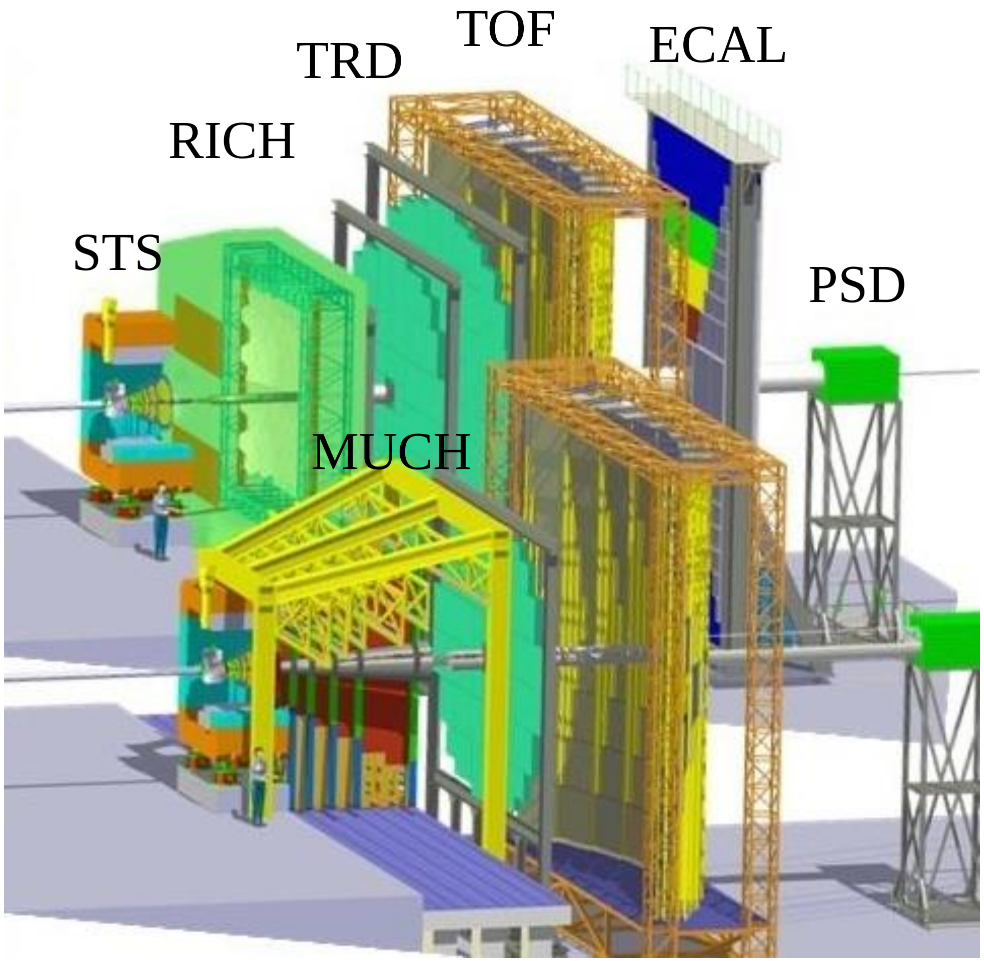
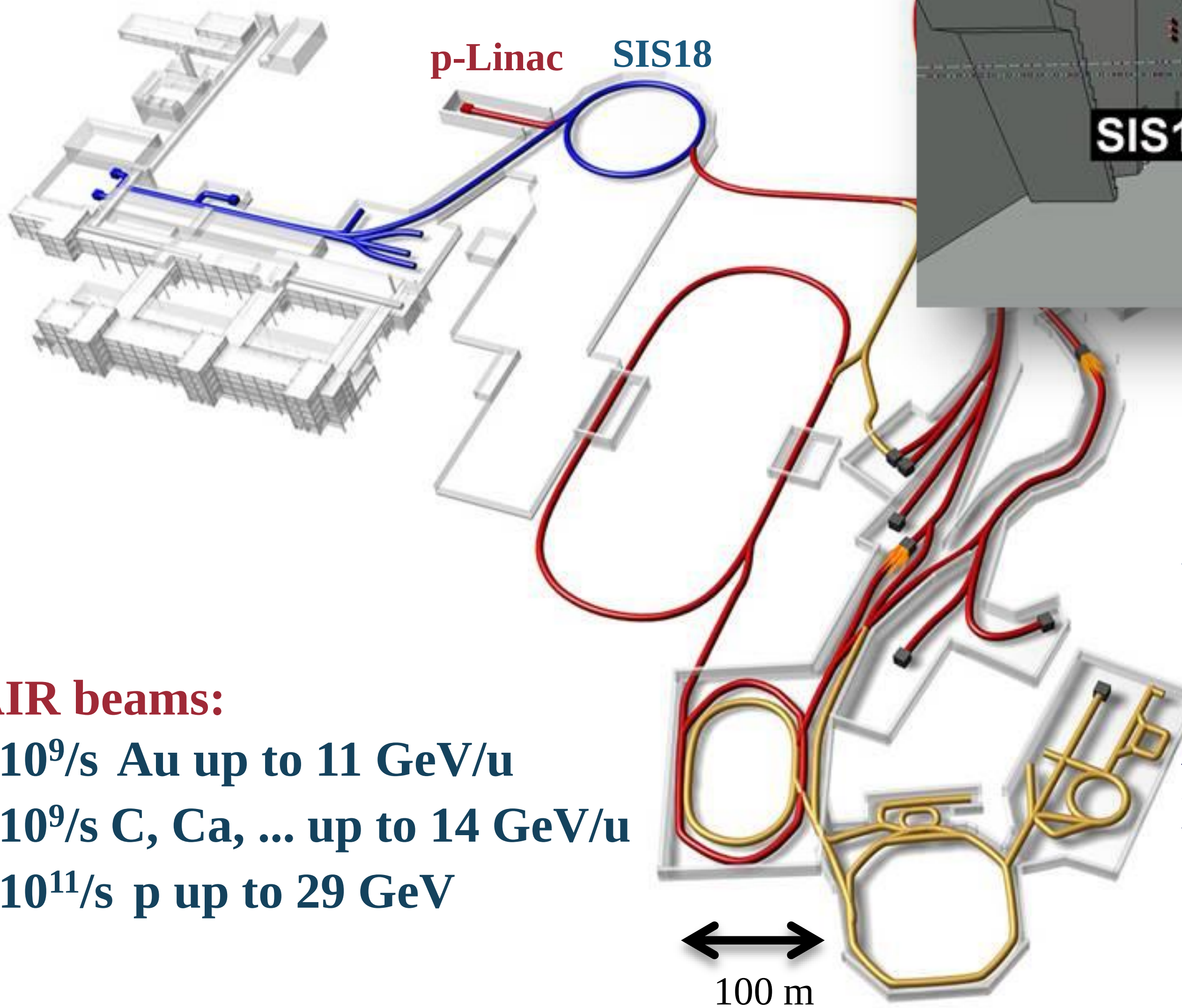
Open Charm measurement with the CBM detector at FAIR

Iouri Vassiliev for the CBM Collaboration



HFM2 Kolkata February 4 2016

Facility for **A**ntiproton & **I**on **R**esearch

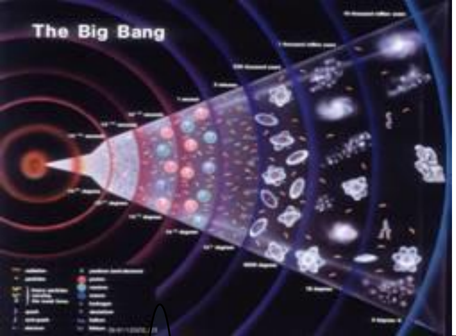


FAIR strategy:
FAIR construction along the beam.

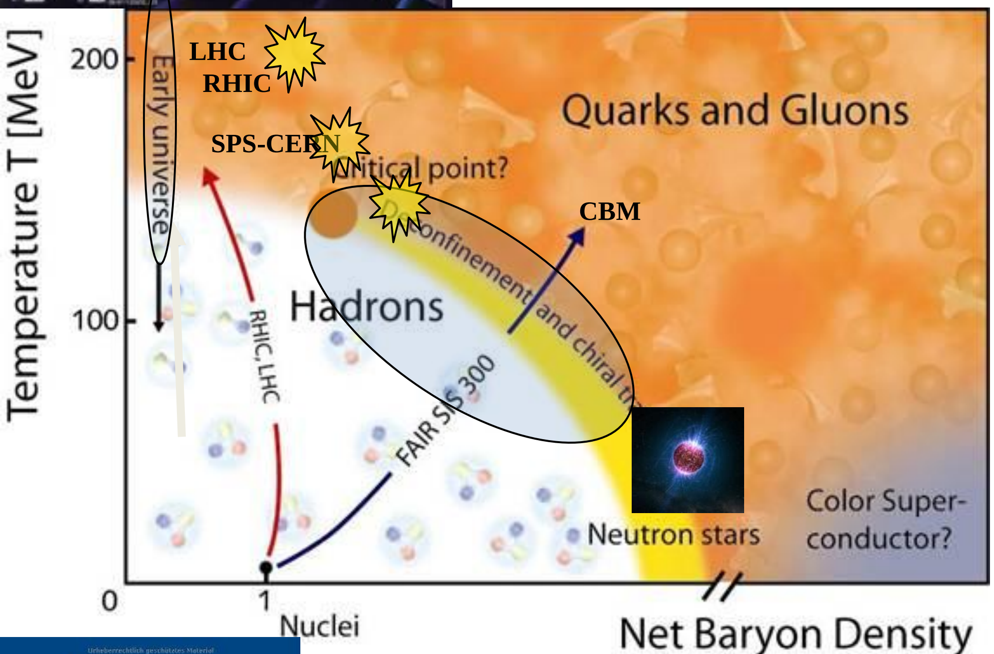
FAIR Day-1 experiment in 2022: CBM
Cave planning completed.
Application for construction permit to be submitted **2016**

FAIR phase 1
FAIR phase 2

FAIR beams:
- **10^9/s Au up to 11 GeV/u**
- **10^9/s C, Ca, ... up to 14 GeV/u**
- **10^{11}/s p up to 29 GeV**



Physics case: Exploring the QCD phase diagram



The equation-of-state at high ρ_B

- collective flow of hadrons
- particle production at threshold energies: **open charm, multi-strange hyperons**

Deconfinement phase transition at high ρ_B

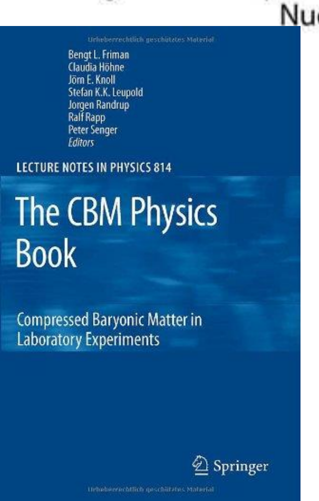
- excitation function and flow of strangeness (K, Λ, Σ, Ξ, Ω) and **charm** (J/ψ, ψ', D^0, D_s, $D^{\pm}$, Λ_c)
- **charmonium** suppression, for **J/ψ** and **ψ**

QCD critical endpoint

- excitation function of event-by-event fluctuations (**K/π**, ... Ξ/ π, **Ω**/ π)

Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$)



Open charm physics case:

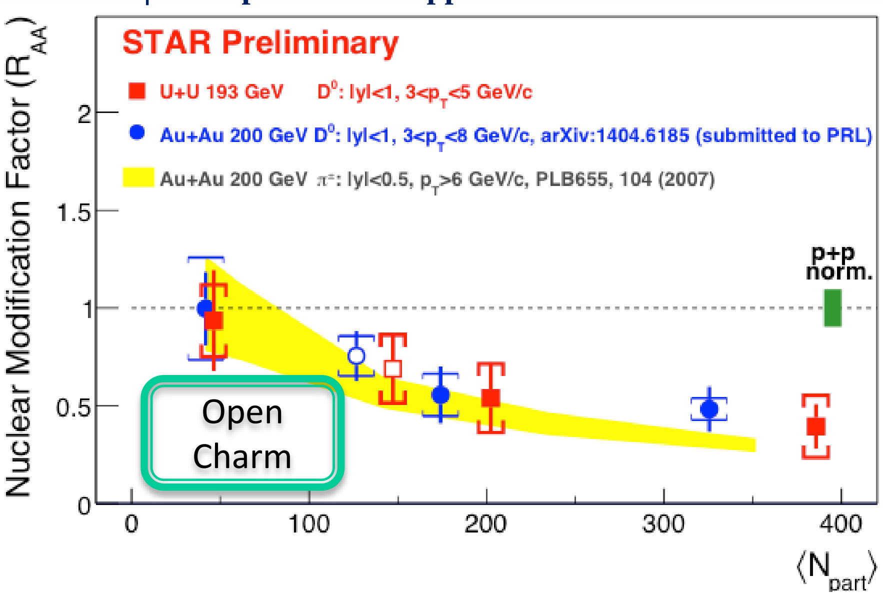
SIS-100

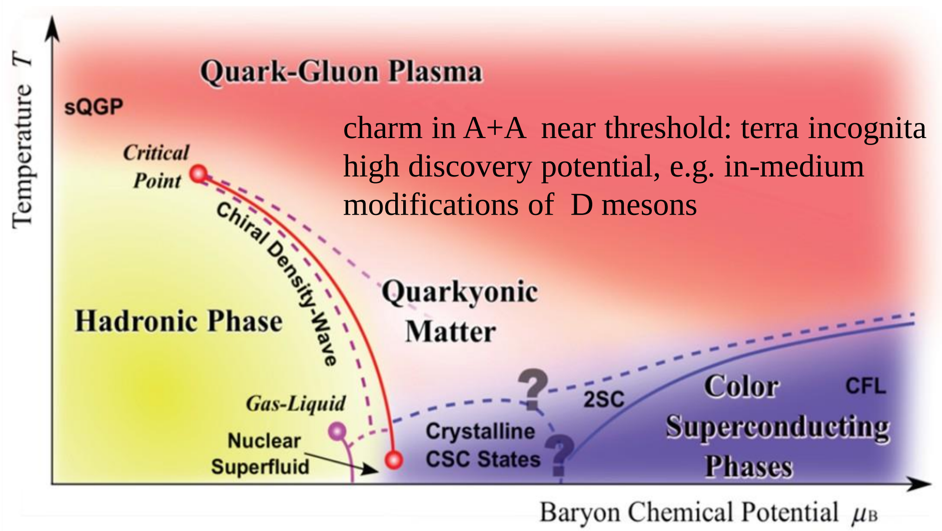
- **What is the production mechanism of charm quarks at threshold beam energies?**
- **How does open and hidden charm propagate in cold and in hot nuclear matter?**

SIS-300

- **Is there a phase transition from hadronic to quark-gluon matter, or a region of phase coexistence?** (excitation function and flow of charm)

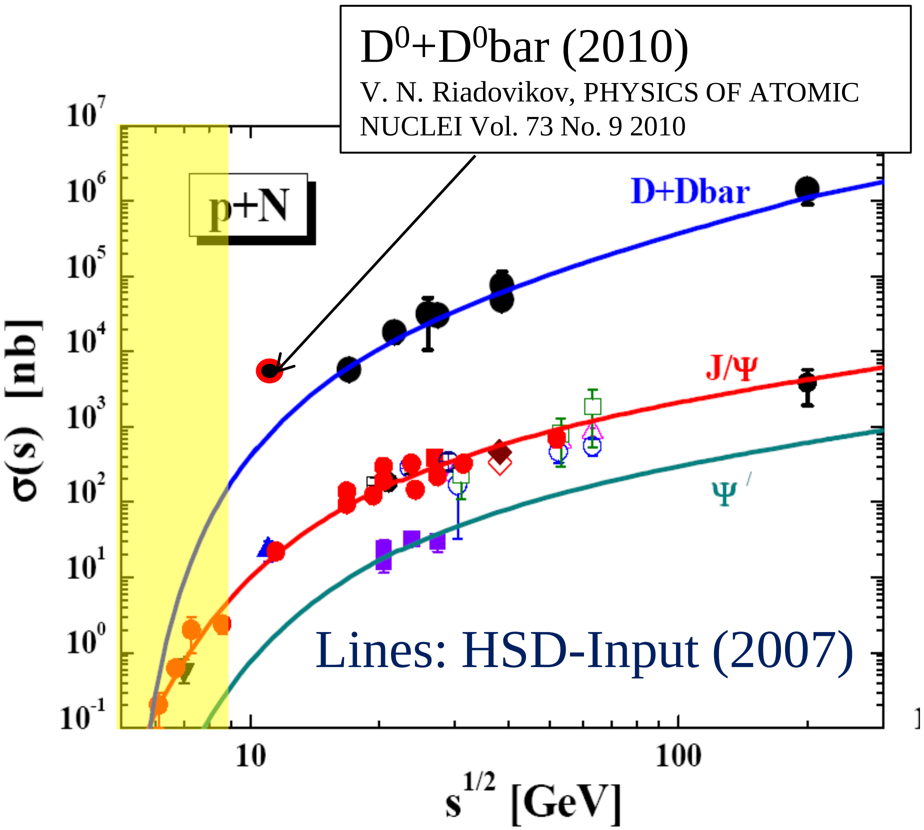
J/ψ and open charm suppression measured



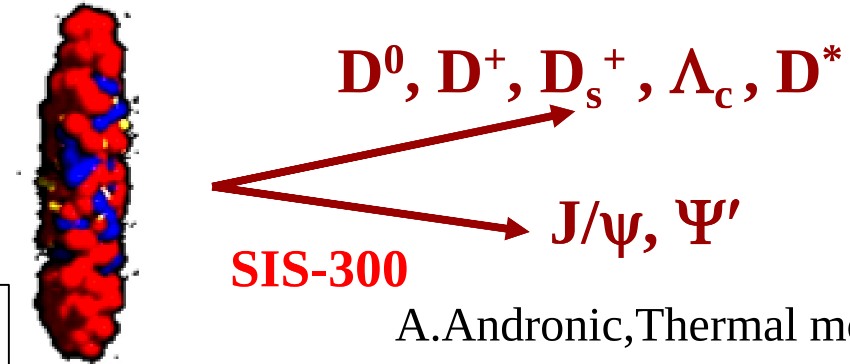


Challenge for open charm measurements at FAIR energies

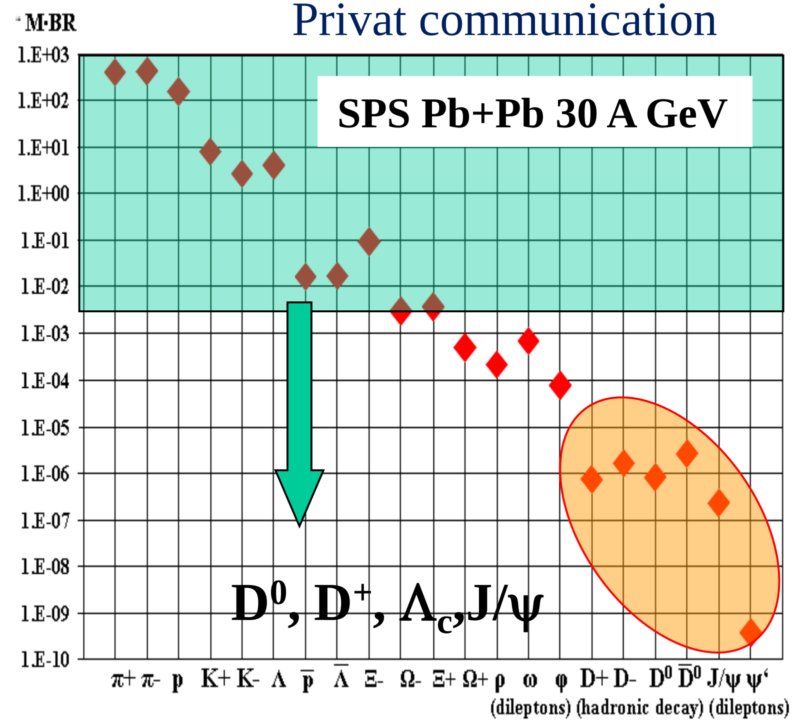
SIS-100



Lynnik et al., Nucl. Phys. A 786 (2007) 183



A.Andronic,Thermal model
Privat communication

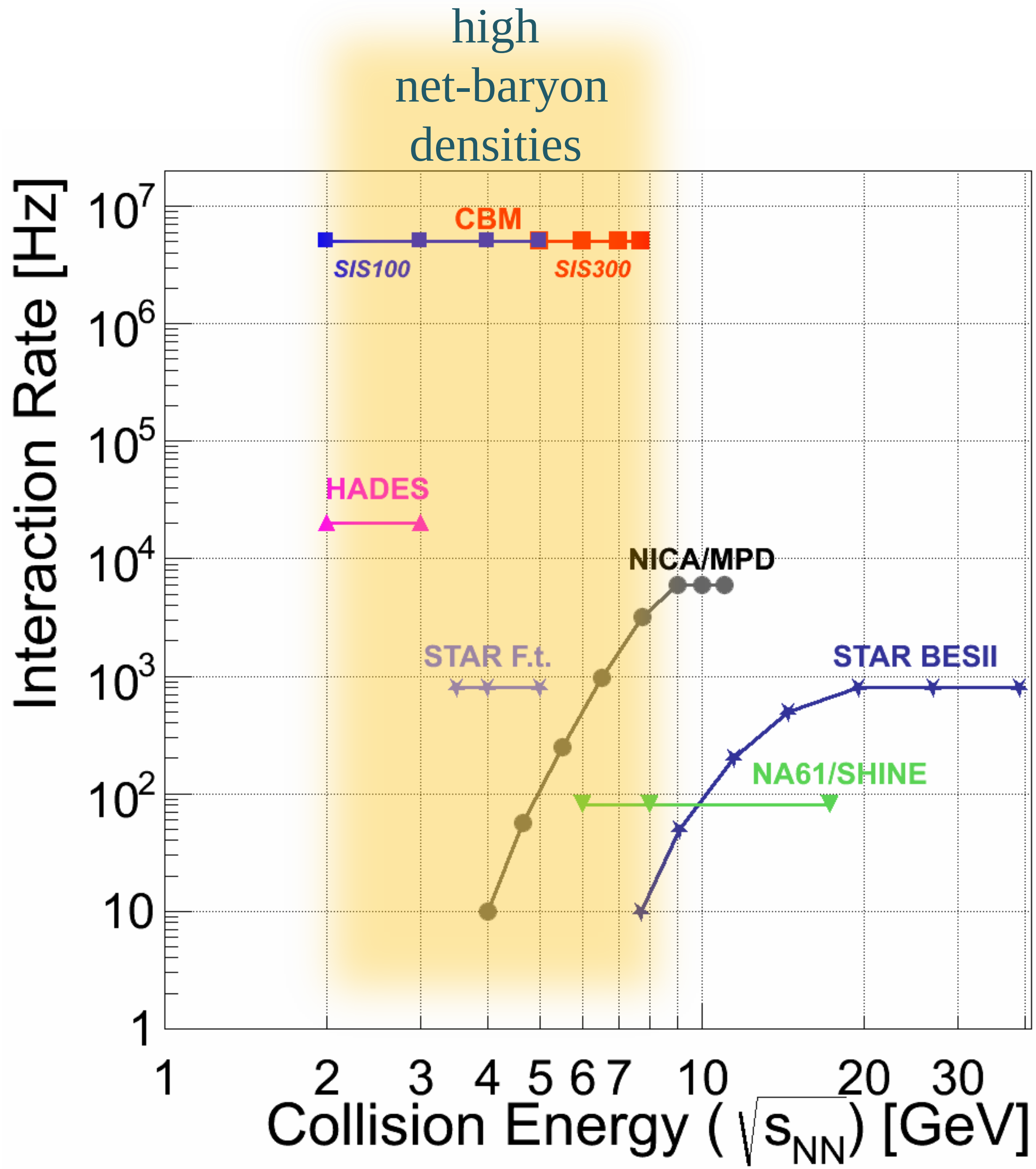


$p + p \rightarrow J/\psi + p + p$ 11.2 GeV

$p + n \rightarrow \Lambda_c + D^- + p$ 12.0 GeV

$p + p \rightarrow D^+ + D^- + p + p$ 14.9 GeV

Experiments exploring dense QCD matter

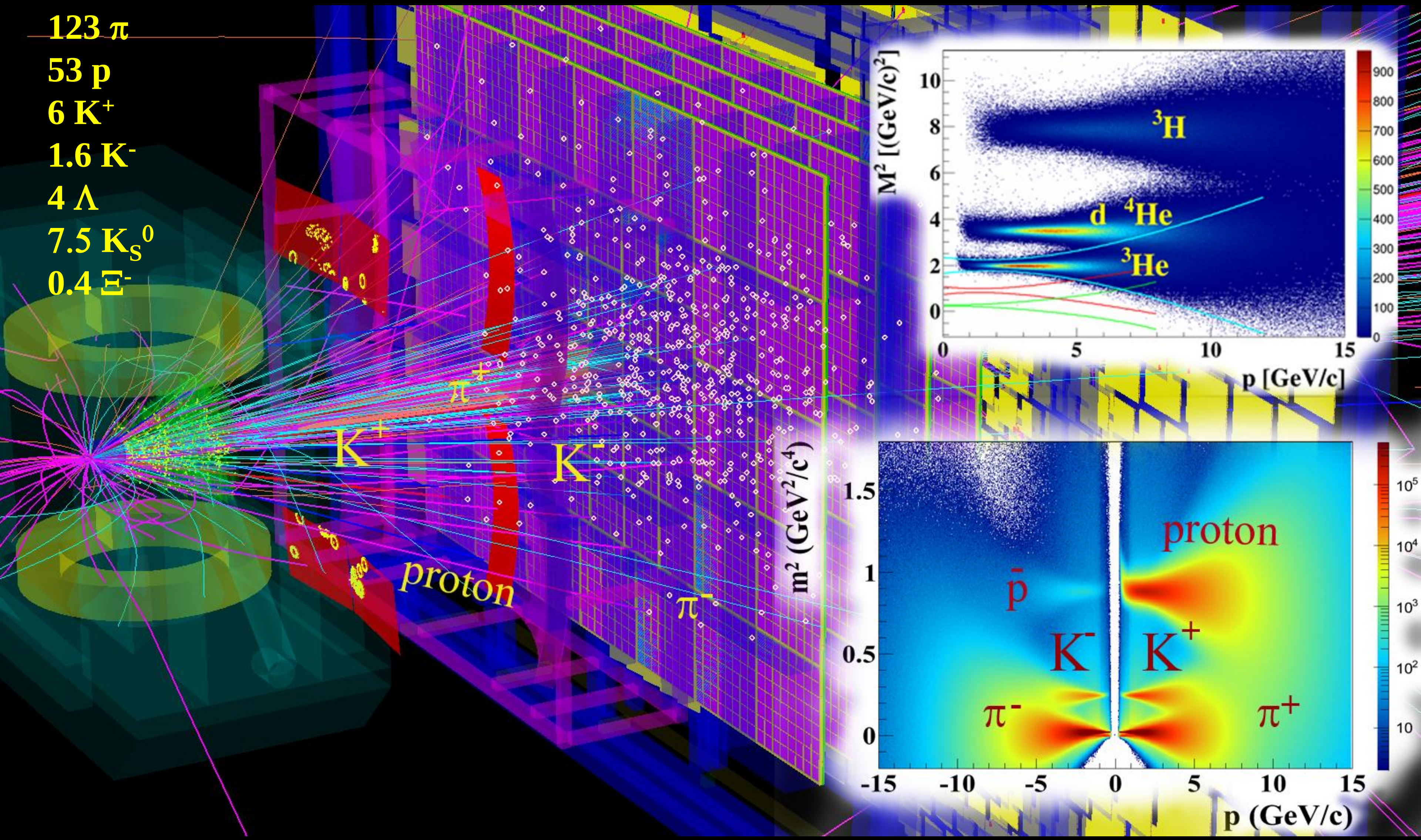


CBM:
world record rate capability

- determination of (displaced) vertices with high resolution (≈ 50 μm)
- identification of leptons and hadrons
- fast and radiation hard detectors
- self-triggered readout electronics
- high speed data acquisition and online event selection
- powerful computing farm 4-d tracking*
- software triggers

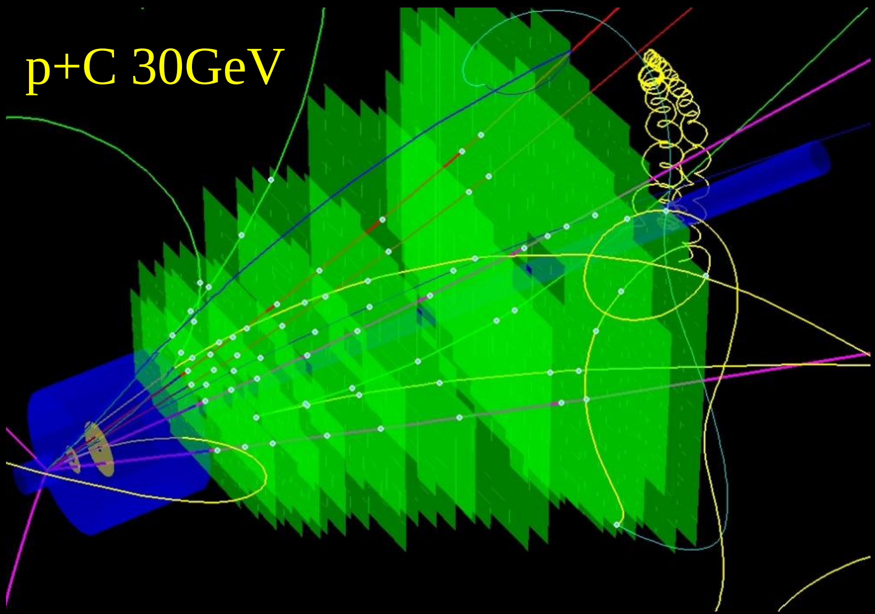
Particle identification with CBM

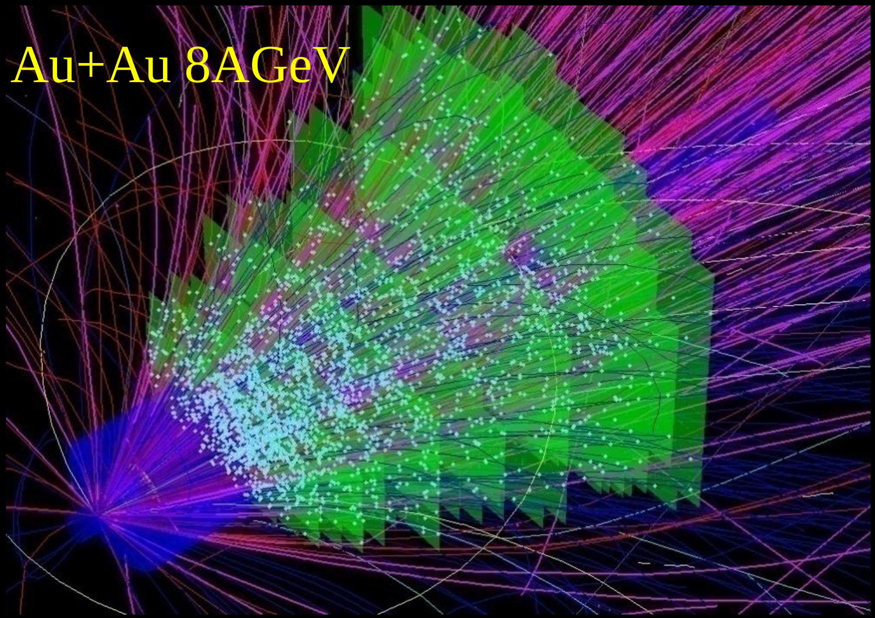
Ni+Ni 15 AGeV
123 π
53 p
6 K^+
1.6 K^-
4 Λ
7.5 K_S^0
0.4 Ξ^-



Central event: 40 (TF) + 7 (PF) ms/core with MVD!
(~ 2 faster w/o MVD)

SIS-100: p + C and Au + Au simulated (UrQMD) events



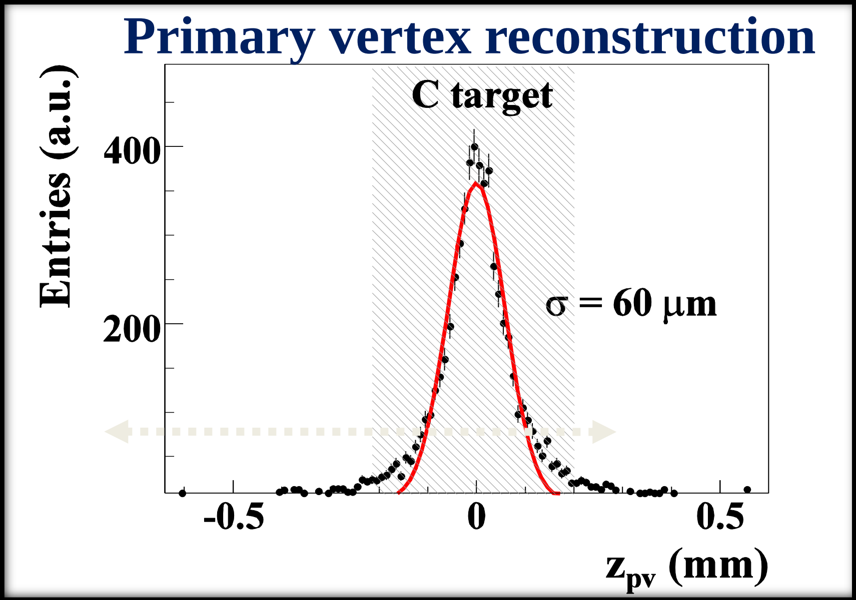


p+C 30GeV

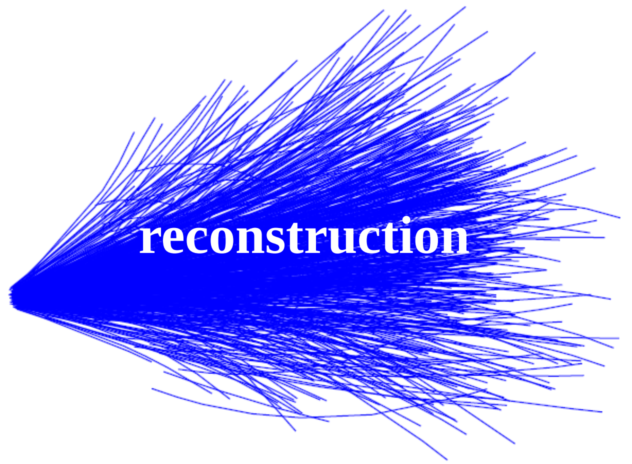
pi+	2.39
pi-	2.12
p	6.65
K+	0.17
K-	0.08
K^0	0.17
Λ	0.1
Σ^0	0.033
Ξ^-	0.0013

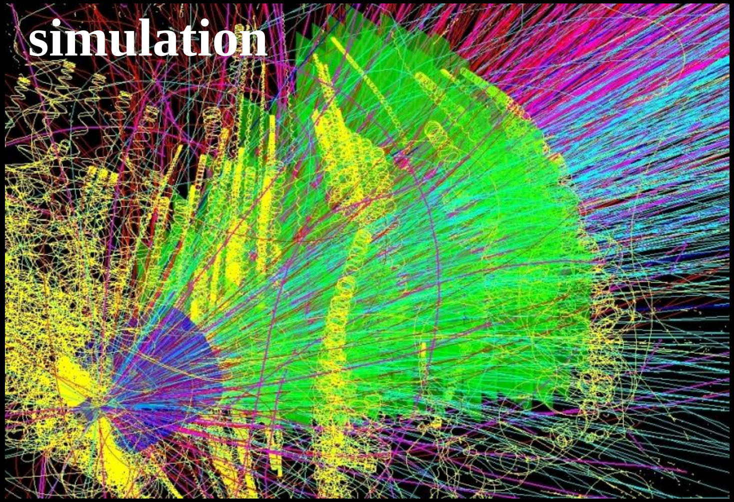
Au+Au 8AGeV

pi+	140.97
pi-	165.62
p	168.97
K+	17.15
K-	2.34
K^0	17.43
Λ	14.23
Σ^0	4.64
Ξ^-	0.268
Ω^-	0.005



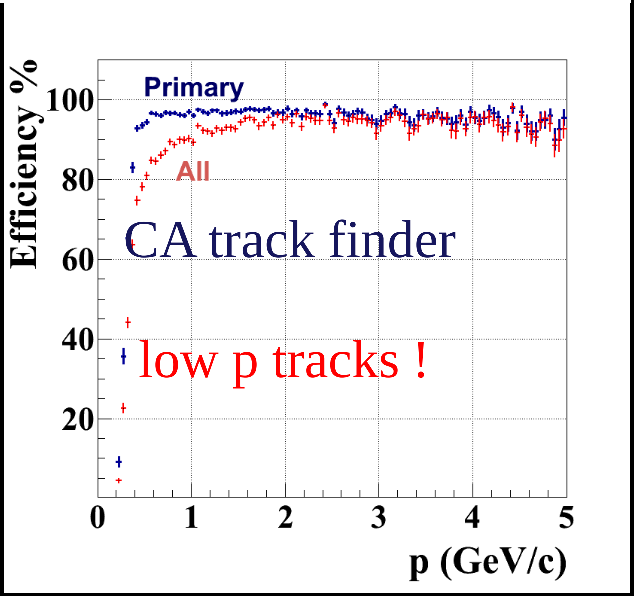
SIS-300: central Au + Au (UrQMD or PHSD) events
Simulation and reconstruction

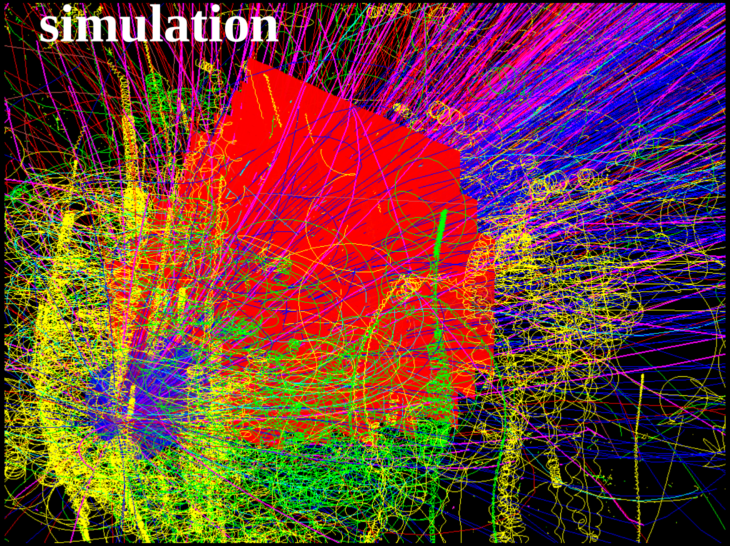




UrQMD

- ~700 π
- 160 p
- 53 K
- 32 Λ
- 27 K_S^0
- 0.44 Ξ^-
- 0.018 Ω^-





PHSD

- ~700 π
- 174 p
- 42 K
- 30 Λ
- 24 K_S^0
- 2.4 Ξ^-
- 0.005 Ω^-

648 recstructed tracks
Ref. prim. eff = 96%
All set eff = 87%
dp/p = 1.2%

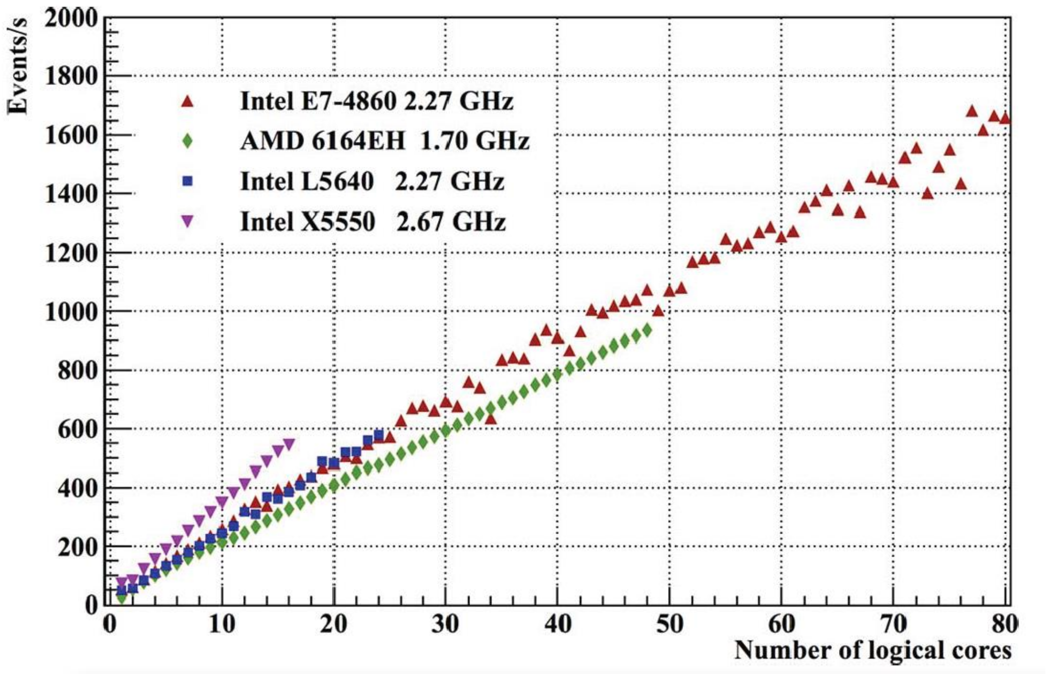
central: 82 (TF) + 16 (PF) ms/core
mbias : 10 (TF) + 2 (PF) ms/core
up to 80 cores/CPU

CBM First Level Event Selection (FLES)

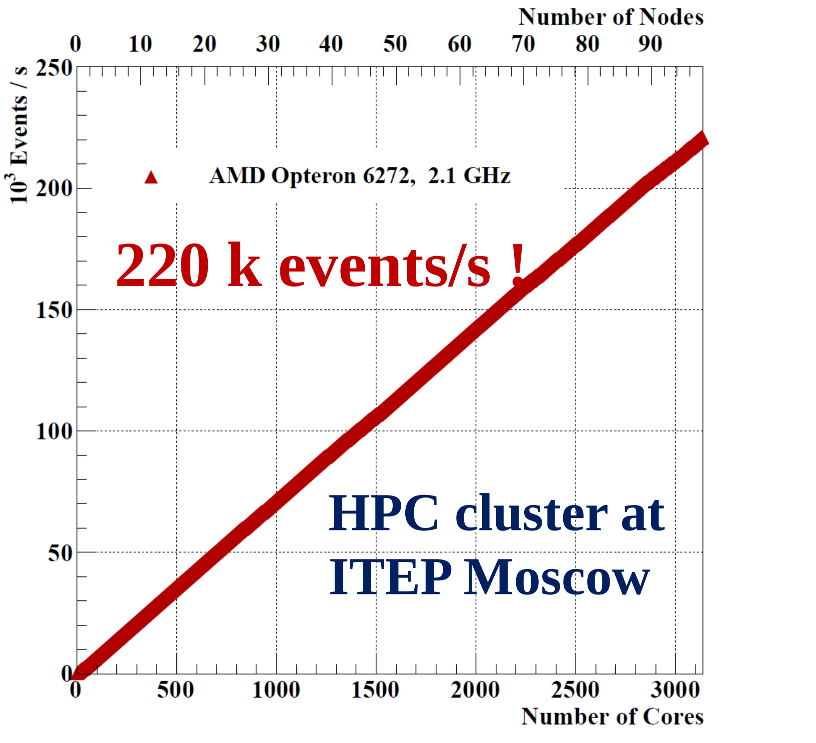
The FLES package is
vectorized, parallelized, portable and scalable up to 3 200 cores

Example:
Full track reconstruction including KF particle analysis of multi-strange (anti) hyperons for min. bias Au+Au collisions at 25 A GeV.

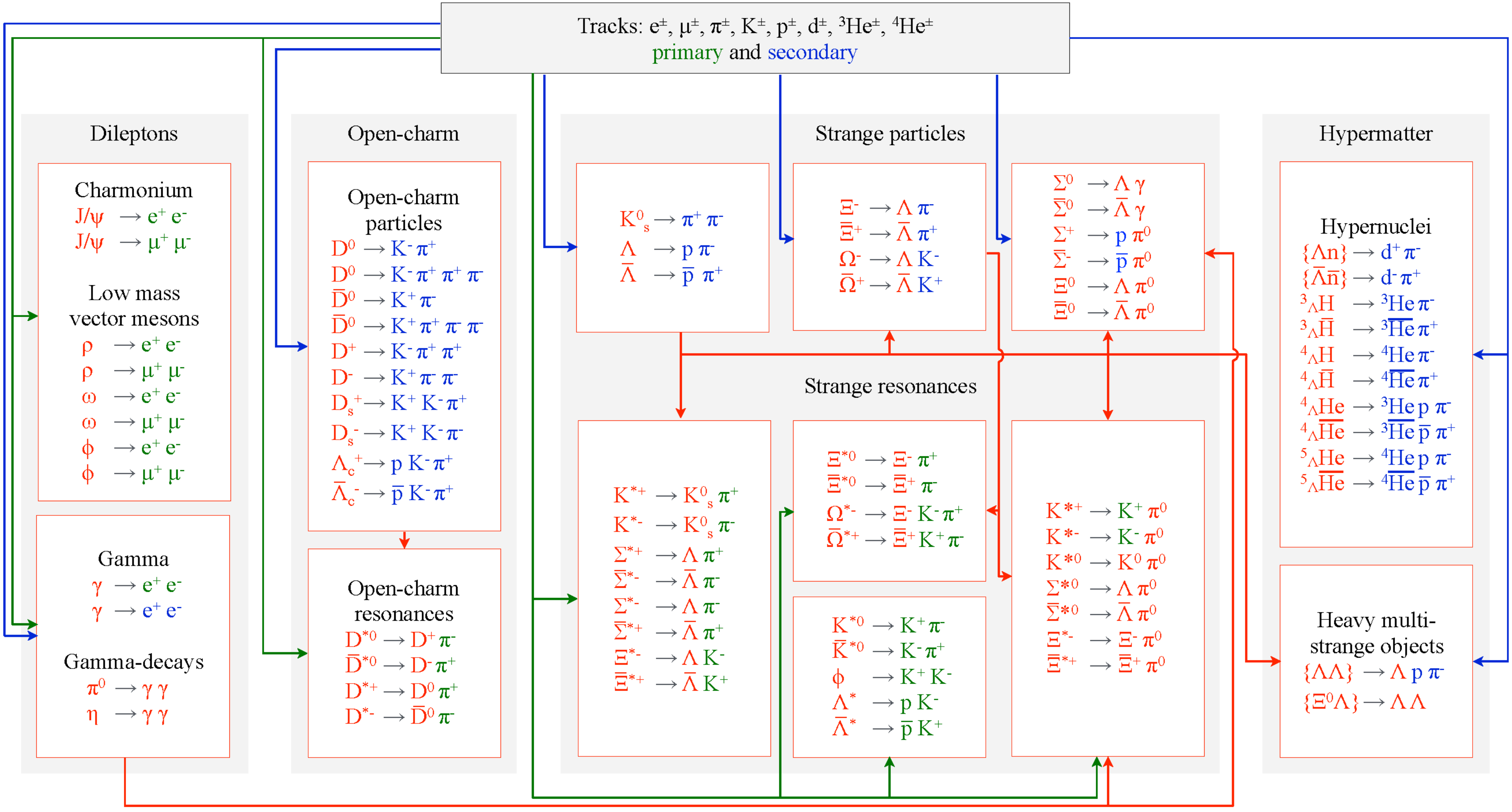
Single node with up to 80 cores



100 nodes with 32 cores each



KF Particle Finder for the CBM Experiment



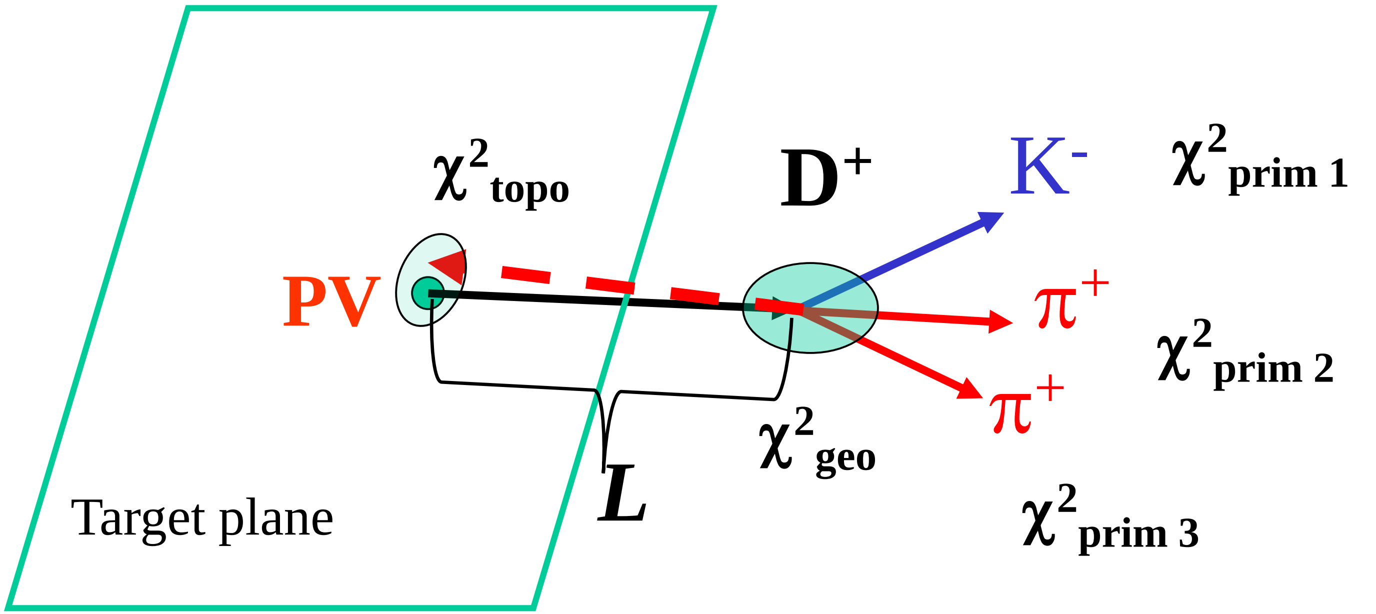
Functionality of KF Particle

Functions	CBM	ALICE	PANDA	STAR
Construction of mother particles	+	+	+	+
Addition and subtraction of the daughter particle to (from) the mother particle	+	+	+	+
+= and -= operators	+	+	+	+
Accessors to the physical parameters (mass, momentum, decay length, lifetime, rapidity, etc)	+	+	+	+
Transport: to an arbitrary point, to the decay and production points, to another particle, to a vertex, on the certain distance	+	+	+	+
Calculation of a distance: to a point, to a particle, to a vertex	+	+	+	+
Calculation of a deviation: from a point, from a particle, from a vertex	+	+	+	+
Calculation of the angle between particles	+	+	+	+
Constraints: on mass, on a production point, on a decay length	+	+	+	+
KF Particle Finder	+	+	+	+

Exactly the same package in all four experiments: CBM, ALICE, PANDA and STAR

Allows to reconstruct open charm decays

Open charm decay topology



$c\tau$ = 60…312 μm !

Strategy: background suppression keeping maximum of efficiency

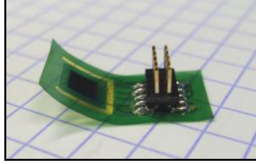
single track parameters based cuts:

- χ^2_{prim} impact parameter value 6.0-7.5
- **IP** impact parameter cut (upper value) 0.5 mm
- Kaons, protons ID by TOF

multiple track (**KFParticle**) parameters based cuts:

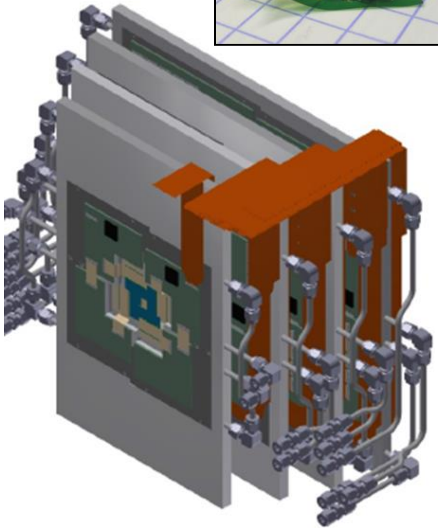
- χ^2_{GEO} geometrical constrained fit 3.0
- χ^2_{TOPO} topological constrained fit 3.0
- L/dL > 10
- charm particle to primary vertex DCA < 3σ (30 μm)
- Z_{vertex} < 2(3.5) mm Λ_c

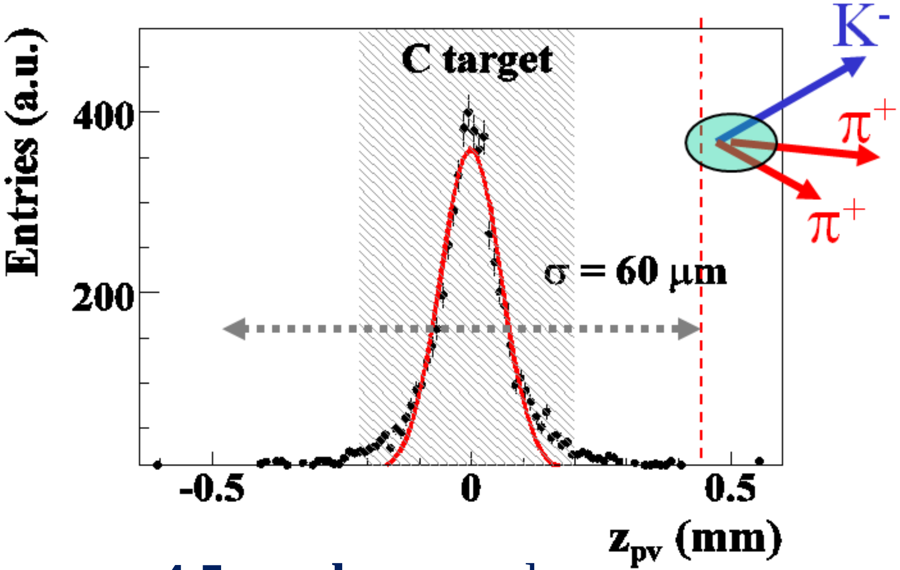
Primary vertex reconstruction in CBM



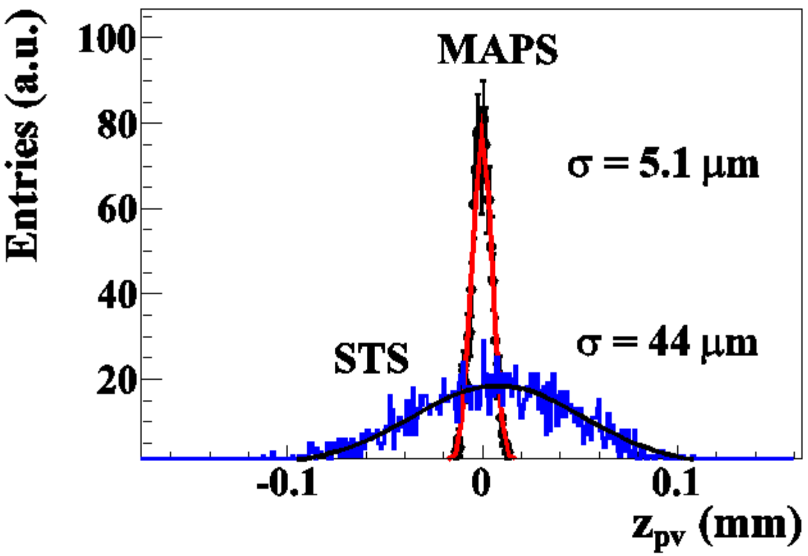
Monolithic Active Pixel Sensors
(MAPS, also CMOS-Sensors)

- Invented by industry (digital camera)
- Modified for charged particle detection since 1999 by IPHC Strasbourg
- Installed at **STAR**
- Also foreseen for **ALICE**…





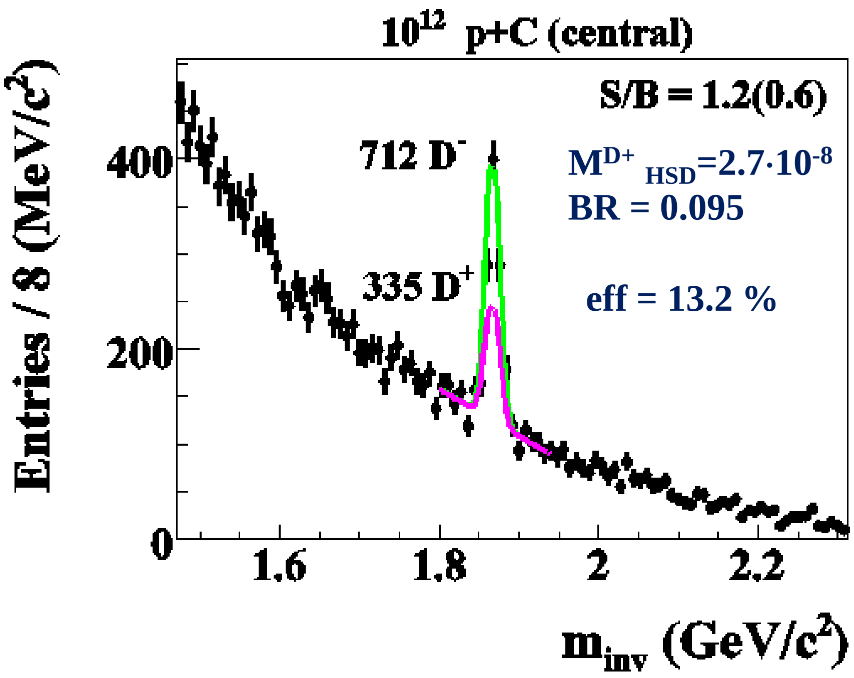
4.5 tracks central
1 track mbias



450 tracks central
100 tracks mbias

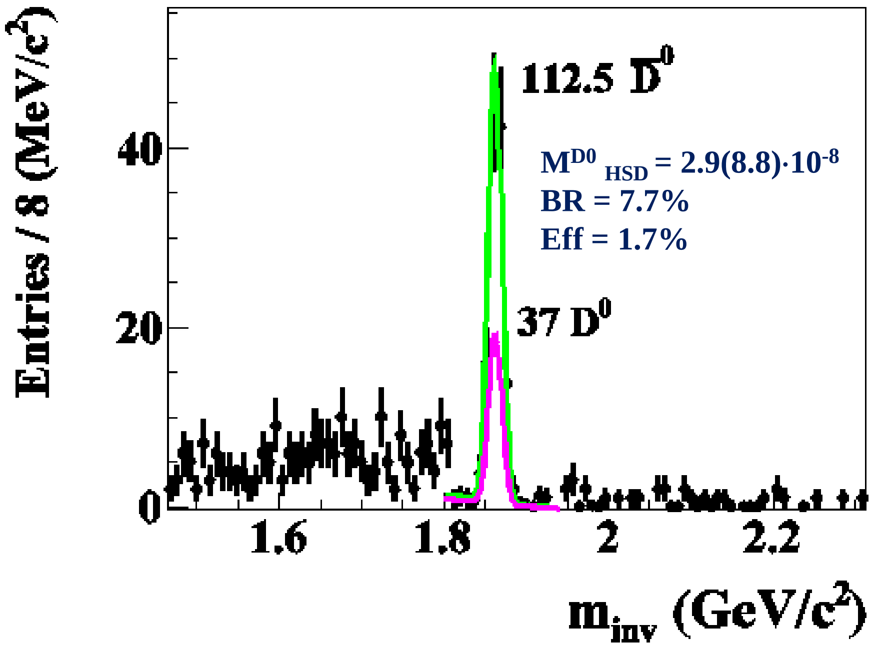
CBM performance at SIS-100: D-meson reconstruction in p-C collisions at 30GeV

$D^+ \rightarrow K^- \pi^+ \pi^+$



$D^0 \rightarrow K^- \pi^- \pi^+ \pi^+$

10^{12} central events

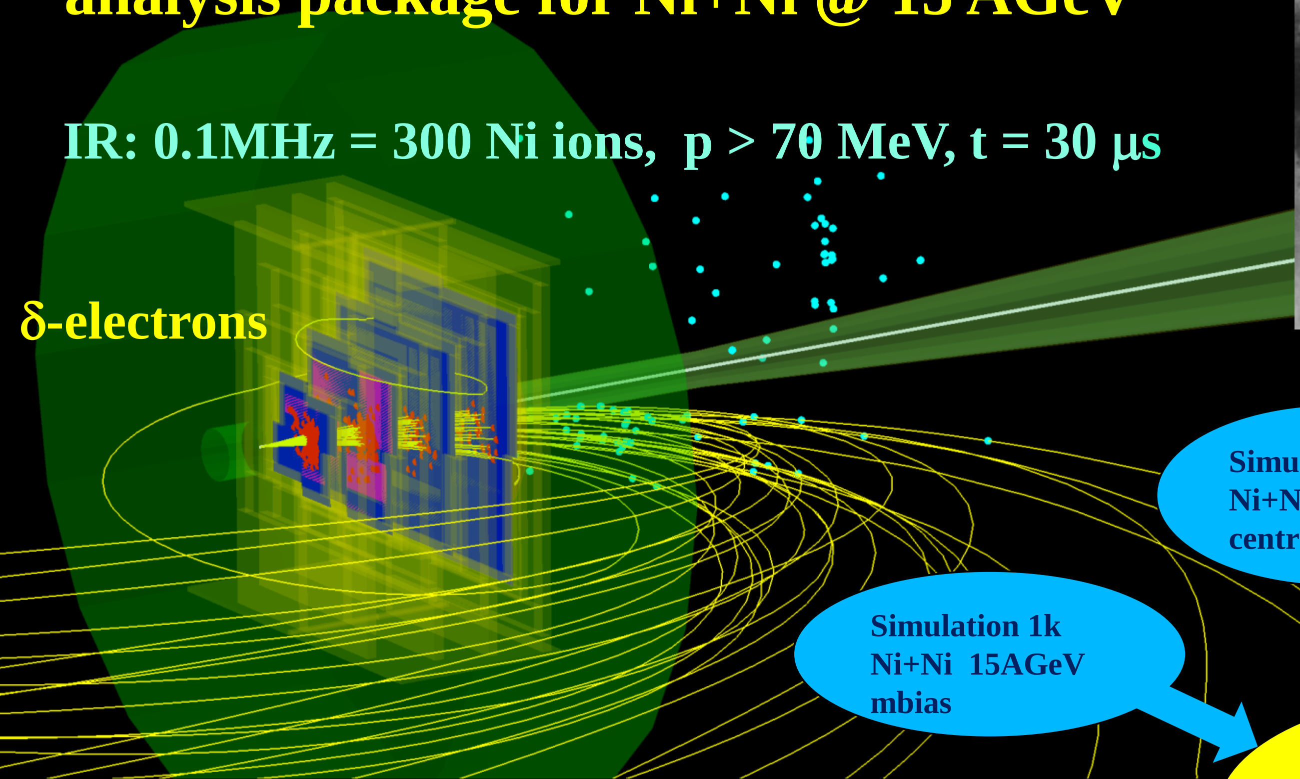


In 10 weeks: 18k $D^{\pm}$ and 3k D^0 at 10 MHz IR

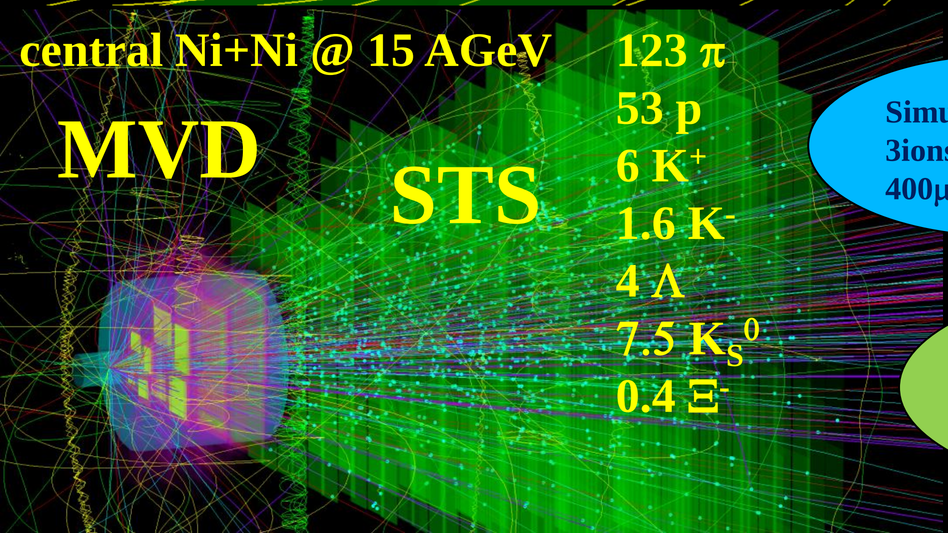
with PV BG suppressed 10-30 times!

CBM performance at SIS-100: D-meson analysis package for Ni+Ni @ 15 AGeV

IR: 0.1MHz = 300 Ni ions, p > 70 MeV, t = 30 μs



central Ni+Ni @ 15 AGeV



- 123 π
- 53 p
- 6 K^+
- 1.6 K^-
- 4 Λ
- 7.5 K_S^0
- 0.4 Ξ^-

Simulation 5M Ni+Ni 15AGeV central

Simulation 5M D^0 T = 150 MeV E_{beam} = 15GeV

Simulation 1k Ni+Ni 15AGeV mbias

Simulation 1k 3ions Ni beam on 400μm Ni target

Reconstruction 5M events Global Tracking

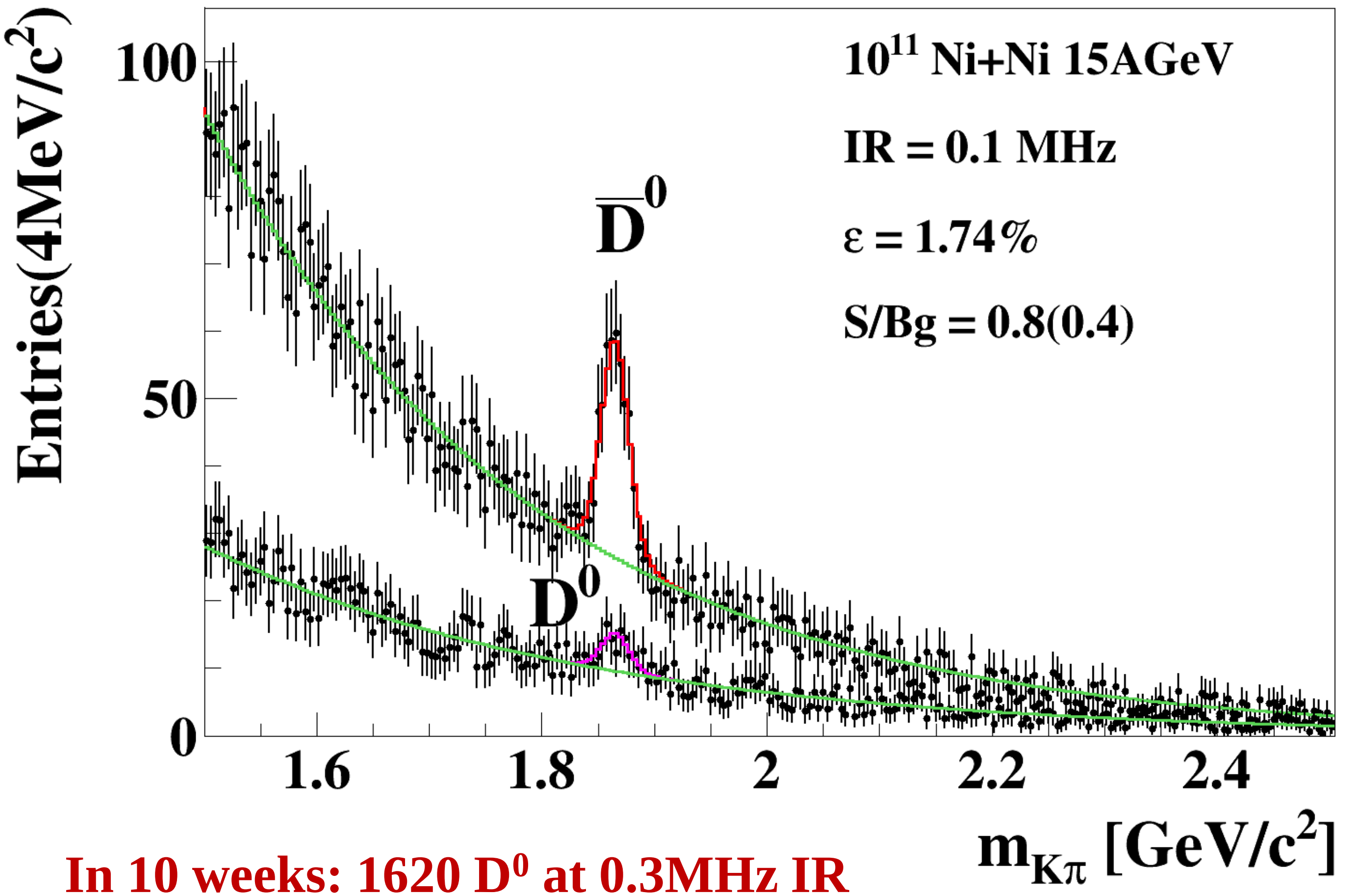
ME → Analysis 5B mixed event

EbE → Analysis 5M event by event

CBM performance at SIS-100: D-meson reconstruction in Ni+Ni collisions at 15 AGeV

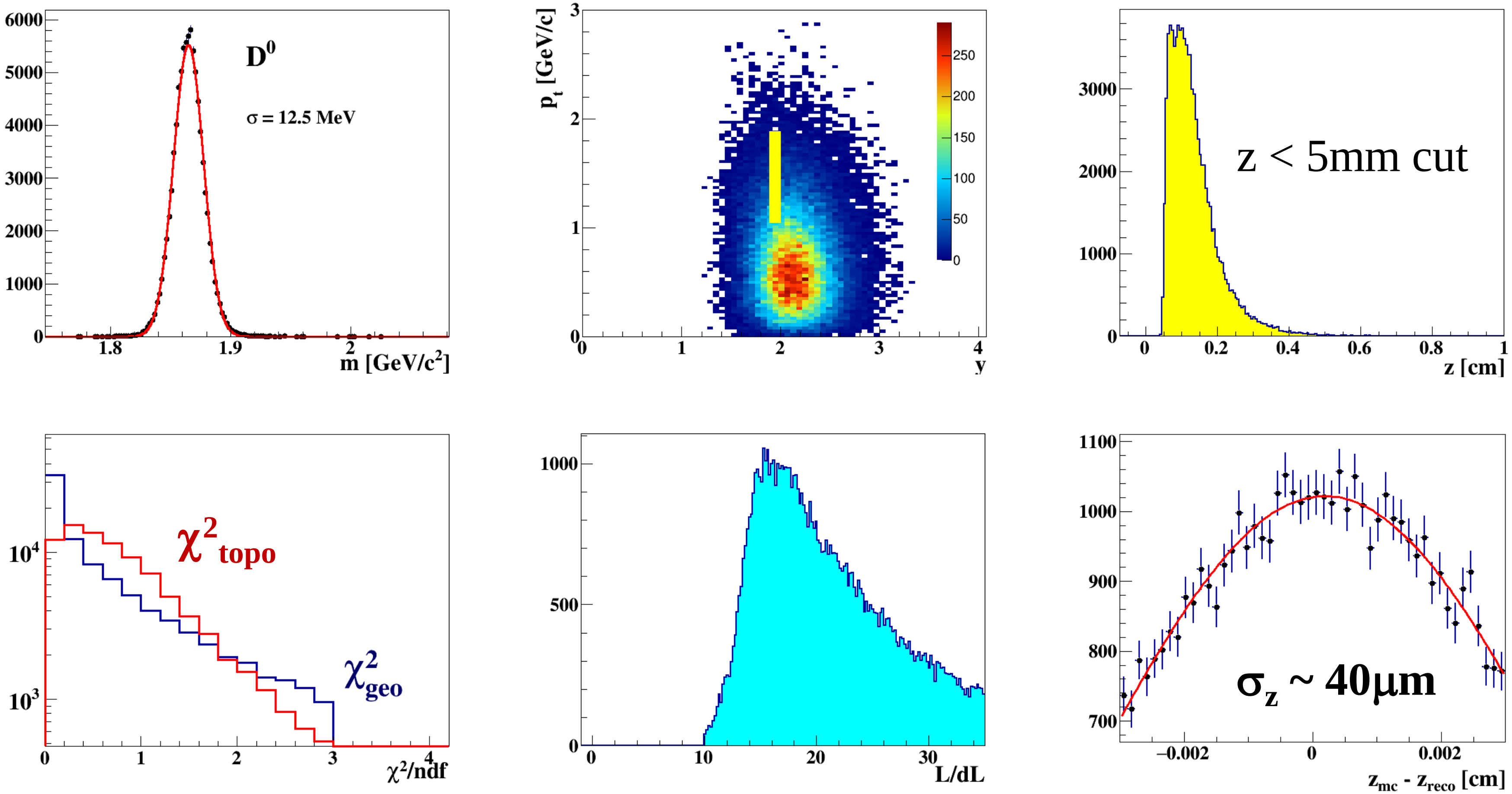
M: D^0 6.5 E^{-7} , $\bar{D}^0$ 3.8 E^{-6} BR: pdg 2015

Thermal (J. Cleymans) model by *V.Vovchenko*



In 10 weeks: 1620 D^0 at 0.3MHz IR

SIS-100 Ni+Ni @ 15 AGeV D^0 embedded, QA-plots:



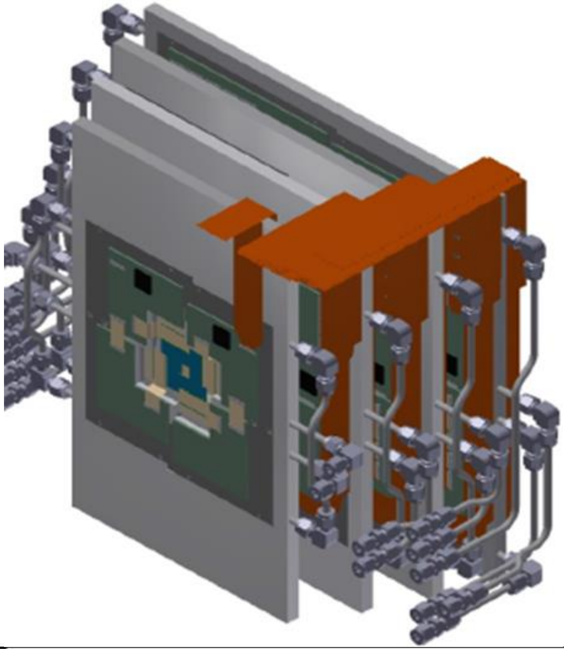
STS $\mathbf{D^0}$ reconstruction efficiency: **ε =18.5 %**

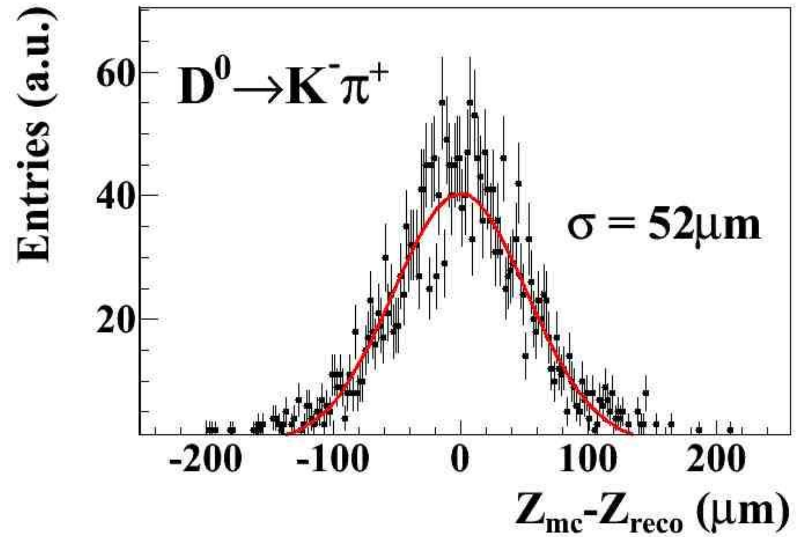
$\varepsilon^{D0}_{\text{ToF Embedded } \delta \text{ 100 kHz 3 mbias pile up}}$ = 1.74 %

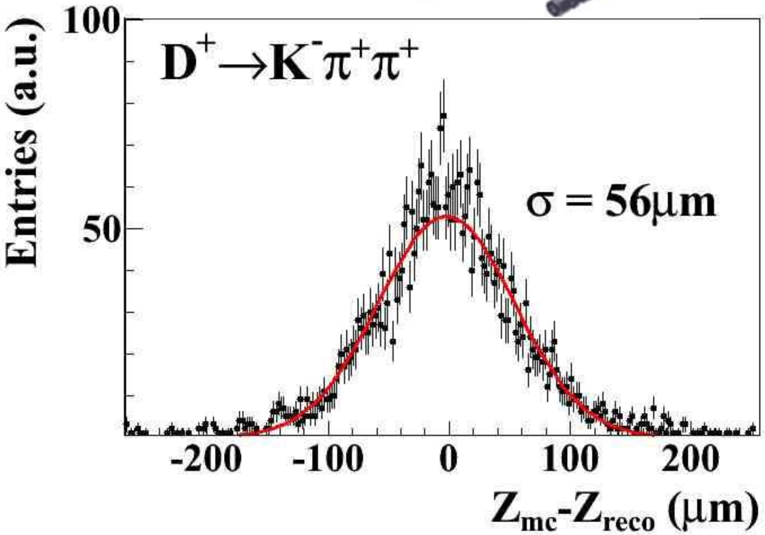
Expected statistics for open charm mesons in Ni+Ni collisions at 15AGeV (SIS-100)

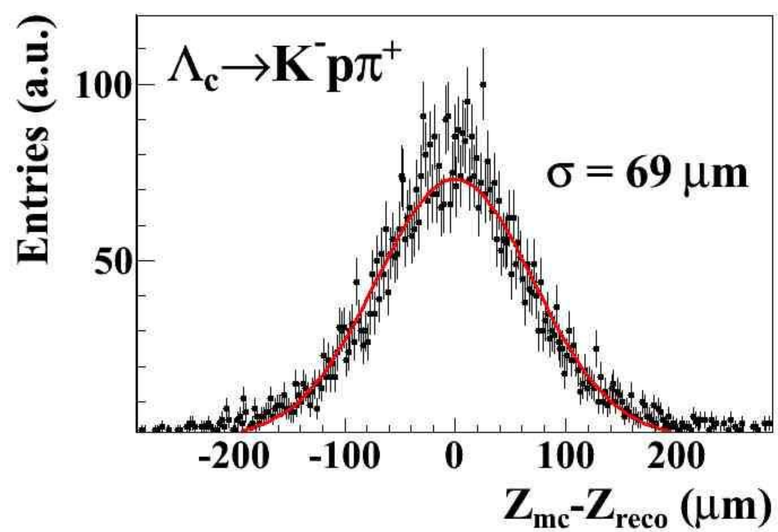
	$\bar{D}^0+D^0$	D^++D^-	D_s^+	Λ_c^+
decay channel	$K^-\pi^+$	$K^-\pi^+\pi^+$	$K^-K^+\pi^+$	$p\,K^-\pi^+$
M_{SM} (J.Cleymans)	$4.5\cdot10^{-6}$	$2.2\cdot10^{-6}$	$1.1\cdot10^{-6}$	$3.6\cdot10^{-6}$
BR(%)	3.8	9.5	5.3	5.0
geo. acc.(%)	30	40	33	70
z-resolution (μm)	40	48	50	60
total eff. (%)	1.8	2.3	0.5	0.05
σ_m (MeV/c²)	12	~12	~12	~12
$S/B_{2\sigma}$	0.8/0.4	-	-	-
Yield/10 weeks, 0.3 MHz IR	1620	2620	160	50

SIS-300 Open charm (Au+Au @ 25 AGeV) 0.1 MHz
z-vertex reconstruction

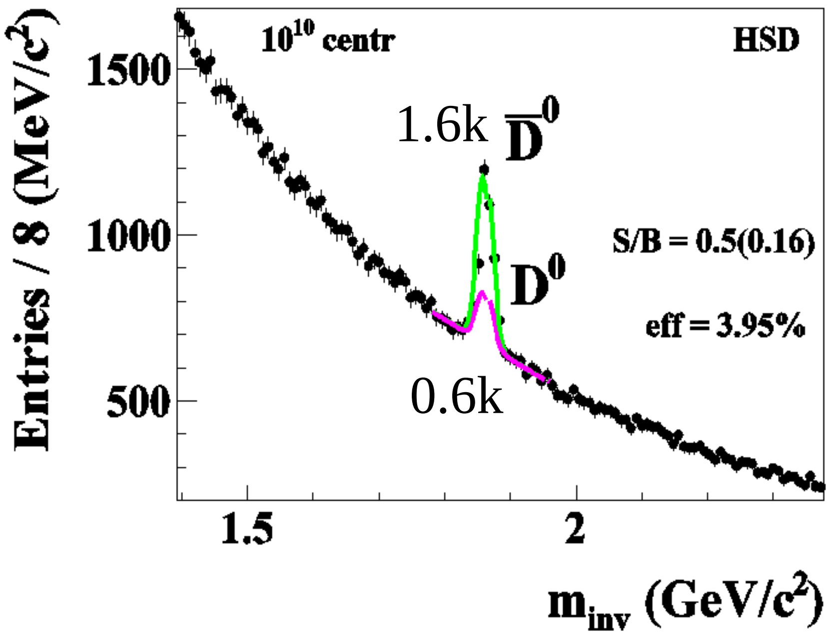


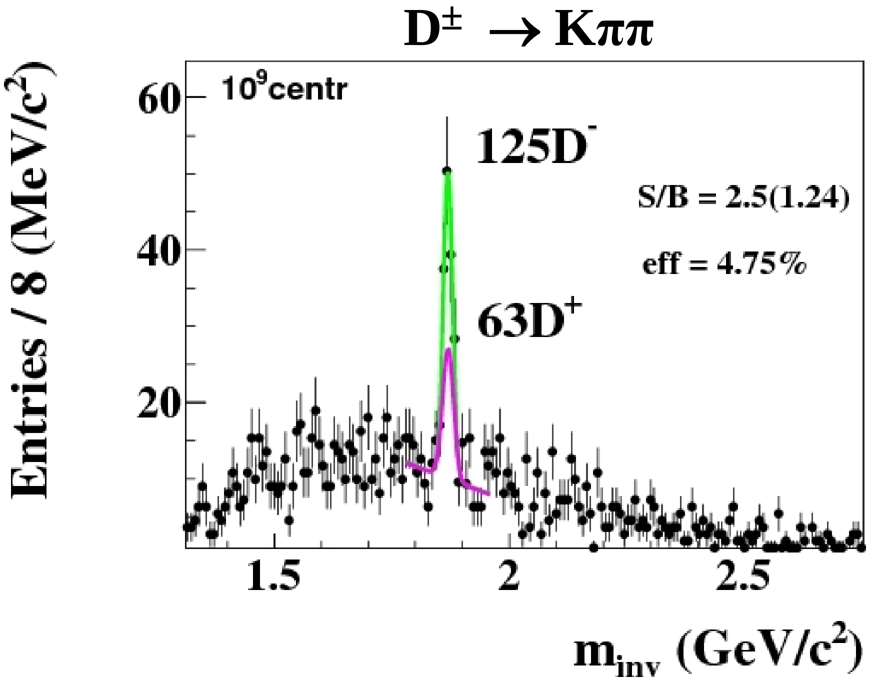


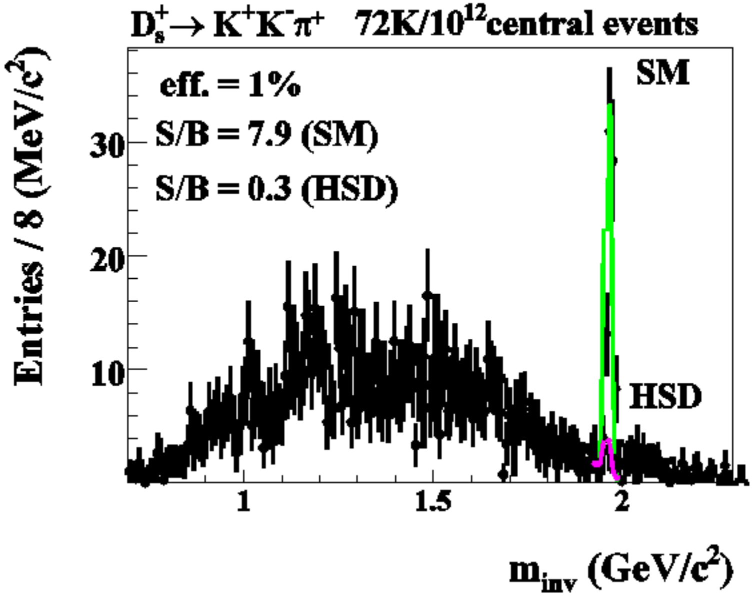


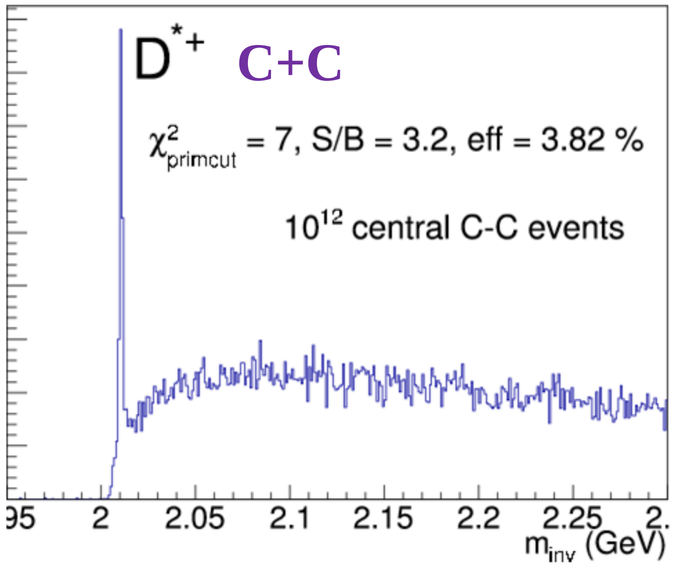


CBM performance at SIS-300: D-meson reconstruction in Au+Au collisions at 25 AGeV









Expected statistics for open charm mesons in Au+Au collisions at 25AGeV (SIS-300)

	$\bar{D}^0+D^0$	D^++D^-	D_s^+	Λ_c^+
decay channel	$K^-\pi^+$	$K^-\pi^+\pi^+$	$K^-K^+\pi^+$	$p K^-\pi^+$
M_{HSD}	$1.5\cdot10^{-4}$	$4.2\cdot10^{-5}$	$5.4\cdot10^{-6}$	
M_{SM}	$8.2\cdot10^{-4}$	$8.4\cdot10^{-5}$	$1.4\cdot10^{-4}$	$4.9\cdot10^{-4}$
BR(%)	3.8	9.5	5.3	5.0
geo. acc.(%)	29.2	40.1	32.8	71
z-resolution (μm)	52	56	60	69
total eff. (%)	3.95	4.75	1.0	0.05
σ_m (MeV/c^2)	~11	~11	~11	~11
$S/B_{2\sigma}$	0.16/0.5	1.24/2.5	5.0	0.6
Yield/10 weeks, 0.1 MHz IR HSD	40.5k	34k	510	
Yield/10 weeks, 0.1 MHz IR SM	220k	68k	13.2k	2.2k

Summary

CBM@SIS100: Open charm production at threshold

Proton beams up to 30 GeV

- Excitation function of charm (production mechanism)
- Charm propagation in cold nuclear matter

Light nuclei (Ni) beams up to 15 GeV

- Charm production & propagation in hot nuclear matter

CBM@SIS300: Open charm production at high densities

Proton beams up to 90 GeV

- Excitation function of charm production at higher energies

Heavy-ion beams (Au) at 15-35 GeV

- Charm production & propagation through high density nuclear matter

CBM requirements

Rare probes:

- High-speed DAQ and online event selection

Open charm reconstruction:

- Fast tracking (STS) + decay daughter identification (TOF)
- Displaced vertex reconstruction (MVD)
- Topology reconstruction algorithm (KFParticleFinder)

The CBM Collaboration: 60 institutions, 530 members

Croatia:
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang

Czech Republic:
CAS, Rez
Techn. Univ.Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
Frankfurt Univ. ICS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.
ZIB Berlin

India:
Aligarh Muslim Univ.
Bose Inst. Kolkata
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
IOP Bhubaneswar
IIT Kharagpur
IIT Indore
Gauhati Univ.

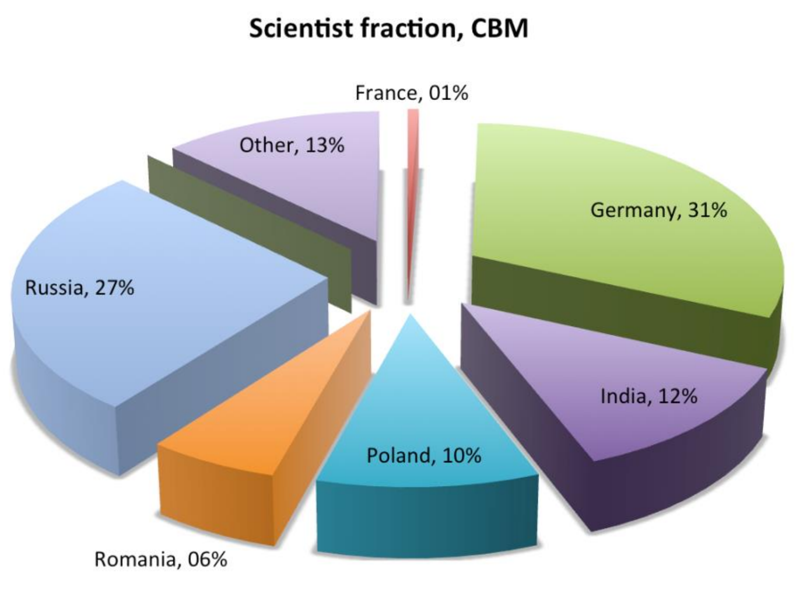
Korea:
Pusan Nat. Univ.

Poland:
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.
Warsaw TU

Romania:
NIPNE Bucharest
Univ. Bucharest

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg Polytech. Univ.
Ioffe Phys.-Tech. Inst. St. Pb.

Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research



CBM Technical Design Reports

#	Project	TDR Status
1	Magnet	approved
2	STS	approved
3	RICH	approved
4	TOF	approved
5	MuCh	approved
6	HADES ECAL	approved
7	PSD	approved
8	MVD	submission 2016
9	DAQ/FLES	submission 2016
10	TRD	submission 2016
11	ECAL	submission 2016