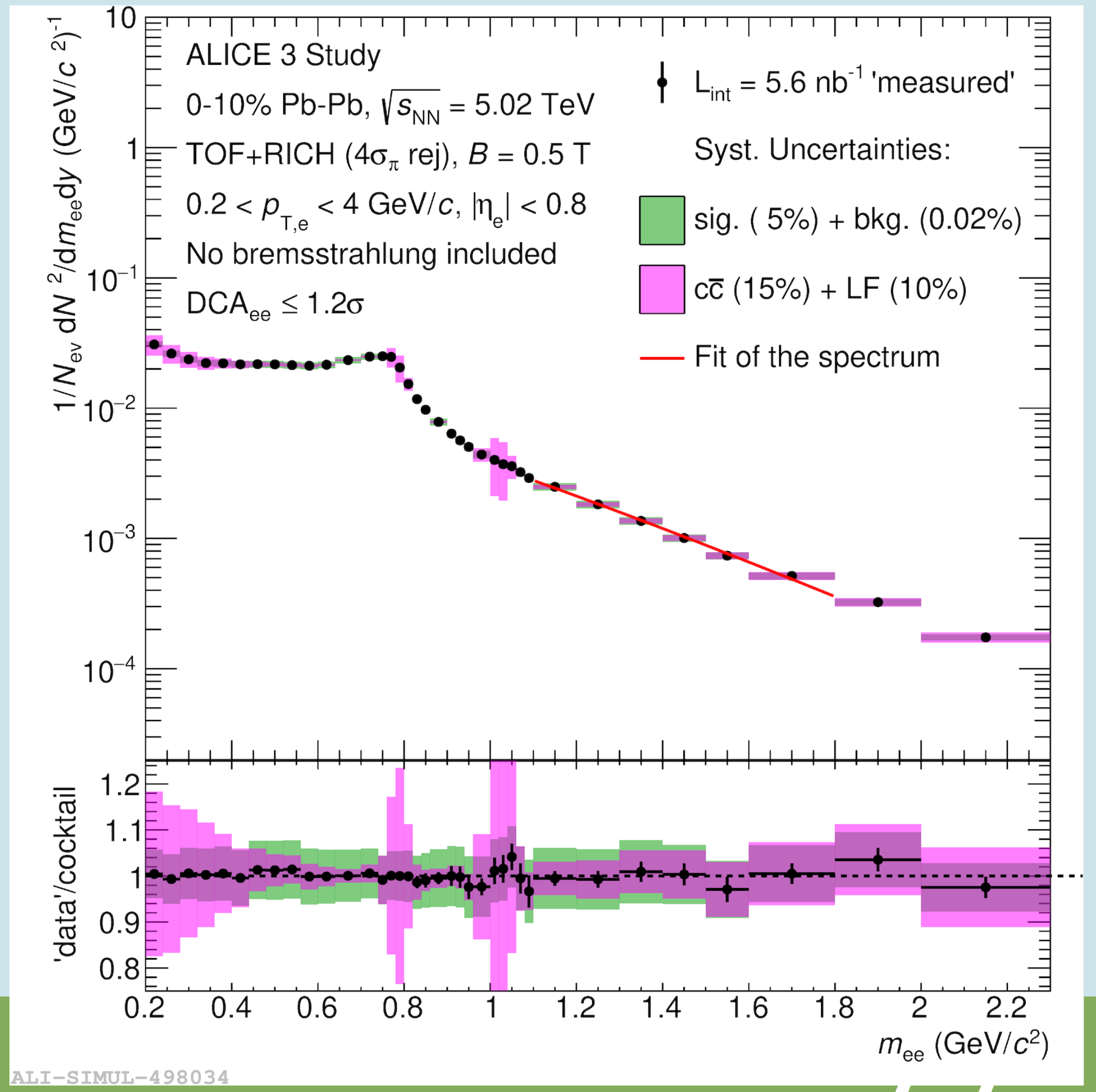


Expected excess



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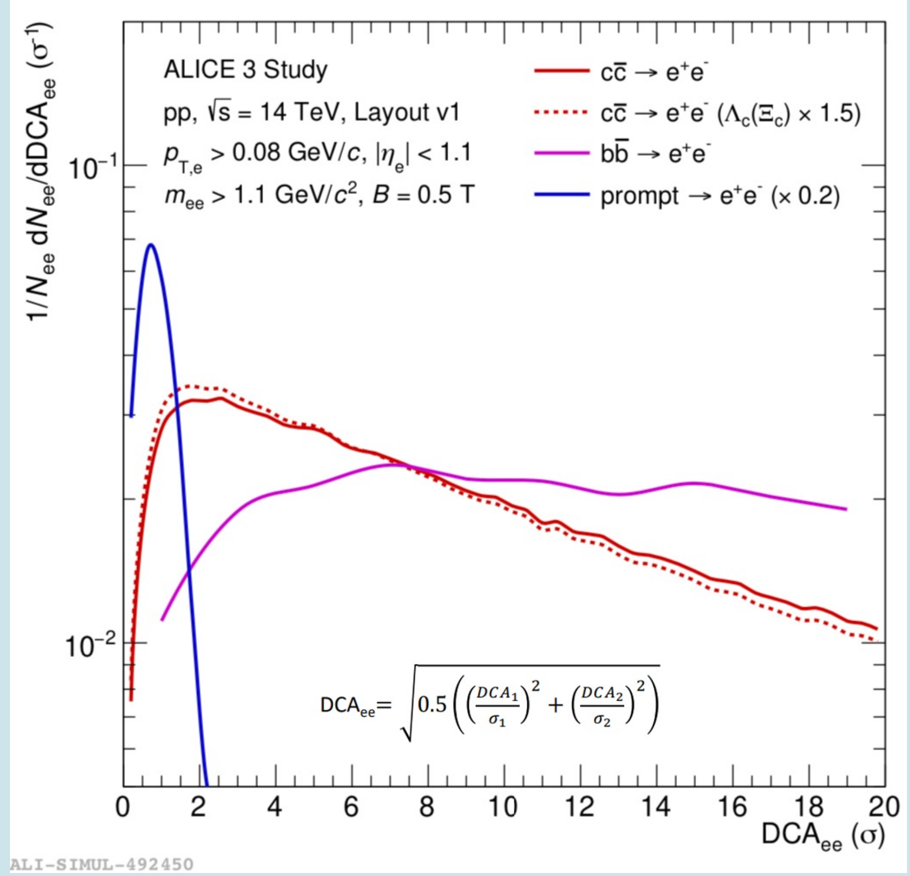
  - Able to measure with > 10% uncertainty in the mass region where 20% enhancement is expected due to chiral mixing (ideal detector performance)
- No dimuon performance expectation yet
  - Rejection of huge combinatorics
  - Expect better DCA resolution than dielectron
  - No evaluation of dimuon measurement

Pair DCA



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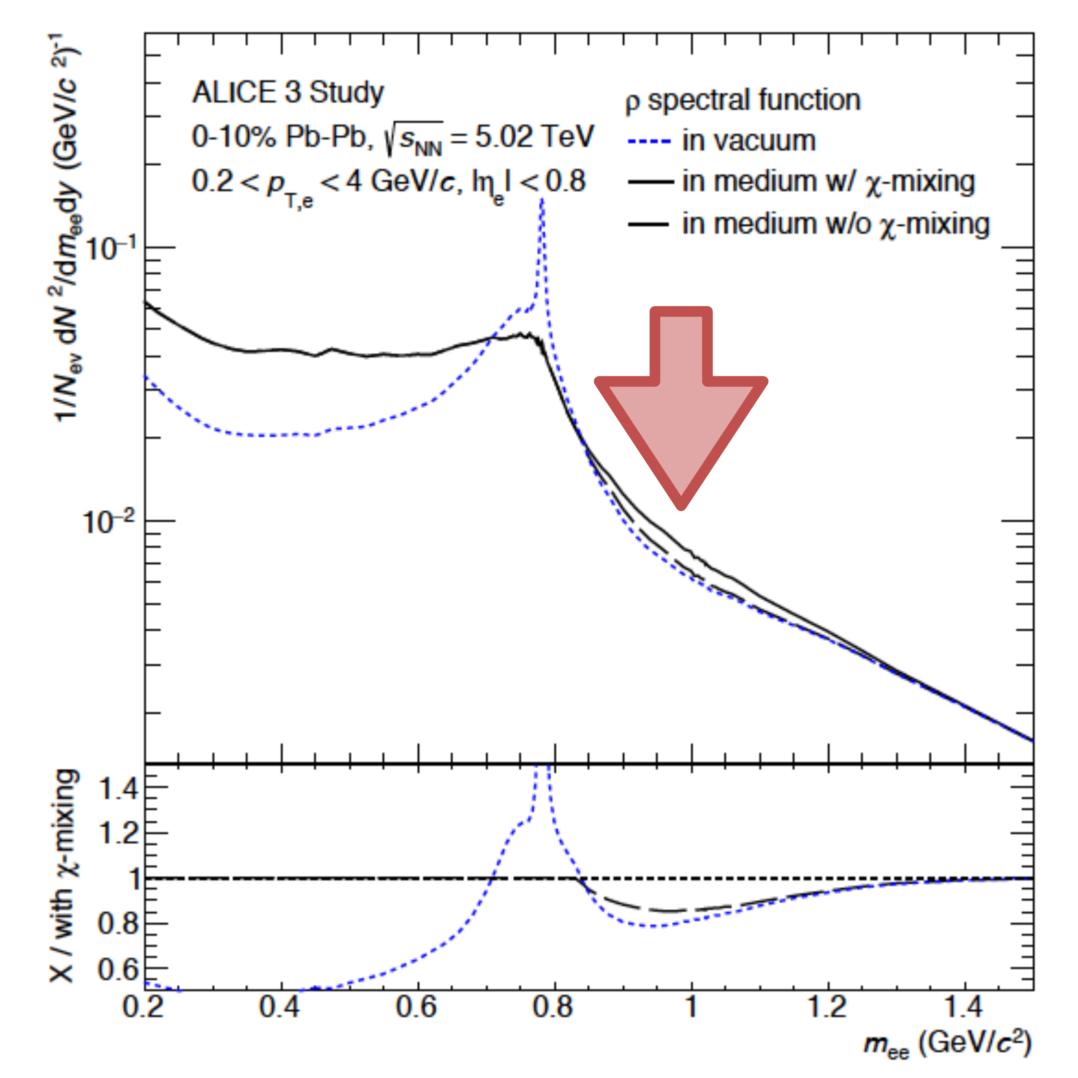

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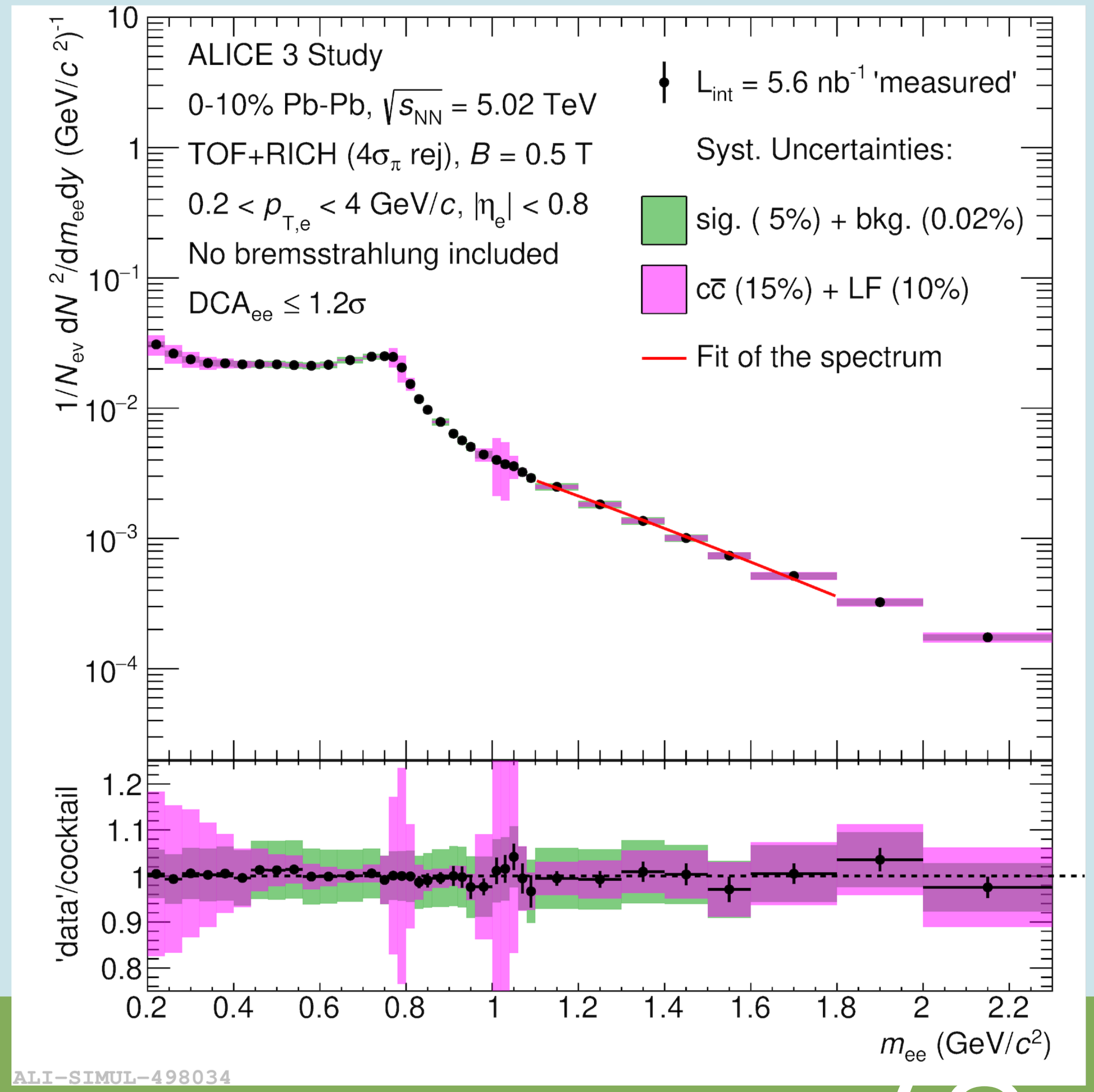

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- LMRとIMRのレプトン対測定がSPS、RHIC、LHCで長年行われてきた
  - 多くの実験がLMRの質量分布の変化を捉えた
  - 低エネルギー実験では、IMRの分布を用いて衝突初期の温度を測定した
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  - 初期温度測定、LMRの質量変化の原因解明、カイラルミキシングの信号を検出には、より多くの統計、コンビナトリアルバックグランドの削除、HFレプトンの削除が課題である

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  - 高性能なVertex検出器を開発（しかし、これは限界に近づいている）
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- 多くの次世代実験において、LMRとIMRのレプトン対測定のパフォーマンスを見積もった研究が乏しい
  - 電子を使った測定は限界がちかい。
  - ミューオン測定はまだまだ成熟していない。改善の余地あり。LMR、IMRレプトン対測定において、衝突点前方ミューオンには無限の可能性が広がっている。


Muon identifier
Dipole magnet
RICH
EMC
Vacuum
Tracker
RICH
Vertex detector