UNIVERSITÀ
DI TORINO

INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

CGEM software review

Stefano Spataro for the CGEM software & analysis groups

BESIII Italia – Ferrara – 06/11/2023

The first match

Friday, 3rd November 2023

https://indico.ihep.ac.cn/event/20839/

8:30 AM → 8:40 AM	**Introduction to the review process** Speaker: Wolfgang Gradl (Institute of Nuclear Physics, Johannes-Gutenberg University Mainz) cgem-review-kickof...	10m
8:40 AM → 9:00 AM	**Overview and status of the CGEM project** Speaker: Gianluigi Cibinetto (INFN Sezione di Ferrara) 20231103_CGEM_i...	20m
9:00 AM → 9:15 AM	**General overview of the CGEM software** Speaker: Liang-Liang Wang (Institute of High Energy Physics (Beijing)) 20231103_CGEM-IT...	15m
9:15 AM → 9:35 AM	**Simulation of the CGEM geometry** Speaker: Isabella Garzia (高能所) 20231103_CGEMIT-...	20m
9:35 AM → 10:00 AM	**Digitization and tuning of the CGEM-IT** Speaker: Linghui Wu (IHEP) CgemDigitizationAn...	25m
10:00 AM → 10:15 AM	**Break**	15m
10:15 AM → 10:40 AM	**Offline track reconstruction** Speaker: Liang-Liang Wang (Institute of High Energy Physics (Beijing)) 20231103_CGEM_O...	25m
10:40 AM → 11:10 AM	**Impact of the CGEM-IT on benchmark physics channels** Speaker: Stefano Spataro (Università di Torino and INFN) 20231103 - CGEMR...	30m
11:10 AM → 11:30 AM	**Plans for detector calibration** Speaker: Riccardo Farinelli (INFN Sezione di Ferrara) 20231103_Calibrati...	20m
11:30 AM → 11:50 AM	**CGEM-IT track-based offline alignment** Speaker: Aiqiang GUO (Institute of modern physics, Chinese Academy of Sciences) BESIII_Cgem_Align...	20m
11:50 AM → 12:10 PM	**Discussion and final remarks**	20m

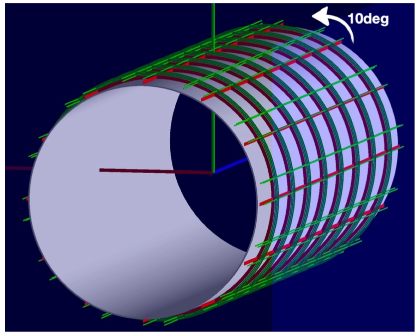
The Basic Concept

Offline software (p)review

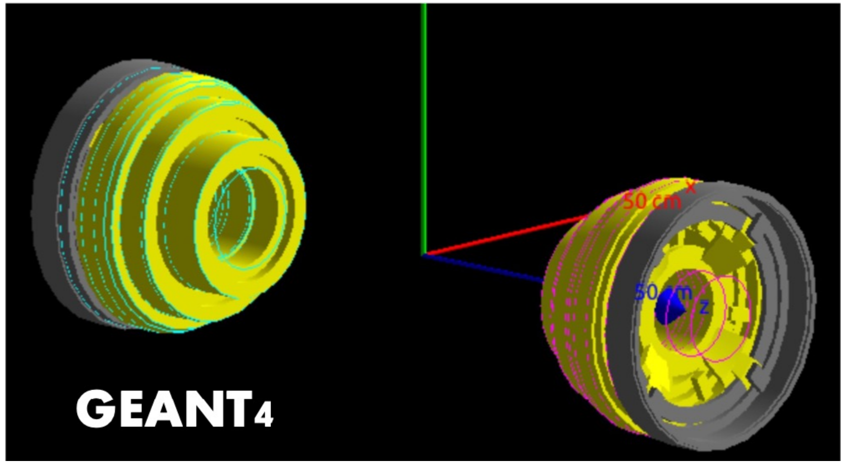
Geometry	Implementation of the definitive design of the complete CGEM detector Estimation of the radiation length, and of possible effects on the EMC
Digitization	Complete description of the MC signal modelling, from ionization to the electronics readout response Comparison of simulation with real data from 2-layer cosmics data (run 17)
Global Tracking	Complete reconstruction of charged tracks using outer MDCs and CGEM Characterization of tracking performances (resolution, efficiency) with particle gun, comparison with standard MDC
Analysis of benchmark channels	Performance (reconstruction efficiency, invariant mass resolution, vertex resolution) compared to standard MDC tracking

- → phase space events with n-prong pions
- → low multiplicity events (such as $e^+e^- \rightarrow p\bar{p}$)
- → standard charmonium decays $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$
- → higher multiplicity events (i.e. over DD threshold)
- → hyperon production (to study displaced vertices)

Geometry

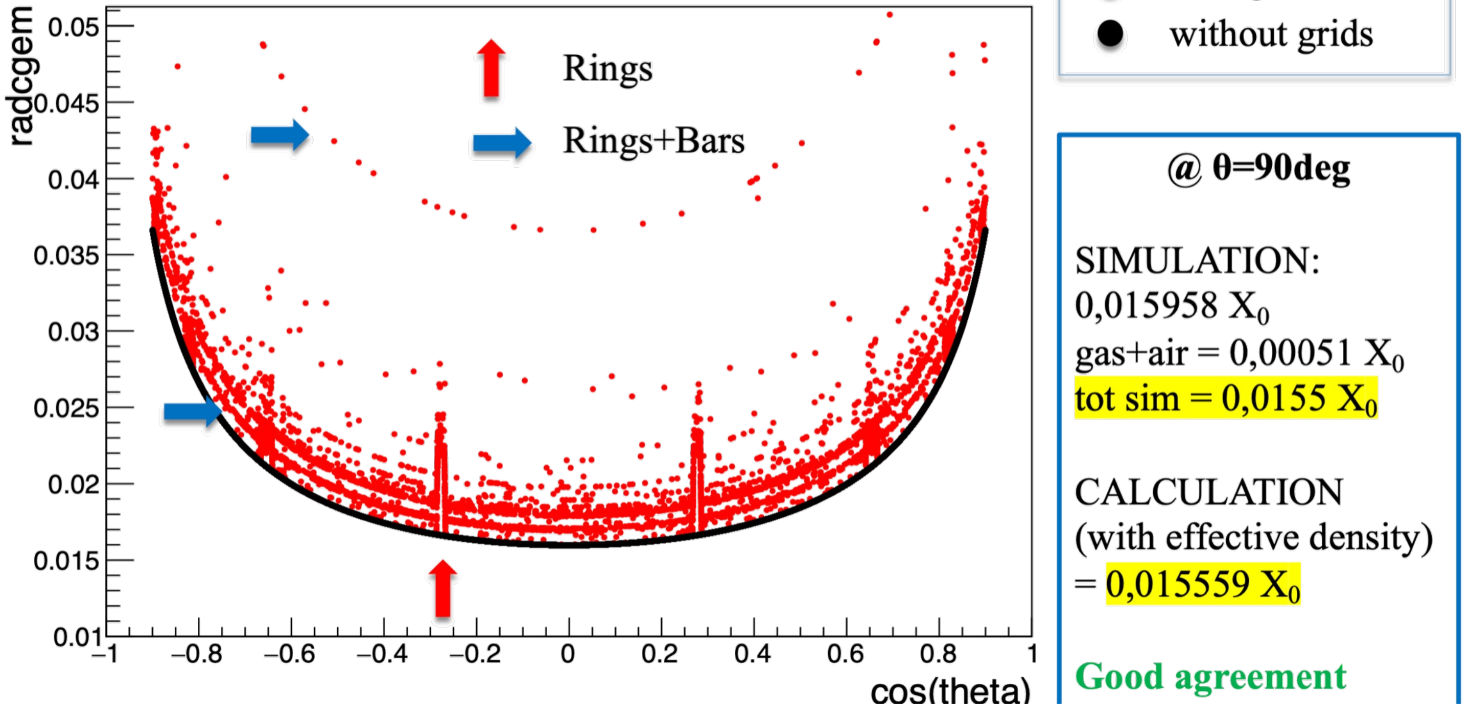


Task completed



Comparison between calculation and simulation

- without holes and strips simulation

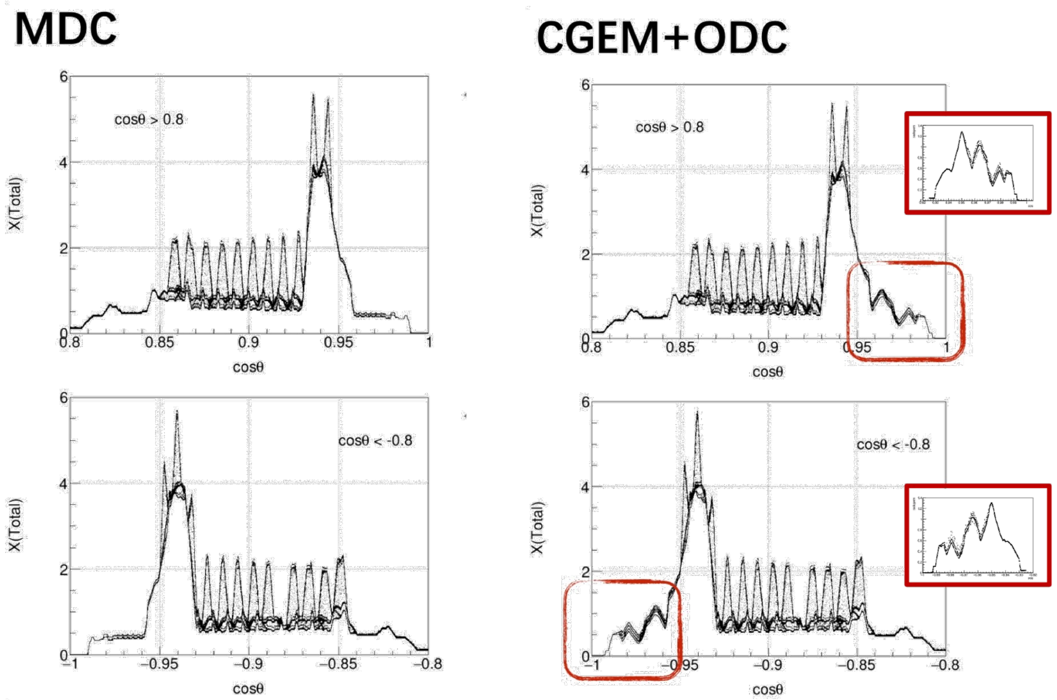


@ θ=90deg

SIMULATION:
0,015958 X_0
gas+air = 0,00051 X_0
tot sim = 0,0155 X_0

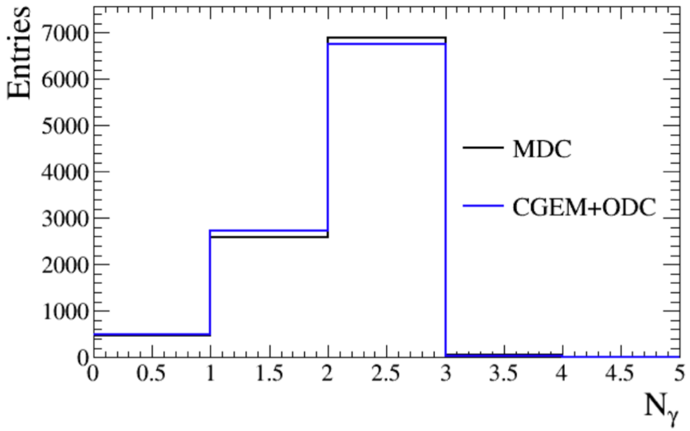
CALCULATION
(with effective density)
= 0,015559 X_0

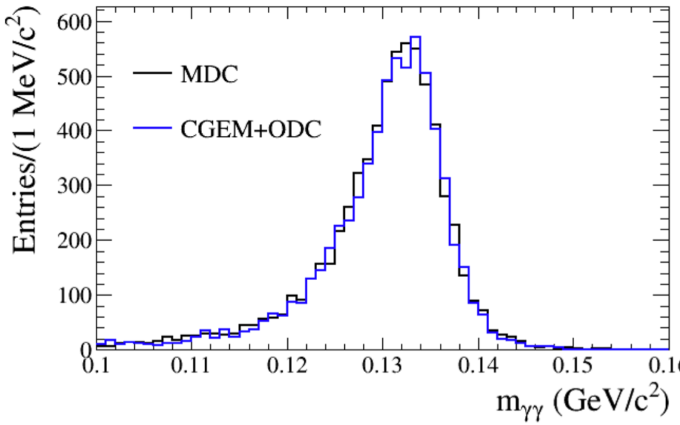
Good agreement



Geometry

Simulated sample: $\pi^0(\rightarrow\gamma\gamma)$ with momentum 0-1 GeV/c, cosθ in (-1,1)

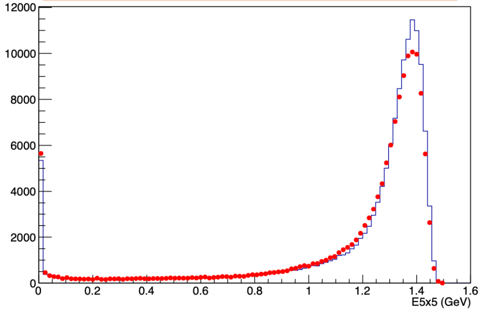


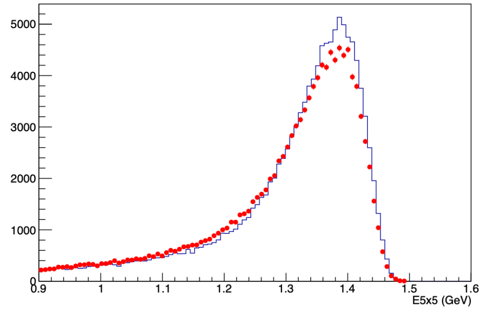


Good photon selection:
Barrel (|cosθ|<0.8), E_γ>25 MeV
Endcaps (0.84<|cosθ|<0.92), E_γ>50 MeV

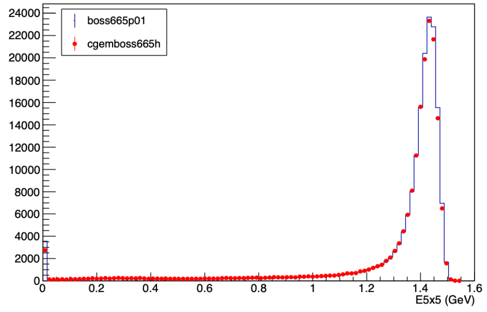
$N_{\pi 0}$(CGEM+ODC)/$N_{\pi 0}$(MDC)–1=(–2.30 +/– 0.98)%
Mass resolution comparable

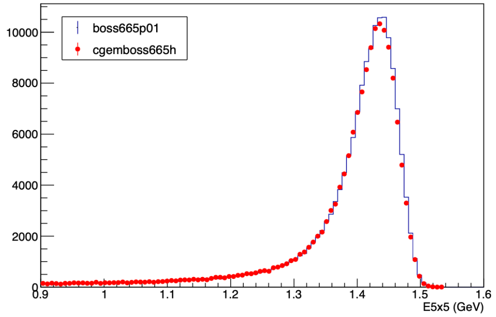
EMC Endcaps: 0.85<|cosθ|<0.93





EMC BARREL: |cosθ|<0.83



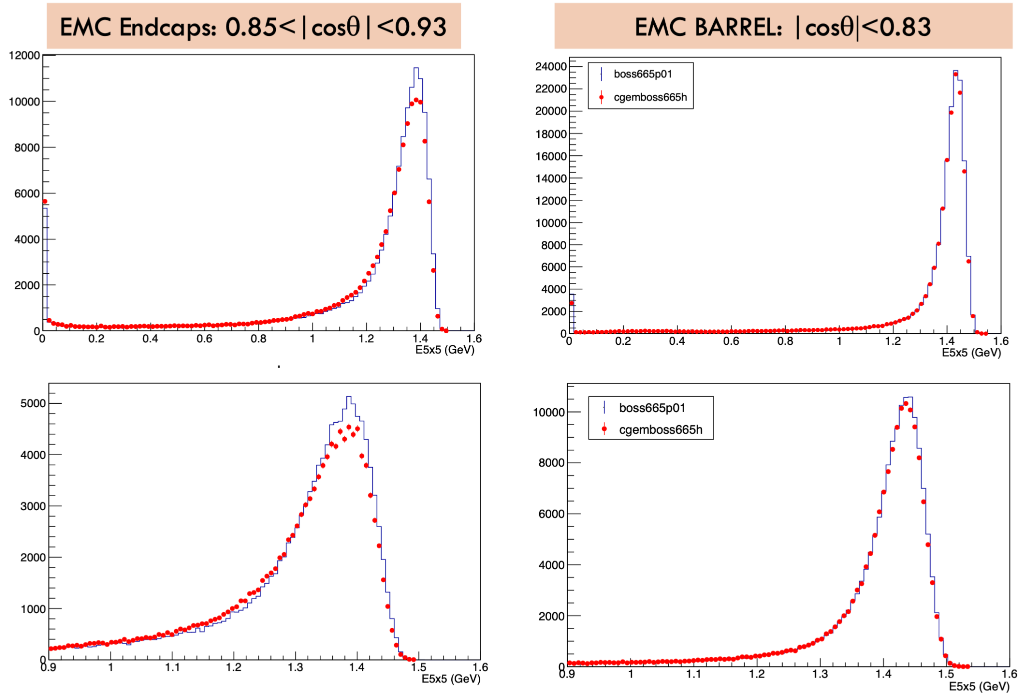


Substantially no effects on EMC

Geometry: questions, remarks…

Is EMC recalibrated for CGEM design?

NO, and we (CGEM) cannot do it, we expect with new calibration better agreement



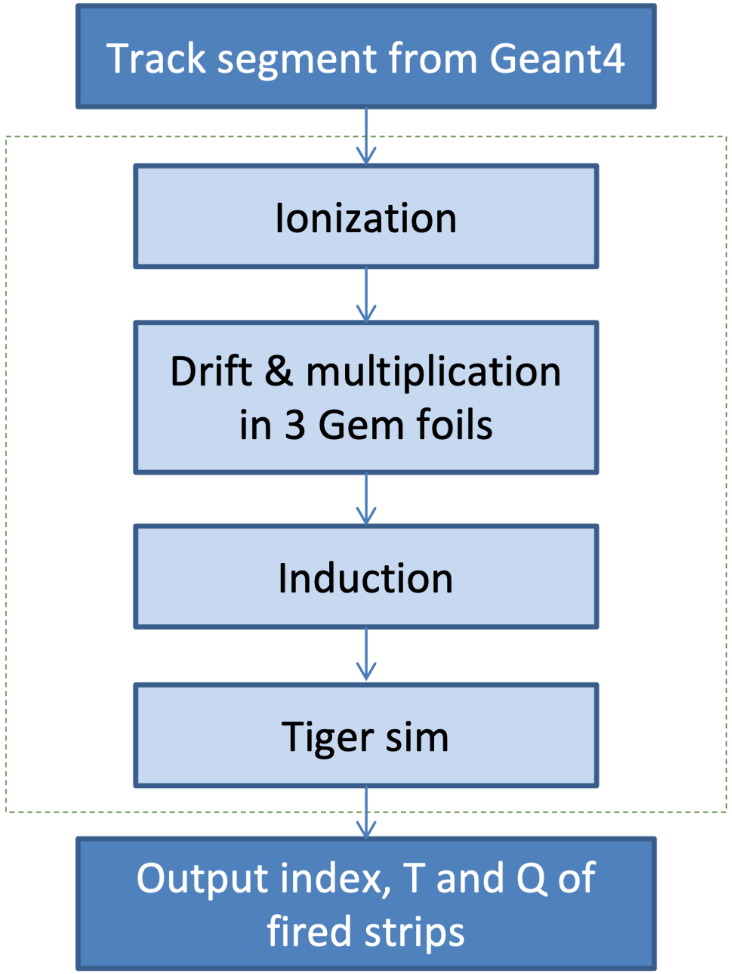
How much CPU time?

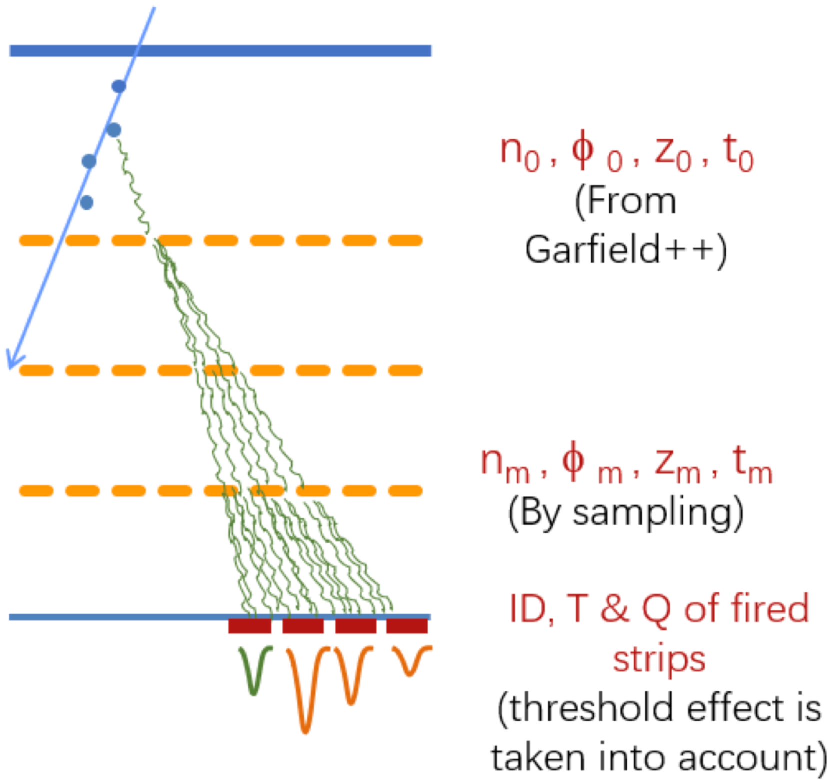
We need to measure it, anyway not so much

Comparison with MDC radiation length

A waste of time, but fine…

Digitization

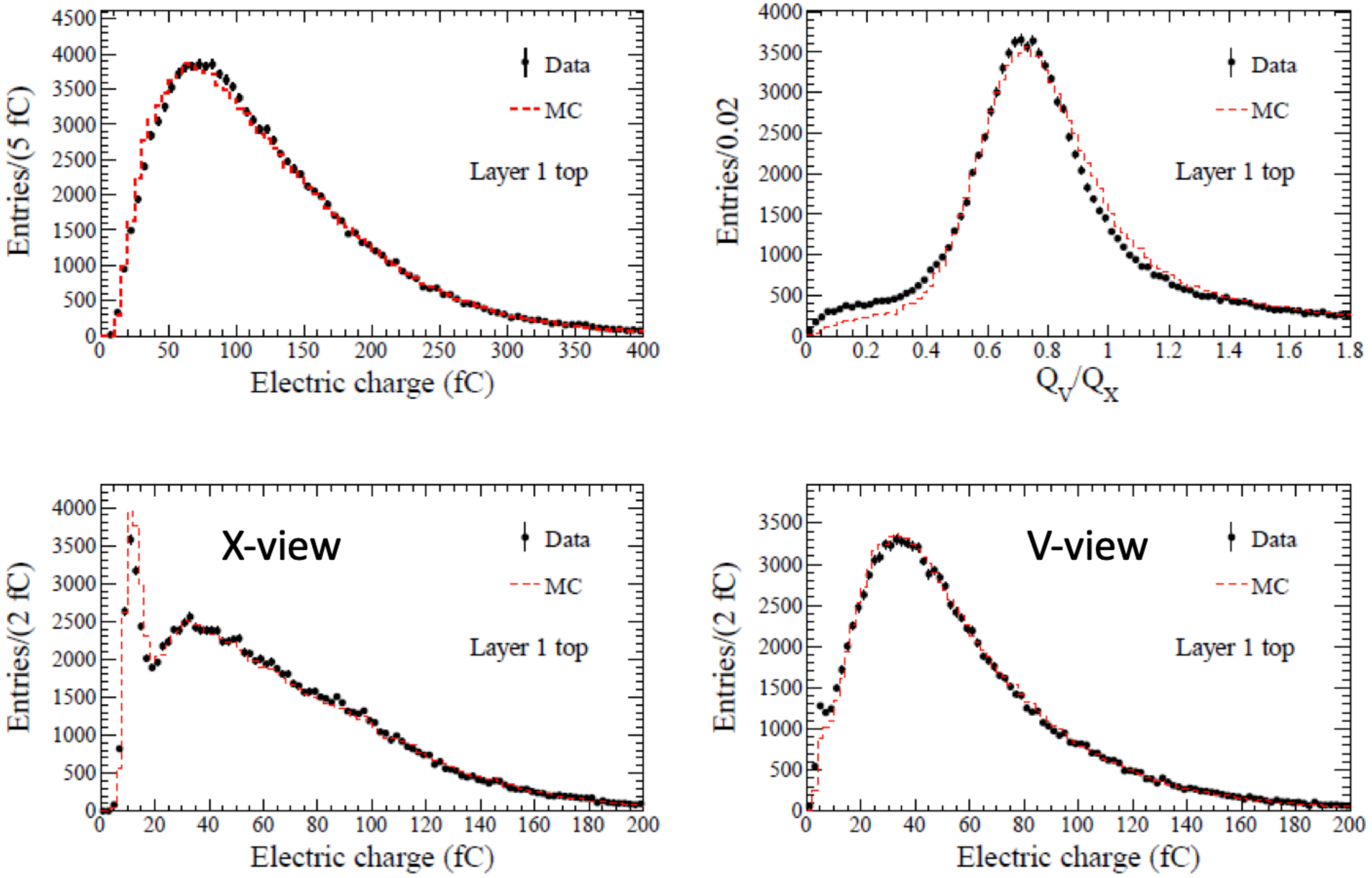




- A service package (CgemDigitizerSvc) has been developed to implement the digitization of CGEM-IT in CgemBoss
- Paper published: Radiation Detection Technology and Methods (2020) 4:174–181

Digitization

- Consistency between data and MC is good after tuning



Paper published: JINST 18 P05027

Digitization: questions, remarks

What about TIGER noise?

Not yet implemented

On silicon negligible (< 0.5 fC), on strips… ?

I believe we should provide an answer

Anyway, the tuning includes the shaping of the noise, then it should not affect the final results

We should include also noisy hits as random signals according to noise rate

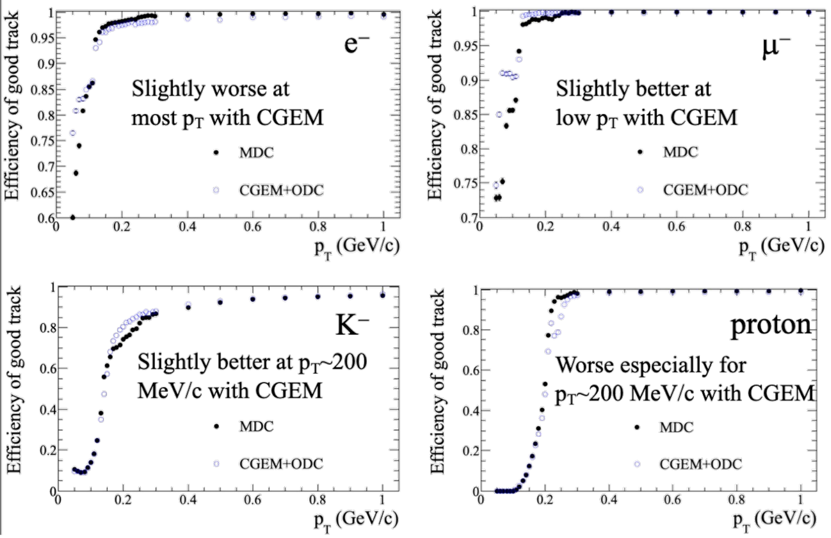
Dummy questions about gain and Garfield…

Not worth to mention

Tracking

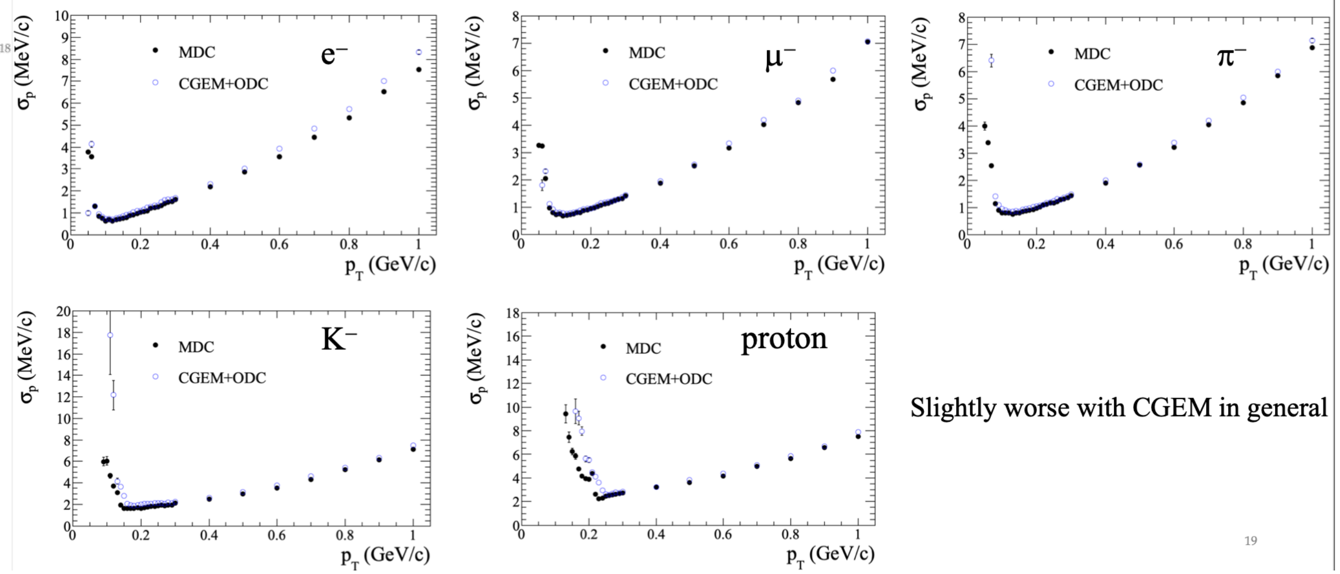
Efficiency of good track

- Global tracking with **Hough Transform** for CGEM+ODC
- Default tracking for MDC (PAT + TSF etc.)
- Good track: V_{xy}<1 cm, $|V_z|$<10 cm, $|\cos\theta|$<0.93, correct charge



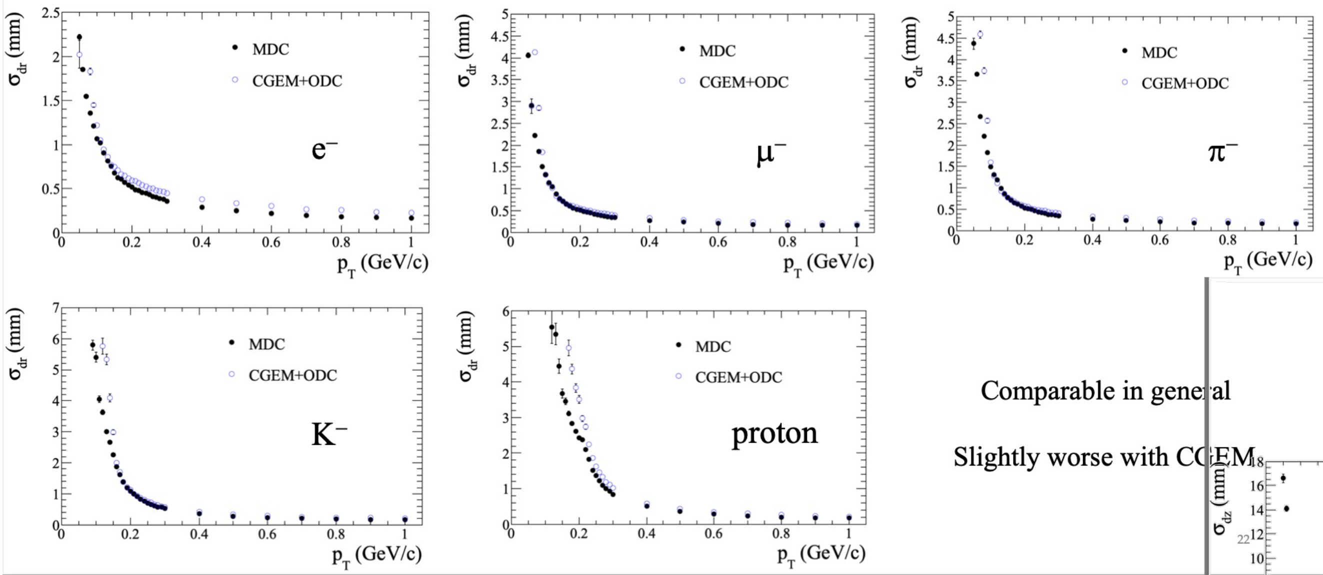
- Particle type and momentum dependent
- Worse for low p_T proton a expected
- Comparable in most p_T

Momentum resolution after Kalman Filter



Slightly worse with CGEM in general

Closest approach resolution in transverse plane after Kalman Filter



Comparable in general

Slightly worse with CGEM

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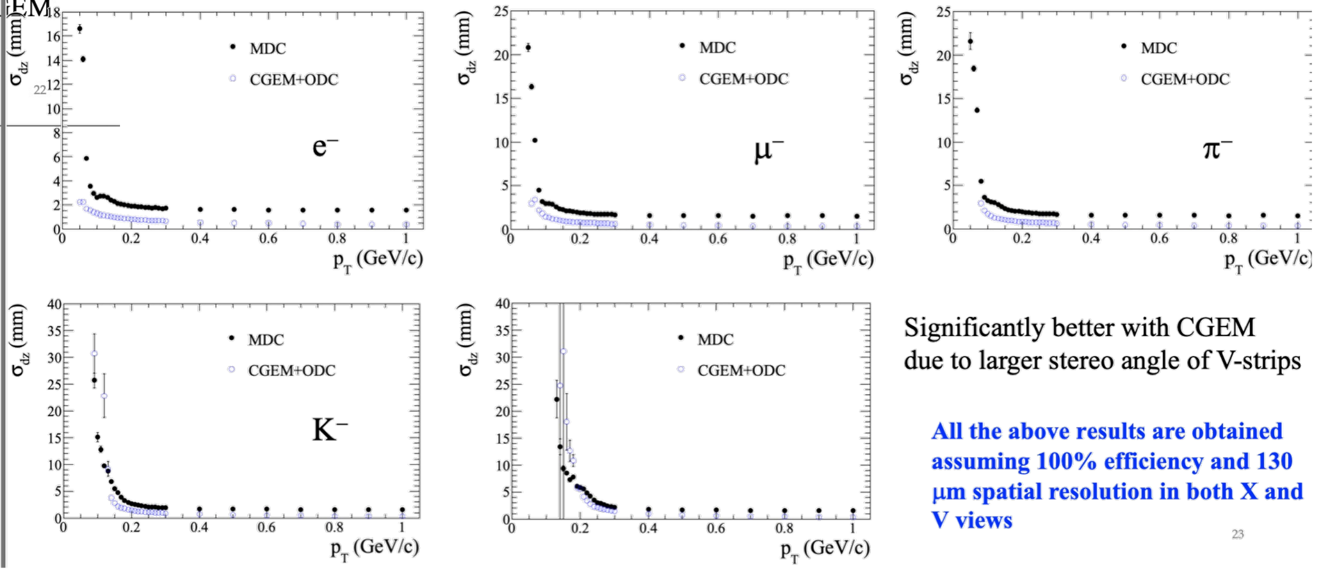
Closest approach resolution in z after Kalman Filter



Significantly better with CGEM due to larger stereo angle of V-strips

All the above results are obtained assuming 100% efficiency and 130 μm spatial resolution in both X and V views

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Tracking: questions, remarks…

Evaluate ghost tracks, clones

Not for single tracks, but for multi-track events

Check effect of nonhomogeneous materials, fixed low pt, efficiency vs theta

Estimate the effect of noise

We have the tools, it was done in the past but no real problematics, it will be redone

Effects of real efficiency and resolution

After cosmics performance studies

Performances

Phase space events with 2-, 4- and 6-prong pions → Extension of single particle studies

$e^+e^- \to p\bar{p}$ @ J/ψ → 2 tracks, high energy loss

$e^+e^- \to \psi(2S) \to J/\psi\pi^+\pi^-, J/\psi \to \mu^+\mu^-$ → 4 tracks, low and high p_T

$e^+e^- \to \psi(2S)\pi^+\pi^-, \psi(2S) \to J/\psi\pi^+\pi^-$ @ 4.612-4.946 GeV → 6 tracks, low and high p_T

$e^+e^- \to h_c(2P)\pi^+\pi^-, h_c(2P) \to DD^*$ → 8 tracks, very low p_T

$e^+e^- \to \Lambda\bar{\Lambda}$ @ $\psi(2S)$ → displaced vertices

The following variables will be studied and compared ⇒

- reconstruction efficiency
- invariant mass resolution
- vertex resolution

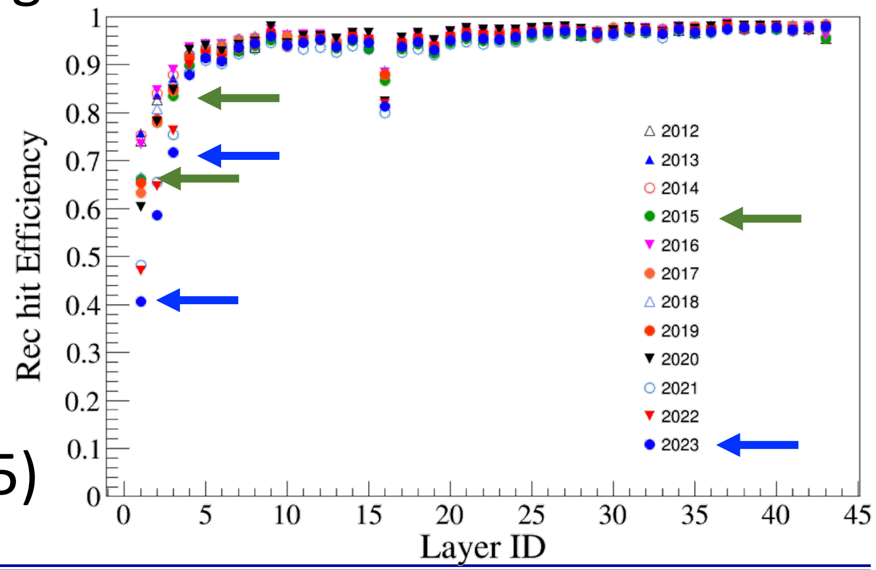
The Software

CgemBoss665h for CGEM+ODC simulations

- Definitive CGEM geometry
- Toy MC clusters
  (ε=100% and σ=130μm per view)
- Realistic Global Tracking
  - ✓ Hough Transform from ~2020
  - ✓ Local track finding under development (not used here)
- NO Background

BOSS665p01 for MDC simulations

- Full MDC geometry
- Realistic Reconstruction
  - ✓ PAT + TSF + etc…
  - ✓ many years of tracking improvements
- NO Background



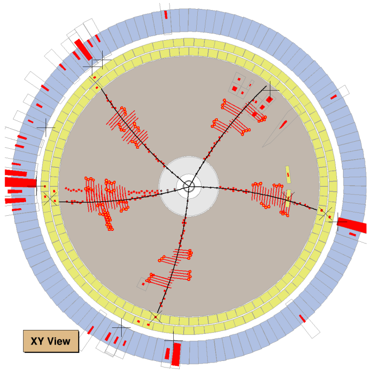
run number 43253 (2015) - Y(2175)

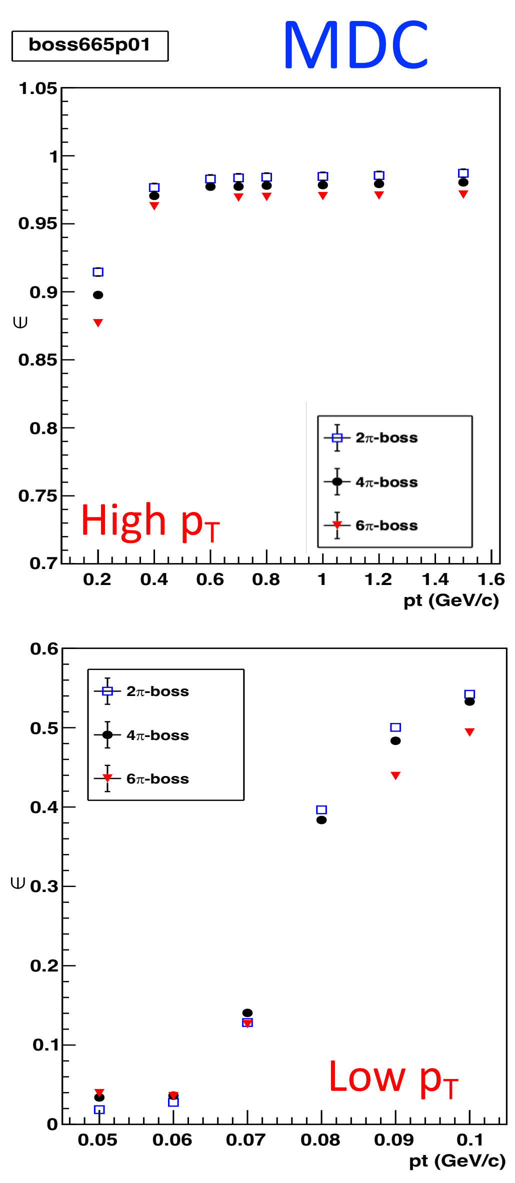
Particle Gun With High Track Multiplicity

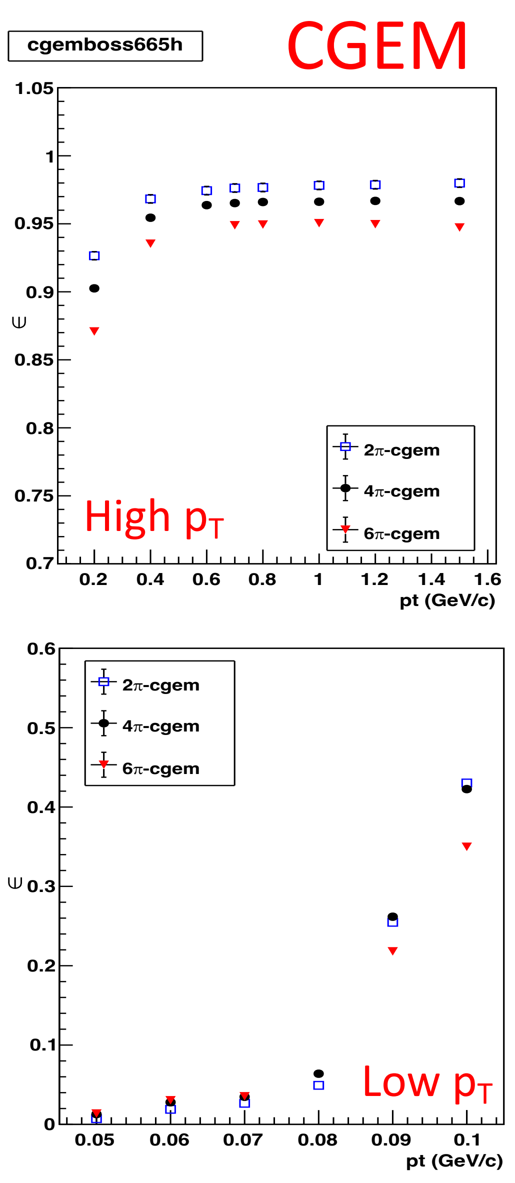
Goal → check how the performances vary increasing the number of particles in the event

Generator

- π^- particle gun
- 2, 4, 6 particles per event
- Uniform $|\cos\theta|<0.93$
- Uniform φ
- Fixed p_T [0,05 - 1,5] GeV/c

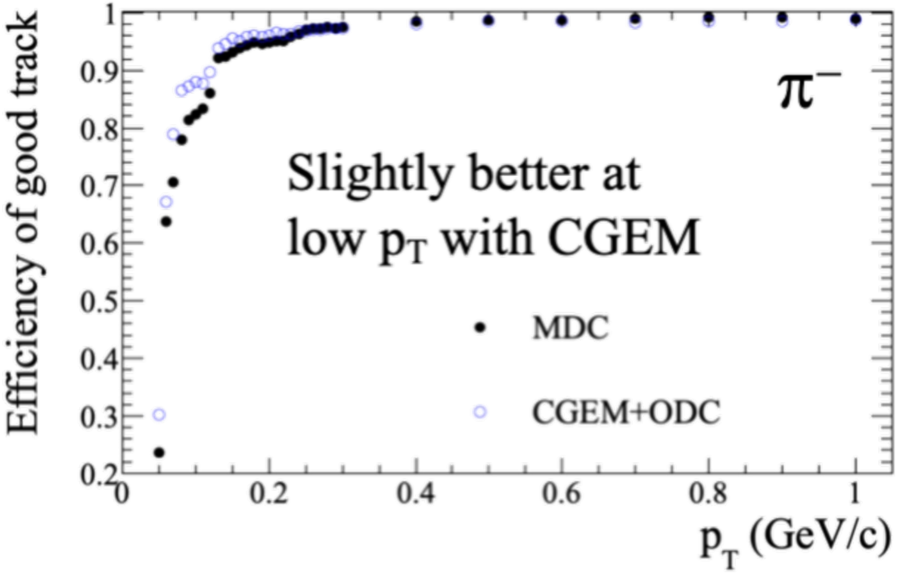






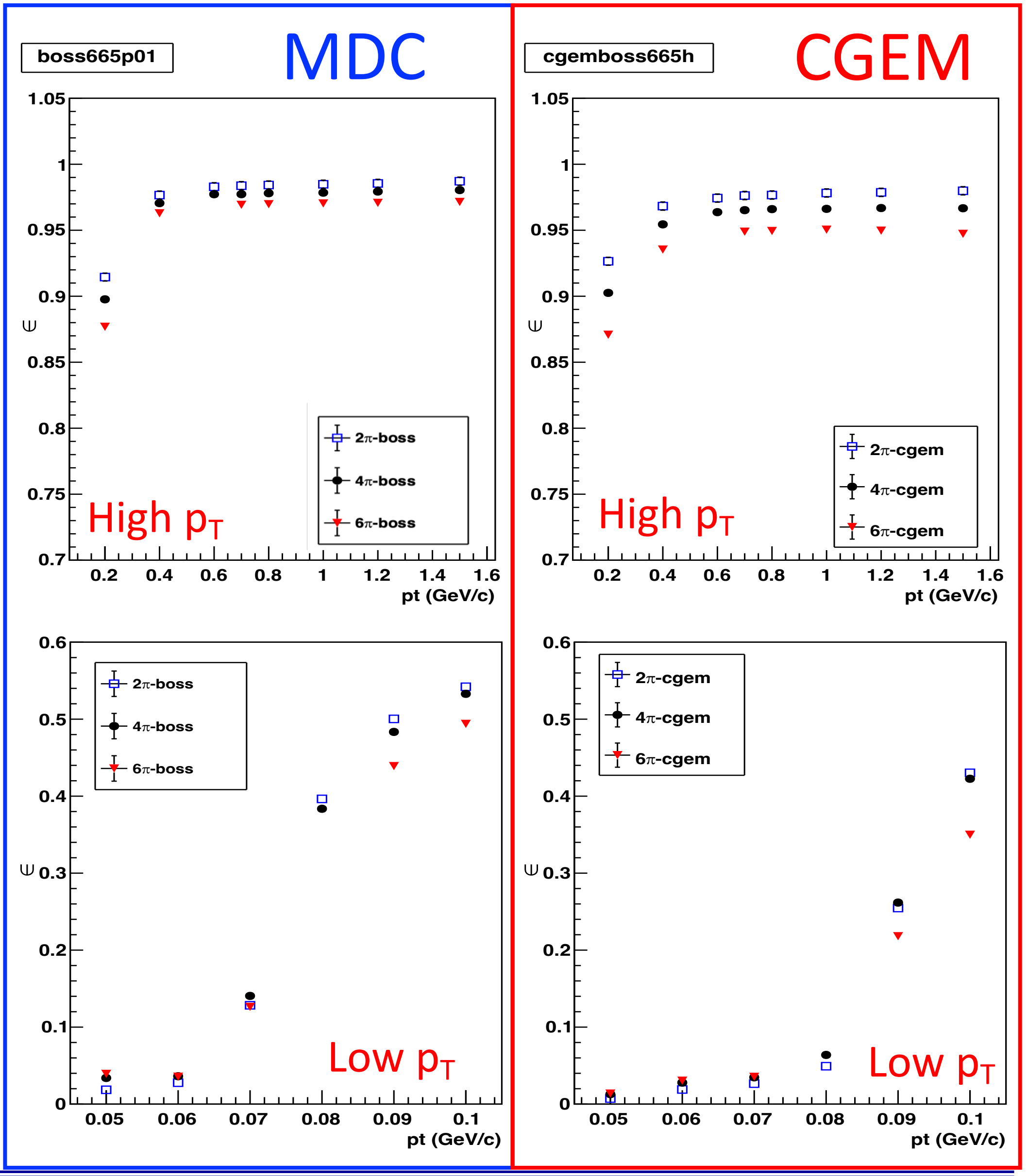
- By increasing the number of tracks, the single-track efficiency decreases for both MDC and CGEM
- The CGEM efficiency decreases more

Particle Gun With High Track Multiplicity



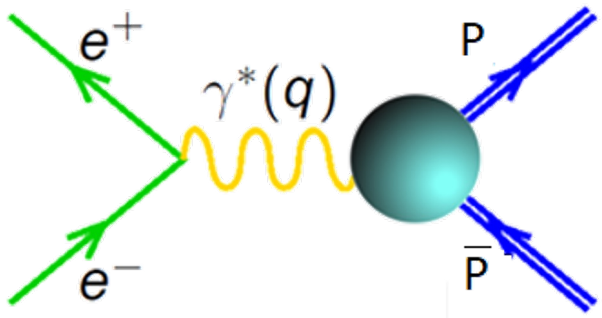
Not in agreement with single track studies for low pt

It has to be better understood



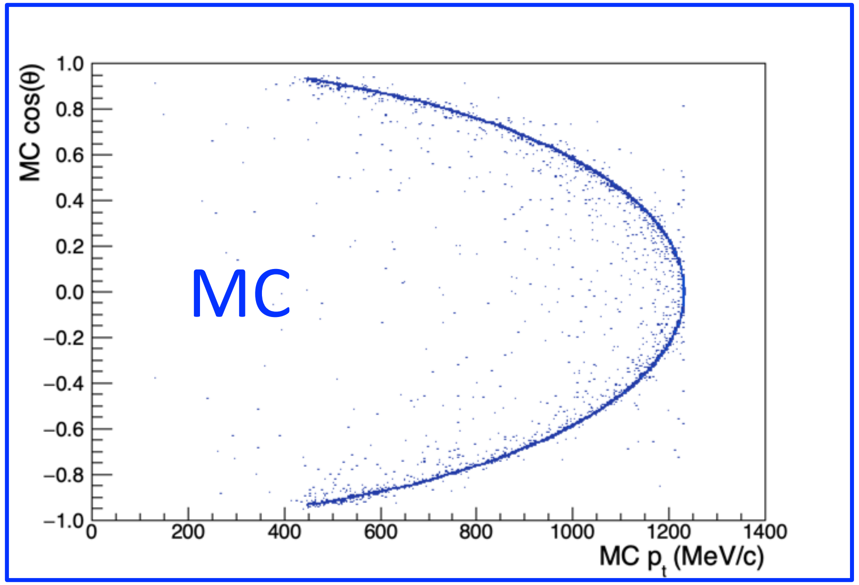
$e^+e^- \to p\bar{p}$ (γ)

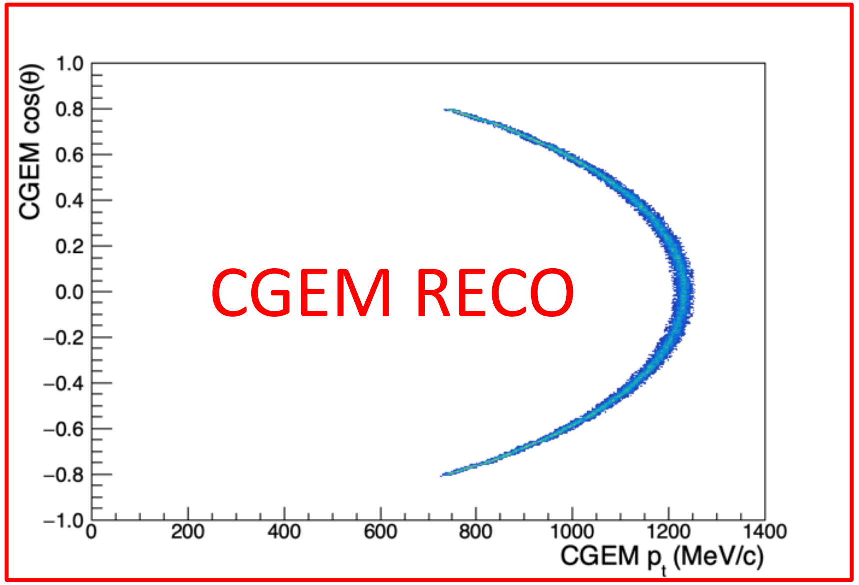
- Generator: KKMC + EVTGEN



Simple topology

- Two high momentum tracks
- Back-to-back

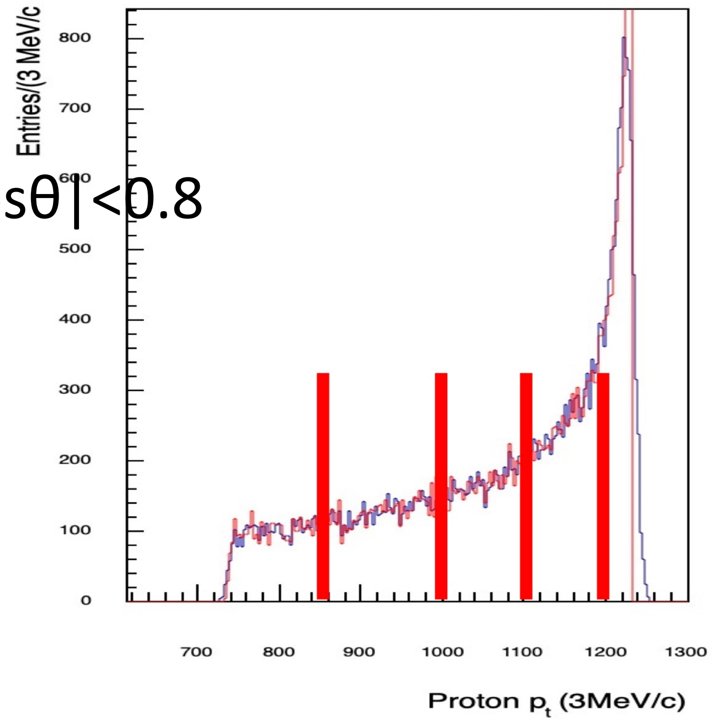


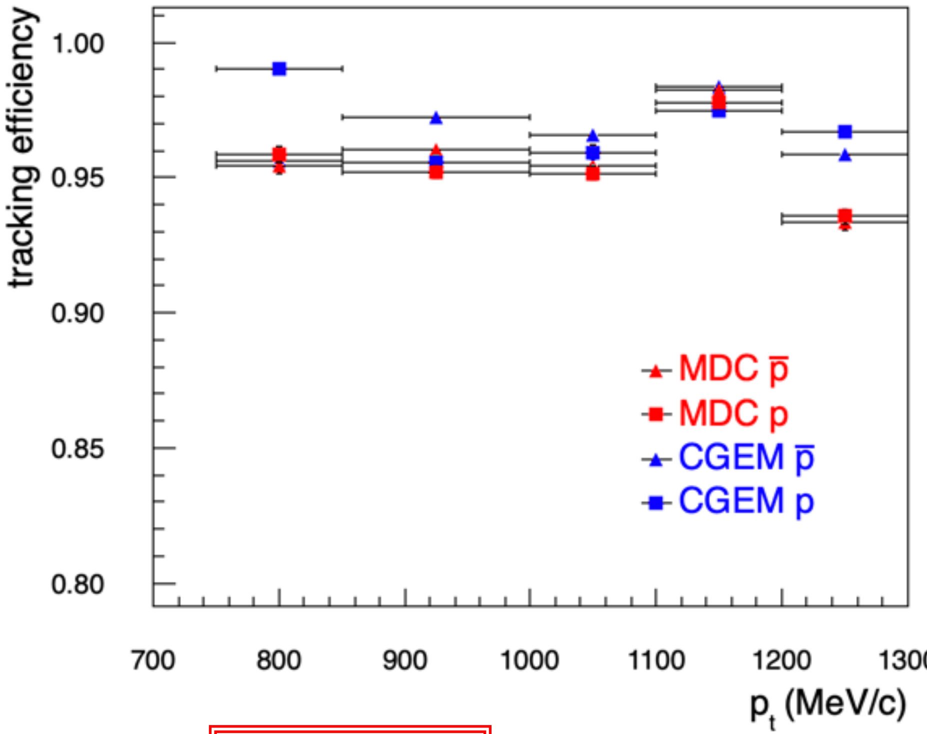


$e^+e^- \to p\bar{p}$ @ J/ψ

Selections

- R_{XY} < 1cm, R_Z < 10 cm, |cosθ|<0.8
- Opening angle > 178°
- E/p < 0.5





	GOOD	theta	vtxok	opening	E/p (p)	P range (3σ)	pid	TOT EFF
CGEMBOSS	43958	36686	35030	33935	33903	32397		(64.8+-0.2)%
BOSS	42455	35259	34645	33639	33611	32489		(65.0+-0.2)%

Comparable reconstruction efficiency

Francesca De Mori

$e^+e^- \rightarrow \psi(2S) \rightarrow J/\psi\pi^+\pi^-$

$e^+e^- \rightarrow \psi(2S) \rightarrow J/\psi\pi^+\pi^-, J/\psi \rightarrow \mu^+\mu^-$

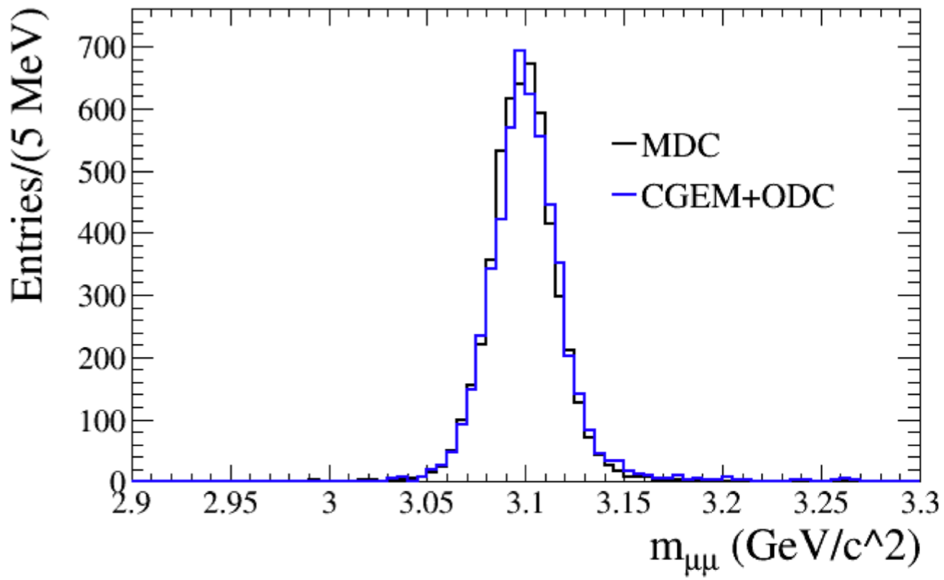
- Four particles: 2 low momentum, 2 high momentum

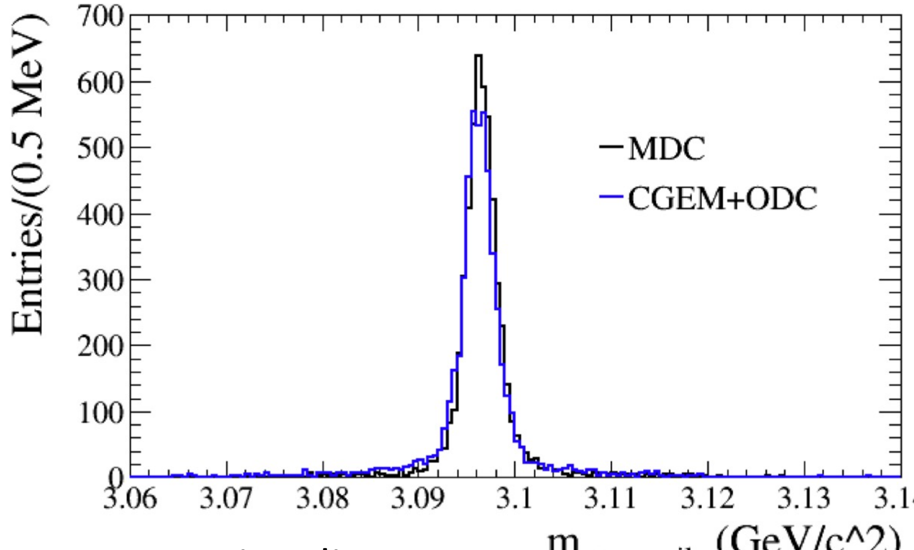
Selections

- R_{XY} < 1 cm, R_Z < 10 cm, |cosθ|<0.93
- PID – π: p < 0.8 GeV/c, μ: p > 0.8 GeV/c
- Loose J/ψ mass cuts
- 4C Kinematic fit χ^2<60

	MDC	CGEM+ODC
Efficiency	52.5% (PAT+TSF etc.)	44.1% (Hough Transform)

- Comparable mass resolution
- Lower CGEM reconstruction efficiency



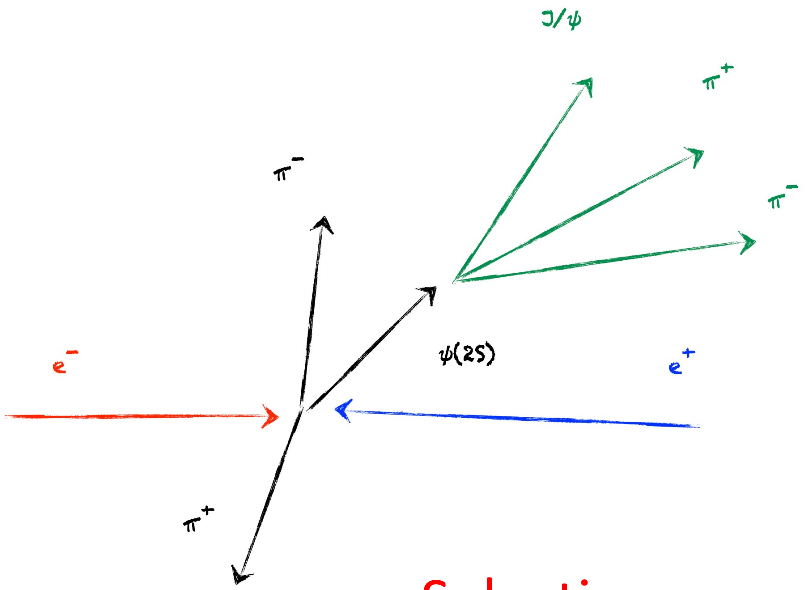


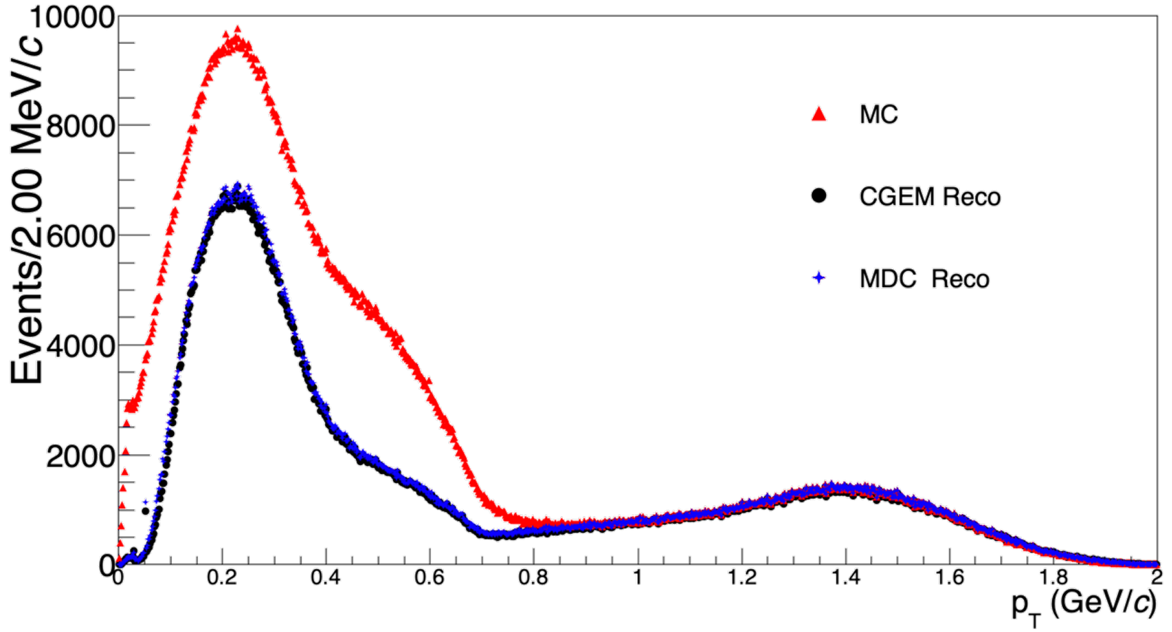
Liangliang Wang

$e^+e^- \to \psi(2S)\pi^+\pi^-$

$e^+e^- \to \psi(2S)\pi^+\pi^-, \psi(2S) \to J/\psi\pi^+\pi^-$ @ 4.612-4.946 GeV

- Six particles, low and high momenta





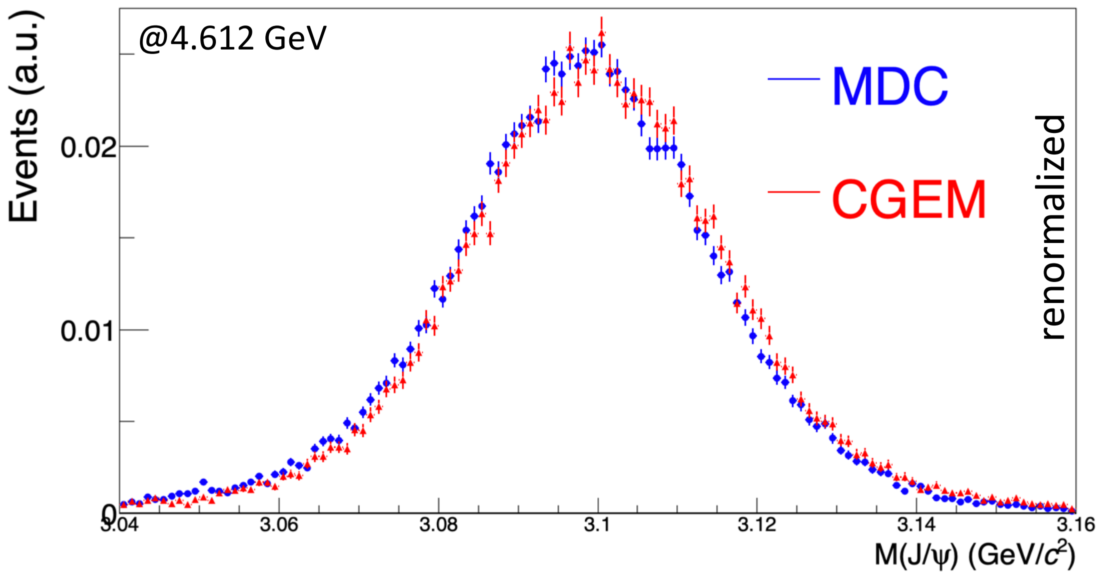
Selections

- $R_{XY} < 1$ cm, $R_Z < 10$ cm, $|\cos\theta| < 0.93$
- PID – π: p < 0.85 GeV/c, e, μ: p > 1 GeV/c, E/p
- 6C Kinematic fit

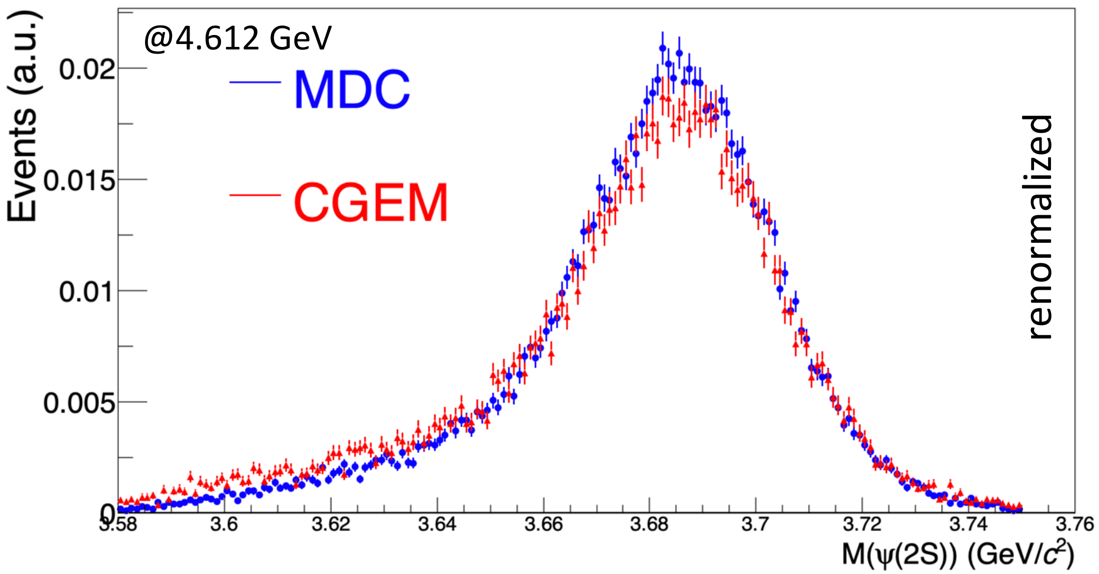
Marco Scodeggio

$e^+e^- \to \psi(2S)\pi^+\pi^-$

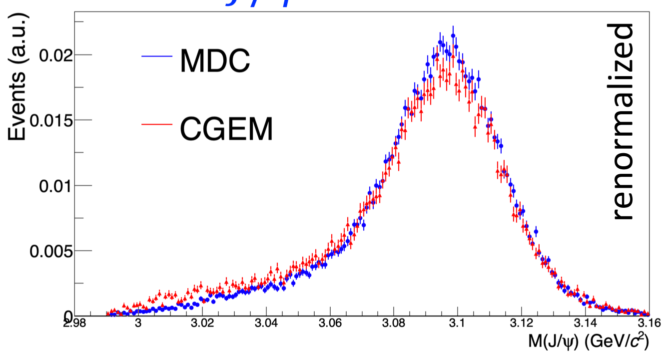
$J/\psi \to \mu^+ \mu^-$



$\psi(2S) \to \mu^+ \mu^- \pi^+ \pi^-$



$J/\psi \to e^+ e^-$



√s = 4.612 GeV	Resolution (CGEM) [MeV]	√s = 4.612 GeV	Resolution (Boss) [MeV]
Muons (J/ψ)	17	Muons (J/ψ)	16
Electrons (J/ψ)	18	Electrons (J/ψ)	18
Muons (ψ(2S))	17	Muons (ψ(2S))	17
Electrons (ψ(2S))	19	Electrons (ψ(2S))	18
√s = 4.946 GeV	**Resolution (CGEM) [MeV]**	**√s = 4.946 GeV**	**Resolution (Boss) [MeV]**
Muons (J/ψ)	17	Muons (J/ψ)	16
Electrons (J/ψ)	17	Electrons (J/ψ)	16
Muons (ψ(2S))	17	Muons (ψ(2S))	17
Electrons (ψ(2S))	19	Electrons (ψ(2S))	18

Comparable invariant mass resolution

$e^+e^- \to \psi(2S)\pi^+\pi^-$

√s = 4.612 GeV	Subdivision	Events (MDC)	Events (MDC)	Efficiency [%]	√s = 4.612 GeV	Subdivision	Events (CGEM)	Events (CGEM)	Efficiency [%]
NTot		300000			NTot		300000		
NCutCh		245441		**81,81**	NCutCh		226623		**75,54**
NCutGoodCh		204497		**68,17**	**NCutGoodCh**		180740		**60,25**
	Electron		97035	64,69		Electron		83903	55,94
	Muon		107462	71,64		Muon		96837	64,56
NCut_6trks		91255		**30,42**	**NCut_6trks**		59425		**19,81**
	Electron		39015	26,01		Electron		24223	16,15
	Muon		52240	34,83		Muon		35202	23,47
NCut_Alltrks		140852		**46,95**	**NCut_Alltrks**		101275		**33,76**
	Electron		60505	40,34		Electron		41340	27,56
	Muon		80347	53,56		Muon		59935	39,96
√s = 4.946 GeV	**Subdivision**	**Events (MDC)**	**Events (MDC)**	**Efficiency [%]**	**√s = 4.946 GeV**	**Subdivision**	**Events (CGEM)**	**Events (CGEM)**	**Efficiency [%]**
NTot		300000			NTot		300000		
NCutCh		249799		**83,27**	NCutCh		231838		**77,28**
NCutGoodCh		204271		**68,09**	**NCutGoodCh**		182552		**60,85**
	Electron		97248	64,83		Electron		85215	56,81
	Muon		107023	71,35		Muon		97337	64,89
NCut_6trks		93651		**31,22**	**NCut_6trks**		63030		**21,01**
	Electron		40407	26,94		Electron		25687	17,12
	Muon		53244	35,50		Muon		37343	24,90
NCut_Alltrks		136153		**45,38**	**NCut_Alltrks**		99693		**33,23**
	Electron		58941	39,29		Electron		40850	27,23
	Muon		77212	51,47		Muon		58843	39,23

MDC

CGEM

Decrease in global event reconstruction efficiency ~10%

(corresponding to 5% single track CGEM efficiency less than MDC)

Marco Scodeggio

$e^+e^- \to \pi^+\pi^- h_c(2P)$ @ 4.640-4.660 GeV

$h_c(2P) \to D^{*+}D^- + \text{c.c.}$

$D^- \to K^+\pi^-\pi^-$ (9.4%)

very low p

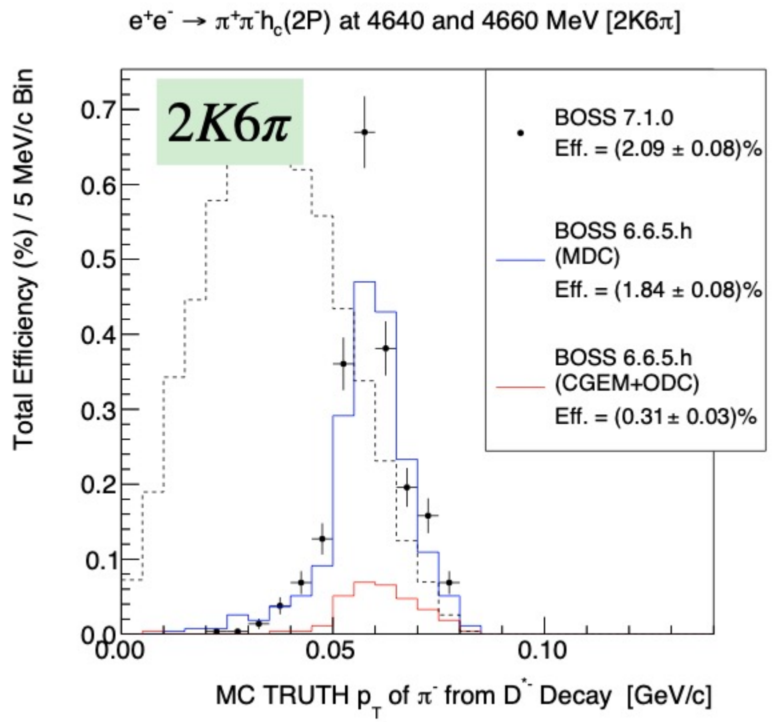
$D^{*+} \to \pi^+ D^0$ (67.7%)

$D^0 \to K^-\pi^+$ (3.9%) and $K^-\pi^+\pi^0$ (14.4%)

- Eight particles
- Very low momentum pion

$K^+K^-\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$ (2K6π) and

Plotting MC Truth Kinematics for accepted events



Selections

- MM selections, or 4C/5C KF chi2 cuts

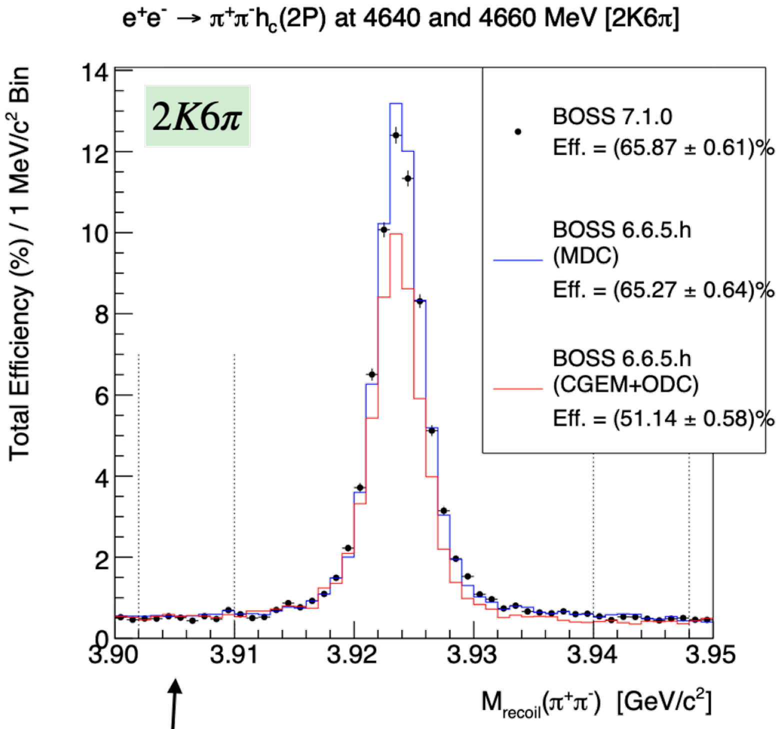
Ryan Mitchell

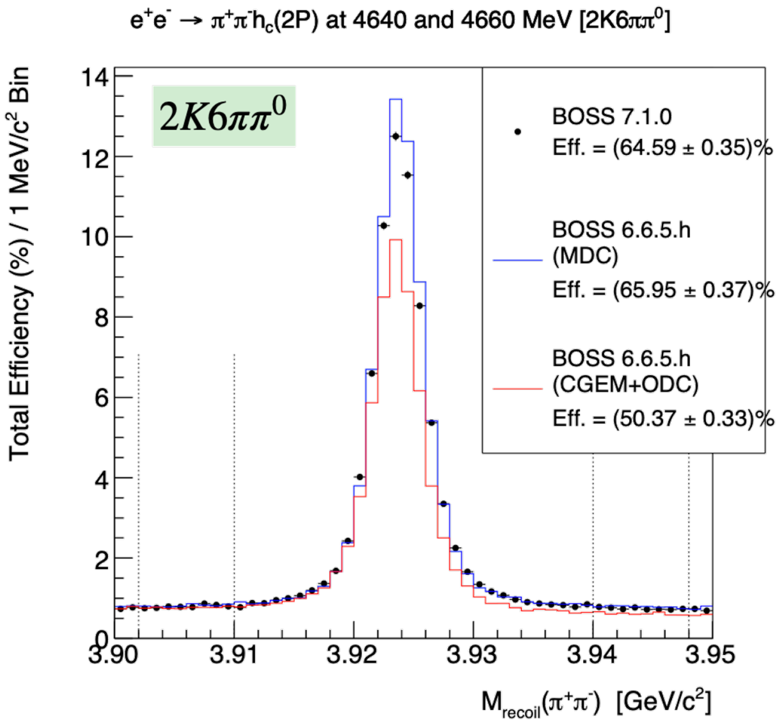
$e^+e^- \to h_c(2P)\pi^+\pi^-$

$e^+e^- \to \pi^+\pi^- h_c(2P)$

$\pi^+\pi^-$ inclusive analysis

(to avoid the low momentum pion)





Subtract left and right sidebands when calculating efficiencies, since combinatorial backgrounds are larger in the inclusive $\pi^+\pi^-$ case.

- Comparable invariant mass resolution
- ~15% lower CGEM reconstruction efficiency

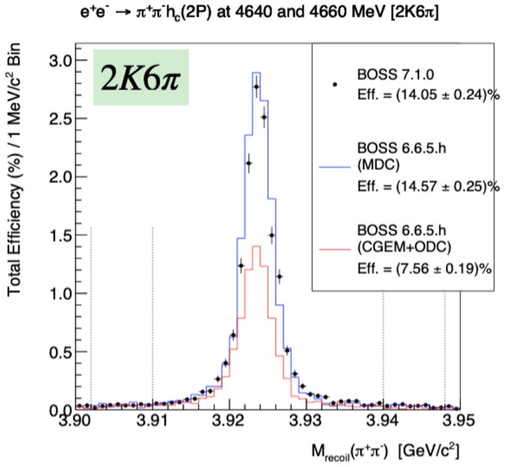
Tracking efficiency seems suffering crowded events

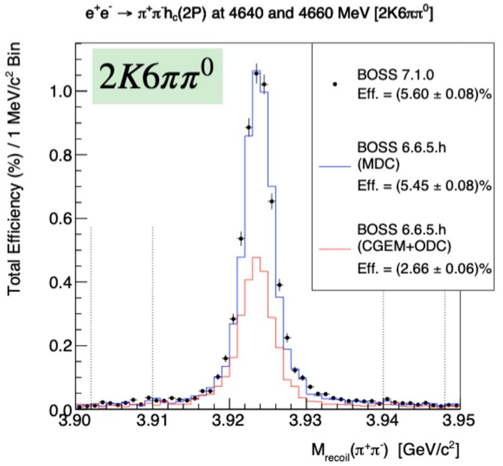
Ryan Mitchell

$e^+e^- \to h_c(2P)\pi^+\pi^-, h_c(2P) \to DD^*$

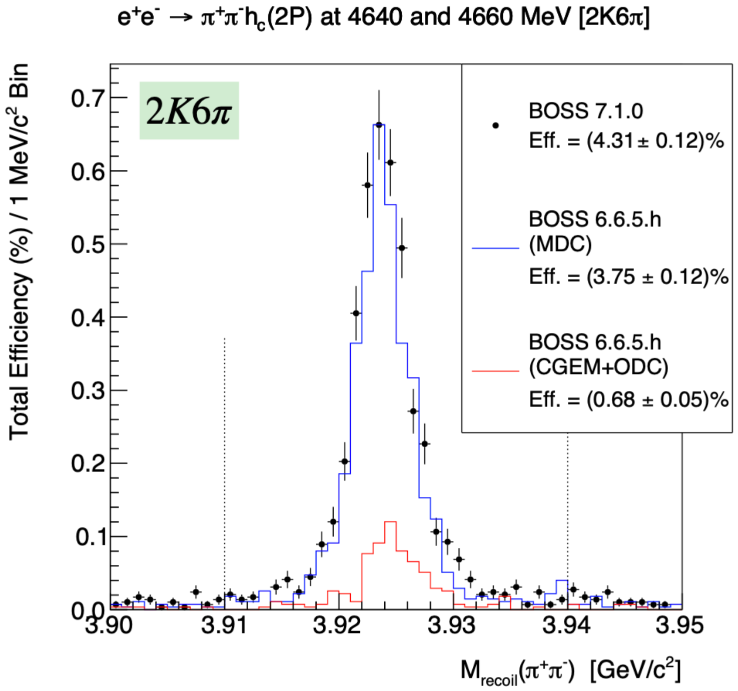
METHOD: Don't reconstruct the $\pi^\pm$ from $D^* \to \pi D$

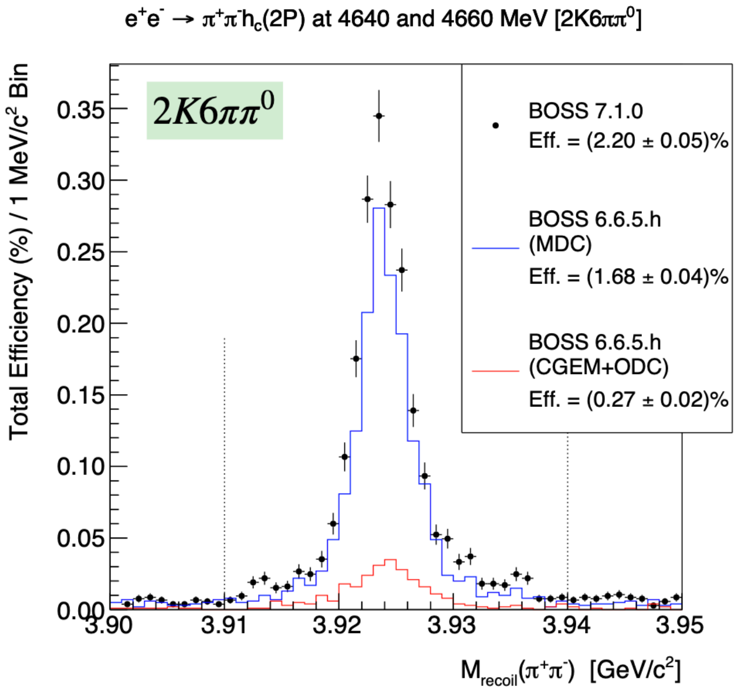
Miss the π^+
(cuts on D^-, D^0, and D^{*+} (using recoil mass))





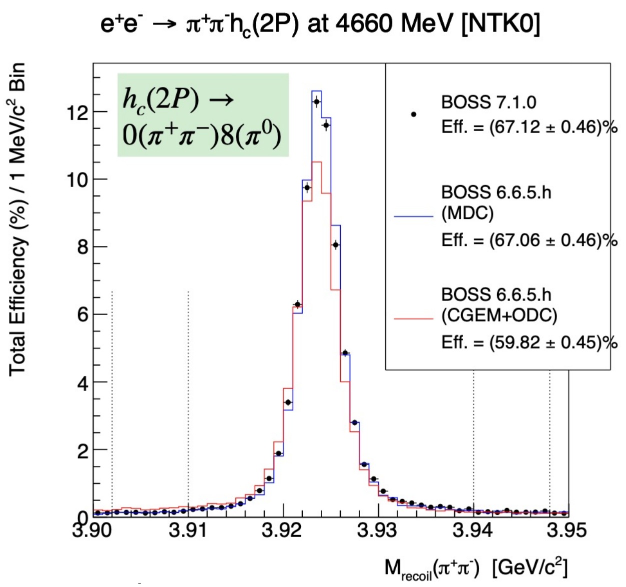
All eight particles combinations
(all the D and D mass cuts, 4C/5C Kinematic Fit)*

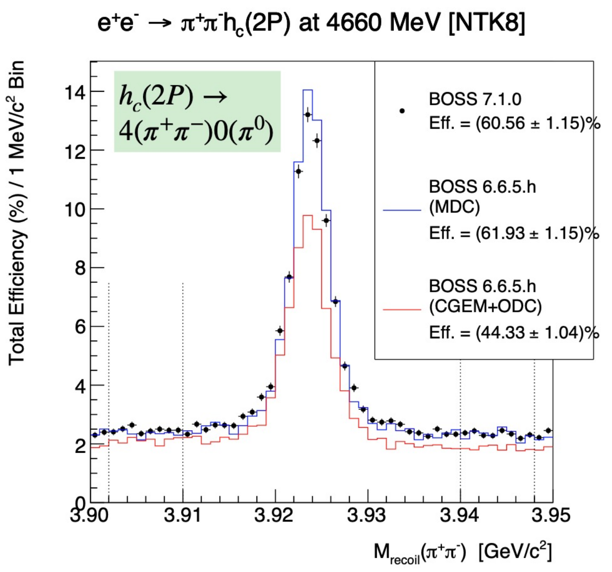




Ryan Mitchell

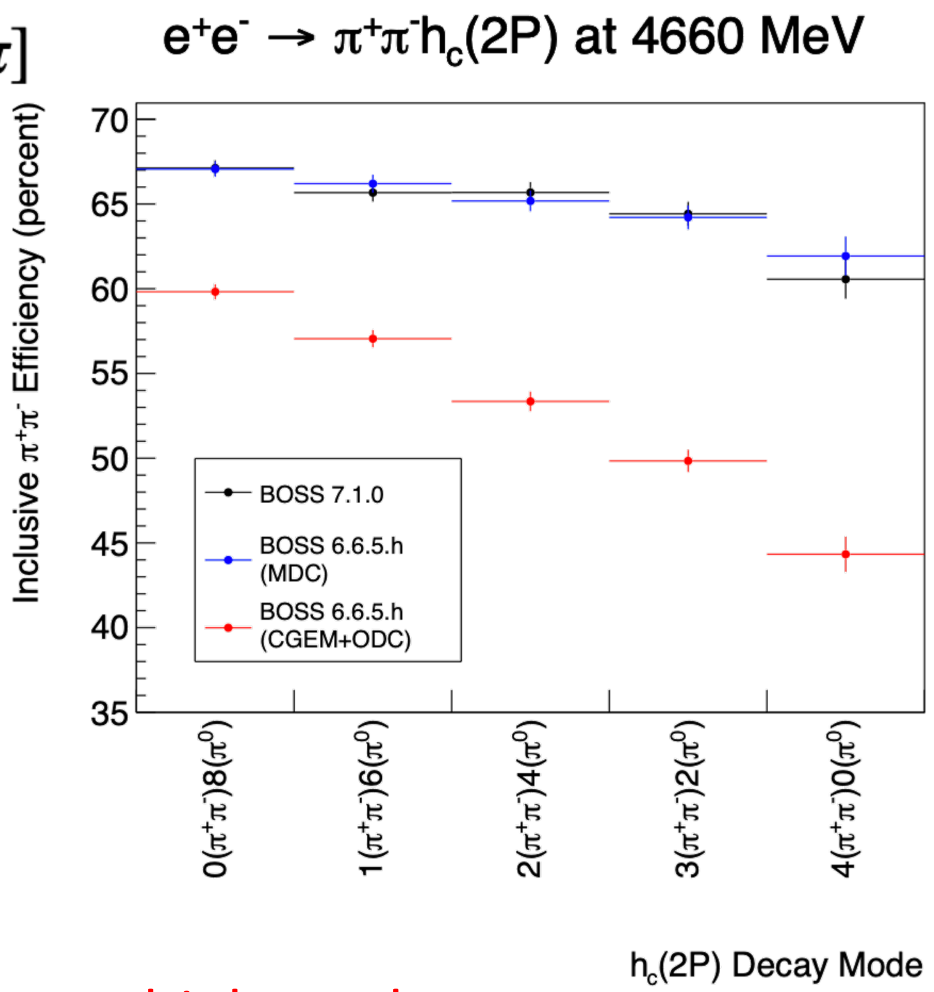
BESIII $e^+e^- \to h_c(2P)\pi^+\pi^-, h_c(2P) \to 8\pi$





$h_c(2P) \to N(\pi^+\pi^-)M(\pi^0)$ [8π]

```
Particle  chi_c2p  3.924  0.0001

Decay psi(4260)
1.00  pi+ pi-   chi_c2p   PHSP;
Enddecay

Alias  PIN  pi0

Decay chi_c2p
1.0  PIN PIN PIN PIN PIN PIN PIN PIN  PHSP;
1.0  pi+ pi- PIN PIN PIN PIN PIN PIN  PHSP;
1.0  pi+ pi- pi+ pi- PIN PIN PIN PIN  PHSP;
1.0  pi+ pi- pi+ pi- pi+ pi- PIN PIN  PHSP;
1.0  pi0 pi0 pi0 pi0 pi0 pi0 pi0 pi0  PHSP;
1.0  pi+ pi- pi0 pi0 pi0 pi0 pi0 pi0  PHSP;
1.0  pi+ pi- pi+ pi- pi0 pi0 pi0 pi0  PHSP;
1.0  pi+ pi- pi+ pi- pi+ pi- pi0 pi0  PHSP;
1.0  pi+ pi- pi+ pi- pi+ pi- pi+ pi-  PHSP;
Enddecay

Decay PIN
1.0  nu_e  anti-nu_e   PHSP;
Enddecay


End
```



CGEM Tracking not optimized for multiple tracks events

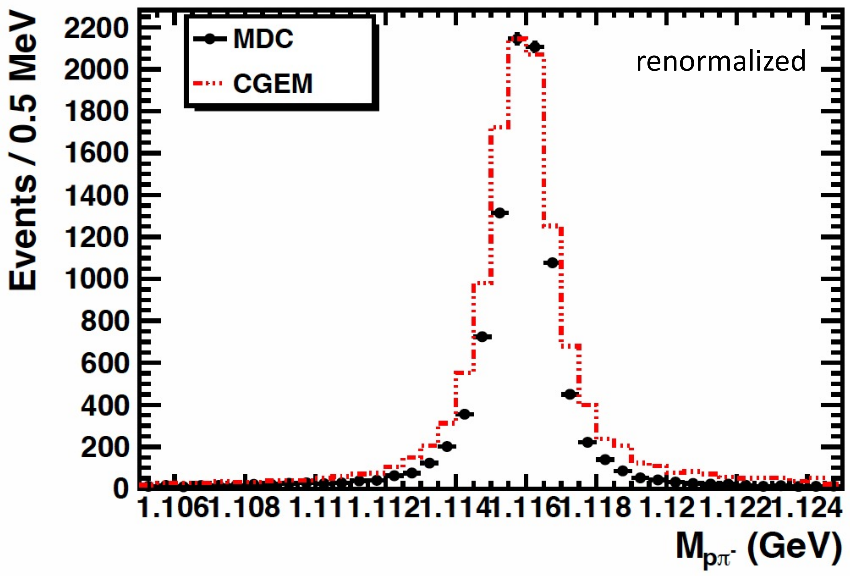
Efficiency decreases with increasing track multiplicity

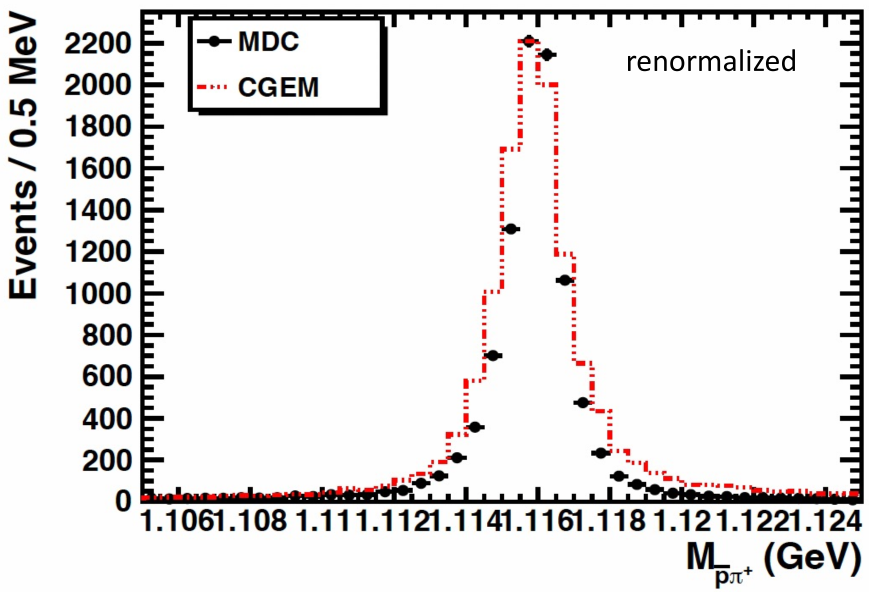
Ryan Mitchell

$e^+e^- \to \Lambda\bar{\Lambda}$ @ $\psi(2S)$

$e^+e^- \to \Lambda\bar{\Lambda}$ @ $\psi(2S)$

- Four particles
- Displaced vertices





Selections

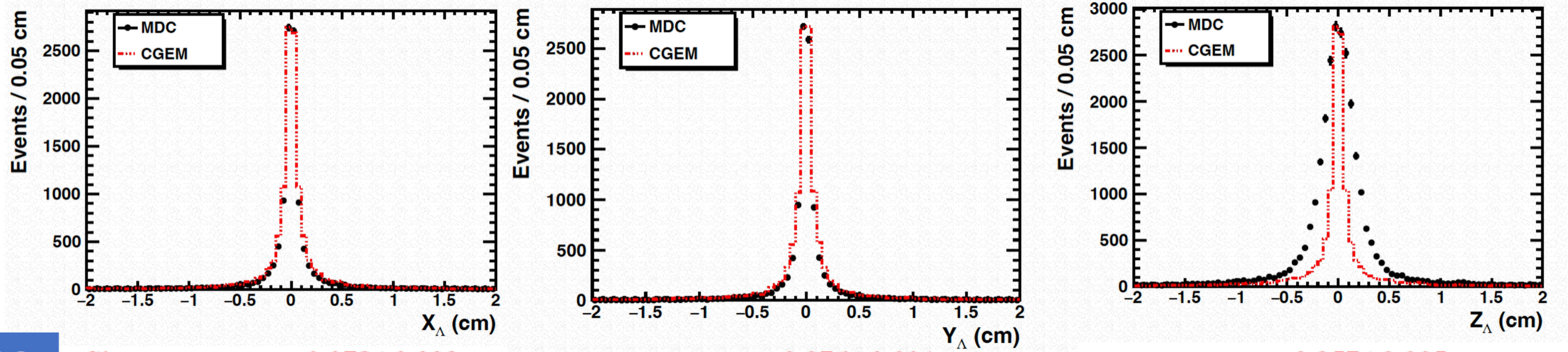
- |cosθ|<0.93
- PID – π: p < 0.6 GeV/c,
  p: p > 0.8 GeV/c
- Secondary vertex fit
- 4C Kinematic Fit $\chi^2 < 200$

	Λ	$\bar{\Lambda}$
σ MDC	1.11 ± 0.02 MeV/c	1.09 ± 0.02 MeV/c
σ CGEM+ODC	1.41 ± 0.04 MeV/c	1.40 ± 0.04 MeV/c

Slightly worse mass resolution

Jianing Guo, Liang Yan

$e^+e^- \to \Lambda\bar{\Lambda}$ @ $\psi(2S)$



MDC	**Sigma**	**0.078±0.002 cm**	**0.076±0.001 cm**	**0.257±0.005 cm**
CGEM	Sigma	0.086±0.002 cm	0.085±0.002cm	0.084±0.002 cm

	CGEM		MDC	
Total number	50000	100.00%	50000	100.00%
Good charged track	24341	48.68%	33478	66.96%
pppipi num	20597	84.62%	30680	91.64%
Lambda	18870	91.62%	29702	96.81%
Lambdabar	17204	91.17%	28686	96.58%
LL candidates	17204	100.00%	28686	100.00%
Kinematic Fit	13237	76.94%	25978	90.56%
Total Efficiency	-	26.47%	-	51.96%

- Much better Z resolution
- Slightly worse XY resolution
- Lower reconstruction BUT Hough not efficient for displaced vertices

(local track finding under development)

Jianing Guo, Liang Yan

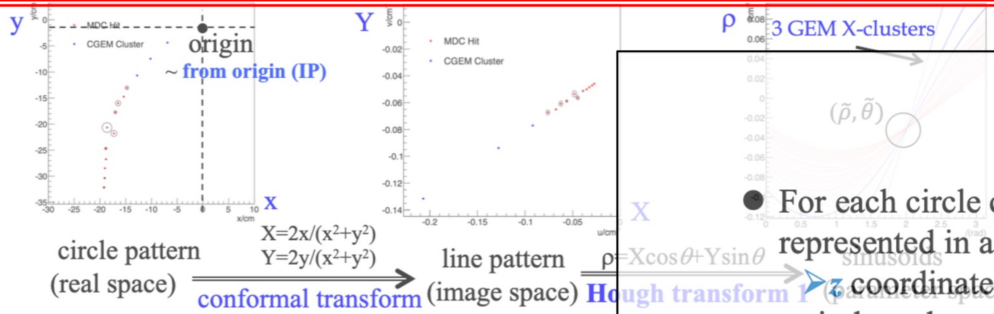
Optimizing tracking parameters ?

Circle finding with Hough transform

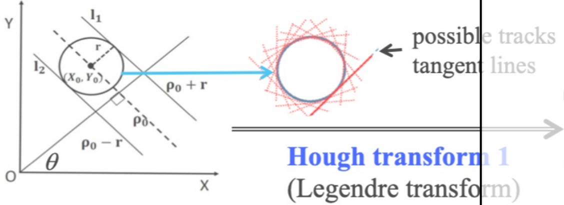
- Circle finding with all X-view hits
- Use 2D histogram to find peaks in parameter space (number of bins optimized with single μ^-)
- Get track parameters from peak position : $(\tilde{\rho}, \tilde{\theta}) \Leftrightarrow (\varphi_0, \kappa)$
- Associate X-view hits to the track candidate (selection criteria studied with single μ^-)

Several parameters for hit association and cell binning too loose

A good assumption for most tracks: circles passing origin

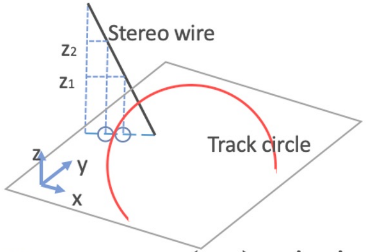


- One detail: Hough transform of the drift circles of ODC hits can be recognized as the Legendre transform for circles

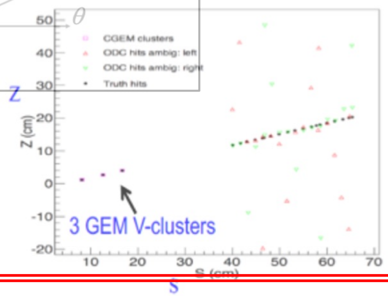


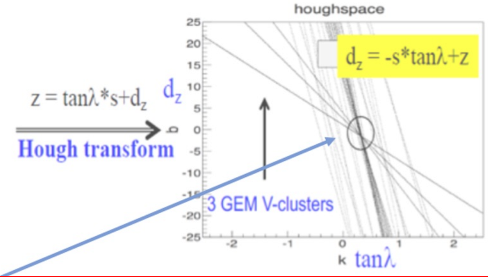
V-view hits association

- For each circle candidate, the intersected V-view hits can be represented in a *s-z* plane
  - *z* coordinate can be calculated by tangency between drift circle and track circle in x-y plane
  - *s* is trajectory length in the transverse plane
- V-view hits belong to the same track are co-linear in *s-z* plane (image spcae)



- Use **Hough transform** to convert (*s, z*) pairs into lines in d_z-tanλ plane (parameter space)





- The cell with the maximum votes (peak) => parameters **dz, tanλ** (number of bins optimized with single μ^-)
- Associate V-view hits layer by layer (selection criteria studied with single μ^-)

Overlapping tracks let the finding fail

We need to be more selective

Liangliang Wang

Status and Results

- The CGEM+ODC tracking code is ready for physics analysis

  from the software point of view

- Momentum and invariant mass resolution comparable to MDC tracking
- Vertexing along Z much better for CGEM, XY almost comparable
- CGEM+ODC tracking suffers in many-tracks events,

  efficiency becomes worse increasing the number of tracks in the event

  ⇓

  Optimizing tracking parameters for many-tracks events

  Test and validate the local track finding (displaced vertices, many-tracks…)

Benchmark: questions, remarks...

Is the dramatic efficiency drop connected to soft pions?

It seems not, from a preliminary investigation on numbers. We need to check with MonteCarlo truth, soft pion efficiency for high multiplicity events

Is it connected to higher material budget?

No, in case we should see this effect also in single track events

Worse resolution with $J/\psi \rightarrow e^{+}\ e^{-}$

Bremsstrahlung is higher, but algorithms can be developed to recover (Panda,B2)

Check the maximum efficiency with ideal tracking

Good idea, we had not time, let’s see in December

Benchmark: questions, remarks…

We will have higher energies, higher track multiplicities, higher background, more displaced vertices. We need additional benchmark channels with heavy baryons

Good idea, please give us the manpower to analyze such channels (ask physics coordinators)

Do we have a strategy to recover for the efficiency loss?

Now we know what is going wrong, we have several ideas on what to improve, in December we will show our path towards the solution

Timeline?

Time schedule 2023-2024

year	2023		2024								
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
New cosmic-ray based study		New cosmic-ray analysis (1-2 persons)									
		Calibration (Riccardo)									
		CGEM Alignment (Aiqiang)									
		Digitization tuning (1 person)									
Global alignment of CGEM+ODC	Test with simulated events (Linghui Wu and Han Miao)										
Track reconstruction	Implementation of the local track finding with CA (L.L. Wang)				Optimization of CA (L.L. Wang)						
	Benchmark channels check based on HT (several colleagues, see Stefano's talk)				Benchmark channel check based on CA						
Codes merging						Merge CGEMBOSS into the latest BOSS (Linghui Wu & L.L. Wang)					

Ready for the 2nd round?